AUTOMOTIVE LIDARS UTILIZED TO PROVIDE REAL TIME SNOW DEPTH MAPPING FOR AVALANCHE FORECASTING AND DECISION-MAKING IN SKI RESORTS

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ABSTRACT: LiDARs are used for snow depth mapping for all scales, from satellites, airplanes, drones, mobile vehicles, and terrestrial based since about 20 years now. The technology provides high resolution and accurate spatial measurements of snow surfaces. Further, snow depth maps are created via differential maps calculated from a snow on and off surface (or snow surfaces at different stages of evolution). In this project we utilize low-cost automotive LiDARs to provide real time snow depth maps that are used for avalanche forecasting and decision-making. At our avalanche test site at Lech am Arlberg, Austria, we installed 4 Livox Avia LiDARs, each monitoring a range of about 150 m to cover an avalanche prone slope that is loaded by snow drift events that form a significant cornice at the ridge. Avalanche events happen both, naturally and triggered by explosives. We tested our measurement set-up against a commonly used laser scanner (Riegl VZ6000) and a continuous 1-d laser (Lufft SHM31), which has not been done before and determined the accuracy of our set-up. Most work was invested in providing a reliable solution in terms of a self-sufficient power supply and solid installation as well as straightforward post processing including filtering of air particles and web data display, which we discuss. The advantage of such permanent installations is the possibility of measuring the snow pack evolution in high time frequency. Any time a reliable spatial snow depth measurement covering an area of 600 m (four LiDARs in action) in a point resolution of 10 cm can be conducted. At our avalanche prone slope we were able to follow the accumulation of snow due to snowdrift and/or snow precipitation as well as melting and mass movement of avalanche events in a spatial content. The results we show and discuss provide a useful improvement for avalanche forecasting and decision-making compared to the commonly used 1-d snow depth sensors as e.g. spatial dimension of snow drifts can be detected and the use of explosives can be initiated or a ski run can be closed.

KEYWORDS: LiDAR, laser scanning, snow depth, snow accumulation, low-cost

1. INTRODUCTION

Snow fall, wind slab formations, caused by wind-driven snow redistribution, cornice growth, and melting are spatially heterogeneous in avalanche terrain and there extend is difficult to predict in particular on a local scale (Hancock et al., 2020). While areas of snow accumulation and snow erosion can be modeled and forecasted to a certain extent, the amount of snow that is involved in all those processes remains unknown and therefore a precise estimation of the spatial snow depth distribution in avalanche prone slopes is challenging (Aksamit and Prokop, 2026; Schneiderbauer and Prokop 2016). Therefore spatial measurements in high temporal repetition are needed and have to be cost-effective to be applied for avalanche forecasting on a slope scale. In the framework of the “RSnowAut” research project we utilized low-cost automotive LiDARs for the first time to provide real time snow depth maps that are used for avalanche forecasting and decision-making. In our first attempt we used a hand held Oyster LiDAR integrated in MOLISENS (Goelles et al., 2022 and Kapper et al. 2023) After satisfying results we installed four Livox Avia LiDARs at two different locations, each monitoring a range of about 150 m to cover important parts of our test area at Lech am Arlberg similar to Ruttner et al. 2025.

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2. METHODOLOGY

2.1 Test site and installation

Our test site at the ski resort at Lech am Arlberg, Austria covers cornice growth, wind driven snow redistribution, and due to its south-east exposition significant melting processes. Due to its location above an important ski run, information about

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those processes is crucial for local avalanche warning and decision making (Fig.1)

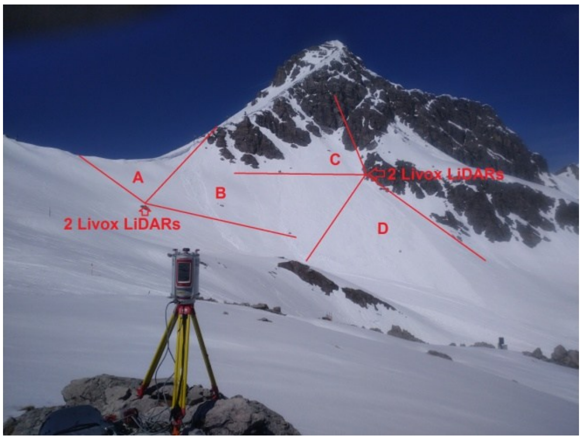

Figure 1: Location of the LiDAR measurement units in the avalanche prone slope. Areas A,B,C,D are covered by 4 independent Livox Avia LiDAR devices at 2 different logging stations.

Figure 2: Installation at 2 different locations: Left: 2 Livox Avia LiDARs at a full automated meteorological and snow station, where power supply exists. Right: Energy self sufficient installation in an avalanche safe location in a rock wall.

