Shaking shores: Progress in seismic monitoring of rocky coasts

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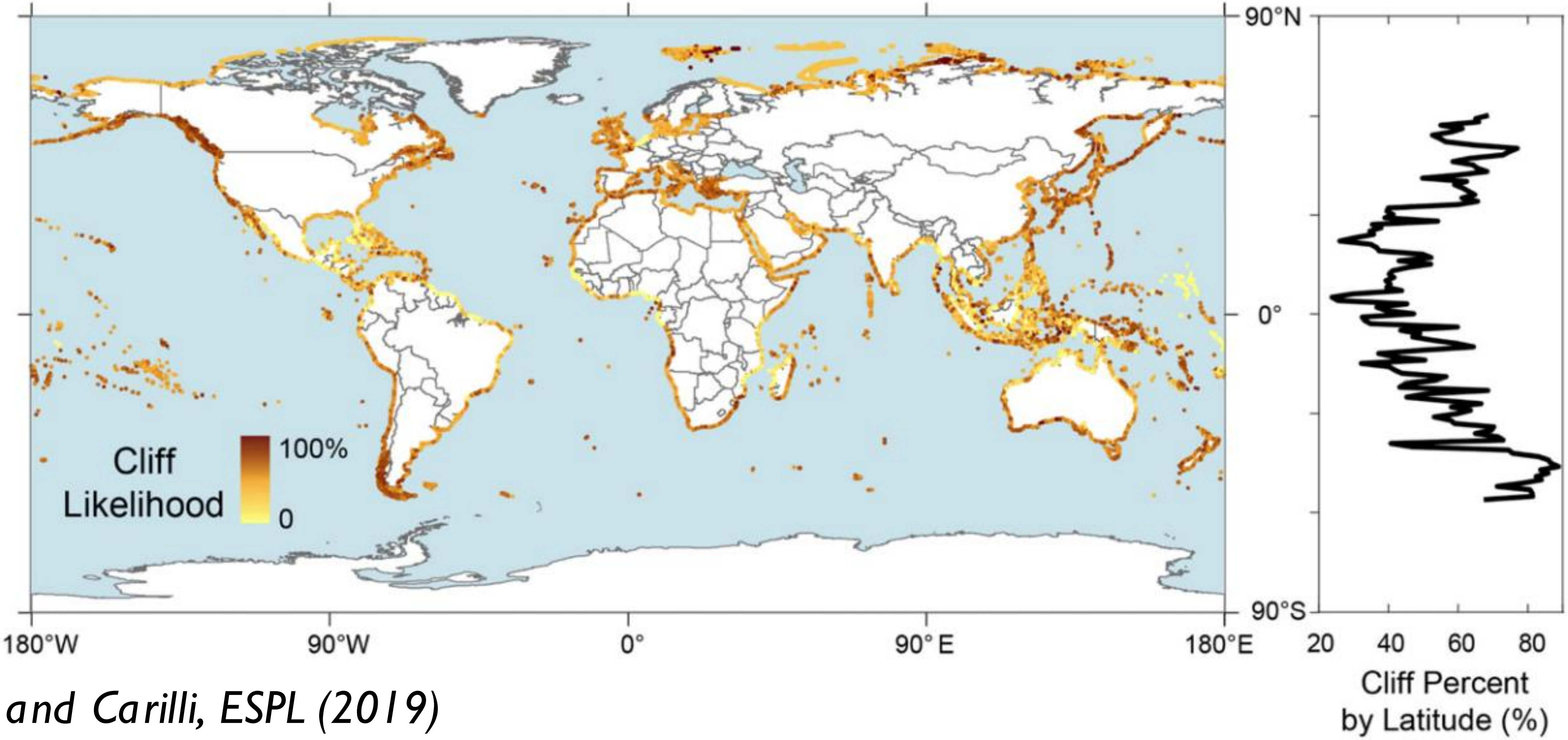
Orkney Islands, UK

Rocky coasts make up ~50% of the world's coastlines

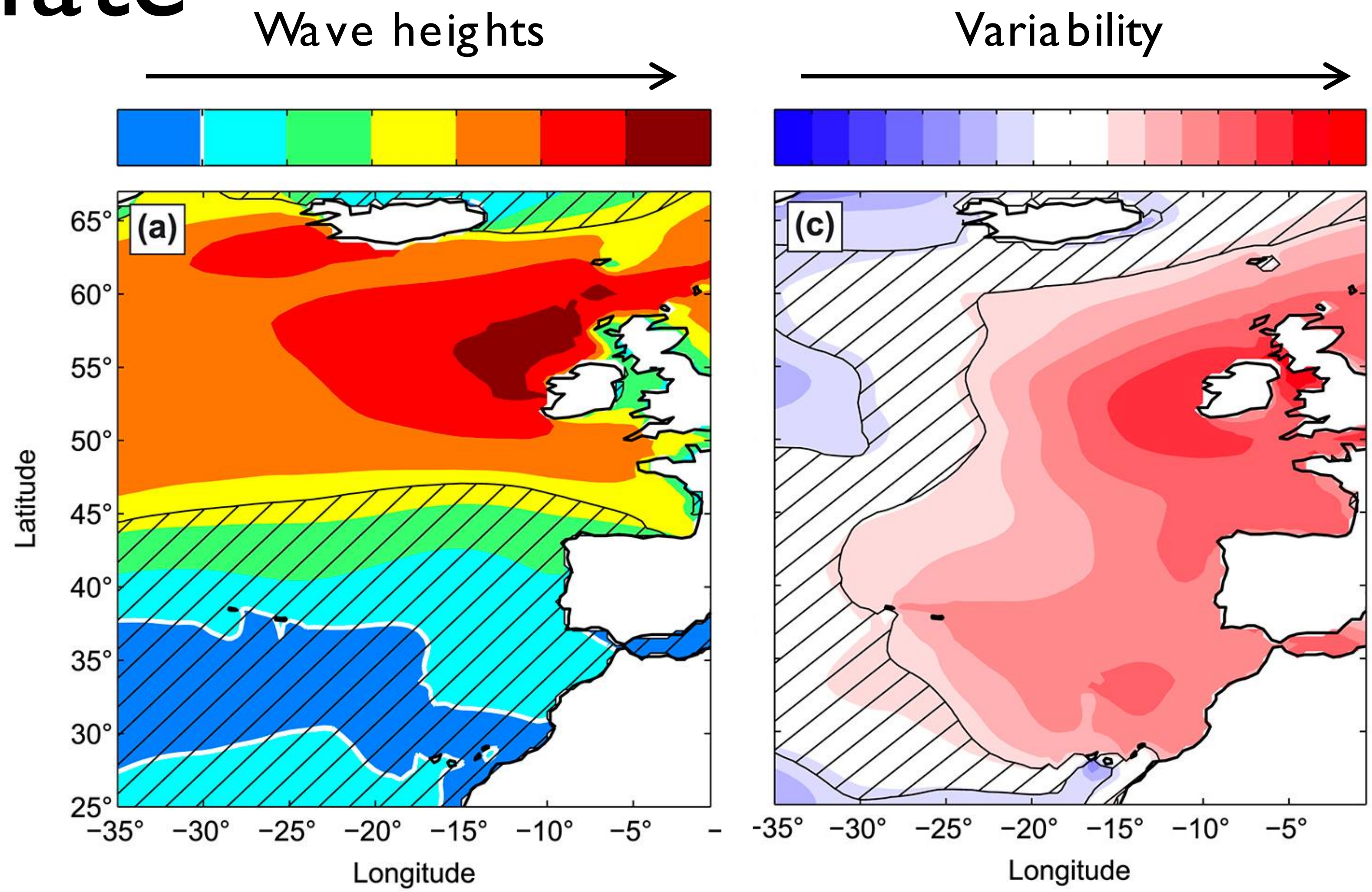


Young and Carilli, ESPL (2019)

Hazards on rocky shores in a changing climate

Wave height and variability increasing across W. Europe

How sensitive are rocky coasts to a changing wave climate?



Castelle et al., 2018

Under what conditions do cliffs erode?

Erosion is governed by episodic collapse events

Under what conditions do cliffs erode?

Spoiler: We still don't know

Why do we still not know?

- Episodic cliff collapse does not always occur during most intense environmental conditions (e.g. Lim et al., 2010)

- Tensile strength of rock far exceeds stresses of individual crashing waves and other environmental forces (1-10 MPa vs. 10-100 kPa)

- Cliff erosion is infrequent, rates hard to measure

- Near-shore environments are hard to instrument and near shore ocean wave transformation is not well-constrained

White Cliffs of Dover, UK

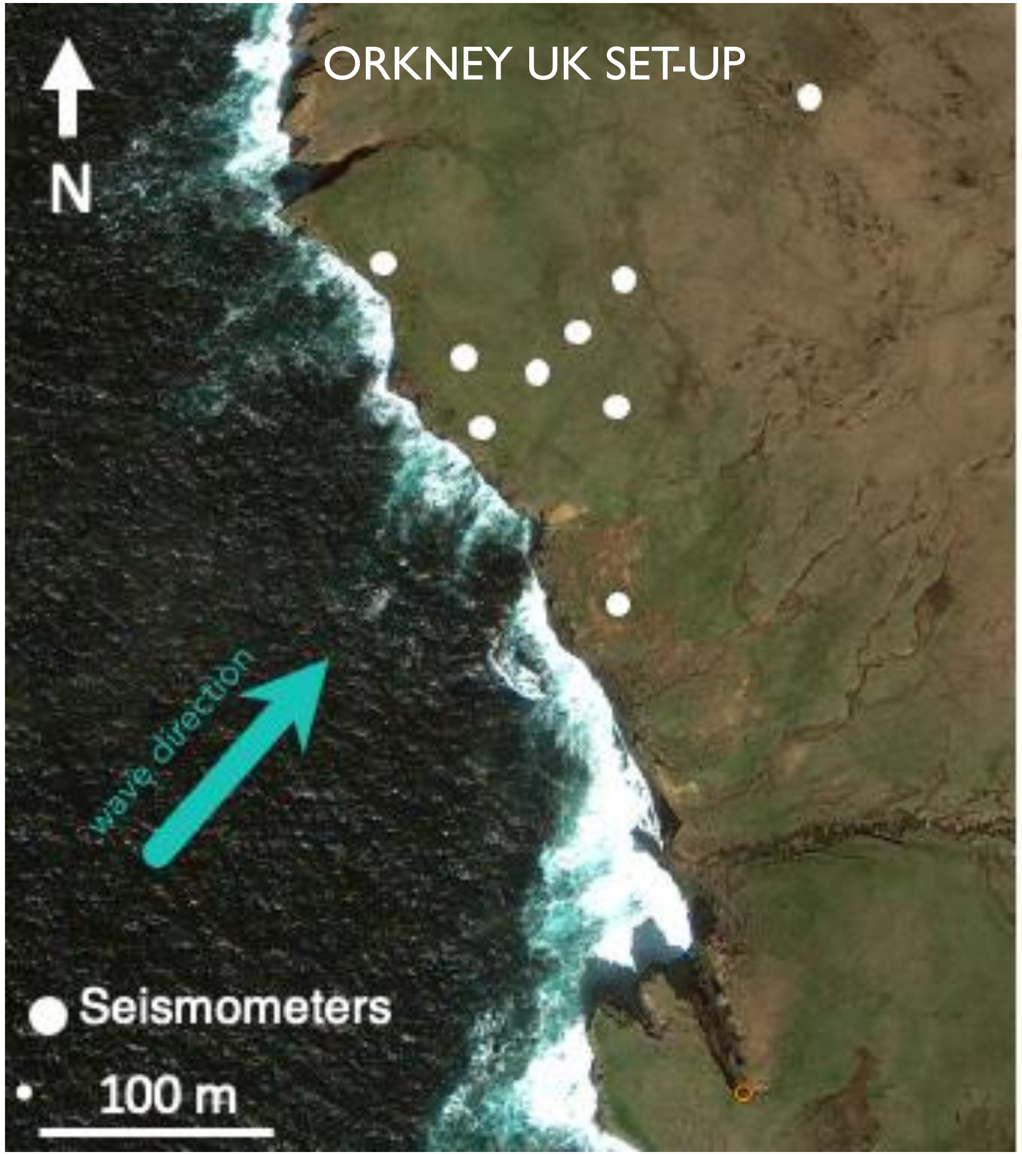
Opportunity for environmental seismology

Towards establishing a link between environmental forcing, cliff strength, and cliff failure

