Snow avalanches under climate change in the Ukrainian Carpathians

Kholiavchuk, Dariia; Zelenchuk, Volodymyr
Yuriy Fedkovych Chernivtsi National University, Chernivtsi, Ukraine

Introduction

- Due to the combination of air temperature increase and precipitations shifting from solid to liquid, the seasonal snowline reaches higher elevations, and the snow season gets shorter; thus, the snow-avalanche regime is affected in all mountain ranges.
- Over the last decades either lower number of occurrences of snow-avalanche events at high altitudes and a higher one at lower altitude have been documented.
- An increasing number of warming and extreme precipitation events have contributed to the intensification of snow avalanches in subalpine areas as witnessed by the studies in the Himalayas, Alpine Region, Rocky Mountains.
- Warming air temperature in winter and early spring has favoured the wetting of snow and the formation of wet snow avalanches, which are able to reach down to subalpine slopes, where are located the anthropogenic infrastructures, therefore prone to cause damage.
- Over Ukrainian Carpathians, which have a high predisposition to snow avalanches, the snow covers got limited attention in the literature.

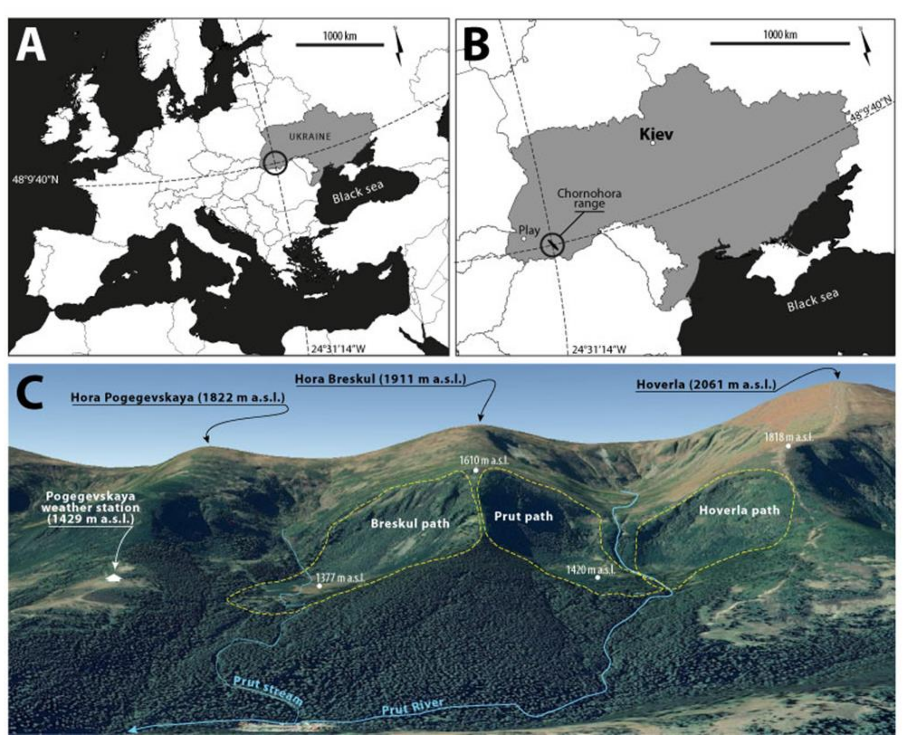

Figure 1. Location of the study area: in Ukraine (A), Chornohora range (B) is investigated on the north-eastern facing slope of the main eastern Chornohora massif range, in between Hoverla and Breskul Peaks (C), where three snow-avalanche paths are investigated (image GoogleEarth 3d, October 1, 2017)

- In the Ukrainian Carpathians, the most eastern mountains in Europe, snow avalanches are changing the vertical distribution of mountain ecosystems, triggering disturbance of forest ecosystems. Chornohora massif in the Ukrainian Carpathians prone to snow avalanches in subalpine regions and the most popular touristic winter destination is considered (Fig. 1).
- The study aims at attributing snow avalanche activity and runout distribution in the Ukrainian Carpathians because of climate change.

