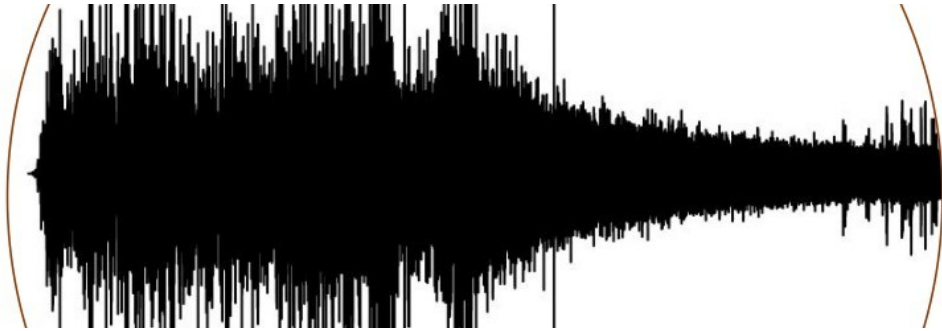


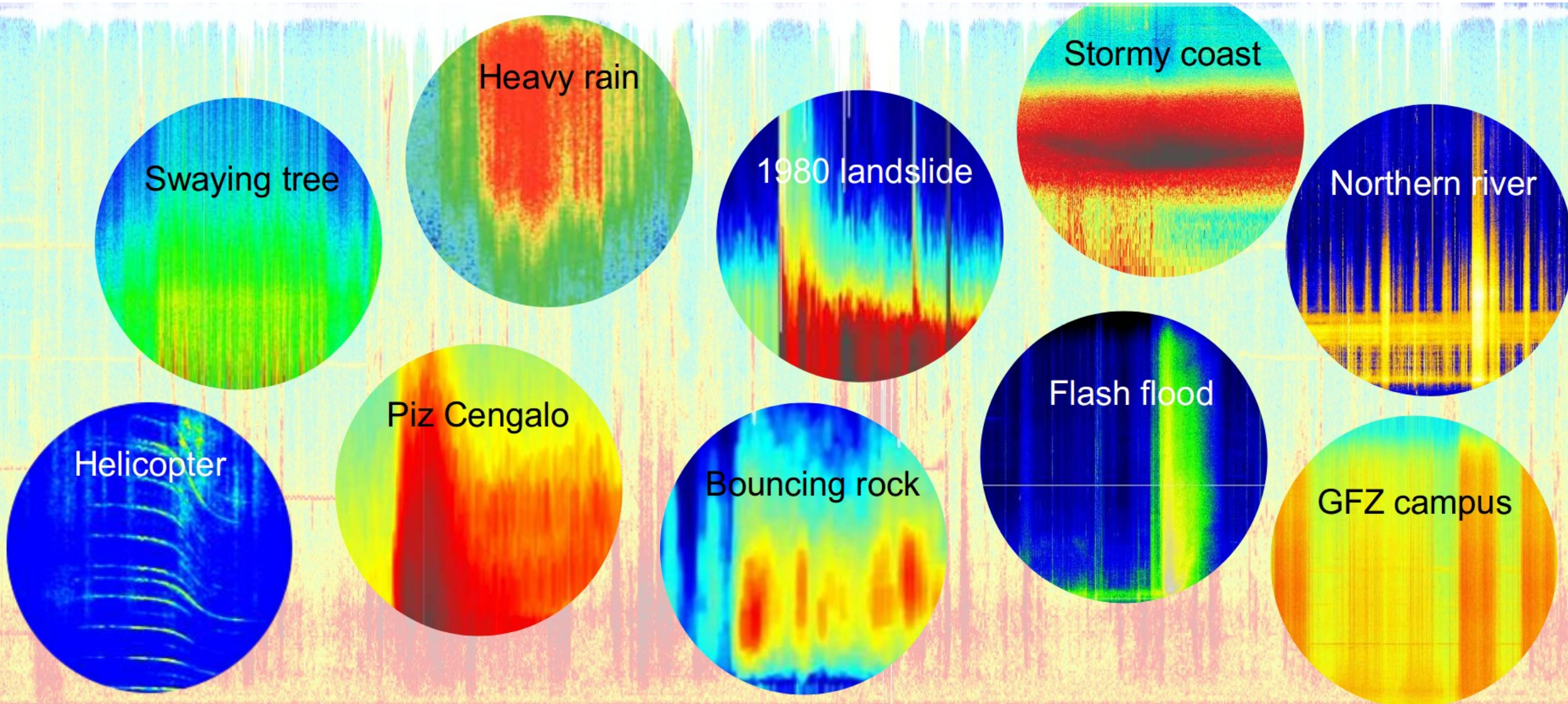


We need more models!

How geomorphology in seismic models leverages
our understanding of landscape dynamics

Michael Dietze
RWTH Aachen

A kaleidoscope of seismic signals as spectrograms of episodes of Earth surface activity



A textbook collection of geomorphic processes

weathering

frost

thermal

salt

clay expansion

debutressing

chemical

biological

mass wasting

rockfall et al.

landslide et al.

dry granular

debris flow

creep & slide

avalanches

rock glaciers

rivers & water

river flow

bedload

turbidity current

overland flow

groundwater

suspension

karst

atmosphere

air pressure

wind action

rainfall

hail & snow

saltation, repat.

glacial

cracking

deformation

calving

subglacial flow

A textbook collection of geomorphic processes

weathering

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thermal

~~salt~~

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mass wasting

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glacial

cracking

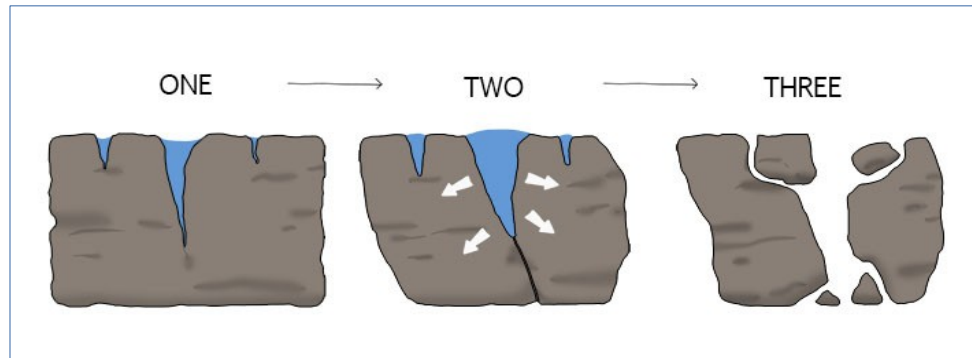
deformation

calving

subglacial flow

What do we know?
Can we model physically?

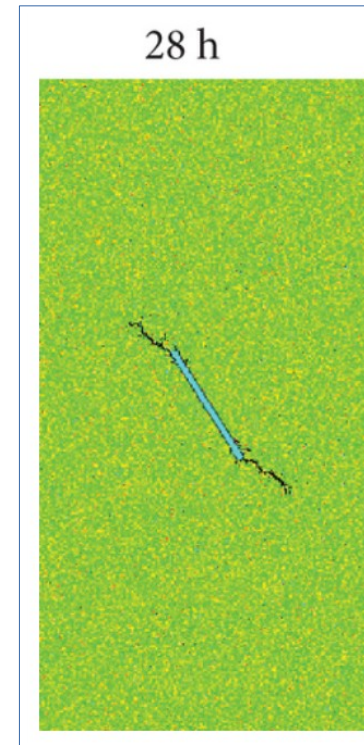
The action of frost on rock



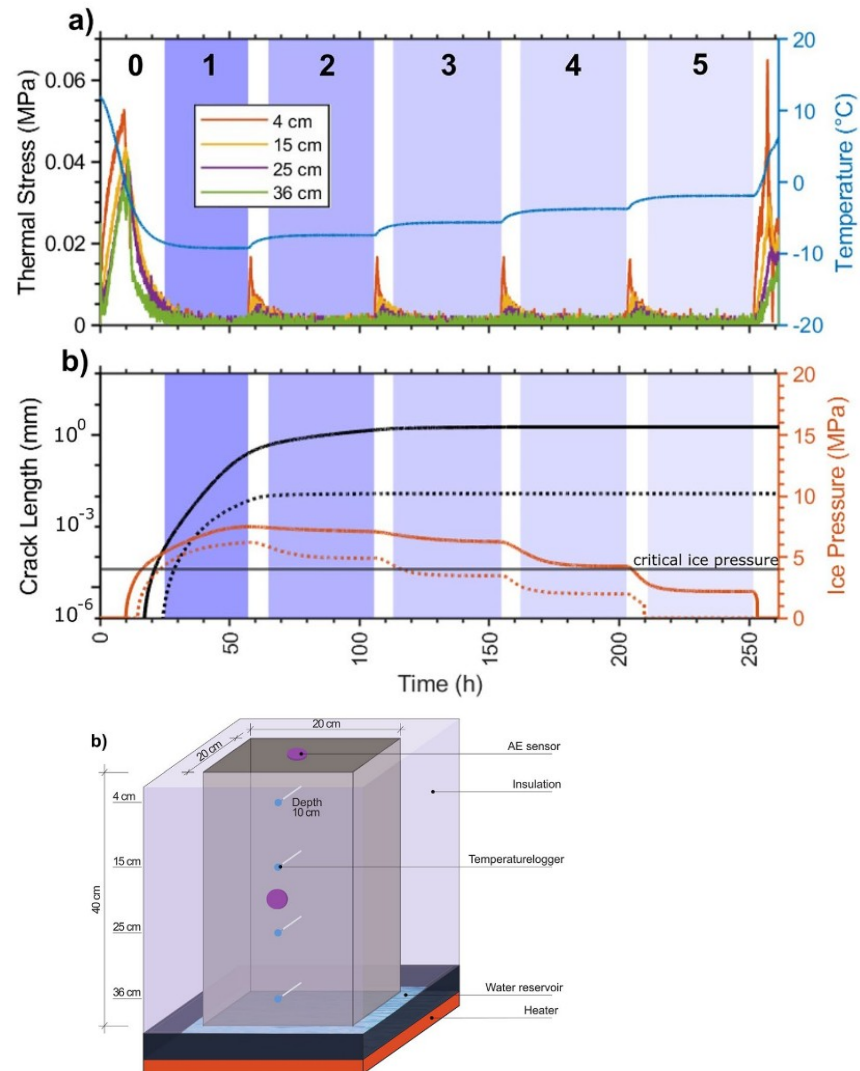
Arctic and Alpine Research, Vol. 18, No. 1, 1986, pp. 27–32

THE PHYSICAL BASIS OF FROST WEATHERING: TOWARD A MORE FUNDAMENTAL AND UNIFIED PERSPECTIVE

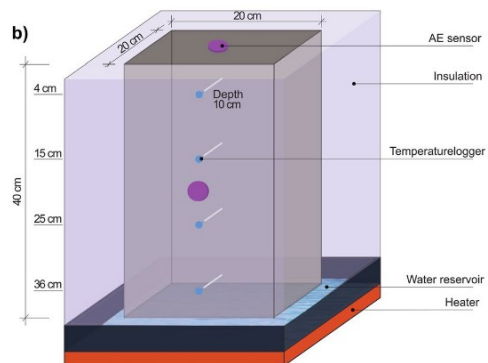
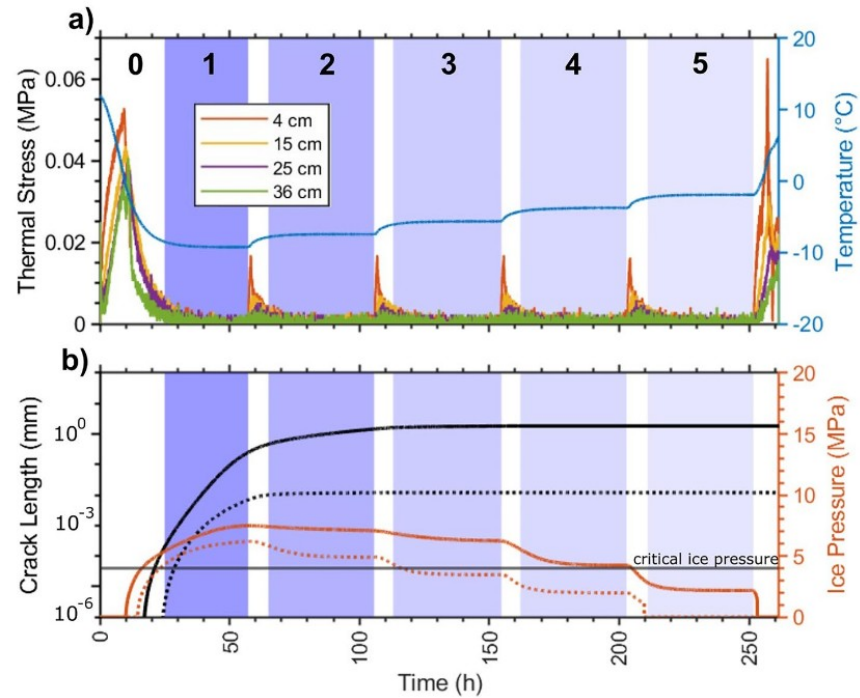
JOSEPH S. WALDER AND BERNARD HALLET
*Quaternary Research Center and Department of Geological Sciences
University of Washington, Seattle, Washington 98195, U.S.A.*



The action of frost on rock



The action of frost on rock

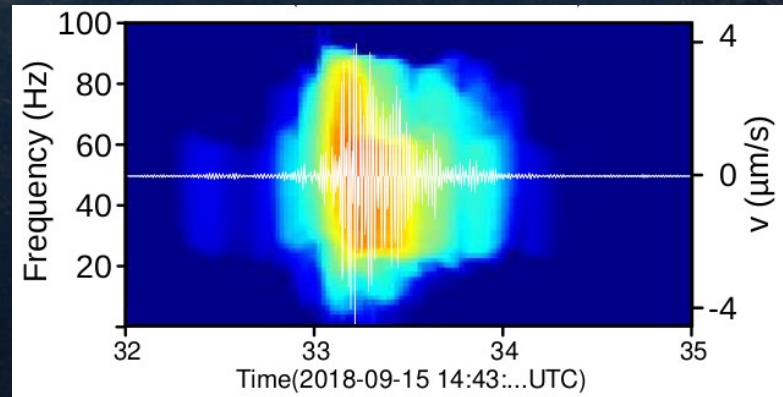


What
Where
When
(Why)

