Seismic monitoring of the Séchilienne Rockslide (French Alps): analysis of seismic signals and their correlation with rainfalls

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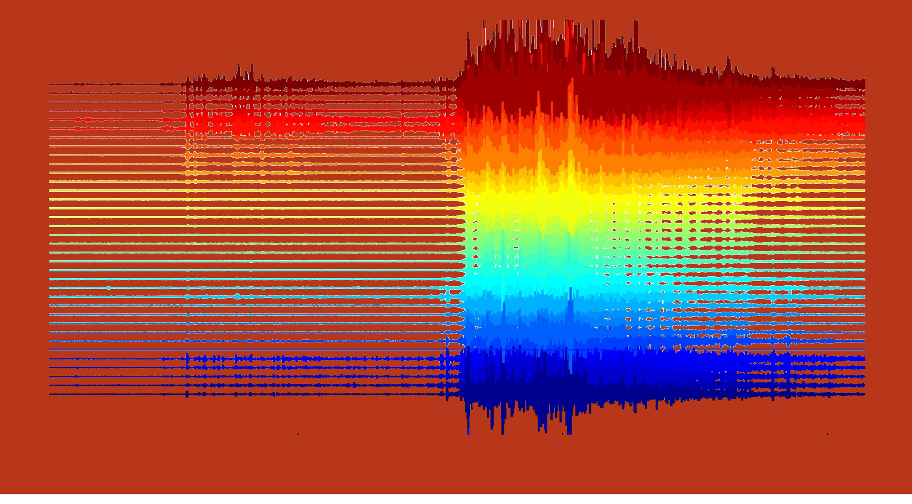

Séchilienne rockslide and monitoring network

The Séchilienne landslide is located in the southwestern Belledonne massif about 30 km south east from Grenoble. This rockslide presents a high risk in terms of socio-economical outcomes. The failure of this landslide (3 to more than 10 millions m³) is likely to form a dam which could block the Romanche river. Its rupture would have devastating consequences downstream for people and facilities. In addition, the rockslide is located less than 1 km away from the Belledonne Border fault, which could produce a m=6 earthquake with a mean recurrence time of 10000 yrs.