Methods

To interpret the climate change impact on snow avalanches in the area, the number of evidences is addressed:
1) hydrometeorological data from two weather stations Play and Pogegevskaya adjacent to Breskul path in the years 1961-2015. Daily weather data (raw data, average and extremes of temperature, precipitation, wind, and snow cover) and stationary snow-avalanche observations are available from the Pogegevskaya weather station (1429 m a.s.l.);
2) historical data of snow avalanche events from Snow avalanche cadaster of Ukraine over the period of 1967-2012 in the Ukrainian Carpathians, and in the Prut River upper catchment (Fig. 2).
3) evidence provided by the forest and touristic services and narratives from local residents;
4) tree-ring records. Field observations enabled to identify typical signs of disturbances (tilted and/or wounded stems, uprooted and/or topped trees, topped crown) on the spruce trees bordering due to the mechanical impact caused by snow avalanches. Dendrogeomorphic sampling involved a total number of 242 trees (Fig.3).

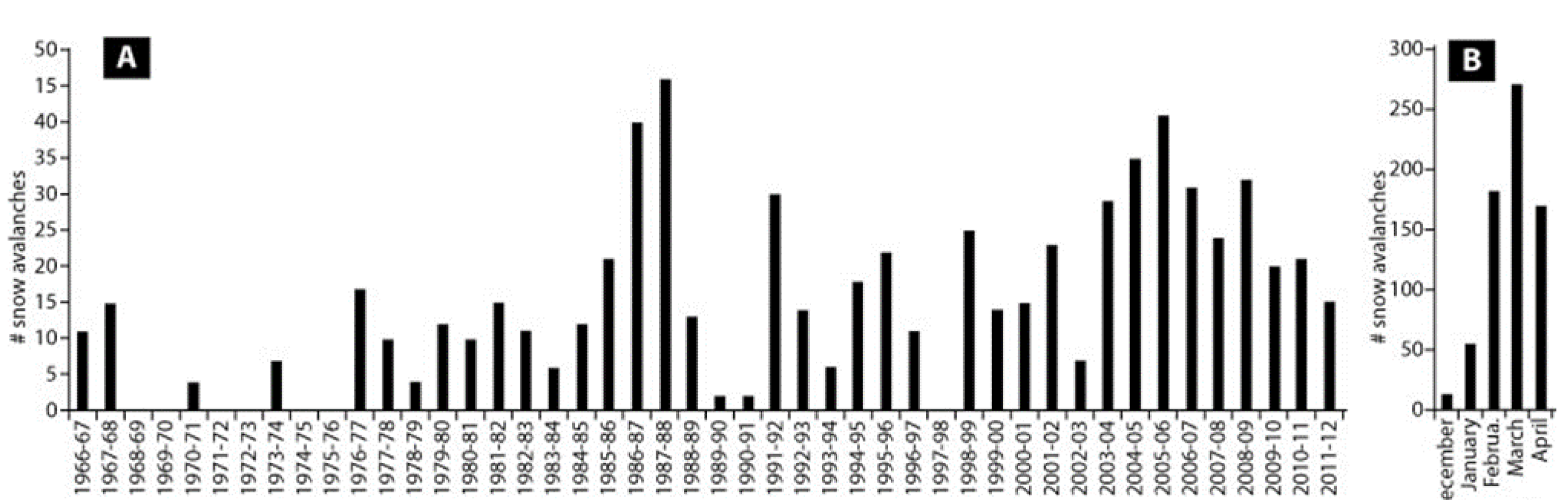

Figure 2. Historical chronicles of snow-avalanche events observed within the Prut upper catchment (A), and monthly snow-avalanche distribution (B) over the period 1966-2011

