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ANALYSIS OF SNOW AVALANCHE FROM MARS 07, 2007 WITHIN THE CĂLŢUN-NEGOIU AREA, IN THE FĂGĂRAŞ MASSIF (SOUTHERN CARPATHIANS)

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Abstract: On March 7th, 2007, in the Călţun-Negoiu region two large snow avalanches have occurred: one on the eastern slope, the other on the western slope. The last snow avalanche has caught 10 climbers who were in a training session and who did not heed to the warnings issued by the Public Service SALVAMONT Bâlea Lake. The purpose of this study is to assess the topographical factors and climatic variables which have determined the accumulation of snow on one hand and on the other is to highlight the outbreak and the onset of snow avalanches. Therefore, using GIS, we have analyzed the topographic factors in order to obtain thematic maps (elevation, slope and aspect) and weather variables (temperature, solid precipitation and snow depth). In the same context, we have analyzed the synoptic situation and the changing weather and snow parameters using nivologic polls obtained by the members of the Nivologic Laboratory of Bâlea Lake. For the analysis of our results we used CROCUS Program MEPRA PC, version Romania 2004.

Key words: snow avalanche, topographic factors, climate variables, Călţun-Negoiu, Făgăraş Mountains, Southern Carpathians

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INTRODUCTION

The purpose of this paper is to assess the conditions which led to large amounts of snow accumulation in the Făgăraş massif between 05 and 07 march 2007 and to the concomitant triggering of two snow avalanches in the Călțun-Negoiu area, one of which caught a group of 10 climbers from a training camp. In this context to be distinguished, according to de Quervain (1972, quoted by Höller, 2009) between spontaneously (naturally) released avalanches or catastrophic avalanches and avalanches triggered by skiers or tourist avalanches. The two types manifest in different space and time the conditions for catastrophic avalanches are determined by heavy snowfall and tourist avalanches by snow depth (de Quervain, 1972, quoted by Höller, 2009). In both cases, the meteorological factors determine snow pack stability. The release of snow avalanches depends on three variables (LaChapelle, 1980): (meteorology, snow structure and snow mechanics. On the other hand McClung and Tweedy (1994) divided these variables in three classes: stability factors, snow pack parameters and meteorological parameters.

The important role that weather situations plays on snow avalanches has been studied by several authors in the world: by Fitzharris, Schaerer (1980) and Fitzharris (1987) for Canada, by Björnsson, (1980) for Iceland, by Ikeda *et al.* (2009) for Japanese Alps, by Fitzharris, Bakkehöi (2007) for Norway, by Whetton *et al.* (1996) for Australian Alps, by Fitzharris (1976) and Hendrikx *et al.* (2005) for New Zealand, by Armstrong, Armstrong (1987), Birkeland, Mock (2001), Lachapelle (1966) and Mock, Birkeland (2000) for North American continent.

It is known that snow avalanches within the Făgăraş Massif is a reality (Voiculescu, 2009). Snow avalanches have a high prevalence and frequency, registering human injuries and fatalities almost every year, as shown by the statistics of the Mountain Rescuers or by the annual reports developed within the nivo-meteorological program of the National Administration of Meteorology (2004-2005, 2005-2006, 2006-2007, 2007-2008).

Snow avalanches are some of the most important natural hazards that act mainly on the high mountain environment and cause each year injuries and fatalities (Höller, 2007, 2009; Jamieson and Stethem, 2002; Keiler, 2004; Keiler *et al.*, 2005; Voiculescu, 2009) and serious damages on human settlements and infrastructures (Fuchs et al., 2004; Fuchs, Bründl, 2005; Fuchs *et al.*, 2005; Jamieson and Stethem, 2002; Stethem *et al.*, 2003; Voiculescu, 2009).

STUDY AREA

The Făgăraş Massif is located in the Southern Carpathians, at the intersection of the 45˚30’ N parallel and 24˚30’ E meridian. The Făgăraş massif has approximately 1500 km^2 and is like a huge ridge (70-80 km long) with an east-west orientation from which two slopes detach - the northern and the southern one. The Făgăraş massif distinguishes through its highest massiveness and the highest altitudes in all of the Romanian Carpathians, notably with the following peaks: Moldoveanu (2544 m) and Negoiu (2535 m). They also show the most important inherited glacial relief in the Southern Carpathians and present-day periglacial processes. The studied area (figure 1) is the connecting ridge between Negoiu and Călțun peaks, situated in the glacial central sector (Voiculescu, 2002).

