Decoding Instability: Linking Microseismicity Patterns, Deformation Monitoring and Ambient Seismic Noise at the Åknes Rock Slope

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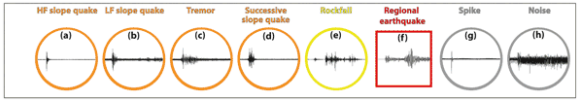
Listening to the Earth

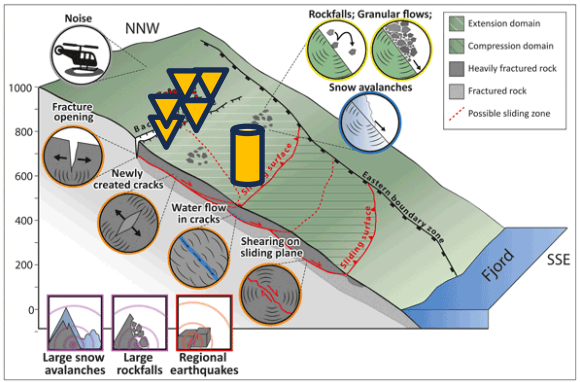
The Åknes instable rock slide & instrumentation

18-54 Mill m^3 rock mass moving with 3-5cm/year -> may generate 30-80m high flood wave!

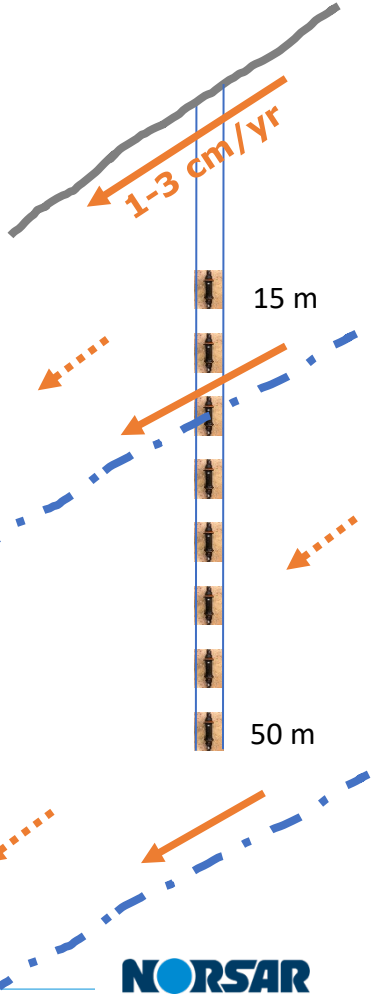
Comprehensive monitoring:

Surface geophones, borehole geophones, broad-band seismometer, GPS, InSAR, extensometers, hydrology, …





(Langet & Silverberg, Earth Surface Dynamics, 2023)



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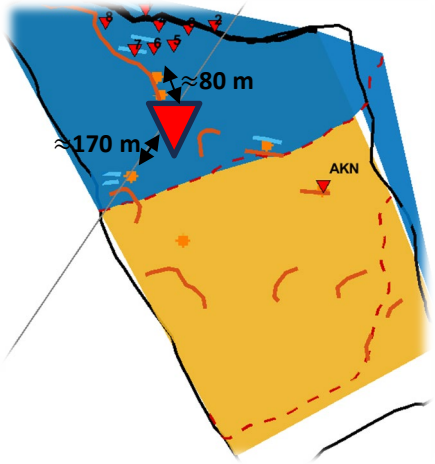
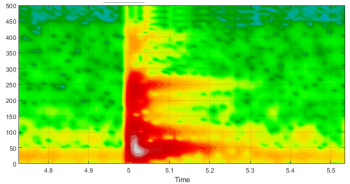
2 Sliding planes



