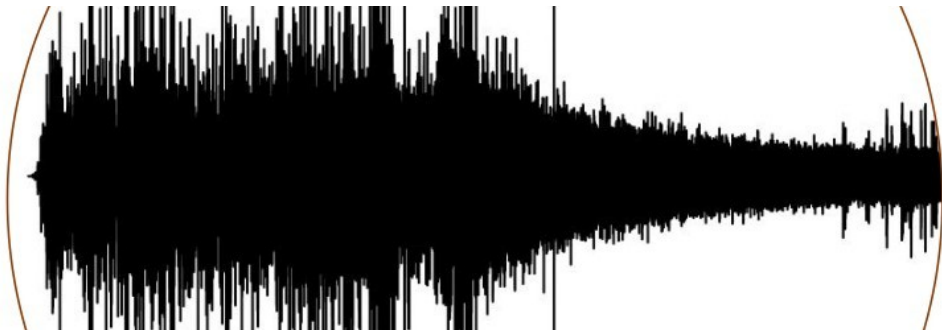




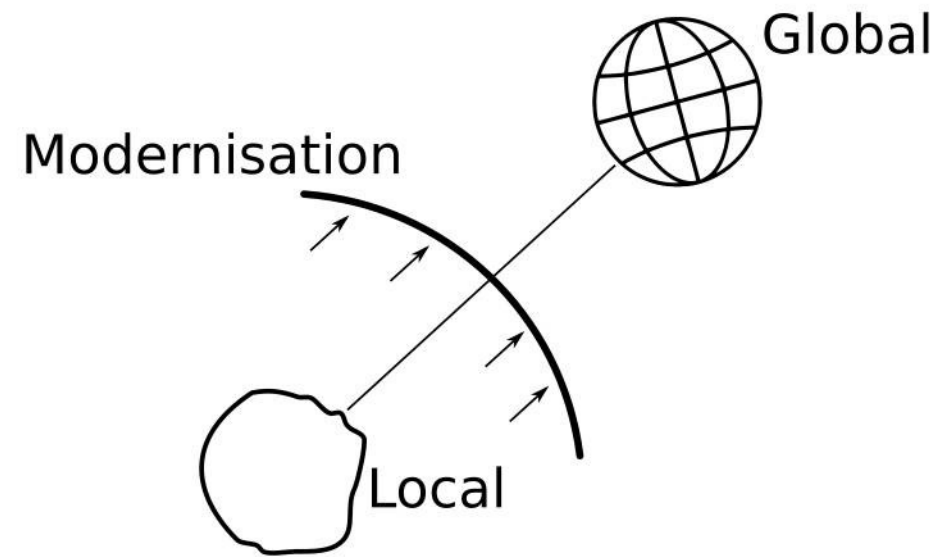
Impakt von Umweltprozessen auf die menschengemachte Welt im Wandel

Umweltseismologie als neues Kapitel der geographischen Forschung

Michael Dietze
RWTH Aachen

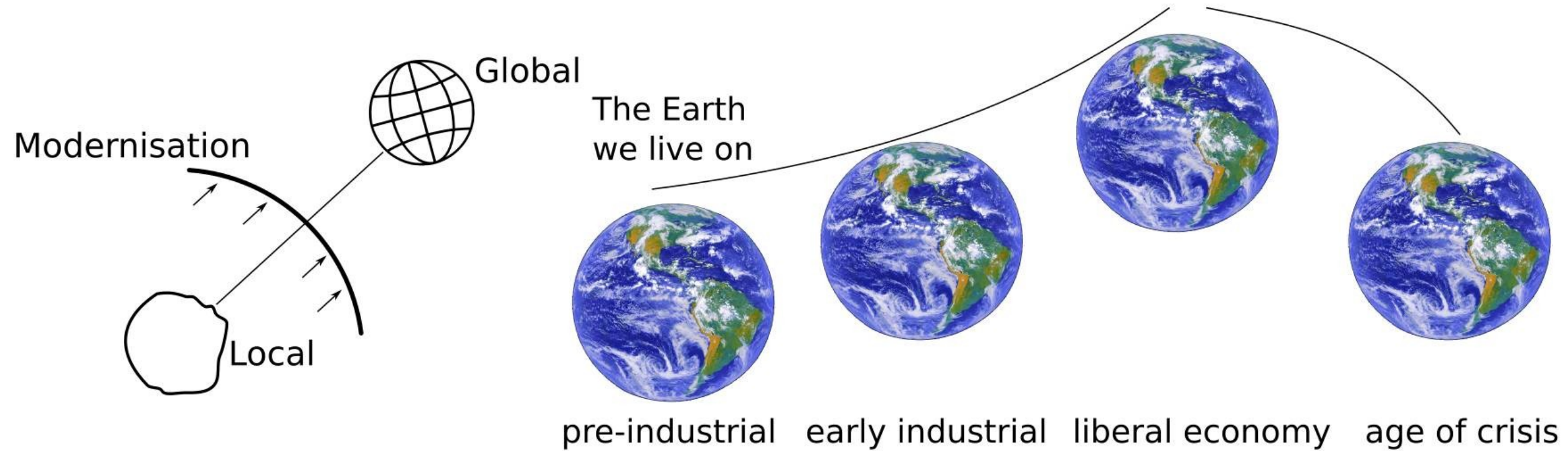
A broad research motivation

A TERRESTRIAL PERSPECTIVE ON CHANGE



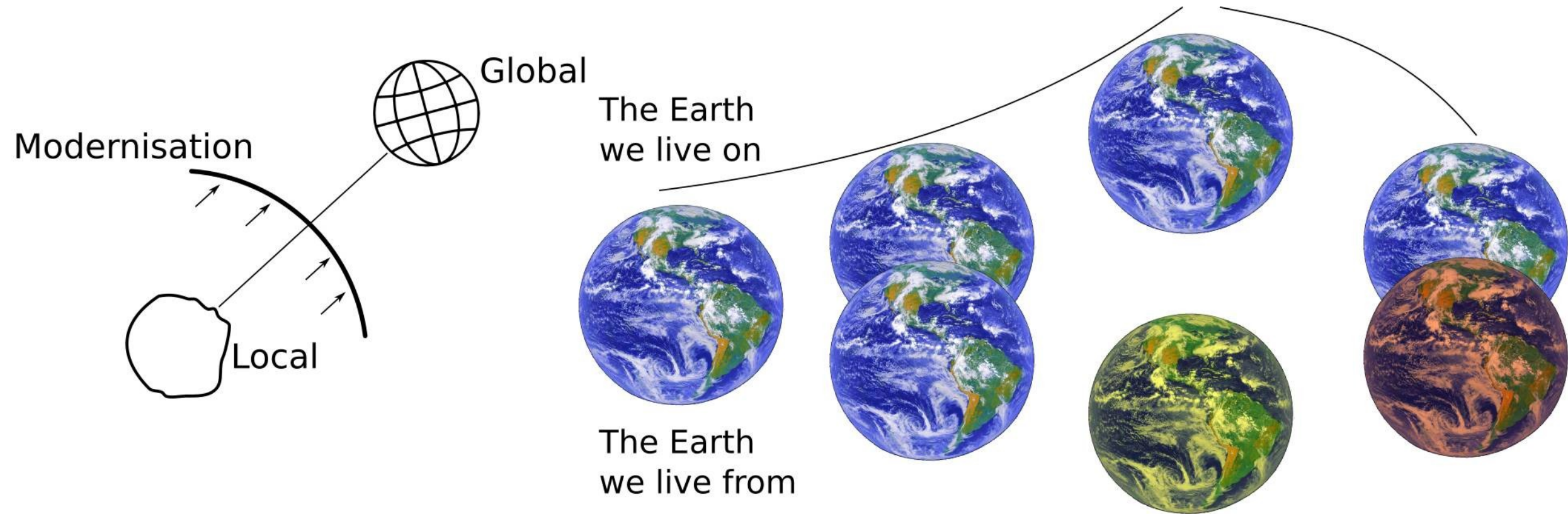
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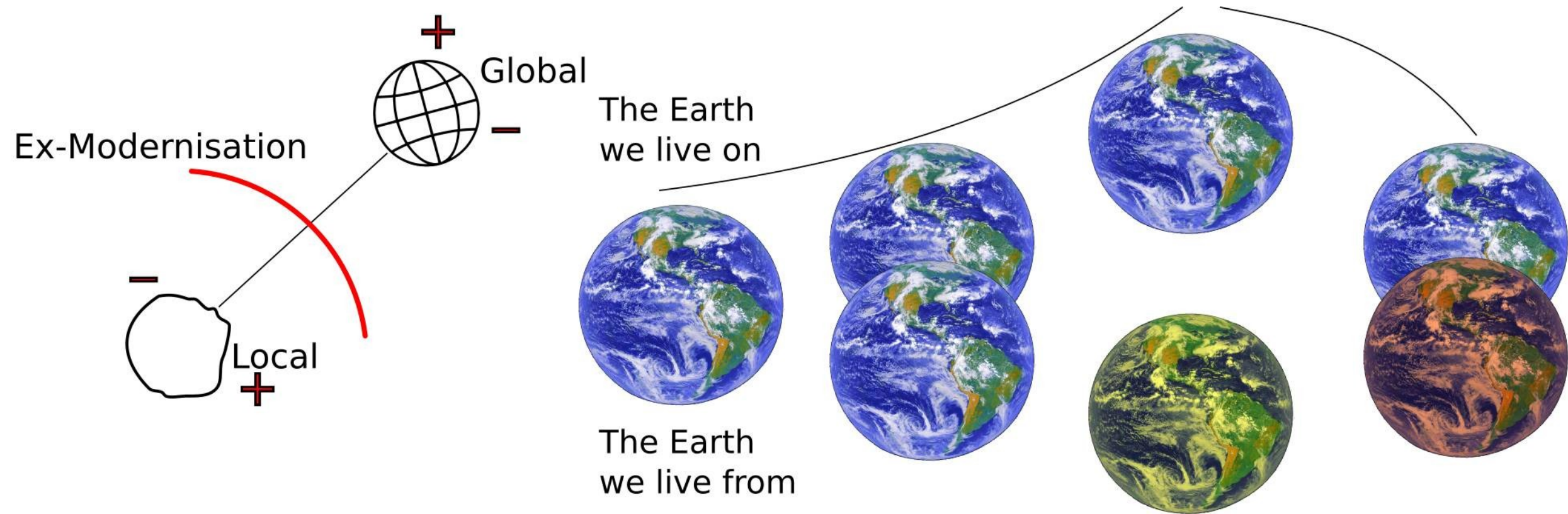
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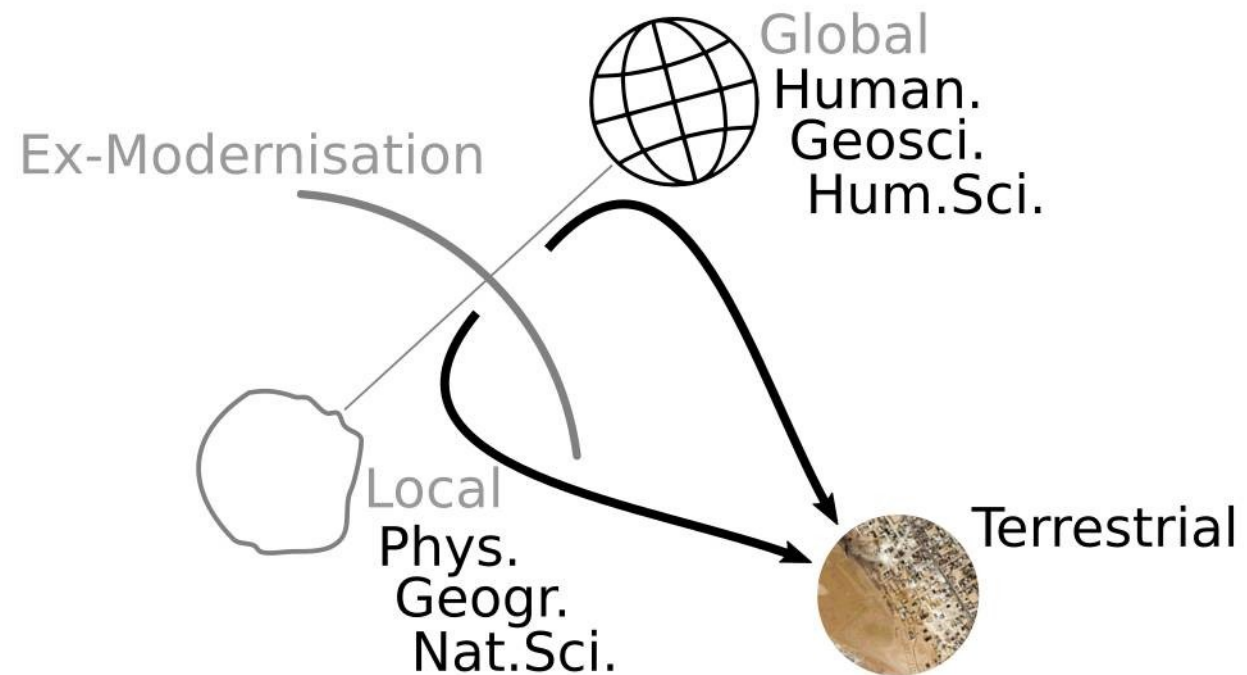
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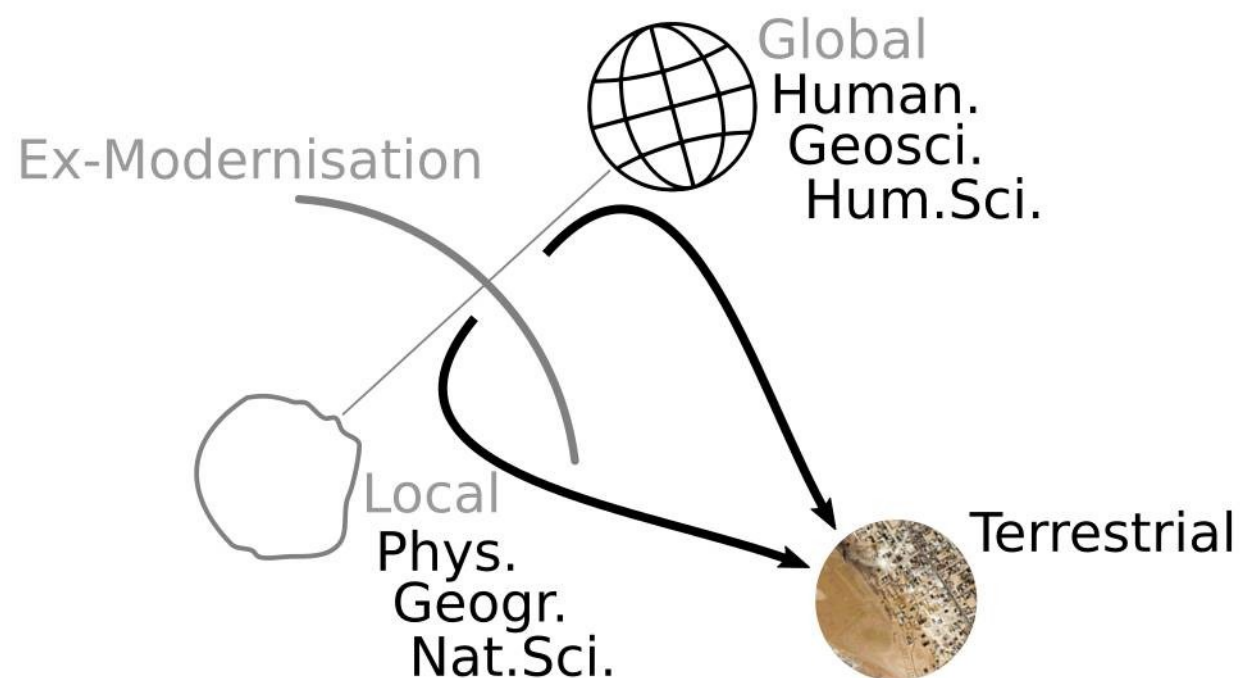
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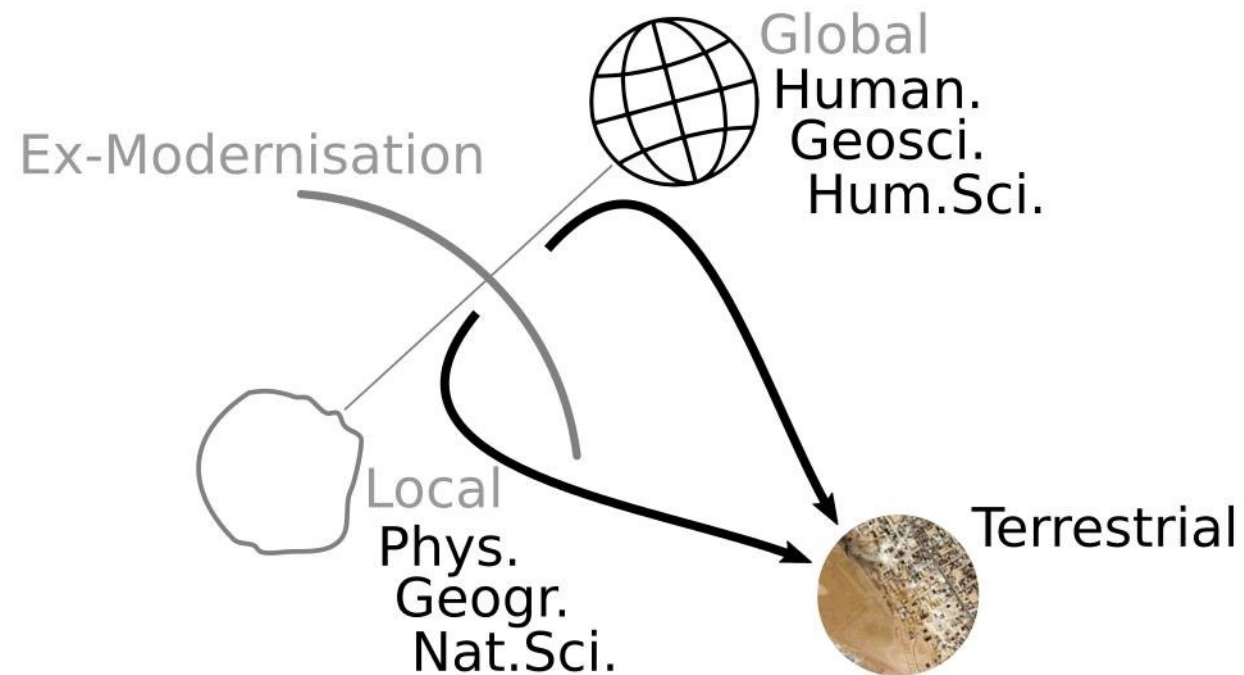
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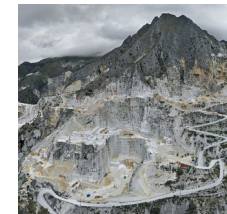
Measure what happens on our planet and what has left its *signatures* in landscapes
→ We need empirical data to test hypothesis, validate models, estimate impacts

A broad research motivation

A TERRESTRIAL PERSPECTIVE ON CHANGE



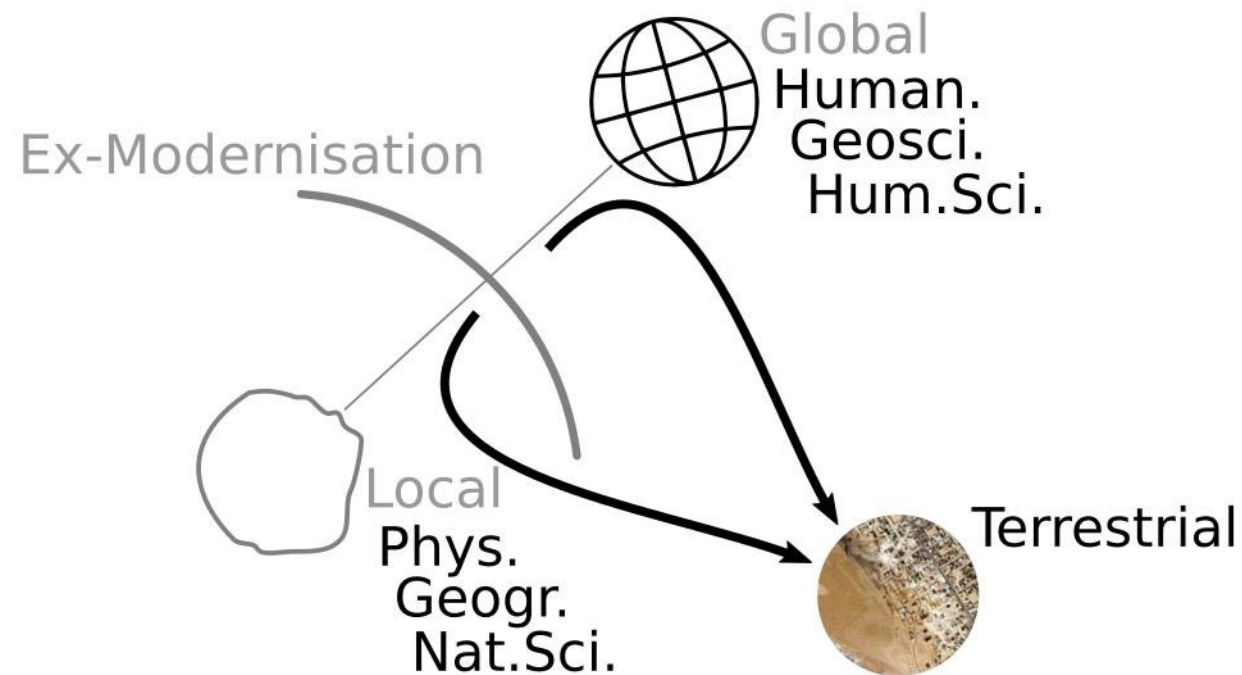
Measure what happens on our planet and what has left its *signatures* in landscapes
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Embrace *Earth System Science* as feedback framework *including human* actions
→ Approaches to societal problems must include society as problem & its solution

A broad research motivation

A TERRESTRIAL PERSPECTIVE ON CHANGE



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Embrace *Earth System Science* as feedback framework *including human* actions
→ Approaches to societal problems must include society as problem & its solution



Include the *public and stakeholders* in our research process
→ Science is for society, and knowledge transfer is mutually beneficial



April



Saevar River, N-Sweden (2018)

03 June ➤

Short introduction to environmental seismology

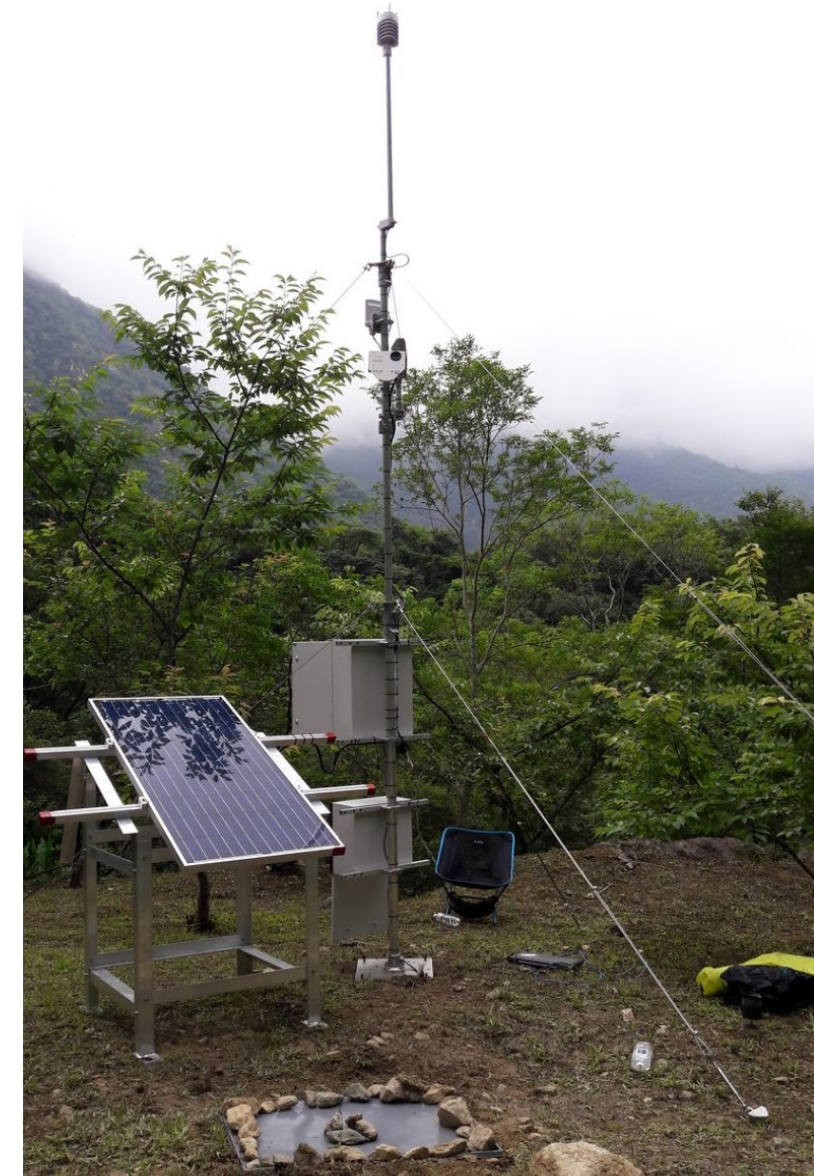
HOW EARTHQUAKE SENSORS WORK AND WHAT WE CAN RECORD WITH THEM



Negev-Wüste, Israel



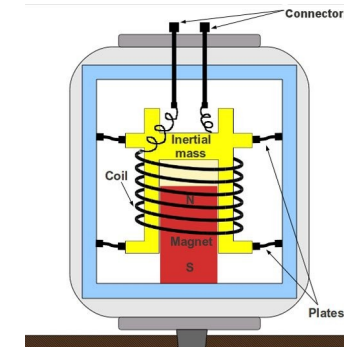
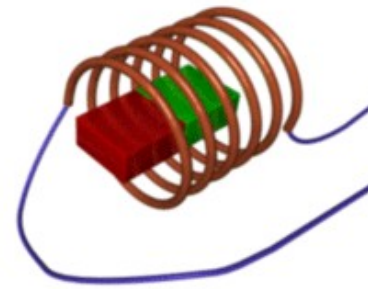
Insel Orkney, Schottland



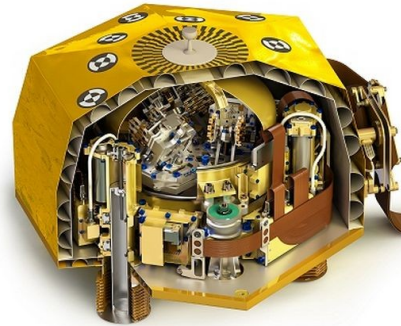
Taroko-NP, Taiwan

Short introduction to environmental seismology

HOW EARTHQUAKE SENSORS WORK AND WHAT WE CAN RECORD WITH THEM



Prinzip: magnetische Induktion & Feder



132 AD, Zhang Heng

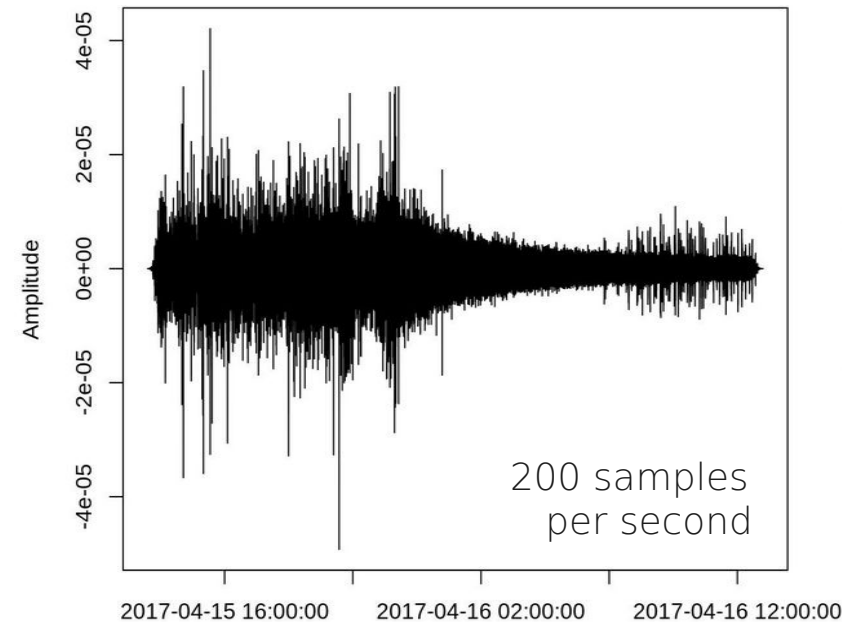
2018, elektrodynamisch auf dem Mars ...

Short introduction to environmental seismology

HOW EARTHQUAKE SENSORS WORK AND WHAT WE CAN RECORD WITH THEM



Seismograms (time series)

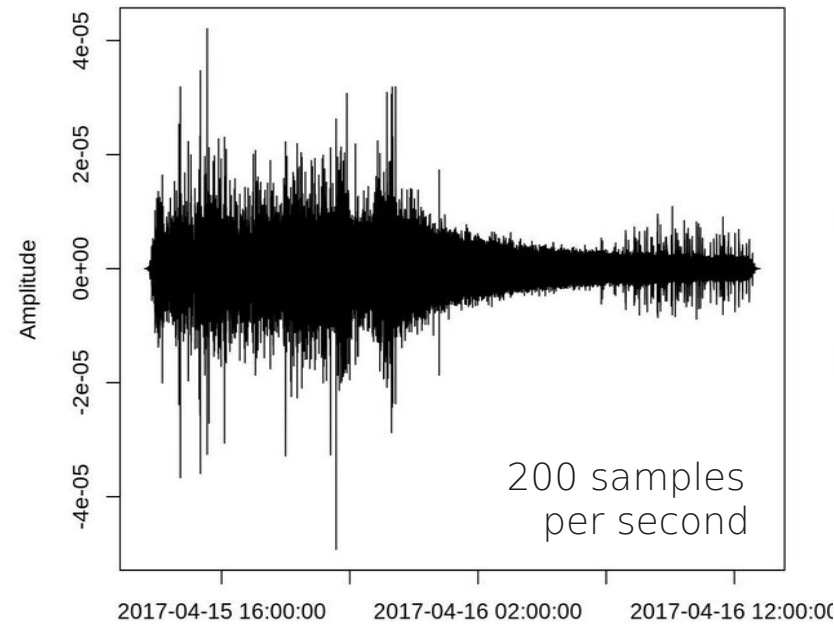


Short introduction to environmental seismology

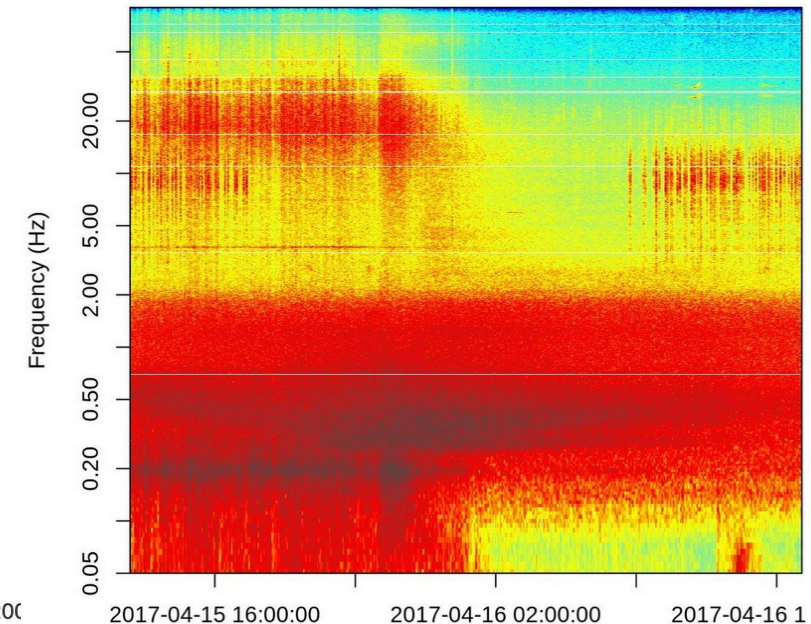
HOW EARTHQUAKE SENSORS WORK AND WHAT WE CAN RECORD WITH THEM



Seismograms (time series)



Spectrograms (time series by freq.)

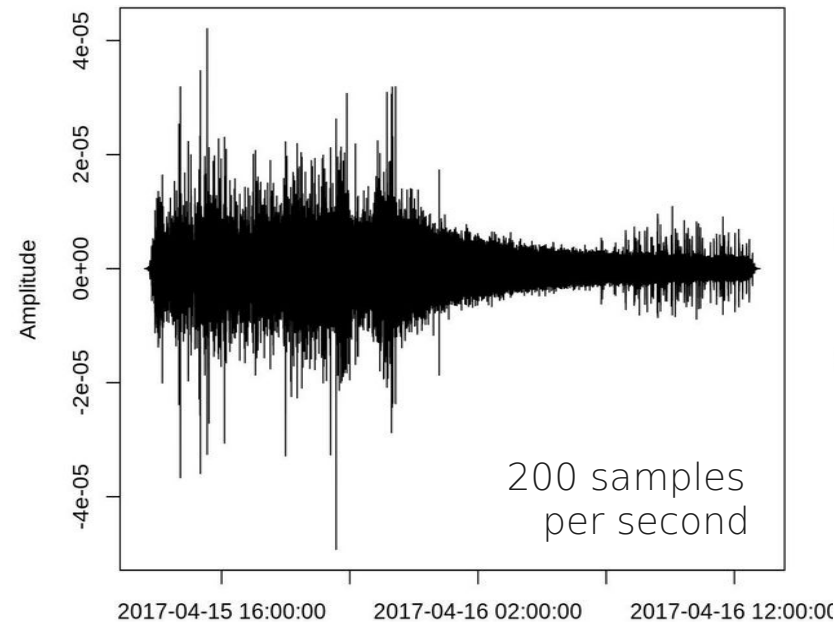


Short introduction to environmental seismology

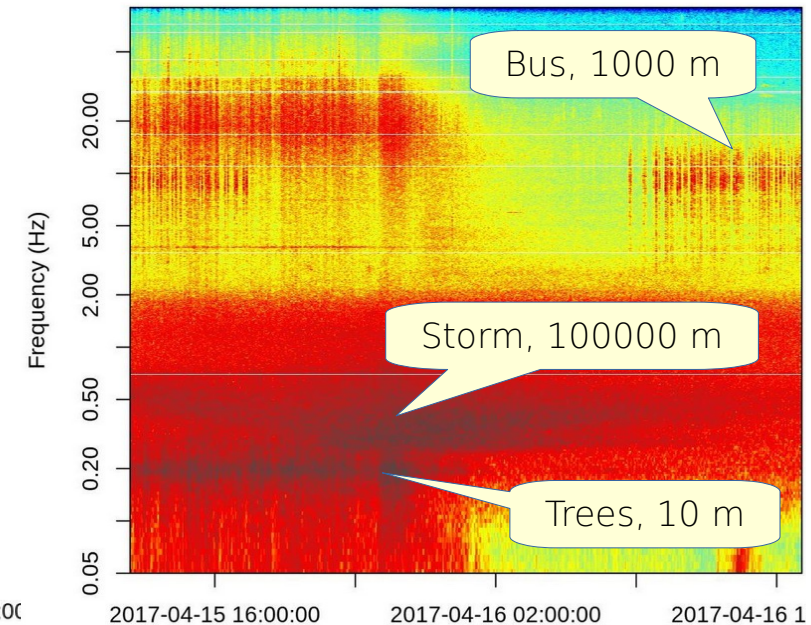
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Spectrograms (time series by freq.)

