AN AUTOMATED ALARM AND WARNING SYSTEM FOR THE BIS GLACIER ICEFALL, SWITZERLAND, USING A 5 KM RADAR AND HIGH-RESOLUTION DEFORMATION CAMERAS

Lorenz Meier[1], Mylène Jacquemart[1], Richard Steinacher[1], Martin Funk[2], André Burkard[3], Evelyn Zenklusen Mutter[3], Martin Proksch[3], Norbert Carlen[4], Pascal Stoebener[4]

[1] Geopraevent AG, Technoparkstrasse 1, 8005 Zurich, Switzerland
[2] ETH Zurich, Laboratory of Hydraulics, Hydrology and Glaciology, 8093 Zurich, Switzerland
[3] geoformer igp AG, Sebastiansplatz 1, 3900 Brig-Glis, Switzerland
[4] Canton of Valais, Cours d'eau, géologie et dangers naturels, 1950 Sion, Switzerland

ABSTRACT: We presents results from a novel warning and alarm system aimed at predicting and detecting ice avalanches starting on the steep icefall on Bis glacier near the municipality of Randa, canton of Valais, Switzerland. Every 15-20 years, depending on snow conditions, avalanches starting in the icefall reach the valley bottom, where they impact road and railway. Operational since 2017, the system uses two high-resolution cameras to measure the surface velocities in the icefall to predict breaking off of large ice volumes. In addition, a Doppler radar system with a range of 5 km detects the moving avalanches after they have released, regardless of whether they consist of snow, ice, or a combination of both. The system is set up to automatically close the road and stop trains in the valley, a feature that will be fully implemented in late 2018.

1. INTRODUCTION

The Bis glacier starts between the summits of the Weisshorn (4506 m a.s.l.) and the Bishorn (4151 m a.s.l.) down to an elevation of about 2500 m a.s.l. Its steep icefall between 3300 and 2800 m a.s.l. is the source of frequent ice avalanches. In addition, the hanging glacier on the steep northeast face of the Weisshorn is also a source for ice avalanches, albeit less frequently. Depending on the volume of the ice avalanches and the snow conditions in the runout area, icefall from these areas can trigger large combined ice/snow avalanches. During the last 300 years, these avalanches have managed to reach the bottom of the Matter valley every 15-20 years, where they impact the railway and the road. In some cases, the powder part of the avalanche reached the village Randa and caused damage there. We present the implementation of a combined warning and alarm system that makes use of state-of-the-art Doppler radar technology and high-resolution 42 megapixel cameras. We understand a warning system to provide valuable information to decision makers about the state of a potential hazard - in this case the glacier surface velocities paired with high resolution images of the icefall. An alarm system, on the other hand, is designed to trigger an immediate response (i.e., the closure of a road), without human intervention (Sättele et al., 2012, Meier et al., 2016a). Alarm systems for snow avalanches are increasingly becoming an integral part of hazard mitigation efforts (e.g., Van Herwijnen and Schweizer, 2011; Thüring et al., 2015; Kogelning et al., 2013), with Doppler radar being the state-of-the-art tool to detect moving avalanches at a distance (Meier et al., 2016b, Meier and Lussi, 2010) in all weather conditions. Novel about the system implemented at Bis glacier is, that, in addition to detecting avalanches in motion, the high-resolution cameras allow authorities to gauge the risk of impending avalanches based on glacier motion in the icefall.

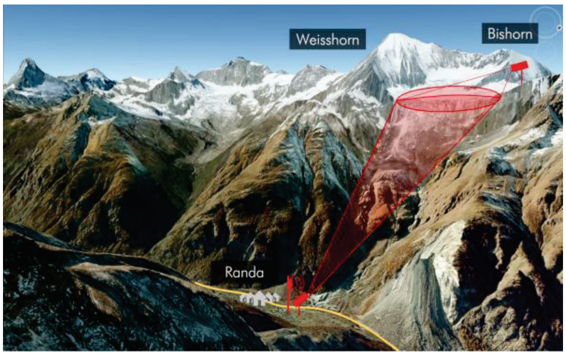

Figure 1: The municipality of Randa in the Matter valley at the base of Weisshorn and Bishorn. The doppler radar and one of the high-resolution cameras are mounted on the opposite side of the valley. The second camera is installed above the icefall, providing a good view of the sérac zone from an elevated position.

Figure 2: Radar systems (middle) and high-resolution camera looking up at Bis glacier near the municipality of Randa.

