REAL-TIME AVALANCHE DETECTION WITH LONG-RANGE, WIDE-ANGLE RADARS FOR ROAD SAFETY IN ZERMATT, SWITZERLAND

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ABSTRACT: Two notorious avalanche gullies threaten the only access road to Zermatt, Switzerland. Avalanches are released artificially by helicopter blasting whenever conditions permit, and a system of trigger lines has offered additional protection for the last 30 years. In December 2015 we replaced the trigger line system with a state-of-the-art radar-based detection system. Located on the opposite side of the valley, two Doppler radars detect avalanches in the gullies within an area of about two square kilometers at a distance of up to 2,000 m.

The data from the Doppler radars is analyzed in real-time. As soon as an avalanche is detected, five stoplights immediately turn red and four barriers are lowered to block access to the sections of the road at risk. Local authorities are alerted by voice and text messages and can instantly verify the location of the avalanche and the distance it traveled on a password protected website. They can also access three webcams that offer live images of the threatened road sections to see if they are covered by avalanche debris. If the road is clear, traffic lights and barriers can be reset from any computer or mobile device, reducing the time needed to reopen the road to just a few minutes. Between December 2015 and April 2016, the system detected 27 avalanches without any false alarms.

KEYWORDS: avalanche alarm system, road safety, radar, avalanche detection

1. INTRODUCTION

The only access road to Zermatt, Switzerland's prime mountaineering and skiing destination, is threatened by two notorious avalanche gullies at the entrance to the town. Most tourists travel to and from Zermatt by train, and the railway line is well protected by an avalanche gallery. The cantonal road, however, essential to residents and commercial vehicles as well as buses and taxis, is not protected by any physical structure. Large avalanches that reach the road are rare, but do happen every few years.

To ensure road safety, avalanches are released artificially by helicopter blasting when visibility and meteorological conditions permit. For the last 30 years, a system of several trigger lines protected the road when helicopter flights were not possible. After each avalanche, the trigger lines needed to be replaced, requiring technicians to access the steep slopes. Not only did this system put the staff at risk, but it also meant that at times the road had to be closed entirely until the lines could be renewed.

In 2015 we replaced the trigger lines with a new system that prevents unnecessary road closures and no longer requires sending technicians into hazardous terrain. The new system uses Doppler radars to detect avalanche activity. Radar detection is advantageous because it can cover a large area from a distance and is largely unaffected by low visibility conditions.

A variety of avalanche detection systems have been described in scientific literature, making use of geophones (e.g. Van Herwijnen and Schweizer, 2011; Valt and Pesaresi 2009), infrasound sensors (e.g. Thüring et al., 2015; Kogelnig et al., 2013), acoustic fiber optic sensors (Prokop et al., 2013), as well as Doppler radars (Kogelnig et al., 2012; Meier and Lussi, 2010). Drawing on these technologies, Gubler (2000) has pioneered efforts to combine avalanche detection and road closure with medium-range radars.

The aim of this paper is to describe the first application of a long-range, wide-angle radar based avalanche detection system that is integrated into a fully operational warning system that detects avalanches and closes the road without human intervention.

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2. SYSTEM DESCRIPTION

2.1 System setup

Zermatt is located in southern Switzerland, in the canton of Valais. Surrounded by many of Switzerland's highest peaks, it is an important tourist destination, registering more than 2 million overnight stays every year with a year round population of roughly 6,000. The cantonal road leading from Täsch to Zermatt hugs the west side of the valley below cliffy slopes that are persistently steeper than 30 degrees (pink areas in Fig. 1).

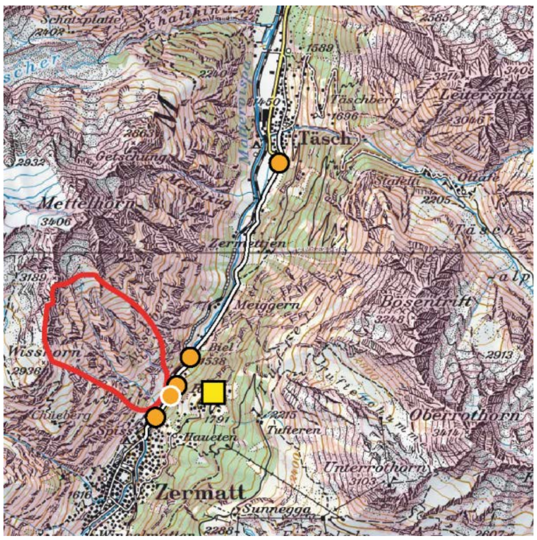

Fig. 1: Location of Zermatt, Täsch and the monitored avalanche gullies (red outline). Areas shaded in pink are steeper than 30 degrees. Orange dots are stoplights with cameras (white outline = no camera), the radar system is placed at the yellow square. Map source: Swisstopo

Starting at an altitude of around 2800 m a.s.l, the avalanche gullies *Lüegelti* and *Schussloubina* end right above the cantonal road, more than 1,000 m below. In order to detect avalanches in these gullies, we mounted two Doppler radars and a camera on the opposite side of the valley, keeping all technical components and personnel out of harm's way. Installed along the road are another three cameras equipped with IR spotlights for night vision, five traffic lights and four road barriers. Four of the stoplights and the barriers are installed in close proximity to the avalanche gullies, whereas a fifth light is mounted near Täsch and prevents traffic from entering the larger hazard area. The webcams are mounted on three of the upper four stoplights. A fourth was omitted because it doesn't offer a view of the hazard zone (see Fig. 1).

