Gravity and geodetic integrated measurements in Tatra Mountains

V. Szalaiová, P. Zahorec, A. Panáček, A. Alföldyová
Geocomplex, a.s.[1]

R. Pašteka, M. Katona
Department of Applied and Environmental Geophysics, Faculty of Natural Sciences[2]

M. Mojzeš, J. Papčo, R. Čunderlík, L. Husár, J. Janák
Department of Theoretical Geodesy, Faculty of Civil Engineering[3]

Z. Mikušová
Student of Geodesy and Cartography at Faculty of Civil Engineering, Slovak University of Technology

Abstract: All territory of Slovakia is covered by regional gravity measurements in mapping scale 1:25000 (4–6 points/km^2) except the area of High Tatra Mountains because of the problems with geometrical levelling and older gravity meters working range in such extremely rough terrain. Nowadays, GPS method in combination with quasigeoid is used for determination of physical heights with accuracy of several cm, GPS providing also the spatial position. The working range of new generation gravity meters has also enlarged. Therefore, in the frame of the project "The Gravity Mapping of Tatra Mountains", a joint gravity, GPS and astronomical measurements have been realised in the most uncovered parts during the summer 2004. Acquired data were used for calculation of new Bouguer gravity anomaly map and for calculation of improved local quasigeoid in this area. In total, 145 gravity points plus 8 base GPS stations were measured. Astronomical measurements have been performed at 14 sites.

Key words: gravity measurements, astronomical measurements, GPS methods, new Bouguer gravity map, new quasigeoid

[1] Geologická 21, 822 07 Bratislava, Slovak Republic; e-mail: gravity@geocomplex.sk
[2] Comenius University, Mlynská dolina, 842 15 Bratislava, Slovak Republic; e-mail: pasteka@fns.uniba.sk
[3] Slovak University of Technology, Radlinského 11, 813 68 Bratislava, Slovak Republic; e-mail: marcel.mojzes@stuba.sk

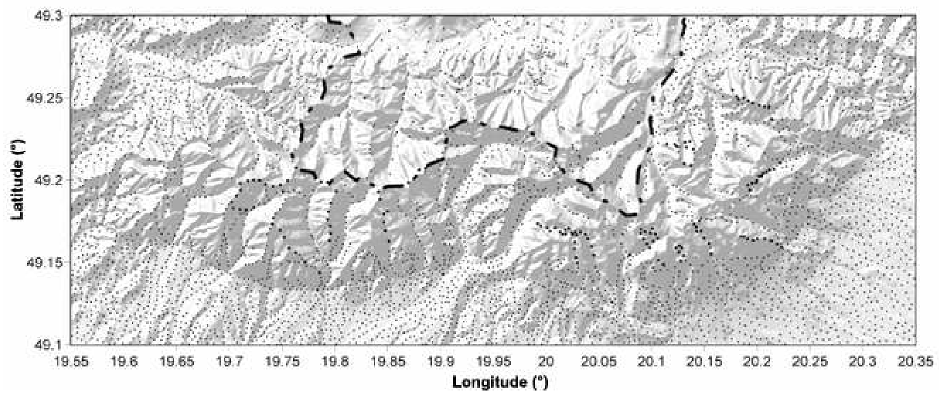

Fig. 1. The position of new and old measured gravity points for Bouguer anomaly map. Explanations: • – old measured gravity point; ● – new measured gravity point.

1. Introduction

In the framework of the project "The Gravity Mapping of Tatra Mountains" a new gravity survey was conducted. Measurements were realized by the methodology for gravity measurements in the scale 1:25000 (ČGÚ, 1975) mainly on the touristic paths. By measuring relative values of the gravity acceleration a CG-3 Gravity meter (Scintrex Ltd.) was used. In total, 145 gravity points plus 8 base GPS stations were measured (Fig. 1).

