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Statens vegvesen

# Lidar on UAS to support avalanche monitoring

Findings from demonstration in Trollstigen, October 2021

STATENS VEGVESENS RAPPORTER Nr. 825

Photo: Regula Frauenfelder

**Tittel**
Lidar on UAS to support avalanche monitoring

**Undertittel**
Findings from demonstration in Trollstigen, October 2021

**Forfatter**
Edward McCormack (editor) with co-authors from Statens vegvesen and NGI (see page 3)

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Tore Humstad

**Godkjent av**
Viggo Aronsen

**Emneord**
drone, snøskred, skred, UAS, GEOSFAIR, Borelis, naturfare

**Sammendrag**
Statens vegvesen erkjenner at droner (UAS) gir nye bruksområder som kan være nyttig for å løse samfunnsoppdraget. De inviterte en rekke leverandører til en demonstrasjon i Trollstigen 25.–27. oktober 2021. Målet var å teste lidarsensorer montert på droner for å evaluere nytteverdien for snøskredovervåking.

Sju leverandører og Statens vegvesen fløy over tre områder av ulik kompleksitet og samlet inn data ved hjelp av lidarsensorer som varierer i pris mellom 16 000 og 160 000 NOK. Datasettene ble analysert mtp. nøyaktighet og anvendelse i skredfarevurdering.

Resultater, evaluering og fremtidige forbedringer er drøftet i denne rapporten.

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**Title**
Lidar on UAS to support avalanche monitoring

**Subtitle**
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**Author**
Edward McCormack (editor) with co-authors from Statens vegvesen and NGI (see page 3)

**Department**
Planning and Engineering Services

**Section**
Geomechanics

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**Project manager**
Tore Humstad

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Viggo Aronsen

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**Summary**
The Norwegian Public Roads Administration (NPRA) recognizes that unmanned aircraft systems (UAS) have applications that support their mission. In October 25–27, 2021 at Trollstigen, Norway, they invited to a demonstration to evaluate the usability of lidar sensors on UASs for snow avalanche monitoring.

Seven vendors and the NPRA flew over three field sites of varying complexity and collected data using lidar sensors that vary in cost between 16,000 and 160,000 NOK. The resulting datasets were analyzed for accuracy and for usability for avalanche hazard assessment.

Results, evaluation and future improvements are discussed in this report.

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# Lidar Carried on Unmanned Aircraft to Support Roadside Snow Avalanche Monitoring

Demonstration Findings from Trollstigen, Norway, October 2021

**Evaluation Team**


Edward McCormack, NTNU
Emil Solbakken, NPRA
Tore Humstad, NPRA
Halgeir Dahle, NPRA
Torgeir Vaa, NPRA
Dag Theodor Andreassen, NPRA
Karl Magne Nilssen, NPRA
Christian Skjetne, NPRA
Regula Frauenfelder, NGI
Sean Salazar, NGI



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## EXECUTIVE SUMMARY


The Norwegian Public Roads Administration (NPRA) recognizes that unmanned aircraft systems (UAS) have applications that support their mission. Following UAS demonstrations in 2016 and 2018, the NPRA sponsored a field demonstration in October 25–27, 2021 at Trollstigen, Norway to evaluate the usability of lidar sensors on UASs for snow avalanche monitoring. Lidar is an attractive option for exploring snowpacks, particularly in northern latitudes, as it can be used in low light or dark conditions. Seven vendors and the NPRA flew over field sites of varying complexity and collected data using lidar sensors that vary in cost between 16,000 and 160,000 NOK. The resulting datasets were analyzed for accuracy and for usability for avalanche hazard assessment.

The demonstration found that, in general, the lidar data was within a level of precision and accuracy that could be used for monitoring of the snowpack and avalanche risk. The data could (when combined with bare earth data) be used to determine snow depth and snow volume, and with repeated flights, could also track changes in the snowpack. The lidar returns also provided usable information on the surface of the snowpack and of the surrounding terrain.

The use of UAS for avalanche monitoring on an operational level depends on the ability of the aircraft to fly and to collect data in a range of weather conditions in rugged terrain, so there is some uncertainty on how well lidar data can be collected routinely and operationally in all situations.

The demonstration highlighted room for improvement in the collection of UAS lidar data. Even the lidar professionals at this demonstration, at times, produced inaccurate or sub-optimal results and some results showed signs of systematic errors. This suggests a successful lidar data collection operation will require detailed knowledge of the technology (both of the UASs and the lidar), good referencing systems, extensive testing, and foolproof survey workflows.

Lidar point clouds result in large data sets so the data collection and storage should be optimized according to need and automatic processing and analysis routines should be established.

The UAS industry and airborne sensor industry is growing rapidly and the NPRA should continue to explore their capabilities. Future steps are suggested which include continuing to evaluate lidar on small UASs for routine NPRA operations, with additional research needed to explore the economics of lidar. In particular, the NPRA will need to decide if losing an aircraft with a costly lidar sensor is acceptable. Related research should explore if UASs routinely operated by NPRA staff trained primarily as geologists can accurately and economically capture snow conditions data in a timely manner.

Lidar could be usefully paired with information from other sensors resulting in enhanced value or better data that could be collected in a greater range of weather and lighting conditions or in more locations. This should be explored.

The NPRA should continue to track the regulatory issues which will impact the usability of UASs and consider the use of these aircraft to fly remote missions without observers directly involved.

# 1 INTRODUCTION

Staff at the Norwegian Public Roads Administration (NPRA) recognizes that unmanned aircraft systems (UAS) (also commonly known as drones) and the cameras and sensors they can carry are increasingly available and potentially have applications that support NPRA's data collection, natural hazards detection, and transportation system monitoring needs. The NPRA, following up on tests in 2016 and 2018, funded a three-day demonstration at Trollstigen (at county road 63 in Møre og Romsdal county) evaluating lidar carried on small UASs and used to provide information on the snowpack and the surrounding terrain. The findings from the demonstration are used to provide greater knowledge about the possibilities and limitations of the use of lidar to support snow avalanche monitoring and to develop guidelines for UAS usage by the NPRA.

This effort is part of the NPRA led GEOSFAIR project [1] which is exploring the use of instrumented UASs to make faster and better assessments of avalanche danger to roads, and this report is published as one of the outcomes of the GEOSFAIR project. The field demonstration is also funded by and connected to the NPRA's E8 Borealis project which is a national test laboratory for new technology.

# 2 BACKGROUND

## 2.1 General

Small unmanned aircraft have become capable, affordable, and commercially available. There has been a wide range of transportation-related applications of this technology including for natural hazards monitoring, infrastructure inspection, surveying, and mapping [2, 3].

The NPRA is responsible for maintaining roads located in a cold, northern climate, often with severe winter weather. Part of the NPRA's mission is to pro-actively monitor and react to snow avalanche hazards in steep areas above their roads. A common situation is where a road is closed due to a snow avalanche (this also applies for rock falls and landslides). NPRA's geological and geotechnical staff are required to determine as quickly as possible if it is safe to reopen the road or if it is necessary to do roadway clearance work. If clearance is required, NPRA staff need to evaluate if it is safe for the maintenance workers responsible for removing snow debris. This can be a challenging task since the clearance activity can take time, thus increasing the workers' exposure to avalanche risk. In addition, the assessment challenge is also greater if there are multiple avalanche release zones.

NPRA staff uses a variety of means to view and evaluate avalanche areas, including roadside observations with binoculars and travel by foot, ski, snowmobiles, and manned helicopters. If the geologists can adequately view, inspect and analyze the release area and the avalanche path, they typically can make a quick assessment whether to open the road or to keep it closed.

Given the growth of commercially available UASs and of lighter weight sensors able to be flown on these unmanned aircraft, the NPRA has been evaluating if these technologies could replace or enhance their current methods of monitoring avalanches. One notable motivation was the possibility that UASs could make avalanche monitoring safer by permitting staff to view avalanches without traveling close to the avalanche release area or without having to fly expensive manned helicopters in the mountains. The use of UASs potentially could support more effective monitoring, perhaps with a quicker response time.

Outside of the NPRA, there has been limited exploration of the use UASs for operationally focused, roadside snow avalanche monitoring and control by transportation organizations. These applications include early and on-going tests in Washington state, USA [4, 5] and a project supported by the Ministry of Transportation in British Columbia, Canada to test photogrammetry tools to support roadside avalanche assessment [6].

### 2.2 Rational for the 2021 Lidar Demonstration

This demonstration builds on NPRA tests in March 2016 where Norwegian UAS vendors demonstrated their system's ability to operate in mountains in winter weather [7] and a test in March of 2018 that explored the ability of ground penetrating radar (GPR), photogrammetry (structure from motion or SfM), and digital cameras to detect characteristics of the snowpack that are relevant for avalanche hazard monitoring [8].

Digital cameras on UAS were used to view surface features of the snow in the 2018 test at Andøya, Norway and this visual output was found to be usable to the avalanche experts at NPRA. The use of SfM derived from digital cameras was thought to be able to map snow surface conditions and measure snow depth. Both measurements are of value for avalanche hazard assessment.

One attraction of SfM was that it is perceived as a lower cost substitute for lidar and perhaps more suitable for use on UAS where there is increased risk of aircraft loss or damage. Lidar, which stands for Light Detection and Ranging, is a remote sensing 3D scanning technology that uses light in the form of a pulsed laser to measure variable distances to the Earth and to develop a point cloud with each point holding information and representing one laser scan. Lidar designed for UASs are commercially available and researchers have used lidar on UASs to look at the snow surface and the distribution of snow [9, 10, 11]. As an example, a 2017 Italian study compared lidar readings to manual probing and found that lidar "represent a competitive choice among existing techniques for high-precision high-resolution remote sensing of snow" [12]. Other studies have found that lidar can provide usable snowpack information, but these studies collected data in more ideal research (as opposed to an operational) settings [13]. This use of lidar for snow depth measurement typically requires a bare earth baseline survey when the snow is absent. Lidar could potentially also be used to survey the surface of the snow to look for features that indicate avalanche hazards such as cracks in the snow but research for this application was not found.

The Trollstigen demonstration was set up in acknowledgement that lidar, while traditionally expensive, could potentially provide better data in more variable conditions than SfM, particularly in poor light or low contrast conditions. Processing of lidar data is also far less computationally demanding than SfM processing. A downside to lidar was the expense of the lidar sensor and the risk related to flying a costly sensor on a UAV in rugged mountain terrain and potentially in bad weather. Recently the cost of commercially available sensors usable on UASs has dropped, with some lidar sensors reported to cost as low as 2,000 NOK[i] making this technology more feasible for the NPRA.

## 3 PROJECT ORGANIZATION

### 3.1 Project Goals

The Trollstigen demonstration was organized to learn about lidar technology that can be carried on unmanned aircraft and to explore if it can be used to routinely monitor and assess roadside snow avalanche risk in winter conditions, as well as potentially assessing other natural hazards risks. This was motivated in part by the fact that lidar sensors have become less expensive and lighter, both of which makes this technology more feasible for use on UASs in the rugged mountain environments that generate snow avalanches.

The purpose of the demonstration was to:

1. Allow vendors an opportunity to present the capabilities of lidar on unmanned, aircraft systems to staff from the NPRA, from other Norwegian governmental agencies and research institutes engaged in a research collaboration project with NPRA.
2. Provide vendors with input on what data and approaches might be useful to Norwegian roadway owing agencies responsible for avalanche risk monitoring.
3. Provide vendors an opportunity to suggest other approaches that use UASs to collect snow information that may be of value to the NPRA.

The main requirement of the demonstration was to determine if UAS mounted lidar sensor output could support the NPRA’s avalanche experts. In a larger sense, this demonstration explored if the lidar sensors could detect the following snow features linked to avalanches [14]:

- **Snow depth and volume** is of interest because it indicates how much snow is available to be released by an avalanche or can help determine if a surface has been swept clean by previous avalanches.
- **Snowpack surface and the surrounding terrain** can indicate avalanche risk to experts. They look for features such as cracks in the snow surface, signs of previous avalanches, concave or convex slopes, cornices, and snow anchors such as trees or rocks.
- It is not anticipated that lidar will be able to provide information on **snowpack composition.** Snow deposition rates and depth vary depending on the temperature, wind, and location. This creates a snowpack with weak and strong layers which change over time as the snow settles and consolidates. It is the relationship between these layers that is closely examined for avalanche hazard forecasting. Weak layers combined with a slope greatly increase the chance of a snow avalanche.

### 3.2 Participant Selection

The NPRA circulated a tender which invited UAS and lidar developers, owners, operators, and manufacturers to apply to demonstrate their systems on unmanned aircraft. Successful applicants were awarded 150,000 NOK (including VAT) to participate in the demonstration.

This demonstration required that the vendors show that their lidar systems can support the existing and future aerial surveillance needs of the NPRA for snow and avalanche monitoring in winter weather. This included the ability to collect information from snow covered surfaces as well as on rock and earth surfaces adjacent to areas which generate snow avalanches.

While the NPRA was primarily interested in lidar, the successful applicants were asked to provide a UAS to carry the lidar equipment as part of the demonstration.

The minimum requirements as part of the tender are shown in table 3.1. Successful applicants had to provide information to show that they could meet these minimum requirements.

