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# Verification of Accuracy of the New Generation Elevation Models

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**Abstract:**

*Military and civil applications use more and more often digital elevation models (DEM) in order to get terrain spatial information. During last two decades in the Czech Republic there were used several DEMs. The accuracy and details of the models are no longer meeting current requirements, so in 2008 there was worked out the project of forming the new altimetry of the Czech Republic for 2009-2015. It is based on a modern technology of airborne laser scanning. On the basis of laser data there are gradually formed new elevation models – Digital terrain model of the 4th generation and the 5th generation (DMR 4G, DMR 5G) and Digital surface model (DMP). This paper deals with aerial laser scanning of the Czech Republic and the accuracy verification results of continuously formed DMR 4G and DMR 5G.*

**Keywords:**

*DTM (digital terrain model), DEM (digital elevation model), aerial laser scanning (ALS), accuracy analysis.*

## 1. Introduction

The knowledge of information dealing with the environment and our position is required from time immemorial. People always needed to know such information. At the very beginning it was necessary for them to be able to survive, later on to improve the quality of their lives. For that reason people have been recording information about the landscape into different maps, drawings, diagrams and other sources for centuries. The methods of creating maps and other geospatial products have been improved and specified. At the same time the possibilities of their usage have been extended and these products have penetrated many branches of human activity. The information about elevation proportions is one of essential details which are important for working with

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geographic data. In the first maps there were used the pictorial form of relief and hatching [1]. Much more accurate depiction could be achieved by using contour lines and elevation points [2] which are the basic way of depiction on present altimetry maps. In some cases, the special maps could be supplemented or replaced with a shaded relief model or hypsometry.

The DTM creation was initiated with the digital technology development [2, 3]. Digital elevation models have been used in a broad spectrum of natural and social scientific disciplines. Due to DTM, users are able to create a 3D conception of local relief division. (DTM of the Czech Republic has been in the process of its creation and the contribution will offer a wider range of digital elevation products, and their bigger practical usage.) A user can carry out various terrain analyses and simulations of activities above the terrain. On the basis of the information, users can create theories and forecasts of the state or situation in a monitored area.

The usage of DTM is most common especially in these areas:

- urbanism, urban planning [4, 5] and transport [6, 7];
- agriculture and water management [8, 9];
- photogrammetry and remote sensing [10, 11];
- industry and power engineering [12];
- military [7, 13 and 14].

## 2. Technology of Aerial Laser Scanning

Aerial laser scanning (ALS) is one of the state-of-art technologies which enables to acquire spatial geographic data and consequently to create DTM [15]. This technology is used especially for creating very precise DTM and in situation where a great amount of input data is required. Previous geodetic and photogrammetric methods had a lot of limitations, the most significant of them being, according to [11], time intensity and considerable personnel proficiency during the terrain data collection. Another important disadvantage of the photogrammetric data collection is the photograph taking dependency on the season and weather conditions. For these reasons an operator must be present during this process and thus it is impossible to use automatic data collection without any supervision. These aspects together with the development of technologies contributed to the implementation of mass automatic determination of spatial points, so called 3D scanning, especially the methods of laser scanning.

The ALS system is composed of the laser scanner, the GPS receiver, the inertial measuring unit (IMU) and the control unit [15]. This system is usually complemented with a device recording an image of the scanned area (for example RGB scanner, video camera and suchlike). The laser scanner works on the principle of a high-speed rangefinder with passive reflection. The laser scanner pulses are emitted to the interest directions and after their reflection from the measured objects they are captured by the sensor of the scanner. Thanks to the GPS and IMU the location and orientation both of the scanner and of the emitted and received rays are determined at any instant. From the measured time-of-flight of the ray to the measured object and back the distance between the measured object and the scanner sensor is determined. From the known parameters it is possible to compute spatial coordinates of every detected point using the spatial polar method (Fig. 1). The result of this process is so called “cloud” of 3D points. Consecutively the reflection intensity is evaluated. Some scanners are even able to record the serial number of the reflection (so called echo).

