Operational avalanche detection systems: Experiences, physical limitations and user needs

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ABSTRACT
Due to the increased mobility demands of societies, long-lasting closures of traffic infrastructure are less and less accepted. The application of detection systems, such as radar or infrasound, allow a reduction of closure times combined with a reduction of residual risk. Especially in critical periods during the winter season these systems have proven to deliver very valuable information to an avalanche forecasting team. Especially when visual or other observations are hardly possible. A large variety of technology has been deployed and multiple verification campaigns within (local) avalanche control operations have been conducted over the years. The resulting datasets allow to provide a robust estimate of the physical limitations of each system. We present the physical limitations and the operational applications of commonly used detection systems with a focus on infrasound, radar and geophone systems. Case studies, based on different operational needs of the client, will illustrate how different detection systems are incorporated in optimized ways. An example of the importance of a simplified and user friendly user interface for the operators is illustrated.

En raison de la demande accrue de mobilité des sociétés, les fermetures durables de l'infrastructure de la circulation sont de moins en moins acceptées. L'application de systèmes de détection, tels que les radars ou les infrasons, permet une réduction des temps de fermeture combinée à une réduction du risque résiduel. Surtout pendant les périodes critiques de la saison hivernale, ces systèmes ont fourni des informations très précieuses à une équipe de prévision des avalanches. Surtout quand les observations visuelles ou autres ne sont guère possibles. Une grande variété de technologies a été déployée et plusieurs campagnes de vérification dans le cadre d'opérations de contrôle des avalanches (locales) ont été menées au fil des ans. Les jeux de données qui en résultent permettent de fournir une estimation robuste des limites physiques de chaque système. Nous présentons les limites physiques et les applications opérationnelles des systèmes de détection couramment utilisés en mettant l'accent sur les systèmes infrasons, radar et géophone. Des études de cas, basées sur différents besoins opérationnels du client, illustreront comment les différents systèmes de détection sont incorporés de manière optimisée. Un exemple de l'importance d'une interface utilisateur simplifiée et conviviale pour les opérateurs est illustré.

1 INTRODUCTION

Snow avalanches pose a direct threat for people and infrastructure during winter time. 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.). The preventive release of snow avalanches along traffic routes has been applied since many years as permanent measures are too expensive or not feasible to construct for certain areas. Furthermore, due to the increased mobility of people, long-lasting closures of roads and railway lines are less and less accepted. The preventive release methods are much more effective when the success of preventive releases can be verified reliably. The application of detection systems allows a reduction of closure time of roads in combination with a reduction of residual risk and aid the avalanche control team in their decision making. Site-specific alarm thresholds can be set for automatic closure of traffic lines. In addition, the knowledge of the occurrence, frequency and size of avalanche events can assist regional or local authorities who are responsible for the control and forecasting of avalanche hazard.

A variety of systems for the detection of avalanches was tested in recent years and 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 to protect, the most suitable system should be selected (Table 1).

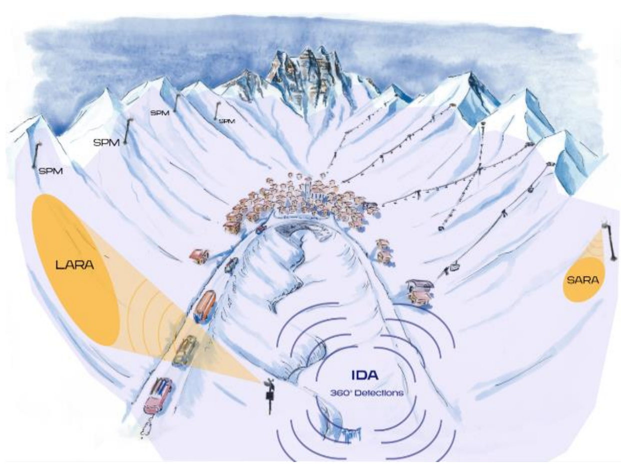

Figure 1. Overview of avalanche detections systems (infrasound, radar and geophones).

