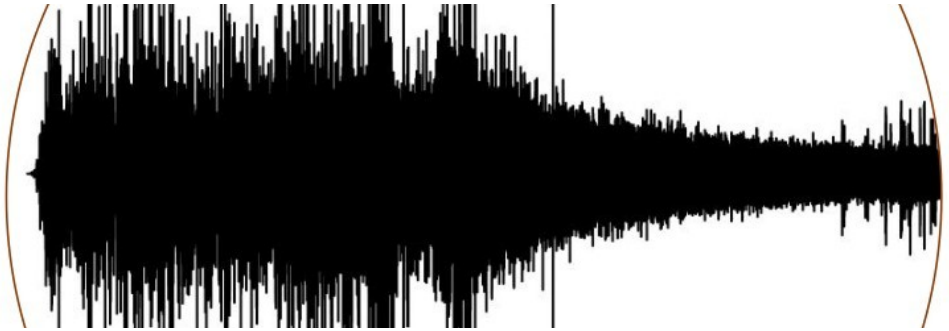


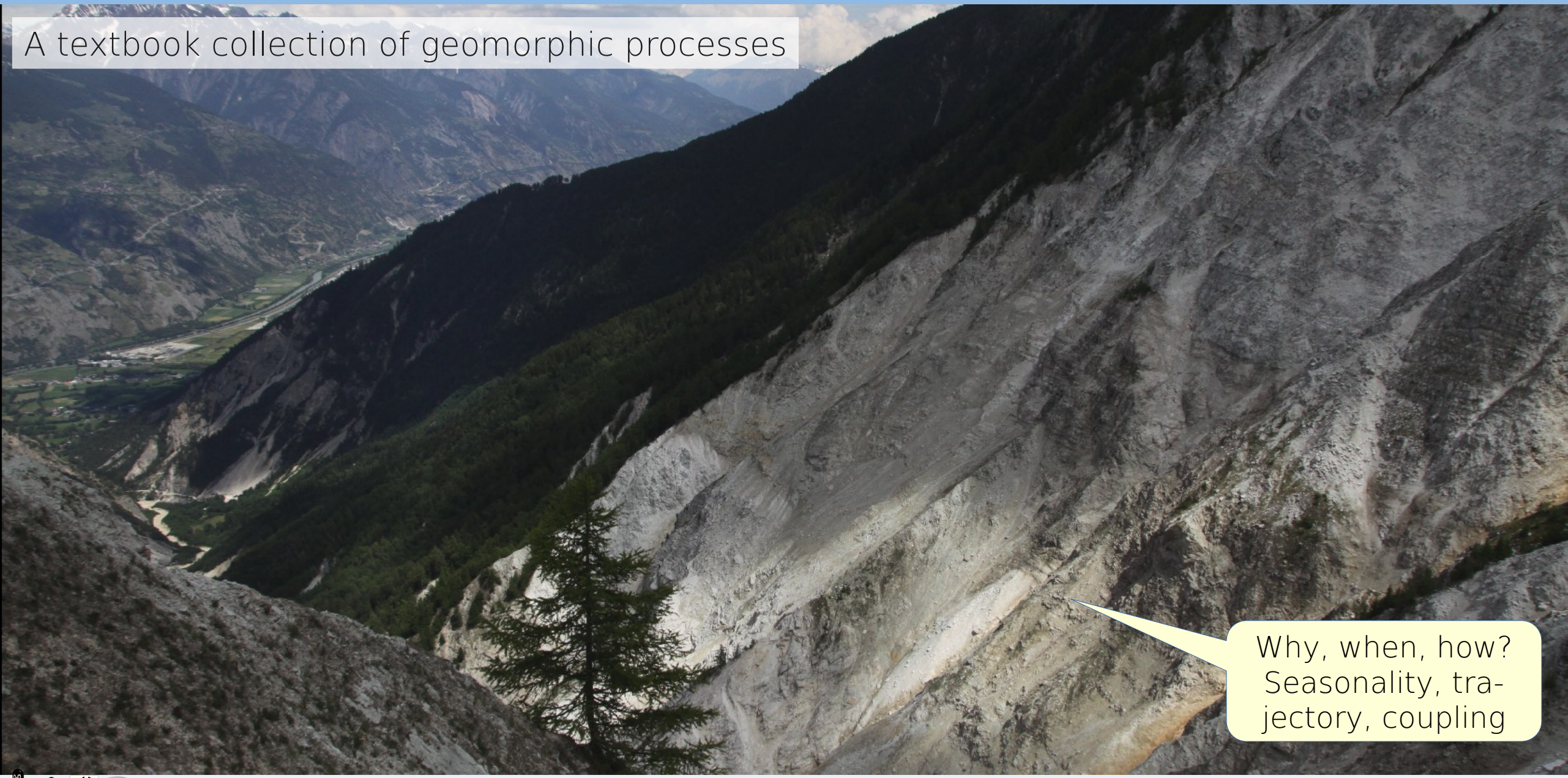

Existing and envisioned Environmental Seismic Models to leverage our understanding of landscape dynamics

Michael Dietze
RWTH Aachen

A textbook collection of geomorphic processes

Uplift = Erosion…
but how?

A textbook collection of geomorphic processes



Illgraben, Switzerland

A textbook collection of geomorphic processes

Ahr Valley, Germany

So…

Processes that happen

distributed in space,

stochastic/episodic in time,

over orders of magnitude

intrinsically coupled & interacting

Sensor systems that

take point-like measurements

(or) yield time-discrete information

usually deliver dedicated metrics

sit in harms way

So…

Processes that happen
distributed in space,
stochastic/episodic in time,
over orders of magnitude
intrinsically coupled & interacting

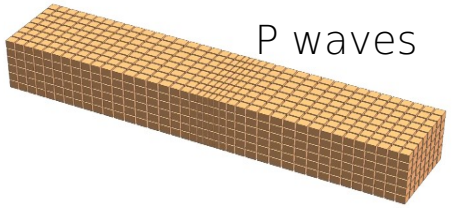
Sensor systems that
take point-like measurements
(or) yield time-discrete information
usually deliver dedicated metrics
sit in harms way

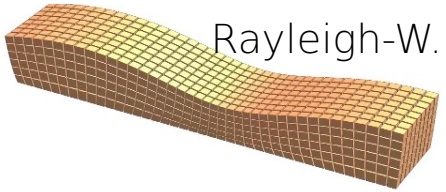
Hence: complement existing approaches by instruments that can provide
distibuted, continuous, multi-purpose data → seismo-acoustic networks

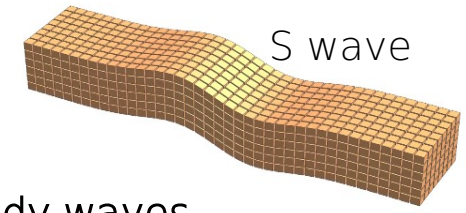
And: models that allow for inversion of data for target processes

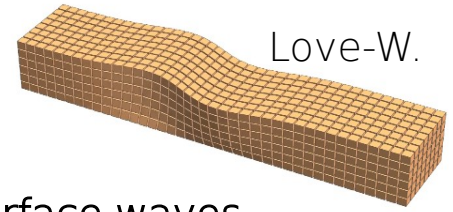
Model, here: set of physically based equations that relate
a measurable metric to underlying sources/causes

So...





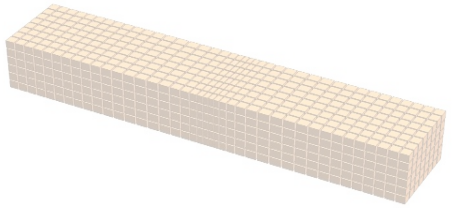


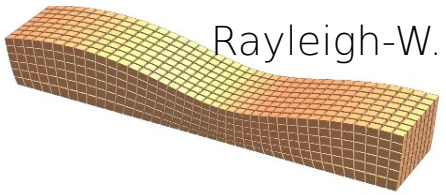


Body waves

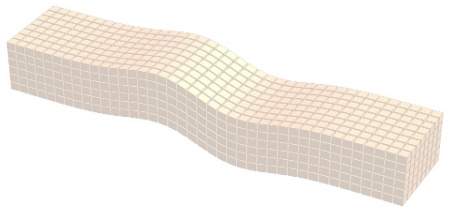
Surface waves

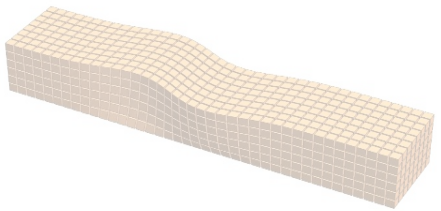
So...





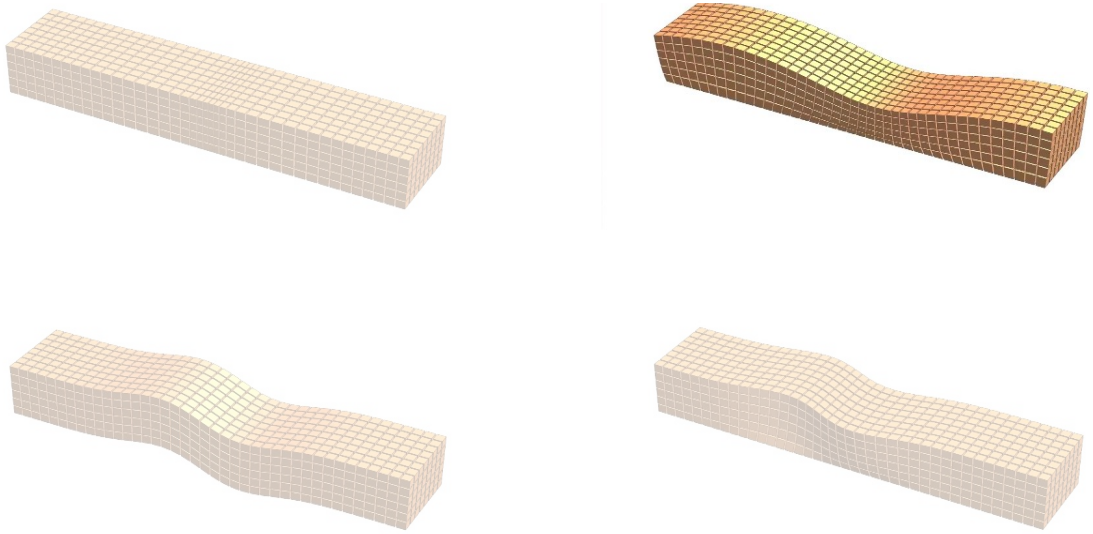
Rayleigh-W.





heute, elektrodynamisch

So…



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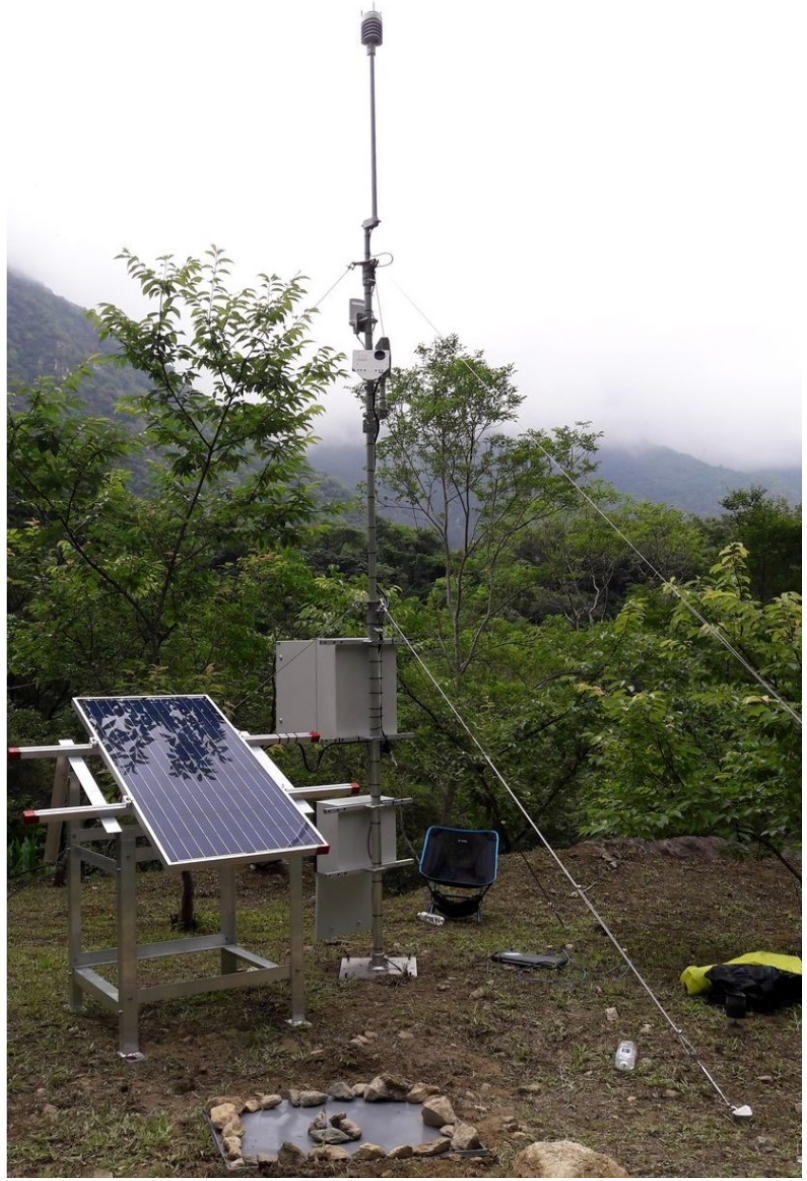
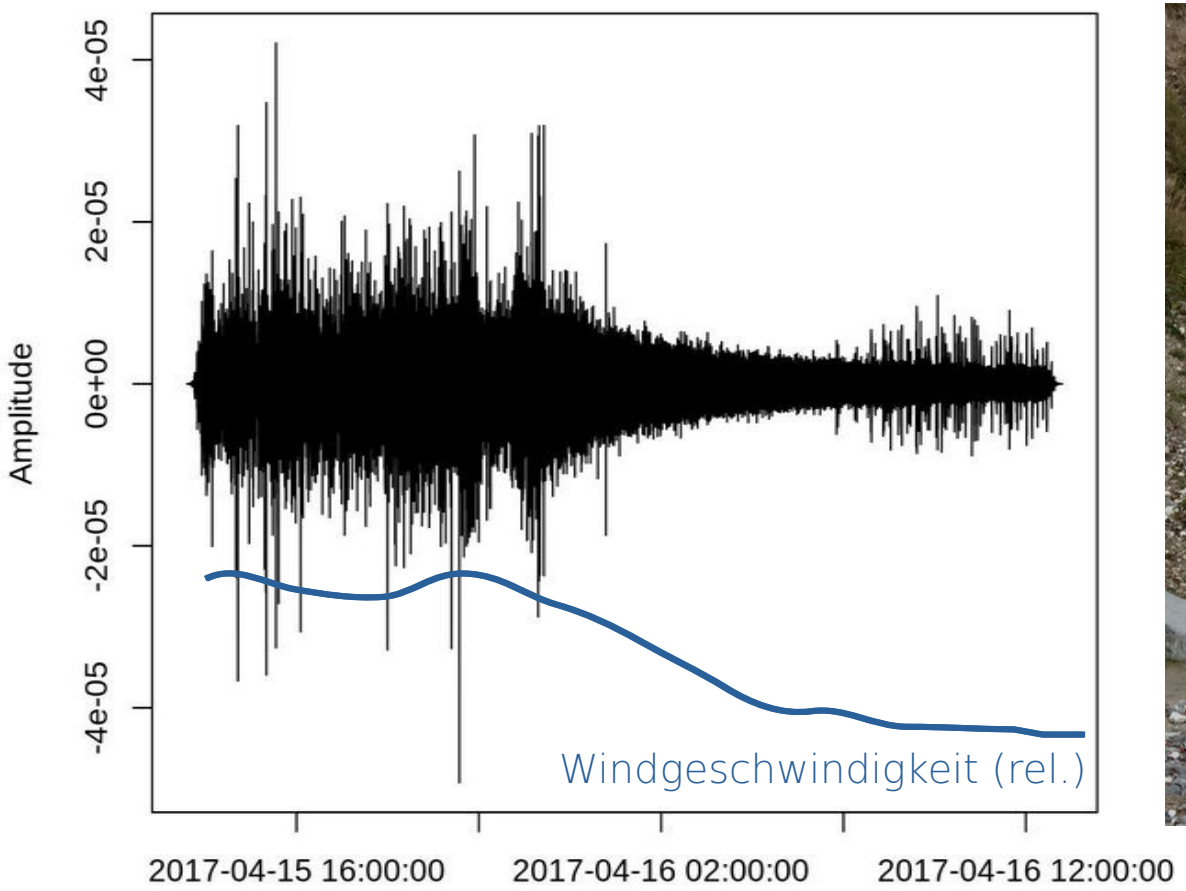
So...



So...

