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SNOW ACCUMULATION AND ABLATION IN THREE FORESTED MOUNTAIN CATCHMENTS

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The study was focused on vegetation and topography effects on snow accumulation and ablation, with special interest in the role of the forest affected by the bark beetle (Ips typographus). We selected eight predictors related to winter meteorological conditions and the character of specific localities. The vegetation structure was described using parameters calculated from hemispherical photographs. The degree-day approach was used to calculate melt factors for sites with different vegetation and aspects. Multiple regression was further applied using snow water equivalent (SWE) data measured at 47 localities in winter seasons from 2010 to 2014. The SWE in forest sites was by 32% lower than in open areas. The snow ablation in large openings was on average more than two times faster compared to forest sites. Snow ablation was by 33% faster after forest defoliation (due to the bark beetle) and we expect even faster ablation in case of complete forest decline. The results indicated that topography is more important predictor for open areas, while leaf area index is more important for forest sites. Despite the significance of the correlations found, parameters applied in this study could only partly explain the snowpack variability.

KĽÚČOVÉ SLOVÁ: bark beetle; degree-day; leaf area index; snowpack variability; snow accumulation and ablation

AKUMULACE A ÚBYTEK SNĚHU VE TŘECH LESNÍCH HORSKÝCH POVODÍCH. Studie je zaměřena na sledování vlivu vegetace a topografie na akumulaci a tání sněhu v horských povodích s důrazem na roli lesa postiženého lýkožroutem smrkovým (Ips typographus). Bylo vybráno osm prediktorů popisujících meteorologické podmínky dané zimy a charakter jednotlivých lokalit. Struktura vegetace byla popsána na základě obrazové analýzy hemisférických snímků oblohy a vegetace na všech měřených lokalitách. Výpočet teplotních faktorů tání v různých vegetacích a orientacích svahů byl proveden pomocí metody degree-day. Vícenásobná regrese byla použita na data vodní hodnoty sněhu (SWE) měřené na 47 lokalitách v zimním období 2010-2014. Výsledky terénních měření ukazují, že v jehličnatém lese je SWE nižší v průměru o 32 % oproti otevřeným plochám. Tání sněhu na otevřených plochách je více jak dvakrát rychlejší než v lese. Rychlost tání se výrazně zvýšila v důsledku rozpadu stromového patra vlivem lýkožrouta smrkového, a to v průměru o 33 %. Výsledky ukázaly, že topografické charakteristiky jsou dominantním prediktorem otevřených ploch, zatímco leaf area index je dominantní prediktor u lesních lokalit. Ačkoliv nalezené vztahy jsou většinou statisticky významné, prediktory použité v této studii pouze částečně vysvětlily celkovou variabilitu sněhové pokrývky.

KEY WORDS: lýkožrout smrkový; degree-day; leaf area index; variabilita sněhu; akumulace a tání sněhu

Introduction

Snow is important component of hydrological cycle in the central Europe. Large quantity of water is accumulated in form of snow during winter period and this water flows into rivers in relatively short time during spring period. Therefore, the knowledge of water volume accumulated in the snowpack and its spatial distribution represent the basic information for hydrological forecasting.

Large-scale variations of snow accumulation are controlled by temperature, which is be related to elevation and latitude (Kucerova and Jenicek, 2014). However, at smaller scales, the snow accumulation and snowmelt are more driven by topography and vegetation (Jenicek et al., 2012; Jost et al., 2007; López-Moreno and Stähli, 2008; Parajka et al., 2012; Šípek and Tesař, 2014). The forest influences snow interception, wind

redistribution and the density of snowpack during snow accumulation. Additionally, the forest reduces the amount of short-wave solar radiation and thus snowmelt rates (Hribik et al., 2012; Pomeroy et al., 2012).

The bark beetle (*Ips typographus*) outbreak occurs in the Sumava Mountains (Bohemian Forest) and the Bavarian Forest national parks in the Czech Republic, Germany and Austria. The bark beetle attack causes drying of needles and thus tree defoliation. Therefore, snow interception becomes less important during accumulation period which results in higher snow storages at the specific site. However, accumulated snow melts faster due to the increasing amount of solar radiation. Additionally, current climate changes and consequent changes of winter and spring runoff represent positive feedback and might further underline the impact of land cover changes on runoff (Langhammer et al., 2015; Vlcek et al., 2012).

