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Alarming and monitoring system on the Simplon Pass

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Abstract

The Simplon pass culminates at 2006 m above sea and is one of the principal alpine roads crossing the Alps in the North-South direction. It is extremely important for intra-European goods transportation, as it is open over the winter and is only protected by avalanche galleries and does not cross a tunnel, so that dangerous goods like chemicals can be transported safely all year round on this road. On the 29th of June 2024, following a few days of high intensity precipitation, several massive debris flows originating from the region of the Hübschhorn rock glacier entered the Engi gallery that is normally protecting the road from avalanches in winter and deposited a layer of more than one meter debris over several tens of meters, causing the closure of the road. The Hübschhorn rock glacier had been melting substantially over the last decade so that a combination of high temperature and important cumulative precipitation could mobilize the debris. The road had to be reopened as rapidly as possible and the debris flow channel had to be raised to avoid new damages to the road in case of events, but this meant performing construction works in a region with frequent rockfall and high debris flow activity. The Federal Roads Office (FEDRO) mandated Geoprevent to rapidly install both a monitoring system to provide some information about the state of the rock glacier and a multi-component alarm system to detect debris flows and rockfall, close the road and trigger a local alarm on the construction site in case of events. This paper introduces the different components of these complex monitoring and alarming systems and presents some insights about the challenges faced during their installation and operation.

Keywords

Radar, Rockfall, Warning systems, Alarm system.

1 Introduction

The Simplon Pass is one of the most important transalpine transport routes in Switzerland. It connects the Rhone Valley in Valais with the Italian Val d'Ossola and lies at an altitude of 2006 meters above sea level. Due to its year-round trafficability, the Simplon is particularly important for heavy and hazardous goods traffic, as many transports are not allowed to pass through the Gotthard tunnel. However, the topography and geological conditions in this high mountain region make the infrastructure particularly susceptible to gravitational natural hazards such as rockfalls, debris flows and landslides. On June 29, 2024, a massive debris flow occurred above the Engi snow shed following heavy rainfall. Debris from the Hübschhorn rock glacier were mobilized and buried several meters of the pass road. There were no injuries, but the national road had to be closed immediately. The clean-up work proved to be difficult and dangerous due to the continuing unstable situation and the risk to which workers were exposed. To improve safety for road users and construction crews, Geoprevent deployed a monitoring system to provide some information about the state of the rock glacier and a multi-component alarm system to detect debris flows and rockfall, close the road and trigger a local alarm on the construction site in case of detections.

2 Monitoring system setup

On behalf of the Federal Roads Office (FEDRO) and in collaboration with natural hazard experts from geoformer igp AG, Geoprevent developed a comprehensive monitoring system (Figure 1)in just a few weeks. The solution consists of two central components: a warning system for long-term monitoring of the Hübschhorn block glacier and an alarm system for real-time response to short-term hazard processes such as rockfalls or debris flows.