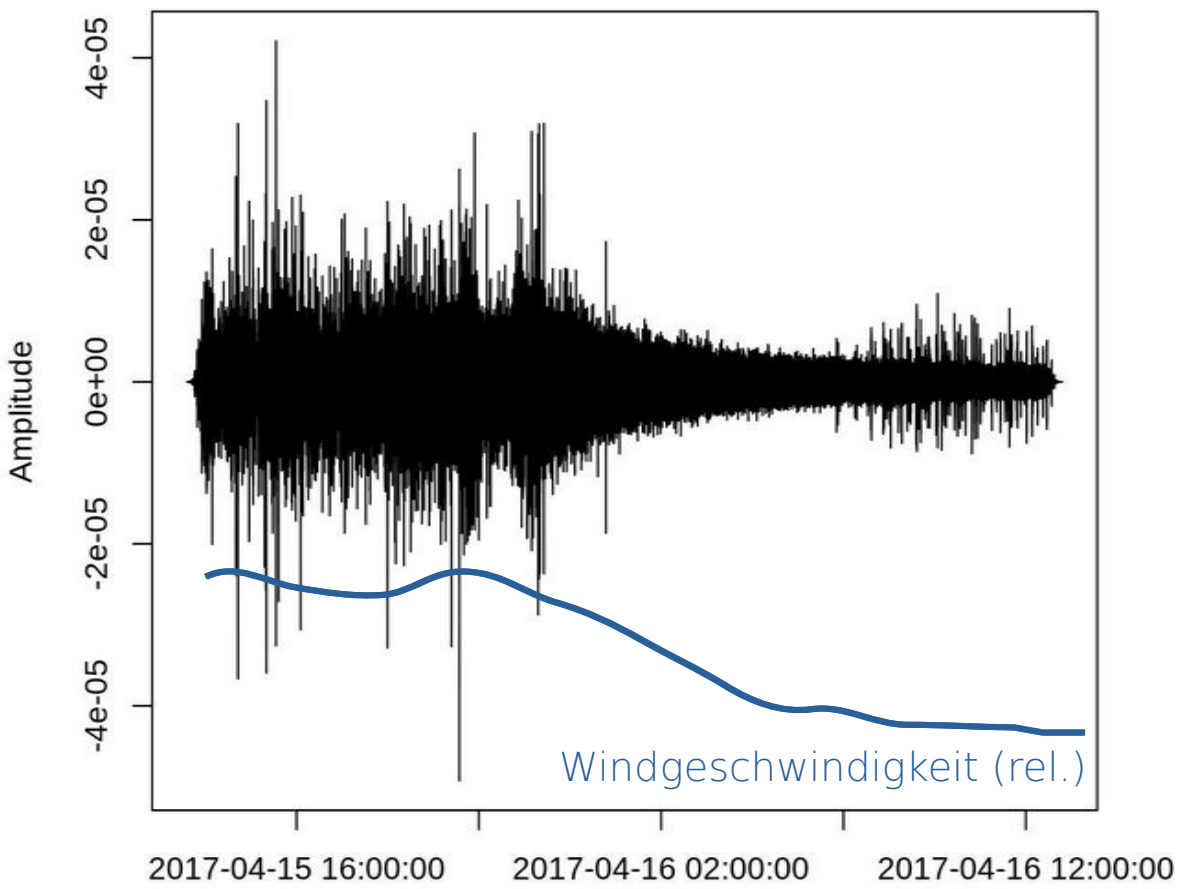
The seismogram (time series of ground motion velocity)

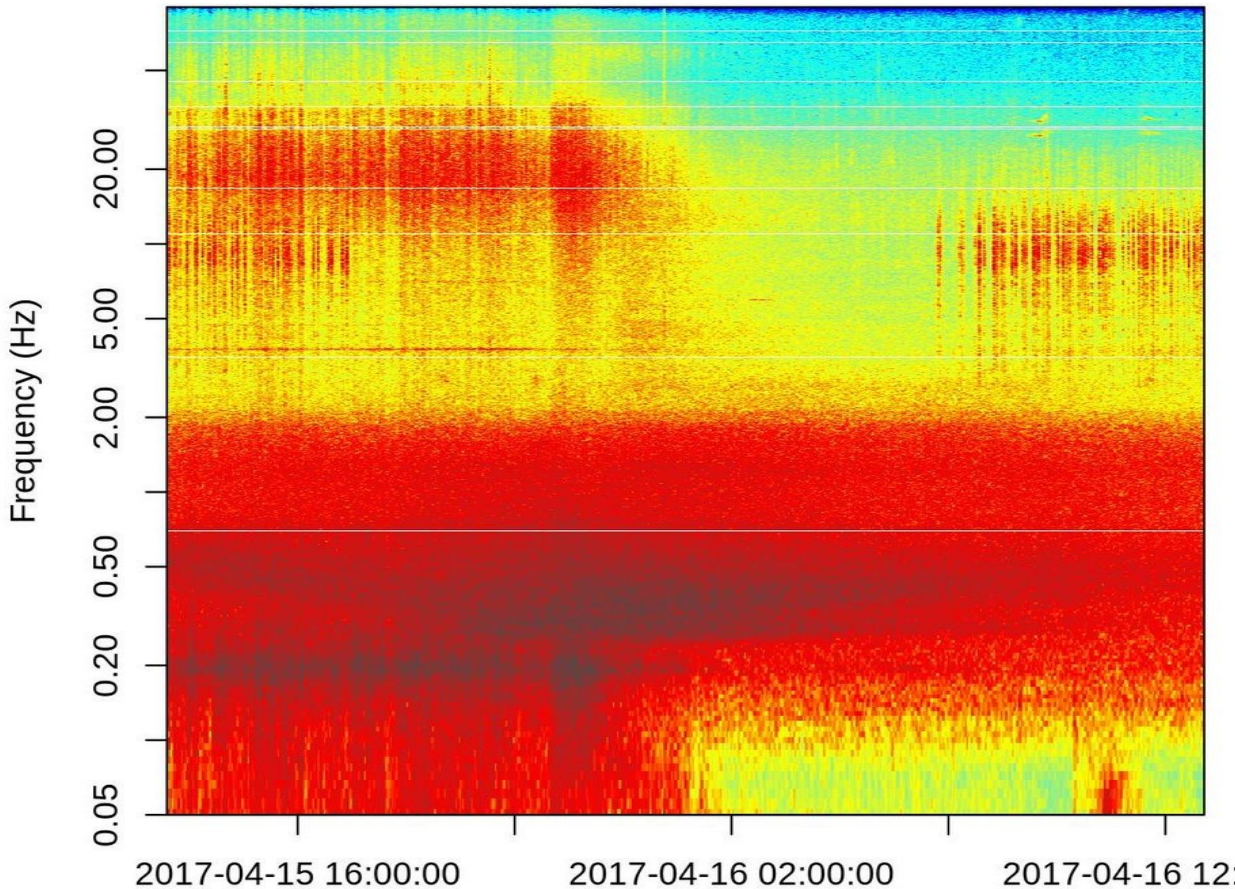


A seismogram of a stormy day at the Baltic Sea coast, Kreidefelsen Rügen, Germany

So…

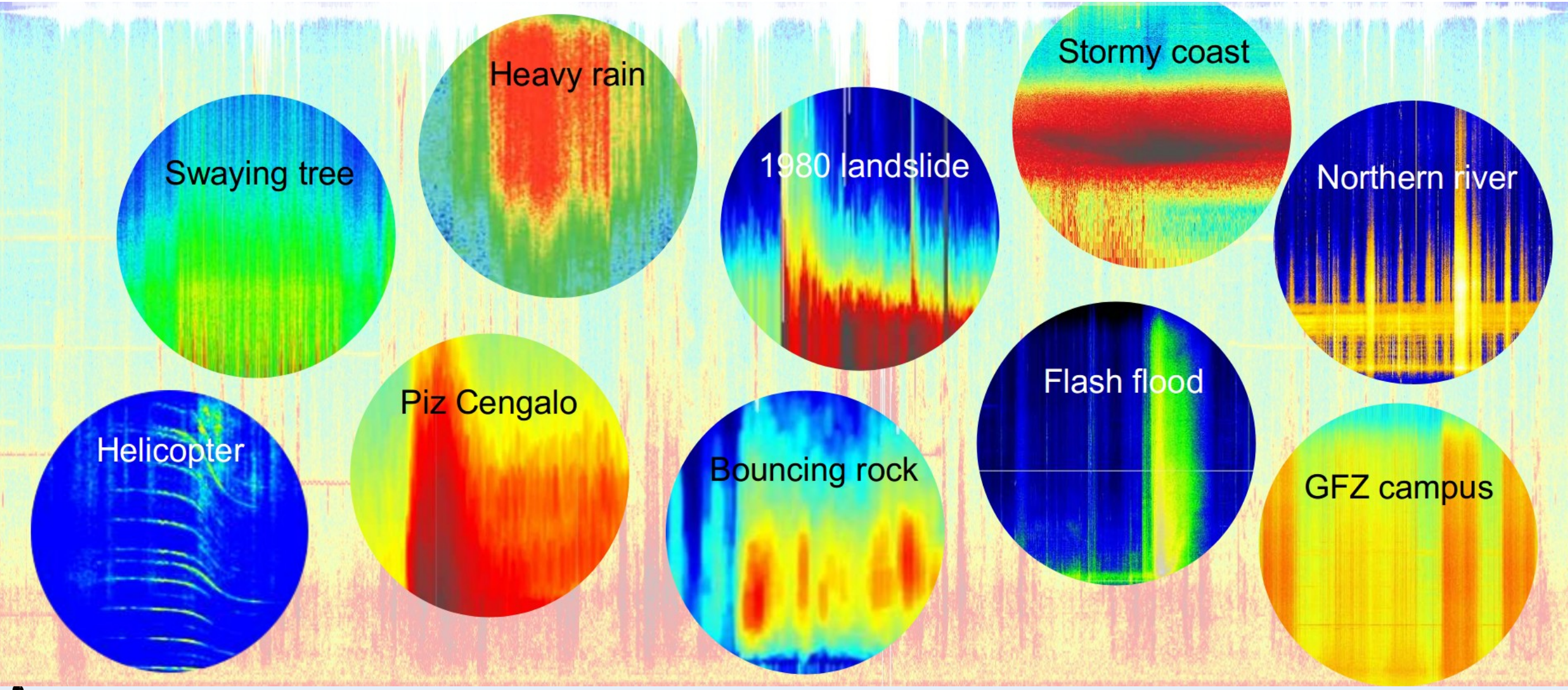
The seismogram (time series of ground motion velocity) → The spectrogram (time resolved frequency info)



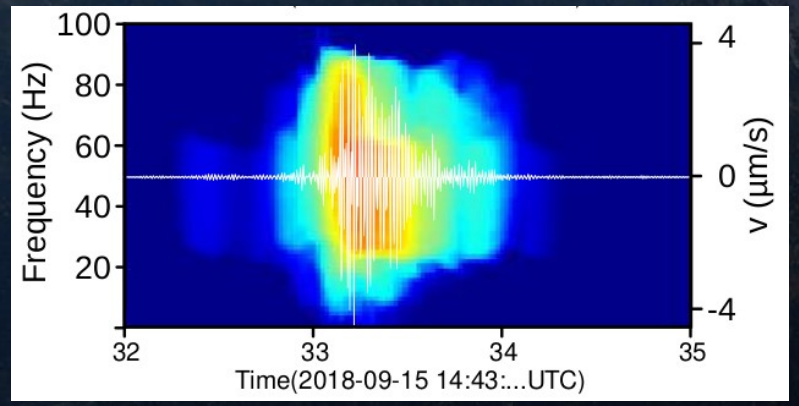


A seismogram of a stormy day at the Baltic Sea coast, Kreidefelsen Rügen, Germany

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

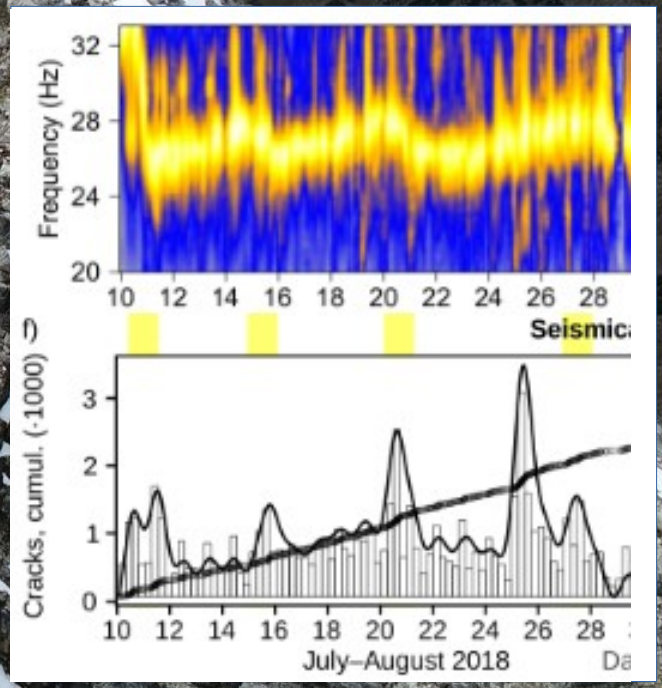


The reaction of rock to stress



What
Where
When
(Why)

But: no model



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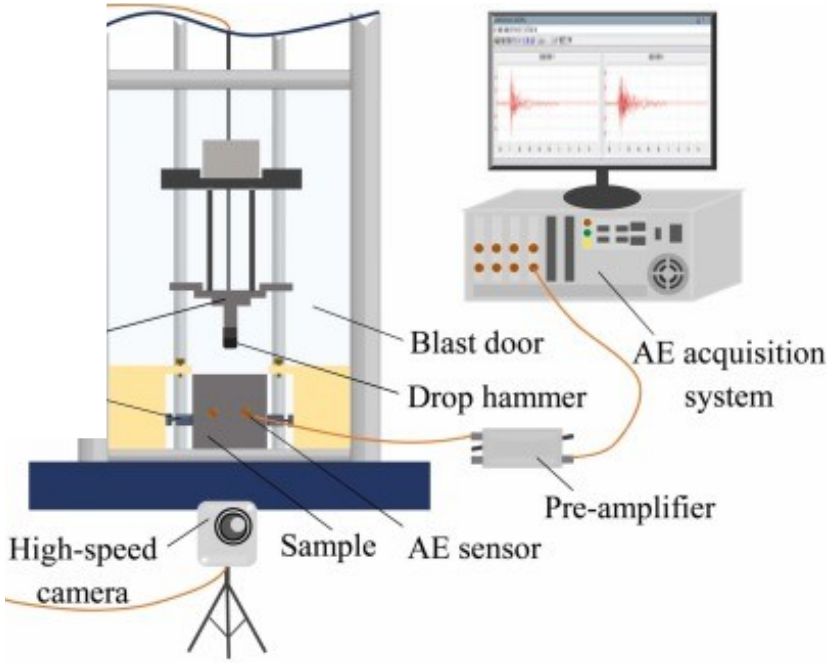
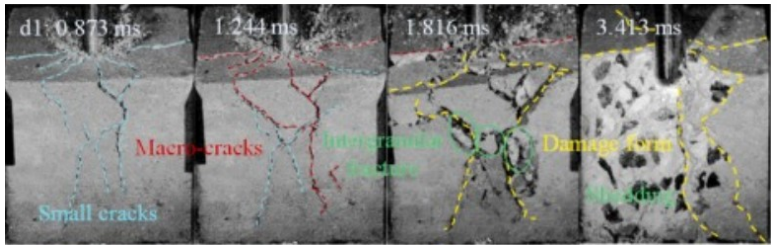
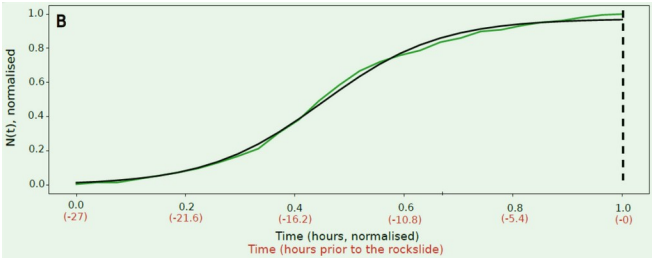




