

AVALANCHE SAFETY OPERATIONS IN GLACIER NATIONAL PARK SUPPORTED BY THE AVALANCHE DETECTION NETWORK, BRITISH COLUMBIA, CANADA

Jim Phillips¹, Lisa Dreier^{2*} and Walter Steinkogler²

¹ Parks Canada, Mt Revelstoke and Glacier National Park, BC, Canada

² Wyssen Avalanche Control, Revelstoke, BC, Canada

ABSTRACT: Glacier National Park in British Columbia is managed by Parks Canada. Two important transportation routes, the Trans-Canada Highway and the Canadian Pacific Railway run through the park and over Rogers Pass, the highest point of the highway, which is a popular destination for back-country enthusiasts. A total of 135 avalanche paths endanger the highway and railroad in the park. Parks Canada's Avalanche Control Section (ACS) is responsible for public safety in Glacier National Park. ACS in partnership with Canadian Armed Forces monitors avalanche activity, conducts avalanche control to keep the public safe on the transportation routes and provides an avalanche bulletin for back-country users. Parks Canada installed the Avalanche Detection Network (ADN) in the fall of 2018 and 2019 in Glacier National Park. ADN is unique and the largest avalanche detection network worldwide with thirteen (13) infrasound avalanche detection arrays and four (4) long-range avalanche radars. The systems are installed along the highway corridor to monitor relevant avalanche paths affecting the transportation routes. ADN became an important tool for the Avalanche Control Section and changed the way operations are conducted as for example avalanche forecasting, control operations and monitoring of avalanche activity. With more than 1970 infrasound and 140 radar avalanche detections in winter 2022-2023 ADN notified avalanche forecasters in real-time of relevant avalanche activity and confirmed avalanche control results which helps forecasters to be more time efficient and increases safety for personnel and ultimately the public. ADN proved especially useful to forecasters at night and during snowstorms enhancing their usual method of visual or audible observation from the highway.

KEYWORDS: Avalanche Detection Network, infrasound, radar, avalanche monitoring, Parks Canada, Glacier National Park.

1. INTRODUCTION

The Trans-Canada Highway (TCH) is a critical transportation corridor within British Columbia and a vital link in Canada's national highway network (Figure 1). The operational efficiency of this section of highway in Glacier National Park (GNP) in the winter months relies heavily on effective avalanche control using both passive and active mitigation strategies. 135 avalanche paths endanger the Trans-Canada Highway and railway throughout the park.

In 2015, the Government of Canada launched the Trans-Canada Highway - Avalanche Mitigation Project for Glacier National Park. The objectives of this project are to reduce closures and improve winter road safety through numerous strategies including traffic storage expansion, snow shed rehabilitations, improved signage, and upgraded avalanche mitigation structures and systems. Two 105 mm Howitzers move between 17 roadside gun platforms to fire an average of 700

rounds per year at 270 unique targets. The program also includes Remote Avalanche Control Systems and permanent defense structures (including but not limited to snow sheds, retaining berms and snow nets) in select paths. The Avalanche Detection Network ADN is realized within this framework and is the world's largest and a unique avalanche detection project (Sanderson et al. (2022), Hendrikx et al. (2017)).



Figure 1: The Trans-Canada Highway corridor through Glacier National Park. Source: Sanderson et. al (2022).

* Corresponding author address:

Lisa Dreier, Wyssen Canada Inc., PO Box 99,
Revelstoke, BC, Canada;
tel: +1 250-814-3624;
email: lisa@wyssen.com

