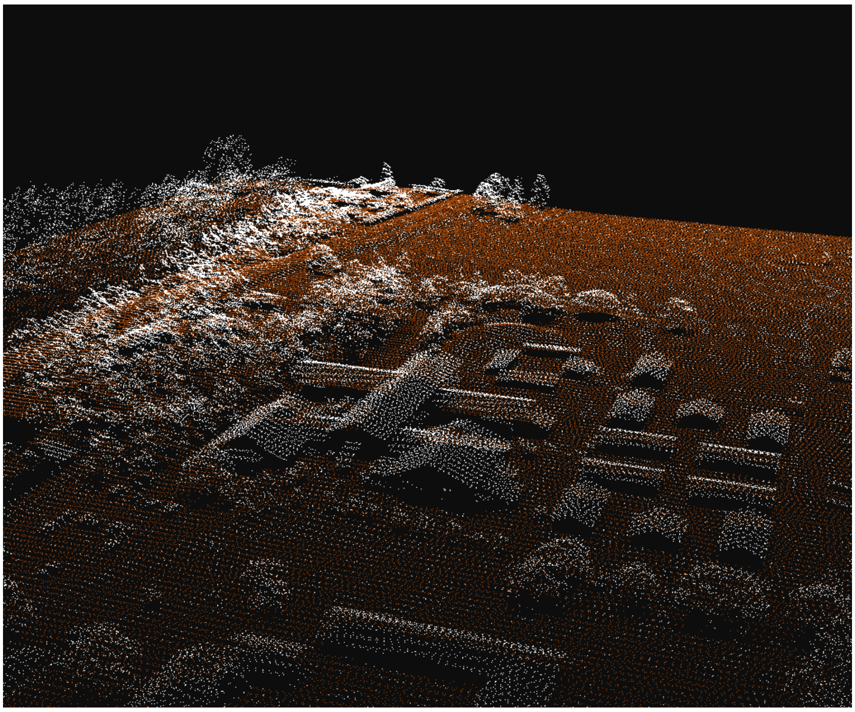
Date: 2019-10-01

Document version: 1.1

Quality description of laser data



List of contents

1. Introduction 3
2. General information about quality 3
3. Data capture 4
   3.1. Lineage 4
4. Quality description 5
   4.1. Completeness (point density/coverage) 5
   4.2. Classification 7
      4.2.1. Classify laser points 7
      4.2.2. Known deficiencies in the classification 8
   4.3. Positional accuracy 15
      4.3.1. Absolute accuracy 15
      4.3.2. Relative accuracy 15
5. Other factors affecting quality 15
   5.1. Scanning on several occasions/during different seasons 15
   5.2. Different types of scanner system 18

1. Introduction

This appendix describes the general quality of laser data and provides an overview of deficiencies that may exist.
The quality is presented using the quality parameters described in the Standard SS-EN ISO 19157:2013 Geographic information - Data quality.

The quality description applies to all product variants of laser data, Laserdata NH and Laserdata Skog.

Laser points classified as ground and water are also used to produce the National Elevation Model.

2. General information about quality

The measured or estimated quality applies to the entirety of the surface scanned. It is therefore important to, for the area in question, refer to metadata such as survey technique, time of scanning and point density. Good knowledge of the local terrain conditions is also valuable in the interpretation of data.

In order to achieve the best ground presentation, scanning needs to be done when as many laser pulses as possible have a chance of reaching the ground. Scanning in the summer means that leaves and undergrowth prevent laser pulses from reaching the ground. In the autumn, high-growing plants can prevent the laser pulses from reaching the ground, even if the leaves have fallen from the trees. In wintertime, a blanket of snow thicker than a few centimetres provides an inaccurate picture of the ground surface contours. In spring, large quantities of melted snow and ice can constitute an obstacle to scanning, as the water conceals the ground surface. This means that the time window in which a good scan can be achieved is not so wide. The best conditions for scanning occur outside of the growing season, i.e. in the spring and late autumn.

Those parts of Sweden that are mainly covered by deciduous trees, i.e. southern Sweden have with a few exceptions been scanned outside of the growing season. The rest of the country has been scanned regardless of the season and may therefore have areas with relatively dense vegetation.

Table 1 Quality themes and quality parameters

More detailed description of lineage and quality can be found in the text below.

Data quality element	Data quality subelement	Quality
Completeness (Point density/coverage)	Omission	Point density, only the last return is counted. The figure is a mean value of the point density in cells of 10 x 10 metres in each scanning area. **Laserdata NH** At least 95% of the total scanned surface (water excluded) achieves at least 0.5 points/m^2, in some bare mountains without infrastructure at least 0.25 points/m^2. **Laserdata Skog** At least 95 % of the total scanned surface (water excluded) achieves 1,0 points/m^2
Thematic accuracy	Classification accuracy	The accuracy of the classification is generally good, but some misclassification occurs.
Positional accuracy	Absolute accuracy	On open flat hard surfaces, the standard error < 0,1 m in height < 0.3 m in plane
	Relative accuracy	Height difference between flight lines, standard error < 0.15 m

3. Data capture

3.1. Lineage

Laser data is captured through airborne laser scanning of the terrain.

All points are preserved throughout the entire production chain, including incorrect points at high or low altitude.

Some facts about the scanning for **Laserdata NH** (approximate values):

- Point density: 0.5-1 points per square metre (down to 0.25 points per square metre in the bare mountains).
- Flying altitude: 1 700-2 300 metres (up to 4 000 metres in the bare mountains).
- Scanning angle: maximum ± 20°.
- Side overlap: 10-20 %.
- Footprint on the ground: 0.4-0.9 metres, depending on flying altitude.

