USING MODERN GIS TOOLS TO RECONSTRUCT THE AVALANCHE: A CASE STUDY OF MAGURKA 1970

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Abstract

A huge avalanche released on 14 March 1970 from the saddleback of Ďurková below the Low Tatras mountain ridge, which ran down through the whole valley and stopped close to the settlement of Magurka. The length and height of the avalanche path was enormous reaching 2,2 km and 22 meters high respectively. Taking other parameters into consideration (the length of the avalanche, the height of the avalanche release zone, total volume of snow) it can be categorised among the greatest avalanches ever observed in Slovakia. The major causes for such a big avalanche were unfavourable long-lasting snow and weather conditions. However, the starting mechanism was, as in most cases, a man. RAMMS model was used for avalanche reconstruction. It allows modelling the height of avalanche deposition, the speed of an avalanche flow and also the maximum pressure that was reached. All the required input data were derived from historical information, photographs and maps and also from the statements of the witnesses of this avalanche event. The avalanche has been successfully simulated and reconstructed. The total volume of deposited snow (relative deviation 0.16%) revealed that the simulated released area and other input parameters were precisely approximated. Small deviation between simulated and measured avalanche runout zone refers to good calibration of friction parameters. The result of the modelling will enable us a better understanding of the complete progress and action of this avalanche during its motion. The results can be also applied to planning and constructing of anti-avalanche structures and to minimizing the negative consequences of similar avalanche in the future.

Keywords: avalanche, modelling, reconstruction, Magurka, runout zone

INTRODUCTION

For centuries, people have been altering the Earth's surface to produce food and gain material or energy through various activities. The urban areas are being enlarging backcountry skiing areas spreading fast etc. Over the last years, more people are coming to the mountains, building new cottages and cabins underneath, spending more time in the countryside. Magurka surroundings are no exceptions. The mountains are becoming overcrowded and the fact that people are dramatically enhancing the avalanche risk is well known. This was also the case of the Magurka 1970 tragedy, when four skiers triggered the avalanche. Three of them died. To avoid the risk of tragedies in the mountains of Slovakia, it is important to undertake more studies involving GIS. This paper deals with avalanche reconstruction applying the avalanche dynamics program RAMMS. Modern numerical simulation tools are frequently used for avalanche prevention in USA, Canada and some alp countries, especially in Switzerland and Austria. On the other side, in Slovak Republic as well as in Czech Republic, these tools have not been used yet. The aim of the paper is to show that this historical process can be reconstructed with modern technologies and give some useful information, which can be used nowadays

DESCRIPTION OF AVALANCHE EVENT

Weather conditions were good on March 14, 1970. Four skiers came to the saddleback of Ďurková passing the main ridge from Chopok. One of them was slightly injured, so they decided to go down all the way to Magurka settlement. They started to traverse to the right crest, and so releasing one of the greatest avalanches in Slovak history. The total amount of deposited snow was 65 000 m^3, i.e. about 200,160 tons of snow. This snow deposition was stretching over 1.8 km and the front was from 20 to 25 m high. This mass of snow did not melt the following summer. The avalanche was 2.2 km long and was extending on the total area of 35.8 ha. The release area was 340 metres wide and the vertical drop between the top of the release and avalanche front was 620 m. The released snow layer varied from 1.8 metres on side ridges to 12 metres in gullies. In this mass of snow the rescue team (517 rescuers) could not find the victims for 26 days. The last victim's body was found on 6 June.