It is characterized by the most impressive glacial relief of the massif, with high vertical drop, highlighted mainly by the quaternary glacial erosion, long and steep slopes.

In this area there are also some of the greatest heights of Făgăraş Mountains, represented by the double peak Călțun-Lespezi (2517 m, 2505 m respectively) and Negoiu (2535 m), the second peak in the Făgăraş massif. The landscape is dominated by an impressive rocky component, with large masses of different size detritus, some fixed and some mobile, large boulders and stone blocks on the base of the slope. Between the Vârful dintre Strungi (2475 m) and Negoiu peak there is a huge and strongly inclined passage, called Strunga Dracului (Devil’s Passage). The passage is included in the tourist routes of the Făgăraş Massif and is secured by chains and cables fixed in the rock, requiring the tourists a good climbing experience and knowledge of the local conditions.

In this area, on 07 March, near the Negoiu peak, two avalanches occurred, soon after one another. The first one occurred on the western slope of the glacial valley Căldarea Berbecilor. Split thickness measured about 1 m and the width was over 200 m. The second avalanche, the one that we refer to, occurred on the eastern slope of the ridge connecting the Vârful dintre Strungi and Negoiu peaks. The snow avalanche was triggered by the breaking of a piece of the overhanging cornice on Devil's Passage, due to the shock of the previous snow avalanche and intervention of the ten climbers group, who tried to cut the cornice in order to exit on the ridge. According to the snow avalanche description sheet, the snow avalanche occurred at 11.30, to a -15 ^{o}C air temperature; the triggering line was linear, and the deposit in the form of a truncated cone or funnel. Although the group was warned by the Mountain Rescue team and the meteorologists from the Bâlea-Lac station that the estimated avalanche risk was high, the phenomenon resulted in 4 injured climbers, 3 of them in need of urgent medical care on site.

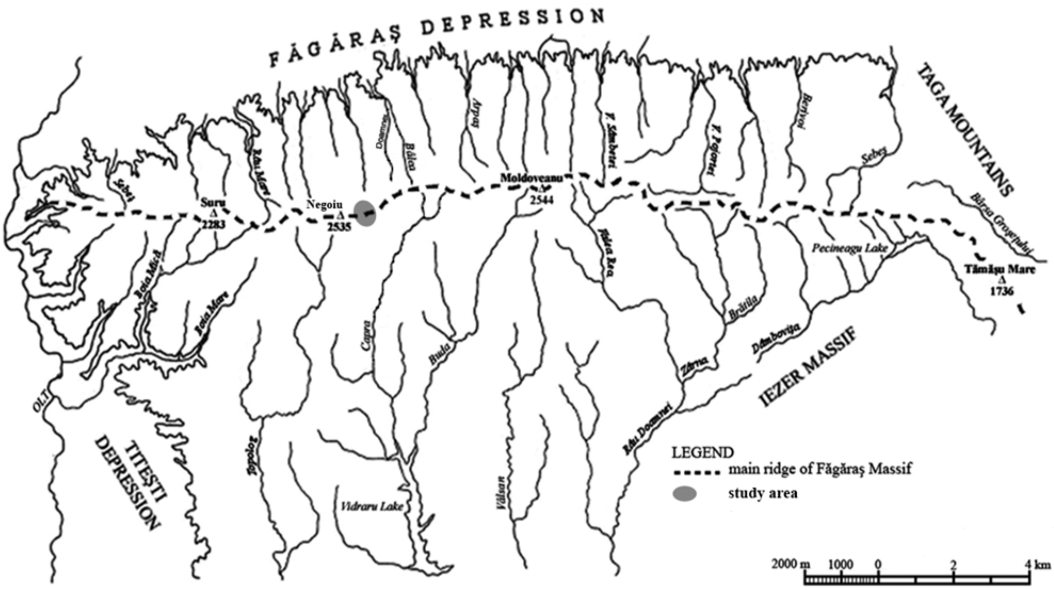

Figure 1. Localization of the area affected by the avalanche on the 07th of March, 2007

METHODS AND RESULTS

According to several studies, terrain factors and climatic variables can be used to evaluate the magnitude and frequency of the snow avalanches (Birkeland, Mock, 2001; Butler, 1979; Butler, Malanson, 1985, 1992; McClung, Schaerer, 1993; McClung, 2001; Schaerer, 1967; Smith, McClung, 1997a, 1997b; Weir, 2002).

