# Ambient Noise Tomography fundamentals

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# Recap

tomographic techniques:

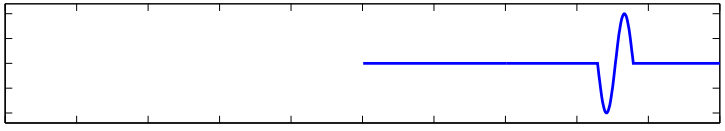
- refraction tomography
- local or teleseismic earthquake tomography
- surface wave tomography

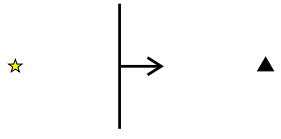
## common approach

Infer information about the medium from the observable interaction of a wavefied during the propagation from its **source** to a set of **receivers**.

# Recap

source-receiver geometry





We can directly measure the impulse response (Green's function).

# Recap

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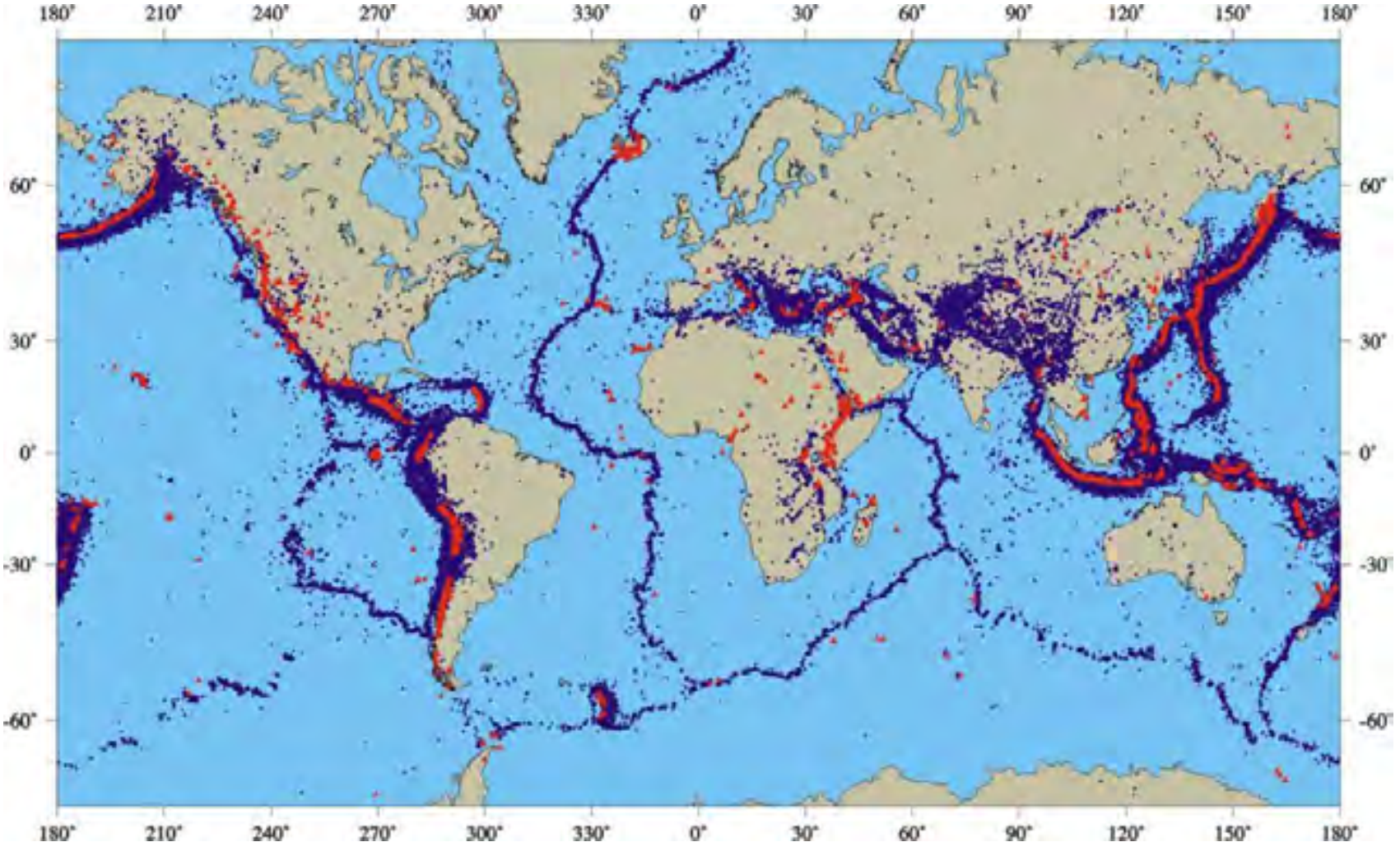
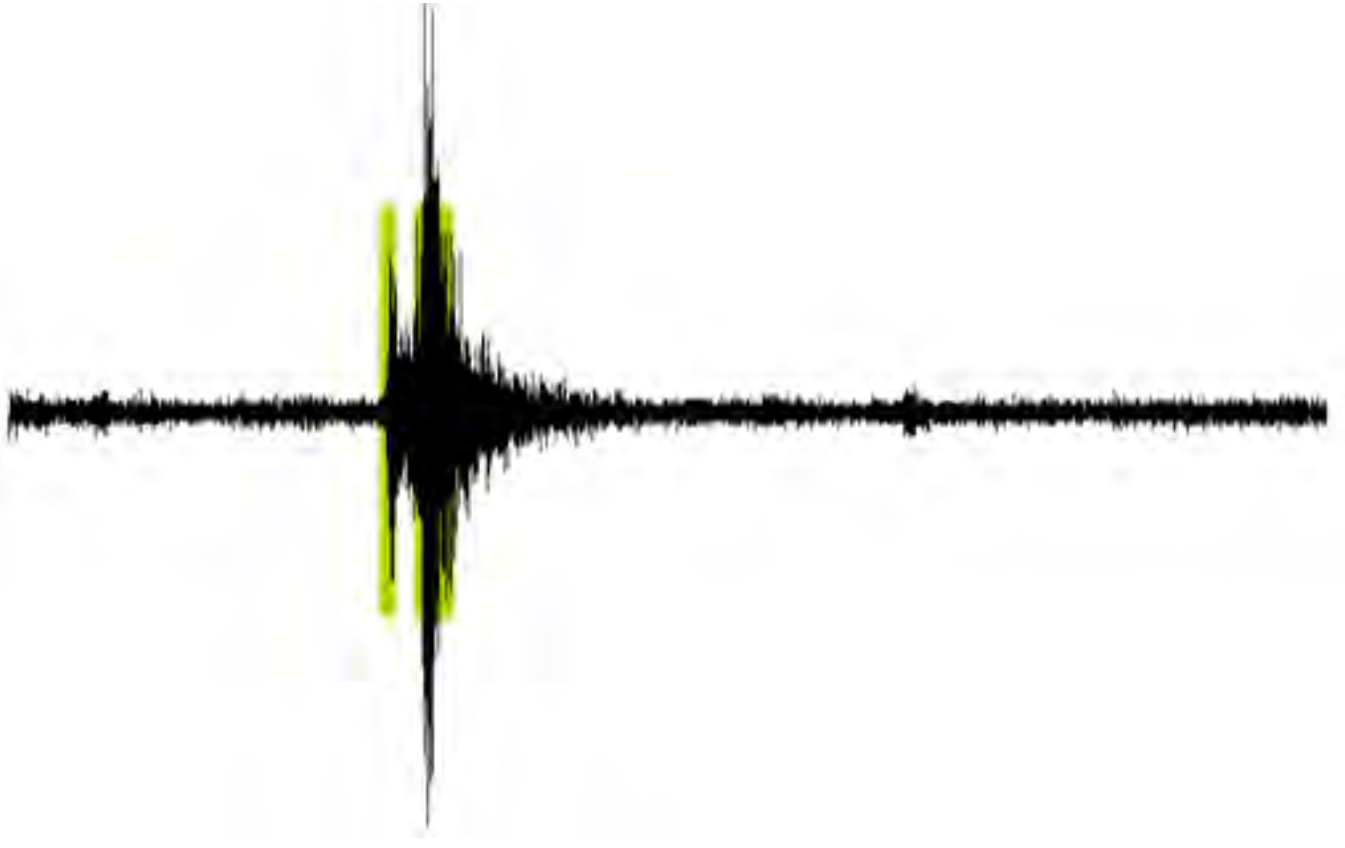


