

INTRODUCTION



THE LAUTERBRUNNEN VALLEY



APPROACHES



SEISMIC SIGNALS



ROCKFALL DYNAMICS



Approaching a more Complete Picture of Rockfall Activity

Seismic and LiDAR Detection, Location and Volume Estimates

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2 - University of Tübingen, Department of Geology and Geodynamics

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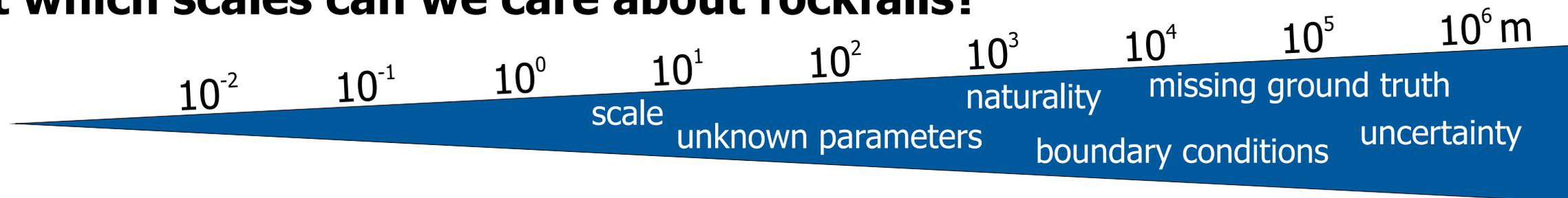
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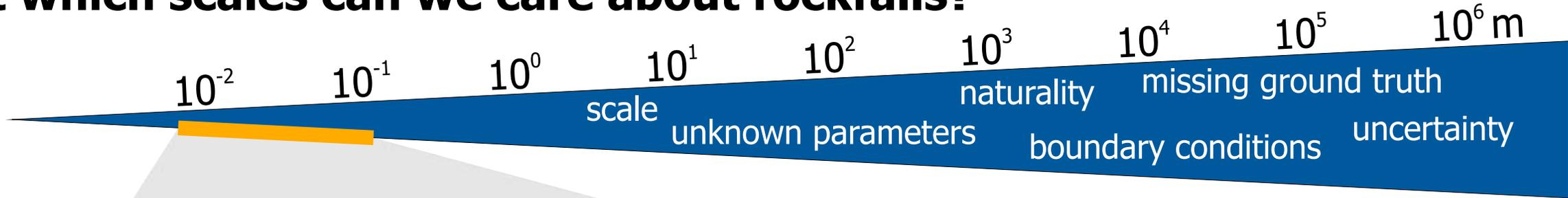
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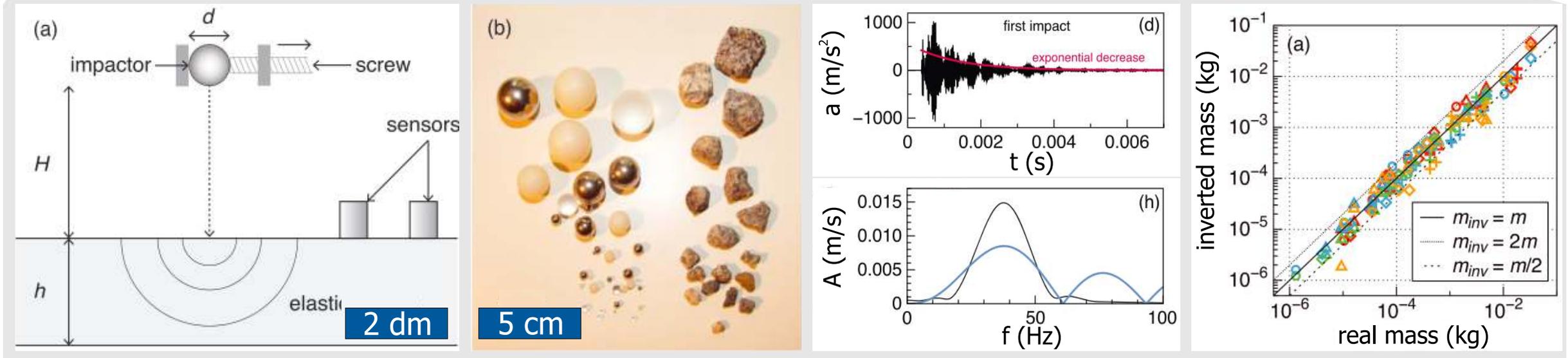
At which scales can we care about rockfalls?



At which scales can we care about rockfalls?



Laboratory scale

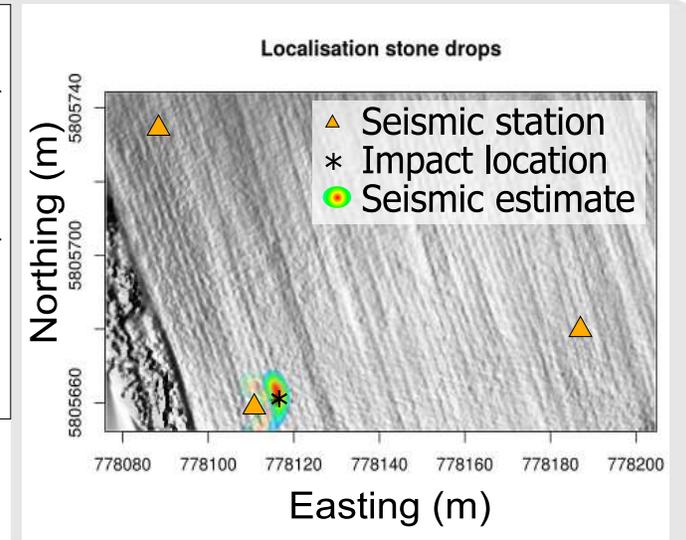
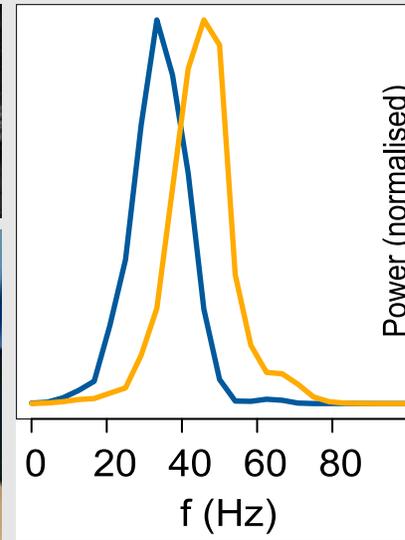
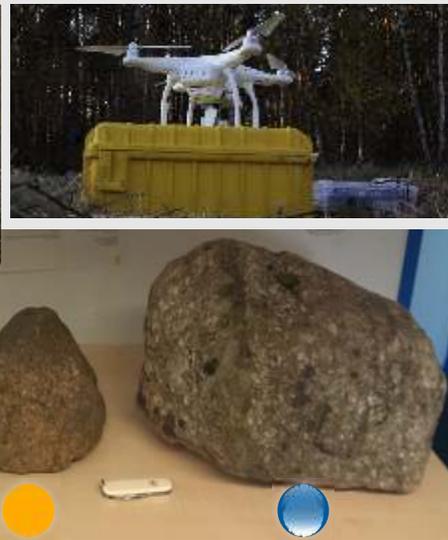


Farin et al. (2015)

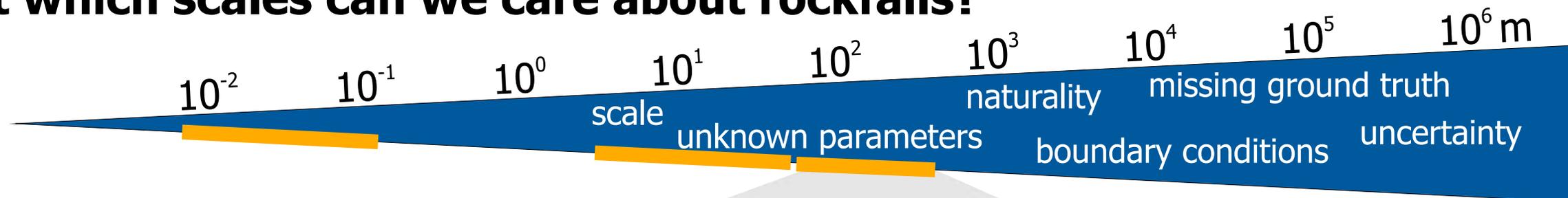
At which scales can we care about rockfalls?



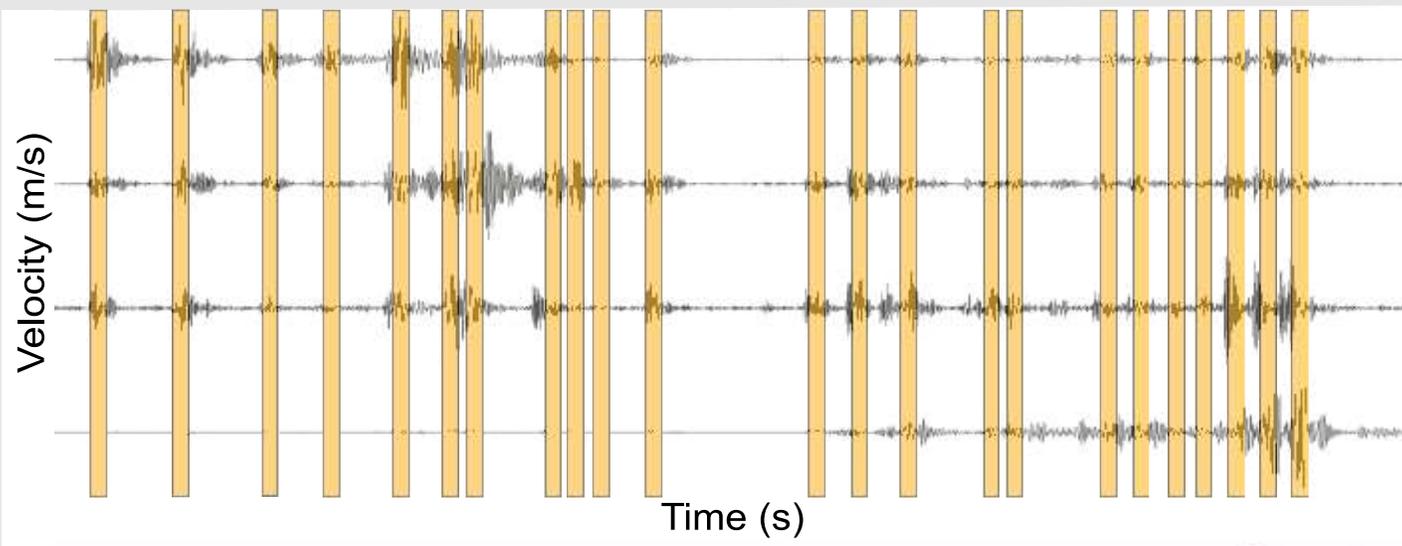
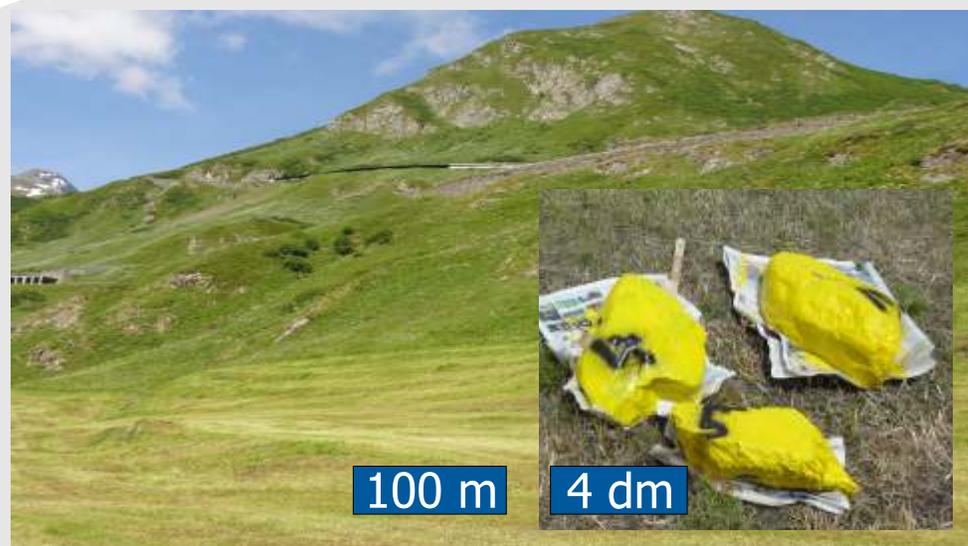
“One foot out of the laboratory”-scale



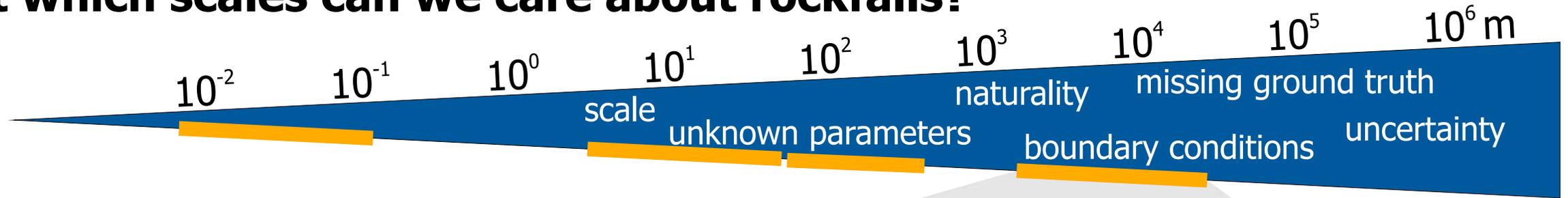
At which scales can we care about rockfalls?



