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Seismic Monitoring of a Huge Rockslide (Séchilienne, French Alps)

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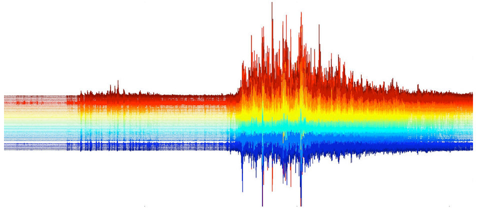
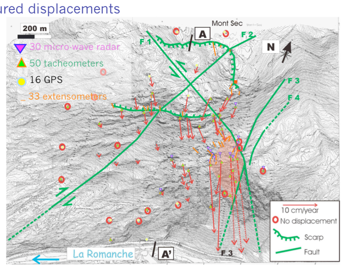


Séchilienne rockslide

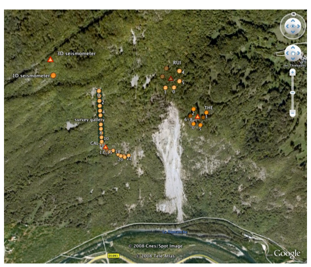
The Séchilienne movement is located in the French Alps near Grenoble, in the Romanche Valley. The slope is made of micaschists with subvertical foliation at right angle with the valley and is affected by subvertical fractures. The part of the slope which exhibits signs of current instability is located in the middle of the hill, at an elevation between 700 m and 850 m, and involves a rock volume estimated to about 3×10^6 m^3

Geodetic network and measured displacements

This area has been extensively instrumented since 1988 by CETE Lyon, with extensometers, inclinometers, strainmeters, GPS and distancemeters (laser and radar) [Evrard et al 1990; Lemaître et al, 2004].



Seismic Network



Two stations ('THE' and 'RUI') have been installed in may 2007 for passive monitoring of Séchilienne landslide. Each station is connected to 6 vertical 2 Hz sensors and one 3-components 2 Hz seismometer. Station 'RUI' is located just above the unstable area, station 'THE' is closer to the Thiebauds village. The typical distance between sensors is about 50 m. A 24-channels station ('GAL') with 4.5 Hz geophones (21 vertical sensors, and one 3 -components) has been installed in April 2008 in the 240 m long survey gallery close to the unstable area. The stations were generally recording in trigger mode at 250 Hz, but for some periods the sampling rate was higher (500 or 1000Hz), or the stations were recording continuously.

Objectives

The goals of this study are:

- to detect, characterize, and locate, seismic signals generated by the movement
- to analyse the structure of the movement, with P-wave tomography, seismic noise correlation, or « H/V » ratio
- to analyze the amplification of seismic waves (for earthquakes or noise) due to the presence of a damaged zone
- to study the interactions between local seismic activity, remote earthquakes, displacement and climate change

Detection, classification and location of seismic events

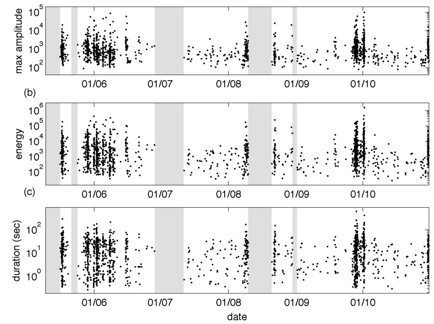
Since the installation of the first 2 stations in may 2007, several thousands events have been recorded by each station. A pseudo-automatic program has been developed to detect and classify events. The method is based on the analysis of the spectrogram averaged over all channels at each station. An event is declared if the amplitude in the frequency range 1-50 Hz exceeds a signal/noise ratio of 3. More tests are then applied to distinguish real events, based mostly on their frequency content and on the correlation between traces. We then look at all events manually to classify events as real events, regional or worldwide earthquakes, and 'natural' and 'local' events. Most events are due to "noise" or artificial events (hydroelectric plant, helicopters, people or animals passing by the sensors, wind, storms, electronic noise ...). But we also record many natural events of different types, although the distinction is sometime difficult or rather arbitrary.

- **rockfalls,** with duration of a few tens of seconds, frequency generally lower than 50Hz, and with severals bursts associated with successive impacts. In addition the source seems to propagate downward with time.
- **short local events**, either isolated or within a sequence of repeating events. The amplitude is usually maximum around 20Hz, but can be larger than the noise level up to 100Hz, for sensors very close to the source. Sequence of micro-events may in fact be successive impacts of a falling block.
- **regional earthquakes and teleseisms.** Earthquakes within tens ok km from Séchilienne show an impulsive start and distinct P and S waves. Frequency content of these signals sometimes reaches 200 Hz, higher than for events within the rockmass!
- **tremor:** low frequency signals (<40Hz) of long duration (>20s), with small variations of amplitude with time, a spectrum broader than man-induced tremor (hydraulic conduits), and a position that seems stable in time

Most local events are likely very shallow (signal amplitude is usually larger outside the gallery), but we have also detected a few "deep" local events, with impulsive start and largest amplitude inside the gallery. The depth of events is not constrained yet, because the geometry of the network is not ideal, and because the seismic wave velocity is yet unkown.

Seismic activity: characteristics and temporal variations

This figure shows the charac-teristics of natural (noise removed) and local events (without distant earthquakes) recorded by station THE from May to October 2007. There is a large variabiality of signals size and duration, and also strong temporal variations of seismic activity. The grey area indicates the station was not working at that time.