# Seismic records



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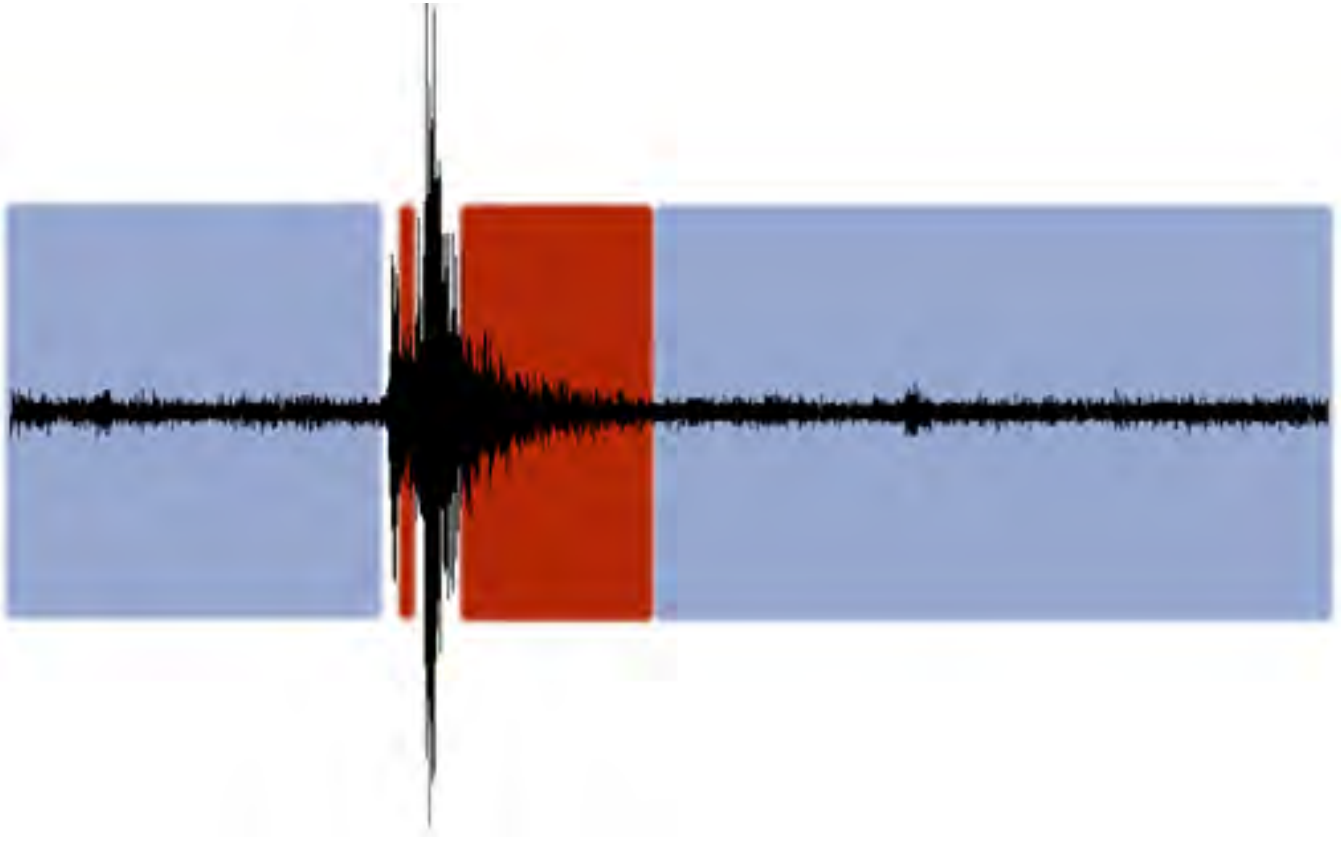

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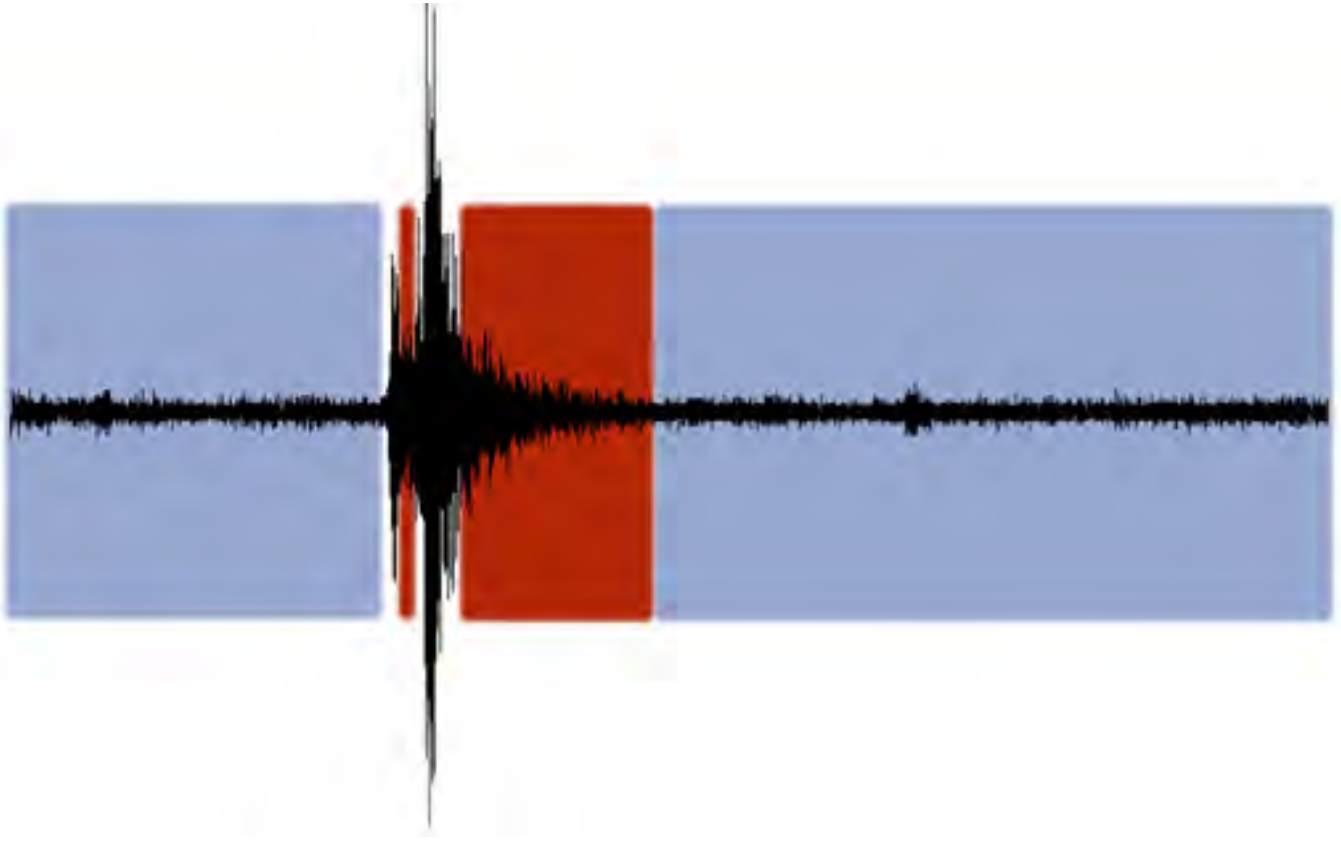
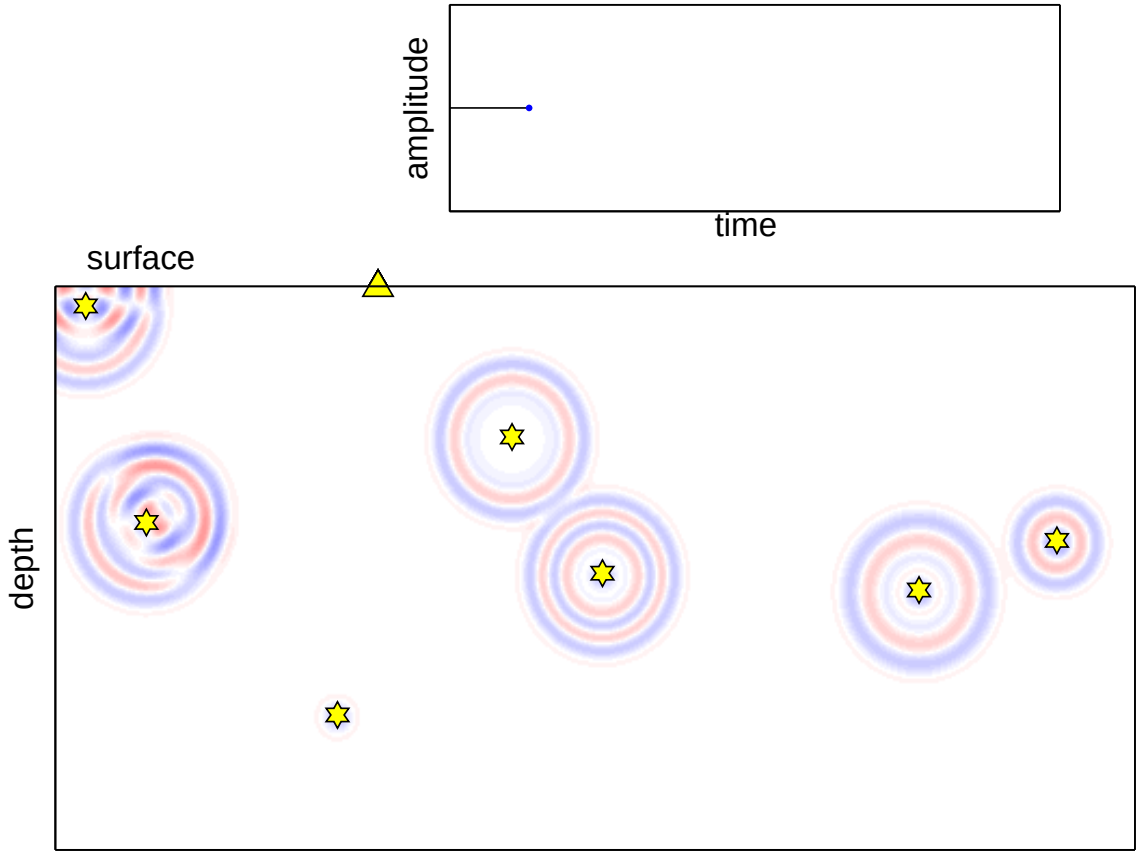


Signals from impulsive localized sources make up a tiny fraction of the records only. Most of it is NOISE.