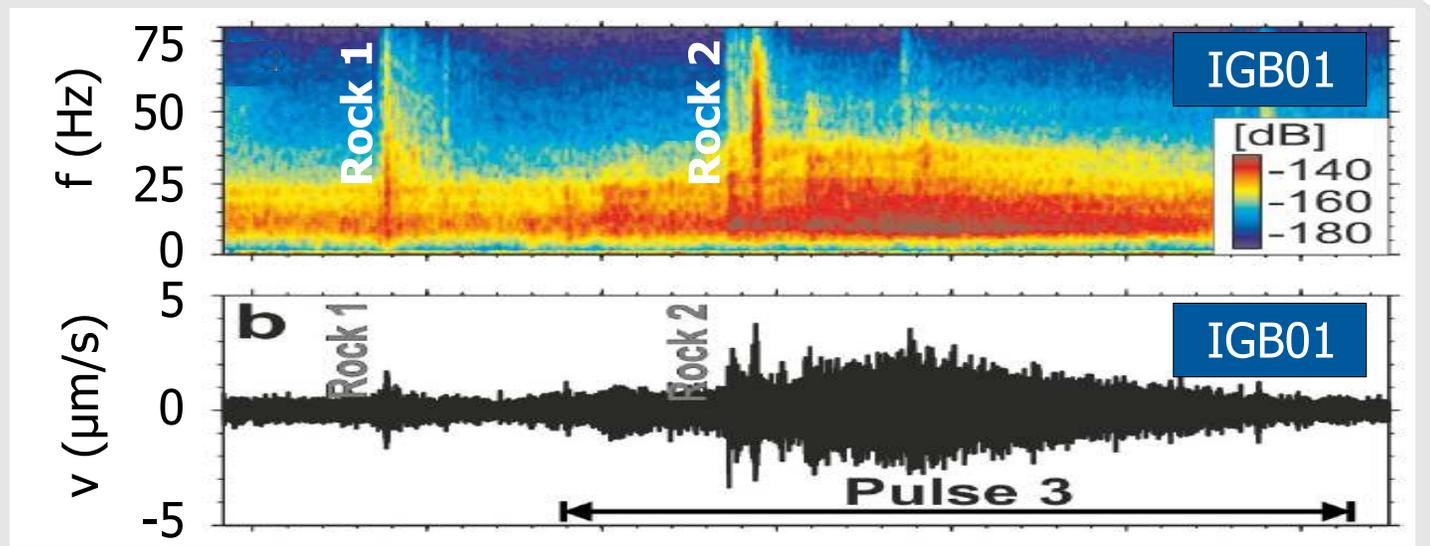
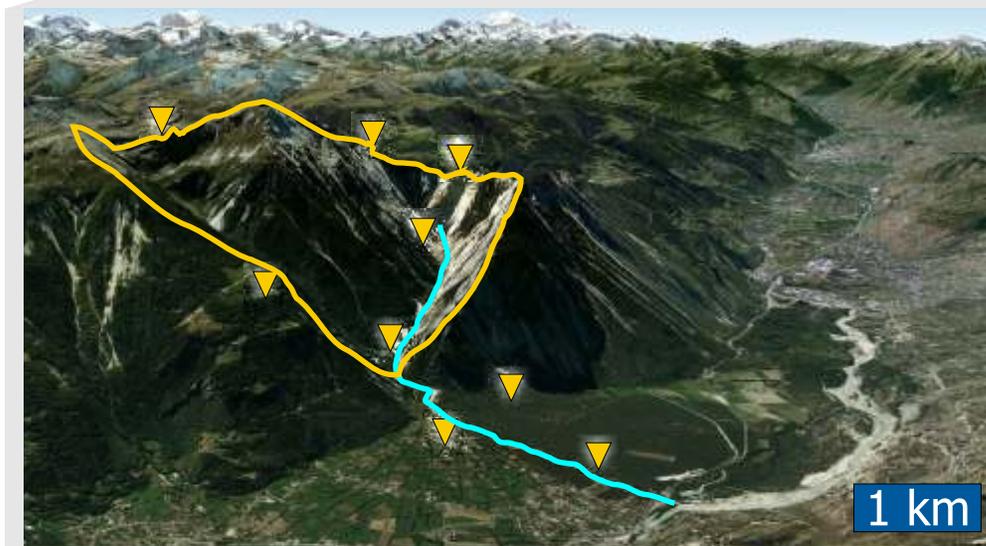
Slope scale



At which scales can we care about rockfalls?

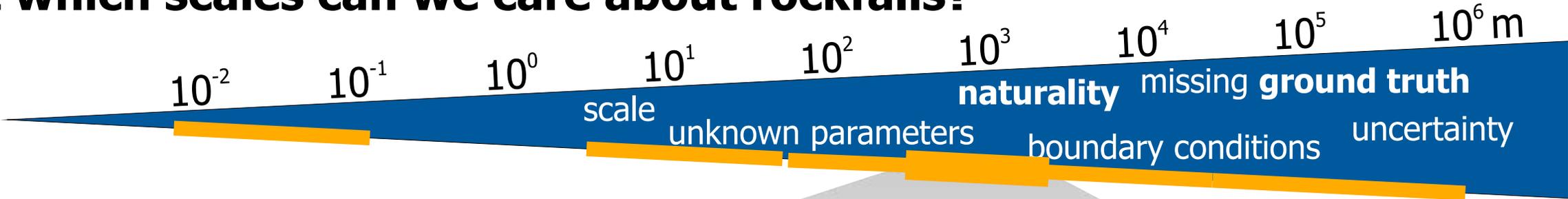


Catchment scale



Burtin et al. (2014)

At which scales can we care about rockfalls?



Covering (almost) catchment scale but maintain high-resolution independent confirmation data

Testing applicability of seismic monitoring in cliff landscapes (rather than slopes)

Analyse individual and global temporal and spatial patterns of rockfall dynamics

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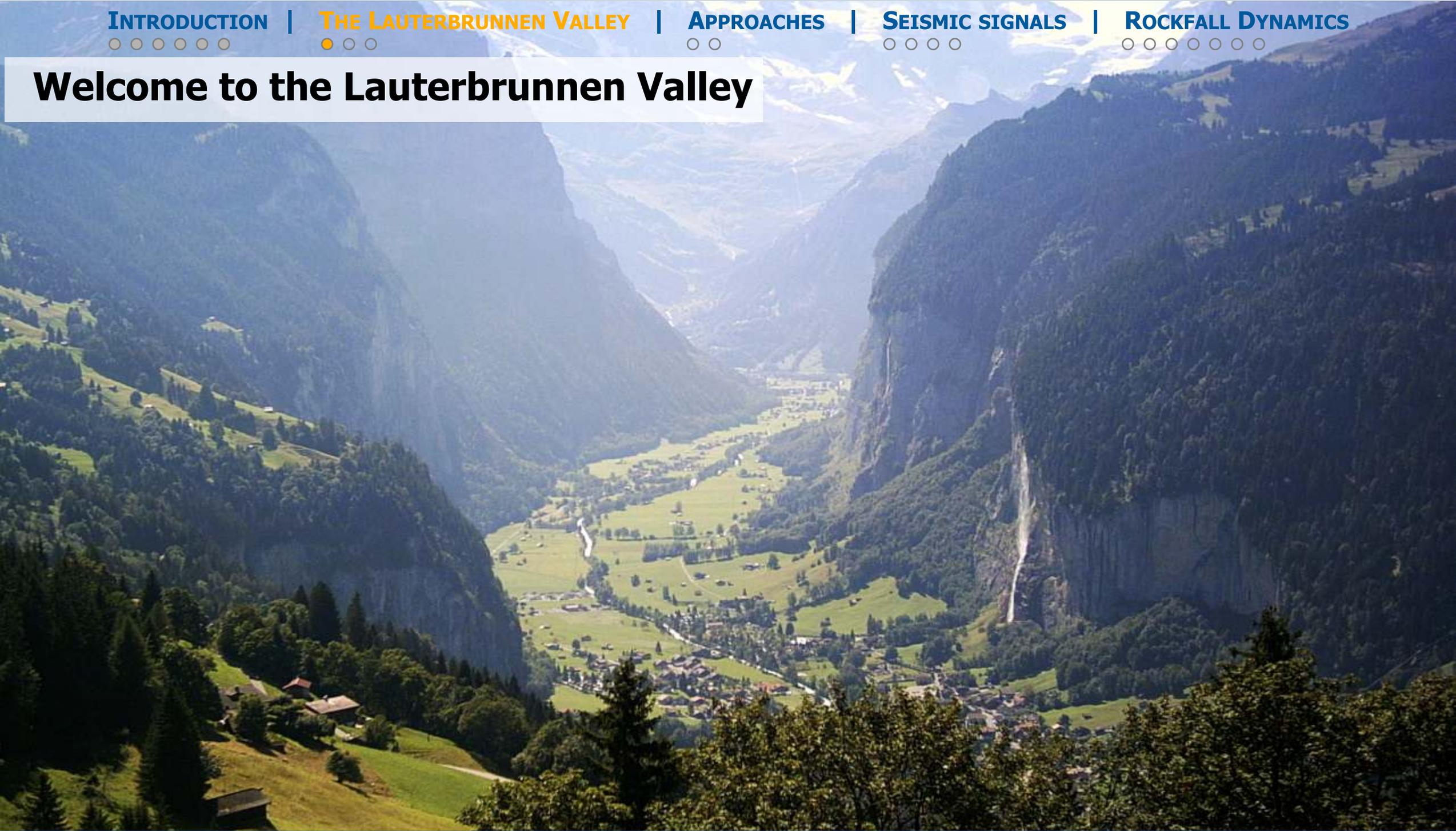
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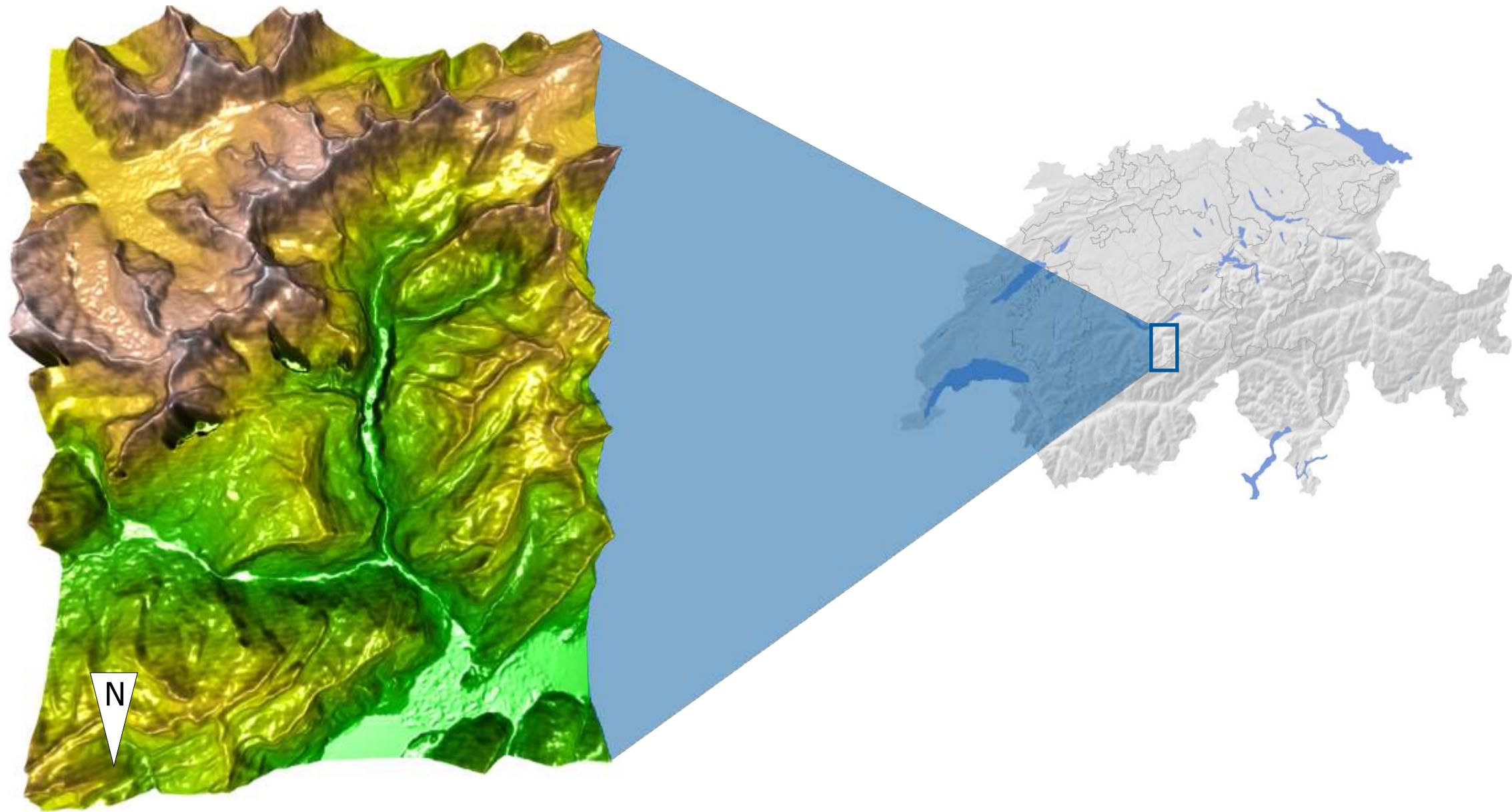
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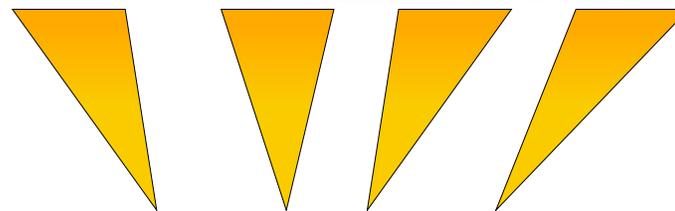
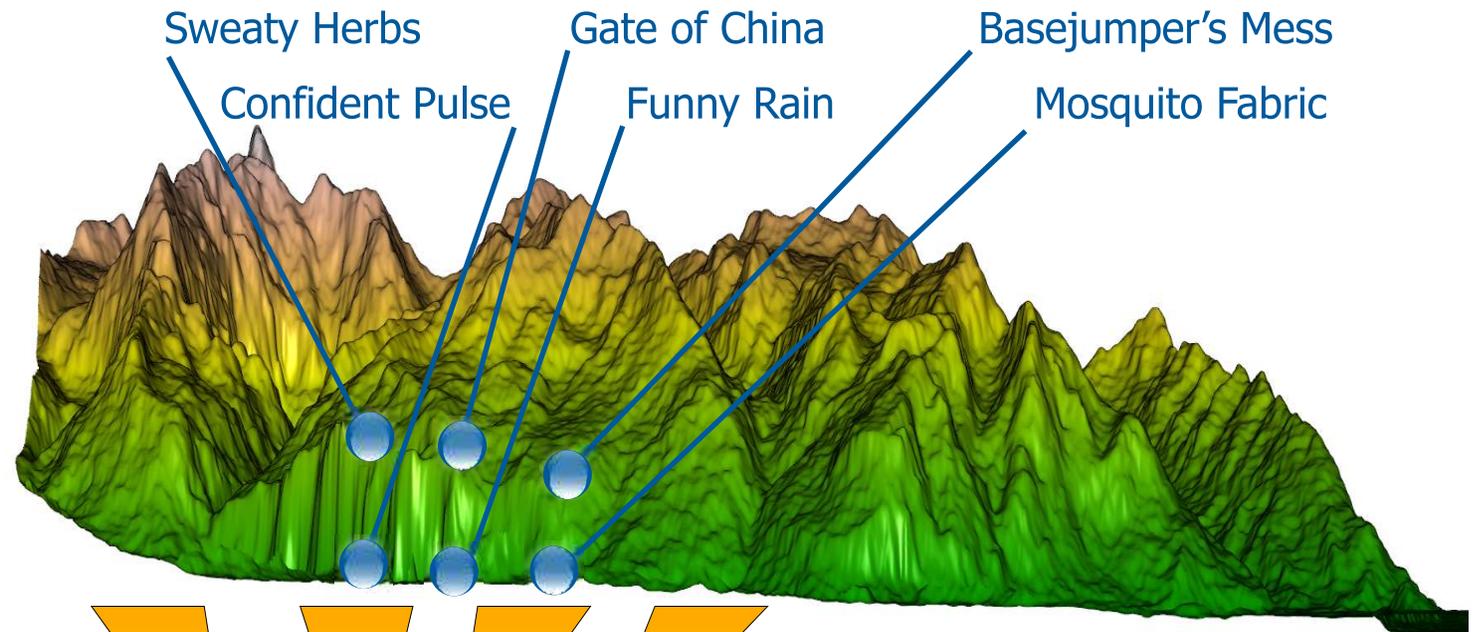
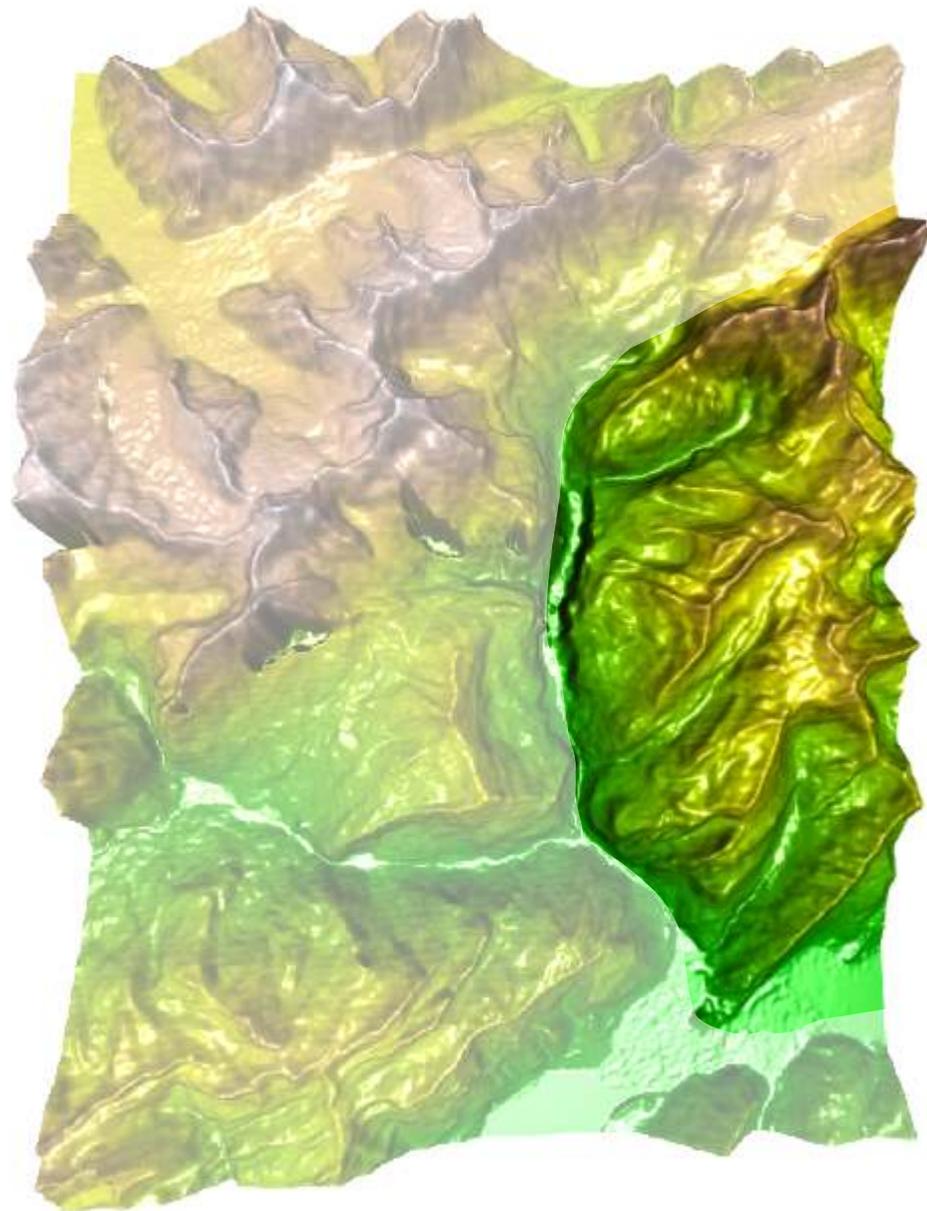