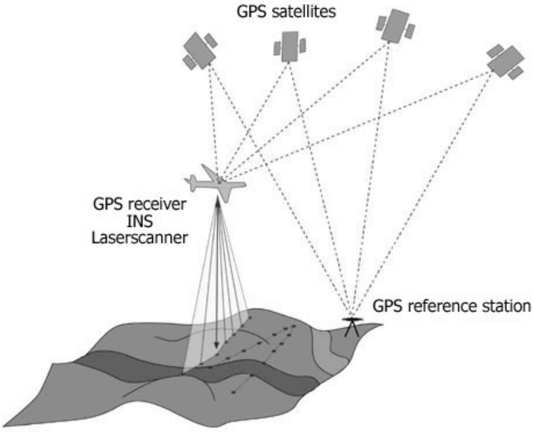

*Fig. 1 Principle of the method ALS* [16]

The size of the radiated angle differs according to various scanning systems. The density of the obtained points is thus dependent on the flight velocity and height. The emitted beam has a divergent character. This means the beam has a very small diameter at the moment of its emission and till the moment of the beam reflection the beam diameter is getting bigger. Depending on the height of the flight the border lines of the beams may come closer or even overlap. The average value of the beam is chosen from the range of 0.1m to 3.8m depending on the type of the system and the height of the flyover (Fig. 2).

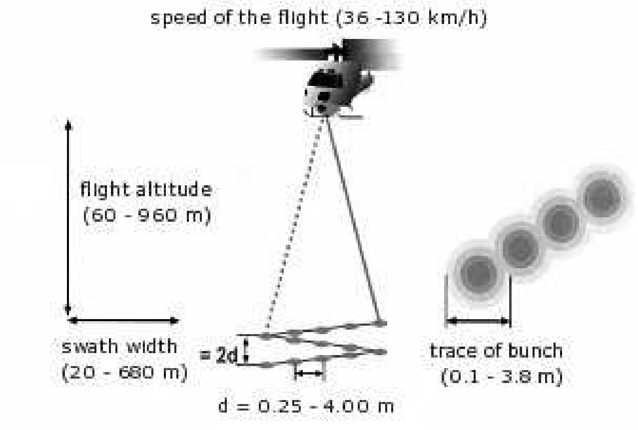

*Fig. 2 Parameters affecting the diameter of the traces of bunched beam* [5]

Laser scanning as an active digital system offers many advantages, especially:

- independence on the sunlight intensity, the measurements can be done 24 hours a day;
- collection of a vast amount of spatial data within a short period of time with high points density;
- high labour productivity;
- high internal accuracy of the measured spatial data (centimetres to tens of centimetres).

The main disadvantages are:

- limitations by weather conditions (atmospheric refraction);
- limitations by the terrain conditions (for example absorption by water in waterlogged areas );
- limitations resulting from the geometry of the scanned objects (shading);
- difficultly detectable edges;
- functional and technological limitations (structure of the optical-mechanical elements);
- high quality of hardware requirements due to the large volume of processed data;
- highly time-consuming processing;
- special software apparatus for processing of the “clouds” of points.

## 3. The ALS Results in the Czech Republic

In the past decades a few digital height models were created in the Czech Republic. These models were made using either cartometric methods by deriving from topographic or basic maps, or stereo photogrammetric methods by evaluation of the aerial survey photographs. In the civil sector these models are labelled ZABAGED (Czech acronym for “fundamental base of geographic data”). Nowadays two models are provided to the users, ZABAGED- altimetry 3D contour and ZABAGED – altimetry grid 10x10 [17]. In the military sphere two kinds of models of the relief are provided: DTED (Digital Terrain Evaluation Data) Level 0, 1 and 2 and also DTM 1, 2, 2.5 and 3 [18].

