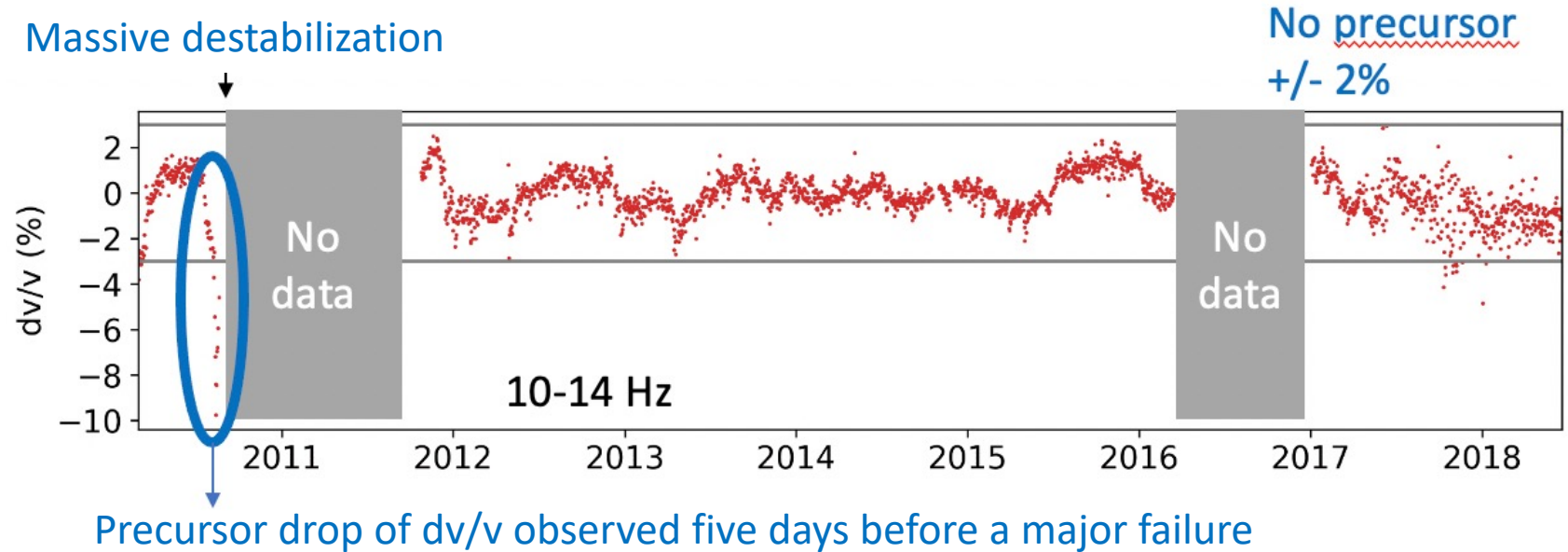


Updates on ambient noise correlation for landslide monitoring

Eric Larose, Mathieu Le Breton, **Noélie Bontemps**, Antoine Guillemont, and Laurent Baillet



This technic led to :

- ~ 10 monitored landslides
- ~ 20 scientific publications
- Numerous applications :
 - 2 precursors of landslide massive mobilization ;
 - observation of co seismic drop of a landslide rigidity ;
 - 3 cryosphere & permafrost monitoring ;
 - observation of rigidity healing after mobilization (in the absence of precipitation and seismic shakings)
 - Etc.

Updates on ambient noise correlation for landslide monitoring

Eric Larose¹, Mathieu Le Breton², Noémie Bontemps¹, Antoine Guillemot¹, Laurent Baillet¹

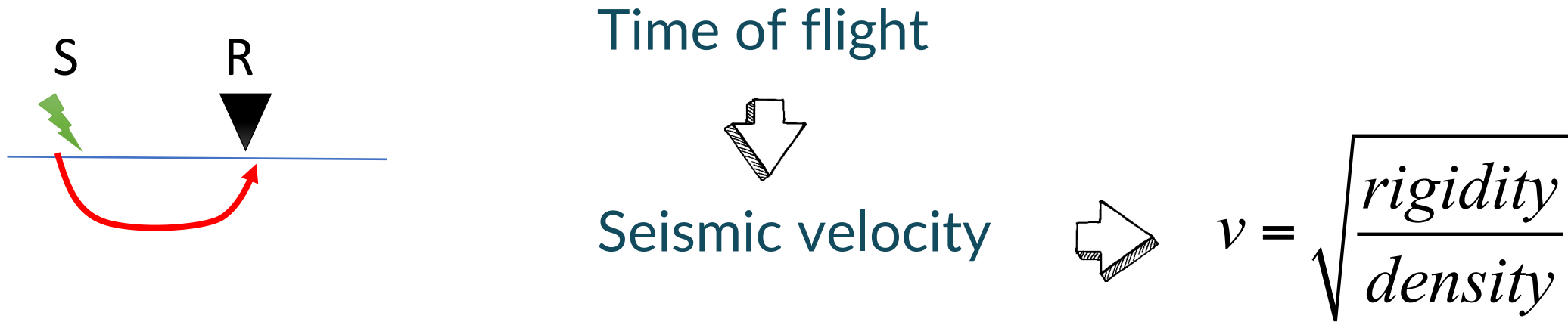
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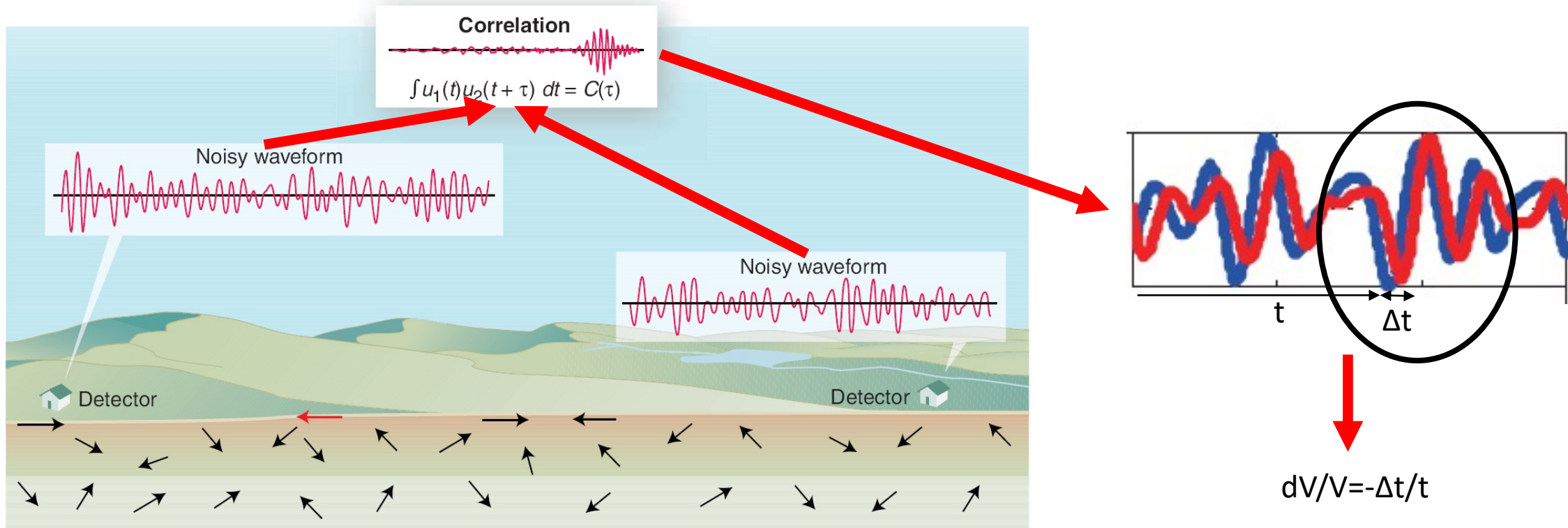
Seismic wave velocity - definition



