WHAT DO FIELD OBSERVATIONS TELL US ABOUT AVALANCHE DANGER?

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ABSTRACT: The avalanche forecast regions in Canada range from 100 to 30,000 km^2, far larger than the 10 km^2 covered in a typical backcountry day. This difference in scale could cause the danger a recreationist is exposed to, the local avalanche danger, to differ from the regional bulletin. This study examines the relationship between field observations (instability, snowpack, and weather factors), which do not require digging a snow profile, and the local avalanche danger. The results were grouped for analysis by the dominant avalanche character of the day: Loose Dry, Wet (loose and slab), Wind Slab, Storm Slab, Persistent Slab, and Deep Slab. Throughout the past 6 winters we have created a unique dataset of 28 field observations from 425 field days. Univariate and multivariate cross-validated classification trees were built to examine the predictive capability of the observations for the local danger. Storm, Persistent, and Wind Slab avalanche characters had the most field observations correlate significantly with the local danger, and Wet (loose and slab) had the least. Observations of Slab Avalanche Activity, New Snowfall, and Tree Bombing were applicable for the most avalanche characters. Univariate and multivariate classification trees can be useful to recreationists in interpreting critical observations and the combinations of these observations that indicate elevated danger.

KEYWORDS: Local avalanche danger, avalanche character, avalanche forecasting, recreationist

1. INTRODUCTION

On a typical backcountry day, a recreationist ski tours, split boards, snowshoes, or snowmobiles through avalanche terrain. Typically recreationists travel in avalanche terrain less than 20 days per year (Bakermans et al., 2010). Jamieson et al. (2008) estimated a recreationist's area of exposure to avalanche hazard at 10 km^2, which is approximately the area of one mountain drainage. This area is referred to as the local avalanche area, and the avalanche danger rating for this area is the local avalanche danger (D_{LN}).

The Canadian regional avalanche bulletin is an expert assessment of the avalanche danger for a specific region, which range in size from 100 to 50,000 km^2 (Haladuick, 2014). This is not the same as the local avalanche danger (10 km^2). In fact, Jamieson et al. (2006) found that this rating differed from the local avalanche danger rating in 36-43% of cases. The difference in spatial scale is one of the main reasons for the discrepancy. Other reasons include the difference in temporal uncertainty between the local nowcast and the regional forecast, the spatial variability of the avalanche danger (Schweizer et al., 2008), the inaccuracy of available data when the forecast was made (Jamieson et al., 2009), and error by human forecasters or forecasting models (Jamieson et al., 2009). In addition, the regional bulletin is not available in certain areas (Haladuick, 2014).

It is useful for recreationists to use additional sources of information to verify or, potentially, adjust the regional bulletin to their local area. To localize the avalanche danger, professionals and experienced recreationists rely on weather, avalanche and snowpack observations, as well as observations from snow profiles and snowpack tests that require digging a pit. They also rely on their previous experience travelling in similar conditions, and their intuition (Stewart-Patterson, 2008), which has been developed over years of operating in avalanche conditions. By contrast, recreationists usually do not dig pits due to the time and training requirement. They also have less experience operating under similar avalanche conditions and do not have the wealth of experience required to calibrate accurate intuitive decisions. Therefore, non-digging field observations play an important role in the localization of the avalanche danger for recreationists. This study assesses the relationship between field observations and the local avalanche danger for different avalanche characters.

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2. METHODS AND DATASET

A typical field day replicated a recreationist's backcountry day. The field team ascended from the trailhead with skis or snowmobile, performing a set of 28 field observations (Table 1) along the way to the decision point. The decision point was the point at which the team decided whether or not to enter more hazardous avalanche terrain. At the decision point the main avalanche character of the day was identified from a list similar to Haegeli et al. (2010) (Figure 1). The field team then descended back to the trailhead, again performing the field observations. At the trailhead they rated the local avalanche danger. The local danger was rated for the vegetation bands that the team members were confident rating, using all of the information available to them.

Over the past six winters field teams collected data during 425 days throughout the mountains of western Canada. Figure 1 shows the relative frequency of the field days grouped by avalanche character.

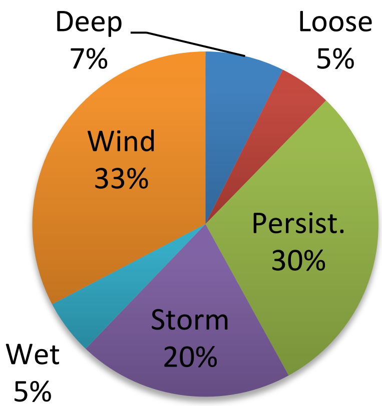

Figure 1: Relative frequency of field days grouped by avalanche character.