# The ambient wavefield



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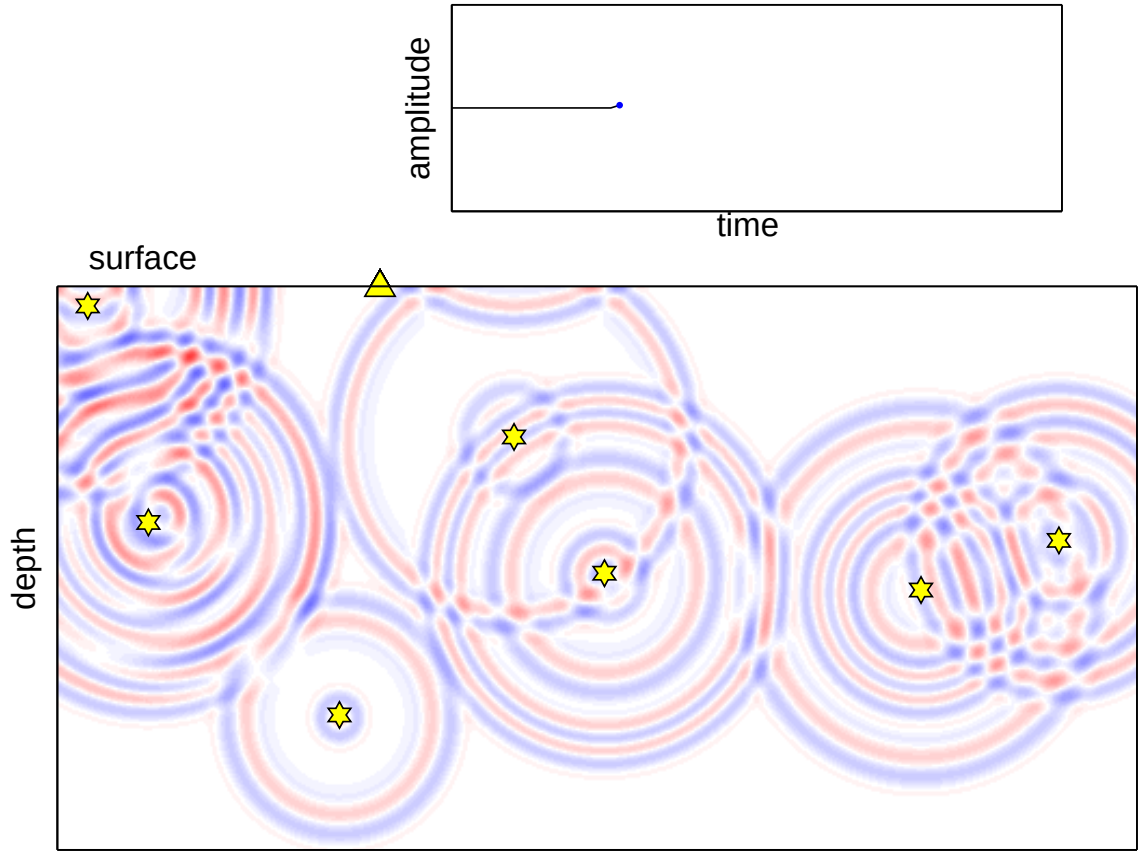

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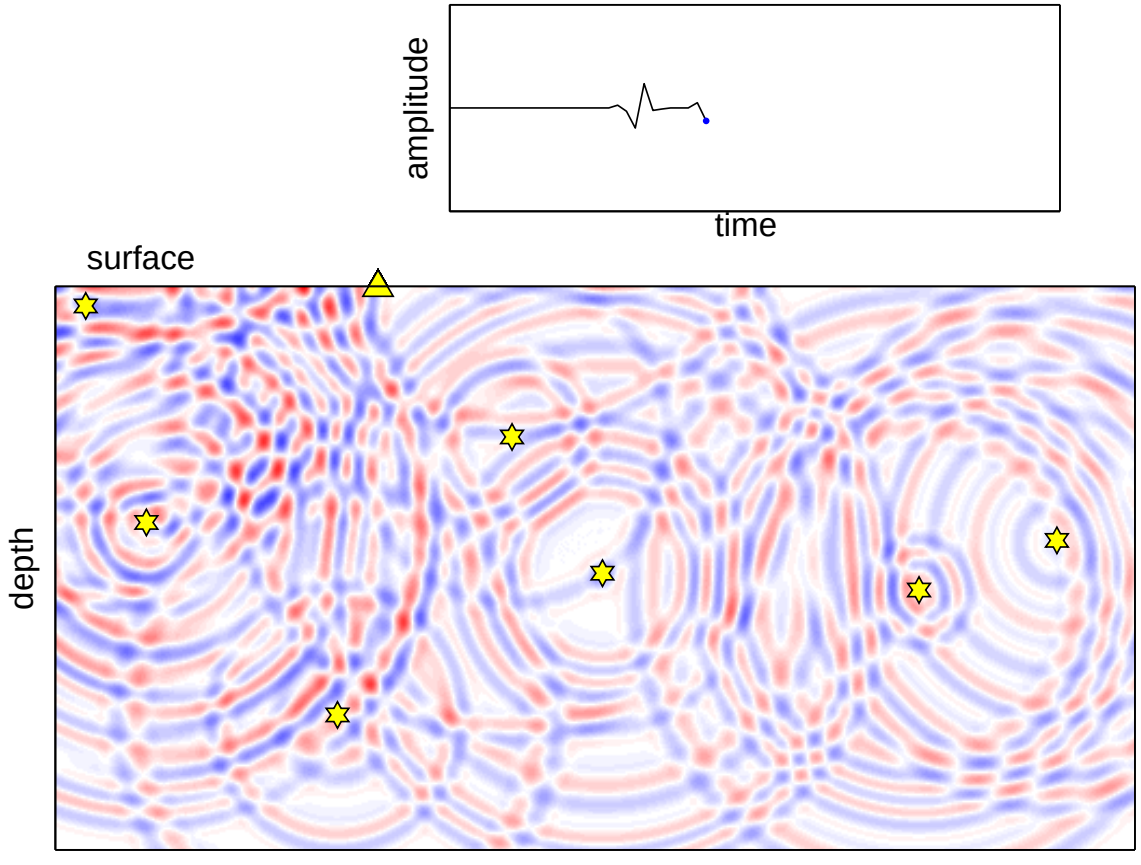

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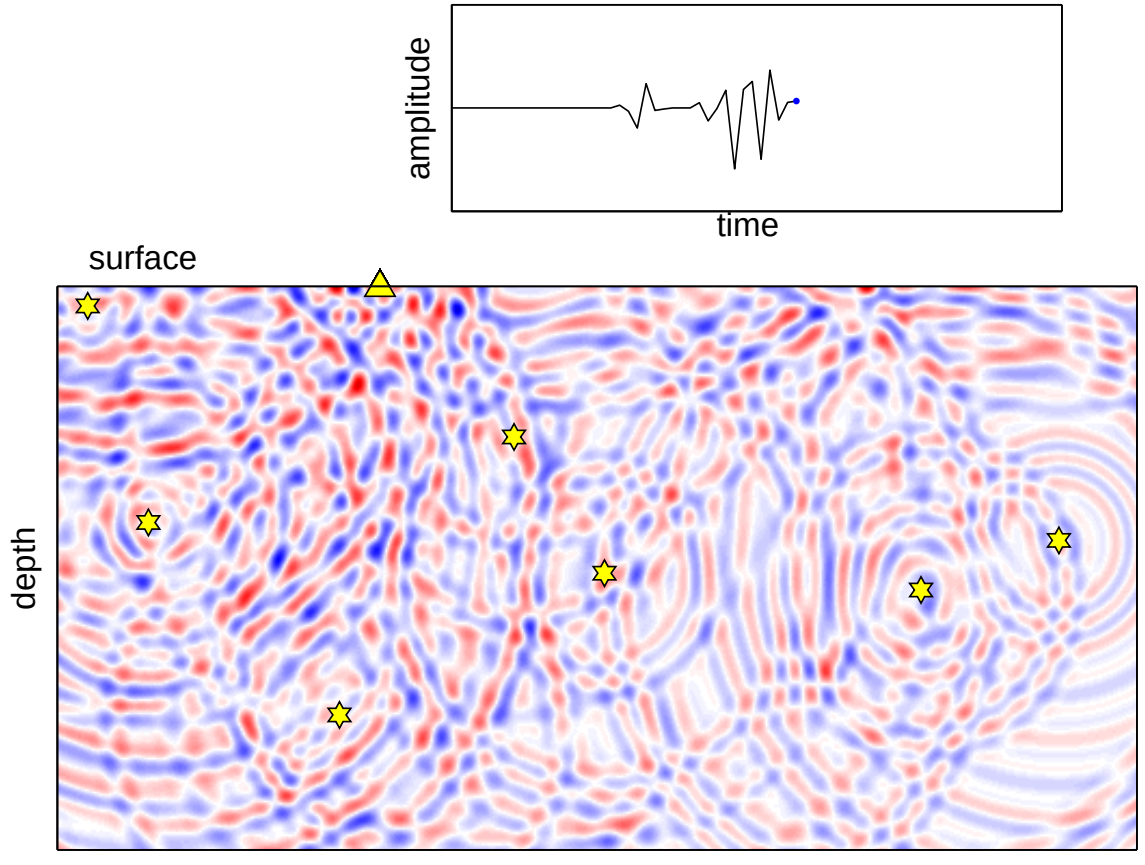

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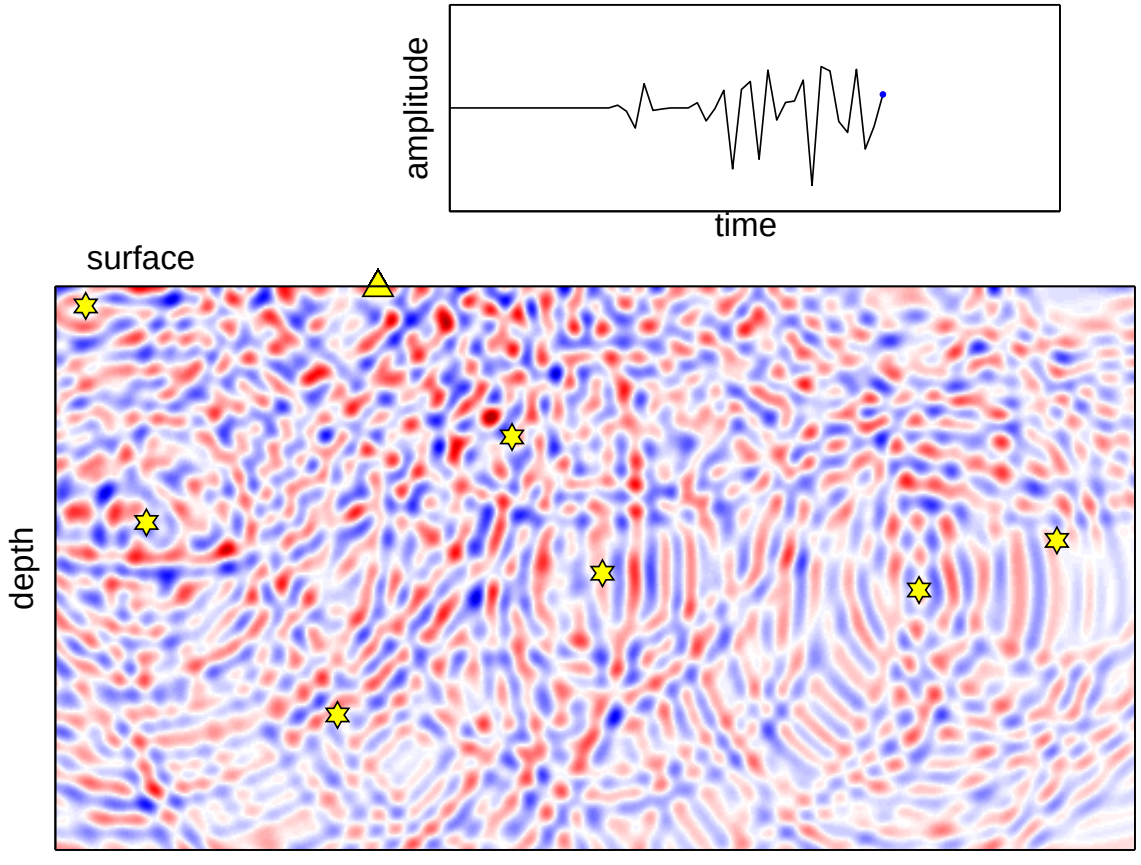

