Near real-time snow depth monitoring with low-cost lidar sensors for road safety decisions

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ABSTRACT:

Operational avalanche safety decisions often must be taken under conditions of limited direct observations and sparse spatial data coverage. In particular, information from avalanche release zones during periods of low visibility is rarely available. As a result, decisions typically rely on a combination of expert judgment, avalanche bulletins, and data from nearby weather stations. Since November 2023, we operate low-cost lidar sensors that measure the snow depth distribution in an avalanche release area above a road close to Davos, Switzerland, at high temporal (1 h) and spatial (0.5 m) resolution. Our results can capture the evolution of new snow accumulation and redistribution even during relevant snowfall periods. To illustrate the achieved information, we present a case study from February 2026. During this event, a spontaneous avalanche release occurred overnight, which we could detect and quantify with our in-situ lidar measurements and directly influenced the decision-making of the local avalanche safety experts. The dataset provides direct input for avalanche dynamics simulations, enabling the estimation of potential runout distances for road safety applications. Our findings underline both the potential and the constraints of low-cost lidar systems for snow depth distribution monitoring in avalanche release areas. Beyond operational applications, the dataset provides a valuable benchmark for validating snow depth models and improving our understanding of snow depth distribution in avalanche-prone areas.

KEYWORDS: Remote Sensing, Snow Depth Monitoring, Low-Cost Lidar, Road Safety

1. INTRODUCTION

Avalanche forecasting and hazard mitigation rely on an accurate understanding of snowpack evolution and the conditions leading to avalanche release. In particular, the spatial distribution of snow depth strongly influences snow loading, slab formation, and snowpack stability, making it a key variable for operational forecasting and numerical avalanche modelling (Schweizer et al., 2003; Reuter et al., 2016). However, direct observations from avalanche release areas remain scarce, especially during snowfall events and periods of poor visibility, when operational safety decisions are most critical. As a result, avalanche hazard assessments often depend on indirect information such as weather station measurements, avalanche bulletins, and expert judgment.

Advances in remote sensing have substantially improved the observation of snow depth distribution in complex alpine terrain. Terrestrial laser scanning and photogrammetric methods provide high-resolution spatial information over large areas on ground-based, drone-, airplane- and satellite plattforms (Prokop, 2008; Deems et al., 2015; Bühler et al., 2015; Vander Jagt et al., 2015; Marti et al., 2016). More recently, low-cost lidar systems have enabled continuous monitoring at both high spatial and temporal resolution (Goelles et al., 2022; Ruttner et al., 2025). Such observations offer new opportunities to capture snow accumulation, redistribution, and avalanche-related snow cover changes in near real time.

In this study, we demonstrate the use of a permanent low-cost lidar monitoring system installed in an avalanche release area above a road near Davos, Switzerland. Using a natural avalanche event from February 2026, we show how high-resolution snow depth observations captured snowfall, and an avalanche release, and how these data supported both operational avalanche safety decisions and avalanche simulations.

2. DATA AND METHODS

This study uses snow depth data acquired at the Braemabuel test site in the Dischma valley near Davos, Switzerland. Since November 2023, two permanent monitoring stations equipped with Livox Avia lidar sensors have continuously observed the northeast-facing release area of the Wildi avalanche path (2150–2250 m,a.s.l.; 30–45 degrees). The sensors view the slope from different angles and jointly cover approximately 14,500 m^2 (see Fig. 1).

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Lidar scans are acquired hourly and registered to the Swiss national coordinate system (LV95/LN02). The resulting point clouds are processed into digital surface models and snow depth maps with a spatial resolution of 0.5 m. Snow depth changes are derived from differences between consecutive snow surface models. The accuracy of the resulting snow depth data is estimated at 0.1–0.3 m. Further details on the instrumentation, processing workflow, and data quality are described in Ruttner et al. (2025).