The laser scan is performed using instruments that can provide at least four returns from the same laser pulse. In case of more than four returns, we have chosen to store as many as technically permitted by the standard LAS 1.2., i.e. up to 7.

Intensity (the strength of the reflected laser pulse) is recorded for the first three returns.

Some facts about the scanning for **Laserdata Skog** (approximate values):

- Point density: 1-2 points per square metre
- Flying altitude: ca 3 000 metres
- Scanning angle: maximum ± 20°.
- Side overlap: at least 20 %.
- Footprint on the ground:< 0,75 metres, depending on flying altitude.

The laser scan is performed using instruments that can provide at least four returns from the same laser pulse. Percentage transmitted laser pulse that cause more relevant returns should in forest amount at least 30 %.
In case of more than four returns, we have chosen to store as many as technically permitted by the standard LAS 1.2., i.e. up to 7.

4. Quality description

4.1. Completeness (point density/coverage)

The point density on ground varies with terrain type, type of vegetation, the season during which laser scanning was performed and a number of other factors. This variation means that in some areas there are deficiencies in the point density, while in other places the point density is high.

Open areas and overlap zones have the highest density of points on the ground. Deficiencies in point density on the ground are mainly found in areas with dense vegetation that have been scanned during growing season. The dense vegetation has obstructed the path of the laser pulses to the ground. In these cases, the point density may be good in the laser point cloud but poor in the classified ground point layer: strikes on ground may be entirely absent within a given area (see Figure 1 and under Section Vegetation below).

In very hilly terrain, strikes on steep terrain forms (e.g. vertical rock faces) can be completely absent. This depends on the scanning angle when the aircraft passed. Furthermore, if there is dense forest or other dense vegetation in the steep terrain, the opportunities for strikes on ground are obviously diminished (see Figure 2).

There may be a complete absence of returns from laser pulses that have struck water, certain rooftops (se Figure 19), new asphalt or other objects that reflect poorly. In this situation, holes appear in the laser point cloud.

Water absorbs most of the pulses, except when they hit the surface in such a way that they can be reflected, as in a mirror. An irregular point density is achieved over water.

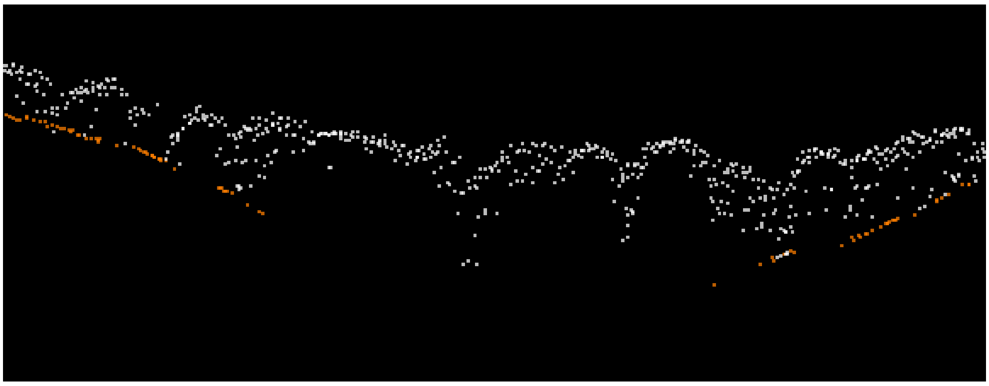


Figure 1: Due to the dense vegetation, no laser points have reached the ground in the depression. The classification was accurate, but there is a shortage of ground points. When the terrain model is created, this surface will be interpolated. White points are unclassified, orange points are ground.

Figure 2: In very rough terrain, the ground surface generally becomes difficult to define, especially with low point density. As the terrain model is being produced based on laser points classified as ground, this type of mountain slopes may entail major local errors in the terrain model.
Photo: Andreas Rönnberg

4.2. Classification

The classification levels used for scanning areas are described in the table below.

Classification level	**Explanation**
1	Automatic classification of ground, water and other.
2	Classification of bridges and the refined ground classification of dams.
3	Improved classification of water and smoothing of water surfaces in the terrain model.

4.2.1. CLASSIFY LASER POINTS

In **Laserdata NH** laser points are classified in following classes – point on ground, point on water, point on bridge or unclassified point.

In **Laserdata Skog** laser points are classified in following classes – point on ground, point on water, low point (noise), high noise (point above ground, vegetation, building for example cloud), point on bridge (only classification level 3) or unclassified point.

Classification level 1

Classification of laser points as ground, water or other is done using automatic methods.

Water polygons and building surfaces from the GGD (Lantmäteriet's basic geographical databases) are among the elements used as support in **Laserdata NH**. Three different parameter sets are used for different types of terrain, based on a rough division of the country.

Water polygons from the GGD (Lantmäteriet's basic geographical databases) are among the elements used as support in **Laserdata Skog**.

A limited manual review, based on error signals and employing random sampling, is carried out following the automatic classification. It is difficult to detect whether points have ended up in the wrong class, so a small amount of incorrectly classified points may remain.

Classification level 2

The identification of bridges is achieved using Trafikverket’s (the Swedish Transport Administration) databases BaTMan (Bridge and Tunnel Management), the NVDB (National Road Database) and the GGD, as well as automatic algorithms. The classification of bridges means that laser points on the part of the road surface with air underneath is classified as bridge. Bridges with a span less than three metres, as well as tunnels, are not classified.