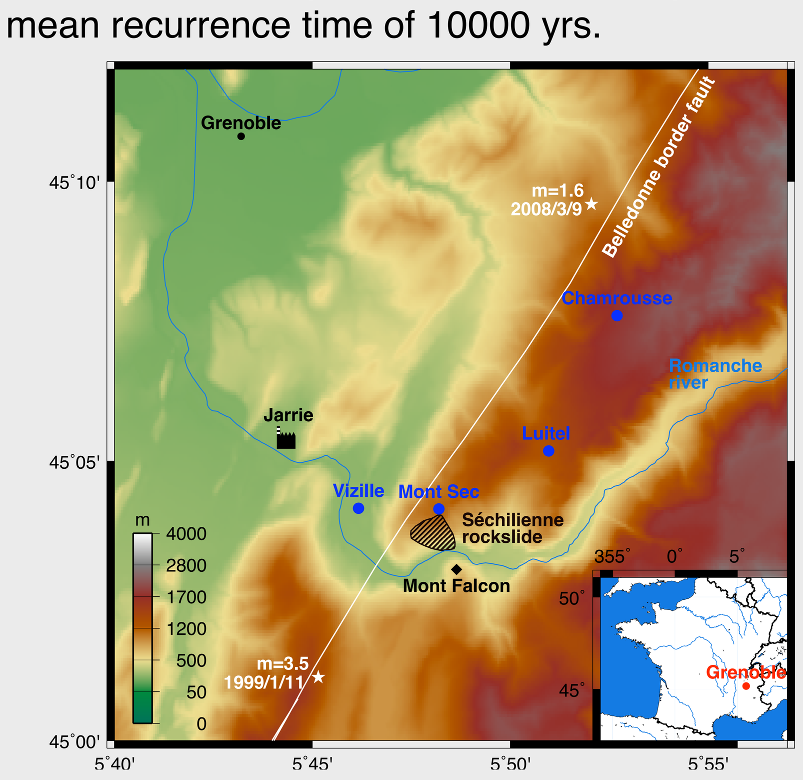

Fig 1: location of Séchilienne rockslide

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. The unstable zone extends up to the Mont-Sec scarp at the top of the hill and represents a volume of 100×10^6 m³. The most active zone (red contour in Fig 2b) represents a volume of about 3×10^6 m³ and moves at about 1 m/yr. Its velocity has doubled since 2000.

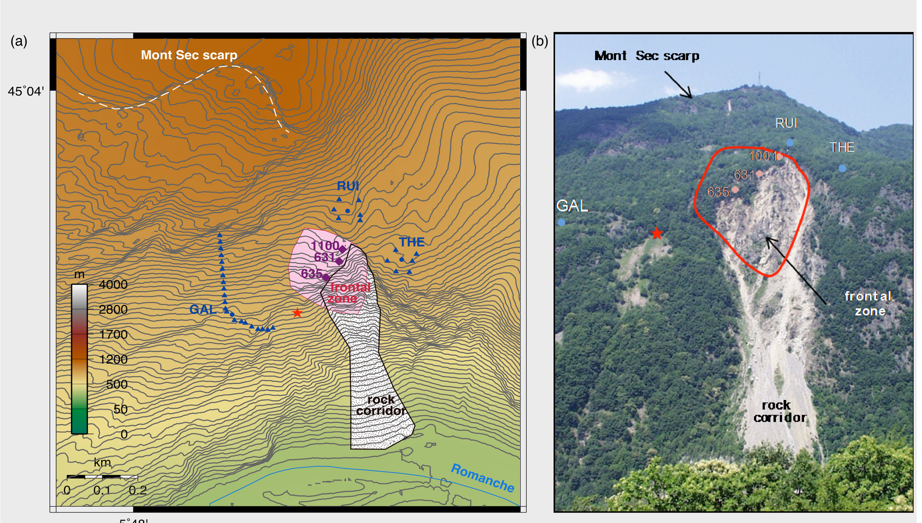

Fig 2: (a) Map of the rockslide and of the monitoring network: vertical sensors (circles) and 3-component seismometers (triangles) for the 3 stations. Also shown are the locations of 3 benchmarks of the displacement network (diamonds) and the location of a shot on 24 June 2008 (red star). (b) photo of the rockslide and limit of the most active zone (red contour).

This area has been extensively instrumented since 1988 by CETE Lyon, with extensometers, inclinometers, strainmeters, GPS and distance-meters (laser and radar) [Evrard et al 1990; Lemaître et al, 2004]. The seismic network was installed in 2007 around the most active zone. It consists of 3 antennas (Fig 2a). Stations THE and RUI are connected to 6 vertical 2 Hz sensors and one 3-components 2 Hz seismometer with a distance between sensors of about 50 m. Station GAL was installed later in april 2008 and consist of 24 vertical 4.5 Hz geophones with an inter-trace of 20 m. Channels 1 to 12 are located inside the 240m long survey gallery.

Seismic signals

More than 15000 events have been detected since april 2007. A pseudo-automatic programme has been developed in order to detect, classify, and locate these events. Most events are rockfalls located in the most active zone. There are also micro-earthquakes (inside rockslide) and external earthquakes. See examples in Fig 3.

