TECHNOLOGY GUIDE

FOR MONITORING OF GRAVITATIONAL NATURAL HAZARDS

GEOPREVENT
Räffelstrasse 28
8045 Zurich
Switzerland

Tel. +41 44 419 91 10
info@geoprevent.com

Initiated by the Swiss Federal Railways (SBB).

Picture credits:
GEOPREVENT of active systems

Suggested form of citation:
GEOPREVENT (2022): Monitoring systems for gravitative natural hazards, Zurich, Switzerland

Title page: Interferometric radar Piz Cengalo (Bondo), Switzerland

OVERVIEW

INTRODUCTION

This technology guide provides an overview of electronic monitoring systems for gravitational natural hazards and can provide guidance for selecting the best suited systems. We use the term "monitoring system" to describe the technical equipment for various purposes, ranging from long-term monitoring of characteristic parameters, early detection of an impending event, and real-time event detection with automatic actions1. The guide is divided into three parts:

1 INTRODUCTION TO MONITORING SYSTEMS

We differentiate between two types of monitoring systems: Warning and alarm systems. In this section we explain these different system types, their ideal applications, the parameters they measure and some common technologies. We further define and explain the central parts of a monitoring system including sensors, warning and alarm components (e.g., sirens, gates), as well as measurement visualization on an online platform.

2 DETECTING NATURAL HAZARDS

Gravitative natural hazards include flooding, snow and ice avalanches, as well as landslides (which in turn comprise rockfall, rock avalanches, debris flows, and slower slope instabilities). The hazard process is crucial for choosing a suitable system and technology. Where cascading hazards are present, warning and alarm systems can be combined to monitor entire process chains. For instance, our system in Bondo, Switzerland monitors instabilities on a rock face that can deliver large amounts of debris to the valley below. An alarm system in the valley, in turn, warns residents and road users of approaching debris flows.

In this second chapter we lay out different technological options for best detecting the different kinds of hazards. We compare their coverages, accuracies, and effectiveness under different weather and visibility conditions. The selection of technologies mirrors current state-of-the-art and is non-exhaustive.

3 TECHNOLOGIES

In this last part we focus on different technologies and some of our reference projects in more detail, to highlight how various technologies can complement each other. As a hazardous situation evolves, different technologies or system components may be added to an existing system. The selection of presented technologies is again non-exhaustive.

[1] according to the definition of monitoring and early warning systems in

- BAFU (2015). Vollzugshilfe Schutz vor Massenbewegungsgefahren
- Sättele M., Bründl M. (2015) Praxishilfe für den Einsatz von Frühwarnsystemen für gravitative Naturgefahren, WSL-Institut für Schnee- und Lawinenforschung SLF, Bundesamt für Bevölkerungsschutz/BABS, Bern

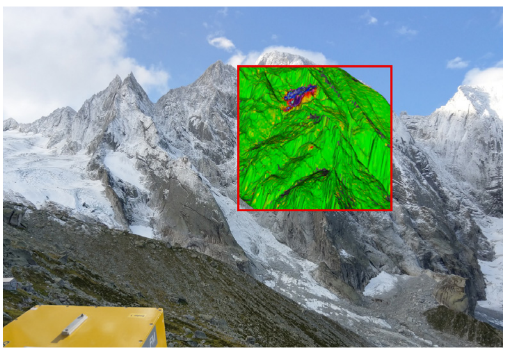
1 INTRODUCTION TO MONITORING SYSTEMS

Deformation camera Ochsenstock, Switzerland

1.1 SYSTEM TYPES

We differentiate two types of monitoring systems: warning and alarm systems. A warning system delivers information about a possibly hazardous process to decision makers, so that they can make well-informed decisions and take actions when necessary (like initiating an evacuation). An alarm system is designed to trigger an action (like closing a road) without human intervention if a hazard is detected and there is no time to evaluate options.

	WARNING SYSTEM	ALARM SYSTEM
PURPOSE	Measure precursory signs of impending hazard	Automatic detection of hazard
LEAD TIME	Hours – weeks	Seconds – minutes
ACTIONS	Interpretation of information by experts & decision makers to initiate appropriate action (e.g., an evacuation)	Immediate and automatic trigger of response (e.g., road/railroad closure, set off beacons/sirens etc.)
APPLICATION	For slow processes like rock face deformation, creeping slopes, snow accumulation etc.	Spontaneously releasing or fast moving processes like debris flows, avalanches etc.
MEASURED VARIABLES	Deformation, precipitation, snow depth, river level, temperature, ground motion, activity (e.g., rock fall, avalanche)	Deformation, pressure, velocity, river level, ground motion, flow height
TECHNOLOGIES	• Interferometric Georadar • Deformation camera • Crack meter, Inclinometer • Pressure gauge • Motion sensors, GPS • Weather station	• Avalanche radar • Rockfall radar • People radar • Level gauges • Trigger lines
EXAMPLES	• Rock face monitoring Pizzo Cengalo • Slope instability monitoring Moosfluh, Aletsch region, Switzerland	• Avalanche radar with automated road closure, Zermatt, Switzerland • Debris-flow alarm system, Spreitgraben, Switzerland



Interferometric radar Piz Cengalo (Bondo), Switzerland

Avalanche radar with automatic toad closure, Zermatt, Switzerland

1.2 OPERATING MODES

A monitoring campaign can be conducted in different temporal operating modes:

1. **Continuous, long-term monitoring** for persistent hazards (acute or quiescent)
2. **Continuous, temporary monitoring** for temporary dangers (e.g., at a construction site)
3. **Periodic, short-term monitoring** for repeat, individual measurements (e.g., once per year)

The choice of operating mode depends on the type of hazard, the monitoring technology, as well as the impacted area. Monitoring an acute hazard frequently requires continuous measurements through darkness and poor weather. For slow processes that are not critical, repeat measurements at daily to yearly intervals may suffice.

OPERATING REQUIREMENTS

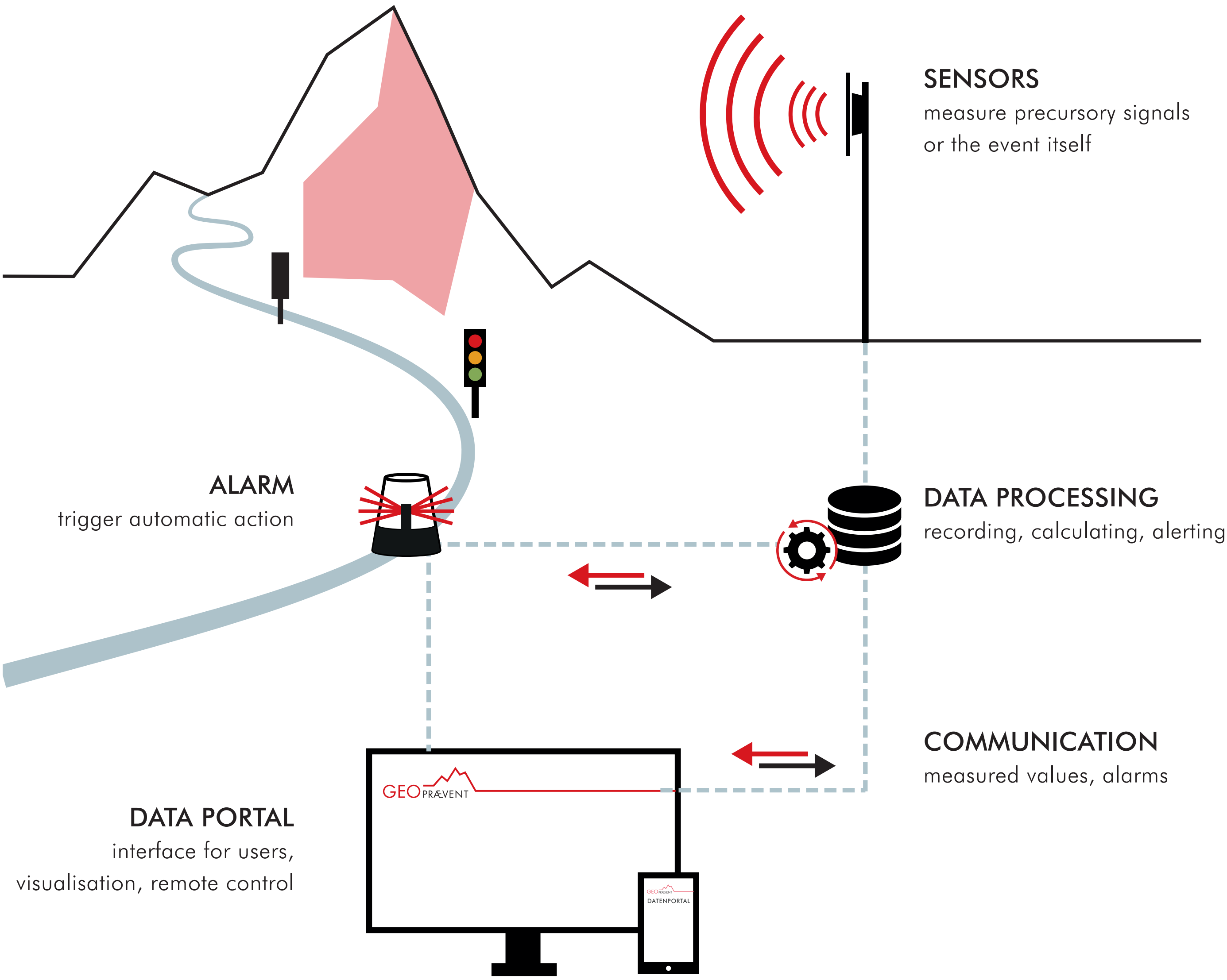
The system requirements vary based on the choice of operating mode, but the primary condition in all cases is that the measurements, data analysis and transmission, as well as the visualization in the data portal are automatable. Additionally, an independent power supply is needed, and, where a high system availability (system performance at all times of day and in all weather) is required, redundant components might be necessary. Alarm systems, by definition, need to be run continuously, warning systems can be operated in continuous or periodic mode.

	CONTINUOUS, LONG-TERM	CONTINUOUS, SHORT-TERM	PERIODIC, SHORT-TERM
SYSTEM TYPE			
DATA ANALYSIS, TRANSMISSION & VISUALISATION	Automatic data selection and analysis, continuous transmission with live-views and immediate visualization in the data portal	Automatic data selection and analysis, continuous transmission with live-views and immediate visualization in the data portal	Manual data selection and analysis, no automatic visualization, (optional) periodic measurement report
APPLICATION	Most common system type	For acute, temporary dangers. Typically with alarm component	For slow, uncritical processes
EXAMPLE	Avalanche or rock fall radar for long-term protection of a road or railroad	Interferometric radar for protection of workers cleaning up after a rockfall event or for protection of a constructions site	Yearly laser scans and measurements with interferometric radar to determine instabilities on a rock face

1.3 MONITORING SYSTEM SETUP

In the following we describe the main components that make up all monitoring systems. **Sensors** measure the physical properties of the process of interest, like deformation (in mm per day) or the flow height (in m). A **data logger** then digitizes and records the measured values, and performs any necessary calculations. In an alarm system, the data logger detects the hazardous event and issues the alarm, thereby triggering gates or traffic lights and disseminating the necessary messages (SMS, email, radio etc.) to emergency personnel. All continuously operating systems transmit their measurements, images, and analyses to a password protected **online data portal** for the users to access. The data portal also offers functionality to control system components like traffic lights or cameras. **Communication** components are critical to all systems, whether to transmit alarms and data or to control individual system elements. Lastly, the system **power supply** can come from the local grid or be fully autonomous.