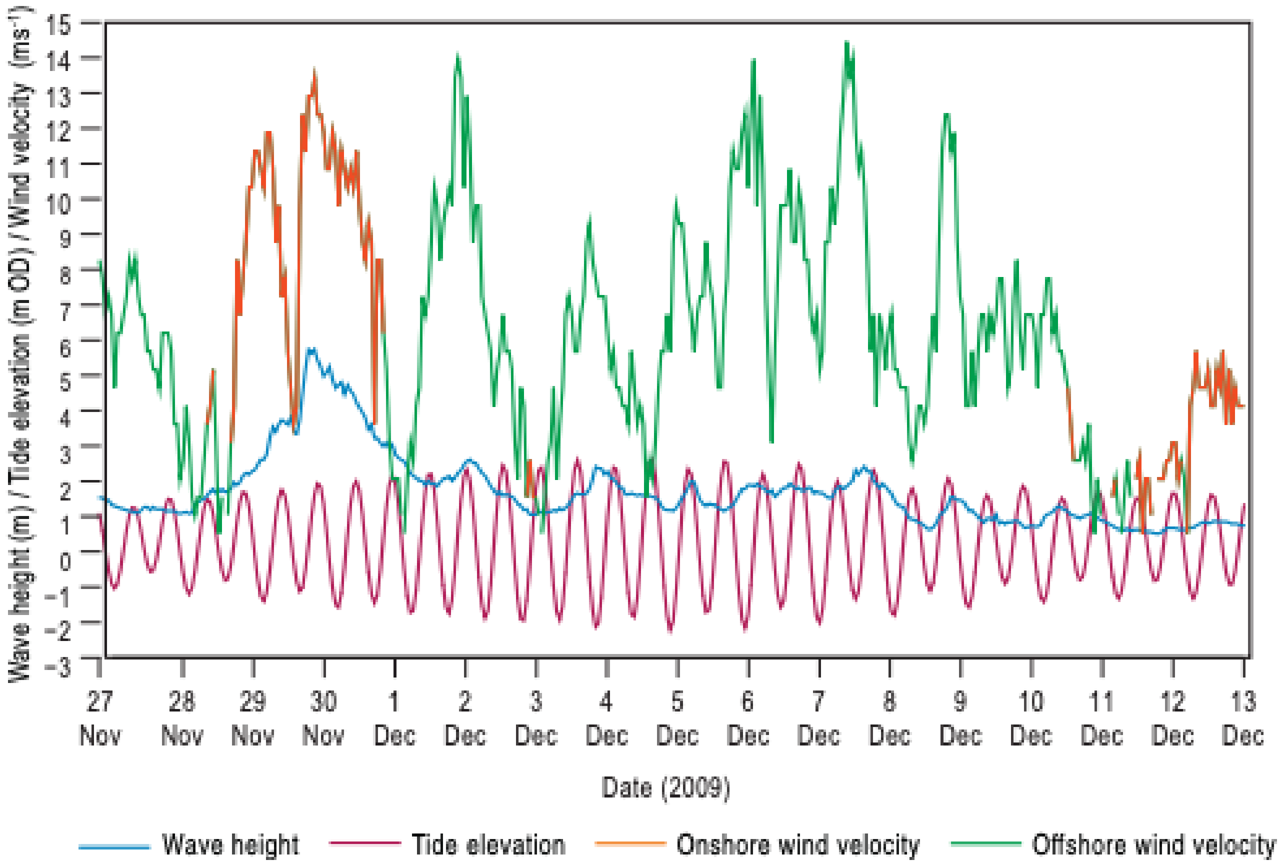
Capture cliff response to environmental conditions at a high resolution

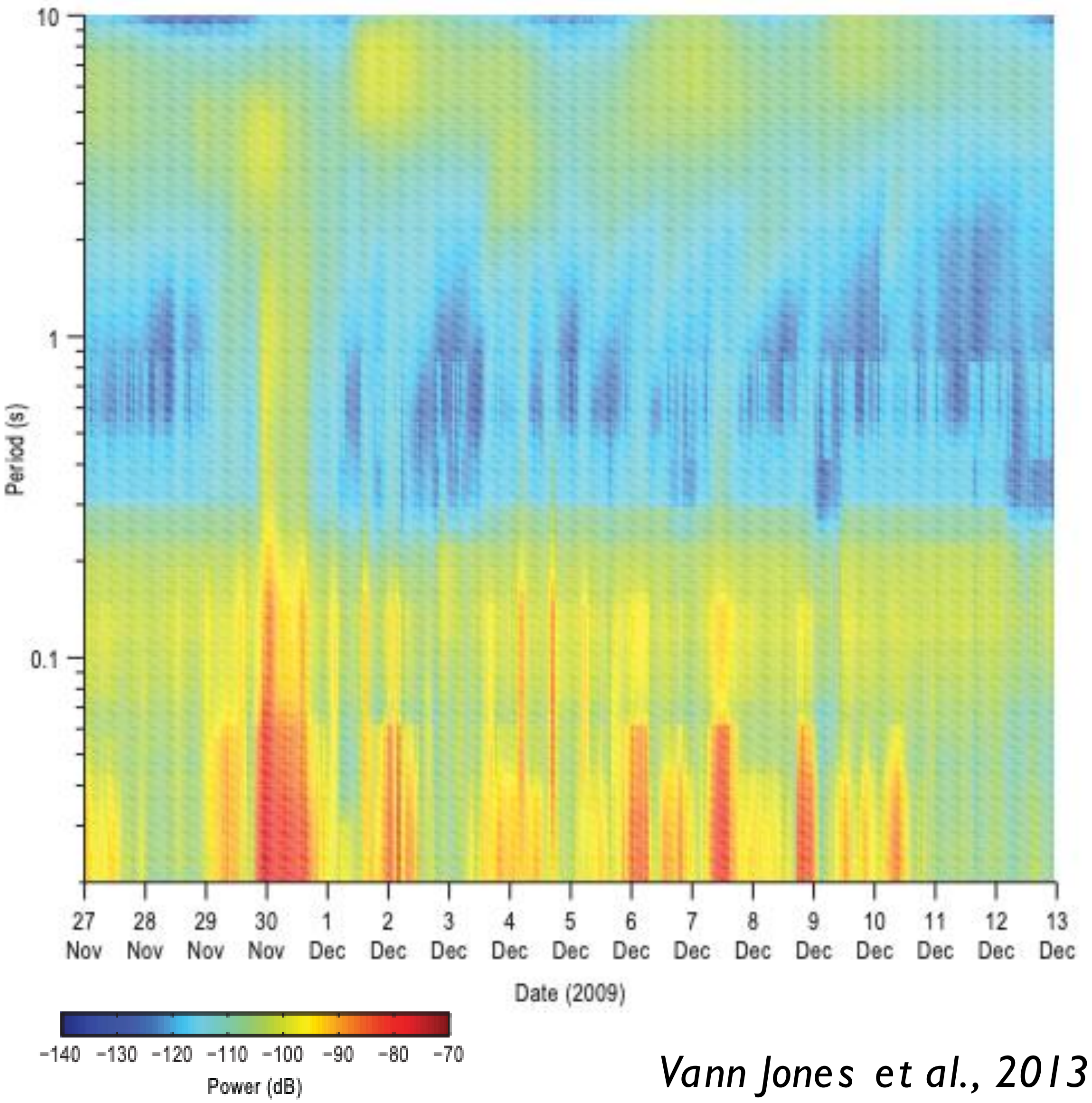
Resolve timing and size of individual cliff erosion events

Infer coastal erosion processes over short timescales



First step: Disentangling environmental forces and cliff response

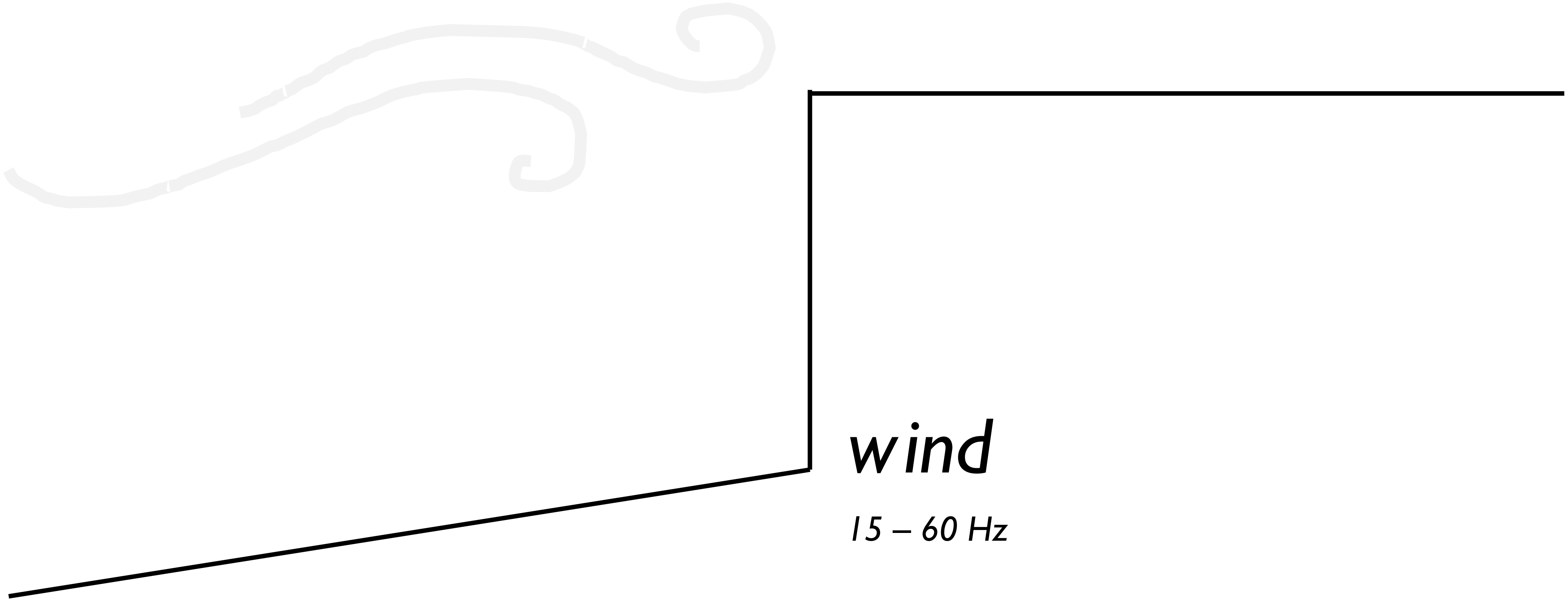




Common approach: Compare cliff shaking to available environmental datasets

Vann Jones et al., 2013

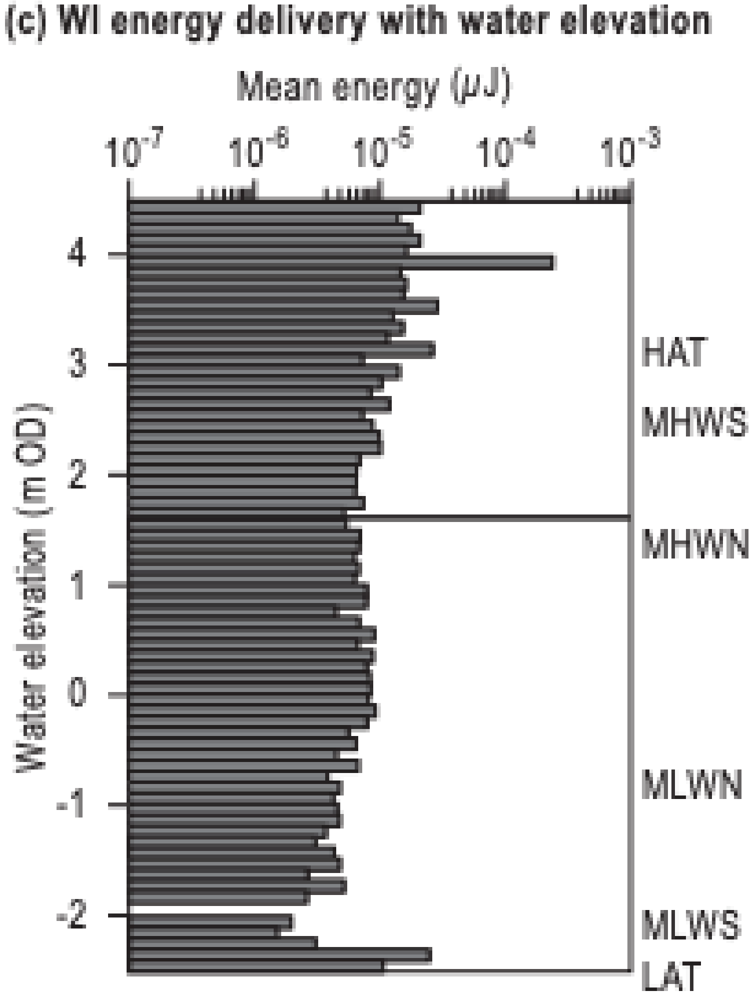
Seismic signals on rocky coasts



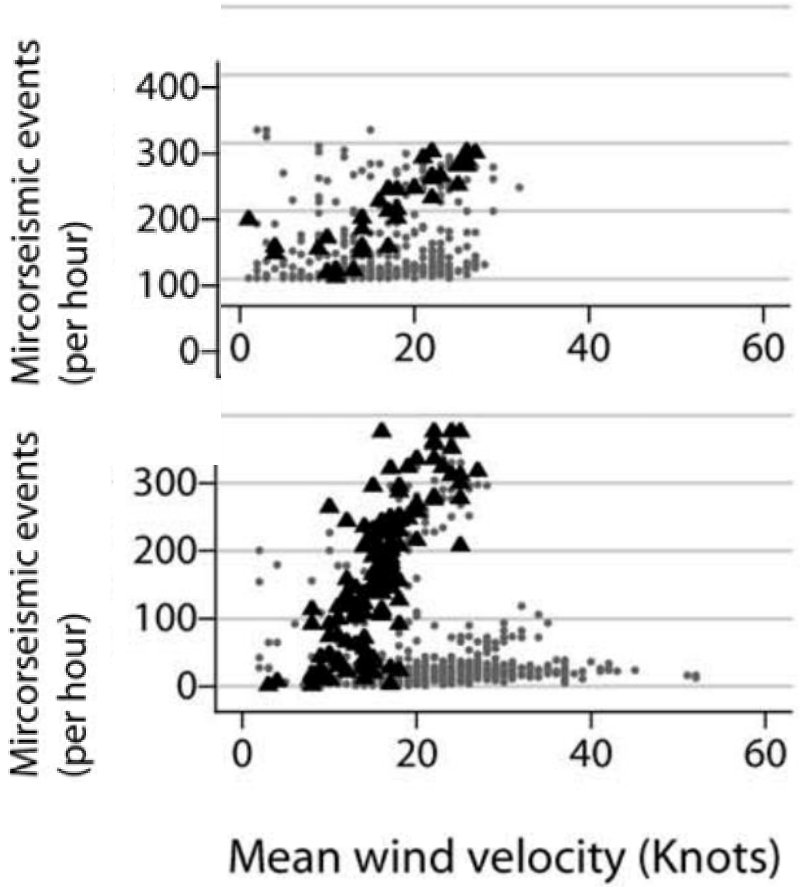
Wind is persistent, but weak!

