How can seismological observations inform us about physical processes across the scales?

Prof. Dr. Céline Hadziioannou
Institute for Geophysics, University of Hamburg

What is Seismology?

Venezuela – 21.08.2018 (Magnitude 7.3)

What is Seismology?

Japan – 11.03.2011 (Magnitude 9.1)

What is Seismology?

Italien – 23.08.2016 (Magnitude 6.2)

What about seismology without the earthquakes?

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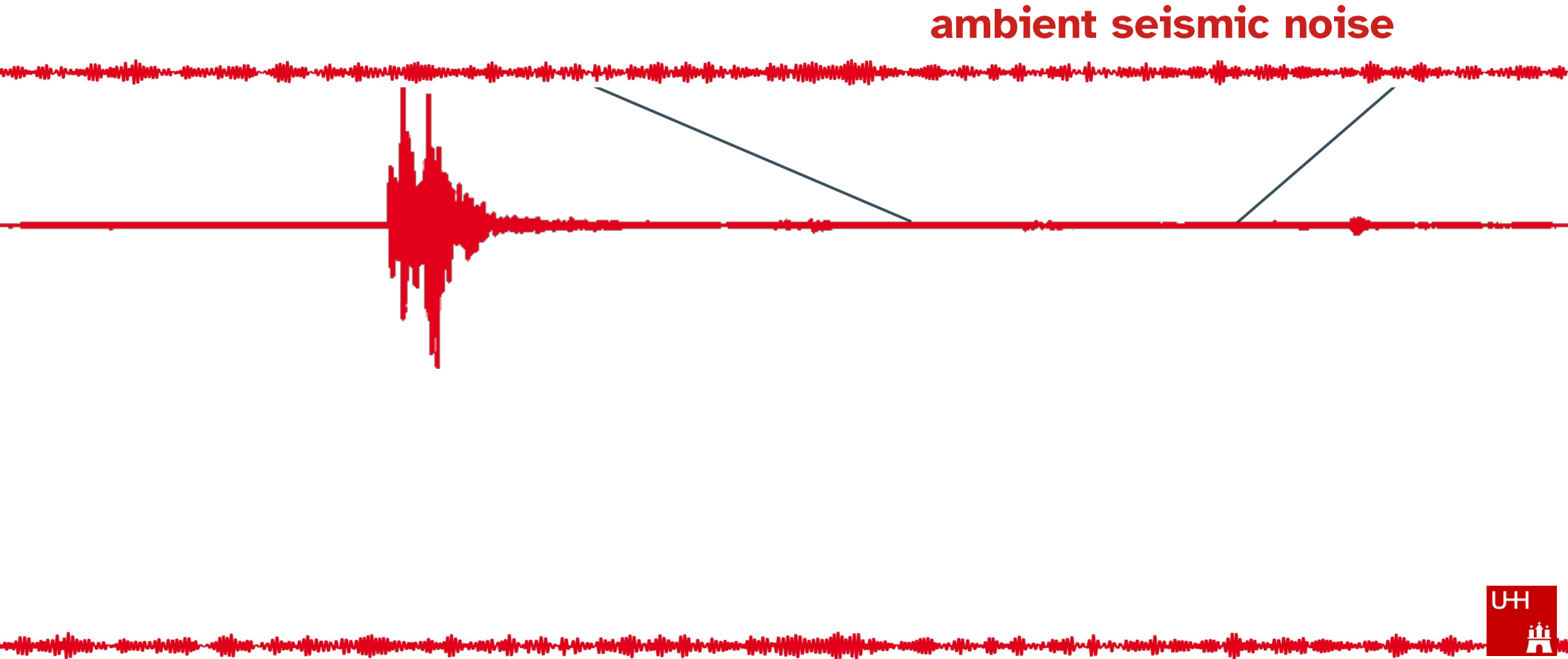

What can we learn about the Earth by **listening** to ambient seismic noise?

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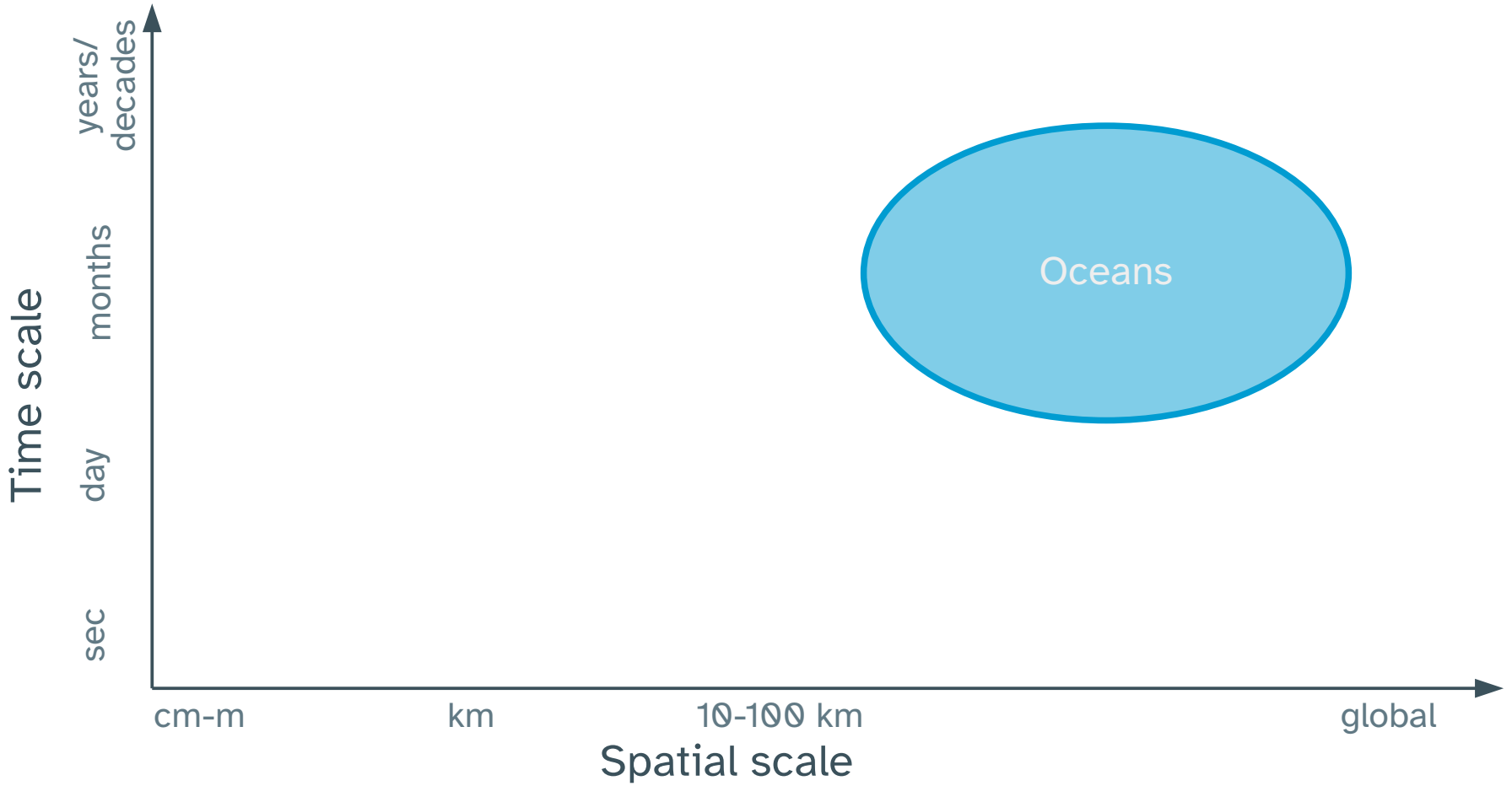
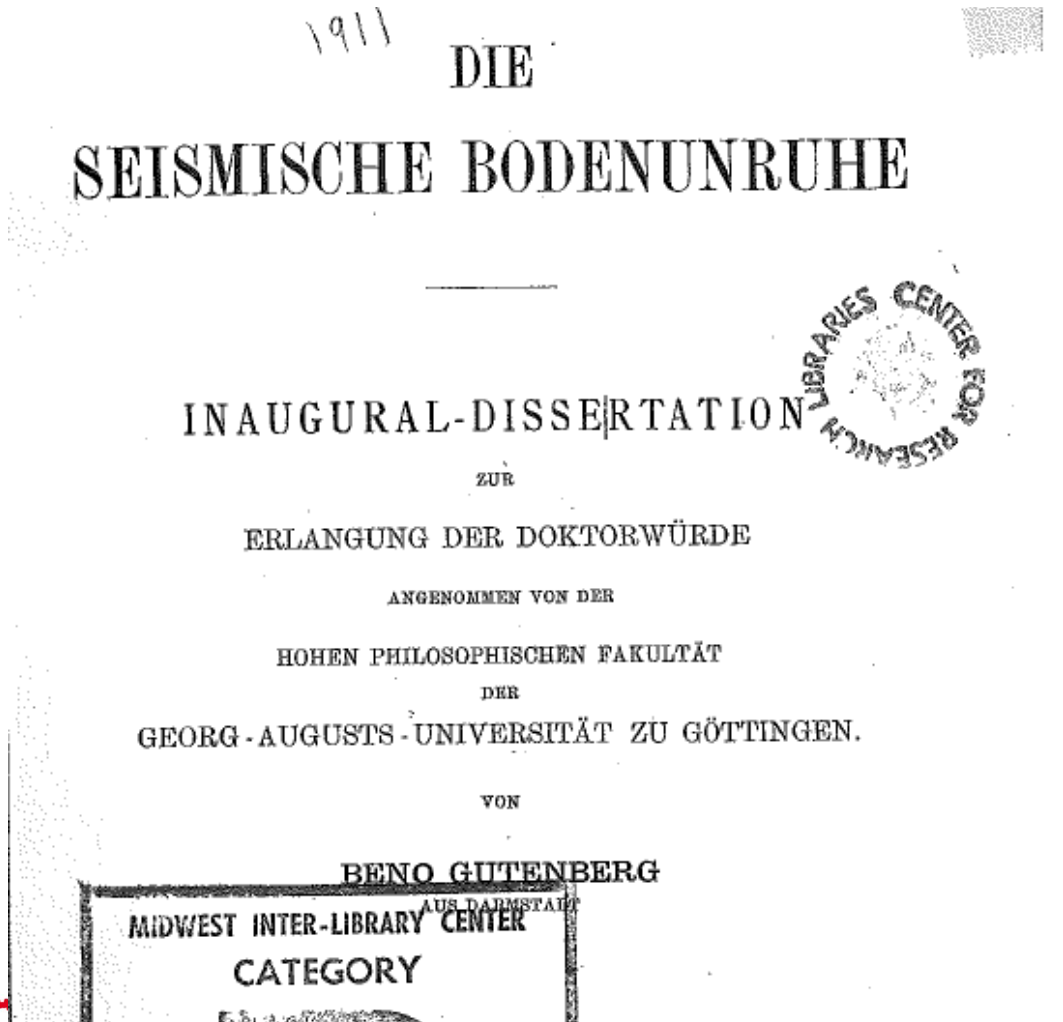


Beno Gutenberg‘s PhD thesis, 1911



1911

DIE

SEISMISCHE BODENUNRUHE

INAUGURAL-DISSERTATION

ZUR

ERLANGUNG DER DOKTORWÜRDE

ANGENOMMEN VON DER

HOHEN PHILOSOPHISCHEN FAKULTÄT

DER

GEORG-AUGUSTS-UNIVERSITÄT ZU GÖTTINGEN.

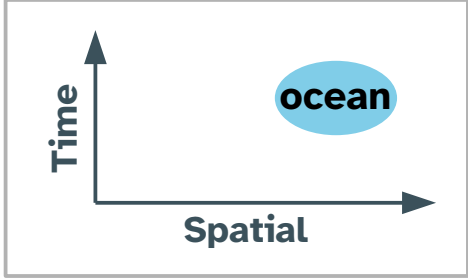
VON

BENO GUTENBERG

AUS DARMSTADT

“Schon bald nach Einführung der Seismographen wurde man auf Bewegungen aufmerksam, die sich durch völlig andere Art und durch ihre längere Dauer von den Bewegungen bei den eigentlichen Erdbeben unterschieden, und die man als “*Pulsationen*” bezeichnete.”

How is noise generated / where is it coming from?



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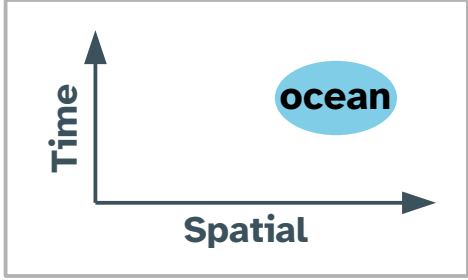
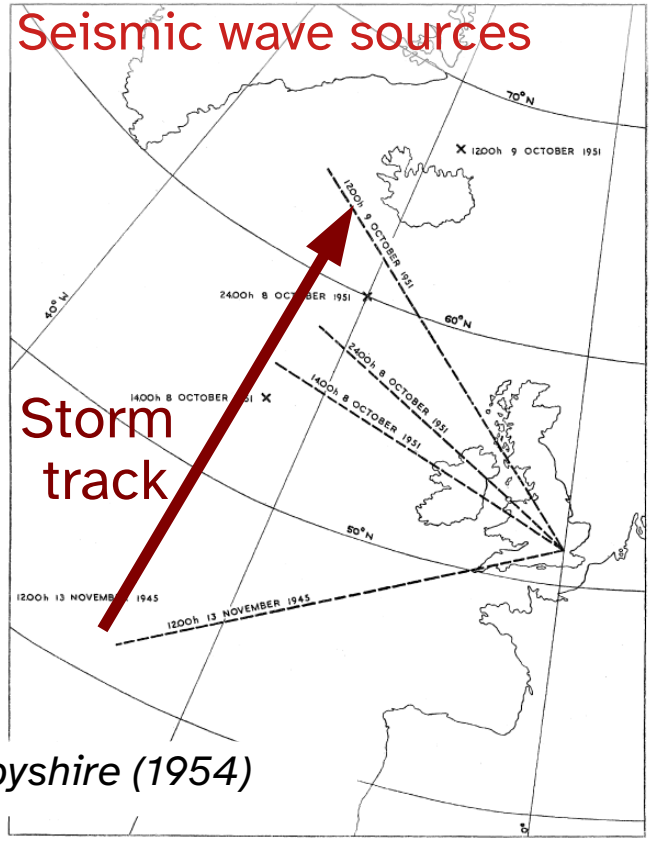


Observations

Seismic wave sources



Darbyshire (1954)

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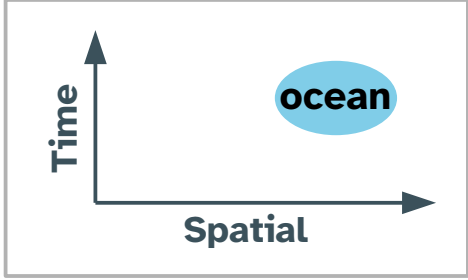

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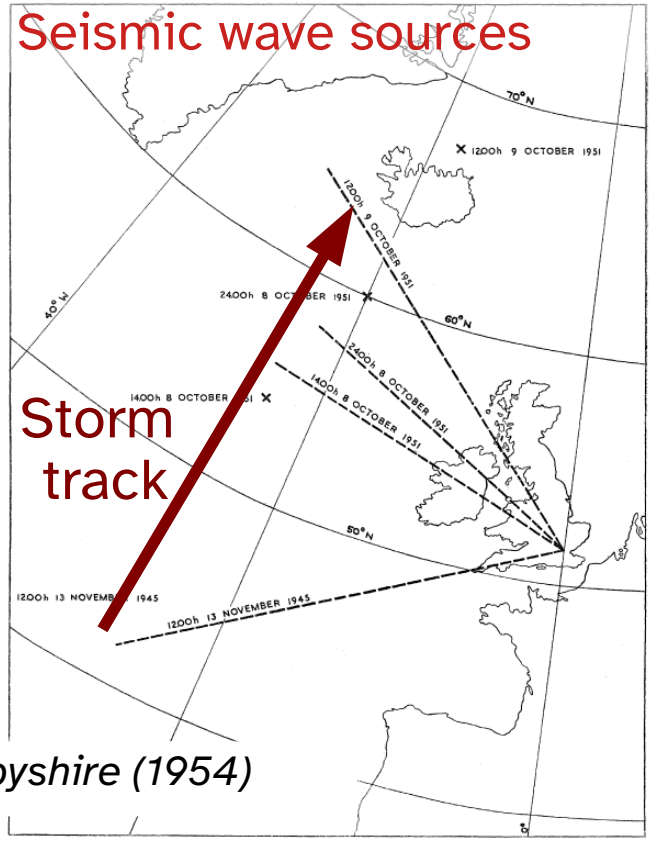

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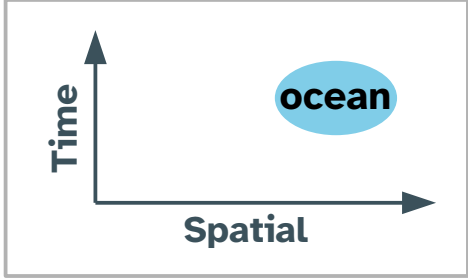

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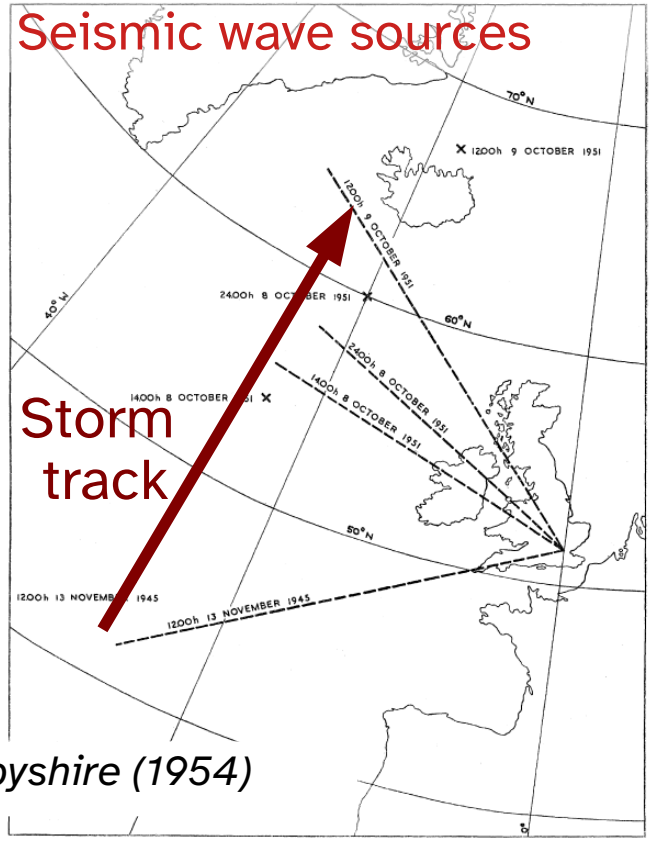
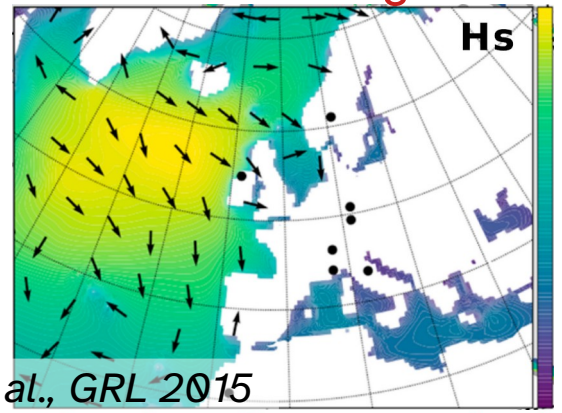


Darbyshire (1954)

Satellite measurements

Ocean wave height



Ardhuin et al., GRL 2015

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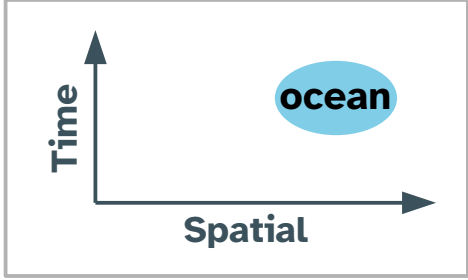

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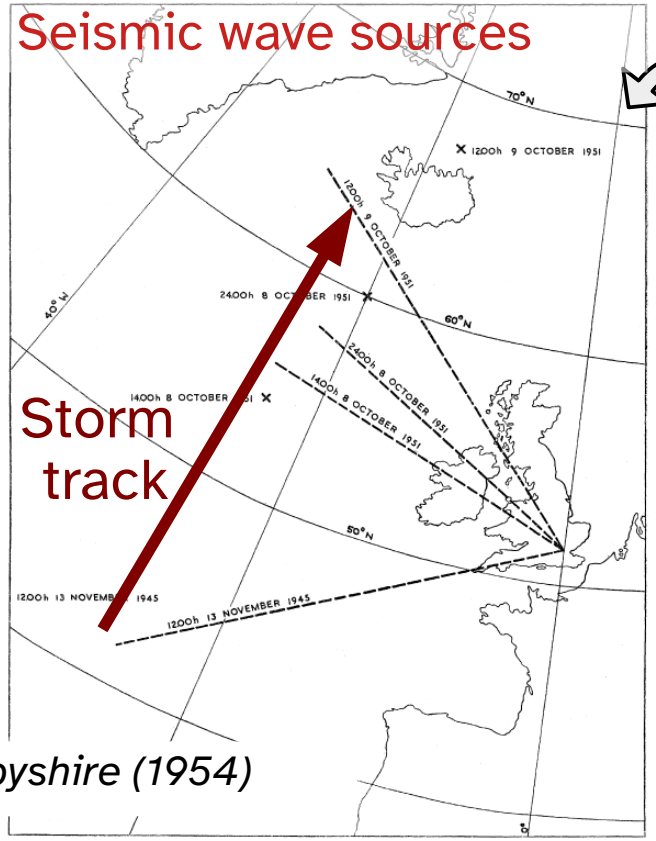
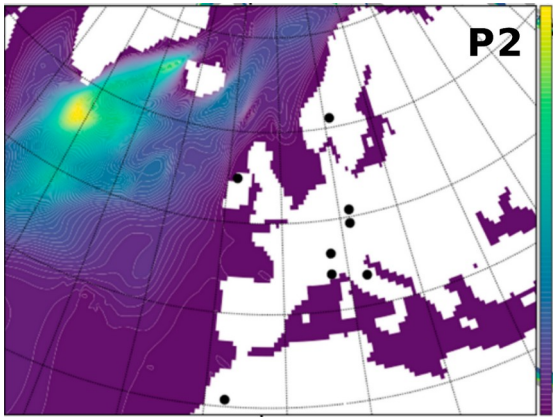


Darbyshire (1954)