In this study we focus on gathered operational experiences and recent developments of infrasound, radar and geophone systems (Figure 1). Furthermore, the necessary incorporation of these systems in a practitioner-friendly and easy to operate platform is described. Other methods for the detection of avalanches exist, such as trigger lines in the path, but are not discussed in this paper. It is important to note that the presented results are only valid for the applied technology and not necessarily in general for other radar, infrasound or seismic technologies or products.

Table 1. Overview of different avalanche detection systems and their suitability for different operations.

	Preventive avalanche release	Alarm systems	Avalanche warning
	Verification of blasting result	Automatic closing of traffic routes	Verification of avalanche activity
Infrasound	✓	X	✓✓
Long Range Avalanche Radars	✓	✓✓	✓
Short Range Avalanche Radar	✓✓	X	-
Seismic systems: Seismometer, Geophone	✓	✓	-

2 OPERATIONAL SYSTEMS

2.1 Radar systems LARA and SARA:

Technical description:

Radars have been applied for the detection of avalanches for many years. In most cases (pulsed or frequency modulated) Doppler radars are used (Gubler and Hiller 1984, Gauer et al. 2007, Fischer et al. 2014), emitting electromagnetic waves at a certain frequency, which are then reflected and travelling back to the radar. To detect an avalanche by radar, the avalanche movement must at least partly be directed towards the radar, as the line-of-sight component of the velocity is measured. The avalanche velocity leads to a Doppler-shifted signal in frequency space, allowing the radar to discriminate between moving and static targets. Hence, avalanches can only be detected by radar once they are in motion.

Experience with LARA/SARA:

In 2011 Wyssen Avalanche Control AG installed the first version of the Long range Avalanche Radar, LARA, in Ischgl, Austria (Figure 2, left). The purpose of the radar installation was i) Verification of the controlled release and ii) Gathering information about spontaneous avalanche activity. Over the last years, the radar has been working very reliably and satisfactorily and it became a standard operational tool of the safety staff. Consequently, three more radars of the same type were installed in Austria and Switzerland. The big advantage of the radar is the accurate detection of even small avalanche events, e.g. preventively released ones. The shorter the distance to the radar antenna and the better the weather conditions (i.e. no rain, no snowfall), the smaller the detectable avalanches are (events of a few 100 m³ in a distance of 1.5 km were detected with radars of the newest generation). On the contrary, the monitored area is limited to the area within the beam of the radar antenna and therefore often only covers a few avalanche paths. Multiplexing with multiple antennas is possible and applied in some locations. However, it has some limitations as multiplexing more than two or three antennas can become difficult. Typically, measurements are taken once per second per antenna, i.e. with three antennas each antenna would be 'blind' for 2 seconds. Still, even three 5 degrees antennas only cover a limited area compared with the new 90°x10° radars.

The newest generation of long range radars (Range-Doppler Radar operating at the X band) have a lateral opening angle of 90° and 15° in vertical direction. Maximum operation distances are currently up to 5000 m (Figure 3). Power can be provided by fuel cells or by permanent power supply if available. To ensure the system reliability of the radars they are constantly monitored remotely and maintained on-site every year.

Since radar systems provide data in real-time, alarm thresholds can be defined which allows to also use the system for the automatic closure of traffic lines. Up to five independent algorithms look for patterns in the radar data that are typical for avalanches. Depending on the local requirements for detection probability and the tolerance for false alarms, between one and five algorithms are necessary to trigger an alarm.

Based on the success of the avalanche radar, short distance avalanche radars with less energy consumption was developed. They are mounted directly on remote avalanche control systems RACS such as the Wyssen avalanche towers (Figure 2, right) to get immediate information about the success of the avalanche release within the effective range of the system. This is a much-needed feature for verification of preventively released avalanches. Furthermore, other uses of this radar types, such as the detection of persons moving in the area endangered by avalanches, were successfully tested (Video: http://gpr.vn/PETRA).

By the end of winter season 2018 multiple long and short-range radar systems of the newest version have been installed and successfully operated in the Alps, North and South America to monitor both frequent spontaneous and also blasted avalanche events.