Welcome to the Lauterbrunnen Valley

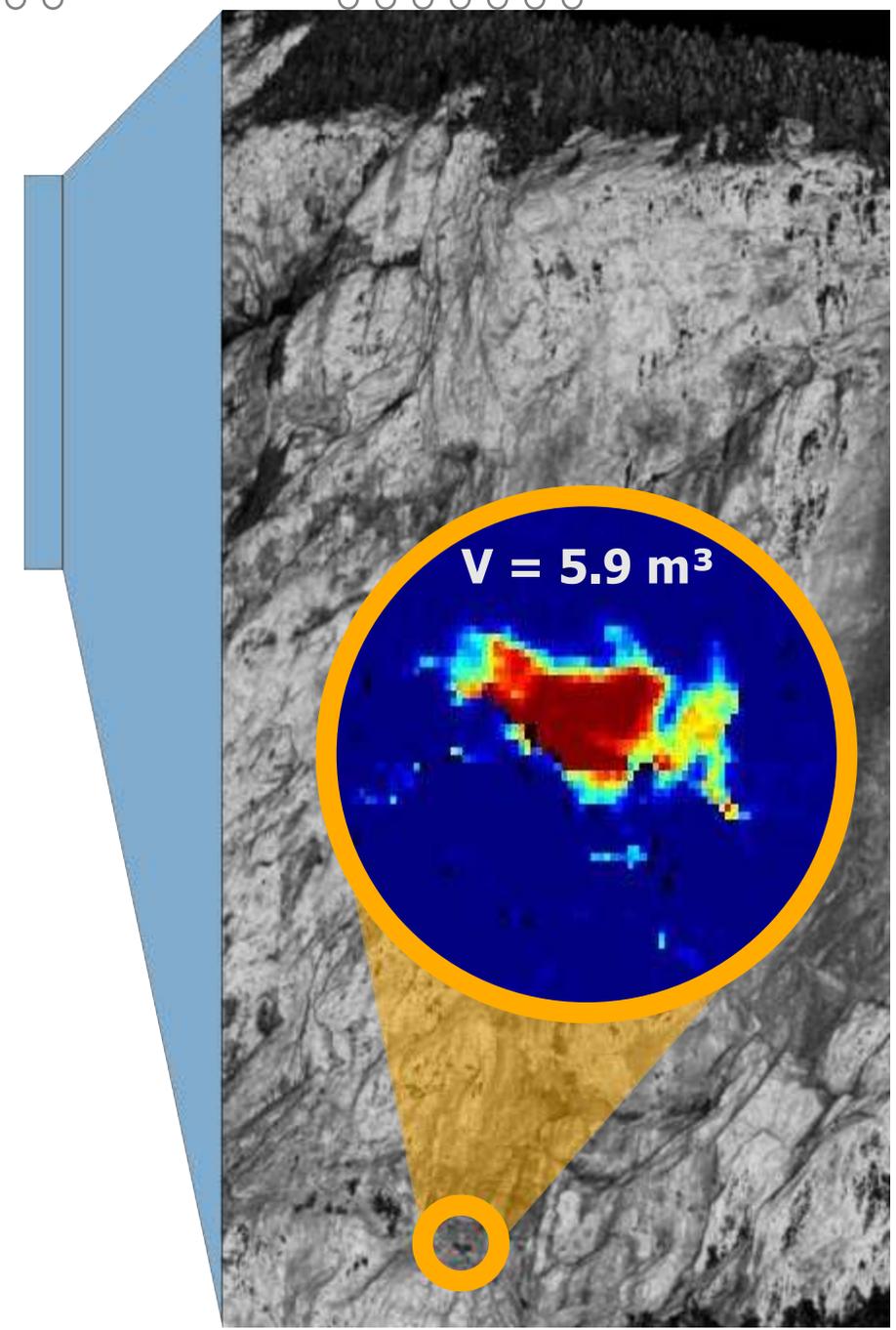
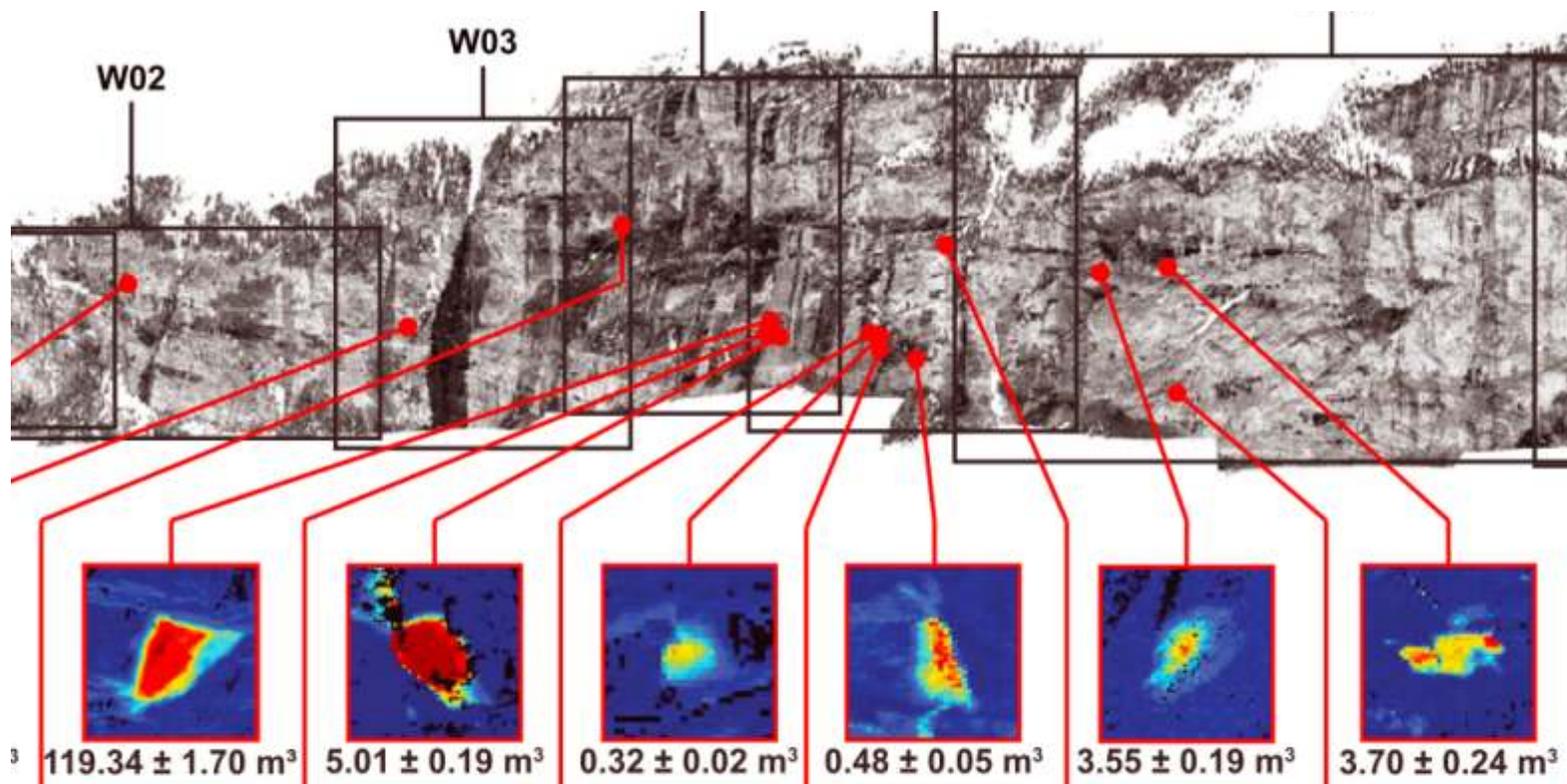




