FORECAST AVALANCHE DANGER AND AVALANCHE ACCIDENTS IN COLORADO, USA, WINTERS 2014 TO 2018

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ABSTRACT: The Colorado Avalanche Information Center (CAIC), Colorado USA, has been using the same format for public avalanche forecasts since the winter of 2013-14. This follows the adoption of the North American Avalanche Danger Scale (NAADS) and the Conceptual Model of Avalanche Forecasting (CMAH). In this paper, we examine the frequency of forecast danger ratings, and relate the danger ratings to avalanche involvement since the adoption of the NAADS. Over the study period, the CAIC forecast an avalanche danger of Low (Level 1) 17% of the days, Moderate (Level 2) 57% of days, Considerable (Level 3) 19% of days, and High (Level 4) 3% of days. There is little difference in the distribution of danger ratings compared to 1996 to 2006. That suggests that the CMAH and NAADS refined but did not dramatically change the danger ratings. About 31% of avalanche involvements and 40% of fatal avalanches occurred when the forecast danger was Considerable (Level 3), supporting the "dangerous" descriptor of the NAADS. Between 1996 and 2006, half of avalanche fatalities in Colorado occurred at a Moderate danger. Changes in users, user behavior, seasonal snowpack characteristics, and better public messaging could all account for the changes in fatality distributions. Our initial experiences with the NAADS and CMAH show that the CAIC is effectively communicating with the public. The shift in fatality distributions suggest that communication is improving at all levels of avalanche conditions, not just when conditions are benign or very dangerous.

KEYWORDS: avalanche forecasting, public communication, avalanche danger scale, avalanche accidents

1. INTRODUCTION

The Colorado Avalanche Information Center (CAIC) is one of many groups worldwide tasked with improving public safety with respect to avalanches and producing forecasts of avalanche danger for mountain recreation. Like many of these groups, the CAIC uses a tiered approach to present information and public safety messages of varying complexity (also termed the information pyramid) (Statham et al., 2018; Winkler and Techel, 2014, Klassen, 2012). The avalanche danger rating is an integral part the public avalanche forecast product. The CAIC uses the North American Avalanche Danger Scale (NAADS) (Statham et al., 2010), which describes the likelihood of triggering and avalanche and the destructive potential of that event. NAADS has five levels, with Level 1 (Low avalanche danger) representing the least amount of danger and Level 5 (Extreme avalanche danger) representing the highest. The CAIC's Tier I product (T1) consists of one avalanche danger rating. Tier II of the public product includes the location, likelihood, and size of different Avalanche Problems (Statham et al., 2018) as well as a discussion of the current and future avalanche danger. Tier III products include raw data and tools to analyze it for various applications.

The avalanche danger scale is the primary tool forecasters use to communicate with the public (Tier I). The CAIC fully adopted the North American 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. Over the past five winters the format of the CAIC's public products has not changed. The internal process CAIC staff use to produce the forecasts has remained similar, too. Using guidance based on the CMAH, forecasters conduct a virtual meeting and reach consensus on danger ratings prior to issuing the public forecasts.

As part of our ongoing effort to better understand the danger ratings issued by the CAIC and its role in public communication, we collected danger ratings and avalanche involvements from this five-year period and compared them. We also compared trends from this recent period to trends from a decade ago to see if there were any significant differences.

1.1 Previous work

In a 2006 paper, Greene et al. (2006) compared accidents and danger levels across five forecast regions in the United States, including the CAIC, and four countries. They found the CAIC forecast danger distributions skewed towards Moderate compared to other US forecast centers. Normalized avalanche fatalities per danger rating also

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skewed to Moderate for the CAIC, compared to other countries.

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 km2. 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 via a website. Products are stored in a database. We extracted the danger ratings from the database. If there were duplicate forecasts for a day and zone, we used the last issued product.

The CAIC issues public forecasts for eight month 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 danger ratings.

The CAIC issued danger ratings for three elevation bands (below treeline, near treeline, and above treeline). The highest of the three ratings is the summary danger (T1). This study focused on the Tier I danger ratings, to allow comparison with previous research.

2.3 Avalanche Accidents

The CAIC has collected information on fatalities and non-fatal avalanche involvement in Colorado since its inception in 1973 (Williams 1975). Documentation for fatalities include as much site detail, avalanche measurements, and interviews with involved parties as possible. Not-fatal incidents are documented to varying degrees, some with full investigations and some recorded from second-hand information with little verified data. Information on the avalanche fatalities is thorough and well documented. Therefore we can examine with certainty the incidence of avalanche fatalities by danger rating. There is much greater uncertainty with non-fatal accidents.

Over the study period, the CAIC recorded 231 avalanches that involved people, a median of 49 incidents each winter. There were 296 people touched by or caught in avalanche debris, a median of 53 per winter. Twenty people were killed in 19 avalanche accidents, a median of 3 fatalities a winter.

3. RESULTS AND DISCUSSION

3.1 Distribution of danger ratings

The majority of danger ratings T1 were Moderate (Level 2). In 3% of forecasts there was no danger rating issued (No Rating, represented as Level 0), primarily in one data-sparse forecast zone. There was only one day when a rating of Extreme (Level 5) was issued during the study period.

The distribution of danger ratings from 1996 to 2006 is in Figure 2. “No Rating” was not used during that period. Ignoring the “No Rating,” the distributions between the periods are not significantly different (p=0.4042, Fisher’s exact test). That suggests that adopting the CMAH and NAADS did not dramatically change the danger ratings.