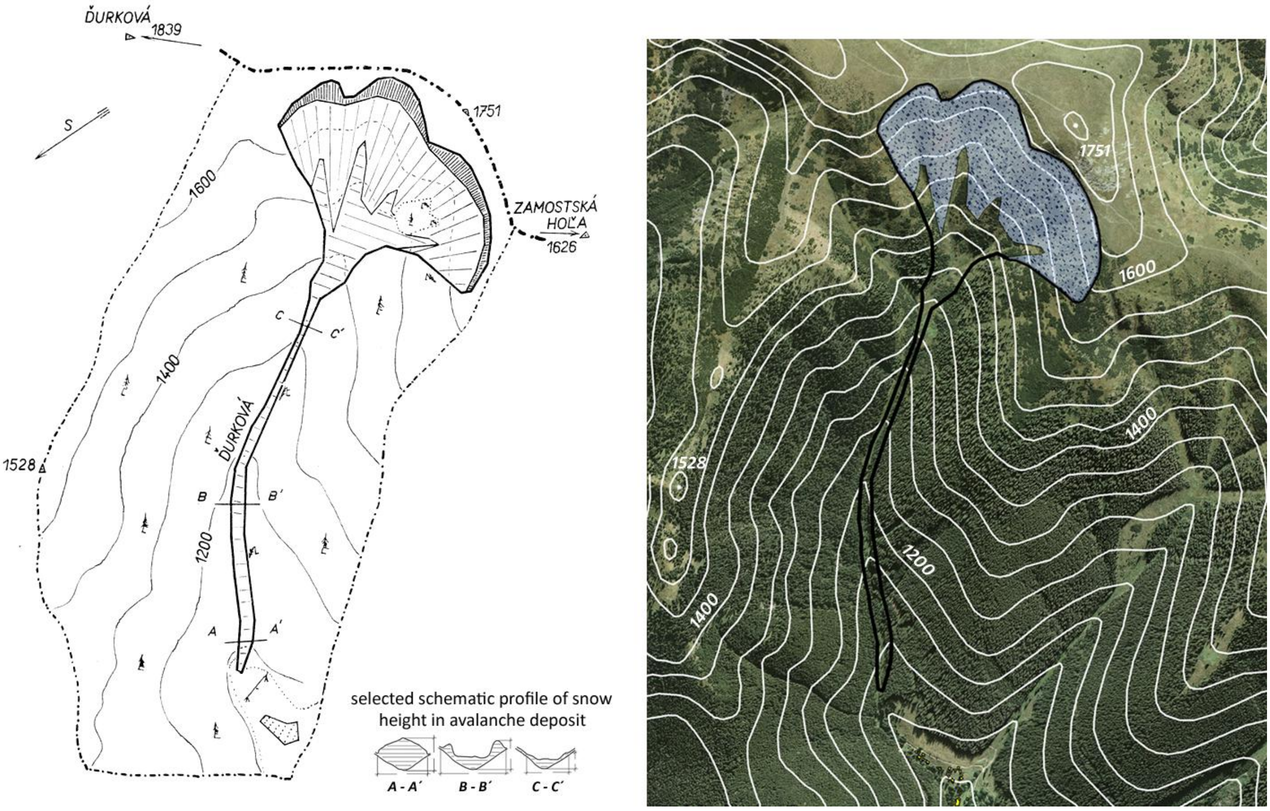

Fig. 1. Schematic location outline and its presentation in ArcMap software

AVALANCHE SIMULATION

Modern numerical simulation software package RAMMS was used for avalanche simulation. RAMMS (*RApid Mass MovementS*) model calculates the motion of geophysical mass movements (including snow avalanches) from initiation to runout in three-dimensional terrain (Christen, 2010). It has been developed at the WSL Institute for Snow and Avalanche Research SLF in Davos. Model RAMMS can be used for accurate prediction of avalanche runout distances, flow velocities and impact pressures of avalanches. For this case of study, we have used this model for calculating the snow height in avalanche deposition and for understanding the avalanche motion. Input data were gained from historical records, studies and photos. The same data were used also for calibrating the model (calibration of friction parameters) to obtain sufficiently accurate simulation. Required input data for model RAMMS are mentioned below. Well prepared data are essential for the quality of the model results.

