Insights on rockslide controlling factor for slope failure from pre-event cracking

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Motivation

- Mass wasting events are hard to predict (when and why?)

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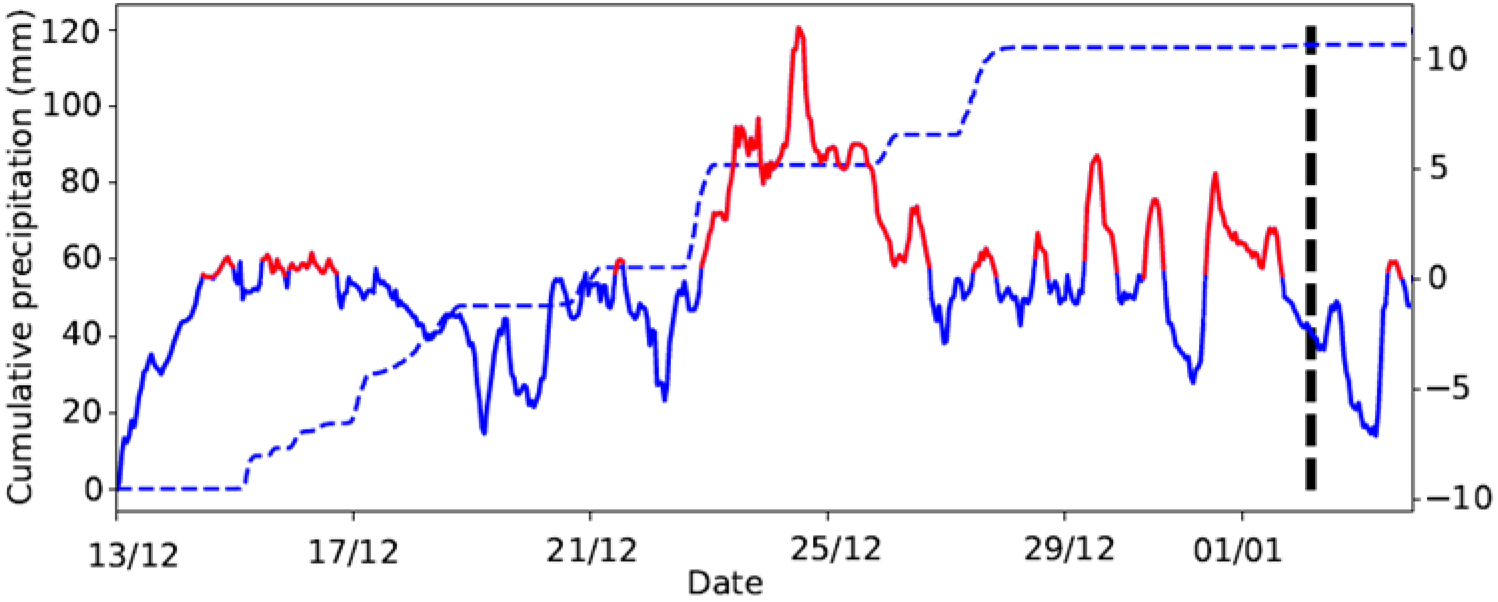
- Sometimes no clear trigger prior to failure

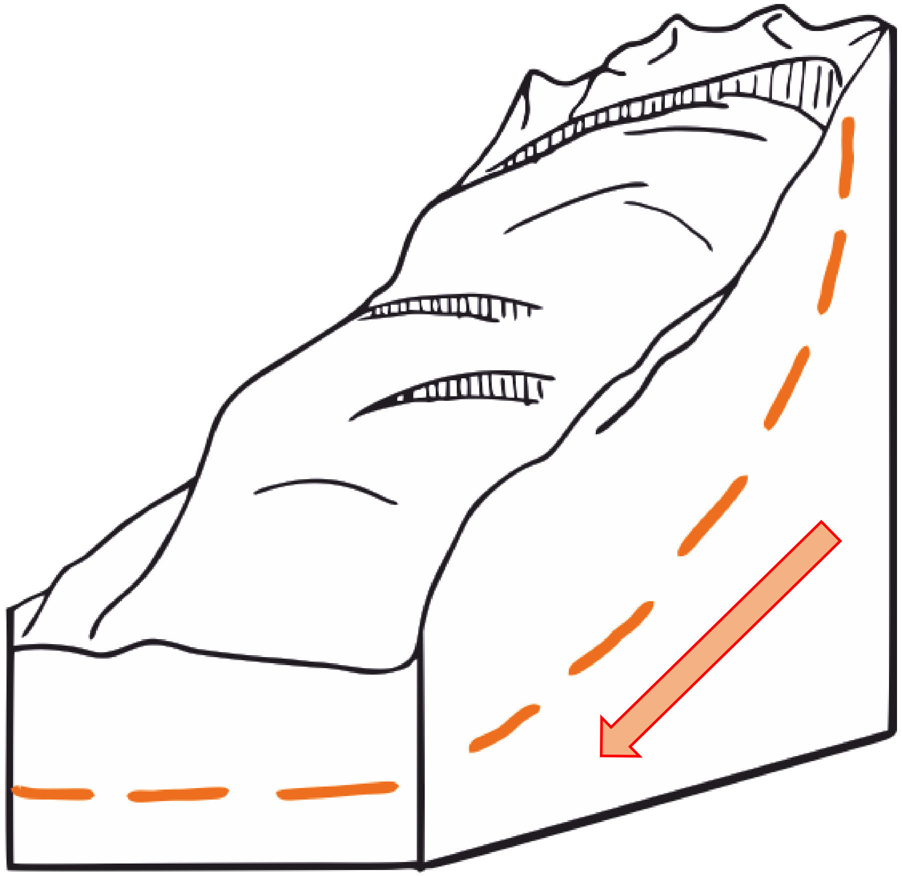


Motivation

- Lack of data on the failure plan

→ Impossibility to have direct insight on it

- Even with seismometers located on the failure site, cracks on the failure plane are difficult to retrieve with common techniques (STA/LTA, cross-correlation), because of the low signal to noise ratio



