VARIABILITY IN SNOW COVER CONDITIONS AT THE CERTOVA LOUKA AND THE MODRE SEDLO SITES (GIANT MTS.) DURING THE PERIOD 2003-2013

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ABSTRACT

This work summarizes one decade of spatial snow cover distribution research on the highest plateau of Eastern Giant Mountains. This research was done in respect to periglacial landforms, which develop on these localities. The research was carried out during winter seasons from 2003/2004 until 2012/2013 on Certova louka meadow and Modré sedlo saddle. The main goal of the study was to analyze spatial snow depth variability during the season. Next goal was to analyze of possible interaction of snow distribution between both localities. The measurement was carried out manually by snow probe within regular net of 141 points. Our data were further compared with snow depth on professional meteorological station near Lucní bouda chalet and with regular measurements of mountain rescue guards. As the main indicator of spatial snow distribution during the season was calculated general variability index. The highest values of snow depth were regularly reached at central terrain depression at Certova louka meadow (max. 570 cm). On the other hand the lowest values were reached on the edge of Modré sedlo saddle (max. 35 cm). The difference between those two localities is also documented by values of general variability index for Certova louka meadow (97) and for Modré sedlo saddle (33). The greatest values were usually measured during February and the snowpack regularly lasted at least until April with the maximum of 227 days. The method of general variability index showed good results and seemed to be an appropriate method for comparing of spatial distribution of snow depth between two localities. The hypothesis of interaction between both localities was not confirmed nor refused.

Keywords: snow cover, Giant Mountains, variablity, snow depth, distribution

INTRODUCTION

Importance of snow cover can be divided into several basics effects. Due to the high albedo and low thermal conductivity snow affects the local climate [1]. In hydrological terms it is snow important as a source of groundwater, surface water, the vater levels and flows in the periods of thaw [2]. Snow cover also contributes to the formation of relief in a passive and active way [3]. Sufficient and permanent snow cover prevents deeper soil freezing, edaphon death and in spring months also rapid development of vegetaion [4]. It also contributes to the preservation of endemic species specialist for alpine mountain climate [14] and also to reduce altitude of the alpine treelines [15]. In botanical viewpoint the positive role to vegetation have an avalanche, which contribute to conservation biodiversity environment [4]. Snow also has

implications in the economic sphere e.g. forestry damage, flood hazards or stimulation of seasonal tourism.

Due to the action of many effects, there is not snow dislocation uniform and the thickness can fluctuate considerably. The first general regularities of the distribution of snow in the Giant Mountains characterized Partsch already in 1894 [5]. He indicates in his work that the thickness of snow cover in Giant Mountains depends primarily on wind flow and morphology of relief. Deposit of snow affets wind flow during the snowfall, but there is also a secondary fanning to leeward areas during off-season precipitation. Prevailing westerly wind flow, depositing snow and impact orientation leaders valley of Giant Mountains, planed surface, described Jenik [10] in his theory anemo-orographic systems (A-O systems). Due to the A-O system of Údolí Bílého Labe valey serving Certova louka meadow with significant terrain depression at the center, as a significant snow accumulation zone. This system also affects the deposition of snow in sub-horizontal relief Modré sedlo saddle, it s bordered by morfologically significant edge on the southeast [12]. Under this edge is significant terrain depression, which serves as a deposit area and turns into a avalalanche slope of the Modrý důl valey. Both areas are also under research due to abundant presence of specific relict and recent periglacial formations [3]. Due to snow conditions on the deployment and activities of these periglacial shapes in this area dealt Janásková [5], moving of ploughing blocks an Certova louka meadow Horáčková [7], which previously also evaluate snow conditions in this area [6].

The goal of the reserach was to evaluate and characterize snow conditions and their variability in Certova louka meadow and Modré sedlo saddle from the winter season 2003/2004 to winter season 2012/2013, on the basis of regular fieald mwasurement snow depth. Further compare these snow conditions with meteorological data obtained from meteorological station at Luční bouda chalet and previous state of eobservation in the Giant Mountains.