Terrain factors

To highlight the characteristics of snow avalanche gliding surface and according to McClung (2001), Perla & Martinelli (1976) and Schaerer (1977), we performed the morphometric analysis of the sector where the snow avalanche occurred. Therefore, according to Cherubini et al., (2000); Ciolli et al. (1998); Comunello et al., (2001); Ghinoi, Chung, (2004); Nagel, (2000); Walsh et al., (1994) and using GIS Softwares, the terrain digital model (figure 2) and thematic maps (hypsometry, declivity, aspect) have been obtained (figure 3).

The hypsometric map highlights the high altitudes of the examined sector, with values that reach and exceed 2400 m in the starting area, 2000-2300 m along of the track and 1900-2000 m in the runout areas. The mean value exceeds 2170 m.

Slopes play a determining role in snow avalanche triggering and represent the primary variable in snow avalanche terrain (Maggioni, Gruber, 2003; Luckman, 1977, 1978; McClung, Schaerer, 1993). As mentioned in the literature, the optimal slopes for snow avalanches are between 25^o and 50^o (Ancey, 2001; Armstrong et al., 1994; Embleton, 1979; McClung, Schaerer, 1993; Schaerer, 1977).

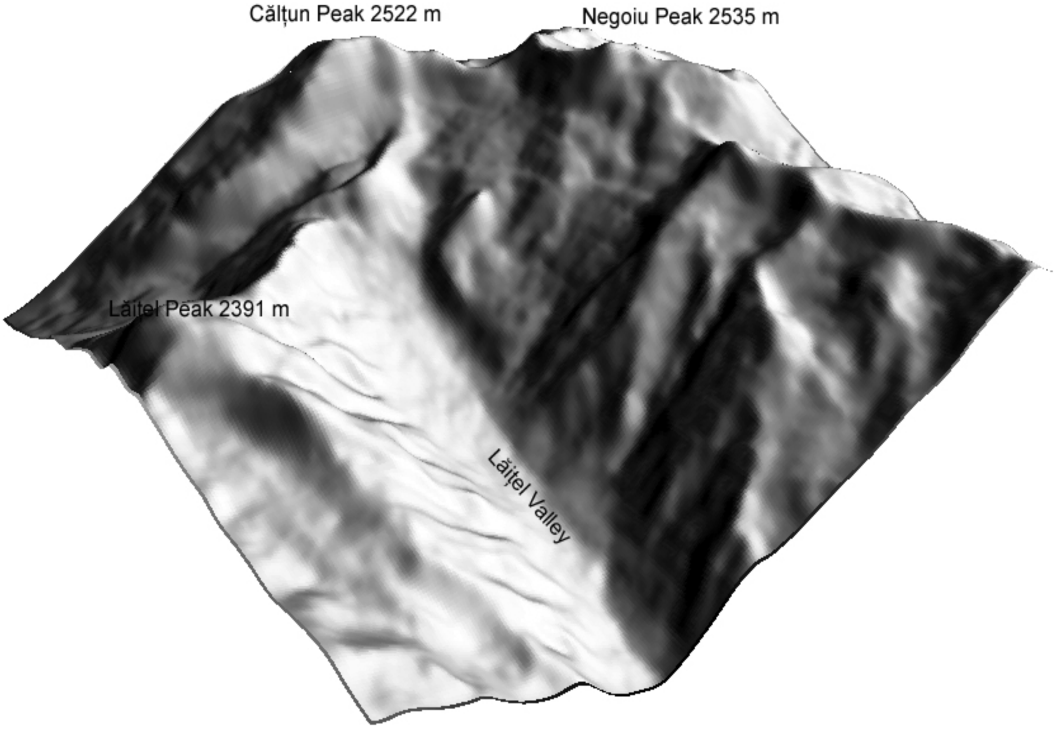

Figure 2. The digital terrain model of the Călţun-Negoiu area

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). The declivity map highlights the slopes steeper than 35^o in the starting zone, 15^o-25^o-35^o in the tracking zone and 10°-15^o in the runout zone. The aspect map highlights the predominance of the eastern and north-eastern exposures in the studied area, followed by the south-eastern and south-western ones. These values are very important if we consider the amount of solar energy that an area receives during winter or spring. The radiation of the sun usually controls snow surface temperature more than air temperature, playing an important role in snow instability (McClung, Schaerer, 1993) and determining the snow avalanches type. 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, p. 3).