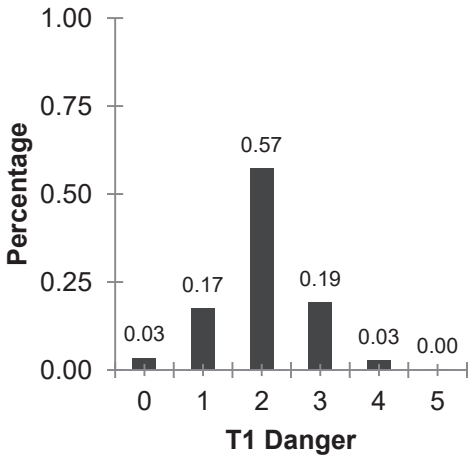

Figure 1. The T1 avalanche danger ratings issued by the CAIC for winters 2014 through 2018. Data have been normalized.

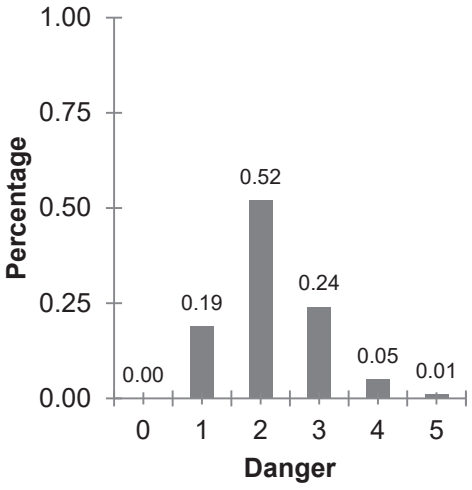

Figure 2. The avalanche danger ratings issued by the CAIC for winters 1996 through 2006, from Greene et al 2006. Data have been normalized.

3.2 Involvement and Fatalities

The distribution of avalanche fatalities was concentrated on days with a Moderate (Level 2) or Considerable (Level 3) rating (Figure 3). The distribution of involvements skews towards lower danger ratings compared to fatalities. That suggests that people are caught in lower-consequence avalanches at lower danger levels. There were 231 people caught in avalanches where the CAIC was able to document a Destructive size (American Avalanche Association, 2016). Of those caught, we know 88 (30%) were involved in avalanches D1.5 or smaller—generally too small to bury or kill a person.

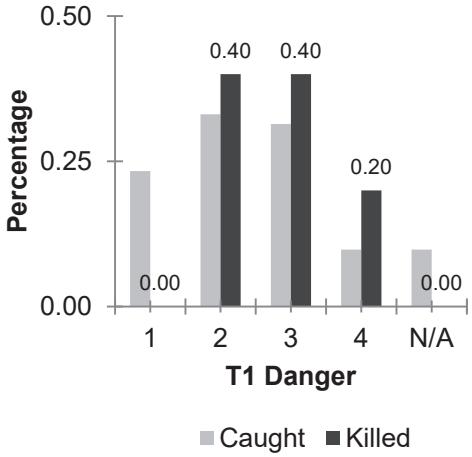

Figure 3: Avalanche involvements (people Caught) and avalanche fatalities (people Killed) by T1 danger ratings. Data has been normalized.

Compared to previous work, the current distribution of avalanche fatalities has shifted to higher ratings (Figure 4). The differences are statistically significant (p=0.0346, Fisher's exact test). Accidents between the two periods are not directly comparable. Changes in users, user behavior, seasonal snowpack characteristics, and better public messaging could all account for the changes in fatality distributions. The change in distributions does suggest, however, that the current CAIC danger ratings are capturing the "dangerous" conditions better than the period from 1996 to 2006.

We can estimate the probability of a fatal avalanche accident occurring within a zone, given the danger rating for the day (Table 1). Because fatal avalanches are infrequent events, the probability of an accident in any one zone on any given day is very small. There is a notable increase in accident probability as the danger increases. McClung (2000) suggested that probabilities should increase by orders of magnitude between danger levels. While the probability of fatalities does not increase by a full order of magnitude, it does increase dramatically with each increase in avalanche danger level.

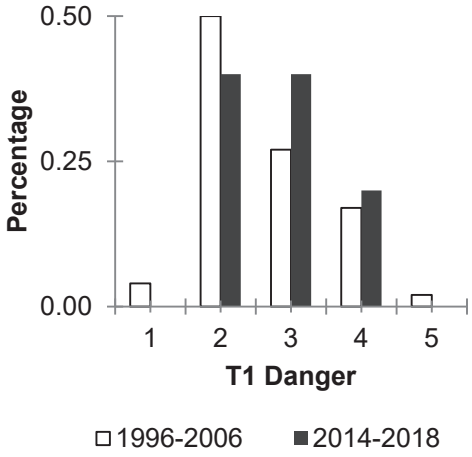

Figure 4. Comparison of avalanche fatalities (people Killed) from 1996-2006 (Greene et al 2006) and 2014-18. Data has been normalized.

T1	*Number of days with T1 rating*	*Number of days with fatal accidents*	*Probability of fatal accident, given T1 danger*
NR	242	0	0.0000
1	1230	0	0.0000
2	4061	8	0.0020
3	1359	7	0.0052
4	187	4	0.0214
5	1	0	0.0000

Table 1. The number of days, by T1 danger rating, without or with a fatal avalanche accident. Note that two people were killed in one accident, so the 20 fatalities occurred on 19 different days. We estimated the probability of a fatal avalanche occurring within a forecast zone given the issued danger rating.

4. CONCLUSIONS

We examined the backcountry danger ratings issued by the CAIC. Our objective was an increased understanding of the CAIC forecasts after the adoption of the CMAH. The distribution of danger ratings has not changed, compared to a pre-CMAH period. The danger rating for days with avalanche fatalities has shifted. That suggests the current ratings are better capturing the dangerous conditions when fatalities occur. We calculated the probability of a fatal accident, given a danger rating. Although fatalities are very infrequent events in Colorado, there are notable increases with increasing ratings.

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