THE RELATIONSHIP BETWEEN WHUMPF OBSERVATIONS AND AVALANCHE ACTIVITY IN COLORADO, USA

Jason Konigsberg[1], Ron Simenhois[1], Karl Birkeland[2,3], Erich Peitzsch[4], Doug Chabot[5], and Ethan Greene[1]

[1] Colorado Avalanche Information Center, Denver, CO, USA
[2] Friends of the Colorado Avalanche Information Center, Evergreen, CO, USA
[3] Birkeland Snow and Avalanche Scientific, Bozeman, MT, USA
[4] U.S. Geological Survey, Northern Rocky Mountain Science Center, West Glacier, MT
[5] Gallatin National Forest Avalanche Center, Bozeman MT, USA

ABSTRACT: Triggering whumpfs is a primary indicator of unstable snowpack conditions. Although backcountry travelers and avalanche forecasters rely on whumpfs as a warning sign of potential avalanches, there is little formal research to confirm this relationship. This study investigated the temporal correlation between whumpfs and avalanche activity in data from Colorado's Front Range and southern San Juan Mountains between the winters of 2010/11 and 2022/23. To assess changing conditions over a variety of seasons, we compared the timing of whumpfs and avalanches to the total snow depth at a representative site. We used a 13-inch (33 cm) rolling-window median snow depth versus the median for observed whumpfs, and small avalanches (D1 to D1.5), and large to very large avalanches (D2 and greater). Our results support informal observations that whumpfs are important indicators of avalanche activity, especially at shallower snow depths. Later in the season, when snow depths are deeper and basal weak layers become more difficult to trigger, whumpfs become less common even during periods of increasing avalanche activity. Some of our results may be due to the thin, weak, and wind-affected snow in the Colorado Front Range, where whumpfing typically occurs due to collapsing basal depth hoar. Our findings are important for backcountry travelers assessing stability and for backcountry avalanche forecasters communicating conditions to the public. Our data show that although whumpfs generally indicate unstable conditions and correlate with avalanche activity, the largest avalanches of the winter may not always be preceded by whumpfing.

KEYWORDS: whumpf, avalanche forecasting

1. INTRODUCTION

A whumpf is a propagating collapse of a weak layer under a cohesive slab of snow. Human-triggered whumpfs are widely recognized as obvious signs of instability. Public avalanche forecasts typically warn backcountry travelers to recognize three obvious signs of instability, including recent avalanches, shooting cracks, and whumpfs. The forecasts recommend avoiding steep slopes with similar aspects and elevations when backcountry travelers observe any of these signs.

* *Corresponding author address:*
Jason Konigsberg, Colorado Avalanche Information Center, 1313 Sherman Street Denver, CO 80203 USA;
tel: +1 303-499-9650;
email: jason.konigsberg@state.co.us

Despite broad acceptance that whumpfs are important indicators of dangerous avalanche conditions, no formal research exists that quantitatively correlates whumpf observations and avalanche activity. In a study by Schweizer (2010), professional observers noted obvious signs of instability, such as whumpfs, and avalanche danger. Surprisingly, they found that whumpfs were observed 35% of the time at danger levels Low or Moderate. Clearly, whumpfs sometimes occur during relatively safer conditions. Whumpf observations increased with the observed danger level, peaking at 100% of the observations during High avalanche danger. The authors concluded that professional observers noted whumpfs without recent avalanches fairly often and sometimes without an elevated avalanche danger. Similar anecdotal observations by Colorado Avalanche Information Center (CAIC) forecasters reinforce these findings, with some periods having minimal avalanche activity but numerous whumpf reports. Conversely, at other times there are few whumpf observations when avalanche activity has increased.

Our study aims to quantitatively examine the correlation between whumpfs and avalanche activity to determine: 1) if and when whumpfs are good indicators of snow instability, 2) whether snow depth influences whumpf observations, and 3) whether or not whumpf observations are more commonly associated with avalanches of a certain size range.