Single event characteristics



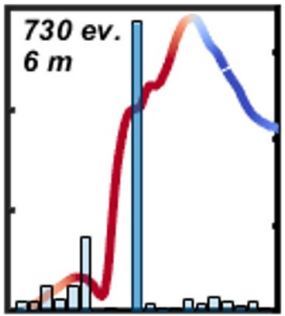
Displacement in wells

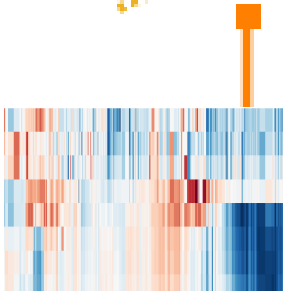
Borehole sensors

Similar events

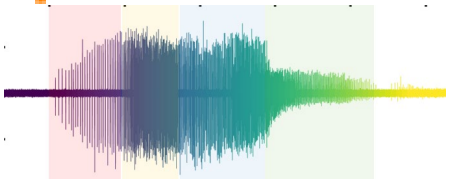
Events at depth levels

Fluids & events

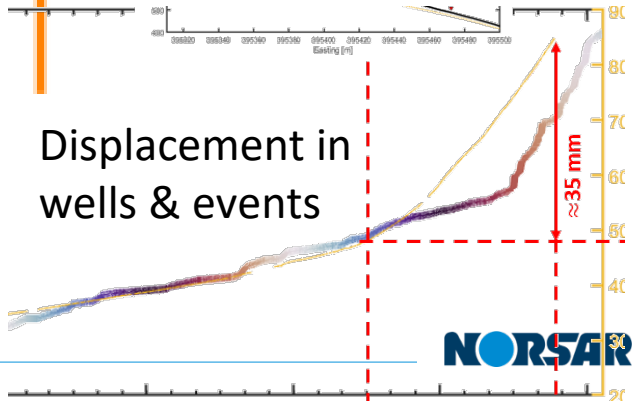




Ambient Noise & dv/v



Episodes over hours



Displacement in wells & events

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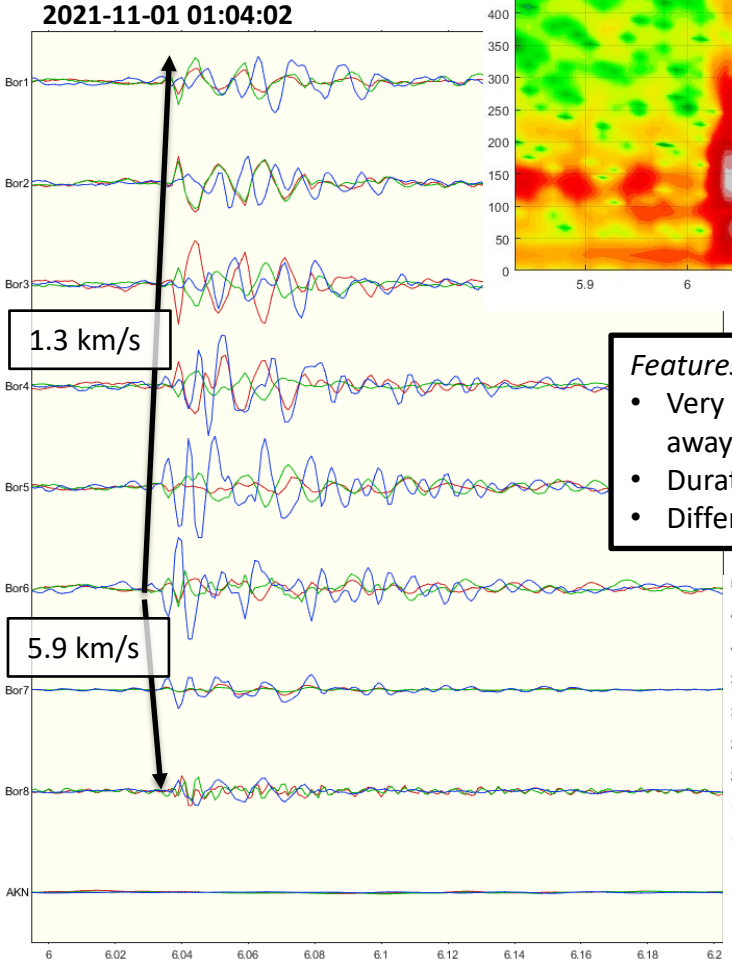
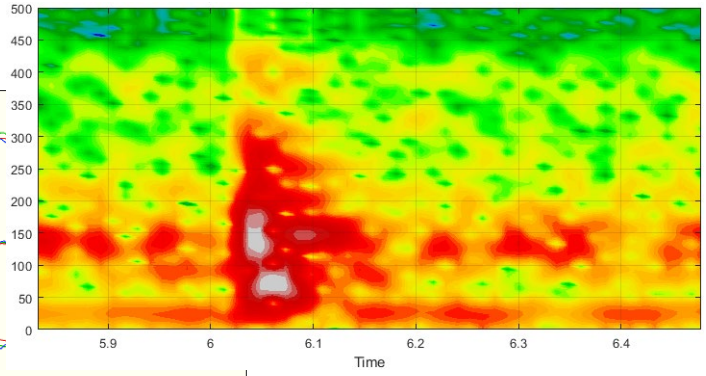
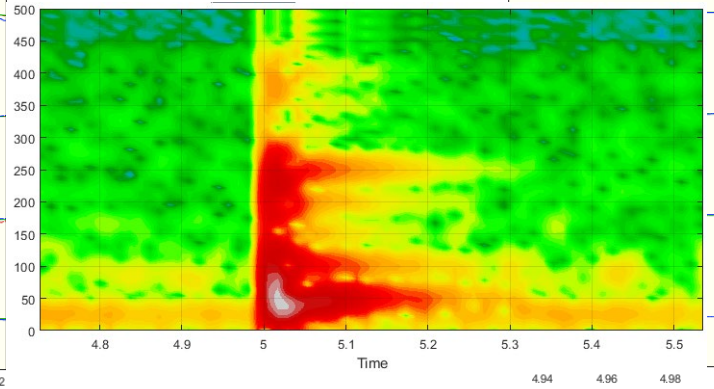
Microseismic events



