

## Winter types and snow avalanche activity along the Arpaş and Bâlea glacial valleys - Făgăraş massif (Southern Carpathians)

Mircea Voiculescu<sup>1</sup>, Alexandru Onaca<sup>1</sup>, Patrik Chiroiu<sup>1</sup> and Dana Micu<sup>2</sup>

<sup>1</sup>West University of Timișoara, Department of Geography, Timișoara, Romania,  
Bdul Vasile Pârvan, 4, 300223-Timișoara, Romania

<sup>2</sup>Institute of Geography of the Romanian Academy, 12 Dimitrie Racovita, Bucharest, Romania

**ABSTRACT.** This paper discusses the correlation between winter types and snow avalanche activity, in the Arpaş and the Bâlea glacial valleys, located on the northern slope of the Făgăraş massif - Southern Carpathians (Romanian Carpathians). The high altitudes, the massiveness and the harsh climate represents a great attraction for winter tourism activity. According to Sibiu Mountain Rescuer Public Service statistics (founded by Ministerial Decision 140/1968), between 1968 and 2011, in Bâlea glacial were recorded 40 fatalities and 42 burials/injuries.

The thermal variability of winters was calculated in order to obtain Winter Standardized Index. Between 1979 and 2011, were recorded 15 normal winters or 46.9%, 10 cold winters or 31.3%, 6 warm winters or 18.8% and only one very cold winters or 3% of total. To reconstruct the past distribution of snow avalanches we used dendrogeomorphological method and we set Avalanche Activity Index (AAI). We sampled and we collected 232 samples from 116 trees (*Picea abies*) in ARP1 stand (Arpaş glacial valley), 88 samples from 44 trees (*Picea abies*) in BLC1 stand and 70 samples from 35 trees (*Picea abies*) in BLC2 stand (Bâlea glacial valley). We have also determined three types of snow avalanche in our study area, small snow avalanches (AAI  $\geq$  10%), major snow avalanches (AAI  $\geq$  20%) and large snow avalanches (AAI  $\geq$  30%).

We can conclude that the majority of snow avalanches occurred in normal and cold winters.

**KEYWORDS:** winter types, snow avalanches, Arpaş and Bâlea glacial valleys, Făgăraş massif, Southern Carpathians, Romanian Carpathians

### 1 INTRODUCTION

Snow avalanches are common geomorphic processes and also natural hazards that occur in alpine and subalpine mountain environments (Strunk, 1991), have major impacts about human settlements and infrastructures (Fuchs, Bründl, 2005; Fuchs et al., 2005; Jamieson and Stethem, 2002; Stethem et al., 2003; Voiculescu, 2009), on human life and affects the skiing industry in particular (Höllner 2007, 2009; Keiler, 2004; Keiler et al. 2005; Stethem et al., 2003).

Snow avalanches represent an unquestionable reality in the Southern Carpathians - Romanian Carpathians. The highest incidence of a snow avalanches is recorded in Făgăraş massif, where the terrain factors, the climate and winter tourism practices, determine an important snow avalanche activity.

Therefore, the Mountain Rescuer Public Service was set according to Ministerial Decision 140/1968. This service is administrated by district councils and have the role to registers all types of mountain accidents including damage from snow avalanches and to prevent survey, coordinate and organize mountain rescues. Later, in 2004-2005 was founded the Programme of Nivometeorology within the National Administration of Meteorology (PN-NAM). The PN-NAM has one Bâlea Work Nivometeorology Laboratory in the Făgăraş massif, at 2070 m. The main purpose of PN-NAM is to study snow and its future evolution as well as snow avalanche triggering conditions and issuing bulletins on snow avalanche risk.

According to Sibiu Mountain Rescuer Public Service and Bâlea Work Nivometeorology Laboratory, between 1968 and 2011, were recorded 40 fatalities and 42 burials/injuries only in Bâlea glacial valley.

