

# Fundamentals of Seismology

A data-focused view

Turkey & Syria  
06.02.2023  
Magnitude 7.8



Myanmar  
28.03.2025  
Magnitude 7.7





Italy

23.08.2016

Magnitude 6.2



Japan  
11.03.2011  
Magnitude 9.1



Targets



Data



# Targets



# Data



# Targets

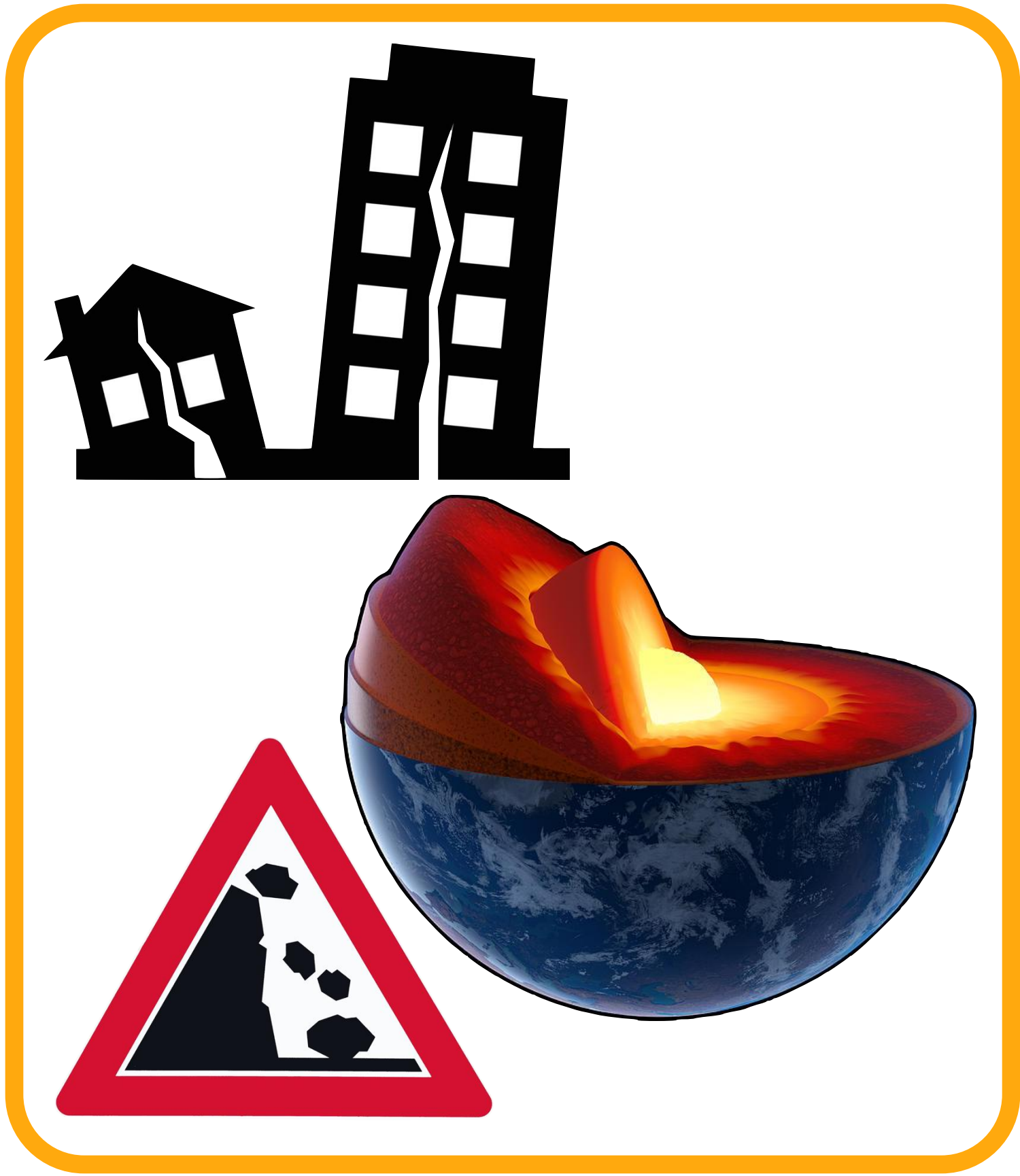


# Data

Raw data

Derived data

# Targets

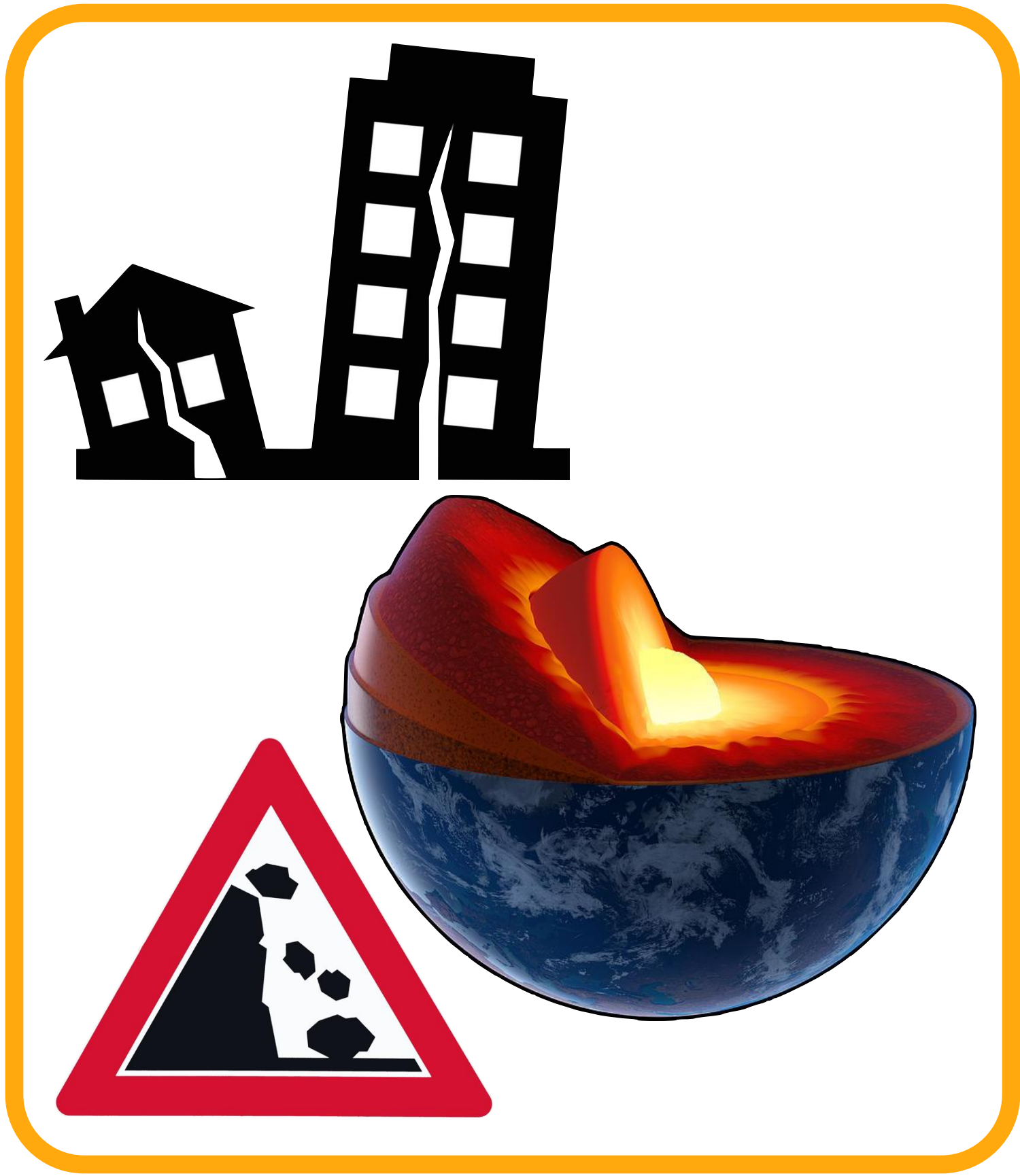


# Data

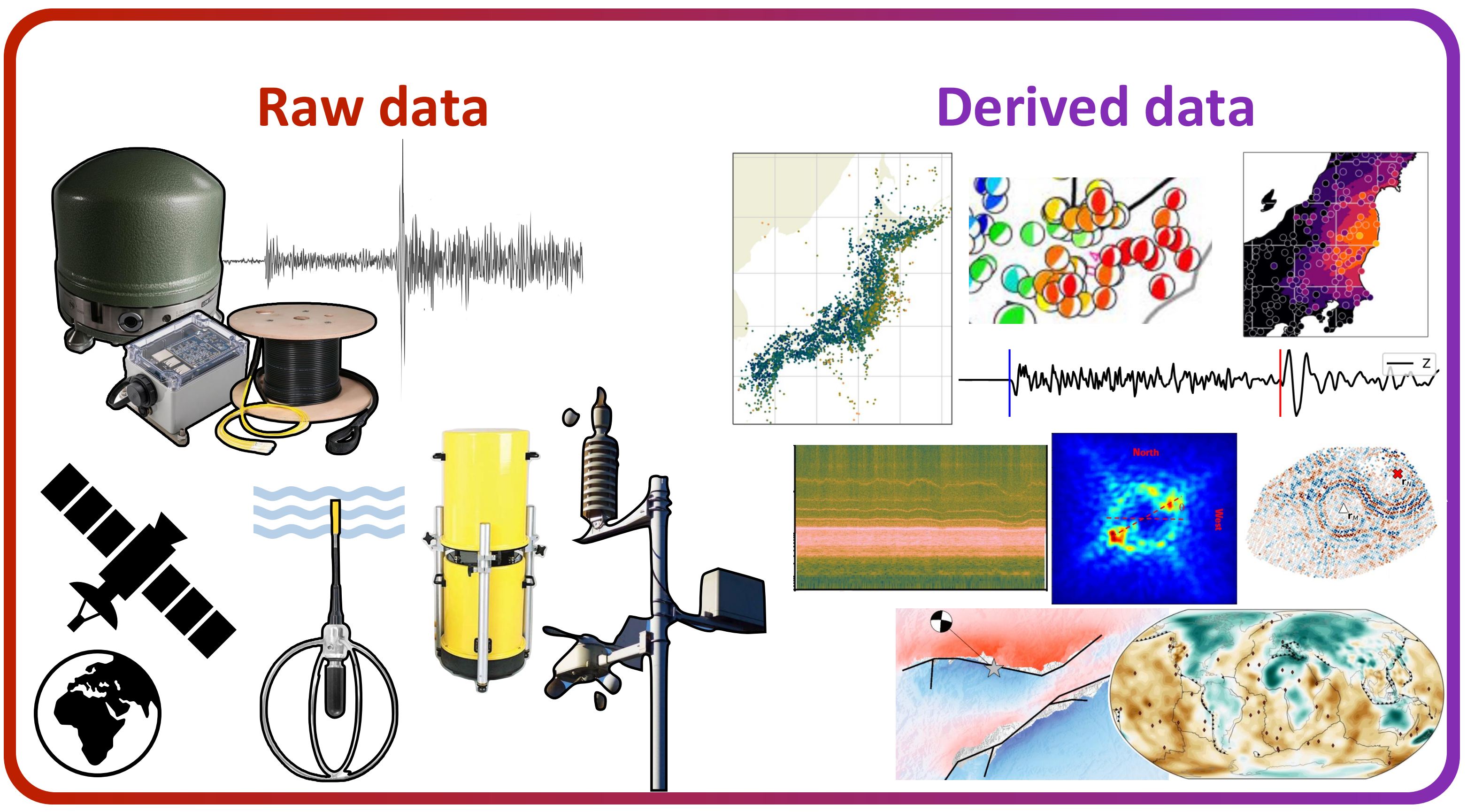
**Raw data** **Derived data**

This complex block contains various icons related to data collection. At the top left, there is a green radar dome on a pedestal, connected to a grey electronic control box and a spool of black cables. To the right of these is a black waveform graph. Below the radar is a satellite with solar panels and a small globe of the Earth. In the center, there is a hydrophone with blue wavy lines above it. To the right of the hydrophone is a yellow cylindrical buoy. On the far right, there is a complex sensor rig with a vertical pole, a horizontal arm, and a sensor head.

# Targets



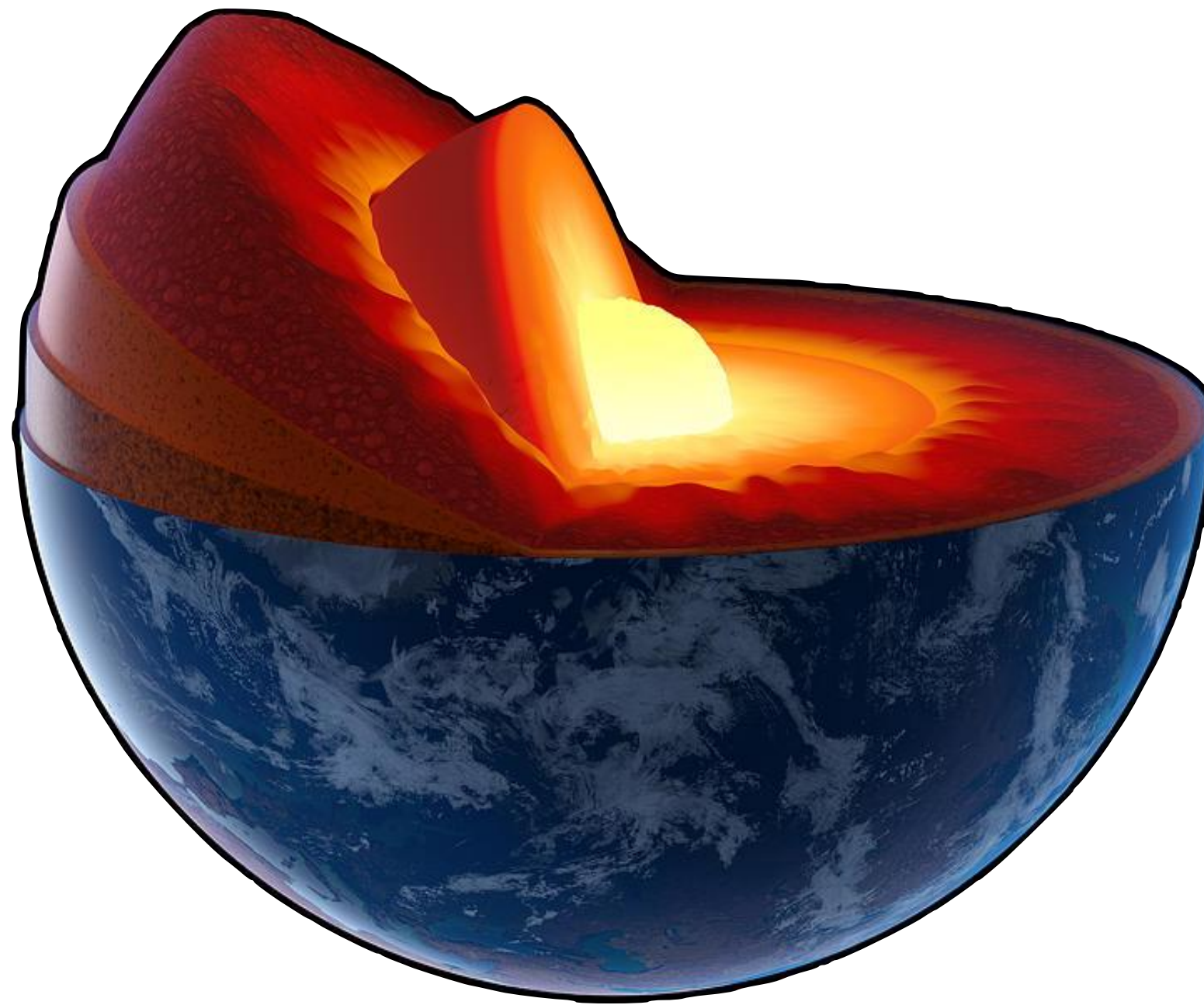
# Data



## Earthquakes



## Earth structure



## Environment



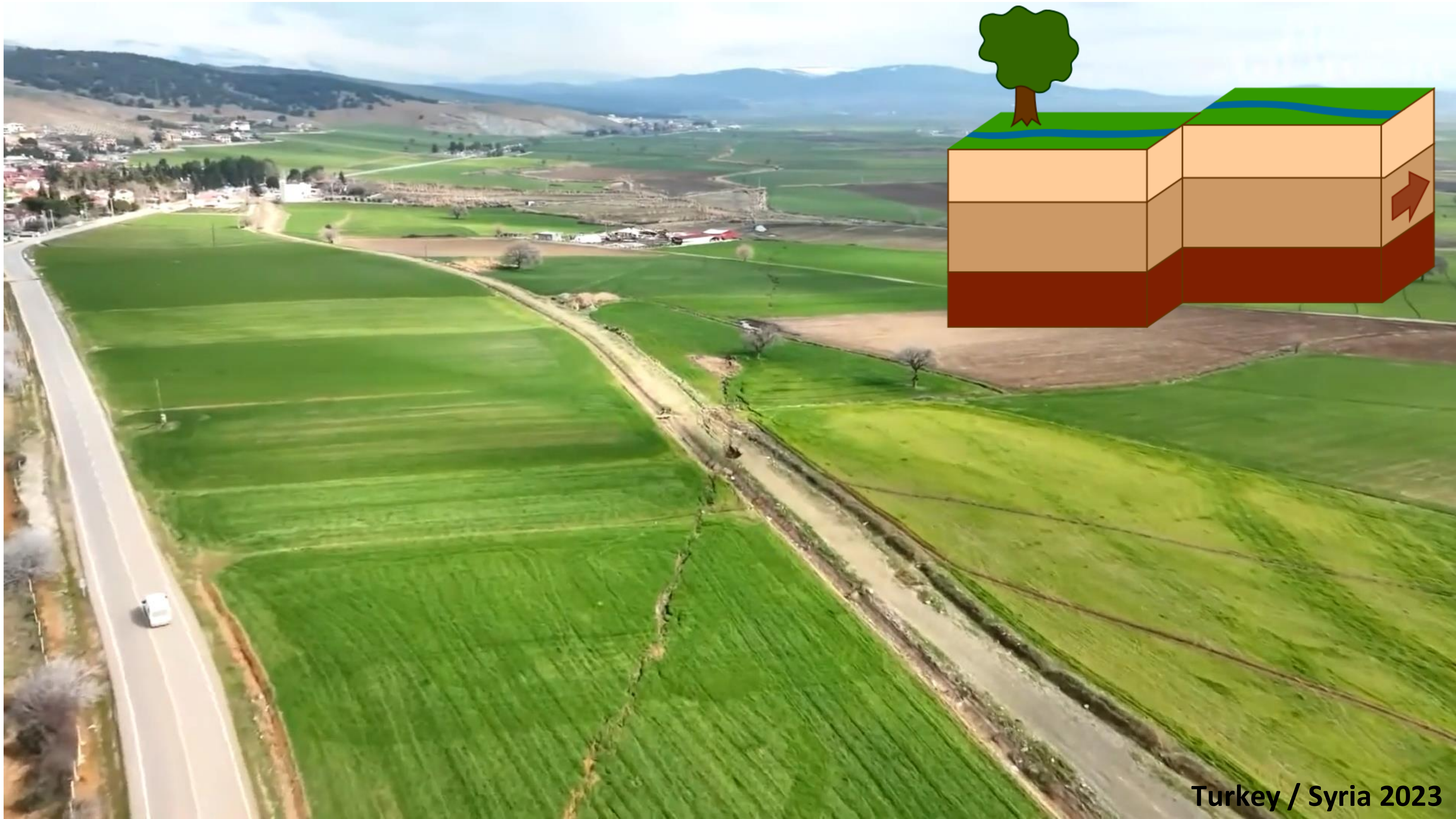
# Earthquakes



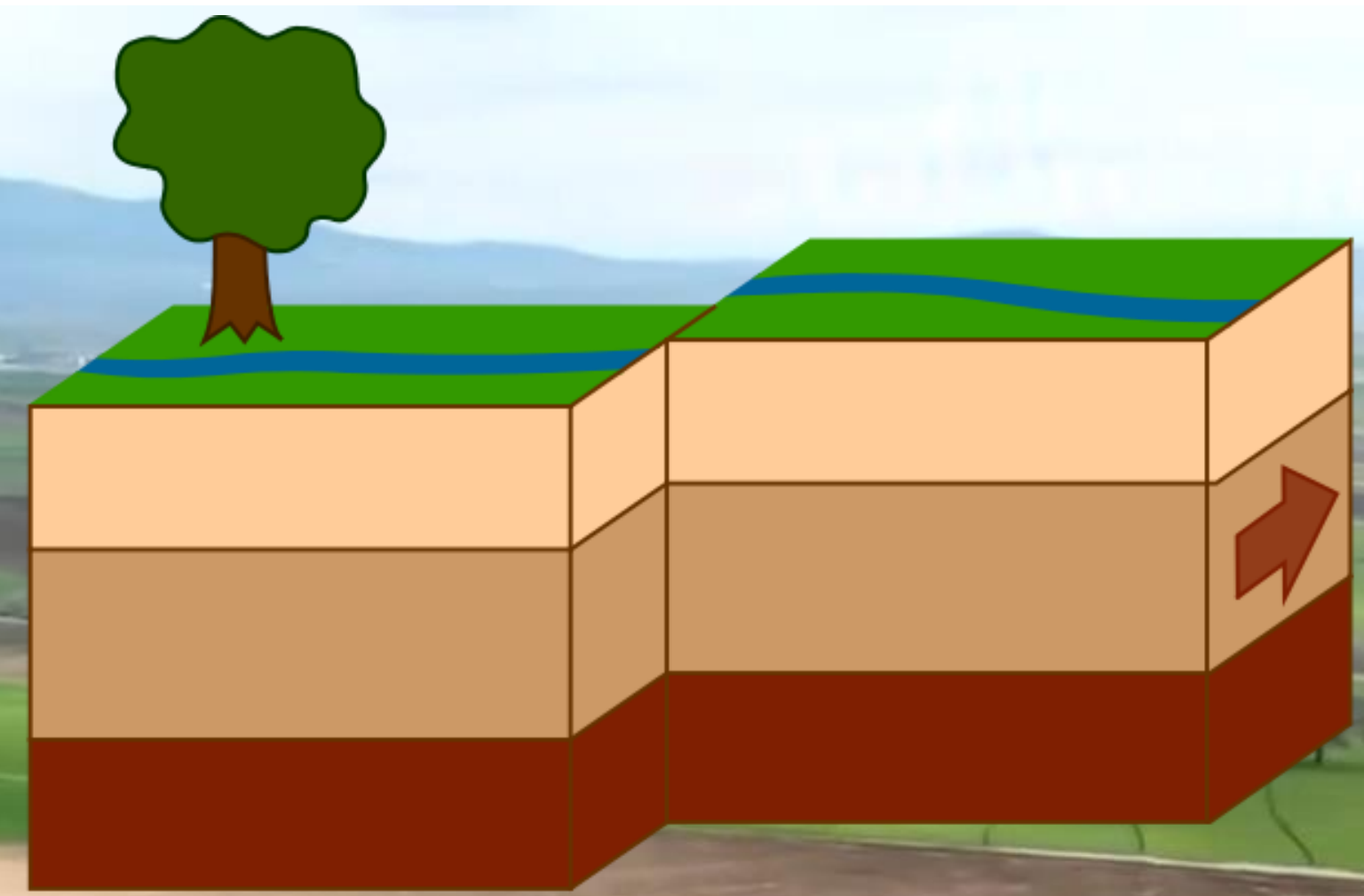
# Earthquakes | What is an earthquake?



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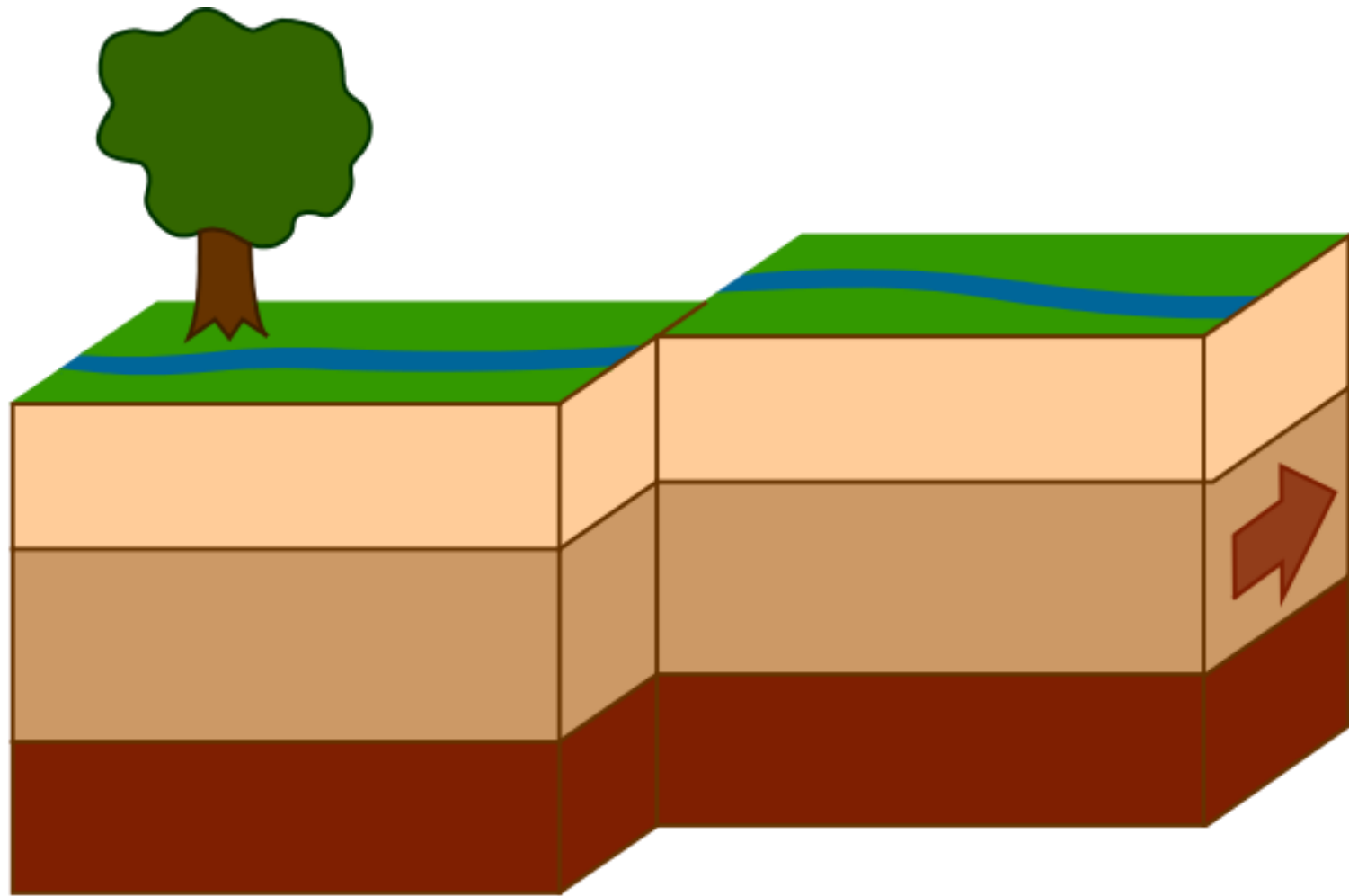
Strike-slip fault



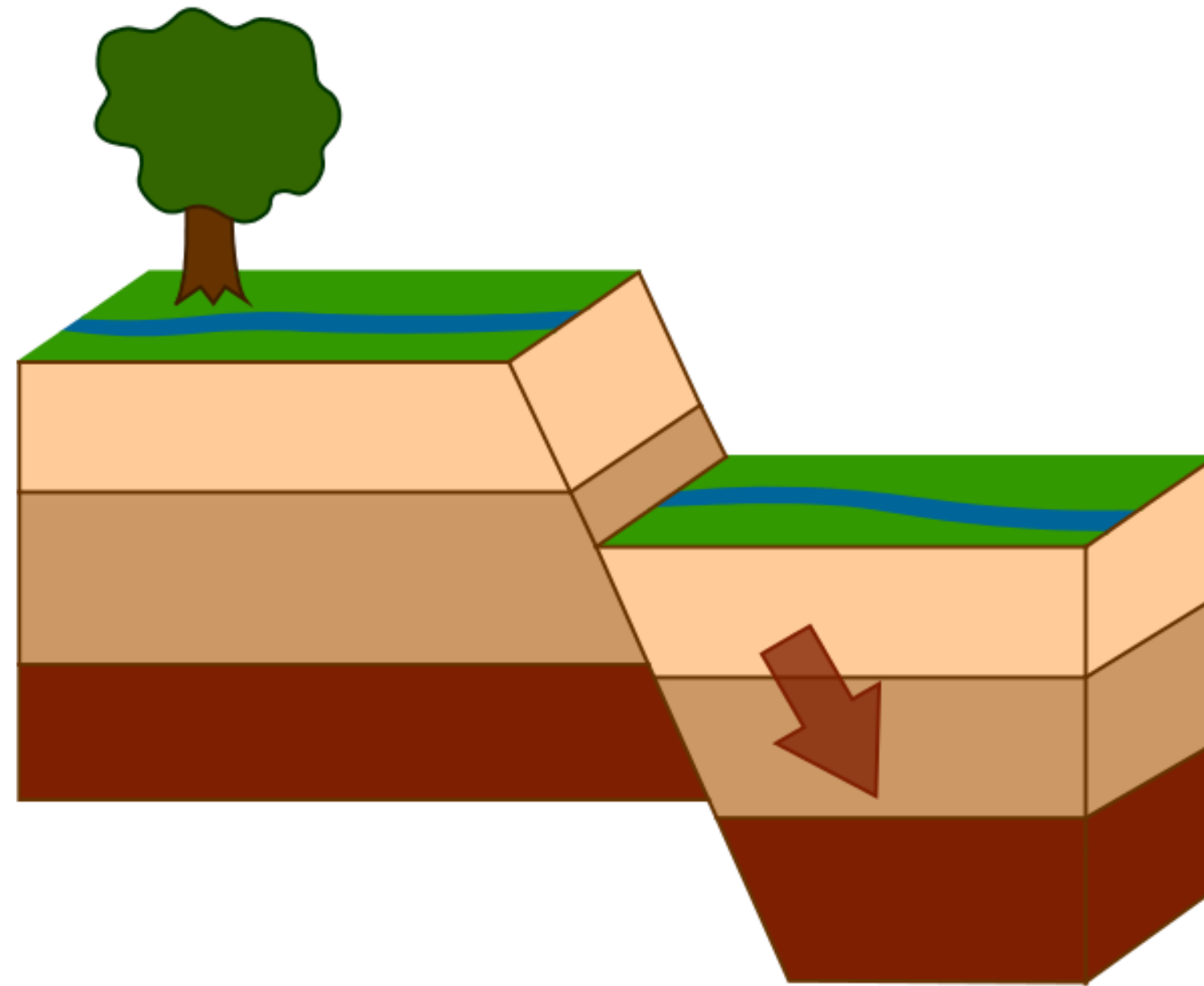
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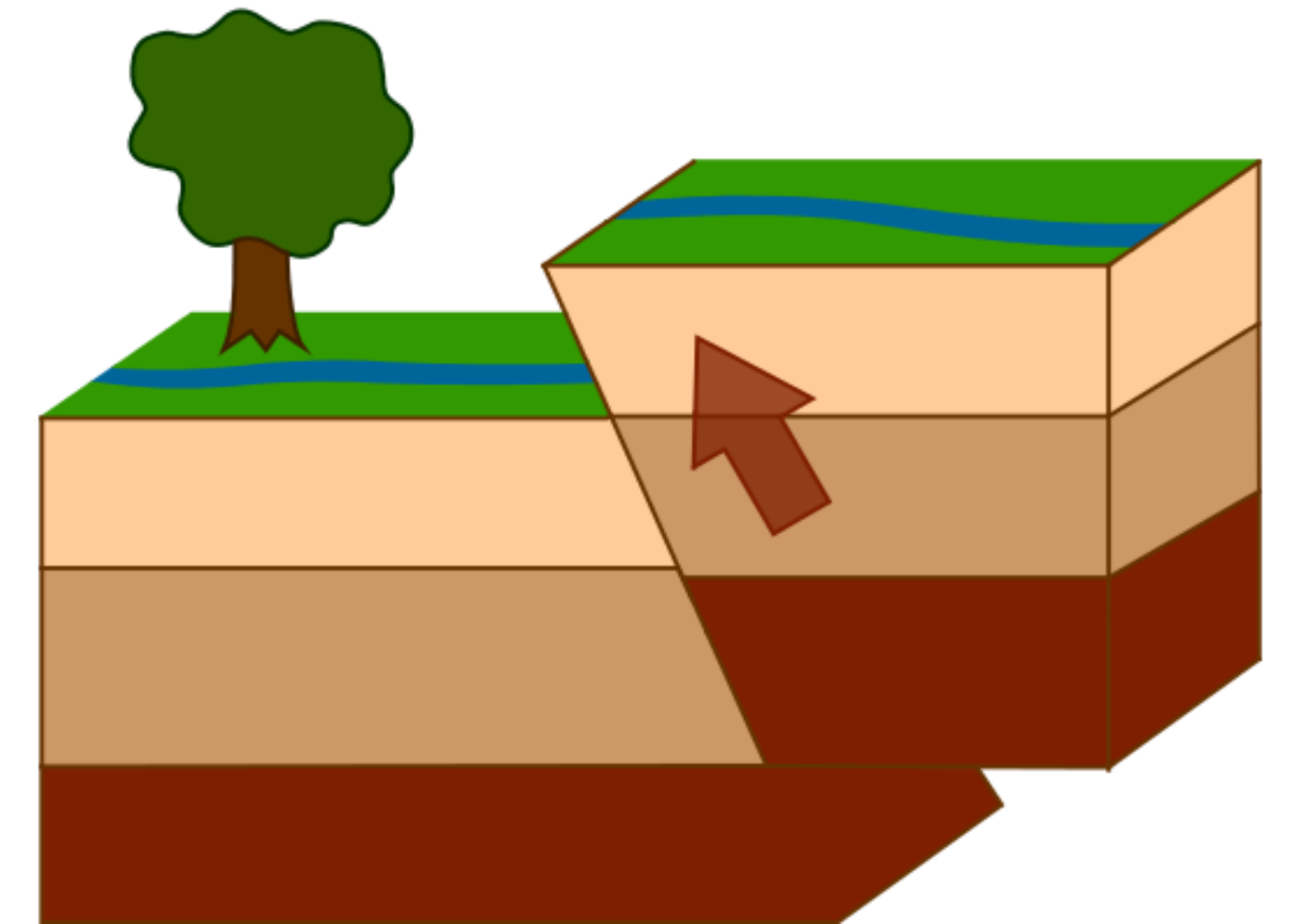
Strike-slip fault



Normal fault



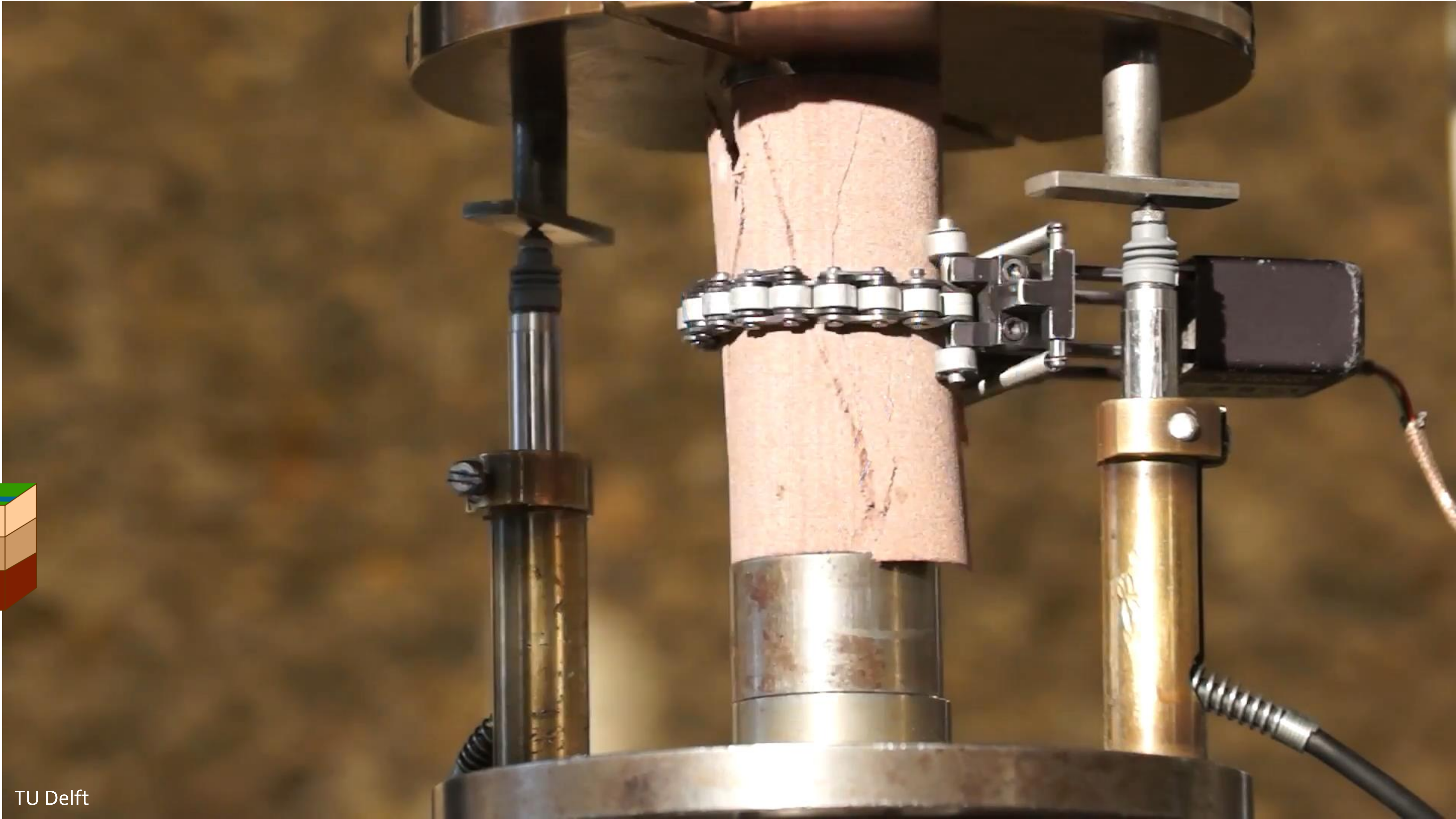
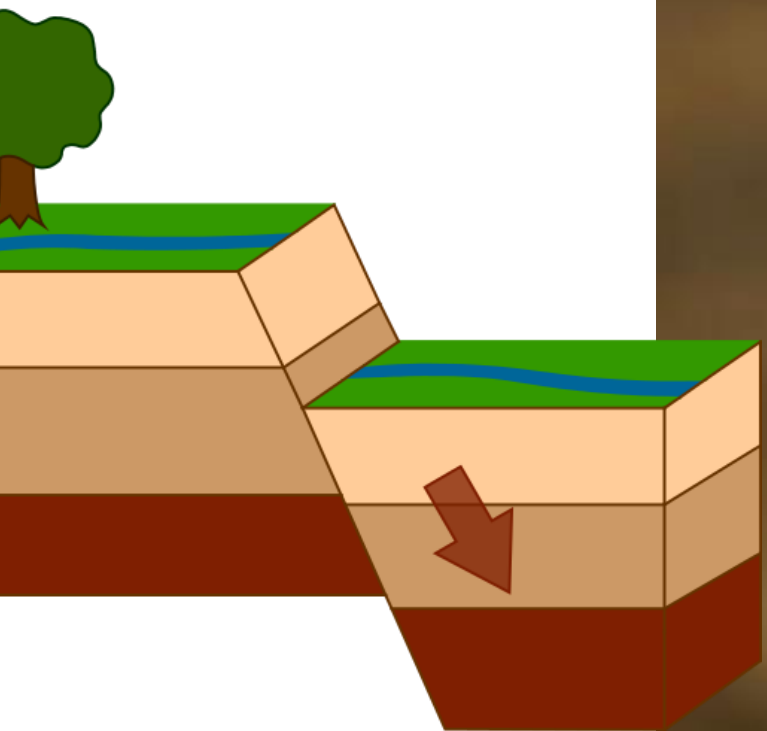
Thrust (reverse) fault



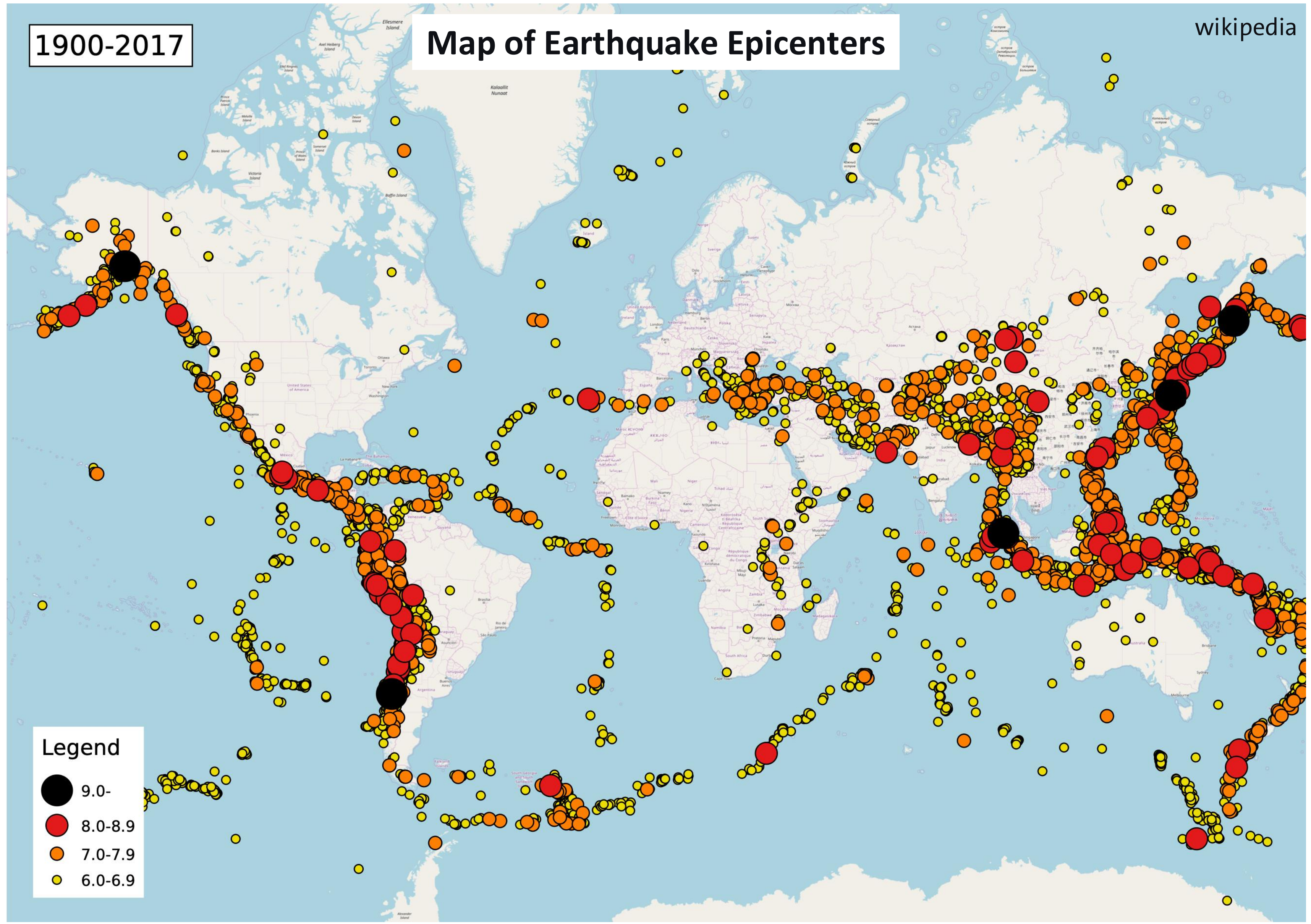
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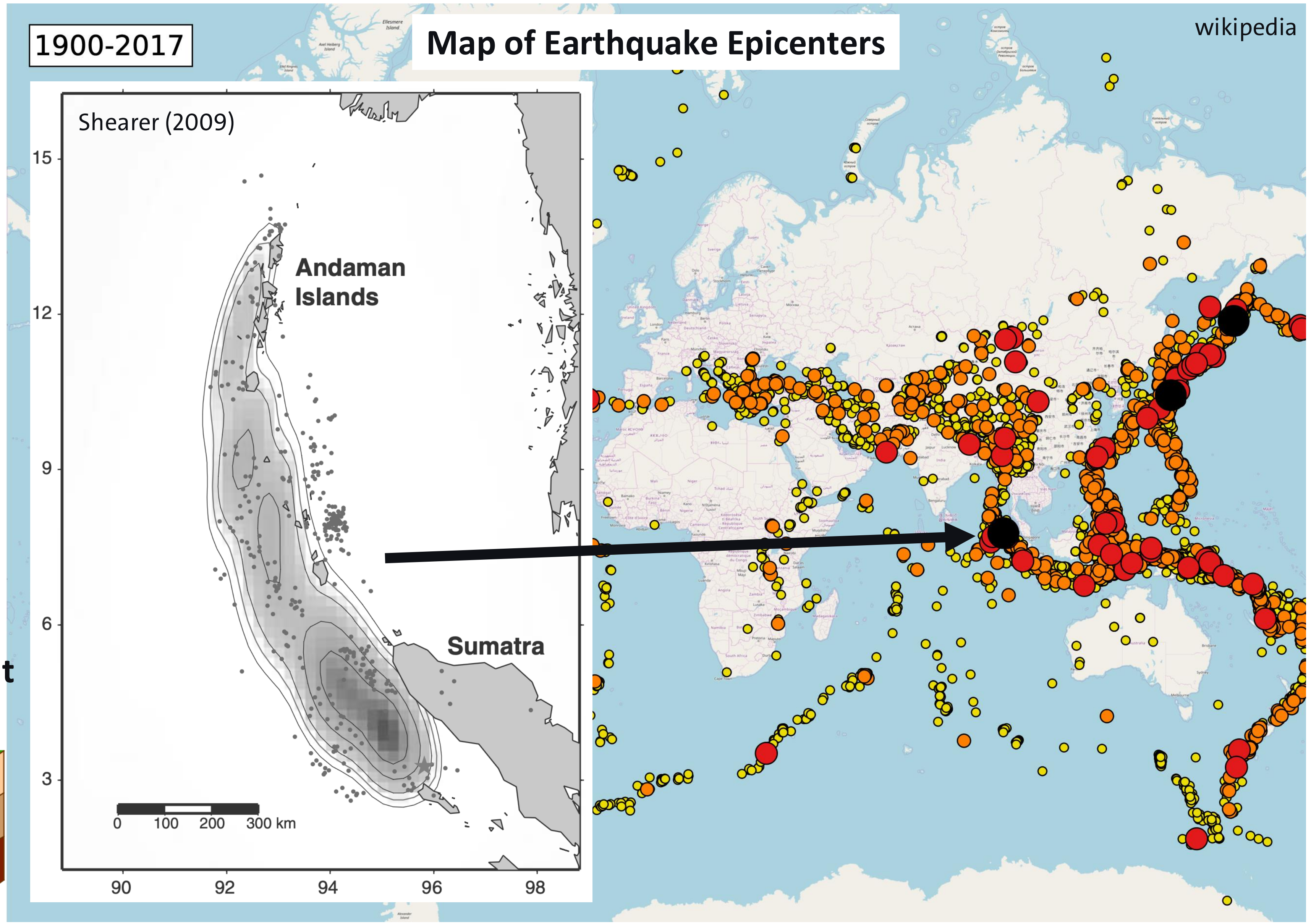
Normal fault



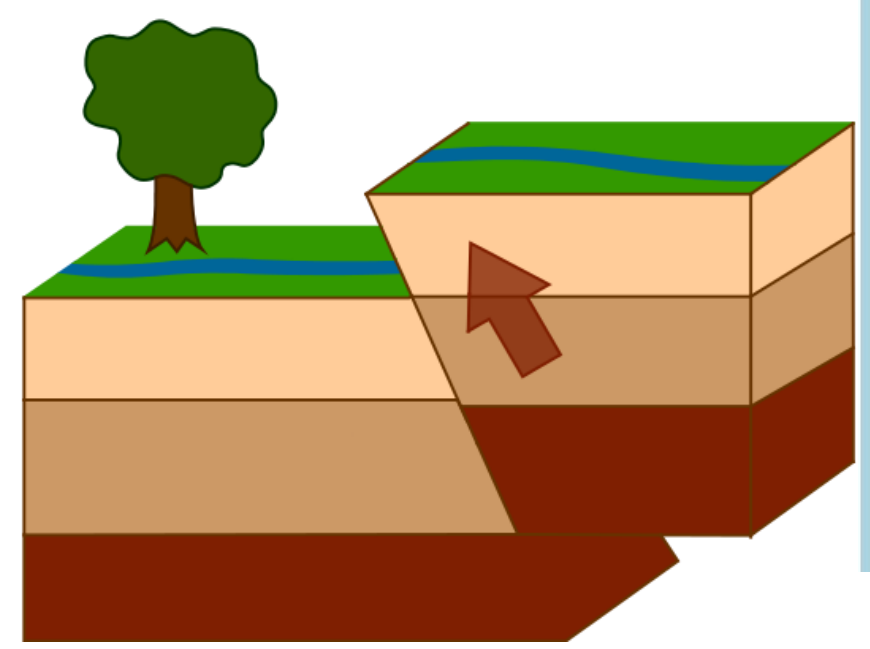
# Earthquakes | Where do earthquakes occur?



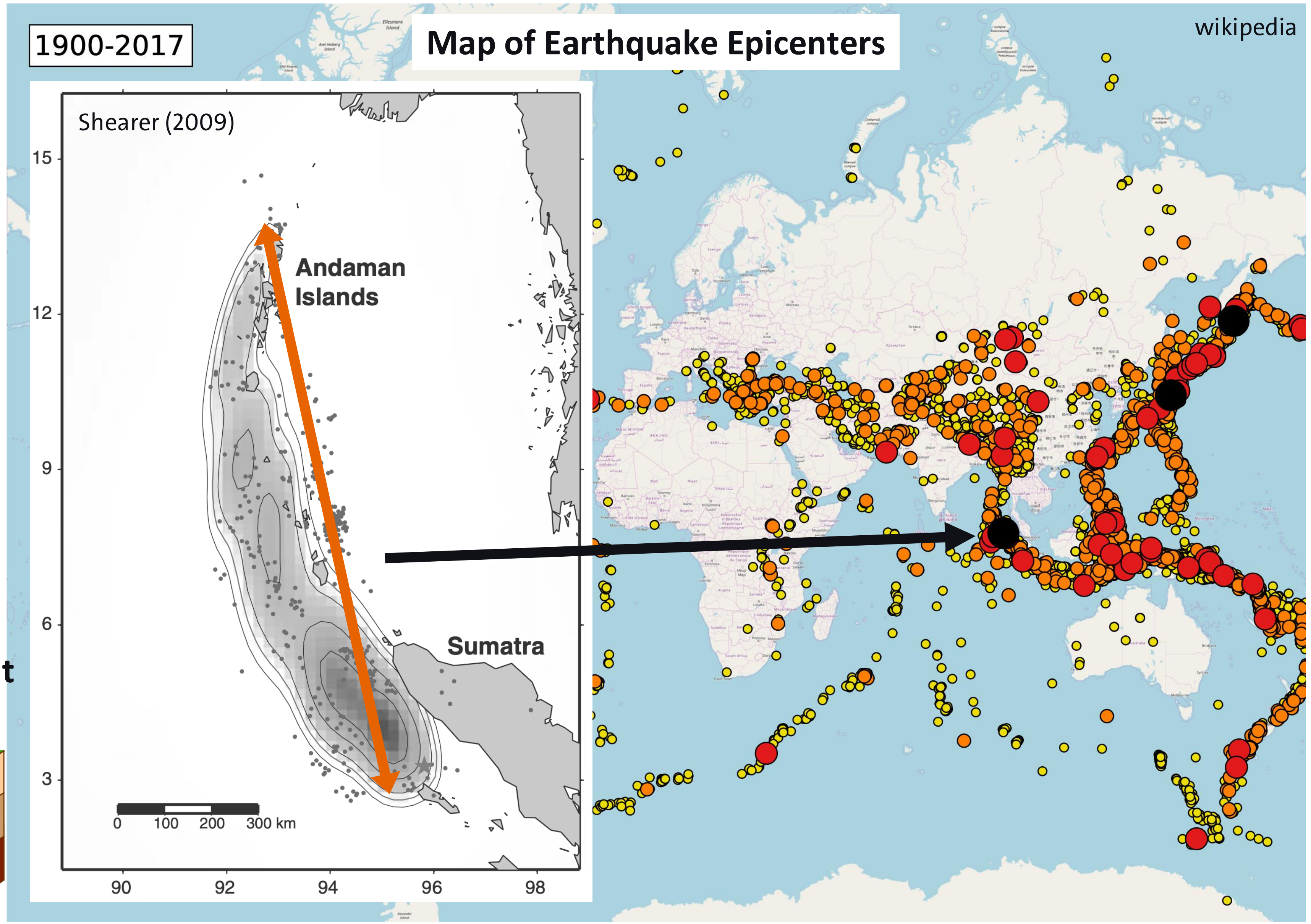
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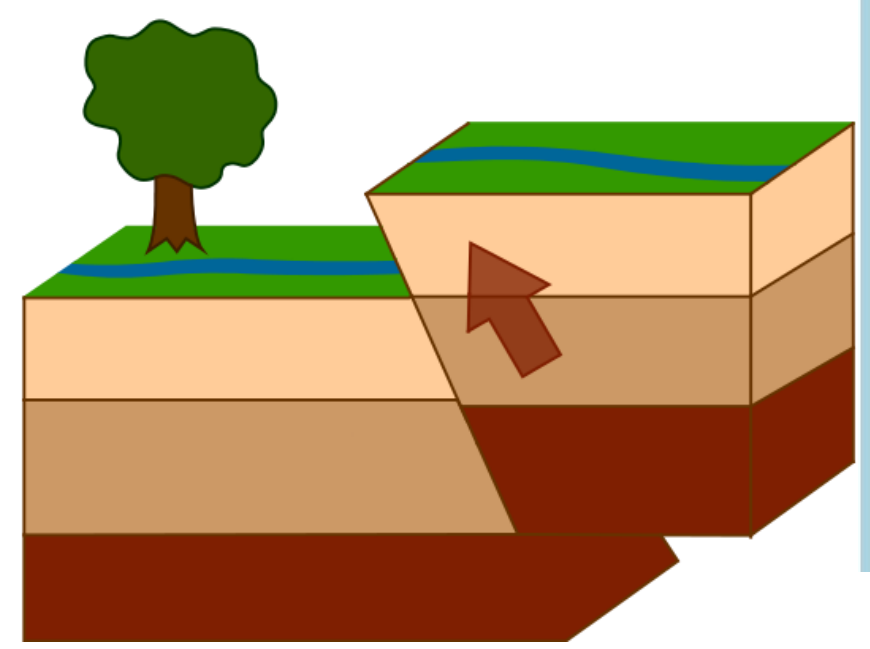
Thrust (reverse) fault



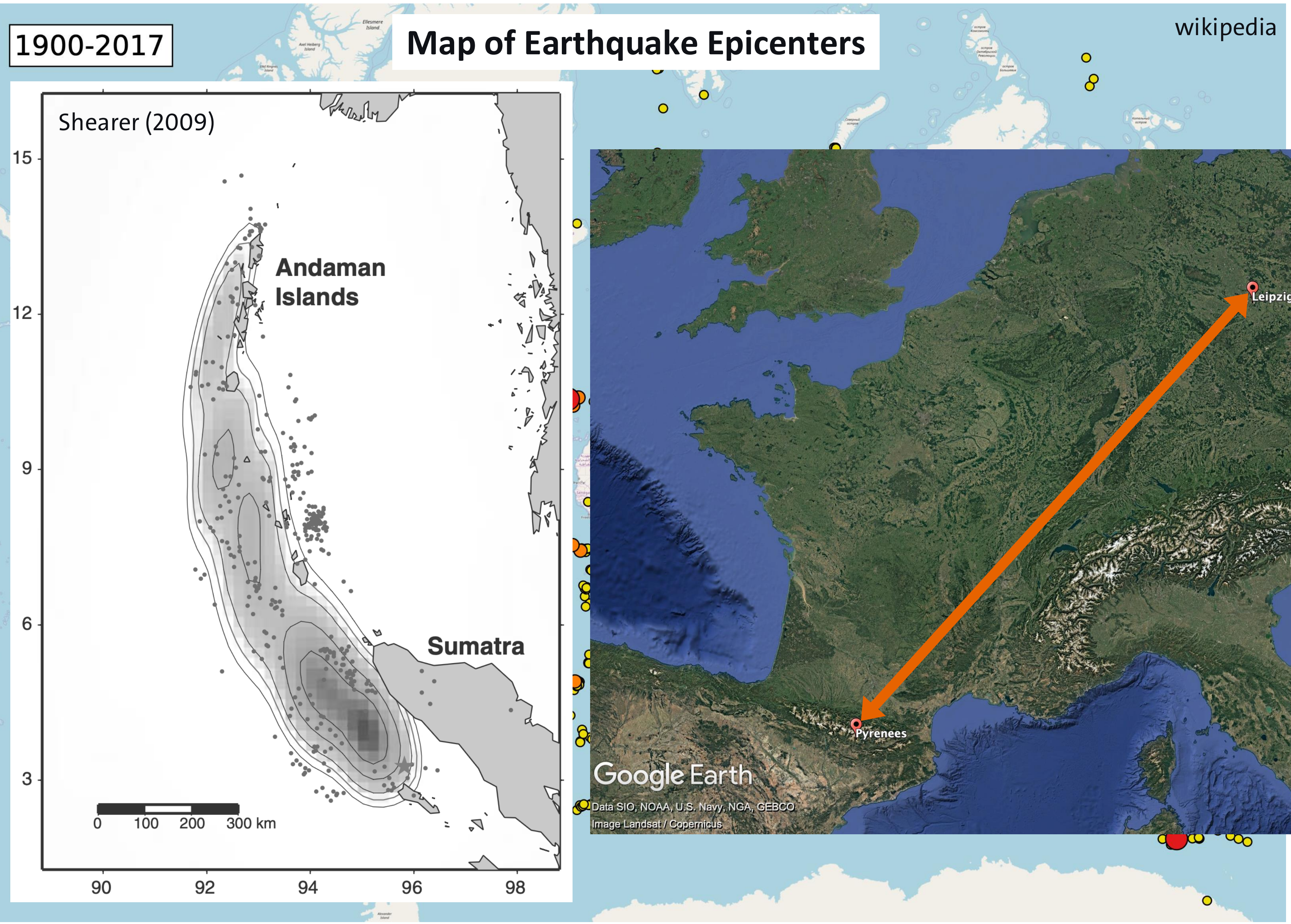
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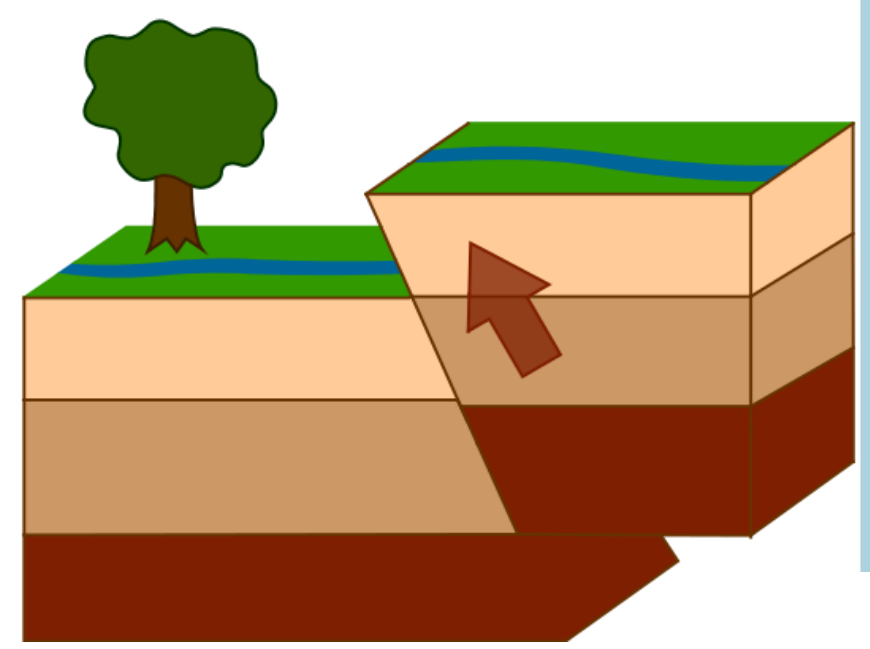
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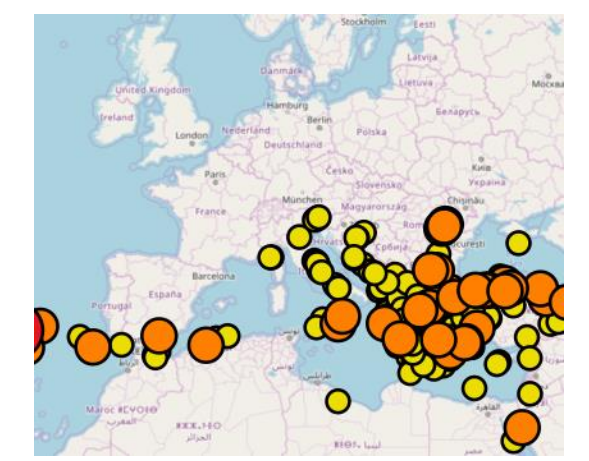
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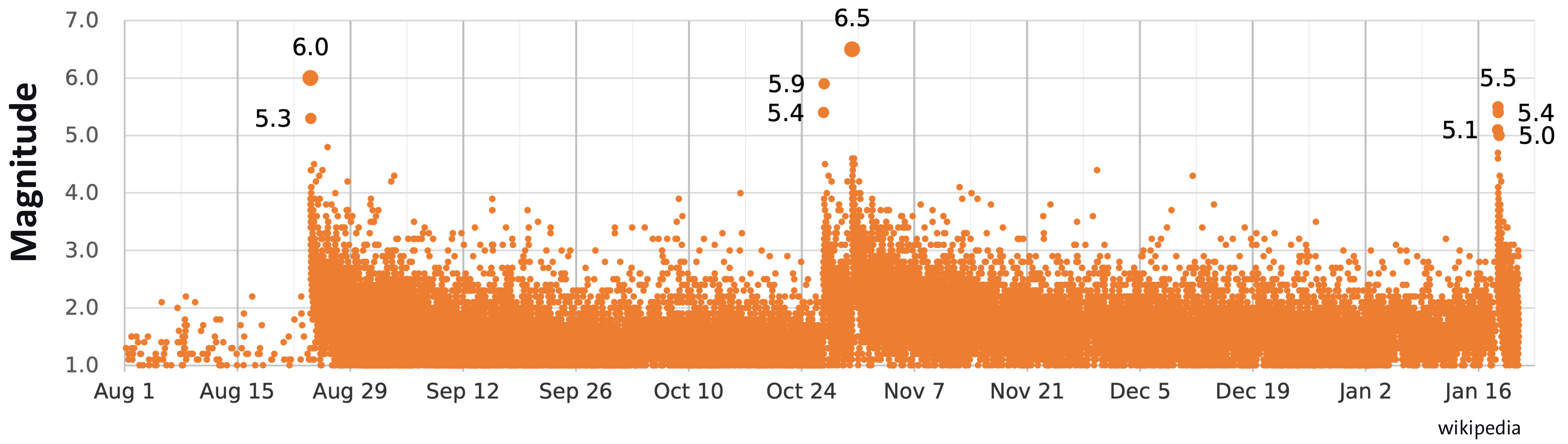
Thrust (reverse) fault



# Earthquakes | What are some important characteristics?

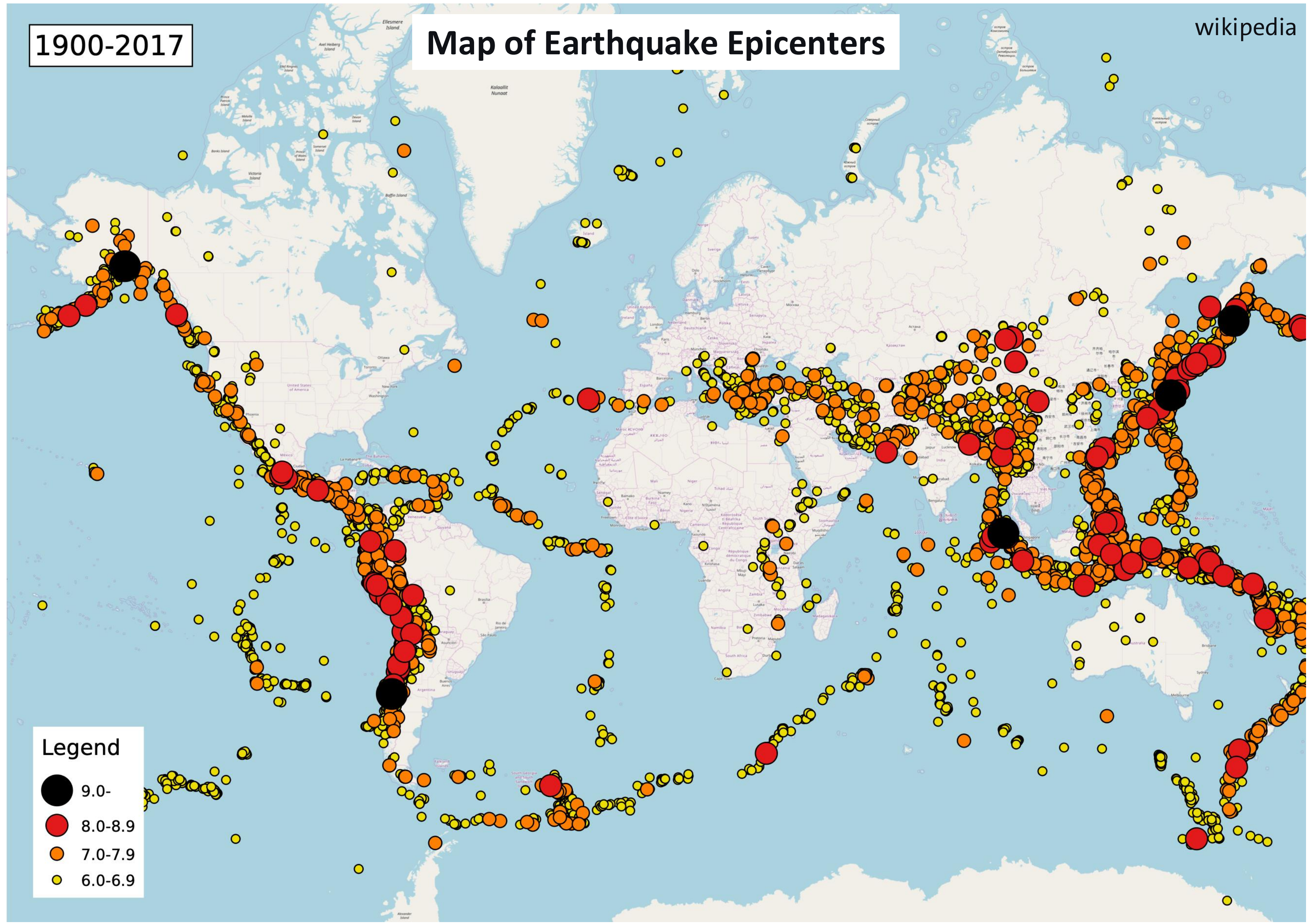


2016-2017 Central Italy earthquakes (magnitude)



wikipedia

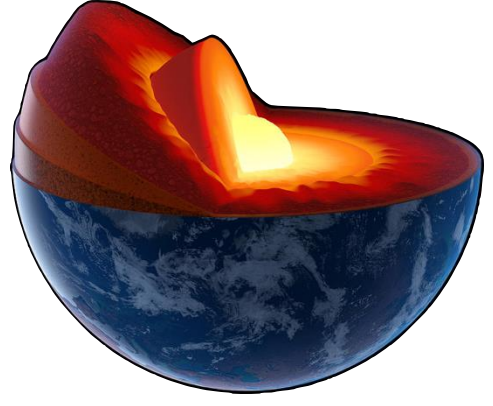
# Earthquakes | Why do earthquakes cluster?



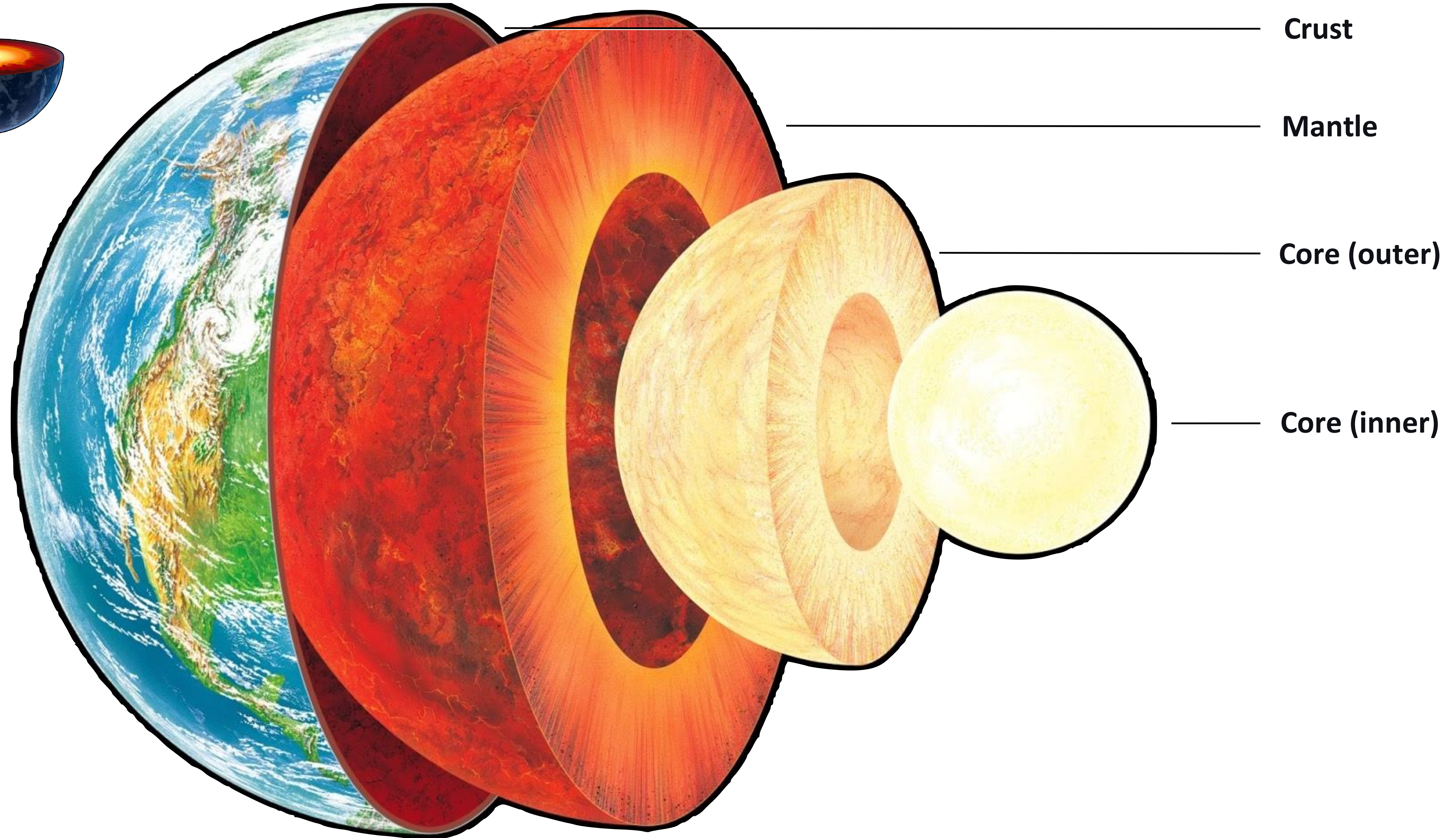
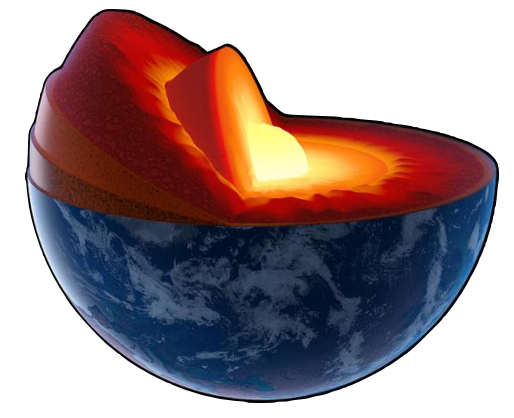
# Earthquakes | Why do earthquakes cluster?



# Earth structure



# Earth structure | What is it globally?



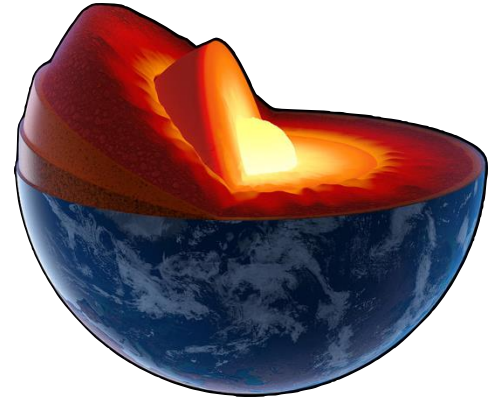
**Crust**

**Mantle**

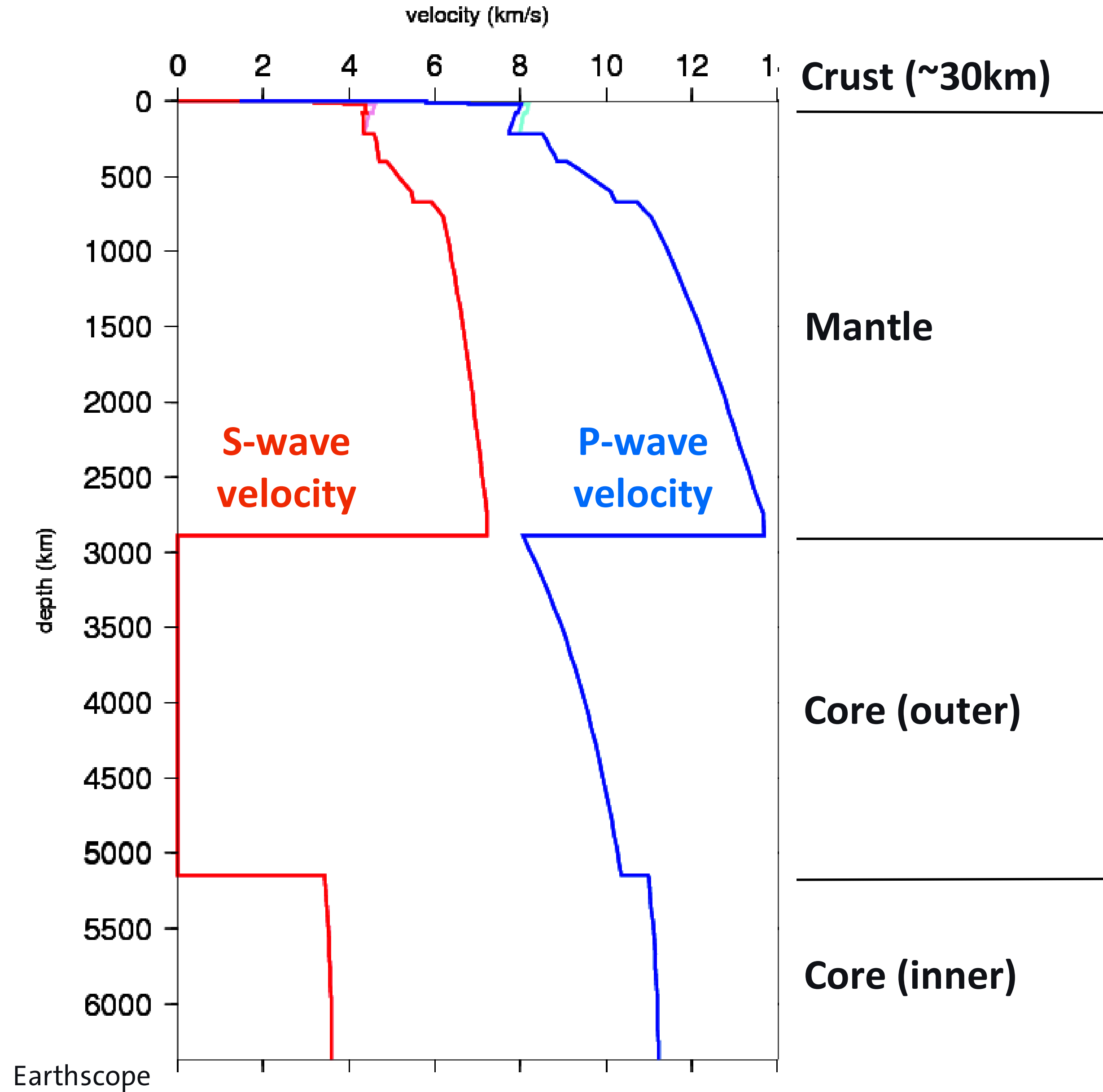
**Core (outer)**

**Core (inner)**

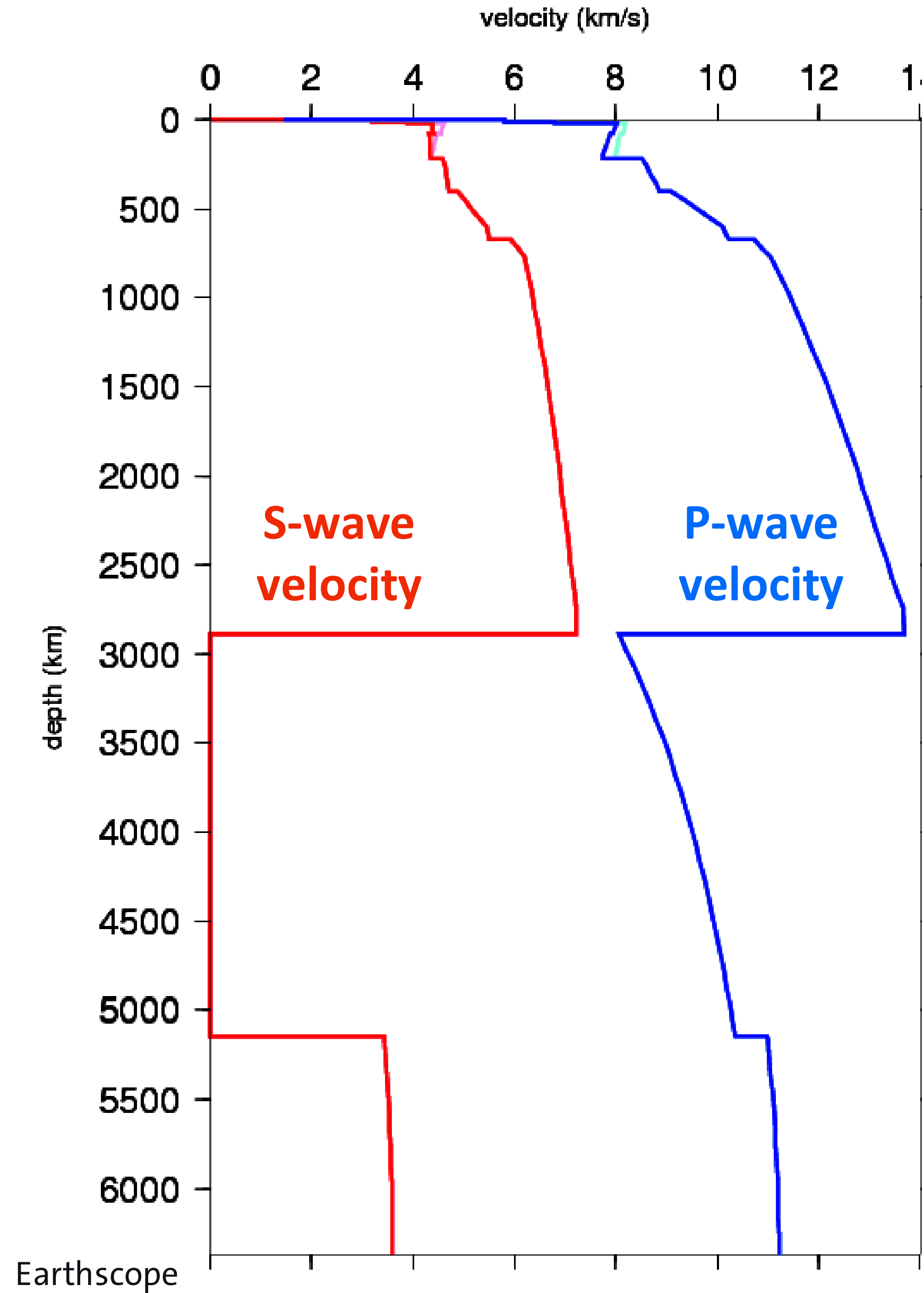
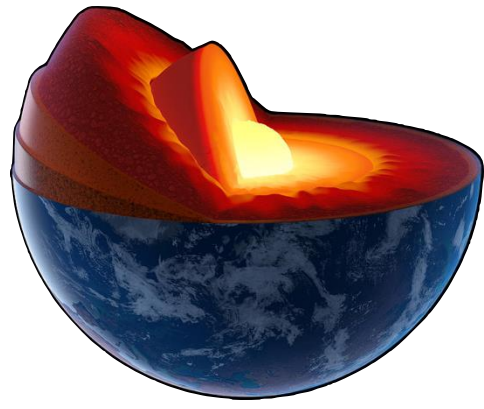
# Earth structure | What is it globally?