2. Bouguer anomaly map

New values of complete Bouguer anomalies were calculed by means of the

$$\Delta g_{\mathrm{B}}(\phi,\lambda,h) = g(\phi,\lambda,h) - g_{\mathrm{n}}(\phi) + R_{\mathrm{F}}(\phi,h) - \delta g_{\mathrm{SPH}}(h) + \\ + T(\phi,\lambda,h) + \delta g_{\mathrm{atm}}(h),$$

where
$g(\phi,\lambda,h)$ - observed gravity
$g_{n}(\phi)$ - normal gravity (Somigliana formulae)

$R_F(\phi,\lambda)$ - free air correction term; Taylor series expansion to the 2^{th} order (Wenzel, 1985 in *Torge, 1989)*
$\delta\ g_{PHS}(h)$ - gravitational attraction of the spherical layer
$T(\phi,\lambda,h)$ - terrain corrections up to the distance 166.7 km
$\delta\ g_{atm}(h)$ - atmospheric gravity reduction.

The most problematic part of compilation of Bouguer gravity anomalies is evaluation of terrain corrections because of the extremely rough terrain in the acquisition area. A suitable detailed digital elevation model (DEM) and verified algorithms of its calculation are the basic points of a reliable approach. Evaluation up to the zone O2 (166.735 km) was performed using the standard division into zones: T1 (0 - 0.25 km), T2 (0.25 - 5.24 km), T31 (5.24 - 28.8 km) and T32 (28.8 - 166.735 km). The DEM used for the regional gravity database in the scale 1:50 000 was insufficient for this calculation (differences between levelled and interpolated elevations for the measuring points varied within the interval from –239.79 m to 155.95 m), therefore the more detailed DEM was created using all available information, i.e. maps in the scale 1:10 000, GPS and optical slope measurements in the close surroundings of the measurement points (differences varied within the interval from –8.58 to 25.23 m). Calculated magnitudes of terrain correction were relatively high and for the separate zones the values vary within the following intervals: T1 (0.040 - 5.914 mGal), T2 (1.581 - 44.042 mGal), T3 = T31 + T32 (2.035 - 29.706 mGal). It is interesting to mention that the maximum value of the terrain correction for the regional gravity database of the Slovak Republic is 40.856 mGal, while the maximum value calculated in the frame of the presented project is 79.662 mGal (approx. twice of the mentioned regional value!). Comparison of various approaches, used for the terrain correction calculation has shown that the task needs more detailed study.

The face of the Bouguer anomalies in Tatra Mountains region has changed after new measurements have been assumed (Fig. 2). Differences between the previous and new Bouguer anomalies vary approximately from –5 mGal to 8 mGal (in sense of new anomalies minus previous anomalies). The local quasigeoid model has slightly changed as well. The differences in quasigeoid models (new minus previous) vary from –3 mm to 8 mm. The astronomical measurements (astronomical latitude and longitude) have been used for compilation of deflections of the vertical and can serve for testing of slope of the quasigeoid model.

3. Position measurements

Spatial positions of gravity points were measured using two double-frequency GPS receivers Trimble 5700, one serving as a base station and the second working as a rover. In total, the position of 8 reference points and 145 gravity points have been determined. Observation time at every gravity point was 20 min. and elevation mask was set to 15°.