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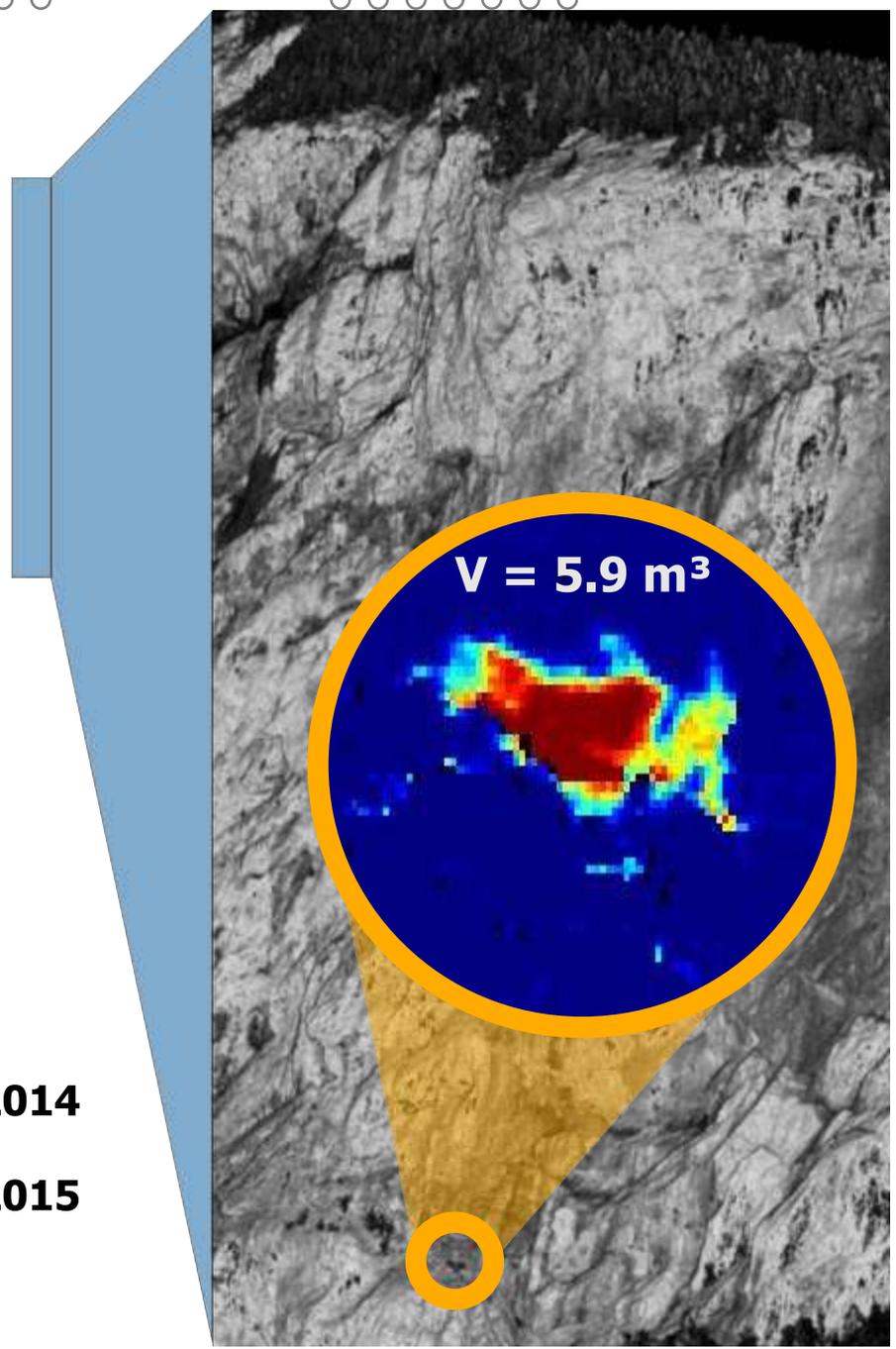
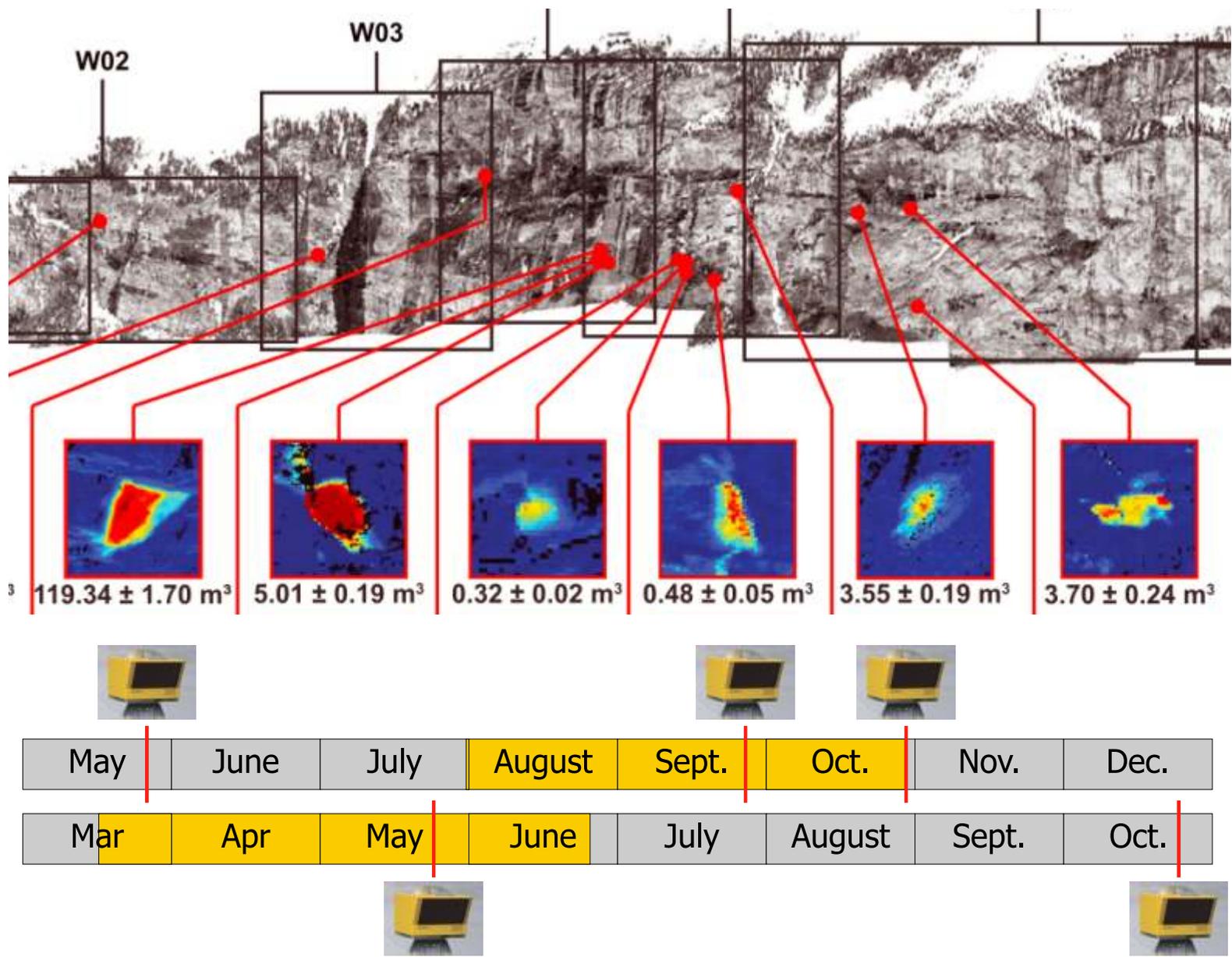


LiDAR scans provide location and volume data



GFZ Scan compilation (February 2012 to July 2013) by Strunden et al. (2014)

LiDAR scans provide location and volume data



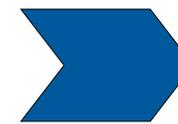
Scan compilation (February 2012 to July 2013) by Strunden et al. (2014)

The approach - seismic data analysis

Pick instantaneous seismic activity



Model source location likelihood



Manual inspection of event validity

classic STA/LTA-picker

DEM-based signal migration

Two eyes and one brain



...



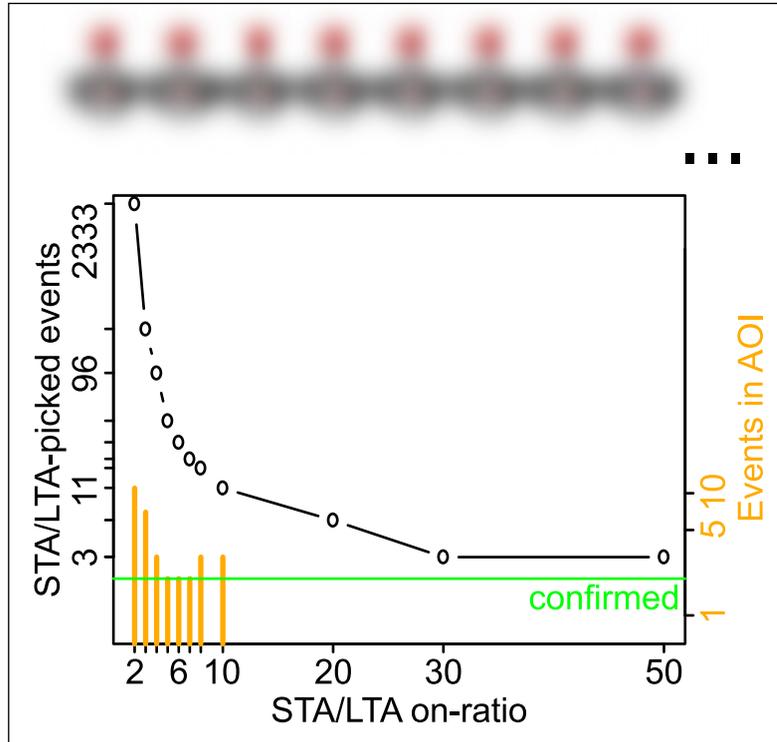
The approach - seismic data analysis



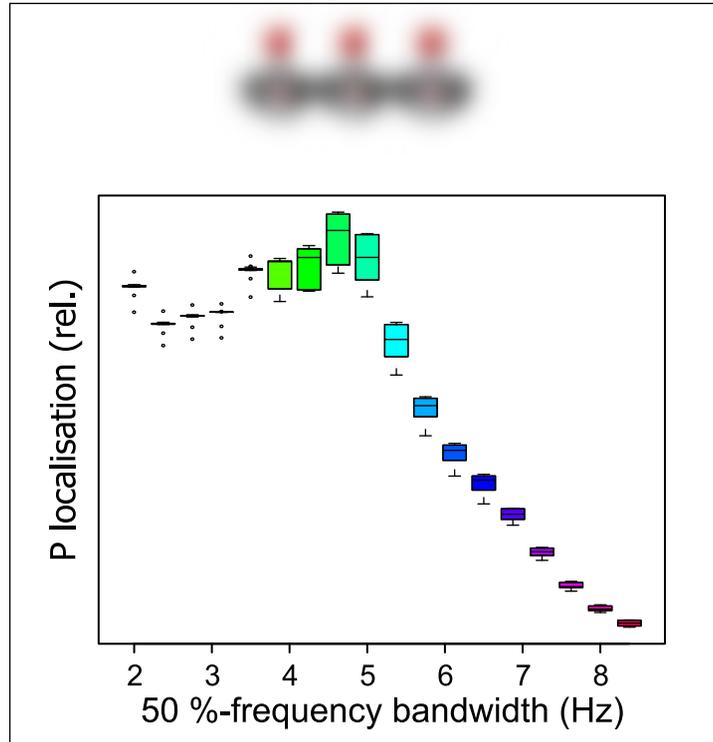
classic STA/LTA-picker

DEM-based signal migration

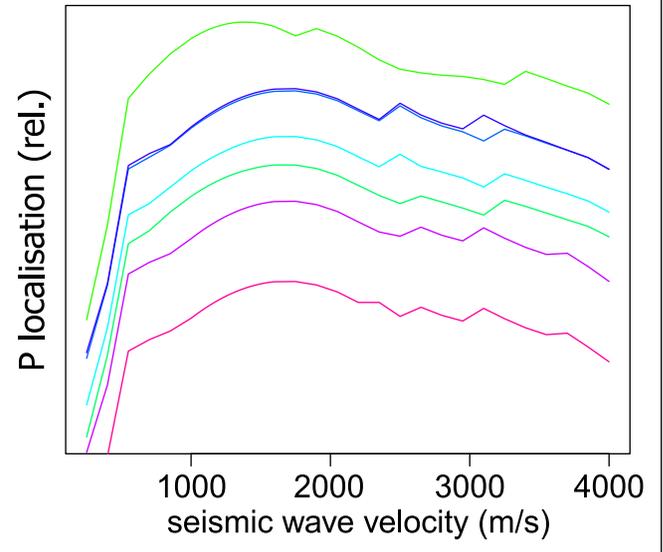
Two eyes and one brain



f 1 - 20 Hz | ratios 5 - 3
time 0.5 - 120 s | duration 0.1 - 10 s



$$f = f_{\text{central}} \pm 2, \dots, 6 \text{ Hz}$$



$$v = 1300, \dots, 1900 \text{ m/s}$$

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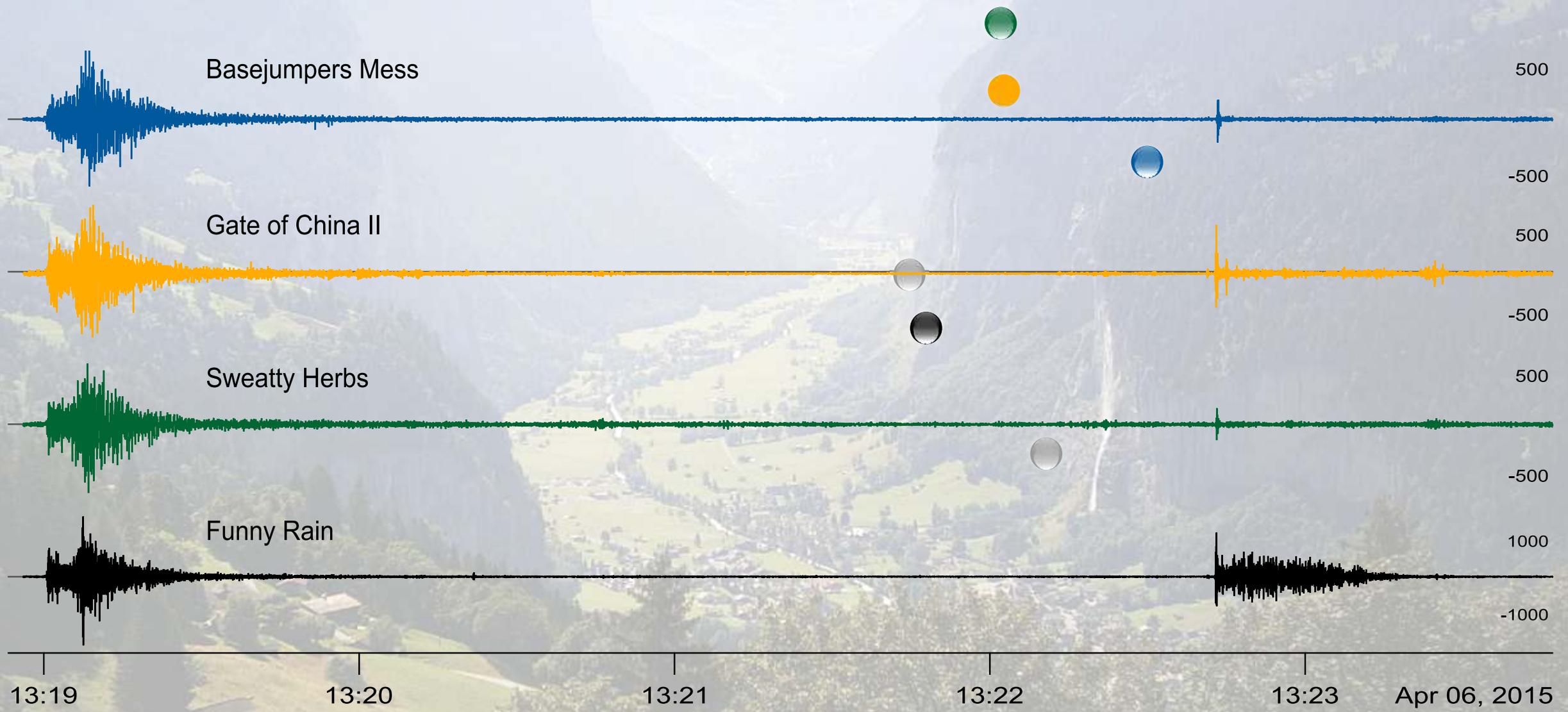
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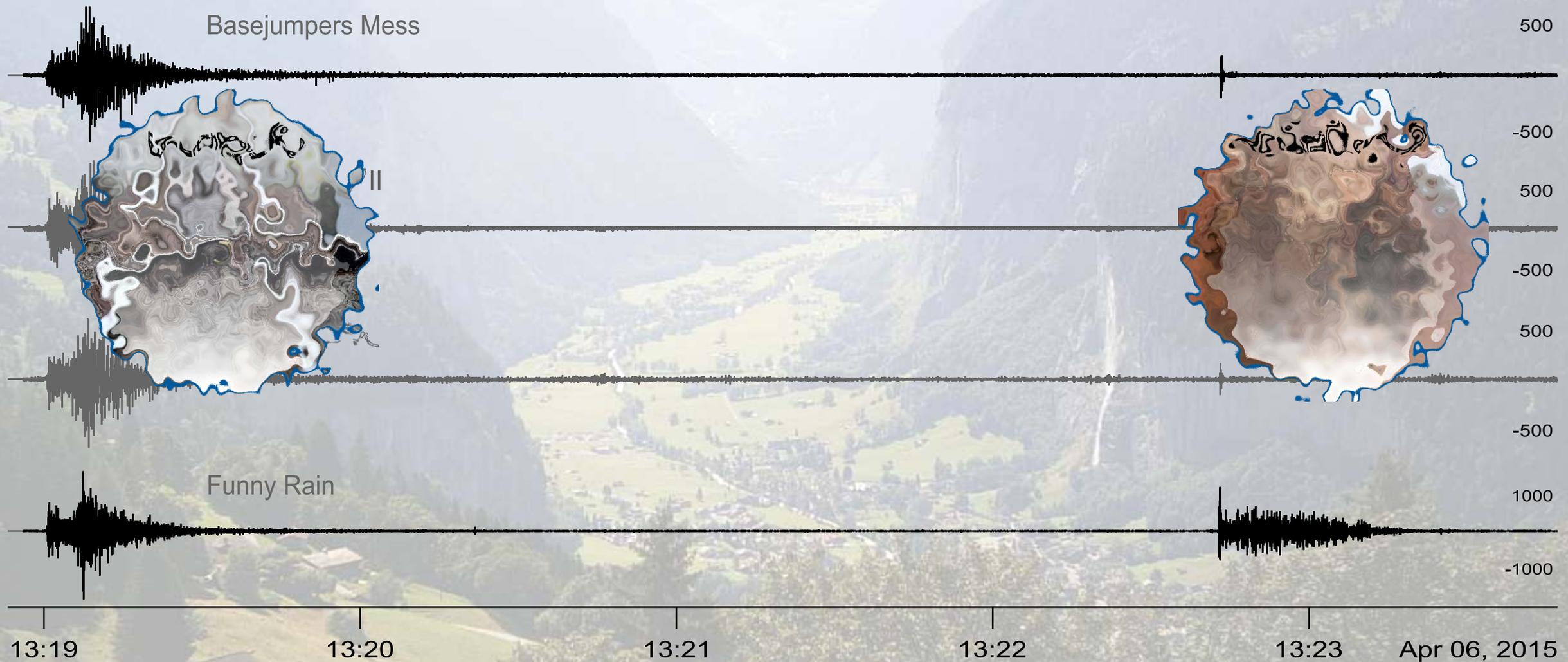
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A glimpse at the signals



