Searching fore- and afterslides of gravitational mass movements

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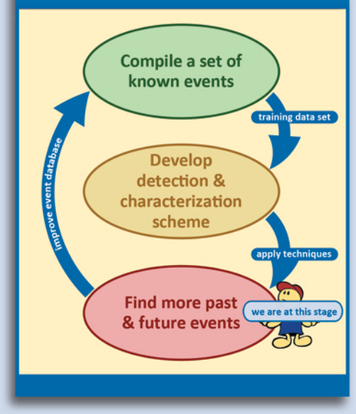
Abstract

Environmental seismology is an emerging field with strong implications for better understanding and mitigating natural hazards. Continuous real-time records of seismic stations allow the precise detection of rapid gravitational mass movements such as rockfalls and landslides on various scales – from local slope monitoring to regional or global detection of large-scale events. Especially when compared with classical detection methods for wide-area coverage, such as remote sensing, seismology has the advantage of providing continuous records with precise time stamps.

The seismic waves generated by rapid mass movements enable us to study e.g. repeated failures of a slope with a temporal resolution opens up new possibilities: E.g. we can discriminate subsequent events from the same source region, such as potential foreslides and afterslides, which might otherwise be registered as just a single failure, or with insufficient timing precision. In this study we analyze seismic records obtained from permanent and temporary seismic networks in the Alps and search for fore- and afterslides around the catastrophic 2017 Piz Cengalo, Switzerland rockslide and a series of rockfalls in the Glockner Group, Austria that have occurred in October 2017.

Workflow



Motivation

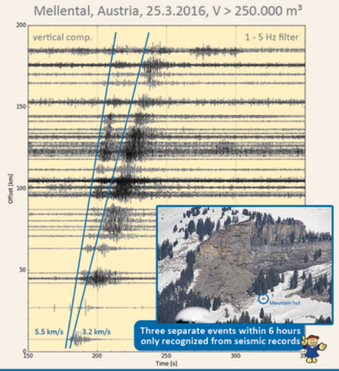
... with waveforms example

- Rapid **gravitational mass movements** pose a **serious hazard** to population in alpine areas

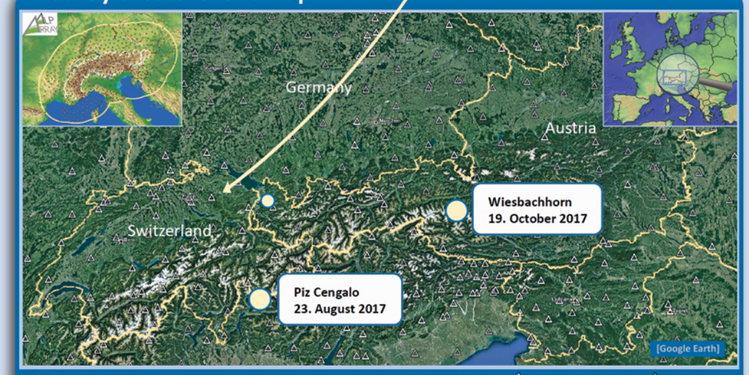
- Continuous **real-time seismic records** allow detection of mass movements with **exact origin time**
- Seismic networks enable us to **systematically search** for potential **fore- and afterslides** of main events

Starting point

2 large-scale **rockslides** in Austria and Switzerland that occurred in **2017** and were detected by the **AlpArray** network