In dependence on new users’ requirements dealing with the quality and accuracy of the altimetric data, opening GIS programme environment technologies to a large number of new users, and new technologies enabling more effective and accurate data collection, in 2008 a new project covering new mapping of the altimetry of the Czech Republic was started. Civilian sector, as well as the military one, takes part in this project which was designed under the Cooperation contract on the digital database creation of the altimetry of the Czech Republic made by the Czech Geodetic and Cadastral office, the Ministry of Defence and the Ministry of Agriculture [19]. The project is a foundation for the creation of a new altimetry model of the Czech Republic using the ALS technology. In the years 2010 to 2011 the scanning took place in predefined sectors and after a year-long suspension of work it was finished in 2013 (Fig. 3).

Due to the project these new products will be released in the years 2013 to 2015:

- Digital terrain model of the Czech Republic 4th generation (DTM 4G);
- Digital terrain model of the Czech Republic 5th generation (DTM 5G);
- Digital surface model of the Czech Republic 1st generation (DSM 1G).

DTM 4G shows earth’s terrain (natural as well as modified by the human activities) in a digital form showing the altitudes of individual points in a regular grid of points 5x5 m with coordinates X, Y, H, where H means the altitude in the Baltic Vertical Datum - after the adjustment with a total standard error of 0.3 m of height in the bare terrain and 1 m in a forested terrain. DTM 4G resulted from gradual scanning of relevant areas and was formed within 6 months since the beginning of scanning. By the end of 2013 it was processed for the whole Czech Republic [20].

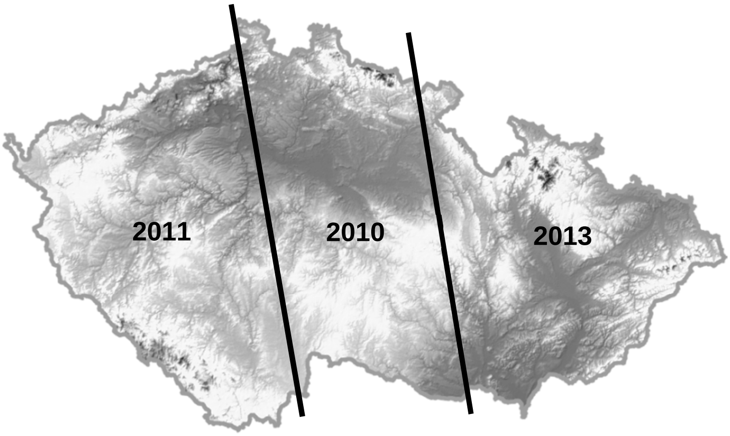

*Fig. 3 Zone of the scanning for creating a new generation of DTM*

DTM 5G represents a picture of earth's terrain in a digital form as well, however it shows the altitudes of individual points in an irregular triangular network (TIN) with a total standard error of height 0.18 m in the bare terrain and 0.3 m in a forested terrain. According to [21] the DTM 5G is supposed to be gradually formed within 30 months after the terrain scanning. The state of DTM 5G processing up to 29th October 2013 is shown in Figure 4.

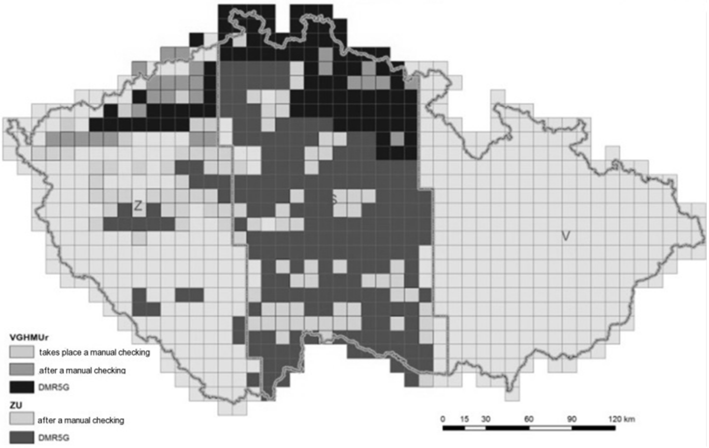

*Fig. 4 Stage of process up to 29th October 2013* [VGHMÚř Dobruška]