$$N(t) \quad \frac{A_{tot}}{1+\exp\left(\frac{-t}{\tau}+b\right)}$$



What
Where
When
Why

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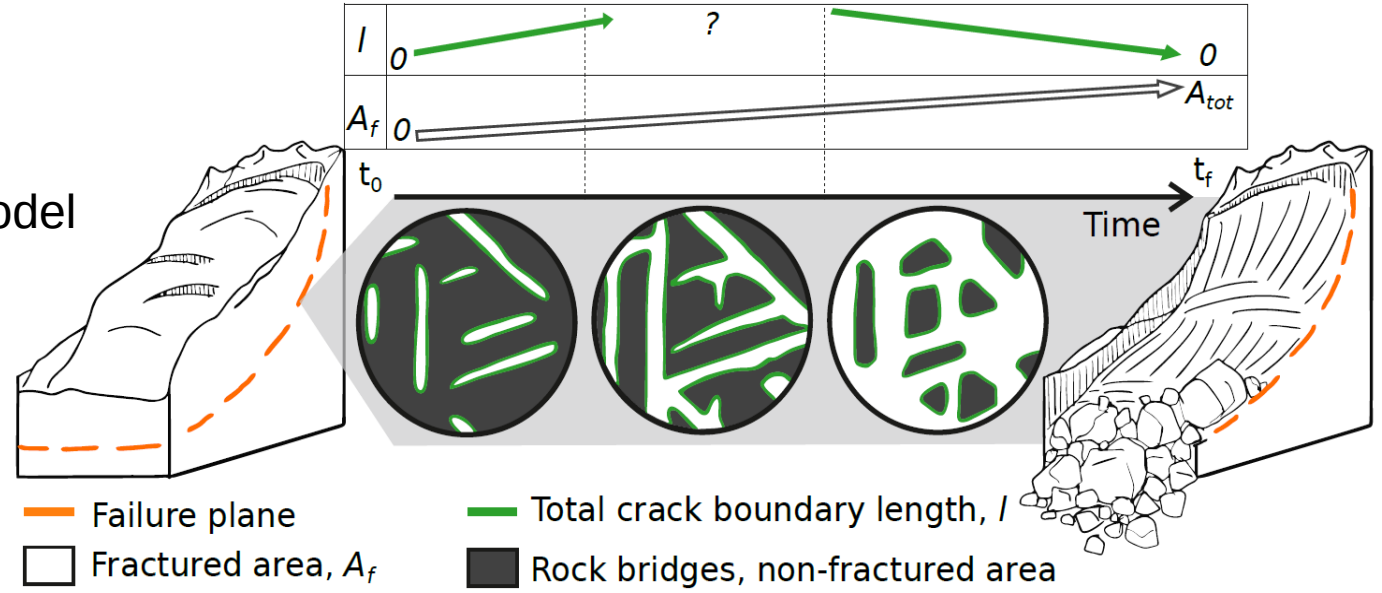
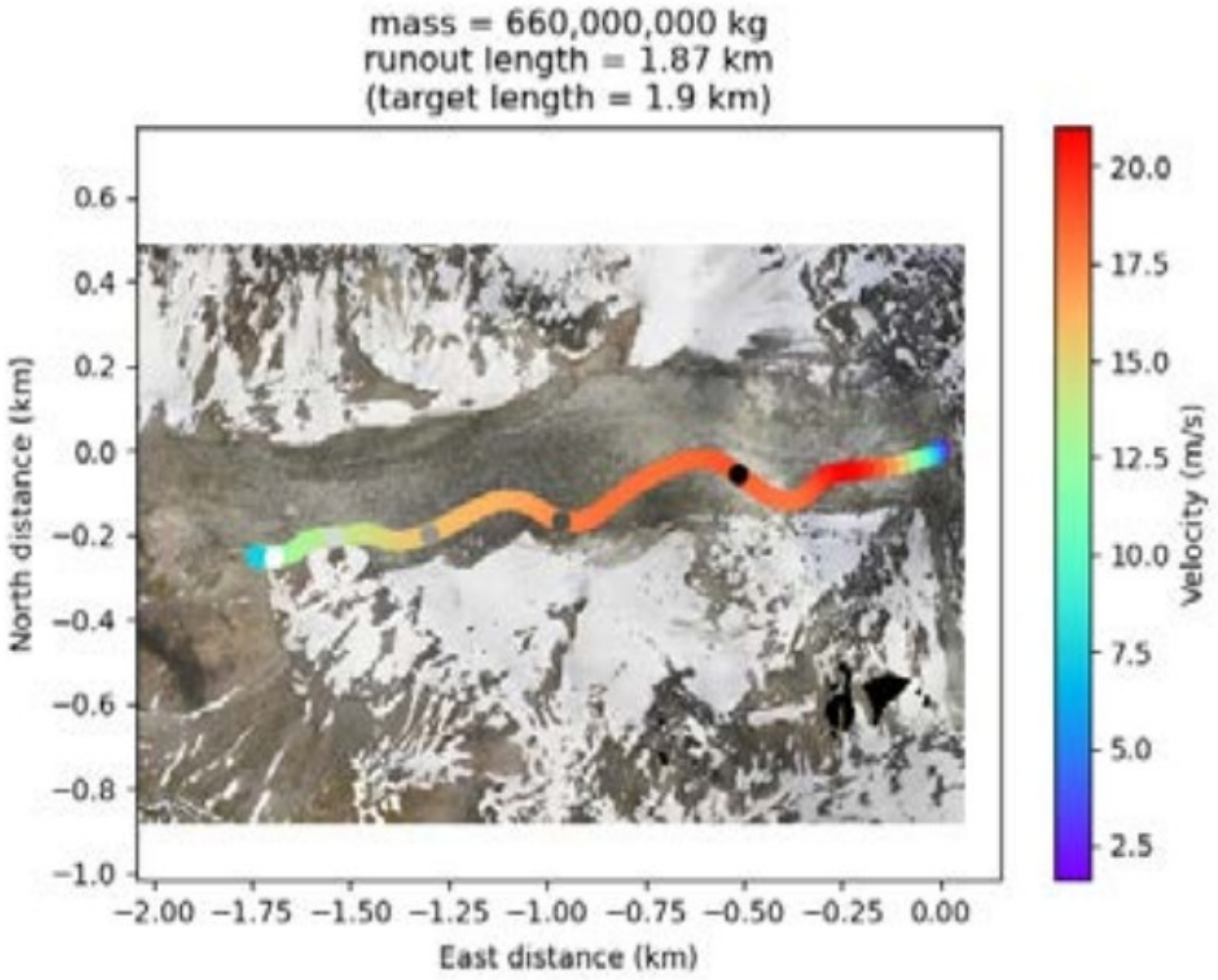


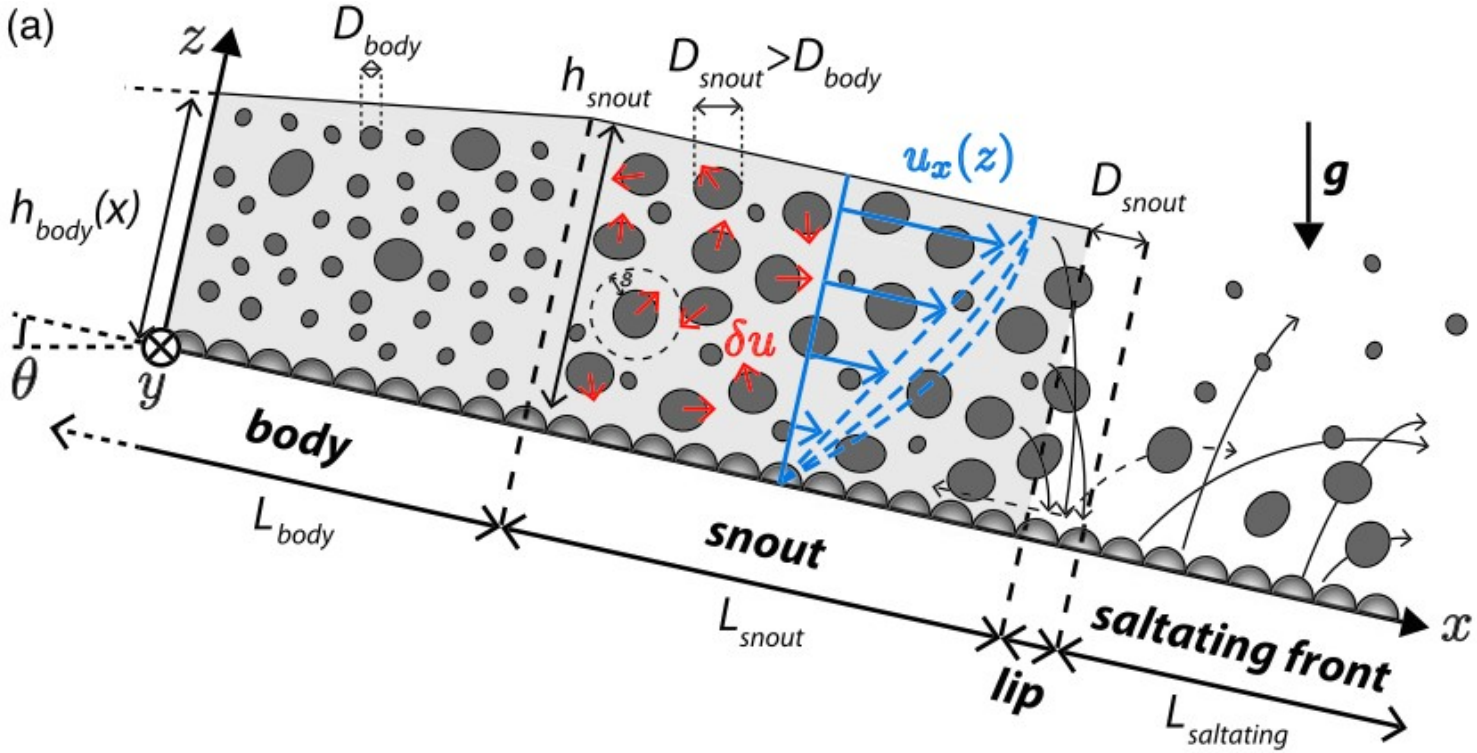
The action of gravity… Example A: large volume mass wasting events

Fluchthorn, AT
11.06.23
15:05:17
144 s
10^6 m³ rock

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

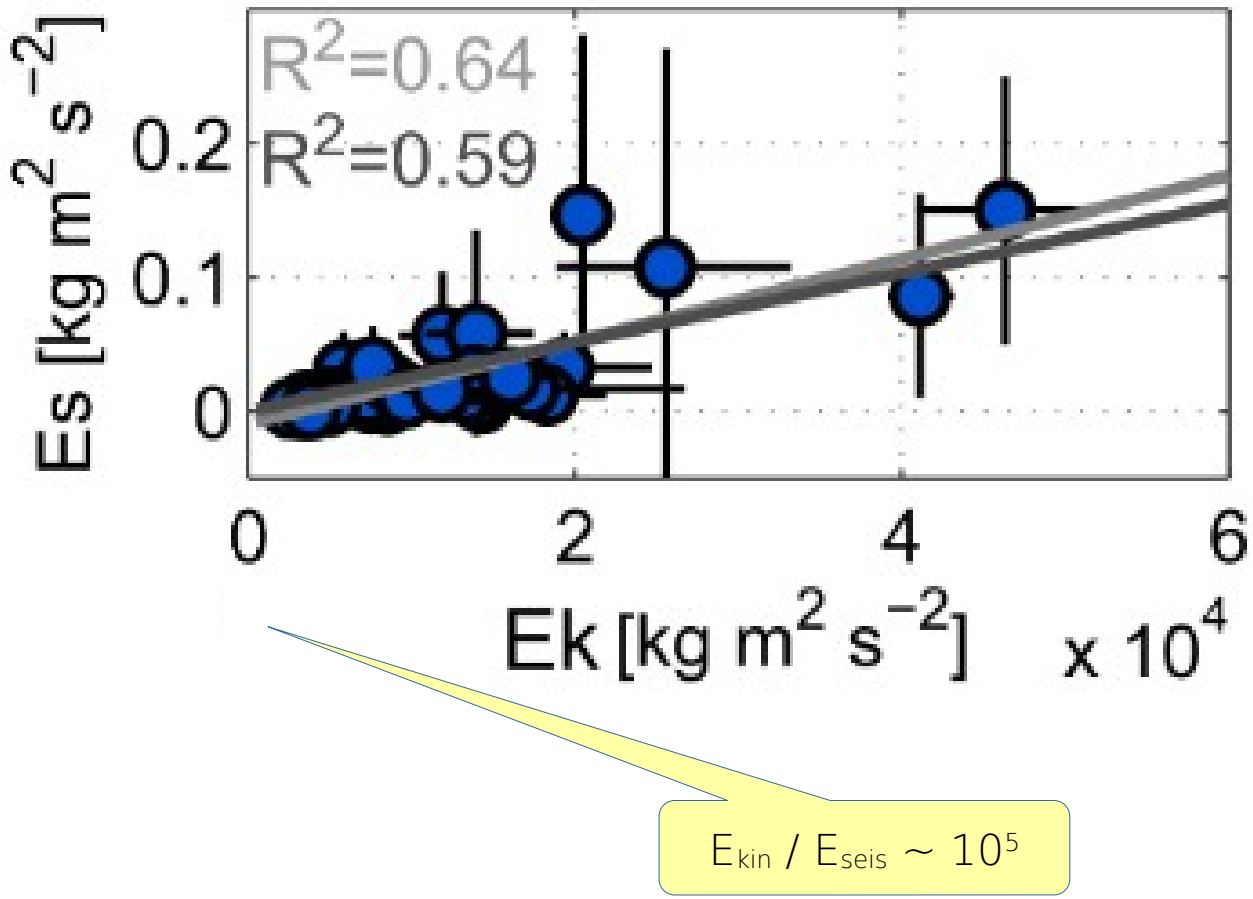


The action of gravity… Example B: debris flow-like granular systems

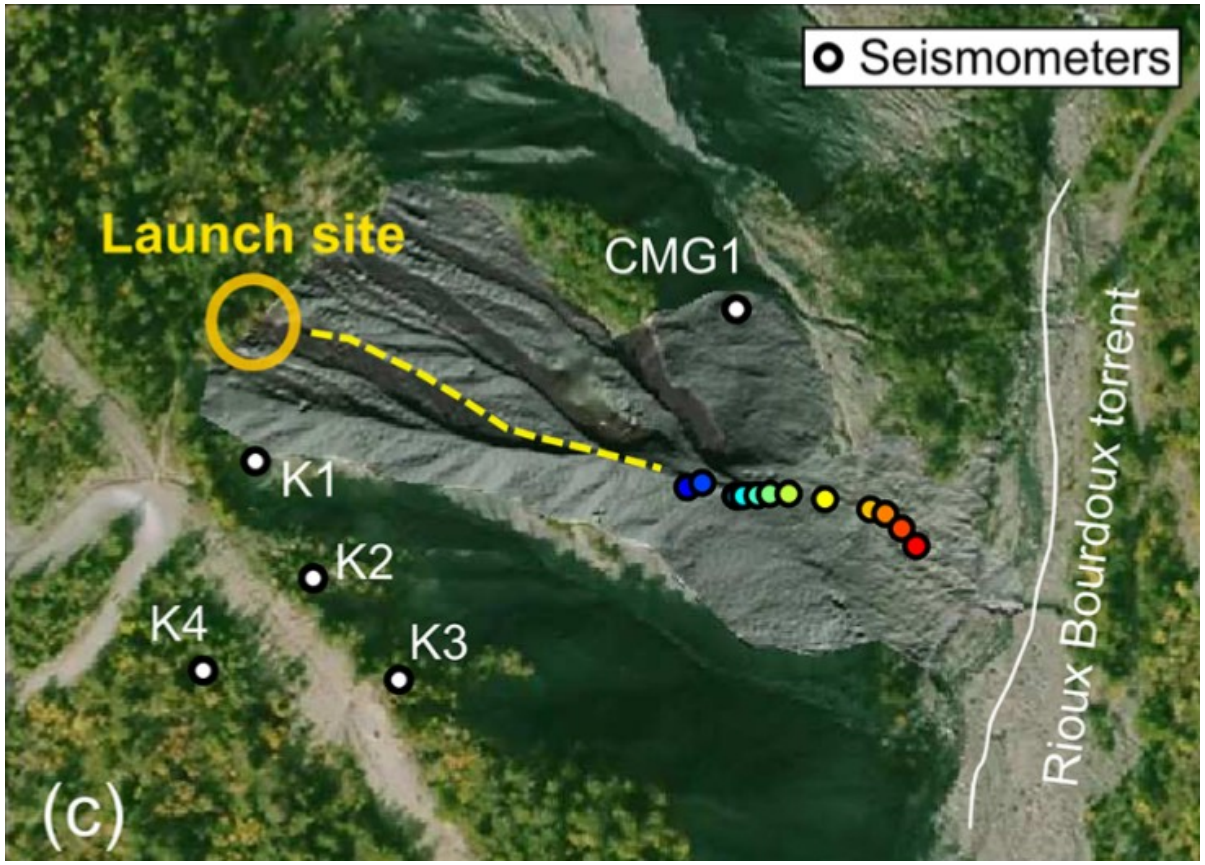


$$PSD(f, r_0, t, D) = R_{impact} W \frac{\pi^2 (1 + e_b)^2 m^2 \bar{u}_x^2 f^3}{4 \rho_0^2 v_c^3 v_u^2} N_{jz}^2 f_j^2 \chi(r_0, f)$$