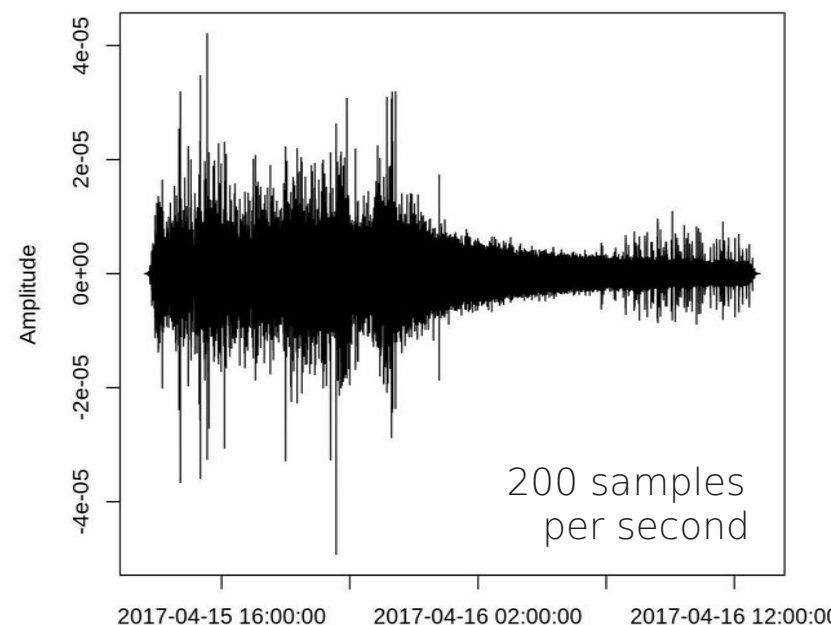


Short introduction to environmental seismology

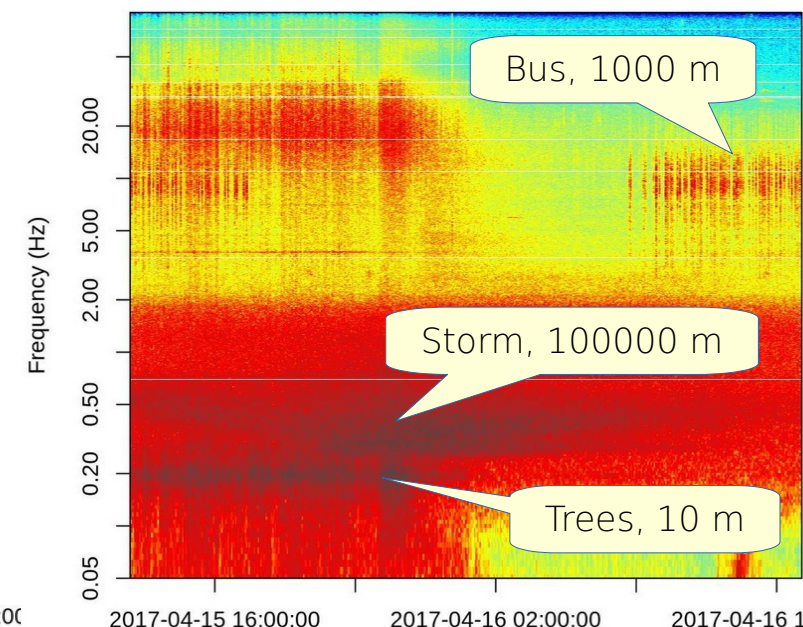
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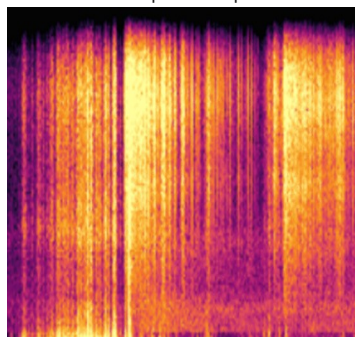
Seismograms (time series)



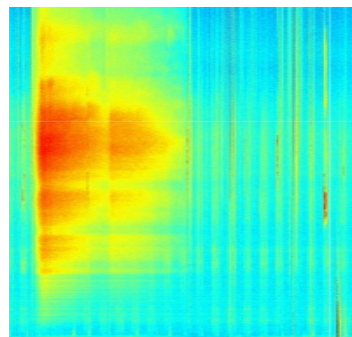
Spectrograms (time series by freq.)



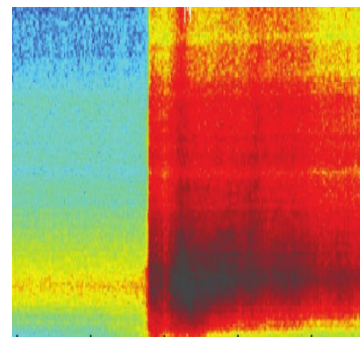
Raindrop impacts



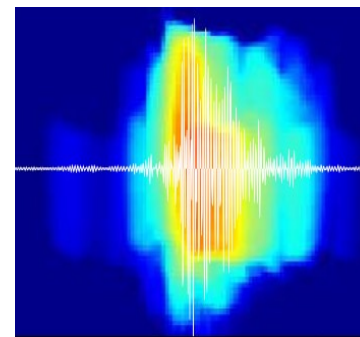
Debris flows



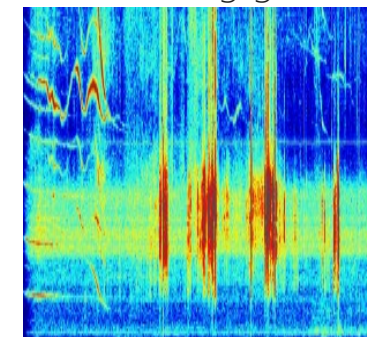
Lake outburst flood



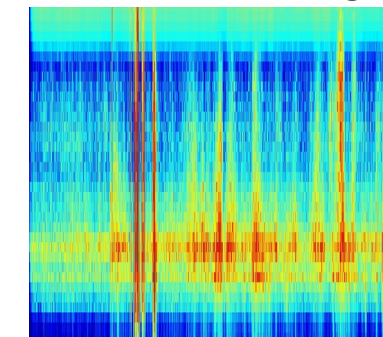
Brittle rock failure



Fish moving gravel

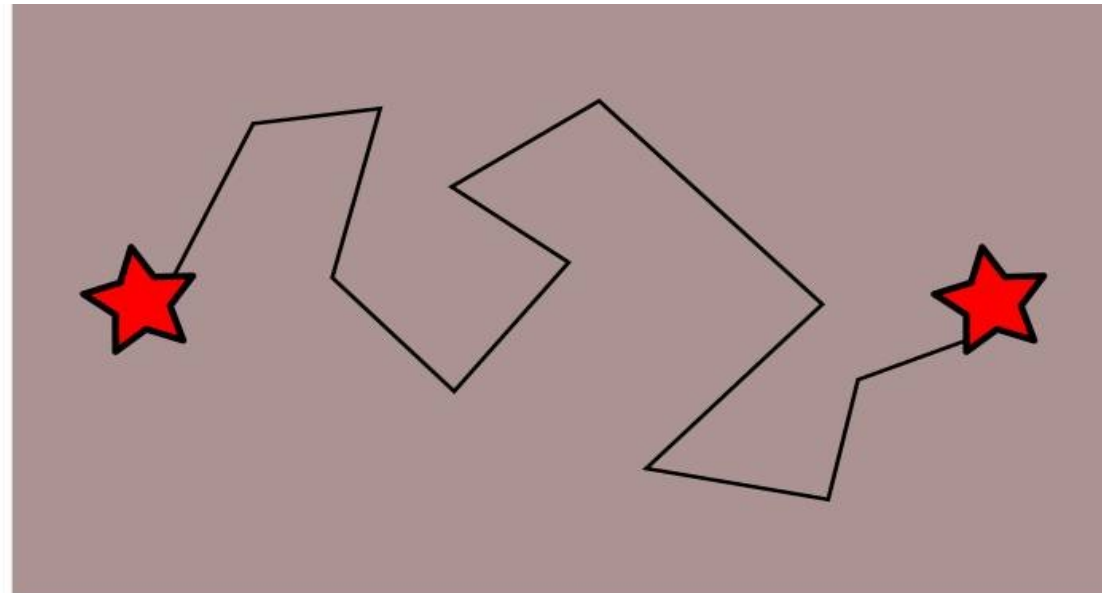
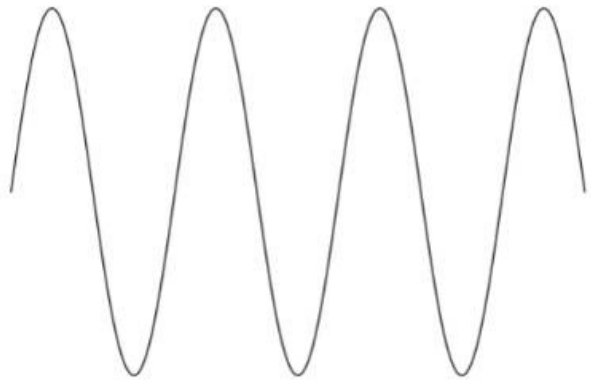


Earthworm mixing soil



Short introduction to environmental seismology

HOW EARTHQUAKE SENSORS WORK AND WHAT WE CAN RECORD WITH THEM



Seismic station pairs,

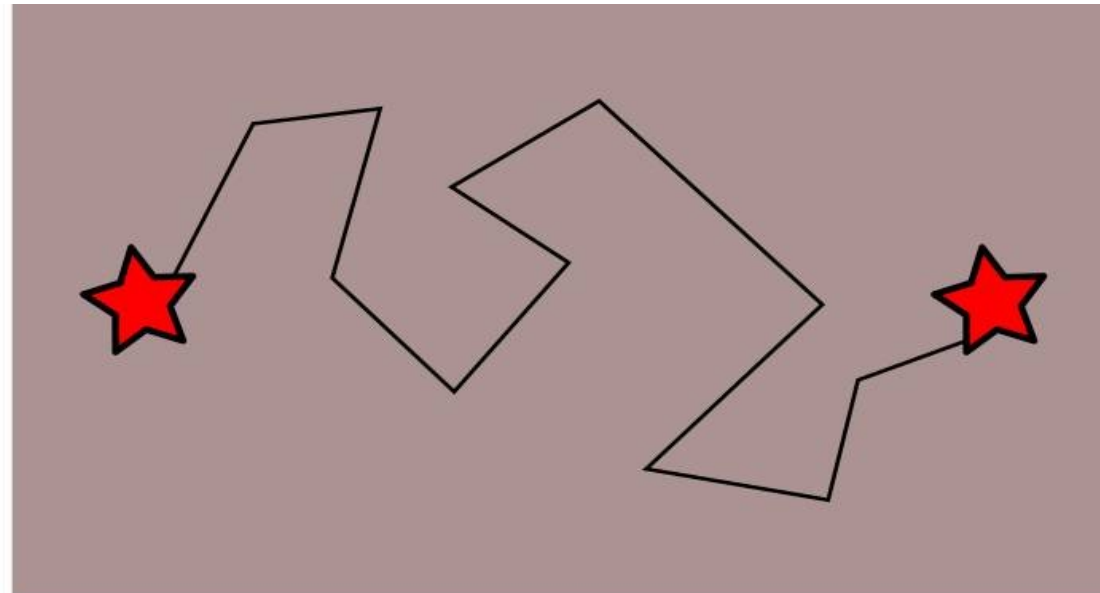
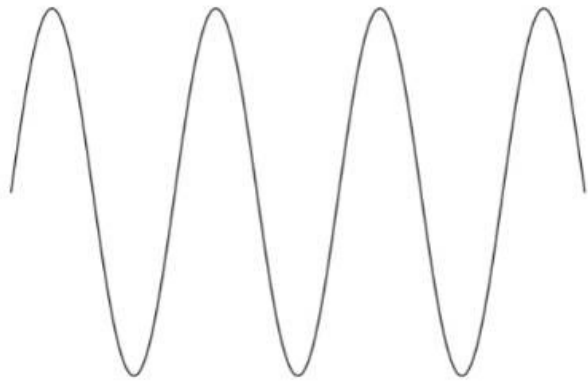
- A serves "source",
- B serves as "receiver"
- (and vice versa)

Medium between A and B
changes the signal

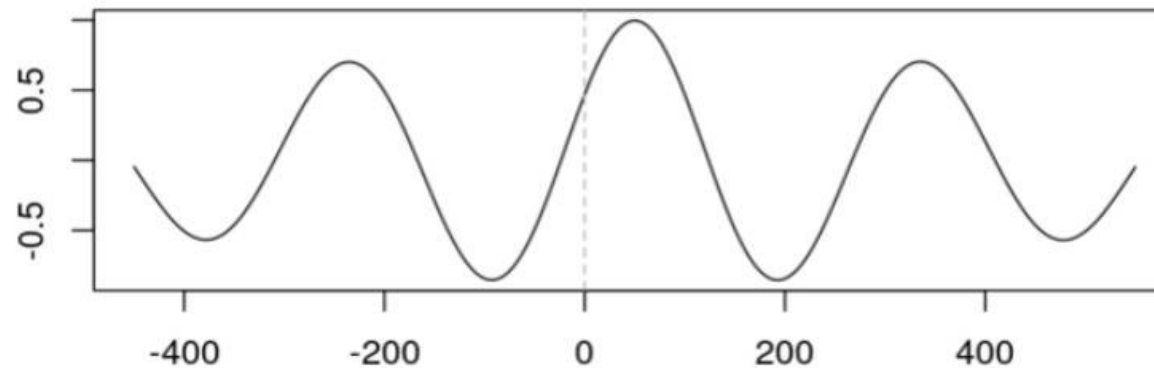
Due to frequency-dependent
scattering

Short introduction to environmental seismology

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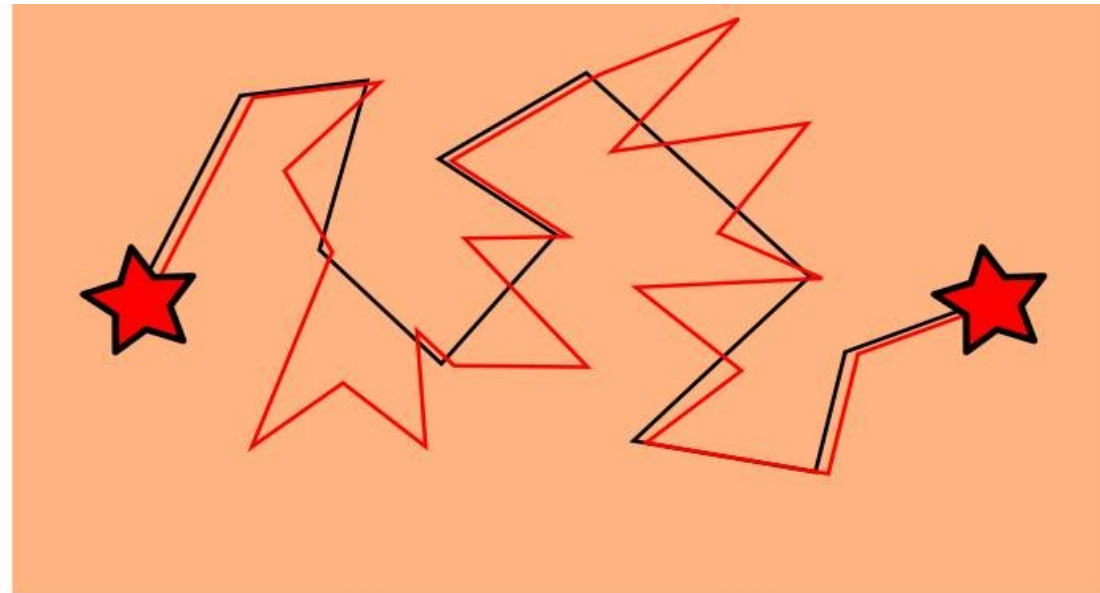
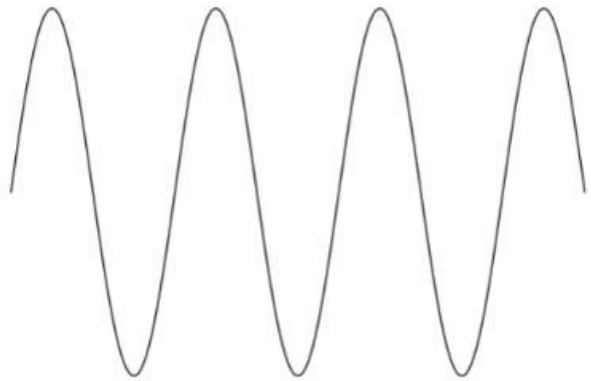
Correlating A and B gives
a characteristic correla-
tion function



Cross-correlation maximum
is shifted from zero if
noise source is not equally
distributed

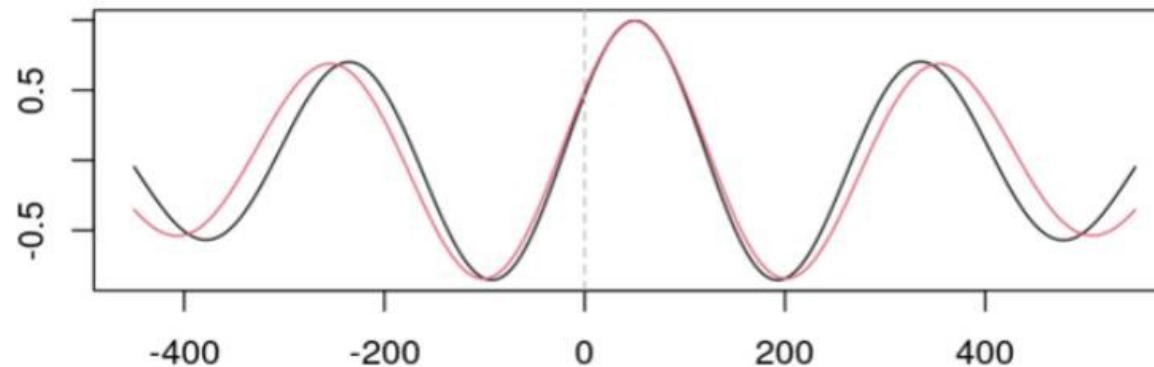
Short introduction to environmental seismology

HOW EARTHQUAKE SENSORS WORK AND WHAT WE CAN RECORD WITH THEM



Any change in medium (i.e. ground properties) changes the correlation function

Relative velocity change



Maxima are left untouched
But stretched cc-function is a direct proxy of ground property change with time

Short introduction to environmental seismology

HOW EARTHQUAKE SENSORS WORK AND WHAT WE CAN RECORD WITH THEM



Compact, flexible sensor systems that can be deployed in (almost) all kinds of landscapes, also at ocean bottoms, transmitting at near real time

Ability to record continuous (over decades), at high resolution (100's of samples per second), a wide range of signal types (raindrops to rock slides)

Analysis of discrete, short pulses of seismic activity

Analysis of spatial propagation of geomorphic processes

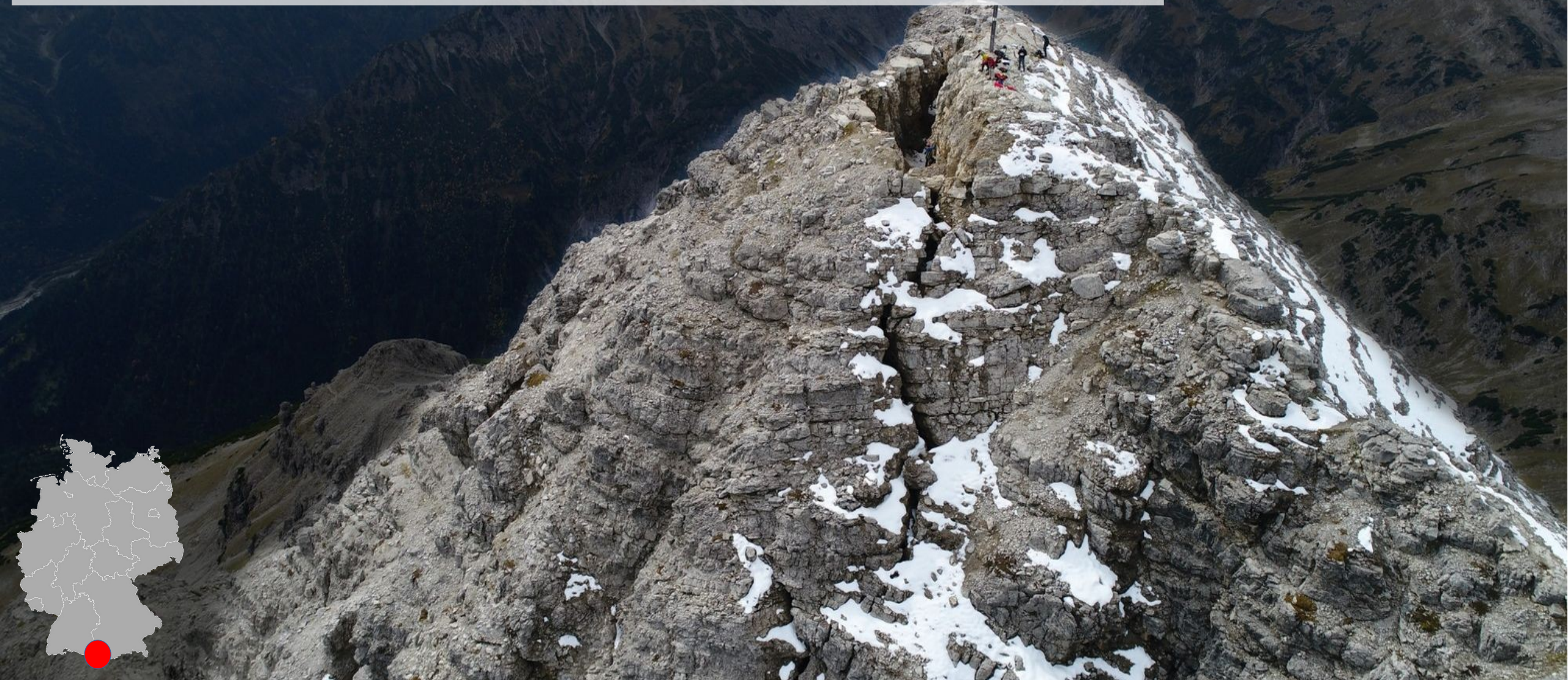
Analysis of long-term, transient change

Analysis of landform resonance & ground property change

Analysis of interaction of landscape elements

Example 1: Mass wasting hazards in populated mountain landscapes

A SOLITARY ALPINE PEAK THAT IS DEEMED TO FAIL, BUT WITH UNKNOWN PRECURSORS AND LIKELIHOOD



Example 1: Mass wasting hazards in populated mountain landscapes

A SOLITARY ALPINE PEAK THAT IS DEEMED TO FAIL, BUT WITH UNKNOWN PRECURSORS AND LIKELIHOOD

When do I fail?

How will I fail?

Where will I fail to?

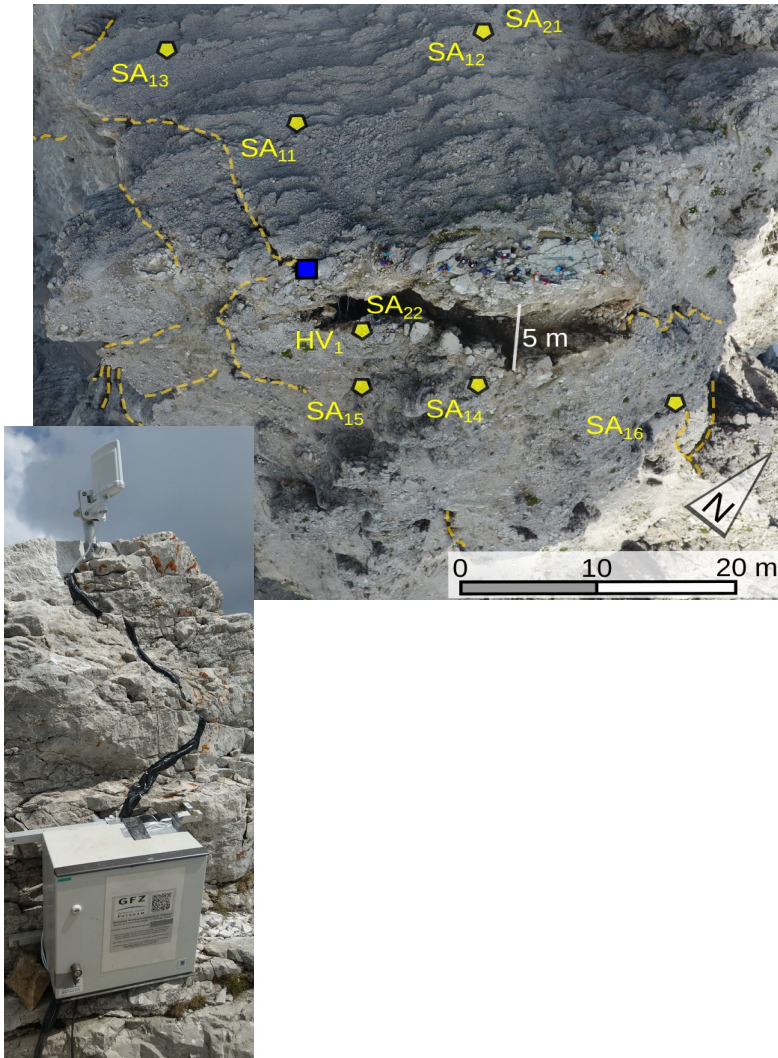
What drives my failure?

How to probe my fate?



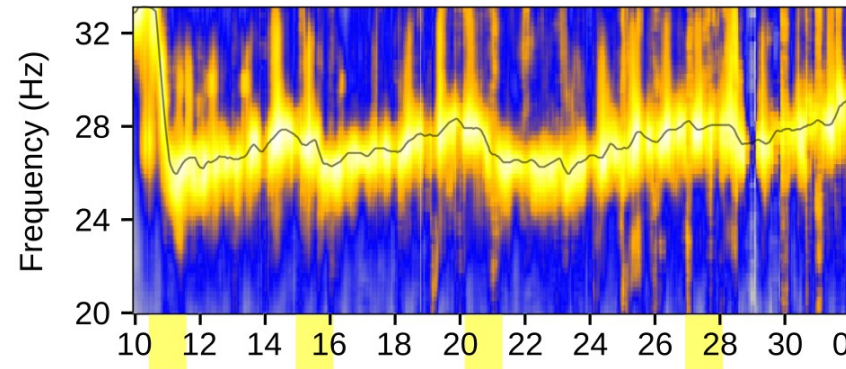
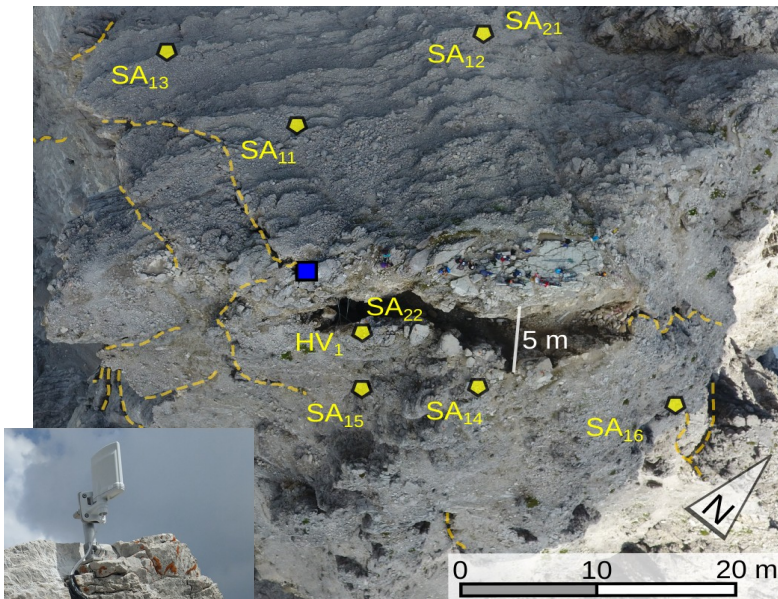
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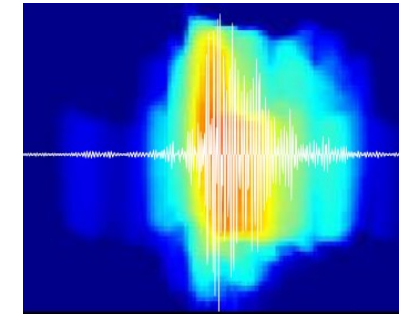
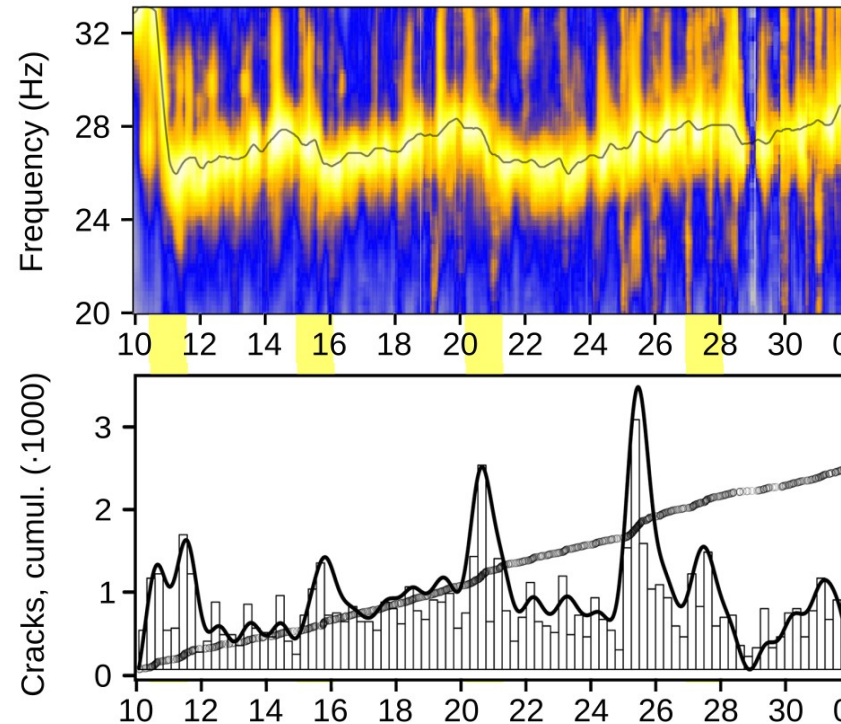
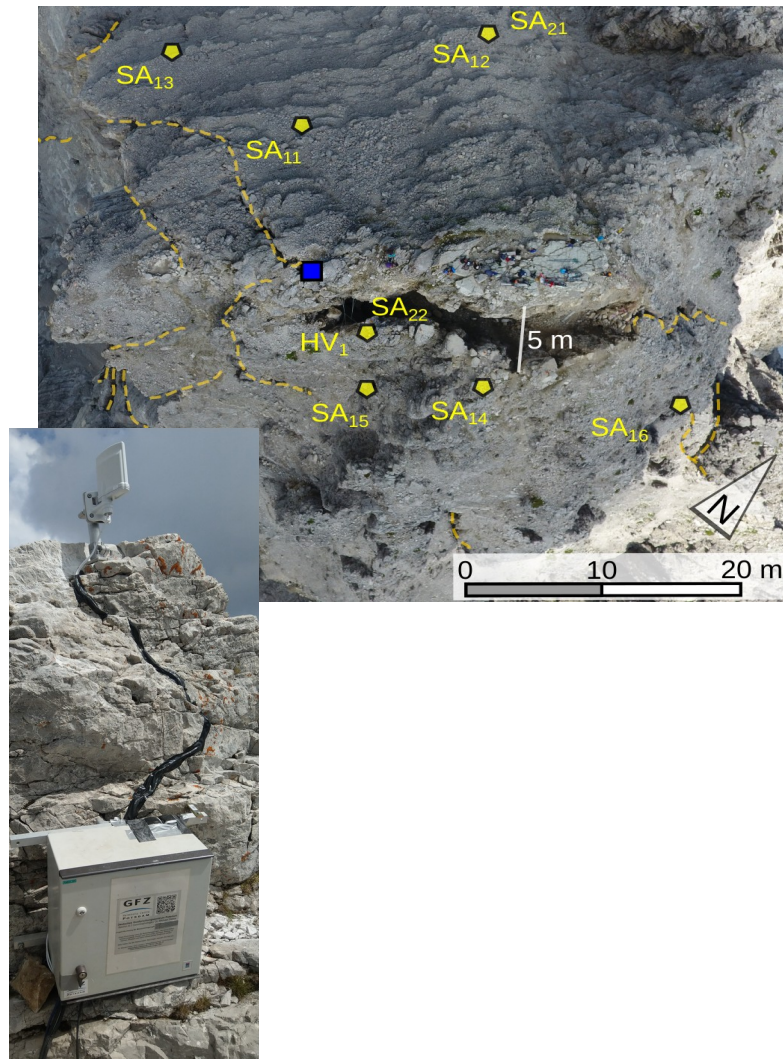
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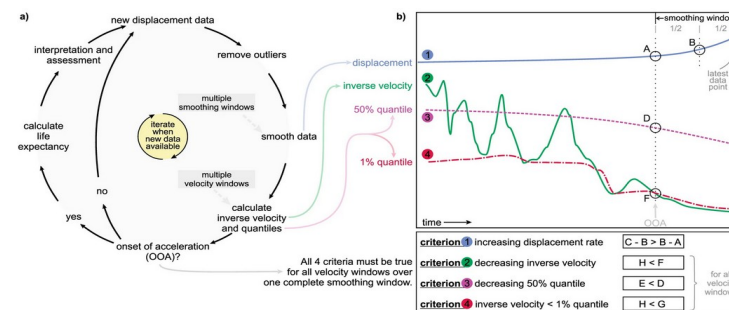
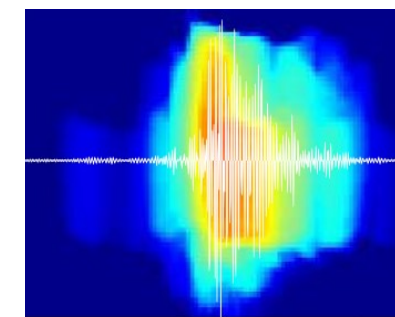
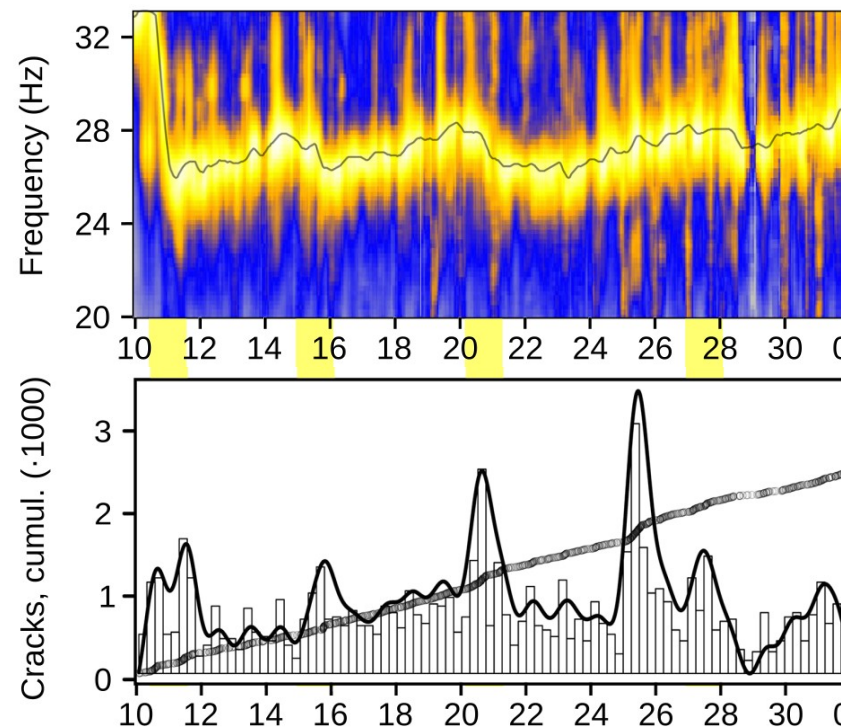
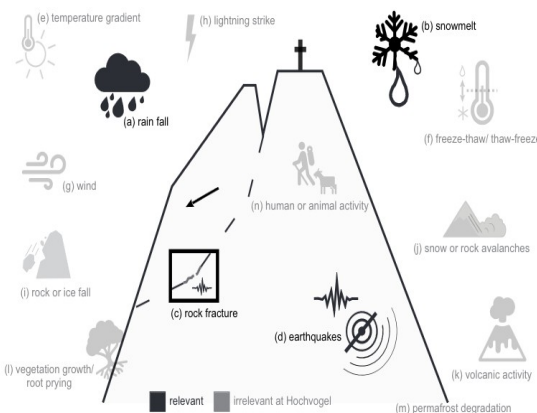
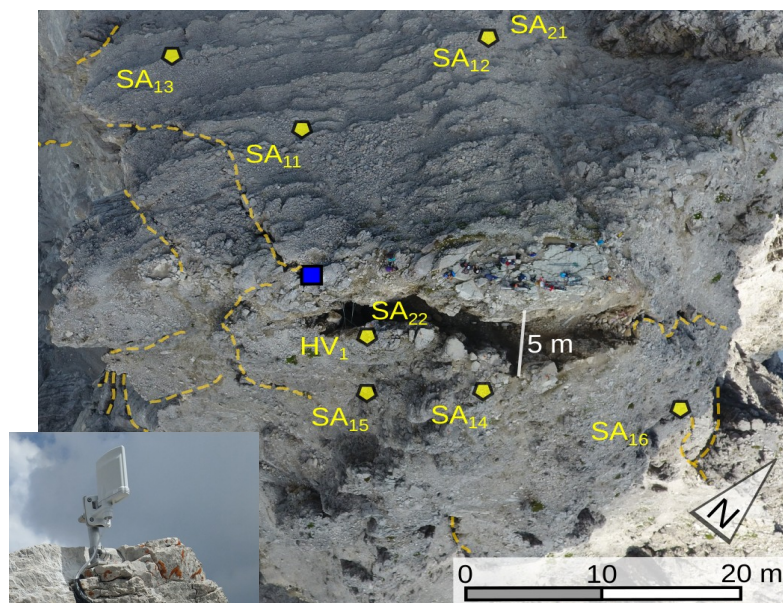
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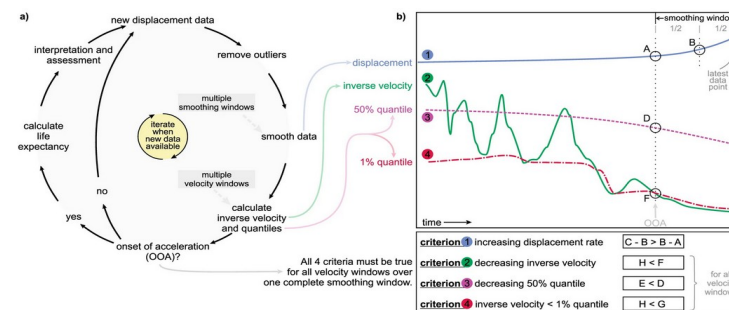
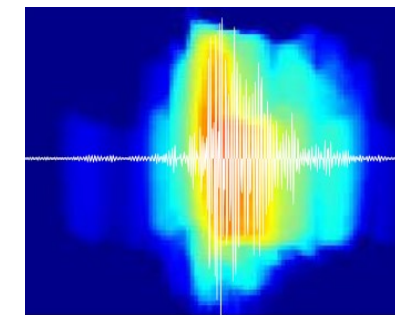
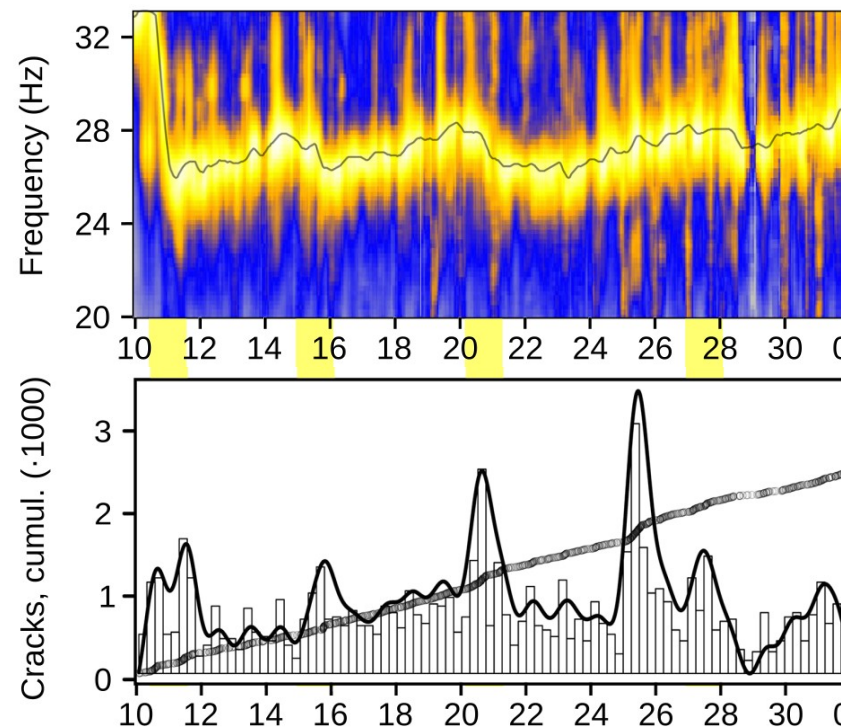
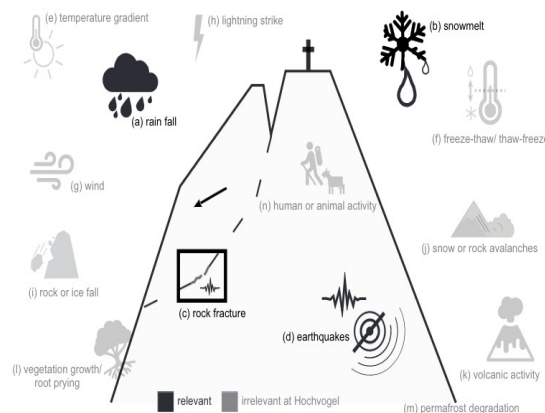
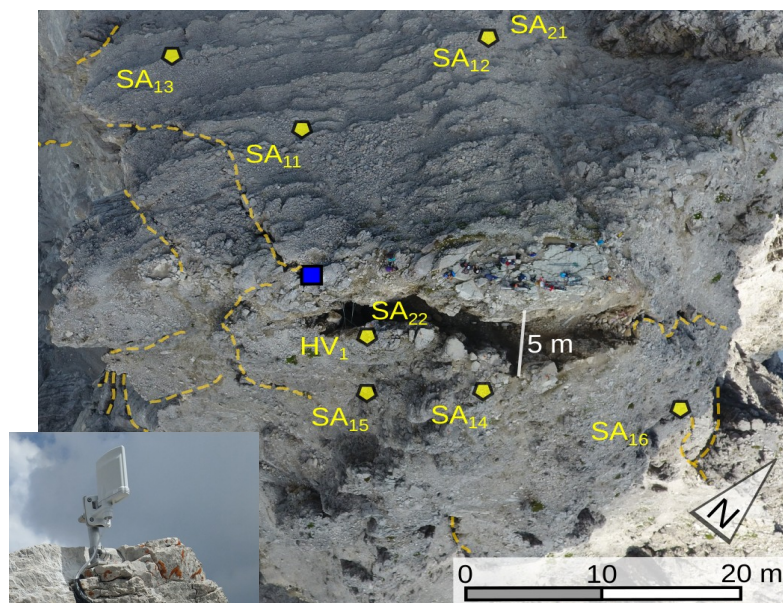
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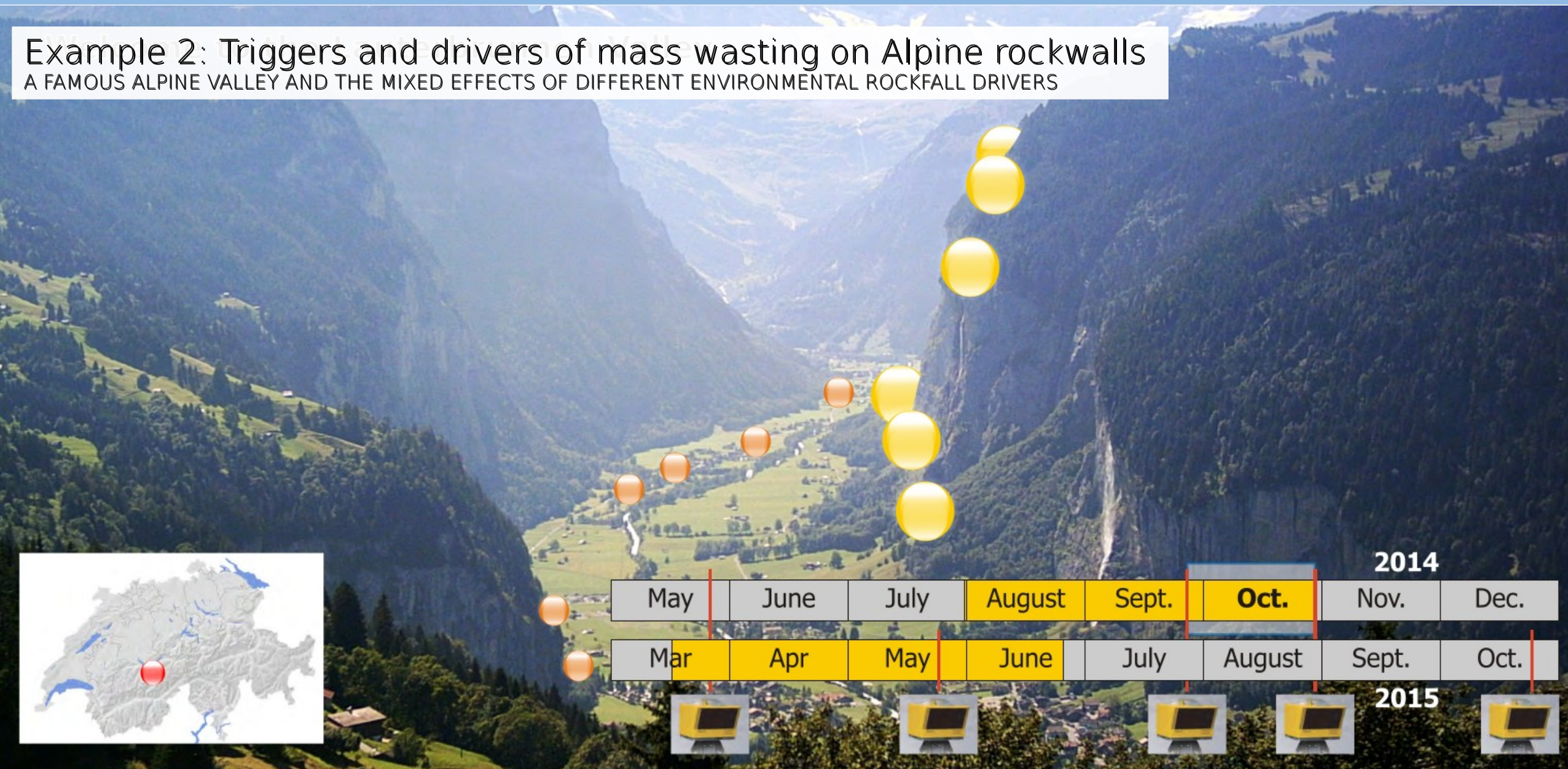