2. DATA AND METHODS

We obtained observations of whumpfs and avalanches from the CAIC database for the winters from 2010/11 to 2022/23. Observations were contributed by CAIC forecasters, professional observers, and the public. We ran a database search for the word whumpf or collapse, spelled numerous ways, and found 6428 observations. We eliminated observations where the observer noted the absence of whumpfing or collapses (i.e., “no cracking, collapsing, or avalanches observed”), resulting in a total of 4585 whumpf observations from across the state.

CAIC observations are collected in ten regional zones. We used data from two of these zones: the Front Range and the southern San Juan Mountains (Figure 1). These two areas have different weather and snowpack conditions. Located east of the Continental Divide, the Front Range is typically windy, cold, and dry, resulting in a classic continental snowpack dominated by depth hoar weak layers (Mock and Birkeland, 2000). In contrast, the southern San Juan Mountains often have a deeper snowpack, less wind, and warmer temperatures. Many winters, the snowpack in the southern San Juan Mountains is best characterized as intermountain. From our 4585 statewide snowpack whumpf observations, 660 observations are from the Front Range, and 405 are from the southern San Juan Mountain zone. We have 5811 avalanche observations for the Front Range and 2597 for the southern San Juan Mountains during our study period. We compared all avalanches to whumpf activity, and we also filtered the avalanche data by avalanche destructive size, D1 and D1.5 (small avalanches), and D2 and greater (large and very large avalanches) to compare whumpf activity and avalanche size. We removed wet loose-snow avalanches, dry loose-snow avalanches, roof avalanches, and cornice fall avalanches from the dataset as these avalanches are normally not associated with whumpfing.

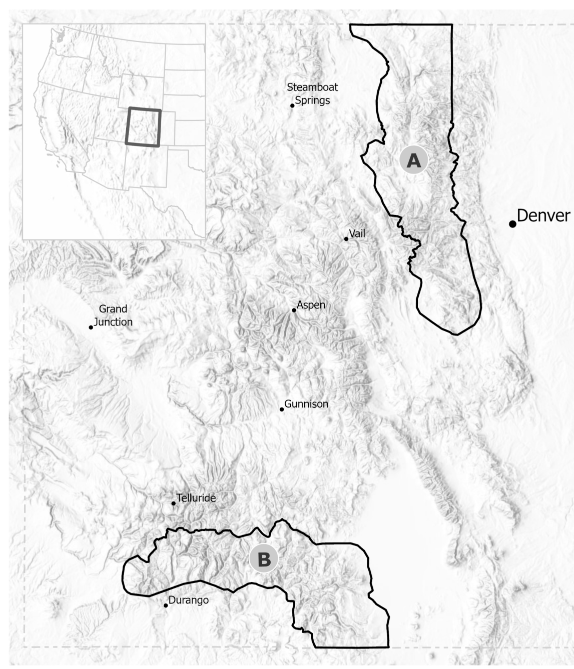

Figure 1: Map of the study areas in western Colorado, USA. We used data from the Front Range Mountains (A) and the southern San Juan Mountains (B). Map: Esri, USGS.

Making meaningful comparisons between whumpfs and avalanches across multiple seasons with varying snowpacks was challenging. To compare these variable years better, we used total snow height (HS) as our timeline measurements rather than the calendar date. Our snow height measurements come from Natural Resources Conservation Service (NRCS) SNOTEL sites. For the Front Range, we used snow depth data from the Berthoud Summit SNOTEL, and for the southern San Juan Mountain analysis, we used data from the Wolf Creek Summit SNOTEL.

We then totaled the number of whumpfs and avalanches for each snow height value over our study period. Finally, we smoothed our data by calculating a rolling-window median using a window of 13 inches (33 cm) for whumpfs and avalanches at each snow height.

