Seismic characterization of a clay-block rupture in the Harmalière landslide (French Western Alps)

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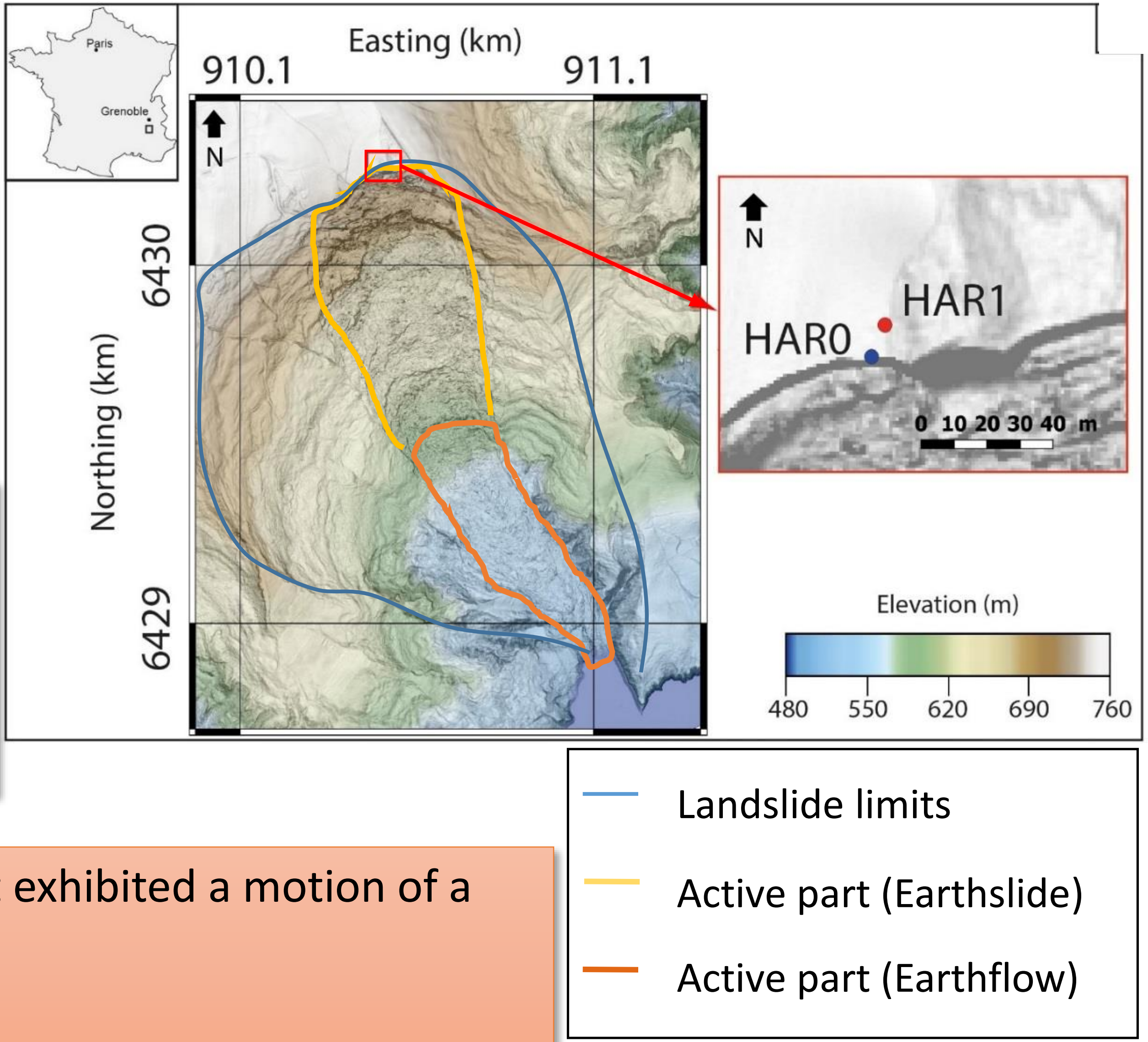
Study site

The Harmalière landslide:

- 30 km South of Grenoble, France.
- 1450m-long.
- 300m-wide.
- Mean slope of 9°.

Lithology :

- alternation of mixed pebbles/disturbed clay (proximity of the glacier) and lacustrine clay (thickness 0 to 250m).
- Overly a Jurassic carbonate bedrock.



The latest major events occurred in late June 2016. It exhibited a motion of a few meters per hour along the major headscarp.

=> Are there any seismic precursors to the reactivations?

