LINKING MODELLED POTENTIAL RELEASE AREAS WITH AVALANCHE DYNAMIC SIMULATIONS: AN AUTOMATED APPROACH FOR EFFICIENT AVALANCHE HAZARD INDICATION MAPPING

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ABSTRACT: Snow avalanches are a major threat for people and infrastructure in alpine regions. In Switzerland and other countries in the Alps, long term experience lead to an integral avalanche protection approach covering organizational measures, hazard maps and structural measures such as avalanche barriers or dams. However, in numerous regions around the world reliable hazard maps, combining avalanche cadaster information with terrain analysis, information on snow climatology, numerical modelling and expert knowledge are not yet elaborated because of uncomplete information and high costs. Even in Switzerland, detailed hazard maps with different danger levels only exist for selected areas where people and infrastructure are at high risk. In the canton Grisons, which is entirely covered by mountains, this is only the case for approximately 10% of the total area.

To provide reliable information on potential avalanche hazard in regions without detailed hazard maps, we develop an automated approach combining the delineation of potential avalanche release areas (PRA) with snow depth information and avalanche dynamic simulations. This approach, producing hazard indication maps over large regions for different scenarios (e.g. frequent and extreme), can be applied to any regions where high spatial resolution (2 – 10 m) digital elevation models (DEM) with an adequate quality and snow depth information are available. To assess the significance of the automated approach, we compare the result to detailed hazard maps available in the settlement area of Davos, Grisons, Switzerland where good avalanche cadasters exist. From the preliminary evaluation in collaboration with the canton Grisons, we conclude that the proposed approach has a big potential to produce large scale hazard indication maps, providing valuable first information on potential hazard. This is of particular interest in regions where no or only limited information on avalanche hazard exists, for example if new infrastructure is planned outside the settlement area.

KEYWORDS: Large Scale Hazard Mapping, avalanche engineering, digital elevation model, release area, avalanche mitigation

1. INTRODUCTION

Avalanche hazard maps are today an essential tool for hazard mitigation in Switzerland and most alpine countries. They are based on avalanche cadaster information, terrain analysis, field investigations and numerical avalanche simulations combined by expert judgment (Rudolf-Miklau et al., 2014). However, this approach is very expensive and requires experienced experts as well as good avalanche cadaster information. This is often not available, in particular in developing countries or remote regions.

Hazard indication maps on the other hand provide an area-wide overview of areas possibly affected by extreme avalanches. These maps are on a lower level of accuracy and detail than hazard maps. But they can provide an overview and first hint on potential avalanche hazards where a more detailed assessment is needed. Hazard indication maps should indicate all area potentially endangered by avalanches. Such maps can be generated automatically based on the delineation of potential release areas (PRA) in combination with numerical avalanche dynamic simulations. This was already performed for entire Switzerland based on a 25 meter resolution DEM within the SilvaProtect project finished in 2004 to assess the protective function of forest over the whole Swiss Alps (Gruber and Baltensweiler, 2004).

The availability of high spatial resolution digital elevation models (DEM) also for high alpine areas (Bühler et al., 2012), opens the door for more detailed and accurate PRA delineation and numerical modeling of avalanche flow (Bühler et al., 2011).

Barbolini et al. (2000) and Maggioni and Gruber (2003) started investigations to automatically delineate PRA with DEM resolutions from 25 to 30 meters. With the availability of higher spatial resolution DEMs refined algorithms were developed (Barbolini et al., 2011; Bühler et al., 2013; Chueca Cía et al., 2014; Pistocchi and Notarnicola, 2013; Veitinger et al., 2016). The validation of the algorithm performance is very difficult as meaningful reference data is scarce. But qualitative and partially quantitative assessments of the results indicate a good quality.

These recent algorithms were only connected with numerical avalanche dynamics simulation at selected avalanche tracks and were not used to produce large scale hazard indication maps.

Bühler et al. (2018) connect automatically delineated PRA with RAMMS numerical avalanche simulations (Christen et al., 2010) to produce a spatially continuous hazard indication map for a large region.

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In this paper we give an outline of these results.