*Seismic*



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*Seismic*

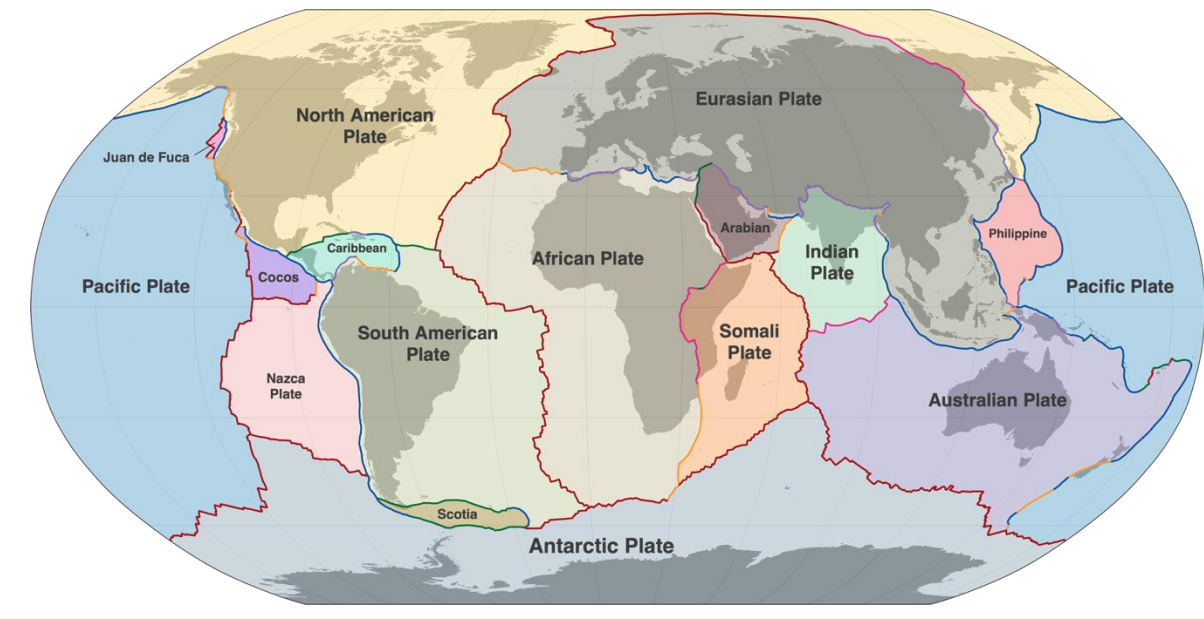
*Geodynamic*

**Crust (~30km)**

**Lithosphere (~100km)**

Asthenosphere

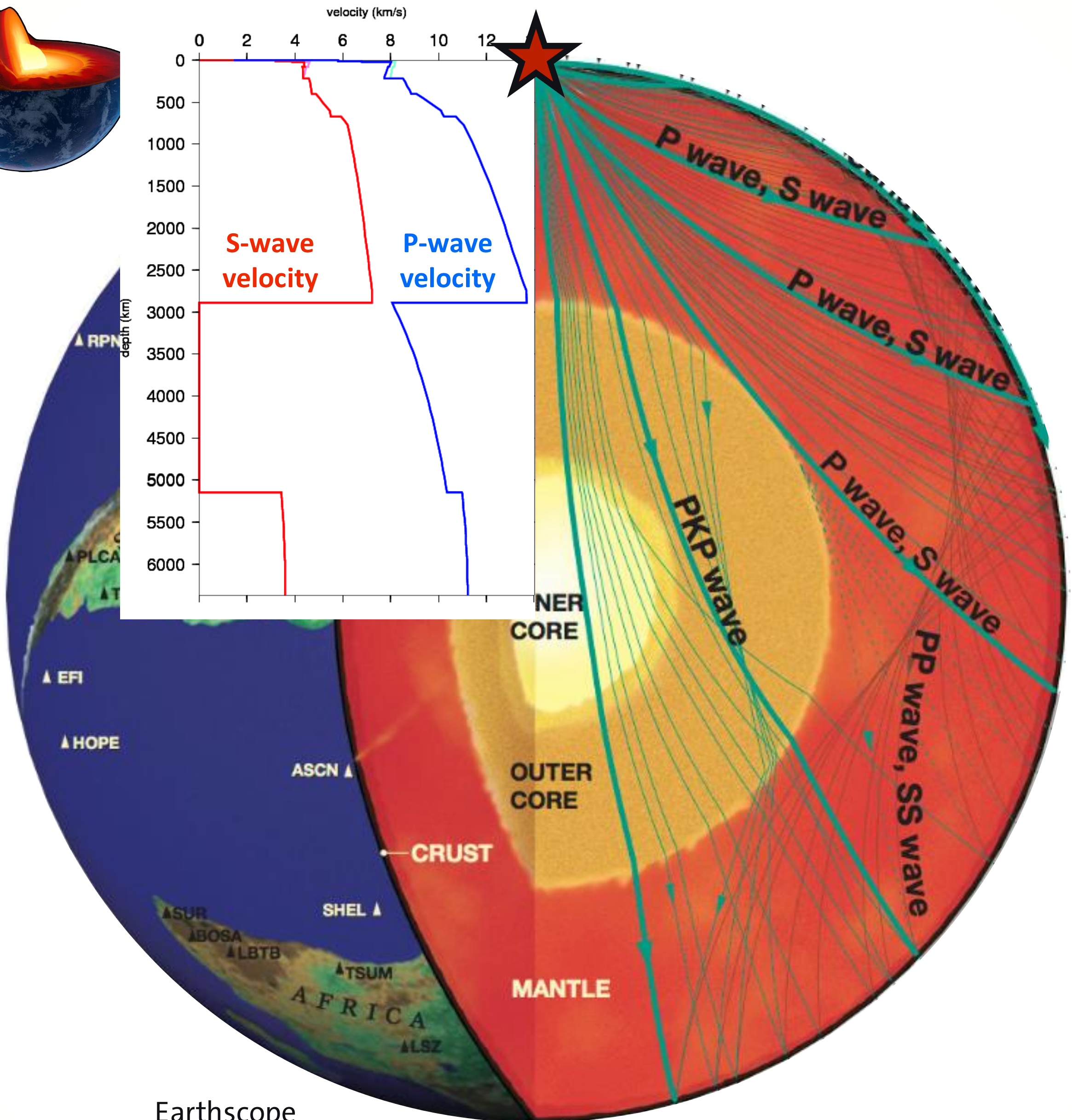
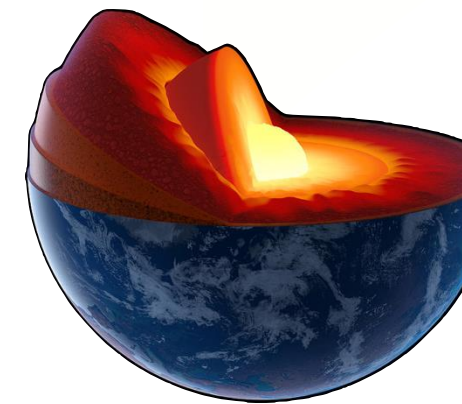
**Mantle**



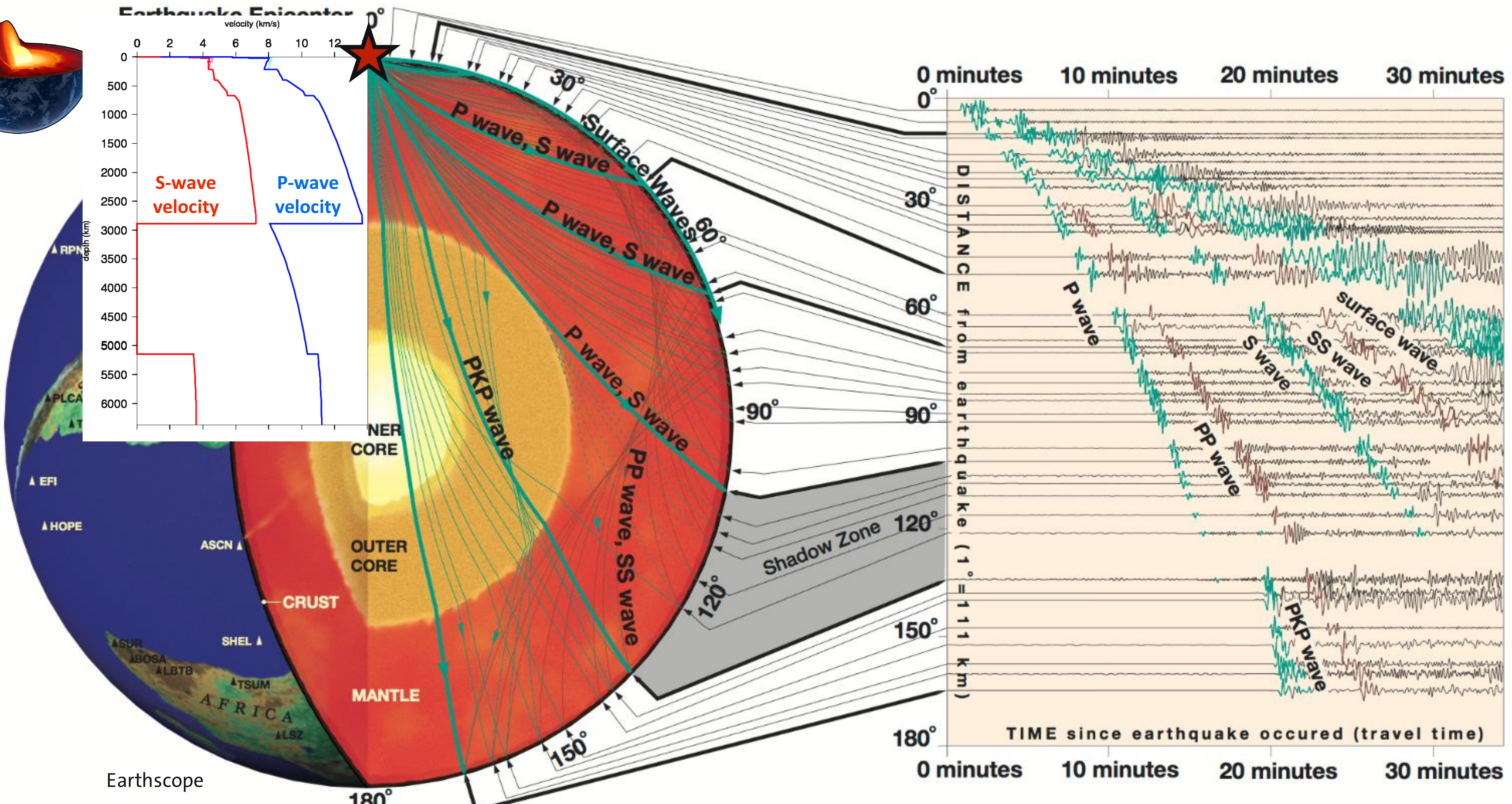
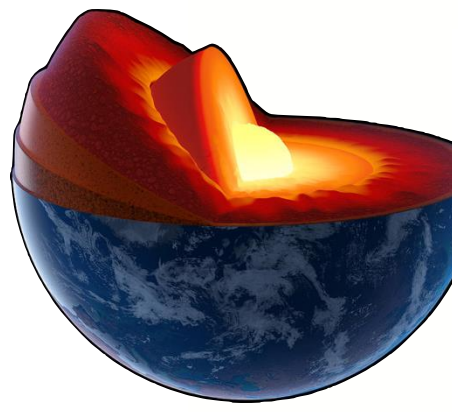
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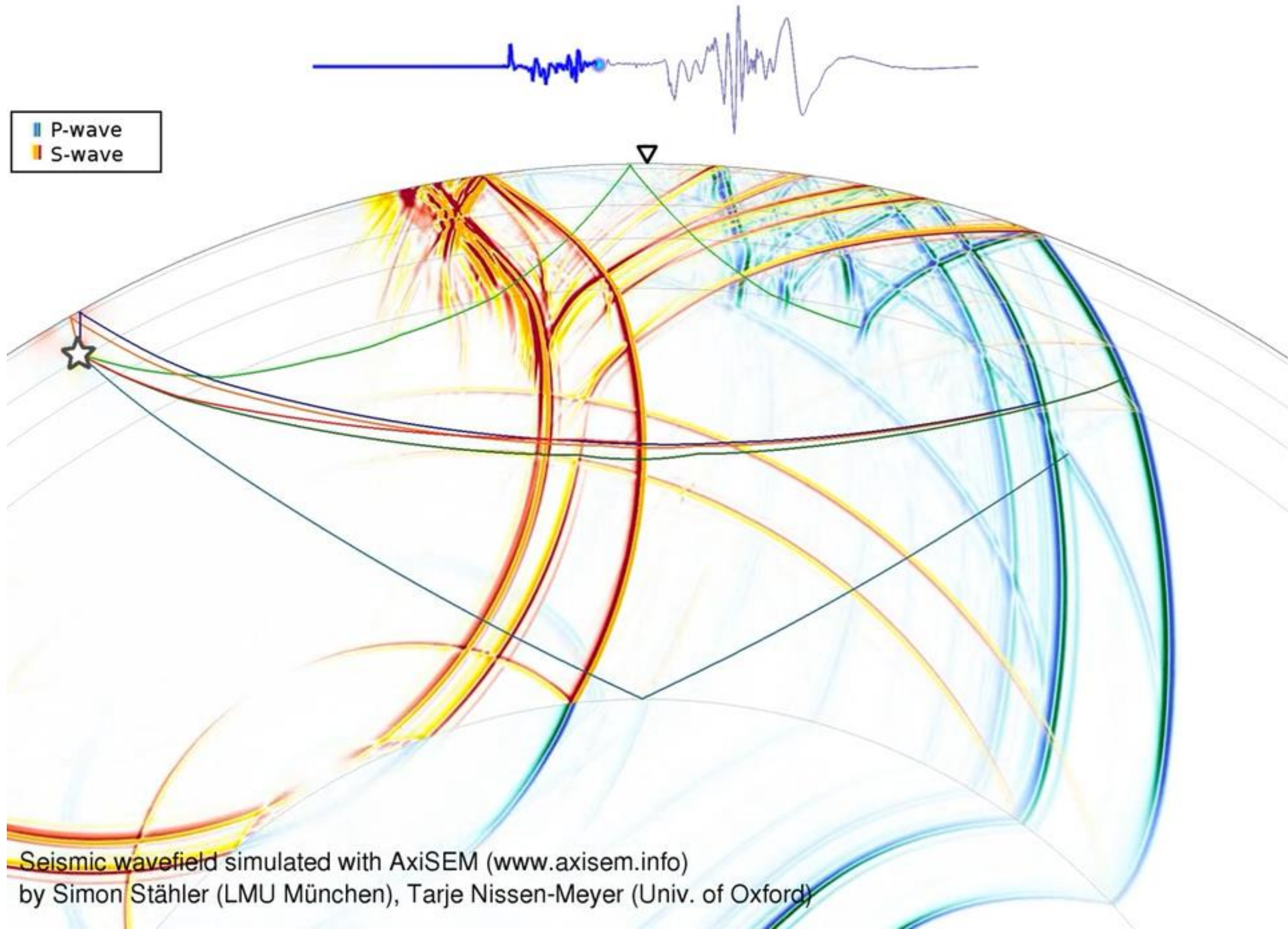
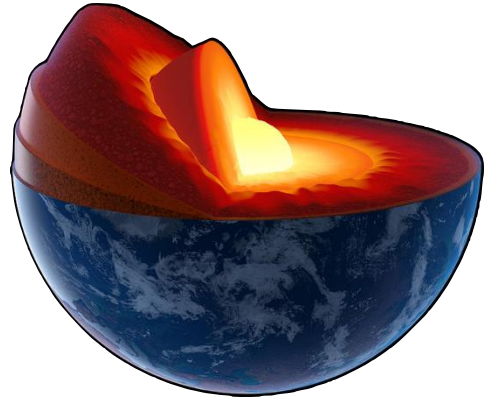
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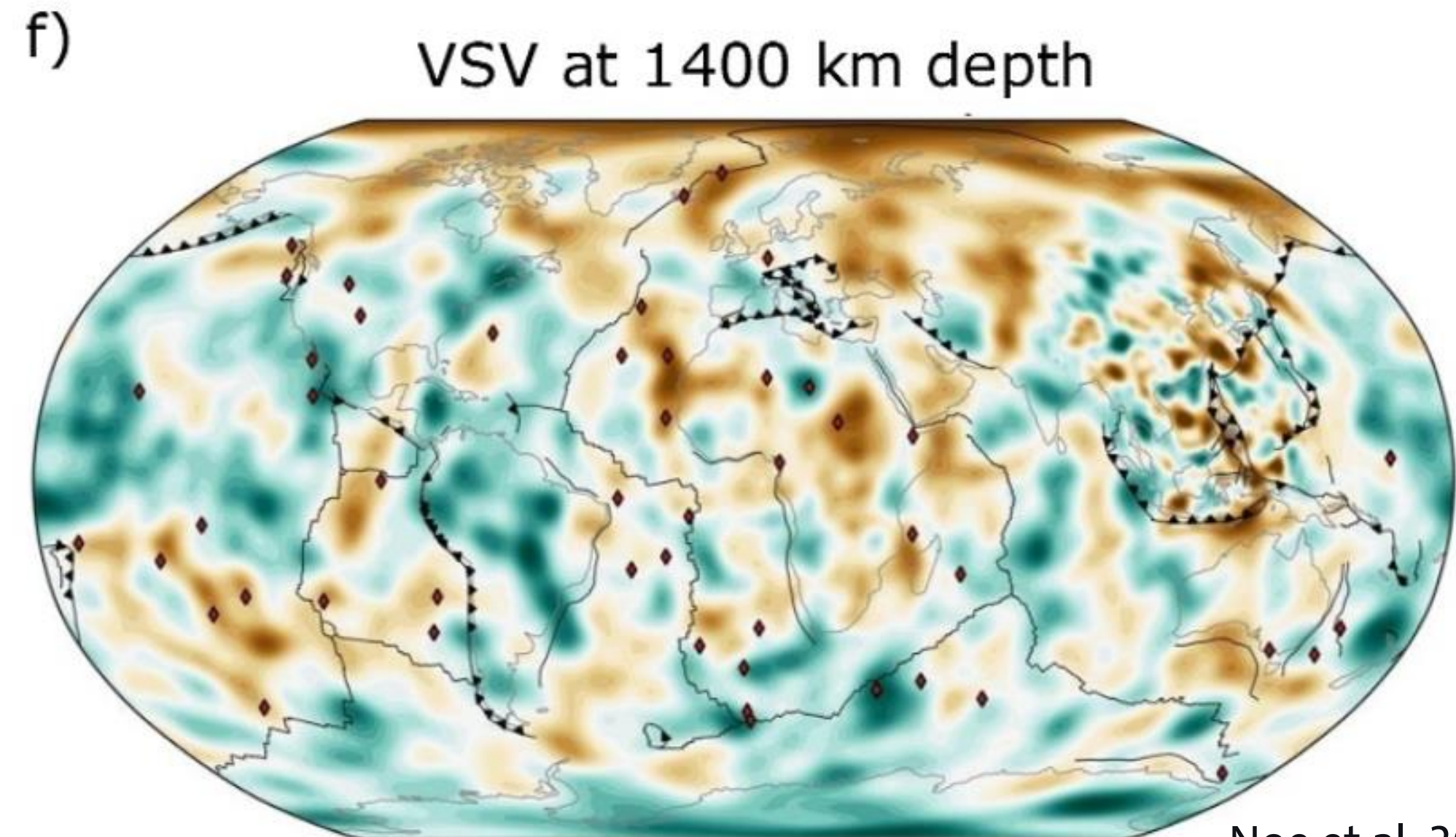
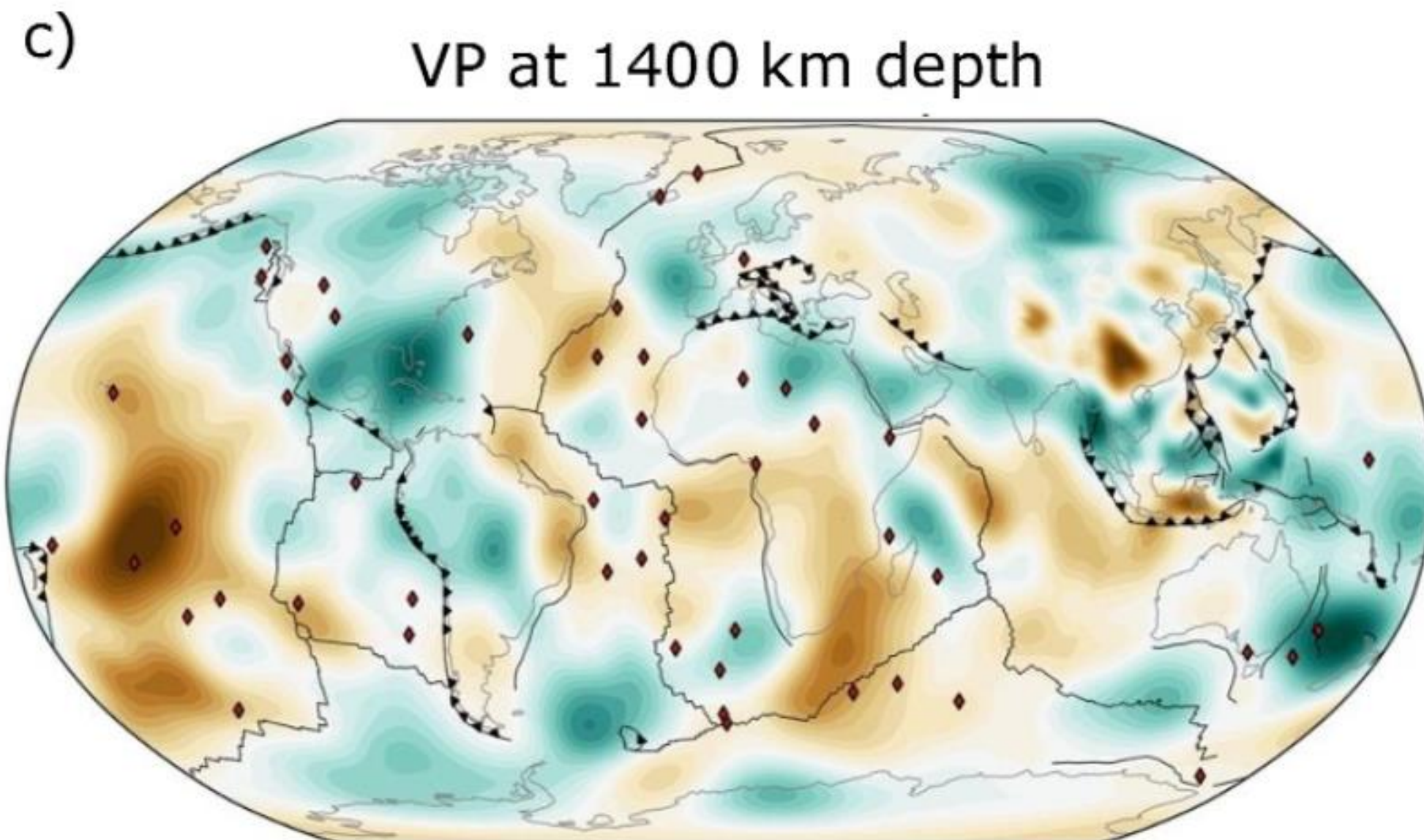
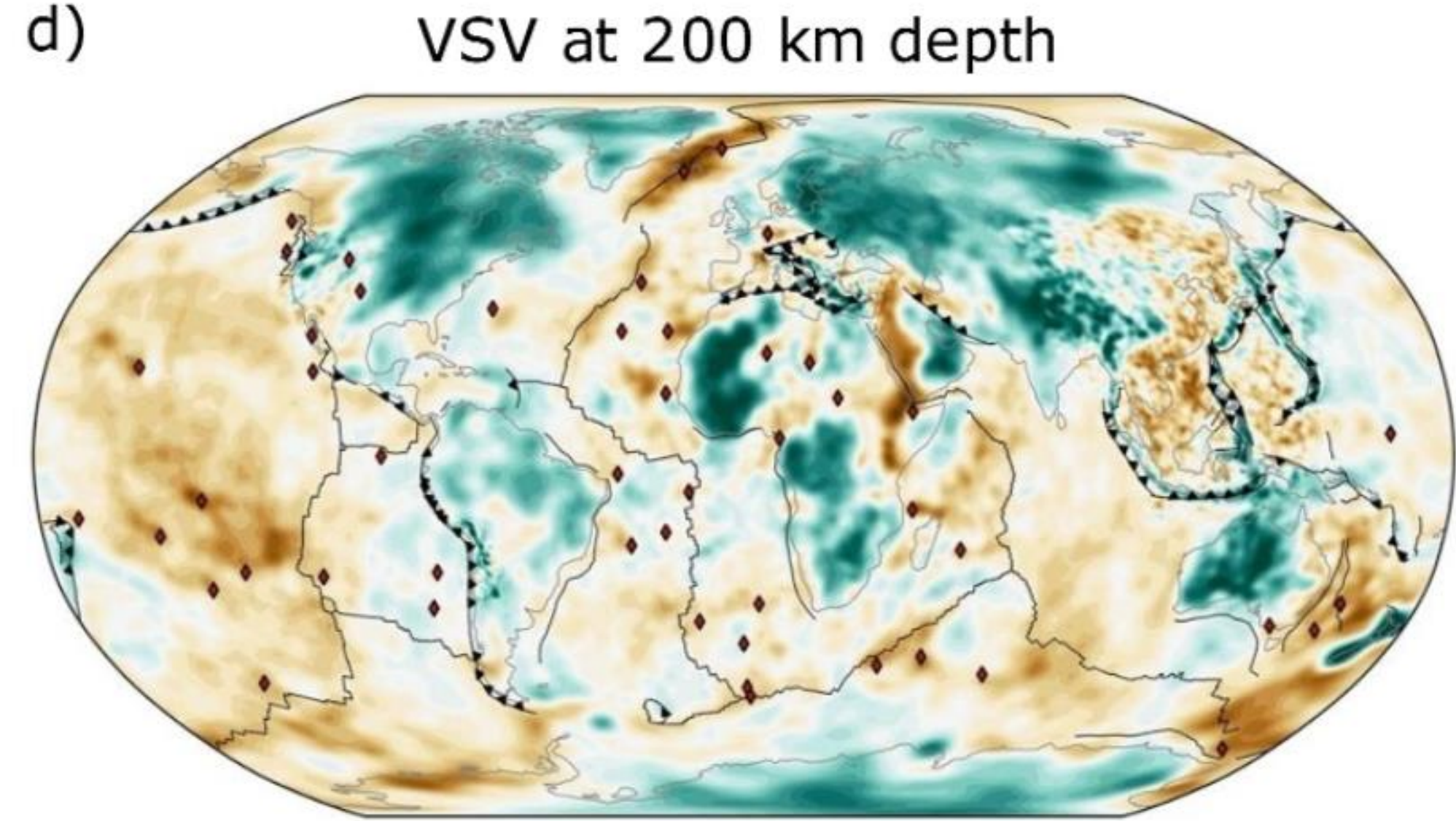
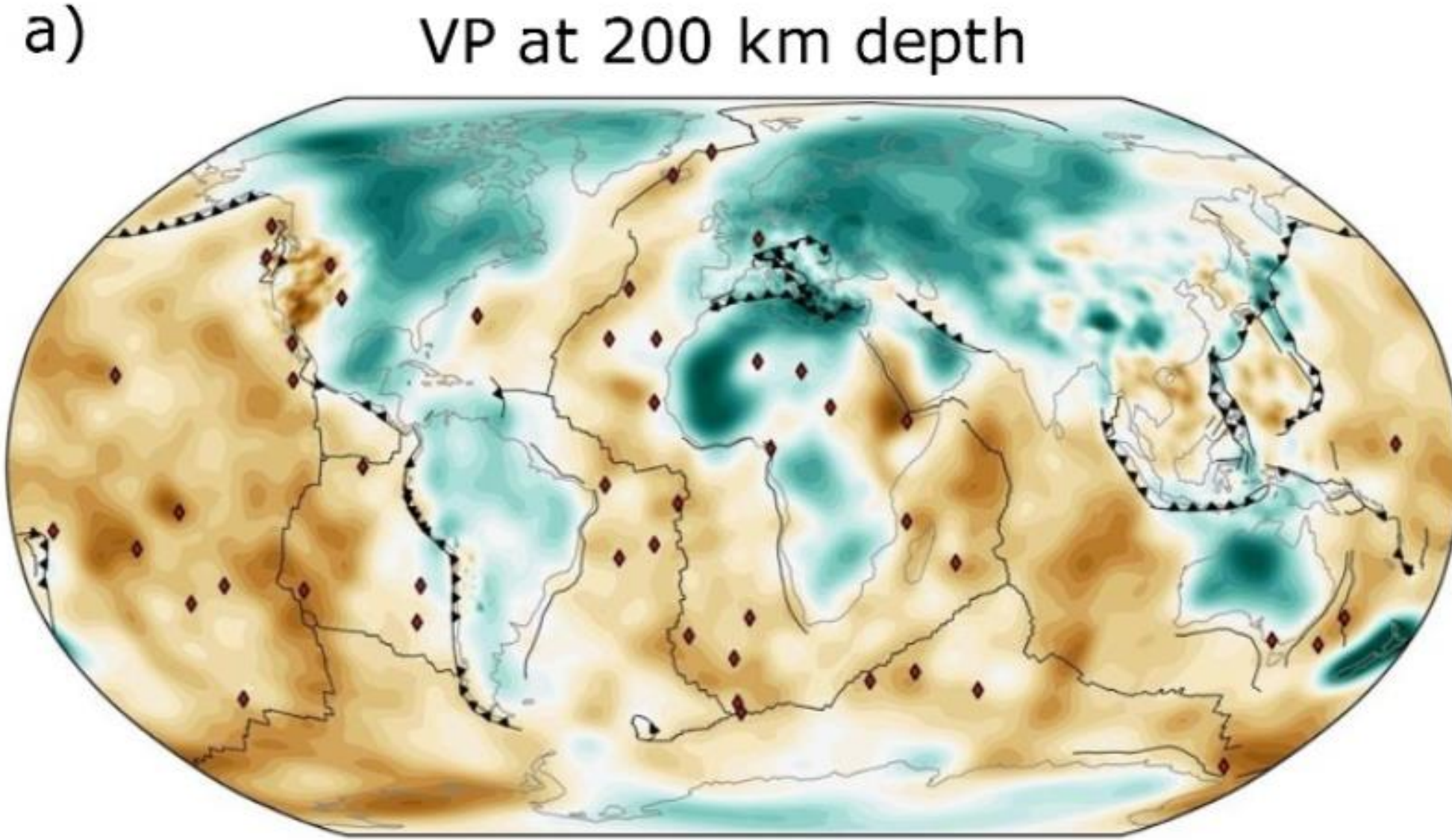
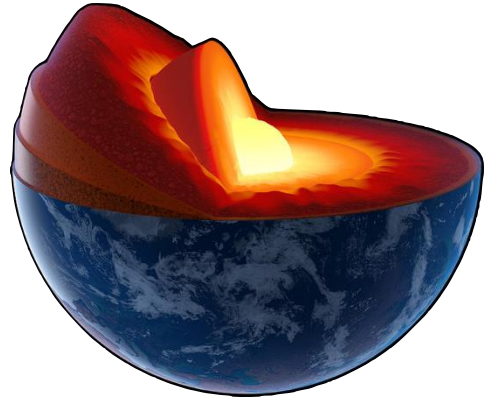
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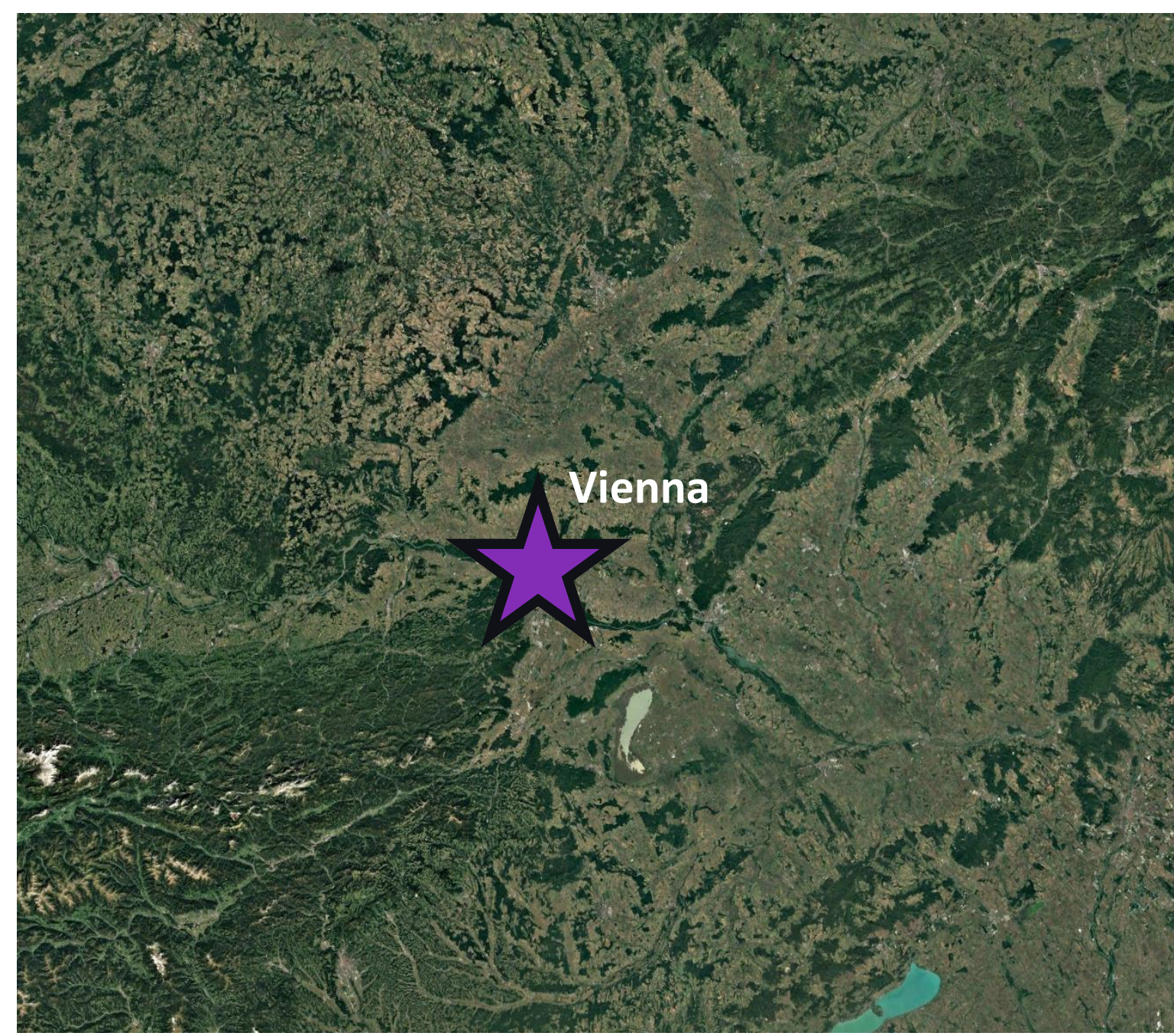
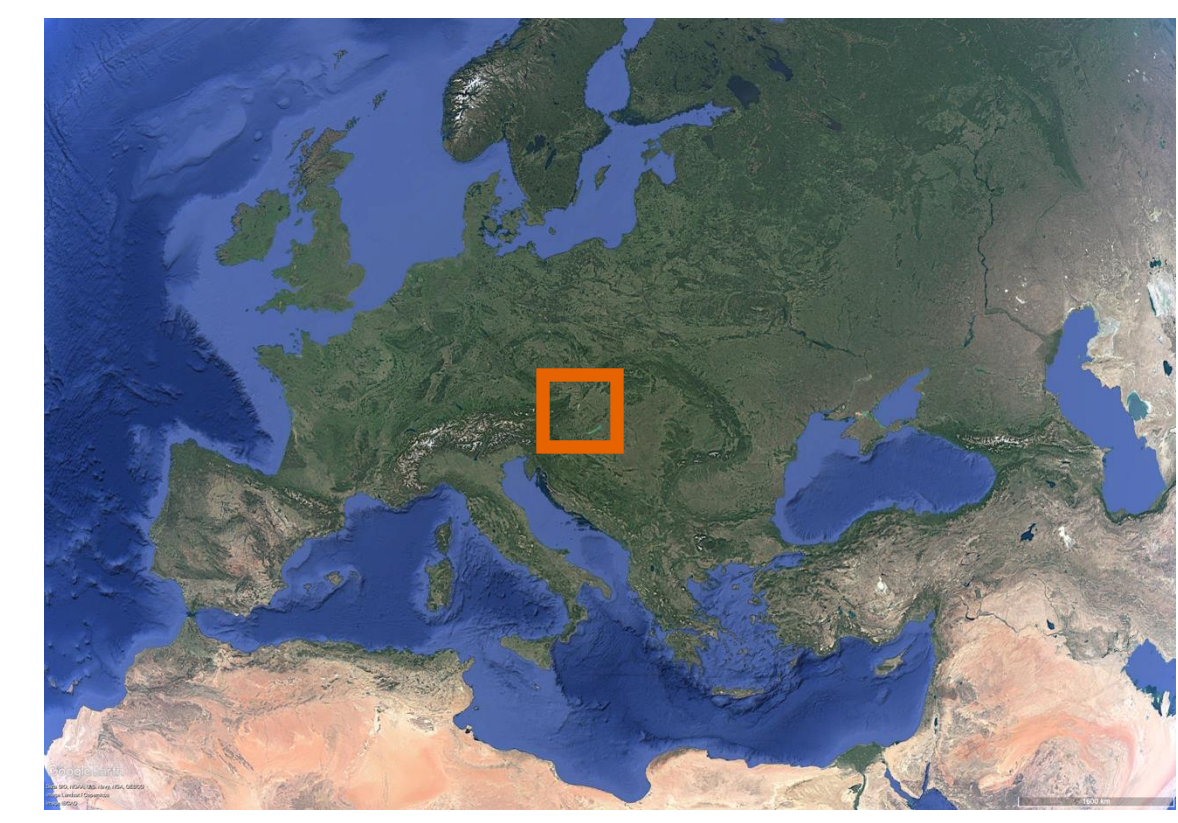
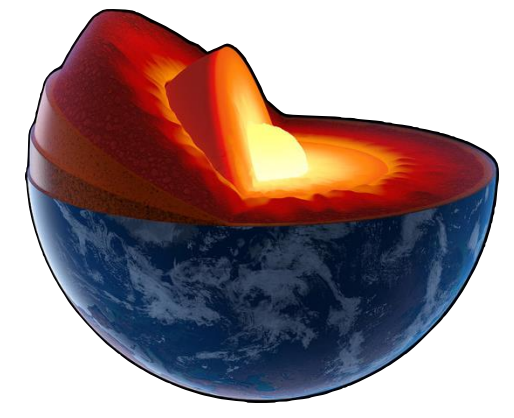
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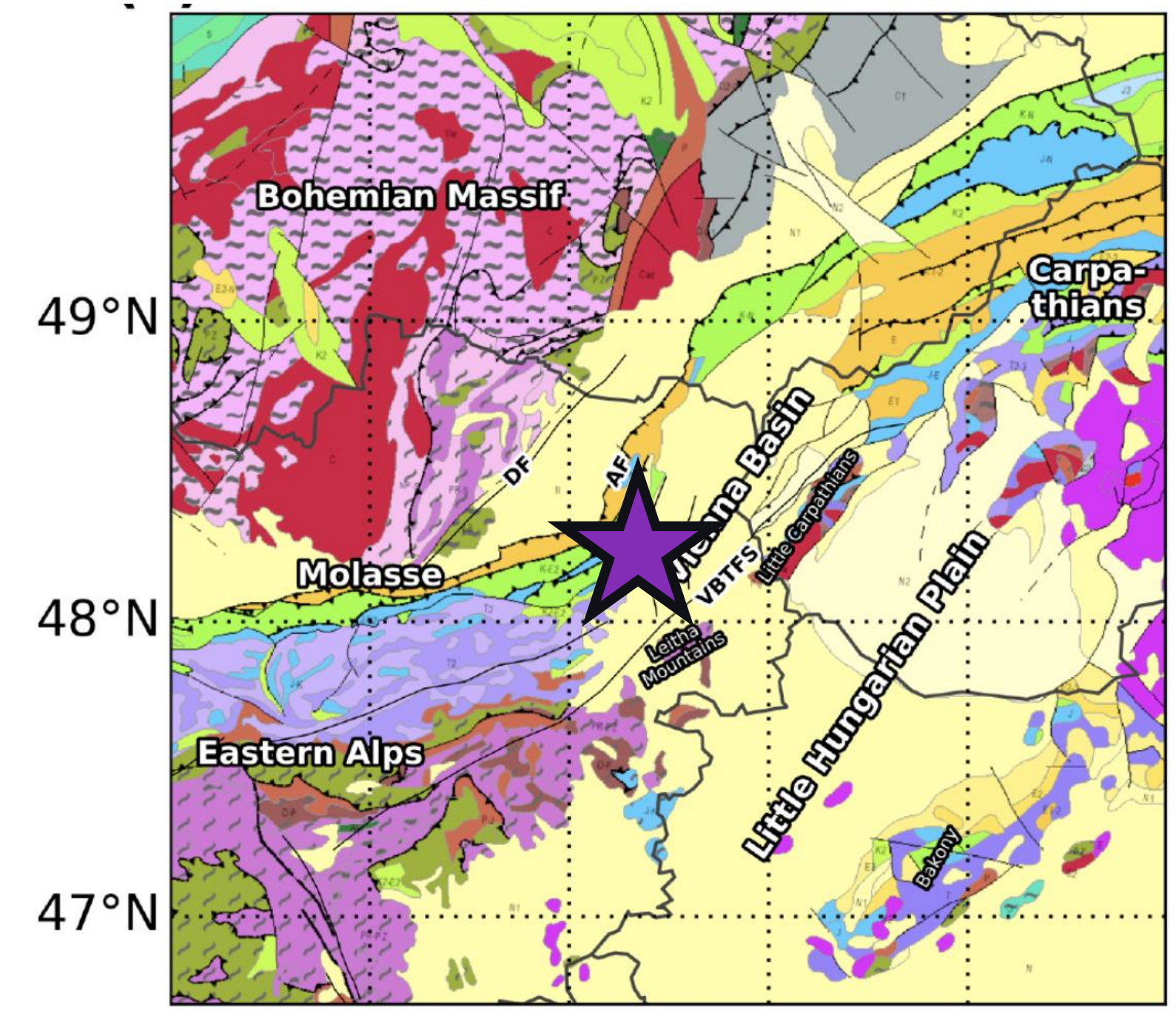
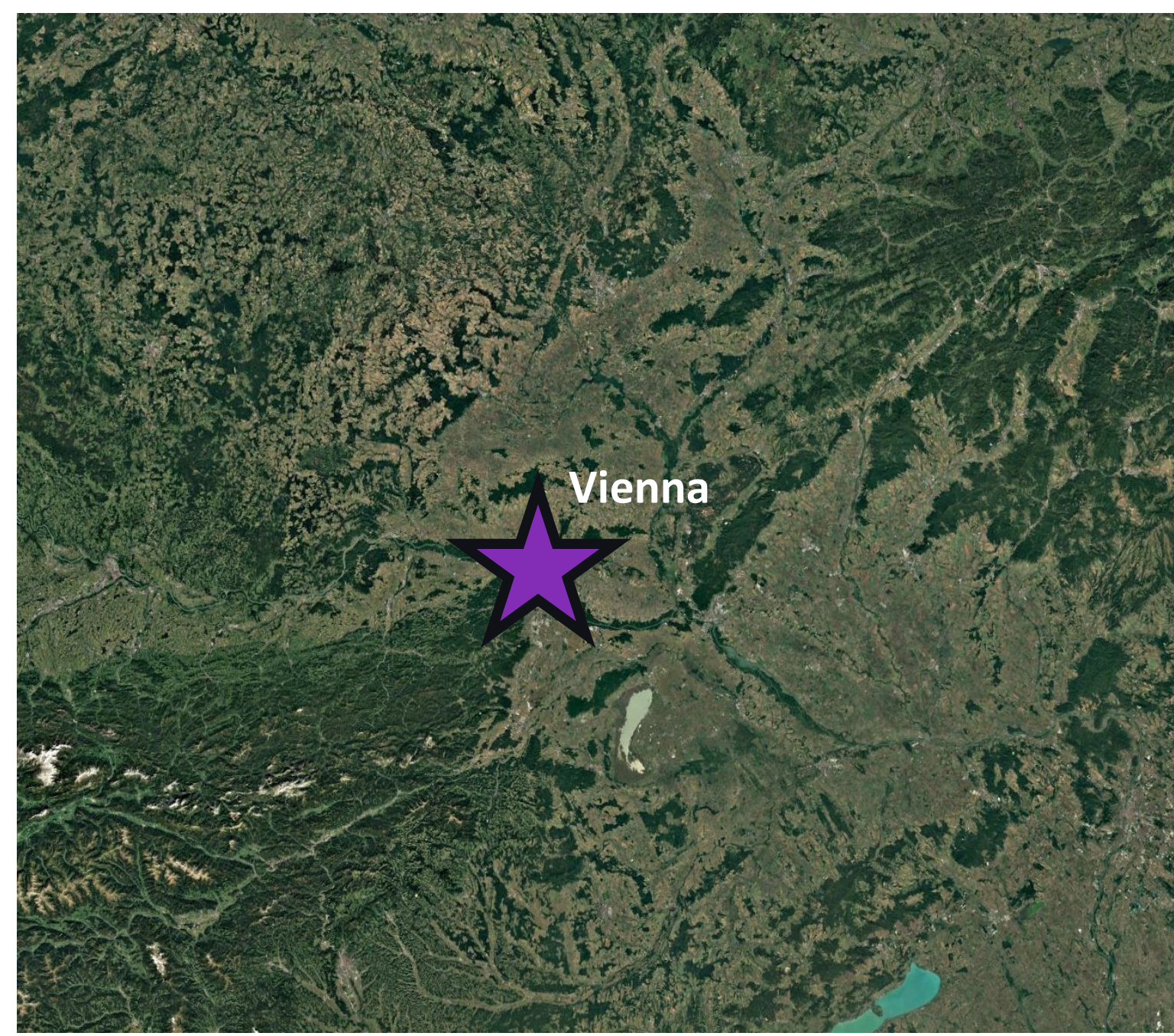
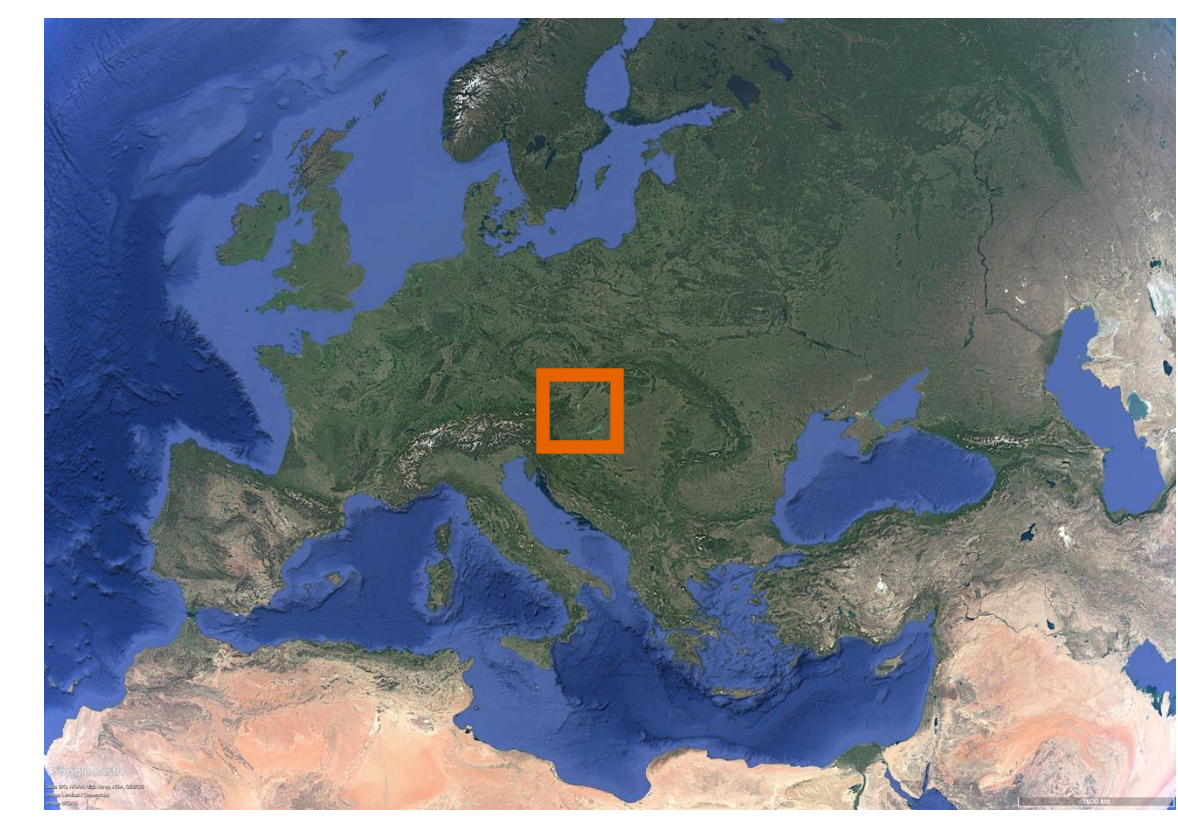
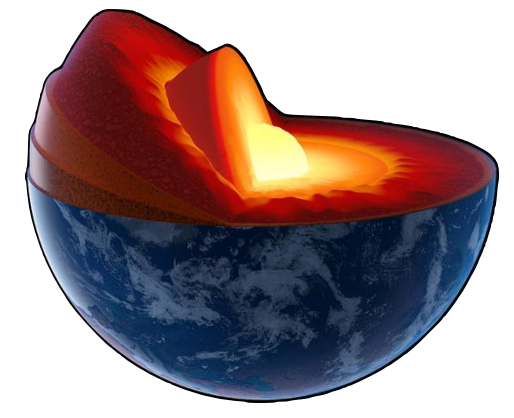
# Earth structure | What is it globally?



# Earth structure | What is it “locally”?

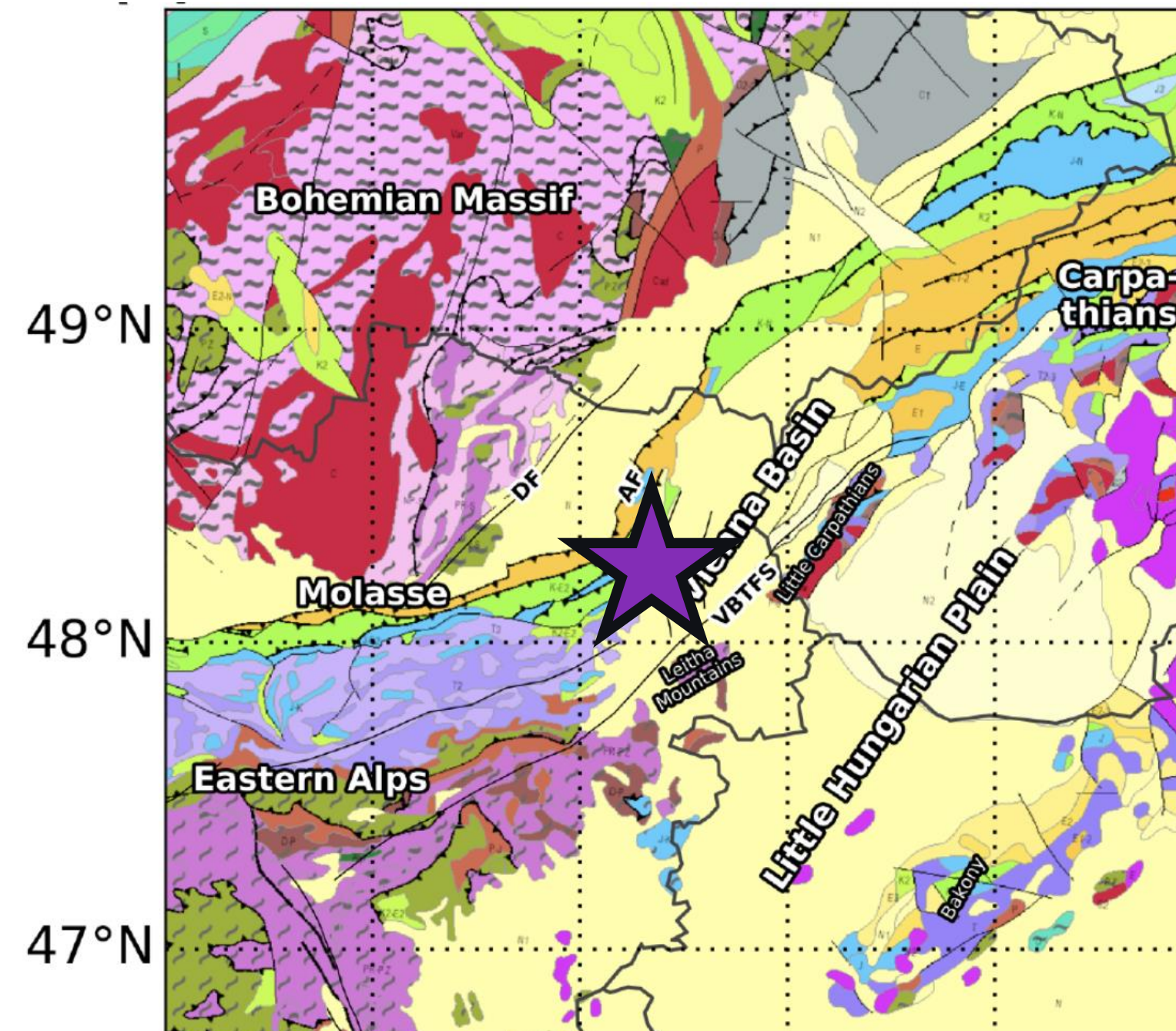
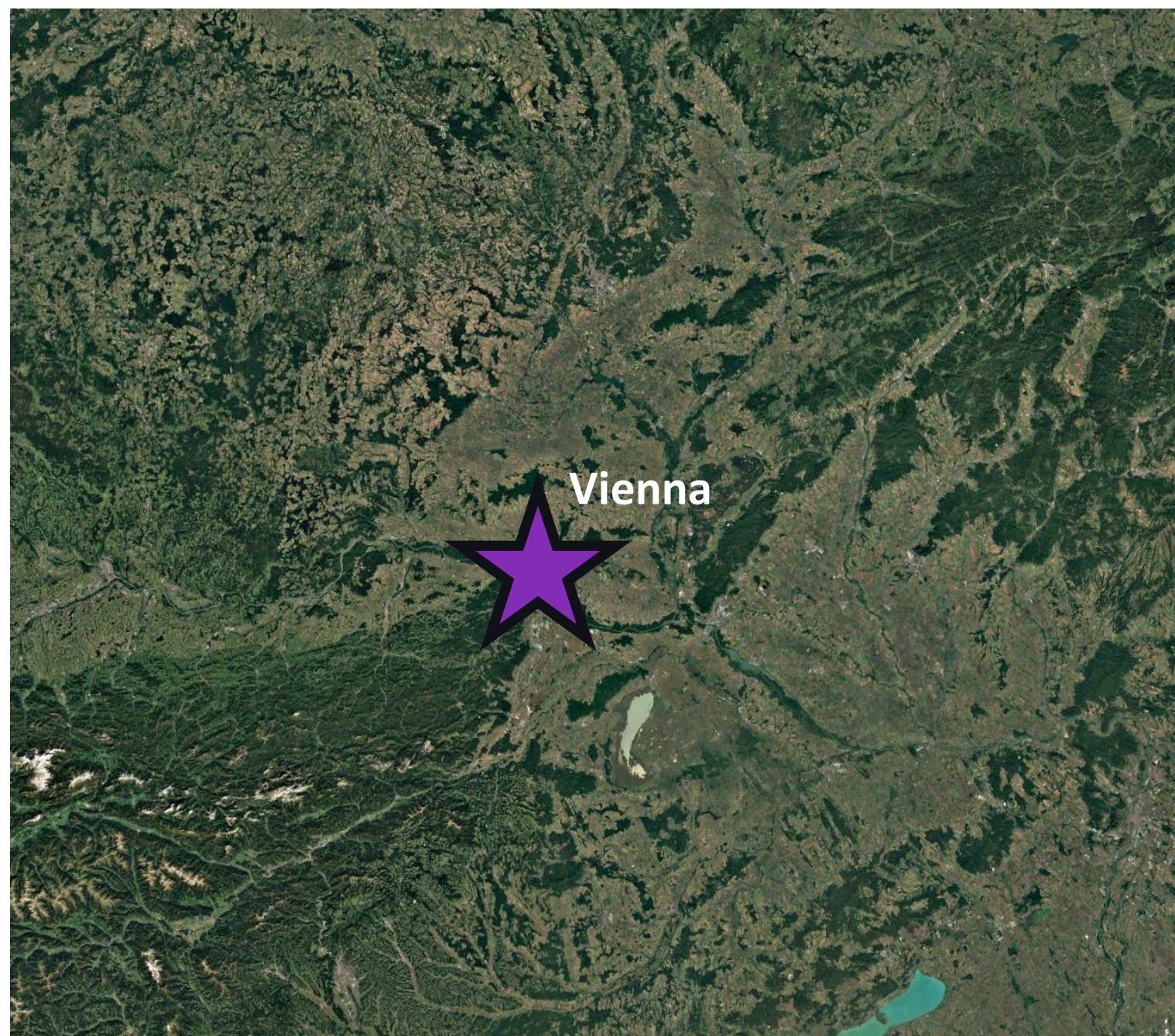
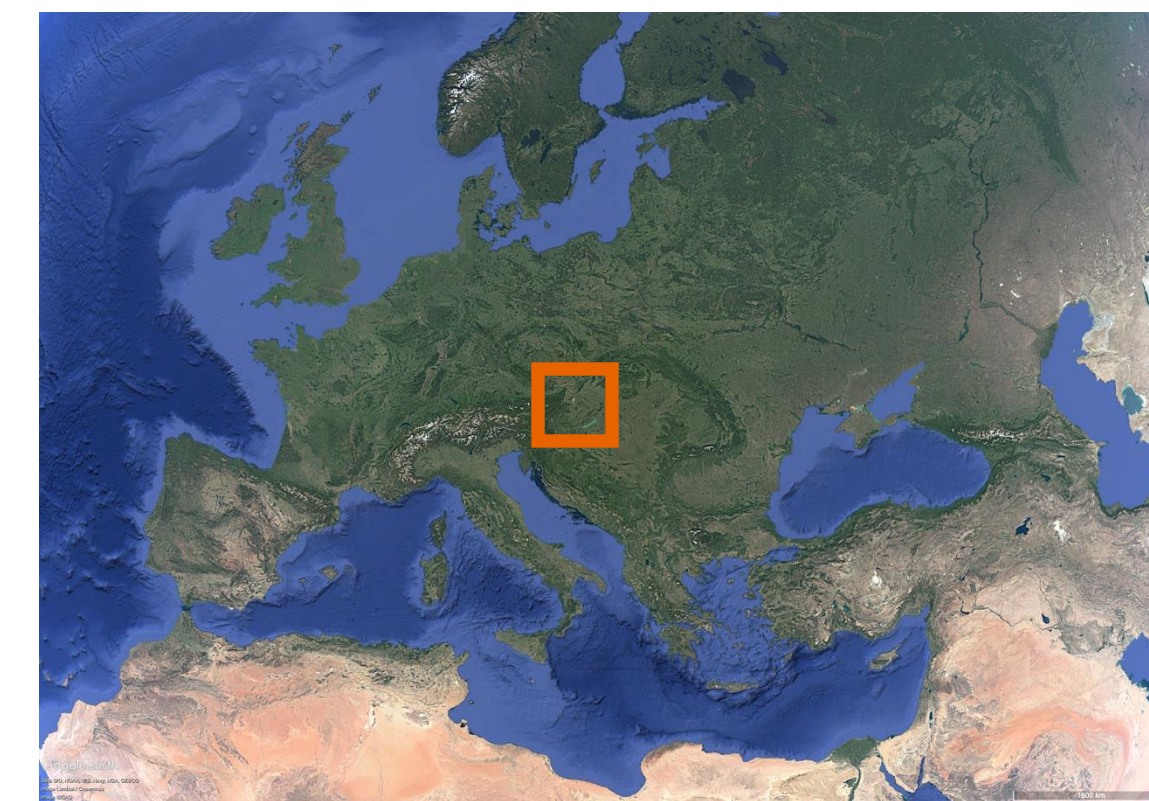
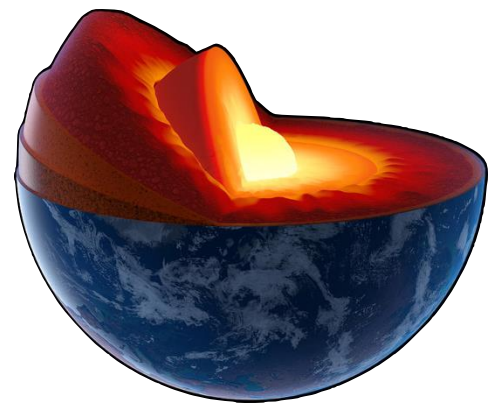


# Earth structure | What is it "locally"?

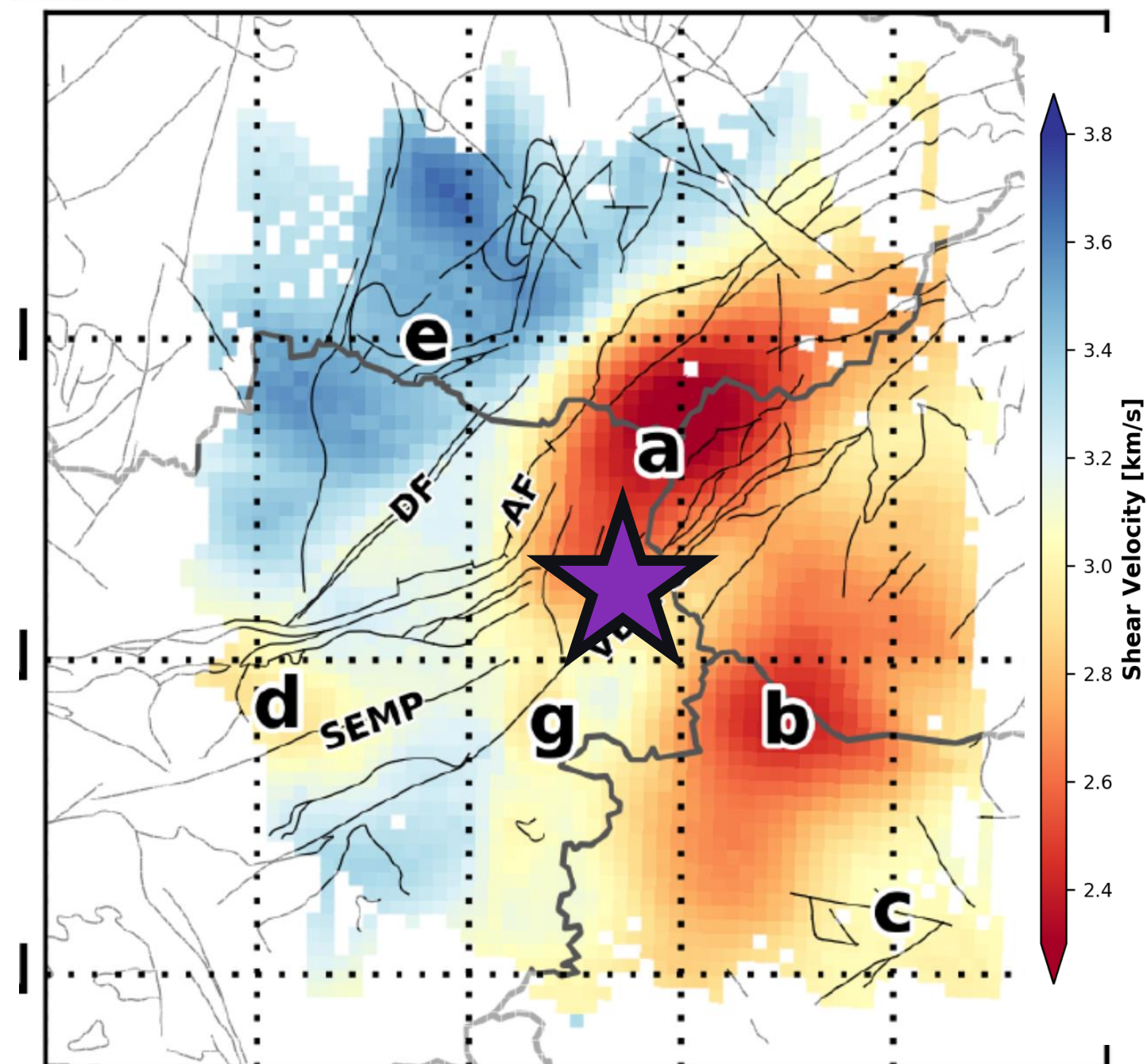


- Geological Units**
- Quaternary
  - Cenozoic
  - Cretaceous
  - Jurassic
  - Triassic
  - Permian
  - Carboniferous
  - Devonian
  - Silurian
  - Ordovician
  - Cambrian
  - Precambrian

# Earth structure | What is it "locally"?



4km



Schippkus et al. 2018

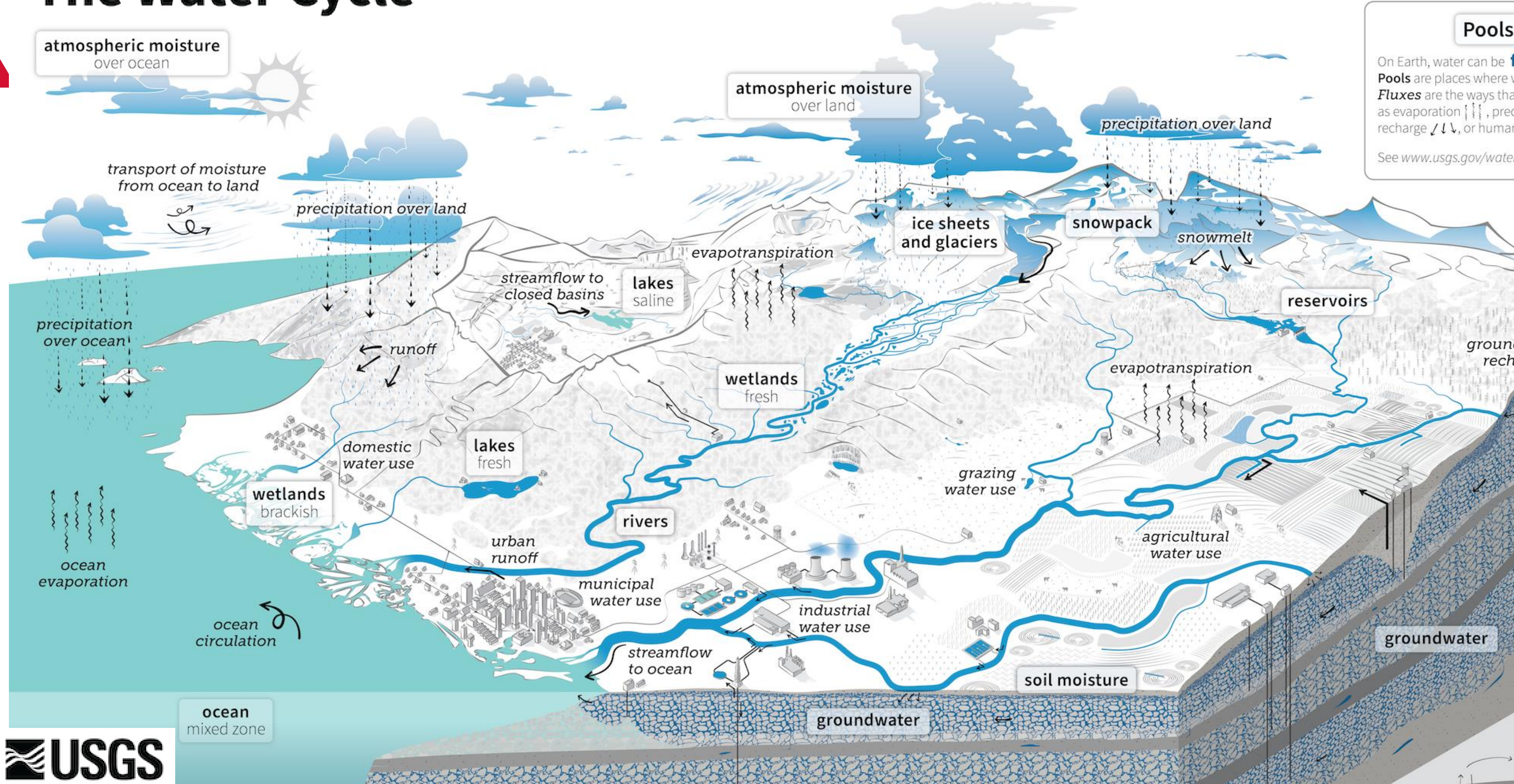
# Environment | What other processes are seismic waves sensitive to?



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## The Water Cycle



**Pools**  
On Earth, water can be found in many different places. **Pools** are places where water is stored for a long time. **Fluxes** are the ways that water moves from one place to another, such as evaporation, precipitation, recharge, or human use.

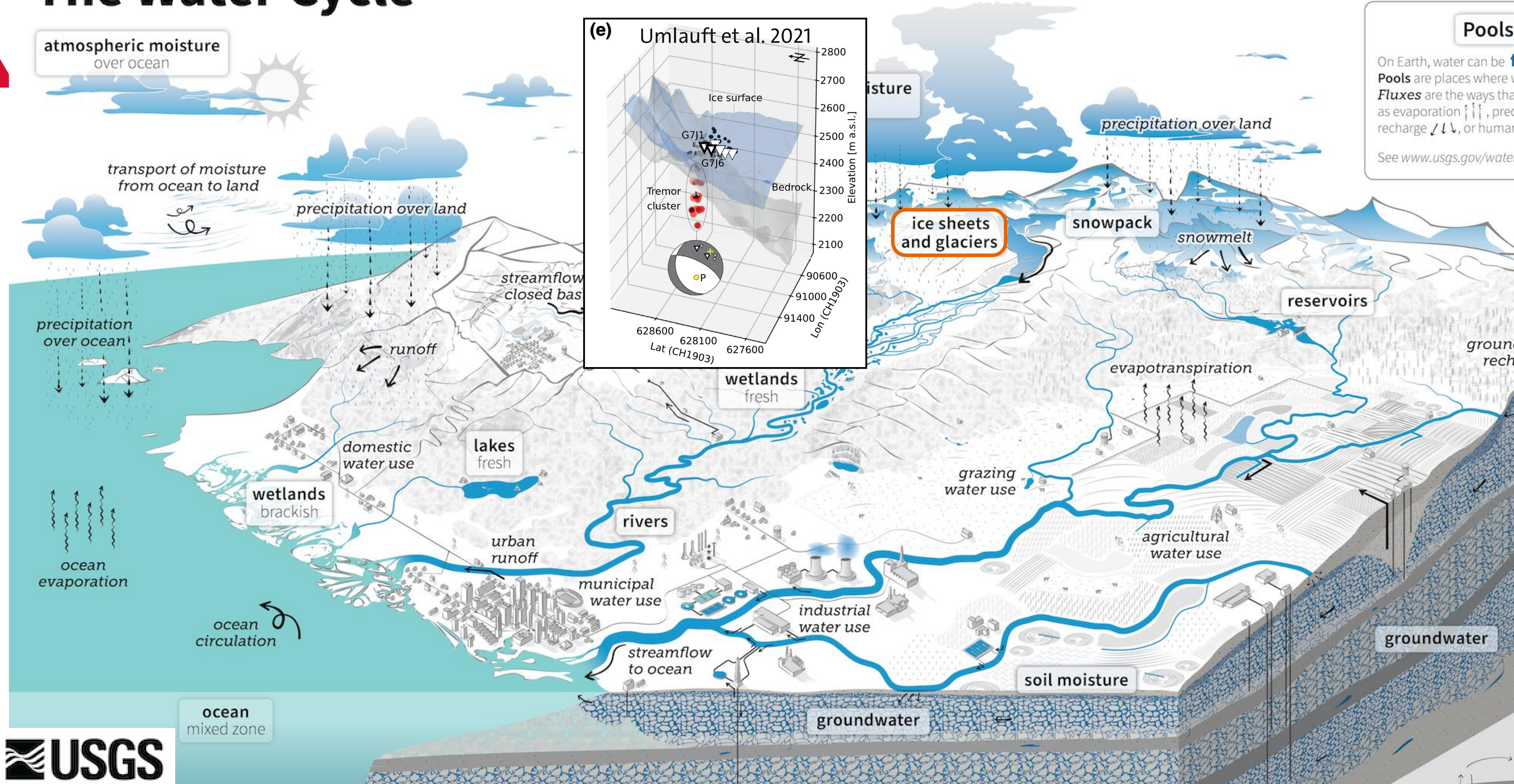
See [www.usgs.gov/water](http://www.usgs.gov/water)



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## The Water Cycle



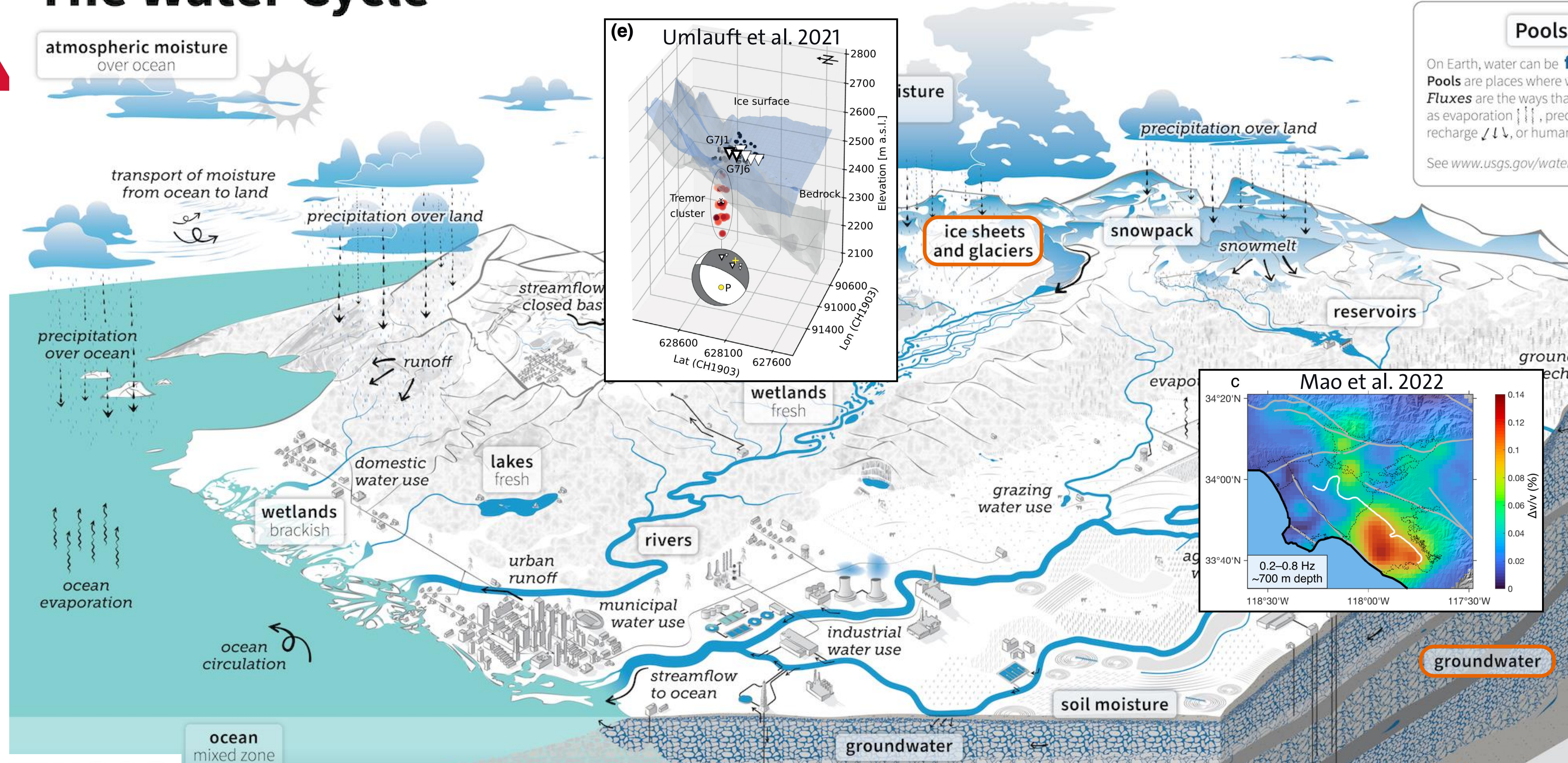
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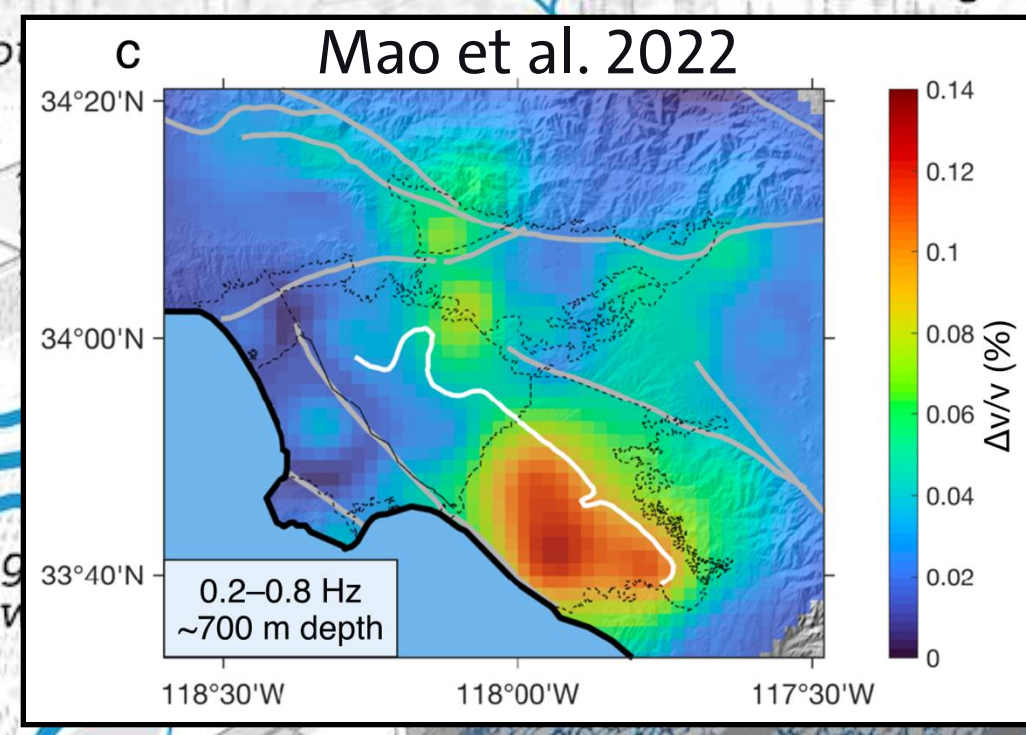
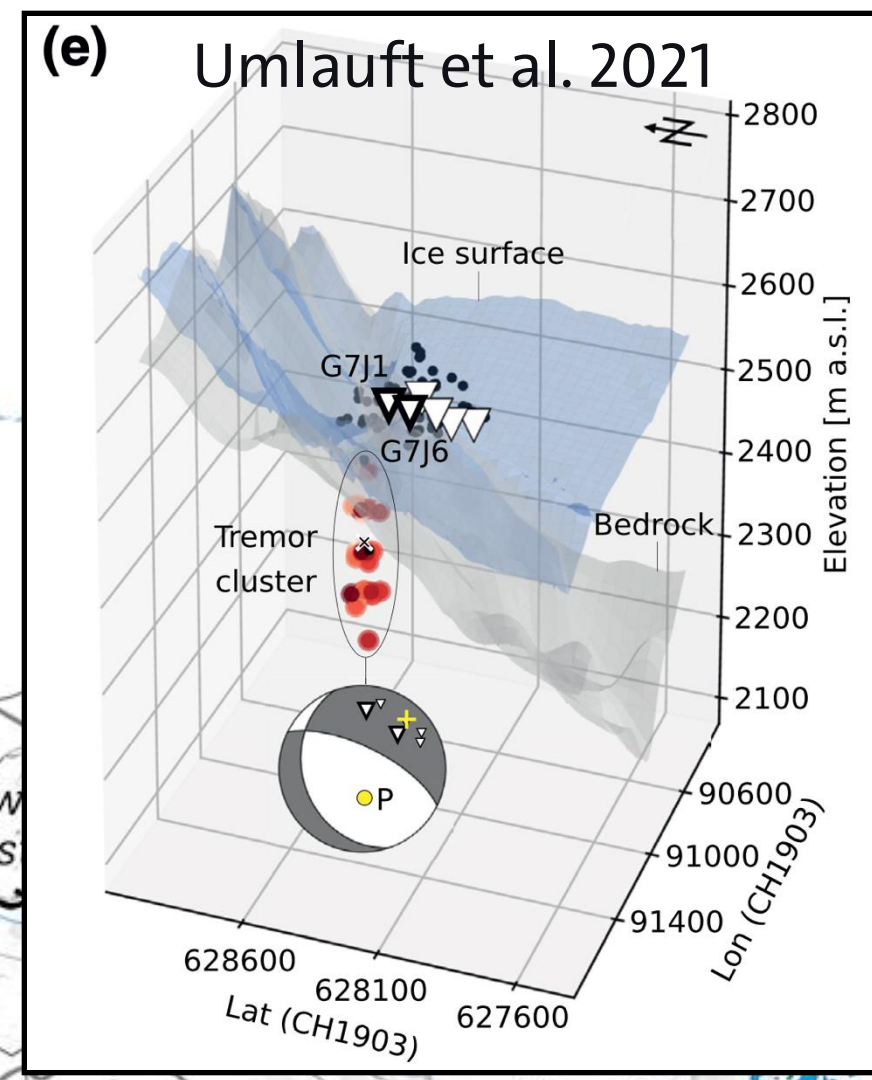
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## The Water Cycle