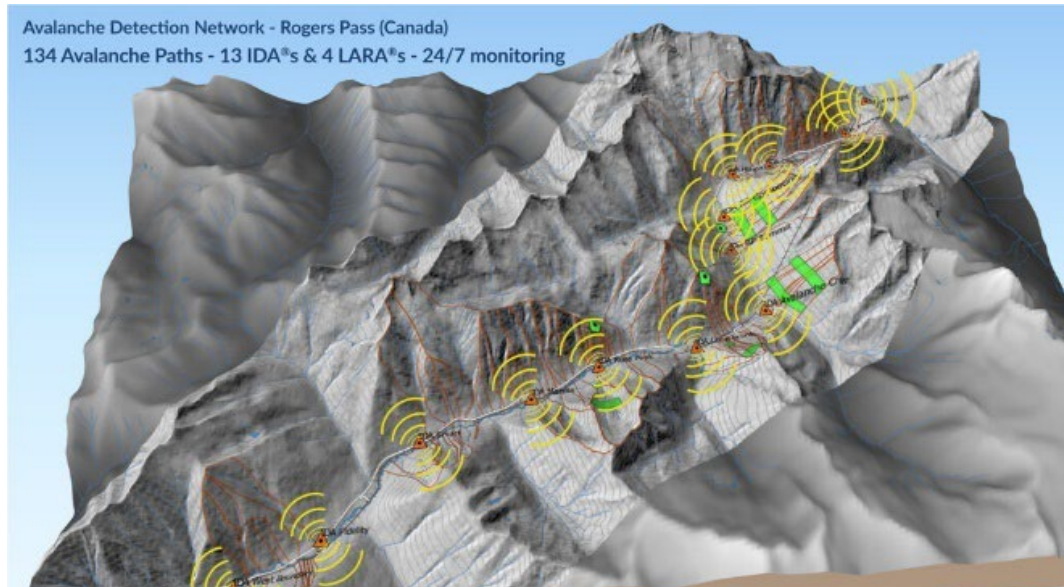


Figure 2: Overview of the Avalanche Detection Network ADN at Rogers Pass.

2. THE AVALANCHE DETECTION NETWORK

The avalanche detection network consists of 13 infrasound and 4 radar systems (Figure 2) and covers the entire corridor of approximately 30 km.

2.1 Infrasound avalanche detection

Infrasound waves are low frequency (<20 Hz) sound waves that travel through the air at the speed of sound (~340 m/s). Array processing techniques showed that back azimuth and apparent velocity of infrasound generated by snow avalanches can be traced at a source-to-receiver distance of 2 km and can be used to evaluate avalanche front velocity (Steinkogler et al. (2016, 2018)).

Each infrasound array comprises a central cabinet, which houses power, data processing and communications hardware, and four sensors installed ~100 m from the cabinet in a radial configuration (Figure 3). Infrasound arrays in GNP were typically installed in flat, forested, valley bottom locations near the highway, which have little solar input, so methanol fuel cells were used to supplement solar power.

Infrasound detection system arrays cover the whole highway corridor through GNP. They deliver a complete picture of natural avalanche activity during every day and night time as well as confirmation of results of artificial avalanche control with artillery and other means to the forecasters. The arrays are installed at the valley bottom and listen for infrasound waves produced by avalanches on all surrounding slopes.

2.2 Long-range avalanche radar

Radars have been applied for the detection of avalanches and other mass movements for many years. In most cases (pulsed or frequency modulated) Doppler radars are used emitting electromagnetic waves at a specific frequency, which are then reflected and travel back to the radar.

The radar measures the component of the avalanche velocity along its line-of-sight direction, detecting movement towards or away from the radar. Radar will not detect movement perpendicular to the viewing direction. The avalanche velocity leads to a Doppler-shifted signal in frequency space, allowing the radar to discriminate between moving and static targets. Using this approach, radar can be used to detect avalanche motion, avalanche velocity, runout distance, and approximate avalanche size (Caviezel et al. (2018)).

Each radar system comprises a cabinet, which houses power, data processing and communications hardware, and a mast atop which is mounted a Doppler radar unit. Three radar systems were installed in remote (helicopter access) locations and one was installed at highway level. Power for remote radar systems comprises both solar and methanol fuel cell. An example of a radar detection system for MacDonald West Shoulder is shown in Figure 3.

