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Processing airborne data to

Digital Surface Model and Digital Terrain Model.

Final report

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Content

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Objective of study

Objective of study: to process airborne data acquired by optical and LIDAR sensors to DSM and DTM products, and investigate what kind of features (for example: buildings, trees, bushes, hedges etc.) can be distinguished in the dataset, collected with parameters described below, and describing potential accuracy and demonstrating applications of such data.

Resources: The JRC Agriculture and Fisheries Unit provide:

- LIDAR data acquired with a density of approximately 1 point per 1m, collect on 14th of April 2005. The data will be delivered as ASCII files containing XYZ coordinates of first and last pulse, together with the strength of the signal, in UTM 32N zone (WGS-84 ellipsoid), data coverage: ~3860ha.

- Optical Imagery from the ADS40 – digital camera with linear sensor:
    - Level 2 imagery – orthophoto with 0,2m ground sampling distance, prepared by CGR, Parma, Italy with use of abovementioned Lidar data and imagery acquired on 7th of May 2005 above the site of Ispra, Italy, in UTM 32N zone (WGS-84 ellipsoid),
    - Level 1 imagery – raw imagery, again ADS40 digital sensor, from 2 different flights:
        1. At an altitude of around 5000m, corresponding to 0,5m ground sampling distance. The flight was done on 26th of April 2005, above the site of Ispra, Italy,
        2. At an altitude of around 2000m, corresponding to 0,2m of ground sampling distance. The flight was done on 7th of May 2005, above the site of Ispra, Italy,
    - Level 0 imagery - from the flight at altitude of around 2000m, corresponding to 0,2m of ground sampling distance. The flight was done on 7th of May 2005 above the site of Ispra, Italy.
- Ground control points – XYZ coordinates (in UTM 32N zone (WGS-84 ellipsoid)) of 7 (premarked) ground control points measured with Trimble 5700, dual frequency with postprocessing of the data.
- Additional ground control (GPS) will be acquired as needed by the Agriculture and Fisheries Unit.

Resources: The contractor is responsible for:

- The hardware (i.e., portable USB/Firewire harddisk) necessary for the transfer of the data;
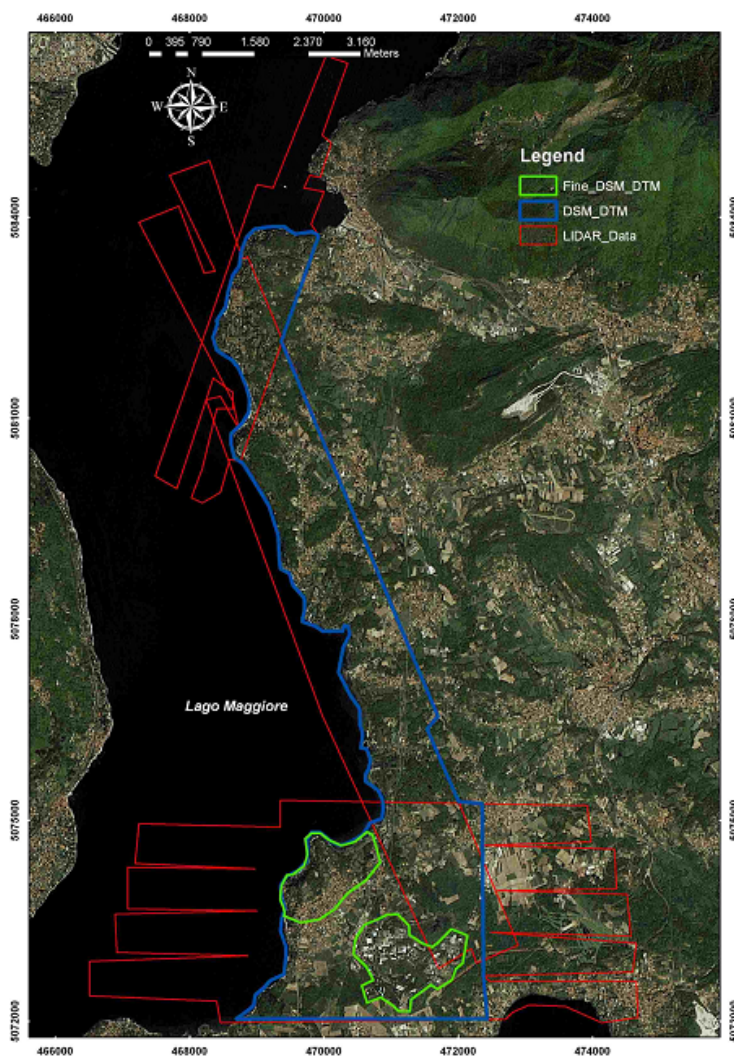- Selection and provision of the software environment for all the processing.

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Test area

The area of interest in the project is according document JRC IPSC
(12/07/2007 JRC IPSC/G03/P/SKA/asi D(2007)(8094) D/16759, Annex 3):

- *Test area* ~ 1860ha,

- *Sub test area* ~300ha.

Test area – blue, *sub-test area* – green [after JRC IPSC/G03/P/SKA/asi D(2007)(8094) D/16759, Annex 3]

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General

In the report folder and file names (with extensions) are printed in *italics*.

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Software and delivered data

The following software was in the project applied:

- TerraSoild/Microstation

- Geomedia Professional/Geomedia GRID

TerraSoild was applied to:

- read original laser data

- save original laser data in ASCII format (*laserdata_txt - Str_1.all….*)

- classify all original data (2 classes: ground, and low vegetation, medium vegetation, high vegetation, building) - (all strips are saved in TerraSoild binary format - *laserdata_edited - str_1_edited.bin....*, and in ASCII format)

- classify original data for sub test areas (6 classes: low points, ground, low vegetation, medium vegetation, high vegetation, building, (all strips are saved in TerraSoild binary format - *laserdata_sub_test_area - part_1_edited.bin....*, and in ASCII format))

- GRID data generation (DTM, DSM)

  ° for all data of 1 m pixel size: DTM (*GRID_DTM_1m - str1_dtm.xyz ....*), DSM (*GRID_DSM_1m - str1_dsm.xyz ....*)

  ° for sub test areas of 1 m pixel size: DTM (*GRID_DTM_sub_test_area-part1_dtm.xyz, part2_dtm.xyz*), DSM (*GRID_DSM_sub_test_area-part1_dsm.xyz, part2_dsm.xyz*)

  ° for accuracy analysis - 5 sub sub test area of 0.1m pixel size:

    - format TerraSoil (*laserdata_samples_accuracy_analysis - probka1_edited.bin...*)

Geomedia Professional/Geomedia GRID was applied to:

- difference map generation (DTM minus original laser point for inner accuracy assessment and DTM minus in-situ GPS measurements for external accuracy analysis)

- statistical error analysis (average of difference map and its standard deviation, histogram generation)

- database generation (format ESRI, shp) - points containing differences between DTM (GRID) and Lidar measured highs (inner accuracy)

- database generation (ESRI, shp) - points containing differences between DTM (GRID) and highs measured in-situ using RTK (external accuracy)

- overlay DSM on DTM (DSM contains points above 3m above the ground)

  - ° for all data and for sub area: *str1_dsm_dtm….., part1_dsm_dtm…,* (ASCII format, xyz)

- overlay DSM on DTM (DSM contains: buildings and vegetation: low, high, middle)

  - ° for sub area: *part1_dsm_dtm_all_veg (part2….),* (ASCII format, xyz)

- DSM layers: low, middle, high vegetation, for sub area

  - ° *part_1_dsm_high_veg, part_1_dsm_mid_veg, part_1_low_veg, (part_2_....),* (ASCII format, xyz)

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Data processing – workflow

LIDAR data were analyzed for:

- DTM, DSM generation (for all strips and in details for sub test area)

- Testing of the procedure of height layers classification

- Accuracy analysis

Raw LIDAR data were processed in TerraSoild according diagram on the figure (0). In the LIDAR data processing, intensity of LIDAR signal was not used (the first and the last pulse was treated as equal), although it could be useful in detailed works for buildings detection.

Firstly, the data were classified into 2 layers, for all strips. Layers were saved in TerraSolid format. Layers: ground and high vegetation were exported to ASCII format for all strips (original measured points). LIDAR data: ground and high vegetation, interpolated as a GRID (DTM, DSM) were saved in ASCII format. The DSMs were overlaid on the DTMs in Geomedia and exported to ASCII format[1]. Strips are processed separately and was not matched (because of lack of the trajectories parameters). The strips could be however overlaid each other because the differences between strips are not significant.

Then, 2 test sub areas were extracted from the raw data. Manual corrections of ground layers were made for the areas. Next, the ground layers were interpolated to GRIDs (1m) and exported to ASCII format (xyz).

Layers: low, middle, high vegetation and buildings, for sub test areas, were:

- Saved , as original measurements in ASCII format

- Saved in GRID model (1m) in ASCII format

- Overlaid on the DTMs to obtain DSM, saved in ASCII format

[1] Notice: Geomedia Grid exports xyz with "tabs" but ArcGis reads only with "space"

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Accuracy analyze was made on the base on DTMs. Five test areas were chosen in the 2 sub test areas for detailed accuracy analysis (inner and external accuracy).
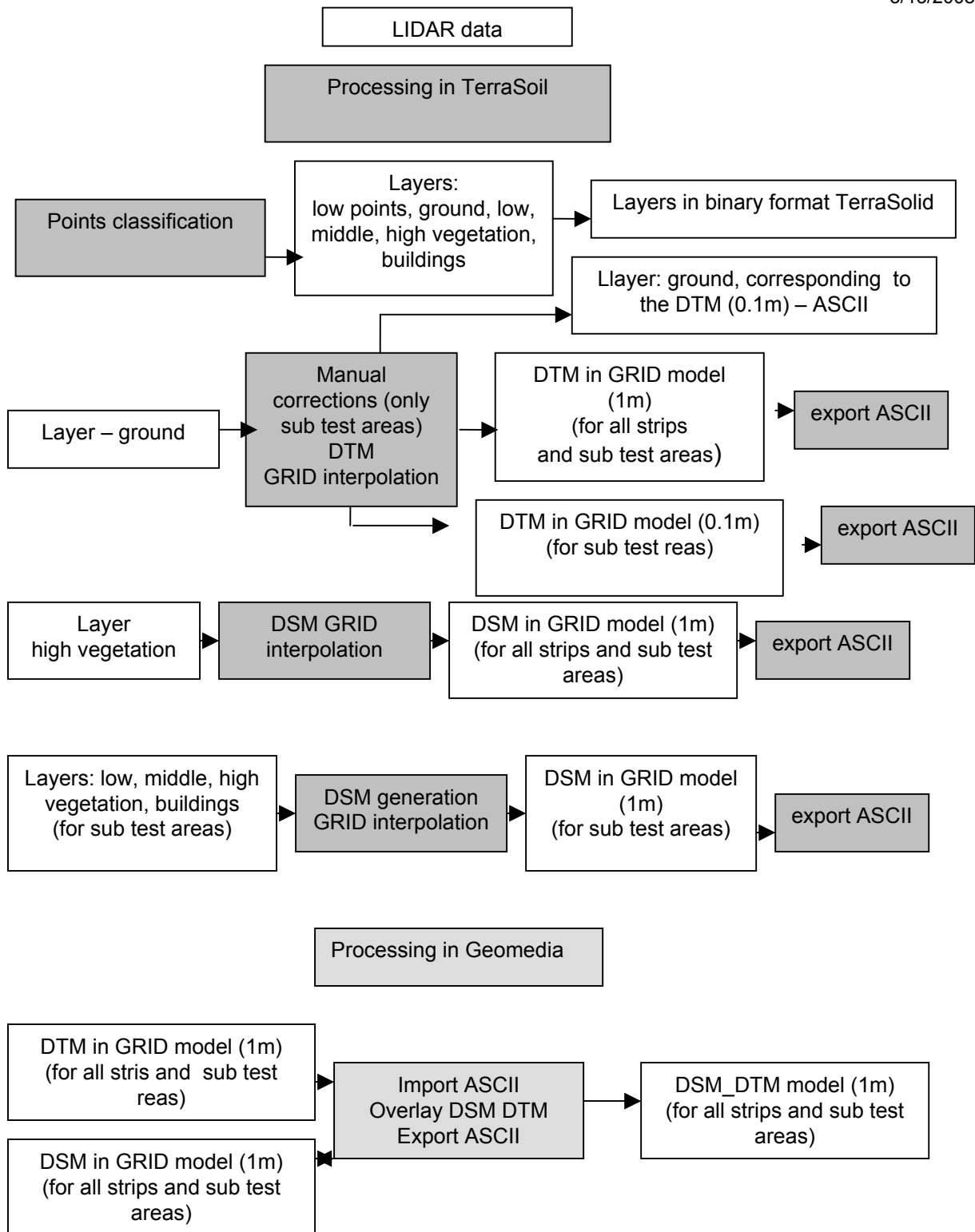
Layers: ground were interpolated into GRIDs (0.1m) for the 5 areas (see the distance between raw LIDAR points on figures: 0 and 0). Raw LIDAR data were exported to ASCII for the 5 areas. Raw data mean original, measured points, after classification and manual, corrections, i.e. data used for DTM interpolation.

GRIDs of 0.1m were compared with the raw data (after rasterization) for inner accuracy estimation. Besides, in-situ RTK measurement were taken for the external accuracy assessment (see workflow on figure: 0).
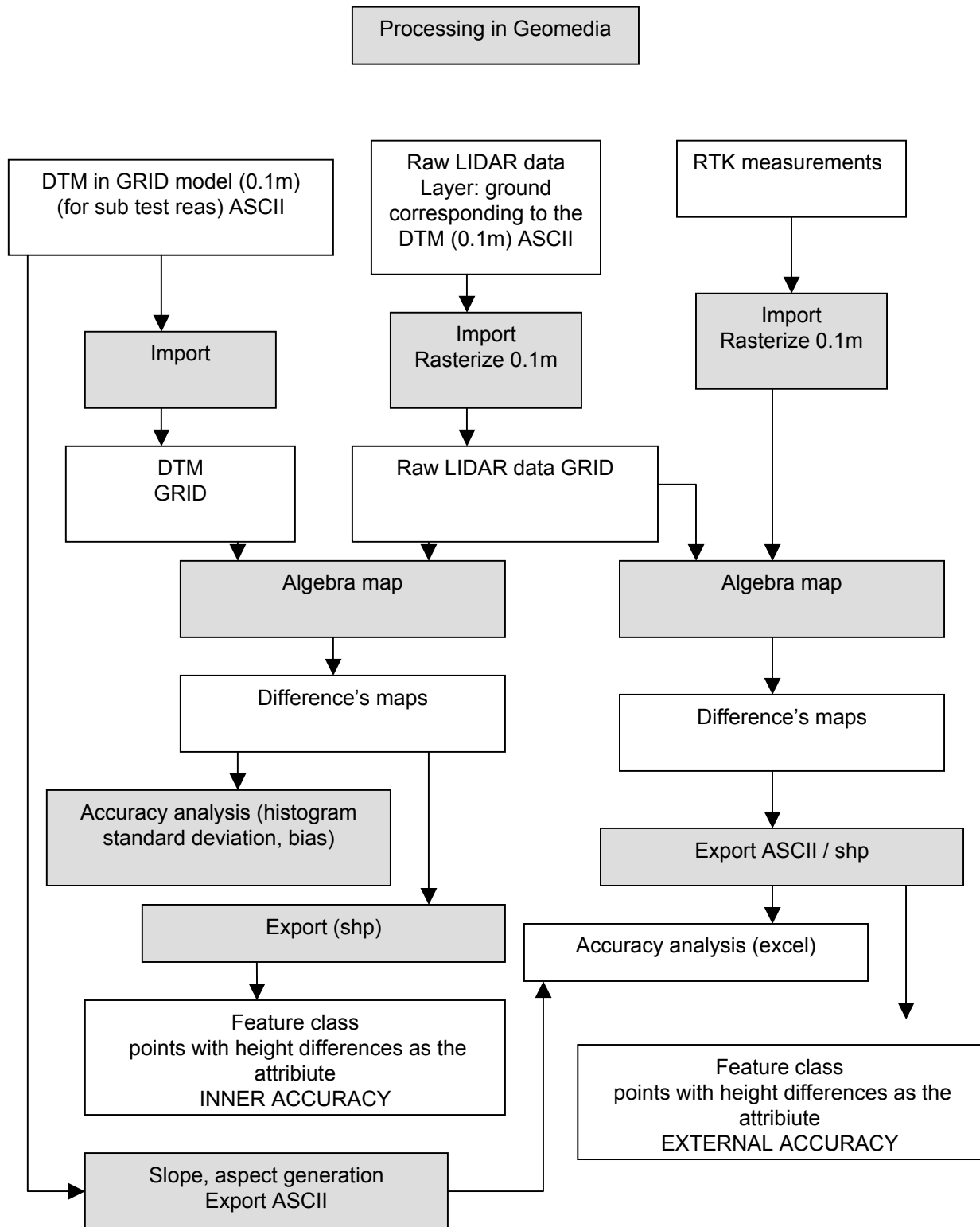
Some procedures shown on figure (0) were tested in the previous works [2]. Assumed parameters in data processing were described in the next part of the report. Some procedures were especially tested in the project, for example: interpolation method for GRID generations.

