THE AVALANCHE CHARACTER FREQUENCY OF REPORTED AVALANCHE EVENTS IN COLORADO, USA, 2011-2016

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ABSTRACT: North American avalanche practitioners developed nine Avalanche Characters, based on risk treatment strategies, weak layer, and slab characteristics of avalanches. Previous research in Canada and the United States classified the avalanche character in fatal avalanche accidents. In this study, we used a similar automated classification to categorize the avalanche character of avalanche events recorded by the Colorado Avalanche Information Center during avalanche years 2011-2016. The classification scheme categorized 52% (n=8546) of the avalanche events into Character. There was insufficient data recorded to categorize the remaining 48% of events. Storm and Wind Slab avalanches accounted for 22% of events, Persistent Slab 13%, Deep Persistent Slab 2%, Loose Wet 11%, and Wet Slab 3%. Compared to our previous study of avalanche fatalities, Persistent or Deep Persistent Slab avalanches resulted in 90% of fatalities, but only 15% of events. This highlights the hazard that Deep Persistent and Persistent Slab avalanches pose to the recreating public. Our research allows for year-to-year and even day-to-day characterization. This could be used as a further tool to characterize current events and compare against past avalanche cycles.

KEYWORDS: avalanche character, avalanche events, accidents.

1. INTRODUCTION

The Avalanche Character (AC) classification system segregates potential avalanche events into risk treatment categories. In 2004, Roger Atkins proposed a framework for considering avalanches "tied directly to different risk-management strategies" (Atkins 2004). In the intervening years the list was simplified into nine categorizes and incorporated into the Conceptual Model of Avalanche Hazard, a structured approach to evaluating avalanche hazard (Statham et al. 2010). Eventually AC became one element of a tool to communicate the avalanche hazard in public safety products in North America, South America, and New Zealand (Lazar et al. 2013).

The Colorado Avalanche Information Center (CAIC) now uses AC as the organizing framework for their public avalanche forecasts. We are continuing to improve our understanding of this system as we rely more and more on the concept. In past studies, we examined the frequency of the different categories involved in fatal avalanche accidents (Logan and Greene 2014).

In this study, we use similar methods to examine the AC category of actual avalanche events. The CAIC records observed avalanche event characteristics (Greene et al. 2010) in a database. The CAIC typically documents about 2700 avalanches each avalanche year. A better understanding of the distribution and frequency of avalanche that fit into the AC categories, and timing of different events will improve the CAIC forecasting and public messaging.

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2. METHODS

We used an automated classification schema to sort observed avalanches into AC categories.

2.1 Study location and Dataset

The state of Colorado is located in the central Rocky Mountains of North America (Fig. 1). It is characterized by a continental snow climate (McClung and Schaerer 2006). Winter temperatures are relatively cold, leading to persistent structural weaknesses in the snowpack.

The CAIC issues backcountry avalanche forecasts for ten zones in the state (Fig. 1). 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.

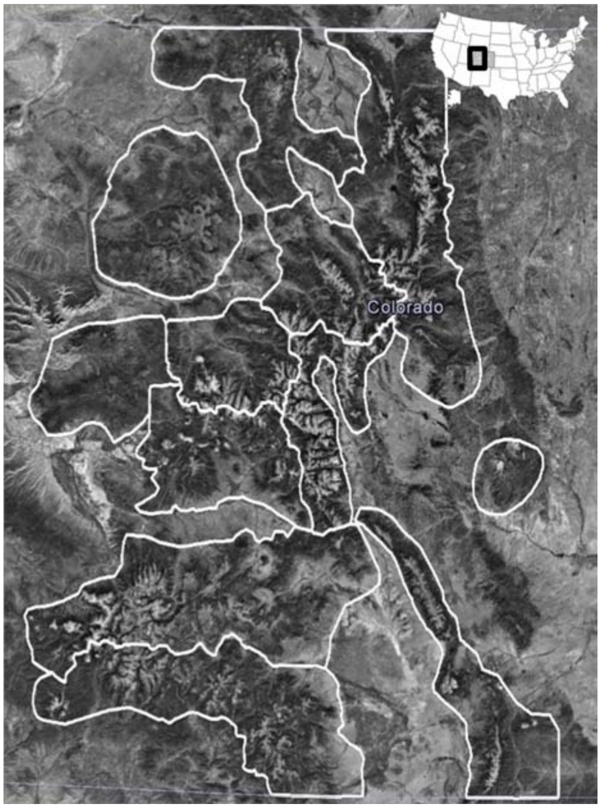

Fig 1: Map of the study area in western Colorado, USA. CAIC forecast zones are outlined in white. All avalanche events within the dataset occurred within a forecast zone.