Research questions

1. Can we have a better insight on crack propagation within the failure plane ?

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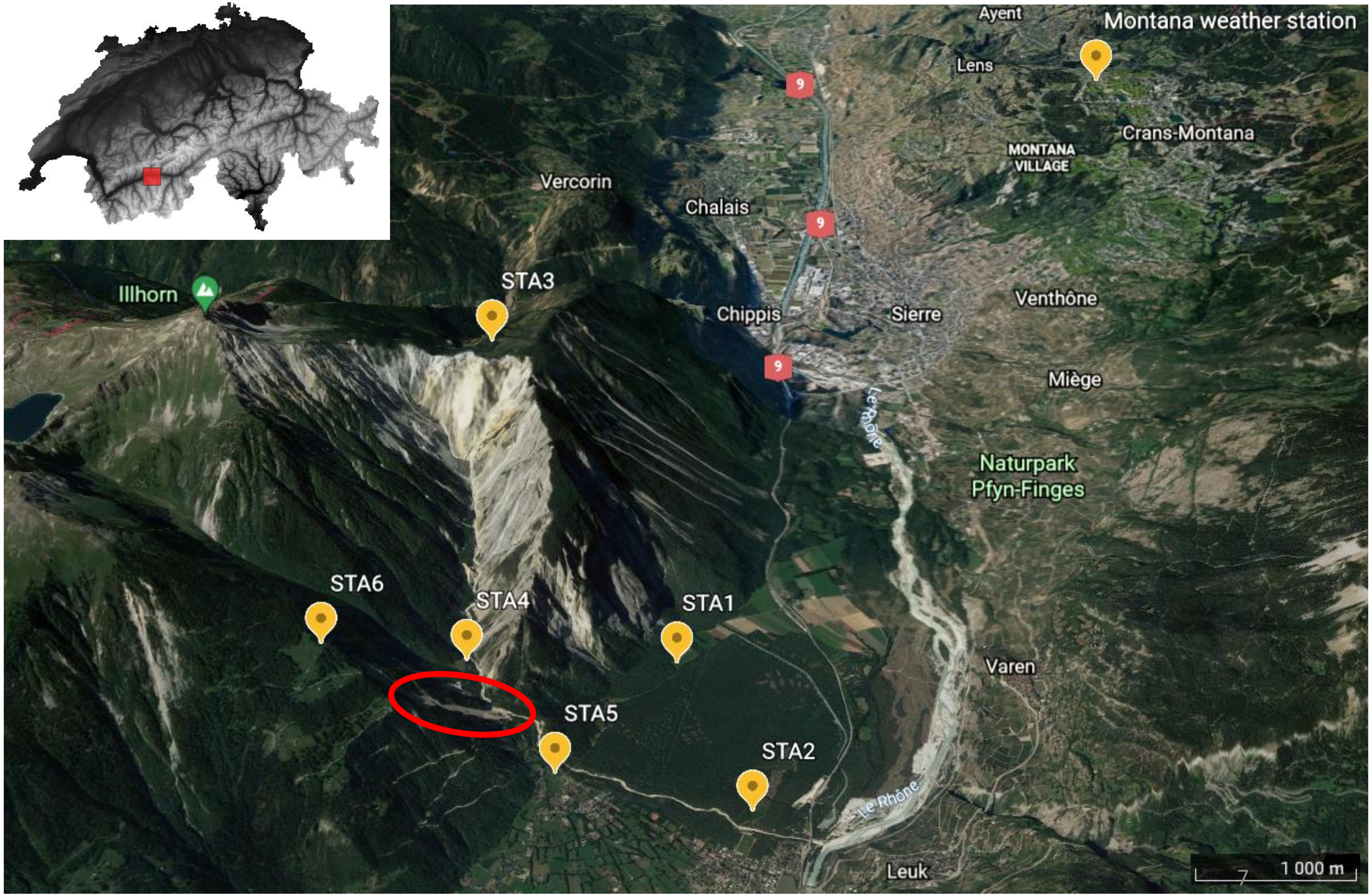
2. If yes, what can we learn about the controlling factors for slope failure ?

Study site and investigated event

- Array of 6 broadband seismometers
- One weather station retrieving temperature and precipitation

Series of mass-wasting events,
main rockslide on the 2nd January 2013 at 03:42

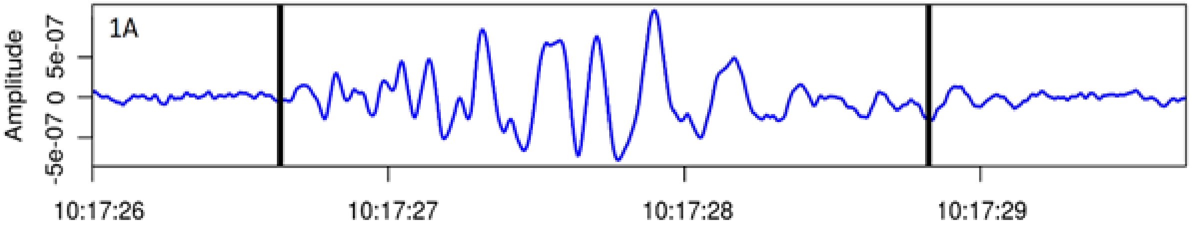


1. Can we have a better insight on crack propagation within the failure plane ?

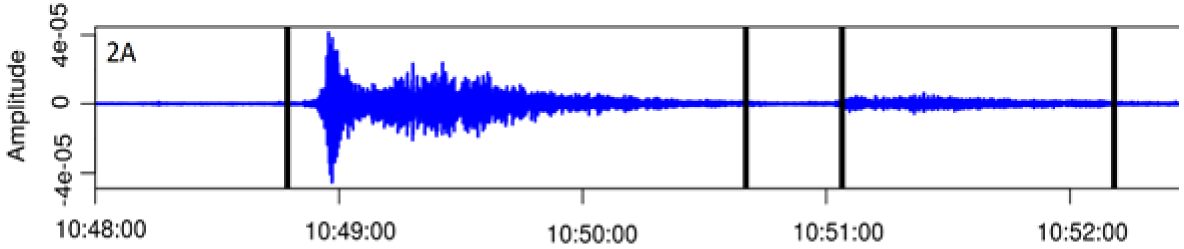
→ Use of a state-of-the-art machine learning technique based on Hidden Markov Model (HMM)

Event class and reference events

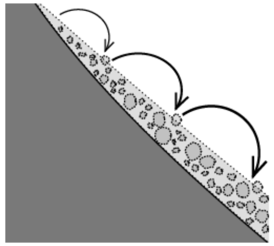
Crack → single crack signal



Slope failure → failure and subsequent rockslide

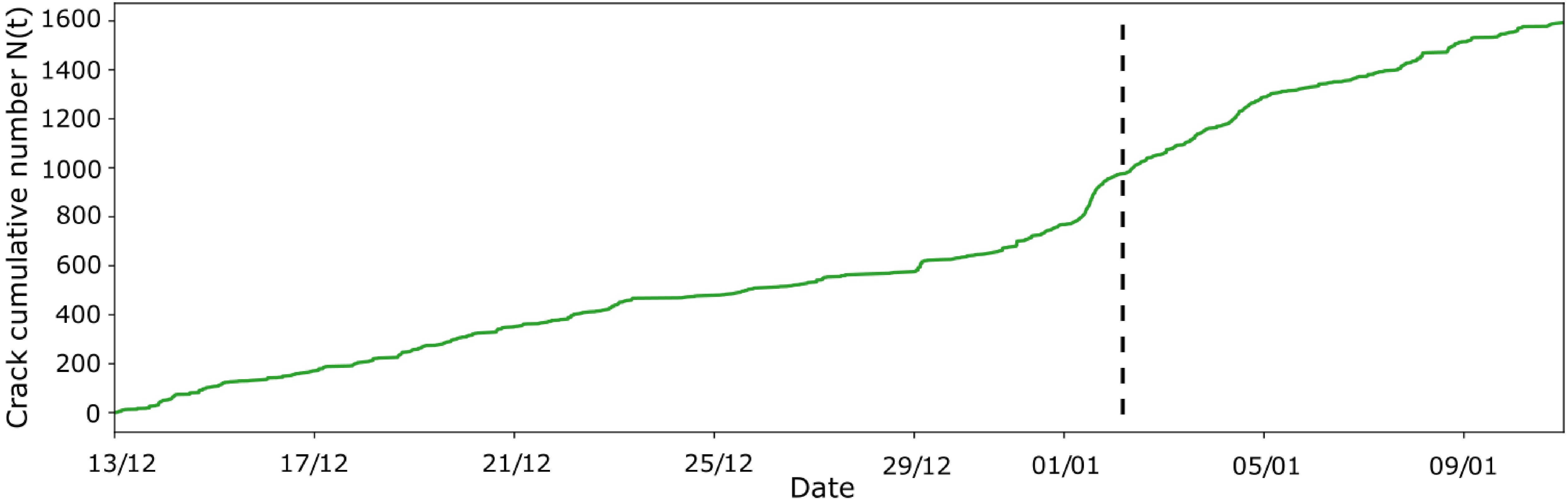


Debris mobilisation → rock avalanche activity due to the remobilization of debris

