APPLICATIONS FOR RADAR AVALANCHE DETECTION AT NORTH AMERICAN SKI RESORT OPERATIONS INTERNATIONAL SNOW SCIENCE WORKSHOP 2026, WHISTLER, CANADA

Reid Nolan[1]*, Nicole Koshure[2], and Tim Haggerty[3]

1 Kirkwood Ski Patrol, Kirkwood, CA, USA
2 Blackcomb Ski Patrol, Whistler BC, Canada
3 Whistler Ski Patrol, Whistler BC, Canada

ABSTRACT: Automated avalanche detection systems (AADS) have been utilized by a wide range of operations but have only recently been adopted by North American ski resorts. We look to share our experiences incorporating Radar Detection into a ski resort operation and highlight some of the unique benefits and challenges of using detection in an environment where high skier volume, snowcat traffic and other resort infrastructure is present in the monitoring area. This poses a challenge to accurate monitoring not found in many past radar installations where the area being monitored is more remote and the avalanche size to impact the resource being protected is typically much larger.

KEYWORDS: Avalanche Detection, Avalanche Forecasting, Radar, Automated Avalanche Detection Systems (AADS), Ski Resort, Avalanche Risk Management

1. INTRODUCTION

An Automated Avalanche Detection System (AADS) was tested at Whistler Blackcomb and Kirkwood Mountain Resort over the course of the 2026 season to examine the performance and feasibility of incorporating radar detection into a ski resort avalanche mitigation program. Both locations used the Gravimon Avymonster radar (Gravimon, 2026). This doppler radar can detect all sizes of avalanche activity in all weather, lighting and visibility conditions.

The use of an automated avalanche detection system, such as the Gravimon Avymonster radar, provides highly valuable insight into past and current avalanche activity when visual observations are interrupted. This can be due to a number of reasons such as inadequate visibility, additional snowfall obscuring past results or a lack of safe access to a position where results can be observed during storm events.

Prior operational studies have shown that remote avalanche detection can support avalanche professionals during poor visibility, verify artificial avalanche releases, and provide occurrence data for avalanche danger assessment (Meier and Lussi, 2010). More recent Doppler-radar deployments have demonstrated continuous all-weather detection, support for RACS verification, and the importance of site-specific calibration and sensitivity settings (Walberg et al., 2024; Stähly et al., 2024).

Key benefits of Radar in Avalanche Forecasting include:

- 24/7 all-weather monitoring with the ability to track activity overnight and during heavy snowfall, dense fog and blowing snow.
- Real-time event detection, signaling a forecaster during the exact moment an avalanche releases and connecting natural avalanche triggers to specific real-time weather changes.
- Provide advanced dynamic data on speed, start zone, flow, runout zone and information to help calculate the size and destructive potential of an avalanche.
- Remote spatial mapping of larger ranges in a single pass with the ability to locate avalanche debris fields by analyzing surface changes and provide insight into whether natural avalanches are occurring on predicted aspects and elevations.
  Verification of naturally and artificially triggered avalanches in connection with Remote Avalanche Control Systems (RACS) (Stähly et al. 2024).

* *Corresponding author address:*
Reid Nolan, Vail Resorts
Kirkwood Mountain, CA 95646
Email: Rnolan@vailresorts.com

https://doi.org/10.15788/1790099190

2. SYSTEM AND INSTALLATION DETAILS

2.1 Radar Details

The system utilizes pulse-Doppler radar technology to detect moving targets by tracking shifts in radio wave frequency (Stähly et al. 2024). It consists of two primary components: the radar head and a dedicated communications module. Its compact footprint and low power consumption enable flexible installation options, making it easy to relocate the unit across different monitoring sites throughout the season.

A video camera is integrated directly into the radar head to automatically record each detected event. The radar unit has an operational range of up to 5 km and features an expanded aperture angle of XX° horizontally by XX° vertically, providing enhanced downward visibility.

System sensitivity and signal filtering are fully customizable in software to align with specific operational requirements (Gravimon, 2026). While the radar can detect small volumes of moving snow, high sensitivity in an active resort environment can trigger false positives from skiers, snowcats, or nearby lift infrastructure. To mitigate this, proprietary algorithms fine tune the filtering to match the unique background noise profile of each site.

