A VERY LARGE WET SLAB AVALANCHE SURPRISED US, WHICH IS FUNNY BECAUSE THE SAME THING HAPPENED 31 YEARS EARLIER

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ABSTRACT: Wet slab avalanches at Alyeska Ski Resort in Girdwood, Alaska, have historically caused significant infrastructure damage and are among the most unpredictable. Our literature review, spanning decades of observation and research, illustrated that the avalanche industry has identified common ingredients of wet slab avalanches and emphasized that many of these ingredients may be present without an avalanche occurring. Reardon and Lundy's 2004 wet slab conceptual model provided a helpful framework for analyzing these forecasting challenges. We present a case study of two very similar, significant wet slab avalanches at Alyeska, separated by 31 years. In April of 2024, a very large, unexpected wet slab (R4, D4) necessitated extensive terrain closures and operational impacts at Alyeska Resort. A snowcat grooming at night triggered the avalanche that started in closed, gated terrain and flowed across multiple groomed runs. Despite its magnitude, the avalanche caused no injuries or damage to infrastructure. Looking back to April of 1993, a nearly identical avalanche occurred. In an attempt to make sense of the 2024 event, we compared the snowpack and weather for the 1993 and 2024 avalanches. In addition, we applied the wet slab conceptual model as a valuable tool to qualify the wet slab hazard leading up to both the 1993 and 2024 avalanches. Finally, we discuss updating our team's collective mental model for forecasting wet slabs. We gained a more nuanced understanding of monitoring a base area stream gauge and recognizing the presence of a hydraulic barrier within the snowpack. This analysis also highlighted a heuristic trap that we believe is unique to ski area avalanche mitigation. The recognition of which may help shift our hazard reduction mindset for the future. We hope our insights may be useful to practitioners who may be dealing with wet slab avalanches more frequently in a warming climate, or in another 31 years.

KEYWORDS: Wet slabs, operational forecasting, crusts, mental models.

1. INTRODUCTION

In the early morning of April 28, 2024, a D4 wet slab occurred at Alyeska Resort in Girdwood, Alaska, in a gated area known as Peel Off. The avalanche was large, unexpected, and hit a snowcat with the driver on board. The avalanche was triggered by the snowcat while grooming an adjacent run. It hit and carried the snowcat about 9 m (30 ft), with no harm to the machine or driver. The avalanche was up to 325 cm (128 in) deep and approximately 300 m (1,000 ft) wide. The debris crossed multiple named ski runs with a run distance of about 940 m (3084 ft) horizontally. The bed surface was an early season crust that formed after a wet storm around Thanksgiving (November 23, 2023) with a persistent weak layer of near-crust facets. The avalanche led to extensive terrain closures, including a retreat from the upper mountain for the remaining three days of the season.

Industry consensus is that forecasting for wet slab avalanches is difficult and less well understood when compared to dry snow avalanches (Reardon and Lundy, 2004; Baugher and Birkeland, 2014; Guy and Peitzsch, 2023). The Alyeska forecasting team agrees, and historically wet slab avalanches at our ski area present the most challenging forecast conditions and occasionally the largest avalanches of the season due to the high volume and flow pattern. Wet slab avalanches occur due to free water interacting with specific snow stratigraphy in non-linear and spatially heterogeneous ways (Peitzsch et al., 2008; Mitterer and Schweizer, 2014). As the volumetric liquid water content in the snow increases, fracture propagation propensity and strength of snow rapidly change, causing instability (Mitterer and Schweizer, 2014; Reiweger et al., 2016). In addition, hydraulic barriers in the snow stratigraphy such as crusts or capillary barriers cause free water to pool or drain downslope parallel to the snow surface in the snowpack (Wakahama, 1975; Miller et al., 2023). As water flows along these barriers, the liquid water content in that layer can quickly increase, leading to rapidly decreasing weak layer strength (Schlumpf et al., 2023; Birkeland, 2025). Furthermore, as Moderow et al. (2024) and Schauer et al. (2024) explored, crust layers and associated crust-adjacent weak layers pose significant problems for avalanche

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forecasting during dry snow conditions. Wet snow conditions pose an even greater challenge because it is difficult to determine whether a crust will form a hydraulic barrier or not (Peitzsch et al., 2008) and the ingredients for a wet slab may only exist together for hours, not the days or weeks that dry slab instability may linger (Birkeland, 2025). This makes a very difficult spatiotemporal forecasting problem.