MATERIALS AND METHODS

This work continue on previous research and observation in the monitored areas Certova louka meadow and Modré sedlo saddle. The area is located in the eastern Giant Mountains, related to Giant Mountains ridges. The study area on Certova louka meadow located on the SE slope of Certův hrbet ridge, which protruding from Stříbrný hřbet ridge. The meadow is oriented on South and extends on 1410 - 1450 m a.s.l. The upper part of the slope reaches a ridge and there is a shallow terrain depression, in the middle of the steepest part of slope is large terrain depression, which contionous at the lowest part source area of Stříbrná bystřina creek with gentle slope. The study area Modré sedlo saddle belongs to Bohemian internal ridge between Luční and Studniční horou mountain. The saddle is oriented on the SE and extends an altitude of 1505 – 1510 m a. .l. The upper part is flat passes through a terrain edge in to the upper part of the avalanche slope Modrý důl valley (Figure 1).

Monitored area Certova louka meadow from season 2003/2004 was defined by 52 points, disposed apart 20-25 m, which create polygon with dimensions 275 x 65 m elongated N-S direction (Figure 1). Since season 2004/2005 has been added 32 points at the top of locality, where was polygon extended to 135 m in order to cover a larger areas of occurrence ploughing blocks. After that was total measured at 84 points. Monitored area Modré sedlo saddle in season 2003/2004 was defined by 74 points,

disposed apart 10-20 m. In the following winter the number of points reduce to 57 with a regular distance of 15 m, while maintaining the corner points (Figure 1). At the end of the winter was used auxiliary points to the correct scope and depth of the snow fields at the both studied locationst.

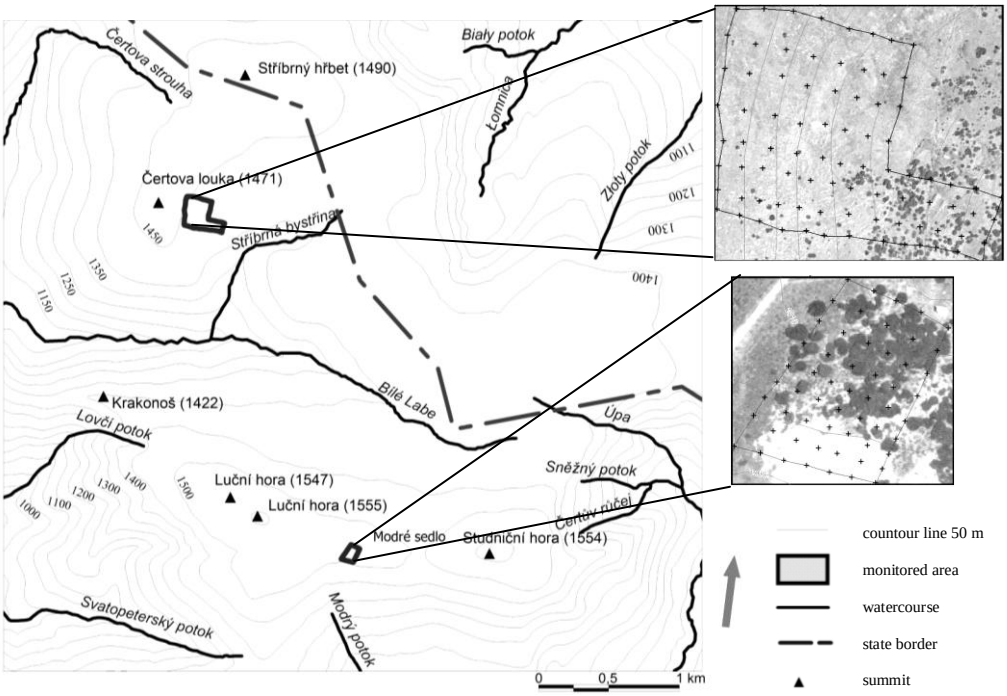

Figure 1: Monitored area

Snow cover was measured using an avalanche probe. The position of individual measuring points were located using a GPS device. The first measurements were made after stabilization height coherent snow cover mostly during December (even in November). The following measurement were done at monthly intervals, which could be due to the current weather conditions adjusted for several days. At the end of the winter was measuring interval reduced to half for a more accurate recording of the melting snow cover.