2.2 Categorizing Avalanche Character

We used Avalanche Type (AT), destructive size, and bed surface (Greene et al. 2010) to categorize recorded avalanches into one of seven AC categories. We combined Storm Slab and Wind Slab avalanches because AT and sliding surface were insufficient to distinguish between them. We did not include Glide avalanches because there are very few events in the CAIC database that fell into this category. The categorization schema was refined from a previous effort (Logan and Greene 2014) and is similar to that used in Canada (Jamieson et al. 2010).

Avalanche Type was the primary categorization factor (Fig. 2). We used this portion of the avalanche occurrence record to categorize four AC, Loose Dry (L), Loose Wet (LW), Wet Slab (WS), and Cornice (C) avalanches. Hard and soft slab avalanches required further categorization. Storm Slab and Wind Slab avalanches (S/W) had a bed surface within or at the storm snow interface. They could not be further differentiated based on information in the occurrence data. Bed surfaces in old snow or the ground separated the storm issues from persistent weak layers. Destructive size and average fracture depth were used to differentiate Persistent avalanche (PS) from Deep Persistent Slab avalanche (DPS) categories, with DPS requiring a D3 or greater size or average crown depth of 1 m or greater.

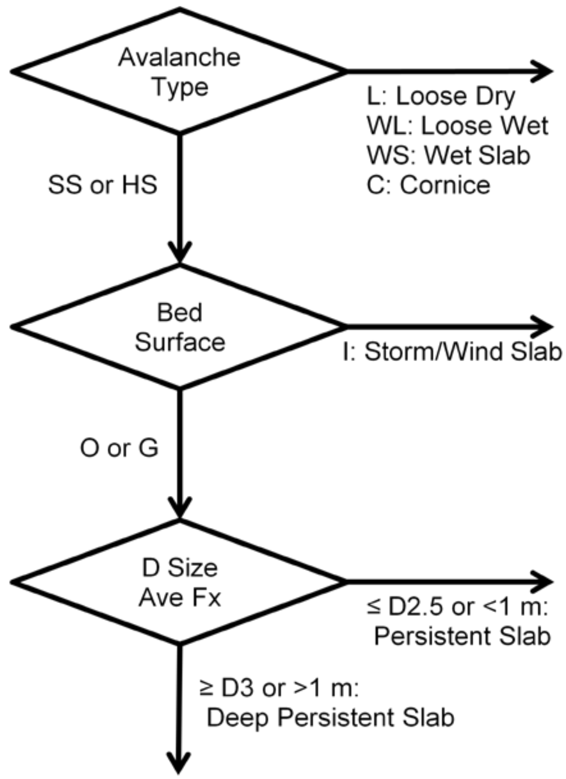

Fig. 2: Classification schema for the automated selection of AC category

3. RESULTS

There were 16270 avalanche events recorded in the CAIC database over the six years.

3.1 Categorizing Avalanche Character

The classification schema was able to categorize 52% (8546) of the total avalanches (Tbl. 1). Of characters associated with dry snow, Storm and Wind Slab avalanches (S/W) was the largest group at 22%, followed by Persistent Slab avalanches (PS) at 13%. Deep Persistent Slab avalanches (DPS) accounted for 2% of the total avalanches, and Cornice avalanches(C) less than 1%. Eleven percent of avalanches were categorized as Loose Wet avalanches (LW), and 3% as Wet Slab avalanches (WS).