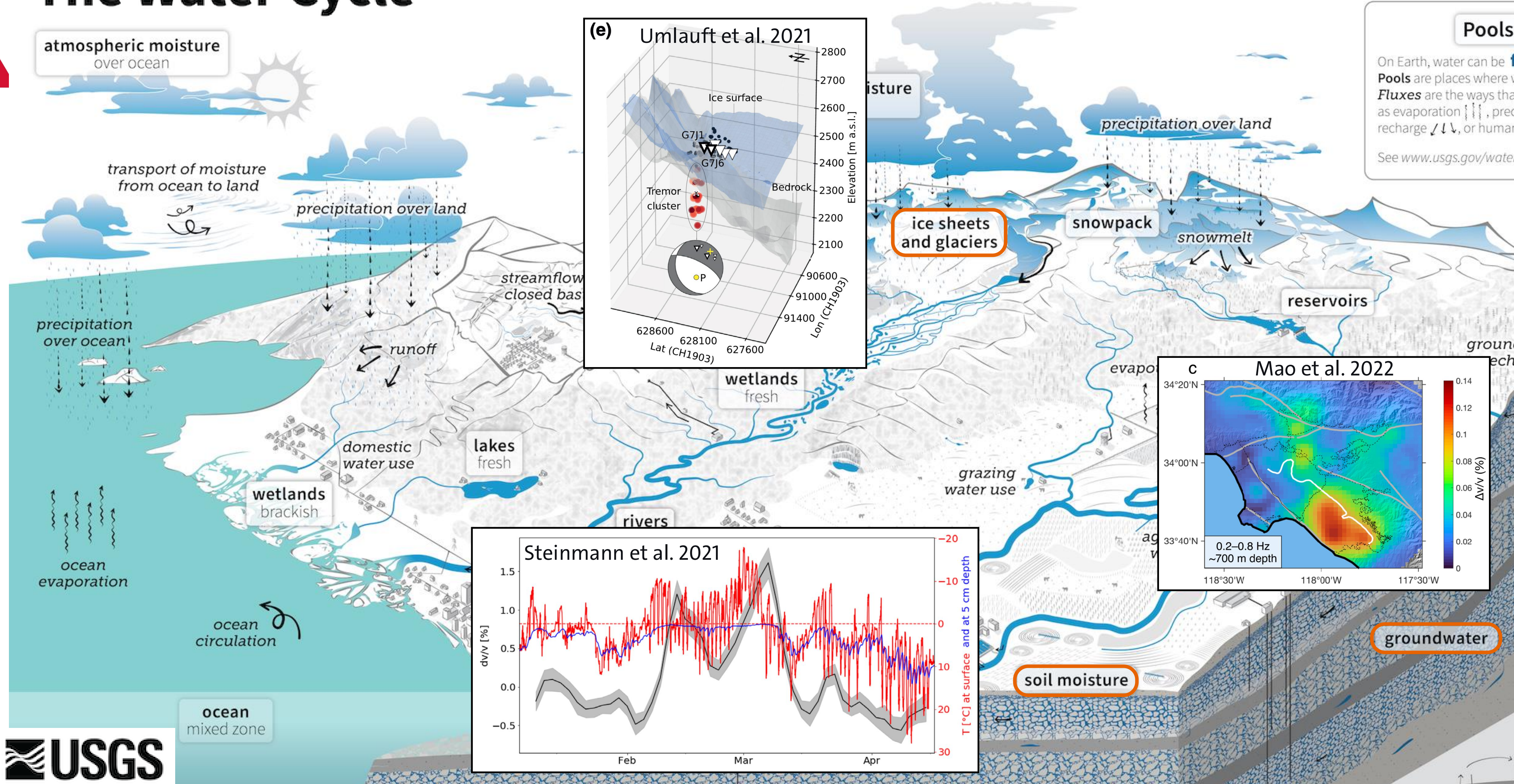
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See [www.usgs.gov/water](http://www.usgs.gov/water)

# Environment | What other processes are seismic waves sensitive to?



## The Water Cycle

atmospheric moisture over ocean

transport of moisture from ocean to land

precipitation over land

streamflow closed basin

runoff

domestic water use

lakes fresh

wetlands brackish

wetlands fresh

rivers

grazing water use

evaporation

precipitation over land

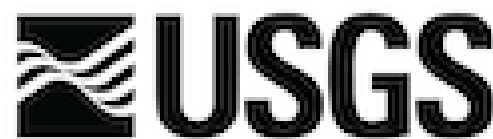
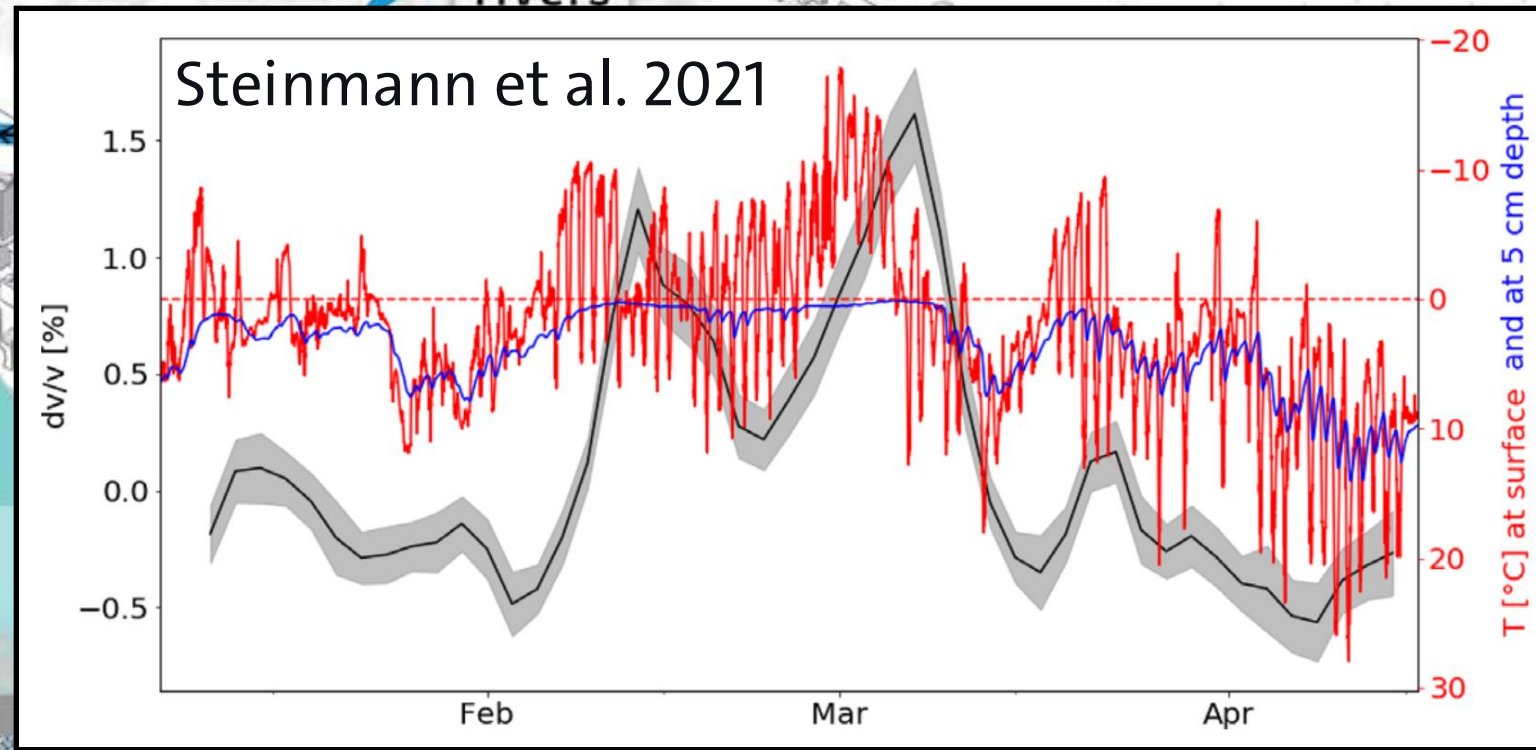
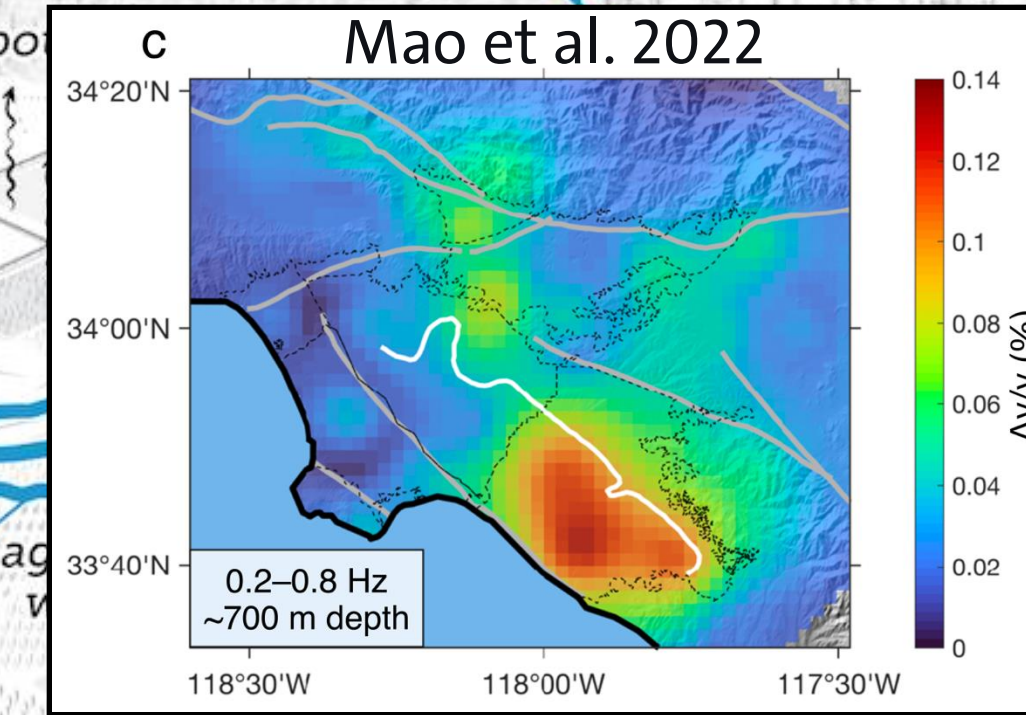
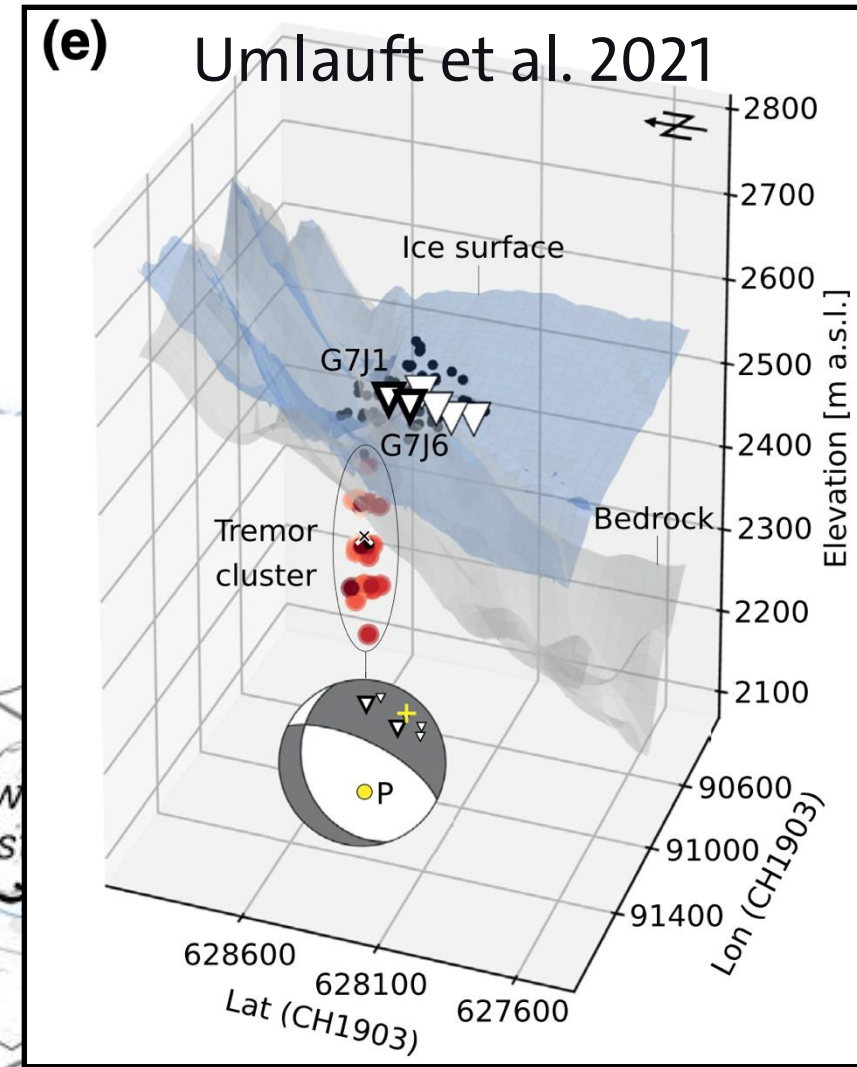
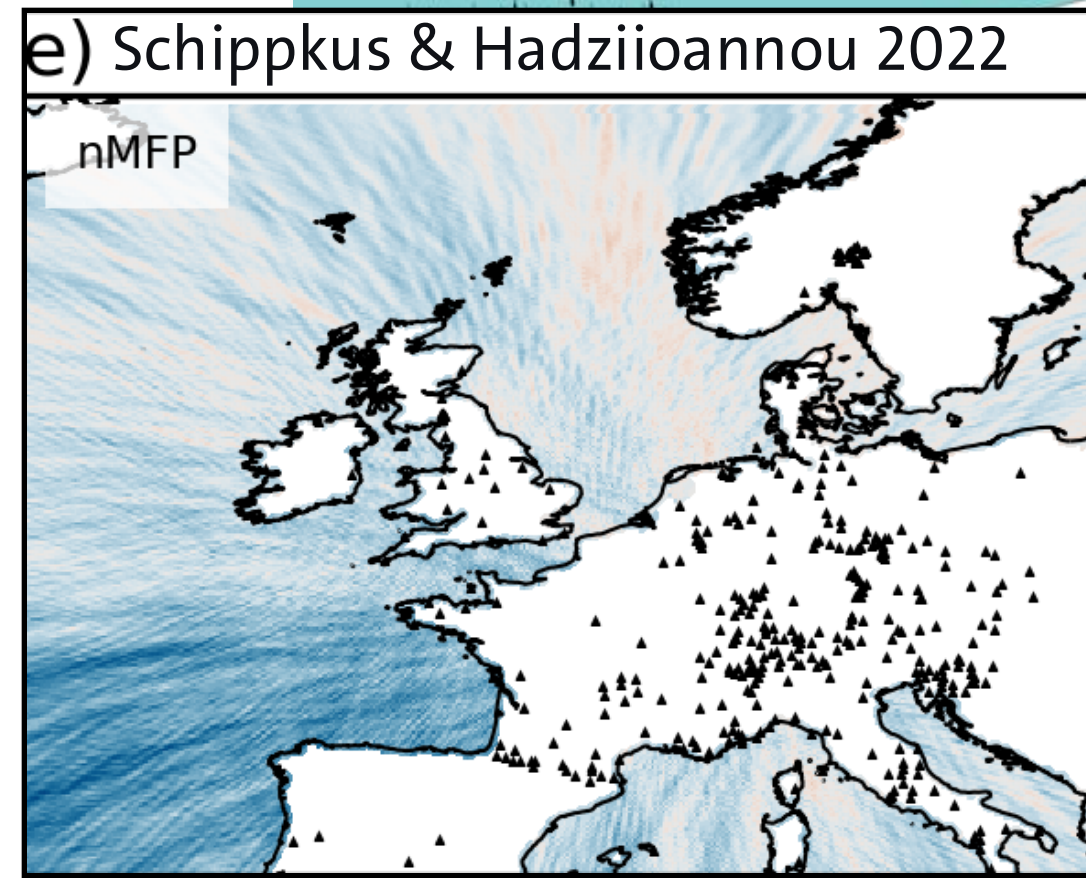
snowpack

snowmelt

reservoirs

Pools

On Earth, water can be... Pools are places where... Fluxes are the ways that... as evaporation... recharge... or human... See [www.usgs.gov/water](http://www.usgs.gov/water)



ocean mixed zone

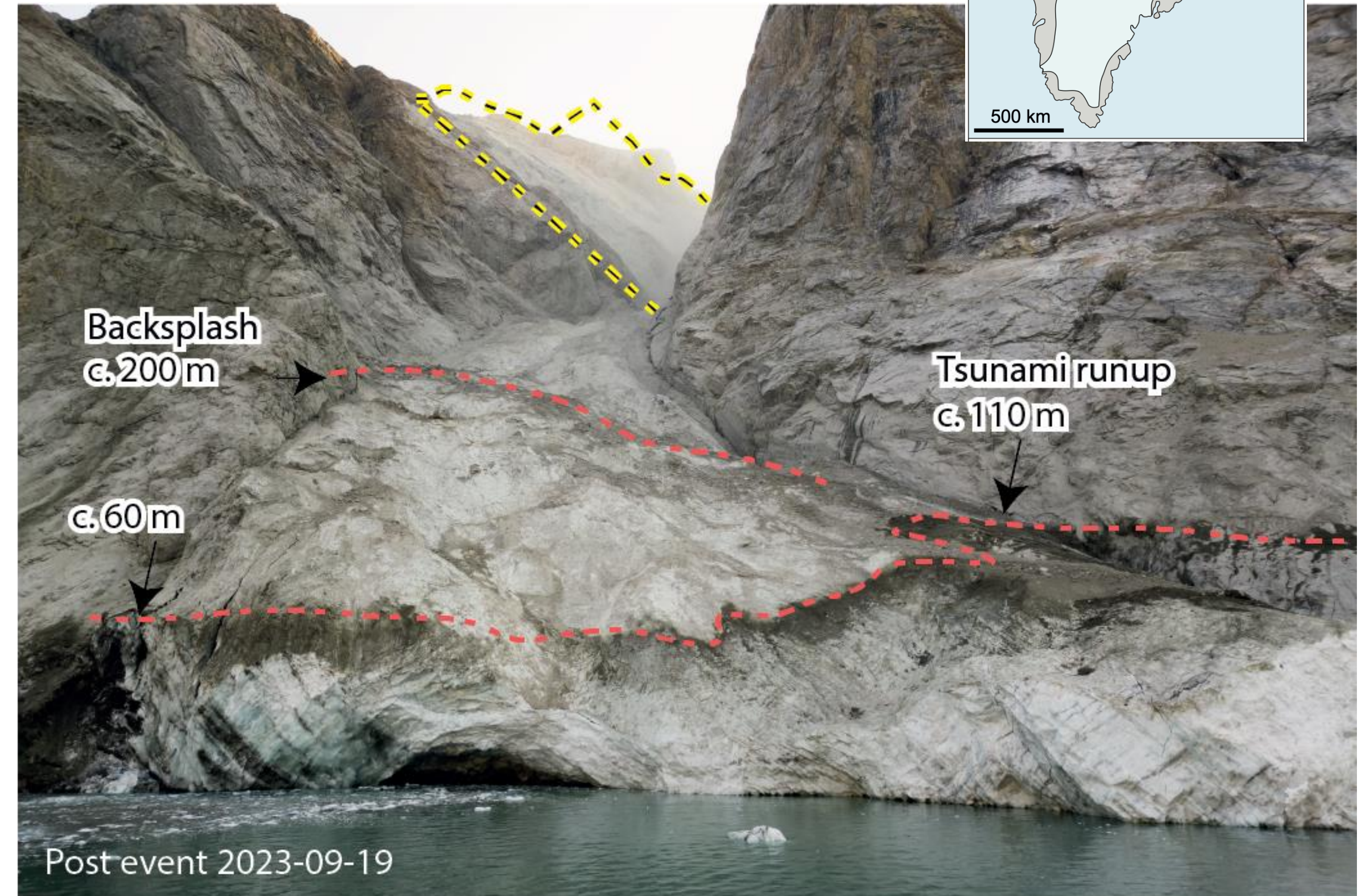
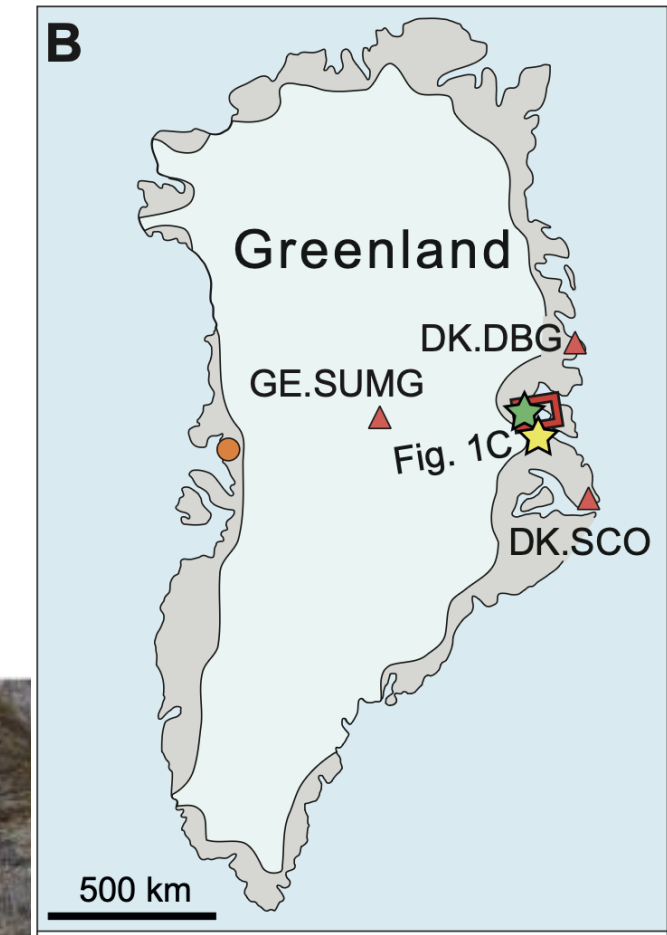
groundwater

soil moisture

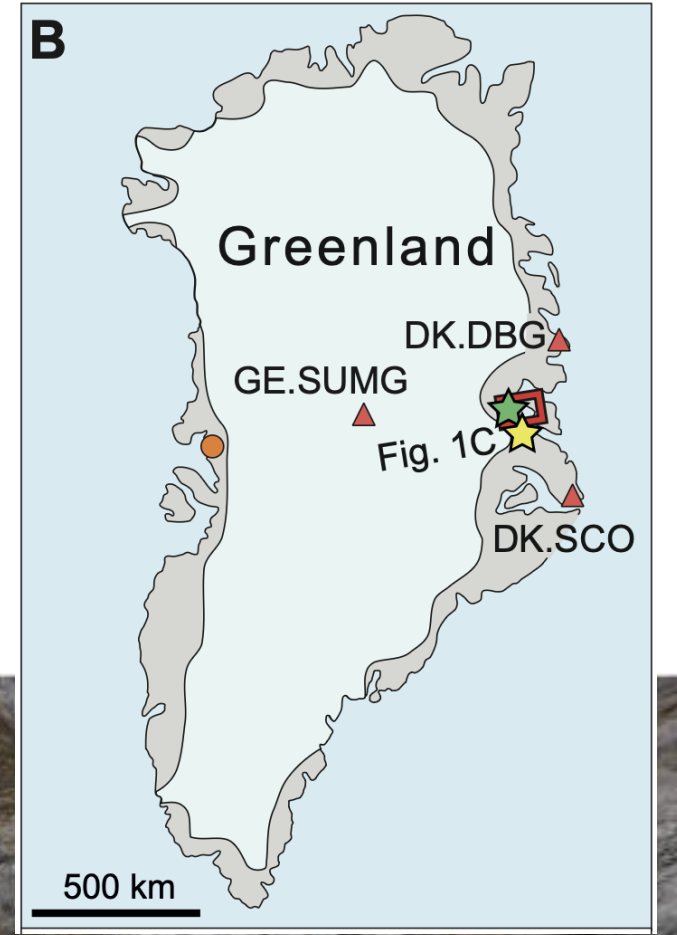
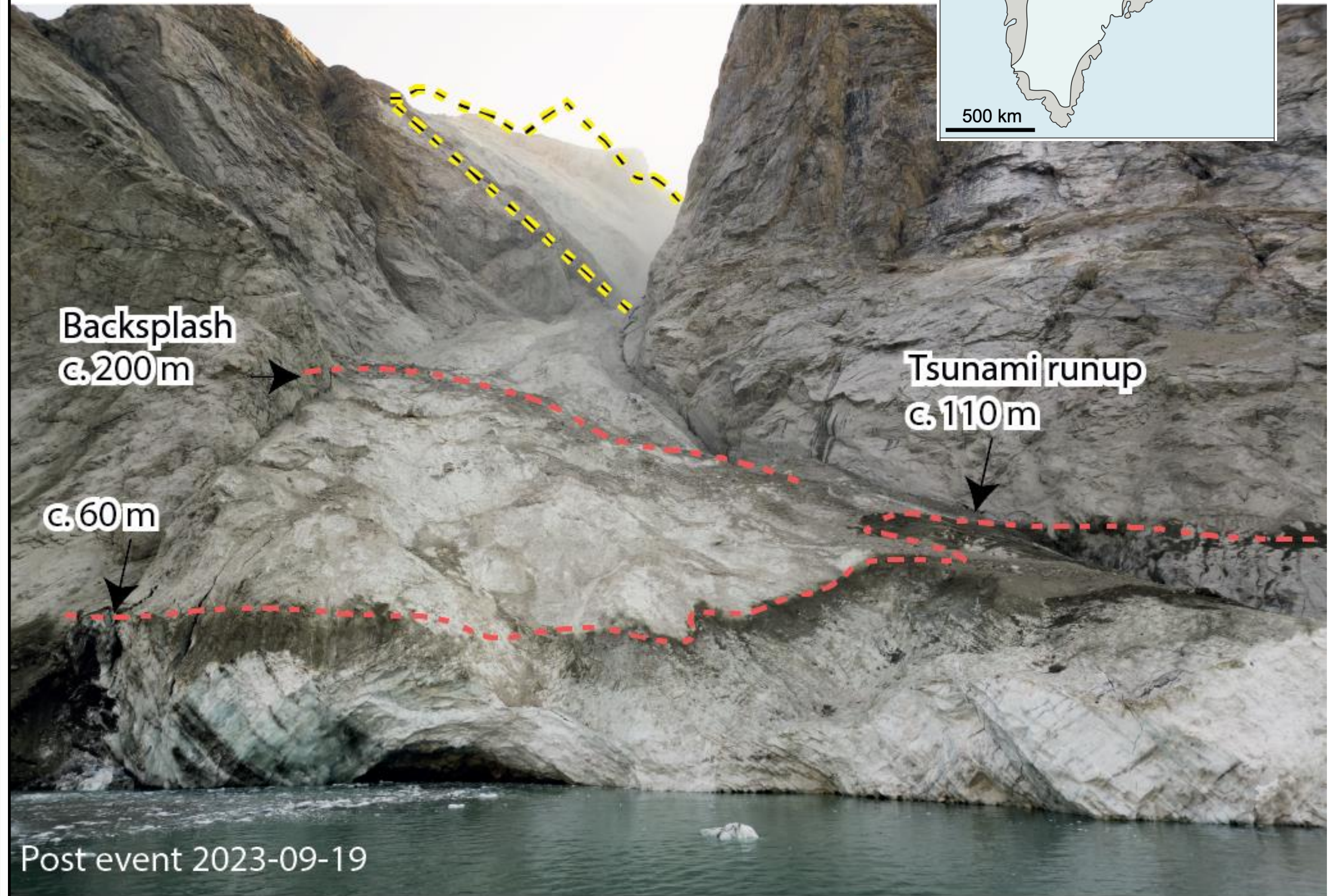
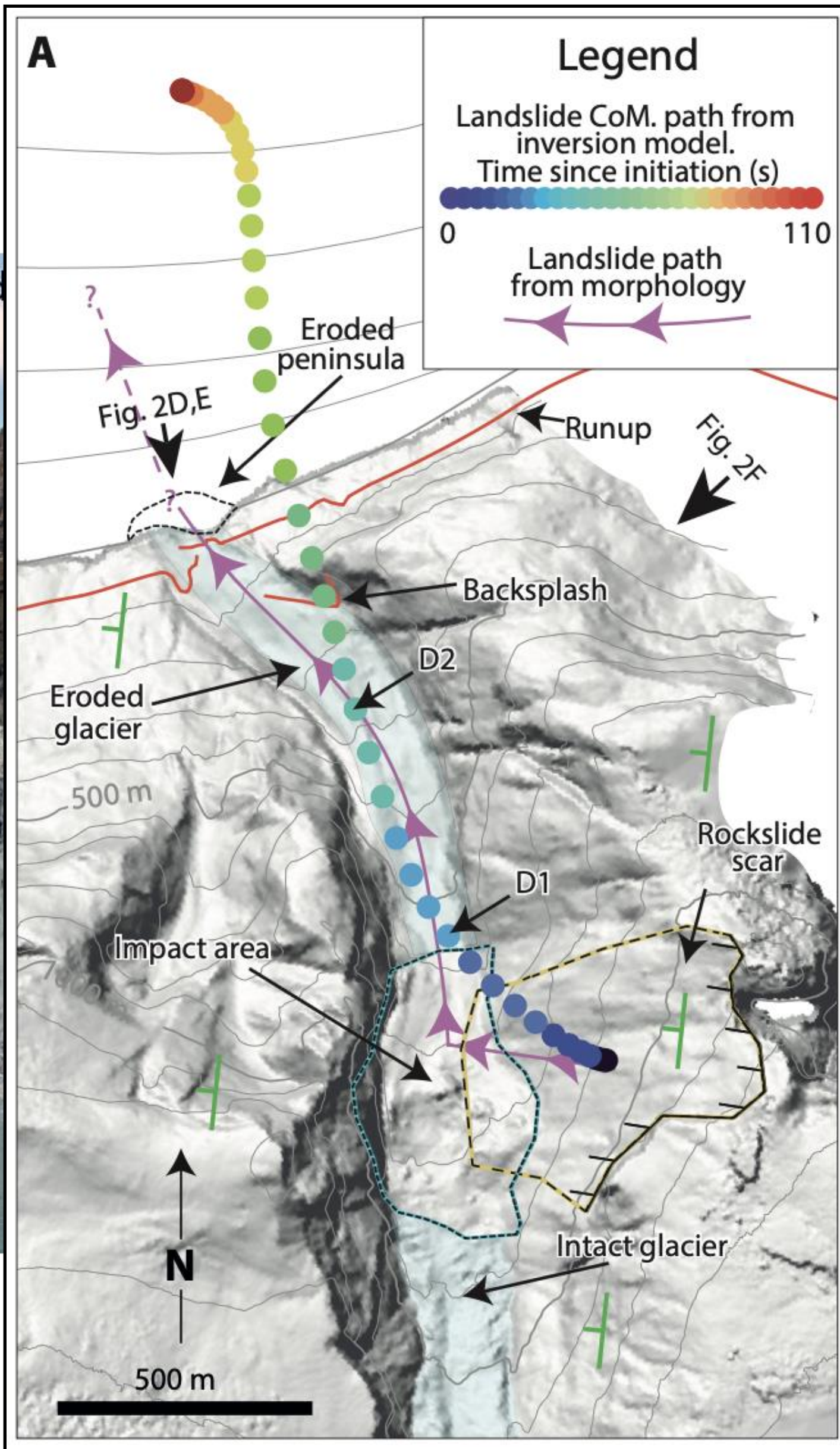
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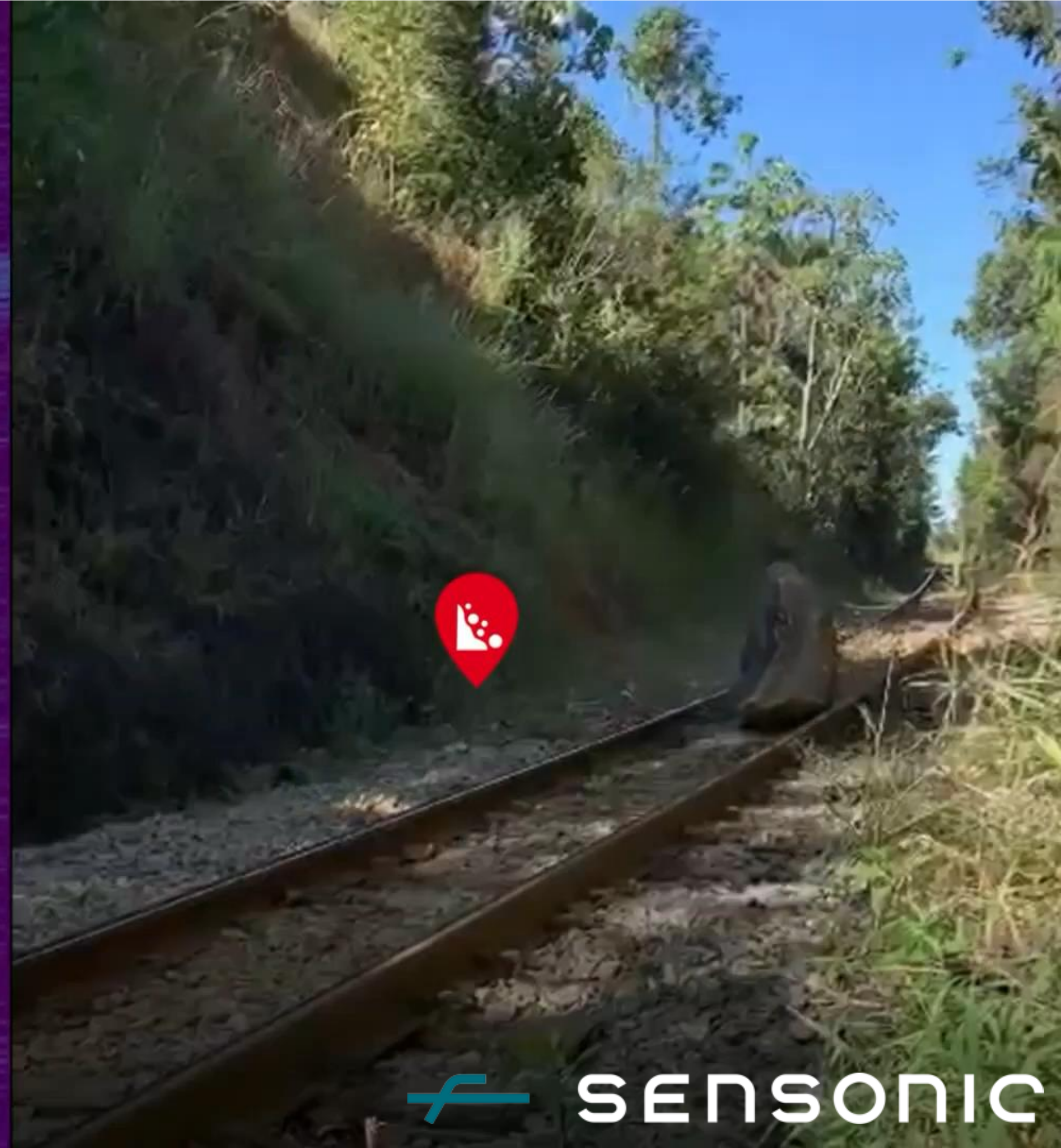
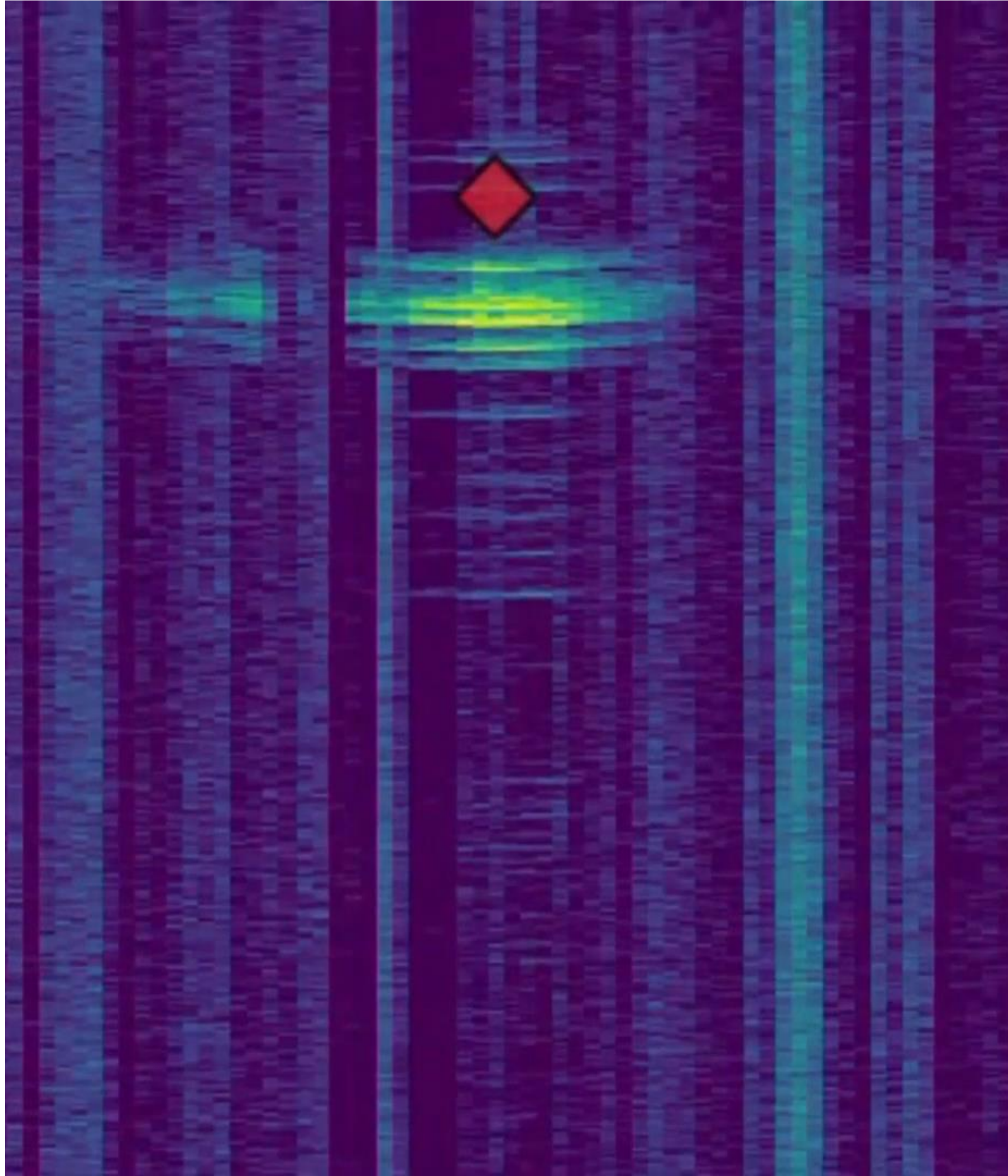
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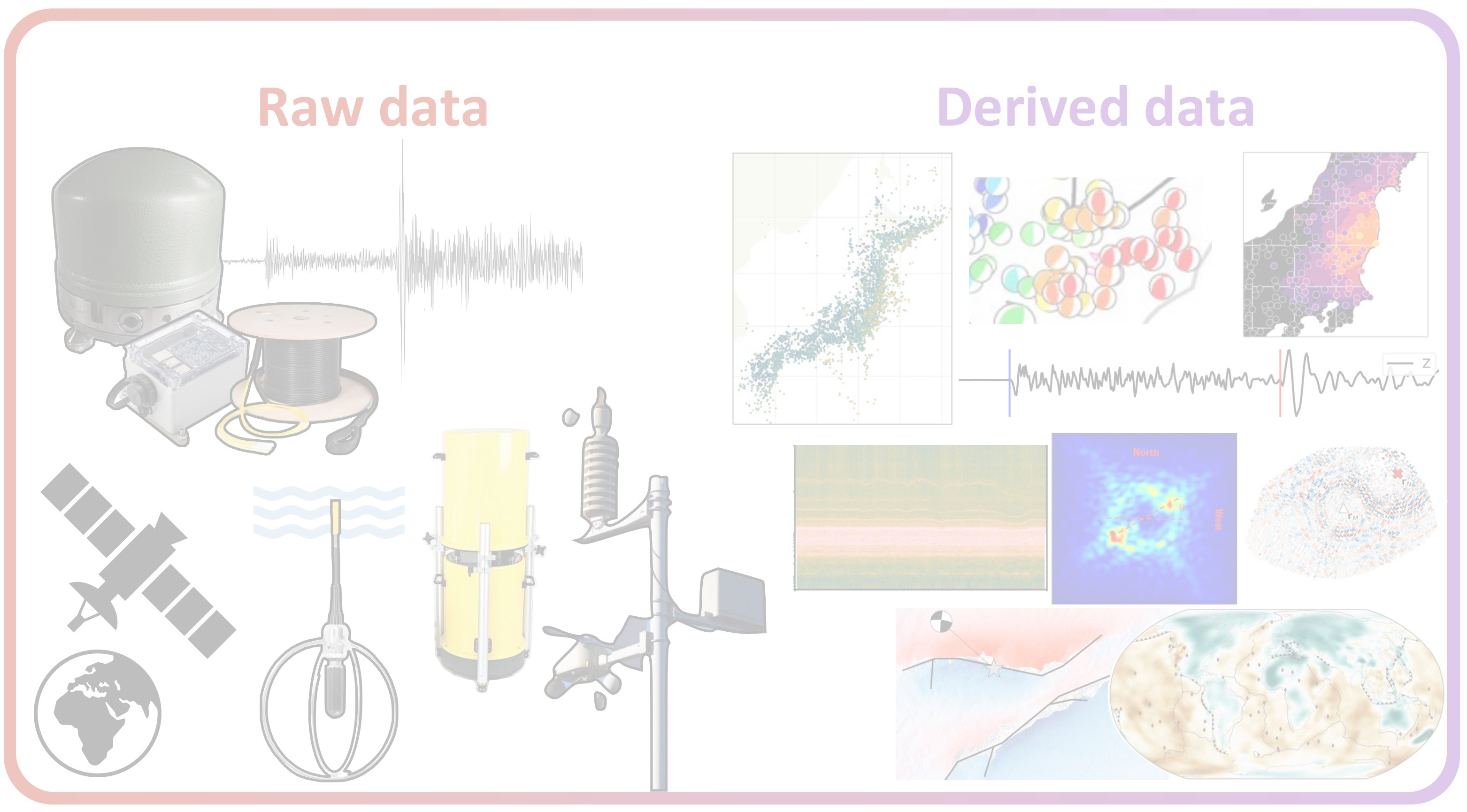
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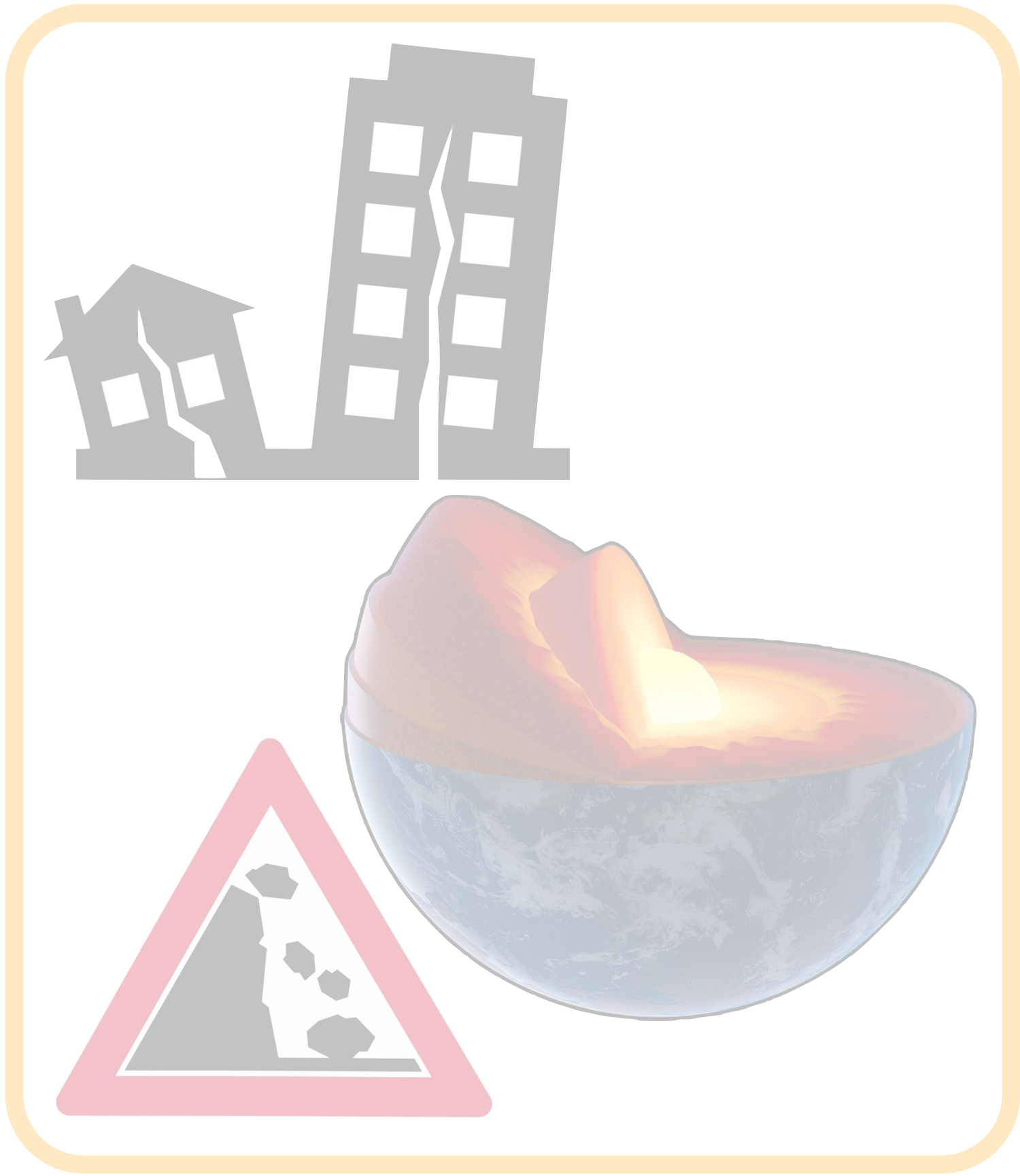
# Targets



# Data



# Targets



# Data

**Raw data**

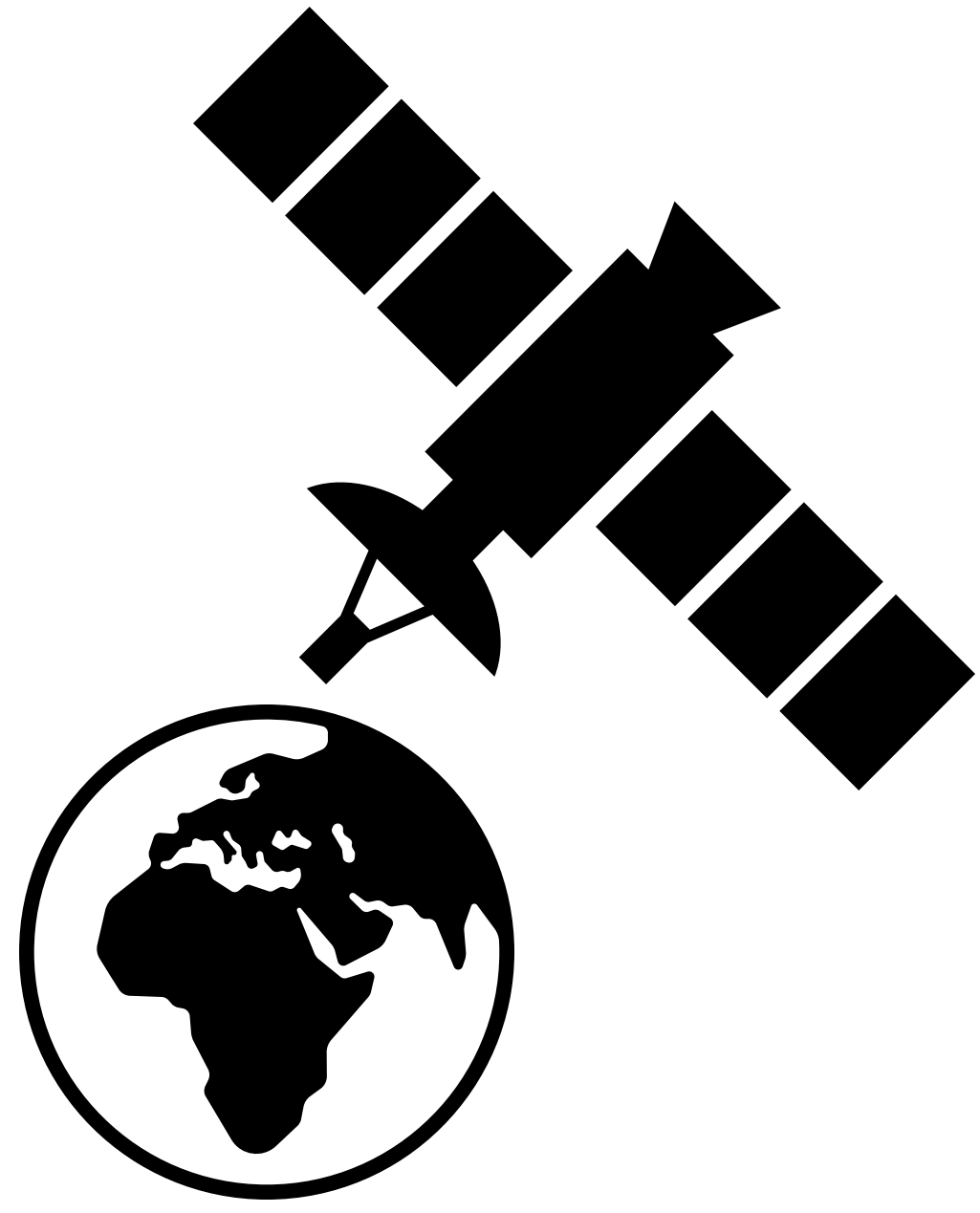
**Derived data**

A collage of data visualization elements. The 'Raw data' section includes a radar dish, a satellite, a hydrophone, a yellow cylindrical sensor, and a microphone. The 'Derived data' section includes a scatter plot on a map, a 3D molecular model, a heatmap of a coastline, a cross-section of a seabed, a heatmap with 'North' and 'West' labels, a circular data plot, a map of a coastline with a star, and a topographic map of a region.

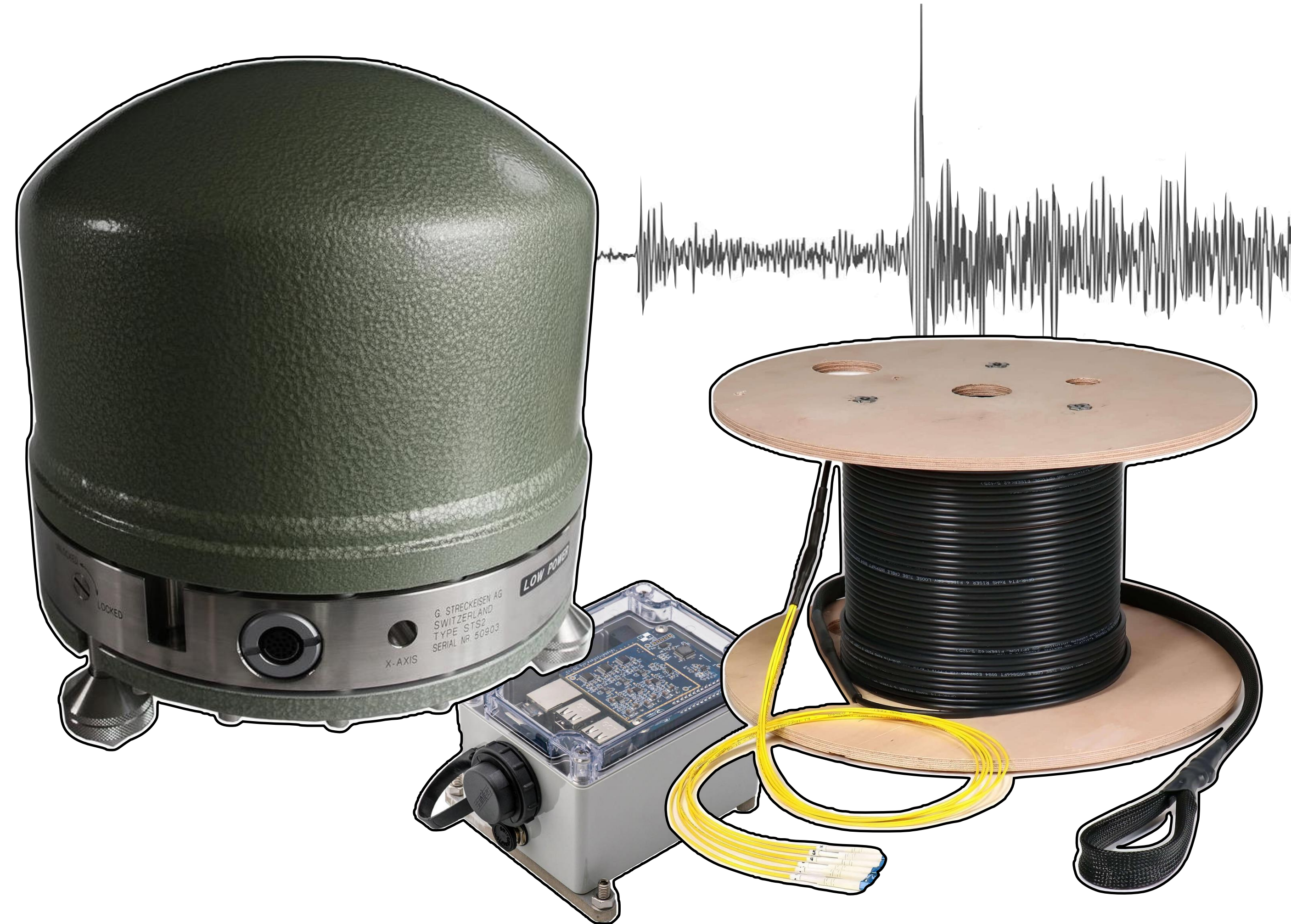
# Ground motions

# Satellite-based

# miscellaneous



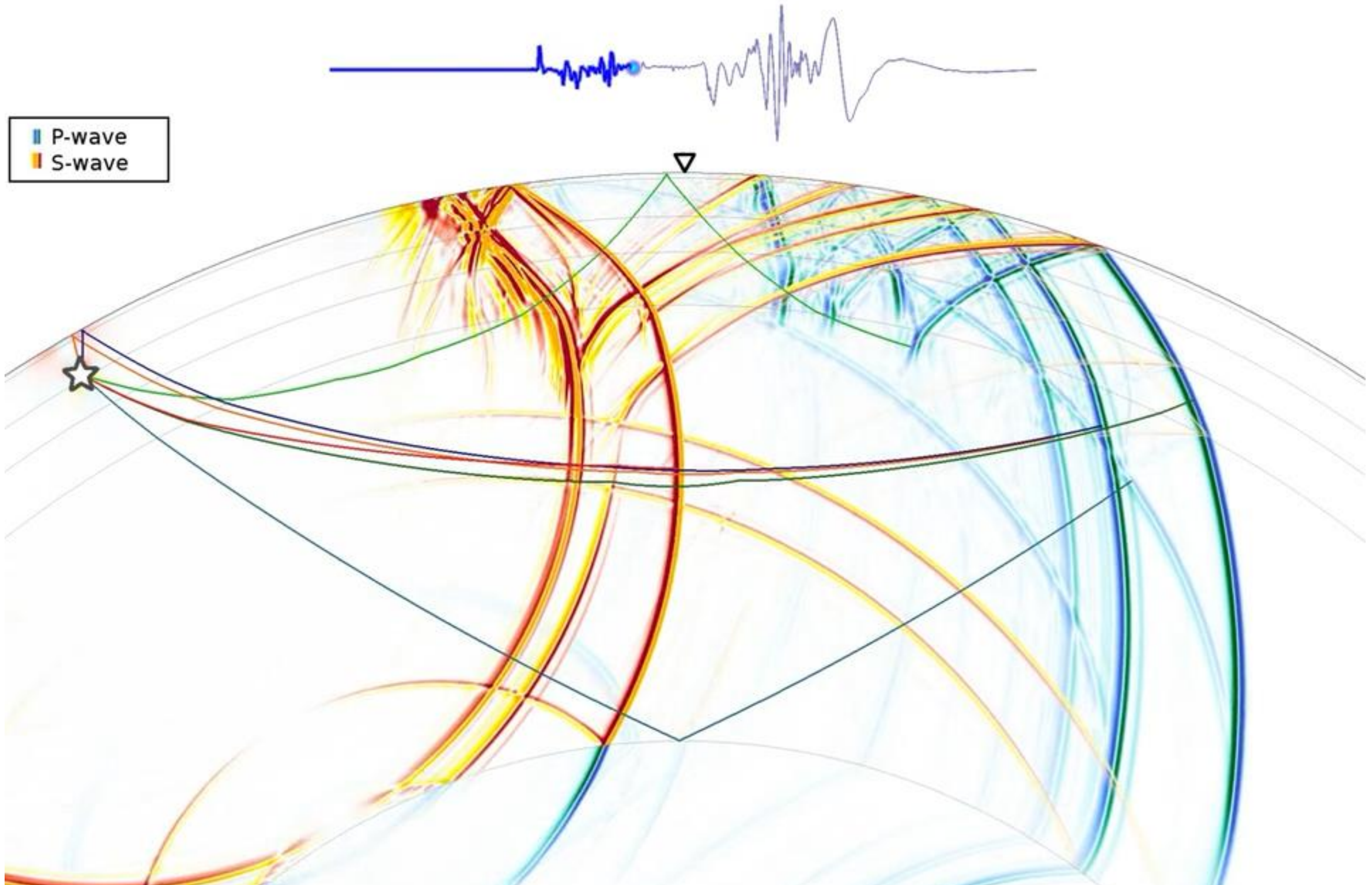
# Ground motions



# Satellite-based miscellaneous



# GROUND MOTIONS | What is elastic ground motion?

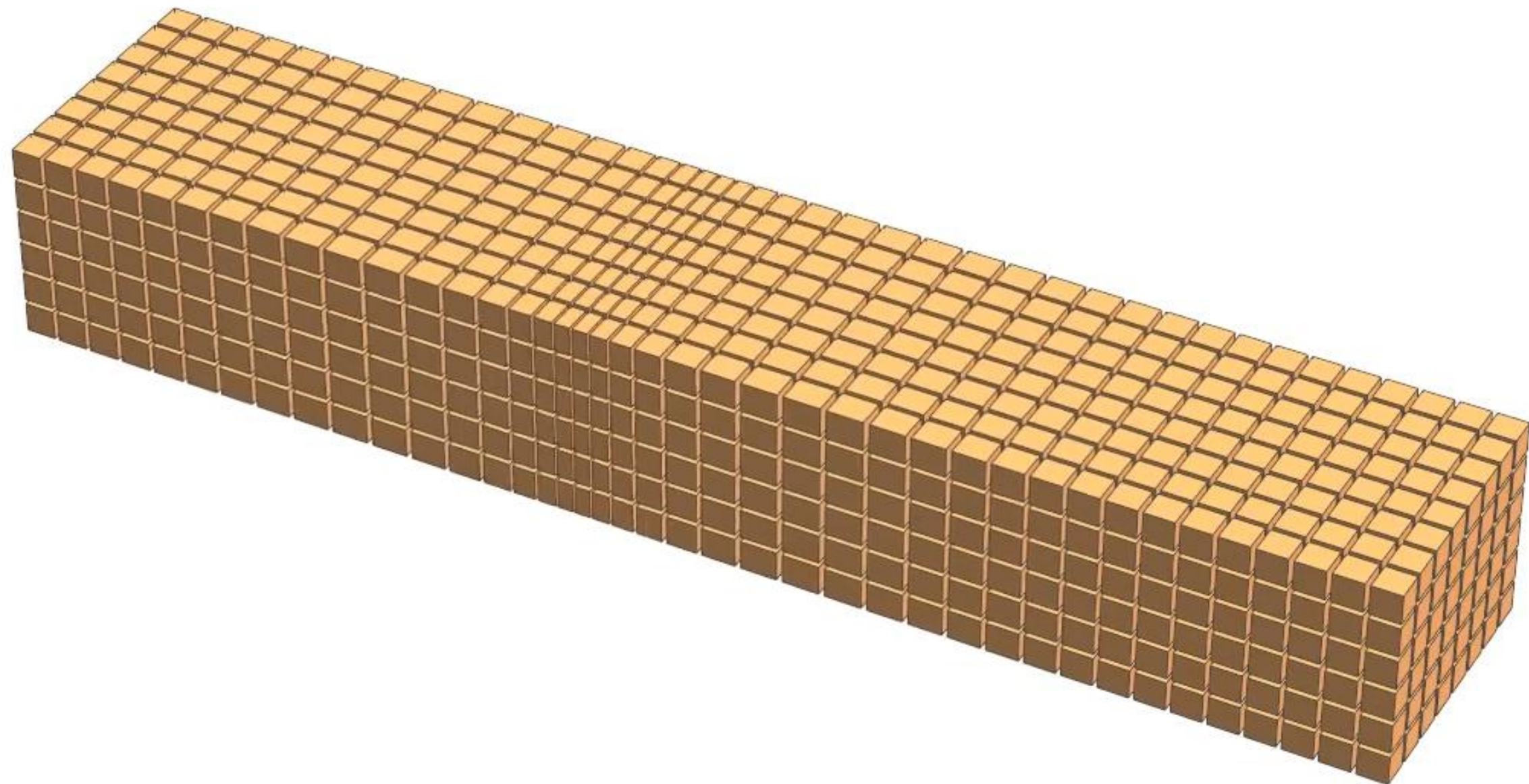


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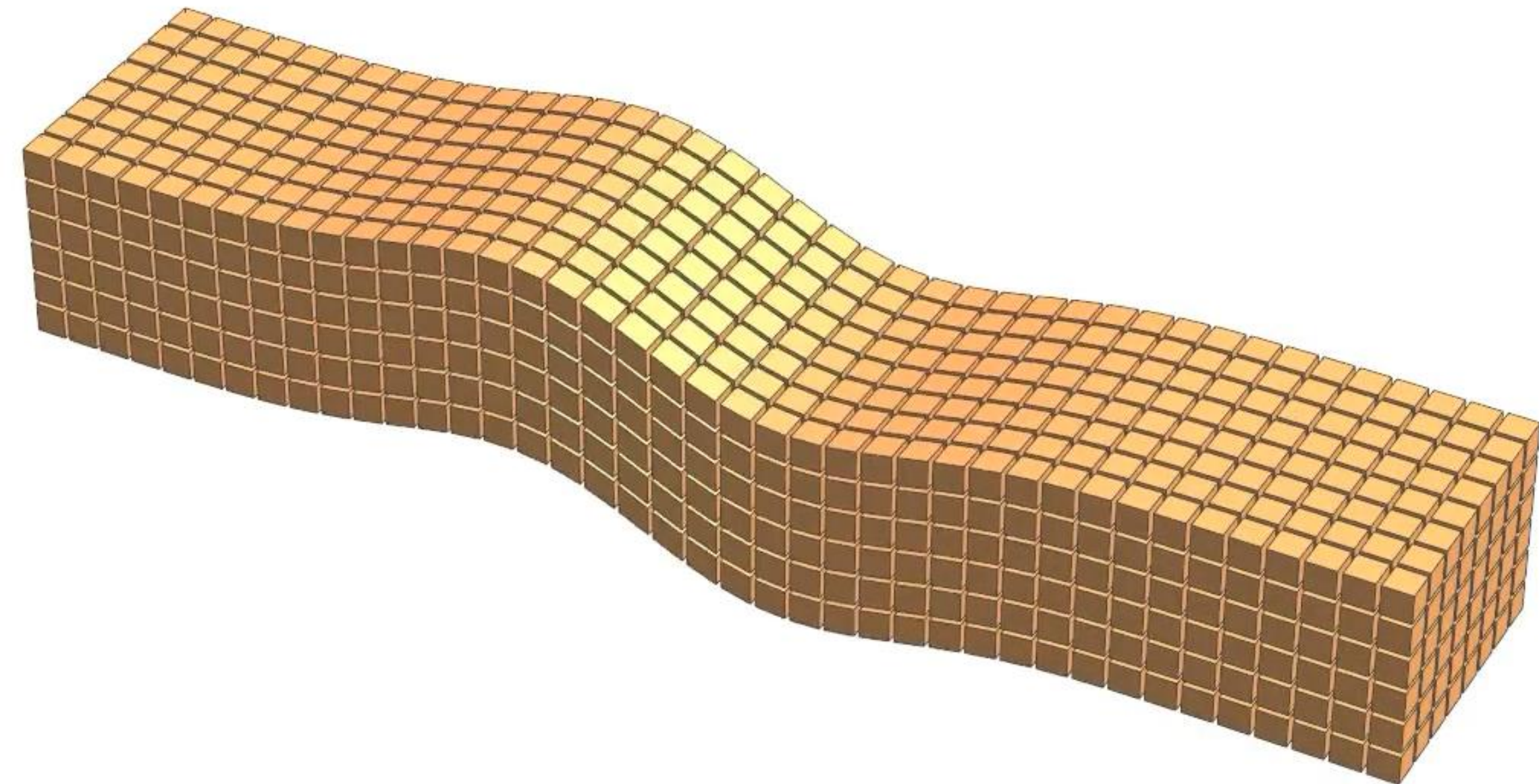


## Body waves

P-Waves



S-waves



# GROUND MOTIONS | What is elastic ground motion?



**Acoustic waves have only P-motion!**

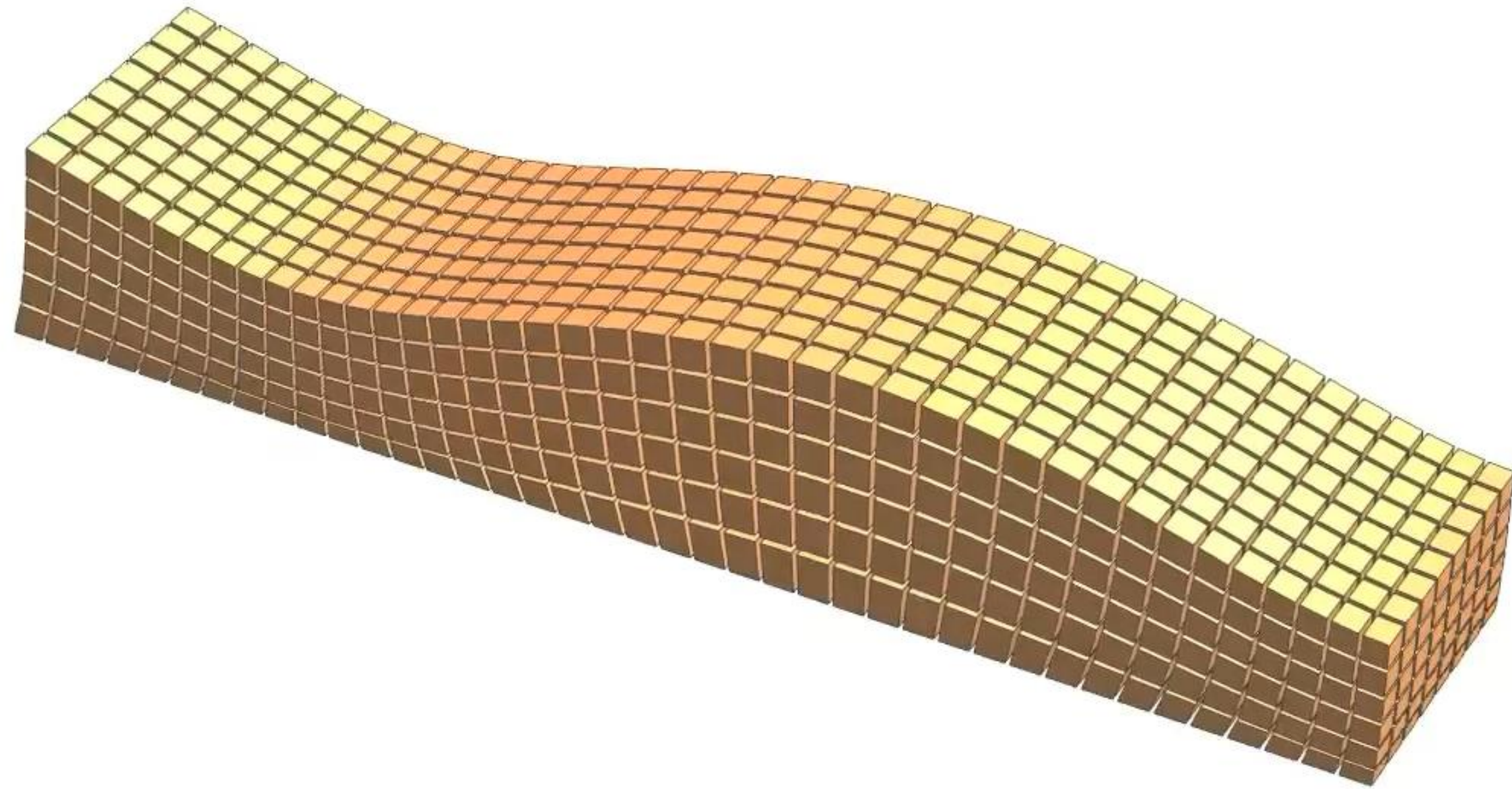


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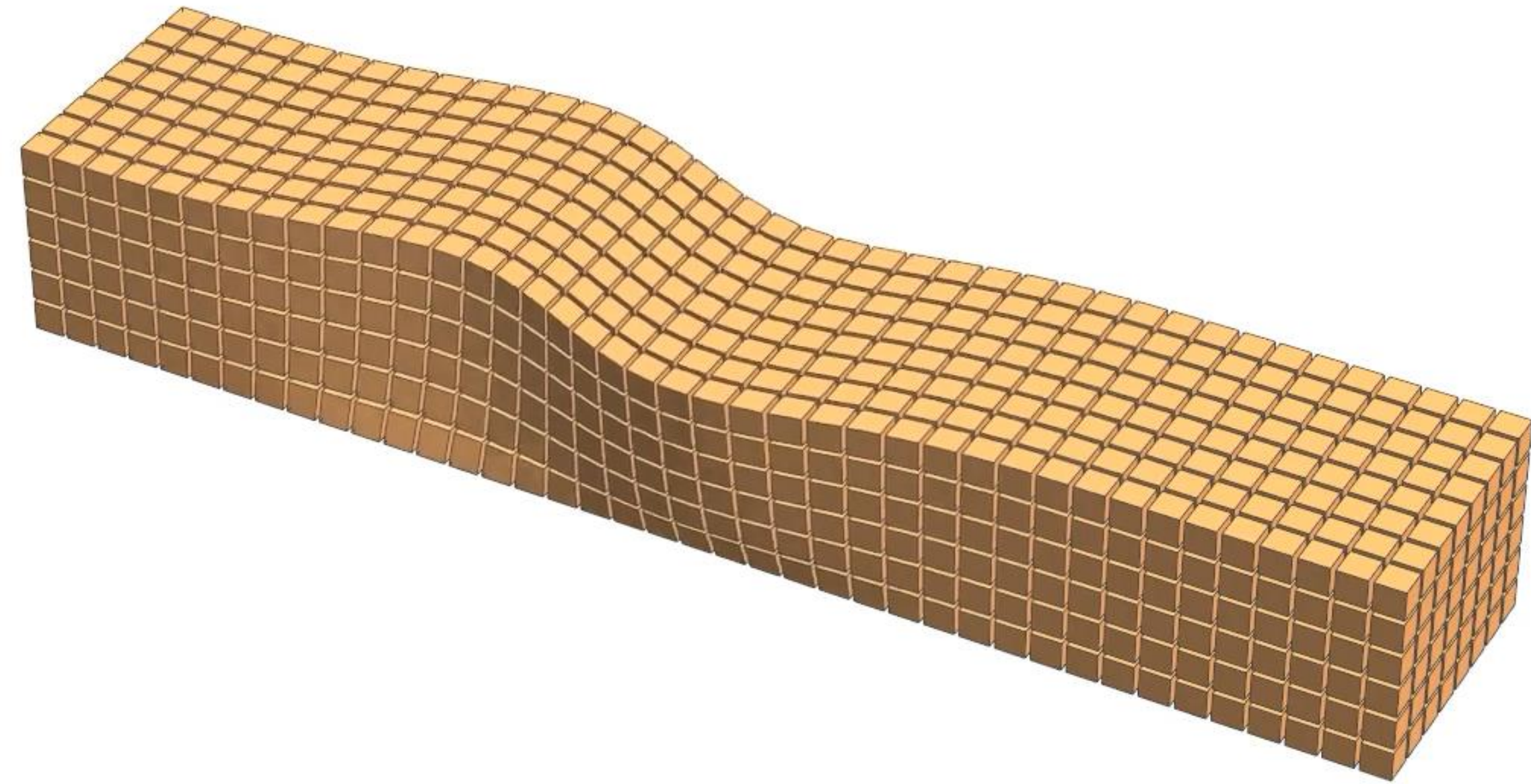


## Surface waves

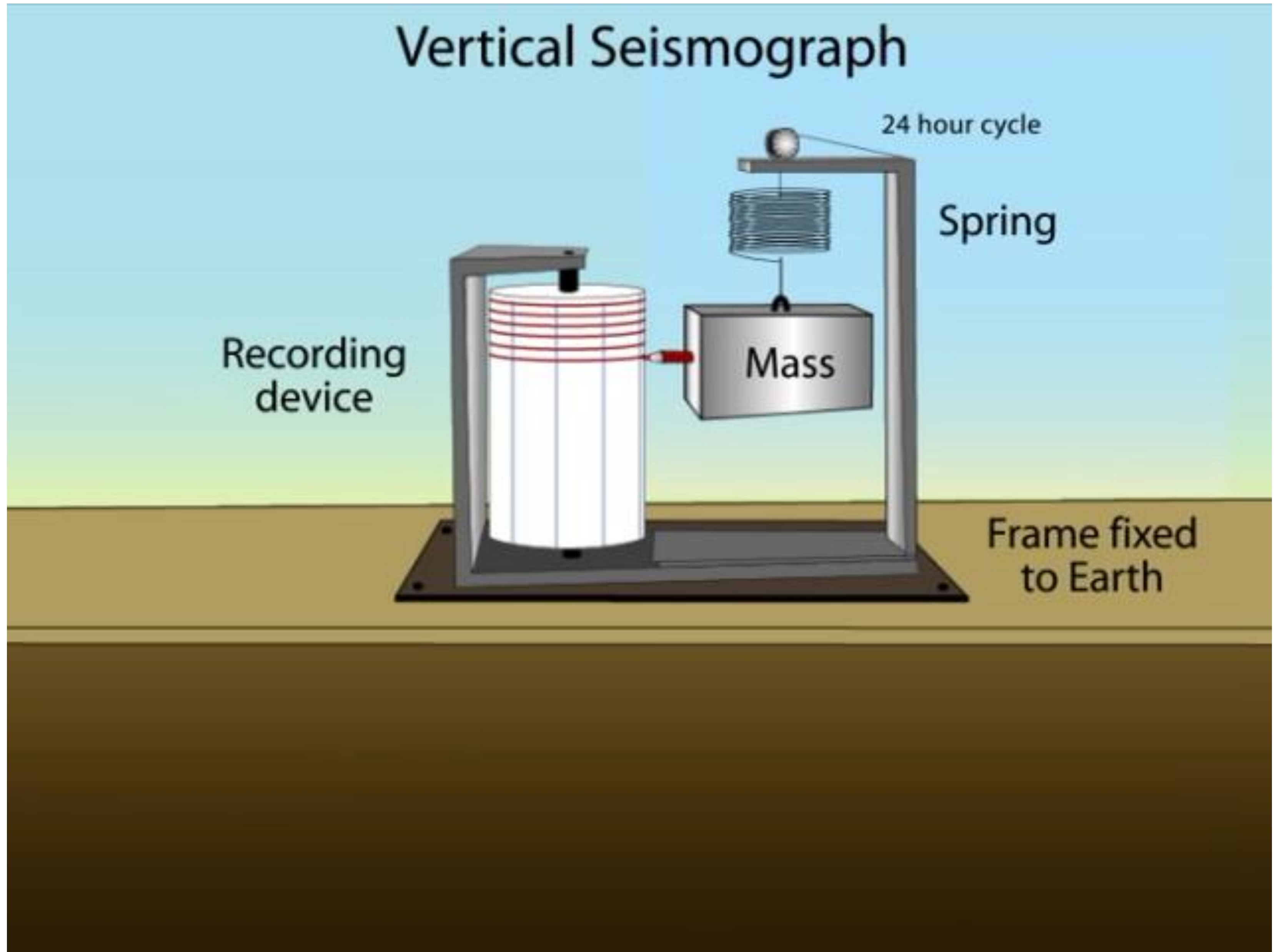
Rayleigh waves



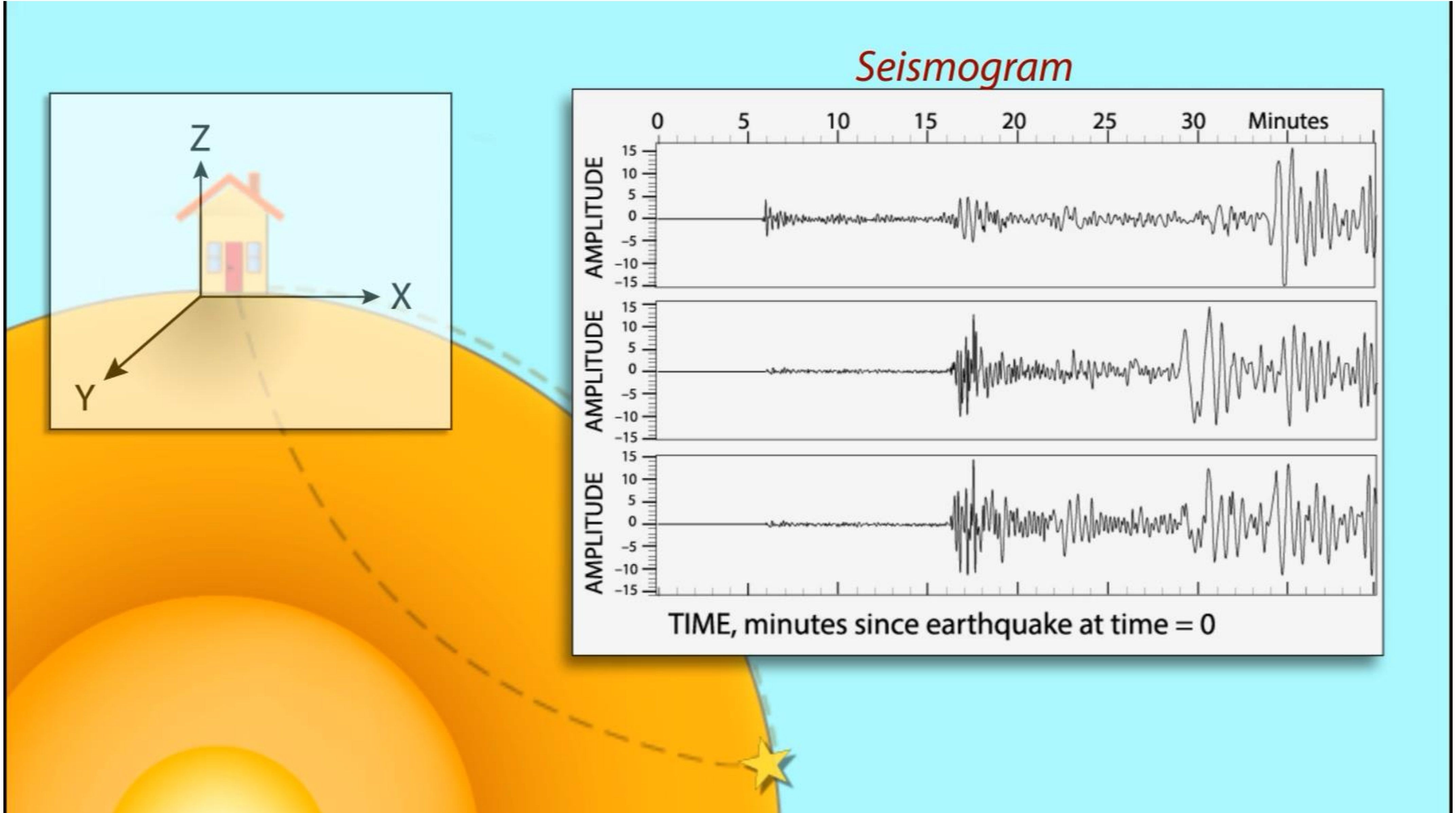
Love waves



# GROUND MOTIONS | How does a seismometer work?



# GROUND MOTIONS | Are all seismometers the same?

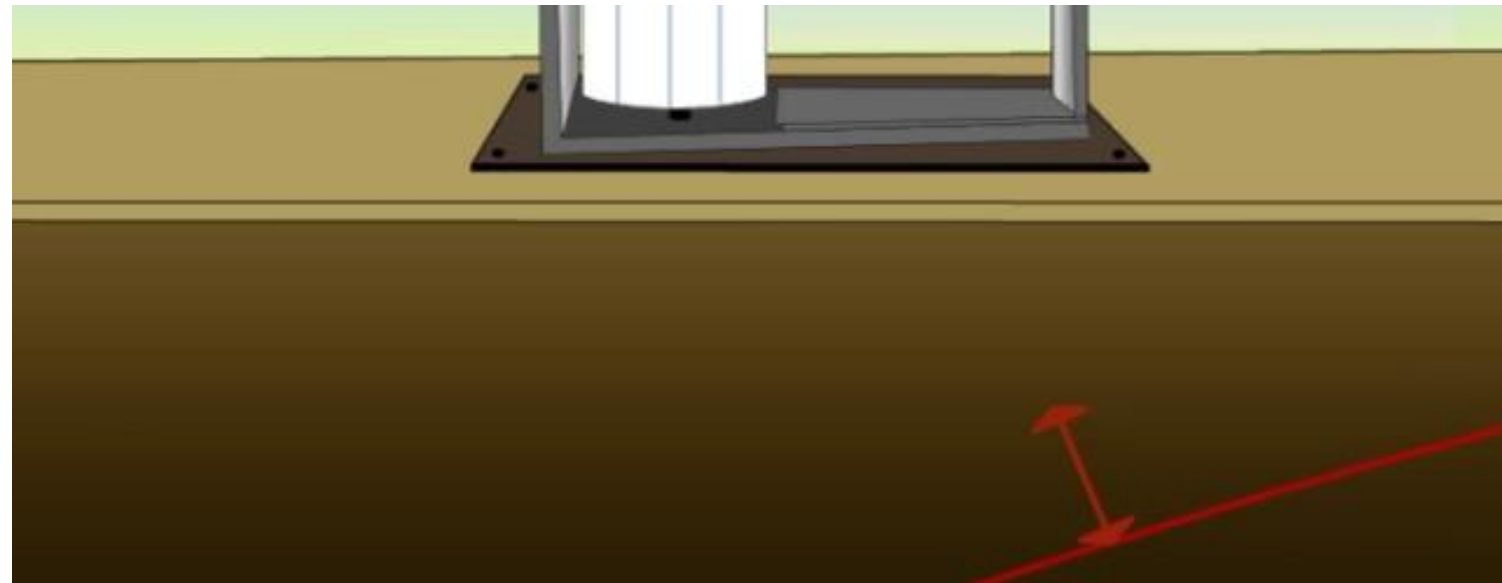
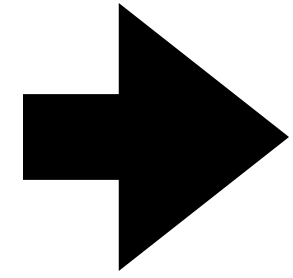