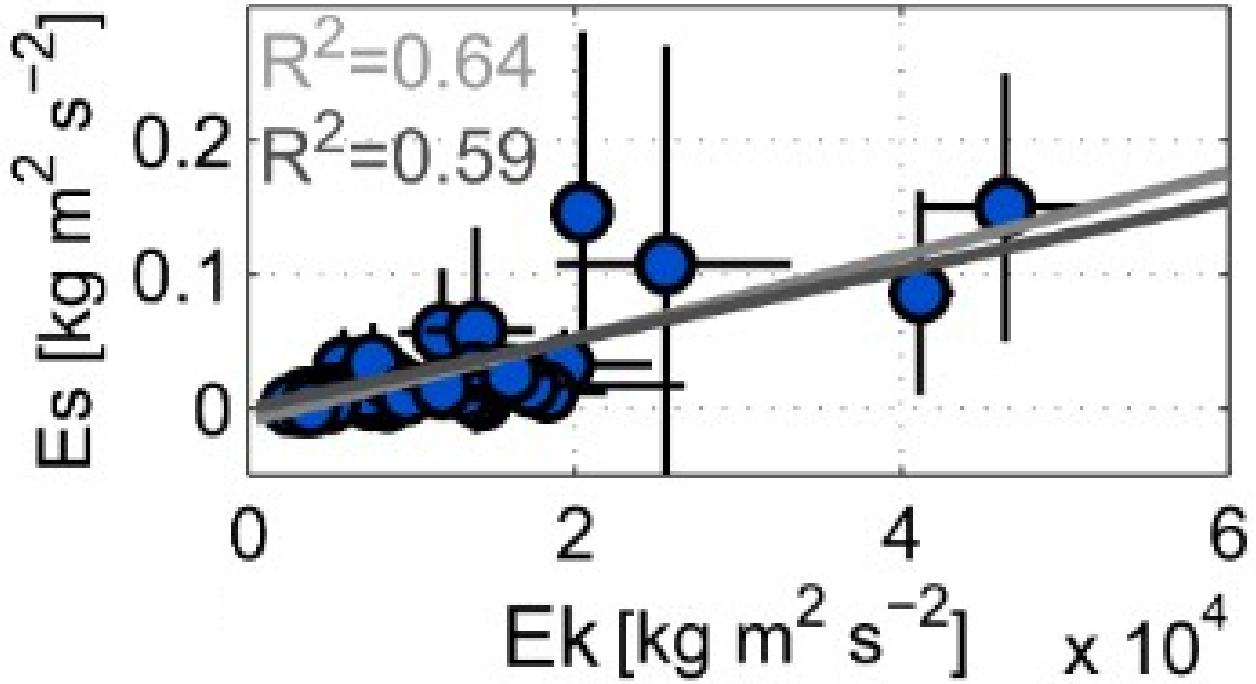
The action of gravity… Processes in between



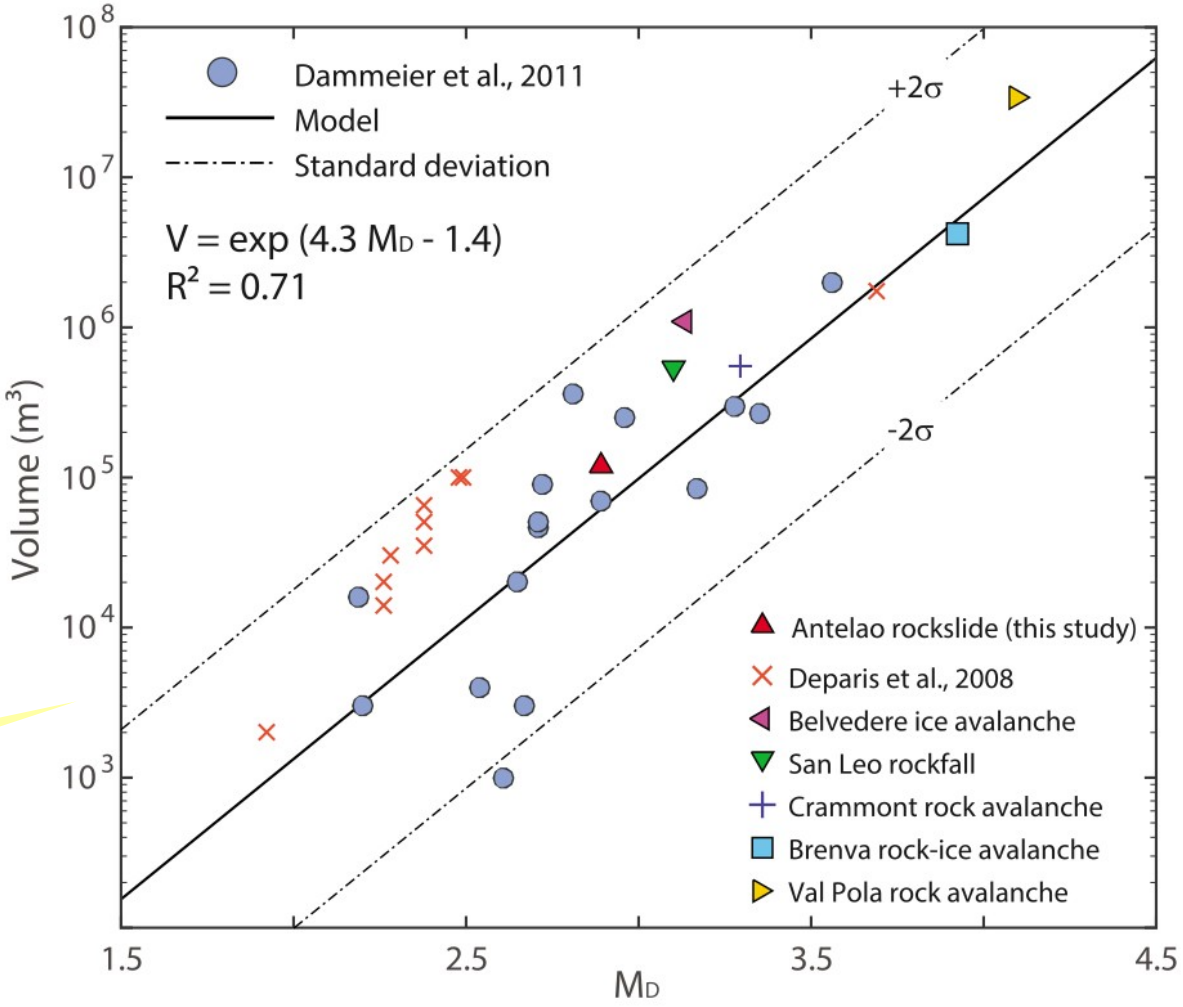
E_{kin} / E_{seis} ~ 10^5



The action of gravity… Processes in between

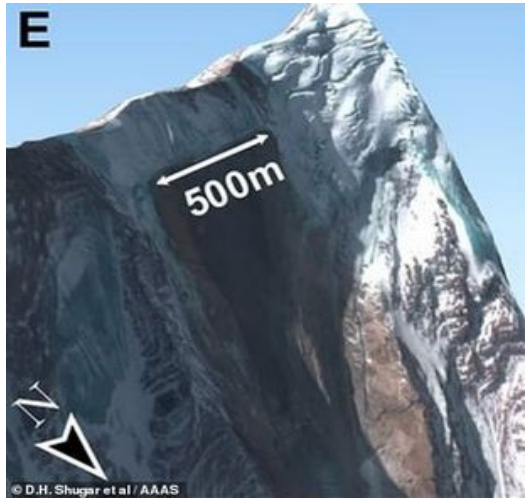


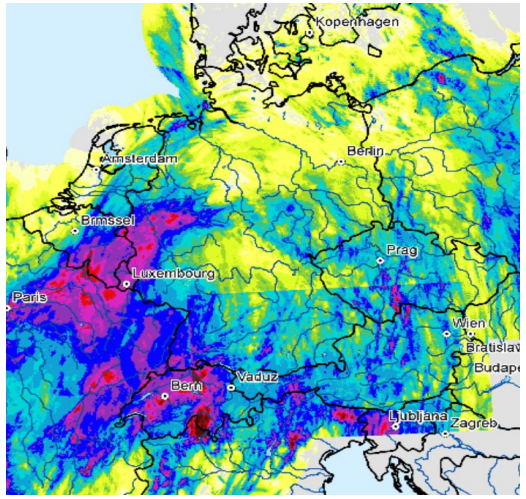
"Only" correlative understanding



The consequences of flowing water (2021)

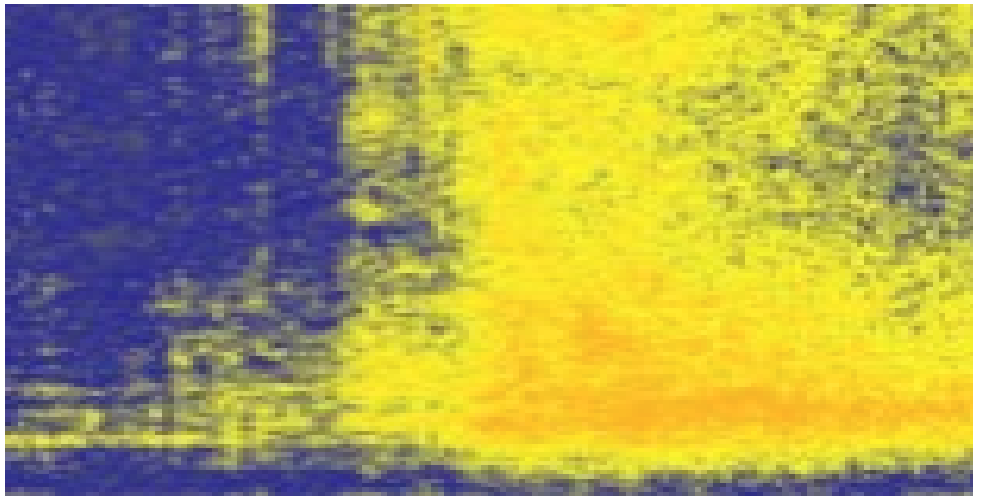
The causes

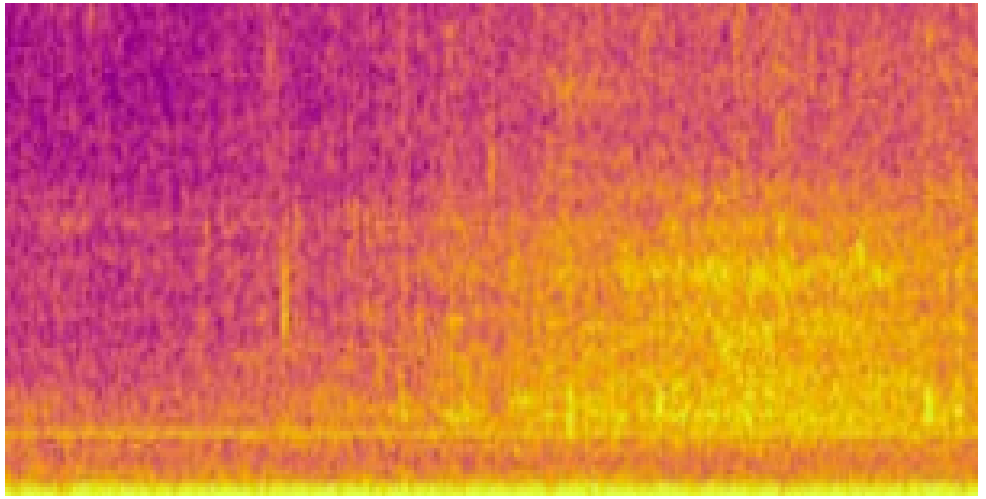




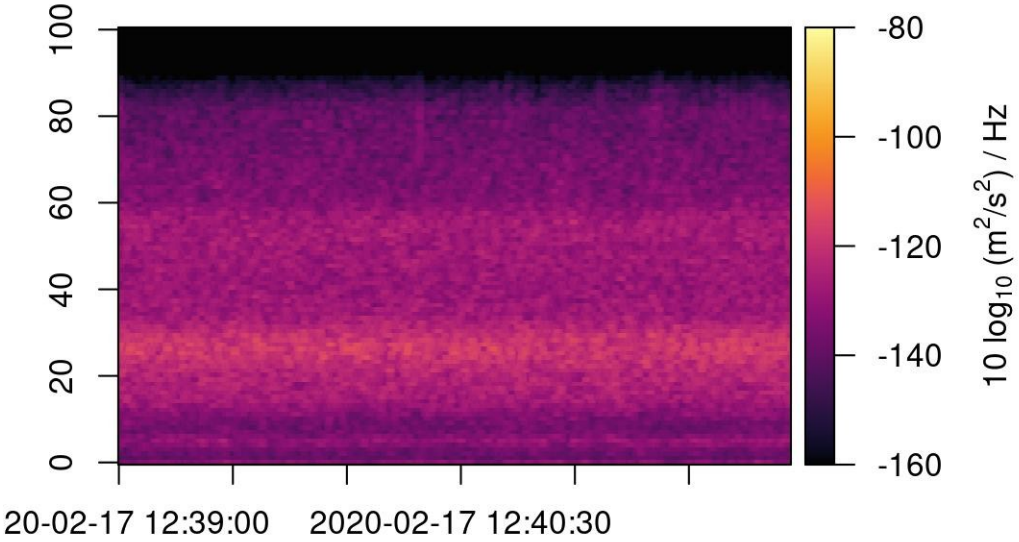
The consequences

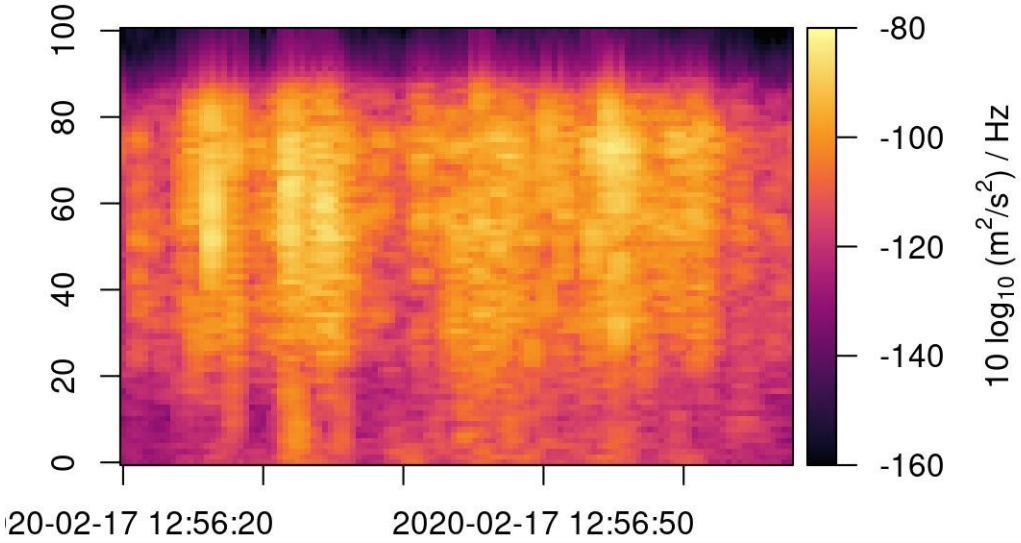
The seismic imprints (0.5–10 Hz, 1 h duration)





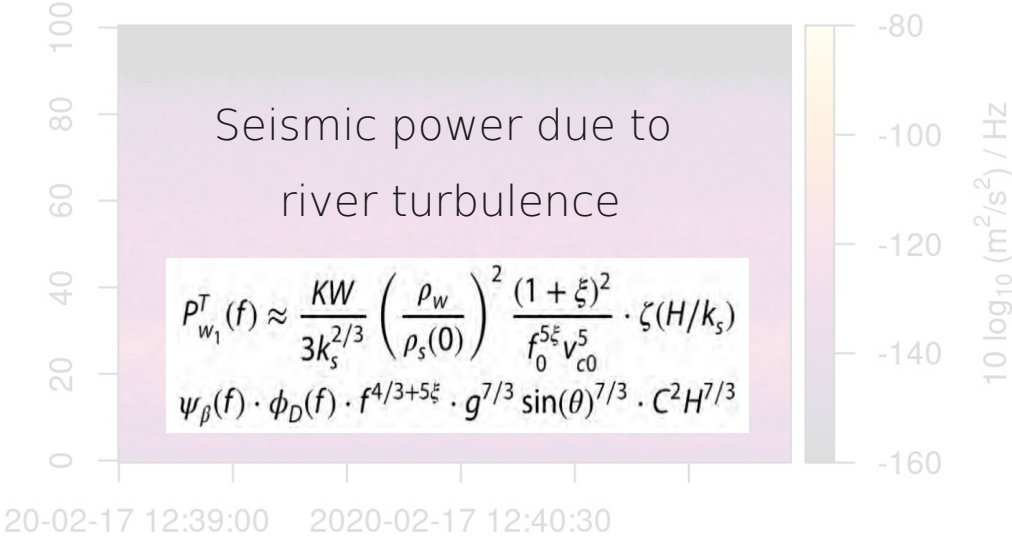
Water moving sediment, probing the hidden dynamics