A negative Variation of the seismic velocity ($dv/v < 0$) can be caused by:

- an Increase of the density i.e. an increase of the water content in the ground
- a decrease of the rigidity of the soil i.e. fracturation/damage of the ground by mobilization, seismic shakings

Ambient noise correlation technique

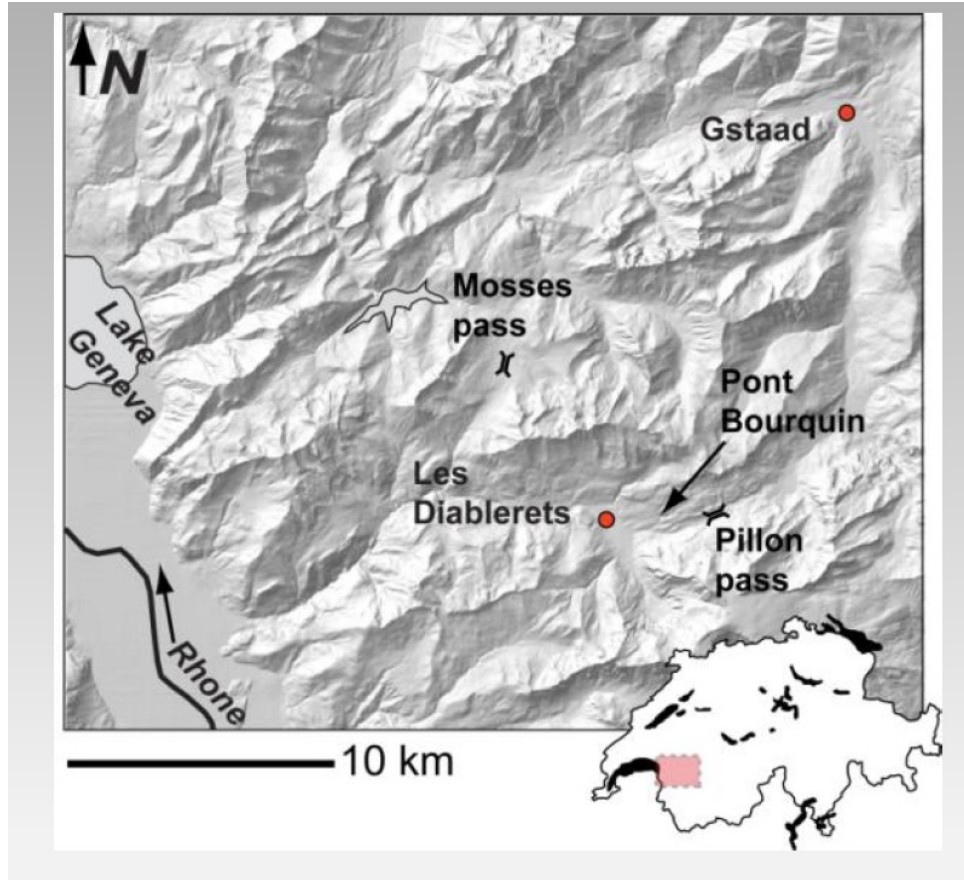


Weaver et al, Phys Rev Let. (2001); Campillo et al, Science (2003), Larose et al, J. Appl. Geoph. (2015)

By correlating the noise recorded by two different sensors, we can retrieve the impulse response of the soil between these two sensors as if one sensor was the source and the other the seismometer. By comparing this impulse response from one day to another we can monitor the changes of the seismic wave velocities in the ground between these two sensors.