There were 7724 avalanches that could not be categorized (UNK). For 1257 avalanches, observers did not report an AT category. The majority (6202) of UNK were soft or hard slab avalanches where observers did not report a bed surface or dimensions.

Tbl. 1: AC categories by avalanche year

	Avalanche Year						
AC	*11*	*12*	*13*	*14*	*15*	*16*	*Total*
LD						204	204
S/W	1598	372	573	353	397	301	3594
PS	177	388	550	409	255	269	2048
DPS	45	62	96	64	11	44	322
C	32	4	14	1	0	14	65
LW	292	84	336	172	585	306	1775
WS	83	59	73	52	216	55	538
UNK	1497	1265	1205	958	1496	1303	7724
	3724	2234	2847	2009	2960	2496	16270

3.2 Character by Avalanche Year

The number of avalanches recorded per year varied from about 2000, in 2014, to 3700 in 2011 (Tbl. 1), with a median of 2672. The number of events in each AC varied greatly from year to year. None of the categories showed statistically significant linear trends from season to season.

3.3 Character by Aspect and Elevation

The CAIC frequently summarized avalanche activity in aspect elevation diagrams (Fig. 3). Avalanches were recorded as starting Below Treeline, Near Treeline, or Above Treeline, which also correspond to elevation bands in the public forecast products. Starting zone aspects were recorded as a single ordinal direction. Figure 4 shows aspect/elevation diagrams for the three dry-slab ACs, summed over the six years of the study. We compared aspect elevation diagrams from year to year to examine yearly differences (Fig. 5).

3.4 Character by day of the Avalanche Year

We converted calendar dates into day of avalanche year (October 1 is day 1, September 30 of the following year day 365). Doing so allowed us to compare avalanche cycles and timing from character to character and year-to-year (Figs. 6 and 7).

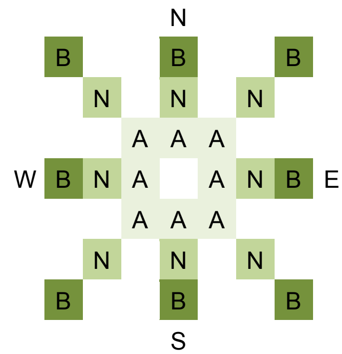

Fig. 3: Aspect/elevation diagram keyed to show aspects and elevation bands used by the CAIC (B=below treeline, N=near treeline, A=above treeline)

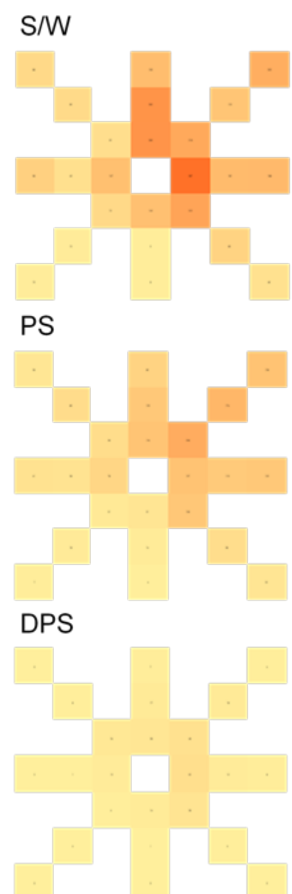

Fig. 4: Aspect/elevation diagrams for the three dry-slab AC summed over all six years. The color ramp runs from 0 in pale yellow to 400 in dark orange.