We used the Pearson Correlation test to determine the correlation between whumpfs and avalanches at different snow height ranges. We chose snow height ranges based on our visual interpretation of graphs of avalanche activity and whumpfs, looking at the relationship between whumpfs and avalanches for three ranges of snow depth: 1) whumpfs increase as avalanches increase 2) whumpfs begin decreasing as avalanches continue to increase 3) whumpfs and avalanches both decrease. For each snow height range, we calculated the correlation coefficient (r) and p-value for all sizes of avalanches and whumpfs, for small avalanches and whumpfs, and for large to very large avalanches and whumpfs.

3. RESULTS

For the Front Range, we found strong positive correlations between the 13-inch rolling median of all avalanche sizes and the 13-inch rolling median of whumpfs at snow depths ≤36 inches (Figure 2, Table 1). Between snow heights of 37 to 46 inches (93 to 117 cm), there were strong negative correlations between whumpfs and avalanches of all sizes, with whumpfs trending downward while avalanche activity continued to increase (Figure 2). From a snow height of 47 to 100 inches (118 to 254 cm), we found strong positive correlations as both avalanches of all sizes and whumpfs decreased.

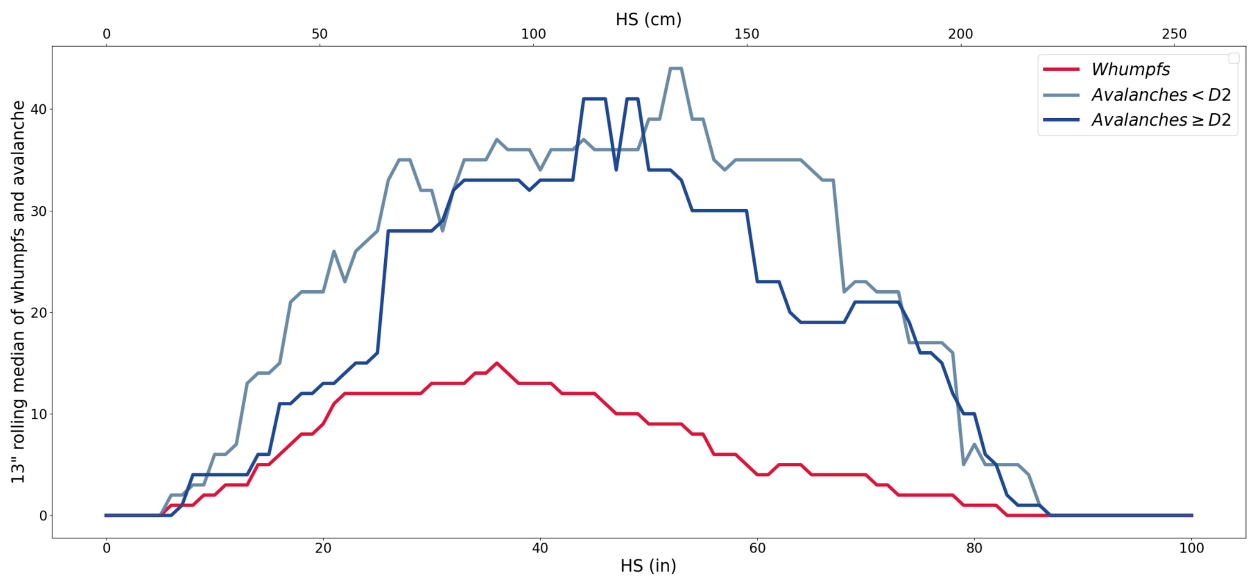

Figure 2: Front Range rolling median for whumpfs (red line) and avalanches (blue lines) peak at different snow heights (cm scale on the top and inches at the bottom). Whumpfs peak at 36 inches, while small avalanches (D1 to D1.5), and large to very large avalanches (D2 and greater) avalanches peak at a snow heights of 46 and 52 inches respectively. There is a strong inverse relationship between whumpfs and avalanches (both size classes) between 37 and 46 inches. After 46 inches, avalanches and whumpfs decrease similarly.

