A DECADE OF AUTOMATIC SNOW MEASUREMENTS AND OBSERVATIONS WITHIN MOUNTAIN REGIONS OF SLOVAKIA

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It has been a decade since the first automatic weather station has been built in Slovak mountains. The stations have been operated by the Avalanche prevention center and are used for wide range of purposes: avalanche forecasting and prevention, rescue missions, flight operations etc... The stations are located in different terrain and altitudes and are particularly useful for analysis of snow distribution in alpine environment. Besides operational usage, these stations are valuable source of long term meteorological data. The presentation is focused on the climatological analysis of the long term automatic snow measurements and observation. During the last decade, the stations have witnessed several extreme events such as extremely large avalanche in Žiarska dolina or extremely snow poor winters, when almost no snow persisted whole winter in middle altitudes of Slovak mountains. The data from automatic weather stations are crucial in monitoring the response of very sensitive alpine environment to climate change.

Keywords: snow, snow measurements, mountains, avalanche prevention, weather station

INTRODUCTION

Weather monitoring in Slovakia is, according to the law, carried out by the Slovak Hydrometeorological Institute (SHMÚ). The network of profesional weather stations is focused mainly on places with main human activity. That is why the network is quite sparse in the mountain. On the other hand, the actual meteorological data from the mopuntains are strongly demanded by the mountaineers, climbers, skiers or avalanche specialists. The Mountain Rescue Service of Slovakia tried to change the situation in recent years by a specialized center - Avalanche Prevention Center (SLP-HZS). Building and operating a network of automatic weather stations (AWS) became one of the priorities of the center (SLP-HZS). The first AWS was, as a prototype, built at in Demänovská dolina -Jasná in 1999. A plan was, to build the AWS network (11 stations) in the high mountains of Slovakia. However, the financial reasons did not allow construction a new AWS in that time. Later on, during the 2006-2007 situation has changed and five new meteorological stations were built under the project INTERREG IIIA of the European Union "Strengthening the cooperation of the Slovak and Polish Mountain Rescue Service". The five stations were not enough to fulfill the demand on data for avalanche forecasting. This inadequate status lasted for another 7 years, but in 2014-2015 another 14 AWS were built. In 2016, an experimental station was added to the network at the peak of Príslop in the Western Tatras. The total number reached 21, and it could be said that, there is a quite dense network of AWS and it is enough to have an actual information about the weather in the mountains. AWS are located in all the high mountains of Slovakia: High, West, Belian and Low Tatras, in the Veľka and Malá Fatra and in the Chočské vrchy at altitudes from 1225 to 2142 m above sea level (Figures 1 and 2).

This article provides an assessment of the 10-year functioning of the first automatic meteorological stations in the high mountain terrain (2007-2017).

Figure 1. Automatic weather station, High Tatras

MATERIALS AND METHODS

AWS are able to measure, record and send the data about air temperature and humidity, wind direction and speed, snow, solar (global) radiation, and temperatures at different heights of the snow cover using sensors and controllers. Some of the AWS have the connection to electric grid (230V), but the others are autonomous and use the solar panels as an energy source. In addition to meteorological sensors, the AWS also includes a webcam that sends a snapshot of the station's surroundings to the server of the Avalanche Prevention Center every hour. The view of the webcam is usually focused to dangerous avalanche slopes, so in addition to meteorological data, the AWS also provides information about the occurrence of the avalanches. Meteorological data

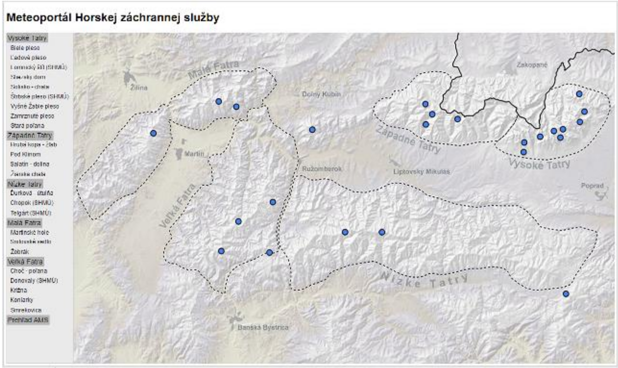

Figure 2. Distribution of the AWS in high mountains (web interface)

are measured and sent at frequency every 10 minutes. Outputs are available for the public at website meteo.hzs.sk, also SHMÚ mountain stations are included (Fig.2).