2. METHODE

2.1 Potential Release Area (PRA) delineation

As base for the PRA delineation we use the SwissALTI^{3D} DEM with an original spatial resolution of 2 meters provided by swisstopo. We resample the DEM to a spatial resolution of 5 meters and derive the following derivatives for the analysis:

- Slope angle
- Aspect sectors
- Plan curvature
- Ruggedness (Sappington et al., 2007)
- Fold (Schmudlach and Köhler, 2016)

We combine these layers with a binary forest layer to feed an object based image analysis (Blaschke, 2010) processing tree. We produce two scenarios:

- Frequent, with smaller PRA corresponding to a return period from 5 – 30 years (Figure 1a)
- Extreme, with large PRA corresponding to a return period from 100 – 300 years (Figure 1b)

2.2 Calculation of release depth (d0)

To perform numerical avalanche dynamics simulations, we need to estimate the average release depth of every individual PRA to calculate the avalanche release volume. We apply the procedure developed by Salm et al. (1990) that is operationally applied to generate avalanche hazard maps in Switzerland. We calculate d0 individually for every PRA based on three days snow depth increase (ΔHS3) measured at nearby observation stations with an observation period of more than 80 years. We automate this process in a python script. In the future more detailed and spatial continuous mapping of snow depth distribution based on remote sensing (Bühler et al., 2016; Bühler et al., 2017; Bühler et al., 2015) may help to refine these assumptions.

2.3 Numerical avalanche dynamics simulations

In a next step we perform an individual avalanche simulation with RAMMS for every single release polygon applying the standard friction values for the respective scenario. For the simulations we apply the DEM resampled to a spatial resolution of 10 meters. To handle the large amount of data generated and to efficiently calculate a high number of simulations we developed RAMMS::LSHM (Large Scale Hazard Mapping). We run the software on a high-performance computer with 56 cores and 256

GB RAM. With this infrastructure the calculations for the region of Davos (480 km^2) takes about 8 hours. In the end we combine all avalanche simulation into one layer for maximum pressure and one layer for maximum flow height by taking the maximum value reached at every grid cell in all simulations. To be able to document from which release zone the values originate, we generate individual outline polygons of every simulation.

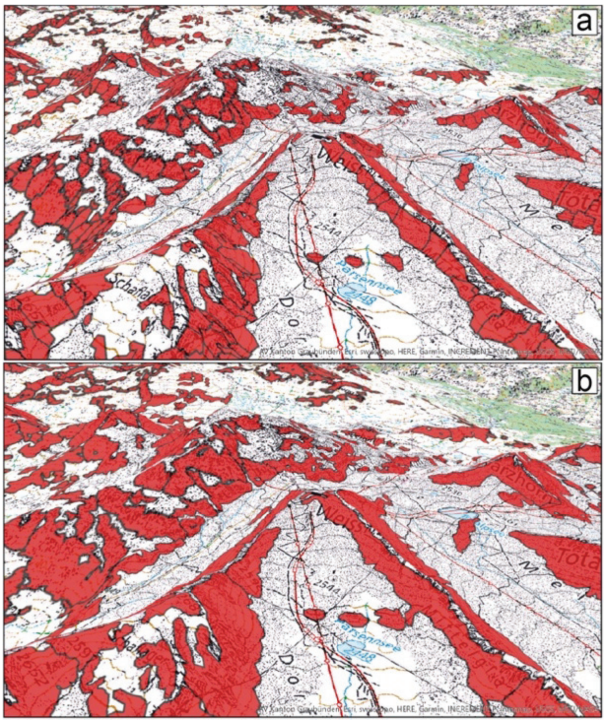

Figure 1: Results of the automated PRA delineation (Bühler et al., 2018) for the scenarios frequent (a) and extreme (b). Pixmaps©2018 swisstopo (5704 000 000), reproduced by permission of swisstopo (JA100118).

3. RESULTS

The simulation results for the region of Davos (500 km^2) for both scenarios are illustrated in Figure 2. For the scenario frequent there were more than 35’000 simulations with a mean release volume of 4’000 m^3 and for the scenario extreme more than 8’000 simulations with a mean release volume of 42’000 m^3.

In the high-alpine region of Davos, the results suggest that a large part of the area is potentially endangered by avalanches. This applies for 60% of the total area in the scenario frequent and even for 80% in the scenario extreme (threshold max. pressure > 1 kPa).