In connection with the classification of bridges, a refined ground classification of dams is carried out. This means that points are manually classified as ground along the whole ridge of the dam. The identification of dams is achieved using SMHI's database SVAR (Swedish Water Archive), as well as the GGD.

Classification level 3

In order to improve the classification of what was actually ground at the time of scanning carefully mapped shorelines are required which correspond to the water level at the time of scanning. Lakes and watercourses have been newly mapped and their elevation is determined based on points on the water surface.

In **Laserdata NH** produced before year 2017, water surfaces have been mapped using manually methods. The water surface of seas, lakes less than 0.25 km^2 and watercourses narrower than 6 metres are not included. The original classification of water in laser data is being reassessed for the entire scanning area. The classification is being done using the newly mapped shorelines, with the GGD being used where these are not available.

In **Laserdata NH** produced from year 2017 and after as well as **Laserdata Skog**, water surfaces have been mapped using automatic methods. Most of the sea, lakes and watercourses is included but smaller watercourses are often missing. The original classification of water in laser data is being reassessed for the entire scanning area. The classification is being done using the newly mapped shorelines.

4.2.2. KNOWN DEFICIENCIES IN THE CLASSIFICATION

Vegetation

There are two reasons why vegetation can sometimes be wrongly classified as ground. Firstly, technological limitations with laser scanning entail that returns from a short distance (about 2 metres) following a preceding return cannot be registered, and secondly, the vegetation is sometimes so dense, e.g. cereals or shrubbery, that no laser pulses can penetrate to the ground (see Figure 3-Figure 7). When one of these phenomena causes a total absence of points on the surface of the ground, the overlying vegetation may be classified as ground (see Figure 7-Figure 8).

Figure 3: At this gravel pit, which is overgrown with dense deciduous brushwood, the terrain model has registered 2-3 m above the actual ground surface.
Photo: Andreas Rönnberg

Figure 4: Dense thickets of deciduous brushwood grow rapidly in many clearings. In this clearing, the elevation model has in parts registered about 2 m above the actual ground surface.
Photo: Andreas Rönnberg

Figure 5: On open ground with dense crop growth, the elevation model may also register above the actual ground surface.
Photo: Andreas Rönnberg

Figure 6: In this sparse but damp pine forest, the ground is completely covered by relatively high mixed herbaceous vegetation. Scanning does not penetrate to the ground when this vegetation is thick, while scanning during spring and late autumn gives a better result.
Photo: Andreas Rönnberg

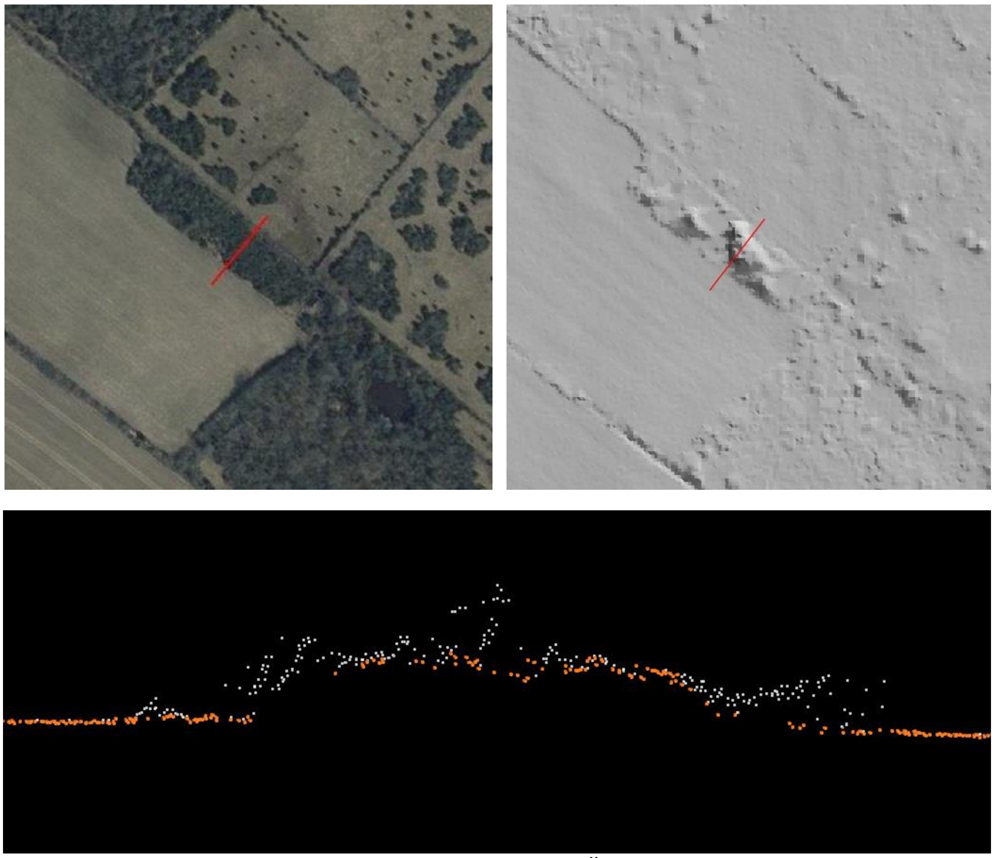


Figure 7: Dense low shrubbery, like juniper bushes on Öland's bare limestone, may register as land, i.e. small hills in the terrain model. As no laser pulses have penetrated the shrubbery and reached the ground, and as the bushes have a “smooth transition” to the ground, the bushes are perceived as ground by the algorithm in the automatic classification.