# GROUND MOTIONS | What do we actually record?



**Ground motion**

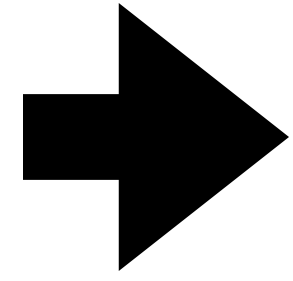
[m/s] or [m] or [m/s<sup>2</sup>]



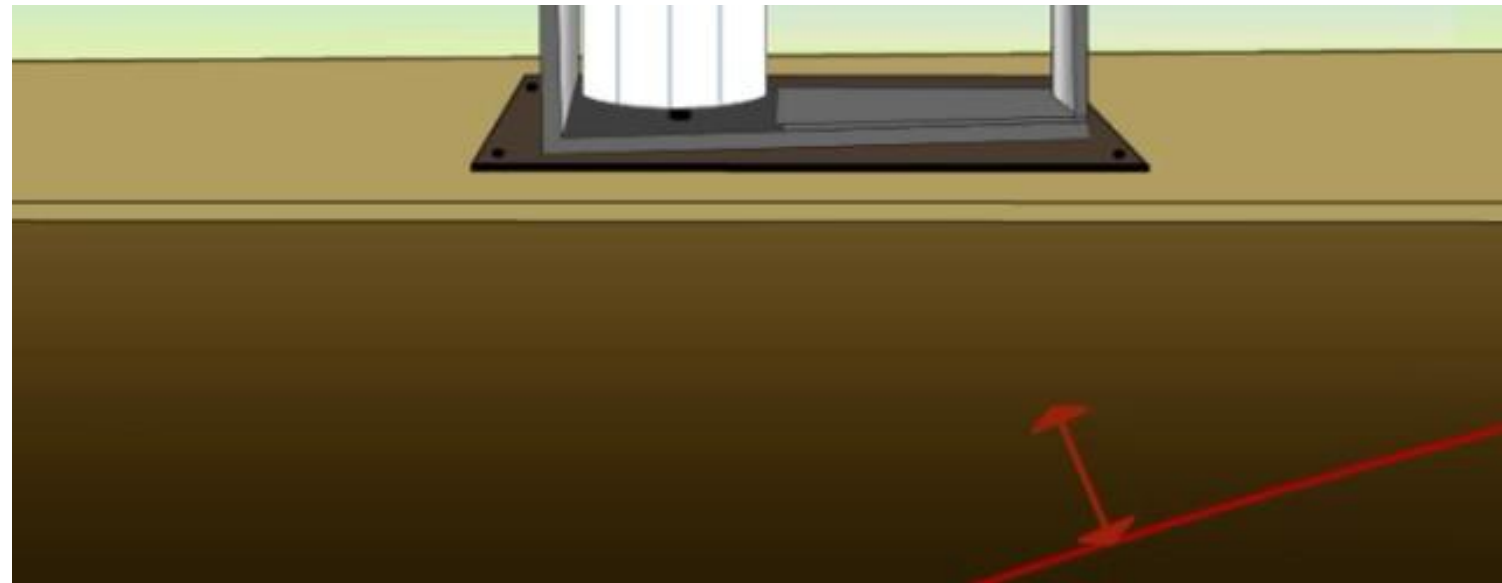
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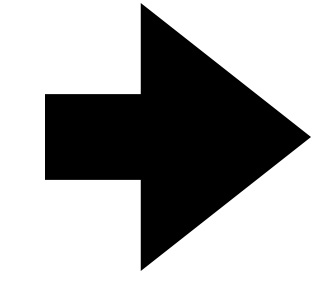
**Sensor response**  
[m/s] -> [V]



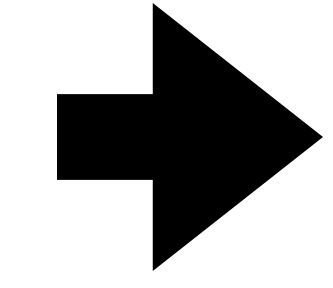
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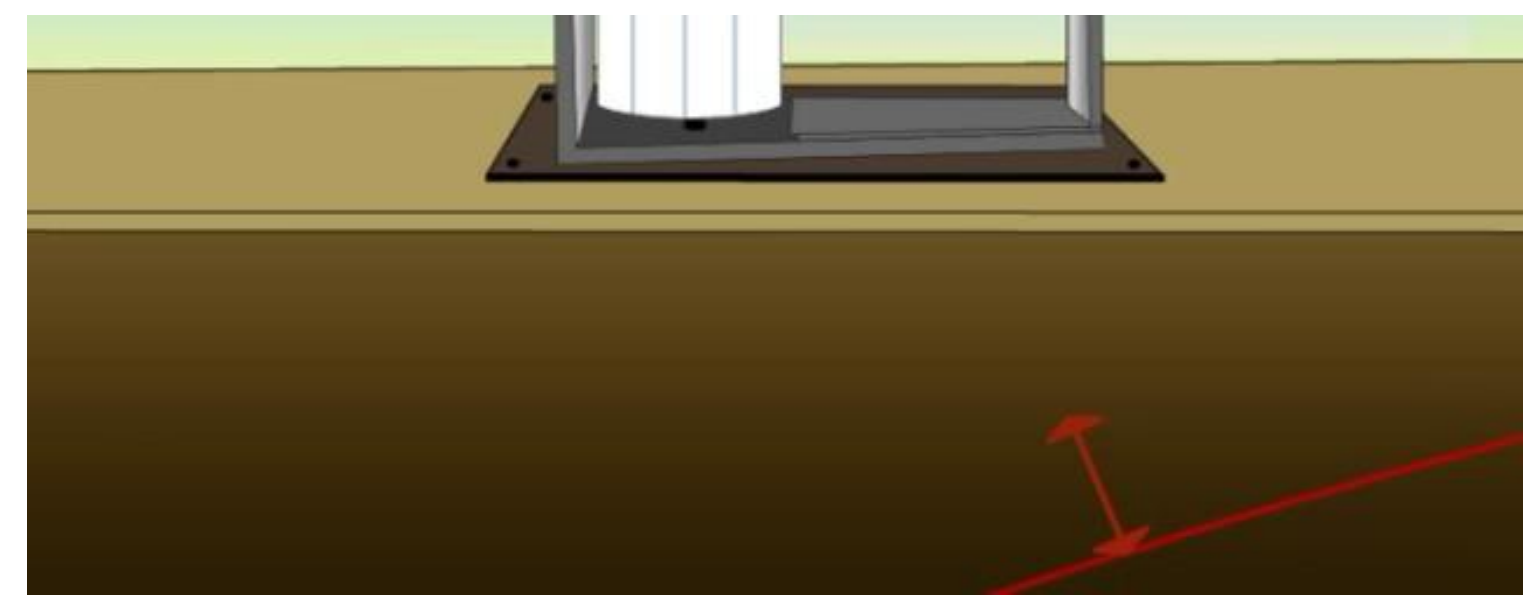
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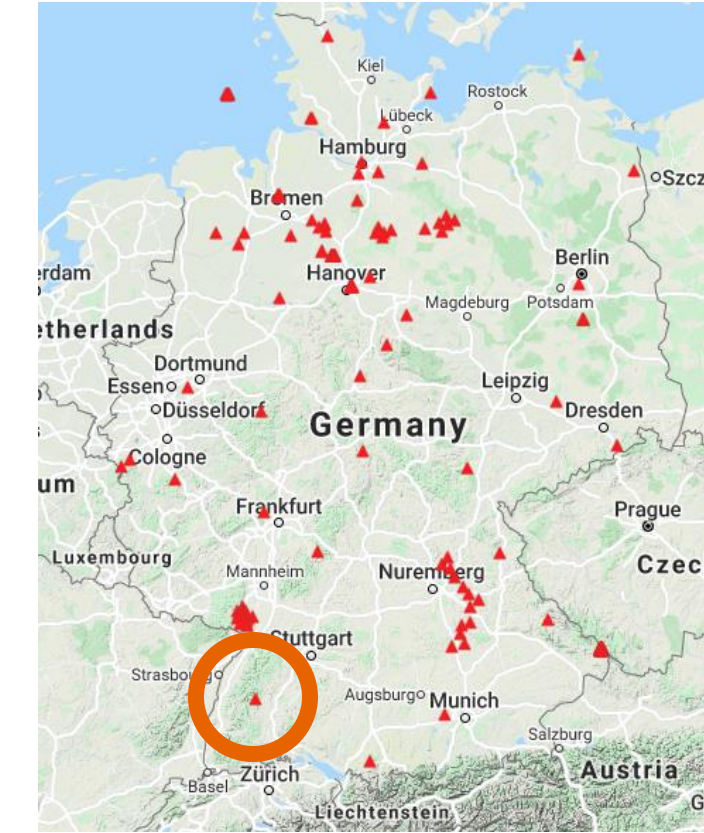
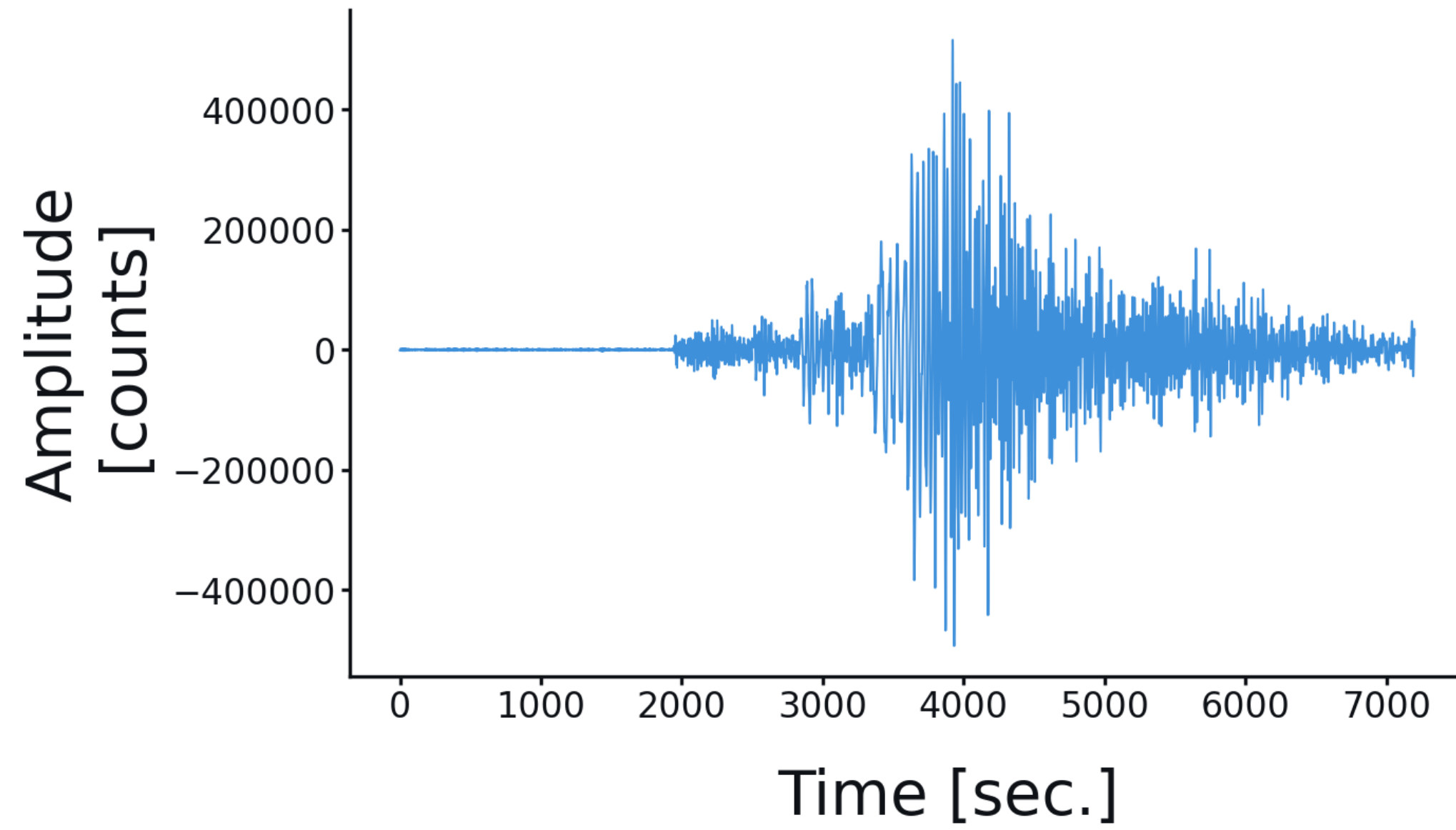
**Sensor response**  
[m/s] -> [V]



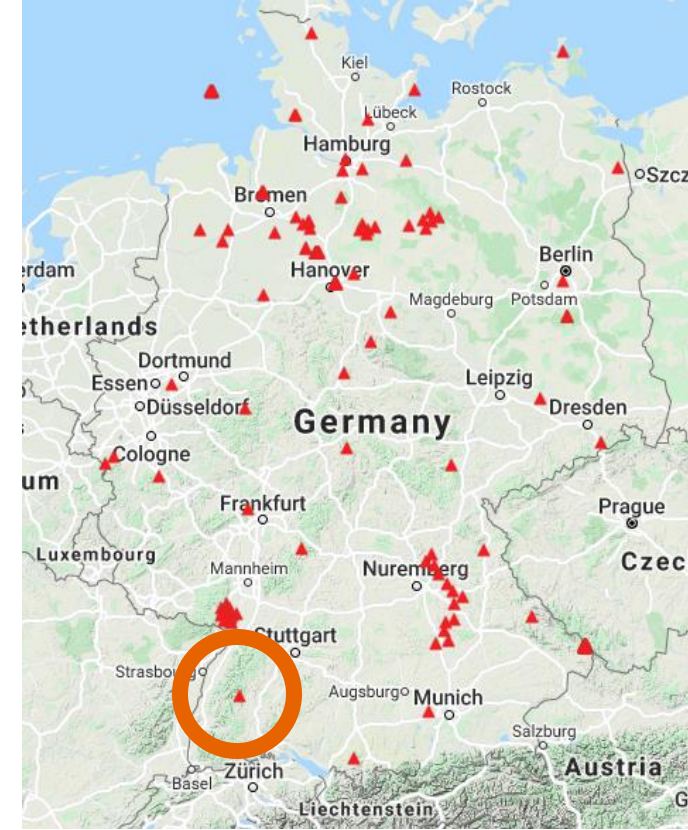
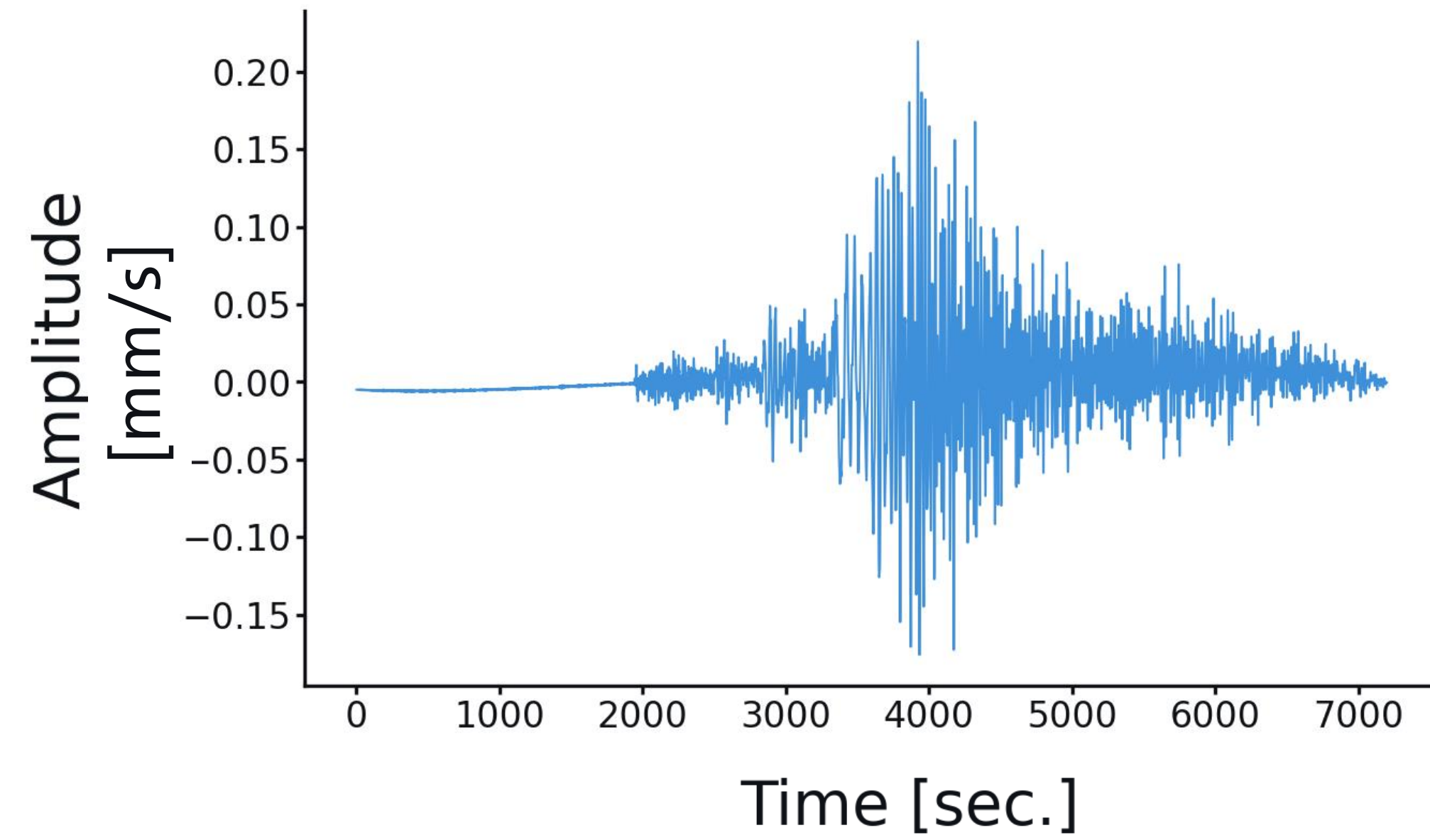
**Digitizer**  
[V] -> [counts]



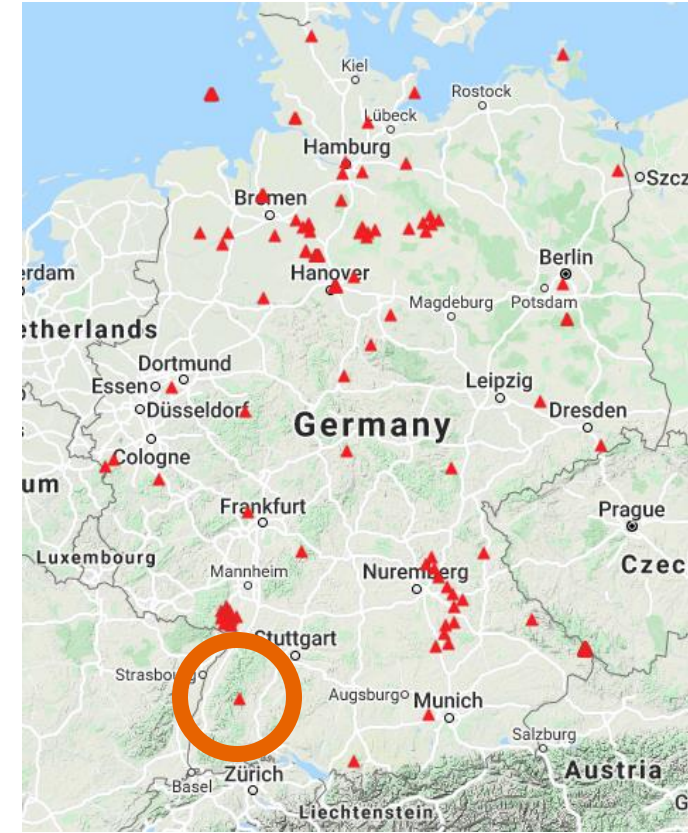
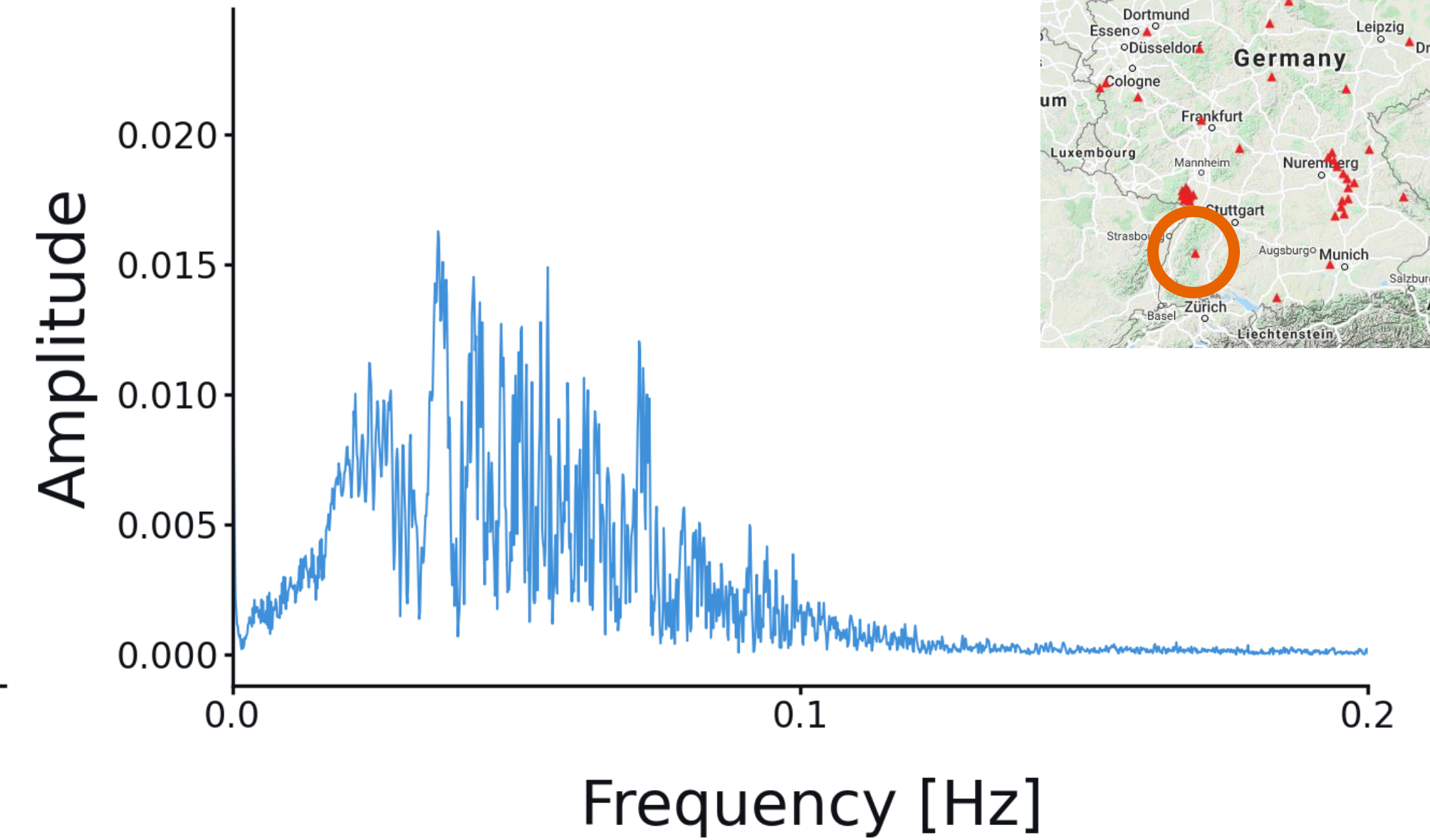
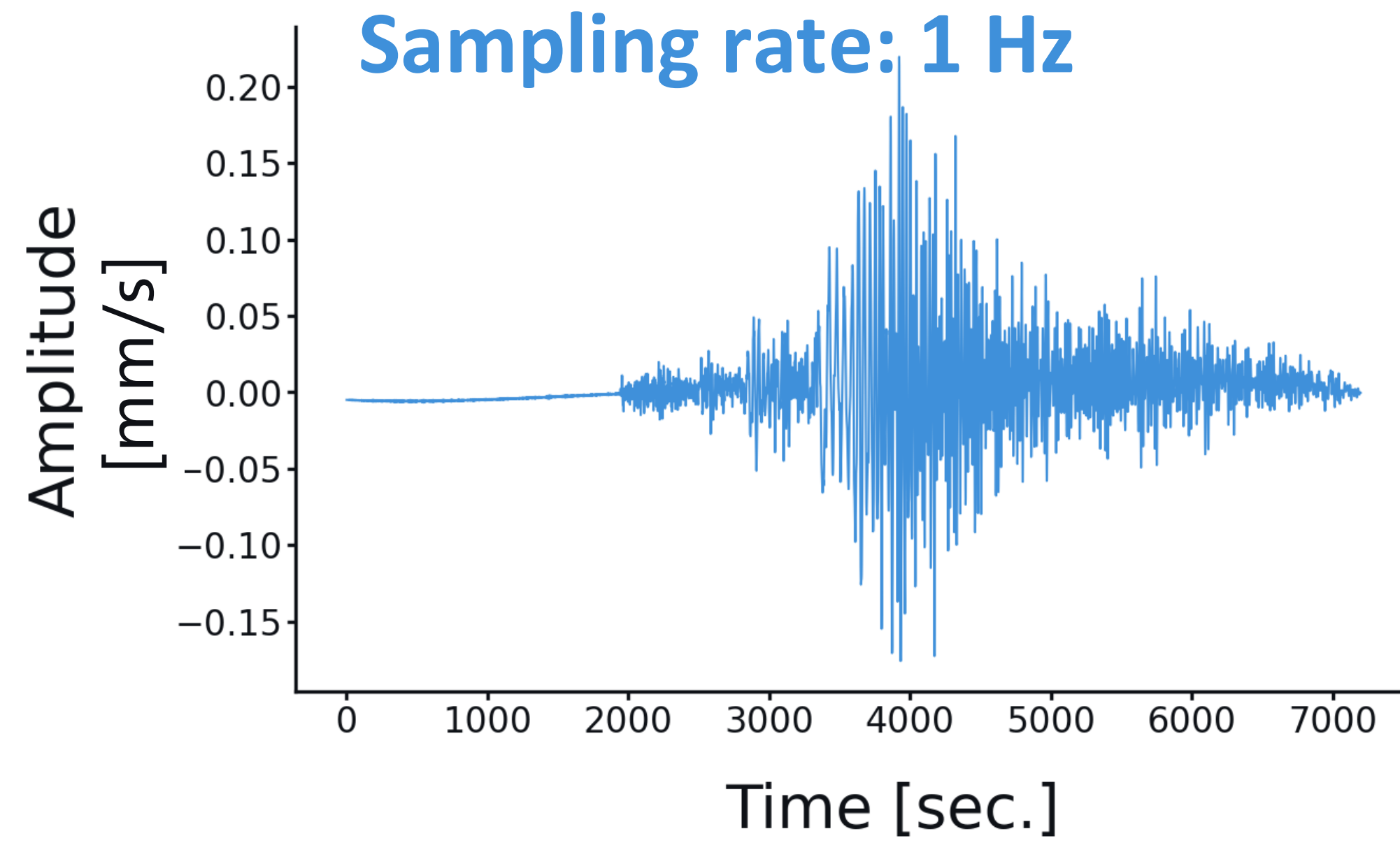
# GROUND MOTIONS | Do all seismograms contain all information?



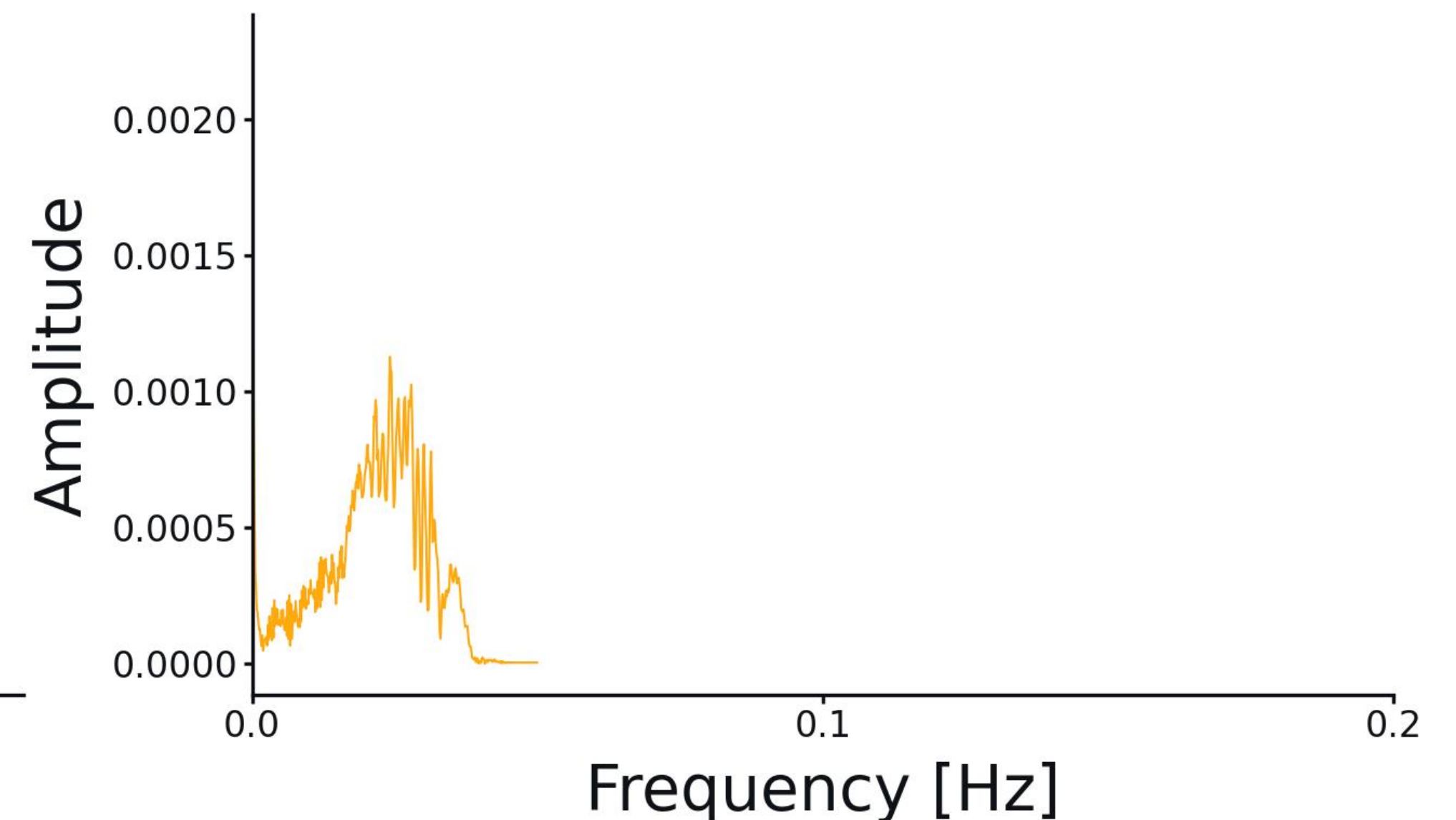
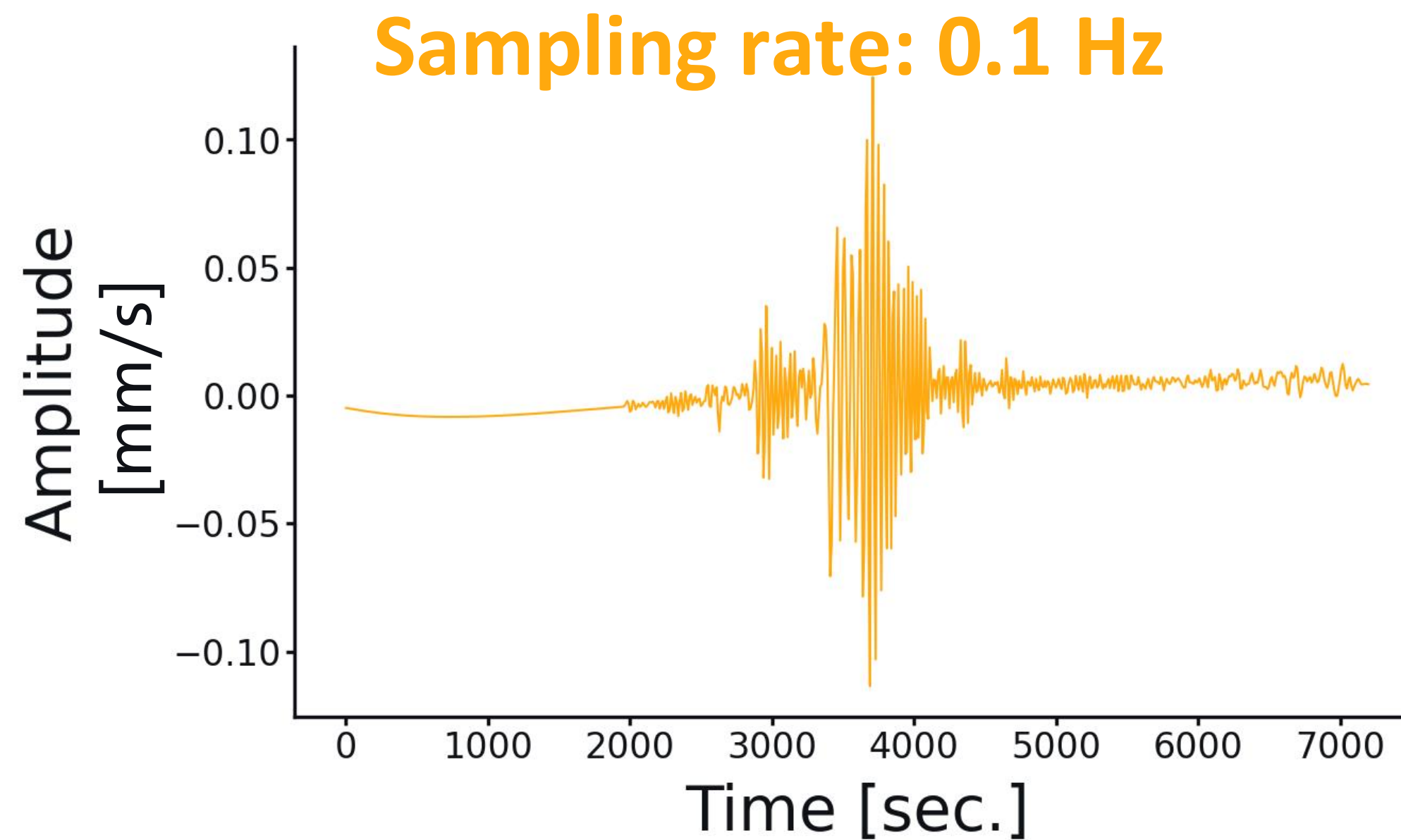
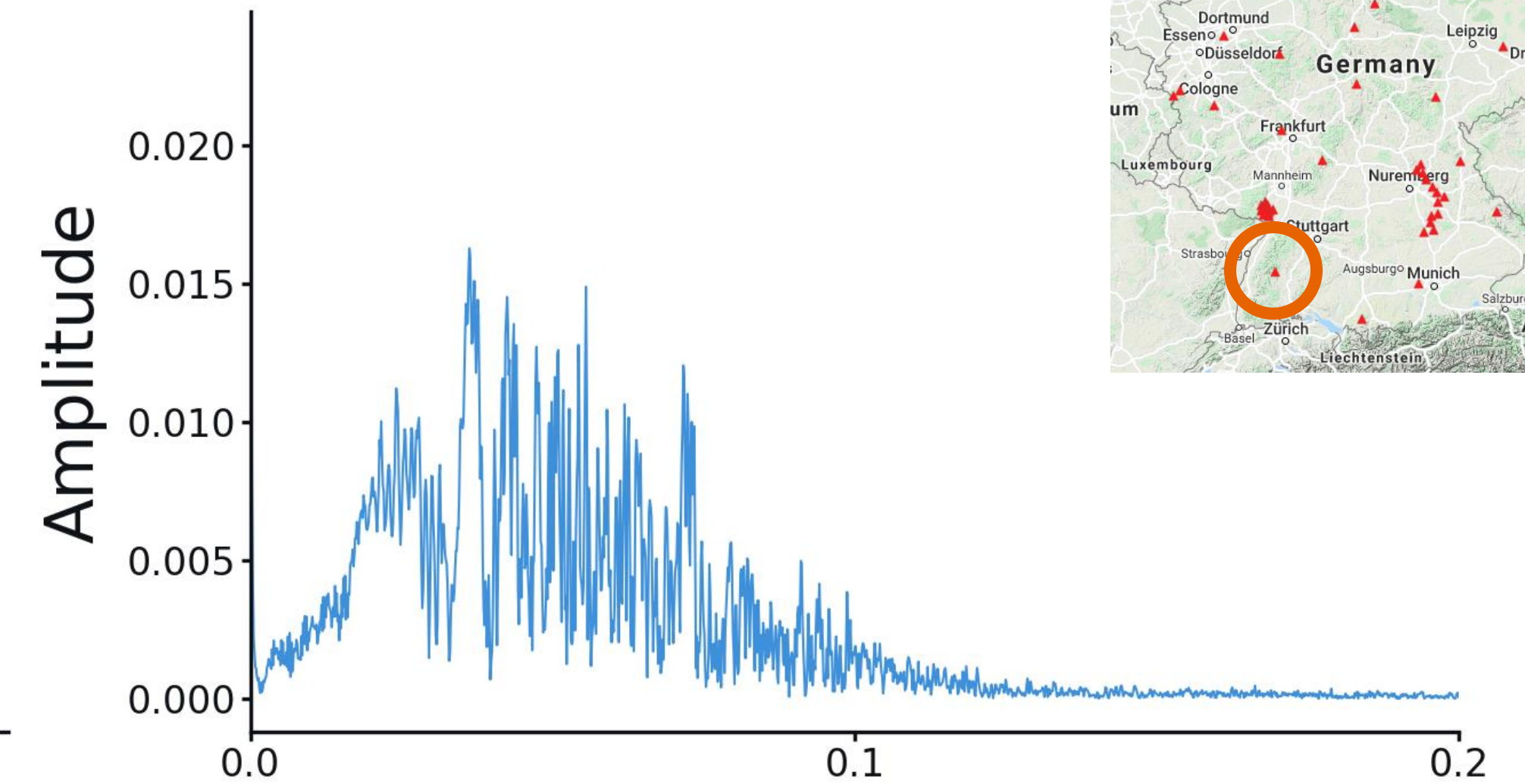
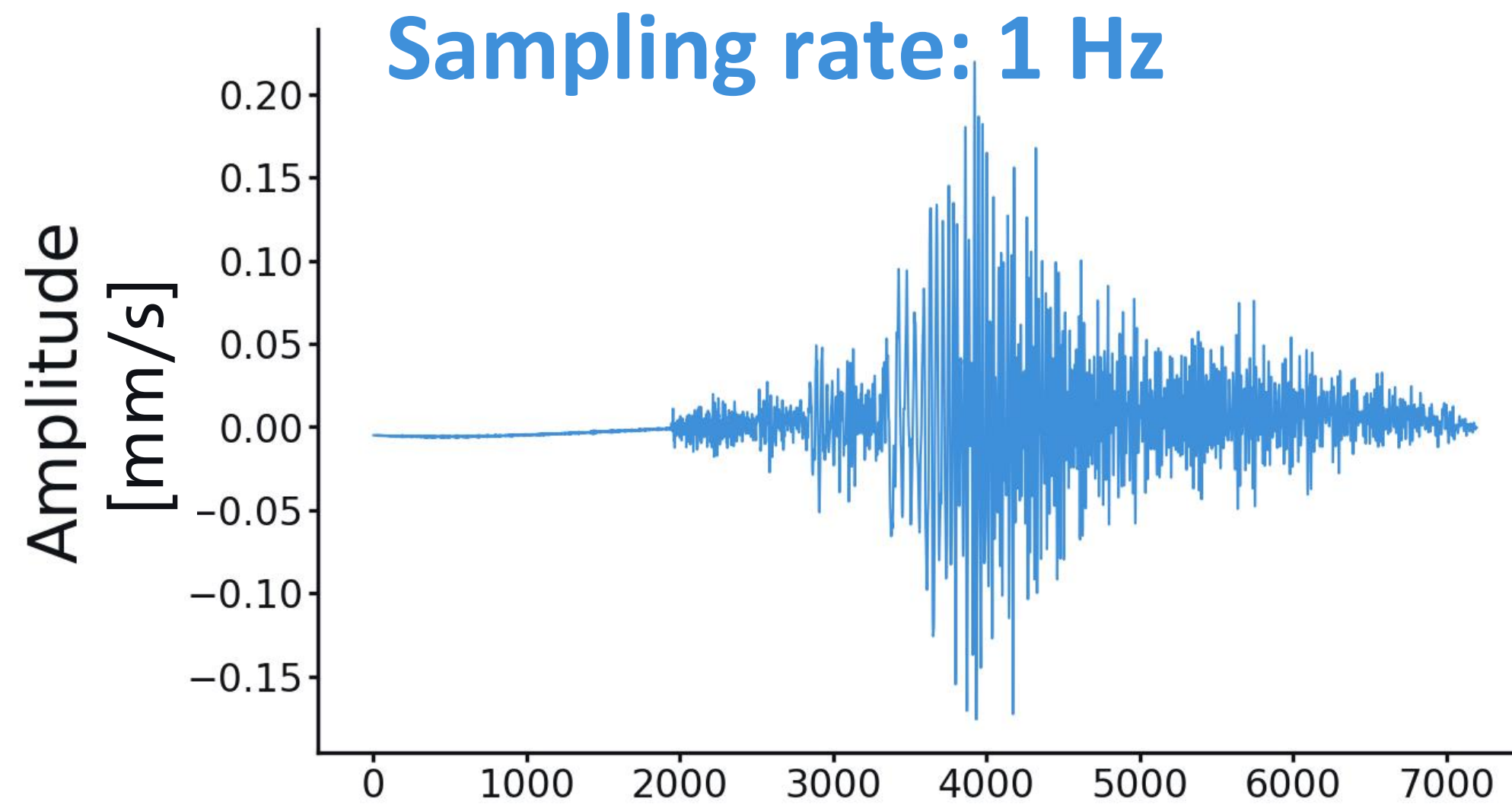
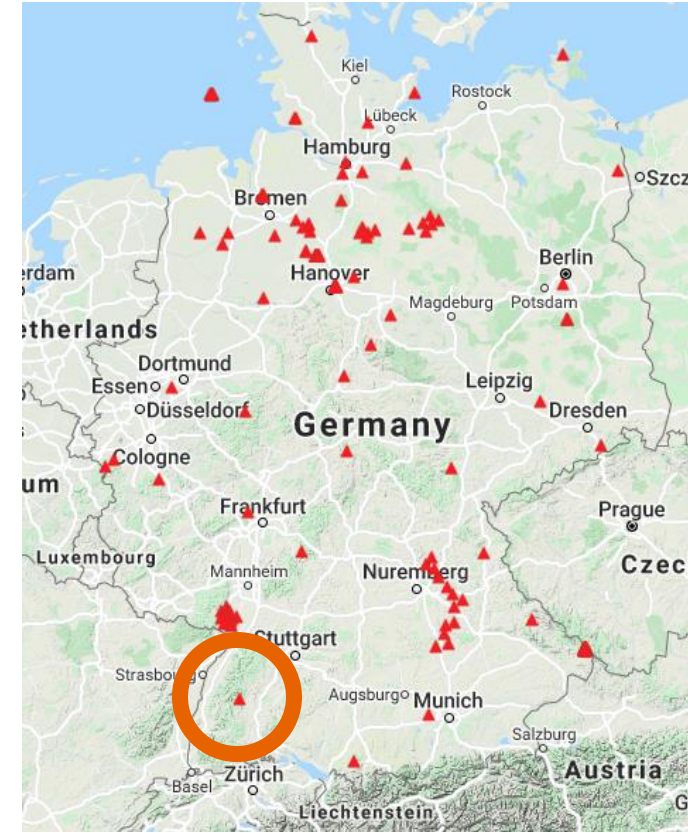
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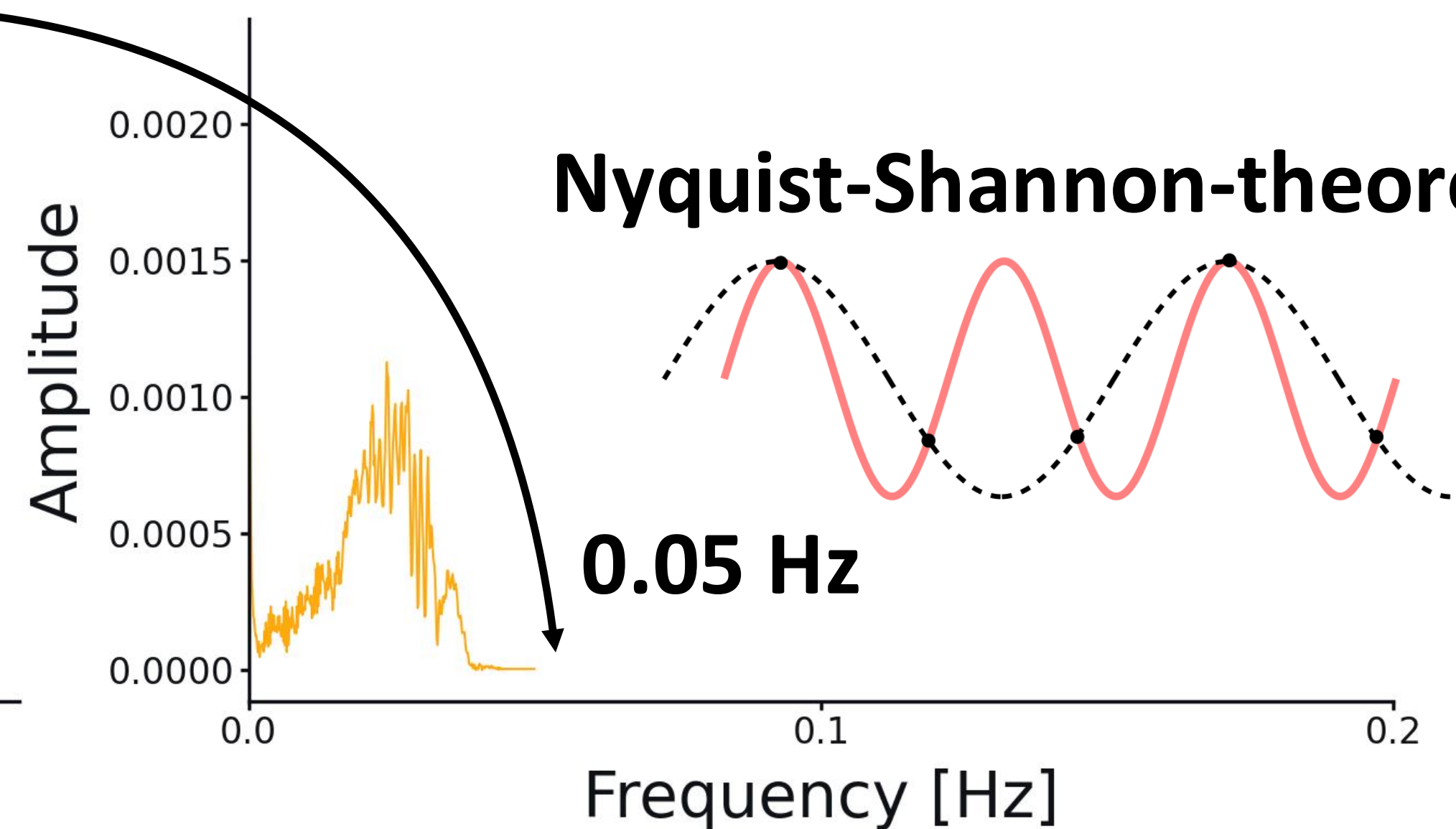
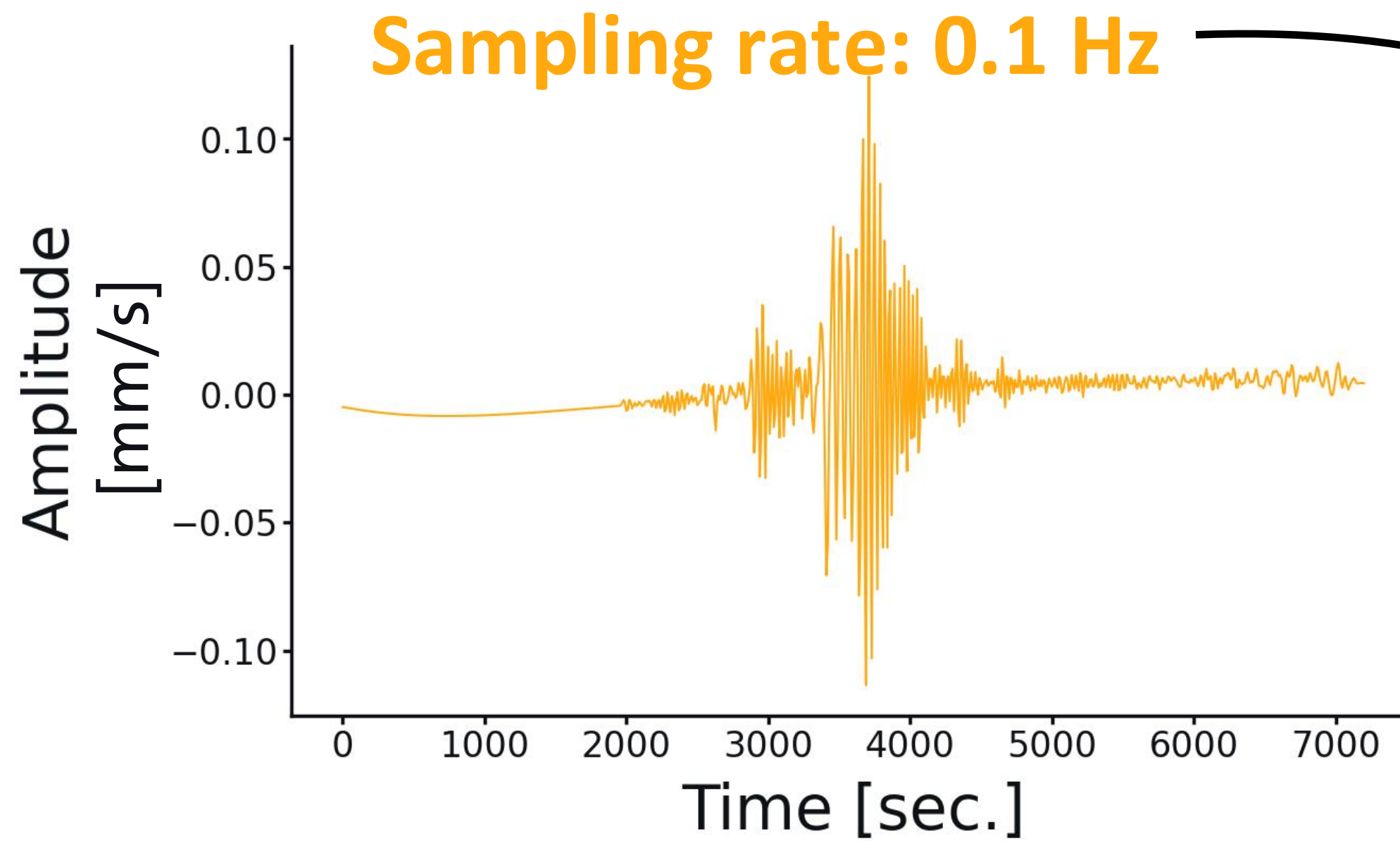
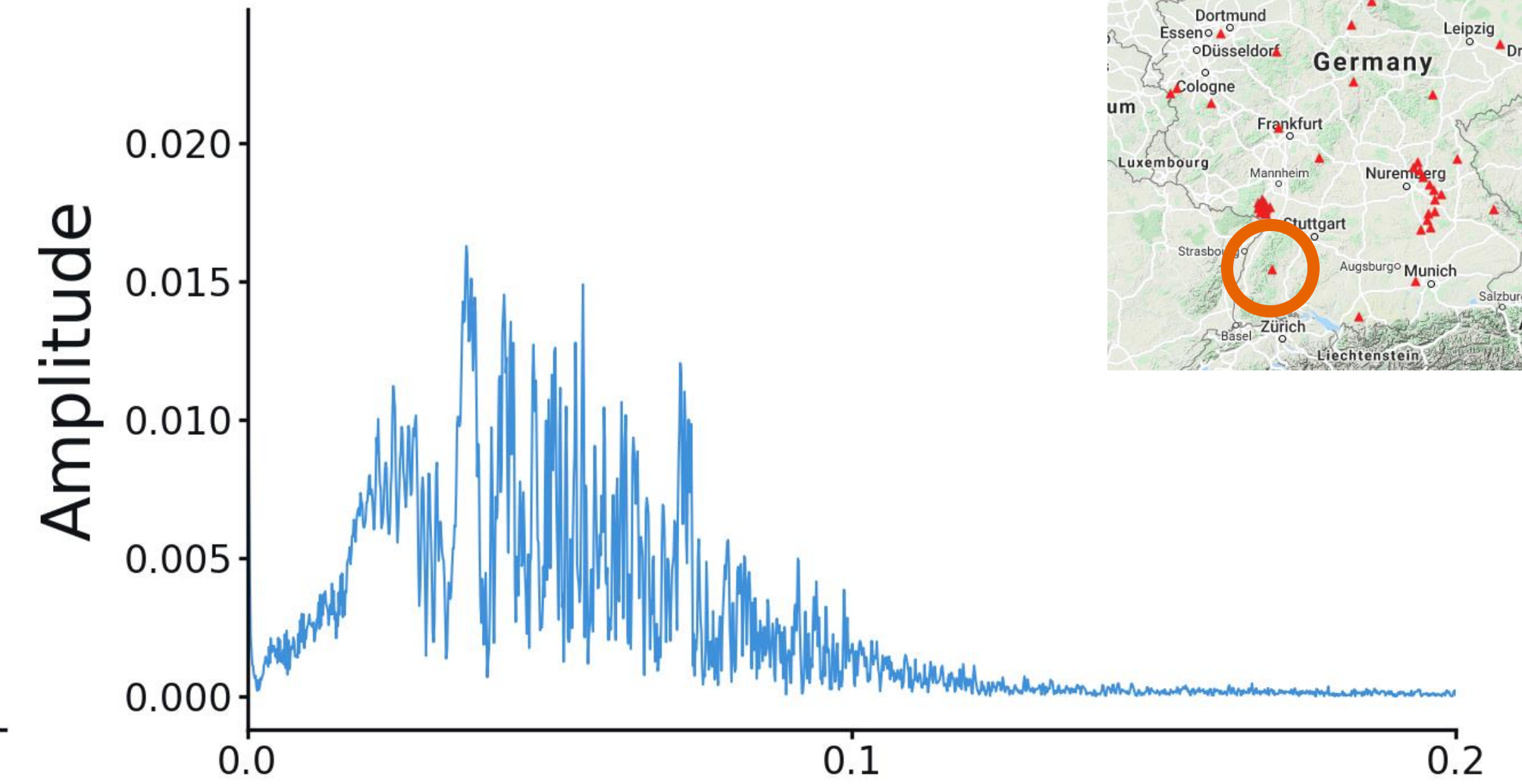
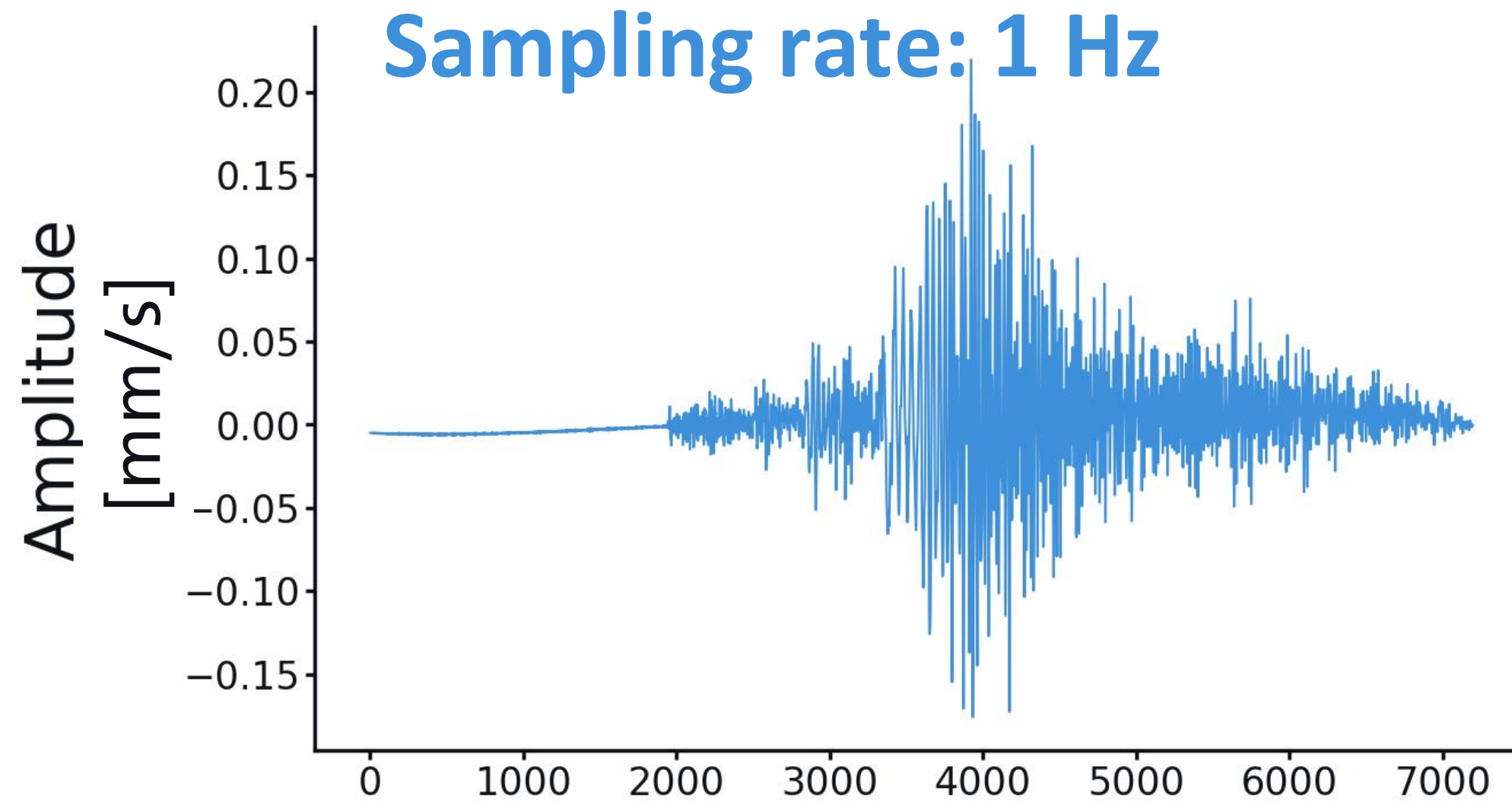
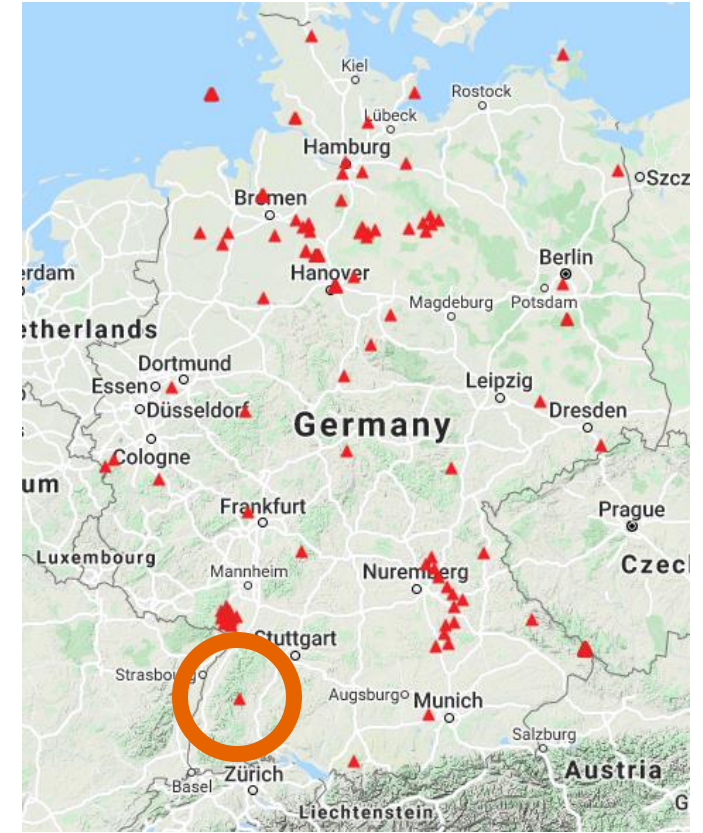
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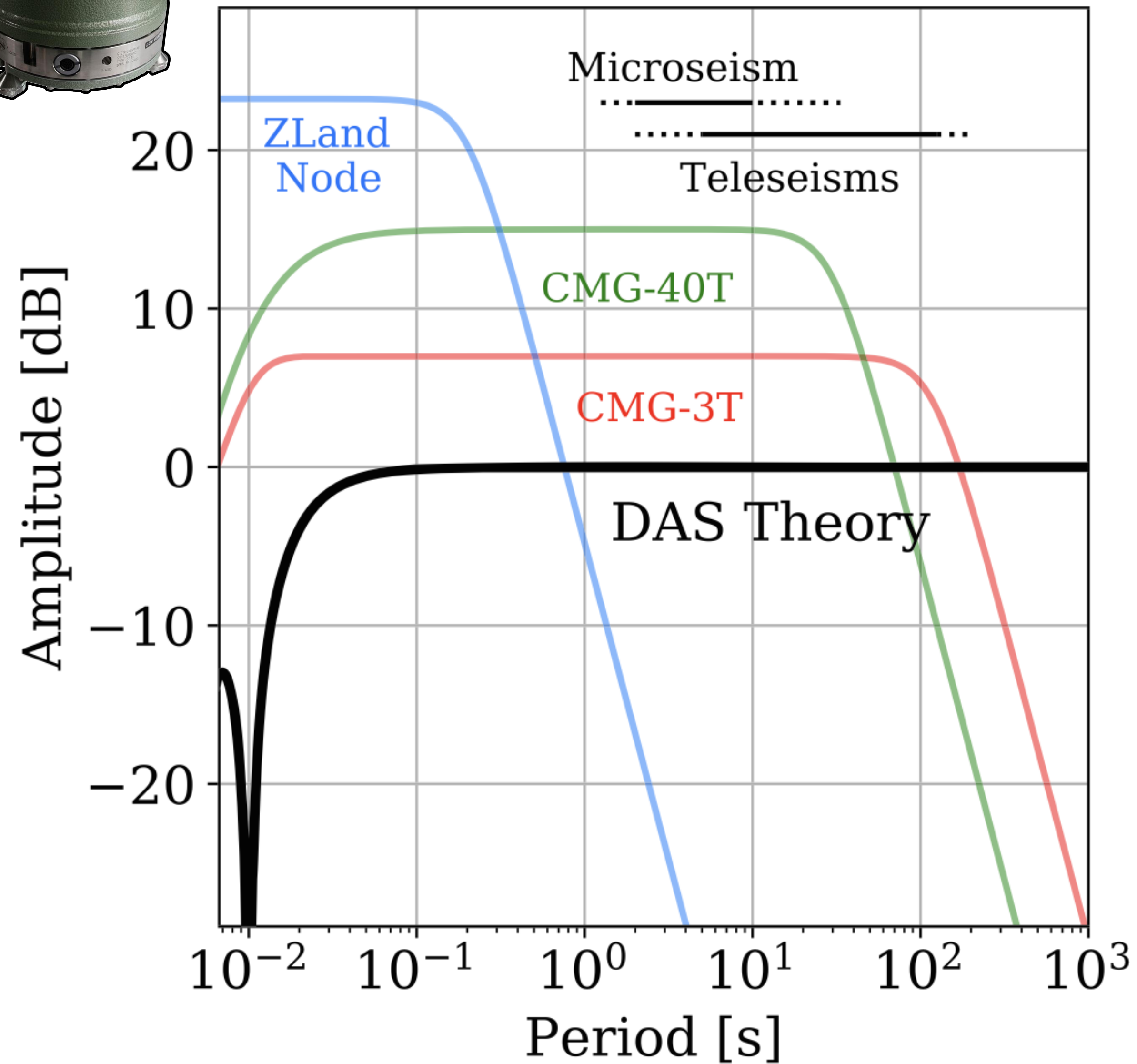
# GROUND MOTIONS | Do all seismograms contain all information?



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# GROUND MOTIONS | Are all seismometers the same?



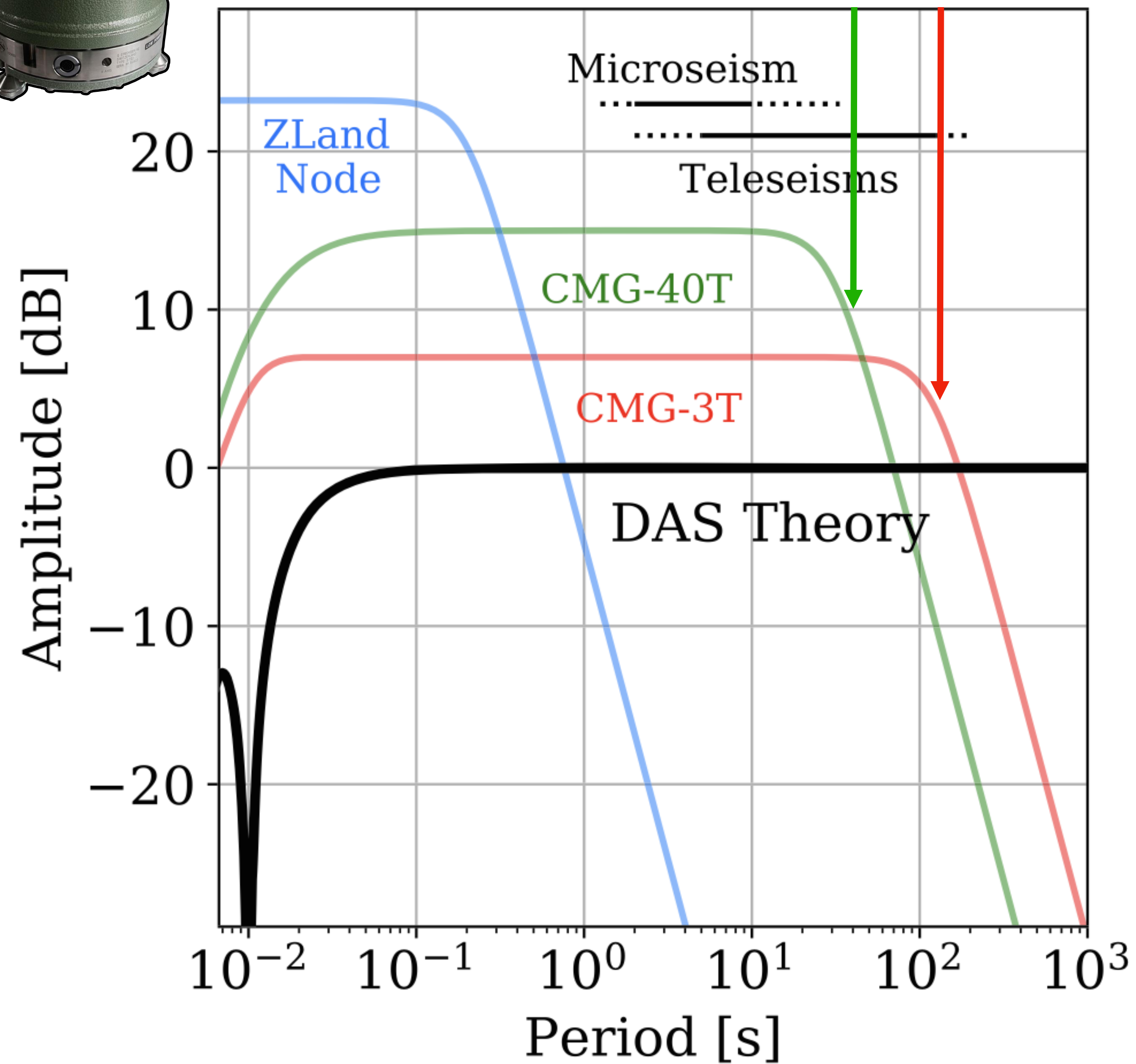
# GROUND MOTIONS | Are all seismometers the same?