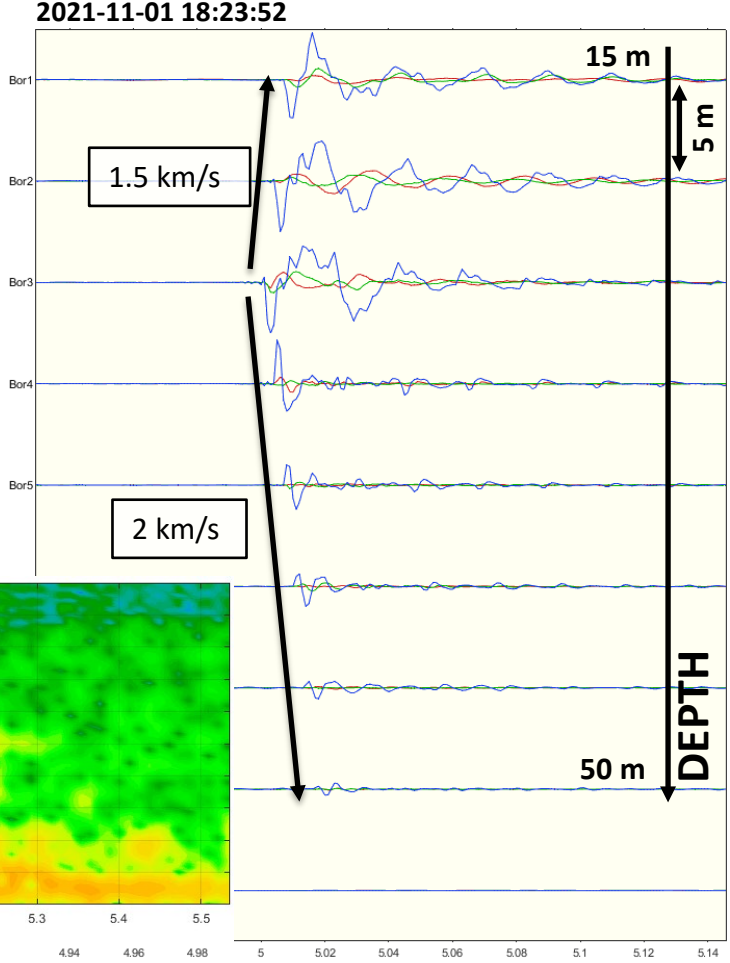


Features:

- Very high frequencies → max. 100 m away from borehole
- Duration < 200 ms
- Different move-outs ⟺ event depth



High frequency events



2 March 2024 episodic tremor

First onset observed at the deepest geophone (50 m)

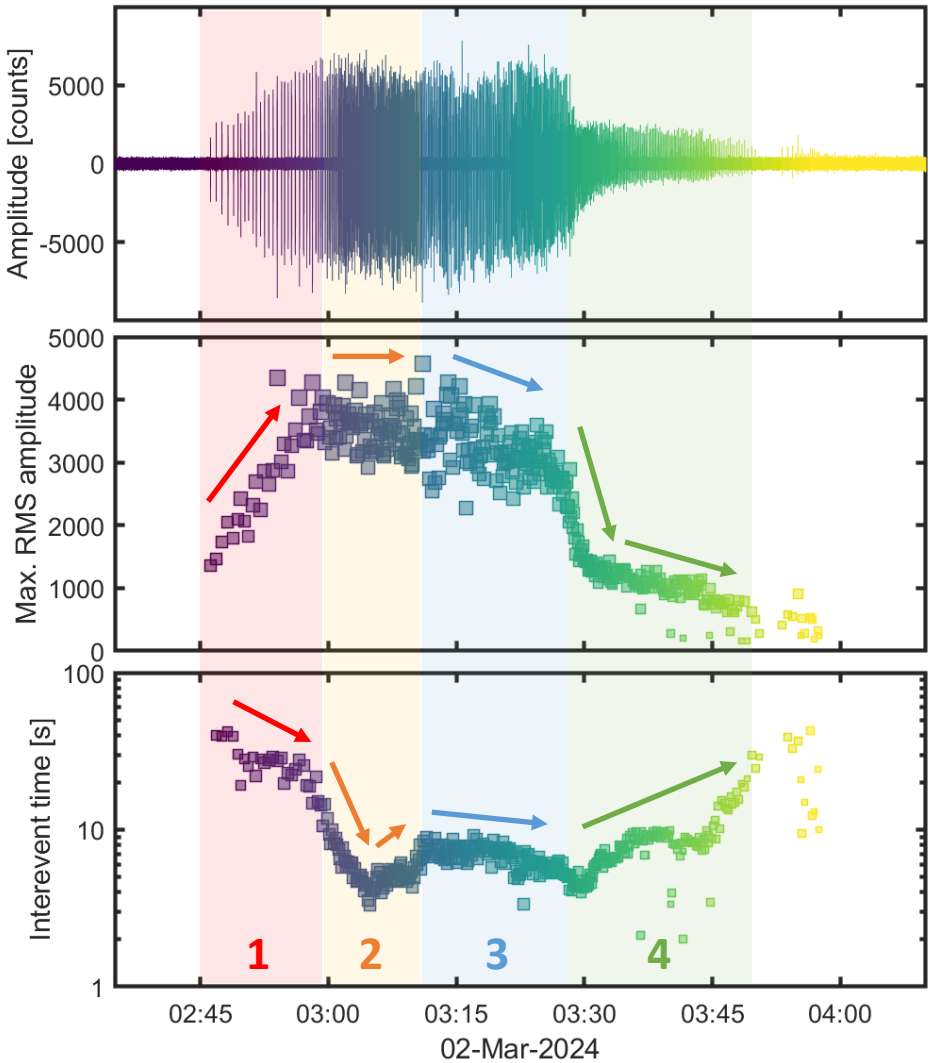
4 main phases:

(1) Rapid increase in amplitude;

