# APRIL-FOOLED IN THE FLATHEAD: THE HAZARD OF LATE-SEASON PERSISTENT WEAK LAYERS

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ABSTRACT: The Flathead Avalanche Center in northwest Montana has seen a spike in late-season near-misses and accidents. Surprisingly, many incidents have involved professional snow workers. April now ranks as the month with the second highest tally of incidents in the region (10), behind only February (29; 2017-2023). We examine meteorological and snowpack data leading to the events. The avalanches released on near-surface persistent weak layers. We conclude that the antecedent weather conditions are precipitation-free periods and diurnal melt-freeze cycles that occur during atypically dry conditions. These conditions are favorable for producing near-surface persistent weak layers. Backcountry riders often adopt an "open-season" mindset during these periods. When snowfall returns, a persistent slab avalanche hazard develops rapidly, yet riders may not adjust their mindsets with the same speed, leading them to mis-identify avalanche problems and rely on mitigation tactics inappropriate for the conditions. A similar inertia may leave forecasters reluctant to add Persistent Slab avalanche problems or increase danger ratings. We conclude with recommendations for how the regional avalanche centers might adjust messaging to prevent similar accidents.

KEYWORDS: avalanche accidents, near-surface persistent weak layers, decision-making

## 1. THE APRIL FOOLS AVALANCHE CYCLES OF 2020 AND 2023

In early April, 2020, the Flathead Avalanche Center (FAC) received three reports of near-misses as a result of large to very large (D2-3) unintentionally- or remotely-triggered avalanches. All the avalanches failed on a persistent weak layer consisting of near surface facets resting on a melt-freeze crust. Two of the parties involved included professional avalanche workers who were recreating.

Three seasons later (2023), again at the start of April, the Flathead Avalanche Center received four reports of near misses and accidents as a result of unintentionally- or remotely-triggered large avalanches. Again, the triggered avalanches failed on a persistent weak layer consisting of near-surface facets. In some cases, the facets rested on a hard melt-freeze crust. Three incidents also involved professional snow workers, including an FAC forecaster who was on the clock.

Fool us twice, shame on us. In an effort to prevent future accidents, we investigated the two cycles for common weather, snowpack, and human factors.

## 2. ANTECEDANT WEATHER AND SNOWPACK CONDITIONS

The weather preceding both cycles was marked by extended periods of high pressure and diurnal melt-freeze cycles. During this time the avalanche danger rating was Low for a week or more (Figures 1 and 2).


Figure 1: Avalanche events (bars; color coded by size) and danger ratings (grid; color-coded by danger rating) for the 2020 April Fools cycle.


Figure 2: Avalanche events (bars; color coded by size) and danger ratings (grid; color-coded by danger rating) for the 2023 April Fools cycle.

### *2.1: 2020 Weather*

The nearest automated weather station (Emery Creek SNOTEL, 1326 m, 10-48 km northwest;) recorded 5 mm of precipitation between March 18 and 25. During this period, the station reported a loss of 46 mm of SWE and the Height of Snow (HS) dropped from 135 to 109 cm. Daily mean

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temperatures during this period steadily warmed from -2.2°C to 2.5°C, then dropped to freezing on March 24.

Similar conditions occurred at a second but more distant station at a similar elevation as the reported incidents (Noisy Basin Snotel, 1841 m, 30 km southwest or 26 km west). That station did not, however, record a loss of SWE or snow height during the period. It did show a similar diurnal melt-freeze cycle with a general warming trend (Figure 3). The total March 2020 precipitation at the two stations (89 and 76 mm respectively) represented 253% and 38% of the 1991-2020 median March SWE accumulation at the stations. The striking difference between the stations in March 2020 suggests that conditions at mid elevations (represented by Noisy Basin SNOTEL) were anomalously dry that month.

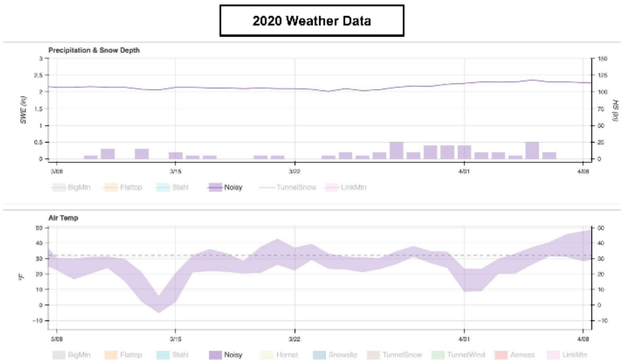


Figure 3: Precipitation (top, bars), snow height (top, line), and air temperature (bottom, band) at at Noisy Basin SNOTEL for March 8 to April 8, 2020.