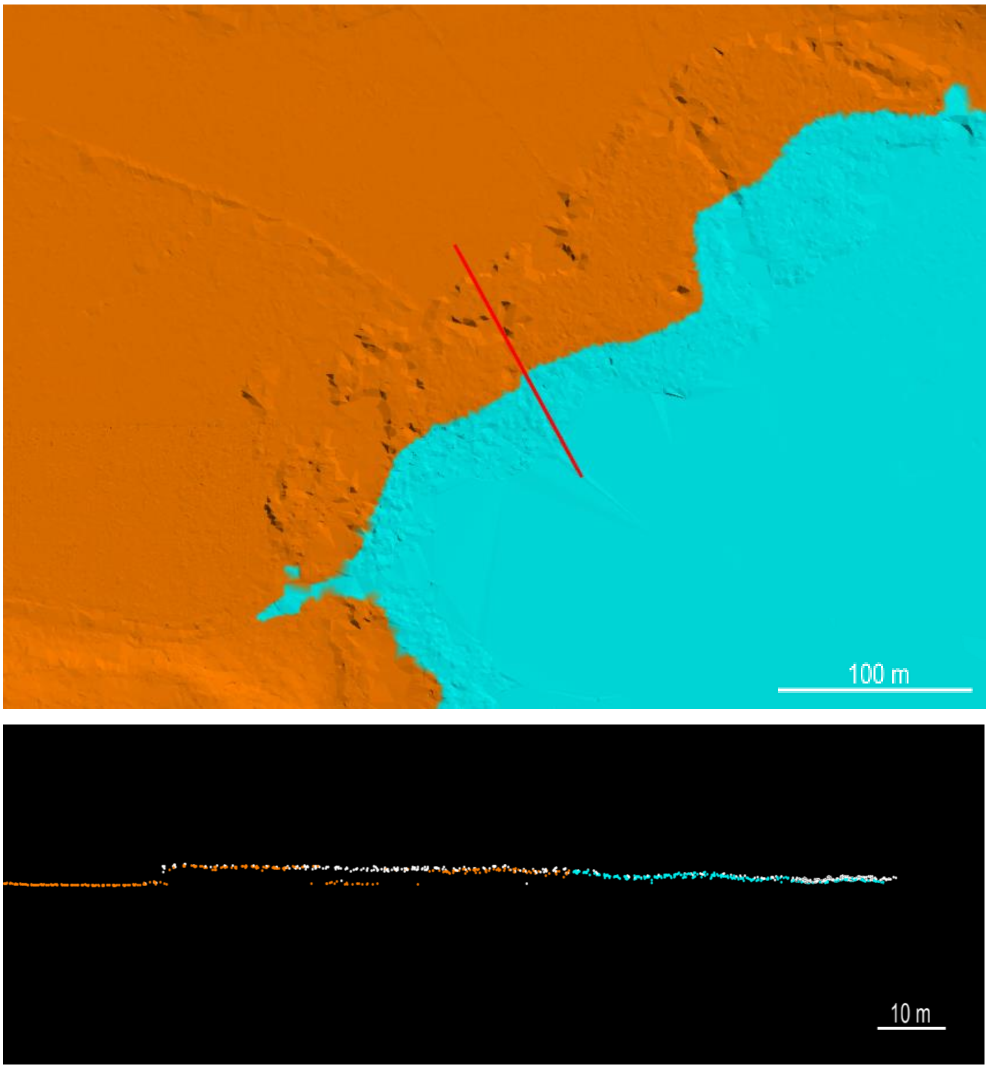


Figure 8: There is often a lack of points on the ground or water in dense reeds, and the reeds have been classified as ground in the automatic classification. Here, water is classified based on a water polygon in the GGD (classification level 2). The red line is the profile in the image beneath. The difference in elevation of a few metres between the ground and the reeds is clearly visible.

Steep terrain

In extremely hilly terrain with marked changes in elevation, the ground classification may be incomplete. The reason is that the algorithm for ground classification may perceive markedly divergent points as buildings or vegetation (see Figure 9-Figure 13).

Gravel and rock quarries and similar variable environments are not adjusted in the classification.

Figure 9: This type of terrain with steep slopes and boulders may be presented inadequately. Laser points on the steep slopes may be unclassified, and the slopes thus become somewhat smoothed out in the terrain model. Photo: Stig Lövborg.

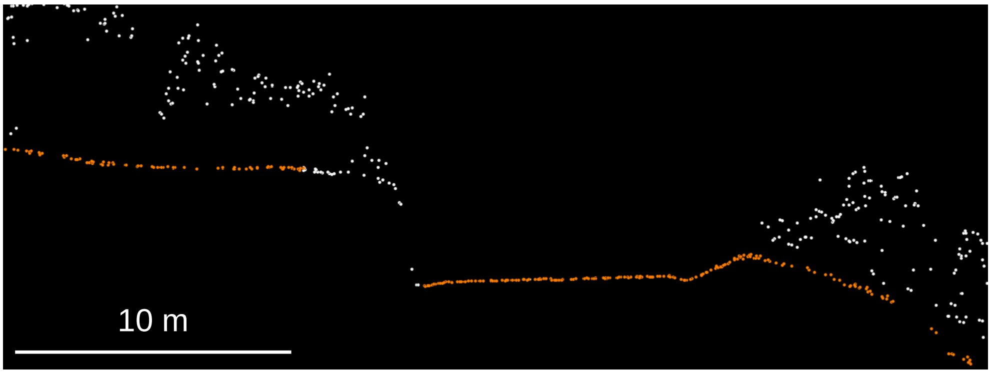


Figure 10: Rock wall by a road that has not been classified as ground, probably due to the steep incline. The profile is drawn according to the red line in the image below.