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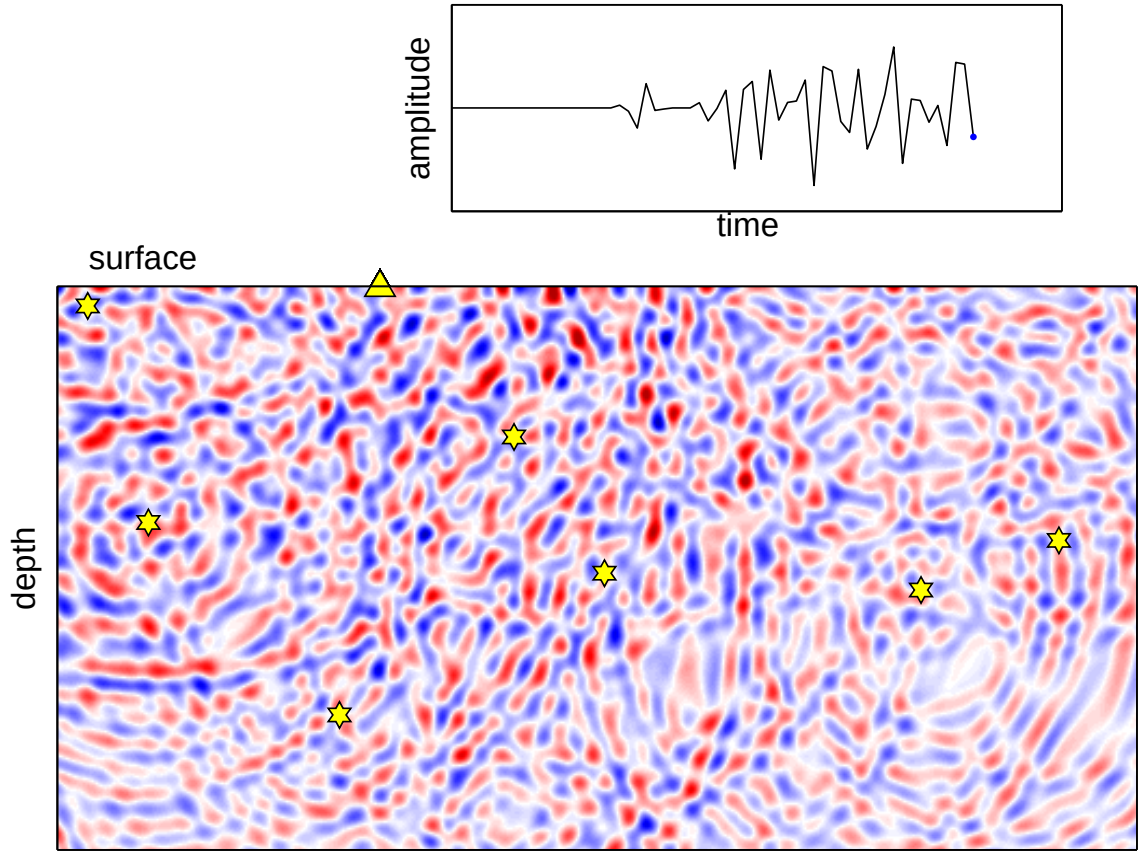

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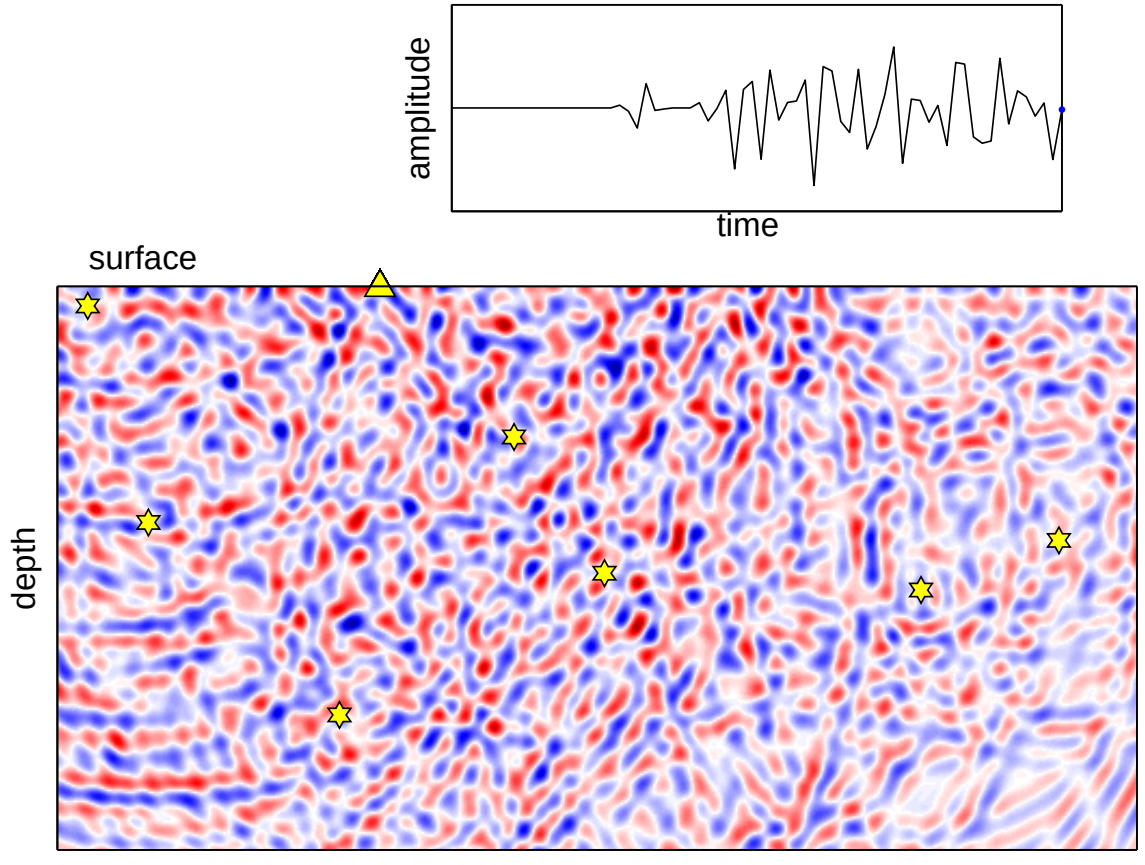

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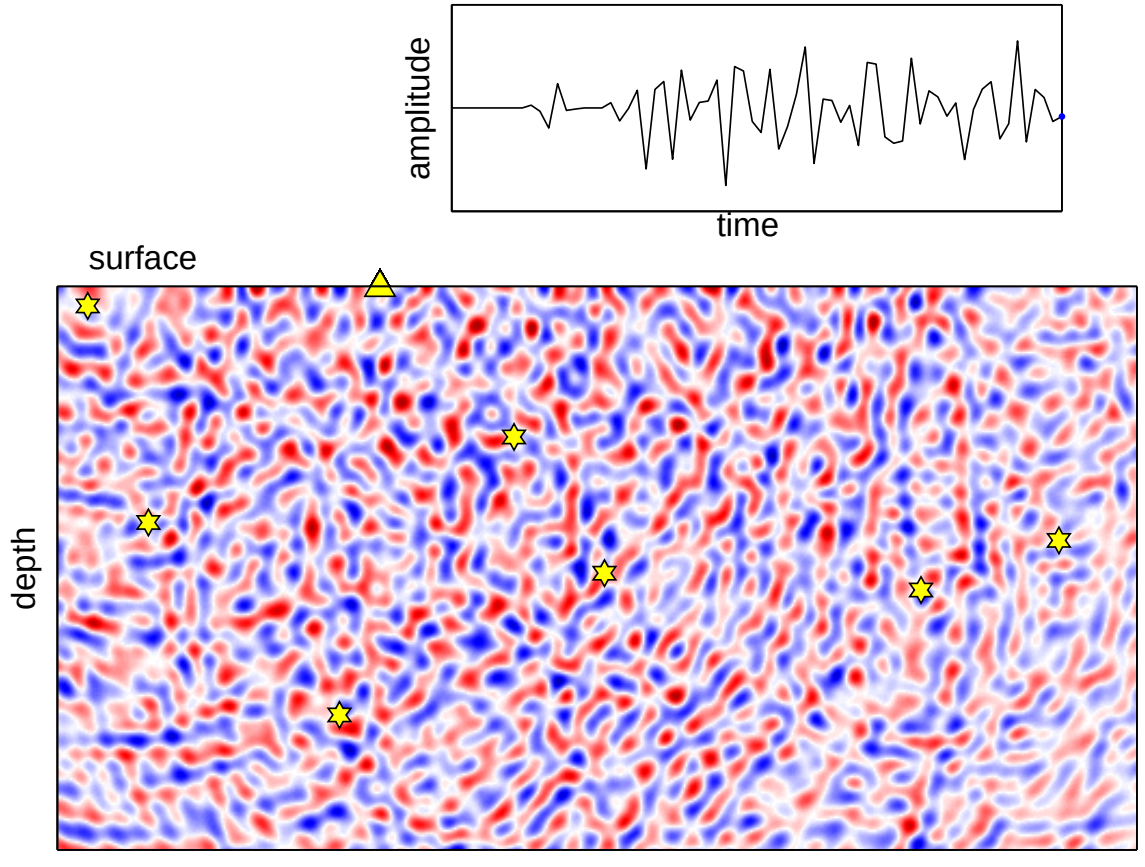