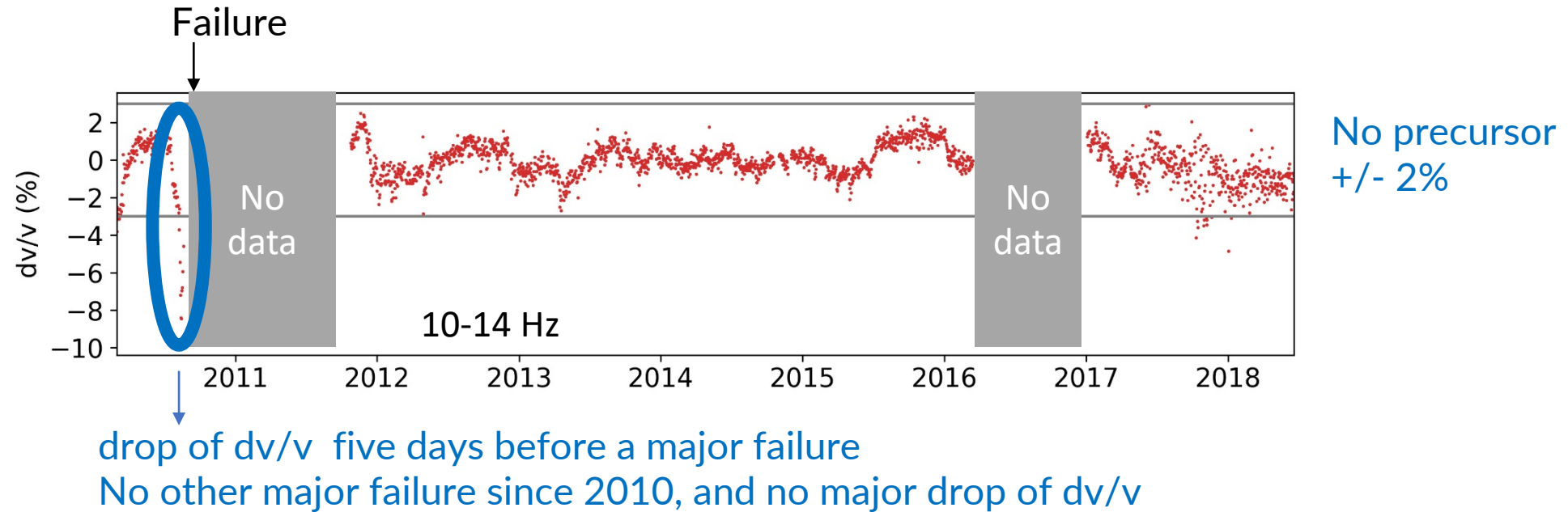
This allows to detect a change in the rigidity and the density of the soil with time.

First application to a landslide: Les Diablerets (Switzerland)



First application to a landslide:

Les Diablerets (Switzerland)



Drop in velocity associated with a decrease in the rigidity of the soil during a partial fluidization at the base of the moving layer caused by an increase of water pore pressure

(Mainsant et al., 2012b; Larose et al., 2015; Bièvre et al., 2018, Le Breton et al. 2020)

Other example of precursory drop

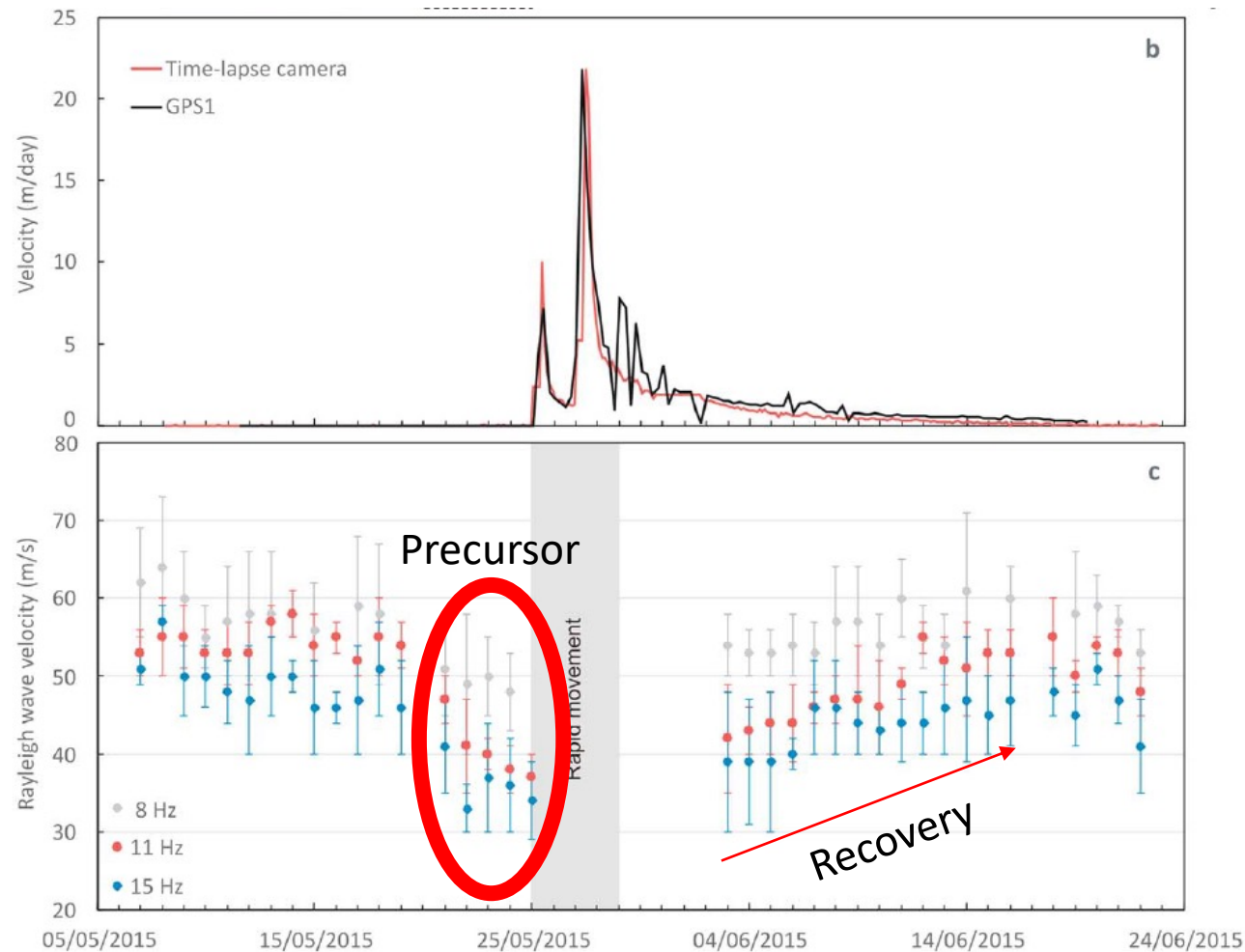
Montevecchio landslide, Italy

Seismic monitoring



Other exemple of precursory drop

Montevecchio landslide, Italy



- 4 days before the failure : dv/v dropped
- After the failure : dv/v slowly recovers showcasing a healing of the soil and an increase in it's rigidity