Table 1: Field observations and their associated values

Field observation	*Values (ordered low to high rank)*
Current Loose Avalanches	0, 1, 2, 3+
Current Slab Avalanches	0, 1, 2, 3+
Recent Loose Avalanches	none, 24-48 h, <24 h
Recent Slab Avalanches	none, 24-48 h, <24 h
Whumpfing / Shooting Cracks	0, 1, 2, 3+
Cracking at Skis	none, occasional, frequent
Pin Wheeling	0, 1-2, 3+
Tree Bombing	none, occasional, frequent
Hand Shear Resistance	no result, hard, moderate, easy
Hand Shear Character	break, resistant planar, sudden planar
Hand Shear Depth	cm
Snow Surface Condition	dry fresh, settled, sticky, wind stiff, moist / wet coarse, crust
Surface Crust Supportive	yes, no
Surface Crust Thickness	cm
Ski Penetration	cm
Ski Pole Probe	gradually increasing resistance, a hard layer over a soft layer, buried crust (CR), obvious weak layer (WL)
Precipitation	snow: 0, <1, 1, 2, 3+ (cm / h) or rain: light, moderate (according to CAA, 2007)
Wind Speed	calm, light, moderate, strong/extreme (according to CAA, 2007)
Blowing Snow	none, at ridge, below ridge
Wind Scouring	none, 24-48 h, < 24 h
Wind Deposits	none, 24-48 h, < 24 h
Sky Condition	clear, few, scattered, broken, overcast, obscured (according to CAA, 2007)
HN24	cm
HN48	cm
Ta Trend in 24 h	°C, either positive or negative
Ta Warming to 0 °C	yes, no
Overnight Freeze After Thaw	thaw and refreeze, no thaw, thaw and no refreeze

This dataset was analyzed using both univariate and multivariate techniques. The Spearman rank (Walpole et al., 2007, p 690-691) and Kruskal-Wallis (Kruskal and Wallis, 1952) tests were used in a univariate selection process to determine the avalanche character and field observation categories that were significant. Categories significant on both tests were selected for further analysis.

Univariate and multivariate cross-validated classification trees were built based on the results of the selection process. The target variable for the classification trees was a binary version of D_{LN}, for which Low and Moderate danger were categorized as 0, and Considerable and higher were 1. This simplified the interpretation of the results of the trees. Univariate classification trees were built for each of the selected avalanche character and field observation categories. The critical value or criterion from the first split in these trees indicates elevated avalanche danger. Multivariate classification trees were built for each avalanche character, using all of the selected field observations for each character as inputs. These trees show the combinations of field observations that can lead to elevated danger.

Two levels of cross-validation were used to build the trees. The inner level was used to prune the final tree to the best level. The outer level was used to build a 2x2 contingency table (Doswell et al., 1990) of model forecasted results compared to actual observed results. This contingency table was used to calculate the validation parameters for each tree. Five validation parameters were used: percentage correct (PC), true skill score (TSS), probability of detection (POD), probability of false detection (POFD), and false alarm rate (FAR) (Doswell et al., 1990).

3. RESULTS AND DISCUSSION

Figure 2 shows a sample of the results from this study, the multivariate classification tree for Storm Slab avalanche character.

The tree in Figure 2 can be interpreted in the following way. The first field observation selected was HN48, with a criterion of 13 cm or greater. Since this observation was selected first it was the most important observation for Storm Slab, which is not surprising as it is an indication of new snowfall. If there was less than 13 cm of HN48 but there was a 'failure' on the Hand Shear Test then the danger was elevated. This is because a result on the hand shear test means a near surface (top 40 cm) instability exists.

If the HN48 was critical and if there was 28 cm or more Ski Penetration, or 'calm' Wind Speed, or Blowing Snow 'below ridge' then the danger was elevated. The combination of HN48 and Ski Penetration selected days with recent unsettled snow. The sign for Wind Speed was reversed, with 'calm' indicating elevated danger. This is counter intuitive; however, it is due to the interaction between the avalanche character and Wind Speed. Days with higher Wind Speed were probably already filtered out of the Storm Slab dataset by the field team defining the avalanche character and placed in the Wind Slab dataset. The selection of Blowing Snow in the fourth level of the tree shows that the combination of new snowfall and wind transport is still important for Storm Slab.

This tree had a cross-validated PC of 68%; however, it had a relatively low TSS of only 34%. This was because it had a high POFD of 43% relative to the trees built for the other characters. This means that nearly each second time when the actual local danger was Low to Moderate the tree incorrectly predicted the local danger as Considerable or higher. The full results and discussion can be found in Haladuick (2014).