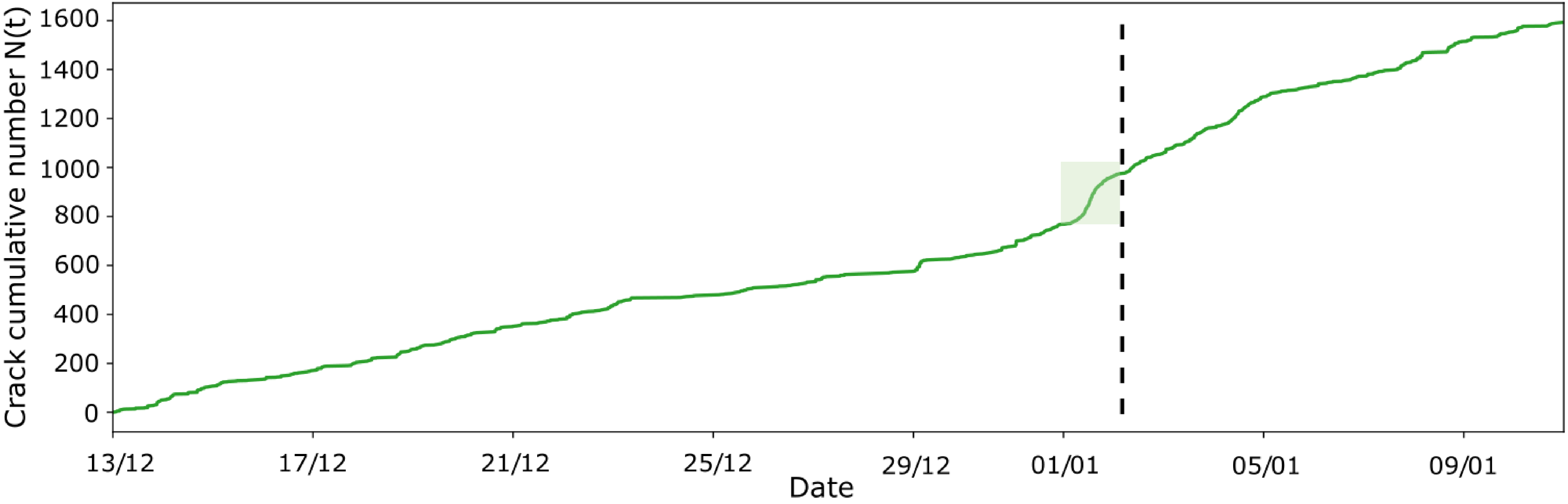


starting time	duration	type
2012/12/12 03:52:01.600	1.2	crack

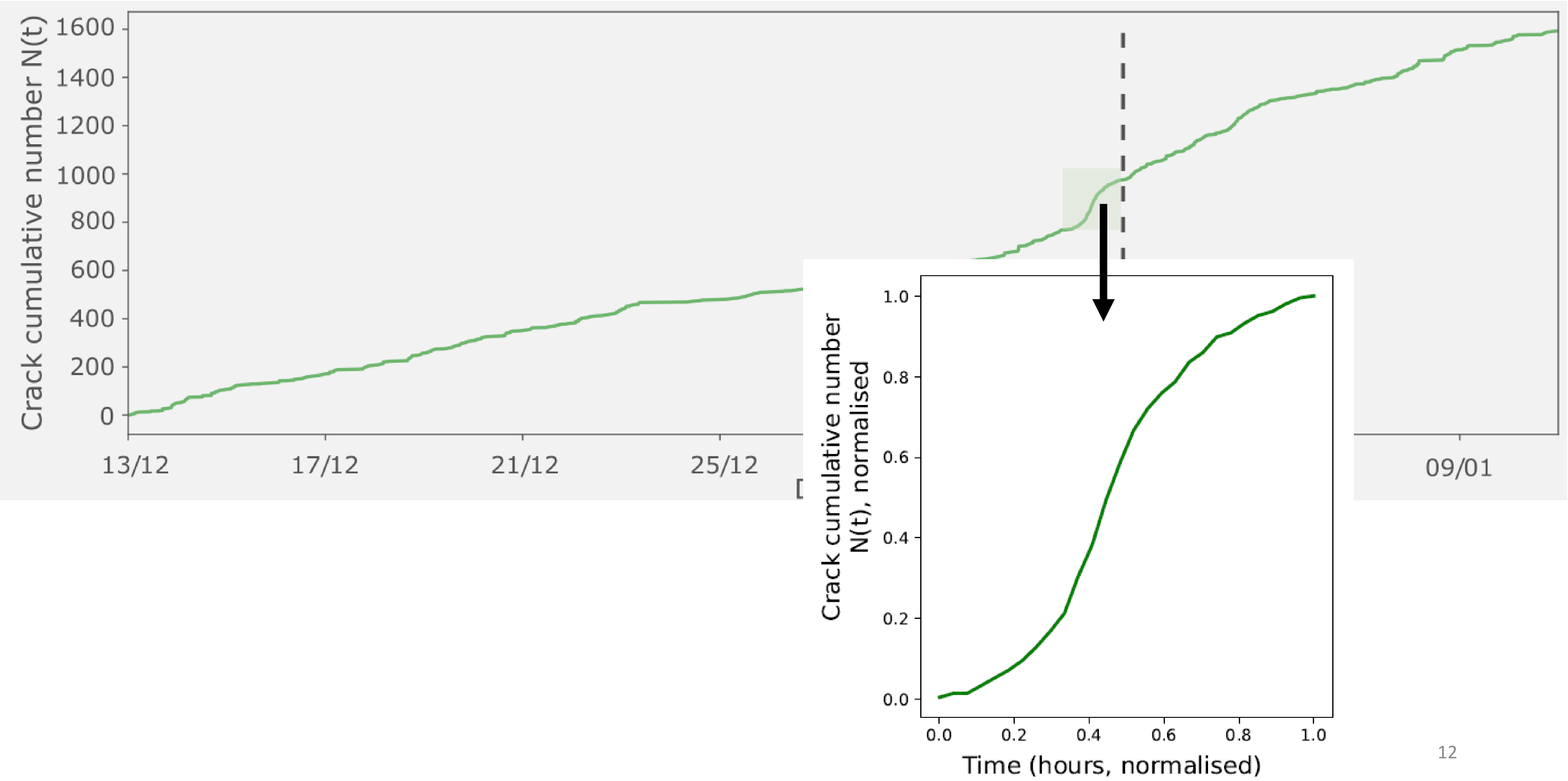
Classification results



Classification results



Classification results

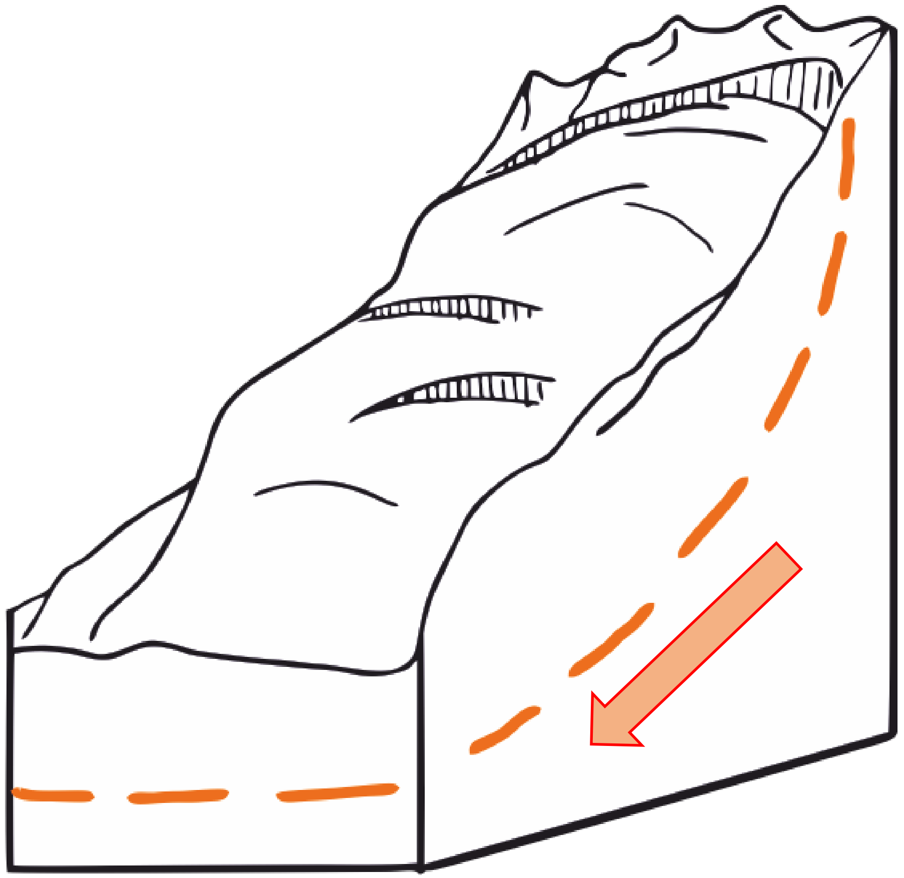


2. What can we learn about the controlling factors for slope failure ?

→ Construction of a simple physical model to explain the "S-shape" in $N(t)$ in the hours prior to the main failure

Modelling crack behavior in the hours prior to the rockslide

- Initially, the mass above and below the failure plane are connected
- For the rockslide to occur, the complete failure plane area needs to be disjoined

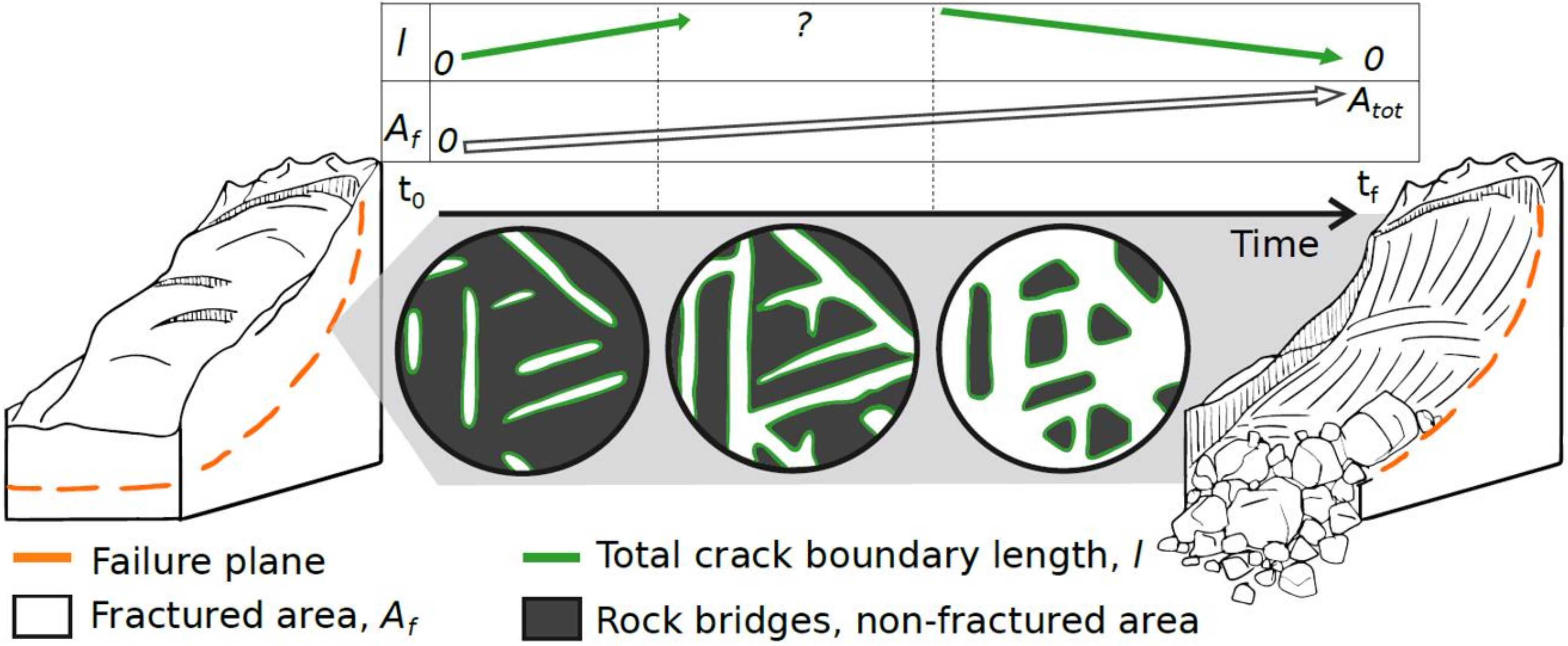


Assumptions:

1. The cumulative number of crack $\mathrm{N(t)}$ is proportionnal to the fractured area $\mathrm{A_f}$:

$$\mathbf{N}(\boldsymbol{t}) \sim \boldsymbol{A_f}(\boldsymbol{t})$$

Modelling crack behavior in the hours prior to the rockslide



2. The crack length boundary l is a parabola function of the fractured area $\mathrm{A_f}$:

$$\boldsymbol{l}(\mathbf{A}) \sim \frac{\mathbf{1}}{\boldsymbol{\tau}} \boldsymbol{A_f}(\mathbf{1} - \boldsymbol{A_f})$$

Modelling crack behavior in the hours prior to the rockslide

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3. The fractured area is related to the crack length boundary following:

$$\frac{\mathbf{d}\boldsymbol{A_f}}{\boldsymbol{dt}} \sim \boldsymbol{l}(\mathbf{A})\boldsymbol{V} \Rightarrow \frac{\mathbf{d}\boldsymbol{A_f}}{\boldsymbol{dt}} \sim \boldsymbol{l}(\mathbf{A})$$

With V the crack velocity, a constant.