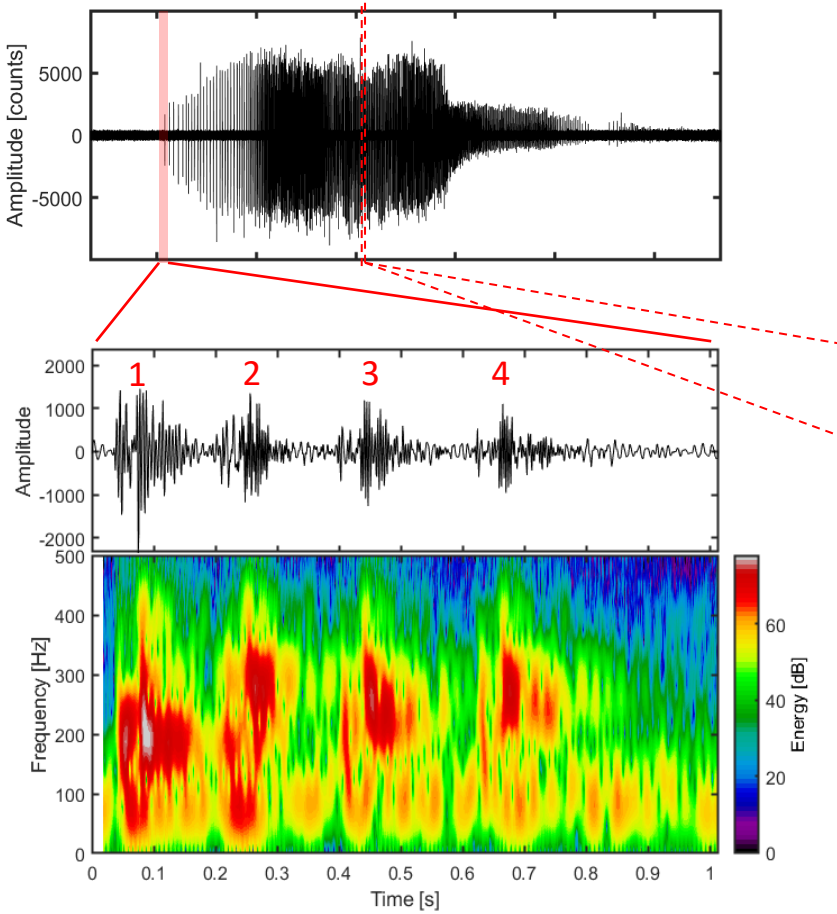
(2) Intensification of seismic activity (decrease of inter-event time), stable amplitude;

(3) Stable amplitude, stable inter-event time;

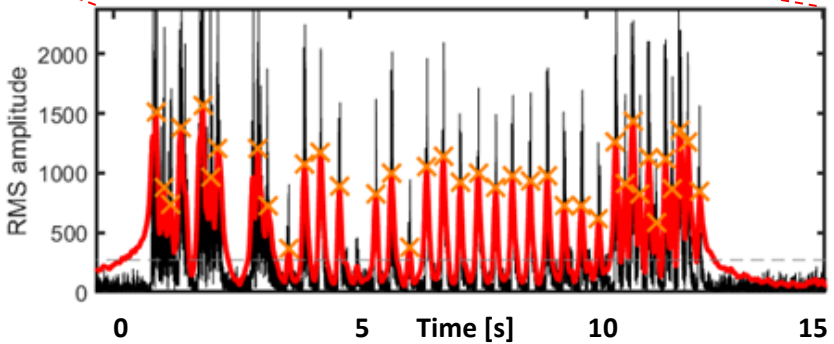
(4) Decrease in amplitude together with deceleration of seismic rate.



Episodic Tremor – 70 min duration, on 2 March 2024



- We found here 371 detections
- Each detection contains about 3 to 50 short events
- Running a finer detector on signal smoothed envelopes -> we identify and characterize 2656 events.
- We apply waveform cross-correlation and hierarchical clustering analysis.