The average snow depth was calculated as the arithmetic average snow depth at all points each for the respective measurement date.

The most appropriate method for estimatind spatial distribution, with the smallest quadratic error for the monitored area came Natural Neighbours method [8].

To express the degree of variability of snow cover on the monitored areas was used general index of variability [9], which has the highest positive correlation with the measured values.

$$\sigma_t = \sqrt{\frac{\sum_{i=1}^{N} P_i^2}{N} - \frac{\left(\sum_{i=1}^{N} P_i\right)^2}{N^2}},$$

Pi is the depth of snow cover at the i^{th} nodal point and N is the total number of nodes in the area of interest, in this cas the monitored locations. Sice general variability index actually indicates the value of the standard deviation of snow depth on the monitored areas espressing spatial dispersion around mean.

General index of variability was calculated binary type: to determine the variability between individual winter seasons and to determine the variability between individual month measurements using data for the entire measurement period from the begining of the season 2003/2004 until the end of the season 2012/2013.

If in a given month more measurements were made, these measurement were averaged. Spatial variability was calculated from the database to Certova louka meadow and Modré sedlo saddle, as a general index of variability for each point when counting all measurements in a given year.

From the meteorological station at Luční bouda challet were processed daily data of absolute height of snow cover, which was always determined to the date of measurement at studied areas. Its overall average was calculated from the data of daily measurement data, from the first occurence of a coherent snow cover till its complete thawing. Processed data included time of commissioning at 20. 1. 2009. To determine the period of coherent snow cover on Luční bouda challet was used data from the Mountain Rescue Service Krkonoše, which served as an annual benchmark. For comparison a more accurate description of the evolution of snow during the winter season were utilized results and evaluation from previous work dealing this monitored area [5,6,8].

RESULTS

The highest snow depth at the site Certova louka meadow was recorded in the central terrain depression where there was a shift of the maximum values only within a depression (Fig. 3). The maximum of snow depth in this depression was 570 cm (18. 2. 2012). It is also a place where snow persists for the longest time as a snow field (till 20. 6. 2008, 227 days). Low snow cover depth was conversely observed in the lower part of the area in dwarf pine vegetation (max 160 cm, 28. 2. 2005). On Modré sedlo saddle was confirmed minimum value concentration close to the terrain edge where it was measured at a maximum only 35 cm snow depth (Fig. 3).

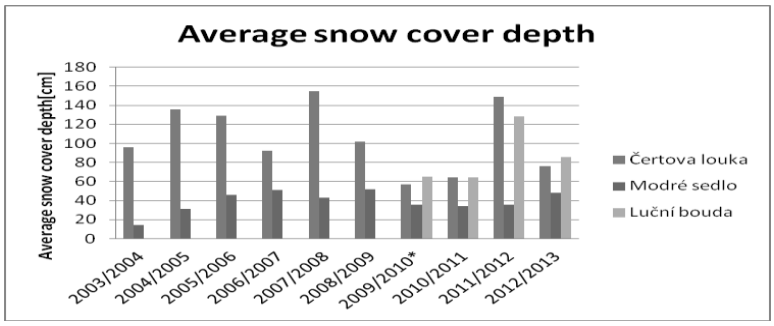

Figure 2: Average snow cover depth on studied areas (*in season 2009/2010 was measurement caried from March)

On Certova louka meadow was observed a maximum in February (5 cases – year 2005, 2007, 2011, 2012, 2013) and subsequently in March (3 cases – year 2006, 2009, 2010) adn April (2 cases – year 2004 and 2008). Maxima in 7 cases (except the years 2004, 2007, 2008) connected with the highest minimum height adn the highest avereage snow depth. I 9 cases (except winter 2003/2004) is the highees average snow depth reached together with the highest minimum.

