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Analysis of Mountain Relief for the Causes of Snow Avalanches

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Abstract. The descent of avalanches is quite a usual phenomenon for the Ukrainian Carpathians, as well as for the conditions of mountain terrain in general. The Gorgany range of the Carpathian mountains is a typical avalanche-prone territory. Avalanches cause significant damage to forestry and may lead to casualties. Therefore, descent of avalanches has for a long time been a subject of fundamental research in geomorphology, meteorology, topography, photogrammetry and GIS technologies. Using photogrammetric mapping, we analyzed the causes of the descent of one of the largest avalanches in the Ukrainian Carpathians for the past 15 years. The avalanche fell from Poliensky mountain in the Gorgany mountain range in 2006, causing destruction of a great amount of forest. The main causes of avalanches were divided into two groups, the first including more or less stable factors caused by impact of terrain and somewhat less by solar radiation and the second group comprising meteorological factors, such as prolonged snowstorms and snowfall, that is, different fluctuations in weather. The main attention was paid to the first group of factors. For this purpose, a digital terrain model (DTM) of the study area was developed, visualizing the terrain, demonstrating the studied slope of the mountain along which the avalanche slid. According to the digital model, we developed maps of the steepness and exposition of the slope. Also we calculated the coefficient for solar radiation incident on the slope and which depends on the height of the Sun above the horizon and the coordinates of the slope. Using these data, the illuminance map of the Poliensky mountain area was developed. Studies conducted using GIS technologies led to the conclusion that the determining factors that triggered the powerful avalanche from Poliensky mountain were the great steepness and length of the slope, as well as the absence of forest at the top of the mountain, i.e. at the beginning of the avalanche track.

Keywords: avalanche; mountainous terrain; relief; illumination; slope; forest; geoinformation technologies; visualization

Аналіз гірського рельєфу щодо причин виникнення снігової лавини

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Анотація. Виконано аналіз причин сходження однієї з найбільших снігових лавин в Українських Карпатах за останні 15 років, – тієї, що зійшла з гори Полєнський гірського масиву Ґорґани 24 березня 2006 року і призвела до знищення великої кількості лісу. Основні причини сходження снігових лавин розділено на дві групи. До першої віднесено більш-менш стабільні чинники, викликані морфометричними факторами, а саме впливом рельєфу та, дещо меншою мірою, сонячної радіації. До другої групи віднесено чинники, які можуть значною мірою змінюватися з часом. Це метеорологічні фактори, а саме – тривалі заметілі та снігопади, тобто різні коливання погодних умов. Основну увагу приділено першій групі чинників. Для цього створено цифрову модель рельєфу досліджуваної території, що дозволило візуалізувати рельєф, наочно представити досліджуваний схил гори, по якому зійшла лавина. За даними цифрової моделі побудовано карти крутизни та експозиції схилів. Також розраховано коефіцієнт сонячної радіації, яка потрапляє на схил і залежить від висоти Сонця над горизонтом та координат схилу. За цими даними створено карту освітленості району гори Полєнський. Проведені дослідження з використанням ГІС-технологій дозволили зробити висновок, що визначальними чинниками, що призвели до сходження потужної снігової лавини з гори Полєнський, були велика крутизна та довжина схилу, а також відсутність лісу на вершині гори, тобто на початку шляху лавини.

Ключові слова: снігова лавина, гірська територія, рельєф, освітленість, схил, ліс, геоінформаційні технології, візуалізація

Introduction. Analysis of causes of avalanches – such as for example prolonged blizzards and snowfalls, rapid fluctuations of weather conditions and temperature due to radioactive melting of snow, terrain and vegetation of an area, etc – indicates that they could be divided into two groups. The first group comprises factors which are unstable and may change over time, while the second one includes factors which to some extent or other in a particular area could be considered stable. Locations of slides of avalanches or avalanche-prone areas are characterized by stable factors such as relief of the Earth`s surface and to a certain extent the amount of solar radiation incident on the area. These aspects will be analyzed in this article.