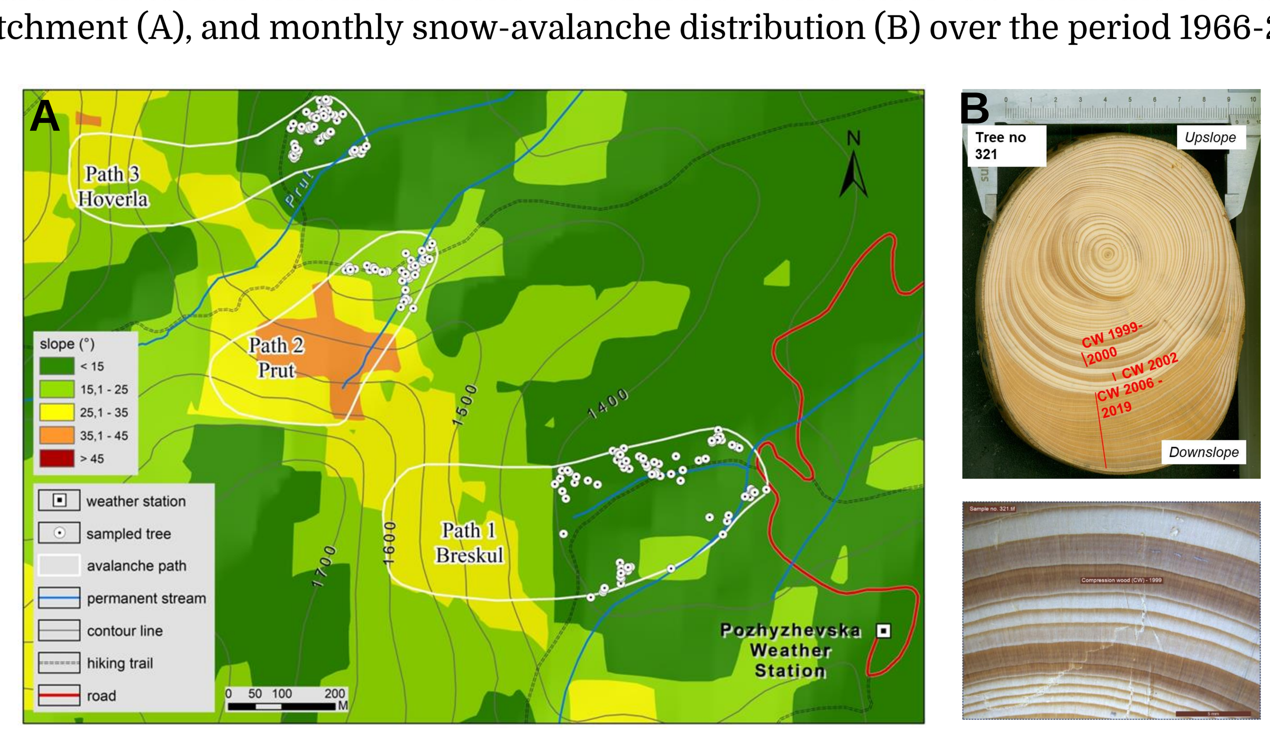

Figure 3. Location of sampled trees in Breskul, Prut and Hoverla snow-avalanche paths(A); disturbed sample of Picea abies (B)

A spatio-temporal reconstruction of the avalanche winters, the calculated return periods the Avalanche Activity Index (AAI) for each year have been finally obtained for the avalanche paths. The avalanche winters extracted from the AAI results were correlated with synoptic events and 50 monthly climate variables (1961-2015) using multiple regression.

Results

The tree ring reconstruction points to several winters with snow avalanches impacting the trees over the period 1902-2018 (Fig. 4).