Under the terrain edge on Modré sedlo saddle in the accumulation area of the avalanche path Modrý důl valley (in 2005 a 2007, the maximum measured in the top

part) was the most frequently measured in February (7 cases: years 2005 – 2007 and 2010 - 2013). Maxima in 9 cases (except year 2012, about 2 cm) was associated with the hithest avarage elevation of snow on the area. Coherent snow cover occuring in the terrain edge, which is greatly affected by exposure to the south and espacialy wind flow blowing snow from there. If the snow depth at this edge has reached 15 cm (3 cases - 2006, 2009, 2013) occurs in the same dat as the maximum height and maximum average height. Maximum snow depth 210 cm was achieved while at the same time as in the Certova louka meadow 18. 2. 2012.

At the beginning of the winter season during the formation and accumulation of snowfall the most evident effect of dwarf pine vegetation is on the ridge part of Modré sedlo saddle, where this precipitation is caught and stored. On Certova louka meadow in early winter dominates accumulation in the central part of terrain depression. Effect of dwarf pine vegetation in the ongoing winter season, in case save them under the firn snow layer, significantly decrease. During defrost the snow is not as significant as the beginning of winter.

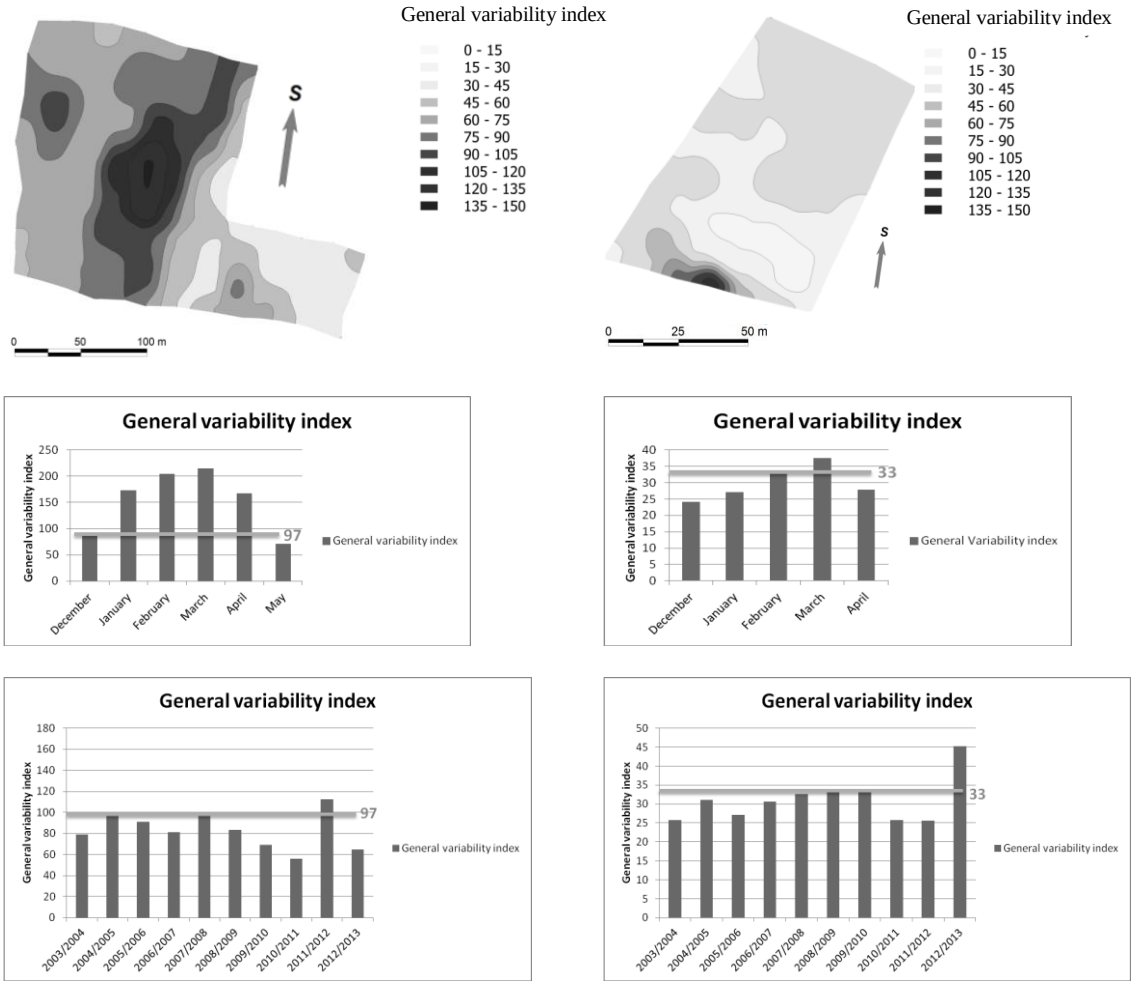

Figure 3: On the left values General variability index on Certova louka meadow (spatial distribution in the season 2012/2012; monthly and yearly variability), on the right side values General variability index on Modré sedla saddle (spatial distribution in the season 2012/2013; monthly and yearly variabilty)

Table 1 shows differences in duration coherent and incoherent snow cover on the monitored location Certova louka meadow, Modré sedlo saddle and the meteorological station at Luční bouda challet.

year/snow cover [day]	First snow	Coherent snow cover Cl.	Coherent snow cover Ms.	Coherent snow cover Lb.	Snow cover Cl.	Snow cover Ms.	Snow cover Lb.