DSM 1G represents the image of the territory including buildings and vegetation in a form of an irregular network of altitudinal points (TIN) with a total standard error of the height 0.4 m for precisely delineated objects (buildings) and 0.7m for objects that are not precisely limited (forests and other vegetation elements). According to [19] the DSM 1G is supposed to be gradually formed within 30 months after the terrain scanning.

## 4. Check Geodetic Measurement

Several reference data sources are used to verify new elevation models accuracy [20, 21]:

- sets of checkpoints at special comparison bases;
- heights of chosen fundamental horizontal control points;
- local check geodetic measurements.

In this case the method of check geodetic measurements was chosen. The choice of this method was based on the accessibility of areas with already processed DTM and on its suitability for data collecting within final student projects of Military geography and meteorology specialization at the University of Defence [22, 23]. Terrain checkpoints heights were determined trigonometrically with the help of total station Leica TC 1500. On the grounds of an easier approach and orientation there were used near points of the fundamental horizontal control, trigonometric stations, and net densification points the heights of which were determined trigonometrically or by levelling.

There were chosen four areas nearby Velká Bíteš in which more than 800 checkpoints were surveyed. In all areas for checkpoints net surveying with the help of cross sections there were used mainly terrain lines (edges) of roads with longitudinal ditches and vicinity. The schematic picture of the cross sections with the checkpoints location on individual terrain lines (edges) is given in Figure 5.

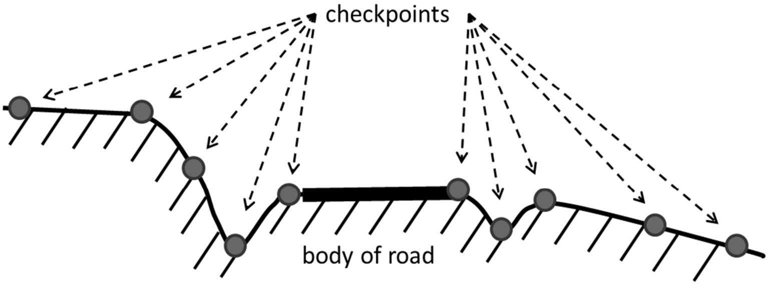

*Fig. 5 Schematic layout of control points in the cut of terrain*

The aim was to determine the interpolation accuracy of DTM 4G points heights in chosen areas. At the same time, there characteristics of the surface and the vegetation cover of individual measured checkpoints were recorded – if it is paved surface (usually the edge of the road), arable soil, grass surface, shrubbery or avenue.

As an example an area is presented with net densification point number 215 (see Fig 6) the height of which was determined by levelling. The terrain relief is quite broken mainly in the immediate neighbourhood of the net densification point. It was possible to choose checkpoints on terrain lines because the road is partly run in a trench and partly on an embankment, and on both sides of the road there are ditches.

From the point of view of the coverage, the terrain in this area is also very convenient for check measurements. Individual points were determined on the edge of the asphalt road, on the grass surface, in low shrubberies, under the avenue, and on a cultivated land. In this area two measurements were carried out in different seasons and in total, nearly 340 checkpoints were determined.