Upon detecting an avalanche, the system sends immediate alerts via email, SMS, or push notification. Users gain instant access to both video footage and an animated representation of the radar return that illustrates signal density and plots the avalanche's primary track. The duration, speed, run length as well as the starting and ending elevation are displayed

2.2 Kirkwood

The radar site was selected to monitor a series of highly active avalanche paths primarily mitigated using artillery (Figure 1). Starting zones of the avalanche paths being monitored are located in a permanently closed area. The lack of skier compaction typically leads to the formation of a more complex snowpack creating a more demanding environment for avalanche forecasting. The average distance from the radar head to the paths being monitored was 1.5 km. In total, the system monitored 0.75 km² of terrain.

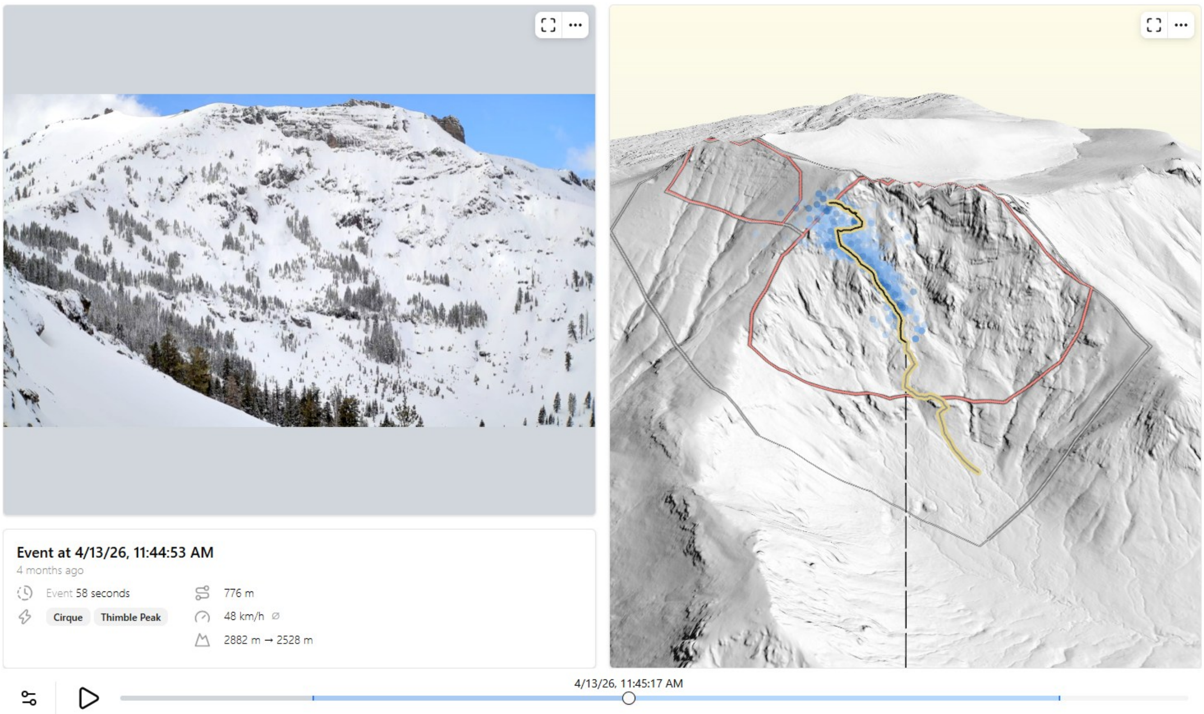

Figure 1: Example of radar output. The camera and animation are both synced to the time slider.

The targeted avalanche paths feature an average vertical drop of 350 m and are capable of producing avalanches up to size 3.5. During multi-day loading events, extended periods often pass without visual observation of natural or artificial avalanche activity. Furthermore, continuous snowfall following mid-storm avalanche activity regularly obscures even large avalanche debris. This gap in avalanche occurrence data reduces forecaster confidence while reopening terrain.

Following installation, adjustments to radar sensitivity were made to reduce the potential for false positives to be triggered by equipment or humans travelling in the monitored area while still reliably detecting small size 1 avalanche occurrence.