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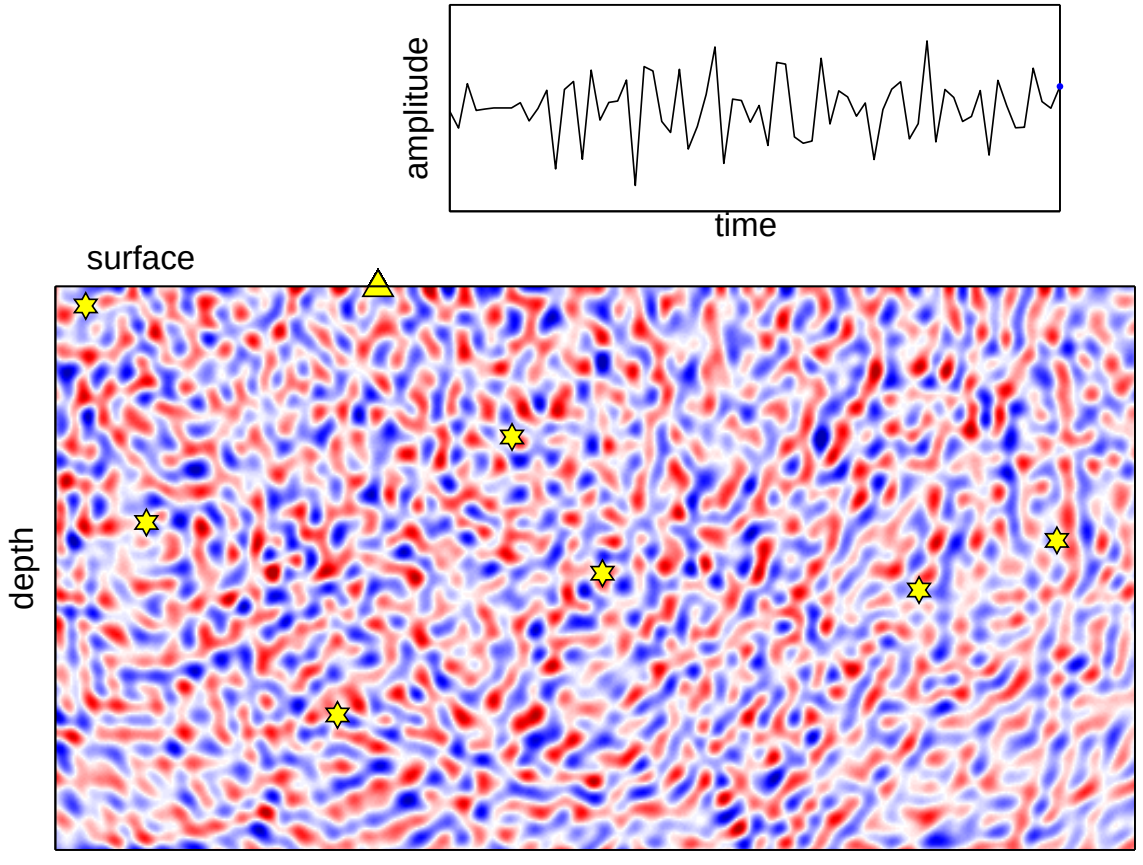

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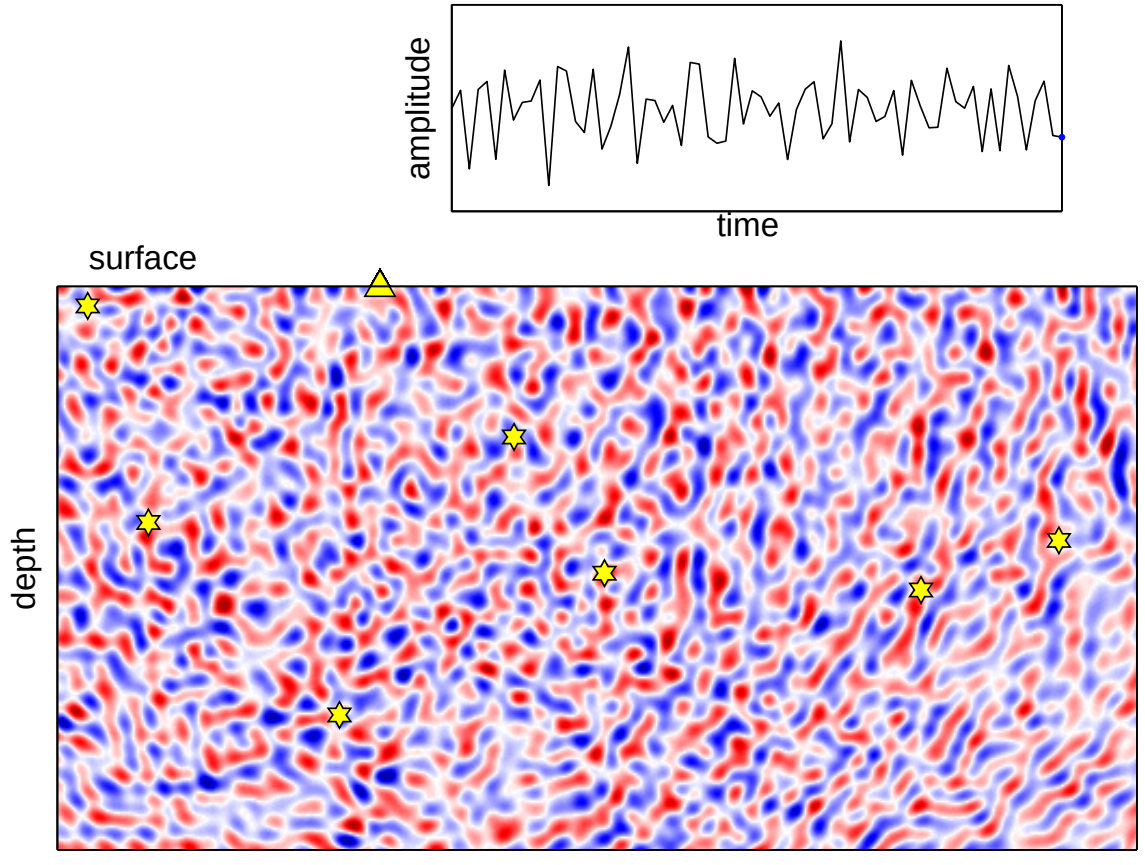

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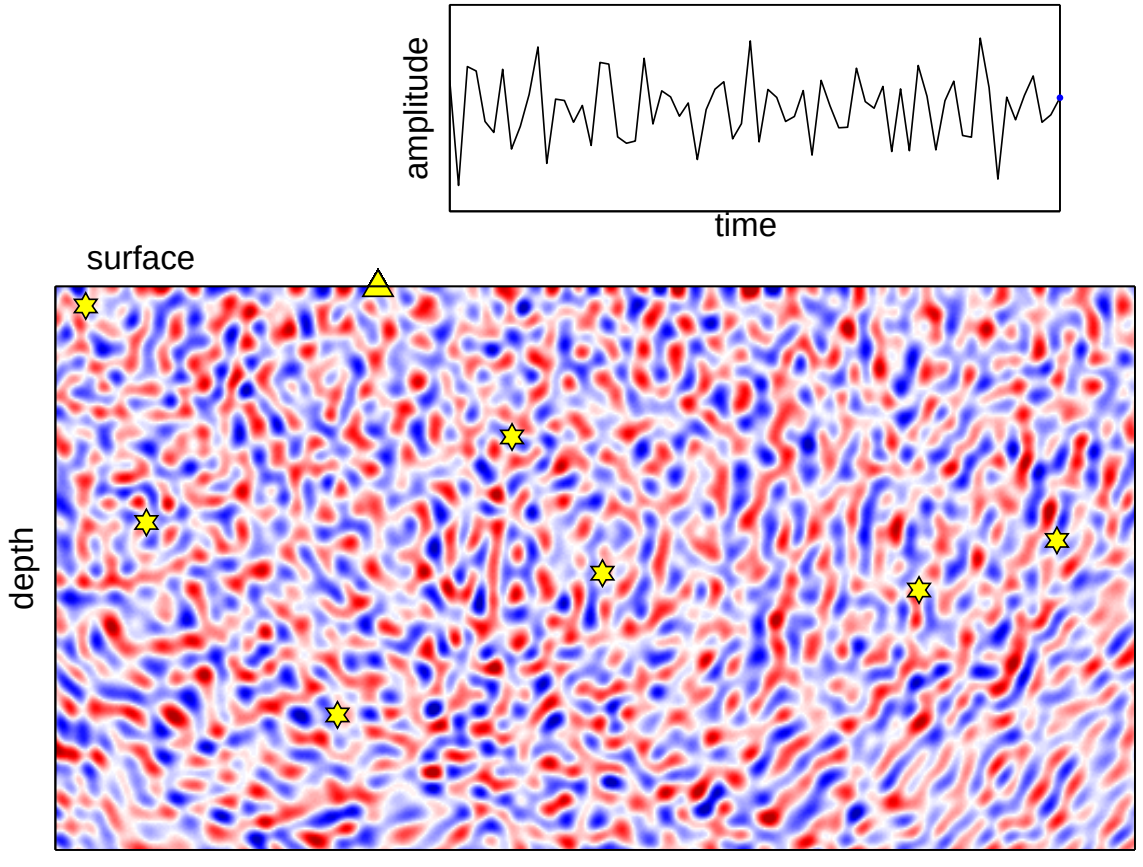

