Avalanche detection systems: A state-of-the art overview on selected operational radar and infrasound systems

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ABSTRACT

The application of detection systems allow a reduction of closure time of roads in combination with a reduction of residual risk. Over the last years, the developments and advances of radar (LARA) and infrasound (IDA) avalanche detection systems and especially the integrated visualization (PIA) significantly improved the operational applicability and showed their capability to support the avalanche control work. In this work, we present results from operational experience and recent developments of these systems. The results from verification campaigns, such as minimum detectable size, longest distance of detection and detection of wet snow avalanches are discussed. Furthermore, we indicate current shortcomings and future development directions.

KEYWORDS

Avalanche Detection; Radar LARA/SARA/PETRA; Infrasound IDA; Integrated Visualisation PIA

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.

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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. Depending on the aim of the operation and the object to protect, the most suitable system should be selected (Table 1).

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

	blasting result	of traffic routes	avalanche activity
IDA Infrasound Detection of Avalanches	✓	X	✓✓
LARA Long Range Avalanche Radar	✓	✓✓	✓
SARA Short Range Avalanche Radar	✓✓	X	-
Seismic systems: Seismometer, Geophone	✓	✓	-
Mechanical systems: trigger line, rope with pendulum	X	✓✓	X

In this study we focus on gathered operational experiences and recent developments of radar (LARA, SARA, PETRA) and infrasound systems (IDA) (Figure 1). Furthermore, the inevitable incorporation of these systems in a practitioner-friendly and easy to operate platform (PIA) is described. Other methods for the detection of avalanches exist, such as geophones in the release area or along the path, or trigger lines in the path, but are not discussed in this paper as here we focus on remote detection methods.

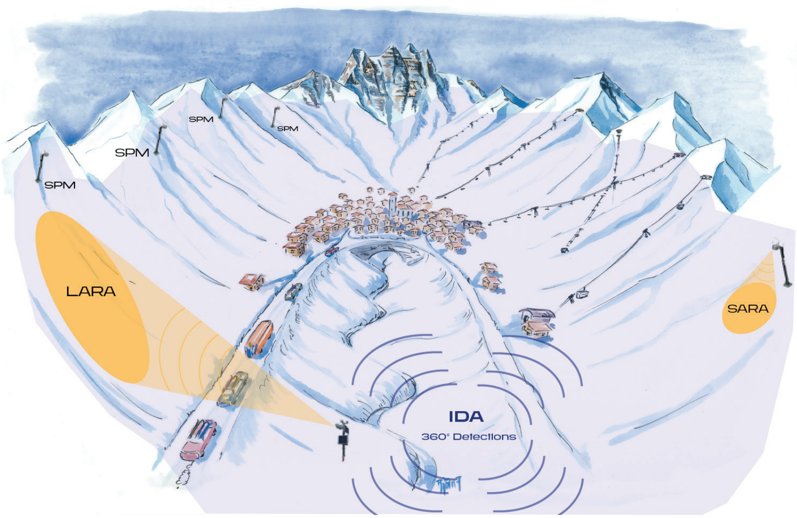

Figure 1: Schematic overview of operational radar (LARA, SARA) and infrasound (IDA) detection systems.

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 m^3 in a distance of 1.5 km were detected with radars of the newest generation). On the contrary, the monitored area is limited to one single avalanche path. 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' during 2 seconds. Still, even three 5 degrees antennas only cover a limited area compared with the new 90°x10° radars.

Figure 2: A LARA (left) and a SARA (right) installation used for avalanche detection for operational road protection.

To account for the limited size of the monitoring area, a new radar system with a much wider opening angle (up to 90°) was tested to account for this shortcoming. The newest avalanche radar version is a Range-Doppler Radar operating at the X band, with the ability to measure azimuth angle, range and velocity. It has an opening angle of 90° horizontally and 10° vertically and captures all movements within this area (Figure 3). It can detect a large avalanche up to a range of 2000 m (LARA) or 500 m (SARA), covering an area of up to 1 km^2 (LARA). 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.

