Winter terrain roughness as a new parameter to define size and location of avalanche release areas

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ABSTRACT: Location and size of avalanche release areas are crucial inputs in modelling of avalanche dynamics as, together with fracture depth, they determine the initial avalanche volume. One difficulty in estimating avalanche release areas is that they vary in location and size within the same topographical basin due to variation in snow cover distribution. During the snow accumulation season, terrain features successively disappear leading to increasingly homogeneous deposition patterns during storm events and, thus, to a progressive smoothing of the terrain surface. These changing deposition patterns might therefore explain the differences in release areas. To characterize the smoothing effect of snow on terrain we use the concept of roughness. Roughness is calculated for several snow surfaces and their corresponding underlying terrain. To this end, elevation models of winter and summer terrain are derived from high-resolution measurements performed by airborne LIDAR. The winter datasets correspond to snow cover scenarios with varying snow depths ranging from 1m to 4m. For one scenario, six avalanches were artificially triggered and an additional laser scan was performed after the releases. We show that for both summer and winter surfaces, low roughness values are organized in clusters. Further, the clusters obtained from the snow scenario with avalanches are able to reproduce location and size of the observed release areas.

KEYWORDS: roughness, slab avalanche, snow distribution

1 INTRODUCTION

Location and size of avalanche release areas are crucial inputs in modelling of avalanche dynamics as, together with fracture depth, they determine the initial avalanche volume. The evaluation of release area size is very complex and still typically requires considerable expert knowledge and experience. Existing tools for the automatic detection of avalanche release areas (Maggioni and Gruber, 2003; Bühler et al., 2013) are exclusively based on topographical parameters and are therefore mainly suited for the definition of extreme avalanches whose extents are strongly controlled by topography. These algorithms often fail especially to estimate smaller avalanche release areas that vary in location and size within the same topographical basin.

One reason might be the modification of the terrain surface due to snow cover distribution. During the snow accumulation season, terrain features successively disappear leading to a smoother snow surface. This effect is often discussed in literature together with surface roughness. For a shallow snowpack, terrain roughness can have a stabilizing function hindering the formation of continuous weak layers (Schweizer et al., 2003) as well as providing mechanical support to the snowpack (McClung, 2001; van Herwijnen and Heierli 2009). When the snowpack is deep enough to form a smooth surface, the stabilizing effects of terrain roughness are cancelled out (McClung and Schaerer, 2002). The bed surface of slab avalanches is not the bare ground anymore but the much smoother winter terrain (except deep slabs). At the same time, a smoother surface leads to increasingly homogeneous deposition patterns during storm events (Mott et al., 2010). This facilitates the formation of continuous weak layers and slabs which favours fracture propagation (Simenhois and Birkeland, 2008). This suggests that progressive smoothing of snow surface could partly explain the differences in release area size and location we observe in alpine terrain.

In a recent study, Veitinger et al. (2013) have shown that surface roughness is often persistent in between winter seasons for scales larger than the size of drift features such as dunes or cornices. The study suggests that persistent regions could represent areas where avalanches generally release whereas regions with strongly varying surface roughness may explain differences in release area size.

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The hypothesis we want to put forward in this study is that clusters of low surface roughness may be generally more favourable for avalanche release than clusters with high surface roughness. With increasing snow depth, we expect clusters with low surface roughness to increase in size, allowing the formation of potentially larger release areas. Therefore in this study we compare the spatial organisation of winter terrain roughness to the summer terrain. To this end, elevation models of winter and summer terrain are derived from high-resolution snow depth measurements performed by airborne LIDAR at the Vallée de la Sionne test site. The avalanche test site is located in the south-western part of Switzerland in the canton of Valais, near Sion (Figure 1). We evaluate the ability of winter terrain roughness to define size and location of avalanche release areas by comparing clusters of low surface roughness to measured release zones.

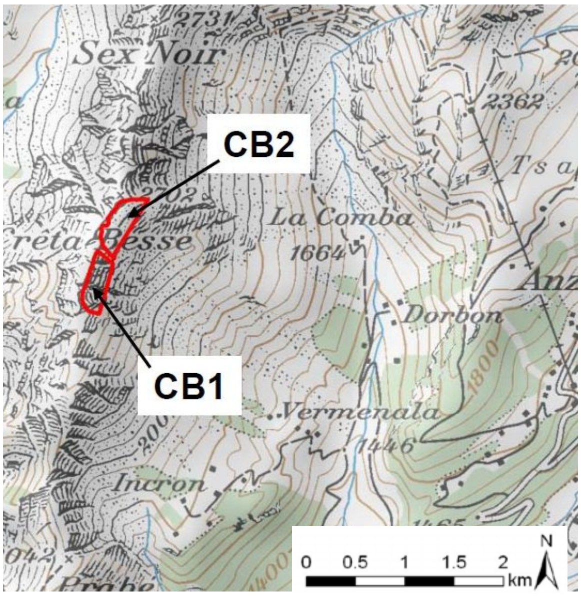

Figure 1. Location of the fieldsite Vallée de la Sionne. In red are marked the two geomorphological different sub areas CB1 and CB2.

