USING TIME LAPSE PHOTOGRAPHY TO DOCUMENT TERRAIN PREFERENCES OF BACKCOUNTRY SKIERS

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ABSTRACT: This paper presents a method developed to capture the terrain metrics of all visible skiers on an avalanche-prone backcountry slope. A remote time-lapse camera focused on Saddle Peak, a high skier-use backcountry slope in the Bridger Mountain Range of southwest Montana, USA captured 31,960 photos of 525 skiers descending in ten-second increments on 13 unique days. Skier locations (7,499 location-points) were digitized from the photos, then transformed onto a geo-referenced digital elevation model (DEM) such that terrain metrics could be applied to each of the 7,499 skier locations. Analysis of terrain metrics for each skier point compared slope, profile curvature (downslope), and plan curvature (cross-slope) over days with three different forecasted avalanche hazards (Con, Mod, Low). Terrain metrics on Considerable avalanche hazard days differed significantly from Moderate or Low avalanche hazard days (p-value < 0.001). Skier location-points transformed from the oblique photos to a geographic coordinate system had an observed horizontal spatial accuracy of 49-m with a 95% confidence interval. By capturing all visible skiers on a slope anonymously, the data provides a large and diverse data set of the terrain preferences of backcountry skiers under varying conditions.

Time lapse photography presents a simple and inexpensive tool for effectively monitoring skiers in avalanche terrain. Skier images can be useful in determining high-use areas of skier traffic, crowding or congestion issues, documenting avalanches, and recording avalanche control operations. It has also proven to be useful with assisting avalanche emergencies by providing visual survey of the avalanche path including determining number of people (if any) involved, identifying triggers and last seen points, and assessing residual risk to responders.

KEYWORDS: terrain, avalanche, time-lapse photography

1. INTRODUCTION

Between 1996 – 2016, the Colorado Avalanche Information Center (CAIC) reported 56 “Side-country rider” fatalities in a total of 556 U.S recreational avalanche fatalities (CAIC, 2016). Additionally, between 2003/04 -2008/09, 23% of recreational avalanche fatalities in Europe and North America were reported in out-of-bounds terrain (Gunn, 2010). In the same time, rapid growth in backcountry skiing is evident in increased attendance in avalanche education courses, expanded media coverage, and significant growth in backcountry equipment sales (Birkeland et al., 2017; SIA, 2017). As well, many ski areas across North America have adjusted boundary policies that allow for skiers to utilize the ski area to access adjacent backcountry avalanche terrain.

Current research on terrain metrics of backcountry skiers studies the GPS tracks of professional ski guides and recreational skier volunteers. The GPS tracks capture real-time, terrain focused decision-making outcomes of the guide. Findings report that steeper, more open, and more convoluted slopes were skied under lower avalanche hazard conditions (Hendrikx and Johnson, 2016a; Hendrikx and Johnson, 2016b; Thumlert and Haegeli, 2017).

This research uses a time lapse camera to capture recreational skier locations every ten seconds descending an avalanche prone slope. The skier locations are geo-referenced and transformed onto a digital elevation model. Terrain metrics (slope, downslope curvature, and cross-slope curvature) from the DEM are attached to skier locations and compared against days of different forecasted avalanche hazard. By capturing all skiers on a slope, the data collected provides a snapshot of the terrain preferences of backcountry skiers under varying conditions as defined by the terrain metrics of slope, downslope curvature, and cross slope curvature.

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This paper describes a method that expands the dataset of skiers to include all levels of recreational skiers including those that may not participate in volunteer-based avalanche research. Interestingly, the research documented numerous examples of individuals skiing without a partner in avalanche terrain.

2. METHODS

2.1 Study Area

Saddle Peak is in the Bridger Mountains in the Custer Gallatin National Forest of southwest Montana, USA. The slope is adjacent to the south boundary of the Bridger Bowl Ski Area and is highly visible from the Schlasman's lift within the ski area. Saddle Peak is a popular destination for backcountry skiers and almost exclusively accessed through a gate from the ski area. Saddle Peak is uncontrolled, backcountry avalanche terrain within a public avalanche forecast region (Gallatin National Forest Avalanche Center).

