PATTERNS IN AVALANCHE EVENTS AND REGIONAL SCALE AVALANCHE FORECASTS IN COLORADO, USA

Spencer Logan[1]*, Ethan Greene[1]

[1] *Colorado Avalanche Information Center, Boulder, CO, USA*

ABSTRACT: The Colorado Avalanche Information Center (CAIC) issues backcountry avalanche forecasts daily through the winter. In this paper, we relate the forecast danger ratings and problem types to documented avalanche activity. The forecasts include avalanche danger ratings for three elevation bands (below treeline, near treeline, above treeline). The Tier I (TI) danger is highest of the three danger ratings. Avalanche Problem Types describe avalanche risk treatments and supplement the danger ratings. The CAIC documents characteristics of avalanche events including size and location. Over the study period, the CAIC forecast a TI avalanche danger of Low (Level 1 of 5) 17% of the days, Moderate (Level 2 of 5) 57% of days, Considerable (Level 3 of 5) 19% of days, and High (Level 4 of 5) 3% of days. Avalanche events occurred on one third of the forecast days. The number of avalanche days per TI danger increased almost linearly from 8% of days at a TI of Low to 75% of avalanche days at a TI of High. Elevational band dangers showed similar patterns, but with much greater numbers of non-avalanche days. The Destructive Size of the observed avalanches increased with greater danger ratings. The increased corresponded with the expected size of avalanches in the danger scale descriptions. Two Avalanche Problem categories, Persistent (PS) and Deep Persistent Slab (DPS) avalanches, account for the majority of avalanche accidents in Colorado. The backcountry forecasts capture those events well, and 50% of PS/DPS avalanches occurred when the danger rating was Considerable, or “dangerous.”

KEYWORDS: avalanche forecasting, avalanche danger, avalanche problems, risk communication

1. INTRODUCTION

Avalanche danger ratings are at the heart of public avalanche forecasts. The danger ratings provide a probabilistic description of the likelihood of a backcountry recreationalist to encounter an avalanche and the destructive potential of that avalanche. The Colorado Avalanche Information Center (CAIC) fully adopted the North American Public Avalanche Danger Scale (NAADS; Statham et al 2010) and Conceptual Model of Avalanche Forecasting (CMAH; Statham et al., 2018) in the winter of 2013-14. To better understand the process CAIC forecasters use to evaluate the avalanche hazard and explain the danger to the public, we examine the avalanche occurrence record in relation to forecast danger ratings.

2. METHODS

2.1 Study Site

The CAIC backcountry forecasts cover ten regional zones within Colorado. The total forecast area in Colorado covers approximately 65,000 km^2. The area of forecast zones ranges from about 3,900 km^2 to about 11,700 km^2.

2.2 Avalanche Danger Ratings

The CAIC disseminates forecasts to the public through a variety of digital communication conduits. Forecast products are stored in a database. We extracted the danger ratings from the database to create a dataset for this study. If there were duplicate forecasts for a day and zone, we used the last issued product.

The CAIC issues public forecasts for eight months of the year, October through May. Forecast products with danger ratings were issued between November and April, a median of 145 days each winter over the study period. We considered 708 forecast days and 7080 TI danger ratings.

The CAIC issues avalanche danger ratings for three elevation bands: below treeline (<TL), near treeline (TL), and above treeline (>TL). The highest of the three ratings is the summary danger (TI). There were 21,240 elevational danger ratings for the 708 forecast days.

Supplementing the danger ratings are Avalanche Problems, “a set of factors that describe the avalanche hazard” with type, location, likelihood, and size (Statham et al., 2018). There are nine avalanche problem types, and CAIC forecaster can use up to three problems in each forecast product.

* *Corresponding author address:*
Spencer Logan, Colorado Avalanche Information Center, Boulder, Colorado 80305;
tel: +1 303-499-9650;
email: spencer.logan@state.co.us

2.3 Avalanche Occurrence

The CAIC collects avalanche occurrence data from a variety of sources. CAIC staff contributes the majority of the data, recording highway mitigation results, natural or triggered occurrences, and backcountry avalanches. Avalanche professionals including ski patroller and guides, and the recreating public contribute the rest of the data.

