New tool for avalanche forecasting in the Krkonoše Mountains

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ABSTRACT: The Krkonoše Mts., with the highest peak reaching 1602 m a.s.l., is the highest mountain range in the Czech Republic. Despite its low altitude they experience considerably high avalanche activity, even causing fatalities. Unfortunately, and so far, the local authorities do not have available a professional tool for avalanche forecasting. A new project, which started in 2013, focuses on the creation of a mathematical model based on statistical analysis of historical data, weather forecast and detailed terrain analysis. Because the project is at the beginning, therefore this contribution describes only methods to be employed and data available.

The study area is 454 km^2 and includes 53 permanent avalanche paths, which are very well surveyed and documented. The avalanche paths have been scanned by LiDAR to get very accurate slope and terrain characteristics. In addition a landuse survey is being carried out to obtain information about possible avalanche triggering zones and terrain roughness. Weather and snow condition data covering more than 1100 avalanche events in the last 50 years are being analysed for fitting and calibrating statistical models. Historical data on avalanche types and movement will be compared with terrain surveys and simulations using physical models like RAMMS, Flow-R, AVAL-1D and SAMOS. These data sets will be used for the development of a new avalanche forecasting model, which will be well suited to be employed as a public avalanche alert system for the Krkonoše Mts. and consequently will be extended to other mountain ranges in the Czech Republic.

KEYWORDS: Czech Republic, expert forecasting system, modelling

1 INTRODUCTION

The avalanche forecasting systems are widely used in the areas, where the avalanches represent considerable hazard during the winter period (e.g. Schweizer and Föhn, 1996; Vizhakat, 2003). This kind of prediction tool is missing in the Krkonoše Mts., the highest mountains in the Czech Republic. With the rising popularity of winter sports (skitouring, freeriding or walking on snow shoes) increases the number of persons buried by avalanches. According to Mountain Rescue Service in the Krkonoše Mts. 95 % of all released avalanches where a person was buried, were triggered by the victims themselves. Other statistics reveals that 52 % of all avalanche victims did not survive (HSCR, 2011).

Nowadays is the avalanche hazard determined every day, using the meteorological condition at 7 A.M., weather forecast, snowpack condition obtained from snow pit and its likely development during the day and finally the local distribution of susceptible areas. The whole process is done only by members of the Mountain Rescue Service using their rich experience. They do not use any expert avalanche forecasting system (Floyer and McClung, 2003; Ramos et al., 2009) or snow development forecasting system (e.g. Bartelt and Lehning, 2002), which are common in other mountainous areas.

The main target of the running project is to develop a tool for avalanche hazard assessment