→ Quantification of summit-wide stick-slip evolution

→ Long-term and real-time access to first order warnings on mass rockslides

Example 2: Triggers and drivers of mass wasting on Alpine rockwalls

A FAMOUS ALPINE VALLEY AND THE MIXED EFFECTS OF DIFFERENT ENVIRONMENTAL ROCKFALL DRIVERS



Example 2: Triggers and drivers of mass wasting on Alpine rockwalls

A FAMOUS ALPINE VALLEY AND THE MIXED EFFECTS OF DIFFERENT ENVIRONMENTAL ROCKFALL DRIVERS



Earthquakes



Volcanism



Snow avalanches



Rainfall



Human action



Lightning strike



Freeze-thaw/
thermal forcing



Fluvial activity



Wind

Example 2: Triggers and drivers of mass wasting on Alpine rockwalls

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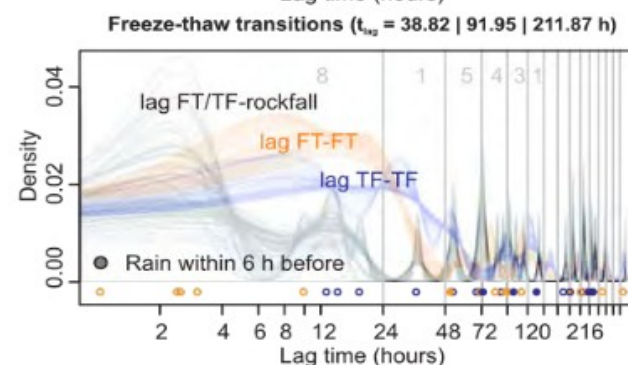
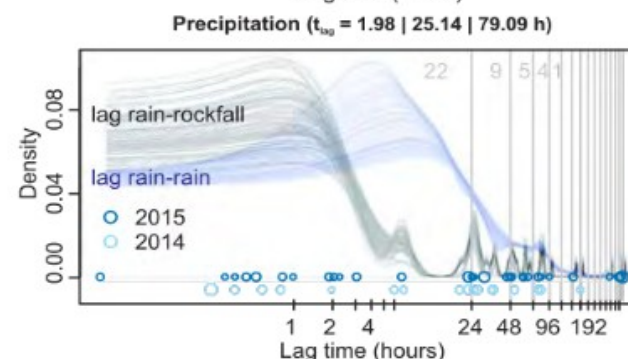
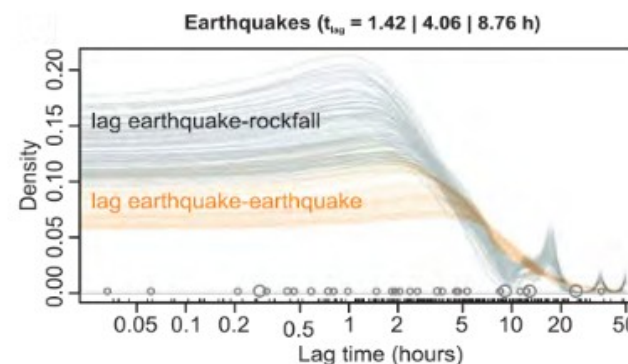
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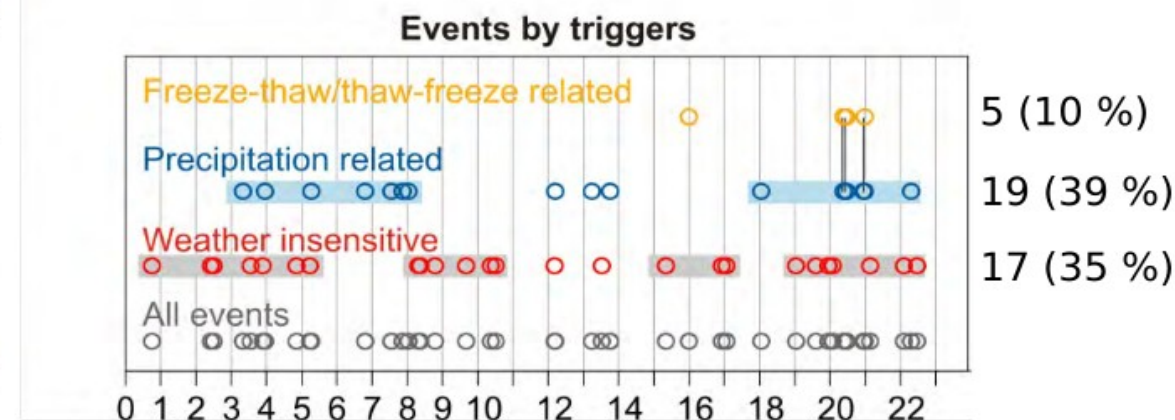
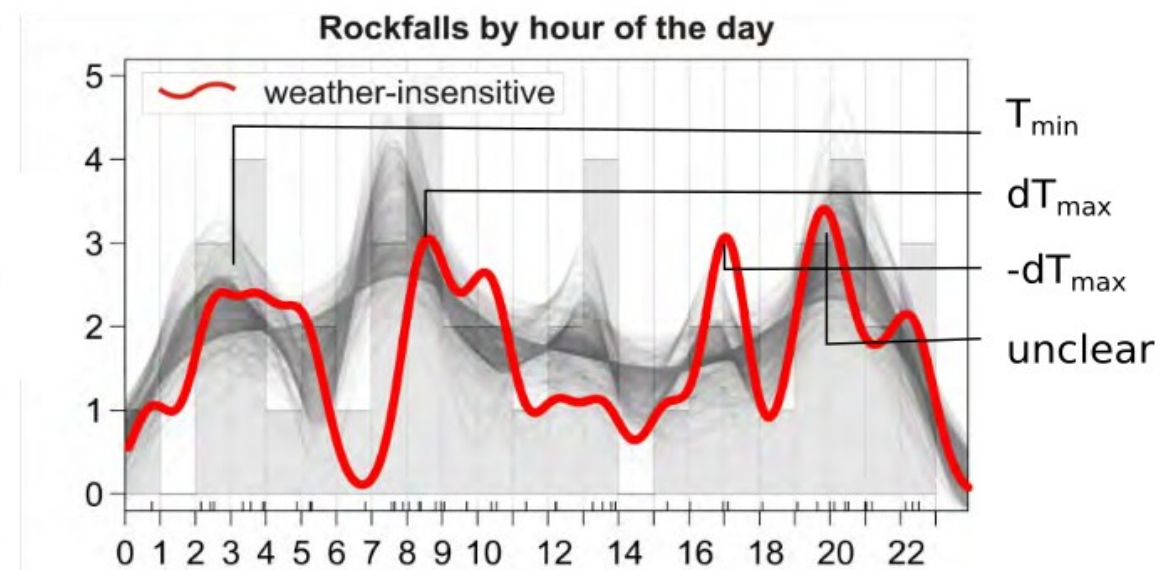
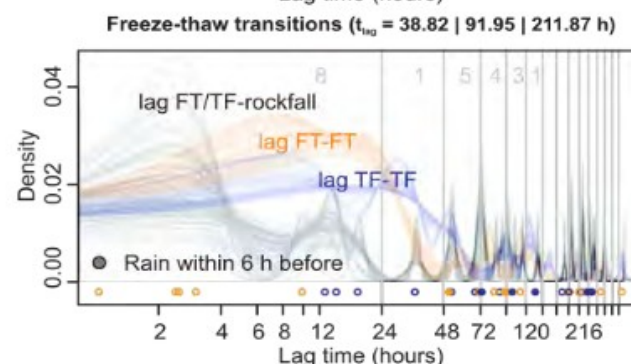
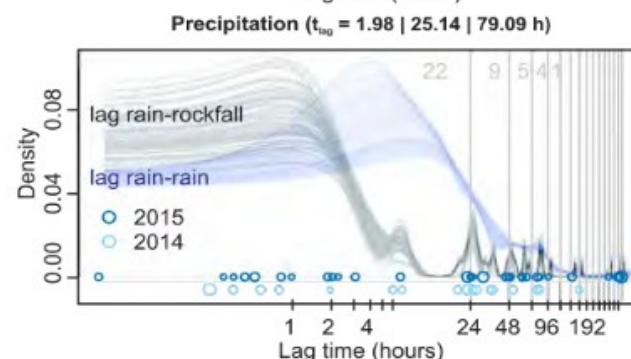
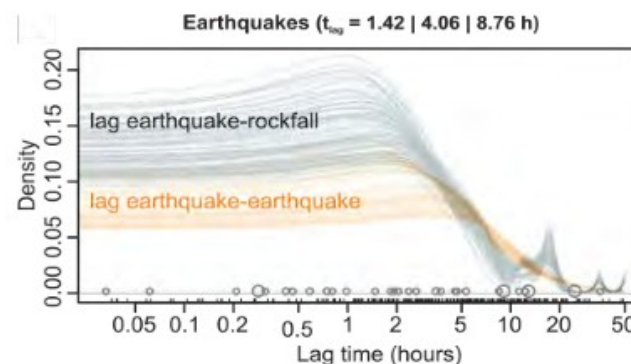
Earthquakes



Rainfall

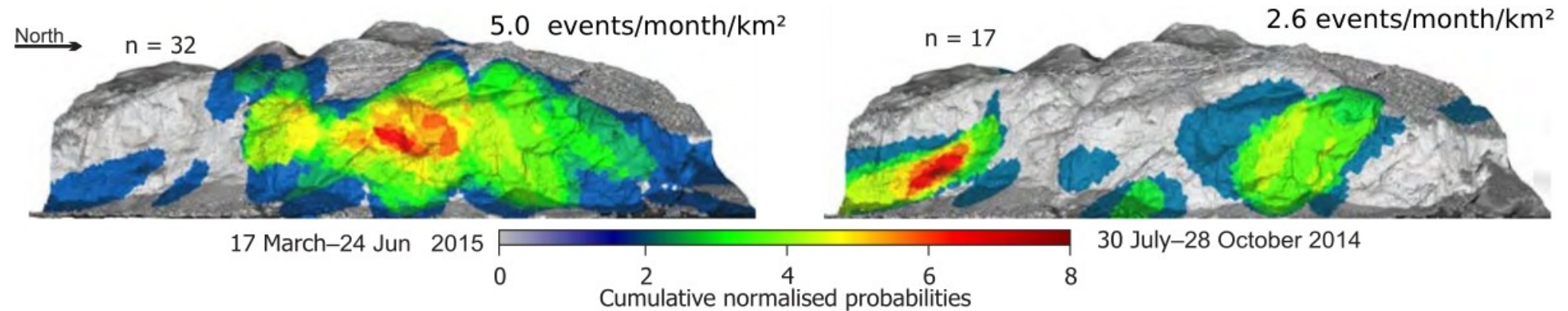


Freeze-thaw/
thermal forcing



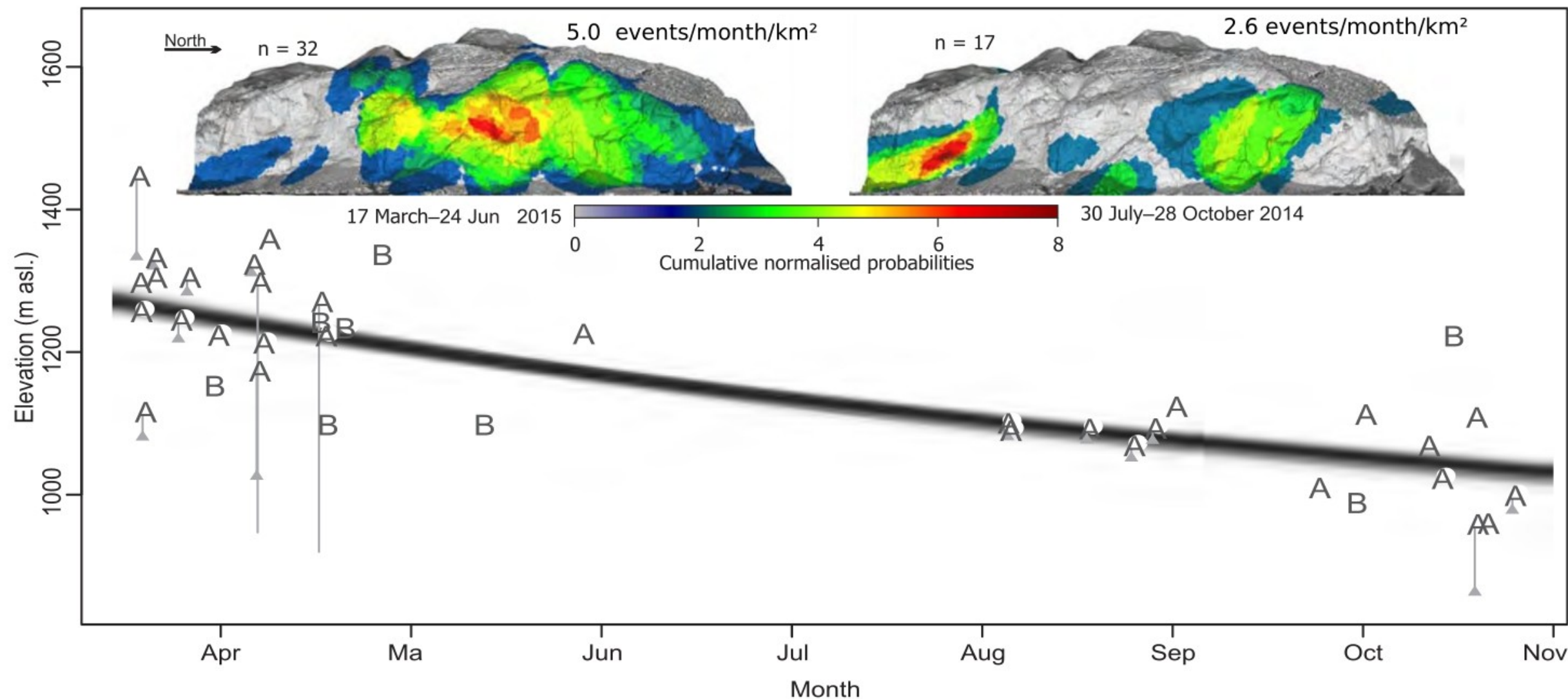
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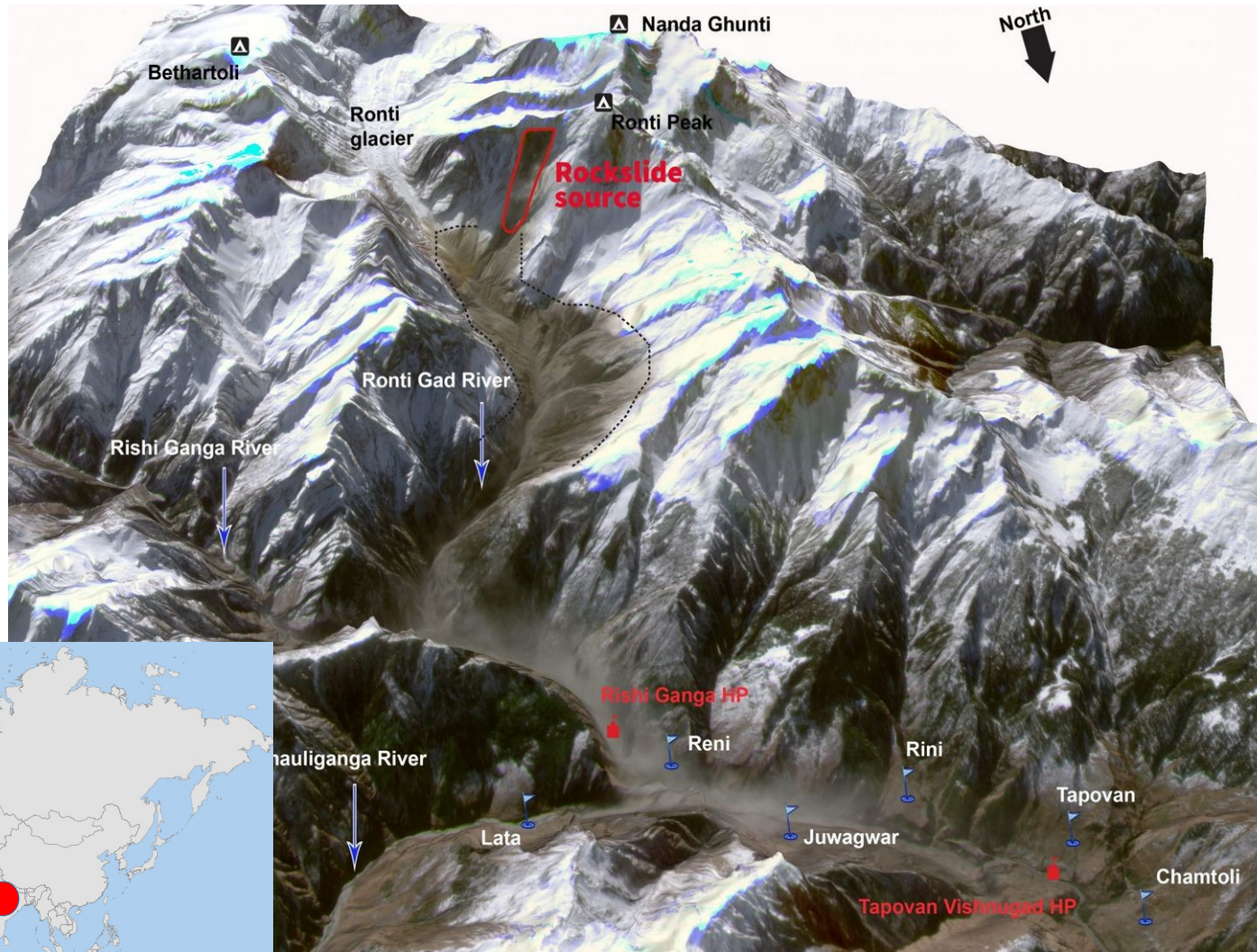


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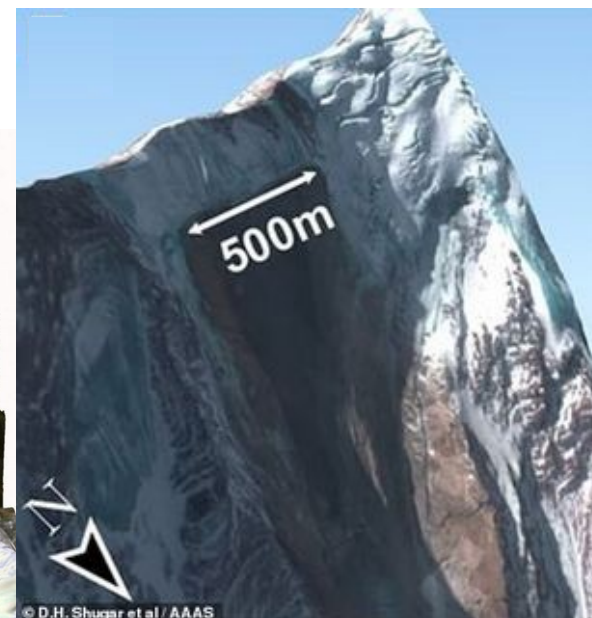
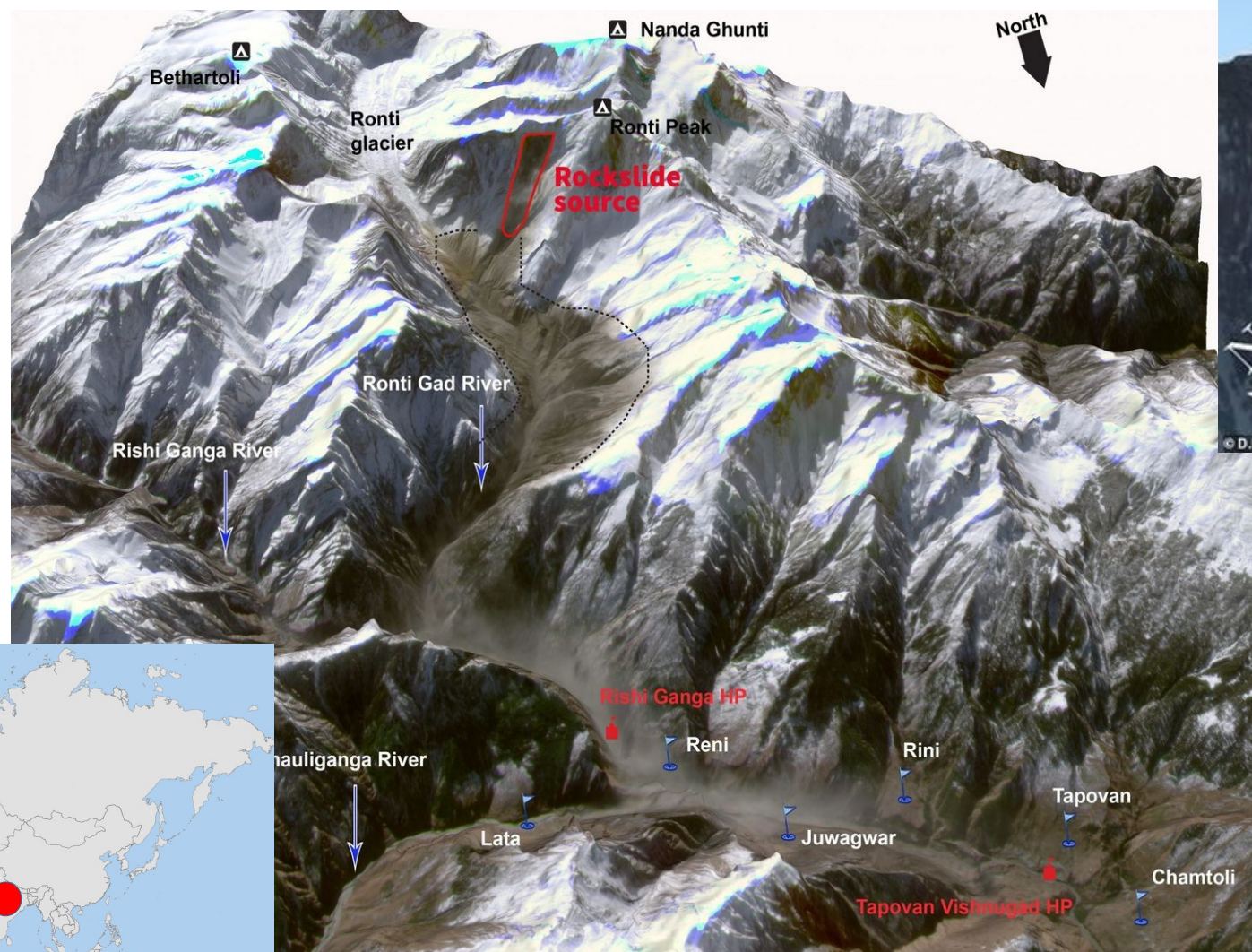
Example 3: Insights into a coupled hazard event

ANATOMY OF THE CHAMOLI ROCKSLIDE-TO-DEBRIS-LADEN FLOOD EVENT, 7 FEB 2021



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ANATOMY OF THE CHAMOLI ROCKSLIDE-TO-DEBRIS-LADEN FLOOD EVENT, 7 FEB 2021

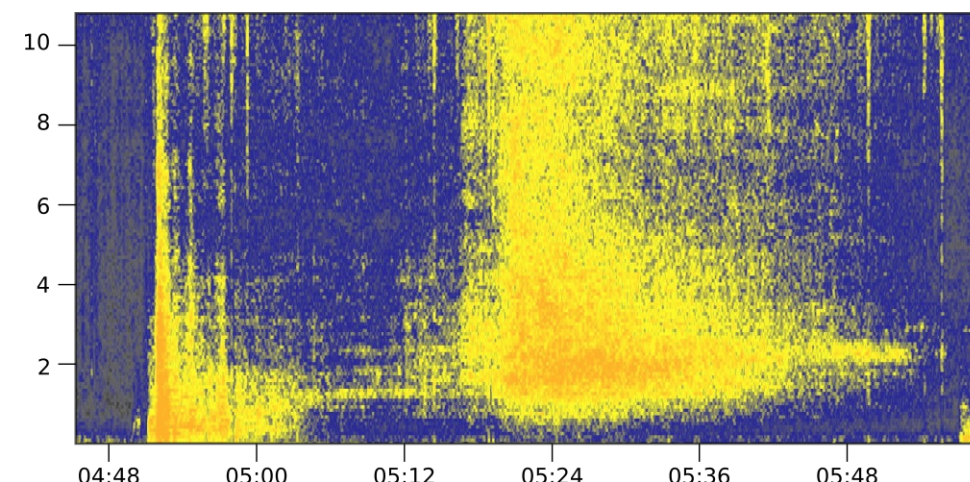
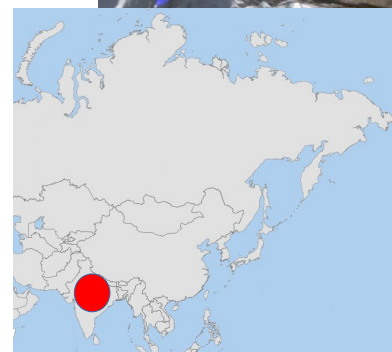
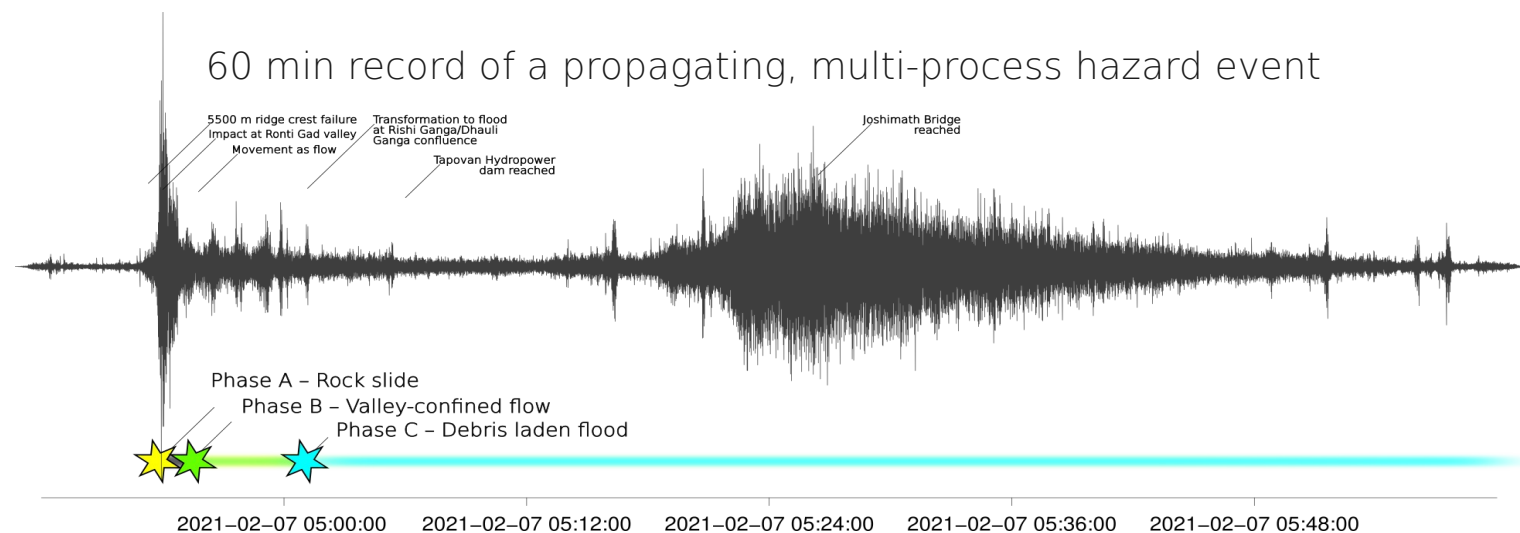
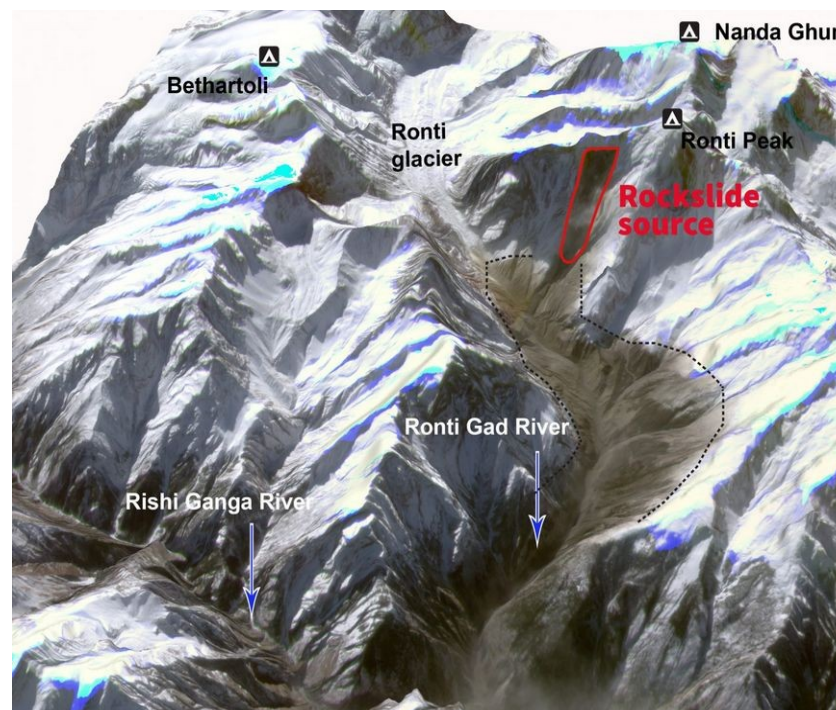


