# FORECASTING FOR DRY AND WET AVALANCHES DURING MIXED RAIN AND SNOW STORM EVENTS

Scott Savage[1], Erich Peitzsch[2,3], Simon Trautman[4], Ben VandenBos[1]

[1] U.S.D.A. Forest Service Sawtooth Avalanche Center, Ketchum, Idaho, USA.
[2] U.S. Geological Survey Northern Rocky Mountain Science Center, West Glacier, Montana, USA
[3] Snow and Avalanche Lab, Department of Earth Sciences, Montana State University, Bozeman, Montana, USA
[4] U.S.D.A. Forest Service National Avalanche Center, Bozeman, Montana, USA

ABSTRACT: Natural wet slab avalanches release when rain or melt water decreases snowpack strength, and natural dry slab avalanches release when an increased load overcomes snowpack strength. This study investigates avalanche activity resulting from mixed rain and snow falling on a faceted snowpack. This scenario produced an extensive slab avalanche cycle in March 2018 in the mountains near Ketchum, Idaho, when a 24 hour storm deposited 50 to 65 mm of water. We investigate the contributions of the pre-existing snowpack structure and weather to avalanching, and suggest possible mechanisms for the observed slab avalanche activity. At upper elevations, expected widespread, 0.5 to 3 m deep, dry slab avalanche activity occurred on many aspects. However, at middle elevations (2300 m to 2700 m) near the fluctuating rain-snow line, a low frequency return period avalanche cycle occurred in a much smaller geographical area, and was concentrated around north-northwest aspects. This differs significantly from avalanches above this elevation that spanned all aspects. This scenario illustrates the challenges forecasting and communicating these events. In our experience, some avalanche cycles exist in a continuum of avalanche types that are not easily sorted into simple “wet” and “dry” categories. We discuss challenges in using current advisory and bulletin communication tools. Furthermore, it is possible that a changing climate will increase the frequency of mixed rain-snow events in areas with traditionally drier and colder climates. We believe the avalanche community will benefit from the refinement and development of tools and techniques to describe and forecast this challenging problem.

KEYWORDS: Wet Avalanche, Rain-On-Snow, Conceptual Model for Avalanche Hazard

## 1. INTRODUCTION

The U.S.D.A. Forest Service Sawtooth Avalanche Center (SAC) issues avalanche advisories for the mountains near the south central Idaho communities of Stanley, Fairfield, and Ketchum-Sun Valley. Winter precipitation totals average from 500-1000 mm in the northern and western zones and 175-500 mm in the southern portion of the advisory area. Snow storms are frequently followed by extended periods of high pressure, promoting faceted crystal growth. Historically, rain events affect elevations below 2300 m up to a few times each winter, seldom affect terrain near 2440 m, and very rarely impact elevations over 2600 m (personal communication Abromeit, Bachman, Bingham, Gardiner, Kellam). Anecdotal evidence suggests two major rain-on-snow induced avalanche cycles (December 1996 and February 1999) within the past 30 years. The snow climate transitions from an intermountain regime in the northern and western zones to continental farther south and east (Mock and Birkeland, 2000). This paper focuses on the Wood River Valley zone in the southeastern portion of the advisory area.

### *1.1 Winter History*

The SAC’s Wood River Valley (WRV) zone harbored a shallow, weak, snowpack with faceted snow crystals from December (December weak layer) through early January 2018. Below 2300 m, many slopes were devoid of snow. Upper elevation and alpine starting zones contained snow, but several strong wind events scoured many exposed slopes. From early January through mid-February, light to moderate snowfall interspersed with dry, cool, sunny periods formed a layer of near-surface faceted crystals associated with crusts on some aspects (Figure 1). This layer was subsequently buried on 14 February. A storm on 1-2 March deposited approximately 50 mm of snow water equivalent (SWE) producing an extensive natural avalanche cycle on the December and

* *Corresponding author address:*
Scott Savage, Sawtooth Avalanche Center, Ketchum, ID;
tel: +1 406.580.8142;
email: scott@sawtoothavalanche.com

14 February weak layers. Additional snowfall from 14-17 March caused another round of natural avalanche activity on the 14 February layer.