The main problem and the challenge of operation of AWS's is their reliability. The weather conditions in the high mnountains are extreme. Strong ice-coating, blizzards, electrical discharges and other phenomena mean the fight of technique with nature. Therefore, sometimes it happens that the station is "broken down". Mostly, it is because damages of the sensor or dataloggers, or mechanical damages. Data transmission is provided by a mobile operator, and signal quality is sometimes problematic in the mountains. Routine maintenance and service are also very demanding. Access to some stations takes 2 to 3 hours by foot or by skis.

This paper is focused on the analysis of 10-year long time series of snow depth data from automatic meteorological station Žiarska chata located in the Western Tatra mountains. The Žiarska chata station was chosen because it provides the most reliable data. It has the connection to the electrical grid, so the energy source is not a problem. On the other hand it is located in the middle of the valley (1280 m a.s.l.) so it is not exposed to very strong wind, ice-coating or lightnings. It is also easily reachable by the off-road vehicle or skis (in winter), so the maintenance is much easier in comparison to other stations located in remote areas.

The snow depth is measured using an ultrasonic sensor with an accuracy of +/- 1 cm. During the first six years data were measured in hour time stamp. Later on, the the mesurement device was changed and the data became available in the 10 min time stamp. Snow data were preprocesed, controlled and harmonized by the automatic procedure. Not realistic data were excluded from the analysis.

RESULTS

Most extreme event

Variability of snow depth within the study period was high. The most extreme was winter and spring 2008/2009. 2008/2009 winter started without extremes in December and January and it was a bit under averade, but heavy snowfall occurred in March and snow depth increased from less than 80 cm to more than 230 cm during only two weeks. This extreme event caused extreme avalanche that damaged meteostations in the Žiarska valley (Fig.3, Fig. 4). The avalanches at Žiarska valley had the character of more than 100-years avalanche. Except the AWS, two mountain chalets and more than 15 ha of forest were destroyed, some of the trees were older than 100 years.

Figure 3. Žiarska valley, extreme avalanche - March 25, 2009

Figure 4. AWS Žiarska chata damaged by extreme avalanche - March 25, 2009

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Long term analysis

Snow depth measured in the AWS Žiarska chata is presented on fig. 5. Within the study period it is possible to identify three groups of winters: the snow rich winters and snow poor winters and medium winters. The first group represents winters 2007/2008, 2011/2012 and especially the winter 2008/2009. On the contrary, snow poor winters were in 2009/2010, 2010/2011, 2013/2014 and 2015/2016.

