Snow Stability Trends At Wolf Creek Pass, Colorado

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ABSTRACT: While studying historical weather and avalanche data for Wolf Creek Pass (US 160), Colorado, I identified a relationship between average new snow density during a storm cycle and the average new snow density for an arbitrarily chosen seven day period immediately preceding the onset of that storm cycle. Using the reported length of the highway centerline covered with avalanche debris as a measure of avalanche intensity, lighter density snow often preceded heavier density snow during a storm and this regularly led to more avalanche activity affecting the highway. The opposite relationship led to less severe avalanching affecting the highway. At the same time, other snow stability relationships were identified. This paper will describe how these relationships were identified and are now used to assist in avalanche forecasting for Wolf Creek Pass.

KEYWORDS: Avalanches, avalanche forecasting, snow stability, weather and avalanche historical data.

1. INTRODUCTION

In 1992 the Colorado Avalanche Information Center (CAIC) entered into an agreement with the Colorado Department of Transportation (CDOT) to provide avalanche forecasting personnel on major Colorado highways threatened by avalanches. That fall a pilot program began in Silverton (Red Mountain, Molas, Coal Bank, and Lizard Head Passes), and in 1993, additional offices were opened at the Eisenhower Tunnel (Interstate-70, Berthoud and Loveland Passes), and Pagosa Springs (Wolf Creek and Monarch Passes). In 1994 an office was added in Carbondale for McClure Pass, Grand Mesa, and other passes on the Western Slope.

The main threat on Wolf Creek Pass is from ten avalanche paths on the west side that have a generally east through southern exposure with starting zones that sideload from the steady southwest flow during storms. Two paths on the east side of the pass have southeast through north starting zone aspects and the highway is protected by a large snowshed. The only fatalities involving motorists occurred here on December 30, 1951, when three truckers were caught and two killed. Vertical fall distances to the highway range from 180 to 660 m (600 to 2200 feet). The highway crosses most avalanche paths in the lower part of the avalanche track.

Avalanches at Wolf Creek Pass are currently controlled using the 105 mm howitzer. Helicopter delivered handcharges and the Avalauncher are also used to a lesser degree. Permanent protective works include a snowshed at the Alberta group and earth mounds in the runouts of three of the four 160s. Highway closure during high avalanche hazard, despite its limitations, remains an important part of the avalanche protection program, particularly on the west side of the Pass.

From 1950 to the present, only 10% (26 of 260 recorded occurrences) of avalanches that have hit the highway were artificially triggered. The percentage since the onset of the forecasting program, which coincided with more timely avalanche control work, has increased to 21% (14 of 63 occurrences). Several of the avalanche paths have no history of hitting the highway with artificial control. Active control work is not attempted during storm periods due to the lack of

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visibility, long distances to the targets, and generally small starting zone targets presented to the gun positions.

The major source of avalanche research about the San Juan Mountains was done in Silverton by the Institute of Arctic and Alpine Research (INSTAAR) in the 1970s. The INSTAAR team was composed of well known avalanche workers: Richard and Betsy Armstrong, Ed LaChapelle, Rod Newcomb, Don Bachman, among others. Silverton, in the northwest San Juan Mountains, is about 128 km (80 miles) along the Continental Divide from Wolf Creek Pass in the southeast San Juans.

The INSTAAR team described the San Juans as a radiation snow climate (Armstrong and Ives 1976): "The combination of high altitude, low latitude, and predominately continental climate produces a specific radiation snow climate. . . extreme nocturnal radiational cooling occurring on all exposures produces snowpack temperature gradients of a magnitude sufficient to cause significant recrystallization of temperature gradient metamorphism. The second factor is the substantial amount of solar energy available to slopes with a southerly exposure. This daytime condition causes melt at the snow surface and subsequent melt-freeze crusts. These two situations continue to influence the snowcover throughout the winter. The resulting stratigraphy is highly complex and often unstable."

Melt-freeze crusts, surface hoar, and near surface faceting are present at Wolf Creek. The degree and extent of these phenomena can vary greatly across an avalanche starting zone due to the amount and intensity of solar gain caused by subtle changes in aspect and slope angle. All avalanche activity affecting the highway has been brought on by precipitation events. Wind events or wet slide activity that caused avalanches affecting the highway has not been observed or recorded. Not all avalanche crowns are accessible after a storm cycle, but the crown profiles and observations that have been made in the last seven winters in avalanches that affect the highway show multi-layered slabs failing on thin layers of buried kinetic forms, often adjacent to or sandwiched between melt-freeze crusts. These slabs often step down into older layers as they descend the starting zone.

The INSTAAR team made some observations for the Silverton area that hold true for Wolf Creek Pass: The amount of new snow or water equivalent from a storm is not a good indicator of avalanche intensity. And, the predominant avalanche type in the San Juans is the climax soft slab (a slab consisting of one or more old snow layers). This places the main forecasting emphasis on understanding the local snowpack.