Release zone

Sufficiently precise reconstruction of avalanche release's parameters has the biggest influence on exactness of simulated result. The characteristics of release determine directly the volume of avalanche snow mass. They determine the velocity of avalanche and the kinetic energy of avalanche together with the influence of terrain attributes. Hence, the reconstructed allocation of release, its shape and length of the avalanche has to be done correctly not to derive incorrect inputs. The reconstruction was deduced from schematic location outline, historical records and pictures. The main attributes of avalanche release are mentioned in Table 1. The maximum of 12 m height release were recorded in the channel due the weather conditions. Snow accumulation is taking place, especially in channels or smaller gullies under the main range. So, 12 m height is not a rare value. According to the attributes, primarily to the length, it is one of the largest avalanches observed in Slovakia. Fig. 1. shows the location outline of avalanche area, which was geotransformed and subsequently vectorised in ArcMap.

Table 1. Basic parameters of avalanche release

length of fracture line	maximal snow height	minimal snow height
1500 m	**12 m**	**1.8 m**

One of the fundamental problems in avalanche modelling is an accurate definition of release zones. It is very difficult to define release areas with responsible release heights in three-dimensional terrain. In avalanche modelling, it is common to set one release height for whole release area because of ease, simplicity and rate of calculation. In this case we have tried to simulate and reconstruct historical avalanche with big span of threshold release heights (1.8 m – 12 m). With consideration to the biggest approximation to the reality, our approach the release area was to divide it into few smaller areas with different release heights.

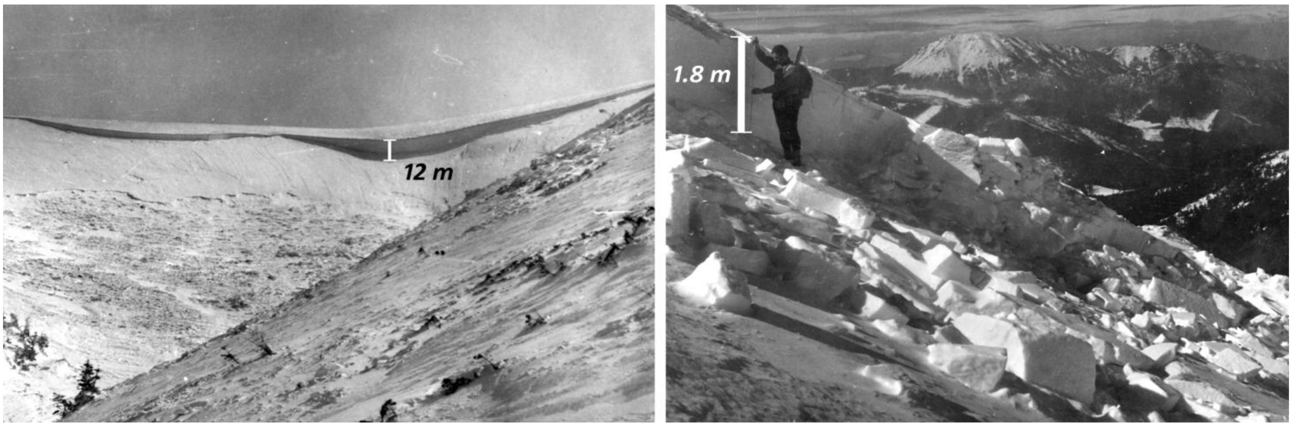

Fig. 2. Big differences in release snow height in range 1.8 up to 12 m

Terrain parameters

A terrain is considered to be a permanent, stationary factor in avalanche forecasting. So, we can use present terrain parameters also for simulation of historical avalanche events. We do not assume that there were some considerable changes in terrain proportions between years 1970 and 2010. We used digital elevation model of the study area for simulation in model RAMMS. It was derived from contours in a basic topographic map of research area with scale 1:10 000. Spatial resolution of DEM was set to 2 m (this is the value recommended for detailed avalanche simulation in RAMMS). This is accurate enough for including small terrain features, like big boulders, gullies, needles and depressions into the simulation. A good digital representation of the topography is crucial for the accuracy of the model results, especially in sensitive areas, such as small gullies and mountain ridges (Haeberli et al., 2004). In this case, interpolation method Topo to Raster in ArcMap software was used to determine the digital terrain model of study area.