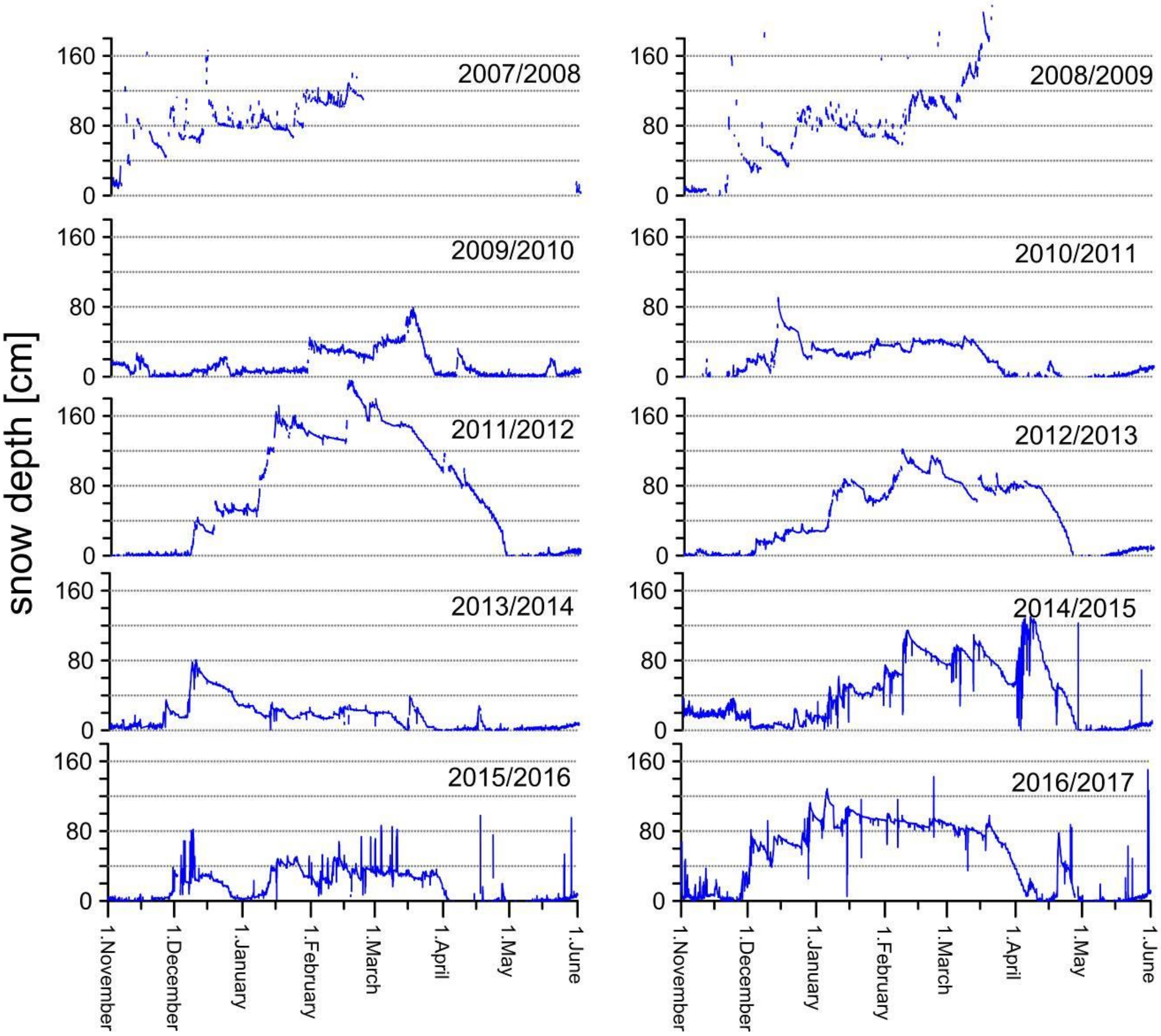

Figure 5. AWS Žiarska chata – snow depth in last 10 winter seasons

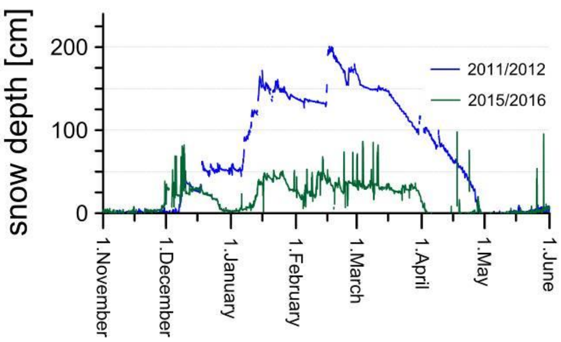

Figure 6. AWS Žiarska chata – snow depth in winter seasons 2011/2012 and 2015/2016

2014/20152016/2017 were medium winters. In case of snow rich winters and medium winters there can be seen one significant maximum of snow depth usually in the end of March. The maximum value was mostly higher than 150 cm. This is the typical condition when snow is accumulated during the whole winter and than it melts in relatively short period. On the other hand, there is a group of snow poor winters, these winters have no individual snow depth maximum and there are more melting events also during the January and February. Rainfal is also very common in this group of winters. This kind of winters were more usual in lowland environments of Slovakia in previous years. If we compare winter 2011/2012 and 2015/2016 (Fig. 6), we can see very significant difference. 2011//2012 have maximum of snow cover about 200 cm, but the 2015/2016 only about 60. It is less than 30 %. The snow pack duration was very different, too. In 2015/2016 snow completely melted in the beginning of April and in 2011/2012 lasted till end of April.

CONCLUSION

The analysis showed very high variability of snow depth within the 10 years long period. The 10 years of measurement is not enough to see long term changes, but the high variability can refer to climate changes. The mountain environment and especially snow cover is very sensitive to changes and only a change in teplerature of few degrees can change the precipitation from solid to liquid. Extreme weather leads to extreme events, such as avalanche in 2009. That is why, it s very importatnt to operate, maintain and build weather station in the mountains.