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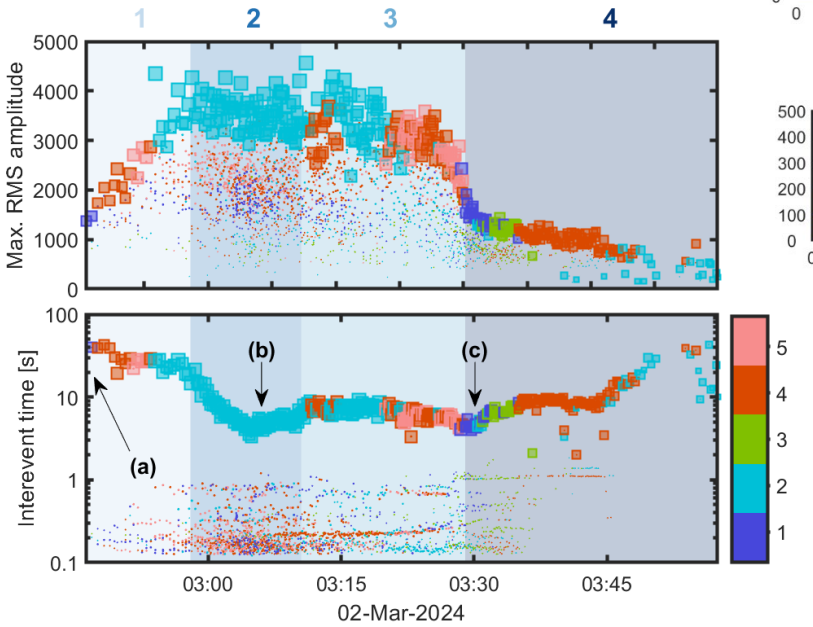
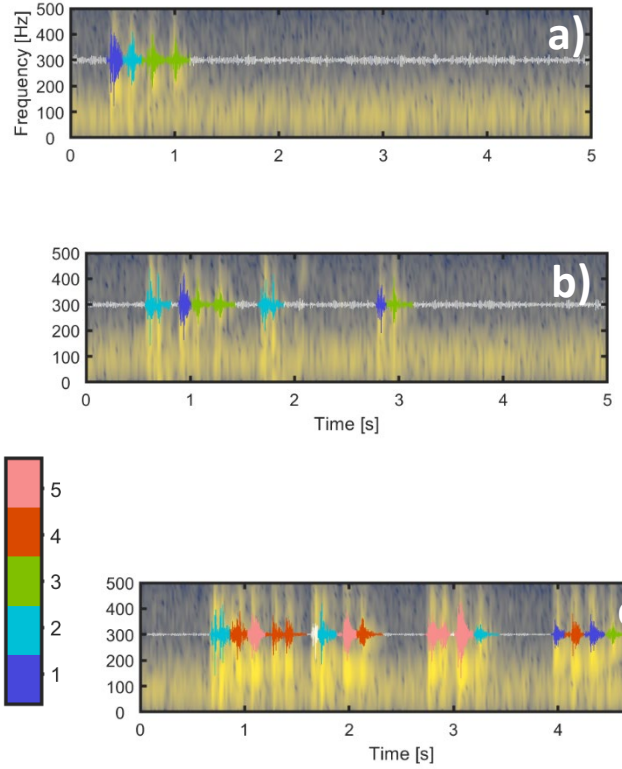
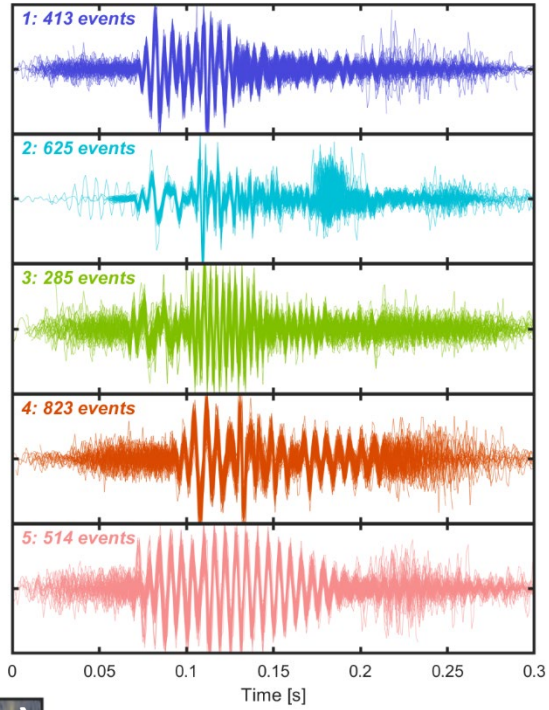
2 March 2024 episodic tremor

- 5 main families of events
- Tiny interevent times
- Activation of small asperities?
- Other episodes have extremely similar characteristics and waveforms.