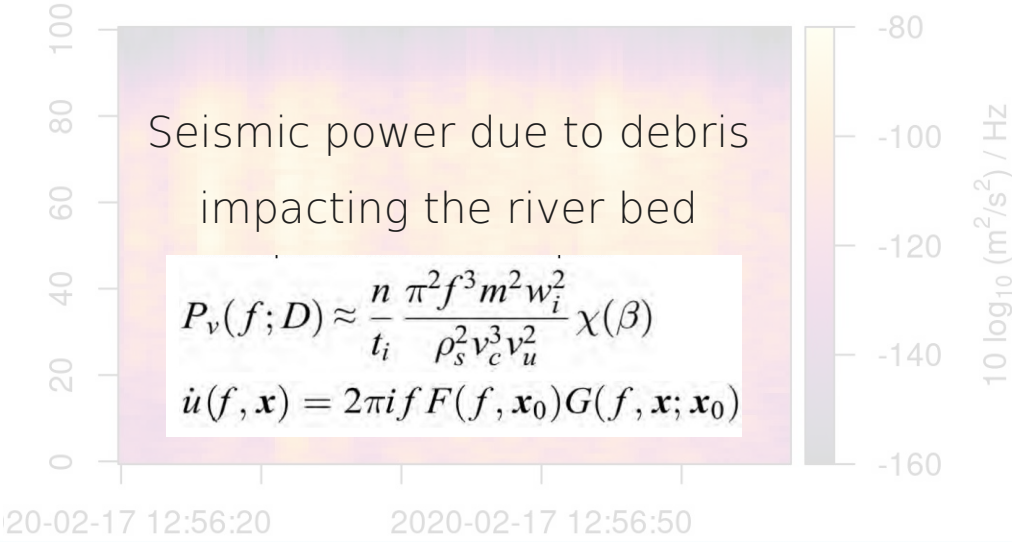




Matthews et al. (2022, EGU Sphere)

Water moving sediment, probing the hidden dynamics

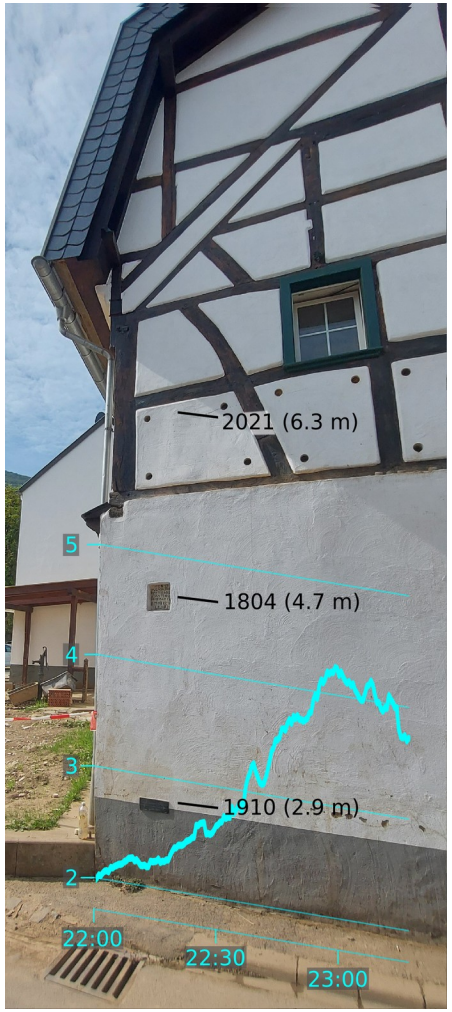


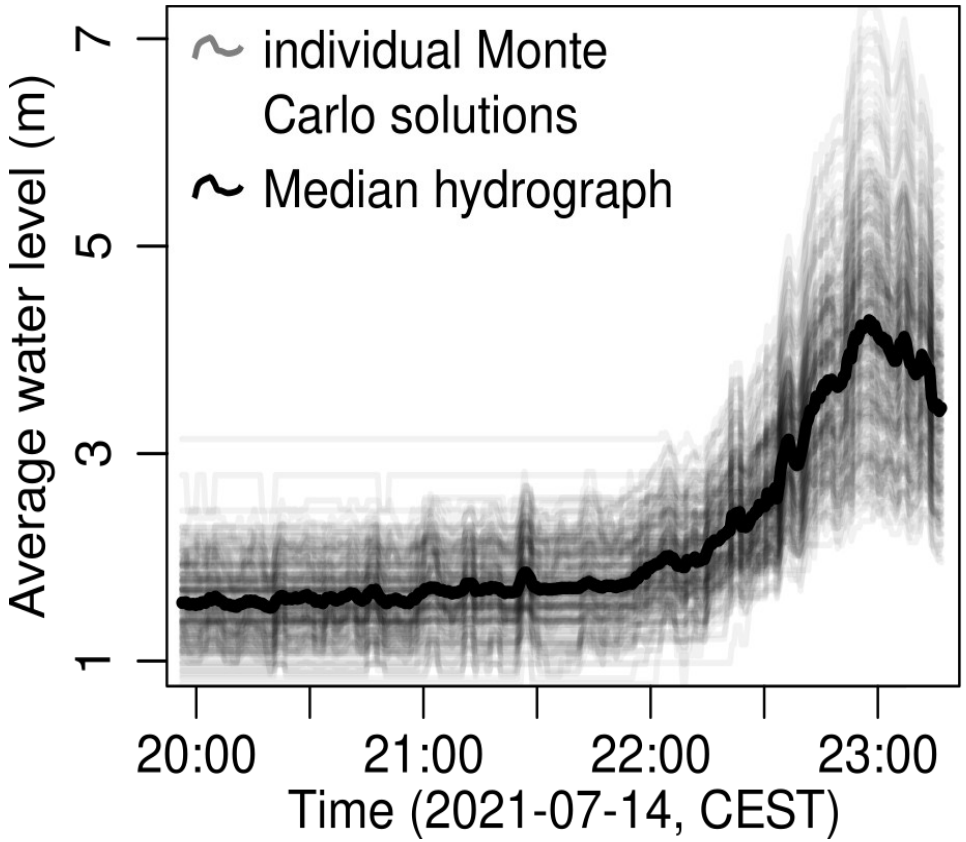


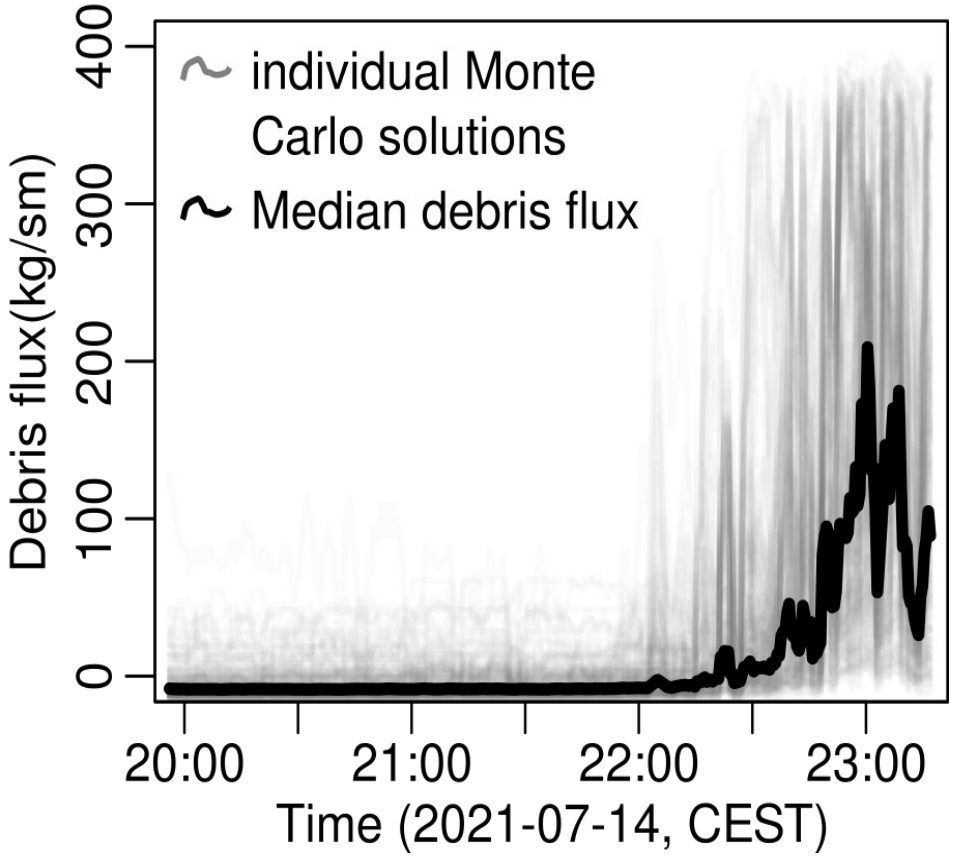
A meteorological extreme that drove a **hydrological** extreme that triggered a **geomorphic crisis**, which implemented most of the damage.

Aerial image, Ahrweiler, Germany (DLR, 2021) Dietze & Ozturk (2021, Science)

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







All excellent and fine? Unsolved issues with the approach

Particles & obstacles

Process

Wave representation

Ground architecture

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)

2) *Modes of bedload transport* based on saltation, only (n.b. Gimbert et al. (2018) modify towards other processes)

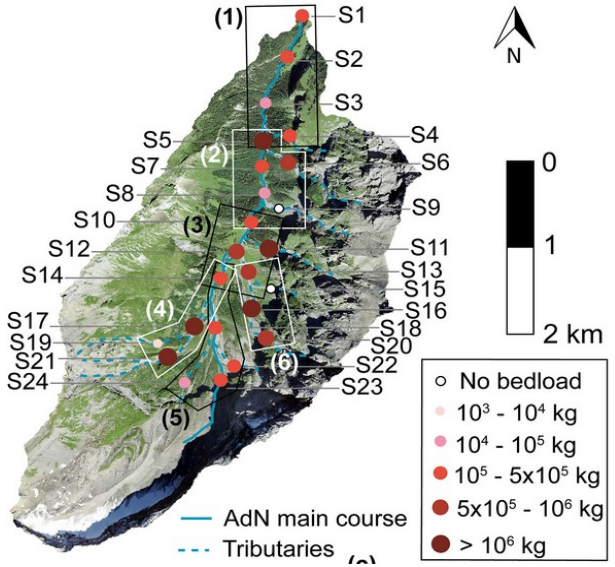
3) Depth-dependent attenuation of Rayleigh wave *particle motion* not not accounted for (see rain model)

4) Very simplistic, time-invariant ground property representation (*Greens function*)

Why carrying on?

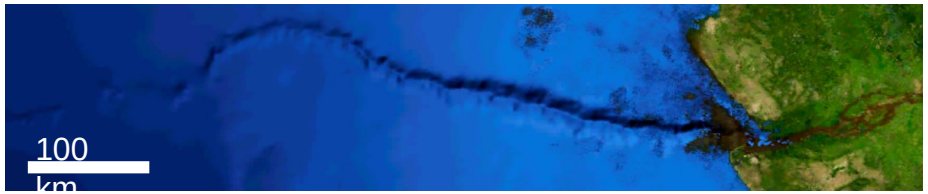
Look below ice & into karst systems

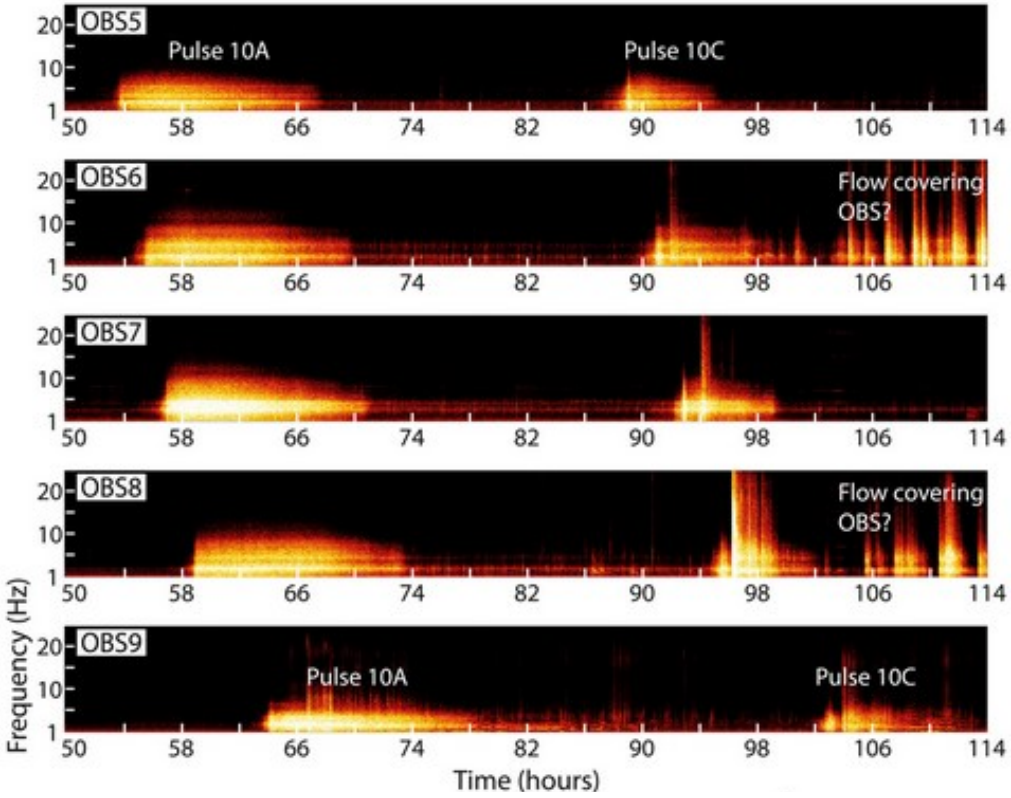
Catchment-wide process propagation



Quantify biogeomorphic effects

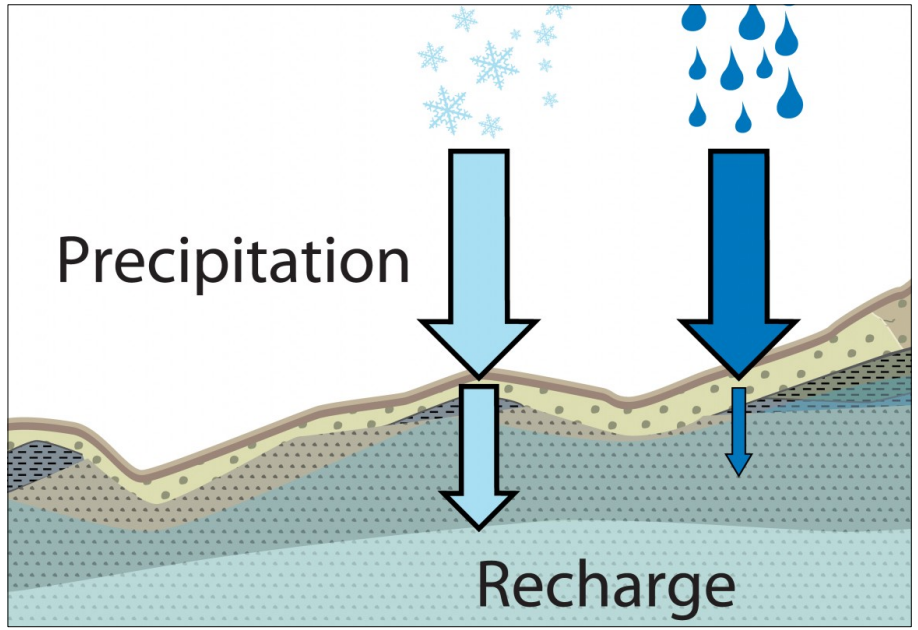
Beyond-continent fluxes of mass & carbon



