CHAPTER 7

National Gravimetric Database of the Slovak Republic

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7.1 INTRODUCTION

The territory of the Slovak Republic (except the inaccessible area of the Tatra Mountains) is covered by regional gravity measurements in the scale 1:25,000, which represents 3–6 points/km^2. The measurements were realized during a long period from the 1950s up to the 1990s (Fig. 7.1). The project goal was to create a high definition gravity map for mineral exploration and basic geologic interpretations. Various types of gravity meters were used during the data acquisition time period (GAK PT, Worden, Canadien CG-2, Scintrex CG-3M). Different approaches to complete Bouguer anomaly (CBA) calculation were used, including different normal field formulas, different equations for "Bouguer" correction and atmospheric correction, as well as various methods of the terrain correction estimation. A complete recalculation of the entire database was performed in the frame of the earlier project *Atlas of geophysical map and lines* (Grand et al., 2001). Several hundreds of random error points (with errors in their heights or positions) were identified—these points have been removed from the final Bouguer anomaly evaluation. Systematic errors in the outer zone terrain corrections (outer zone T3 from 5.24 to 166.7 km) were eliminated (Fig. 7.2). However, large errors in the inner zone terrain corrections were still expected because of the inaccurate elevation models available that time (2001).

In addition to the regional gravity measurements, a quantity of local detailed gravity surveys was realized in Slovakia during the last

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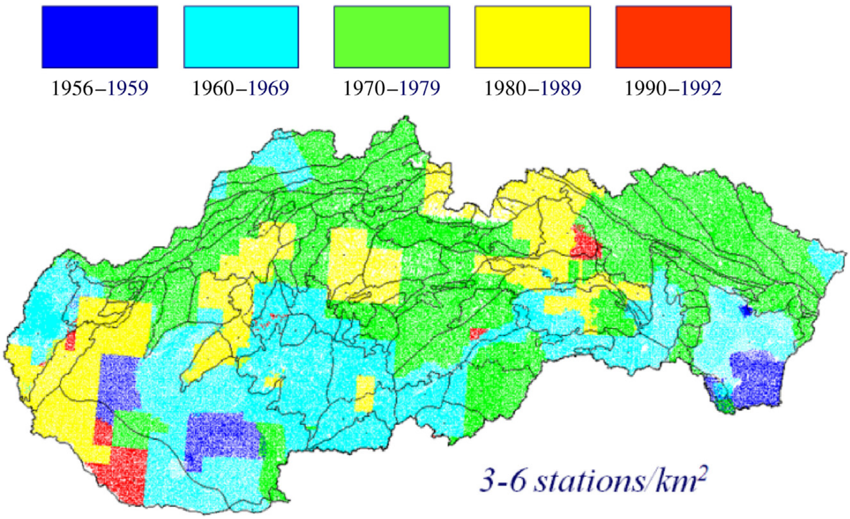

Figure 7.1 Time period of regional gravity database measurements.

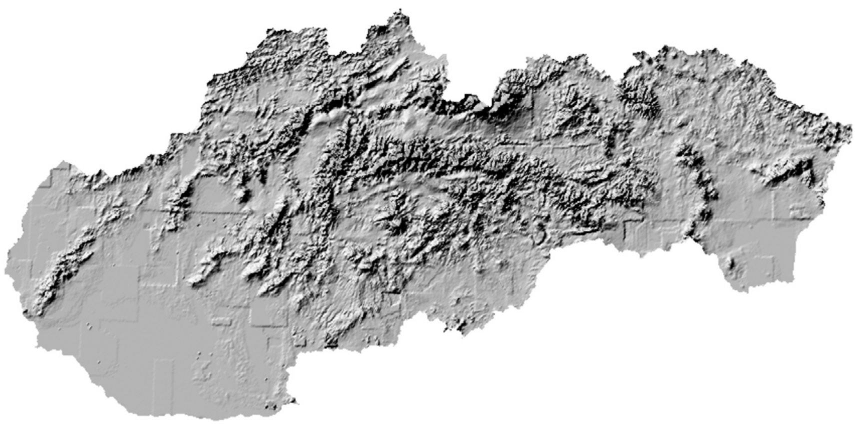

Figure 7.2 Shaded relief map of the older version (1992) of the outer zone terrain corrections T3 from 5.24 to 166.7 km (range from −0.67 to 6.46 mGal for the density 1.0 g/cm^3); after Grand et al. (2004). The pattern following the map sheets margins is clearly visible.