Poliensky mountain is located in the Ukrainian Carpathians, within the Gorgany Nature Reserve, and particularly Nadvirniansky district of Ivano-Frankivsk Oblast, south of Chernik village and east of Bystrytsia village. The name of the mountain derives from the word "poliana" (locally "poliena" [Ukr. поляна, полєна – glade – *Translator`s note*]), therefore, perhaps, the mountain would be better called Polienska, and not Poliensky [referring to feminine gender of the word – *T.n.*]. The mountain is located in the north-west part of the Dovbushanka range. Its altitude equals 1,693 m, the northern and eastern slopes are steep and inaccessible. The top and pre-top slopes are not forested, with rocky screes, in some places with krummholz of bog pine (*Pinus mugo*); lower there are located forests composed of softwood tree species, particularly spruces, bog pines, cedar. North-east of the peak Kozlii Gorgan mountain (1,617 m) is located , while south-east of the peake are Vedmezhyk (1,737 m) and Dovbushanka mountains (1,754 m).

High avalanche danger is seen in high mountain areas of the district – Bratkivska and Dovbushanka. In total, within this district, 248 avalanche-prone areas were found, where avalanches occur mostly in the winter-spring period. Avalanches occur every year, most often in snowy years; mainly dry-snow avalanches of fresh snow, or after blizzard, more rarely - wet-snow avalanches (during thaws and melting of snow).

Objective and relevance. The objective of this article was performing analysis of causes of one of the biggest avalanches which occurred in the Ukrainian Carpathians over the last 10-15 years, namely the one which fell from Poliensky mountain on 24th March of 2006, causing destruction of a large part of the forest in the Gorgany Natural Reserve. Along its way the avalanche destroys not only a great amount of productive forest but young trees as well, it sweeps all this material down to the foot of the mountain, altering the terrain. From the philosophical point of view, the surface is both cause and effect of the avalanche.

Fig. 1 and 2 show a satellite image of Poliensky mountain, indicating the avalanche track, and a photograph of the northern slope, showing the aftermath of the avalanche.

Figures 1 and 2 show that the avalanche plummeted from the northern slope of the mountain, causing significant losses of forest which still has not recovered, though 14 years have passed. The total length of the avalanche track is 1,380 m, width – 50 to 110 m. The length of non-forested part of the pathway equaled 437 m. Thus, the area of lost forest accounts for around 6.3 ha. Assuming that the average height of trees is 30 m, and the thickness of the trunk – 25 m, distance between the trees – 3 m, we obtain losses of 8,440 trees or 12,410 m^3 of wood.

Therefore, study of snow-sliding processes and analysis of their causes are quite relevant, because apart from financial losses, large avalanches can lead to human casualties.

Analysis of the literature sources. Because avalanches have been studied over several centuries, this topic is described in a large amount of scientific literature sources (Bellaire et al., 2016; Canadian Avalanche Association, 2002; Hendrikx, Murphy & Onslow, 2014; Tykhanovych & Bilaniuk, 2015; Rudyi & Husar, 2011; Rudyi et al., 2012; Rudyi, 2018). The most recent in-depth studies include analysis of physical properties of snow and the soil beneath it. Particularly, one article indicates priority influence of the terrain and presence of forest, especially hardwood tree species on the mountain slopes (Tykhanovych & Bilaniuk, 2015). The surveys of Japanese scientists were focused on the problems of modeling using satellite technologies of spatial distribution of snow cover in mountainous countries (Asaoka & Kominami, 2012). As for the Ukrainian Carpathians, the creation of a digital model of the terrain of avalanche-prone territories as a tool of mapping using GIS-technologies has been substantiated (Hrytskiv, Laikun, & Babii, 2016).

The latest publications of Canadian researchers include a large amount of references to the literature sources (Bellaire et al., 2016; Canadian Avalanche Association, 2002; Hendrikx, Murphy & Onslow, 2014; Margreth, 2007; McClung & Schaerer, 1993; Pistocchi, 2002). Particularly, they note that in studying the causes of avalanches one should take into account determining territorial conditions. One might add that this should be also taken into consideration while choosing tourist itineraries (Kolotukha, 2008).