Comparisons between the simulation results of the scenario extreme and official hazard maps, generated by qualified engineering offices, show in general a good agreement but show distinct differences, which we explain in (Figure 3).

The hazard maps are only generated for selected areas, where buildings or other infrastructure is at high risk because they are costly. All other areas are not considered. For the high-alpine canton Grisons in Switzerland only about 10% of the area are covered with official hazard maps. The hazard indication maps on the other hand are spatially continuous and provide information on potential avalanche hazard for the entire area. At the location of difference 1 in Figure 3 no hazard zones were established.

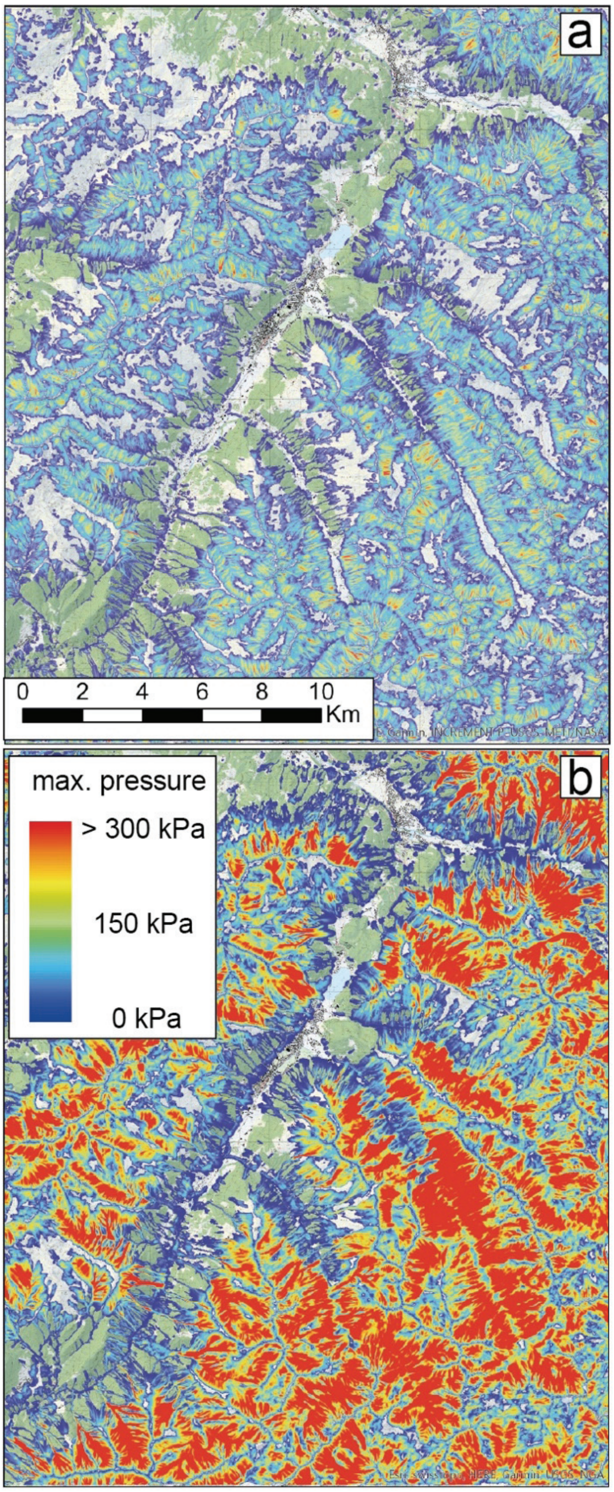

Figure 2: Simulation results for the region of Davos, Switzerland for the scenario frequent (a) and extreme (b). Pixmaps©2018 swisstopo (5704 000 000), reproduced by permission of swisstopo (JA100118).

However, there are some reports of large avalanches occurring at this location several decades ago. Today the relevant release zones are partially covered by light forest. This is an example how hazard indication maps could serve as second opinion to indicate locations where the elaboration of a hazard maps should be considered.