40 years. These data were not incorporated into the unified database before the current project.

7.2 COMPILATION OF INTEGRATED GRAVITY DATABASE

In the frame of actual research project APVV-0194-10 *Bouguer anomalies of new generation and the gravimetrical model of Western*

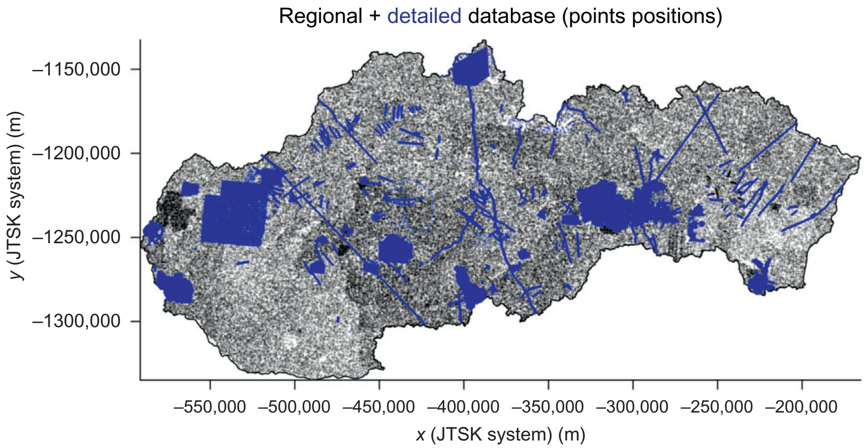

*Figure 7.3 Location of regional (*black*) and detailed (*blue *(gray in print versions)) gravity points.*

Carpathians, all available gravity data in Slovakia were integrated into the unified gravimetric database. The existing regional gravity database (212,478 points) was supplemented with 107,437 detailed gravity points, as seen in Fig. 7.3.

The detailed gravity database is composed of approximately 100 various local projects for the oil-and-gas, mineral and geothermal exploration, basic geology and environmental applications (mainly from archives of Geocomplex, Ltd. and other cooperating organizations in the frame of the actual project). These measurements were realized during the last 40 years, from the 1970s until today. Our analysis indicates that especially the older datasets (measured before 1990s) contain random or systematic errors in the positions, heights, and/or gravity values. Several hundreds of evidently incorrect points (scattered points, local points with the extreme height differences compared with the elevation model, etc.) were excluded from this detailed database. We have tested the accuracy of the original coordinates, which were derived manually from maps in the scale 1:25,000, because they were not surveyed in the field during the gravity measurements. We have digitized about 50 original map sheets and compared the acquired point coordinates at 8797 points with the original ones. As can be seen in Fig. 7.4, there are some points with position differences of hundreds of meters (which can lead to large errors in Bouguer anomaly).

However, on average, the position differences are on an acceptable level. We note that this test does not deal with the real

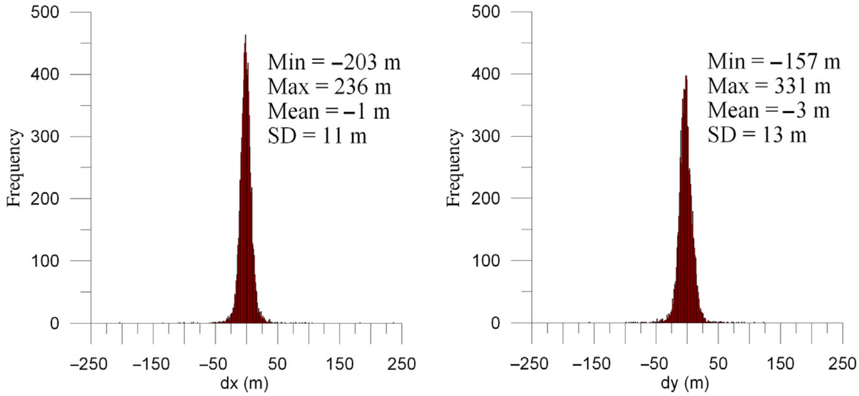

Figure 7.4 Differences between digitized and original manually derived coordinates at 8797 points in x*-coordinate (left) and* y*-coordinate (right).*