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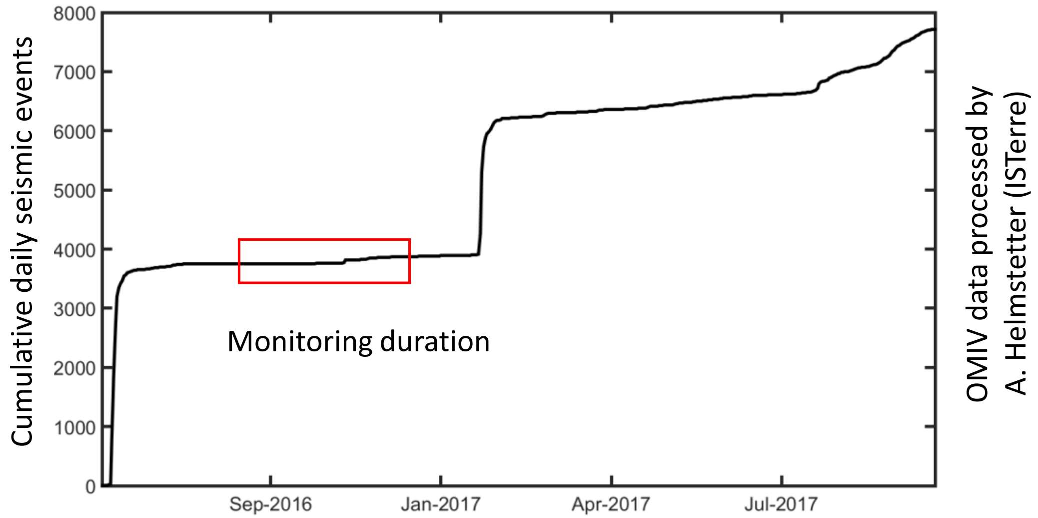
Study site

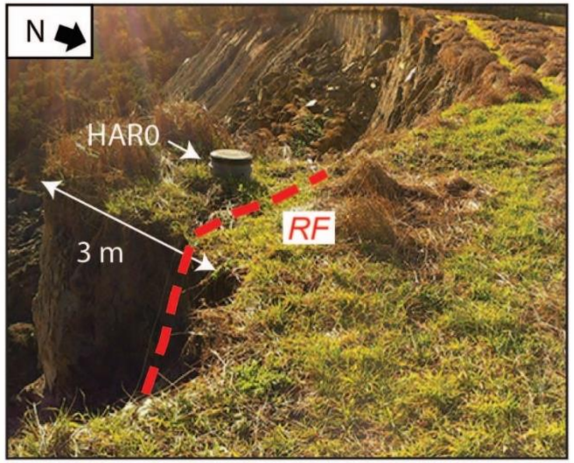
Reactivations of 2016 - 2017:

- Major event in June 2016.
- Succession of smaller events until January 2017.



Object of study :

- Clay block (around 100 m^3)
- 2 sensors (3C) :
  - HAR0 close to the rear fracture (RF)
  - HAR1, 10 m behind.
- Continuous recording during the 4 months prior to rupture.



What types of seismic precursors can be found?

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Seismic events

a) Number of seismic events:

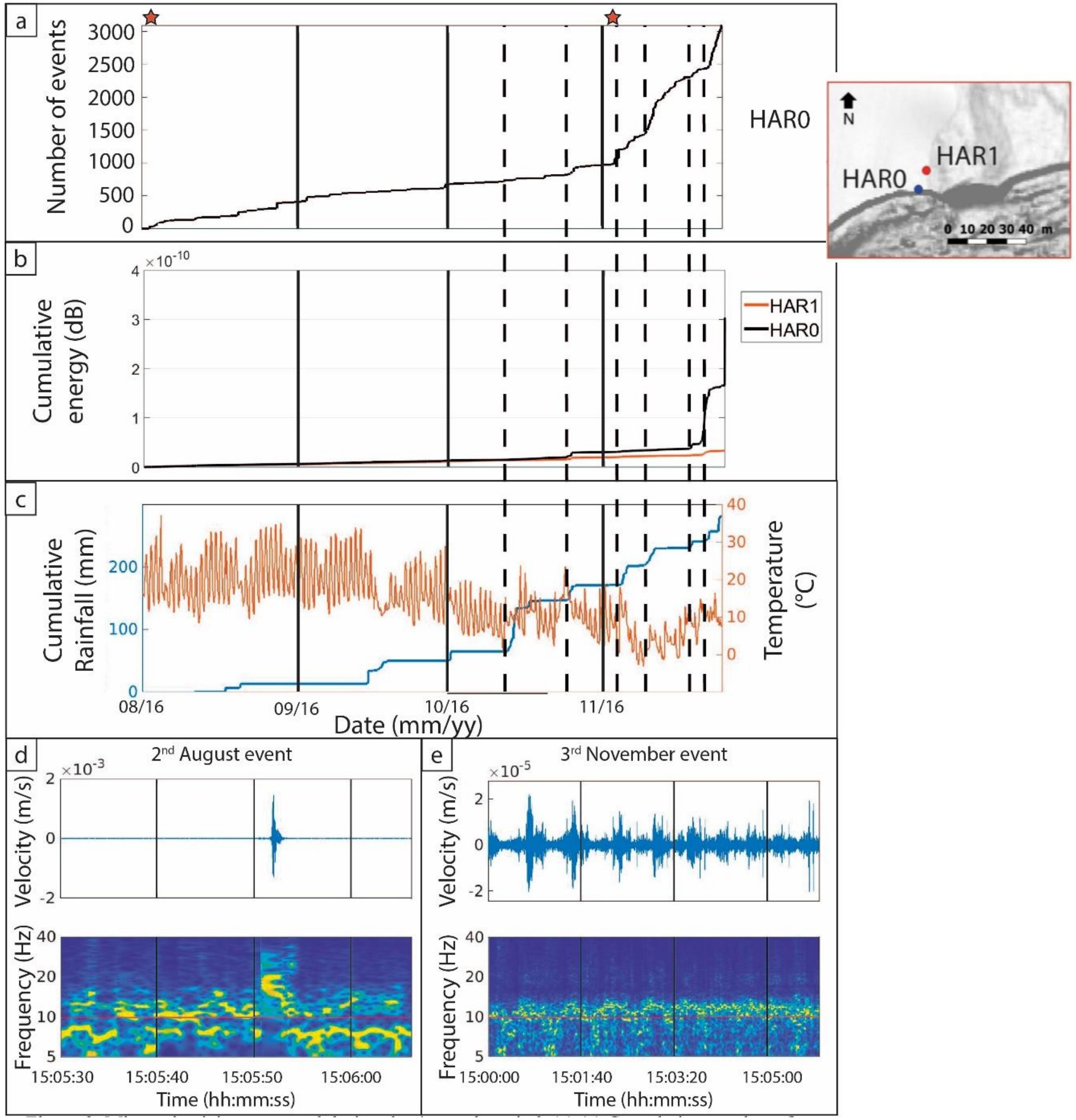
- Event detection : STA/LTA
- Low influence of environmental parameters.
- Increases 1 month before rupture.