2 orders of magnitude lower than energy flux from waves or tides

Weak correlation between wind direction and erosion (r^2 ~0.4).

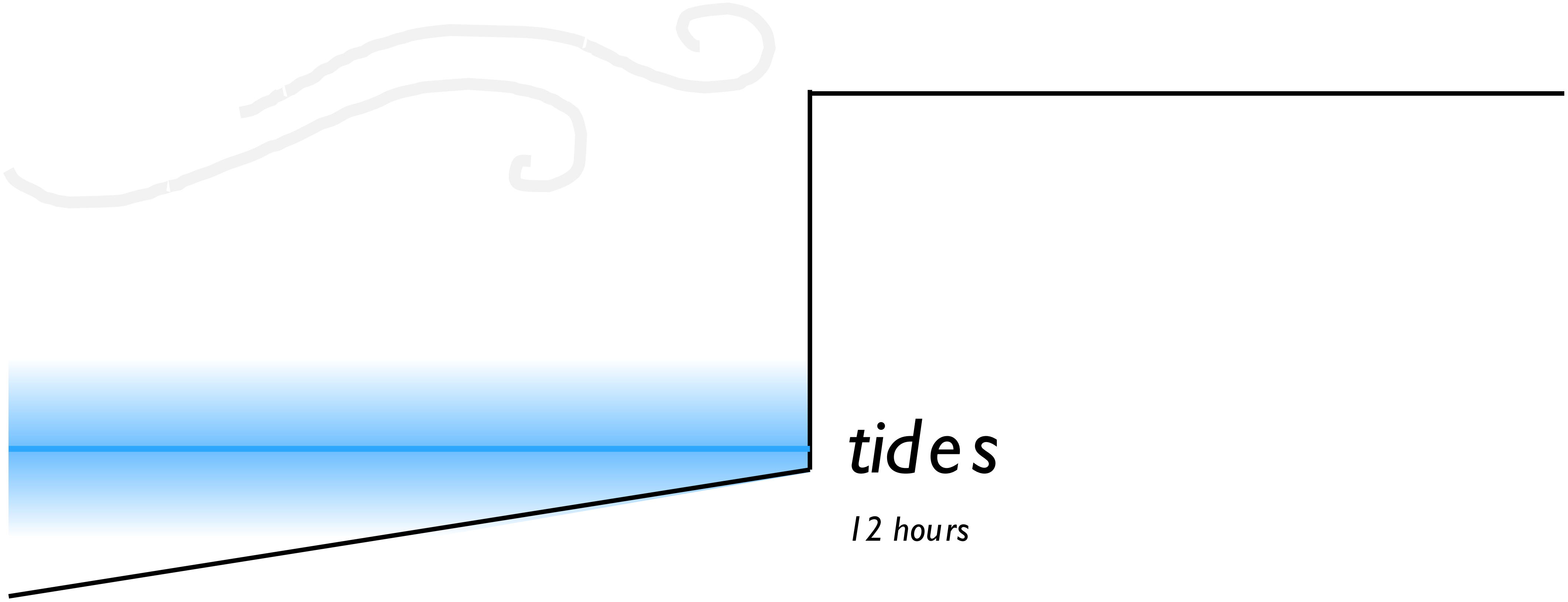


Vann Jones et al., 2013

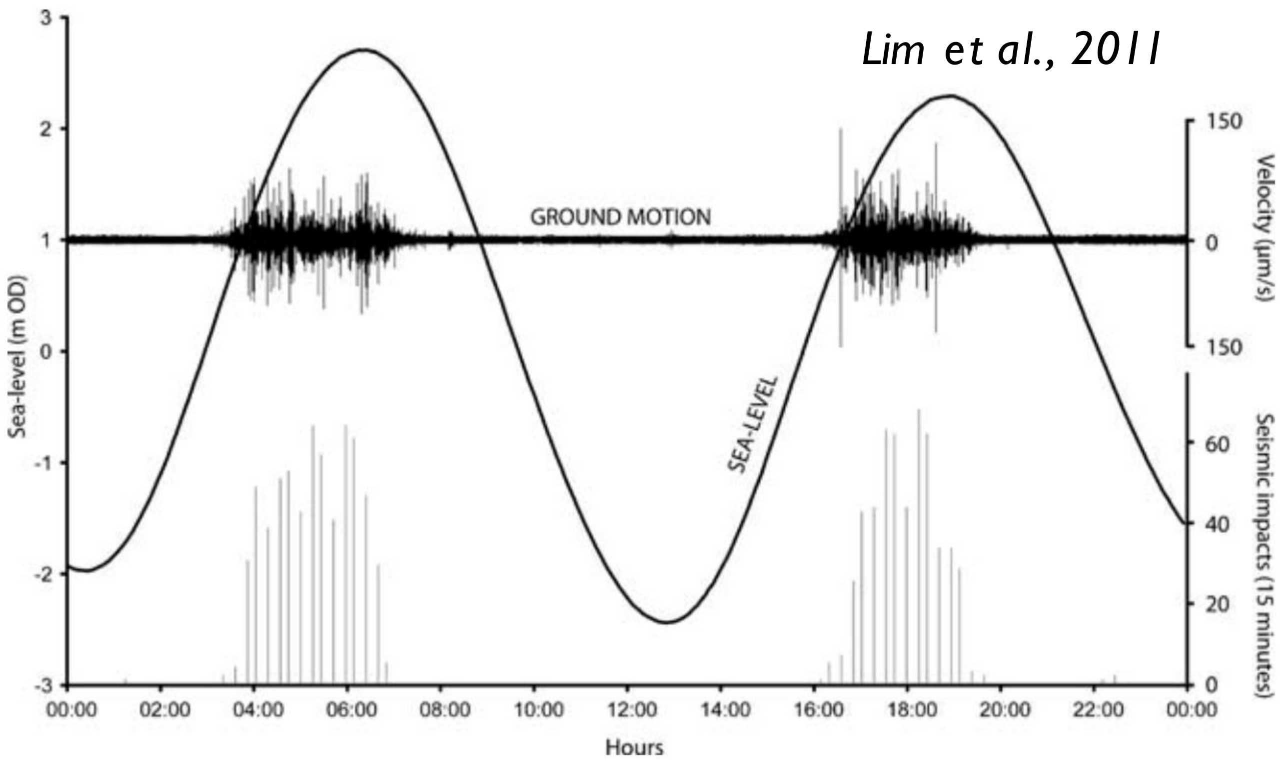


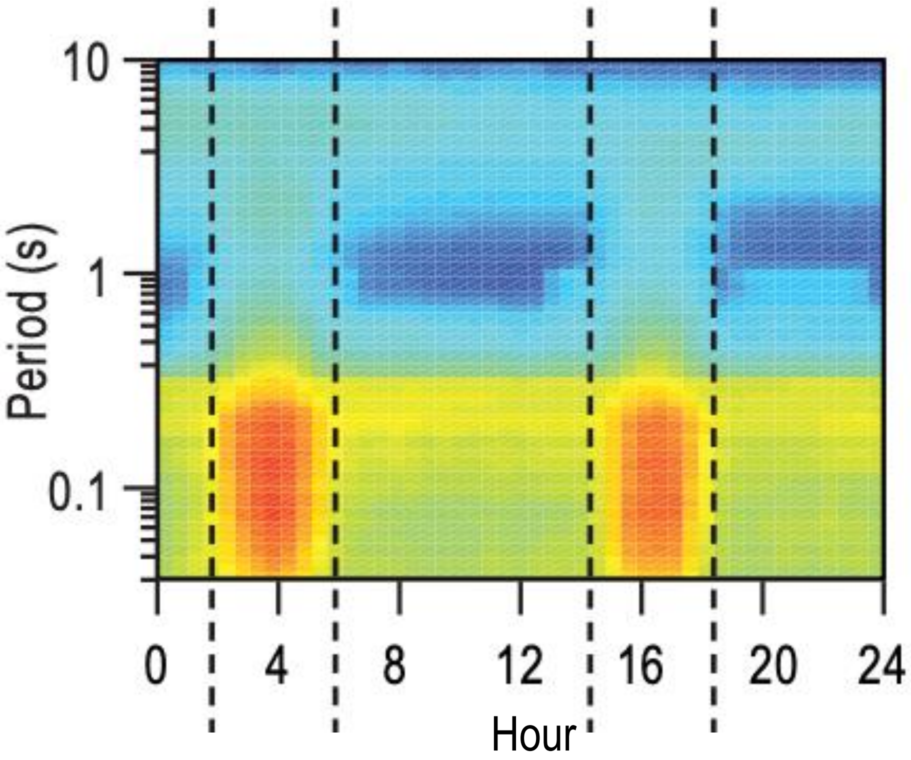
Lim et al., 2011

Seismic signals on rocky coasts



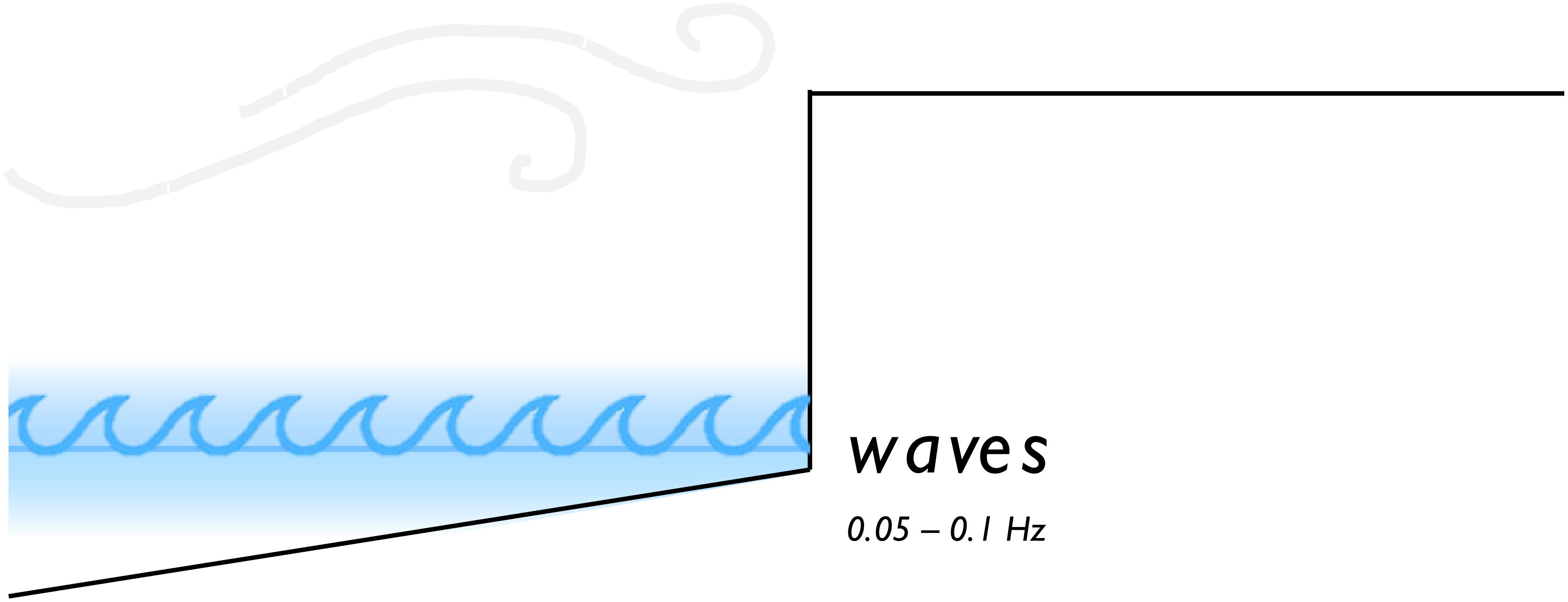
Tides amplify wave signals





- Shifts wave breaking closer to cliff face, increasing ground motion

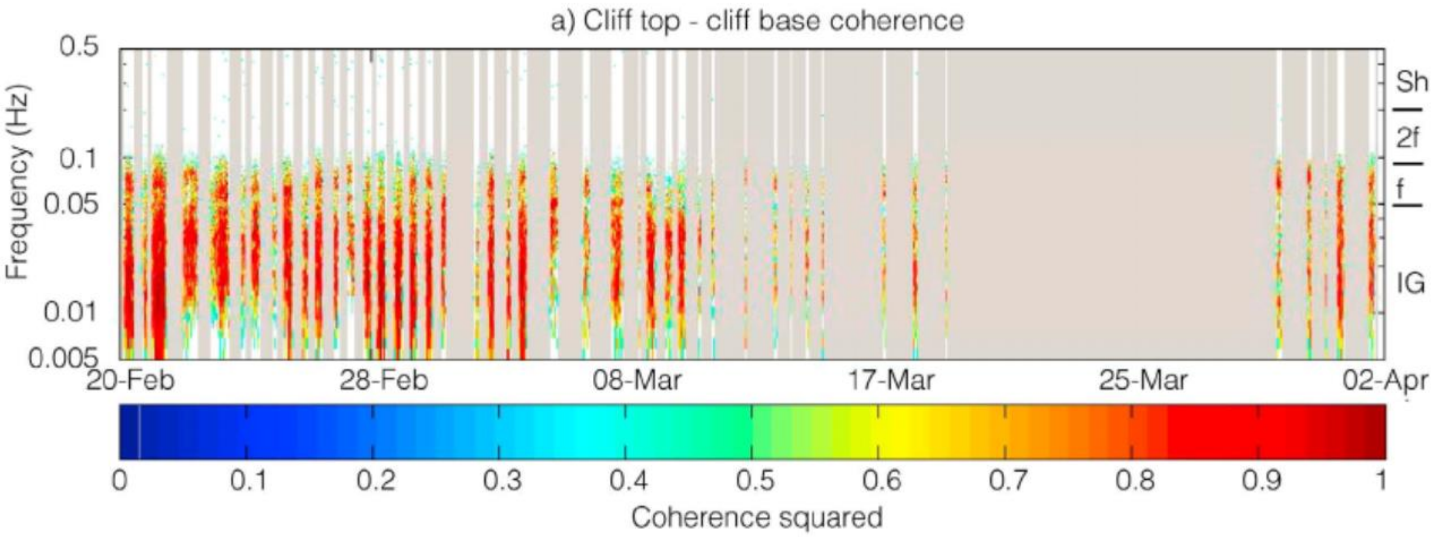
Seismic signals on rocky coasts

