POSITIONING OF AVALANCHE PROTECTION MEASURES USING SNOW DEPTH MAPPING VIA TERRESTRIAL LASER SCANNING

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ABSTRACT: In recent years snow depth mapping via terrestrial laser scanning has become increasingly popular as a measurement method used for snow and avalanche research. Due to technological advancements, it is now possible to measure the spatial snow depth distribution on slopes over an area of 4 km² in a horizontal resolution of 3 cm (at a distance of 100 m), with an accuracy of 5 cm. In this presentation we discuss how the measurement technique was applied to determine the exact positions of permanent, as well as temporary, avalanche protection measures. This includes the positioning of snow fences for snow drift control, the positioning of stabilization structures to control avalanche release and the positioning of blasting devices such as gas explosion tubes or towers from which explosives are ejected. The focus of these investigations lies in the determination of areas with increased snow accumulation due to wind induced snow drift. Locations where such increased snow heights are measured with the laser method and the terrain has a slope inclination exceeding a critical threshold, avalanche releases are to be expected and protection measures should be applied. To precisely determine the most effective position and dimensions of protection measures for preventing or controlling localized snow accumulation on steep slopes, snow depth mapping has been combined with snow drift analysis using basic terrain parameters or wind field modeling to provide additional information regarding the source of the hazardous accumulation to aid decision making. Several case studies in the Austrian Alps are presented and finally the reliability of the presented methodology for positioning and dimensioning of protection measures in alpine terrain is discussed.

1. INTRODUCTION

Terrestrial laser scanning (TLS) is used in this study to measure the variable snow depth distribution within potential avalanche release zones. TLS is an affordable method to gain 3-dimensional high resolution snow height data (Prokop, 2008a; Prokop et. al, 2008; Prokop 2009). Next to the spatial snow height measurements the wind field is modeled to determine the exact positions of permanent, as well as temporary, avalanche protection measures.

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2. METHODOLOGY

The methodology presented is based on the outcome of previous work dealing with the evolution of spatial snow depth distribution on slopes in mountainous terrain (Prokop 2007, Schirmer and Lehning 2011, Schirmer et al. 2011). Analyzing numerous TLS measurement campaigns of the spatial snow height distribution of the same slope it can be concluded that: 1) the snow accumulation patterns over a whole winter season are similar in different years of observation, with variations only in absolute snow depth and 2) single storm events from the prevailing wind direction produce similar snow accumulation patterns as the absolute seasonal snow depth distribution. The existence of a prevailing wind direction at the site is mandatory for these results. For the current study it can therefore be concluded that, if one prevailing wind direction is apparent at an area of interest, the knowledge of the spatial snow depth distribution of even one winter season provides a reliable basis for the planning and dimensioning of constructions as long as the extrapolation for extreme events is included. Therefore the methodology presented contains of 4 parts.

2.1 Meteorological and snow conditions at the test site

An automated measurement stations at the area of interest delivers important data of meteorological and snow condition. Even though this data is measured only at the point the station is positioned, the data is necessary to acquire input data for wind field modeling (or to validate the model) and for the knowledge of snow pack conditions.

2.2 Wind field modeling

As the meteorological station provides wind parameters at the point of measurement only, different methods were used for modeling the windfield. The mesoscale atmospheric model ARPS (Advanced Regional Prediction System) was used for the 3-dimensional modeling of microscale airflow within the test site (Xue et al., 2000a, 2000b). SnowDrift3D was used for analyzing single snow drift events (Schneiderbauer and Prokop, 2011) or simplified we used basic terrain parameters (Winstral et al. 2002) To fulfill the requirements of the work, a resolution of 5 m was found to be sufficient to reproduce the characteristic flow features in the complex terrain (Mott and Lehning, 2010).

2.3 Snow height mapping (terrestrial laser scanning)

For the current study the Riegl LPM-321 (www.riegl.com) laser scanning device was used. For the method of measurement the reader is referred to Prokop (2008) and Prokop (2009). Post processing of the data was done according to Prokop and Panholzer (2009). The resolution of the measurements was higher than 0.3 m (average horizontal point spacing smaller than 0.3 m). The accuracy of the measurements achieved is in a range of 0.1 m, determined by reproducibility tests.