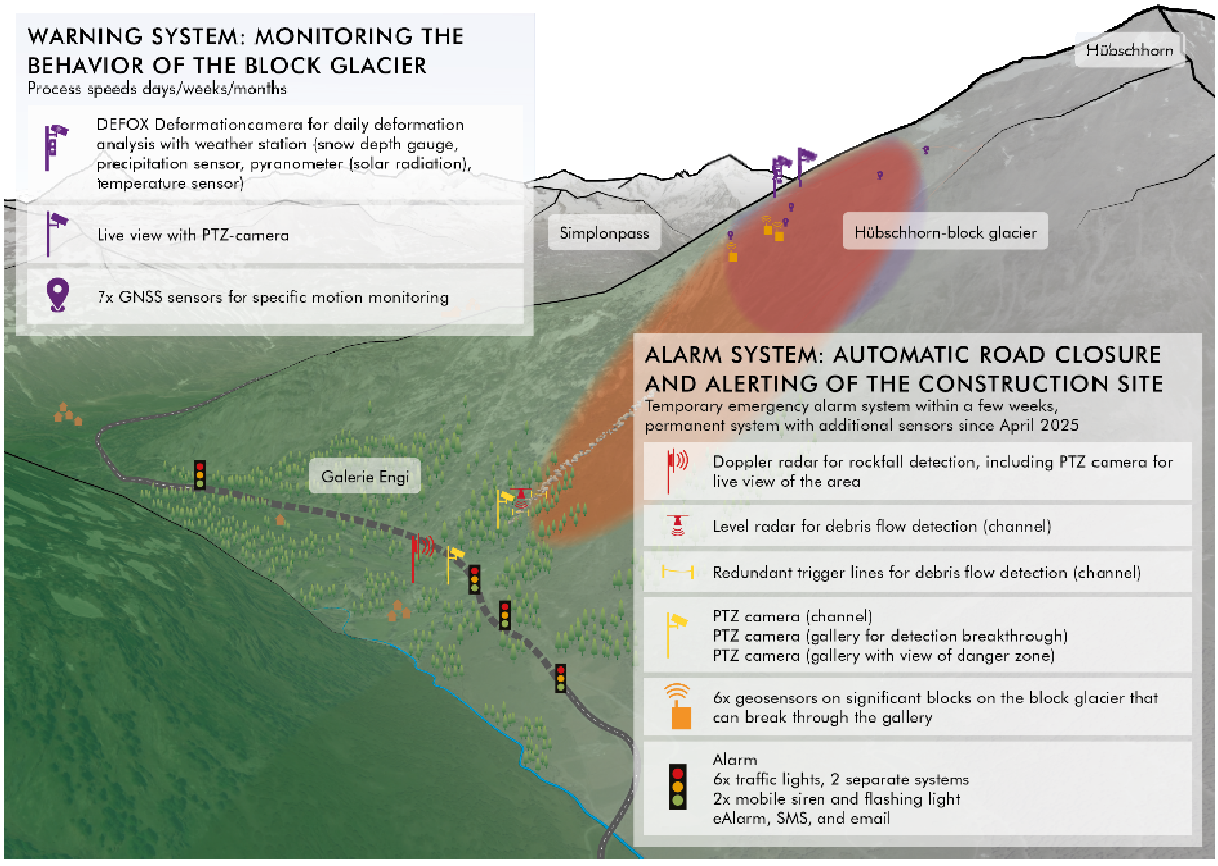


Fig. 1 Schematic representation of the monitoring system on the Simplon Pass.

3 Warning system

A comprehensive multi-component warning system was progressively installed in the Summer of 2024to continuously monitor the glacier area above the pass road. Various state of the art measuring techniques are used for this (Loew et al. 2025). A high-resolution 42 megapixel PROCam camera system (Figure 2) provides hourly images of a critical zone of the rock glacier, which are

automatically analyzed to detect large-scale deformations. Geoprevent DEFOX® deformation analysis method, uses the PROCam optical data to measure the two-dimenstional displacement field in image space based on a cross-correlation algorithm. Through fully automated deformation analysis based on the comparison of high-resolution images, displacements of just a few centimetres can be detected quickly and effectivelyvia the GRAVX online data portal (Figure 3).The visual monitoring is supplemented by a solar-powered PTZ camera, which enables remote live assessment. A weather station was also set up to assess external influencing factors, providing continuous data on precipitation, temperature, snow depth and solar radiation. As precipitation here substantially increases the frequency of occurrence of debris flows and rockfall events, different warning thresholds are defined based on the instantaneous and cumulated precipitation data.



Fig. 2 DEFOX PRO camera (42 MP) with weather station and PTZ camera close to the rock glacier.