Forest cover

The forest cover significantly inhibits or even stops avalanche flow. Thus, it significantly influences avalanche flow direction, flow velocity, and subsequently also the resulting shape of an avalanche path. To reach the most precise reconstruction of the avalanche, impact of the given forest cover was also needed to be included into the simulation. But, when the impact pressure of avalanche is more than about 100 kPa (threshold value for uproot mature spruce), inhibiting effect of the forest cover become insignificant. Large avalanches often break trees and develop into a mixed flow of snow and trees, creating greater mass with increasing damage potential. As we wanted to include information about the forest cover into the simulation, we needed to obtain this information from the date before March 1970. For this purpose the basic topographic map from the year 1956 was used. The comparison between the forest cover before simulated avalanche and the present state of the forest cover is shown in Fig. 3. Forty years are quite a long term and differences in the forest cover are significant. Therefore it is so important to use adequate information about the forest cover for avalanche modelling. Other important factors related with the forest cover (cover density, height of trees, species diversity) have influence, but the forest occurrence is sufficient for precise modelling results using model RAMMS (boolean raster layer: 0 for no forest, 1 for forest areas).

Fig. 3. Differences in forest cover in years 1956 and 2010

Inhibiting and obstacle effect of dwarf pine was not considered into this calculation due to extensive height of snowpack. The dwarf pine cover influences avalanche formation only in case, when the height of the snowpack is smaller than the height of the dwarf pine cover.

Snow density of release area

The density of released snow is another important factor linked with avalanche modelling and with model RAMMS. There are no precise measurements of snow density in historical records. However, it can be assumed that reconstructed avalanche was a hard dry slab avalanche. This precondition was derived on the grounds of historical photos (Fig. 4). A hard slab usually has large chunks of debris in the deposit. They are evidently recognized on these photos. A sharp bounded breakaway wall of top periphery of the slab is another characteristic feature for dry slab avalanches. It is also visible on these figures. Large amount of snow in gullies is the result of snow transporting due to blowing wind. Wind packing can produce dense, cohesive snow, which aids in slab formation (McLung & Schaerer, 2006). These slabs are usually very brittle with low cohesion with the snow layer beneath. Generally speaking, most slabs consist of cohesive wind-deposited or well-bonded old snow. Average density for such snow is about 200 kg/m^3 with the range of 50 to 450 kg/m^3 (McLung & Schaerer, 2006). From the sample on Fig. 4., nearly 90% of these avalanches have average densities between 100 and 300 kg/m^3. Densities below and above this range are rare. The value 200 kg/m^3 was set as the best estimation and was used in the avalanche simulation in model RAMMS. Dry slabs are responsible for most of the damage and fatalities from avalanches. According to world injury statistics, 90 % of these slab avalanches were triggered by mountain visitors themselves.