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[2] Łukasz Kulesza, „Automatic building modeling based on airborne laser scanning" – Master Thesis, 2007 – AGH
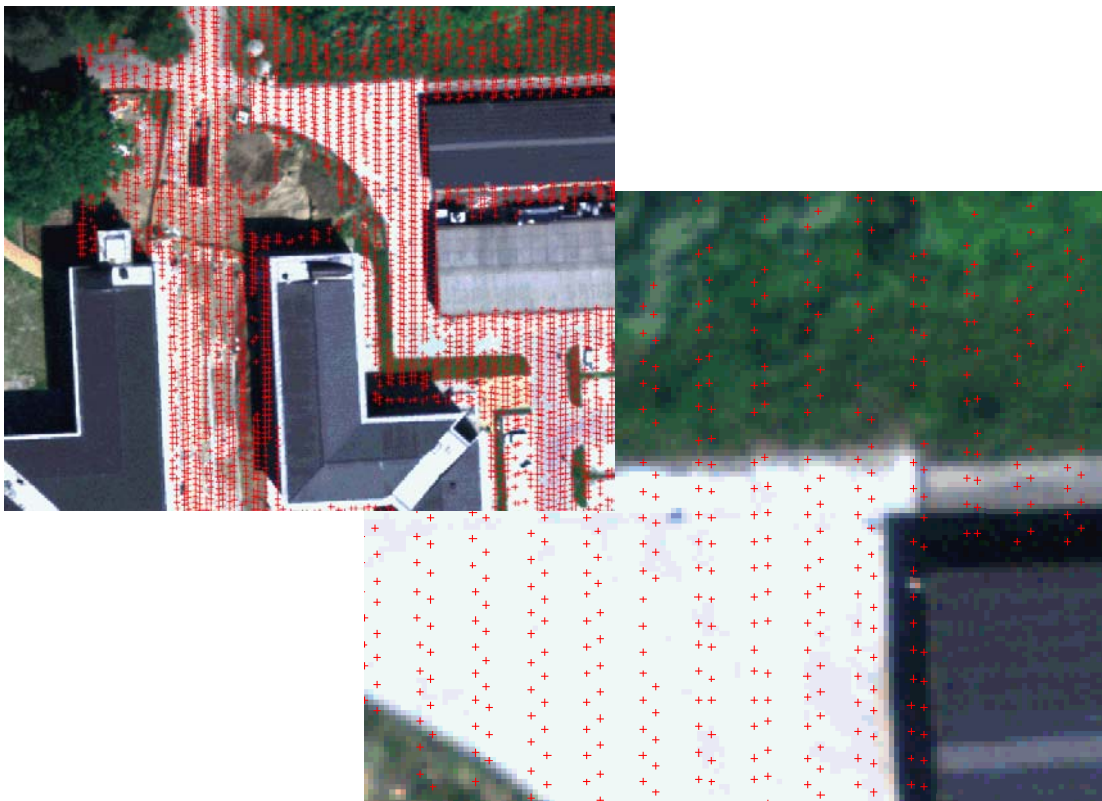Natalia Borowiec, " Roof shapes modeling based on airborne laser scanning" – PhD Thesis, in preparation

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LIDAR data

Processing in TerraSoil

Points classification

Layers:
low points, ground, low, middle, high vegetation, buildings

Layers in binary format TerraSolid

Llayer: ground, corresponding to the DTM (0.1m) – ASCII

Layer – ground

Manual corrections (only sub test areas)
DTM
GRID interpolation

DTM in GRID model (1m)
(for all strips and sub test areas)

export ASCII

DTM in GRID model (0.1m)
(for sub test reas)

export ASCII

Layer high vegetation

DSM GRID interpolation

DSM in GRID model (1m)
(for all strips and sub test areas)

export ASCII

Layers: low, middle, high vegetation, buildings
(for sub test areas)

DSM generation
GRID interpolation

DSM in GRID model (1m)
(for sub test areas)

export ASCII

Processing in Geomedia

DTM in GRID model (1m)
(for all stris and sub test reas)

Import ASCII
Overlay DSM DTM
Export ASCII

DSM_DTM model (1m)
(for all strips and sub test areas)

DSM in GRID model (1m)
(for all strips and sub test areas)

LIDAR data processing in TerraSolid

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Processing in Geomedia

| DTM in GRID model (0.1m) (for sub test reas) ASCII | Raw LIDAR data Layer: ground corresponding to the DTM (0.1m) ASCII | RTK measurements |

Import

Import Rasterize 0.1m

Import Rasterize 0.1m

DTM GRID

Raw LIDAR data GRID

Algebra map

Algebra map

Difference's maps

Difference's maps

Accuracy analysis (histogram standard deviation, bias)

Export ASCII / shp

Export (shp)

Accuracy analysis (excel)

Feature class
points with height differences as the attribiute
INNER ACCURACY

Feature class
points with height differences as the attribiute
EXTERNAL ACCURACY

Slope, aspect generation
Export ASCII

Accuracy analysis

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One of the 5 small areas for accuracy analysis (0.1 m GRIDs)

Distance between points is about: 0.3 – 0.6 m for vertical strips (or less)

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TerraSoild – classification

TerraSoil allows, among others, for the raw laser data classification.

- the "low points" classification to find the lowest points

- ground points classification to find points belonging to the terrain

- classification: „below surface"

- classification : „by height from ground"

- buildings classification
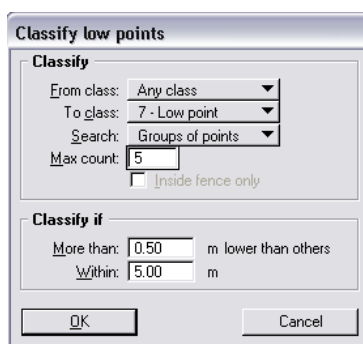
The "low points" classification to find the lowest points.

TerraSolid options for „low points"

Ground points classification to find points belonging to the terrain.

On the base of maximum building size, algorithm finds in the square of building size at least one point, initially understanding as a ground point. So the initial collection of grounds point is created (tin). The triangles are initially a little bit below the terrain, only some of the points are touching the terrain. In the next step, the algorithm adds the points and modifies the model to be better matched to the terrain. So, initial surface is modeled basing on the lowest points, then iteratively (iteration angle and distance) points better approximate terrain. Adding the point's algorithm applies: iteration angle and iteration distance. The values define how near to the triangle plane must be the point to be classified as a terrain point.
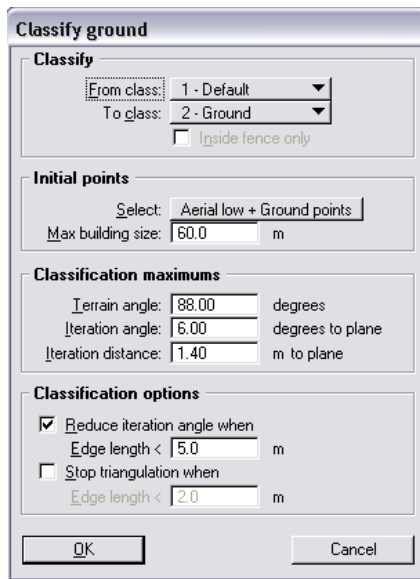
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TerraSolid options for „classify ground"

After ground classification it is recommended to analyze obtained ground model to find some "shots" – points below terrain (it is probably special algorithm in Terrasolid - different to the "classify ground"). We follow the according Terrasoild manual, firstly generating ground points (starting from the lowest points), then analyzing the lowest points and eventually moving them to the layer: "low points" (see 0).

Classification: „Below surface"

So, for better DTM generation the function for "below surface classification" can be apply to find points just below the surface.
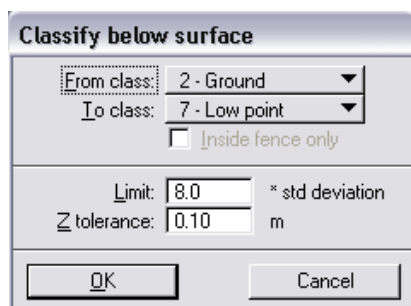
TerraSolid options for „classify below surface"

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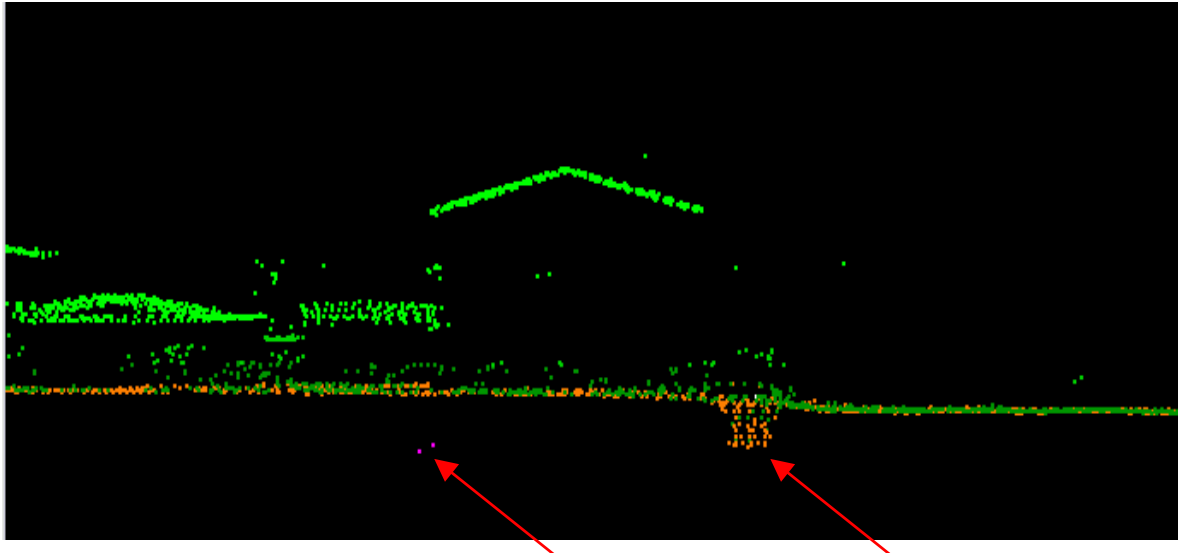
Results of classification: low points, (sometimes- „shots", sometimes - ditch near the building - see arrows)

Classification : „by height from ground"

According to the height from the ground can be the 3 following categories classified:

- low vegetation (max. 1.5m),

- medium vegetation (1.5m – 3.0m),

- high vegetation (max. >3.0m).

Maximum triangle (0): 100 m is used as default for classification in this algorithm; it is not the same parameter that we tested in TIN/GRID generation (at the beginning of part 0 of the report).

TerraSolid options for „ by height from ground"

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Buildings classification

Buildings classification is possible, on the base on two layers: ground and high vegetation, after assuming the parameters shown on the figure (0).

In our research we assumed, among others, the following parameters:

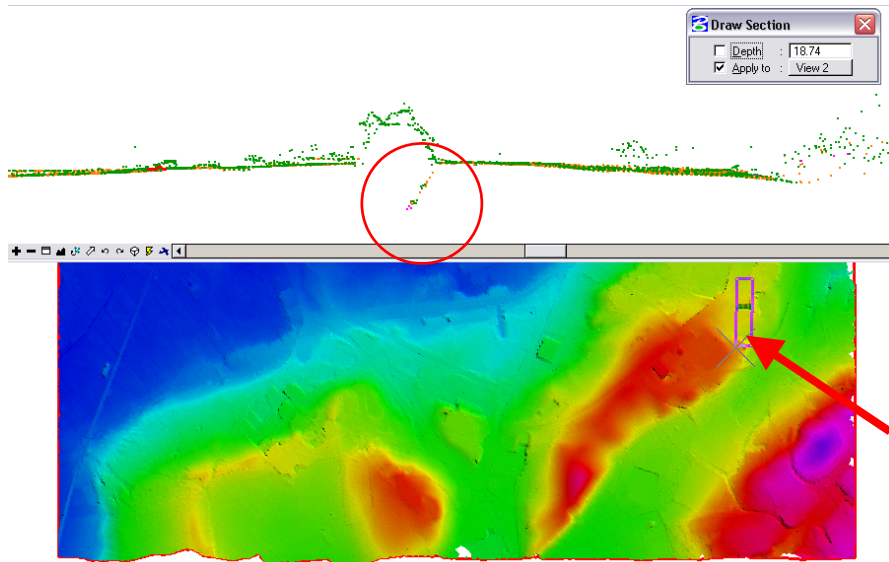- Maximum building size: 40 m

- Elevation tolerance: 0.2 m
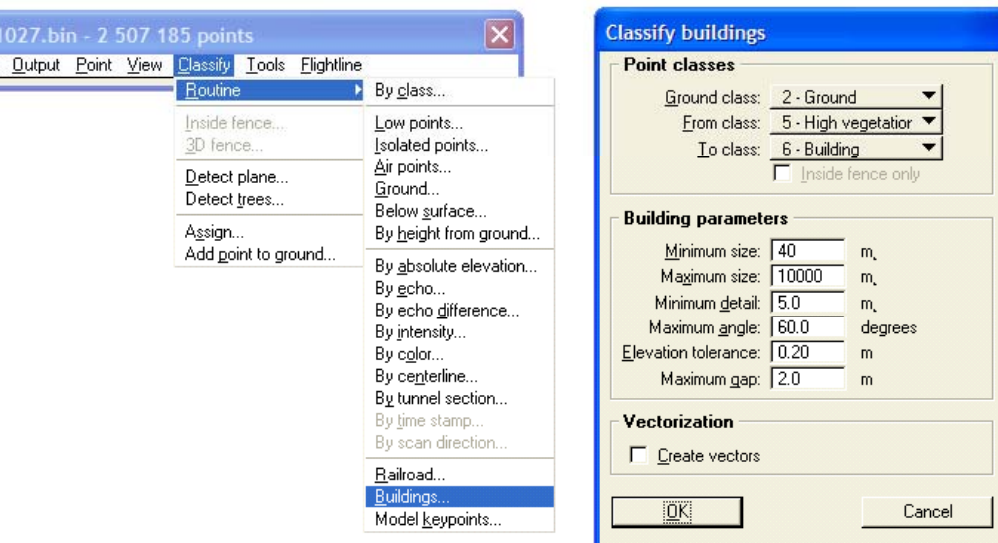
TerraSoild options for; „buildings classification)

DTM generation - manual correction (Sub test area 1)

Manual corrections were performed to delete points below the terrain for sub area. Example of the procedure applied to correction is presented on the following figures (0, 0). DTM before manual correction is shown on the figure (0), circles contain chosen areas with points below terrain. Points below terrain can be also noticed on the profile, in the circle (0). Correction consists of: marking the points below terrain (see magenta color) and deleting these points. On the figure 0 you can see the corrected DTM (arrow shows corrected place). Second example is presented in the same manner (0 and 0). In summary, uncorrected (0) and corrected (0) DTMs are shown. Please notice some roughness on (0) in compare to the (0). Manual correction is of course time consuming.
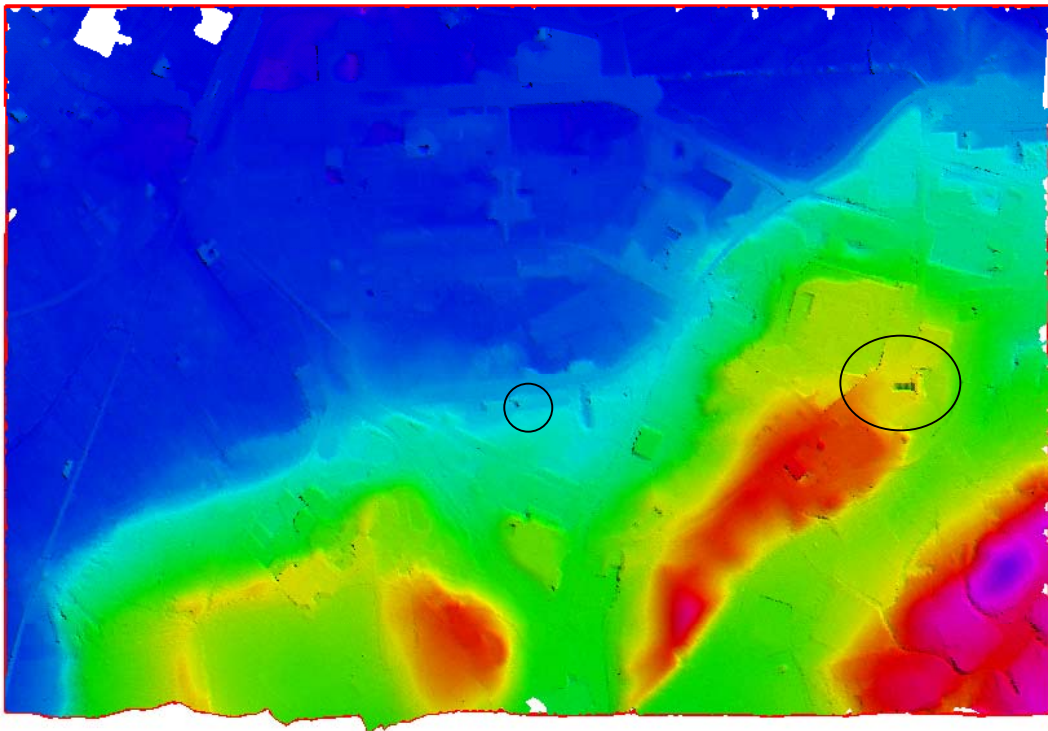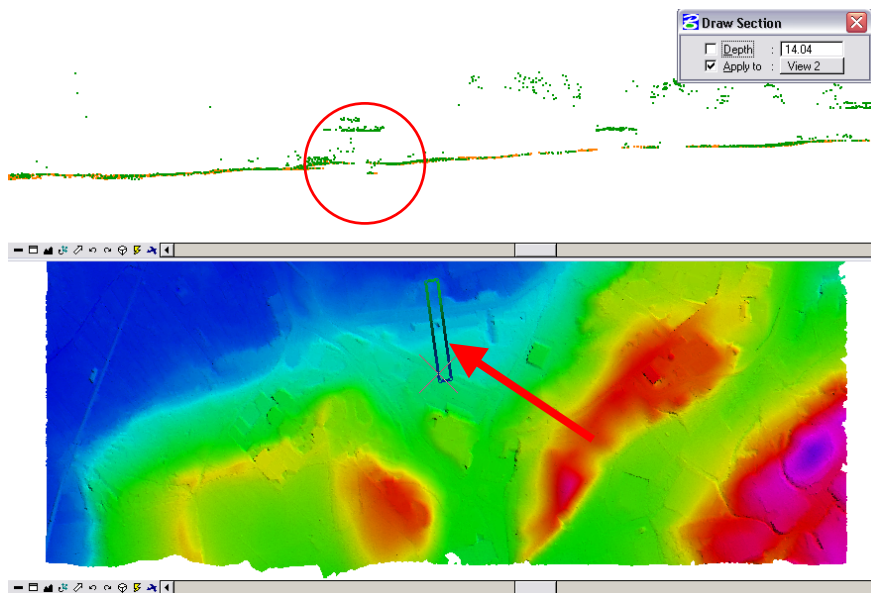
DTM before manual correction – looking for the area of low points to find area that should be corrected
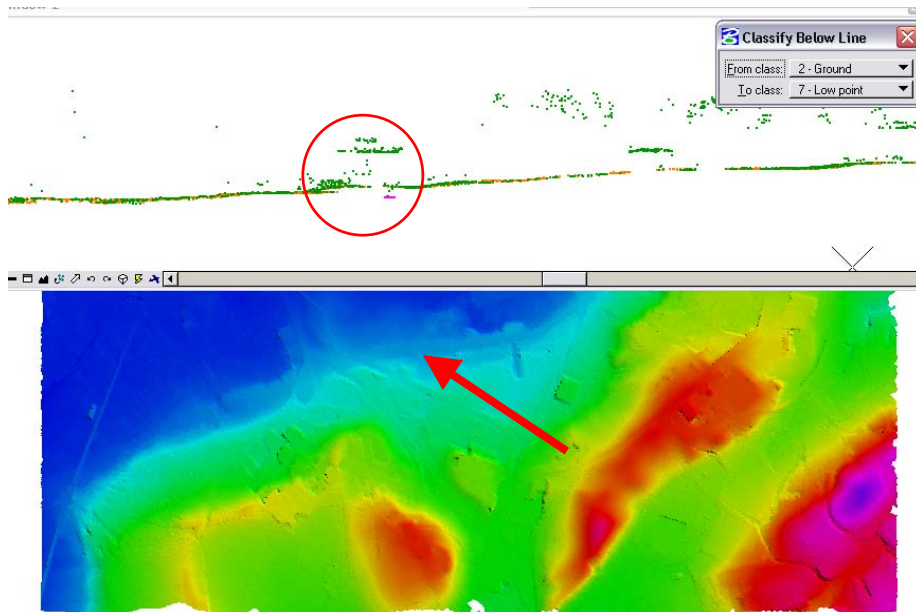