Ocean models

Seismic source term



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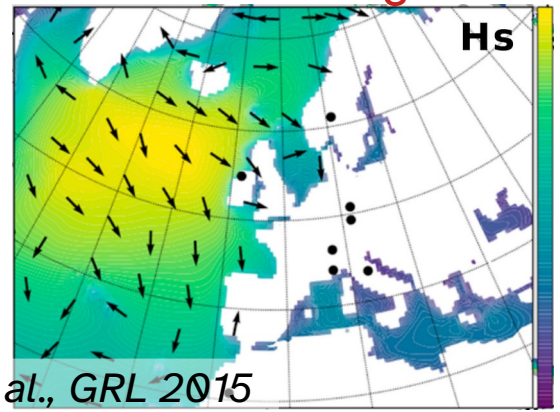

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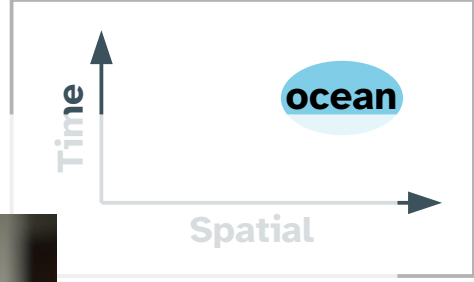

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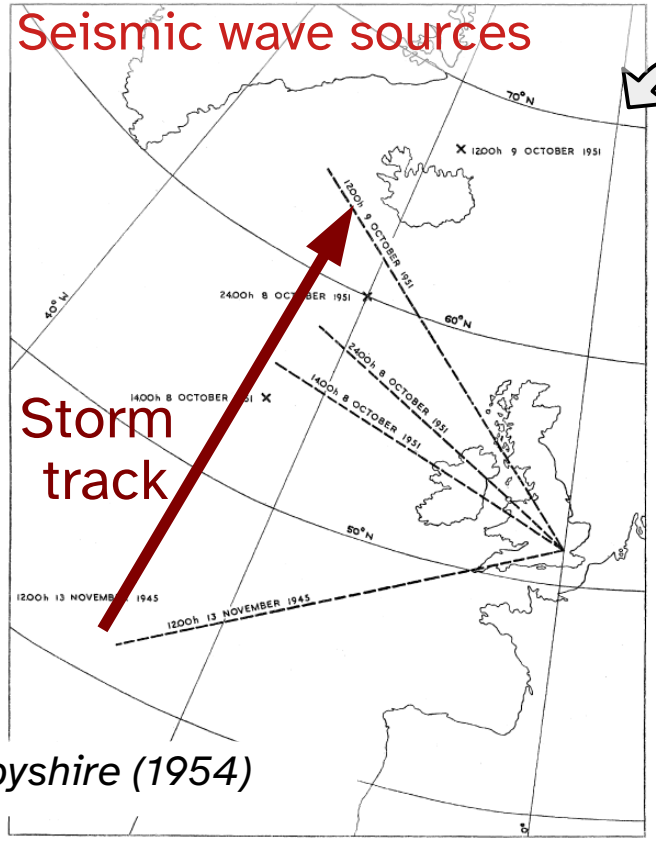

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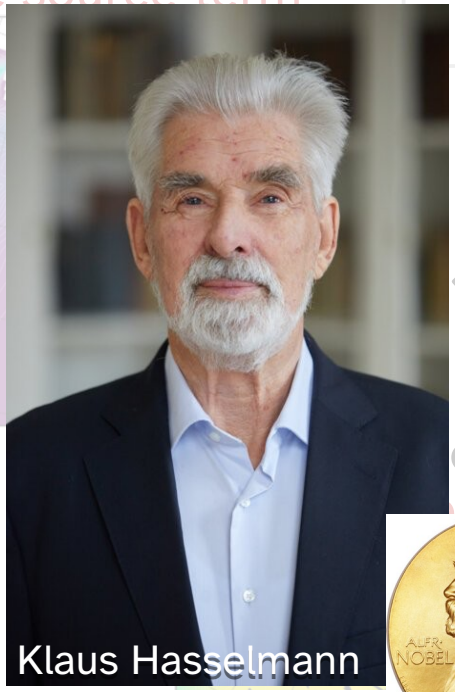

easurements

height

Hs

REVIEWS OF GEOPHYSICS VOL. 1, NO. 2 MAY 1963

A Statistical Analysis of the Generation of Microseisms

K. HASSELMANN

Ardhuin et al., GRL 2015

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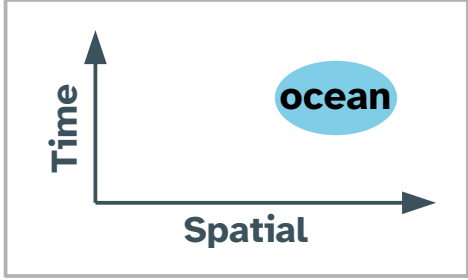

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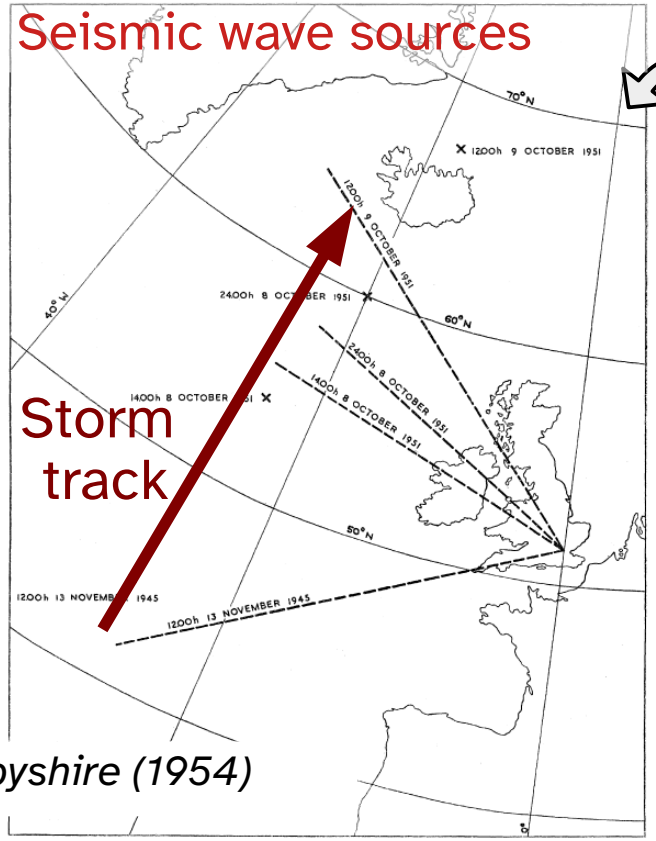

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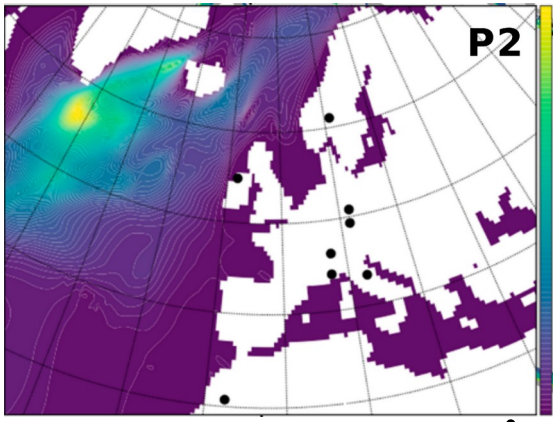

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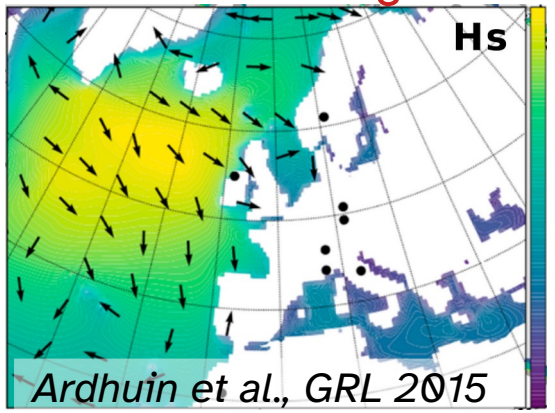

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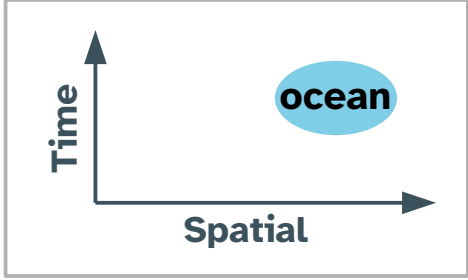
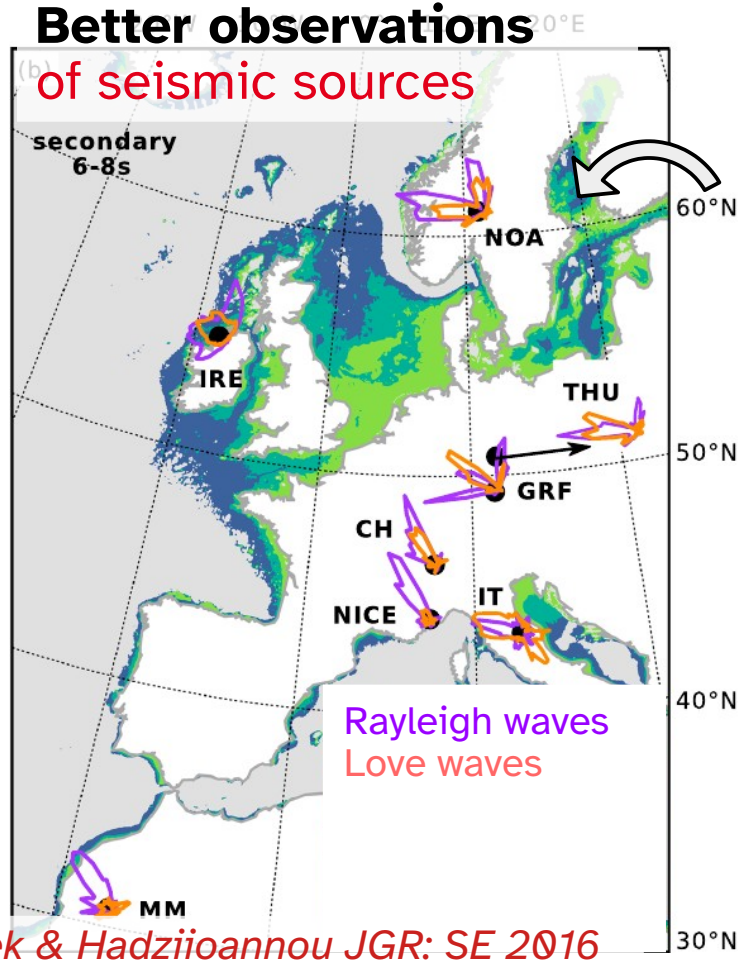


Better observations
of seismic sources



Juretzek & Hadziioannou JGR: SE 2016
Juretzek & Hadziioannou GJI 2017

Ocean models
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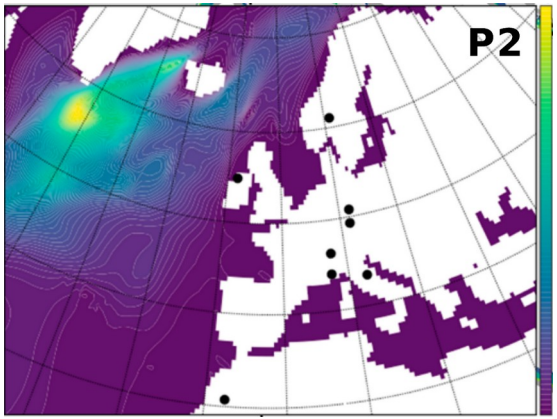

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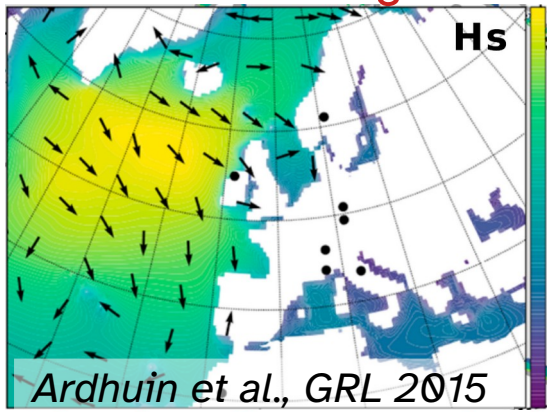

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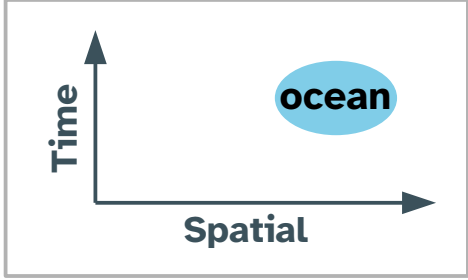

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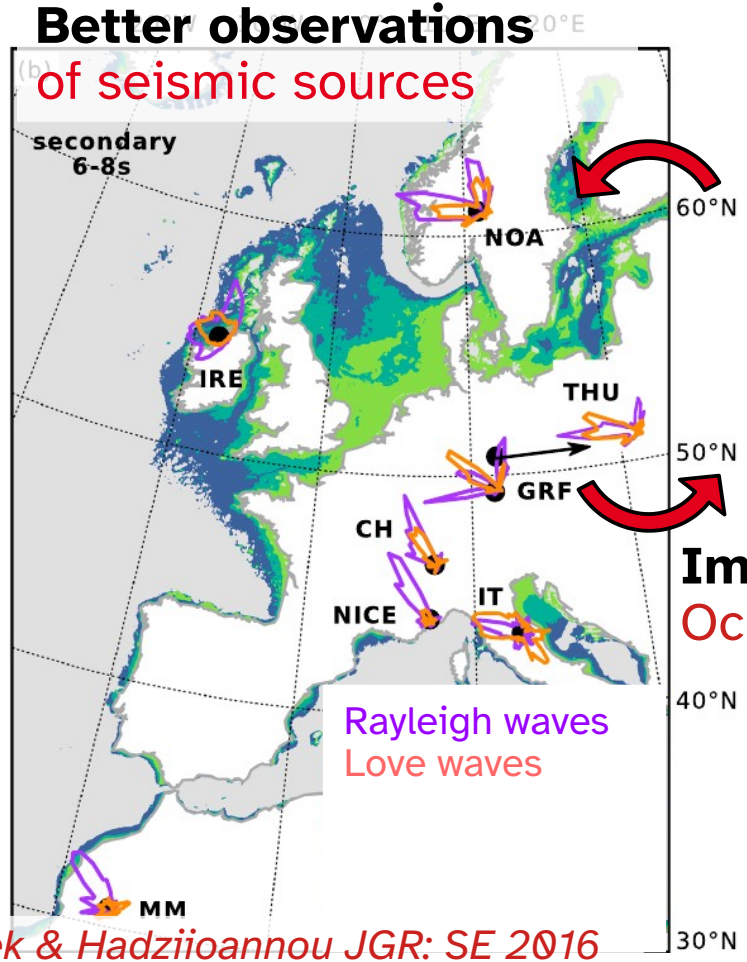

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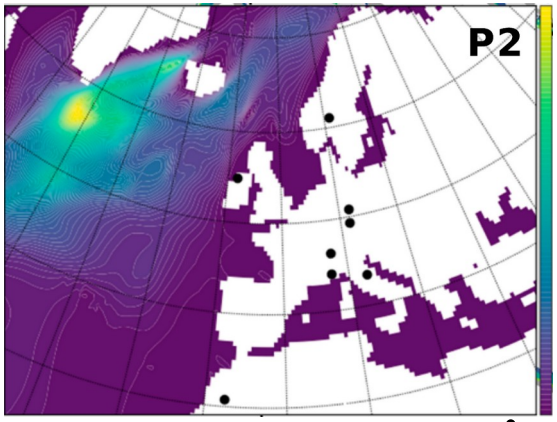
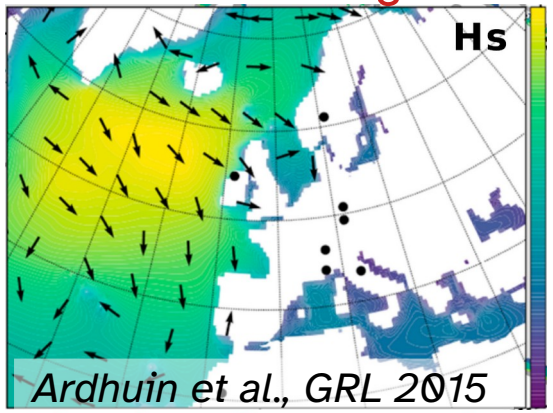


Improve
Ocean models

Satellite measurements
Ocean wave height



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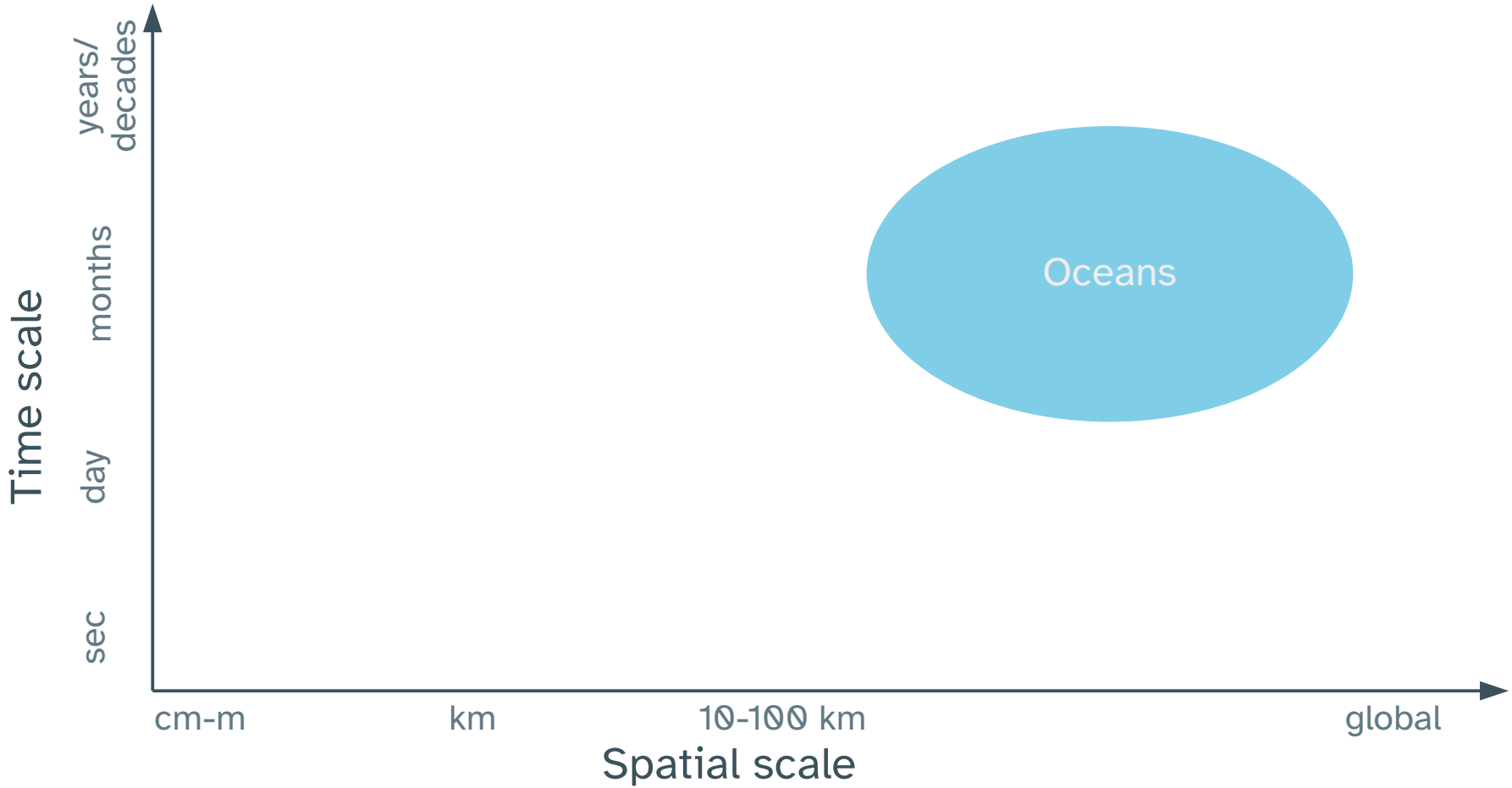