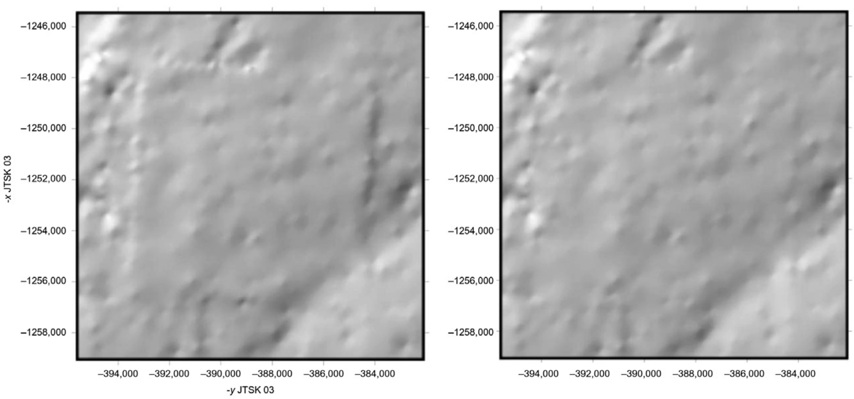

Figure 7.5 Shaded relief map of Bouguer anomalies with well visible systematic error of about +0.6 mGal within a single map sheet before (left) and after (right) correction.

accuracy of the gravity-point position, but with the accuracy of their manually derived coordinates.

Several hundreds of points with systematic errors in the measured gravity were corrected on a basis of the control field measurements as a part of this data merge project. An example of such systematic error within a single map sheet is shown in Fig. 7.5. As we found during the verification measurements, the measured gravity on points within this map sheet (probably by the same operator) was systematically incorrect to about 0.6 mGal.

In addition to performing visual qualitative control and identifying so-called bull-eye anomalies, all data were also analyzed by the quantitative criteria. We compared the heights of measured points with the actual detailed digital elevation model (DEM) of Slovakia DMR-3 (Topographic Institute, 2012). Points with the height residuals larger than ±40 m were considered to be probably erroneous points (this limit was estimated on the basis of DEM quality control; see the next section). We also compared the calculated CBA values with the recalculated regional CBA map of Slovakia (the same processing was used). Points with residuals larger than ±5 mGal were also considered to be probably erroneous points. We left such points in the database (marked by a special quality code), so that they can be further scrutinized during subsequent interpretation.

Detailed gravity data were archived in various coordinate systems as well as gravimetric reference systems, and therefore they had to be unified. The transformation among used coordinate systems (S-JTSK (JTSK03), S-1942, S-1952, ETRS89) was performed using the software Univcol (Marušiak, 2012). S-JTSK (realization JTSK03) is the national coordinate system in Slovakia. It is based on Bessel ellipsoid with the Krovak conical projection in common position. Transformation to the European Terrestrial Reference System 1989 (European version of the global coordinate system known as the International Terrestrial Reference System) is based on the Bursa-Wolf 6-parameter transformation. Transformation parameters are in full compliance with the official instruction of the National Mapping Agency. The official coordinates S-JTSK03 and ETRS89 are archived in the final database. We have analyzed in detail the transformation between the former gravity reference system (Gravity system 1964) and actual Gravity system 1995 (the system is realized by 10 absolute gravity points and 278 points of the basic gravity network), using 28 identical reference points. Differences between these systems vary from −13.97 to −13.77 mGal within the territory of Slovakia (Fig. 7.6). We recognized that there is an indication of the dependency between these differences and the gravity value itself. However, for practical reasons we used the average constant value of −13.84 mGal for the transformation of gravity data from the system 1964 to the system 1995. For comparison, the previous (2001) recalculation and compilation chose a nearly identical value of −13.80 mGal.