2.3 Whistler

The radar unit was mounted to the side of the Whistler Village Gondola station to monitor Whistler and Glacier Bowl (Figure 2). The average distance from the radar head to the paths being monitored was 1.45 km. In total, the system monitored 1 km² of terrain. The targeted avalanche paths feature an average vertical drop of 200-300 m and are capable of producing avalanches up to size D3.5.

Figure 2: Camera view of Glacier Bowl from Gravimon unit located on Whistler. Right side of image shows the Peak zone rockfall.

This installation location was selected to monitor some of our largest avalanche paths that affect groomers and the general public. We are able to conduct avalanche mitigation in these two large bowls in whiteout conditions, with limited visibility. We can often only confirm results in these bowls by our avalanche technicians entering the bowls and exposing themselves to the remaining hazard.

We were able to confirm natural and explosive triggered avalanches from size 1-3 during this time. As a forecaster, the ability to see the exact timing of natural avalanche cycles is invaluable when assessing the avalanche hazard and managing the exposure to public and staff. For instance, groomers on the night shift are exposed to this terrain. Notification of the first size 1 avalanche detected in this terrain allows the forecaster to close the area to the staff before the hazard potential grows to size 2 during storm cycles, while still maximizing operational efficiency.

In this location we were able to adjust the sensitivity to see staff and guests moving through terrain displacing snow. Future applications may include the use of radar systems to help clear the zone of effect before commencing avalanche mitigation work or employing the use of a RAC.

2.4 Blackcomb-Lakeside

The installation location was selected to monitor a series of south facing avalanche paths that can be triggered naturally due to solar warming, especially during the late spring operating season. Because the specific radar unit we were using had a 40 degree view angle we needed to mount the radar unit further away. The radar was mounted at the bottom of Harmony Chairlift on Whistler Mountain and shot across the valley towards Lakeside Bowl on Blackcomb Mountain (Figure 3). There was an average distance of 4.2 km from the radar head to the paths of interest with a total of 2.5 km² of terrain in the monitored area.