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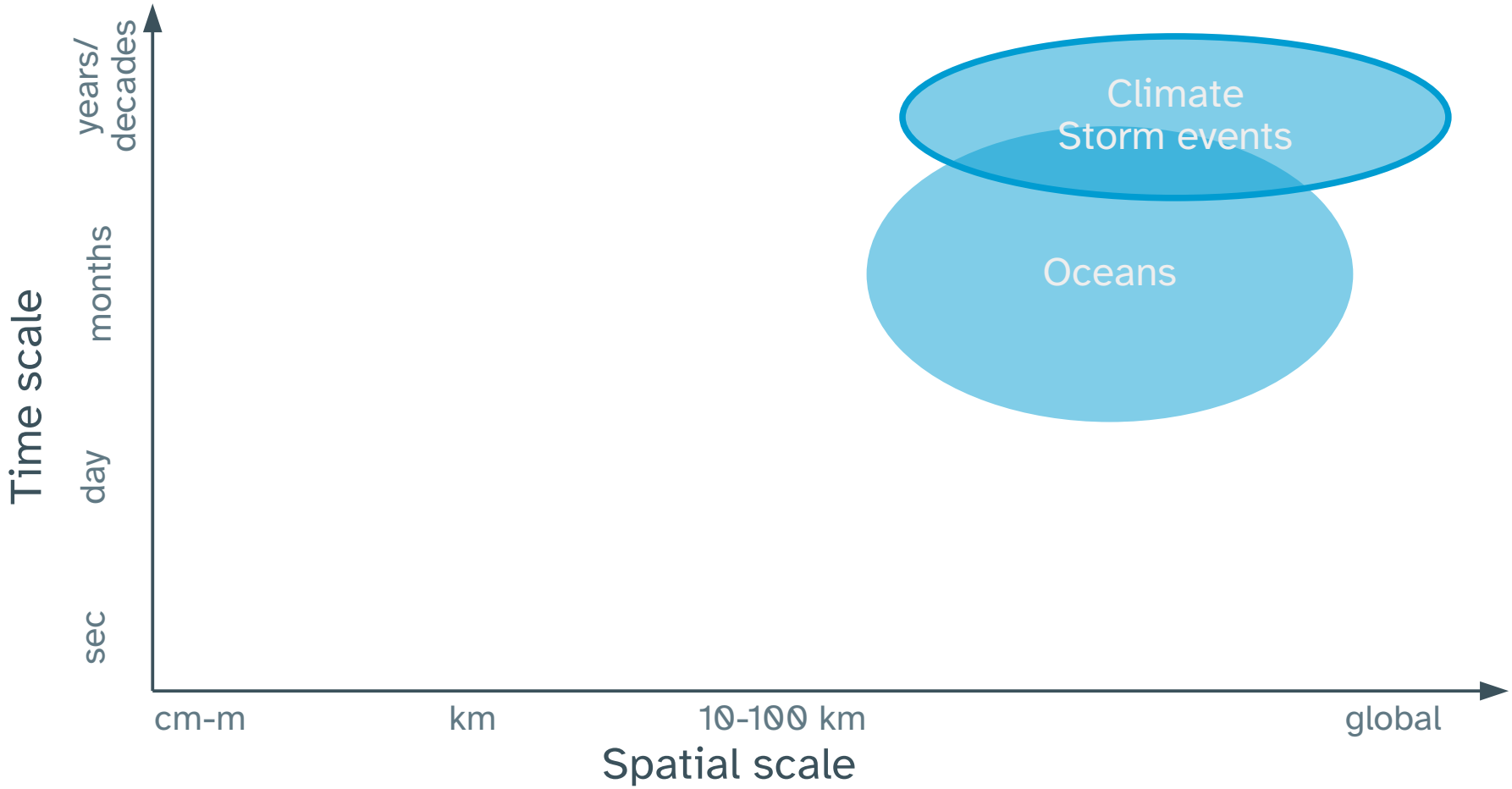
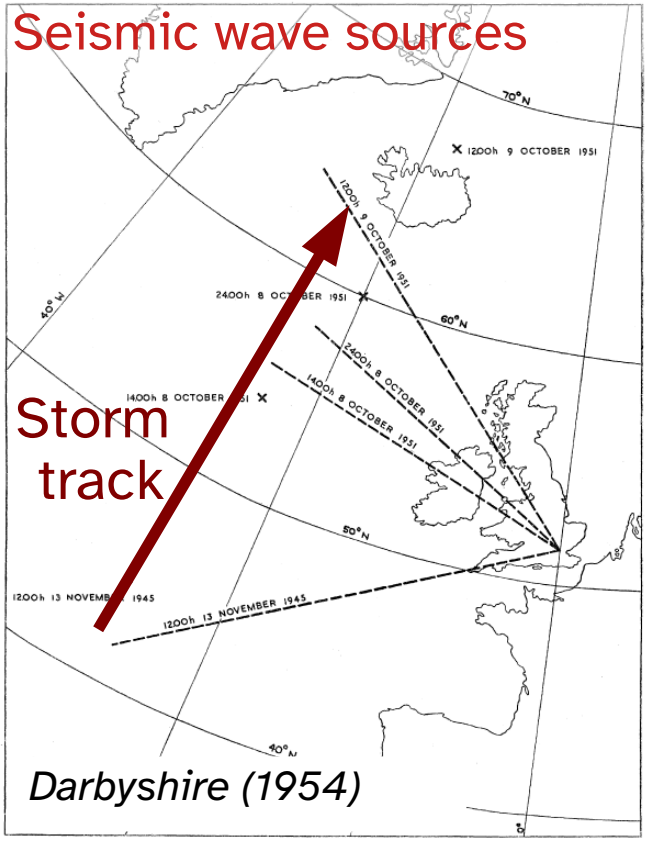


Tracking Storm events → climate change

Observations

Seismic wave sources



Darbyshire (1954)

Retailleau & Gualtieri, GRL 2019

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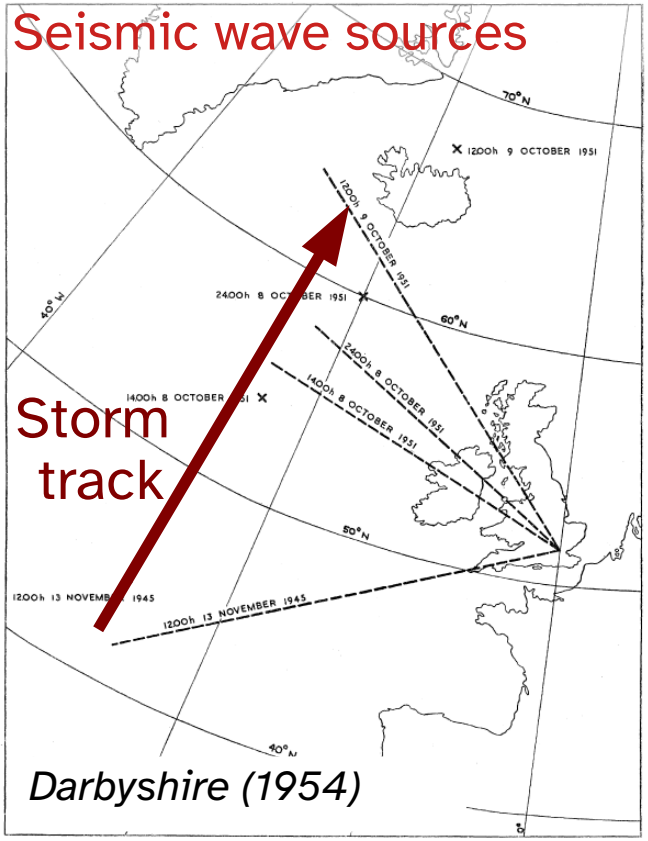
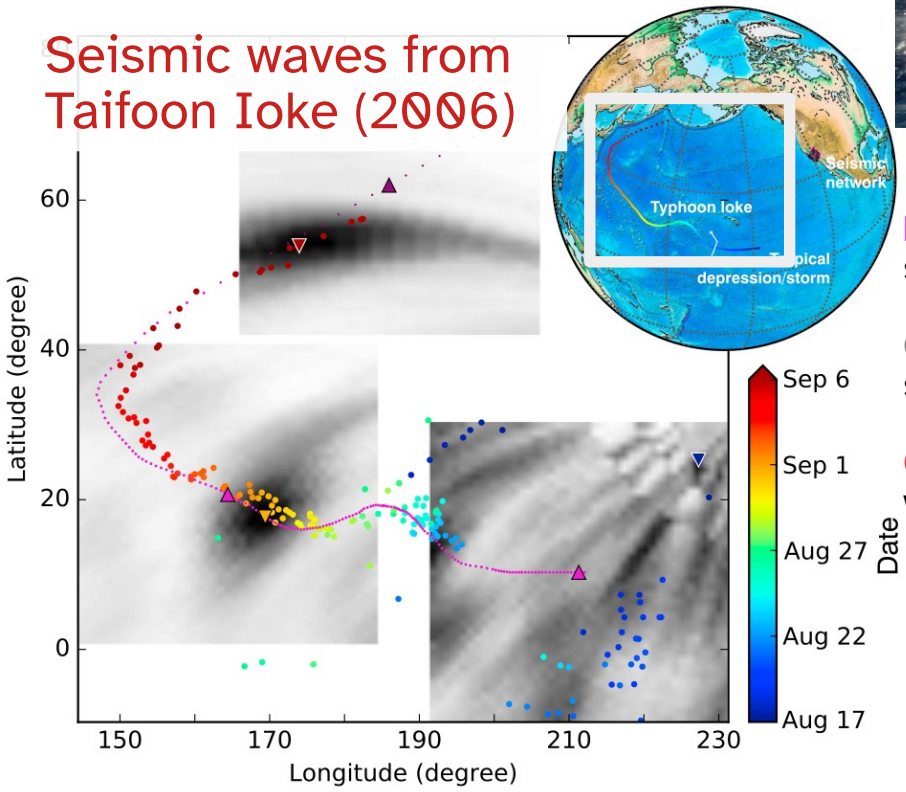


Seismic waves from Taifoon Ioke (2006)



Pink: Taifoon track from satellite

Grey: backprojection seismic signals

Colored Points: Seismic waves are excited here

Retailleau & Gualtieri, GRL 2019

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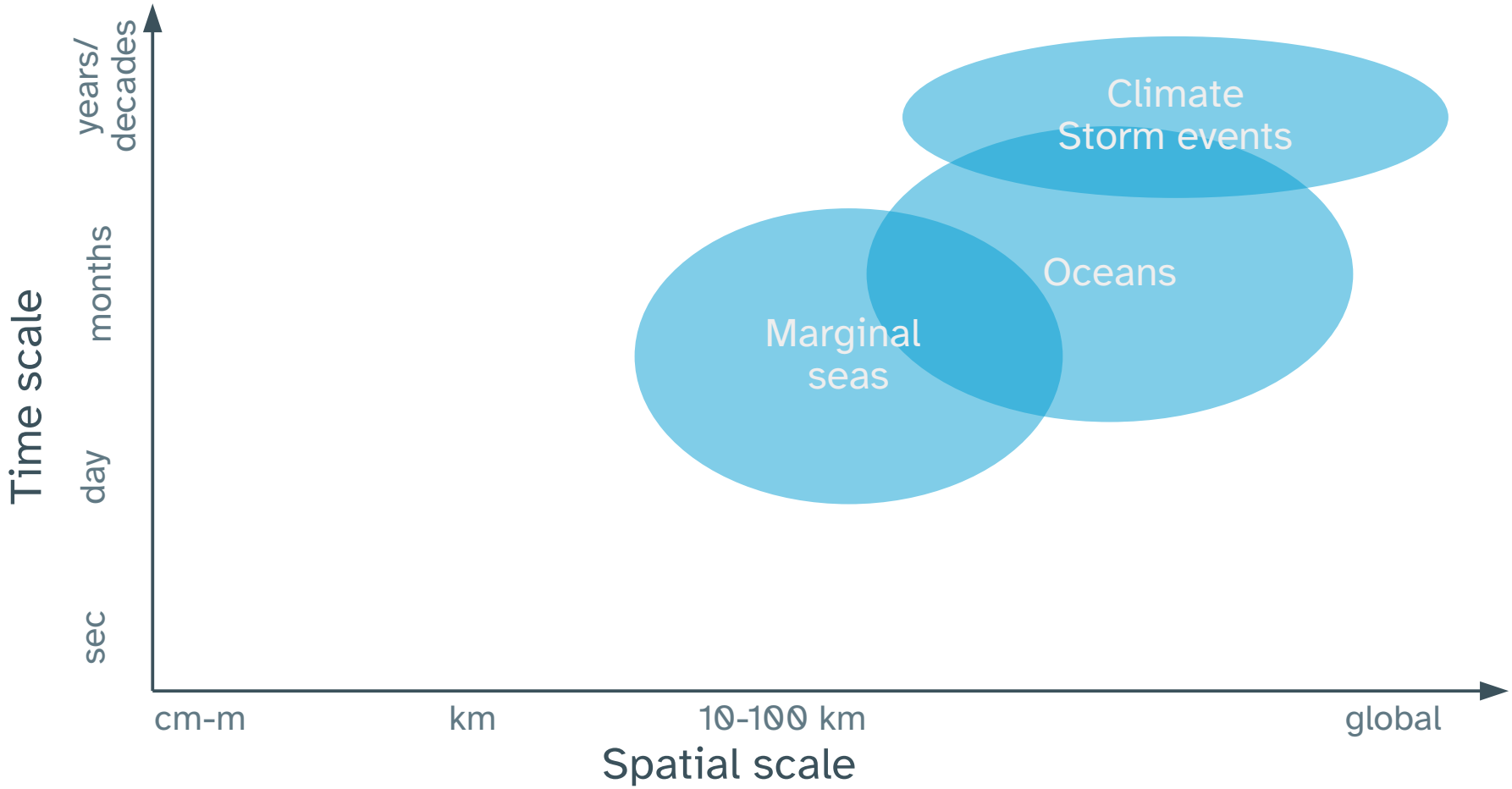

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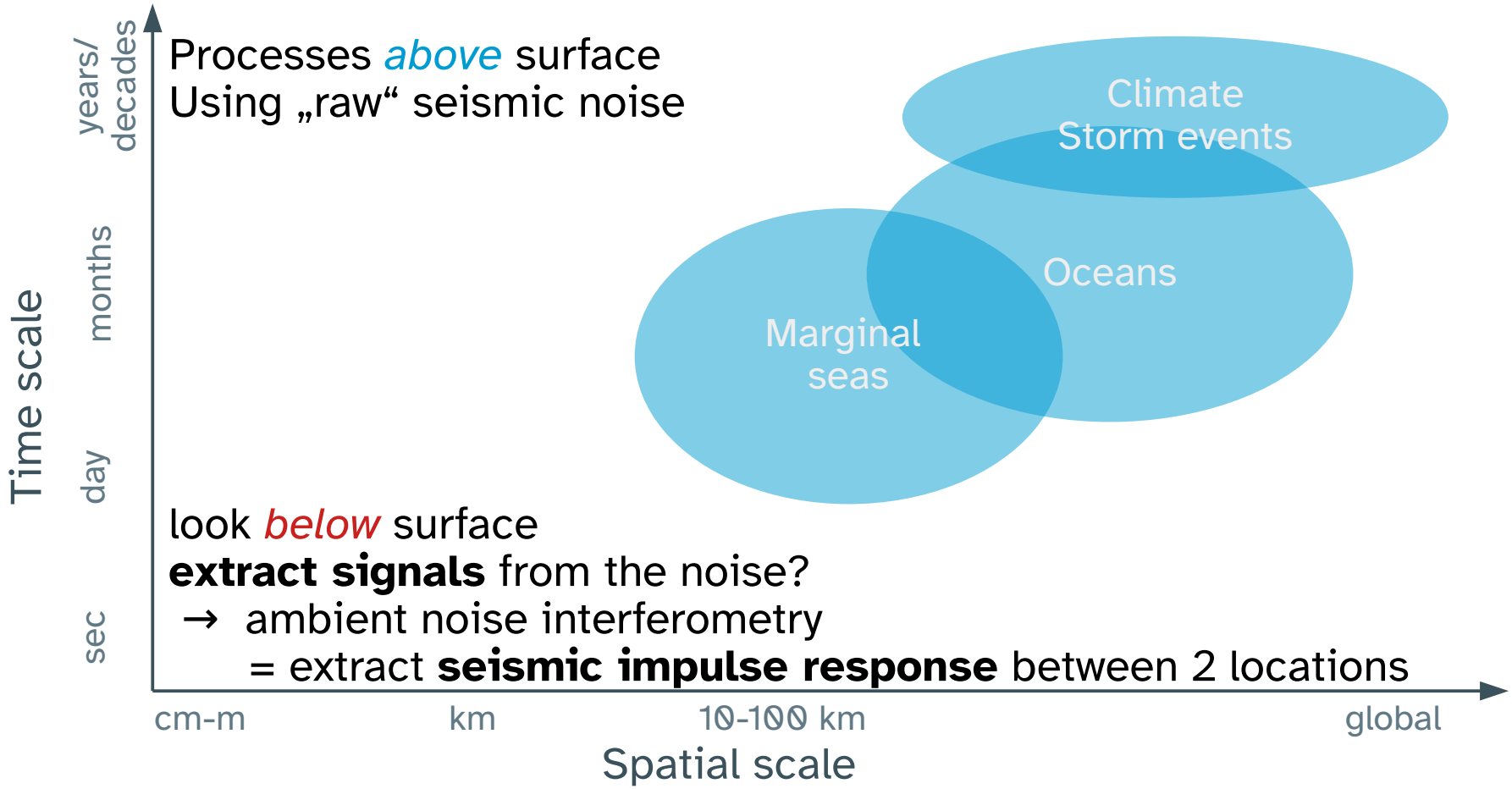

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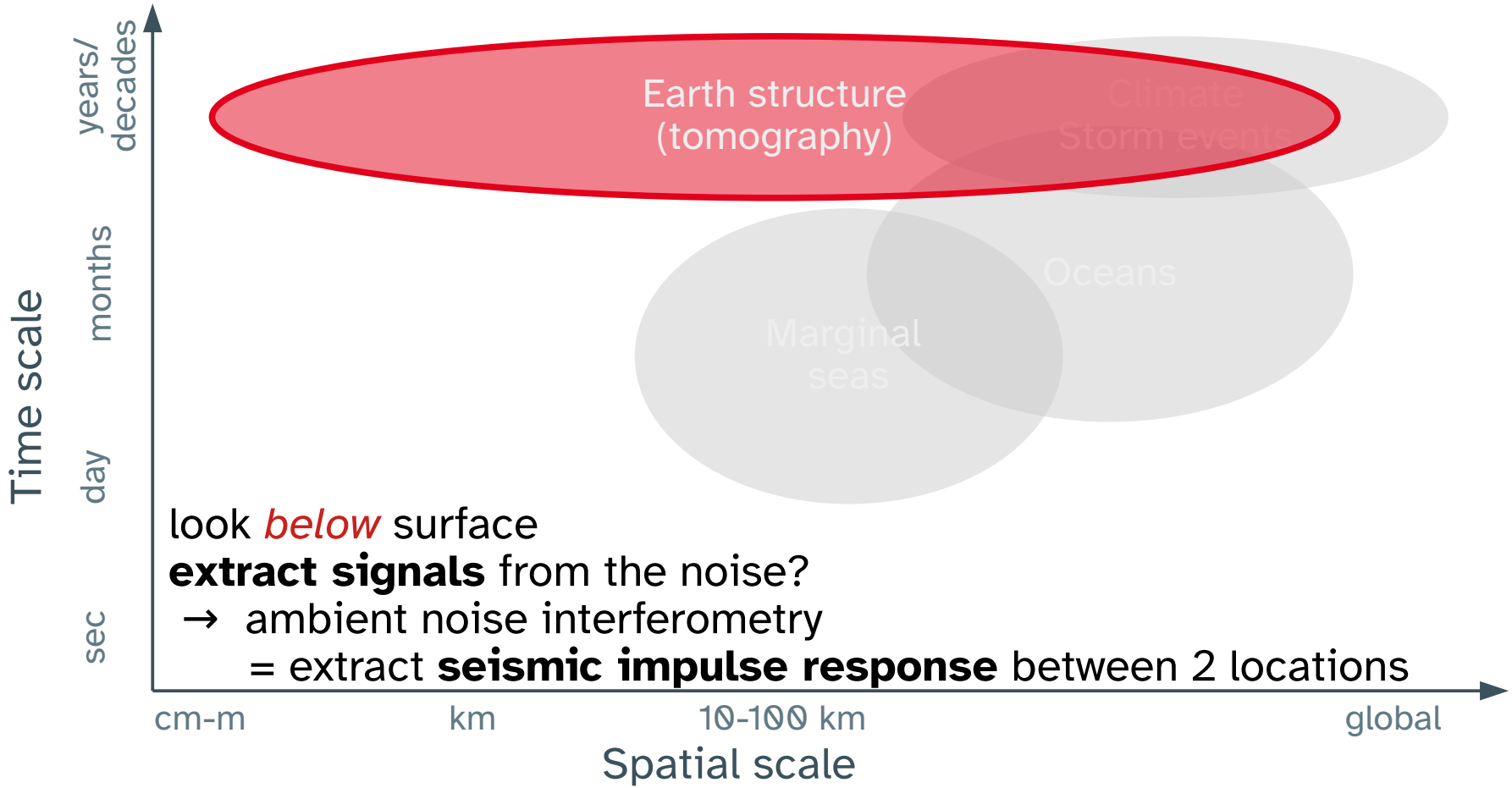
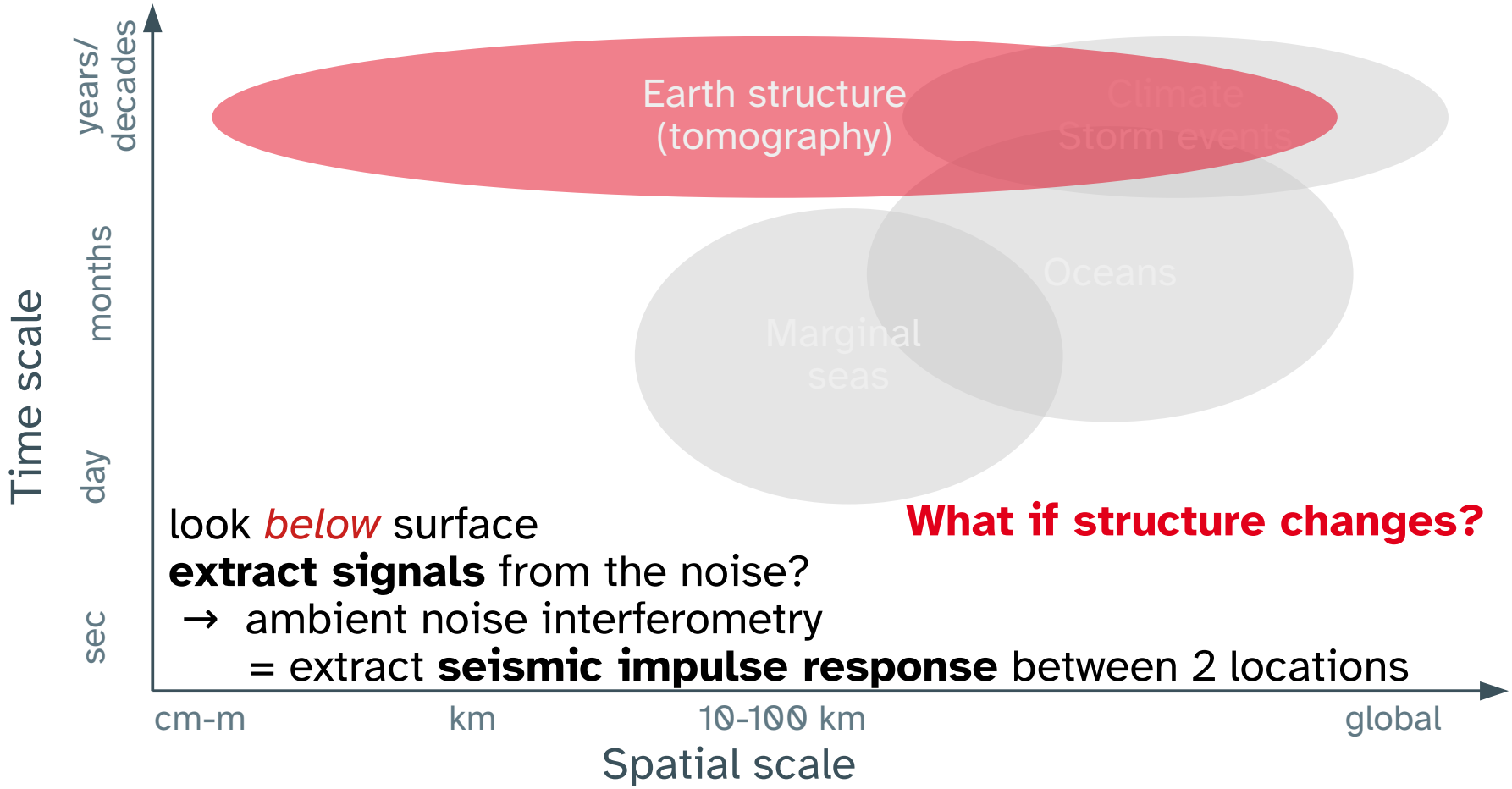


look *below* surface
extract signals from the noise?
→ ambient noise interferometry
= extract **seismic impulse response** between 2 locations

What can we learn about the Earth by **listening** to ambient seismic noise?