The objective of our study is to determine main factors governing the variability of snow accumulation and ablation by means of repeated measurements of snow depth and snow water equivalent (SWE) in selected study areas. Besides, we want to estimate the role of forest, forest clearings and disturbed forest on snow accumulation and more importantly, on the snow ablation process. Although, we are aware that snow ablation is driven by complex energy balance of snowpack, our aim was to apply simple degree-day approach as it enables easier application in areas without detail meteorological monitoring. We benefit from a large data set sampled at 47 localities for five years covering a wide range of snow conditions.

Material and methods

Study area and data monitoring

The research is situated into three small mountain catchments, Bystrice River basin (9 km^2), Zlaty Brook basin (5.5 km^2) and Ptaci Brook basin (4 km^2, Fig. 1); The Bystrice and Zlaty Brook basins are in the Krusne Mountains in the northwest part of the Czech Republic. Both catchments are located from 760 to 1050 m a.s.l. Slopes are oriented mainly to the south in case of the Bystrice River basin with mean gradient 4.5°. On the contrary, north slopes are typical for the Zlaty Brook basin and its mean slope gradient is 11°. Forest cover is 52% in the Bystrice River basin. Forest cover in the Zlaty Brook basin is about 91%. The dominant tree species is Norway spruce (*Picea abies*).

The Ptaci Brook basin is located in the Sumava Mountains (Bohemian Forest) in the southwest part of the Czech Republic. The catchment is located from 1130 to 1330 m a.s.l. partly on west and partly on east oriented slopes with mean slope gradient 6° (with maximum up to 30°). The typical vegetation cover is Norway spruce forest, although large parts were damaged by the bark beetle (*Ips typographus*).

All catchments are equipped with water level measurement and with measurement of standard meteorological variables supplemented with automatic ultrasonic measurement of snow depth.

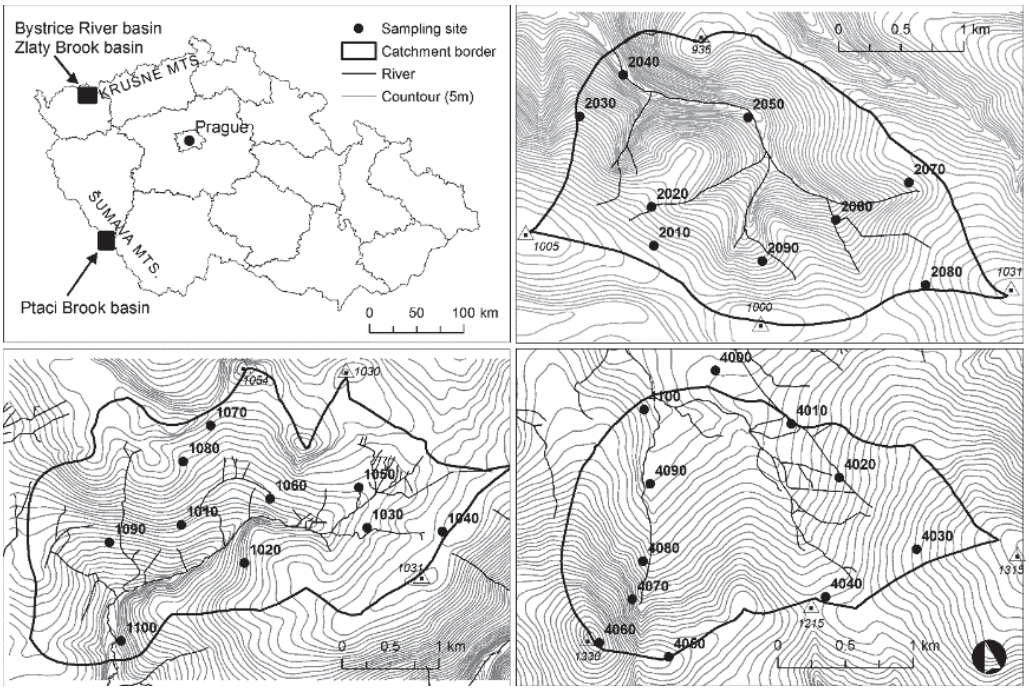


Fig. 1. Geographical location of the Bystrice River, Zlaty Brook and Ptaci Brook basins.
Obr. 1. Geografická poloha povodí Bystřice, Zlatého potoka a Ptačího potoka.

