AVALANCHE DETECTION SYSTEMS FOR OPERATIONAL USE: SUMMARY OF THREE YEARS EXPERIENCES

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ABSTRACT: Avalanche detection systems have become more popular in recent years, however few people know of their capabilities and limitations. This article summarizes experiences gathered with the two most promising technologies for avalanche monitoring, radar and infrasound, in operational use for the last three years. In 2011 Wyssen Avalanche Control installed their first avalanche detections system, a Doppler Radar unit called LARA, in combination with avalanche towers in Ischgl, Austria. The purpose of the radar installation was i) Verification of the controlled release and ii) Gathering information about spontaneous avalanche activity. After some initial problems the system worked very satisfying the past three winters. The radar has the capability to detect also small avalanches (e.g. artificially released) very reliable. Up to now, five LARA systems are installed in Austria and Switzerland. Additionally, for a more widespread information, in 2012 IDA, an infrasound array consisting of 5 sensors, was installed, also in Ischgl, Austria. The infrasound technology allows monitoring of avalanche activity from all directions. The goal was to gather information about avalanche events from all avalanche paths in the area, to assist the local avalanche control team. Over the last years, these avalanche detection systems worked very reliable and showed their capability to support the avalanche control work.

KEYWORDS: detection, radar, infrasound, avalanches.

1. INTRODUCTION

Temporary avalanche protection methods such as controlled avalanche release and detection become increasingly important in the Alps (Rudolf-Miklau et al. 2011). With the technological development in computational power, sensors and data transmission, detection systems have become more capable, easier to install and maintain and better visualization methods are available. State of the art technology nowadays enables very small and robust installations, which can operate in temperature ranges from -40° up to 70° with very low power consumption, enabling supply by fuel cell or sometimes even solar panels are sufficient.

Data is automatically transmitted using the mobile network and most commonly visualized on a webpage. With these technologies detection systems allow a reduction of closure time of roads in combination with a reduction of residual risk. The experiences show that if using controlled avalanche release methods, a verification of the actual blasting result is often hard to achieve due to bad visibility. Detection systems can assist in such situations for the verification of blasting results, providing important information for the avalanche control team for decision-making. On the other hand detection systems are running 24/7, providing also a lot of information about natural avalanche activity, which can assist in avalanche forecasting or hazard assessment.

Currently there are a few different technologies existing, but not all of them work reliable and their specific capabilities and usage is often unknown. Therefore the present paper gives an overview over the most common technologies (radar and infrasound) nowadays used in the Alps for avalanche detection and their physical principles.

2. DETECTION FUNDAMENTALS

If a monitoring or detection systems should assist mitigating an avalanche problem, several factors have to be considered.

First of all the Geology, Topography, Vegetation and Distance source-receiver, has to be taken into account in order to choose the right sensor. Moreover a good spot for installation (safety, power supply, data transmission) has to be found.

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Data transmission nowadays is often done by means of mobile network, which has the advantage of relatively high transmission rates and high reliability but on the other hand does not guarantee 100% availability, especially in catastrophic scenarios. If a redundant and time-sensitive (< 2s) alarming is needed radio, transmission is more applicable.

Alarm systems generally have the purpose to automatically close an endangered area as e.g. a road or railway by means of traffic lights. Mandatory is a sufficient pre-warning time to enable a closure/evacuation of the endangered area in time. This means that vehicles can be stopped in time outside of the endangered area or do have enough time to pass through, before the avalanche hits the road. In consequence, events have to be detected in an early stage, right after the release (Gubler H., 1999).

Monitoring systems in contrast are not that time-sensitive (> 2 min). They provide information for decision-making, but the decision itself is still made by human beings.

3. RADAR

3.1 Radar Basics

Radars have been used for many years for avalanche detection or monitoring. Most of the time, Pulsed Doppler Radars are used, emitting electromagnetic waves at a certain frequency, which are then reflected and travelling back to the radar.