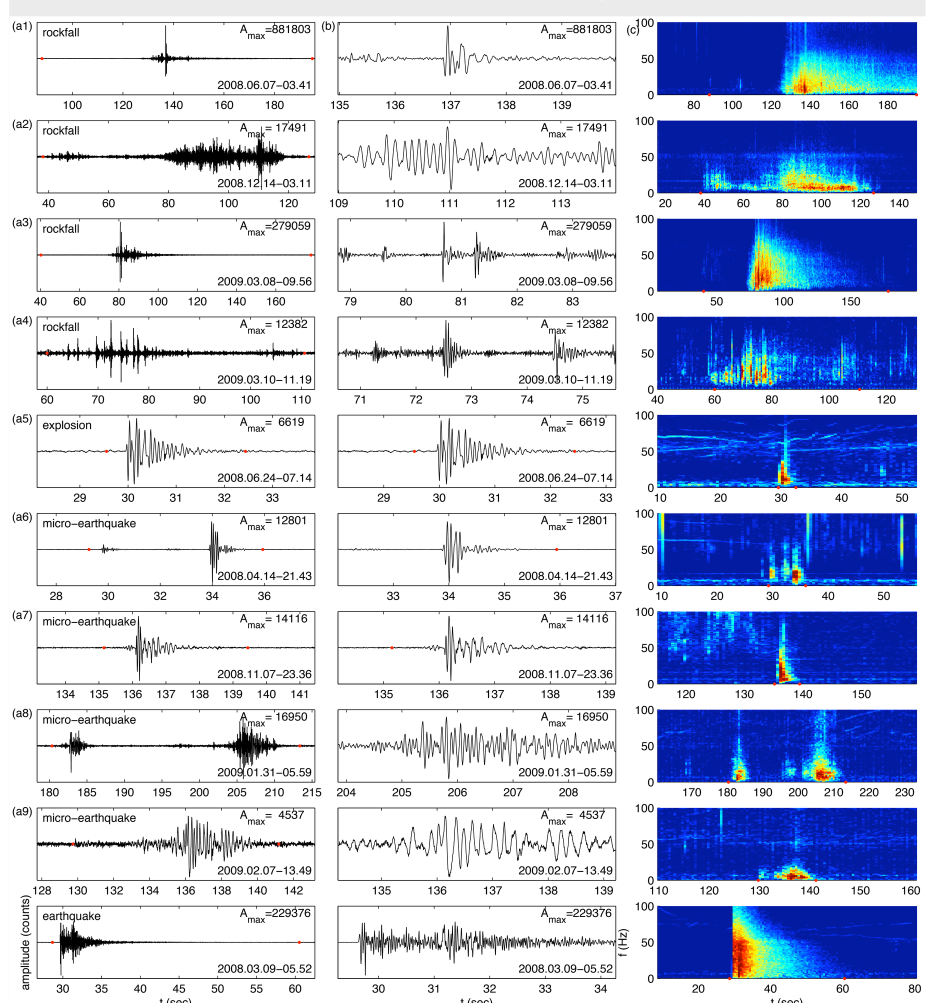

Fig 3: A selection of different types of signals. (left) Seismograms recorded by station THE and (middle) zoom for a window of 5 s around the peak of amplitude. (right) Spectrograms.

Events detected by all 3 stations can be located using a beam-forming method [Lacroix and Helmstetter, 2010]. This methods offers the advantage of being fully automatic and applies well to emergent signals. Most rockfalls and micro-earthquakes are located in the most active zone, with also some events close to the Mont-sec scarp. See also poster SD5/P1/ID1 by Lacroix and Helmstetter.