Based on our own experience with hand held automotive LiDARs (Kapper et al., 2023) and information found in literature (Ruttner et al., 2025) we chose the Livox Avia LiDAR for our installation. This device has a wavelength of 905 nm, which is suitable for measuring snow and ice (Prokop 2008), covers a distance of up to 450 m and has a FoV of 70.4 ° x 77.2 °. Furthermore, this sensor can operate at temperatures as low as -20 °C, making it suitable for Alpine conditions (Livox, 2020).

2.2 *Data transmission and processing*

Our LiDAR measurement setup as shown in Fig. 1 and 2 include two Livox Avia sensors and controller which are mounted on site and a server for data processing. The controller includes a data logger implemented as a Raspberry Pi 5 with 8GB RAM running Robot Operating System (ROS) 2 Humble on Ubuntu Server 24.04.1 LTS (64-bit). Furthermore, a router was mounted in the controller to connect the sensor with the data logger and provide mobile network connection. As explained by the figure 3, the sensor passes raw data to the data logger, which then stores it in files. Each file is transmitted to the server and processed there. The file and retrieved data are stored and can be accessed via an API (Wallner et al. 2026).

Using the API, difference plots for any sensor can be generated between two timestamps. This is done by sending a POST request to https://api.avalanchemonitoring.com/data/diff-plots/bysearch following a successful user login. The request requires several parameters, including the sensor ID (sensor_location_id), a reference timestamp (datetime_ref), a comparison timestamp (datetime_to_compare), and the desired export format (e.g., "png"). Additionally, optional parameters can be specified to customize the output, such as the coordinate reference system (crs_to), the plot buffer size, and visualization limits for distance differences (vmin and vmax). The API returns a job ID in response, which can then be used to retrieve the generated plots once processing is complete.(Gölles et al. 2025) For this calculation the official M3C2 algorithm implemented in CloudCompare was used. The advantage of that algorithm is a cloud comparison based on surface normals rather than just nearest neighbor distances (Lague et al., 2013).

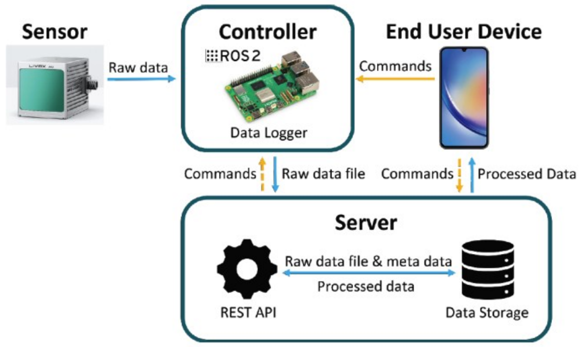

Figure 3: Components of the LiDAR sensing solution and the data flow between them (blue arrows) as well as the actual direct remote-control path with commands (yellow arrow) and the improved future one via the server (dashed yellow arrow, Wallner et al., 2025)

3. RESULTS

During the whole winter season 2024/25 and 2025/26 the sesning stations made automated scans in a preconfigured interval of 15 minutes or one hour and transmitted them for asynchronous processing to the REST API server. The recording and data transmission worked reliably and more than 250 GB of data has been generated and transferred. Based on the transmitted data, scans from different time steps can be compared and the change in snow thickness is calculated. The calculated difference of the scans is plotted for visualization and easy understanding of the condition at the avalanche prone slope (Fig. 5).

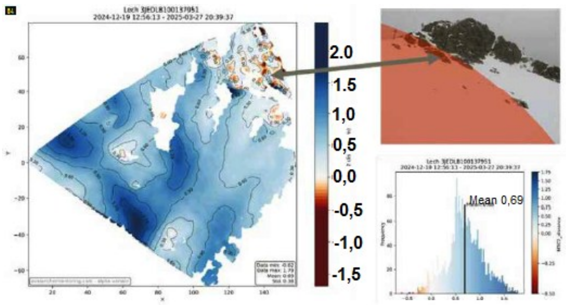

Figure 4: Spatial snow thickness distribution between December 12th, 2024 and March 27th 2025 measured by the LiDAR covering area B Figure 1. A mean snow difference of 0,69 m was measured, rock wall for reference.

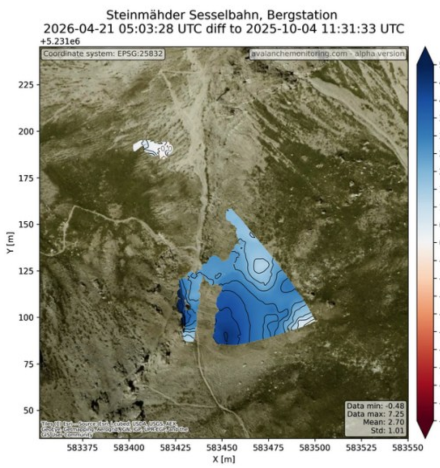

Figure 5: Spatial snow thickness distribution between September 4th, 2025 and April 21st 2026 covering area A in Fig.1. as displayed at https://avalanchemonitoring.com/en/ and as provided to ski patrollers and avalanche commission.