Precipitation returned to the region on March 24-25. A warm, wet, and windy storm brought the snow/rain line up into the middle elevation band (1500-2000 m). Observations from the Flathead Range noted abrupt increases in storm snow totals between 1675 and 1825 m. The Emery Creek SNOTEL recorded 46 mm of SWE between March 25 and April 1, while the Noisy Basin SNOTEL reported 53 mm. Manual observations at study plots near Essex (Dave Hamre and Associates) measured new snow densities of 100 $g\ m^{-3}$ and 67 $g\ m^{-3}$ on March 31 and April 1.

### 2.2: 2023 Weather

For 2023, more site-specific weather data was available thanks to the installation of the Tunnel Ridge Snow and Wind Stations in 2021 (1800 and 2070 m). These stations sit 0.8 to 12 km from the sites where the reported incidents occurred. Tunnel Snow recorded only 8 cm of snow between March 11 and March 30, with HS dropping from 269 cm to 236 cm in the period. The Emery Creek and Noisy Basin SNOTELs recorded 36 and 18 mm of SWE during the same period, in storms March 13, 24 and 26. Both stations showed HS dropping 20 cm. The monthly SWE gain at the two stations of 56 and 48 mm of SWE represents 143% and 24% of the 1991-2020 medians. Again, mid-elevation conditions for the month were anomalously dry. All stations again showed a diurnal melt-freeze air temperature cycle, with an average low at Tunnel Snow of -8.5°C and the average high temperature of 1.1°C.

On April 1st of 2023, the Tunnel Ridge weather station recorded 33 cm of new snow over a 48-hour period. During the precipitation event, freezing levels hovered around 1500 m. Though not as dramatic as in 2020, observations noted increased snow totals at around 1825 m.

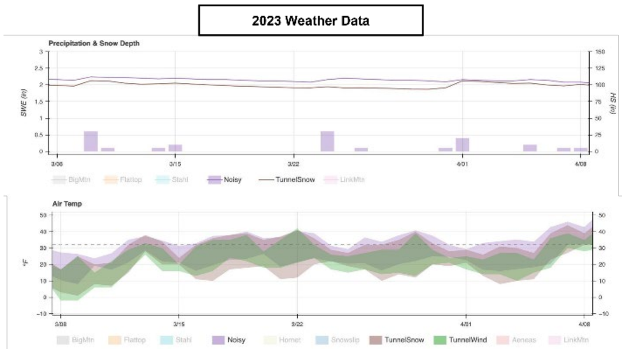


Figure 2: Precipitation (top, bars), snow height (top, line), and air temperature (bottom, bands) at Noisy Basin SNOTEL and the Tunnel Ridge weather stations for March 8 to April 8, 2023.

### 2.3: Snowpack Structure

In 2020, snowfall on March 24 buried a variety of snow surfaces that developed over the dry spell. These included melt-freeze crusts and small faceted grains. The warm storm brought rain to roughly 1800 m and several observations in late March noted wet snow to about that elevation. On higher, colder slopes, however, the near-surface facets survived, sitting on melt-freeze crusts at some sites.

Similarly in 2023, snowfall on March 30 buried a variety of snow surfaces that developed over the dry spell. Crown profiles and observations noted small faceted grains, in some cases resting on a melt-freeze crust.

The primary difference in structure between the two seasons were slab hardness and thickness. In 2020, the triggered slab ranged from soft to hard, and slab depths averaged 60 cm deep. In 2023, all reported avalanches were soft slabs with slab depths averaging 30 cm.

## 3. SUMMARY OF EVENTS

A narrative summary of each incident is below; additional details can be found in Table 1.

### 3.1: April 1, 2020:

Wahoo Creek: A group of three remotely triggered a D2.5 from ridgeline. This avalanche was triggered by boot penetration while a group of 3 skiers were ripping skins before their descent. The avalanche took out part of their skin track. The party included two FAC forecasters recreating.

Figure 5: An FAC forecaster investigating the crown of the April 1, 2020 Wahoo Creek incident.

Patrol Ridge: A group of two unintentionally triggered a large avalanche while ascending. The team spaced out to navigate a short, steep pitch to reach a ridgeline. When Skier One (a Transportation infrastructure avalanche worker) made it to the ridge and called out "clear," Skier Two triggered the avalanche just below their skin track. The avalanche took out part of their uptrack.