In order for an avalanche to be detected by the radar, the avalanche movement must be towards the radar. This means the radar must be installed on the opposite side, facing the avalanche path. Through the movement of the avalanche, the electromagnetic waves are reflected by the avalanche front with a frequency shift proportional to the velocity of the avalanche. Therefore the radar can only detect an avalanche, as soon as it starts moving.

The maximum detection range of radar systems nowadays is approximately 2 km. Depending on the type of antenna and the distance, the monitored area is a stripe of 150 m to 200 m width. This means, most of the time only a part of the avalanche starting zone or the channel can be observed. Through modulation and analysis of the electromagnetic waves, the radar can measure distances and hence divide the avalanche path into different sections, so called “range gates”. This allows in consequence using only some of the sections for signal analysis. False alarms are significantly reduced by this technique because sections causing a lot of interfering signals can be neglected. Further information about Doppler radar and range gates can be found in Gauer (2007) and Rammer (2007).

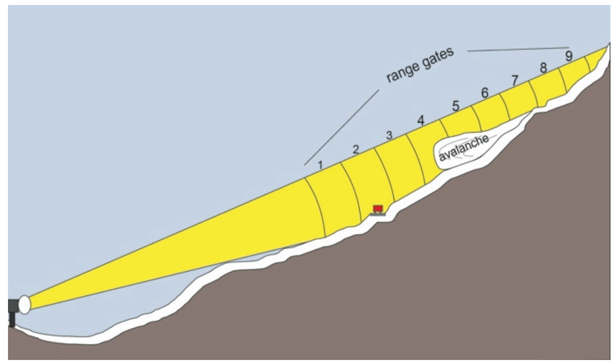


Figure 1: The radar offers the possibility do divide the monitored area into different sections, so called „Range Gates“.

3.2 Avalanche Radar LARA

Up to now four avalanche radars have been installed in Switzerland and Austria. All of them were installed in combination with artificial avalanche release systems for road protection; in consequence their primary goal is verification of the blasting results. However, it turned out, that they deliver valuable information about natural avalanche activity as well.

The main challenge is to find a good spot for the radar installation on the opposite site of the avalanche path, with a clear line of sight to the track. A power connection is preferable, as the radar has relatively high power consumption. Otherwise a combination of fuel cell and solar panels is needed, which has been implemented once, but is significantly more costly.

The LARA avalanche radar has the possibility to send an alarm as an email or text message in case of exceedance of predefined threshold values. Otherwise the data is visualized on a webserver.

3.3 Radar Projects

The first radar device was installed at the Grosstal avalanche path in Ischgl, Austria in 2011. The avalanche radar is installed down in the valley bottom, focused on the starting zone and the upper track of the Grosstal avalanche (Fig. 2). It is placed next to a tennis court, which allows power supply by cable and good coverage of mobile network. In addition, the place is easy to reach also in wintertime, which was crucial within this pilot project for control and maintenance.

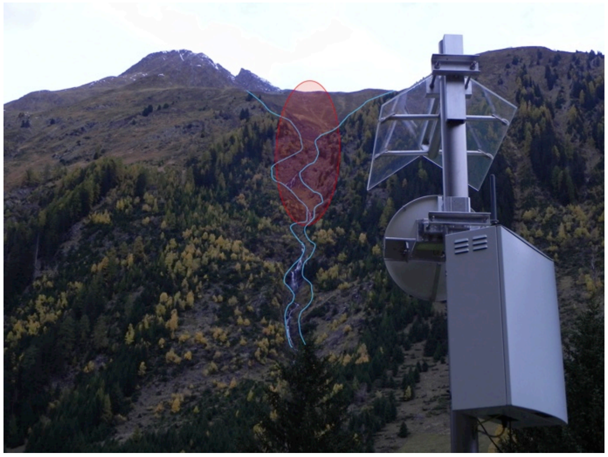


Figure 2: LARA avalanche radar installed in Ischgl, Austria. The red ellipse marks the monitored area and the blue lines the avalanche path.