look *below* surface

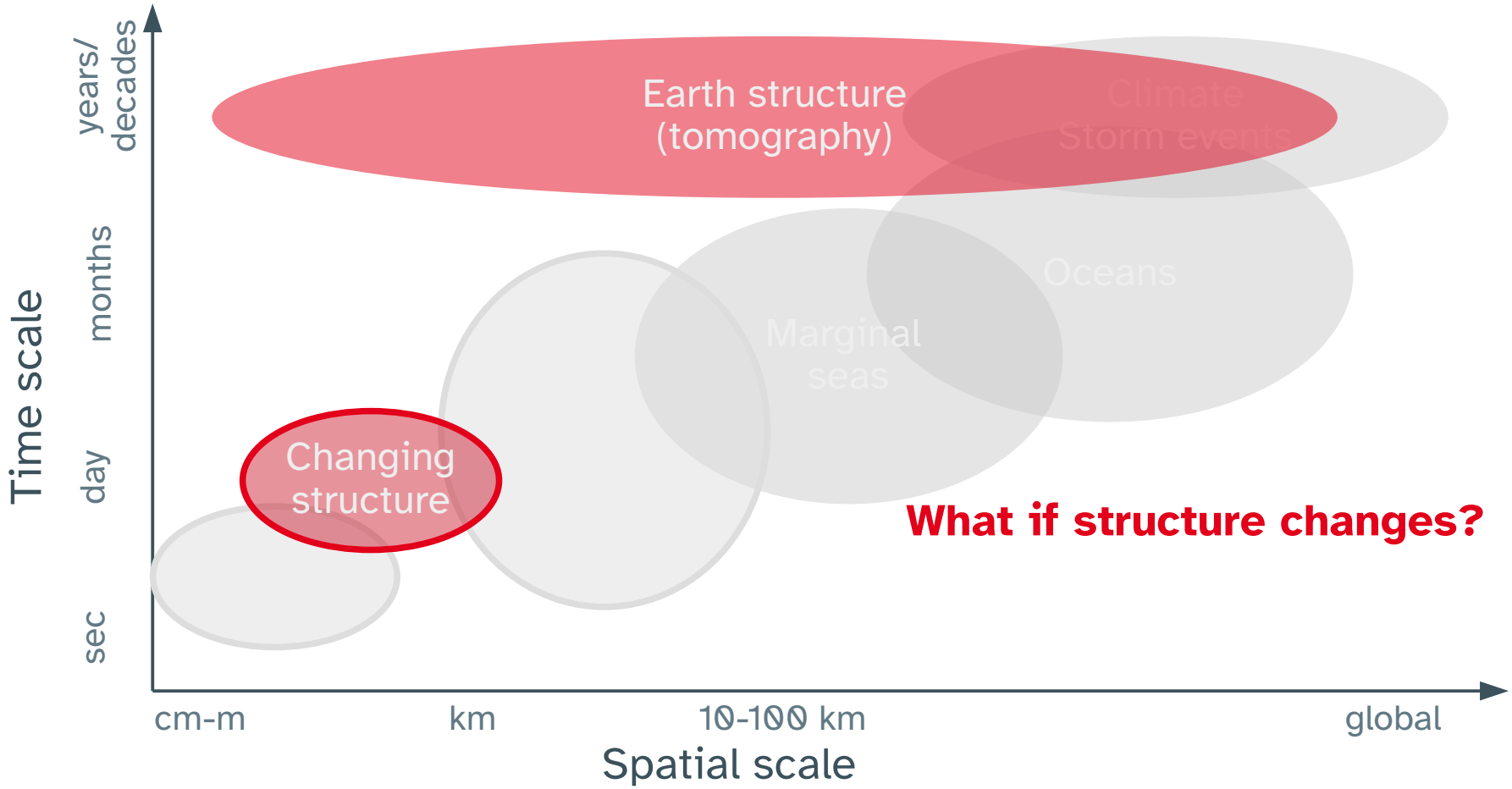
extract signals from the noise?

→ ambient noise interferometry

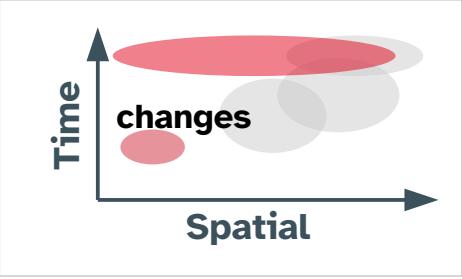
= extract **seismic impulse response** between 2 locations

What if structure changes?

What can we learn about the Earth by **listening** to ambient seismic noise?



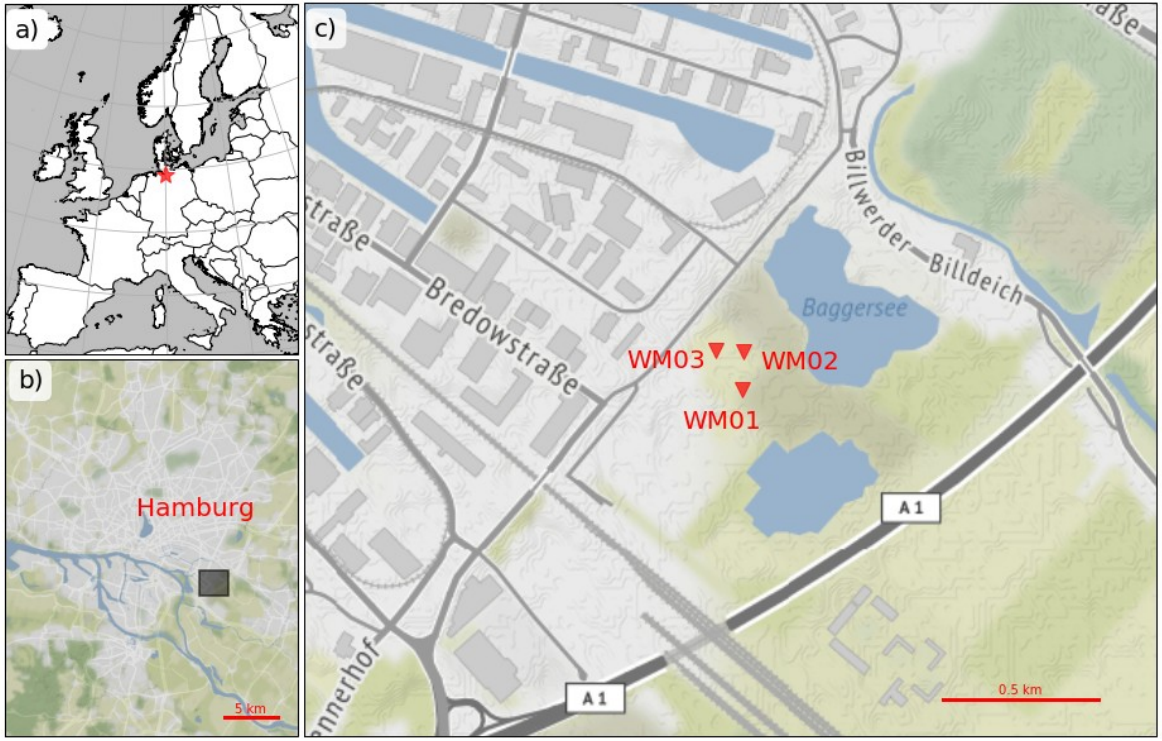
Monitoring: seismic monitoring of urban near surface



3 seismic stations ▼

In situ soil temperature & groundwater measurements

Focus on the top few meters of subsurface



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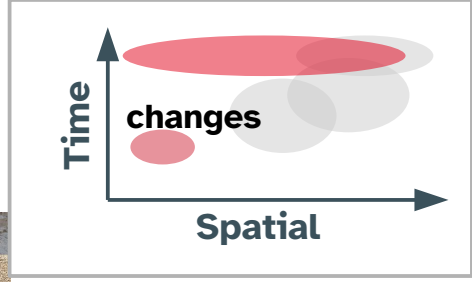
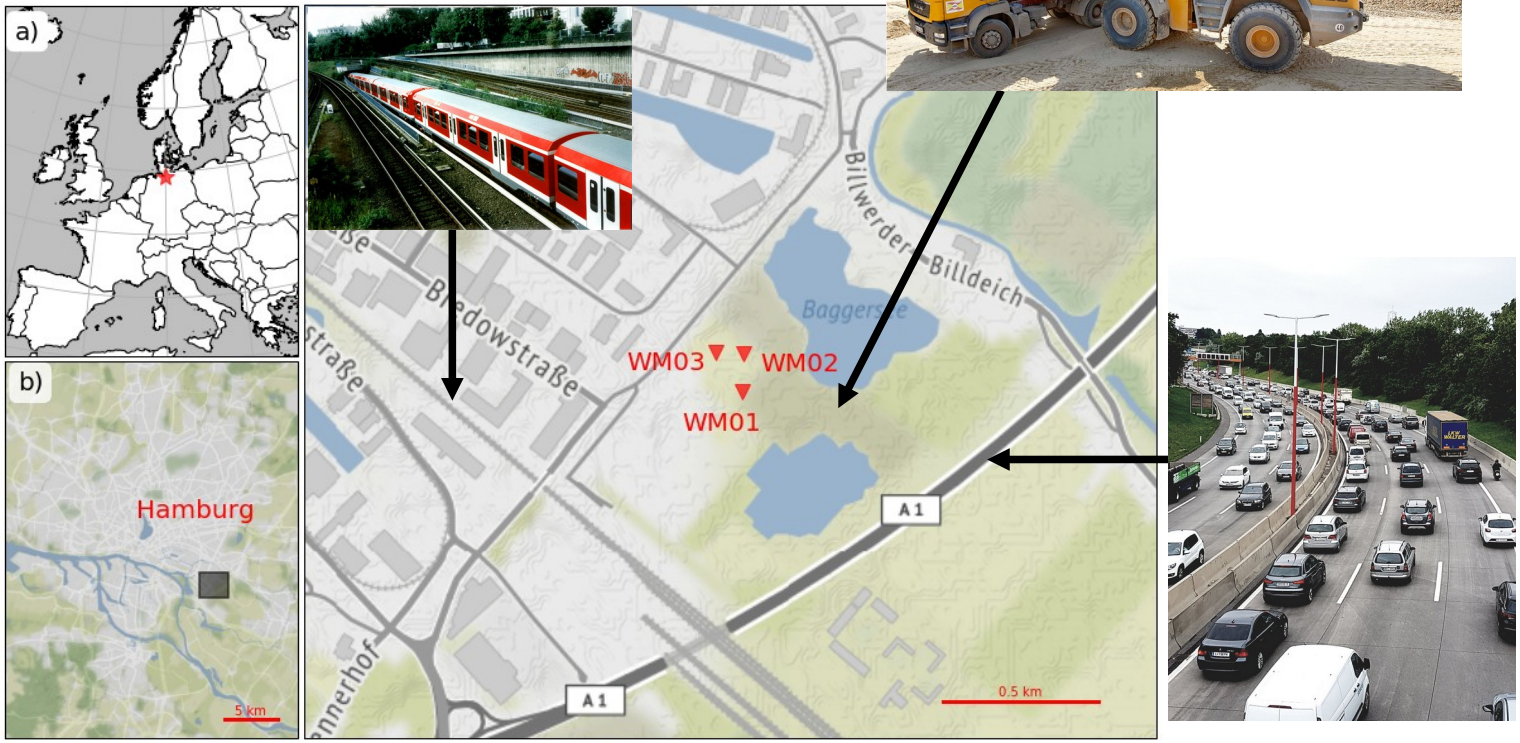


Lots of urban seismic noise!



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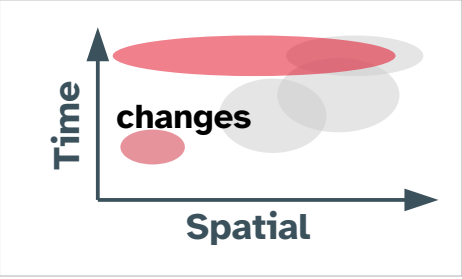
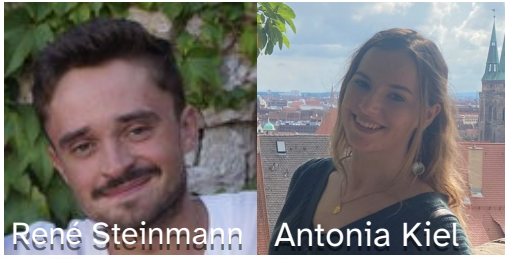


Project Goal:
monitor water content, effect of rain/precipitation on the near surface
Here: monitor frozen soil

Approach:
- Extract impulse response with noise interferometry: one signal every 2 hours
- measure relative seismic wave speed changes between the seismic stations



Work continued by: Antonia Kiel
Steinmann, Larose, Hadziioannou – Geophys. J. Int. 2021

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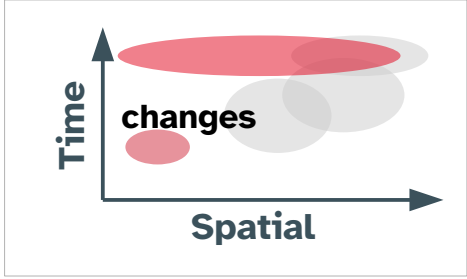
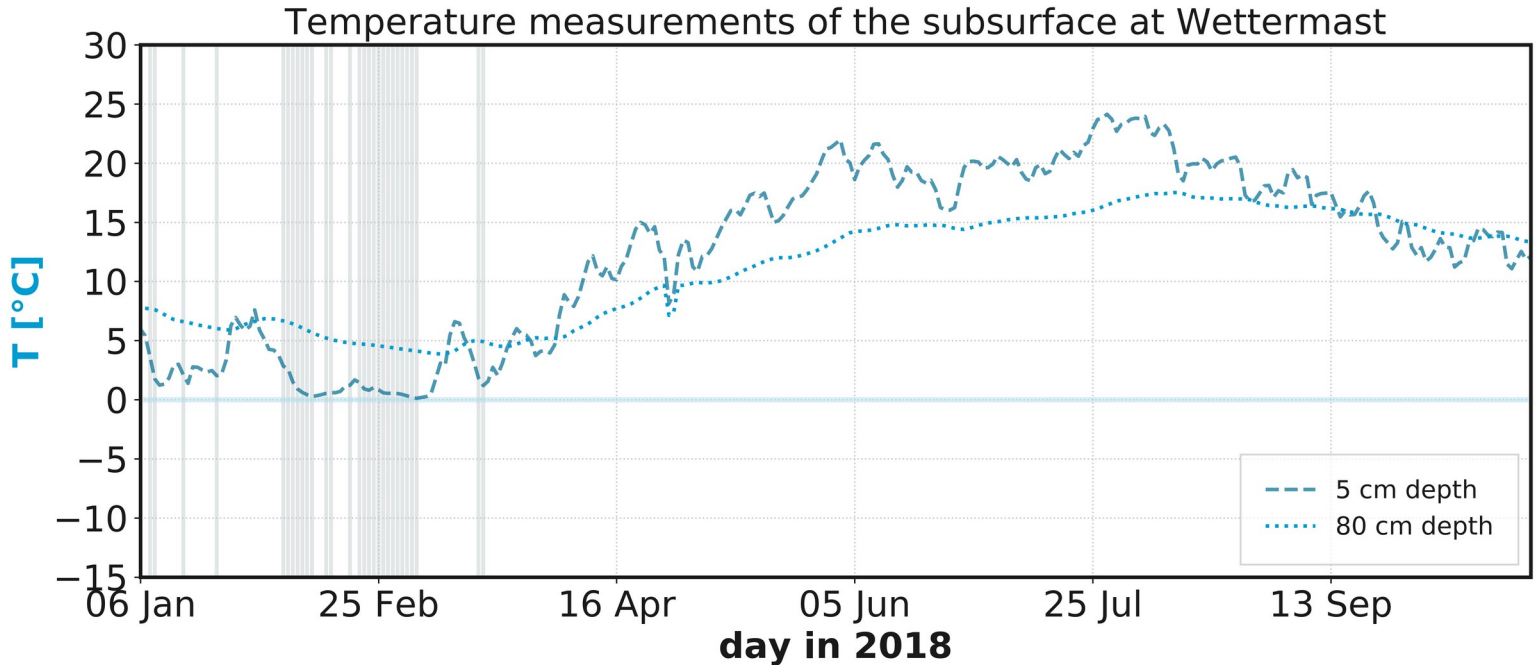


Subsurface temperature

- Grey = subzero at surface
- T at 80 cm depth
- T at 5 cm depth



Steinmann, Larose, Hadziioannou – Geophys. J. Int. 2021

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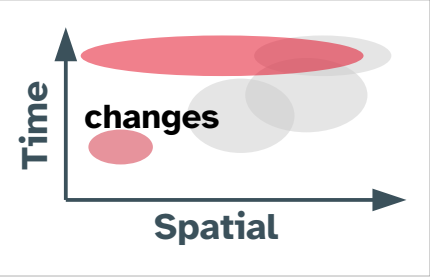
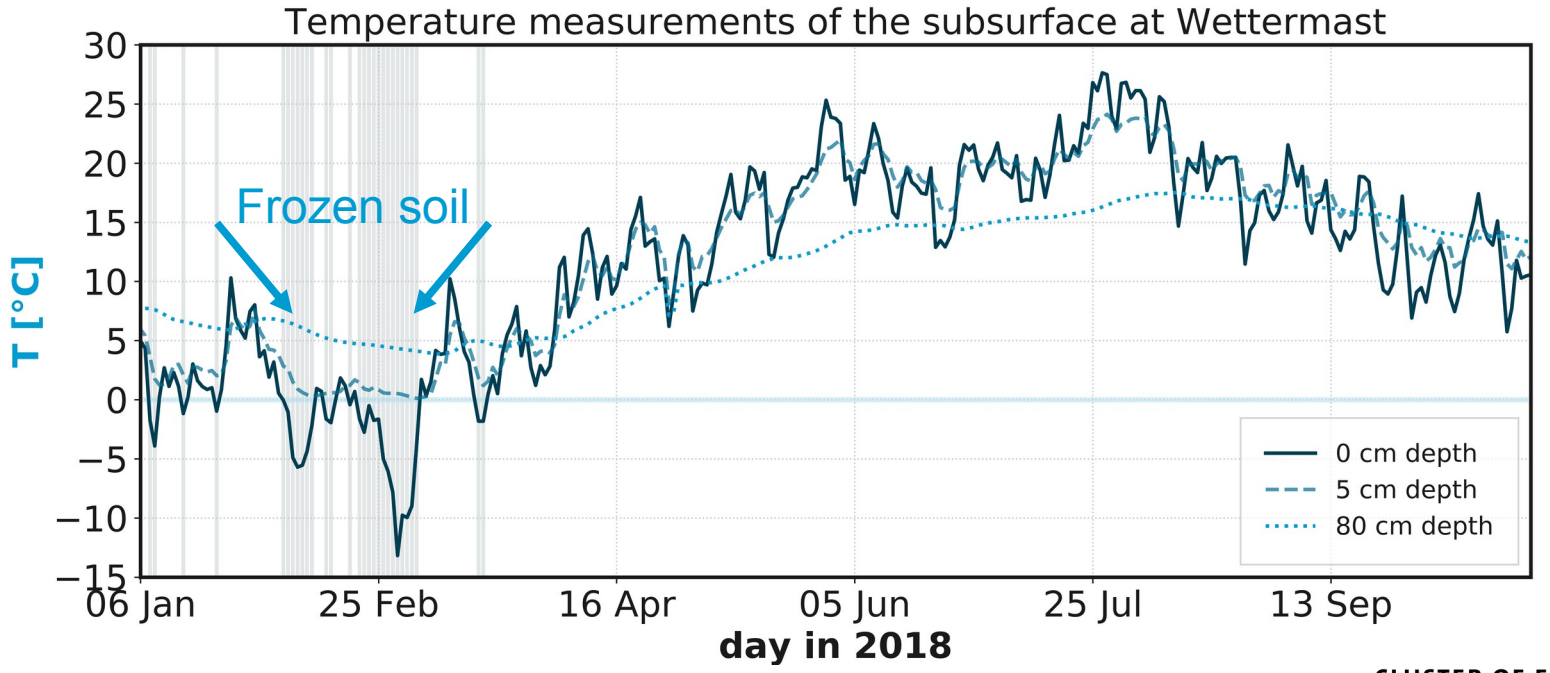


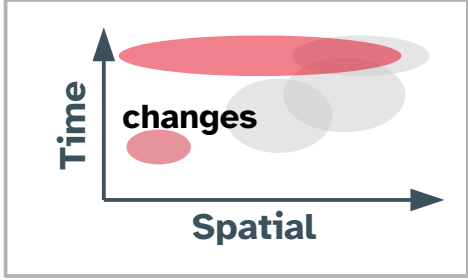
Subsurface temperature

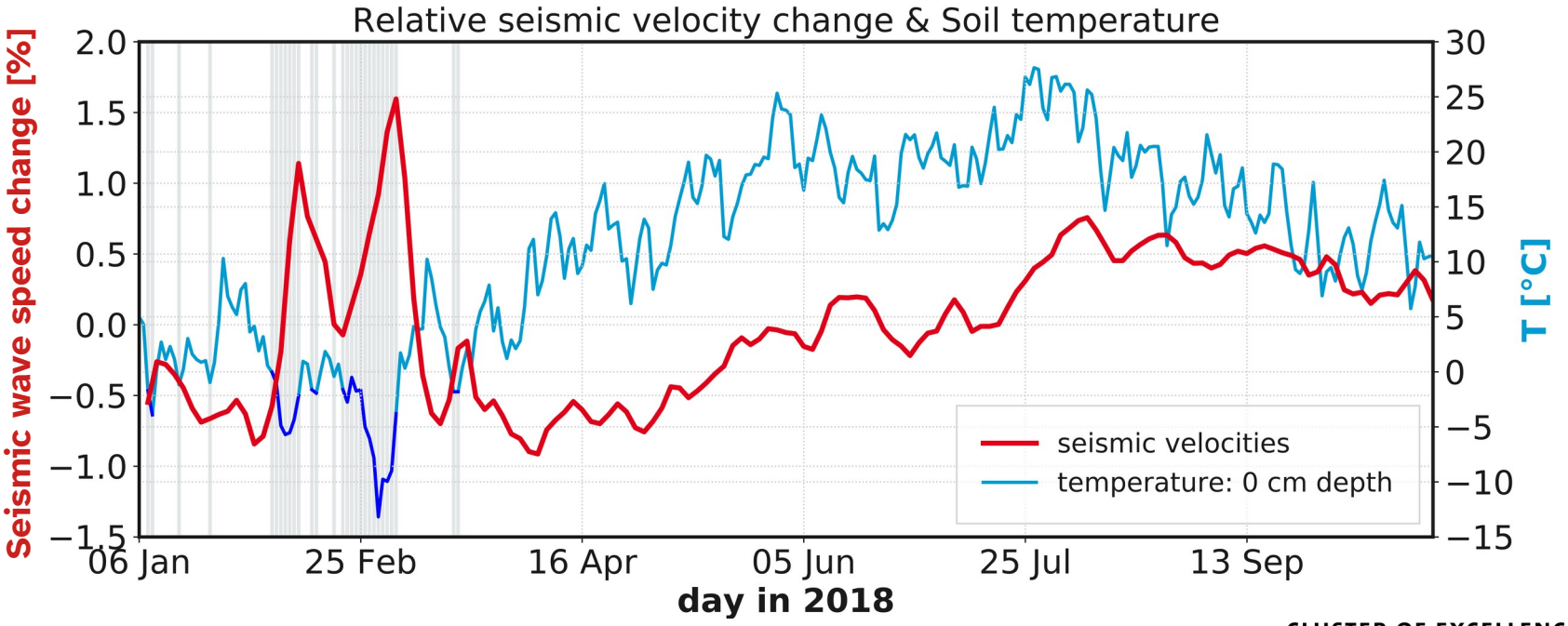
- **Grey** = subzero at surface
- T at surface