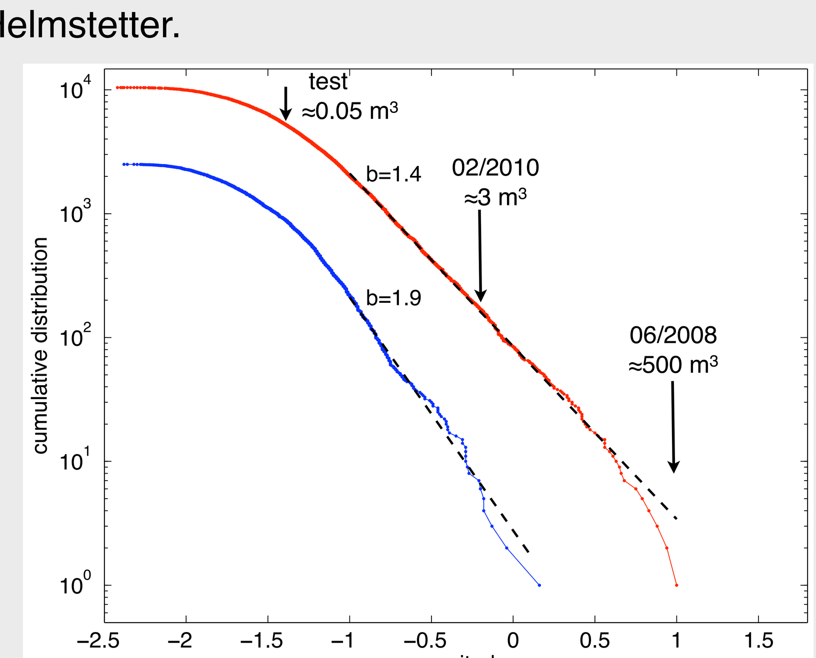

Fig 4: magnitude distribution for rockfalls and micro-earthquakes.

The largest rockfall occurred in June 2008 with a volume of a few hundreds m³. The smallest event has a volume <0.01 m³. A few large events were also detected by a video camera installed by CETE Lyon in 2009. Micro-earthquakes have magnitudes between -2.5 and 0.2 and a large b-value, much greater than for crustal earthquakes but similar to values found for volcanoes or induced seismicity.

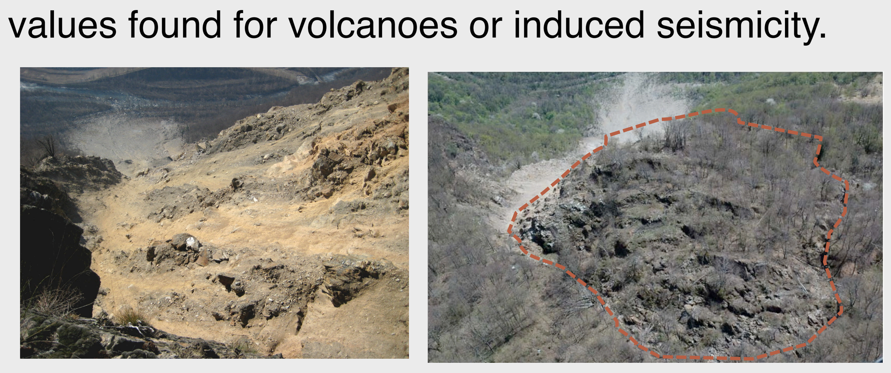

Fig 5: Rockfall corridor (left) and most active zone (right) [photo Y. Kaspersky].

Correlation with displacement and precipitatoins

Rockfalls and micro-seismicity occur in burst of activity, which are weakly but significantly correlated with rainfall. Rockfall activity is also correlated with the rockslide displacement rate, probably because both the rockfall activity and the displacement are activated by rainfall (Fig 6).