Avalanche occurrences include date of occurrence, elevation band, and starting zone aspect. We used Avalanche Type (AT), destructive size, and bed surface (American Avalanche Association, 2016) to categorize recorded avalanches into one of seven Avalanche problem type categories (AC). The categorization schema was refined from previous efforts (Logan and Greene 2014, 2016) and is similar to that used in Canada (Jamieson et al., 2010).

During the study period, the CAIC recorded 12,834 avalanches. Of those, we sorted 3388 (26%) into an AC. Starting zone elevations were reported for 11,807 (92%) of avalanches. For comparing occurrence to TI danger ratings, we considered an Avalanche Day any day with avalanche activity in that backcountry zone. For elevational danger ratings, we considered an Elevational Avalanche Day any day with avalanche activity documented within that elevation band. We used the TI danger for the 8% of avalanches without elevation data.

3. RESULTS AND DISCUSSION

3.1 Tier I Rating and Avalanche Occurrence

Avalanche activity occurred on 2178 (31%) of the forecast days (Table 1). The percentage of days, by rating, with avalanche activity increased almost linearly from rating to rating (Figure 1, R2=0.983). The increase in avalanche occurrence tracks well with the increasing likelihood of avalanches as danger ratings increase. At a High (Level 4) danger rating avalanches are "likely." The CAIC has adapted IPCC likelihood terms (Mastrandrea et al., 2010), and considers "likely" to be a 66 to 100% probability of occurrence. That avalanches occurred on 75% of days with a forecast danger of High (Level 4) fits well. Likewise, at Considerable (Level 3) danger avalanches are possible to likely. Adapted from the IPCC, possible is 11 to 66% probability. Avalanches occurred on 54% of the days with a TI rating of Considerable.

TI Rating	*Number of days*	*% days with Rating*	*% Avalanche Days*
0	242	0.03	0.01
1	1230	0.17	0.08
2	4061	0.57	0.29
3	1359	0.19	0.54
4	187	0.03	0.75
5	1	0.00	1.00

Table 1. The frequency that TI ratings were issued, and proportion of Avalanche Days at each rating.

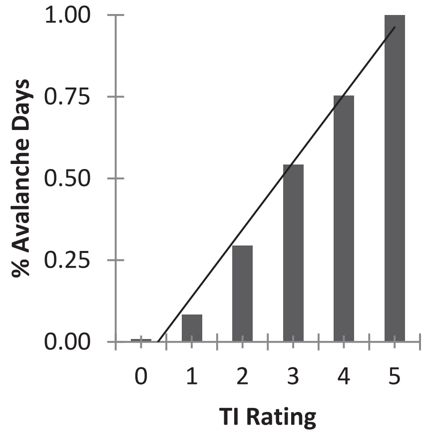

Figure 1. The proportion of Avalanche Days at each TI rating.

Comparing avalanche activity to the elevational danger ratings gives similar results (Table 2). The number of avalanche days ranged from 11 to 17% of forecast days, much smaller than the TI danger. The proportion of avalanche days does increase with danger rating (Figure 2). The distributions for each elevation are different from the TI distributions (all p values less than 0.05, Fisher's exact test). Similar distributions of elevational avalanche days would suggest that a single rating would suffice. That the distributions differ suggests there is utility for the end users in danger ratings by elevation band.

TI Rating	*ABV*	*NR*	*BLW*
0	0.00	0.00	0.00
1	0.06	0.04	0.04
2	0.18	0.13	0.15
3	0.34	0.32	0.33
4	0.44	0.53	0.52
5	0.00	0.00	0.00

Table 2. The proportion of Elevational Avalanche Days at each danger rating.

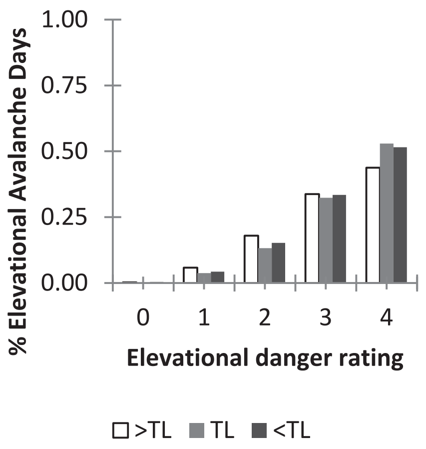

Figure 2. The proportion of Elevational Avalanche Days at each danger rating.

