Testing EGM08 using Czech GPS/leveling data

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Abstract. The new Earth Gravitational Model 2008 (EGM08) was tested using a set of 1024 high-accuracy GPS/leveling stations in the Czech Republic. Values of height anomalies synthesized from the new model were compared with those derived by the combination of leveled Molodensky-type normal heights and GPS-based geodetic (ellipsoidal) heights. The standard deviation computed from the obtained differences was equal to ±3.3 cm. For comparison purposes, the previous model EGM96 has been tested with the same data set. Compared to this model, the new gravitational model fits five times better to the GPS/leveling height anomalies.

1   Introduction

In this report, we describe a test procedure performed in order to verify the quality of the latest Earth Gravitational Model 2008 (EGM08) released in April 2008 (Pavlis et al. 2008) using independent GPS and leveling data on territory of the Czech Republic. The test was conducted in the frame of a joint working group of the International Association of Geodesy (IAG) and the International Gravity Field Service (IGFS) that was established in 2007 in order to test the new model by using various independent data available to members of the working group.

As a test area, the territory of the Czech Republic, a landlocked country in Central Europe, was used. As test data, 1024 discrete values of the height anomaly (ellipsoidal surface normal deviations of the quasi-geoid form the international reference ellipsoid) were utilized. The report describes the origin, distribution and quality of the reference values (Section 2) and provides results in terms of interpolated 2D surfaces based on residual differences as well as their basic statistical values (Section 3). To prove the tremendous improvement the new model represents over the test territory, results based on the previous EGM solution, EGM96 (Lemoine et a. 1998), are also shown.

2 GPS/leveling data

1024 GPS/leveling stations were used to validate EGM08 over the territory of the Czech Republic. These GPS/leveling stations provided a nice sample of independent reference data, although covering only a relatively small region in the Central Europe.

The stations have a known value of the Molodensky-normal height estimated through very precise leveling from closest points of the national leveling network. A length of leveled traverses did not exceed the distance of 5 km. Since the error of precise leveling is ±1.7 mm/km, the total error can be computed through the well known formula $\pm1.7 \times \sqrt{5} \doteq \pm4$ mm (Hrabě and Beneš 1997). Thus, the estimated rms error of the leveled heights of the stations is estimated to be at the order of ±5 mm. If digital leveling instruments would be used, errors might remain below ±1 mm over the 5 km distance.

GPS heights of the stations were estimated through static 8-hour GPS observation campaigns with an average length of baselines between the stations at the level of 10 km. Their accuracy estimated from the adjustment is at the order of ±1 cm. Combining the errors of the leveled and GPS heights, the accuracy of height anomalies estimated at the GPS/leveling stations can approximately be characterized by the rms error of ±2 cm. Although small in the geographical coverage, the stations have the advantage of being homogeneous with respect to one height system used in the Czech Republic.

The leveling network of the Czech Republic is based on networks of several orders measured in due time. Stability and possible vertical movements of the leveling benchmarks were investigated through repeated leveling campaigns. Namely heights of the first-order vertical network were re-estimated in the recent years. Results of repeated leveling campaigns showed a small tilt in the NW-SE direction, see Figure 1 (Zeman 2001), where detected vertical changes over the period of the last 33 years are shown. The range of the tilt is from $+5$ to -3 cm at the boundaries of the country. The estimated annual vertical motion of the leveling network is then shown in Figure 2 (Zeman et al. 2007). The rate of change is within -1 to
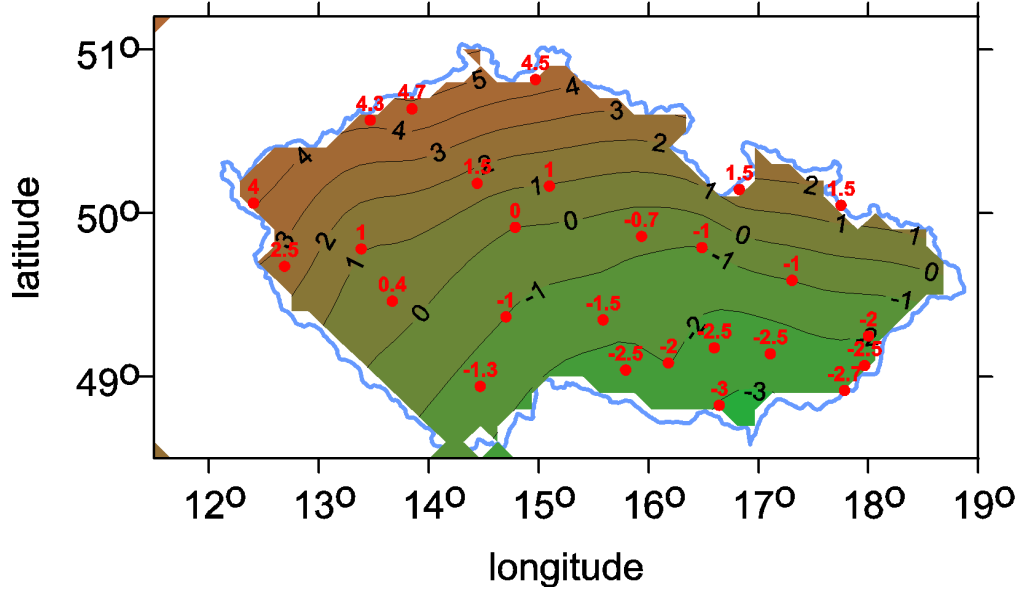
Figure 1: Vertical changes in the Czech leveling network over last three decades (cm)