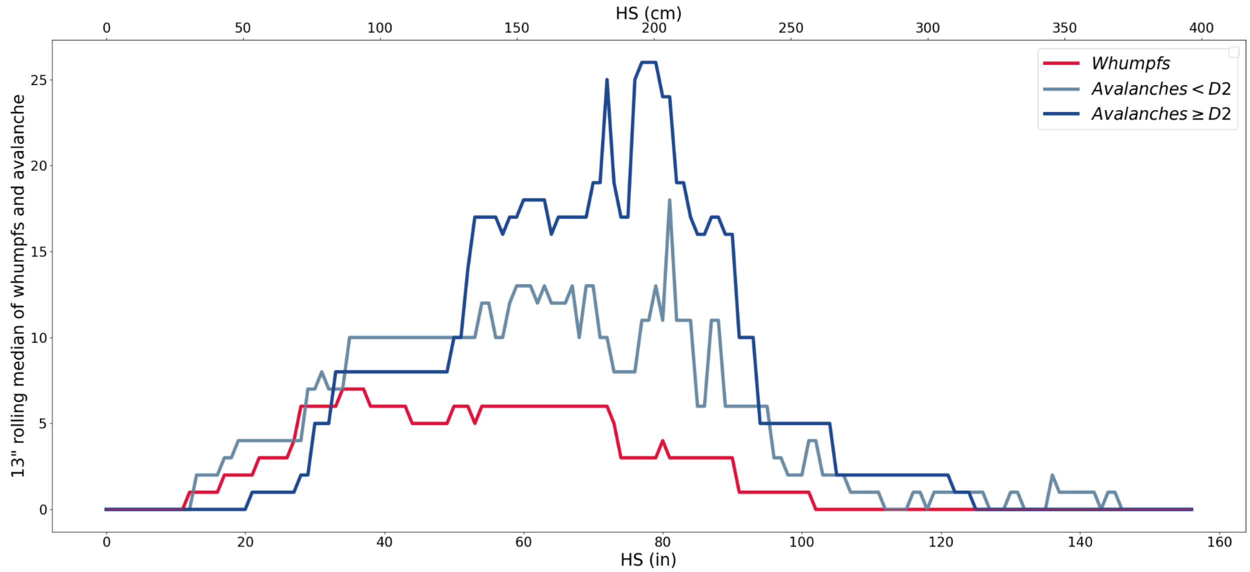

Figure 3: Results from the southern San Juan Mountains are similar to the Front Range with a peak in whumpfs (red line) around 36 inches. However, avalanches in the southern San Juan Mountains peak at a higher snow height than in the Front Range, and whumpfs decrease more gradually. Following the peak of whumpfs, small avalanches follow a similar trend to whumpfs, while large and very large avalanches continue to increase.

Table 1: This table shows Pearson's r and corresponding p-values for correlations between whumpfs and avalanches. In the Front Range, there is a strong correlation between whumpfs and avalanches at all snow height ranges. In the southern San Juan Mountains, there are strong correlations between whumpfs and avalanches at the lower and upper snow height ranges. In the middle snow height range, small avalanches correlate with whumpfs, while there was no significant correlation between whumpfs and large avalanches

Front Range	*r*	*p-value*	***Southern San Juan Mountains***	*r*	*p-value*
All size avalanches			**All size avalanches**		
0 to 36 in (0 to 92 cm)	0.95	<.001	0 to 36 in (0 to 92 cm)	0.9	<.001
37 to 46 in (93 to 117 cm)	-0.81	0.004	37 to 77 in (93 to 196 cm)	-0.07	0.65
47 to 100 in (118 to 254 cm)	0.98	<.001	77 to 100 in (196 to 254 cm)	0.74	<.001
Small avalanches (<D2)			**Small avalanches (<D2)**		
0 to 36 in (0 to 92 cm)	0.93	<.001	0 to 36 in (0 to 92 cm)	0.94	<.001
37 to 46 in (93 to 117 cm)	-0.71	0.02	37 to 77 in (93 to 196 cm)	0.53	<.001
47 to 100 in (118 to 254 cm)	0.96	<.001	77 to 100 in (196 to 254 cm)	0.52	0.034
Large to very large avalanches (≥D2)			**Large to very large avalanches (≥D2)**		
0 to 36 in (0 to 92 cm)	0.97	<.001	0 to 36 in (0 to 92 cm)	0.87	<.001
37 to 46 in (93 to 117 cm)	-0.77	0.009	37 to 77 in (93 to 196 cm)	-0.24	0.131
47 to 100 in (118 to 254 cm)	0.97	<.001	77 to 100 in (196 to 254 cm)	0.83	<.001