2. SYSTEM DESCRIPTION

We installed the Doppler radar in the valley bottom, from where it permanently monitors the critical part of the glacier and the runout zone between 1800 and 3300 m a.s.l., at distances of up to 5 km (Figure 1). Any avalanche activity in this zone is immediately detected by the radar. The Doppler radar emits electromagnetic waves of a set frequency, and measures the frequency change of the reflected signal that is caused by moving objects in the target area. If an avalanche approaches the radar, the reflected signal will be of a higher frequency. Advanced algorithms analyze the signal in real time and classify the targets based on different criteria into avalanches or other objects (like rain drops, helicopters, etc.). The doppler radar has a 10 m range resolution, which allows us to precisely track avalanches on their way down the mountain. The warning time for the road and the railway is limited: it takes a car about 30 s to pass through the hazard zone, while a train is exposed for about 60 s. The system must therefore trigger the alarm no later than 30 s before the avalanche reaches the road and 60 s before the avalanche reaches the railway. This requires deciding about whether or not to trigger a closure when the avalanche is still high up on the slope, where it is not clear whether it will reach the valley bottom or not. In fact, most avalanches stop far above the road and railway. In order to prevent unnecessary closures, we apply two strategies:

First, the system will automatically cancel the alarm if the avalanche stops on the slope, therefore minimizing closure time. This is possible, because almost the entire avalanche path down to approximately 1800 m a.s.l. is visible to the radar. Secondly, the mobility of an ice avalanche starting in the icefall depends strongly on the snow conditions on the glacier below. The system therefore takes daily forecasts of avalanche danger into account when setting triggering thresholds. When the avalanche danger is high, small ice avalanches can trigger much larger snow avalanches. Consequently, small avalanches released in the icefall will trigger an alarm. When the avalanche danger is low, only avalanches that exceed a predefined size threshold trigger an alarm. Note that this distinction only applies to avalanches released from within the steep glacier zone. Avalanches starting on the lower slope will always trigger an alarm, regardless of their size. All avalanches are visualized online including metadata about time, length, duration and front velocity together with several photos triggered automatically by the radar (Figure 3).

In order to identify instabilities in the icefall at an early stage, we installed two high-resolution cameras (42 megapixels) to monitor the glacier (Figure 1). One camera is located north of the icefall at 3400 m a.s.l., looking at the sérac zone from an elevated position. The other camera is installed at the radar location, aimed towards the glacier at an oblique angle from below (Figure 2). The system captures several images per day and immediately sends them to a server, where the surface motion is automatically determined on a daily basis using 2-D cross-correlation analysis. The results of this analysis are then immediately made available to local authorities on a password protected website (Figure 4). Camera images can be georeferenced and converted to real-world deformations (meters/day), however, the relative changes from one day to the next are sufficient to detect accelerated ice surface areas and assess the situation in the steep glacier zone. If a large unstable ice mass is detected in the icefall, authorities have ample time to monitor the situation and plan emergency measures. Detection of glacier instabilities in the steep glacier zone relies on optical feature tracking which requires good visibility to the target area and stable features. An all-weather alternative would be to use a ground-based interferometric radar system (Margreth et al., 2017), but the cameras are substantially more cost-effective and provide sufficient long-term monitoring capabilities in absence of a dire emergency.

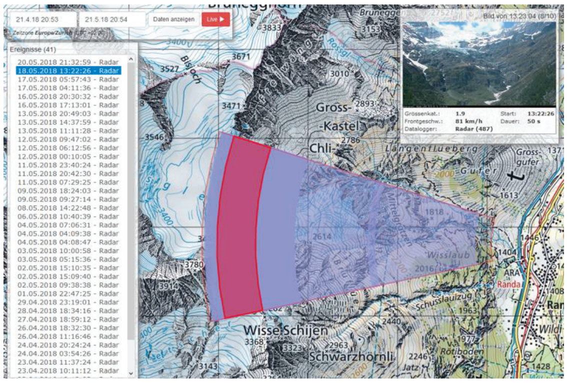

Figure 3: All data and detection events are available to local authorities on a password-protected website. Seen here are all the avalanches detected by the radar (left). The red bar shows the area in which the avalanche was detected. Additionally, images and metadata are automatically uploaded to the platform.