Our aim is: (i) to reconstruct of snow avalanche chronology in Făgăraş massif (Southern Carpathians) using the dendrogeomorphological method using Avalanche Activity Index (AAI); (ii) to determine the type of winter where snow avalanches have the greatest occurrence using Winter

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*Corresponding author address:* Mircea Voiculescu, West University of Timișoara, Department of Geography, Bdul Vasile Pârvan, 4, 300223+Timișoara, Romania;  
tel: +40256592117; fax: +40256592224;  
email: mircea.voiculescu@cbg.uvt.ro

Standardized Index (WSI) and (iii) to highlight the relationship between the magnitude of snow

avalanches and type of winter.

## 2 STUDY AREA

The Făgăraș massif (2544 m) is located in the Southern Carpathians (45° 30' N; 24° 30' E) (Figure 1) and is a huge ridge 70-80 km long with an east-west orientation from which two macro slopes detach - the northern and the southern one. The Făgăraș massif has the highest massivity and the highest altitudes in all of the Romanian Carpathians (Moldoveanu - 2,544 m and Negoiu - 2,535 m). They also show the most important inherited glacial relief and very active periglacial processes. Our study area is

represented by Arpaș and Bălea glacial valleys, located in the central glacial sector of the Făgăraș massif, on its northern slope (see Figure 1). The high peaks of the Făgăraș massif are an important orographic obstruction, disrupting the paths of moist air currents coming from both the northwest (maritime influences) and the west (cold arctic influences), and creating conditions for abundant snowfall on the northern slopes. The climate is harsh, characterized by a long cold season (8-9 months/year with a snow layer) (Table 1), there is a permanent snow avalanche risk.

