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SNOW AVALANCHE - DISTURBANCE OF HIGH MOUNTAIN ENVIRONMENT. CASE STUDY - THE DOAMNEI GLACIAL VALLEY THE FĂGĂRAŞ MASSIF-SOUTHERN CARPATHIANS, ROMANIAN CARPATHIANS

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Abstract: In March of 2005, a series of snow avalanches of varying magnitudes were produced in the Făgăraş massif (Southern Carpathians - Romanian Carpathians), affecting especially forestlands and roads. In this study, the snow avalanches which we will focus upon were produced in the Doamnei glacial valley. These snow avalanche were part of a series produced in this area, affecting a surface area of approximately 5.9 ha with a subalpine starting zone level at an altitude of 1950 meters and a runout zone of approximately 1420 m. Along its path, this avalanche destroyed approximately 3 ha of mature spruce fir forest situated between 1420 and 1640 m of elevation. The scope of this research is to evaluate this snow avalanche both of physico-geographical and also of environmental point of view, using the terrain factors and climate variables, the geomorphic and vegetative indicators. To do this, we made use of dendrochronological method to analyze 42 samples. Using this approach, we were able to calculate the age of the trees affected by snow avalanches throughout the track zone and runout zone, thus establishing the age of the forest.

Key words: snow avalanche, disturbance, environmental high mountain, terrain factors, climatic variables, geomorphic and vegetation indicators, dendrocronological method, Făgăraş massif, Southern Carpathians

1. INTRODUCTION

The aim of this study is the study of huge snow avalanche, like disturbance of high mountain landscape produced in the Doamnei glacial valley from Făgăraş massif (Southern Carpathians-Romanian Carpathians) in March 2005. The snow avalanches can be analyzed both in terms of physico-geographical and environmental.

Currently there are several main directions of research approaches the snow avalanches from a physico-geographical perspective. The snow avalanches demonstrate a very active geomorphic process by its role in the present shaping of relief and contribute to permanently slope denudation in high mountain areas (Gardner, 1970; Peev, 1966; Rapp, 1960; Luckman, 1977, 1978, 2007) and by transporting and redistributing debris at the exit area of the snow avalanche track or at the lap of the slope (Jomelli & Bertran, 2001; Luckman, 1977, 1988). From another point of view, snow avalanches are one of the most important natural hazards which acting on the mountain environment and cause each year several fatalities (Höller, 2007; Jamieson & Stethem, 2002; Keiler, 2004; Keiler et al., 2005; Voiculescu, 2009) and serious damages, about human settlements and infrastructures (Fuchs et al., 2004; Fuchs & Bründl, 2005; Fuchs et al., 2005; Jamieson & Stethem, 2002; Stethem et al., 2003; Voiculescu, 2009).

In the second case, of environmental topic, snow avalanches and snow avalanche paths, represents a form of dynamics in time and space and are one of the major disturbances of the mountain environment, at the subalpine level and at the contact zone with the treeline or timberline (Bebi et al., 2001, Kulakowski et al., 2006; Rixen et al., 2007; Walsh et al., 1994), inducing the vertical forest zonation patterns on the slopes (Butler, 1979). By dynamic, features, paths, landforms and impact snow avalanches provide increasing complexity mountain areas, especially in its upper. The high mountain is defined in bioclimatic terms by alpin, subalpine and forestry levels. Between forestry and subalpine levels develop the Alpine Treeline or Timberline and Alpine Treeline Ecotone (ATE), defined as: a transition from a treed/forested environment to a non-forested, respectively the transition between woody subalpine plant communities and non-woody alpine plant communities (Butler et al., 2003; Butler et al., 2007). These are a primarily a result of some aspect of topographic, climatic or edaphically control (Butler et al., 2007). In this context of the mountain landscape we can understand the importance of snow avalanche paths on the dynamics of mountain and on Alpine Treeline and Alpine Treline Ecotone, affecting altitudinal position and their general features and in the same time at regional level (Butler et al., 2003; Rixen et al., 2007; Walsh et al., 1994; Walsh et al., 2004).

Snow avalanches play an very important role in shaping ecosystems dynamics, cause disturbances in mountain landscape and underlying dynamics of forests both at local and regional level (Butler et al., 2003; Walsh et al., 1994; Walsh et al., 2004). It should be noted that the local disturbances, determined by de snow avalanches: depress treeline along elevation and moisture gradients or as a consequence of topographic, structural and lithologic controls of snow avalanches and their corresponding morphometry (Walsh et al., 1994). Also, snow avalanches play an important role in structuring the biodiversity and forestry and in processing matter and energy (Malanson & Butler 1986). Therefore, forestry vegetation which is in itself a distinctive level, plays an important functional role in protecting the environment, against natural hazards, as snow avalanches (Bebi et al., 2001; Schönenberger et al., 2005). Forestry vegetation has intrinsic value as indicators of mountain ecological conditions (Butler & Malanson, 1985a; Molina et al., 2004).

The subalpine mountain forests plays in the Alps a role against snow avalanches (Bebi et al., 2001) occupying about 30% of their surface (Schönenberger et al., 2005). This is important, because the snow avalanche paths covering more than one quarter of subalpine forest belt in these mountains (Rixen et al., 2007).

In Făgăraş massif, the forests with a protection role against of snow avalanches is a functionally distinct subtype that has an 1851.1 ha totals, representing 2.3% of the total forested area of Făgăraş massif. On the northern slope of Făgăraş massif where is located our area, it occupies 1745.9 hectares, representing 9.4% of the total forested area of the northern slope of Făgăraş massif. Also in the Doamnei glacial valley, the forests occupy 286.9 ha a total area of forests with a protection role against snow avalanches occupies 95 ha, representing 33.1% of total forest area of the Doamnei glacial valley (Voiculescu, 2002).

2. STUDY AREA

Our research takes place in the Făgăraş massif of the Southern Carpathians (Fig. 1). The Făgăraş massif has a surface area of approximately 1500 km^2 with slope aspects predominantly to the east and west in both northern and the southern ranges. The predominant altitude is between 2400-2500 m and alpine and subalpine levels are well developed. Likewise, the massif is characterized by a significant glacial relief inherited also from periglacial processes of an extensive spatial dynamic (Voiculescu, 2002).