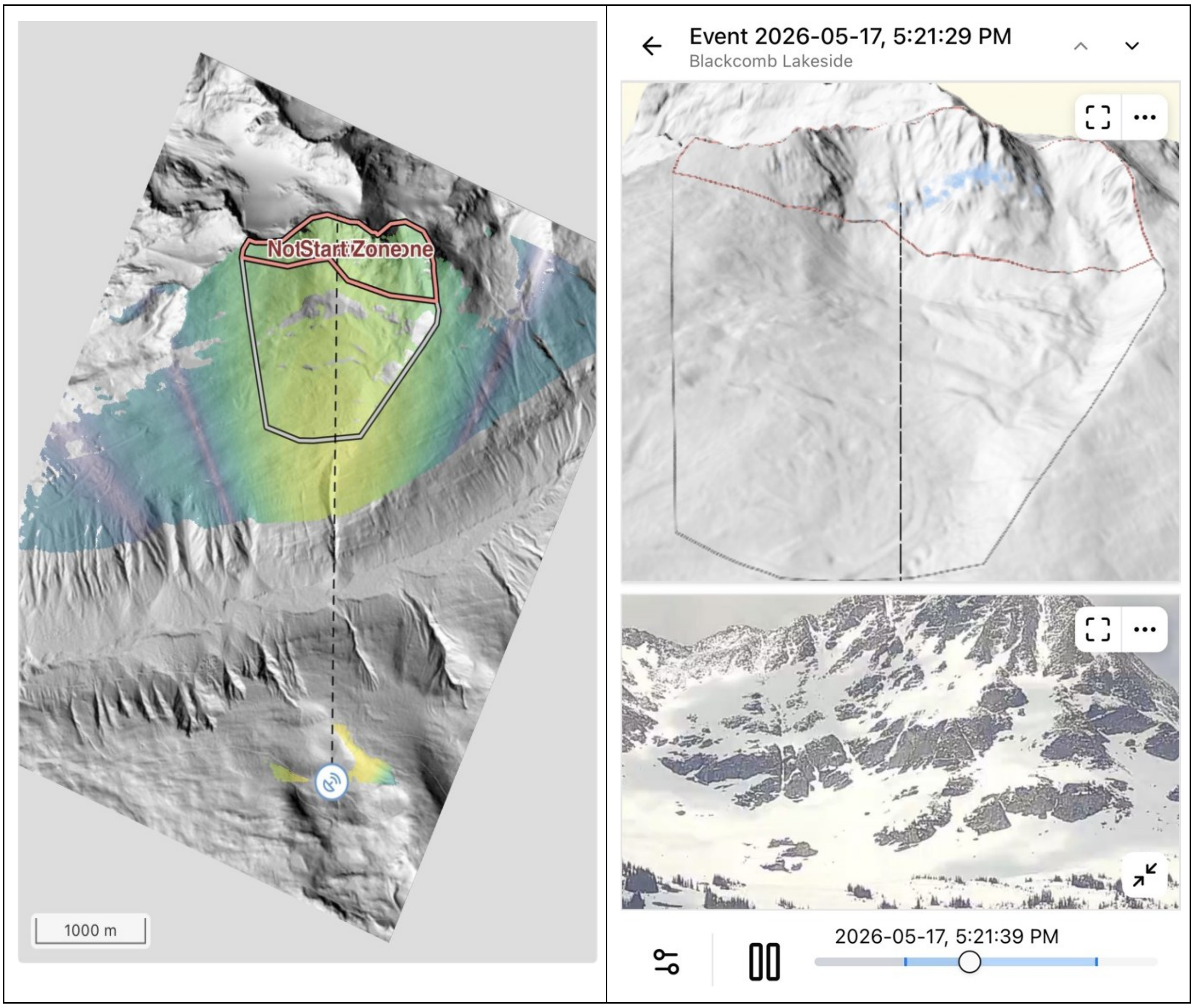

Figure 3: Radar unit shooting 4.2km across the valley to monitor Lakeside Bowl (left) and Detection of Wet Loose avalanche event (right)

The avalanche paths being monitored in Lakeside have a vertical fall of 180-350m and can produce avalanches up to D3.5 in size, especially during late spring wet slab events. During typical solar warming events following a recent storm cycle or in late spring we see on average D1-D2 wet loose activity. It is this natural wet loose activity triggered by solar input that causes us to close this terrain to the public. This requires the forecasting team to continually monitor this terrain for indicators of increasing instability such as: natural snow balling or pinwheeling; notable water flow along rocks and cliff faces; and, the breaking down of surface melt freeze crusts.

2.5 Blackcomb -Showcase

The installation location was selected to monitor a series of avalanche paths along a corniced ridge line which makes up the Horstman Peak control route (Figure 4). These paths affected the Showcase Chairlift work site on the Horstman Glacier on Blackcomb Mountain. There was an average distance of 450-625m from the radar head to the paths of interest with a total of 0.15 km² of terrain in the monitored area.