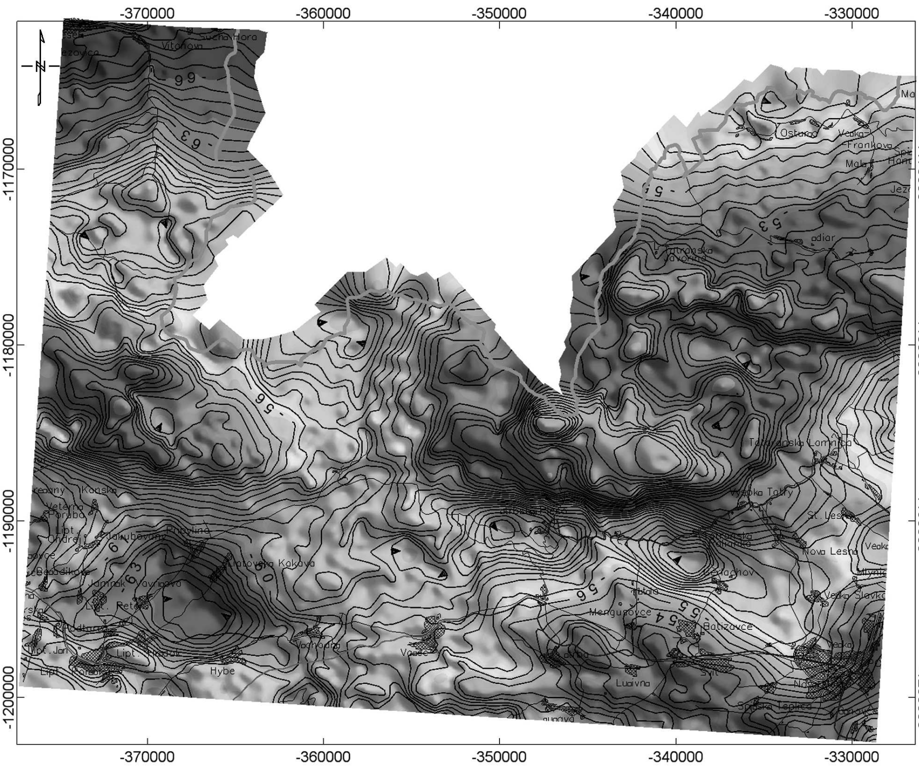

Fig. 2. New compiled Bouguer anomaly map in the area of High Tatra Mts. (density: 2.67 g.cm^{-3}, isoline step: 0.5 mGal).

Number of measured points: Žiarska dolina – 15, Baranec – 8, Otrhance – 14, Tomanova dolina - Bystrá – 16, Východná Vysoká – 7, Furkotská dolina - Mlynická dolina – 13, Zlomisková dolina – 11, Batizovská dolina – 8, Slavkovský štít – 8, Brnčalova chata - Baranie sedlo – 12, Nefcerka – 11, Česká dolina – 1, Belianske Tatry – 10, Široká – 9, Skalnaté Pleso – 1, Lomnický štít – 1.

GPS measurements were processed in Trimble Geomatics Office software connecting to GANP permanent GPS station. Final coordinates are in ETRS-89 coordinate system, see e.g. *(Kostelecký, 1998)*. Standard deviation of horizontal position of gravity points varies from 1 to 15 cm and standard deviation of ellipsoidal height varies from 5 to 20 cm. Ellipsoidal heights above the GRS-80 ellipsoid *(Moritz, 1992)* have consequently been transformed into Molodensky's normal heights using the quasigeoid model of Slovakia GMSQ03CF *(Mojzeš et al., 2004)*.

4. Impact of new measurements on gravity disturbances

For an illustration, the 3-D maps showing gravity disturbances generated from old measurements, generated from updated measurements and their differences are shown in Fig. 3. In a closer look, it can be seen that the updated gravity disturbance field, in particular areas (e.g. Baranec), is very realistic.

5. Impact of new measurements on local quasigeoid model

The new gravimetric quasigeoid model, based on the updated measurements, has been compiled and compared with the previous guasigeoid model of Slovakia. The following differences (in sense of updated minus previous) have been obtained: minimum value of -3.5 mm and maximum value of 8.5 mm. Graphical representation of the differences is depicted in Fig. 4.