In March of 2005, a huge snow avalanche in Doamnei glacial valley was researched in depth. It is placed on the northern slope of the Făgăraş massif, longitudinally placed on north-south direction (Figure 2). In the upper part it is dominated by two peaks that reach 2400 m. Doamnei glacial valley has two glacial cirques: the first is suspended at 2200 m made of huge masses debris as well as of huge boulders, chaotically placed, the second one had an obsequent character shaped by the glacier.

3. MATERIAL AND METHODS

3.1. Terrain factors and climate variables. Avalanche classification

The destructive character of the snow avalanche in the Doamnei glacial valley were influenced first by the accumulation of a massive amount of snowfall in the upper part of the slope, and second by the characteristics of the terrain; especially the degree of declivity. If we consider that this huge mass of subalpine snow extended over a large surface area with high levelling, then we can begin to understand the magnitude and velocity that went into producing the destructive effects of these occurrences. Terrain factors and the climate variables play a very important role in triggering and dynamics of snow avalanches (McClung & Shaerer, 1993; McClung, 2001) and can be used to evaluate the magnitude and frequency of the snow avalanches (Butler, 1986; Butler & Malanson, 1985b; McClung & Schaerer, 1993).

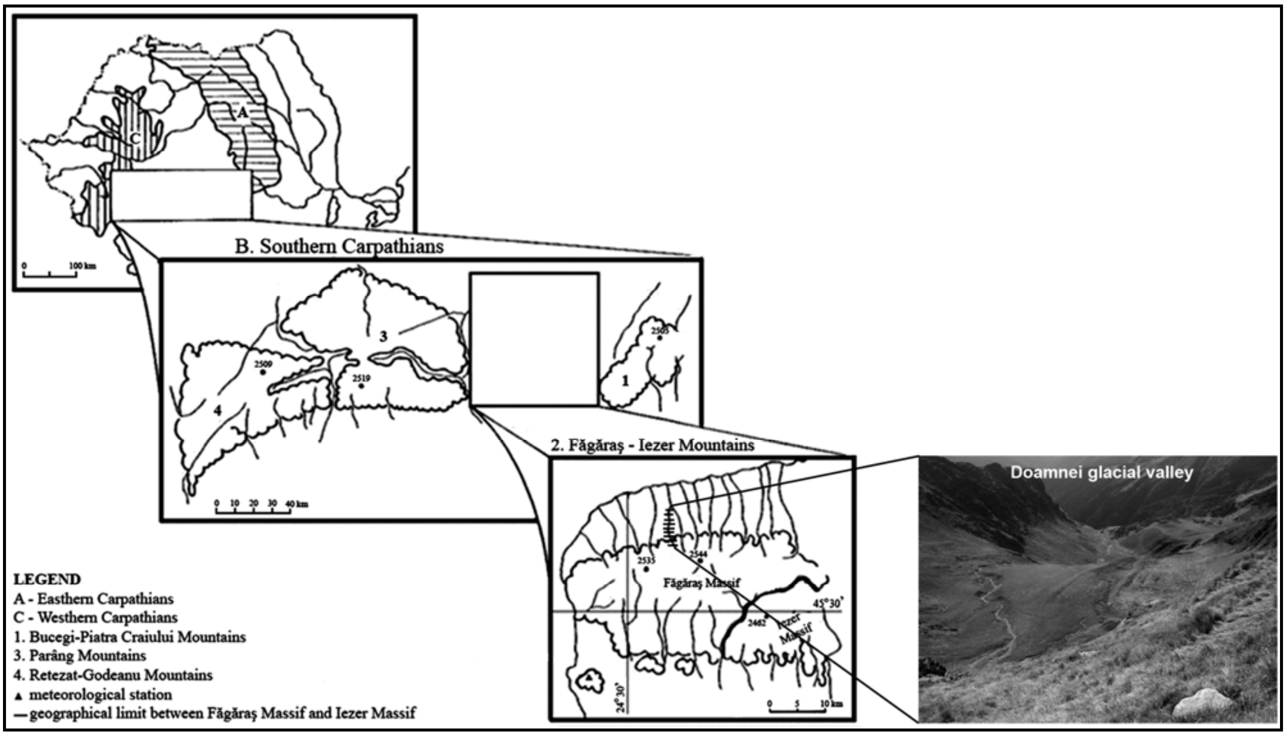


Figure 1. Făgăraş massif location

3.2. Geomorphic and vegetative indicators

Snow avalanches behave differently depending on the quantity of snow, altitude, exposition, slope length, declivity and vegetation. Snow avalanches velocities and impact pressures can be estimated using geomorphic and vegetation indicators (Boucher et al., 2003; Weir, 2002) especially since cold environment avalanches affect trees drastically (Shroder, 1980). Snow avalanches affect relief, soil and vegetation which are why the most important traces are to be found on those parts of the environment.

The geomorphic and vegetative indicators are used successfully in assessing of snow avalanches (Butler & Malanson, 1985a; Weir, 2002). In this context forest structure and composition affect the frequency and magnitude of snow avalanches in mountain areas and the occurrence of snow avalanches is determined by the topography of the place and the features of the snow (Bebi et al., 2001; Rixen et al., 2007; Weir, 2002).

3.3. Dendrocronological analysis

The use of dendrocronological method for tree ages and year chronology opened new away of analysis a snow avalanches, used in several studies (Boucher et al., 2003; Butler & Sawyer, 2008; Casteller et al., 2007; Germain et al., 2005, 2006; Molina et al., 2004; Muntan et al., 2004). Considering the scope, magnitude and frequency of past avalanche events in subalpine sites (Germain et al., 2006), we limited ourselves to the date when trees were killed as a result of tearing or uprooting from avalanche momentum.

4. RESULTS

4.1. Terrain factors

To highlight the characteristics of the terrain which provided a sliding surface for these snow avalanche (McClung, 2001), we conducted morphometrical analysis on the Doamnei glacial valley and the snow avalanche by using both the Idrisi Kilimanjaro and ArcGIS programmes in order to create a digital model of terrain (Fig. 2) and thematic maps (hypsometry, declivity, aspect), according to Cherubini et al. (2000); Ciolli et al. (1998). The hypsometric map analysis outlines high elevation in this area, with values over 2300-2400 m (see Fig. 2). It is easy to remark that maximum altitude is nearly 2400 m, and minimum over 1330 m in Doamnei glacial valley. The mean value of study area exceeds 1900 m.