b) Seismic energy:

- Behaviour different from the number of events.
- Increases a few days before rupture.

Monitoring the number of events and the seismic energy shows a precursor to rupture but at different times (robustness?).

Are there other, more robust precursors?



From Fiolleau et al. (2020)

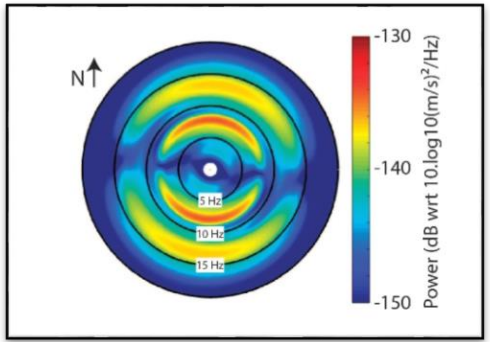
Spectral analysis

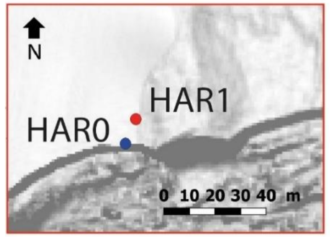
Excited frequencies (Power Spectral Density-PSD):

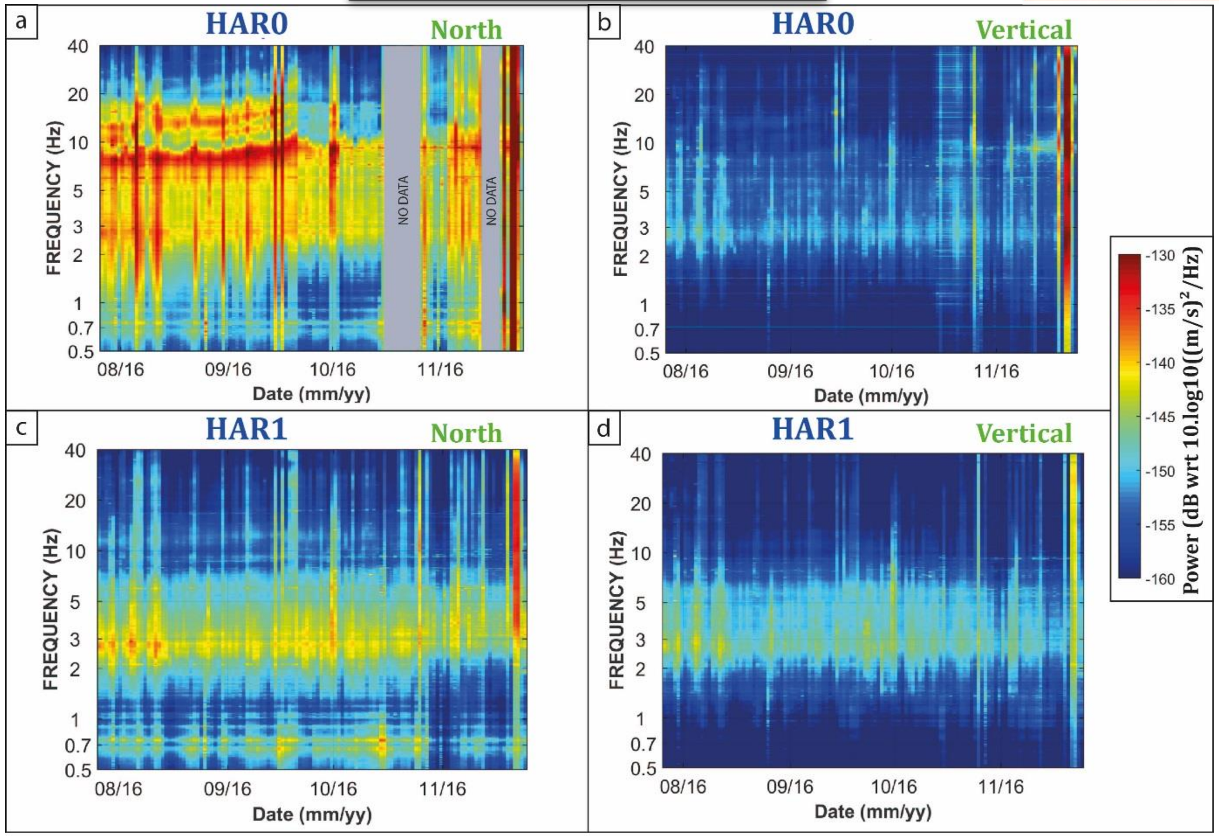
- Around 3 Hz for all components.
- Around 0,7 Hz on the North component.
- Around 9Hz North component of HAR0 (block).