2.2 Infrasound system IDA

Technical description:

Infrasound waves are low frequency (<20 Hz) sound waves (pressure fluctuations) traveling through the air at the speed of sound (340 m/s). They occupy a relatively narrow frequency band (0.001 Hz – 20 Hz), too low to be perceived by the human ear. Very little attenuation travelling the atmosphere occurs compared to seismic waves propagating in the ground. For other applications, the infrasound technology is widely used for the detection of different natural (e.g. volcanic eruptions) and artificial phenomena (e.g. nuclear explosion). For avalanche monitoring the infrasound technology has significantly improved in recent years in terms of sensor design, noise reduction and processing algorithms (Bedard, 1994, Kogelning et al., 2011, Ulivieri et al., 2011, Thüring et al., 2015).

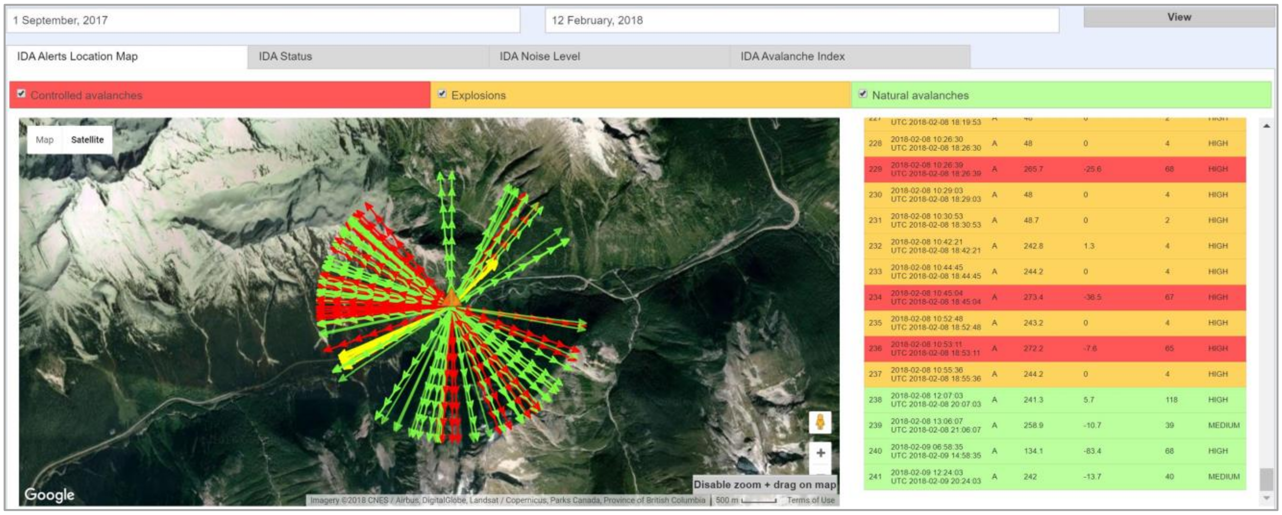

Figure 2. Example of infrasound detections at Rogers Pass (Canada). The system detects natural avalanches (green), controlled avalanches (red) and detonations from remote avalanche control systems RACS or artillery (yellow).

Typically, an infrasound detection system, such as the presented systems, consists of a 4 to 5-element infrasound array, with a triangular geometry and an aperture (maximum distance between two elements) of approximately 150 m (Marchetti et a, 2015). The sensors housings and cables can be buried in the ground which minimizes the environmental impact. During the winter season, the sensors are covered with snow, which further dampens ambient noise. This setup allows monitoring of the avalanche activity from all directions within a radius of 3 - 5 km.

Experience with infrasound:
To gather information on avalanche activity of a larger area and to assist the local avalanche control team an infrasound was firstly installed in 2012 in Ischgl, Austria. The goal was to gather information about avalanche activity from all avalanche paths in the area. The system worked very well already in the first year, and in the second year the detection capabilities could be even enhanced.
Based on this success additional systems were installed and currently four systems are used in Switzerland and three in Norway. Since 2016 an infrasound is very successfully operated at Rogers Pass in Canada and in Alta (USA).