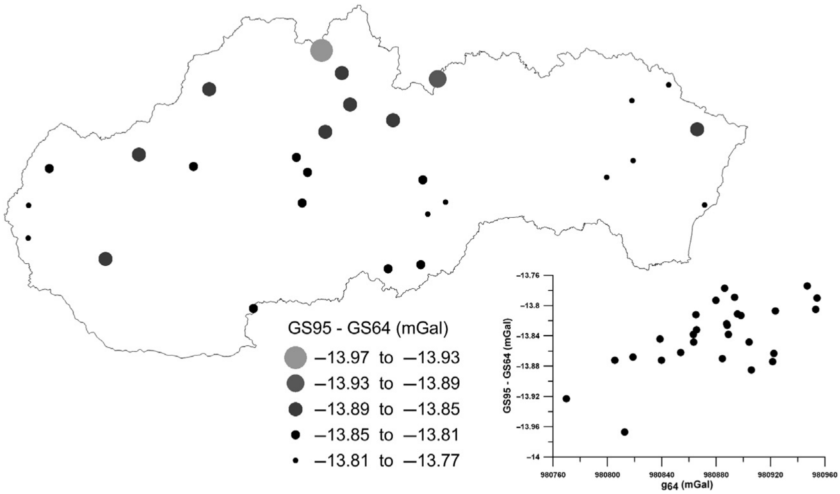

Figure 7.6 Differences between the former and actual gravity reference system on 28 points of basic gravity network. Their dependency on gravity value itself is shown in bottom right.

7.3 NEW GENERATION BOUGUER ANOMALIES

Once the above-mentioned quality control, transformation, and unification aspects were complete, the full database (almost 320,000 points) was reprocessed to the CBA values. One of the most important steps of this process is the precise evaluation of the terrain corrections, especially in mountainous countries like Slovakia. We used a new program Toposk see Chapter 6, Numerical Calculation of Terrain Correction Within the Bouguer Anomaly Evaluation (Program Toposk) in this book and a well-established approach to divide the calculated area into four zones (Grand et al., 2001): inner zone T1 (0−250 m), intermediate zone T2 (250−5240 m), outer zones T31 (5.24−28.8 km), and T32 (28.8−166.7 km). Different numerical approaches and different digital elevation models with the increasing resolution toward the calculation point are used within particular zones. The concept of interpolated heights of the calculation points within the inner zone T1 was used (instead of the measured ones), which we found as a reasonable approach (Grand et al., 2001; Zahorec, 2015). The new detailed digital elevation model was compiled by combination of DMR-3 and DMR-4 (Topographic Institute, 2012) with shuttle radar topography mission (SRTM) data (Jarvis et al., 2008) outside the Slovak territory. Detailed models DMR-3 as well as DMR-4 are connected to the same Slovak local

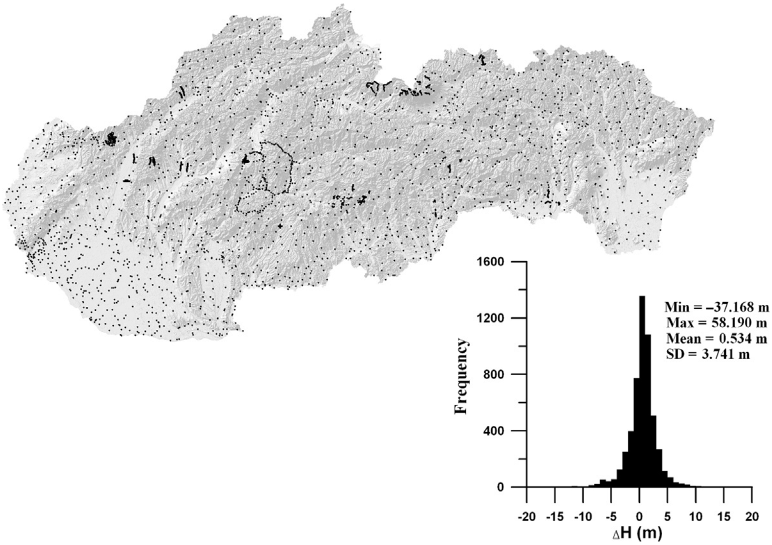

Figure 7.7 Accuracy of the new compiled detail DEM tested on a set of 5299 geodetic and gravity points.

