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Elevation models on a sample area of Bőszénfa

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A B S T R A C T

Terrain models are widely used in several fields. Besides commercial Digital Elevation Models, there are open access models, as well. The available drone technology is also suitable to create elevation models. The characteristics, such as resolution, accuracy, fields of use of various models can be different.
In the present study we investigate the potential use of various DEMs on a sample field in Bőszénfa, Somogy county. If the user's aim is only to get general information on surface characteristics of a given area or there is no need for high quality geodesic data, then alternative models, such as open source DEMs are reasonable options instead of expensive, commercial models.

1. Introduction

1.1. Elevation models

Digital Elevation Models are applied to graphically represent terrains, topography of fields. Practice uses several terms for elevation modelling, however the term for digital topographical models is Digital Elevation Model. Digital Surface Models (DSM) contain data of terrain and objects as well, A Digital Terrain Model (DTM) only represents the terrain without objects on it. A DSM can be assembled from aerial photos with appropriate overlaps; while a DTM is generated by active remote sensing (RADAR, LIDAR) (Barna, 2020). Elevation models' graphical illustrations are either raster or contour line maps.

A raster DEM is a dot matrix data structure that represents a rectangular pixel grid (e.g. digital photo). Each pixel is equal to the altitude measured at that point. A contour line map is a vector representation. A contour line connects the points which are in same altitude.

Several studies have been published on DEMs. In addition to the general elevation model descriptions (Fleming et al., 2010; Telbisz et al., 2013), there are studies on individual models, e.g. Rabus et al., (2003) describe SRTM, Tachikawa et al. (2011) present ASTER GDEM.

Many authors have examined the accuracy of these models, such as Höhle and Höhle (2009) or Szabó and Szabó (2010). There are articles about comparing different relief models in different sample areas (Wang and Wade, 2008; Hayakawa et al., 2008; Rayburg et al., 2009; Szabó et al., 2015; Varga and Bašić 2015; Hu et al., 2017). Elevation models provide a number of possible applications, for example, geomorphology (Badura and Przybylski, 2005; Szabó et al., 2004), flood frequency detection (Ettritch et al., 2018), or estimation of landslide susceptibility (Józsa et al., 2019).

1.2. Pleriminary experiment

On the area of the Game Management Centre (Bőszénfa) in 2018 surface data were collected through a drone flight in order to collect surface cover information (Barna & Nagy, 2020). An

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orthophoto was purchased taken in 2015 with a spatial resolution of 40 cm/pixel and a contour line map with the HD72/EOV Coordinate Reference System (CRS) of the investigated area from the Department of Geodesy, Remote Sensing and Land Offices, under the Government Office of the Capital City Budapest (the former Institute of Geodesy, Cartography and Remote Sensing, FÖMI).

Figure 1 shows the commercial orthophoto, red line indicates the experimental field. From the contour line vector layer a Digital Terrain Model (DTM) was generating by using a GIS software. The resolution of created raster is 6.8 m/pixel. The altitude difference between the lowest and highest points is 97.5 meter (167.5 and 265 m, respectively). This generated DTM was used as the basis for the comparisons.