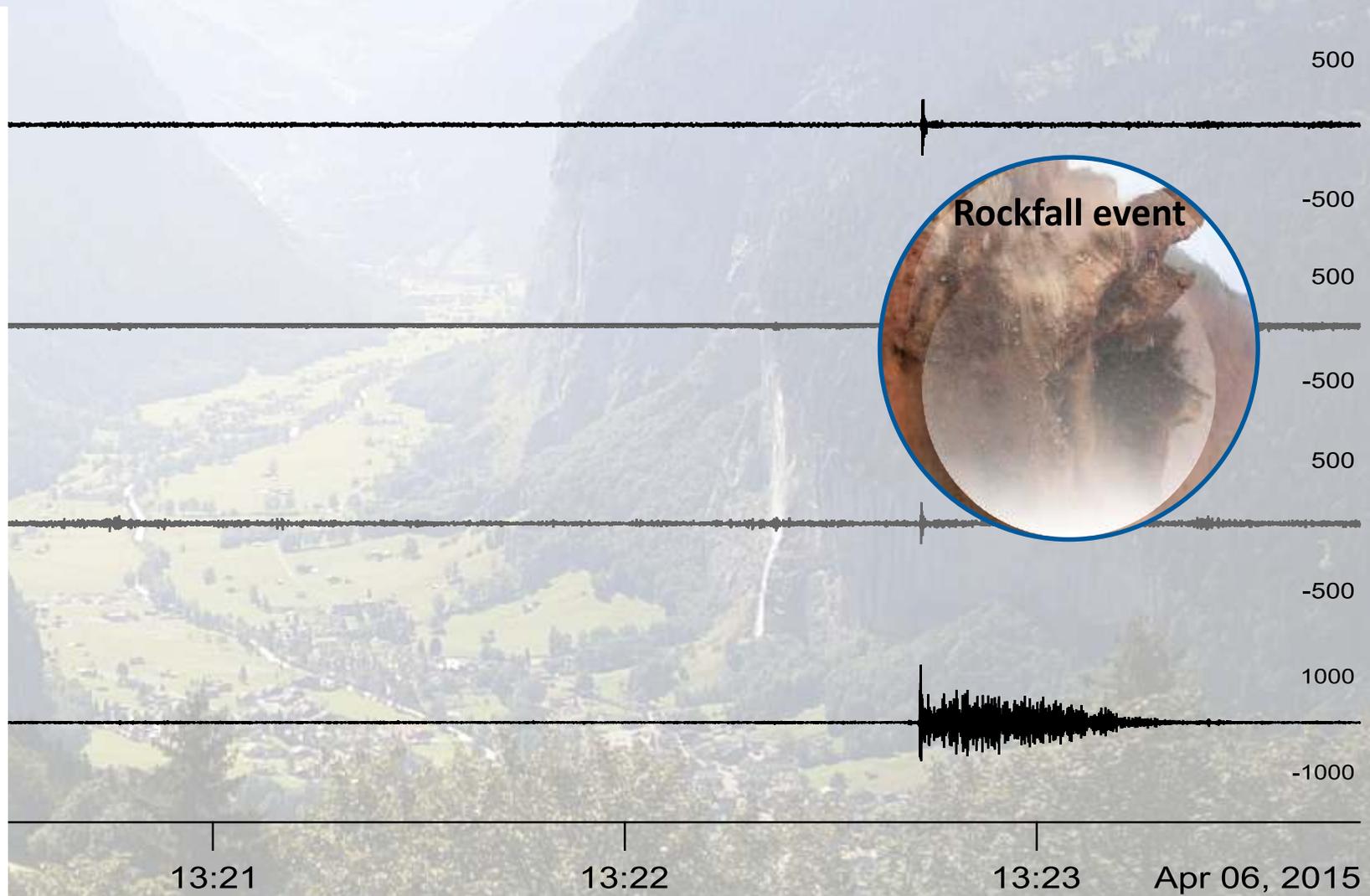
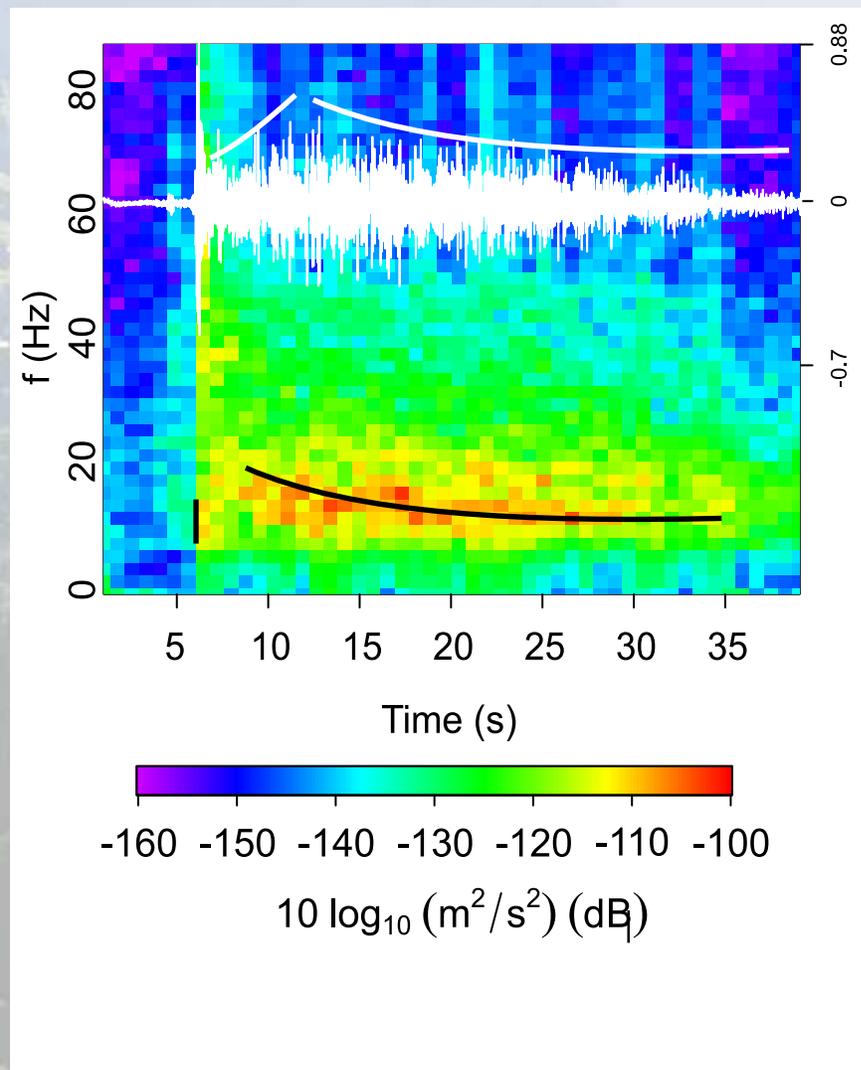


A glimpse at the signals



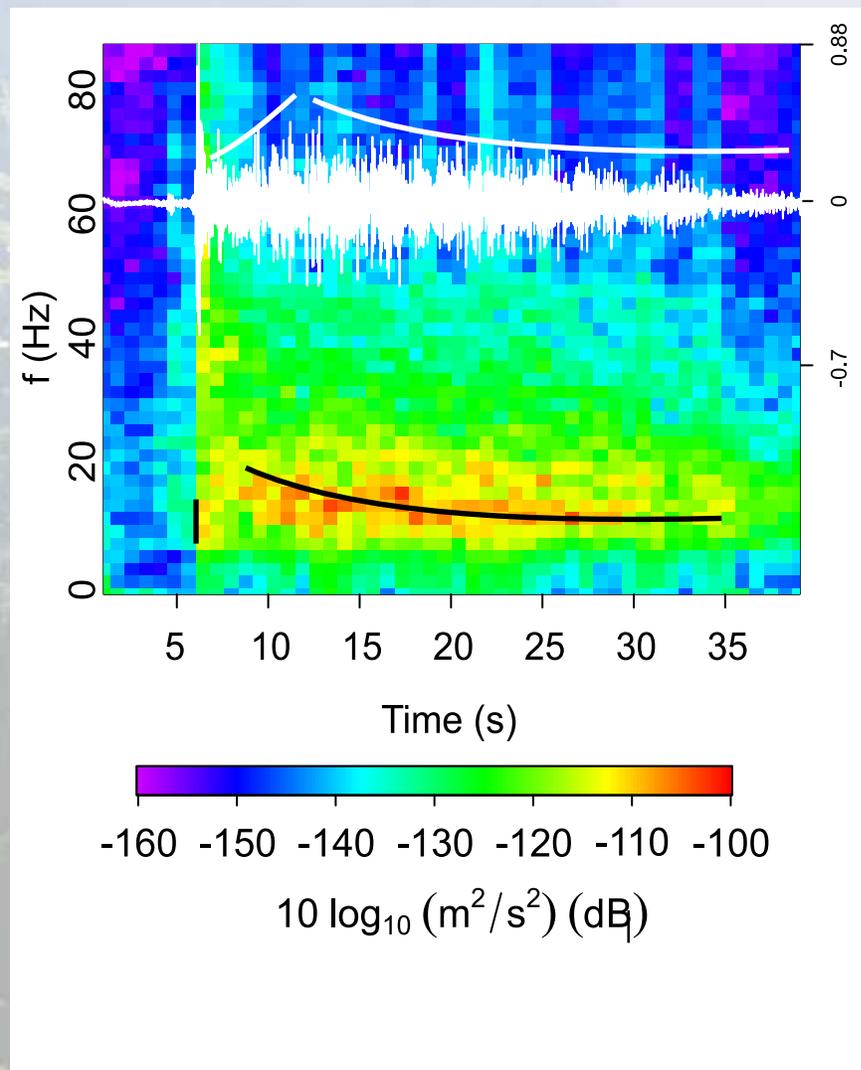
A glimpse at the signals

Anatomy

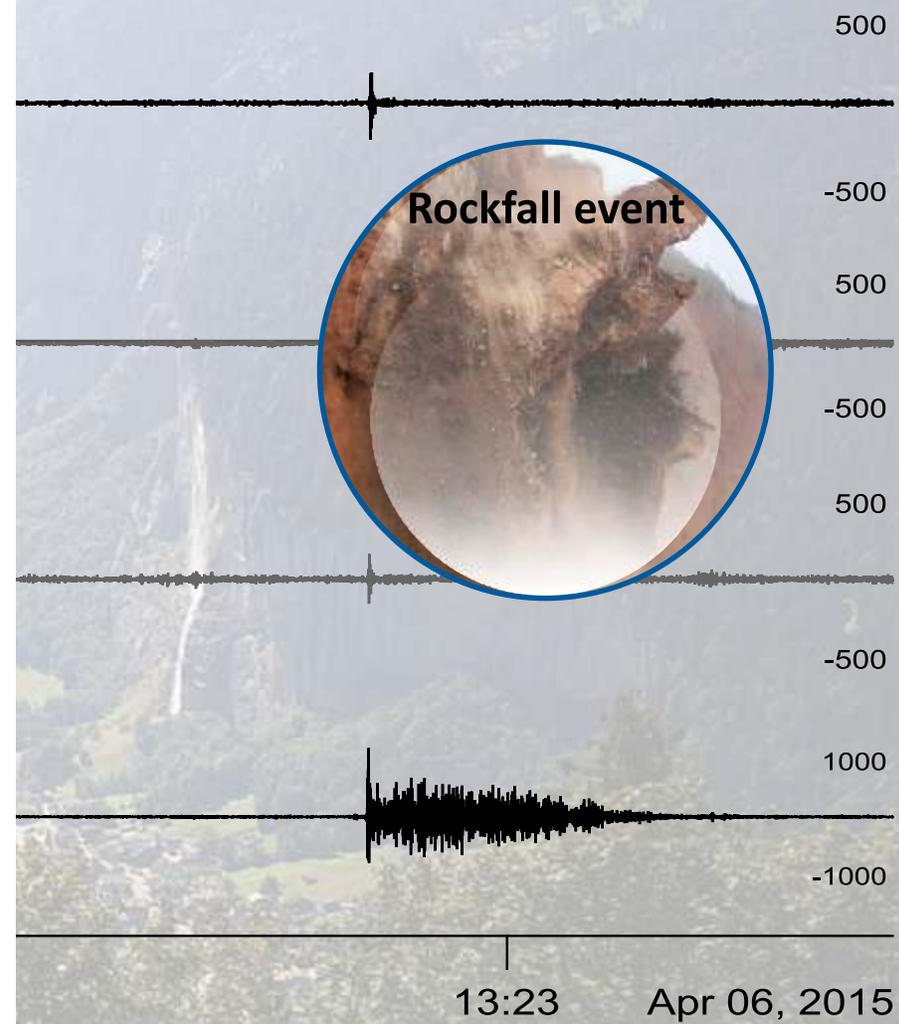
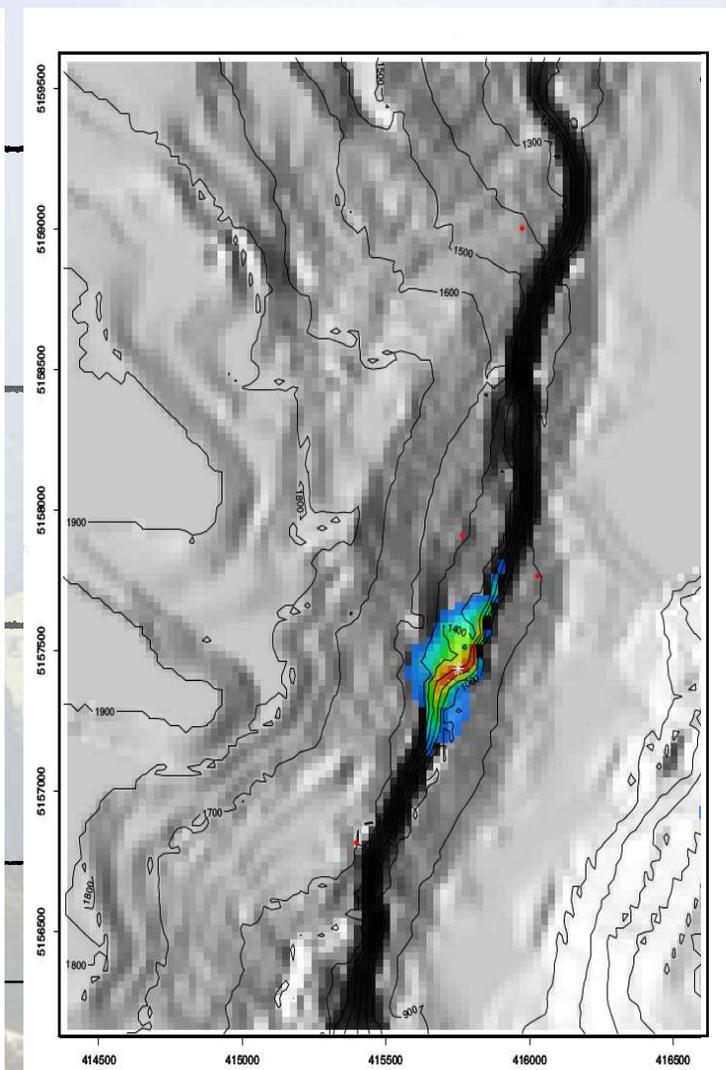


