EVALUATION OF AN INFRASOUND DETECTION SYSTEM FOR AVALANCHES IN ROGERS PASS, CANADA

Jordy Hendrikx[1]*, Lisa Dreier[2], Giacomo Ulivieri[3], Jaime Sanderson[4], Alan Jones[5], Walter Steinkogler[6]

[1] *Snow and Avalanche Laboratory, Montana State University, Bozeman, MT, USA*
[2] *Wyssen Avalanche Control, Revelstoke, British Columbia, Canada*
[3] *iTem s.r.l and Department of Earth Science, University of Florence, Florence, Italy*
[4] *McElhanney Consulting Services Ltd., Canmore, Alberta, Canada*
[5] *Dynamic Avalanche Consulting, Revelstoke, British Columbia, Canada*
[6] *Wyssen Avalanche Control, Reichenbach, Switzerland*

ABSTRACT: Infrasound array technology for the detection of snow avalanches was tested at Rogers Pass, BC, Canada over the 2016-17 winter season (24 December 2016 to 11 May 2017). The summit area of Rogers Pass, Glacier National Park was selected as the test location for single array deployment due to its proximal location to avalanches from different aspects on several paths combined with a robust manual observational record. This setting, which is representative of the Rogers Pass area, permitted easy installation and maintenance of the system and guaranteed an effective reduction of the acoustic noise produced by wind, road and railway traffic, and proved to be optimal for the robustness of the monitoring system.

Using both quantitative statistical and qualitative case-study approach methods, the performance of single infrasound array was evaluated for one season. This was achieved by comparison to detailed observations of avalanche occurrences, at distances up to 4 km from the array and ranging from Size 1.5 to 3.5, as collected by Parks Canada Agency's Avalanche Control Section (ACS) and supplemented with additional manual observations. Quantitative Statistical analysis shows a probability of detection (POD) of 0.41 within 4 km range and for >= Size 1.5 avalanches both of dry and wet type, and with consistently reliable detections up to 2.5 km. These results are relatively poorer than similar studies carried out in other locations (e.g. Norway and Switzerland). This difference is attributed to a combination of factors, including: the difference in avalanche control (i.e. artillery at Rogers Pass versus air-blast from Wyssen tower), number of avalanches and lack of full documentation (i.e. natural backcountry activity), the duration of the trial (i.e. one season only), and the number of sensors installed (i.e. a single array). These results demonstrate the performance for a rapid "out-of-the-box" deployment for a single infrasound array, before any site specific calibration is applied.

KEYWORDS: Infrasound, Avalanche Detection, Evaluation.

1. INTRODUCTION

This research was undertaken as part of a contracted report for Parks Canada Agency (PCA), through McElhanney Consulting Services Ltd. The purpose of the research was to document the evaluation of an infrasound detection system for avalanches in Glacier National Park (Rogers Pass), British Columbia (BC), over the winter season of 2016-17.

The main objectives of the system installation at Rogers Pass Summit were to; (i) Evaluate the infrasound system performance at Rogers Pass Summit during a trial period during winter 2016-17; (ii) Evaluate the limitations and performance characteristics of the system at this location, including the range of detection and size and type (wet, dry, powder) of avalanches that can be detected, and any system customizations needed for operation in Rogers Pass; and (iii) Utilize the information obtained during this installation for the development of system specifications for tendering purposes on behalf of Parks Canada Agency (PCA) Highway Engineering Services (HES).

* Corresponding author address:
Jordy Hendrikx, Department of Earth Sciences
Montana State University, Bozeman, MT, USA;
tel: +1 406 994 6918; fax: +1 994 6923
email: jordy.hendrikx@montana.edu

2. BACKGROUND

Obtaining the precise timing of avalanche activity and the extent and success of avalanche control, under all conditions, including at night or during periods of poor visibility and in remote areas, can significantly improve operational avalanche forecasting.

