

# New Automatic Accuracy Evaluation of Altimetry Data: DTM 5G Compared with ZABAGED<sup>®</sup> Altimetry

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**Abstract** The paper tackles the issue of accuracy of digital terrain models, which is a long term research area at the University of West Bohemia in Pilsen. In 2014, a new generation of digital terrain models were completed in the Czech Republic. This fact initiated an impulse for new measures and tests in this field. The accuracy tests have been realized by comparing the Digital Terrain Models (DTM) of the Czech Republic—the 5th Generation (DTM 5G) and the previous generation of altimetry data from ZABAGED<sup>®</sup>. The test have been performed in two selected test fields in the Pilsen Region. This comparison was done already in previous research, but it was built on pre-released laser scanning data before the final filtration and gross error clearing. In order to confirm the results from the previous testing, the comparison has been repeated using the final dataset. The robust method of DTM accuracy evaluation developed at the University of West Bohemia in Pilsen and a highly automated implementation of the comparative method on 250 local test sites (total area of 85 km<sup>2</sup>) have been applied in this project. The algorithm's implementation is based on ArcPy libraries provided by Esri. The key parts of the Python source code are described in detail and the whole algorithm is published as open-source. The tests proved that the pre-release dataset was good enough for accuracy testing. The results are similar with the previous research. It underlines the value of the new generation of altimetry data in the Czech Republic. Their accuracy is significantly higher than the previous generation in ZABAGED<sup>®</sup>.

**Keywords** Automated processing · ArcGIS tools · Gross error visualization · Pilsen region · Altimetry

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## 1 Introduction

This work builds on the knowledge of previous works made at the University of West Bohemia in Pilsen (UWB). The quality and accuracy of state maps' DTMs were tested by Vyčichlová and Čada (2001), Šíma and Egrmajerová (2004). The original methodology for a robust DTM checking was presented by Fiala and Šíma (2006) and applied by Čada and Šilhavý (2013) when the product ZABAGED<sup>®</sup> altimetry—3D contour lines (furthermore referred to as the ZABAGED<sup>®</sup> altimetry) was tested.

The statistical methods are commonly used to assess DTM accuracy when the differences in z-value are calculated. Höhle and Höhle (2009) compares DTMs from airborne laser scanning (ALS) and digital photogrammetry with limited number of check points from ground surveying using GPS/RTK. Müller et al. (2014), Fiala and Šíma (2006) compare tested DTM against referenced DTM which leads to more values used in statistic computations. The mentioned authors do not automate the assessment process. Otherwise, this research comes with automatic tool for DTM accuracy evaluation based on methodology from Fiala and Šíma (2006).

Two generations of qualitatively different DTMs covering the Czech Republic were analysed. The previous generation is represented by the ZABAGED<sup>®</sup> altimetry and the new generation by the Digital Terrain Model (DTM) of the Czech Republic—5th Generation (furthermore referred to as DTM 5G).

This paper is bound to previous research by Čada and Šilhavý (2013), who used the pre-release ALS data after automatic classification of laser beam before the final filtration and gross error clearing (furthermore referred to as DTM from ALS). Nowadays, the new generation DTM 5G is available on the market.

The goals of this paper are to confirm the previous results achieved by Čada and Šilhavý (2013), make comparison on larger area and present the algorithm which is able to automatically compare two DTMs without subjective area delimitation according to terrain type and land cover.

## 2 Digital Terrain Models' Characteristics

The ZABAGED<sup>®</sup> altimetry was created during the years 1994–2000 by digitizing the analogue Base Map of the Czech Republic (Základní mapa ČR) 1:10,000. The altimetry has a form of 3D contour lines and covers the whole area of the Czech Republic. The basic 2-m contour interval is complemented with 1-m contours or a net of points in flat areas. In mountainous areas, the contour interval is 5 m. The altimetry accuracy is characterized by the root mean square error (mH) which depends on the terrain slope (mH = 1 m where the slope is 0°, mH = 1.5 m where the slope is up to 10° and mH = 2.5 m where the slope is up to 25°).