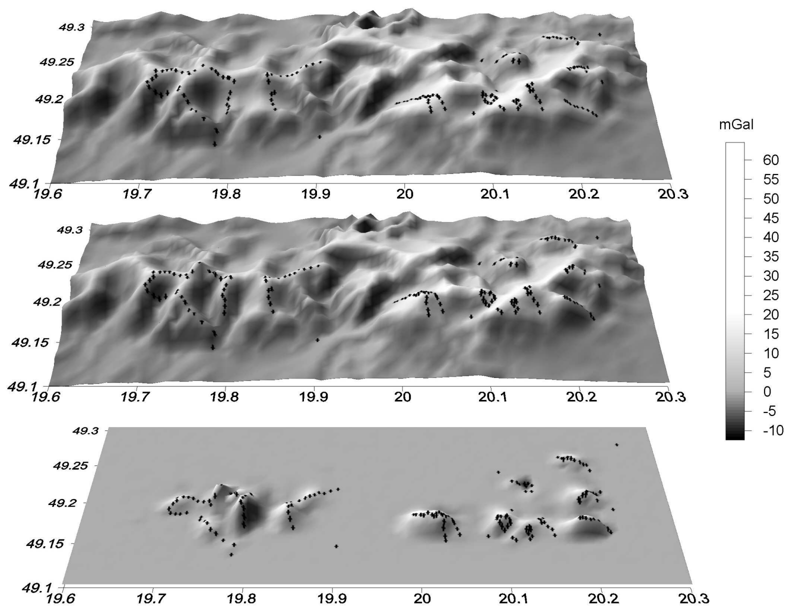

Fig. 3. From the top: gravity disturbances based on old measurements, gravity disturbances based on updated measurements, differences (updated minus old).

6. Astronomical measurements

Astronomical coordinates (latitude Φ and longitude Λ) have been measured at 14 sites, see Fig. 5, to serve as independent control points for gravimetric quasigeoid model. These measurements were performed by Circumzenithal 50/500 optical astronomical instrument, see e.g. *(Hefty et al., 2002)*.

7. Conclusion

This project was realized by simultaneous geophysical and geodetical methods. Combination of the gravity and GPS field measurements is very

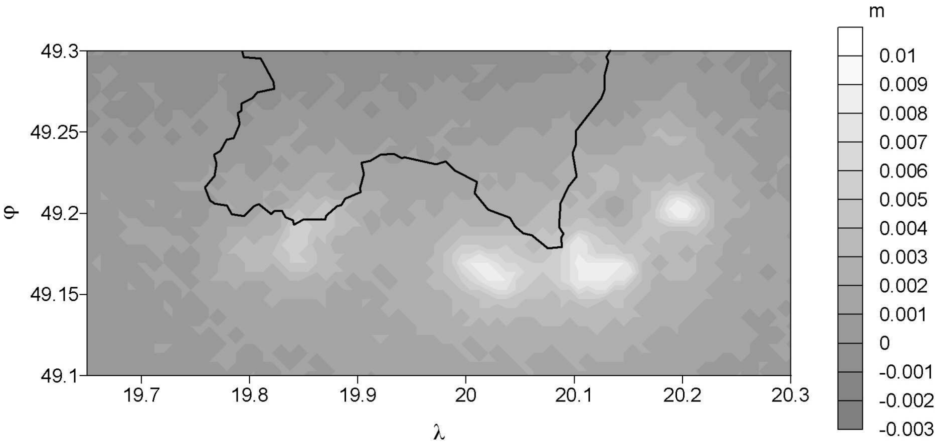

Fig. 4. Differences of the quasigeoid models.

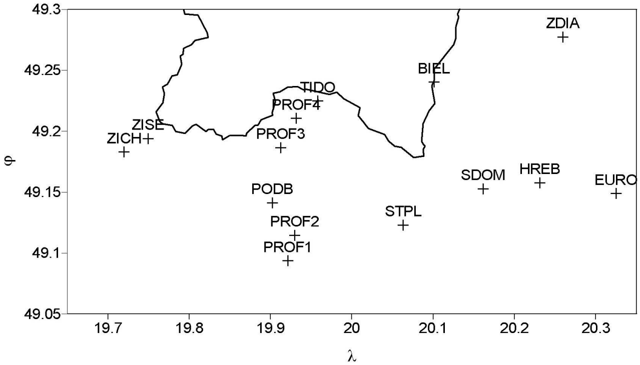

Fig. 5. Distribution of the astronomical points.

suitable, because despite of very rough terrain we are able to relatively quickly acquire very accurate data. During the data processing we have found out the great signification of the estimation of the topographical correction in such mountaneous areas.

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