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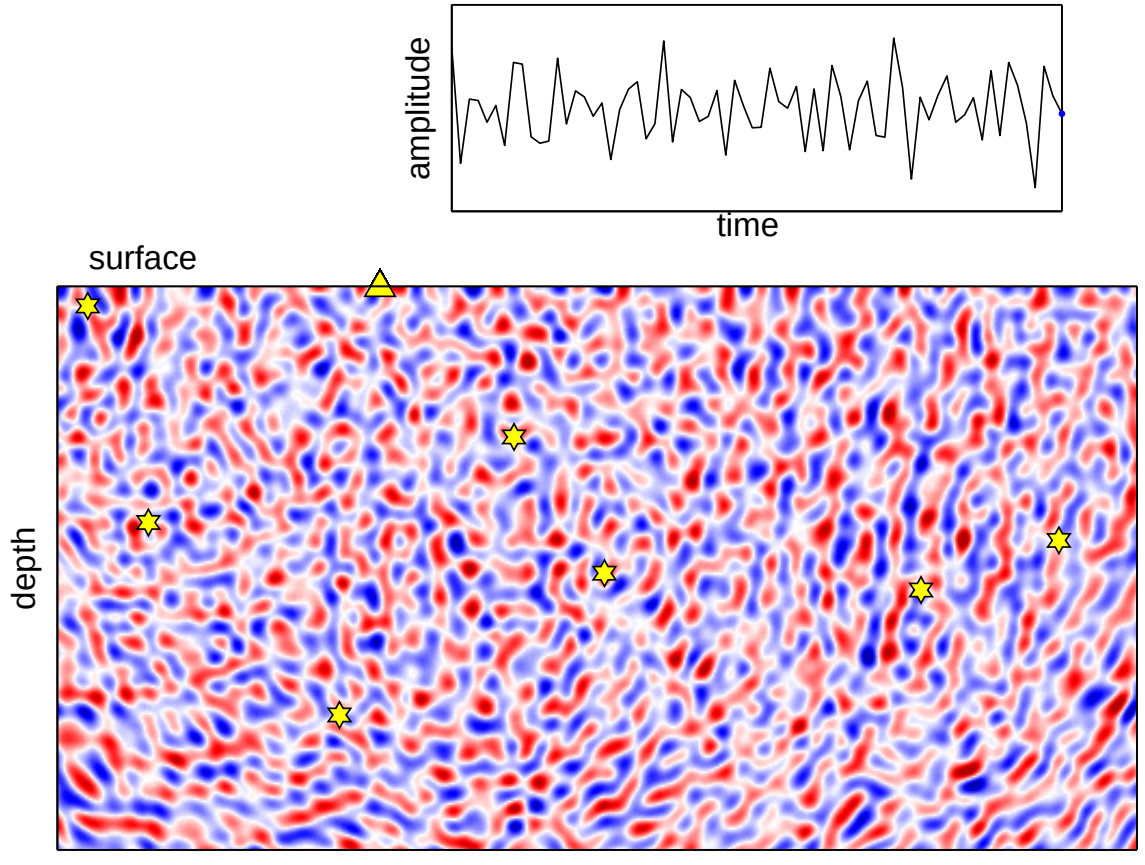

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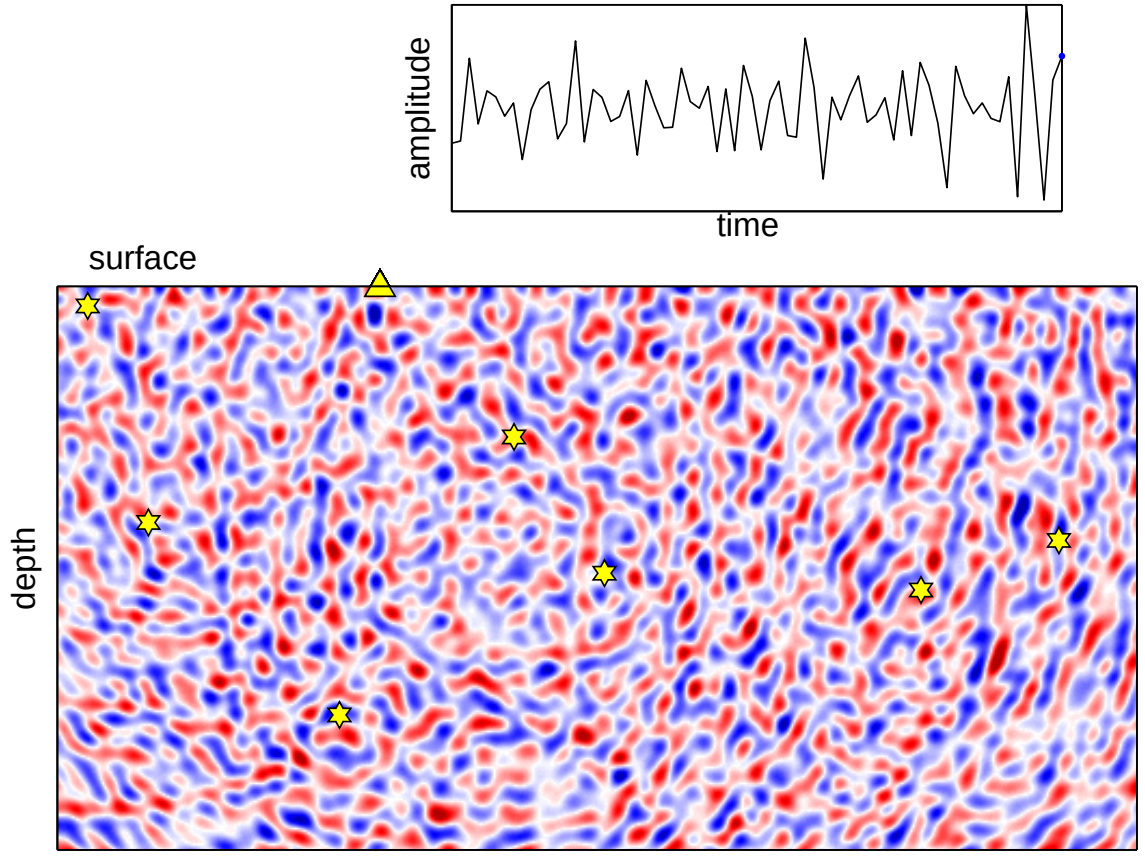
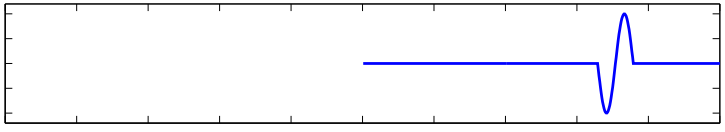


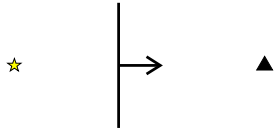

How to make use of these random oscillations?

# Seismic Interferometry (SI)

Use the correlation properties of the field – not the field itself!

impulsive source





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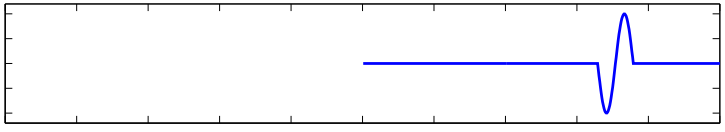
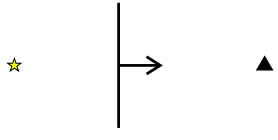
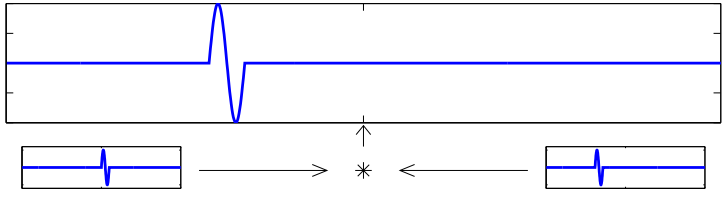
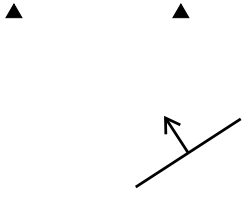




random sources





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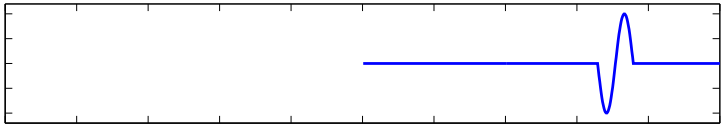

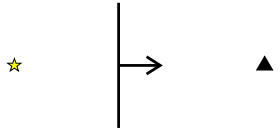

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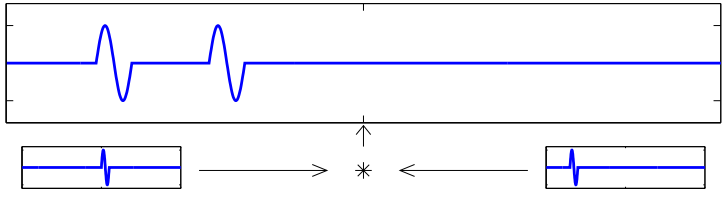

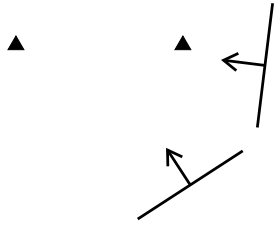

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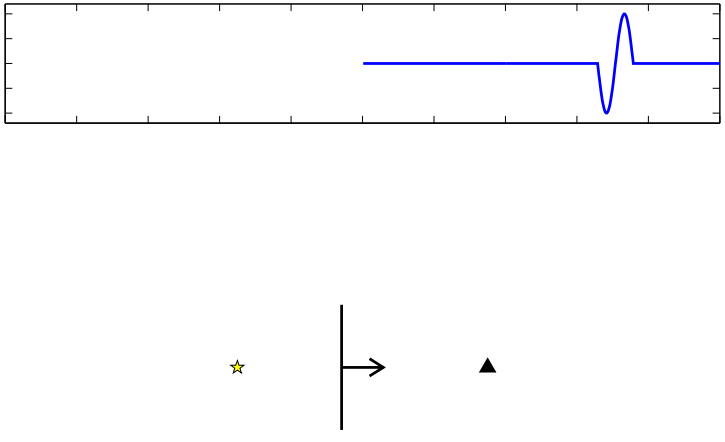