Sampling strategy

Manual field measurements of the snow depth and SWE were carried out from winter season 2009/2010 to 2013/2014; it means that data from 5 consecutive winter seasons were available for this study. The snow depth and snow water equivalent were manually measured at 47 localities located throughout all catchments either in forest or in open area/clearing. In total, we used data from 21 forest sites (including 3 sites with forest affected to the bark beetle), 14 clearings (open areas protected from solar radiation and wind by surrounding trees) and 12 large open areas. At each location, the snow depth was measured 5 times along 50 m long transect in regular step. The SWE was measured 2 times along the same transect using snow tube.
Data were sampled several times during five winter season. We performed 4 data sampling in 2010 (2 in snow accumulation and 2 in snowmelt periods), 5 sampling in 2011 (2 in snow accumulation and 3 in snowmelt periods), 10 sampling in 2012 (6 in snow accumulation and 4 in snowmelt periods), 8 sampling in 2013 (5 in snow accumulation and 3 in snowmelt periods) and 2 sampling in 2014 (both in snowmelt period). Different climatic conditions in each winter enable us to sample the data during different snow conditions, such as early winter snow accumulations with low snow densities, mid-winter accumulations with or without partial melting caused by rain-on-snow events and high snow densities during snowmelt periods. The R software (http://www.r-project.org/) and Statistica software (http://www.statsoft.com/) were used for all calculations in this study.

Predictors and response variables

We selected eight variables related to the status of specific localities and to winter and spring meteorological conditions. These variables were used to explain the variability of snow accumulation and ablation in study areas. Both elevation and slope were expressed as real values (in m a.s.l., respectively in decimal degrees) calculated from digital terrain model. The slope orientation (aspect) was expressed as southing which transforms aspects using sinus function into values ranging from 0 to 1. Value 1 represents south orientation, value 0 is north orientation and 0.5 represents both east and west orientations (Eq. 1).

$$Southing = (sin(aspect_{rad} - (\pi /2)) + 1) / 2 \quad (1)$$

The effect of vegetation was described by parameters derived from hemispherical photographs of the sky and canopy: i) Leaf area index (LAI), ii) percentage rate of pixels representing canopy to pixels representing sky (percentage of canopy openness) and iii) the amount of shortwave radiation calculated as a sum from November 1 to April 30. Overall, 74 hemispherical photographs (2 at each locality) were taken in study areas. The images were taken using camera with fish-eye lens (Sigma Circular Fisheye, focal length 4.5 mm). All photographs were analyzed using Gap Light Analyzer software (Frazer et al., 1999).
The sum of new snow depth and the sum of positive air temperatures were used as predictors describing the evolution of meteorological conditions during specific winter season. Both variables were calculated from December 1 to the day with field measurement using data from most suitable near meteorological station (Fichtelberg for locations in the Krusné Mts. and Grosser Arber for locations in the Sumava Mts.).
Above described predictors were tested to explain the variability of three response variables describing snow conditions: i) SWE measured at all localities during snow accumulation period, ii) SWE measured at all localities during snowmelt period and iii) melt factor (also known as degree-day factors) calculated from measured data according to the degree-day approach. This method comes out from the simplified energy balance of the snowpack, which is described only with the air temperature and melt factor (Eq. 2).

$$M = m_f (T_a - T_c), \quad (2)$$

where m_f [mm °C^{-1} d^{-1}] is the melt factor, which is the SWE decrease in a day caused by the air temperature change T_a of 1°C compared to the critical value T_c in which the melting process begins.

The melt factors for different types of vegetation and for different slope orientations were calculated based on measured SWE decreases between two measurement dates. In total, 229 m_f values were analyzed from all study areas from 2010 to 2014. The air temperature from 6 climatological stations placed inside catchments was used for the melt factor calculation. Critical temperature T_c was set up to 0°C in this study.

Multiple linear regression model

To describe the role of different factors on the snowpack spatial distribution, the multiple regression was used. The SWE were used as response variable. The elevation, slope, slope orientation and vegetation (expressed by several parameters as described earlier) were used as predictor variables (expressed as normalized values using standard score). In case of non-normal distribution of data (according to the Shapiro-Wilk test) a square-root transformation was used. All calculated models were considered as linear. As the parameters derived from photographs are mutually dependent, we always used only one of these parameters with the highest coefficient of determination resulting from the stepwise-forward linear regression model.
To make interpretation easier and to allow for comparison between all years, the goal was not to find the best

regression model for all years. We aimed to find a typical set of predictors although it is likely that the importance of individual predictors might vary in each year depending on previous meteorological conditions.