Manual correction – 1 example – profile analyze

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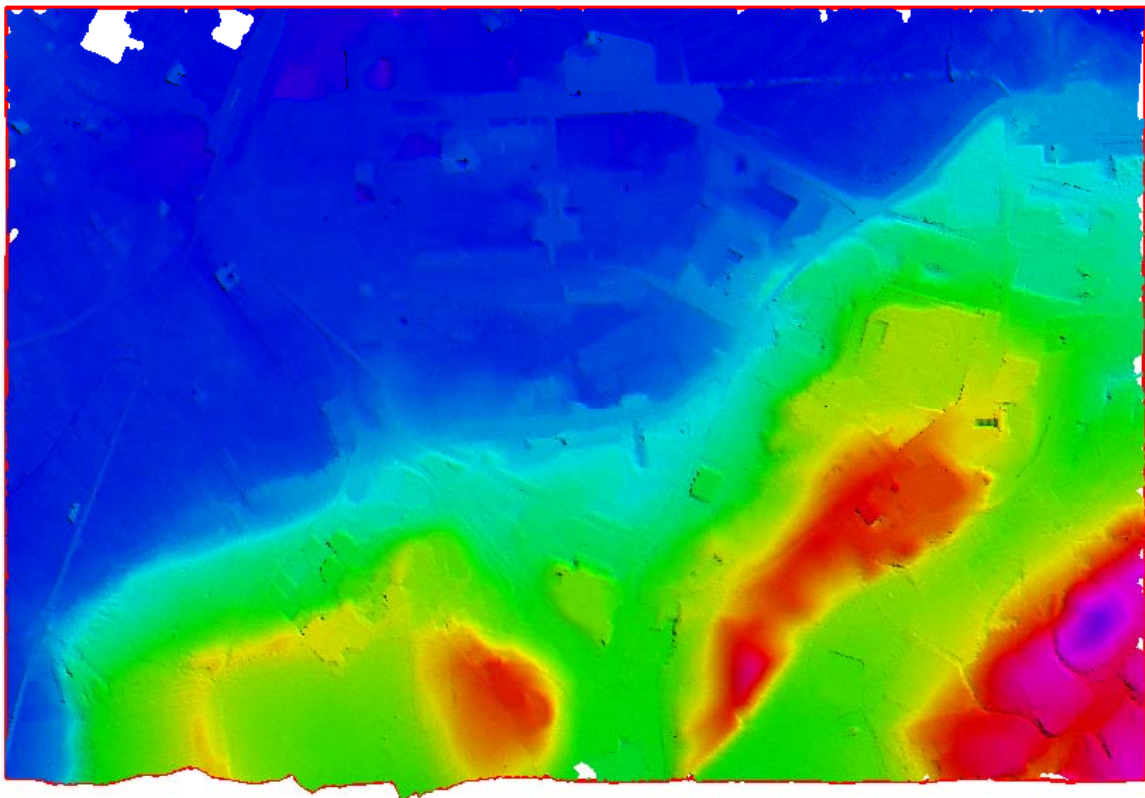Ul. Dolnych Mlynow 7/1, 31-124 Krakow, Poland, geo-staszic@wp.pl
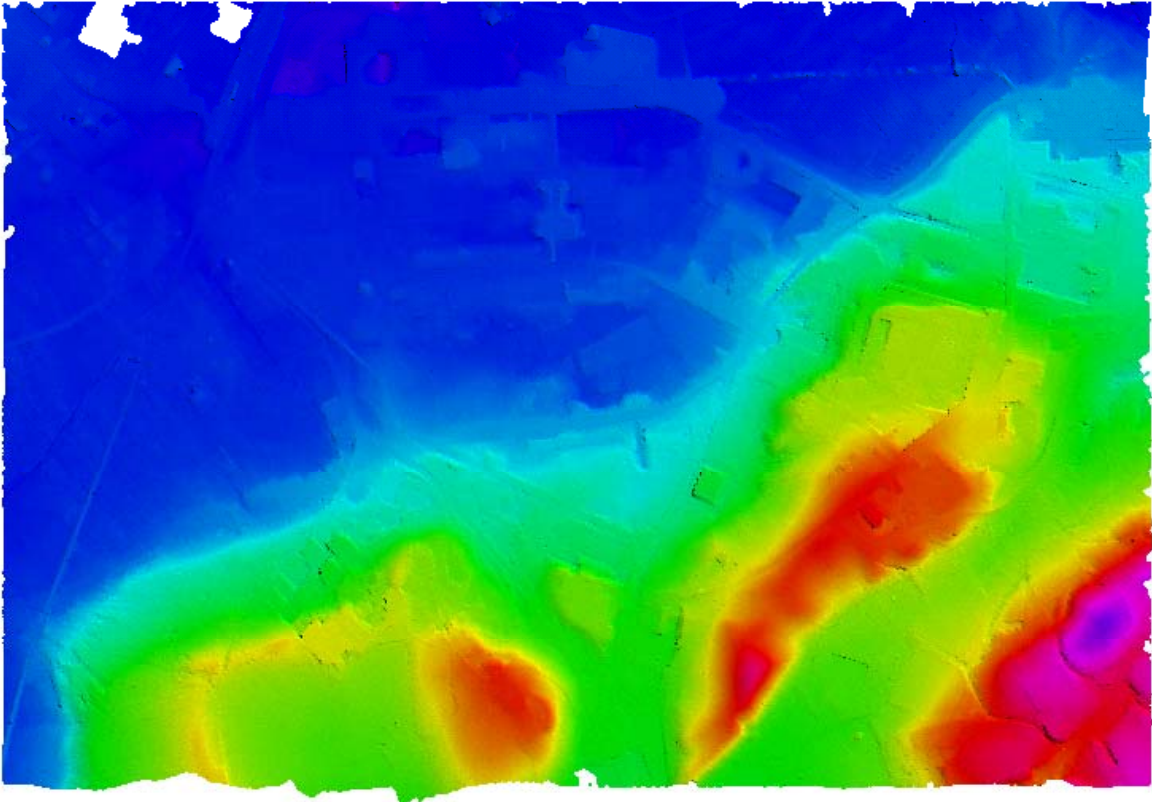
3/13/2008
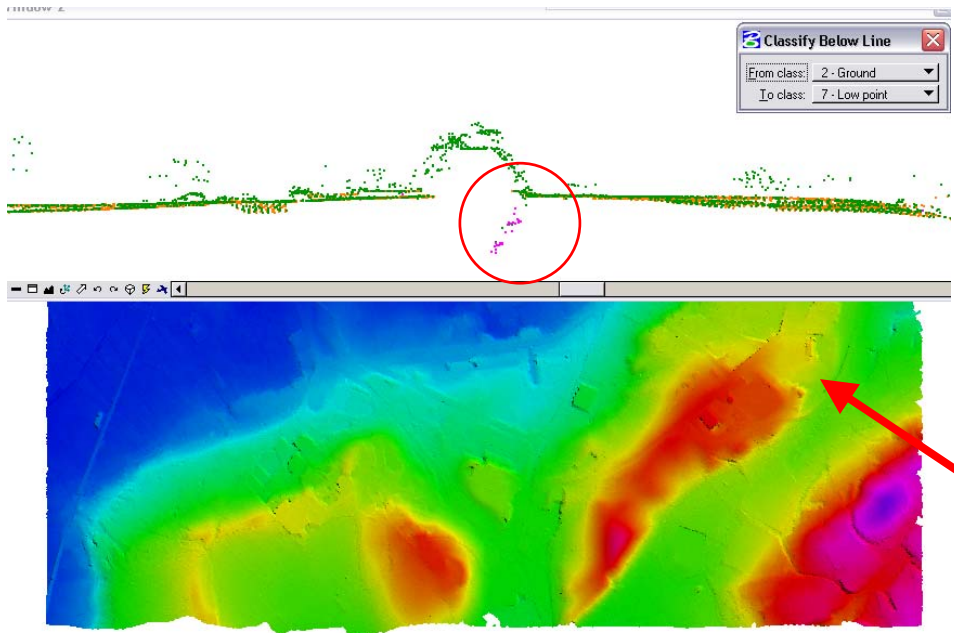
Manual correction – 1 example – correction

Manual correction – 2 example – profile analyze

Manual correction – 2 example – correction, action

DTM before manual correction – try to find some area containing low points

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DTM after manual correction – please notice corrected area

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LIDAR data processing for DTM and DSM generation – methodology

TerraSoild was applied to DTM and DSM generation for all strips and subtest areas.

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1.1 DTM generation

DTM in GRID model is calculated after ground classification using 2 algorithms: triangle method (assuming maximum triangle length) or average (assuming amounts of the points). Different tests were performed to assign the optimal one. Main aim was to find "the best way": maximum triangle length and minimum error (comparing to the raw data) and continuous DTM (without any holes!). The following triangle lengths were tested: 2m, 15m, 45 m, 70m. In average method different amount of points were tested: 3, 10 and 30 points. After accuracy analysis, triangle method with 45 m triangle length was selected to the all processing.

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1.1.1   DTM for all strips

DTMs for all strips were generated automatically:

- LIDAR points classification: ground

- Triangulation: triangle length: 45 m
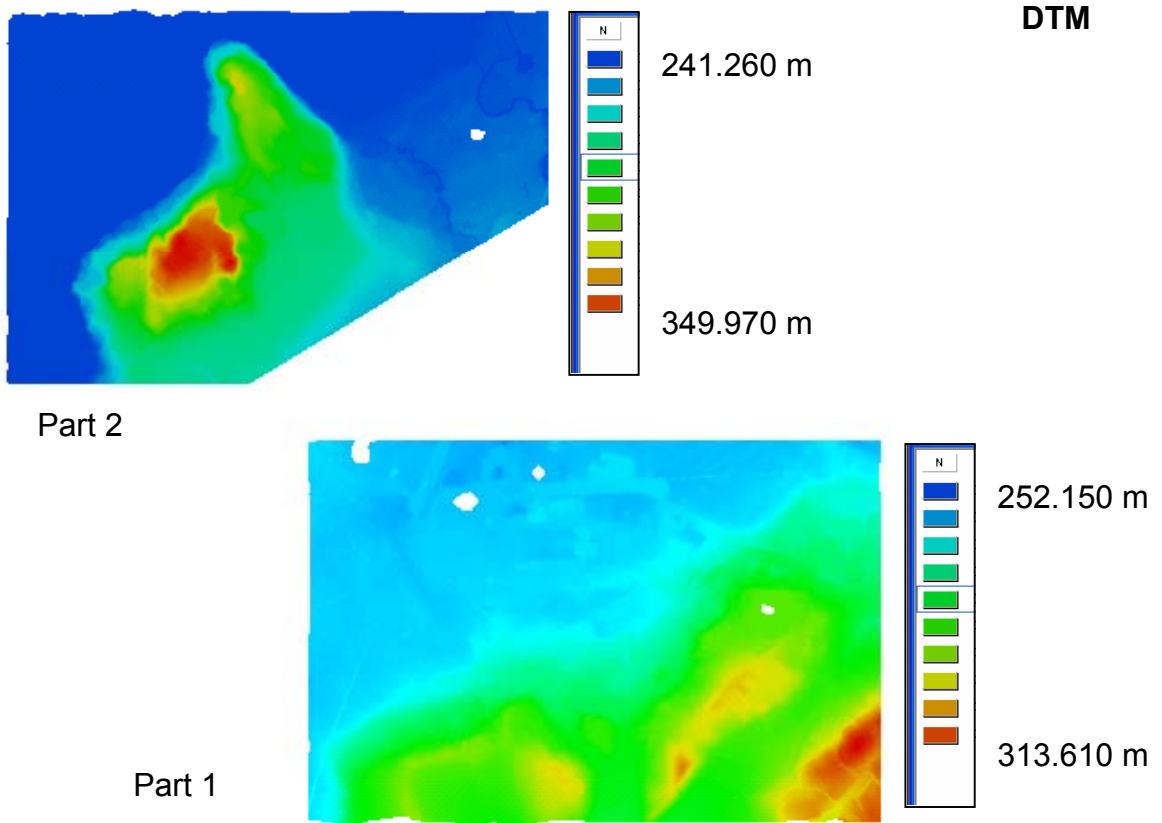
- TIN to GRID procedure (1m pixel size)

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1.1.2   DTM for sub test areas

DTMs for sub test areas were generated automatically/manually:

- LIDAR points classification: ground

- Manual corrections

- Triangulation: triangle length: 45 m

- TIN to GRID procedure (1m pixel size)

DTMs of sub test areas are shown on the figure (0). No data on DTM are in white color on this figure. It means that triangle length was two short.

DTM

241.260 m

349.970 m

Part 2

252.150 m

313.610 m

Part 1

DTM of sub test area (white areas – no DTM - show places where triangle length was two short)

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1.2 DSM generation

DSMs generation were performed generally for all strips and more detailed for sub test areas.

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1.2.1 DSM for all strip

DSMs for all strips were generated automatically:

- LIDAR points classification: high vegetation (above 3 m)

- TIN to GRID procedure (1m pixel size)

We assumed height limits equal 3 m to obtain in DSMs only stable objects, i.e. buildings, infrastructure, trees etc., no crops, bushes, or small anthropogenic objects.

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1.2.2   DSM for sub test areas

DSMs, for sub test areas, were generated as for the all area (0). In this case, DSM is understood as surface above 3 m. The white areas on DSM (0) mean that there is no any point above 3 m, so DTM=DSM. DSM can be easy overlaid on DTM (all such data for all area and for sub area, are delivered in digital form: *str1_dsm_dtm….., part1_dsm_dtm…,* ASCII format, xyz; as was described in part 0 of the report).

DSMs for sub test areas were also more detailed classified (high vegetation, middle vegetation, low vegetation, buildings) and manually corrected (big shots, evident errors on streets or on squares). All layers are saved in ASCII format (see part 0 of the report). Then, the layers were merged together and overlaid on DTM to obtain DSM.

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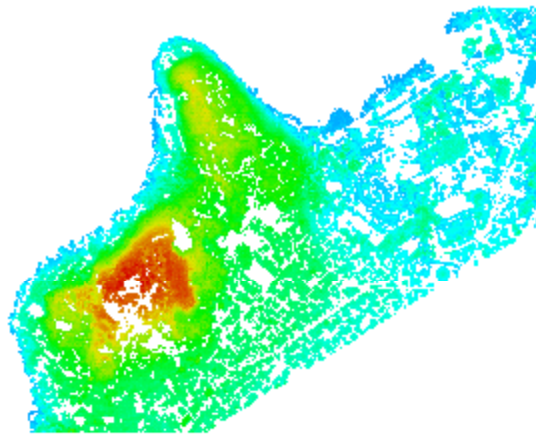
241.290 m

DSM

368.790 m

Part 2
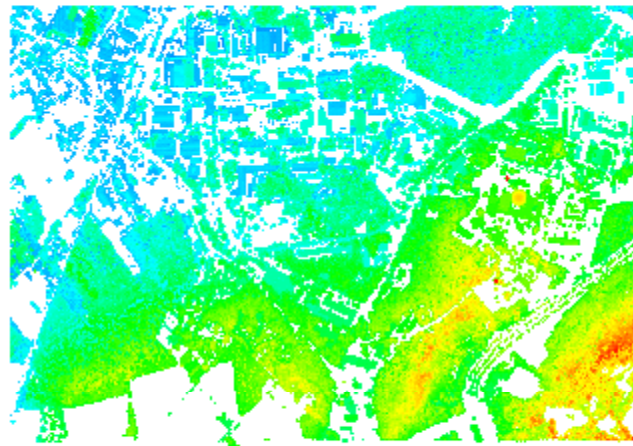
257.890m

365.240 m

Part 1

DSM of sub test area (white areas – no objects above 3 m, it means in this area DSM=DTM).

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1.3 Overlaying DSM on DTM

For all strips and for sub test areas, DSMs were overlaid on DTM for continuously surface model generation.

The DSMs, constructed in this way, for sub test areas, are presented on figure (0).