The declivity map (Fig. 3) points out the great high degree of declivity of the study area. The values between 1^{o}-15^{o} represent 17.6% (1.15 km^2) from the surface of Doamnei glacial valley. The values between 25^{o}-45^{o} represent 68.1% (4.50 km^2) from the surface of Doamnei glacial valley and the values over 45^{o} represent 14.3% of the total area. Slope plays a determining role snow avalanche creation and is the primary variable in avalanche terrain (Maggioni & Gruber, 2003; McClung & Schaerer, 1993). Optimal slopes for snow avalanches are between 25^o and 50^o (Ancey, 2001; McClung & Schaerer, 1993). Snow layer thickness also contributes to snow avalanche occurrences and so the following categories have been established for corresponding slope degrees and snow thickness: 50^o for 5 cm of snow; 30^o for 15 cm of snow; 22^o for 50 cm of snow (Pissart, 1987). Taking into account that the snow avalanche was produced in spring, „the temperature increase enhances stability of snowpacks on shady slopes and instability on sunny slopes" (Ancey, 2001; Török-Oance et al., 2010).

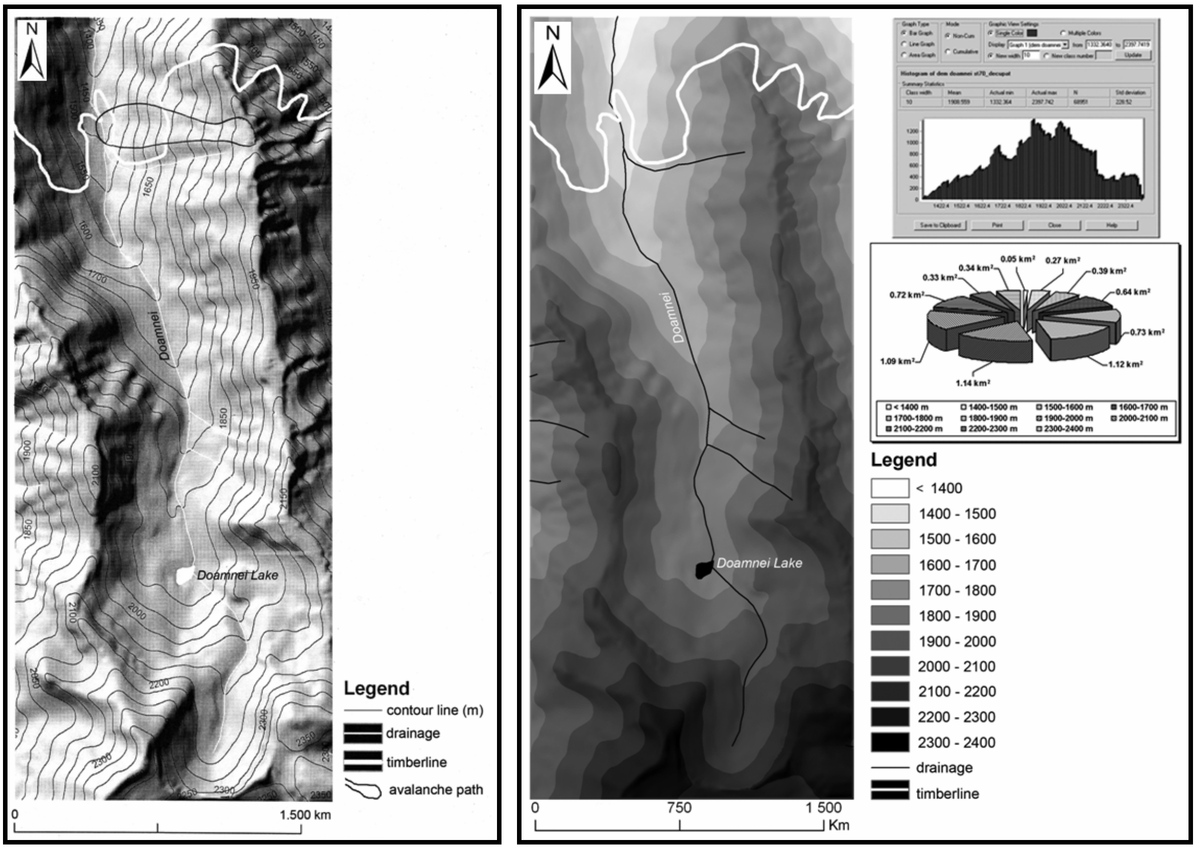
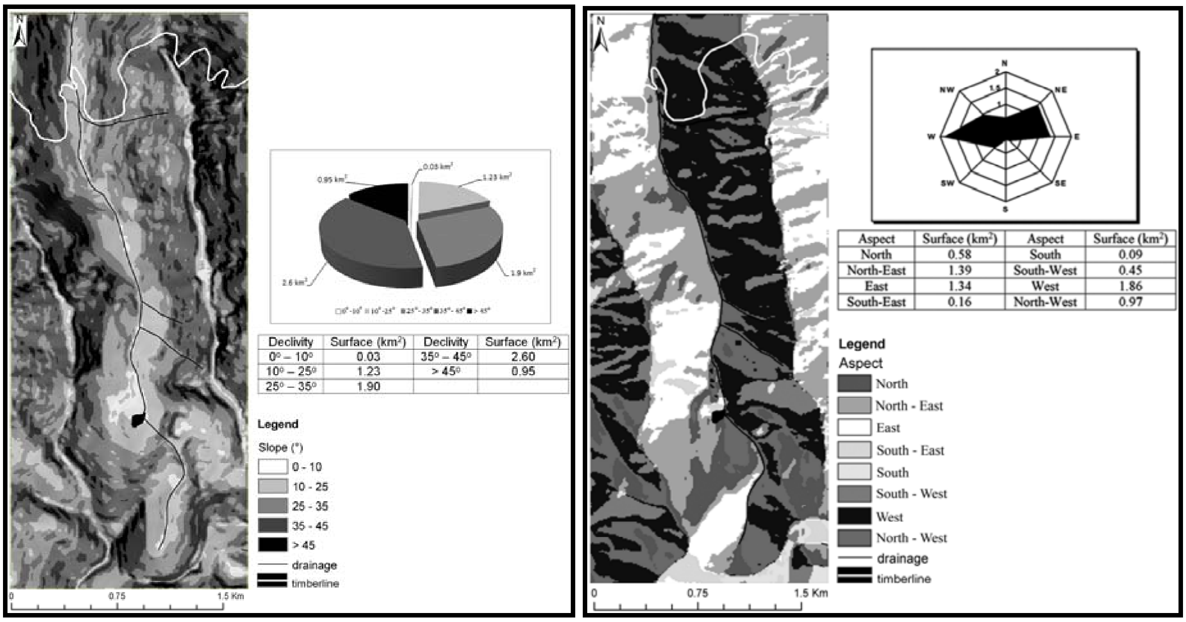


Figure 2. Doamnei glacial valley - digital model of terrain with snow avalanche track (on the left) and Doamnei glacial valley - hypsometry map (on the right).



