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Snow and weather conditions fostering avalanche releases in forests: Rare situations with decreasing trends during the last 41 years

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Snow avalanche formation is a complex interaction between terrain, snowpack and meteorological conditions. So far, research on meteorological contributory factors focused mainly on avalanches in open unforested terrain, since the occurrence of avalanches in forests is not primarily a meteorological phenomena. Furthermore, mountain forests play a crucial role in avalanche control by preventing avalanche formation. The main effect of forests is the modification of the snow's mechanical properties and, therefore, the reduction of forming unstable continues snow layers. Nevertheless, snow avalanches may occur in forests and these so-called 'forest avalanches' are important disturbances that affect mountain ecosystems and can pose hazard to human settlements and infrastructures. Therefore, an improved understanding of snow and weather conditions which increase the probability of forest avalanche releases could be highly valuable for avalanche warning and forest services.

We present a comprehensive analysis of snow and weather conditions fostering avalanche releases in forests and their potential changes during the last decades. We applied a hierarchical clustering method based on 21 snow and weather variables in order to best reproduce the potential underlying structure in our dataset on 189 observed forest avalanche events. Two types can be defined: Type 1 avalanches are 'new snow forest avalanches' releasing in periods of heavy snowfall (3-day new snow sum > 50 cm) and under stormy (3-day maximum wind speed > 17 m/s) and permanently cold conditions (1-, 3- and 5-day mean air temperature < 0°C). They mainly occur in open coniferous forest at the upper treeline at elevations above 1700 masl and are concentrated on north-exposed slopes. Forest avalanches of type 2 ('old snow forest avalanches') tend to release at all expositions below 1700 masl after periods of high insolation (5-day sum of sunshine duration > 240 min) and an increase in air temperature. Snow and weather conditions of type 1, but not of type 2 avalanches, are rare and clearly distinguishable by classification trees from those of avalanches released in open unforested terrain. In the next step, we analysed if the occurrence of these two typical snow and weather situations did change during the last 41 years (1970/71-2010/11). Therefore, we counted the number of days between November and May where forest avalanches are likely to occur using data of 14 snow and weather stations which are well distributed regarding the different climatic regions of the Swiss Alps. Then, we used logistic regression to test for long-term trends in the occurrence of favourable conditions for forest avalanches at each station. The number of days with meteorological conditions which foster the occurrence of new snow forest avalanches decreased at 11 stations during the last 41 years; also trends for old snow forest avalanches are negative at 12 stations independent from altitude and climatic region.

The past negative trends in the occurrence of snow and weather conditions which foster forest avalanche releases suggest a further decrease under a changing climate. Nevertheless, such events will also occur in the future and the presented combinations of meteorological parameters could support avalanche warning and forest services in forecasting forest avalanches.