INFRASOUND DETECTION OF AVALANCHES: OPERATIONAL EXPERIENCE FROM 28 COMBINED WINTER SEASONS AND FUTURE DEVELOPMENTS

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ABSTRACT: We present an overview of multiple verification campaigns performed to evaluate the performance of and experience with IDA® (Infrasound Detection of Avalanches) operational systems in Austria, Switzerland, Canada, Norway and the USA. This work focuses on operationally relevant facts and recommendations for the design of infrasound systems. The comprehensive dataset consists of 28 combined operational winter seasons at 10 different locations, covering a wide range of avalanche sizes and types, snow climates (stratigraphy and snow depth), topographies and site-specific characteristics. The IDA® systems automatically detected natural avalanches, artillery gun shots and detonations as well as explosions from different remote avalanche control systems. Results show that the operational reliability of IDA® is limited to avalanches of size class > 2.5 (corresponding to ~ 500 m of run-out distance and 5 ha), both dry and wet, within a distance of 3-4 km from the array, with a probability of detection (POD) between 40 and 90% and a false alert ratio (FAR) between 0 and 20%. The POD increases with size and decreases with distance. Differences in performance are mainly related to site-specific characteristics. Site-specific calibration of the automatic algorithm as well as tuning of the thresholds is a key factor for the performance optimization. The presence of local terrain features and complex topography can limit the monitoring of certain avalanche paths. Preliminary results suggest the use of multiple arrays and adapted algorithms can be an effective solution to mitigate this limitation. Wind noise, ice layers or a dense snowpack can significantly reduce the detection capability and in extreme cases render the system inoperative. However, a detailed design study, optimized site selection, properly installation solutions, hardware robustness improvements and a clear definition of the operational requirements of the local avalanche control team can help minimizee these limitations.

KEYWORDS: Infrasound detection, avalanche, operational

1. INTRODUCTION

Snow avalanches pose a direct threat for people and infrastructure during winter. Governmental agencies protect settlements and traffic routes using permanent measures (tunnels, steel structures, etc.) and/or active and passive temporary measures (e.g. road closures, evacuations, preventive avalanche release, avalanche forecasting, etc.). In this context, by providing more timely information on avalanche activity, automatic avalanche detection systems could help reduce closure times of roads and facilitate decision making for local avalanche control services. In addition, knowledge on the occurrence, frequency and size of avalanches could assist regional safety services responsible for the control and forecasting of avalanche hazard.

In recent years ground based operational avalanche detection systems (Steinkogler et al. 2018), such as infrasound (Marchetti et al. 2015), radar (Fischer et al. 2014, Gauer et al. 2007) or seismic based technology (Heck et al. 2017) have emerged to support avalanche safety personnel in their daily decision-making. A variety of systems for the detection of avalanches has been developed and evaluated and