For continuous and reliable monitoring of natural hazards, all components need to defy the harsh conditions found in high mountains, pass rigorous system tests, and offer multiple levels of redundancy, especially for alarm systems.



1.4 SYSTEM COMPONENTS

SENSORS

Many different sensors exist, and the choice depends on the hazard process, the local circumstances and the type of system. Examples:

- **Local measurements:** crack meters, radar gauge, geophone, GPS, motion sensors, force gauge
- **Remote measurements:** interferometric radar, deformation camera, avalanche radar, rockfall radar

DATA PROCESSING

Digitises measured values, makes calculations, and issues alarms.
The choice of logger depends on:

- Necessary computing and storage capacity
- Measuring frequency
- Power consumption
- Alarm logic
- Environmental constraints (water proof, low temperatures etc.)

ALARM

The alarm can be triggered in different ways:

- Traffic lights and gates
- Sirens for construction sites
- Radios with head phones for noisy environments
- Messaging through SMS, email, automated calls (prioritized services)
- Further interfaces (alarm forwarding)

DATA PORTAL

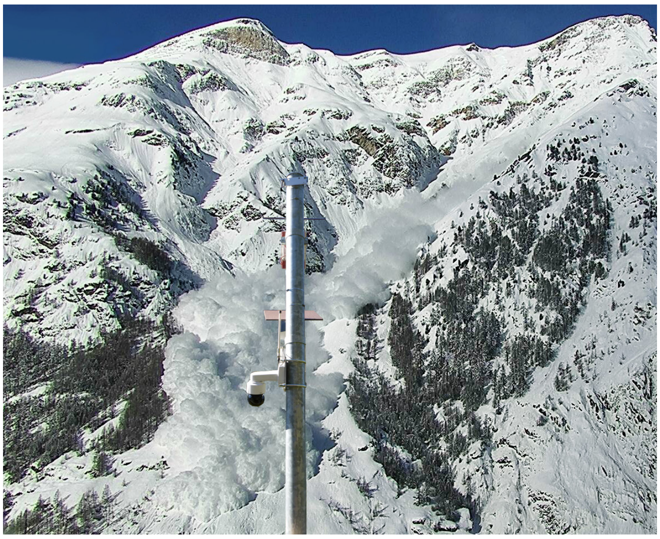
Password protected online platform accessible from PC, smartphone or tablet.
Functionalities include:

- Data time-series visualization
- Deformation analysis projected on DEM
- Interactive map with event tracks (e.g., avalanches)
- Live-views and image archive
- Remote control of gates, cameras etc.

COMMUNICATION

Data transmission between sensors, data portal, alarm infrastructure and servers.

- Possible communication channels: GSM (cellular network), Wifi, fiberoptic, radio, LoRa-WAN (sensor dependent)
- For issuing alarms we suggest working with two independent communication channels
- Directional radio systems possible



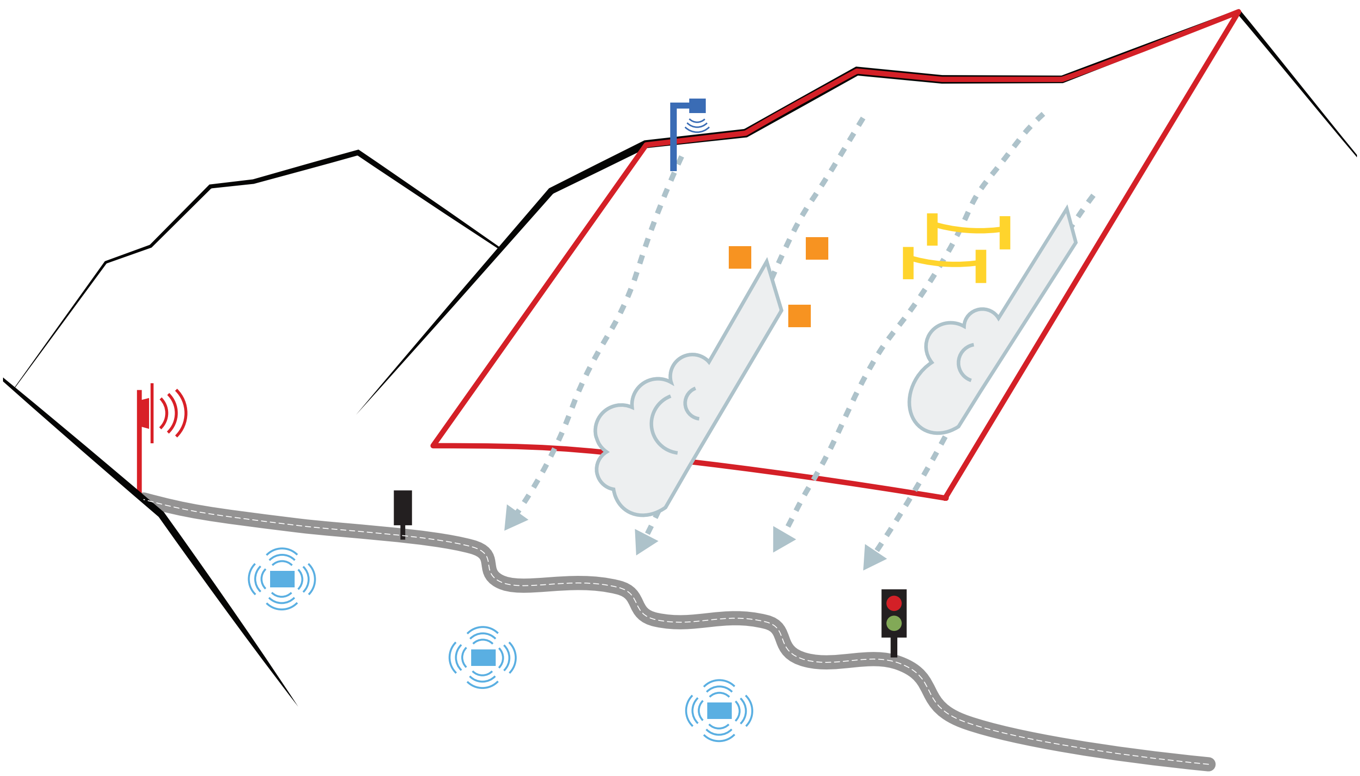
Avalanche radar Zermatt, Switzerland

2 DETECTING NATURAL HAZARDS

Rockfall Brienz/Birnzauls (Switzerland), avalanche Ningunsaw pass (Canada), debris flow Parghera (Switzerland), landslide Moosfluh (Switzerland)

2.1 AVALANCHES

Avalanches occur suddenly, and are hard to predict. An alarm system with automatic avalanche detection makes it possible to detect an avalanche early on (i.e., high on the mountain), in order to close roads or railways, or evacuate a construction site. Additionally, where avalanches are triggered artificially, this system can verify avalanche release when visibility is limited (due to darkness or bad weather). There are various ways to detect avalanches that differ depending on the exact purpose of the system.



AVALANCHE RADAR

Doppler radar detects moving snow masses on entire hillside.

GEOPHONE/ SEISMIC

Avalanche is detected through the ground shaking it produces.

TRIGGER LINE

Avalanche disrupts mechanical trigger line.

INFRASOUND

An avalanche emits infrasound that can be detected by sensors in the valley.

SNOW HEIGHT

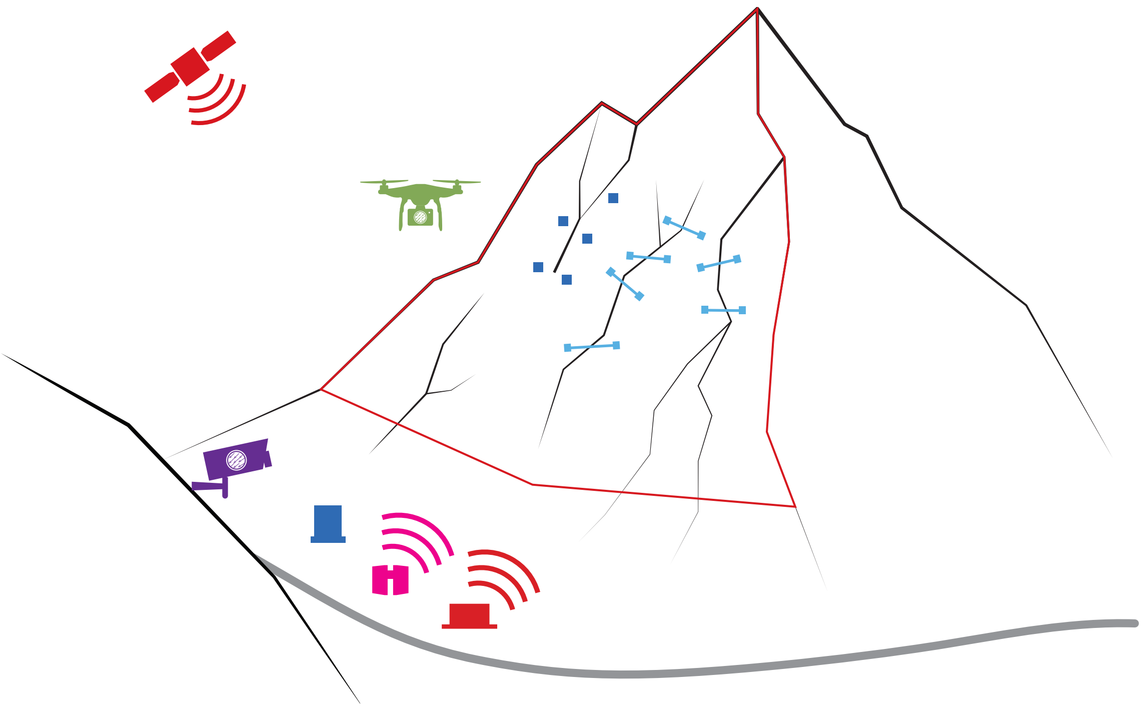
A sudden reduction of snow height in a release zone can be detected.