Declivity	Surface (km^2)	Declivity	Surface (km^2)
0° – 10°	0.03	35° – 45°	2.60
10° – 25°	1.23	> 45°	0.95
25° – 35°	1.90		

Aspect	Surface (km^2)	Aspect	Surface (km^2)
North	0.58	South	0.09
North-East	1.39	South-West	0.45
East	1.34	West	1.86
South-East	0.16	North-West	0.97

Figure 3. Doamnei glacial valley: declivity map (on the left) and aspect map (on the right).

The snow avalanche produced in the Doamnei glacial valley had a start zone at 1950 m in the subalpine level and had a runout zone of 1450 m (see Fig. 3). It affected a total surface area of 5.9 ha; out of which 2.8 ha are in the subalpine level, capturing between 1950 - 1690 m (timberline) and approximately 3 ha of forest, ranging between 1690 and 1450 m. The remaining 0.4 ha was in the Doamnei glacial valley.

Any sliding surface along which the avalanche was made presents longitudinal morphology or three major morphological units: the starting zone (or source area where the snow avalanche initiate and accelerate), the track zone (where the snow avalanche reach maximum velocity) and the runout zone (where the snow avalanche decelerate and leave depositions) (Muntan et al., 2004; Walsh et al., 2004) (Fig. 4).

In this case, the starting zone is on leeside slopes which accumulate snow by drifting (Rapp, 1960). Declivity is contained between 26^{o} and 30^{o}. Optimal slopes in starting zone are between 25^{o} and 45^{o} or 50^{o}, very important for snow avalanche activity (Luckman, 1977, 1978). The starting zone overlaps the entire subalpine level that is characterized by grasses, small herbaceous plants, shrubs, *Pinus mugo* bushes and small rock outcrops.

The track zone has an open slope character with large disruptions in the transverse profile and with average slope angles between 25^{o} and 50^{o}. The track zone overlaps forest which is predominantly constituted by fir trees, and which also has a few exposed rock faces and unconsolidated rock deposits which could provide a source for rockfall, rockslide or debris falls after the avalanche.

The snow avalanche runout zone is found on an open slope and has a declivity between 10^{o} and 12^{o}. The runout zone overlaps the lower part of the forest on the right slope of the Doamnei glacial valley. In this context, the longitudinal profile made along the slope surface reveals the characteristic sectors, slope declivity and the length of the previously shown sectors. In order to show the open slope characteristic of the avalanche track, four transversal sector profiles were made within the characteristic sectors as follows (Figure 5).

4.2. Climate variables

Romania is in the temperate-continental climate zone which is characterized by marked snowfalls and snow avalanches when near maritime and transitional zones (Birkeland & Mock, 2001). As a function of its geographic position, many types of climate influences can be identified on the Romanian territory. For example, the northern slope of the Făgăraş massif, where Doamnei glacial valley can be found, is under an influence of the humid oceanic western wind and the southern slope of the Făgăraş massif is under the influence of the southern front of wind. As such, the regional climate also determines the mode of avalanche manifestation with a powerful influence from solar radiation, temperature, and snowfall quantity and type (McClung & Schaerer, 1993; Weir, 2002).

The features of the alpine climate of the Făgăraş massif (Table 1) are registered at the meteorological station at Bâlea Lake, situated on the northern slope at an altitude of 2070 m in the glacial cirque of Bâlea Lake. At the altitude of the meteorological station at Bâlea Lake, average temperature is 0.2^{o}C.

The isotherm of 0^{o}C is situated at the altitude of 2050 m (Voiculescu, 2002). Snow avalanches are a response to climate variations whenever they appear at altitudes that reach near the isotherm of 0^{o}C (Germain et al., 2006). An example of this is the snow avalanche in Doamnei glacial valley which had a start zone situated approximately at an altitude of 1950 m. In subalpine and alpine levels of the Făgăraş Massif, between 1600 - 1700 m and 2200 - 2300 m respectively, with the highest ridges between 2200 and 2300 m, the annual number of days with snow and the annual number of days with rain are favorable to solid precipitations when values are between 1.26 and 1.50 (Voiculescu, 2002).

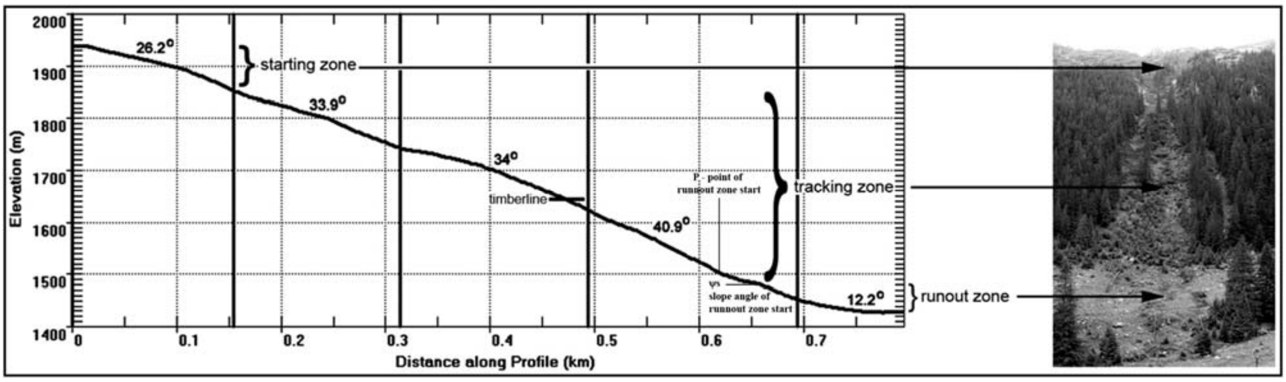


Figure 4. The major characteristic sectors of the track snow avalanche.