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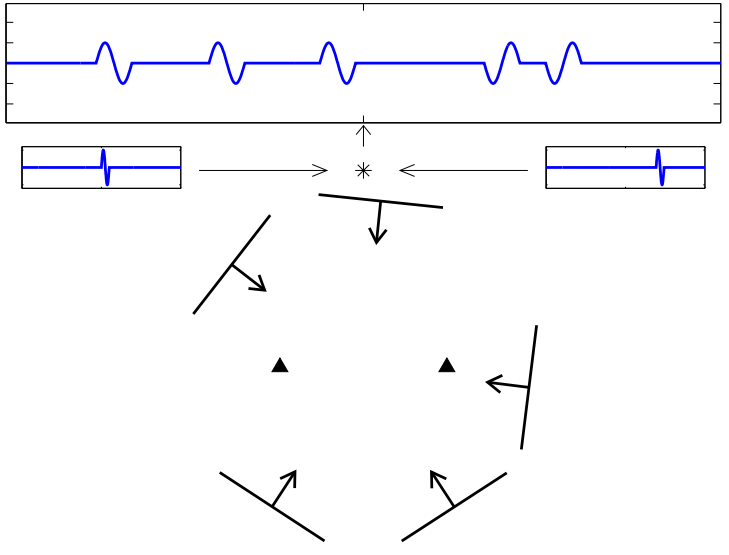

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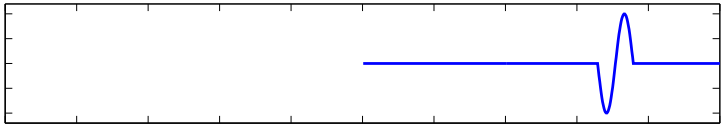

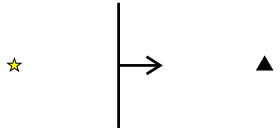

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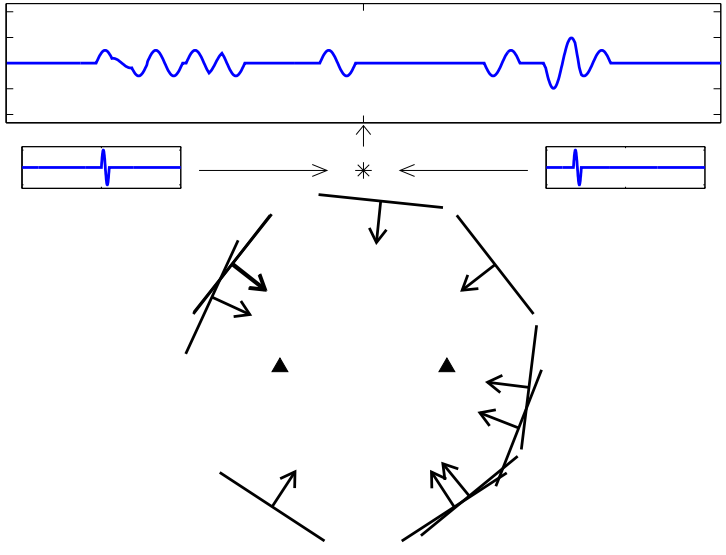

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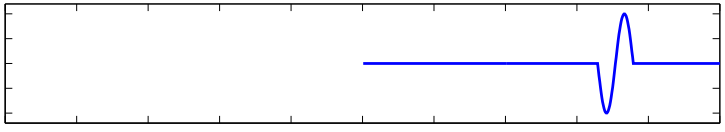

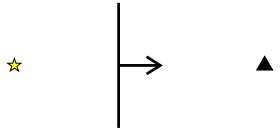

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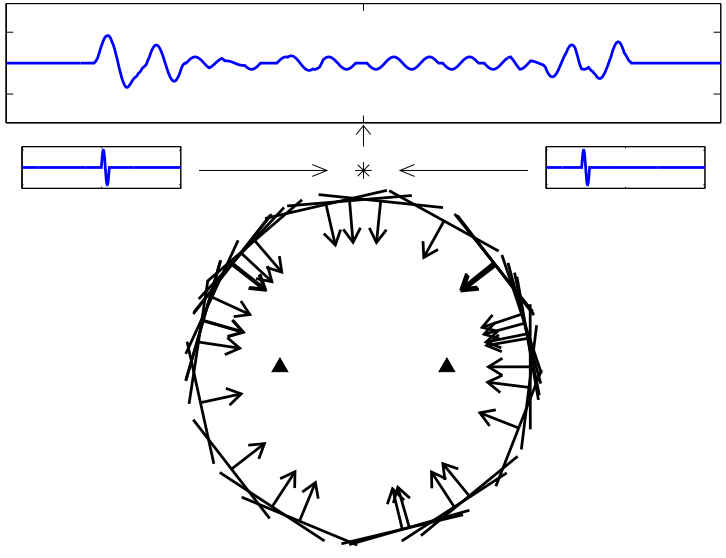

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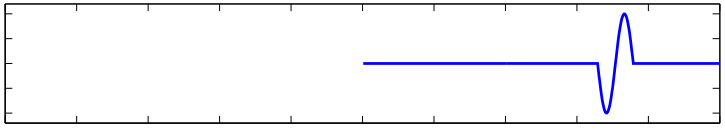

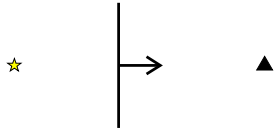

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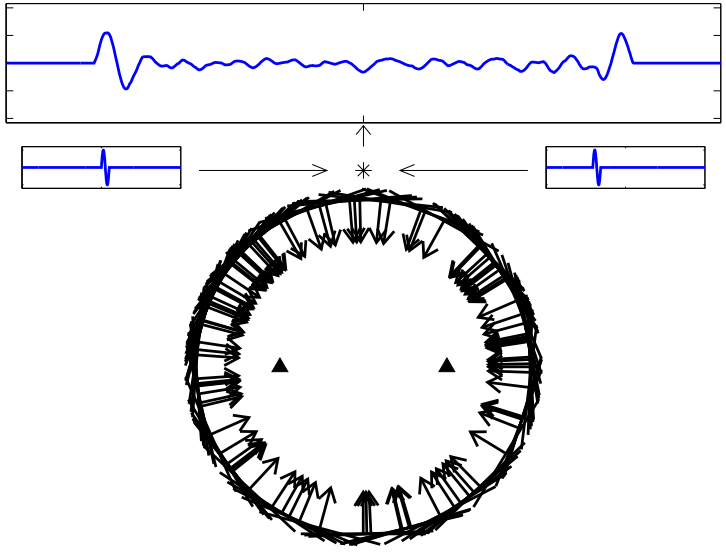

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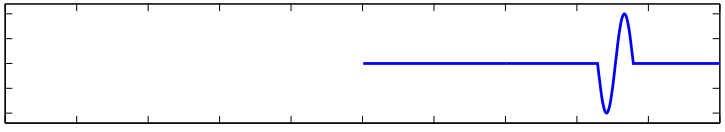

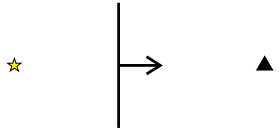

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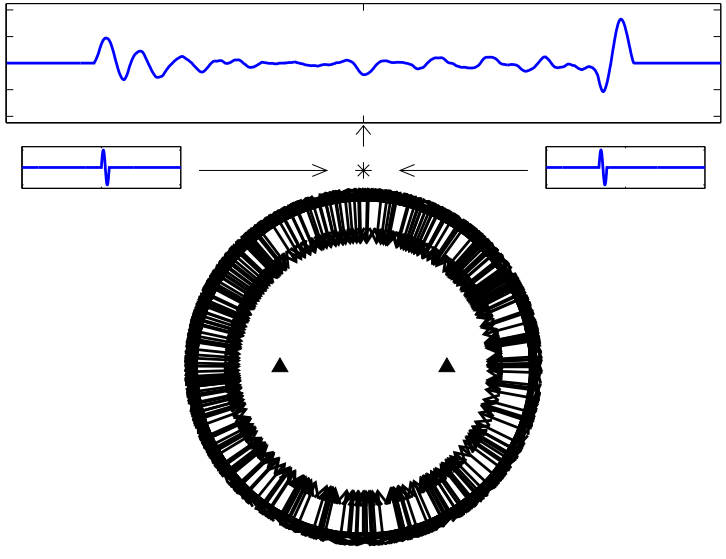

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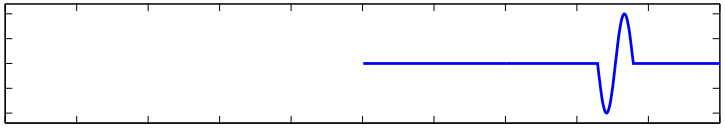

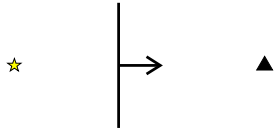

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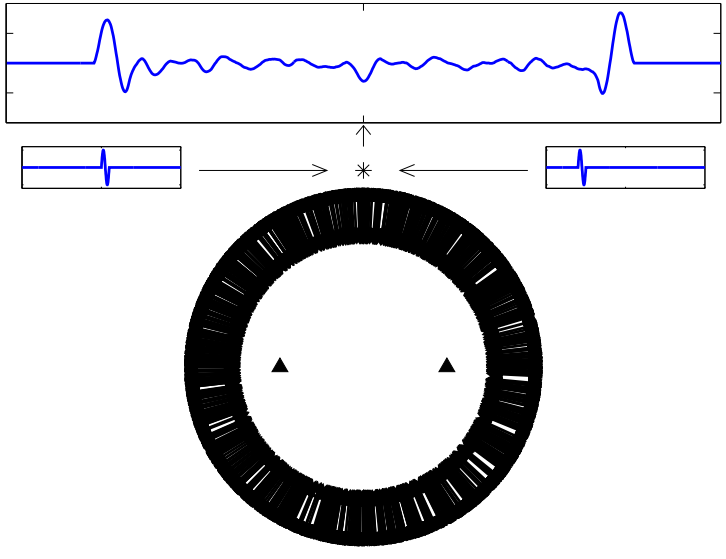

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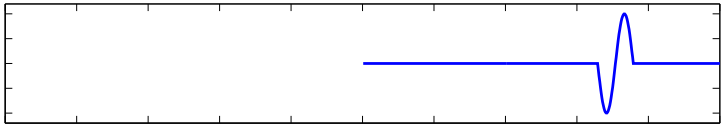