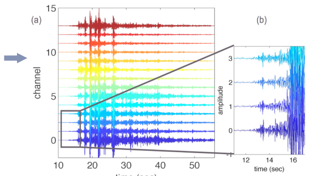
Events location

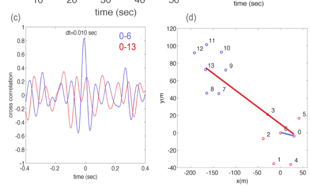
Event location is difficult because most signals recorded lack impulsive waves, so that we can't point the time of the first arrivals. Instead, one has to use cross-correlation of signals recorded at different sensors in order to measure time delays between sensors. We then look for the source position and seismic wave velocity that best explains the observed time delays.

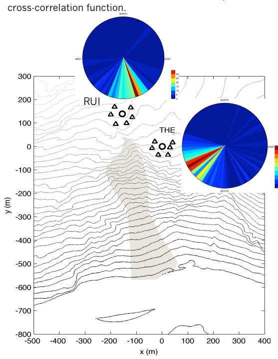
The method has several problems;

- we assume a constant velocity, while it varies with time (mixture of waves of different types) and in space
- the correlation is very weak at large distance, so it is difficult to estimate time delays
- if the source is outside the array, the direction of the signal can be estimated but the depth and distance are not constrained

(a) seismic signal generated by a rockfall recorded by station THE (traces 0 to 6 bellow) and RUI (7 to 13), and (b) zoom of the beginning of the signal. (c) shows the cross-correlation of two nearby sensors (0 and 6, blue curve) and 2 distant channels (0 and 13, red curve), for frequencies lower than 50 Hz. Sensor location is shown in (d). Nearby sensors are well correlated, and the time delay between traces can be estimated from the peak of the cross-correlation function.

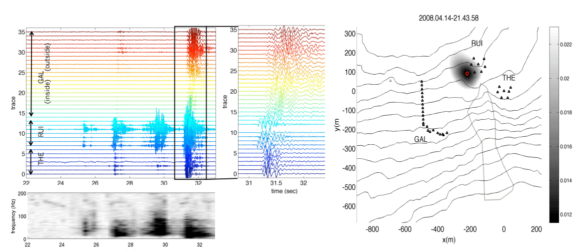






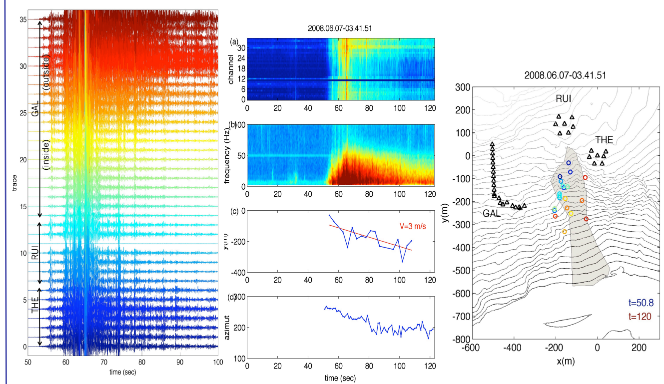
We have not yet located all events recordeed by all stations. We have first looked at each station independently and located all events. With a single station only the azimuth is relatively well constrained. The rose diagrams show the direction of natural local events recorded by station RUI (207 events) and THE (349 events) from 10/4/2008 to 7/2008. Both stations suggest that most events originate from the top of the zone of fallen rocks shown in grey.

Sequence of short impulsive events



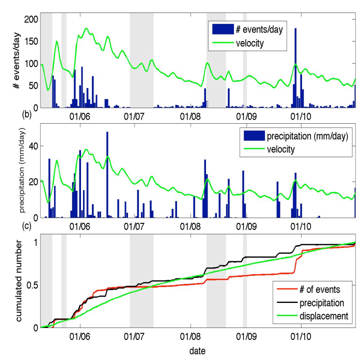
Seismograms for vertical channels of all 3 stations, zoom of the largest event, and spectrogramm. The amplitude is not normalized on the left plot: largest amplitude is observed for sensors closest to the source. Right plot shows a map of event location. The grey color scale indicates the residual of time delays (sec). Depth is estimated to be ≈ 37m, and seismic wave velocity V≈1500m/s.

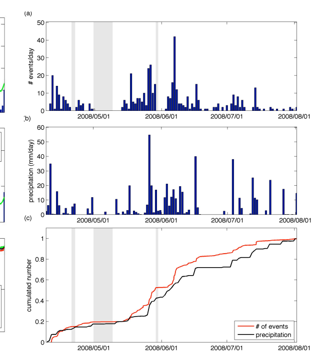
Rockfall propagation



(left) Seismograms of all vertical channels of the 3 stations for the largest recorded rockfall event of June 7th 2008.
(center) (a): amplitude of each trace as a function of time; (b) spectrogramm, averaged over all channels; (c) north-south coordinate of the source estimated in a sliding time window of 4 sec using all 3 stations; (d) direction of the source relative to the center of station THE, for a sliding time window of 1 sec, using only the seismograms of station THE.
(right) location estimated with all 3 stations in a sliding time window of 4 sec. Color scale indicates the time, from blue to red

Interactions with displacement and precipitations





Comparison of seismic activity, rain, and displacement (for target #625 located in the most active zone. (left) Station THE from Mai to October 2007. (right) station RUI from April to August 2008. The seismic activity is very variable, from a few events per day to more than 100 events per day during seismic crisis. Most peaks are associated with precipitations, with a time delay smaller than 1 day between rain and triggered seismic events. Seismicity is also corelated with accelerations of the movement.

Perspectives

- Installation of a camera and video to observe rockfalls, and to calibrate the volume of rockfalls
- Boreholes will be drilled and instrumented with seismometers, inclinometers, and piezometers to measure fluid pore pressure. Seismometers at depth should help us to better constrain the depth of seismic events.
- Shots have been performed in June 2008, and will allow us to do P-wave and surface wave tomography. Using a realistic seismic wave velocity model should also improve the location of seismic events.

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Acknowledgements

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