A time lapse camera was mounted to an abandoned concrete 75 mm recoilless rifle bunker platform within the Bridger Bowl Ski Area and northeast of Saddle Peak. Taking one photo every ten seconds between the hours of 10:00 am – 4:00 pm, the camera captured backcountry skiers on the east face of Saddle Peak (Figure 1). The resolution of the images made tracking and identifying individual skiers possible, but not detailed enough to identify any distinguishing characteristics of skiers.

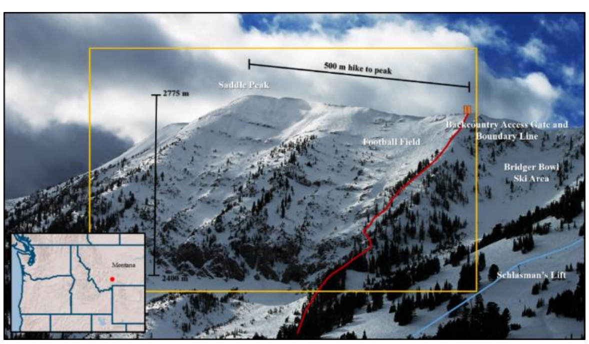


Figure 1. The east face of Saddle Peak located adjacent to the Bridger Bowl Ski Area, in Montana, as photographed from the time lapse camera; the study area is outlined in the gold box. Saddle Peak is accessed by riding the Schlasman's Lift (blue line) and exiting the boundary at the backcountry access gate at ridgetop (gate and red line).

From the captured photography, skier location-points were identified in each photo. Then using a projective transformation, skier location-points were georeferenced to a digital elevation model (DEM) of Saddle Peak (ArcMAP, 2017). From the DEM, terrain metrics were applied to each skier location-points and compared against days of different forecasted avalanche hazard.

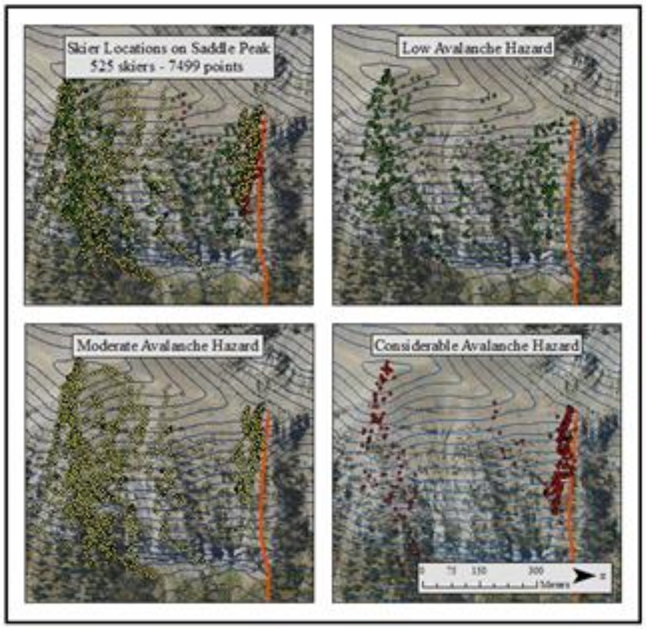
2.2 Data Collected

In this paper we will only present the analysis for 13 days, a subset of our full data set. We documented 525 skiers and 7499 skier-point locations in total, of which 182 skiers (1995 skier-points) were on four days of Low avalanche hazard, 175 skiers (4254 skier-points) were on four days of Moderate avalanche hazard, and 168 skiers (1250 skier-points) were on five days of Considerable avalanche hazard. We documented fewer average number of skiers under Considerable hazard than Moderate or Low. However, the highest skier days recorded were 130 skiers under Low hazard on March 27, 2016 and 129 skiers under Considerable hazard on February 14, 2016 (Figure 2).

Group size and solo skiers on Saddle Peak were also documented. Out of 525 skiers captured on Saddle Peak, 94 (18%) were not in a group. On days of Considerable hazard solo skiers represented 33% (56 of 168) of skiers on Saddle Peak. Solo skiers represented 15% (26 of 175) on Moderate hazard and 7% (12 of 182) under Low hazard (Figure 2).