Problematic

To date ~10 landslides have been monitored with this method

- dv/v is a good indicator for failure
- the precursor are often seen after the event
- **Early warning systems are needed**

Challenges for operational early warning applications :

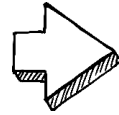
- 1) to detect velocity changes both rapidly and with confidence
- 2) to check for potential instabilities in measurements
- 3) to account for seasonal and daily environmental influences

Detect velocity changes both rapidly and with confidence

Each landslide is different !

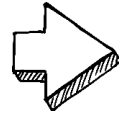
Key factors are :

➤ filtering frequency



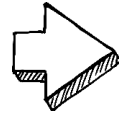
will influence the investigation depth. We want to look at velocity variations of wave who actually travel through the landslide

➤ the correlation time window



Will influence the type of seismic waves you are looking at, and hence the investigation depth

➤ the choice of temporal resolution

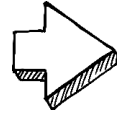


will influence the rapidity of the early warning (Today cross correlation functions are average over 24 h and more for a good signal stability)

Check for potential instabilities in measurements

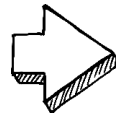
Potential environmental factors that can lead to spurious variations in the computed apparent velocity are :

➤ Variation in sources of ambient noise



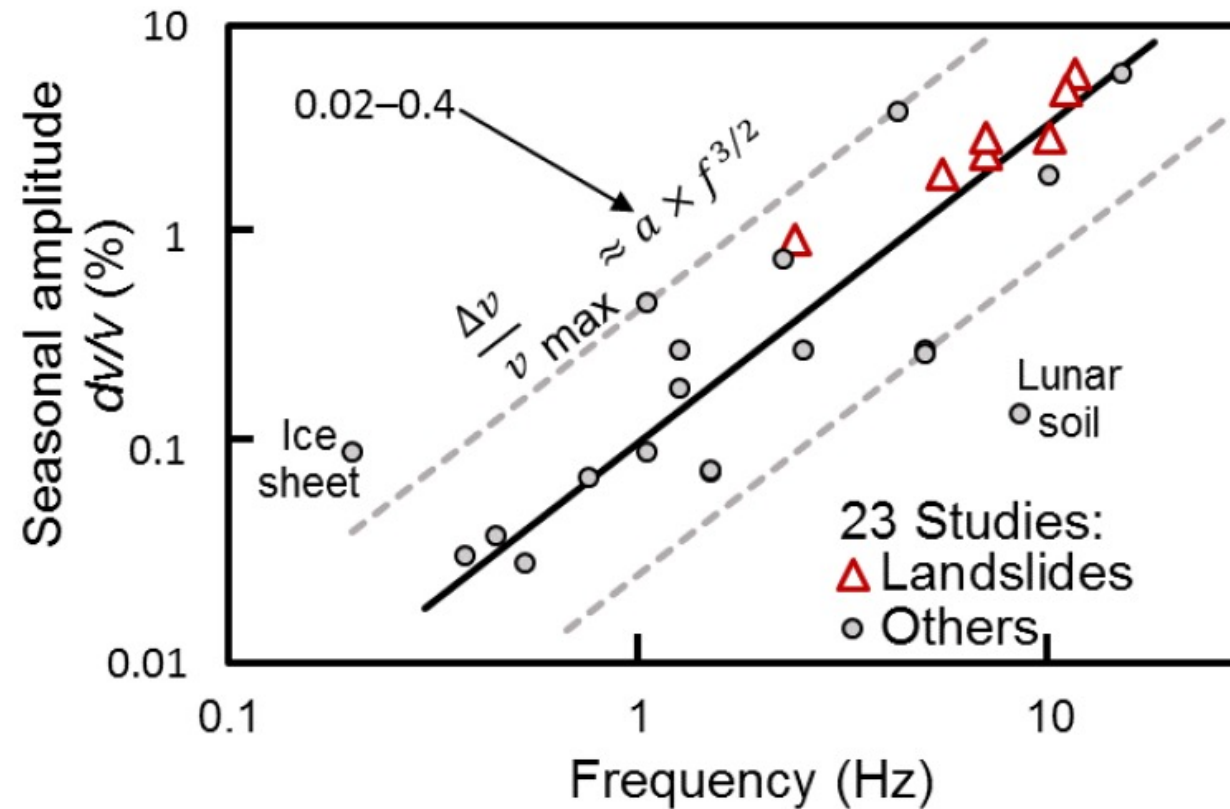
Identifying seismic noise sources is a key challenge to be undertaken before computing the CCFs, as variations in the sources may influence the resulting apparent dv/v

➤ loss of correlation coefficient when computing the cross correlation function due to a changes of the scatterers in the propagation medium



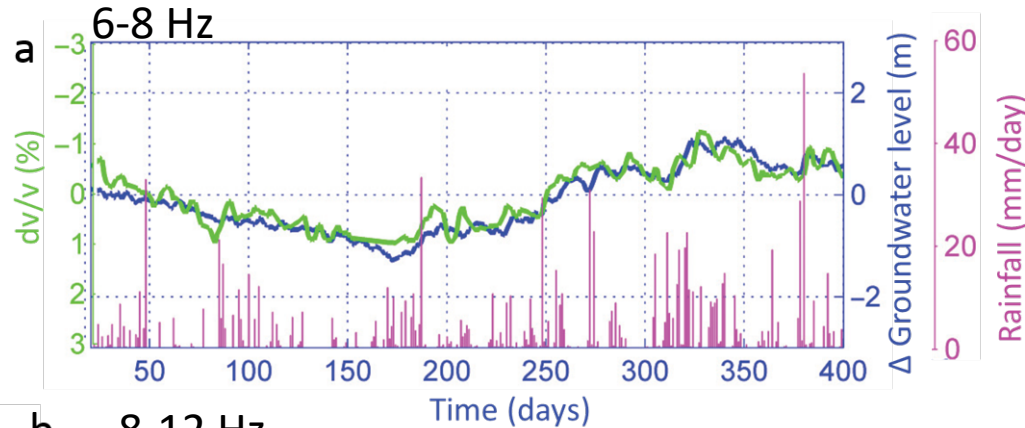
Can be used as an additional indicator but stable scatterers are a requirement for monitoring over the long time.