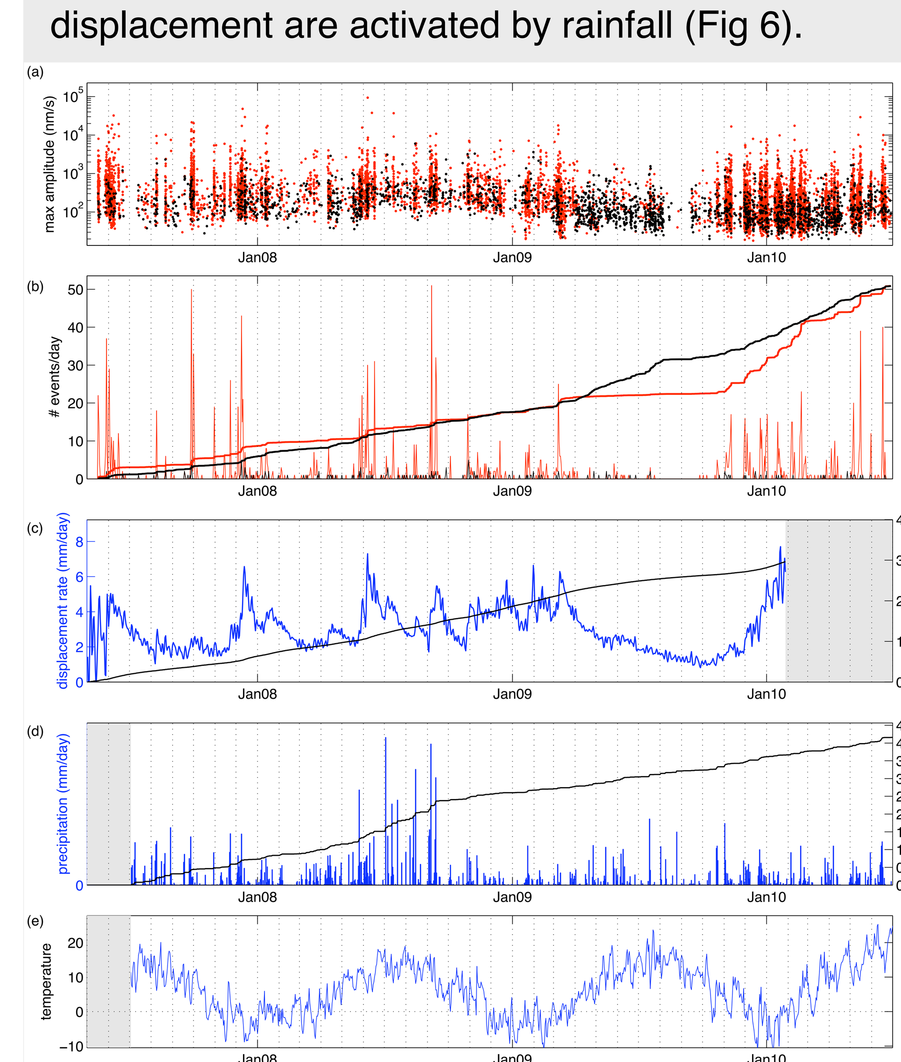

Fig 6: time series of (1) amplitude of rockfalls (red) and micro-earthquakes (black), (b) rate of events (c) displacement of target 635 (data from CETE Lyon) (d) precipitations and (e) temperature recorded at Luitel (data from LTHE).

We used the cross-correlation function to analyze the relation between precipitations and other variables (Fig 7). The rockfall activity increases almost immediately after precipitations (correlation is maximum for a time lag of dt≈30 mn) and relaxes over severals days. Micro-earthquakes are less clustered and less correlated with precipitations, and the time lag and relaxation time are longer. The displacement rate reaches its peak several days after the precipitation and returns to its average value after one month.