The object of the research presented in this article is the extremely destructive avalanche which

Fig. 1. Poliensky Mountain (from open internet source)

descended from Poliensky mountain in the Ukrainian Carpathians on 24th of March 2006, and the subject is the terrain of the territory of its occurrence.

Materials and methods of study and results. To analyze the causes of avalanches from Poliensky mountain, we used the methods of geoinformational modeling. Experimental researches were performed using the materials (digital terrain models, DTR) at the Scientific-Research Institute of Geodesy and Cartography using SURFAR software pack on the basis of photo-material collected by the authors (Rudyi & Husar, 2012). The size of the territory the DTR was created for accounts for 15.2 X 14.1 km or 21.5 thou ha. Distance between the nodes of the grid of the digital model was 15 m. Fig. 3 shows a map of the research area. Fig. 4 provides a more detailed image of Poliensky mountain and the slope where the avalanche occurred. The size of the digital model of Poliensky mountain equals 3.2 X 4.3 km or 1.4 thou ha. Distance between the nodes of the grid of the digital model equals 4 m.

Fig. 3 shows that the terrain of the studied area of the Gorgan territory is complex, deeply divided,

Fig. 2. Northern slope of Poliensky Mountain (Rudyi & Husar, 2012)

making it especially avalanche-prone. In many places, avalanches reach the bottom of the gorges, thus blocking the mountain rivers and forest roads.

Methods of digital modeling visualized the terrain of the area, demonstrating the surveyed slope of the mountain along the track of the avalanche , allowing us to analyze its morphometric factors, particularly steepness, length and exposition of the slope. For this purpose, according to the data of the digital model of the terrain, we developed maps of exposition and steepness of the slopes, given in Fig. 5 and 7.

This map indicates the image of orientation of the slopes of Poliensky mountain in relation to the cardinal directions, blue indicates the northern slopes, red – southern, green – western, yellow – eastern.

Regarding exposition, southern slopes are considered to be more prone to avalanche-formation than the northern one, western and eastern being average in this respect. It is explained by the fact that the southern slopes are better heated, and the snow melts there more intensely (Rudyi et al., 2011). In our case this factor is not the determining one, because the avalanche descended along the northern slope. Illuminance of the slopes is another factor leading to avalanche. The current of solar radiation onto the slope S_C depends on the height h and azimuth of the sun A, inclination angle v and azimuth of slope α:

$$E_C = E_O \cdot \left[\cos h \cdot \sin \nu \cdot \cos\left(A - \alpha\right) + \sin h \cdot \cos \nu\right] = E_O \cdot K_S$$

where E_O – current of direct solar radiation onto the surface which is perpendicular to the sunrays of the area of 1 m^2 per 1 sec:

$$E_O = 1.36 \cdot 10^3 \mathrm{W/m^2 \cdot sec.}$$

The coefficient Ks, which is the cosine of the angle between the direction of the Sun and the normal