2 FIELD SITE AND DATA

At the Vallée de la Sionne test site, the zone of the potential release areas is characterized by elevations between 2300m.a.s.l. and 2679m.a.s.l. and the orientation ranges from E to SE. The site can be divided into two different Basins characterized by distinct topography: Crêta Besse 1 (CB1) is steeper and rougher whereas Crêta Besse 2 (CB2) is less steep and shows a very homogenous terrain surface without major ridges or cliffs (Figure 1). The whole area is steeper than 30° and mean slope varies between 42.4° with a standard deviation of 6.0° for CB1 and 36.2° with a standard deviation of 3.9° in CB2.

At the Vallée de la Sionne, airborne laser scanning (ALS) measurements are performed before and after avalanche events using a helicopter based system and a detailed description of the method can be found in Sovilla et al. (2010). The accuracy of the data is 0.10m. We use elevation models with a resolution of 1m. Three ALS measurements were performed in three different winter seasons. The three scans were taken at significantly different stages of the accumulation season. Table 1 shows the snow cover characteristics of all acquisitions for the basins CB1 and CB2. The scan acquired on the 8 March 2006 can be considered close to the peak accumulation of the winter. The scan of the 25 January 2009 is the result of several snowfalls within the winter season. Both scans show a significantly larger standard deviation. Finally, the scan of the 8 December 2011 was performed after the first significant snowfall of the winter season, and represents a very homogeneous snowpack where little redistribution has taken place.

Table 1. Mean snow depth $\overline{\mathbf{HS}}$ and standard deviation, σ(HS), of laser scan acquistions in the Vallée de la Sionne.

Crêta Besse 1		
Date	$\overline{HS}$	$\sigma(HS)$
(1) 08 Mar 2006	2.71	0.78
(2) 25 Jan 2009	1.36	0.64
(3) 08 Dec 2011	1.39	0.30
Crêta Besse 2		
Date	$\overline{HS}$	$\sigma(HS)$
(1) 08 Mar 2006	3.68	0.61
(2) 25 Jan 2009	2.13	0.62
(3) 08 Dec 2011	1.36	0.23

Further, six dry slab avalanches were artificially triggered on the 8 March 2006 and an additional laser scan was performed after the releases (Figure 2). The triggered slabs consisted of the new snow layer of the previous snowfall period and the slabs were running on the winter terrain previous to the snowfall period. We could observe two large slabs were the fracture propagated over a larger distance within the very smooth parts of CB2 and south of CB1 (#1 and #6 in Figure 2). The slab on the southern end of CB1, despite being small still shows clear fracture propagation (#3 in Figure 2) whereas the other slabs within CB1 were quite small with only very little or no fracture propagation (#3, #4, #5 in Figure 2).

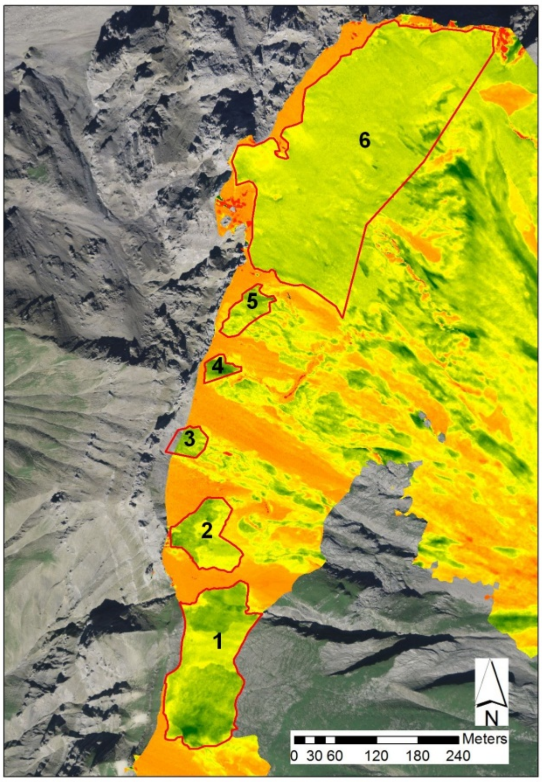

Figure 2. Difference of snow depth before and after artificial avalanche release obtained from the scans of 8 March 2006. The six release zones are also visible

3 ROUGHNESS CLASSIFICATION FOR POTENTIAL RELEASE ZONE DEFINITION

To determine surface roughness of the summer terrain and the corresponding winter surfaces we use the vector ruggedness measure (VRM) of Sappington et al., 2007. Roughness is calculated by taking into account changes of slope and aspect within a 3x3 neighbourhood window of every grid cell. In this study slope and aspect are calculated using the multiscale definition of Wood (1996). This definition allows deriving slope and aspect estimates for different scales. It is thus possible to account for scale by selecting the corresponding slope and aspect estimate in the roughness calculation.

We calculated roughness for the winter and summer terrains at different scales. Figure 3 shows roughness at a scale of 5m for a winter and a summer terrain. We see that the winter terrain is generally smoother. Roughness due to single rocks is smoothed out whereas the larger structures persist. We further observe that larger clusters of low roughness evolve.