In our analysis, the Alyeska forecasting team found Reardon and Lundy's 2004 conceptual model for wet slab avalanches a valuable tool for synthesizing the variables leading to wet slab release (Reardon and Lundy, 2004; Fitzgerald, 2014). Their conceptual model for anticipating wet slab release focuses on three questions:

1) Is there a slab? 2) Is there a water factory? 3) Is there "funny business" below the slab?

In this paper, we discuss how this avalanche fits into the wet slab conceptual model and share our experience with wet slab forecasting in the operational environment. Additionally, we describe an avalanche nearly identical in size and timing in the same location that occurred in April of 1993. In doing so, this paper summarizes the weather and snowpack conditions that led to these avalanches, discusses variables unique to Alyeska's low elevation and northern latitude, and reviews lessons delivered to the Alyeska Ski Patrol.

Figure 1: Aerial photo of the April 2024 Peel Off avalanche.

Figure 2: April 2024 avalanche crown, ski patroller for scale.

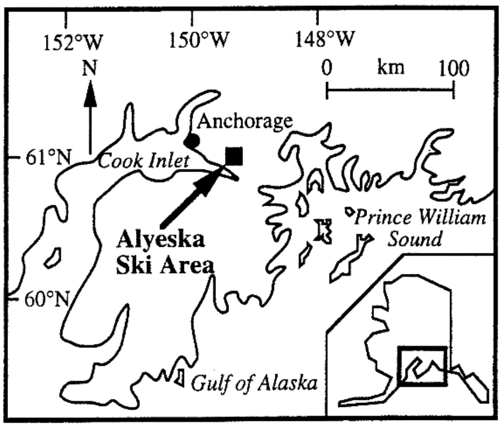

Figure 3: Location of Alyeska Resort (Mock, 1996).

Figure 4: Avalanche debris at the toe of the runout, ski patroller for scale.

2. SITE DESCRIPTION

Alyeska Resort is in the western Chugach Mountains at latitude 60.96° north, approximately 50 km (31 miles) east of Anchorage on the north side of the Turnagain Arm of the eastern Cook Inlet. Sitting approximately 5 km (3.1 miles) north of the Turnagain Arm and approximately 30 km (18.6 miles) west of the Prince William Sound of the Gulf of Alaska, Alyeska is typically a maritime avalanche climate (Mock, 1996). The ski area base is at approximately 76 m (250 ft) elevation, and the highest chairlift at Alyeska reaches approximately 838 m (2,750 ft) of elevation. The ridgeline of the headwall above the ski area is between 915 m (3,000 ft) and 1,218 m (3,997 ft). The main ski area sits in a west-facing bowl, with the steep northerly face of Mt. Alyeska as part of the skiable terrain when conditions allow. Five weather stations track meteorological data relevant to the ski area operation, with a dataset going back to 1970. The Summit station is on the headwall ridge at 1,097 m (3,600 ft), Max's Mountain station is further west on the bowl ridge at 1,036 m (3,400 ft), the Top of Quad station is at the top of the highest lift at 838 m (2,750 ft), Midway station is at 518 m (1,700 ft), and the Base station is at 76 m (250 ft).