27 Mio m³
1.8 km vertical drop
Snow-ice-rock mix



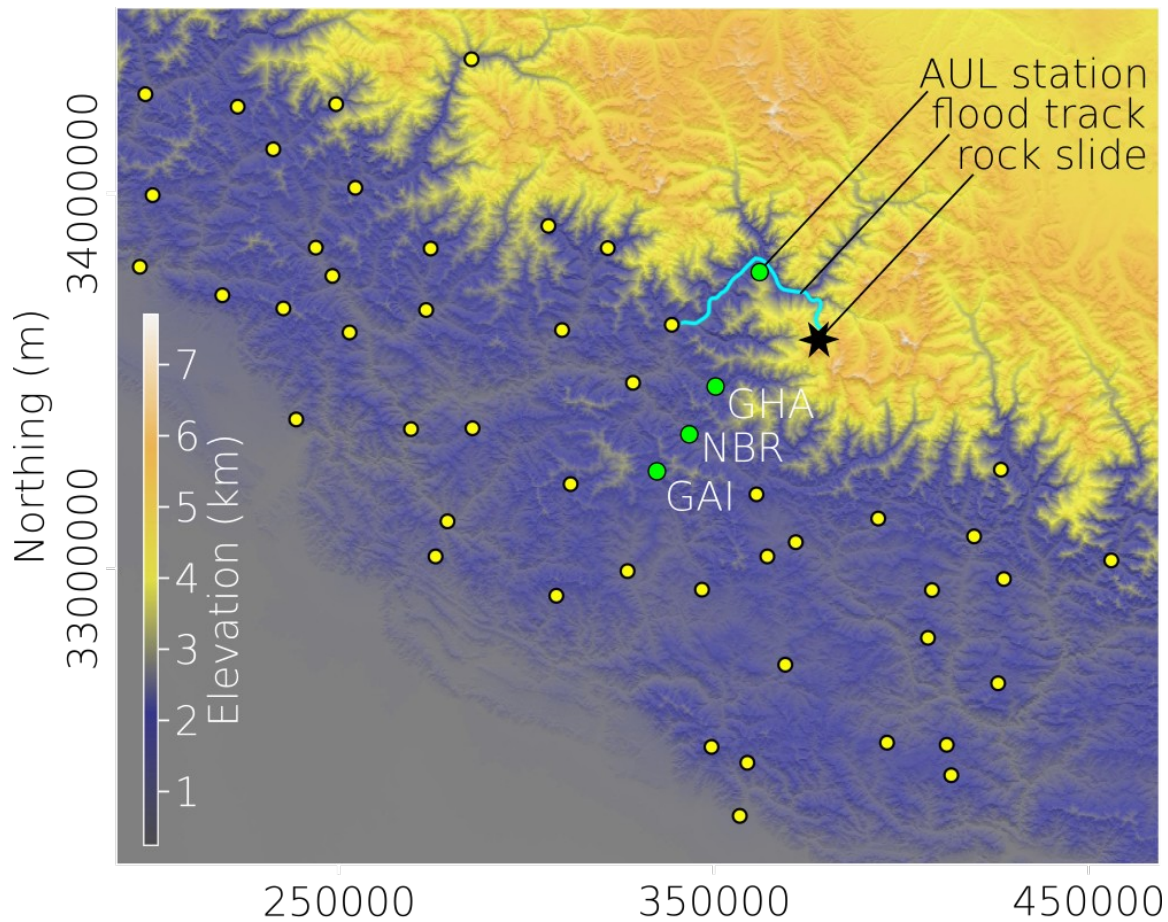
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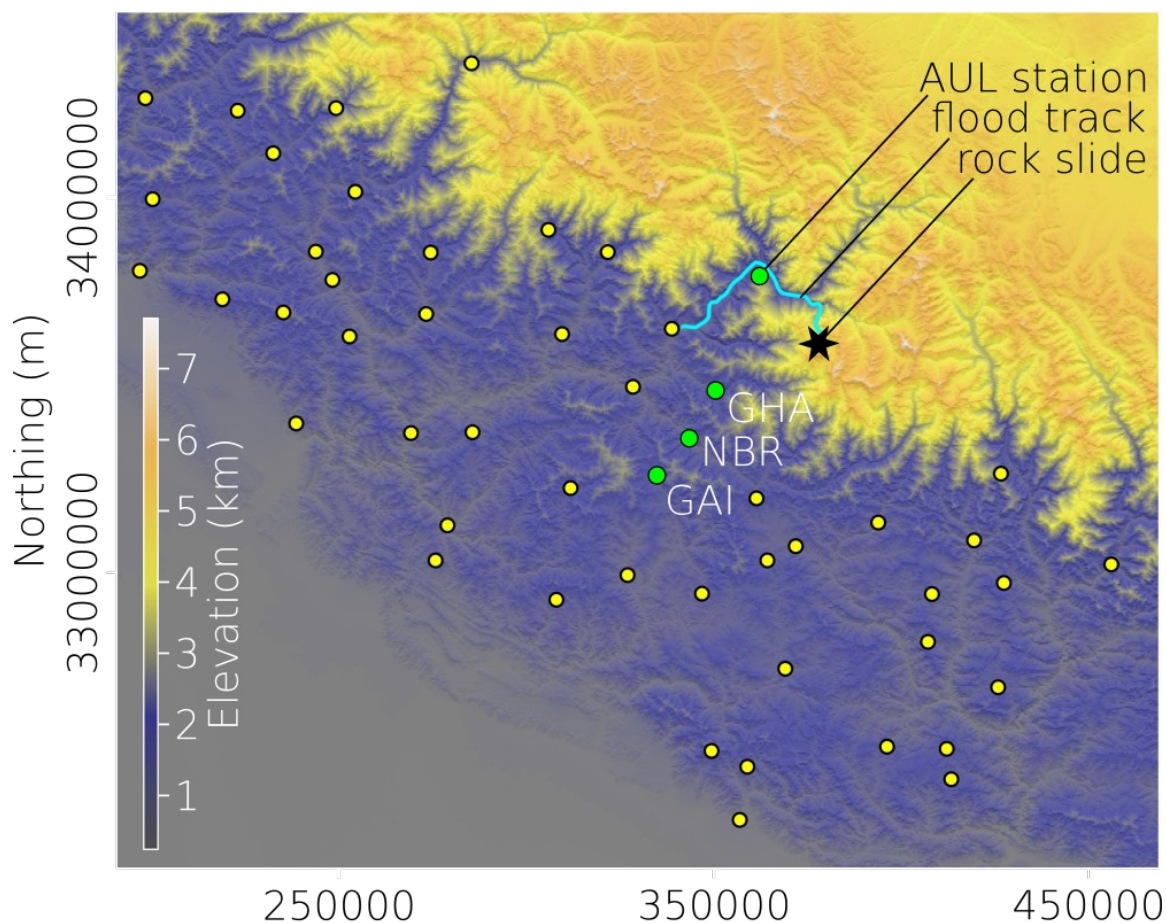
SEISMIC NETWORK AS PRECONDITION



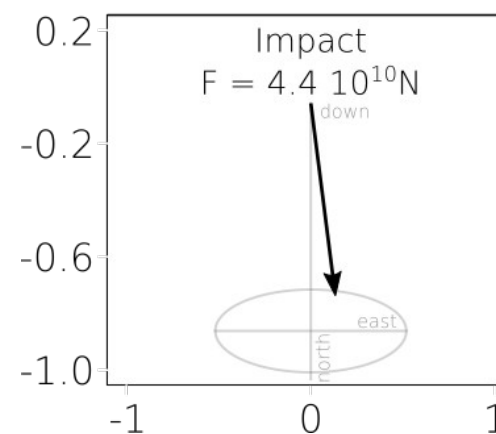
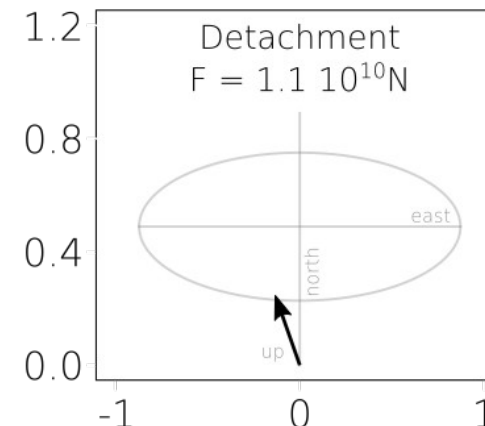
Network of seismic stations with available data
to track the 500 km propagation range

Example 3: Insights into a coupled hazard event

SEISMIC NETWORK AS PRECONDITION → ALLOWS TO QUANTIFY THE FORCE OF THE EVENT



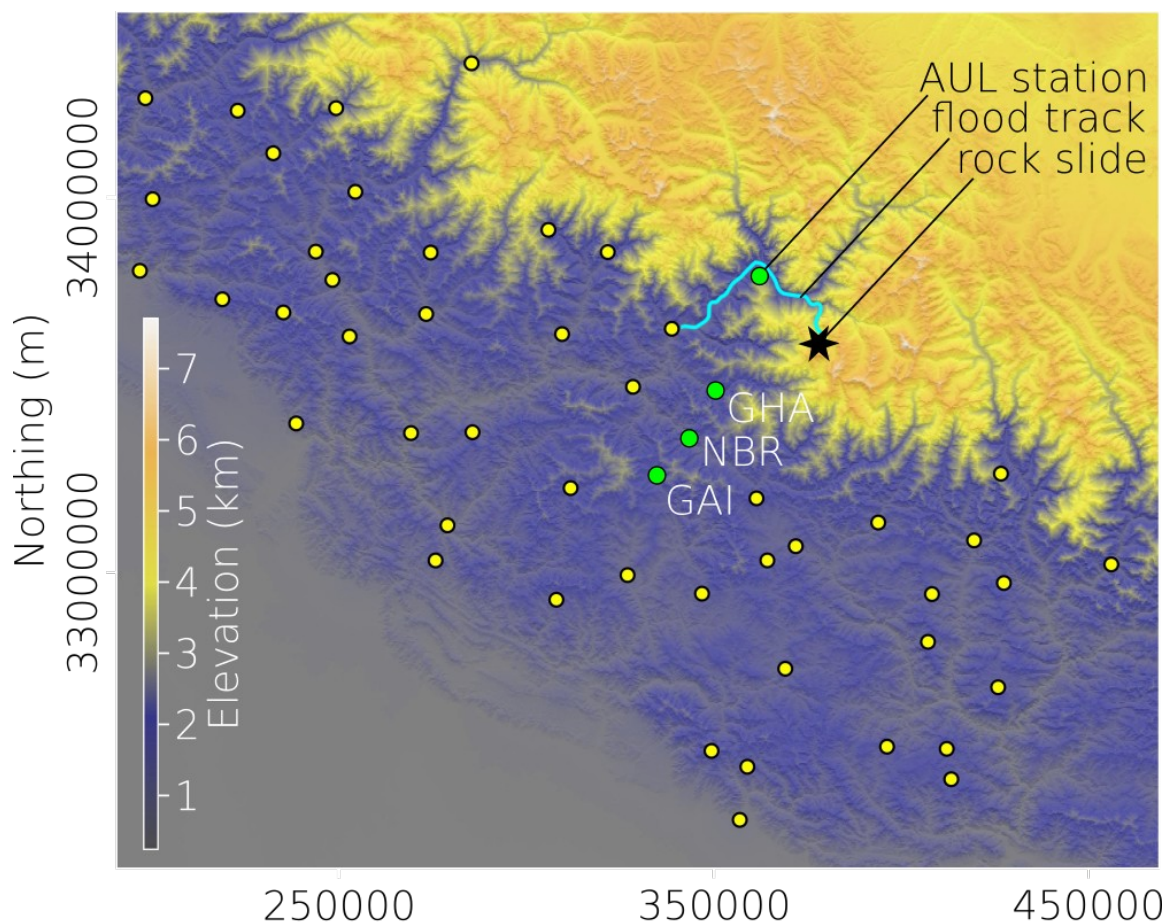
Network of seismic stations with available data to track the 500 km propagation range



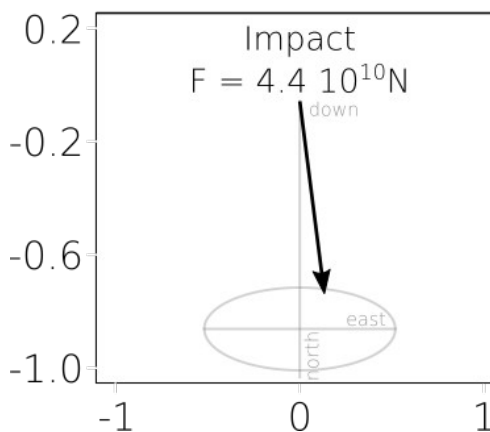
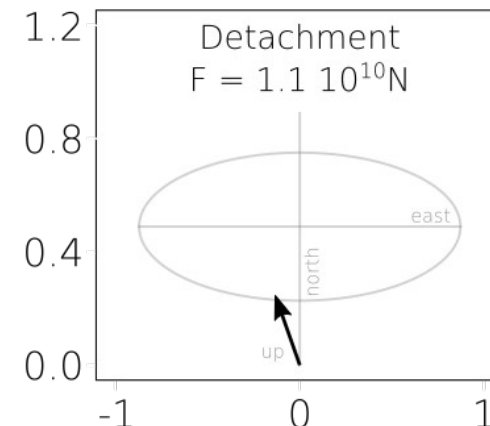
~25 000 Space Shuttles
11 vs. 44 GigaNewton

Example 3: Insights into a coupled hazard event

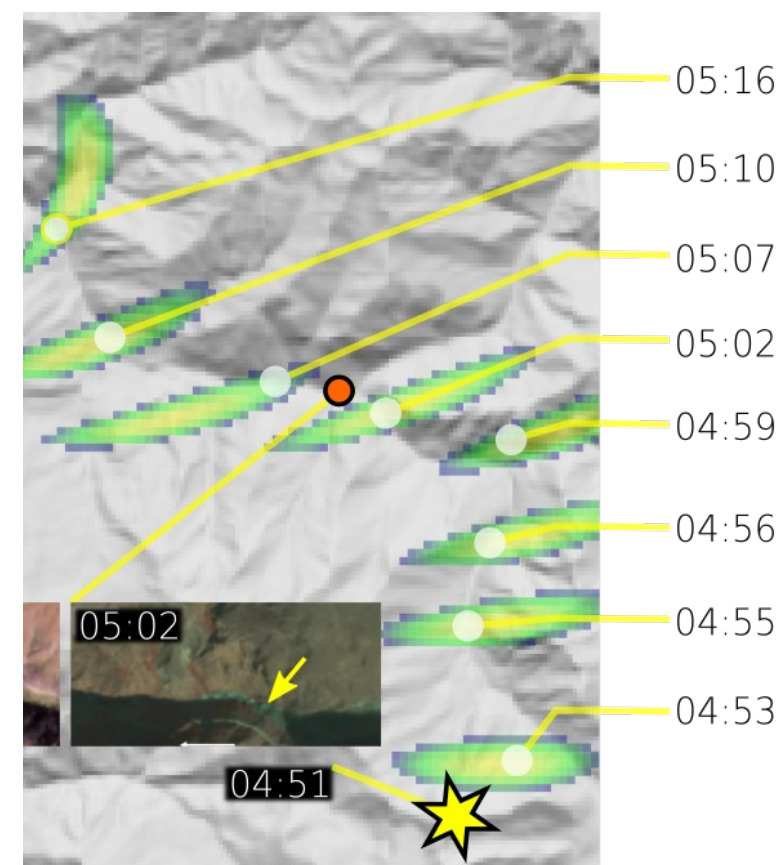
SEISMIC NETWORK AS PRECONDITION → ALLOWS TO QUANTIFY THE FORCE OF THE EVENT → AND TO LOCATE & TRACK THE EVENT



Network of seismic stations with available data to track the 500 km propagation range



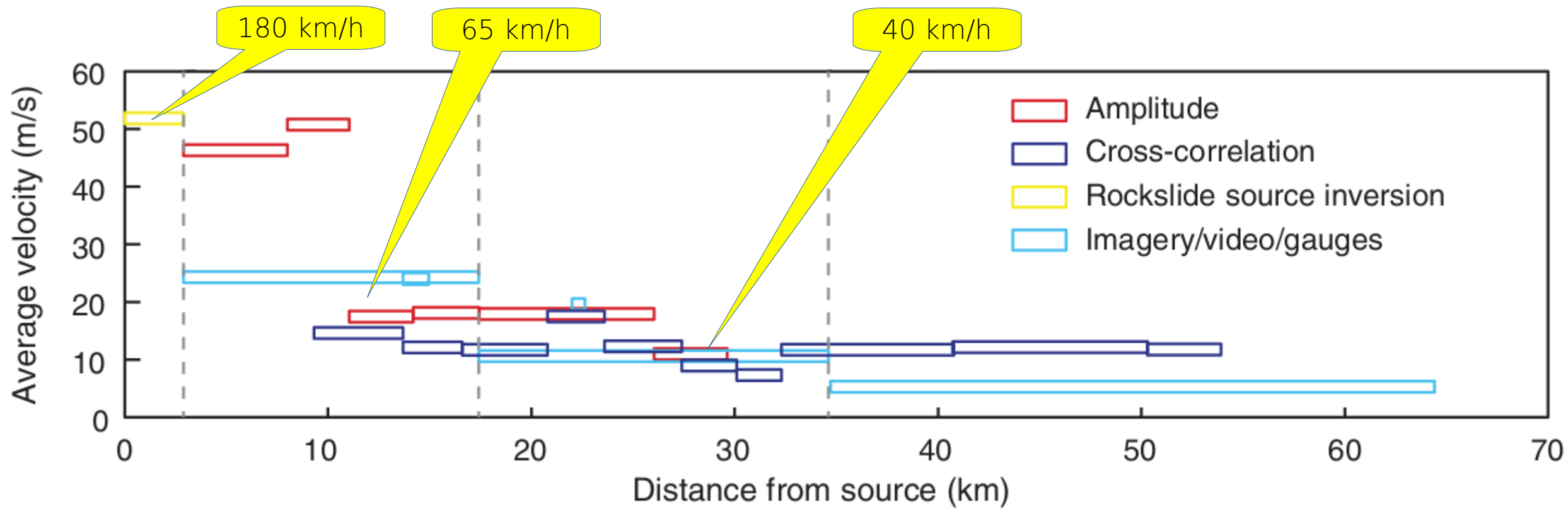
~25 000 Space Shuttles
11 vs. 44 GigaNewton



Location and tracking

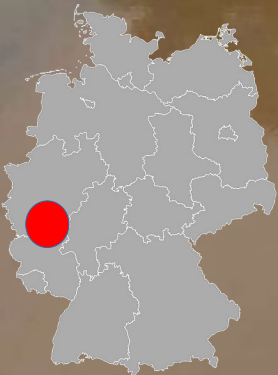
Example 3: Insights into a coupled hazard event

SEISMIC NETWORK AS PRECONDITION → ALLOWS TO QUANTIFY THE FORCE OF THE EVENT → AND TO LOCATE & TRACK THE EVENT



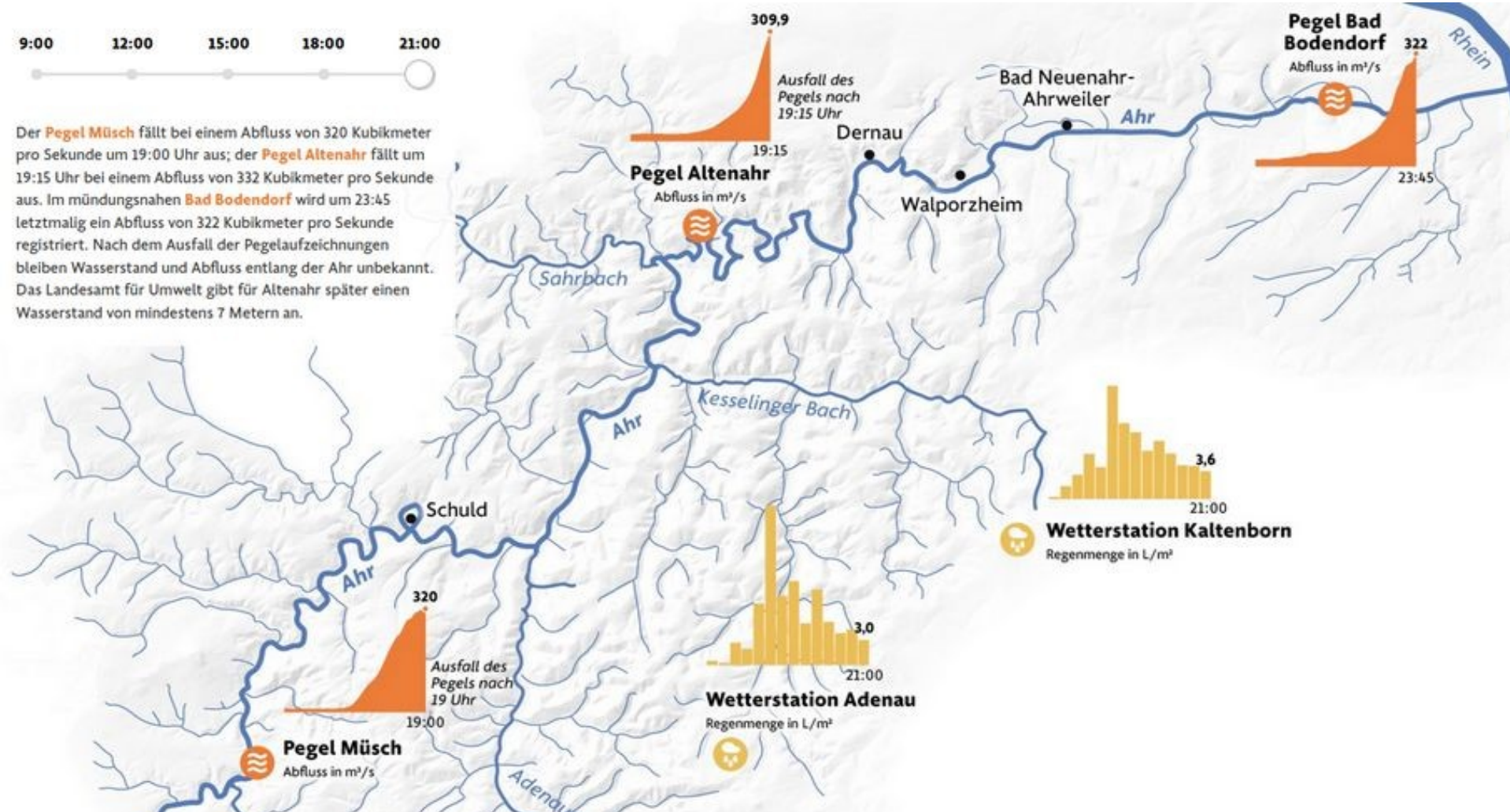
Hydrological extremes in inhabited & transformed European uplands

SEISMIC EARTHQUAKE NETWORKS SERVING AS REPLACEMENT RIVER GAUGES DURING EXTREME FLOOD EVENTS



Hydraulic properties from existing sensors, live? Not possible

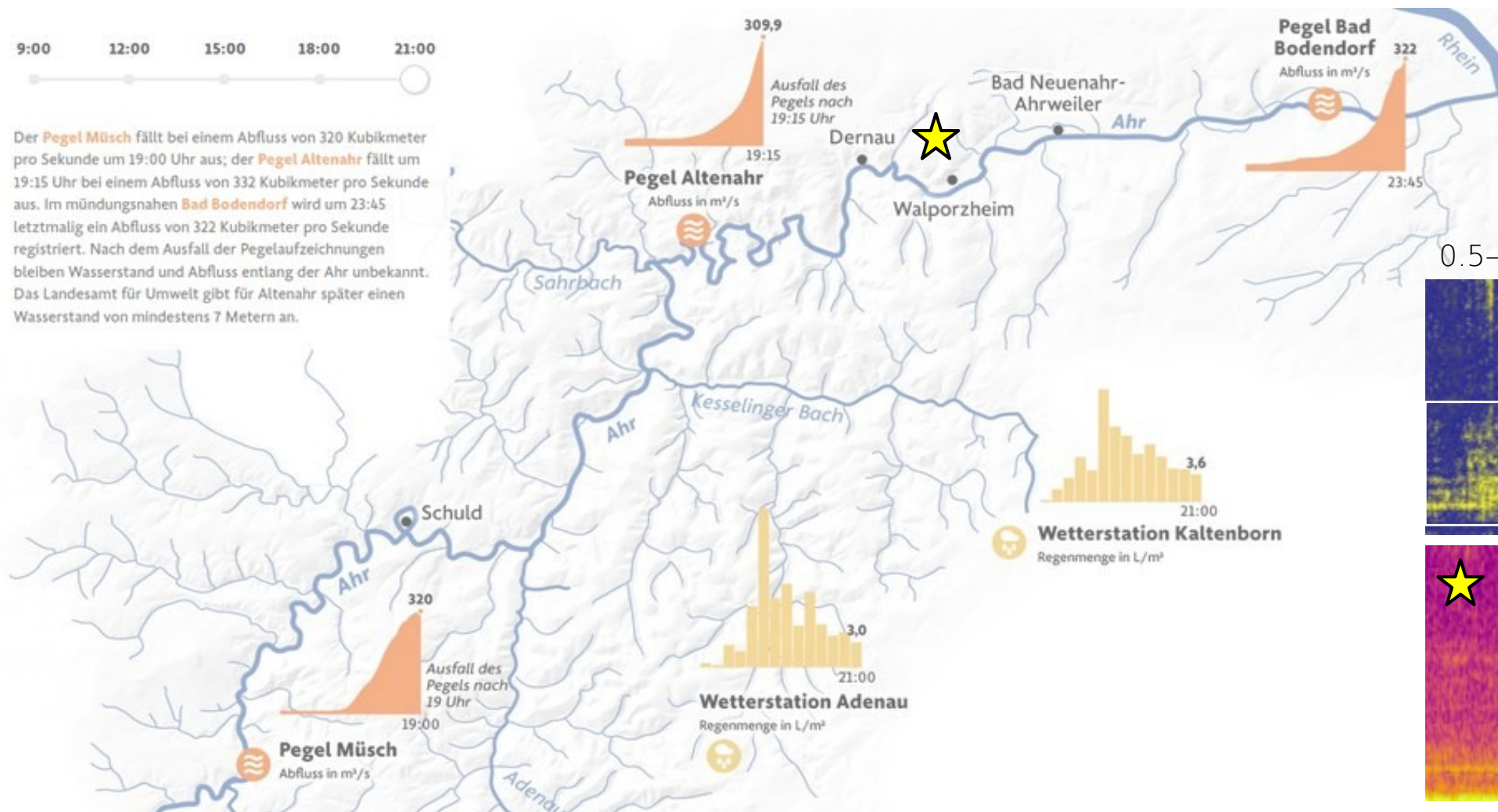
GAUGING STATIONS ARE TOO FAR APART, ONLY RECORD MINIMUM INFORMATION, AND FAIL EARLY ON



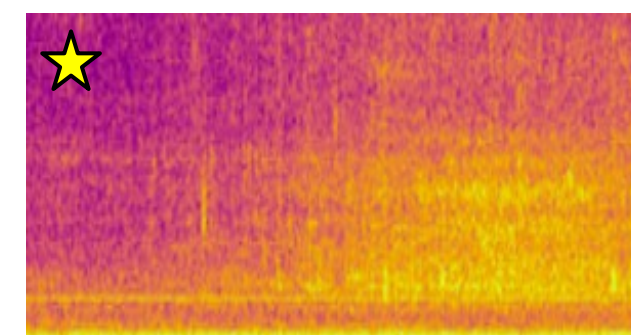
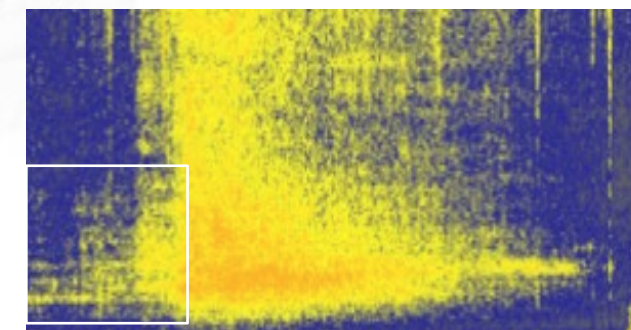
900 km²,
80 km by 30 km
MQ = 6 m³/s
HQ_{ext} ~ 1000 m³/s

An alternative: a seismic network station run for earthquake detection

REGISTRATION OF THE SEISMIC FOOTPRINT OF THE APPROACHING FLOOD

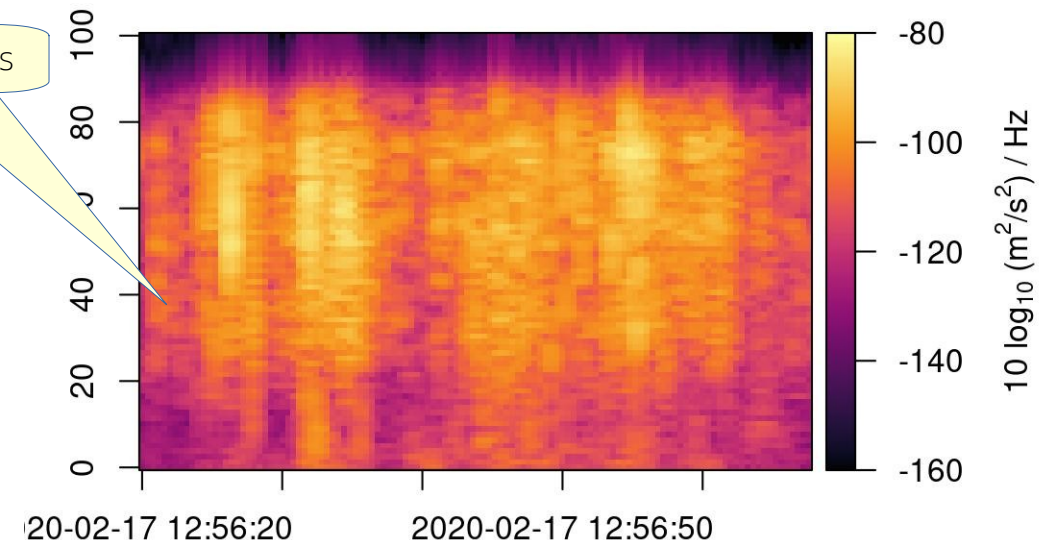
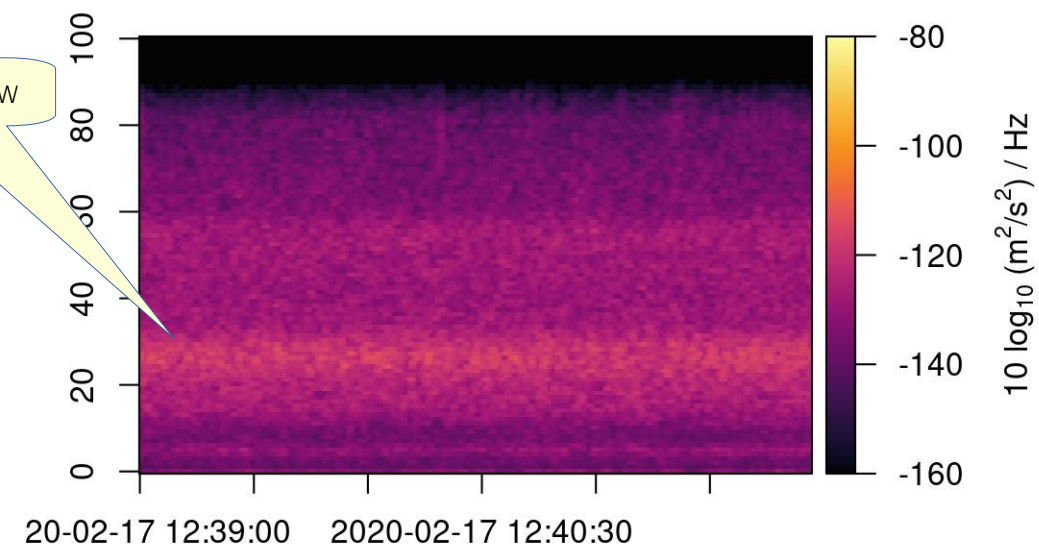
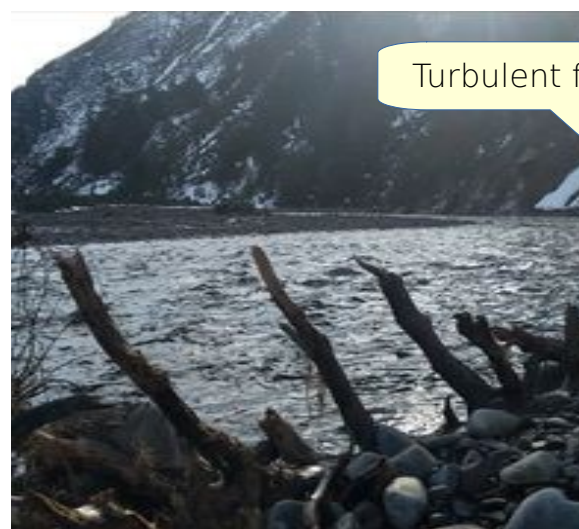


0.5–10 Hz, 2 vs. 1 h duration



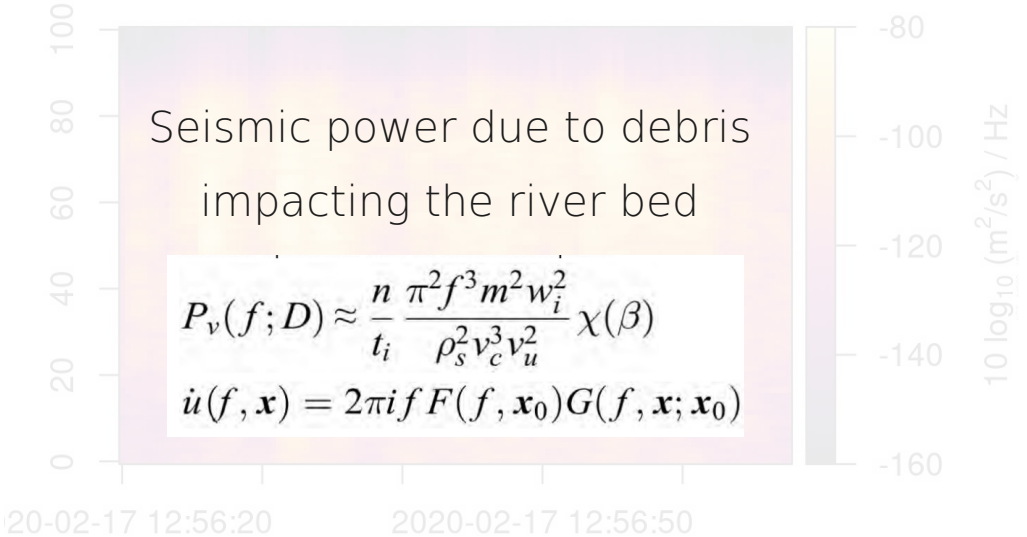
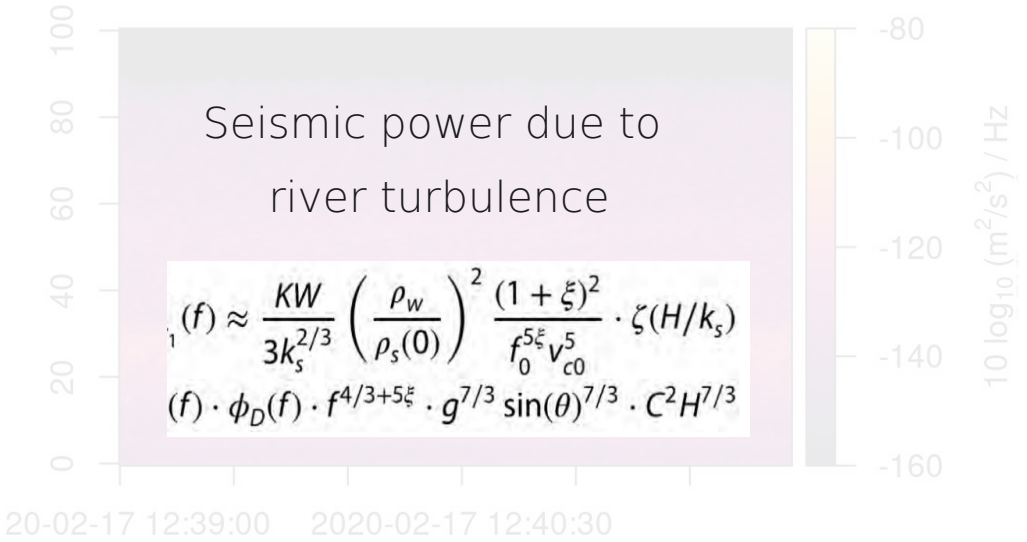
Further valuable information contained in seismic data near rivers

TWO SEPARATE SIGNATURES OF POWERFUL RIVERS: TURBULENCE STRUCTURE AND BEDLOAD SEDIMENT TRANSPORT



Further valuable information contained in seismic data near rivers

TWO SEPARATE SIGNATURES OF POWERFUL RIVERS: TURBULENCE STRUCTURE AND BEDLOAD SEDIMENT TRANSPORT

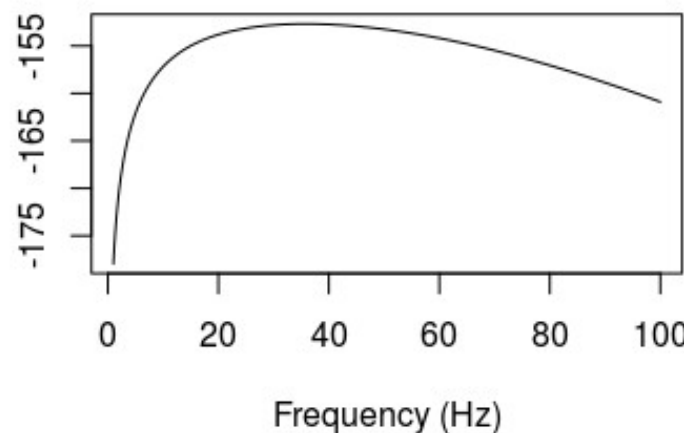


Further valuable information contained in seismic data near rivers

TWO SEPARATE SIGNATURES OF POWERFUL RIVERS: TURBULENCE STRUCTURE AND BEDLOAD SEDIMENT TRANSPORT

```
model_turbulence(d_s = 0.03,
  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)
```