**Table 3.1 Minimum Requirements**

| Minimum Criteria | Required information |
|---|---|
| 1. The lidar system must be able to collect information on snow surface features (cornices, sluffs, etc.) and/or measure snow volumes or depth. The lidar system should also be able to collect information on non-snow-covered areas adjacent to snow avalanches paths. | Technical specifications of the lidar including detection range, field of view, and point cloud resolution and accuracy. |
| 2. The lidar must be eye safe. | Confirm. |
| 3. The lidar system must be portable and can be transported by a standard car or truck. | Provide system weight and size while being transported in a vehicle. Provide ground control system footprint while in operation and aircraft size and weight. |
| 4. The lidar system must be usable in the winter conditions that typically generate avalanche risks. | Confirm the system meets minimum qualification which is the ability to operate in winds up to at least 5 meters/second and in temperatures down to 0° C. |
| 5. Flight duration /data collection time | The UAS with lidar must have minimum flight duration/data collection time of 20 minutes. |
| 6. The lidar output must be processed in a timely manner and provide readily usable output. | The processed data should be available with usable output within 8 hours after the flight is completed. Specify what software is required to process the raw data. Specify the output formats of the point cloud data. The point cloud acquired during flight must be available in, at a minimum, LAS file format. |
| 7. Cost | Provide the approximate cost of the lidar sensor and indicate if the lidar can be mounted on a range of unmanned aircraft. If the lidar only works on one aircraft, provide the cost of that aircraft. |

In addition, the vendors were asked to document any desirable capabilities as guided by Table 3.2. Category 7, "Other capabilities" was used to account for technologies or processes that are unfamiliar to the NPRA or unique to a vendor and that may be of value to the NPRA. The capabilities in the table were used to select the most qualified applicants for the demonstration.

**Table 3.2 Desirable Capabilities**

| Desirable Capabilities | Points |
| --- | --- |
| 1. Additional information collection capabilities including point clouds from vertical faces and overhanging surfaces. | 10 |
| 2. Additional all-weather capabilities including the ability to collect data in winds above 5 meters/second, in temperatures below 0° C, and in rainfall and snowfall. | 10 |
| 3. Flight duration/data collection time that exceeds 20 minutes. | 10 |
| 4. Processing efficiency including the ability to generate near real time or real time results in the field. | 10 |
| 5. Additional sensor or data output benefits such as colorized point clouds and the ability to integrate data from multiple point clouds. | 10 |
| 6. Specific experience processing and analyzing data related to snow conditions and snow avalanche risk. | 10 |
| 7. Other capabilities that would be useful for snow avalanches or natural hazard monitoring by NPRA staff. | Up to 10 points based on NPRA needs |

### 3.3 Evaluation Team

This demonstration's evaluation team had experience with avalanche monitoring, UASs operations, winter road maintenance, lidar data usage and analysis, remote sensing, and technology evaluation (table 3.1).

**Figure 3.1 Evaluation Team.**

The team members and their areas of expertise were:

- Edward McCormack: Civil Engineering Professor at NTNU and University of Washington, transportation technology evaluation
- Emil Solbakken: Geologist at NPRA, avalanche monitoring and control, UAS operations
- Halgeir Dahle: Engineering Geologist at NPRA, avalanche monitoring and control, UAS operations
- Tore Humstad: Senior Principal Engineer at NPRA, avalanche monitoring and control
- Torgeir Vaa: Senior Principal Engineer at NPRA, winter maintenance and technology
- Dag Theodor Andreassen: Senior Geotechnical Engineer at NPRA, UAS operations, and avalanche monitoring and control.
- Karl Magne Nilssen: Senior Advisor at NPRA, technology evaluation
- Christian Skjetne: Senior Engineer at NPRA, data collection and analysis
- Regula Frauenfelder: Technical Expert at the Norwegian Geotechnical Institute (NGI), remote sensing and GIS, avalanche science
- Sean Salazar: Project Engineer at NGI, UAS operations, remote sensing specialist

The submissions were reviewed by the evaluation team and seven vendors were selected for the demonstration. The selected vendors were:

1. KVS Technologies AS/Terratec AS (Norway)
2. Svarmi EHF/ Verkís HF (Iceland)
3. Romvesen AS/Skred AS (Norway)
4. Senseloop AS (Norway)
5. Orbiton AS (Norway)
6. Norse Asset Solutions AS (Norway)
7. Nordic Unmanned AS (Norway)

## 4 DEMONSTRATION FLIGHTS

### 4.1 Test Sites

Three sites at Trollstigen (at county road 63) were selected for the demonstration. An overview map is shown in figure 4.1. The vendors were provided with maps of the test sites and digital terrain models were available to the demonstration participants from the Norwegian Mapping Authority (Statens kartverk) through its website [hoydedata.no](hoydedata.no).

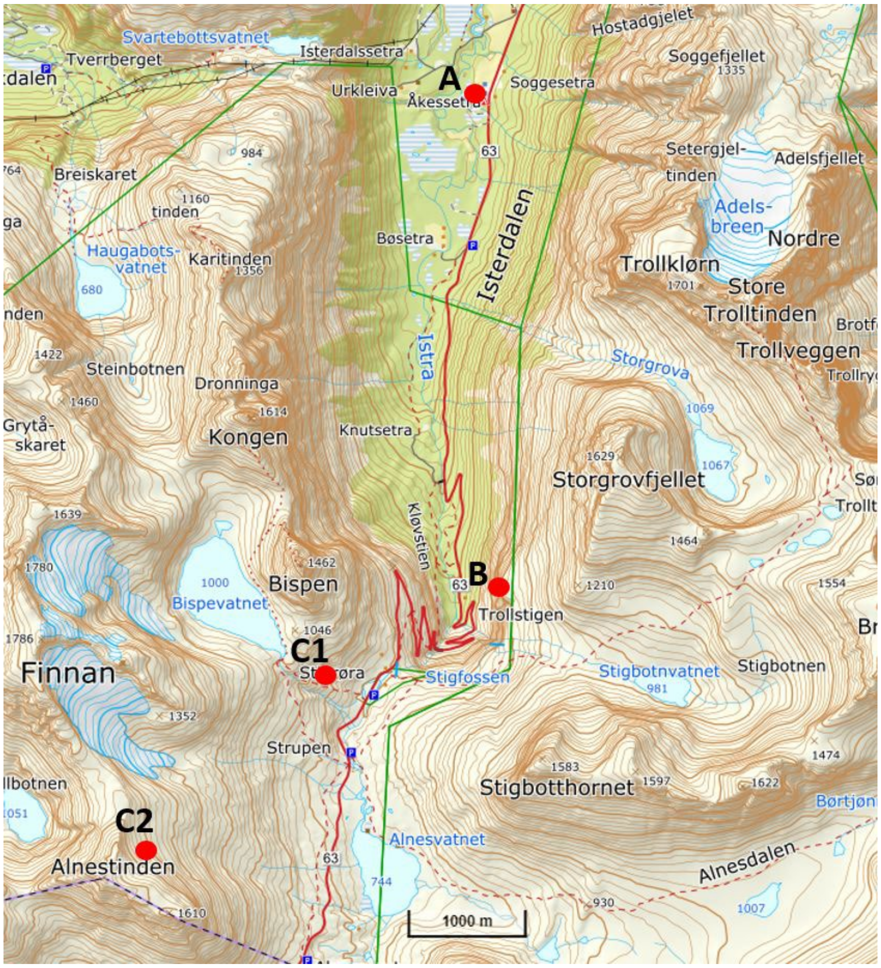



**Figure 4.1 Overview Map of Test Locations.**

**Site A** was designed to be the easiest to fly and to allow vendors to collect lidar data in ideal circumstances (figure 4.2). The flight area was on the grounds of Trollstigen Camping and Gjestegård in Isterdalen and was generally flat and the takeoff and landing area was in a large parking lot. Ground control points were placed in the test site and the coordinates were provided to the vendors. Both Telenor and Telia had cellular coverage in this area, which was relevant since some vendors used mobile networks to control their aircraft. All vendors flew this site on October 25 and provided lidar data.

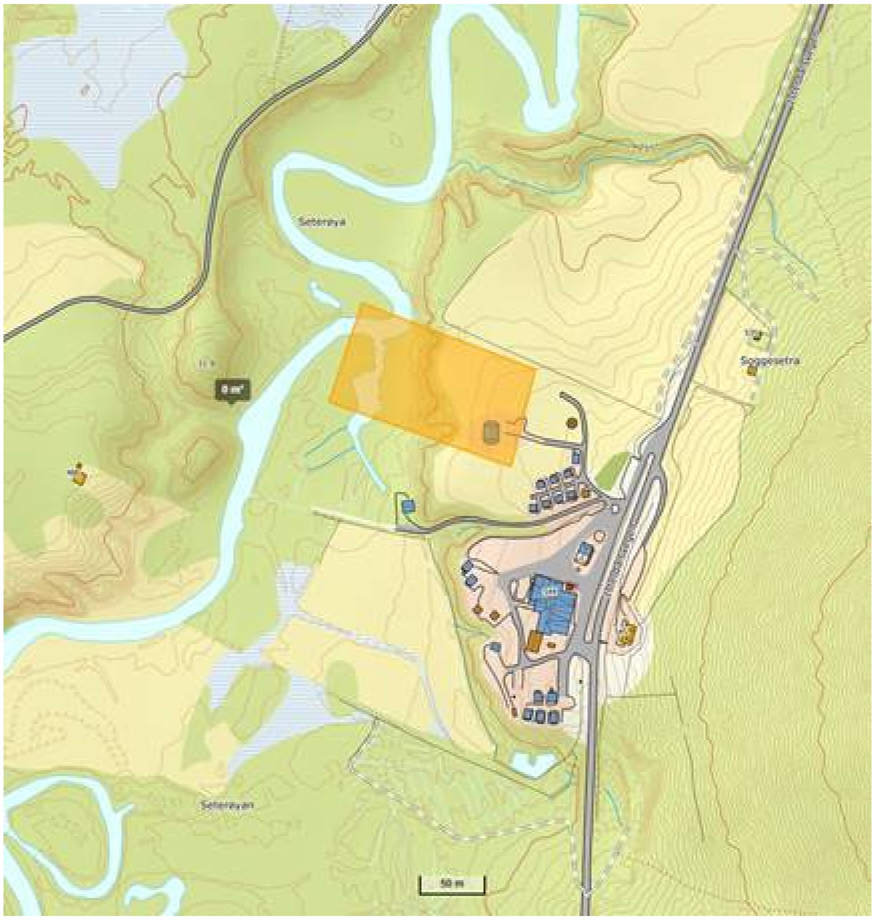



**Figure 4.2 Map of Test Site A**

**Site B** was designed to replicate the collection of lidar data in realistic operational conditions in mountainous terrain above a roadway (figures 4.3 and 4.4). The area was steep with a vertical cliff that extended up to 500 meters in elevation above the takeoff spot. The flight area was approximately 400 meters (horizontal distance) from the takeoff and landing area which was in the parking lot, with a 10 m x 10 m operations area. Both Telenor and Telia had cellular coverage in this area. All the vendors flew this site on October 25 and provided lidar data.

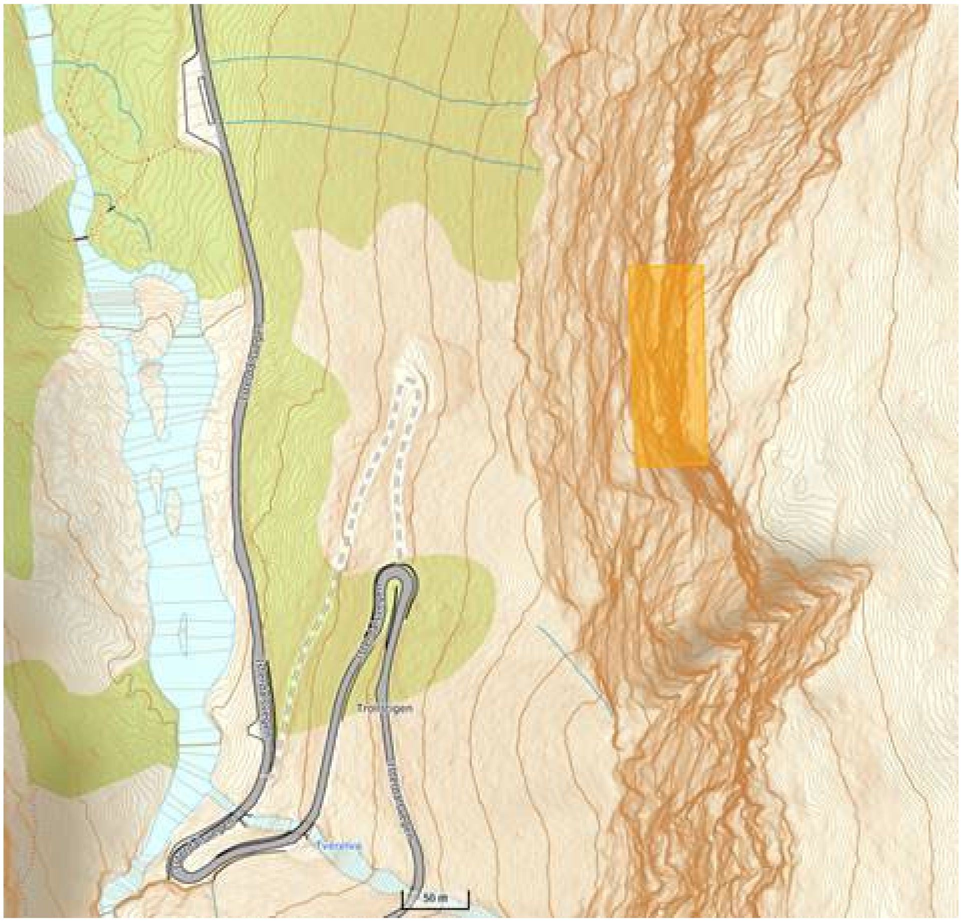


**Figure 4.3 Map of Test Site B.**

**Figure 4.4 Image of Test Area B.**

**Site C** had two flight areas (C1 and C2) and was selected to be a challenging site partly covered with snow and designed to replicate a situation where the NPRA needs to collect information in a steep, rugged area a considerable distance above a roadway. This site's location was selected during the demonstration by NPRA staff based on the weather, location of snow, and roadway access. C1 was a slope next to the road with scattered snow patches (figure 4.5). C2 was steeper and was up to 500 meters in elevation above the roadway and had partial snow coverage (figure 4.6). Only Telia had cellular coverage at this site. All vendors except Nordic Unmanned flew this site on October 26 and provided lidar data.