A range of different approaches have been used to improve the observation of avalanches, including radar (e.g. Rammer et al., 2007; Vriend et al., 2013), seismic sensors (e.g. Van Herwijnen and Schweizer, 2011; Vilajosana et al., 2007), videogrammetry (e.g. Vallet et al., 2004) and infrasound (e.g. Scott et al., 2007; Ulivieri et al., 2011; Havens et al., 2014a; 2014b; Thüring et al., 2015; Steinkogler et al., 2016). In particular, the use of infrasound for operational avalanche monitoring has been increasing in the recent decade with significant improvements in sensors and automatic avalanche detection (Marchetti et al., 2015).

Infrasound waves are low frequency (<20 Hz) sound waves that travel through the air at the speed of sound (~340 m/s). Infrasound detection has made significant improvements in system design in recent years. After the initial work with single infrasound sensors (e.g., Bedard, 1989), the use of infrasound arrays has significantly improved the signal-to-noise ratio (e.g., Scott et al. 2007; Ulivieri et al., 2011; Havens et al., 2014a), thus resulting in a larger efficiency of infrasound in detecting snow avalanches even at larger (i.e. a few km) distances. 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 (Ulivieri et al., 2011) and can be used to evaluate avalanche front velocity (Havens et al., 2014). Recently, a network of three infrasound arrays deployed in three different valleys in Valle d'Aosta, Italy, permitted detection and location of a Size 3 avalanche at a source-to-receiver distance of ~ 20 km (Ulivieri et al., 2012).

Currently, in North America there are several infrasound installations used for avalanche detection, including the Wyoming Department of Transportation (WYDOT) on Teton Pass (Scott et al., 2007; Scott, 2008), the Utah Department of Transportation (UDOT) in Little Cottonwood Canyon Road (Vyas, 2009), and research focused systems by Boise State University and Idaho Transportation Department on Highway 21 (Havens et al., 2014b). There are also several infrasound installations in Europe, including: one in Ischgl, Austria (Marchetti et al., 2015), four in Switzerland (Steinkogler et al., 2016), and two in Norway (Indreeidsdalen and Grasdalen) (Humstad et al., 2016). In all of these locations, infrasound systems are used to confirm avalanche control blasts and their resulting avalanches, as well as to detect and provide warning of natural avalanche occurrences. Operations that currently use detection systems note the effectiveness of their systems in improving the program, with demonstrable qualitative and quantitative benefits to program performance, improved safety and reduced closure times

3. METHODS

3.1 Equipment and Installation.

The infrasound monitoring system deployed at Rogers Pass Summit consisted of a 4-element array, with a triangular geometry and an aperture of approximately 100 m. Three sensors were placed on the ground, and the forth sensor was housed in the central unit, which consisted of a small wooden hut with local power supply. The infrasound array was installed in the forest on the valley bottom with views towards multiple different avalanche paths nearby. Shortly after installation, the three infrasound sensors distant from the central unit were covered with snow, which further dampened ambient background noise and reduced the impact of wind and other noise disturbance.

The four elements of the infrasound system were equipped with a differential pressure transducer (iTem-prs0025f) with high sensitivity (200 mV/Pa), broad-band frequency range (0.01-50 Hz) and low noise level (<0.01 Pa). Analog to digital conversion of pressure, temperature and battery voltage is performed at each array element, and digital data are transmitted using fiber optic cables to a central data collector, and are stored at 50 Hz sampling rate and 24 bit of resolution. The system was equipped with a GPS receiver, which ensured the absolute time synchronization. The raw infrasonic record was then transmitted real-time using a cellular data modem, and analysis was done from an off-site server.

3.2 Avalanche control and observations

Observation of both natural and controlled avalanches were made by ACS for the entire road corridor, as a routine component of their avalanche forecasting and management program for the highway. The records of avalanches observed and avalanche control undertaken within a 5 km radius of the infrasound system were provided. During this winter season ACS increased their efforts to record smaller avalanches (≥1.5) in this area to support this study.