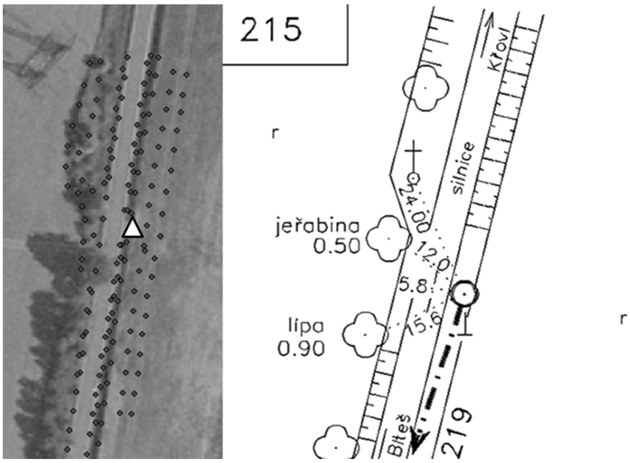

*Fig. 6 Area with net densification point number 215*

## 5. Sets of Deviations Testing and Accuracy Verification

By the comparison of the altitude of the geodetically determined points with the altitude of the corresponding point in DTM we obtain sets of deviations. Using these sets of deviations it is possible to verify the accuracy of the newly formed altimetry model. Due to the vast number of the localized measured altitudinal points, we can presume that the distribution of the deviations $\varepsilon$ lies in the closed interval around the zero value and their distribution has the shape of normal division. For the sets with normal division it is possible to determine the value of the mean error and compare it to the stated value of the altimetry model, using the formula:

$$m = \sqrt{\frac{\sum \varepsilon^2}{n}} \tag{1}$$

Despite a significantly large set of the localized points $n$, it is impossible to exclude the possibility of the presence of systematic and other phenomena that could affect the results. Therefore, it is necessary to carry out the tests of normality for the given sets before the actual calculation of mean errors. For normality tests empiric moments and three statistical tests were used:

- null hypothesis testing;
- asymmetric distribution testing;
- distribution eccentricity evaluation.

All the three tests are used for the geodetic measurements testing and they are defined for example in [24].

The null hypothesis testing is used to verify whether the set of random variables has a mean value equal to zero. If the mean value of the given set satisfies the condition:

$$-t_\alpha \sigma_{\overline{X}} \leq \overline{X} \leq t_\alpha \sigma_{\overline{X}} \tag{2}$$

where $\sigma_X$ is the standard deviation of the chosen set and $t_\alpha$ is the coefficient of the distribution function of normal division for the chosen level of significance, it is possible to accept the null hypothesis on the given significance level.

When testing the skewness using the 2nd and 3rd central moment according to the formula (3) we can calculate the coefficient of asymmetry $A$ and the standard deviation of this coefficient $\sigma_A$. The central moments are used regarding the elimination of the effect of the possible distribution centre shift.

$$A=\frac{M_3}{M_2^{3/2}} \quad , \quad \sigma_A=\sqrt{\frac{6(n-2)}{(n+1)(n+3)}} \tag{3}$$

In case of normal division it applies that $A = 0$, if on the defined level of significance the condition stated in formula (4) applies, we cannot reject the hypothesis staying that the coefficient of asymmetry equals zero.

$$-t_\alpha \sigma_A \le A \le t_\alpha \sigma_A \tag{4}$$

The kurtosis (eccentricity) criterion serves to evaluate spikiness of the frequency curve of the chosen set compared to the normal distribution characterized by the Gauss curve. For the consideration of the eccentricity existence, the eccentricity coefficient $E$ and its standard deviations $\sigma_E$ are used. These values are calculated according to the formula (5) using the 2nd and 4th central moment.

$$E=\frac{M_4}{M_2^2}-3 \quad , \quad \sigma_E=\sqrt{\frac{24n(n-2)(n-3)}{(n+1)^2(n+3)(n+5)}} \tag{5}$$

If on the chosen level of significance the following condition applies, we do not reject the hypothesis that the eccentricity coefficient of the tested set equals zero.

$$-t_\alpha \sigma_E \le E \le t_\alpha \sigma_E \tag{6}$$

For the testing of all the sets of deviations the selected level of significance was $\alpha = 0.05$. In Table 1 there are basic characteristics for individual sets of deviations which is the number of points, minimal and maximal value of the deviation, median and mean. There are also the real values of asymmetry and eccentricity of the sets and the limits for the tested level of significance. The values are stated in metres.