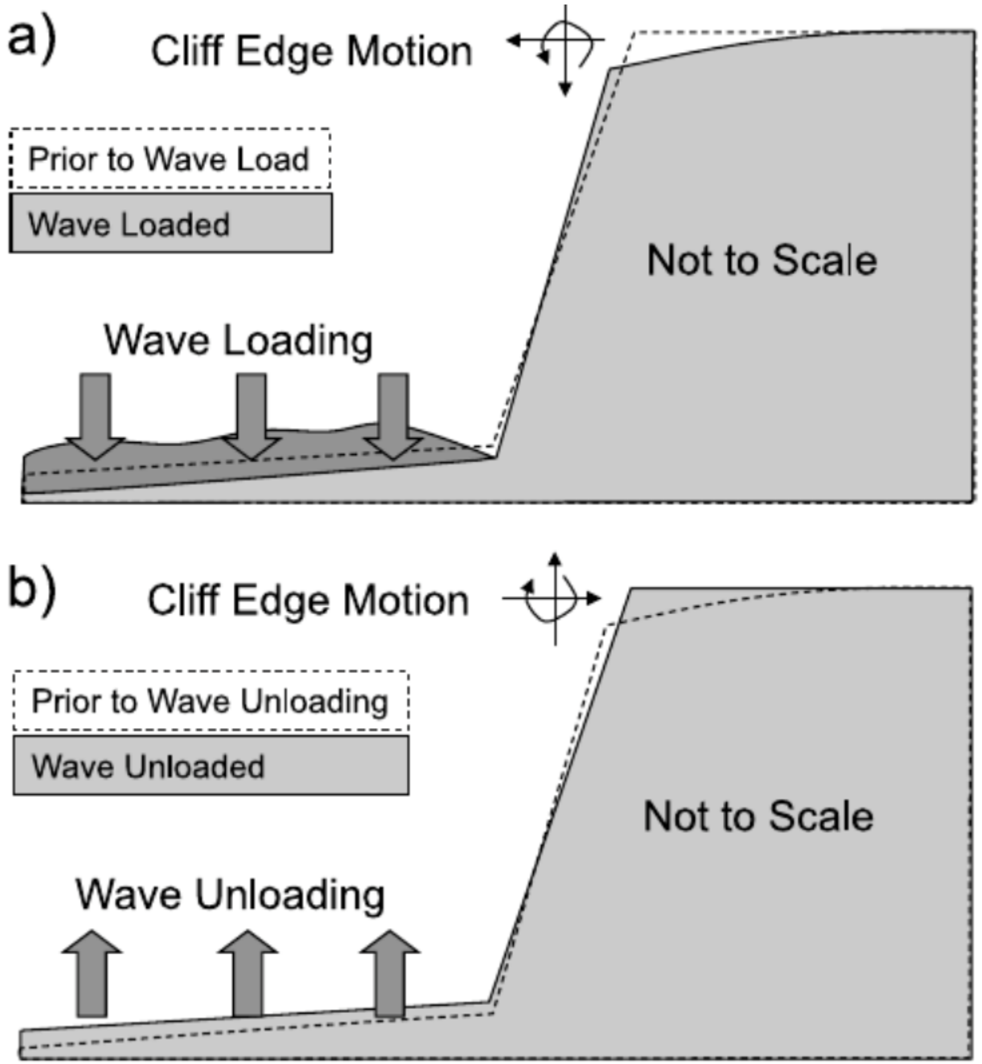


Coherent cliff “sway” with ocean swell

Loading and unloading of shore platform

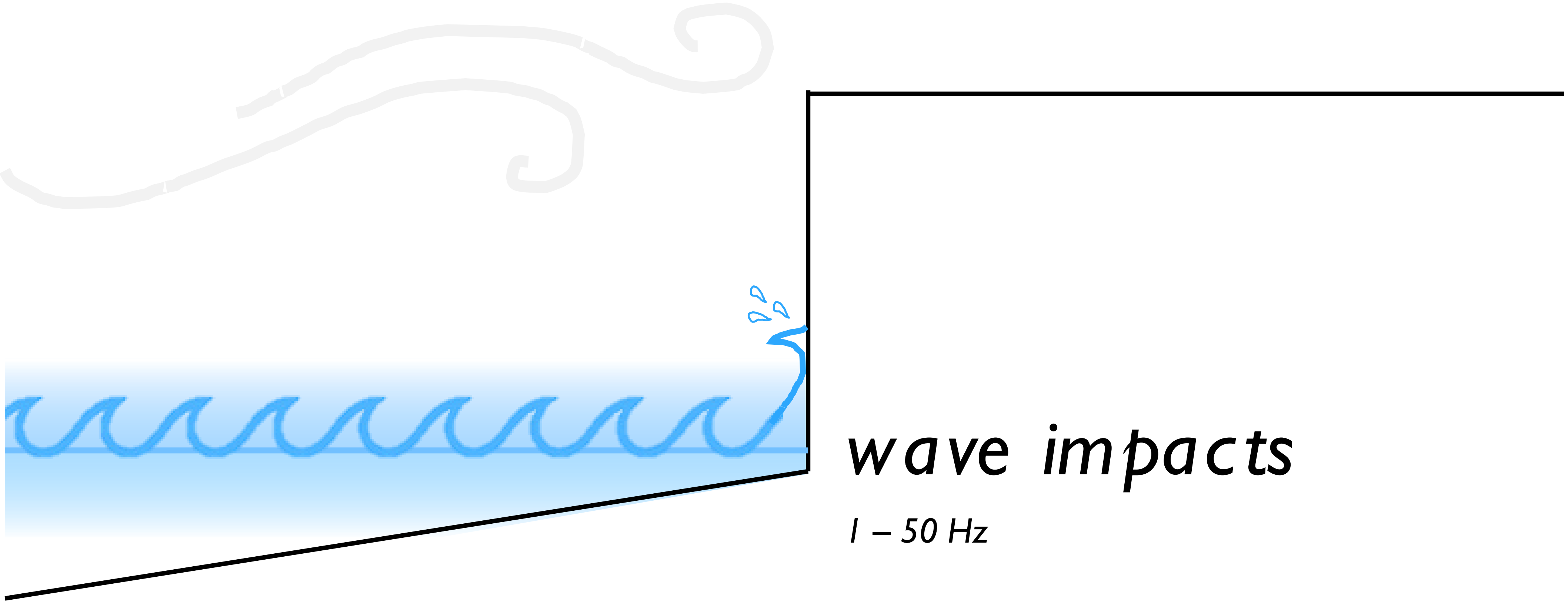
Relationship to cliff erosion remains unexplored





Young et al., 2011

Seismic signals on rocky coasts



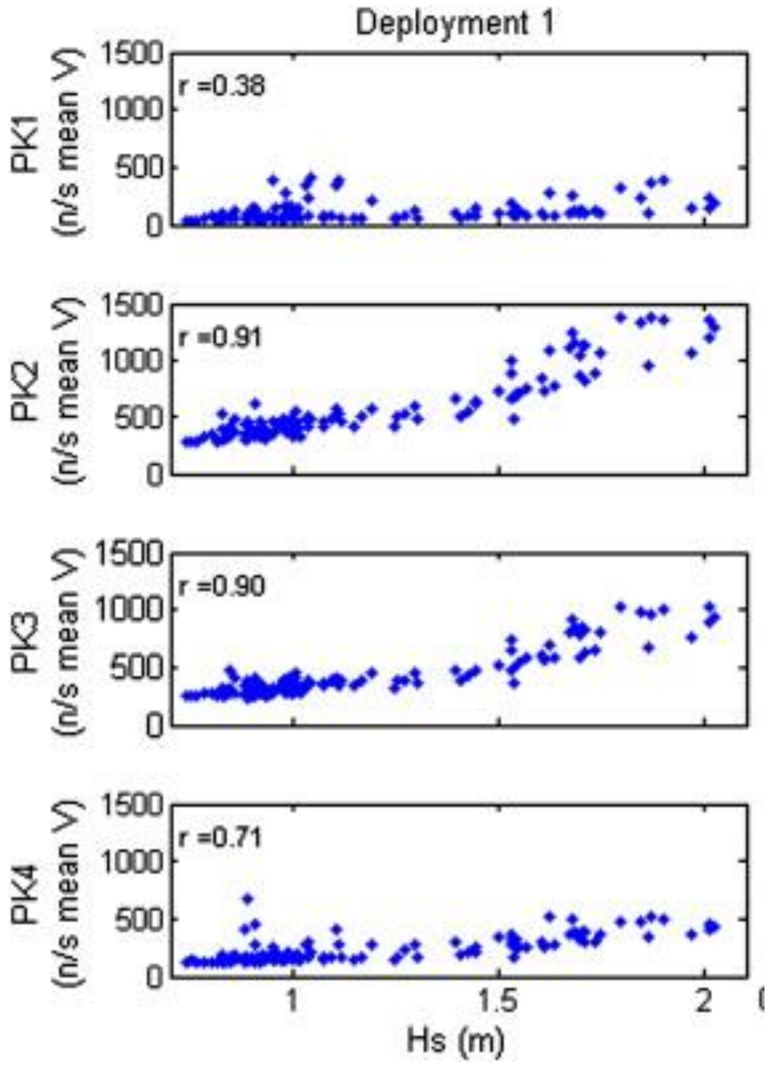
wave impacts

1 – 50 Hz

Bigger waves, more shaking

On average, ground motion correlated to significant wave height, H_s

Dickson and Pentney, 2012

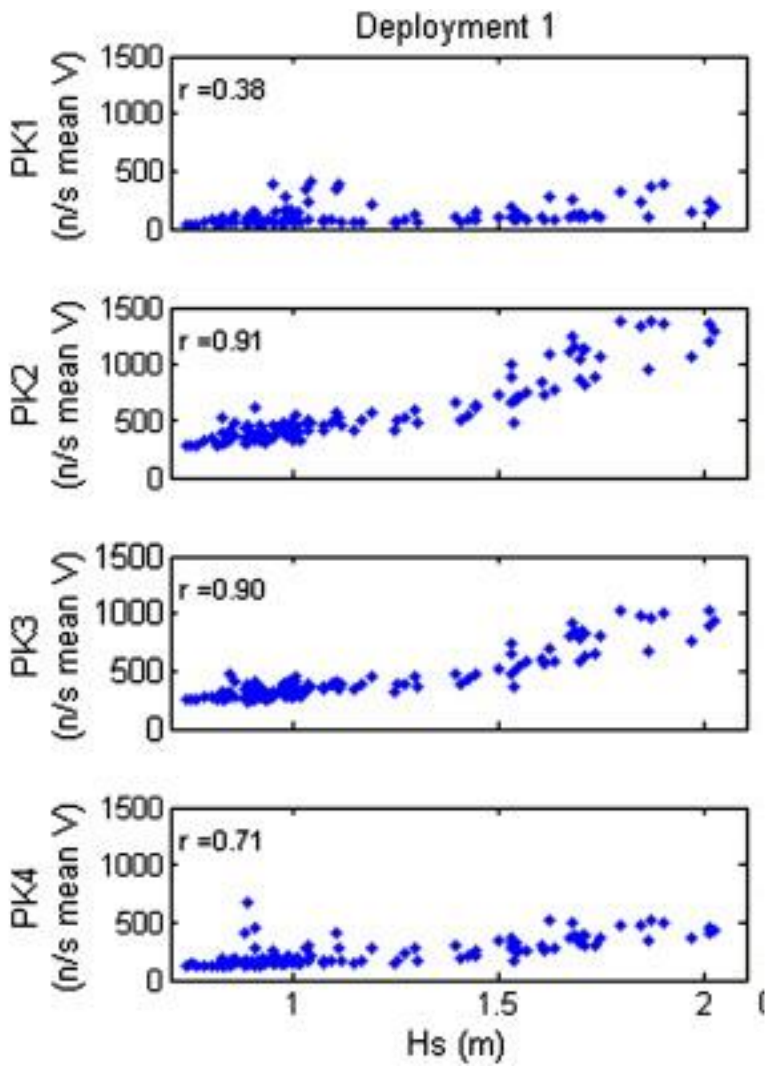


Bigger waves, more shaking...?