A glimpse at the signals

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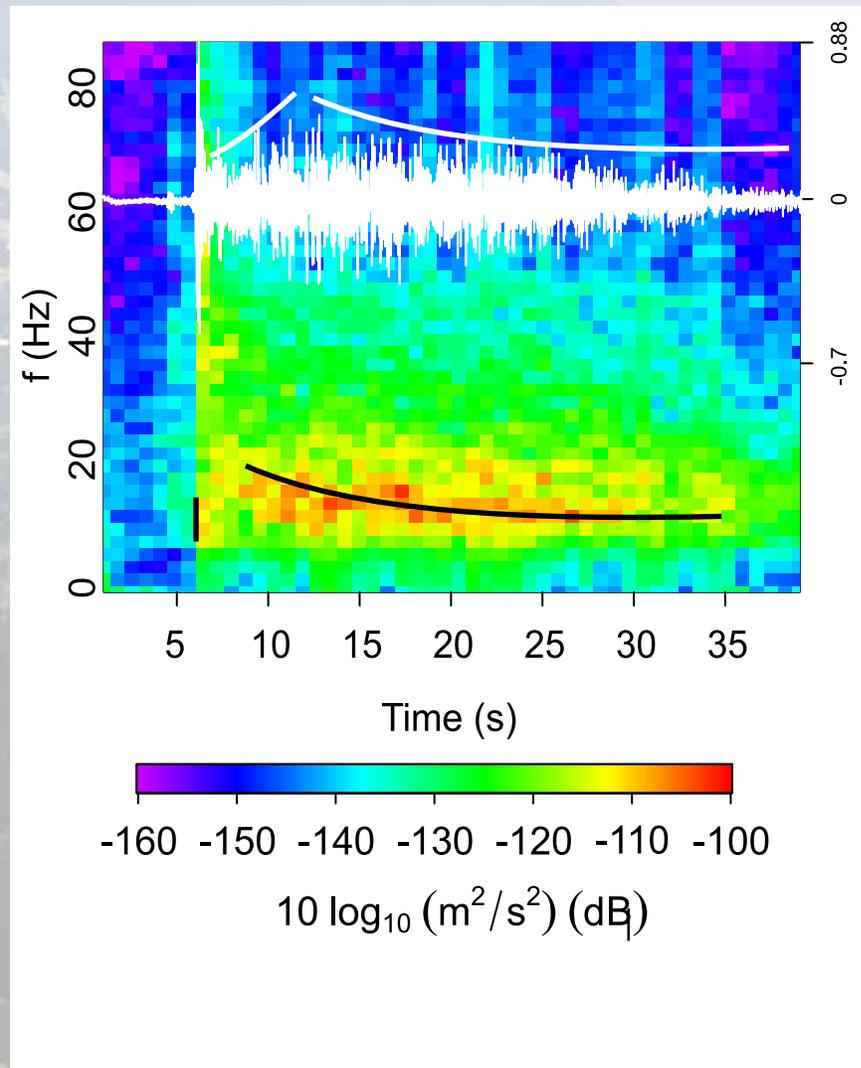


Localisation

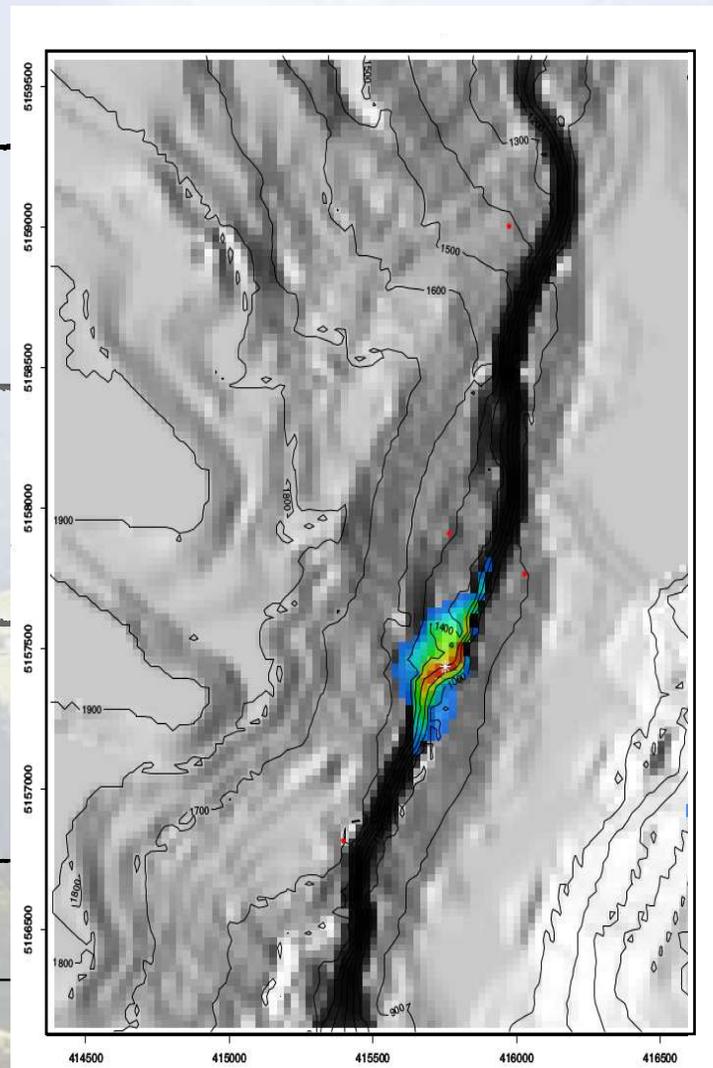


A glimpse at the signals

Anatomy



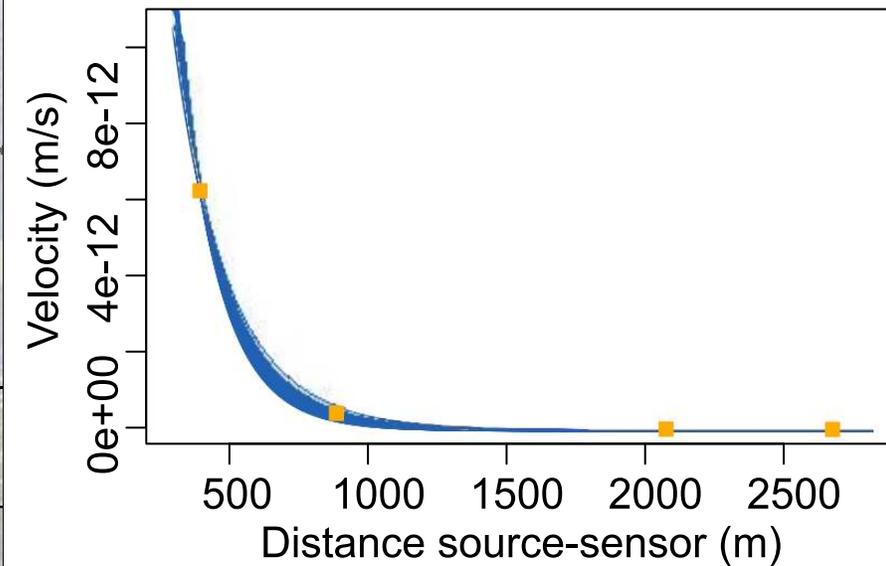
Localisation



Energy estimates

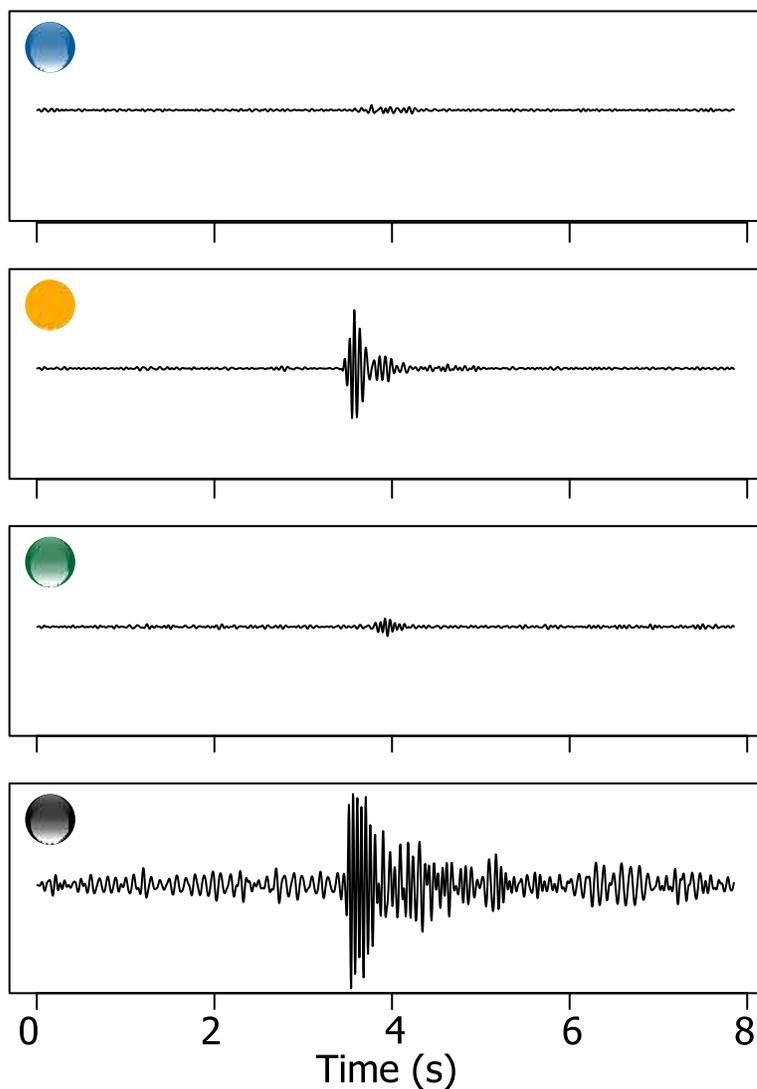
$$A(d) = \frac{A_0}{\sqrt[2]{d}} \cdot \exp\left(-\frac{\pi f d}{Qv}\right)$$

Quality factor
wave velocity

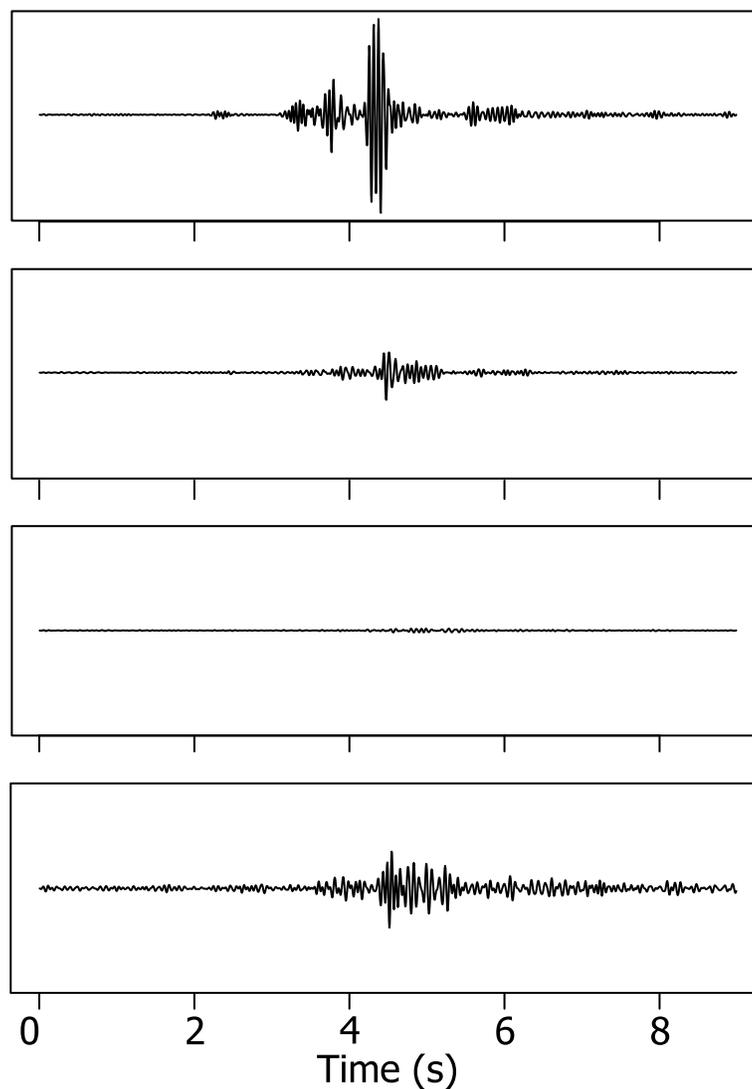


Synopsis of 2015 rockfall types (n = 26)