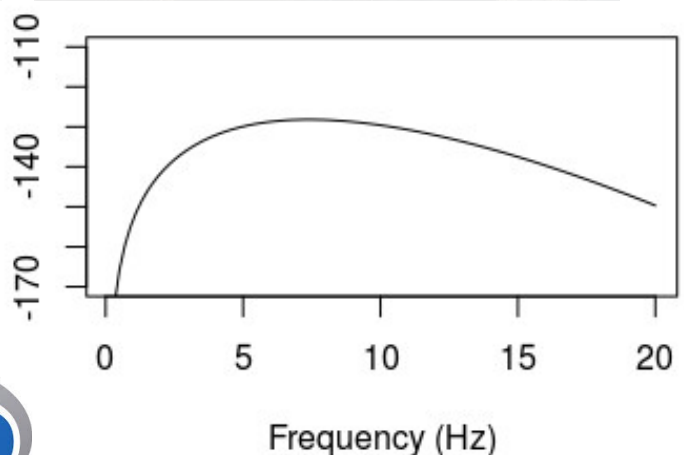
Seismic power due to
river turbulence

$$P_t(f) \approx \frac{KW}{3k_s^{2/3}} \left(\frac{\rho_w}{\rho_s(0)} \right)^2 \frac{(1+\xi)^2}{f_0^{5\xi} v_{c0}^5} \cdot \zeta(H/k_s)$$

$$P_t(f) \cdot \phi_D(f) \cdot f^{4/3+5\xi} \cdot g^{7/3} \sin(\theta)^{7/3} \cdot C^2 H^{7/3}$$

10 log₁₀ (m²/s²) / Hz

20-02-17 12:39:00 2020-02-17 12:40:30



Seismic power due to debris
impacting the river bed

$$P_v(f; D) \approx \frac{n}{t_i} \frac{\pi^2 f^3 m^2 w_i^2}{\rho_s^2 v_c^3 v_u^2} \chi(\beta)$$

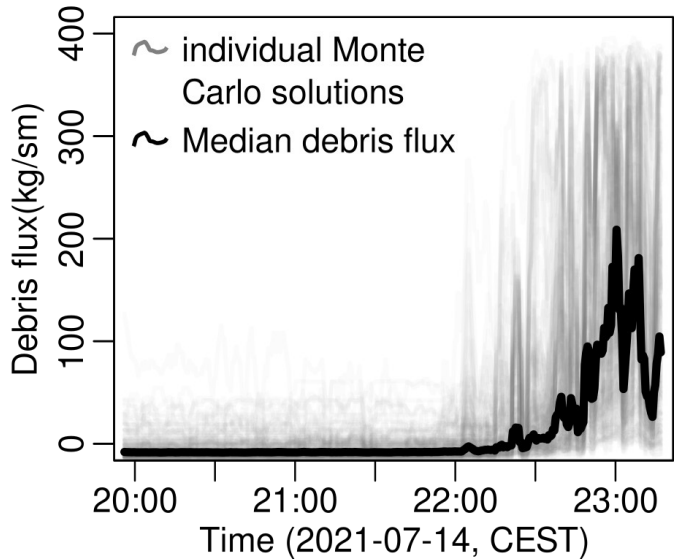
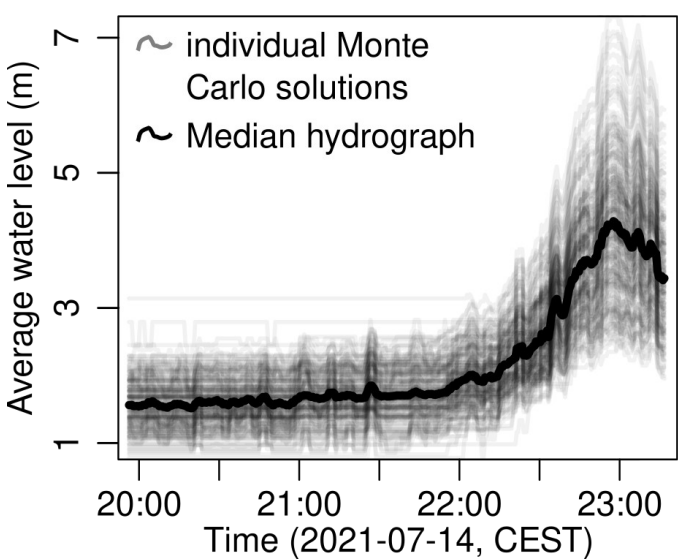
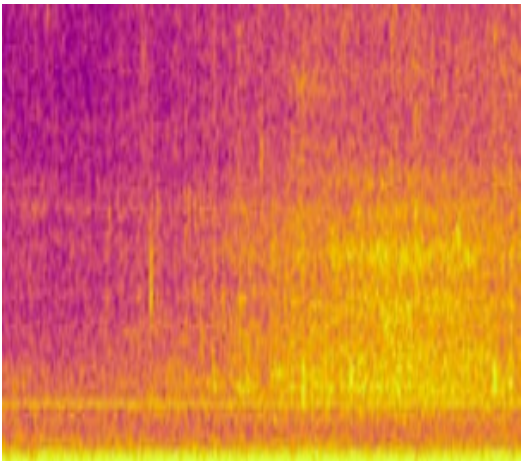
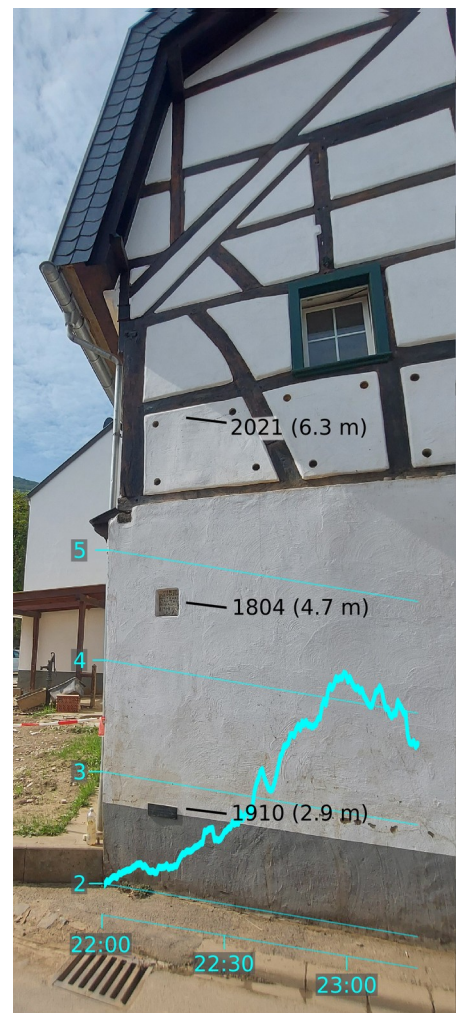
$$\dot{u}(f, \mathbf{x}) = 2\pi i f F(f, \mathbf{x}_0) G(f, \mathbf{x}; \mathbf{x}_0)$$

10 log₁₀ (m²/s²) / Hz

20-02-17 12:56:20 2020-02-17 12:56:50

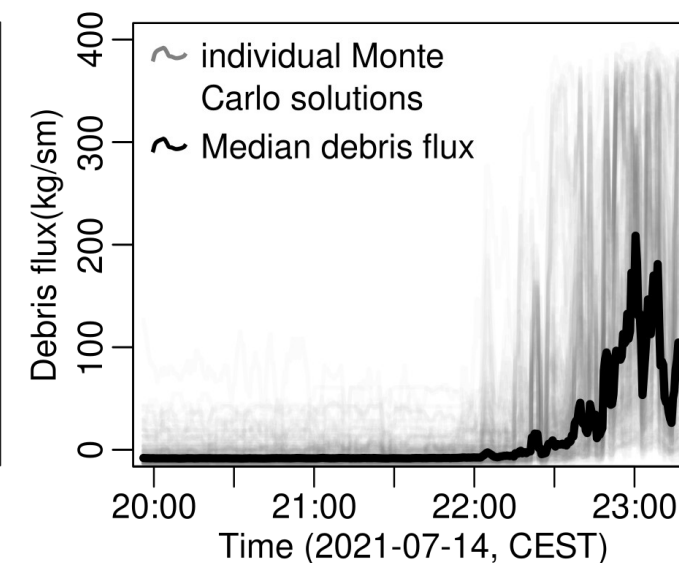
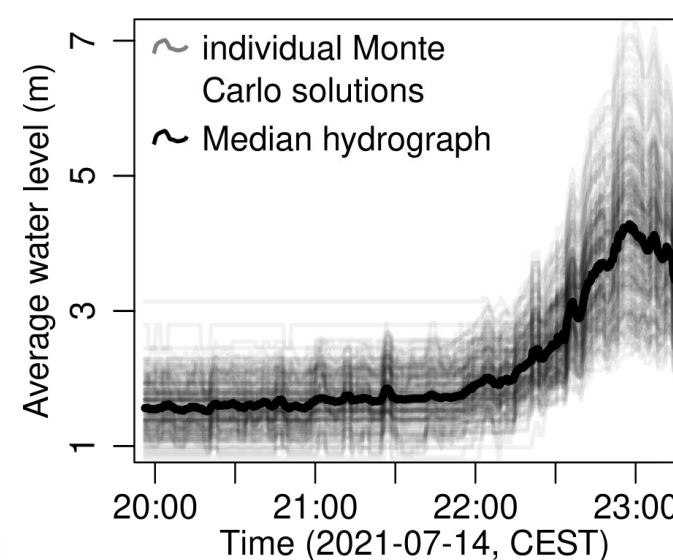
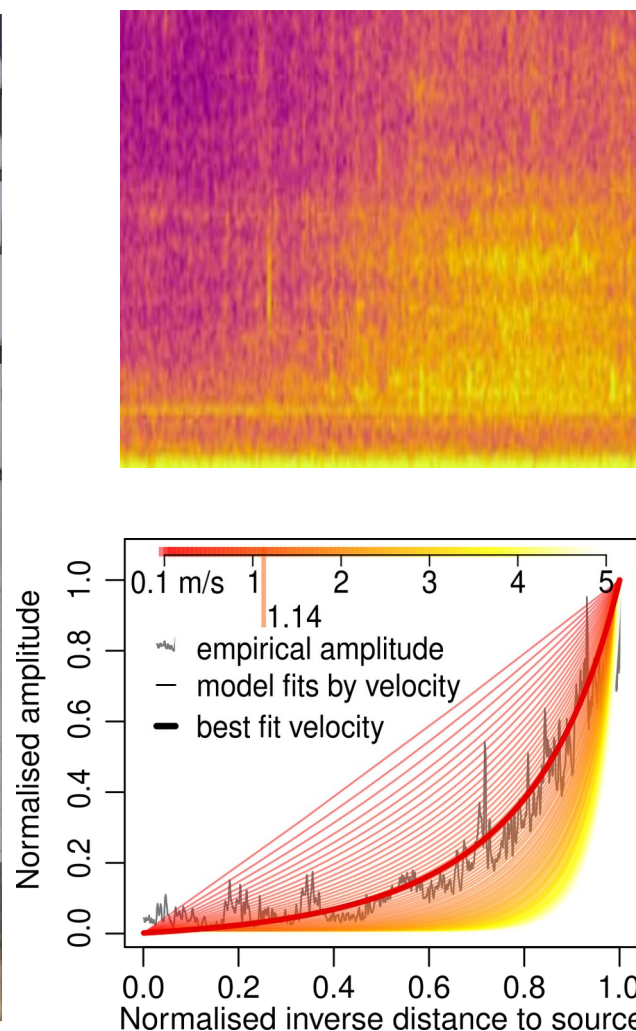
Further valuable information contained in seismic data near rivers

TWO SEPARATE SIGNATURES OF POWERFUL RIVERS: TURBULENCE STRUCTURE AND BEDLOAD SEDIMENT TRANSPORT



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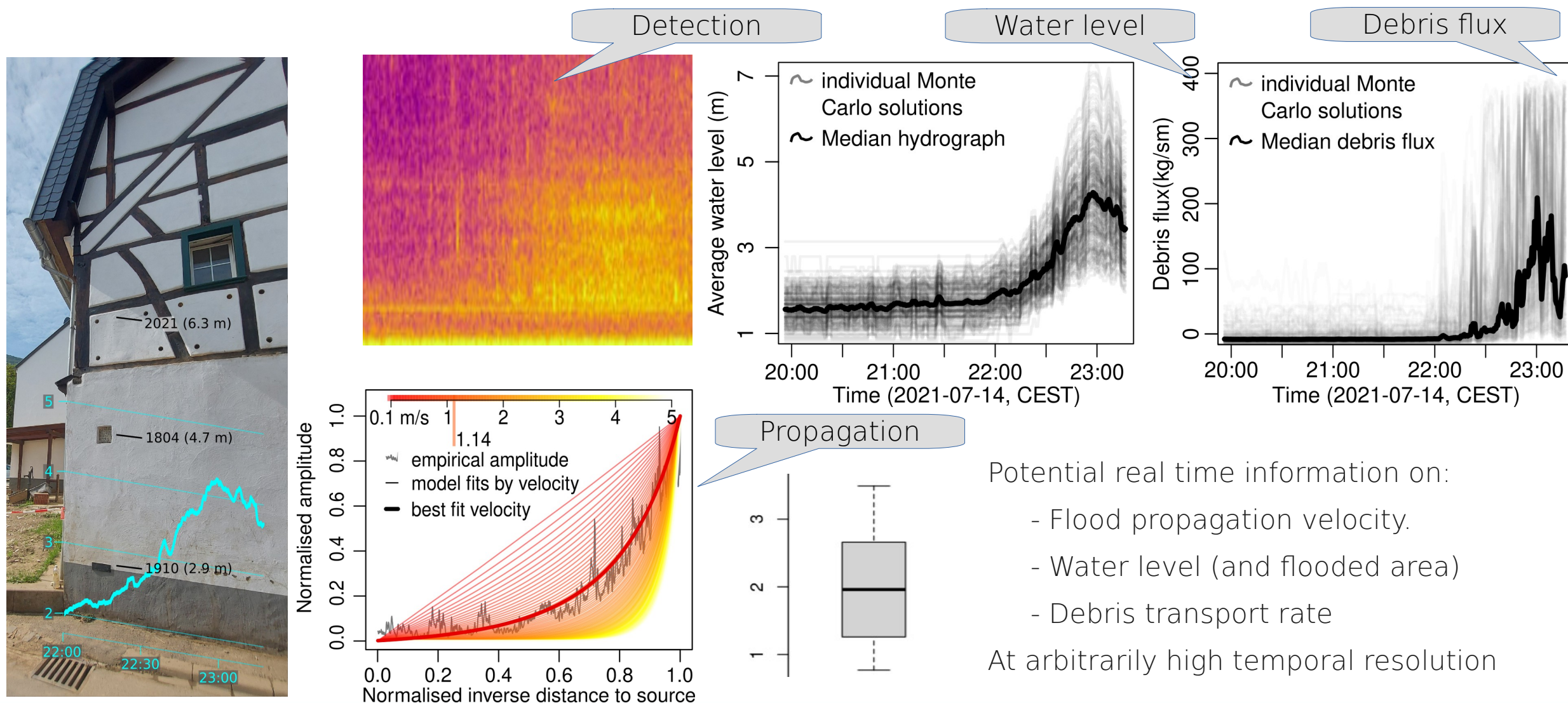


Seismic amplitude with respect
to source distance

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

Further valuable information contained in seismic data near rivers

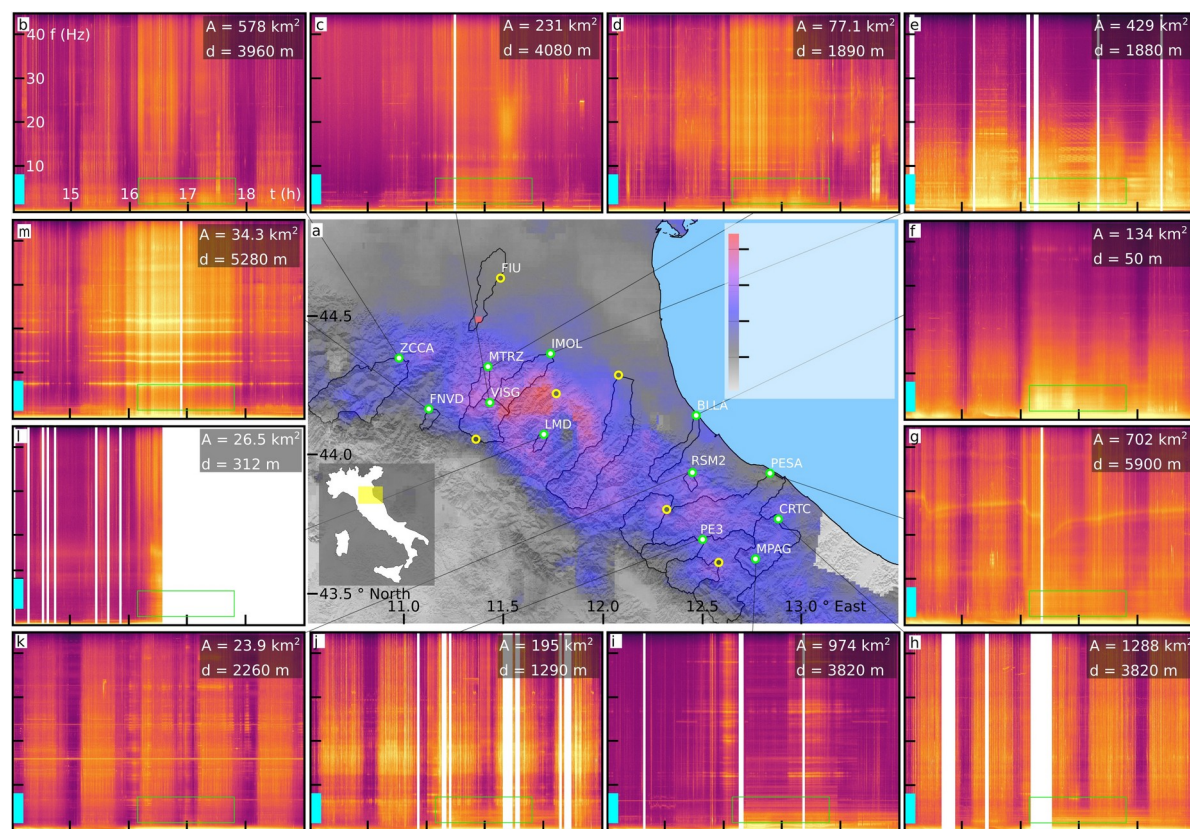
TWO SEPARATE SIGNATURES OF POWERFUL RIVERS: TURBULENCE STRUCTURE AND BEDLOAD SEDIMENT TRANSPORT



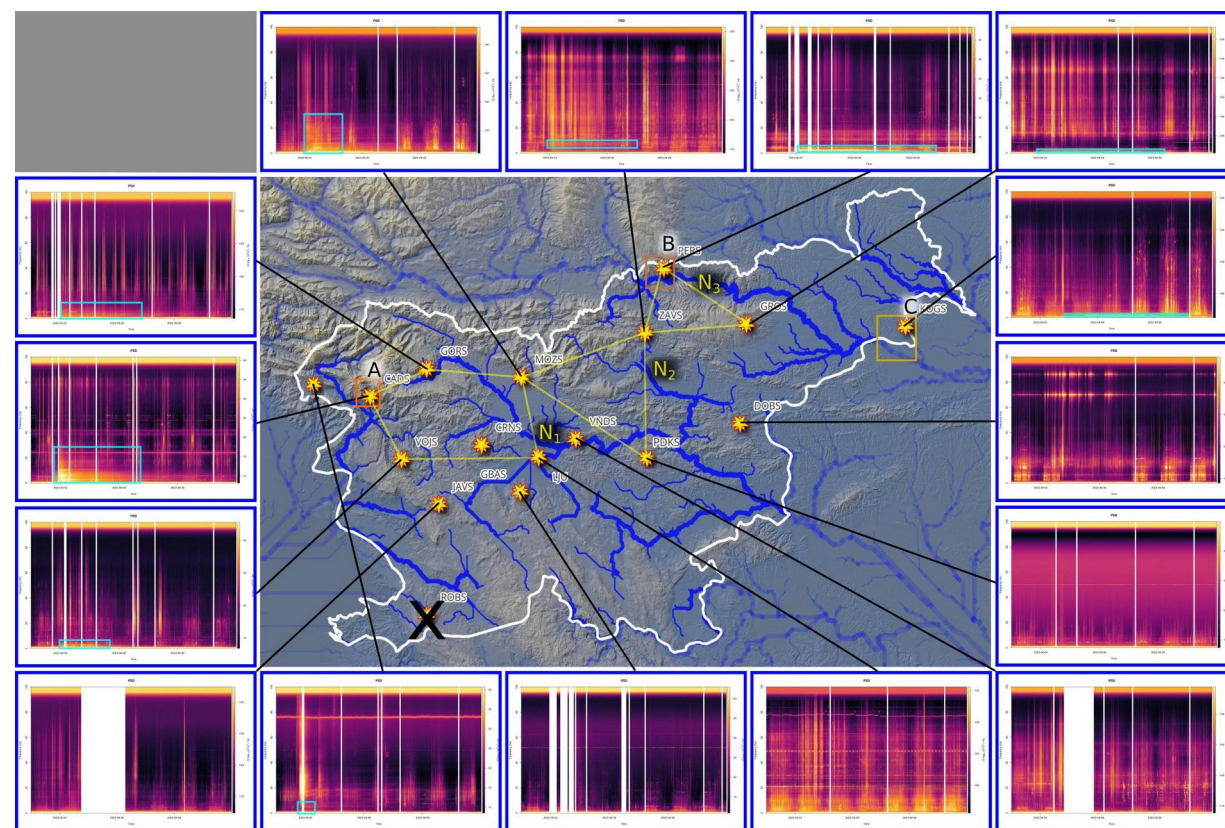
Going the next steps: enrolling the method at regional scale

TWO EXAMPLES OF SEISMIC FLOOD ANATOMY (AND FUTURE EARLY DETECTION) FROM EUROPE

Italian Flood Event 2022



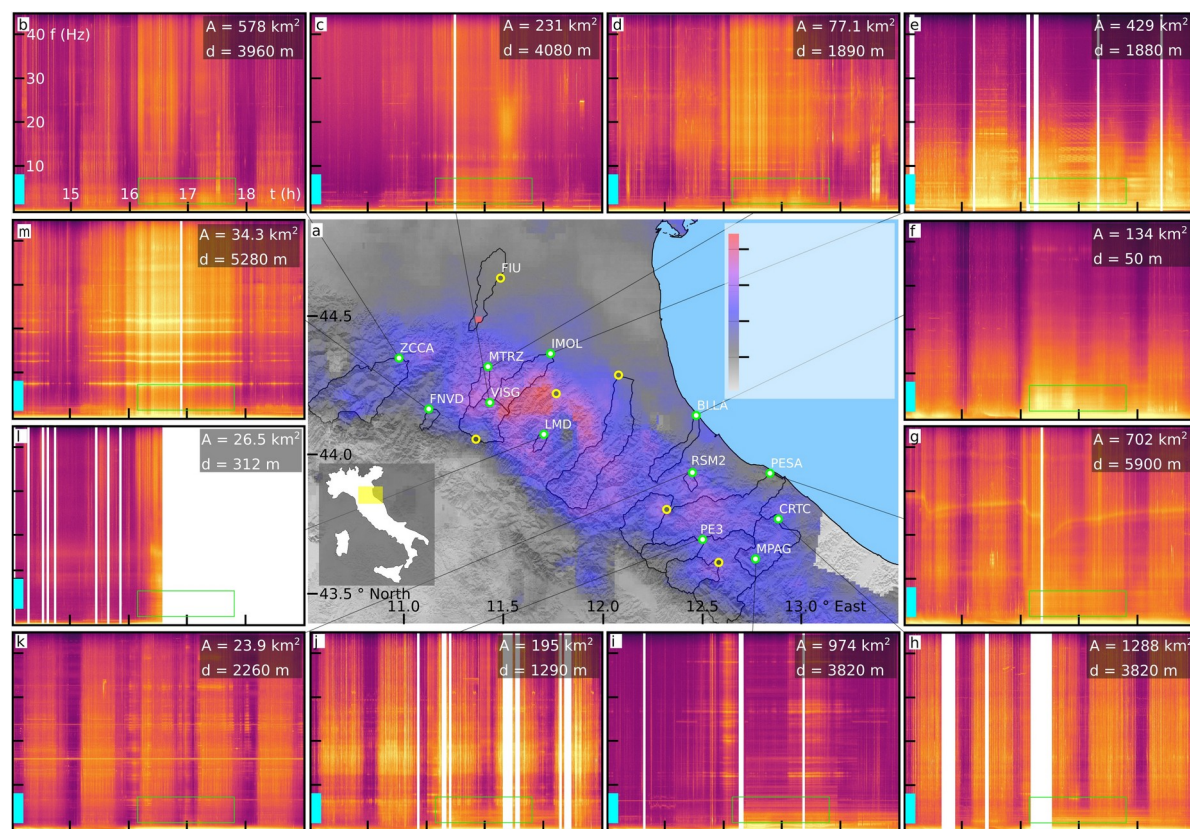
Slovenian Flood Event 2023



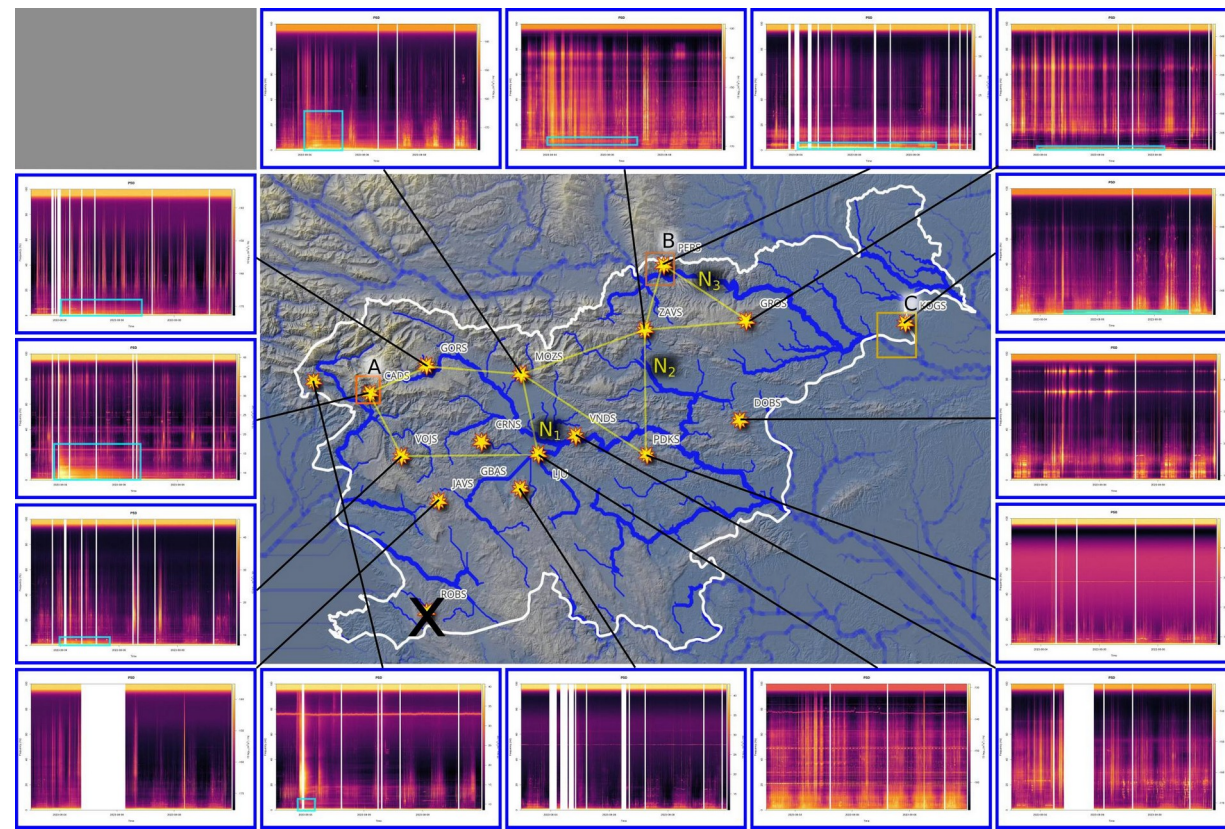
Going the next steps: enrolling the method at regional scale

TWO EXAMPLES OF SEISMIC FLOOD ANATOMY (AND FUTURE EARLY DETECTION) FROM EUROPE

Italian Flood Event 2022



Slovenian Flood Event 2023



2024 To-do's: Austria, Poland, Slovakia, Spain, India, Nepal, ...

The long lasting breath of extreme floods for affected hillslopes

DEBUTRESSING OF OLD SLOPE INSTABILITIES TRIGGERS REACTIVATION WITH MONTH LONG TIME LAGS

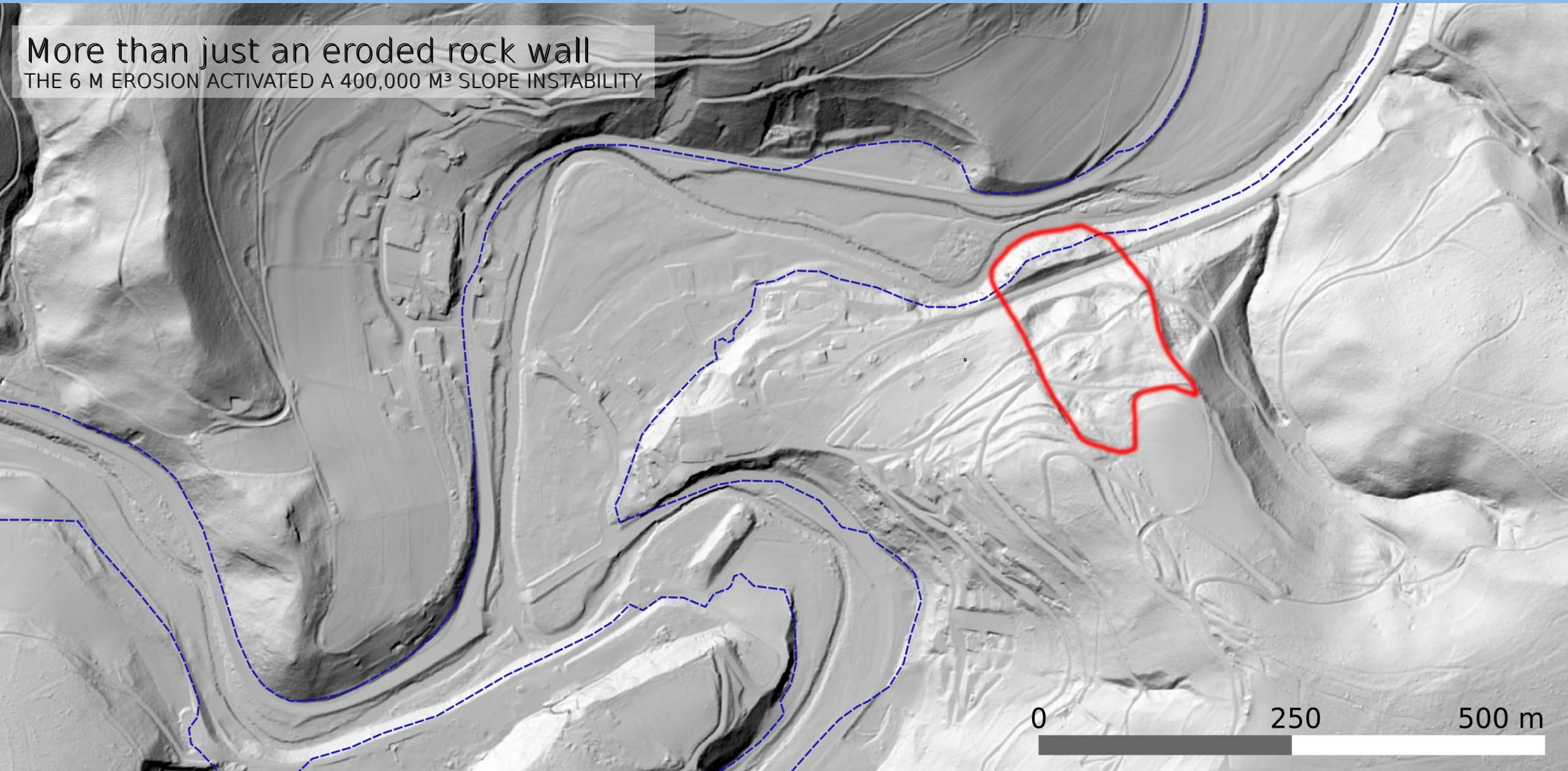


Zooming into the structure of the failure

GEOMORPHIC MAPPING AND ERT SURVEYS PROVIDE GEOMETRY DETAILS



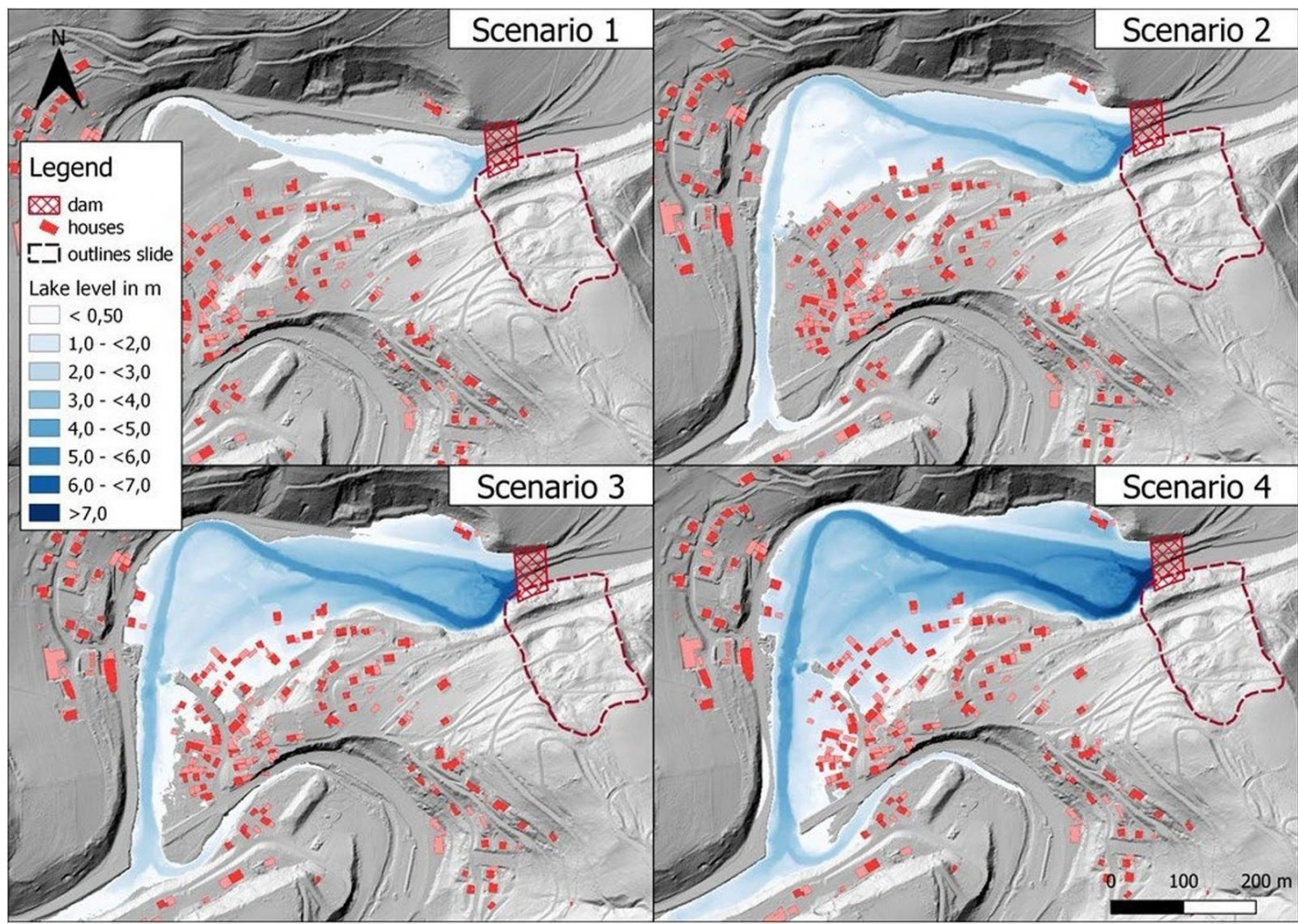
More than just an eroded rock wall
THE 6 M EROSION ACTIVATED A 400,000 M³ SLOPE INSTABILITY