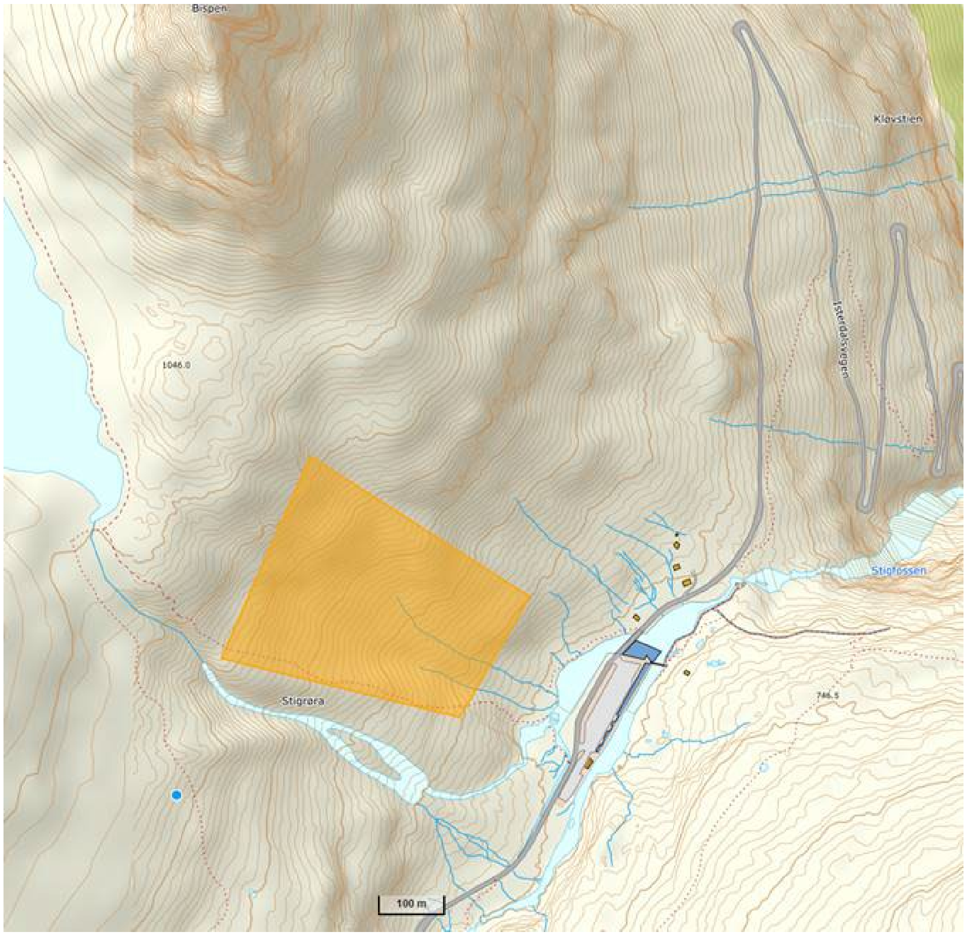



Figure 4.5 Map of Test Site C1.


**Figure 4.6 Map of Test Site C2.**

## 4.2 Arrangements

The NPRA has staff experienced conducting UAS operations and they ensured that the flights to the test sites followed Norwegian Aviation Authorities (Luftfartstilsynet) rules. A Notice to Airmen (NOTAM) was completed.

The project team cleared the UAS flights with the landowner at Trollstigen and made arrangements with the county road office to have keys to the gates on roadway over Trollstigen (which was closed to the public) and to snow plow the road as necessary. Arrangements also included obtaining permission to operate at Trollstigen Camping, providing food at Site A for the demonstration participants, and traffic cones and tape to mark out flight operation areas.

Communications included sending out flight operations information prior to the demonstration, a safety meeting with all participants at the start of the first day, and distribution of handheld radios to each vendor group and to the evaluation team. The vendors were invited to present their lidar findings at various times during the demonstration.

The weather for both days with flights was variable with a low temperature of around 5 °C and a high of about 10 °C. It was mostly cloudy with occasional clearing with sun. The wind, at times, was gusty (5 to 10 meters per second). Wind gusts at site C1 and especially at site C2 shortened many of the vendors' flights both in duration and range. The only location with snow was at sites C1 and C2. All flights were conducted in daylight.

### 4.3 Vendor Reports

Each vendor completed flights and collected lidar data on some of the test areas as shown in the table 4.1 below.

Table 4.1. Test Site Flight Completed by Each Vendor and the NPRA.

| Vendors | Site A | Site B | Site C1 | Site C2 |
|---|---|---|---|---|
| **KVS Technologies / Terratec** | X | X | X | - |
| **Svarmi/Verkís** | X | X | X | - |
| **Senseloop** | X | X | X | - |
| **Romvesen/Skred AS** | X | X | X | - |
| **Obitron** | X | X | - | X |
| **Norse Asset Solutions** | X | X | - | - |
| **Nordic Unmanned** | X | X | - | - |
| **NPRA** | - | - | X | - |

As required by the contract, each vendor also provided LAS files (a standard binary format for storing lidar point cloud data) and an after-flight mission report. The following sections present each vendor's activities and technologies used during the tests and show a sampling of images they provided. The cost of the lidar sensor is noted if this information was available from a manufacturer's website or from the vendor.

**KVS/Terratec:** This vendor used an internally developed quadcopter carrying a Livox Avia lidar scanner (figure 4.7) This sensor costs around 13,000 NOK. They flew test sites A, B and C1. The vendor delivered LAS files, a TIF file with a shaded relief of the test areas, and a 3D model of test area B. Figure 4.8 show the aircraft and van-based control room used by this vendor. Figure 4.9 shows output from KVS/Terratec from site A. Figure 4.10 is a 3D-model of the terrain surface of site B as provided by the vendor.


**Figure 4.7 KVS Quadcopter with Lidar Sensor.**


**Figure 4.8 KVS Control Room.**

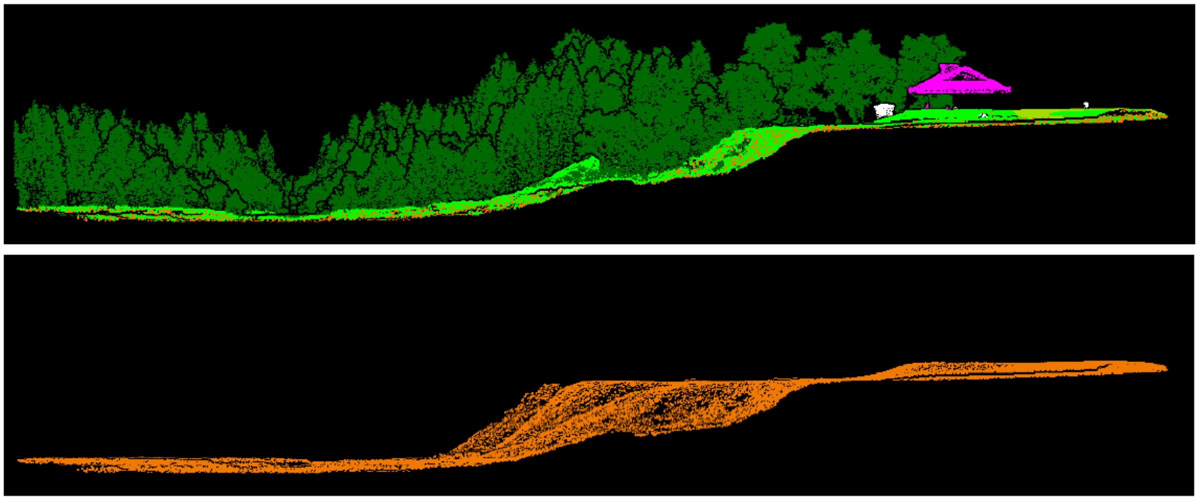


**Figure 4.9 Output from KVS of site A showing point cloud and the terrain only.**

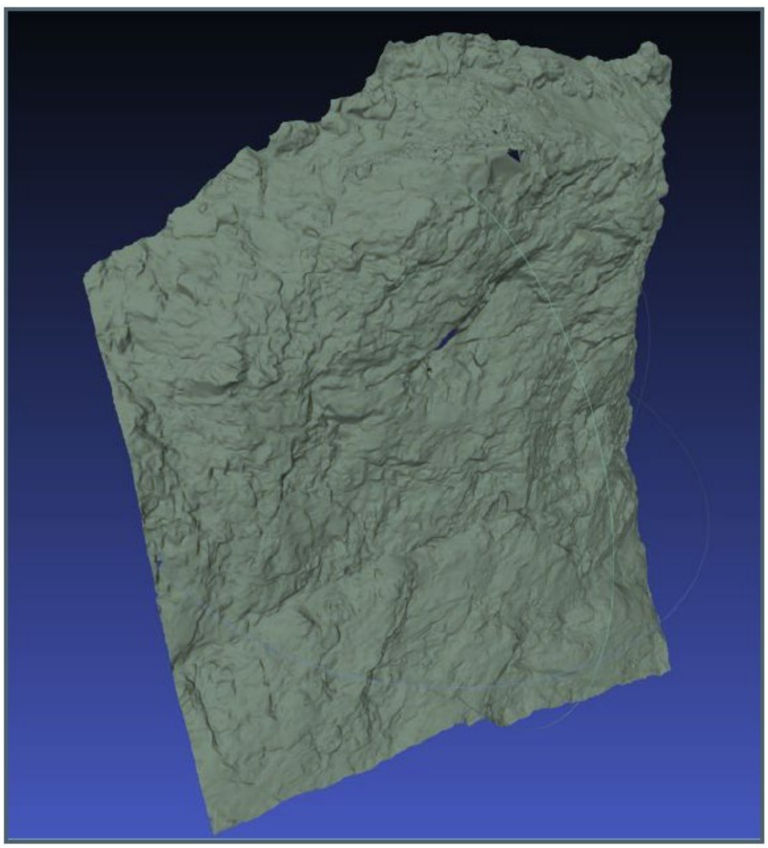


**Figure 4.10 3D-modeled terrain surface of area B provided by KVS.**

**Svarmi/Verkís:** This vendor used a DJI M600 Pro UAV (a six-rotor copter) and Riegl MiniVUX-1 scanner to fly sites A, B, and C2. The vendor provided LAS, TIFF files, and raw imagery (JPG). Figure 4.11 shows a point cloud of site A provided by the vendor. Figure 4.12 shows their snow depth map for site C1.

**Figure 4.11 Point cloud of Site A provided by Svarmi/Verkís.**

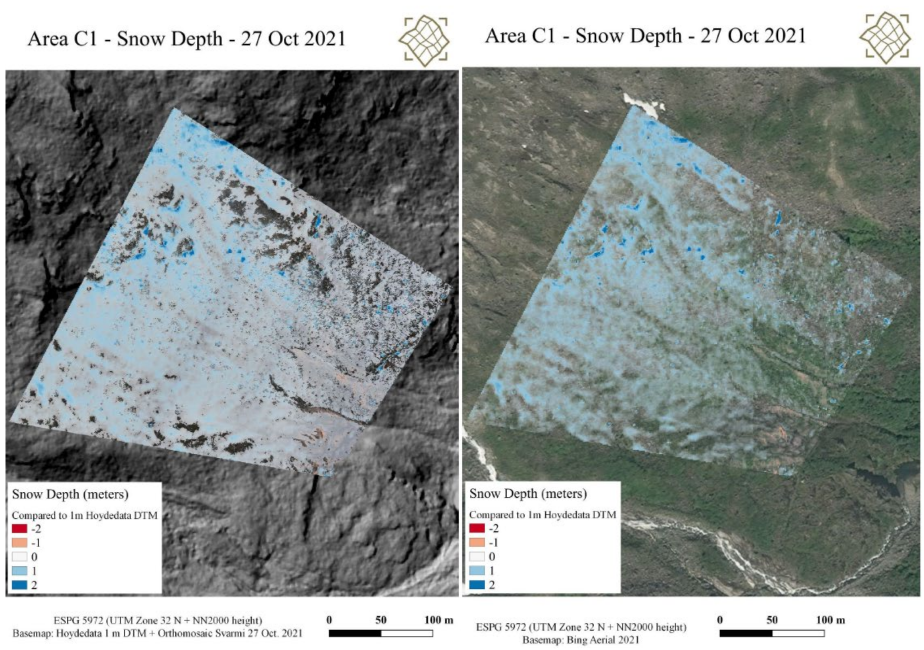



**Figure 4.12 Snow depth map (Svarmi Lidar minus Hoydedata 1 m DTM) provided by Svarmi/Verkís.**

**Senseloop:** This vendor flew a DJI M600 copter (6 rotors) carrying a Riegl miniVUX-1UAV scanner over sites A, B and C1. The vendor provided DEM, LAS, TIFF, JPEG files and raw imagery, as well as contours and slope gradient maps on site A and C1. Figure 4.13 shows their lidar image from site A.