Modelling crack behavior in the hours prior to the rockslide

$$N(t) \sim A_f(t)$$

$$l(A) \sim \frac{1}{\tau} A_f(1 - A_f)$$

$$\frac{dA_f}{dt} \sim l(A)$$

$$\Longrightarrow$$

$$\frac{dN}{dt} \sim l(A) \sim \frac{1}{\tau} N(t)(1 - N(t))$$

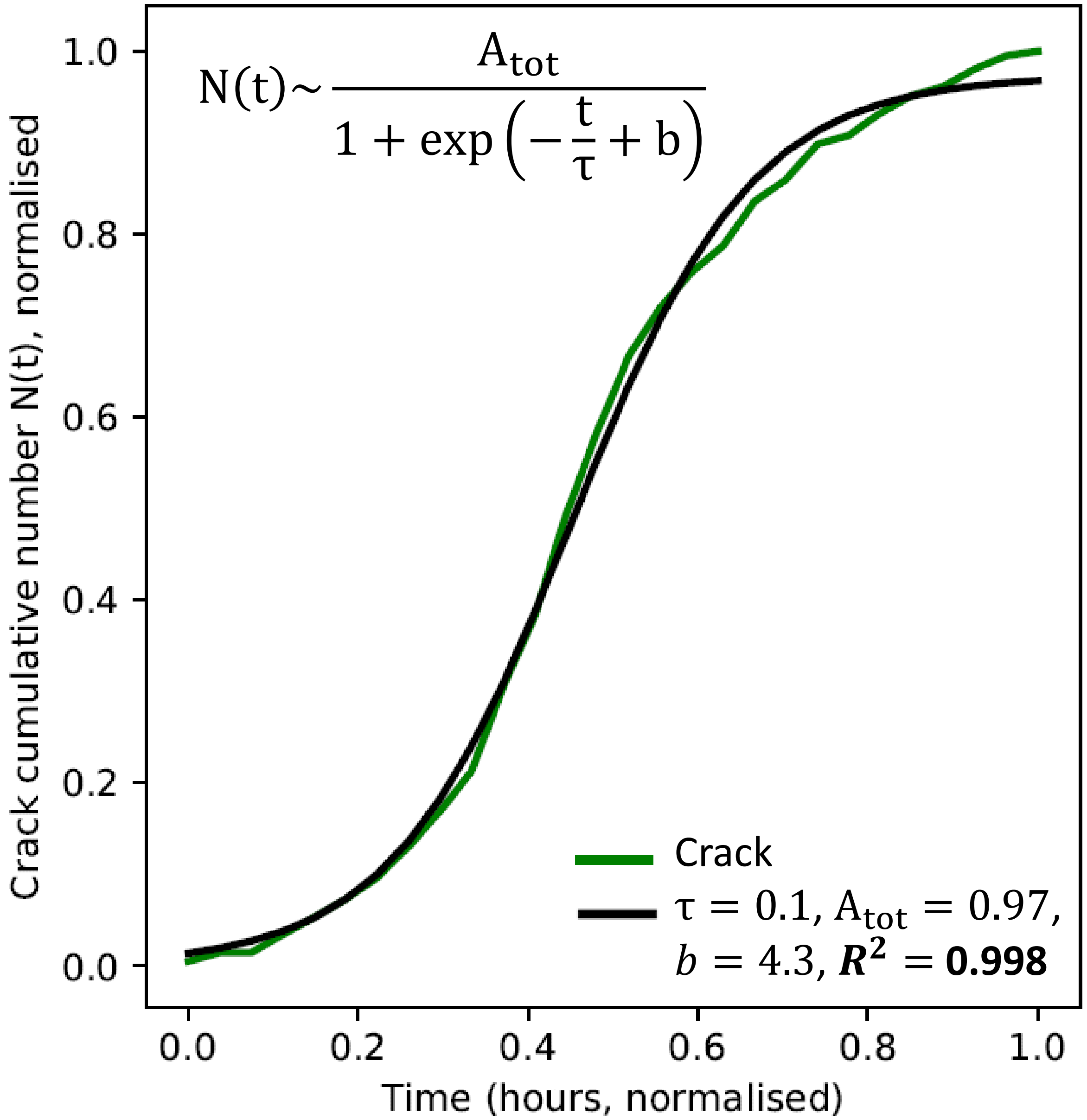
$$\downarrow$$

$$\mathbf{N(t)} \sim \frac{\mathbf{A_{tot}}}{\mathbf{1 + exp}\left(-\frac{\mathbf{t}}{\boldsymbol{\tau}} + \mathbf{b}\right)}$$