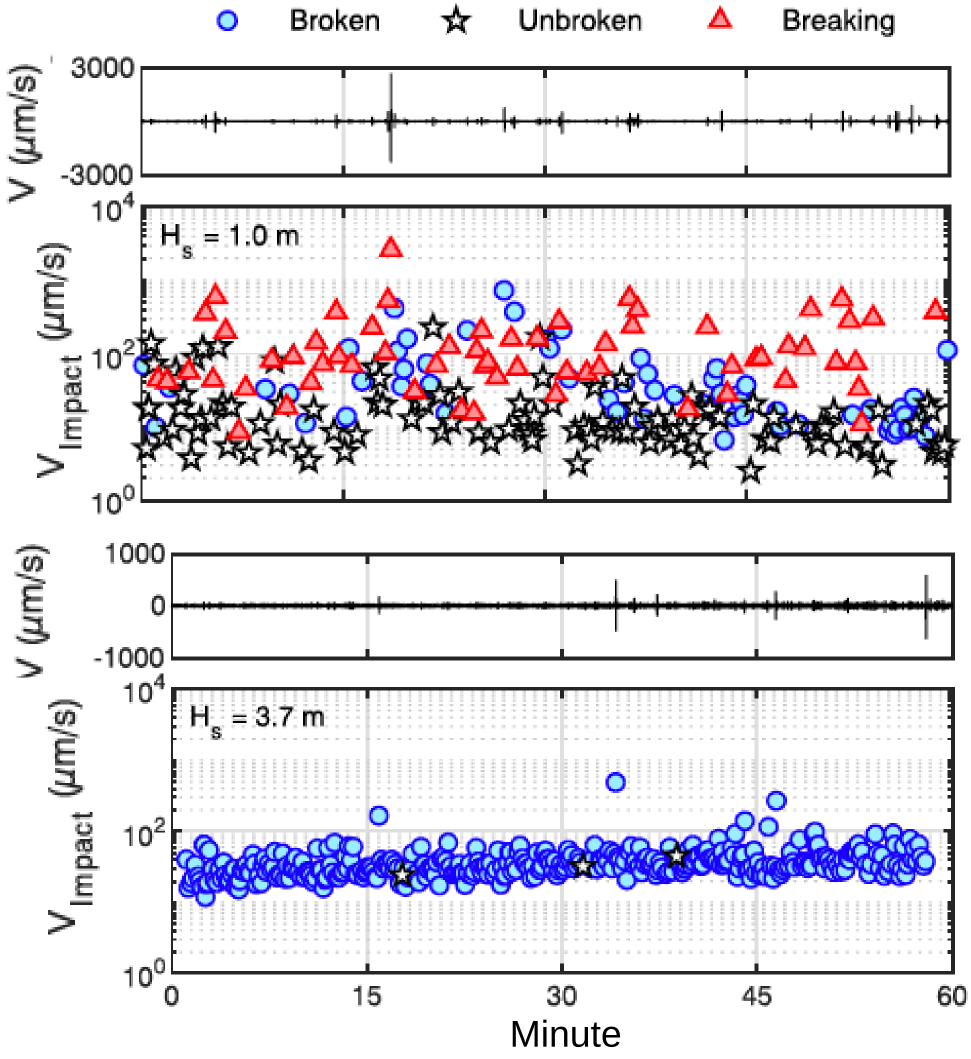
On average, ground motion correlated to significant wave height, H_s

Breaking waves have outsized effect

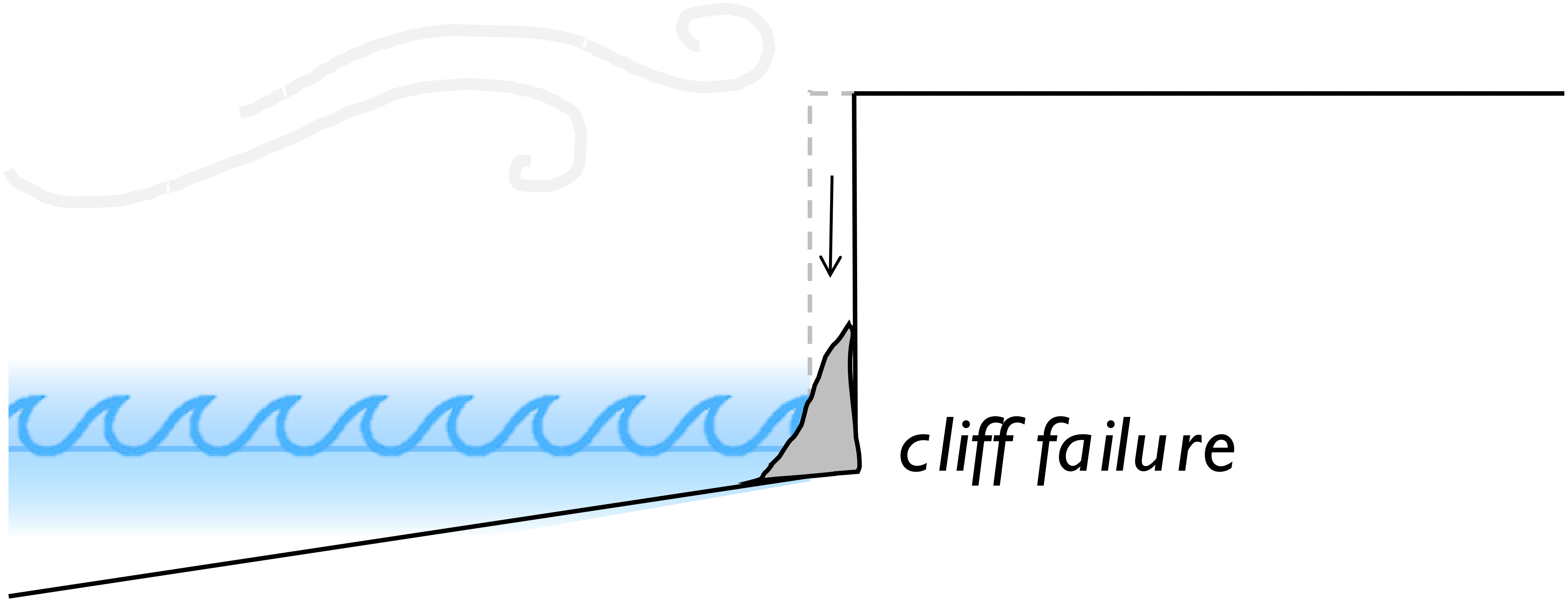
Dickson and Pentney, 2012



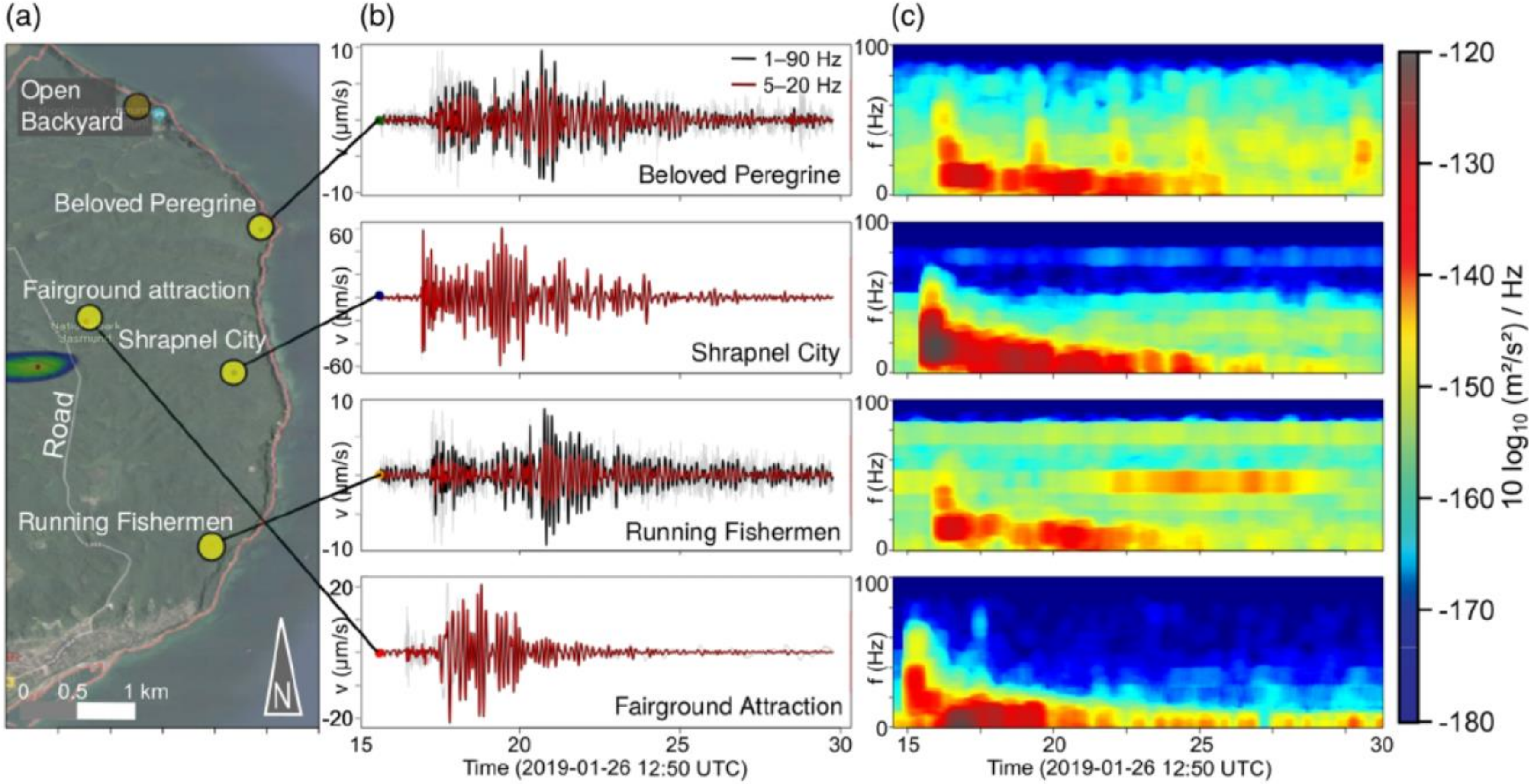
Thompson et al., 2019



Seismic signals on rocky coasts



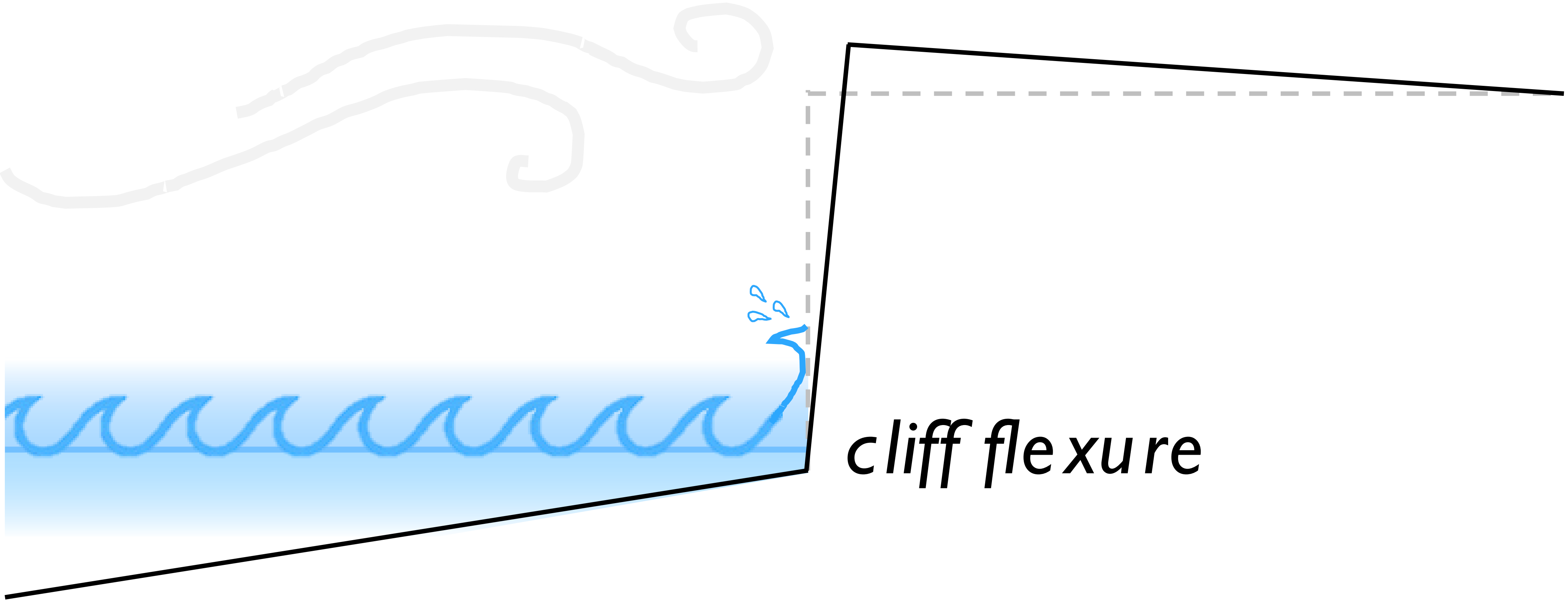
Event location and eroded volume estimation is possible, but observations are rare!