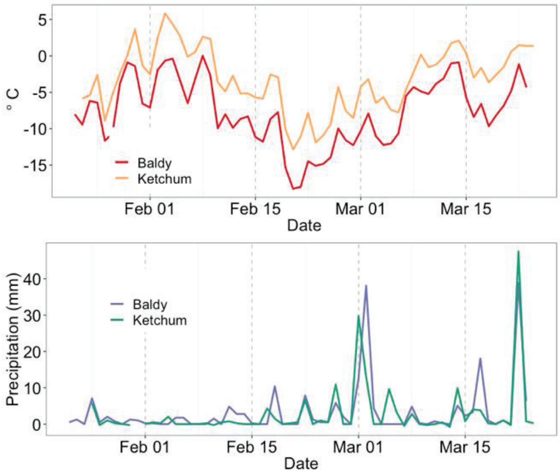


Figure 1: Top panel: daily temperature for Mt. Baldy (blue, 2747 m) and Ketchum Ranger Station (green, 1795 m) automated weather stations (AWS) from 22 January to 24 March. Bottom panel: daily precipitation for the same AWSs and time period.

## 2. CASE STUDY

### *2.1 Weather*

A southwest flow delivered a warm, wet storm system beginning early on 22 March. In the 24 hours following the onset of precipitation, remote weather stations near Ketchum-Sun Valley recorded 45-65 mm of precipitation. Direct observations of surface crusts in the following days indicated rain-snow levels ranged from 2350-2635 m during the storm accompanied by moderate to strong south/southeast winds.

### *2.2 Avalanche Activity*

Field observers were able to trigger size D1-2 dry slab avalanches on wind loaded slopes at ridgelines (approximately 2650 m to 3000 m) from 15:00-17:00 on 22 March. Avalanche mitigation at a nearby ski area resulted in intentionally triggered multiple D1 loose wet avalanches failing on near-surface crusts on steep slopes between 2300-2750 m. By sunset on 22 March, no substantial debris was observed or reported in any large runout zones near the valley floors. Better visibility in the following days allowed better observations. As expected, widespread D2-D4, natural dry slab avalanches occurred throughout the advisory area at upper elevations above 2750 m. Crown depths ranged from one to over three meters. The upper elevation events were clustered on west, north, and east aspects. This natural activity was present in much of the advisory area and was most pronounced in the Pioneer Mountains of the WRV zone. Here, widespread 60-105 cm deep, D2-D3 natural slab avalanches also released in middle elevation starting zones between 2300-2700 m. This middle elevation activity occurred on west, north, and east aspects but was more narrowly focused on northwest aspects (Figure 2). Many slides occurred in paths where activity has not been observed in the previous 30 years. The widespread, natural middle elevation activity was confined to a relatively small area in the WRV zone.