3. WEATHER AND SNOWPACK SUMMARY

Two large storms in early November started the 2023-24 winter season off strong. From November 5th to the 24th, Alyeska received 24.05 cm (9.47 in) of SWE and 302.26 cm (119 in) of snow at the Top of Quad weather station at 838 m (2,750 ft), making the total height of snow 124.46 cm (49 in). Over Thanksgiving weekend, a warm and wet storm from November 22nd to the 25th produced rain to 1,220 m (4,000 ft) across the region. As temperatures dropped below freezing again on the 26th, a stout 15 cm (6 in) rain crust formed that became known as the Thanksgiving Crust (TGC). This crust would eventually become the bed surface for the Peel Off avalanche in April. After the crust formed, late November and early December storms buried the TGC under multiple feet of snow, and near-crust facets formed during an extended clear spell. Natural avalanche cycles occurred on that weak interface, as well as multiple notable avalanches released during mitigation work at the ski area.

Mitigation on December 11th produced multiple avalanches to the TGC. One such avalanche occurred with a 0.9 kg (2 lb) hand charge air blast in steep, gated access terrain, releasing a D2.5 soft slab with a 0.5-1 m (2-3 ft) crown. Another hand charge air blast in a different steep, gated access area released 110 cm (3.5 ft) down to the TGC on December 13th. A pulse of weather on December 17th initiated a widespread natural cycle with multiple recordable natural avalanches and extensive mitigation results. The last recorded avalanche in the ski area that released to the TGC was part of this cycle, when a rarely skied, steep, gated access chute produced a natural D3 avalanche with a crown 1.8-2.4 m (6-8 ft) deep. Notably, a natural avalanche also occurred in the Peel Off start zone during this December 17th cycle, but it was confined to new snow instability. Control work in the same zone on December 24th included an air blast that produced a 0.3 m (1 foot) soft slab in the new snow.

After weeks of tracking the deep persistent problem, the nearby Chugach National Forest Avalanche Center (CNFAC) removed the TGC and near-crust facets from their forecast problem list on December 30th (CNFAC, 2023). The TGC and near-crust facets dropped off the Alyeska Ski Patrol operational problem list on January 9th, after not seeing any additional results failing to that layer since December 17th. The TGC dormant period lasted through January and did not reactivate until the April wet cycle.

April 20th marked the first spring day with the low temperature above freezing at the Top of Quad weather station. This lasted for two days from April 20th to April 21st, with the low temperature freezing again on April 22nd. Highs were above freezing for this period. Lows were in the freezing range and evening crust formation continued until the morning of April 28th in both the Alyeska and the CNFAC weather records. April 28th, the evening of the Peel Off avalanche, was the first night not to reach freezing ambient temperatures for the low at the 830 m (2,750 ft) Top of Quad weather station.

4. AVALANCHE SUMMARY

The wet slab avalanche occurred at 2:00 a.m. on April 28th, 2024, as a snowcat was grooming the southern boundary of normally open terrain and triggered a wet slab in the adjacent gated area known as Peel Off. A small portion of the debris flow hit the cat and carried it 9 m (30 ft). The operator and machine were unharmed. The operator reported struggling for traction while free grooming. The operator stated that before the release, "the snow was very soft, and tracks were spinning." He described "crabbing" uphill, meaning one track was less throttle or stationary while the other track made slow progress uphill. In other words, a 9,000 kg (20,000 lbs) machine was sawing through the snowpack adjacent to the start zone.

The avalanche was classified as a WS-AKu-R4-D4-O. The starting elevation was 740 m (2,428 ft) and the debris came to rest at 440 m (1,444 ft), dropping 300 m (984 ft) vertically and traveling 940 m (3,083 ft) downslope. The avalanche occurred in a closed gated area but crossed multiple groomed runs that were open to the public during the operational day on the 27th. With a 366 m (1,200 ft) wide crown, an average depth of 2.44 m (8 ft), distance from crown to stauchwall of 182.88 m (600 ft), and an estimated snow density of 280 kg/m^3, the volume of start zone debris was calculated at 163,319 m^3 and the slab mass at 45,729 t using the start zone method of the Avalanche Destructive Size Estimator tool developed by Peitzsch et al. (2026).