Dietze et al., 2020

Many case studies, especially in hard rocks, don't capture failure during deployment

Seismic signals on rocky coasts



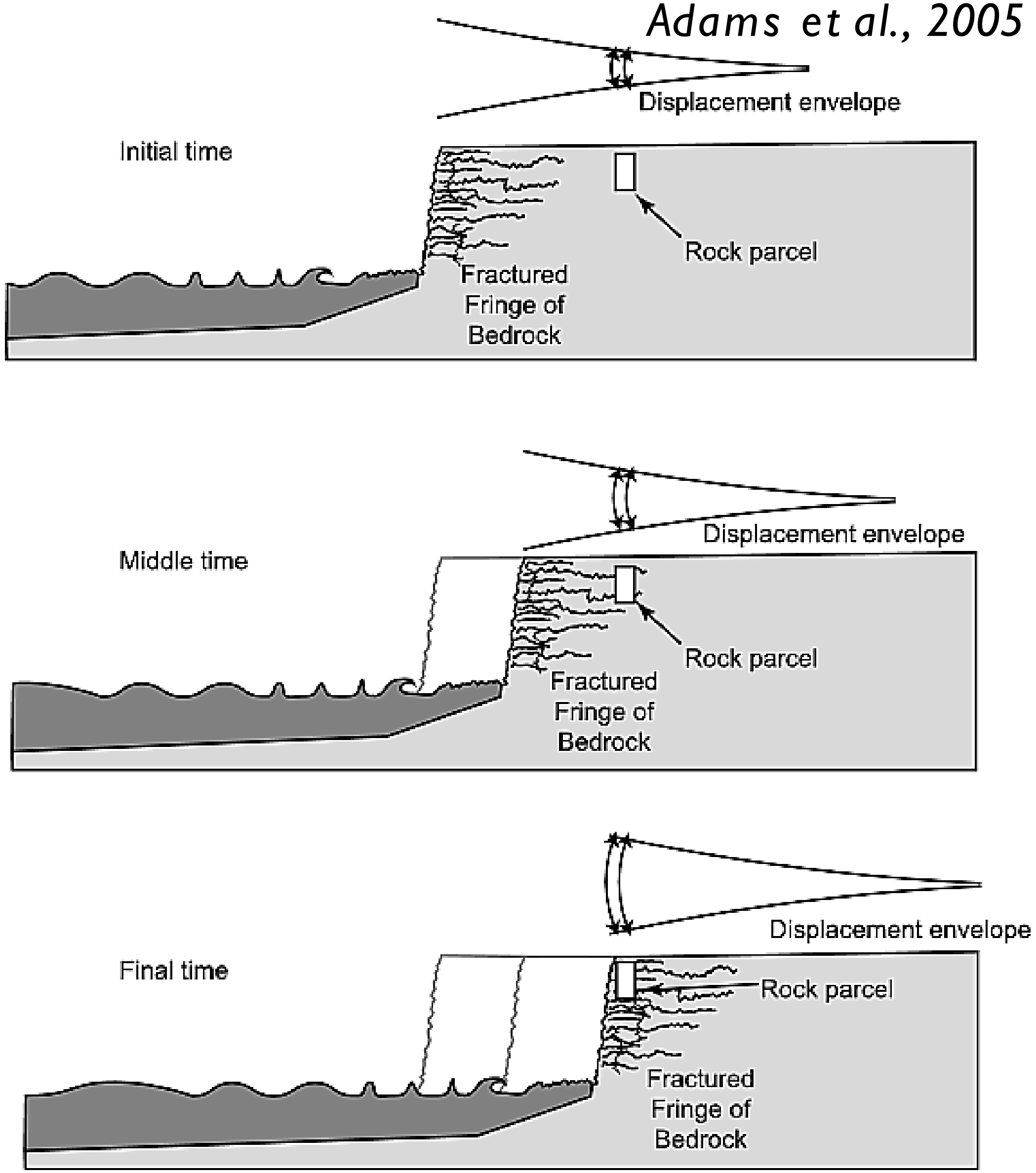
Cliff flexure primes cliffs for failure?

Adams et al., 2005

Observation: Ground motion decays with distance landward

Adams (2005) Hypothesis: Repeated cliff flexure drives rock damage, preconditioning rock for erosion

Important note: Observation has never been explicitly tied to rock properties



Exploring links between wave climate, cliff shaking, and potential for rock damage

Consistent sandstone lithology across sites

Ground displacement metrics extracted every hour

Paired with near-shore buoy data and bathymetry

n = # of seismic stations

Masteller et al., in prep

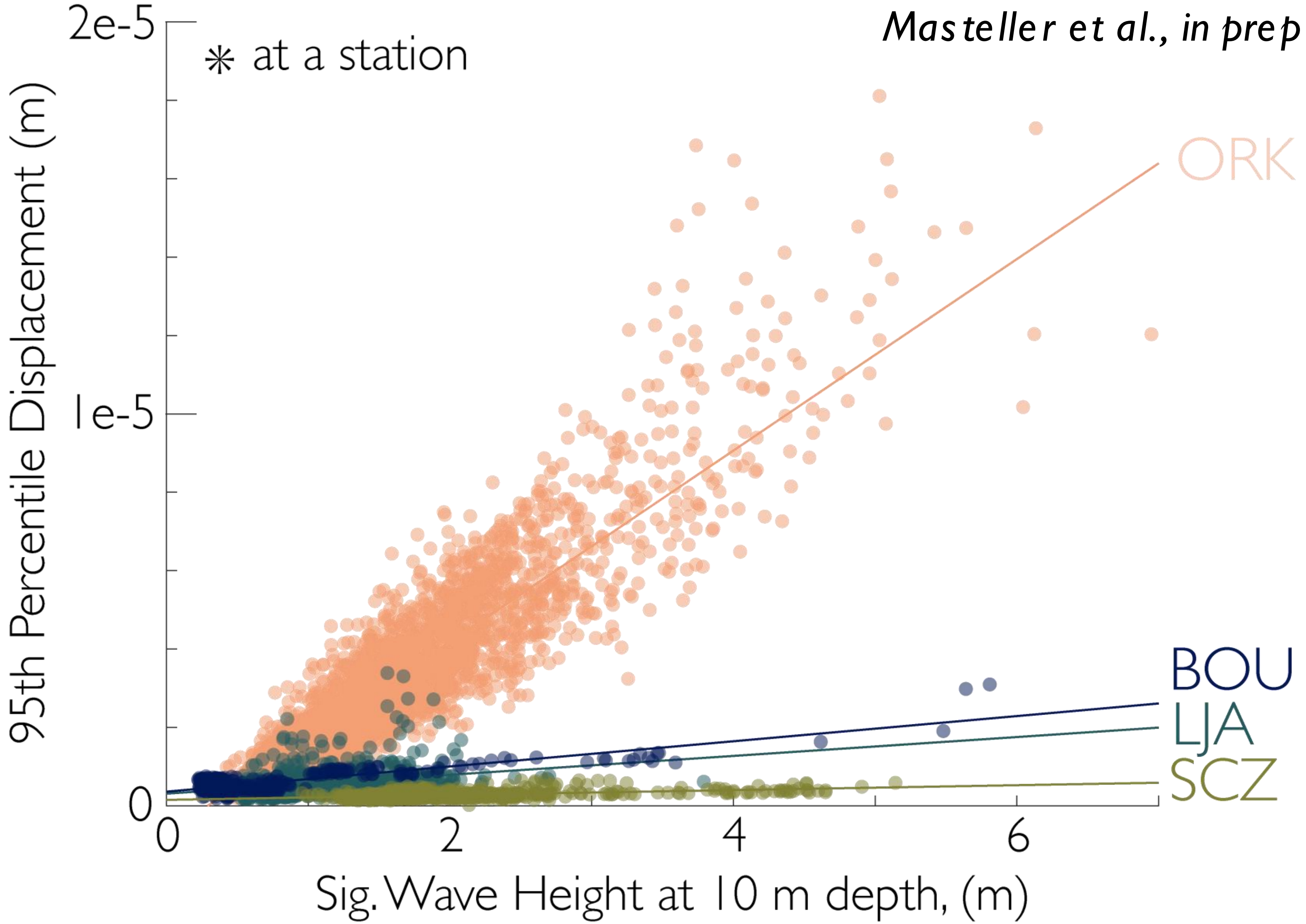
Site-specific sensitivity of ground motion to wave height

Ground displacement increases with wave magnitude in all cases

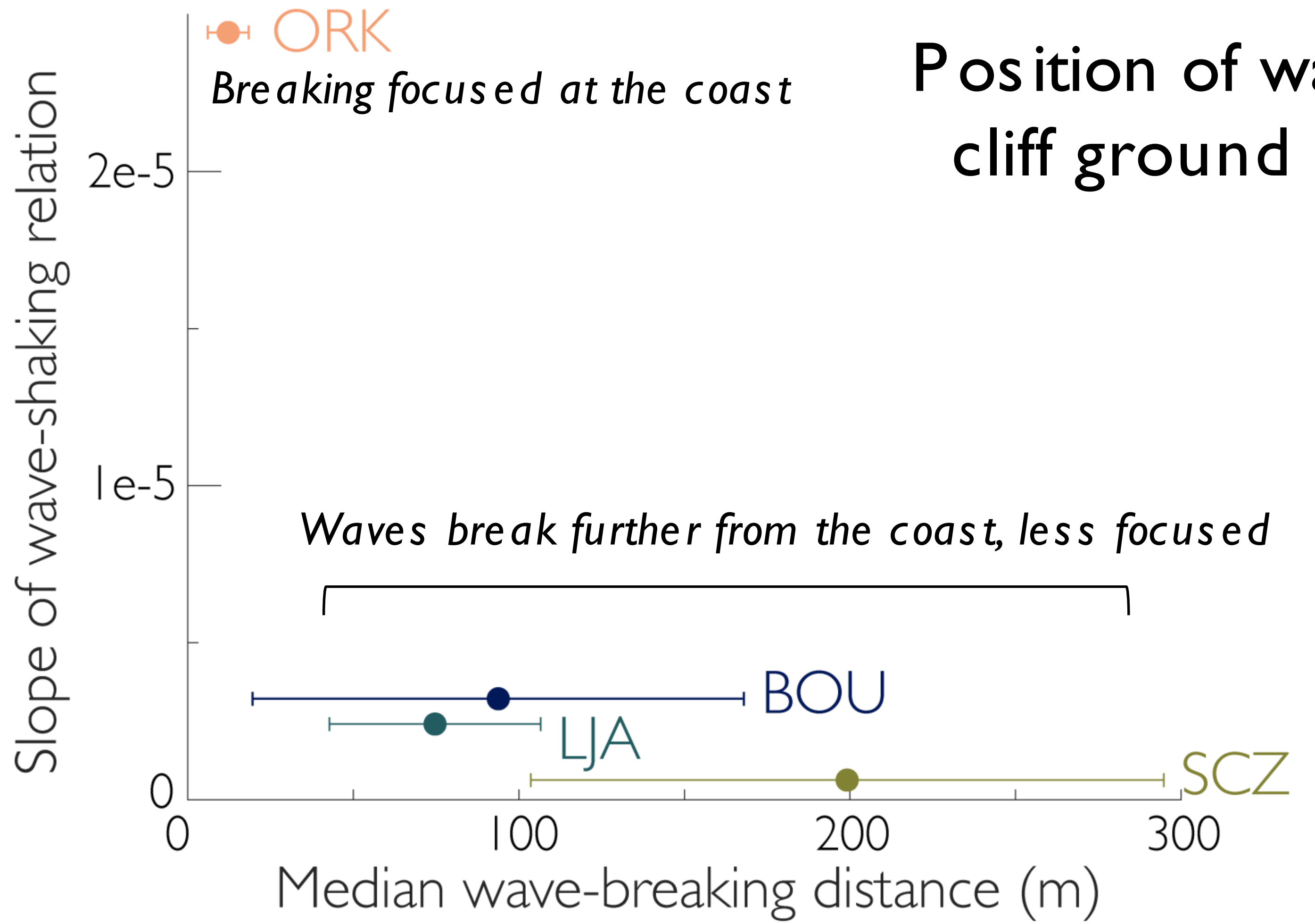
Boulby, La Jolla, and Santa Cruz all have moderate sensitivity to changing wave magnitude

Orkney site significantly <u>more sensitive</u> to changes in wave height

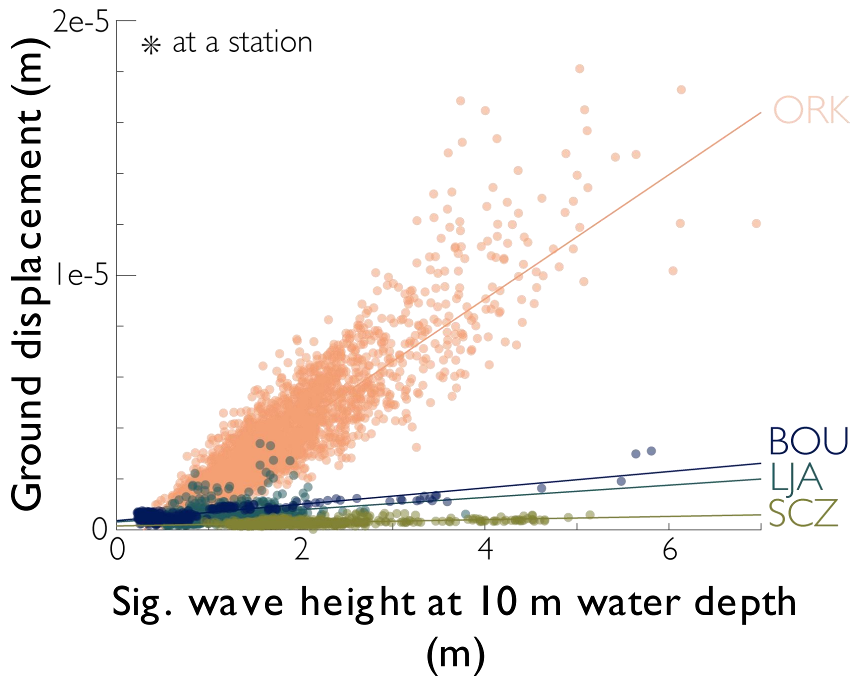
<u>Steeper</u> slopes = <u>more sensitive</u> to changes in wave height