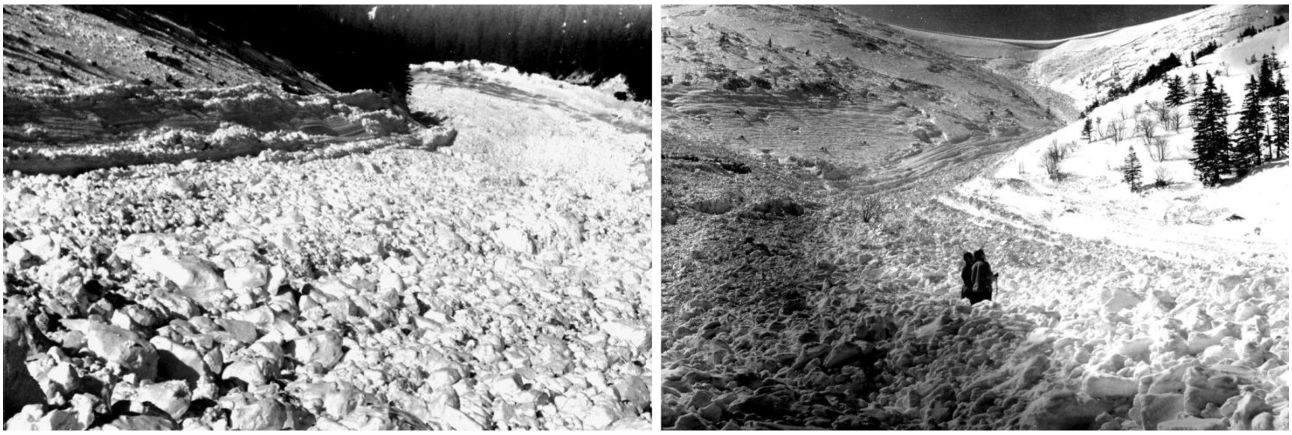

Fig. 4. Large chunks of debris in the deposit, typically for dry slab avalanches

SIMULATION ACCURACY

Simulation accuracy is given by comparison of the simulated results with the real measured data obtained by the field research in 1970. The differences between the simulated results and the measured values are shown in the Table 2. It is necessary to mention that the precise measurement of parameters (volume, area) in 1970 was difficult. Still, it is impossible today to make precise measurements of such a big avalanche without using GIS technologies (LIDAR, modelling, etc.). Due to proper calibration method close approximation of real measured avalanche runout zone (Fig. 5.) was reached. The deviation from the real measured runout zone was statistically insignificant as well as the deviation of total avalanche volume. In spite of this, the height of avalanche front was not successfully restored (Fig. 6.). The real height of avalanche front exceeds simulated value considerably. The difference in the total avalanche area is observed mainly on the upper right part of the slope. This is due to inaccuracies in DEM representation and in localization of release area. Comparisons of all simulated results with real measured data are shown in Table 2. The relative deviation from the measured data was calculated as the ratio of difference to the measured value in 1970. The value of total area was set to recalculated data from 1970 using GIT (39.1 ha). Sequences of avalanche simulation in different computing time steps are shown in Fig. 7. A single sequence is showing the maximum height of moving snow. Profile B (Fig. 5.) is revealing a significant unevenness in the deposit surface. It was testified by eyewitnesses and historical photos.

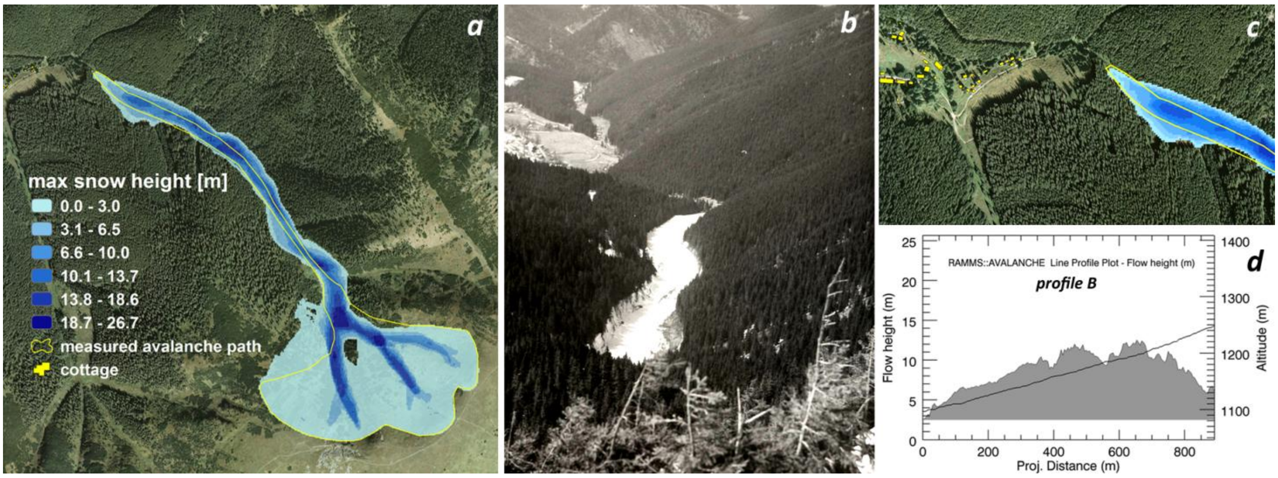

Fig. 5. Maximal snow height from avalanche simulation (a) and comparison of its runout zone with real measured data (c). Simulated snow height in longitudinal profile of avalanche deposit (d), which is captured in the historical photo (b)