height system—Kronstad-based system Baltic after adjustment (Bpv). Transformation of directly measured ellipsoidal height from global navigation satellite system (GNSS) in ETRS89 (ellipsoid GRS80) to this local height system Bpv is made by the Slovak local quasigeoid DVRM (Klobušiak et al., 2005) related to the same ellipsoid GRS80. Local quasigeoid DVRM is in very good agreement with EGM96 due to its remove-restore creation technique. Differences between them in the area of Slovakia are within the range of -1.5 to 0.3 m, which is definitely better than the precision of the SRTM model.

We tested the new DEM on a set of the state geodetic network points as well as a set of our recent gravity points (measured using GNSS methods). Statistics in Fig. 7.7 show the maximum height differences of several tens of meters even in the highest mountains, which is considerably better than former models, although there are still local errors. The quality of the new compiled DEM has the greatest impact on improving the terrain corrections.

The impact of the new version of terrain corrections is clearly visible at the local CBA map from the Tatra Mountains area (Fig. 7.8). The presence of the local "bull eye" anomalies is visible in the case of the old version of terrain corrections. Maximum differences between the old and new terrain corrections (and consequently the CBA values) are approximately ± 6 mGal for the correction density 2.67 g/cm^3.

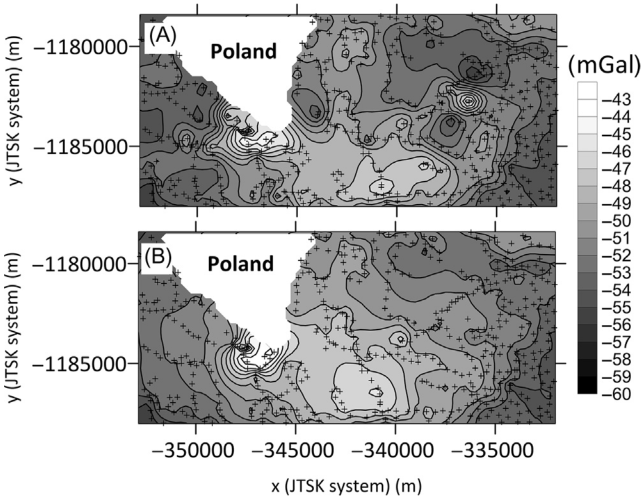

Figure 7.8 Comparison of the local CBA map (a part of the High Tatra Mountains) constructed with the old (A) and new (B) versions of the terrain corrections.

The CBA was calculated following the equation:

$$\mathrm{CBA} = g(P) - \gamma(P_0) - \delta g_F(P) - \delta g_{\mathrm{sph}}(P) + \mathrm{TC}(P) + \delta g_{\mathrm{atm}}(P)\ (\mathrm{mGal}), \tag{7.1}$$

where $g(P)$ is the drift-corrected measured gravity acceleration related to Gravity system 1995, $\gamma(P_0)$ is the normal gravity field (Pizetti-Somigliana formula with GRS80 reference system parameters) on the ellipsoid, $\delta g_F(P)$ is the free air correction term in a second degree approximation (Wenzel, 1985), $\delta g_{\mathrm{sph}}(P)$ is the gravitational effect of truncated spherical layer (Mikuška et al., 2006) with the truncation angle of $1°29'58''$ (corresponding to 166 730 m) and the density 2.67 g/cm^3; this term is known as a Bouguer correction (in spherical approximation), TC(P) is the terrain correction calculated to 166 730 m with the Toposk program (2.67 g/cm^3), and $\delta g_{\mathrm{atm}}(P)$ is the atmospheric correction calculated by the effect of the true atmosphere (Mikuška et al., 2008), using the real topography model and the effect of spherical shell with radially dependent density (Karcol, 2011). The final CBA map is shown in Fig. 7.9.