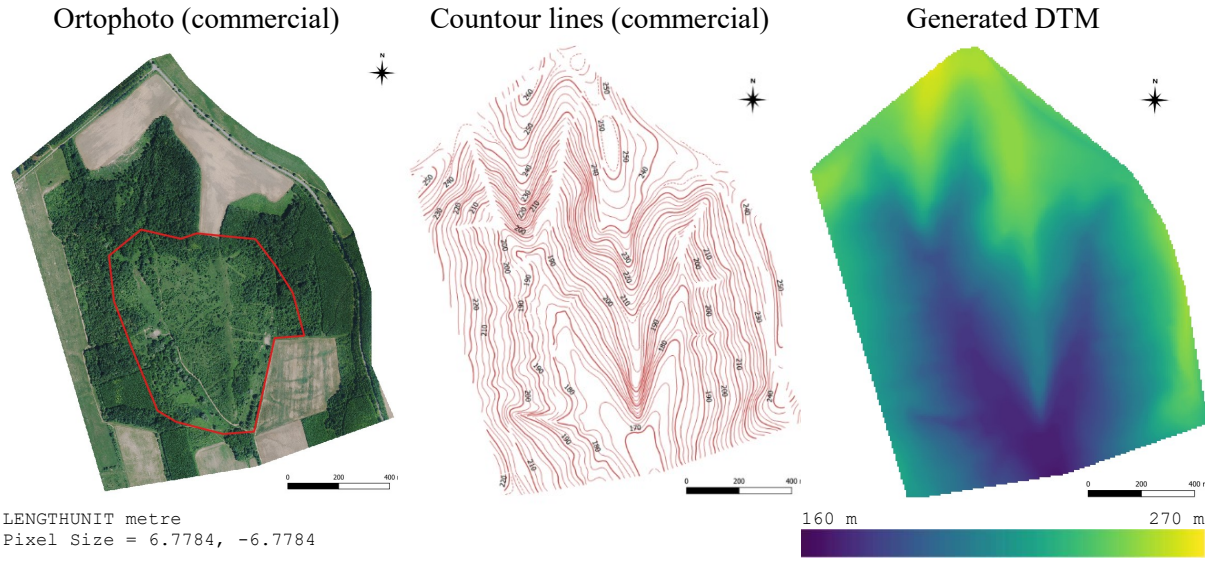


Figure 1: Ortophoto, countour lines and generated DEM of the sample area

2. Objectives of the study

In the study we demonstrate the descriptive statistics of various elevation models, including a commercial, three of our own records and open access models. The hypothesis is that open source models are equally exact with the commercial. We also prove that our own data from drone flight over the area has the same quality as the official models.

In circumstances, where exact geodesic measures are not necessary (as in our case), the potential use of open source models on the basis of their accuracy was also question of the analysis.

3. Materials and methods

2.1. Data

The analysis targeted the comparison of quality of various elevation modelling. The altitude values (response variables) of the models (factor variables) were taken on the sample area of Bőszénfa. The compared elevation models were a) a generated DTM from official commercial contour line map; b) own drone flights (Barna & Nagy, 2020); c) four open source DEMs.

2.1.1. Drone flights

On three different days (15 March n=553, 1 May n=491 and 17 June n=540) aerial photos were taken with DJI Phantom 4 Pro drone FC6310 camera at 130 meters height of flight. In order to ensure the processing quality, the set side overlap was 60%, the front overlap was 80%; and before and after the flight tracks an additional zone of minimum 50 meter was left.

An elevation model was generated from the photos taken by a drone.

Due to vegetation covering the camera cannot "see" the ground everywhere, so the terrain model contains the surface of the vegetation, too; therefore the generated model was a Digital Surface Model (DSM). The DSM was clipped to the area of the sample field and the originally used WGS84 coordinates from drone's navigation system were converted into HD72/EOV coordinate system.

2.1.2. Official DEMs

The comparison was based on the Digital Terrain Model generated from commercial contour lines map described above.

The following open source elevation models were used and downloaded in GeoTIFF format: SRTM3 (CGIAR-CSI, 2020), SRTM1 (USGS, 2020) ASTER GDEM (ASTER GDEM, 2020), AW3D30 (JAXA, 2020) and EU-DEM (Copernicus Land Monitoring Service, 2020)

The open source elevation models were clipped to the area of the generated DTM in QGIS 3.16. In order to make uniform coordinate system for the comparison, the clips' coordinates were converted to HD72/EOV.

2.2. Methods applied in the analysis

The generated DTM and the results of drone photos (DSMs) were compared with one-way ANOVA. Then the data were studied with QGIS Profile Tool. Further, the horizontal deviations were described with the help of Map swipe tool QGIS module.

The generated DTM and the converted open source DEMs were compared with one-way ANOVA. In the next step, the differences of altitudes were calculated of clipped overlapping layers. The QGIS raster calculator was used to subtract the altitude values of generated DTM and open source DEMs.

In each case of ANOVA, response variable was the altitude recorded for the pixels of the maps in Excel program.

3. Results

3.1. Own experiment

The surface models of the experimental area are shown in Figure 2. The drone based photos indicate the surface cover including vegetation, while generated DTM is plainer. Also the vegetation phases of the trees can be seen on the photos taken in March and later in the year.

Looking at the average altitude values, the results of photos taken on 1 May are more similar to the generated DTM (Table 1). Neither the photos taken on 17 June are different from the generated DTM. However the results form drone flight on 15 March are significantly higher than the generated DTM and 1st May photos.