+5 mm per year depending on the location. The largest changes are along the western boundary of the country. These figures are very important for the analysis of possible trends in the estimated differences between the tested and reference values in our test: trends, that have a different shape or magnitude, cannot be related to the tilt of the leveling network. In contrary, they can be attributed to observation errors in leveling and/or eventual errors in the EGMs.

Besides the accuracy of GPS/leveling values, it is also the size of the data area that is relevant to the testing procedure. In order to detect eventual deficiencies in the entire spectrum of the EGM, the test data should continuously cover the entire Earth's surface. EGM08 is limited to maximum degree and order of the spherical harmonic expansion at the level of 2160 that correspond to the angular resolution of 5 arcmin $\times$ 5 arcmin (9 km $\times$ 9 km $\cos\phi$ at the Earth's surface, ϕ is latitude). Our test area covers the territory of the Czech Republic, i.e., the area of some 90,000 km^2 that indicates limitations of the test data. Long-wavelength or low-frequency errors in the model cannot be detected through our test data. However, it is their high quality and bias-free characteristics that may provide some insight into the performance of EGM08 in the geographically limited test area. The quality of EGM08 is judged by goodness-of-fit between the EGM08 quasi-geoid and its geometric counterpart estimated through combination of GPS-based geodetic (ellipsoidal) and leveled Molodensky-normal heights.
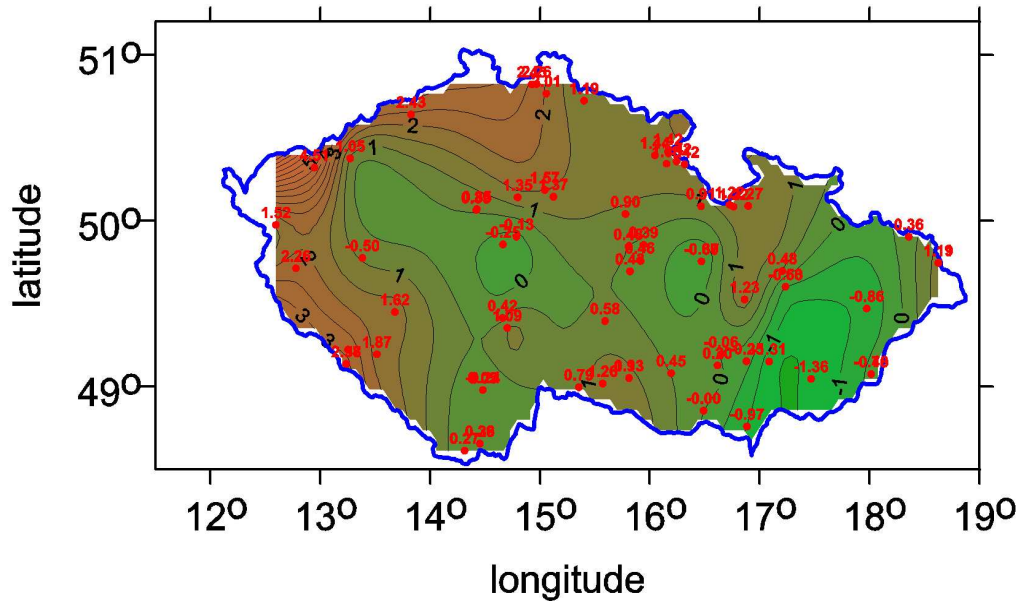
Figure 2: Estimated annual vertical motion over the territory of the Czech Republic (mm/y)