Monitoring: seismic monitoring of urban near surface

Subsurface temperature + seismic wave speed change





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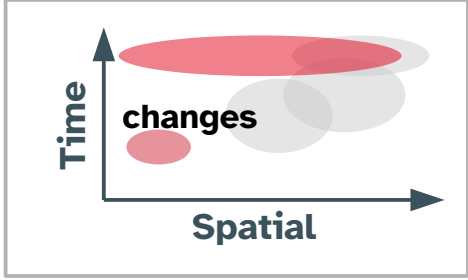
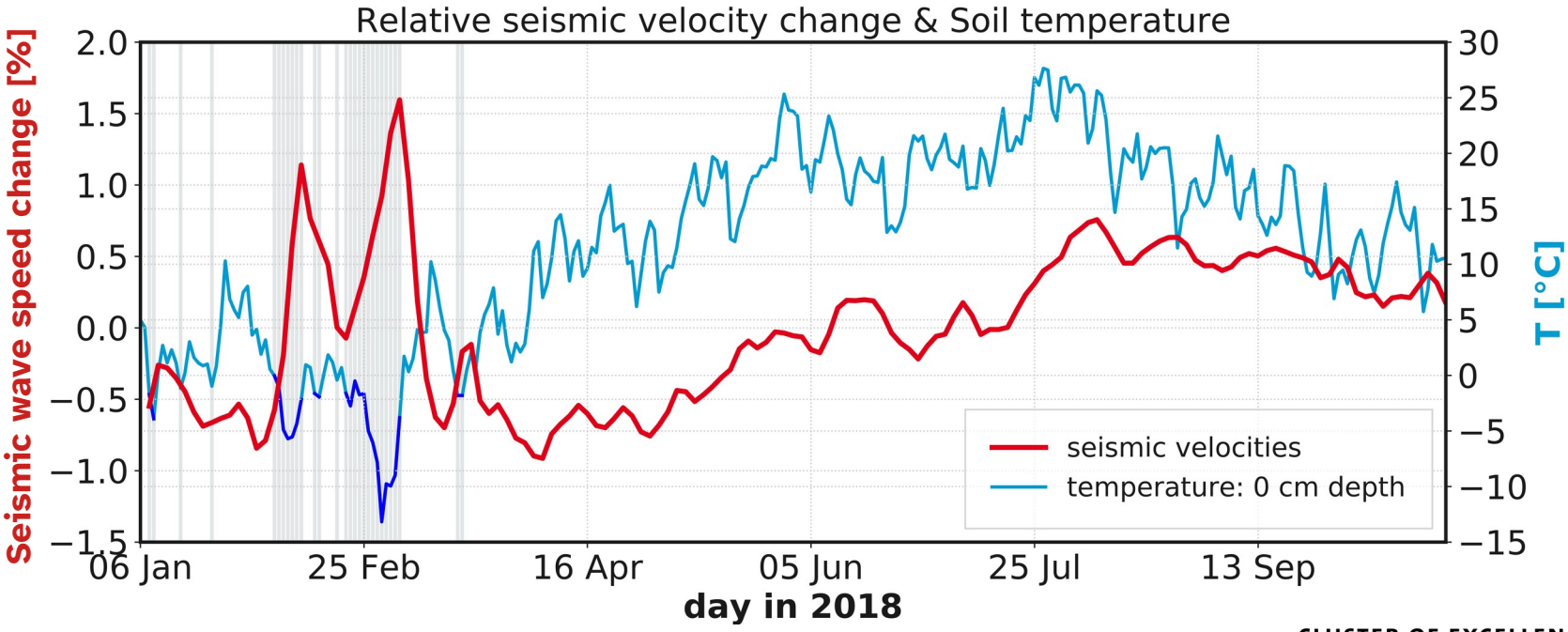
Monitoring: seismic monitoring of urban near surface



Subsurface temperature + seismic wave speed change

- seismic wavelength @3Hz approx 30m! **Frozen layer <5cm!**



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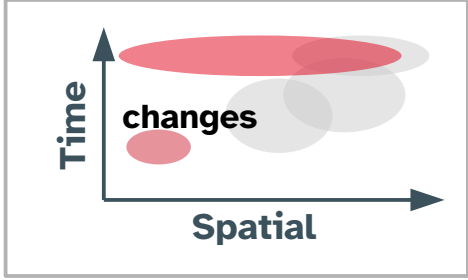
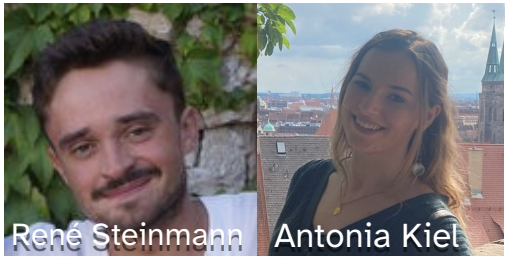


We use the seismic noise from urban traffic to **illuminate the subsurface**
Monitor seismic wave speed changes in the shallow subsurface (<10m)



Youtube:

Work continued by: ***Antonia Kiel***
Steinmann, Larose, Hadziioannou, Geophys. J. Int. 2021

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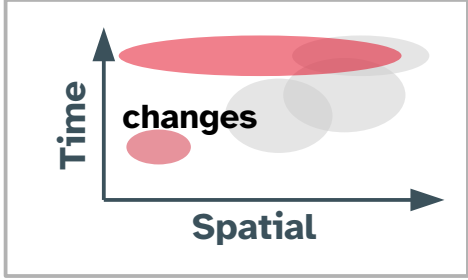

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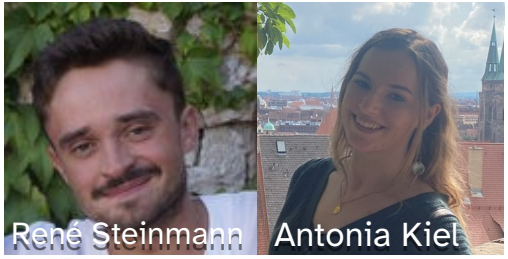

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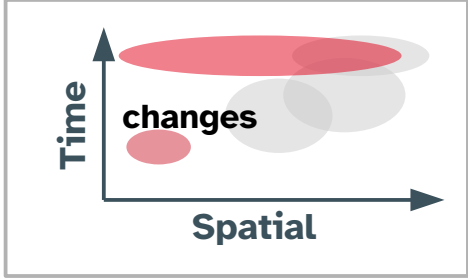

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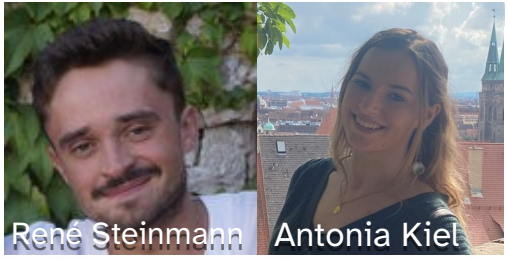
→ Applications in **permafrost monitoring?**



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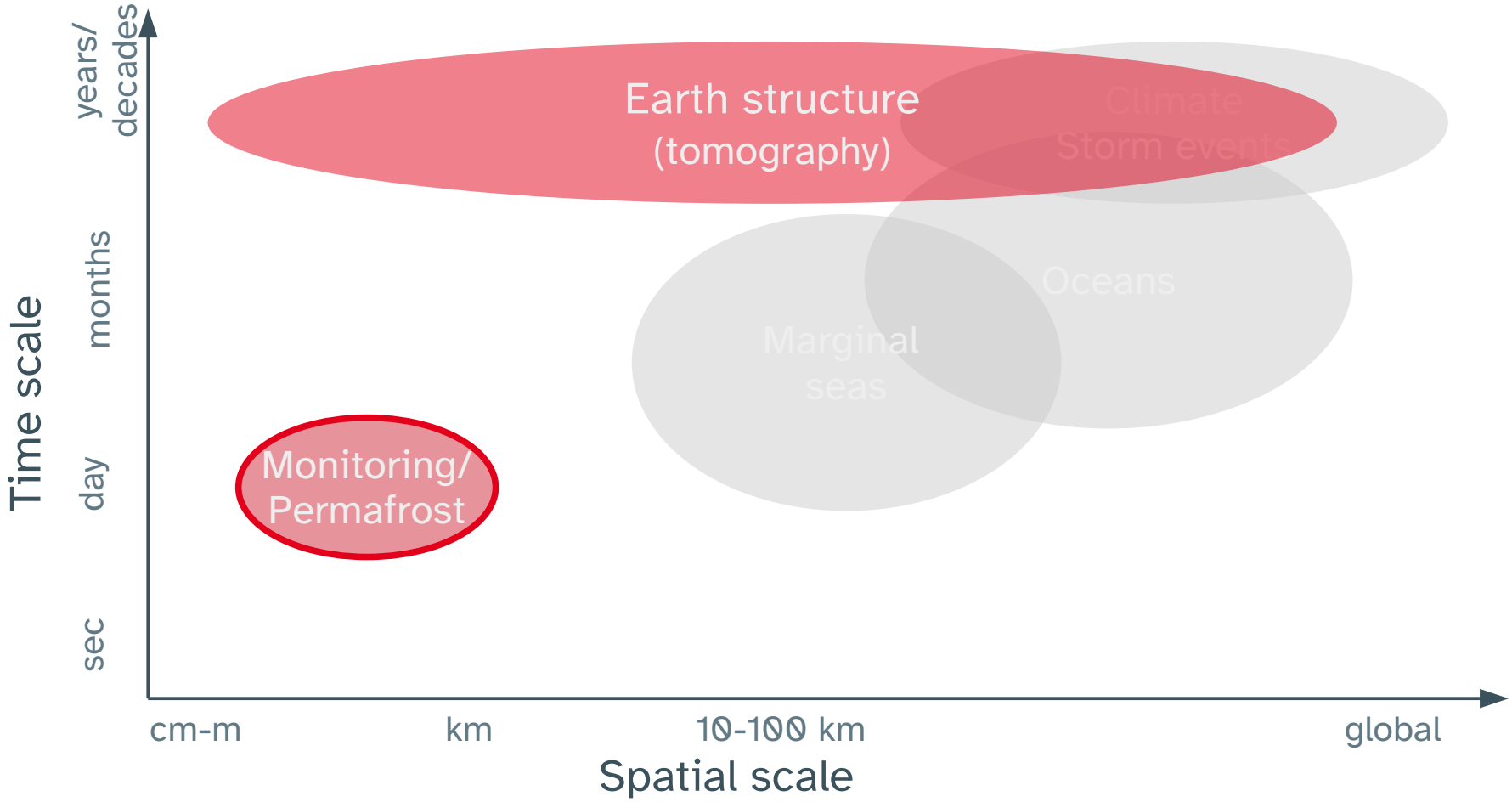
What can we learn about the Earth by **listening** to ambient seismic noise?



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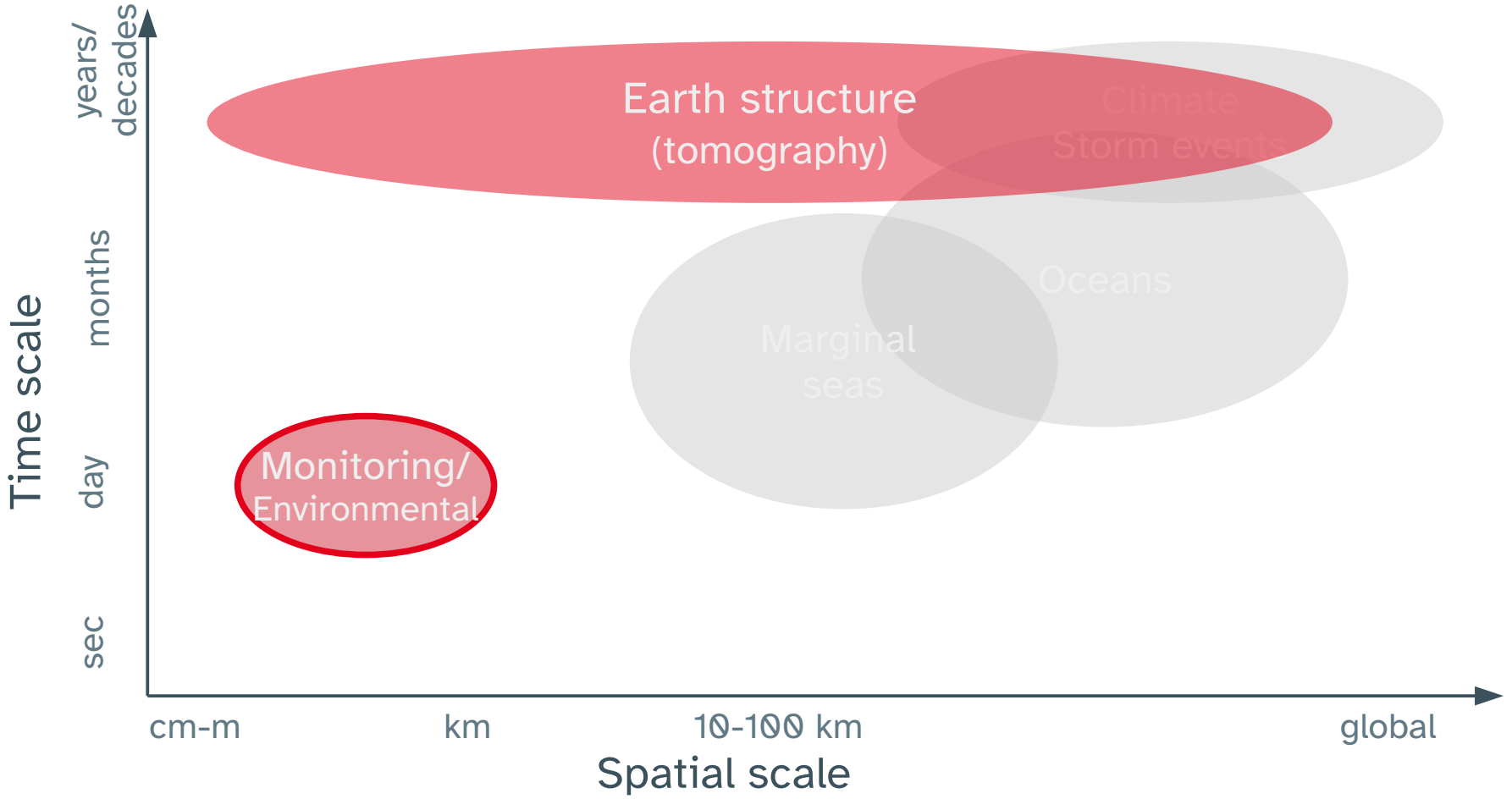

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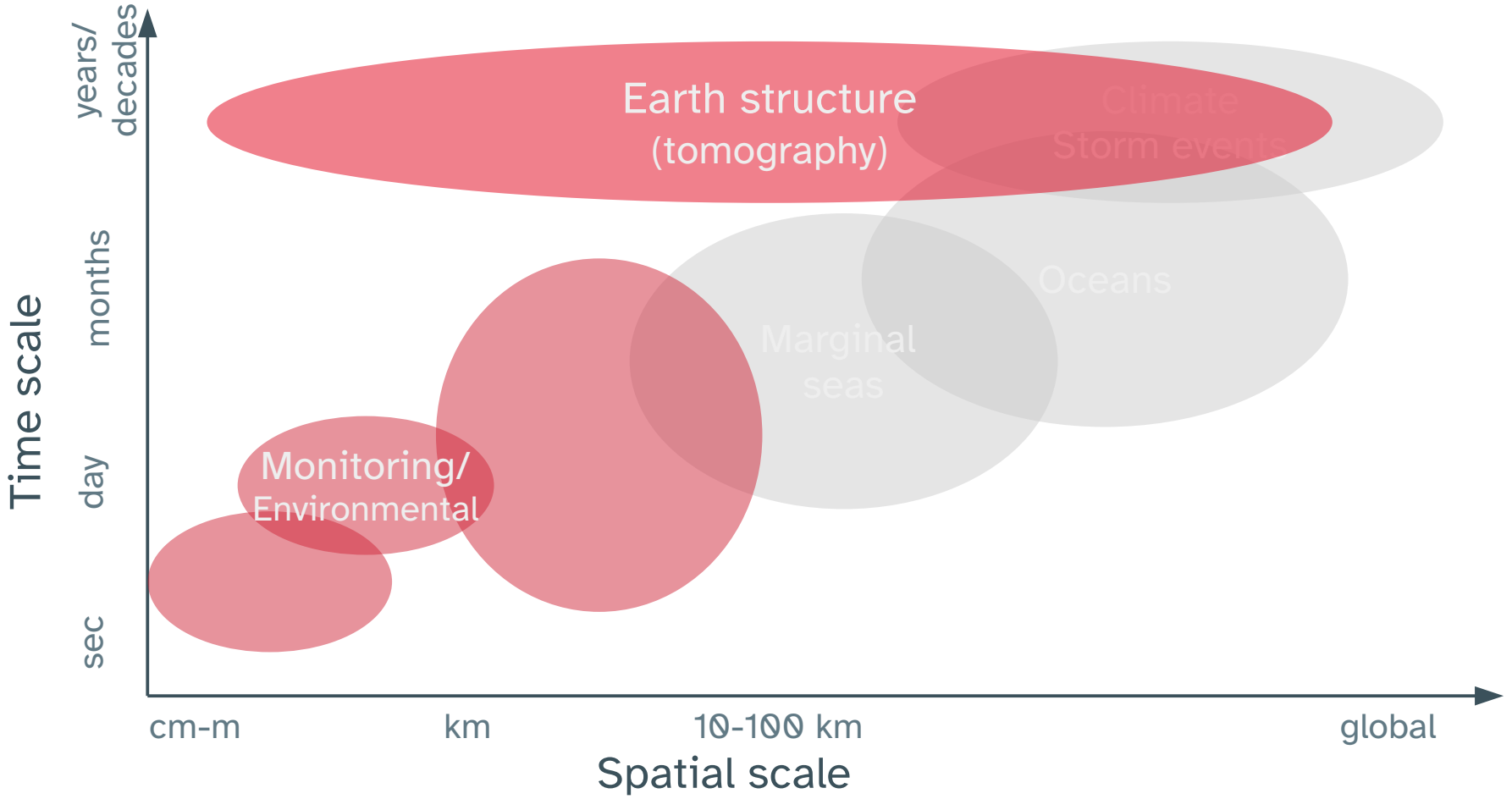

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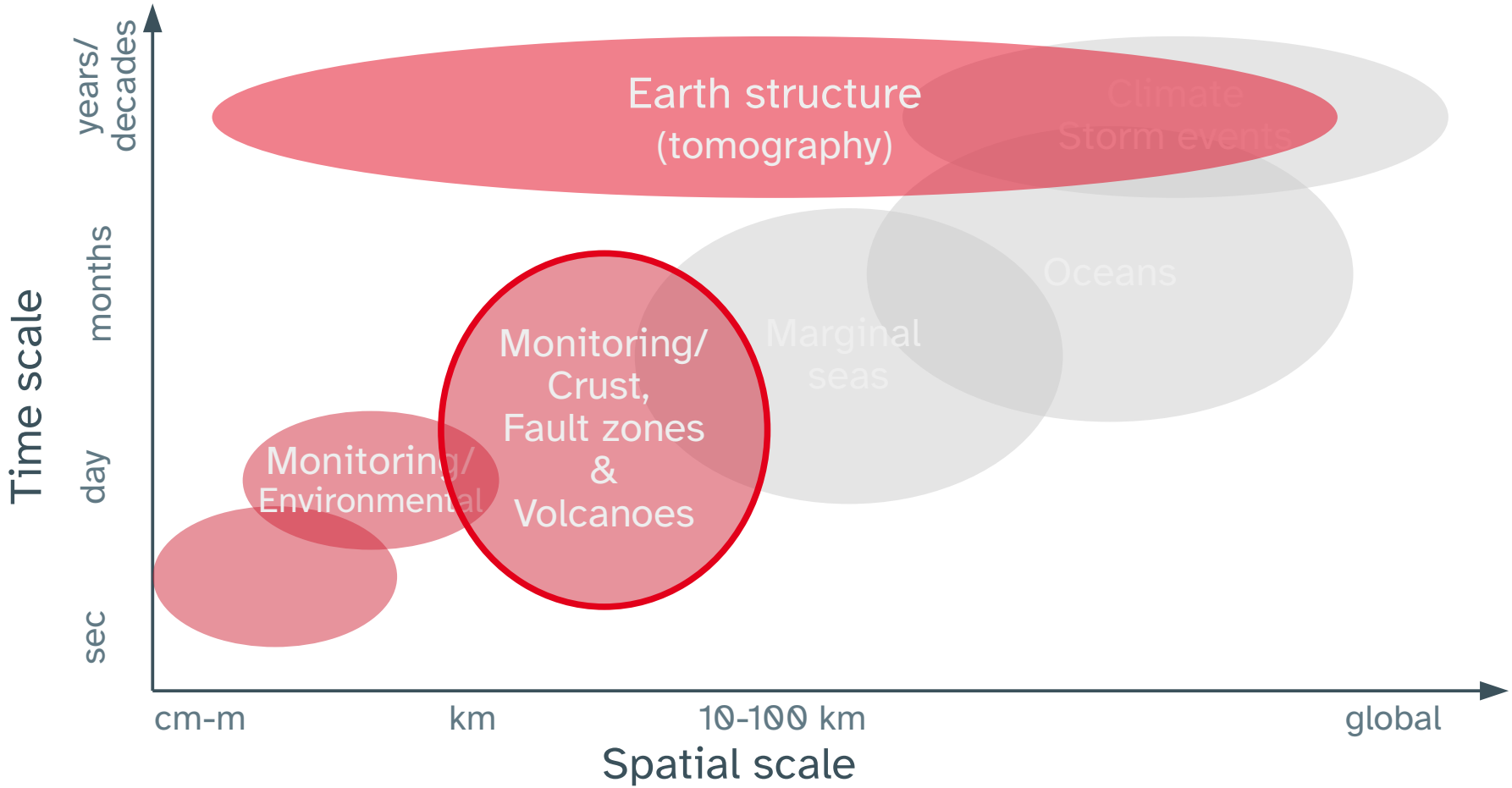
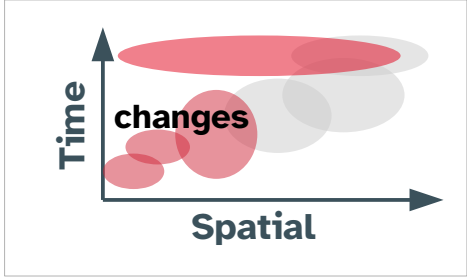
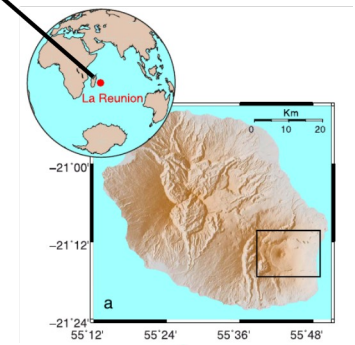