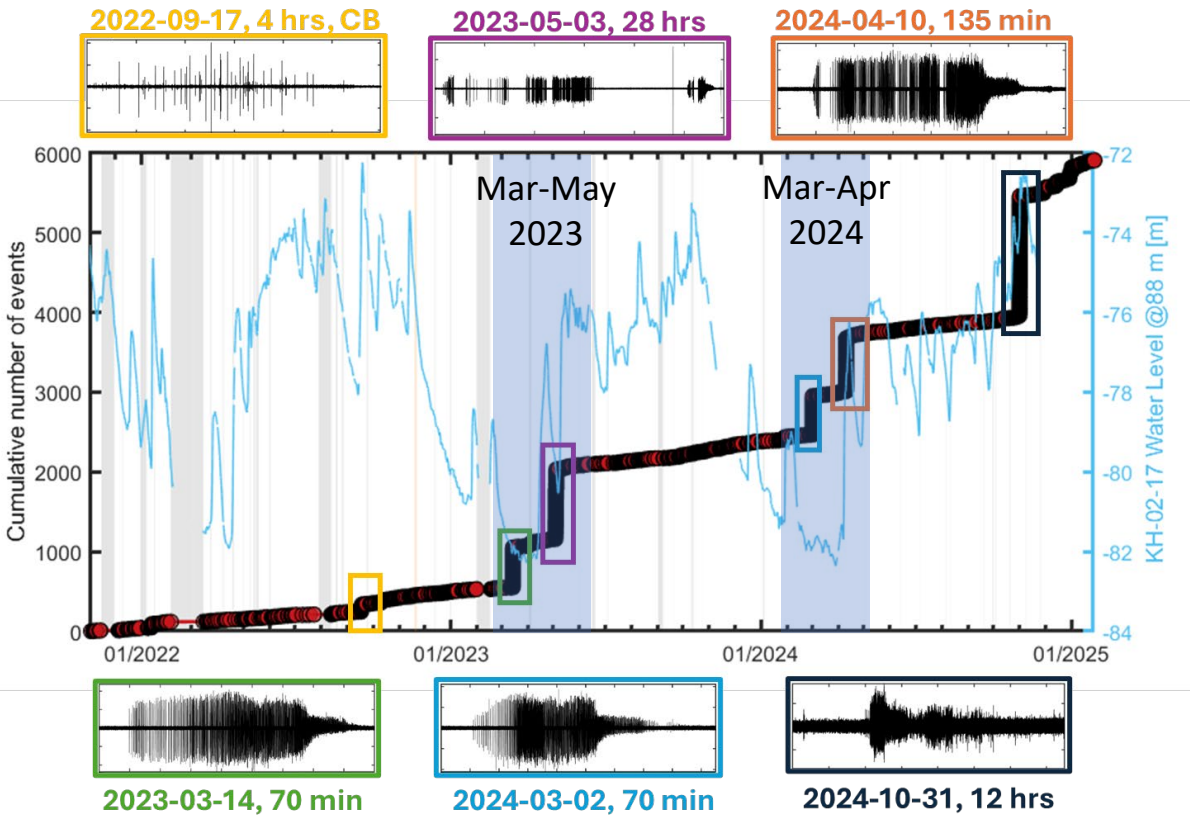






100 best correlations, vertical component, deepest geophone

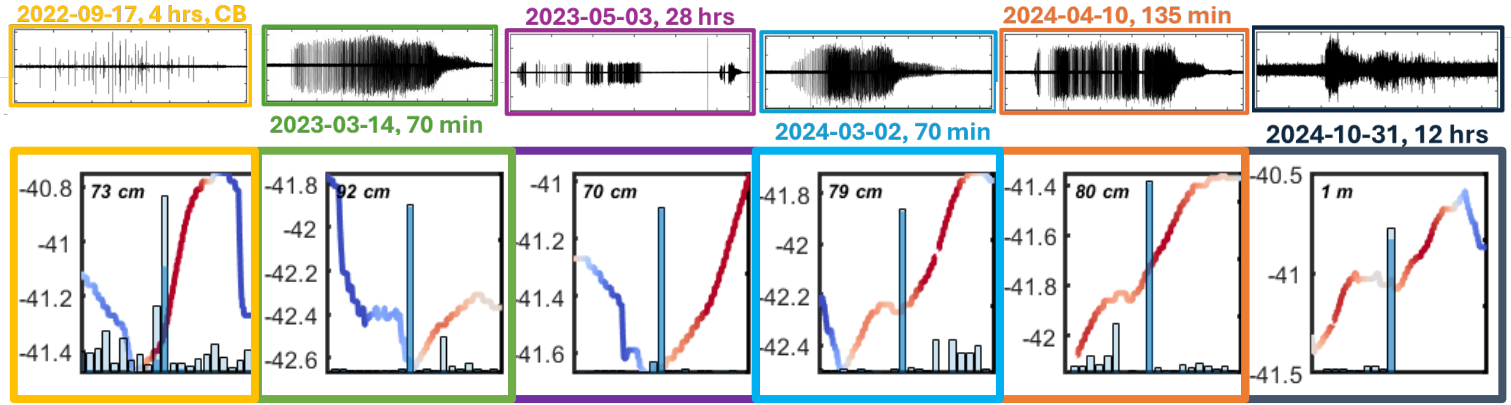
Other observations of episodic tremors



Most tremors occur during spring (Mar-May) and are likely related to snow-melt.

Last tremor in October is different and coincides with large tremor activity at the near surface or upper sliding plane.

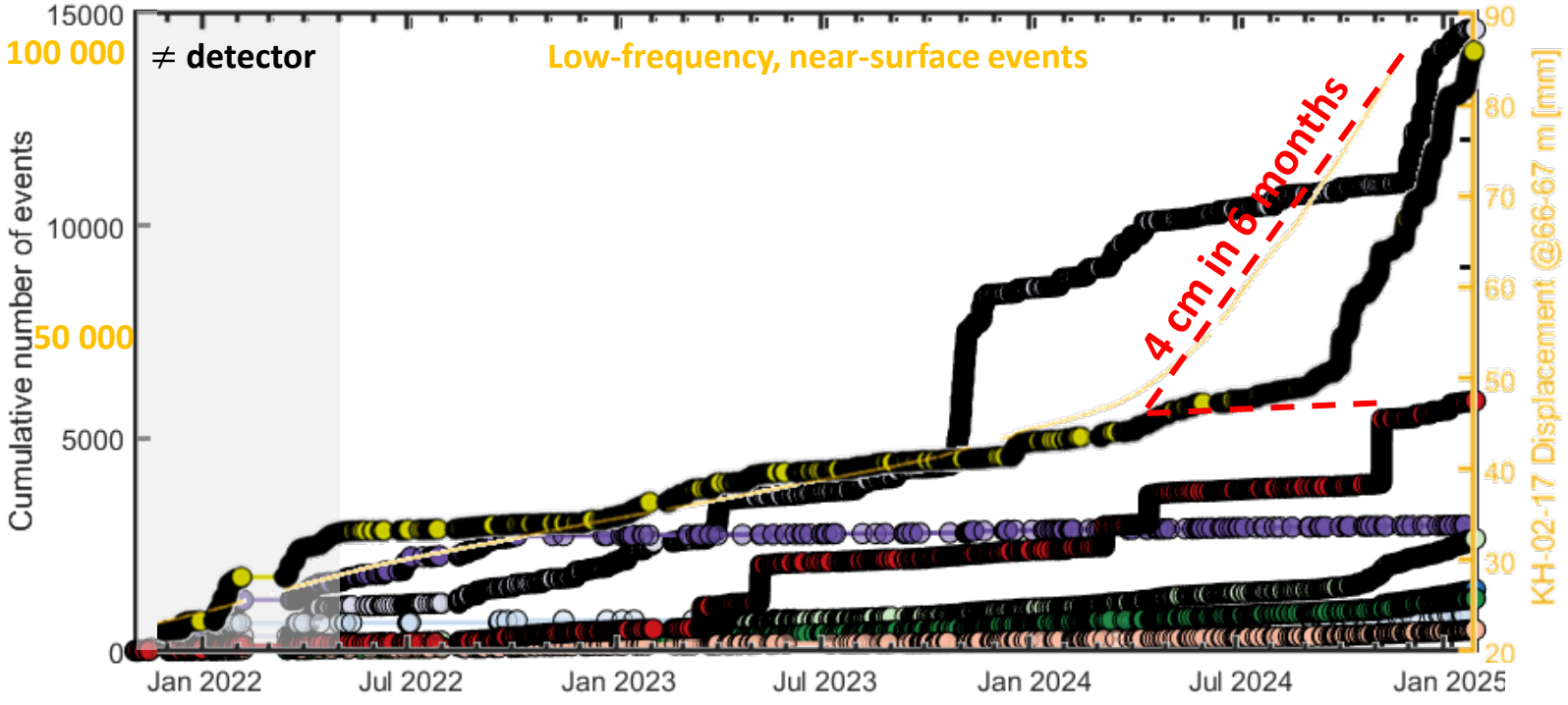
Water level changes during episodic tremors