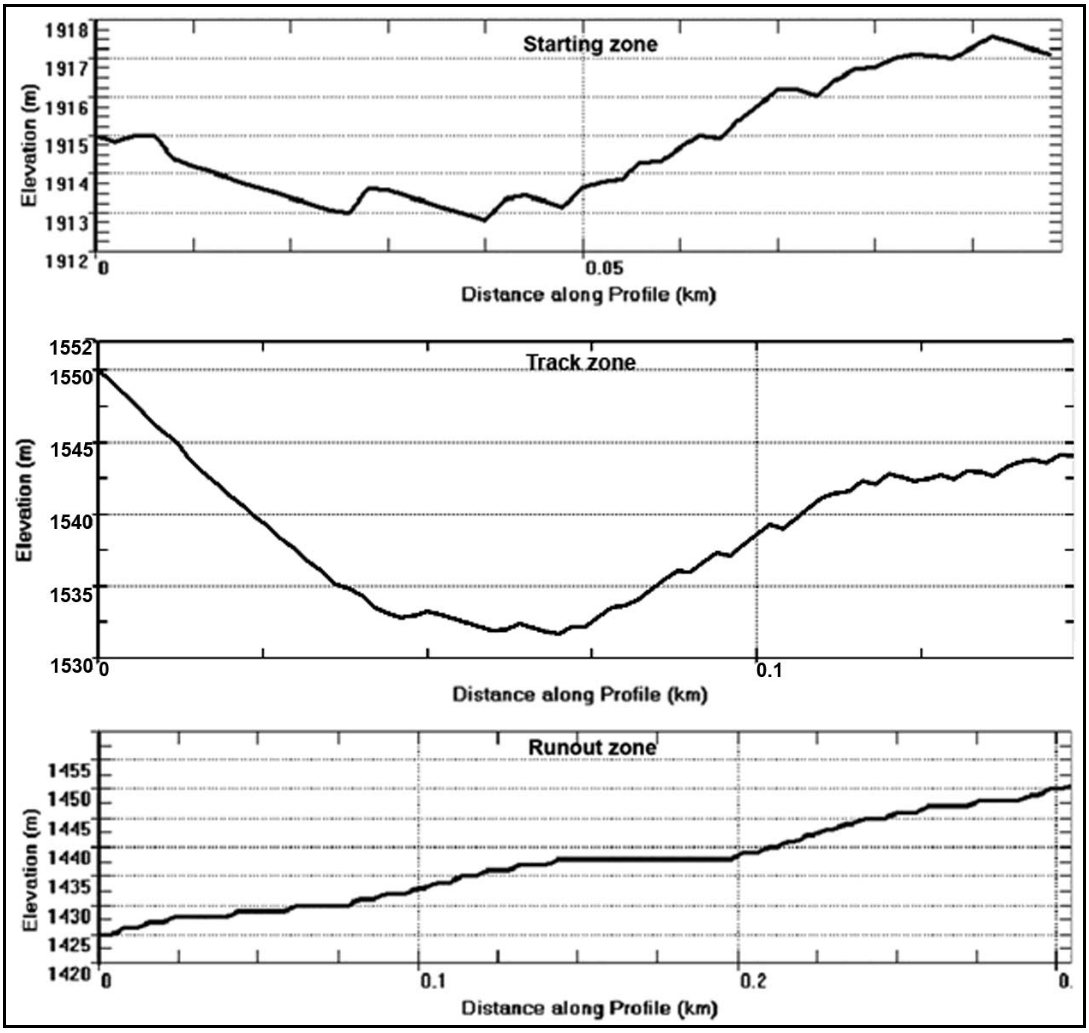


Figure 5. Transversal profiles on the avalanche track.

Table 1. The climate features of the Făgăraş massif (average annual values).

Weather station (m)	Lat. N.	Long. E.	T°C			Pp (mm)	Air humidity (%)	Days with snow	Days with snow cover	Depth of snow (cm)	Sunny days while there is snow cover
			Ann.	Min.	Max.						
Bâlea Lake-2070	45°36'	24°37'	0.2	-8,4	8,8	1246,2	83	>96	>224	66.4	45-50

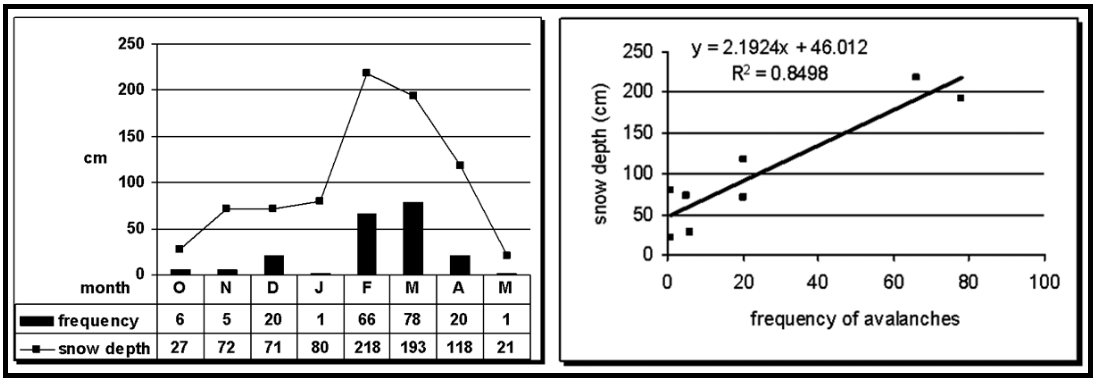


Figure 6. The variation in snow layer thickness and the frequency of snow avalanches in Bâlea glacial valley (on the left) and relationship between the snow layer thickness and snow avalanche frequency in Bâlea glacial valley (on the righ).

In March, 2005 there were variations in the thickness of the snow layer due to the quantity of snowfall, but also to the powerful winds which stirred up and redistributed the snow. Between March 5 - 6 and 9 - 10, snow depth grew by more than 20 cm for each period. On March 10th, the thickest snow layer for the whole month was recorded at 281 cm.

The wind is a factor which strongly influences the stability of snowpack (Ancey, 2001, McClung & Schaerer, 1993). Between March 15 and 20, a strong wind, predominantly from the East - West direction, formed cornices of large dimensions along the ridges. Strong winds play a powerful role in snow avalanche formation and are an implicit part of avalanche activity (Gardner, 1970; Meister, 1989).