3. DATA ACCURACY

The physical position of the camera naturally introduces error due the oblique angle it views Saddle Peak and captures skiers. Additionally, when the data is transformed onto the DEM, the positional accuracy of the transformed skier location data set is affected. The DEM used in this study reported 10-m accuracy (U.S. Geological Survey, 2017). As this DEM is a representation of bare ground, the snow surface may be significantly different (smoothed) due to wind drift and loading. As well, in this study we established a 49-m spatial accuracy (for 95% confidence interval) for our data resulting from the digitization and transformation of skier-location points. To account for less precision in the skier-location dataset, the 10-m DEM was resampled to 30-m and terrain metrics were recalculated to skier points. This was done to better understand the accuracy of our data and to account for known



Date	Av Hx	No. of Images	Location -points	Total Skiers	Solo Skiers
1/14/16	Con	1802	109	18	4
2/5/16	Con	2879	20	1	1
2/7/16	Con	2879	92	18	3
2/14/16	Con	2879	882	129	37
3/20/16	Low	2879	408	15	1
3/26/16	Mod	2879	2097	52	3
3/27/16	Low	2789	1254	130	7
1/7/17	Mod	1980	185	13	1
1/8/17	Con	1853	147	21	11
1/15/17	Low	1782	286	34	4
2/22/17	Low	1691	47	3	0
3/2/17	Mod	3509	1152	76	17
3/5/17	Mod	2159	820	34	5
	Total	31960	7499	525	94

Figure 2. Skier-locations classified by forecasted avalanche hazard and table summarizing days of analysis. Red dots represent Considerable avalanche hazard skier locations, yellow dots represent Moderate, green dots represent Low.

precision error. A 30-m slope raster was recalculated, and a 90-m downslope and cross slope curvature raster were extrapolated from the 30-m resampled DEM.

4. RESULTS

This study considers how skier terrain choices change under different avalanche conditions. Terrain metrics of slope, profile curvature (downslope) and plan curvature (cross-slope) were compared against days of different forecasted avalanche hazard. The Kolmogorov-Smirnov (K-S) test was used to determine the statistical significance of skier terrain metrics on days of different avalanche hazard.

The one-sided K-S calculated on the terrain metrics from the resampled 30 m DEM cell size found strong evidence (p-value < 0.001) that the terrain metrics (slope, downslope curvature, and cross-slope curvature) of Considerable hazard days are statistically different than Moderate or Low days. Slope testing indicated a statistical significance between Considerable and Moderate and Considerable and Low hazard days. While the overall differences in median slope angle values were small, the median slope angles on Considerable days was less than both Moderate and Low. This suggests skiers were on lower angled terrain with days of more challenging forecasted avalanche conditions. Downslope curvature testing indicated a statistical difference between all hazard days suggesting that skiers were on more concave (supported) terrain with more challenging forecasted avalanche conditions. Cross-slope curvature testing indicated a statistical difference between Considerable and Moderate and Considerable and Low hazard days. Results suggested skier locations were on more ridge-like features as avalanche hazard increased. Additionally, the spread of data indicated less extreme convex or concave terrain overall. Thus, under Considerable hazard, the terrain chosen was more planar.

Median Values by Av Hx	Con	Mod	Low
Slope	34.14	34.95	34.82
Profile (downslope)	-0.26	-0.14	-0.10
Plan (cross-slope)	0.35	0.08	0.25
No. of skier location-points	1250	4254	1995

Figure 3. Median values by avalanche hazard for terrain metrics analyzed with resampled 30 m DEM.

5. CONCLUSION

This paper develops a technique to study all recreational skiers on a backcountry avalanche slope, including those who may not participate in volunteer-based studies. We found that terrain choices are statistically different with different avalanche hazard, even in terrain with limited options. In general, skiers chose more conservative terrain as avalanche hazard increased. Full results and further analysis can be found in Saly (2018).

A time-lapse camera provides constant monitoring of terrain that can frequently avalanche or commonly has incidents. Interestingly, our research documented numerous individuals skiing alone in avalanche terrain. We did find it promising our results align with other studies of avalanche terrain use in that skiers generally opt for less hazardous terrain as avalanche hazard increases (Hendrikx and Johnson, 2016c; Thumlert and Haegeli, 2017; Sykes, 2018).

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