Account for seasonal and daily environmental influences

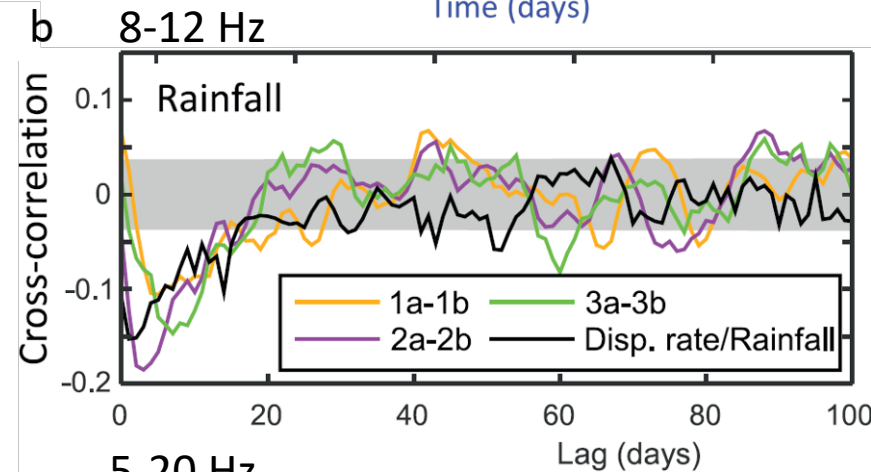


- Dv/v fluctuates seasonally, not only on landslides
- Fluctuation amplitude depends on frequency (proxy to investigation depth)
- The same processes may occur on landslides or on stable grounds

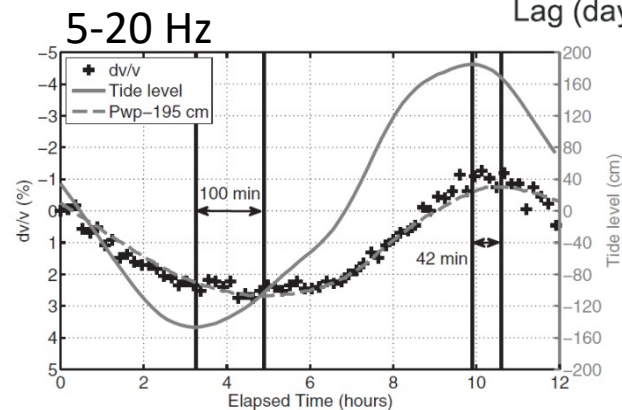
Influence of groundwater



Yearly negative correlation between groundwater and dv/v , on Utiku landslide (Voisin et al. 2016)