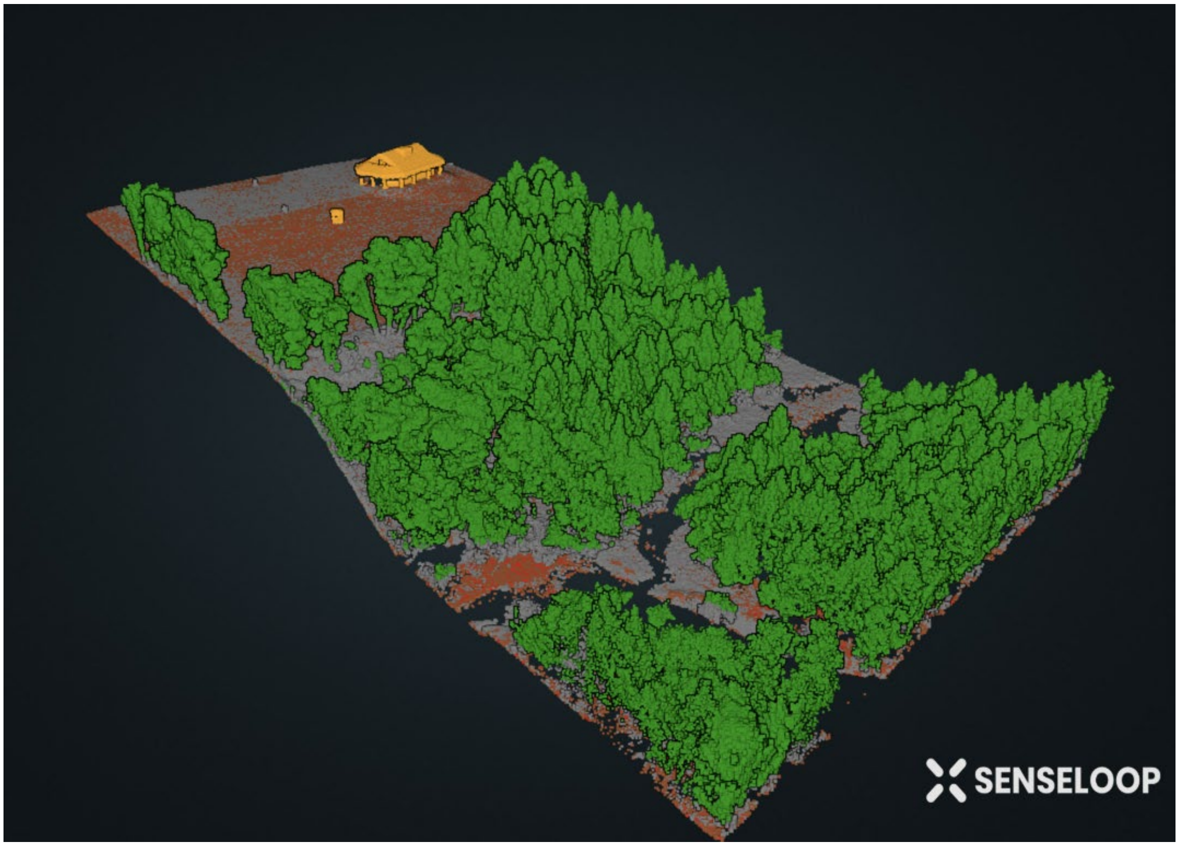



**Figure 4.13 Classified point cloud of site A provided by Senseloop.**

**Romvesen/Skred AS:** This vendor used a Quadrotor DJI M300RTK with a GreenValley V70 fixed scanner to fly sites A, B and C1. The vendor provided LAS, TIFF files, Shape files and raw imagery in JPG format. Figure 4.14 shows a colorized point cloud of site A as collected by this vendor. Figure 4.15 shows their point cloud and the flight path for site C1.

**Figure 4.14 Colorized point cloud of Site A provided by Romvesen/Skred AS.**

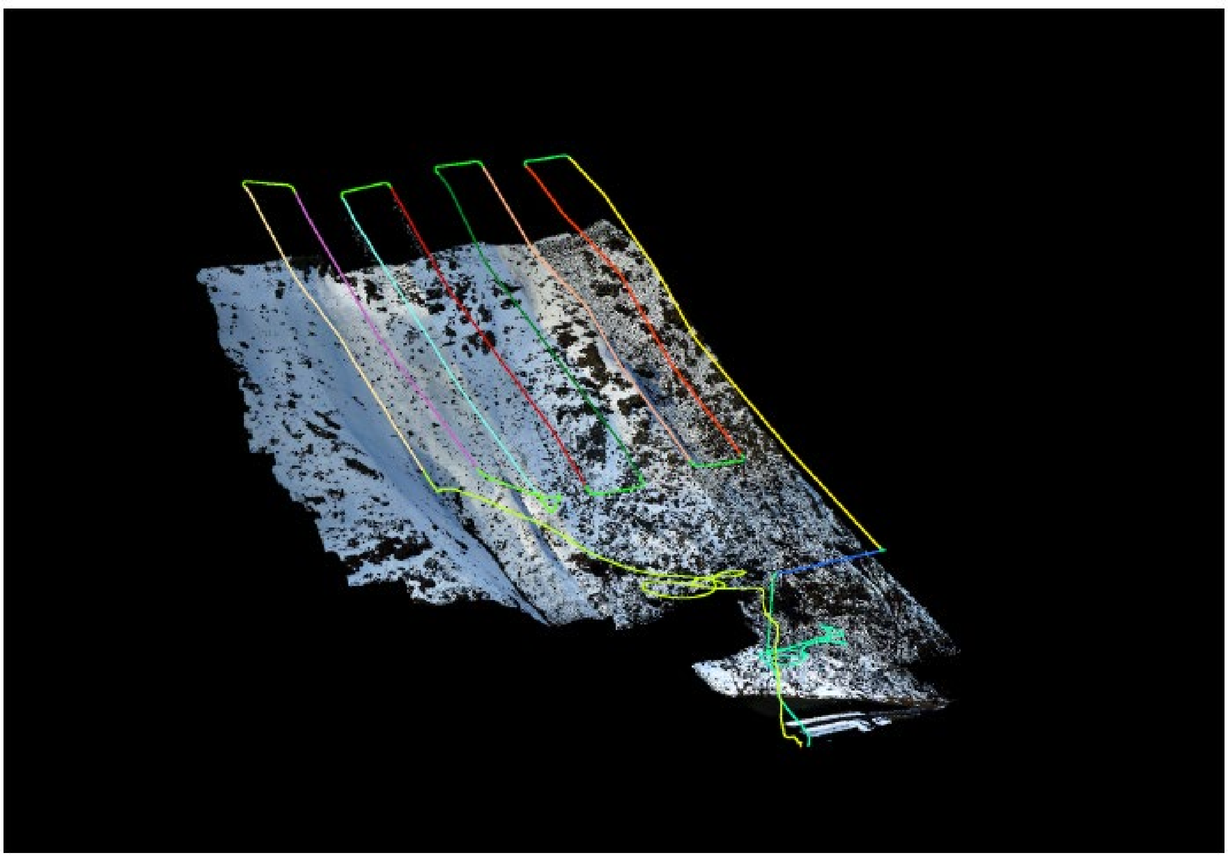


**Figure 4.15 Point Cloud and Flight Path for C1 Provide by Romvesen/Skred AS.**

**Orbiton:** This vendor used a Velos single rotor aircraft with a Yellowscan VX20-300 Scanner (figure 4.16. This vendor flew test areas A, B and C2. The flight to area C2 collects some data but was aborted due to gusty winds. The vendor provided LAS, TIFF file and raw imagery in JPG format. Figure 4.17 shows vendor results from Area A and figure 4.18 shows the vendor flight path and results from site B.

**Figure 4.16 Velos Helicopter with Lidar Scanner.**

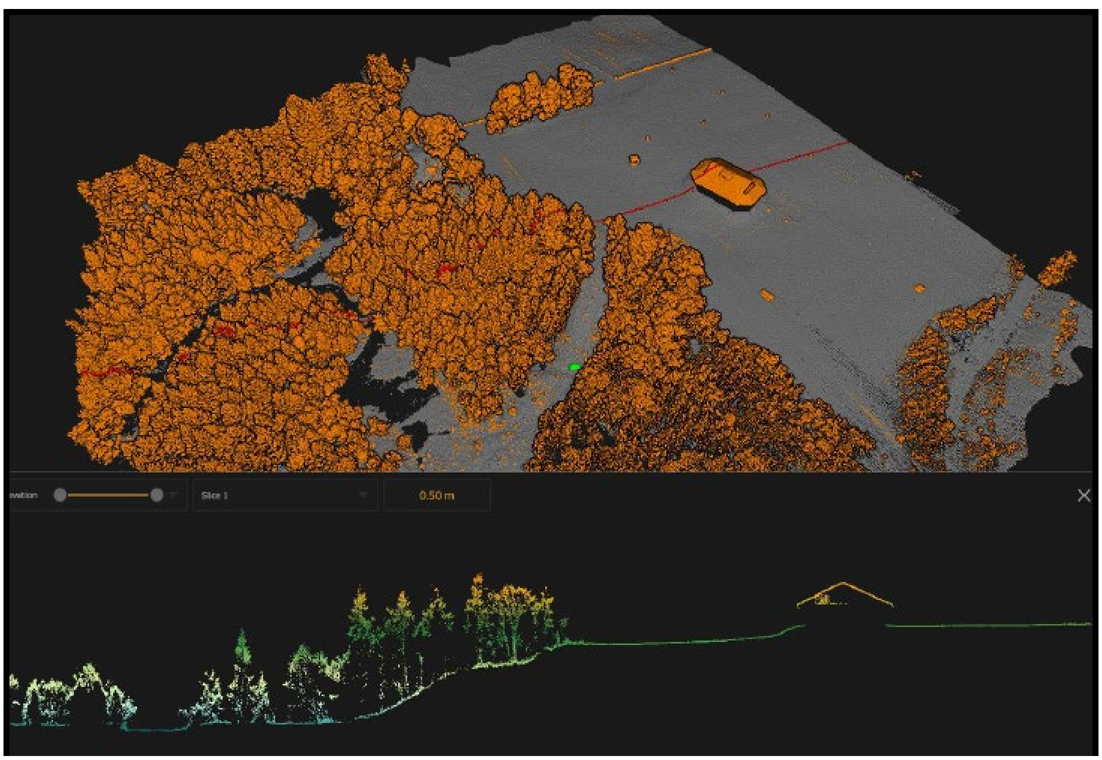



**Figure 4.17 Classified point cloud and section profile from Site A provided by Orbiton.**

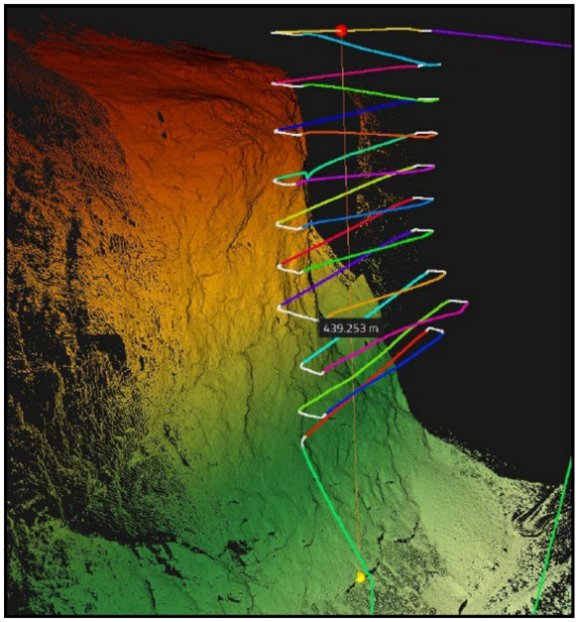



**Figure 4.18 Flight path and Lidar point cloud colorized by elevation from Site B provided by Orbiton.**

**Norse Asset Solutions:** This vendor flew site A with a QuantumSystems Trinity F90+ UASs carrying a Qube 240 lidar sensor. At site B and C1 they flew a DJI M600 with Velodyne Ultra Puck lidar. The vendor proved data in LAS files. The vendor's quadcopter is shown in figure 4.19.