But: no model



Or the other way around: the reaction of rock to stress

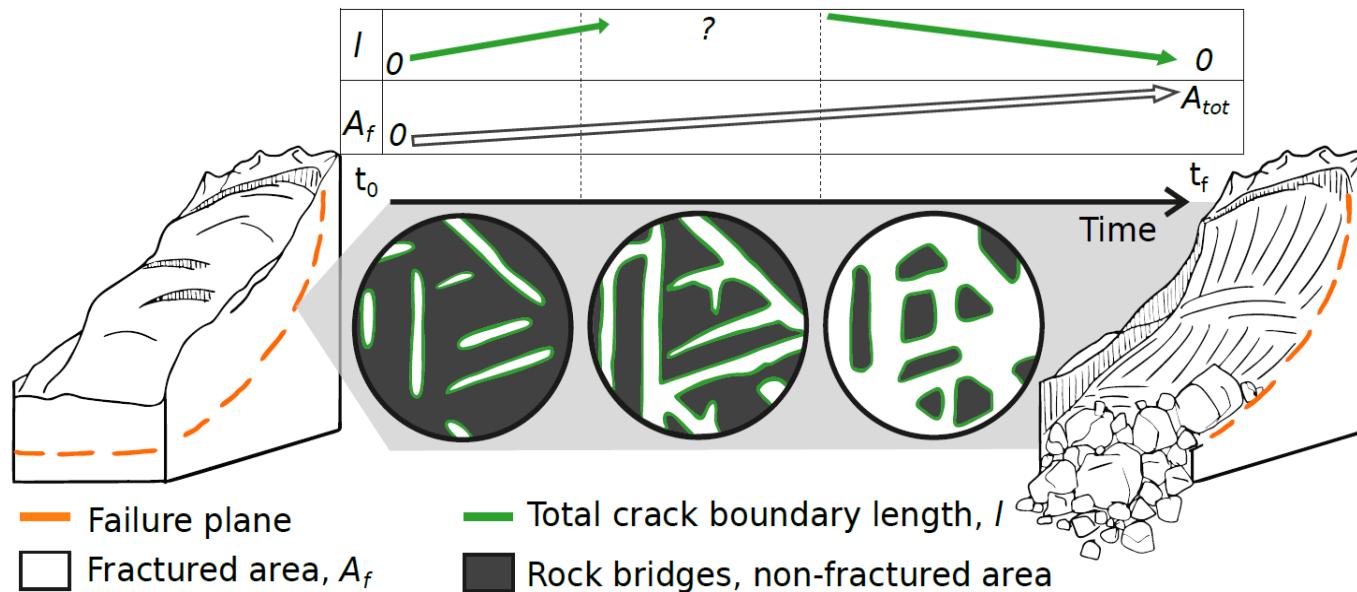
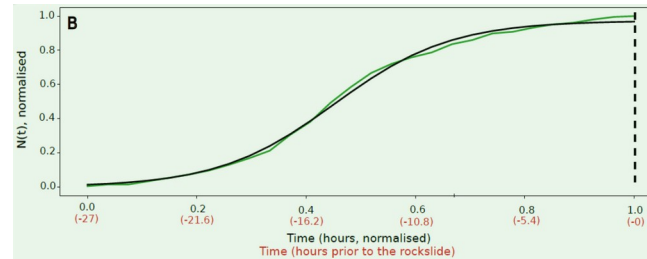


What
Where
When
(Why)

But: no model

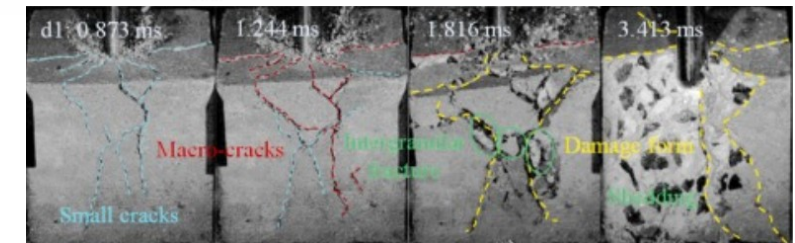
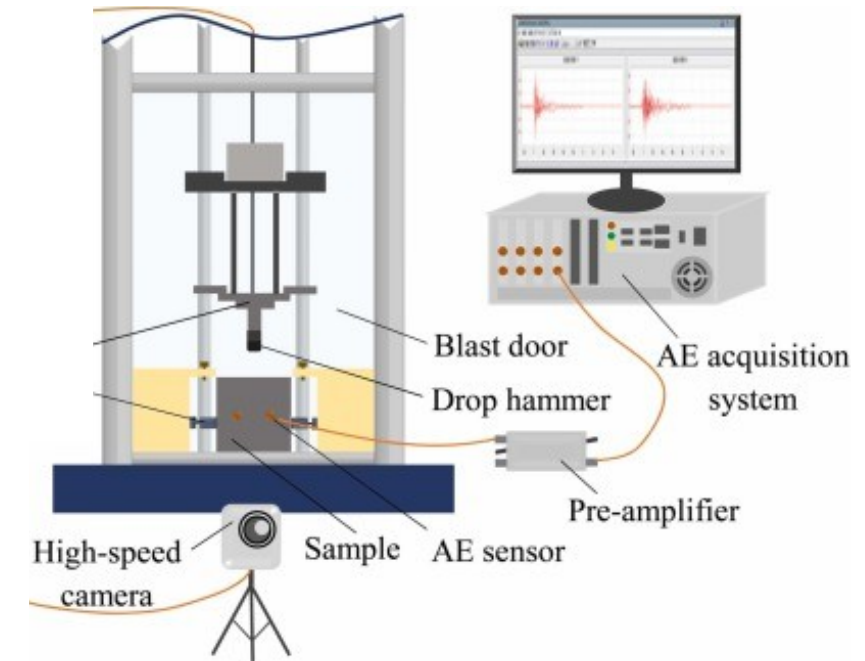
Or the other way around: the reaction of rock to stress

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



What
Where
When
Why

But: no model



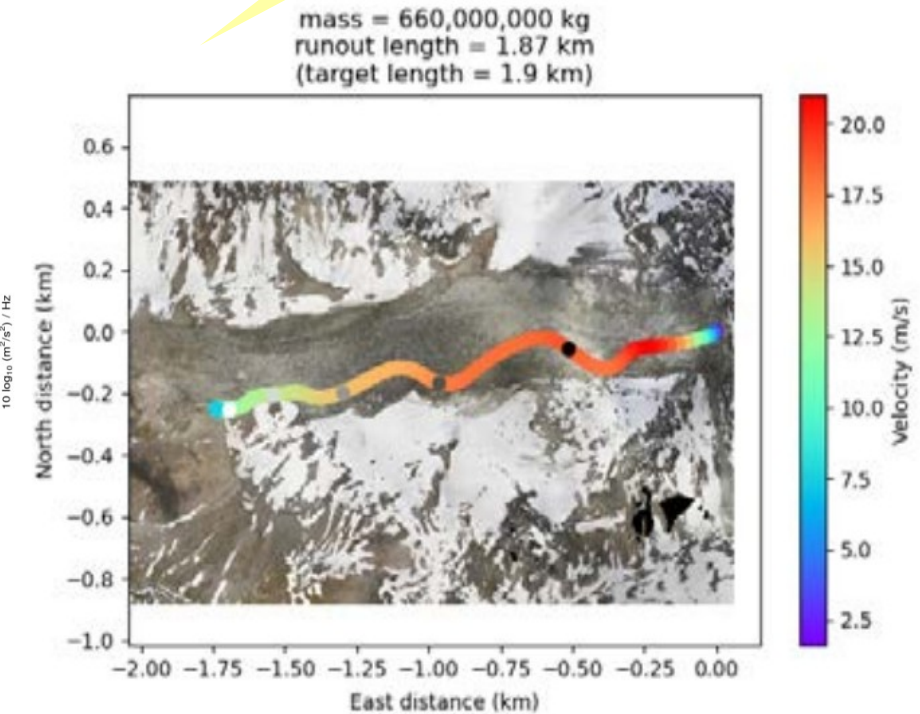
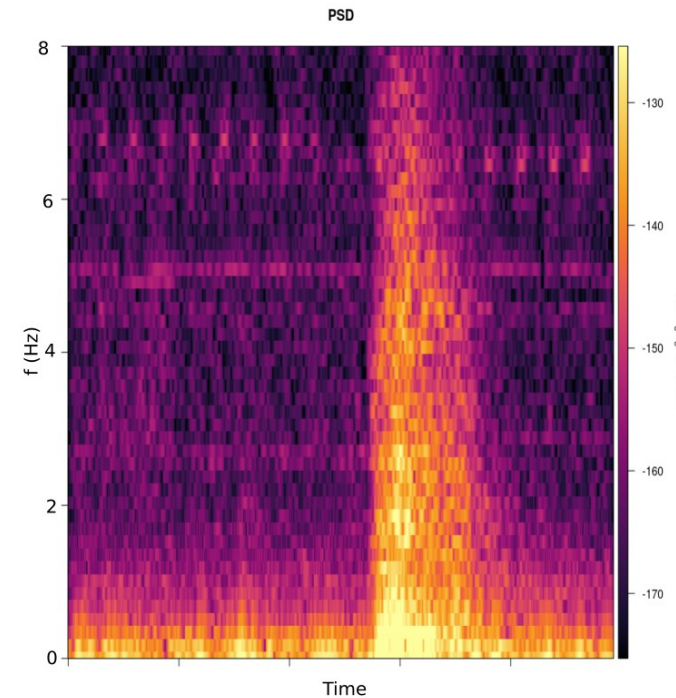
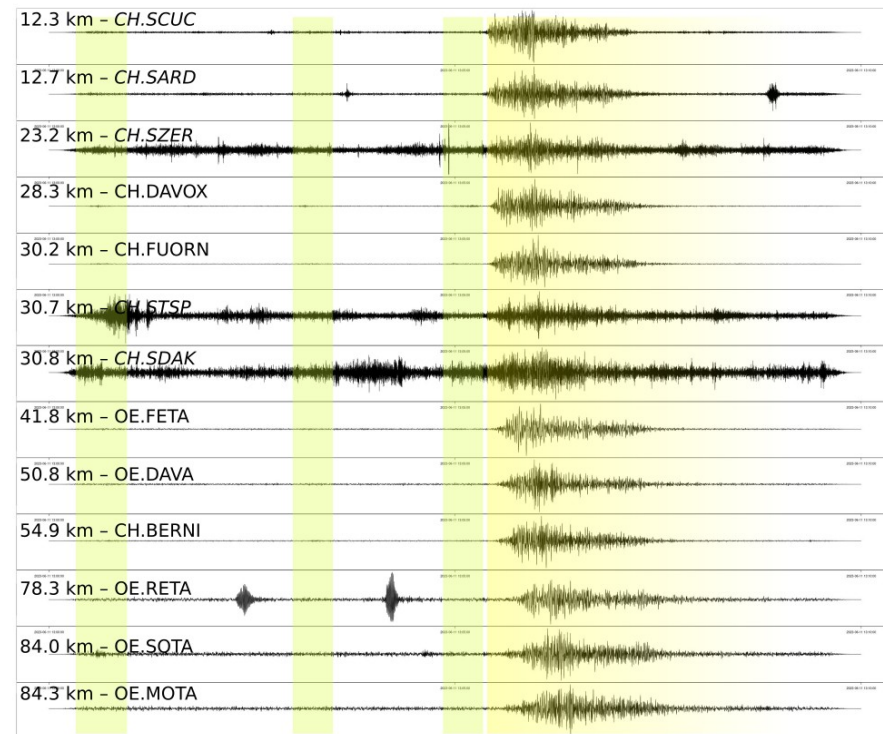
The action of gravity... Example A: large volume mass wasting events

11.06.23
15:05:17
144 s
 10^6 m^3 rock

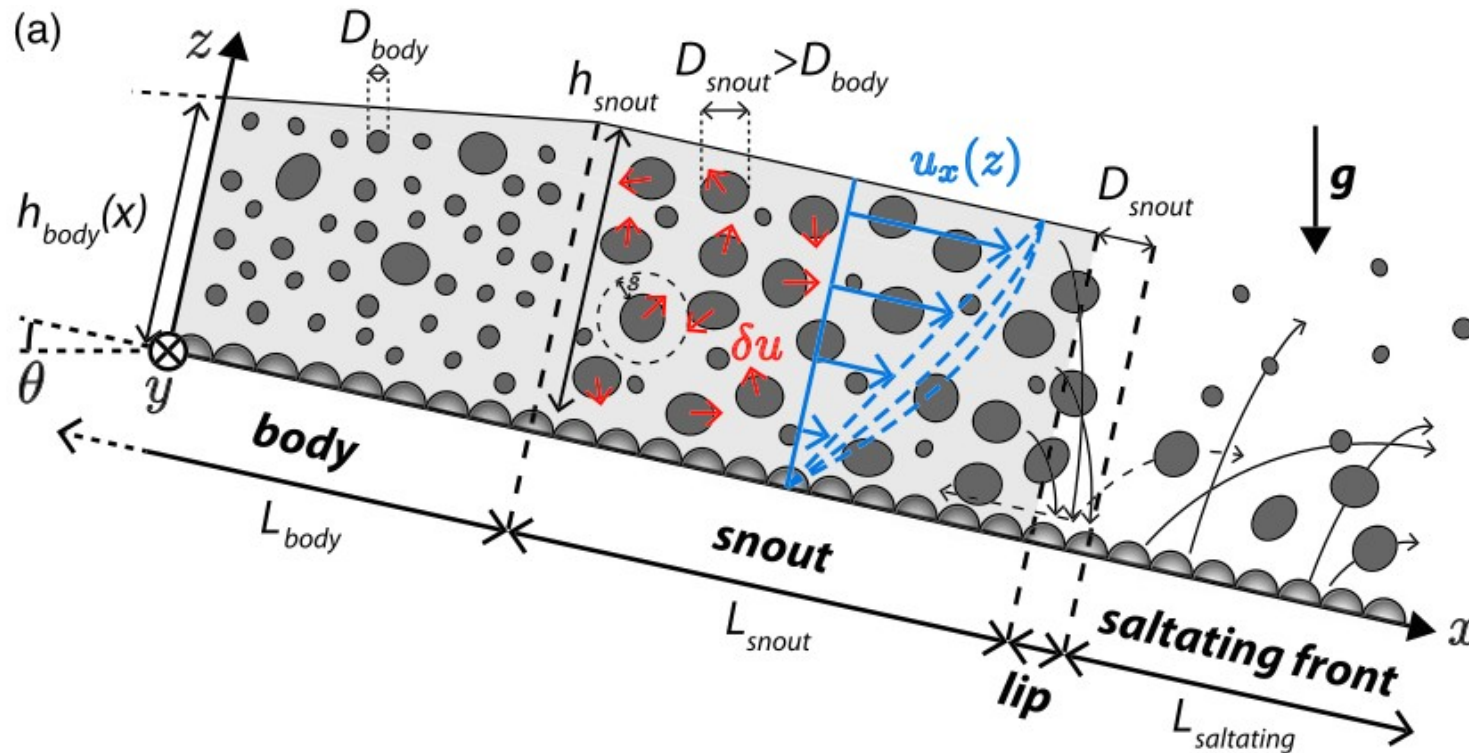
The action of gravity... Example A: large volume mass wasting events

Time-force vector, i.e.:

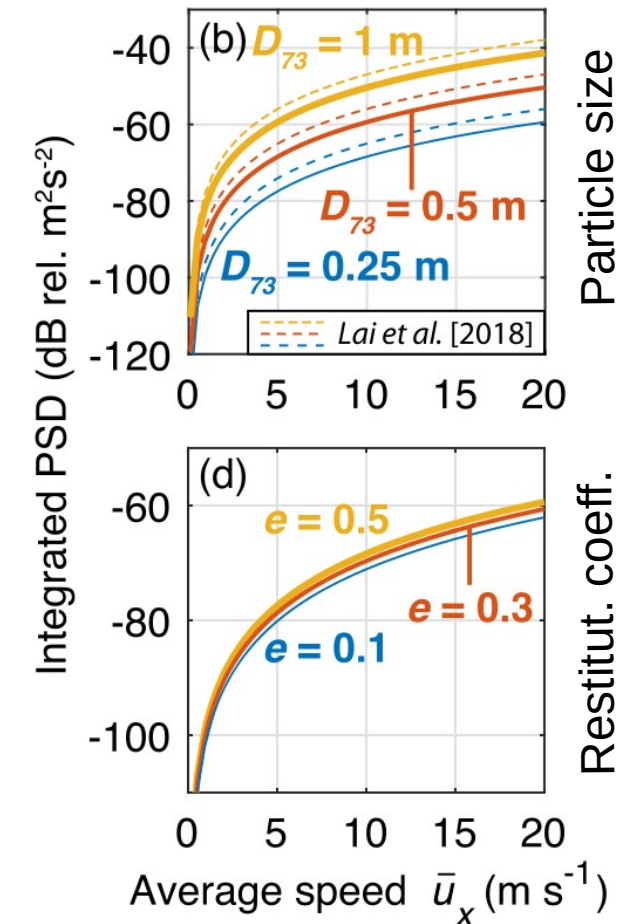
- How much mass
- Along which trajectory
- With which velocity



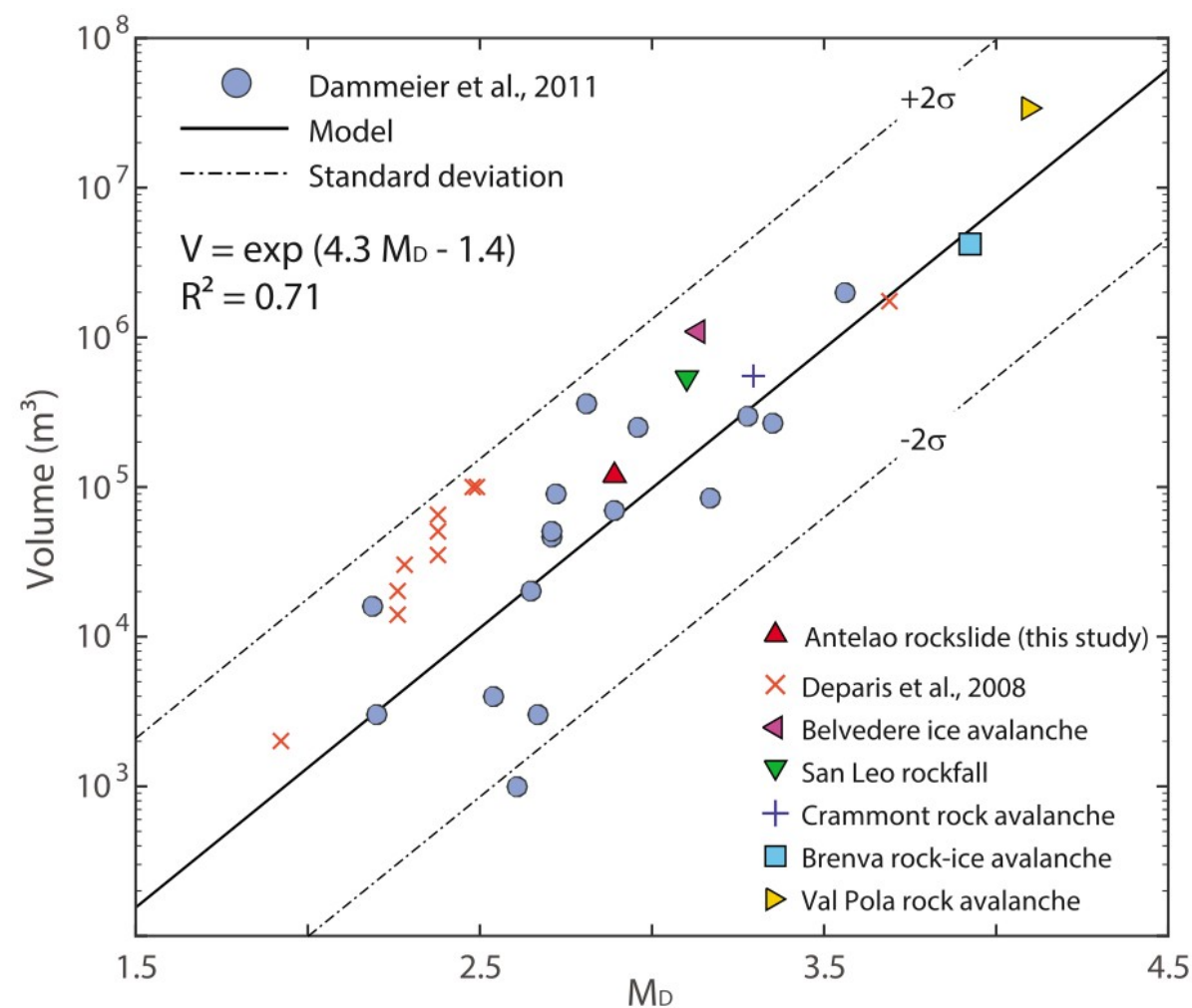
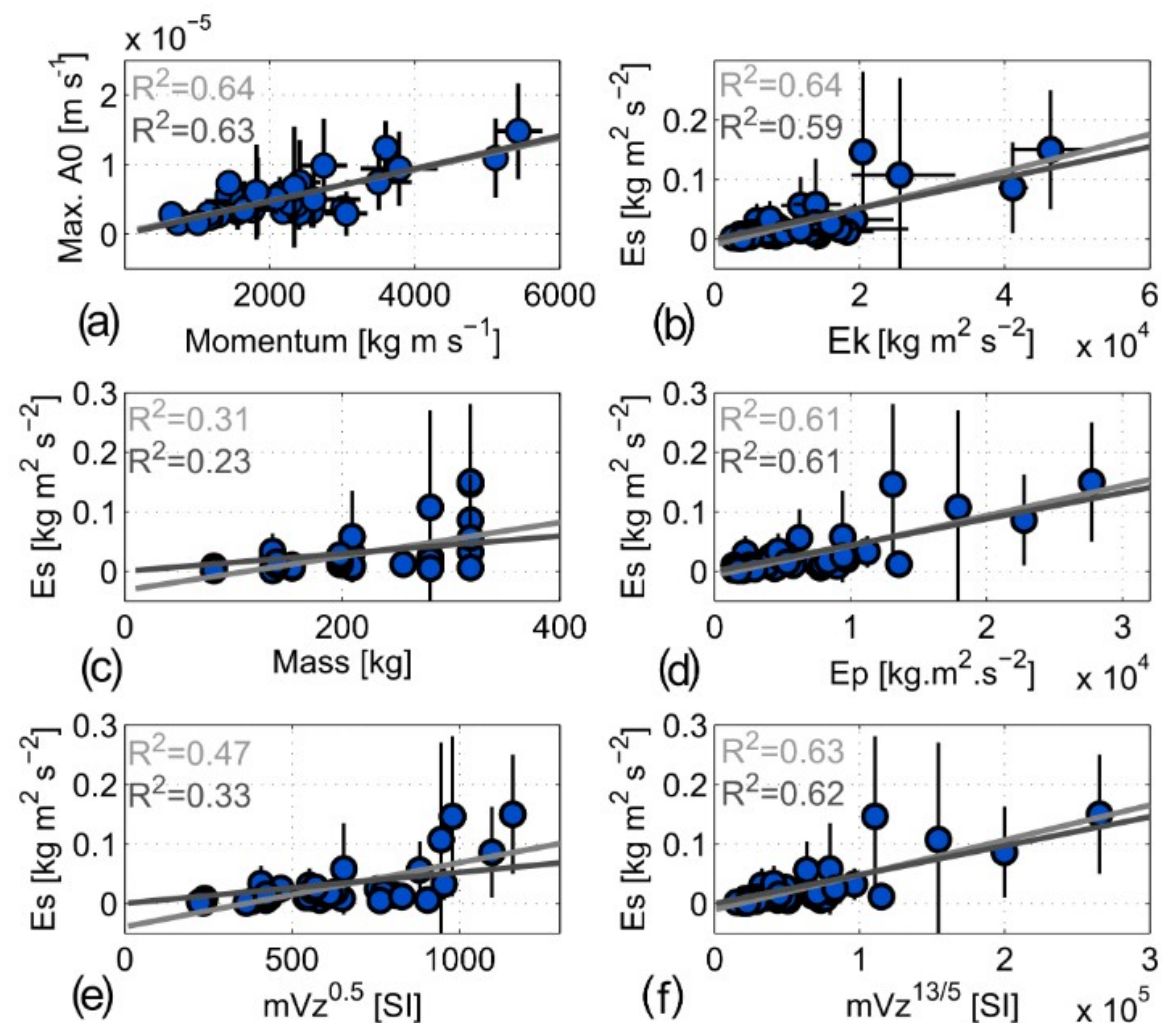
The action of gravity... Example B: debris flow-like granular systems



$$PSD(f, r_0, t, D) = R_{\text{impact}} W \frac{\pi^2 (1 + e_b)^2 m^2 \bar{u}_x^2 f^3}{4 \rho_0^2 v_c^3 v_u^2} N_{jz}^2 f_j^2 \chi(r_0, f).$$

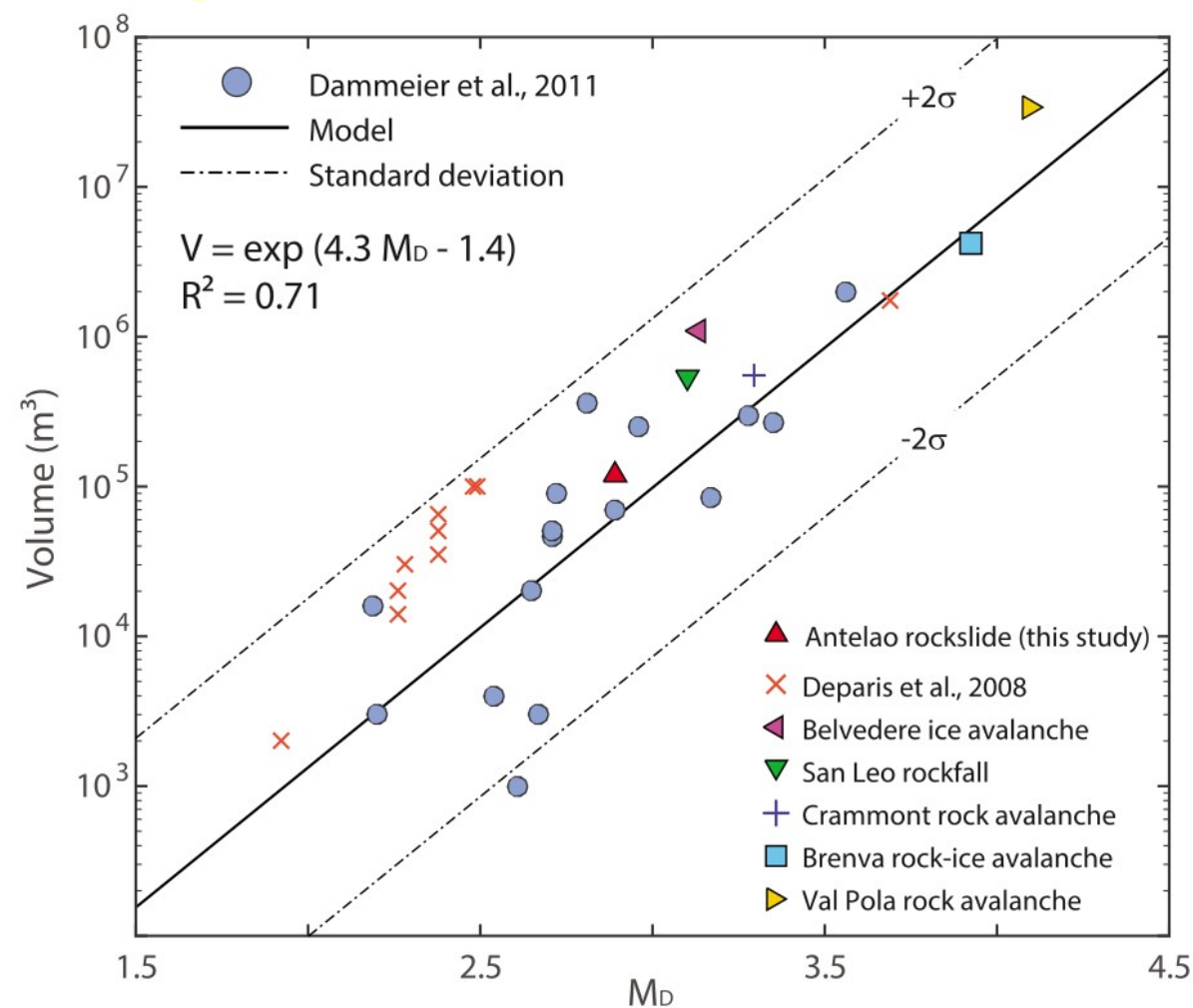
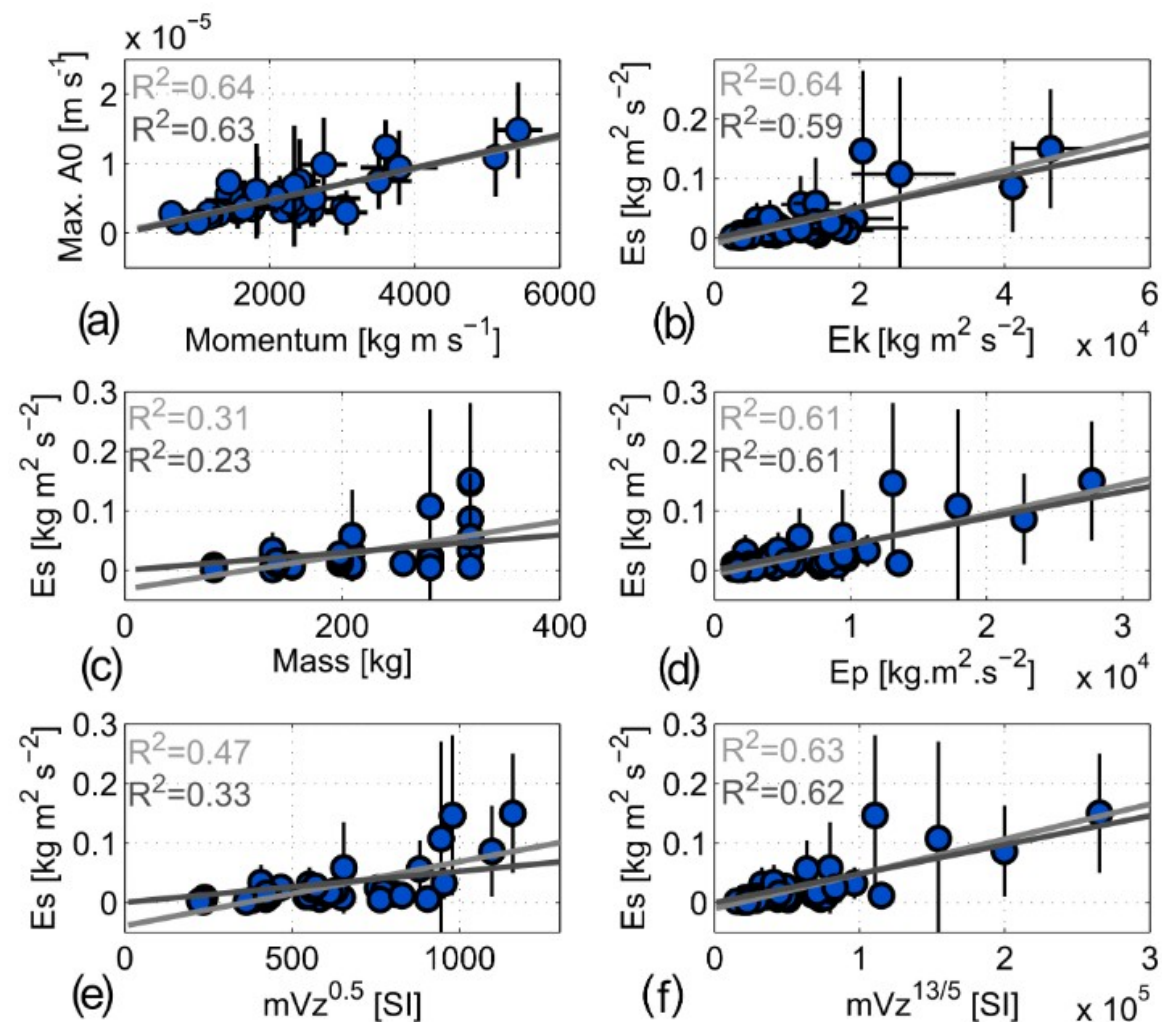