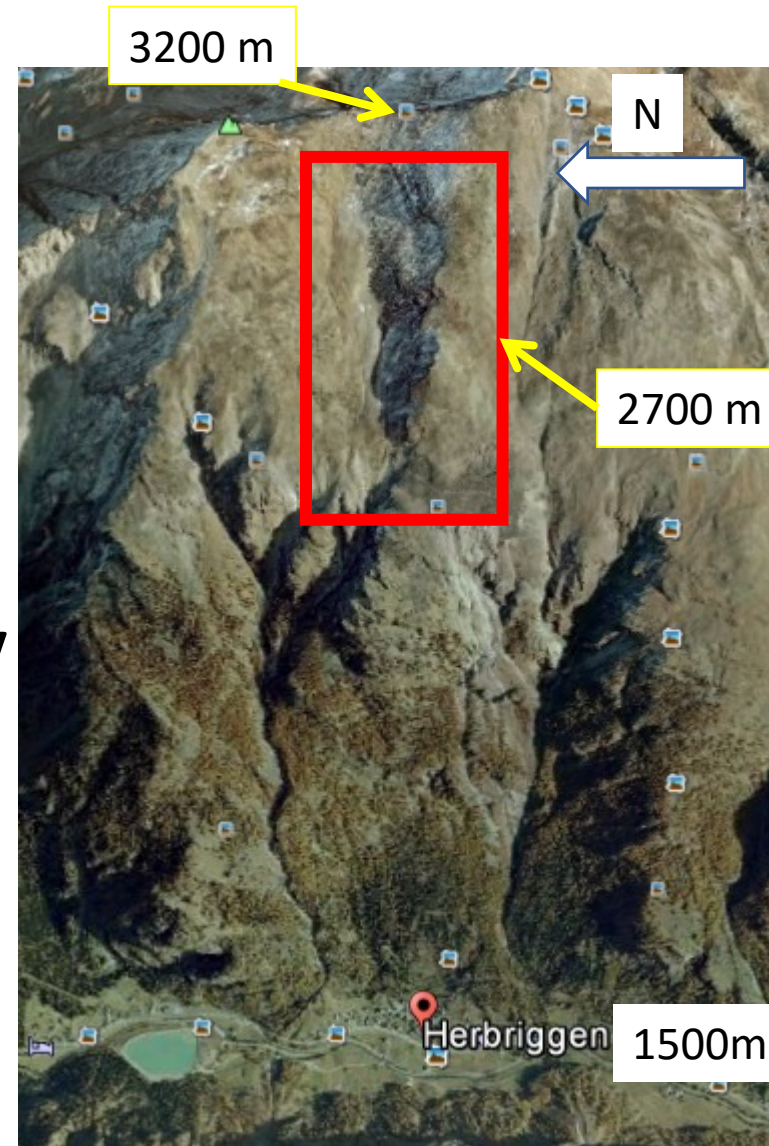
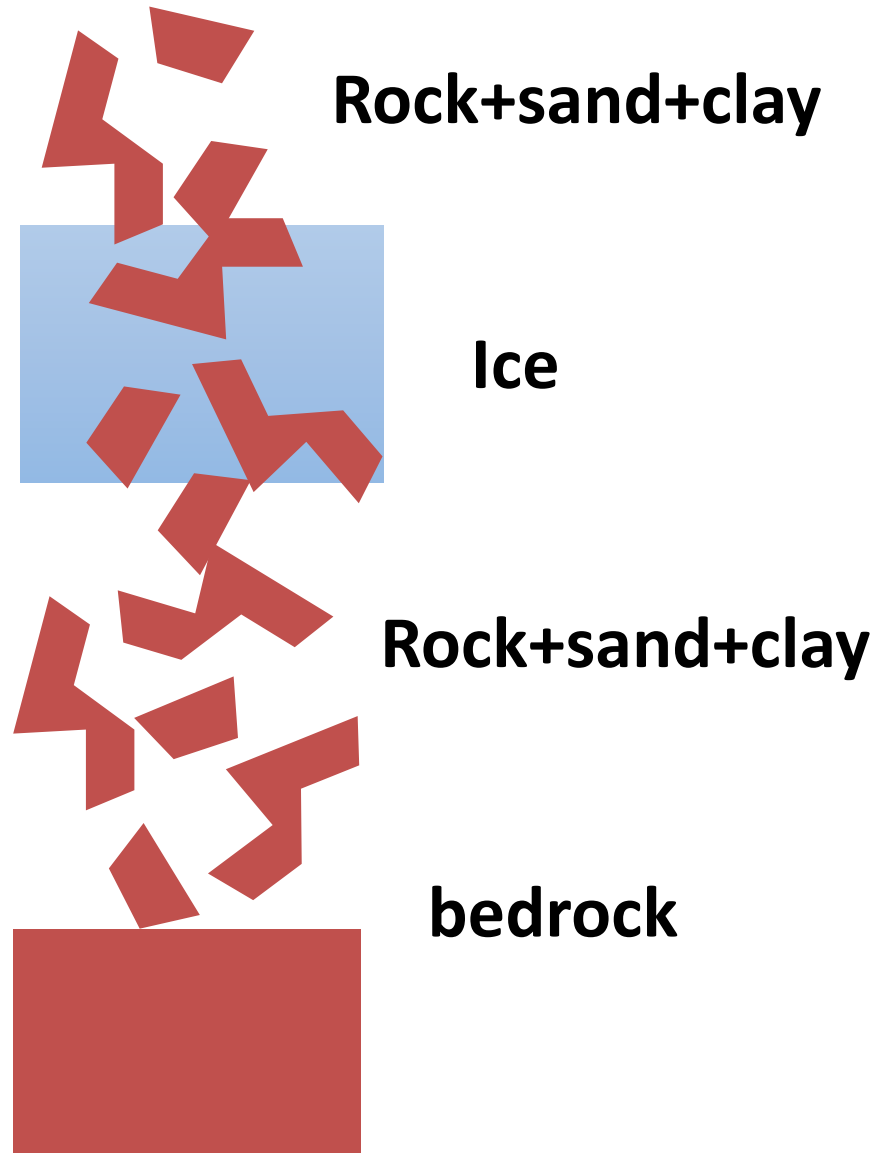
Rainfall is correlated with a negative peak of dv/v , on Pont-Bourquin landslide (Bièvre et al. 2018)



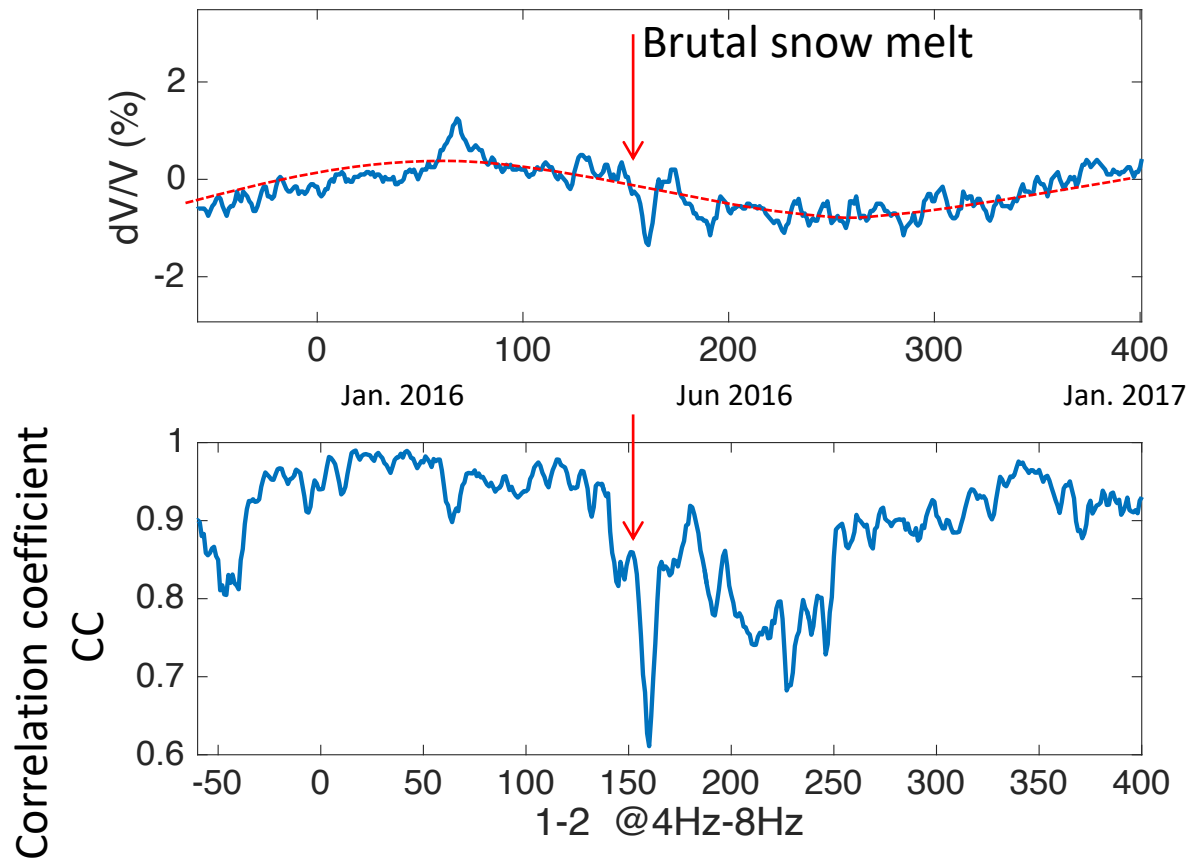
Groundwater level is negatively correlated, on a 12-hour periods, created by tides, on a coast (Planès et al., 2017)