**Figure 4.19 Norse Asset Solution's DJI M600 with Velodyne Ultra Puck lidar.**

**Nordic Unmanned:** This vendor completed flights at site A and B but left the demonstration after the first day due to other obligations. The vendor provided RAW files. The vendor offered to complete a separate lidar test at a different area and will provide the result to the NPRA evaluation team. This will be reported separately.

**NPRA:** The NPRA itself also owns a DJI M300 UAS quadcopter system with a DJI lidar sensor (Zenmuse L1) (figure 4.20). Several data collection flights were completed by the evaluation team using this system at site C1.

**Figure 4.20 NPRA drone, DJI M300. (Photo: Ove Kristian Leirgulen)**

Table 4.2 contains details about the aircraft and sensors used and as reported by each vendor and as supplemented from manufacturer's specification.

**Table 4.2 Specification of Aircraft and Lidar Sensors.**

| Vendor | Aircraft | Lidar Sensor | Sensor Weight (Kilo-grams) | System or Scanner Cost | Scanner Field of View (Degrees) | Lidar Processing Software | Scan Speed (points per second) |
|---|---|---|---|---|---|---|---|
| KVS/Terratec | Quadrotor developed by KVS | Livox Avia 5 | ~1.0 | ~178,000 NOK | Non-rotating Lidar (70°) | TerraPos v2.5 | 240,000 |
| Svarmi/Verkis | DJI M600 Pro Quadcopter | Riegl MiniVUX-1 Scanner[1] | 2.0 | 1,000,000 NOK | Effective 180° | PosPac UAv 8.4 & PosPac UAv 8.4 and RiProcess program RiProcess program | 100,000 scans/sec |
| Senseloop | DJI M600 copter (6 rotors) | Riegl miniVUX with APX 20 IMU[1] | 2.5 with IMU | 1,000,000 MNOK | Up to 360, effective 270 | Applanix PosPac and Riegl RiProcess | 100,000 |
| Romvesen/Skred AS | DJI M300RTK | GreenValley V70[2] | 1.1 | ~170,000NOK | 70.4 degrees (Repetitive Scanning Pattern), Fixed angle/non-rotating lidar | LiGeoreference and LiDAR360 | dual return; 480.000 pt/s |
| Orbiton | Velos Helicopter | Riegl VX20 300 YellowScan VX23 integrating the Riegl miniVUX 3 and the Applanix APX20 | 2.85 (VX20) | 1,600,000 NOK | 120deg at 300 KHz, 180deg at 200 KHz ( | CloudStation (YellowScan own extraction software)<br>POSPac UAV from Applanix (INS manufacturer) | |
| Norse Asset Solutions | Fixed wing, Trinity F90+ | Yellow Scan Velodyne VLP-32[3] | 0.75 | ~492,000 NOK | 75 (fixed scanner) | Qbase (flight log), PosPAC UAV (trajectory), Yellowscan Cloudstation (pointcloud) | 240,000 shots per second |
| Nordic Unmanned | NA | NA | 5.36 | NA | 110° (360°) | Inertial Explorer, Spatial Explorer, Microstation with Terrasolid / Cloud processing LiDARMill A | 32l (10min-100max) |
| NPRA | DJI M300 | Zenmuse L1 | 0.93 | 70,000 NOK | 70.4 | DJI Terra | 240,000 |

[1] http://www.riegl.com/products/unmanned-scanning/riegl-minivux-1uav/
[2] https://greenvalleyintl.com/LiAirV70/
[3] https://www.yellowscan-lidar.com/products/surveyor-ultra/

## 5 LIDAR RESULTS

This section analyzes and compares the lidar result from each vendor.

### 5.1 Site A

An overview of the main data acquisition parameters at site A is given in table 5.1. The table includes the vendor's flight as well as a comparison flight using an NPRA aircraft and lidar sensor. All the vendors covered the specified survey area well. Different strategies regarding survey altitude, speed, and overlap resulted in large variations in the number of points collected. The reported flight time spans from 4 to 10 minutes, and the average point density varies from 206 to 1023 points per square meter.

**Table 5.1 Main data acquisition parameters from Site A. Number of collected points and average point density is calculated within the specified survey area.**

| | KVS/ Terratec | Svarmi/ Verkís | Senseloop | Romvesen /Skred AS | Orbiton | NAS | Nordic Unmanned | NPRA |
|---|---|---|---|---|---|---|---|---|
| **Survey altitude (AGL)** | - | 58 | 80 | 50 | 65 | 80 | 76 | 60 |
| **Survey flight speed (m/s)** | - | 6 | 3 | 5 | 5 | 18 | 4 | 7 |
| **Flight duration (min)** | - | 3:42 | 10:03 | 5:00 | 6:00 | 7:43 | 5:00 | - |
| **Collected points** | 11 014 966 | 2 214 484 | 5 223 538 | 3 267 253 | 5 343 244 | 6 556 678 | 3 325 772 | 5 314 676 |
| **Average point density (pts/m2** | 1023 | 206 | 485 | 303 | 496 | 609 | 309 | 493 |

Table 5.2 shows the vertical error on 12 ground control points (GCP) in site A. Where available, errors are shown for both raw (no GCPs used for georeferencing) and adjusted (3 GCPs used for georeferencing) point clouds. Errors are calculated as GCP elevation subtracted from average point cloud elevation within a vertical cylinder centered at the GCP (diameter = 20 cm), using the M3C2 plugin in CloudCompare. The GCP locations were measured with an RTK GNSS receiver obtaining standard deviations less than 2 cm vertically and less than 1 cm horizontally (n = 3).

**Table 5.2 Vertical error on 12 ground control points. RMSE = Root-mean-square error, SD = standard deviation.**

| | KVS/Terratec | | Svarmi/ Verkís | Senseloop | | Romvesen/ Skred AS | Orbiton | | NAS | Nordic Unmanned | | NPRA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Raw* | *Adjusted* | *Adjusted* | *Raw* | *Adjusted* | *Adjusted* | *Raw* | *Adjusted* | *Raw* | *Raw* | *Adjusted* | *Raw* |
| **RMSE (m)** | 0.059 | 0.023 | 0.028 | 0.052 | 0.018 | 0.017 | 0.019 | 0.023 | 0.510 | 0.059 | 0.034 | 0.088 |
| **Mean (m)** | 0.058 | 0.020 | 0.010 | -0.051 | 0.013 | -0.011 | 0.013 | -0.018 | 0.510 | 0.058 | 0.030 | 0.087 |
| **Min. (m)** | 0.041 | 0.003 | -0.049 | -0.072 | -0.007 | -0.047 | -0.017 | -0.041 | 0.481 | 0.045 | 0.001 | 0.055 |
| **Max. (m)** | 0.078 | 0.040 | 0.040 | -0.036 | 0.030 | 0.004 | 0.031 | 0.002 | 0.542 | 0.077 | 0.055 | 0.113 |
| **SD (m)** | 0.011 | 0.011 | 0.027 | 0.011 | 0.012 | 0.014 | 0.015 | 0.014 | 0.018 | 0.009 | 0.016 | 0.019 |

The RMSE (root-mean-square error) indicates the absolute accuracy of the point clouds. RMSE is the standard deviation of the residuals which is commonly used to compare errors between different data sets. Except for the point cloud from Norse Asset Solutions, which is consistently elevated by around half a meter compared to the others, all point clouds have RMSEs well below 10 cm. Generally, the RMSE of raw point clouds are around twice the RMSE (1.9–5.9 cm) of the point clouds adjusted to 3 GCPs (1.7–3.4 cm). The raw point cloud from Orbiton stands out with the RMSE being significantly smaller than for other raw point clouds, and also smaller than the adjusted version of the same cloud.

Mean errors vary from -5 to 6 cm and indicate that accuracies are affected by systematic errors causing consistent vertical offset both between vendors and compared to the GCPs. Combined with the small standard deviations (0.9–2.7 cm), it seems likely that a large part of the obtained RMSEs is related to such systematic errors. This further suggests that for many of the vendors, the potential accuracy of the system used is better than what the RMSE from this test indicates.

As the standard deviations of GCP errors show, the survey-scale precision is good across all vendors. On the smaller scale, the spread of neighboring points ("fuzz") is considerable. This is illustrated by the section clouds shown in figure 5.1. The standard deviations from mean point elevation vary from 1.5 to 3.3 cm between the vendors, which indicate small-scale variations with about the same magnitude as the variation in GCP error. Point elevation is also observed to vary with 5–10 cm over very short distances.

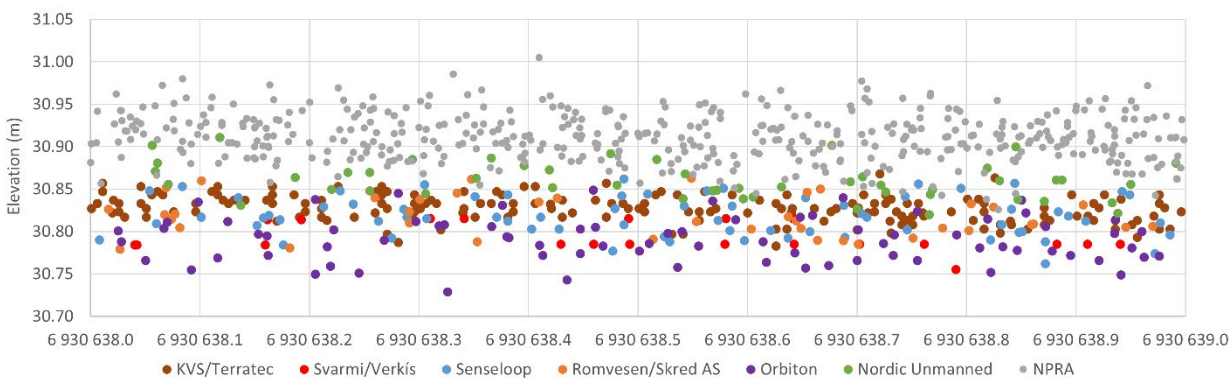



**Figure 5.1 Small-scale point cloud precision illustrated by points collected in a 1 x 0.2 m nearly flat region covered by compacted gravel. The surface roughness of the gravel is estimated to be around 1–2 cm.**

Overall, results from site A show that all vendors use systems that can efficiently provide point clouds with high resolution and consistent, high accuracy on even surfaces. For raw point clouds without using GCPs for georeferencing, the smallest vertical RMSE was less than 1.9 cm. This level of error is similar to the uncertainty associated with the GCP measurements and is about as good as possible within this test. Although obtained accuracies are generally good, signs of systematic errors indicate unexploited potential. The results further show that with the systems and flight plans used at site A, the point density must be very high to reliably capture topographic features on the centi- to decimeter level.

## 5.2 Site B

Performing surveys at site B turned out to be a difficult task due to strong winds and turbulence high up by the rock face. In addition, not all of the vendors used systems suited for mapping of vertical faces. Although all vendors managed to capture data from parts of the specified survey area, only five produced usable point clouds. Out of these five, three were able to cover overhanging areas, which was a prerequisite for full coverage of the area. Survey data and coverage is summed up in table 5.4 and figure 5.2.

**Table 5.4 Main data acquisition parameters at site B. Number of collected points refers to points within the specified survey area. Average point density is calculated on the best-fit plane within the survey area.**

| | KVS/ Terratec [5] | Svarmi/ Verkís | Senseloop | Romvesen/ Skred AS [4] | Orbiton | NAS [5] | Nordic Unmanned [6] |
|---|---|---|---|---|---|---|---|
| **Survey range (horizontal distance to rock wall, m)** | - | 90 | - | 15–80 | 100 | 80 | - |
| **Survey flight speed (m/s)** | - | 6 | - | 5 | 7 | 5 | - |
| **Survey duration (min)** | - | 8:15 | 12:19 | 29:00 | 28:00 | 15:37 | - |
| **Collected points** | 16 829 244 | 3 836 390 | 4 831 677 | 11 431 262 | 9 134 677 | 14 616 707 | 1 218 169 |
| **Average point density (pts/m2)** | 580 | 132 | 167 | 394 | 315 | - | - |

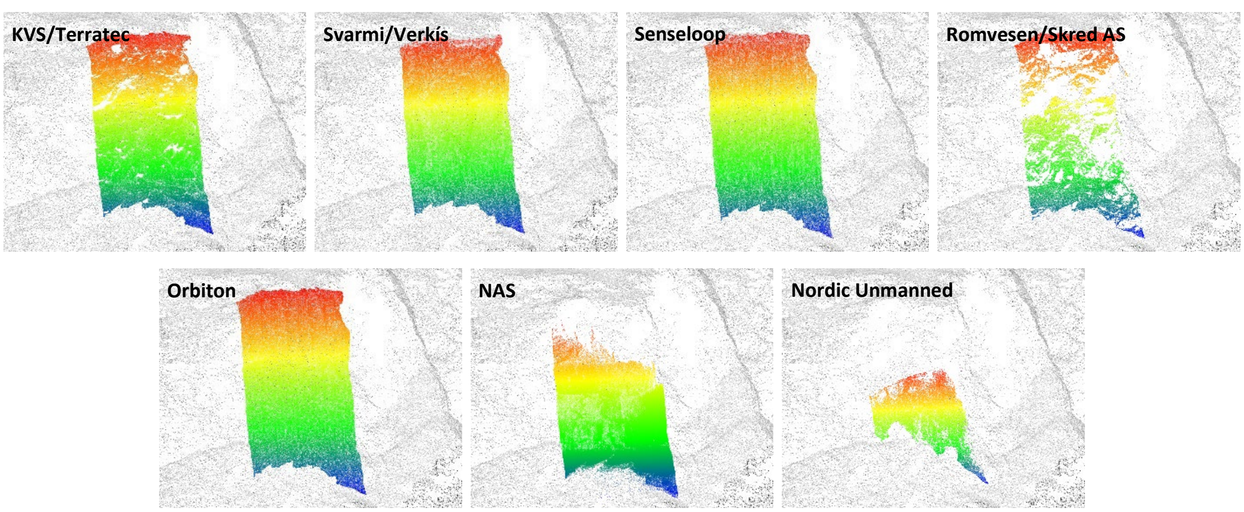



**Figure 5.2 Area coverage at site B shown by colorized points from within the specified survey area. Point cloud from the National Elevation Model (NDH) from the Norwegian Mapping Authority is shown in grey.**

[4] Used fixed, nadir pointing Lidars with limited field of view.
[5] Point cloud showed very high levels of noise. Average point density is not calculated due to low coverage.
[6] Point cloud had a vertical offset >30m. Average point density is not calculated due to low coverage.