	AVALANCHE RADAR	GEOPHONE/ SEISMIC	TRIGGER LINE
TYPE	2D remote measurement	Local point measurement	Local point measurement
CHARACTERISTICS	Large coverage, avalanche tracking and mapping	Suitable for individual, well channelized avalanches	Simple, cost-effective system for individual avalanche paths
COVERAGE	Multiple avalanche paths with one radar. Range: 5km Coverage: 10km^2	Multiple geophones per avalanche path, larger areas with seismic arrays	Several trigger lines per avalanche path
WEATHER	All weather functionality	All weather functionality	All weather functionality
LIMITATIONS	• Avalanche area needs to be visible from radar position	• Large amounts of snow can dampen signals • Other seismic sources (e.g., earthquakes)	• Trees and animals may cause false alarms • Lines need to be replaced after each event
ALARM SYSTEM	Possible	Possible	Possible

	INFRASOUND	SNOW HEIGHT
TYPE	2D remote measurement	Local point measurement
CHARACTERISTICS	Large coverage, for activity monitoring	Provides crown height measurement
COVERAGE	Several avalanche paths with multiple sensors	One point in a single avalanche path
WEATHER	High winds reduce sensitivity	Depending on sensor, measurement can be unreliable during storm/ fog
LIMITATIONS	• Not all avalanches generate enough infrasound (e.g., wet snow avalanches) • Weather	• Point measurement • Unfavorable as detection technology • No information about avalanche size
ALARM SYSTEM	Not recommended	Not recommended

2.2 ROCK INSTABILITIES/ROCKFALL

Rock monitoring systems can be divided into two categories: Those that monitor slow or accelerating deformations that occur over the course of hours to years, and those that detect the fast motion of rocks or ground material after their release. Here we describe the technologies that can be used to monitor the slow, long-term deformation of unstable hillslopes. Such monitoring can take place continuously (for acute hazards), or periodically (for non-critical situations). Measurements can be made from a distance or locally and provide individual point or 2D measurements.



INTERFEROM. GEORADAR

Spatial measurement of deformations on a slope with ground- or satellite based interferometric radar.

TERRESTRIAL LIDAR

Laser measurement of a hillslope to detect deformations.

DEFORMATION CAMERA

Detection of motion from automated image analysis on high-resolution images.

TOTAL STATION

Selective position measurement of certain points using a reflected light beam.

CRACK METERS

Point measurement of crack width (telejoinmeter, TJM) or deformation within rock formations (extensometer, ETM).

FUTURE TECHNOLOGIES: Mobile measurements using drones are increasingly used for various technologies (cameras, lidar, radar). However, reliable automatic analyses are still being developed and are not yet ready for the market.

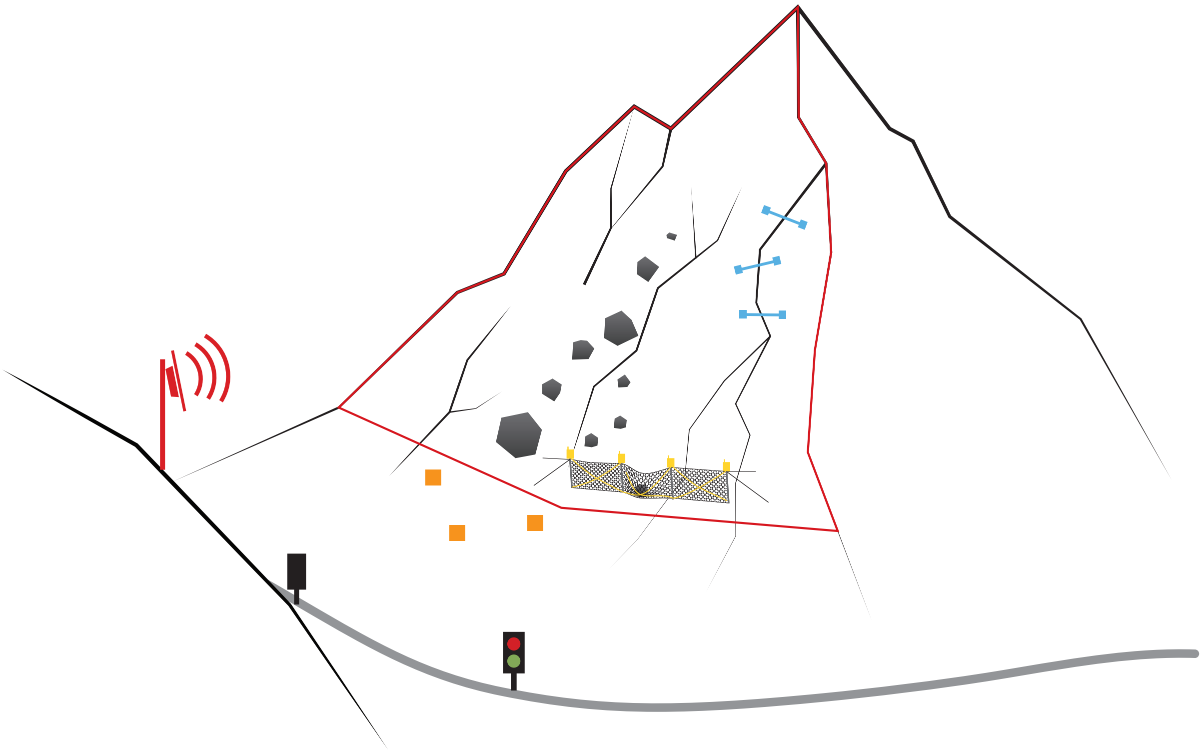
	TERRESTRIAL GEORADAR	GEORADAR (SATELLIT)	TERRESTR. LIDAR
TYPE	2D remote measurement	2D remote measurement	3D remote measurement
ACCURACY*	Sub-mm	mm–cm	A few cm
COVERAGE	Range: up to 5 km Coverage: several km^2	Many km^2 on east and west facing slopes	Range: up to 4 km Coverage: several km^2
EFFECTIVENESS	Always (day/night, rain, snow, fog), quick installation	Depending on return interval of satellite, archived data available	Only in good weather (no rain, snow or fog), quick installation
OPERATION TYPE	Continuous or periodic	Periodic	Periodic
LIMITATIONS	• Vegetation • Snow • Reflections (e.g., on rock fall nets)	• Coverage can be problematic • Return intervals too long for acute instabilities • Snow • Vegetation	• Automated analysis difficult • Tricky for continuous measurements • Snow

	DEFORMTIONS-KAMERA	TOTAL STATION	KLUFTMESS-GERÄTE
TYPE	2D remote measurement	Remote point measurement	Local point measurement
ACCURACY*	A few cm	A few mm	Sub-mm
COVERAGE	Range: up to 5 km Coverage: several km^2	Range: several km Coverage: several km^2	As needed, based on number of installed instruments
EFFECTIVENESS	Only with good visibility (good weather, daytime), quick installation	Visibility required (good weather, day or night)	Always (day/night, rain, snow, fog)
OPERATION TYPE	Continuous or periodic	Continuous or periodic	Continuous or periodic
LIMITATIONS	• High contrast required • Snow cover • Not suitable for acute instabilities	• Point measurement • Mirrors need to be mounted in unstable area • Measurement may be impossible when situation changes • Snow	• Point measurement • Installation in hazardous zone required • Sensors can be destroyed by large deformation or rockfall

* of the deformation analysis. Depends on distance to target.

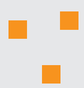
2.3 ROCK INSTABILITIES/ROCKFALL

Here we treat the technologies to monitor fast rock instabilities. With a rock fall alarm system, transportation routes can be closed in real-time, or a construction site can be evacuated when rock fall is detected. The same system can also be employed to monitor rock fall activity from an unstable area. The basic prerequisite for an alarm system is sufficient advance warning time between the detection of the event and the arrival near infrastructure. In some cases, combining a system for slow and fast processes can be beneficial. In addition, we equip protection systems with sensors for status monitoring and alerting in the event of an impact.



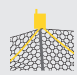
ROCKFALL RADAR

Doppler radar continuously scans a defined area and detects moving rocks.



GEOPHONE/ SEISMIC

Geophone/ seismometer detects ground motion caused by impacts from falling rocks.



COMBI MOTION SENSOR

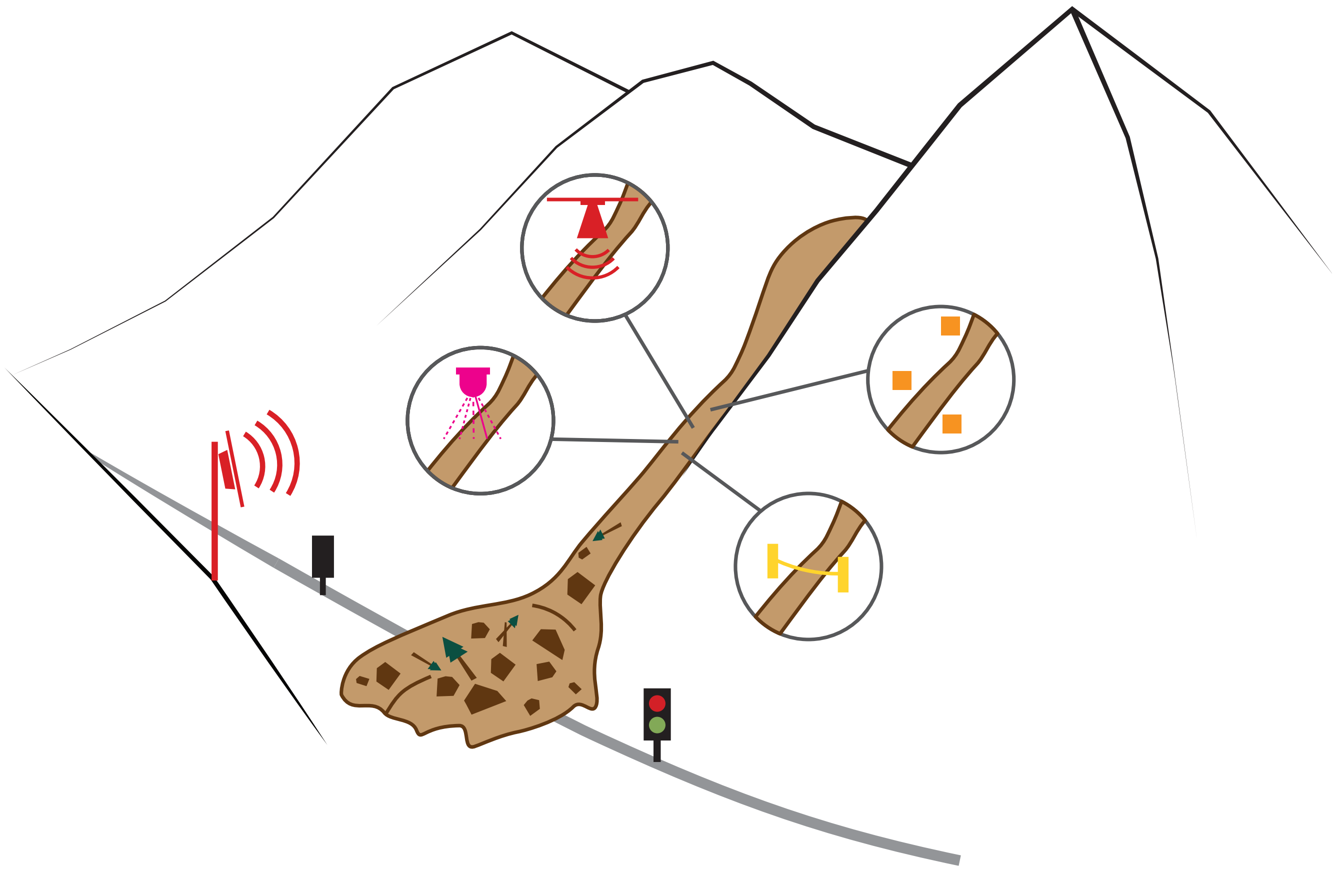
Status monitoring of rockfall protection nets with combination sensor (motion and inclination) and trigger line.