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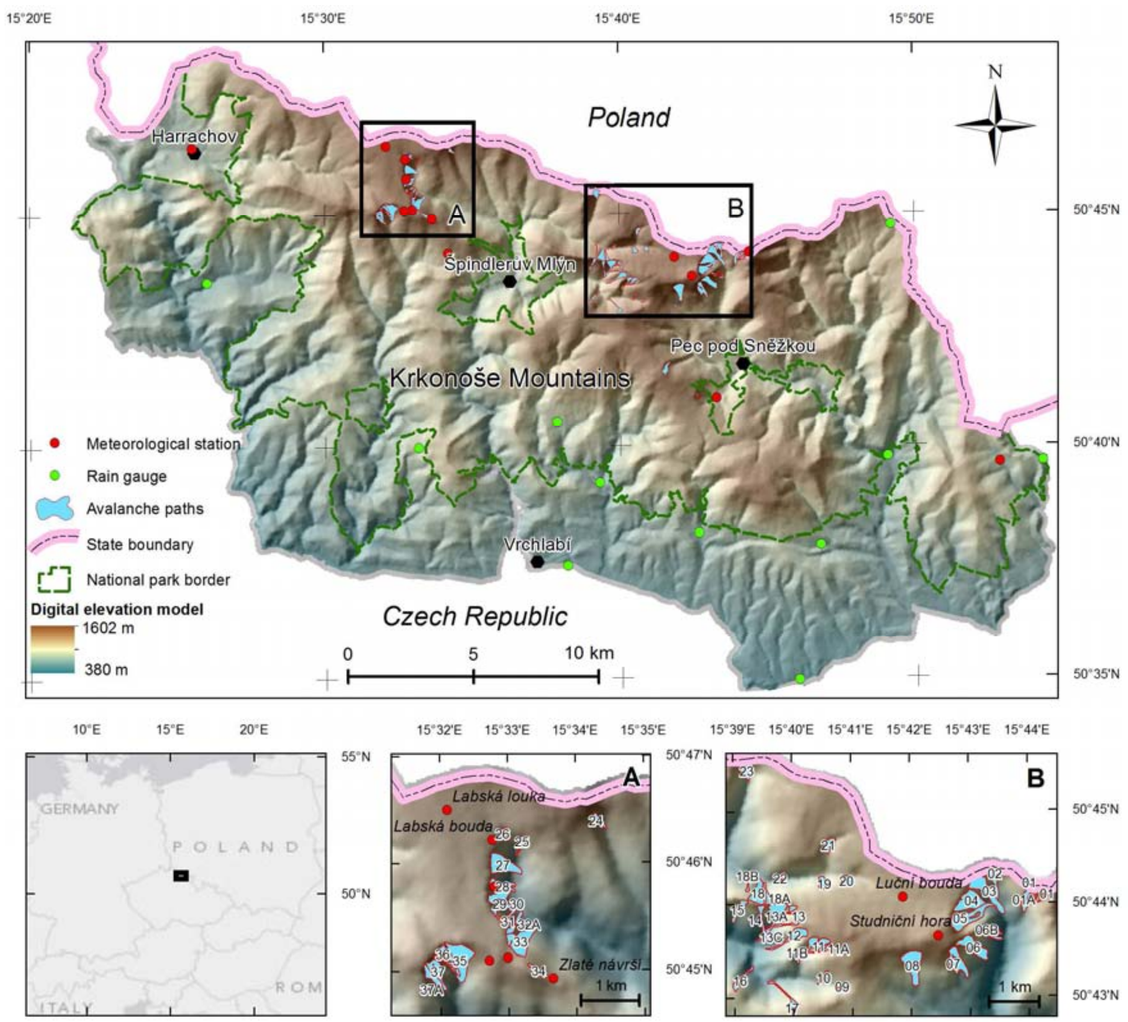

Figure 1. Map of Krkonoše Mts. displays meteorological stations and rain gauge distribution. Details of all avalanche paths are zoomed in the smaller frames.

in the Krkonoše Mts., which will help the members of Mountain Rescue Service with their work. This expert system will operate with huge avalanche database, when present day situation can be compared with historical data. This tool represents an ensemble model using combination of known avalanche models based on terrain sustainability data with present and forecasted meteorological data.

2 STUDY SITE

Krkonoše Mts. are the highest mountains of the Czech Republic (Sněžka – 1602 m a.s.l) and cover an area of 639 km^2, which is split between the Czech Republic (454 km^2) and Poland (185 km^2). They are located at Northeastern border of the Czech Republic (50°44′N ,15°44′E). The main ridge is oriented in NW – SE direction almost parallel with prevailing NW and W winds, which primarily affect snow cover distribution. This influence can be observed especially on leeward slopes (snow patch “Map of Republic” beneath the Modré Saddle 1499 m a.s.l.), where the snow depth reaches over 10 m, but on plateau parts (Vrbatova Bouda 1400 m a.s.l.) is the mean snowpack thickness of 1.8 m. These big amounts of snow are then source for wet slab avalanches (Hejcman et al., 2006). Average air temperature and annual precipitations vary with elevation. On the summit plateau (above 1350 m a.sl.) mean annual temperature ranges between 1 and 2°C and above 1500 mm of precipitation respectively (Halásová et al., 2007; Hejcman et al., 2006) and amount of ¾ of total received water runs out from the area. The important part of this discharge also contains snow melt water, because the snow cover remains in average 180 days of the year on the ground (Halásová et al., 2007).