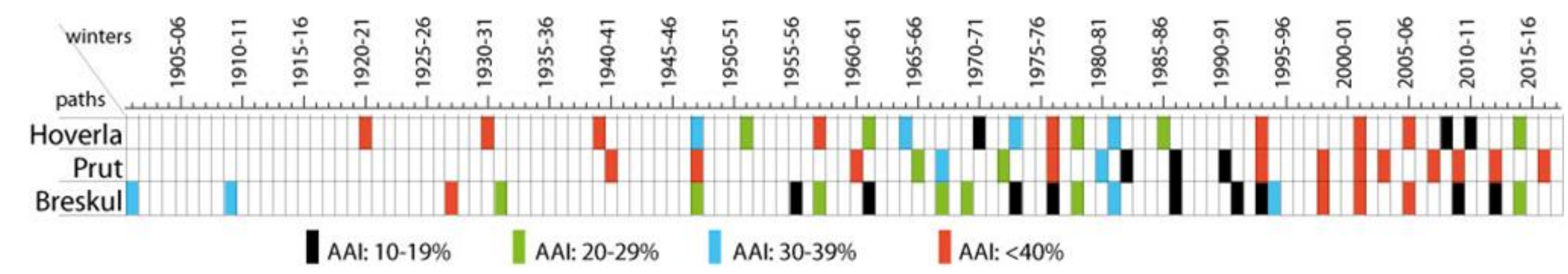

Figure 4. Avalanche winter distribution over time within the three investigated paths, highlighting common activity.

The clear snow-avalanche signals in the dendrologic records enables mapping their maximum runouts over the four main winters common to the three paths (Fig. 5), distinguishing, from the set of living trees at these times, those that were impacted. In all cases, the more distal trees show disrupted tree-ring patterns, indicating that snow avalanches had reached long runout distances during these four winters.

