# THE DISTRIBUTION OF FATALITIES BY AVALANCHE PROBLEM IN COLORADO, USA, 1998-99 TO 2012-13

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

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

ABSTRACT: Avalanche practitioners in North America have developed nine "avalanche problems" based on risk treatment strategies, weak layer, and slab characteristics of avalanches. Avalanche problems are an increasingly popular tool for risk communication in education and forecasting. There is little research about the danger that individual problems pose. In this study, we assigned an avalanche problem to the last 15 seasons of fatal avalanche accidents in Colorado (N=80 accidents, 89 fatalities). Three problems accounted for most fatalities. Persistent Slab avalanches accounted for 66% of the avalanche fatalities. Deep Persistent Slab avalanches (DPS) accounted for 21% of avalanche fatalities. In two seasons with notable DPS problems, they accounted for about 60% of the seasonal fatalities. Wet Slab avalanches accounted for 3% of avalanche fatalities. All three problems are challenging avalanche problems for recreationalists, especially novices, to assess and treat. Because DPS and PS avalanches account for about 87% of avalanche fatalities in Colorado, improved teaching and forecasting that specifically addresses how to best mitigate these avalanche problems could yield the highest reduction in fatalities.

KEYWORDS: avalanche problems, accidents, fatalities

## 1. INTRODUCTION

Avalanche problems focus on risk management strategies for backcountry travelers. They have become increasingly popular for avalanche forecasting and education in North America, South America, and New Zealand. There is little data on the relative danger each of the problems pose. We examined avalanche problems related to 15 winters of avalanche accidents in Colorado. Persistent Slab and Deep Persistent Slab avalanches accounted for the vast majority of avalanche fatalities. This underscores the importance of communicating the danger these problems pose to recreationalists.

In 2004, Roger Atkins proposed a framework for considering avalanche problems "tied directly to different risk-management strategies". Atkins' list was simplified into eight "avalanche characters" and incorporated into the Conceptual Model for Avalanche Hazard Forecasting (Statham et al 2010). With several more years of refinement, "avalanche problems" have become common in avalanche bulletins, forecasts, and education (Lazar et al. 2013). Along with several other forecast centers, the Colorado Avalanche Information Center (CAIC) now uses avalanche problems as the organizing framework for their public avalanche forecasts.

This research project was prompted by a question posed to the CAIC in February 2014. "Just how dangerous are these Deep Persistent Slabs?" By definition, Deep Persistent Slab (DPS) avalanches are low-probability, high consequence events. They are challenging for forecasters to communicate and for recreationalists to mitigate. The question was posed several weeks after forecasters first discussed DPS, and after two fatalities related to DPS occurred. At the time of the question, DPS accounted for 66% of the fatalities within Colorado for that season. The winter of 2012-13, DPS accounted for 60% of the seasonal fatalities. We set out to determine if that proportion of fatalities associated with DPS was common in Colorado.

## 2. METHODS

### 2.1 *Study Location and Data Set*

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.

* *Corresponding author address:*
Spencer Logan, Colorado Avalanche Information Center, 325 Broadway WS1, Boulder, CO 80305;
tel: 303-499-9650;
email: spencer.logan@state.co.us

Fig. 1. Map of western Colorado with CAIC forecast zones outlined. See text for zone abbreviations. The location of PS, DPS, and WET avalanches are marked.

The CAIC issues backcountry avalanche forecasts for ten zones in the state (Fig 1). CAIC forecasters also investigate avalanche accidents. They visit the accident site to document avalanche and snowpack characteristics, and interview survivors, witnesses, and rescuers. Reports are available to the public on the CAIC website (www.colorado.gov/avalanche), and details are recorded into a database. The database has been quality controlled (Logan and Witmer 2012). We believe the database documents all avalanche fatalities within the state of Colorado since October 1 1991.

Our analysis considers only avalanche accidents that resulted in a fatality. This reduced reporting bias. Non-fatal avalanche incidents are frequently not reported to, or fully documented by, the CAIC. For example, in recent years, the CAIC has only had sufficient time to document fully 25 to 30% of the reported non-fatal incidents.

The dataset for this analysis included all avalanche fatalities that occurred in Colorado between October 1, 1998 and September 30, 2013, avalanche years 1999 through 2013 (Jamieson et al. 2010). There were 80 separate accidents, with 133 people caught and 89 killed.

We did examine avalanche accidents prior to winter 1998. Records for earlier accidents were sparse, and several accidents were poorly documented. Using a longer study interval increased the number of Unknown problems, without dramatically changing the proportion of persistent slab, deep persistent slab, or wet slab avalanches.