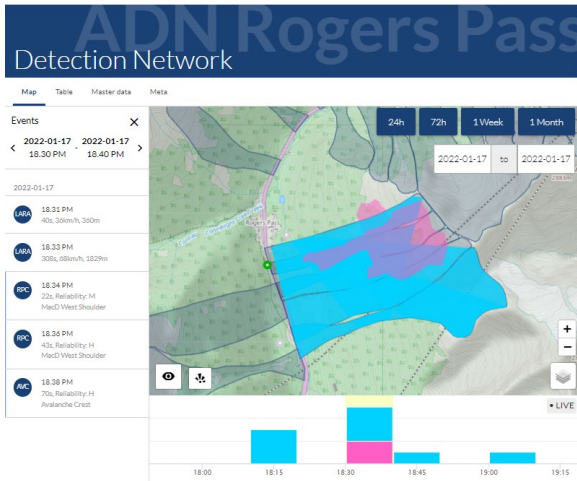


Figure 3: Example of a radar (pink) and infrasound detection (blue) for the same avalanche.

Long-range avalanche radars deliver detailed information about slopes and paths which are of specific interest to the forecasters and used as indicator paths to determine the start of an avalanche cycle. The radar is installed on the counter slope with a direct line of sight of the slope or path and monitors a pre-defined area. A high-resolution camera is triggered to take pictures as soon as an event is detected by the radar and provides additional visual information of the event.

2.3 Interface

The infrasound detection system was installed with a standard calibration and further improved for optimal performance by local calibration of the processing algorithm thresholds. This calibration is based on avalanche observations at each specific site.

The infrasound and radar detection systems produce an immense volume of data that require processing and meaningful visualization. A web-based platform (WAC.3®) is used to allow access from any web-enabled device independent of the avalanche forecasters' location (Figure 5). An integrated alert system sends automatic emails and text messages to the forecasters with details of the detected avalanche event. Text messages were generally found by the operator to be more immediate and directly to their smartphone or tablet, especially when being out on the road.

3. DETECTIONS

After a test period of the first infrasound system in 2016/17 and 2017/18 the initial installation of the first permanent systems were completed for winter 2018/19 (Table 1).

Table 1: Summary of amount of infrasound and radar avalanche detections.

	2018/19 ¹	2019/20	2021/22	2021/22	2022/23
Infrasound	115	1941	1291	2316	1972
Radar	70	252	220	241	141

¹Only 4 infrasound arrays and 1 radar were installed in the first year.

From 1 Nov 2022 to 31 May 2023 the ACS (Avalanche Control Section) recorded 1701 observations in Glacier National Park: 969 natural avalanches and 732 control shots of which 169 were recorded as unknown result and 175 as no result.