The action of gravity... Processes in between



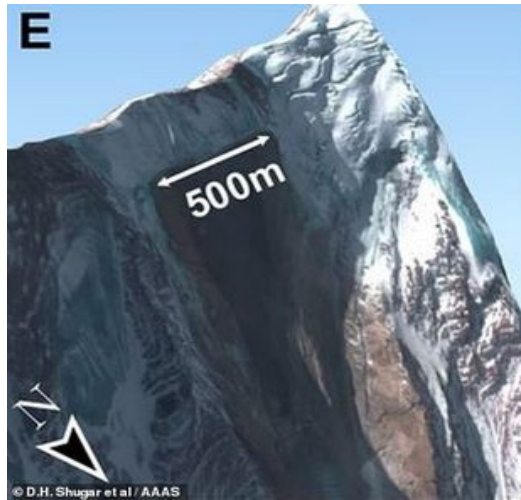
The action of gravity... Processes in between

"Only" correlative understanding

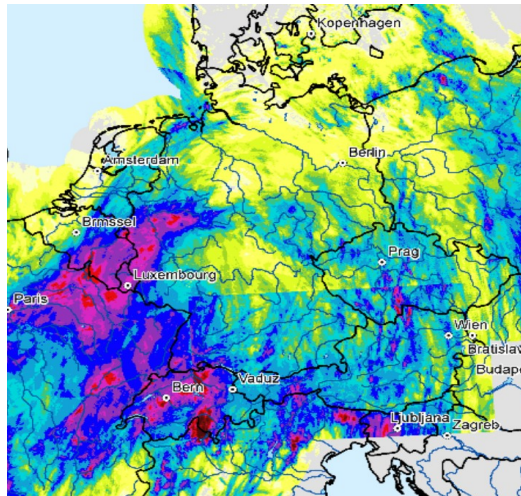


The consequences of flowing water (2021)

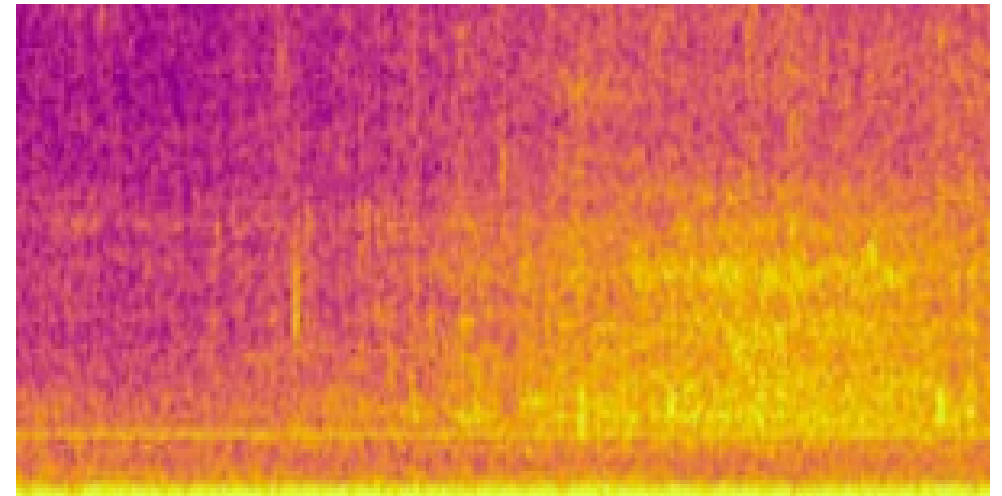
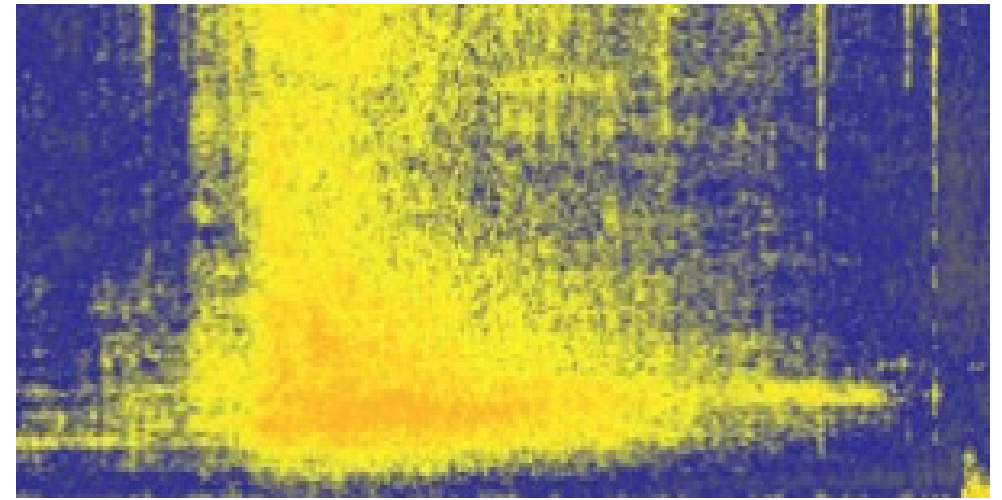
The causes



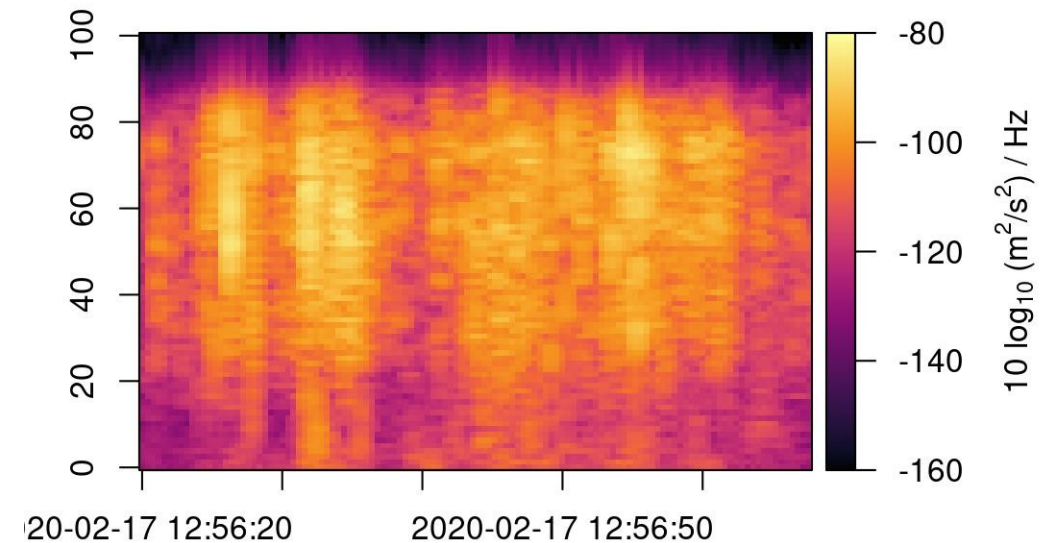
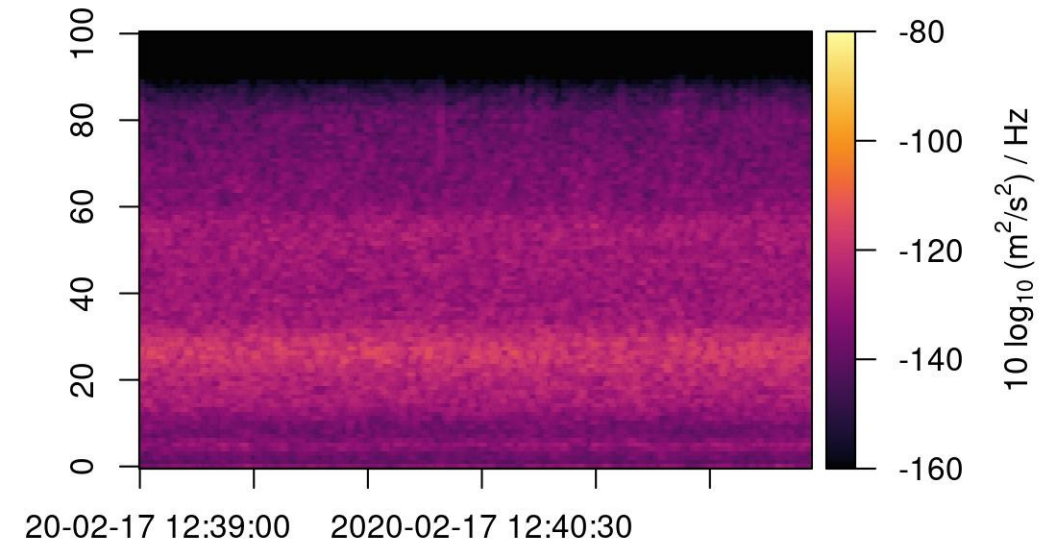
The consequences



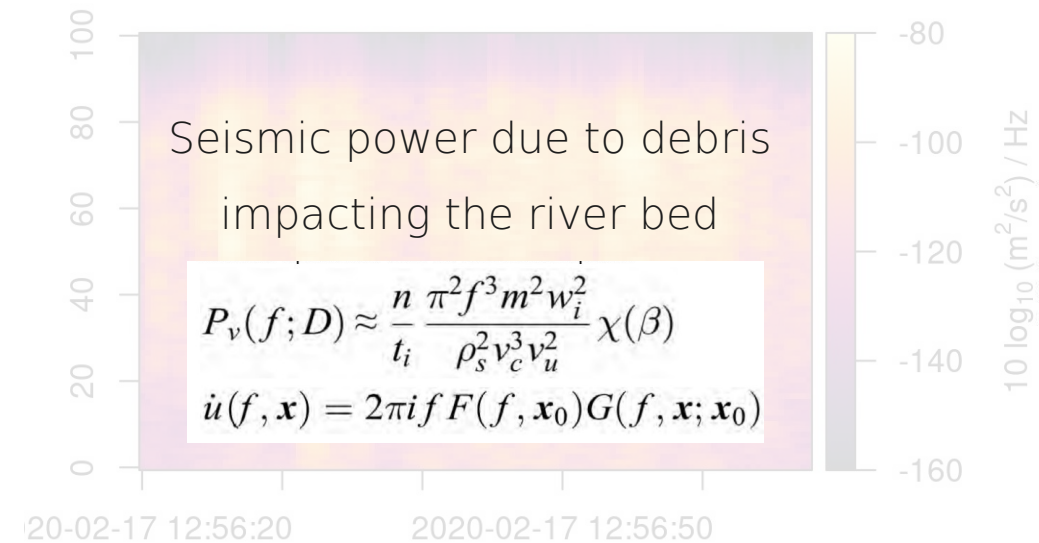
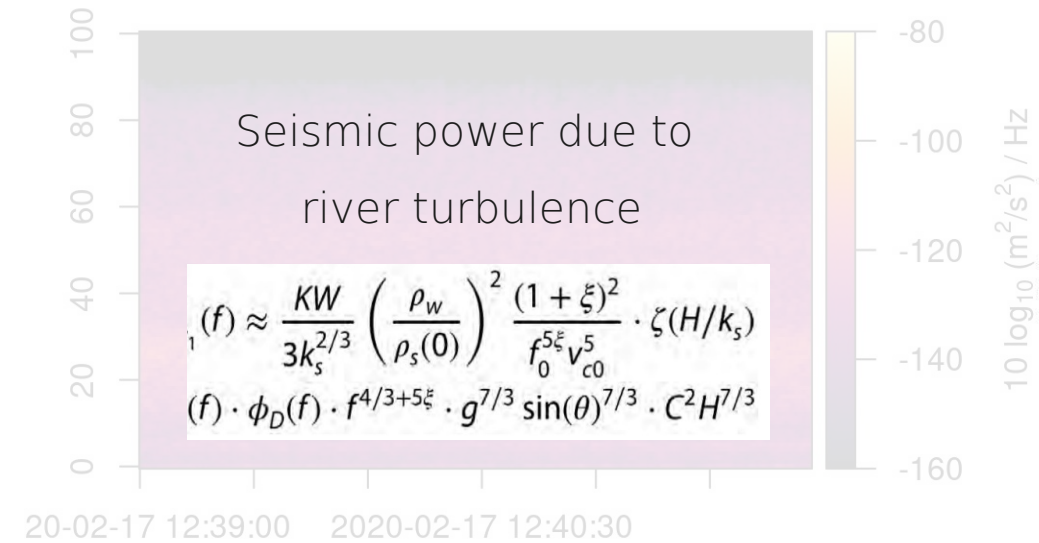
The seismic imprints (0.5–10 Hz, 2 vs. 1 h duration)