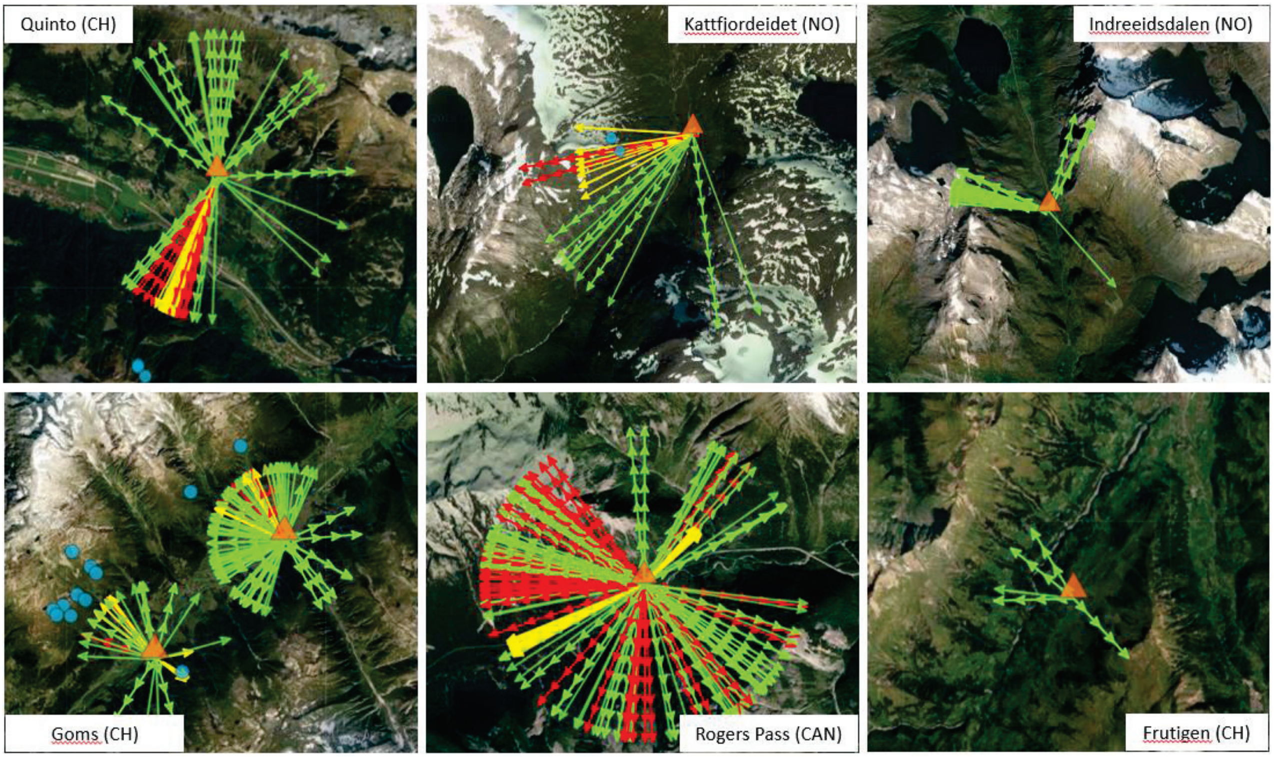

Figure 1: Overview of the automatic detections provided by 7 IDA systems, which were operated during the winter season 2017-18: natural (green) and artificially triggered avalanches (red) as well as detonations from RACS or artillery (yellow) are shown. More than 700 avalanches were detected.

partly transferred into operational use at traffic route operations and ski resorts (Steinkogler et al. 2016). Depending on the aim of the operation and the object at risk, the most suitable system should be selected. Operational systems, such as the presented IDA® system, can provide automatic notifications of avalanche activity over single or multiple paths, regardless of visibility conditions.

The first operational infrasound array, incorporating the presented technology, was installed in 2012 in Ischgl, Austria. The aim was to gather data on avalanche activity of a larger area, develop algorithms and evaluate if such systems can be used in operational context to assist the local avalanche control teams. Based on the experience gathered during these first winters, additional systems were installed and operationally used in Switzerland and Norway. Since 2016 systems were also installed at Rogers Pass in Canada and Alta, USA. In Switzerland, Canada and Norway extensive verification campaigns were carried out over the last years. The main results of these 28 cumulative winter seasons of operation of IDA® are summarized here.

2. METHODS

The infrasound detection systems installed at the various sites for operational use consist of 4 to 5 element infrasound arrays of a small aperture (100-180 m). The systems were powered with autonomous or grid power supply. Infrasound array data were transmitted in real-time to a dedicated cloud server for the near real-time data processing and automatic notification (SMS, e-mail, publication in databases) of alerts. Details on the implemented hardware and processing algorithms can be found in Ulivieri et al. 2011-2016 and Marchetti et al. 2015.

The installation sites cover a wide range of snow climates and avalanche types (from dry to wet flowing avalanches and all avalanche size classes), terrain types (steep avalanche paths to relatively avalanche release areas and paths), vegetation characteristics (open alpine meadows to heavily forested areas) and other potential sources of acoustic noise (e.g. railway, highway, airports, etc.).