Additional backcountry activity was also sporadically added to this database, as time and resources permitted. The quality and quantity of these backcountry avalanche records is variable, but improves the information obtained during critical avalanche cycles. The result of this effort ensured a robust set of avalanche and avalanche control records for all avalanche paths that directly affect the road, and a less robust, but still valuable record of backcountry avalanche activity.

3.3 Signal Processing

The array signal processing is based on the assumption that an infrasound signal is coherent (i.e. as defined by the Fisher statistic) at the different sensors, while noise does not show any correlation. The detection algorithm is based on a multichannel correlation method using different parameters. To identify signals from noise, time correlation, amplitude, wave propagation, back-azimuth, apparent velocity and dominant frequency are calculated. For more details about the specifics of the signal processing for the infrasound system the reader is referred to Ulivieri et al. (2011, 2012).

In this evaluation, two versions of the automatic detection algorithm were employed. Version 1 (v1) of the algorithm has been previously used in Europe with the IDA® system (e.g. Ulivieri et al., 2012). This algorithm has been specifically designed to detect the explosion from a Wyssen tower (i.e. 5 kg explosive air-blast) or a Gazex (i.e. gas explosion in the air) followed by an avalanche. It should be noted that this produces a very different signal to an artillery round (i.e. 2.5 kg on-snow detonation) which detonates on impact with the snow surface. The v1 algorithm specifically checks for the air-blast, and then increases its sampling rate to observe subsequent avalanche activity. Given that both natural and artillery triggered avalanches occur frequently in the Rogers Pass corridor, we anticipate that this v1 algorithm will not fully demonstrate the potential of infrasound in this setting.

Version 2 (v2) of the algorithm is an updated version of the above described algorithm, but rather than specifically using the air-blast to help with avalanche detection, it was designed to detect the firing of the artillery from the highway level, the detonation of the artillery in an avalanche starting zone, and then the subsequent avalanche activity. Due to the low ambient noise setting of the installed infrasound, this algorithm was also able to effectively detect natural avalanche activity. This v2 of the algorithm was prepared at the end of the season (May – July, 2017) and then used to retroactively detect avalanches for the full winter season. Despite this post-season (i.e. non real-time) deployment of this algorithm, the results in real-time usage would be the same, so comparison of the algorithm performance can still be undertaken.

3.4 Data Preparation

Before an analysis of the effectiveness of the infrasound system can be undertaken, the avalanche observation and avalanche control records, and infrasound records need to be connected. To facilitate this, the avalanche paths that the infrasound can accurately detect must be determined. We elected to only use those avalanche paths that are both within the 5 km radius from the Rogers Pass Summit infrasound location, and were also within direct line-of-sight (i.e. within the GIS estimated view-shed). Expert judgement was used to refine this list where there was uncertainty.

Manual matching of infrasound automatic detections and manual avalanche observations was then undertaken for these paths. This used a multi-parameter approach which included the date and time of the detection, the back azimuth of the detection, and cross referencing these to manually observed avalanche events. A multi-sensor system with overlapping view-sheds would permit improved automatic attribution of infrasound detections to specific paths, which has clearly been demonstrated operationally in Little Cottonwood Canyon, Utah (e.g. Scott, 2008, Vyas, 2009).

In addition to tracking all avalanche events within 5 km and within line-of-sight of the infrasound, an Avalanche-Activity Index (AAI) was also calculated. The AAI is the sum of avalanche sizes observed (McClung and Tweedy, 1993) and provides a numerical expression for the scale and intensity of avalanche activity for a given day.

3.5 Data Analysis

To document and describe the performance of the two automatic detection algorithms for the trial period we used standard model assessment metrics, including: the unweighted average accuracy (RPC); the true skill score (TSS); the false alarm ratio (FAR); the probability of detection of events (POD); and non-events (PON). We used the same definitions as documented by Wilks (1995) and Doswell et al. (1990), and as used by Hendrikx et al. (2014) for avalanche-days.