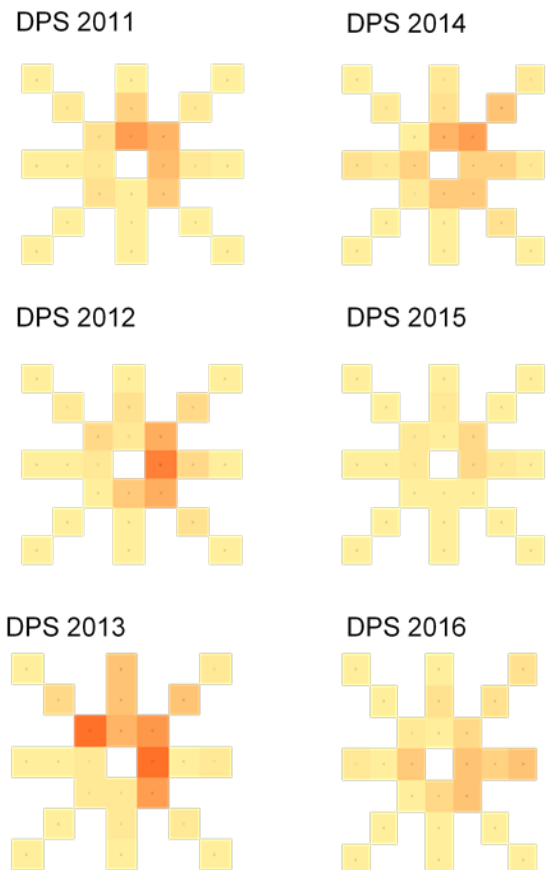

Fig. 5: Comparison of aspect/elevation diagrams for DPS for each of the six winters. The color ramp runs from 0 in pale yellow to 17 in dark orange.

4. DISCUSSION

4.1 Categorization Schema

Avalanche Character and Avalanche Type classification systems approach avalanche phenomena from different directions. Avalanche Type uses physical properties to describe actual events. Avalanche Character uses risk treatment strategies, physical properties, and formation features to sort potential events. We attempted to connect the two approaches with the categorization schema described in the in the methods section.

The automated schema successfully sorted over half of the records in the CAIC database. It provides additional detail than the AT classification and added to our understanding of the dry slab avalanche occurrence data by incorporating size, bed surface, and slab type into one group (Fig. 8).

Avalanche forecasters use many elements of the avalanche occurrence data when evaluating an avalanche cycle. This schema will not replace the eye of an experienced forecaster, but it does provide an effective summary of events, encompassing multiple factors. You can see the utility of this approach in the aspect/elevation distributions for PS and DPS (Fig. 4), or the changes in W/S, PS, and DPS through an avalanche cycle (Figs. 6 and 7).

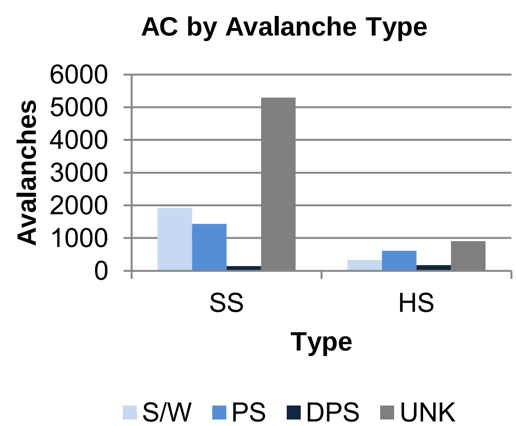

Fig. 8: Automated AC categories of Soft and Hard Slab Avalanche Types.

The data sorted by the automated schema has some limitations. The event database is comprised of observations and documents only reported avalanches. In limited cases, the database is a nearly complete record of avalanche activity, such as avalanches larger than D2 in size that affect a highway section. However, the database likely includes only a small fraction of the total avalanche occurrence.

From a risk treatment perspective, the terrain localization or formation process is the primary difference between Storm and Wind Slab avalanches. Many of the records in the CAIC database do not include enough detail for us to separate the two ACs automatically.

The automated AC schema failed to categorize a large portion of avalanches, mostly when the occurrence record was incomplete (i.e. missing data). Assuming similar proportions of S/W to PS and DPS that were categorized, about 3700 of the UNK could be estimated as S/W, 2100 as PS, and 310 as DPS.