40 s

120 s

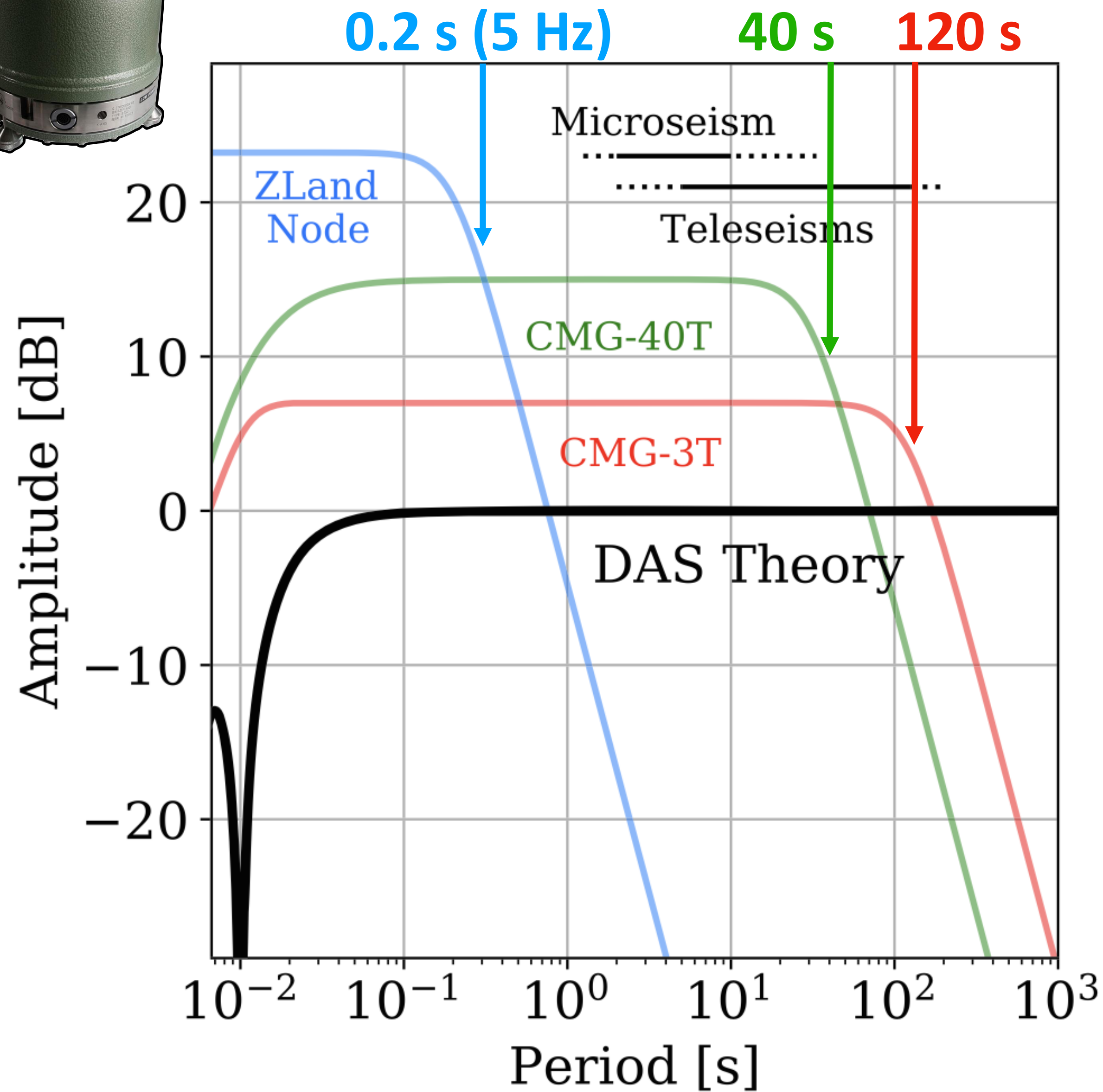
Broadband



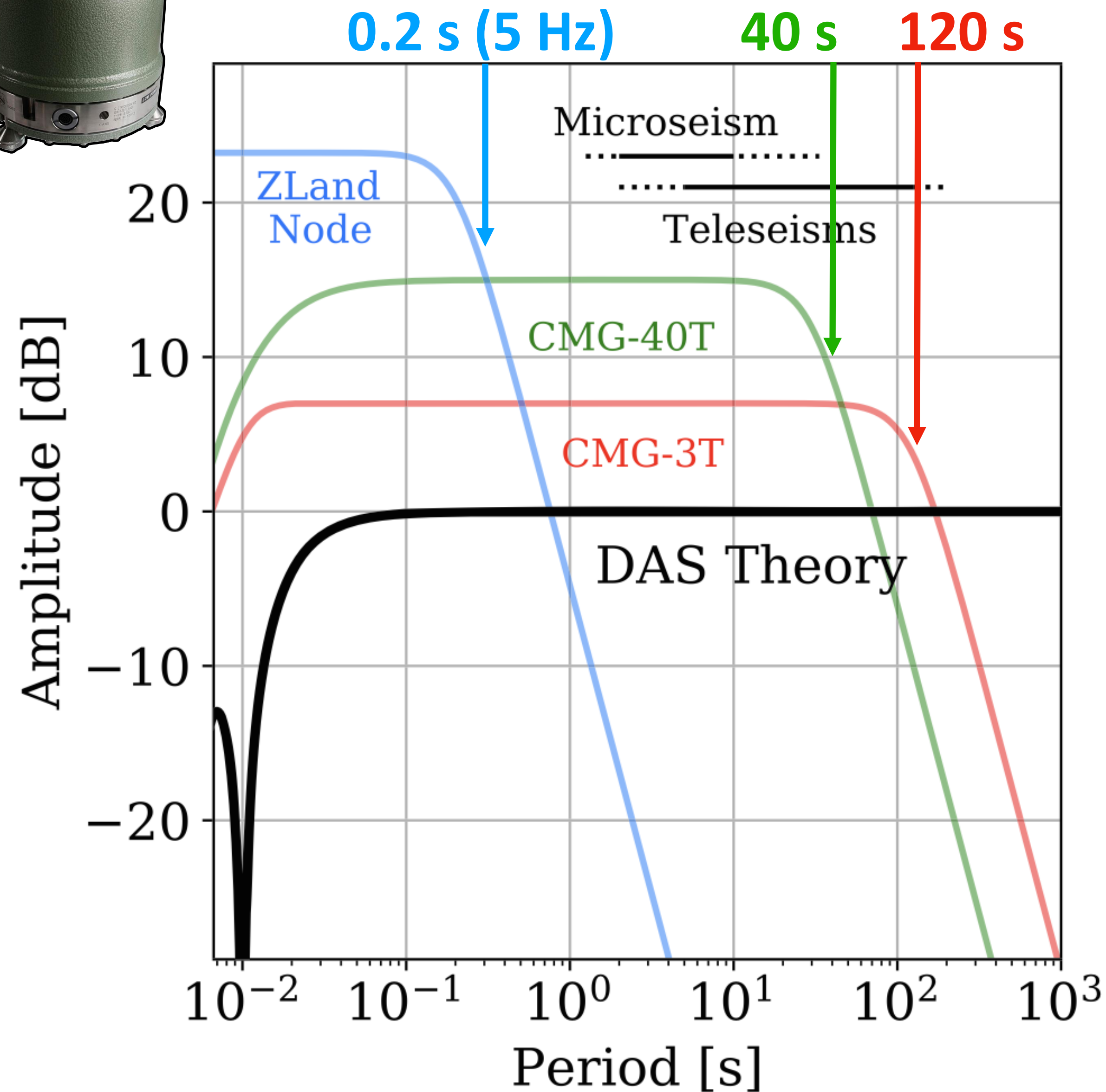
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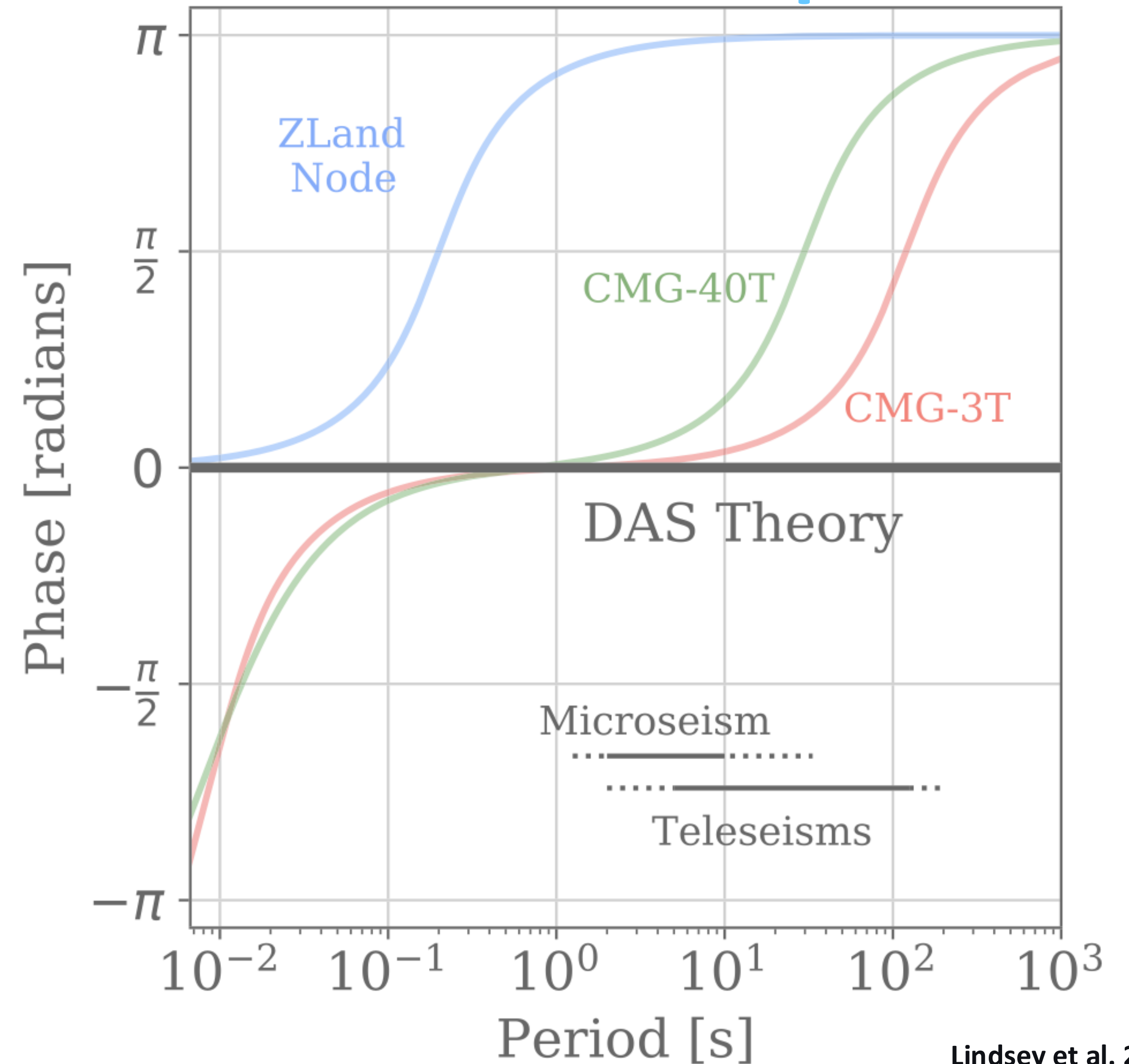
## Broadband vs. Short-period



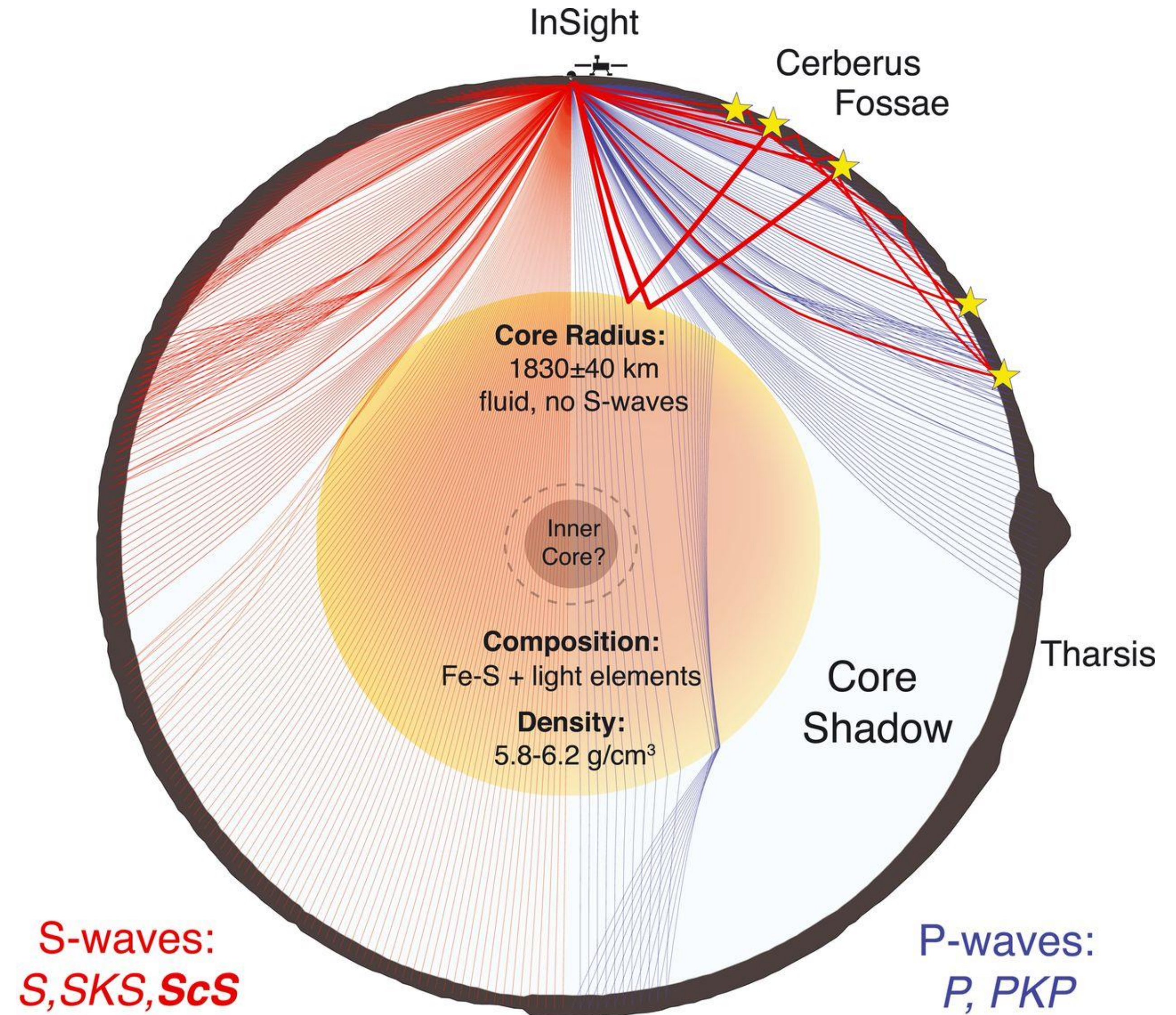
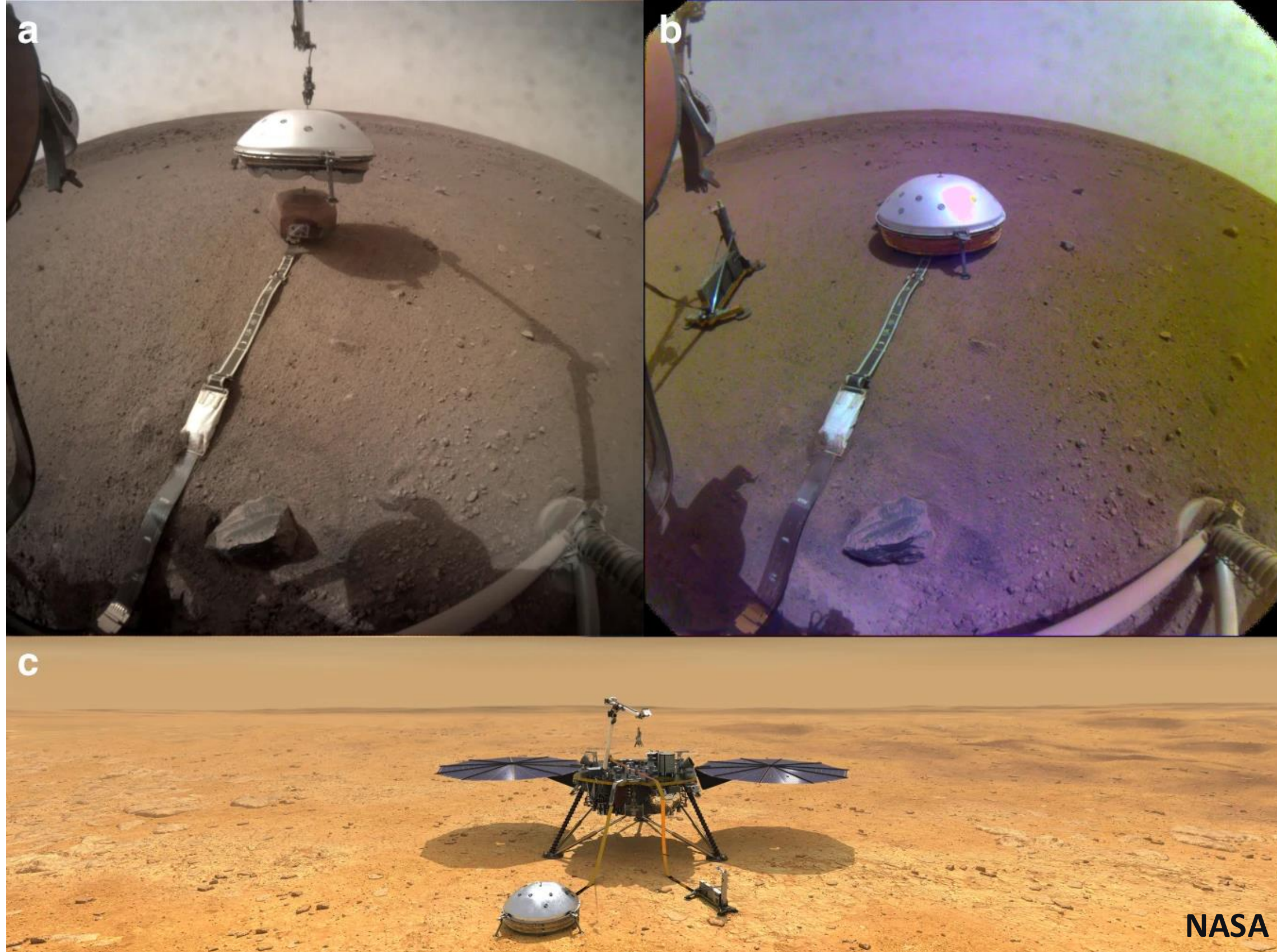
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## Broadband vs. Short-period



# GROUND MOTIONS | Are single stations enough?



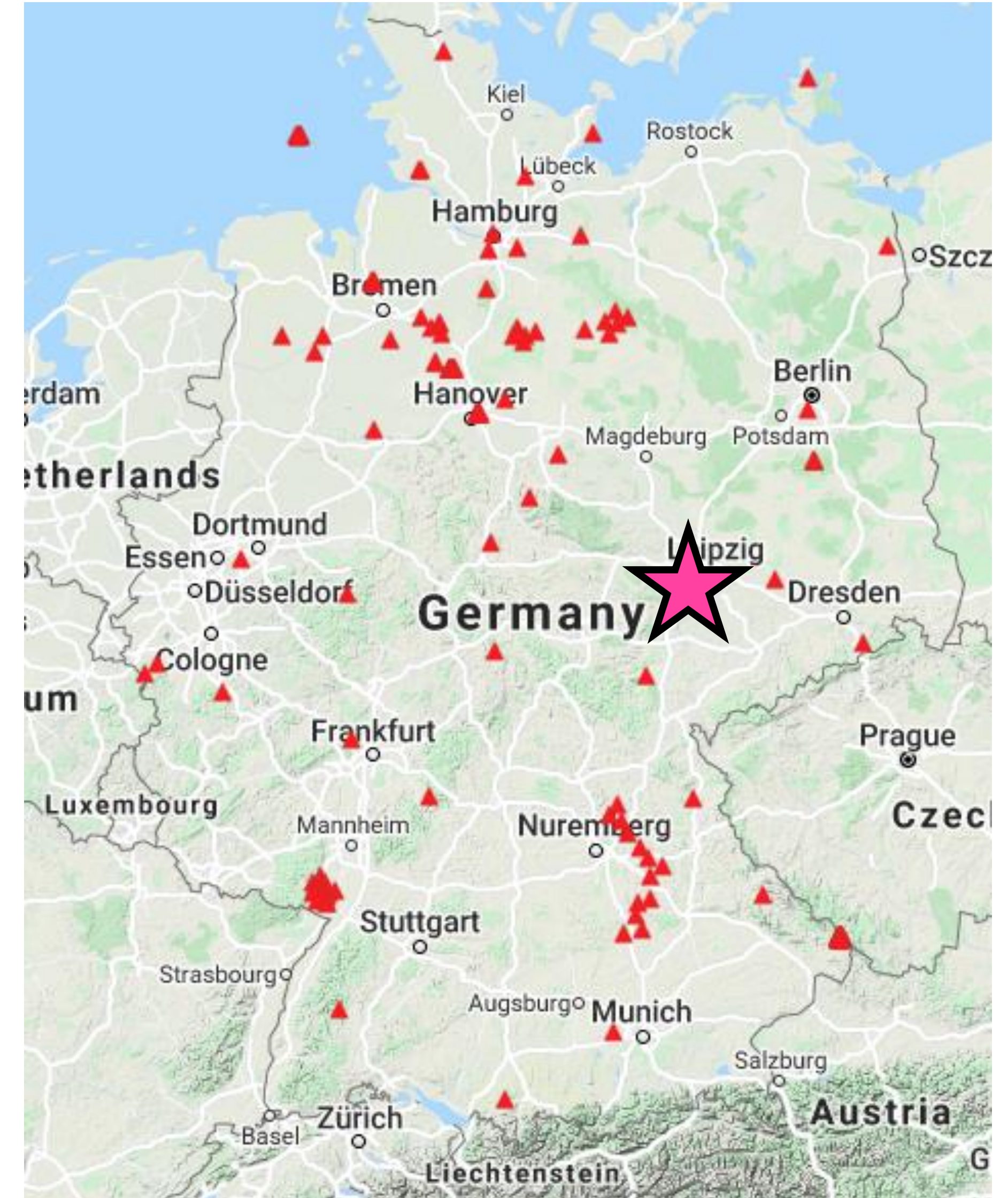


# GROUND MOTIONS | How do we arrange multiple stations?



A **single** station allows to measure **arrival time, amplitude, polarisation (3C)**

A **network** additionally allows to estimate **location**



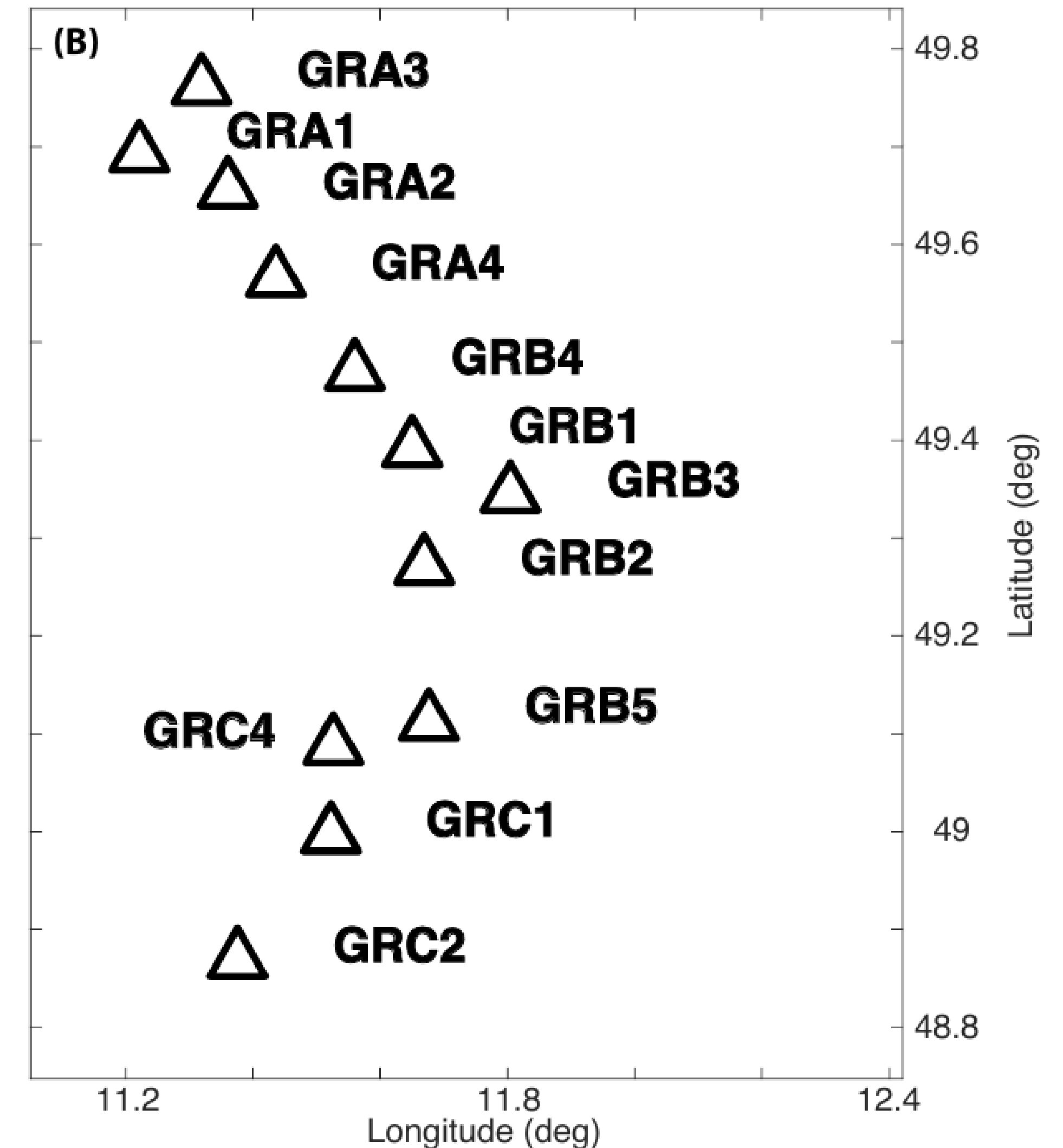
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An **array** (“antenna”) additionally allows to estimate **arrival direction, apparent velocity** and **improve signal-to-noise ratio (SNR), separate coherent from incoherent parts of the signal, ...**



# GROUND MOTIONS | How do we arrange multiple stations?

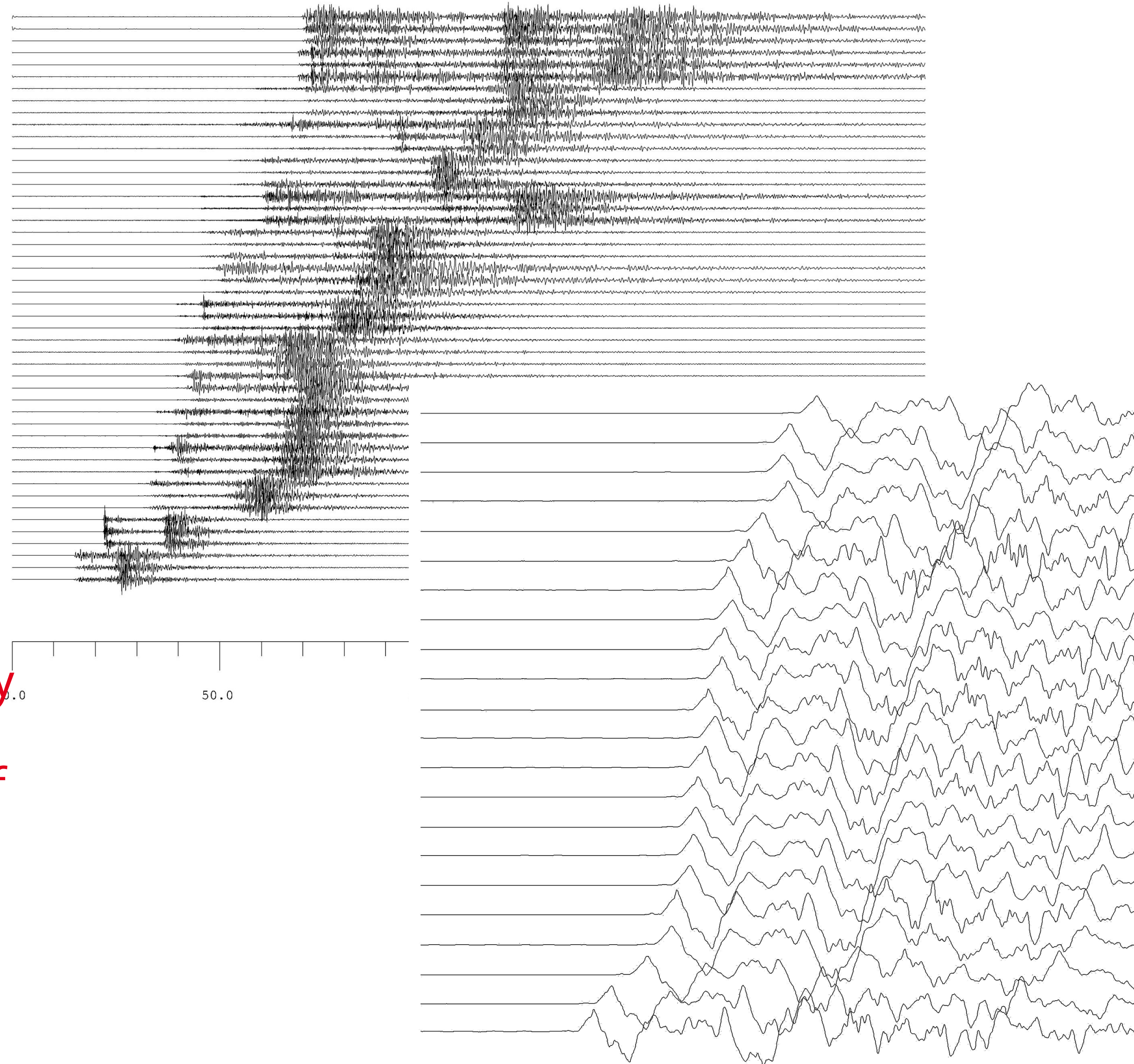


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**A question of scale!**



# GROUND MOTIONS | What wavelengths and scales do we encounter?



approx. wavelengths ( $\lambda = v \cdot T$ )

Body waves

P-Waves

S-waves

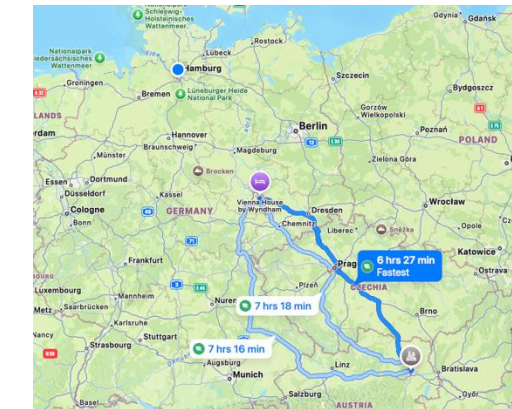
≈ 50 m



≈ 5 km



≈ 500 km



Surface waves

Rayleigh waves

Love Waves

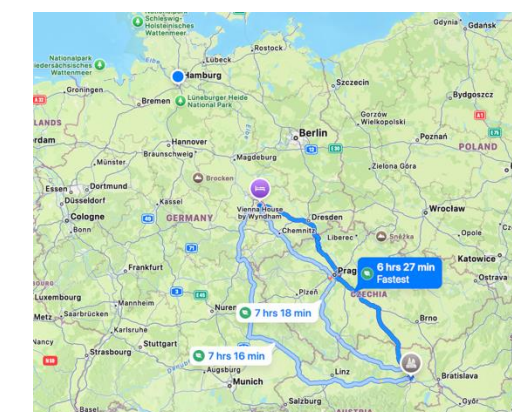
≈ 50 cm



≈ 1 km



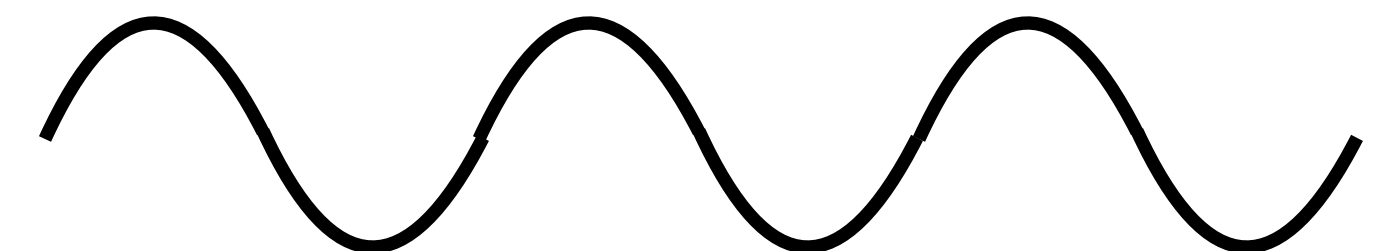
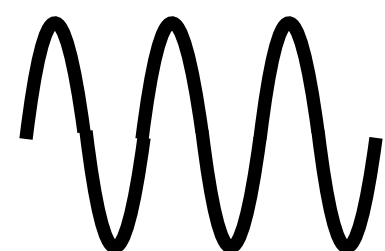
≈ 500 km



0.01 s / 100 Hz

1 s / 1 Hz

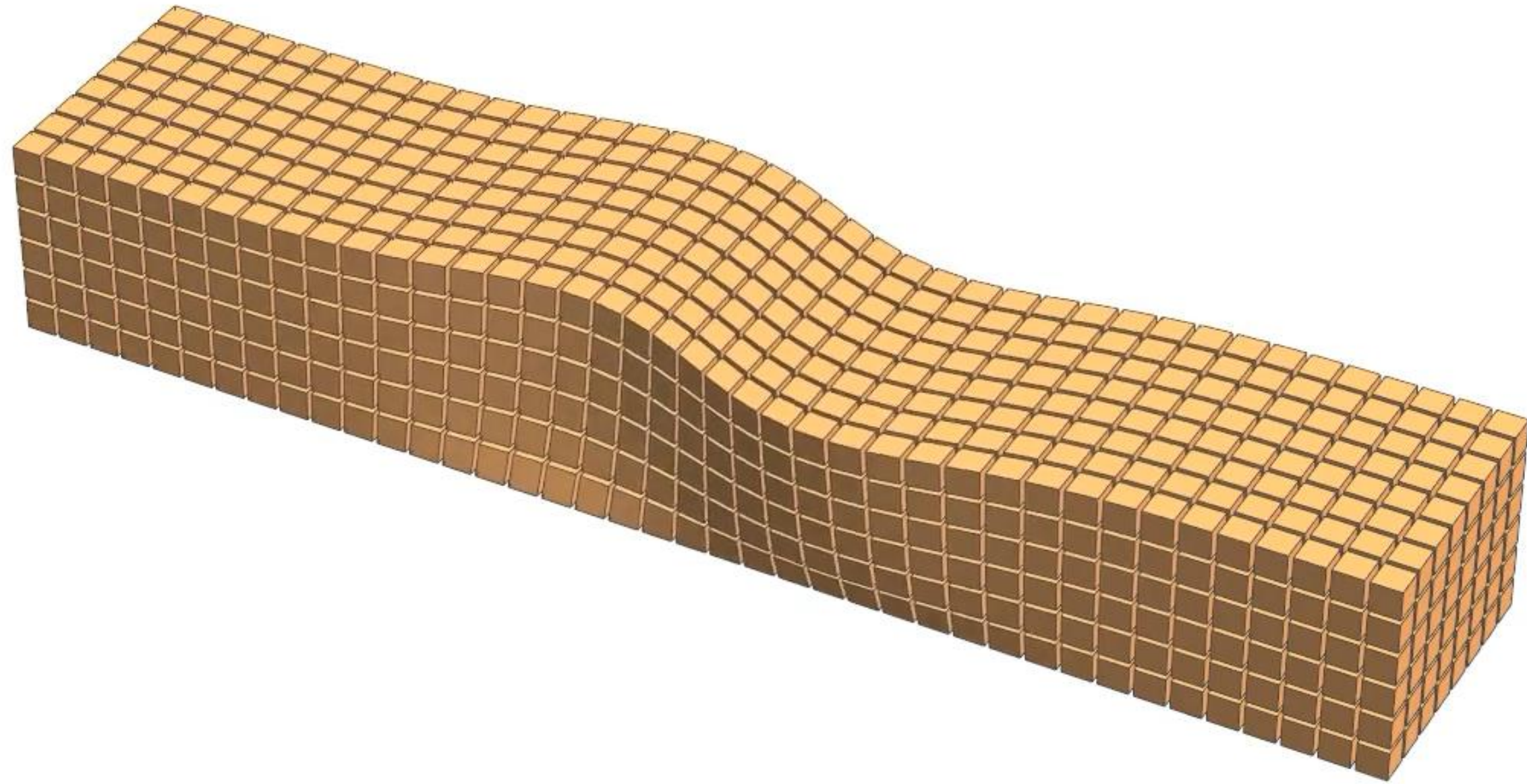
100 s / 0.01 Hz



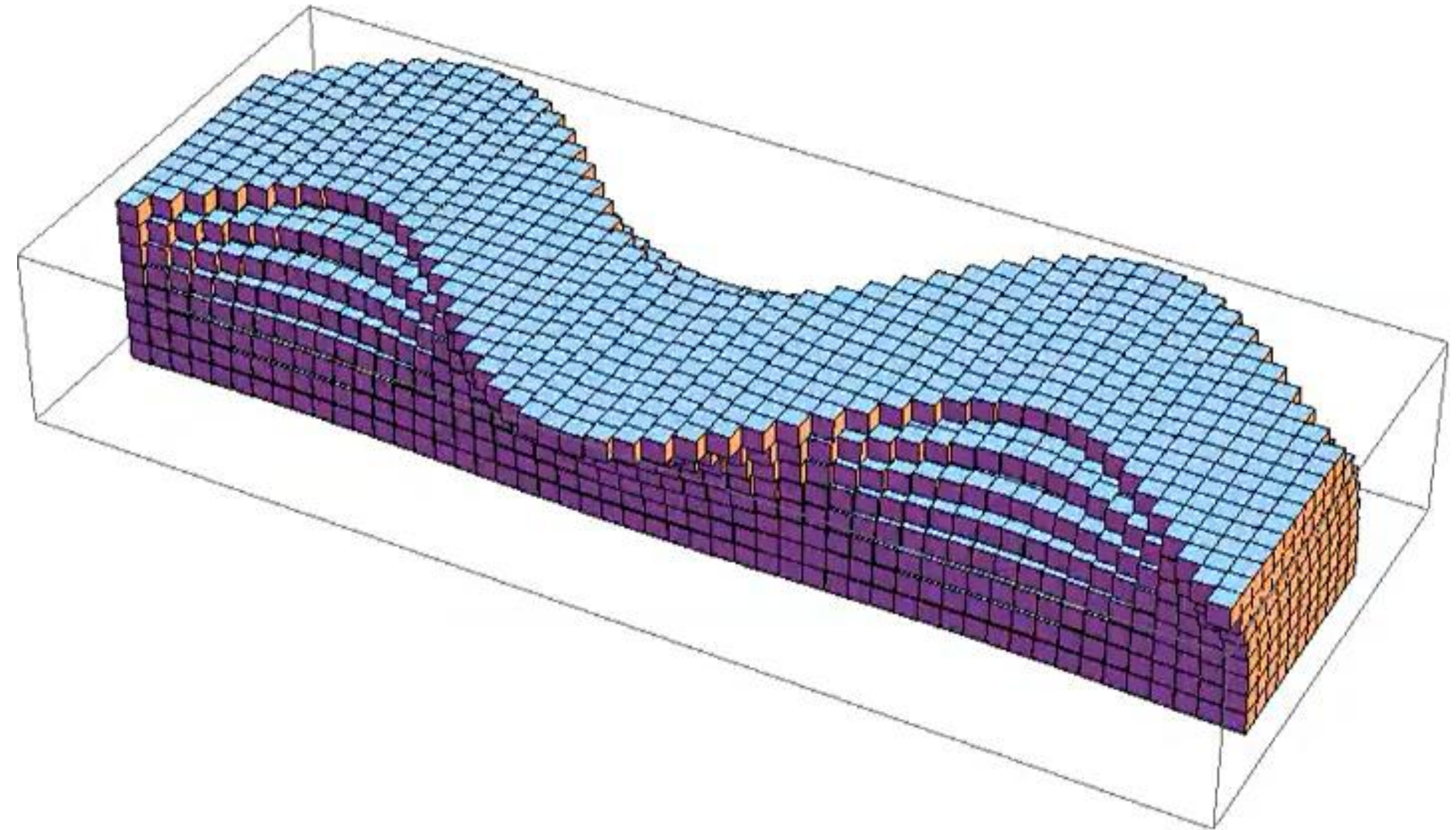
# GROUND MOTIONS | Is this the full ground motion?



Love waves



Love waves



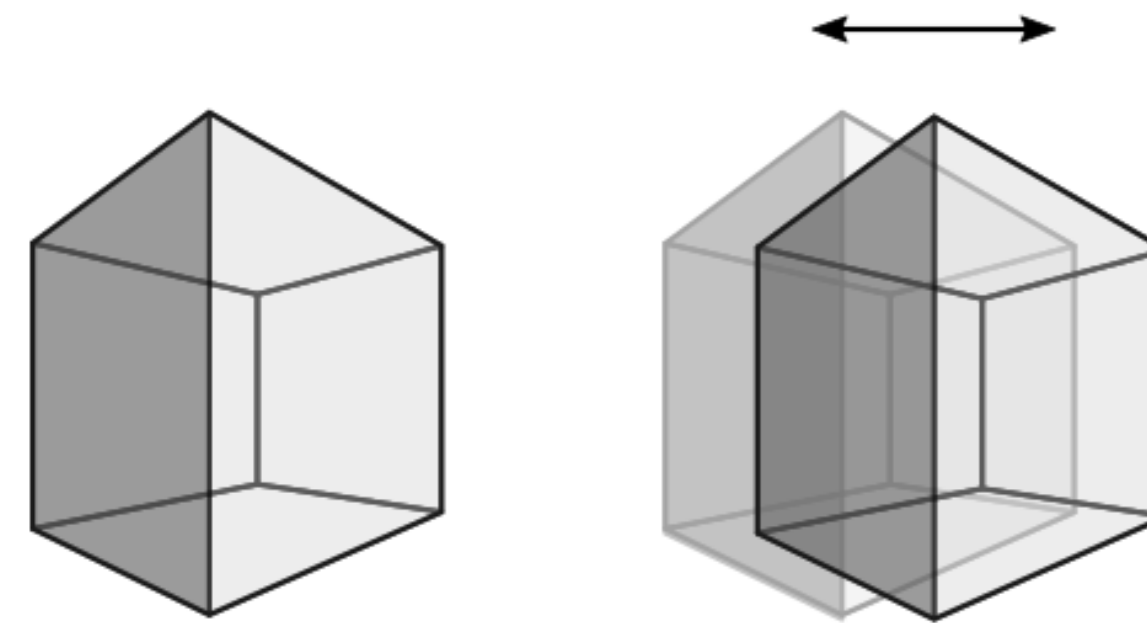
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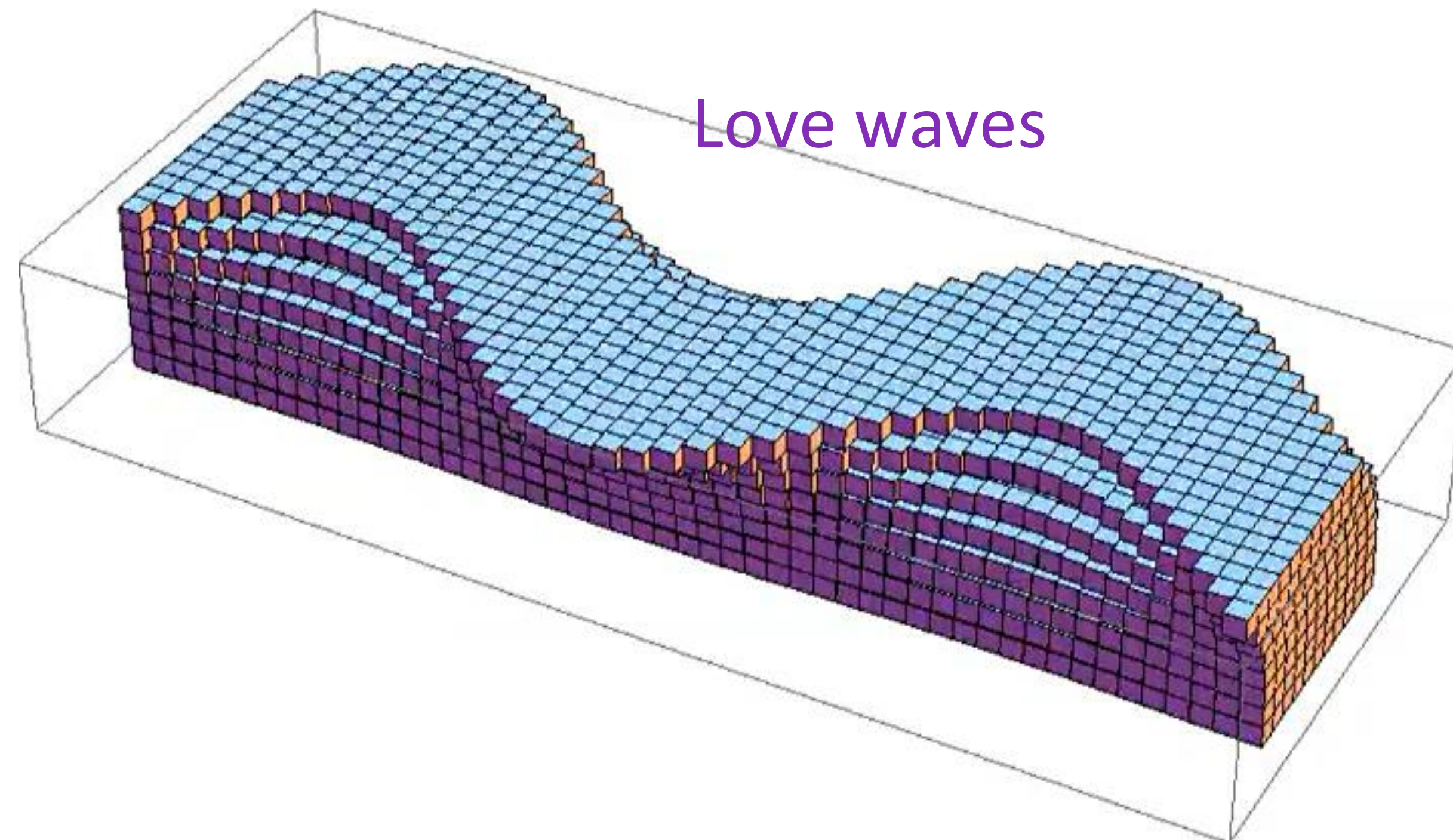
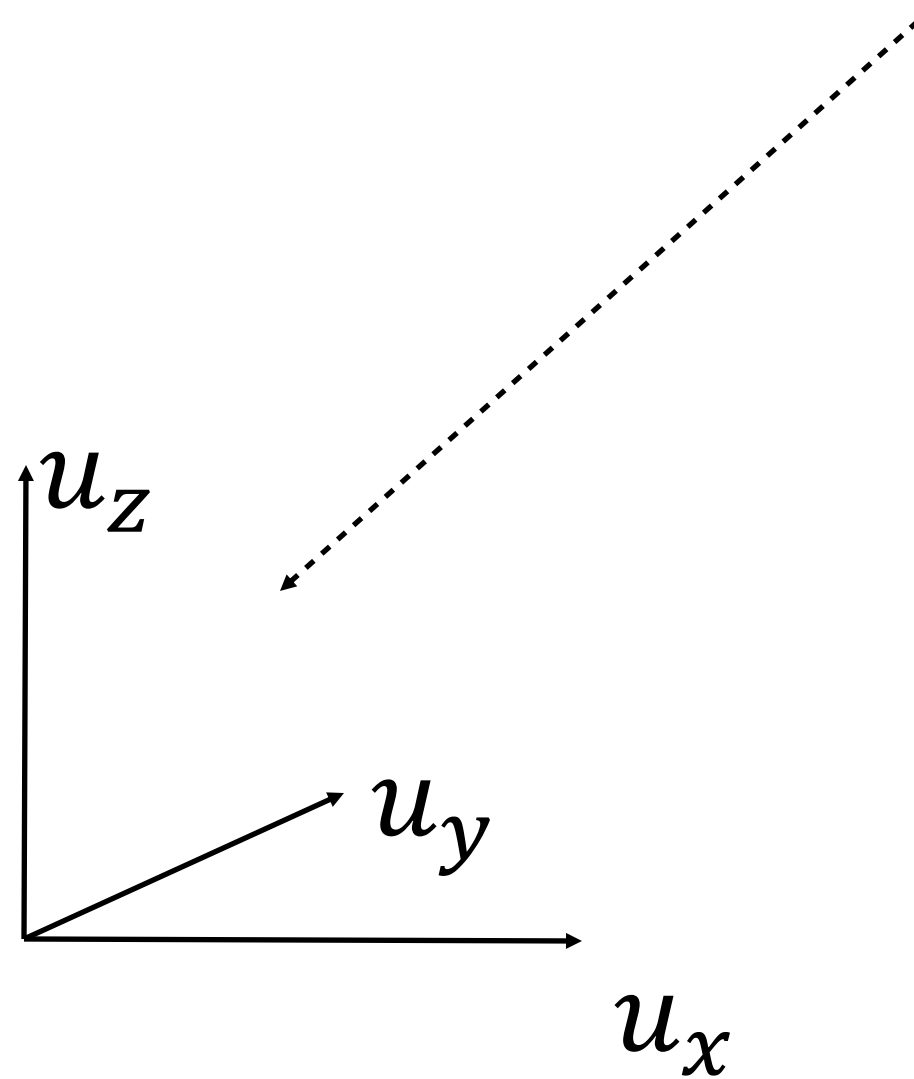
The (full!) ground motion  $u$  at a location close to a another location  $x$  ( $x + \delta x$ ) is  

$$u(x + \delta x) = u(x) + \epsilon \delta x + \omega \delta x$$

## Types of ground motion



**Displacement**  
 "oscillation"  
 3 components  
 (degrees of freedom)

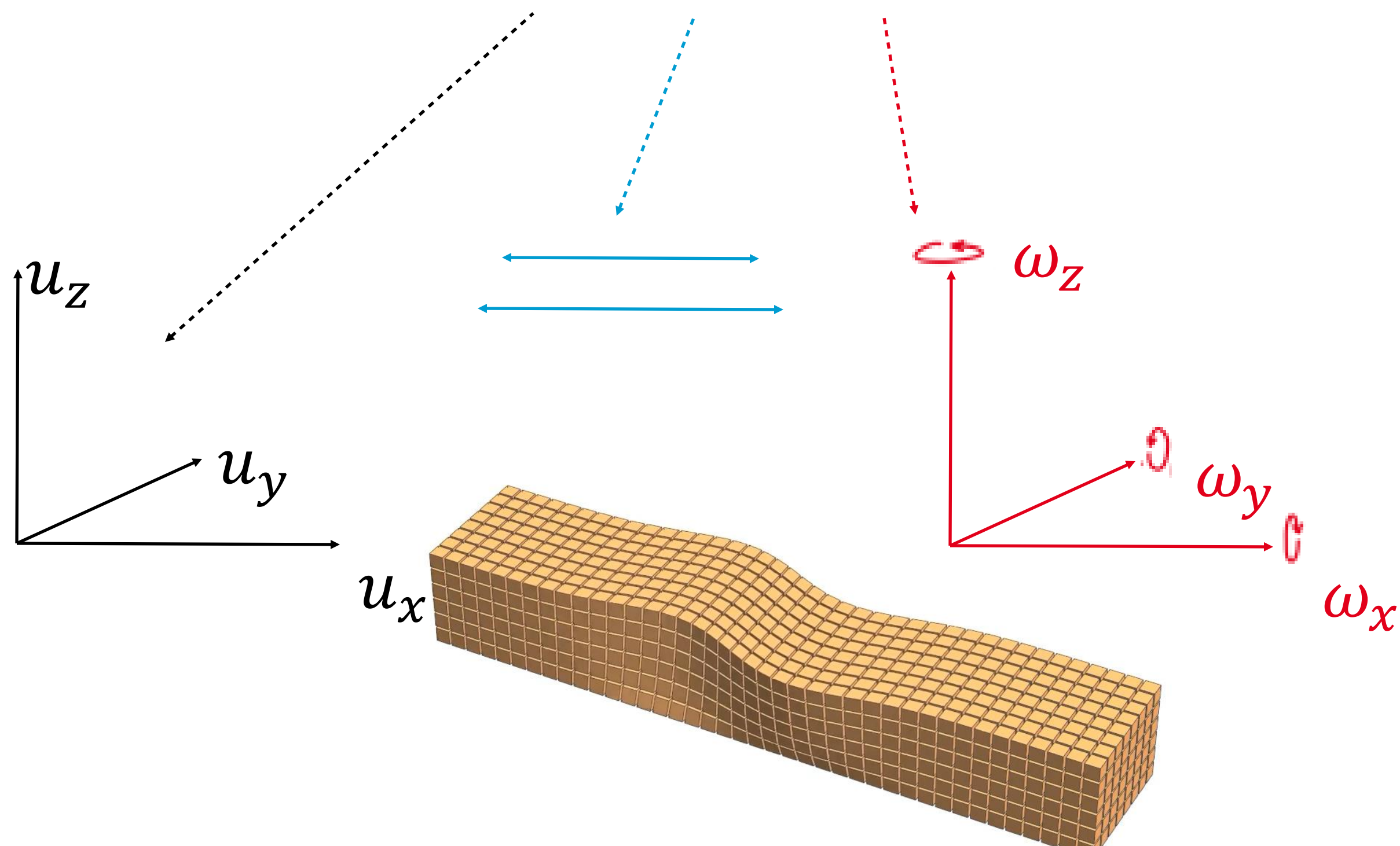


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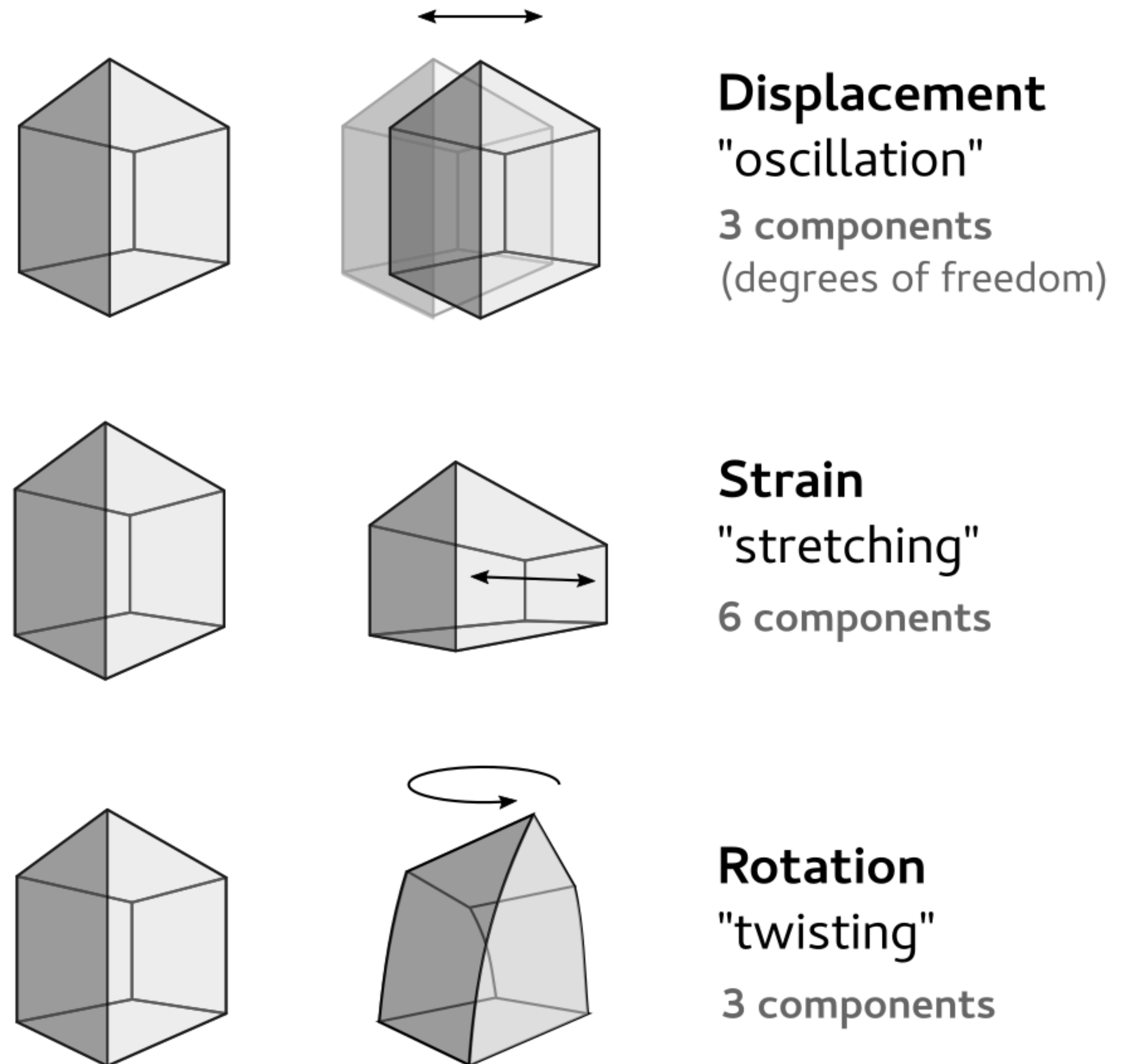


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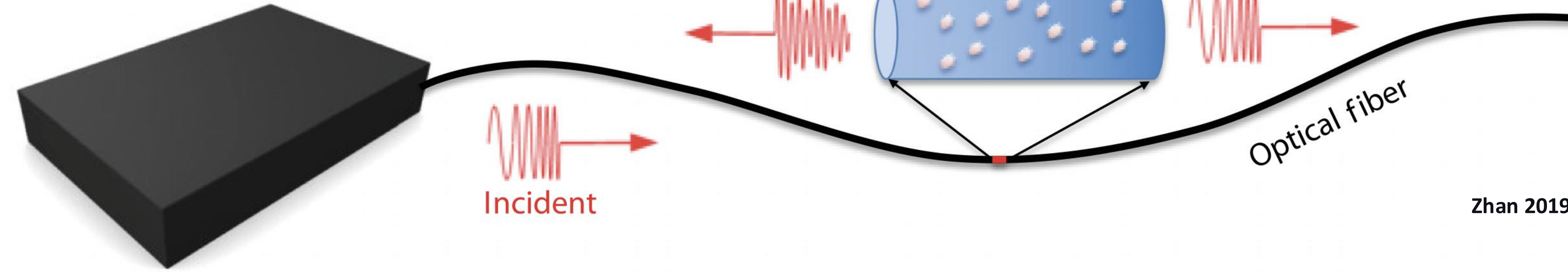
## Types of ground motion



# GROUND MOTIONS | How does fibre-optic sensing work?



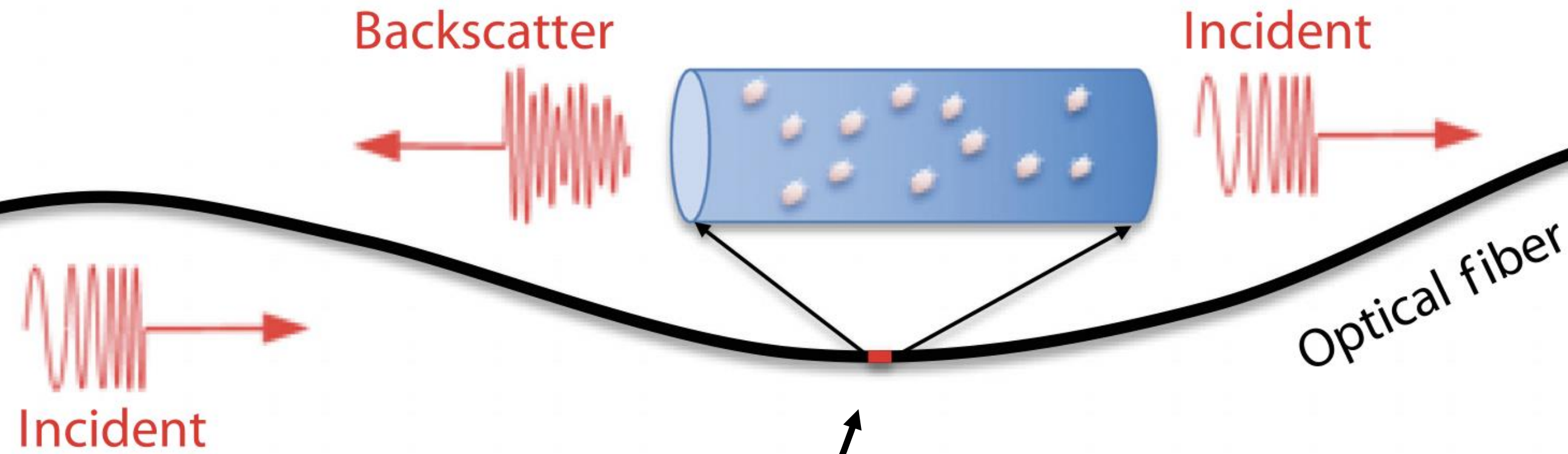
DAS interrogation unit  
Laser + Computer + Storage



# GROUND MOTIONS | How does fibre-optic sensing work?

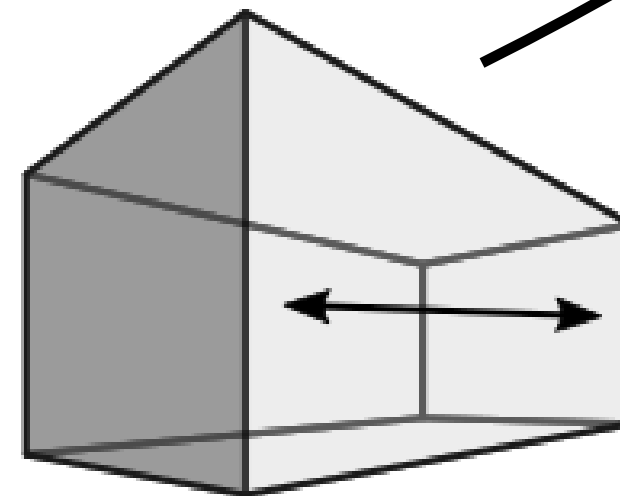
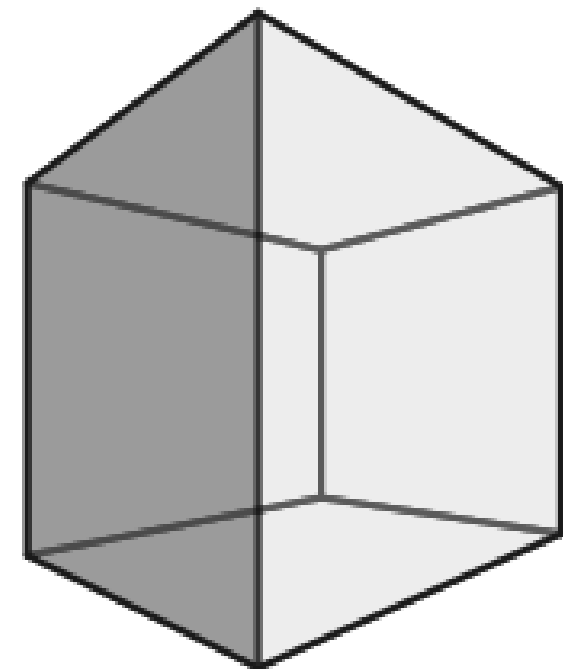


DAS interrogation unit  
Laser + Computer + Storage



Zhan 2019

measures **one(!)** strain component

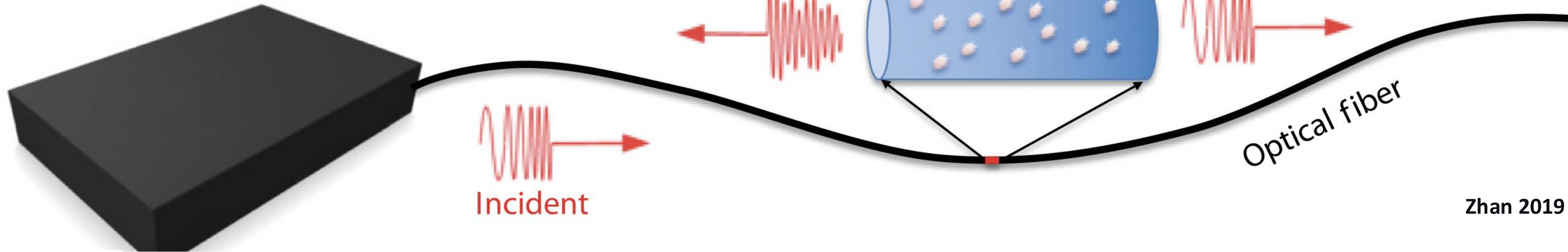


**Strain**  
"stretching"  
6 components

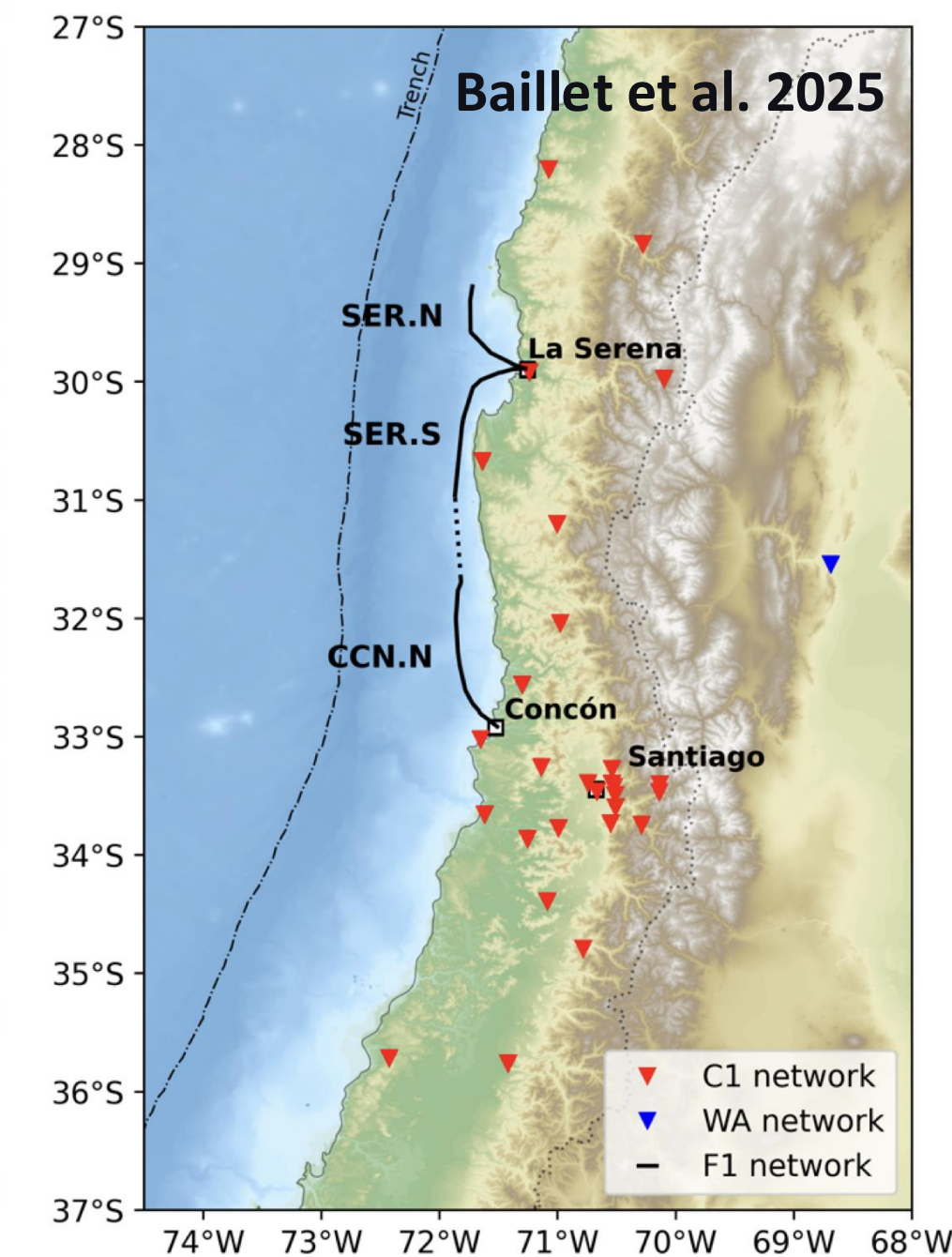
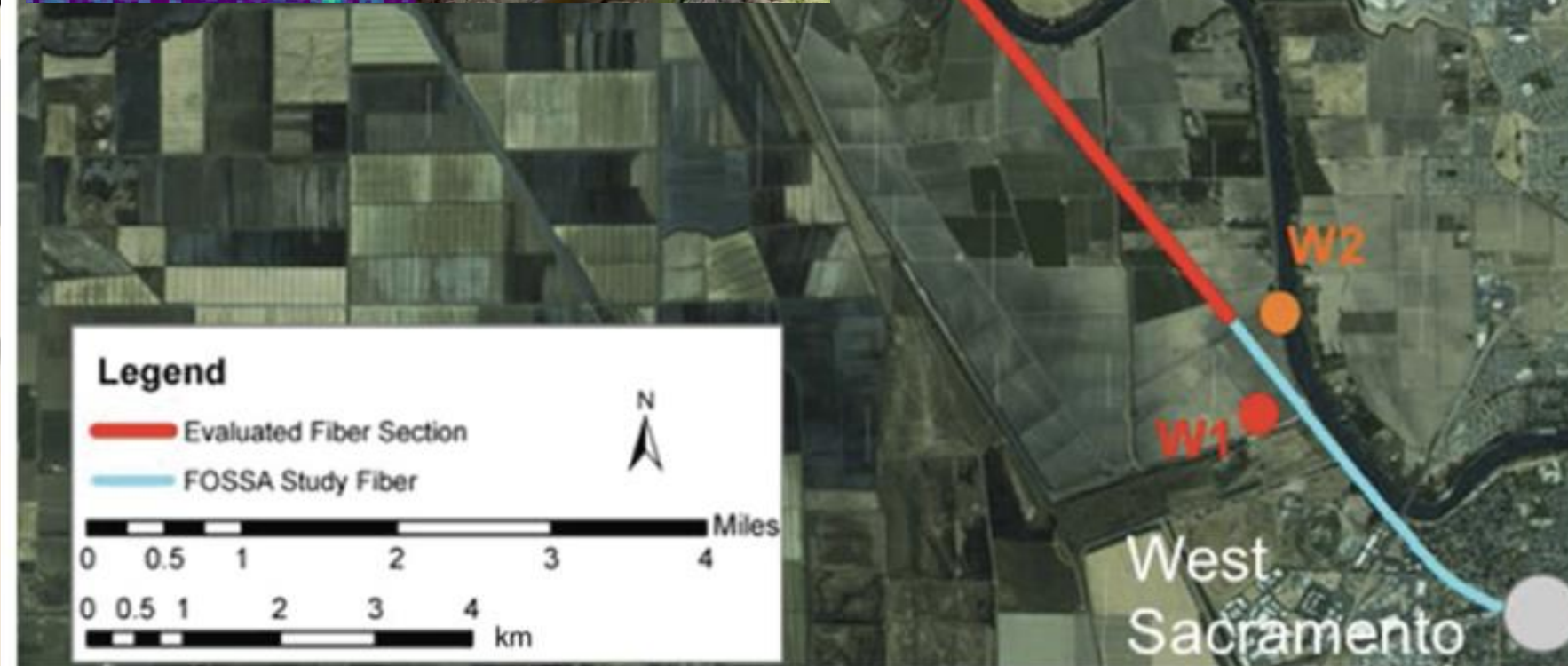
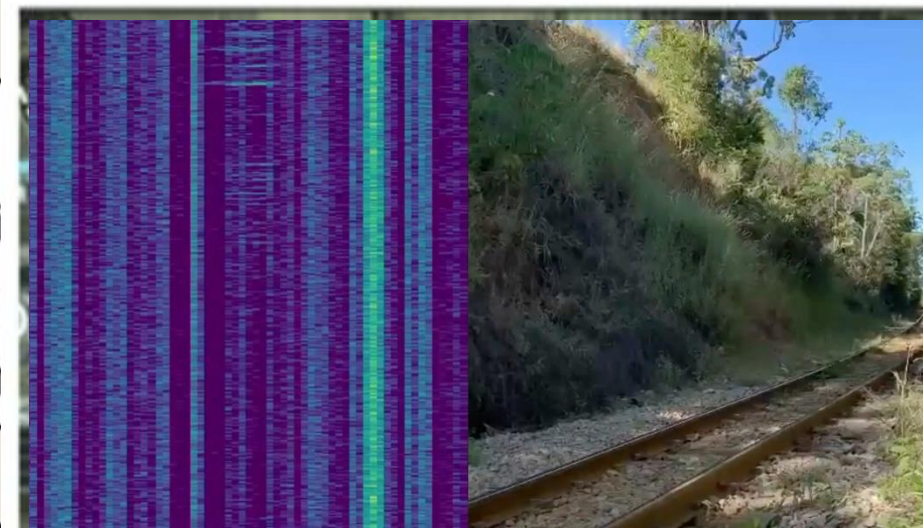
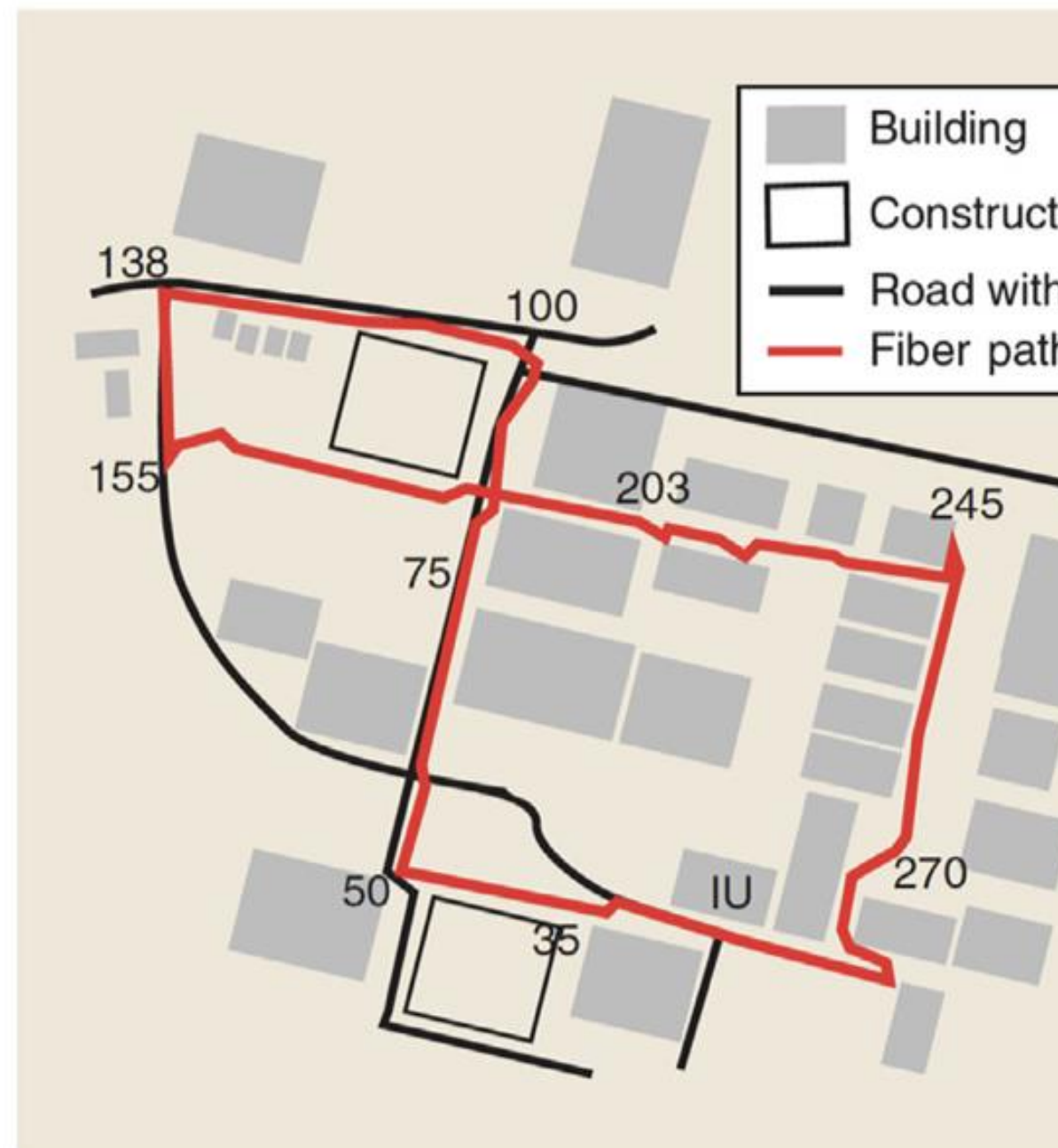
# GROUND MOTIONS | How does fibre-optic sensing work?



DAS interrogation unit  
Laser + Computer + Storage



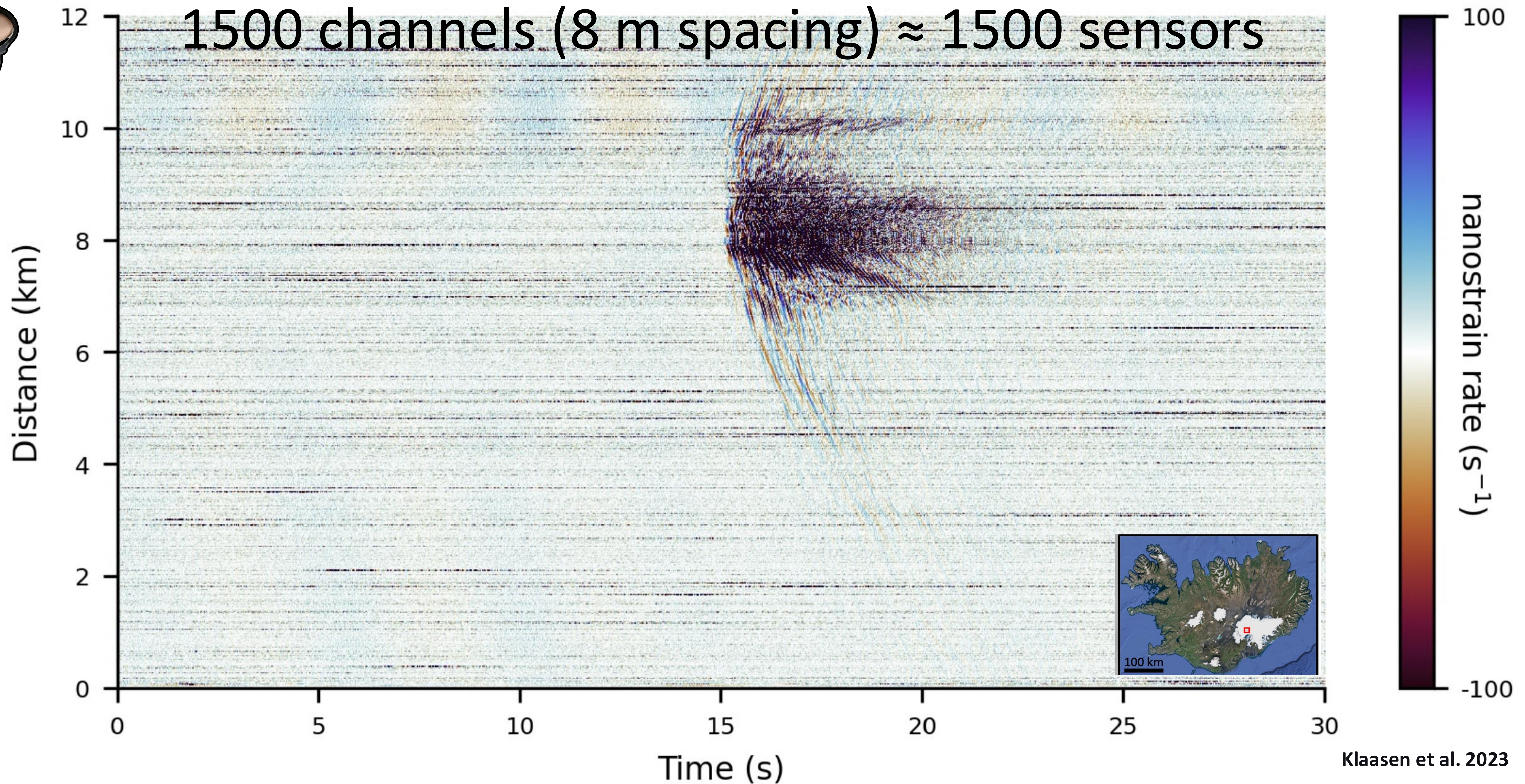
Zhan 2019



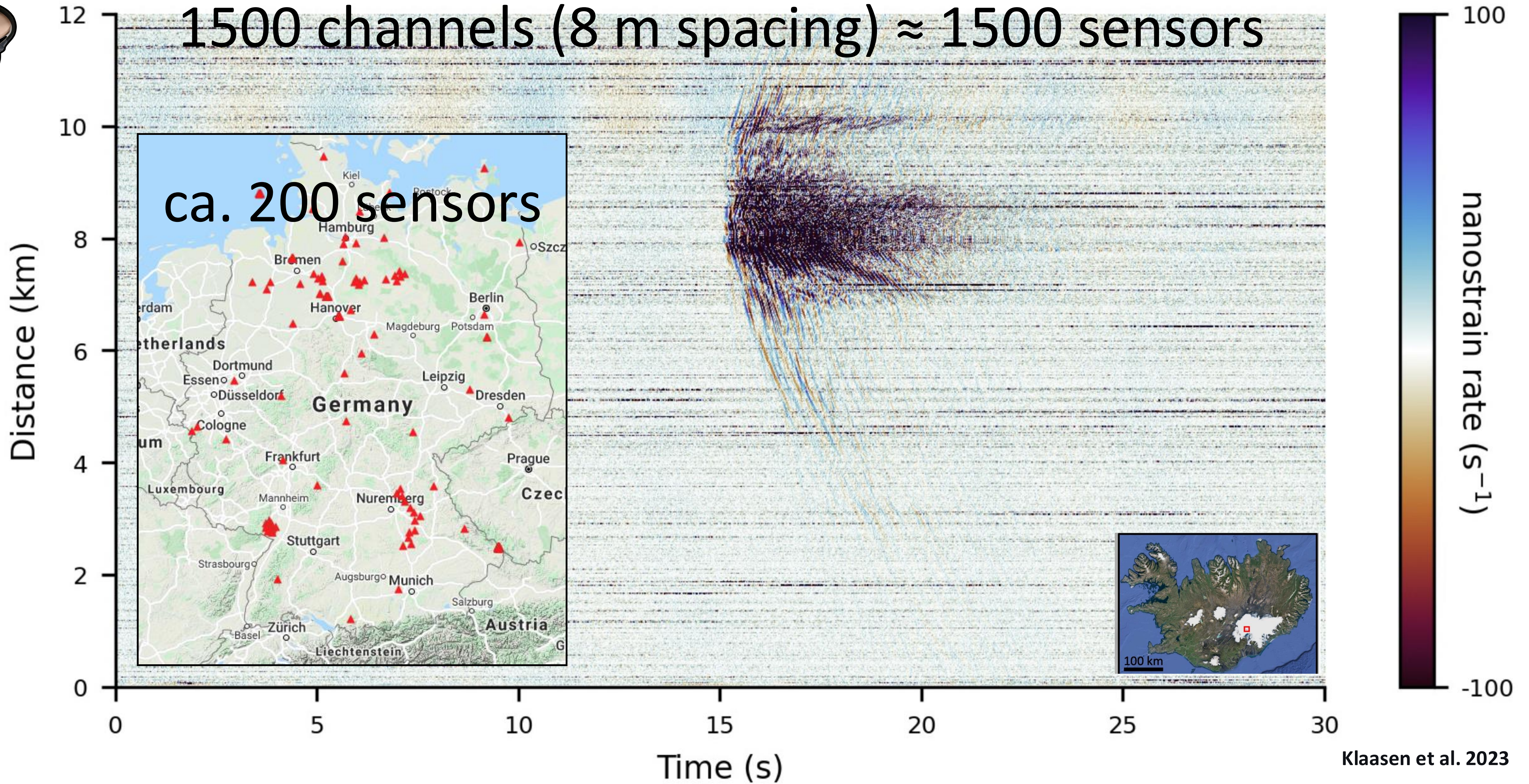
# GROUND MOTIONS | A new flood of data?



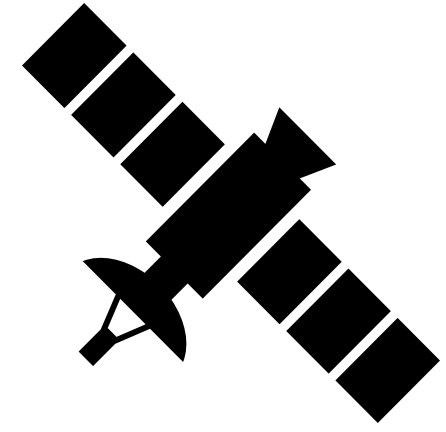
1500 channels (8 m spacing)  $\approx$  1500 sensors



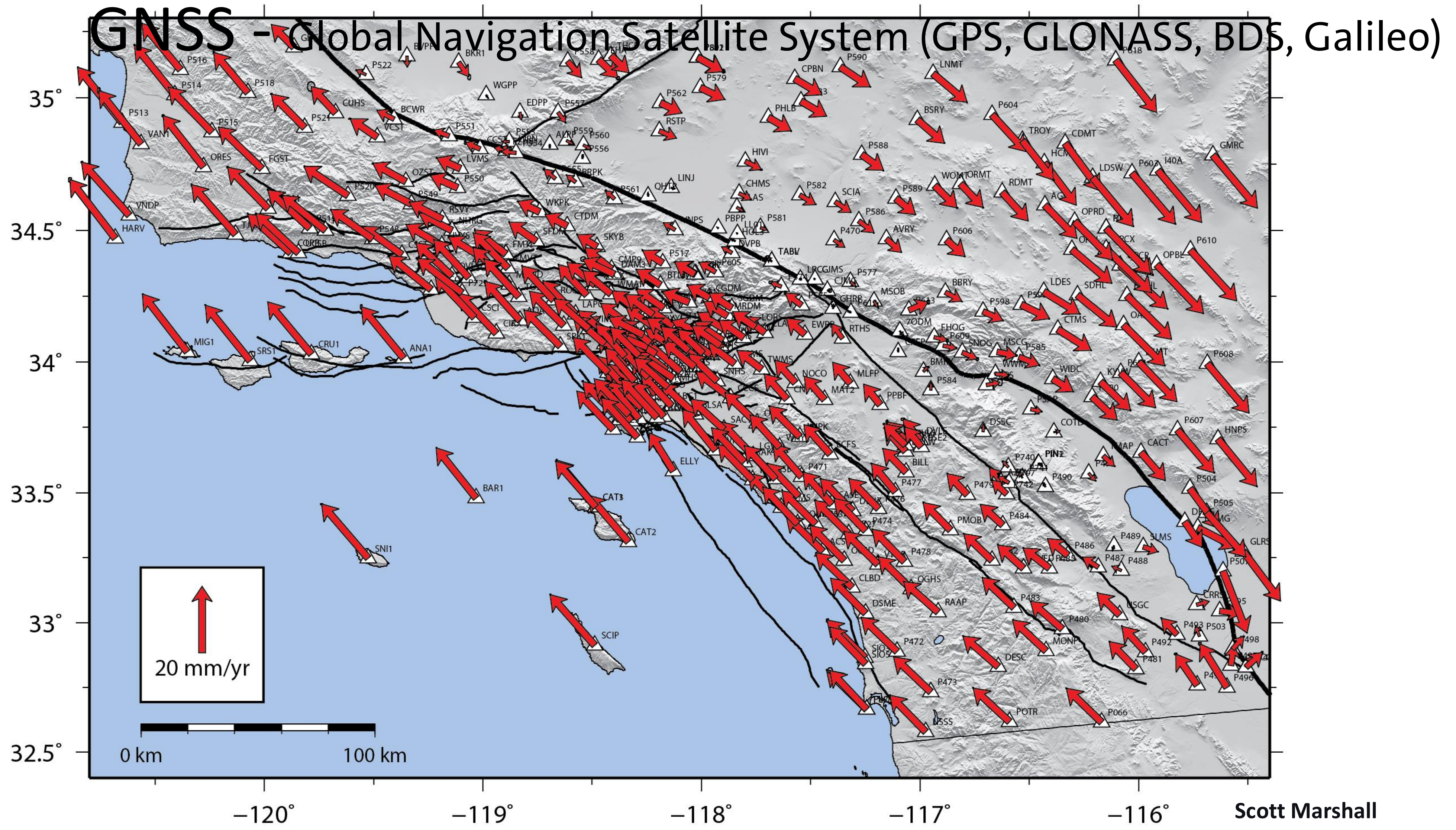
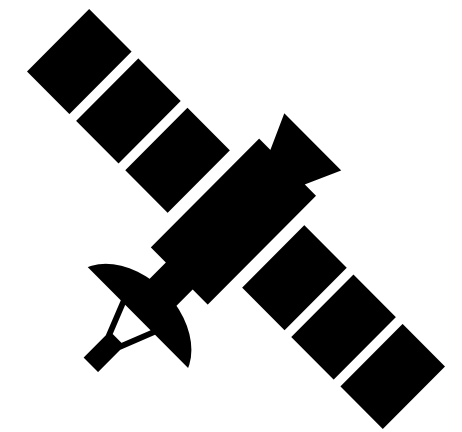
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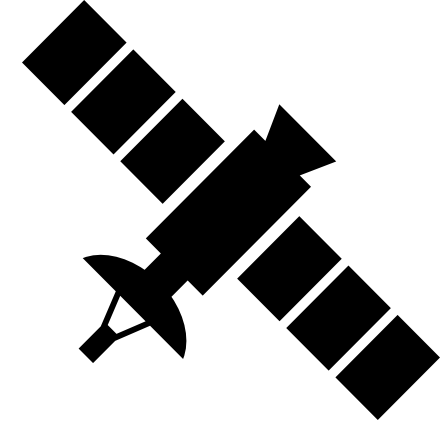
# Satellite-based | What data is useful for seismology?