Sensitivity to wave height variations controlled by wave breaking location



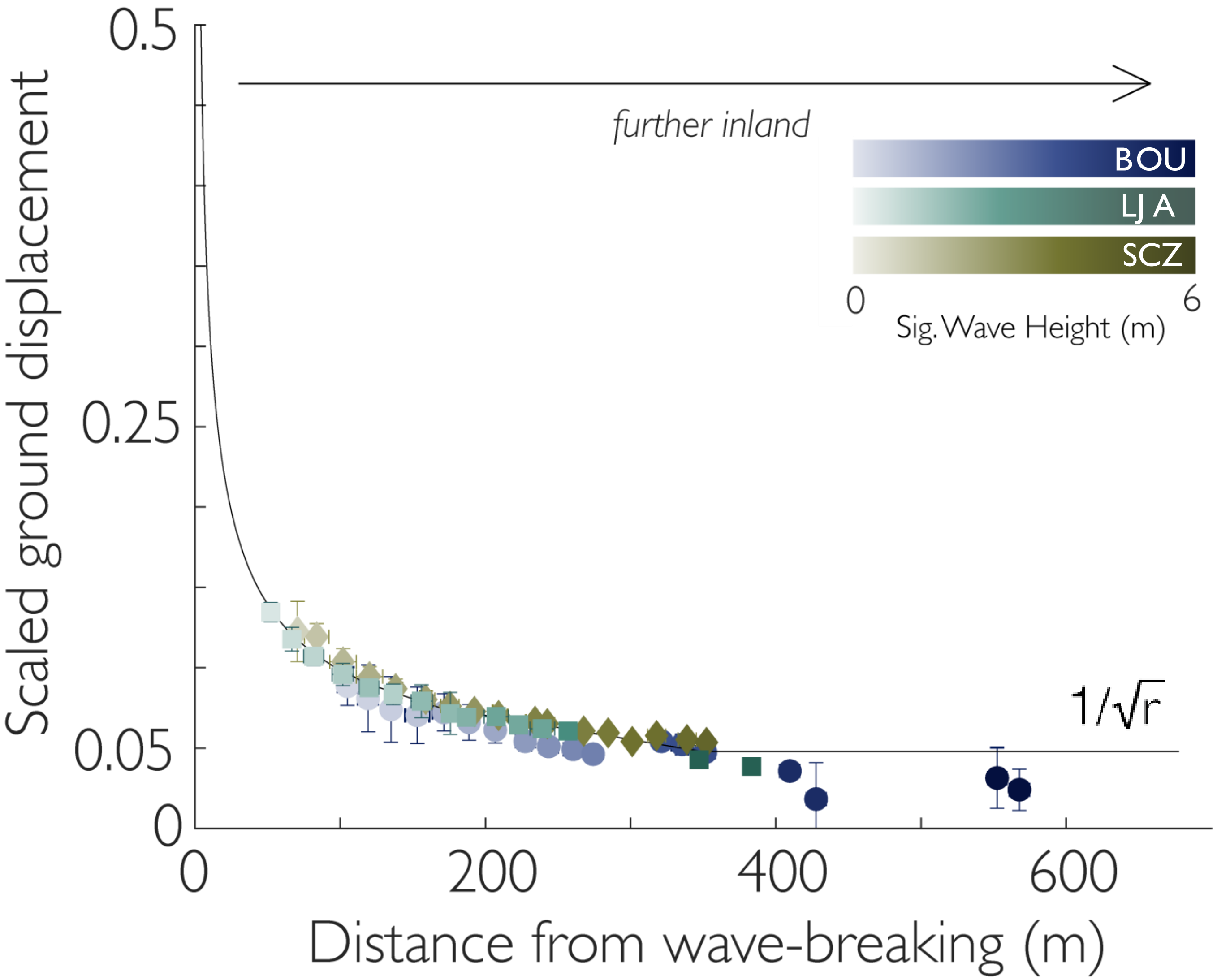
Position of wave breaking sets sensitivity of cliff ground motion to differences in wave height



Consistent patterns in ground motion attenuation across sites

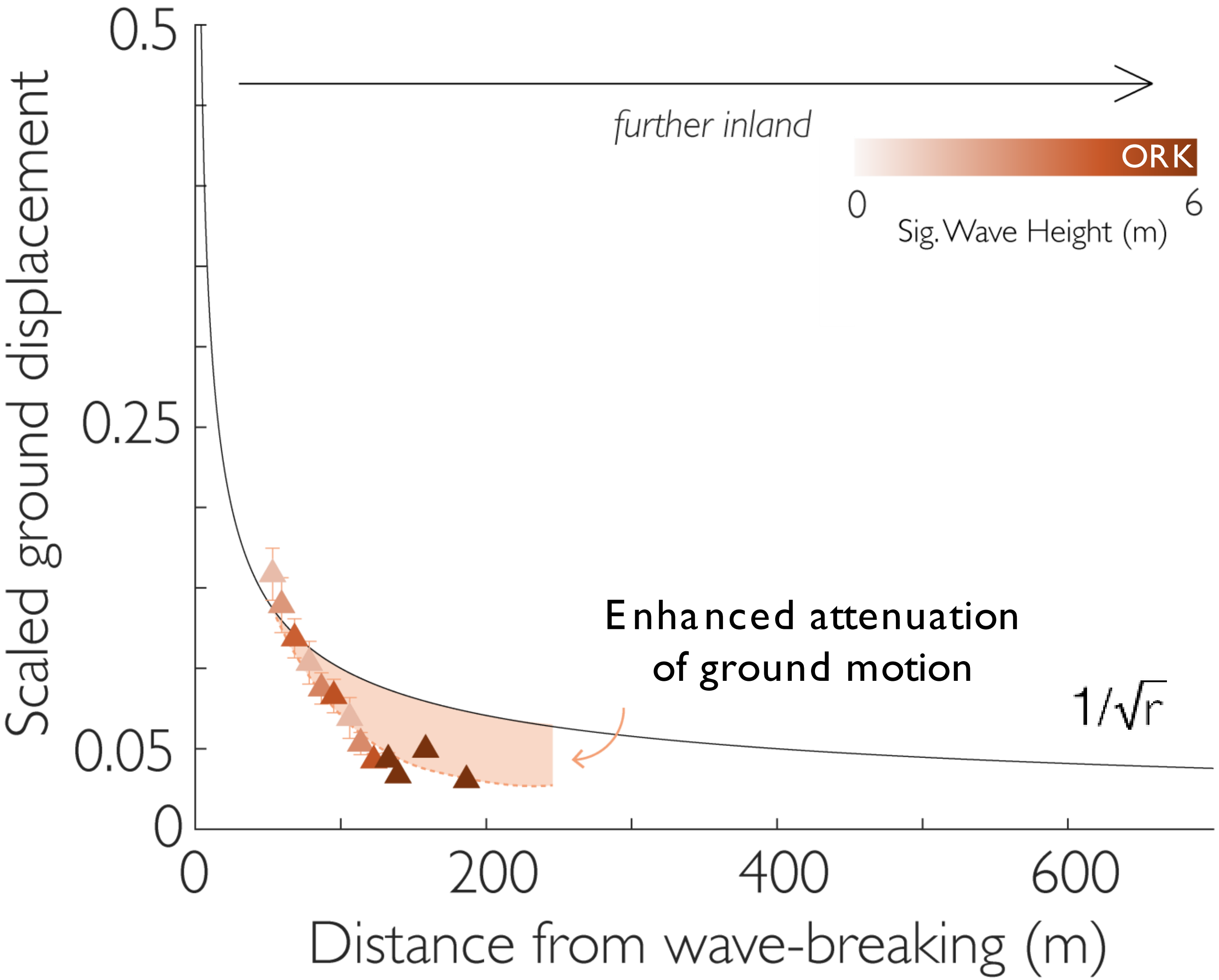
Decay in cliff shaking amplitude agrees with surface wave attenuation

Similar patterns across BOU, LJA, and SCZ



Enhanced attenuation on Orkney

Enhanced decay in seismic signal with distance inland at Orkney



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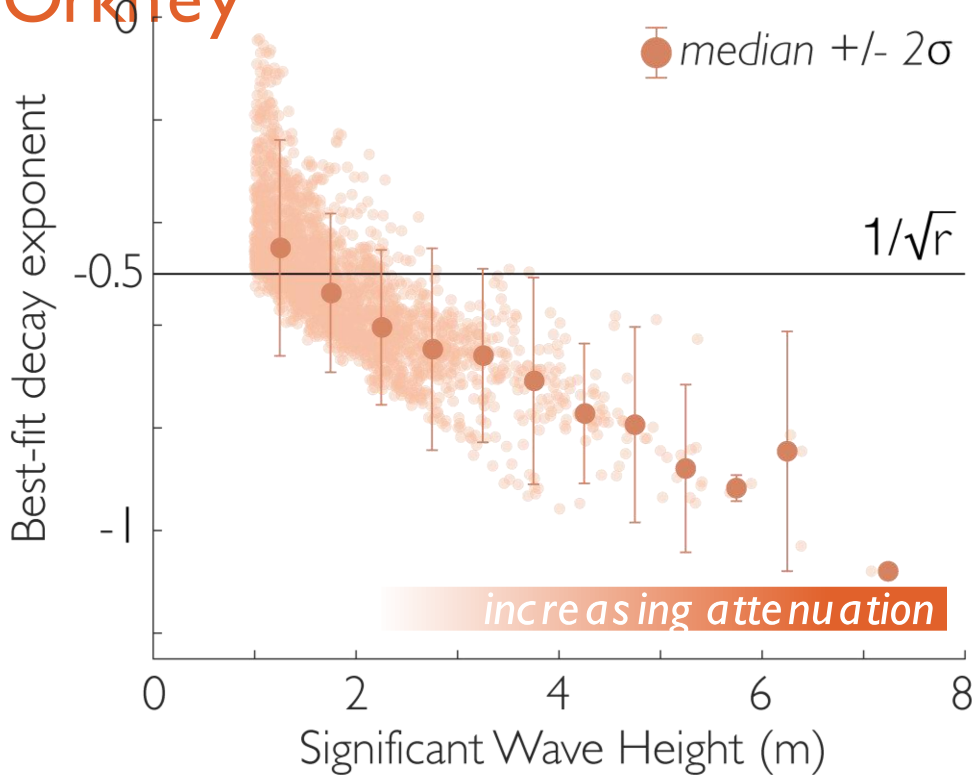
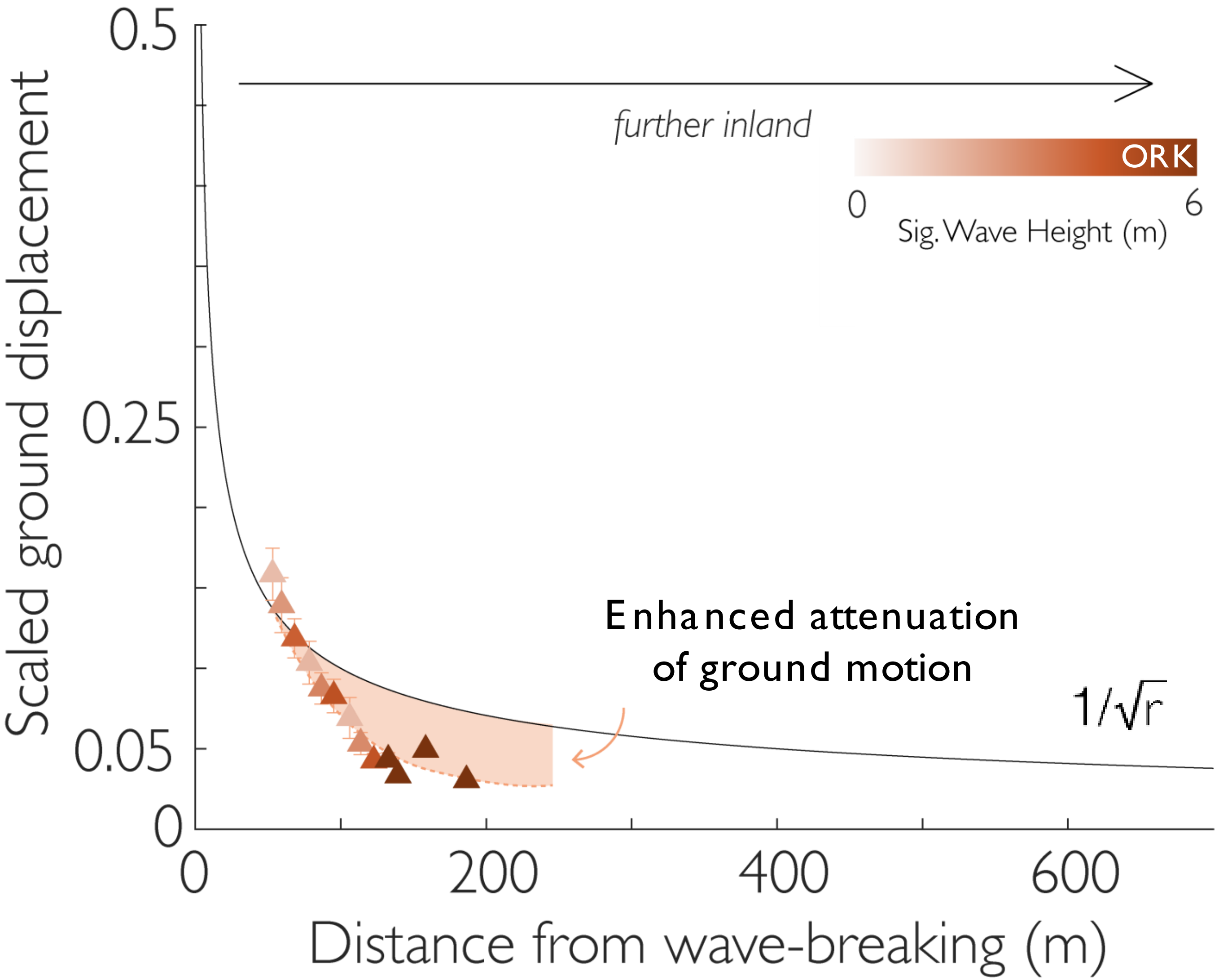