Between the years 2006 and 2008, the ZABAGED<sup>®</sup> altimetry was improved by using a stereo-photogrammetric processing focused on terrain edges (bank lines, earthworks, diggings, terrain steps etc.). The new product was named ZABAGED<sup>®</sup>—improved altimetry.

For the purpose of the models' comparison, the optimized DTM ZABAGED<sup>®</sup> was created from ZABAGED<sup>®</sup> improved altimetry using the ArcGIS Desktop (3D Analyst) environment. The optimization consists of altimetry elimination under specific objects (building blocks, lakes, rocky areas).

### 3 Digital Terrain Model of the Czech Republic—5th Generation (DTM 5G)

DTM 5G originated from airborne laser scanning (ALS) which was completed in 3 periods (the Central zone of the Czech Republic between March and October 2010, the Western zone between March and June 2011 and the Eastern zone until November 2013).

The LiteMapper 6800 system (IGI GmbH) was used for ALS with the RIEGL LMS-Q680 airborne laser scanner which was equipped by Global Positioning System (GPS) and Inertial Measurement Unit (IMU). The average flight heights of the ALS were 1200 and 1400 m above the terrain depending on the height of the vegetation. The scanning blocks were 10 km wide and maximally 60 km long.

The ALS data were georeferenced into the UTM/WGS 84-G873 working coordinate system and the Baltic height reference system for further processing. The automatic land cover and surface objects' data separation was made using the robust filtering method. The success rate of the automatic data separation was estimated to 30–40 % in the time of growing vegetation season and 90 % in the time outside the growing vegetation season (Brázdil 2012).

The errors caused by the automatic data separation were interactively eliminated during the next phase by manual check of the robust filtering method. This phase resulted to the ALS point cloud represented the terrain, vegetation and buildings. This dataset was used in the previous research (Čada and Šilhavý 2013) and is referred to it as DTM from ALS.

Several steps were applied to achieve the final product DTM 5G. An important step was the elimination of low vegetation in the areas covered by agriculture cultivated land (the areas of cultivated land were defined by the state agricultural land registry (LPIS database) or manually digitized by means of hillshade relief) or areas with temporary terrain roughness or areas without terrain breaks (ditches, terrain edges). In those areas, the points with lowest altitude were found in  $5 \times 5$  m grid covering the area. Such identified points were marked as terrain representatives. In other areas the workflow was identical using  $1 \times 1$  m grid.

In areas larger than 25 m<sup>2</sup> where no points were identified (water areas, areas under buildings, partly in dense vegetation), the terrain interpolation was made using 5 × 5 m grid.

The final step of DTM 5G creation consists of terrain representatives selection to achieve the same density of points over the area and smoothing the result surface when the maximal smoothing distance was 0.16 m. The height of every terrain representative point was corrected by the influence of the systematic error. This error was estimated to 0.0034 m based on measuring on comparative baselines (soccer fields, tennis courts, squares) in the Central zone. The accuracy of points on comparative baselines was characterized by root mean square coordinate and height error  $m_{XY} = m_H = 0.03$  m when using the RTK method. The final point cloud in the UTM/WGS 84-G873 coordinate system was transformed to the DTM 5G product in the national S-JTSK coordinate system using local transformation formulae of VÚGTK.

The DTM 5G product is distributed in form of triangular irregular network (TIN). According to Brázdil (2012), the supposed RMSE of heights is 0.18 m in the terrain without continuous vegetation and buildings and 0.30 m in the terrain with dense vegetation.

## 4 Methodology

The Czech method of DTM checking presented by Fiala and Šíma (2006) was applied in the same manner as by Čada and Šilhavý (2013) in order to preserve the same research conditions.