Table 1: Main statistics of the elevation models generated from drone flights

	Generated DTM	March 15 2018	May 1 2018	June 17 201
Resolution m/pixel	6.77	1.12	1.03	1.03
Minimum	170.1	184.35	157.13	173.15
Maximum	239.24	264.14	241.74	258.52
Mean	193.26 [b]	211.66 [a]	190.35 [b]	203.41 [ab]
Standard Deviation	15.39	17.46	17.91	17.05

Notes: different letters indicate statistical differences (P < 5%) One-way ANOVA

Both the zoomed in orthophoto and the drone based surface model suggest the outlines of wood vegetation of the area (Figure 3). Even a cross section profile of a stand alone tree is visible on the surface model. Figure 4 illustrates the cutting plane line of the cross section and the profile of the tree on the orthophoto and the surface model.

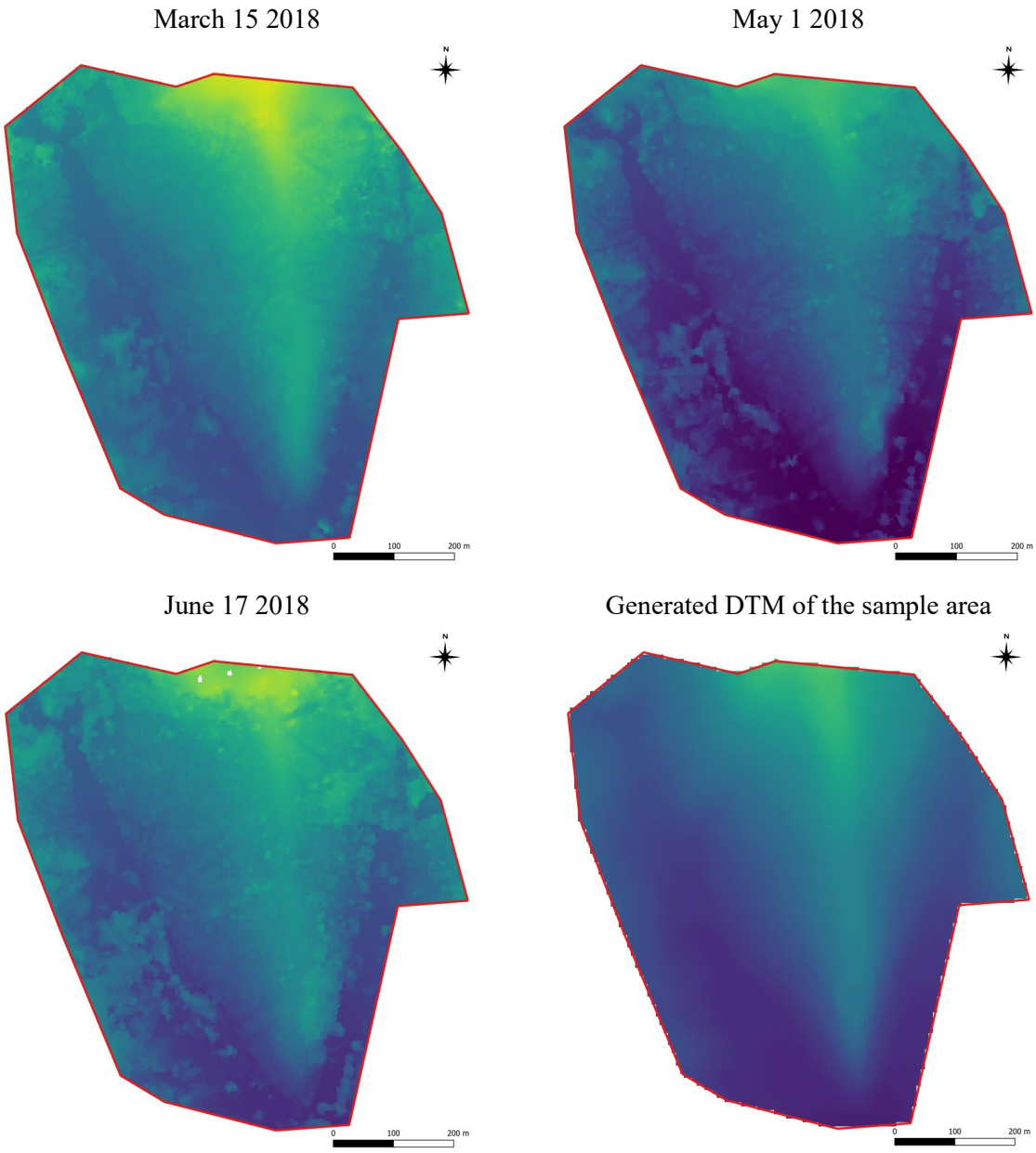


Figure 2: Surface models and generated DTM of commercial contour lines on the sample area