2.4 Extreme value statistics

For the extreme value statistics of the snow height according to Gumbel (1958) snow height data from 5 meteorological stations in proximity to the test areas was used. The data was adapted to the elevation of the test area. The extreme value statistics were done for the 3 days new snow sum and the overall seasonal snow height. The statistical serious was sufficient enough to extrapolate events with a 150 years return period.

3. "THOMASECK AVALANCHE"

The Austrian railways (ÖBB) initiated a risk analysis to determine the potential danger of the Thomaseck-avalanche reaching the ÖBB track Schwarzach St.Veit – Spittal/Millstättersee (Salzburg –Carinthia, Austria) as well as the access road to the Böckstein station (see Prokop and Delaney, 2010).

3.1 Results

The resultant snow distribution can be seen by the snow height maps created from the laser scan data. The two different years of observation delivered very similar results. In the developed area snow bridges cause snow accumulation before and behind those constructions, while steep rock faces within the area present a boarder for snow transport. Snow accumulation occurs on the food of those rock faces (Fig. 1)

Two main types of storm events are visible due to the analysis of the meteorological data of the local weather station. Strong northern winds combined with heavy snowfall deliver the bigger part of snow to the avalanche release area. The second type are southern winds, those are the reason to serious snow drift, but come without snowfall. Therefore they do not deliver important portions of snow to the release area concerning the overall seasonal snow amount

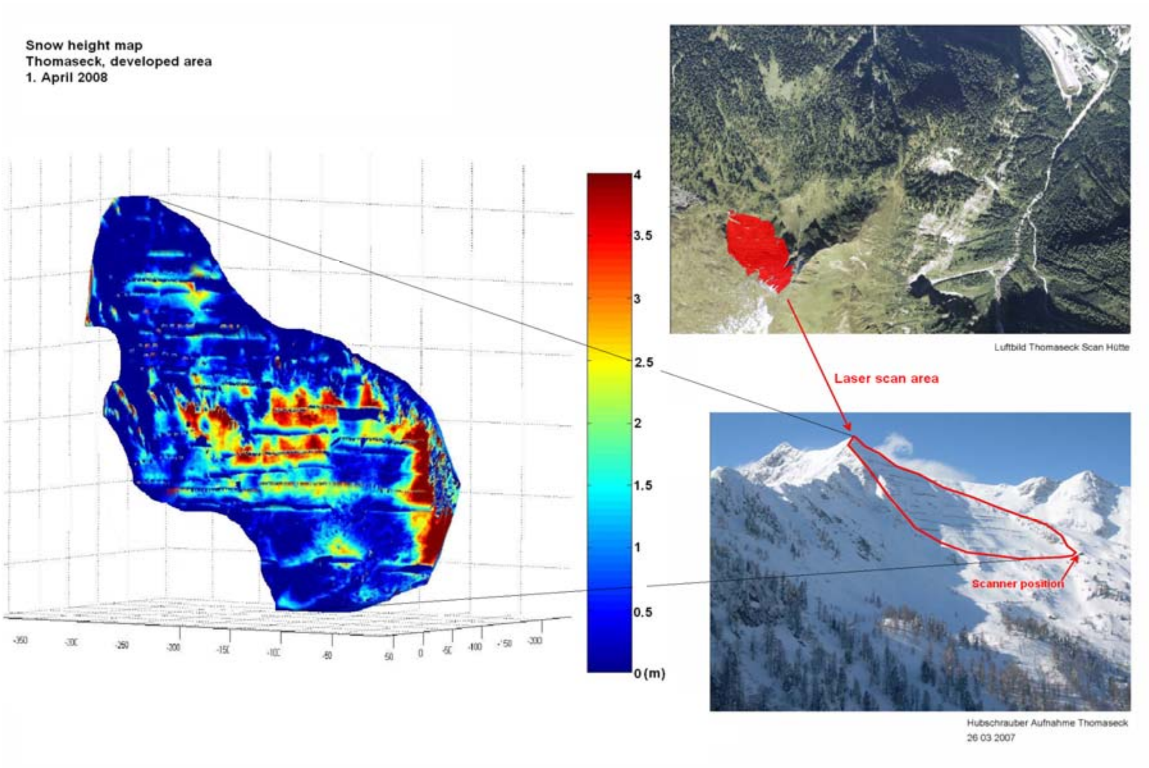

Figure 1: Spatial snow depth distribution according to laser scan data within the developed area at Thomaseck

Comparing the spatial laser scan data with the extreme value statistics it is obvious that the extreme snow height of 5,1 m with a return period of 150 years occurs in reality every year with average seasonal weather conditions in some parts of the avalanche release zone.