2003/2004	7.12.2003	135	88	118	183	143	x
2004/2005	19.11.2004	154	65	158	210	163	x
2005/2006	16.11.2005	145	145	159	183	145	x
2006/2007	16.11.2006	132	x	68	176	132	x
2007/2008	6.11.2007	157	157	141	227	189	x
2008/2009	18.11.2008	143	118	148	204	143	x
2009/2010	9.12.2009	128	61	126	181	150	128
2010/2011	23.11.2010	92	87	122	187	150	120
2011/2012	5.12.2011	131	75	131	185	131	131
2012/2013	1.12.2012	118	118	141	163	163	149
average		134	102	131	190	151	132

Table 1: The duration of snow cover on the monitored locations (Cl.-Certova louka meadow, Ms.-Modré sedlo saddle, Lb.-Luční bouda challet)

To confirm the alleged interdependecies Certova louka meadow and Modré sedlo saddle are taking maximum height and maximum average snow depth in the season. For the entire period of measurement were calculated averages for each every value and these were subsequently compared with the actual measure values. The negative association between maximum snow depth at both locations occured in 60 % of cases, amont the highest avarages for an indeterminate result of 50 %.

DISCUSION

With year-on-year comparison of recorded values, it is possible to pick some recurrent trends of spread of the snow cover for both observed areas in course of winter season, which were already referred to [5,6,8]. Despite the wind flow differing from usual western directions, had the recorded distribution of snow in the areas always the same character, characterized by regular distribution of minimal and maximal strength of snow. Measurement of ten years has also confirmed a long-term prevailing character of growth and degradation of snow cover in the areas [5,6,8]. Other trends resulting from the ten year research are not as significant as those mentioned before. They show some stable characteristics, however, changes are seen in the year-to-year comparison of individual winter seasons.