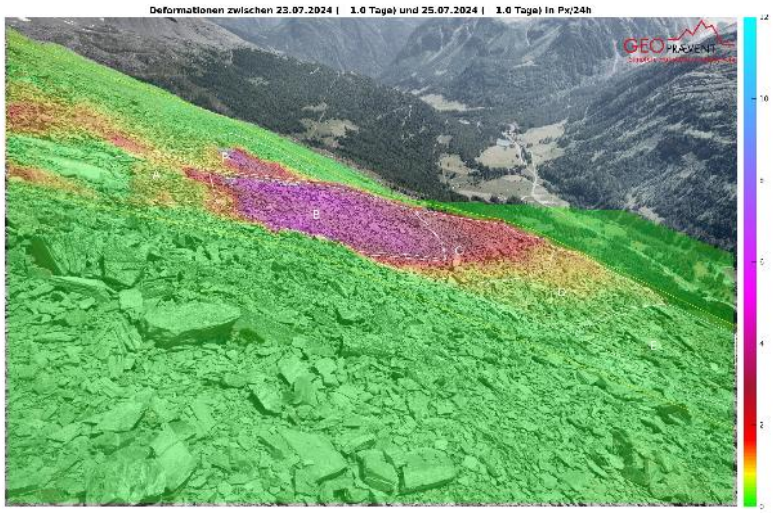


Fig. 3 DEFOX deformation analysis based on the comparison of high-resolution images, for detecting displacements of just a few centimetres.

Several customized GNSS systems were installed on the glacier to record three-dimensional movement (point monitoring). The systems are powered by a solar panel and batteries and provide cm-accurate hourly data in this tough alpine environment (Figure 4).

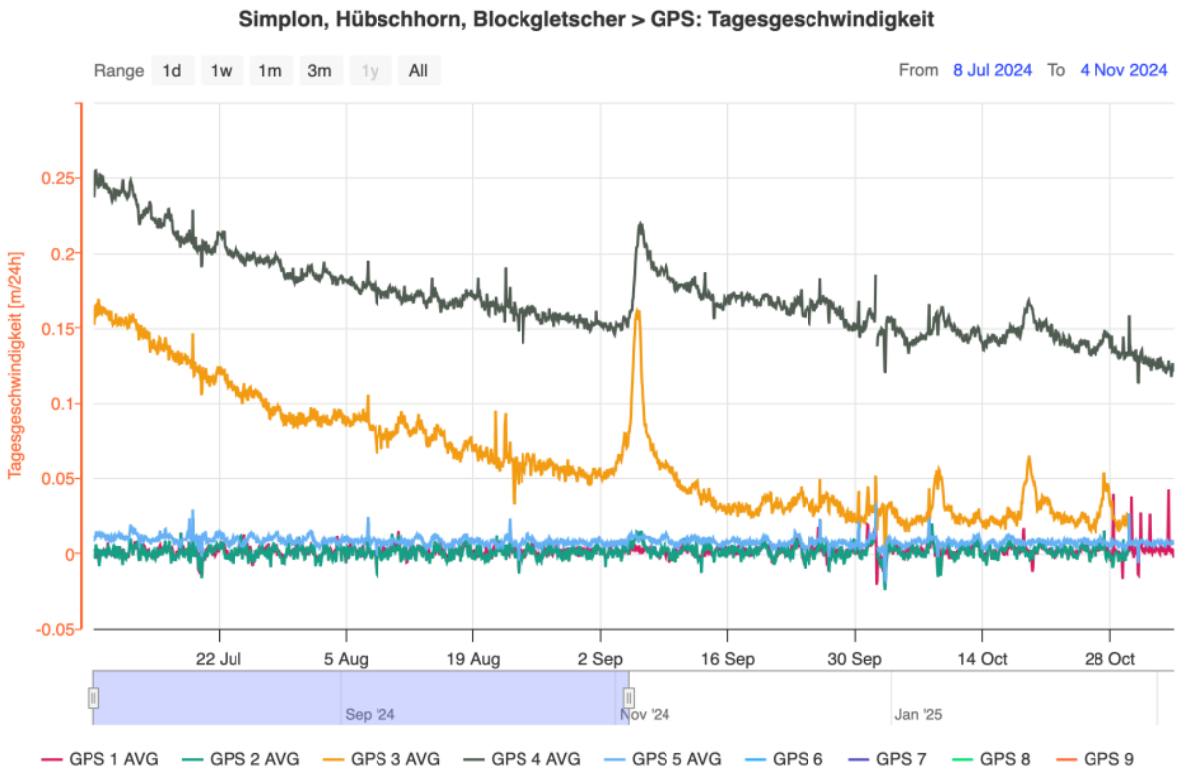


Fig. 4 Movements of individual boulders measured using GNSS sensors.