An ideal model should have a high POD, while maintaining a high PON, thereby predicting events and non-events equally well. This would also reduce the FAR (where 0 is a perfect score) and show in the TSS and RPC (values between 0 and 1) where values approaching 1 are desirable

In addition to these quantitative measures of the infrasound system performance, a series of case-studies of specific avalanche cycles were selected for qualitative analysis. These avalanche cycles were representative of almost the entire continuum of avalanche activity expected at Rogers Pass, from cold and dry powder avalanches in January, February and March, to warm and wet flowing avalanches in May. The intent of this analysis was to evaluate the potential of an infrasound system to detect the full spectrum of avalanche events, and also more closely examine the limitations of the system.

4. RESULTS AND DISCUSSION

For brevity, only a sub-set of our result are presented here. Readers are directed to the full report (Hendrikx et al., 2017) for more results and discussion, especially the detailed case study examples.

4.1 Version 1 algorithm

Using the v1 algorithm over the evaluation period (December 24, 2016 to May 11, 2017), there were 97 recorded avalanche observations in these 10 paths, of which 30 were correctly identified by the infrasound automatically using v1 of the algorithm. A further 17 signals were manually connected to signals in the infrasound record, but were not automatically detected as avalanches. In this analysis these manual assessments are considered separately in the performance metrics, and show potential for improvement in an enhanced algorithm (Table 1).

While the correct detection of avalanches is important for an operational avalanche program, this should not come at the cost of detecting avalanches when they are not occurring (i.e. false alarms). To assess this component of the performance of the infrasound, we randomly selected 100, 1-hour periods with no observed avalanche occurrences. These were selected from the whole season with infrasound observations (24 December, 2016 to 11 May, 2017) using a random number generator from periods of avalanche activity. Where the random number selected a one hour period that coincided with documented avalanche activity, the next random number was selected. This resulted in a set of one-hour periods of non-avalanche events during periods of potential instability, which was then compared to the infrasound detections. No infrasound detections were present during any of these times, suggesting no false alarm signals (i.e. avalanche detection when no avalanche occurred) were generated from the infrasound system. These summary metrics are presented in Table 1.

4.2 Version 2 algorithm

Using the v2 algorithm over this same period, but run in a hind-cast mode for the season, there were a total of 97 avalanche recorded observations in these 10 paths, of which 40 were correctly identified by the infrasound automatically using v2 of the algorithm. Of these 40 correctly identified events, 14 were for controlled avalanches, and 26 were for natural avalanche activity. We used the same 100, 1-hour periods for our non-avalanche events during periods of potential instability, which was then compared to the infrasound detections. As for the above analysis, no infrasound detections were present during any of these times. Summary metrics are presented in Table 1.

Table 1: Performance metrics for the automatic detection algorithm.

Metric	*v1 algorithm*	*v1 algorithm & Manual*	*v2 algorithm*
RPC:	0.65	0.74	0.71
TSS:	0.31	0.48	0.41
FAR:	0.00	0.00	0.00
POD:	0.31	0.48	0.41
PON:	1.00	1.00	1.00

With the assumptions made, regarding avalanche detections that were not connected to documented events in one of the ten paths, there is greater uncertainty in the non-avalanche detection periods, which clearly results in greater uncertainty in some of the performance metrics presented here. Specifically, the unweighted average accuracy (RPC); the true skill score (TSS); the false alarm ratio (FAR); the probability of detection of non-events (PON) have higher levels of uncertainty. The probability of detection of events (POD) can be considered with the greatest confidence, but even this metric is challenged by the fact that we have excluded the infrasound detections of avalanche events from paths outside the 10 selected paths.