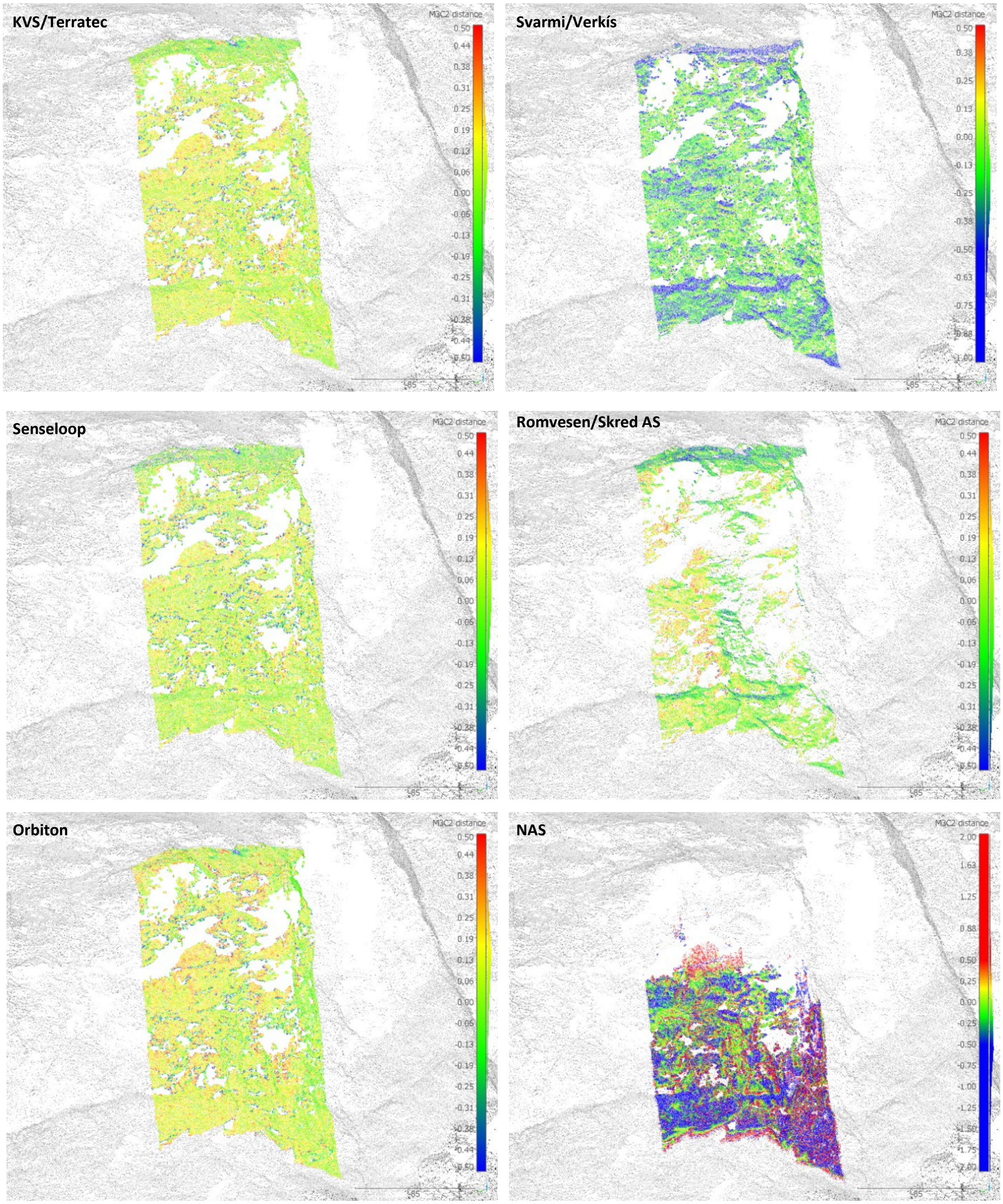



**Figure 5.3 Three-dimensional cloud-to-cloud distance (m) between acquired point clouds and the National Elevation Model (NDH). Distances are calculated with M3C2 plugin in CloudCompare and represent the distance between nearest neighbors along surface normal vectors (15). The color range stretches from < -0.5 m (blue) to > 0.5 m (red). Point cloud from the NDH is shown in grey.**

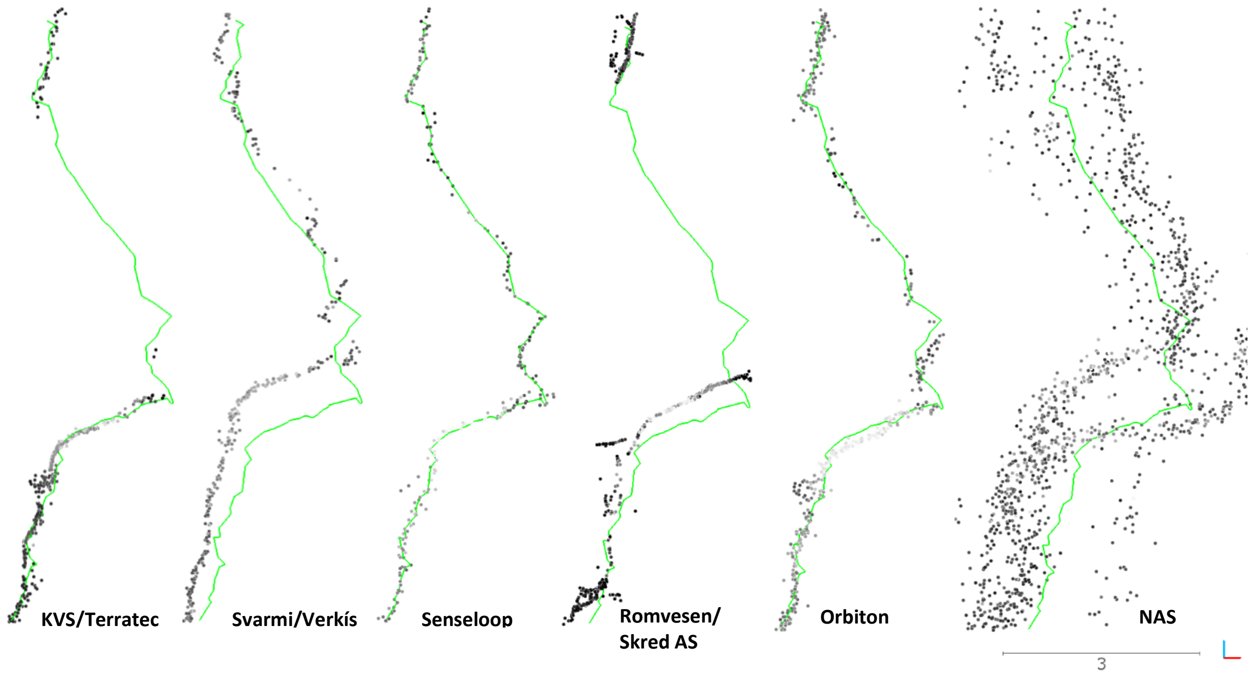



**Figure 5.4 Point cloud sections across an overhanging part of the rock wall. The green line represents a reference surface interpolated from Senseloop's point cloud. Their point cloud shows good coverage in steep areas and good agreement with the National Elevation Model.**

To evaluate the accuracy of the data, the point clouds are compared to the point cloud from the National Elevation Model (NDH) from the Norwegian Mapping Authority (Statens kartverk). The NDH lacks coverage in the steepest parts of the wall, but the comparisons give an idea of the absolute accuracy of each cloud and how they compare to each other. The results are shown in figure 5.3. Three of the point clouds align well with the NDH, while the others show either systematic vertical offset or noise.

Figure 5.4, which shows point cloud sections across an overhanging part of the rock wall, further illustrates the elevation differences and coverage in overhanging sections. The sections also indicate the level at which the point clouds can be used to detect and delineate cracks and other smaller-scale rock surface features. Generally, the acquired point clouds seem usable for reproducing geometry on the meter- to decimeter-level. The point densities and point precisions, however, are insufficient for evaluating rock mass quality and joint parameters important for assessing local stability.

Despite large variation in point cloud quality, the results from site B indicate a potential of using lidar systems for mapping and evaluation of rock faces with emphasis on rock stability. For evaluation of volumes, orientations and angles, i.e., using automatic rock mass classification algorithms [16, 17], lidar point clouds can be valuable and efficiently collected for large rock faces. Future tests should also include close-up scanning of local rock features, repeated surveys for evaluating the level of change that can be detected, and investigation of how lidar data and RGB images can best be combined for rock mass analysis.

## 5.3 Site C1

Site C1 was situated on a partly snow-covered roadside hillside. The snow surface consisted of new snow from the day before, that had become wet due to warm temperatures and rain. The flights were performed in challenging weather conditions, with very variable wind and strong gusts.

**Table 5.5 Overview of main data acquisition parameters at site C1. Collected points and average point density is calculated within the specified survey area.**

| | KVS/ Terratec | Svarmi/ Verkís | Senseloop | Romvesen/ Skred AS | NAS |
|---|---|---|---|---|---|
| **Survey altitude (AGL)** | - | 76 | 80 | 70 | 110 |
| **Survey duration (min)** | - | 8:19 | 10:26 | 25:00 | 14:01 |
| **Survey flight speed (m/s)** | - | 6 | - | 5 | 5 |
| **Collected points** | 19 930 458 | 7 554 897 | 11 721 121 | 27 635 627 | 88 785 236 |
| **Average point density (pts/m2)** | 199 | 76 | 117 | 276 | 888 |

As shown in table 5.5, the variation in flight times and acquired point density was large also here. Resulting snow depth maps and orthophotos from four of the vendors are shown in figures 5.5 and 5.6. The point cloud from Norse Asset Solutions was vertically offset by tens of meters and was not included in the analysis. Snow depths are calculated from Digital Elevation Models (DEMs) with 1 m resolution, with elevation data from the NDH representing snow-free terrain. Where available, only classified ground points were used to generate the snow surface DEMs, to avoid errors related to low vegetation in parts of the survey area. The snow-free DEM was generated from classified ground points in the NDH point cloud.