The method is based on surface differences where the quality of models is determined by difference volume ( $V$ ) related to difference area ( $S$ ). The mean height error ( $m_H$ ) is estimated by empiric equation:

$$m_H^2 = \sigma_H^2 + s_H^2 \quad (1)$$

$$m_H^2 = 1.25 * a_H^2 \quad (2)$$

$$a_H = \frac{\sum |V|}{S} \text{ (m)} \quad (3)$$

$$s_H = \frac{\sum V}{S} \text{ (m)} \quad (4)$$

More detailed description of this method can be found in Fiala and Šíma (2006), Čada and Šilhavý (2013).

## 5 Implementation

Fiala and Šíma (2006) implemented the robust method using the Atlas DTM software. The scripting was not used thus the manual workflow was required. In Čada and Šilhavý (2013), the semi-automated scripts using the ArcGIS software were presented. The scripts are extended to use a full automatic workflow (see Fig. 1).

By user defined processing area is automatically divided into 1 km<sup>2</sup> polygons. The program computes the comparison for each input polygon. It is also possible to provide a path to a directory with a set of shapefiles which includes customized areas to be processed. The statistics are computed for every shapefile separately. It allows defining classes for the computation. This capability can be used for example to separate areas with different slope or vegetation. The area of 1 km<sup>2</sup> is recommended setting for stable computing. More computing memory is required when this value would be increased.

The steps of automatic division are depicted in Fig. 2. The input processing extent is overlaid by an automatically generated grid of polygons, which are intersected by the input extent. It is hard to interpolate TIN analysis for small and narrow polygons, thus polygons smaller than 0.3 km<sup>2</sup> are deleted.

The tested and referenced DTMs in form of TIN representation are required as input to the surface comparison. The TIN representation is interpolated from source data using CreateTIN tool from the ArcGIS Toolbox. In large areas the interpolation of TIN could be demanding on memory and CPU. Therefore the TIN is created from source data for each polygon separately.

The mapping of source data to parameters for the TIN construction is made in the user configuration. The input data path, Z coordinate location and surface feature type are specified in parameters according to the CreateTIN tool. For example:

```
param_TIN(testedDTMDir + "ndexContours.shp", "Shape.Z", "softline")
param_TIN(referencedDTMDir + "kozel.gdb\points_XYZ", "Shape.Z", "masspoints")
```

In this way, the input data can be either ALS point cloud or 3D features such as contours, spot heights and terrain edges.