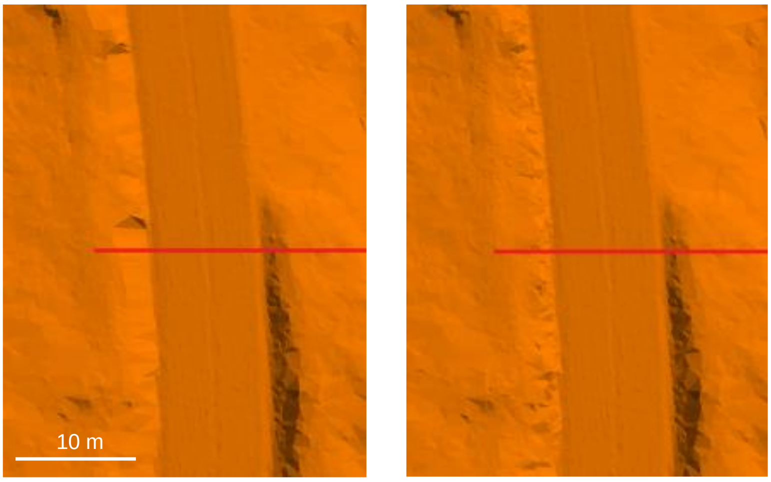


Figure 11: Rock wall next to the road in the ground point layer is shown with terrain shading. Before and after the correction of the classification. The profile in the image above is drawn at the red line.

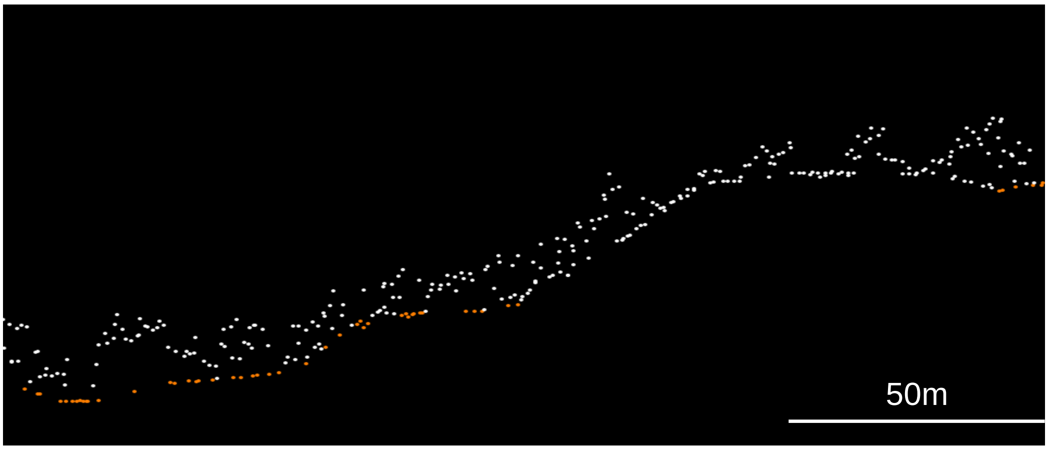


Figure 12: Another example of a hill that has not been classified as ground. The profile is drawn at the red line in the image below.

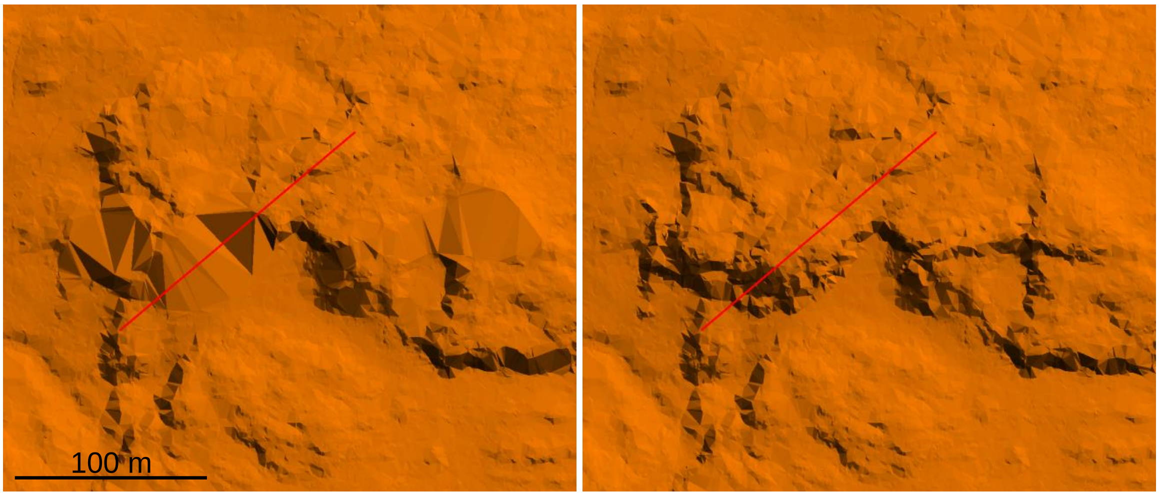


Figure 13: Shaded terrain image of the hill in the previous image. The left image shows how the terrain model looks after the automatic classification. The image to the right shows what the hill actually looks like, i.e. after reclassification.