Results

Effect of vegetation on the snowpack variability during snow accumulation period

Based on derived prediction model (Fig. 2, right), we can calculate the SWE value for the forest having only the value measured in the open area. As the dependence is almost linear, we conclude that the SWE in forest sites is on average by 36% lower than in open areas and clearings and this value does not vary significantly with snow depth or SWE. Considering only the data from accumulation period, the average difference between forests and openings is 32% (Fig. 2, left). It means that the total amount of water available for melt is by 32% lower in the forest than in the open area. Median SWE in open areas are almost same as in the healthy forest indicating faster snow ablation in open areas than in forests. However, Fig. 2 shows large data variability and only 62% of this variability may be explained by vegetation (based on coefficient of determination R^2).
The same dataset as mentioned above was used to estimate the effect of the forest disturbance caused by the bark beetle on snow accumulation in the Ptaci Brook basin. Our data from sites attacked by the bark beetle show that in the defoliated spruce forest with standing trees, the combined effect of snow interception and evaporation causes similar reduction of the SWE compared to the healthy forest (32%). It is probably caused by the fact that our sites with disturbed forest are covered by spruce trees with dense treetops. Therefore, small branches without needles catch similar amount of snow as in case of healthy forest. However, it is expected that the interception effect is likely to decrease due to the gradual fall of branches and stems, and thus snow accumulation increases.
The snow density is another parameter which varies in different types of vegetation. As shown in Fig. 2, the lowest density is usually in the forest (both in snow accumulation and melt periods), although the variability is relatively high. However, in forests disturbed by the bark beetle, the snow density in snow accumulation period increases and the median value is close to median value in open areas. Mentioned effect was not observed for data measured during snowmelt. The variability of snow density in disturbed forest is lower than in healthy forest which might be caused by relatively smaller amount of snow density samples from disturbed forests (50 samples from disturbed forest compared to >300 from other vegetation categories). The highest snow density is mainly in large open areas, most probably due to the combined effect of wind (which affects snow crystals structure) and higher solar radiation which causes melt-freeze cycles, and thus increasing of snow density.

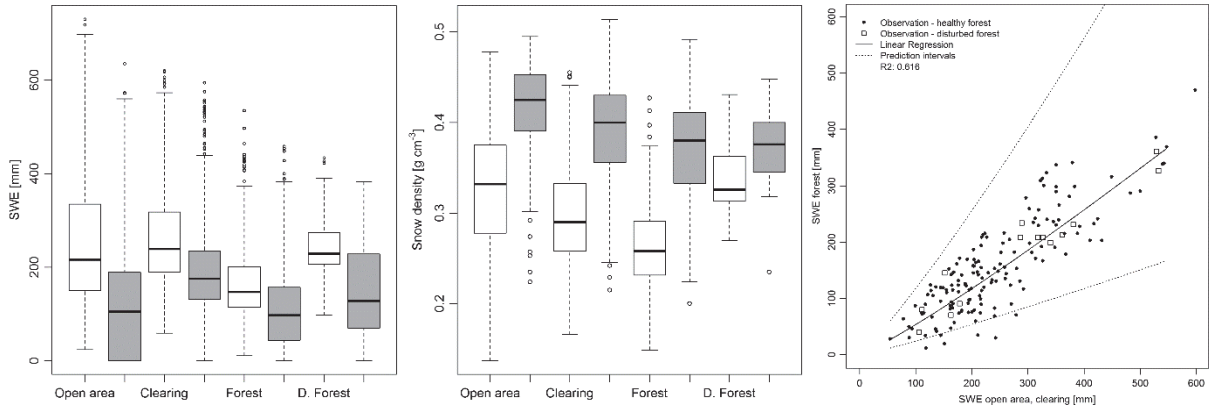


Fig. 2. Left and middle: The SWE and snow density in different vegetation. White box plots represent data from snow accumulation period, grey box plots represent data from snowmelt period. Boxes represent median, 25% and 75% percentile, whiskers represent 1.5 multiplier of interquartile range (IQR). Right: The SWE in open areas and clearings (x-axis) compared to the SWE in the forest (y-axis). Lines represent prediction intervals (5%, 50%, 95%). Data from all study areas from 2010 to 2014.
Obr. 2. Vlevo a uprostřed: SWE a hustota sněhu v různých vegetacích. Bílé grafy označují data z období akumulace sněhu, šedé grafy období tání sněhu. Limity krabicových grafů označují 25%, 50% a 75% percentily, chybové úsečky 1,5 násobek mezikvartilového rozpětí. Vpravo: SWE na otevřené ploše a mýtině (osa x) a v lese (osa y). Linie představují predikční intervaly (5, 50 a 95 %). Data ze všech studovaných povodí z let 2010-2014.

