Accounting for forest effects in avalanche models and risk analysis

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INTRODUCTION

Mountain forests are an effective, economic and ecologic mitigation measure against snow avalanches. Depending on forest structure and terrain characteristics, the probability of avalanche releases is strongly reduced in forested terrain and their runout distances may be shortened (Bebi et al., 2009). In spite of their importance for risk reduction, the effect of different forest types and forest structures has rarely been considered in avalanche models and risk analysis. During the past years, several studies and well-documented observations of avalanches in forested terrain have improved our knowledge on avalanche-forest interactions (Teich et al., 2012; Teich et al., 2014; Feistl et al., 2014)

The aim of this contribution is to synthesize the existing state of research on avalanche-forest interactions towards practical applications. Specifically we address the following questions:

- What are the effects of forest structure and surface roughness on avalanche release and runout distance?
- How do these effects vary depending on topographical settings and snow/avalanche properties?
- How can we account for the effects of different forest properties in avalanche models and risk analysis?

OBSERVATIONS

An analysis of more than 60 avalanche releases in forested terrain (including open forest and gaps with widths <50 m) allowed us to investigate under which conditions avalanches are released and how they decelerate in forests. Forest structural parameters had a significant effect on runout distances of small- to medium-scale avalanches (< 10‘000 m^3) which released in forested terrain, but forest structure had little effect on runout distances of large-scale avalanches (>=10‘000m^3) which started more than approx. 200 m above the treeline (Teich et al., 2012).

The deceleration of small- to medium-scale avalanches could be parameterized by extracting snow from the avalanche (detrainment). Snow is stopped and accumulates behind trees. This process was implemented in the avalanche simulation-software RAMMS and was evaluated by back-calculating well-documented past events and field observations of mean deposition heights in forests (Teich et al., 2014). The amount of snow detrainment depends on forest structural parameters, the cohesive properties of snow and on the associated avalanche velocity. Stem density and diameter, tree species, and increased ground surface roughness were identified to be crucial forest parameters which could be assessed with remote sensing methods and/or additional field data and implemented into RAMMS-simulations (Feistl et al., 2014).

AVALANCHE-FOREST INTERACTION: CASE STUDIES

The application of the detrainment approach is limited to small to medium scale events where trees remain standing after avalanche impact. In contrast, a classical friction approach (where the frictional resistance parameter is adapted) may still be more appropriate where avalanches break, uproot, overturn and entrain trees. A detailed representation of forest structure in avalanche models however allowed the calculation of scenarios of forest cover, management interventions and natural disturbances. Forest structure induced surface roughness (e.g., availability of tree regeneration, stumps or logs) are of particular importance for the release of glide snow avalanches, because their formation depends on the basal friction which changes with vegetation covers. By calculating the required threshold strain rate for failure of the snowpack below the release area (Stauchwall) we were able to model glide-snow

avalanche releases and required basal friction values for typical vegetation patterns which were evaluated based on field data. This enabled to define the required surface roughness to prevent glide-snow avalanche release for a certain slope angle and forest gap length.
We demonstrate the applicability of these relationships using three specific case studies, representing different topographical and forest structure settings and different snow and avalanche properties:

1. A case of a small-mixed-flow avalanche situation in the Bavarian Alps (Fig. 1).
2. A case of glide snow avalanches in Davos.
3. A case of a large and destructive avalanche including broken stems near Zernez.

These three case studies demonstrate that forest effects in release and runout zones of avalanches depend not only on forest and terrain characteristics but also on the avalanche flow regime. Forest effects depend for example strongly on the cohesion of the snow and are reduced for light, cold and cohesionless snow. While trees can break from the loading exerted by the powder cloud of a dry flowing avalanche even if the density and therefore the impact pressure is relatively small, slow moving wet snow avalanches that only affect the stem, exert bending stresses that are high enough to cause widespread damage. Predicting forest destruction - and the potential decelerating and stopping effects of the forest - therefore require consideration of the avalanche flow regime.

CONCLUSIONS

There is generally a great potential for better representing forest structure in avalanche simulation models and risk analysis, but we have to carefully distinguish between different settings given by topography, forest structure, the avalanche flow regime and the assumed return period (e.g., 300 years vs. 10 years event).

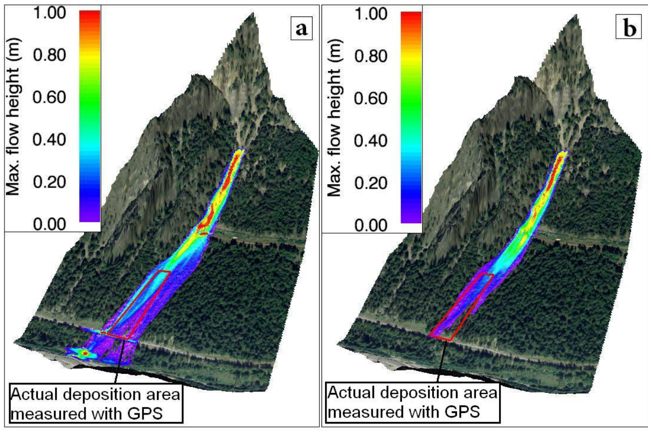

Figure 1. Avalanche simulation of a small-medium dry avalanche (1400 m^3) in forested terrain with the classical friction approach (a) and with the new detrainment approach (b). The runout distance calculated with the detrainment approach corresponds well with the observed deposition area (red); the runout zone calculated by the classical friction approach underestimates the forest effect in this case.

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KEYWORDS

avalanche-forest interactions; avalanche models; protection forest; forest structure; avalanche flow regime

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