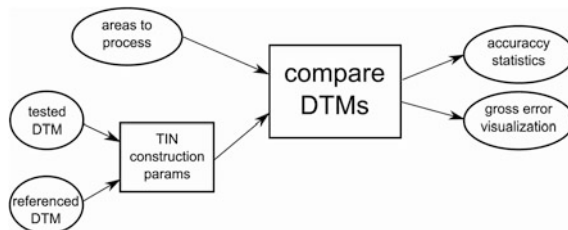


Fig. 1 Schema of algorithm to automatic altimetry accuracy evaluation

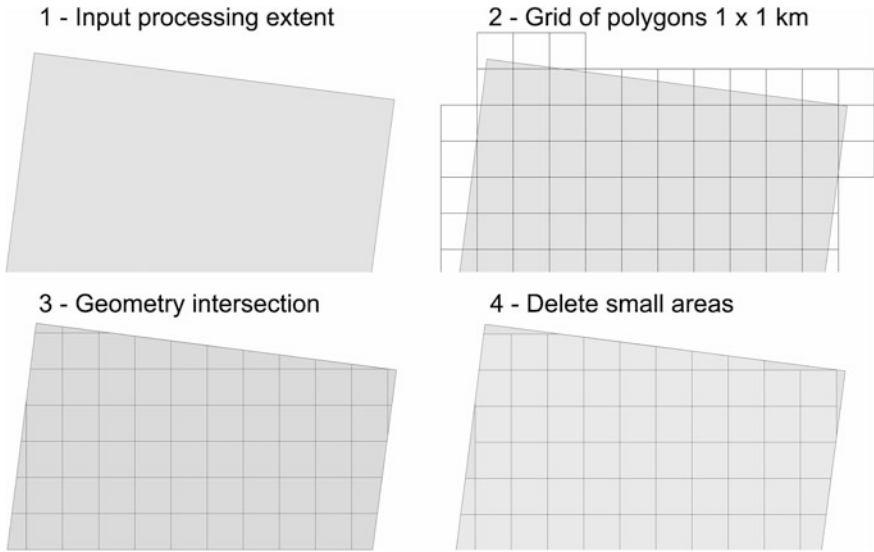


Fig. 2 Automatical creation of process areas

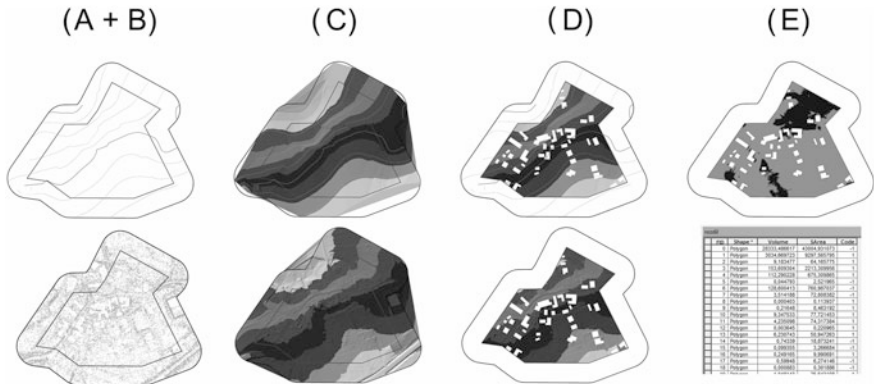


Fig. 3 Algorithm's workflow

The workflow of the algorithm has five key steps (Fig. 3).

- A. Buffer creation around the input polygon
- B. Clipping the source data using the buffer
- C. TIN creation from clipped source data
- D. Clipping TIN to the original extent and erasing areas excluded from the comparison
- E. Computing the surface differences to obtain the statistics

In border areas of the input polygon the quality of TIN interpolation can be affected by missing data due to irregular shape. For this purpose the TIN is calculated inside the buffer zone around the input polygon. The size of the buffer zone is defined by the user as a parameter. It is recommended to estimate it from the characteristics of the source data (shape of the input polygons, the density of source data). In our case, the parameter was chosen 50 m due to average distance between two contour lines in the tested dataset.

After the TIN creation it is cropped to the original size of the input polygon. Moreover, the areas of buildings, lakes and rocks were erased from the TIN. The selection of areas to be excluded was made according to the genesis of DTM ZABAGED<sup>®</sup>. The Edit TIN tool was used with the parameter hard clip set to input polygon and parameters hard erase set to layers representing areas to be excluded.

In final step the geometric comparison between the tested and reference surfaces is made in order to get the volumetric differences. The Surface Difference tool from the ArcGIS Toolbox has two important outputs. The output raster contains height differences between surfaces interpolated for each cell. The output polygons contains all necessary information to compute accuracy statistics.

## 6 Results

The three datasets used in this research are shown in Fig. 4—(A) Plzeň, (B) Kozelsko, (C) Brdy. The small polygons depicted inside datasets A and B represent the original tested areas used in previous research Čada and Šilhavý (2013).