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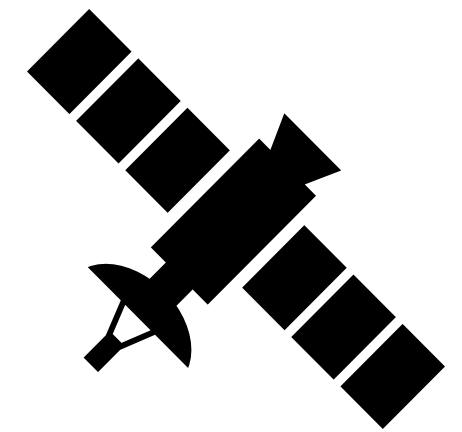
## SAR - Synthetic Aperture Radar

ScanSAR mode  
100km swath width  
20m resolution

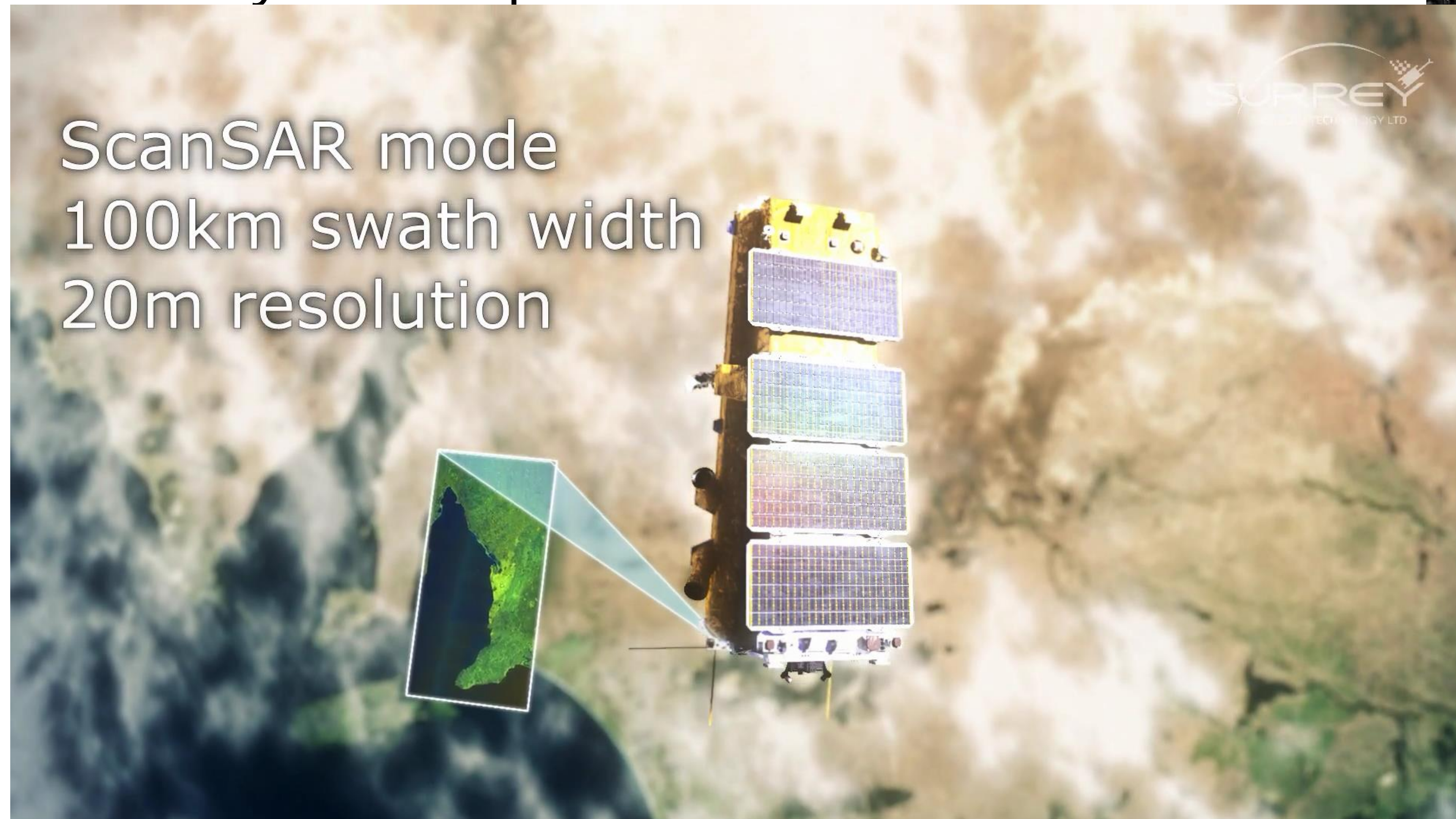


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# Satellite-based | What data is useful for seismology?



## SAR - Synthetic Aperture Radar



### 16cm spatial resolution!



# Miscellaneous | What does environmental data look like?



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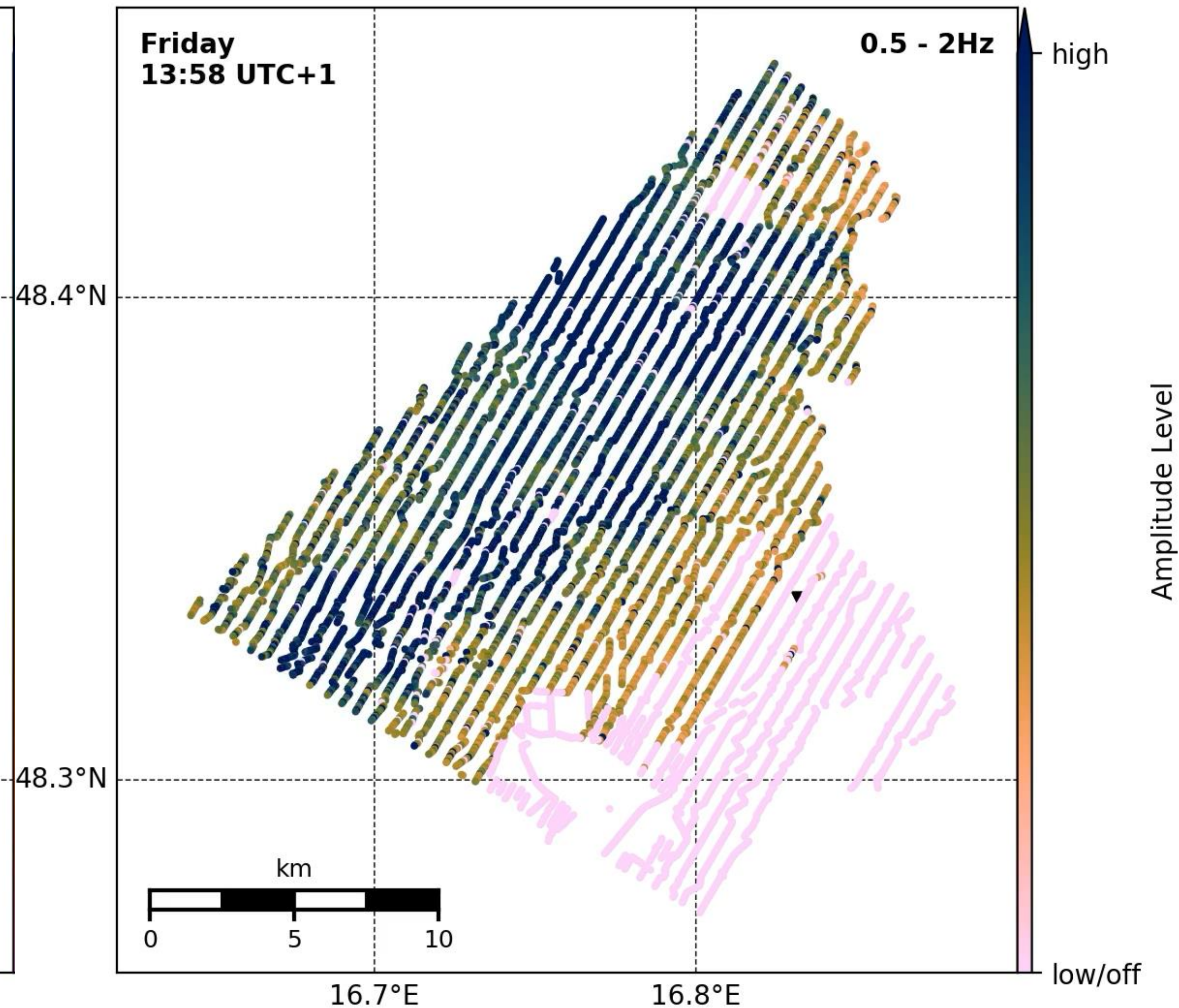
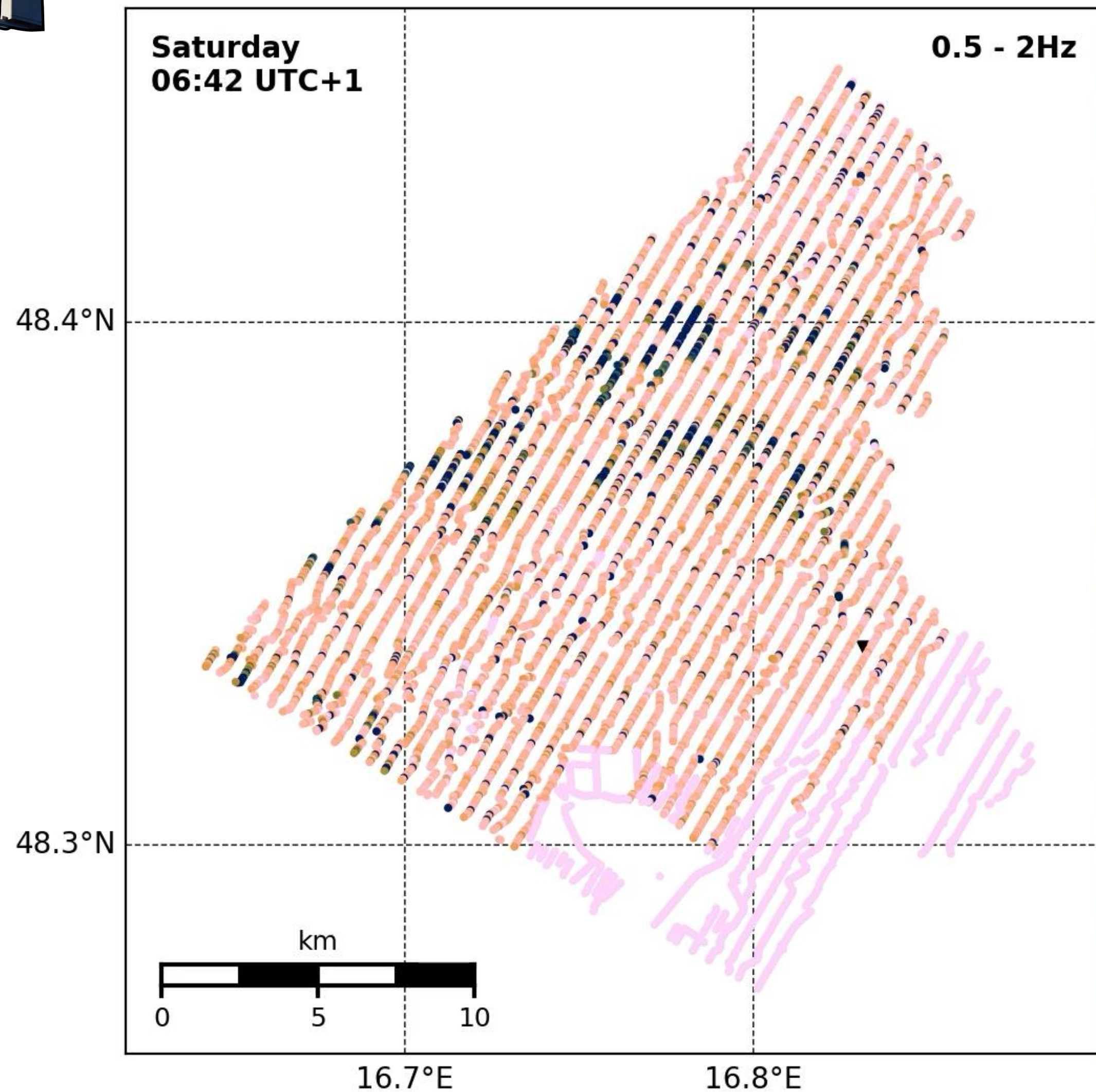
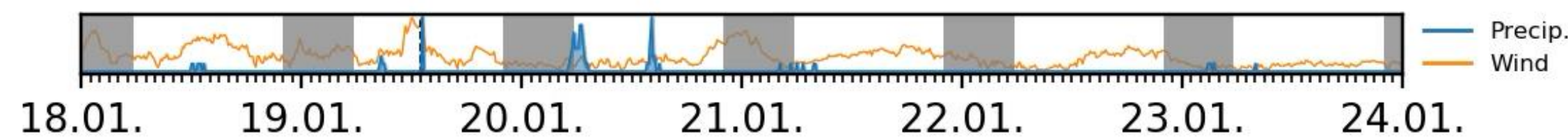
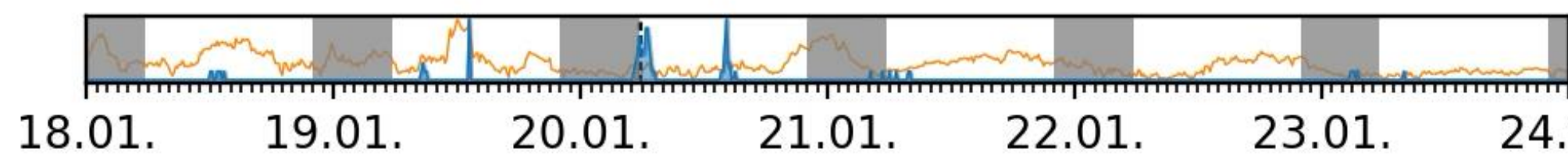


Temperature - Air  
 Temperature - Soil  
 Wind speed, gusts, direction, ...  
 Precipitation  
 Pressure  
 Humidity, Dew point  
 Soil moisture  
 ...

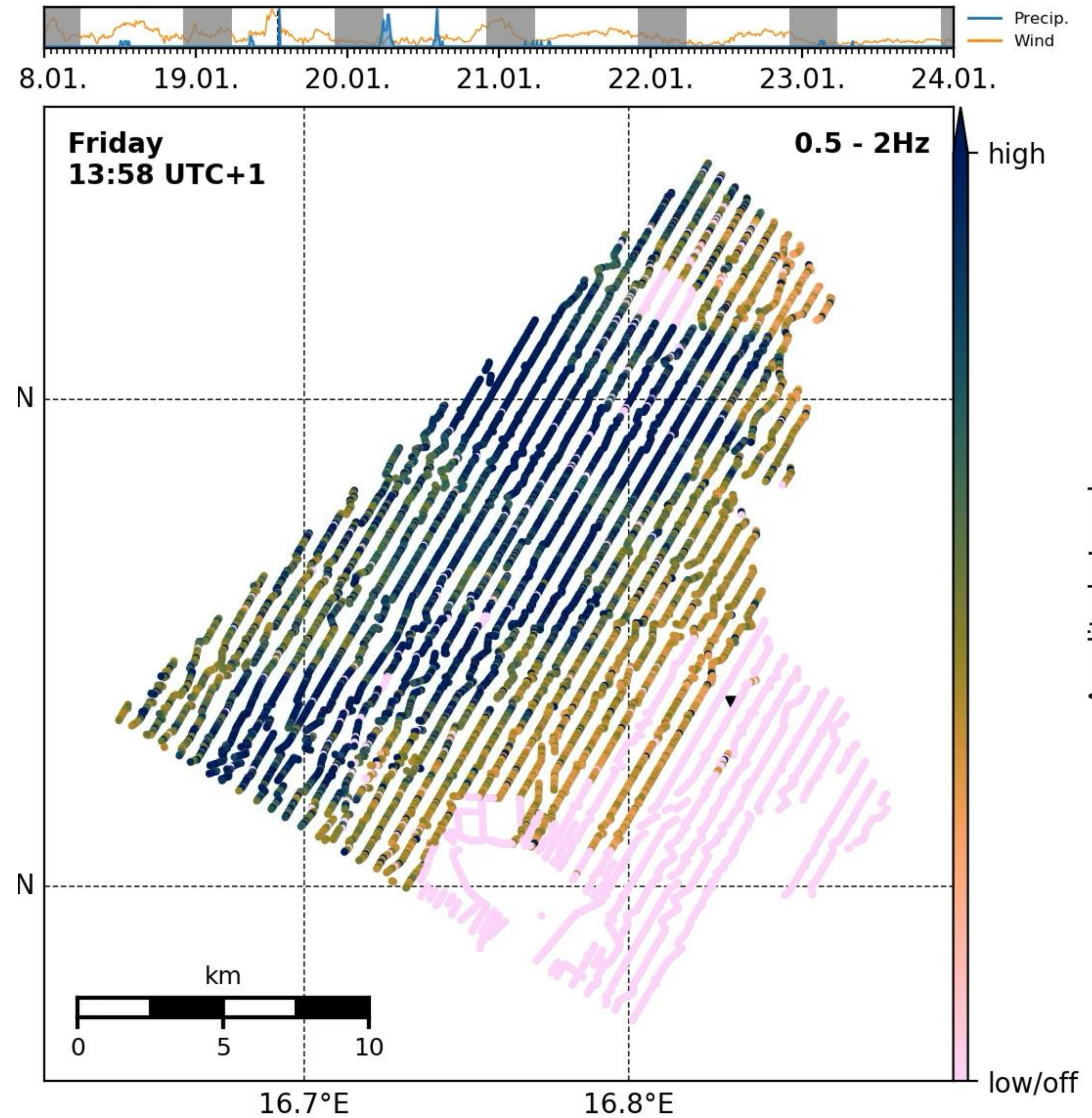
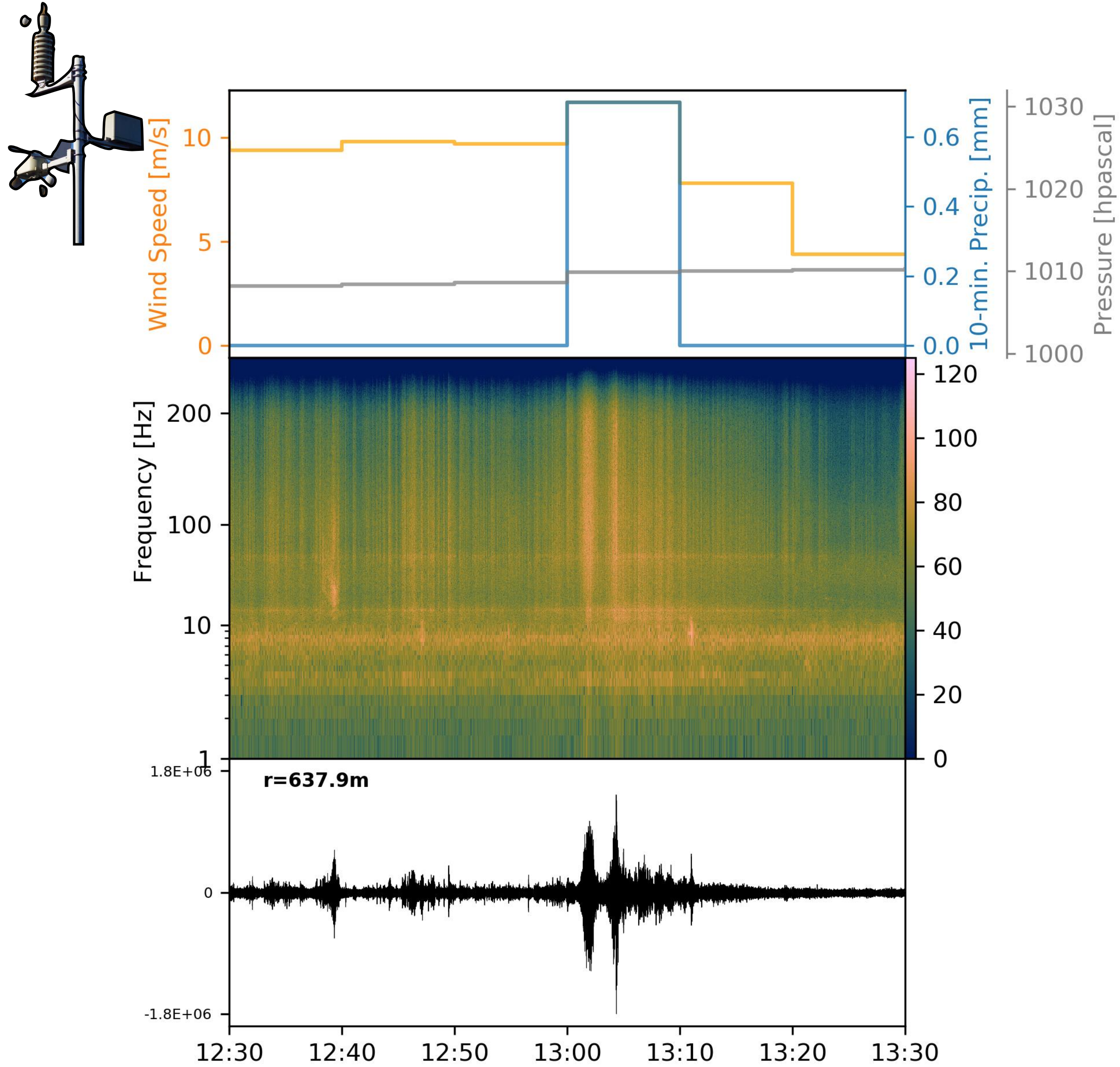
**Sampling rate: ~0.0015 Hz (10 min interval)**

datum	stdmin	statnr	dd	ff	ddx	ffx	zeitx	rr	p	pred
1180101	10	11085	130	18	128	26	5	0	9924	10104
1180101	20	11085	134	18	124	26	19	0	9922	10103
1180101	30	11085	123	24	122	32	26	0	9922	10103
1180101	40	11085	116	25	114	35	39	0	9920	10101
1180101	50	11085	122	34	125	48	49	0	9919	10099
1180101	100	11085	131	52	138	70	56	0	9918	10098
1180101	110	11085	131	57	138	77	109	0	9918	10098
1180101	120	11085	128	51	134	73	110	0	9914	10094
1180101	130	11085	130	42	126	55	123	0	9914	10094
1180101	140	11085	137	47	131	64	139	0	9912	10092
1180101	150	11085	136	38	138	62	140	0	9913	10093
1180101	200	11085	136	45	135	64	158	0	9913	10093
1180101	210	11085	144	39	131	53	200	0	9913	10093
1180101	220	11085	137	37	135	51	210	0	9911	10091
1180101	230	11085	137	36	135	49	227	0	9911	10091
1180101	240	11085	149	36	141	61	231	0	9912	10092
1180101	250	11085	151	33	151	44	247	0	9911	10091

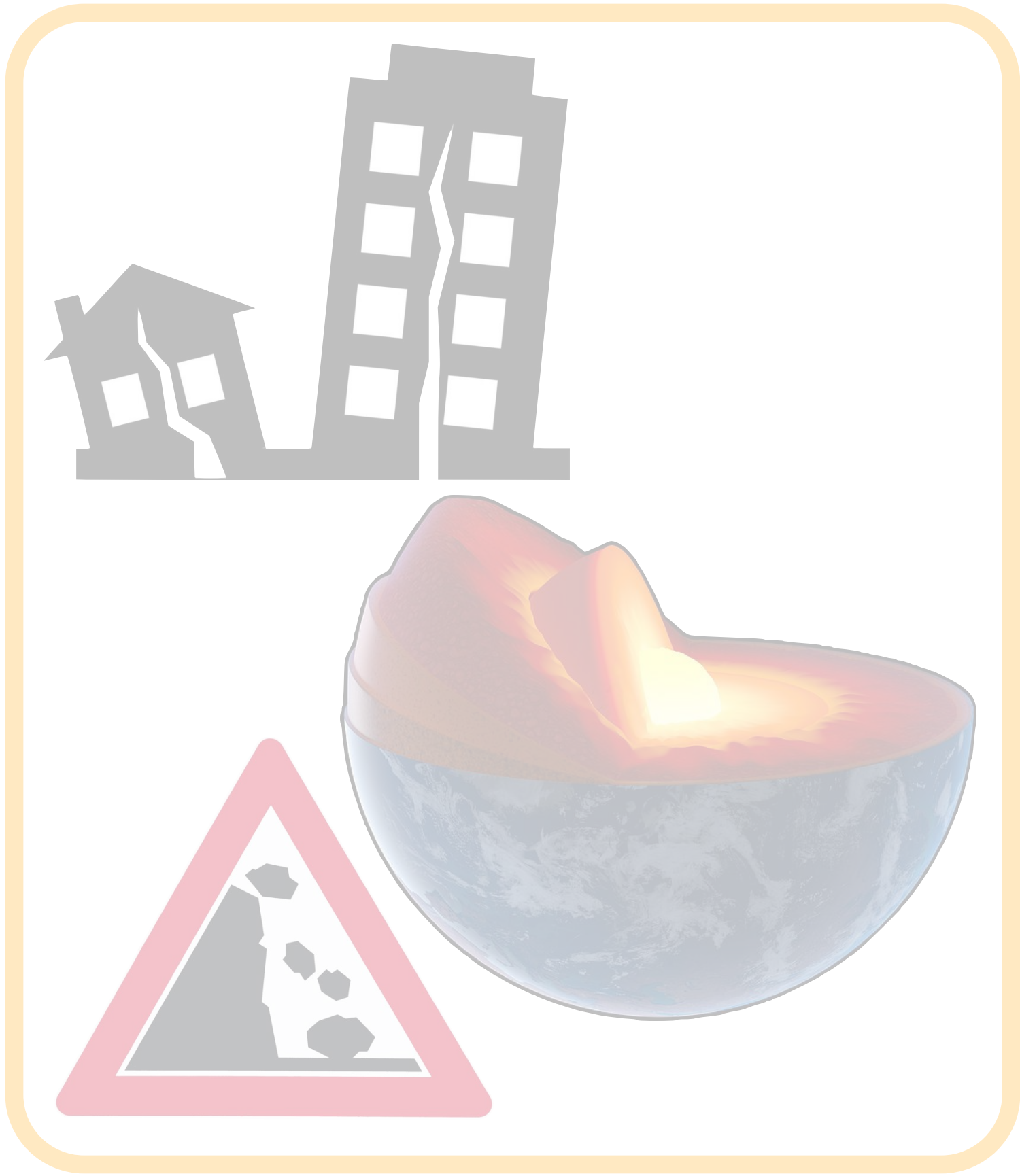
# Miscellaneous | What does environmental data look like?



# Miscellaneous | What does environmental data look like?



# Targets



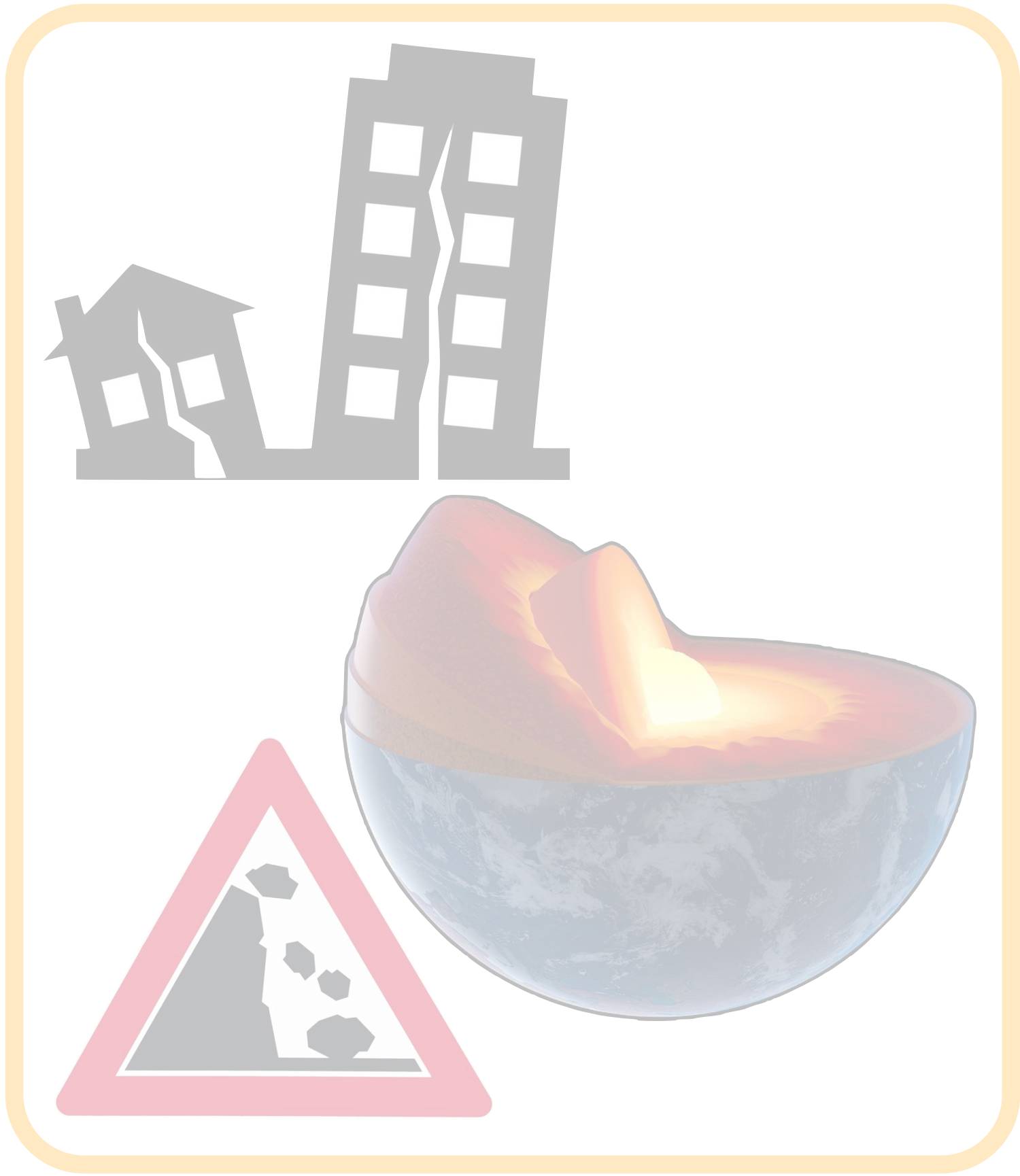
# Data

**Raw data**

**Derived data**

A collage of images representing data collection and processing. The 'Raw data' section includes a green dome-shaped sensor, a grey electronic device, a spool of black cable, a satellite, a globe, a hydrophone, a yellow cylindrical sensor, and a mechanical sensor. A waveform is shown between the dome sensor and the hydrophone. The 'Derived data' section includes a scatter plot on a map, a cluster of colorful spheres, a heatmap of a coastline, a waveform with a 'z' label, a cross-section of a seabed, a heatmap with 'North' and 'West' labels, a circular data visualization, a map of a coastline with a star, and a topographic map of a region. The entire collage is enclosed in a rounded purple border.

# Targets



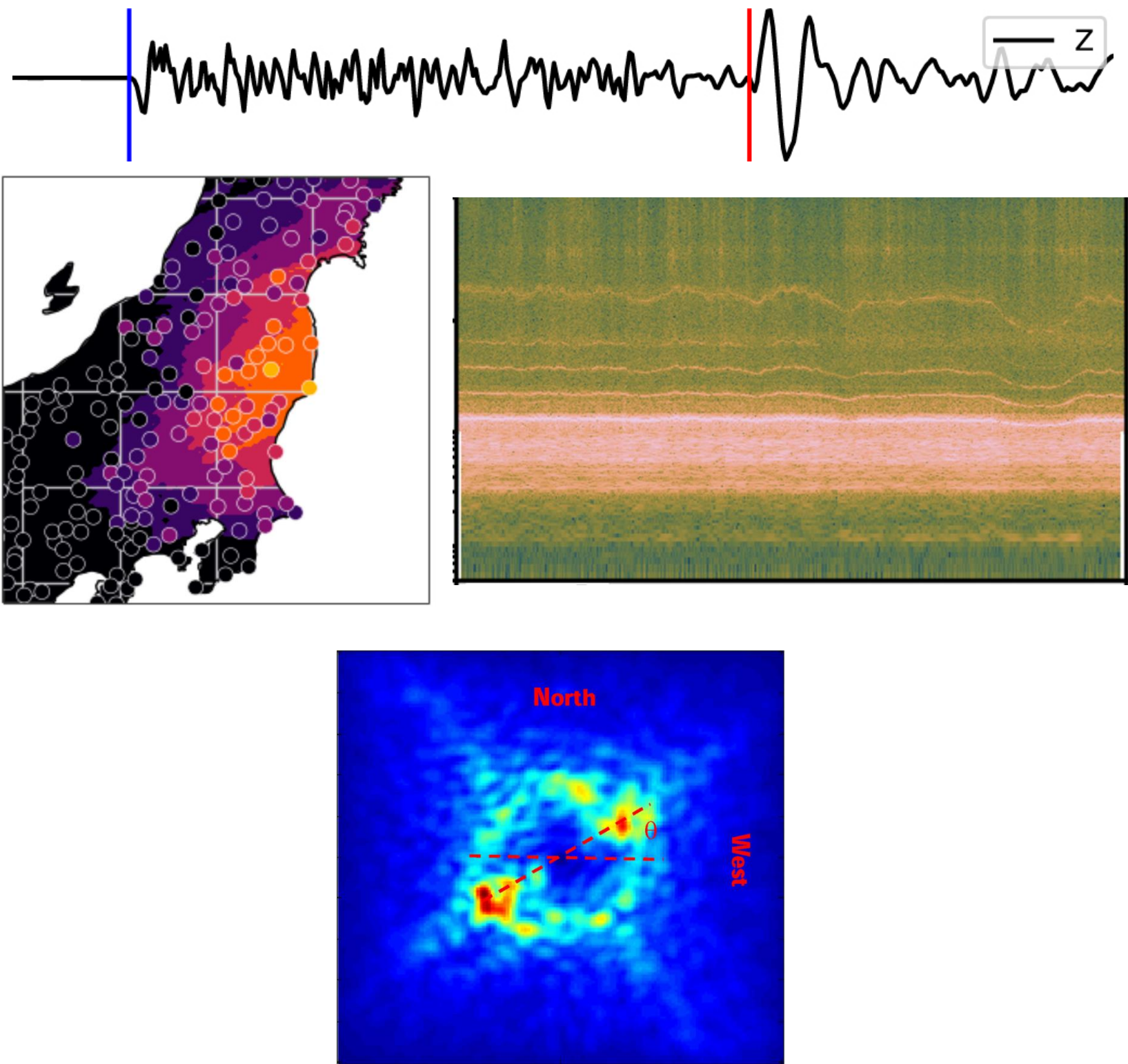
# Data

**Raw data**

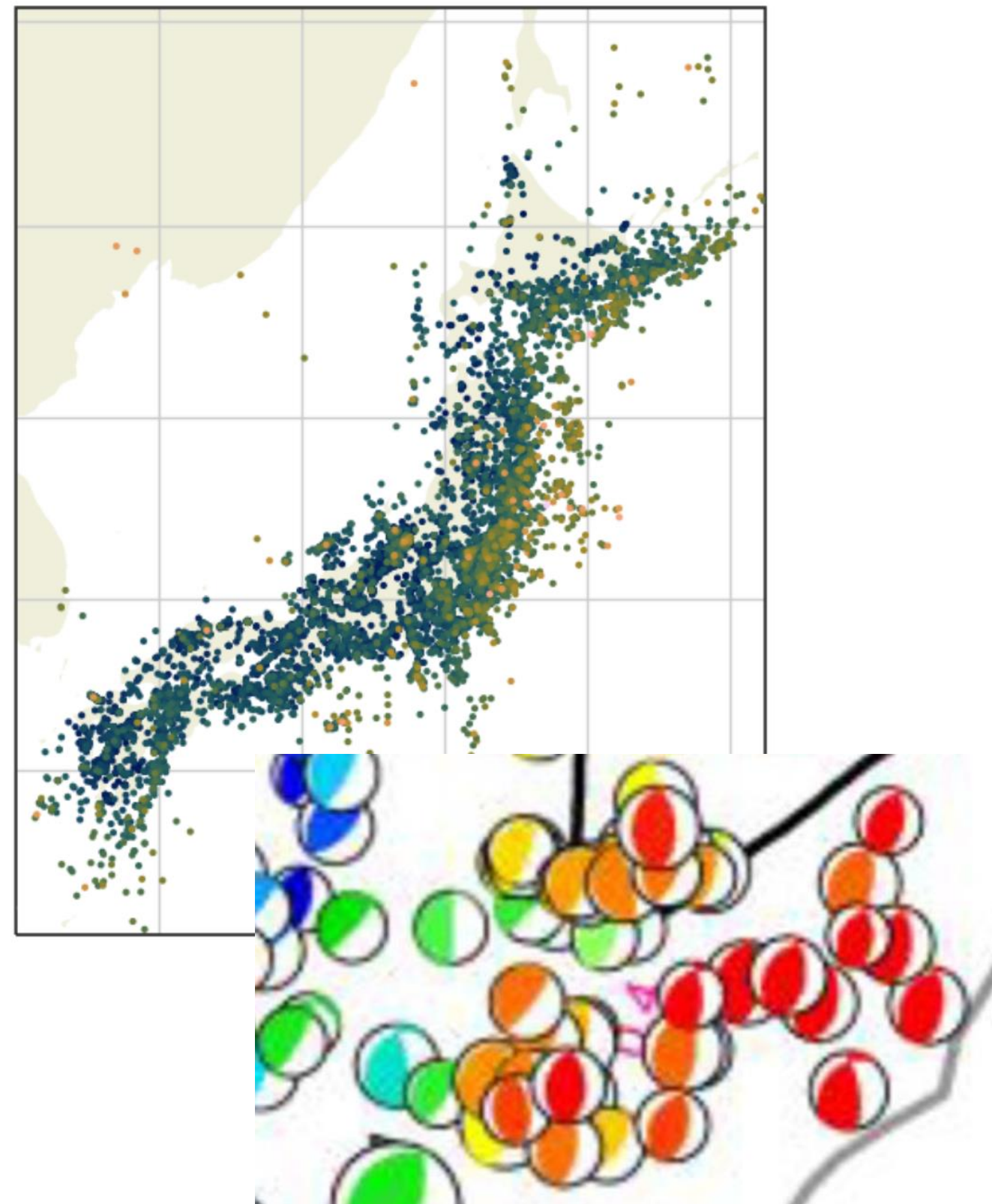
**Derived data**

A collage of various data visualization and sensor-related elements. On the left, under the 'Raw data' heading, there is a satellite, a globe, a hydrophone, a yellow cylindrical sensor, and a seismometer. In the center, there is a large waveform plot. On the right, under the 'Derived data' heading, there is a scatter plot on a map, a 3D molecular model, a heatmap of a coastline, a cross-section of a geological layer, a circular data plot, and a global map with a red star and a scale bar.

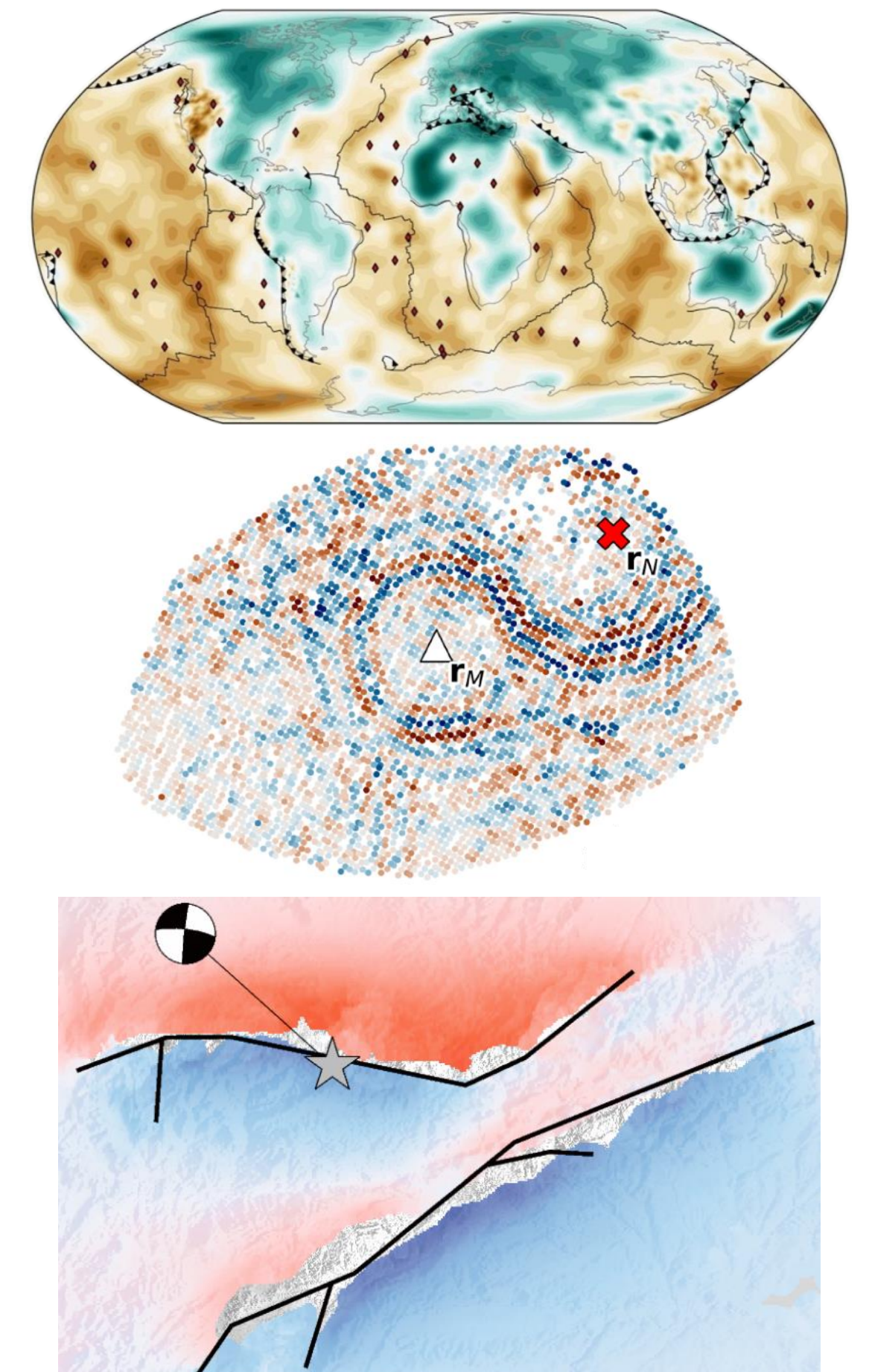
# wavefield abstractions



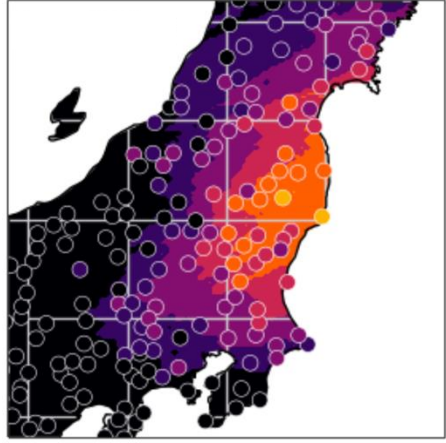
# Earthquake metadata



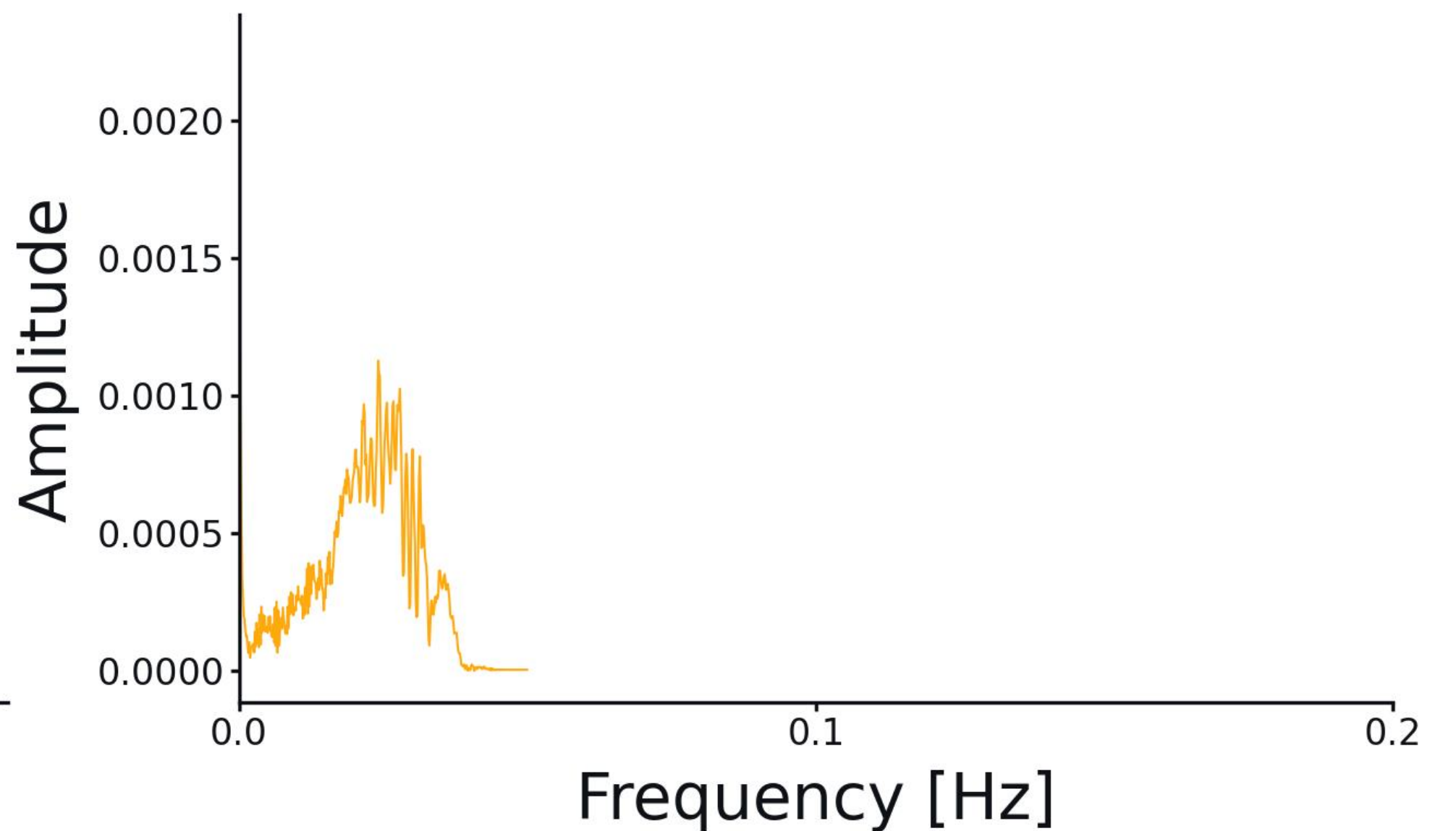
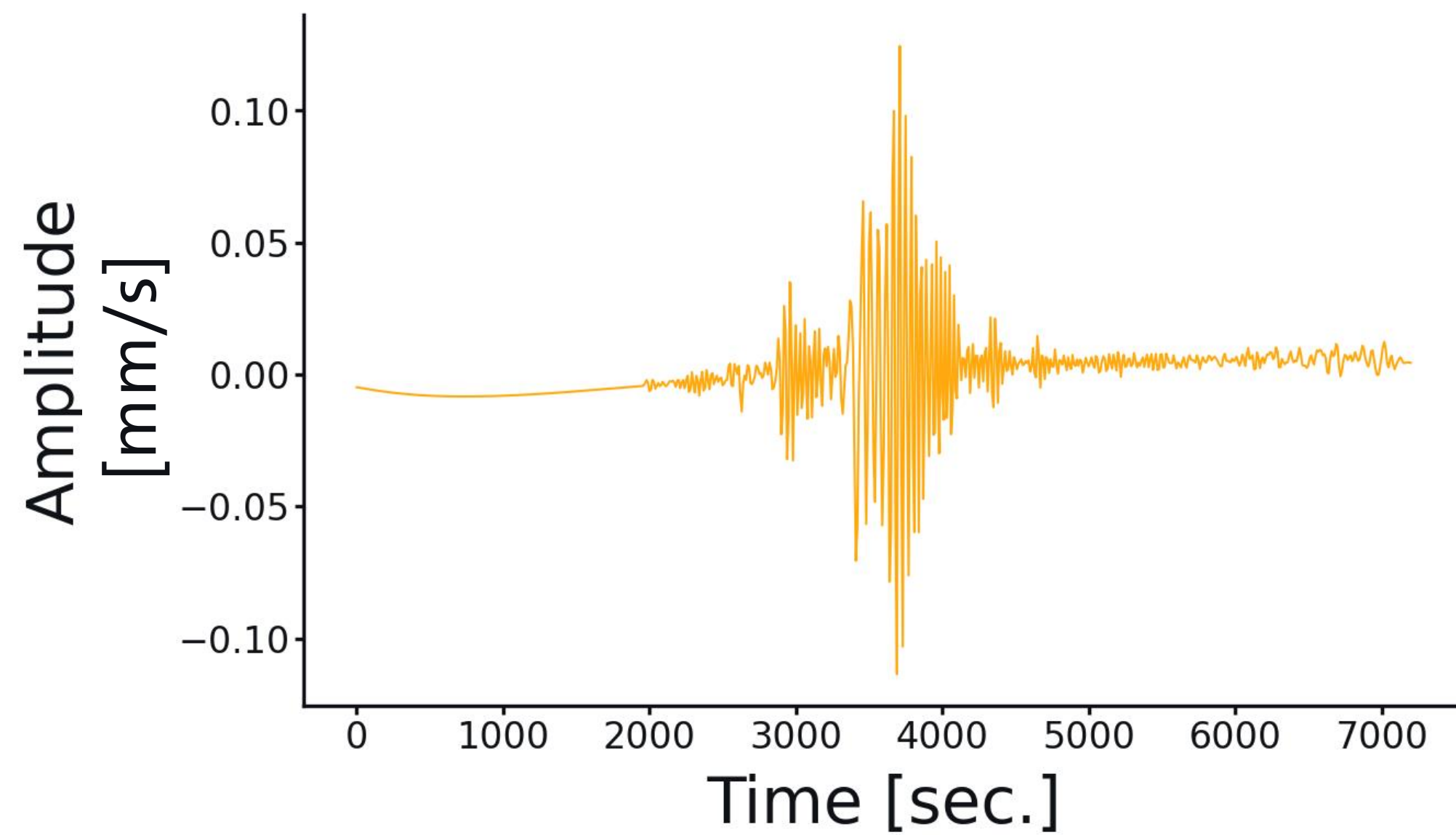
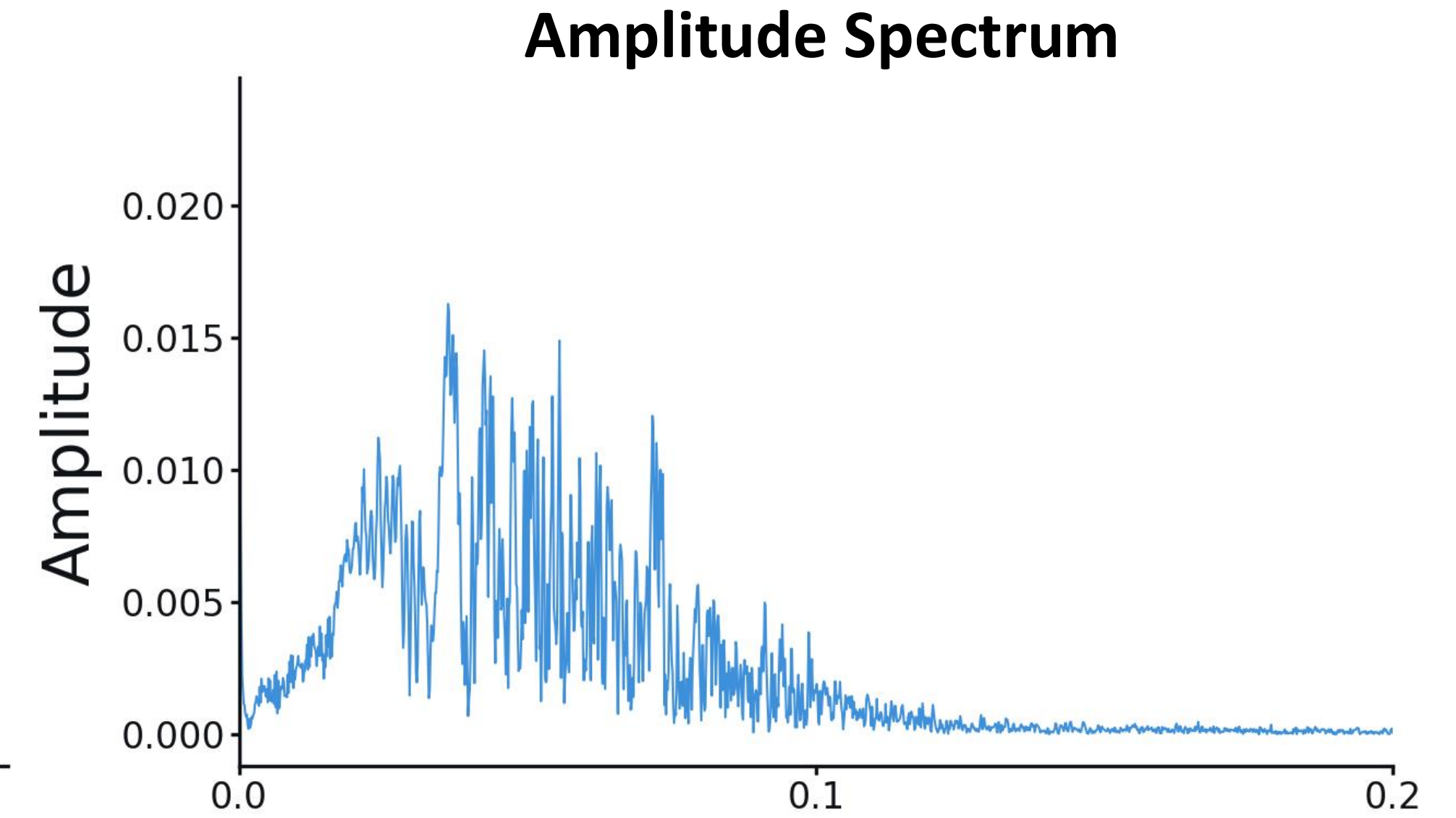
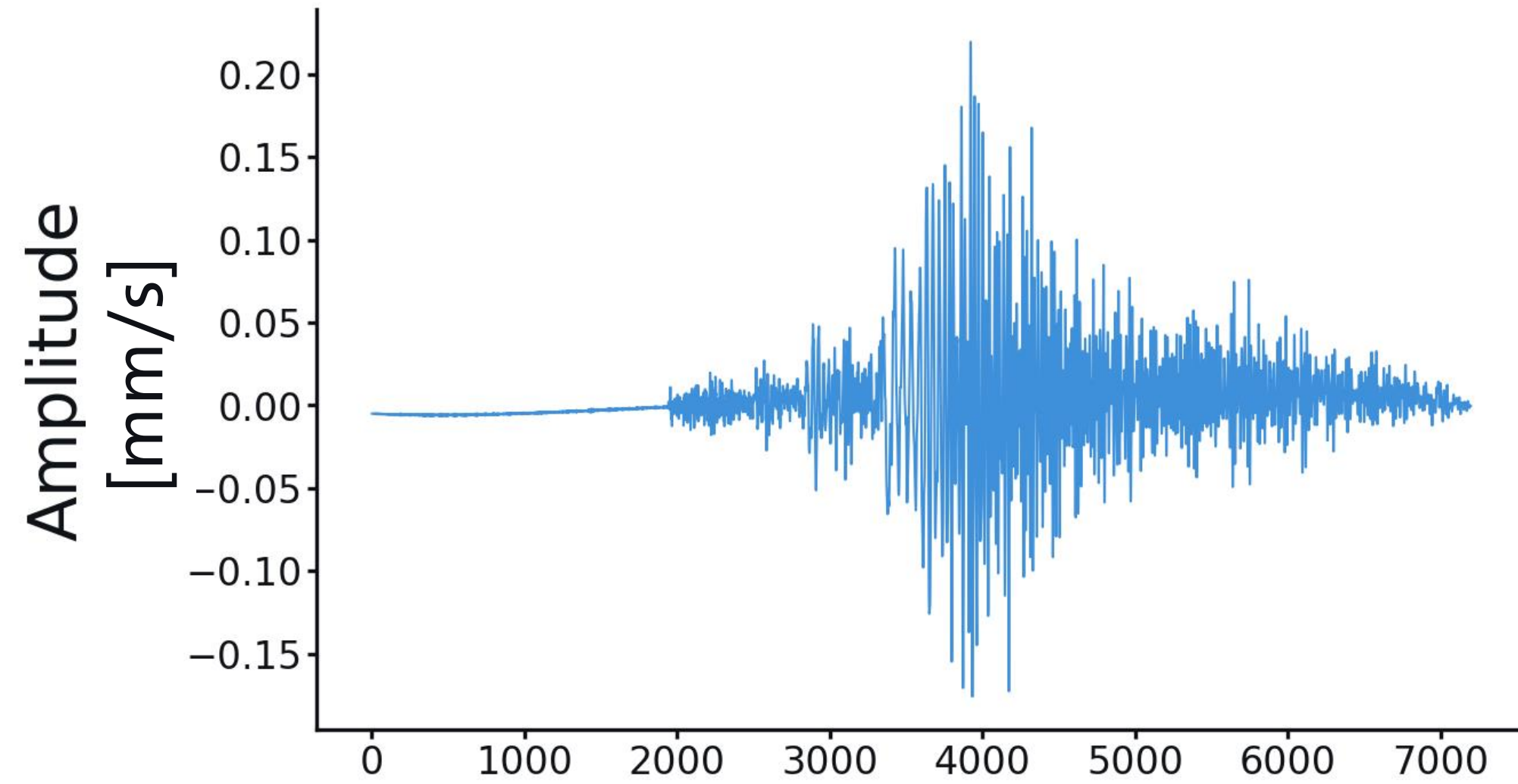
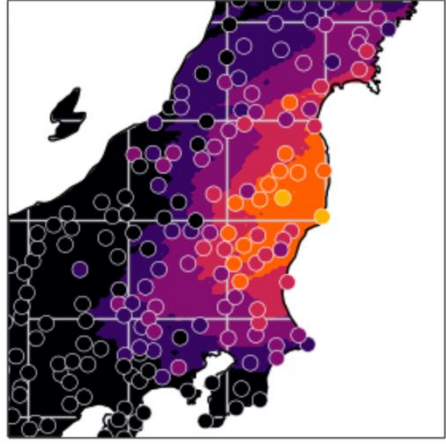
# miscellaneous



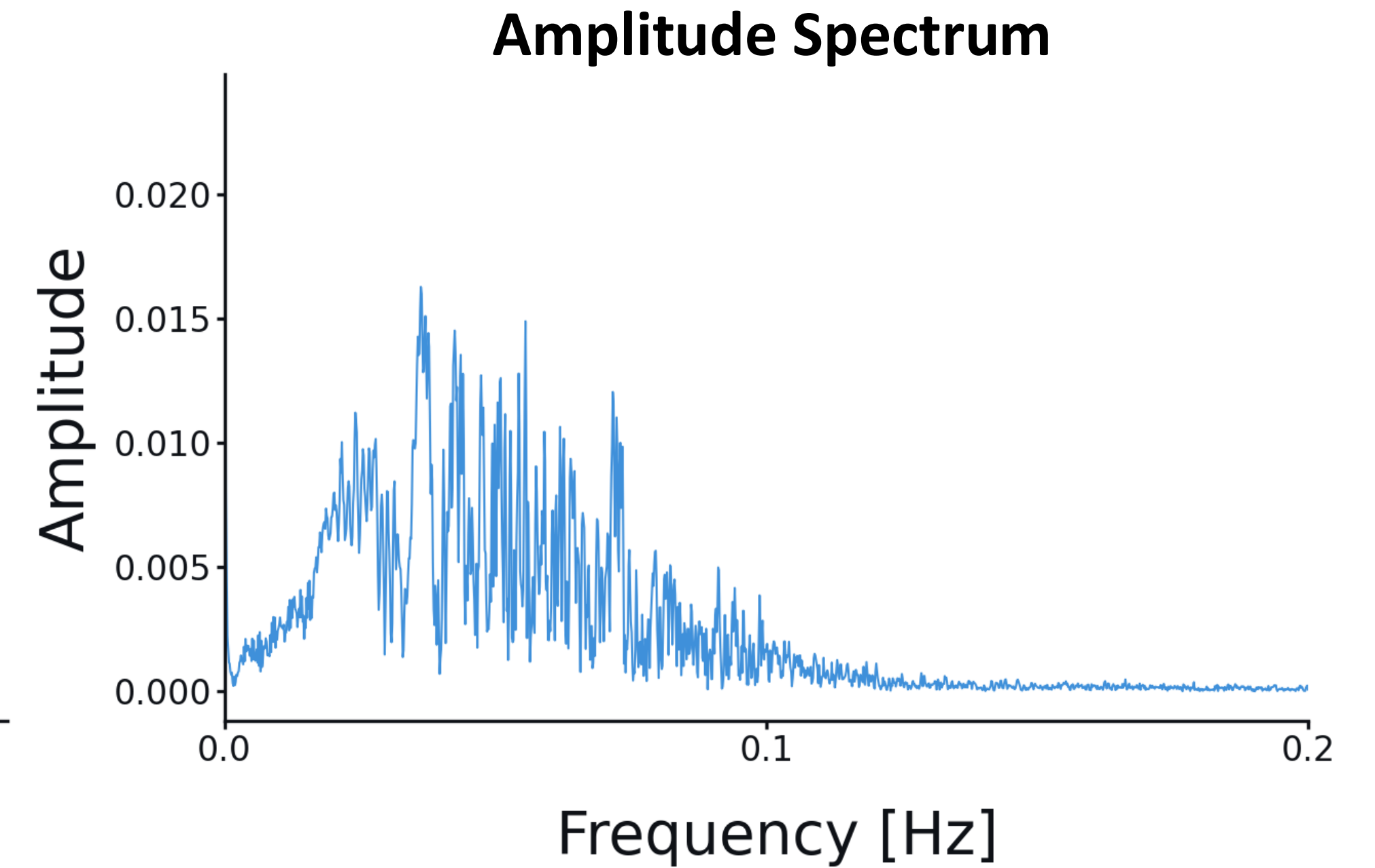
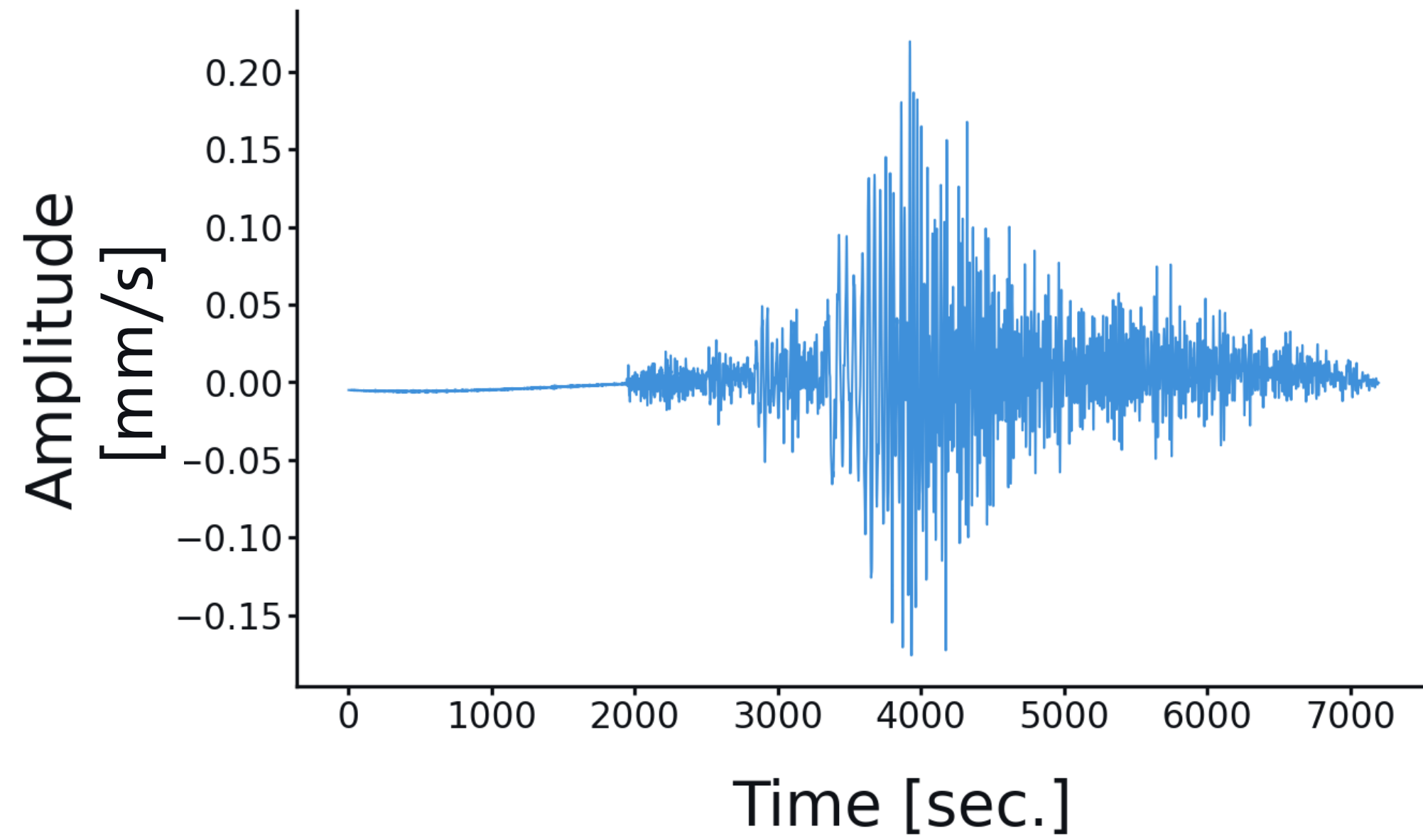
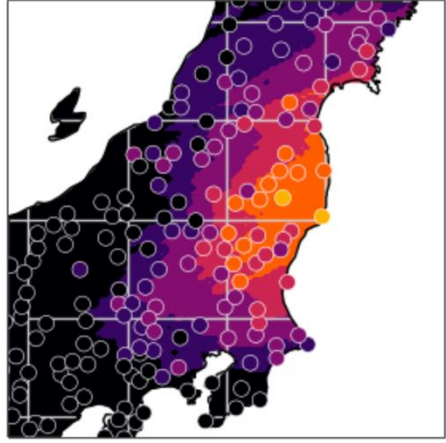
# Wavefield Abstractions | What is a spectrum?



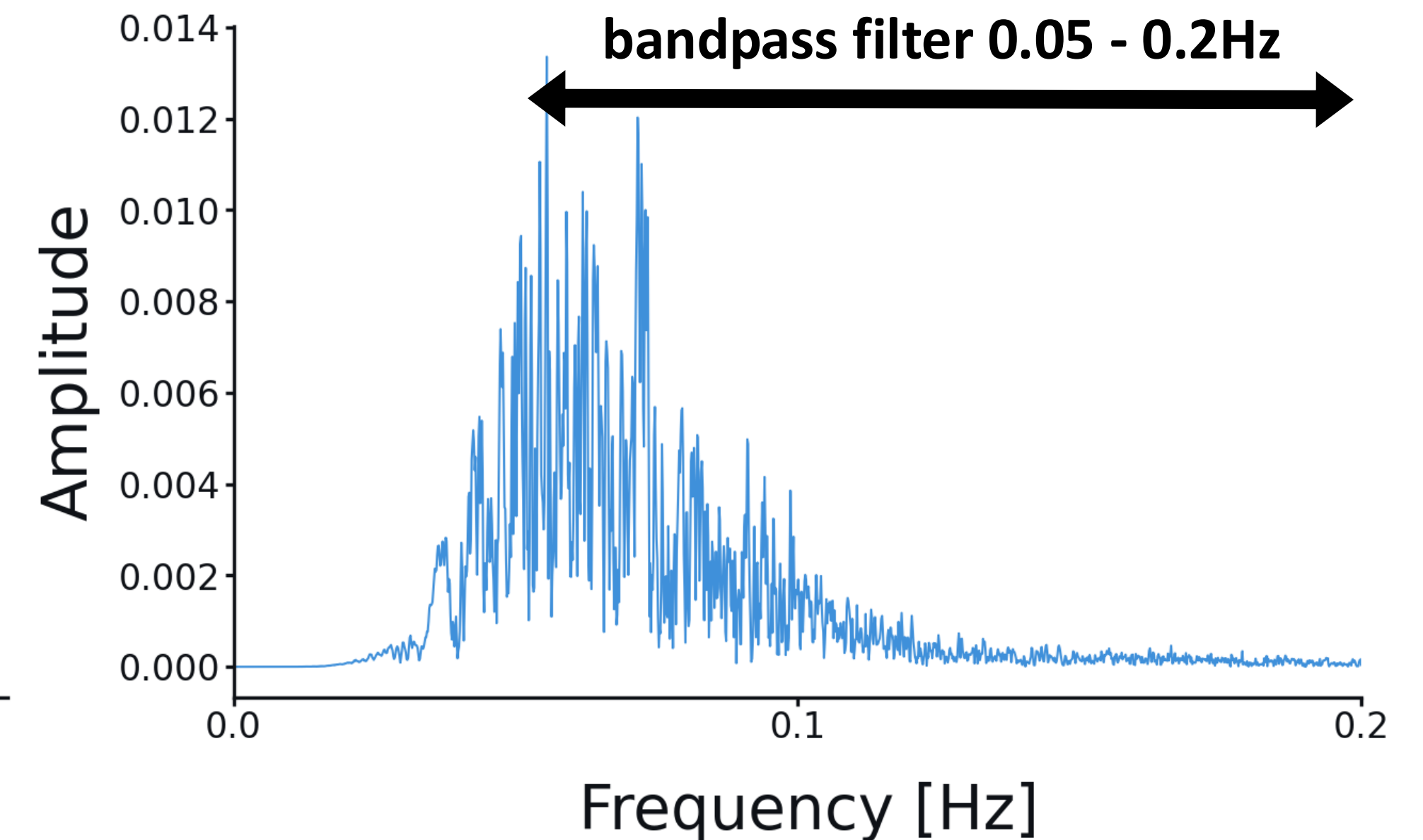
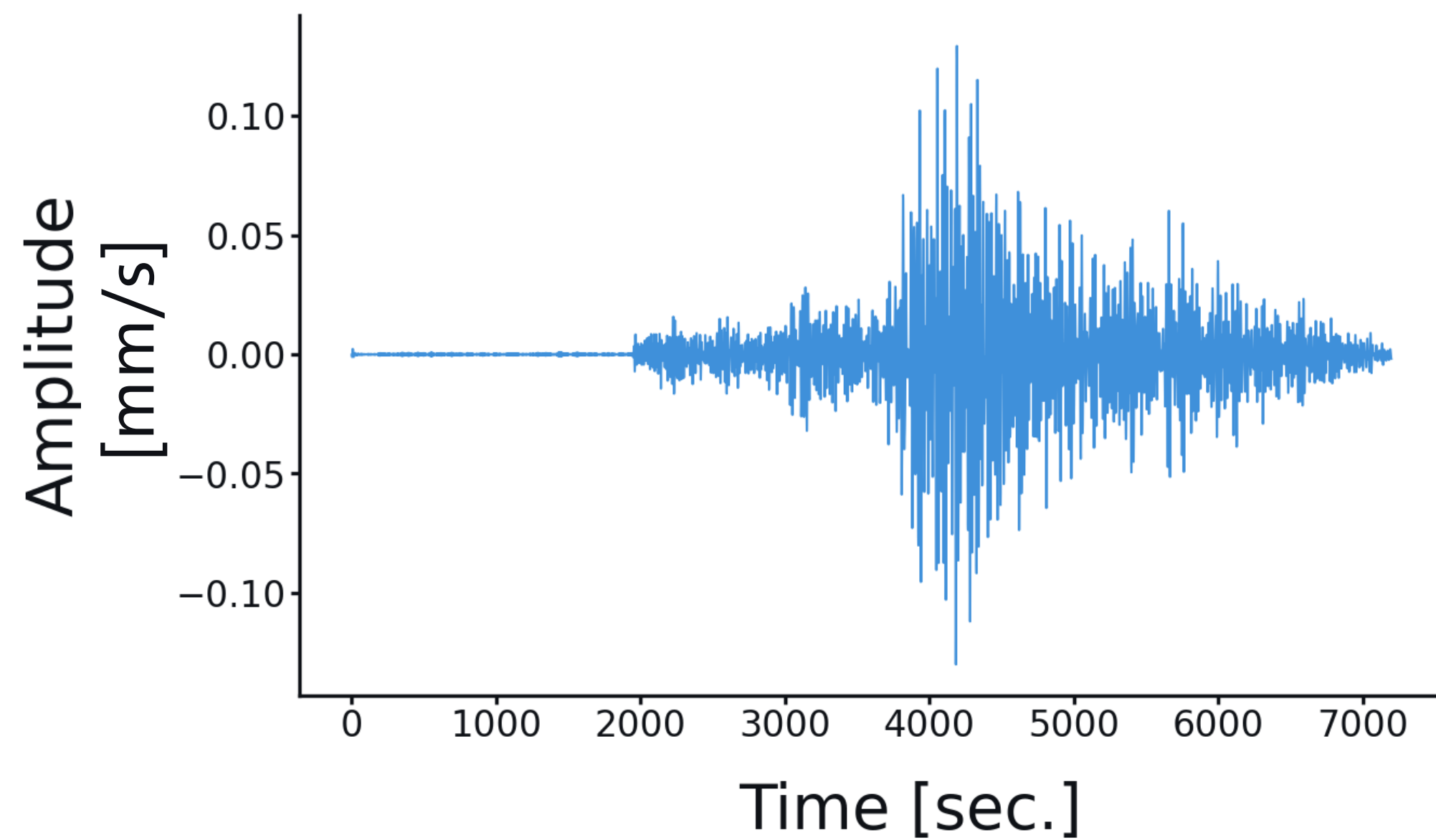
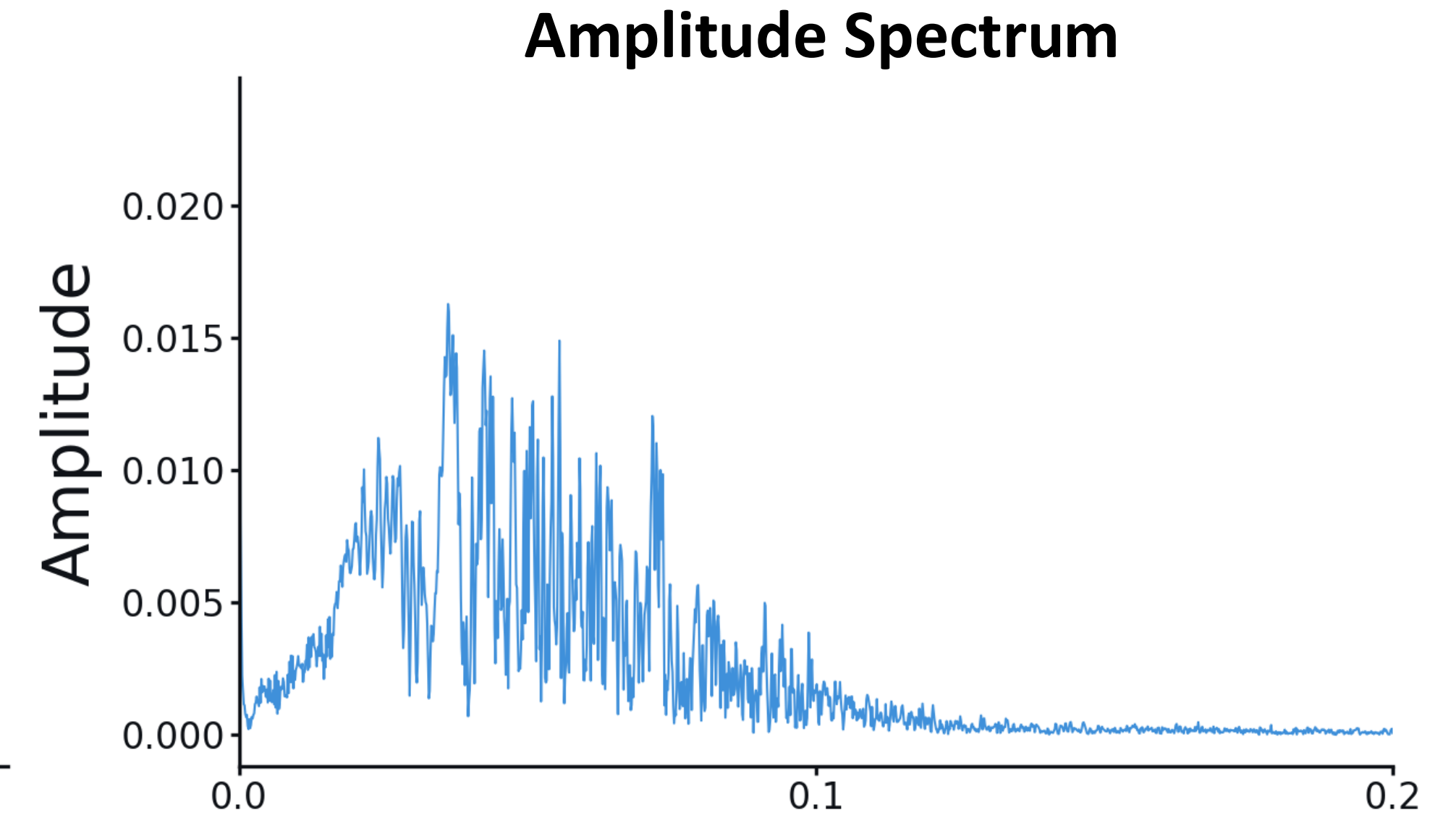
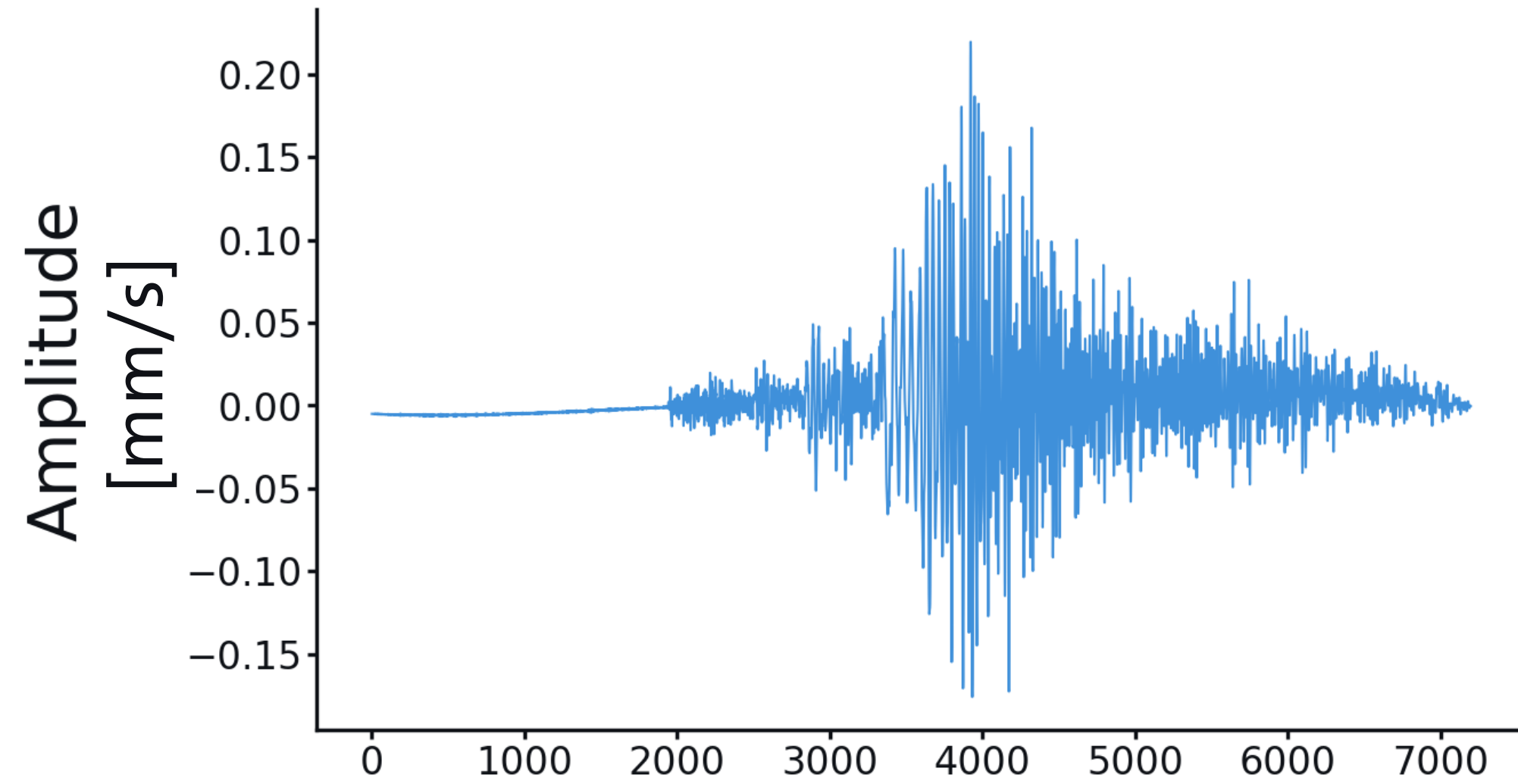
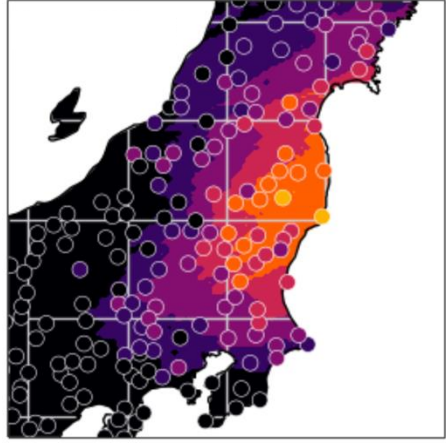
# Wavefield Abstractions | What is a spectrum?