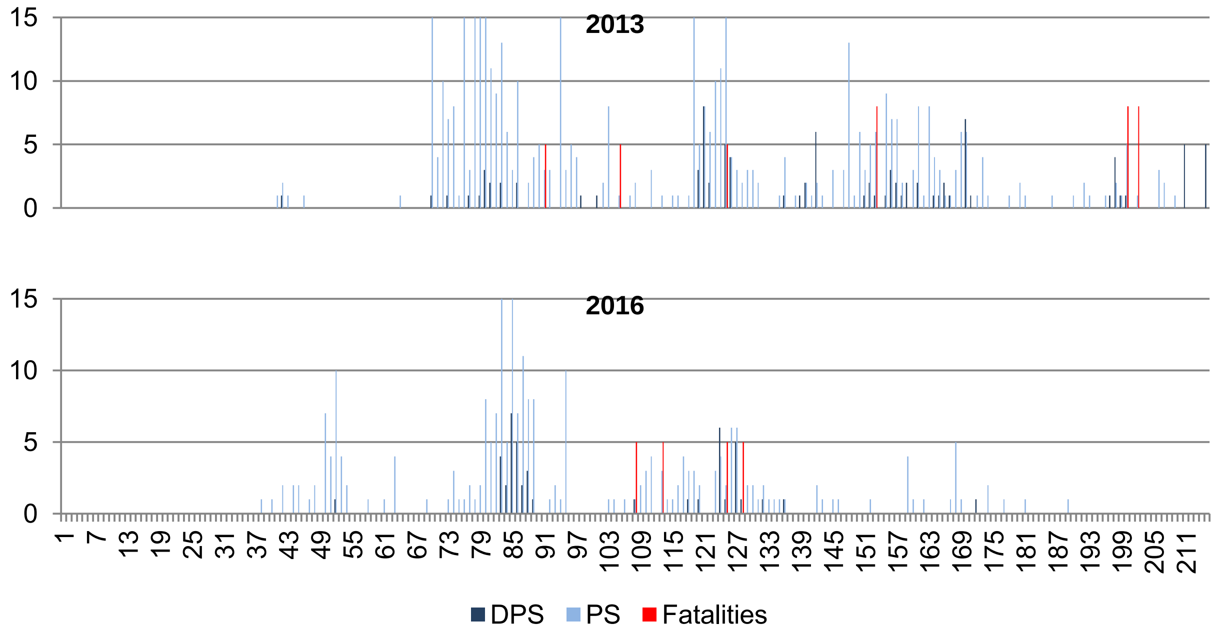

Fig. 6: The number of Persistent Slab (PS) and Deep Persistent Slab (DPS) avalanches plotted by day of avalanche year for 2013 (an “unstable” year) and 2016 (a “stable” year). Fatalities are plotted in red, at a value of 5 for Persistent Slab and 8 for Deep Persistent Slab avalanches..