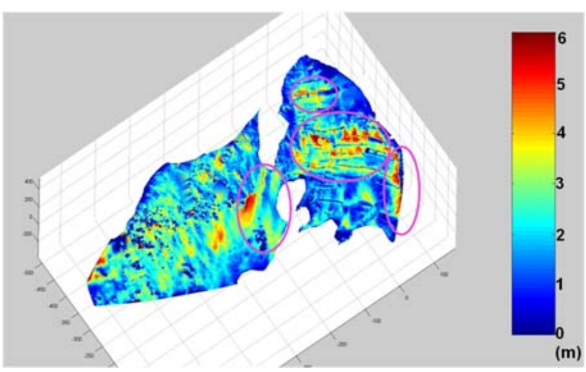

Figure 2: Areas (pink circled) of insufficient protection measures as annual snow heights reach under average winter conditions extreme values.

In other areas wind patterns prevent the accumulation of snow. Even under extreme weather conditions it is not expected to reach the snow height of 5, 1 m. The used high resolution method allows detailed instructions for the design and dimension of protection constructions. Areas where the existing constructions are not sufficient enough and areas where additional constructions are needed could be identified (Fig. 2).

4. "PURTSCHAKOPF" SNOW DRIFT FENCES

The methodology was applied to a project site, which was chosen based on a request by the local authorities to assess the functioning of existing snow drift constructions. The site is located in western Austria in the province of Vorarlberg, district Bludenz. As seen in Figure 3, the topography is steep alpine terrain prone to wind drift events from a prevailing main wind direction. The average elevation is 2300 m. The windward slope of interest has a length of approximately 1 km with an average upward slope of 20°, increasing to 30° in the final 100 m. The ridge is limited in width (8-20 m) and drops off steeply on the leeward side into an avalanche release area that has a width of 120 m and an average inclination of 40°.

Figure 3: Aerial photograph of the topography of the "Purtschakopf" test site. Red dot indicates location of the local meteorological station.

4.1 Results

Figure 4 shows the change in snow depths over the scanning period (red is higher depth or depositional areas, and blue is lower depth or erosional areas; see scale bar). The snow distribution in the fetch area was as expected; eroded areas occurred on the windward side of large and small terrain features, all of which were oriented to suggest erosion by a SW wind. Similarly, deposition was apparent on the leeward side of the corresponding terrain features. There are patterns of extreme erosion on the windward slope as well as high deposition at the windward foot of the fences, corresponding to those patterns seen in the overlapping snow map (Figure 4).

More specifically, the areas of high deposition (red circles) around the top three fences are clearly visible in both image layers, as well as the erosional areas (blue circles) on the immediate windward side and in the gaps between fences. Heavy deposition can be seen around the middle of each fence. Past the upper four fences, this accumulation extends well into the immediate and down slope area of the snow bridges due to the limited depositional extent on the ridge. The snow map reveals a second area of heavy deposition on the far orographic right side of the bridge area. This can be thought of as a "topographical deposition" as it is a function of the steep rise in topography, which obstructs the wind flow and causes a decrease in snow carrying capacity. Snow maps from 1999 and 2003 showed identical depositional patterns, differing only in relative depths.

4.1 Fence re-planning

Some shortcomings in fence functioning were immediately clear upon observation: a) the protection distance is inadequate but will remain so due to topographical limitations, b) over-snowing of the fences occurs in moderate to heavy winters and indicates inadequate fence height, c) gaps between fences create wind acceleration and significant erosion in desired depositional areas, and d) two main areas of inadequate fence functioning lead to direct deposit of drifted snow onto the snow bridges.