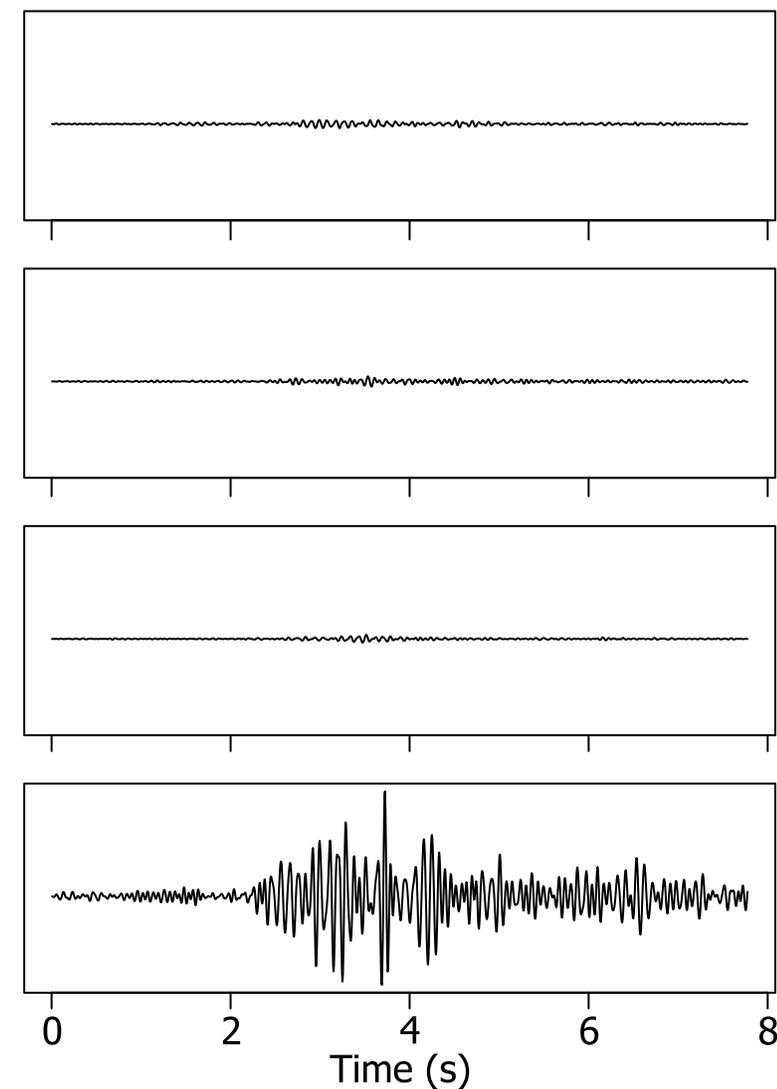
Single impact (40 %)



Multiple impacts (35 %)

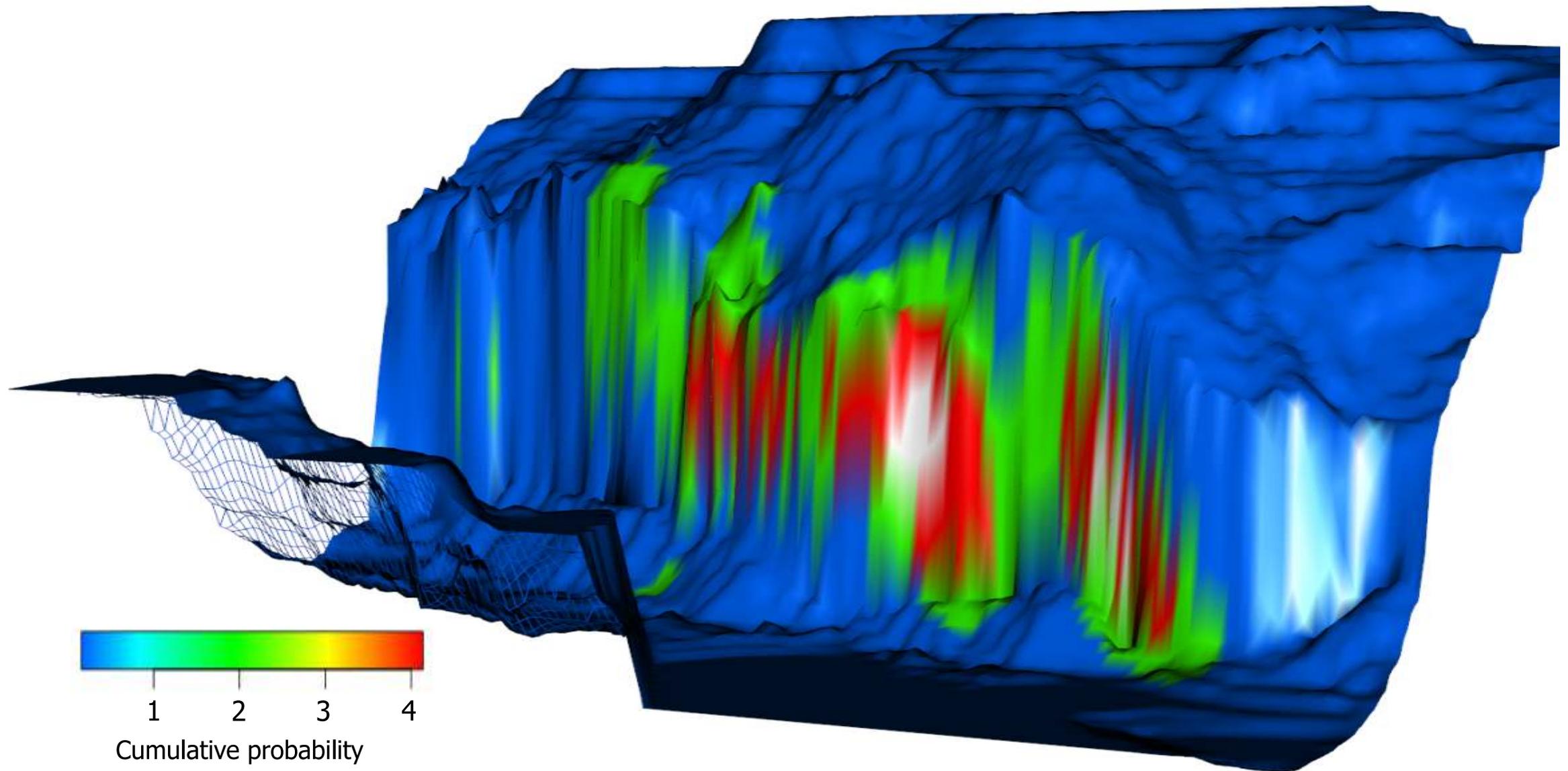


Avalanche-like (25 %)



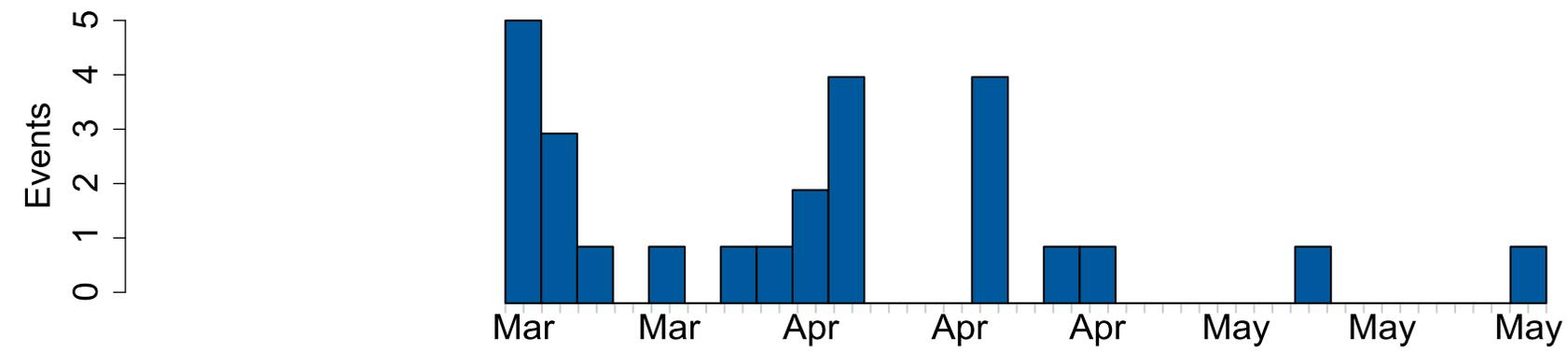


Spatial activity map of the 2015 time series



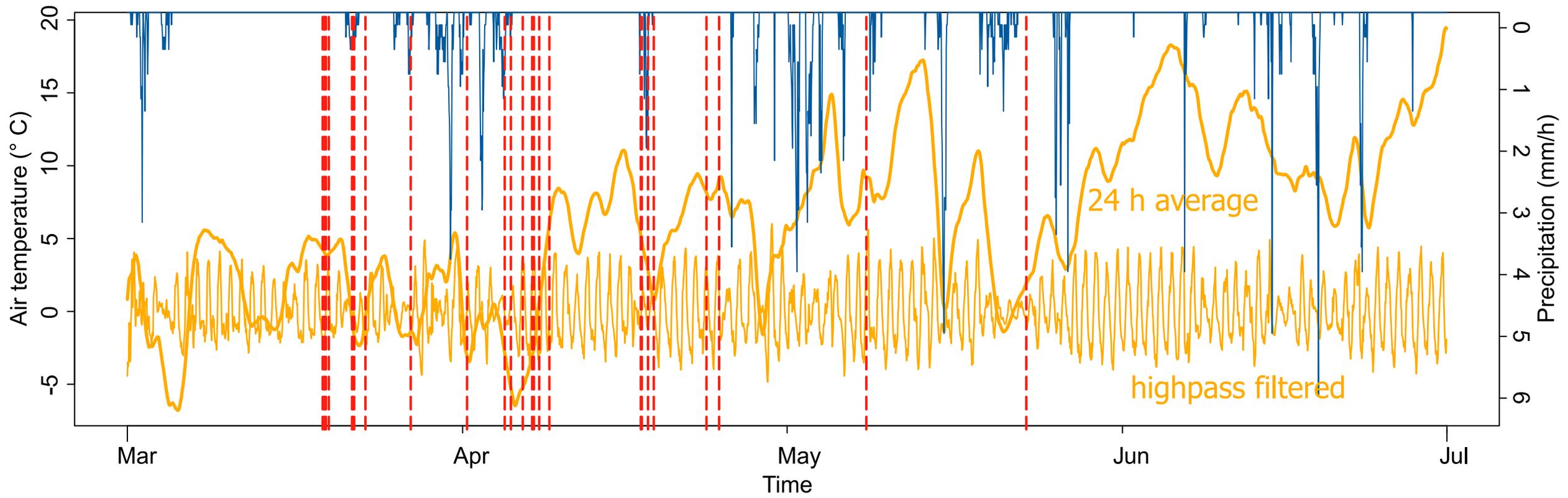
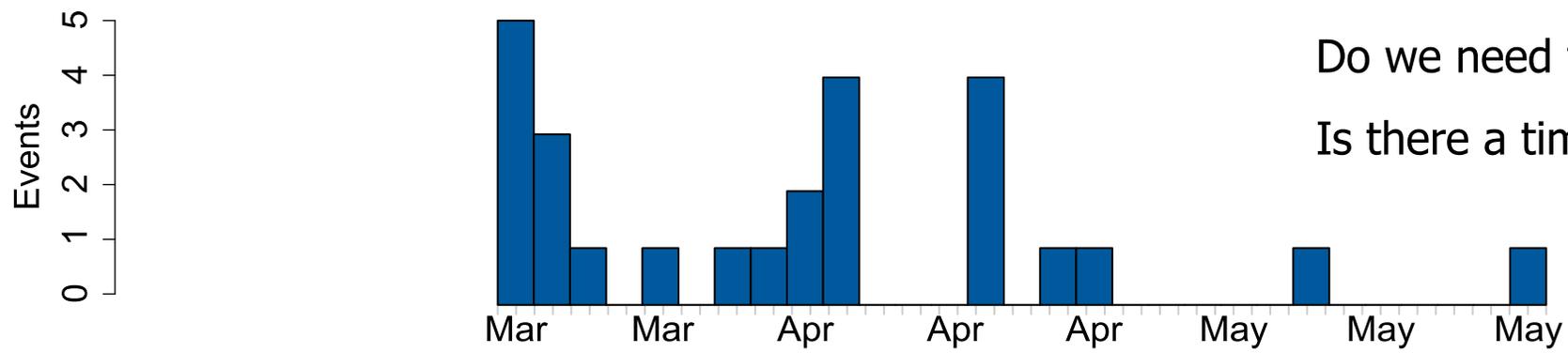


A time series of the 2015 events



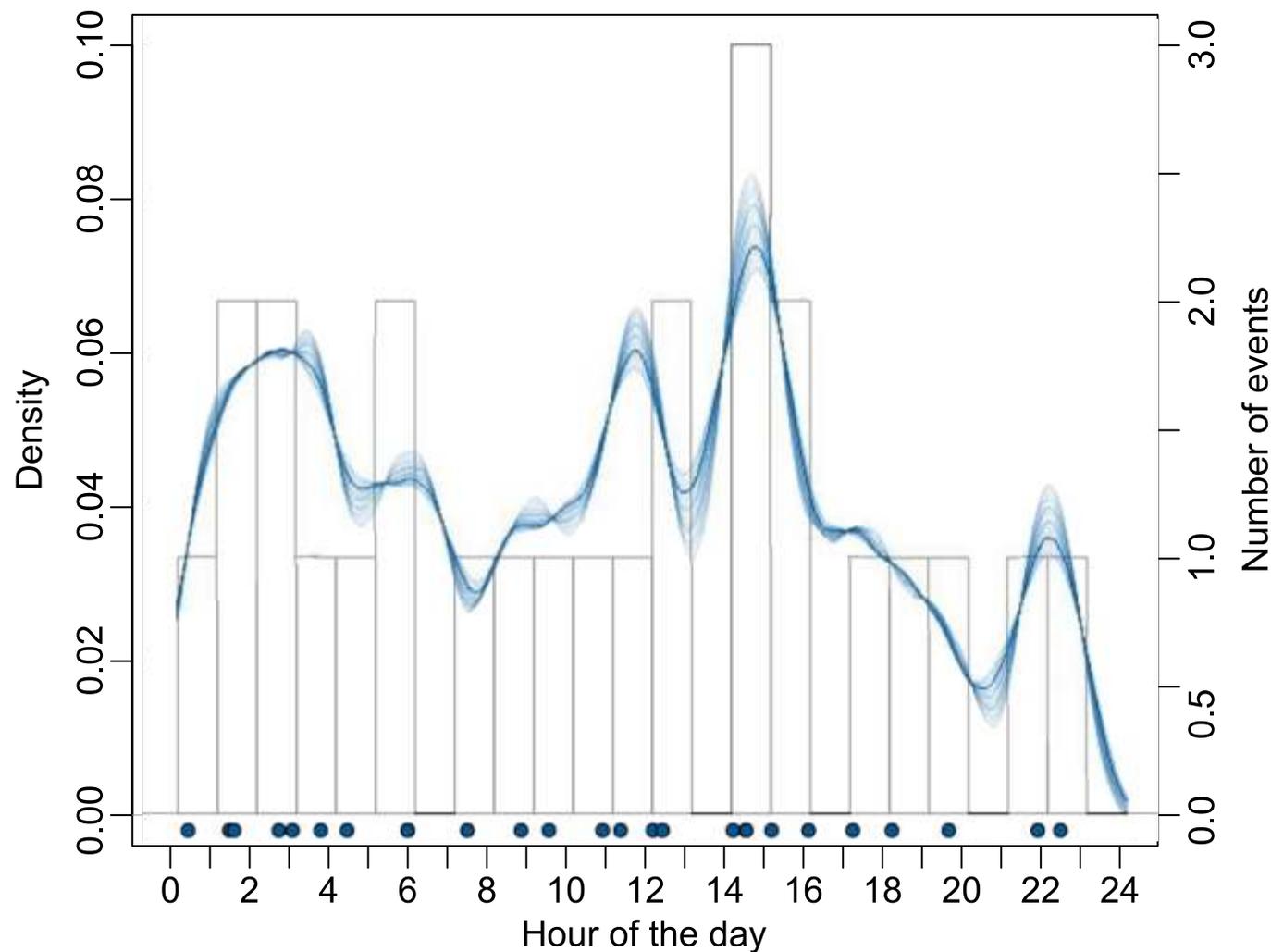
A time series of the 2015 events

Do we need rain? Yes and No.
Do we need freeze-thaw? Yes and No.
Is there a time lag? No, or hours to weeks.