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DSM overlaid on DTM

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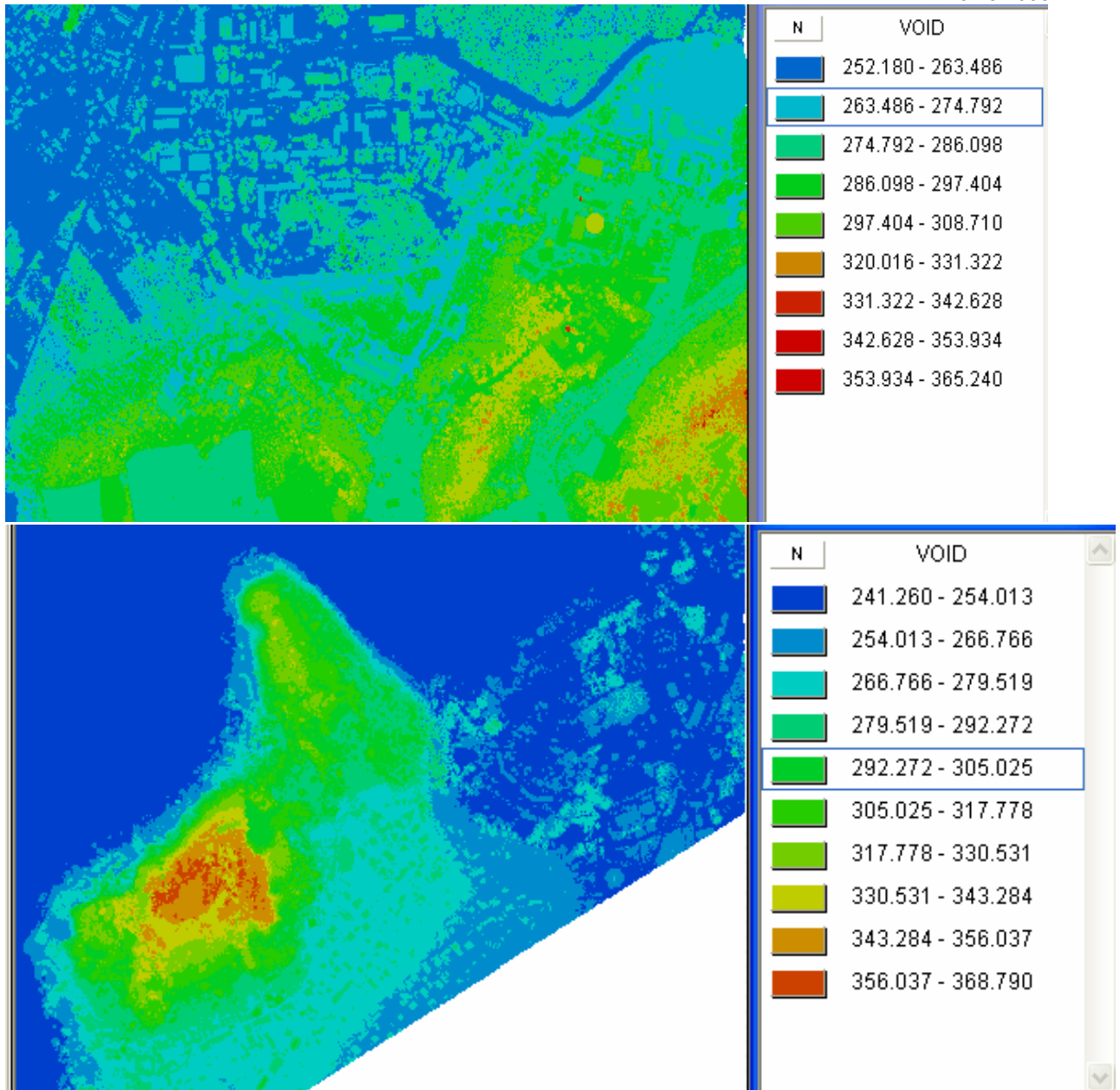
Accuracy analysis

Accuracy analysis was performed by comparing DTM (grid) with the source points (LIDAR measured points used for DTM generation), we call it: internal accuracy. Internal accuracy analysis was performed on 5 test area (3 JRC, 2 on lake board), 0. For the accuracy analysis DTM of 0.1m pixel size were generated. External analysis was made using in-situ GPS-RTK measurements.

1.4 Internal accuracy analysis

DTM or DSM generated from Lidar raw data in GRID model needs any interpolation method. GRID size generated in the project was 1m, it means that registered high (raw data) differs from DTM (DSM) in GRID model. So the first step in accuracy analysis is to define so called "inner accuracy", accuracy that depends ONLY on interpolation method (software, calculation algorithm). The differences between DTM and the Lidar raw data were calculated in GeomediaGRID. In this moment, "raw data" should be explained. In inner accuracy, only the DTM was concerned (so, there are no data to be compared in some areas). Raw data were specially prepared, that we would have the same data which were applied in GRID generation (including for example manual correction). Thus, we compared DTM and Lidar data, used to DTM generation (raw data after rasterization). The raw Lidar data were read in Geomedia, as a text file (xyz). Then, Lidar data were rasterized (vector/raster conversion) to related DTM (GRID). Then, these two layers were compared (subtracted, DTM – raw Lidar data). For the analysis, the results were converted to vector and saved in ACCESS data base (then exported to SHP). Histograms of the difference maps, with the corresponding legend used on figures (0, 0, 0), can be seen of the figure (0) – values of differences are in meters. On the histograms, you can see the relationship between frequencies of the error and the error values (like classical error distribution – but notice logarithmic scale, in normal scale histogram is very sharp). Histogram of the errors (discrepancies between DTM and Lidar raw data) shows only a distribution of the error value. Spatial distribution of the errors can be seen on the map (0, 0, 0). Following ranges of errors were marked with colors (compare (0)):

- <-0.2 m – red

- -0.2;-0.1 m – magenta

- -0.1;0.1 – grey

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- ▪ 0.1;0.2 – green

- ▪ >0.2 m – yellow.
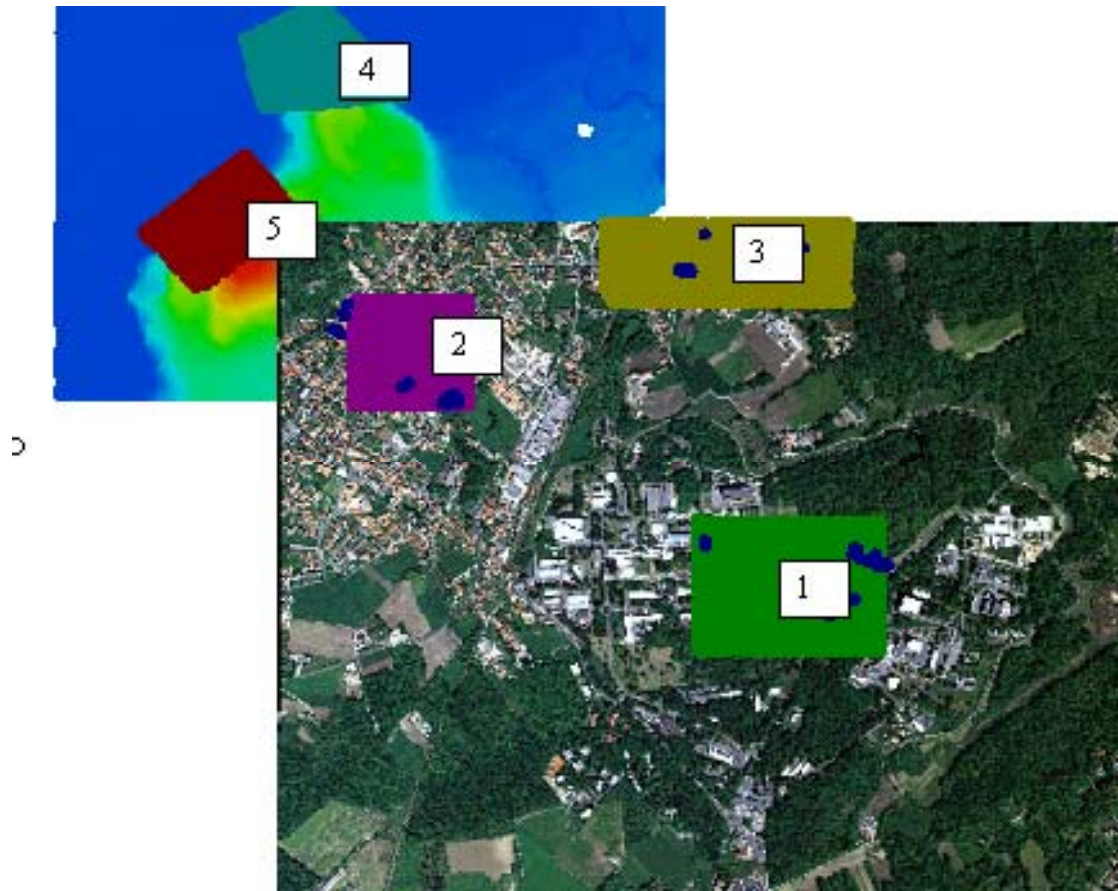
Sub sub test areas of 0.1m pixel size to internal accuracy assessment, points in dark blue point measured in-situ – GPS-RTK
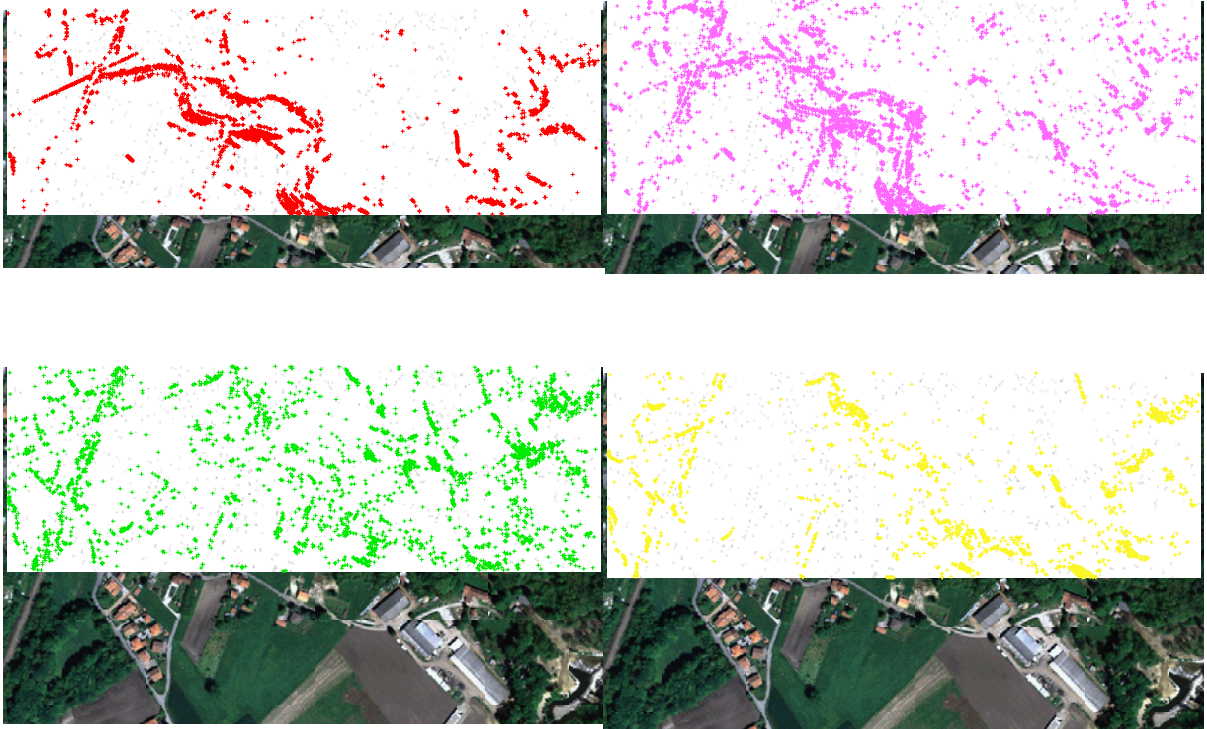
3/13/2008
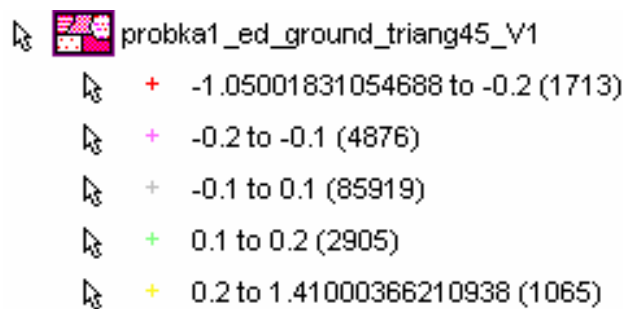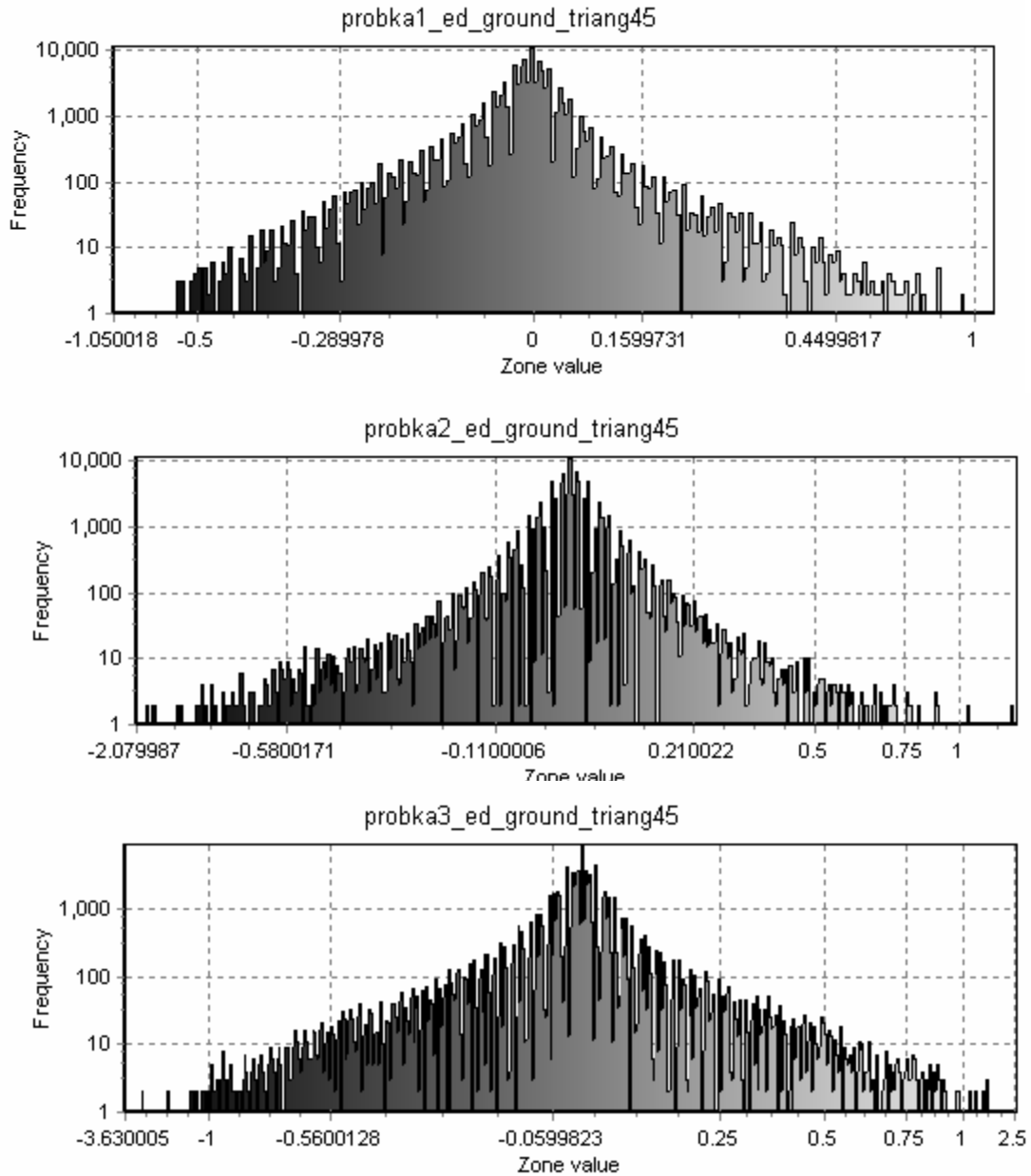
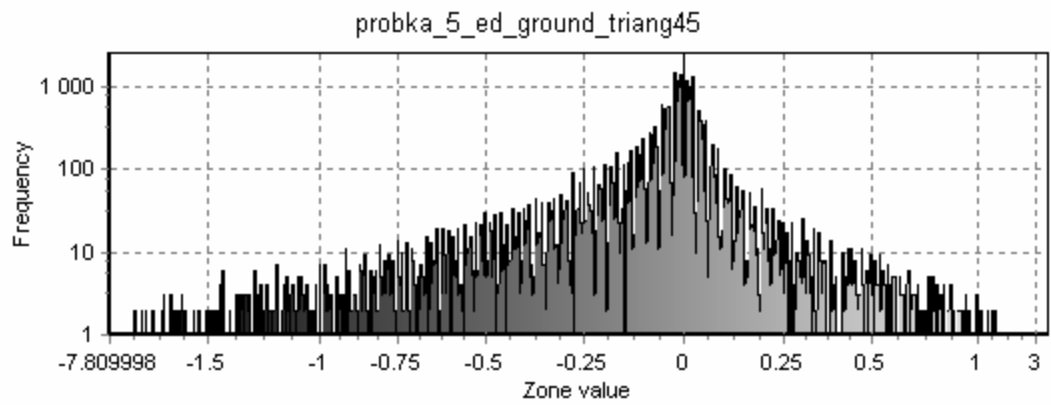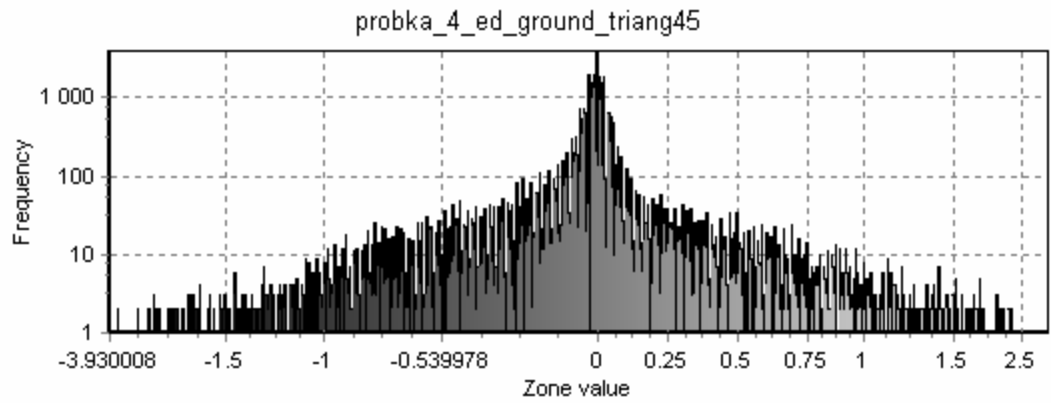Histograms of difference maps [m] with the legend used in the next figures (area 1, 2 , 3)