	ROCKFALL RADAR	SEISMOMETER	COMBI MOTION SENSOR
TYPE	2D remote measurement	Local to remote area-wide measurement (depends on array geometry)	Local point measurement
CHARACTERISTICS	Localization, tracking and mapping of rock fall	Large coverage, no line-of-sight requirement	Detection of an impact in the protection net, status overview of all nets
SENSITIVITY	Up to 0.1 m^3 @ 100 m, 1 m^3 @ 1 km	Less than radar, depends on local conditions*	Small events trigger only motion sensor, larger events tear the trigger line and activate an alarm
COVERAGE	Range: up to 4 km, Coverage: several km^2	Range: up to 20 km, depending on situation*	Ideally one combi motion sensor per post and two trigger lines per net
WEATHER	Independent of weather	Independent of weather	Independent of weather
LIMITATIONS	• Rock fall area needs to be visible from radar position • Reflections (e.g., on rock fall protection nets)	• Many potential noise sources (e.g., helicopters)	• Trigger line requires manual repair after an event • False alarms due to snow or other objects
ALARM SYSTEM	Possible	Not recommended	Possible
ACTIVITY MONITORING	Possible	Possible	Possible

* subsurface characteristics, distance, type of seismometer, size of event.

2.4 DEBRIS FLOWS

Debris flows belong to the fast developing processes that often require the use of an alarm system with automatic actions, such as a road closure or construction site evacuation. There are different methods for detecting a debris flow, with most solutions installed in or above the stream bed. Debris flows are a mix of water, sediment and rocks, with a turbulent, badly defined surface, which makes the measurement difficult. Where the debris flow channel is visible from a distance, remote detection with a debris flow radar is possible.



RADAR GAUGE	GEOPHONE	TRIGGER LINE	LASER	DEBRIS FLOW RADAR
Distance measurement to the channel bed. Debris flow detection upon rapid increase of flow height.	Detection of debris flow from ground shaking.	Alarm is issued when the debris flows disrupts the trigger line.	Flow stage or channel profile scans with laser. Debris flow detected when profile changes rapidly.	Doppler radar detects motion in the channel remotely and issues an alarm.

	GAUGE RADAR	GEOPHONE	TRIGGER LINE
TYPE	Local point measurement	Local point measurement	Local point measurement
CHARACTERISTICS	Continuous monitoring of river stage	Robust sensors, no access to channel necessary	Simple and cost-effective solution
COVERAGE	Min. of 2 gauges per channel (redundancy), range of sensor up to 50 m	Min. 2 geophones per channel (redundancy)	Min. 2 trigger lines per channel (redundancy)
WEATHER	Weather independent	Weather independent	Weather independent
LIMITATIONS	• Limited view of channel	• No information on river stage • Calibration with events necessary • Signal depends on type of debris flow	• No information on river level • Trigger line needs replacement after each event
ALARM SYSTEM	Possible	Possible in most cases	Possible

	LASER (-SCANNER)	DEBRIS FLOW RADAR
TYPE	Local point measurement	2D remote measurement
CHARACTERISTICS	Continuous monitoring of river stage / channel profile	Localization, tracking and mapping of debris flow
COVERAGE	Range: approx. 30 m	Range: up to 4 km, Coverage: several km^2
WEATHER	Weather independent at short distances	Weather independent
LIMITATIONS	• Laser measurements not reliable during rain or fog and on turbulent surfaces	• Channel needs to be visible from radar location • Strong reflections (e.g., from buildings)
ALARM SYSTEM	Limited use	Possible

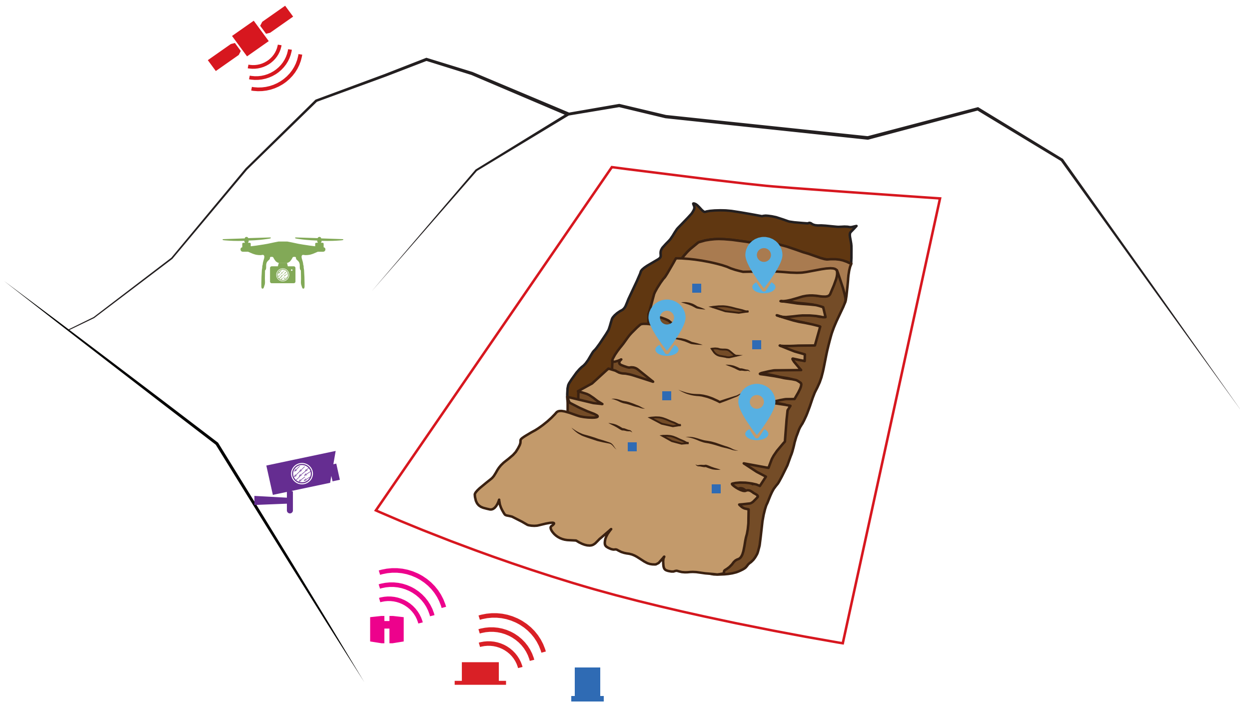
REMARKS REDUNDANCY:

Depending on the technology applied, we recommend using several sensors for the following reasons:

- Coverage of the entire river bed for wide trenches (e.g. gauge radar, trigger lines)
- Interferences; signal of one sensor is not reliable enough (e.g. with geophones)
- Combination of two sensors based on different and independent technologies

2.5 SLOPE FAILURES

Slope failures are often slow moving processes that are monitored over long time spans. A warning system is often the right choice when a sudden acceleration of a flowing or creeping hillslopes is expected. Various different techniques exist: Remote sensing with radar, unmanned aerial vehicle (UAV) based photogrammetry, lidar or GPS. Early warning can be achieved by defining thresholds of motion. If surpassed, automatic messages are sent to responsible personnel.



INTERFEROM. GEORADAR

Spatial measurement of deformations on a slope with ground- or satellite-based interferometric radar.

TERRESTRIAL LIDAR

Laser measurement of a hillslope to detect deformations.

DEFORMATION CAMERA

Detection of motion from automated image analysis on high resolution images.

TOTAL STATION

Selective position measurement of certain points using a reflected light beam.

GNSS (GPS)

Positional point measurement with GPS and an associated base station.

FUTURE TECHNOLOGIES: Mobile measurements using drones are increasingly used for various technologies (cameras, lidar, radar). However, reliable automatic analyses are still being developed and are not yet ready for the market.

	TERRESTRIAL GEORADAR	GEORADAR (SATELLITE)	TERRESTRIAL LIDAR
TYPE	2D remote measurement	2D remote measurement	2D remote measurement
ACCURACY*	Sub-mm	A few mm–cm	A few cm
COVERAGE	Range: up to 5 km Coverage: several km^2	Many km^2 on east and west facing slopes	Range: up to 4 km Coverage: several km^2
EFFECTIVENESS	Always (day/night, rain, snow, fog), quick installation	Depending on return interval of satellite, archived data available	Only in good weather (no rain, snow or fog), quick installation
OPERATION TYPE	Continuous or periodic	Periodic	Periodic
LIMITATIONS	• Vegetation • Snow • Reflections (e.g., on rock fall nets)	• Coverage can be problematic • Return intervals too long for acute instabilities • Snow • Vegetation	• Automated analysis difficult • Tricky for continuous measurements • Snow

	DEFORMATI-ONSKAMERA	TOTAL STATION	GNSS (GPS)
TYP	2D remote measurement	Remote point measurement	Local point measurement
ACCURACY*	A few cm	A few mm	About 1 cm
COVERAGE	Range: up to 5 km Coverage: several km^2	Range: several km Coverage: several km^2	As needed, large areas require many GPS units
EFFECTIVENESS	Only with good visibility (good weather, daytime), quick installation	Visibility required (good weather, day or night)	Always (day/night, rain, snow, fog)
OPERATION TYPE	Continuous or periodic	Continuous or periodic	Continuous or periodic
LIMITATIONS	• High contrast required • Snow cover • Not suitable for acute instabilities	• Point measurement • Mirrors need to be mounted in unstable area • Measurement may be impossible when situation changes • Snow	• Only point measurement • Access to moving area required • Satellite visibility can be tricky in narrow valleys

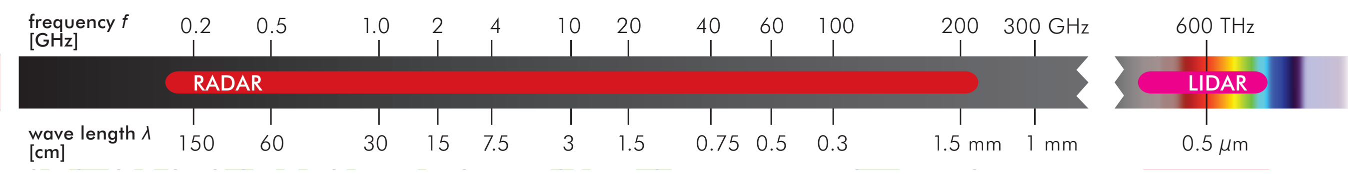
* of the deformation analysis. Depends on distance to target.