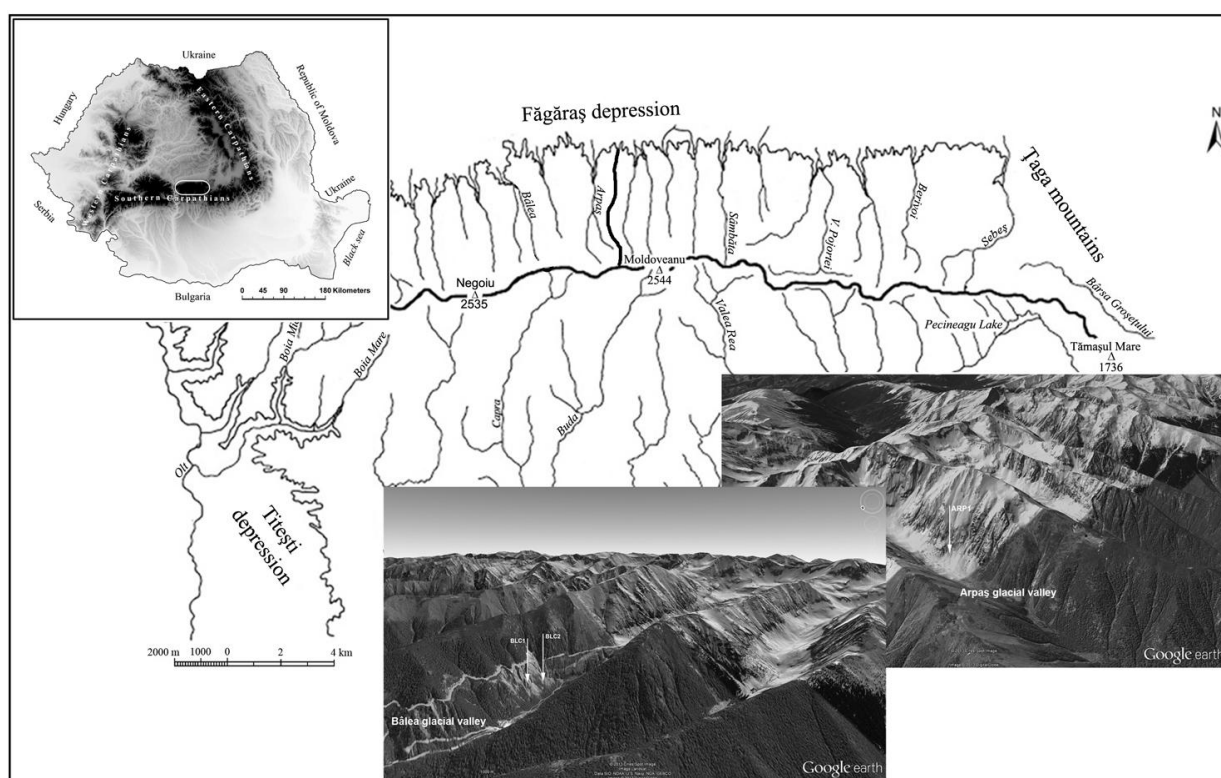


Figure 1. Location of the Făgăraș massif and of our study area

Table 1. Patterns of climate in our study area

Weather station (m)	Lat. N	Long. E	T°C			Pp (mm)	Air humidity (%)	Days with snow	Days with snow cover	Snow depth (cm)	Sunny days while there is snow cover
			Ann.	Min.	Max						
Bălea Lake-2070	45°36'	24°37'	0.2	-8,4	8,8	1246,2	83	> 96	> 224	66.4	40-45

## 3 METHODOLOGY

### 3.1 Winter Standardized Index

Considering that the high snow avalanche activity occurs in cold winters (Castebrunet et al., 2012; Corona et al., 2012) we use Winter Standardized Index (WSI):

$$WSI = (t_i - t_{mean}) / \sigma, \text{ where}$$

$t_i$  is the mean winter temperature (°C),  $t_m$  is the mean multi-annual winter temperature (°C) and  $\sigma$  is the standard deviation

Using a classification grid (Table 2), and according to Micu (2009) we calculate the thermal variability of winters (DJF), based on the study of mean temperatures from December to

February, or the Winter Standardized Index (WSI), for Bâlea weather station, between 1979

and 2007.

Table 2. Winter severity classification grid

Winter type	Mean temperature winter (°C)	Winter Standardized Index values
very warm	> 0.5	> 1.5
warm	-1.3, ..., 0.5	0.5 – 1.5
normal	-3.1, ..., -1.3	- 0.5, ..., 0.5
cold	-4.9, ..., -3.1	-1.5, ..., -0.5
very cold	< -4.9	< -1.5

On the other hand and according to several authors (Butler and Sawyer, 2008; Casteller et al., 2012; Decaulne et al. 2012; Germain et al., 2009, 2010; Luckman, 2010; Muntán et al., 2004; 2009) we used dendrogeomorphological method to reconstruct the past distribution of snow avalanches, to determine the snow avalanche activity area, and to analyse the magnitude of snow avalanches in our study, we

used a dendrogeomorphological method, applied with great success in the world to examine this type of natural hazard (Butler and Malanson, 1985a, 1985b; Butler and Sawyer, 2008; Decaulne and Sæmundsson, 2008; Decaulne et al. 2012; Germain et al., 2009, 2010; Luckman, 2010; Mundo et al., 2007; Muntán et al., 2004 2009; Szymczak et al., 2010).

### 3.2 Sampling strategy and sample analysis

Therefore, we sampled trees and we collected with a Haglöf increment borer 232 samples (with Ø 5.15 mm and various heights) from 116 trees (*Picea abies*) in ARP1 stand (Arpaş glacial valley) and 88 samples from 44 trees (*Picea abies*) in BLC1 stand and 70 samples from 35 trees (*Picea abies*) in BLC2 stand (Bâlea glacial valley), respecting recommended minimum 20 trees/snow avalanche path (Decaulne et al., 2012; Hebertson and Jenkins, 2003). We obtained also the coordinates (longitude, latitude and altitude) of the sampled trees, using a GarminGPS76CSx. The increment cores were analyzed following the standard dendrogeomorphological procedures described

by Bräker (2002) and Stoffel and Bollschweiler (2008). The counting of the tree rings and the measuring of tree-ring widths were performed with a digital LINTAB measuring device connected to a Leica stereomicroscope and to TSAP WIN software (Rinntech, 2006). All the samples were then analyzed visually in order to capture growth disturbances (GD): reaction wood (RW), callus tissue (CT), tangential rows of traumatic resin ducts (TRD) and abrupt growth decrease (AGD). For TRD and CT we determined the precise location of the damage within the annual tree ring to distinguish between snow avalanche and other geomorphologic processes (e.g. rockfalls). Therefore we considered only the TRD located at the beginning of the earlywood.