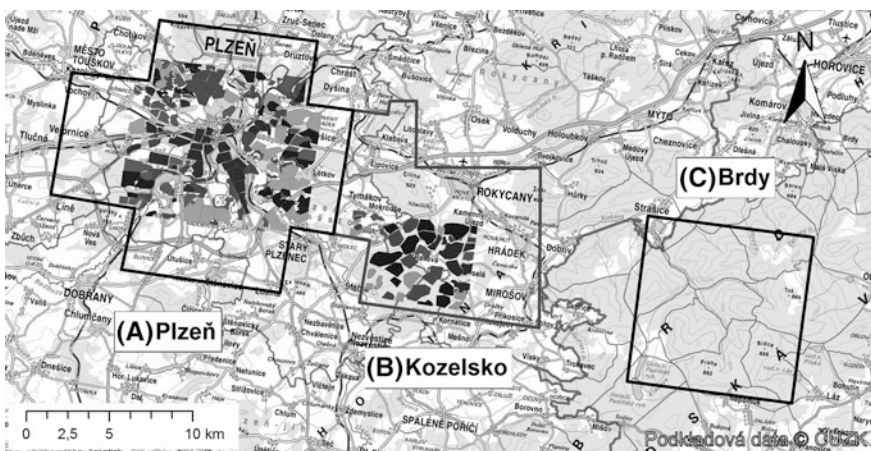


Fig. 4 Overview of tested areas

The results of three computations are presented in the form of tables and verbal description. First of all the results from the previous research by Čada and Šilhavý (2013) are summarized. After that the confirmation of these results using the new dataset is shown. Lastly, the modified technology is applied to all tested areas (Fig. 4).

## 7 Previous Research Summary

At the time of the research performed by Čada and Šilhavý (2013) the DTM 5G was not available in the final version for tested areas in the Pilsen Region. Thanks to the collaboration of the UWB with the Land Survey Office the DMR from ALS were obtained for testing.

The quality testing of the DTM ZABAGED<sup>®</sup> altimetry was made in two areas including Plzeň and Kozelsko within the total area of 85 km<sup>2</sup> (small polygons in Fig. 4). The results showed the quality problems in expressing morphological shapes of the relief and the occurrence of extensive areas with height errors exceeding three times the standard deviation. The maximum deviations reached value up to 30 m (see Fig. 5 in Čada and Šilhavý (2013) and example on the server <http://home.zcu.cz/~jsilhavy/hrubeChybyDEM.html>).

The final accuracy of DTM ZABAGED<sup>®</sup> was characterized by RMSE of heights  $mH = 0.86$  m (see Table 1). This parameter was exceeded about 50 % in forested areas. The worst accuracy was recorded in such areas with extreme slope (more than 15°) where the height error reached about 130 % [see Tables 5 and 6 in Čada and Šilhavý (2013)].

The systematic error was  $-0.23$  m. This means that DTM ZABAGED<sup>®</sup> is systematically up the reference model DTM from ALS.

## 8 Influence of Difference Between DTM from ALS and DTM 5G

The discussion about results of the research of Čada and Šilhavý (2013) pointed out that they might be affected by the fact, that the DTM from ALS was used instead of the final DTM 5G product. Thanks to the Land Survey Office, the product DTM 5G was obtained in order to repeat the analysis of the previous research with this new data. The results' summary from Čada and Šilhavý (2013) is shown in Table 1 whereas full results from the new computation in the same areas are shown in Table 2 and Table 3.

The new analysis confirms the original conclusion made by Čada and Šilhavý (2013) that the local gross errors in results are not caused by using DTM from ALS. Therefore this dataset can be used for the accuracy evaluation of DTM ZABAGED<sup>®</sup>.