Buildings

Buildings may be incorrectly classified as ground if they cover a large area or if they have a smooth transition to the ground surface (see Figure 14-Figure 15). To avoid this, building polygons from the GGD are used to dismiss points on large buildings prior to the ground classification. In most cases, other buildings are handled correctly, and any errors that still persist are remedied following the ground classification using semi-automatic methods.

In densely built-up areas, elements such as elevated courtyards and parking structures with low flat roofs may be classified as ground. It can be difficult, both with automatic and manual methods, to determine what is actually ground and where the ground level should actually be (see Figure 16).

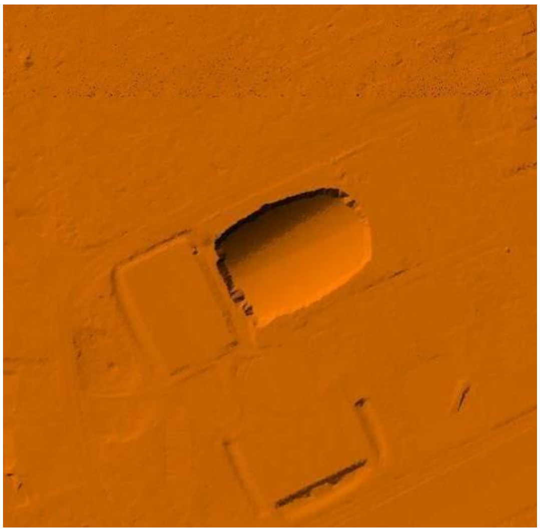


Figure 14: Göransson Arena, Sandviken, was newly built and not registered in the GGD. The structure did not have sufficiently defined edges to be perceived as a building in the automatic classification and was therefore classified as ground. This type of error is usually detected during quality controls and is corrected by the operators. The image shows laser data with terrain shading.

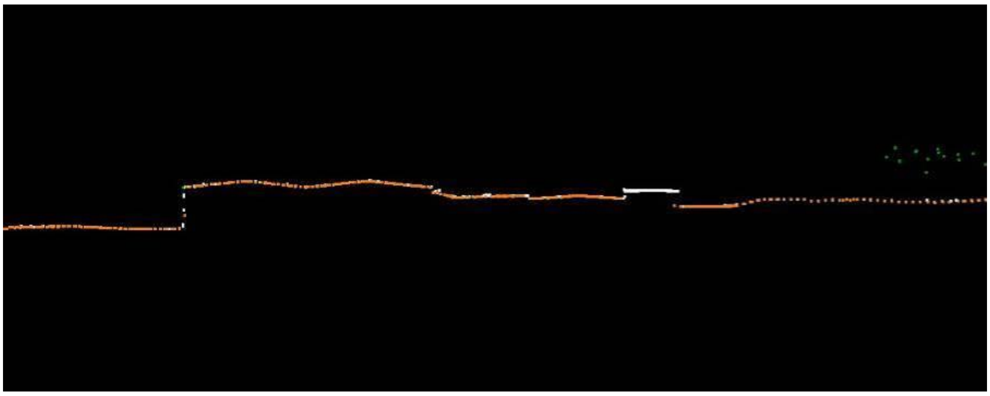


Figure 15: Another example of a building that has not been included in the building polygons from the GGD, and which has not been perceived as a building in the automatic classification.

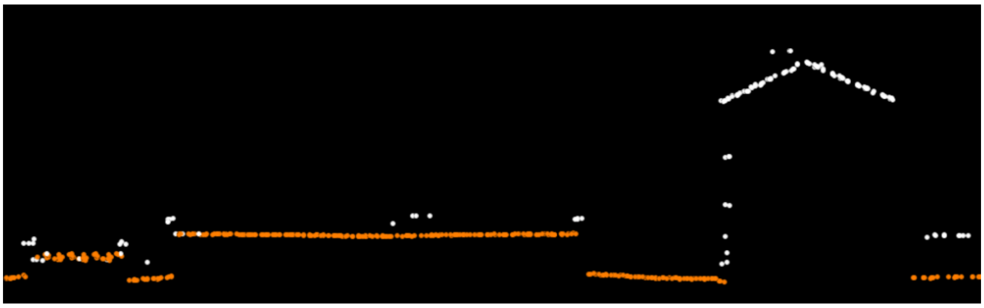


Figure 16: The roof of a parking structure has been classified as ground. The question is, however, where the ground should be.

Low points

Low points usually occur due to reflections in reflective surfaces, which means that they are commonly found adjacent to buildings. However, low points can also be caused by temporary faults in the laser scanner's length measurement.

4.3. Positional accuracy

4.3.1. ABSOLUTE ACCURACY

To ensure seamless elevation data with high accuracy across the country, a fitting of the laser point cloud is performed. To support the fitting process, points measured on the ground in both plane and height in SWEREF 99 TM/RH 2000 are used (control points). The accuracy in both plane and height is then verified against measured check points.

The accuracy in plane of individual laser points is typically many times less than in height. In fairly flat terrain, this is no problem, but in steeply sloping terrain, this affects the accuracy in height, which deteriorates as the gradient increases.

4.3.2. RELATIVE ACCURACY

To minimize internal contradictions between flight lines a flight line equalization is performed, where the position for all flight lines in a scanning area is adjusted until they best match each other. Despite this, minor contradictions remain and can be visible on well define surface inside the zone where flight lines overlap. If flight lines are scanned on different occasions may also for example different water level cause contradictions.