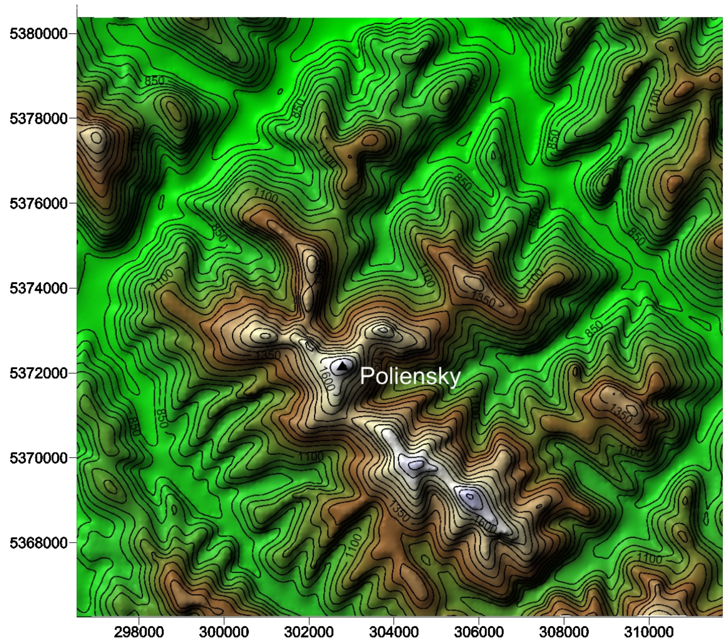

Fig. 3. Digital model of the studied area

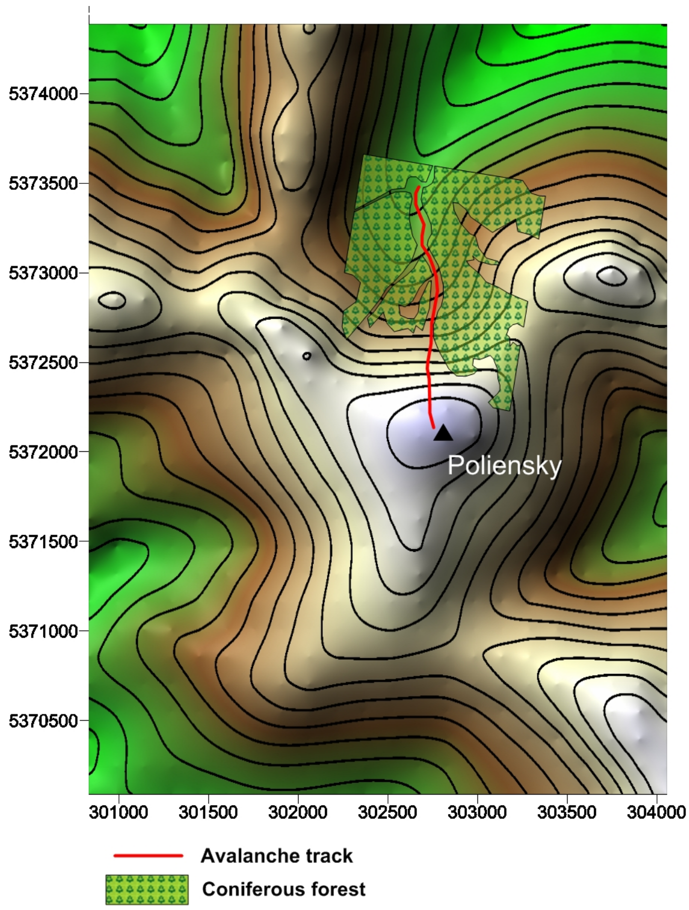

Fig. 4. Digital model of the slope where the avalanche struck

to the earth's surface, was calculated and a map of the illumination of the Polensky mountain area according to these data was created.

We calculated K_S coefficient which is the cosine between the direction towards the sun and the normal to the earth surface = normal surface of the Earth`s surface, and according to these data, we developed the map of illuminance of Poliensky mountain given in Fig. 6.

According to the content of Fig. 6 which shows the division of the territory of Poliensky mountain according to the angles between the direction towards