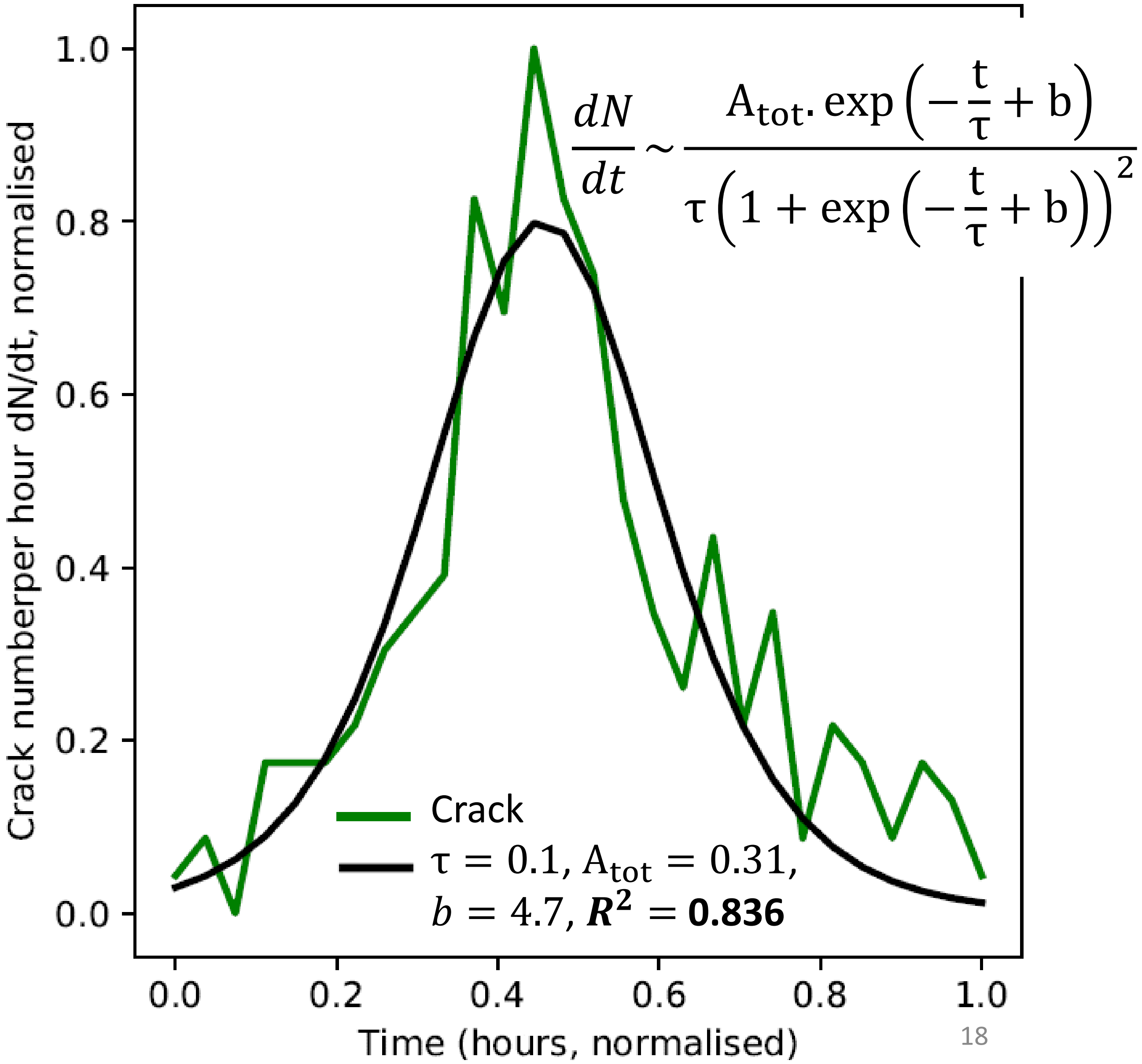
$$\downarrow$$

$$\frac{\mathbf{dN}}{\mathbf{dt}} \sim \frac{\mathbf{A_{tot}}.\,\mathbf{exp}\left(-\frac{\mathbf{t}}{\boldsymbol{\tau}} + \mathbf{b}\right)}{\boldsymbol{\tau}\left(\mathbf{1 + exp}\left(-\frac{\mathbf{t}}{\boldsymbol{\tau}} + \mathbf{b}\right)\right)^{\mathbf{2}}}$$

Results

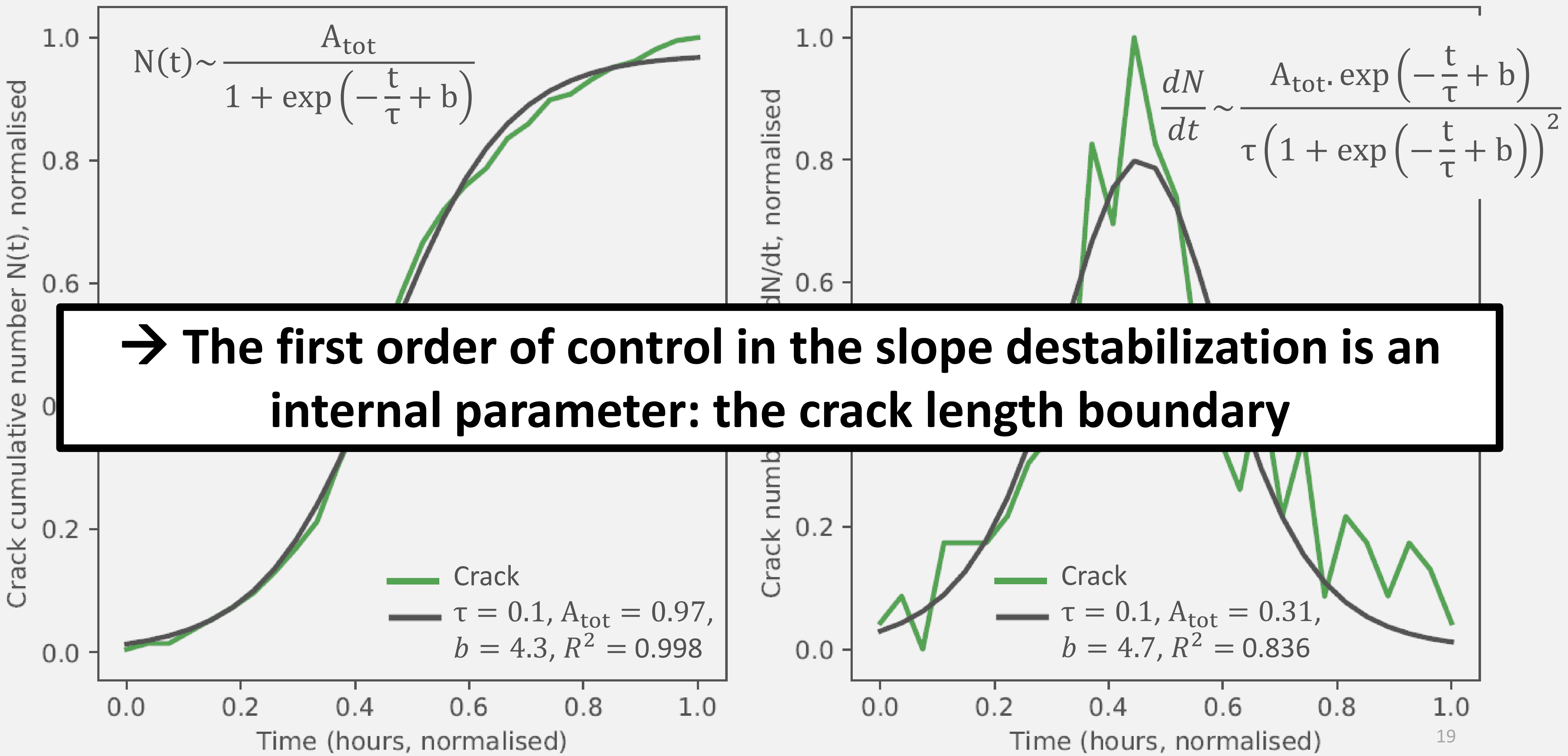


$N(t) \sim \frac{A_{tot}}{1 + \exp\left(-\frac{t}{\tau} + b\right)}$
Crack cumulative number N(t), normalised
Time (hours, normalised)
1.0
0.8
0.6
0.4
0.2
0.0
Crack
$\tau = 0.1$, $A_{tot} = 0.97$,
$b = 4.3$, R^2 = **0.998**