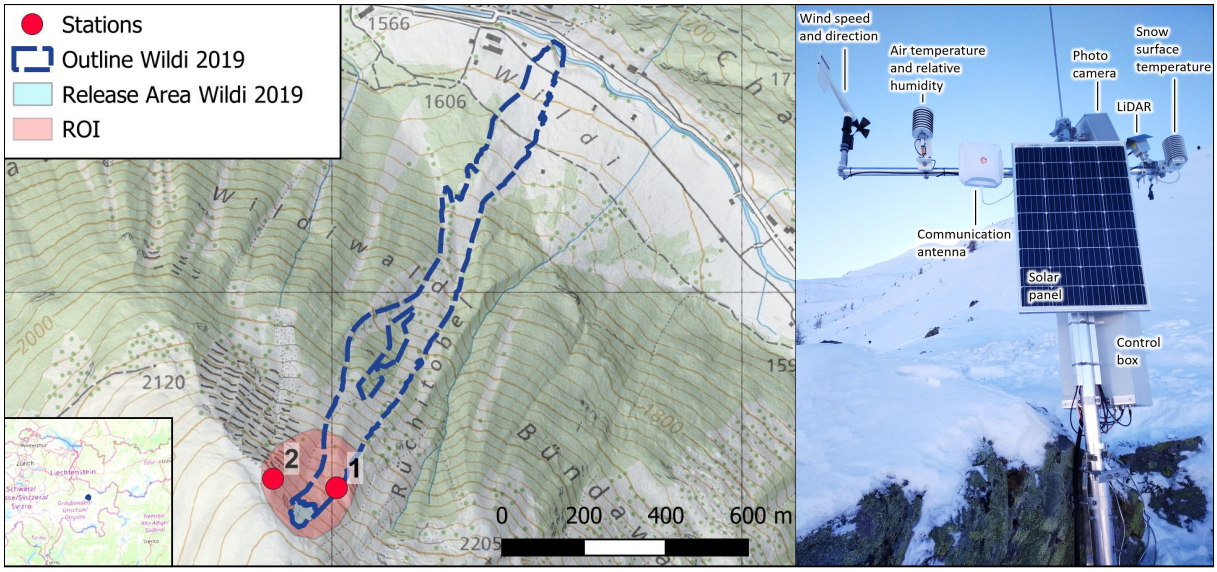


Figure 1: Overview of the study area with the locations of the stations, outlines of an avalanche from 2019 for context, and the monitored region of interest (ROI), and photo of station 1.

Figure 2 gives an overview of the mean snow depths in the test area of the last three winter seasons. Winter 2023/24 had substantially greater snow depths than the other two seasons, reaching a maximum mean snow depth of approximately 2.2 m in early April. In contrast, winters 2024/25 and 2025/26 were characterized by comparatively low snow depths, with seasonal maxima of not much more than 1 m. The generally wider standard-deviations in 2023/24 indicates greater spatial variability in snow depth during this comparatively snow-rich winter.

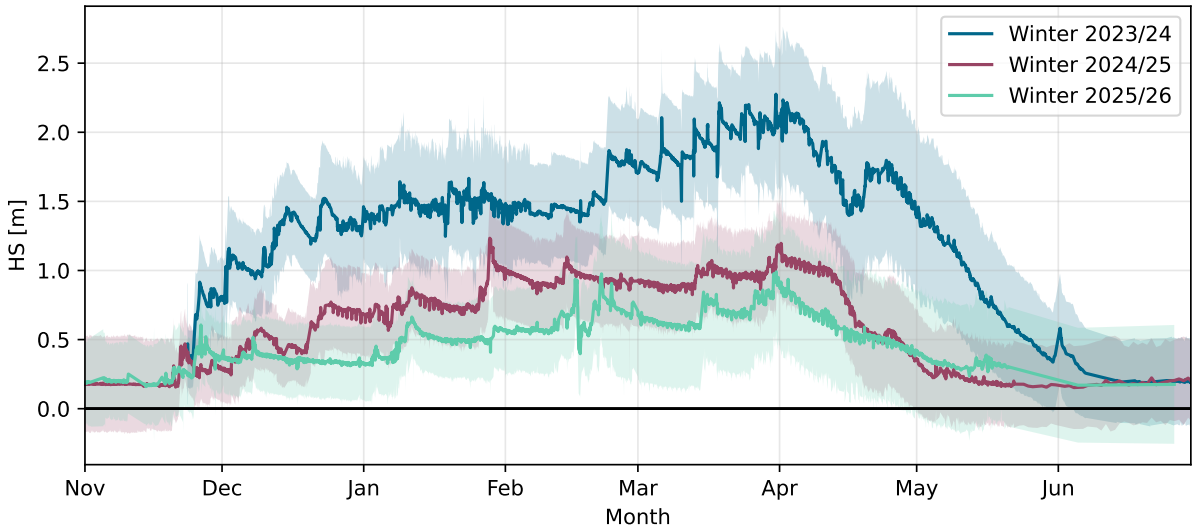


Figure 2: Mean snow depth and corresponding standard deviation derived from lidar observations for the winters 2023/24, 2024/25, and 2025/26.

3. RESULTS

Throughout the winter leading up to the event, the snowpack was characterized by a persistent weak layer problem. Successive snowfall periods from 16 February onward substantially increased the load on the weak snowpack, with the most intense snowfall occurring during the initial cold phase of the event. During the night of 16 to 17 February, a natural avalanche released on the Brämabüel slope and largely depleted the Wildi release area. The lidar measurements capture the associated sudden decrease in mean snow depth between 16 and 17 February 2026 (Figure 2).

To examine the avalanche release in greater temporal detail, lidar scans acquired from 17:00 UTC on 16 February to 07:00 UTC on 17 February were analysed. Intense snowfall reduced the spatial coverage of many scans; nevertheless, the available measurements show continued accumulation before the release. By 00:00 UTC, the release area was largely depleted, indicating that the avalanche had already occurred. The 01:00 UTC scan provides slightly better coverage and reveals substantial amounts of snow remaining along the right side of the release area. Parts of the release crown are also visible in this scan, as the crown's orientation towards the scanner provided a favourable incidence angle and enabled lidar returns despite the large scanning distance.