The maximum depth of the crown was 325 cm (10.5 ft). The aspect was due west, and the maximum slope angle was 35°, while the average was 18°. The bed surface was the stout TGC formed on November 23, 2023, near the bottom of the snowpack (Figure 5).

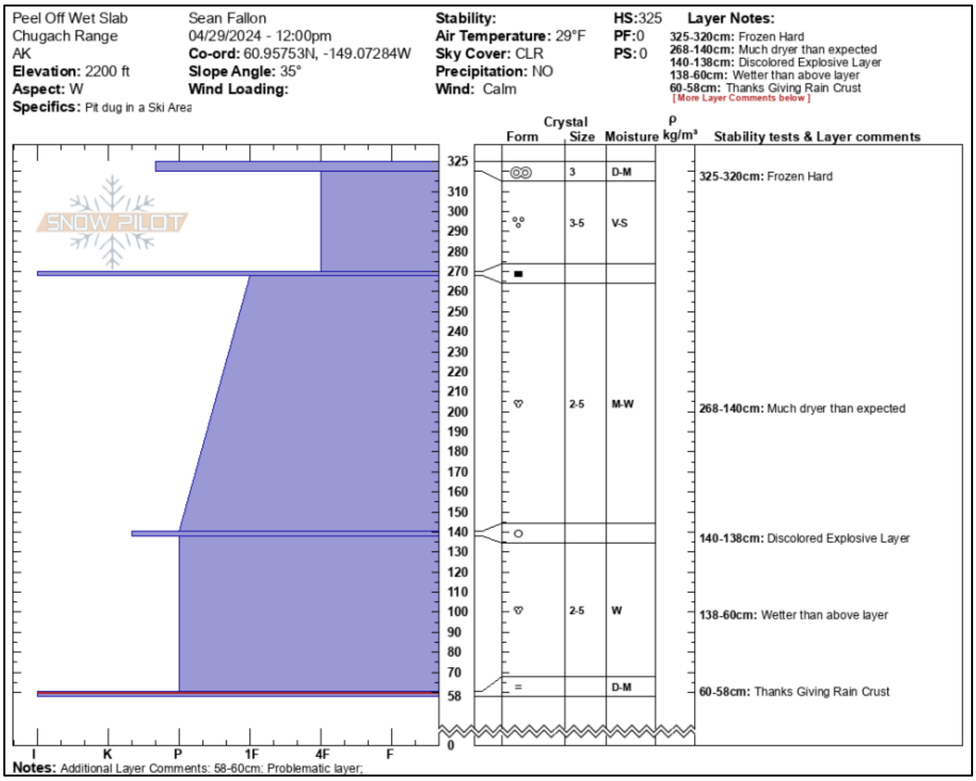

Figure 5: April 2024 Peel Off crown profile. The near-crust facets observed earlier in the season adjacent to the TGC were not identifiable in the crown profile.

5. REGION WIDE WET SLAB CYCLE

The Peel Off avalanche occurred as part of a region-wide cycle of large wet slab avalanches beginning on April 22nd in Portage, approximately 32 km (20 miles) to the southeast. On April 24th, a wet slab released near Girdwood on Penguin Ridge, and then a very large wet slab released on Orca (two ridge lines west of Alyeska) on the 26th. On the 27th, a large wet slab released in Johnson Pass, 38 km (23 mi) south of Alyeska.

6. HISTORICAL CONTEXT

This path released at least one similar wet slab in the recorded history of Alyeska Resort. On April 25th, 1993, at 7:30 pm, approximately two hours after closing the ski area for the season, a very large wet slab was triggered by a wet loose avalanche from the slope above (Figure 6 and Figure 7).

7. COMPARING THE 2024 AND 1993 AVALANCHES

Reardon and Lundy's 2004 wet slab conceptual model helped organize the variables that contributed to both events.