The fewer elevational avalanche days may point to issues with the occurrence data. A person must observe and record an avalanche occurrence. Poor weather conditions can hamper observations. Observers may avoid avalanche terrain in challenging or dangerous backcountry travel conditions, and therefore not see avalanche activity. The elevational avalanche day distributions for a single backcountry zone with relatively high observation density shows similar patterns.

3.2 Elevational Avalanche Ratings and Destructive Size

Observers reported Destructive Size for 1,929 (15%) of the avalanche occurrences that also have an associated avalanche dagger rating. The observed D-size can easily be related to the expected size of avalanches (Table 3) at a given danger rating. Small (<D2) avalanches are most common at Moderate danger (Table 4). Large (D2 or D2.5) and Very Large (>=D3) avalanches are most common at Considerable danger. The subset of avalanches with recorded destructive sizes suggests that the danger ratings do reflect to observed avalanche activity.

Descriptor	*Destructive Size*
Small	< D1.5
Large	D2 to D2.5
Very Large	> D3

Table 3. Avalanche size descriptors, as used in the NAADS and CAIC forecasts, and Destructive Size.

D Size	*1*	*2*	*3*	*4*
1	100	324	232	6
1.5	29	220	181	10
2	18	291	327	35
2.5	1	26	60	11
3	0	15	37	5
3.5	0	1	0	0

Table 4. The number of avalanche occurrences by Destructive size, at each T1 danger rating.

3.3 AC by Danger Ratings

We were able to assign an AC to 26% of the avalanche occurrences. There are four categories of AC of particular interest to CAIC forecasters (Table 5). Persistent Slab avalanches (PS) and Deep Persistent Slab avalanches (DPS) account for the majority of avalanche accidents in Colorado (Logan and Greene 2014). Wet avalanche activity follows seasonal patterns, with an increasing number of avalanches in the spring and summer. Wet Loose avalanches (LW) tend to be small and pose little hazard to backcountry travelers, while Wet Slab avalanches (WET) tend to be hard for backcountry travelers to predict and avoid.

AC	*1*	*2*	*3*	*4*
PS	65	375	241	105
DPS	0	12	35	29
LW	25	168	176	13
WET	22	118	69	13

Table 5. The number of avalanche occurrences by AC, at each elevational danger rating.

Of the four AC, DPS and LW follow the anticipated pattern of increasing occurrence at higher danger ratings. Both PS and WET have the highest occurrences reported at Moderate (Level 2) elevational danger ratings. This provides little conclusion, but does offer interesting speculation. Does this indicate poor forecasting, with CAIC staff discounting the occurrence of some avalanches or providing less conservative forecasts? Are there issues with data reporting, both in the number of avalanches as above, and in the details that allow for the categorization? In the case of PS and DPS, does the change reflect the danger better capturing DPS avalanche events, by definition very large, in the ratings that describe very large avalanches occurring at Considerable (Level 3) or greater ratings? Are backcountry users more adventurous at lower danger ratings, and documenting or triggering more avalanches by venturing into avalanche terrain?

4. CONCLUSIONS

Comparing avalanche activity to forecast danger ratings is one method to assess the accuracy of the ratings. In this study, we compared five seasons of avalanche activity to forecast danger ratings. The proportion of days with avalanche activity at a given rating increased with the danger rating. The issued ratings capture the increasing likelihood of avalanches at greater ratings. The overall TI rating showed the greatest corresponded with avalanche activity. The distributions of avalanche days for the elevational forecast bands were different that the overall rating. This suggests that the elevational ratings do reflect the avalanche activity. Therefore, they provide additional information to the end users.

The Destructive Size of reported avalanches increased with danger ratings. The occurrence size matched with the likelihood terms in the NAADS. The CAIC forecasts seem to capture the observed size of avalanches.

Categorizing the reported avalanches into Avalanche Problem Types allowed us to compare the frequency of AC at danger ratings. The occurrence of several AC changed in similar manner to the interpretations of the danger. This method raised more questions than it provided insight.

Improving observational density and quality will certainly improve the forecasting. Backcountry avalanche danger ratings are probabilistic, and while observational data can inform the process, it should not be used as the sole verification metric.

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