Sub test area 1, differences between DTM and raw Lidar data;
legend like on the figure (0)

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Sub test area 2, differences between DTM and raw Lidar data;
legend like on the figure (0)

Sub test area 3, differences between DTM and raw Lidar data;
legend like on the figure (0)

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Histograms of difference maps [m] with the legend used in the next figures (area 4, 5)

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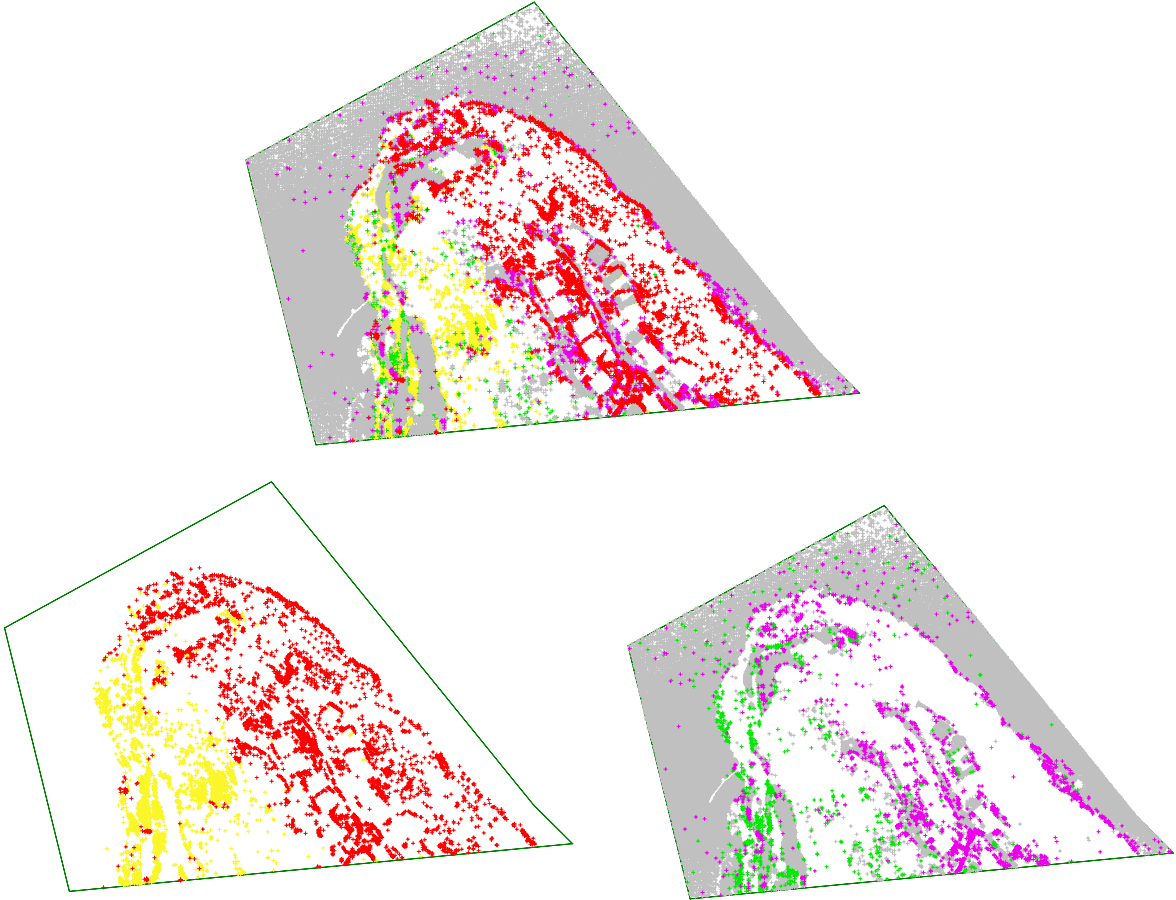
Sub test area 4, differences between DTM and raw Lidar data;
legend like on the figure (0)

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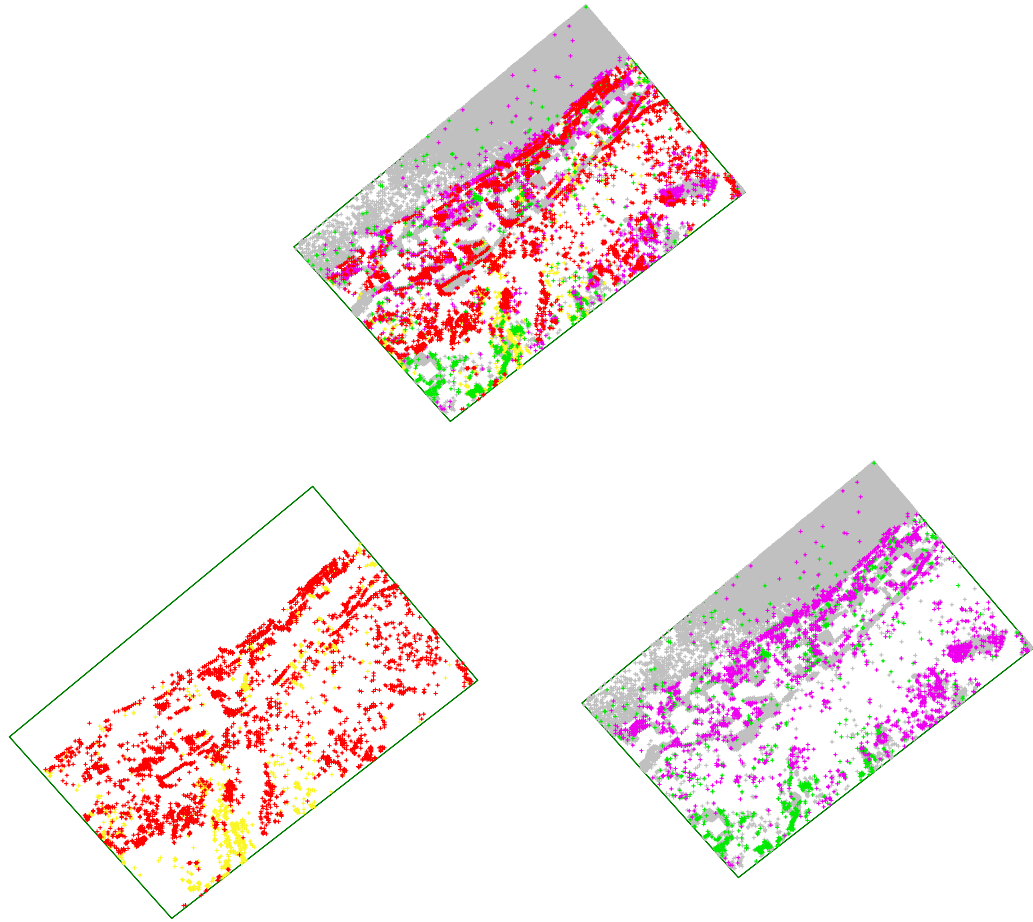
Sub test area 5, differences between DTM and raw Lidar data;
legend like on the figure (0)

Results of comparison between DTM and raw Lidar data are presented in tables (Tab. 1 and Tab. 2). According to the accuracy analysis can be stated as follows:

- Accuracy depends on the surface characteristic

- JRC – standard deviation is: 0.09 m

- Lake area – standard deviation is : 0.29 m

- Small systematic error was observed : -0.04 and -0.033 m

Tab.1 Accuracy analysis test area – JRC

No of test area	Number of points	Average of difference (m)	Standard deviation of differences (m)	Min Δh (m)	Max Δh (m)
1	96478	-0.0074	0.073	-1.05	+2.46
2	83596	+0.0007	0.083	-2.08	+2.93
3	81006	-0.0061	0.125	-3.63	+2.50
Average (m)		**-0.04**	**0.09**		

Tab.2 Accuracy analysis test area – lake board

No of test area	Number of points	Average of difference (m)	Standard deviation of differences (m)	Min Δh (m)	Max Δh (m)
4	36723	-0.0164	0.316	-3.93	+9.86
5	27003	-0.0496	0.272	-7.81	+10.64
Average (m)		**-0.033**	**0.29**		

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1.5 External accuracy assessment

External accuracy analysis was performed basing on the RTK GPS measurements taken by Ms A. Sima.

Tab.3 Accuracy analysis – RTK GPS

Number of points	Average of difference (m)	Standard deviation of differences (m)
66	-0.009	0.907

Slope and aspect were calculated from DTM in all in situ measured points to analyze the correlation between discrepancy between DTM and slope or aspect.
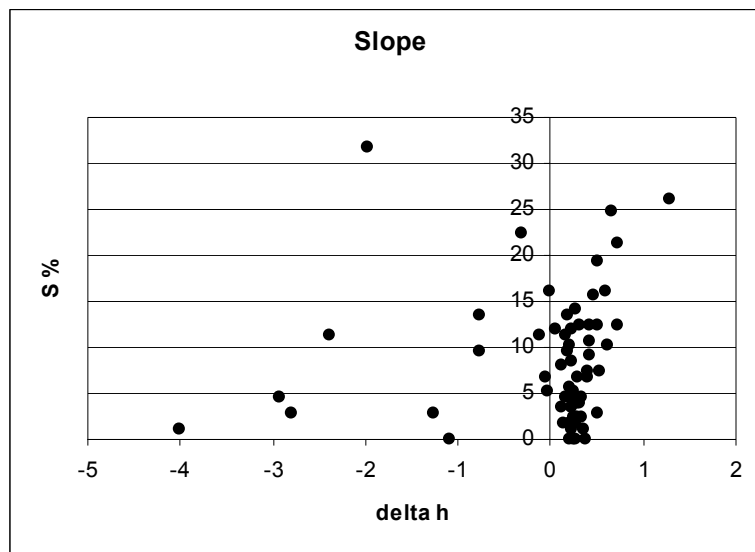
Relationship between slope and deltah (m)
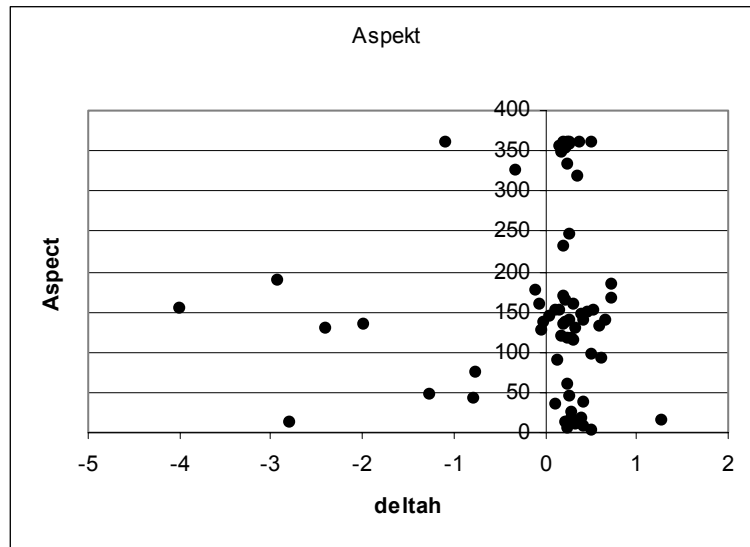
Relationship between aspect and deltah (m)
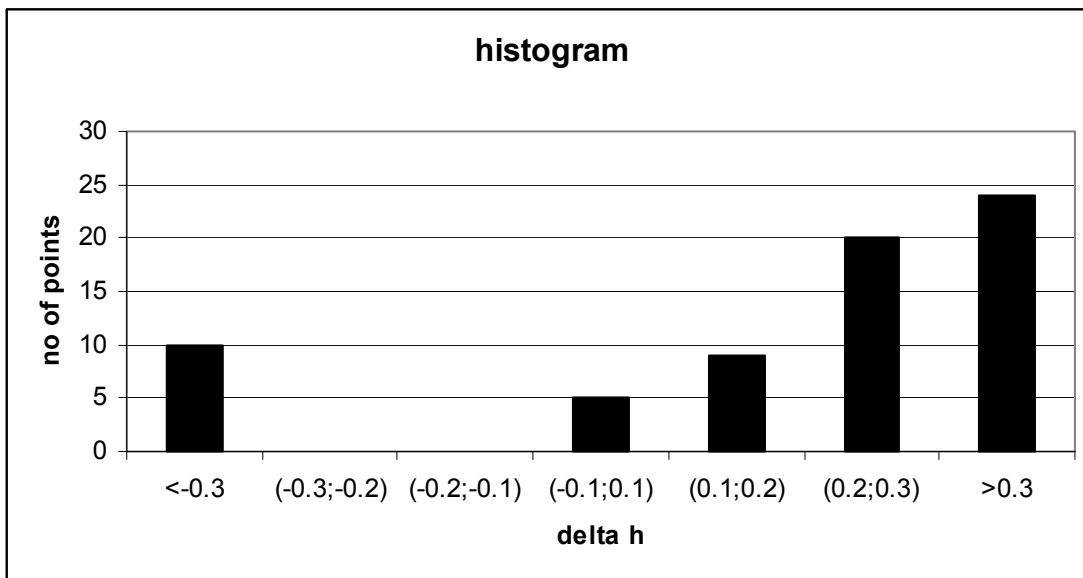
Histogram of DTM error (in-situ measurements)

Summary

Generally, DTM can be generated in GRID or TIN models. TIN models base on the all points (in the case of the in-situ surveying methods or even using photogrammetry). However, in the case of dense LIDAR data, TIN is build not on the all points, from the layer classified as a ground, but on the some chosen points. There is also possible to make conversion TIN to GRID. This two steps: TIN and GRID generation are the source of errors.   Therefore, in the project DTMs, in GRID model, were compared to the original LIADR points (classified as a ground). The accuracy was called: inner accuracy. External accuracy was also checked in points, measured in-situ (GPS RTK).

In summary, concerning the accuracy of DTM can be stated as follows:

- The crucial, for good quality of DTM, generated in TerraSolid, using triangle method, is triangle length assumption. According our tests, made in the project, we assumed 45 m as a triangle length.

- Internal DTM accuracy (standard deviation of differences between DTM and raw Lidar data) obtained from the analysis varies: 0.1-0.3m

- DTM (GRID) was below the raw Lidar data of about: 0.04 m

- External accuracy basing on In-situ measurements:

    ○ 50% of the measured points – error (-0.1;0.2)

    ○ 50% of the measured points – error (<-0.3 and >0.3)

    ○ 0% of measured points – error (-0.3;-0.1)

According our research, accuracy of DTM, dependent on interpolation, is about +/-0.5 m, (90%). External accuracy is difficult to estimate unequivocally, because of the shape of error distribution function (0). However, taking into consideration the standard deviation of the errors, external DTM accuracy is about +/-1.5 m (90%). Relative accuracy of DTM (higher than external) would have to be analyzed, for example using the stereoscopic models. The ditches wider than 1 m should be seen on the DTM. There is also possible to analysis LIDAR data in details instead of DTM (differences might be +/- 0.5 m).

DSM is composed of the objects above the DTM. The LIDAR data classification depends on the height of the objects. Buildings classification requires also some special parameters (0). Crucial in DSM generation is LIDAR data classification. The results of the height classification contain points lying in defined height range. The layers can be used to DSM generation into the GRID model. Interpolation method deforms original data, especially in the case of DSM generation, where there are many sharp edges (0 - 0). This deformations are easy to notice on the separated layers (0, 0), but they appear also on DSM. The raw classified layers, containing the LIDAR data, seem to be more useful for precisely analysis of the objects on DTM, instead of interpolated GRID (0 - 0).

The classification procedure, in TerraSoild seems to be effective. The results of DSM classification depend on the quality of LIDAR data, and it couldn't be valuated on the base on the one example.

Buildings and high vegetation are on the same layer, assuming height limit: 3 m (some separation between buildings could be made in "buildings classification" in TerraSolid). Buildings of the height below 3 m are on the layer middle vegetation (1.5-3 m). Generally, in some cases, without any other information, for example from ortophotomap, it is not possible to separate buildings from high or middle vegetation. This problem might be solved using LIDAR intensity – not tested in this study. In many cases, buildings must be corrected manually, there is no any special algorithm to help this process, as yet.

Bushes and hedges can be seen on the middle vegetation layer. It could be possible to make classification of LIDAR data in other limits, for example instead of : 1.5-3 m, for special purposes, for example: 1-2m.

On the layer: low vegetation (0,1.5), there are only corps, grass, small bushes or small anthropogenic objects.

Generally, layers with points below 3 m, contain not only stable objects (for example, hedges, concrete cotes etc.), but also not stable objects (growing vegetation, wood cotes, moving cars etc.). Therefore, for DSMs, for all test area (all strips), we decided to assume the height limit of 3 m.