In addition to the mentioned standard steps of the CBA calculation, we also calculated the distant topography and bathymetry effects (including the ice effect) for the entire database. However, these effects are not incorporated into the anomaly computation for the present analysis; they will be included into the next update of this database. We also recognized that the so-called geophysical indirect effect has a long-wave

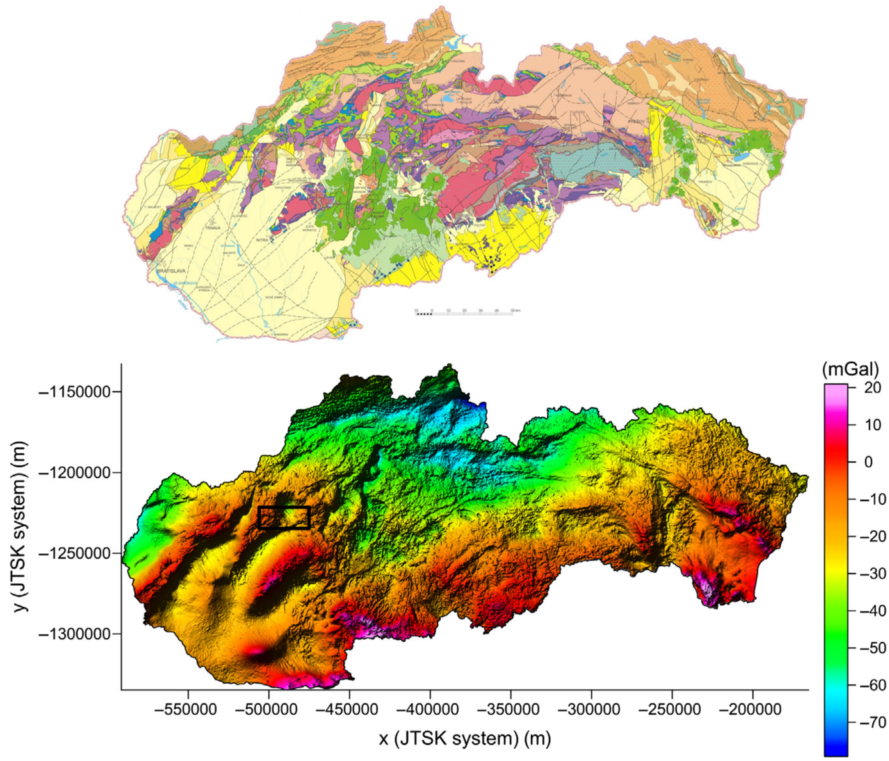

Figure 7.9 Complete Bouguer anomaly map of Slovakia (2.67 g/cm^3) and its comparison with geological map (after Biely et al., 1996). Black rectangle indicates the region with field measurement verification profiles shown in Fig. 7.10.

character which does not affect the local gravity field interpretations. Therefore we use the normal heights, not the ellipsoidal ones.

The final gravimetric database contains the following data (in the American Standard Code for Information Interchange (ASCII) format): point number, year of acquisition, quality code, x-coordinate (S-JTSK03), y-coordinate (S-JTSK03), longitude (ETRS89), latitude (ETRS89), elevation (Bpv), observed gravity (GS95), near topographic effects NTE1, NTE2, NTE31, and NTE32 (for density 1.0 g/cm^3), terrain corrections T1, T2, T31, and T32 (for density 1.0 g/cm^3), distant topographic effect, distant bathymetric effect, atmospheric effect, CBA (2.67 g/cm^3).