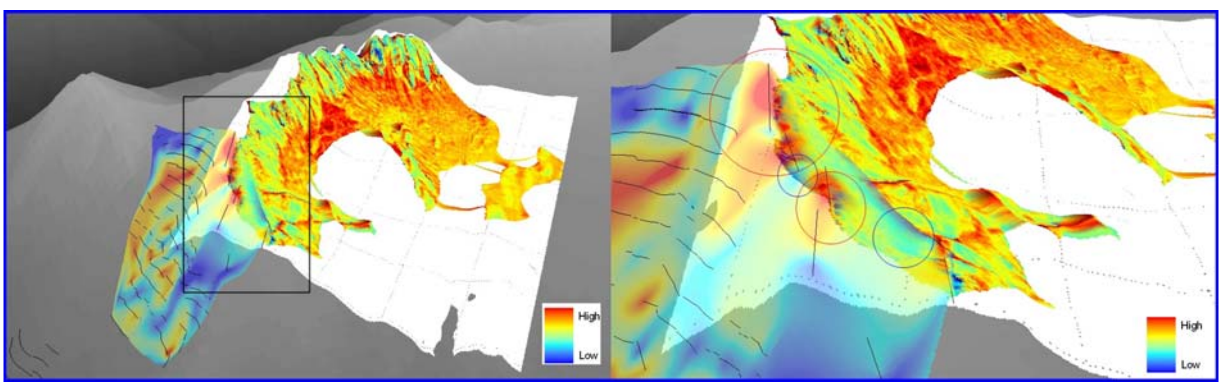

Figure 4. Spatial snow distribution on the ridge and the lee zone. Areas of erosion (blue) and deposition (red) illustrate the functional deficiencies of the fences.

The primary goals of reconstructions, therefore, were to find ways in which to increase the depositional capacity, to encourage a shift in depositional pattern (increased windward and shorter leeward), and to prevent drifted snow from directly reaching the snow bridges. Construction suggestions were kept as realistic as possible and avoided excessive rebuilding.

5. POSITIONING OF BLASTING DEVICES AT THE SKI RESORT LECH AM ARLBERG

The test site is located in Lech am Arlberg (Austrian Alps) and was surveyed using TLS over several years (2005-2010). This site was chosen because the ski resort authorities planed to apply blasting devices due to avalanche activity in the past (Fig. 5). The site represents typical snow-drifted alpine terrain, that is, a prominent ridge with wind-drifted snow accumulations in the lee area that depend on wind direction and speed. Snow depth changes of single storm events as well as absolute snow heights over the whole winter season were recorded.

Figure 5: Slab avalanche at the site "Lech am Arlberg"

5.1 Results

The results of the TLS measuring campaign can be seen in Figure 6. It can be concluded that: 1) the snow accumulation patterns over a whole winter season are similar in different years of observation, with variations only in absolute snow depth (Figure 6C, 6D, 6E, 6F) and 2) single storm events from the prevailing wind direction produce similar snow accumulation patterns as the absolute seasonal snow depth distribution (Figure 6B). The existence of a prevailing wind direction at this site is mandatory for these results.

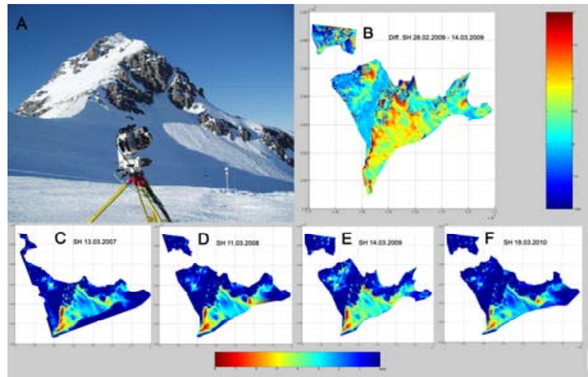

Figure 1. Spatial snow depth distribution at Mohnenfluh: A: Topography of test site and measuring device; B: Snow height changes between 28 February 2009 and 14 March 2009;
C: Absolute snow height on 13 March 2007;
D: Absolute snow height on 11 March 2008;
E: Absolute snow height on 14 March 2009;
F: Absolute snow height on 18 March 2010.

5.2 Planning of blasting devices

The position of blasting towers was chosen according to the results of the TLS snow depth mapping campaign. Trough the high resolution picture of the spatial snow depth distribution it was easy for the operator to define the area of slab release. The cornice at the leeward side of the ridge had to be controlled as well as the snow accumulations at the eastern part of the area.

6. CONCLUSION

In conclusion, this study illustrated that TLS is effective for high resolution snow mapping - erosion and accumulation zones during snow drift events can be defined and maximum spatial snow heights over a complete winter season can be quantified. An adequate description of the site- and year-specific snow accumulation patterns was captured for different study sites and allowed for confidence in the positioning of snow fences for snow drift control, the positioning of stabilization structures to control avalanche release and the positioning of blasting devices.
The presented methodology allows a more detailed picture of the snow cover dimensions at

an avalanche release zone, therefore detailed instructions for avalanche protection measures to authorities could be given.

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