Block frequency => difficult to follow on PSD at the end of the period.

Site/Reference ratio in the North direction.







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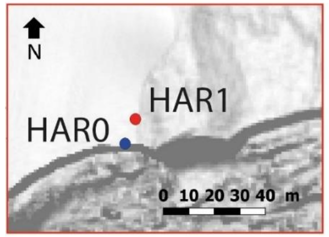
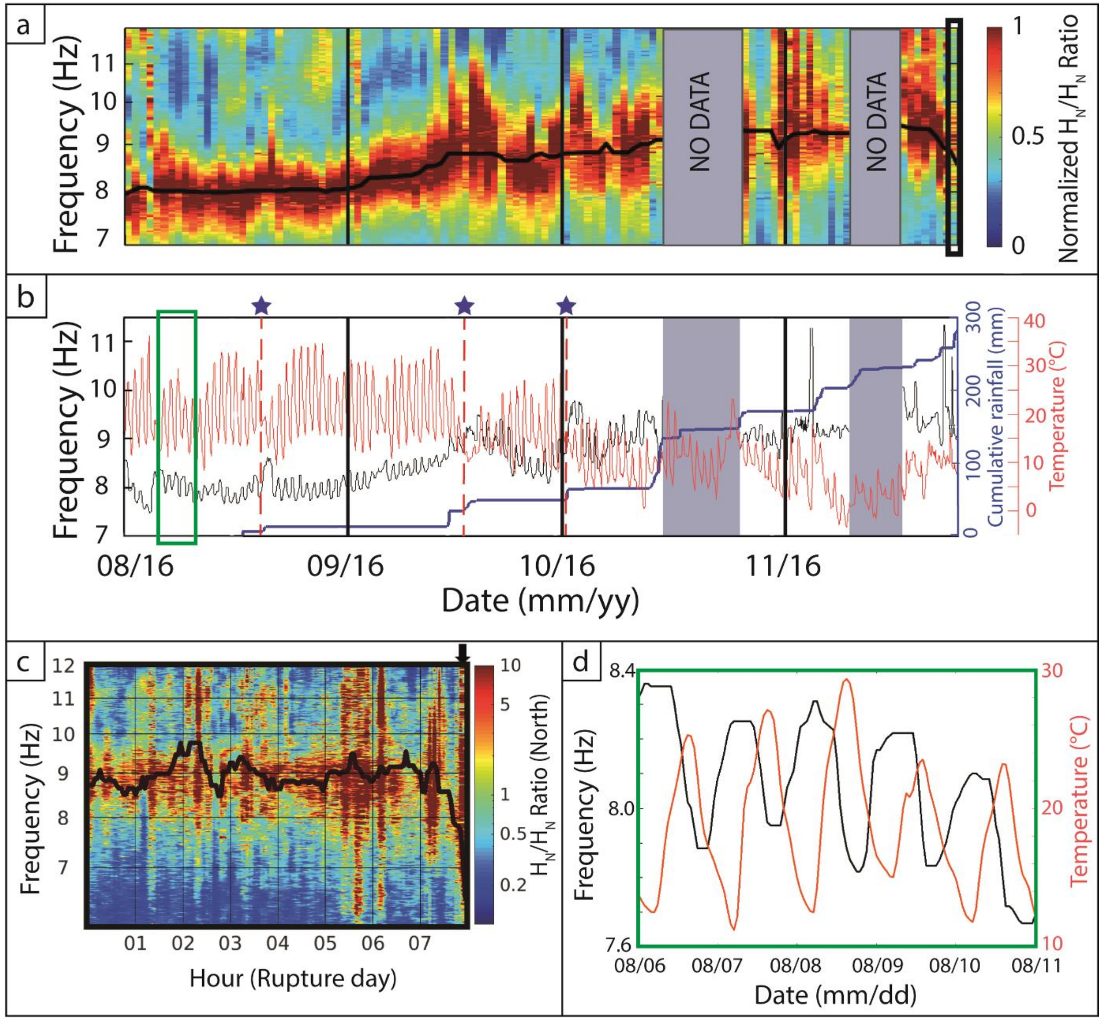
H_0/H_1 Ratio (North)



- Daily H/H in North direction.
- Continuous increase from 7.5 to 9 Hz -figure (a)-.
- Drop of the resonance frequency one hour before the rupture -figure (c)-.
- Correlation between temperature and frequency variations -figure (b and d)-.

Seismic precursor easy to calculate but little time to react.

What is the influence of temperature variations on the resonance frequency?
Could another seismic precursor predict the rupture more prematurely?