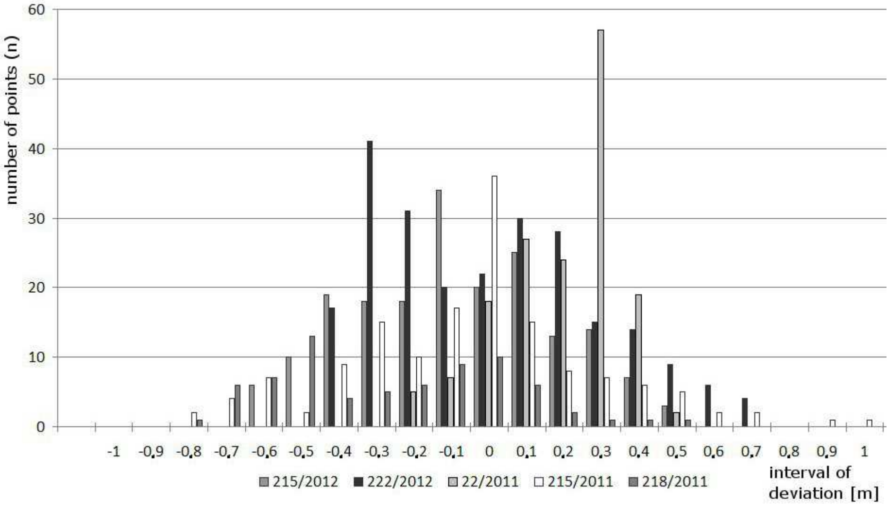

*Fig. 7 Histogram distribution of deviations in individual sets*

The results of normality tests did not confirm normal distribution of the deviations in individual sets. For most of the sets it was necessary at least two tests to reject the normality hypothesis on the selected level of significance. These results are also obvious from the histogram (Fig. 7). That is why all the deviations were put together into one large set which was then retested. In this case the results were favourable and there was no reason to reject the normality hypothesis. The histogram for all the deviations is in Figure 8. Because we were not able to prove the normal distribution of the altitudinal deviations, the 95% confidential interval was used to determine the accuracy. If we compare the measured values with a double mean error of the tested DTM 4, we can say that regarding accuracy the model amounts to the stated values.

*Tab. 1 Basic characteristics for individual sets of deviations*

| **locality (year)** | **215 (2012)** | **222 (2012)** | **22 (2011)** | **215 (2011)** | **218 (2011)** | **SUM** |
|---|---|---|---|---|---|---|
| number of points ($n$) | 187 | 237 | 159 | 151 | 72 | 806 |
| $\varepsilon_{min}$ | –0.66 | –0.46 | –0.25 | –0.83 | –0.89 | –0.89 |
| $\varepsilon_{max}$ | 0.41 | 0.69 | 0.45 | 1.28 | 0.44 | 1.28 |
| median | –0.11 | –0.06 | 0.2 | –0.08 | –0.29 | –0.05 |
| mean ( $\overline{X}$ ) | –0.124 | –0.036 | 0.153 | –0.074 | –0.308 | –0.051 |
| $t_\alpha \sigma_{\overline{X}}$ | 0.0378 | 0.0358 | 0.0236 | 0.0579 | 0.0704 | 0.0015 |
| asymmetry ($A$) | 0.0081 | 0.4520 | –0.7711 | 0.7125 | 0.1843 | 0.0527 |
| $t_\alpha \sigma_A$ | 0.3529 | 0.3132 | 0.3832 | 0.3933 | 0.5739 | 0.1693 |
| excess ($E$) | –0.7633 | –0.7286 | –0.1394 | 1.7744 | –0.8441 | 0.3412 |
| $t_\alpha \sigma_E$ | 0.6747 | 0.6043 | 0.7266 | 0.7437 | 1.0207 | 0.3351 |
| **percentile 95%** | **0.57** | **0.49** | **0.34** | **0.11** | **0.73** | **0.61** |

