UNDERSTANDING THE SPATIAL VARIABILITY OF SURFACE HOAR AT THE MOUNTAIN RANGE SCALE

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ABSTRACT: Surface hoar once buried, often produces a persistent weak layer that commonly causes instability in the snow pack in many areas around the world. It is relatively well understood that aspect plays an important role in the location of the growth, and survival of surface hoar. However, this alone does not explain the complex spatial pattern of these grains forms at larger, mountain range scales. Furthermore, previous studies of surface hoar have either only taken observations on one or two slope, or modelled the distribution across larger spatial scales.

In this paper we present an analysis of the spatial variability of surface hoar, using data from a detailed case study located on Pioneer Mountain at the Yellowstone Club in southwestern Montana, USA. We examine two winters of paired meteorological data and surface hoar observations for 127 days for 16 sites distributed across all four aspects and at different elevations on Pioneer Mountain. These data were collected between December 2011 and April 2014. Using these snowpack data, combined with topographic variables and sky view we examine the dominant controls that can explain the spatial patterns of surface hoar at this scale. Our preliminary results show that small-scale site characteristics which influence micro-meteorological conditions can greatly influence the spatial variability of surface hoar, over and above that which aspect alone can explain. These results highlight our incomplete understanding of the processes at this scale, and have implications for both regional and local scale avalanche forecasting.

KEYWORDS: Spatial variability, Surface hoar, Forecasting.

1. INTRODUCTION & BACKGROUND

Knowledge of spatial and temporal variations in snow stability and snowpack properties is critical for understanding and predicting snow avalanches. One type of weakness that is commonly responsible for slab avalanches is surface hoar (Schweizer and Lutschg, 2001). Though recent research has investigated the spatial variability of various weak layers on individual slopes (e.g. Birkeland et al., 2004; Landry et al., 2004; Lutz et al., 2007), and more recently at larger mountain range scales (e.g. Feick et al., 2007; Borish et al., 2010; Borish et al., 2012), almost all of the previous work has simply looked at a single snapshot in time of an extremely dynamic system. The studies that have considered the temporal component are limited to small, uniform study slopes, and not of the wider mountain-range scale (e.g. Hendrikx et al., 2009; Lutz, 2009; Lutz and Birkeland, 2011). In sharp contrast, this larger mountain range scale is the typical scale at which avalanche forecasts are issued.

This paper aims to provide data towards understanding the spatial variability of surface hoar growth at a large, mountain range scale. This work is an extension to previous work by Hendrikx et al., (2012), but focusses solely on terrain based analysis of surface hoar occurrence.

2. METHODS

2.1 Field Data

Over the period of two winter seasons, 16 mini-temperature and relative humidity sensors (HOBO U23 Pro v2) which were mounted inside solar radiation shields (RS3). These were installed across all four aspects and at different elevations on Pioneer Mountain, at the Yellowstone Club in SW Montana. Topographic attributes including aspect, elevation and wind exposure were recorded or calculated for each site. In addition, a hemispherical fisheye lens was used to capture 180° circular

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fisheye photos facing upwards and level for later calculations of hemispheric sky visibility.

Each sensor was installed on a PVC pipe, 1.5m above the snow surface. As needed, these sensors were moved up or down the pipe to ensure that observations were made at approximately 1.5m ± 0.2m above the snow surface. Automatic observations of air temperature (°C), relative humidity (%) and calculated dew point temperature (°C), were made every 15 minutes. In total, across the 16 sensors, more than 500,000 lines of data were recorded for the two seasons. These data will not be presented in this paper, but will be used for subsequent analysis. This paper will focus solely on terrain based relationships.

At each of these sites, we also collected field data, at sub-weekly intervals, on the presence / absence and size of surface hoar and near surface facets. In total, over the two year period, 127 days of manual field observations were collected from all 16 sites.

2.2 Data Analysis

The observations of surface hoar presence / absence for each individual site were summarized, so that the frequency of occurrence of surface hoar could be calculated for each site.

Key terrain parameters including slope, elevation, aspect and an estimated wind exposure index were extracted or calculated for each site using a 1m LiDAR derived DEM. These parameters were extracted within a GIS. The hemispheric sky visibility was calculated for each site using Gap Light Analyzer (GLA) (Frazier et al., 1999).

For this paper, we then calculated a simple coefficient of determination (or r^2) to examine the relationship between the frequencies of surface hoar occurrence at each site, for each year, with the selected terrain parameters extracted.

3. RESULTS

Our preliminary analysis shows that all of the selected terrain based parametrs have little relationship to the occurrence of surface hoar at the 16 sites with very low coefficients of determination (Table 1). However, the percentage sky view has a substantially higher coefficient of determination, especially for the 2012/13 season.

Table 1: Coefficients of determination for surface hoar frequency at sites and selected terrain based parameters, and measured hemispherical skyview.

	2012/13 Season	*2013/14 Season*
Elevation	0.20	0.33
Slope	0.01	0.02
Aspect	0.03	0.00
Wind exposure	0.01	0.02
Skyview	0.89	0.50

4. DISCUSSION AND CONCLUSIONS

The results presented here are only a brief overview of 127 days of manual observation and detailed terrain analysis and a more in depth analysis is required. However based on this preliminary analysis, we note that sky view is likely more important for the preferential development of surface hoar than other, terrain based parameters such as aspect or elevation at these sites. This is consistent with some previous work, e.g. Shea (2011) who examined surface hoar sizes and found positive correlations between surface hoar size and open skyview percentage at the slope scale. However, it is contrary to our understanding of the dominant role of aspect on surface hoar formation at the slope scale (e.g. Cooperstein et al., 2004; Lutz and Birkeland, 2011) This preliminary, and very simple analysis supports the previous findings by Hendrikx et al., (2012) which highlighted that small-scale site differences can influence the occurrence of, and therefore spatial variability of surface hoar, over and above that which aspect alone can explain. These differences in skyview likely influence the micro meteorological conditions at these sites to favor or deter the development of surface hoar.

However, a much more in-depth study, including quantitative modeling of solar radiation across these spatial scales is needed, to better understand the controls of the spatial distribution and occurrence of surface hoar at these larger spatial scales. Our current lack of understanding at these spatial scales, compound our efforts to spatially extrapolate point information at these larger mountain range scales. A better understanding of these limitations in our abilities to extrapolate these data is likely to have implications for both regional and local scale avalanche forecasting in environments where surface hoar can cause persistent instabilities.

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