- Most water level changes at **upper borehole** show increase of water levels **before/during** episodic tremor
- Most water level changes at **lower borehole** show increase of water levels **during/after** episodic tremor.
- Is the tremor triggered by fluids, and then enhancing the fluid flow?
- However, no clear knowledge on flow directions, remaining uncertainty on exact location of tremor.

Detection overview for different event types, not only episodic tremors

High frequency events (with depth estimation based on moveout)



➔ Different behaviour depending on depth…

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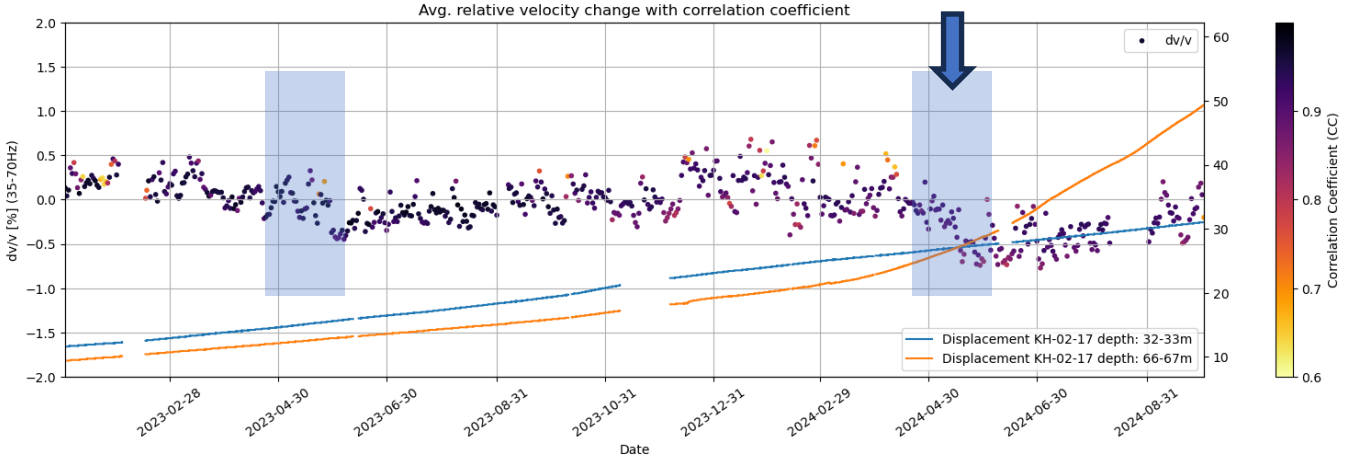
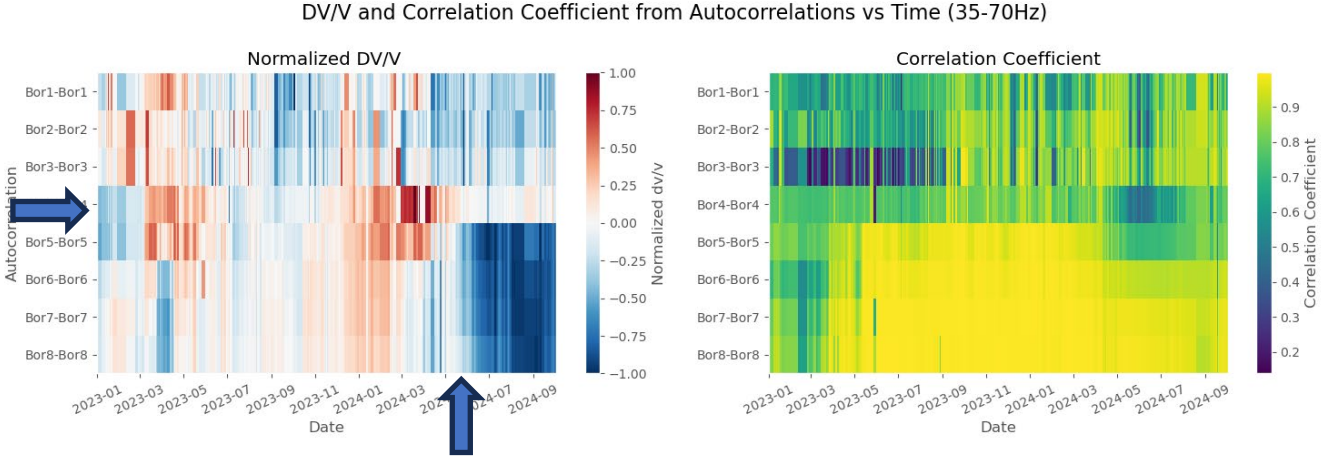
Ambient noise study to identify relative velocity changes (dv/v)



- Velocity drops during snow melt season. Additional drop with onset of displacement in lower shear zone in 2024.