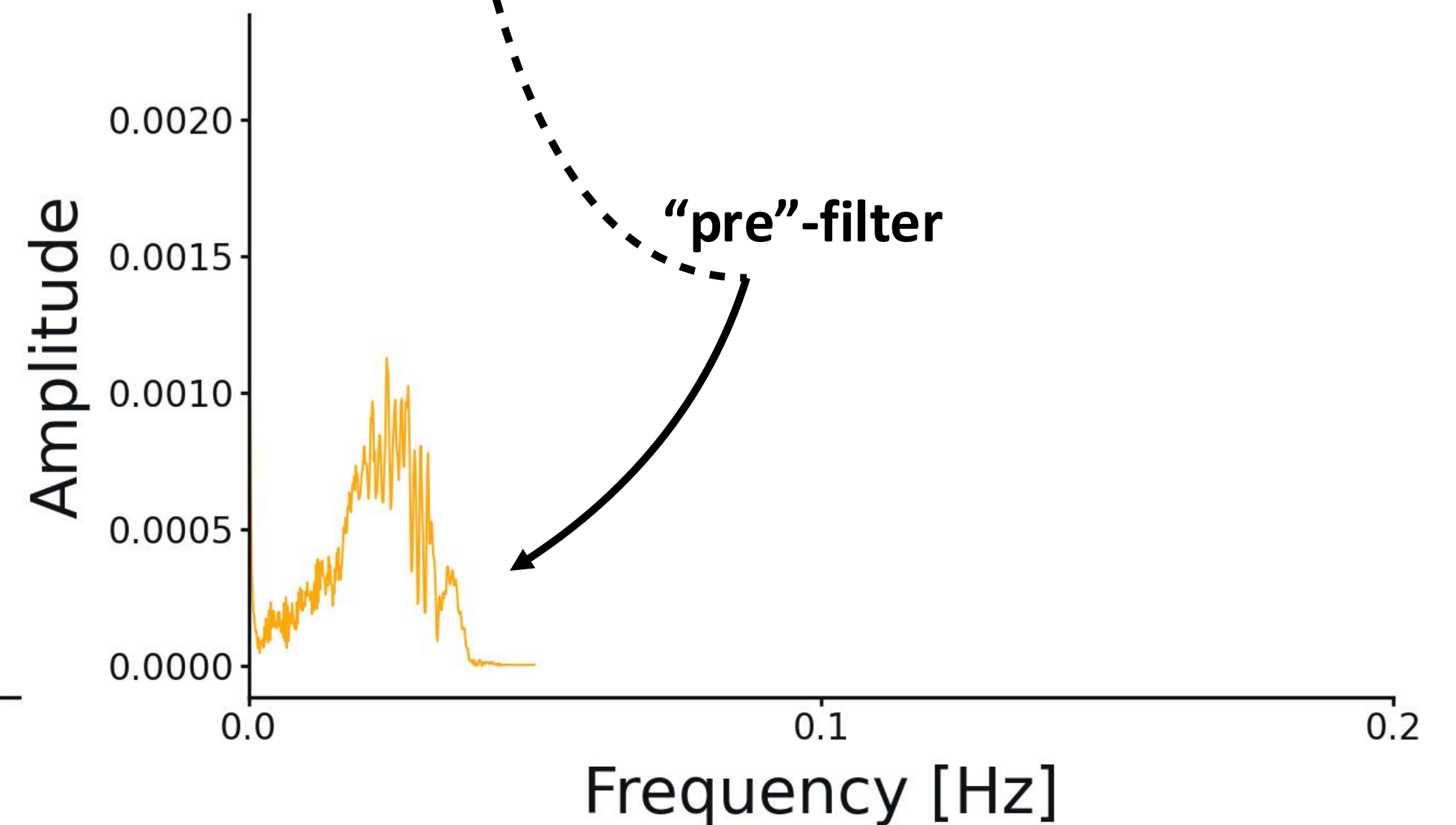
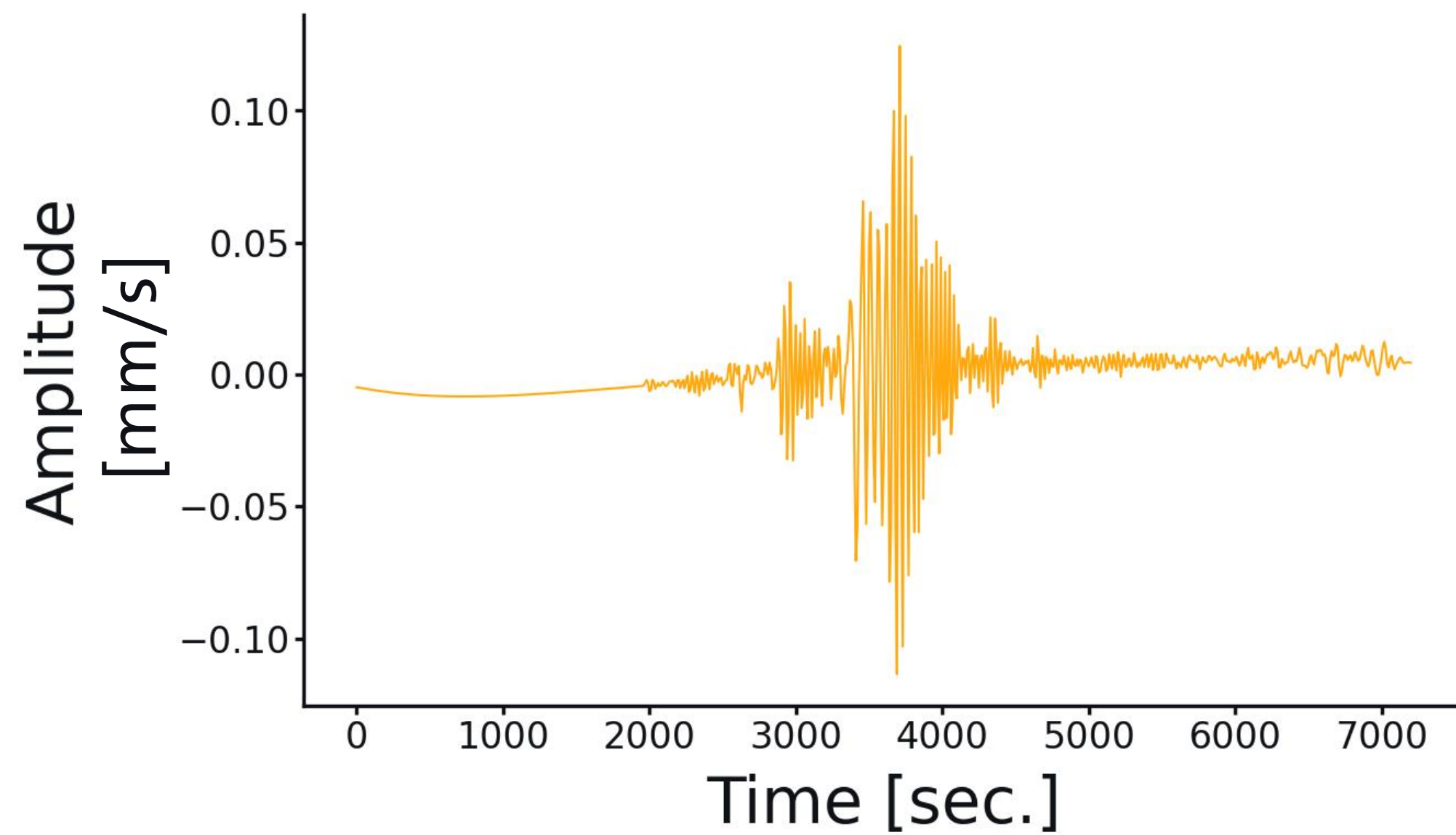
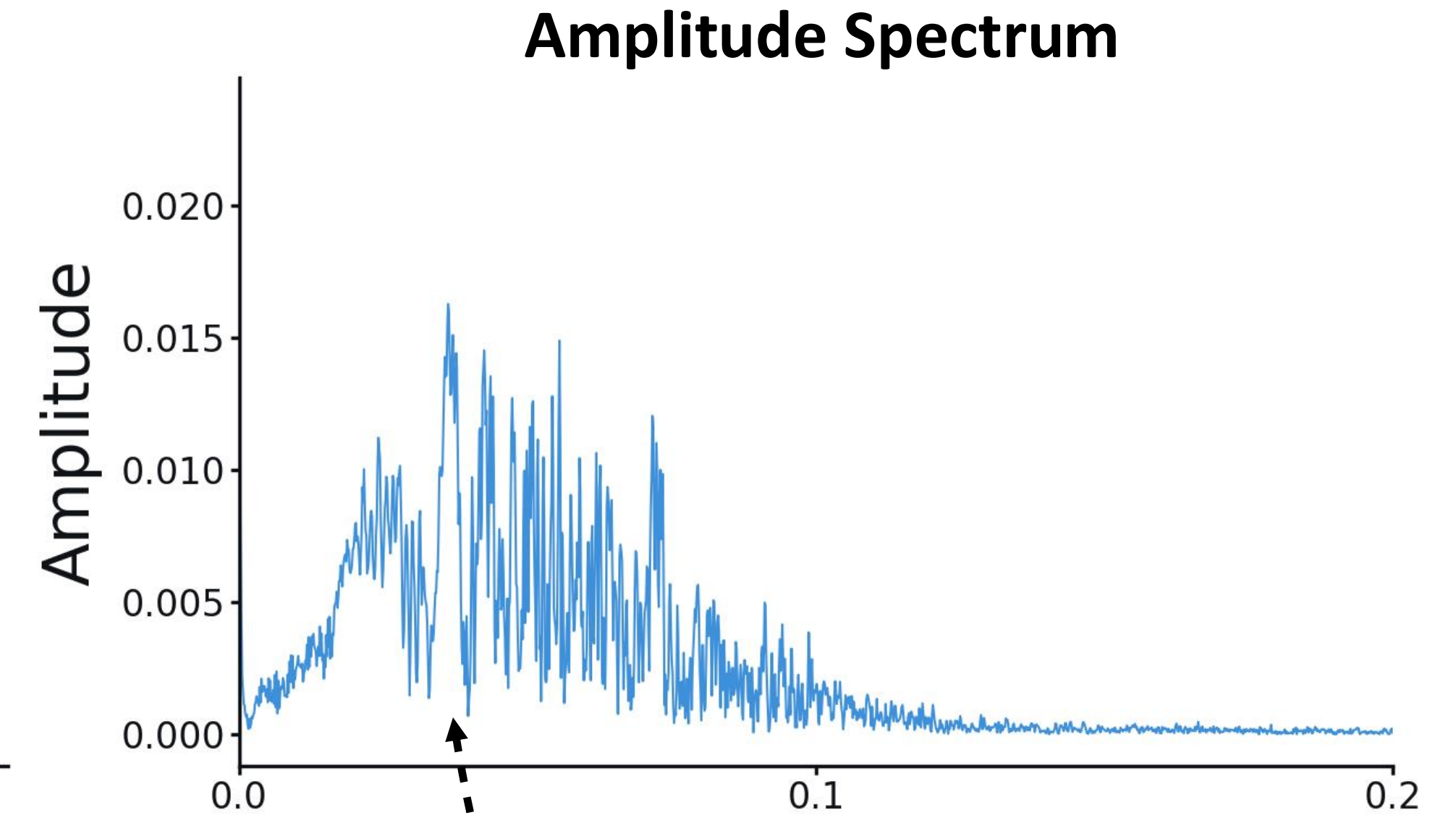
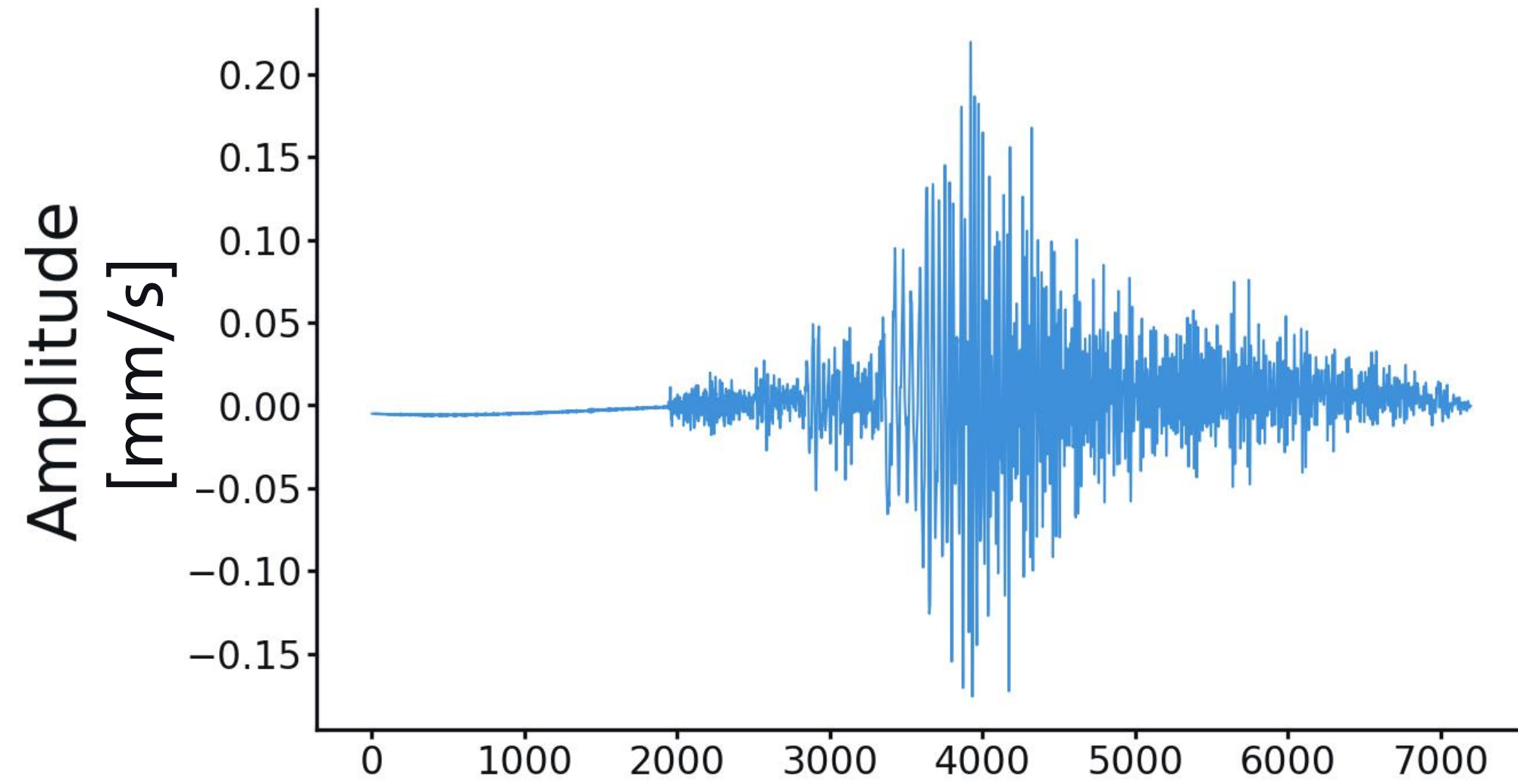
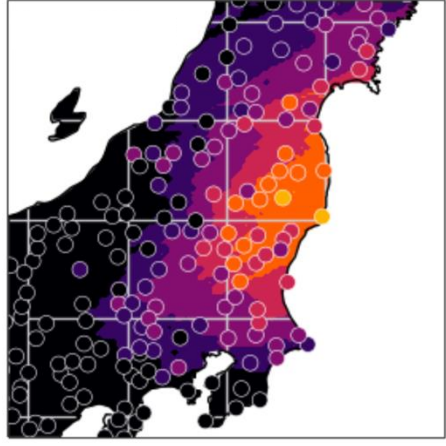
# Wavefield Abstractions | What is filtering?



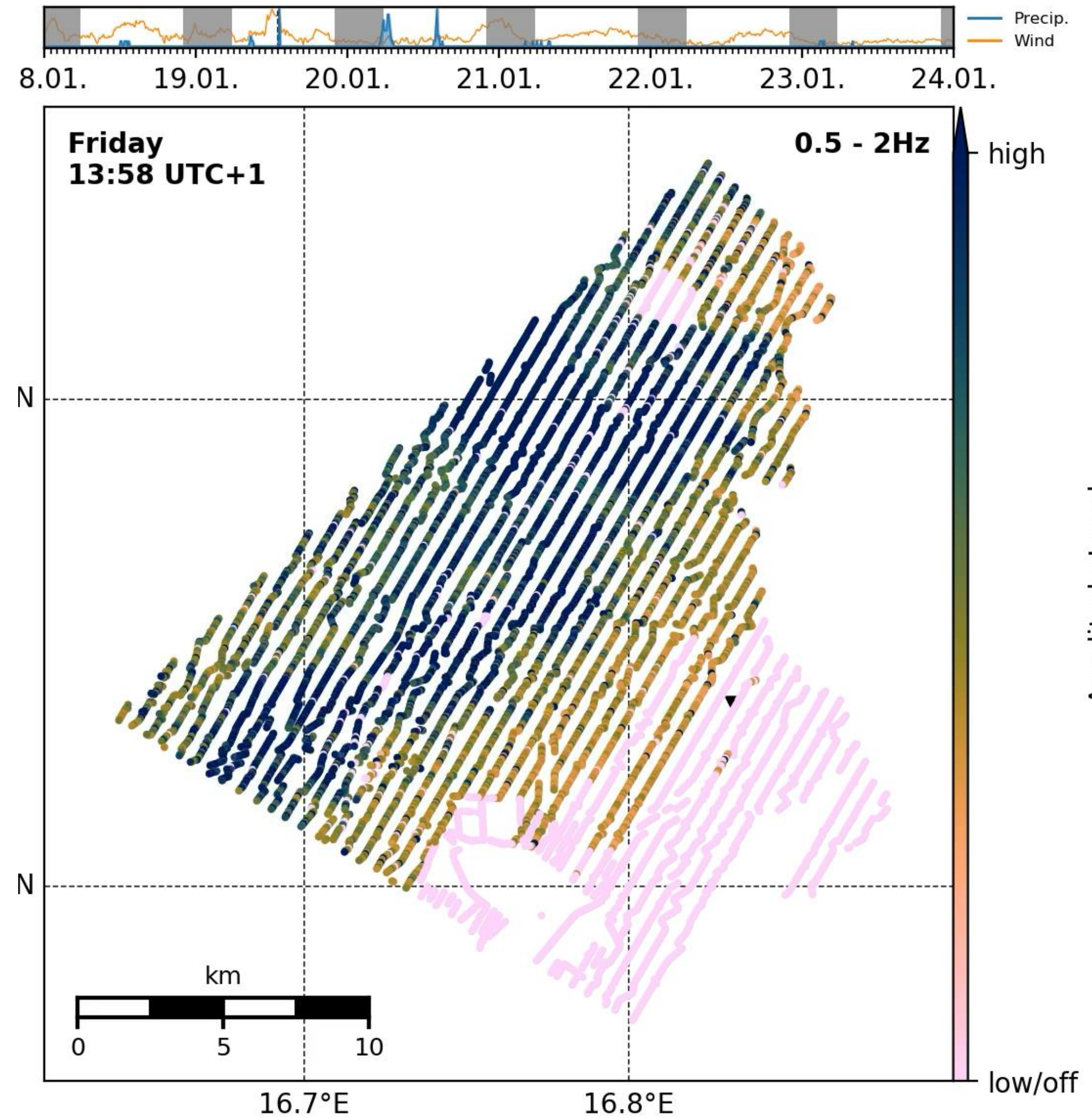
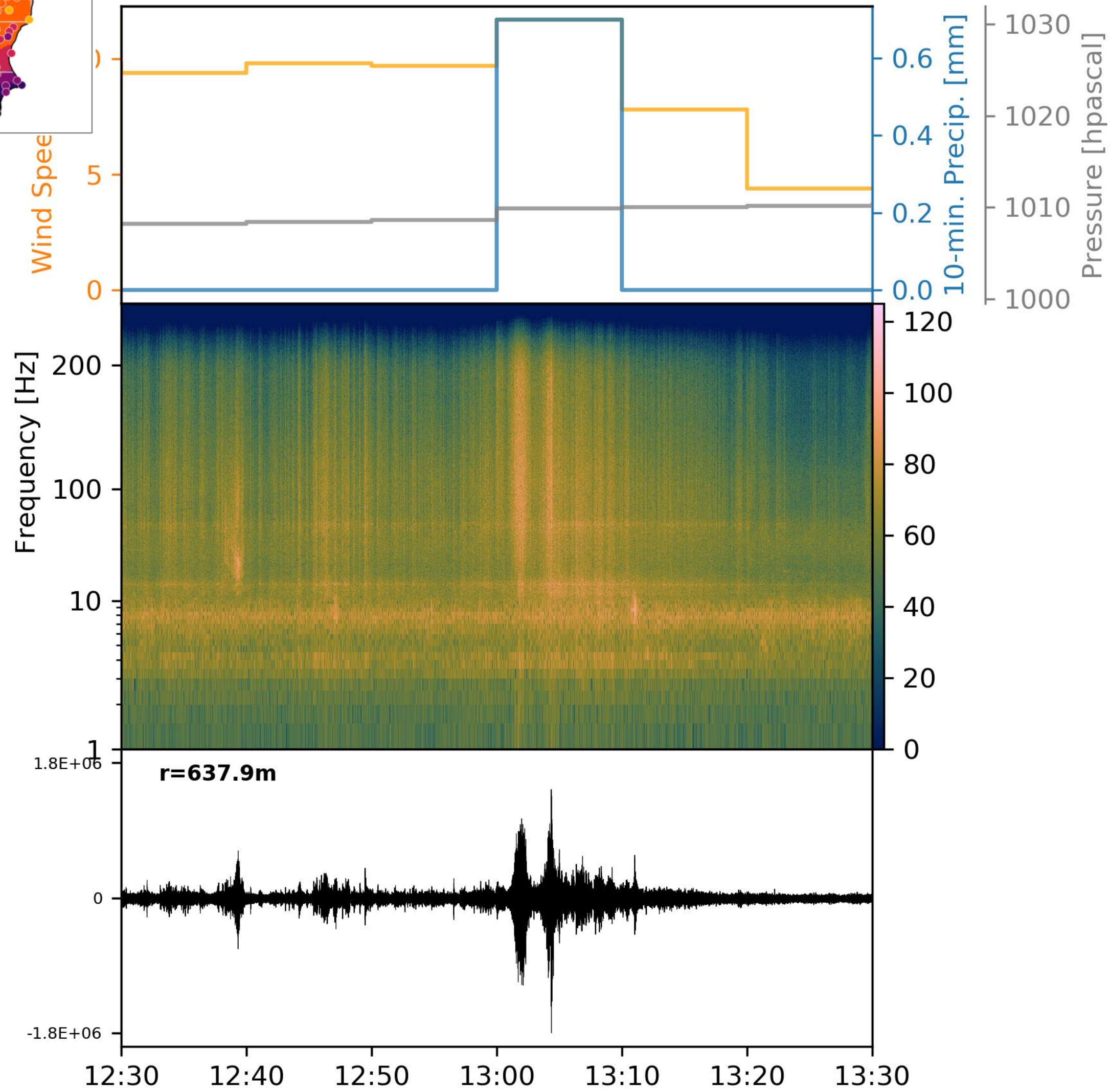
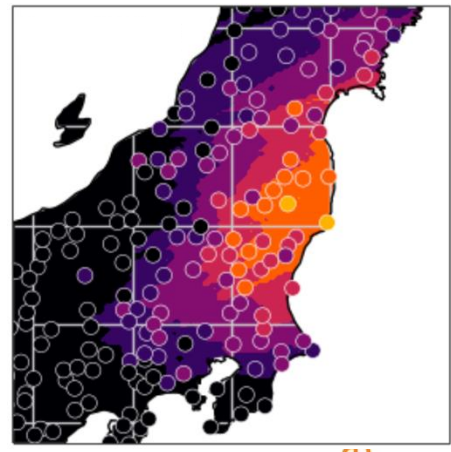
# Wavefield Abstractions | What is filtering?



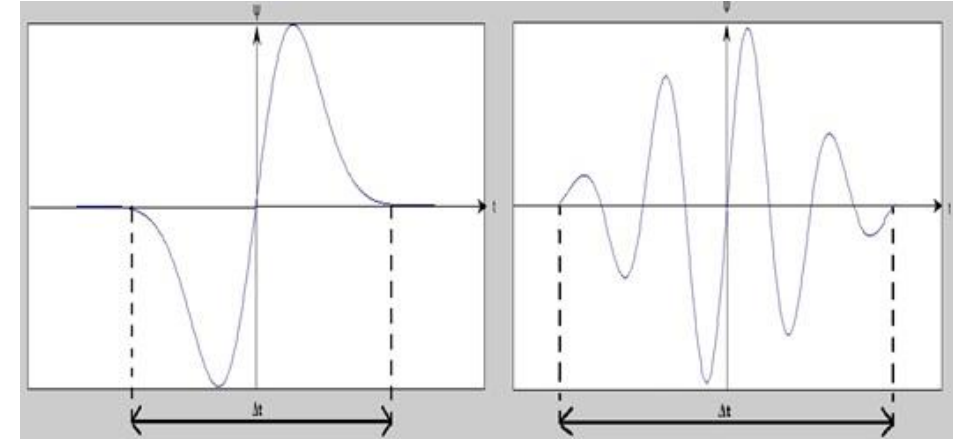
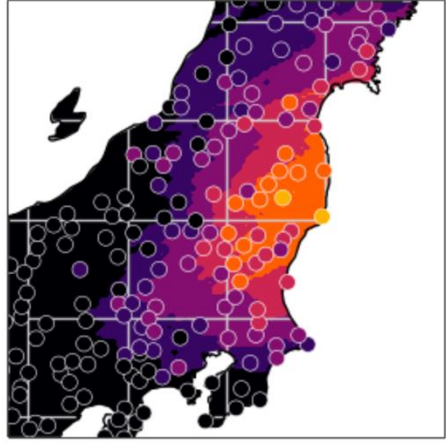
# Wavefield Abstractions | What is filtering?



# Wavefield Abstractions | What is a spectrogram?

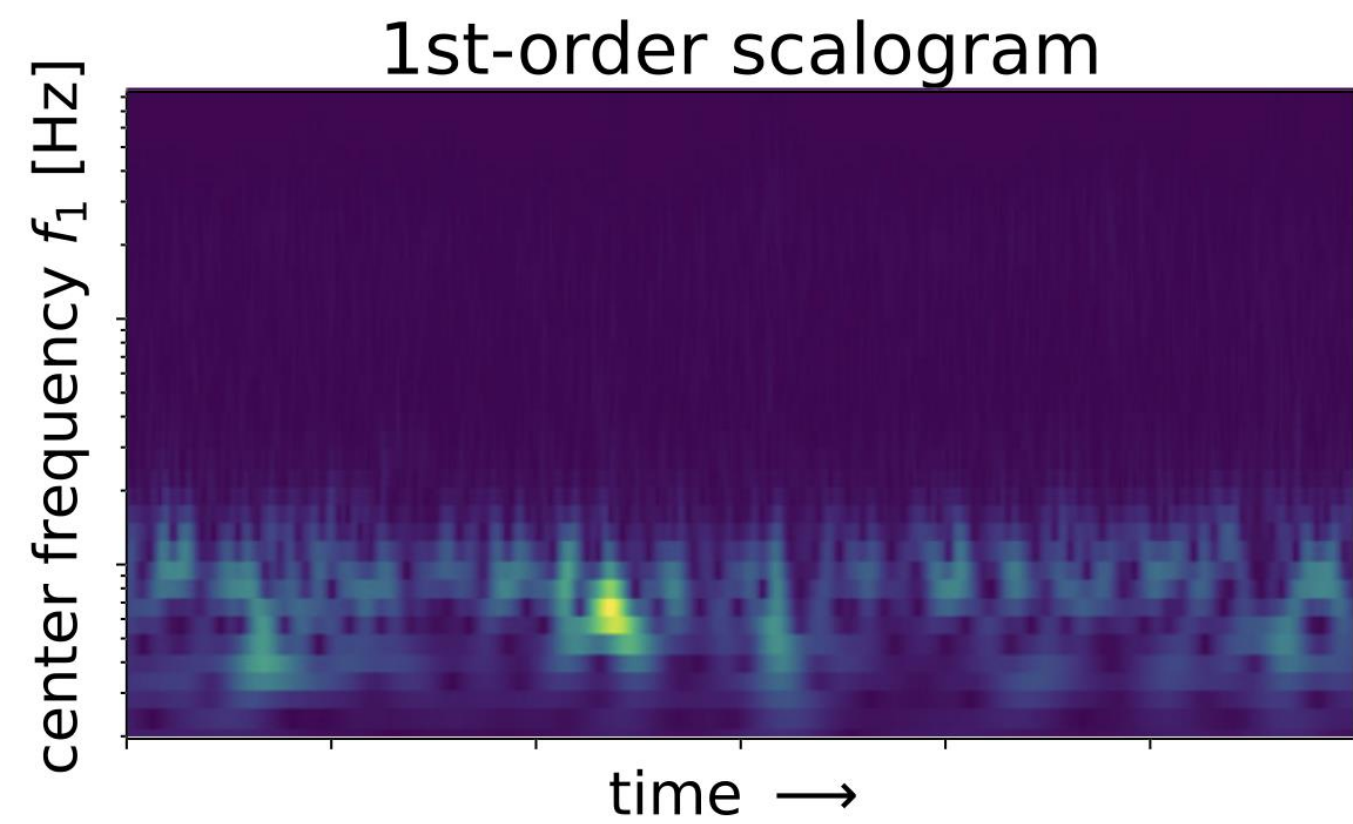
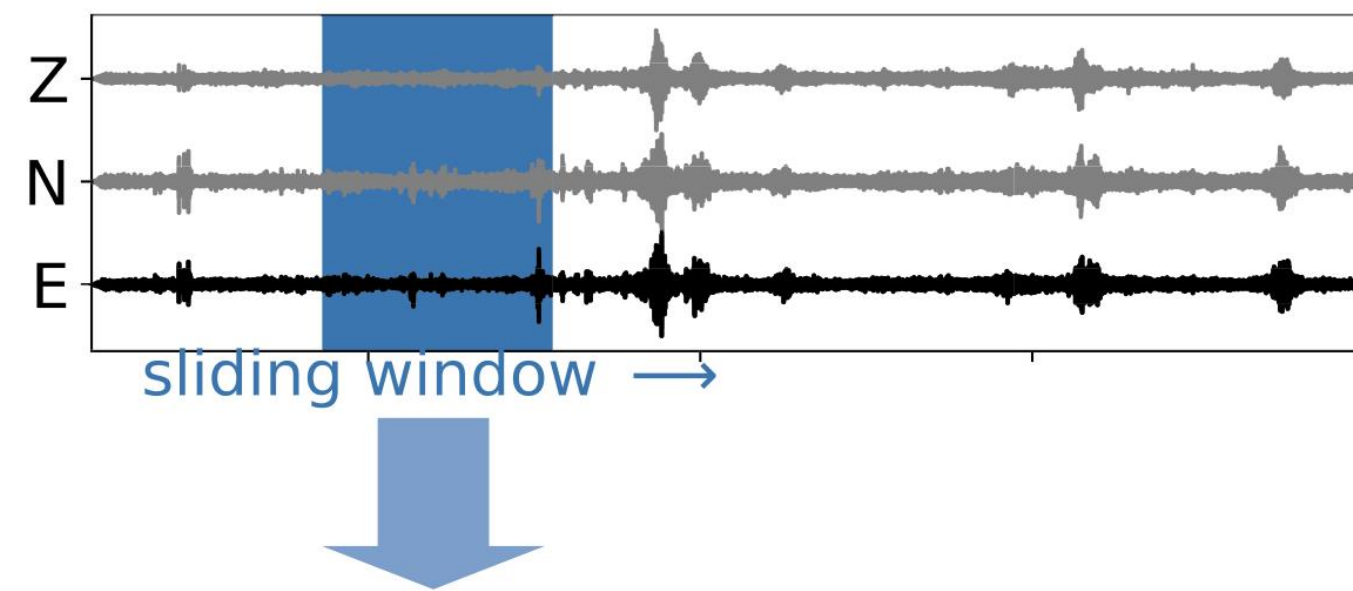


# Wavefield Abstractions | What other transforms exist?

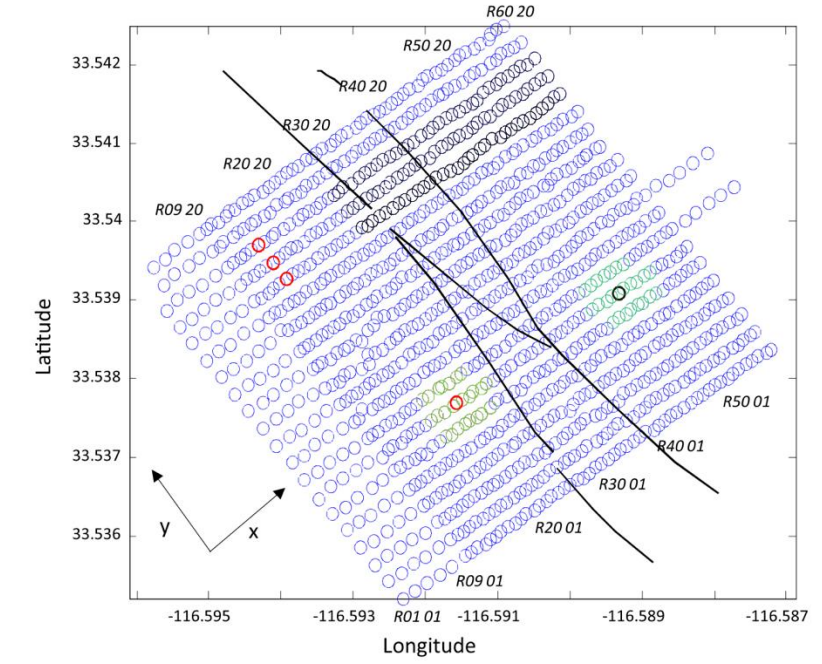
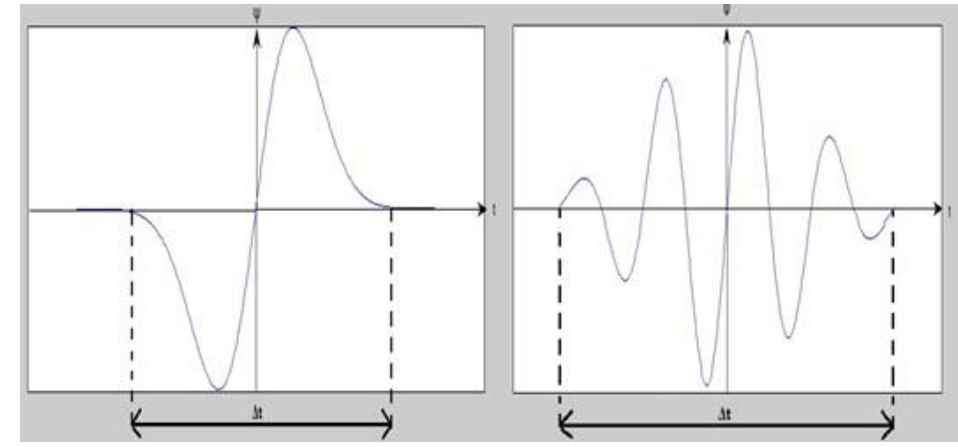
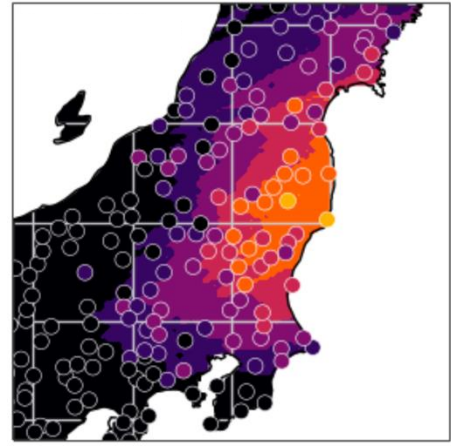


## Wavelet transform

(wavelet basis functions instead of sin/cos)

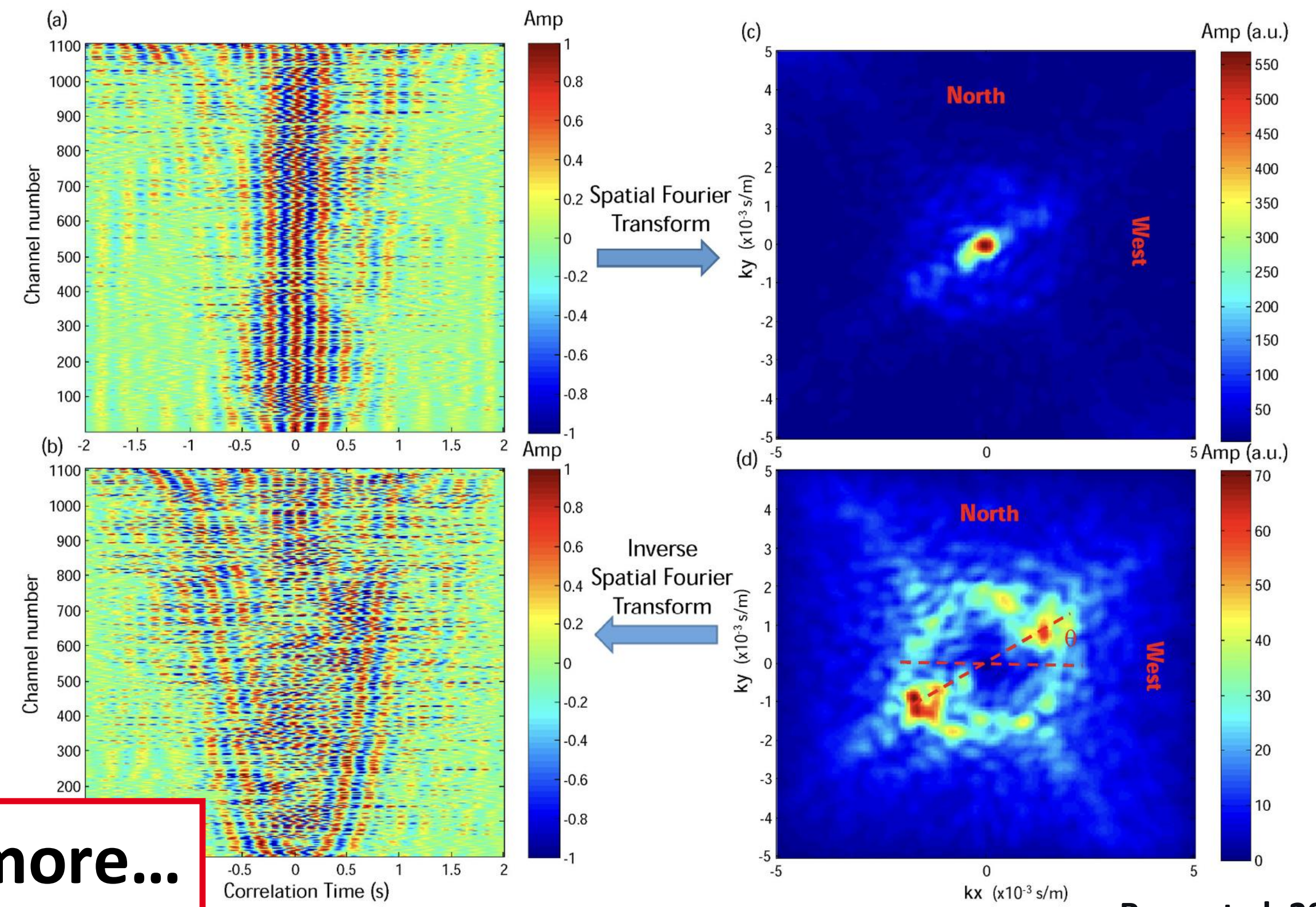
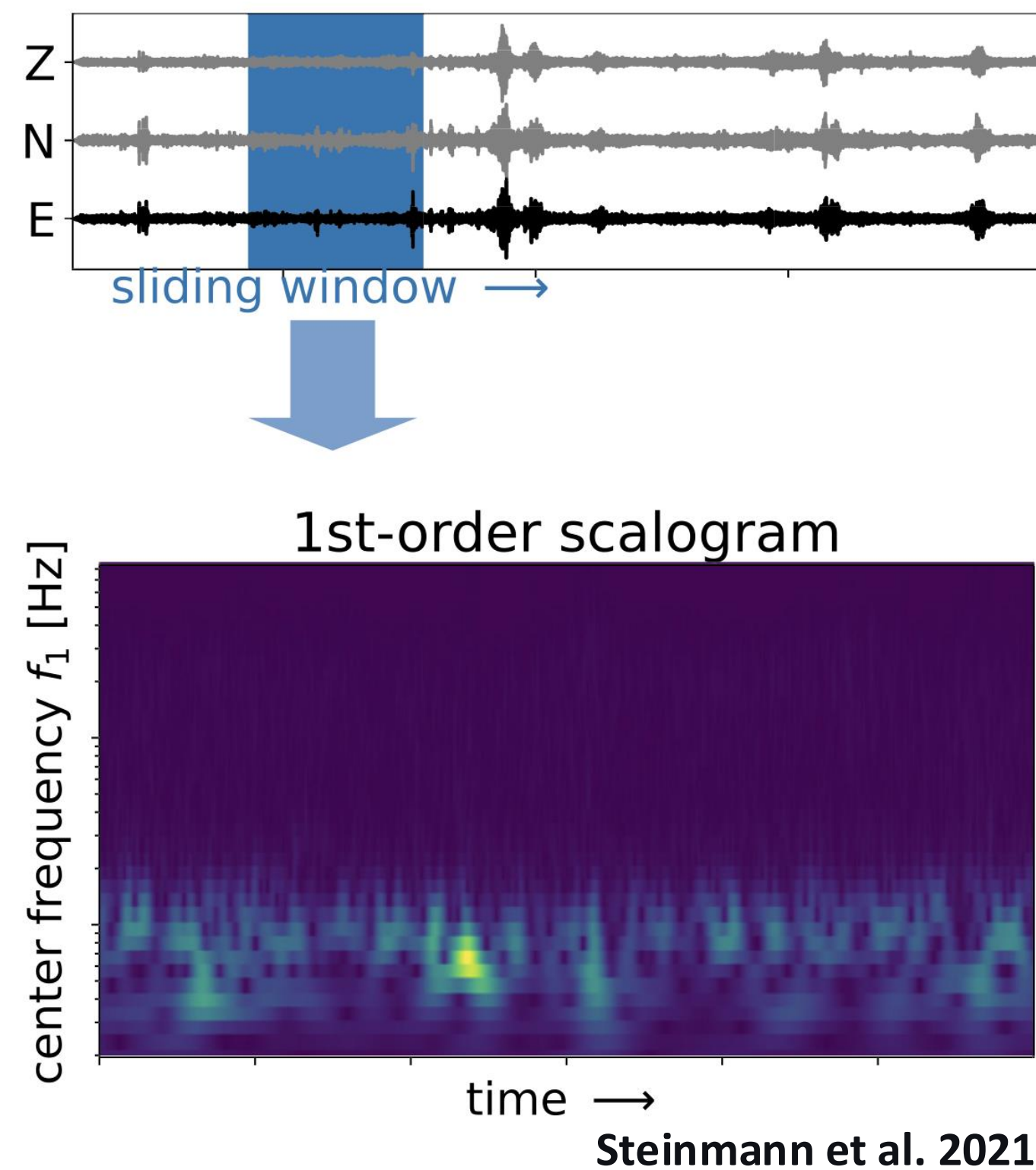


# Wavefield Abstractions | What other transforms exist?



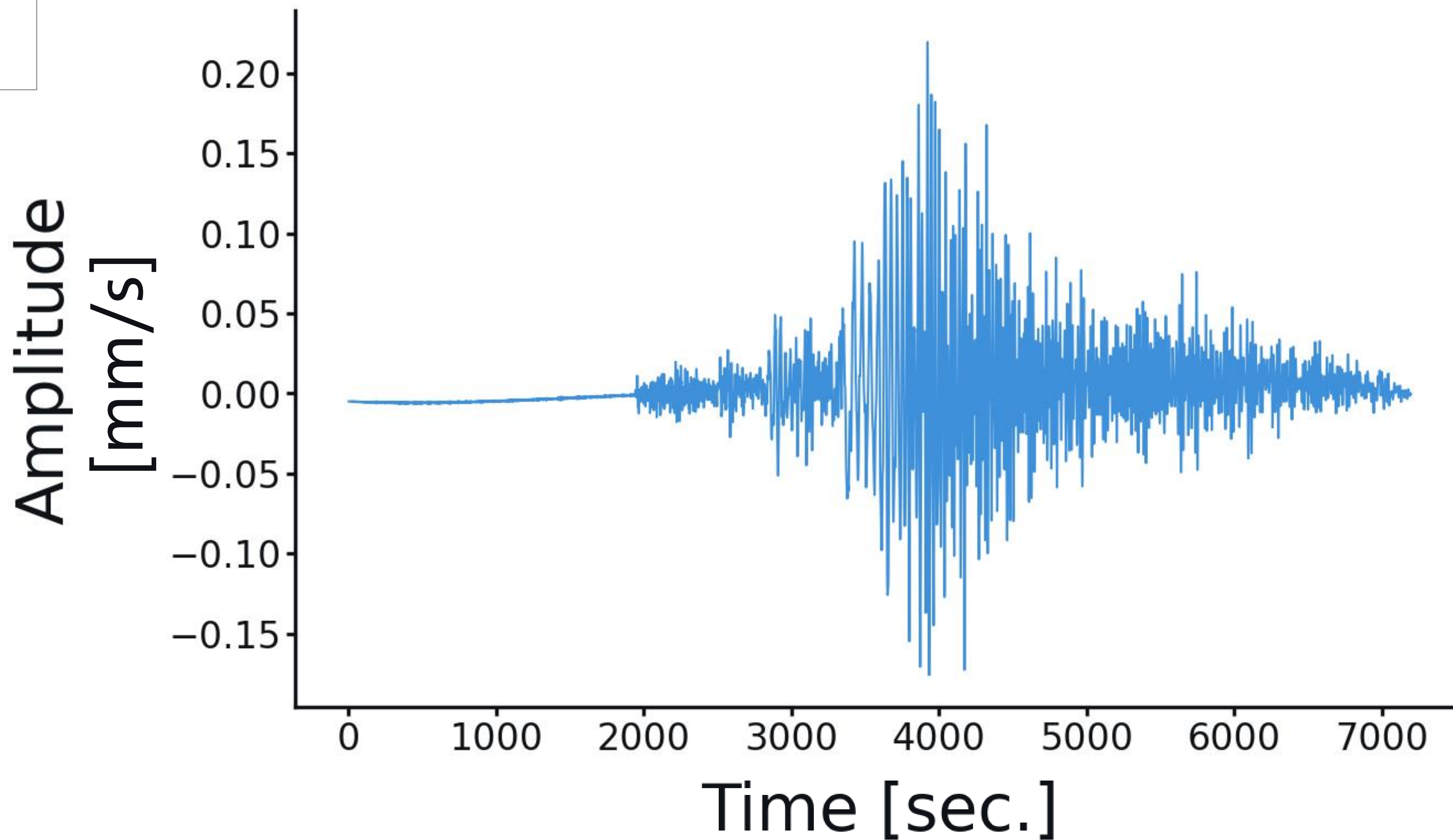
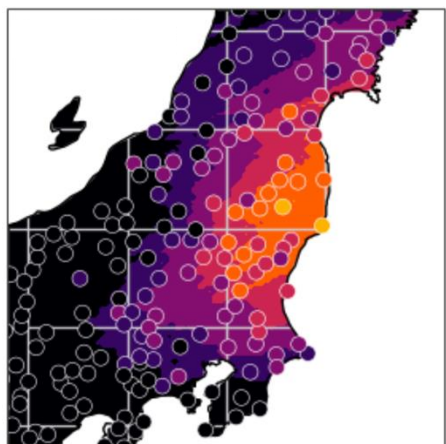
**Wavelet transform**  
(wavelet basis functions instead of sin/cos)

**Wavenumber (k) transform**  
(Fourier transform in space)

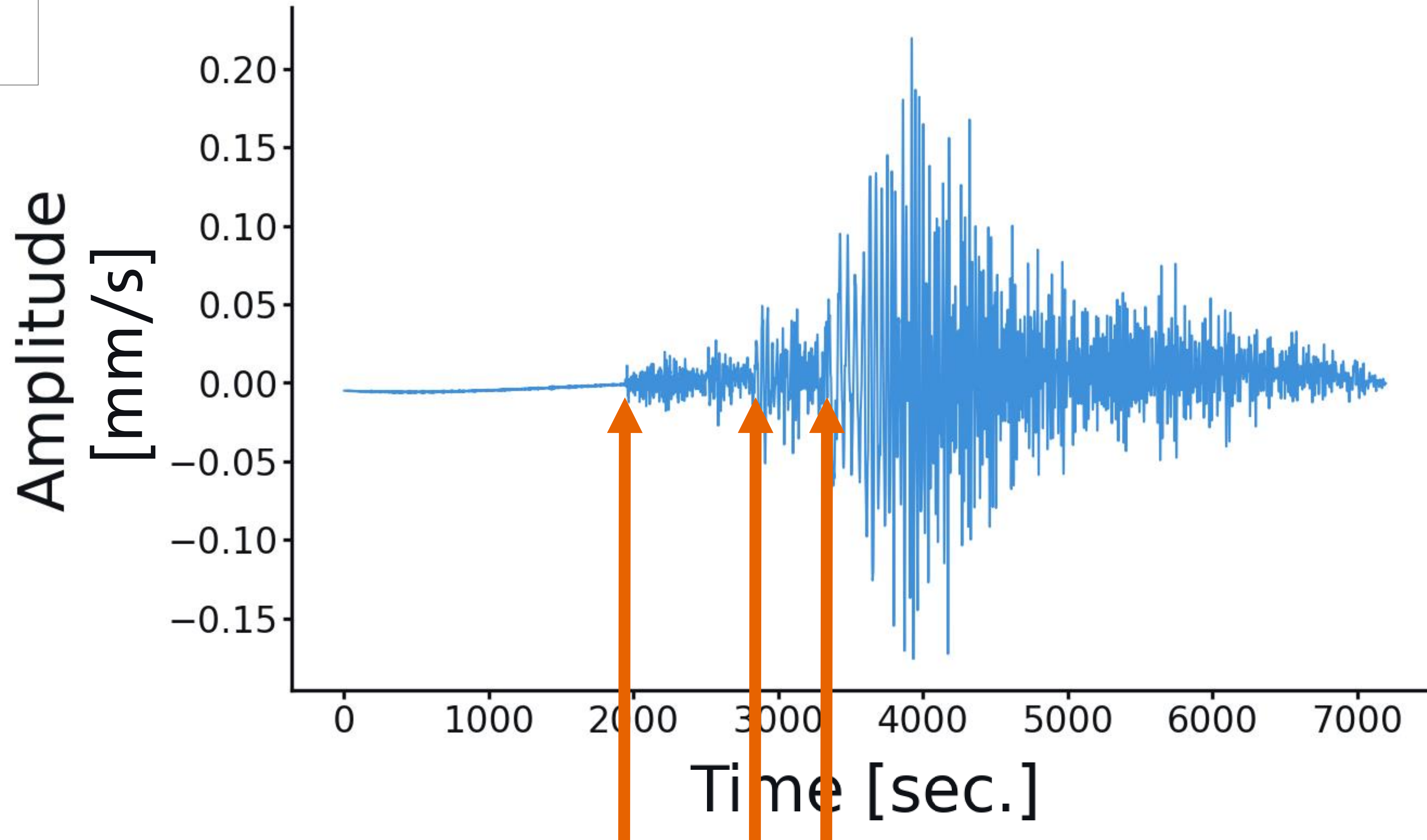
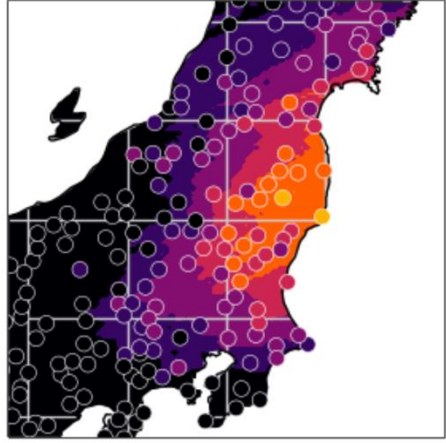


**and many more...**

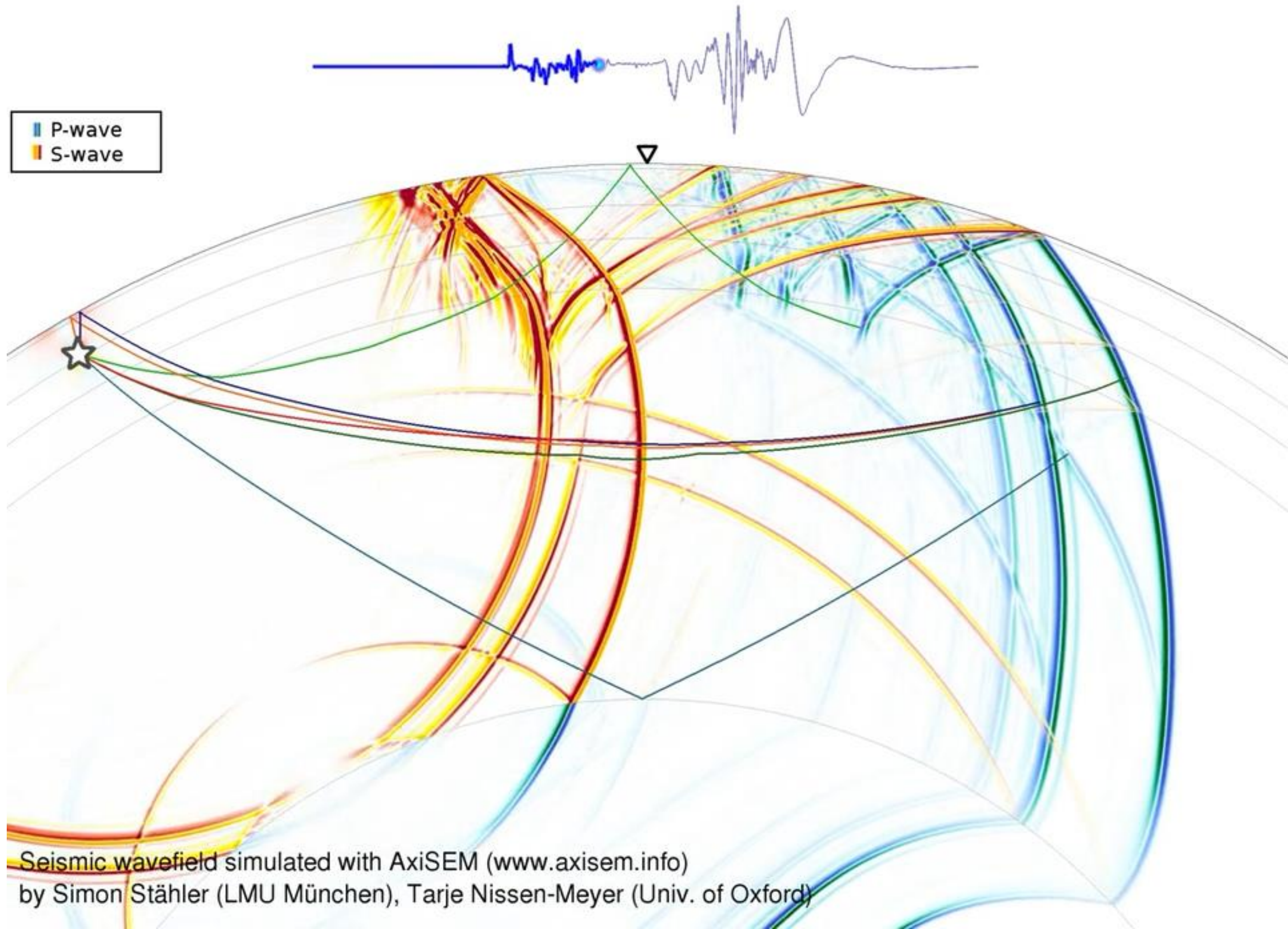
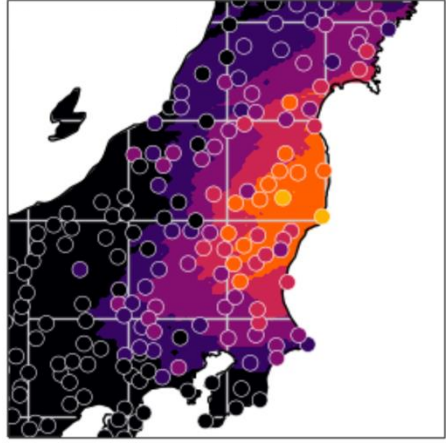
# Wavefield Abstractions | What is a seismic phase?



# Wavefield Abstractions | What is a seismic phase?

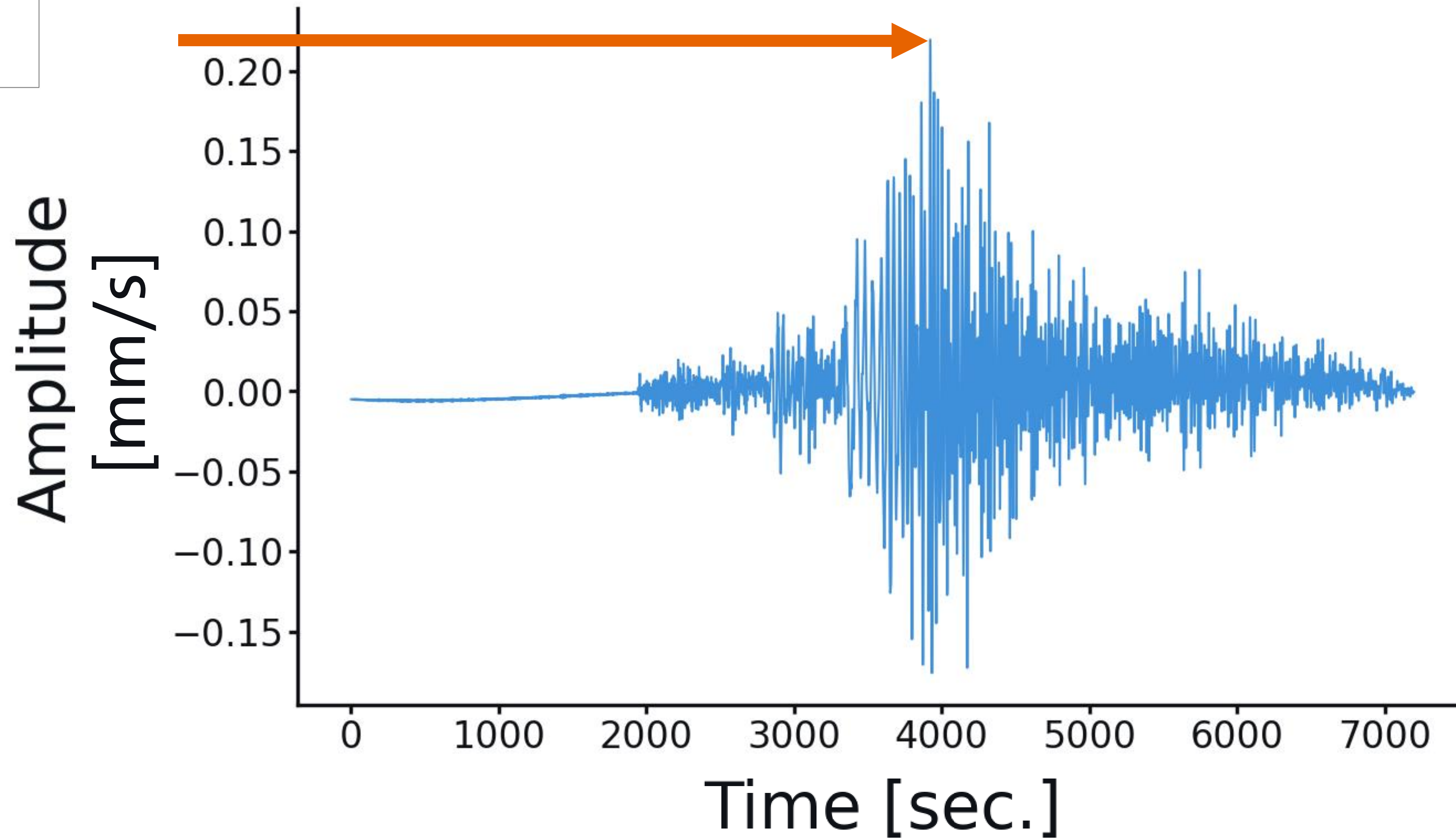
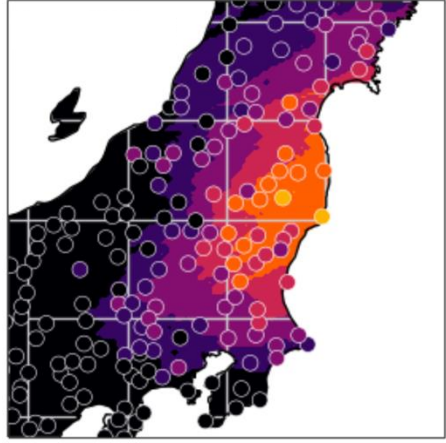


# Wavefield Abstractions | What is a seismic phase?

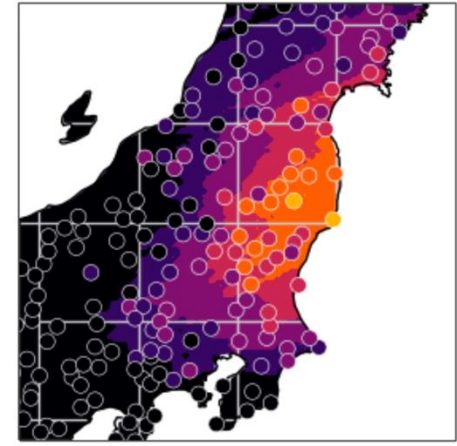


Seismic wavefield simulated with AxiSEM ([www.axisem.info](http://www.axisem.info))  
by Simon Stähler (LMU München), Tarje Nissen-Meyer (Univ. of Oxford)

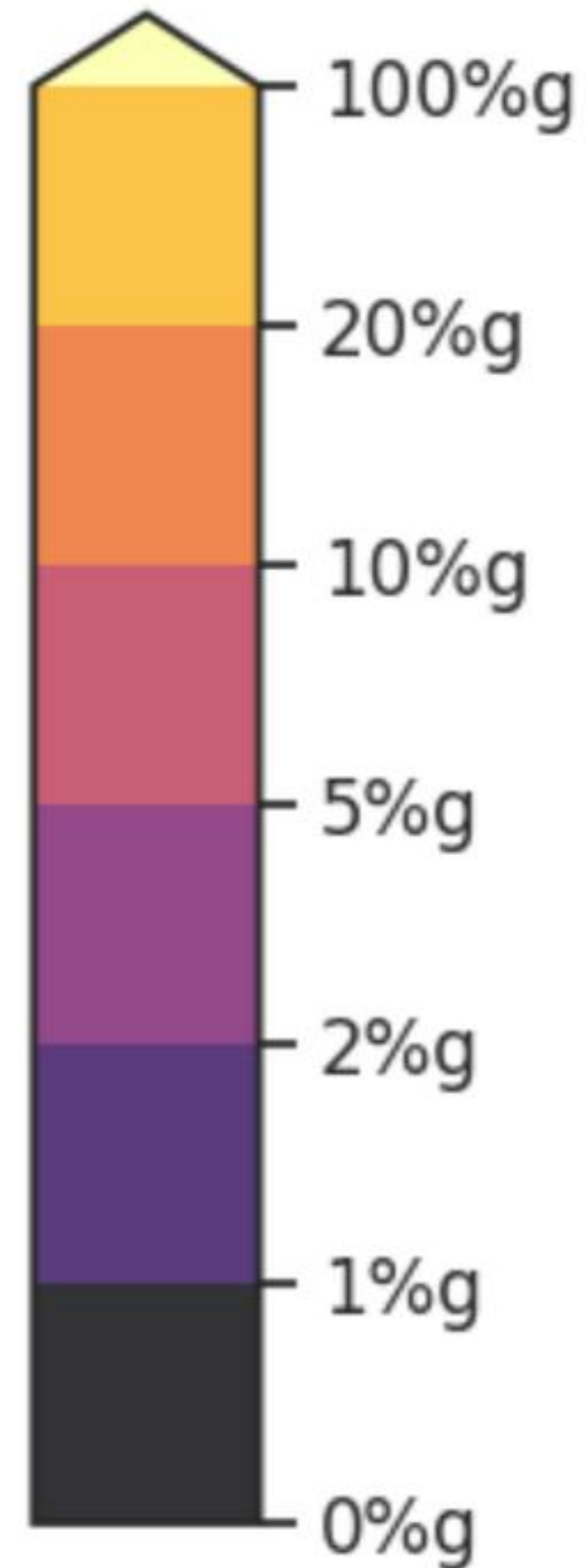
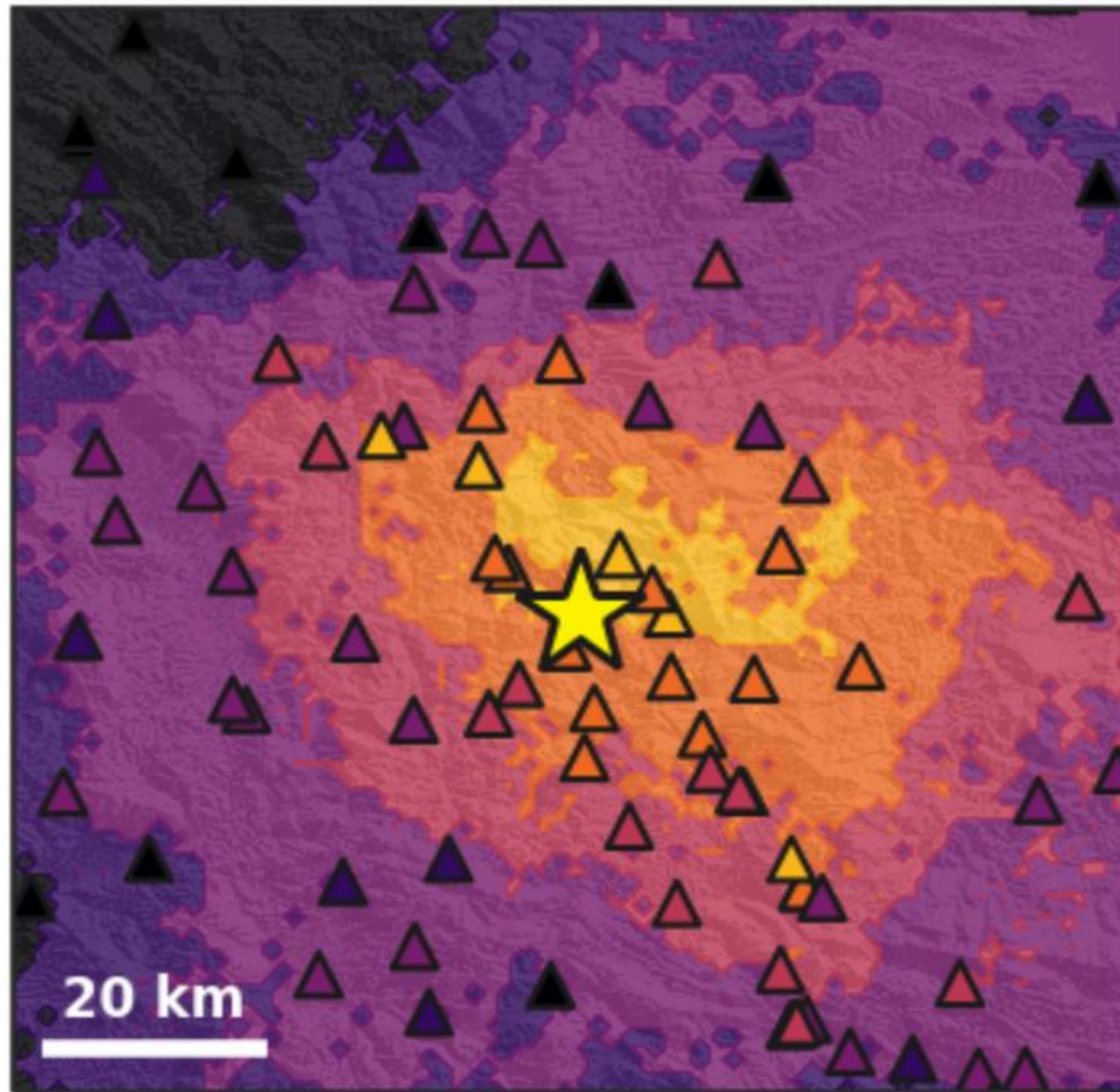
# Wavefield Abstractions | What is peak ground motion?



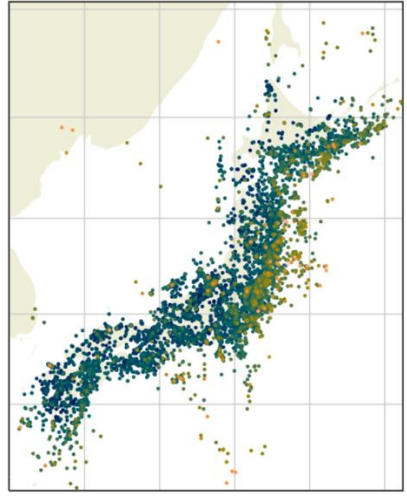
# Wavefield Abstractions | What is peak ground motion?



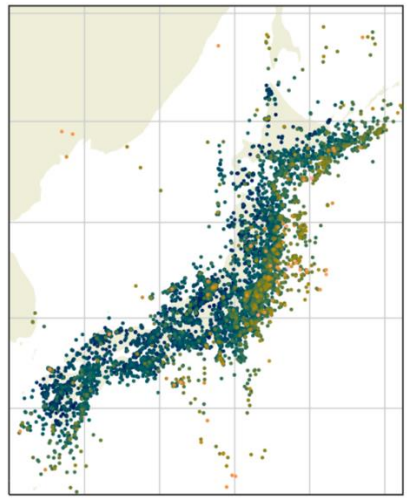
## Peak Ground Acceleration



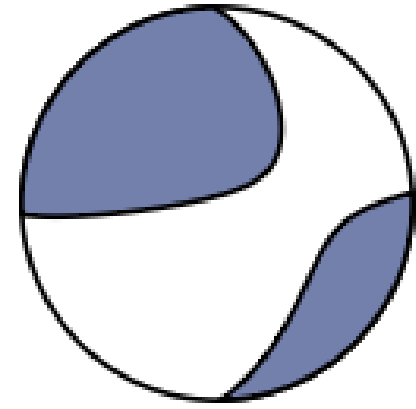
# Earthquake Metadata



# Earthquake Metadata | What is an earthquake catalog?



**F-E Region** Myanmar  
**Time** 2025-03-28 06:20:54.1 UTC  
**Magnitude** 7.7 (Mw)  
**Epicenter** 95.99°E 22.00°N [↗](#)  
**Depth** 10 km (fixed) [?](#)  
**Status** M - manually revised [?](#)



**GEOFON** Legal Notice | Data Protection

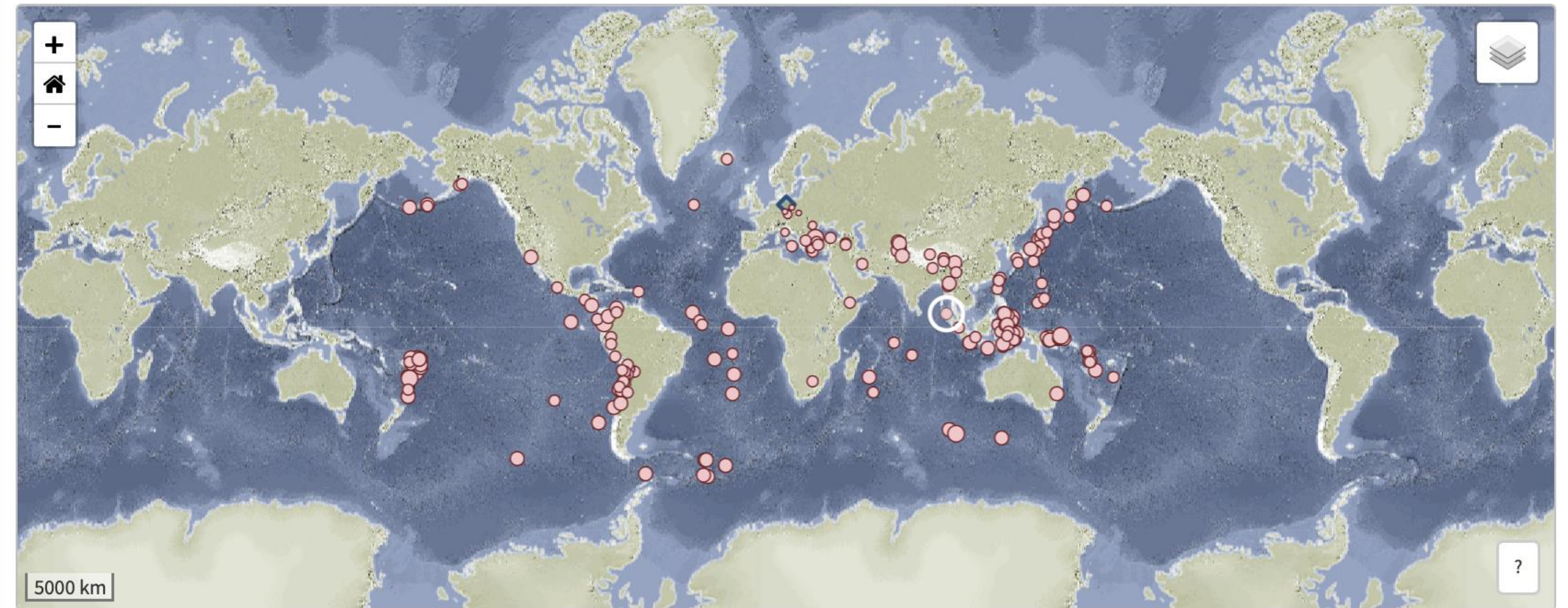
**GFZ** Helmholtz Centre for Geosciences

- Home
- Mission
- Earthquake Info
- Waveform Access
- Software
- Contribute
- About

GE global seismic network

Seismic waveform data archive

Rapid earthquake information



**WARNING FOR USERS OF NAYPYITAW DATA**

⚠ April 2025: We have detected problems with timing quality and metadata of all channels at DMH/GEOFON Station Naypyitaw (GE.NPW) and have updated metadata for this station. See our [Forum post](#).

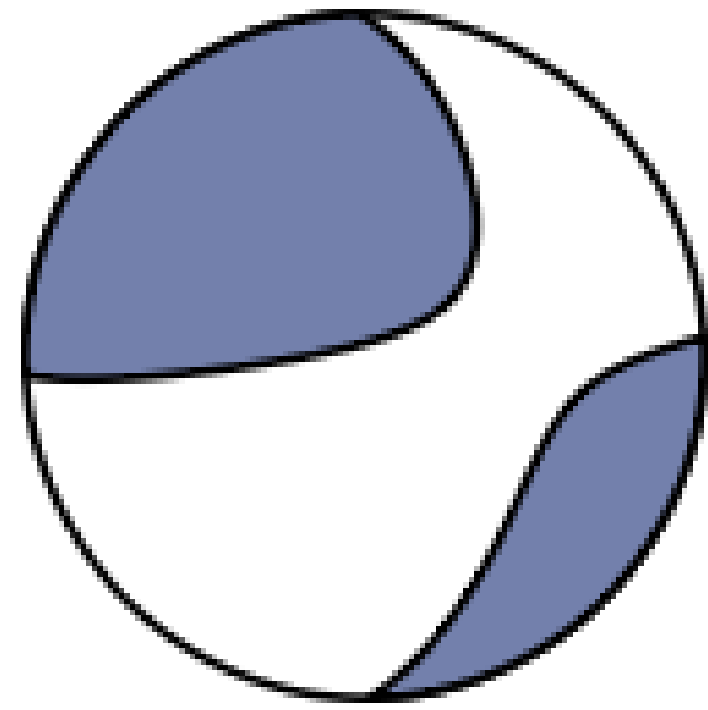
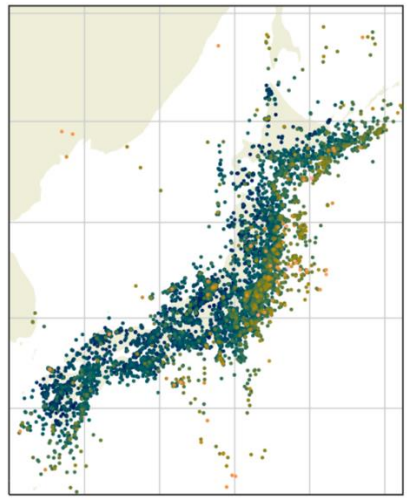
**MOST RECENT EVENTS**

4.5	2025-04-27 02:23:38	<a href="#">Nicobar Islands, India Region</a>
5.3	2025-04-26 18:54:08	<a href="#">East of South Sandwich Islands</a>
4.6	2025-04-26 10:36:13	<a href="#">Hindu Kush Region, Afghanistan</a>

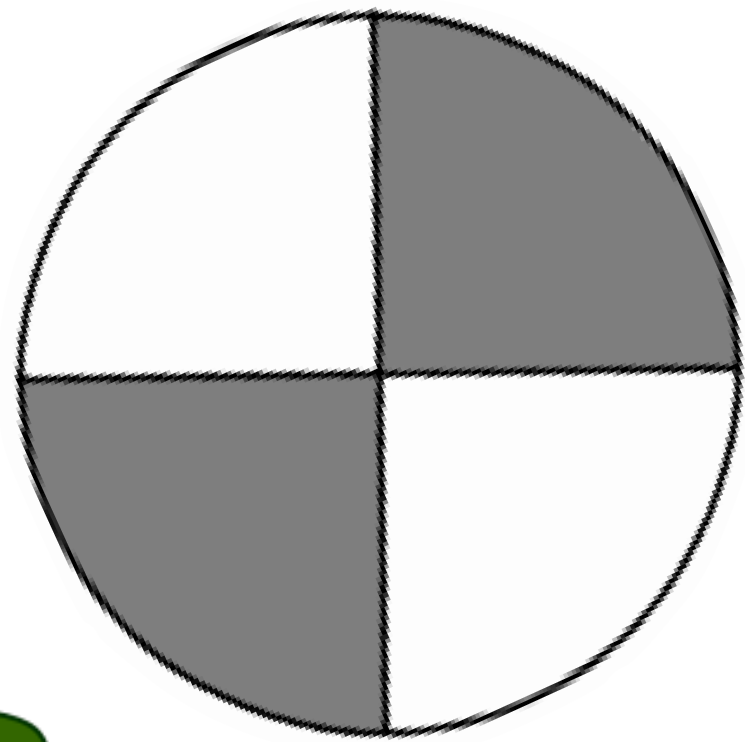
**GEOFON NEWS**

- [2025-04-10: Info for users of GE.NPW data](#)  
On March 28, 2025 there were gaps in data from ...
- [2025-04-03: Metadata for GE.NPW](#)  
We have detected problems with timing quality and metadata of ...

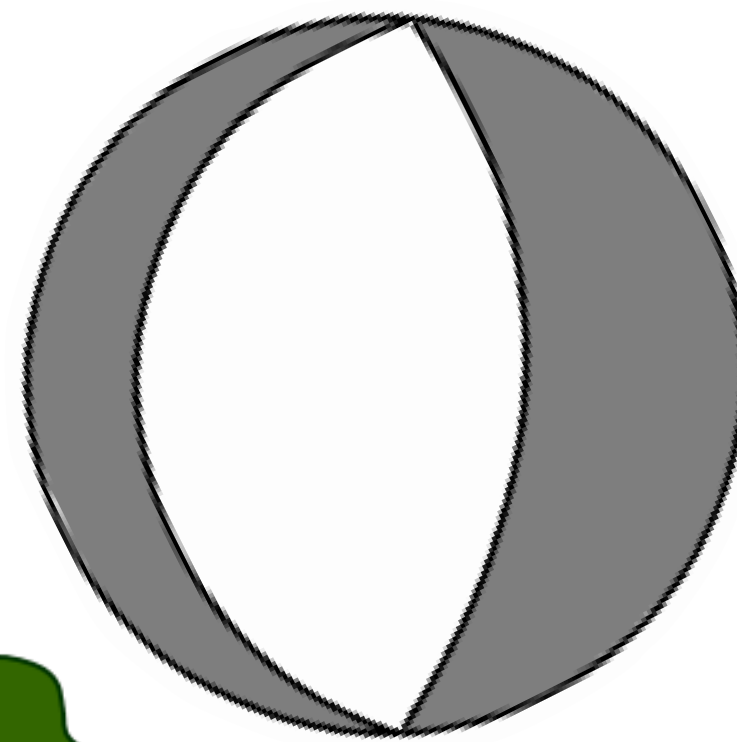
# Earthquake Metadata | What is a source mechanism?