Water moving sediment, probing the hidden dynamics



Water moving sediment, probing the hidden dynamics



Water moving sediment, probing the hidden dynamics

```

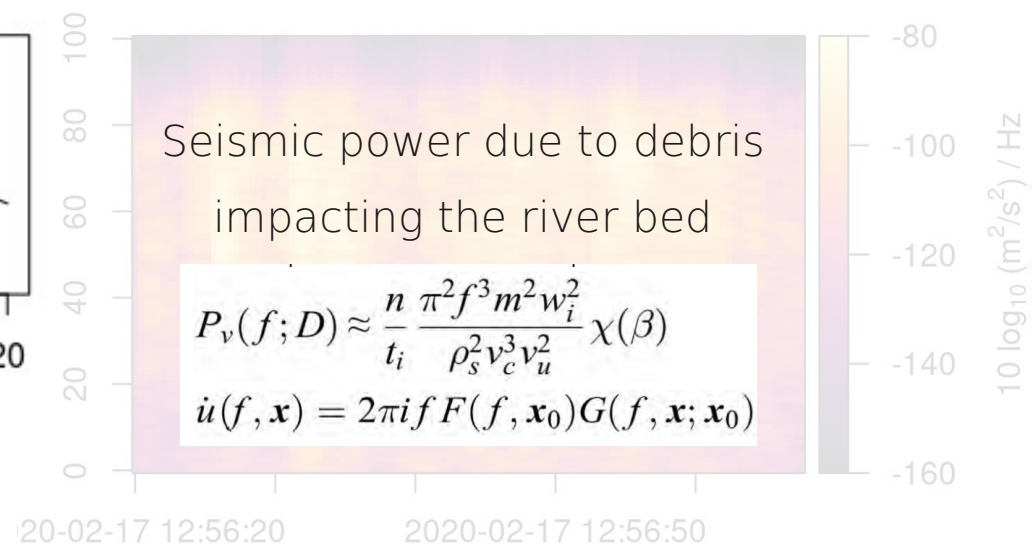
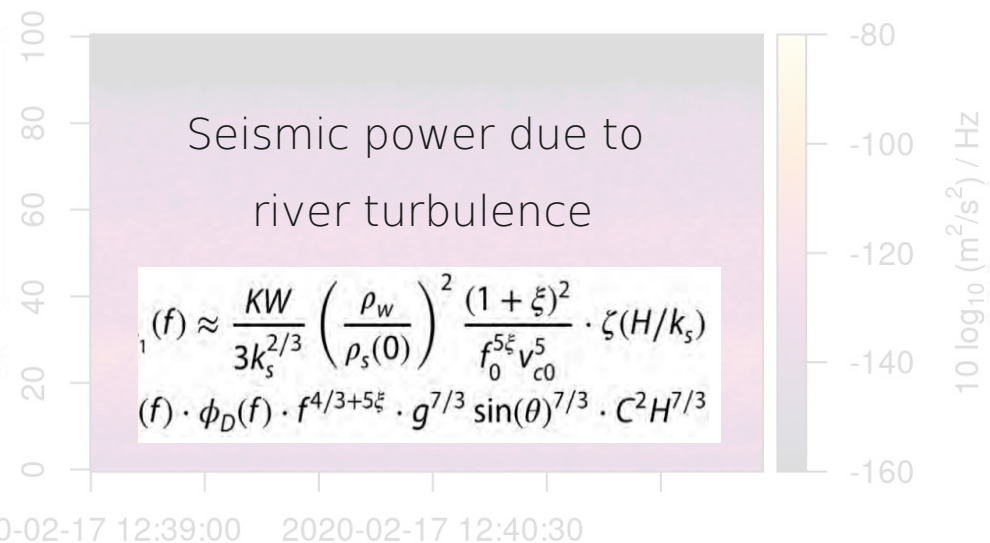
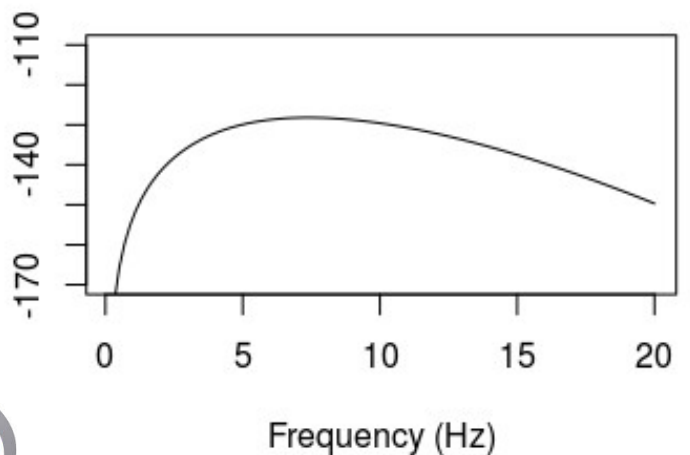
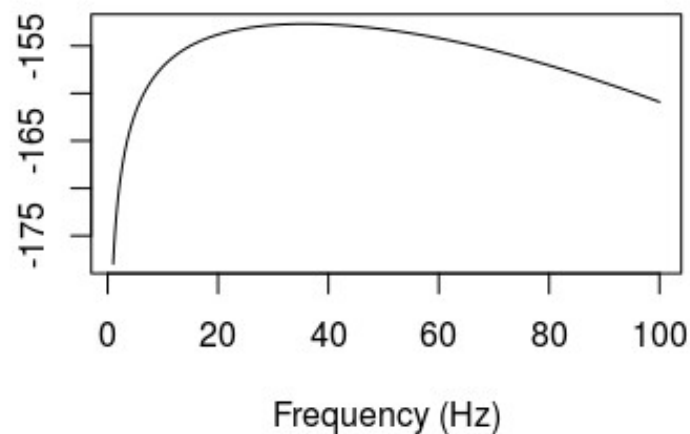
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  s_s = 1.35,
  r_s = 2650,
  h_w = 0.8,
  w_w = 40,
  a_w = 0.0075,
  f = c(1, 100),
  r_0 = 10,
  f_0 = 1,
  q_0 = 10,
  v_0 = 2175,
  p_0 = 0.48,
  n_0 = c(0.6, 0.8))

```

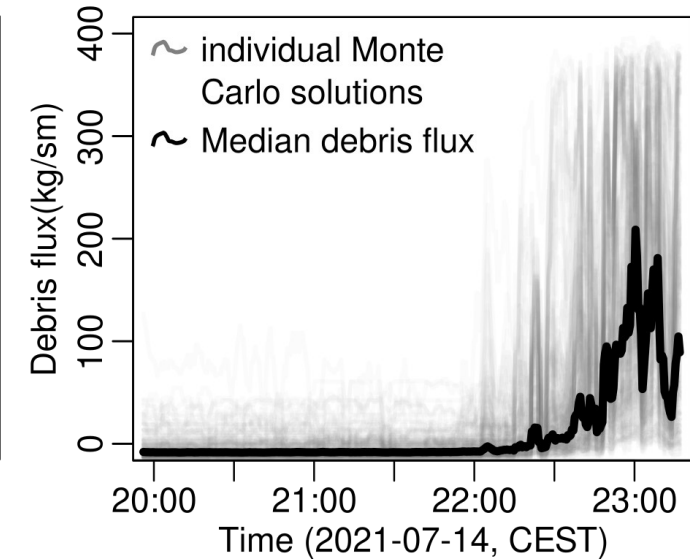
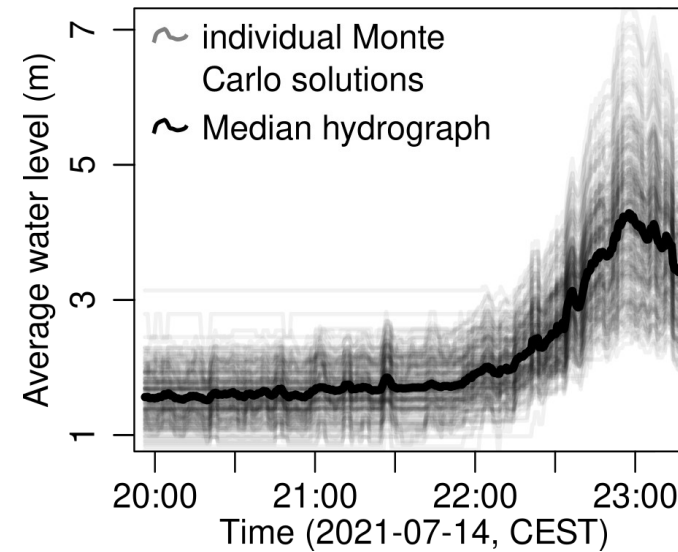
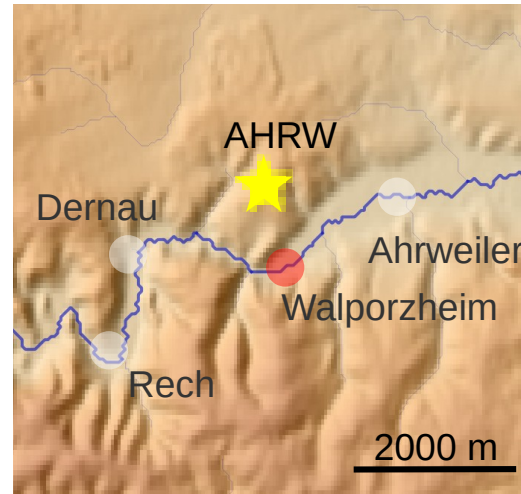
```

model_bedload(d_s = 0.7,
  s_s = 0.1,
  r_s = 2650,
  q_s = 0.001,
  h_w = 4,
  w_w = 50,
  a_w = 0.005,
  f = c(0.1, 20),
  r_0 = 600,
  f_0 = 1,
  q_0 = 20,
  e_0 = 0,
  v_0 = 1295)

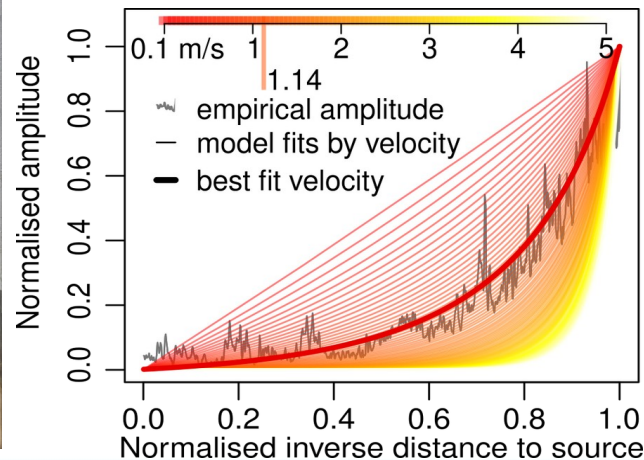
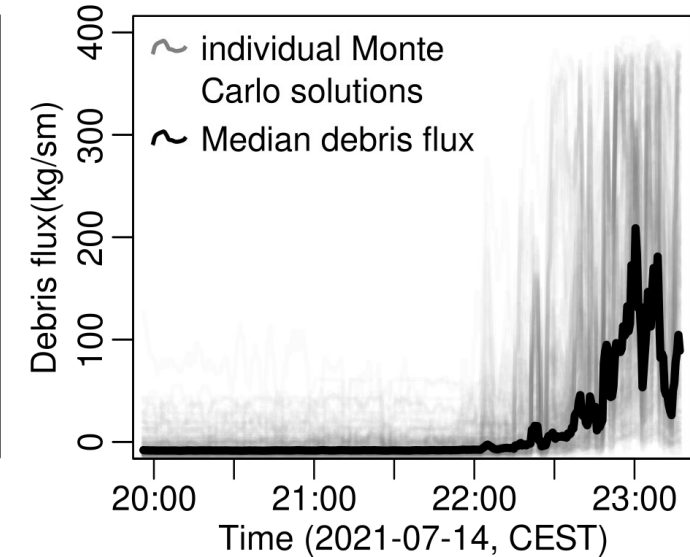
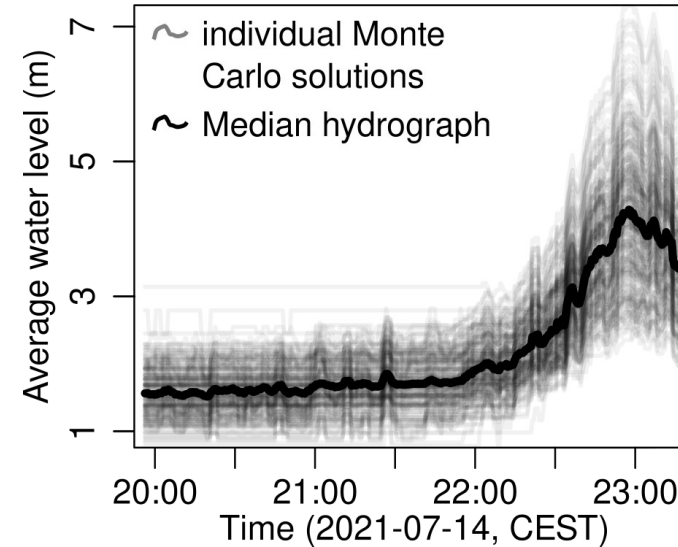
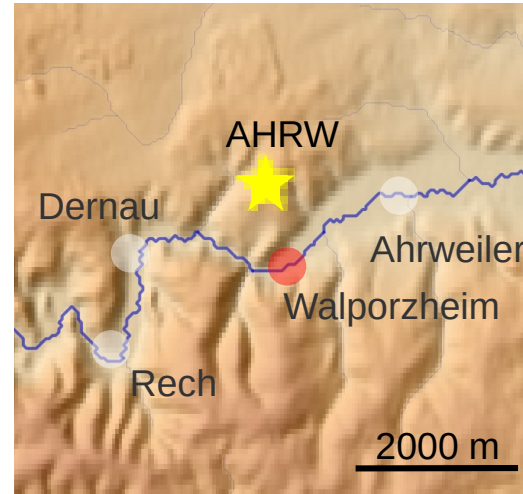
```



Water moving sediment debris, an example from the Ahr Valley (2021)



Water moving sediment debris, an example from the Ahr Valley (2021)



Seismic amplitude as function
of distance

$$A_i(R) \approx \frac{S_{\text{flow}}}{\sqrt{R}} \times \exp\left(\frac{\pi f R}{Q_c V}\right)$$

All excellent and fine? Unsolved issues with the approach

Particles & obstacles

Process

Shortcomings & Unknowns

- 1a) Models operate with *parametric* (unimodal) grain size distribution
- 1b) *Bed and mobile* fraction are treated Identical in models
- 1c) *Obstacles* change hydraulic geometry (Nativ et al., 2025)

Wave representation

Ground architecture

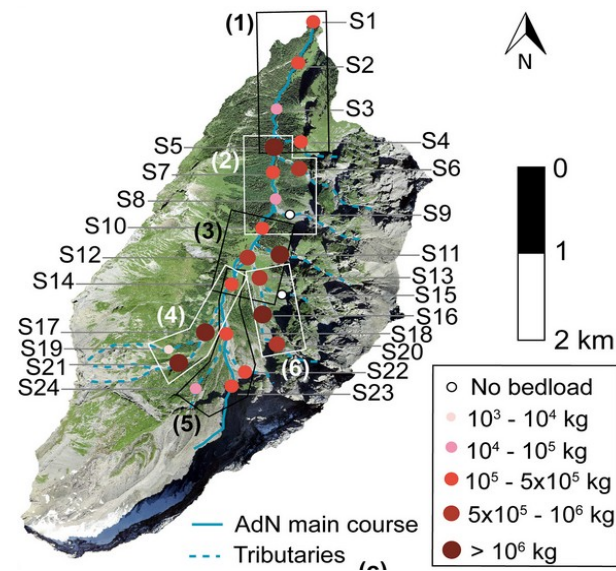
- 2) *Modes of bedload transport* based on saltation, only (n.b. Gimbert et al. (2018) modify towards other processes to some extent)
- 3) Depth-dependent attenuation of Rayleigh wave *particle motion* not accounted for (see rain model)
- 4) Very simplistic, time-invariant ground property representation (*Greens function*)

Why carrying on?