Effect of vegetation on the snowpack variability during snowmelt period

Assessing the effect of different vegetation structures on snowmelt is important with respect to the runoff generation. Fig. 3 shows calculated melt factors (basic parameter for the degree-day approach, see methods) for different vegetation. Despite the large data variability it is clear that the snowmelt rate increases with an increasing amount of solar radiation caused by sparser canopy cover. The snow ablation in open areas is more than two times faster compared to forest sites. On the contrary, the snow ablation in clearings partly protected from solar radiation is only by 38% faster than in the forest.

All described differences are caused mainly by the different amount of solar radiation at the specific site. We observe lower interception (and thus higher snow accumulation) and faster snow ablation in the disturbed forest, compared to the healthy forest. The snow ablation is by 33% faster after forest defoliation and we expect even slightly higher values in case of complete forest decline due to further increase of solar radiation.

The slope orientation is also important, especially the presence of southern slopes in catchments. As expected, there are almost no differences between melt factors in different slopes in the forest. On the other hand, there is clearly faster snow ablation in clearings oriented to the south compared to other orientations (by 21%). Almost no difference in snowmelt rates in open areas is probably caused by the lack of data from cold aspects (E-N-W). The lack of data from particular aspects is a problem for sites in the disturbed forest as well.

It is important to mention that the results shown in Fig. 3 should not be interpreted as values which may be used for other world regions. The variability of each land cover category is relatively large, especially in case of clearings and large openings, data are almost equally distributed within their range.

Multicriterial analysis of the SWE and melt factors

The Pearson correlation coefficients displayed in Table 1 indicates high correlations of melt factors m_f and variables related to the land cover (calculated from hemispherical photographs). It is important to say that the percentage of canopy openness, LAI and radiation parameters are mutually dependent. The results displayed in Table 1 indicate that topography (especially southern slopes) is more important for open areas (typical for the Bystrice River basin), while LAI descrybing canopy structure is more important for forest sites (typical for the Zlaty Brook and Ptaci Brook basins).

As expected, sum of positive air temperatures is important especially for SWE measured during snowmelt period in all study areas. Lower correlation coefficients of SWE and sum of new snow depth indicated that SWE was influenced by several periods with positive air temperature and thus partial melting of snowpack. However, correlations of SWE with both sum of new snow depth and sum of positive air temperature was generally low and not significant in some cases.

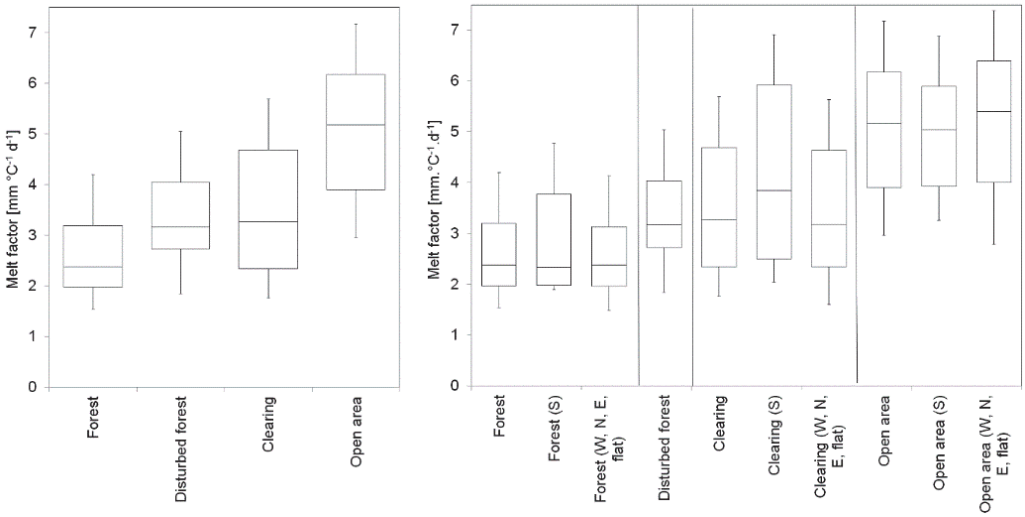


Fig. 3. Melt factors for different vegetation covers and slope orientations in study areas based on measured data from 2010 to 2014. Boxplots represent median, 25% and 75% percentile, whiskers represent 10% and 90% percentiles.