### *2.2 Assigning Avalanche Problems*

A single researcher coded an avalanche problem for each accident in the study period. A second researcher independently coded a random sample of 16 (20%) accidents. We then compared notes and resolved differences in discussion. Information used included avalanche dimensions, snow profiles, photographs, and accident investigators' descriptions of the avalanche. We used the following criteria to assign avalanche problems, and added two additional classifications beyond the nine problems:

Deep Persistent Slab (DPS):

- Persistent weak layer of either faceted grains or depth hoar
- Average crown of 1.2 m (4 ft) or greater
- Destructive size of D3 or greater. Since accident investigators did not use D size prior to 2004, we used photos or notes describing broken trees in the debris

Persistent Slab (PS):

- Persistent weak layer of surface hoar, faceted grains, or depth hoar, or bed surface in old snow (O)
- Average crown of 4 feet (1.2m) or less
- Destructive size of 2 or 2.5, or lack of broke trees in the photos or notes

Storm Slab (SS):

- Bed surface in recent storm snow (S) or at the new/old snow interface (I)
- Accident investigator described Storm Slab

Wind Slab (WIND):

- Bed surface in recent storm snow (S) or at the new/old snow interface (I)
- Accident investigator described Wind Slab
- Photographs showed characteristic lens shape of Wind Slabs

Loose Dry (LD):

- Snow was dry
- Did not release as a cohesive slab

Wet Loose (WL):

- Snow was moist or wet
- Did not release as a cohesive slab

Wet Slab (WET):

- Snow was moist or wet in the starting zone
- Released as cohesive slab

Glide (G):

- Released as wet, cohesive slab
- Released on the ground.

Cornice Fall Avalanches (C):

- Failure of overhanging masses of snow

Roof (ROOF):

- Occurred on the roof of a structure
- Bed surface was the structure

Unknown (U) avalanches:

- Lack of data prevented us from coding into one of the above avalanche problems.

## 3. RESULTS

We classified avalanche accidents within the study period into six of the nine avalanche problems, and two additional categories. Table 1 shows the number of accidents and fatalities by problem code, mean fatalities per accident, and the percent of fatalities by problem. Avalanches breaking on persistent weak layers, PS and DPS, accounted for 87% of the fatalities. WET avalanches accounted for 3% of the fatalities.

Tbl. 1: Accidents and fatalities by avalanche problem. See text for problem codes.

| *Problem Code* | *Accidents (Fatalities)* | *Fatalities per accident* | *Percent of fatalities* |
|---|---|---|---|
| PS | 57 (59) | 1.04 | 66 |
| DPS | 13 (19) | 1.46 | 21 |
| WET | 3 (3) | 1.00 | 3 |
| LD | 1 (1) | 1.00 | 3 |
| SS | 2 (2) | 1.00 | 2 |
| WIND | 1 (1) | 1.00 | 1 |
| ROOF | 1 (2) | 2.00 | 2 |
| U | 2 (2) | 2.00 | 2 |
| Total | 80 (89) | 1.11 | |

PS avalanches were the only problem that occurred every winter of the study. DPS avalanches in eight of the winters. Table 2 shows fatalities by avalanche season for those two problems. WET avalanches occurred in three winters.

Tbl. 2: PS and DPS fatalities by avalanche season. Avalanches killed a median of 6 people per winter during the study period. For the last five seasons, 2008 to 2013, avalanches killed a median of 7 people.

| *Winter* | *PS* | *DPS* | *Seasonal Fatalities* | *Percent DPS* |
|---|---|---|---|---|
| 1999 | 3 | 2 | 5 | 40 |
| 2000 | 5 | 2 | 8 | 30 |
| 2001 | 3 | 0 | 4 | 0 |
| 2002 | 5 | 1 | 8 | 10 |
| 2003 | 4 | 2 | 6 | 30 |
| 2004 | 2 | 1 | 3 | 30 |
| 2005 | 4 | 0 | 5 | 0 |
| 2006 | 4 | 0 | 4 | 0 |
| 2007 | 4 | 0 | 4 | 0 |
| 2008 | 2 | 3 | 5 | 60 |
| 2009 | 4 | 0 | 4 | 0 |
| 2010 | 5 | 0 | 8 | 0 |
| 2011 | 5 | 1 | 7 | 10 |
| 2012 | 6 | 0 | 7 | 0 |
| 2013 | 3 | 7 | 11 | 60 |
| *Total* | 59 | 19 | 89 | 20 |

PS, DPS, and WET avalanches occurred at different times through the winter. Table 3 breaks out fatalities for the three problems by month.