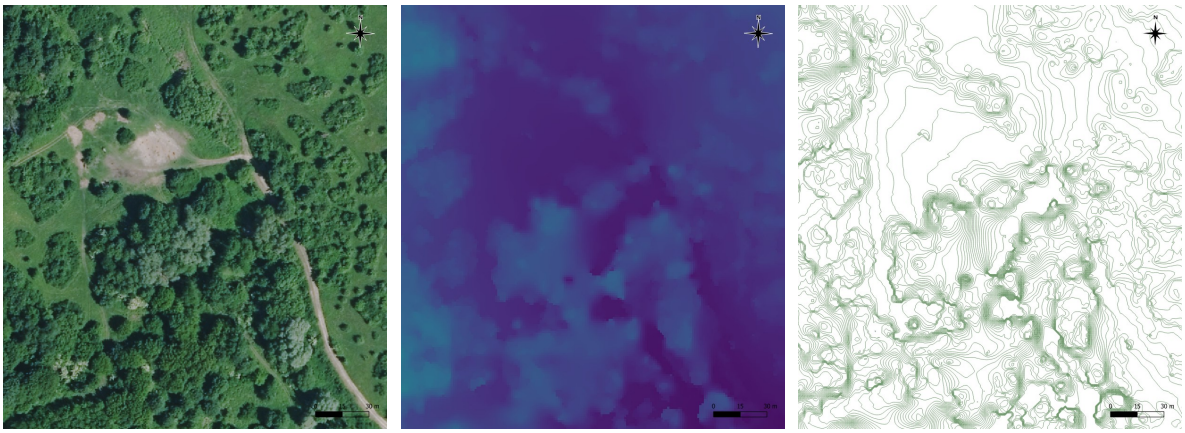


Figure 3: Sections of orthophoto, surface model and contour line map of wooded area

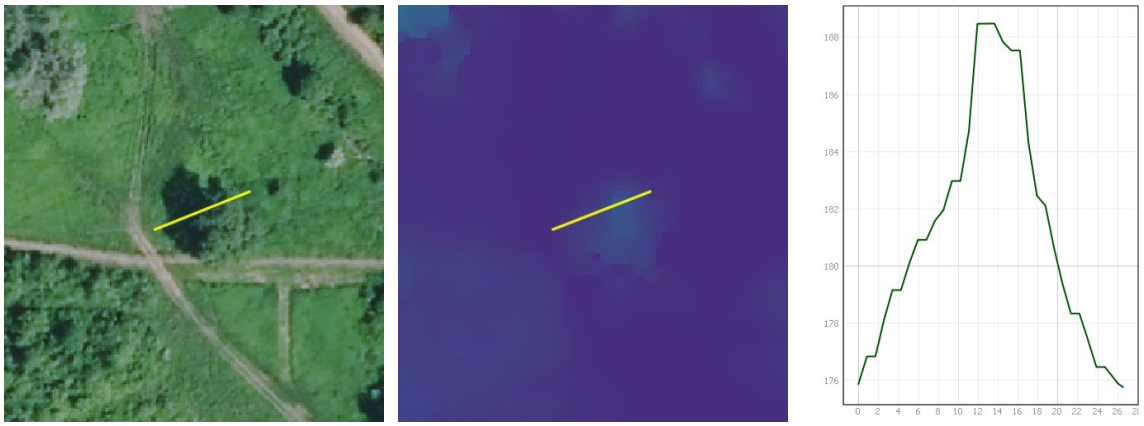


Figure 4: Cross-section of a stand-alone tree on the sections of orthophoto and surface model

The profile shapes of elevation models illustrate that the drone photos include the vegetation in the surface model, while the commercial surface model does not (Figure 5). Moreover, the difference of height of each flight is stable along the whole profile.