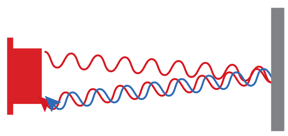
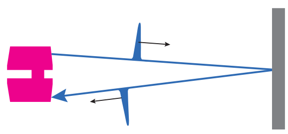
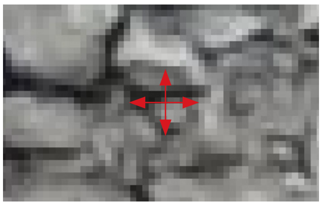
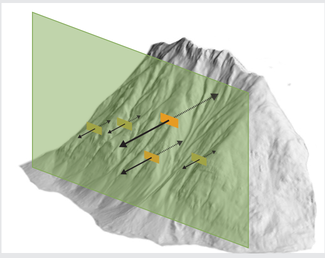
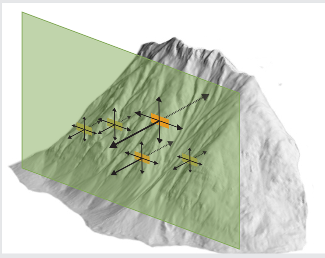
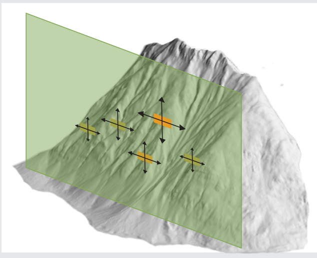
3 TECHNOLOGIES

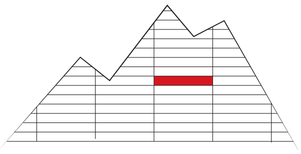
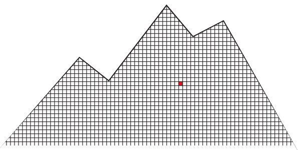
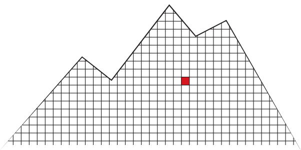
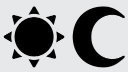
Autonomous avalanche radar Gonda, Switzerland

3.1 DEFORMATION ANALYSIS: A TECHNOLOGICAL COMPARISON

Spatial deformation analysis instruments can remotely assess landscape changes through time and over large areas. The analysis is always based on the comparison of data acquired at two different points in time. The following table provides an overview of the most common techniques (radar, lidar, cameras) for natural hazard monitoring.
All of these technologies make use of electromagnetic waves at different frequencies:



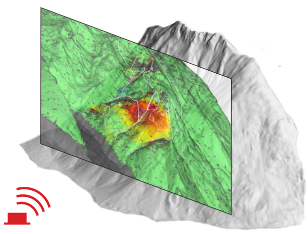
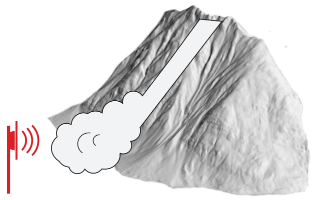
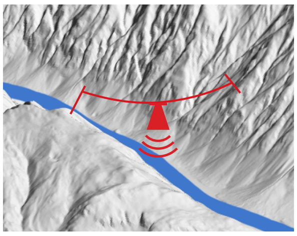
	INTERFEROMETRIC RADAR	TERRESTRIAL LIDAR	DEFORMATION CAMERA
TYPE	2D (3D with DEM) remote measurement, relative	3D remote measurement, absolute	2D (3D with DEM) remote measurement, relative
FREQUENCY/ WAVE LENGTH	Microwave (17 GHz)	Near infrared (800–1600 nm)	Visible light (380–780 nm)
MEASURING PRINCIPLE (SIMPLIFIED)	 Radar measures phase of reflected microwaves. → Target moves → Second measurement from same position → Phase change of microwaves → Comparison of two phase measurements to calculate deformation	 Lidar measures time of light of reflected light pulse. → Distance to target → Georeferencing, classification etc. → Digital elevation model / point cloud → Comparison of two point clouds to calculate deformation	 High resolution images (42 megapixel) of rock face or glacier. → Comparison of images by tracking groups of pixels → Deformation measurement based on displacement of tracked pixel groups
MEASURED DISPLACEMENT	 In line-of-sight of radar	 Line-of-sight & transverse plane	 Transverse to line-of-sight

	INTERFEROMETRIC RADAR	TERRESTRIAL LIDAR	DEFORMATION CAMERA
SPATIAL RESOLUTION (@ distance of 1km, 45° angle)*	 1 m x 4.4 m	 ca. 20 cm x 20 cm	 ca. 2 m x 2 m
WEATHER (Works during)			
ATMOSPHERE	**Atmospheric conditions (humidity, pressure, temperature, wind, turbulences etc.) influence the propagation of electromagnetic waves. Depending on wavelength, this effect can be more or less pronounced and corrected for.**		
	Changes in atmospheric conditions can lead to **errors on the order of several mm**. Using known stable areas, this can be mostly corrected for.	Due to the **short wavelength** of near infrared and visible light (Lidar, cameras), atmospheric conditions can lead to **errors on the order of several cm**. These errors can be mostly corrected by using stable reference areas, but lead to a **decrease in accuracy** of the measurements.	
REFLECTIVITY	Excellent results on glaciers and hard rock surfaces. When surfaces change significantly (erosion, vegetation growth etc.) coherence is lost and measurements cannot be compared.	Excellent results on all solid objects. Can't reflect off of water (= transparent) and snow (= absorptive).	Everything human eyes can see is visible to the camera.
ACCURACY OF DEFORMA-TION ANALYSIS*	**0.5–2 mm** (in line-of-sight)	**1–10 cm** (in line-of-sight and transverse plane)	**1–10 cm** (transverse to line-of-sight)
SUGGESTED USE	For continuous or periodic, **weather independent monitoring of very small deformations** (mm per day to year), e.g., critical instabilities.	To periodically **detect significant changes** (1–10 cm) over long time spans and for **volume estimates**. To create current DEM.	**Cost effective long-term monitoring** of uncritical instabilities (weather permit-ting). Detection of accelera-tion, situational changes.

* under ideal conditions. Resolution depends on instrument and distance or lens.

3.2 RADAR

Radar stands for radio detection and ranging and refers to a variety of different detection and localization techniques. A radar instrument emits electromagnetic waves, that are reflected by the target, and then received by the instrument. The received signals then get analyzed based on different criteria. Because a radar emits its own signal, it works at night and during bad weather. Three types of radar are common in natural hazard monitoring:

	INTERFEROMETRIC GEORADAR	DOPPLER RADAR	RADAR GAUGE
TYPE	2D remote measurement	2D remote measurement	Local point measurement
FREQUENCY*	17 GHz	10 GHz	24 GHz
MEASURING PRINCIPLE	 The interferometric radar measures the phase of the reflected wave. Phase changes between measurements translate to deformation.	 This instrument makes use of the Doppler Effect of moving objects and can therefore differentiate between moving and stationary targets, measure their velocity and direction.	 The radar gauge sends short radar pulses toward its target. Based on the time of flight, the distance is calculated.
USE	Deformation analysis with sub-mm accuracy.	Automatic detection of mass movements like avalanches, rockfall, debris flows or people. With alarm function.	Automatic detection of debris flows and floods. With alarm function.
MORE INFO	Page 29	Page 30, 31, 32	Page 33
EXAMPLE STATION IMAGE	 Interferometric radar Piz Cengalo (Bondo), Switzerland	 Avalanche radar Gonda, Switzerland	 Gauge radar Bondo, Switzerland

* frequency (range) of the radar equipment we use.

3.2.1 INTERFEROMETRIC GEORADAR

The interferometric Georadar is used for large-scale monitoring of unstable rock faces, glaciers or hillslopes. Independent of visibility, the interferometric Georadar can monitor large areas from a safe distance so that possible break-off events can be predicted early on.

ADVANTAGES

- **Large-scale, very reliable remote measurement** of rock faces and glaciers
- Deformation analysis with **sub-mm accuracy**
- **Early warning** of rock and ice break-offs and size/volume estimate
- Analysis of slow deformations (mm per week to years)
- Range up to **5 km**, coverage **> 5 km²**
- **Independent of weather** and daylight
- Suitable for mountain use
- **Continuous or periodic operation** (depending on urgency)
- Very fast installation
- For continuous operations, all data, webcam images and analyses are accessible on our **online data portal**

LIMITATIONS

- Changes in vegetation or snow make measurements hard to compare, strong reflectors like protection nets are opaque to radar waves
- Only the line-of-sight component of deformation can be measured
- Radar measures differential (relative) deformations and not absolute positions

REFERENCE PROJECTS

Bondo, Switzerland
Continuous monitoring of Pizzo Cengalo since the 2017 rock avalanche and analysis of slow deformation (mm over several months). Precise prediction of several small events.

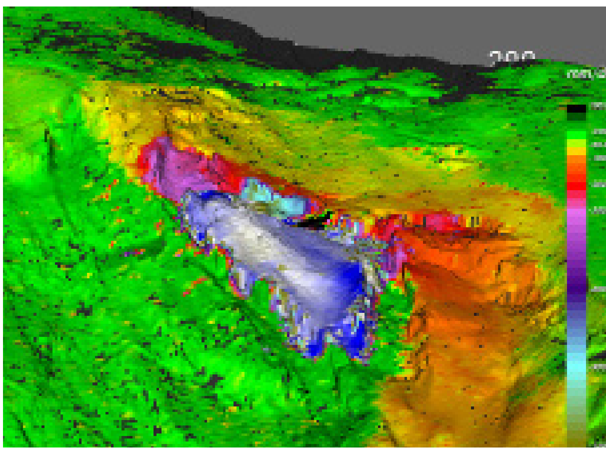
Weissmies Glacier, Switzerland
The interferometric Georadar was installed immediately after the deformation camera detected an acceleration of the hanging glacier. Precise prediction of the break-off event of 10 September 2017.

Preonzo, Switzerland
Temporary monitoring of a rock instability and precise prediction of a large rockfall on 15 May 2012.

Barry Arm landslide and tsunami hazard, Alaska, US
Autonomous monitoring of unstable slope that poses a potential tsunami hazard. Remote setup with radio link station for communciation.

System type	
Distance/range	
Weather	
Resolution	
Accuracy of deformation analysis	0.5–2 mm
Costs	$$–$$$
Suitable for monitoring of	

Interferometric radar Chli Windgällen at 5km distance, Switzerland (above),
Weissmies glacier (Saas Fee), Switzerland (below)



3.2.2 AVALANCHE RADAR

The avalanche radar detects and tracks avalanches independent of weather and daylight conditions. The radar continuously scans the avalanche area and immediately issues an alarm (e.g., a road closure) if avalanche motion is detected.