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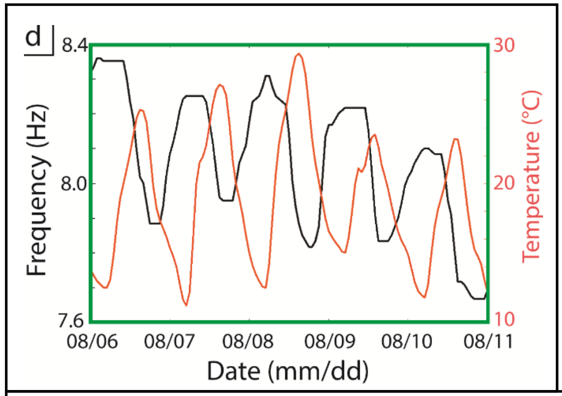
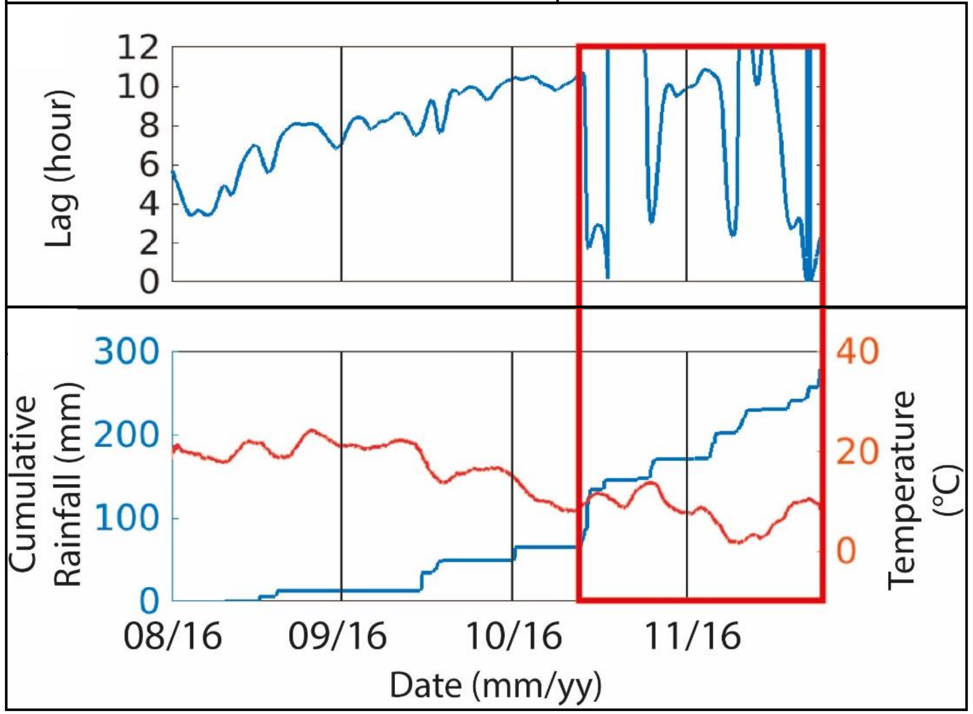
Influence of temperature variations

- The frequency decreases when temperature increases.
- The time lag between temperature and resonance frequency variations increases from 4 to 10h -figure (a)-
- Intense rainfall events in mid-October prevent this monitoring by completely disrupting the environment.





The influence of temperature, which is complicated to understand, needs to be investigated further in order to remove it from the signal.

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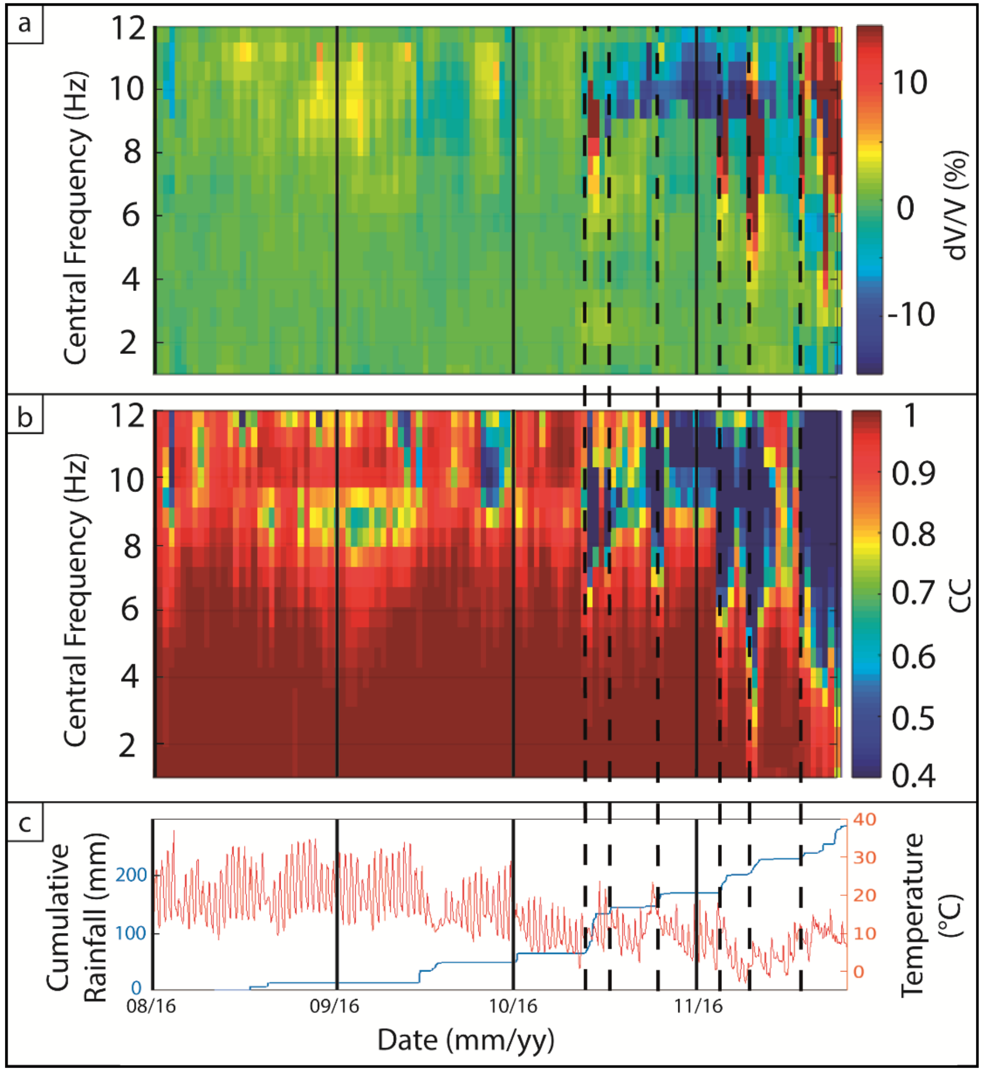
Seismic cross-correlations