4 Alarming System

While the warning system is primarily intended to monitor longer-term slope developments, the alarm system is conceived for the real-time detection of rapid processes and the initiation of automatic response measures. This distinction is particularly important in the case of rockfalls and debris flows, which may occur within a matter of seconds, especially following intense precipitation. Under such conditions, the available time between event detection and the potential impact of a rock block on the gallery may be limited to approximately 30 to 50 seconds. Consequently, the alarm has to be transmitted automatically and in a redundant way.

While warning systems are sufficient to permit evacuation of the exposed area, alarming system technologies like Doppler radars and trigger lines support the implementation of organizational risk-mitigation measures, such as automatic road closures or on-site alarming on construction sites, as a cost-effective alternative to structural protective measures. In this context, Meier et al. (2016, 2017) demonstrated the successful integration of Doppler radar into local alarm systems for the detection of rockfall events, thereby enabling the timely closure of threatened transport infrastructure.

4.1 Rockfall Doppler radar setup

In response to the rockfall activity originating from the Hübschhorn rock glacier, a Doppler radar detecting fast moving objects was installed at the foot of the slope (Figure 5). Object localization is achieved through the combined analysis of Doppler-derived velocity information and range estimation based on signal travel time, allowing moving targets to be spatially resolved within the monitored domain (Schneider et al. (2023)).Owing to its independence from ambient light and its robust performance under adverse weather, the radar provides 24/7 operational capability at a maximal range of ca. 2 km. Two areas of interest were defined. The upper boundary of the observed sector lies at an approximate distance of 1.5 km from the radar location. The system acquires data at one-second intervals, tracking individual events continuously from their initial detection until the material either reaches or exits the observation areas. In the event of a detection, the radar automatically activates a coupled PTZ (pan-tilt-zoom) camera, thereby enabling immediate visual assessment of the event and of the monitored slope. An example of a detected rockfall event, together with selected event attributes and associated images, is presented in Figure 6 as displayed in GRAVX™, Geoprevent's online data portal, where all detections are archived for subsequent visualization and analysis.



Fig. 5 Doppler radar system with PTZ camera.

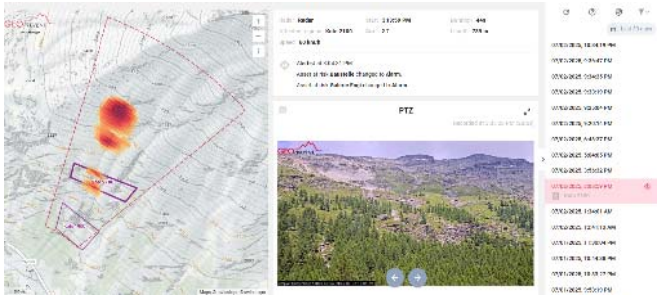


Fig. 6 Rockfall events displaced on the GRAVX platform.

As example Figure 7 summarizes rockfall activity during the 2025 monitoring period by showing daily detected events and their cumulative development over time. The data indicate a clear concentration of activity in spring and early summer, particularly between April and July, when most events were recorded. By the end of this period, the cumulative event count had already reached more than 2,000, while the total number of detected events over the full year exceeded 2,300.