Table 2. Comparison of the simulated results with real measured data

Parameter name	Measured 1970	Simulated 2010	Difference	Relative deviation
Avalanche length	2 200 m	2 221 m	21 m	0.95 %
Snow deposition length	1 800 m	1 725 m	75 m	4.17%
Snow deposition volume	625 000 m^3	626 028.7 m^3	1028.7 m^3	0.16 %
Front height	20 – 25 m	4 – 5 m	16 – 20 m	80.00%
Total area	35.8 ha (39.1 ha)	51.38 ha	12.28 ha	31.41 %
Vertical drop	620 m	622 m	2 m	0.32 %

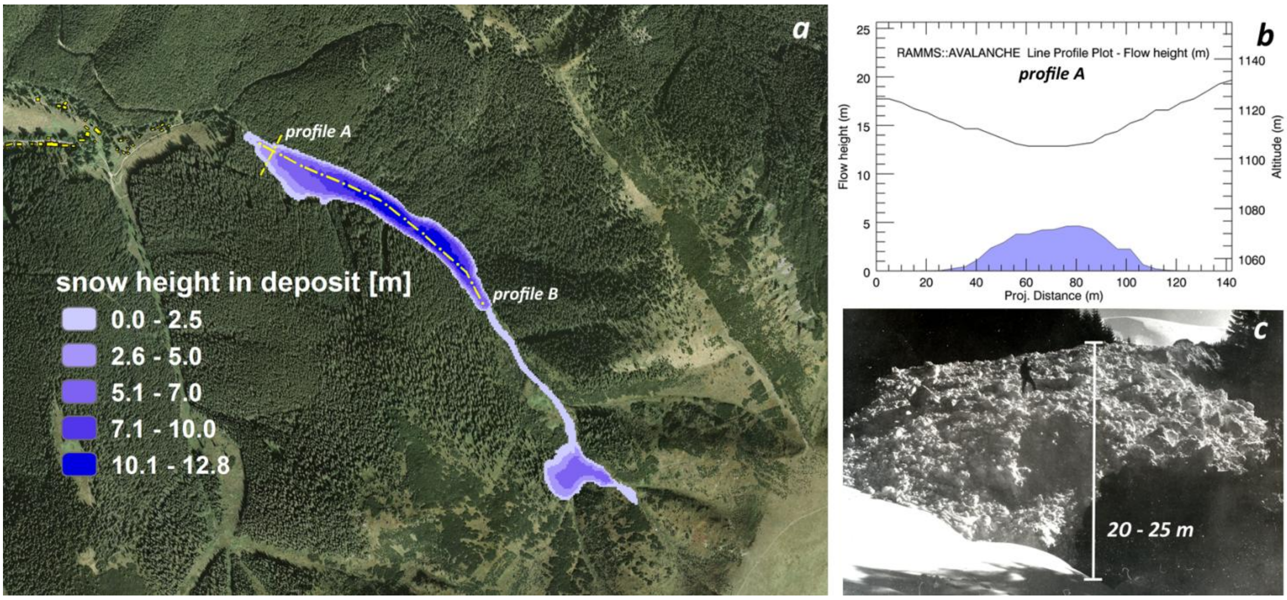

Fig. 6. Snow height in avalanche deposit and lines of cross and longitudinal profiles A and B (a). Real snow height of avalanche front (c) exceeds simulated value in profile A (b) considerably