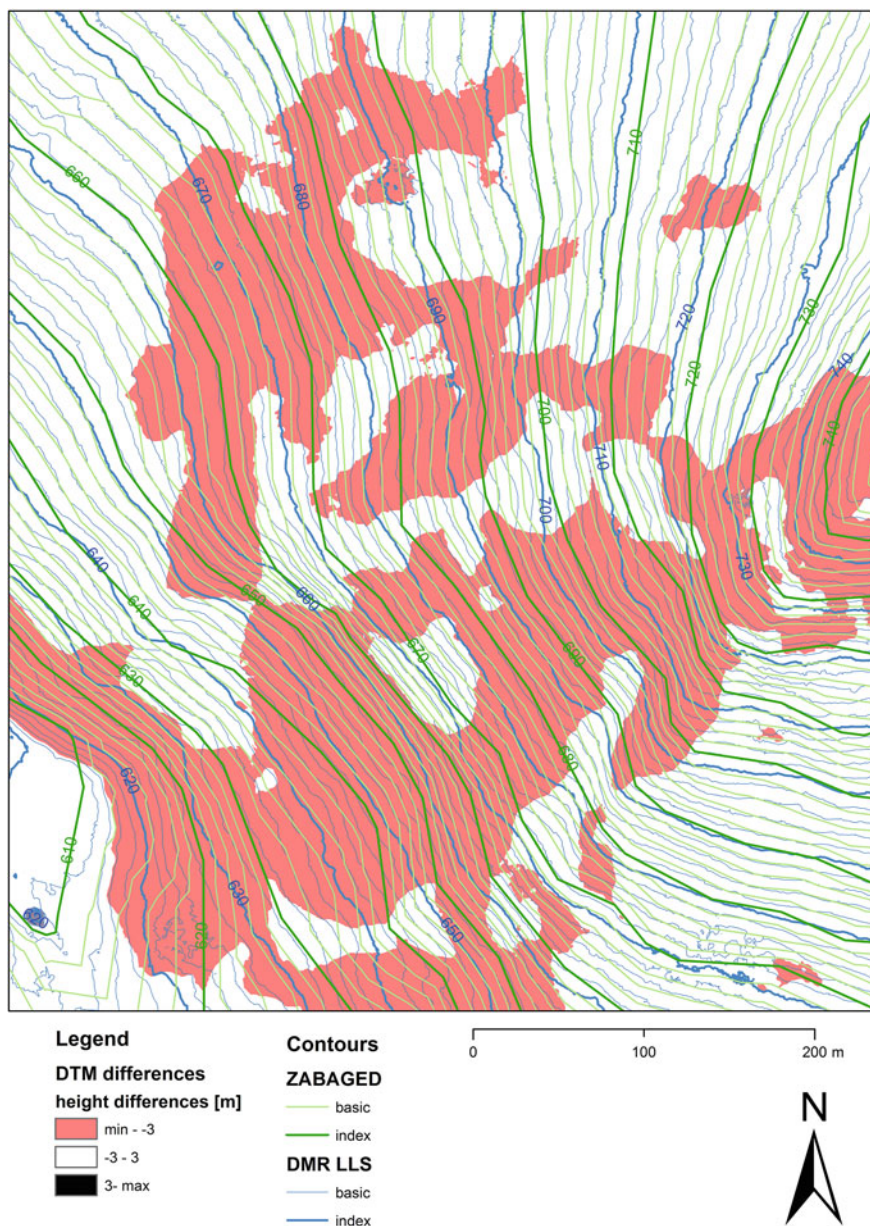


Fig. 5 Gross error occurrence in the area Brdy

**Table 1** The summary of results from research work of Čada and Šilhavý (2013)

Area	aH (m)	sH (m)	$\sigma$ H (m)	mH (m)	$\sum V $ (m <sup>3</sup> )	$\sum V$ (m <sup>3</sup> )	S (km <sup>2</sup> )
Plzeň DTM ALS	0.76	-0.16	0.94	0.95	16,828,420	-3,474,831	22.1
Kozel DTM ALS	0.66	-0.25	0.78	0.82	38,637,139	-14,839,135	58.8
Total	0.69	-0.23	0.83	0.86	55,465,559	-18,313,966	81.0