Obr. 3. Faktory tání v různých vegetacích a orientacích svahů v studovaných územích na základě dat 2010-2014. Limity krabicových grafů označují 25%, 50% a 75% percentily, chybové úsečky představují 10% a 90% percentily.

The stepwise forward linear regression of 618 SWE values (294 from snow accumulation periods, 324 from snowmelt periods) from all study areas and years shows the importance of the land cover structure (expressed using LAI) as a predictor especially during accumulation periods. Besides vegetation, the effects of elevation and slope orientation are significant in the most of measurement dates during snowmelt.

Fig. 4 shows the overall assessment of all linear models considering all study catchments and years. As expected, the model calculates better in case of data measured during snow accumulation periods before melting. The model explains 79% of the SWE variability during snow accumulation. Only 66% of the SWE variability was explained by the regression model during snowmelt which could be linked to the increasing role of other factors influencing snowmelt, such as solar radiation and processes related to the ripening process of snowpack (due to the increasing role of positive air temperatures and rain-on-snow events). However, there is still large variability which cannot be explained by the selected set of predictors.

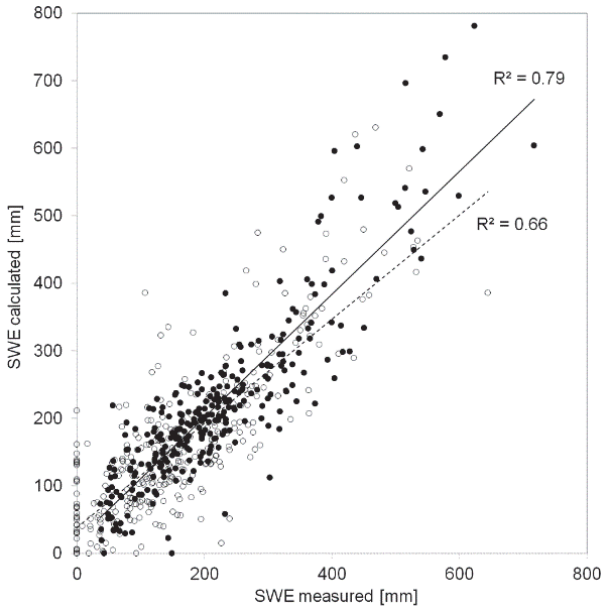


Fig. 4. Measured SWE and SWE calculated from the linear regression model from all study catchments from 2010-2014. Black points and solid lines represent data from accumulation periods; transparent circles and dashed line represent snowmelt periods.
Obr. 4. Měřená SWE a SWE vypočtená na základě regresního modelu ze všech studovaných území od 2010 do 2014. Černé body a souvislá linie představují data z období akumulace sněhu, průhledné body a čárkovaná linie představují data z období tání sněhu.

Table 1. Pearson correlation coefficients of 1) SWE and 2) melt factors m_f as response variables, and all predictors. Values in bold are statistically significant at α = 0.05 level
Tabulka 1. Pearsonovy korelační koeficienty mezi 1) SWE a 2) faktory tání a všemi prediktory. Tučně vyznačené hodnoty jsou staticky významné na hladině α = 0,05

Parameter	SWE accumulation / SWE melting				Melt factor m_f			
	Whole dataset	Bystrice	Zlaty	Ptaci	Whole dataset	Bystrice	Zlaty	Ptaci
Elevation	**0.62** / **0.39**	**0.48** / **0.31**	**0.30** / **0.29**	**0.44** / 0.15	**0.23**	0.03	**0.35**	0.24
Southing	0.02 / 0.05	**-0.24** / **-0.18**	-0.05 / 0.02	**0.23** / -0.02	**0.31**	**0.44**	-0.05	0.14
Slope	**-0.12** / -0.08	**-0.44** / **-0.37**	**-0.17** / **-0.21**	**0.20** / 0.14	**-0.15**	0.04	**-0.33**	-0.12
% Canopy Openness	**0.42** / **0.29**	0.11 / -0.05	**0.55** / **0.53**	**0.49** / **0.16**	**0.54**	**0.48**	**0.52**	**0.45**
LAI	**-0.46** / **-0.33**	**-0.21** / -0.03	**-0.59** / **-0.56**	**-0.47** / -0.15	**-0.48**	**-0.42**	**-0.43**	**-0.40**
Shortwave radiation	**0.45** / **0.31**	**0.14** / -0.03	**0.55** / **0.52**	**0.48** / **0.18**	**0.52**	**0.44**	**0.54**	**0.42**
Sum of T>0°C	**0.20** / -0.03	-0.05 / **-0.17**	0.09 / **-0.41**	**-0.41** / **-0.60**	0.12	-0.21	-0.15	0.21
Sum of new snow depth	**0.46** / **0.28**	**0.18** / 0.11	**0.26** / 0.02	0.04 / **0.33**	0.02	0.10	0.02	-0.11