Any sliding surface along which the path of snow avalanche presents longitudinal morphology (Walsh *et al.*, 2004) or three major morphological units (figure 4): the starting zone (source area), the tracking zone and the runout zone (Burrows, Burrows, 1976; McClung, Schaerer, 1993; Muntan *et al.*, 2004; Walsh *et al.*, 2004; Weir, 2002); start zone, upper and lower track, runout track (Germain *et al.*, 2005); failure zone, tracking zone and deposition zone (Ishikawa *et al.*, 2003); zone de départ (zone d'accumulation), zone de transit supérieur et zone de transit inférieur (zone de transfer) and zone de dépot (zone d'arrivée) (Ancey, Charlier, 1996).

In the starting zone snow avalanches initiate and accelerate, in the tracking zone snow avalanches reach maximum velocity and in the runout zone decelerate and leave depositions (McClung, Schaerer, 1993).

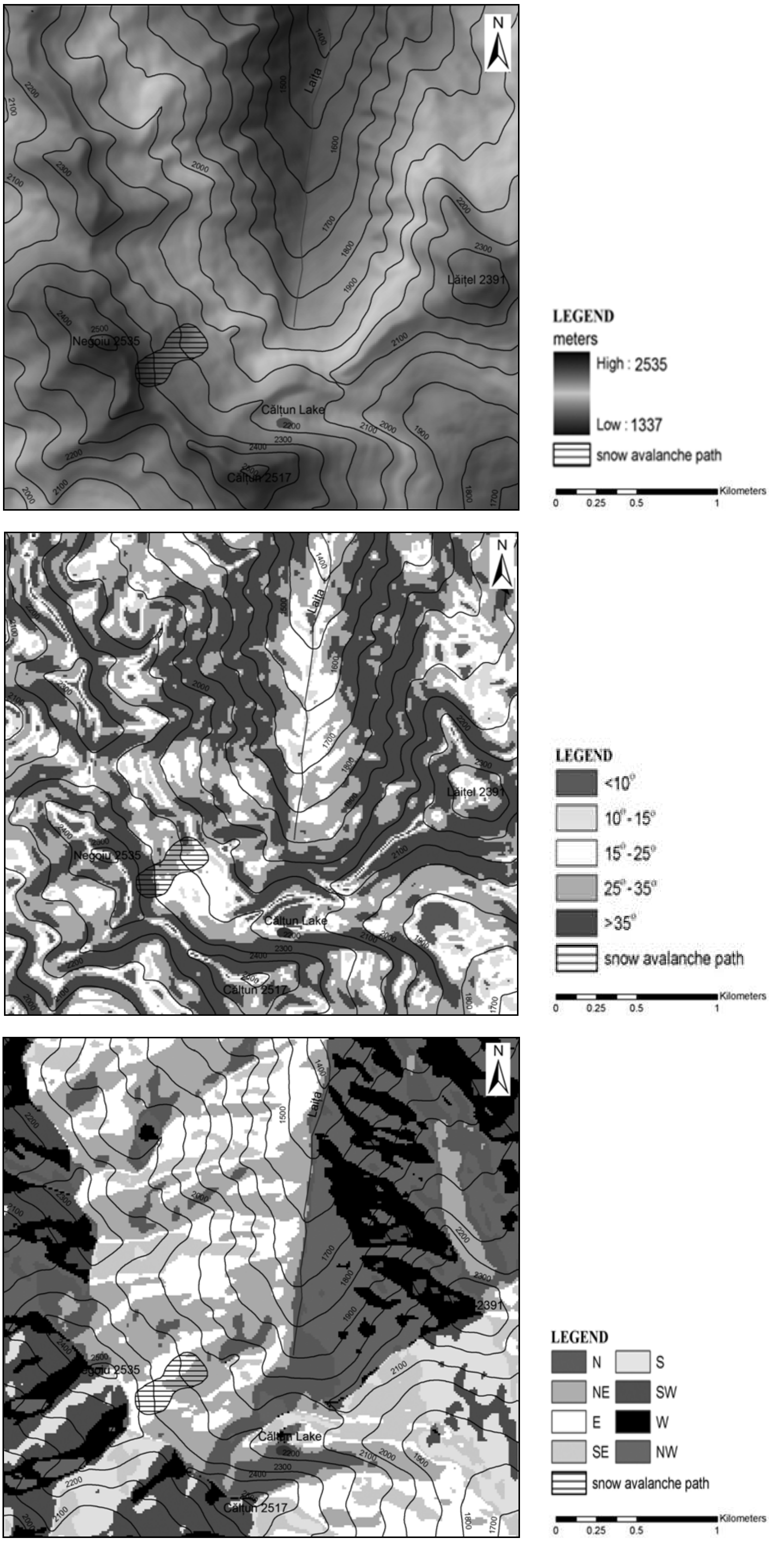

Figure 3. Thematic maps: hypsometry, declivity, aspect

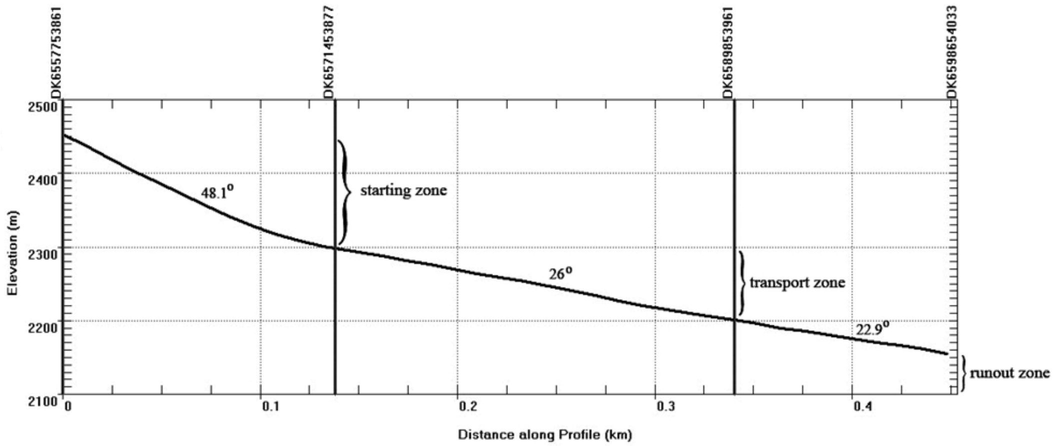

Figure 4. The major morphological units of snow avalanche from Călțun-Negoiu area

Climatic variables

Romania is situated in the temperate-continental climate area, which is characterized by intense snowfalls and snow avalanches (Birkeland, Mock, 2001; Hägeli, McClung, Schaerer, 1993; Mock, 1995, 1996).

Because of its geographic position, many types of climatic influences can be identified on the Romanian territory.The northern slope of the Făgăraş massif, where Călțun-Lespezi and Negoiu sector can be found, is under the influence of the humid western oceanic wind. As such, the regional climate also determines the mode of snow avalanche manifestation, with a powerful influence from solar radiation, temperature, snowfall quantity and type (McClung, Schaerer, 1993; Weir, 2002).

Characteristics of the alpine climate of the Făgăraş massif (table 1) are registered at the mountainous weather stations Cozia and Bâlea-Lac in the Făgăraş massif, and Vf. Omu in Bucegi Mountains. Cozia weather station used to function between 1981 and 1999 and was located at 1577 m on a southern slope at the bottom of the alpine floor. Bâlea-Lac weather station is located at 2070 m altitude in the median floor of the glacial valley with the same name, on a northern slope. The Vf. Omu weather station is situated at 2505 m in the upper alpine floor of the Bucegi Mountains, located near the Făgăraş massif, and thus is representative for our study.

