Can a point measurement represent the snow depth in its vicinity? A comparison of areal snow depth measurements with selected index sites.

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ABSTRACT: Information on the amount of snow stored in a catchment or on a mountain is an important issue for hydrology, natural hazards, winter tourism or mountain ecology. Area-wide measurements of the snow depth in an appropriate spatial and temporal resolution are usually not available as they are costly and difficult to obtain. In practice one often relies on few, selected point measurements, like meteorological stations which measure snow depth at a specific location in a high temporal resolution and one assumes that these index sites represent the snow cover of their vicinity. Such index sites are usually located in flat and sheltered terrain and it has been questioned if such places are really capable to represent the snow cover of their larger surrounding. In this study we use a large data set of areal snow depth measurements obtained by airborne laser scanning in different mountain regions and analyse, if virtual index-sites within the study areas do represent the real snow distribution of their direct vicinity and of the entire catchment. We show that single stations are not able to represent the snow cover and that most stations tend to clearly overestimate snow depth. There are, however, also index sites which measure lower snow depths than the surrounding area. Such stations are typically dominated by strong winds. We also show that elevation gradients of snow depth are qualitatively captured by index sites, even though quantitative estimation of real gradients using index sites has a large error.

KEYWORDS: index-site, representativeness of point measurement, snow depth, airborne laser scanning, LiDAR

1 INTRODUCTION

The mountain snow cover is typically shaped by the processes of deposition, redistribution and ablation. These processes strongly interact with the local terrain and result in a strong spatial variability of the snow depth distribution. Typical patterns are deeper snow packs in sheltered locations or an increase of snow depth with elevation.

Many applications ranging from avalanche warning to hydrologic modelling depend on quantitative information on snow amounts. Such snow depth data which serve as input for spatial models or for extrapolation, are usually obtained from point measurements like automatic stations or manual snow cores/pits. The problem with such measurements is i) that there are usually only few stations available even if a large area is considered and ii) that the stations might not correctly represent the area they are located in.

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The aim of this paper is therefore to present a case study that assesses if such index-sites are capable to represent their surrounding area at different scales.

2 DATA AND METHODS

For the study we analyze a large data set consisting of high-resolution snow depth maps obtained by airborne laser scanning (ALS) from different mountain regions of the world. ALS was shown to be an appropriate technique to gather snow depth in high spatial resolution and accuracy (Deems and Painter, 2006; Hopkinson et al., 2004). In total data from six areas, four located in the Alps, one in the Pyrenees and one in the Rocky mountains were available. For most data the ALS surveys represent the peak of local accumulation season. The spatial resolution is 1 m and the vertical accuracy is between 10 and 30 cm (DeBeer and Pomeroy, 2010; Geist et al., 2009; Grünewald et al., 2010; Moreno Banos et al., 2009). More detailed information on the data can be found in Grünewald et al. (2013). In this paper we exemplary focus on one of the sites that is the Wannengrat area, located near Davos in the eastern Swiss Alps.

Two different approaches were performed to assess the representativeness of index-sites for the area: The fist is to identify typical stations in terms of topography and then to assess how their snow depth relates to the one in their vicinity. The second approach is to search for cells with "representative" snow depths and then to analyze the topographic characteristics of these cells.

Index stations as commonly set up in mountain regions are characterized by three criteria: The direct surrounding should be relatively flat, have a homogeneous snow cover and not be significantly affected by wind (Lehning et al., 1998). A GIS algorithm automatically indentifies all pixels which meet these criteria. The selected cells were then defined as potential index-sites to compare the snow depth at these stations with the snow depth in their vicinity. To assess different scales, we define this vicinity with circles of increasing radius. The fist circle has a radius of 20 m the next 50, 100 up to 400 m. Finally we compare the stations with the mean of the entire catchment.

The second approach aims to answer the question: Where are sites, which represent the average snow depth of the catchment? All pixels which deviate less than 10% from the catchment mean, are defined as being representative for the area. These cells are automatically identified in GIS and it is then tried to discover if there are typical topographic characteristics for these cells.

Finally the relationship between snow depth and elevation (Grünewald and Lehning, 2011; Pipp, 1998; Rohrer et al., 1994) as represented by the index stations is compared to the real elevation gradient, which is calculated from the mean of 100 m elevation bands of obtained from the ALS data.