Crystal Creek: A group remotely triggered a Very Large (D3) avalanche from a ridgeline. It is unknown whether the group was skinning or transitioning to descend. The observation noted the group was standing above the slope, and the avalanche was triggered by one member of the group stomping a ski.

<u>*3.2: April 2-8, 2023*</u>:

Tunnel Ridge: A group of two triggered a large avalanche while skinning. The party - an FAC forecaster and an avalanche educator - was attempting to avoid a slab of wind-drifted snow and triggered the avalanche from the ridgeline. One member of the party was caught and carried a short distance.

Figure 5: Looking up at the crown of the slide triggered on Tunnel Ridge, April 2, 2023.

Wahoo Creek: A group of three riders intentionally triggered a small soft wind slab. After investigating the crown, one member of the group descended the bed surface and triggered a subsequent avalanche that stepped down below the bed surface of the intentionally triggered avalanche. The rider was caught and carried a short distance. The party was comprised of a forecaster, an educator, and an advanced recreationalist.

Crystal Creek: A snowboarder triggered an avalanche while backflipping off a large cornice. The rider was caught and briefly carried before regaining balance and riding off the debris. The group of three included a professional ski patroller.

South Dickey Creek: On April 8, the third rider in a group triggered and was briefly caught in a slide before skiing out.

| Date | Site | Event | Party Size | # Pro Work ers | # Caught | Travel Mode |
|---|---|---|---|---|---|---|
| 20200401 | Wahoo Creek | SS-ASur-D2.5 | 3 | 2 | 0 | Transition |
| 20200401 | Patrol Ridge | HS-ASur-D2 | 2 | 1 | 0 | Ascent |
| 20200401 | Crystal Creek | SS-ASur-D3 | U | U | 0 | Transition ? |
| 20230402 | Tunnel Ridge | SS-ASu-D2 | 2 | 2 | 1 | Ascent |
| 20230402 | Wahoo Creek | SS-ASu-D2 | 3 | 2 | 1 | Descent |
| 20230402 | Crystal Creek | SS-ASu-D2 | 3 | 1 | 1 | Descent |
| 20230408 | Dickey Creek | SS-ASu-D2 | 3 | U | U | Descent |

Table 1: Details of the 2020 and 2023 April Fools incidents. Reports of each incident can be found on the observations tab at flatheadavalanche.org

## 4. FINDINGS

We solicited and analyzed accounts from the parties involved in the incidents to identify any commonalities in the decisions leading up to the avalanche events. We also characterized the physical characteristics of the slopes where the avalanches occurred and the avalanche events themselves. Lastly, we reviewed the avalanche forecasts issued for the two days when six of seven incidents occurred to determine how accurately they described conditions and whether they provided useful travel advice.

<u>*4.1: Notable demographic and/ or decision-making commonalities*</u>

1. Of the seven groups involved in the incidents, five included professional avalanche workers. All groups with the exception of one were not working at the time. Three groups included multiple professionals.
2. Nearly all groups reported that one person voiced concerns or misgivings that were either ignored or delayed until a regroup location.
3. Several groups observed but ignored or mis-interpreted recent avalanche activity and collapses. In particular, parties mis-identified the avalanche hazard as a Storm Slab avalanche problem and underestimated the propagation potential of recently-formed slabs.
4. Four of seven of the groups were ascending or transitioning when they triggered the slides.

### *4.2: Common Physical Characteristics of the Events and Terrain*

1. Seven of seven avalanches occurred on north to east aspects.
2. Seven of seven avalanches occurred between 5900'-6500'.
3. Five of seven avalanches failed on slopes with slope angles 30-35 degrees
4. The FAC received no reports of incidents in the other two zones within its forecast region.

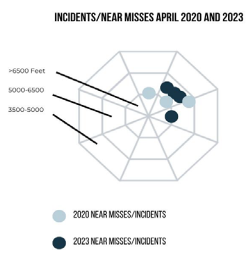


Figure 6: Aspect/ Elevation rose depicting the locations of the 2020 (light gray) and 2023 (dark grey) incidents.

### *4.3: Avalanche Forecast Review*

Archived copies of the forecasts for the two days are available at flatheadavalanche.org.