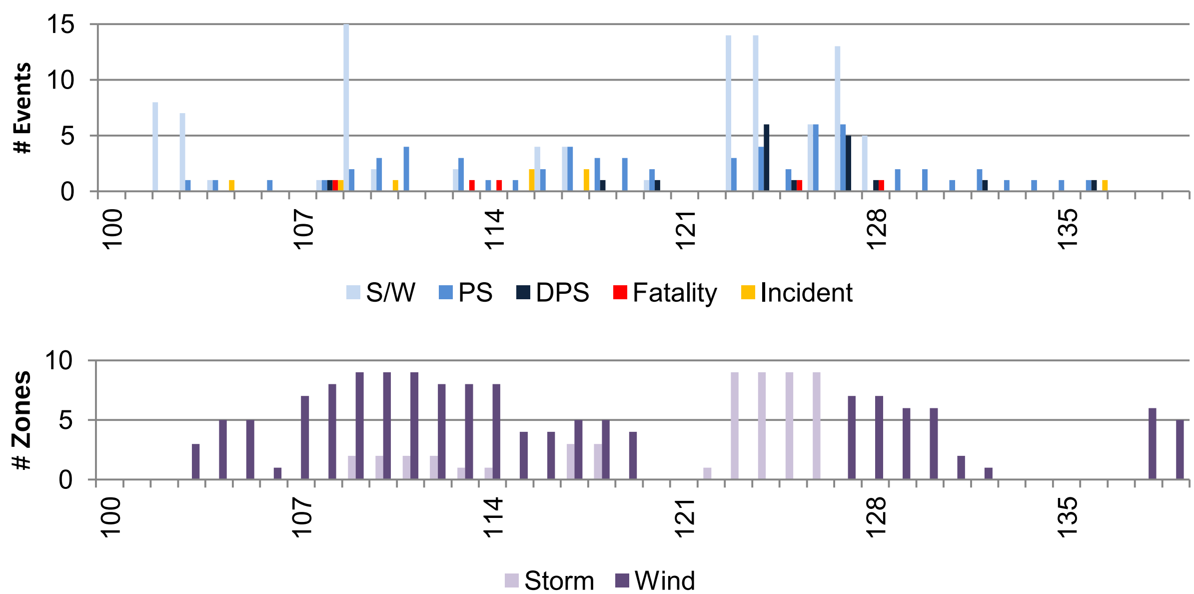

Fig. 7: January 8 to February 17, 2016, avalanche year day 100 to 140. The upper panel shows observed AC and recorded human involvement for each day. The lower panel shows the number of zones (maximum of 10) where Storm Slab or Wind Slab avalanches were included in the forecast. Persistent Slab avalanches where included in all forecast zones for the entire period.

A further limitation of the automated AC schema was the reliance on Avalanche Type. Type was the only categorization factor for WL, WS, LD and C. The schema did not add additional insight to those events. With WL and WS, the year-to-year aspect/elevation and timeline methods discussed in this paper did indicate large year-to-year differences and distinct relationships with time of year. Future operational forecasting efforts could incorporate these techniques.

4.2 Year-to-year differences

We found no significant linear trends in the number or proportion of events categorized into each AC from year to year. We would expect significant trends if the CAIC staff changed the way they recorded events as they became more familiar with the Conceptual Model. The lack of trends suggests that differences between years are not due elements of data recording.

The number of events categorized as PS or DPS each year parallels the general characterization of the CAIC forecasters. 2013 and 2014 were notably "unstable" winters, with dangerous conditions and a large number of avalanche accidents associated with DPS (Tbl. 2; Logan and Greene 2014). Both winters had a high number of both PS and DSP avalanches. Especially in comparison to 2016 and 2015, which forecasters characterized as "relatively stable" and safer winters (Fig. 5).

The categorization schema provided an indication of the relative frequency of different ACs. We estimated odds ratios by combining the frequency of AC in events with the AC in fatal accidents. That provides an over-approximation of the odds ratio with values ranging from 1.5 to 15 for each of the six years in this study. The rough calculations indicate that being exposed to (caught in) PS or DPS avalanches leads to a much greater chance of death. For all other problems, the odds ratios were much less than one.

4.3 Time series

The time series highlight additional differences year-to-year (Fig. 6). In both 2013 and 2016 there were PS and DPS avalanche cycles in late December and early January (around day 90), and again in late January and early February (around day 120). The numbers of reported PS and DPS avalanches were much higher in 2013, and the cycles extended over longer periods. In 2016, PS and DSP avalanches tapered off after the February cycles, and the rest of the season was relatively quiet. Avalanche cycles continued through

Tbl. 2: Percentage of events and events associated with a fatal accident, categorized into AC by avalanche year.

Avalanche Year		*11*	*12*	*13*	*14*	*15*	*16*
AC Events	Total	2227	969	1642	1051	1464	1193
	% S/W	72	38	35	34	27	25
	% PS	8	40	33	39	17	23
	% DPS	2	6	6	6	1	4
Fatalities	Total	7	7	11	8	3	5
	% S/W	14	0	0	13	0	0
	% PS	71	86	27	25	100	80
	% DPS	14	0	64	63	0	0

March of 2013 (through day 180), with a resurgence of DPS and associated accidents in late April (day 195).

The time series also showed the temporal evolution of problems. By definition, S/W avalanche activity happens during or a few days after snowstorms. Continuing avalanches then become PS, on the assumption that the bed surface is old snow and no longer storm instabilities or storm interfaces (Lazar et al. 2013).