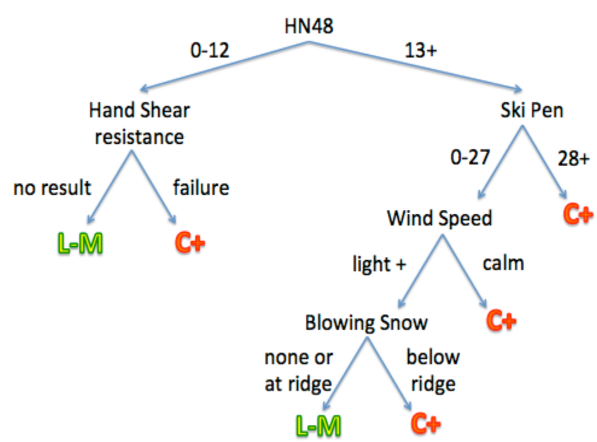

Figure 2: Multivariate classification tree for Storm Slab avalanche character.

The avalanche characters that had the most indications of avalanche danger were Storm Slab, Persistent Slab, and Wind slab, in that order. This implies that these characters are the easiest for a recreationist to localize the danger under, and potentially the easiest to forecast the regional danger under. Conversely, the avalanche character that had the fewest indications of increased danger was Wet (loose and slab). This indicates that this character is the most difficult for a recreationist to localize the danger under, and potentially the most difficult to forecast.

The field observations that were the most applicable (useful under the most avalanche characters) were Slab Avalanche Activity, New Snowfall, and Tree Bombing. The field observations that were highly specific to certain characters (in bold) were:

- **Deep Slab**: Recent Loose Avalanches, Recent Slab Avalanches, Pin Wheeling, Wind Speed, Blowing Snow, Wind Deposits
- **Loose Dry**: Recent Loose Avalanches, Pin Wheeling, Wind Scouring, T_a Trend in 24 h, lowest CT score (CT)
- **Persistent Slab**: Hand Shear Character, Wind Deposits
- **Storm Slab**: Wind Speed, Blowing Snow, T_a Trend in 24 h
- **Wet**: Recent Loose Avalanches, Pin Wheeling, T_a Trend in 24 h

4. CONCLUSIONS

On 425 days over the past six winters, field teams performed 28 different field observations, rated the local avalanche danger, and identified the main avalanche character across the mountains of western Canada. The field observations were analyzed with respect to their univariate and multivariate relationship with the local danger.

Univariate classification trees showed the critical range of the observations that indicated increased avalanche danger. Multivariate classification trees showed how the field observations can be combined to predict the avalanche danger. Recreationists can use these trees to help interpret their field observations when travelling in avalanche terrain. These trees may also prove useful in future decision support schemes.

Storm, Persistent, and Wind Slab had the most indications of instability. Wet (loose and slab) had the least indications. Slab Avalanche Activity, New Snowfall, and Tree Bombing were the field observations that were applicable to the most avalanche characters.

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REFERENCES

Bakermans, L., Jamieson, B., Schweizer, J., Haegeli, P. 2010. Using stability tests and regional avalanche danger to estimate the local avalanche danger. Annals of Glaciology, 51(54), 176-186

Doswell III, C., Davies-Jones, R., Keller, D. 1990. On summary measures of skill in rare event forecasting based on contingency tables. Weather and Forecasting, 5(4), 576-585

Haegeli, P., Atkins, R., Klassen, K. 2010. Decision Making in Avalanche Terrain. Canadian Avalanche Centre, Revelstoke, BC, Canada. 62 pp.

Haladuick, S. 2014. Relating field observations and snowpack tests to snow avalanche danger. MSc Thesis, University of Calgary, Calgary, AB, Canada

Jamieson, B., Schweizer, J., Haegeli, P., Campbell, C. 2006. Can stability tests help recreationists assess the local avalanche danger? Proceedings of the International Snow Science Workshop, Telluride, CO, USA, 1-10

Jamieson, B., Campbell, C., Jones, A. 2008. Verification of Canadian avalanche bulletins including spatial and temporal scale effects. Cold Regions Science and Technology, 51 (2–3), 204–213

Jamieson, B. Haegeli, P. Schweizer, J. 2009. Field observations for estimating the local avalanche danger in the Columbia Mountains of Canada. Cold Regions Science and Technology, 58(1-2), 84-91

Kruskal, W., Wallis, W. 1952. Use of ranks in one-criterion variance analysis. Journal of the American Statistical Association, 47(260), 583-621

Schweizer, J., Kronholm, K., Jamieson, B., Birkeland, K. 2008. Review of spatial variability of snowpack properties and its importance for avalanche formation. Cold Regions Science and Technology, 51(2–3), 253–272.

Stewart-Patterson, I. 2008. The role of intuition in the decision process of ski guides. Proceedings of the International Snow Science Workshop, Whistler, BC, pp. 530-537

Walpole, R., Myers, R., Myers, S., Ye, K. 2007. Probability and statistics for engineers and scientists. Eighth edition. Upper Saddle River, NJ, Prentice Hall. 690-691