7.4 NEW LINEAR FEATURES RECOGNIZED IN THE BOUGUER ANOMALY MAP

Several new regional linear features were recognized during the CBA map analysis. We have used the detailed field measurements to confirm

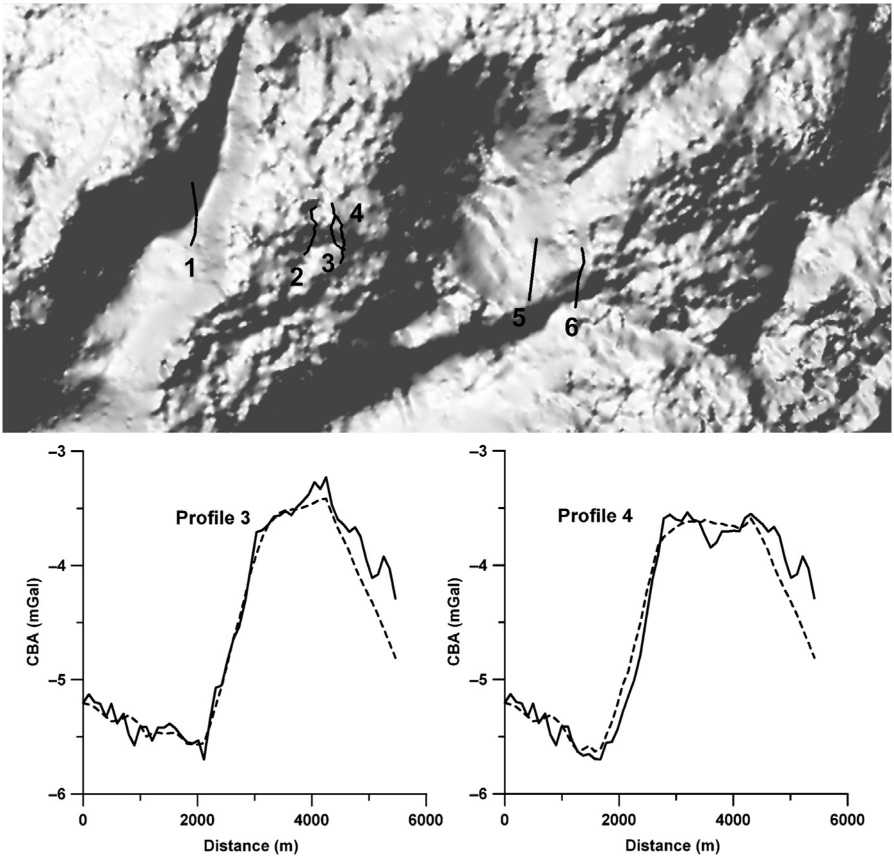

Figure 7.10 In-situ measured control profiles. Comparison between measured values (solid lines) and values interpolated from regional CBA map (dashed lines) along two profiles.

one of them, which is running in the approximate W−E direction (Figs. 7.9 and 7.10). Several profiles were realized in the areas, where the linear structure is visible and not visible, respectively. Comparison of the interpolated CBA values with the measured CBA values along two verification profiles (from area where the structure is clearly visible in the map) is shown in Fig. 7.10. As can be seen, the in-situ measurements confirm the sharp gradient in the CBA values along the properly situated profiles intersecting the linear regional structure. This linear feature has an unexpected strike, and its geological interpretation is still under discussion.

7.5 NEW SOFTWARE FOR THE RECONSTRUCTION OF THE GRAVITY FIELD FROM THE BOUGUER ANOMALY MAP

A new software solution CBA2G_SK (Marušiak et al., 2015) for the recomputation of the gravity acceleration from the newly completed Bouguer anomaly grid was developed. The goal is to estimate the gravity acceleration everywhere within the Slovak territory with the highest possible accuracy. The recalculation process is defined by the reverse equation in regard of the CBA:

$$g(P) = \mathrm{CBA} + \gamma(P_0) + \delta g_F(P) + \delta g_{\mathrm{sph}}(P) - \mathrm{TC}(P) - \delta g_{\mathrm{atm}}(P)\ (\mathrm{mGal}), \tag{7.2}$$

(explanations of symbols are given below Eq. 7.1).