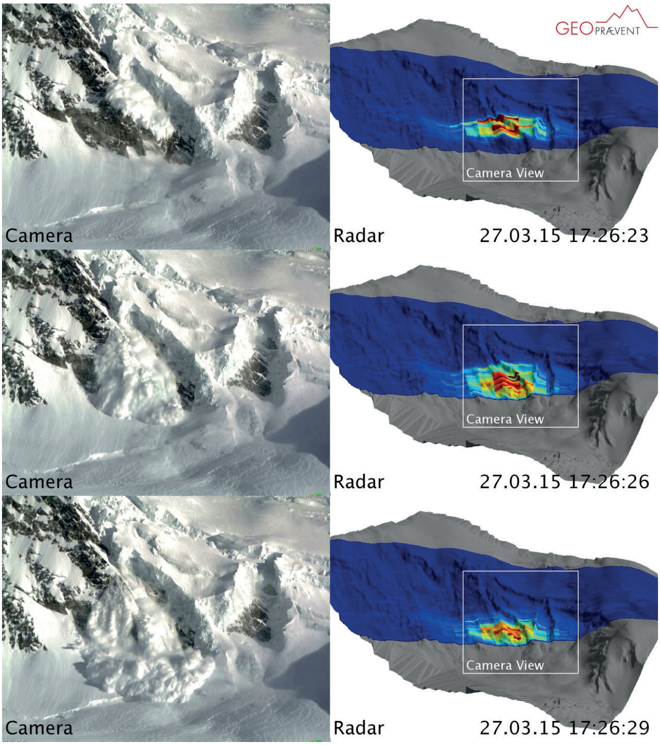

Figure 3: Example of LARA of newest generation monitoring an ice avalanche. Camera view of moving avalanche (left) and corresponding radar image (right, colors showing signal strength).

Based on the success of the avalanche radar, the Short distance Avalanche Radar SARA with less energy consumption was developed. It was mounted directly on 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 SARA, such as the detection of persons moving in the area endangered by avalanches, were successfully tested (Video: http://gpr.vn/PETRA).

Between November 2014 and now, SARA/LARA systems of the newest version have been installed at six different locations. Three SARAs were mounted on Wyssen Avalanche Towers, and three LARAs were installed at locations where frequent spontaneous and blasted avalanche events occur. One of these locations is the Triftglacier at Weissmies (Figure 3), where a variety of other detection systems are deployed (see L. Preiswerk et al, INTER-PRAEVENT paper). In total, about 10 terabytes of data were gathered and more than 200 avalanches identified (Video: http://gpr.vn/LARA).

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).

Typically, an infrasound detection system, such as IDA, consists of a 4-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 are 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 IDA:

To gather information on avalanche activity of a larger area and to assist the local avalanche control team an IDA 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 IDA 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 two in Norway.

In Switzerland an extensive verification campaign was conducted in Winter 2014/15. IDA was used to monitor certain avalanche paths which endanger a local road 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 azimut 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 IDA system.

In the case of wet snow avalanches some of the larger events were not detected by IDA automatically. Yet, post-processing of the data revealed that the system recorded the avalanches but the signal did not fulfill the detection criteria, which were defined for dry slab avalanches. Even though the main source of infrasound from avalanches is produced by the powder cloud, these results indicate that larger wet snow avalanches do produce enough infrasound to be detected by IDA. Strong ambient noise, such as wind, has shown to complicate the identification of the avalanche signal.

Furthermore, the IDA system was also tested if it is also suitable for use in climatic conditions of high alpine areas in Norway. Multiple avalanches were automatically detected and several others by post-processing of the data after the season. 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. Therefore, the overall impact on the system due to large snow depths will be further investigated in the next winter season.

IDA proved to be a very valuable tool for gathering information about avalanche activity of multiple avalanche paths in a larger area. Since IDA 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).

PLATFORM OF INTEGRATED AVALANCHE INFORMATION PIA:

For road authorities operating several avalanche release and detection systems, simplicity is one of the key demands. In order to satisfy this need, an interdisciplinary project was launched in 2013 to develop an online information platform, PIA, Platform of Integrated Avalanche information. The goal was to gather relevant information from avalanche release systems (e.g. avalanche towers) and detection systems (e.g. geophones, LARA, IDA) 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. PIA has been successfully applied in operational use for road protection in Gonda, Switzerland since winter 2013/14 (Figure 5).