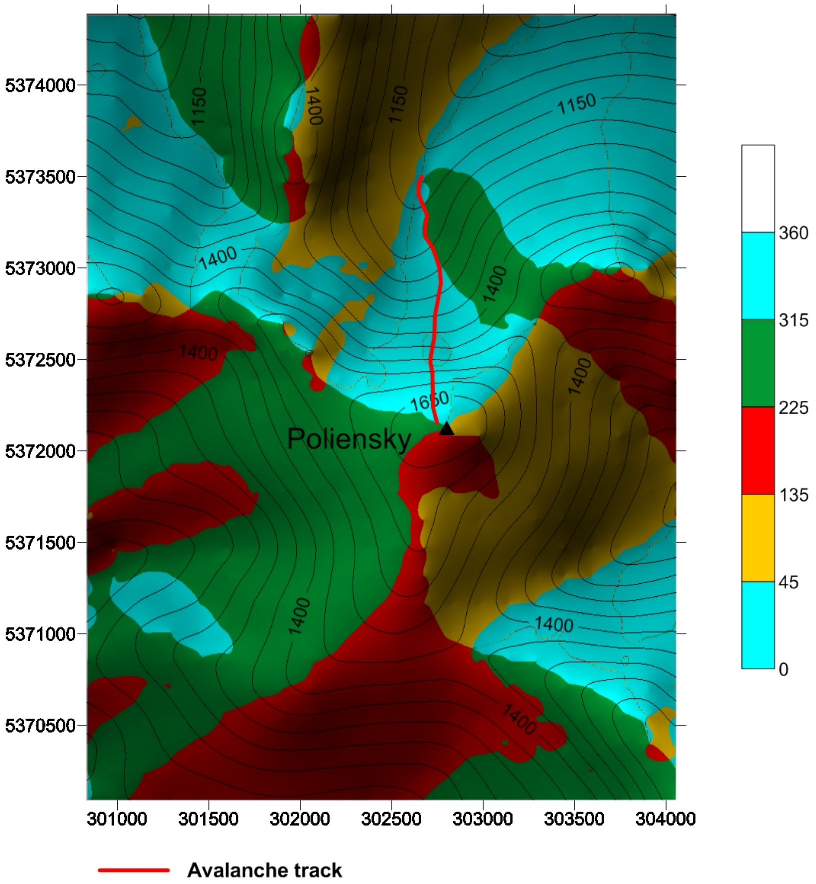

Fig. 5. Map of the exposition of the slope

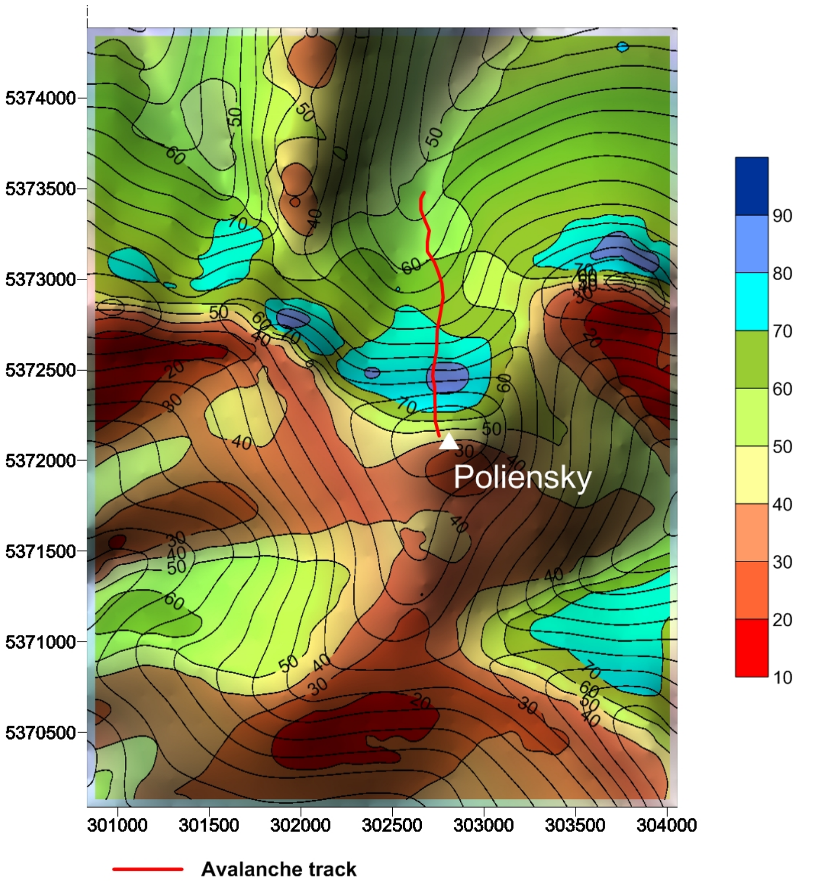

Fig. 6. Map of the illuminance of Poliensky mountain (Levchenko & Shynkarenko, 2003)