To find out if these clusters could potentially define potential release areas we need to have an idea of typical roughness values of a bed surface from real slab avalanches. Therefore we calculated mean bed surface roughness of all observed avalanches. Mean roughness of the bed surfaces ranged from 0.00025 up to 0.0015. The higher values where generally observed in the smaller release zones.

To validate if surface roughness patterns can discriminate the observed release areas from the surrounding areas where no avalanches occurred, we should ideally dispose of a surface model of the snow surface preceding the snowfall period creating the avalanches (corresponding thus to the bed surface of the released avalanches). As this does not exist we assume that the snow surface obtained just before the artificial release is still similar enough to the bed surface to use it for the validation. This can be justified by the still very thick snowpack after the release (between 1.5m and 2m) meaning that the terrain was already quite strongly smoothed. Therefore, in a next step we classified both summer and winter terrains into Potential Release Area (PRA) and No Potential Release Area (nPRA). To discriminate between the two we choose a threshold of 0.001, corresponding to an average upper limit for bed surface roughness. We assigned all pixels exceeding the threshold of 0.001 to the class nPRA, whereas values equal or smaller than the threshold were assigned to the class PRA.

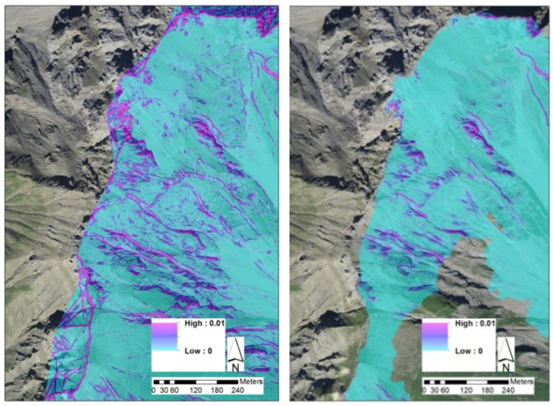

Figure 3. Surface roughness at a scale of 5m of the summer terrain (left) and the winter terrain for the scan of the 8 March 2006 (right).

Figure 4 shows an example of the PRA classification for the winter terrain surface of 8 March 2006 and the summer terrain. We clearly identify significant differences between winter and summer terrain. The area classified as PRA is significantly larger in the winter terrain than in the summer terrain.

We further observe that numerous clusters of small separated areas of low roughness of the summer terrain connect and form larger areas in the winter terrain. These larger areas correspond qualitatively well to the observed avalanche release zones. Most of the observed release zones are classified as potential release areas, especially for the area in vicinity of the crown. Lateral boundaries of the slab are often well reproduced, suggesting that changes of morphology might play an important role in the definition of release area size. However lower parts of the release area are less well reproduced. This can be partly explained by the difficulty to identify the stauchwall within a release area which was not always possible in our data, especially for the small avalanches with little fracture propagation. Therefore, parts of the avalanche flowing zone might have been erroneously integrated in the release area.

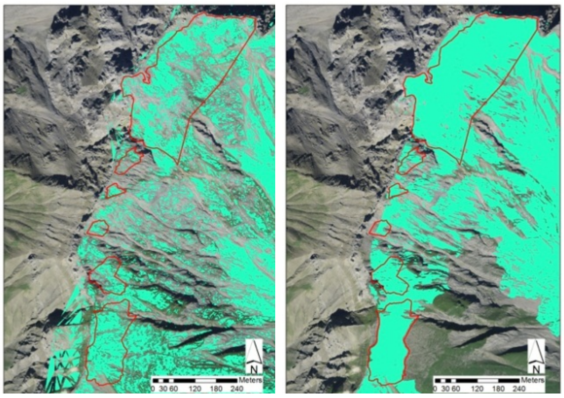

Figure 4. Potential Release Areas (PRA) for bare ground (left) and a smoothed winter terrain (right) are marked in green. In red the boundaries of the slab releases occurred on the 8 March 2006.

5 CONCLUSIONS

Our preliminary results show that the winter terrain surface can serve as a valuable input for a better definition of potential avalanche release areas. Using a roughness parameter we showed that the winter terrain can reproduce to a much better extent release area size and position than the summer terrain. Further our results suggest that a single roughness measure based on changes of slope and aspect might be well suited for a delimitation of potential avalanche release areas. Taking into account the morphological changes of the winter terrain during the accumulation season could thus allow deriving scenarios of different potential release zones as a function of the snow cover distribution.

However this approach has to be strengthened and confirmed with more avalanches occurring under different snow cover distributions also on other field sites. We further note that the mechanical properties of snow also play an important role in defining potential avalanche size and location and are not taken into account in our study. Still we believe that surface morphology has a significant influence on avalanche release.

6 ACKNOWLEDGEMENTS

Funding for this research has been provided through the Interreg project STRADA by the following partners: Amt für Wald Graubünden, Canton du Valais - Service de forêts et paysage, Regione Lombardia, ARPA Lombardia, ARPA Piemonte, Regione Autonoma Valle d'Aosta.

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