ADVANTAGES

- Globally unique, very reliable detection technology with **large coverage (up to 10 km²)** and **range (5 km)**
- A single radar can monitor **multiple individual avalanche paths** (unique worldwide)
- **Independent of weather** and daylight
- Automatic, **real-time alarm function** (e.g., road closure with gates or traffic lights)
- **Automatic reopening** if avalanche does not reach designated area (globally unique)
- **Different sensitivity** in subregions possible (globally unique)
- **Easy-to-read map** with avalanche tracks, event size and velocities, and associated photos (visibility permitting)
- Access to data from all recorded avalanches, live-view into the hazard area, remote control of alarm components (gates, traffic lights, etc.) via **Geoprevent online data portal**
- Integration with **smartphone** and **tablet**

LIMITATIONS

- Can only detect events that are within the field of view of the radar and not obstructed by terrain or other features
- Minimum avalanche size and duration (a few seconds) necessary

REFERENCE PROJECTS

Zermatt, Switzerland: Securing of access road with automatic road closure. Operational since 2015, first system of its kind in the world.

Holmbuktura, Norway: Two radars monitor a large slope at a distance of up to 3.5 km. Automatic road closure and reopening.

Randa, Switzerland: detection of ice and snow avalanches at a up to 5 km. Automatic closure and reopening of road and railroad.

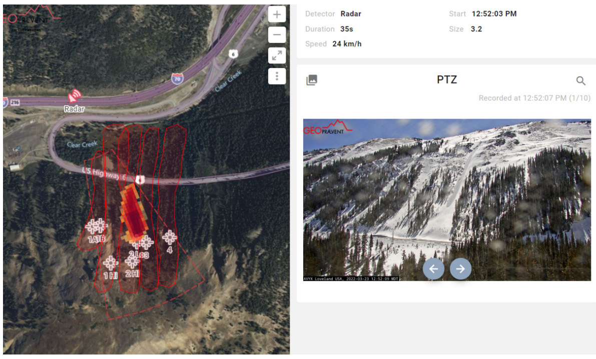
Bear Pass, Canada: Two autonomous radar stations and a dedicated repeater station for 9 tracks in total (since 2019).

Rogers Pass, Canada: Four radars for avalanche activity monitoring and blasting verification.

Ningunsaw Pass, Canada: Autononmous radar station with satellite communication (since 2021).

System type	
Distance/range	
Weather	
Avalanche tracks	
Costs	$$–$$$
Suitable for monitoring of	

Double Avalanche radar setup Zermatt, Switzerland (above),
Avalanche radar at Loveland Pass, Colorado, USA (below)



3.2.3 ROCKFALL RADAR

The rockfall radar can be used to monitor rockfall activity or to automatically issue alarms upon detecting a rockfall event. Depending on the situation, it can be used in conjunction or as a replacement for constructional measures.

System type	
Distance/range	
Weather	
Costs	$$–$$$
Suitable for monitoring of	

ADVANTAGES

- Automatic detection of **falling rocks**
- Range more than **1 km**, coverage **1 km²**
- **Independent of weather** and daylight
- Automatic, **real-time alarm function** (e.g., road closure with gates or traffic lights)
- **Easy-to-read map** with rockfall tracking, event size and velocity, and associated photos (visibility permitting)
- Access to data from all recorded events, automatically captured images, remote control of alarm components (gates, traffic lights, etc.) via **Geoprevent data portal**
- Integration with **smartphone** and **tablet**

LIMITATIONS

- Can only detect events that are within the field of view of the radar and not obstructed by terrain or other features
- Minimum event size necessary
- Detection of individual moving blocks is currently limited

REFERENCE PROJECTS

Brinzauls, Switzerland
Monitoring of active rockfall area with automatic road closure and reopening. Worldwide first system of its kind.

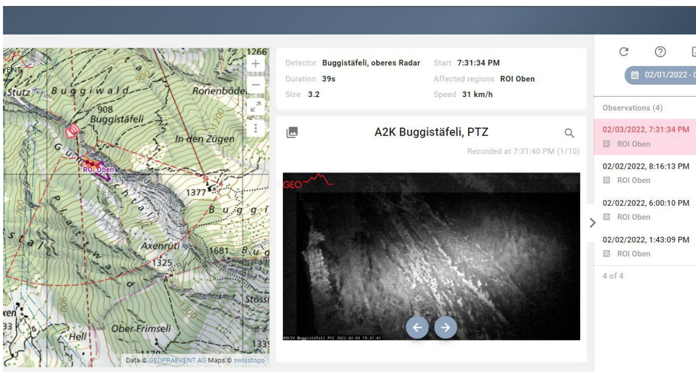
Gumpisch valley, Axenstrasse, Switzerland
Comprehensive rockfall alarm system with two radar heads and sensor fusion with seismic sensors for event verification due to short warning time. Automatic closure and reopening of main European corridor. Reopening scheme with rockfall detection in lower slope through motion sensors and trigger lines. Since 2019.

Ruinon landslide, Bormio, Italy
Detection of rockfall and automatic road closure and reopening on access road to Santa Catarina (2020–22).

MORE INFORMATIONS

Scientific publication
Conference proceedings of the RocExs 2017 Interdisciplinary Workshop on Rockfall Protection, Barcelona, Spain

Rockfall radar Brienz/Brinzauls (above) and rockfall map and event images at Gumpisch valley, Axenstrasse (below), Switzerland



3.2.4 PEOPLE RADAR

The people radar detects persons in motion and is used to secure areas at risk from avalanche mitigation work. Day or night and regardless of weather, safety managers can use this system to ensure no skiers or hikers are within an avalanche mitigation perimeter.

System type	
Distance/range	
Weather	
Costs	$$–$$$
Suitable for monitoring of	

ADVANTAGES

- Automatic detection of people at a **range** of **1 km** within an **area** of **1 km²**
- **Independent of weather** and daylight
- **Detection, tracking and mapping** of all motion within a pre-defined area
- Time-lapse image sequences (weather permitting)
- Definition of virtual areas and **automatic alarm issuing** if motion is detected in a defined area (e.g., sirens, flashing lights)
- **User-friendly, online control-interface** with access to system status information, last detected movements, current webcam images, remote control of alarm components
- Integration with **smartphone** and **tablets**
- **Combination** of multiple radars to **maximize coverage** and **secure neuralgic locations** possible
- Automatic data deletion to ensure **data protection and privacy**

LIMITATIONS

- Can only detect events that are within the field of view of the radar and not obstructed by terrain or other features
- Radar also detects animal movements, though that of small animals can be filtered to not trigger an alarm

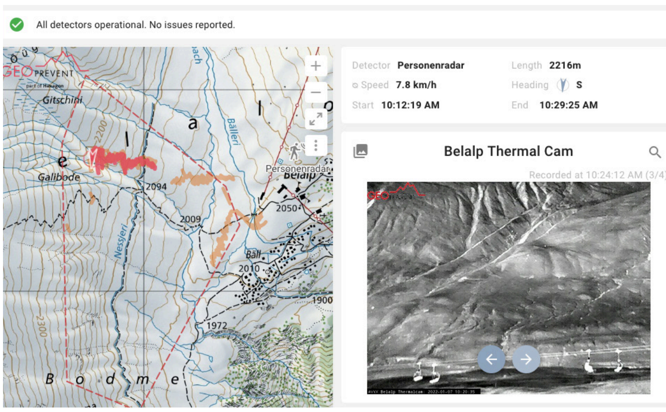
REFERENCE PROJECTS

Zermatt, Switzerland
Four stations with people radar, cameras and gates. Alarms can be issued if closures are ignored.

Belalp, Switzerland
Integrated avalanche and people detection system for monitoring of the Grat Avalanche, that is frequently triggered artificially.

Val Bever, Switzerland
Artificially triggered avalanches threaten a popular ski mountaineering route. A people radar is used to monitor the area before avalanches are triggered.

People radar Zermatt (above), combined avalanche and people radar Belalp (below), both Switzerland



3.2.5 RADAR GAUGE

The radar gauge measures the flow height of a river or creek. A sudden rise in water level (flood, debris flow) triggers an alarm and can subsequently close roads or initiate the evacuation of a construction site.

System type	
Distance/range	
Weather	
Costs	$–$$
Suitable for monitoring of	

ADVANTAGES

- **Reliable technique** to measure flow height of turbulent surfaces like that of debris flows or flood waves
- **Independant of weather** and daylight conditions
- **Contact free measurement** that is not disrupted by the event itself (typically mounted below a bridge or suspended from steel cables tensioned across the river)
- **Alarm** (road closure or message dissemination) is issued if pre-defined flow height threshold is surpassed
- Online data portal provides constant access to **real time measurements**, **time-series** and **camera images** (visibility and system permitting)

LIMITATIONS

- Only events within field of view of radar can be detected. To monitor a wide river bed and for redundancy we recommend the use of two radar gauges
- Sensor may be directly exposed to a major event and could be damaged

REFERENCE PROJECTS

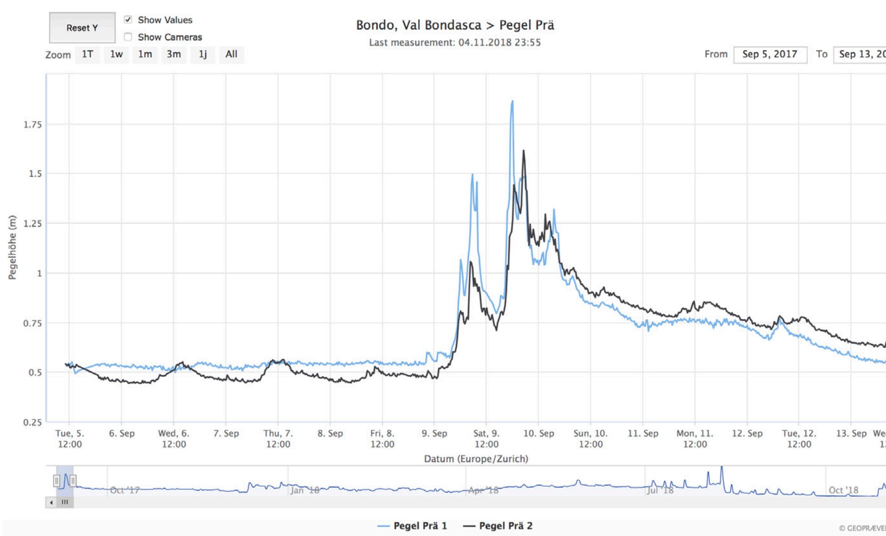
Bondasca Valley (Bondo), Switzerland
Extensive debris-flow alarm system with a total of four radar gauges that provide different advance warning times for automatic closure of the main valley road.

Kazbegi, Georgia
Extensive debris-flow alarm system that protects the access road to the nearby border control post (Georgia-Russian border).

Spreitgraben, Switzerland
Extensive debris-flow alarm system that protects travelers by automatically closing the Grimsel Pass Road in case of a debris flow.

Muotathal, Switzerland
Debris flow alarm system at Teufbach with automatic closure of three different roads in the village of Muotathal.

Gauge radar and event camera Steinach (above), Gauge radar Bondo (below), both Switzerland



3.3 LIDAR – TERRESTRIAL LASER SCANNER

Lidar (light detection and ranging) is an optical method that uses laser beams to measure distances and velocities. Lidar uses electromagnetic waves in the visible or near infrared spectrum that are much shorter than those of radar. It is the ideal technology for high-precision, 3D surveys of large areas. Additionally, lidar scans can be used to estimate displacement and volumes.