The January and February 2016 avalanche cycles illustrated the evolution well. Figure 8 shows the period from 8 January to 17 February 2016, days 100 to 145. The S/W avalanches indicate the near-weekly storms through January. Lower-frequency PS avalanches continued between storms. There are only a few DPS avalanches prior to day 124, 1 February 2016, when a four-day cycle of DPS avalanches began.

The lower panel of Figure 8 shows the corresponding AC from the CAIC backcountry zone forecasts. For the most part, forecasters introduced Storm Slab avalanches into the forecasts at the onset of the storms. The lower panel suggests that forecasters retained Storm or Wind Slab avalanches longer than necessary during this period.

Persistent Slab avalanches were included in each zone for the period displayed in Figure 8. PS avalanches occurred every few days during the period, which supports the forecaster's continued use of this AC. Forecasters never included DPS avalanches during the period. The automated AC schema categorized 12 avalanche events as DPS between days 124 and 128. CAIC forecasters discussed adding Deep Persistent Slab avalanches to the forecasts during this period, but felt their inclusion made the public messaging too confusing, and that the of Persistent Slab avalanches conveyed risk strategies adequately. This underscored the difference between using AC to communicate risk to public safety verses a categorization of avalanche events.

5. CONCLUSIONS

The automated AC categorization schema is an experiment to see if we can use a system created to describe potential events, to describe observed ones. The criteria for each AC category contain a mix of factors that range from physical characteristics to suggested risk management behaviors. Experienced avalanche forecasters are quite adept at using the AC system to group potential events. With the current descriptions, it is much more difficult to determine the AC of an observed event. As with any classification system that attempts to sort all events into a limited number of categories, many events fall easily into one group. Other events lie on the border and are more difficult to sort correctly. Although many of the unclassified events were due to missing portions of the data record, the automated scheme failed to sort about half of the avalanches in the dataset.

The AC schema appears to be a useful technique despite some limitations. Occurrence data run through this filter show greater detail than data sorted by Avalanche Type, the classification used since the early 1970s. Aspect and elevation diagrams of the filtered data correlate with forecaster perception of year-to-year variability. The filter and this visualization also shows the change in exposure (in this case an allegory for encounter probability) of backcountry travelers during different avalanche years.

The automated scheme provides some insight into the utility of the AC system. Although the system makes intuitive sense to avalanche forecasters, it is unclear if it offers much as a risk communication tool. The percentage of different AC events compared to the percentage of AC accidents suggests that using AC could be a useful communication tool. Although we observe far more Wind and Storm Slab avalanches each year, more people die in Persistent and Deep Persistent Slab avalanches. This automated version of the AC system successfully collected the events with the greatest potential danger.

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REFERENCES

Atkins, R. 2004: An avalanche characterization checklist for backcountry travel decisions. Proceedings of the International Snow Science Workshop, Jackson Hole, WY, 462-468.

Greene, E., D. Atkins, K. Birkeland, K. Elder, C. Landry, B. Lazar, I. McCammon, M. Moore, D. Sharaf, C. Sterbenz, B. Tremper, and K. Williams, 2010. Snow, Weather and Avalanches: Observation Guidelines for Avalanche Programs in the United States. American Avalanche Association, Pagosa Springs, CO.

Jamieson, B., P. Haegeli, D. Gauthier, 2010: *Avalanche Accidents in Canada*. Volume 5, Canadian Avalanche Association, 431 pp.

Lazar, B., E. Greene, and K. W. Birkeland, 2013: Avalanche Problems and Public Advisories. The Avalanche Review Volume 31 Number 2.

Logan, S. and E. Greene, 2014. The Distribution of Fatalities by Avalanche Problem in Colorado, 1998-99 to 2012-13. Proceedings of the International Snow Science Workshop 2014, Banff AB.

McClung, D. M. and P. A. Schaerer, 2006: *The Avalanche Handbook*. 3rd ed The Mountaineers, 347 pp.

Statham, G. , P. Haegeli, K. W. Birkeland, E. Greene, C. Israelson, B. Tremper, C. Stethem, B. McMahon, B. White, J. Kelly, 2010: A conceptual model of avalanche forecasting. Proceedings of the International Snow Science Workshop, Squaw Valley, CA, 686