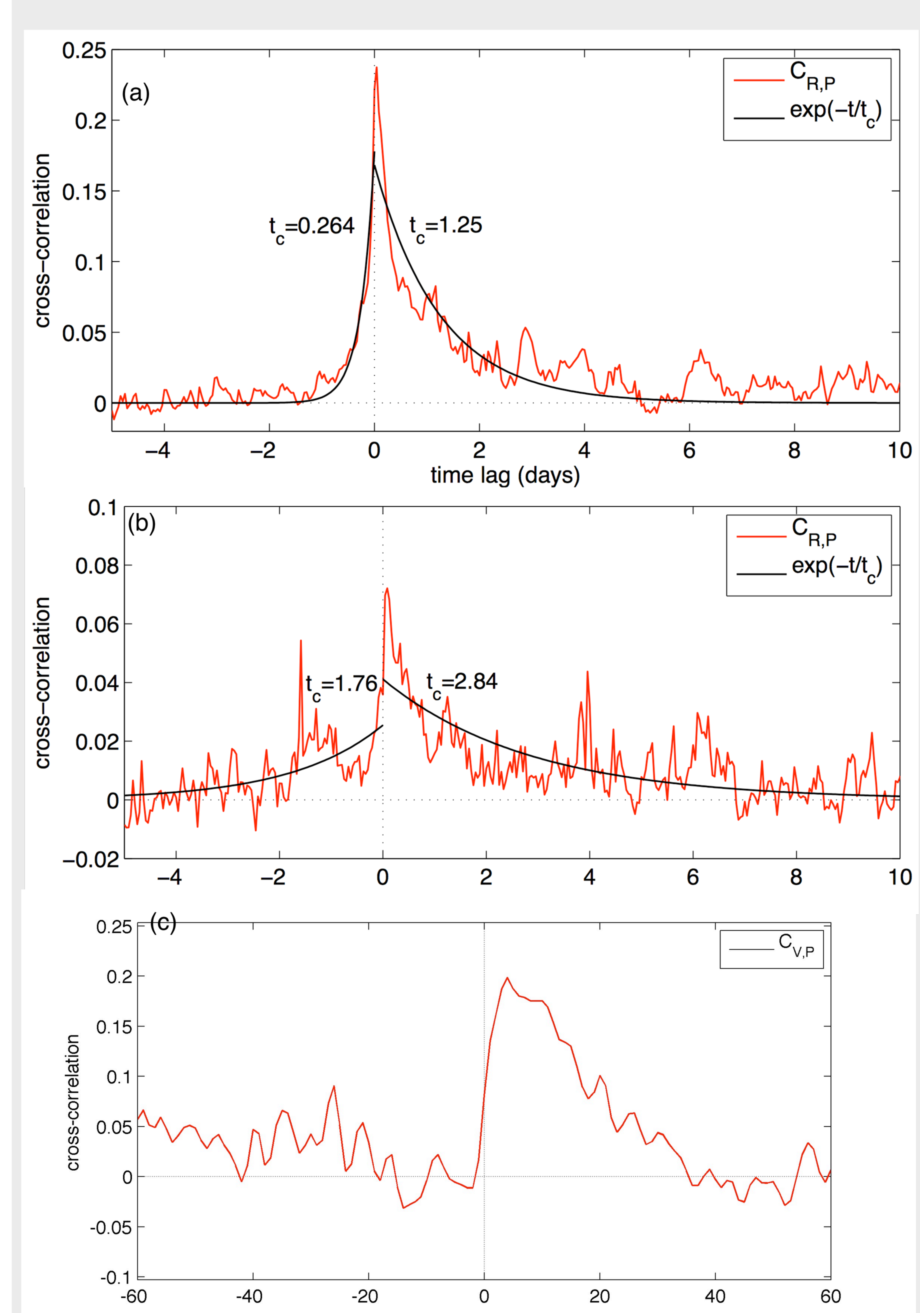

Fig 7: cross-correlation between precipitations and (a) rockfall rate (b) micro-earthquakes and (c) rockslide displacement rate.

Triggering of rockfalls by rainfall

To account for the influence of previous rainfall on the rockfalls triggering, we used the «Antecedent rainfall water model» [Glade et al., 2000] defined as $P_c(t_j)=\sum_{ti<t} P_c(t_i) \exp[-(ti-t_j)/t_c]$. The relaxation time t_c=0.25 day is estimated by maximizing the correlation between rockfall rate $R(t)$ and $P_c(t)$. Taking into account antecedent rainfall clearly improves the correlation between rockfall occurrence and rainfall (Fig 8 and 9).

