AVALANCHE TRIGGER LOCATIONS IN COMPLEX TERRAIN

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EXTENDED ABSTRACT

More winter recreationists are venturing into “extreme” terrain each year, and avalanche fatalities in that terrain are increasing. The slope-scale spatial variability of snow stability and how it relates to this complex terrain is critically important but poorly understood. Persistent weak layers account for the failure layer in most avalanche fatalities (Schweizer and Jamieson, 2001). Although many studies have characterized these depth hoar, surface hoar, and near surface faceted layers (e.g., Akitaya, 1974; Birkeland, 1998; Lang et al., 1984), few studies have attempted to predict their presence at the slope scale. The results from studies characterizing the spatial variability of snow on slopes have varied tremendously (Schweizer et al., 2008), but terrain is commonly cited as a potential source of variability (e.g., Campbell and Jamieson, 2007; Föhn, 1989; Harper and Bradford, 2003; Jamieson, 1995). Only a few studies have attempted to use terrain to model weak layer presence, but these were all on relatively simple slopes below treeline (Birkeland et al., 1995; Lutz and Birkeland, 2011; Shea and Jamieson, 2010). This extended abstract summarizes a unique study that characterizes and models persistent weak layers and slabs on slopes in complex, alpine terrain. More details about this work can be found in Guy (2011) and Guy and Birkeland (under review).

In this study, we use terrain parameters to model potential trigger locations (PTLs) of slab avalanches, which are defined based on slab thicknesses and weak layer presence. In a sample of seventeen couloirs from five different cirques on Lone Mountain, Montana, field teams tracked and mapped persistent weak layers and slabs with probe and pit sampling over two winters. We sampled the entire length and width of each couloir without bias in a stratified sampling scheme. We derived twelve terrain parameters from a one-meter Digital Elevation Models, such as relative elevation, slope angle, and slope curvature, to explore the relationships between PTLs and terrain. For a robust statistical analysis, we employed several different techniques and modeling structures: KS-tests (Massey, 1951), classification trees (Breiman et al., 1993), Random Forests (Breiman, 2001), and multi-model logistic regression (Hosmer and Lemeshow, 2000). Our analysis includes two PTL types (depth hoar or near surface layers) and three scales (the individual couloir scale, the cirque or headwall scale, and the mountain scale). With the goal of assessing which terrain parameters are most influential in describing the location of PTLs, we used different measures from each modeling technique to assess the importance of each of the twelve terrain parameters (Guy, 2011; Guy and Birkeland, under review).

The successful modeling results, particularly for individual couloirs (with success rates frequently exceeding 70% for depth hoar layers and 80% for near surface layers), confirm that the terrain in each couloir is strongly related to the snowpack that develops within it. In other words, we can do a reasonable job of explaining observed patterns given our terrain parameters. Given the highly complex and variable nature of these couloirs and their snowpack, finding statistically valid relationships is encouraging. The widely varying results from couloir to couloir and decreasing model performance from the couloir scale to mountain scale have strong implications: relationships between terrain and PTLs in each couloir exist but are unique and highly complex, although some patterns exist across cirques. A simple “rule of thumb” to relate PTLs to terrain is inadequate; terrain interacts with the snowpack differently in each couloir, making extrapolating results from one couloir to other couloirs challenging and potentially misleading (Guy, 2011; Guy and Birkeland, under review).

Of the twelve parameters used to model these steep alpine couloirs, relative elevation, distance from the edge of the couloir, wind exposure relative to prevailing winds, terrain exposure, and down-slope curvature are most frequently the best predictors of PTLs (Figure 1).