Table 1. Climatic characteristics of the Făgăraş massif (average annual values)

Meteo station (m)	T°C			Pp (mm)	Days with snow	Days with snow cover	Depth of snow (cm)	Sunny days while there is snow cover
	Ann	Min	Max					
Vf.Omu - 2505	-2.5	-10,9	5,8	1246.2	> 130	320	36.9	78.9
Bâlea Lac - 2070	0.2	-8,4	8,8	1246,2	> 96	> 224	66.4	40-45
Cozia - 1577	3	-6,3	12,3	844,2	> 63	150	39.5	30-35

In these conditions, it should be noted that snow avalanche activity has been well monitored by members of the nivo-meteorological program founded in February 2004 at Bâlea-Lac meteorological station, within the National Administration of Meteorology, in partnership with Météo-France, Centre d'Études de la Neige-Grenoble. The main purpose of the program is to study snow and its future evolution, as well as avalanche triggering conditions (Nivological Annual Report, 2004-2005, National Meteorological Administration). The Crocus MEPRA PC program, version Roumanie 2004, offers an opportunity to assess the evolution of snow structure and an estimation of the avalanche risk for different orientations, slopes and/or altitudes, based upon the observations of snow structure (Giraud *et al.*, 2002).

Meteorological parameters are taken from GELINIV program (those already noticed) or from the numerical models, for the next hours: rainfall, humidity, cloudiness and wind speed. Simulations can be made for each massif, on six different orientations (North, East, West, South, South-East, South-West) and three slope inclinations (0°, 20°, 40°). Finally a simulation of snow evolution is obtained for each massif, with an estimated natural and accidental risk of avalanches. Snow avalanches activity has noticeably grown, and when snow avalanches triggering conditions are met, snow depth is regarded as a causal variable in snow avalanches production (Birkeland, Mock, 2001; Fitzharris, Bakkehøi 1986).

DISCUSSIONS

To highlight the climatic characteristics of the Făgăraş massif and of the studied area as well, an assessment of the synoptic situation and evolution of meteorological and specific snow parameters was made, using observations from the Bâlea-Lac meteorological station, and maps representing the synoptic conditions before and during the day of March 7 (figure 5). Thus, until the date of March 4, the Icelandic Depression acted over the European continent, with the corresponding altitude structure. Meanwhile, Romania had been passed by several frontal systems associated with cyclonic centers. In the afternoon of March 4th, the Azorian High entered over Romania, with the corresponding altitude.

The temperature at the level of 850 mb, decreased from 5^{o}C (on March 2nd) to 0^{o}C on March 4th, and -5^{o}C on March 5th, then began to increase up to -1^{o}C on March 6th and 5^{o}C again on March 7th. The 0^{o}C isotherm height decreased from 1800 to 1500 m altitude on March 3rd, then down to 1100 m on March 5th, and then began to increase, first to 1600 m (on March 6th) and then to 2200 m altitude, on March 7th. Under these conditions, poor quantitative snow felt down up to March 3rd, and the snow depth had no important variations. From the afternoon of March 3rd, weather has cooled and it started to snow. Up to the morning of March 5th the layer new snow reached 43 cm. The evolution of meteorological and snow parameters showed a number of features of the period between the 3rd and the 7th of March.