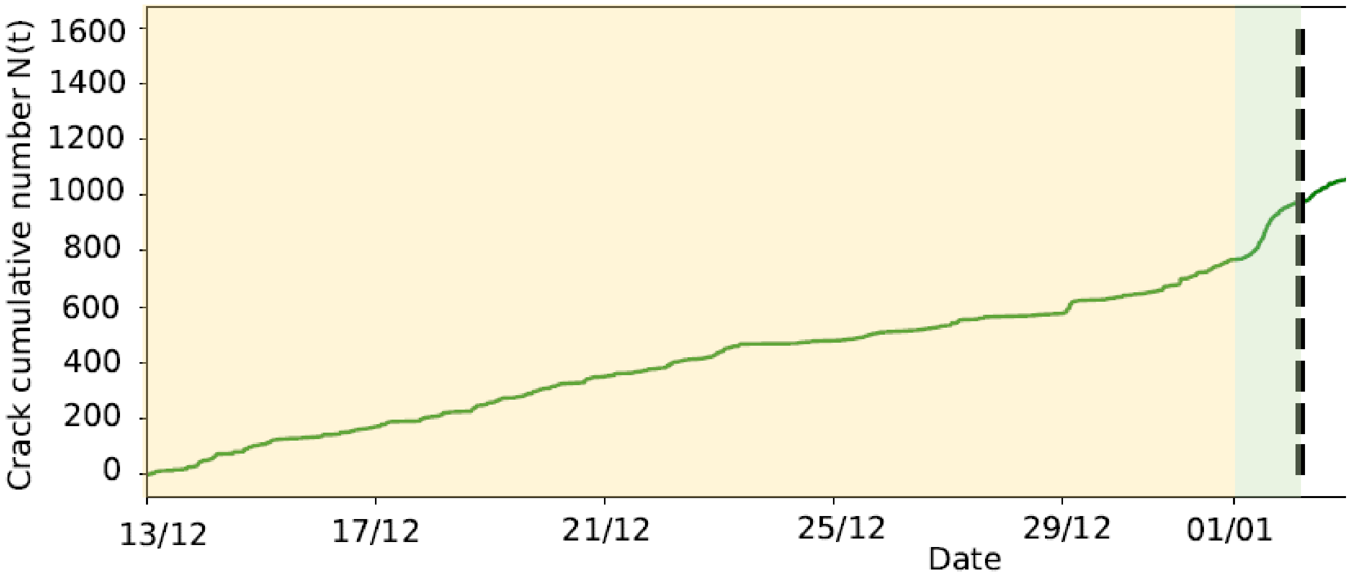
$\frac{dN}{dt} \sim \frac{A_{tot}.\exp\left(-\frac{t}{\tau} + b\right)}{\tau\left(1 + \exp\left(-\frac{t}{\tau} + b\right)\right)^2}$
Crack numberper hour dN/dt, normalised
Time (hours, normalised)
1.0
0.8
0.6
0.4
0.2
0.0
Crack
$\tau = 0.1$, $A_{tot} = 0.31$,
$b = 4.7$, R^2 = **0.836**

Results



→ The first order of control in the slope destabilization is an internal parameter: the crack length boundary

Discussion: Two-phase failure evolution from distributed to localized effects



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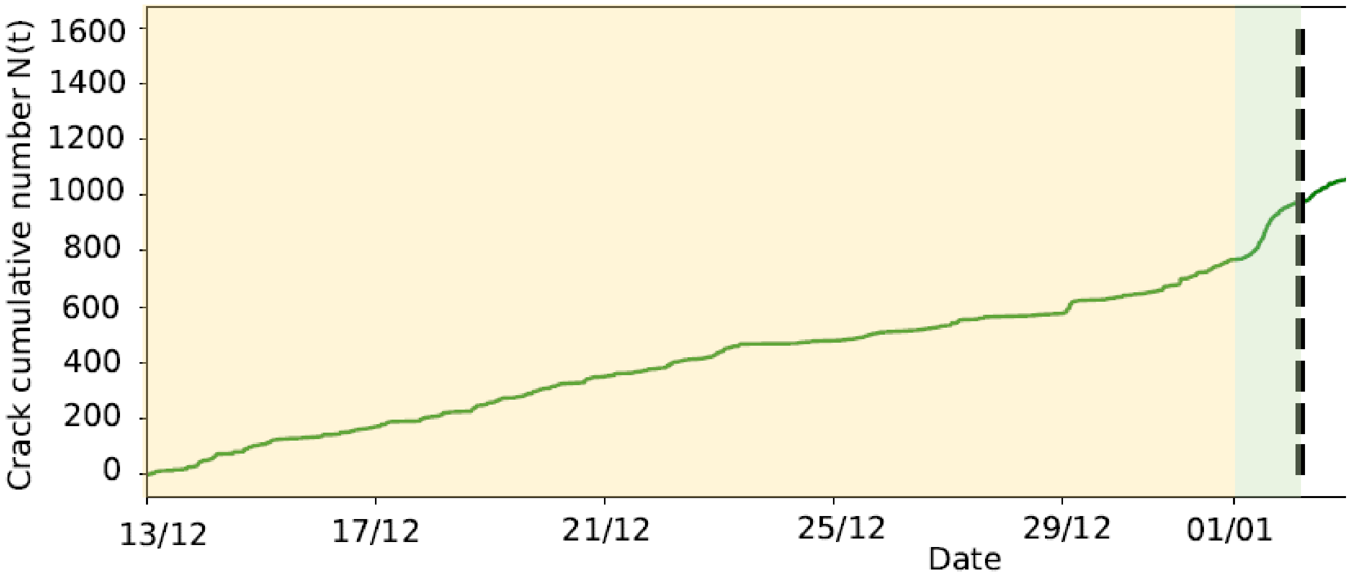

(a) intact (b) deformed creep

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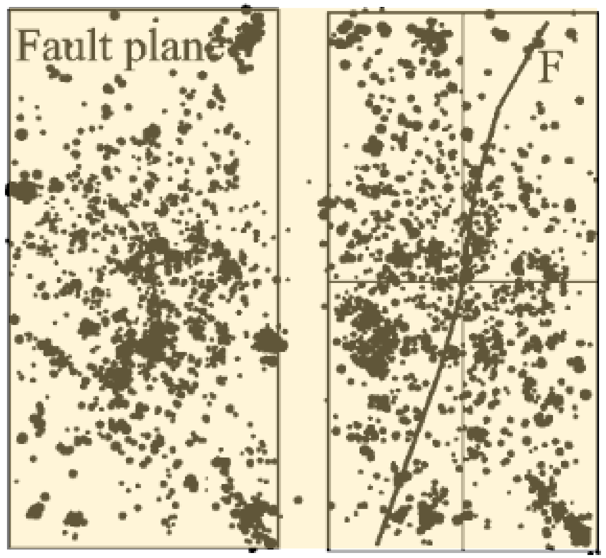
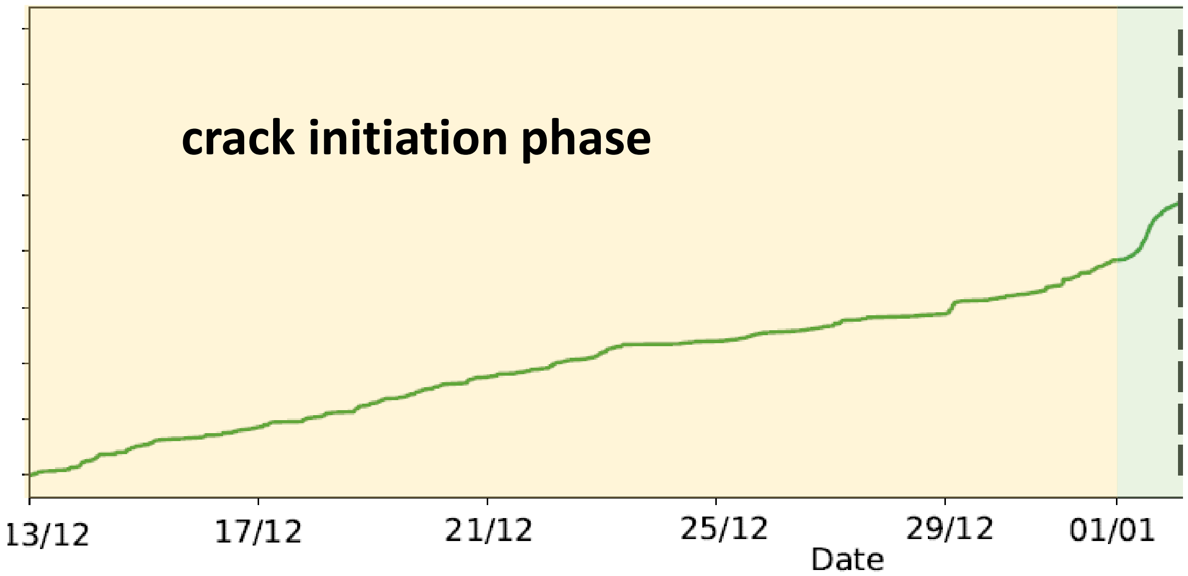