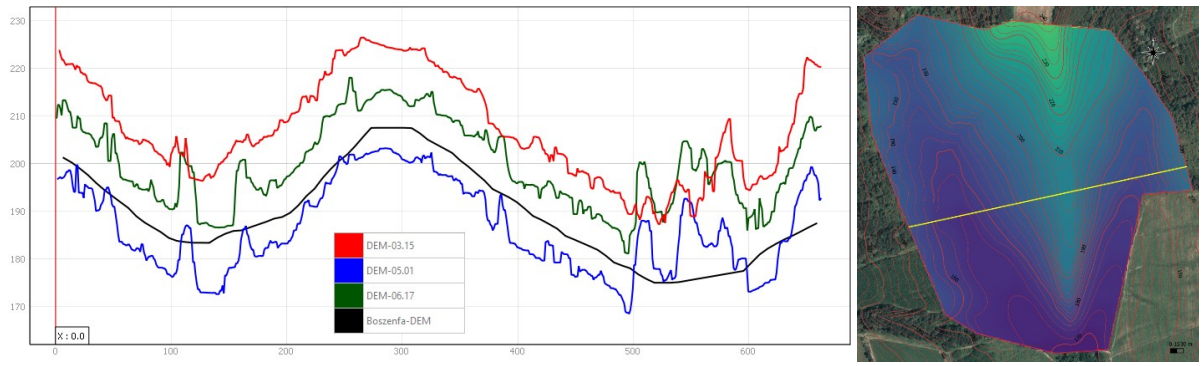


Figure 5: Profiles generated from various DEMs

The differences can not be only found vertically in case of elevation models but horizontally in case of ortophotos, too (Figure 6). This pattern originates in the GNSS (Global Navigation Satellite System) of the drone. The receiver uses both GPS and GLONASS, but without RTK (Real-time Kinematic), which would give a cm accuracy. The GNSS receiver of the drone is 3 to 5 m accurate horizontally. In case of GNSS vertical deviation could be even greater, up to 10 meters. In cases where accuracy is required, with the help of Ground Control Points (GCP) horizontal accuracy can be increased by post-processing. Our case did not required this work.



Figure 6: Horizontal deviations of various drone photos (15 March, 1 May)

3.2. Open source DEM-s

Figure 7. indicates the sample area section of various surface models. Beneath the clipped area data represent the characteristics of the original CRS, and those of converted for EOV and the statistics for altitudes. With the exception of EU-DEM elevation models use degree-unit WGS 84 reference system. The resolution of SRTM3 is 3 arc-second (~ 90 m); that of SRTM1, ASTER GDEM and AW3D30 is better, only 1 arc-second (~ 30 m). The EU-DEM has 25 m spatial resolution in the meter-unit ETRS 89 coordinate system. EOV-converted elevation models' resolution is different from the original because of the different Geodetic datum.