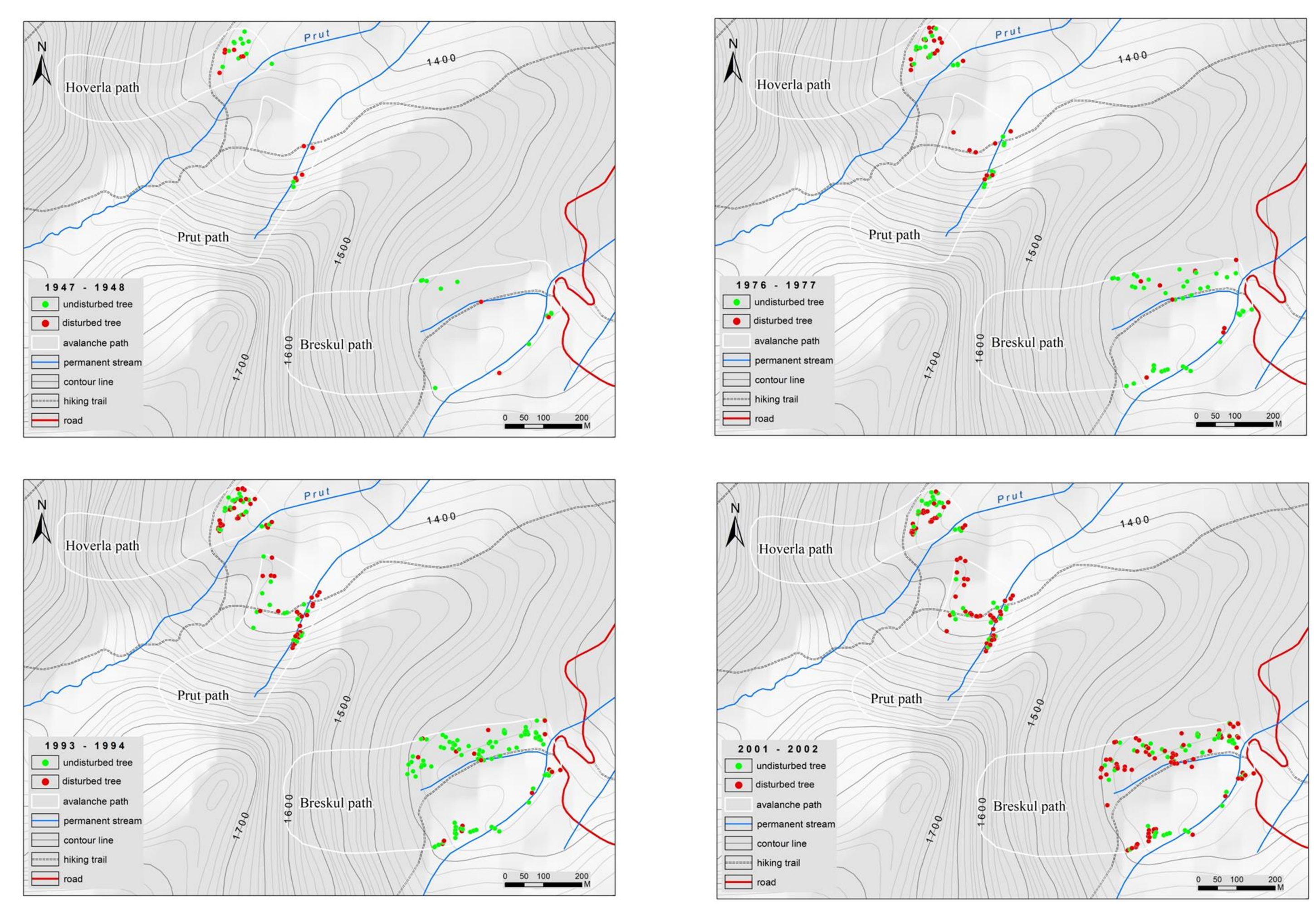

Figure 5. Maps of reconstructed extent of snow avalanche by dendrologic data during the four main winters (1947-48, 1976-77, 1993-94, 2001-2002) that snow-avalanche activity was recorded in the three paths investigated.

The variables retained by the regression allowed the identification of scenarios for the occurrence of major avalanches. Factors favourable to the occurrence of major avalanches are:
1) the presence of very heavy rainfall at the beginning of the avalanche season (Days with ppt> [AV (ppt) + Ppt SD] nov).
2) destabilisation of the snow layer in February by passing the temperatures above the threshold of 0 o C (No. of consecutive days with T med> 0 ° and snow> 5 cm feb).
3) maintaining a consistent layer of snow in April (Snow days ↑> AV (snow ↑) + snow ↑ SD Apr).
The unfavourable factors:
1) maintaining a medium-thick layer of snow over a long period of time in January (Snow days 50-60 cm in January).
2) the presence of very hot consecutive days at the beginning of the avalanche season which can lead to the melting of the snow layer (Days with Tmax> [AV (Tmax) + 2 * TmaxSD)] apr).
3) High average temperatures in March can lead to melting snow (Tmed apr).

Conclusions

- Snow avalanches that are the most intense in forest damages and extensive in the runout distribution are distinguished in the first decade of the 21st century. This is the time when the climate change shift to warming was detected in the area.
- February, March, and April are the most common months when avalanches were detected, especially in the last two decades when precipitation is insufficient in the other cold months.
- Under the permanent temperature increase in the area the avalanche series in the last two decades are triggered by the long-lasting combination of temperature increase, snow accumulation, snowfall with windy weather.
- In the 21st century snow avalanches are related to the north and west cyclonic weather types bringing excessive precipitation and finally ending with the penetration of southwestern anticyclonic weather and warm spell.
- Increase in the occurrence of wet-snow avalanches associated with intensive precipitation and warming episodes that are related to the south-western cyclonic circulation patterns is found.
- Events derived from tree-ring data coincide with the detected snow avalanches reaching 1250-1400 m taking place in February –March with warming episodes
- Abrupt warming events with the temperature increase 1°C per hour has become the dominant snow avalanche trigger in March-April.

Acknowledgements

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