Potential effects of landslide activation

LOCATION IN NARROW VALLEY SECTION YIELDS RAPID PONDING

200000 – 400000 m³ material available
10000 – 80000 m³ required for damming



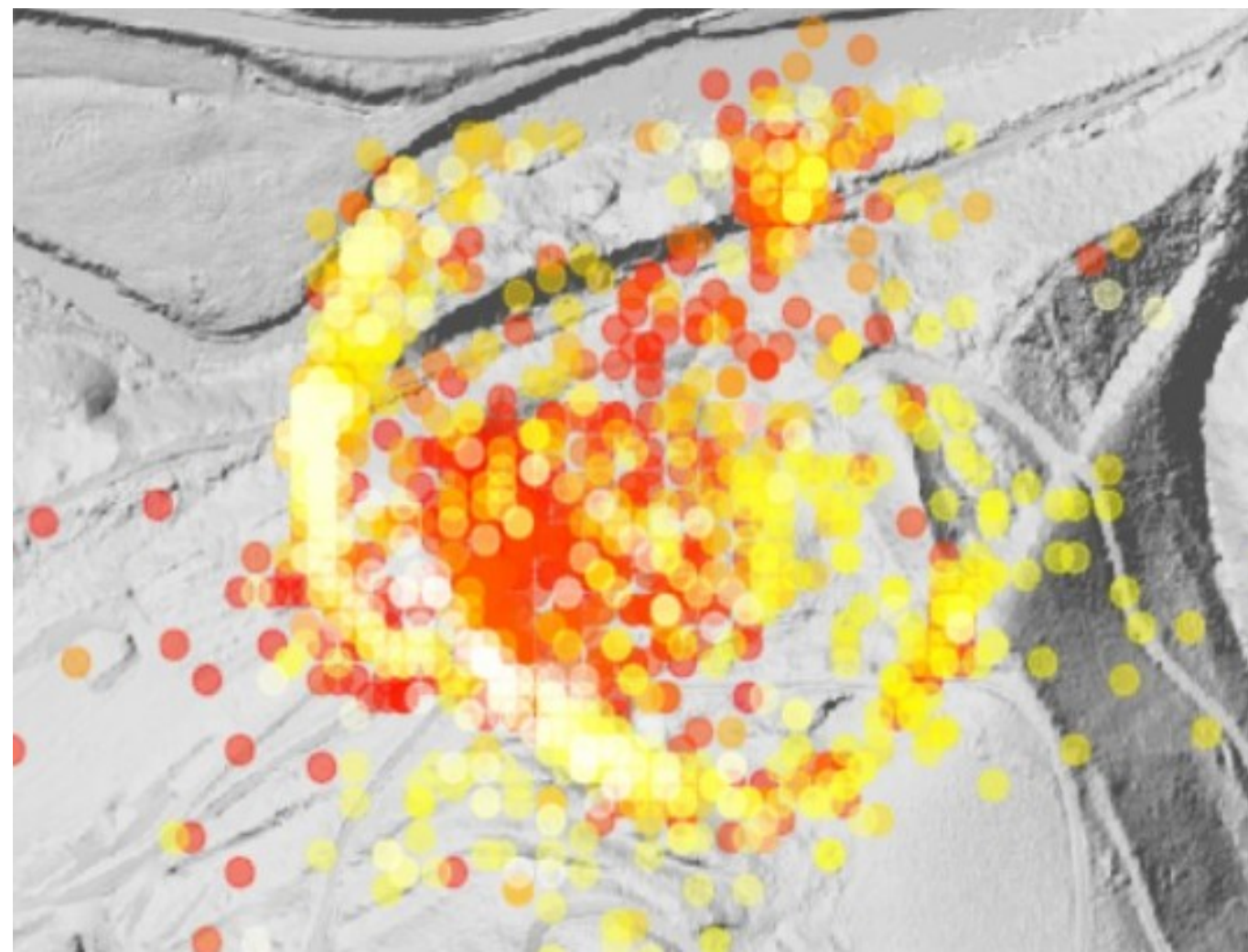
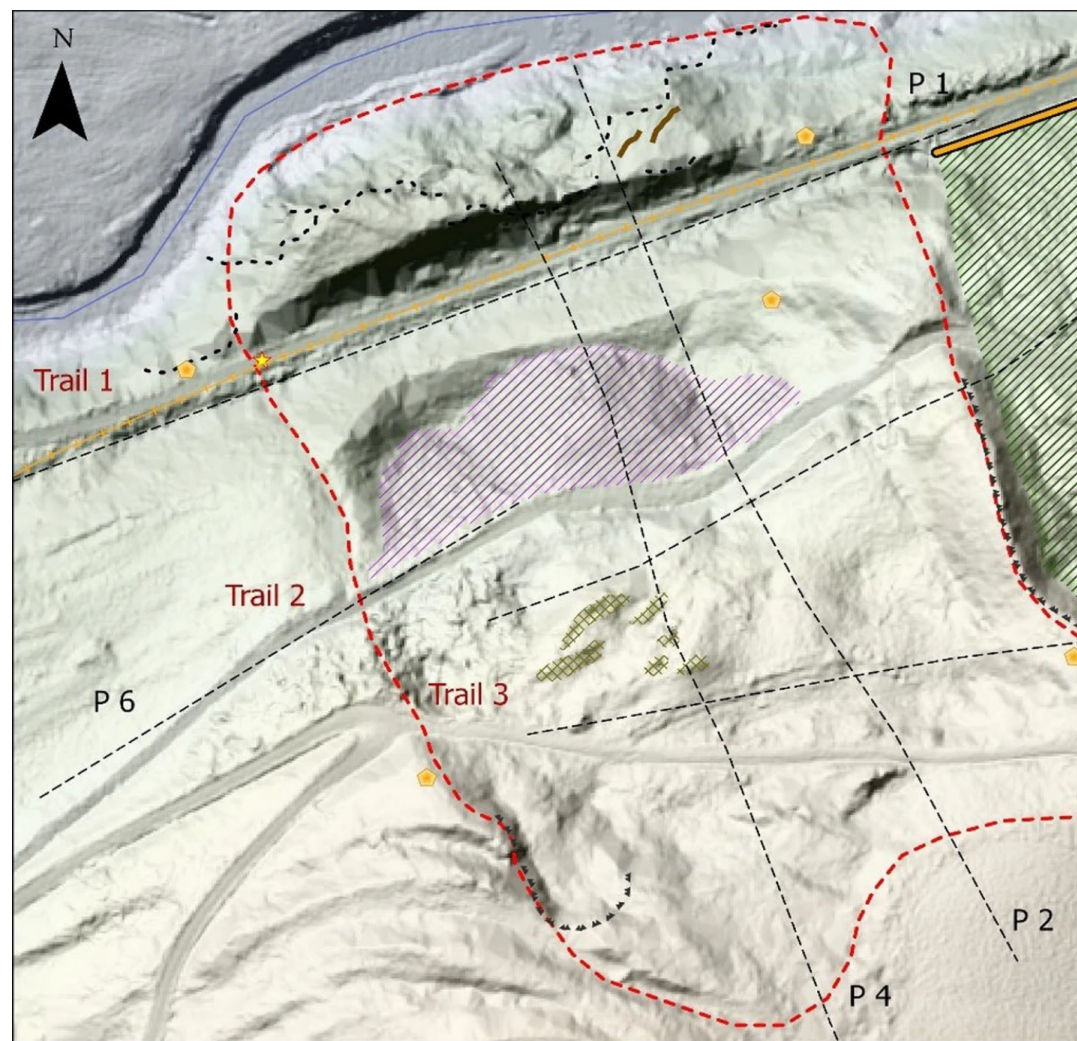
Lake Volume MQ (4.5 m³/s) HQ5 (86.7 m³/s)

Scenario 1 (20,700 m ³)	1.2 h	3.9 min
Scenario 2 (117,000 m ³)	7.2 h	22.4 min
Scenario 3 (208,900 m ³)	12.8 h	40.1 min
Scenario 4 (331,900 m ³)	20.4 h	1.06 h

- > Small failure volume sufficient to pond lake that can inundate and pose break-out flood
- > Reaction time window minimal for co-acting rain and river discharge

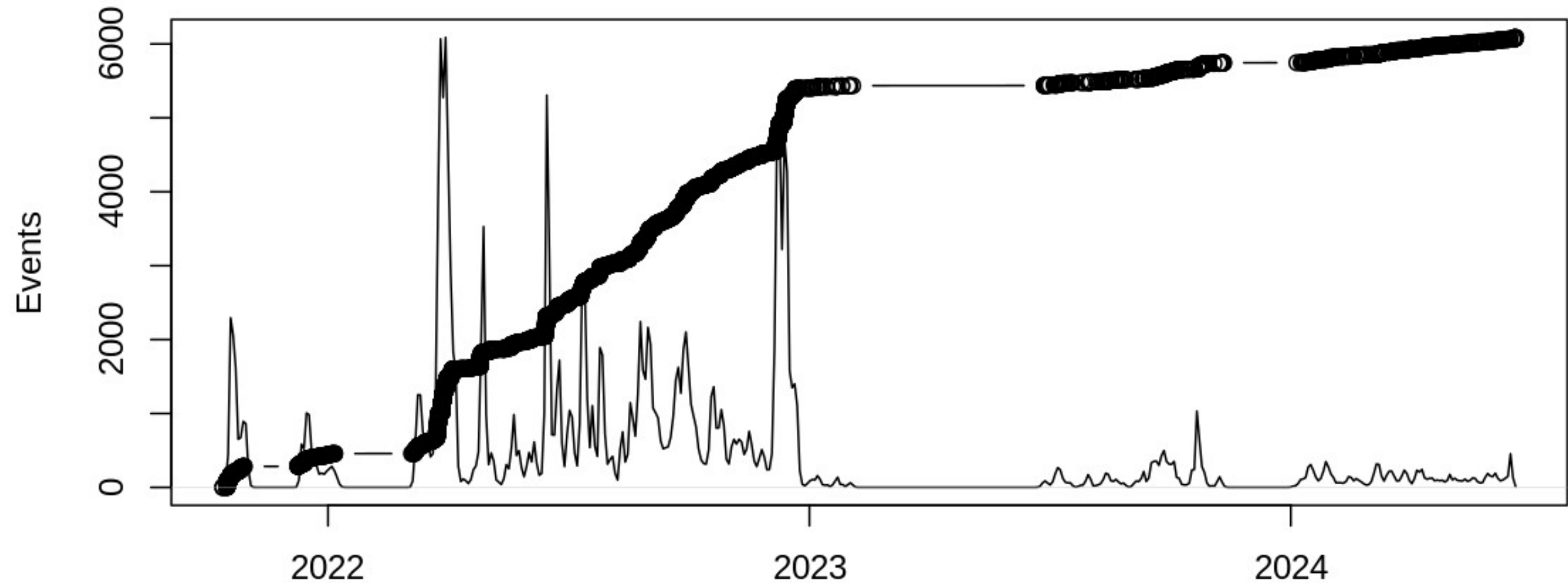
Seismic events are focussed at the margins of the failure

SEISMIC SOURCE LOCATIONS (AMPLITUDE MODELLING), COLOURED BY TIME RED TO WHITE



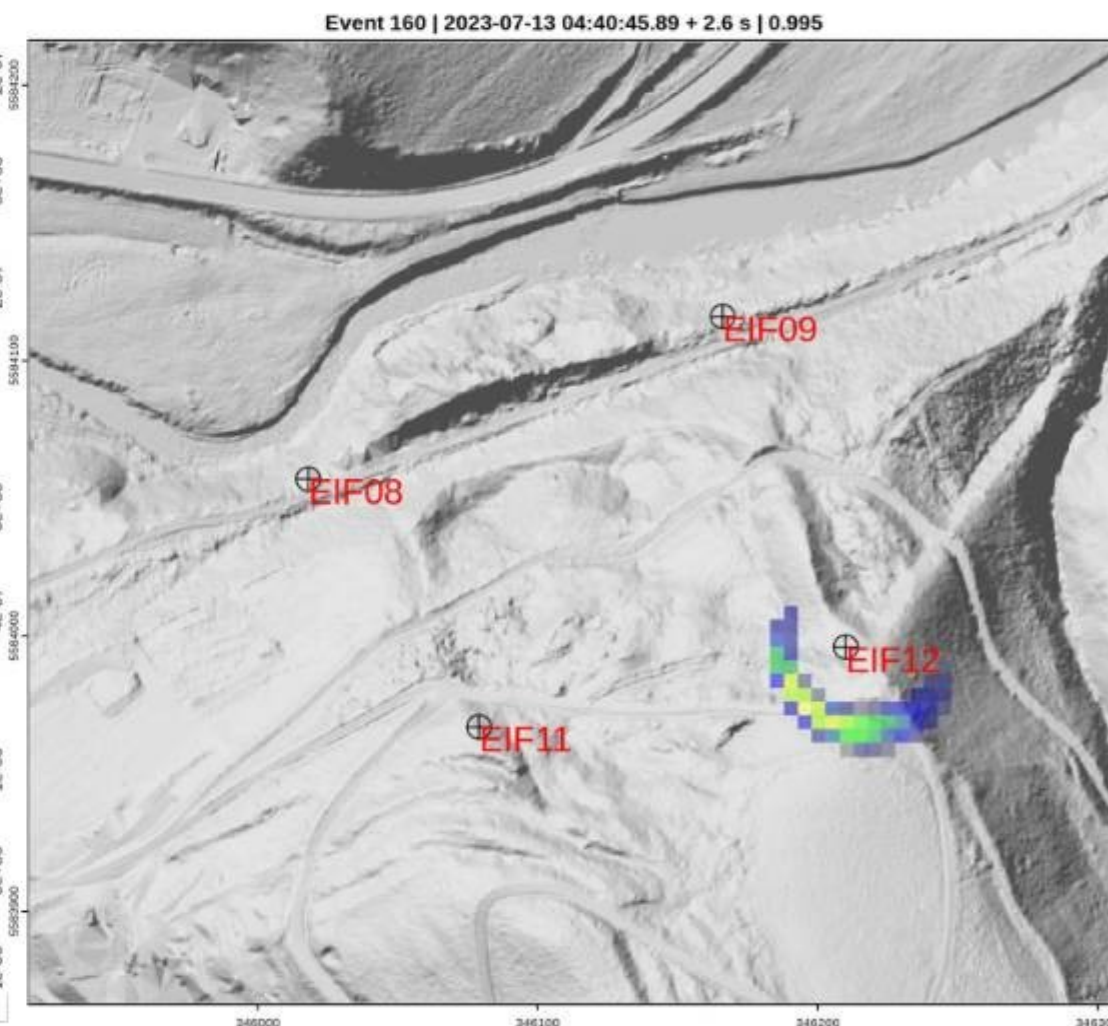
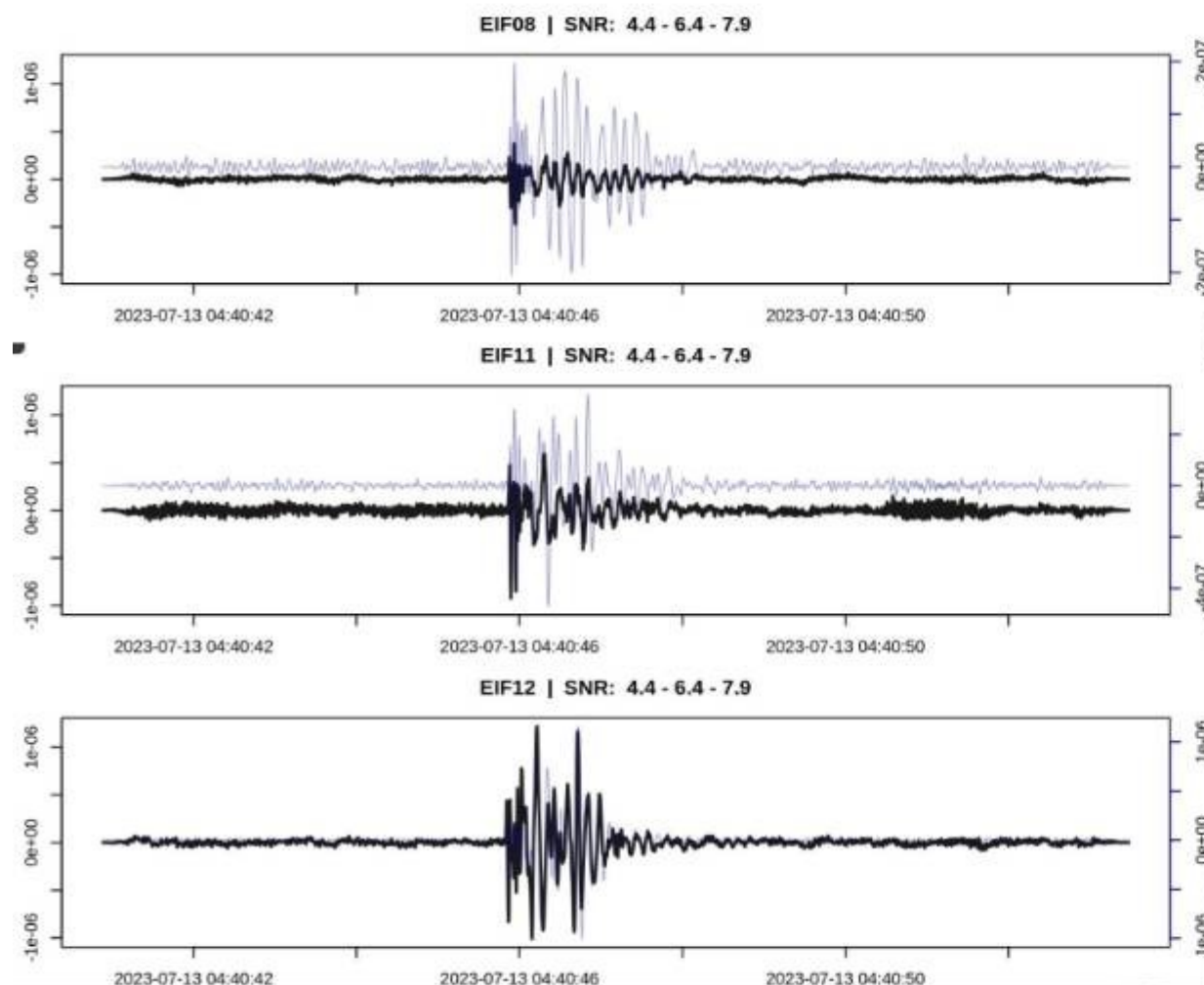
Emergence of seismic signals through time

TIME SERIES OF (MANUALLY CONFIRMED) SEISMIC EVENTS SINCE INSTALLATION



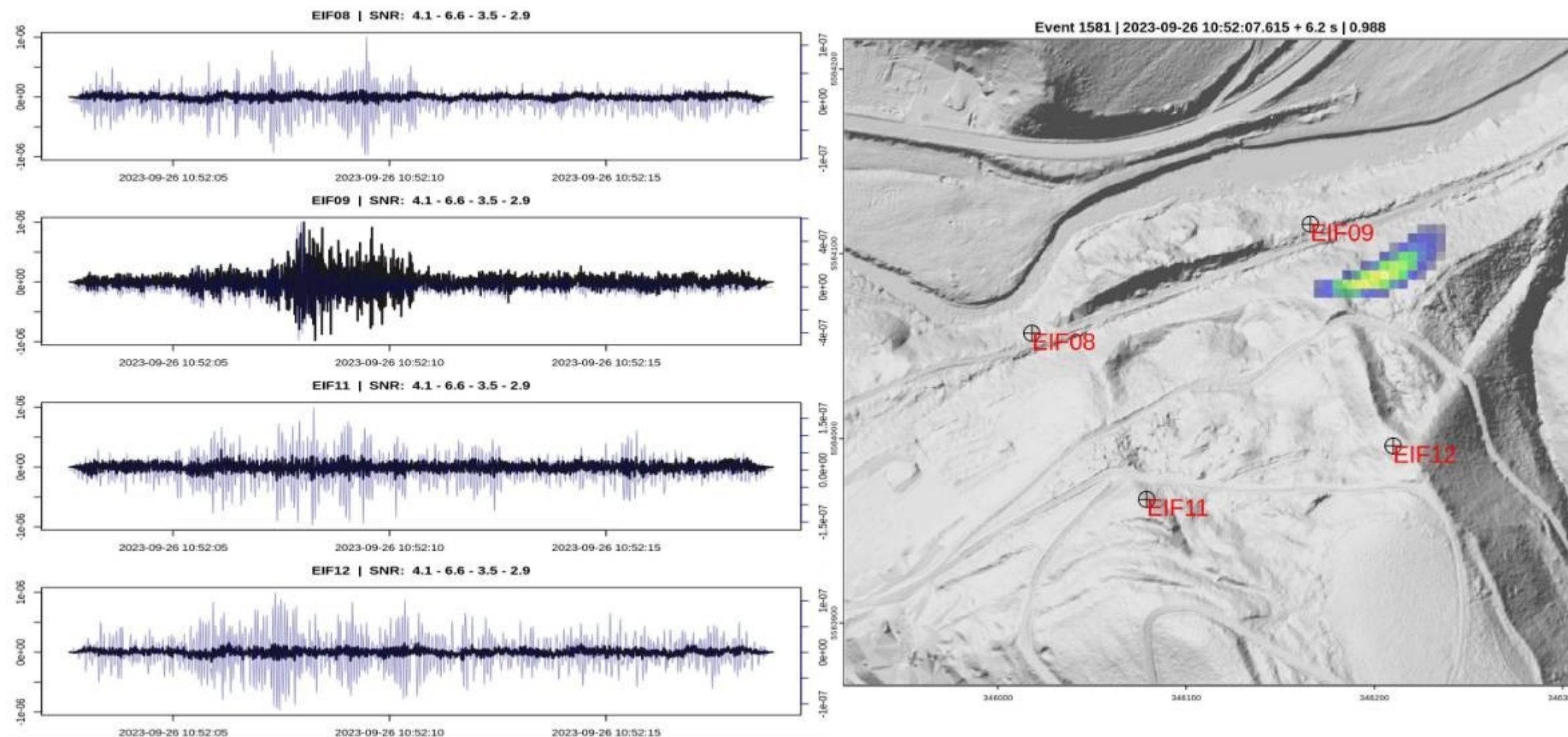
Short event type – an example from July 2023 aka CRACKING

SEISMIC WAVEFORMS AND SOURCE LOCATION OF A 2.6 s LONG EVENT



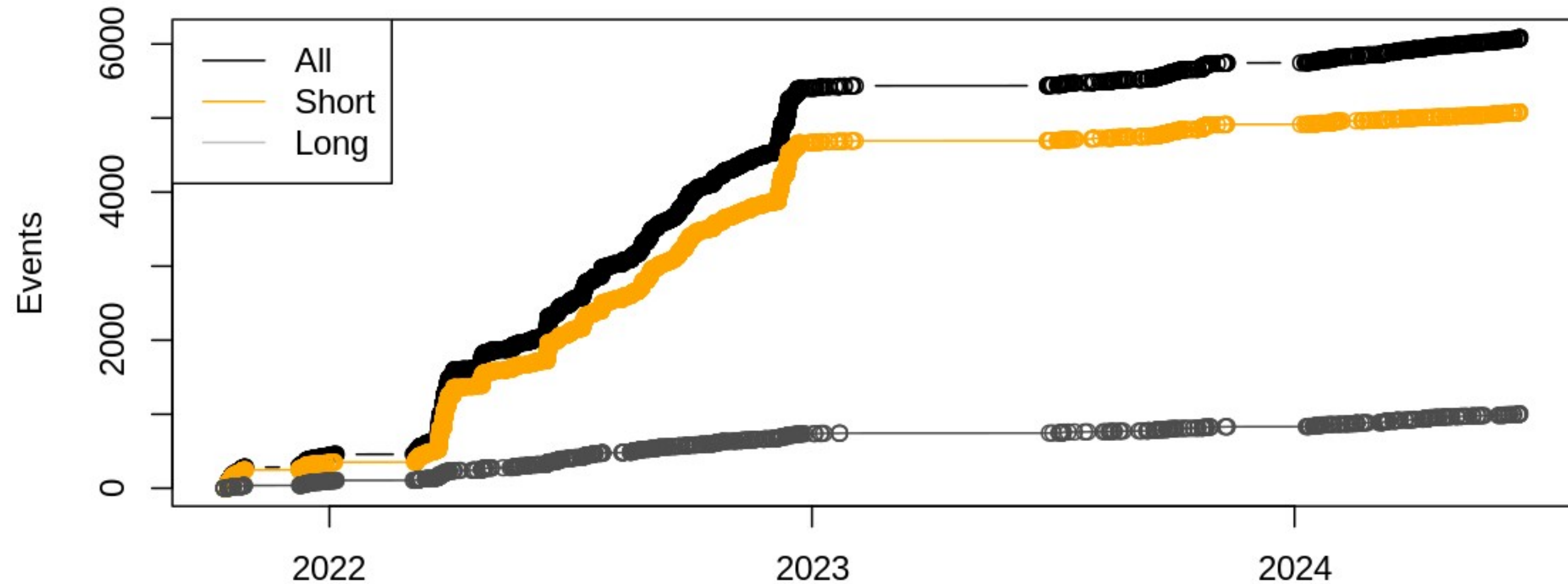
Long event type - an example from September 2023 aka SLOPE ACTIVITY

SEISMIC WAVEFORMS AND SOURCE LOCATION OF A 6.2 s LONG EVENT



Evolution of the two main events classes

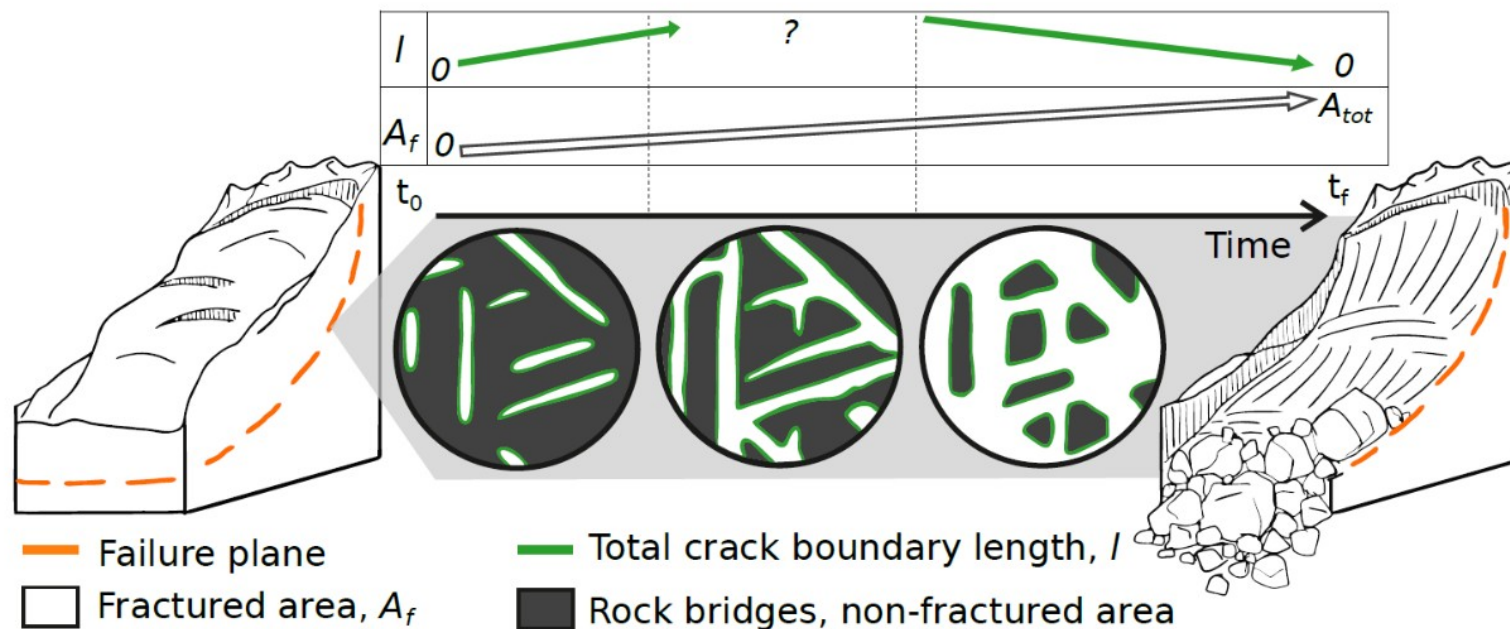
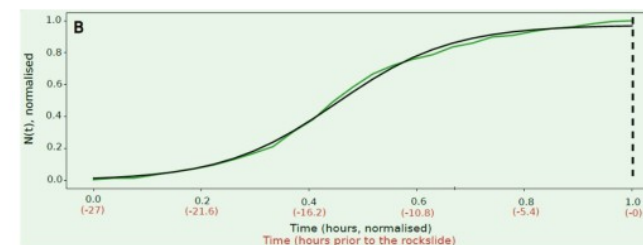
TIME SERIES OF (MANUALLY CONFIRMED) SEISMIC EVENTS BY DURATION



Evolution of the two main events classes

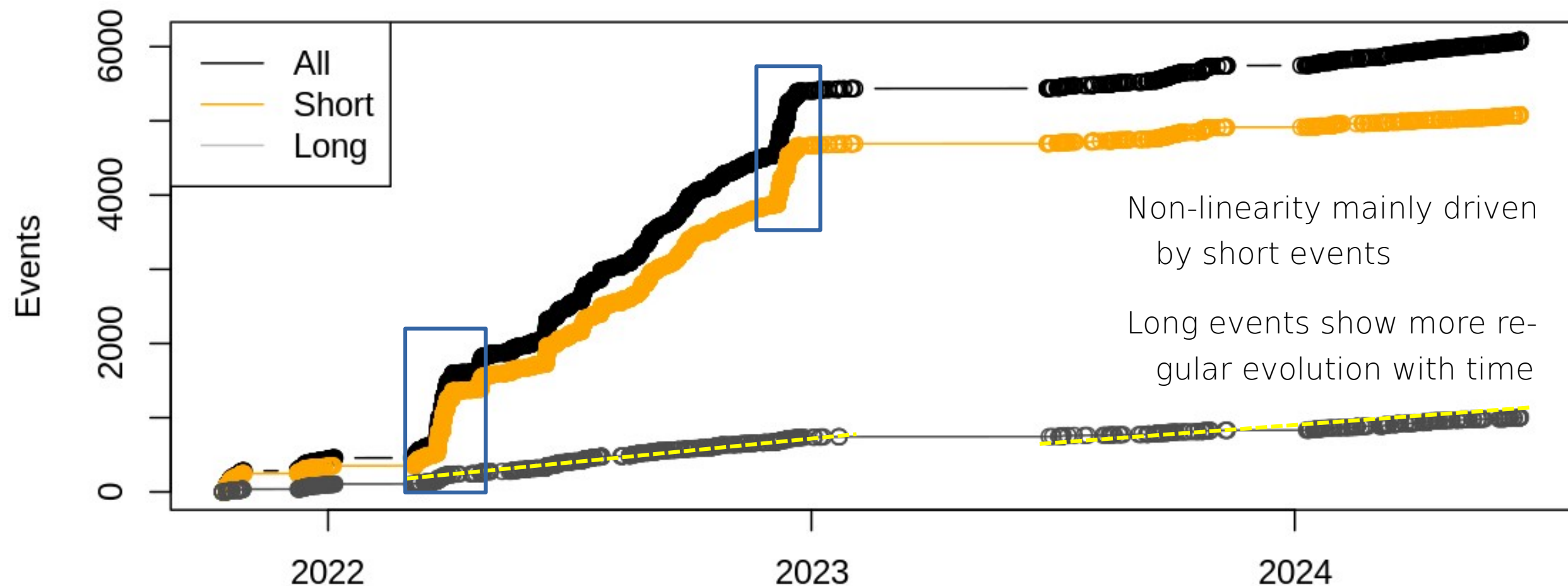
TIME SERIES OF (MANUALLY CONFIRMED) SEISMIC EVENTS BY DURATION

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



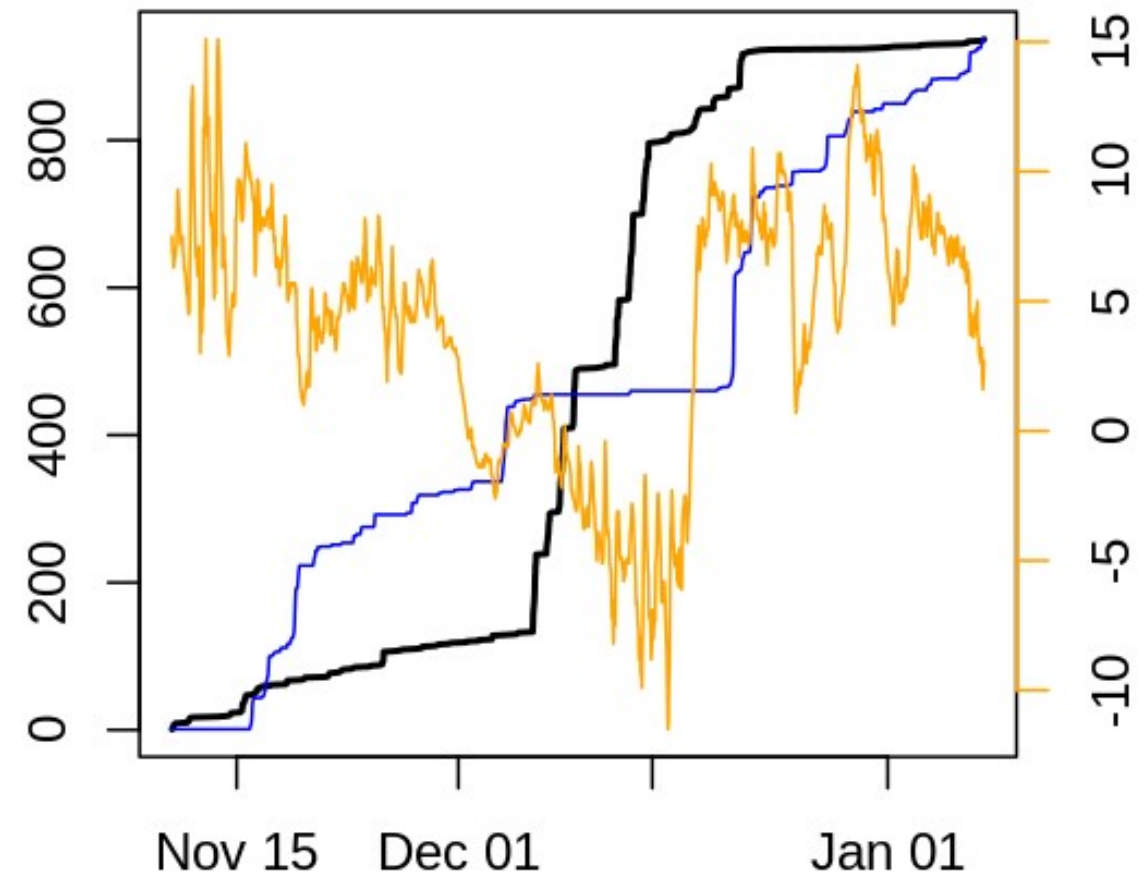
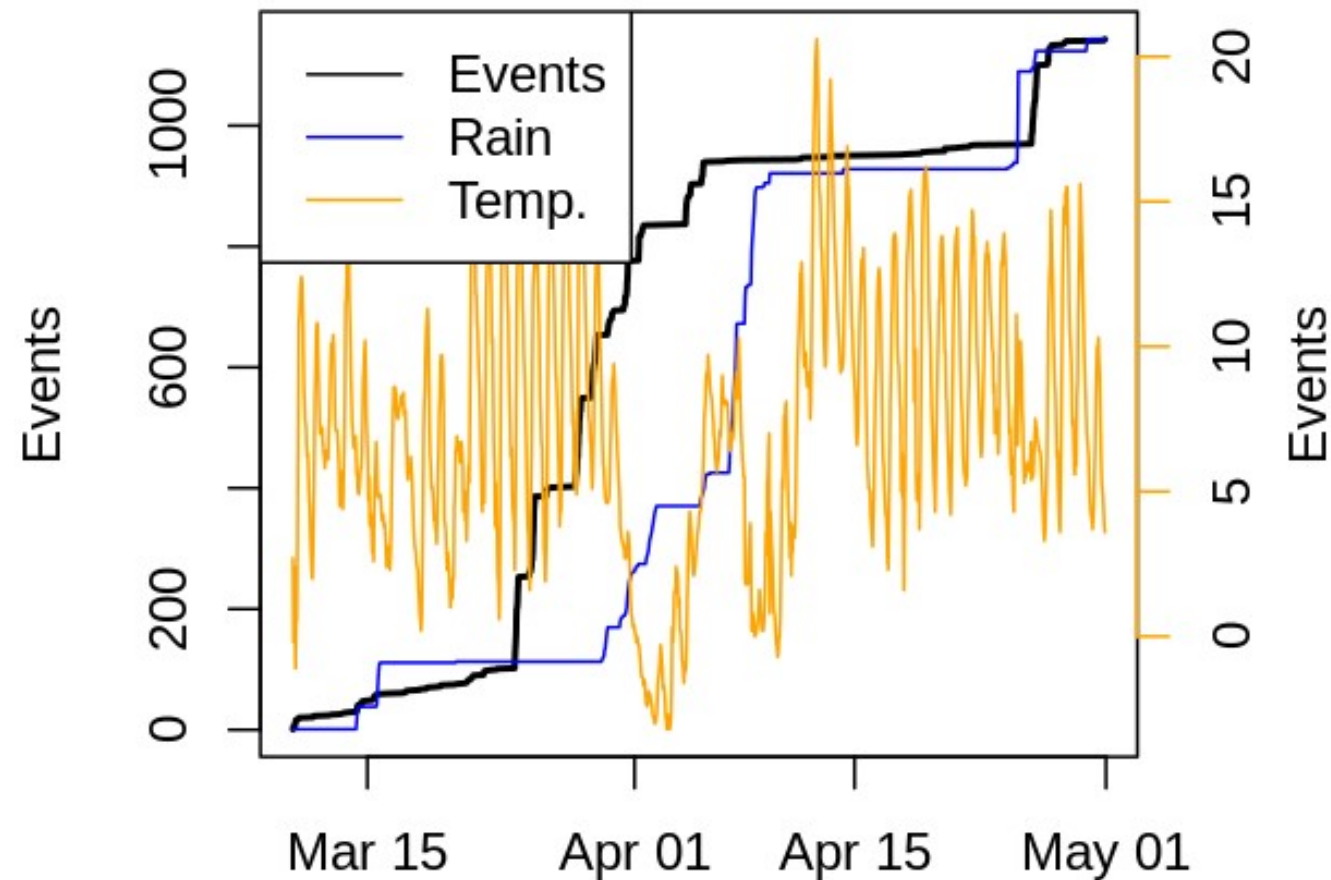
Evolution of the two main events classes