System type	
Distance/range	
Weather	
Resolution	
Accuracy of defomration analysis	1–10 cm
Costs	\$\$–\$\$\$
Suitable for monitoring of	

ADVANTAGES

- **Large-scale survey** of rock walls or glaciers with mm precision and **high spatial resolution** (min. 0.5 x 0.5 m, distance dependent)
- Data basis for the creation of **digital elevation models**
- **Volume estimate** for rock and ice break-offs
- **Independent of daylight**, but requires good weather
- Range up to **4 km**, coverage of several **km²**
- Deformation analysis for detecetion of **large displacements** (1–10 cm and more)
- **Vegetation** can be filtered
- **Periodic measurements** often combined with interferometric radar
- Very fast installation
- Analysis delivered as periodic reports

LIMITATIONS

- Lidar only detects large changes (1–10 cm and more, distance dependent). See details on page 26
- Clear view of target necessary (measurements difficult in foggy, rainy or snowy conditions)
- Results depend on algorithms used for point cloud comparison

REFERENCE PROJECTS

Biasca, Switzerland

Periodic measurements of a large rock face (combined with interferometric radar) for the Swiss Federal Railways to detect deformation and estimate volumes of rockfall events.

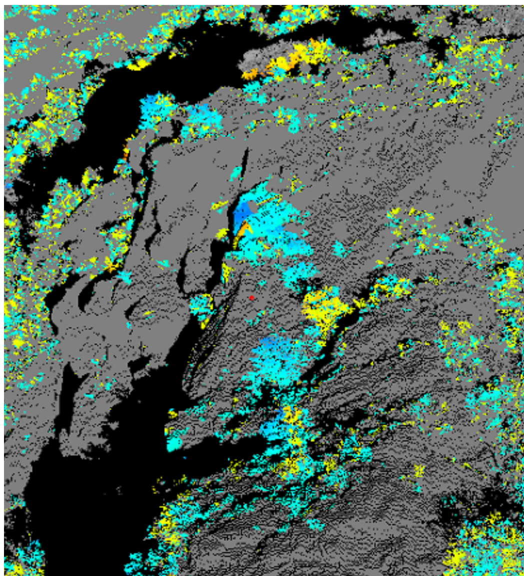
Liechtensteinklamm, Austria

Periodic measurements (combined with interferometric radar) of the rock face that produced the 2017 rockfall at Liechtensteinklamm (tourist attraction).

Saulcette, France

Periodic measurements of a sliding hillslope above a railroad of the French National Railways SNCF. Measurement combined with interferometric radar.

Laser scan Axenflue (Flüelen), Switzerland



3.4 OPTICAL – DEFORMATION CAMERA

The deformation camera is a cost-effective method to monitor large instabilities from a distance. Thanks to the fully automated deformation analysis, displacements of just a few cm can be detected.

ADVANTAGES

- **Cost-effective monitoring** technology to detect acceleration or slowdowns of displacements
- **Automated image processing** and selection thanks to sophisticated algorithms
- **Color coded** displacement visualization
- Convenient image visualization with **powerful zoom option**
- **Flexible choice of analysis intervals** (daily, every two days, weekly, seasonally)
- Displacement analysis and raw images always available via **Geoprevent online data portal**
- **High resolution photos** for manual analysis of change

LIMITATIONS

- Only effective during good visibility (daytime, good weather)
- Not suitable for critical instabilities
- Contrast limited: Reliable image analysis requires high contrast images. For demanding applications, HDR processing can improve contrast and facilitate analysis
- Only component of velocity normal to line-of-sight is measured
- Snow cover

REFERENCE PROJECTS

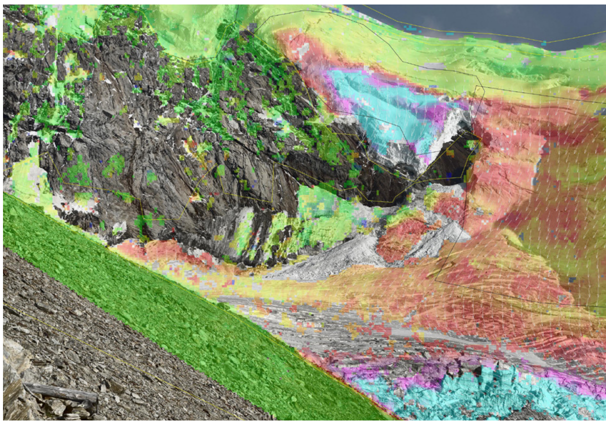
Weissmies Glacier, Switzerland
The deformation camera detected the acceleration of the hanging glacier. Interferometric radar was subsequently used to monitor the critical instability.

Moosfluh landslide, Switzerland
Monitoring of a large slope instability in the Aletsch Region from across the valley.

Bis Glacier, Switzerland
Ice avalanche monitoring of the steep part of the glacier with three cameras as well as an avalanche radar and automatic alarm functions. Monitoring of hanging glacier on Weisshorn at 4133 m asl.

System type	
Distance/range	
Weather	
Resolution	
Accuracy of defomration analysis	1–5 cm
Costs	\$–\$\$
Suitable for monitoring of	

Deformation camera Weisshorn (Randa) at 4133 m asl (above) and at Weissmies (Saas Fees) (below), both Switzerland



3.5 OTHERS

3.5.1 CRACK METERS

Two types of crack meters can be used to closely monitor motion of individual rock formations: Telejointmeters measure the widths of clefts and extensometers measure expansion and compression of joints within a rock formation. Both are local point measurements that require access to the hazard area.

ADVANTAGES

- **Telejointmeter:** Measurement of **differential surface motion** between two rock bodies with a measurement accuracy of 0.2–1 mm, depending on installation location, crack width and solar radiation (diurnal cycle)
- **Extensometers** are placed **in boreholes** and measure **relative displacements** between the surface and the rock at different depths with an accuracy of about 0.1 mm
- **Independent of weather** conditions and daylight
- **Automatic alarm** can be triggered if pre-defined (relative or absolute) displacement thresholds are surpassed
- Continuous measurement, data transmission by cable or radio, access to data via the **Geoprevent online data portal**

For large scale surveillance of rock formations we recommend the interferometric Georadar. Telejoinmeters are the ideal addition to closely monitor critical weaknesses.

LIMITATIONS

- Measurements only represent motion in the immediate vicinity of the crack meters and only in the direction the instrument is mounted
- Installation requires access to hazardous terrain
- Instruments can get destroyed or damaged in break-off events, and are then no longer available to monitor further motion in the affected area
- Instruments themselves can be exposed to rock fall and require protection

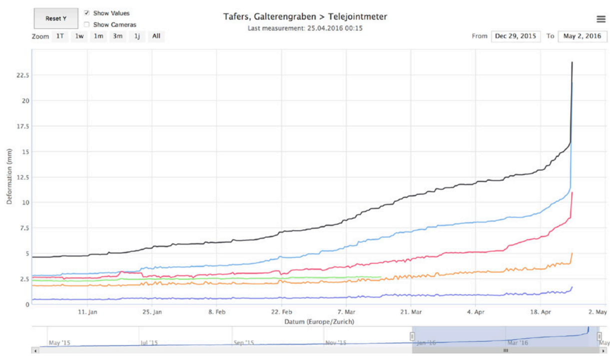
REFERENCE PROJECTS

Tafers rockfall, Switzerland
Monitoring of a rock instability above a residential building and recreational area. Precise measurements aided in timely evacuation of residents.

Gurtnellen rockfall (2012), Switzerland
Comprehensive monitoring during rock stabilization work above the north-south axis of the Swiss Federal Railways.

System type	
Distance/range	
Weather	
Accuracy of deformation analysis	>10 cm
Costs	$$–$$$
Suitable for monitoring of	

Crack meters Limmern (above), crack meters with slope failure Tafers (below), both Switzerland



3.5.2 GEOPHONES AND SEISMOMETERS

Geophones and seismometers detect mass movements based on the ground motion these cause, with seismometers being several times more sensitive than geophones. Both are installed locally, and reliable event detection typically requires several redundant sensors. It is possible to have the system issue alarms and trigger automatic responses such as disseminating messages or closing a road.

ADVANTAGES

- **Local, relatively simple detection method** for avalanches and debris flows
- **Robust** sensors well suited for harsh mountain environments
- **Independent of weather** conditions and daylight
- **Automatic, real-time alarm** functions
- **Seismometers** are more sensitive than Geophones and can also be used to **monitor rockfall activity** at a distance of several kilometers
- Access to ground motion data and camera images is always provided through the **Geoprevent online data portal**
- Integration with **smartphone** and **tablet**

LIMITATIONS

- Sensors and cables can be damaged by avalanches or debris flows
- Detection difficult if detection threshold is not reached by mass movements (e.g., old avalanche deposits dampen signals)
- False alarms caused by other noise sources: earthquakes, thunder, animals, people

REFERENCE PROJECTS

Gumpisch valley, Axenstrasse, Switzerland
Sensor fusion with rockfall radars for event verification due to short warning time. Automatic closure and reopening of main European corridor road.

Bondo, Switzerland
Three seismometers serve as a redundant detection system for debris flows in the Bondasca Valley. In addition, the seismometers indicate rockfall activity from Pizzo Cengalo, higher up the valley.

Quinto, Switzerland
Geophone as addition to an avalanche radar system: Geophones indicate how far the avalanche has run out on the lower slope that is not visible to the radar.

System type	
Distance/range	
Weather	
Avalanche tracks	
Costs	$–$$*
Suitable for monitoring of	

* depending on number of sensors

Geophone

Seismic sensor Bondo (Switzerland)

3.5.3 TRIGGER LINE

Trigger lines are typically stretched across channels and pulled out by descending avalanches or debris flows. A predefined breaking point ensures immediate breakage at a defined force that triggers the alarm. Trigger lines need to be replaced after each event.

ADVANTAGES

- **Simple and cost-effective detection method** for avalanches and debris flows (among others)
- **Independent of weather** and daylight
- Automatic, real-time **alarm** functions
- **Several types available** (ropes, metal bars, etc.)

LIMITATIONS

- Need replacement after each event
- Detection can be inhibited because…
  - event fails to destroy trigger line (e.g., anchor above channel is torn out instead)
  - event destroys trigger line outside predetermined breaking point
  - event changes course and misses trigger line
- False alarm if line is triggered by animals or people
- Depending on type of trigger line used, the status of the individual lines cannot be checked remotely and regular inspections are necessary

REFERENCE PROJECTS

Bondo, Switzerland
The trigger lines that were part of a debris-flow alarm system installed in 2015 detected the debris flow following the 2017 rock avalanche on Pizzo Cengalo and immediately closed the roads in the valley.

Kazbegi, Georgia
Extensive debris-flow alarm system that protects the access road to the nearby border control post (Georgia-Russian border).

Spreitgraben, Switzerland
Extensive debris-flow alarm system that protects travelers by automatically closing the Grimsel Pass Road in case of a debris flow.