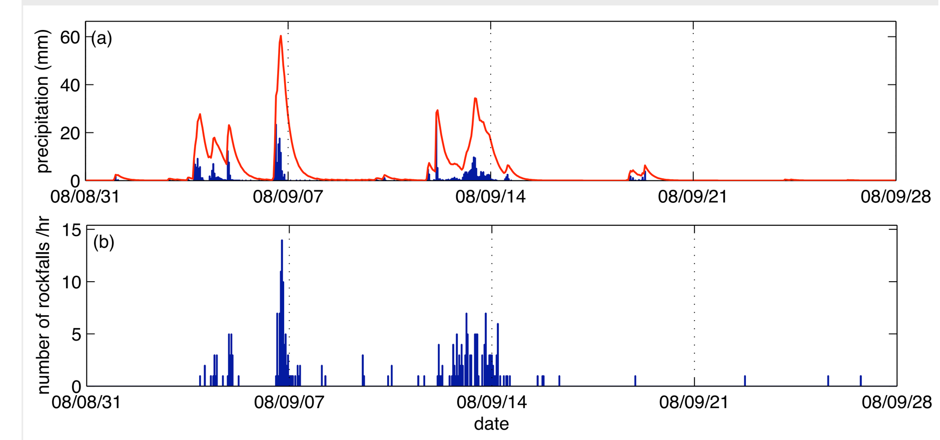

Fig 8: (a) hourly precipitation (blue) and antecedent rainfall $P_c(t)$ (red), (b) number of rockfalls per hour.

The correlation between precipitation or $P_c(t)$ and rockfall activity is significant but weak. Rockfall activity shows strong fluctuations for the same rainfall intensity and many rockfalls have occurred without precipitations (Fig 9).

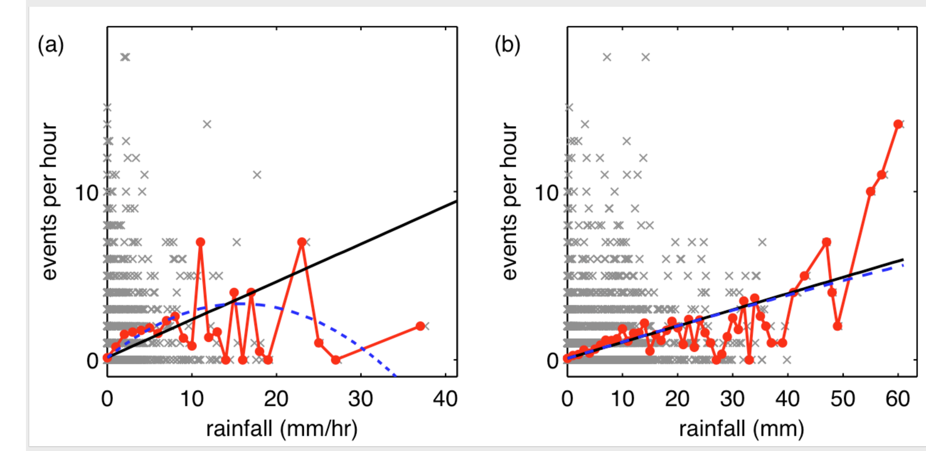

Fig 9: Rockfall rate as a function of (a) hourly precipitation and (b) antecedent rainfall $P_c(t)$. Grey crosses are the raw data while red dots show the data averaged over bins of precipitation. Black lines are linear fits of the raw data.

Conclusions and perspectives

The rockslide dynamics is influenced by precipitations. Triggering is more important for rockfalls than micro-earthquakes. The rockslide also accelerates following rainfall, but with longer time delay and relaxation time (water infiltration? snow melt? nucleation time? inertial effects?)

➡ Comparing seismic signals and video to better constrain the rockfall volume and mechanism.

➡ Physical modeling of the coupling between precipitations and rockslide dynamics.

References

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For more information see:
www-lgit.obs.ujf-grenoble.fr/observations/omiv

Acknowledgements