The deviations in the tested area show a probable systematic shift amounting to centimetres towards the negative values. That could be caused by several factors. The most significant of them are:

- the vegetation occurred at the tested area during the scanning which affected the quality of reflection;
- the interpolation model chosen for the creation of DTM 4 smoothes the terrain unevenness down;
- the chosen localities come from a relatively homogenous area, so the systematic influence in the determination of the reference points altitude can occur.

Nowadays the collection of data from other localities is in progress (the environs of Brno). These data will be used to verify the findings and together with the data collected earlier will be used to verify the accuracy of another DTM 5 model.

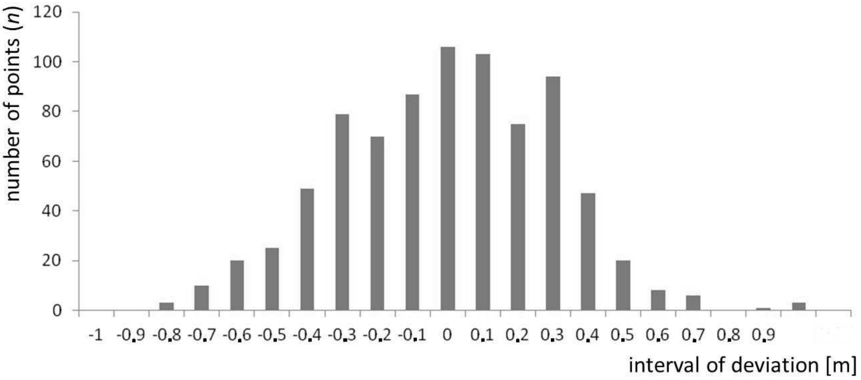

*Fig. 8 Histogram for all deviations*

## 6. Conclusion

For the accuracy verification of the new generation altimetry model DTM 4 in selected areas it was not proven that the values of the altimetry model deviations from the real terrain exceed the determined altitudinal accuracy. On the level of 95% significance we can set the maximal deviation as 0.6m. This value corresponds to the declared mean error of the model in the open terrain 0.3m [20]. Closer examination of the individual deviations distribution in the terrain confirmed that bigger errors appear mainly at the areas covered with vegetation and in places of microrelief elements (trenches, earthworks). Nevertheless the new altimetry model outshines the older models considering its accuracy. This model will be used especially in the field of altitudinal ratios modelling, radio and optical visibility analysis, crisis management support, military geographical analysis, solving water outflow rates in a given area, land erosion state observation, the creation of the terrain databases for simulators, and many other applications in both military and civilian sectors.

Until the full DTM 5 is created, the DTM 4 will still be the most accurate altimetry model of the Czech Republic. Even after finishing the DTM 5 it is expected that the DTM 4 will still be used especially for its simple data structure and lower probability of altitudinal information outdating.

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## References

[1] HARLEY, J. and WOODWARD, D. *The History of cartography*. Chicago: University of Chicago Press, 2003.

[2] ROBINSON, AH. et al. *Elements of cartography*. 6th ed. New York: Wiley, 1995. 688 p. ISBN: 978-0-471-55579-7

[3] HOŠKOVÁ-MAYEROVÁ, Š., TALHOFER, V., and HOFMANN, A. Mathematical model used in decision-making process with respect to the reliability of geo

database. *Procedia – Social and Behavioral Sciences*, 2011, vol. 9, no. 1, p. 1652-1657.

[4] HAALA, N., BRENNER, C. and ANDERS, KH. 3D urban GIS from laser altimeter and 2D map data. *International Archives of Photogrammetry and Remote Sensing*, 1998, vol. 32, p. 339-346.