Although the area of Krkonoše Mts. seems to be small, the avalanche activity is significant and causes several injuries or fatalities almost every year. After 50 years of avalanche monitoring and over 1100 avalanche events were separated 53 avalanche paths which mostly occur on cirques or valley slopes.

3 DATA

Avalanche monitoring in the Krkonoše Mts. has been carrying out over 50 years, which cover unique set of data containing of 1128 avalanche-fall records and 50 winters of continuous weather recording in daily step (wind speed, wind direction, temperature, snow depth and sunshine duration), which provided 13 meteorological station (formal and present) and 11 rain gauges (Figure 1). These meteorological data are supplemented by snow pit data, which are crucial for avalanche forecasting.

The new tool for avalanche hazard prediction in Krkonoše Mts. will consist of two main parts. First of all the terrain analysis for avalanche susceptibility and hazard assessment will be done in ArcGIS environment. This section represents the static (background) part of the model. As a base layer for this analysis will be used digital elevation model (DEM) created from airborne LiDAR scanning. Secondly, the historical meteorological data will be analysed with the respect of historical avalanche triggering. These results will be subsequently used as a model calibration and represent the dynamical part of the model. Since the meteorological situation is considered as a factor for avalanche forecasting, the model will work as a distributed model. For practical use will the model show a prediction of avalanche hazard at least once a day using ALADIN data (grid size 4.7 km), which are provided by Czech Hydro-meteorological Institute.

4 AVALANCHE SUSCEPTIBILITY AND HAZARD ASSESSMENT

Assessment of snow avalanche susceptibility in the Krkonoše Mts. has already been done by Blahůt (2008) and Suk and Klimánek (2011), but they used less accurate DEM and also considered less morphological parameters. New terrain avalanche vulnerability assessment will be carried out using more complex morphologic characteristics as variables. Blahůt (2008) and Suk and Klimánek (2011) considered these variables: slope inclination, slope orientation, elevation, curvature parallel to fall line, curvature perpendicular to fall line and terrain roughness (Corine Land Cover). We will additionally use these variables: type of forest (dense or sparse), presence of water source (brook, bog and spring) and surface roughness data generated from the comparison of prepared DTM and DSM. Additionaly, climatic data (average wind speed, wind direction, snow depth, precipitation, temperature, sunshine duration) will used as model inputs. Consideration of climatic data within the avalanche susceptibility assessment is very important, because Krkonoše Mts. are affected by so called anemo-orographic systems driven mostly by W and NW winds (Jeník, 1961), which are able to redistribute large amounts of snow.

5 AVALANCHE SITUATION

In this chapter we introduce the avalanche situation in Krkonoše Mts., where three basic types of avalanche paths can be distinguished (Fig. 2). The avalanches in cirques are the most frequent and contain 29 of single avalanche paths and during the 50 years period (1962 – 2013) 852 avalanches in total were recorded. The next important areas for avalanching are river valleys, where 21 avalanche paths are presented and 246 avalanche events were recorded. The minor part of avalanche track list represent 5 paths, which can't be count neither to cirques nor valleys because of their different morphologic properties and represent the third group. There were recorded 30 avalanche events within the last avalanche paths group. All avalanche groups can be also divided into subgroups, where the single paths are gathered according to their geographic position (Figure 2).

All fallen avalanches were classified according to de Quervain et al. (1973) by Spusta et al. (2003), but unfortunately later records have not been published yet. Most of the avalanches originated as slab avalanches (68 %). Loose snow avalanches represents minor portion (5 %) of Krkonoše avalanches. Significant part (19 %) of avalanche trigger was caused by cornice fall and 8 % originate as a mixed type.

The most avalanches classified according to position of sliding surface fell as a surface snow avalanche (89 %) and truly full depth avalanches represent only negligible (4 %) portion of all avalanche events. The rest of all avalanches originated as a mixed type of first two types (7 %).