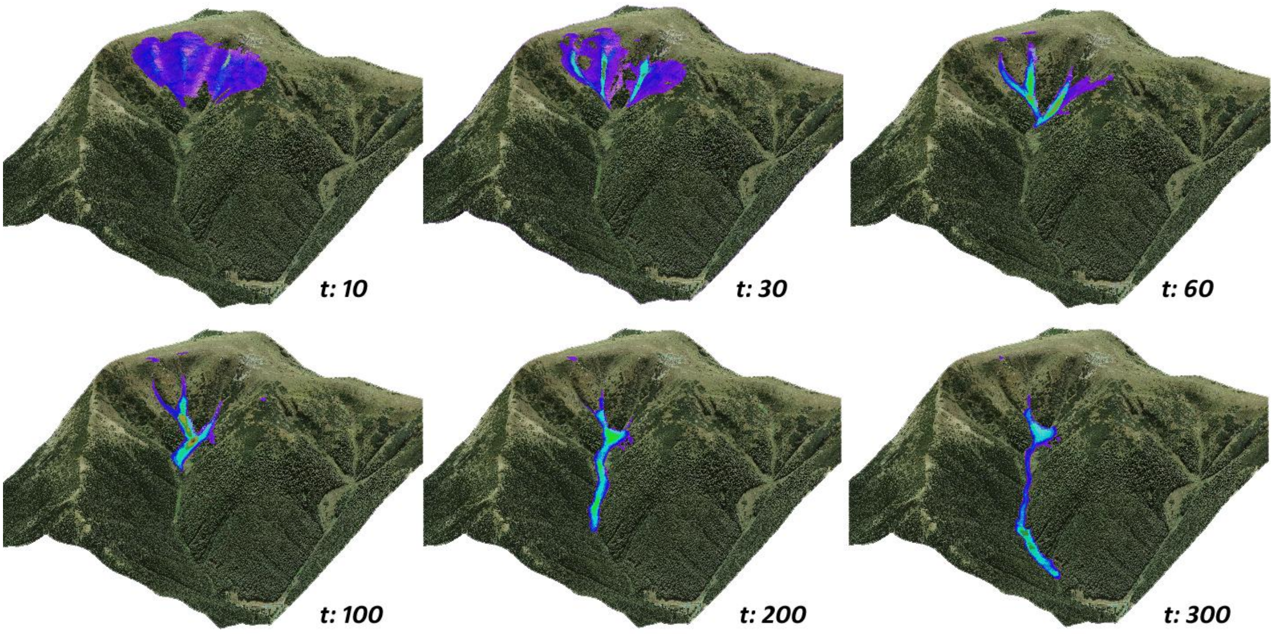

Fig. 7. Sequences of simulation in different time steps of calculation (t: 10 – t: 300)

RESULTS APPLICATIONS

One way of simulation results applications is determining established calibration friction coefficients (*Mu, Xi*). These friction coefficients determine the surface friction in different heights. Coefficients, which were determined and used in one valley, can also be used in avalanche simulations in the adjacent valleys. There is a big probability that surface resistance to the avalanche flow will be similar in adjacent valleys as well. This piece of knowledge was used for modelling potential avalanche events in the valley of Viedenka, which is situated to the west of Ďurková valley. In contrast with the reconstructed avalanche in the Ďurková valley, similarly great avalanche in the valley of Viedenka will affect significantly the urban space of Magurka settlement. Many cottages in this settlement will be damaged or ruined as a consequence of destructive power of a similar avalanche. In this locality, some experimental simulations were calculated with different heights of potential release zones. Fig. 8. shows results of particular cases of these simulations. It is obvious that a fracture height more than 2 m causes a significant spreading of the runout and more cabins are endangered.