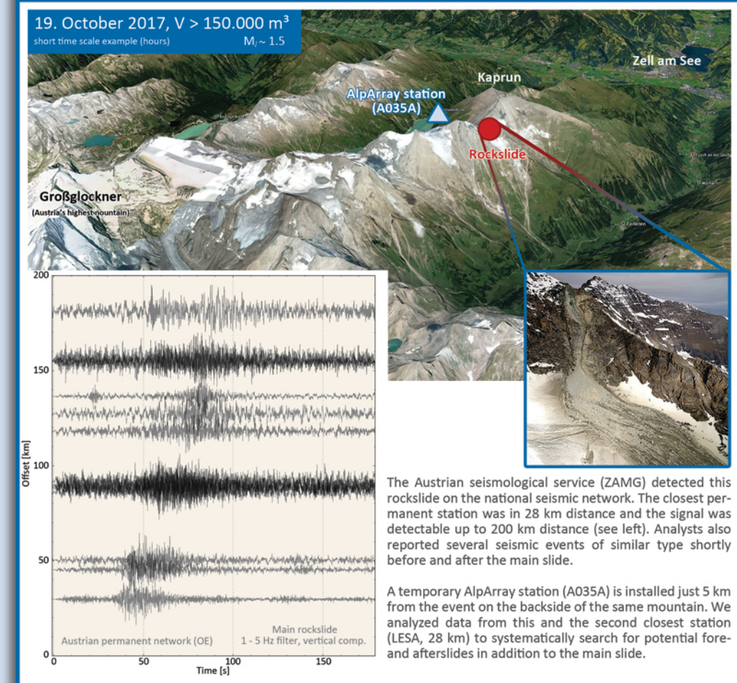


Study area & event map



Rockfall location | Seismic station: permanent | AlpArray

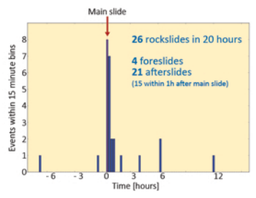
Wiesbachhorn / Kaprun - Hohe Tauern region, Austria

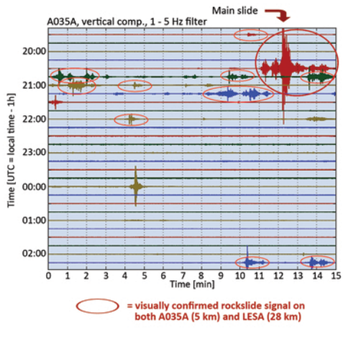


The Austrian seismological service (ZAMG) detected this rockslide on the national seismic network. The closest permanent station was in 28 km distance and the signal was detectable up to 200 km distance (see left). Analysts also reported several seismic events of similar type shortly before and after the main slide.

A temporary AlpArray station (A035A) is installed just 5 km from the event on the backside of the same mountain. We analyzed data from this and the second closest station (LESA, 28 km) to systematically search for potential fore- and afterslides in addition to the main slide.

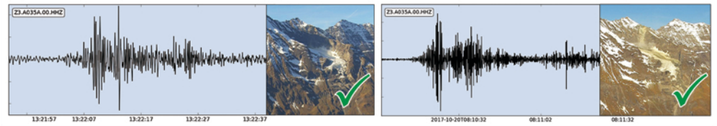
The plot on the right-hand side shows 8 hours of seismic records from station A035A, located 5 km from the rockslide . All signals encircled in red mark events which are drastically different from common earthquake signals, but are also observed on the second closest station LESA at 28 km distance. We conclude that all of these are associated with mass movements and are **fore- and afterslides** of the main rockslide. The histogram below shows the corresponding **rockslide rate** as a function of time around the main slide.



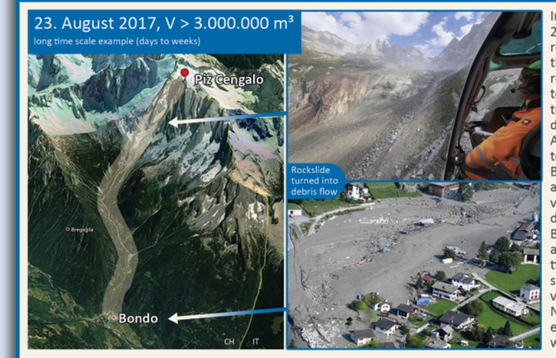


How to **confirm seismic signals** recorded by only **one station**? We need **independent observations**!