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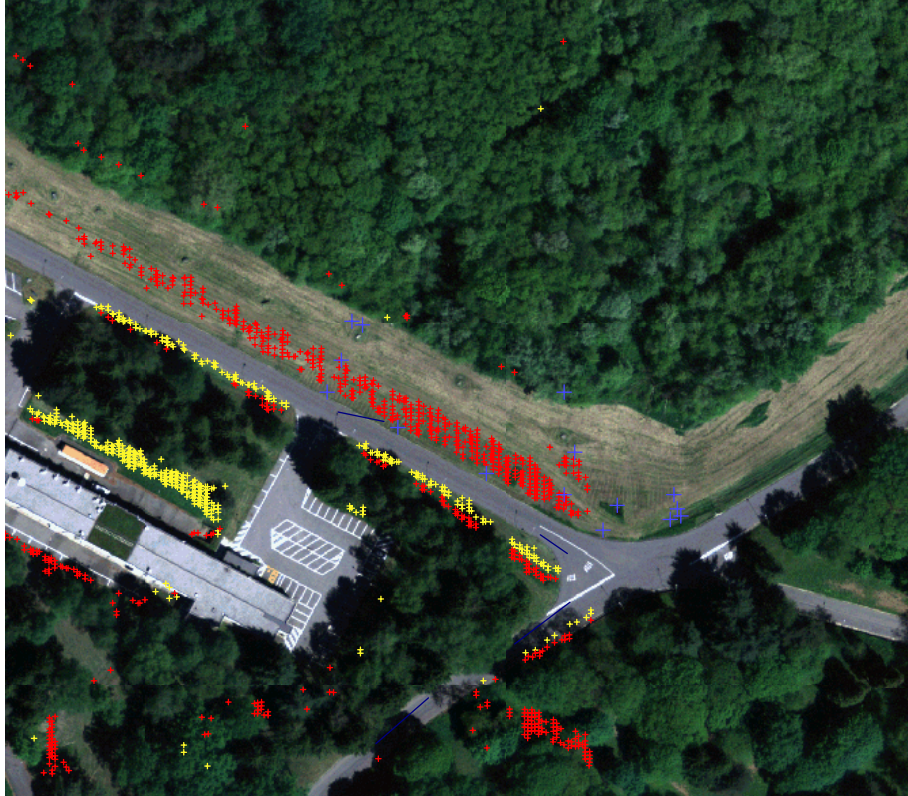Ul. Dolnych Mlynow 7/1, 31-124 Krakow, Poland, geo-staszic@wp.pl

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DSM wasn't compared to the other sources: field or photogrametric measurements. It is possible, but it exceeds range of the project. External accuracy of DSM, estimated after the DTM accuracy, could be probably also about +/-1.5 m or less, and it's depend on the cover type.

Another question concerns the relative sensitivity of LIDAR data, and possibilities of small objects recognition. Relative DSM accuracy is of course higher than external accuracy. Not significant, relative height differences could be measured. Without optical information, it is however difficult to decide what kind of the object is measured.

3. Hejmanowka

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Attachment 1 - In-situ measurements

delta_h – 0,25-0,30 blue in-situ
S 1-6
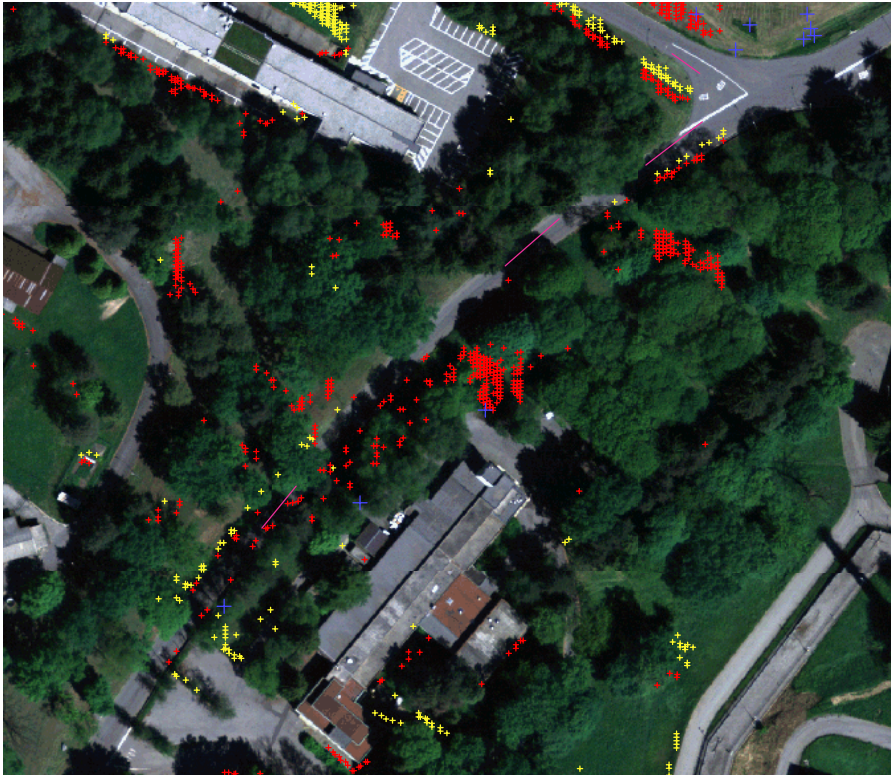
delta_h   0,25-0,3 blue in-situ
S   1-22

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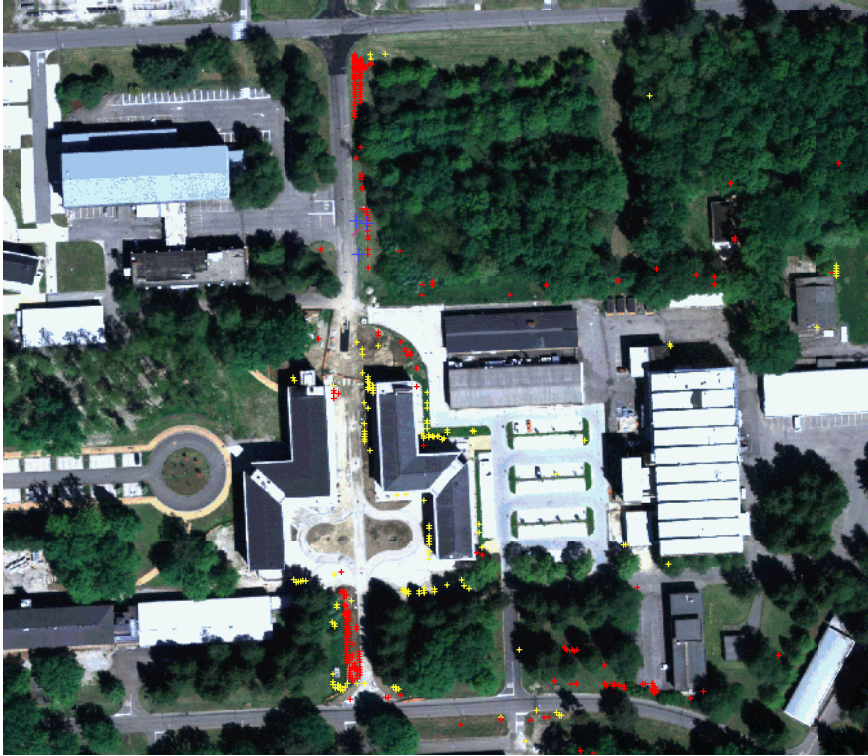
delta_h   0,32-0,62 blue in-situ
S =10 – delta_h = 0,62

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delta_h   0,20-5.0 blue in-situ
S do 26

Attachment 2 – TerraSolid, ground classification – tests of iteration angle, distance

Sub test areas are composed from few strips and during initial works were merged. Points were read as following: first pulse – first layer, last pulse – low vegetation. Line of the connections between areas is shown on the figure: (0)

Strips merging

TerraSolid options for „classify ground"

Parameters:

- Iteration angle

- Iteration distance

The parameters define how near to the triangle flat must be the point to be classified as a ground one.

Terrain angle defines maximum slope:

- 80º-90º - if artificial objects appear on the surface (buildings, engineering objects)

- 20º-40º - for not sophistical terrain

- about 60º for middle mountain area.

Iteration angle:

- defines maximum angle between

this is an angle between triangle plane and a line connecting potential point with the closest triangle vertex

- about 4º - 6º

Iteration distance:

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- this is maximum distance from a point to the triangle plane

  ° distance usually is from 0.5m to 1.5m

  ° reduces eagerness to classify points inside small triangles

Terrain angle tests were performed for different angle values. An example of: 25 and 88 degree to plane is presented on the figures: (0 - Rysunek 3). In the urban area it is recommended as 88 degree, that it seems to be correct, comparing the results: (Rysunek 1, Rysunek 3). Too big blur of anthropogenic objects appears in the case of 25 in compare to the 88, of course not in all cases.
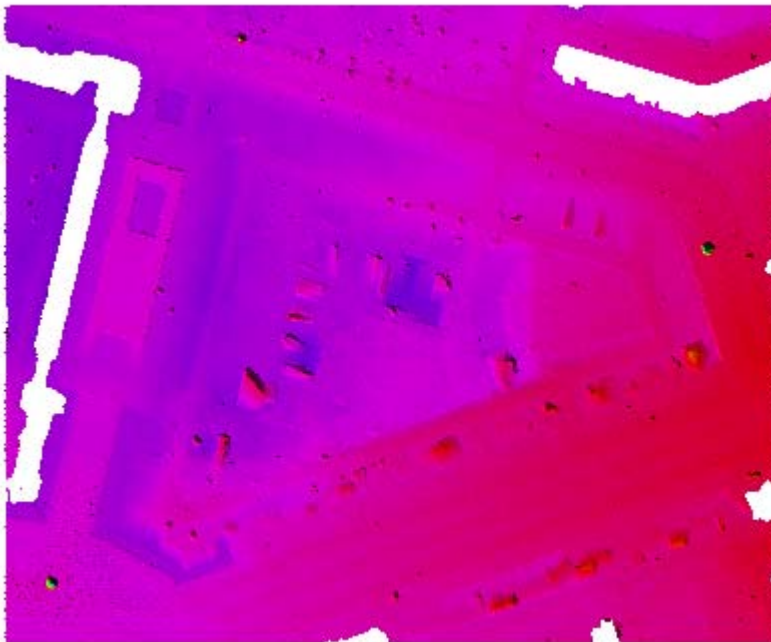

TerraSolid options for „classify ground" – terrain angle tests

Rysunek 1. TerraSolid options for „classify ground" – terrain angle tests: 25, 88 (first example)

Rysunek 2. TerraSolid options for „classify ground" – terrain angle tests - statistics

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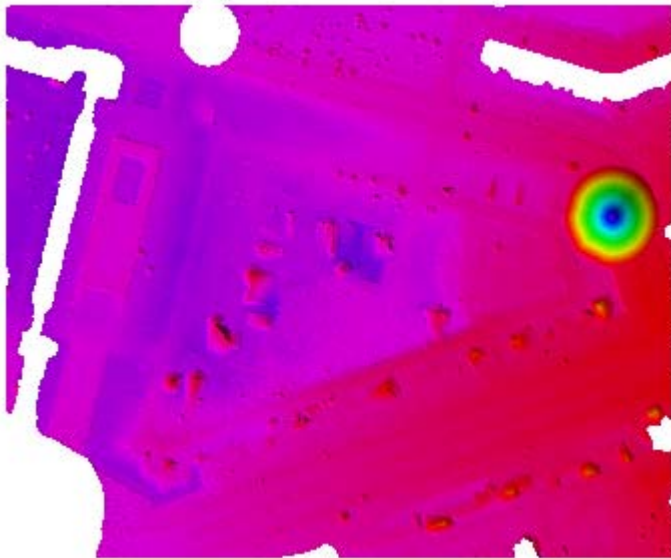
25

88

Rysunek 3.　　　TerraSolid options for „classify ground" – terrain angle tests: 25, 88 (second example)

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Attachment 3 - DSM layer classification in raster model

Terrasolid enables Lidar data classification as:

- Low vegetation (0-1.5m), (0)

- Middle vegetation (1.5-3m), (0)

- High vegetation (higher than 3 m), (0)

- Buildings, (0)

- Buildings with high vegetation, (0)

All mentioned layers were classified automatically from Lidar data and grided to 1m pixel size. The GRIDs separately should be analyzed carefully; because of grid interpolation, (some "buffer" is noticeable (0, 0)). In fact, only the layers composed of the raw LIDAR data should be used in detailed analysis (see last part of the attachment, 0, 0, 0).

DSMs in GIRD model (1m) only generally can be analyzed on figures (0-0) because of "buffering" effect caused by griding (in TerraSolid). The buffers appear always on interpolated layers, but this effect could be less then on the figures.
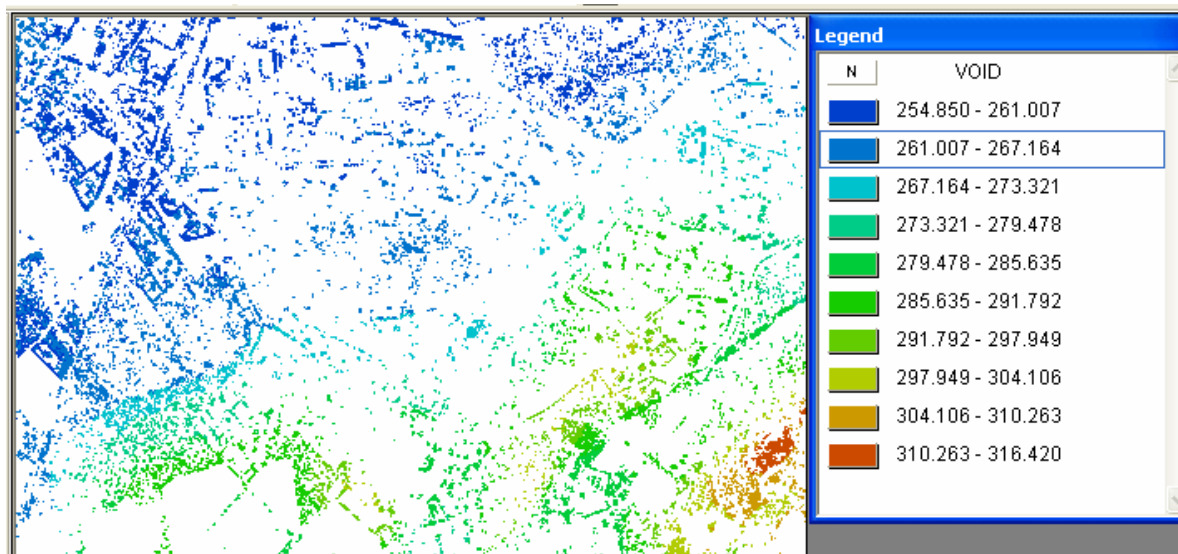
On the figures (0-0), areas, not belonging to the layer, are shown (in white). There are on the areas points above or below the high limits. Generally, buildings classification is the most difficult in Lidar data processing. We can meet problems during automation of the process. Some of them can be noticed on the figure (0). On the other hand, an example of well buildings classification result can be observed on the figure (0). Buildings are on the figures in red color. Automatically classification of buildings, surrounded by high vegetation, can be even not feasible[3].
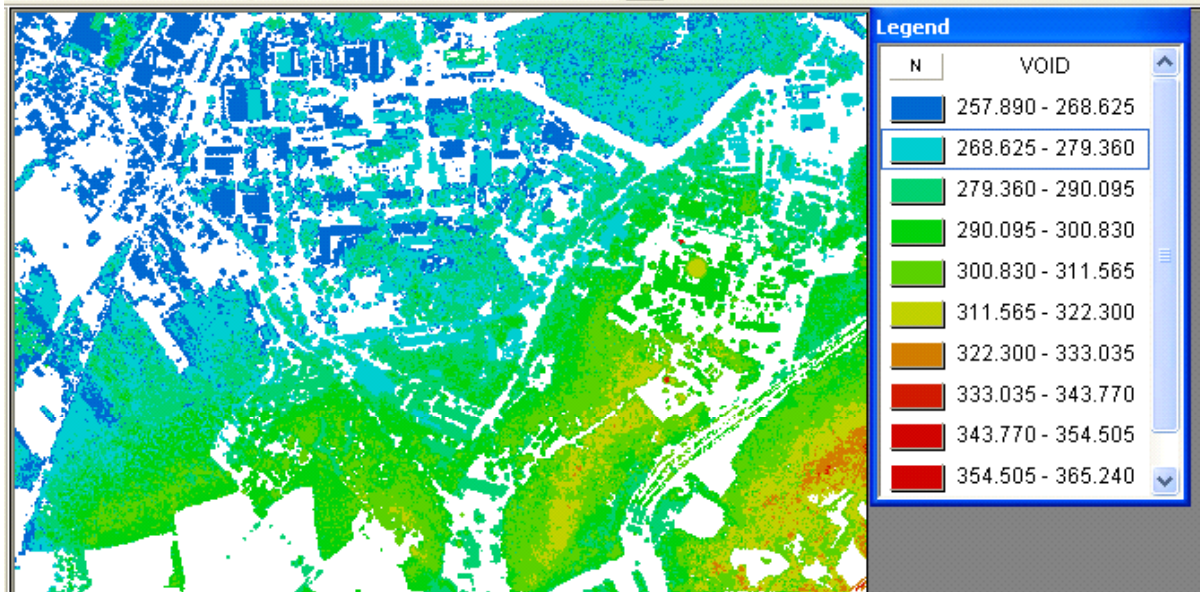
---