The winter first 2011/2012 was characterized by remarkably high snowfalls in Austria, and therefore a good evaluation of the system was possible. At the beginning a few false alarms were sent and in consequence it was necessary to calibrate the automatic detection parameters to the environmental conditions. False alarms were caused by strong winds, producing vortices of snow particles in the starting area of the Grosstal avalanche. The challenge was to define the automatic alarm parameters in a way that they are not triggered by these snow vortices, but that already small, artificially released avalanches are detected.

Table 1 gives an overview of the avalanches and alarms during winter season 11/12. The third column lists the alarms, whereas "Yes" indicates that the radar detected the avalanche, "No" indicates that the radar did not detect the avalanche and "False Alarm" indicates that there was an alarm but no avalanche. After a calibration phase of one month (December 2011) and a few false alarms the alarm parameters were adjusted and the radar worked reliable during the rest of the winter. Also in the two following seasons the radar worked very reliable without false alarms or the need of recalibration.

Similar experiences were made also on the other radar installations. At the beginning a few avalanches and bad weather situations are needed in order to calibrate the alarm parameters to the local conditions.

Table. 1: List of alarms winter 2011/12. "Yes" meaning avalanche detected, "No" avalanche not detected and "False Alarm" alarm but no avalanche.

Date	*Time*	*Alarm*
07.12.2011	unknown	Yes
08.12.2011	unknown	False Alarm
17.12.2011	unknown	Yes
17.12.2011	unknown	Yes
22.12.2011	15:34:26	No
22.12.2011	17:18:00	No
30.12.2011	10:17:30	No
31.12.2011	17:18:00	False Alarm
31.12.2011	23:25:04	Yes
05.01.2012	13:41:38	Yes
06.01.2012	06:51:49	Yes
06.01.2012	17:43:41	Yes
08.01.2012	14:15:37	Yes
11.01.2012	15:21:15	Yes
20.01.2012	17:01:05	Yes
22.01.2012	03:35:43	Yes
15.02.2012	12:38:03	Yes
15.02.2012	18:27:31	Yes
15.02.2012	19:54:17	Yes
16.02.2012	08:35:31	Yes
24.02.2012	19:19:13	Yes
23.03.2012	16:23:44	Yes

Most of the time the local avalanche control team is using the web visualization of the radar, as they are sitting anyway in front of the computer, during the use of the artificial release systems. The automatic alarm text message gives information about natural avalanche activity and it is possible to view the data on a computer and get more details (size/run-out length) about the event.

Following the promising results of the first winter of the Ischgl radar, a second one was installed in summer 2012 in Kaunertal, Austria. Again in combination with an avalanche tower, for road protection with temporary measures. The third avalanche radar in Austria was installed in summer 2013 in combination with 3 avalanche towers in Kappl (road protection).

The fourth radar was installed at the Gonda avalanche (Engadin) in Switzerland in autumn 2013. The challenge was the installation at an altitude of 2324 m, with an autarky power supply, a combination of fuel cell and solar panels (Fig. 3).