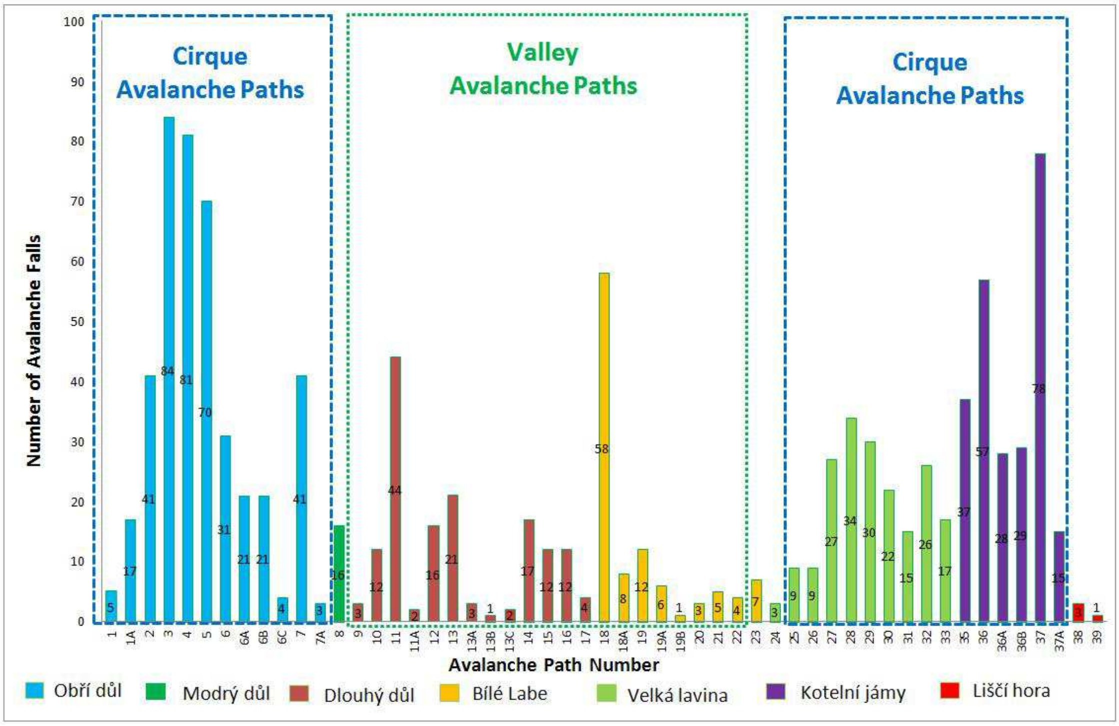

Figure 2. An overview of all avalanche paths related with the fallen avalanches. In Krkonoše Mts. can be distinguished three types of avalanche paths: cirque path, river valley paths and other avalanche paths. Morphological subgroups are separated by unique colours.

According to snow moisture content the dry avalanches (61 %) prevail over the wet avalanches (13 %) and the rest (25 %) is represented by a mixture of both types. Considering the form of motion the flow avalanches (80 %) dominate over the powder avalanches (12 %) and minor part is classified as a mixture of both types (8 %).

6 CONCLUSION

Although the monitoring of avalanches has been lasting over five decades and 1128 avalanche events have been recorded, there has been no expert avalanche forecasting system introduced in the Czech Republic yet. The avalanche hazard prediction is done only by members of the Mountain Rescue Service. Although this kind of prediction is driven by long term experience, the whole process takes a lot time every day and can be predisposed to human errors. The proposed expert system should help to shorten the prediction process and to help to list in the database, which will be also created. The system becomes more needed, especially with the rising winter activities like freeriding and skitouring in Krkonoše Mts.

Great advantage of the prepared model will be the database of fallen avalanches and meteorological situation before each event. These data will enable us to carry out precise model calibration for nowcasting prediction using ALADIN data provided by Czech Hydrometeorological Institute.

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