[3] Notice: on the figures: 0-0 are shown the results of vegetation classification (by height). It means that on the layer we can find also buildings.
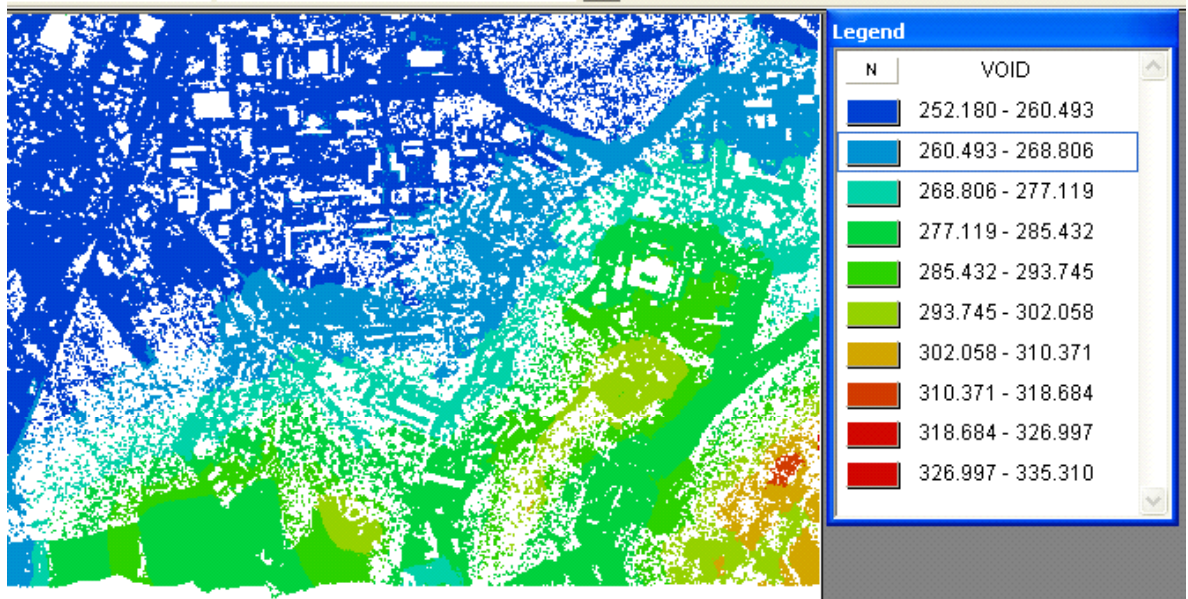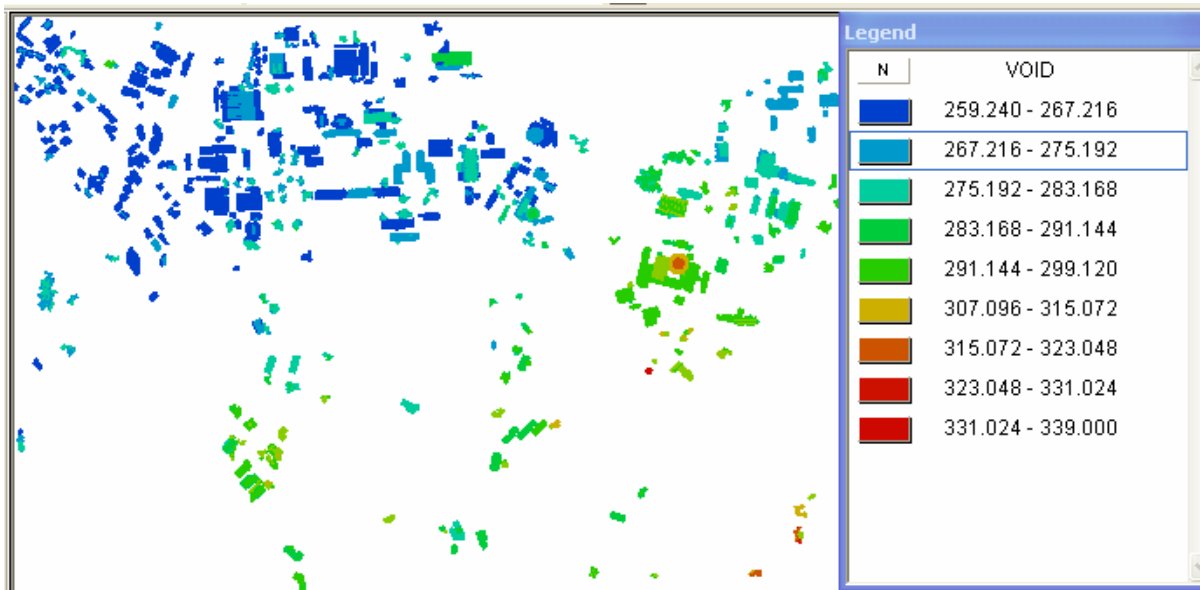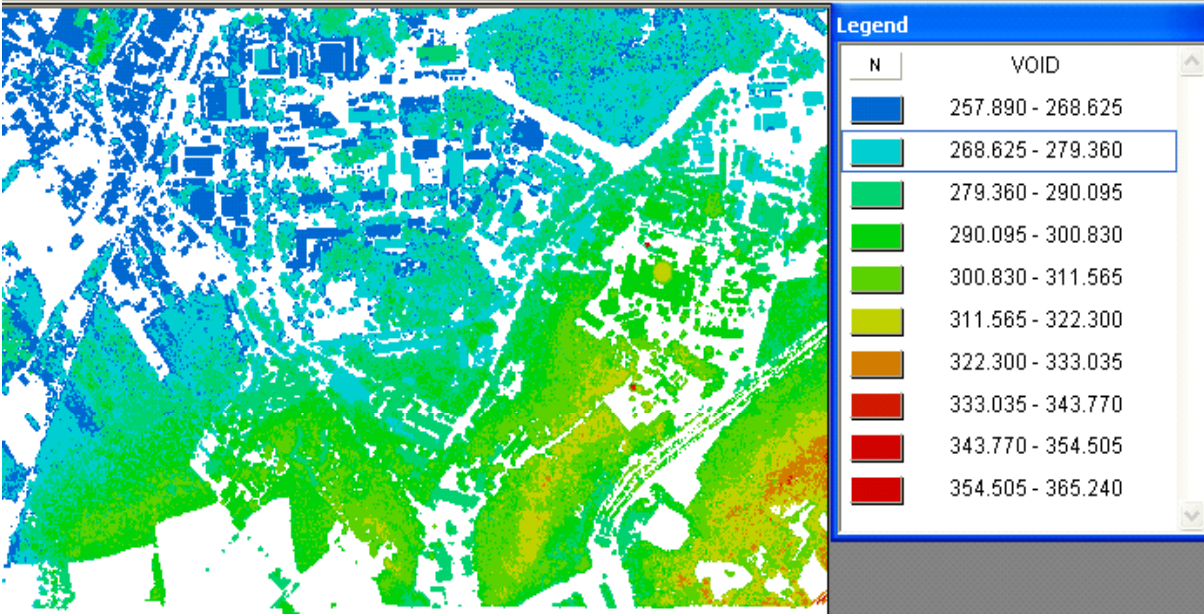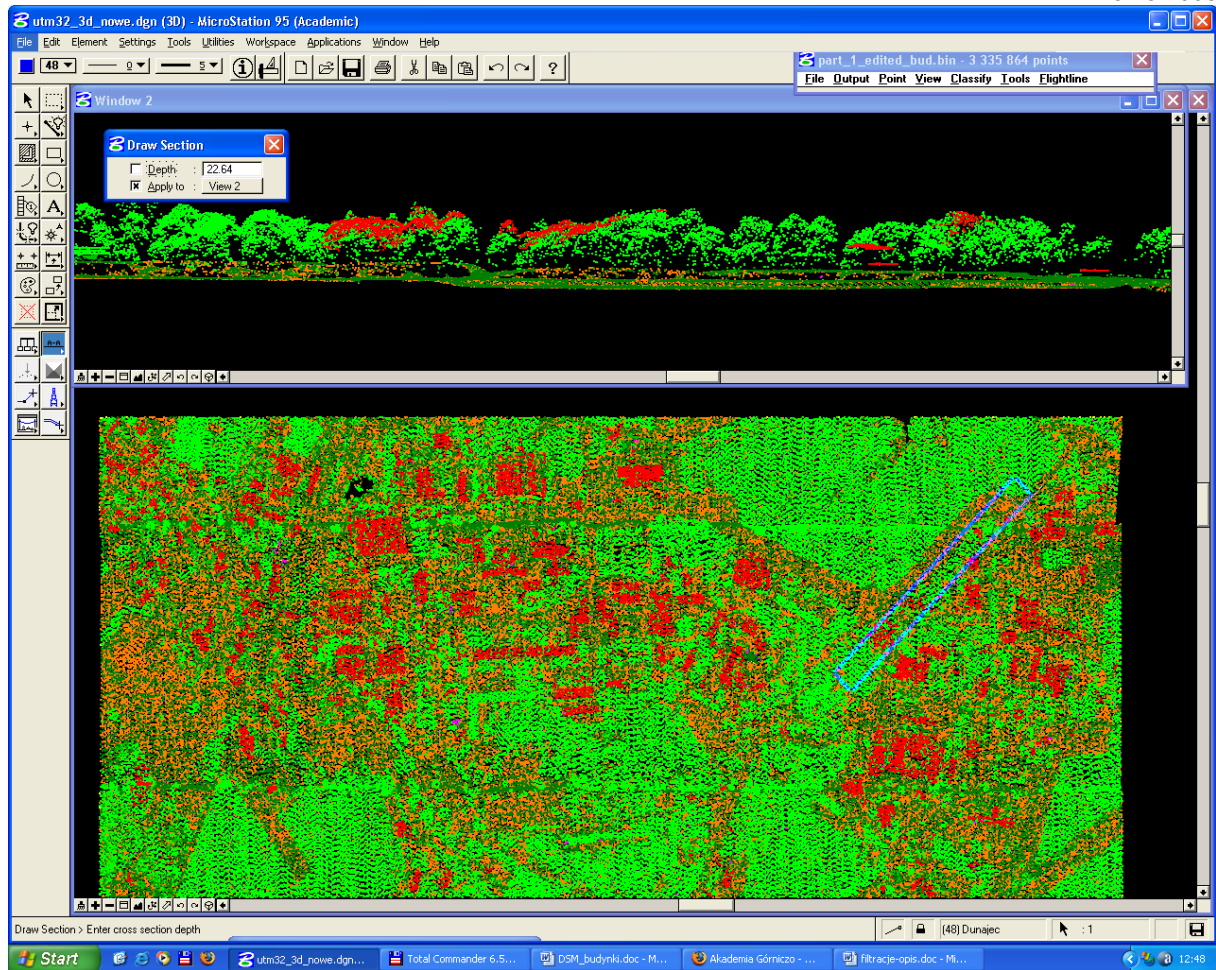
Layer: low vegetation

Layer: middle vegetation

Legend	
N	VOID
	257.890 - 268.625
	268.625 - 279.360
	279.360 - 290.095
	290.095 - 300.830
	300.830 - 311.565
	311.565 - 322.300
	322.300 - 333.035
	333.035 - 343.770
	343.770 - 354.505
	354.505 - 365.240

Layer: high vegetation

Legend	
N	VOID
	259.240 - 267.216
	267.216 - 275.192
	275.192 - 283.168
	283.168 - 291.144
	291.144 - 299.120
	307.096 - 315.072
	315.072 - 323.048
	323.048 - 331.024
	331.024 - 339.000

Layer: buildings

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Layer: buildings and high vegetation

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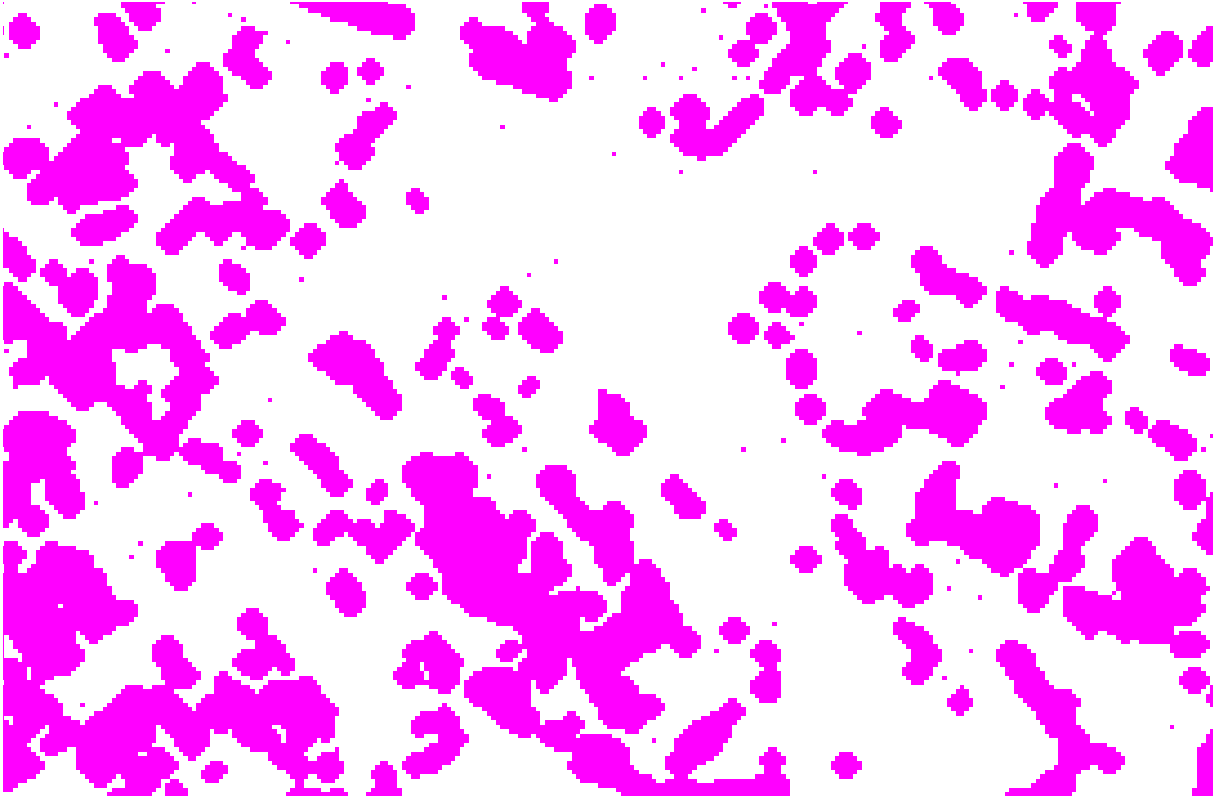Ul. Dolnych Mlynow 7/1, 31-124 Krakow, Poland, geo-staszic@wp.pl

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Example of wrongly classified points to the building layer, cross section shown above is
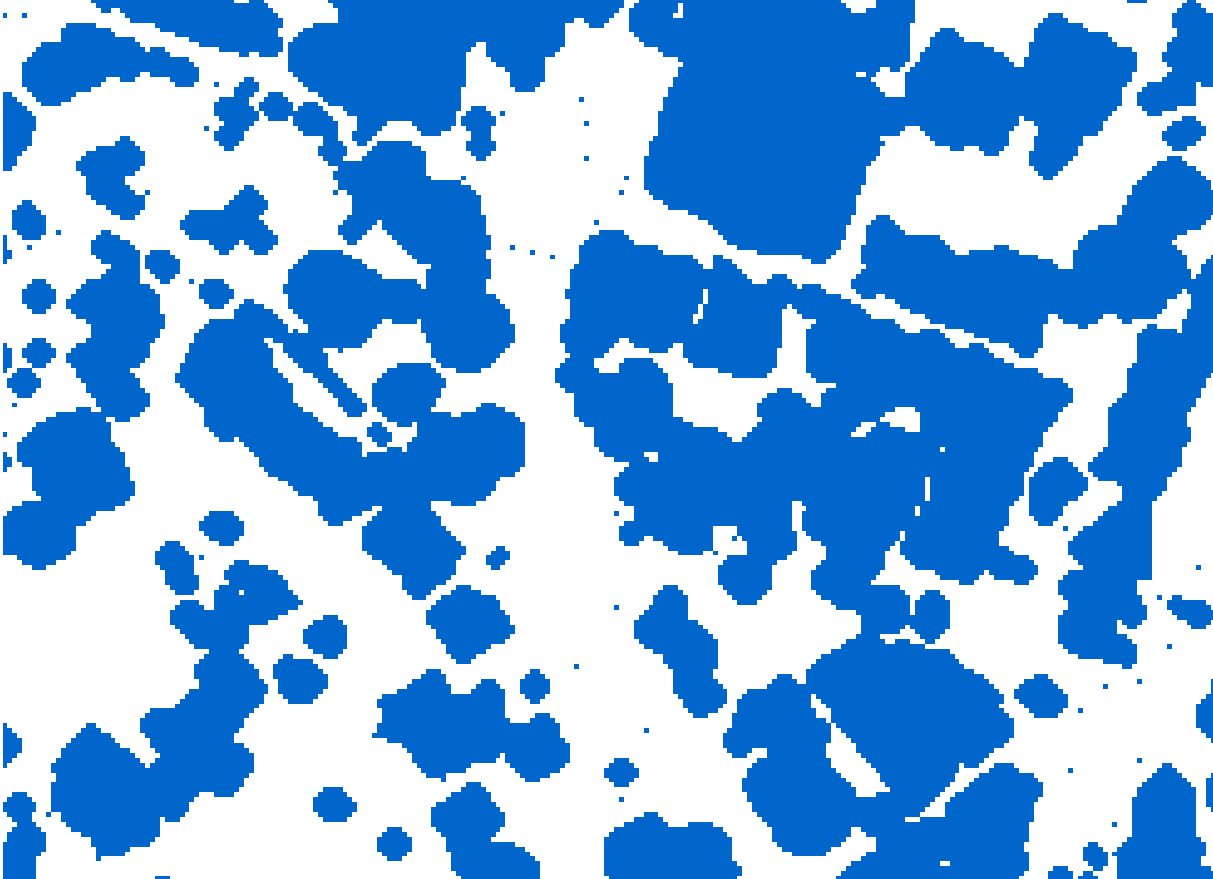collected from blue rectangle (sub test part1), buildings in red