Look below ice & at episodic events

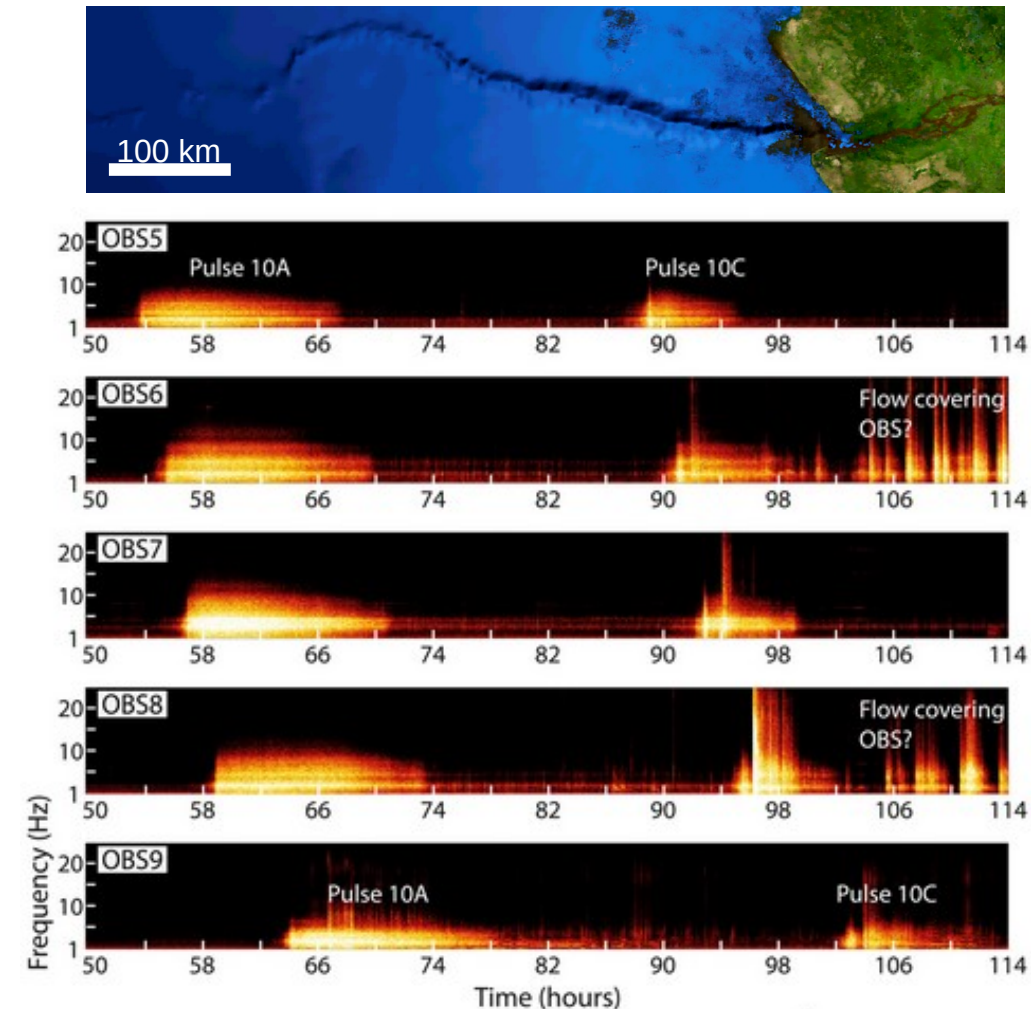


Catchment-wide process propagation

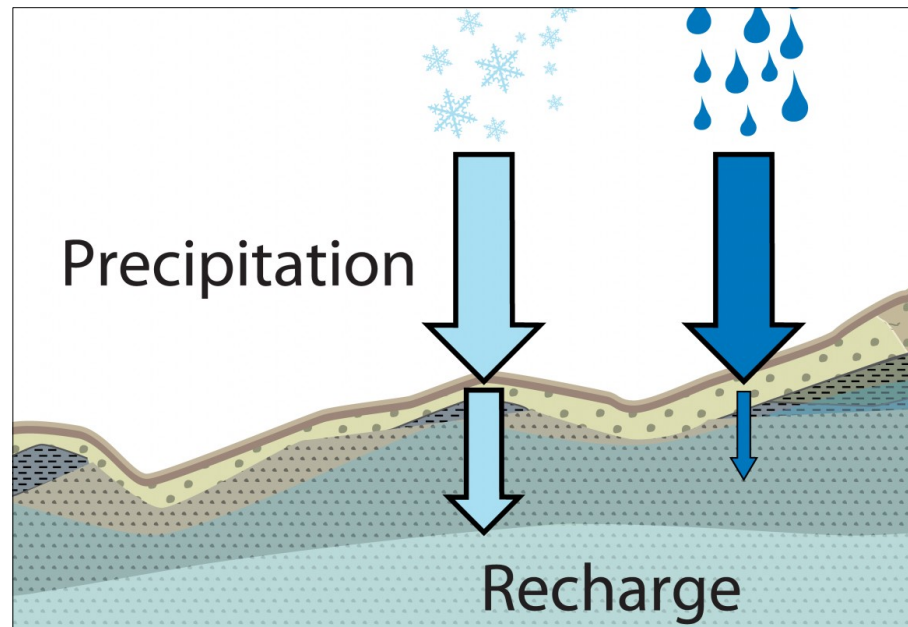


Quantify biogeomorphic effects

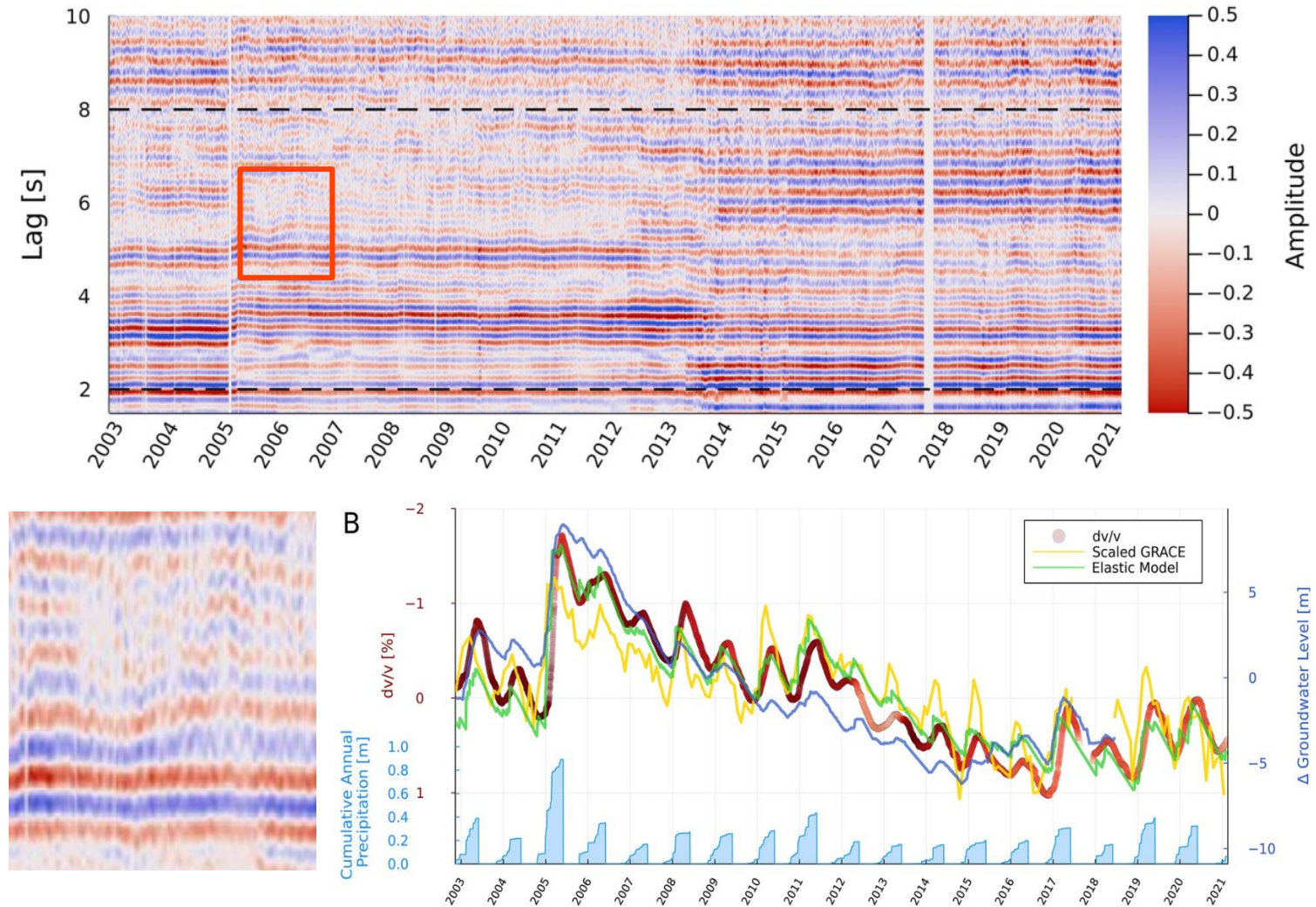
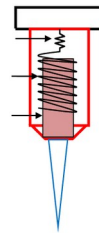
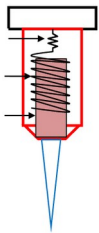
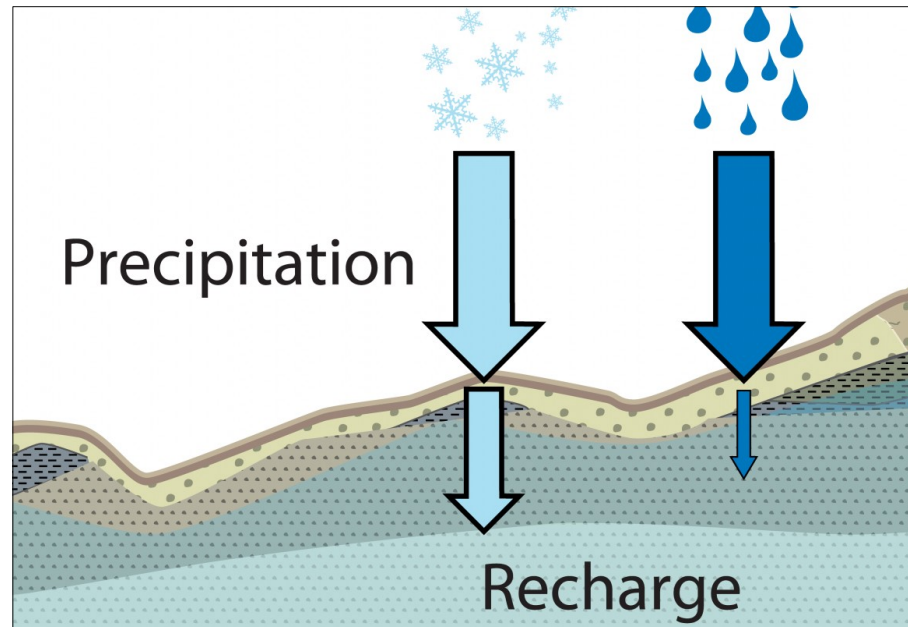
Beyond-continent fluxes of mass & carbon



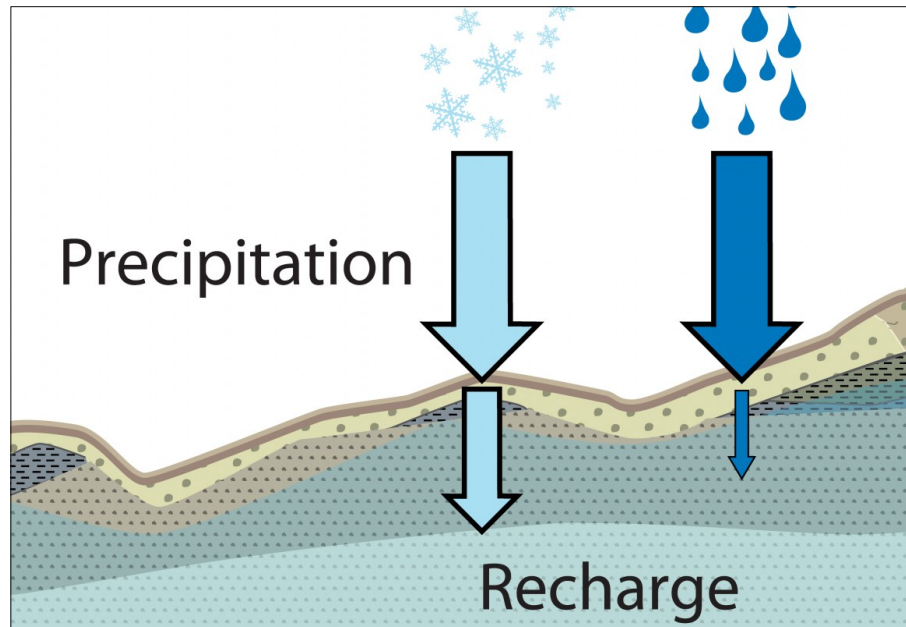
Water below our feet



Water below our feet



Water below our feet



$$\Delta h(t) = \sum_{i=0}^n \frac{P_i}{\phi} e^{(-a(t-t_i))}$$

GW discharge

$$P(z, t) = \frac{B(1 + \nu_u)}{3(1 - \nu_u)}$$

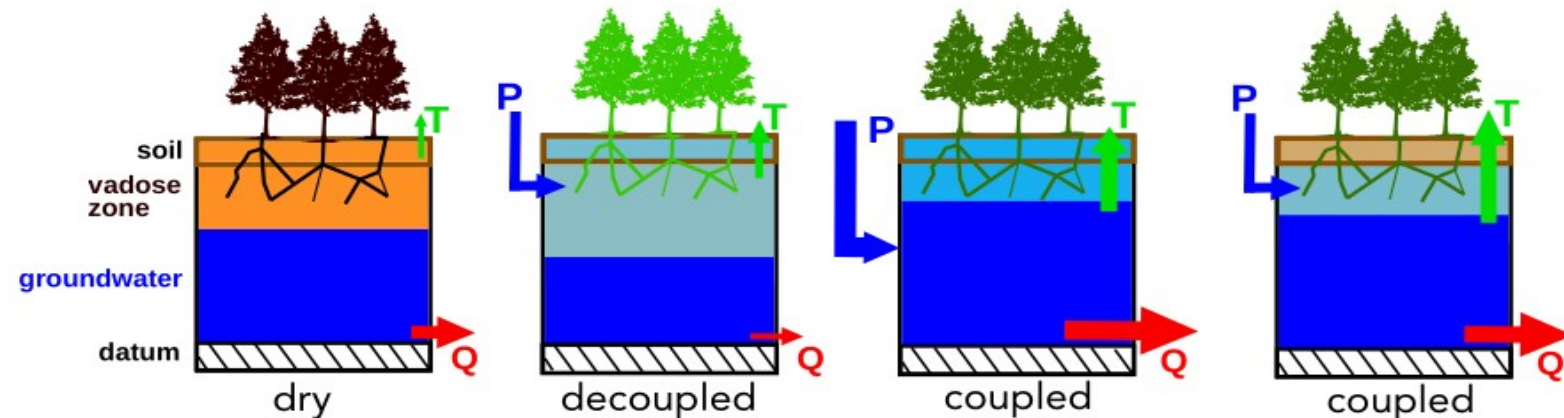
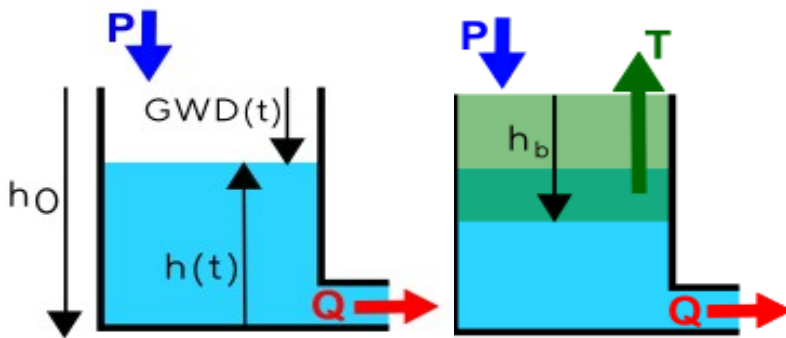
Poroelastic load effect

$$\sigma_{ij} - \frac{\nu}{1 + \nu} \sigma_{kk} \delta_{ij} = 2G \epsilon_{ij}$$

Hydr. head & pore pressure

$$CDM_{ik} = \sum_{j=1}^i P_i - \bar{P}_{ik}$$

K days rain deficit reaction



Water below our feet ... but not as deep as groundwater



Post-fire landscape evolution – insights from passive seismic monitoring of atmosphere-weathering zone coupling at the Quesenbank succession site, Harz mountains, Germany