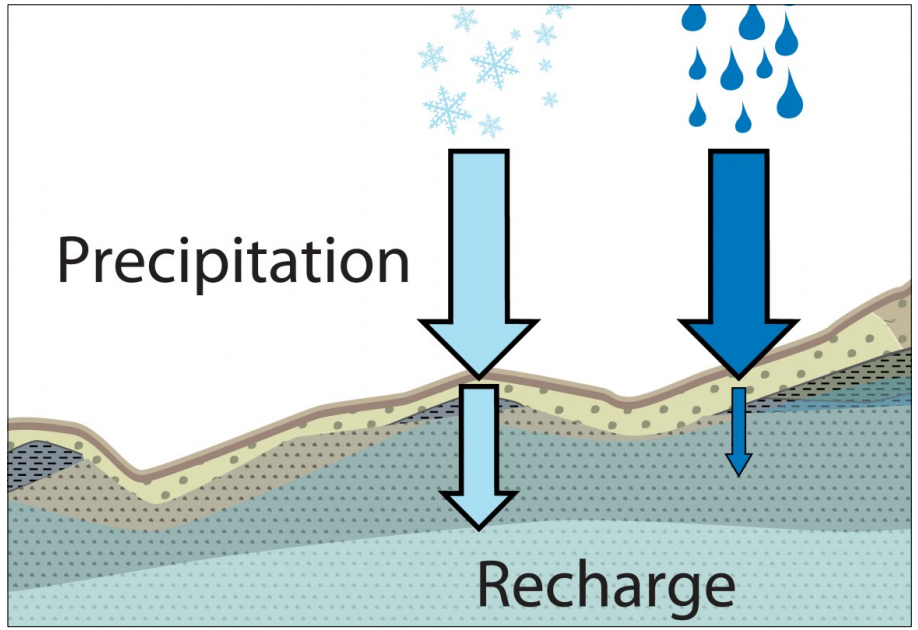


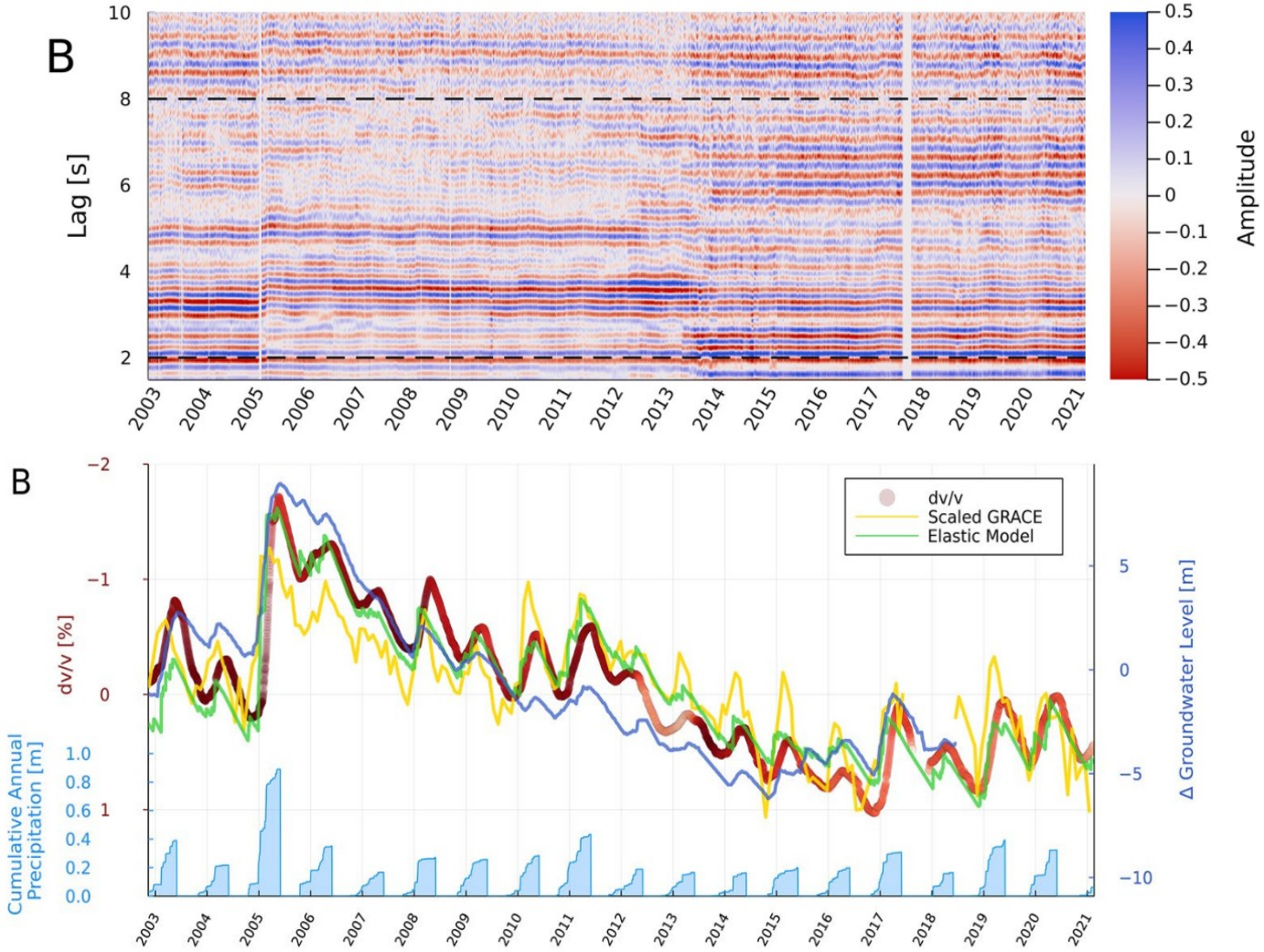
Wolf et al. (in prep.), Antoniazza et al. (2023, JGR), Baker et al. (2024, GRL)

Water below our feet

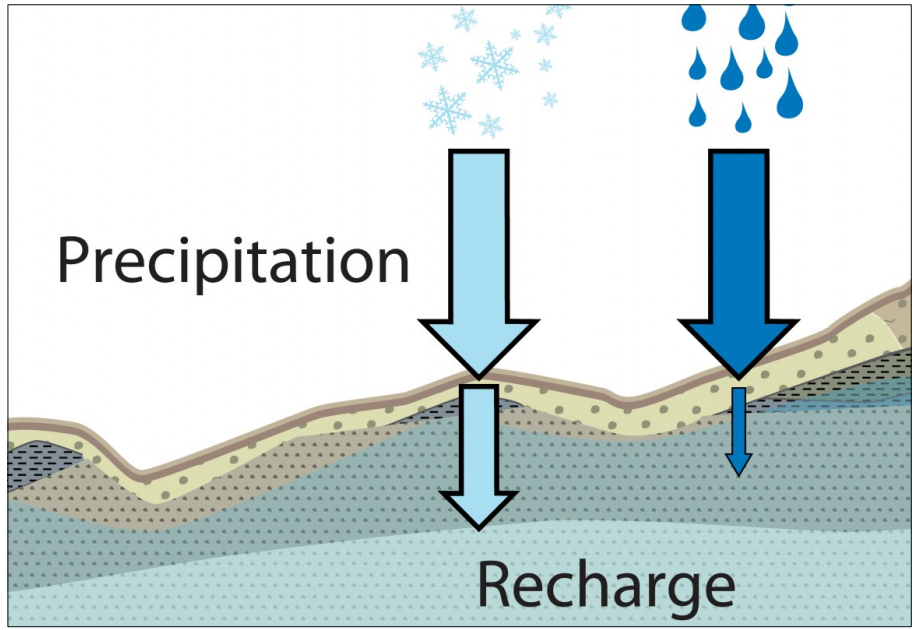


Water below our feet





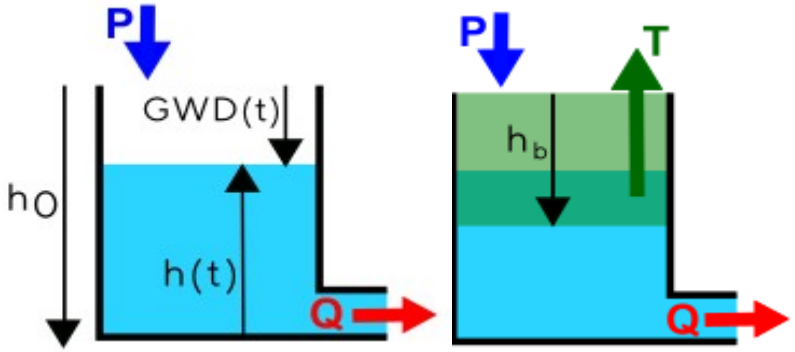
Water below our feet

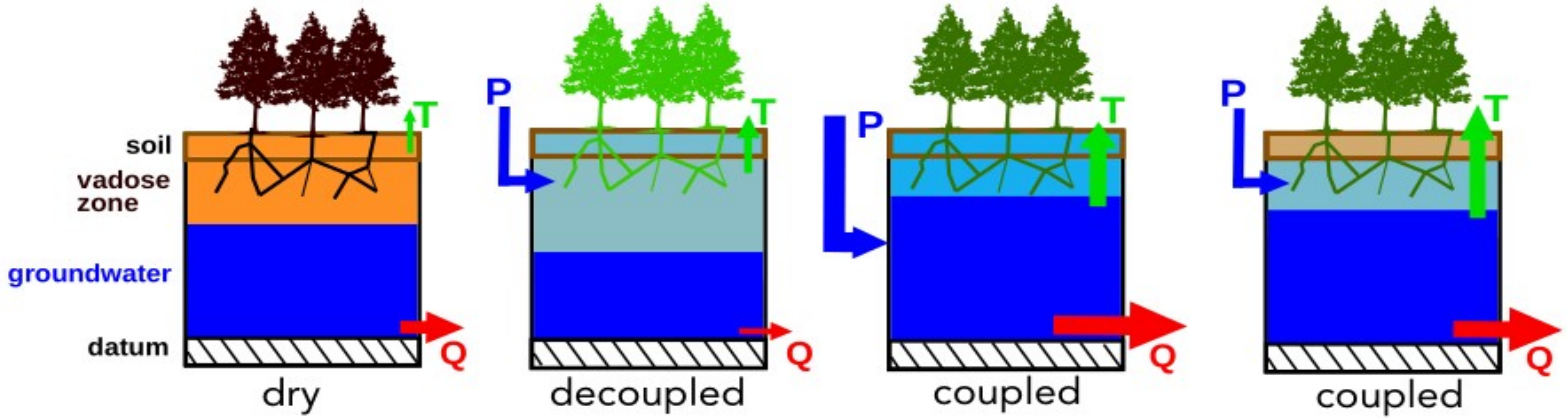


$$\Delta h(t) = \sum_{i=0}^{n} \frac{P_i}{\phi} e^{(-a(t-t_i))}$$ GW discharge

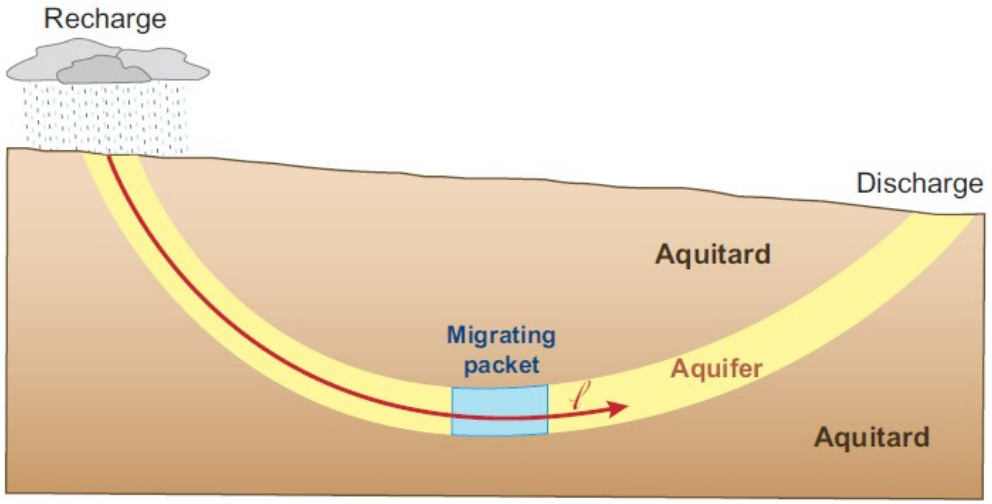
$$P(z,t) = \frac{B(1+\nu_u)}{3(1-\nu_u)}$$ Poroelastic load effect

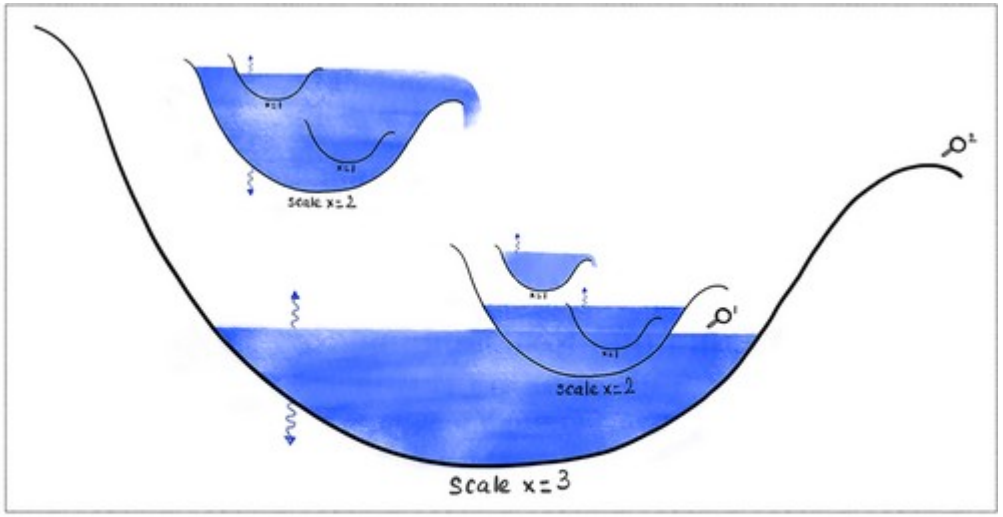
$$\sigma_{ij} - \frac{\nu}{1+\nu}\sigma_{kk}\delta_{ij} = 2G\epsilon_{ij}$$ Hydr. head & pore pressure