- Normalized dv/v in upper shear zone increases during snow-weight, decreases below after snow melt
- Stable correlation coeff.

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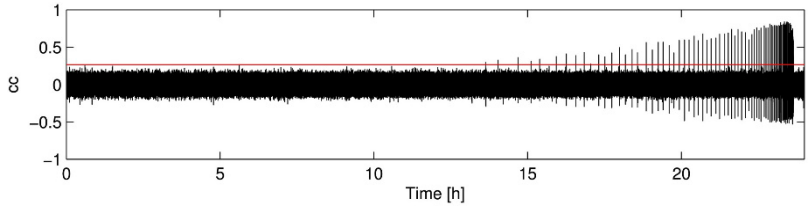
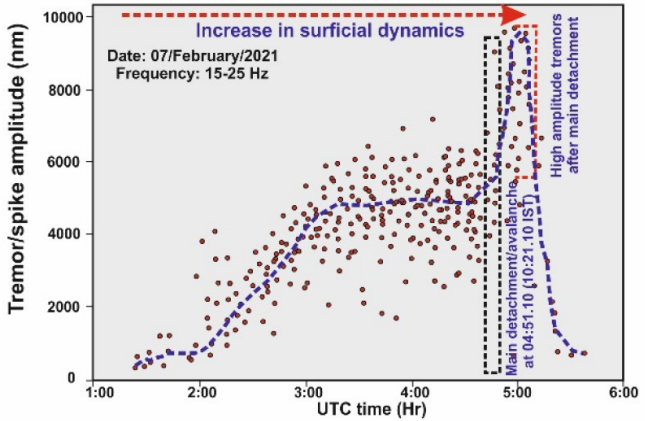
Similar observations of tremors before ruptures/landslides

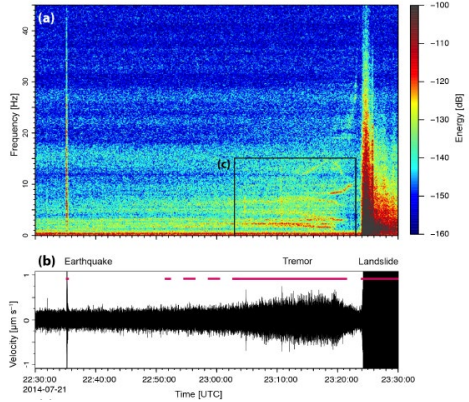
Greenland – *Poli, GRL, 2017*
35-51 million m^3, closest station at 32 km, landslide equivalent magnitude M≈4





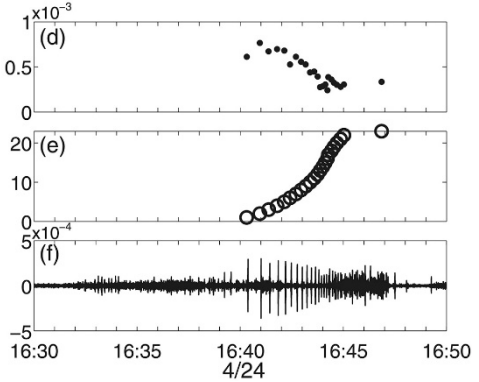
Himalaya - *Tiwari et al., ScReports, 2022*

Rock-ice avalanche (27 million m^3)
Closest station at 12 km.



Iceland - *Schopa et al., ESurf, 2018*

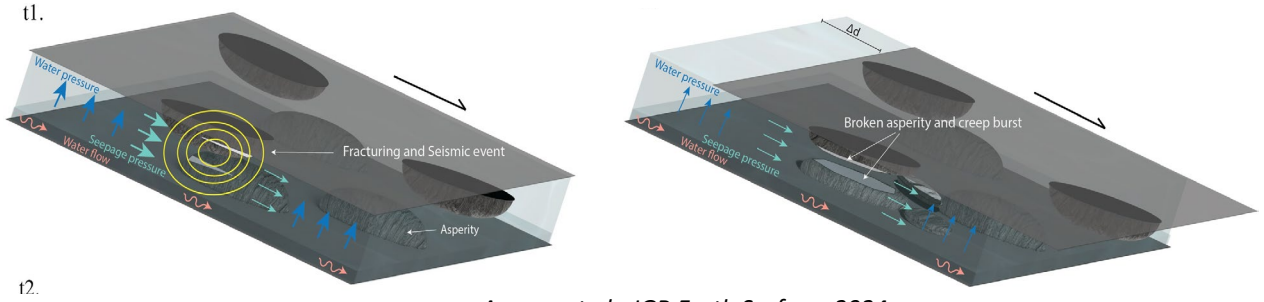
35-80 million m^3, closest station at 3.5 km



Japan - *Yamada et al., GRL, 2016*
0.62 million m^3, closest stations at 850 m, local magnitude of largest precursor event M=-1

What we decoded so far…

- Episodic tremors occur in relation to snow melt, increased water levels.
- Correlation between displacement in shear zones in wells and seismic events.
- High correlation in event waveforms, pointing towards activity at certain asperities.
- Difference in depth levels of events points towards activity on different sliding planes.
- Correlation seen on ambient noise indicates dv/v changes in relation to displacement, snow weight and melting season.
- Conceptual model established
- **So far, all episodic tremors at Aaknes stopped before catastrophic failure.**



Aspaas et al., JGR Earth Surface, 2024