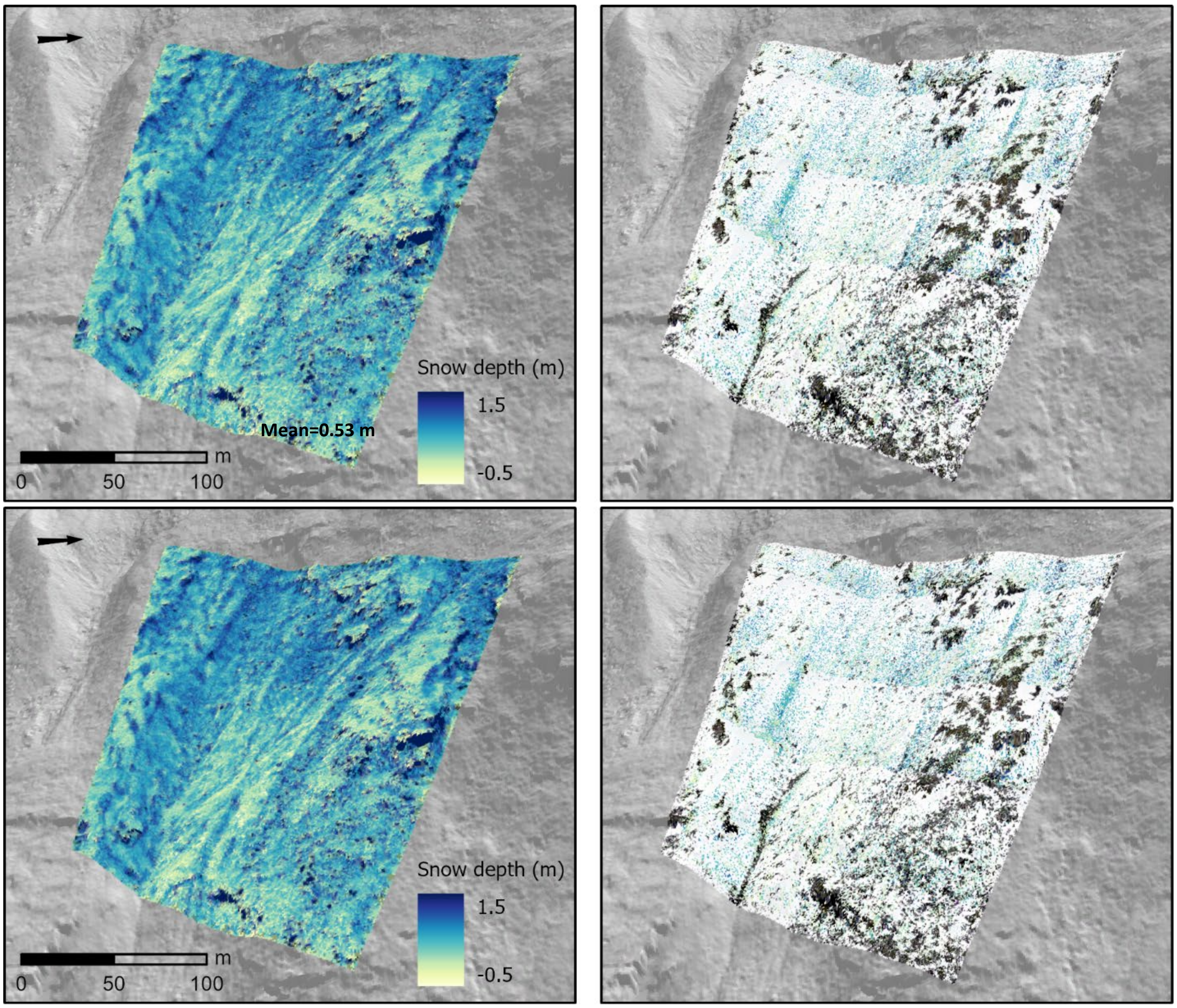
The snow depth maps show similar depositional patterns, but as for site A and B, there are systematic elevation differences between the point clouds from the different vendors. The point clouds from Svarmi/Verkís and Senseloop are located below the point clouds from KVS/Terratec and Romvesen/Skred AS and mostly below the NDH on snow-free terrain. The elevation differences are also apparent from mean snow depths, ranging from 0.27 m (Svarmi/Verkís and Senseloop) to around 0.5 m (KVS/Terratec and Romvesen/Skred AS).

Apart from these systematic differences, the main snow depth errors are found next to cliffs and steeper terrain, where both small horizontal offsets and the generation of raster cells may produce larger elevation differences. Errors and differences may also arise from different classification algorithms, as well as the much lower point density in the NDH snow-free point cloud.

Point cloud sections shown in figure 5.7 generally show that lidar returns from the snow surface are consistent and dense, although some noise and outliers can be seen in the point cloud from Senseloop. The point cloud from Romvesen/Skred AS lie below the others, but otherwise there are no obvious elevation differences. This indicates that the elevation differences vary and that other errors are affecting point cloud accuracy than just general elevation offsets.

Figure 5.8 illustrates how lidar point clouds also can be used to evaluate snow surface conditions. The shaded relief, generated from the point cloud from KVS/Terratec, provides similar information about drainage patterns on the snow surface as the orthophoto from Svarmi/Verkís. This show that despite the inherent “fuzz” in the point clouds, useful information about small-scale features can be extracted as long as the point density is large enough.

**KVS/Terratec** **KVS/Terratec** **KVS/Terratec**



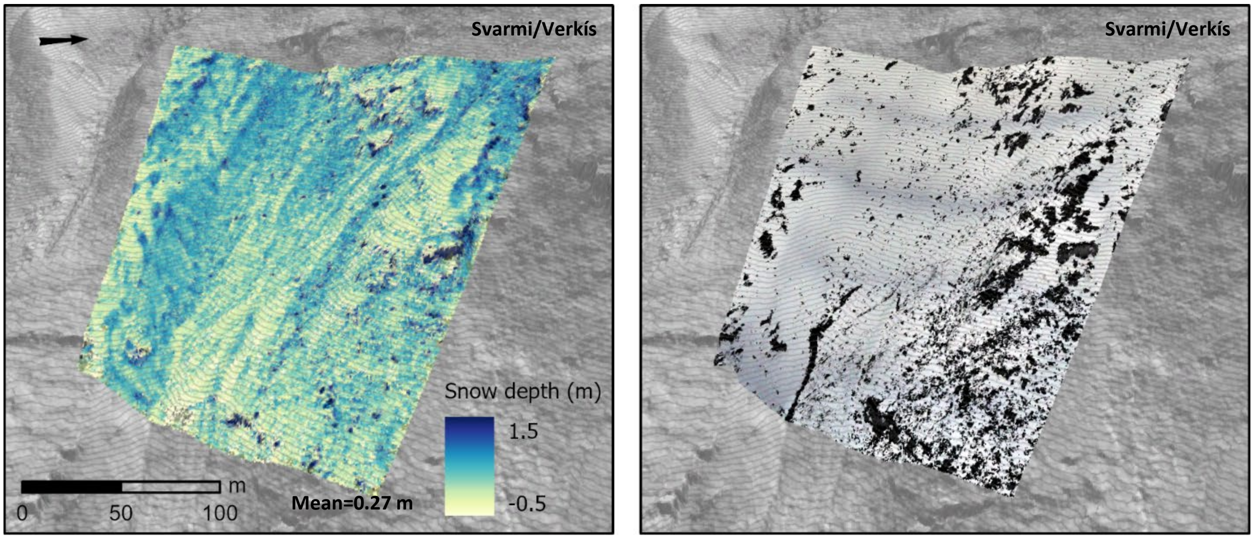
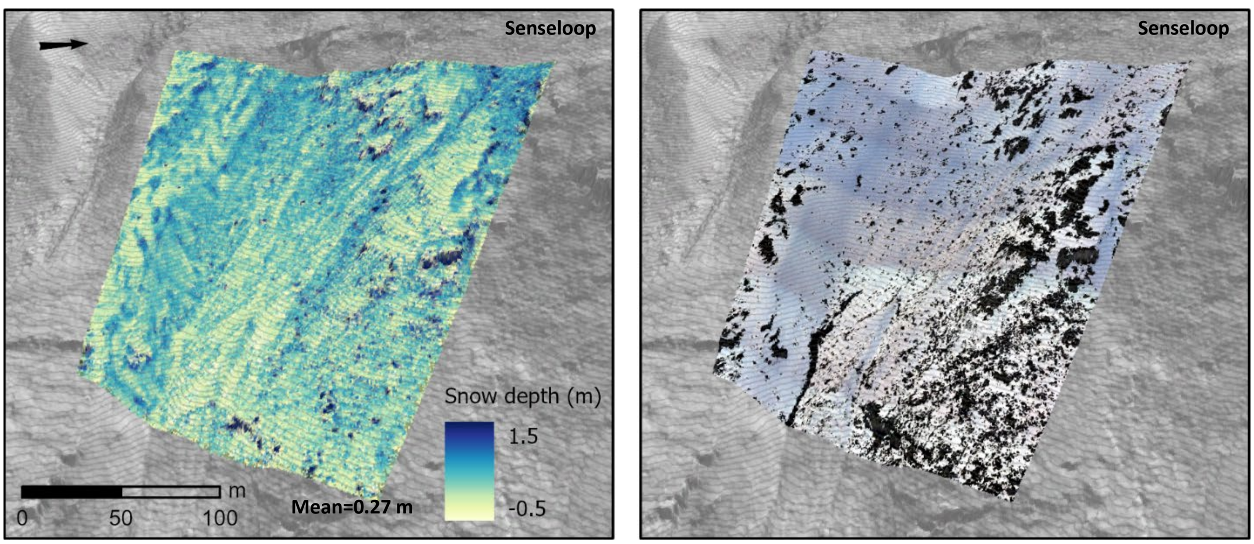



**Figure 5.5 3D view of snow depths and orthophotos from site C1 (KVS/Terratec and Svarmi/Verkís). Black arrows indicate north.**




Romvesen/Skred AS

Romvesen/Skred AS

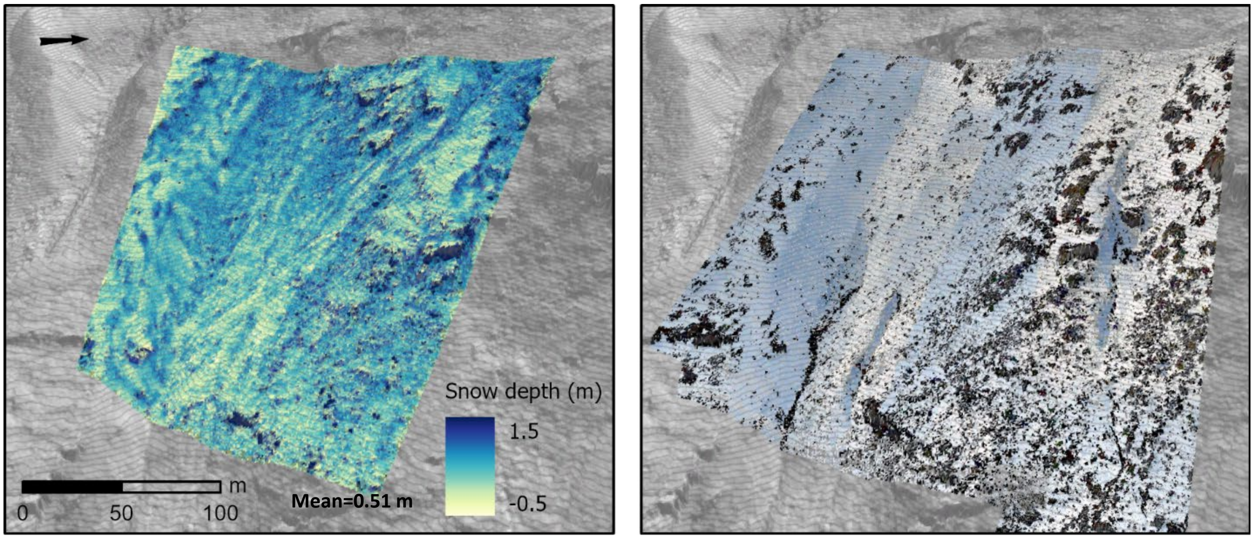



**Figure 5.6 3D view of snow depths and orthophotos from site C1 (Senseloop and Romvesen/Skred AS). Black arrows indicate north.**

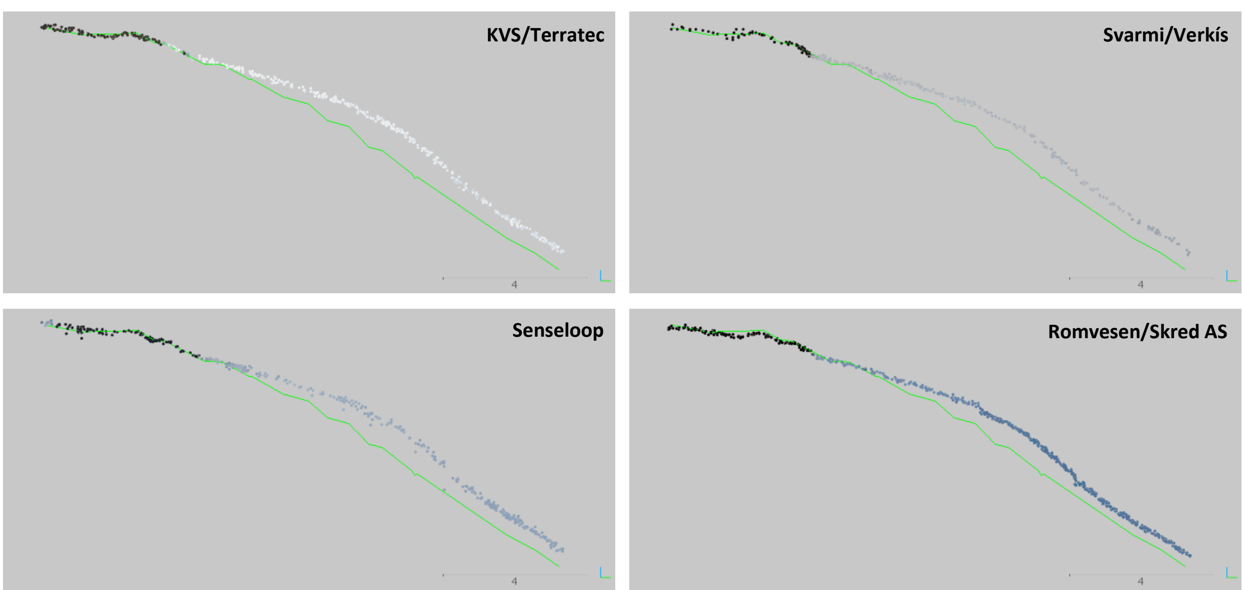
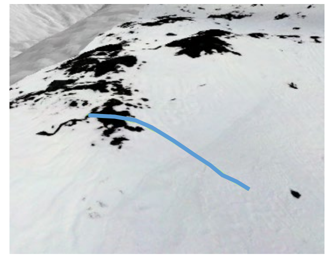