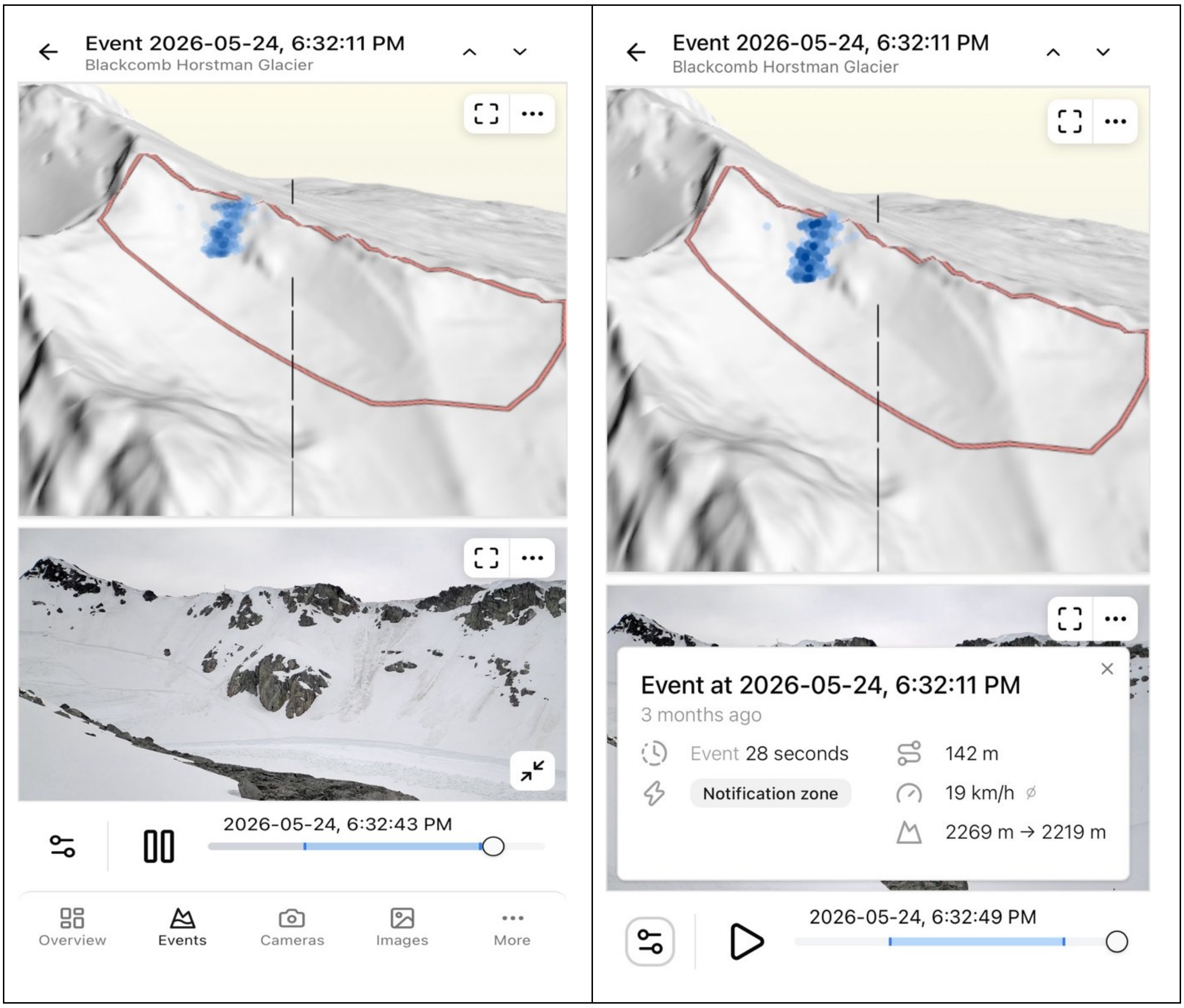

Figure 4: Radar Detection of Wet Loose avalanche at the Showcase worksite

The avalanche paths being monitored along the Hortman Peak control route have a vertical fall of 100-200m and can produce avalanches up to D3 in size during large storm events and when a persistent weak layer is present. Natural cornice failures during late spring warming events are also a concern, and were the primary trigger being monitored by the Radar unit above the worksite along with wet loose, wet slab and glide crack events. Secondary to avalanche activity was the concern for rockfall out of the unsupported ridge line slopes as the winter snowpack continued to melt. This terrain has become increasingly unstable due to accelerated glacial recession of the Horstman Glacier.

3 APPLICATIONS AND PERFORMANCE

3.1 Detection during storm events

The system demonstrated high reliability across all weather conditions throughout the season, with no false positives observed from high intensity precipitation or wind-transported snow (Table 1). During a single 16-hour storm window characterized by over 1 meter of new snowfall and sustained winds exceeding 100 km/h the radar accurately identified 17 distinct avalanche events.

Recording reliable real time avalanche activity during prolonged storm cycles was the primary objective for acquiring the radar system. Tracking when and where avalanches occur without exposing personnel to hazardous terrain, substantially enhanced forecaster decision making and improved situational awareness for the forecasting team. Additionally, receiving near instant alerts of natural avalanches in closed terrain provided critical data needed to safely manage operations in adjacent open terrain.

Table 1: Detections by Gravimon radar units. False detections were skiers displacing snow at high sensitivity, this was confirmed with the built in camera on good visibility days.

Location	*Total Detections*	*False Detections*
Kirkwood	76	1
Whistler Glacier Bowl	329	170
Blackcomb Lakeside	2	0
Blackcomb Showcase	32	0

Real-time notifications allowed for assessing the effectiveness of mid-storm mitigation work. Furthermore, having an accurate, path-by-path record of prior avalanche activity improved the effectiveness of targeted mitigation work and terrain opening procedures. Historically, results simply went unknown during large storm cycles. With the use of the radar, forecasters were able to adjust mitigation work based on prior natural results and/or adjust artillery firing plans as a mission progresses.