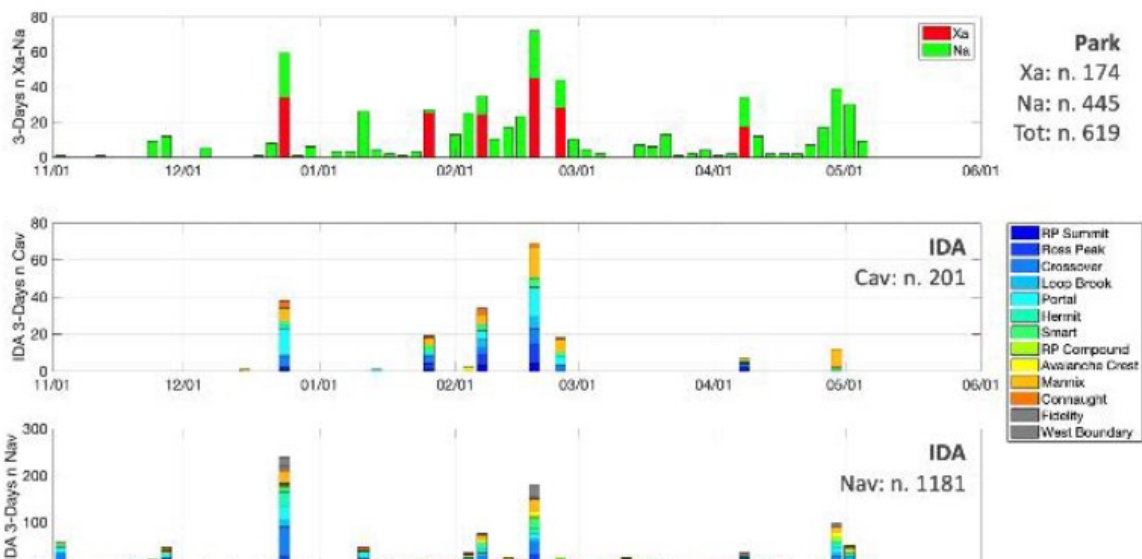


Figure 4: Overview of relevant avalanche observations recorded by Parks Canada (top) and controlled (middle) and natural avalanches detected with infrasound (bottom) in winter 2022/23.

The number of relevant observations for comparison with automatic detections resulted in a total of 619 recorded avalanches consisting of 445 natural avalanches and 174 controlled avalanches. The infrasound systems detected a total of 1972 events consisting of 1181 natural avalanche, 590 gun shot and 201 controlled avalanche detections (Figure 4). The number of controlled avalanche events detected by infrasound is larger because the detections include double detections as well as detections of avalanches recorded with an Unknown control result and avalanches of size = 2 which were filtered out in the observations data set. The number of natural avalanches detected with infrasound is about three times larger than the amount of recorded natural avalanches. This difference originates from infrasound detecting avalanches that were not observed, multiple arrays detecting the same event and detecting avalanches that were filtered out with the criteria for relevant avalanche observations (e.g., avalanche size ≤ 2 , result recorded as Unknown).

Performance metrics and analysis were evaluated for a variety of detection systems that are similar to the installed infrasound and radar systems (Caviezel et al. (2018), Steinkogler et al. (2016)). Specifically, for the ADN setup at Rogers Pass a yearly analysis was performed for each system and compared to ACS observations (Hendrikx et al. (2017) and Sanderson et al. (2022)).

4. AVALANCHE SAFETY OPERATIONS

The ADN provides real-time confirmation of results from avalanche control, regardless of time of day or weather conditions. This information is useful to ACS for updating their mental model of the snowpack and avalanche problems during avalanche mitigation (i.e., control missions), which can affect their decisions on which targets to shoot in order to most effectively mitigate the hazard to the transportation corridor. Real-time avalanche detections following control add to forecaster confidence in decisions to re-open the roadway. The ADN also provides real-time alerts of natural avalanche activity, regardless of time of day or weather conditions. These alerts inform forecasters immediately when an avalanche occurs (within the ADN range) and assist forecasters in their assessment of avalanche hazard and in their decisions to initiate roadway closures and avalanche control.

4.1 Before an avalanche cycle

Typically, the forecasting team will use ADN as part of their morning meetings with the entire team to discuss the avalanche activity – or lack of

activity - the night before and direct highway patrol observations and make visual confirmation of detections. This information gives them greater confidence in their decisions and assessment as they prepare for the day's operation.

Detection location and frequency are used towards planning and logistical decisions. Example: in the evening when everyone goes home, and ADN starts ramping up with detections they issue and cancel avalanche warnings and use it as decision tool if staff members have to return to the pass. On the other hand, if ADN does not show increased avalanche activity, they will have more confidence in their decision to keep people home overnight (Figure 5).

4.2 During a control mission

ADN has proved valuable in assisting forecaster decision-making by supplementing manual avalanche observations with automated detection, recording and notification of avalanche activity.

Specifically, the ADN avalanche alerts can improve the timing of, and increase forecaster confidence in decisions regarding avalanche control and roadway closures and re-openings. Considering the GNP avalanche program and their partners at the Department of National Defense DND fire an average of 700 artillery rounds for avalanche control, and implement on average 42 individual roadway closures, each winter, the accumulated effects of improved timing and confidence in forecaster decision-making are significant. The forecaster decision support provided by the ADN has improved the operational efficiency of the roadway avalanche operation, and overall risk management, for the TCH through GNP in the winter months. Yet, detections alone don't tell the full story. A technician needs to interpret detections with what they expect to happen from what they know about the snowpack conditions and weather forecasts.