In the southern San Juan Mountains area, we also found strong positive correlations between whumpfs and avalanches at snow heights below 36 inches (Figure 3, Table 1). For snow heights between 37 to 77 inches (93 to 196 cm), there was a moderate positive correlation for small avalanches and no significant correlation for large and very large avalanches. For snow height between 77 to 100 inches (196 to 254 cm), we found moderate to strong positive correlations between whumpfs and avalanches depending on size. This variability may be due to a smaller sample size at this upper range of snow heights.

4. DISCUSSION AND CONCLUSIONS

Our results show that whumpfs are good indicators of unstable snow at snow heights of less than 36 inches (92 cm). There were strong correlations in both zones for all avalanche sizes up to this snow height. This makes sense because when basal persistent weak layers are closer to the surface, and slabs are thin, we can more easily trigger whumpfs and avalanches. Previous research has shown that skier-triggered avalanches are more common with weak layers buried less than 32 to 39 inches (80 to 100 cm) below the surface (McCammon and Schweizer, 2002; Schweizer and Jamieson, 2000).

At upper-range snow heights, there were also strong correlations between whumpfs and avalanches of all sizes. Both whumpfs and avalanches decrease similarly. This is to be expected at these higher snow depths as even in a continental snowpack, basal weak layers gain strength eventually, and both whumpfs and avalanches are harder to trigger.

Our results at the shallower and deeper ranges of the snowpack are an example of what might be expected in a continental snowpack with basal depth hoar layers, such as is found almost every year in the Front Range zone. Interestingly, we found somewhat similar patterns in the southern San Juan Mountains, where the snowpack - while still continental - tends toward more intermountain characteristics.

In our middle-range snow height bin, results are more mixed. We see strong negative correlations between avalanches of all sizes and whumpfs in the Front Range. There is a strong positive correlation for the southern San Juan Mountains for small avalanches, but the correlation is weak for large to very large avalanches. The strong negative correlation in the Front Range does not mean that whumpfs are not a good indicator of instability, but it does show that we see active avalanche periods with a lower frequency of whumpfs than at shallower snow depths. We had about 50% less data for the southern San Juan Mountains area, so the lack of data could limit our ability to make strong conclusions for this zone.

Our method of aligning all seasons by snow height helped us to see trends in whumpfs and avalanches, but a limitation of this method is that it is hard to see singular - but significant - active-avalanche periods in which there were very few whumpf observations. The winter of 2014/15 in the Front Range is a good example (Figure 4). When looking at whumpf and avalanche observations season-by-season (not shown), there are multiple periods of high avalanche activity after March 1, with a deeper snowpack and with few whumpf observations.