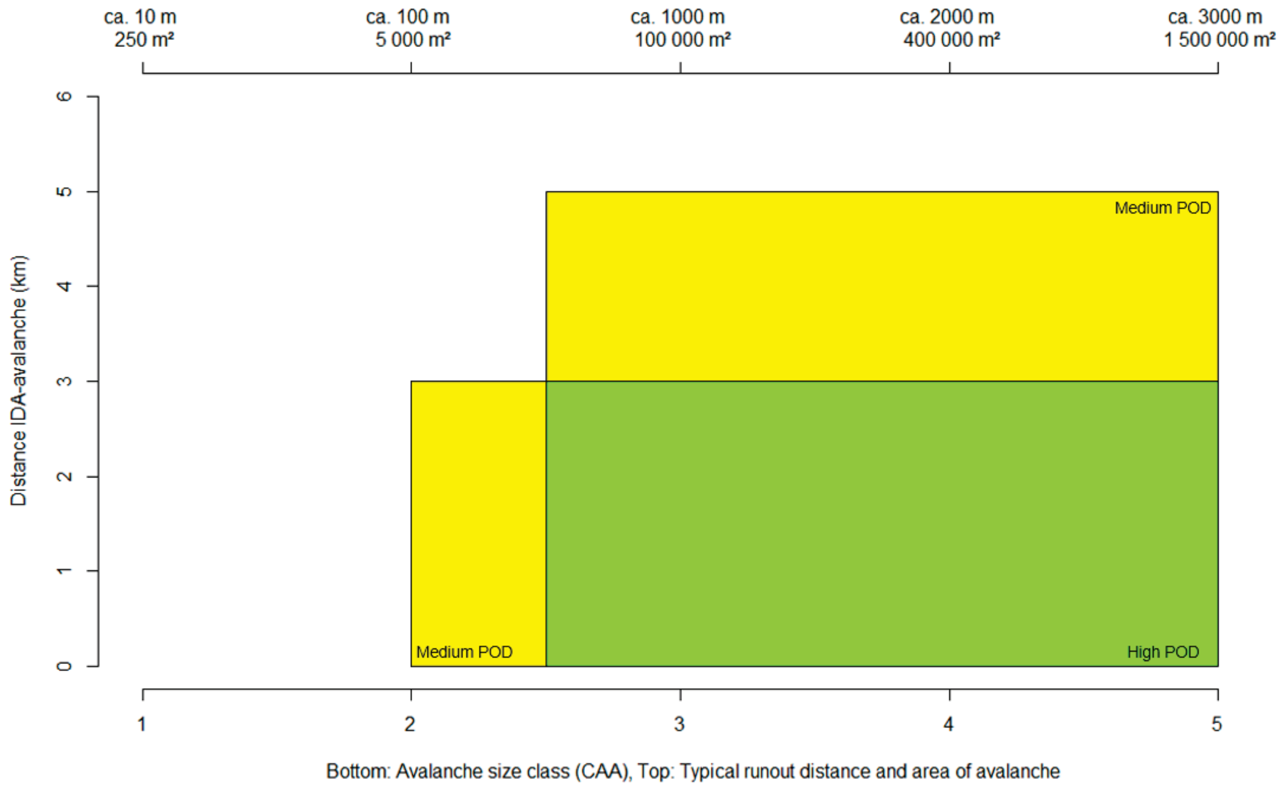

Figure 2: IDA system performances in term of Probability of Detection (POD) as a function of the distance and the size of (dry) natural avalanches (simplified illustration). Yellow and green colors indicate the expected medium or high POD, respectively. The operational needs fit these limitations to ensure the best operational benefit of the system.

In addition to operational applications of the presented infrasound systems we summarize and consolidate the information of the verification campaigns conducted in Norway (Humstad et al. 2016), Switzerland (Mayer S. 2017, Mayer et al. 2018) and Canada (Hendrikx et al. 2017). To have an independent verification data set avalanche occurrence data were collected with traditional manual visual observations and automatic cameras to evaluate system performance and to find the boundary conditions for its effective operational use.

3. RESULTS AND DISCUSSION

3.1 Operational needs and system design

The experience gained during the last 4 years using the IDA® technology, clearly shown the system is an operational tool supporting avalanche control services for the forecasting of avalanche hazard, the management of traffic routes during avalanche cycles and the verification of avalanche control. However, matching between specific needs of the avalanche control teams and the system performance and limits play an important role for a proper system design. The main hazards that should be monitored, e.g. the avalanche sizes and types that are relevant for forecasting, are some examples of site specific needs, while sensor position and geometry as well as custom calibration of the algorithm are some example of system design.

Operational needs criteria:

- ✔ Are the avalanche paths which are of, main and secondary, interest within the physical detection limits of IDA®? (Figure 2)
- ✔ What are typical characteristics of the avalanches (dry/wet, size, runout distance, etc.) and paths in the area of interest?

3.2 IDA® physical limitations

The comparison between IDA® detections and independent observations of avalanche occurrence collected by visual observers and/or cameras was used to the verify the performance of the IDAs.

However, due to limits and uncertainties of the classical avalanches observation (i.e. bad visibility, night, uncertain observation time, etc.) several of the IDA® detections could not be verified by the observations during the various campaigns, thus limiting the validation analysis to a semi-quantitative and qualitative estimate of the performance and highlighting the difficulties to obtain independent verification data to compare IDA® measurements to.

The overall semi-quantitative and qualitative results of these verification campaigns showed that mid-sized and large dry slab avalanches were detected with a Probability Of Detection (POD) of 40 to 90% within a 3 to 5 km radius (Figure 2). The POD is decreasing with increasing distance and decreasing of the avalanche size, with POD reducing to zero for small (size 1) avalanches.

Although both dry-snow, wet-snow and "mixed" slab avalanches as well as glide-snow avalanches were detected by IDA, the data indicates the detection capability for wet-snow avalanches is limited to larger sized events flowing over steep terrain, i.e. with larger accelerations, respect to dry one.