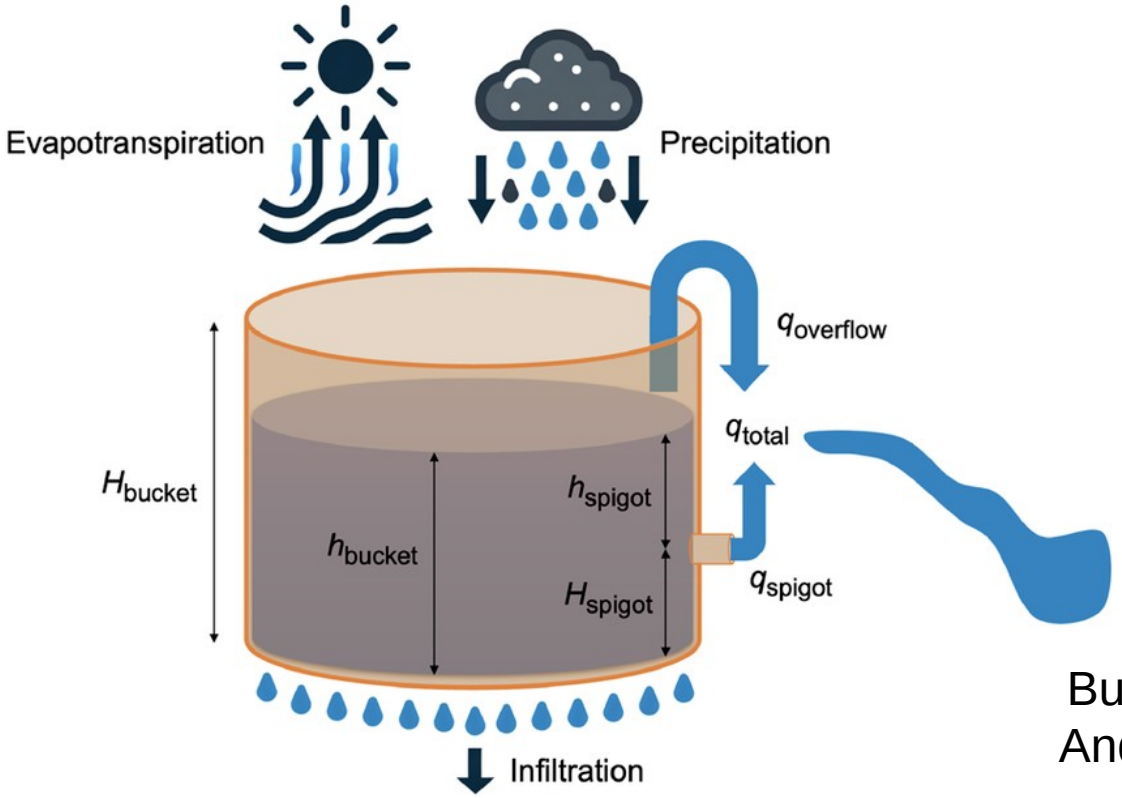




Water below our feet – concepts of piston flow, fill-and-spill, leaky buckets





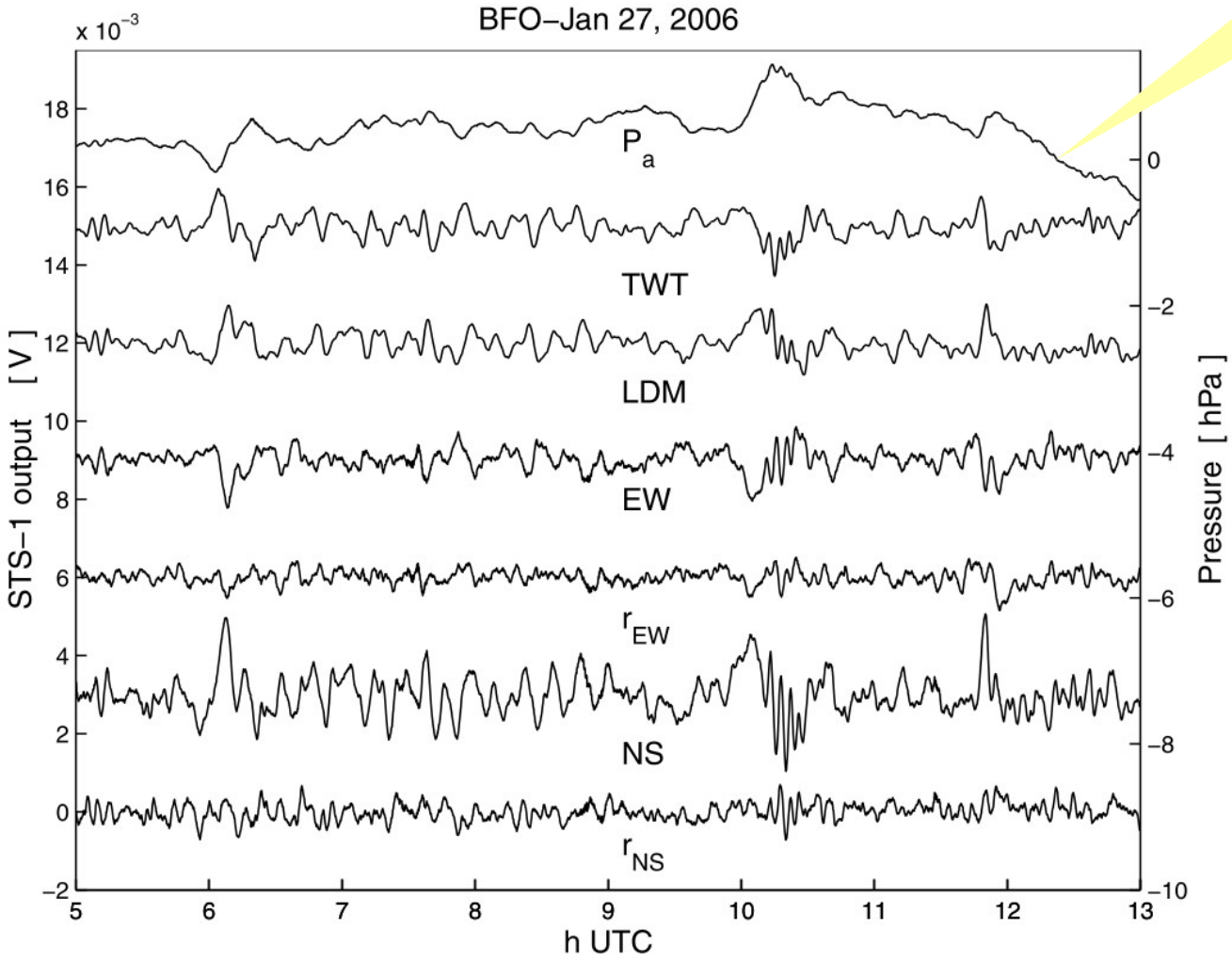


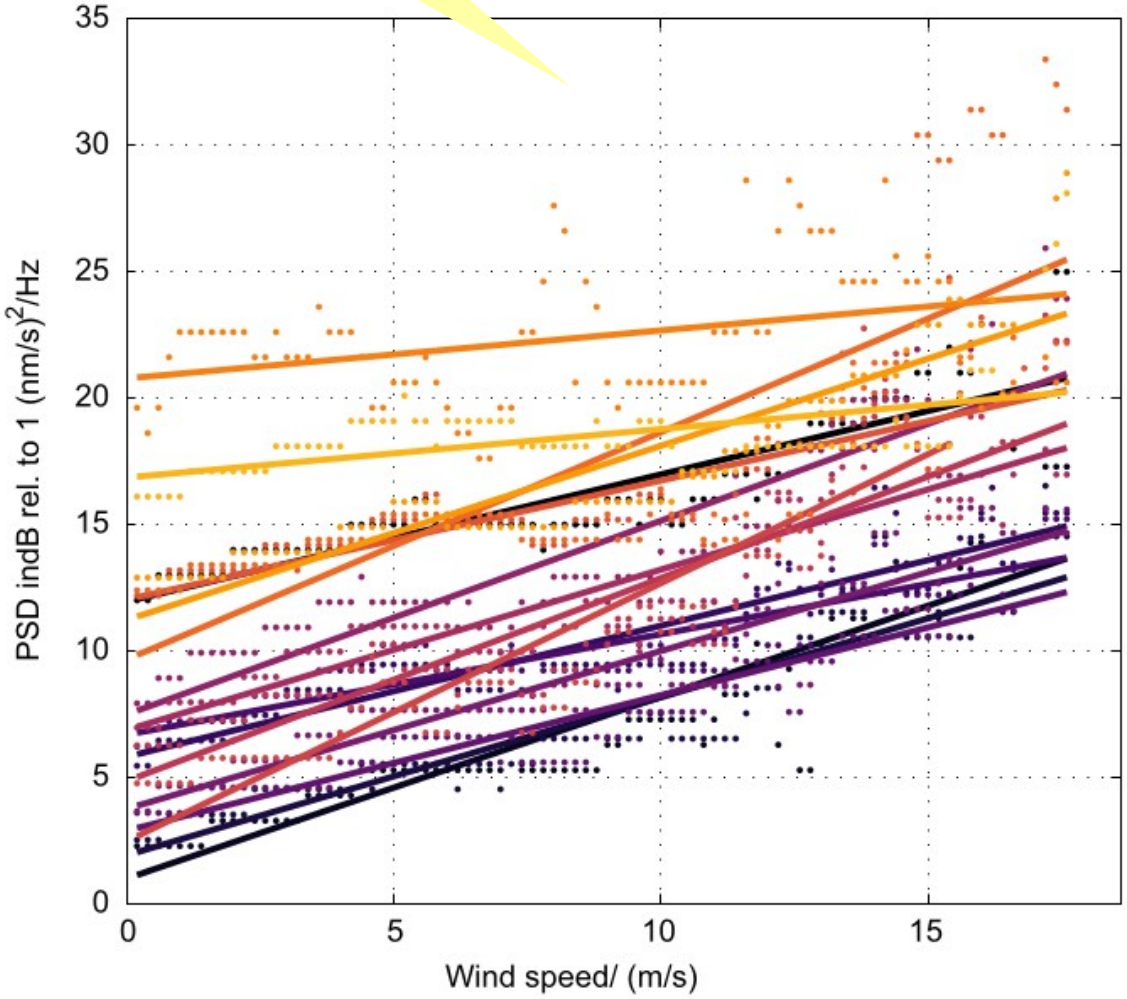
(What)
(Where)
When
(Why)

But: no model
And: simplified approaches

Air pressure systems … and wind effects

Get rid of the noise

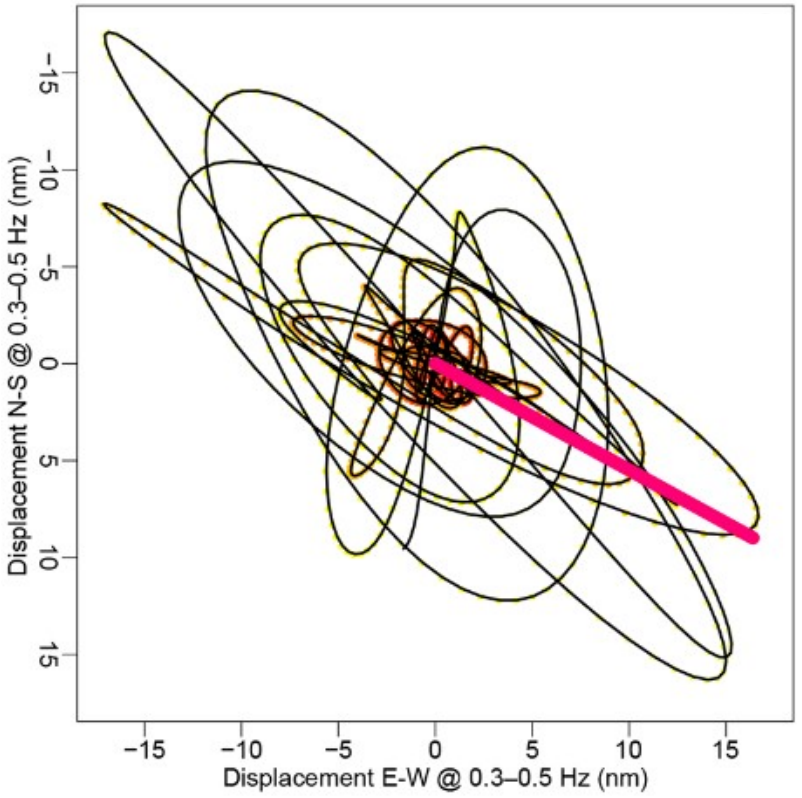




Zürn et al. (2007, GJI)

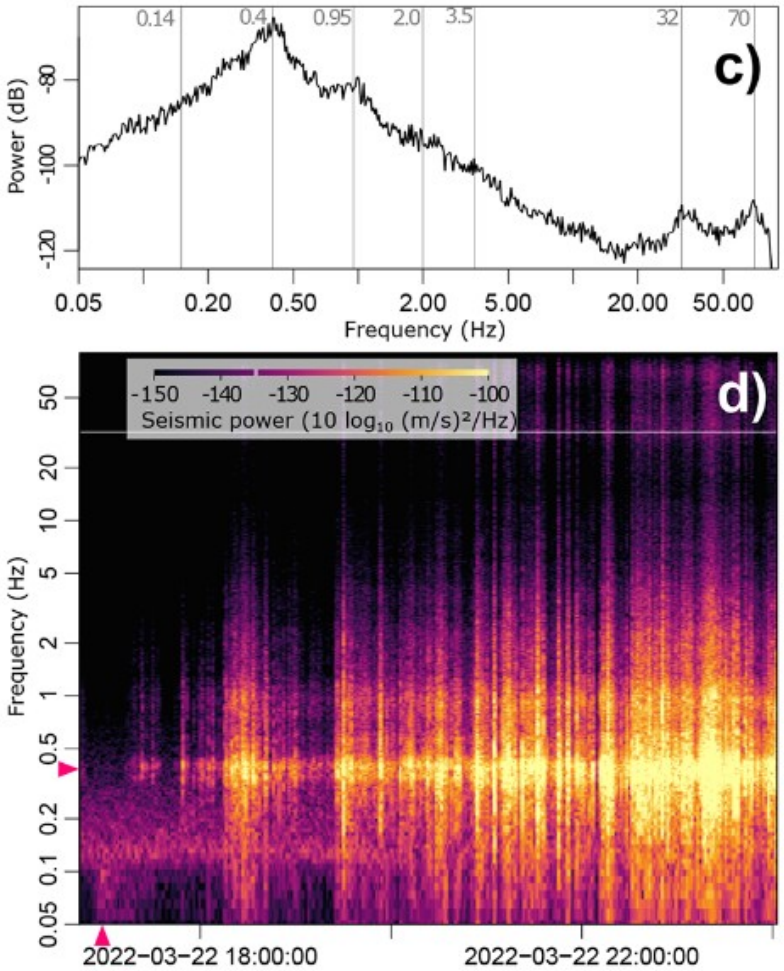
Lott et al. (2017, JApplPhys)

Wind interacting with the biosphere in Patagonia

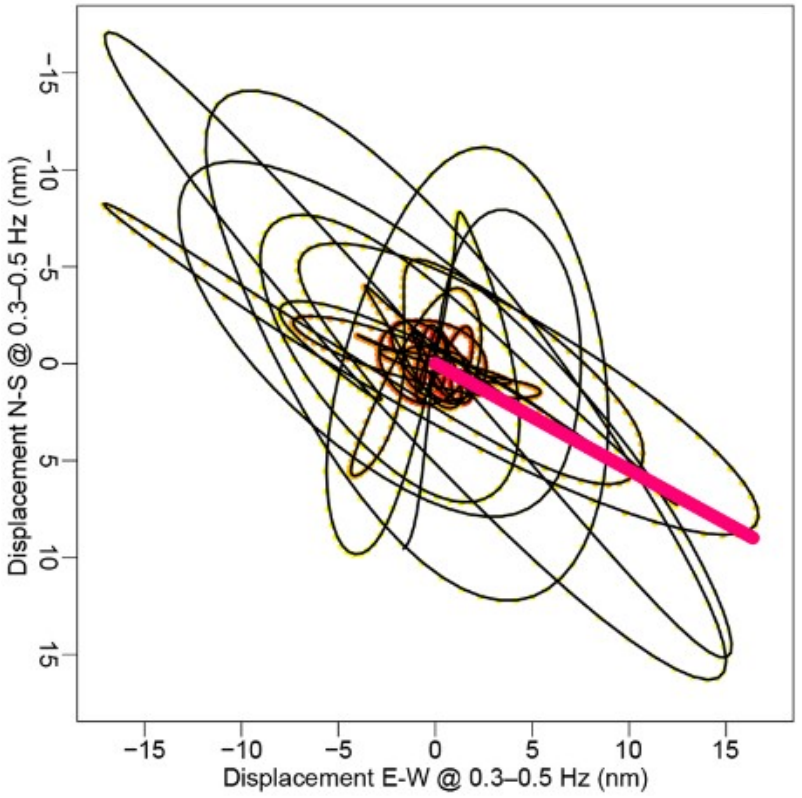


What
(Where)
When
(Why)

But: no model

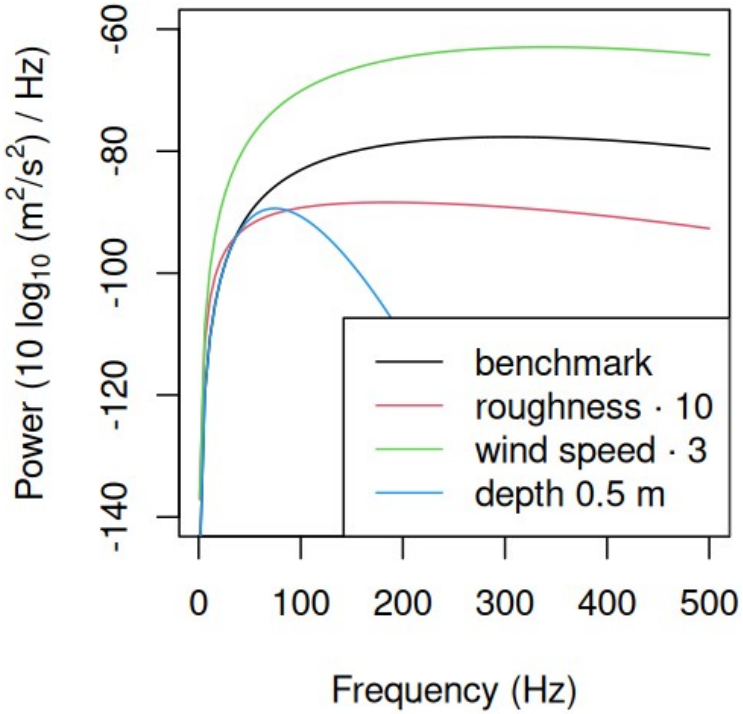


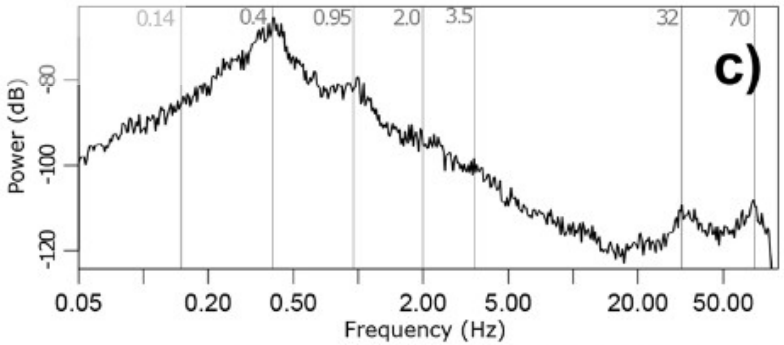
Wind interacting with the biosphere in Patagonia

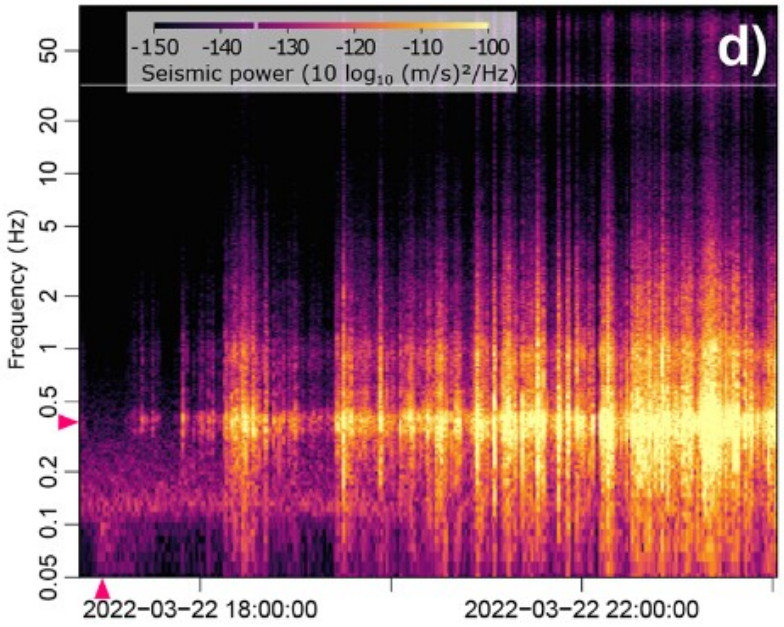


What
(Where)
When
(Why)