3.1 Accuracy

We found similar accuracy ranges as Ruttner et al. 2025 being smaller than 0.15 m. What we like to stress here is that useful results in coverage and accuracy are only possible in a measuring range of 150 m. The large footprint size following the methods in Voordendag et al. (2023) and Schaer et al. (2007), with a unfavorable geometry (100m distance, 70° incidence angle, 35° slope gradient), the vertical uncertainty becomes as large as 0.3 m. Even under favorable geometry conditions above 150 m of distance the vertical uncertainties are getting too large for the purpose of avalanche forecasting. This is obvious when comparing the data to a high performance laser scanner such as the Riegl VZ-6000 as seen in Fig.1. As the measurement geometry usually doesn't change much, relative differences in snow thickness in time can be satisfyingly followed (Fig. 6)

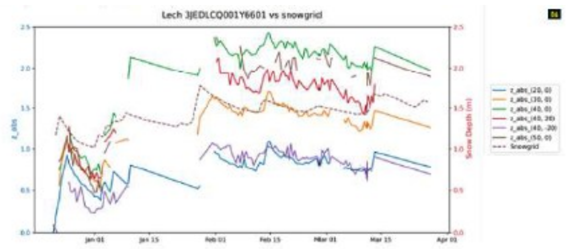

Figure 6: Comparison of modeled (Snowgrid @ Geosphere Austria) and measured data at different locations in the slope.

3.2 Reflectance

As knowledge about the condition of the snow surface right before snowfall is important for avalanche forecasting, in recent years backscattered laser signal intensity that is given by snow reflectance is used to measure and classify snow surface properties automatically (Prokop et al. 2024). So we have compared the intensity of the received laser signal intensity of the Livox Avia LiDAR to the intensity measured by 1-D LiDAR Lufft SHM31 as seen in Fig.2.(left image) and as it was used in former studies. Unfortunately the range dependent lose in intensity of the Livox LiDAR is very large (Fig.7) due to its low laser energy (Aksamit et al., 2026), so the differences in snow surface properties are lost in the signal to noise ratio.

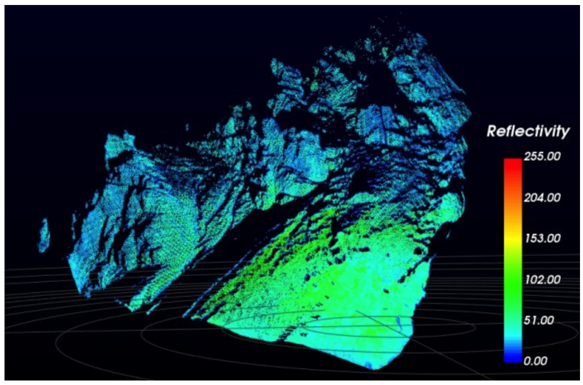

Figure 7: Point cloud of a scan made with the Livox LiDAR covering area C in Fig1. Different colors show a strong distance dependent decrease in reflectivity of the measured surface.

Intense work has to be done to be able to use the laser intensity reflected by snow surfaces to classify snow surfaces when measuring with Livox Avias.

4. CONCLUSIONS

We installed 4 low-cost LiDAR sensors in an avalanche prone slope to survey changes of the spatial snow depth distribution caused e.g. by wind driven snow redistribution, cornice growth or melting. Spatial snow depth maps were transferred to avalanche forecasters and ski patrollers in real time in a temporal resolution of 15 minutes to support decision making for the safety of an important ski piste underneath the avalanche prone slope. In the last 2 winter seasons data was delivered reliably with the measurement setup and post processing routine presented. The coverage of a single low-cost LiDAR, in this study a Livox Avia, is up to a distance of 150 m, accordingly using 4 LiDARs we could cover an area of approximately 600 m. If the position of the scanning LiDAR is chosen carefully, important data for avalanche forecasting can be delivered. We see great potential of such low cost LiDARs to provide important data from local avalanche hot spots, as the delivered spatial snow depth maps contain clearly more valuable information than the currently used 1-dimensional ultrasonic or laser driven snow depth sensors.

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REFERENCES

Aksamit, N. O., Encinas-Bartos, A. P., Hancock, H., and Prokop, A.: Turbulent Snow Transport and Accumulation: New Reduced-Order Models and Diagnostics, https://eartharxiv.org/repository/view/9203/, The Quarterly Journal of the Royal Meteorological Society.2025.