5. Other factors affecting quality

5.1. Scanning on several occasions/during different seasons

One entire scanning area can rarely be completed on one single occasion. If the time between scanning dates is long, vegetation and water level, for example, may have changed between the different flight lines. This means that adjacent areas may differ in the data, even though in reality it is a homogeneous landscape. Human influence can also be a factor changing the appearance of the landscape from one time to another, such as the construction of a road.

If a water surface has been scanned at different times may the water level varied and elevation steps occur, see Figure 17.

It is therefore important to check in the metadata for the area in question to see whether it has been scanned in more than one session or over long-time intervals. If so, it is important to be particularly aware that differences in, for example, vegetation and water level between the scanning sessions may have affected the results. See Figure 18.

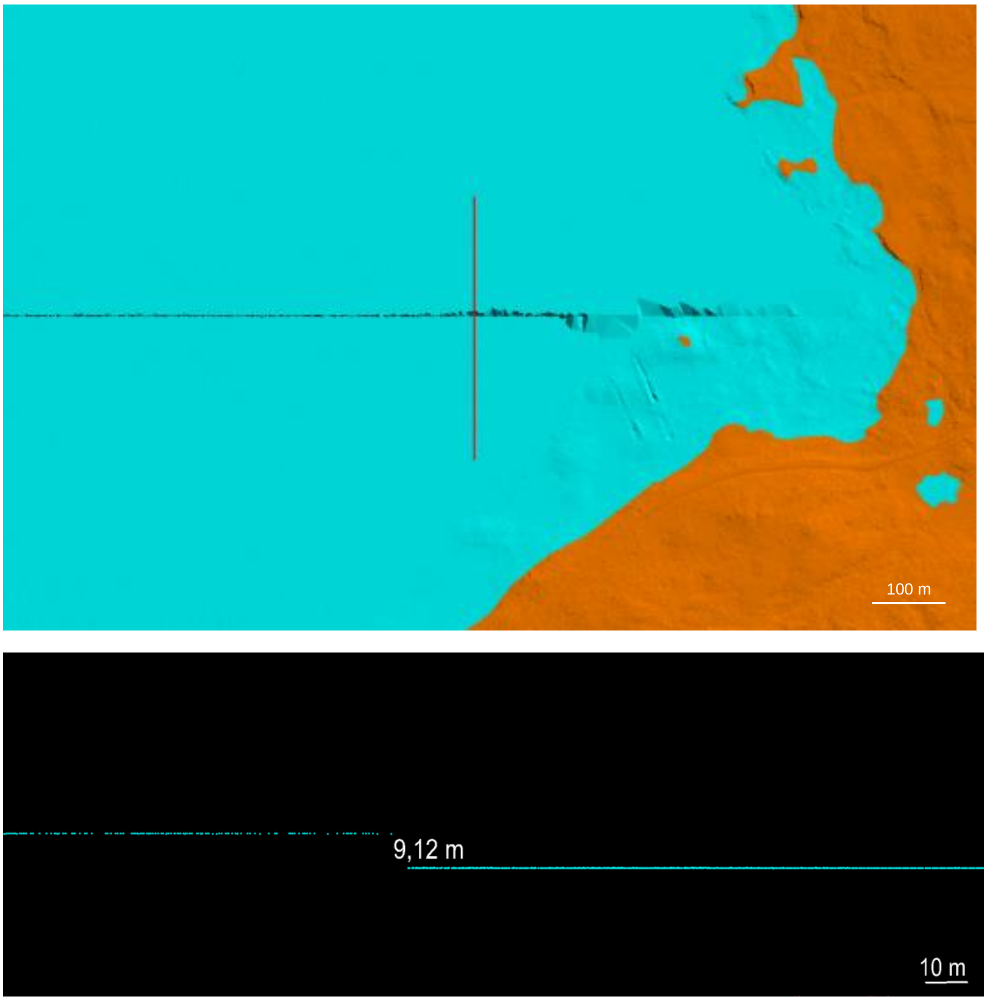


Figure 17: Running horizontally through the top image is a border between two scanning areas that have been scanned on different occasions. The profile presented shows the difference in level of the water in the laser point cloud, which results in elevation steps in the terrain model.