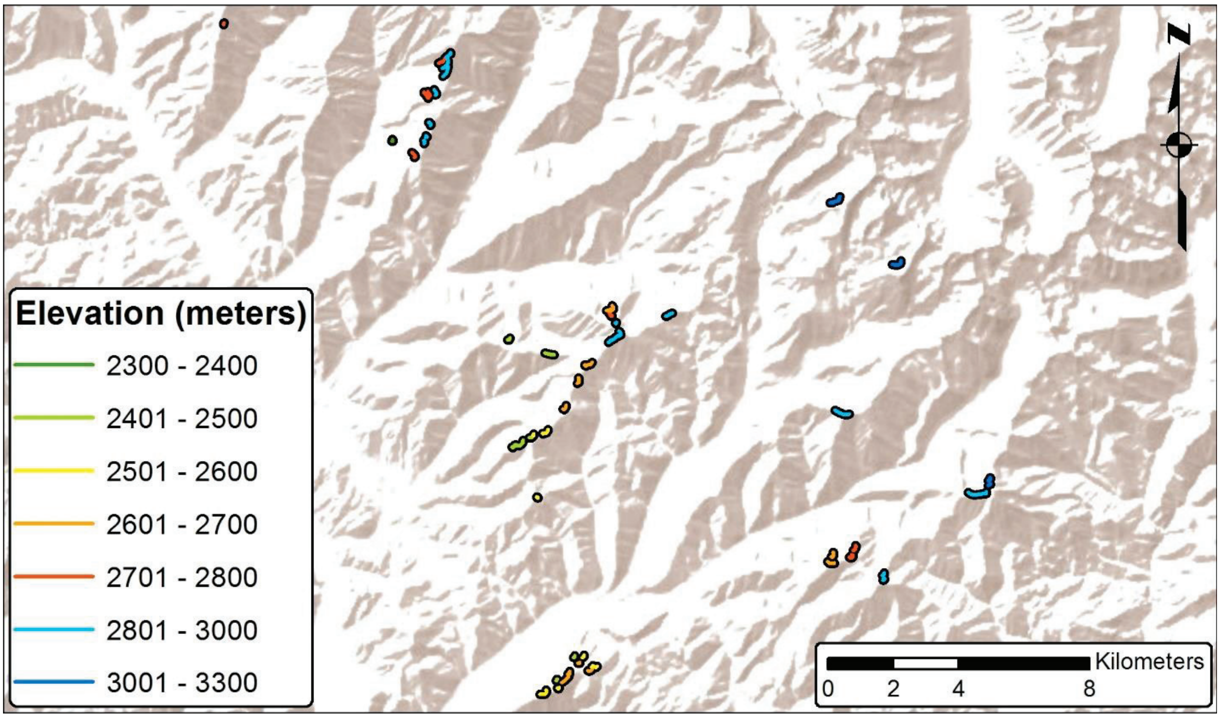


Figure 2: Map of observed crown lines throughout the Pioneer Mountains in the WRV zone. Colors depict elevation ranges. Rain line extended to approximately 2700 m.

We compared crown aspects below rain line (<2700 m) to those above this elevation. The aspects of these two groups differs significantly (p = 0.0001) with the observed crowns below rain line clustering on northwest and north aspects (Figure 3).

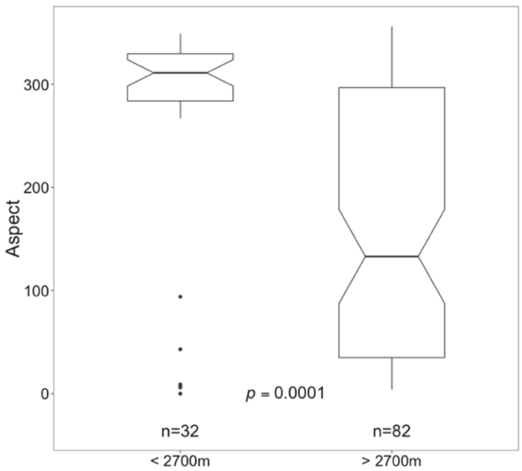


Figure 3: Boxplot depicting the median (thick black line), interquartile range (notched boxes), range (whiskers and dots) of aspect for observed avalanche crowns below rain line (≤ 2700 m) and above rain line (> 2700 m).

2.3 Snowpack Observations

The observed avalanches at middle elevations failed on large (2-3 mm) faceted crystals above an ice crust about 20-40 cm above the ground (14 February layer). The uppermost regions of the starting zones held dry surface snow and did not appear to receive any rain. However, based on field observations, rain fell in substantial portions of many of the starting zones for at least part of the precipitation event. In the lower parts of the starting zones and in the avalanche tracks, the snowpack above the failure layer was much thinner; and free water from rainfall had percolated through the slab to the failure layer and bed surface. At one observed avalanche site, the slab changed from a completely dry, 80 cm thick snow mass at the top of the crown to a thoroughly wet, 20 cm thick slab 100 vertical meters downslope.

## 3. DISCUSSION

### *3.1 Elevation Dependency*

In exposed upper elevation terrain, the combination of existing snowpack structure, heavy snowfall, and extensive wind-transported snow caused the observed avalanche activity. At elevations that received only rain during the precipitation event, wet loose avalanches released. The snowpack at these lower elevations was quite thin, and water from previous warm weather and rain events had eroded the snowpack or previously wetted all layers. Given the temperature and precipitation conditions, we present three possible mechanisms that may explain the widespread middle elevation avalanche activity:

1. Loading the snowpack: Snowfall and wind-transported snow overloaded the upper reaches of the starting zone and caused fracture, independent of the water percolating down to the weak layer lower in the starting zones.
2. Free water weakening: Rainfall percolating through the snowpack in lower portions of the starting zones stressed or weakened the slopes, promoting fracture and subsequent slope failure.
3. Changing slab properties: Snowfall accumulated in portions of the starting zones before rain fell on top of and wetted the dry snow, changing the slab properties enough to induce fracture.