### 3.3 Reconstruction of snow avalanche chronology

All the GD's assigned to snow avalanches were used to build the event response histogram and to calculate the avalanche activity index (AAI with values from 0 to 100%), for each year t, based on the percentage of tree responses (R) in relation with trees alive in year t (Shroder, 1978, Germain et al., 2009, Corona et al., 2010, 2012):

where  $R_t$  is the response of a tree to an event in year t and  $N_t$  is number of living trees in that year. According to several studies (Corona et al., 2010, 2012; Decaulne et al., 2012; Germain et al., 2009, 2010; Reardon et al., 2008), we considered that an event with  $I > 10\%$  and with a minimum number of ten impacted trees represents a major snow avalanche.

$$AAI = \left( \sum_{t=1}^n R_t \right) / \left( \sum_{t=1}^n N_t \right) * 100$$

## 4 RESULTS

### 4.1 Winter severity classification

To determine winter severity classification we used meteorological data from Bâlea weather station, between 1979 and 2011. According to Castebrunet et al. (2012) and Corona et al. (2012) who suggested that most of the high

snow avalanche activity occurs in cold winters because "warm winter spells destabilize the snowpack, leading to the positive contribution of  $T_{max}$  excesses".

Using data from the Bâlea weather station between 1979 and 2007 we obtained the

classification of the winters: 15 normal winters or 46.9%, 10 cold winters or 31.3%, 6 warm winters or 18.8% and only one very cold winters or 3% of total were recorded (Figure 2).

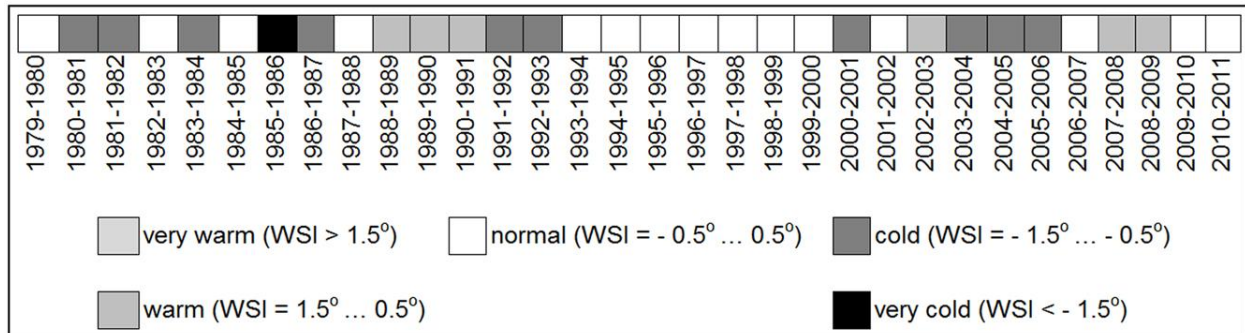


Figure 2. The thermal variability of winters (DJF) over the 1979-2011 period, in terms of Winter Standardized Index values

#### 4.2 Spatial extent of past events

The analysis of the all samples, enabled the following snow avalanche activity: 115 years (between 1896 and 2011) with 1896 representing the oldest and 2011 the most recent years with evidence of avalanche-based disturbances in ARP1 stand, 43 years (between 1968 and 2011) with 1968 representing the oldest and 2011 the most recent year with evidence of avalanche-based disturbances in BLC1 and BLC2 stands.

The distribution of sample trees showing growth disturbances following snow avalanches allows the reconstruction of past events. The spatial extent of past events within the snow avalanche tracking zone suggests in our study area the activity of three major types of snow avalanches.

In the ARP1 stand, 63 event-winters with snow avalanche activity were identified between 1896 and 2011 (Figure 3). 39 event-winters had an AAI < 10% (20 event-winters in the monitored period by PN-NAM, Bâlea WNL), 15 event-winters or small snow avalanches (1912, 1915, 1920, 1935, 1942, 1945, 1950, 1964, 1967, 1977, 1979, 1992, 1998, 2007 and 2008) had an AAI > 10% (5 event-winters in the monitored period by PN-NAM, Bâlea WNL), 3 event-winters or large snow avalanches (1939, 1974

and 2005) had an AAI ≥ 20% and 2 event-winters or large snow avalanches (1925 and 1997) had an AAI > 30% and even > 50% (in the monitored period by PN-NAM, Bâlea WNL).