Acherlibach, Switzerland
Simple debris-flow alarm system for small magnitude and relatively rare events. System is based on trigger lines only and closes a road automatically.

System type	
Distance/range	
Weather	
Avalanche tracks	
Costs	$
Suitable for monitoring of	

Trigger line Bondo, Switzerland (above)
Trigger line near Mt. Kazbegi, Georgia (below)

3.5.4 GNSS (GPS)

Differential GPS stations measure the motion of an unstable area through time, with one station mounted in a stable area as a reference point. The GNSS instruments record satellite derived positions and transmit them to our servers for displacement analysis.

System type	
Distance/range	
Weather	
Costs	$–$$
Suitable for monitoring of	

ADVANTAGES

- **Simple landslide monitoring technique** with an accuracy of about 5–10 mm
- **Calculation of 3D displacement possible** (with slightly lower accuracy in the vertical)
- **Independent of weather** conditions and daylight
- **Warning messages** can be sent when displacement thresholds are surpassed
- Displacement time-series from all individual GNSS instruments are always available through the **Geoprevent online data portal**
- Integration with **smartphone** and **tablet**

LIMITATIONS

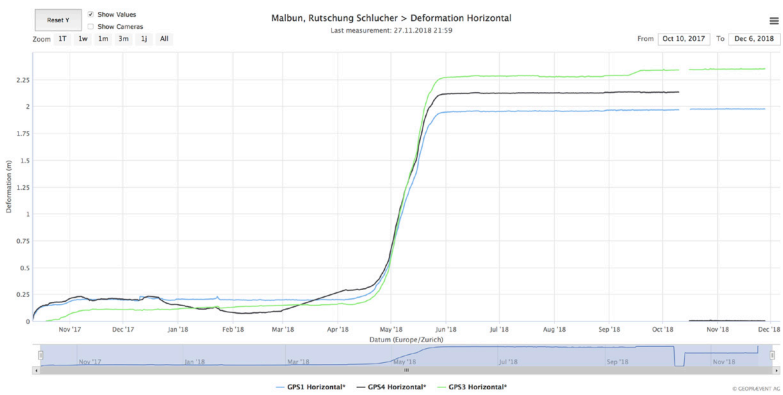
- Measurement only applies to displacement in immediate vicinity of instrument
- Accuracy of measurement depends on the number of visible satellites. Narrow valleys, nearby rock walls or trees can reduce accuracy.
- Measurement impossible when instruments are covered by snow
- Reference station must be mounted on stable ground

REFERENCE PROJECTS

Schlucher landslide, Liechtenstein
Monitoring of Schlucher landslide with three GPS stations.

Zongling landslide, China
Measurement of landslide displacement with seven GPS and one reference station.

GNSS-station landslide Schlucher (Malbun), Liechtenstein



3.5.5 COMBI MOTION SENSOR

Rockfall and debris flow barriers only provide reliable protection if they are intact, making their monitoring essential. Events can damage the nets and impair their functionality resulting in reduced protection against subsequent events. The installation of combined vibration and inclination sensors on the barriers provide valuable information about their current condition. In combination with trigger lines, the system can also be used as alarm system.

System type	
Distance/range	
Weather	
Costs	$$
Suitable for monitoring of	

ADVANTAGES

- **Permanent status overview** of individual protection nets via online data portal
- Combi sensor **registers the slightest change** in position and transmits the data to the receiver station
- **Combination with trigger line**: A trigger rope spanned over the net increases the area to be monitored and detects large events
- Vibration measurement **provides indications of minor events** where the trigger line was not pulled out
- **Lower costs** for the barrier maintenance (no more on-site inspections necessary)
- **Automatic alarm** activation in real time
- **Independent of weather** and daylight
- **Easy installation**
- **Robust and maintenance-free** sensors

LIMITATIONS

- Trigger line requires repair after an event
- false alarms due to snow or other objects possible
- Installation in dangerous area

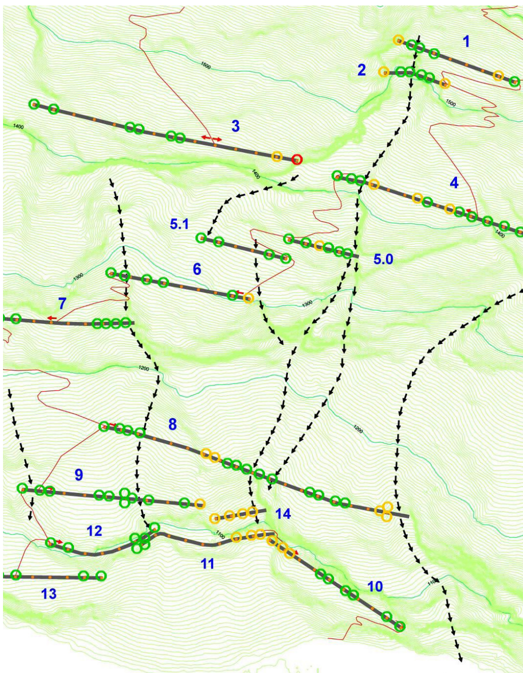
REFERENCE PROJECTS

Ovella, Switzerland
Since summer 2015, more than 100 combi sensors and trigger lines have been monitoring over 1.2 km of protective nets above the construction site of the Inn hydropower plants near Ovella in the Lower Engadine Valley.

Gumpisch valley, Axenstrasse, Switzerland
Debris flow and rockfall protection barrier monitoring above Axenstrasse (major European corridor): Upon rockfall detection in the upper part of the channel (by radar), the system immediately closes the road but will automatically reopen if the combi sensors do not register an impact in the protection nets.

SBB Gotthard Line, Switzerland
Combi sensors monitor rockfall nets at several critical points to protect the SBB (Swiss Federal Railway) tracks through the Alps.

Combi motion sensor at hydro power construction site Ovella, Austria

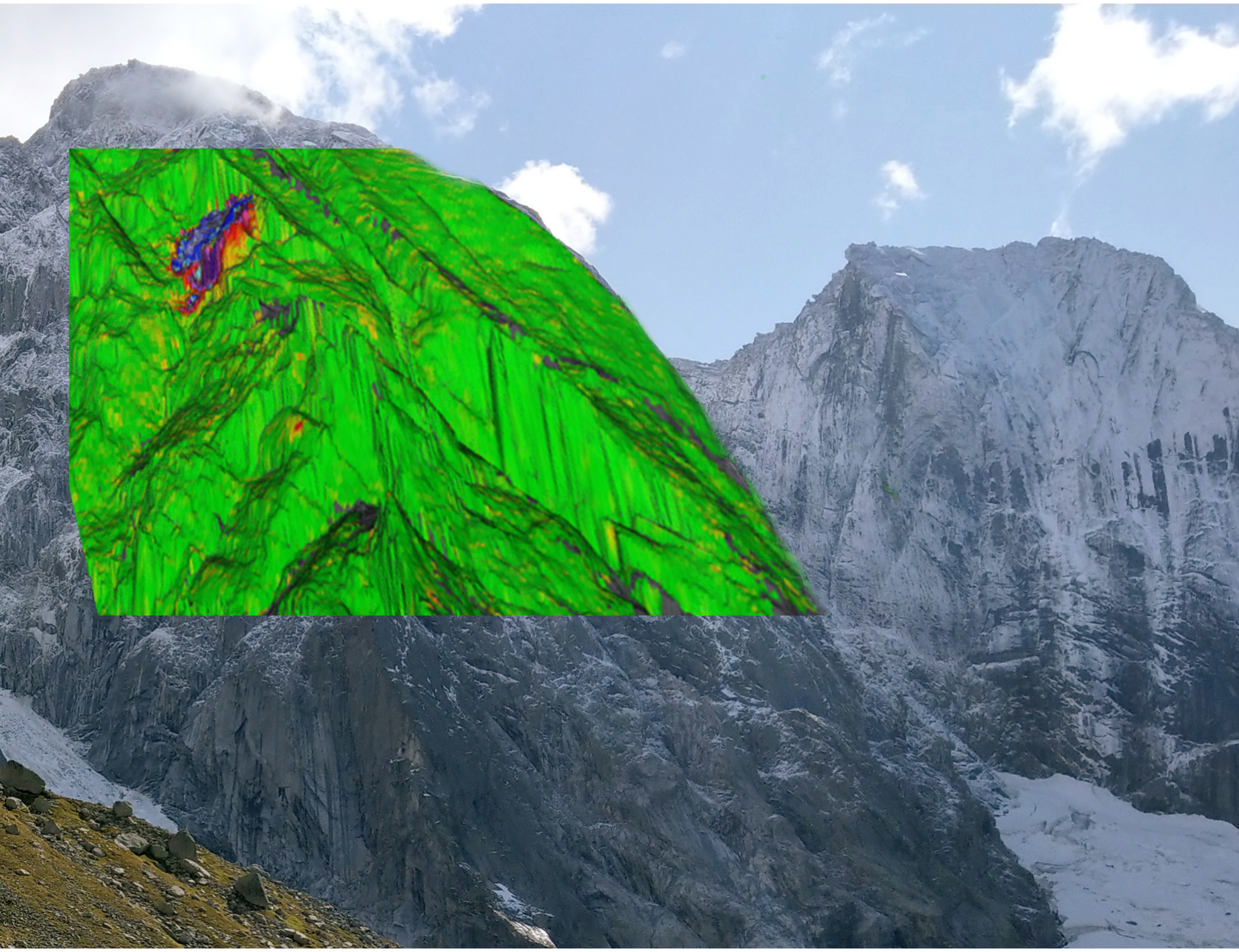


4 APPENDIX

SYMBOLS

- Warning system
- Alarm system
- Sensors
- Data Logger
- Alarm
- Data portal
- Communication
- Weather (day/in good weather, night, fog, snowfall/rain)
- Spatial resolution
- Costs
- Avalanche tracks
Debris flow paths
- Avalanches
- Rockfall
Rock instabilities
- Debris flow
- Landslide
- Flood

- Terrestrial lidar
- Laser(-scanner)
- Avalanche radar
Rockfall radar
Debris flow radar
- Terrestrial Georadar
- Georadar (satellite)
- Gauge radar
- Geophone
Seismic sensor
- Trigger line
- Combi motion sensor
- Deformation camera
- Total station
- Snow height
- GNSS (GPS)
- Crack meters
- Infrasound
- Future Technologies
Drones



Interferometric radar Piz Cengalo (Bondo), Switzerland

ALARM AND WARNING SYSTEMS FOR NATURAL HAZARDS

Geoprevent provides alarm and monitoring solutions for a wide range of natural hazards. We either monitor the hazard zone to measure precursors of an event or we detect the event itself and automatically trigger alarms.
Geoprevent also provides technology to detect people in the hazard zone (e.g. prior to avalanche blastings).

Combined avalanche and people radar Belalp, Switzerland

GEOPREVENT
Räffelstrasse 28
8045 Zurich
Switzerland

Tel. +41 44 419 91 10
info@geoprevent.com

More Info: www.geoprevent.com

Follow us on: