AUTOMATED IDENTIFICATION OF FOREST WITH PROTECTIVE FUNCTION AGAINST SNOW AVALANCHES IN THE TRENTO PROVINCE (ITALY)

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ABSTRACT: Forests have a very significant protective function against the impacts of natural hazards. Identifying the protective forests is therefore of crucial importance in order to define proper technical and silvicultural measures able to maintain or improve their function. The active mitigation function of the forests could completely prevent the triggering of an avalanche; otherwise, the passive function (i.e. increasing the friction of the snow mass while moving) is quite limited or null in case of large sized events. In this work, an automated approach for avalanche hazard mapping is used for identifying the forests playing a protective role in avalanche risk mitigation in the Trento Province (Italy). A digital elevation model with a spatial resolution of 5m was used for the terrain classification; a layer identifying the forested areas was calculated by combining a forest map with the information derived from a canopy height model; the climatic snow cover characteristic, necessary to define the fracture heights, were derived by analysing the data of 53 manual weather stations, which have a recorded dataset longer than 17 years. The potential release areas were automatically defined with an algorithm for a scenario with and one without forest. The fracture heights were defined depending on the micro-climatic area and the elevation of each avalanche release area. Then, the avalanche dynamics model RAMMS was applied to simulate the avalanche tracks and deposition areas for an extreme scenario with a return period of approximately 100-300 years. By comparing the results obtained considering both the forest effects and not, the forests playing an active function for avalanche risk mitigation were identified. Even if we considered an extreme scenario only in which the forests playing a passive protection role have small effects, the passive protection forests were still accounted for hazard indication mapping. The obtained results show the applied automated approach is a big help for large-scale identification of the protection forest. Especially in this period of strong climate changes, both the forest cover and snow cover characteristics can change rapidly; thus faster approaches for their evaluation are even much needed. Even if automated approaches are less precise than an expert based hazard map, they are significantly less expensive both money and time - wise, therefore more suitable to be applied on large areas such as for an entire province.

KEYWORDS: snow, avalanche, dynamics, hazard mapping, protection forest.

1. INTRODUCTION

Mountain forests have a very significant protective function in avalanche protection (Brang et al., 2006). Forest conditions affect avalanche disturbances and, on the other hand, avalanche occurrences are the most important disturbance that affects mountain ecosystems (Bebi et al., 2009). Forest structure is a key factor limiting what is habitable in large areas of the Alps or not (Bebi et al., 2001). The active mitigation function of the forests could completely prevent the triggering of an avalanche (Bebi et al., 2009); otherwise, the passive function (i.e. increasing the friction of the snow mass while moving) is quite limited or null in case of large sized events (Teich et al., 2012).

Measures for mitigating the avalanche risk range from the installation of active and passive avalanche protections to regional planning in order to avoid building where there is an avalanche hazard. In the same way, forest management in prone to avalanches mountain landscapes has the

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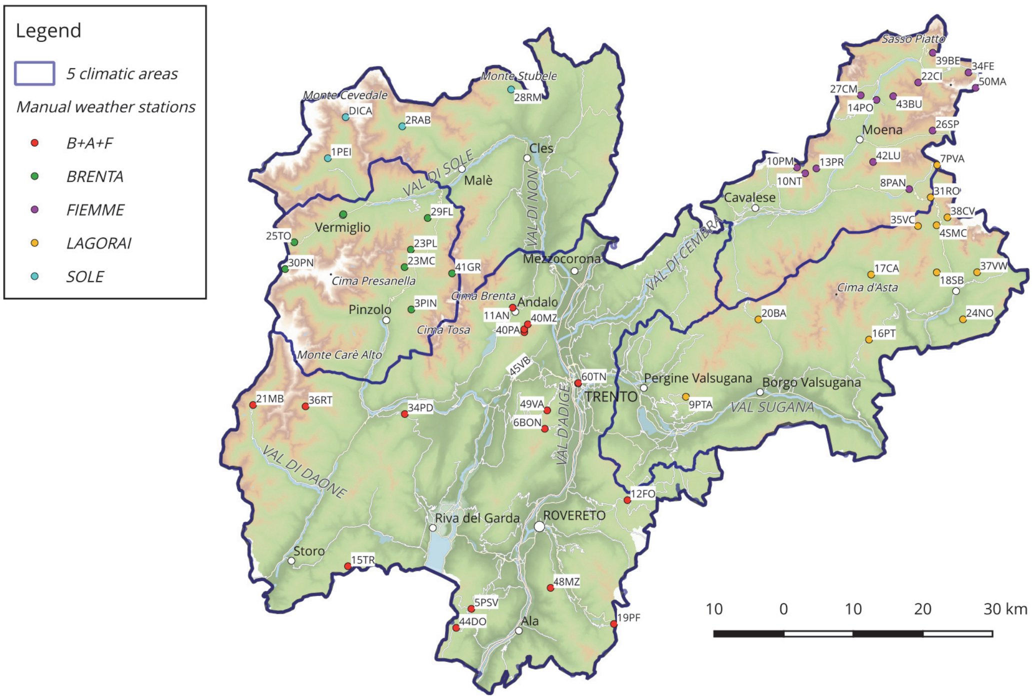

Figure 1: Area of the Provincia Autonoma di Trento split into 5 micro-areas. The respective MWS are showed as well: Bondone – Stivo – Paganella + Adamello Sud – Tremalzo + Prealpi – Piccole Dolomiti – Folgaria (B+A+F); Brenta – Tonale (BRENTA); Valle di Fiemme e Fassa (FIEMME); Lagorai – Primiero (LAGORAI); Val di Sole – Peio – Rabbi – Rumo (SLE).

potential to be an effective avalanche risk mitigation approach (Teich and Baby, 2009). Identifying the protective forests is therefore of crucial importance in order to define proper technical and silvicultural measures able to maintain or improve their function.

Hazard maps show the hazard degree based on the frequency and intensity of avalanches (Bühler et al. 2018) and have the potential to precisely identify the forest with protective function. Their elaboration is very demanding with respect to time and expertise and are usually only applied to investigate very defined and critical situations (Gruber and Margreth, 2001). Even if hazard indication maps are less detailed and accurate than hazard maps, they can give a spatial continuous overview on avalanche hazards based on numerical simulations over large regions (Bühler et al. 2018) and have the potential to be the better tool to identify the forests playing a protective function against avalanche over large areas. First approaches combining automated release are identification with numerical avalanche dynamic simulations have already be performed in 2004 to assess the protective functions of forest within the SilvProtect project in Switzerland (Gruber and Baltensweiler 2004)

In this work, a new automated approach for avalanche hazard mapping is used for identifying the forests playing a protective role in avalanche risk mitigation in the Trento Province (Italy).

2. DATA

To define the fracture depths, the climatic snow cover characteristics of the Province were derived by analysing the data from 53 Manual Weather Stations (MWS) located in the Trento Province (Figure 1). These data range from winter season 1981/82 to 2017/18 (only the CARESER MWS (DICA) has data since the winter season 1934-35). A digital elevation model with a spatial resolution of 5m was used for the terrain classification; a layer identifying the forested areas was calculated by combining a forest map, updated with aerial pictures collected in 2017, with the information derived from a canopy height model (1 m of resolution).

3. METHODS

3.1 Snow cover analysis

By analysing the snow cover data and interacting with the technicians of the Trentino avalanche-forecasting centre, the Province was divided into homogeneous micro-climatic areas. For each micro-climatic area, the estimation of the fracture depth was derived by analysing the yearly maximum snow depth increase within 3 consecutive days (ΔHS_3) of each MWS (Salm et al. 1990). The regional analysis were performed by applying the *index flood procedure* consisting of the combination of the Generalized Extreme Value distribution (GEV) and, to calculate the probabilistic distribution parameters, the *station year* approach (Kite, 1998; Cunnane, 1989; Maione and Moisello, 1993: Hosking and Wallis; 1197, Lu and Stedinger, 1992). The elevation correction was calculated for each micro-climatic area by performing linear regression between the maximum ΔHS_3 of each MWS versus the relative elevation. In this work, only the values representative of the extreme scenario, with a return period of approximately 100-300 years, were used. Finally, to transform the ΔHS_3 derived at the flat field into the inclined slope of the release area the same approach proposed by Bühler et al. (2018) was applied.

3.2 Forest coverage

The province raster showing the areas covered by forests was refined by excluding the areas in which the forest height was lower than 2 meters and the canopy coverage lower than 50% following the Swiss guidelines (Frehner et al., 2005). The canopy coverage was derived by analysing the LIDAR raster with a window size of 10 cells (10m resolution).

3.3 Identification of the potential snow avalanche release areas (PRA)

The PRA were obtained by applying the algorithm proposed by Bühler et al. (2018a and b) based on object based image analysis (OBIA). The DEM derivatives taken into account with this approach were: i) the slope angle; ii) aspect; iii) roughness; iv) curvature and v) fold. At first, OBIA were performed without accounting the forest coverage in order to identify the PRA in a completely forest-free scenario (PRA_{NOF}). Finally, the forest coverage was accounted as binary value (forest/no forest) in order to obtain a PRA scenario closer to the actual one (PRA_F).

Table 1: Coulomb (μ) and Turbulent (ξ) friction parameters used for RAMMS simulations.

Volume categories	μ	ξ
Tiny (< 5000m^3)	0.275	1500
Small (5000 – 25000 m^3)	0.235	2000
Medium (25000 – 60000 m^3)	0.195	2500
Large (> 60000 m^3)	0.155	3000

3.4 Numerical avalanche dynamic simulations

The RAMMS::AVALANCHE software (Christen et al., 2010), adapted for automatically process large number of release areas, was applied for identifying the avalanche paths and deposit areas. Depending on the different PRA sizes, different friction parameter sets were used for running the model (Table 1). This set-up is the same applied by Bühler et al. (2018a and b).

4. RESULTS

4.1 Snow cover analysis

The snow cover analysis helped identifying 5 homogeneous climatic areas (Figure 1). By performing the regional analysis, for each micro-climatic area, the ΔHS_3-normalized values (Figure 2), for return periods ranging to 300 years, were derived. Which, combined with the ΔHS_3 values extrapolated for the different elevations (Figure 3), were used as input values for the OBIA to calculate the fracture depth of each PRA.

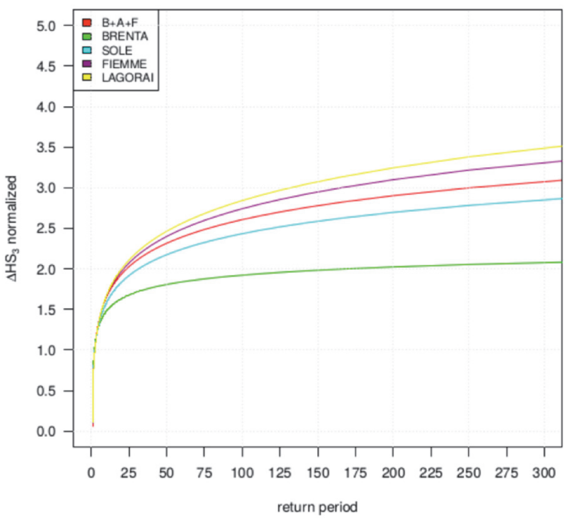

Figure 2: t (return period) versus ΔHS_3 normalized values. Colours represent the 5 MWS micro-climatic areas.