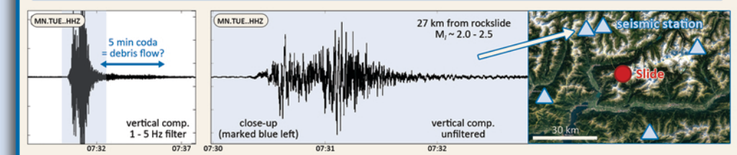
A **webcam** is located 6 km from the rockslide location taking high-resolution images every five minutes. We visually checked all images obtained during daylight the day before and after the main rockslide (which occurred at night). Occasionally **dust clouds** are visible which we can relate in time with seismic signals recorded by A035A. This way we can confirm a rockslide as origin. Below we show two examples. Such confirmed records can be used to **scan the data for more small rockslides** e.g. via cross-correlation techniques (**template matching**).



Piz Cengalo / Bondo - Swiss-Italian border region



In the morning of August 23rd 2017 approx. 3 million m³ of rock detached from the top of the Piz Cengalo mountain. The rockslide reached velocities up to 250 km/h and subsequently turned into a devastating debris flow.
Automatic early-warning systems activated, and the village Bondo was successfully evacuated. A safety dam along the valley minimized the structural damage inside the village.
Both the early-warning system and the dam were built in reaction to a massive rockslide of similar size that occurred at the very same location in 2011. Newspapers reported on several afterslides in the following weeks in 2017.



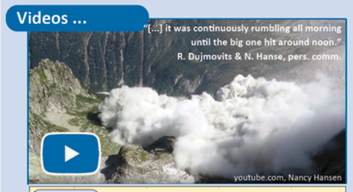
The main rockslide was very clearly recorded by the dense seismic instrumentation in Switzerland and Italy and detected up to more than 250 km distance. Data is available from 5 seismic stations (3 permanent, 2 AlpArray) within 30 km. The good azimuthal coverage allows a more automatic processing.

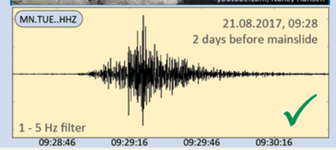
We scanned 4 weeks before and 6 weeks after the main slide for potential rockslide signals using a STA/LTA detector. All detections that overlapped in time with the expected arrival of an earthquake were dismissed (origin times from EMSC world catalog + Swiss and Italian regional catalogs; traveltimes calculated with TauP).

We restricted our further manual analysis to signals that were detected and had a similar arrival time on all 5 stations. We visually identified the most striking potential rockslide signals. Yet again we have to be sure that we are dealing with rockslide signals ...

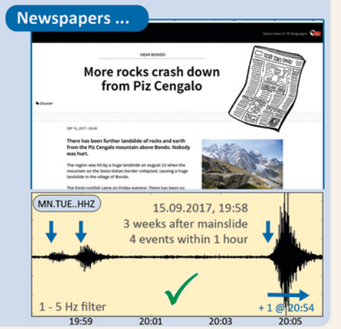
How to **confirm** that potential signals are really due to **mass movements**?

Videos ...

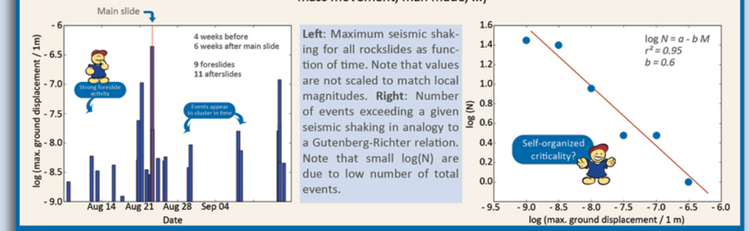




Newspapers ...



In future work we will use these events as **training events** for an **automated event classifier** based on a **random forest algorithm**. This will enable us to safely classify the origin of all detected events (earthquake, mass movement, man made, ...)



Left: Maximum seismic shaking for all rockslides as function of time. Note that values are not scaled to match local magnitudes. **Right**: Number of events exceeding a given seismic shaking in analogy to a Gutenberg-Richter relation. Note that small log(N) are due to low number of total events.

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