- 2 calculated parameters:
  - relative changes in seismic velocity (dV/V).
  - Associated correlation coefficient (CC).
- Hourly and daily cross-correlations :
  - Hourly dV/V => bad CC.
  - Daily dV/V => usable.
- Strong influence of rain on the quality of correlations.
- CC drop from high to low frequencies 1 month prior to rupture.

Why does the CC drop at the end of the period?
Is it a precursor?

Validation of the hypothesis by modelling.



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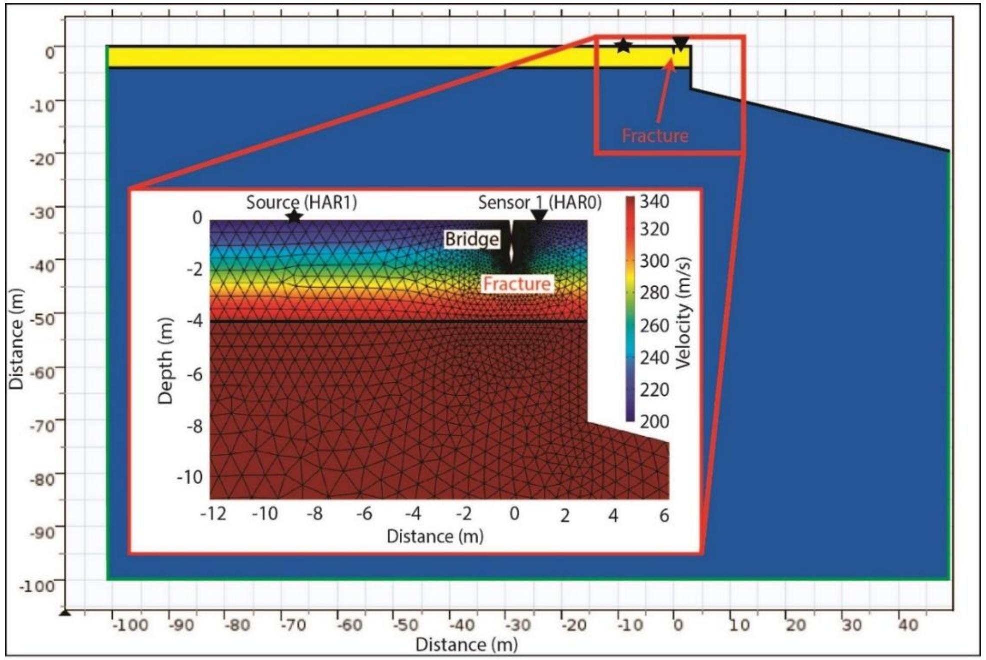
Seismic cross-correlations: numerical validation

- Hypothesis: the opening of the fracture over time acts on the CC.
- 2 models :
  - Simple fracture (without bridge).
  - Complex fracture (with a bridge), opening below the bridge.