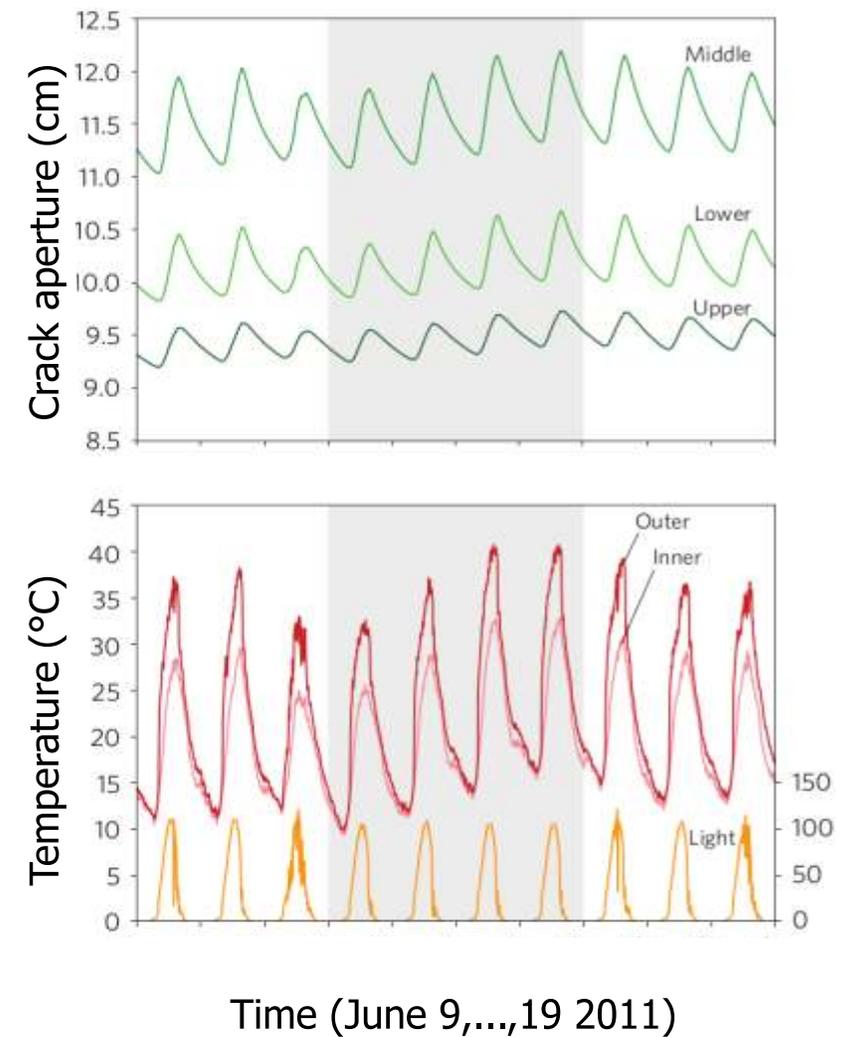


Another temporal and spatial view on the 2015 events

Event frequency by hours (n = 26)

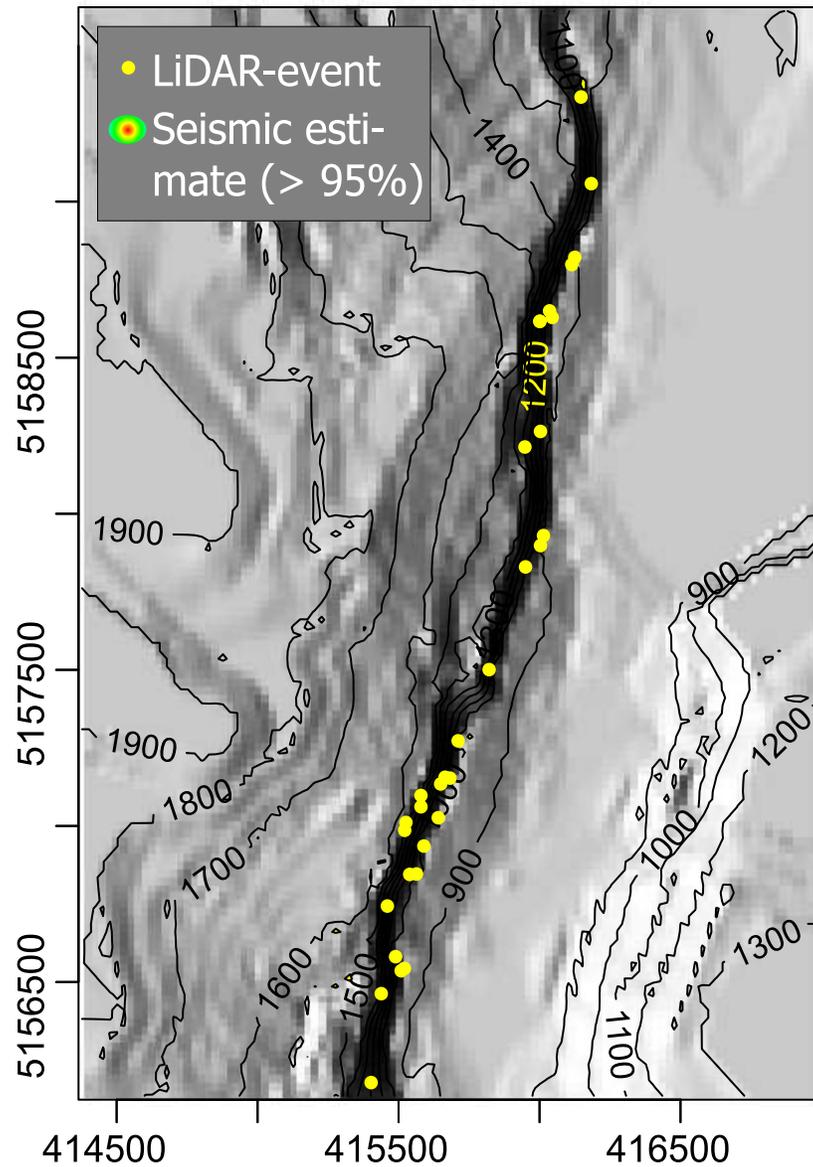


Link to diurnal expansion-contraction?

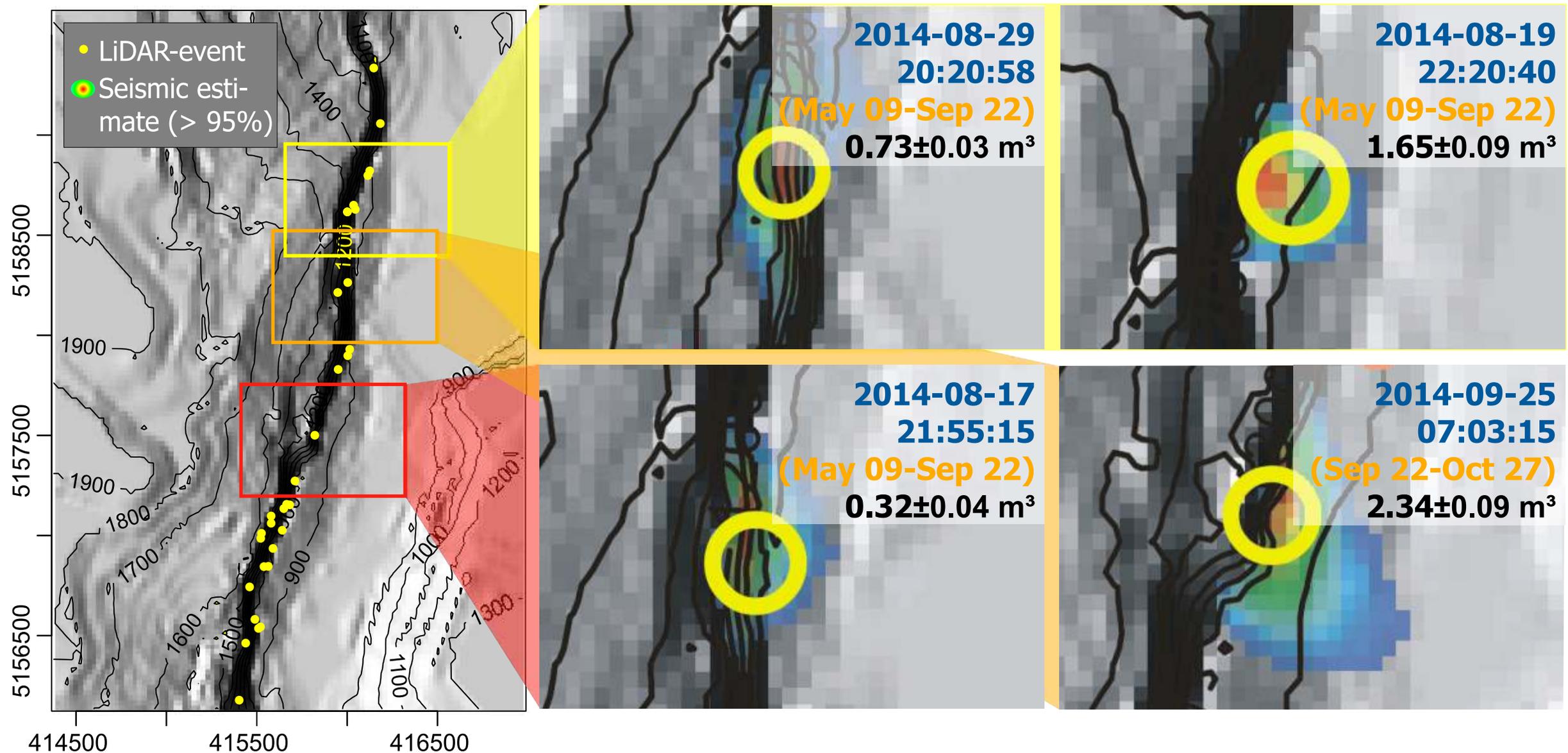




Linking seismic source estimates with LiDAR data



Linking seismic source estimates with LiDAR data



Concluding remarks

Seismic monitoring allows quantitatively characterising rockfall events

Records provide access to timing, location, evolution, energy, perhaps magnitude

Rockfall events are distinct and non-uniform

At least three different seismo-phenological types

Insight to and quantification of event phases possible

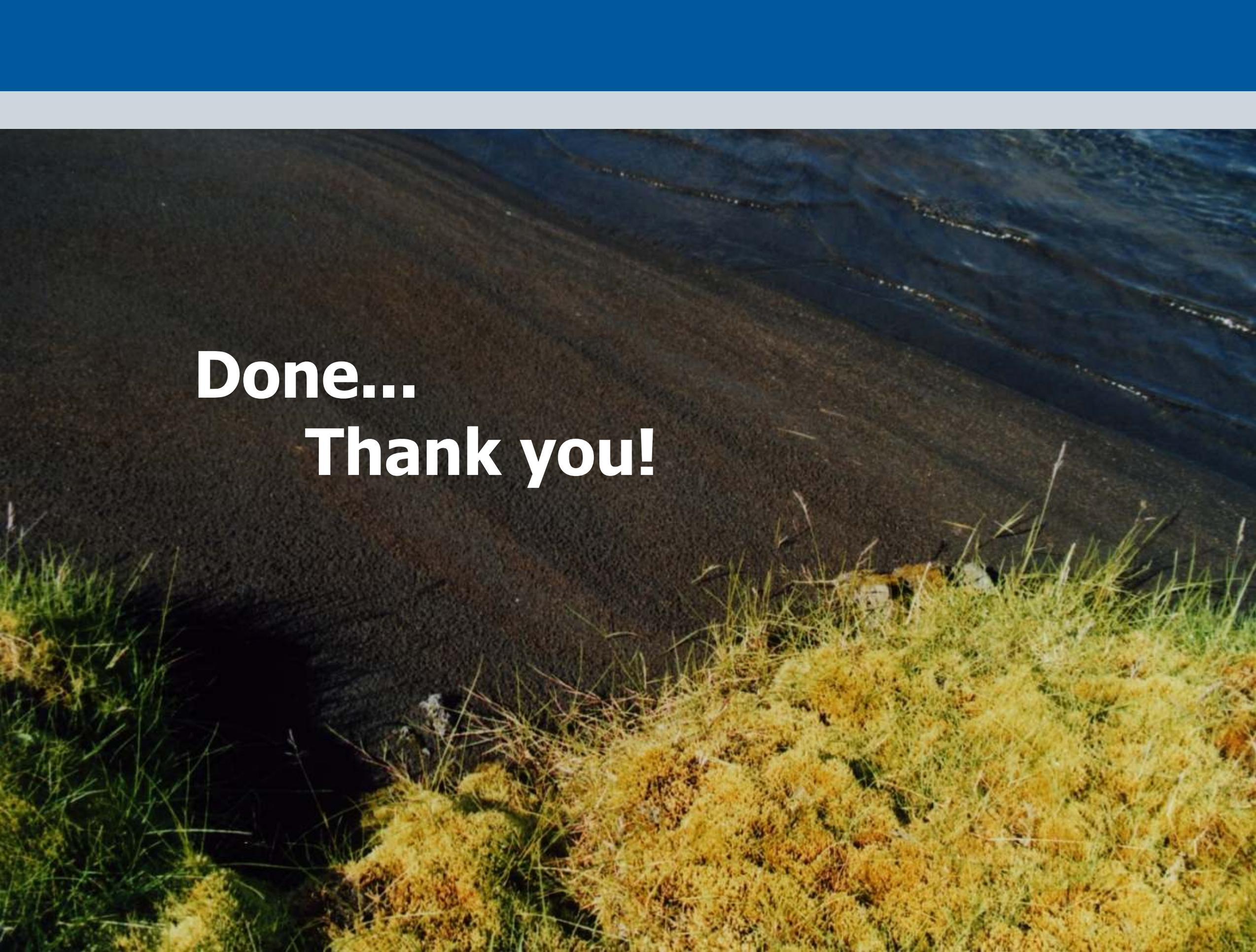
Activity follows diurnal and seasonal cycles

Increased activity at night and during late afternoon as well as during thawing period

Agreement between event detection by LiDAR and seismology, despite mismatches

Non-overlapping observation periods, noisy environment, range of seismic event signatures

More advanced picking methods (e.g., Hidden Markov Models, Zeckra, 2016; Dammeier et al., 2016)

A photograph of a black sand beach. The sand is dark and smooth, with gentle waves lapping at the shore. In the foreground, there is a patch of yellowish-green, mossy-looking vegetation. The sky is a solid blue color at the top of the image.

Done...
Thank you!