In BLC1 23 event-winters with snow avalanche activity were identified between 1968 and 2011 (see Figure 3). 10 event-winters had an AAI < 10% (in the monitored period by PN-NAM, Bâlea WNL), 6 event-winters or small snow avalanches (1987, 1996, 1999, 2002, 2003 and 2008) had an AAI > 10% (in the monitored period by PN-NAM, Bâlea WNL), only one event-winters or large snow avalanche (1995) had an AAI > 20% and 2 event-winters or major snow avalanches (1997 and 2005) had an AAI > 30% and even ≥ 50% (in the monitored period by PN-NAM, Bâlea WNL).

In BLC2 21 event-winters with snow avalanche activity were identified between 1968 and 2011 (see Figure 3). 7 event-winters had an AAI < 10% (in the monitored period by PN-NAM, Bâlea WNL), 6 event-winters or small snow avalanches (1988, 1995, 1996, 1999, 2003 and 2006) had an AAI ≥ 10% (in the monitored period by PN-NAM, Bâlea WNL), only one event-winter or large snow avalanches (2005) had an AAI > 20% and 3 event-winters or large snow avalanches (1987, 1997 and 2002) had an AAI ≥ 30% and AAI ≥ 50%, respectively (in the monitored period by PN-NAM, Bâlea WNL).

#### 4.3 Occurrence of snow avalanches

According to the elevation of the Bâlea weather station, to maritime influences from northwest and to the relatively short period of observation, the occurrence of snow avalanches is the following:

- in the ARP1 stand, the 16.7% snow avalanches occurred in warm winters, 33.3% snow avalanches occurred in cold winters while the 50% snow avalanches occurred in normal winters.

- in the BLC1 stand, 11.1% snow avalanches occurred in warm winters, 33.4% snow

avalanches occurred in cold winters and 55.6% snow avalanches occurred in normal winters.  
 - in the BLC2 stand, the 40% snow avalanches occurred in cold winters, while 60% snow avalanches occurred in normal winters (Table 3).

It should be noted that most small snow avalanches occurred in normal winters and cold winters, followed by major snow avalanches that occurred in normal winters and cold winters and large snow avalanches that occurred in normal winters.