The automatic identification of artillery explosions or the resulting controlled avalanches are usually of secondary importance as team members are close enough to often observe the results directly. Yet, alerts of natural avalanches in the surrounding area are very relevant. Especially to maintain situational awareness of other sectors while focusing on the current sector performing avalanche control.

4.3 At the end of an avalanche cycle

The natural detections are also useful toward the end of an avalanche cycle or post control work as indicators of increasing stability in the snowpack,

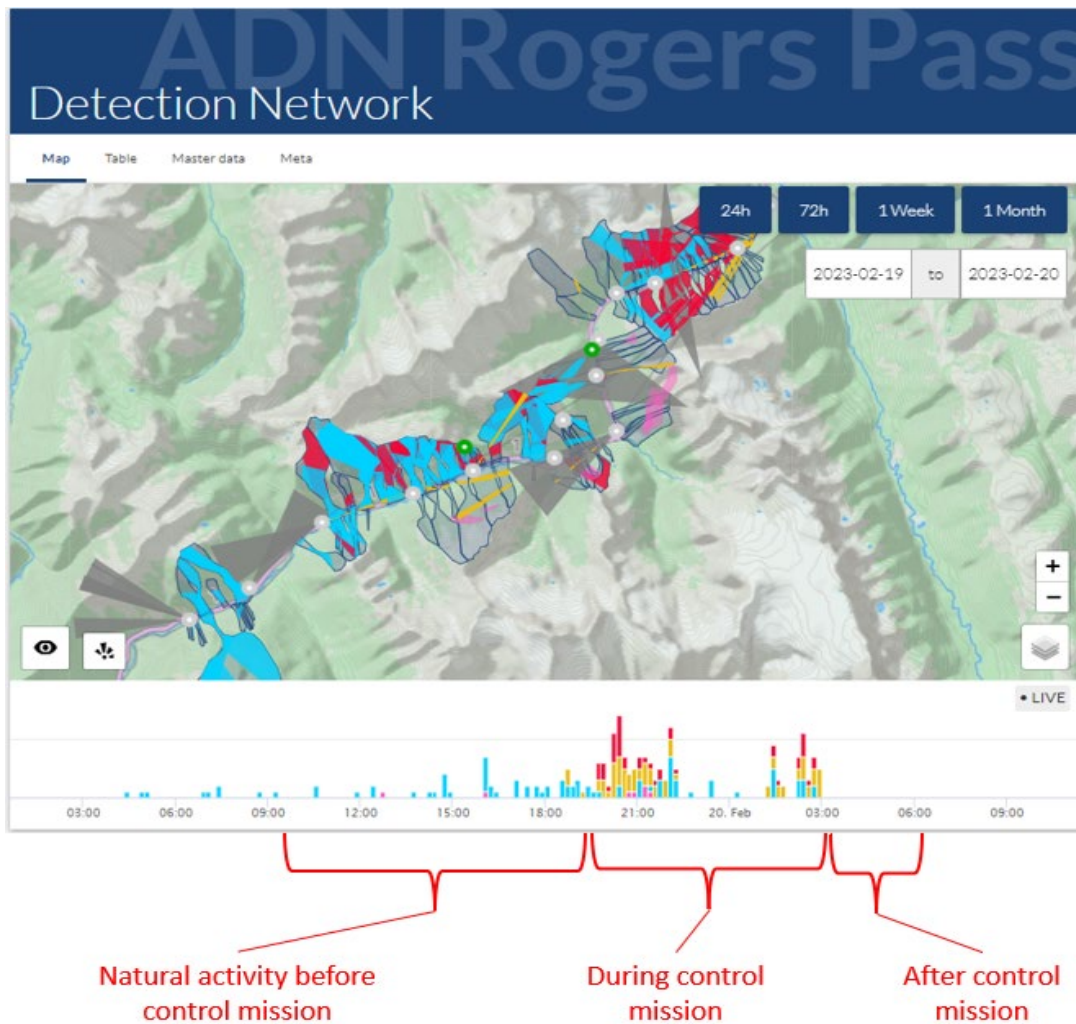


Figure 5: Avalanche activity (natural and controlled) before, during and after a control mission.

which again improves forecaster confidence in re-opening the roadway (Figure 5). Alternatively, it can give an alert to changing conditions if detections are starting to increase in the post-control period.