7.1 Was there a slab in 1993?

Although the recorded details of the snowpack in 1993 are less clear, sufficient snow depth to act as a slab was present, as the total depth at the Midway station was 340 cm (134 in) on April 1st.

7.2 Was there a slab in 2024?

Snow depth at the Midway station reached a maximum of 315 cm (125 in) on April 10th, and in the Peel Off start zone, 244 cm (8 ft) of snowpack was on top of the TGC and associated near-crust facets. (Figure 5)

7.3 Water factory in 1993

On April 20th, 1993, it snowed 53 cm (21 in) for 4.97 cm (1.96 in) SWE at the Top of Quad station and 17.78 cm (7 in) for 2.18 cm (0.86 in) SWE at the Midway station. From April 18th to April 28th, Midway lost 56 cm (22 in) of total depth, flushing the snowpack with water. Starting April 22nd, it barely froze, hitting -0.5°C (31°F) for a short period at Midway. The 24th and 25th did not freeze at all, in step with the established “three days no-freezing” guideline, leading to unstable wet snow conditions (Tremper, 2001).

Figure 6: 1993 start zone image.

Figure 7: 1993 runout image.

7.4 Water factory in 2024

On April 10th, 2024, it snowed 48.26 cm (19 in) for 4.44 cm (1.75 in) SWE at the Top of Quad station and 43.18 cm (17 in) for 3.73 cm (1.47 in) SWE at Midway station. From April 18th to April 28th, at Midway station, 50.8 cm (20 in) of snowpack melted, releasing water into the snowpack. The week leading up to the avalanche in 2024 was slightly more complicated but warmer overall. There were three days above freezing from April 19th to April 22nd at Midway station, with a maximum low temperature of 3.8°C (39°F), followed by three nights that hit 0°C (32°F). However, from the 25th to the 27th it did not freeze, making 2024 also in step with Tremper’s three days above freezing guideline (2001). Additionally, on the evening of the 27th, the freezing elevation climbed above the Top of Quad for the first time, significantly increasing the area of melting snowpack.

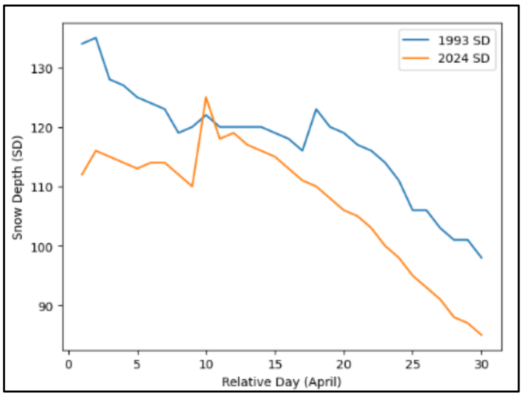

Figure 8: Midway snow depth 1993 vs. 2024.

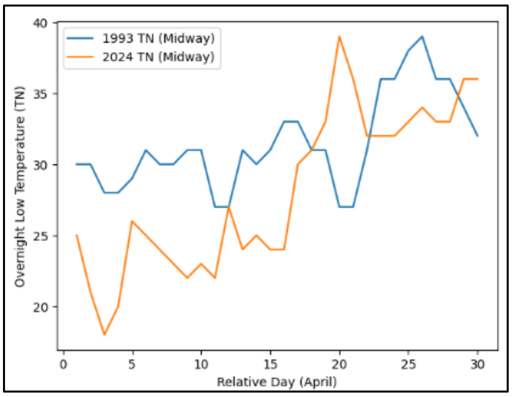

Figure 9: Midway low temperature 1993 vs. 2024.