This can greatly benefit users of RACs by more accurately gauging the effect of each shot, conserving inventory, and reducing the number of times devices need to be reloaded (Stähly et al. 2024). If sensitivity is adjusted high enough the radar can also be relied upon for clearing the area of effect prior to remotely detonating explosives, without exposing workers to avalanche terrain.

The presence of monitoring and real time notification also has benefits for managing open ski terrain during periods of heightened avalanche danger. One incident confirmed this application when a snowboarder unintentionally triggered a size 1 avalanche in open terrain. Referencing the location in the radar notification allowed for a rapid response to the exact location, far faster than the time it would usually take for an avalanche to be reported to the ski patrol. Adequate visibility at the time allowed the site to be cleared quickly by reviewing video evidence from the Radar's camera.

Additionally, radar was relied upon at both operations to improve forecasting for overnight grooming operations. As opposed to only relying on information available from day time operations, access/clearances for workers in avalanche terrain could be adjusted based on the detection of any small natural avalanche activity detected by the radar system. Monitoring for an increase in size or activity assisted forecasters with maintaining adequate safety margins while also minimizing restrictions on travel and maximizing operational efficiency.

3.2 Detection of wet avalanche events

Managing ski resort avalanche terrain during rapid warming, rain-on-snow, or increased solar radiation requires close monitoring because wet-snow conditions can change quickly and critical release conditions may be short-lived (Bellaire et al., 2017). To capture early signs of wet-snow instability, the radar sensitivity was adjusted at both resorts to detect minor loose-wet activity and cornice failures.

An unexpected advantage of the system during wet-snow avalanche cycles was the automatic logging of precise timestamps and location data of minor loose wet activity each day. The ability to easily cross-reference these automated records enhanced forecast accuracy and operational decision making.

The radar system was moved over to monitor the Lakeside area of Blackcomb for typical wet loose and wet slab avalanche events in late April. During the 2026 season, warm storm events with mountain top freezing levels led to several large wet avalanche cycles between January and March. As a result, limited wet avalanche activity was observed in late April/May due to the presence of substantial melt freeze crusts and previously frozen large avalanche debris (Table 1).

Once the radar was relocated to monitor the Showcase worksite, there was more opportunity to test its effectiveness for detecting wet loose avalanche activity through the spring. During this time 37 detections were recorded, some of which included minor snowballing from ridge top (Table 1). This allowed us to confirm that the sensitivity of the radar unit could be adjusted to be effective for monitoring the terrain in Lakeside effectively for public/worker safety in future seasons. The skier accidental detection on Whistler also illustrated how radar would be effective for monitoring Lakeside for a public involvement when it is avalanche closed without having to commit workers into hazardous terrain.

3.3 *Detection of rockfall events*

Doppler radar systems can monitor rockfall as well as snow avalanches, providing continuous event records under all-weather and low-light conditions (Schneider et al., 2023). Several large rockfall events took place on Whistler Peak during the 2026 winter, the largest of which was detected on March 12 at 6:36 a.m. A large portion of rock in the Whistler Bowl area failed. It was too dark at the time for visual confirmation. Push notifications alerted us to the situation, and we were able to close that area of the mountain before exposing avalanche mitigation staff. Continuous monitoring of that zone allowed us to determine the exact timing of further rockfall activity in the area.

Furthermore, while monitoring the Showcase worksite we were able to detect rockfall that would trigger wet loose avalanches on the slopes below and verify this with the camera during periods of good visibility. Being able to detect rockfall reaffirms this system's year round capabilities and usefulness by assisting with forecasting other natural hazards affecting the public and workers in mountainous terrain. In addition the modular design of the radar unit allows for easy monitoring of different locations at different times of the year.

3.4 *Off Season Monitoring*

During the late spring/summer, off-season monitoring was required for the Showcase Chairlift worksite on Horstman Glacier. The use of a radar system greatly enhanced the accuracy of remote forecasting by the forecasting team and reduced the time required traveling on site to record any avalanche observations (Table 1). Furthermore, increased activity detected by the radar system allowed the forecasting team to modify terrain management for worker safety in real time through direct communication with the workers on site.