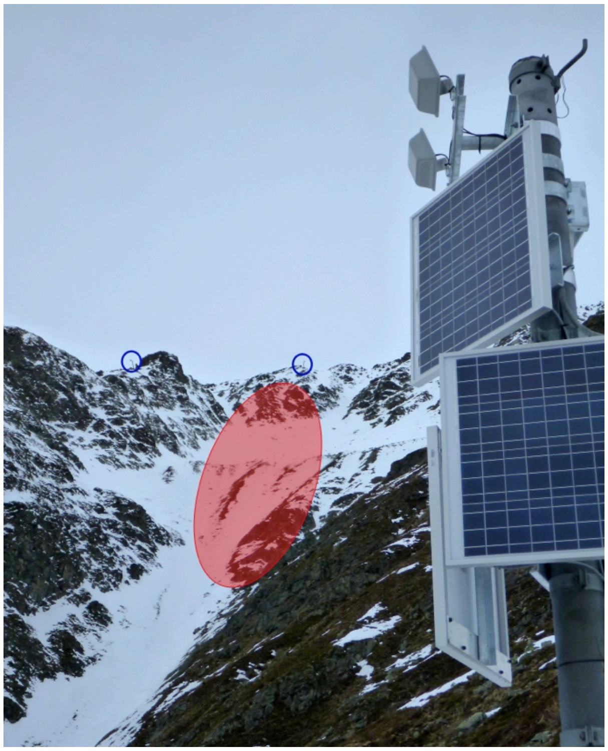


Figure 3: LARA avalanche radar installed at the Gonda Avalanche, Switzerland. The Radar device is hidden behind solar panels (top right). The red ellipse marks the monitored area and the two blue circles, two of the eight avalanche towers.

3.4 *Summary Radar*

The general experiences made with the radar are very good. It detects very small avalanches, e.g. artificially released and is working very reliable, even in severe weather (Lussi et al. 2012).

Most important is to consider already in the planning phase, the calibration period of the radar. The radar needs a few avalanches (2-4) of typical size and at least one month of data, including standard weather situations, to fine-tune the alarm parameters to the local conditions and minimize false alarms. In Kaunertal, the second radar installation in Austria, the first winter happened to be very dry with almost no avalanche activity at all. In this case it was not possible to define the final parameters in this season.

Limitations of the radar are the detection range of max. 2km and the width of the monitored area with ca. 170 m. In most of the cases this is not enough to cover the whole area and the most important spot within the avalanche track has to be chosen. Typically this is the upper part of the avalanche track, where the starting zone is converging to a channel.

4. INFRASOUND

4.1 *Infrasound Basics*

Infrasound technology is widely used for detection of different natural (e.g. volcanic eruptions, meteorites, earthquakes, etc.) and artificial phenomena (e.g. explosions, nuclear explosions, sonic boom, etc.). Infrasound waves are low frequency (< 20 Hz) sound waves (pressure fluctuations) travelling through the air at the speed of sound (344 m/s, at standard temperature and pressure). They occupy a relatively narrow frequency band (0.001 Hz - 20 Hz) too low to be perceived by the human ear. Compared to seismic waves propagating in the ground facing strong attenuation, infrasound has very little attenuation travelling in the atmosphere and can therefore be still be detectable after thousands of kilometers.

An infrasound system typically consist of a 5-element array, with a triangular geometry and an aperture (maximum distance between two elements) of approximately 130 m. The central unit (Fig. 4) is a small hut with power supply by solar panels and fuel cell, data storage and data transmission using the mobile network.

4.2 *Infrasound detection of avalanches*

Previous studies that are documenting infrasound emissions of avalanches exist (e.g. Bedard, 1994, Naugolnykh and Bedard, 2002, Kogelnig et al. 2011). However, the usage of infrasound as an operational avalanche detection tool is rare (Chritin et al., 1996, Scott et al. 2007, Ulivieri et al. 2011). This is mainly because infrasound is strongly contaminated by noise produced by natural (wind, earthquakes) and artificial sources (planes, helicopters, industry).

In the last two decades, infrasound technology has been improving greatly, in terms of sensor design, noise reduction systems and processing procedures (Ulivieri et al. 2011).

4.3 *Infrasound Projects*

The first infrasound monitoring system was deployed in Ischgl, Austria in the winter season 12/13. The array was installed in the forest on the valley bottom, close to the radar unit (see Chapter 3.3) and with different avalanche paths nearby. During the wintertime the infrasound sensors are covered with snow, which further dampens ambient noise.

Figure 4: Central element of the infrasound station with power supply, data storage and data transmission units.

Figure 5: Single sensor element deployed in the field.