In Switzerland, Canada and Norway extensive verification campaigns have been conducted over the last years (Humstad et al. 2016, Steinkogler et al. 2016). The system was used to monitor certain avalanche paths which endanger local roads and to define the smallest avalanche size which can be detected by the system. Although the system detected many of the smaller slides (size 1 – 2), they were not automatically visualized and identified as avalanches as they were below the defined thresholds. Mid-sized and large dry slab avalanches were correctly detected. In azimuth direction the detected avalanches fit the observations with an accuracy of ± 3°. Additionally, large dry avalanches could be detected up to 14 km away from the system.

Recent developments in the algorithm of the presented infrasound system now also allow for a better detection of wet snow avalanches. Strong ambient noise, such as wind, has shown to complicate the identification of the avalanche signal.

The presented system has been deployed in a variety of climatic conditions, ranging from a maritime climate in Norway to lower elevations and high inner-alpine regions in Switzerland and Canada. At one of the locations, more than two metres of dense (250-300 m^3) snow with several ice layers covered the sensors which influenced the quality of the signals. Yet, a generally thick snow cover, without ice layers, has shown to filter out unwanted frequencies and enhance the reliability of the system.

The infrasound system proved to be a very valuable tool for gathering information about avalanche activity of multiple avalanche paths in a larger area. Since it is continuously monitoring it also provides data on spontaneous avalanche activity, which can be very useful information for the local avalanche control team (Figure 4, green arrows). Often it allowed to observe the start of an “avalanche cycle” when indicator paths started to release naturally.

Table 1. Summary and technical details of radar, infrasound and seismic systems

	Radar systems	Infrasound system	Geophone systems
Measurement principle	Direct detection of motion within antenna coverage	Indirect detection of infrasound created by avalanche	Direct detection of ground vibrations induced by avalanche motion
Operational range	Up to 5 km	3 – 5 km	Approx. 50 m
Measurement angles	Up to 90° horizontal and 15° vertical	360°	360°
Max. detection range[1]	2 km	14 km	Approx. 100 m
Smallest avalanche size detectable in operational range	Small avalanches (~100m³)	> Mid-sized dry avalanche	Small avalanches (~100m³) if flowing over geophone
Detection of wet avalanches	Yes	Yes (if moving fast enough)	Yes

[1]of a large avalanche

2.3 Geophones

Technical description:
Geophones detect the ground vibrations induced by an avalanche in rather close distance to the sensor. So far, the installation of geophones was mainly done very close to the flowing path of the avalanche and the release areas. The detection of avalanches can be achieved via a rather simple amplitude threshold and allows reliable detections with approximately 50 m distance to the sensor.
Experience with geophones:
Seismic sensors have been applied for operational and research purposes since many years (Perez-Guillen et al. 2016). Recent research efforts applied seismic arrays which were deployed in avalanche release areas (Heck et al. 2017). Figure *3* shows and example where three geophones are deployed in the release area of a high alpine bowl. Remote avalanche control systems RACS allow to perform avalanche control during day and night and the geophones detect if an avalanche was released.

3 USER INTERACTION AND INTERFACE

For road authorities operating several avalanche release and detection systems, simplicity is one of the key demands. To satisfy this need it is important to gather and integrate all relevant information from remote avalanche control systems RACS (e.g. avalanche towers) and detection systems (e.g. geophones, radar, infrasound) and to visualize the results in a clear and simple way, making it possible to get a good overview at a glance using a mobile phone or laptop. Systems like the Wyssen Avalanche Control Center WAC.3 present the current state of the art and have been successfully applied in operational use for traffic route protection and ski resort management (Figure *3*).

4 RESULTS AND OPERATIONAL EXPERIENCE

From an operational point of view all systems have proven to have reached a technological level at which they work reliable, both in terms of system stability and avalanche detection performance and can significantly assist local avalanche control teams (Table 2). All 3 systems need a calibration period (a few avalanches of typical size for the avalanche path) to optimize the parameters and fine-tune to the local conditions and thus minimize false alarms. Generally, an intensive and well-prepared planning phase is essential to achieve the desired functionality and accuracy of the systems.