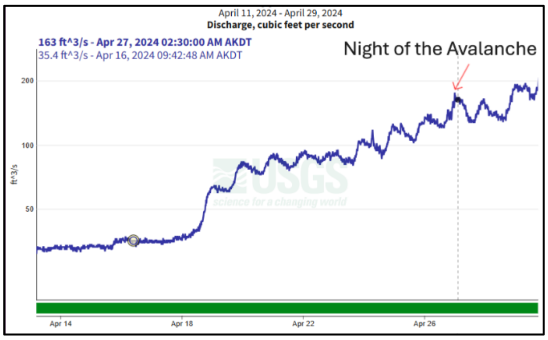

Figure 10: USGS Glacier Creek hydrograph April 11-29

Figure 11: Another 2024 Peel Off aerial image.

7.5 Funny stuff in 1993

Jim Kennedy, the Alyeska Snow Safety Director at the time, wrote in his season-end report, “On December 17th we had a freezing rain event on what was the surface of the snowpack. This ice lens did not break down and remained in the pack throughout the rest of the winter or until spring arrived.” This indicates the presence of a crust and associated near-crust facets that contribute to future instability. Kennedy goes on to describe the wet slab cycle of 1993, stating, “On April 18th the freezing rain that had fallen in December was about to let us know that our suspicions had been correct.” He goes on to describe a series of dry avalanches that triggered wet avalanches stepping down to the December 17th, 1992 crust (Kennedy, 1993).

7.6 Funny stuff in 2024

The previously discussed TGC and associated near-crust facets formed in November 2023 and remained intact near the bottom of the snowpack until it became the bed surface for the April 2024 wet slab (Figure 5).

7.7 Comparison summary

Both snowpacks were sufficiently deep to act as large slabs; both had hydraulic boundary layers in the form of a stout rain crust deep in the snowpack; both had associated problematic weak layers on top of the crust, and both seasons had fresh, significant snowfall to establish a water factory. The 2024 snowpack had significantly more water available to melt. Both seasons had approximately three days above freezing immediately prior to the slides, but 2024 had more days that were warmer and a more abrupt change (Figure 9). The night of the 2024 event was the first time the Top of Quad station recorded above freezing ambient temperatures, greatly increasing the area contributing water to the snowpack, causing an increase in liquid water content in the snowpack and overwhelming the existing drainage. This is reflected in the Glacier Creek stream gauge (Figure 10). Finally, during both seasons, large (size 3+) wet avalanches were observed either at the ski area (1993) or in the adjacent backcountry (2024) in the days prior to the Peel Off avalanches.

8. DISCUSSION

8.1 Operational challenges unique to Alyeska Resort

Unique operational challenges exist at Alyeska that contribute to the difficulty of forecasting an event like the Peel Off wet slab. These include a sea-level ski area, proximity to a large body of water, the northern latitude, and the overhead avalanche hazard from the ridge above the ski area, any of which alone adds complexity. The base area at Alyeska is 76 m (250 ft) above sea level, while the Top of the Quad weather station is at 838 m (2,750 ft) and the top of Max’s ridgeline is at 975 m (3,200 ft). This is a low elevation when compared to the US Mountain West, where many ski areas are at the 1,800 m to 3,000 m (6,000 to 10,000 ft) elevations. The elevation and Alyeska’s proximity to the Gulf of Alaska create challenging situations with rain-on-snow events, crust formation, and rapid warmups that contribute to instability in the snowpack. In addition, Girdwood’s high latitude means that sunlight in December is scarce, while in April there is an abundance of sun. On April 27th, 2024, sunrise was at 5:55 am and sunset was at 9:53 pm for a total of 15 hours and 58 minutes of daylight. Civil twilight lasted until 10:45 pm. A clear sky for all the daylight hours on the 27th led to significant solar heating. The sun was high in the western sky into the evening hours of the 27th and had a nearly perpendicular angle to the Peel Off start zone. The extended daylight hours in April add a longer duration solar load compared to a lower latitude ski area. Much of the steep overhead terrain is mitigated with 105 mm howitzers that initiate avalanches in the upper start zones. Typically, the avalanche flow disturbs most of the downhill skiable zones with debris. A combination of frequent howitzer missions and a typically stable maritime snowpack allows us to safely ski this terrain. The Peel Off start zone is partially protected from overhead avalanche runout by a cliff band. Alyeska avalanche occurrence records for the 2023-24 season show that the weak layer adjacent to the TGC was likely undisturbed in this area during its formation cycle in December, allowing it to remain intact until the wet slab released in April. Moving forward, we are using more explosives in this zone and digging more pits throughout the ski area during the spring melt regime to track the existence of hydraulic barriers and monitor water moving through the snowpack.