**Table 2** The summary of altimetry accuracy in the area Kozelsko

Type of relief	Land cover	aH (m)	sH (m)	$\sigma$ H (m)	mH (m)	$\sum V $ (m <sup>3</sup> )	$\sum V$ (m <sup>3</sup> )	S (km <sup>2</sup> )
Planar	Forest	0.43	-0.17	0.51	0.53	2,039,534	-794,902	4.8
	Field	0.41	0.01	0.52	0.52	629,675	7882	1.5
	Urban area	0.52	-0.20	0.62	0.65	138,032	-52,194	0.3
Slope (up to 15°)	Forest	0.97	-0.26	1.18	1.21	7,628,252	-2,039,891	7.9
	Field	0.52	-0.11	0.64	0.65	1,865,534	-398,590	3.6
	Urban area	0.72	-0.15	0.89	0.90	318,501	-66,753	0.4
Slope (more than 15°)	Forest	1.23	-0.18	1.52	1.53	3,833,945	-567,178	3.1
	Field	0.90	-0.21	1.11	1.13	216,443	-51,135	0.2
	Urban area	0.76	-0.16	0.94	0.95	115,358	-23,923	0.2
Total Kozelsko		0.76	-0.18	0.94	0.95	16,785,275	-3,986,685	22.0

**Table 3** The summary of altimetry accuracy in the area Pilsen

Type of relief	Land cover	aH [m]	sH [m]	$\sigma$ H [m]	mH [m]	$\sum V $ [m <sup>3</sup> ]	$\sum V$ [m <sup>3</sup> ]	S [km <sup>2</sup> ]
Planar	Forest	0.61	-0.36	0.67	0.76	2,767,086	-1,641,262	4.5
	Field	0.34	-0.06	0.43	0.43	1,716,521	-289,563	5.0
	Urban area	0.50	-0.23	0.57	0.62	4,083,105	-1,931,586	8.2
Slope (up to 15°)	Forest	0.75	-0.41	0.85	0.94	5,284,510	-2,861,804	7.0
	Field	0.46	-0.24	0.52	0.57	6,667,702	-3,521,908	14.5
	Urban area	0.65	-0.40	0.71	0.82	4,775,731	-2,926,711	7.3
Slope (more than 15°)	Forest	1.61	-0.18	2.01	2.01	7,739,914	-862,065	4.8
	Field	0.62	-0.28	0.72	0.78	1,992,980	-902,975	3.2
	Urban area	0.96	-0.31	1.16	1.21	3,724,348	-1,209,864	3.9
Total Plzeň		0.66	-0.28	0.78	0.83	38,751,898	-16,147,737	58.4
Total both areas		0.69	-0.25	0.83	0.86	55,537,173	-20,134,422	80.4

**Table 4** The summary of altimetry accuracy in the areas Pilsen, Kozelsko and Brdy

Area	aH (m)	sH (m)	$\sigma$ H (m)	mH (m)	$\Sigma V $ (m <sup>3</sup> )	$\Sigma V$ (m <sup>3</sup> )	S (km <sup>2</sup> )
Pilsen (DTM 5G)	0.61	-0.18	0.74	0.76	114,809,262	-32,913,682	187.8
Kozelsko (DTM 5G)	0.66	-0.14	0.81	0.82	72,989,259	-16,008,122	111.3
Brdy (DTM ALS)	1.12	0.05	1.40	1.40	111,279,613	4,584,583	99.5
Total	0.75	-0.11	0.93	0.94	299,078,133	-44,337,221	398.5

## 9 Evaluating of ZABAGED<sup>®</sup> Altimetry Using Modified Technology

The subjective delineation and classification of areas according to the type of relief and land cover was time consuming in the current method. Moreover, not the whole area is taken into the comparison due to spaces between areas. This reasons led to modify the algorithm to automatically creating of tested areas covering the whole study area. The results using the modified algorithm are summarized in Table 4 for the areas Kozelsko and Plzeň (see Fig. 4a, b).

In both areas 340 automatically generated polygons with the total area of 318 km<sup>2</sup> were tested. The RMSE of heights was found 0.76 m for the Pilsen Region and 0.82 for the Kozelsko region. Better results compared with the previous 0.86 m (see Table 1) might be influenced by larger area with more flat terrain and agriculture land cover.