This first winter season was used to compare the numerous detections of the infrasound system, not only avalanches, with the detections of the radar and the documentations of the local avalanche control team. In consequence the alarm parameters could be modified to minimize false alarms.

The results were quite promising as many avalanches could be detected, also in springtime. The most important criteria for an avalanche to be detected by the infrasound array is size, small snow slabs, moving for only up to 150 m are not detected. Similar to small wet snow slides, which are moving only few meters and not leaving the starting zone.

Avalanches, which were big enough to enter the track or even reach the runout zone down the valley, were clearly detected by the infrasound array.

After the promising results of the first test winter in Ischgl, a second infrasound array was installed in Goms Switzerland. Again the detections of the IDA system were verified by observations of the local avalanche control team. Similar to Ischgl the results were very good, the system was monitoring natural avalanche activity as well as artificially released avalanches.

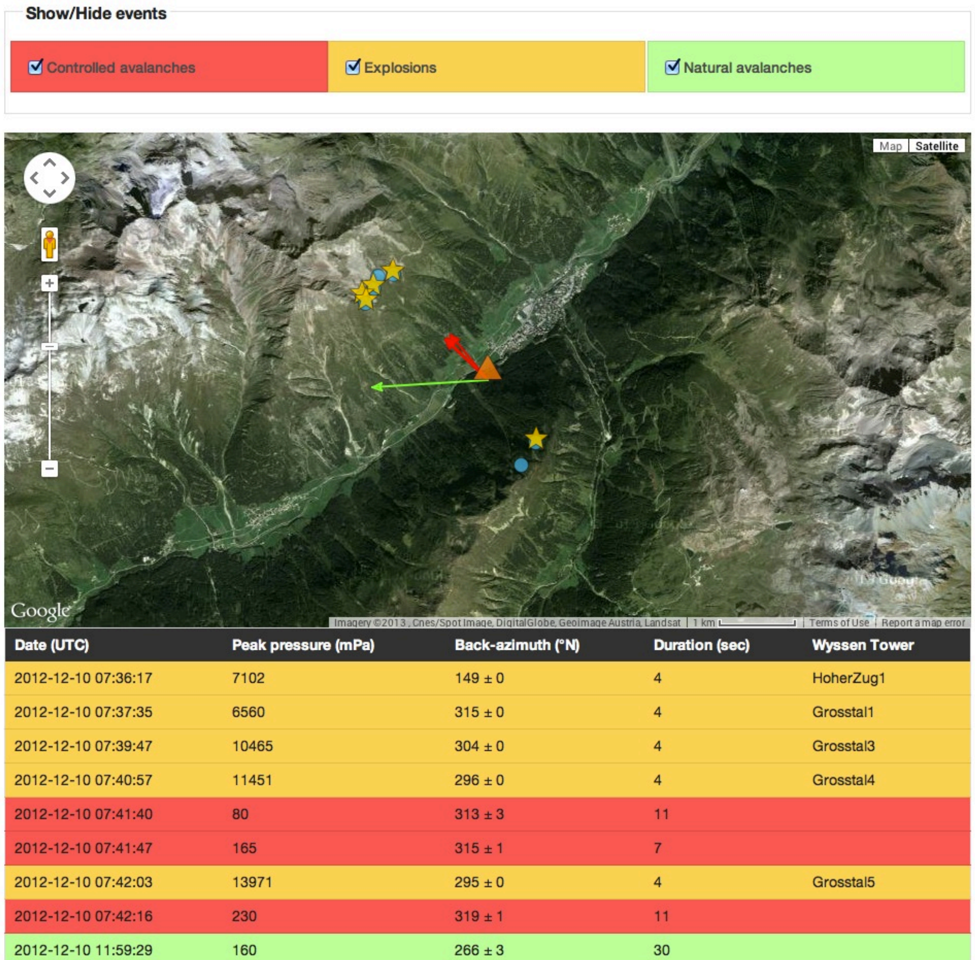
4.4 Infrasound Summary

The general experiences with the infrasound system were very good. Especially the presentation of the detections on the web-application is very easy to use and it is accessible by PC, tablet or smartphone. Figure 6 gives an overview over the web application. The data can be viewed on a Google Maps background with arrows indicating the direction of detections and yellow stars indicating the detection of detonations of the avalanche towers.