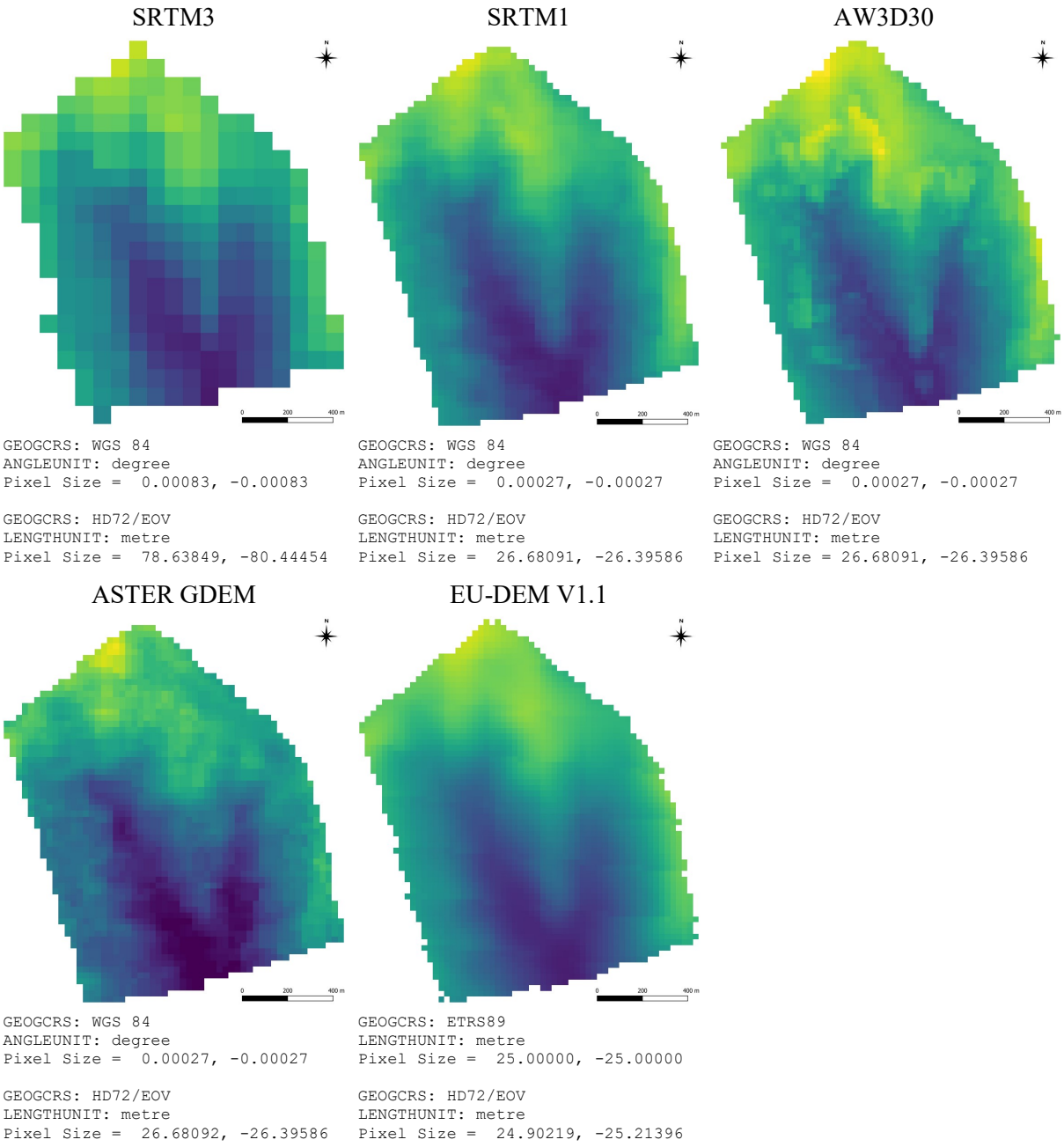


Figure 7: Sections of elevation models for the sample area

Although the differences of resolution are visible in the pictures, the most typical characteristics of the terrain can be seen. Looking at the altitude values of the above DEMs (Table *2*) it is visible that SRTM3, SRTM1 and EU-DEM statistics are more similar to the generated DEM. The data of

AW3D30 is slightly higher, ASTER GDEM is lower. The surface models were compared with one-way ANOVA, which proved no significant differences between the models ($p > 5\%$).

Table 2: Main statistics of the elevation models

	Generated DEM	SRTM	SRTM-1	AW3D30	ASTER GDEM	EU-DEM V1.1
Minimum	167.5	168	168	171	153	169.32
Maximum	264.759	261	265	274	268	262.28
Mean	214.262	213.477	214.420	220.826	205.275	214.085
Standard Deviation	24.11	23.564	23.912	24.774	24.73	23.328
$LSD_{5\%}$	*21.14*					

By subtracting each open access DEMs from the DTM, the difference-layers were obtained (Figure 8). These layers refer to lower (red) and higher (blue) generated DTM altitudes than those of open source DEM. Yellow colour indicates similarities between the altitudes. The raster information of the difference layers can be read under the figures.