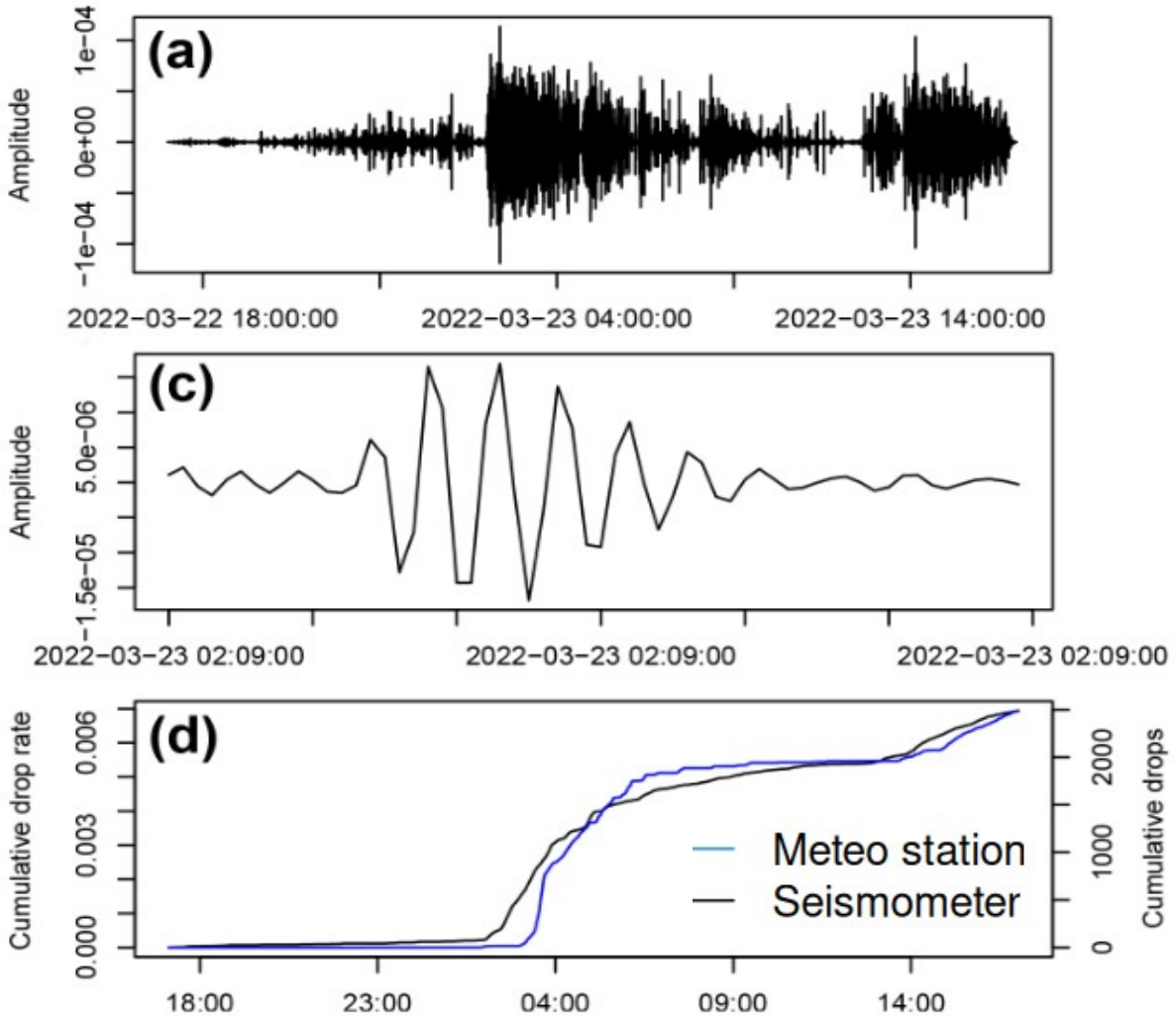
But: no model (yet)



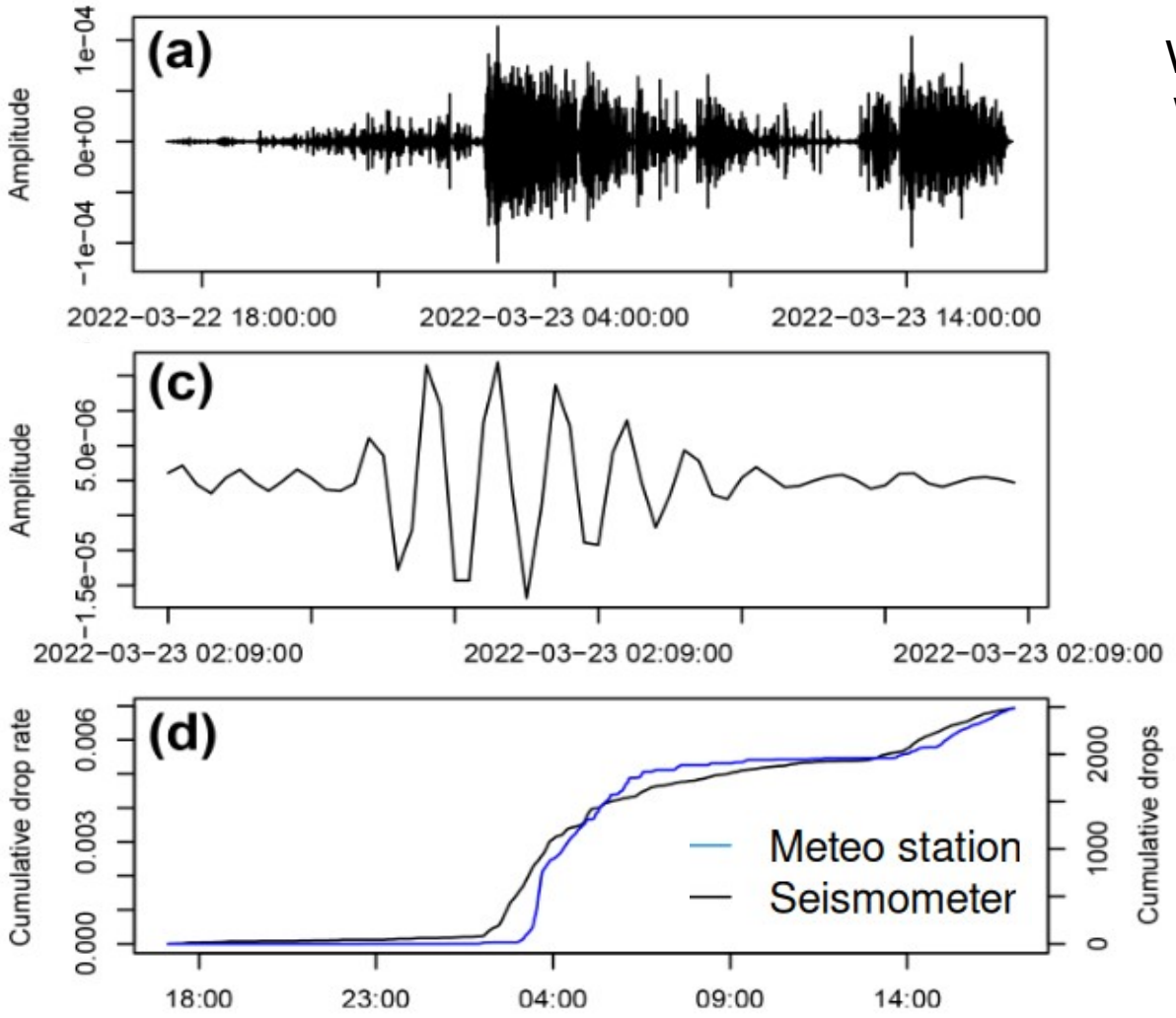




Precipitation interacting with the surface



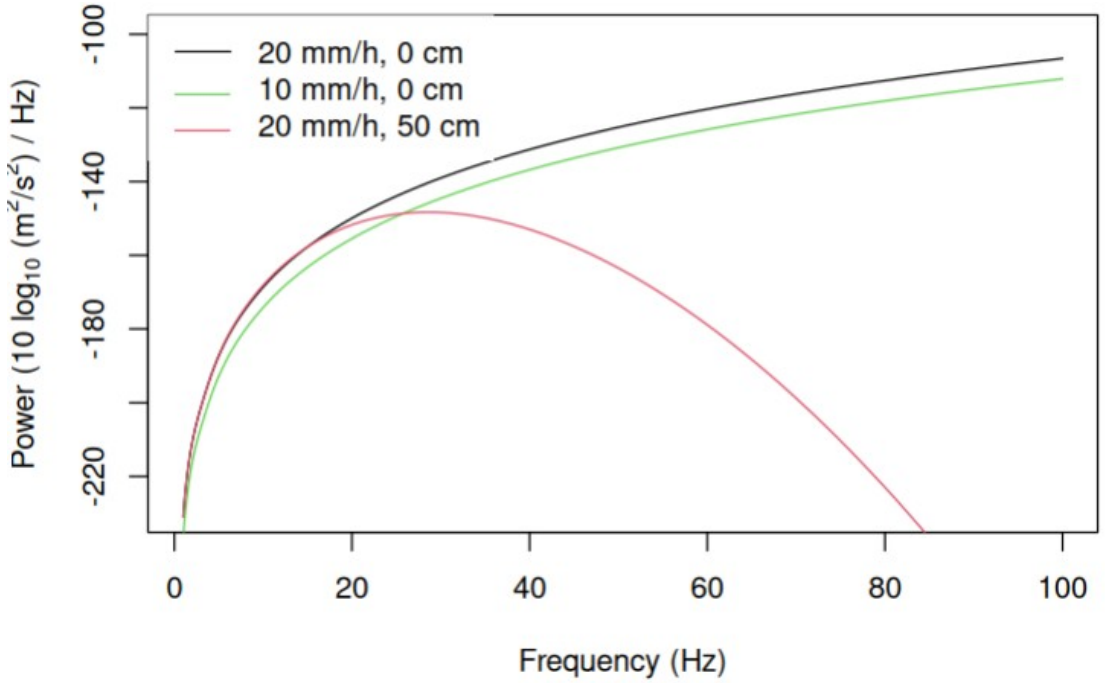
Precipitation interacting with the surface



What
Where
When
Why

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

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



Mohr, Dietze et al. (2024,BioGeoSci)

Bakker at el. (2022, JHydrol), Dietze (2018, ESurf)

So… Where are we?

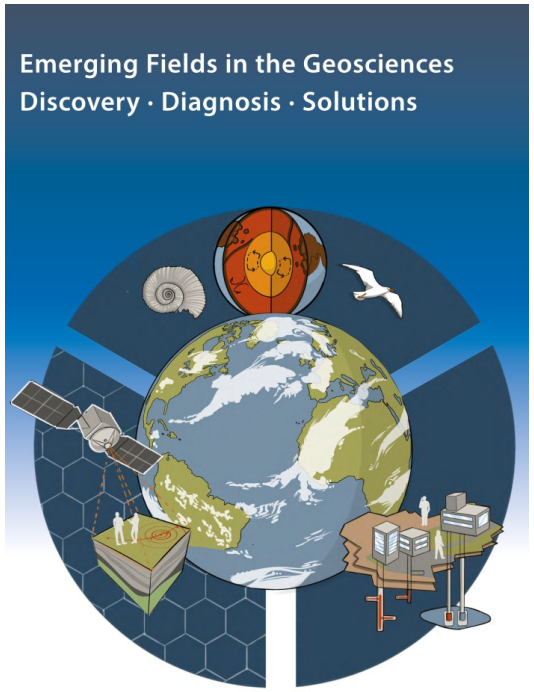
On track:

- Rivers and sediment flux
- Debris flows
- Air pressure and wind
- Precipitation

Pending:

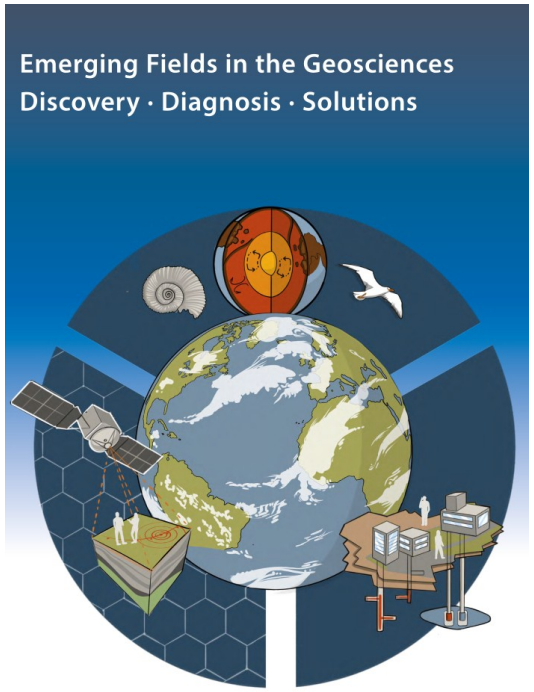
- Stress expression
- Small–medium mass wasting
- Groundwater & Critical Zone

So… Where are we? And why again is this important?



Strategic report on Research agenda in geosciences (in Germany)

So… Where are we? And why again is this important?

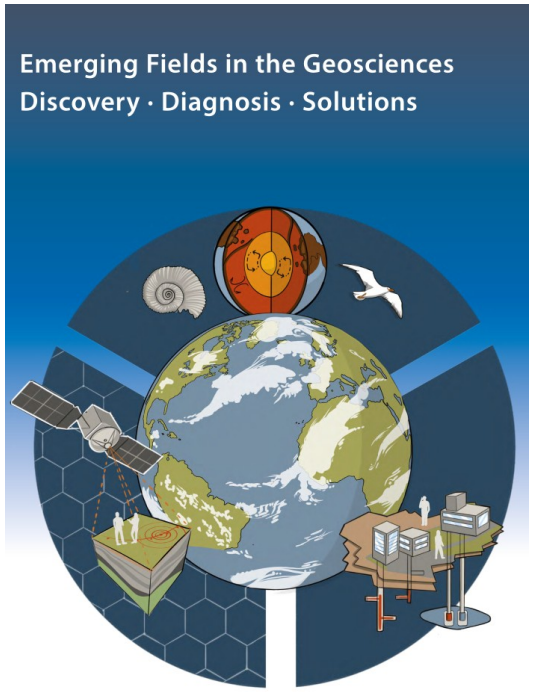


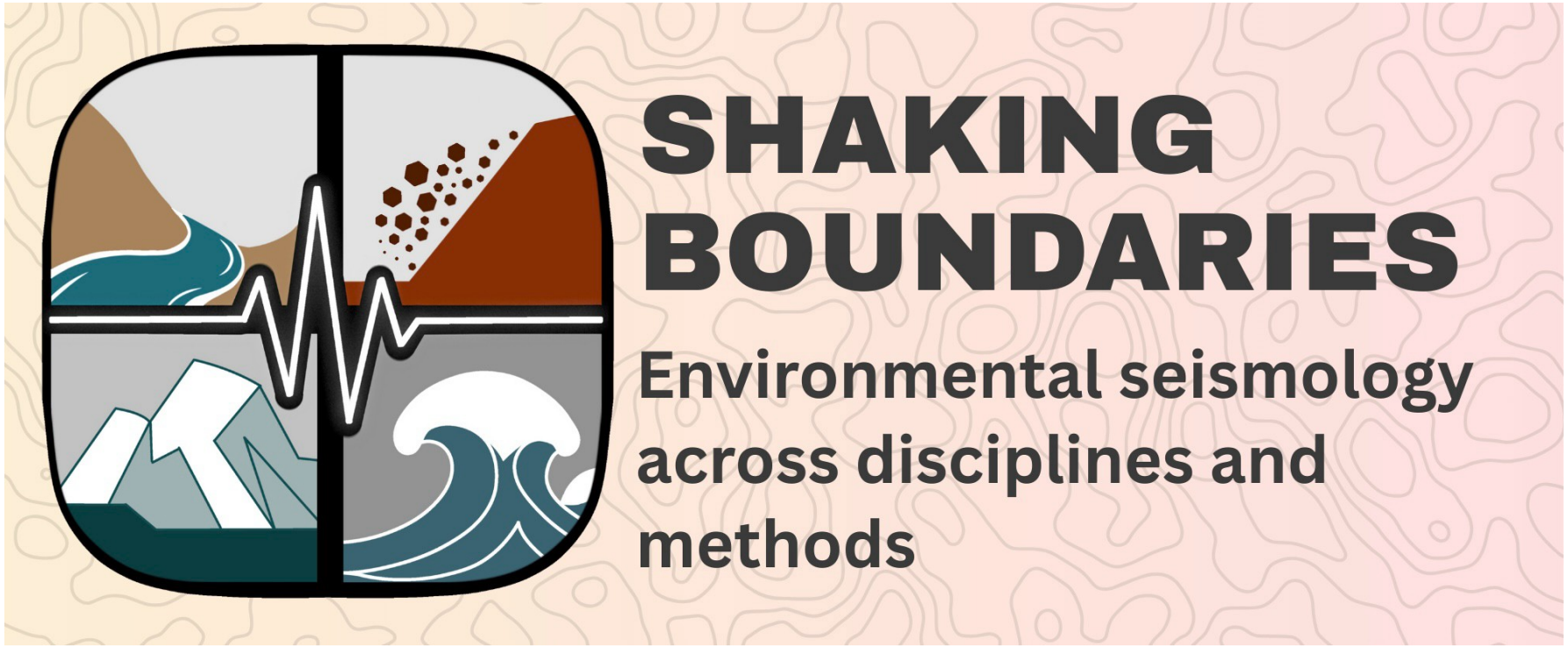
Diagnosis and Simulation of the Earth System and its Interactions

INFOBOX: Environmental seismology .....

Next steps

Thanks!





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