The starting zone of the snow avalanche in Doamnei glacial valley can be included in the wind index 5 based on a subalpine start zone with ridges dominated by steep cliffs, but also in consideration of the snow avalanche start zone wind exposure ranking. Schaerer (1972) describes this ranking as a "start zone on the lee side of a broad, rounded ridge or open area where large amounts of snow can be picked up by the wind". Snow avalanches activity has noticeably grown, and when snow avalanches triggering conditions are met, snowpack thickness is regarded as a causal variable in snow avalanches production (Birkeland & Mock, 2001). The positive relationship between snow layer thickness and the frequency of snow avalanches has been well established. A good example of this relationship has been documented in Bâlea glacial valley (where is situated the meteorological station), the valley parallel with Doamnei glacial valley, where snow avalanches activity is also significant (Fig. 6).

Likewise, the maximum temperature of the air was slightly positive and so between March 23 and 28, at Bâlea Lake, when registered air temperatures were relatively high, the subsequent snowfall was deposited into a layer of wet and heavy snow (National Meteorological Administration, 2004-2005). In this climatologically context, on the foundation of a significant quantity of snow, powerful winds and with snow cornices already formed, the avalanche in Doamnei glacial valley was produced during the third week of the month of March, 2005.

4.3. Snow avalanche classification

Taking into account the definitions of snow avalanche tracks (Suffling, 1993) and the snow avalanche from Doamnei glacial valley had the track zone in subalpine level (between 1950 and 1640 m) and in the same time in forestry level (between 1650 and 1420) we consider that its paths: "is a nonforested strip of meadow, rocky ground, willow shrubs *(Salix* spp.) or similar vegetation, running vertically through the forest of a mountain valley side, and which is caused by avalanches" (Suffling, 1993, pp. 128).

To identify the effects of snow avalanches on trees it is necessary to know some of the characteristics of a snow avalanche; its velocity, type of surface (confined or nonconfined), type of snow, and its frequency (Burrows & Burrows, 1976).

We shall also analyse altitude classification which are important in the present study. The snow avalanche of the Doamnei glacial valley is classified as a medium-high mountain snow avalanche because of the subalpine starting zone and track and runout zones in forest sites. From point of view of morphology of path, the snow avalanche of the Doamnei glacial valley was open flat track or unconfined avalanche (Quinn & Phillips, 2000) or open slope (McClung & Schaerer, 1993).

The snow avalanche was diffuse, according to Burrows & Burrows classification (1976), due to the existence of densely wooded slopes, with *Pinus mugo* in the upper region and with *Picea alba* in the middle and lower regions.

Bringing into discussion other classification criteria such as sliding surface, state of humidity, forms of movement and triggering factors (de Quervain, 1966a), we can designate the snow avalanche in Doamnei glacial valley as within snow cover avalanche, wet snow avalanche, sliding avalanche, spontaneous avalanche and also a natural triggering avalanche.

Taking into account weather factors, the avalanche can be classified as fresh snow avalanche (de Quervain, 1966b) or as a direct action snow avalanche (Capello, 1973; Lachapelle, 1966) considering the fact that it was produced soon after a huge snow fall. Likewise, if we consider the month or season when it was produced, then the snow avalanche can be characterized as typical to the spring season (Luckman, 1977).

On the other hand, snow climate classification, and implicitly snow avalanche classification, depends on climate parameters.

Methodology of classification by Mock & Birkeland (2000) uses the principle climate parameters, mean air temperature, total rainfall, total snowfall, total snow water equivalent and a derived average December snow pack temperature gradient to characterize the local climate in the period between December-March. Due to this, Hägeli & McClung (2004), discuss a new classification described as an avalanche winter regime. From this perspective, we can consider the snow avalanche in Doamnei glacial valley as part of this category.

4.4. Analysis of Geomorphic and Vegetation Indicators

The geomorphic indicators are determined by many more elements of analysis (Weir, 2002): the length of bed surface; general slope of the bed surface; declivity of the sectors; the degree of covering and fixing of the surface with grassy or forest vegetation.

The vegetation indicators are determined by more elements such as (Weir, 2002): the type of vegetation, grass or forest; the structure of the forest; the height and constitution of the forest; the degree of covering within the 3 major morphological units of any sliding surface.

Field research began with considerations of the degree of vegetation cover (forest, bushes and pastures) and the presence of some geomorphologic shapes used to make an identity record (Table 2).

The effects the snow avalanches formed on vegetation and relief will be specified later in the section on avalanche site identification. Field research data can be found in the table below (Table 3). The runout zone, where the whole mass of snow, earth, stones, boulders and any wooden materials is transported and deposited, is also a site of considerable impact.

4.4.1. Geomorphic indicators

A snow avalanche is a very important geomorphic agent, with several effects on the mountain landscape serving to produce characteristic landforms (Jomelli, 1999; Luckman, 1977, 1978, 1992). The most suggestive geomorphic indicators from the track zone are represented by rocks in microshistes cristalines of different sizes, detached and rolled down slope, in debris flows, such as cones, and in forest soil removal (Figure 7).

Figure 7. Cobbles, boulders and blocks of different sizes and debris rolled down slope in the track zone (on the left), erossive processes (on the central) and snow avalanche deposit in the track zone (on the right) (photos by Voiculescu, 2005).

Table 2. The analysed surface cover of the Doamnei glacial valley (percent of total area in each component of avalanche path) is according to Weir (2002)

	Start zone	**Track zone**	**Runout zone**
Dense timber	no	mostly	partially
Scattered timber	no	no	scattered
Brush above 2 m	yes	scattered	no
Brush under 2 m	yes	scattered	no
Grass and shrubs	yes	scattered	no
Large blocks and boulder > 1 m in height	no	yes	no
Blocks and boulder < 256 mm diameter (b axis)	no	yes	yes
Rubble 2-256 mm diameter (b axis)	no	yes	yes
Bedrock (relatively smooth)	no	yes	yes

Table 3. The analysed field evidence of avalanche activity in the Doamnei glacial valley is according to Weir (2002)

A. Normal erect vegetation for site is	**Start zone**	**Track zone**	**Runout zone**
Missing	no	no	no
Unusually sparse and scattered	no	no	yes
Replaced by other species	no	no	no
Broken off near ground	no	yes	yes
Pushed over but not broken	yes	yes	yes
B. Damage to standing trees and brush			
Entire plant bent or deformed	no	yes	yes
Tops broken out	yes	no	yes
Limbs, twings or needles missing	yes	yes	yes
Trunks or tree limbs scarred	no	yes	yes
C. Debris and Colluvium			
Snow abnormally deep or persistent	yes	no	yes
Tree trunks, limbs in debris	no	yes	yes
Branche, needles, brush	no	yes	yes
Cooluvium as cones or mounds	no	yes	yes
Other debris (specify)	-	-	-

In the sectors affected in the track zone, erosive processes occurred later and they were identified as extending along the slope at a length of 20-30 m, as seen in figure 7. In areas affected by the snow avalanche, erosive processes were initiated which later affected soil cover with variably high and low amplitudes. It should be mentioned that in the runout zone, a mixture of materials from vegetation (twigs, branches, broken tree trunks) with earth, stones and boulders of small sizes, determine the occurrence of slush avalanches (see Figure 7). The most snow avalanche impacts are in the track zone area, particularly when forests are damaged.