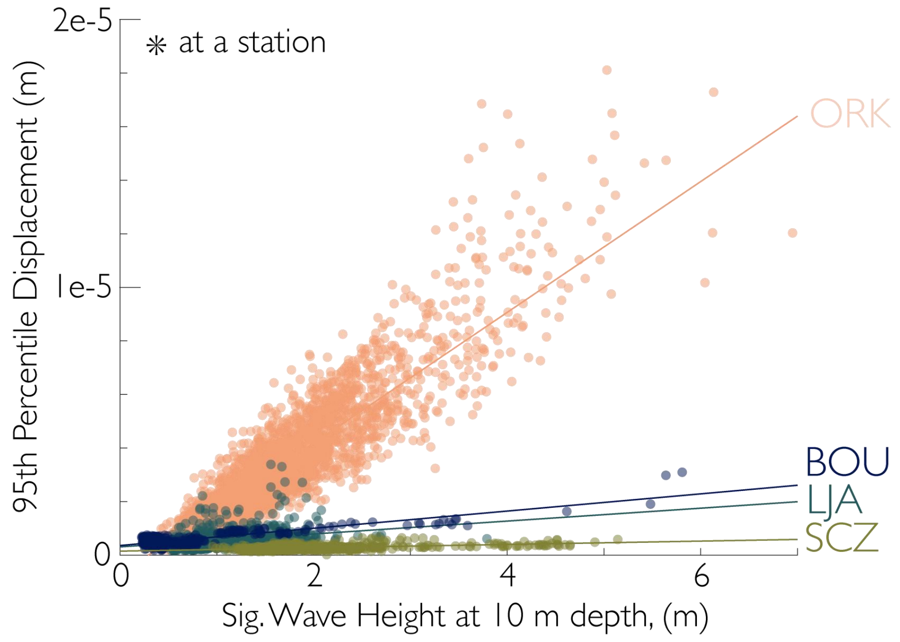


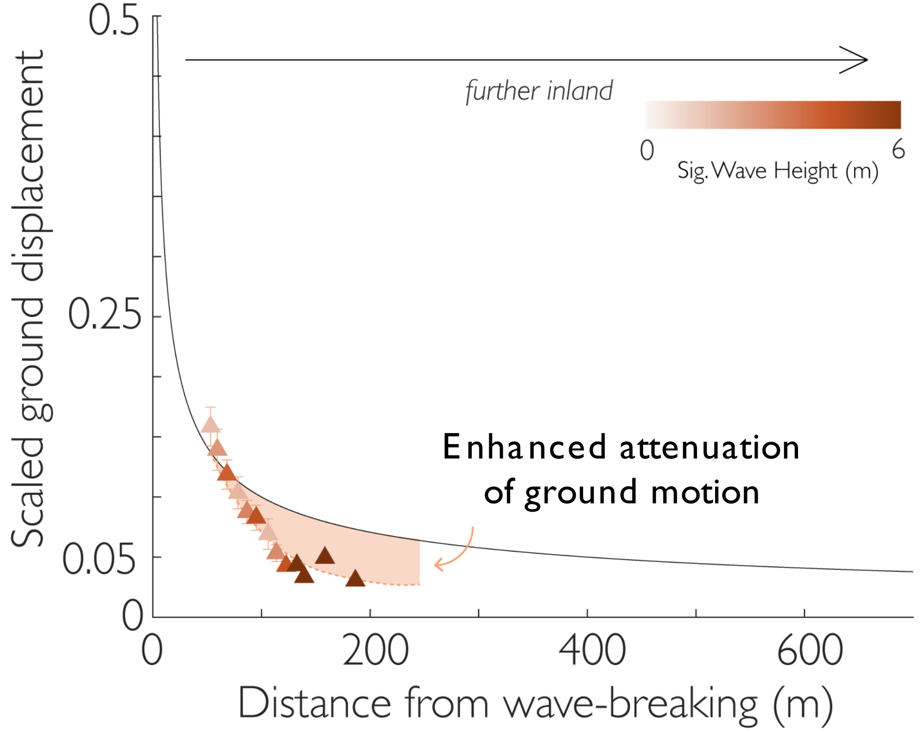
Implications for rock damage development?

Increased potential for damage on Orkney?

We're working on it!

- Further analysis of attenuation patterns
- Active seismic study to interrogate possible damage layer
- Ambient noise techniques to explore temporal changes in cliff properties





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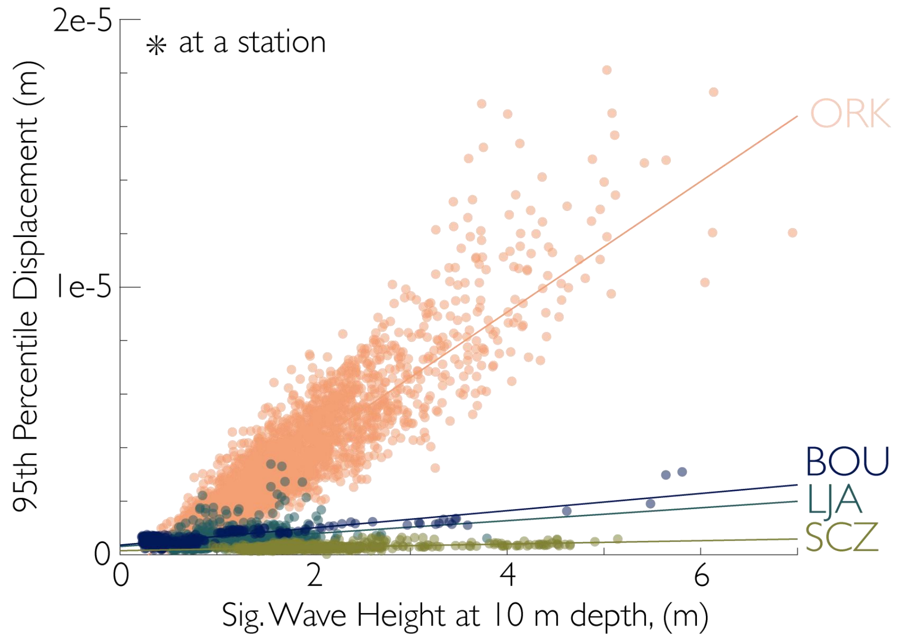
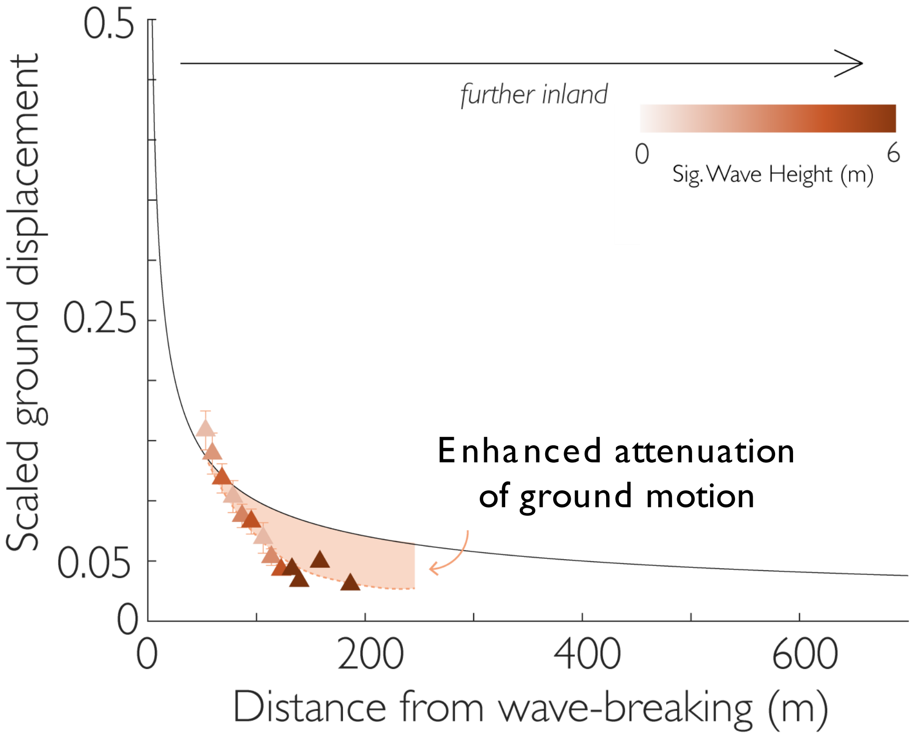
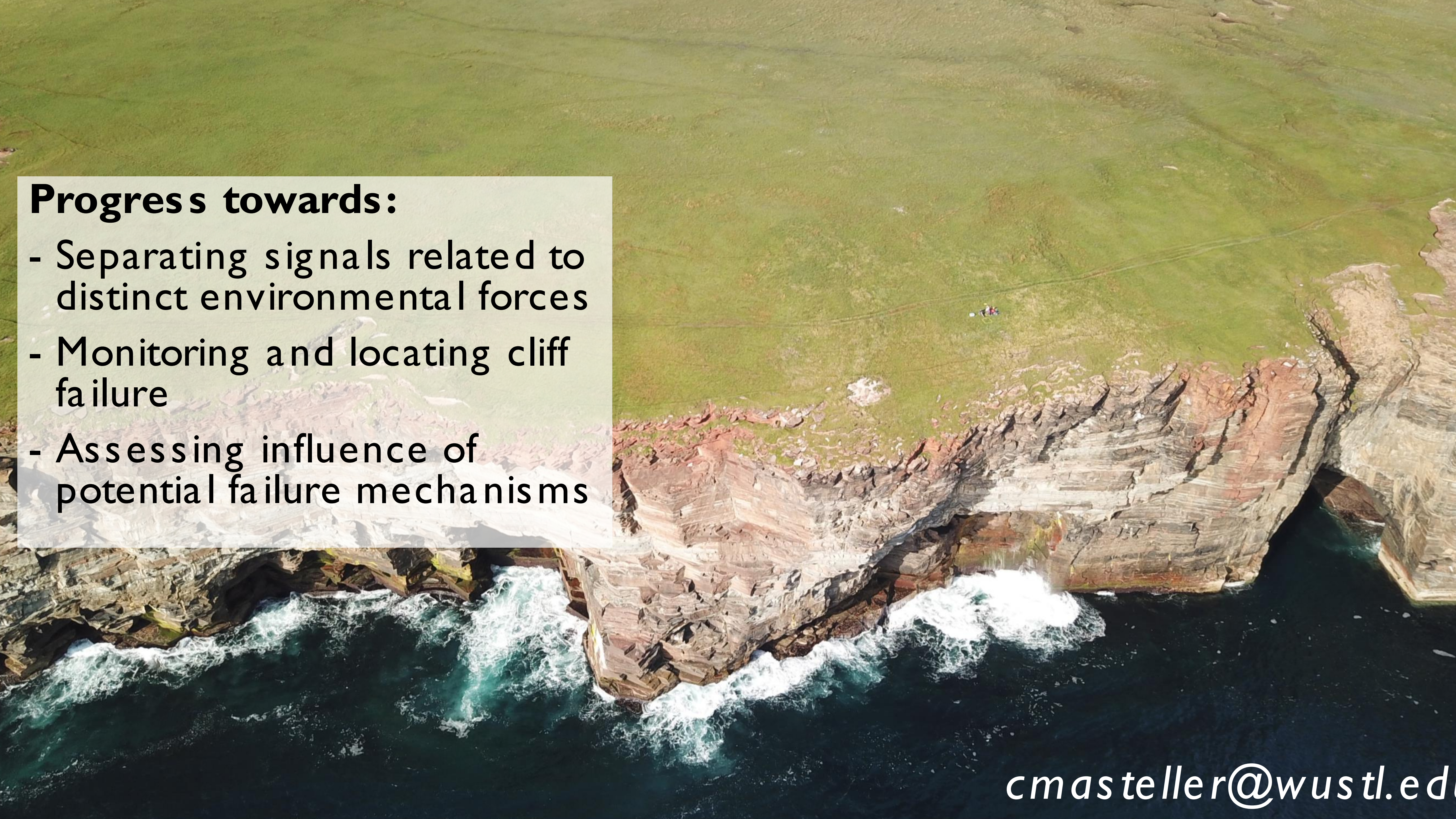
Take home: Local uplift rates and shore platform morphology set the sensitivity of rocky coastlines to variable wave action







Progress towards:

- Separating signals related to distinct environmental forces
- Monitoring and locating cliff failure
- Assessing influence of potential failure mechanisms

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Outstanding challenges:

- Link between environmental forcing and cliff erosion rates
- Limited interrogation of influence and evolution of cliff material properties
- Limited focus on identifying precursors to cliff failure

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Operational challenges and limitations:

- Small number of datasets w/ variable setups
- "Noisy" environments
- Directional sources
- Failure is rare, erosion hard to measure

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