Hans Frutiger, a noted Swiss avalanche researcher, toured Colorado in the early 1960s. His travels took him to Wolf Creek Pass along with other important Colorado highway avalanche sites. Frutiger (1964) identified the 15 most important avalanche paths affecting Wolf Creek Pass. Even with limited time for observations, Frutiger did an excellent job of evaluating Wolf Creek Pass and his work remains a valuable source of information. He classified avalanche frequency for most Wolf Creek avalanche paths as "occasional", running to the highway every 3-6 years. This classification remains valid some 40 years later and again underscores the impression that despite frequent large snowstorms avalanche activity affecting the highway is best forecasted by understanding the local snowpack.

2. DATA COLLECTION

Avalanche data for Wolf Creek Pass is available from 1951 to 1993 from the Westwide Avalanche Network (WWAN). Avalanche occurrences were not always recorded prior to the beginning of the CAIC/CDOT forecasting program depending on the interest and the time available to CDOT personnel for avalanche occurrence record keeping. Length of the highway centerline covered by avalanche debris, an observation that is common to all past and current data, is used as the measure of avalanche intensity.

Weather data has been collected from observations taken at Wolf Creek Ski Area (WWAN data available from 1971 to present), and data collected at CDOT highway maintenance camps just east of the summit, 3201 m (10,670 ft), and halfway down the west side at now abandoned Camp Creek, 2850 m (9500 ft), which is stored at the Colorado Climate Data Center. This data consists of maximum and minimum temperature, total snow depth, 24 hour new snow and water equivalent. This data, plus wind speed and direction data, has been collected since 1994. New snow and its water equivalent is determined by the use of a snow board and snow core tube at the ski area and by CAIC. At the CDOT camps, new snow depth and water equivalent were and still are collected in an 8 inch gauge can. Complete weather and avalanche data are now collected as part of the avalanche hazard forecasting program. Daily air temperature, relative humidity, wind speed and direction data are gathered by a Campbell Scientific unit at Wolf Creek Ski Area, 3540 m (11,800 ft), on the Continental Divide. Total snow depth, interval depths, and snow water equivalent are recorded at the highway summit, 3264 m (10,880 ft). During storms, new snow depths and water equivalents are measured and recorded at 0800 and 1600 hours.

I identified avalanche cycles by going through all the avalanche data, about 300 WWAN entries from 1951 to 1993, and my own data. Reported avalanche occurrence identified periods of weather data to collect. A storm was defined as continuing as long as new snowfall overcame snowpack settlement, the snowpack increased in depth (Mears 1996). This is an appropriate definition at Wolf Creek Pass where most of the paths generally face south and natural stabilization and snowpack settlement can be rapid.

Concurrent historical weather data and avalanche observations were not always available. I investigated 44 storms (9 documented by me and 35 compiled from WWAN records) from 1951-1998 that have deposited avalanche debris on the highway. Forty of those storms have data complete enough to study, and additional information to complete gaps in information is still being sought. Complete data for this inquiry would include daily total snow depth (to define the duration of the storm), 24 hour new snow and new snow water equivalent amounts (to calculate density), and observed avalanche activity and length of the highway centerline covered (to measure avalanche intensity) for the periods of interest. Four storms lacked adequate weather and/or avalanche data. In one case, on January 27, 1957, during the most severe storm on record a large avalanche hit the highway maintenance camp at Camp Creek burying a worker/resident. Fortunately a hand out of the snow saved him, but unfortunately this event terminated weather observations for this important avalanche event.

Because the criteria used to define a storm had broken some periods of continuous precipitation into distinct storms, I included snowfall amounts for an arbitrarily chosen seven days prior to the onset of a storm in the hopes of forging a direct relationship between storm snowfall/water equivalent and avalanche intensity. Again, the choice of seven days was arbitrarily made and other number of days were not considered.

3. RESULTS

I noticed that average snow density in the seven days prior to the storm was often less than the average snow density that fell during an "investigated" storm and this effect regularly led to more severe avalanche activity affecting the highway. I found these results:

- 60% (24) of the 40 storms displayed an increasing (positive) snow density trend. Lighter density snow preceded a heavier density snow during the actual storm (considered a less stable situation).
- 15% (6), displayed no trend (+9.9 kg/m3 to –9.9 kg/m3 change).
- 15% (6), displayed a decreasing (negative) density trend. Heavier

density snow preceded lighter density snow (considered a more stable situation). These storms were some of the least severe in the amount of snow they deposited on the highway centerline.

- Four storms (10%) had 2.5 cm (1") or less new snowfall the seven days prior to the onset of the storm.

The density trend was calculated in this manner:

[Storm Average Snow Density] – [Average Snow Density Previous 7 days] = Density Trend

DENSITY TREND SUMMARY FOR WOLF CREEK PASS STORMS

Density Trend for 40 Storms	Number/ Percent	Average Centerline Covered By Avalanche Debris	Minimum/ Maximum Centerline Covered By Avalanche Debris
Increasing Trend > +10 kg/m3	24 / 60%	437 m / 1455 ft	15 - 2294 m 50 - 7645 ft
No Trend +9.9 kg/m3 to -9.9 kg/m3	6 / 15%	251 m / 838 ft	15 - 523 m 50 - 1743 ft
Decreasing Trend < -10 kg/m3	6 / 15%	50 m / 168 ft	4 - 180 m 12 - 600 ft
No Previous Snowfall or Snowfall < 2.5 cm (1")	4 / 10%	72 m / 240 ft	9 - 218 m 30 - 725 ft

4. DISCUSSION

4.1 Density Trends

Increasing density during a storm is often the source of serious avalanching. Atwater (1968) recognized the affect of rising air temperatures during a storm and characterized it as an "inverted storm", describing it in his classic book, The Avalanche Hunters. While forecasting for Wolf Creek Pass, I have used increasing interval density values as a basis for successful forecasting decisions.