Below the map is a table with date, time, azimuth and duration of the detections. The red colour indicates controlled released avalanches, determined simply by knowing the azimuth of the artificially controlled paths. The yellow colours indicate the explosions of the different avalanche towers, which are clearly recognized according to amplitude, frequency content and correspondence with the azimuth of the artificially controlled paths. Finally, the green colours indicate natural avalanche activity, that's all the detections compatible with the infrasound produced by an avalanche and not preceded by detonations.

Using only one infrasound array, it is not possible to determine a clear location. The array processing allows definition of the directions. In case the avalanche path is near the array, e.g. on the opposite site, the direction indication will clearly point to an avalanche path (e.g. red arrow Fig. 6). But if the avalanche paths are further away to the east or west of the valley, the direction arrow will most probably be less accurate (e.g. green arrows Fig. 6). However, for people knowing the local terrain, still valuable information.

One thing to consider is the occurrence of different avalanches at the same time. In this case the bigger avalanche producing higher amplitude infrasound signal masks the smaller avalanche signal. In consequence if multiple avalanches occur at the same time only the biggest one will be detected by the array.



Date (UTC)	Peak pressure (mPa)	Back-azimuth (°N)	Duration (sec)	Wyssen Tower
2012-12-10 07:36:17	7102	149 ± 0	4	HoherZug1
2012-12-10 07:37:35	6560	315 ± 0	4	Grosstal1
2012-12-10 07:39:47	10465	304 ± 0	4	Grosstal3
2012-12-10 07:40:57	11451	296 ± 0	4	Grosstal4
2012-12-10 07:41:40	80	313 ± 3	11	
2012-12-10 07:41:47	165	315 ± 1	7	
2012-12-10 07:42:03	13971	295 ± 0	4	Grosstal5
2012-12-10 07:42:16	230	319 ± 1	11	
2012-12-10 11:59:29	160	266 ± 3	30	

Figure 6: Web-application of the infrasound system, showing artificially controlled avalanches with red arrows, the explosions with yellow stars and the natural avalanche activity with green arrows.

It is planned to operate the IDA systems again in the coming winter season in Austria and Switzerland, with an automatic alarm text message to the local police and the local avalanche control team. Moreover three more arrays will be installed in Switzerland and Norway.

5. CONCLUSIONS

This paper summarizes the experiences made with infrasound and radar technology for the detection of snow avalanches. Both technologies proved their capabilities in the last three years on different spots in the Austrian and Swiss Alps. However, every system has its pros and cons to consider. LARA, the avalanche radar can detect avalanches very precise within seconds and is therefore suitable for automatic road closures. On the other hand the detection range of the radar is 2 km with a limited monitoring width of ca. 170 m. IDA the infrasound system can monitor a bigger area (ca. 3 -5 km) and locate the origin of the avalanche signal. However, small snow slabs, especially under severe weather conditions are not detected well. The experiences showed, that avalanches of a size relevant for roads are detected well. The events are shown within 2 min, therefore the IDA system is not suitable for automatic road closures, as it is simply to slow. However, it proved to be a great tool for providing information about natural avalanche activity for risk assessment.

Therefore it is necessary to clearly assess the local situation and evaluate which system suits best.

CONFLICT OF INTEREST

The first and second authors of this paper are employees of Wyssen Avalanche Control AG and are involved in the sales of avalanche control products such as avalanche towers and avalanche detection systems.

The second and the third author of this paper are employee of Item s.r.l. and are involved in the development of the IDA infrasound system.

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