Monitoring: Volcanoes



Piton de la Fournaise (la Reunion):

Reunion Island,
Piton de la Fournaise volcano



Obermann et al. JGR (2013)

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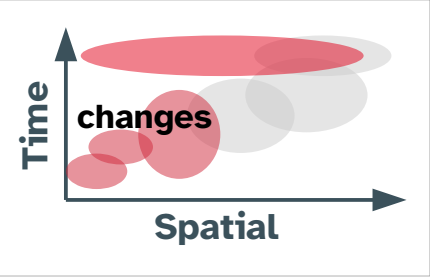

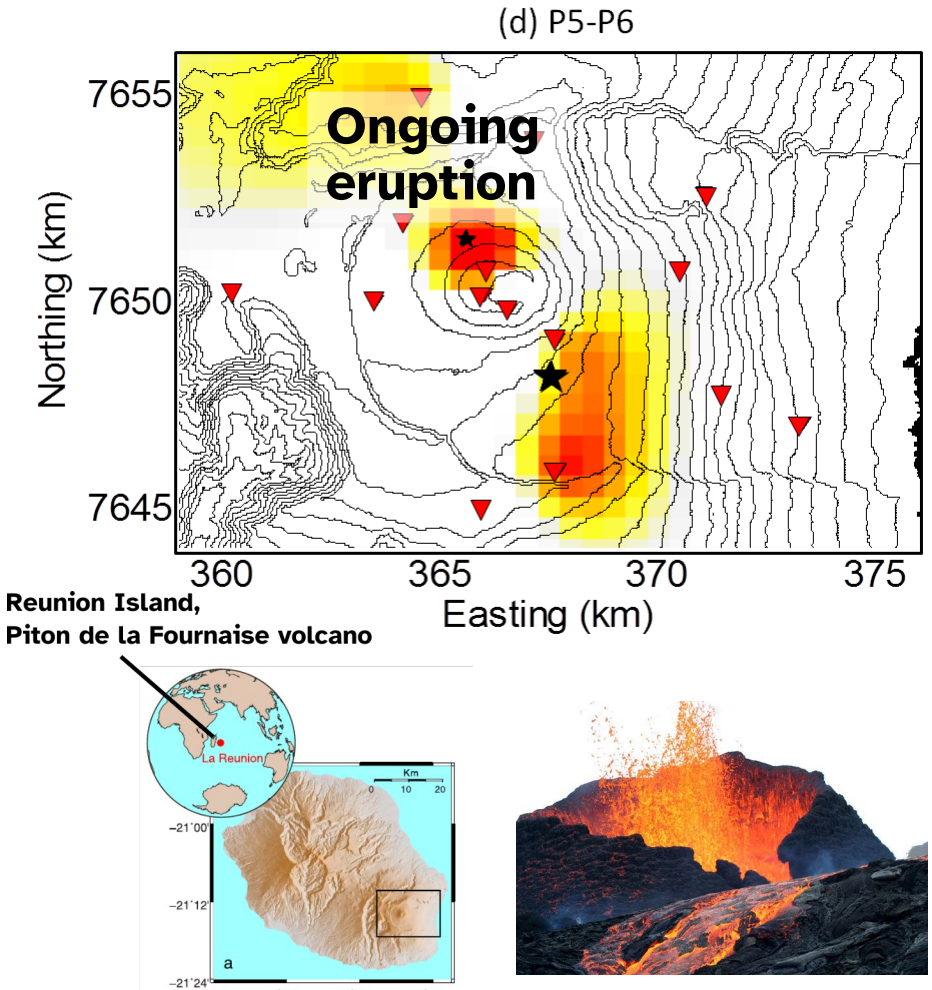

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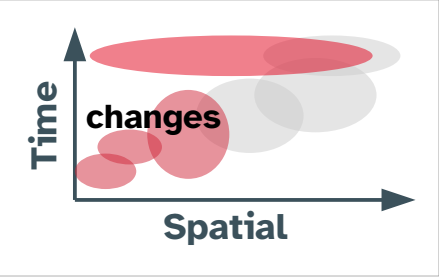
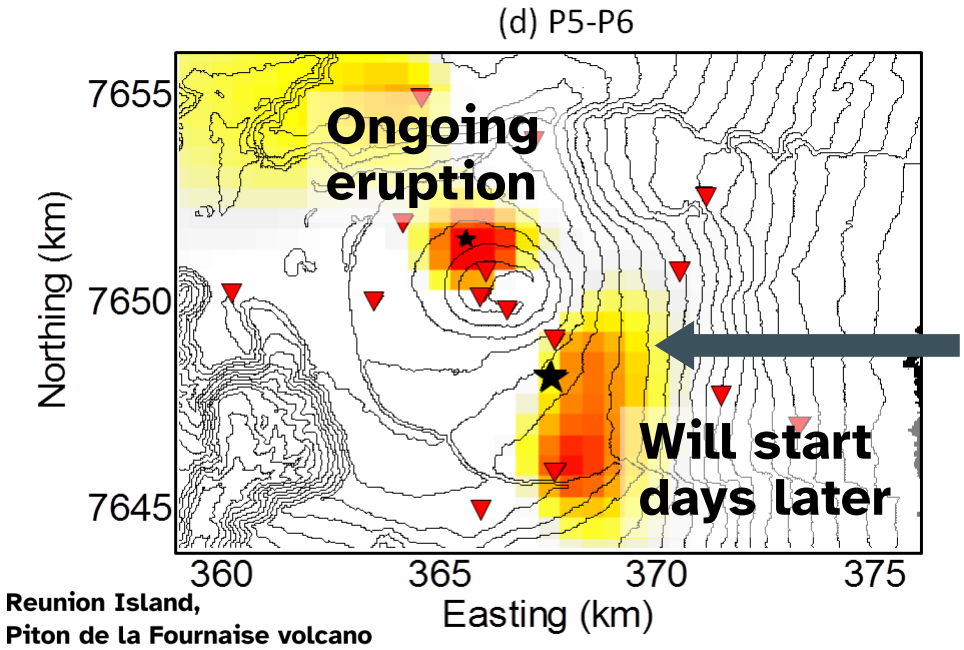
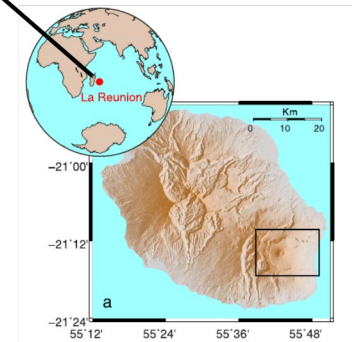




Piton de la Fournaise (la Reunion):

Subtle changes in **structure** days before eruption

Reunion Island, Piton de la Fournaise volcano



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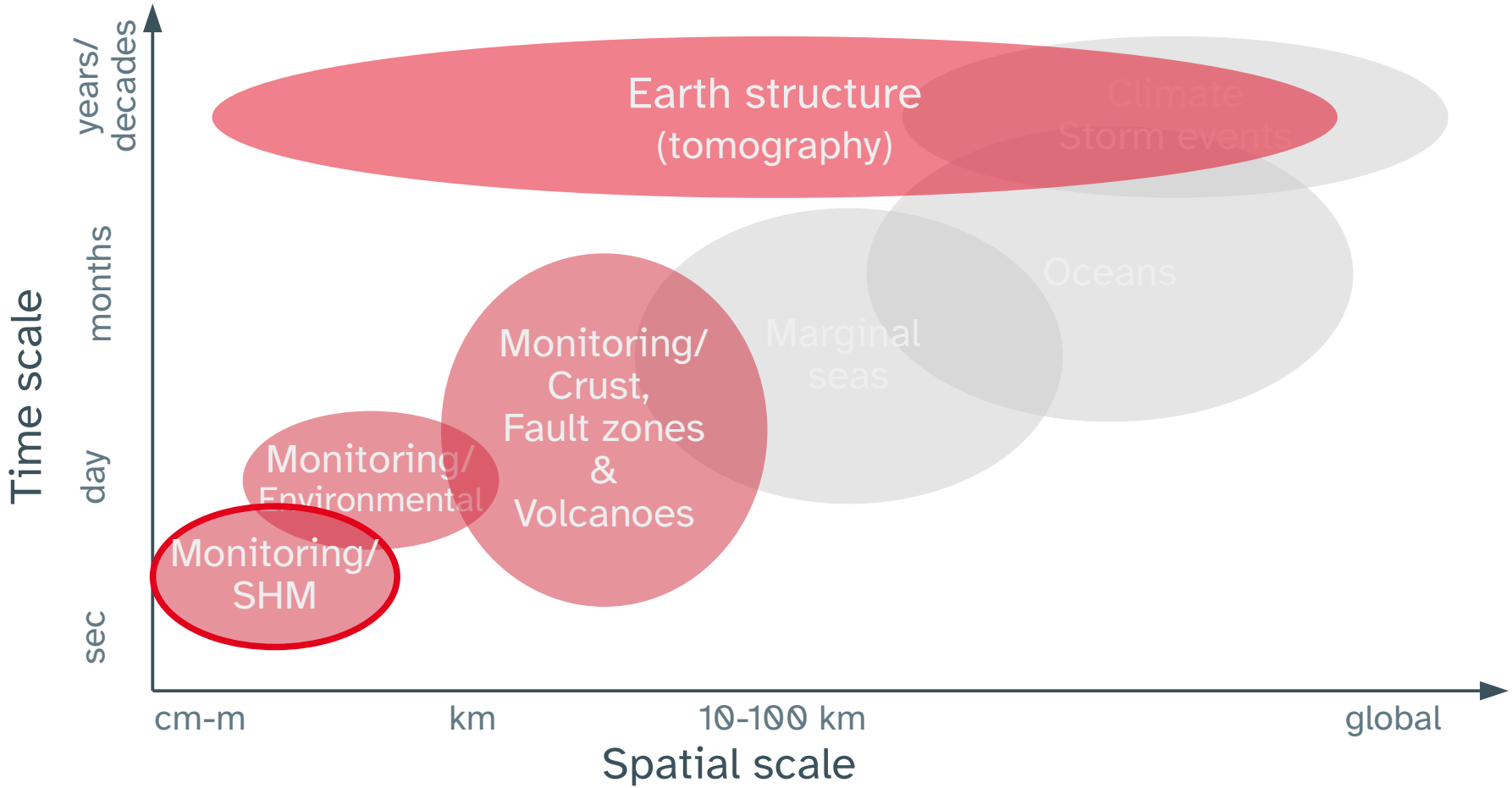

Monitoring: Structural Health Monitoring

Pre-stressed concrete „test bridge“

Results: Chun-Man Liao (BAM)
At UHH: Anjali Dhabu & Marco Dominguez Bureos

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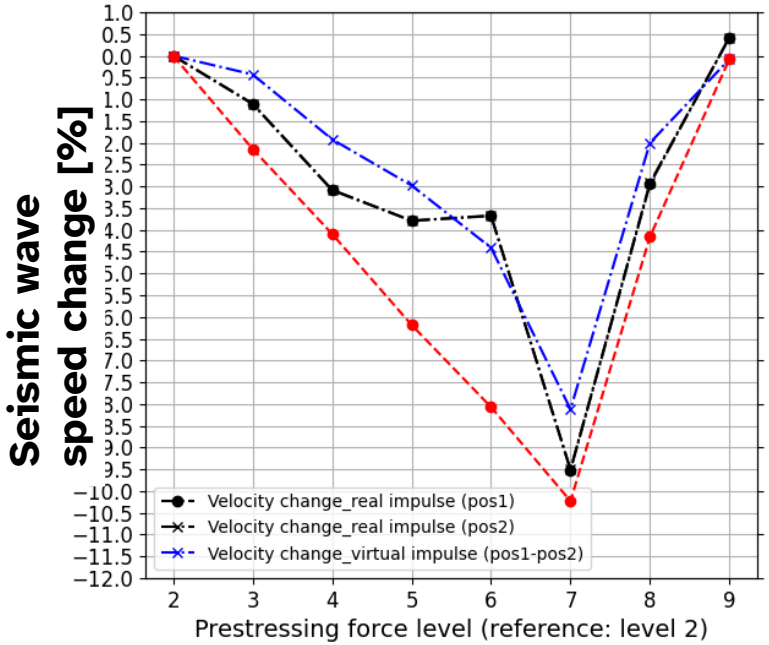
Pre-stressed concrete „test bridge“

Seismic measurements reflect changes of **elastic material properties** due to stress changes



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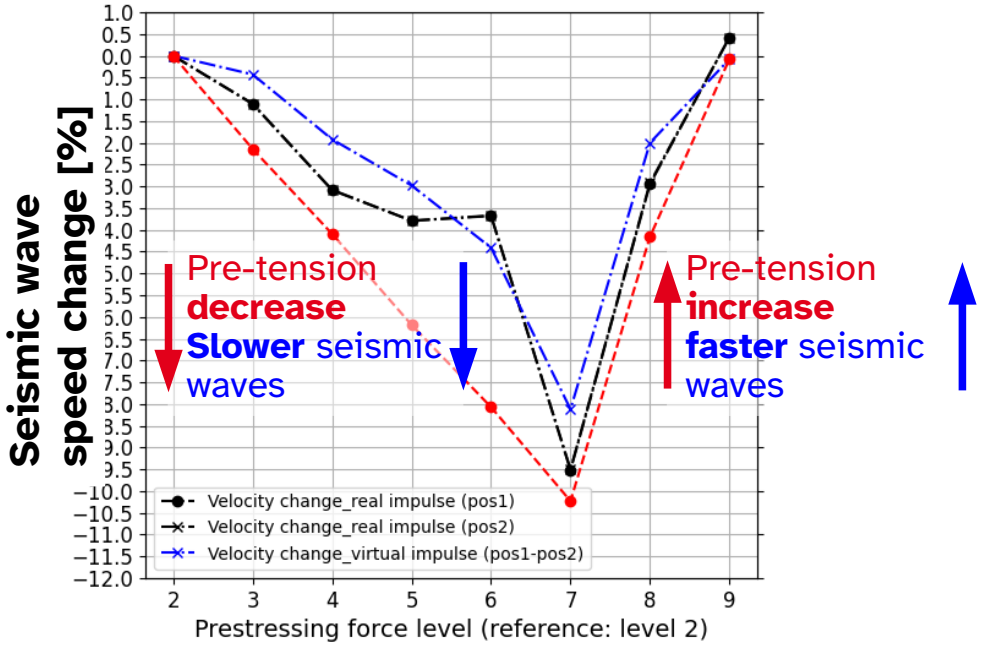

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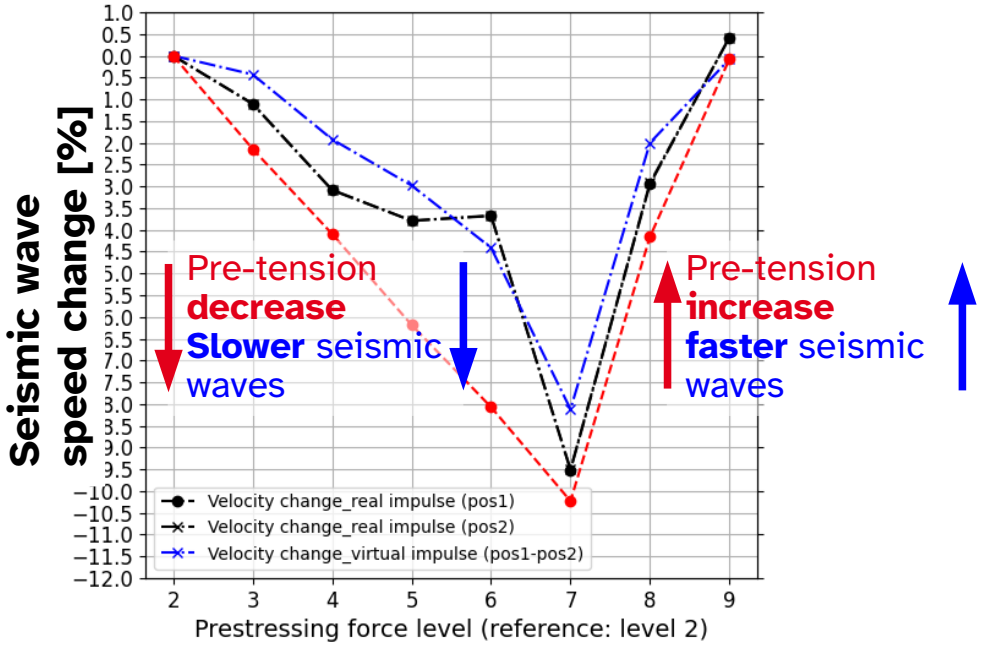
→ signature of **damage** developing?



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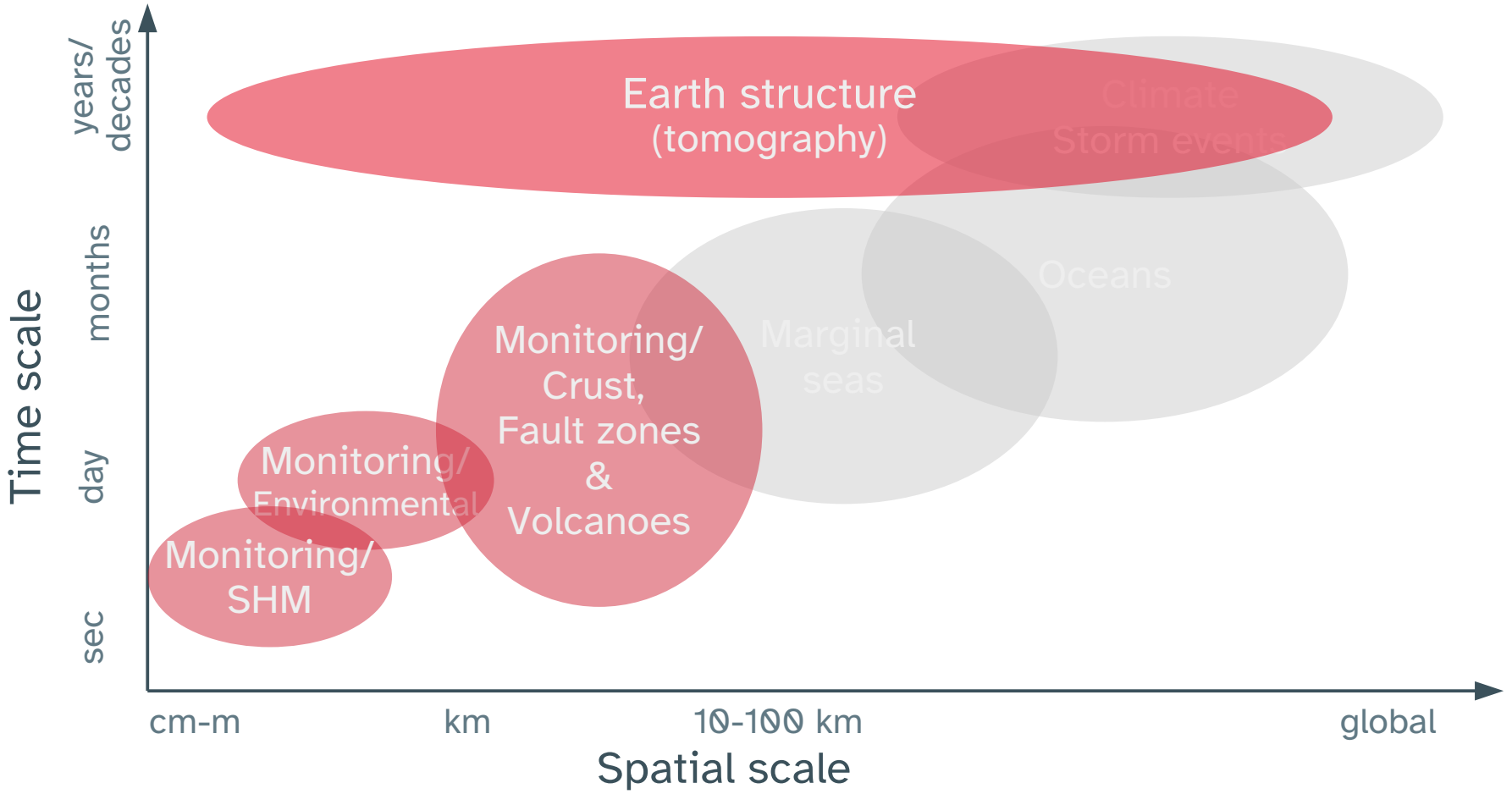

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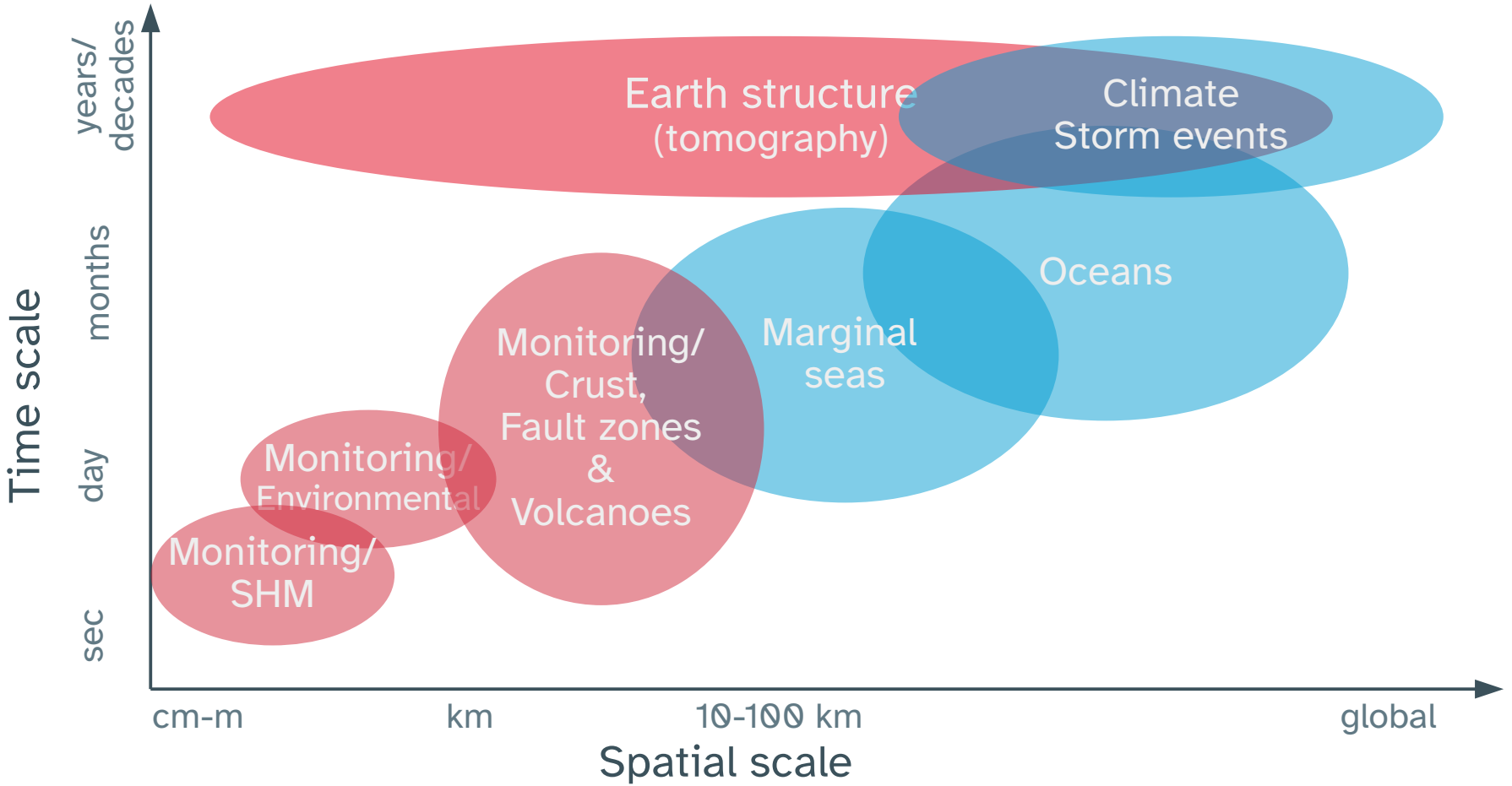
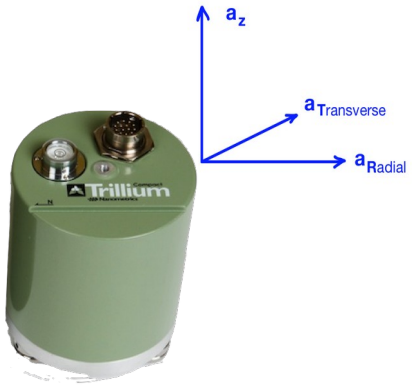