Reviewing the detections on a path-by-path basis can also assist to assess the overall risk reduction and uncertainty, especially for avalanche events that may have been obscured by snowfall or subsequent avalanches.

5. CONCLUSIONS

The efficiency of the GNP avalanche risk management operation directly affects the safety and reliability of the TCH. The ADN provides real-time avalanche activity data which reduces the uncertainty in the avalanche hazard assessment. This is achieved by assisting forecaster decision-making during avalanche control through improved timing of avalanche control and roadway closures and re-openings and increases forecaster confidence in re-opening the roadway. More efficient

avalanche control results in shorter closure durations. Optimized timing of avalanche control and road closures ultimately reduces closure duration. Increased confidence in the hazard assessment and in control results, can reduce both, the frequency and duration of closures, as well as improving safety for roadway users and workers. Additionally, the robust avalanche occurrence dataset produced by the ADN detections forms a comprehensive historical record for future magnitude and frequency analysis of avalanches. This information helps calculate the trend in avalanche risk and inform future planning for potential highway expansion (from 2 to 4 lanes) and additional mitigation measures. It also provides a basis for comparison to other roadways avalanche programs such that overall network reliability can be considered, and resources can be allocated to areas of highest risk.

ACKNOWLEDGEMENT

We would like to thank the Parks Canada forecasting team for continued input and operating the system to keep the public as safe as possible. Thanks to the local Wyssen Canada team Marc Cossette and Dylan Chen for their efforts on all ends to keep the products and services at the highest quality level. Jamie Sanderson (McElhanney) and Alan Jones and Chris Argue from Dynamic Avalanche Consulting.

Wyssen Avalanche Control would like to thank its partners and sub-contractors for their contributions, especially GeCo for their contribution to the infrasound portion and Geopraevent for their contribution to the radar portion.

REFERENCES

- Caviezel, P., Feuerstein, G., Meier, L., Baumann, R., Gubler, H., Wyssen, S., Steinkogler, W. Verification of the Success of Artificial Avalanche Releases in an Operational Project with Radar, Seismology, and Infrasound in Gonda (Lower Engadine, Switzerland). Proceedings of the International Snow Science Workshop, Innsbruck, Austria. 2018.
- Sanderson, J., Hendriks, J., Goodrich, J., Steinkogler, W., Dreier, L., Argue, C. and Jones, A.: EVALUATION OF AN AVALANCHE DETECTION SYSTEM IN GLACIER NATIONAL PARK, XVI World Winter Service and Road Resilience Congress, 2022.
- Steinkogler, W., Meier L., Langeland S., and Wyssen S., Operational Radar and Infrasound Systems for Avalanche Detection. Proceedings of the International Snow Science Workshop 2016, Breckenridge, CO, USA. 2016.
- Steinkogler, W., Olivieri, G., Vezzosi, S., Hendriks, J., Van Herwijnen, A. and Humstad, T., Infrasound detection of avalanches: operational experience from 28 combined winter seasons and future developments. Proceedings of the International Snow Science Workshop 2018, Innsbruck, Austria, 2018.
- Hendriks, J., Dreier, L., Olivieri, G., Evaluation of an infrasound detection system for avalanches, Rogers Pass, Canada; Winter 2016-17. Report for McElhanney Consulting Services Ltd (http://www.montana.edu/earthsciences/facstaff/MSU_Evaluation_Infrasound_RogersPass_Final.pdf). 201