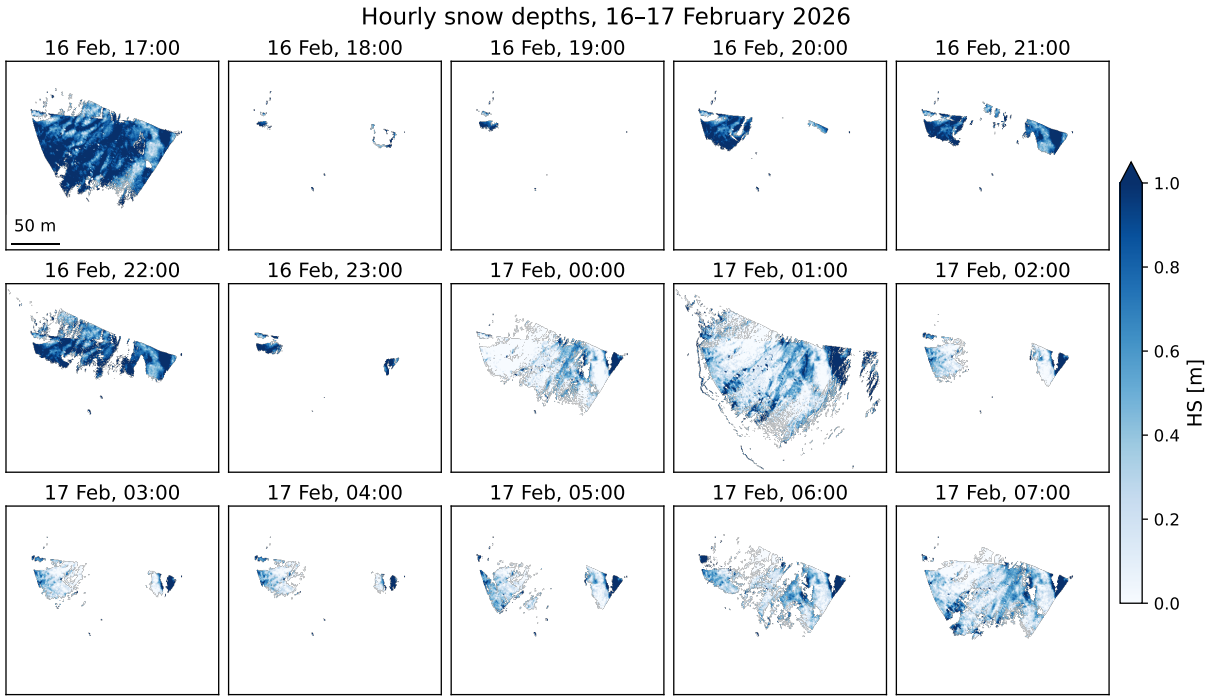


Figure 3: Temporal evolution of snow depth in the Wildi release area during the avalanche event from 16 February 17:00 UTC to 17 February 07:00 UTC

4. DISCUSSION

The February 2026 event illustrates both the operational value and the limitations of continuous lidar monitoring in avalanche terrain. The measurements documented the avalanche-related depletion of the release area and subsequent accumulation at a time when snowfall and poor visibility prevented visual observations. The information on the avalanche release and approximate release volume was immediately communicated to the local avalanche control service, who could adapt their operations based on the additional knowledge. Glaus et al. (2026) provide further insight into the event through Daily Avalanche Probability Indication Maps, which complement the lidar observations by placing the measured changes in snow depth within a broader spatial assessment of avalanche probability. Together, these products illustrate the benefit of combining spatially distributed snow depth measurements with model-based avalanche probability information. However, dense snowfall and fog reduced the measurement range and spatial coverage during parts of the event, particularly when observations were most relevant. Frequent scanning partly compensated for this limitation by increasing the likelihood of obtaining sufficiently complete measurements during brief periods of improved visibility. Lidar observations can therefore strengthen situational awareness during critical periods but should com-

plement model-based products, weather station data, avalanche bulletins, field observations, and expert judgement rather than serve as a standalone basis for operational decisions.

5. CONCLUSIONS

Permanent, low-cost lidar monitoring helps close an important observational gap by resolving the spatial and temporal evolution of snow depth in avalanche release areas. The measurements from February 2026 captured accumulation before the event, constrained the timing and spatial extent of the avalanche release, and documented the subsequent evolution of the release area. The resulting data provide a basis for estimating release heights and volumes and offer valuable input for avalanche dynamics simulations and the evaluation of snow distribution models. More broadly, permanent lidar systems can generate continuous event-scale datasets that improve the understanding of snow accumulation, redistribution, and avalanche release processes. Integrating such systems into existing observation networks could support more spatially explicit and process-based avalanche hazard assessments.

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