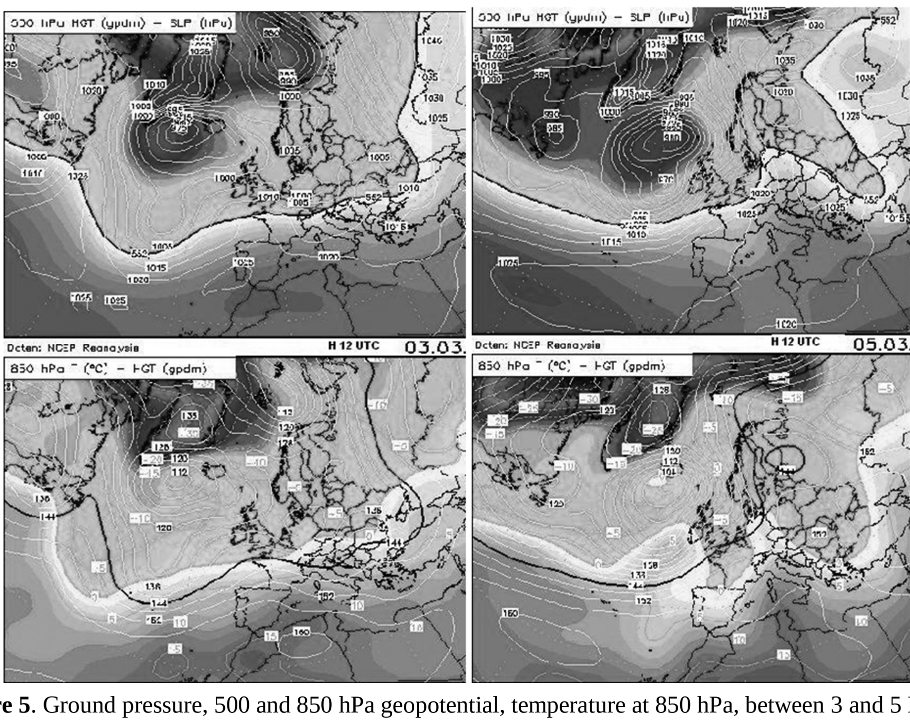

Figure 5. Ground pressure, 500 and 850 hPa geopotential, temperature at 850 hPa, between 3 and 5 March

After a relatively long period in which snow had not varied, since the afternoon of March 3rd, the weather cooled and it started to snow – 9 cm of new snow on the night between the 3rd and 4th of March. On March 4, between 8 a.m. and 2 p.m., the new and fresh snow mounted to about 16 cm, 9 cm until 8 p.m. and added another 9 cm until the next morning - thus, the total amount of new snow measured 43 cm during this period of about 36 hours. By the morning of March 6, temperatures showed no significant variation, and the snow depth decreased by 11 cm (figure 6). Since the day of March 6, the weather heating became quite important, and the maximum temperatures positive: 0°C on March 6 and 2°C on March 7. Also, on the night between the 6th and 7th of March, the temperature was high, reaching a minimum of -1.7°C (figure 7).

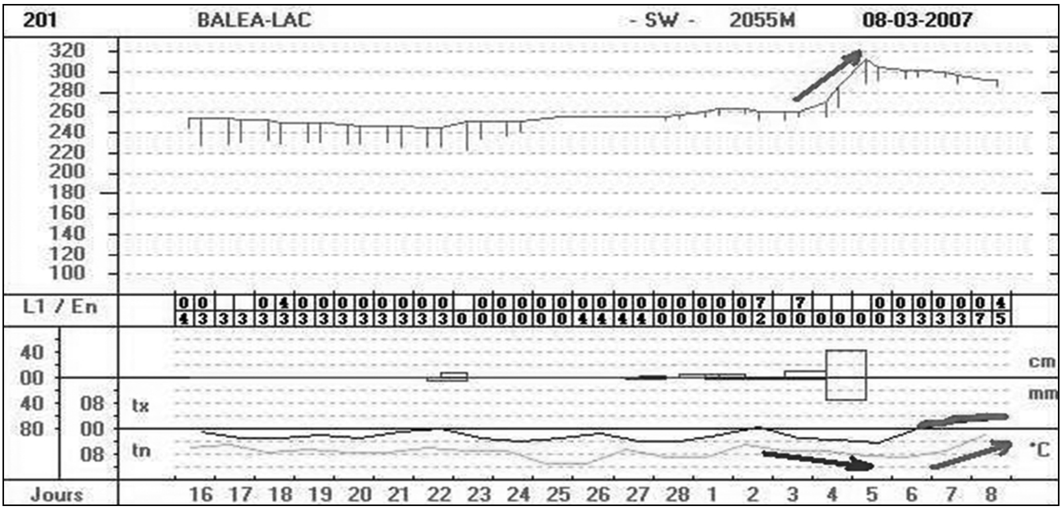

Figure 6. Snow depth, maximum and minimum temperature variation

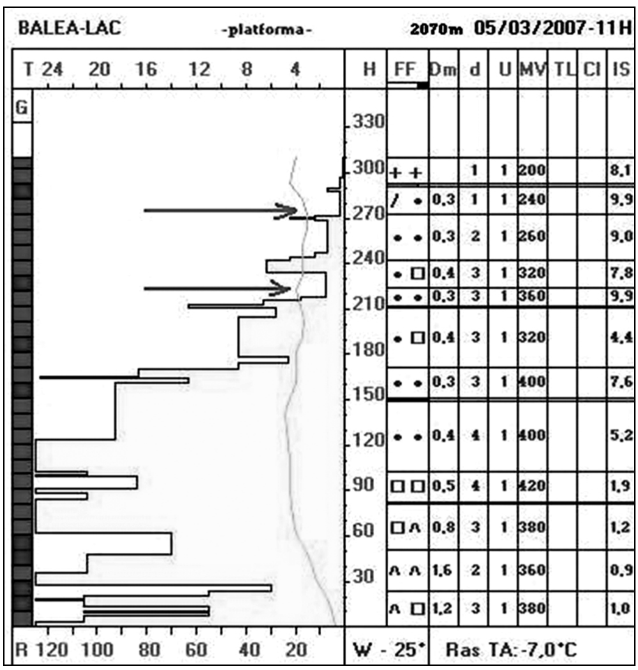

Figure 7. Hardness, temperature and structure inside the snow layer (on the right)