4.4.2. Vegetative indicators

Considering that the snow avalanche was produced in an area high in vegetation cover (pastures and bushes of *Pinus mugo* in the subalpine level of compact forest and *Picea alba* in the forest level), there is the highest frequency of vegetation indicators in our sample. The characteristics of the vegetation can be used for analysis of snow avalanche frequency (Ives et al., 1976). Anomalies found in trees are very informative about snow avalanche impacts, as well as what information can be provided by plants (Burrows & Burrows, 1976; Freer & Schaerer, 1980). It should be mentioned that tilting, scarring and breakage are recognized as vegetation indicators of snow avalanche return period or frequency (Burrows & Burrows, 1976; Butler & Malanson, 1985a; Weir, 2002). Most indicators identified in the track zone were very suggestive of snow avalanche activity (Figure 8).

For example, on the edges of the snow avalanche sliding surface, evidence of the most recent disturbance could be ascertained from the tilting of the trunks of some mature trees (those of about 15-20 m).

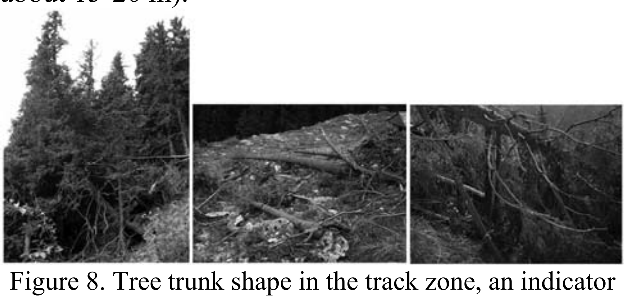


Figure 8. Tree trunk shape in the track zone, an indicator of snow avalanche impact (on the left), uprooted trees rolled in the runout zone (on the central) and broken and split trees in the track zone (on the right)
(photos by Voiculescu, 2005)

Other examples of research using this indicator are Burrows & Burrows (1976) and Schroder (1980). Tilting represents a very effective vegetation indicator with which to determine the year of snow avalanche activity (Butler, 1987). This is particularly clear when tilting is severe (Shroder, 1980). Corrasion or ripping of bark from the trunk of a tree also represents a type of vegetative indicator used for determining the year of snow avalanche impact (Burrows & Burrows, 1976; Butler, 1979). In the superior part, but also in the median part of the track zone, trees suffered the most peculiar impacts from the force of the snow mass but also because of its speed. Some of the trees which were 15-18 m high were torn from their roots; violently uprooted, others were rolled or fouled up in the runout zone (see Figure 8). Whilst still others were simply torn in the lower part of their trunks (see Fig. 8). This reveals an impact pressure of 50-100 kPa or approximately 5-10 t/m^2 (Weir, 2002). As is mentioned in the literature (Burrows & Burrows, 1976), snow avalanche velocities and impact pressures can be estimated from the characteristics of breakage observed in the trees. In some situations, trees were broken 2-3 m from the root and others were split in two (Fig. 9).

Figure 9. Tree broken 2 m from its roots in the track zone (on the left), impact scars from entrained vegetal material in the runout zone (on the central) and tree measurements showing the magnitude of snow avalanche in the lower part of the track zone (on the right)
(photos by Voiculescu, 2005 and Vuia 2005)

At the edge of the avalanche bed, but also in the lower part of the track zone, we identified wooden material (twigs, branches) at the base of standing trees which was transported and deposited by the snow avalanche. In the structure of the deposit we identified, *Pinus mugo* branches, specific to the start zone, as well as twigs and branches of *Picea alba*, specific to the track zone (see Fig. 9).

In the lower part of the track zone, a few situations were identified in which tall trees (12-13-15m) were broken at a level 7 m above the surface of snow avalanche movement. This fact demonstrates the impact force of the huge amount of snow involved. This is an example of longitudinal morphology associated with snow avalanche activity and is a demonstration of the magnitude of impacts resulting from the destructive capacity of snow avalanches (Burrows and Burrows, 1976). Two examples from our research, which were particularly illustrative of this, are a tree broken at 7.40 m and at 7.10 m by sinusoidal propagating of waves of the impact shock in the tree trunk (Stoffel, 2009) (see Fig. 9).

4.5. Tree age

In order to establish the age of these trees, we analyzed the number and distribution of rings grown. Using 42 samples made up of cross and transverse sections, from trees affected by the snow avalanche and from trees unaffected by the snow avalanche in a stable forest, we codified using DMN, in consecutive order from DMN01 to DMN042. In order to date the samples, we used the CAROTA2.1 programme (Popa, 1999, 2004), shown with add-ins for Microsoft Excel.

Statistics were calculated with analysis of the annual rings at a precision of 0.01 mm. After counting the growth rings, we determined that the age of the trees affected by the snow avalanche but also of those in the stable forest spanned a range between 90 and 129 years (respectively samples DMN03 and DMN04 (Fig. 10).