UNIVERSITÄT
GÖTTINGEN

Michael Dietze^{1,2,3}, Laura Rossana Fracica Gonzalez^{1,3}, Elisabeth Dietze¹

1. Institute of Geography, Georg-August-University Göttingen, Göttingen, Germany; 2. Helmholtz Center, German Research Center for Geosciences GFZ, Potsdam, Germany; 3. RWTH Aachen University, Aachen, Germany

Introduction



Figure 1. Quesenbank headwater catchment area, severely affected by forest fire.

The Quesenbank site is a headwater catchment in Harz National Park, severely affected by a forest fire in August 2022. The event disrupted the area's hydrological and ecological balance, with most bark beetle-killed trees burned or weakened, leading to widespread collapse shortly after. While typical post-fire effects like increased runoff and soil erosion were expected, initial observations revealed only weak

The research questions of the study are:

- 1) How does post-fire soil moisture change observed through a seismic approach?
- 2) What can seismic ground motion tell us about the coupling between atmosphere, biosphere and geosphere environment?

- 3) How can environmental seismology add insights into the subsurface water dynamics in this area?

Posters by
Laura Fracica Gonzalez

MON082 & MON083

Findings



Environmental seismology

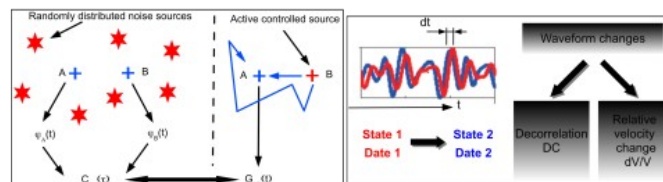


Figure 2. Diagrams explaining the concept of obtaining dv/v. Source: (Larose et al., 2015).

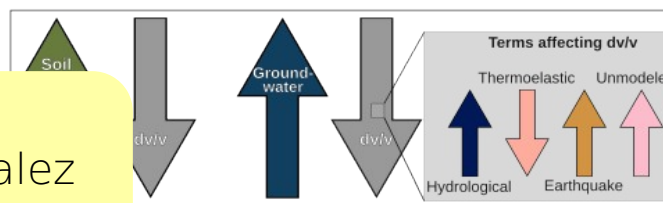
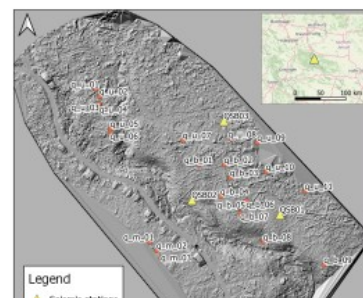


Figure 3. General relation between soil moisture and dv, and groundwater and dv/v. The effects of environmental and tectonic factors affecting dv/v. Sources: (Larose et al., 2023; Dietze et al., 2020)

Data collection



Seismic stations



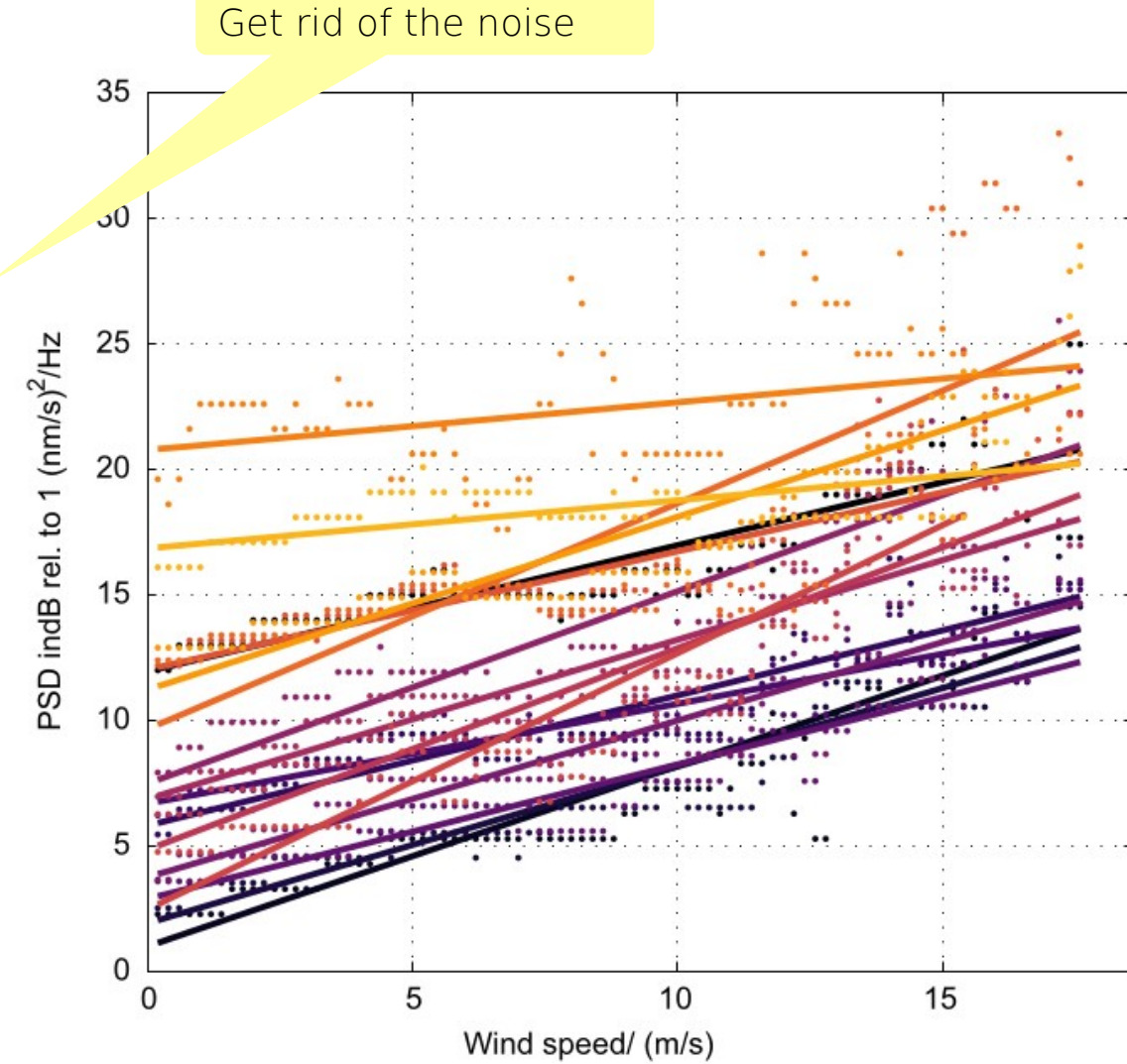
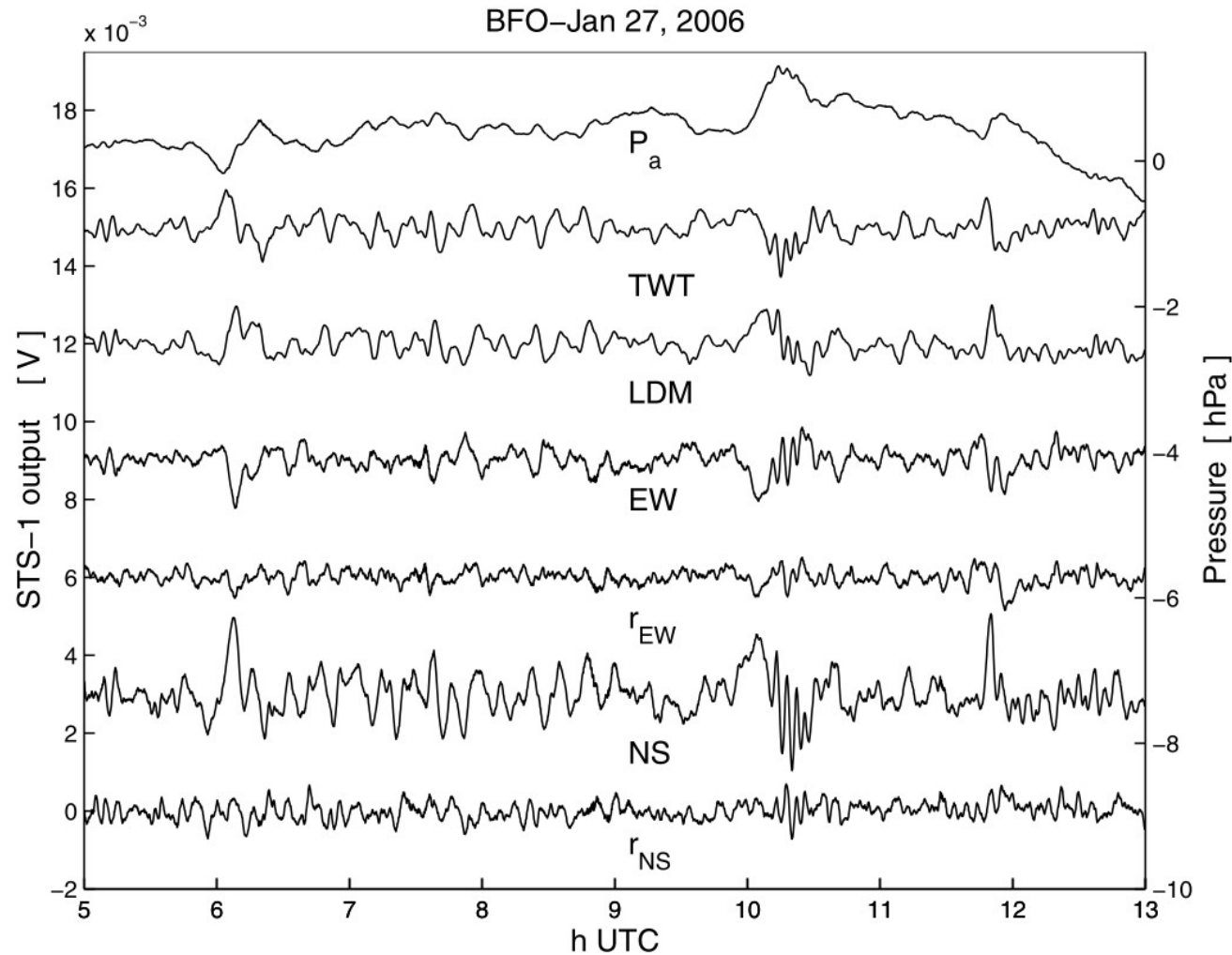
Soil moisture data loggers



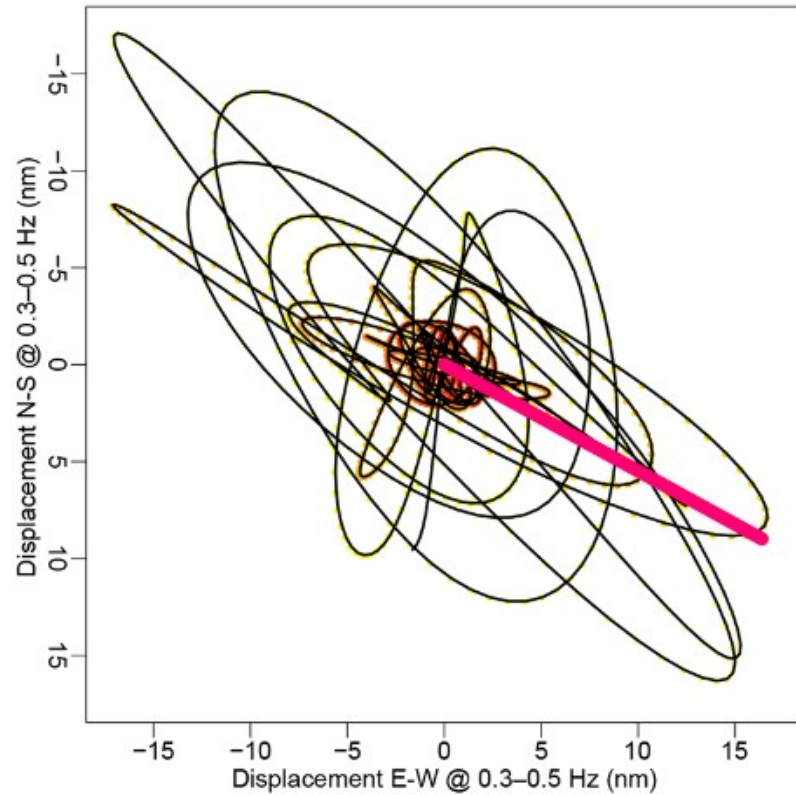
(What)
(Where)
When
(Why)