Aksamit N, M. Nemoto, Y. Ito, 2026: Measurement and tracking of blowing and falling snow particles using an automotive 1550 nm LiDAR. Cold Reg. Sci. Tech., 251, 105073. doi: 10.1016/j.coldregions.2026.105073

Goelles, T., Hammer, T., Muckenhuber, S., Schlager, B., Abermann, J., Bauer, C., Expósito, Jiménez, V.J., Schöner, W., Schratter, M., Schrei, B., Senger, K., 2022. MOLISENS: MObile LIdar SENsor System to exploit the potential of small industrial lidar devices for geoscientific applications. Geoscientific Instrumentation, Methods and Data Systems 11, 247–261. https://doi.org/10.5194/gi-11-247-2022

Goelles, T., Wallner s.,and Eckerstorfer M.: Low Cost lidar monitoring for planning and operation of mitigation measures. Proceedings of International Symposium on Mitigation Measures against Snow Avalanches and Other Rapid Gravity Mass Flows Ísafjörður Iceland, September 30 – October 3, 2025

Hancock, H., Eckerstorfer, M., Prokop, A., Hendrikx, J., 2020. Quantifying seasonal cornice dynamics using a terrestrial laser scanner in Svalbard, Norway. Nat. Hazards Earth Syst. Sci. 20, 603–623. https://doi.org/10.5194/nhess-20-603-2020

Kapper KL, Goelles T, Muckenhuber S, Trügler A, Abermann J, Schlager B, Gaisberger C, Eckerstorfer M, Grahn J, Malnes E, Prokop A and Schöner W (2023) Automated snow avalanche monitoring for Austria: State of the art and roadmap for future work. Front. Remote Sens. 4:1156519. doi: 10.3389/frsen.2023.1156519

Lague, D., N. Brodu, and J. Leroux, “Accurate 3D comparison of complex topography with terrestrial laser scanner: Application to the Rangitikei canyon (N-Z),” ISPRS Journal of Photogrammetry and Remote Sensing, vol. 82, pp. 10–26, 2013.

Livox Technology Co. Ltd., “Livox Avia User Manual,” 2020, [Online]. Available: https://terra-1-g.djicdn.com/65c028cd298f4 669a7f0e40e50ba1131/Download/Avia/Livox%20Avia%20User%20Manual%20202204.pdf.

Prokop, A., 2008. Assessing the applicability of terrestrial laser scanning for spatial snow depth measurements. Cold Regions Science and Technology 54, 155–163. https://doi.org/10.1016/j.coldregions.2008.07.002

Prokop, A., Friedt, J.M., Bernard, E., and F. Tolle. Using backscattered laser signal intensity to measure snow surface properties automatically. , in: Proceedings of the International Snow Science Workshop, Tromsø, Norway, 2024, 1142-1145.

Ruttner, P., Voordendag, A., Hartmann, T., Glaus, J., Wieser, A., Bühler, Y., 2025. Monitoring snow depth variations in an avalanche release area using low-cost lidar and optical sensors. Natural Hazards and Earth System Sciences 25, 1315–1330. https://doi.org/10.5194/nhess-25-1315-2025

Schaer, P., Skaloud, J., Landtwing, S., and Legat, K.: Accuracy Estimation for Laser Point Cloud Including Scanning Geometry, in: 5th International Symposium on Mobile Mapping Technology, Padova, Italy, 29–31 May 2007, https://infoscience.epfl.ch/ handle/20.500.14299/17191 (last access: 25 March 2025), 2007.

Schneiderbauer, S. and Prokop, A.: The atmospheric snow-transport model: SnowDrift3D, Journal of Glaciology, 57, 526–542,https://doi.org/10.3189/002214311796905677, 2011.

Voordendag, A. B., Goger, B., Klug, C., Prinz, R., Rutzinger, M., and Kaser, G.: AUTOMATED AND PERMANENT LONGRANGE TERRESTRIAL LASER SCANNING IN A HIGH MOUNTAIN ENVIRONMENT: SETUP AND FIRST RESULTS, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., V-2-2021, 153–160, https://doi.org/10.5194/isprs-annals-V-2-2021-153-2021, 2021.

Wallner, S., Bergmann, A., Gölles, T., Muckenhuber, S Jonassen, M. O., and S. Wickstroem, 2026. Lidar-Based Detection of Centimeter Snow Depth Variations in Wind-Affected Alpine Terrain. In Proceedings IEEE Sensors Conference 25.-28-10.2026 - Accepted

Wallner, S., Gölles, T., Schlager, B., Prokop, A., Gaisberger, C., Schrattner, M., Muckenhuber, S., 2025. An affordable permanent monitoring solution of potential avalanche sites. Lawinensymposium 2025 (in press)