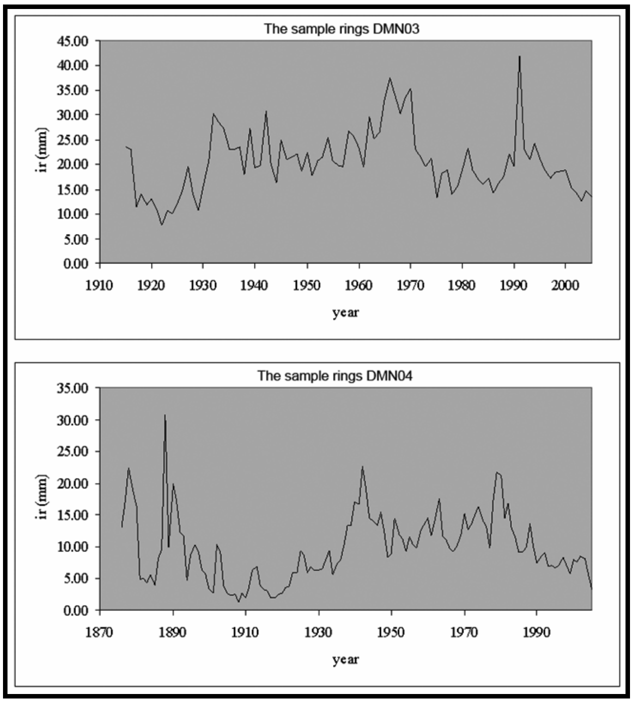


Figure 10. Chronology of radial growth of the sampled rings DMN03 and DMN04

4.6. Snow avalanche rating

The research and the knowledge of snow parameters are important for the meteorological, climatological, geographical and ecological studies. On the other hand, the variability of snow cover depends on topography, climate, vegetation and forest area (Křístek et al., 2011). In our case, use especially the terrain factors, according to Salm et al., (1990) we calculate the snow avalanche dimensions (Table 4).

Table 4. The values of snow avalanche dimensions

Huge snow avalanche, open slope
ξ (turbulent friction factor) = 1000 m/s^2 (uniform slope, low roughness, low confined), tgψ = 10/30 = 0.33, μ (solid friction factor) = 0.155 (huge snow avalanche, elevation > 1300 m, snow depth > 2 m)
Starting zone dimensions are: elevation between 1950-2000 m; width between 100 - 150 m; average declivity is 26.2^o
Snow depth: d_o^x - value which depends on local climate and depending on snowfall for 3 consecutive days and the return period=1.60, T=300 years (wind influence); $f(\psi) = f(\sin 26.2^o) = 0.291/\sin 26.2^o - 0.202\times\cos 26.2^o = 1.11^o$ (small angles lead to a long return period) where f(ψ) is angle factor d_o=1.60×1.21=1.93 (value that is calculated the return period: between 100 - 300 years) where d_o is average snow depth of snow flow
Snow volume of starting zone: V_o (m/s)=[1.21×1000(sin26.2° - 0.155×)]$^{1/2}$=16.38 m/s where V_o is speed of snow on starting zone Q=180×1.93×16.38=5590.41 m^3/s where Q is snow volume V_p = [(5690.41/120) ×1000(sin26^o-0.155×cos26^o)]$^{1/3}$ = 24.20 m/s where V_p is speed of snow avalanche
Speed and snow depth of runout zone: high on d_p=5690.41/(120×24.20)=1.96 m where d_p is snow depth of point of debut of runout zone stopping distance observed between 1480 and 1430 lenght of runout zone was approximately 140 m where tgψ is the angle between 1480 m point and 1430 m point (see fig. 4) tgψs = 50/140 = 0.35; ψs = 18.4^o $d_s=d_p+(V_p)^2/10g$=1.96+(24.20)^2/10g=2.45 m where d_s is average snow depth on runout zone v^2=2.45×1000 (0.155×cos18.4^o-sin18.4^o)=240 m^2/s^2 S=(2.45×1000/2g)×ln (1+(24.2)^2/240=154.4 m where S is stopping distance of runout zone, approximately equal to that observed by us in the field

5. DISCUSSION AND CONCLUSIONS

A combination of geomorphic and vegetative indicators offers the best elements for snow avalanche analysis in the field, particularly in isolated areas where data access is limited.

Geomorphic indicators are an important means for appreciating snow avalanche activity and for understanding its manifestation according to mathematical parameters of the relief (length and width of the snow avalanche sliding surface, levelling between the start and runoff zones, declivity and slope exposition).

The differentiated grade of the slope and the longitudinal arrangement of materials eroded by the snow avalanche, are indicators to recognize landforms whose form is heavily influenced by snow avalanches (Jomelli & Francou, 2000). On the other hand, geomorphologic indicators establish, to a large degree, the manner by which materials are eroded in the starting zone and later transported and accumulated in the runout zone (Luckman, 1992).

The study of how soil is eroded, including torrential processes which occur during the summer time on the track and on the affected surfaces, are also established using geomorphic indicators. Vegetative indicators such as species distribution, and patterns of bent trees and destroyed trunks, show the force of the avalanche impacts.

Specifically, vegetation indicators offer a particularly useful instrument for determining snow avalanche frequency (which can be discerned, for example, by type of vegetation in the track and/or on the slope areas affected by snow avalanche). After examining a length of approximately 1 km of snow avalanche zones and approximately 5 ha of destroyed forest, we can categorize the snow avalanche in the Doamnei glacial valley as a size 4 (after McClung & Schaerer, 1981, quoted by Stethem et al., 2003).

Considering that the area studied was affected by a snow avalanche for the first time in recent history and, on the other hand, that the age of the trees, established through the help of growth graphics, as well as through the appearance, from place to place of younger trees, we can characterize the affected forest as dominated by a more mature pioneering species of uniform age. In this context, the frequency of snow avalanches can be placed in the category which ranges between 30-100 years (according to Mears, 2002, quoted by Weir, 2002).

Using the destructive potential as established by Weir, 2002, a surface area of affected forest which is more than 5 ha, such as the snow avalanche in the Doamnei glacial valley, can be included as a size 4 McClung, Schaerer's classification (1981, quoted by Weir, 2002). Taking account of the fact that snow avalanches represent one main slope process in high mountains (Luckman, 1977) and according to terminology used describe frequency of mountain slope hazard (Gerath et al., 1996, quoted by Weir, 2002), as well as the fact that „snow avalanche frequency would generally be rated as high or very high" (Weir, 2002, pp. 42) we can consider the avalanche of Doamnei glacial valley to be of high frequency with a return period between 1/100 and 1/20 (Gerath et al., 1996, quoted by Weir, 2002).

Using the indicators which can be observed on trees, such as inclination, broken stems and branches, bark abrasion and anomalies in tree rings and other features in the track and the runout zones which can be used to establish the magnitude and frequency of a snow avalanche while also taking into account the fact that high magnitude snow avalanches are very episodic events (Germain et al., 2006, 2008) or historical events (Ives et al., 1976). In the same context, we should mention that if climate change will influence both snow fall and the thickness of the snow layer (Breiling & Charamza, 1999), as well as the distribution, frequency, type and magnitude of snow avalanches (Stethem et al., 2003), then its influence upon long-lasting environmental, concerned about forest and economic consequences (Beniston et al., 2003) will be considerable.

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