The radars have a 90 degree horizontal and 10 degree vertical field of view. We tilted the radars upwards at slightly different angles. In this manner they look at wide bands roughly 800 and 300 vertical meters above the road and at a distance of up to 2,000 m (Fig. 2 and Fig. 3). The upper radar detects avalanches soon after they are released, and the lower one verifies if they reach an area around 1,900 m a.s.l. (±100 m). In the spring, when avalanches can start at lower elevations, the lower radar is the main detection unit.

The radar data is processed in real-time on-site. When the algorithm decides that closing the road is necessary, the command is transmitted to the traffic lights and barriers by optical fibers. At the same time, text and voice messages are sent to all authorized users (municipal and cantonal police, road patrol, local observers). They can then access an online data portal from any computer, tablet, or smartphone and view the radar data and webcam images. If the avalanche has not reached the road, the alarm can be reset from the online platform immediately, reopening the road to traffic. The same functionalities are also available on a touch panel at the central control station in town.

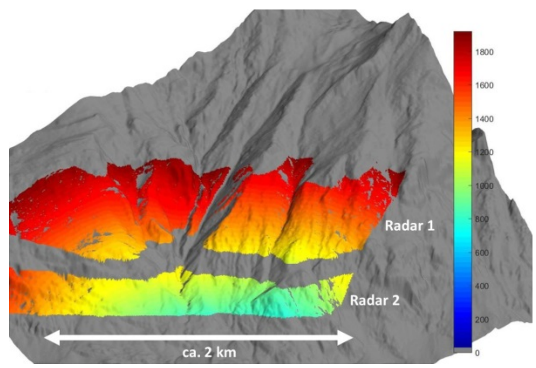

Fig. 2: Simulated radar coverage of the Zermatt avalanche detection system. Areas seen by the radars appear in color. Colors indicate distance to the radar, dark red is approximately 2,000 m.

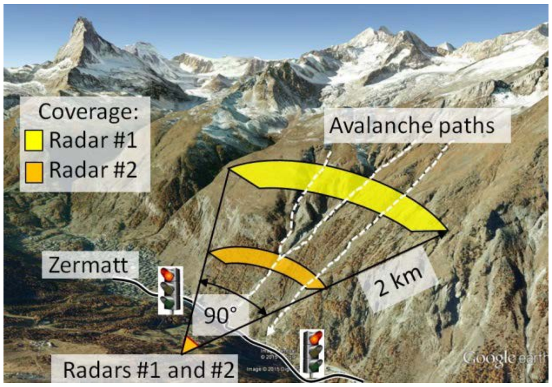

Fig. 3: Avalanche detection and alarm system overview, Zermatt

2.2 *Method*

Radars emit electromagnetic radiation in the range of a few to a few tens of GHz which is reflected back to the radar by objects in the target area. If a target is moving, the frequency of the reflected signal will differ from the emitted one. An object moving towards the radar reflects a higher frequency, objects moving away reflect lower frequencies. This effect, termed the Doppler Effect, can be experienced acoustically when the pitch of an ambulance siren changes abruptly as the vehicle passes the observer. Doppler radars measure the speed and direction of moving objects by measuring the frequency shift of the returned signal (Fig. 3). They are sensitive to any movement within their field of view if the target is large or near enough (for this system about 1,300 m for a human being) – not only avalanches. In Zermatt, helicopters flying up and down the valley are frequently recorded, but the radar will also detect birds, paragliders, trees moving in the wind, as well as flowing water during summer months. Between all these signals, the algorithm needs to decide whether the detected motion is that of an avalanche or not, and if such is the case, whether it is large enough to potentially reach the road. Given the high travelling speed of avalanches (Ancey, 2001), this leaves very little time to decide whether the road needs to be closed or not: Model outputs from RAMMS (Christen et al., 2010) for both *Lüegelti* and *Schusslouina* show that powder snow avalanches moving at 40 – 50 m/s can reach the road within 40 – 75 s. The slower spring-time wet snow avalanches leave up to 150 s to close the road. However, while powder snow avalanches detach in the highest parts of the starting zone, wet snow avalanches can start at much lower altitudes, reducing the warning time.