The same DEMs and the zone division to four zones are used as within the original CBA calculation (user interface of the new software can be seen in Fig. 7.11). Main utilization of this software is for more

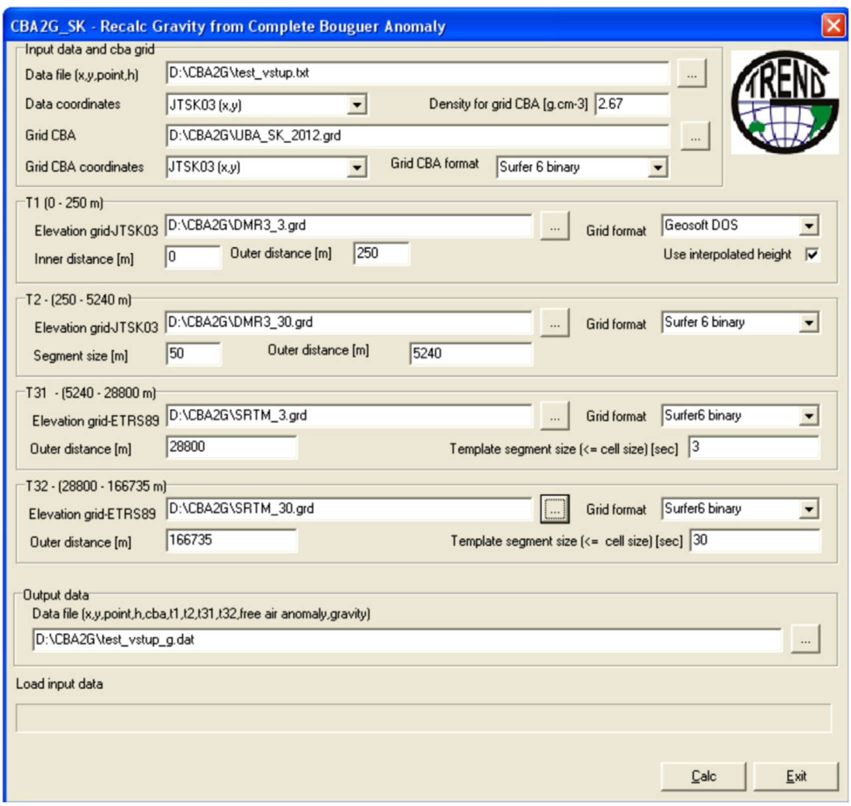

Figure 7.11 User interface of the new software CBA2G_SK.

accurate determination of the normal heights within the leveling networks when the in-situ measured gravity values are not available. The tests on the State Gravimetric Network points (these points were not included in the new CBA map calculation; they serve as control points) show maximum differences of about ± 1 mGal between the measured and calculated gravity values. These results confirm the accuracy of the new CBA map of the Slovakia as well as the correctness of the new software algorithm.

7.6 CONCLUSIONS

Large volume gravity dataset covering Slovakia has been reprocessed during the research project described herein. The former regional gravimetric database (212,478 points) was supplemented with the detailed gravity data (107,437 points) covering the entire territory of Slovakia. The new integrated database was qualitatively and quantitatively analyzed, and many random and systematic errors in coordinates, heights, and gravity values were detected and corrected. Detailed analysis of the transformation between previous and actual reference gravity systems was performed, and the constant value of -13.84 mGal (instead of the previously used -13.80 mGal) was used for the transformation between previous and new systems. Close attention was paid to the terrain correction calculation during the "CBA" calculation process. Newly developed software Toposk (see Chapter 5 in this book) was used for terrain corrections, which included the concept of interpolated heights of the calculation points within the innermost zone T1 (0−250 m). New detailed digital elevation model was compiled by combination of local detailed models and SRTM data. Results of testing demonstrated the high quality of this DEM even in the highest mountains for the regional surveys. Differences between the previous and new versions of the terrain corrections reached ± 6 mGal for the correction density of 2.67 g/cm^3.

New regional linear structures were identified on the CBA map and consequently verified by the detailed gravity measurements. A new software solution for estimation of the gravity acceleration from the CBA values was also developed. We believe that the new CBA map will provide a higher reliability for the geological interpretations, as well as for the geodetic applications. Process of improvement of the current gravimetric database will continue in the future as new measurements and more accurate DEM models become available.

ACKNOWLEDGMENTS

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