Existing mitigation measures such as avalanche barriers or dams are not considered for the automated simulations. This is the case for the Guggerbach avalanche (difference 2 in Figure 3) where a large catching dam is installed in the gully that is not considered properly in the automated simulations. It has to be discussed if and how layers with mitigation measures could be included into the automated process in the future. In the Bildjibach avalanche track on the other hand the hazard map goes further than the simulations (difference 3 in Figure 3). This is because the avalanche flows through a very narrow gully where the friction values for the simulations are hard to determine and the hazard maps also consider the impact of powder avalanches, which are not considered in the simulations. Further multiple avalanches during winter which can cause a lateral deviation of the avalanche flow are not considered in the avalanche hazard indication map. These examples illustrate that the determination of the reliability is very challenging especially for the extreme scenario.

4. CONCLUSIONS

Automated avalanche hazard indication mapping, combining delineation of potential release areas with numerical avalanche simulations proofs to be a powerful tool to generate spatially continuous maps over large areas such as regions or even entire countries.

The comparison with existing avalanche hazard maps and avalanche cadaster information reveals a good agreement. Large differences occur if mitigation measures are present that are considered in the hazard maps but not in the automated procedure. Other large differences occur if the automatic determined PRA are in big difference to the PRA determined by expert judgment caused by considering additional information such as avalanche history, snow distribution in winter or simultaneous release of neighboring release areas. Also the choice of the release depth can lead to disparities. The influence of large snow drift accumulations only considered as lump-sum in the automated approach.

The consideration of the forest and its effect on avalanche release and avalanche flow also leads to differences. An additional evaluation of the products is performed in Aosta valley by Maggioni et al. (2018). Furthermore, the algorithm was applied for the terrain classification maps for Switzerland described in Harvey et al. (2018).

Based on the defensive assumptions (release area size, release depth, friction values) the results of the extreme scenario can be taken as a hazard indication map but are clearly not an official hazard map because important elements such as field verification and expert validation are missing.

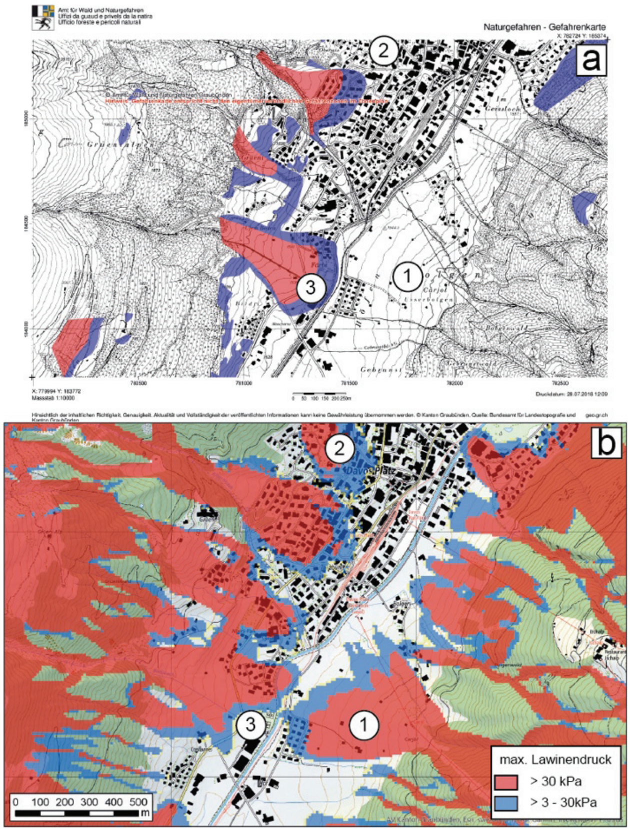

Figure 3: Comparison of the simulation results (b) with the official hazard map for Davos Platz (a), Switzerland. Pixmaps©2018 swisstopo (5704 000 000), reproduced by permission of swisstopo (JA100118).

The big advantages of the automated hazard indication maps are its low costs for generation (time and money) and the spatial continuity. In particular in regions where no hazard maps exist, such information is very valuable for example if new infrastructure is planned.

Currently we apply the algorithms in projects in Grisons CH, Trentino IT (Monti et al., 2018), Chile and Afghanistan in close collaboration with local and SLF avalanche experts. These applications are important to validate and further improve the products. The approach presented in Bühler et al. (2018) and in this paper opens the door for hazard indication maps wherever high spatial resolution DEM data is available and estimations on potential release depth can be calculated.

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