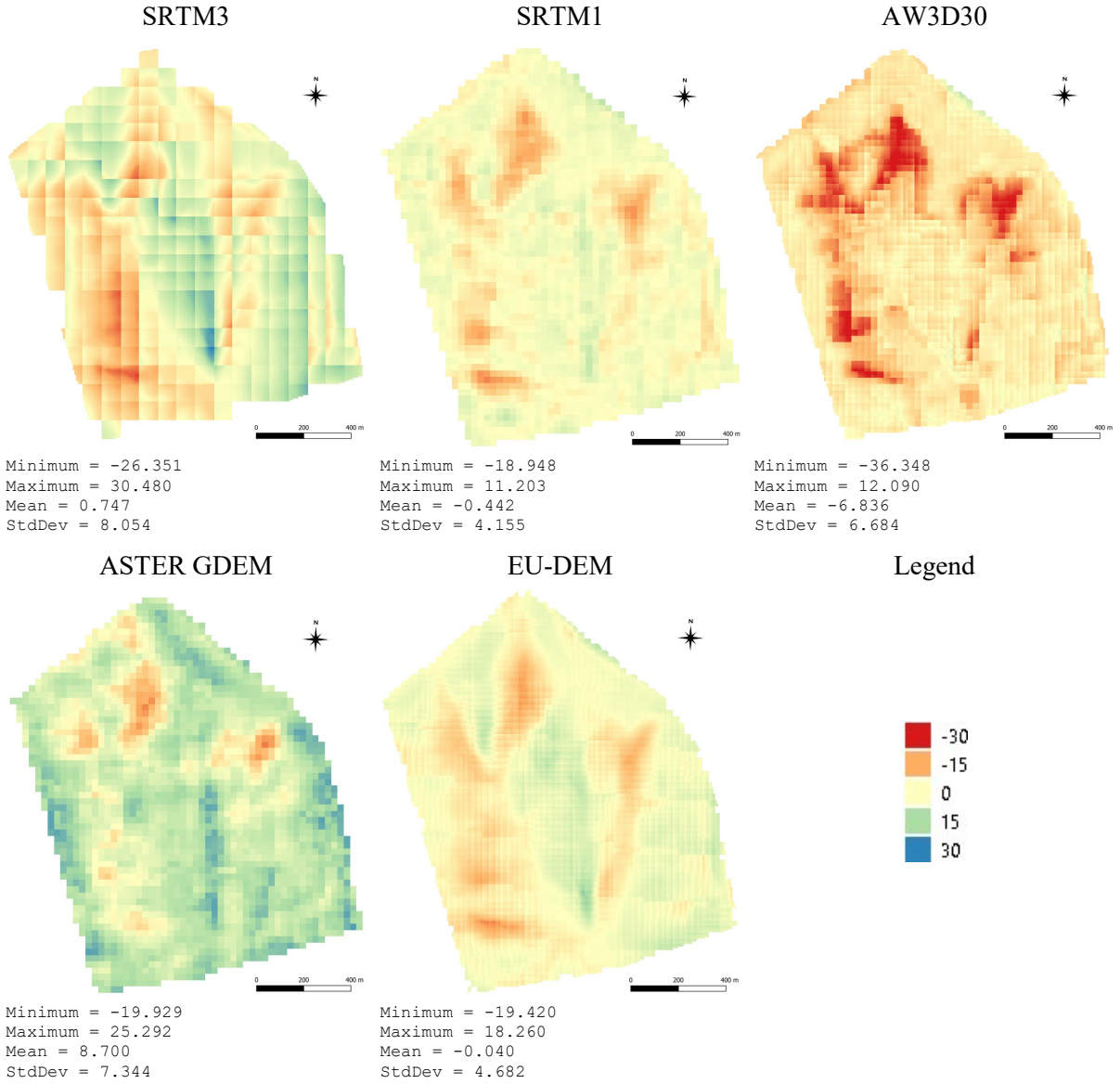


Figure 8: Differences between generated and open source DEMs

According to our anticipations, there is difference between the generated from contour lines and open source models. In case of SRTM3, the difference is huge because of the difference of resolution, too. The AW3D30 elevation values – according to minimum and maximum values – are lower, than the values of the generated DEM. Differences in case of ASTER GDEM also refer to the differences of minimum and maximum values; that is the values are mostly higher than those of generated DTM. It is interesting, that the variation of AW3D30 values is lower than that of ASTER. The most similar values can be seen in case of SRTM1 and EU-DEM, both the minimum and the maximum values and the standard deviation is the closest to the generated DEM. The mean of differences is smaller than 5 centimeters!

Conclusions

The surface model created with drone includes vegetation, therefore it can be used for DTM only post-processing. Despite of this, it shows the characteristics of the terrain; therefore the results can be used, along with the acknowledgement of measuring accuracy.

Open sources surface models are widely available. However, these use different methods, the terrain characteristics are well presented by them. Of course these open source models are not suitable for accurate geodesic analysis. According to the comparison of the models we do not suggest purchase commercial surface models only for getting general information. Out of the analysed surface models, the most similar elevation data to the commercial model is provided by SRTM1 and EU-DEM. It is expected that even more and more accurate elevation models will be available in the future.

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