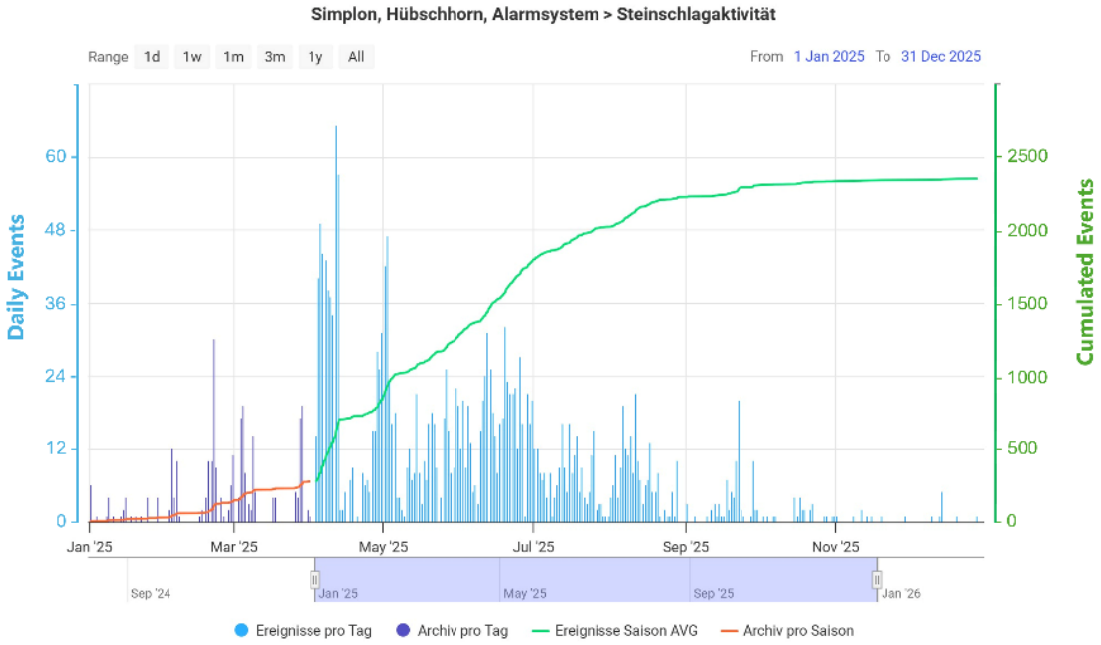


Fig. 7 Rockfall activity recorded during 2025. Bars show the number of detected events per day, and the green curve represents the cumulative event count. More than 2,300 events were detected over the year.

4.2 Level radar and trigger lines

In addition, a level radar is installed in the endangered debris flow channel to detect sudden changes in the water level. This enables the early identification of debris flows. To supplement the system, trigger lines were stretched over the channel at the same location, which immediately trigger an alarm if they come into contact with moving material. Further PTZ cameras were installed at strategically important points to ensure complete visual control of the danger zone.



Fig. 7 Level radar (final& temporary installation) and Trigger lines installed in the hazardous debris flow channel.

4.3 Motion sensors

Three large, instable boulders of several cubic meters located on the rock glacier with the potential to damage the gallery, were equipped with motion sensors (tiltmeters and accelerometers, two sensors per system) (Figure 8).These detect the smallest movements and automatically trigger the alarm units or close the road in case of exceedance of pre-defined thresholds relative to angles and acceleration enable a rapid assessment of the stability of these boulders.



Fig. 8 Geosensor location (left) and fixation (right) on one of the large boulders in the rock glacier. Sensors are mounted on poles because of potential snow cover.

4.4 Traffic lights

If an event is detected, the alarm is triggered automatically in a redundant way. The road is immediately closed by six traffic lights, distributed across two independent systems.

4.5 Local construction-site alarm

In addition, construction workers in the danger zone are warned acoustically and visually by two mobile sirens in combination with flashing lights (Figure 9), which can be activated whenever required. At the same time, the emergency services and specialists are alerted digitally by text message and email. Thanks to direct web access via GRAVX, the situation can be assessed remotely.



Fig. 9 Mobile sirens with flashing lights on the construction site.

5 Conclusion

The monitoring systems installed at the Simplon Pass improve safety for road users and construction workers exposed to rockfalls on the Engli gallery. The installed setup combines a warning system tracking the rock glacier's condition with a multi-component alarm system that detects debris flows and rockfalls, closes the road, and triggers a local construction-site alarm when events are detected. Monitoring data on debris flows and rockfall activity also supports risk management on site.

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