➤ Groundwater elevation has a major (negative) influence on the dv/v

Permafrost monitoring : Rock Glacier “Gugla”- Wallis (Switzerland)



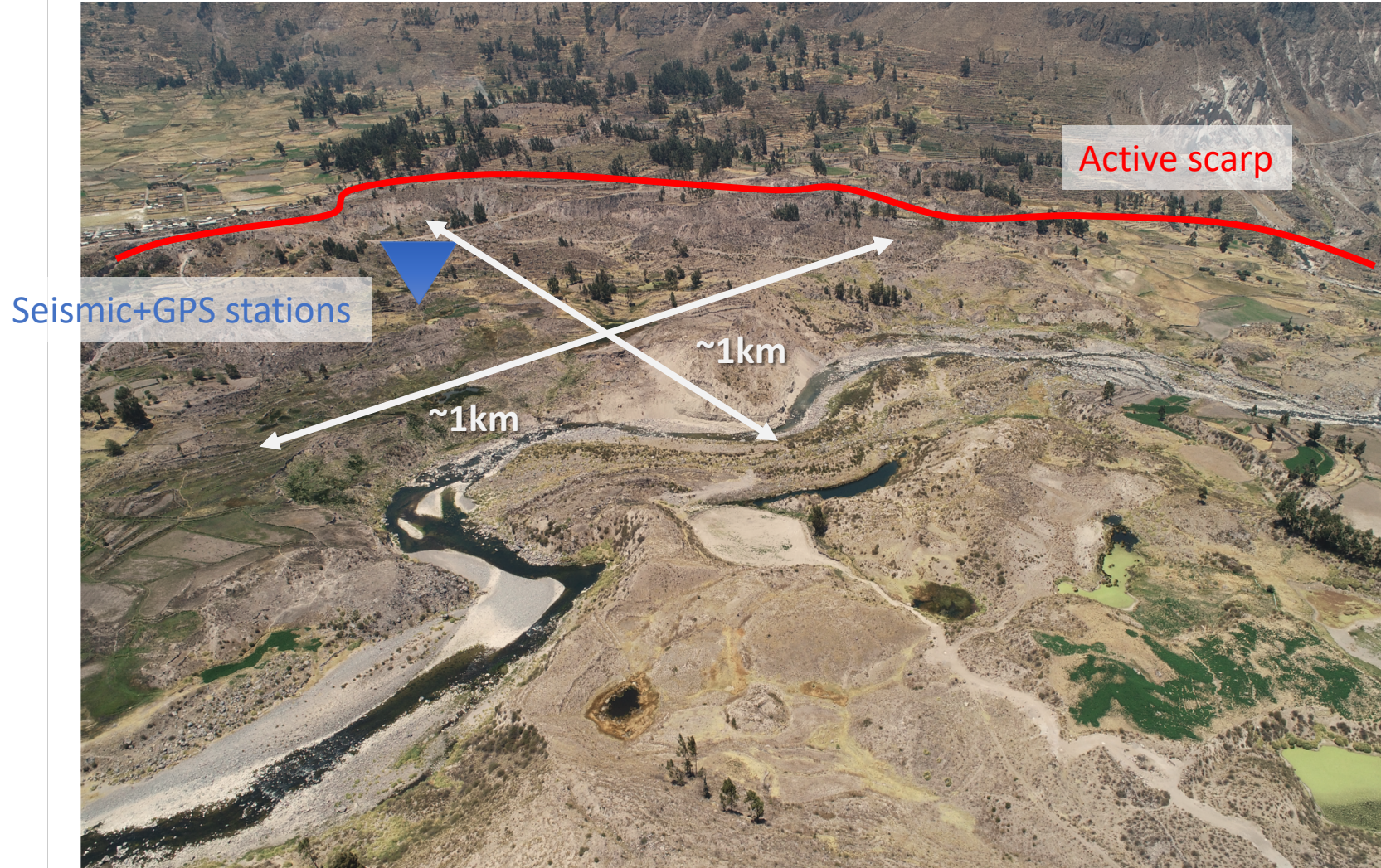
Permafrost monitoring



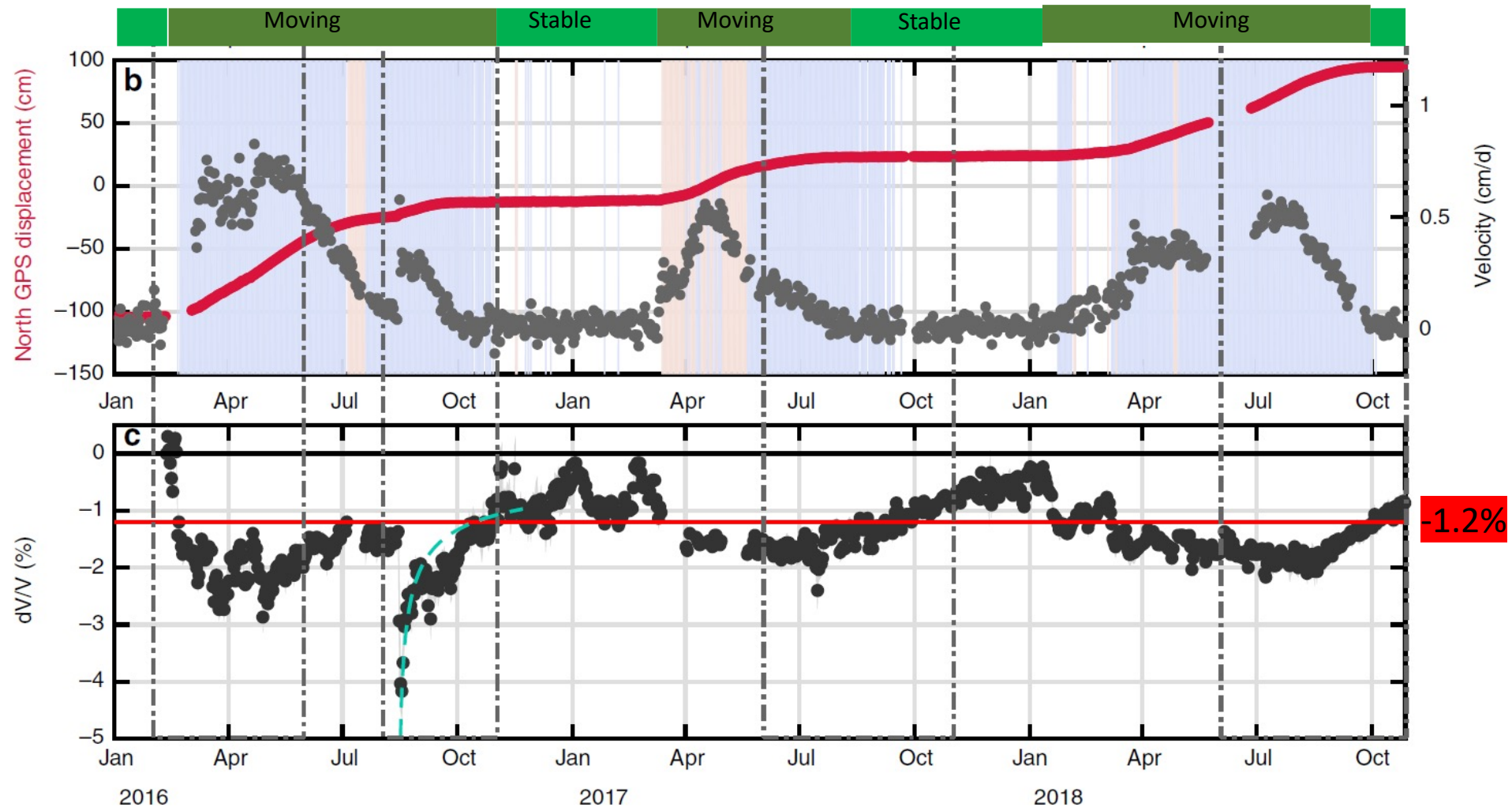
- Seasonal variations of dV/V due to freeze-thawing cycles
- Drops of dV/V and CC during brutal snowmelt periods

Earthquakes impact :

Maca landslide, Peru



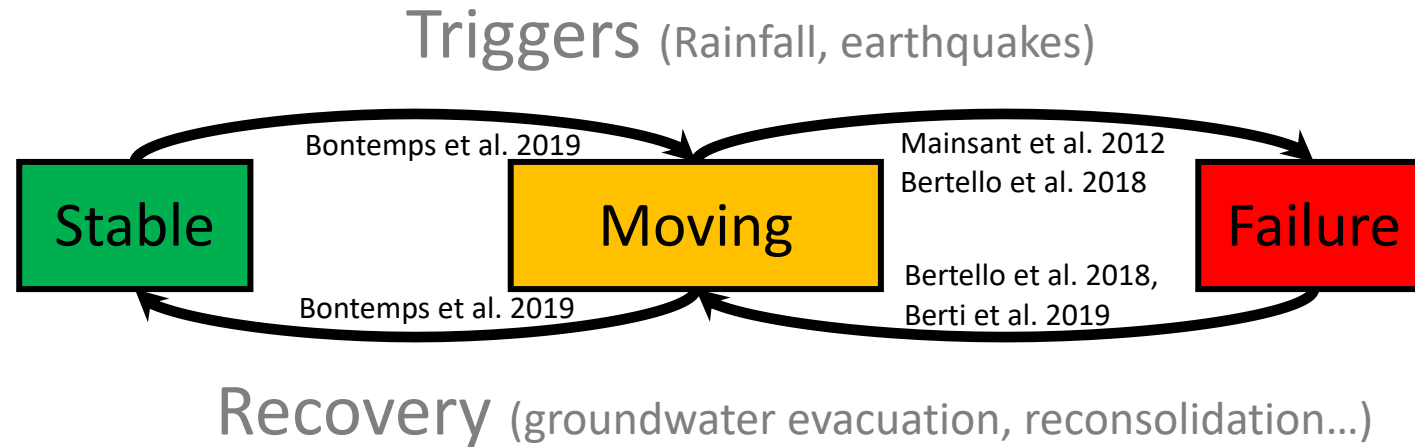
Maca landslide, Peru



- The landslide moves when the $dv/v < 1.2\%$
- Motion is triggered by Earthquake + Rainfall
- dv/v slowly recovers after the failure

Synthesis : three states of stability observed

The transition between states happens when the dv/v crosses a threshold



dv/v , an indicator of landslide stability...

- Before failure (precursor)
- But also after the failure (recovery)

It is important to know the different factors that can influence the stability of the monitored landslide and the potential impact that they can have on the dv/v measured to properly set the parameters for an early warning system

Conclusion

- The observation of seismic velocity changes could contribute in assessing a landslide stability across time, both during the different creeping stages occurring before a potential failure, and during its reconsolidation after a failure.
- Technique used to monitor both landslide and rock glaciers but also water table, volcanos, etc.

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