In addition to avalanche activity, the Gravimon radar was able to pick up rockfall during rapid warming and rain events, resulting in modified terrain management for worker and equipment safety (see Section 3.3).

The forecasting team worked closely with Gravimon to help increase the sensitivity of the unit in order to detect small wet loose events and natural snowballing. Practical testing of the unit in the off-season has helped to inform the level of sensitivity and radar positioning required to better monitor the Lakeside area on Blackcomb for solar warming events, such that less than size 1 indicators of instability can be detected to help inform the forecasting team on when to close this terrain to the public (see Section 3.2).

4 CONCLUSION AND FUTURE WORK

The 2026 deployment of automated avalanche detection systems at Whistler Blackcomb and Kirkwood Mountain Resort demonstrated that radar-based avalanche detection can provide meaningful operational value in a North American ski resort environment. Across a range of installation locations and avalanche problems, the systems provided continuous monitoring when visual observations were limited or unavailable and successfully detected natural, explosive-triggered, and skier-triggered avalanche activity. Real-time notifications and event records improved situational awareness for forecasting teams and provided additional information to support avalanche mitigation, terrain-opening decisions, and the management of staff and public exposure.

The trial also demonstrated some of the unique challenges associated with using radar within an active ski area. Skiers, snowcats, lift infrastructure, and other moving targets can complicate detection compared with more remote installations. Appropriate radar positioning, sensitivity settings, and site-specific filtering are therefore important to reliably detect small avalanche events while minimizing false detections. The ability to adjust these parameters throughout the season proved particularly valuable when monitoring small wet-loose avalanches, snowballing, cornice failures, and other early indicators of instability. The detection of rockfall also demonstrated the potential for the system to support broader year-round natural-hazard monitoring.

Future work should focus on collecting data over additional seasons and a wider range of snowpack and weather conditions to better understand detection reliability, appropriate sensitivity thresholds, and optimal radar placement for ski resort applications. In particular, additional monitoring of spring wet-snow avalanche cycles would help evaluate the system's ability to identify small precursor events that can inform operational closure thresholds. Further development should also examine integration of radar detections with Remote Avalanche Control Systems (RACS), including verification of mitigation results and the potential use of radar to confirm that areas of effect are clear before remote avalanche control work begins. Continued refinement of operational procedures, alert thresholds, and filtering will help determine how AADS can most effectively be incorporated into routine avalanche forecasting and risk-management programs at ski resorts.

REFERENCES

Bellaire, S., van Herwijnen, A., Mitterer, C., and Schweizer, J. (2017). On forecasting wet-snow avalanche activity using simulated snow cover data. Cold Regions Science and Technology, 144, 28-38. https://doi.org/10.1016/j.coldregions.2017.09.013

Gravimon (2026). When you can't see anything, Avymonster can. Accessed August 15, 2026, from https://gravimon.com/avymonster/

Meier, L., and Lussi, D. (2010). Remote detection of snow avalanches in Switzerland using infrasound, Doppler radars and geophones. Proceedings of the International Snow Science Workshop, Squaw Valley, California, USA, 7-12.

Schneider, M., Oestreicher, N., Ehrat, T., and Loew, S. (2023). Rockfall monitoring with a Doppler radar on an active rockslide complex in Brienz/Brinzauls (Switzerland). Natural Hazards and Earth System Sciences, 23, 3337-3354. https://doi.org/10.5194/nhess-23-3337-2023

Stähly, S., Carrel, M., Hahner, M., Fellay, F., Carlen, N., Sierro, P.-A., Bumann, S., and Mayoraz, P. (2024). Avalanche detection and RACS blasting verification using extra long-range Doppler radars: Experience from Saas-Fee and Evolène, Switzerland. Proceedings of the International Snow Science Workshop, Tromsø, Norway.

Walberg, N. A. K., Lohne, P., and Farrér, A. (2024). Automatic avalanche detection using Doppler radars - lessons learned after 1000 detected avalanches in Norway since 2020. Proceedings of the International Snow Science Workshop, Tromsø, Norway.