In Giant Mountains, the maximum of snow cover is most usually stated to be in March, before the general thawing takes place [1]. However this phenomenon is confirmed only in the area of Modre sedlo saddle, in the Certova louka meadow was the maximum in March recorded only in 3 cases. The factor influencing the average depth of snow cover on the Certova louka meadow are the minimal values of the snow depth. The main factor of the average depth of snow cover in Modre sedlo saddle is, on the other hand the reached maximum. The winters with the highest maximal depth of snow cover have reached also the highest average depth of snow cover. (Fig. 2)

The influence of dwarf pine vegetation, which was described earlier on the Polish side of Giant Mountains, was confirmed [11].

Kwiatkowski, Lucernski [11] state further, that long-term snowfields occurring above the upper border of forests last between 160-190 days. As an extraordinary case is given 198,7 days of snow cover on average in period between 1991 – 2001 on the Snezka station [13]. On Certova louka meadow reaches the average value 190 days and this area is thus comparable to the higher located area of Snezka. The longest period of occurrence of snow cover was in the 2007/2008 season (for 227) days. The reason for such high number of days with snow cover is a high accumulation of snow, which forms in the central part of the area. The average duration of snow cover in Modre sedlo saddle is, related to the given values, slightly under-average and reaches its maximum in 2007/2008 season (for 189 days). Coufal and Sebek [1] state that the snow cover in the area of Lucní bouda challet reaches, due to low strengths and high sun exposure, very low values. (for the period of 2009-2013 132 days).

Year-to-year variability of the snow cover on Certova louka meadow and Modre sedlo saddle is closely related to the average depth of snow cover. Index of general variability for the whole period of seasons from 2003/2004 till 2012/2013 equals 97 in Certova louka meadow and 33 in Modre sedlo saddle. The lowest variability on Certova louka meadow was in the season 2010/2011 (56) and in Modre sedlo saddle in seasons 2010/2011 and 2011/2012 (both 26), when winters with the lowes average depth of snow cover were recorded. Index of general variability for individual months of the whole research period also corresponds the flow of their average values (Fig. 3).

The values of index of spatial variability (Fig. 3) were closely correlated with values of the depth of snow cover, where the highest values of the index were reached in the northern part of terrain depression at Certova louka meadow and under the terrain edge in Modre sedlo saddle (Fig. 3). Also the minimums corresponded with the distribution of minimums of depth of snow cover, area of dwarf pine vegatation on Certova louka meadow and the terrain edge on Modre sedlo saddle. Index of spatial variability has been reaching lower values in Modre sedlo saddle than in Certova louka meadow (in spring of 2011/2012).

The dependency of depth of snow cover on the observed areas can be in both cases nor confirmed neither disprove.

CONCLUSION

Ten year long measurements have confirmed long-term prevailing trends of stacking up of the snow cover in highest areas of Giant Mountains mountain range, which confirm the significant influence of the terrain morphology on the stacking of snow precipitation. This results in regular distribution and reaching of minimal and maximal strengths of snow, the way of its both stacking and degradation. Year-to-year variability of snow cover on Certova louka meadow and Modre sedlo saddle is closely related to the average value of depth of snow cover. The values of the index of spatial variability were closely correlated to the values of snow cover depth, where the highest values of the index were reached in the northern part of terain depression at Certova

louka meadow and under the terrain edge of Modre sedlo saddle. Also the minimums corresponded to the distribution of minimums of snow cover depth, area of dwarf pine vegetation on Certova louka meadow and terrain edge on Modre sedlo saddle. Index of general variability reached lower values on Modre sedlo saddle than on Certova louka meadow. The measurements further confirm also the important influence of dwarf pine vegetation, especially by dropping out and streaming of snow precipitation. The results of this work could also help to determine the influence of the occurrence of snow cover on the movement of moving blocks on Certova louka meadow and freezing fragments on Modre sedlo saddle.

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