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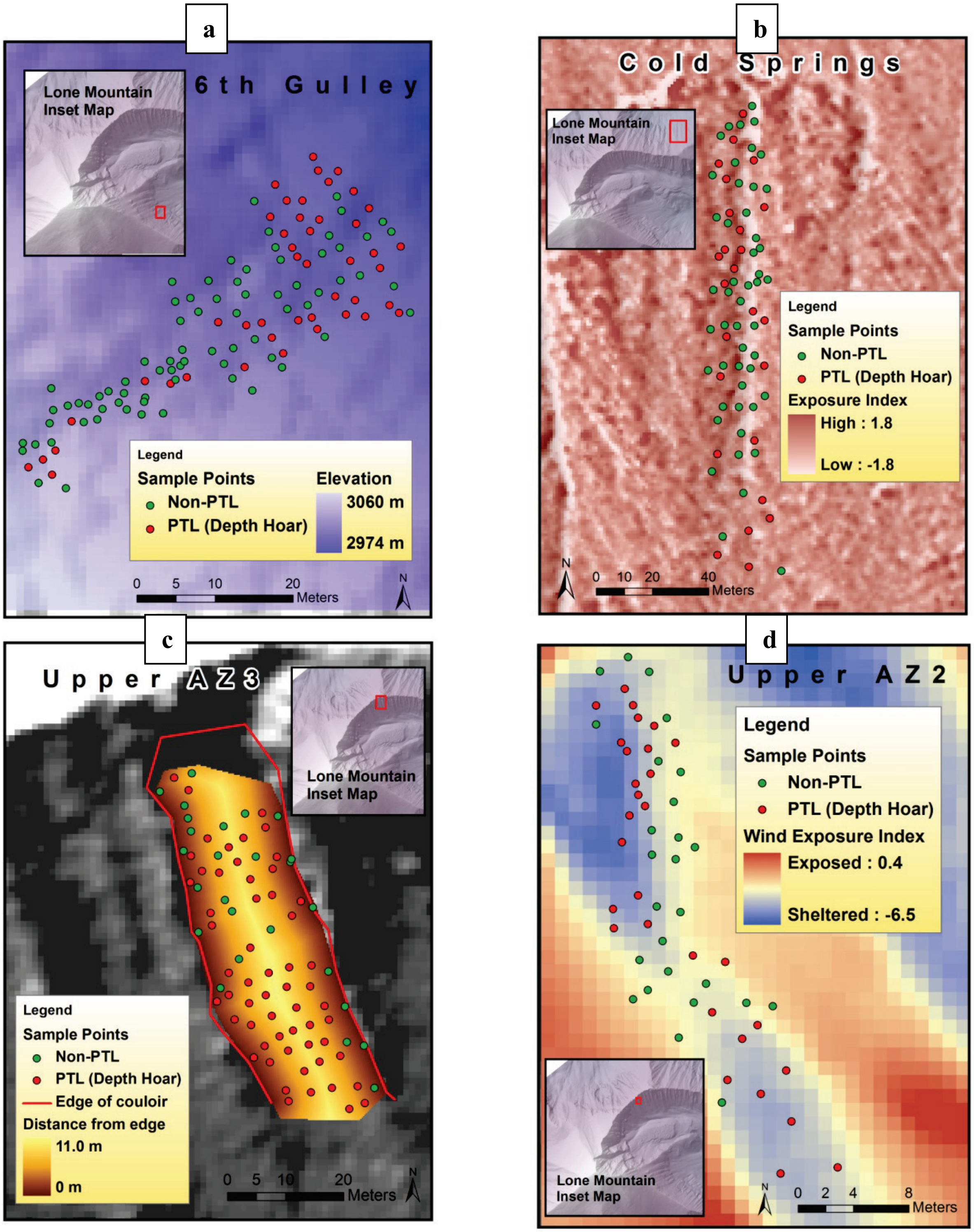

Figure 1: (from Guy and Birkeland (under review), Figure 5). Examples of four parameters that are most commonly associated with presence/absence of PTLs for individual couloirs. (a) Relative elevation (where higher elevation values have a higher relative elevation within the couloir); (b) Distance from the edge of the couloir; (c) Exposure index (where higher positive values indicate the terrain is higher and more exposed relative to its surroundings); (d) Wind exposure index (where higher positive values indicate a greater amount of wind exposure and scouring with prevailing winds).

These parameters are commonly related to wind deposition, wind scouring, or sluffing. The importance of wind-related parameters in alpine terrain is consistent with previous snow depth modeling studies that cite wind as most influential, such as Erickson et al. (2005) and Wirz et al. (2011). The influences of the terrain parameters in this study vary, depending on broader-scale terrain characteristics, prior weather patterns, and seasonal trends. The use of numerous terrain parameters in the various couloir models emphasizes the importance of collectively incorporating all available terrain parameters into the decision-making process, rather than relying on a single parameter. With an understanding of the broader scale influences and physical processes involved, we can use terrain to optimize stability test locations, explosive placements, or route selection.

Because of the statistical scope of this study, these results must be extrapolated with care, especially if they are to be applied to other snow climates or different terrain types. Despite uncertainties involved, this is the first field study to show that snow weaknesses and slabs can be related to terrain parameters in steep couloirs, and it provides an encouraging baseline for improving decision making in this type of terrain as well as for future modeling efforts. One of the practical implications of these findings are that the distribution of PTLs in a couloir is likely to vary depending on the influence of various terrain parameters, so careful consideration needs to be given when assessing the stability from a single point observation or before extrapolating the results from one couloir to the next (Guy 2011; Guy and Birkeland, under review).

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