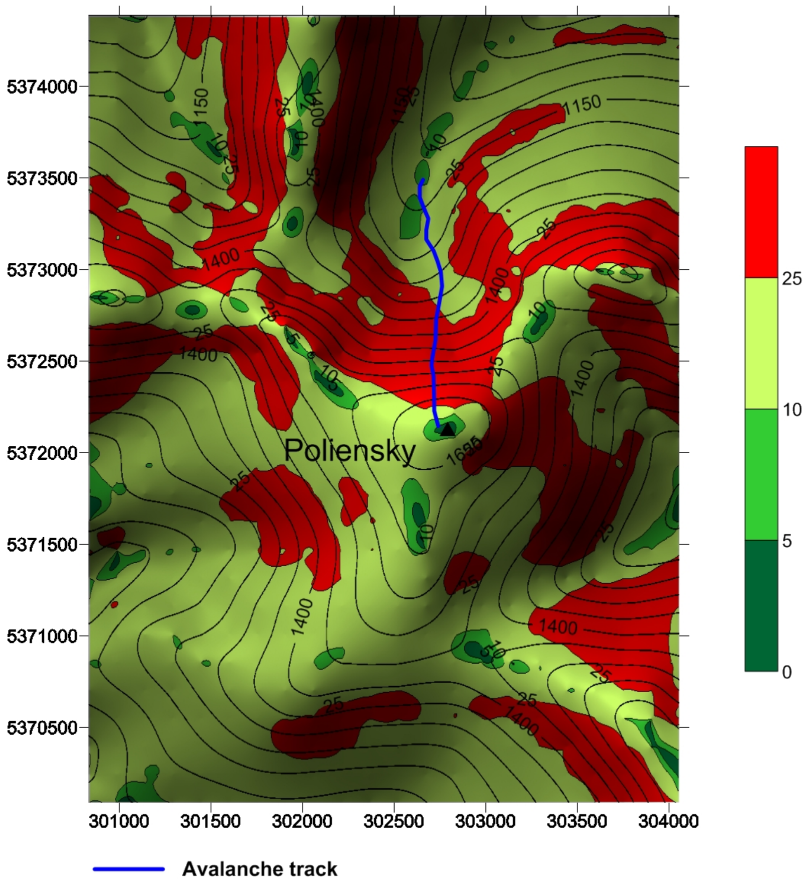

Fig. 7. Map of the steepness of the slope

the sun and the normal towards the earth surface (the lesser this angle, the larger amount of heat is incident on the slope), the avalanche fell along moderately illuminated slope. Thus, the illuminance factor was also not the determining one in this case.

Therefore, the determining factor in this case, apart from meteorological conditions of course, is the terrain of the area. According to the developed map of steepness, the slope on which the avalanche descended is characterized by great angle of steepness. If one does not take into account the height of the mountain with insignificant slope angle of up to 10°, then the first half of the avalanche track runs along the slope with steepness angle of over 25°. The length of the avalanche`s pathway is 1,380 m.

Great length and inclination angles of slopes contribute to occurrences of avalanches in forest cuttings and even in forests. Particularly those factors were determining during the formation of the avalanche on the northern slope of Poliensky mountain. Such conditions of terrain underlie the occurrence of an avalanche of great kinetic energy and development of a wind shock wave which can cause destruction, and even destroy areas of forest on opposite slopes.

Conclusions and perspectives for further studies. The studies performed using GIS-technologies allowed us to state that the determining causes of the avalanche from Poliensky mountain were great steepness and length of the slope and also absence of forest on the mountain peak, i.e. at the starting point of the track of the avalanche (437 m). At the same time, occurrence of the avalanche on the northern slope with low illuminance makes it non-typical, because as we know intense heating particularly of southern slopes leads to development of avalanche processes.

Obviously, apart from morphometric factors, the formation of the studied avalanche and its fall in the indicated place was to a large extent affected by the meteorological factor, particularly great amount of snow, and perhaps formation of a “visor” or “cornice” on the peak and its further dislodging in particular weather conditions, leading to an avalanche, while absence of forest composed of hardwood trees meant there was no obstruction to the sliding. Detailed study of the role of meteorological factors in development of avalanches in the Ukrainian Carpathians in general and the one that descended from Poliensky mountain in 2006 in particular can be one of directions of further studies of causes of development of avalanches.

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