Quantifying the influence of forest and snow characteristics on avalanche protection of forested slopes

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Motivation for this project and overall objectives.

Forests act to stabilize the snow cover and prevent destructive avalanches from releasing. Trees can stop the granular snow flow by a combination of processes: impact followed by jamming, resulting in a sudden and local dissipation of flow energy behind trees or tree groups (Feistl et al. (2014)). The forest structure is then key to allow the mass deposition behind trees.

In spring 2018, a protection forest in the region of Les Diablerets caught fire. Even before the fire, the area was evaluated to have an elevated risk of avalanches, reaching the residential area including a house. A reevaluation of the natural hazard after the fire is therefore crucial.

Until now, all snow avalanche modeling has been carried using state-of-the-art numerical solution methods, by which the forest can only be modeled using an homogeneous friction coefficient, lacking the necessary detail to model the forest canopy structure (tree clusters, trunk diameters, crown coverage, etc.) and its effect on the avalanche behaviour.

This research proposes a novel method allowing to simulate both the release and flow of the avalanche at the slope scale and the interaction between the snow and the forest at every individual tree.

The overall objectives of the research are to implement the Material Point Method (MPM) to evaluate and understand of how forests protect against avalanches and what parameters determine its protective role. In a second step, the findings will be applied to model the real slope in Les Diablerets and evaluate whether the avalanche hazard has increased after the forest fire.

Research questions that you will address / addressed outlining the novelty of your work with regard to previous work.

The avalanche response variables (runout distance, front velocity and released snow) are expected to be strongly dependant on the forest structure. As aforementioned, all previous work has been carried with depth-averaged avalanche equations. In this research, it is proposed to implement the Material Point Method (MPM) as a potential novel approach to model forest and avalanche interactions at a slope scale with an unprecedented level of detail. This method will be first applied in an experimental framework to understand the underlying processes and afterwards in the real case study in Les Diablerets. The research aims to answer the following questions:

1. To what extent do the forest parameters (clustering index, crown coverage, presence of forest) and snow types (friction, cohesion, plastic deformation, compressive strength and tensile strength) have an effect on the release and flow of the avalanche?

2. By how much has the avalanche risk increased after the forest fire in Les Diablerets?

Research methods that you plan to use.

The avalanche protection role of the forest will be first investigated with an experimental setup. The findings will then be applied to the case study in Les Diablerets. Both experiences will be carried out using the MPM model.

The aim of this research is first to assess protection quality of forests by means of avalanche simulations within an experimental framework, implementing the Material Point Method. The protection quality shall be measured by the residual natural risk associated with different forest structures for different types of snow. Analyzing both release and runout of experimental avalanche events in controlled and replicable setups, will allow to test the influence of different parameters and identify the critical ones.

The experimental setups will include 3 different types of snow and 4 forest structure configurations with the same tree density: an ordered tree distribution typical of past afforestations, a random tree distribution characteristic of a forest developed after natural regeneration, and a clustered tree stand as described to optimize the protective function. An additional case without trees will be modelled as control. The avalanche response variables will be modeled as a function of time to evaluate the time-dependant avalanche behaviour of the different configurations. The maximum velocity and the values of the runout distance and percentage of released snow at the end of the simulations will be used to describe the response of the avalanche with single values. To rigorously verify the statistical significance of the forest parameters and snow type effects on the release and flow of the avalanche in the experimental framework, statistical tests will be performed.

In a second step, the simplified set-ups investigated in the experimental framework will be adapted to the case study, implementing the results of the terrain and canopy analysis. The effect of the forest structure will be investigated comparing the avalanche release and runout in the slope with trees and without trees.The effect of the forest fire will be modeled with the real forest configurations before and after the fire, namely different tree densities and release areas, previously characterized with remote sensing data.

The understanding of the influence of different forest parameters in the avalanche behaviour derived from the experimental framework, together with the increased risk evidenced in the case study, will allow for an informed decision-making as part of the eventual risk protection measures that will have to be implemented in Les Diablerets.

Discussion of generalizability of research findings and realisticness of investigated system / problem (external validity).

The described methods will permit to generalize the results to additional cases of similar characteristics to those of the modeled canopies (alpine forests with stand densities of 500 trees/ha, coniferous species such as *Picea abies*, *Abies alba* or *Pinus sylvestris*, and snow types as the ones tested), ensuring the validity of the methodology in future avalanche hazard evaluations.

The realisticness of the investigated system will be assured with the case study, including the calibration of the model with past observations on-site and the comparison with the evaluations carried out in the same zone by the group Vaud-Risques under the mandate of the Canton of Vaud in 2015, and the discussions with their team of experts.

Anticipated societal impact of research findings.

Widespread drying as a result of climate change is driving an increase in forest fires around the world. By the end of the 21st century, Switzerland is expected to experience many more fires than it does today. According to experts, the worst-affected areas will be the Aare valley and lowland areas of Bern Canton. Moderate increases are predicted in Ticino Canton and the Engadin, while larger areas of Valais Canton will likely be set ablaze. These fires could compromise the forest protective role, consequently increasing the avalanche hazards and the entiled socio-economic consequences.
The Swiss law obliges the cantons to evaluate and map the natural hazard to serve as basis for decision making in spatial planning. Proving the powerfulness of this novel method to model forest and avalanche interactions at a slope scale, will greatly enhance the precision of the avalanche hazard models and optimize the reforestation practices (spatial distribution of trees) to minimize the risk and resources allocated to this concern, including territorial planning, risk prevention and protection, and potentially saving lives.