3 RESULTS

For the Wannengrat only four locations were identified which meet all criteria for potential index stations as defined above. Figure 1 shows the mean snow depth as calculated for each station and each of the circular reference areas (with the increasing radius on the x-axis). The dotted black line indicates the mean of the entire catchment. The Figure shows that all stations at the Wannengrat clearly overestimate the catchment mean. When the reference area is increased, this overestimation decreases. Figure 1 also shows that most curves are not smooth: this characteristic reflects the variable influence of the local snow distribution in interaction with the topography, e.g. small accumulation features like drifts or rocky faces with less snow.

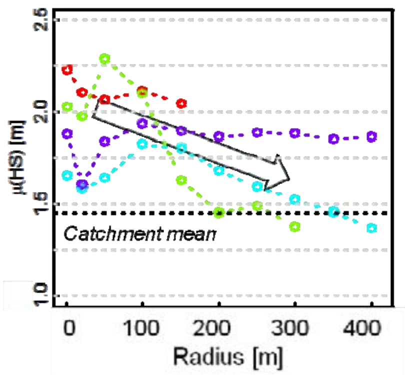

Figure 1. Mean snow depth versus support area for different potential index stations at the Wannengrat. The y-axis indicates the radius of the circular vicinity of the index stations to which the mean refers.

In principal the results are similar for the other data sets (not shown) but there are also stations which underestimate the snow cover in their surrounding area. Such stations are usually located in very wind exposed sites.

Figure 2 shows the cells (green) which were identified as representative for the Wannengrat catchment in terms of snow depth (deviation less than 10% from the catchment mean). The representative cells do not show clear spatial patterns.They rather appear relativly randomly distributed accorss the entire area. Statistical analysis with box-plots (not shown) confirmed this finding, also for the other study sites.

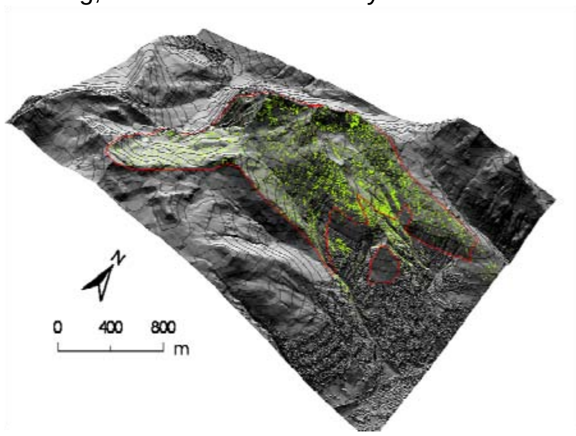

Figure 2: Hillshade-image of the Wannengrat area. The green pixels indicate cells with representative snow depths.

Figure 3 shows the elevation gradient as calculated for the 100 m elevation bands (grey line) and the elevation - snow depth relation for the four selected stations in the Wannengrat area. The figure confirms a clear positive elevation gradient of snow depth for the entire area

(Grünewald and Lehning, 2011). But this trend is not reflected by the selected index-sites (black triangles). Nevertheless most index-sites in the other study areas (not shown) reflect the general elevation trend, even though clear deviations in absolute snow depths exist for many of the index-sites.

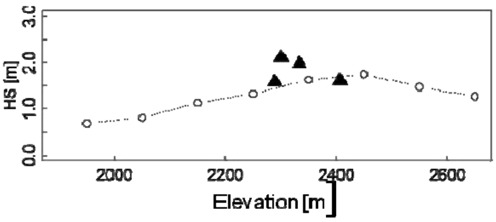

Figure 3: Snow depth versus elevation for the Wannengrat. The black triangles are the four potential index stations. The line indicates the elevation trend derived from the ALS data with 100m elevation bands.

4 CONCLUSIONS

Based on high-resolution digital snow depth and elevation data obtained from ALS, we have presented a systematic analysis on the representativeness of potential index-sites for snow depth. We can conclude that sites for potential index stations are rare in alpine, non-glaciated terrain as analyzed in this study. Most of the potential stations tend to strongly overestimate snow depth, but there are also some index locations which underestimated the catchment mean. Generally a single station appears not to be capable to represent the snow cover of its vicinity, not to mention entire catchments.

Regarding the topographic settings of cells with representative snow depth, we could not identify a clear correlation of these cells with the local topography. It appears that such typical characteristics do not exist, at least not for the data sets analysed in our study.

Elevation gradients are only partly reflected by index-sites. Due to the small number of sites and the large probability of a single station to clearly deviate from the catchment mean, this is not surprising.

The final implication of these results is that one needs to be very careful when working with data of index-sites. The station might not represent the area of interest and correction of the data might not be possible.

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