Despite this, comparison of these results to other examples of the infrasound systems used in Europe highlights the relatively poor performance in this trial at Rogers Pass using the version 1 and 2 algorithms. Humstad et al., (2016) documented much higher success rates with POD of 0.84 to 1.0 and FAR of 0.08 and 0.00 for Gransdalen and Indreeidsdalen Norway respectively. The results from this study show much lower POD, likely attributed to the exclusion of infrasound observations outside of these 10 paths, but with a comparable FAR.

Given the nature of these data, the nuances of these metrics when dealing with missing and or extra observations that are poorly classified into the contingency table, it is also helpful to assess the infrasound system performance in a more qualitative manner. These case-studies are presented in the full report.

5. CONCLUSIONS

An analysis of the 2016-17 season using detailed avalanche observations and compared with infrasound detected avalanche activity was undertaken. Using both quantitative statistical and qualitative case-study approach methods we evaluated the performance of a single infrasound array for one season at Rogers Pass, Canada. This analysis clearly shows the potential of an infrasound system to automatically detect avalanche events, ranging from Size 1.5 to 3.5 at distances up to 4 km, and more reliability at distances less than 3 km. Detailed case-study analyses show the ability of the infrasound system to provide path specific location, point of initiation, run-out distance, and avalanche velocity estimates.

REFERENCES

Bedard, A., 1989. Detection of avalanches using atmospheric infrasound, Proceedings of the Western Snow Conference, edited by: Shafer, B., Western Snow Conference, April 1989, Colorado State University, Fort Collins, CO, USA, 52–58.

Bedard, A., 1994. An evaluation of atmospheric infrasound for monitoring avalanches. Proceedings, 7th International Symposium on Acoustic Remote Sensing and Associated Techniques of the Atmosphere and Oceans, 3–5 October, Boulder, CO.

Doswell, A., Davies-Jones, R., and Keller, D., 1990. On summary measures of skill in rare event forecasting based on contingency tables. Weather and Forecasting, 5, 576-585

Havens, S., Marshall, H. P., Johnson, J. B., and Nicholson, B., 2014a. Calculating the velocity of a fast-moving snow avalanche using an infrasound array, Geophys. Res. Lett., 41, 6191–6198, doi:10.1002/2014GL061254.

Havens, S., Marshall, H.P., Trisca, G., Johnson, J.B., 2014b. Real Time Avalanche Detection for High Risk Areas. Report prepared for the Idaho Transportation Department Research Program. http://itd.idaho.gov/highways/research/

Hendrikx, J., Peitzsch, E.H., Fagre, D.B., 2012. Time-lapse photography as an approach to understanding glide crack avalanche activity. Proceedings of the 2012 International Snow Science Workshop, September 17-21, 2012, Anchorage, Alaska

Hendrikx, J., Murphy, M., Onslow, T., 2014. Classification trees as a tool for operational avalanche forecasting on the Seward Highway, Alaska. Cold Regions Science and Technology. 97, 113-120. DOI: 10.1016/j.coldregions.2013.08.009.

Hendrikx, J., Dreier, L., Ulivieri, G., 2017. 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/fac-staff/MSU_Evaluation_Infrasound_RogersPass_Final.pdf)

Humstad, T., Søderblom, Ø, Ulivieri, G., Langeland, S., Dahle, H., 2016. Infrasound Detection of Avalanches in Grasdalen and Indreeidsdalen, Norway. Proceedings of the International Snow Science Workshop 2016 Proceedings, Breckenridge, CO, USA.

Marchetti, E., Ripepe, M., Ulivieri, G., and Kogelnig, A. 2015. Infrasound array criteria for automatic detection and front velocity estimation of snow avalanches: towards a real-time early-warning system, Nat. Hazards Earth Syst. Sci., 15, 2545-2555, doi:10.5194/nhess-15-2545-2015.

McClung, D.M., and Tweedy, J., 1993. Characteristics of avalanching: Kootenay Pass, British Columbia, Canada. Journal of Glaciology, Vol. 39, No. 132, 316-322.