8.2 Updating wet slab mental model

This event presented an opportunity to clarify details in our mental model that were previously based on some broad assumptions (Maguire et al., 2023). Post-incident, we observed a snowpack with stratigraphy that was drier than expected and had established frozen drainage columns. This incident helped clarify that if the stratigraphy contains a hydraulic boundary layer, the snowpack does not need to be isothermal or fully saturated before a wet slab occurs. Rather, identifying an increase in the liquid water flow rate compared with what the snowpack has already adjusted to, and the presence of hydraulic barriers, is critical for knowing when to reduce exposure. The USGS stream gauge at Glacier Creek is 1.6 km (1 mi) away from the base of the ski area and can be a useful tool for indicating an increase in liquid flow in the snowpack. The stream gauge appears to show melt rate in greater detail than observing the height of snow decrease. An acknowledged limitation of our instrumentation is the absence of measurement of net radiation in the snowpack. We do have incoming solar irradiance instrumentation at our Summit station, but do not measure outgoing radiation to isolate impact to the snowpack.

After three days above freezing, the decision making gets very tricky. Historical observations suggest that the snowpack can be very resilient to above freezing temps and rain. Many seasons, Alyeska does not see wet slab activity during ski area operations, and it is rarely widespread.

In 2024, between the 18th and 27th, it was above freezing for a total of six days, with three days that barely froze. If established drainage pathways through the hydraulic boundary layer are present, the snowpack may be stable. However, the likelihood of wet slab increases when the flow rate surpasses the existing capacity of the snowpack plumbing, and downslope flow occurs along the hydraulic boundary, as was the case on the evening of the 27th 2024. Moving forward, we will focus on the hydraulic boundary layer for saturation of associated weak layers. The presence of a hydraulic boundary layer in combination with an increase in the liquid flow rate should be cause for a conservative mindset shift.

Finally, the authors believe we fell into a heuristic trap related to avalanche forecasting at a ski area. Normally we discredit much of the avalanche activity in the adjacent backcountry because that snowpack is ‘wild’ or natural and not affected by skier compaction and explosives. However, wet avalanche hazard seems to be relatively unaffected by a season of explosive mitigation and skier compaction, as highlighted in the 2005 Arapahoe Basin case study where a mogul-filled slope released a wet slab (Hartman and Borgeson, 2008). If the ingredients described by the wet slab conceptual model are present, it doesn’t matter if a slope has moguls or saw dozens of explosives; it could potentially still avalanche, and we need to be mindful of the adjacent backcountry avalanche activity.

9. CONCLUSION

The wet slab avalanche of 2024 was a 30-year event that updated the Alyeska forecasting team's mental model. It reminded us that the stories of earlier forecasters aren’t merely “big fish tales” but possibilities to consider in the present. Although no person or infrastructure was harmed, this event was a significant near-miss that helped us highlight the variables making such a large avalanche possible. It’s impossible to know if that slope would have avalanched had a snowcat not been sawing through the snowpack. At Alyeska, we have rain-on-snow events with associated crusts nearly every season, followed by significant spring solar radiation. Likely the ingredients capable of producing that avalanche have existed many times in the past, yet no avalanche occurred, because there wasn’t an extra stress/trigger applied at exactly the right moment. As witnesses to this historic wet slab, we are grateful for the experience, have clarified our mental model, and will be diligently observing with a refined focus.

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