Tbl. 3: Fatalities by month for PS, DPS, and WET avalanches.

| *Month* | *PS* | *DPS* | *WET* |
|---|---|---|---|
| Nov | 2 | 1 | 0 |
| Dec | 11 | 1 | 0 |
| Jan | 15 | 3 | 0 |
| Feb | 14 | 2 | 0 |
| Mar | 13 | 5 | 2 |
| Apr | 4 | 7 | 0 |
| May | 0 | 0 | 1 |

Table 4 and Figure 1 show the fatalities by problem and CAIC forecast zone, where SBT is Steamboat, FR is Front Range, VS is Vail and Summit County, SWT is Sawatch, ASP is Aspen, GUN is Gunnison, NSJ is Northern San Juan, SSJ is Southern San Juan, and SDC is Sangre de Cristo zones.

Tbl. 4: Fatalities by problem and CAIC forecast zone. See text for zone abbreviations.

| *Zone* | *PS* | *DPS* | *WET* | *% DPS* |
|---|---|---|---|---|
| SBT | 4 | 0 | 0 | 0 |
| FR | 14 | 8 | 0 | 36 |
| VS | 9 | 3 | 1 | 25 |
| SWT | 3 | 3 | 0 | 50 |
| ASP | 14 | 2 | 0 | 13 |
| GUN | 3 | 2 | 0 | 40 |
| GM | 3 | 0 | 0 | 0 |
| NSJ | 5 | 0 | 2 | 0 |
| SSJ | 4 | 0 | 0 | 0 |
| SDC | 0 | 1 | 0 | 100 |

## 4. DISCUSSION

Only six of the nine avalanche problems caused fatalities during the study period. Though common occurrences in Colorado, Cornice Fall and Loose Wet avalanches did not cause any deaths during the study period. Glide avalanches are infrequently observed in Colorado, and have not caused a fatality since 1950.

The distribution of avalanche problems varied geographically and by CAIC forecast zone (Fig. 1). The three zones with the greatest number of fatalities have high recreational use and easy access (Logan and Witmer 2012).

### *4.1 Persistent and Deep Persistent Slab Avalanches*

Persistent Slab avalanches accounted for 57 accidents and 59 (66%) fatalities in during the study period. PS avalanches were the only problem to cause fatalities every season of the study period. On a seasonal basis, PS avalanches accounted for 30 to 100% of fatalities, median 70%. About one third of the PS fatalities were avalanches that broke on basal weak layers, similar to DPS, but lacked the destructive force or crown depth. PS accidents were distributed throughout the state, as would be expected for a problem that accounted for the majority of accidents (Fig.1).

Deep Persistent Slab avalanches accounted for 13 accidents and 19 (21%) fatalities in during the study period. No DPS broke on surface hoar during the study period. DPS avalanches caused fatalities in eight of the 15 seasons, and in two seasons accounted for 60% of the seasonal fatalities. DPS accidents occur in spatial and temporal proximity during the “bad” seasons. DPS avalanche fatalities were concentrated in the central and northern portions of the state (Fig. 1). These areas typically have a shallow snowpack, extensive and thick basal weak layers, and high wind redistribution of snow.

The 2008 season was a bad season for DPS avalanches. There were 5 fatalities that season. The three DPS fatalities occurred in January, within eight days. Two were in adjacent avalanche paths in the backcountry accessed from Vail Ski Area.

The 2013 season was another bad season for DPS avalanches. Seven of the 11 deaths were related to DPS. It was the second worst season, in terms of fatalities, in Colorado since 1950. One accident, in April 2013, killed 5 recreationalists (Lazar and Greene 2014). It was the worst recreational accident, and second worse for fatalities, in Colorado since 1950. Three days prior, a DPS killed a recreationalist in similar terrain approximately 40 km to the west.

The DPS accidents that occurred in November and December were in heavily cross-loaded terrain. Strong winds had drifted snow into thick slabs, despite early season conditions. Most DPS avalanches occurred in March and April, when the seasonal snowpack had accumulated sufficient depth to produce deep avalanches.

On average, PS killed 1.04 people per accident. Only one PS killed more than one person in an accident. In comparison, three DPS accidents killed multiple people, averaging 1.5 people per accident. One DPS accident in 2013 killed five, the worst recreational accident in Colorado history.

Comparing our study to the Canadian study (Canadian Avalanche Center 2014), Colorado had a higher proportion (3:1) of PS to DPS avalanches than Canada (1.5:1). In Canada, PS accounted for 43% and DPS 28% of fatalities. Several factors may explain the greater percentages of PS and DPS in Colorado compared to Canada.