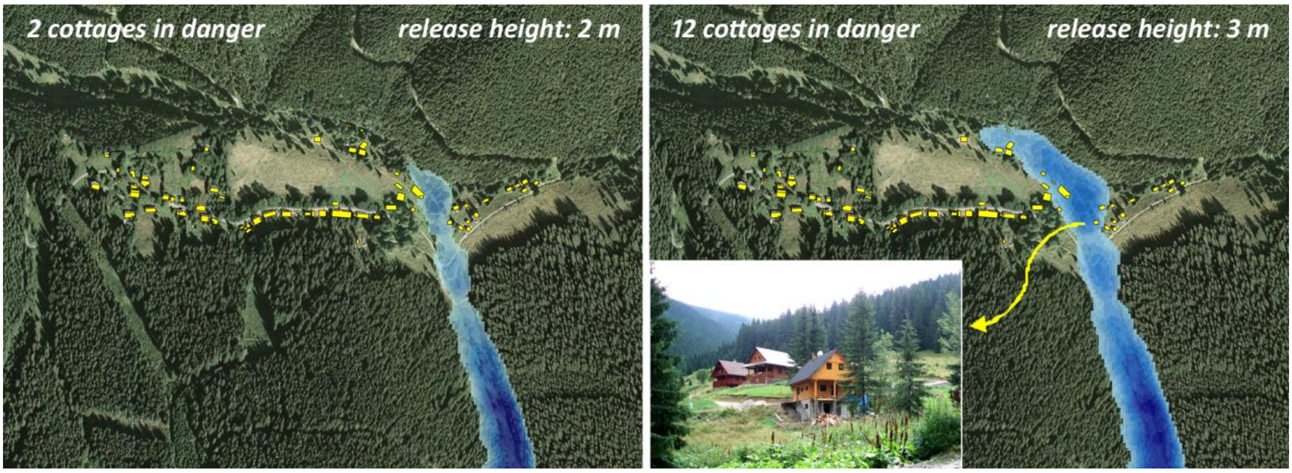

Fig. 8. Comparison of conclusions from potential avalanche with different release heights

We have alluded to prevention until now. Now, we turn to the usage of avalanche reconstruction when endangered areas are revealed. In practice, there are cases, when infrastructure, important facilities or parts of urban sprawl are a part of an endangered area. Model RAMMS can be a useful tool for designing and allocating anti-avalanche barriers, such as an avalanche dam. Parameters of these dams can be included into the digital representation of topology. Avalanche simulation can be undertaken in different scenarios with or without these barriers. A well-placed and designed avalanche dam manages to stop or divert the direction of the potential avalanche flow in order to protect the lower situated infrastructure. For facilities placed in avalanche path, it is the only way of protection.

CONCLUSION

The introduction of GIS technology opened up new perspectives to mapping and assessing hazards from snow avalanches. The purpose of mapping snow avalanche hazards is to consider avalanche risks with respect to land use planning (Haeberli, 2004). Numerical models (like RAMMS), coupled with field observations and historical records are especially helpful in understanding avalanche flow in complex terrain (Christen et al., 2008). They are very helpful in avalanche research in the given region. Simulations, like this in this case of study, are useful in understanding of all processes and actions, which are connected with avalanche. The avalanche modelling is particularly important and applicable in the avalanche protection. The results can be applied to planning and constructing of anti-avalanche structures and in this way they can minimize the negative results of a similarly destructive avalanche in the future. It is obvious that the simulated result differs from the phenomenon measured in 1970, although the deviation is not serious. The most important attribute for the avalanche hazard mapping is the length of the avalanche, which was successfully modelled. There are more reasons why differences in other attributes appeared. First of all, we have to mention that RAMMS simulation result is a model, which cannot include whole complex reality. The next reason is the input data; especially, the digital elevation model uncertainties leading to greater divergence. There will never be a model as same as the true state of nature. It is impossible to include every small bush, the precise distances between the trees etc. in the forest cover, or include every small depression in the valley, which is filled by additional snow. Next is the fundamental modelling problem such as definition of release areas in three-dimensional terrain. The difficult estimation of snow entrainment, which greatly affects overall snow mass, contributes too. One of the other drawbacks is the estimation of the height of stauchwall and the other heights (volume) of released snow. Just because of these drawbacks, it is impossible to make a perfect fit. There are much more reasons, which influence the result e.g. the historical documents (sketches, sampling etc.) were made in the era, when no computers and other advanced tools could help. Despite all these reasons, modern GIS numerical tools are able to truly reconstruct an avalanche event and this research was a good demonstration of it.

ACKNOWLEDGEMENTS

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