**Figure 5.7 Point cloud sections from bare ground into a snow accumulation zone. The points are gathered along the blue line shown in the right image, within a width of 20 cm and from all point classes. The green reference line represents a rough approximation of the snow-free ground interpolated from classified ground points in the NDH point cloud.**



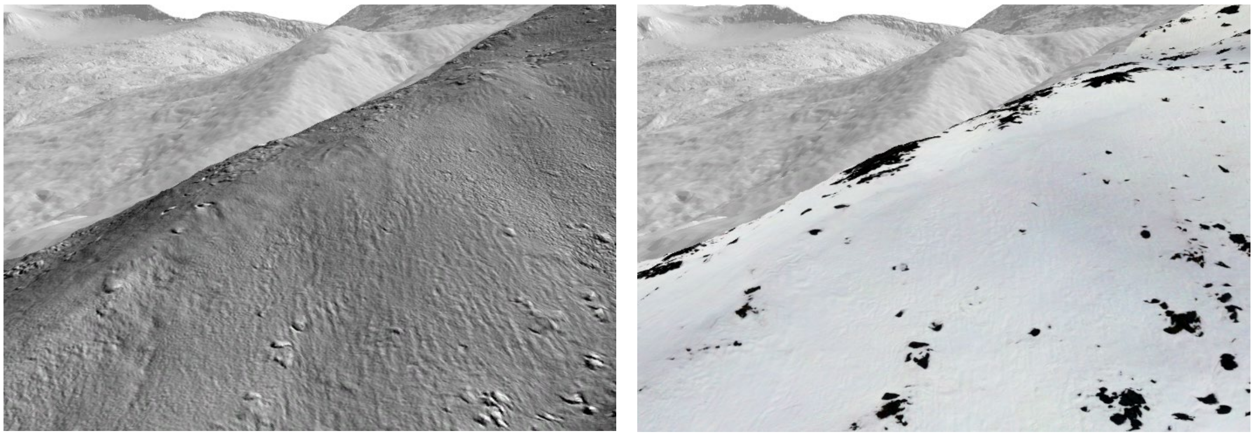


**Figure 5.8 Shaded relief with 10 cm resolution generated from lidar point cloud (left) compared to an orthophoto (right), from the same snow accumulation zone.**

**5.4 Site C2**

Site C2 was the most challenging task given the high altitude and distance from the take-off location. The difficulty was further increased by strong winds from SW, causing strong turbulence on the leeward side of the ridge above the survey area. As a result, only Orbiton surveyed the site. They let their UAV turn around before completing the mission after a loss of radio contact but managed to cover most of the survey area.

Figure 5.9 shows calculated snow depths with NDH representing snow-free terrain. At the time the NDH lidar data was collected, however, there was quite a lot of snow within the survey area. As a result, large parts of the point cloud from Orbiton lie below the NDH point cloud, as illustrated in figure 5.9. Therefore, the calculated snow depths are only shown for areas where the NDH actually represents snow-free ground. In these areas, the snow depths look reasonable and show realistic depositional patterns.

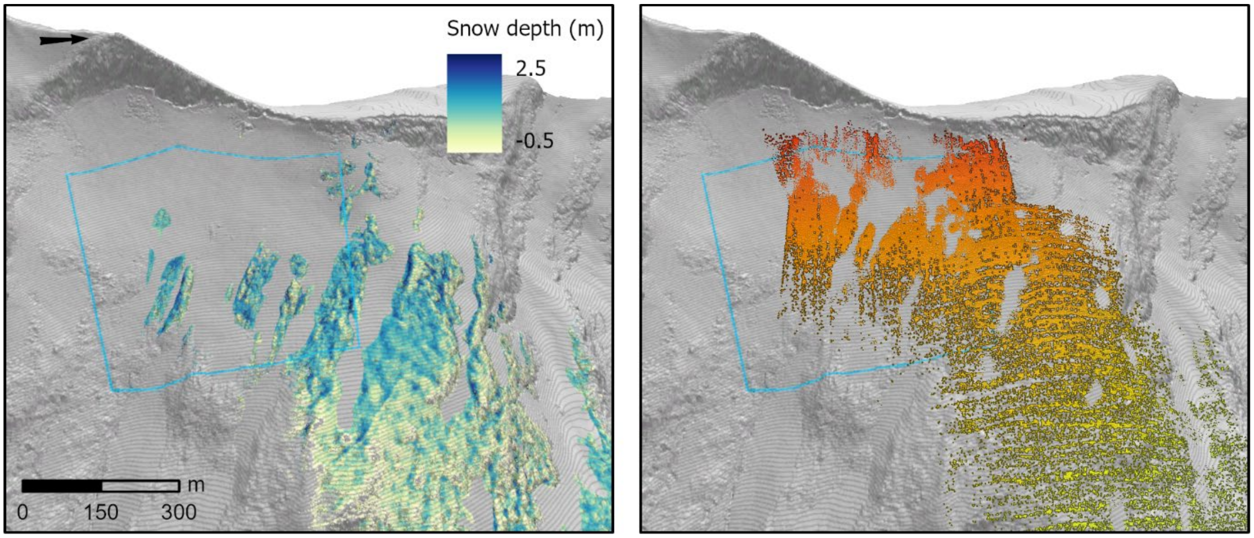



**Figure 5.9 3D view of snow depths (left) and coverage (right) of lidar data from Orbiton at site C2.**

## 6 FINDINGS

Over the three days of the demonstration, the vendors completed a series of flights with UASs carrying lidar at four pre-specified test sites.

An analysis of the lidar data determined the following:

<u>Accuracy:</u> Vertical RMSEs with accuracy down to 1–2 cm was possible. Systematic errors caused vertical offsets and surprisingly large differences between the vendors' results. This underlines the need for careful calibration, processing, and georeferencing routines. Satellite coverage changes over time and this may have contributed to systematic errors, since the data capture was performed over several hours.

<u>Precision:</u> This was good on a survey scale but the small-scale variability (fuzz) was considerable. The level of precision desired for an application will determine the point density (I.e., the number of measurements per area at which the surface is sampled) required from the lidar device.

<u>Mapping of snow surfaces:</u> The lidar returns on wet to dry new snow were good. Low point density (>30–50 points/$m^2$) seem sufficient for snow depth calculation and change detection on even snow surfaces. Higher point density is needed for capturing small-scale snow surface structures. An RMSE below 10 cm is normally sufficient for snow depth calculation. For change detection, accuracy should be as high as possible and preferably below 5 cm.

The following points summarize the overall findings from the demonstration.

<u>In general, the lidar data quality was good and within a level of precision and accuracy that could be used for monitoring of snowpack and avalanche risk.</u> All the point clouds collected by the vendors at site A had RMSEs well below 10 cm. With bare earth data, the lidar data could be used to determine snow depth and snow volume, and with repeated flights, also track changes in the snowpack over time. The lidar returns also provided usable information on the surface of the snowpack and about the terrain in the study area.

<u>There is room for improvement of data collection.</u> Although obtained accuracies are generally good, signs of systematic errors indicate room for improvement. Careful positioning of ground control points would improve accuracy as would suitable point cloud densities.

<u>System operation could be a challenge</u>. Even lidar professionals at this demonstration produced inaccurate or sub-optimal results. Successful operations carried out by NPRA staff will (as of now) require detailed knowledge, extensive testing, and foolproof survey workflows.

<u>Data management should be evaluated:</u> Point clouds collected by lidar can quickly create large files that are computationally demanding to handle. The amounts of data collected and stored should be minimized according to needs. Automatic processing and analysis routines should be established.

The use of UAS for avalanche monitoring on an operational level depends partially on the ability of the aircraft to fly and to collect data in a range of conditions in a range of locations. During this demonstration, different vendors with different aircraft showed a varied level of willingness to fly based on the ruggedness of the terrain and the weather (mainly wind). In addition, the ability to collect good lidar data while snow or rain is falling is uncertain. Since increased avalanche risk often occurs during times of unsettled weather, there is some uncertainty how well lidar data can be collected routinely in all situations.

Collection of lidar data using UASs has other important applications for the NPRA: In this test, mapping of rock faces was demonstrated. It was found that RGB colorized points and coverage in overhanging areas is essential for the output to be useful. The collected data was useful for investigating general geometry of the rock face, but assessment of local rock mass quality and stability parameters requires higher point density and better precision. Monitoring of rock deformation could be possible if the deformation rate is high.

## 7 FUTURE STEPS

The demonstration suggests areas for the NPRA to continue to evaluate and consider UASs and Lidar.

The UAS and airborne sensor industry is growing rapidly and the NPRA should continue to explore their capabilities. UAS and sensor technology, capabilities, availability, and affordability have improved greatly. This growth has enhanced the potential of this technology to address NPRA's needs in terms of avalanche control and winter operations as well as other types of natural hazard monitoring.

Lidar on small UASs should be further explored particularly for routine NPRA operations. The demonstration indicated that lidar output can map snow surface conditions and measure snow depth and volume, all of which are valuable for avalanche hazard assessment. Additional research is probably needed to explore the economics of lidar. The cost of lidar sensors used in this test, as reported by the vendors, ranges from 160,000 NOK to 1,600,000 NOK. Given that avalanche data collection is a high-risk environment, the NPRA will need to decide if possibly damaging or losing an aircraft with a lidar sensor is acceptable. Related to this, is that SfM can collect similar snowpack volume and depth information in daylight conditions using a lower cost digital camera. So, there may need to be some assessment if SfM can be used in some high-risk situations.

The Trollstigen demonstration was designed specifically to collect and compare UAS lidar data. The data collection flights were completed by vendors who were experienced UAS pilots and lidar experts and who had advanced information about the flight locations and, in some cases, conducted pre-flight reconnaissance. In addition, several vendors opted not to fly due to wind. In other words, the flights were optimized to collect lidar data and even in this situation there were inaccurate or sub-optimal results or, due to a decision not to fly, no data. Additional research is needed to explore if lidar on UAS is an effective tool that can be routinely used by NPRA staff, who are not primarily UAS or lidar experts, to collect consistent and usable data to monitor roadside avalanches in a range of realistic conditions.

Additional research could explore if lidar on a UAS accurately captures snow conditions such as snow depth and volume and surface features in areas that are of direct interest to NPRA staff who are responsible for monitoring and forecasting avalanches. In addition, it should be confirmed that NPRA staff trained primarily as geologists can economically and effectively operate UASs to collect relevant lidar data in a timely manner. The use of UAS and lidar contractors should be considered, particularly in situations that do not require immediate data.

Lidar could be usefully paired with other sensors and this should be explored: Lidar data may have enhanced value or better overall data could be collected in a greater range of weather, lighting or more rugged terrain if it is combined with other sensors carried on UASs. For example, lidar paired with ground penetrating radar (GPR) could provide lidar derived UAS on the snowpack depth, volume and surface plus the GPR could help analyze the snowpack's internal layering structure, all of which is valuable for avalanche monitoring. This can occur as part of the on-going GEOSFAIR project which is exploring the use of instrumented UAS to make faster and better assessments of avalanche danger to roads.

The NPRA should continue to track the regulatory issues which will impact the usability of UASs: Past Norwegian aviation rules have made it more difficult to fly to observe terrain features that are out of sight over the tops of mountain and ridges or down valleys due the requirement to fly in Visual Line of Sight (VLOS). Regulations in Norway have opened for beyond line of sight (BVLOS) operations as long as the operator is licensed as professional, using a required organizational setup with routines and procedures, much like an airline company. Professional operators may operate BVLOS below 400 feet above ground level, where most of the operations for the NPRA would be conducted, with a 12-hour notice for the publishing of a NOTAM (Notice to Airmen). This maybe a reasonable approach if the NPRA identifies known areas that need to be routinely monitored or areas such as Trollstigen that require seasonal operations to open after winter closures but the NPRA need to keep tracking the UAS regulations for any changes.

BLOS concerns highlight one potential capability of UAS that is underutilized – these aircraft can fly autonomously. In theory no or minimal human input is required. This suggests that these aircraft could fly missions from a remote garage without observers directly involved and could be used in inaccessible areas or in poor visibility.

The NPRA may want to formalize or further explore the uses of smaller UAS operated by NPRA staff or by contractors. NPRA staff already operate a number of small UASs. It could be valuable for the NPRA to offer training related to operations, flight regulations, and safety of these aircraft and open up the use of these small UASs to more employees. For the NPRA's UASs, there would be applications beyond just winter snow surveillance including geological surveys, mapping and potentially emergency usage such as mapping the extent of floods or debris flows. UAS with lidar operated by private business and contracted by the NPRA could also offer benefits to the NPRA and may help advance the Norwegian UAS industry.

The possible benefits of a UASs to the NPRA, beyond just snow avalanche monitoring, could be large. If there was enough of these systems owned and operated by the NPRA and spread throughout the NPRA regions, this type of aircraft could be available on short notice if needed for urgent projects or emergencies.

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Statens vegvesen
Pb. 1010 Nordre Ål
2605 Lillehammer

Tlf: (+47) 22 07 30 00

firmapost@vegvesen.no

ISSN: 1893-1162

vegvesen.no

**Tryggere, enklere og grønnere reisehverdag**