Discussion

Snow sampling design and uncertainty of input data

It is generally known that the snowpack variability is extremely high in mountainous conditions, while this variability is difficult to describe by point measurements. In general, the biggest differences may be found when comparing snow amounts deposited in forests and in open areas as documented by this study and several other studies (see e.g. Essery et al., 2009; Jost et al., 2007; Šípek and Tesař, 2014). It is clear that more measuring sites would lead to more reliable results. However, to increase their number is hardly possible due to time and financial demands. Therefore, the use of methods applying one or more independent variables leads to applicable results as shown in this study.

Melt factors were calculated using air temperature data measured at climatological stations. These procedure cannot capture the small scale variability of air temperature due to the small scale variability of topography. The minimum temperature strongly varies according to the topography (frost pockets) which could affect the mean daily air temperature used in the melt factor calculation. Local temperature conditions are also affected by the forest structure which is often connected to topography (Tesař et al., 2006). The above mentioned fact could partially explain a relatively high variability of melt factors within one category.

The effect of the wind was not included in the study, although we subjectively observe its impact on snow transport and redistribution at some sampling sites (especially during snow accumulation periods). The use a suitable predictor describing this effect (surface curvature or similar) might bring some improvements of the results. Another important effect of the wind is its influence on the small scale variability of turbulent fluxes during snowmelt (Pohl et al., 2006).

Vegetation structure and its possible consequences to runoff

Based on measured data, the differences in SWE in the forest and in the open area do not significantly vary with total snow accumulations (either snow depth or SWE). This result is in contrast with Stähli and Gustafsson (2006) who concluded slightly decreasing effect of the forest with higher accumulations in Alptal valley in Switzerland, especially in high elevated parts of the basin. However, it is important to say that maximum of SWE in Alptal is somewhat higher than in our study catchments (600-800 mm in Alptal; up to 600 mm in our study catchments). It means we cannot exclude a decreasing effect of interception in our catchments in case of high snow accumulations.

Measurements proved a considerably high effect of forest disturbed by the bark beetle on snow ablation compared to the healthy forest. Our values are in accord with values presented by Pomeroy et al. (2012) simulated by the CRHM model. However, the decrease of snow interception after spruce forest defoliation was not clearly proved, although this effect was demonstrated by Pugh and Small (2013) who explored the effect of the pine forest disturbance in western US. Our results could be influenced by small amount of study sites and by the fact that these sites are located in disturbed forests with dense treetops, and thus there is still a relatively big amount of snow intercept by the canopy formed by small branches. However, it is expected that the interception effect is likely to decrease due to gradual fall of branches and stems, and thus snow accumulation increases.

Despite the significance of the correlations found, there is still large variability which cannot be explained by the selected set of predictors. It is possible that regression models fail because point measurements suffer from several uncertainties arising from sampling design. Therefore, testing of methods which might be able to measure at a plot or catchment scale such as laser scanning and unmanned aerial vehicles (UAV) would be beneficial.

Conclusions

We analyzed the snowpack variability in selected experimental catchments with special interest in the effect of forest structure and forest disturbance on both snow accumulation and ablation. Our study was based on repeated measurements of snow depth and SWE at 47 localities from 2010 to 2014. Based on results from our study sites, we draw up following conclusions:

- The SWE in forest sites is on average by 32% lower than in open areas and clearings. It means that the total amount of water available for melting is by 32% lower in forests than in open areas.
- The snow ablation in open areas is more than two times faster compared to forest sites. On the contrary, the snow ablation in clearings partly protected from solar radiation is only by 38% faster than in the forest.
- We observe slightly lower interception and importantly faster snow ablation in the disturbed forest due to the bark beetle compared to the healthy forest. The snow ablation is by 33% faster after forest defoliation and we expect even faster ablation in case of complete forest decline.
- We found a significant correlation of both SWE and melt factors with parameters describing topography and parameters describing forest structure, such as LAI, percentage of canopy openness and potential amount of solar radiation. The results indicate that topography (especially southern slopes) is more important for open areas, while LAI describing canopy structure is more important for forest sites.
- Despite the significance of the correlations found, there is still large variability which cannot be explained by the selected set of predictors.