What‘s next? Rapid development in **seismic instrumentation**

Traditional:
Broadband seismometer

→ Measure translations
@single point



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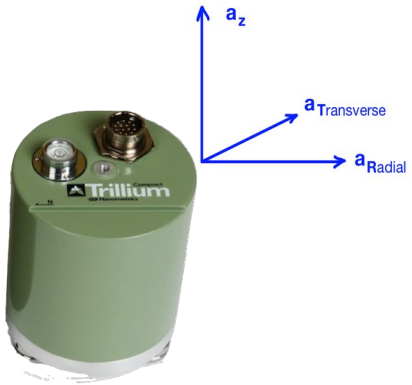

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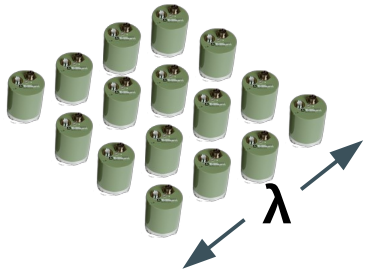

1/ very **dense deployments** of seismic sensors
→ measure whole wave *field*

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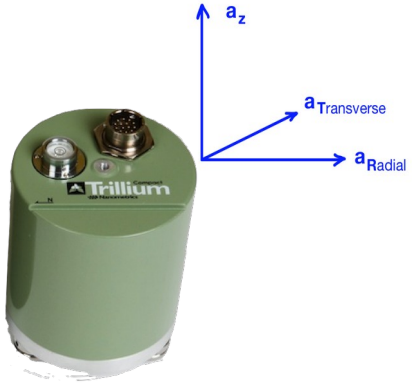

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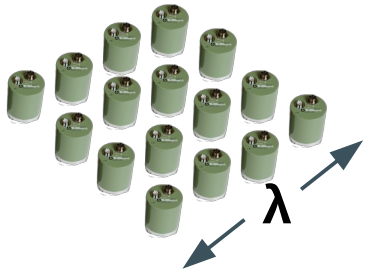

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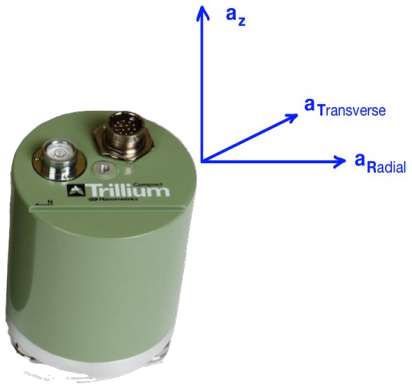

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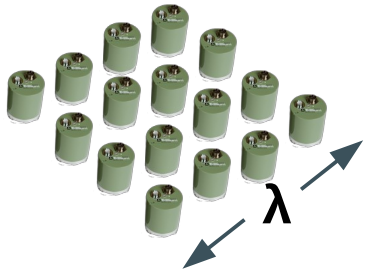

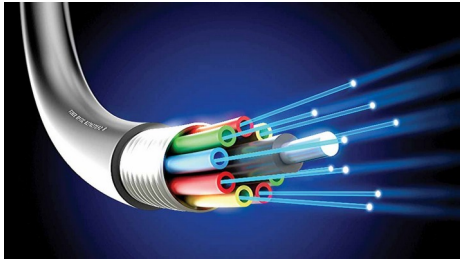

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3/ measure strain along **glass fiber**:
„Distributed Acoustic Sensing“ (**DAS**)
→ extremely high spatial resolution

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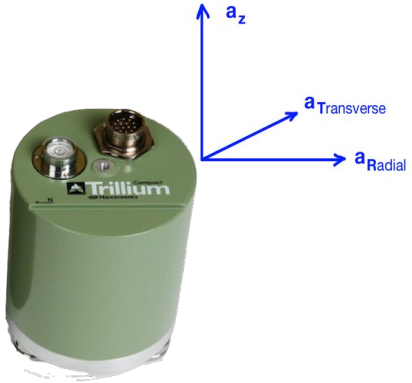

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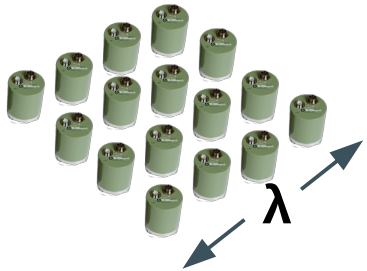

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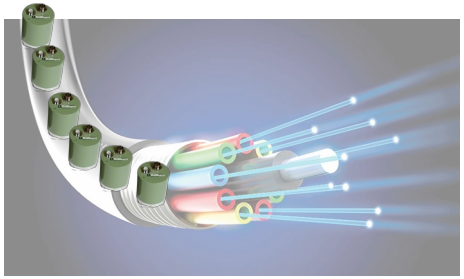

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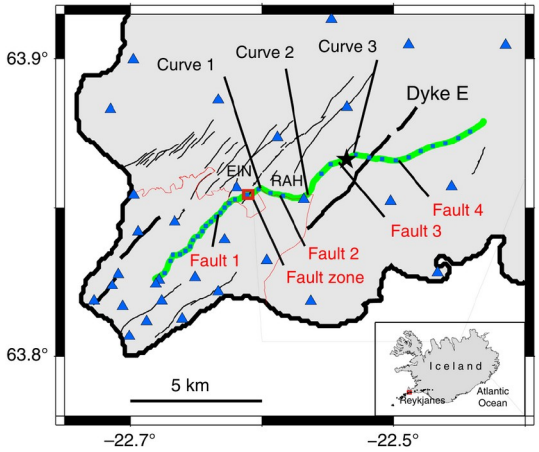
Detecting seismic velocity changes with DAS (Iceland)



Youtube:

Regina Maaß

GFZ Helmholtz Centre Potsdam

UHH

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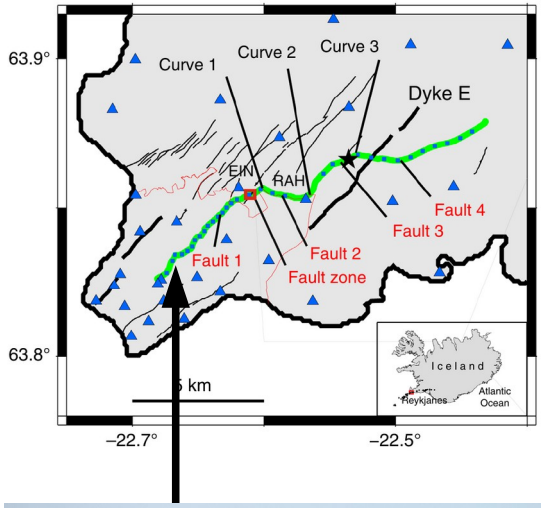

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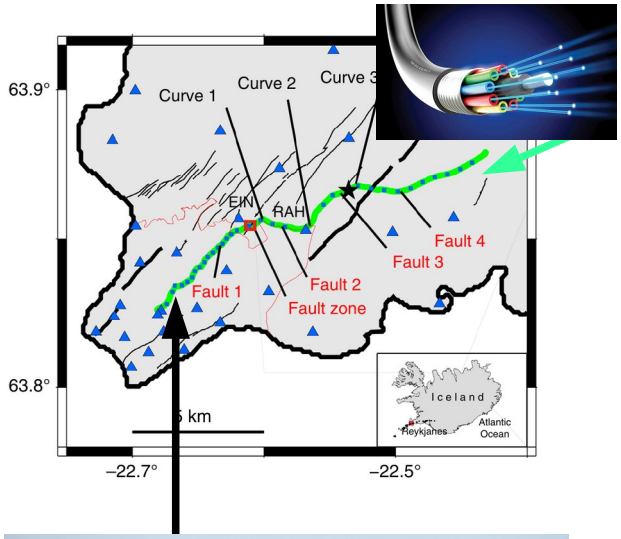

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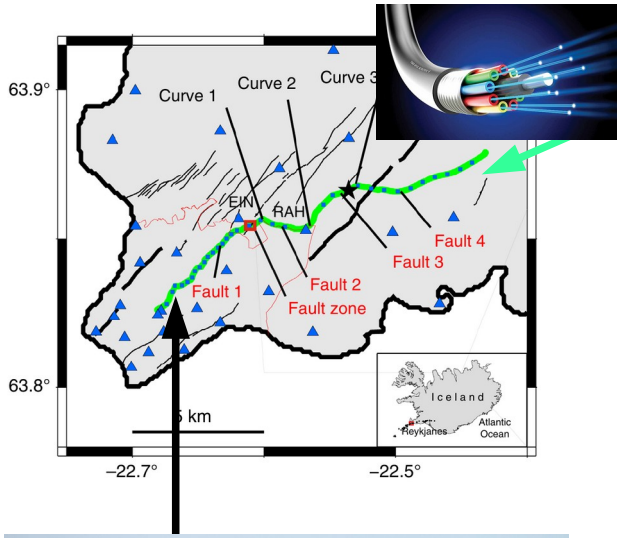

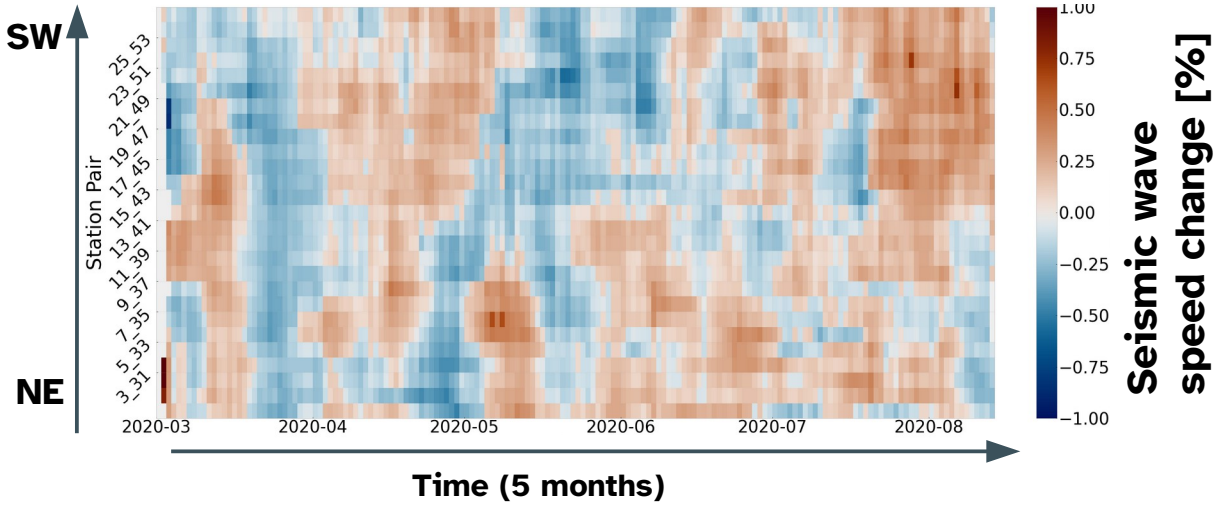

22 km of „dark fiber“ used as seismic sensors
Months before eruption of Fagradalsfjall

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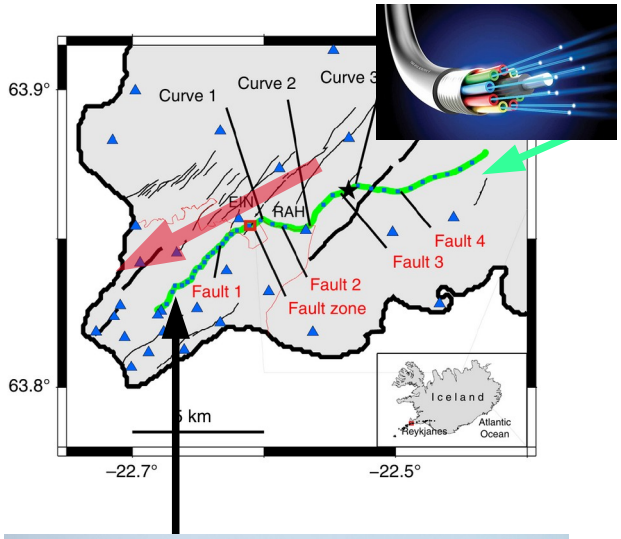

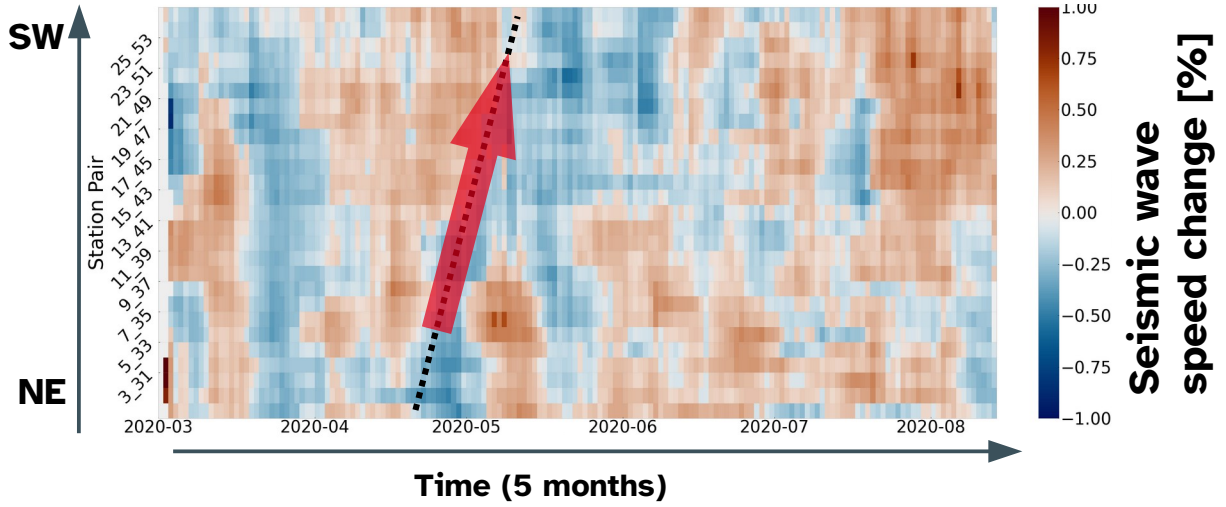

22 km of „dark fiber“ used as seismic sensors
Months before eruption of Fagradalsfjall

Slow material (warm? Soft? Fluid?)
migrating NE-SW
= fluids migrating?
= lava moving?

Youtube:

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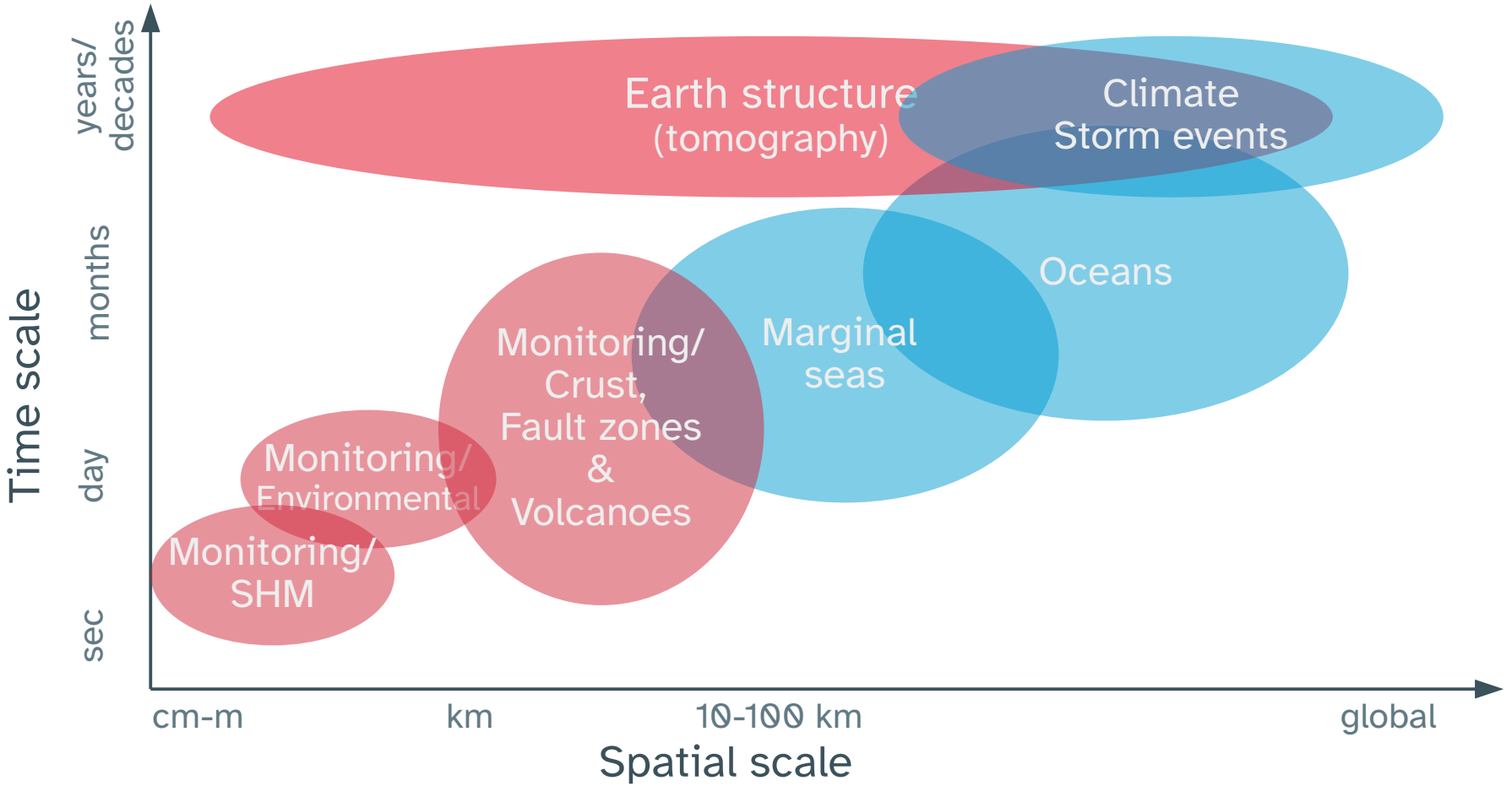
What can we learn about the Earth by **listening** to ambient seismic noise?