3 Results

Point values of the height anomaly obtained through combination of GPS/leveling heights at the 1024 GPS/leveling stations were compared against their respective values synthesized from EGM08. The estimated differences, reduced for their mean value due to different values of W_0 used in definition of the EGM and local vertical datum (so-called "Baltic System" used in Eastern Europe since 1960's), are tabulated along with their respective standard deviations and other statistical parameters. To show the improvement the new EGM represents, differences for EGM96 are also presented in Table 1.

EGM08 has much higher spatial resolution than EGM96: 5 arcmin for EGM08 vs. 30 arcmin for EGM96. Looking at the statistical values in Table 1, namely at the values of the standard deviation, it is obvious that EGM08 outperforms the older EGM96 also in terms of accuracy. The standard deviation for EGM08 is at the level of ±3.3 cm compared to ±16.8 cm for EGM96, i.e., one could conclude EGM08 is approximately five times more accurate than EGM96. However, this conclusion is valid only for the specific region and the used data. We may recall a test performed by the authors of EGM08 (Pavlis et al. 2008) using approximately 12 thousand GPS/leveling points distributed globally. Values of the standard deviation computed from the obtained differences were ±13 cm for EGM08 and ±30 cm for EGM96, i.e., the improvement globally seemed to be less significant. The much better result of this test is at least partially due to having the test data related only to one vertical datum.

model	minimum	maximum	standard deviation
EGM08	− 0.089	+ 0.094	± 0.033
EGM96	− 0.517	+ 0.505	± 0.168

Table 1: Statistics of estimated differences at 1024 GPS/leveling stations (m)
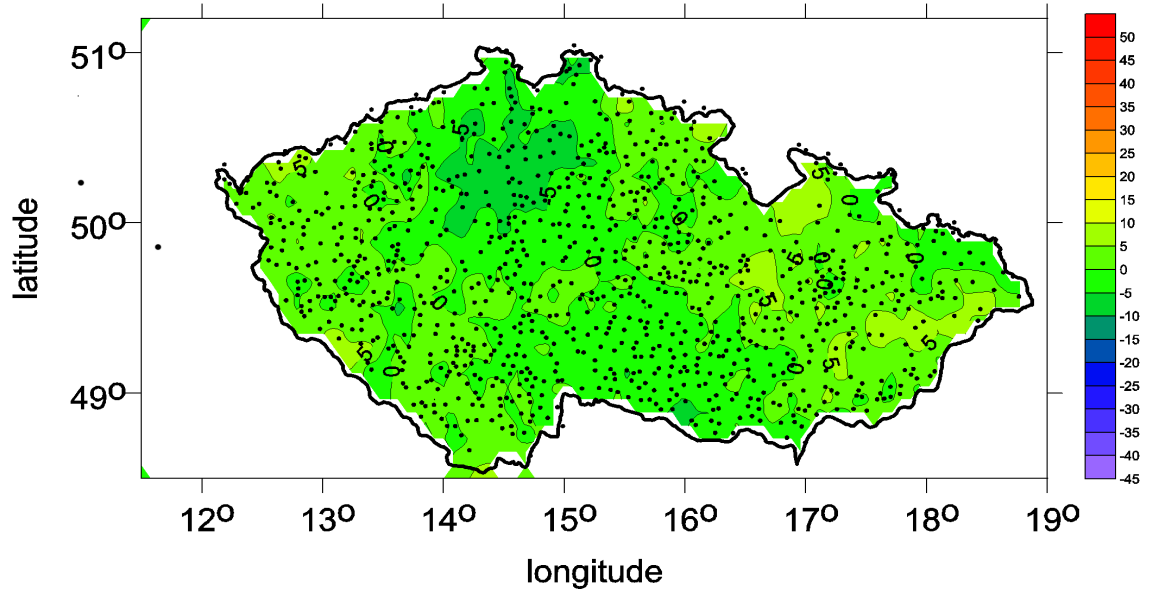