crack initiation phase

Lei et al. 2003



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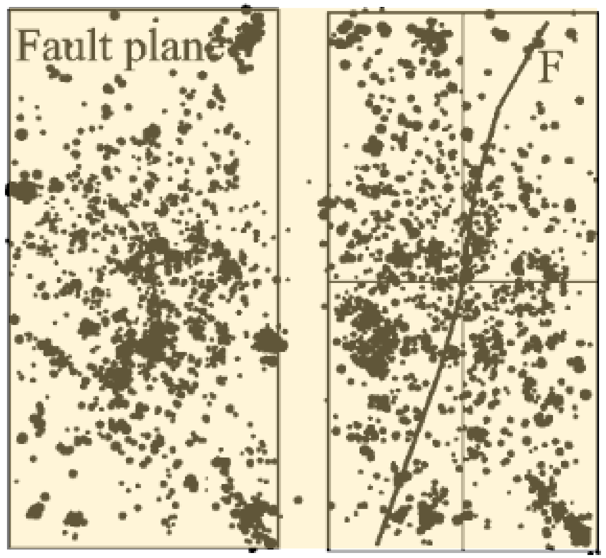
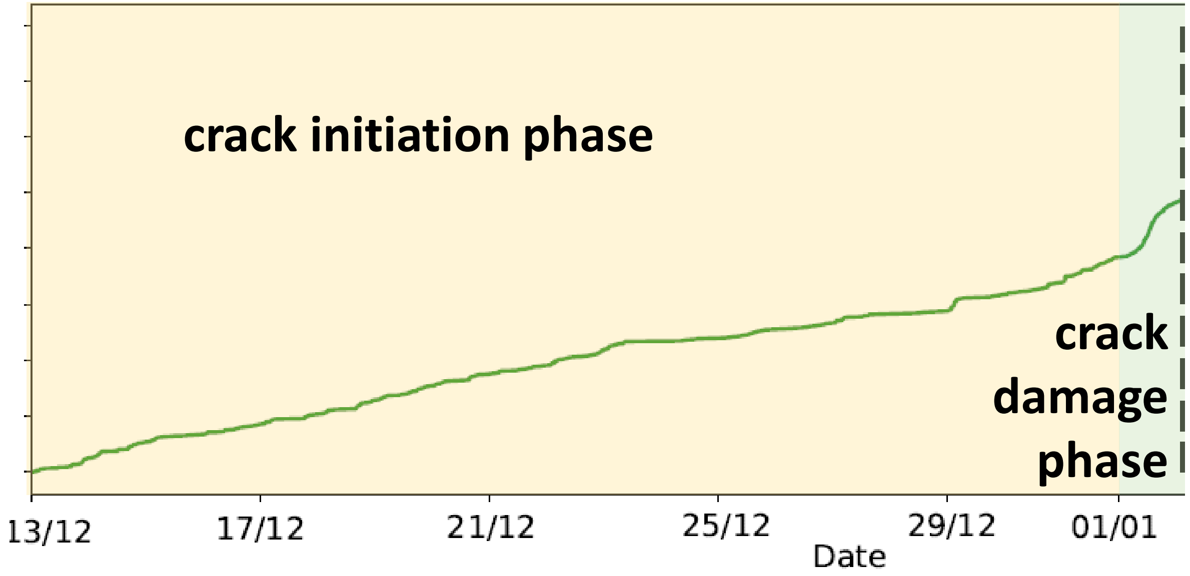
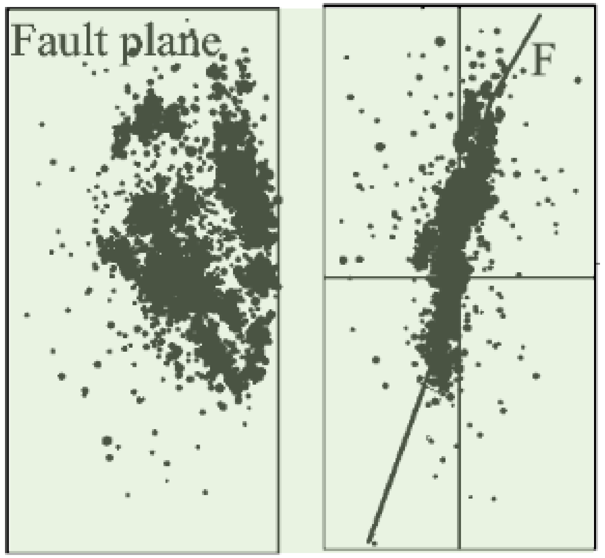
Discussion: Two-phase failure evolution from distributed to localized effects







crack initiation phase

Lei et al. 2003

crack damage phase

Brantut et al. 2013

As in small-scale laboratory experiments, our data confirm the existence of a switch between distributed cracking and localised damage accumulation

Conclusion

1. Can we have a better insight on crack propagation within the failure plane ?

The use of **hidden Markov model allows to detect low signal to noise ratio crack events**.

2. What can we learn about the controlling factors for slope failure ?

Construction of a simple physical model to explain the “S-shape” in $N(t)$ in the hours prior to the main failure

→ **the first order of control in the slope destabilization is an internal parameter: the crack length boundary**

→ indication for future model development and early warning systems.

I am looking for a Post-doc

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Reference: Lagarde, S., Dietze, M., Hammer, C., Zeckra, M., Voigtländer, A., Illien, L., Schöpa, A., Hirschberg, J., Burtin, A., Hovius, N., Turowski, JM. Rock slope failure preparation paced by total crack boundary length, submitted.