The experience gathered with the various operational installations and verification can be used as a guideline for planning new installations and to ensure the defined operational needs (Section 3.1) can be met.

3.3 IDA General and technical limitations

Site specific characteristics, e.g. large terrain features such as ridges, can significantly limit the performance of IDA® and should be avoided when choosing an adequate installation site.

In addition to site selection, it is crucial to calibrate the automatic algorithm criterion as well as tuning of the alert thresholds to the local conditions. Hendrikx et al. 2017 showed that the initial operational year 1 calibration can be increased for year 2 after the first representative avalanches, i.e. avalanches that fit the defined operational needs, were recorded. Based on a test installation at Rogers Pass Summit Hendrikx et al. 2018 showed an increase in POD after the algorithm calibration.

To fulfil operational needs of avalanche safety services, the system needs to work reliable, on a 24/7 basis and with minimal maintenance efforts during the entire winter season. It has proven to be challenging to guarantee system reliability (both hardware and software) due to the often-challenging environmental conditions. Improvements and tests of a variety of solutions have now resulted in a set-up that minimized hardware related issues. Yet, environmental effects, such as strong winds or thick melt freeze crusts inside the snow cover can reduce the performance of IDA®.

Especially in situations when the detection performance is reduced, and automatic detections are only partly possible or with reduced reliability manual analysis had to be performed throughout the season.

In addition to general technical considerations (e.g. power supply, communication) the following technical criteria should be considered:

- Typical seasonal snow cover at IDA location (temporal and spatial coverage, maximum snow depth, crusts, density, etc.)
- Potential noise from wind or other (natural and artificial) sources
- Tree cover (wind noise reduction, solar radiation on-site)
- Hazards for workers and system (flooding, extreme avalanche runout, rockfall, wildlife, access, etc.)

3.4 Notable operational events Winter 2017/18

The IDA® installations that had been used operationally in Winter 2017-18 recorded more than 700 avalanches (Figure 1). Some selected operational examples include:

- The avalanche control team of Quinto (Switzerland) did not only use the detections of IDA® for verification of artificially release avalanche with their RACS but also for monitoring the natural activity on the opposite side of the valley (Figure 1).
- IDA® Frutigen (Switzerland): This installation was a test installation to investigate the performance of IDA® in this (lower elevation) area. In a discussion with the local avalanche safety service, it was decided that the operational needs (detection of avalanches of mainly size 2 at distances up to 7 km) did not match the design and performance of IDA.
- IDA® Goms (Switzerland) and Rogers Pass (Canada): At both locations a large number of infrasound detections (artificial/natural avalanches and explosions) were recorded (IDA® Rogers Pass: 332 detections and IDA® Goms (Switzerland: (160 detections). Avalanche control teams considered the IDAs as a substantial operational benefit.

- ✔ At most sites IDA® provided reliable information on the onset and timing of avalanche cycles as well as real-time verification during ongoing avalanche control work

4. CONCLUSIONS AND OUTLOOK

Experience and independent verification campaigns have shown that infrasound detection of avalanches can be applied in an operational context – provided the operational requirements lie within the physical limitations of the system, the deployment site is adequately chosen and the system (hardware and software) works reliable throughout the season.

The presented infrasound system (IDA®) provided valuable data for local avalanche safety services by gathering information about avalanche activity of multiple avalanche paths in a larger area as well as reliable information for avalanche control verification. Typically, larger dry snow avalanches within a 3 to 4 km radius of the system can reliably be detected. Since it continuously monitors its surroundings it provides data on natural avalanche activity, which can be very useful information for the local avalanche control team. During major avalanche cycles, the system often provided more timely information on the start of the cycle.

The presented simplified overview of research results and operational experiences highlight the strengths and limitations of current IDA® systems and provide a benchmark for the design and installation of future operational infrasound systems.

In the future multi array-processing, with a similar setup as for the Goms installations, will allow to increase the location accuracy of this technology. Based on the experience gathered with the existing installations in challenging environmental conditions, and since most system interruptions were hardware related, based on the field experience a new hardware generation is currently under development (i.e. wireless infrasonic array) to further increase the system robustness and to facilitate its installation.

Merging and integrating with other technologies, such as other detection systems or (modelled) snow cover information, could also allow increasing overall reliability and accuracy. Recent developments in the algorithm of the presented infrasound system now also allow for a better detection of wet-snow avalanches.

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LIMITATIONS

The presented results are only valid for the applied technology (IDA®) and not necessarily for other radar, infrasound or seismic systems.

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