Crown line profiles of avalanches hitting the highway at Wolf Creek Pass show that avalanche crowns include not only the new snow/old snow interface but step down into much older layers. Perhaps the new snow/old snow interface provides the initial failure plane and the moving snow then provides the stress necessary to exploit additional deeper weak layers. In my experience, avalanches involving new snow only have little or no affect on the highway. Entrainment of additional layers is an important contributory effect for avalanches to reach the highway. The density trend may not be the cause but rather a warning sign or indicator of unfavorable conditions that may threaten the highway. A positive density trend has not been present in stable storms, but historical data may not be complete enough to make this same observation over the last 50 years.

A negative snow density trend during a storm most often results in little or no avalanching affecting the highway. A large storm struck the area in April, 1999, depositing 1.5 to 2 m/5 to 7 feet of new snow. Interval new snow densities decreased during the 3-day storm, ending near 40 kg/m3. One medium-sized natural avalanche was observed, post-storm control work released no significant avalanches, and no avalanches affected the highway. Of the six storms with a negative density trend, only one had more than one avalanche affecting the highway and only one covered more than 30 m (100 ft) of the highway centerline.

Little or no snowfall seven days previous to a storm showed the fewest cases of avalanches affecting the highway. The southerly facing avalanche paths may have become quite stable in these cases and although melt-freeze crusts and near-surface faceting often form during extended clear periods, avalanches that include only new snow have a limited affect on the highway.

4.2 Snowfall and Precipitation Intensity

During the tenure of the CAIC/CDOT forecasting program where more specific weather data is available, an average snowfall intensity of 2 cm (.7") per hour or more is present during severe avalanching events. This is an average value calculated after a storm has passed and may have limited value in actual forecasting situations, but snowfall and precipitation intensity is calculated at the twice daily observations.

4.3 Late Season Snowstorms

Snowstorms that arrive during mid-March or later have little impact on the highway. Only four avalanches during three storms have been observed or recorded affecting the highway in this period and the amount of centerline covered has been limited. Late season wet slab and loose snow avalanches, which can be common in other parts of Colorado, have not been observed or recorded at Wolf Creek Pass. No avalanches affecting the highway have been observed or recorded in April or May despite the fact that late season storms can contain more than adequate amounts of new snow 1.5-2m (5-7ft) as mentioned above) or new snow water equivalent 168 mm (6.6") in another case.

Avalanche crown heights in the 2.5 to 3 m (8 to 10ft) range have accompanied some of these storms and still not affected the highway. At this time, a hypothesis is that snowpack conditions have stabilized in the mostly south facing avalanche tracks by late season inhibiting their contribution to avalanche flows. The deposition or erosion of the snowpack in the avalanche track during avalanche release and the subsequent ability of avalanches to reach the highway will be a focus of future research at Wolf Creek Pass. This phenomena may be a significant factor in avalanche forecasting throughout the avalanche season.

5. SUMMARY

At this point it should be emphasized that this study does not pretend to illuminate some new theories of avalanche release. Rather, the point is that a thoughtful study of historical avalanche and weather data can be used to further our understanding of local avalanche characteristics and aid forecasting decisions at a selected site. At Wolf Creek Pass, avalanche hazard assessment remains a traditional blending of weather data and forecasts, snowpack information, and field observations and stability tests. The inclusion of the density trend and other historical weather and avalanche observations only enhances this traditional recipe. The recent avalanche seasons have been fairly quiet since the snowfall density trend relationship was identified and opportunities for field verification have been limited.

Avalanches affecting Wolf Creek Pass are primarily natural releases, not controlled releases, and opportunities for active control work are limited once a storm has begun. Therefore, an initial goal of my research was to find a threshold snowfall or precipitation value that would indicate a high likelihood of an avalanche reaching the highway and therefore the all-important recommendation for road closure. So far, however, my research has not found such a value, so I am now focused on a slightly different question: Is it safe to remain open despite snowfall and water equivalent amounts that are historically sufficient for avalanches to reach the road? Density trend observations and storm timing have aided my decision making process at Wolf Creek Pass.

Future winters will provide the opportunity to further study and observe winter storms with a little more information. Is this density trend (whether it is the direct cause or not) a measure and indicator of potential avalanche activity and will it prove to be a practical forecasting tool? That remains to be seen. But, it is wise to be armed with as much relevant information as possible to fight the Snow War.

Finally, I would like to thank the folks past and present who have made this tremendous weather and avalanche database available to the avalanche community.

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