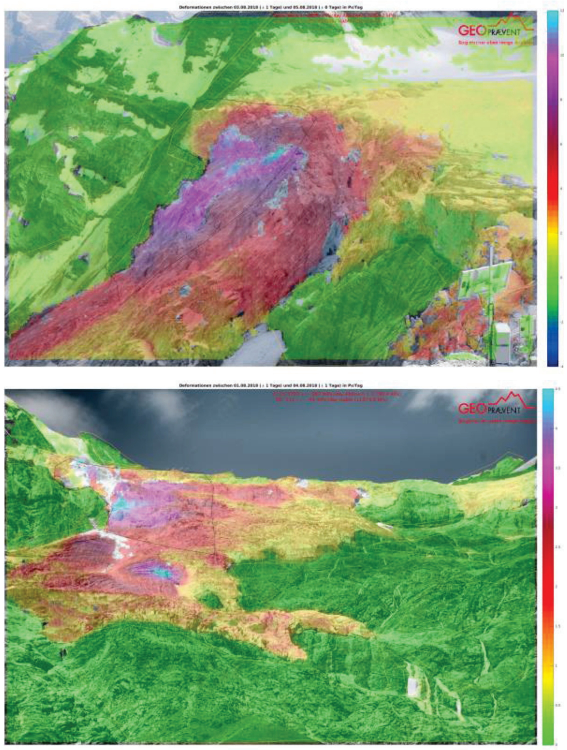

Figure 4: Daily images analysis of the sérac zone with the photos of the upper (above) and lower camera. Color indicate surface velocity.

3. RESULTS AND DISCUSSION

During the first year of operation, the system was tuned to maximum sensitivity. It recorded 800 very small to very large avalanche events, i.e. about two events per day on average. On 100 days, no avalanche activity was detected. On 74 days, exactly one avalanche was recorded, on 68 days, exactly two avalanches. On four days, 10 or more events were registered. The day with most avalanches (24) was January 22, 2018.

The majority of these events were small and no threat to the infrastructure on the valley floor. In the case of large avalanches, however, both the railway and road are at risk. This infrastructure is important for the population and tourism in the valley. Long closures need to be avoided, unless danger from an avalanche is imminent. Even short closures should be kept to a minimum. We therefore will configure the system so that an automatic closure of the traffic lines by the radar system will only be triggered if the avalanche is likely to reach the valley bottom. This will be done based on avalanche size in the starting zone, avalanche location (with the possibility to cancel alarms if the avalanche stops on the way down), and current avalanche danger. The reaction time for the system is limited to about one minute, so the analysis needs to be processed within a few seconds. The automatic closure of the traffic routes is expected to be fully operational by the start of winter 2018/19.

4. CONCLUSION

We demonstrate that high-resolution cameras and a Doppler radar can be combined into a multi-functional warning and alarm system that detects both avalanches in motion and also provides advance warning for emerging glacier instabilities. While the radar-based alarm system works both at night and during bad weather, the camera-based warning component requires good visibility, but comes at a substantially more economical price than an equivalent interferometric radar option.

REFERENCES

A. Kogelnig, S. Wyssen, and J. Pichler (2012): Artificial release and detection of avalanches: managing avalanche risk on traffic infrastructures, a case study from Austria. Proceedings of the International Snow Science Workshop, Anchorage, AK, 535 – 540.

S. Margreth, M. Funk, D. Tobler, P. Dalban, L. Meier, and J. Lauper (2017). Analysis of the hazard caused by ice avalanches from the hanging glacier on the Eiger west face. *Cold Regions Science and Technology*, *144*, 63-72.

L. Meier, and D. Lussi (2010): Remote detection of snow avalanches in Switzerland using infrasound, Doppler radars and geophones. Proceedings of the International Snow Science Workshop, Squaw Valley, CA, 7 – 12.

L., Meier, M. Jacquemart, B. Blattmann, S. Wyssen, B. Arnold, and M. Funk, (2016a). Radar-based warning and alarm systems for alpine mass movements. In *13th Congress Interpraevent 2016: living with natural risks, 30 May to 2 June 2016, Lucerne, Switzerland. Conference proceedings* (pp. 960-968). International Research Society INTERPRAEVENT.

L. Meier, M. Jacquemart, B. Blattmann, and B. Arnold (2016b): Real-time avalanche detection with long-range, wide-angle radars for road safety in Zermatt, Switzerland. Proceedings of the International Snow Science Workshop, Breckenridge, CO.

M. Sättele, M. Bründl, and D. Straub (2012): A classification of warning system for natural hazards. In *10th International Probabilistic Workshop, edited by: Moormann, C., Huber, M., and Proske, D., Stuttgart: Institut für Geotechnik der Universität Stuttgart* (pp. 257-270).

T. Thüring, M. Schoch, A. Van Heerwijnen, and J. Schweizer (2015): Robust snow avalanche detection using supervised machine learning with infrasonic sensor arrays. Cold Regions Science and Technology, 111, 60 – 66.

A. Van Herwijnen, and J. Schweizer (2011): Monitoring avalanche activity using a seismic sensor. Cold Regions Science and Technology, 69, 165 – 176.