Acknowledgement

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AKUMULACE A ÚBYTEK SNĚHU VE TŘECH LESNÍCH HORSKÝCH POVODÍCH

Sníh je důležitou součástí hydrologického cyklu ve střední Evropě. Velké množství vody je v průběhu zimy akumulováno a v relativně krátkém období na jaře odtéká toto množství do řek. Proto je studium procesů akumulace a tání sněhu důležité pro predikci jarních povodní.

Prostorová distribuce sněhu je na velkých územích ovlivněna především nadmořskou výškou, která ovlivňuje teplotu vzduchu a tedy skupenství srážek a intenzitu tání (Kucerova and Jenicek, 2014). Avšak v malém měřítku je distribuce sněhu ovlivněna především topografií a vegetací (Jenicek et al., 2012; Jost et al., 2007; Parajka et al., 2012; Šípek and Tesař, 2014). Během akumulace sněhu je jeho prostorová variabilita kontrolována především strukturou lesa, který má vliv na intercepci sněhu, redistribuci sněhu větrem a hustotu sněhu. V době tání sněhu les snižuje celkový úhrn dopadajícího slunečního záření, což zpomaluje tání sněhu v lese ve srovnání s otevřenými plochami (Hribik et al., 2012; Pomeroy et al., 2012).

Cílem příspěvku je definovat hlavní faktory ovlivňující variabilitu akumulace a tání sněhu za použití periodicky měřených dat výšky sněhu a vodní hodnoty sněhu (SWE) ve vybraných horských lokalitách. Dalším cílem bylo popsat roli zdravého lesa, lesa postiženého kůrovcem, lesních mýtin a otevřených ploch na akumulaci a tání sněhu. Ačkoliv je tání sněhu řízeno komplexní energetickou bilancí, naším cílem bylo použít jednoduchý přístup založený na měřených datech a metodě degree-day. Uvedený přístup je možné použít i na územích, kde neexistuje sledování všech meteorologických veličin nutných pro výpočet energetické bilance sněhu.

Ve studii byla použita data výšky sněhu a SWE měřená na 47 lokalitách v Krušných horách a na Šumavě v letech 2010-2014. Na jednotlivých lokalitách jsou

většinou měřeny dva sněhoměrné profily o délce 50 m. Jeden profil je měřen v zalesněném území a druhý profil je měřen na otevřené ploše. V rámci profilu je 5x měřena výška sněhu a 2x SWE.

Struktura vegetace jednotlivých lokalit byla popsána pomocí hemisférických snímků oblohy a vegetace. Hemisférický snímek byl pořízen pomocí fotoaparátu s objektivem typu rybí oko s ohniskovou vzdáleností 4,5 mm (Sigma Circular Fisheye). Na základě těchto snímků byly pomocí analýzy obrazu v softwaru Gap Light Analyser (Frazer et al., 1999) odvozeny parametry Leaf Area Index (LAI), procento oblohy zakrytí vegetací a potenciální úhrn krátkovlnné radiace nad a pod vegetací. K dalším použitým prediktorům patřily nadmořská výška, sklon svahu, orientace svahu, suma pozitivních teplot vzduchu a suma nového sněhu. Mezi použité nezávislé proměnné patřily měřená SWE a teplotní faktory tání. Ty byly vypočteny pro všechny lokality pomocí metody degree-day, která vychází ze zjednodušené radiační bilance sněhu. K analýze dat byla použita vícenásobná lineární regrese (stepwise forward). Vstupní data byla standardizována a testována na normalitu a v případě potřeby transformována.

Výsledky terénních měření ukazují, že v jehličnatém lese je SWE nižší v průměru o 32 % oproti otevřeným plochám. Tání sněhu na otevřených plochách je pak více jak dvakrát rychlejší než v lese. Naproti tomu tání na mýtinách (částečně chráněných před krátkovlnnou radiací) je pouze o 38 % rychlejší než v lese. Rychlost tání se také výrazně zvyšuje v důsledku rozpadu stromového patra vlivem lýkožrouta smrkového (*Ips typographus*), a to v průměru o 33 %. Výsledky ukázaly, že topografické charakteristiky jsou dominantním prediktorem otevřených ploch, zatímco LAI je dominantní prediktor u lesních lokalit. Ačkoliv nalezené vztahy jsou většinou statisticky významné, prediktory použité v této studii pouze částečně vysvětlily celkovou variabilitu sněhové pokrývky.

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