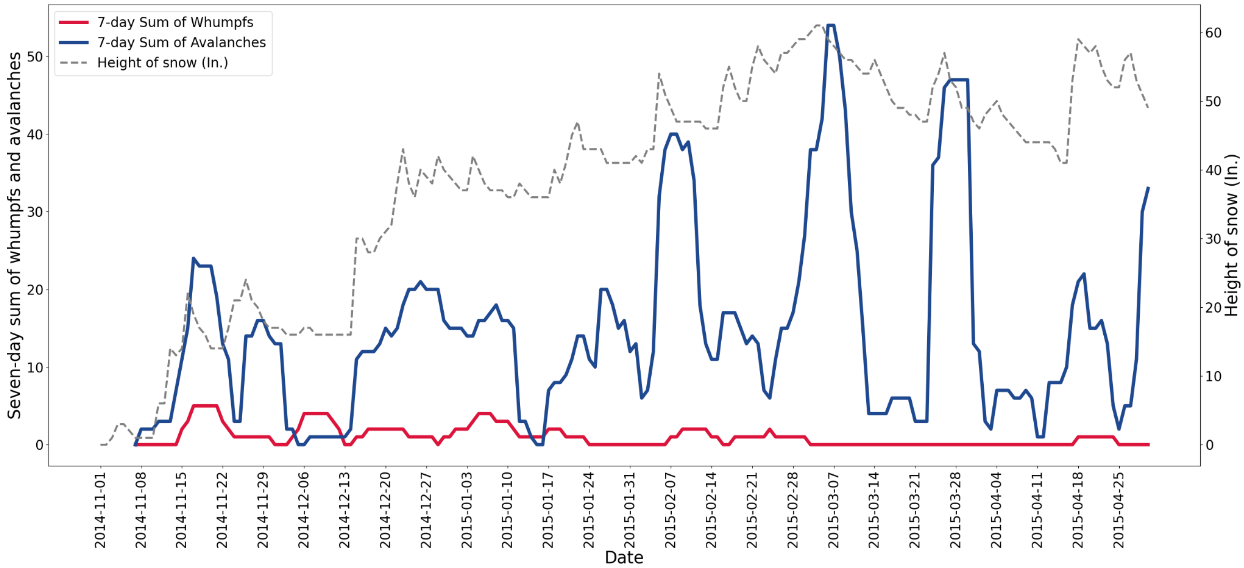

Figure 4: Whumpf and avalanche observations for the Front Range over the 2014/15 season. The trend in whumpfs (red line) closely follows the trend in avalanches for the first three avalanche activity periods (blue line). After March 1, there were several additional avalanche activity periods with relatively few whumpfs.

Why do we continue to see an increase in avalanches, but a smaller proportion of whumpf observations at these deeper snow depths? We suggest these situations may occur when increasing slab depths make triggering more difficult. However, at these times avalanches may still be triggered because snow depths vary more in complex avalanche start zones than in adjacent, simpler terrain (Miller et al., 2022). The increased variability in starting zones means these areas contain more locations where a person could initiate a critical weak layer crack. Additionally, recent research from Simenhois et al. (2023) showed that the snowpack at whumpf-trigger points differs from that found in crown profiles of avalanches. The snowpack at these two points can be different in weak layer depth, slab thickness, and slab hardness. The relatively high spatial variability in start zones compared to flat meadows, where whumpfs are typically triggered, helps explain why we can trigger whumpfs without avalanches, and sometimes we can trigger avalanches without whumpfs.

Our results demonstrate that we cannot always depend on *trends in whumpfs* to correlate to *trends in avalanches*. For our study sites, at intermediate snow depths, whumpfs begin decreasing while avalanche activity continues to increase. Avalanche forecasters often advise the public to look for obvious signs of instability, such as shooting cracks and whumpfing. Our results do not suggest changing this approach, but we should be careful not to equate decreasing whumpf observations with fewer avalanches. In some situations, such as the zones we studied, avalanching may continue to increase after whumpfing begins to decline. During such times, appropriate travel advice may be, “You may not observe whumpfing sounds, an obvious sign of instability, before you trigger a deadly avalanche.” This is not new information for forecast teams who often recognize these changing conditions and coordinate their messaging, but our study helps to validate these anecdotal observations. It also provides ballpark snow depth measurements for when this change occurs in the depth hoar-dominated snowpack in our study area.

We found that whumpfs tend to be good indicators of an unstable snowpack. When whumpfs are observed, avalanches are usually happening, and when there are no avalanches, whumpfs are less likely. However, as snow depths increase and triggering becomes more difficult, the overall number of whumpf observations may decrease while avalanche observations continue to increase. This is also the time when avalanche size is increasing. As such, backcountry travelers should know that they may not observe whumpfing - *or any other obvious sign of instability* - before triggering large or very large avalanches. Further, public avalanche forecasters should keep track of potential shifts in conditions and adjust their public messaging accordingly.

DISCLAIMER

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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