TIME SERIES OF (MANUALLY CONFIRMED) SEISMIC EVENTS BY DURATION



Drivers of short event activity are not straightforward to interpret

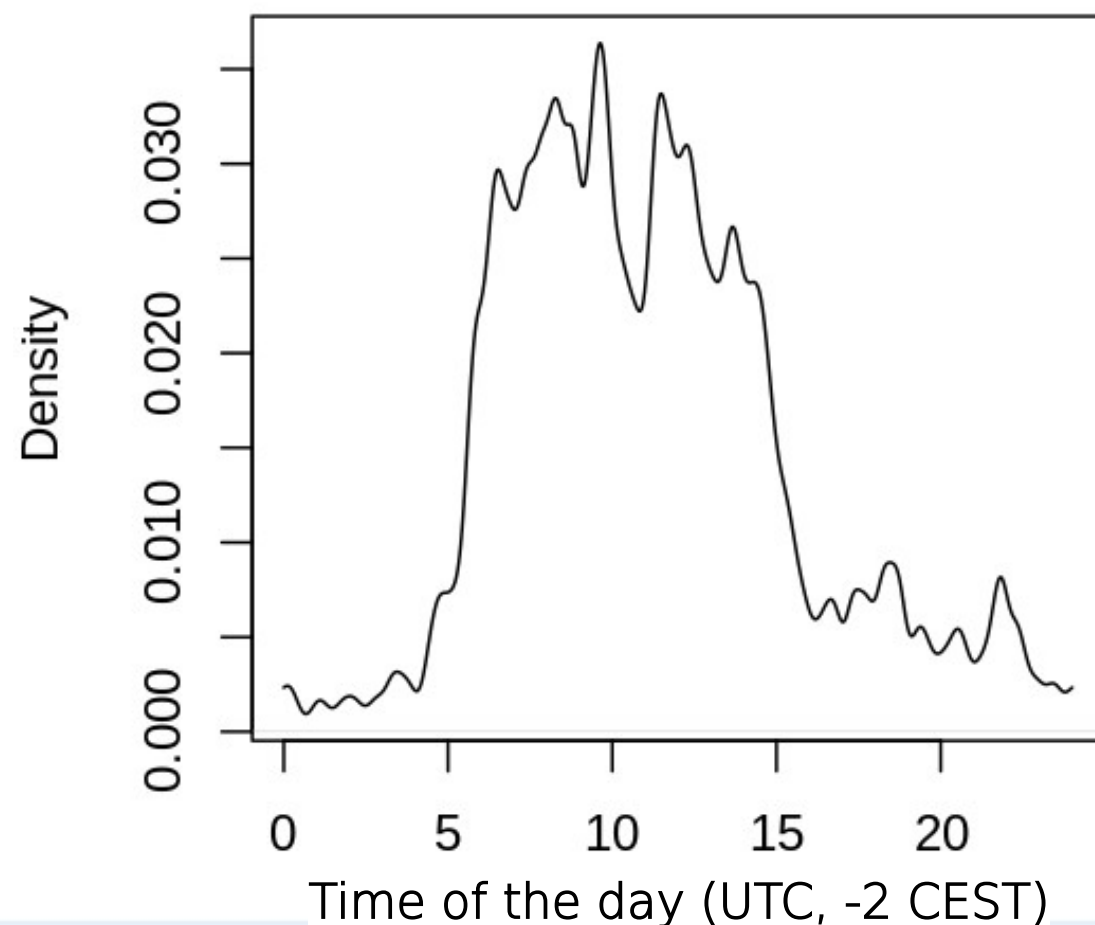
SEISMIC EVENTS (BLACK) IN RELATION WITH PRECIPITATION (BLUE) AND AIR TEMPERATURE (ORANGE)



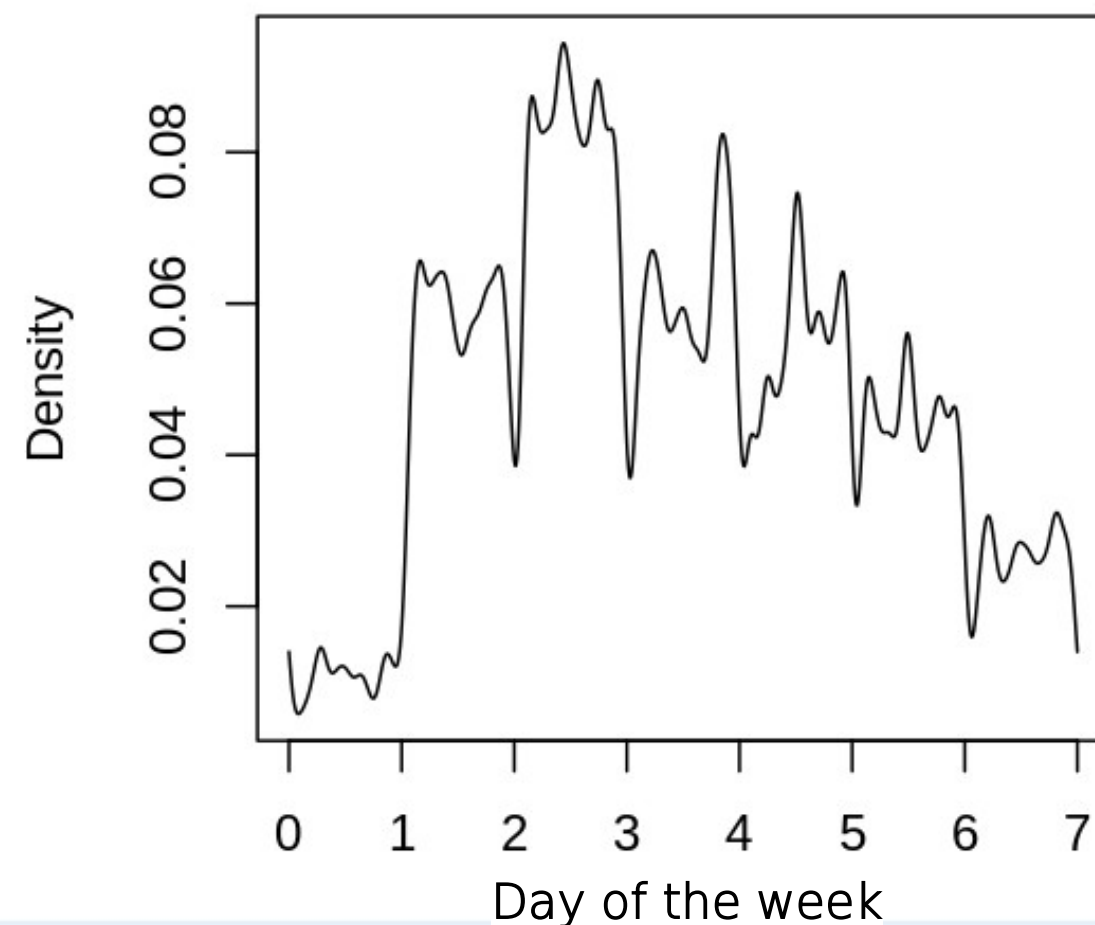
Drivers of short event activity are straightforward but inconvenient to interpret

SEISMIC EVENT OCCURRENCE BY TIME OF THE DAY AND WEEK DAY, BOTH POINTING AT STRONG ANTHROPOGENIC DRIVER

Events by day time



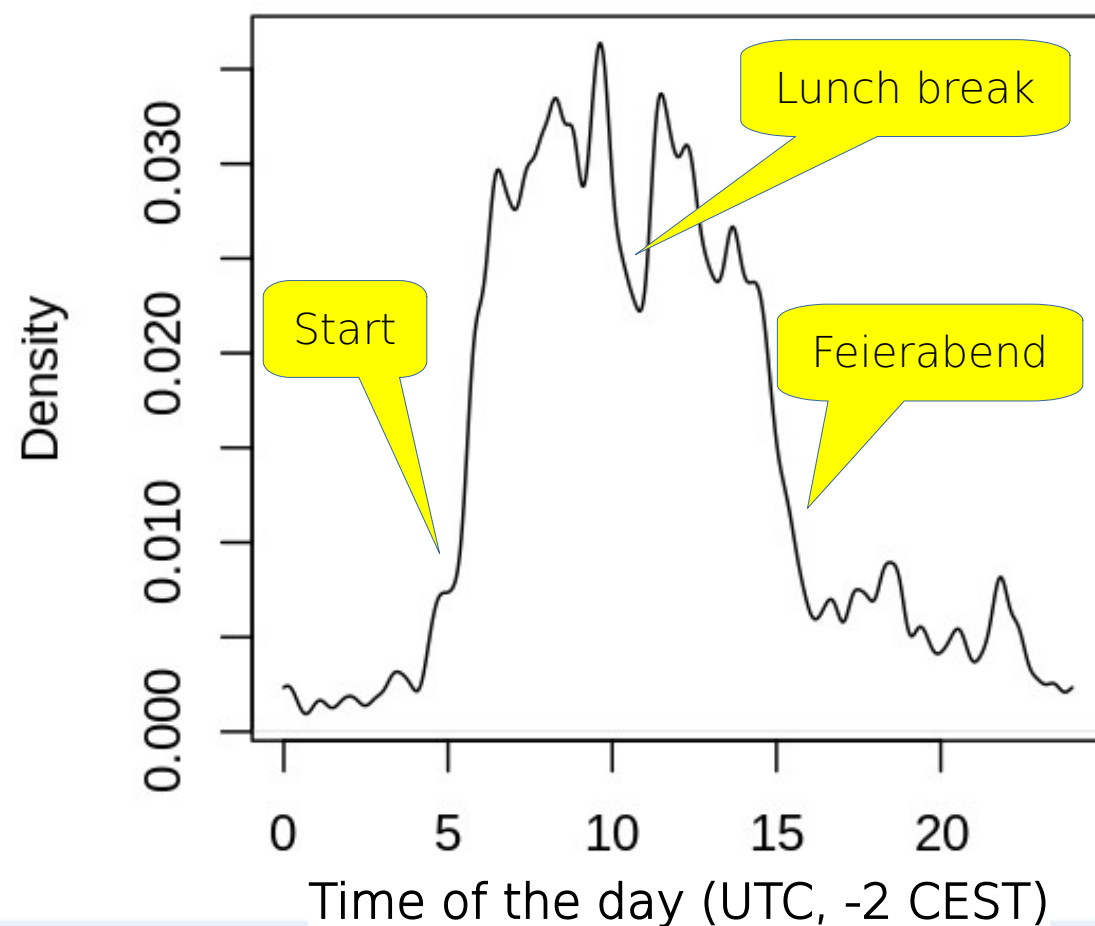
Events by week day



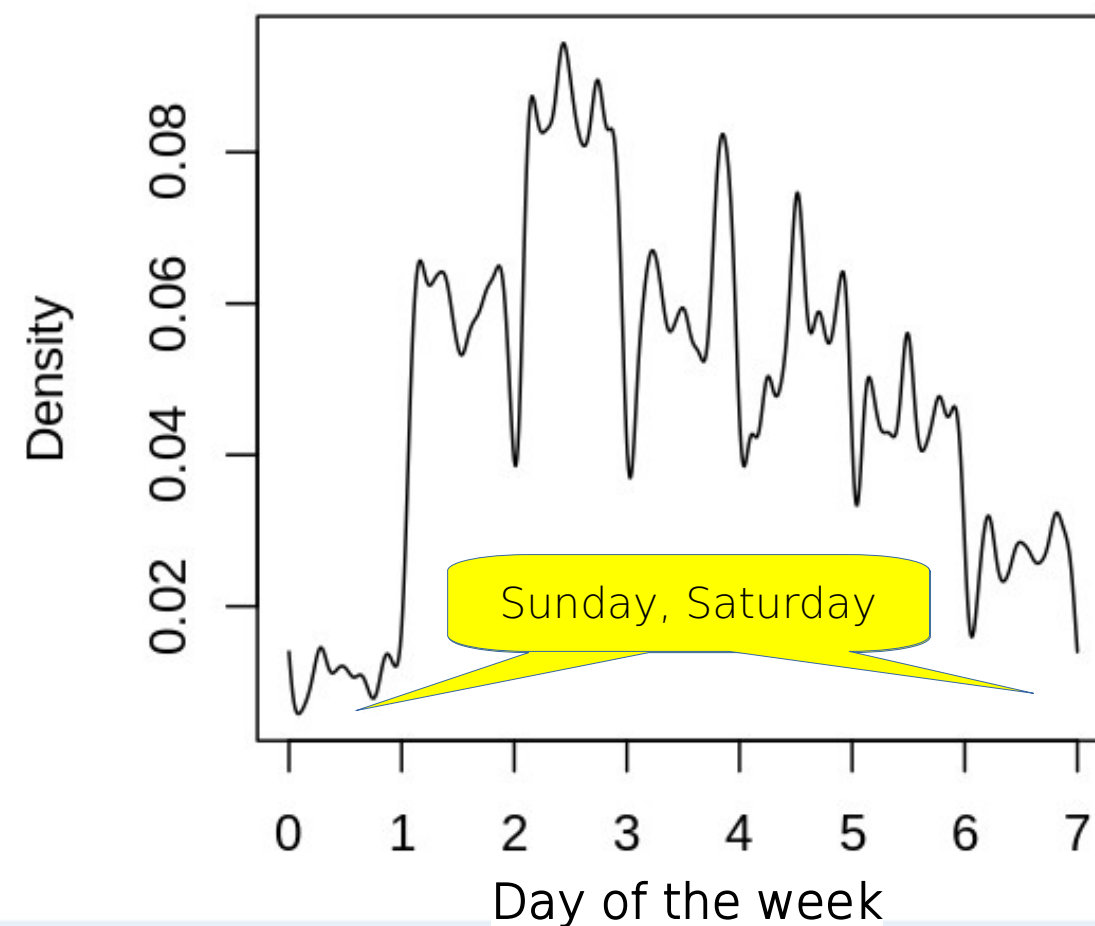
Drivers of short event activity are straightforward but inconvenient to interpret

SEISMIC EVENT OCCURRENCE BY TIME OF THE DAY AND WEEK DAY, BOTH POINTING AT STRONG ANTHROPOGENIC DRIVER

Events by day time



Events by week day

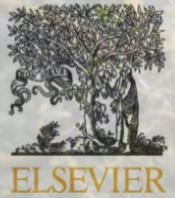


And now to something different
DELVING INTO THE REALM OF BIOGEOMORPHOLOGY



Role of fish in mobilising and reorganising river bed material

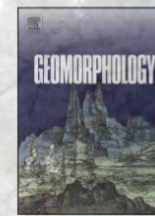
WHY BIOGEOMORPHIC AGENTS NEED TO BE CONSIDERED IN UNDERSTANDING HOW RIVERS OPERATE



Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph



Sex that moves mountains: The influence of spawning fish on river profiles over geologic timescales



GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L04405, doi:10.1029/2007GL032997, 2008

Salmon-driven bed load transport and bed morphology in mountain streams

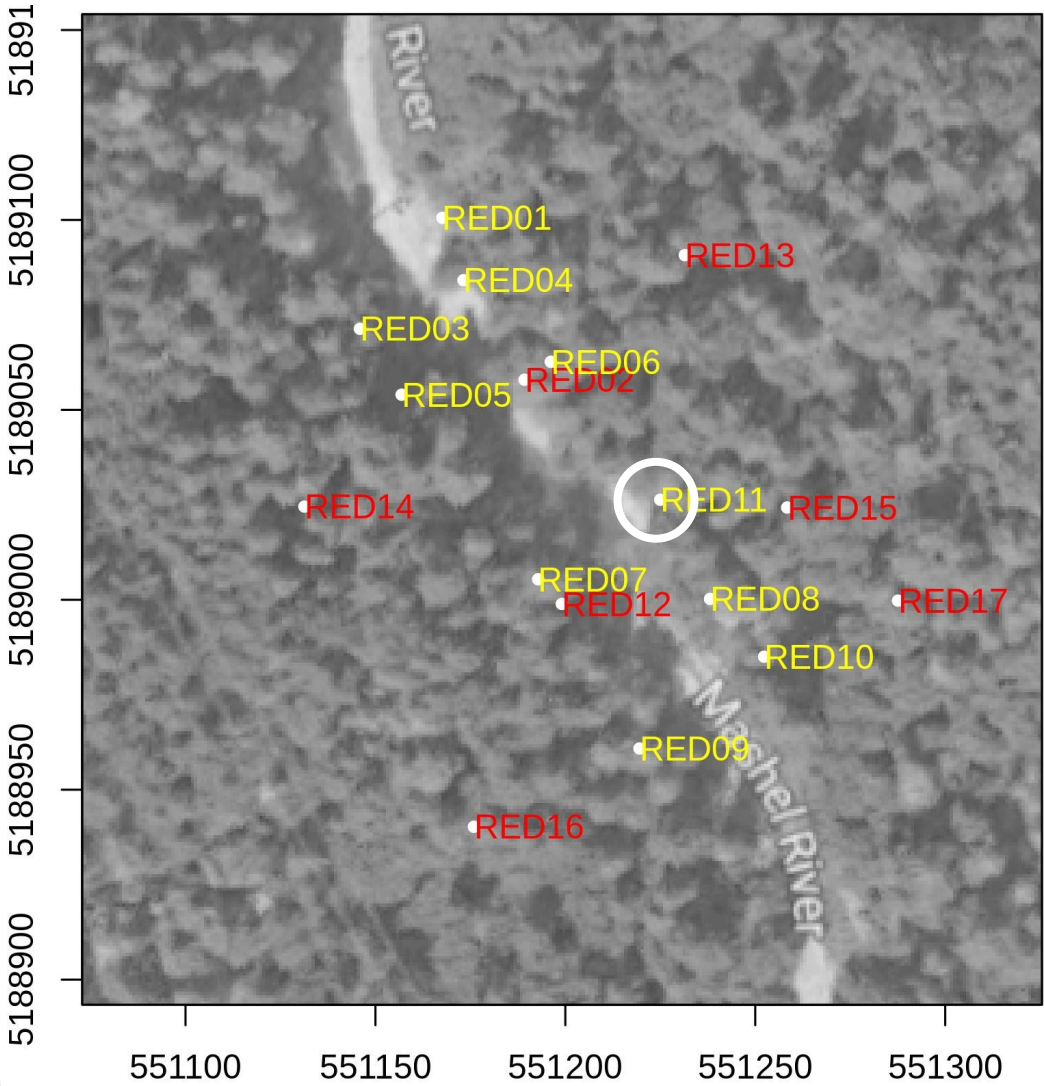
Marwan A. Hassan,¹ Allen S. Gottesfeld,² David R. Montgomery,³ Jon F. Tunnicliffe,⁴ Garry K. C. Clarke,⁵ Graeme Wynn,¹ Hale Jones-Cox,¹ Ronald Poirier,¹ Erland MacIsaac,⁶ Herb Herunter,⁶ and Steve J. Macdonald⁷

Spawning fish species (e.g., Steelhead trout) build nests

REDDING LEAVES METRE LARGE AND DECIMETRE DEEP NESTS OF REORGANISED MATERIAL

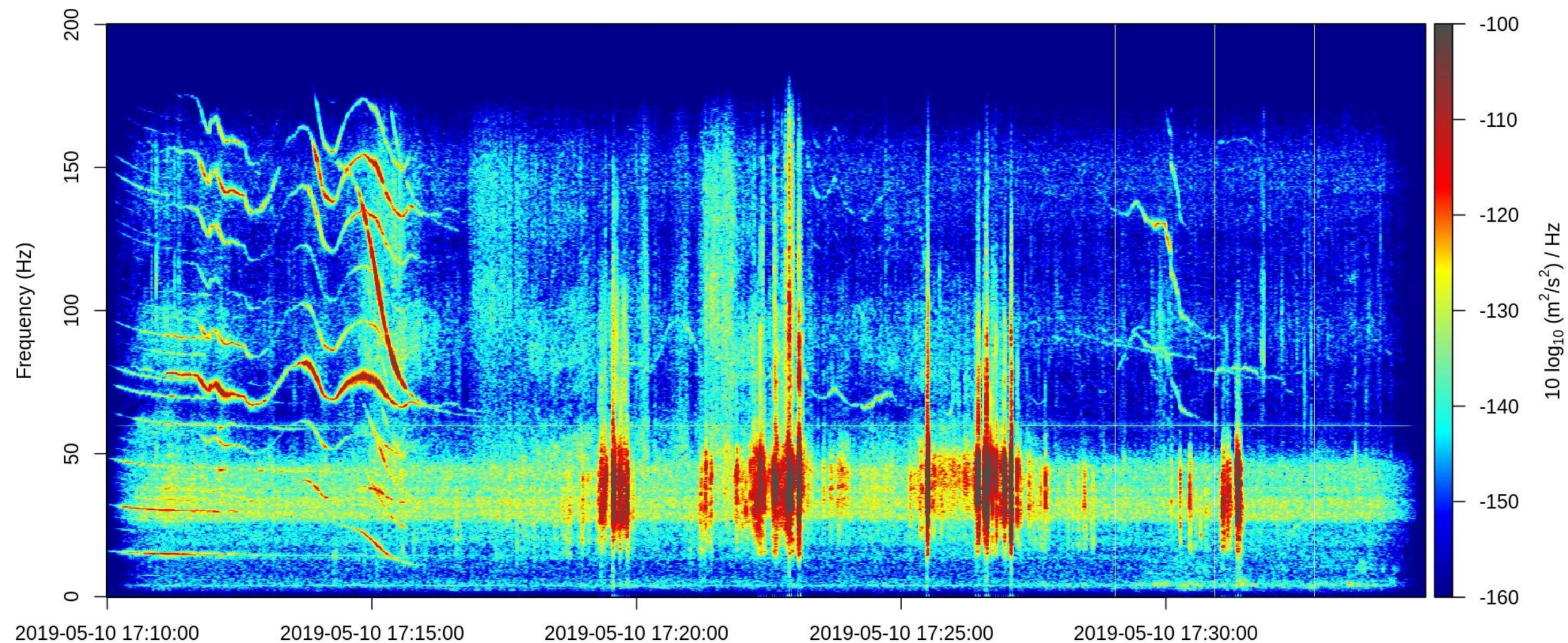


About 2.5 m by 1 m, built 04-15 May 2019



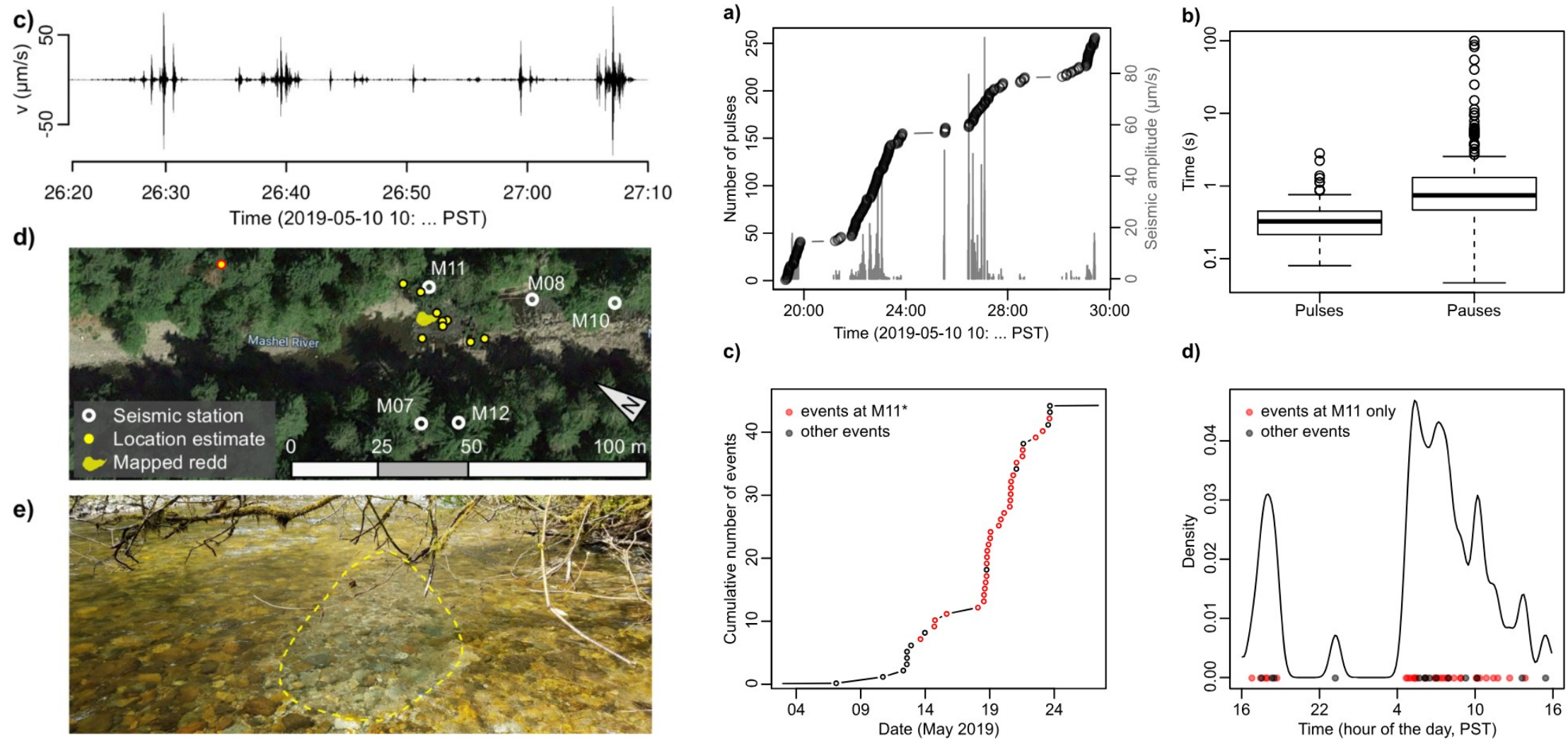
Seismic networks as 24/7 monitoring approach for redding activity

SEISMOMETERS DETECT WHEN, WHERE, HOW, AND HOW OFTEN FISH "WORK" ON THEIR NEST STRUCTURES



Seismic networks as 24/7 monitoring approach for redding activity

SEISMOMETERS DETECT WHEN, WHERE, HOW, AND HOW OFTEN FISH "WORK" ON THEIR NEST STRUCTURES



Towards 3D monitoring of soil macro fauna

LUMBRICIDES AS IMPORTANT HIGH LATITUDE CARBON CYCLE AGENTS



Invasive earthworms unlock arctic plant nitrogen limitation

[Gesche Blume-Werry](#), [Eveline J. Krab](#), [Johan Olofsson](#), [Maja K. Sundqvist](#), [Maria Väisänen](#) & [Jonatan Klaminder](#) ✉

[Nature Communications](#) **11**, Article number: 1766 (2020) | [Cite this article](#)



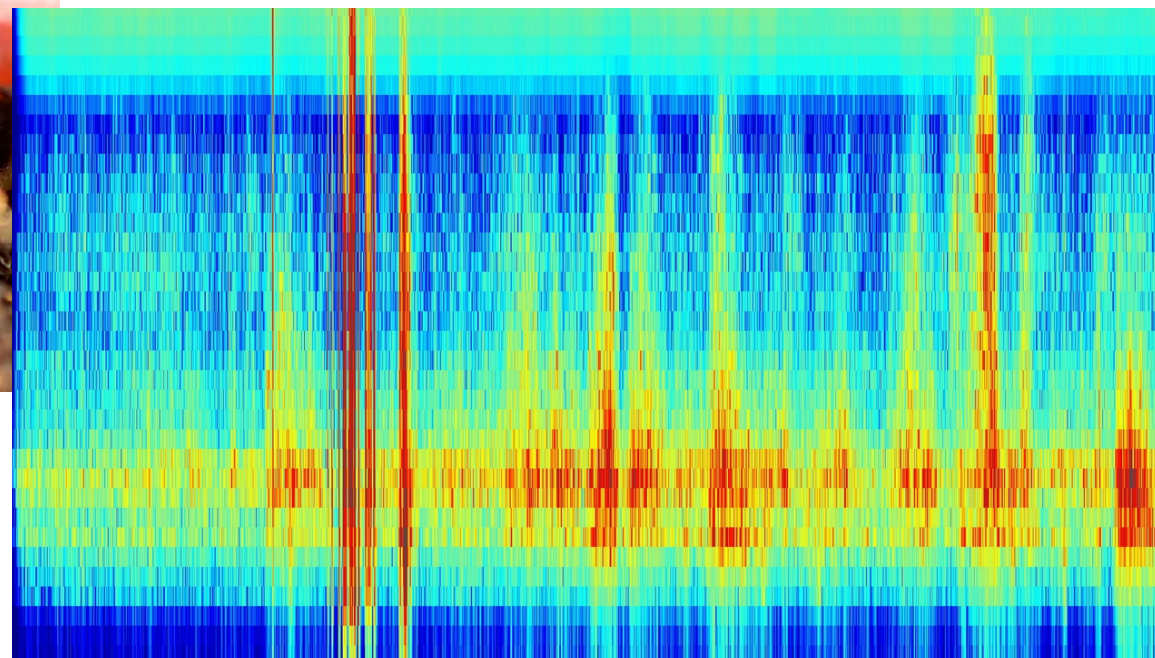
Science of The Total Environment

Volume 859, Part 2, 10 February 2023, 160125



Holes in the tundra: Invasive earthworms alter soil structure and moisture in tundra soils

[J. Klaminder](#)^a ✉, [E.J. Krab](#)^{a,b}, [M. Larsbo](#)^b, [H. Jonsson](#)^a, [J. Fransson](#)^a, [J. Koestel](#)^{b,c}



Into the realm of "suicidal" Patagonian forests

HOW DO TREES MITIGATE ENERGY TRANSFER BETWEEN ATMOSPHERE AND GEOSPHERE?

Extremely high productivity
Extremely high erosion
Extremely short transport ways



Into the realm of "suicidal" Patagonian forests

HOW DO TREES MITIGATE ENERGY TRANSFER BETWEEN ATMOSPHERE AND GEOSPHERE?

Extremely high productivity
Extremely high erosion
Extremely short transport ways

Trees load the hillslope
to a critical state



Rain adds load and
pore pressure

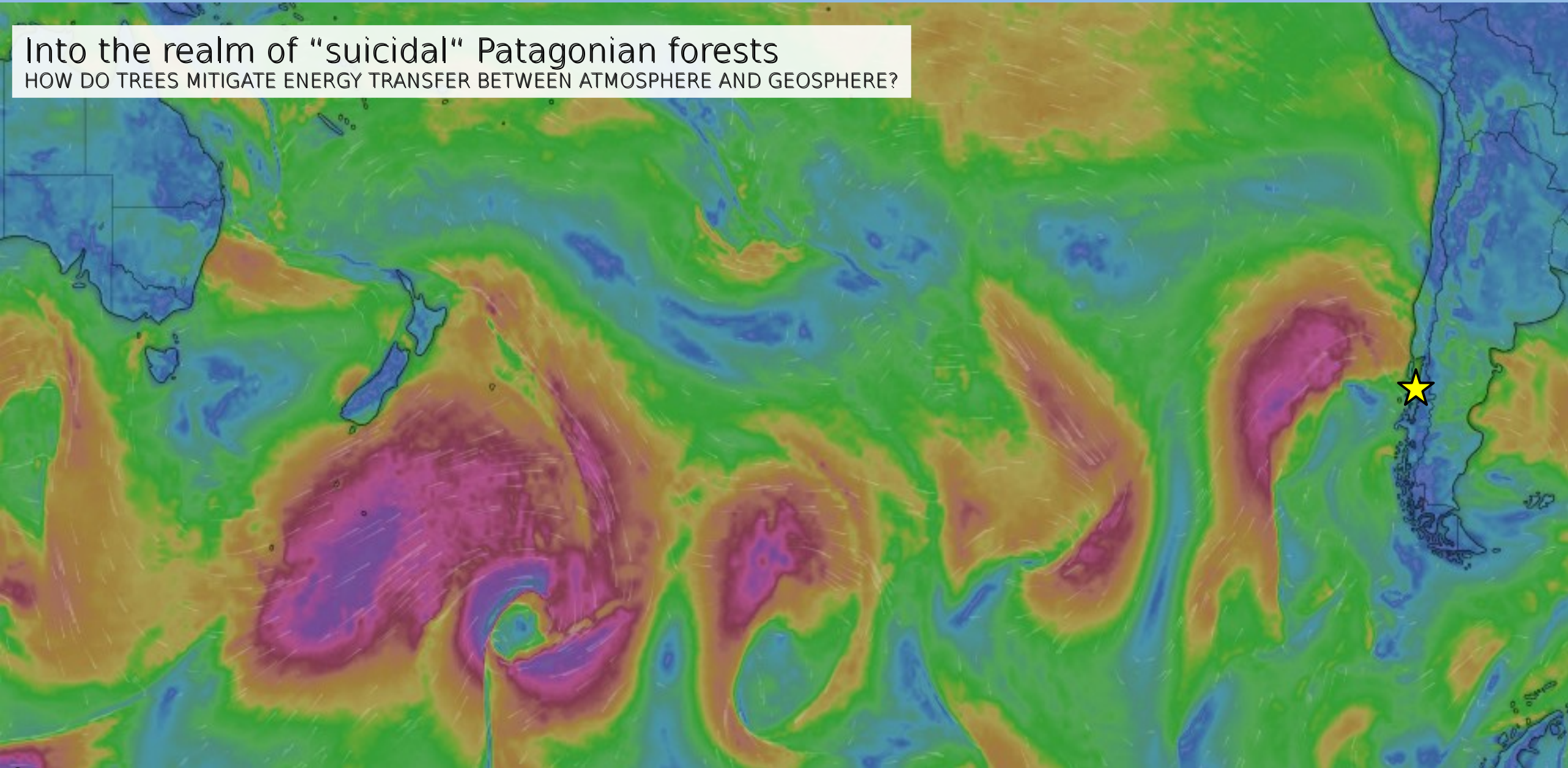
Wind exerts load &
leverage forces



Slopes fail and trigger
follow-on instability

Into the realm of "suicidal" Patagonian forests

HOW DO TREES MITIGATE ENERGY TRANSFER BETWEEN ATMOSPHERE AND GEOSPHERE?