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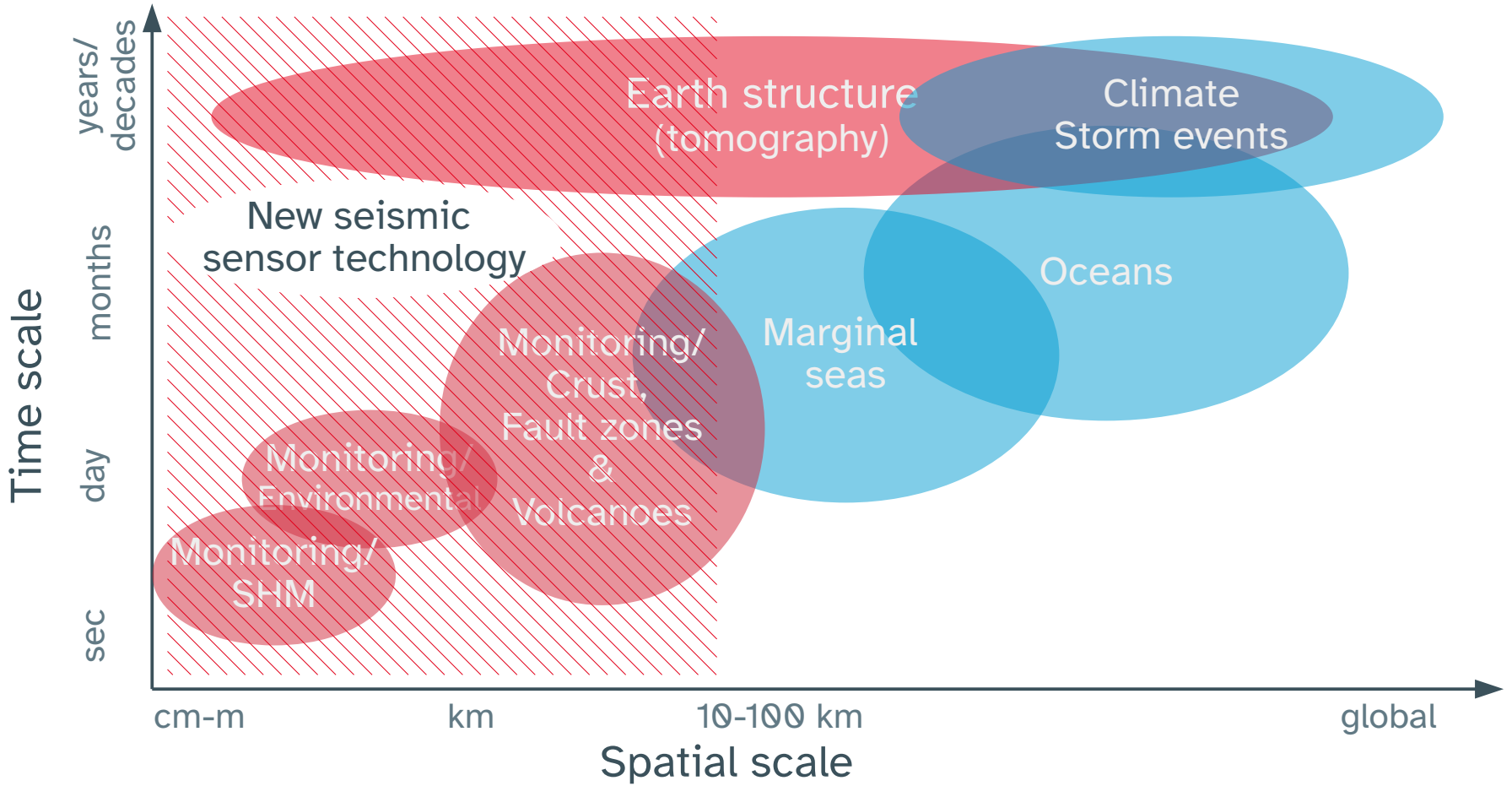

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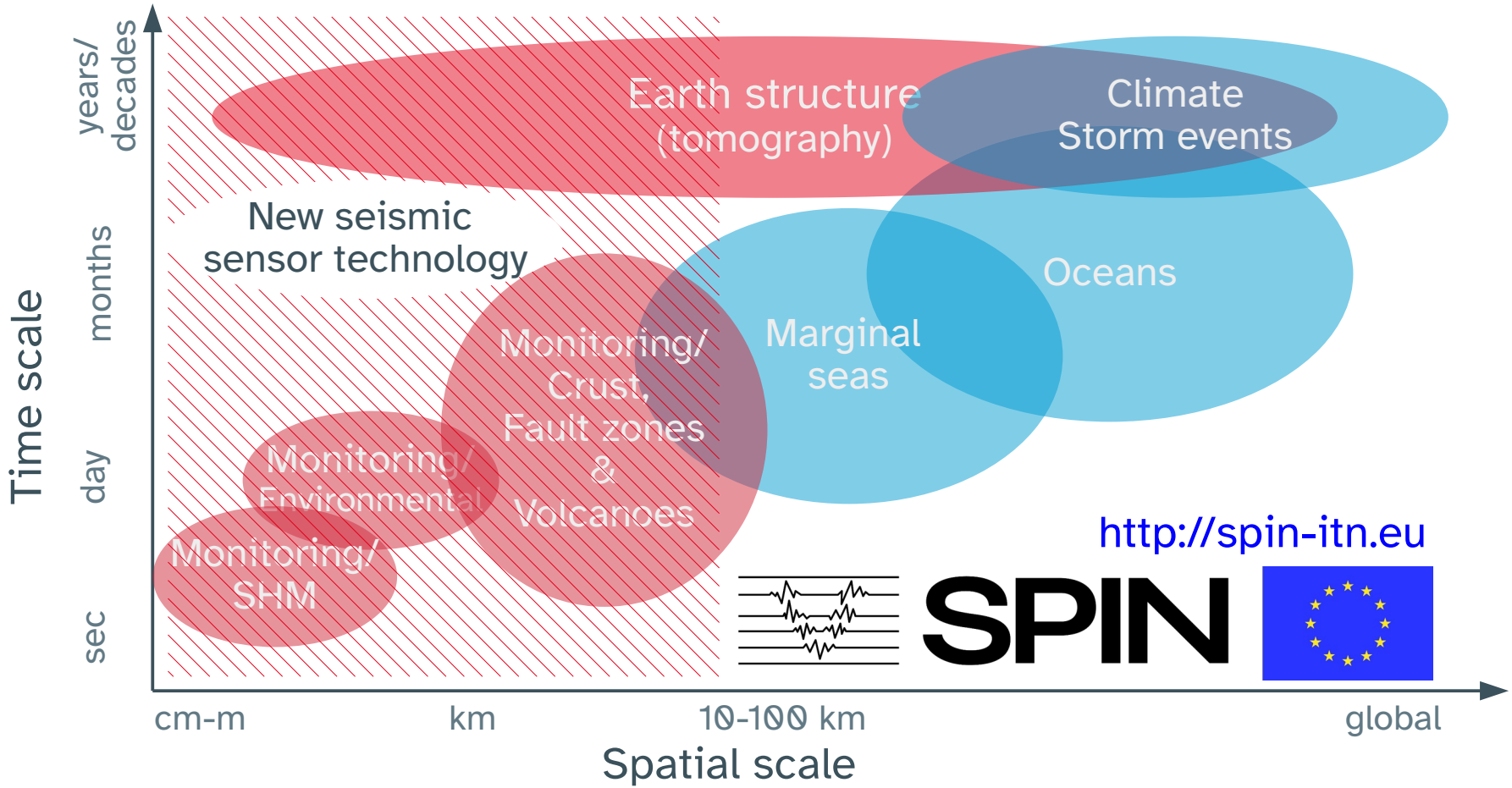
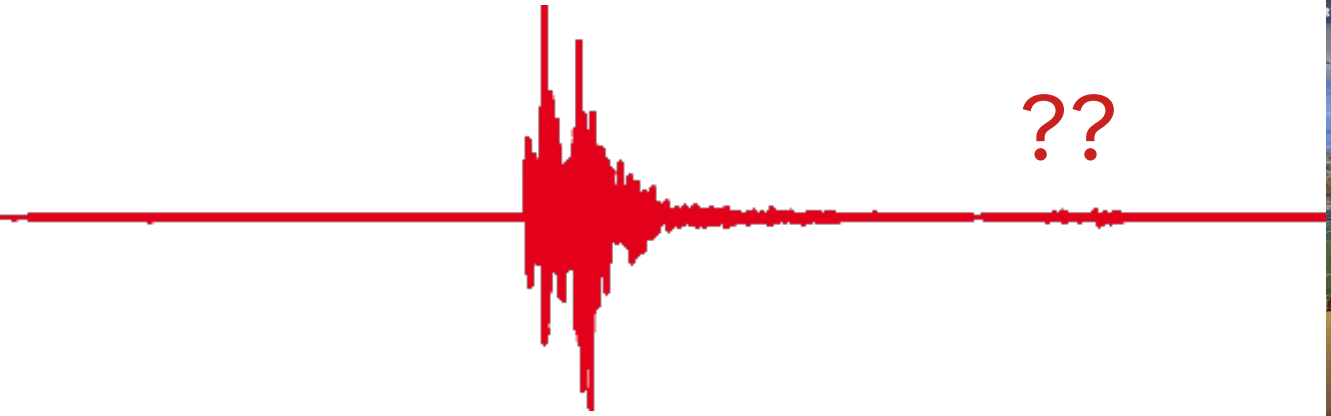


http://spin-itn.eu

SPIN

How can seismology help high-precision physics experiments?



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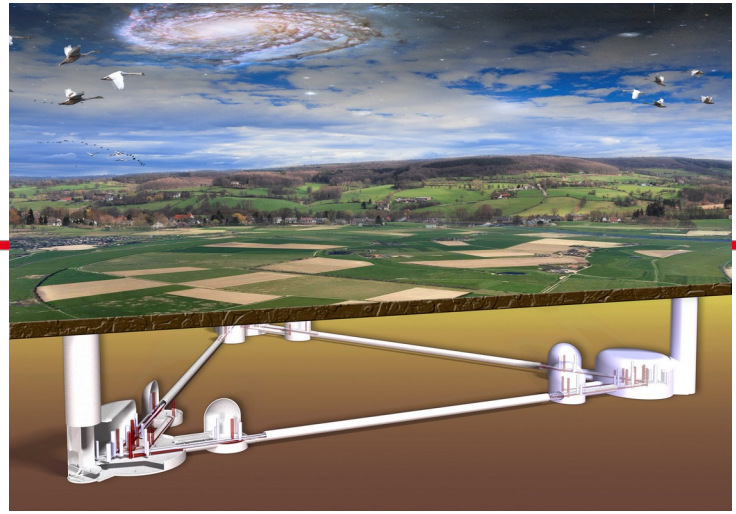

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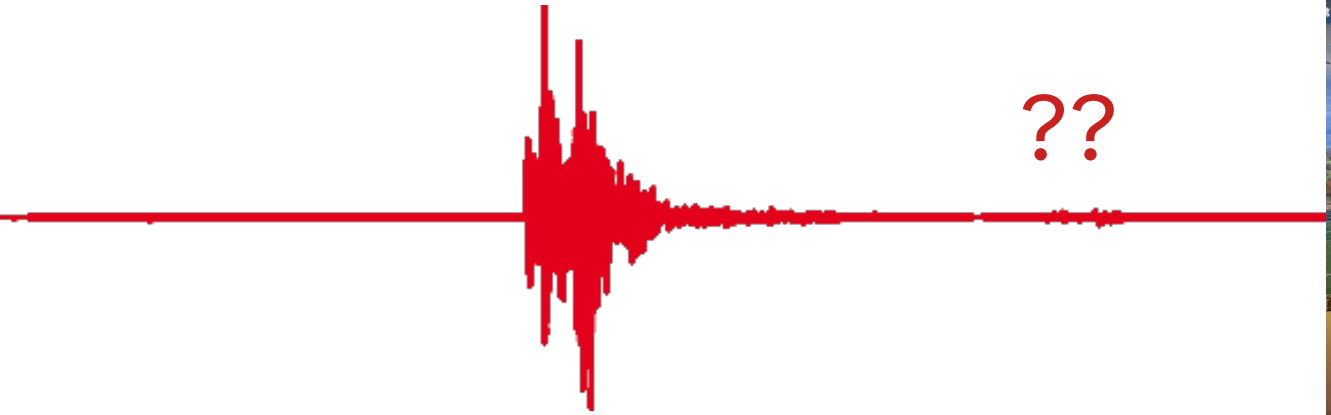

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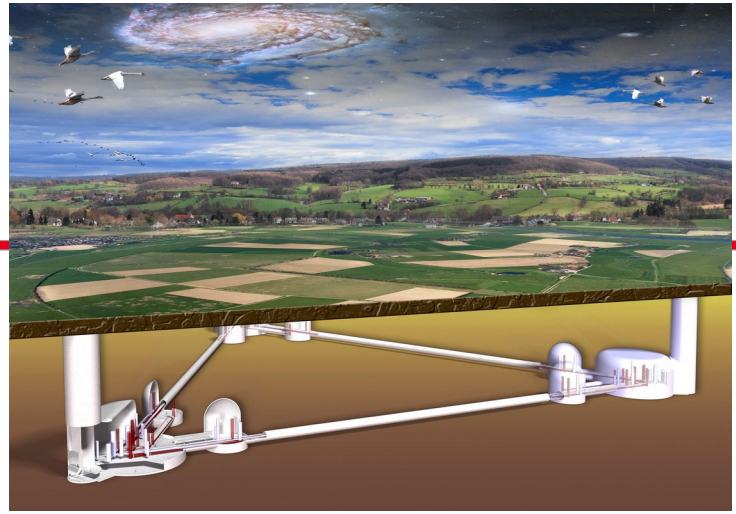

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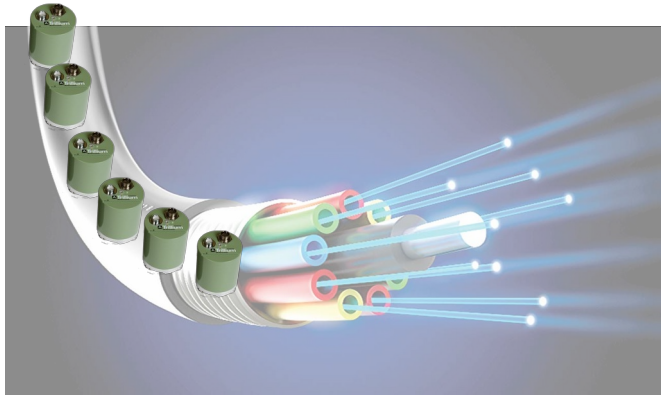
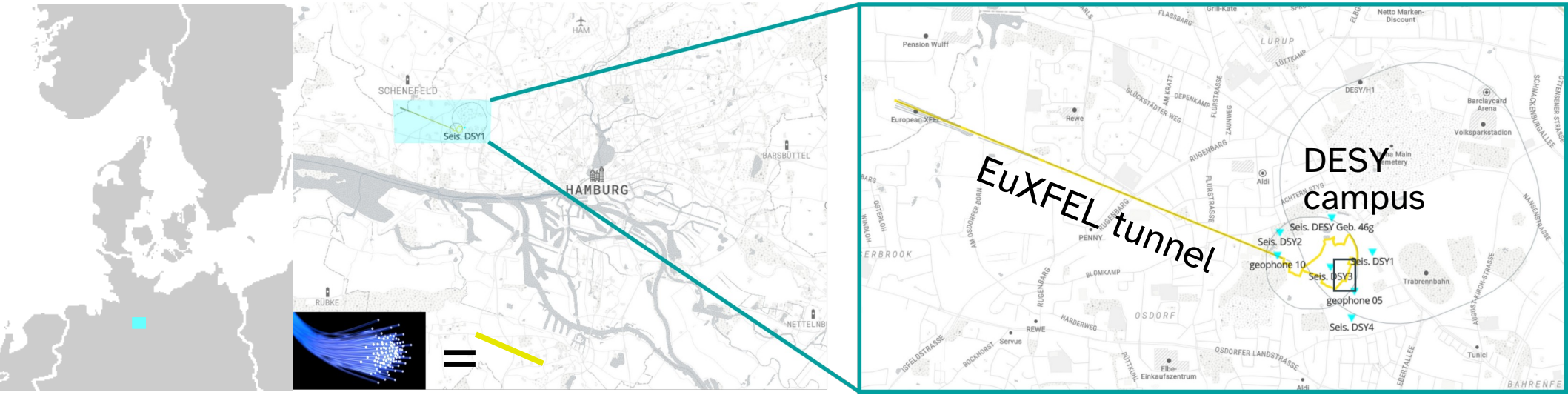


WAVE initiative: proof-of-concept for use of DAS on research campi



DAS → laser pulses to measure strain inside a glass fiber due to external forces
extremely high spatial resolution (~1 – 10m ≈ 0.01λ)
On DESY and EuXFEL campus: Converted **12.6 km „dark fiber“** to seismic sensors
http://wave-hamburg.eu

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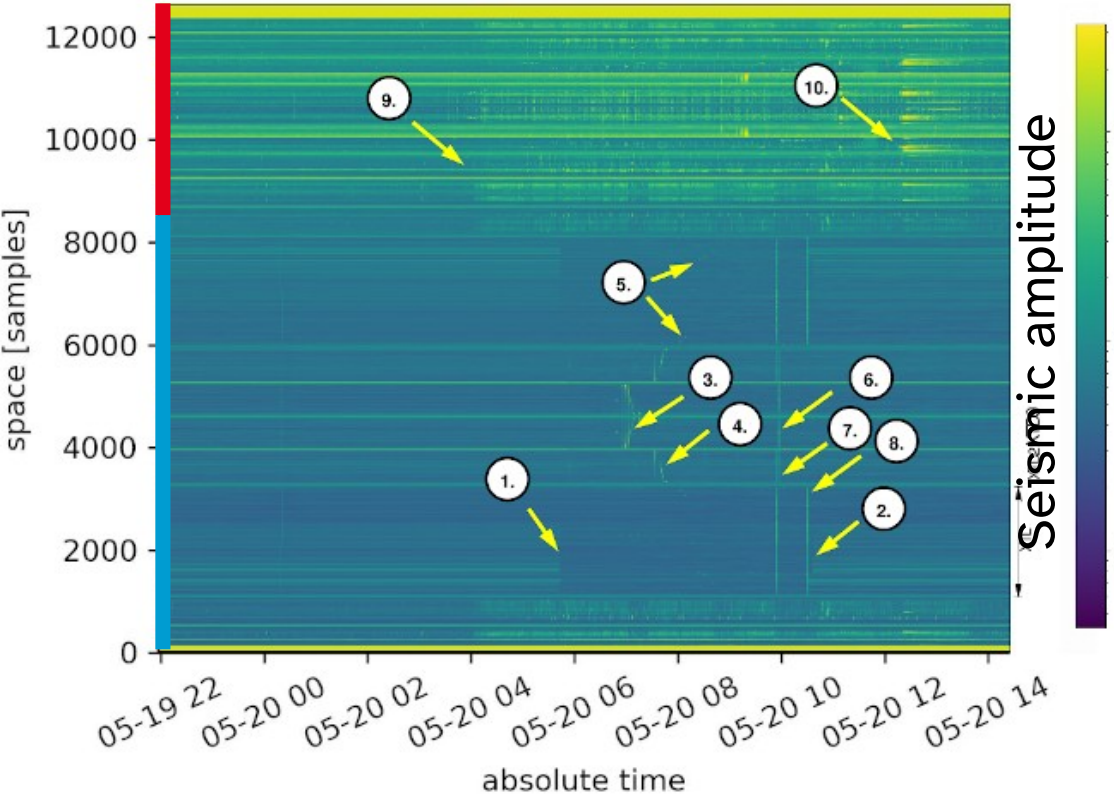

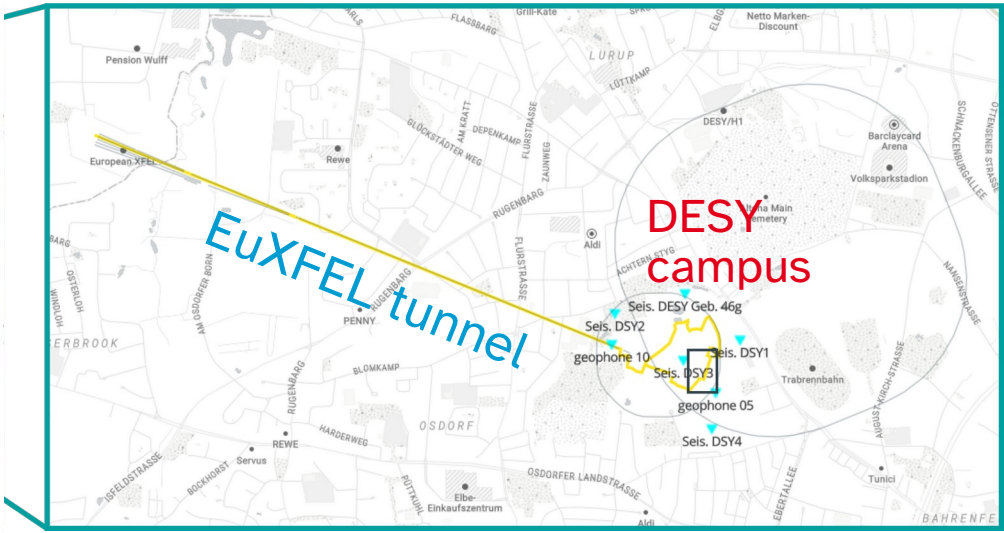

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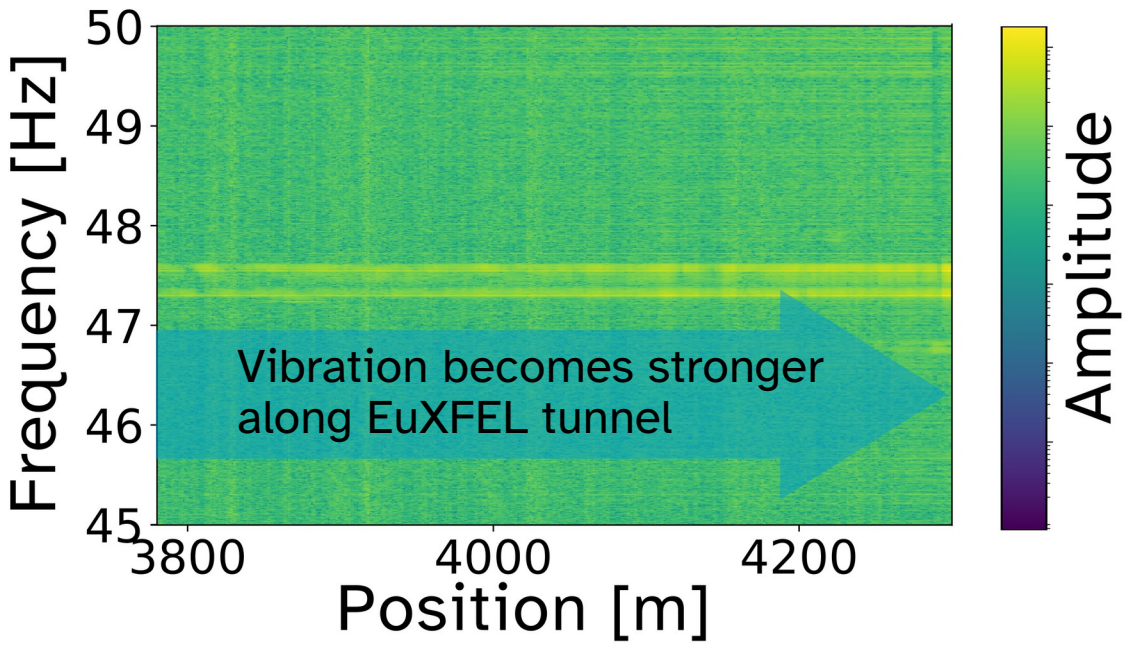
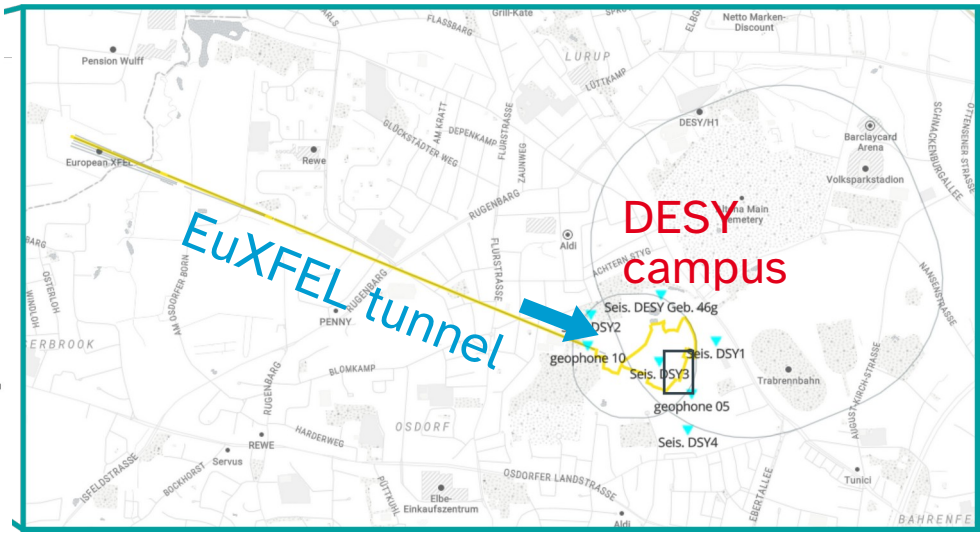
47.5 Hz disturbance on EuXFEL photon beam





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Takeaway message

Listen to the seismic noise!

Youtube:

Contact: celine.hadzii.com

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Ask me anything!

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