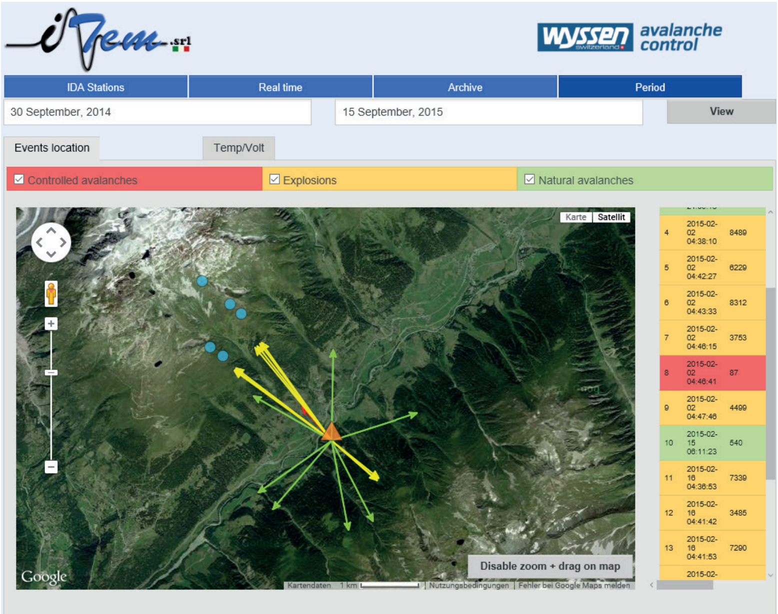

Figure 4: Online map visualization of the IDA system showing preventively released avalanches (red arrows), explosions (orange arrows) and natural avalanche activity (green arrows). Blue circles indicate positions of preventive avalanche release systems.

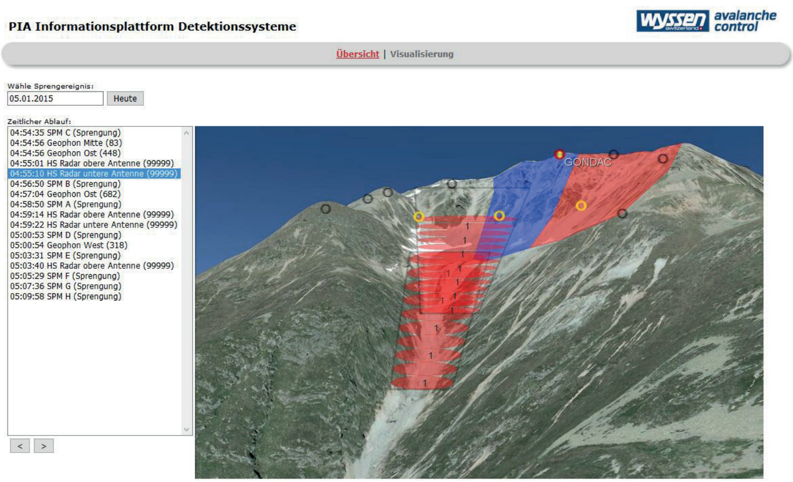

Figure 5: PIA platform showing an operational example of artificial avalanche release and verification for the Gonda avalanche (Switzerland). Black circles indicate the positions of preventive avalanche release systems along the ridge with the red circle and text, e.g. GONDAC, showing the last detonated avalanche tower in the current list of events (left). Yellow circles are geophone locations and red and blue filled areas indicate areas where geophones detected motion. Black rectangles along the path indicate the area monitored by the two radar antennas with detected avalanches in red ellipsoids

RESULTS AND OPERATIONAL EXPERIENCE

From an operational point of view both 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). Both systems need a calibration period (a few avalanches of typical size for the avalanche path) to optimize the alarm 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 LARA are very suitable to monitor a single avalanche path, such as the Gonda avalanche path in Figure 5. Large avalanches were reliably detected and smaller avalanches, i.e. a few 100 m^3, were detected up to a distance of 1.5 km in good weather conditions. Depending on the terrain, the new LARA generation with a horizontal opening angle of 90° allows to monitor multiple avalanche paths (Figure 3). Additionally, the automatic alarm messages reliably inform the local authorities about spontaneous avalanche activity in the corresponding path.

The infrasound system IDA 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 IDA system.

Table 2: Summary and technical details of radar and infrasound systems.

	Radar (LARA; SARA; PETRA)	Infrasound (IDA)
Measurement principle	Direct detection of motion within antenna coverage	Indirect detection of infrasound created by the avalanche
Operational range	0 - 2 km	3 – 5 km
Measurement angle	Up to 90° horizontal and 10° vertical	360°
Max. detection range[a)]	2 km	14 km
Smallest avalanche size detectable in operational range	Small avalanches (~100m^3)	> Mid-sized dry avalanche
Detection of wet avalanches	yes	Partly (better with new algorithm)

[a)] of a large avalanche

CONCLUSIONS AND OUTLOOK

Over the last years, the developments and advances of (radar and infrasound) avalanche detection systems and especially the integrated visualization (PIA) 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 (LARA, SARA, PETRA), future data needs to be gathered on its operation during varying meteorological conditions (e.g. during wet snowfall and heavy rain).

For the infrasound system (IDA), the influence of wind is challenging. A new sensor generation in combination with optical fiber cables will allow for a much better signal-to-noise ratio and looks promising to improve the system performance. As large wet snow avalanches were recorded by the system but not automatically classified them as avalanches, an adaptation of the processing algorithms should allow to also detect these avalanches.

A further improvement of the IDA system will be an index for the general avalanche activity in the area with much less strict filters in the algorithms. Even though this will possibly result in a higher false alarm rate, this should allow measuring a general increase in avalanche activity in the observation area (also of smaller avalanches).

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