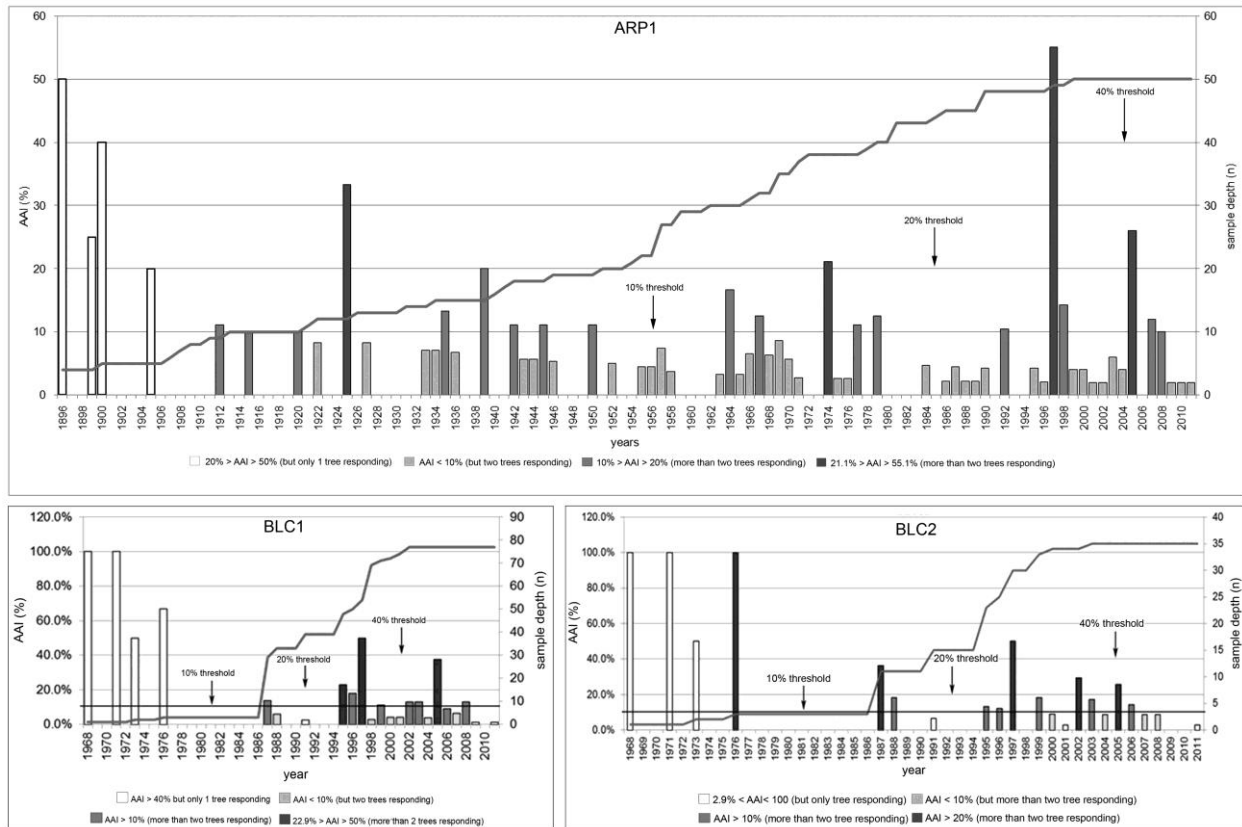


Figure 3. Event-response histogram showing avalanche induced growth response 1896-2011 for ARP1 stand and 1968-2011 for BLC1 and BLC2 stands

Table 3. Winter severity classification in correlation with magnitude of snow avalanches during the operation of the Bâlea weather station (1979-2011)

Stand	warm winters			normal winters			cold winters			very cold winters		
	magnitude			magnitude			magnitude			magnitude		
	1	2	3	1	2	3	1	2	3	1	2	3
ARP1				1998, 2007			1992					
BLC1	2008			1987, 1996, 1999, 2002	1995	1997	2003	2005				
BLC2				1988, 1995, 1996, 1999	1987	1997	2003, 2006	2002, 2005				

- 1 - 10% threshold
- 2 - 20% threshold
- 3 - 30% threshold

### 5 CONCLUSIONS

In this study, we test in Făgăraș massif Mountains the dendrogeomorphological methods in correlation with Winter severity classification. Our results demonstrate that the dendrogeomorphological method is very good tool to dating snow avalanches and their occurrence in the field (Butler and Malanson, 1985a, 1985b; Butler et al., 1987; Muntán et al., 2004, 2009; Stoffel and Bollschweiler, 2008).

The annual distribution of major events in the study area is represented by AAI value. This

index highlights the characteristics of GD in the snow avalanche tracks.

Our results partially confirm the hypothesis of Corona et al. (2011) and Castebrunet et al., (2012, pp. 863), who suggested that most of the high snow avalanche activity occurs in cold and very cold winters because "warm winter spells destabilize the snowpack, leading to the positive contribution of  $T_{max}$  excesses". If we sample several stands, we will obtain more conclusive results from this point of view.

On the other hand, we can consider snow avalanche synchronicity (i.e., two or more tracks

registering events in the same season) (Casteller et al., 2011, pp. 74). Therefore, the snow avalanche events from 1997, 2005 occurred in the ARP1, BLC1 and BLC2 stands, the snow avalanche events from 1996 and 1999, occurred in the BLC1 and BLC2 stands, the snow avalanches from 1987, 1995, 2002 and

2003 occurred in BLC1 and BLC2 stands and the snow avalanche event from 2008 occurred in the ARP1 and BLC1 stands. This synchronicity is remarkable because a large part of the snow avalanche events had an AAI  $\geq 20\%$  or even had an AAI  $> 30\%$ .

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