The modified algorithm did not allow the automatic classification according to the relief type and land cover but it only served for the height accuracy comparison. The automatic classification of the tested areas could extend the algorithm in further research.

## 10 Extending Test Areas to Brdy

It was easy to extend the comparison to the new area using fully automatic method. The data from the research of Vichrová and Čada (2012) in the area of Brdy (see Fig. 4c) was used to compare 107 new areas in total area of 100 km<sup>2</sup>.

RMSE of heights 1.4 m (see Table 4) was influenced by the terrain type where the forested areas with steep terrain are dominated. The accuracy of such a type of terrain was found from 1.21 to 1.53 m in similar terrain in Kozelsko (see Table 2). The gross errors occurrence is depicted in Fig. 5.

## 11 Conclusion

The analyses clearly demonstrated the need to test the ZABAGED<sup>®</sup> altimetry before using it in GIS analyses when the high accuracy better than 1 m is required.

The previous study of Čada and Šilhavý (2013) aimed at getting the results dependent on the relief type and land cover. New results using the DTM 5G confirmed that using the DTM from ALS has no negative impact to accuracy of altimetry comparison when the robust method of DTM checking is used.

DTM 5G is an important source for improving accuracy of ZABAGED<sup>®</sup>. The altimetry is not only an object to be improved. The planimetric component of this database will be also influenced by changes in altimetry (rivers, roads, railroads, walls etc.).

The evaluation of height accuracy of ZABAGED<sup>®</sup> is very important for user applications which still use DTM ZABAGED<sup>®</sup> as an input for analyses (flood modelling, maps as source for insurance contracts, protecting agricultural land from erosion where the land consolidation is designed, creating analytical documentation for local and regional space planning).

The presented tools are able to evaluate the ZABAGED<sup>®</sup> altimetry and effectively visualize areas with the gross errors. The algorithms are available on the website <http://home.zcu.cz/~jsilhavy/DTM>.

## References

- Brázdil K (2012) Technical report DTM 5G. Zeměměřický úřad a Vojenský geografický a hydrometeorologický úřad. [http://geoportal.cuzk.cz/Dokumenty/TECHNICKA\\_ZPRAVA\\_DMR\\_5G.pdf](http://geoportal.cuzk.cz/Dokumenty/TECHNICKA_ZPRAVA_DMR_5G.pdf). Accessed 13 Dec 2014
- Čada V, Šilhavý J (2013) Comparison of accuracy of the ZABAGED<sup>®</sup> altimetry—3D contour lines product with data gained by aerial laser scanning of the entire territory of the Czech Republic. *Geodetický a kartografický obzor* 59/101(8):173–181. ISSN 0016-7096
- Fiala R, Šíma J (2006) The Czech method of DTM checking. EuroSDR Official Publication, vol 51, pp 87–94
- Höhle J, Höhle M (2009) Accuracy assessment of digital elevation models by means of robust statistical methods. *ISPRS J Photogram Remote Sens* 64(4):398–406. <http://dx.doi.org/10.1016/j.isprsjprs.2009.02.003>. ISSN 0924-2716
- Müller J, Gärtner-Roer I, Thee P, Ginzler C (2014) Accuracy assessment of airborne photogrammetrically derived high-resolution digital elevation models in a high mountain environment. *ISPRS J Photogram Remote Sens* 98:58–69. <http://dx.doi.org/10.1016/j.isprsjprs.2014.09.015>. ISSN 0924-2716
- Šíma J, Egrmajerová L (2004) Accuracy verification of DTM ZABAGED<sup>®</sup>. *Geodetický a kartografický obzor* 50/92(11):213–231. ISSN 0016-7096
- Vichrová M, Čada V (2012) Digital terrain model of the second military survey—part of the military training area Brdy. *Geoinformatics* 2011(6):346–353. ISSN 1802–2669
- Vyčichlová V, Čada V (2001) The quality assessment of state map 1:5000. *Kartografické listy* 9:79–92. ISSN 1336-5274