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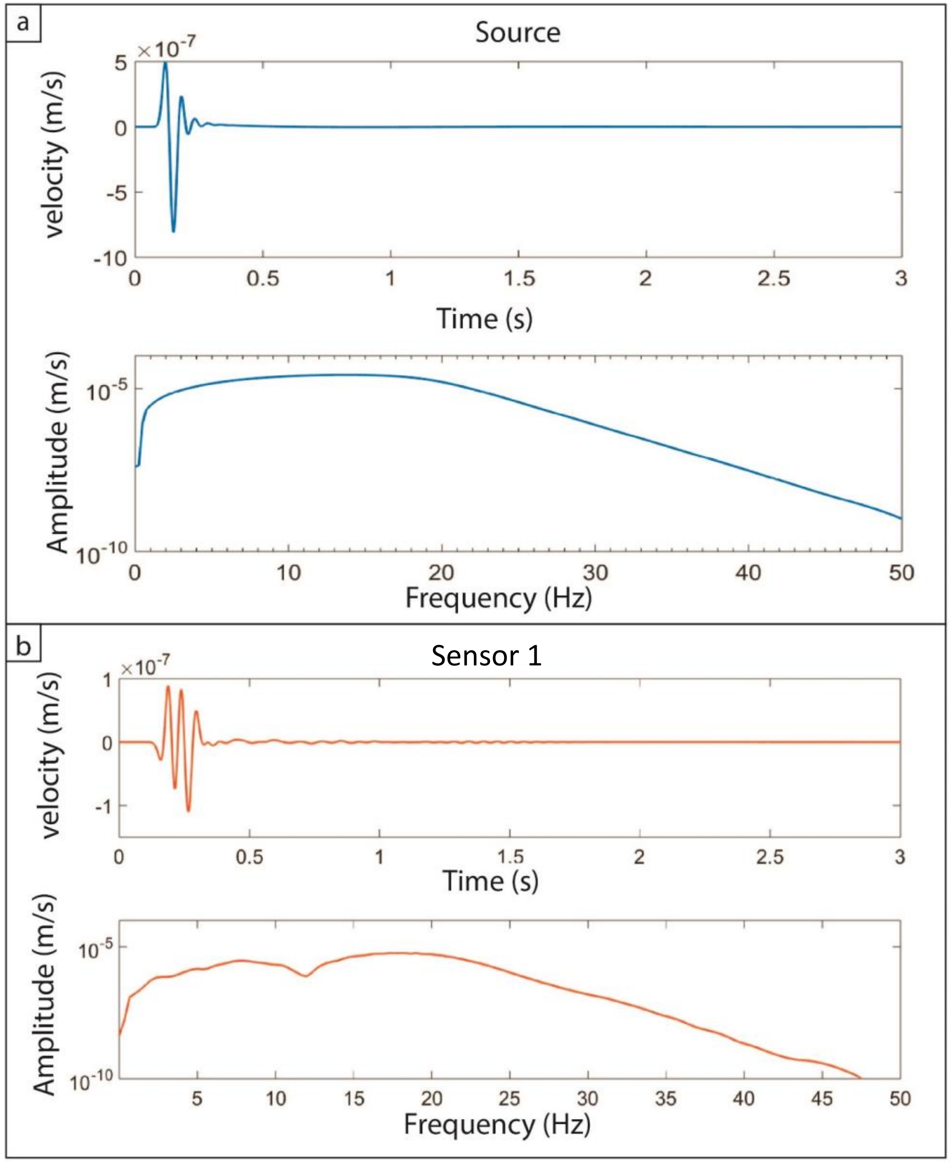

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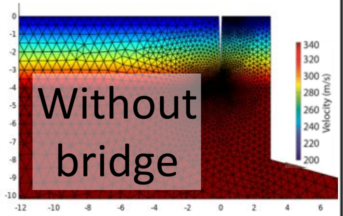
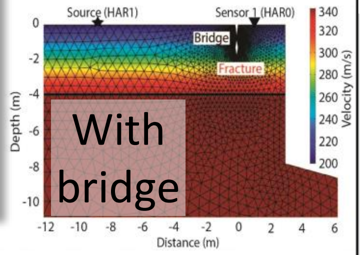
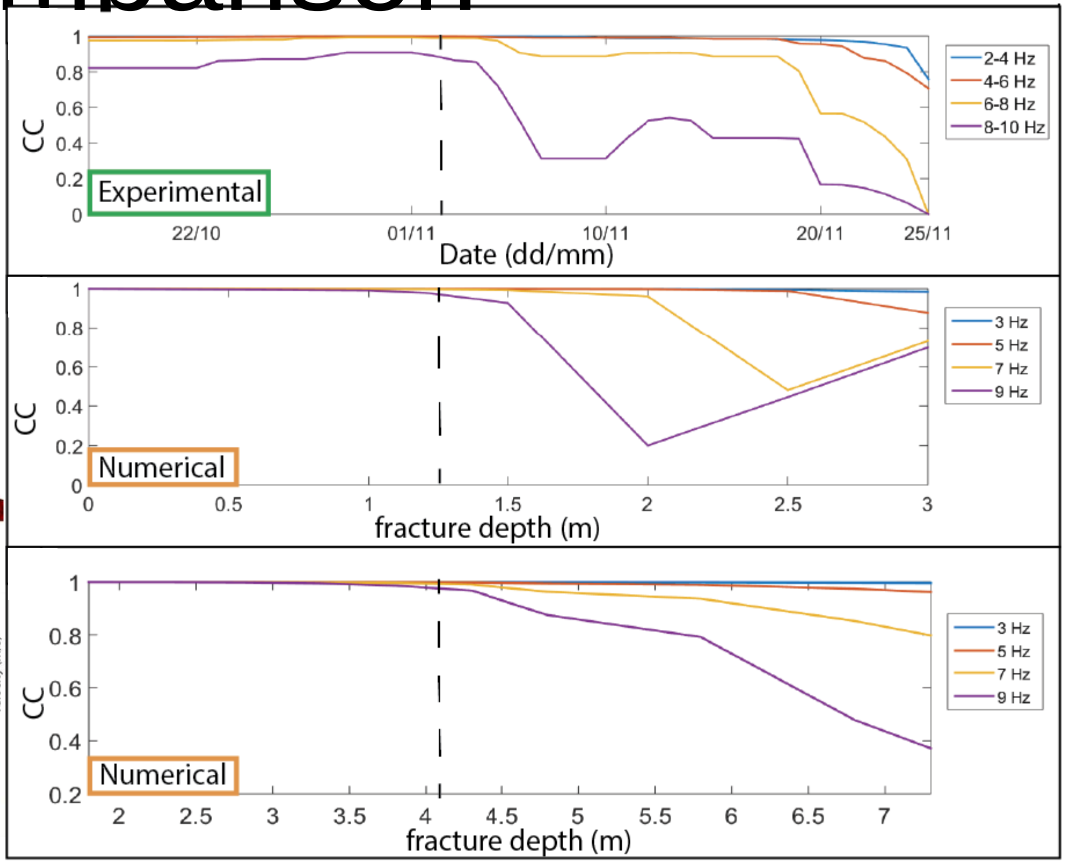
Seismic Intercorrelations: Synthetic/Experimental Comparison