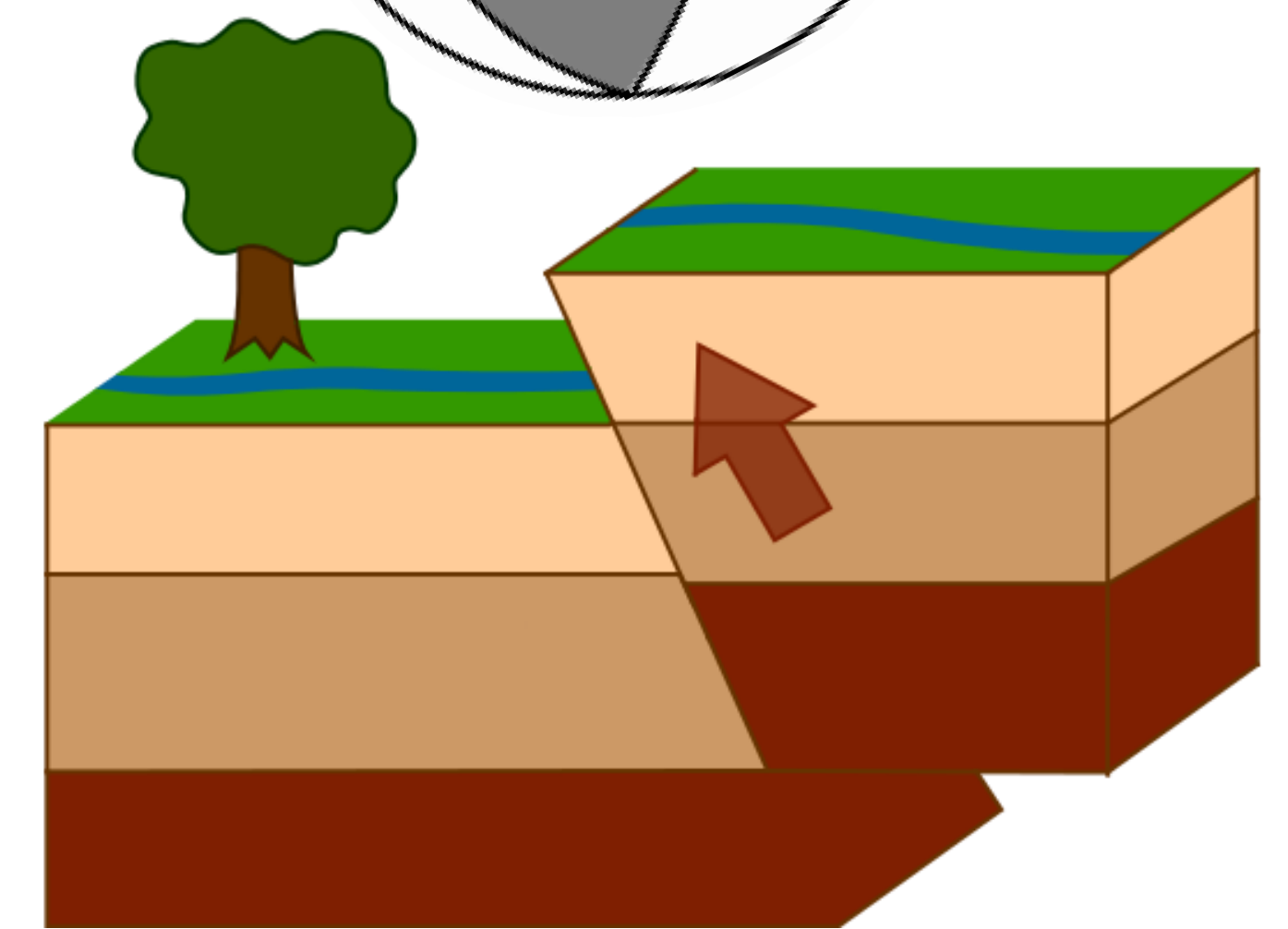
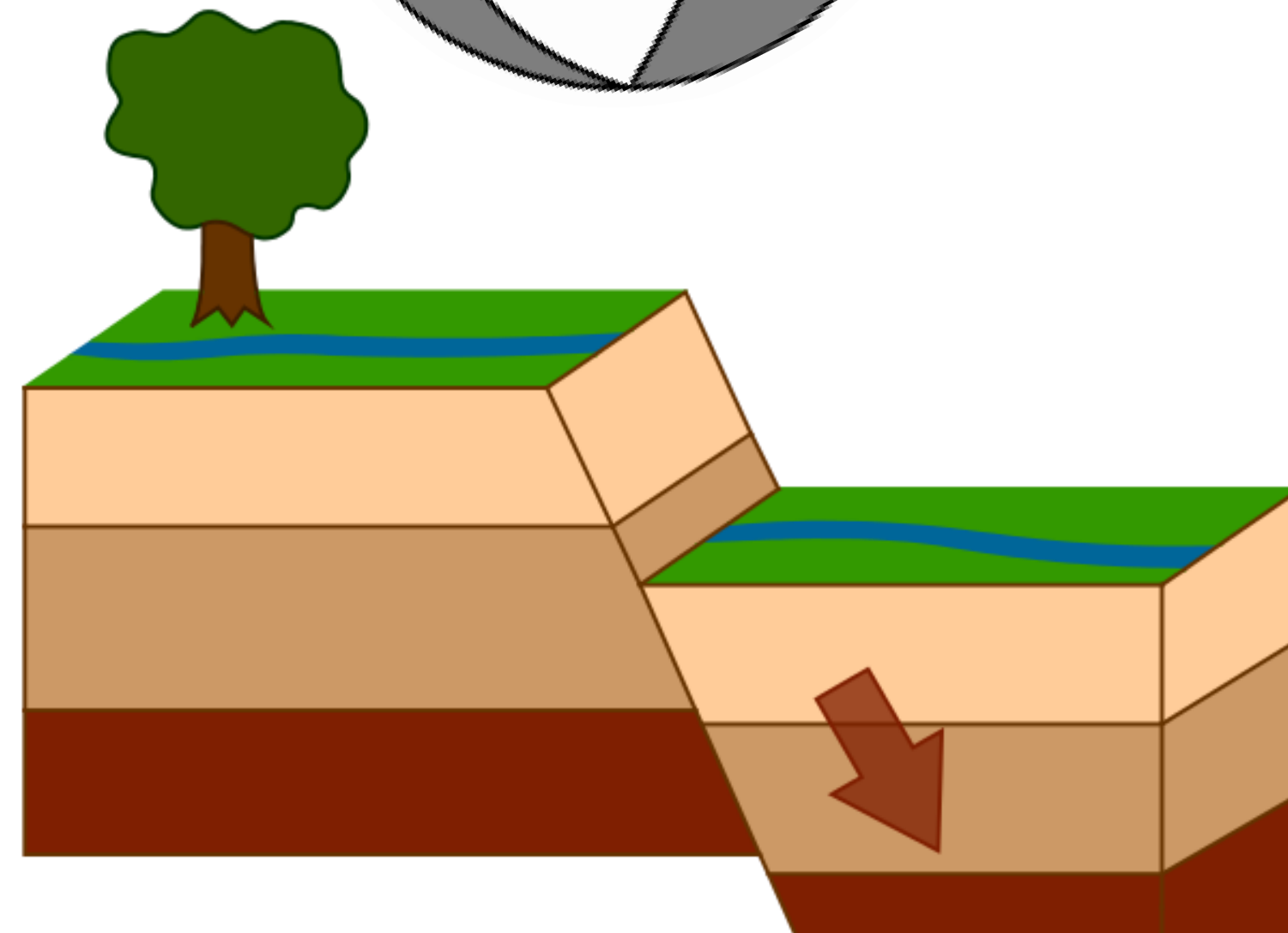
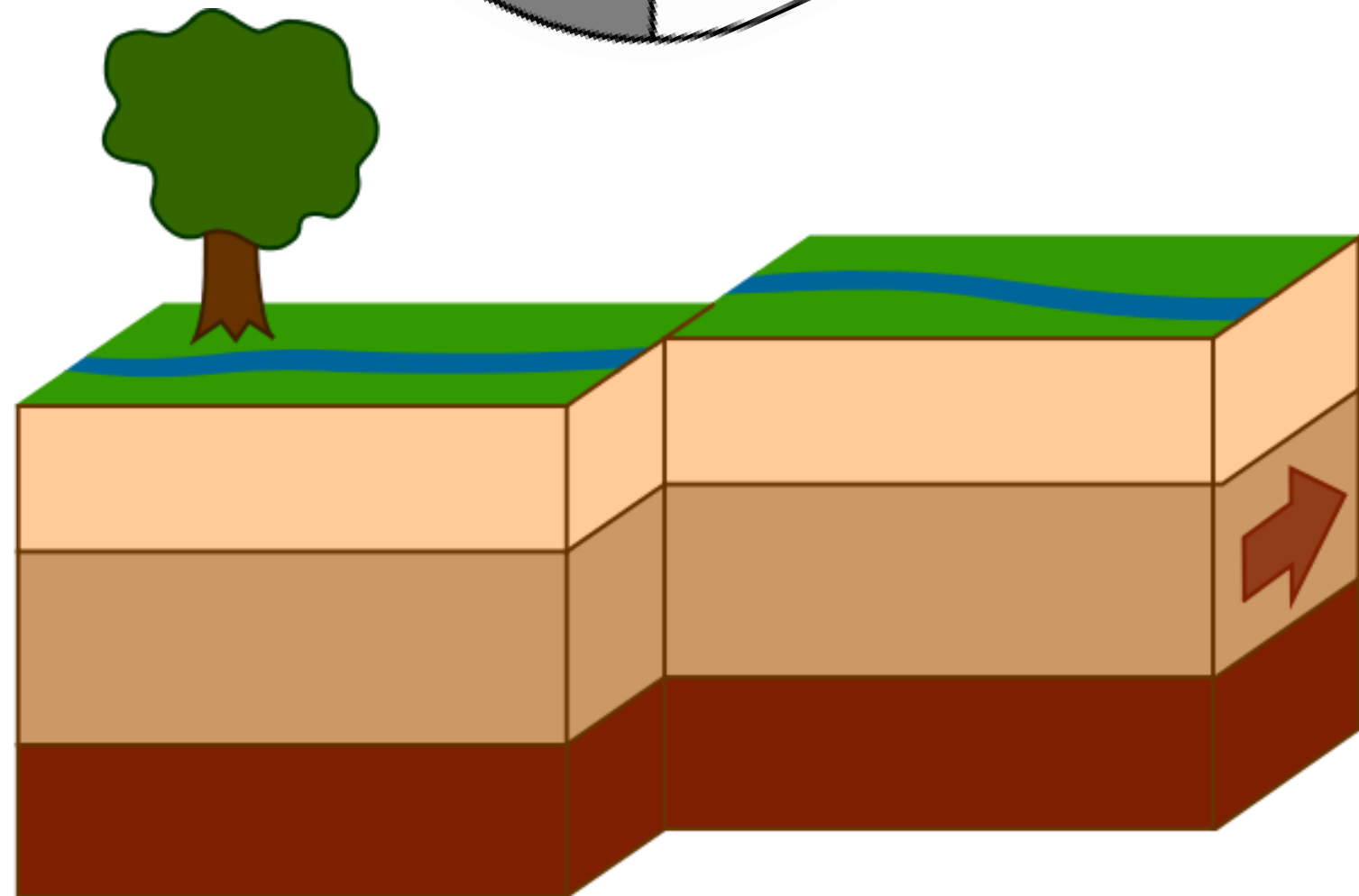
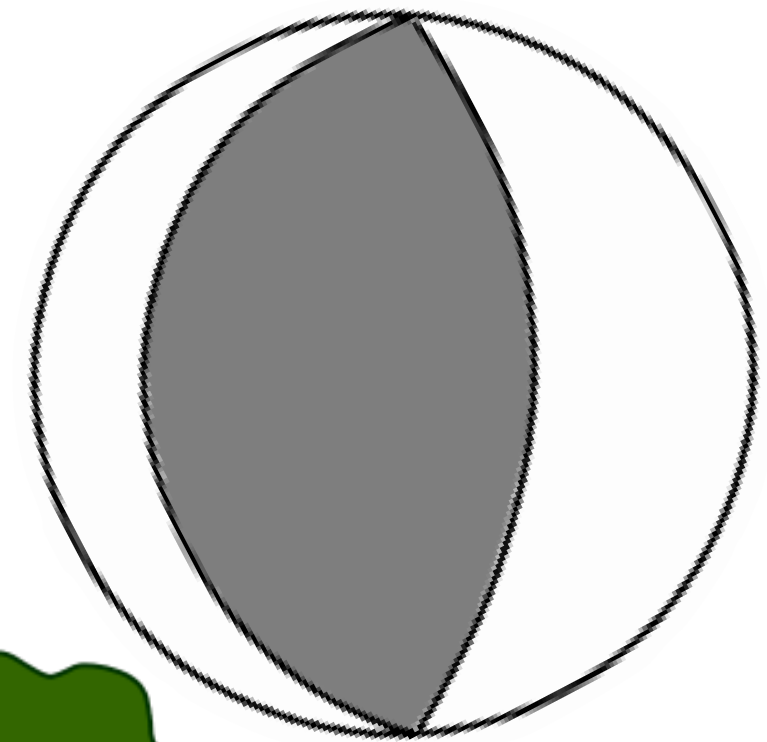
Strike-slip fault



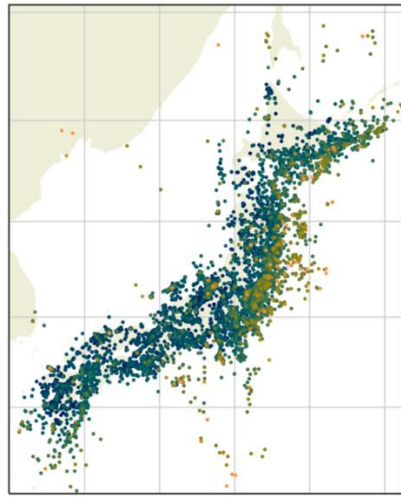
Normal fault



Thrust (reverse) fault



# Earthquake Metadata | What other related data is important?



## Earthquake Hazards Program

In cooperation with: [US](#)

Latest Earthquakes

### Overview

[Interactive Map](#)

[Regional Information](#)

[Contributors](#)

### Impact

[Felt Report - Tell Us!](#)

[Did You Feel It?](#)

[ShakeMap](#)

[PAGER](#)

[Ground Failure](#)

[Aftershock Forecast](#)

### Technical

[Origin](#)

[Moment Tensor](#)

[Finite Fault](#)

[Waveforms](#)

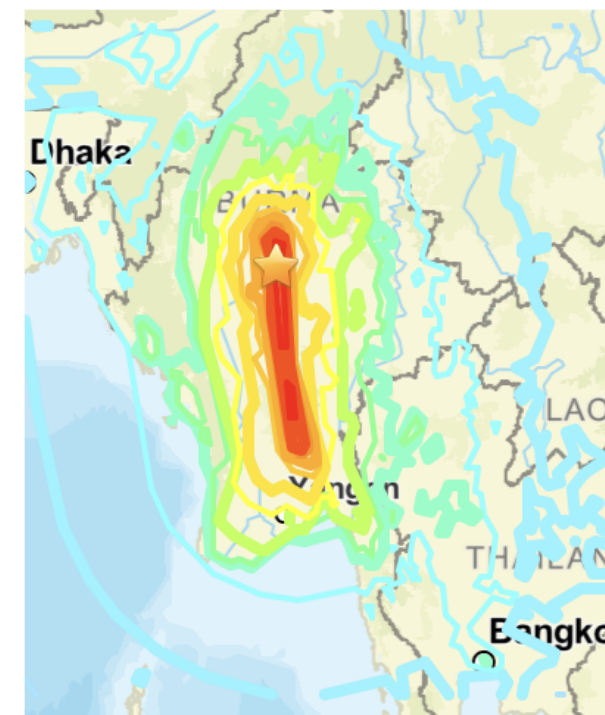
[Download Event KML](#)

[View Nearby Seismicity](#)

# M 7.7 - 2025 Mandalay, Burma (Myanmar) Earthquake

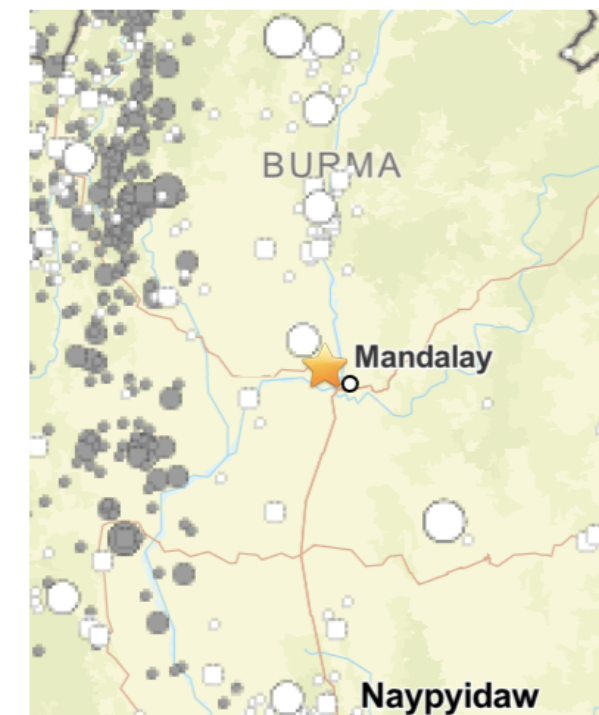
2025-03-28 06:20:52 (UTC) | 22.001°N 95.925°E | 10.0 km depth

### [Interactive Map](#)



Contributed by [US](#)

### [Regional Information](#)



Contributed by [US](#)

### [Felt Report - Tell Us!](#)



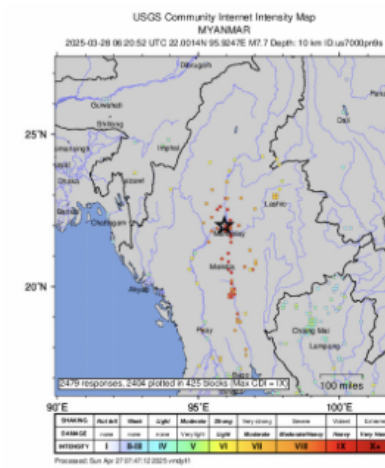
Responses

Contribute to citizen science. Please [tell us](#) about your experience.

Citizen Scientist Contributions

### [Did You Feel It?](#)

**IX**

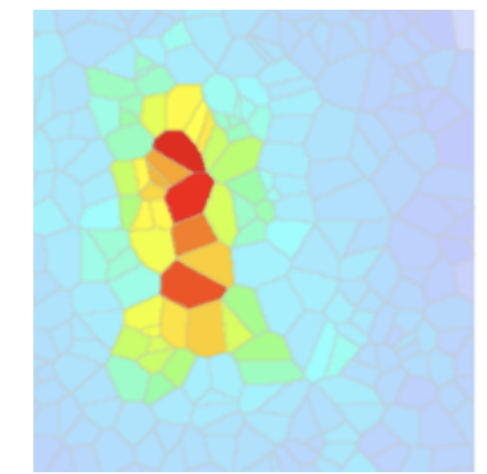


Community Internet Intensity Map

Contributed by [US](#)

### [ShakeMap](#)

**X**

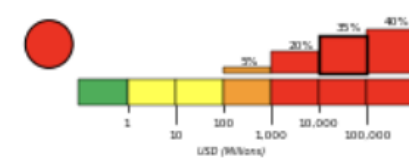


Estimated Intensity Map

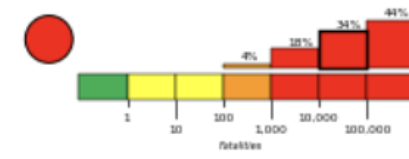
Contributed by [US](#)

### [PAGER](#)

**RED**



Estimated Economic Losses



Estimated Fatalities

### [Ground Failure](#)

#### Landslide Estimate



Extensive area affected  
Significant population exposed

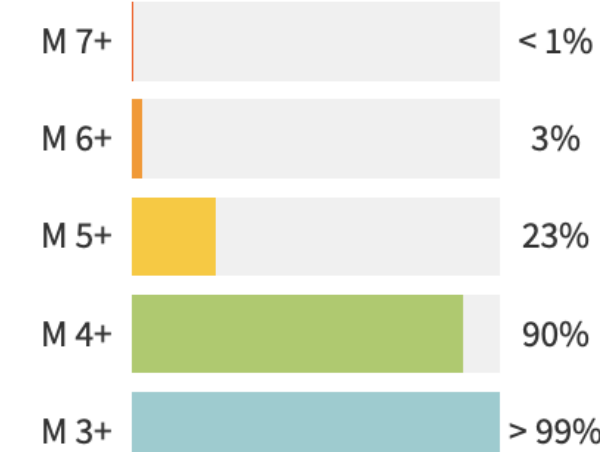
#### Liquefaction Estimate



Extensive area affected  
Extensive population exposed

### [Aftershock Forecast](#)

According to our forecast, the chance of at least one aftershock within the next **week**:



### [Origin](#)

#### Review Status

REVIEWED

#### Magnitude

7.7 mww

#### Depth

10.0 km

#### Time

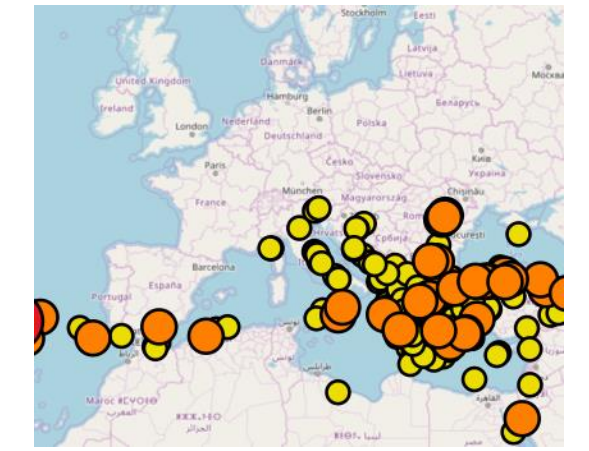
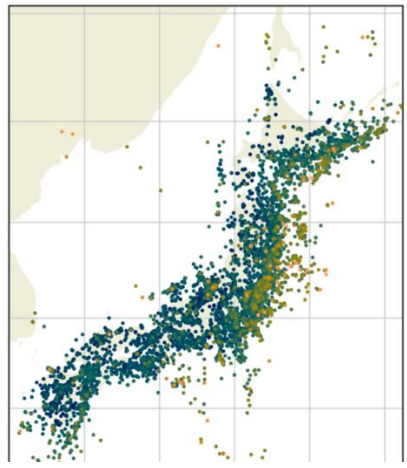
2025-03-28 06:20:52 UTC

### [Moment Tensor](#)

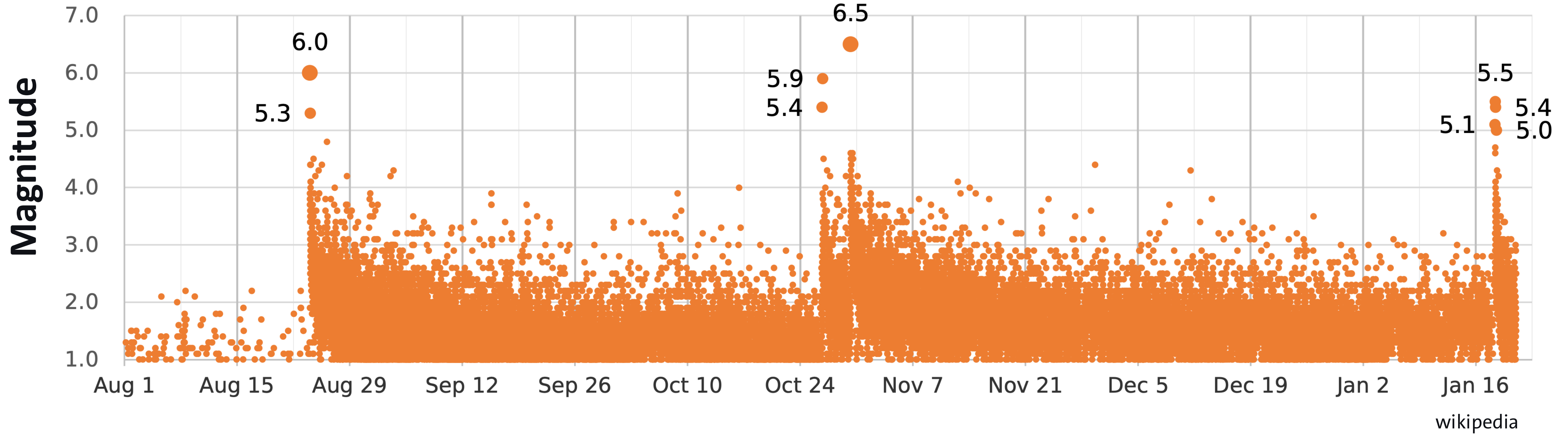


Fault Plane Solution

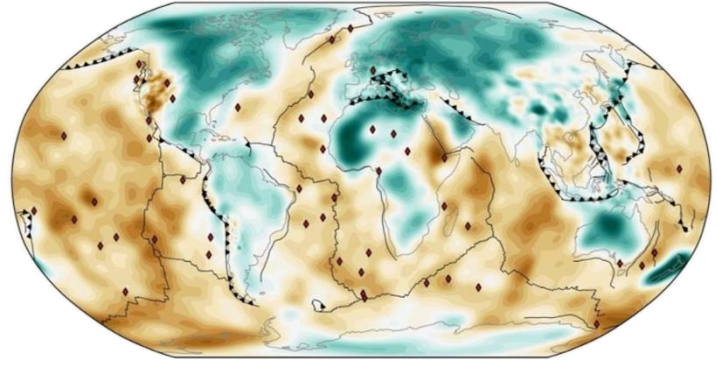
# Earthquake Metadata | What other related data is important?



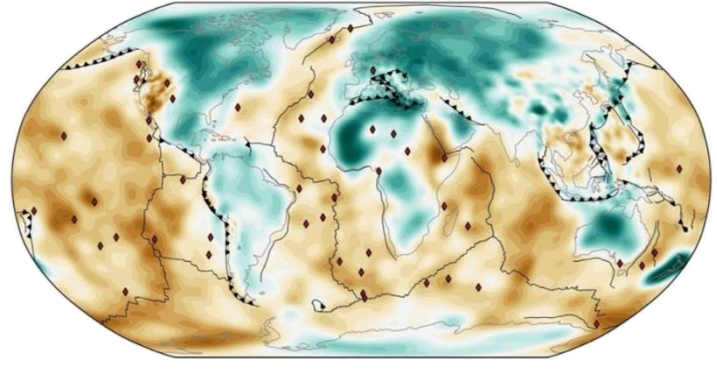
2016–2017 Central Italy earthquakes (magnitude)



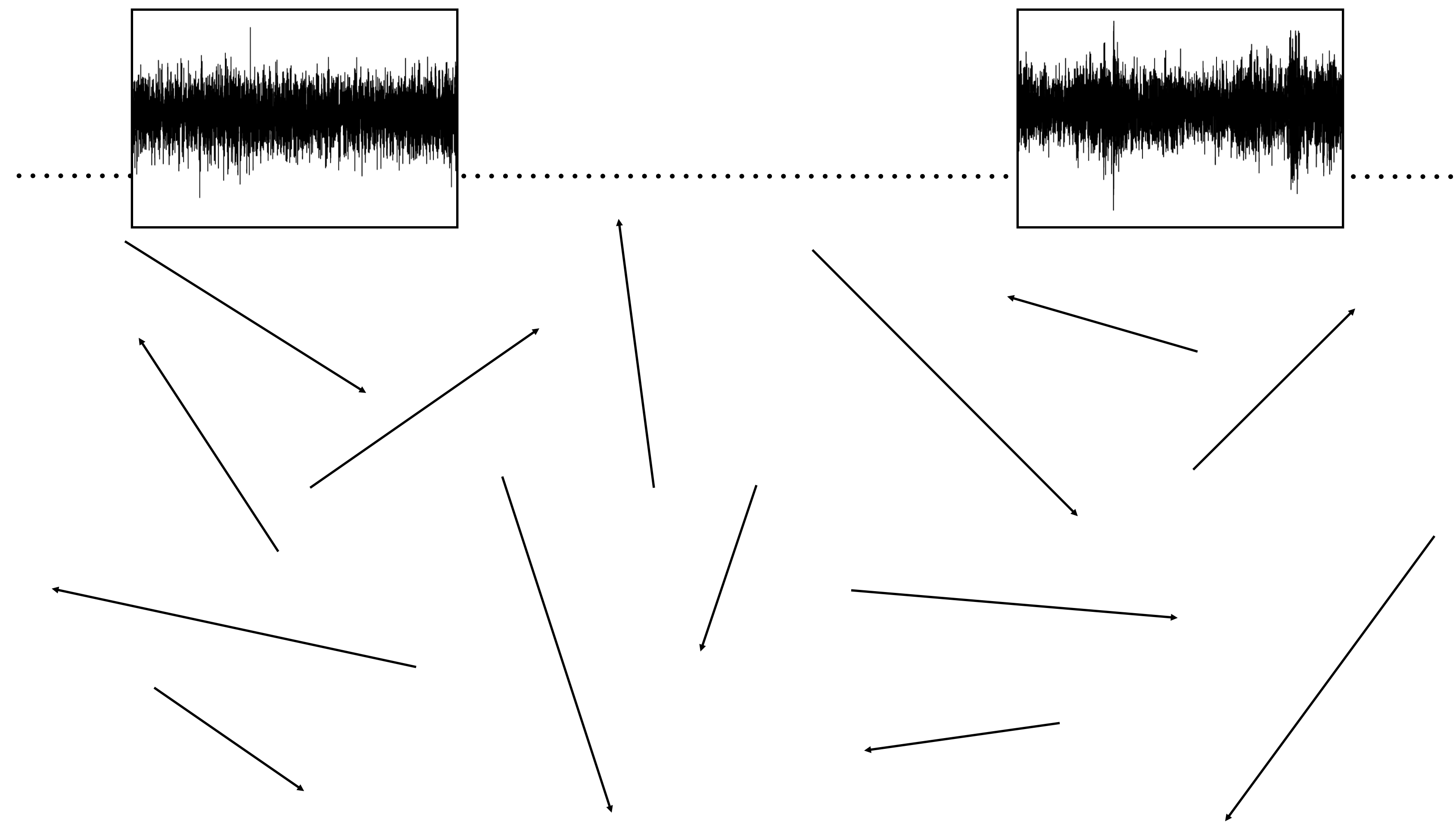
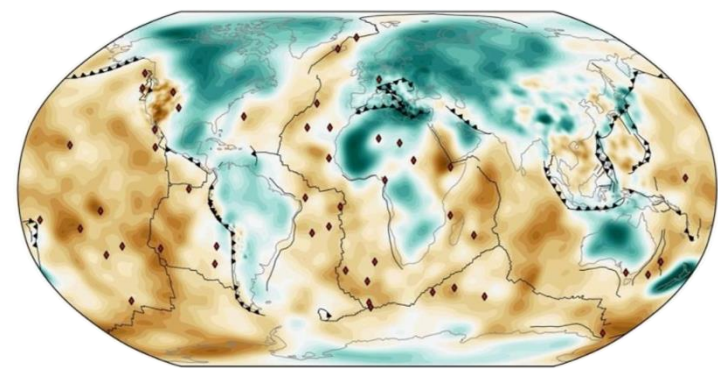
# Miscellaneous



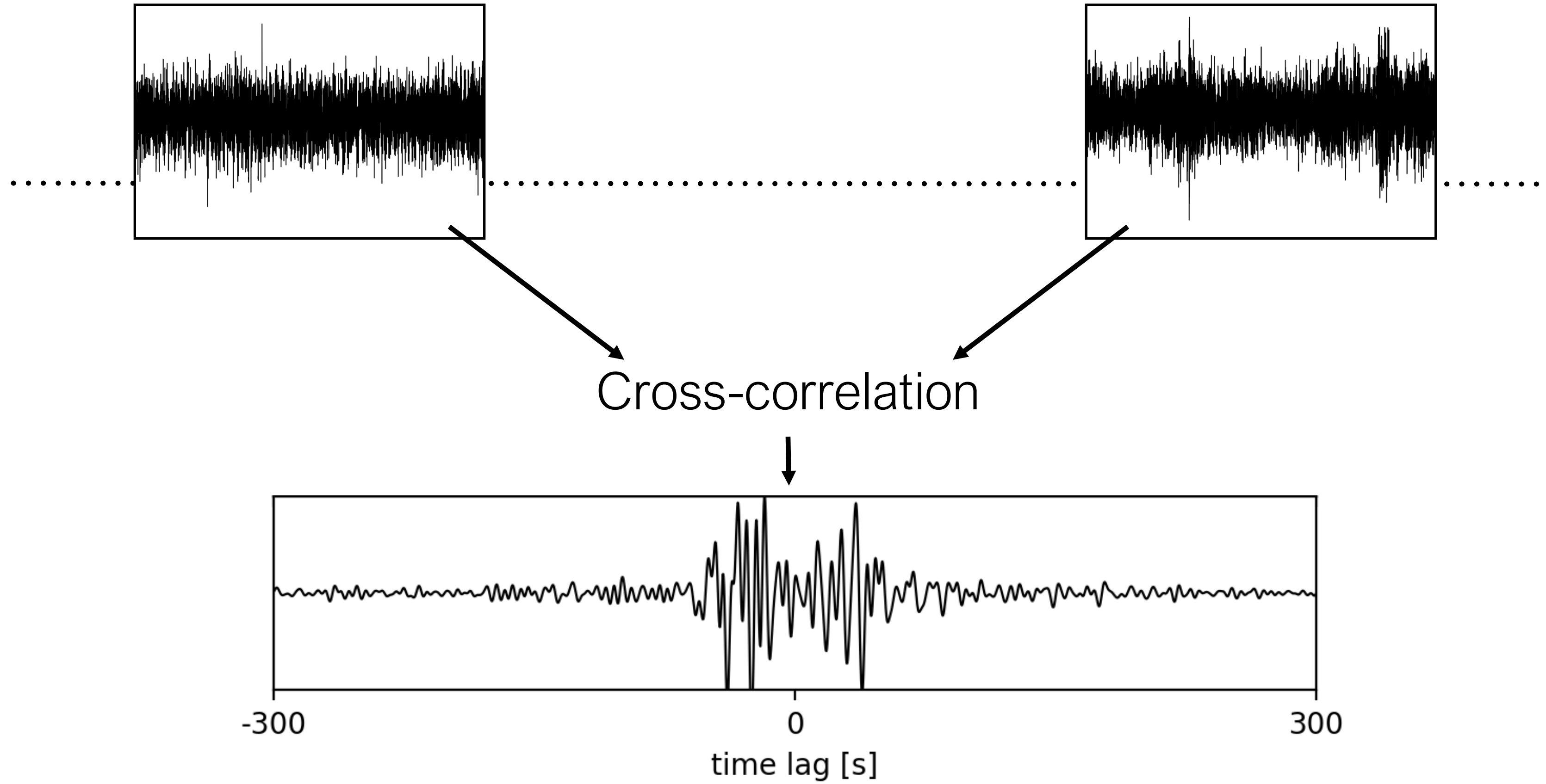
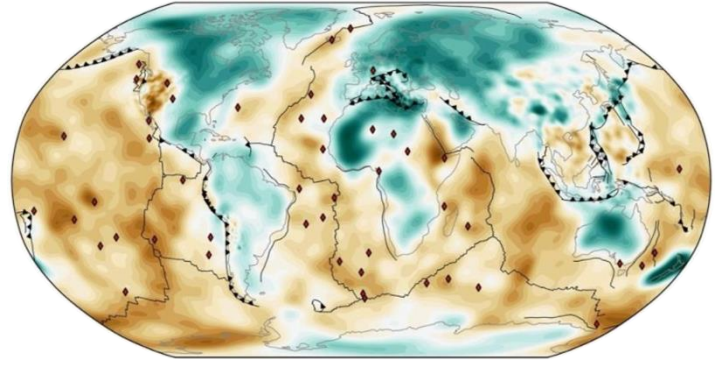
# Miscellaneous | What is a correlation wavefield?



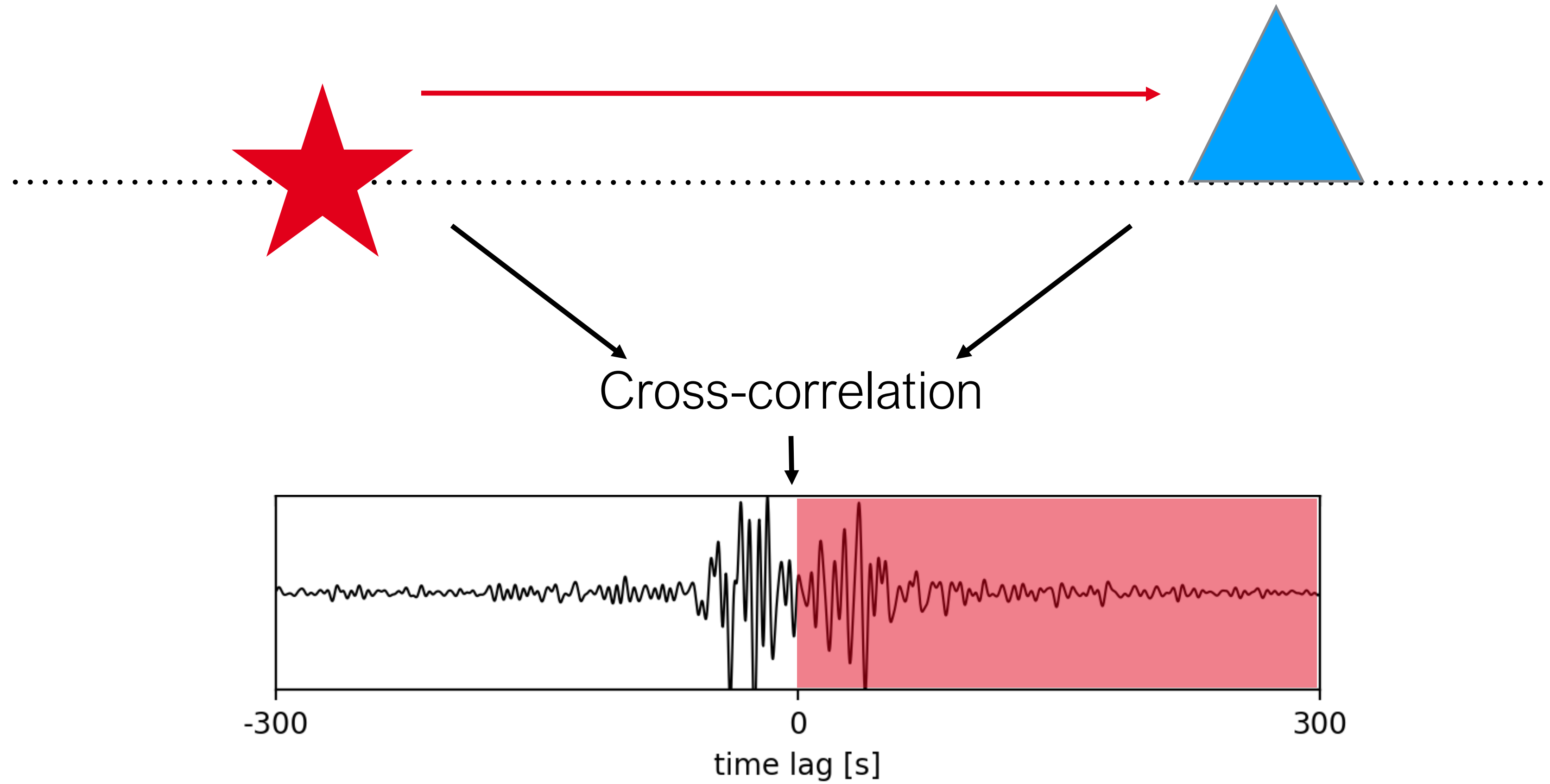
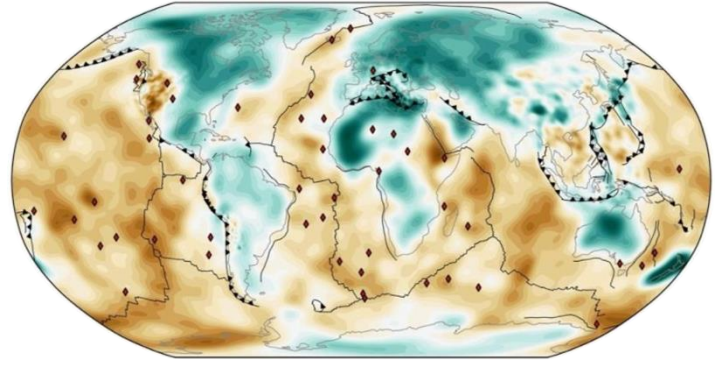
# Miscellaneous | What is a correlation wavefield?



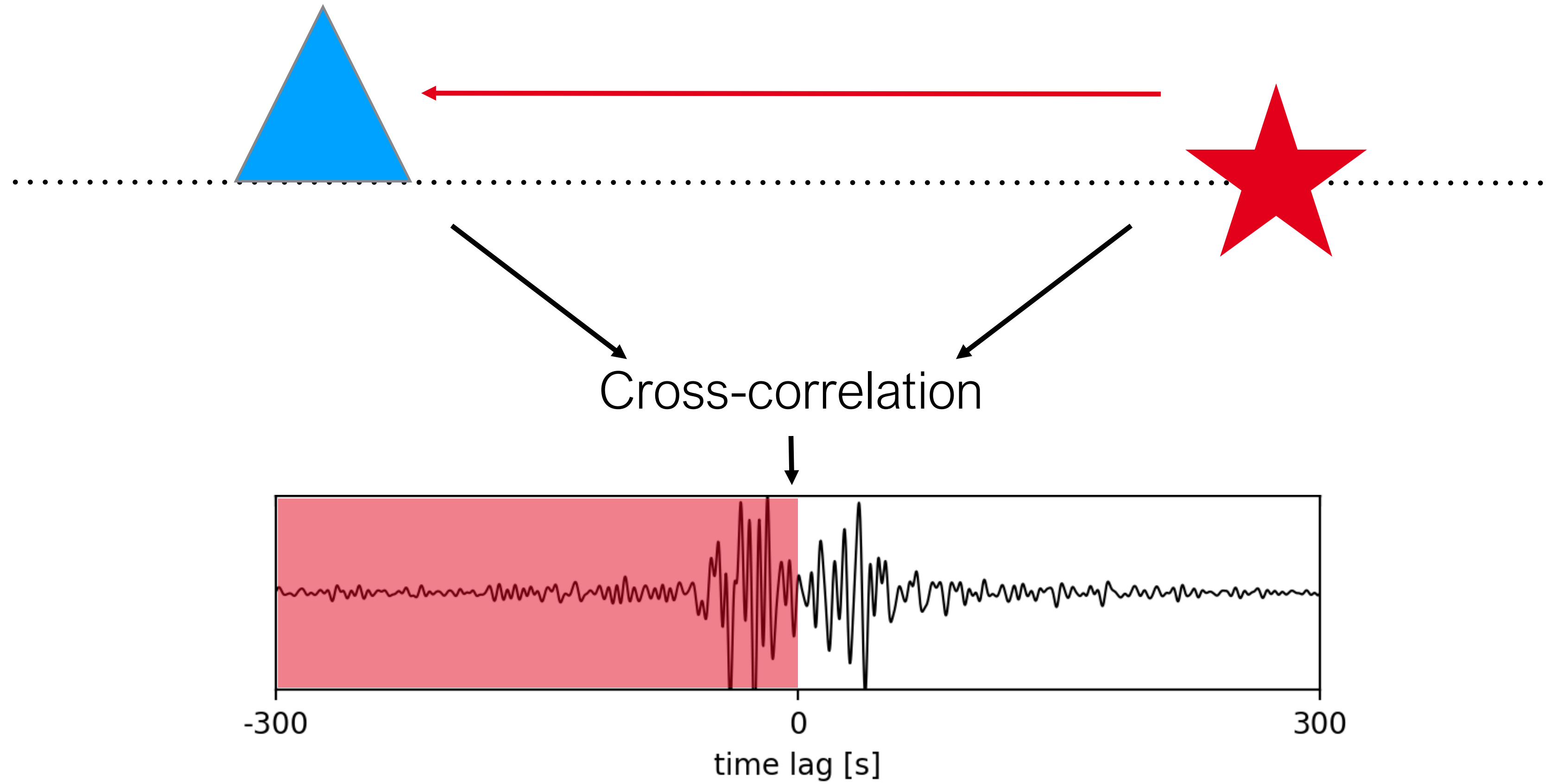
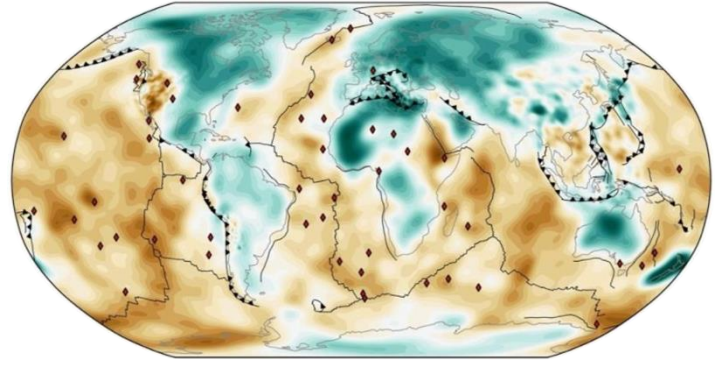
# Miscellaneous | What is a correlation wavefield?



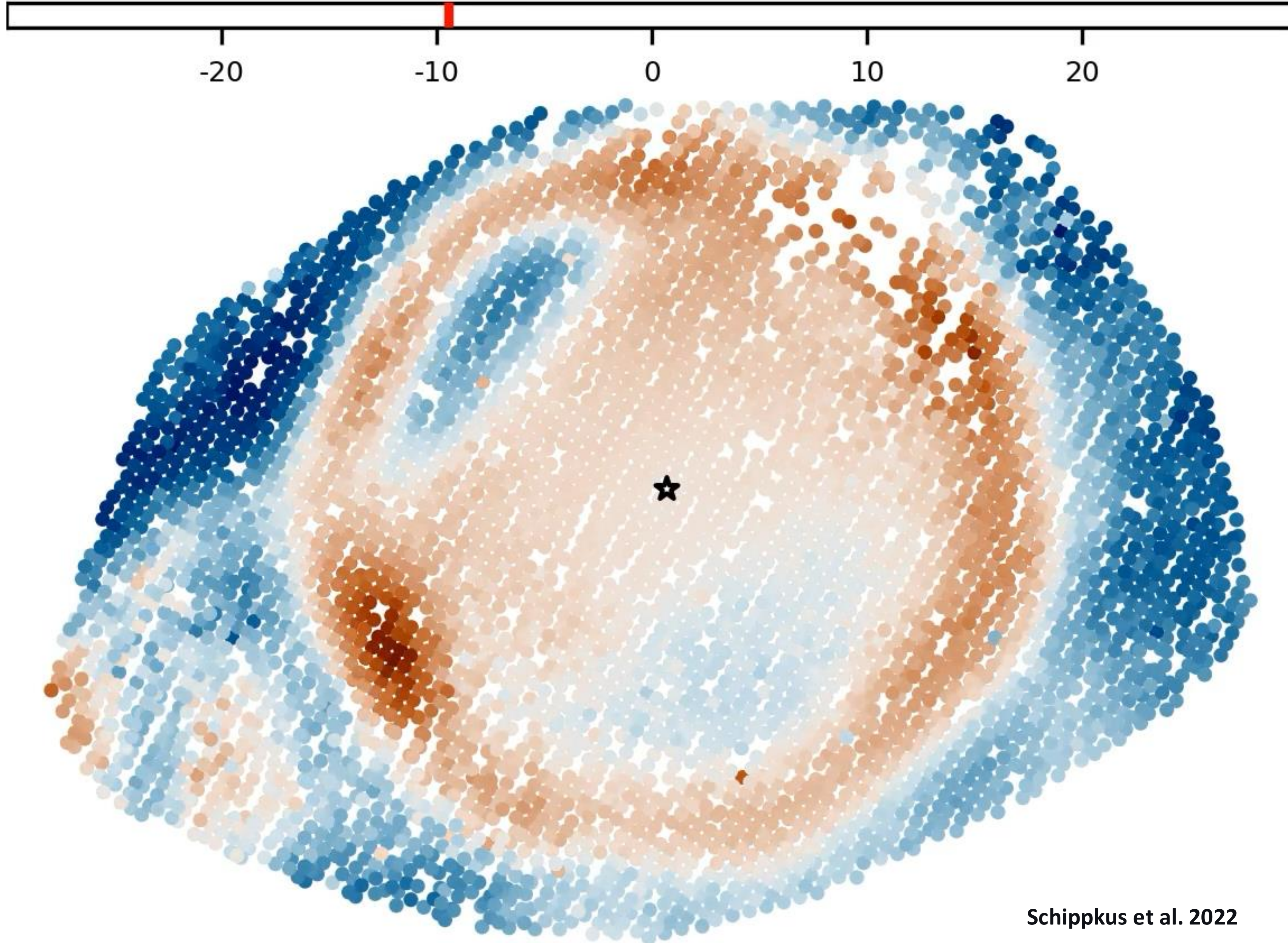
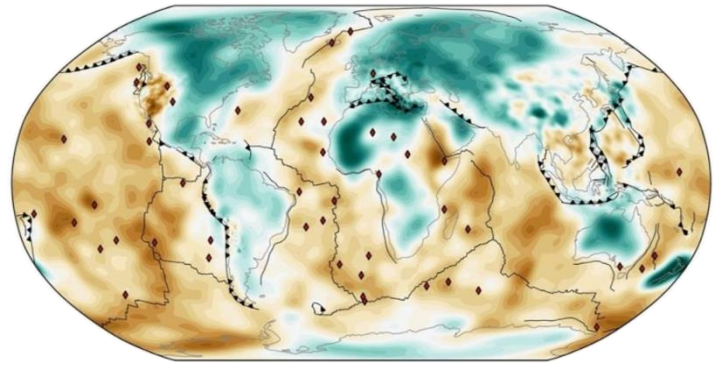
# Miscellaneous | What is a correlation wavefield?



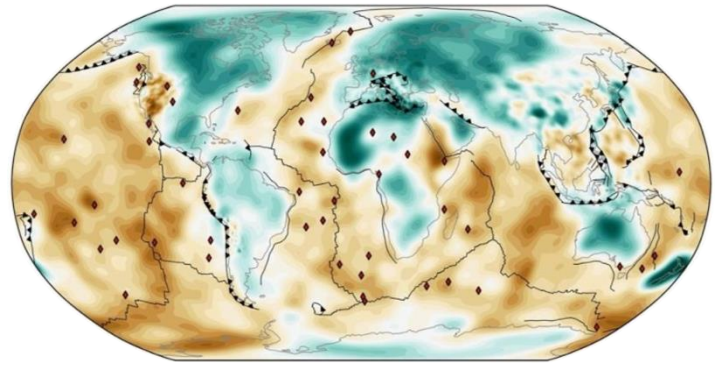
# Miscellaneous | What is a correlation wavefield?



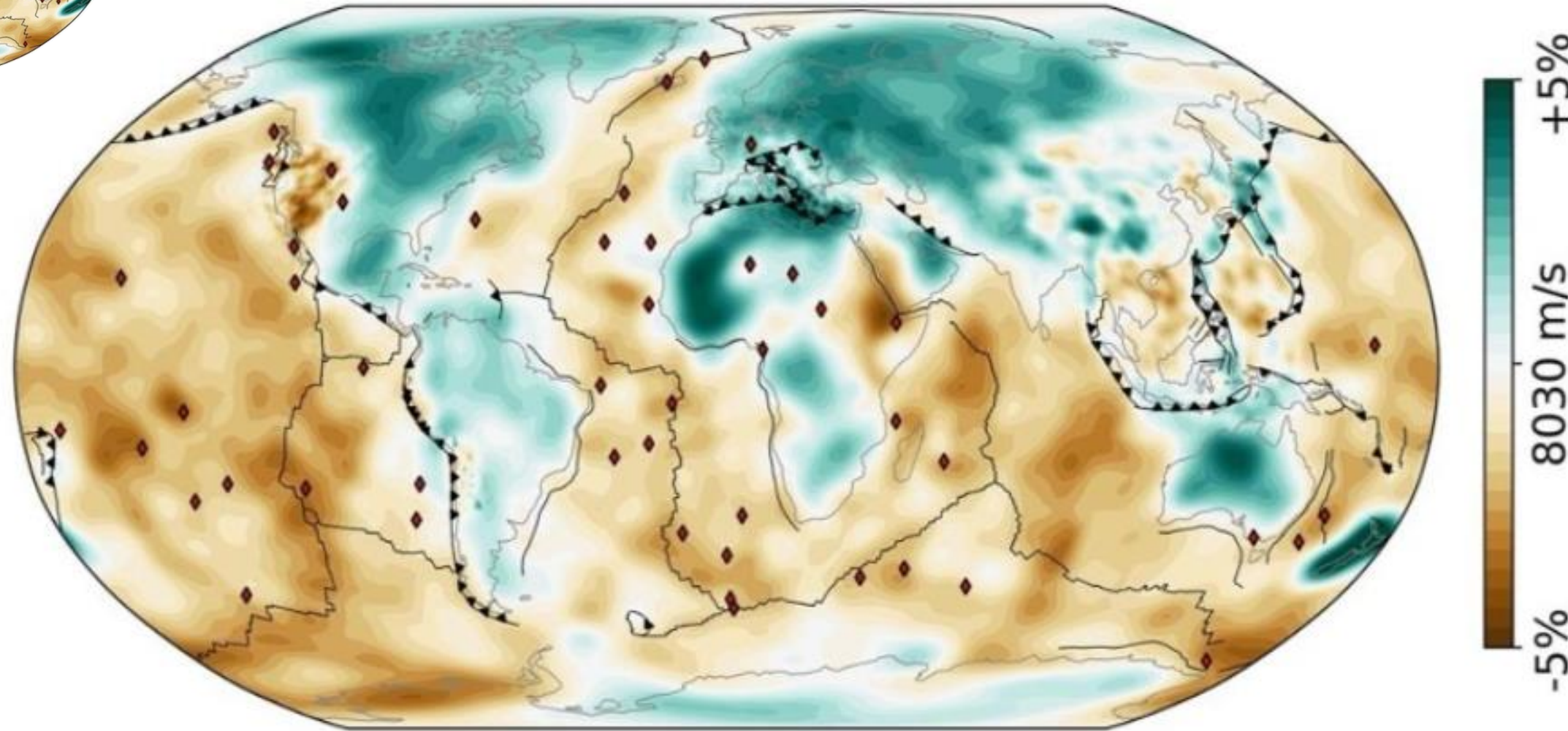
# Miscellaneous | What is a correlation wavefield?



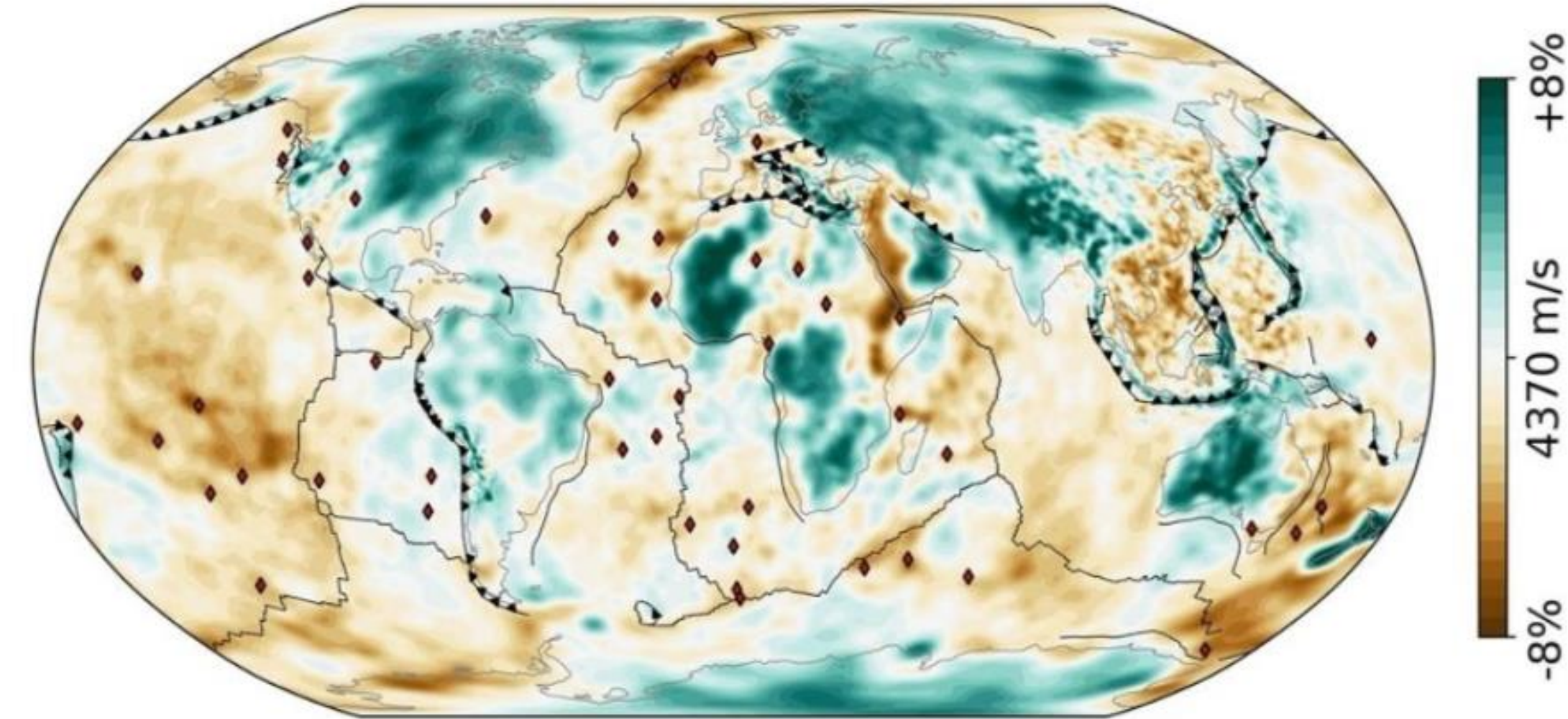
# Miscellaneous | What is a velocity model?



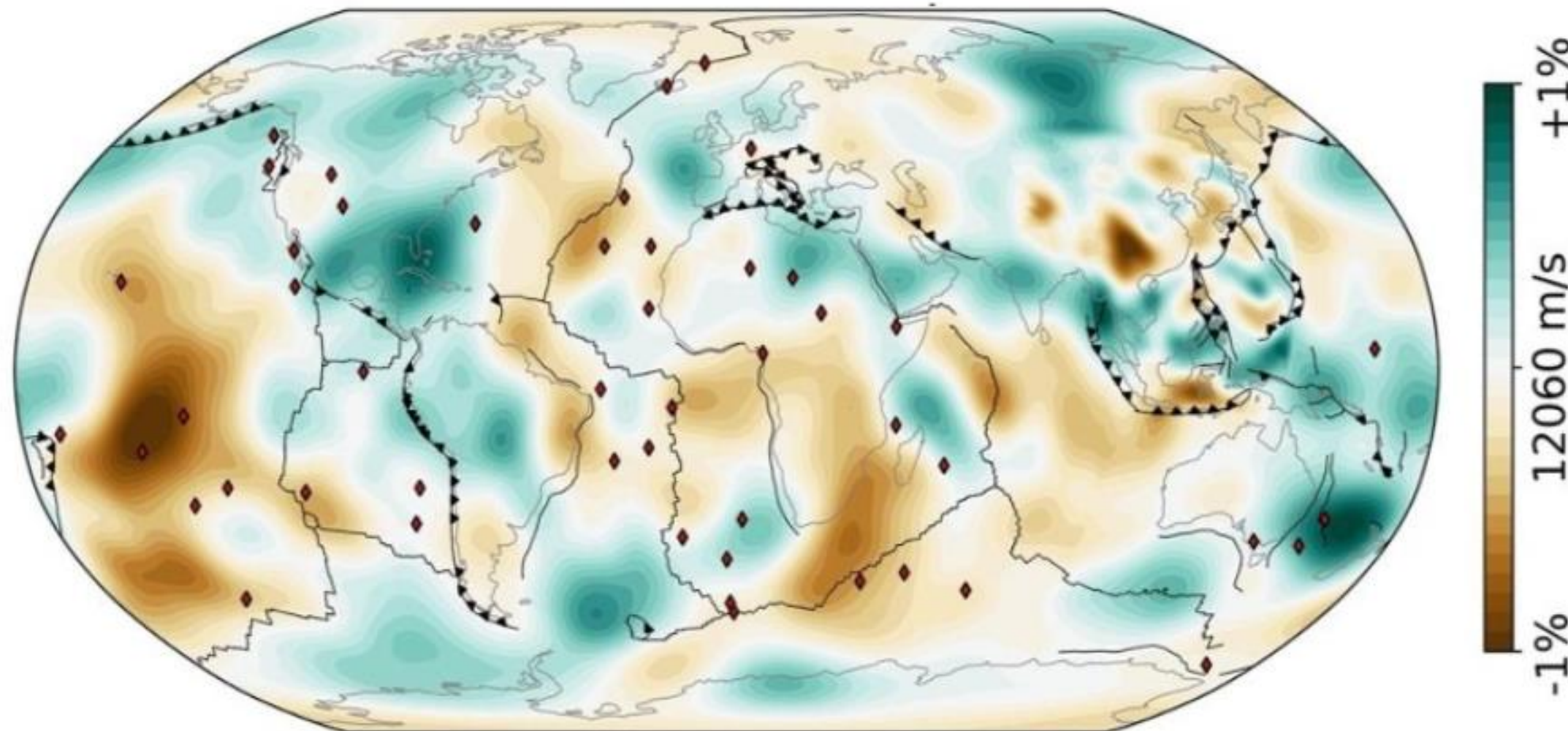
VP at 200 km depth



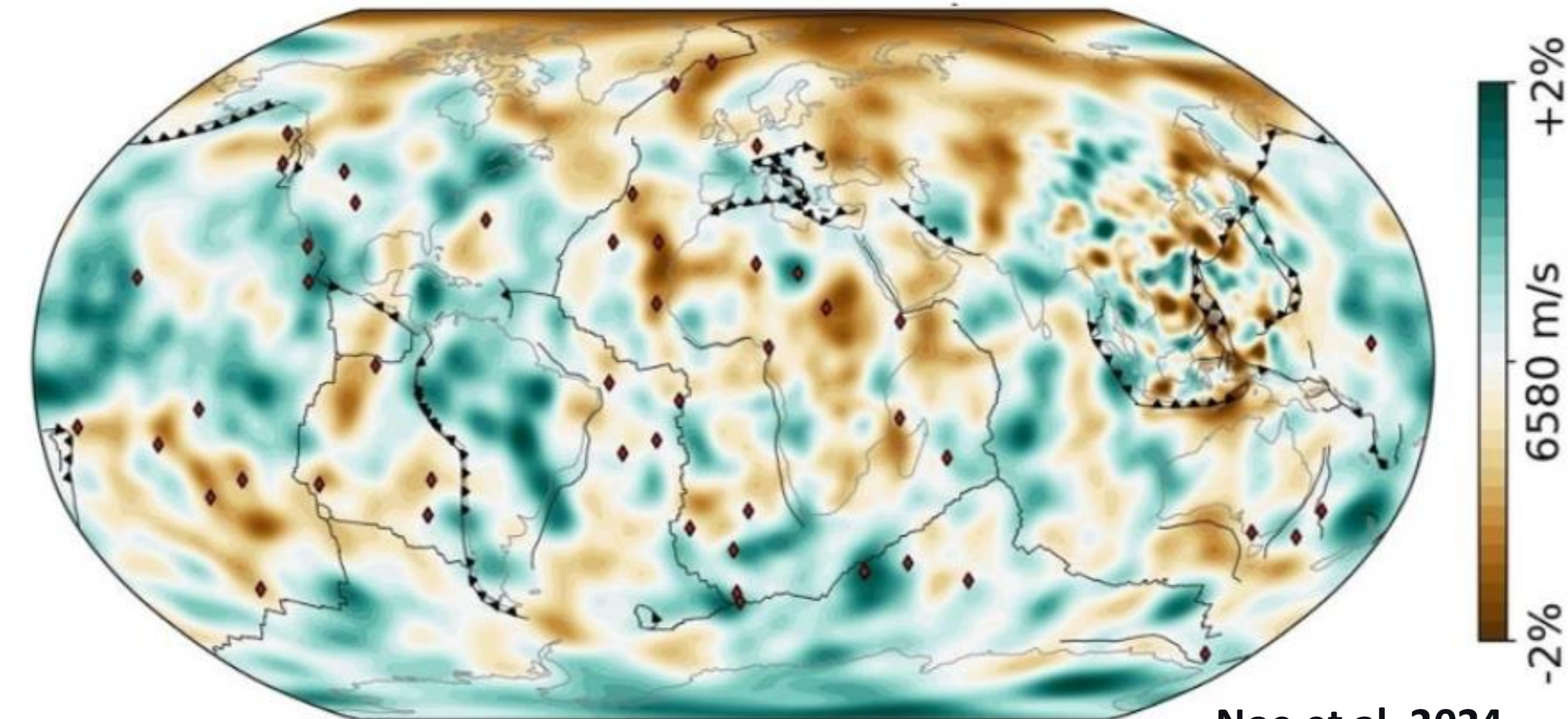
d) VSV at 200 km depth



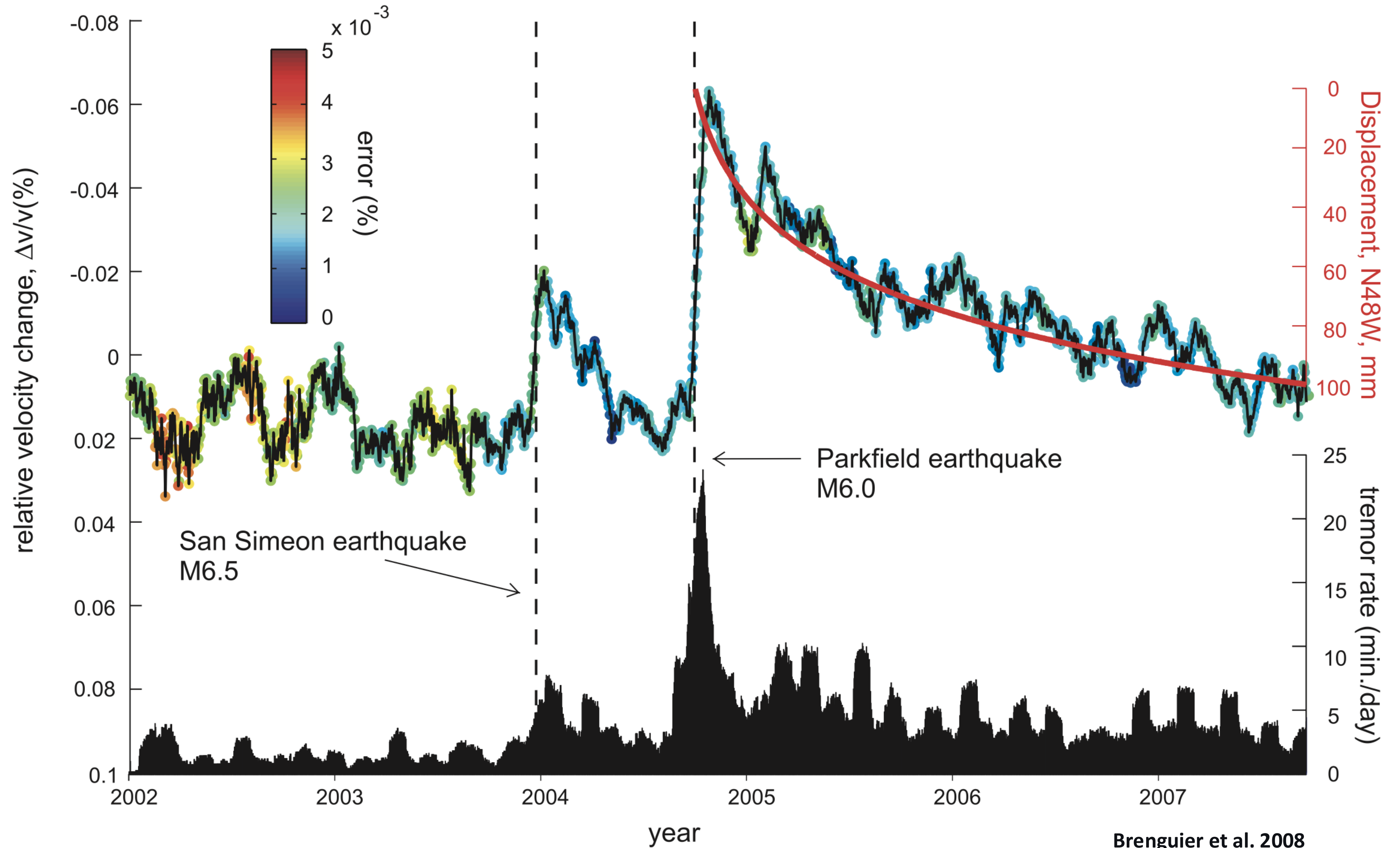
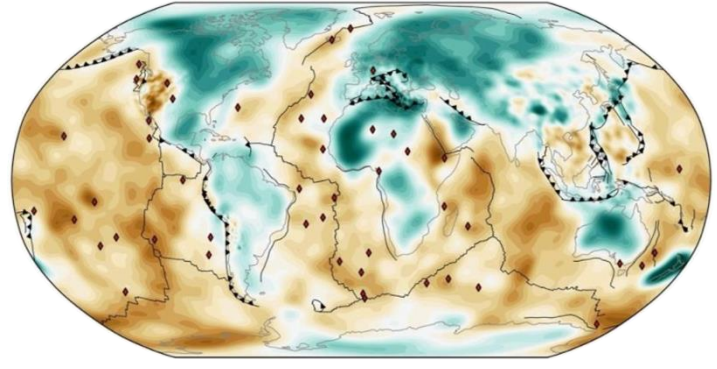
c) VP at 1400 km depth



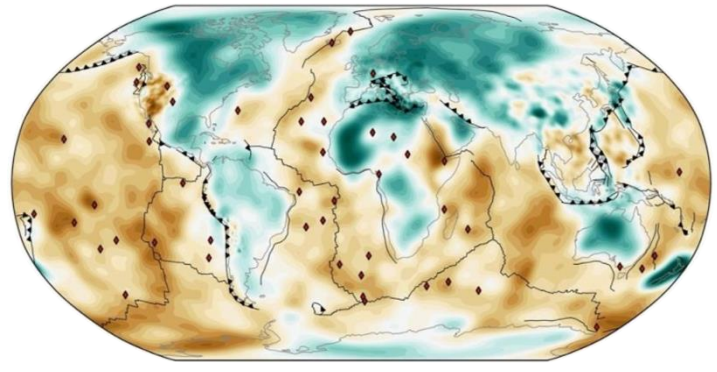
f) VSV at 1400 km depth



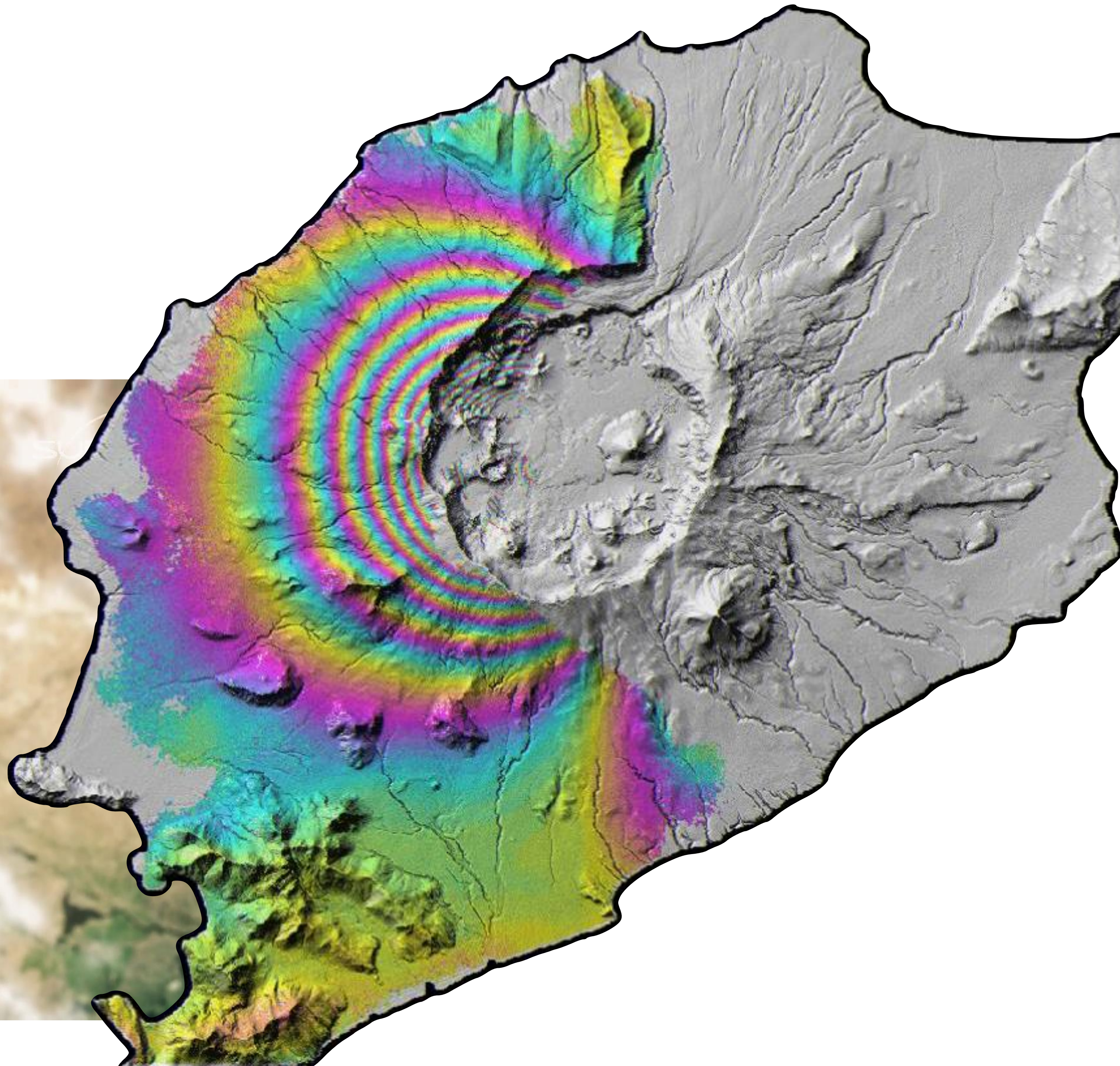
# Miscellaneous | What about velocity variations?



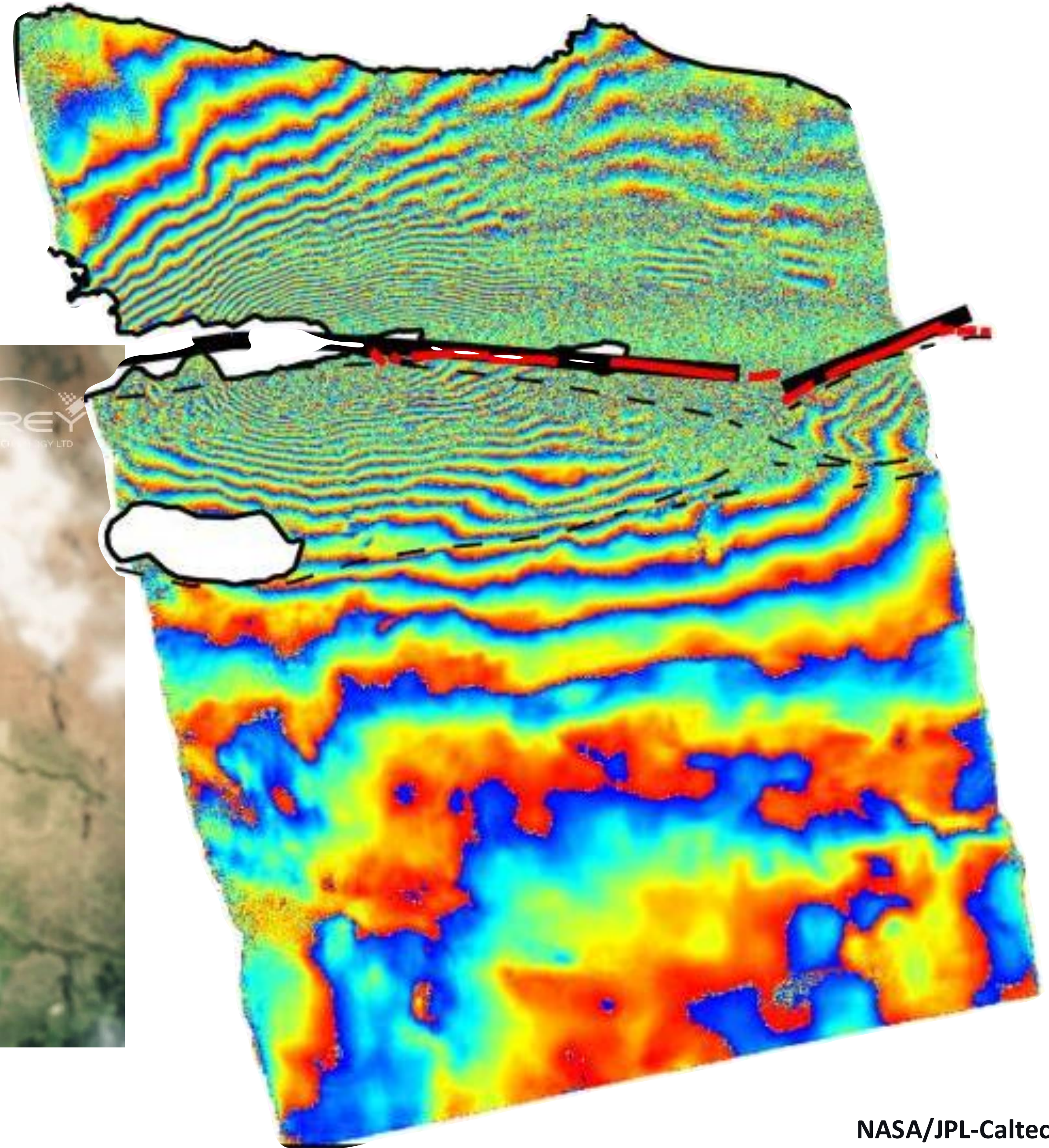
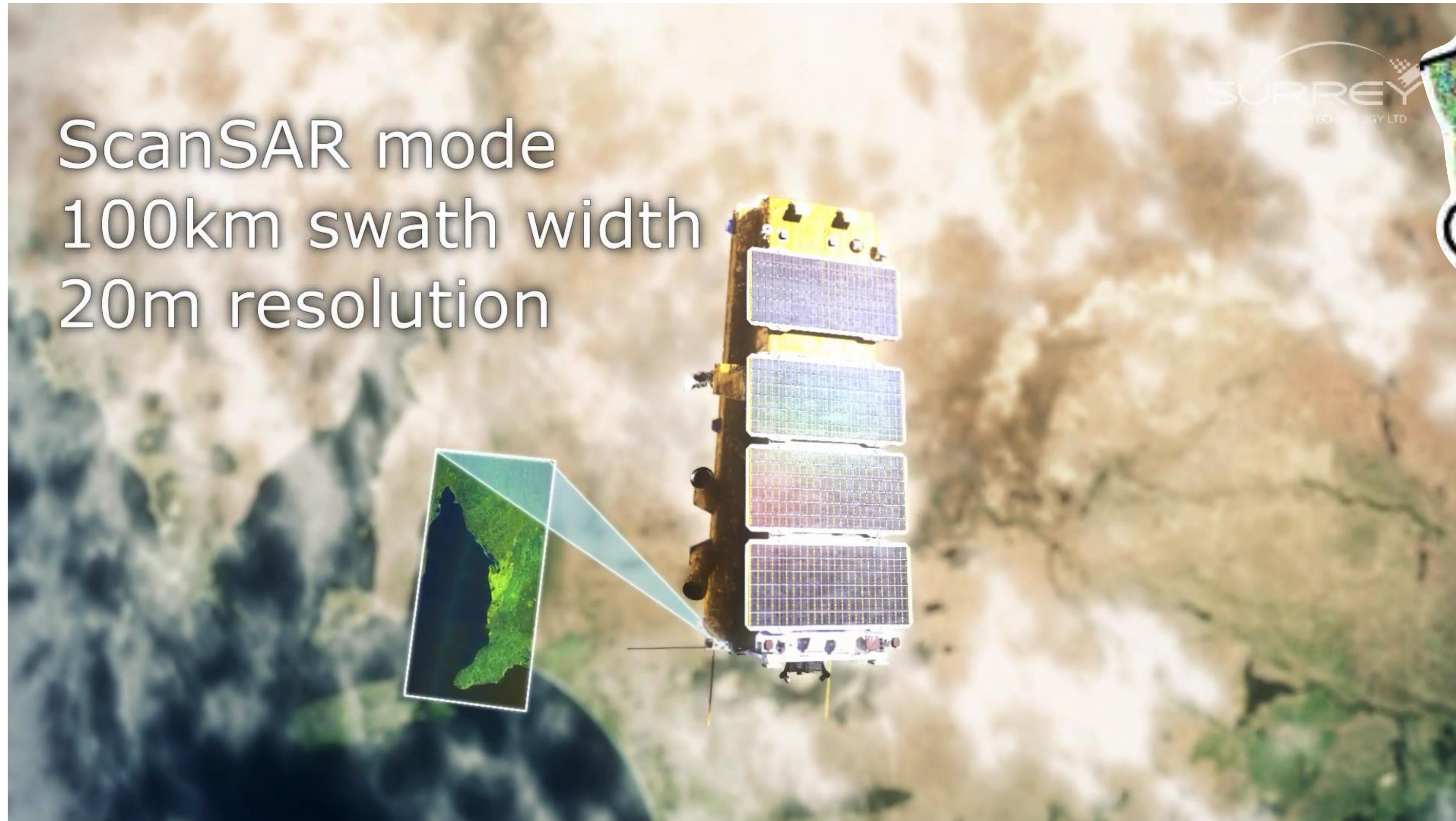
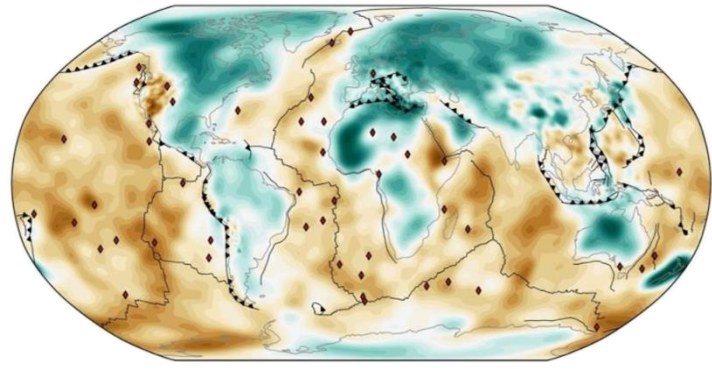
# Miscellaneous | What is InSAR?



ScanSAR mode  
100km swath width  
20m resolution



# Miscellaneous | What is InSAR?



# Targets



# Data

**Raw data**

**Derived data**

A collage of images illustrating raw and derived data. The 'Raw data' section includes a satellite, a seismometer with a waveform, a hydrophone, and a radar. The 'Derived data' section includes a scatter plot, a network graph, a heatmap, a cross-section, a circular data plot, and a topographic map.