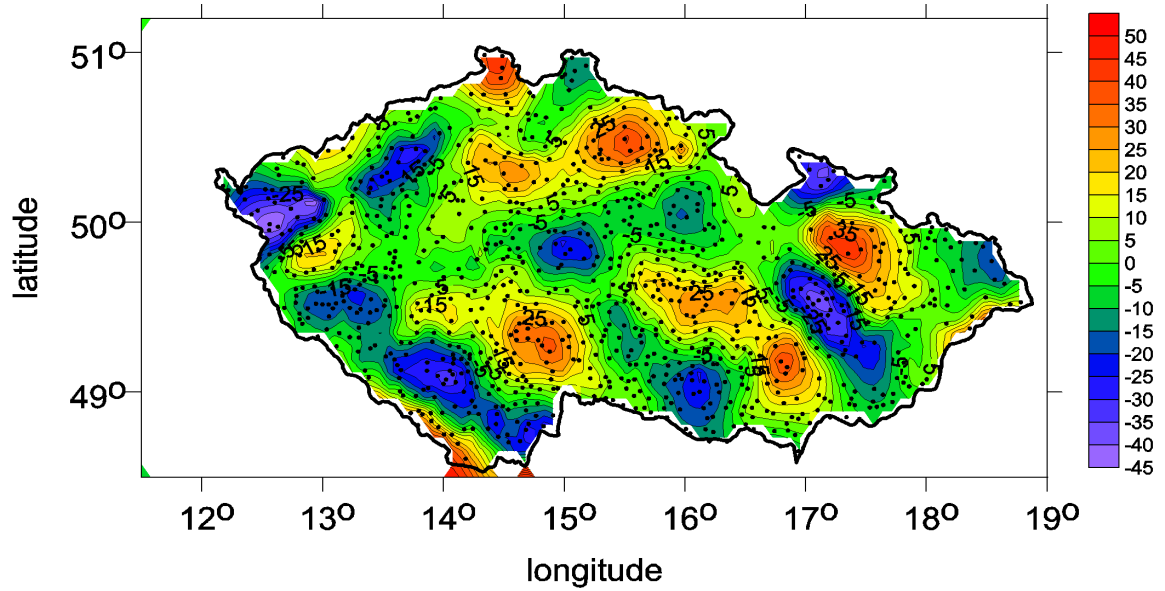Figure 3: EGM08 vs. GPS/leveling height anomalies (cm)

Figure 4: EGM96 vs. GPS/leveling height anomalies (cm)

The fit of the new EGM at the Czech GPS/leveling stations is as good as for a recent high-resolution local quasi-geoid model of the Czech Republic (Novák et al. 2003). Taking into the account the accuracy of leveled and GPS heights discussed in Section 2, one could argue the other way around: the new EGM can be used to test the quality of the national leveling network. Besides the next step in creating a truly global elevation system, this can be yet another important role of the new model: detection of possible long-wavelength (systematic) errors in existing leveling networks (removing vertical movements).

Figure 3 then shows values of the estimated differences for EGM08 and Figure 4 depicts the respective differences for EGM96. Dots represent locations of the GPS/leveling points. Both figures show using the same range of extreme values (those of EGM96) distinct patterns in the computed differences that differ in both geographical distribution and magnitude. Comparing these surfaces with that in Figure 2, there is not much of resemblance (the NW-SE tilt is not visible in the computed differences). The magnitude of the computed differences in Figures 3 and 4 exceeds the size of the estimated vertical changes of the national leveling network in Figure 2, namely those of EGM96. Some of the features in Figures 3 and 4 can at least partially be attributed to systematic observation errors in the national leveling network.

4   Conclusions

Despite the relatively small test area, EGM08 proved to be a significant progress in both accuracy and resolution relatively to EGM96. The new model outperformed EGM96 five times in terms of both characteristics. Moreover, EGM08 reached the accuracy level that was previously achievable only through the combination of global gravitational models and local ground gravity observations. The average fit of the EGM08 quasi-geoid and that computed from the combination of leveled and GPS-based geodetic heights at 1024 points reached the level of ± 3.3 cm. Since this misfit can at least partially be attributed to the observation errors in leveling and GPS positioning, we seem to get closer again – at least regionally – to a long-term target of all geodesists: a one-centimetre geoid model.

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