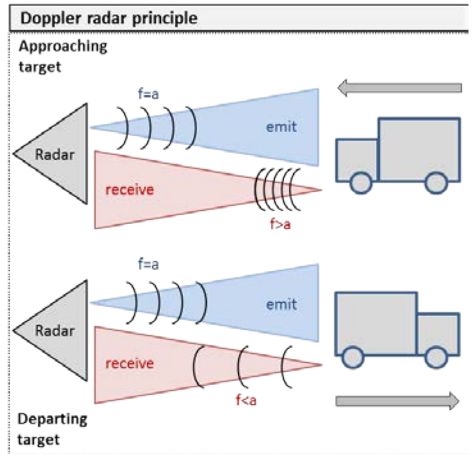

Fig. 4: Doppler radar measurement principle based on the Doppler Effect where f denotes the radar frequency.

The radar cannot only determine the speed, but also the distance of an object, termed range. We can use the range to measure how far an avalanche has traveled within the radar's field of view. All detected avalanches are immediately outlined on a topo map and displayed in the data portal. It is also possible to spatially limit the area in which the radar triggers an alarm, i.e. to a certain gully, even if the radar covers a much larger area.

The algorithm developed to detect avalanches is based on a large amount of training data that was collected over the past few winters in many different locations. More than 1,000 avalanches have provided the data that went into the development of the algorithm, and every further event can be used to iteratively improve the algorithms further.

The same radars – with adapted algorithms – can also detect debris flows and rockfall. More than 90 rockfall events have helped train that particular algorithm, and one debris flow has been detected with radar. The system in Zermatt will thus remain active during the summer months to monitor debris-flow activity in the northern gully.

3. OBSERVATIONS WINTER 2015/2016

Between December 1st 2015 and May 13th 2016, a total of 27 avalanches were recorded by local authorities. All avalanches were detected by the radar system, and the road was closed for 24 of these, but none of the avalanches reached the road. Roughly half were artificially triggered, while the other half detached spontaneously. The alarm system was never triggered in the absence of an avalanche, and therefore produced zero false alarms.

Fig. 5: On February 6 2015, an artificially triggered avalanche covered the road with meters of snow. Source: B. Jelk

The time until the road was reopened decreased from about 20 minutes at the beginning of the season to as little as 5 minutes at the end of the season.

4. DISCUSSION

The detection of avalanches with subsequent warning and road closure faces a classic dilemma: We want to detect the avalanche as early as possible, thus high up on the mountain, in order to have enough time to close the road and ensure nobody is on the road within the hazard area. However, the higher on the mountain the avalanche is detected, the less certain we can be that it will reach the road. Nevertheless, a decision about closing or not closing the road must be made immediately.

As a consequence, the road is closed whenever a large enough avalanche is detected, whether or not it reaches the road. It is thus important to keep the duration of the road closure to an absolute minimum if the avalanche doesn't reach the road. If the road remains closed too frequently for too long, locals will start to ignore the red lights, putting themselves at risk (Breznitz, 1984). The system can only be credible and accepted if closures are short, unless the avalanche actually reaches the road.

There are two ways we can assure a fast reopening of the road with the described system: As soon as local authorities receive the alarm voice or text message, they can check the webcams and radar data and choose to reopen the road remotely from any computer, mobile device or the central control station. For the first alarm of the season, this took more than 20 minutes because the situation was first discussed among the different authorities. By the end of the season, the reaction time declined to about five minutes. Even during two events that happened late at night, at 12.37 am and 01.41 am, the road only remained closed for about 12 minutes. We consider this time to be ok, especially at night, but aim to reduce it further. Ideally, waiting at the stoplight when an avalanche does not reach the road should take no more than one to two minutes – similar to waiting at a crosswalk – but anything below five minutes is considered satisfactory.

While resetting the alarm manually from a computer or mobile device has proven to be reliable and sufficiently quick in most cases, an automated reopening of the road is even faster. The lower radar is designed to do that. If an avalanche is detected by the upper radar, the road is closed. If the lower radar does not register that avalanche reaching its field of view within a predefined time, the road is automatically reopened. This functionality has been implemented and tested, but is not operational yet.

In three cases, the road was not closed because the algorithm decided the avalanche was not large enough to present a danger. It's a fuzzy boundary between avalanches that are clearly large enough to present a hazard and those that are clearly too small. In all three cases the avalanche stopped far above the road. We showed movies of these avalanches to different experts and found that opinions as to whether the system should have closed the road or not differed strongly.

5. CONCLUSION

This paper describes the first long-range and wide-angle avalanche detection system that is integrated into a fully operational alarm system. The system detected all of the 27 avalanches and closed the road in 24 cases. Closing the road in case of an avalanche requires no human intervention and is thus immediate. It's critical to keep the road closure as short as possible when avalanches don't reach the road. This is currently ensured by giving local authorities access to webcam images of the road and the possibility to reopen the road from any computer or mobile device, but can also be performed automatically by the lower radar.

CONFLICT OF INTEREST

At Geopraevent we develop, install and run alarm and warning systems for natural hazards. This study was supported financially by the Canton of Valais and the Municipality of Zermatt. All algorithms were developed, tested and funded by Geopraevent Inc.

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