Systems as long range avalanche radars are very suitable to monitor a single or a few avalanche paths. Large avalanches were reliably detected and smaller avalanches, i.e. a few 100 m³, were detected up to a distance of 1.5 km in good weather conditions. Depending on the terrain, newer generation radars with a horizontal opening angle of 90° allow to monitor multiple avalanche paths. Additionally, the automatic alarm messages reliably inform the local authorities about natural avalanche activity in the corresponding path.

The presented infrasound system proved to be able to successfully monitor the avalanche activity of medium-sized to large avalanches in an area up to 5 km radius. IDA is also able to detect smaller avalanches although they are often not automatically displayed as they do not fulfill all the criteria by the processing algorithms. Furthermore, the accuracy of the system decreases for small avalanches. Small wet avalanches were not detected but larger ones are recorded by the infrasound system.

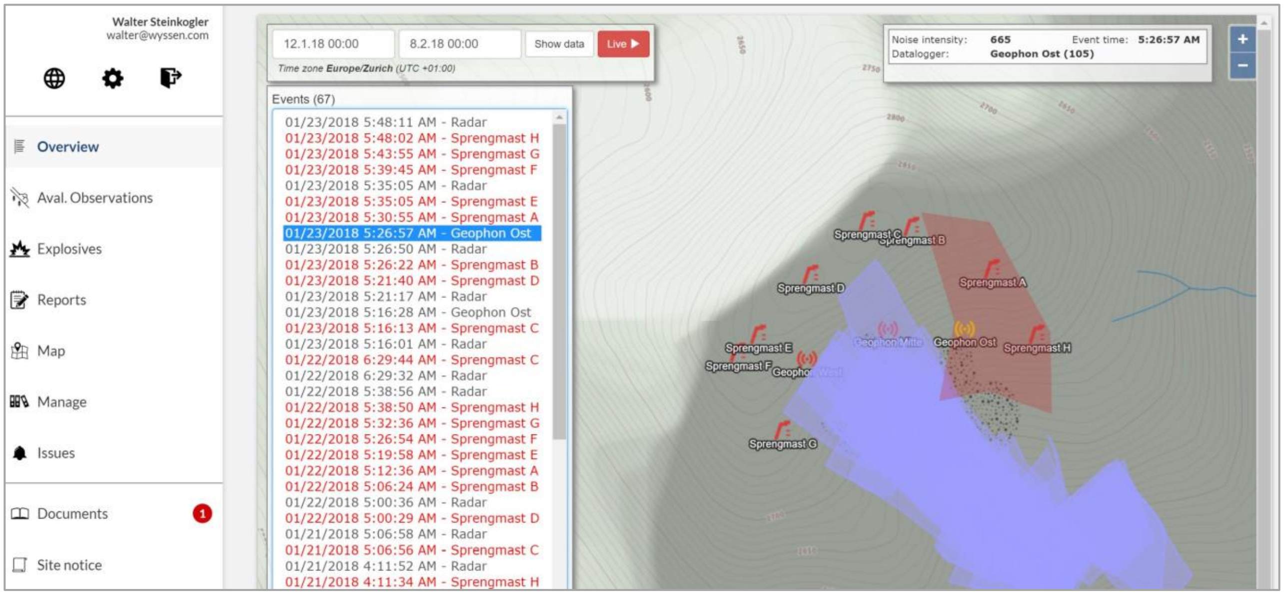

Figure 3. Integration of remote avalanche control systems RACS ("Sprengmast"), geophone ("Geophon West, Mitte and East") and radar (blue areas) detection systems in a user friendly and fast to operate web-based interface.

5 CONCLUSION AND OUTLOOK

Over the last years, the developments and advances of (infrasound, radar and geophone) avalanche detection systems and especially the integrated visualization worked very reliably and showed their capability to support the avalanche control work.

Recent verification campaigns and an increasing number of installations in different climatic regions have allowed to better define the technical capabilities of the systems. For the radar-based detection systems future data needs to be gathered on its operation during varying meteorological conditions (e.g. during wet snowfall and heavy rain).

LIMITATIONS

The presented results are only valid for the applied technology and not necessarily in general for other radar, infrasound or seismic technologies or products.

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