But: no model
And: simplified
approaches

Air pressure systems ... and wind effects

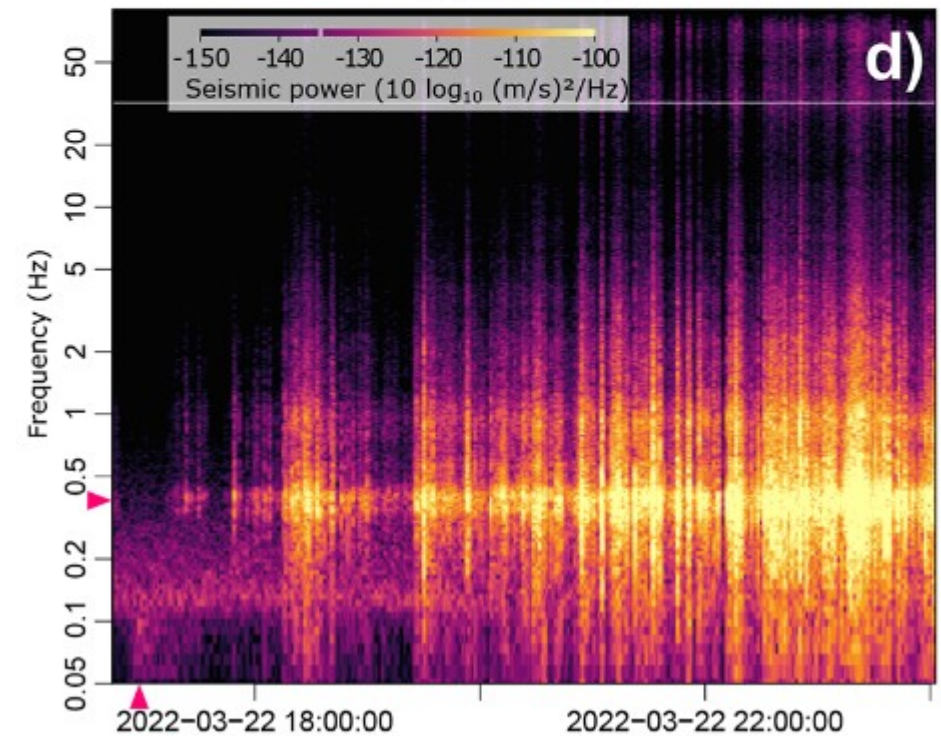
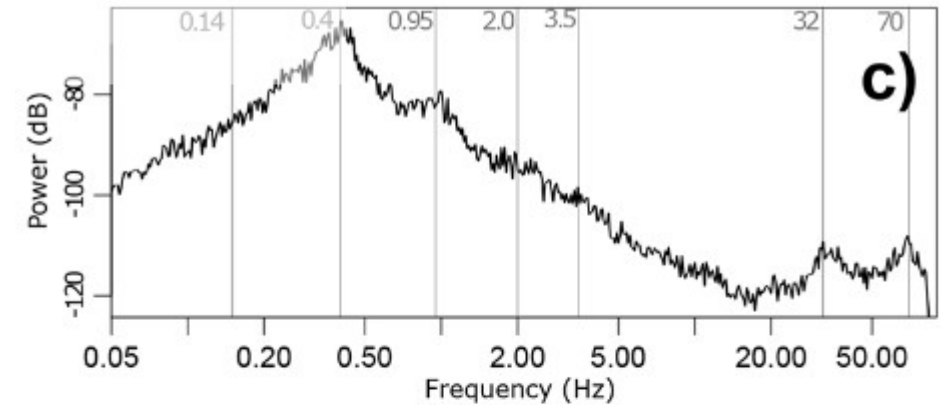
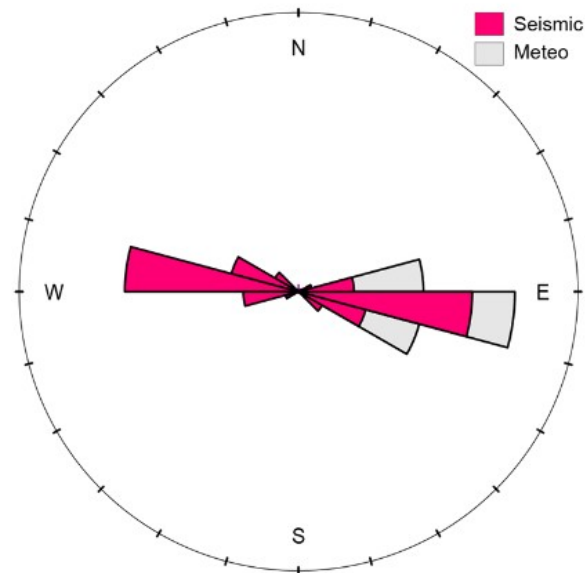


Wind interacting with the biosphere

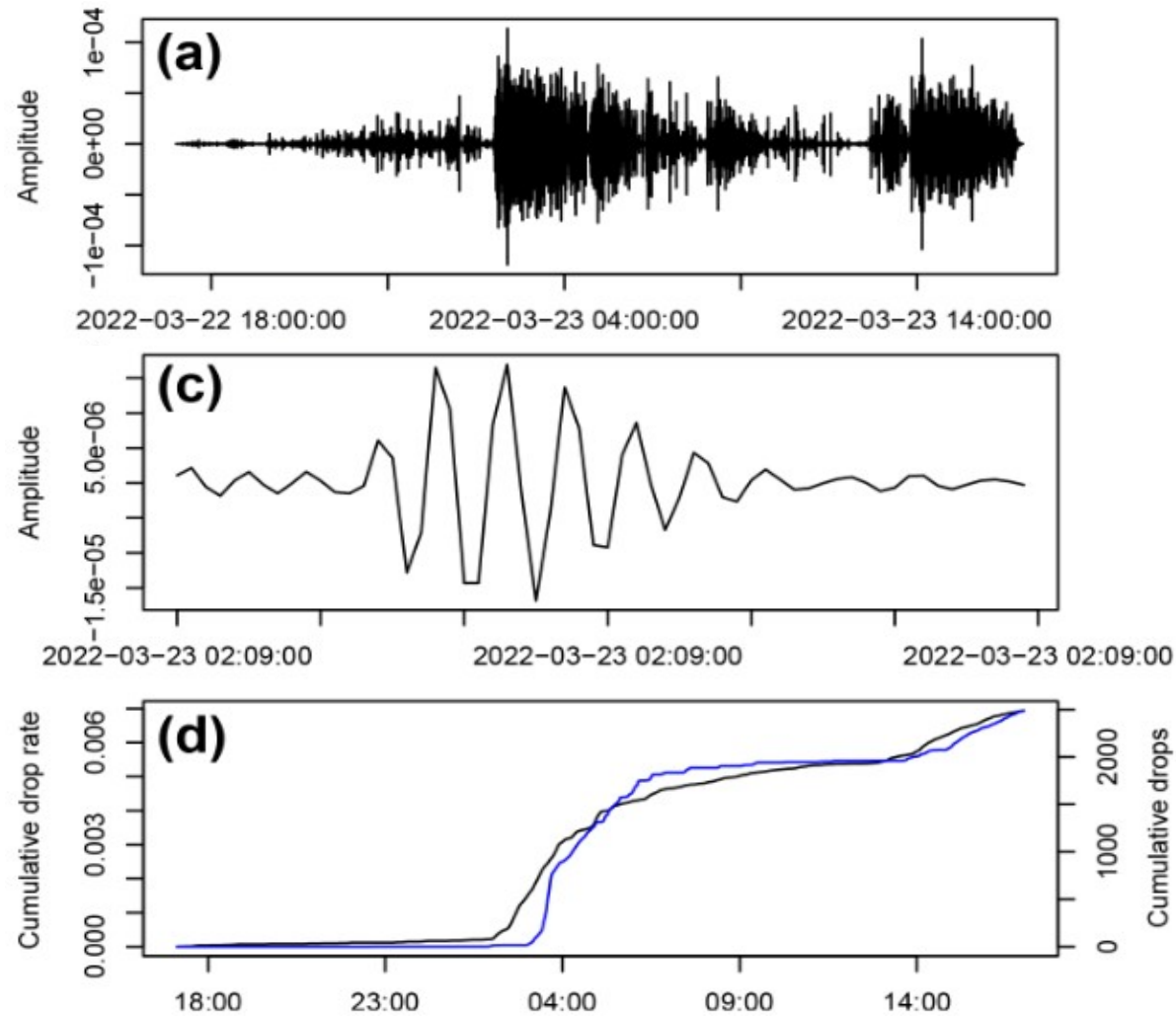


What
(Where)
When
(Why)

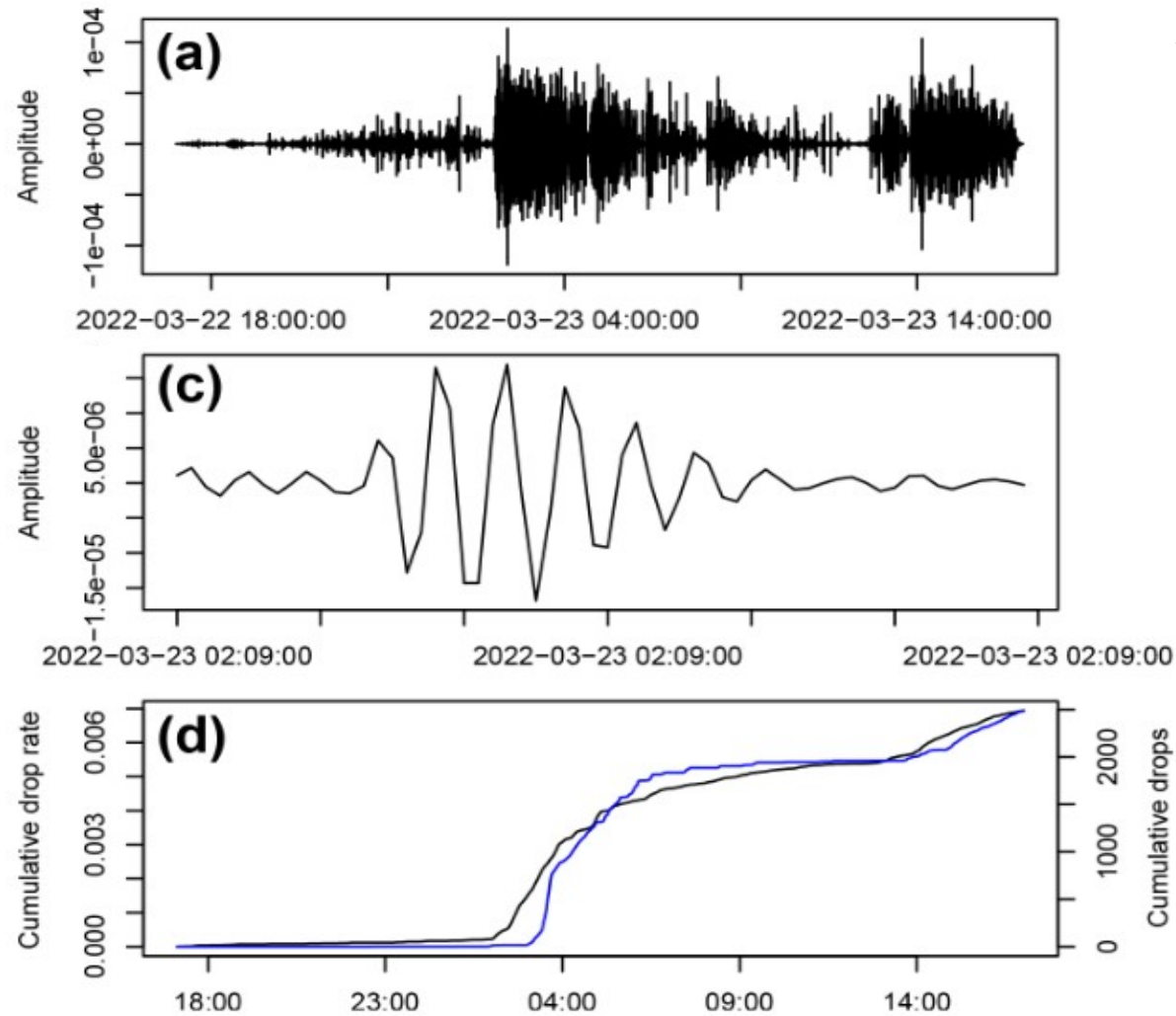
But: no model



Precipitation interacting with the surface



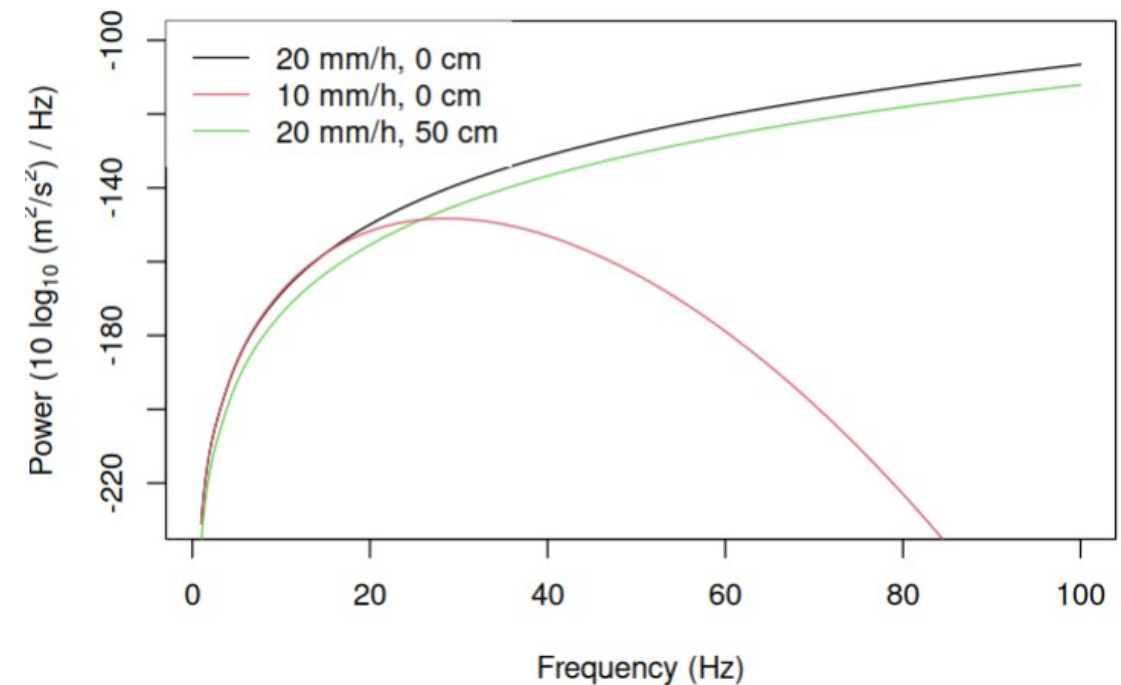
Precipitation interacting with the surface



What
Where
When
Why

$$P(f) = 8\pi^3 f^2 \int_r J_P \tilde{G}^2(f, r) r dr$$

$$J_P = \left(\frac{4}{3} \pi \rho_w \right)^2 \gamma \sum_{i,j} N_{i,j}(D) (0.5 D_i)^6 v_j^2$$



Feeling a bit flattened? Let's recapitulate

For many geomorphically relevant processes there is seismic benchmark experiments, data and expertise available

For some processes there are physical models ready for inversion

For many more processes there are simplistic models, at best

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Real landscapes live from process interaction, instead of isolated processes

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Thanks!