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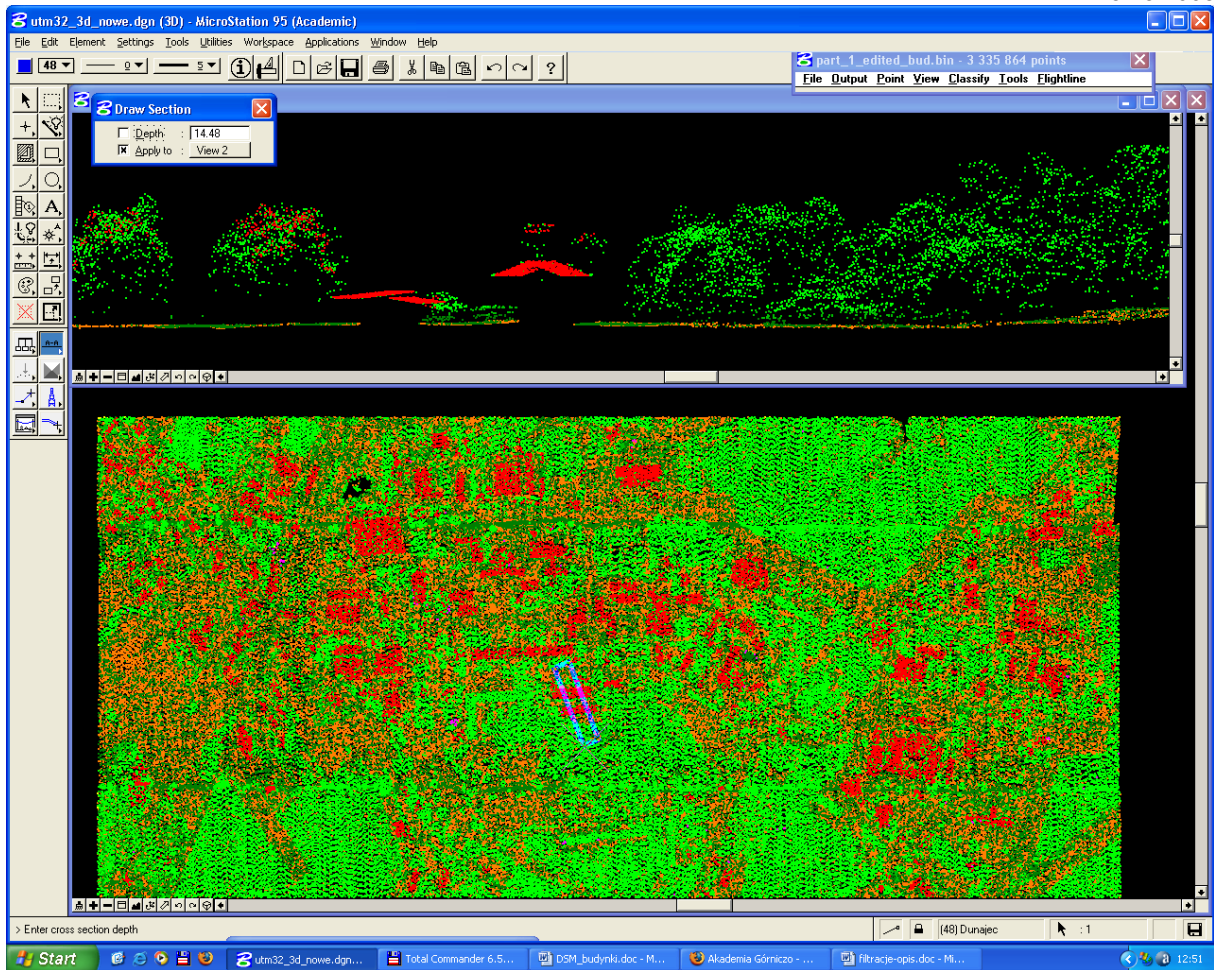
Example of well classified points to the buildings layer, cross section shown above is collected from blue rectangle (sub test area2 - part2), buildings in red
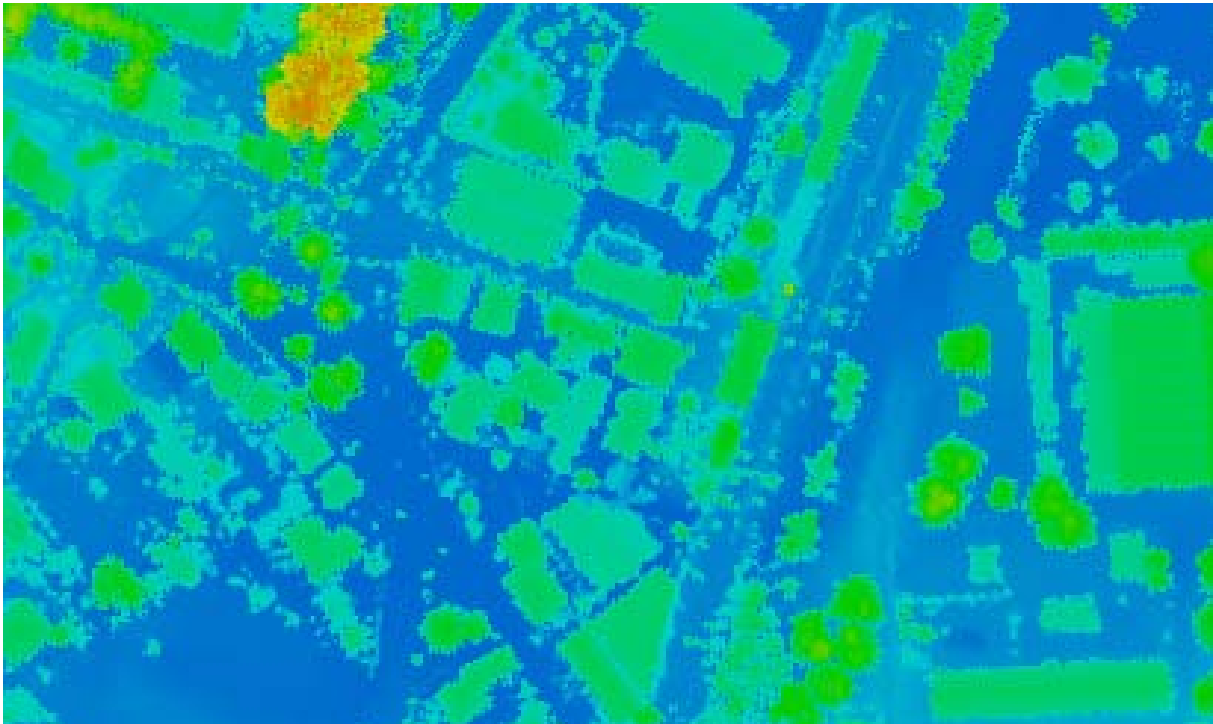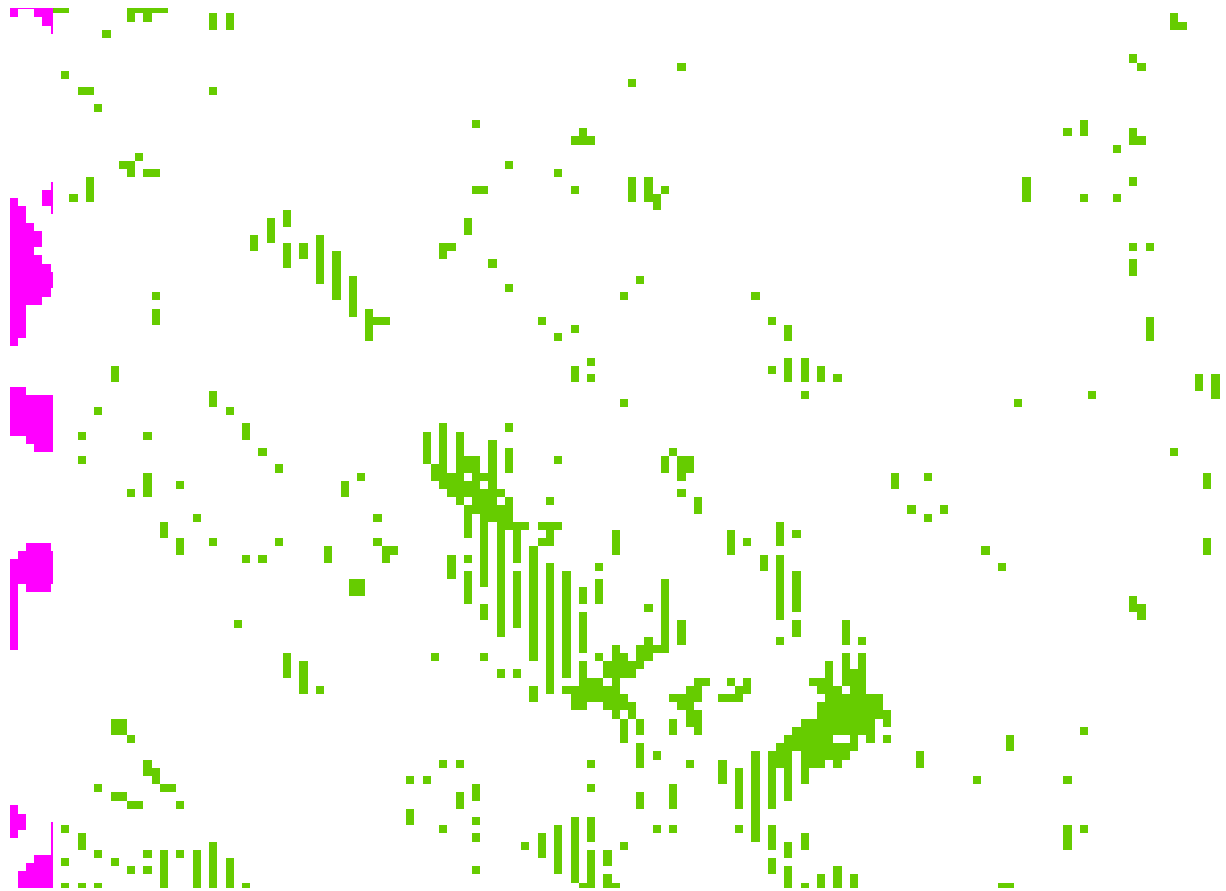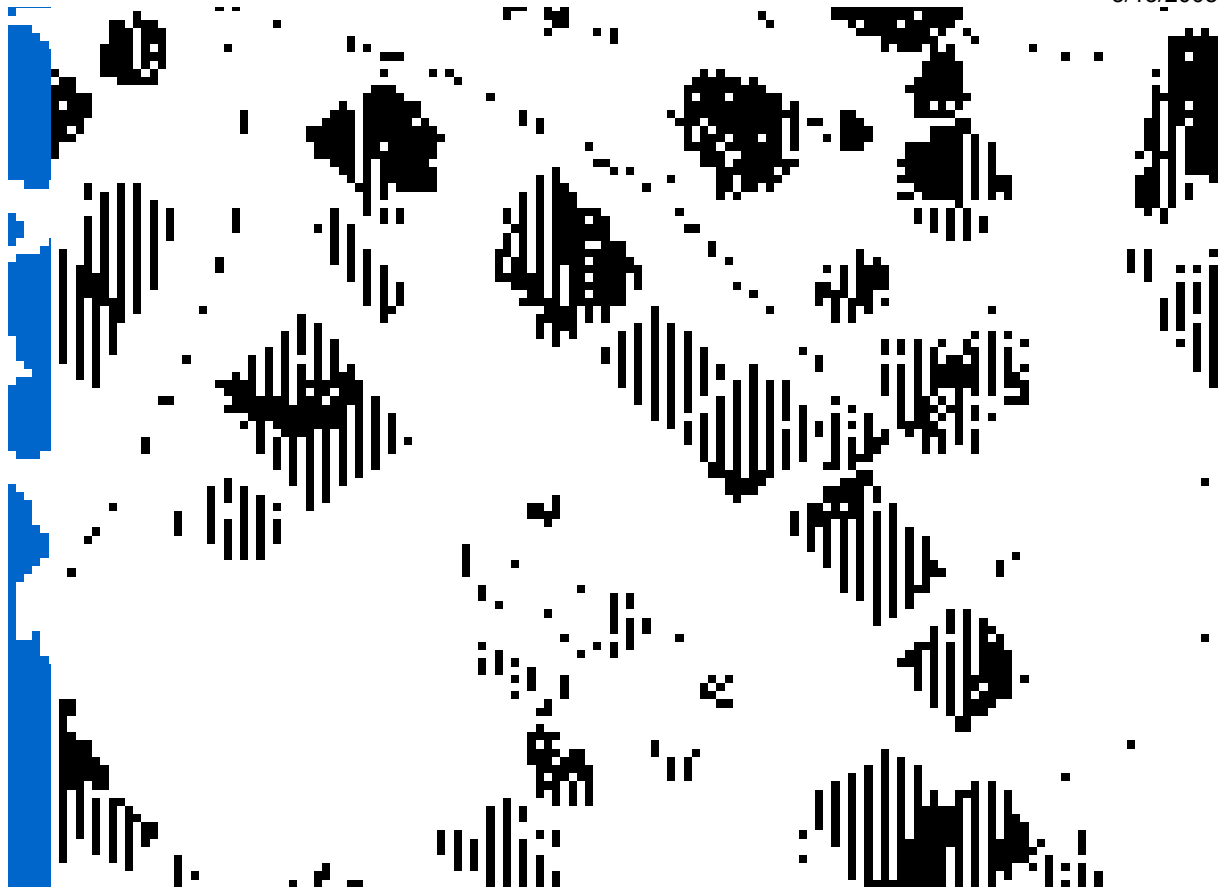
Middle vegetation, result of GRID interpolation

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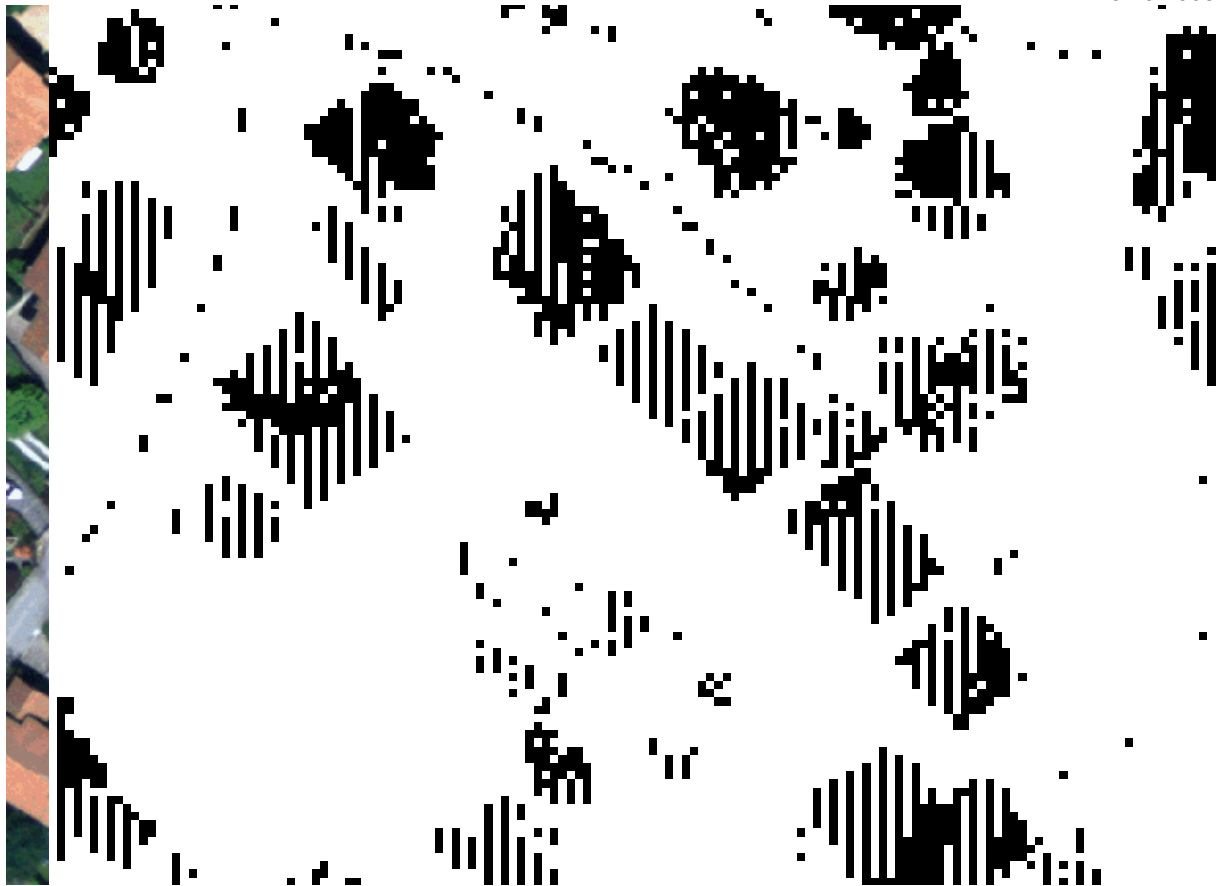3/13/2008

High vegetation, result of GRID interpolation

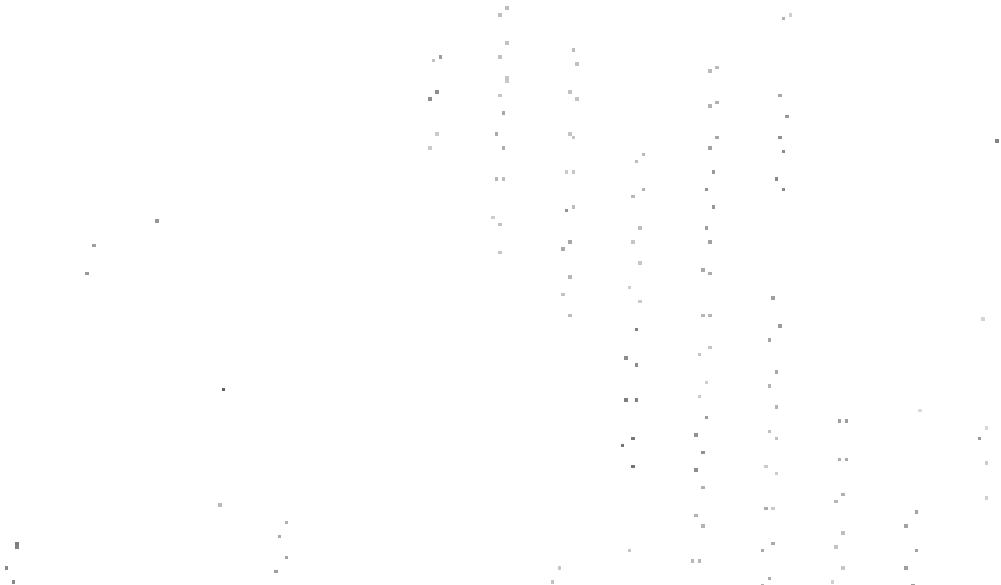DSM_DTM (result of GRID interpolation of all layers together)

Middle vegetation (magenta), GRID 1 m, LIDAR points classified to middle vegetation
(green), raster 1 m

High vegetation (magenta), GRID 1m, LIDAR points classified to buildings (black), raster 1 m

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Middle vegetation (green) and buildings (black) - LIDAR points , raster 1 m

LIDAR points classified to middle vegetation: points (vector) - red crosses, raster 0.1m (grey small pixels), raster 1m (green pixels)

Middle vegetation like above, LIDAR points classified to buildings – black raster (1m), grey raster (0.1m - small pixels)