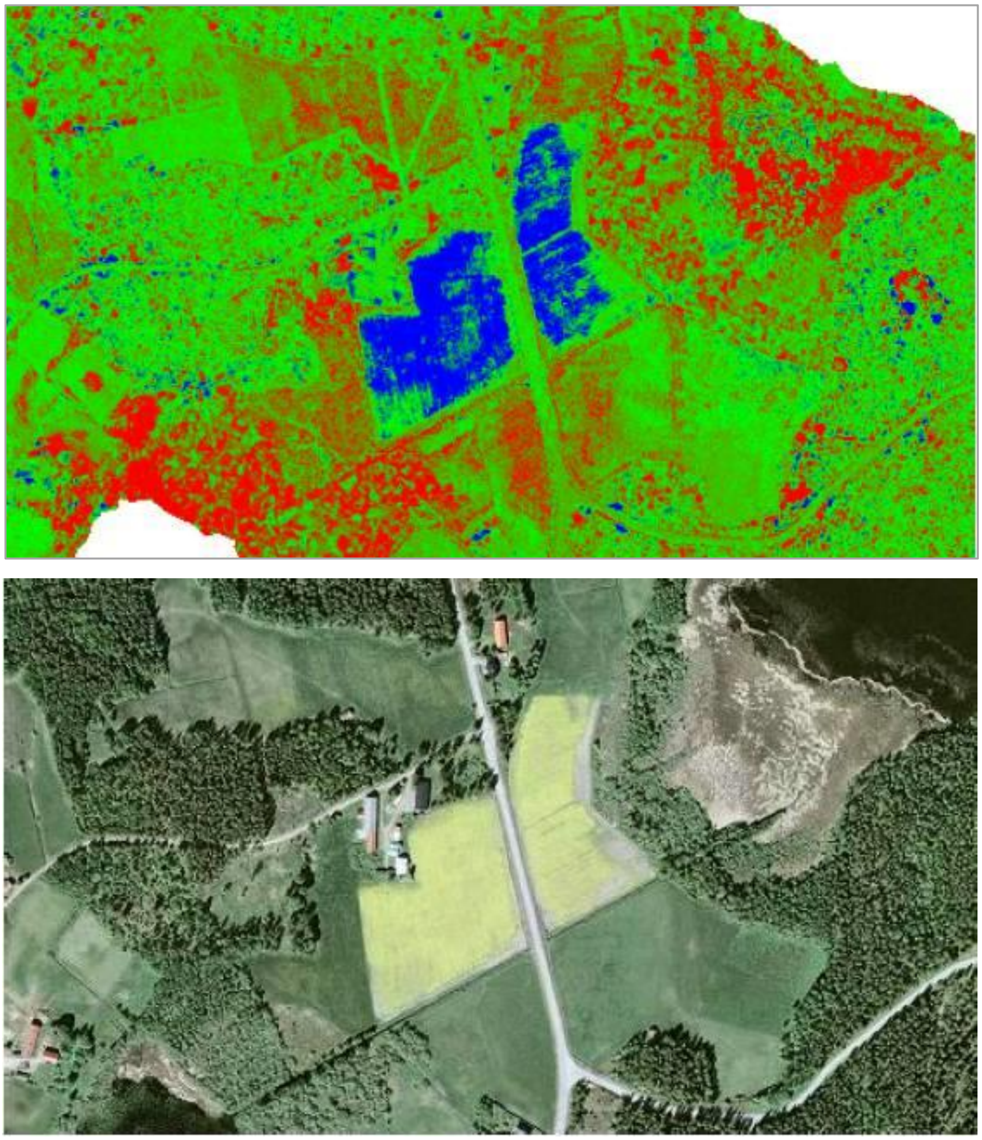


Figure 18: The upper image shows detail from a differential image between two scans conducted during different seasons. The lower image is an aerial photograph of the same section of terrain. The top right is an area of reeds, the middle is arable land, and the bottom left is reeds and other low vegetation. The differential image is green at 0 m difference and becomes totally red or blue at ±0.4 m difference in height.

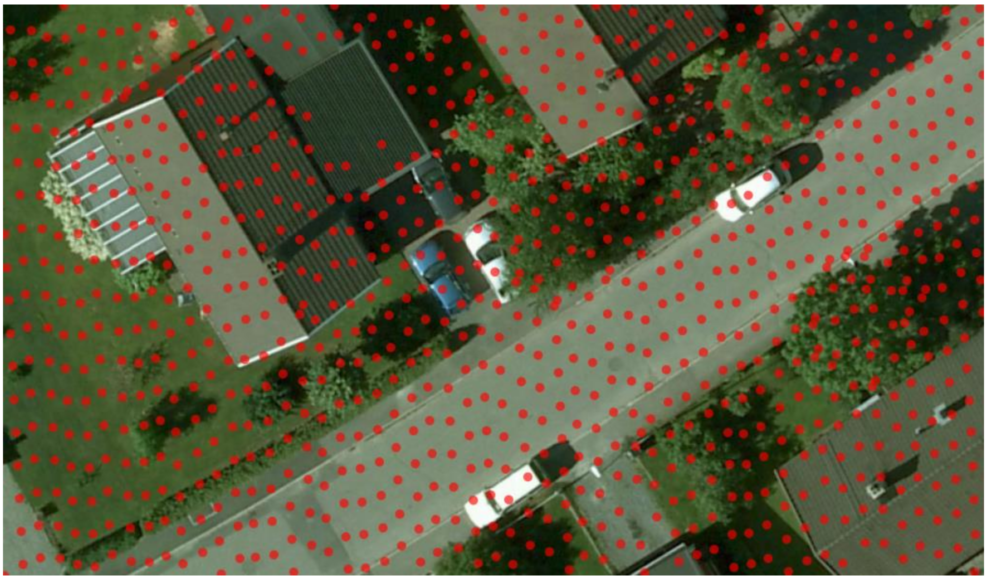


Figure 19: An example of the sparse nature of the laser strikes (all returns) and the actual laser footprint. The image also gives an example of points being absent over a roof.

5.2. Different types of scanner system

Scanning is performed with several types of scanner system with some characteristic differences that one should be aware of. One of the differences is that the various scanners use different scales for registering intensity, as well as having differing scanning patterns. Some scanner system using two separately laser channels which gives double point density.

In most applications these differences have no practical significance since the geometric accuracy is similar in all used systems. The biggest difference is rather in the point density that directly affects what details are visible in the laser data.

Most systems store discrete points in real time, while some store the entire waveform which is then processed to produce discrete points.

The metadata indicates which system has been used for the scan in question.

List of changes

Version	Date	Reason and change from previous version
1.1	2019-10-01	A new point class for Laserdata Skog Updated facts about the scanning for Laserdata NH due to a new scanner from year 2019
1.0	2019-06-11	New document