McClung, D. and Schaerer, P. A., 2006. The Avalanche Handbook, The Mountaineers Books, Seattle, WA, USA, 2006.

Rammer, L., Kern, M. A., Gruber, U., and Tiefenbacher, F., 2007. Comparison of avalanche-velocity measurements by means of pulsed Doppler radar, continuous wave radar and optical methods, Cold Reg. Sci. Technol. 50, 35–54, doi:10.1016/j.coldregions.2007.03.014, 2007.

Scott, E. D., Hayward, C. T., Kubichek, R. F., Hamann, J. C., Pierre, J. W., Corney, B., and Mendenhall, T., 2007. Single and multiple sensor identification of avalanche-generated infrasound, Cold Reg. Sci. Technol., 47, 159–170.

Scott, E.D., 2008. Practical Operational Implementation and Evaluation of Teton Pass Avalanche Monitoring Infrasound System. Client report prepared by Inter-Mountain Laboratories for Wyoming Department of Transportation. Report No. FHWA-WY-09/02F.

Steinkogler, W., Meier, L., Langeland, S., Wyseen, S., 2016. Avalanche detection systems: A state-of-the art overview on selected operational radar and infrasound systems. Proceedings of the 13th Congress INTERPRAEVENT 2016: Living with Natural Risks, 30 May – 2 June, 2016, Lucerne, Switzerland, p 978-987.

Thüring, M. S., van Herwijnen, A., and Schweizer, J., 2015. Robust snow avalanche detection using supervised machine learning with infrasonic sensor arrays, Cold Reg. Sci. Technol., 111, 60–66, doi:10.1016/j.coldregions.2014.12.014.

Ulivieri, G., Marchetti, E., Ripepe, M., Chiambretti, I., De Rosa, G. and Segor, V., 2011. Monitoring snow avalanches in Northwestern Italian Alps using an infrasound array, Cold Regions Science and Technology, Volume 69, Issues 2–3, December 2011, Pages 177–183P

Ulivieri, G., Marchetti, E., Ripepe, M., Chiambretti, I., and Segor, V., 2012. Infrasonic monitoring of snow avalanches in the Alps, Proceedings, 2012 International Snow Science Workshop, 16–21 September 2012, Anchorage, AK, USA, 723–728.

Vallet, J., Turnbull, B., Joly, S., and Dufour, F., 2004. Observations on powder snow avalanches using videogrammetry, Cold Reg. Sci. Technol., 39, 153–159, doi:10.1016/j.coldregions.2004.05.004.

Van Herwijnen, A. and Schweizer, J., 2011. Monitoring avalanche activity using a seismic sensor, Cold. Reg. Sci. Technol., 69, 165–176, doi:10.1016/j.coldregions.2011.06.008.

Vickers, H., Eckerstorfer, M., Malnes, E., Larsen, Y., Hindberg, H., 2016. A method for automated snow avalanche debris detection through use of synthetic aperture radar (SAR) imaging. Earth and Space Science. 3, doi:10.1002/2016EA000168. 2016

Vilajosana, I., Khazaradze, G., Surinach, E., Lied, E., and Kristensen, K., 2007. Snow avalanche speed determination using seismic methods, Cold Reg. Sci. Technol., 49, 2–10, doi:10.1016/j.coldregions.2006.09.007.

Vriend, N. M., McElwaine, J. N., Sovilla, B., Keylock, C. J., Ash, M., and Brennan, P. V., 2013. High-resolution radar measurements of snow avalanches, Geophys. Res. Lett., 40, 727–731, doi:10.1002/grl.50134.

Vyas, 2009. Avalanche Monitoring System Research Evaluation. Client report by Fehr & Peers. Prepared for the Utah Department of Transportation Research Division. Report No. UT-09.01. https://www.udot.utah.gov/main/uconowner.gf?n=7747228490333964

Wilks, D., 1995. Statistical Methods in the Atmospheric Sciences. Academic Press, 467pp.