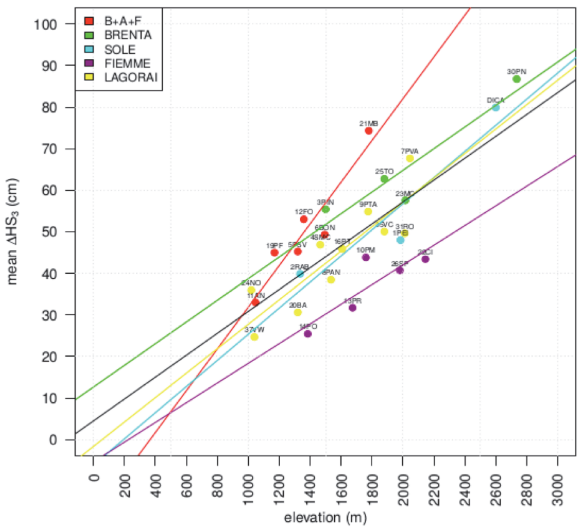

Figure 3: for each MWS with at least 17-winter season data, the mean value of the yearly ΔHS_3 maximum values is plotted versus the respective MWS elevation. Colours represent the 5 MWS micro-areas. The 6 straight lines are the linear regression on the whole dataset (black) and on the 5 different subsets. The R^2 of each subset are: *i)* R^2_{B+A+F}: 0.8883; *ii)* R^2_{Brenta}: 0.8712; *iii)* R^2_{Sole}: 0.8846; *iv)* R^2_{Fiemme}: 0.5761; *v)* $R^2_{Lagorai}$: 0.7623; *vi)* R^2_{Tot}: 0.5545.

4.2 Identification of the forest with a protection function

By comparing PRA_{NOF} and PRA_F, the forests actually playing an active protection function against avalanche releases were identified (Figure 4). Moreover, by overlapping these areas with the layer representing the forest with canopy coverage lower than 50%, the forests with the potential to turn into a protection forest with proper silvicultural measures were highlighted (Figure 4). Finally, by comparing the RAMMS simulations obtained starting from PRA_F to the forest coverage layer, the forest playing an actual passive protection function was identified (Figure 5).

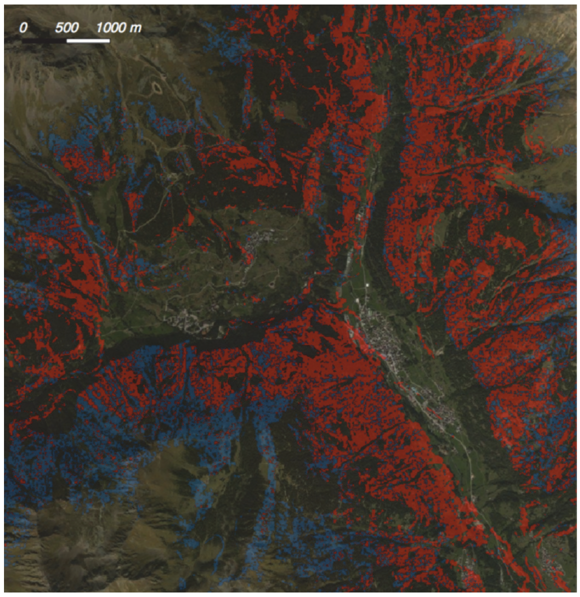

Figure 4: example from the area of Peio of the active protection forest detected by comparing PRA_{NOF} and PRA_F (red). In blue, the forest whit a low canopy coverage for being classified as protection forest.

5. CONCLUSIONS

The obtained results show the automated approach for hazard indication mapping can be successfully adapted for large-scale identification of the protection forest. Moreover, by accounting the potentially exposed assets, the protection forest

Figure 5: 3D model (Dx) showing the forest of the picture (Sx) classified as active protection forest (dark red) and passive protection forest (light green).

can be discriminated in function of its risk mitigation importance. Finally, the obtained map can provide useful information for mountain sylviculture and forest planning.

Especially in this period of strong climate changes, both the forest and snow cover characteristics can change rapidly. These approaches are less precise than an expert based hazard map but, at the same time, are significantly less expensive both money and time-wise. Therefore, they can be more easily updated for accounting changing natural conditions.

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