The Colorado data was from one snow climate. Although there is geographic variation across the Colorado mountains, depth hoar and persistent weak layers are common throughout. These conditions are conducive to forming PS and DPS avalanches. In contrast, the Canadian data comes from a region that includes three snow climates. Persistent weak layers play a less prominent role in maritime snow climates. Including accidents from that snow climate could reduce the proportion of PS and DPS avalanches.

Our coding of problems stressed weak layer character over slab character, per Lazar et al. 2013. When we had to reconcile codes between researchers, it often involved differentiating between an avalanche on a persistent weak layer, or a wind or storm slab. A less restrictive classification could change the distribution of problems.

### *4.2 Wet Slab Avalanches*

Wet Slab avalanches accounted for three (3%) fatalities during the study period. Not surprisingly, WET accidents showed a distinct pattern of timing, occurring in March and May. WET avalanches also showed a geographic distribution, with two of the three in the North San Juan zone.

The two WET accidents in March occurred at the end of the month, on March 30 several winters apart. Both were in the North San Juan zone, one of the southern forecast zones. Both were large and destructive (D3), but did not share terrain characteristics. The WET accident in May was unusual for several reasons. Avalanche deaths in May are rare in Colorado, with only three since 1950. The avalanche occurred on an open piste, unusual in Colorado, and spurred research to better understand wet avalanche dynamics (Borgeson and Hartman 2010).

Several fatal avalanches in the spring started in dry snow and entrained wet snow lower in the track. Accident investigators noted that entrainment. We coded those avalanches as PS or SS, depending on weak layer characteristics. Only avalanches with moist or wet snow in the starting zone were included in our coding of WET avalanches.

### *4.3 Storm Slab and Wind Slab Avalanches*

Storm Slab and Wind Slab avalanches accounted for two (2%) and one (1%) fatalities, respectively. SS and WIND accounted for 19% of Canadian accidents. Again, the inclusion of additional snow climates may account for the difference between the studies.

The changing terminology associated with the avalanche problems was particularly noticeable with Wind Slab avalanches. Slabs formed by wind deposition are very common in Colorado. Several older investigations described “wind slabs” that broke on depth hoar. Witnesses described dramatic whumpfs and extensive propagation. We coded those avalanches as Persistent Slab based on the behavior and presumed weak layer.

### *4.4 Loose Dry Avalanches*

One Loose Dry (LD) avalanche caused one (1%) fatality. The accident was unusual. The victim fell on a groomed piste within a ski area. The victim was presumably knocked unconscious, slid out-of-bounds, where they triggered and were buried in a small loose-dry avalanche.

### *4.5 Roof Avalanches*

One Roof avalanche accounted for two deaths during the study period. In Colorado, roof avalanches are uncommon and kill about one person every ten years.

### *4.6 Uncoded Avalanches*

We could not code (U) two avalanche accidents. In one, the avalanche occurred during a storm, was not reported for several days, after all evidence of the avalanche was obscured. The other occurred in a remote location. It was one of five accidents to occur within four days. CAIC staff was unable to visit the site, and volunteer search and rescue personnel did not document avalanche characteristics.

## 5. CONCLUSIONS

We examined the avalanche problems associated with fifteen years of fatal avalanches in Colorado. About 66% of the fatalities were associated with Persistent Slab avalanches, and 21% with Deep Persistent Slab avalanches. The results are not surprising, given Colorado’s continental snow climate, where structural weaknesses can produce avalanche cycles that last for weeks or months.

Improved teaching and forecasting that specifically addresses how to best mitigate PS and DPS could yield the highest reduction in fatalities. As forecasters and educators, it is important to explain and emphasize the need for careful and conservative terrain selection when dealing with persistent problems. One possibility would be to stress the need for bold and excessive terrain elimination—removing terrain with suspected DPS from the travel plan for the day.

## ACKNOWLEDGEMENTS

Many thanks to everyone who reports and documents avalanche accidents and incidents. Our work relies entirely on the information gathered by avalanche professionals from around Colorado.

## REFERENCES

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

Borgeson, L. E. and H. Hartman, 2010: Predicting Wet Snow Avalanches at the Arapahoe Basin Ski Area. Proceedings of the International Snow Science Workshop, Squaw Valley, CA.

Canadian Avalanche Center, 2014: Avalanche Problems. [http://www.avalanche.ca/cac/library/patterns-in-avalanche-accidents/recreational/characteristics-involvement/avalanche-problem]

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

Lazar, B. and E. Greene, 2014: Reflections: Sheep Creek Avalanche. The Avalanche Review Volume 32 Number 3.

Logan, S. and F. Witmer, 2012: Spatial, temporal, and space-time analysis of fatal avalanche accidents in Colorado and the United States, 1991 to 2011. Proceedings of the International Snow Science Workshop, Anchorage, AK, 479-486.

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

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.