Given the changes in meteorological and nivological parameters outlined above, the members of the Bâlea-Lac station made several snow pits and observations.The measurements made on March 5, have revealed a surface layer of 20 cm new snow with very low resistance, small density and no adherence to the layer underneath, consisting of a thin ice crust.

The top layer consisted mainly of fine grains and less flat faceted, forming an unstable fragile plaque structure of 40 cm, deposited over a thin ice crust, which constituted the second sliding level. At approximately 230 cm over the ground, another sliding level could be identified. Older structures have been found deep inside the layer, like wind plaque and several ice crusts of different thickness. Last 100 cm from the ground surface was formed of cup-type and faceted crystals; snow ram under its own weight has determined the high snow densities and hardness.

Given the above analysis we can thus classify the avalanche from Călțun-Lespezi and Negoiu sector. In the literature, snow avalanches are classified according to several criteria, taking into account topography, climate variables, time of the year, and the triggering mechanism.

According to the geographical classification of Vanni (1966), there are two types of snow avalanches in the Făgăraş massif: medium high-mountain (of slope and couloirs) and valley floor avalanches with a local character. In the first case, avalanches occur within the glacial cirques and in the lower part of the glacial valleys, at altitudes higher than 2220-2300 m, as is the case with the studied area; the avalanche could be classified as one of medium high-mountain. From the path morphology point of view, the snow avalanche of Călțun-Lespezi and Negoiu was an open flat track or unconfined avalanche (the Quervain, 1966) or open slope (Schaerer, 1972; McClung, Schaerer, 1993). Taking into account the weather factors, the snow avalanche can be classified as new snow avalanche (the Quervain, 1966) or as a direct action snow avalanche (Capello, 1973; Lachapelle, 1966), considering the fact that it was produced soon after a huge snowfall. Likewise, if we consider the month or season when it was produced, then the snow avalanche can be characterized as typical of the spring season (Luckman, 1977).

CONCLUSIONS

Given this case, it is once again proven that the human involvement in snow avalanche triggering is present in many situations (Schweizer, Camponovo, 2001, Schweizer, Lütschg, 2001) and the snow avalanche prevention requires a good education.

Establishing specific snow measurements at Bâlea-Lac meteorological station was a necessity and represented a first step in the modern analysis of snow and snow avalanches and towards the understanding of their triggering mechanism. In this context, more snow measurements need to be set in the mountains with snow avalanche risk, in order to collect meteorological data useful for GELINIV and CROCUS-MEPRA PC programs. Using these observations and programs will be useful in the effort to draw the avalanche risk maps, as well as to give daily snow information and warnings for skiers and tourists.

After the European avalanche risk scale was launched in 1993-1994, Romania adopted it, too, due to the need for unique avalanche prevention criteria (Voiculescu, 2009), which is the second important step in this area taken by our country. An important part of the Romanian Carpathians, such as the Eastern and Southern Carpathians (all except for the Western Carpathians), has areas exposed to avalanches. They are recorded in the European Spatial Planning Observation Network (ESPON) Data base (Schmidt-Thomé, 2006).

In the same context of risk prevention, the visual warning system should also be considered. Unfortunately, at the moment, it only exists in the Bâlea glacial valley (from January 2009). Seconded by a good tourists education, this system can be very effective: for example, the avalanche risk can be displayed on panels, together with warnings, as "No Stopping" or "Avalanche Area", like in Canada (Weir, 2002) or other countries.

Multidisciplinary teams need to be formed (geographers, geologists, meteorologists, forest engineers, land-use planners, and also IT specialists), in order to develop programs that should study this problem. The teaching units, the Mountain Rescuers, as well as the media, need to set up educational programs for the population and raise awareness of the measures that need to be taken in order to prevent snow avalanches.

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