[5] KAŠPAR, M. *Laser scanning systems in construction* (in Czech). Hradec Králové: Vega, 2003. 111 p.

[6] RYBANSKY, M. and VALA, M. Analysis of relief impact on transport during crisis situations. *Moravian Geographical Reports*, 2009, vol. 17, no. 3. p. 19-26.

[7] RYBANSKY, M. and VALA, M. Relief Impact on Transport. In: *ICMT'09: International Conference on Military Technologies*. Brno: University of Defence, 2009, 9 p.

[8] VRANKA, P. and SVATOŇOVÁ, H. Continuous soil lost modeling in the Haraska Watershed – an application of 4D digital landscape model. *Moravian Geographical Reports*, 2006, vol. 14, no. 1, p. 38-45.

[9] CIBULKA, M. and MIKITA, T. Accuracy of Digital Terrain Model Generated from Airborne Laser Scanning Data in the Forest. *Geodetický a kartografický obzor*, 2011, vol. 57/99, no. 11, p. 265-269.

[10] WEHR, A. and LOHR, U. Airborne laser scanning—an introduction and overview. *ISPRS Journal of Photogrammetry and Remote Sensing*, 1999, vol. 54. no 2, p. 68-82.

[11] PAVELKA, K. and HODAČ, J. *Photogrammetry 3: digital methods and laser scanning* (in Czech). Praha: ČVUT, 2008, 190 p.

[12] SON, S., PARK, H. and LEE, KH. Automated laser scanning system for reverse engineering and inspection. *International Journal of Machine Tools and Manufacture*, 2002, vol. 42, no 8, p. 889-897.

[13] SOBOTKA, J. Comparison of Elevation Data of the Czech Republic for Design Military Constructions. *Advances in Military Technology*, 2012, vol. 7, no. 2, p. 57-63.

[14] KOVAŘÍK, V. Possibilities of Geospatial Data Analysis using Spatial Modeling in ERDAS IMAGINE. In *Proceedings of the International Conference on Military Technologies 2011 – ICMT'11*. Brno: University of Defence, 2011, p. 1307-1313.

[15] VOSSELMAN, G. and MAAS, HG. *Airborne and terrestrial laser scanning*. Boca Raton: CRC Press, 2010. 318 p.

[16] Technologies: Laser scanning. Terra Imaging [online]. [cit. 2014-04-05]. Available from: <http://www.terraimaging.de/index.php/en/technologie>.

[17] Geoportal ČÚZK (in Czech) [online], Praha: ČÚZK, 2010 [cit. 2014-02-04]. Available from: <http://geoportal.cuzk.cz>.

[18] MO ČR, Geografická služba AČR. *Catalogue of geographic products* (in Czech). Dobruška: MO ČR, 2007.

[19] BRÁZDIL, K. et al. *Detail design of elevation data processing* (in Czech). ZÚ Pardubice, VGHMÚř Dobruška, 2009. 44 p.

[20] BRÁZDIL, K. et al. *The technical report to the digital elevation model 4th generation DMR 4G* (in Czech). ZÚ Pardubice, VGHMÚř Dobruška, 2012. 11 p.

[21] BRÁZDIL, K. et al. *The technical report to the digital elevation model 5th generation DMR 5G* (in Czech). ZÚ Pardubice, VGHMÚř Dobruška, 2012. 12 p.

[22] ČEPLOVÁ, L. *Accuracy analysis of digital elevation models* [Diploma thesis] (in Czech). Brno, University of Defence, 2013.
[23] KRÁLOVÁ, B. *Development and analysis of the accuracy of digital elevation models* [Diploma thesis] (in Czech). Brno: University of Defence, 2011.
[24] BÖHM, J. *Theory of errors and adjustment calculation* (in Czech). Praha: Geodetický a kartografický podnik, 1990, 416 p.