- Simple model doesn't fit well with observations => more complex configuration.
- Progressive drop with time from high to low frequencies.
- The fracture acts as a low-pass filter.
- Interpretation => progressive opening of the rear fracture under the bridge over time.
- In the field case, it would rather be an evolution of the environment at the level of the fracture.

The CC appears to be sensitive to progressive changes within the fracture => good precursor.





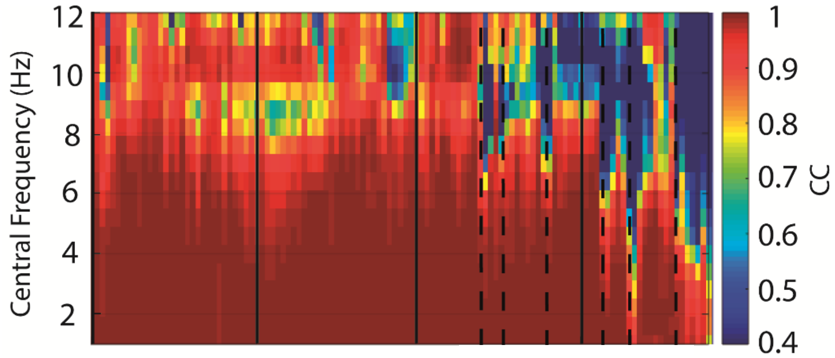


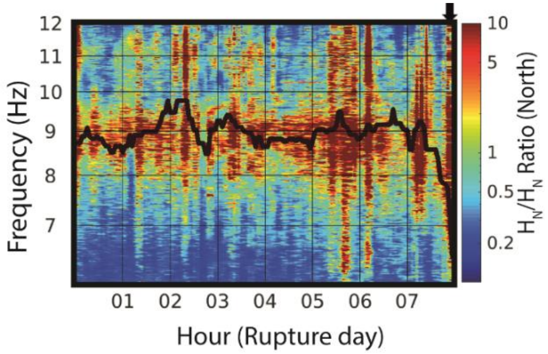
Conclusions

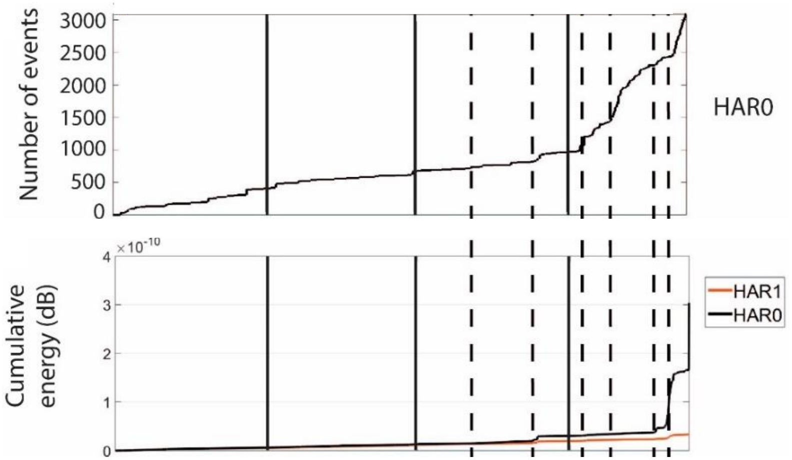
The study identified seismic precursors:

- Drop in **resonance frequency** a few hours before rupture.
- **CC** drops one and a half month before rupture.
- Acceleration of **microseismic** activity one month before rupture.

▪ Highlighting the importance of the fracture configuration on CC and dV/V.







Perspectives

- A more in-depth analysis of the reversible variations must be carried out in order to find the precursors more precisely.
- Is it applicable for the reactivation of larger structures such as a landslide?

Reference : S Fiolleau, D Jongmans, G Bièvre, G Chambon, L Baillet, B Vial, Seismic characterization of a clay-block rupture in Harmalière landslide, French Western Alps, *Geophysical Journal International*, Volume 221, Issue 3, June 2020, Pages 1777–1788, https://doi.org/10.1093/gji/ggaa050

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