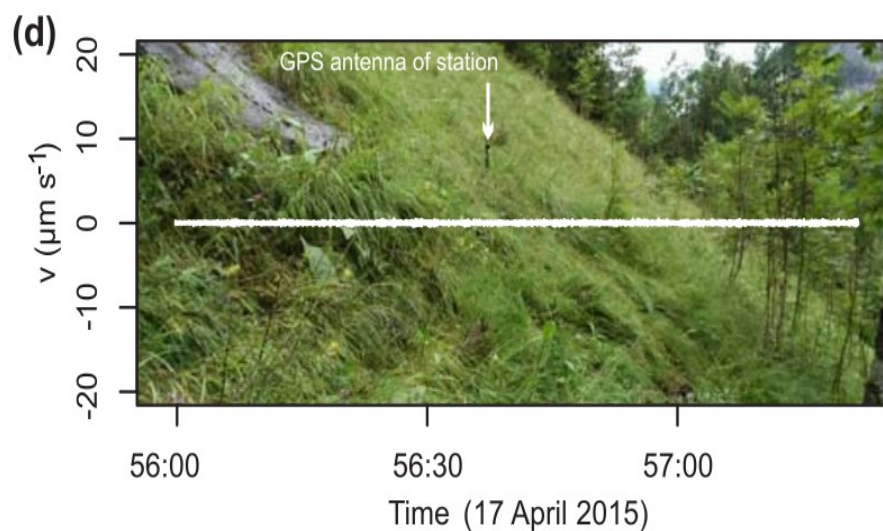
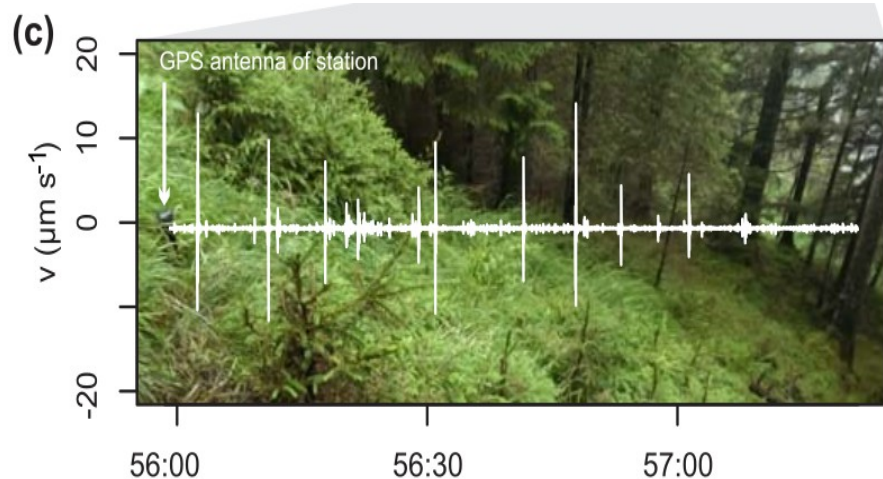
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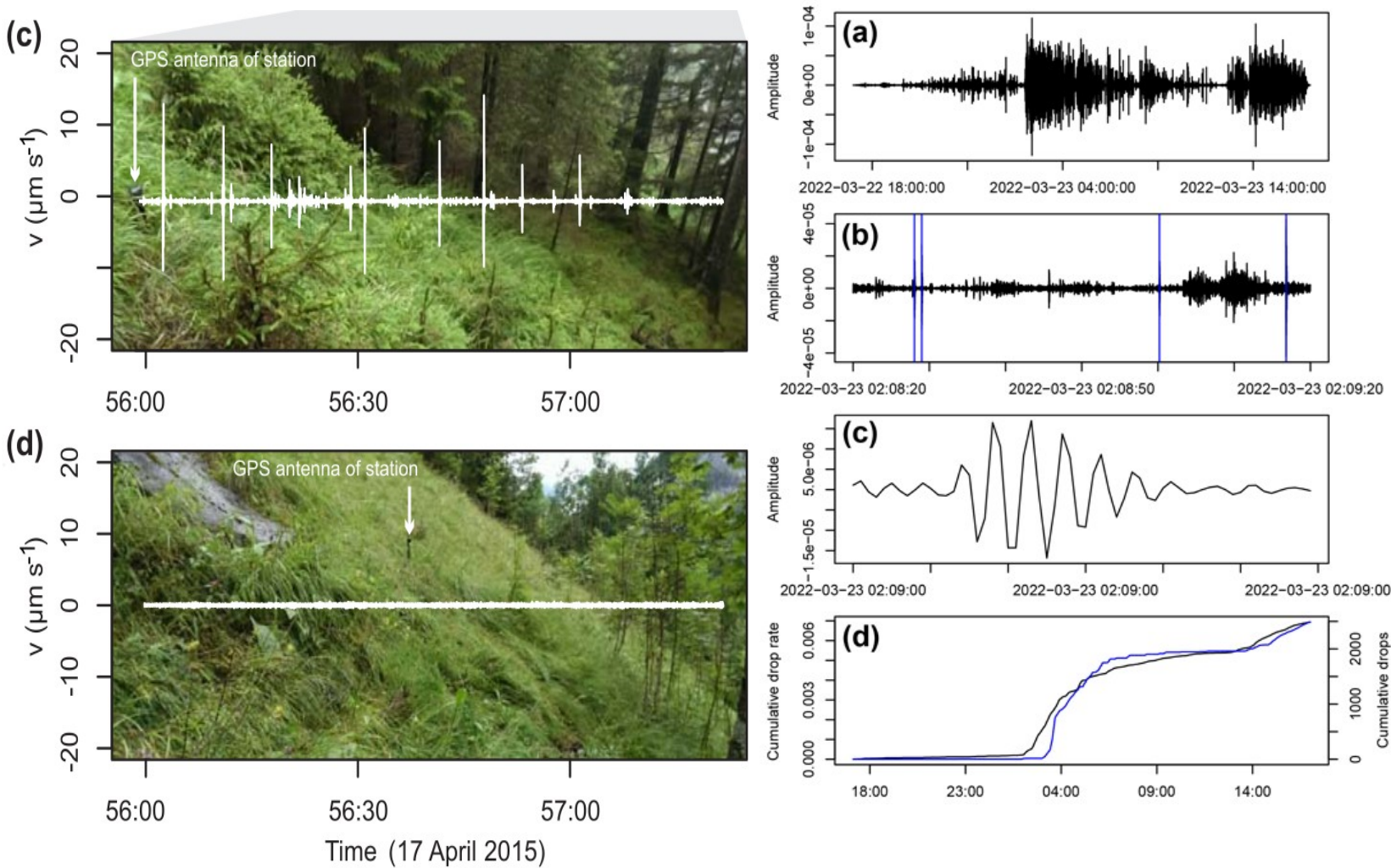
Surveying the distributed effect of rain input

SEISMOMETERS AS MEANINGFULLY AVERAGING GAUGES & DISTROMETERS



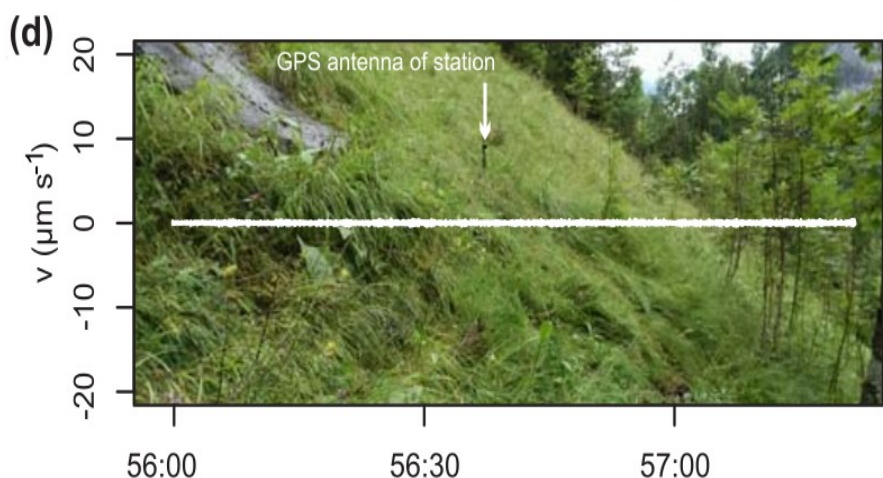
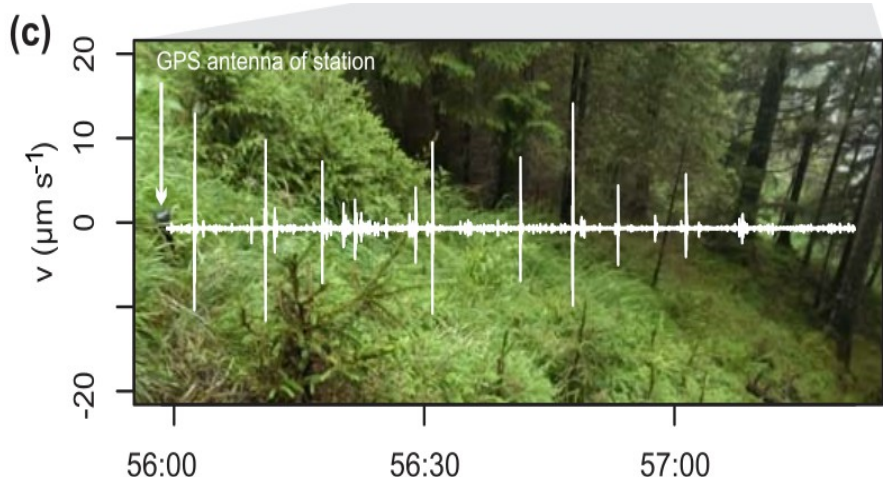
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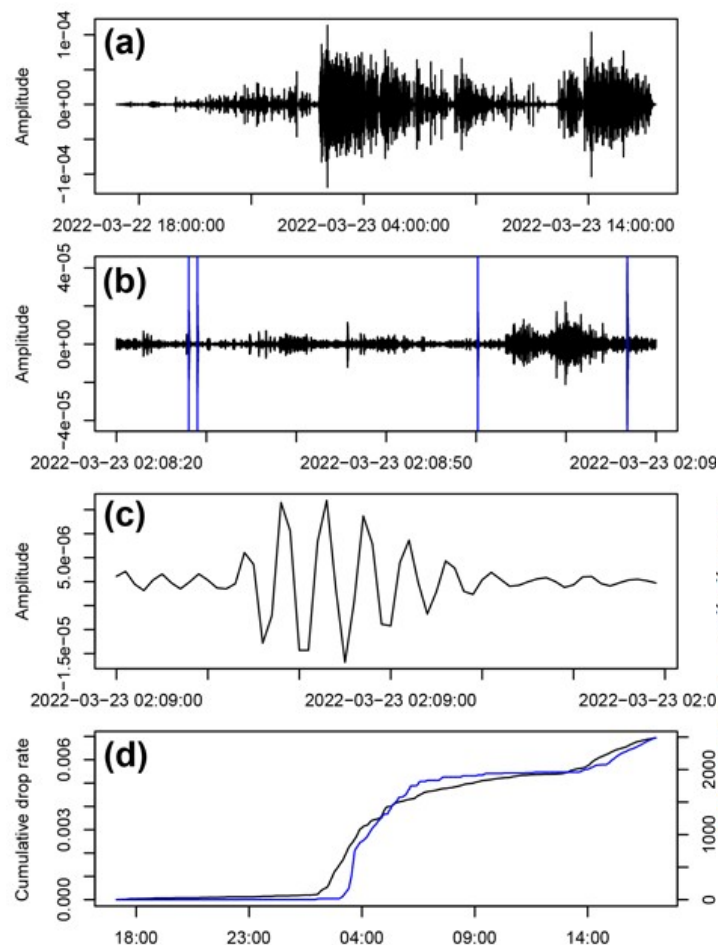


Surveying the distributed effect of rain input

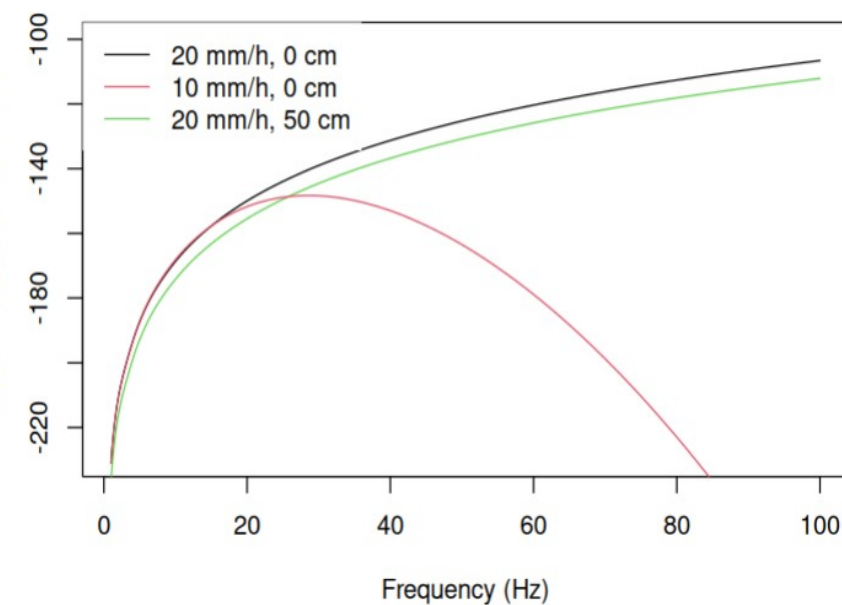
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Time (17 April 2015)

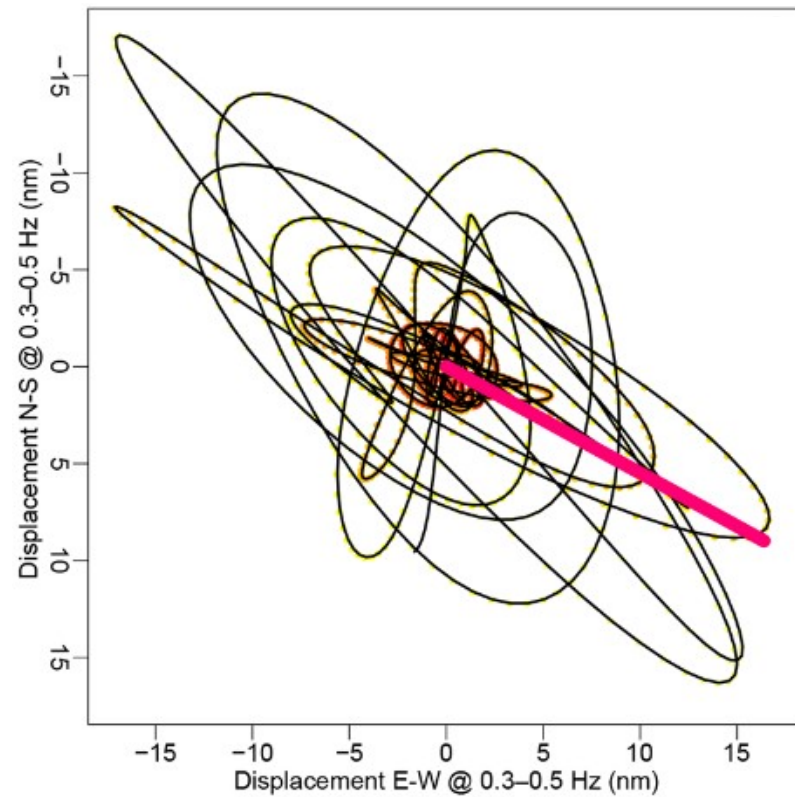


$$P(f) = 8\pi^3 f^2 \int_r J_P \tilde{G}^2(f, r) r dr$$



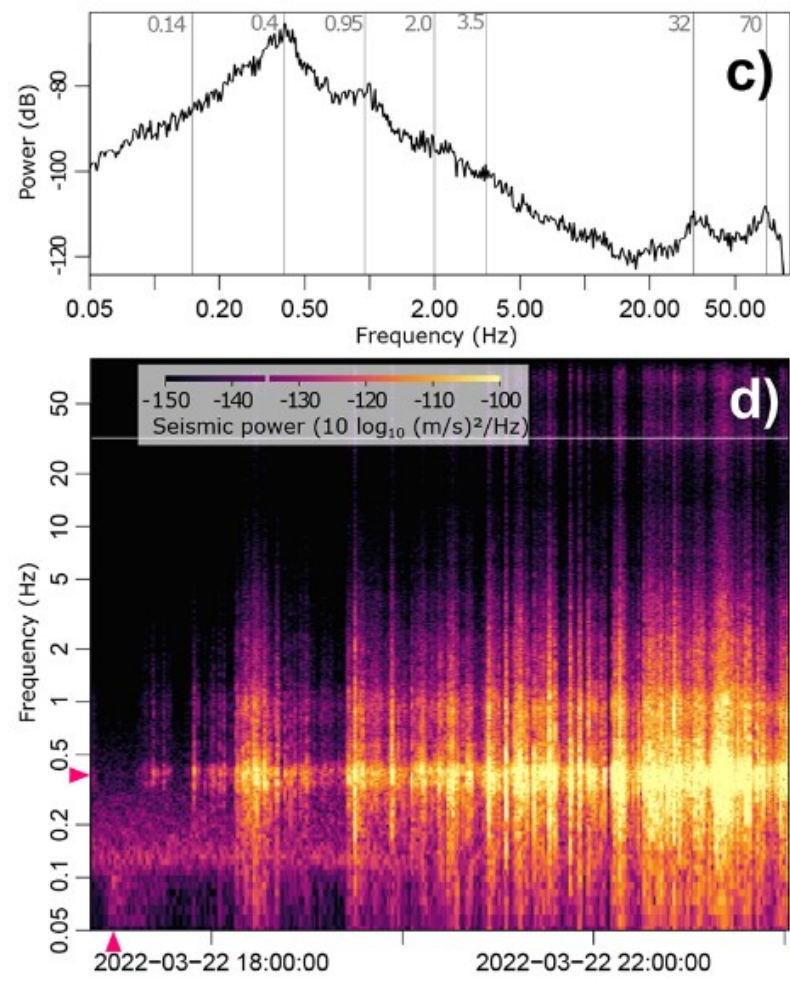
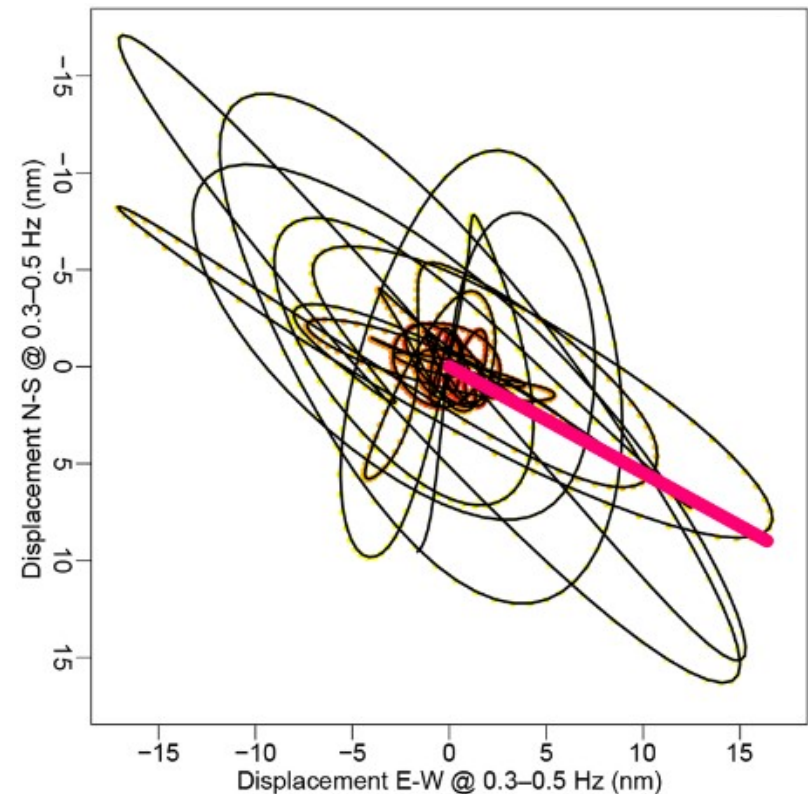
Sensing wind interacting with vegetation

SEISMOMETERS AS ANEMOMETERS AND DIRECTIONAL SWAY SENSORS



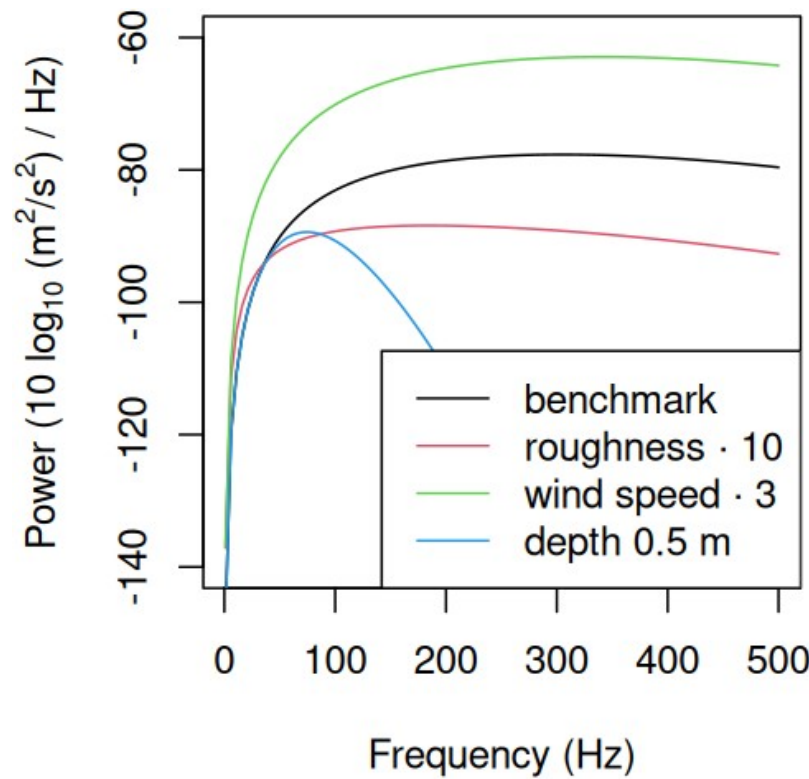
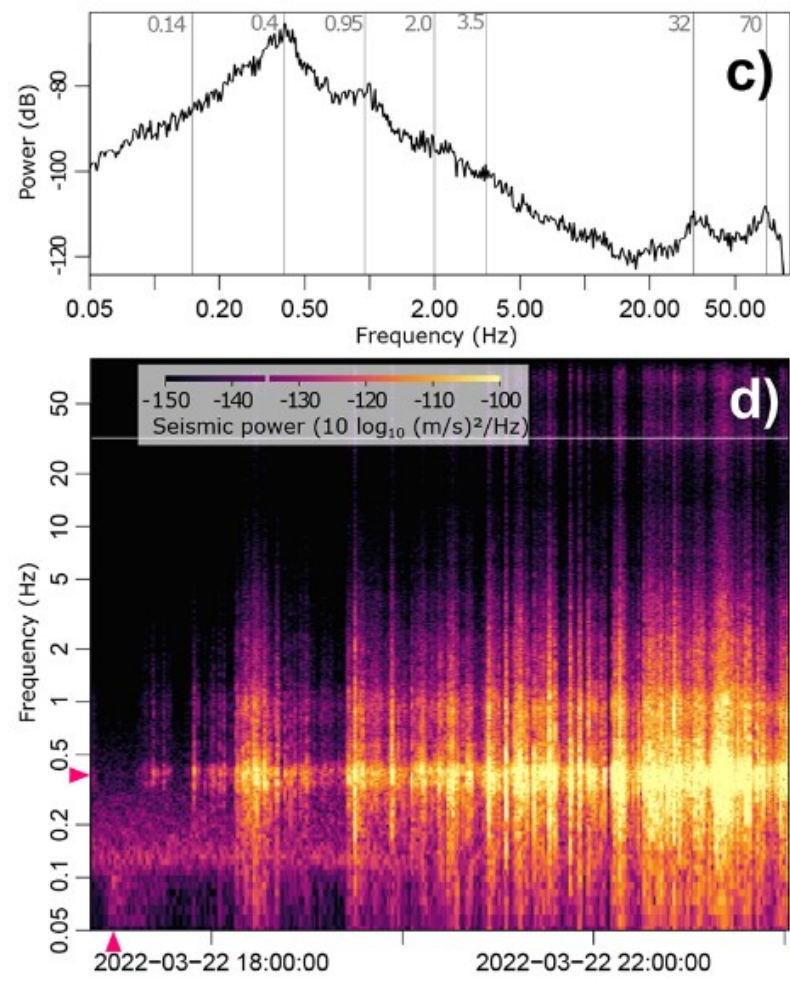
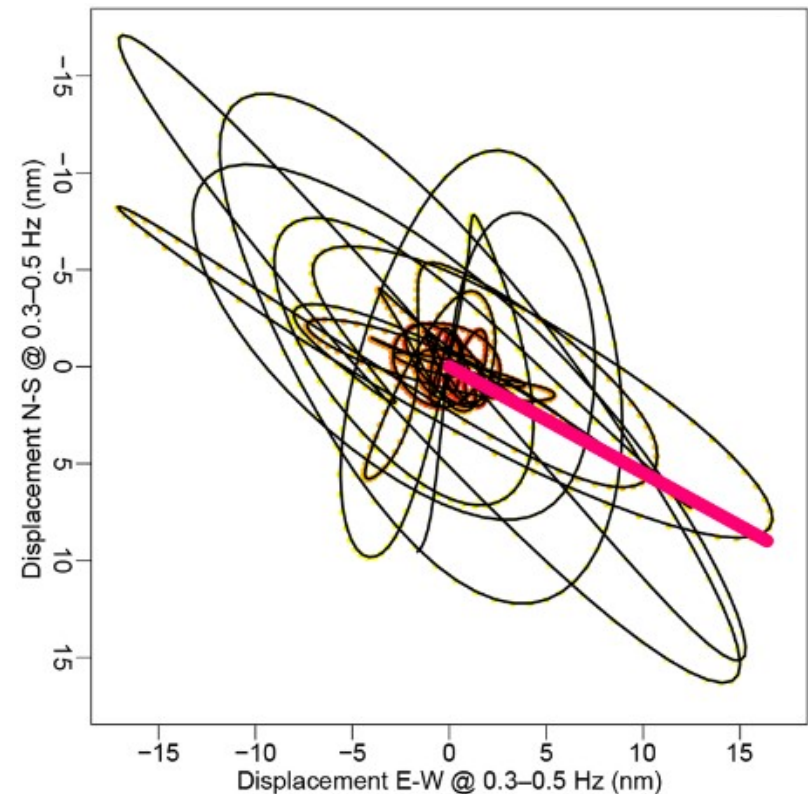
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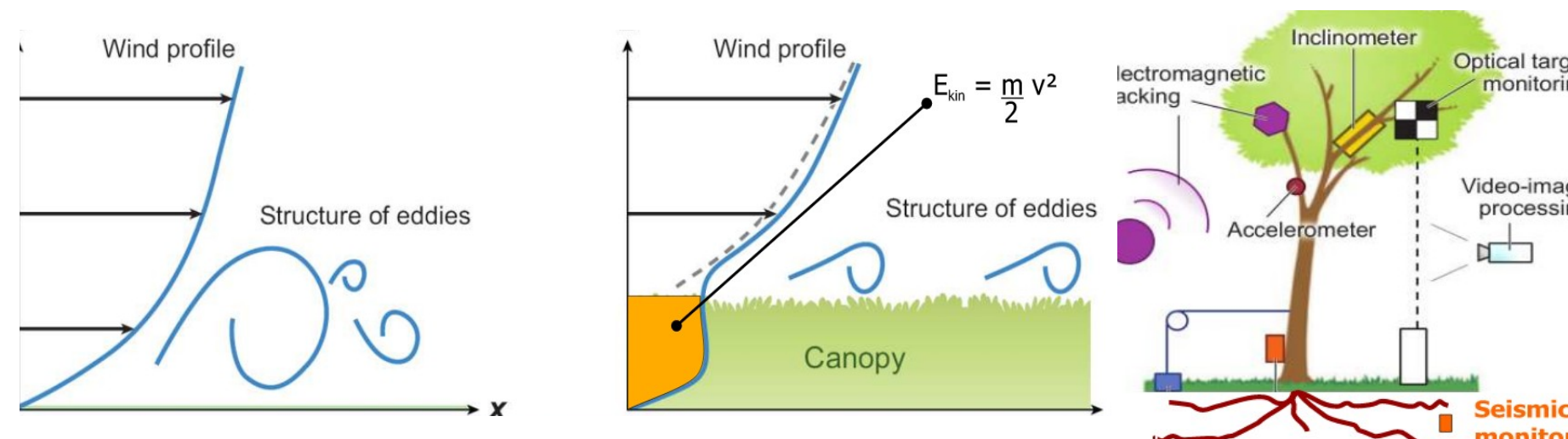
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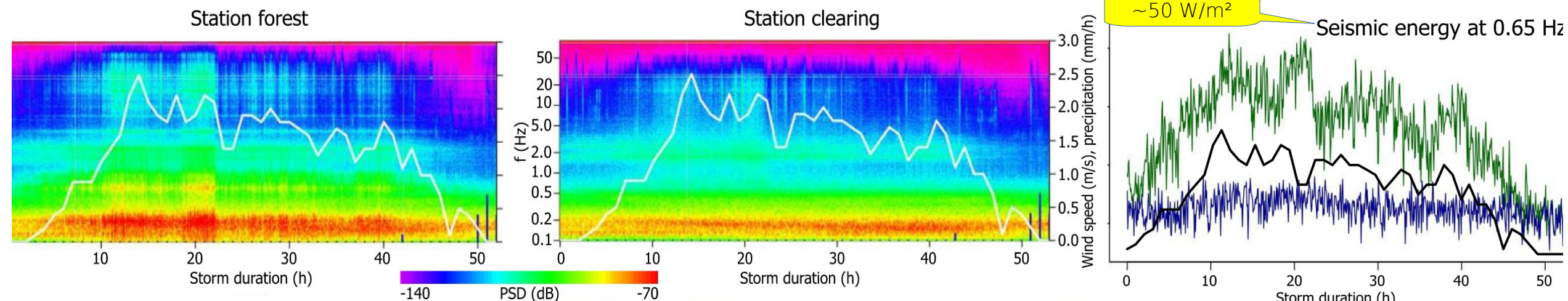
Beyond vibrational analysis of tree motion in wind fields

SEISMOMETERS AS TOOLS TO QUANTIFY THE KINETIC ENERGY EMITTED INTO THE GROUND



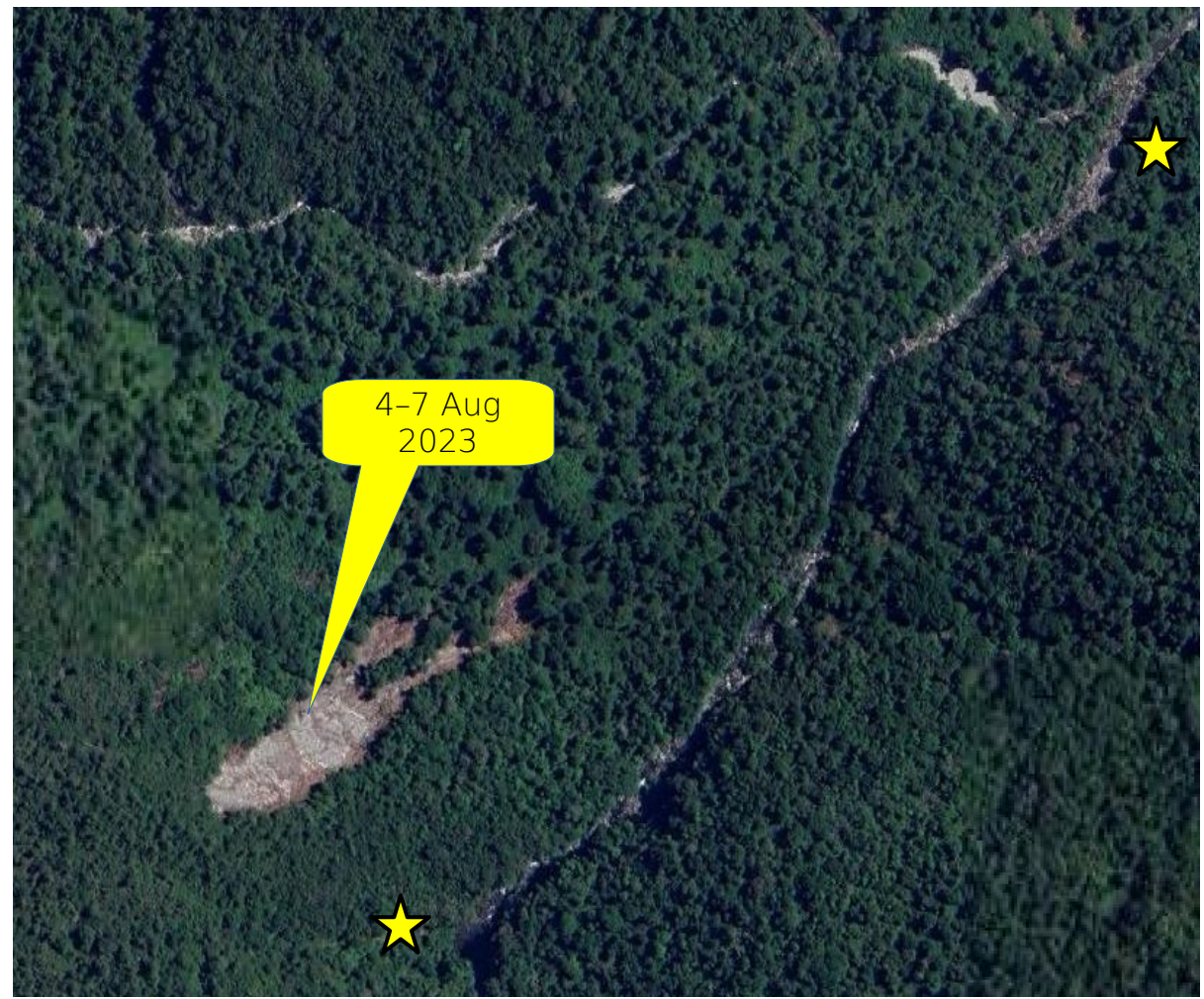
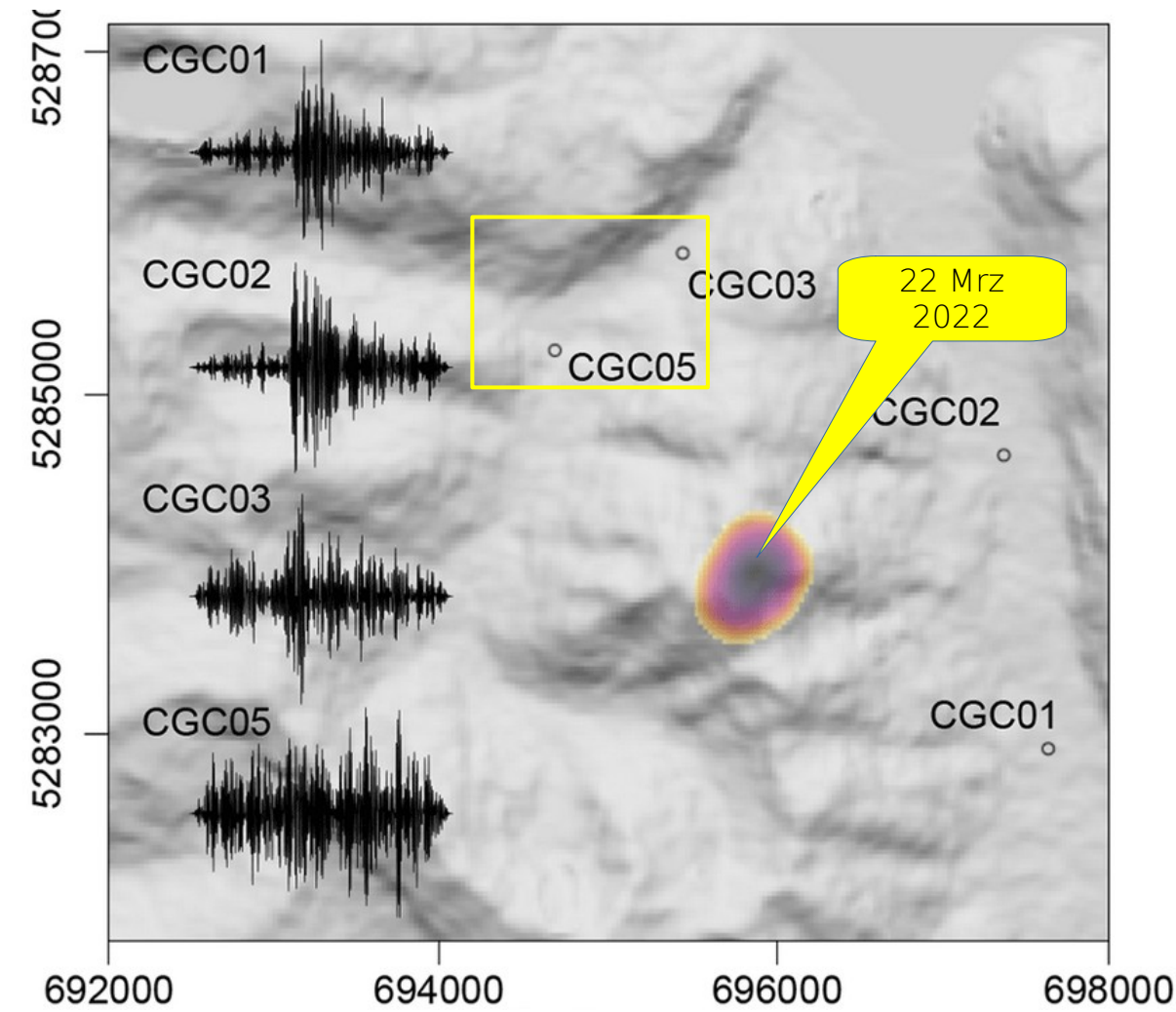
Seismic quantification of the drag component at the fluid-solid boundary

Inverse modelling of frequency resolved input of kinetic energy into the ground.



Detecting and locating hillslope activity

SEISMOMETERS AS LANDSLIDE QUANTIFICATION SYSTEMS



Into the realm of "suicidal" Patagonian forests

HOW DO TREES MITIGATE ENERGY TRANSFER BETWEEN ATMOSPHERE AND GEOSPHERE?

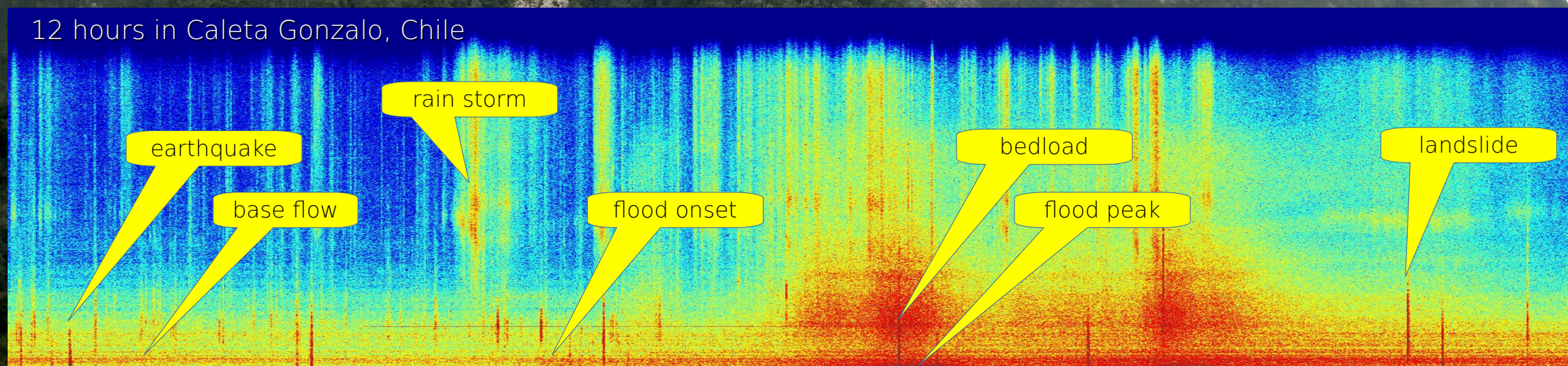
Trees load the hillslope to a critical state

Rain adds load and pore pressure

Wind exerts load & leverage forces

Slopes fail and trigger follow-on instability

12 hours in Caleta Gonzalo, Chile



Feeling a bit flattened? Let's recapitulate



Seismology is an established discipline with a rich tradition in methods

Application to environmental problems is a rather young offspring

Seismic methods provide plentiful chances of highly complementary, high resolution, continuous and integrating information

Mass wasting: precise timing, location, tracking, trigger attribution, ...

River systems: bedload transport, turbulence structure, flood detection, ...

Bio-geo-Systems: activity insights, "sphere" coupling, signal propagation, ...



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Thanks!