Given the uncertainty associated with rain-on-snow induced slab avalanches failing on persistent weak layers, we see a need for synthesizing observations and insight from this case study into a hypothesis. We suggest a combination of the three stated mechanisms – and possibly other mechanisms not yet observed or characterized – caused the fractures. This hypothesis is consistent with the observed elevation dependency of the low frequency, middle elevation activity during this storm.

### *3.2 Structure – Aspect, Spatial, and Elevation Patterns*

The frequency of middle elevation slab releases on northwest aspects in a relatively small area in the Pioneer Mountains was notably different than crowns observed above the rain line. Differences in snowpack depth and structure dependent on aspect and elevation appear to be a primary factor in this difference. Field observations suggest that strong northwest wind events in December and January scoured snow from many exposed northwest-facing slopes, resulting in a thinner overall snowpack and enhanced faceting in early February on those aspects. Lesser snowfall amounts in late January and early February, relative to neighboring areas, produced prime conditions for near-surface faceting to occur in the thinner layer of low-density new snow at the surface. Warm weather and rain completely wetted areas with a shallower snowpack prior to the 22 March storm, and slopes with thicker snowpack were stronger or released on the 14 February weak layer during large loading events earlier in March.

## 4. IMPLICATIONS

North American avalanche professionals based in maritime snow climates commonly observe avalanche activity due to mixed rain-snow events, typically in the absence of pronounced faceted layers. Professionals working in areas with more faceted intermountain or continental snowpacks commonly see wet slab avalanche activity involving faceted layers resulting from solar and temperature induced spring snow melt. However, widespread avalanching involving faceted layers during mixed rain-snow events is rarely observed and is not as well-understood. This case presented forecasting and communication challenges.

### *4.1 Forecasting*

Extensive slab avalanching occurred in a single mountain range near the rain-snow line in a narrow elevation band, on a narrow range of aspects, over a relatively short time period. Precipitation type, amounts, and pre-existing snowpack structure produced the rarely-observed avalanche activity in this area. Several factors contributed to the difficulty forecasting this avalanche cycle:

1. Precipitation models under-predicted precipitation by a factor of 2-3.
2. Detailed snowpack structure observations were limited by the regional operational scale.

3. Staff had little to no experience observing or forecasting previous, similar events.

### *4.2 Communication*

In North America, many operations use a conceptual model of avalanche hazard (CMAH) (Statham et al., 2017) as a general framework for assessing and forecasting avalanche hazard. The regional forecasting community and individual operations develop decision trees and communication platforms based on the CMAH. These tools work well in the vast majority of scenarios when transitions between avalanche problems are clear; graphics and text describing avalanche location, likelihood, and size sequentially follow the avalanche problem type. However, when forecasters are not certain which problem type to select, public messaging clarity can suffer. This case study of mixed wet-dry slab avalanches illustrates some challenges associated with using the current set of nine discrete problem types and related public messaging tools.

Considering and addressing uncertainty is paramount in avalanche hazard forecasting and public communication (Lachapelle, 1980; Jamieson et al. 2015). CMAH authors acknowledge "agreeing on the specific type of problem and when to transition from one problem to another is challenging." Public avalanche bulletins and advisories do not graphically display the degree of uncertainty directly associated with illustrating the day's avalanche problem(s). One way to mitigate this issue is to describe the uncertainty around the avalanche problem illustration in the product text. Yet a potential pitfall exists because some risk communication product consumers may view textual admissions of uncertainty as "indicators of ignorance" instead of actionable information (Lewandowski et al. 2015). We suggest developing communication tools that better handle a continuum of avalanche problems – especially wet-dry - and can facilitate communicating uncertainty in selecting the primary avalanche problem type. While current communication products work well for "typical" avalanche conditions, improvements may help communicate dangerous, infrequent events.

### *4.3 Future Work*

Professionals in coastal and some inland mountain ranges regularly face mixed rain-snow events. Southern and central Idaho have not experienced these events frequently, but climate models suggest a higher frequency in the future due to a changing climate (Lazar and Williams, 2008; McCabe et al., 2007; Musselman et al., 2018). We encourage future work investigating wet snow avalanches and developing professional and public communication tools and platforms to handle scenarios as we have described in this paper.



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