1. The April 1, 2020 forecast listed Persistent Slabs as the primary avalanche problem. Indeed, the forecaster listed the problem for the first time that day based on propagating test results reported in the Flathead Range the previous day.
2. The April 2, 2023 forecast listed Wind Slabs as the primary hazard. The Tunnel Ridge Wind site had recorded south-southwest winds of averaging 20 km h and gusting to 115 km h in the previous 48 hours.
3. The danger ratings of the two forecasts diverged, with the 2020 forecast rating upper elevations as Considerable. The 2023 rated the hazard as Moderate at both mid and upper elevations.
4. Both forecasts identified the potential size of triggered slides relatively accurately. The April 1, 2020 forecast was within a half step (D2.5 forecast vs. D3 triggered). The avalanche events on April 2, 2023 were all D2, which was the forecast size.
5. The avalanche events all occurred on the aspects identified by the forecasts as most dangerous. However, the April 1, 2020 product showed the hazard only at upper elevations (above 1980 m). All the reported events that day occurred at or below that elevation. The reported events on April 2, 2023 occurred within the elevation range identified in the forecast.
6. The travel advice included in both forecasts accurately warned users that conditions would get more complex at higher elevations and/or that triggered slides could propagate wider than expected. Of note, on both days the forecaster highlighted uncertainty around new/recent snow landing on weak, faceted snow.

## 5. DISCUSSION

Notable among the demographics of the parties involved is the high percentage of professional snow workers. The surprised parties included forecasters, educators, patrollers, and a technician for a railway forecasting program. Without demographic data for all parties in the backcountry on the days of the events, it is unclear whether avalanche workers were more involved in near misses that day, or, because it was late in the season, comprised an unusually high percentage of the user population. It is also unknown if other users were involved in unreported near-misses or accidents.

Regardless, the parties that included snow workers mis-identified the primary avalanche problem and applied travel techniques that were, in hindsight, inappropriate for the conditions (Statham et al, 2018). Similarly, only one of the two forecasts listed Persistent Slabs as the primary avalanche problem. Perhaps it seemed abrupt or unlikely to go from a long period of low hazard and an "open-season mindset" (Atkins, 2014) to a Considerable danger with a Persistent Slab avalanche problem more typical of mid-winter conditions.

Another factor may have been a sense that Persistent Slab avalanche problems in the region aren't typically reactive immediately after a storm, as they were in this case. Instead, they tend to develop gradually with incremental loading. That was more the case in 2020, when snowfall that buried the weak layer occurred over multiple days.

We attribute the inaccuracies in the forecasts and decision making to inertia due to a recency or availability bias (Tversky and Kahneman, 1973). That is, people tend to base decisions on the most recent or most easily recalled information. In this case, that might be conditions prior to the weak layer being buried and a slab forming, when conditions were relatively stable for an extended period. Similarly, an extended cycle of diurnal melt-freeze conditions feels more like spring and less like winter, when Persistent Slab avalanche problems are more common.

## 6. CONCLUSION

We conclude that extended periods of dry conditions in late winter could be highlighted for the potential to produce reactive avalanche conditions when snowfall returns and buries weak snow surfaces. The weak snow surfaces may be localized, as evidenced by the fact that no incidents were reported from the FAC's other two forecast zones. Sadly, these conditions may become more common. In the past five seasons, average precipitation during the month of March at the Noisy Basin SNOTEL has dropped from 182.3 mm (48-year mean) to 104 mm SWE (5-year mean).

Other regional avalanche centers have experienced similar cycles that involve multiple parties caught immediately or shortly after spring storms bury late season persistent weak layers. On April 16, 2020, the Utah Avalanche Center received reports of 31 triggered avalanches with four people caught and carried (Utah Avalanche Center, 2020). Most of these incidents involved freshly-buried near-surface facets above a melt-freeze crust.

Future avalanche forecasts could improve by effectively communicating similar types of events as the ones described. This would require anticipating conditions in order to overcome inertia and recency biases. Some suggestions and tactics for avalanche centers to try are:

1. Focus fieldwork by avalanche forecasters on identifying and mapping the presence of near-surface faceted grains during extended periods of dry weather.
2. In public messaging, highlight the effects of extended periods of dry weather prior to and during a loading event.
3. Highlight propagation potential and uncertainties in the Bottom Line of the forecast.
4. Broaden the distribution (elevation and aspect) of the avalanche problem immediately following a loading event on a persistent grain type.
5. List Persistent Slab immediately following a loading event on a persistent grain type, or specifically address the propagation propensity of slabs with recent storm snow sitting on a persistent weak layer.

We would like to expand this research to include accidents and near-misses during late season Persistent Slab problems from other regional avalanche forecast centers to identify similarities or differences in demographics of those involved. We would also like to investigate possible thermal or mechanical properties of the slabs – such as rapid settlement – that might increase their sensitivity to human triggers.

## ACKNOWLEDGEMENTS

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