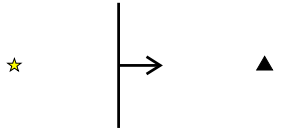

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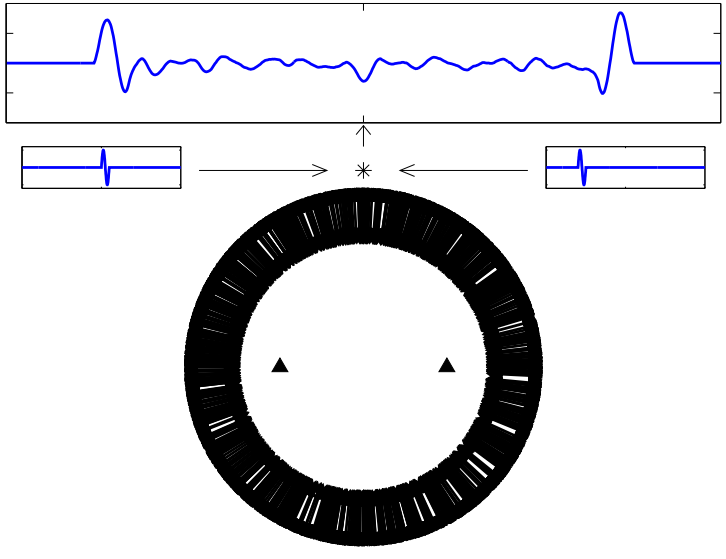
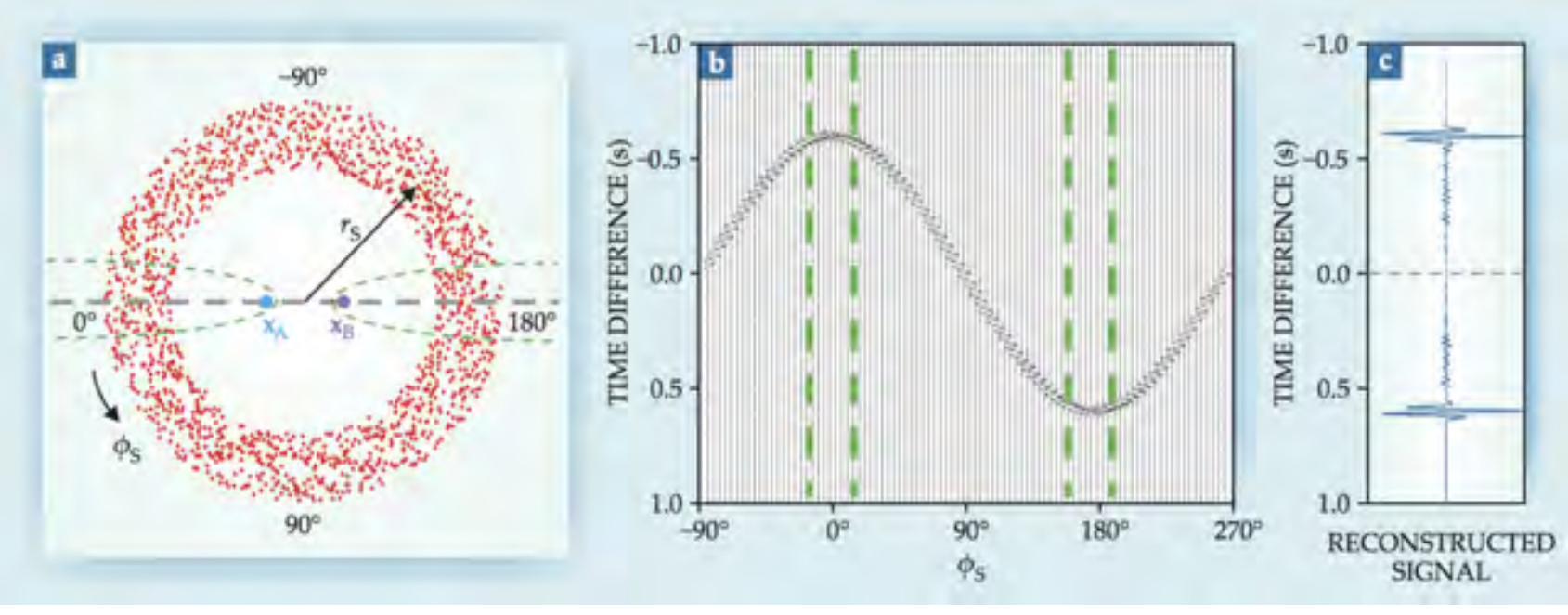


One can create data for tomography from random fields by correlating records from different locations!

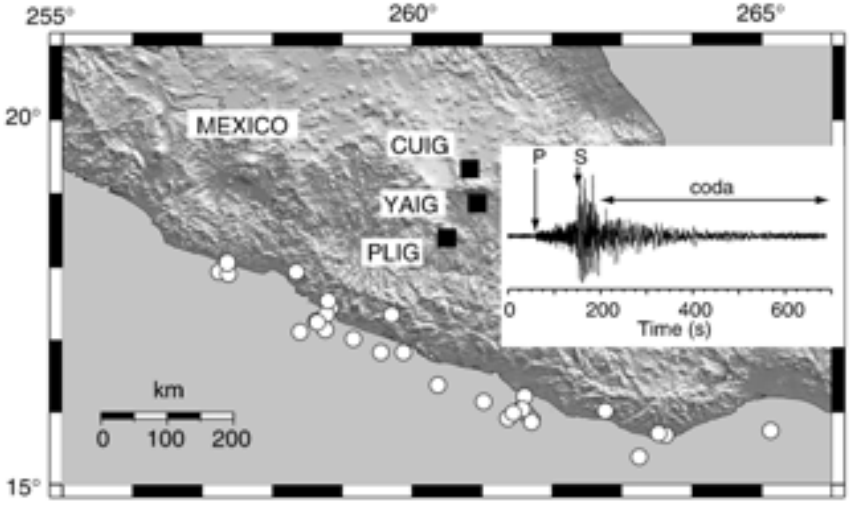
# Seismic Interferometry (SI)

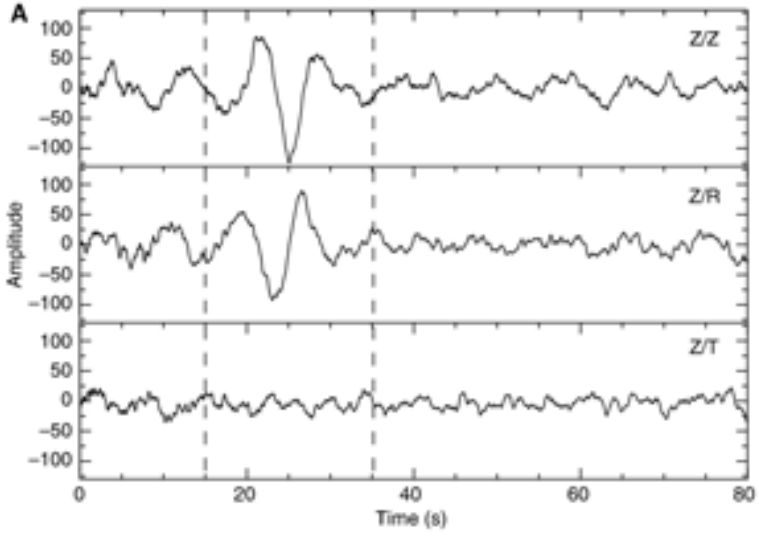
Green's functions extraction:

$$G(\mathbf{x}_B, \mathbf{x}_A, t) + G(\mathbf{x}_B, \mathbf{x}_A, -t) \propto \int_S G(\mathbf{x}_B, \mathbf{x}, t) + G(\mathbf{x}_A, \mathbf{x}, -t) dS$$



# Application 1: coda correlation

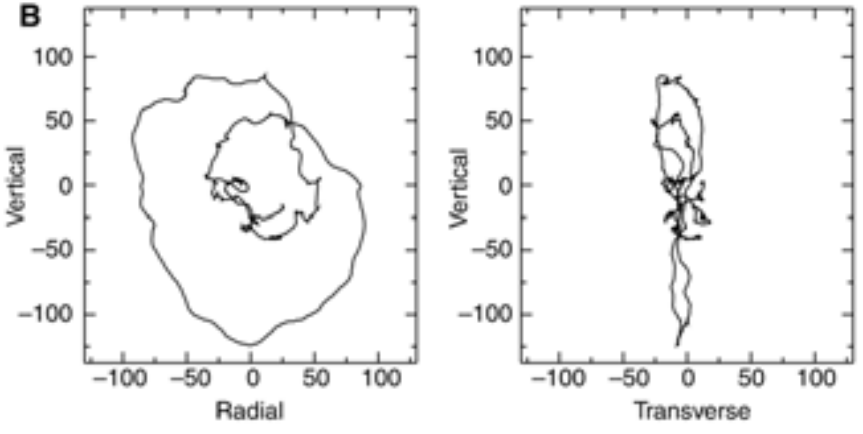


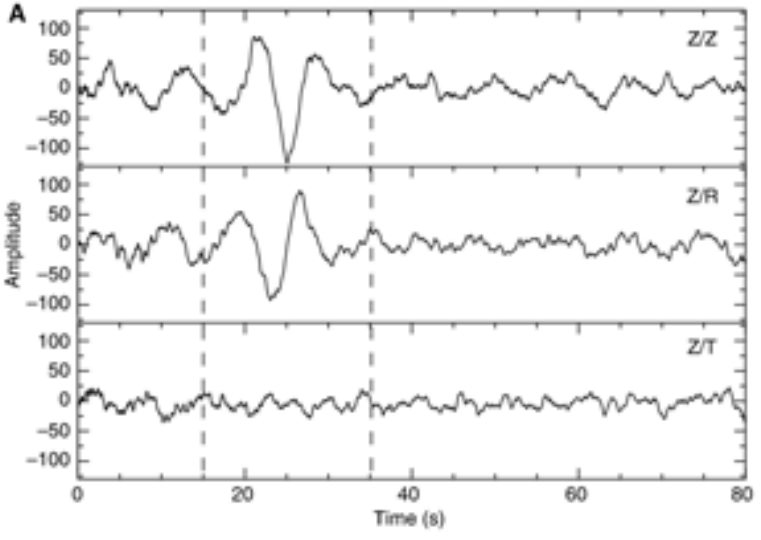




[Campillo and Paul, 2003]

# Application 1: coda correlation

particle motion



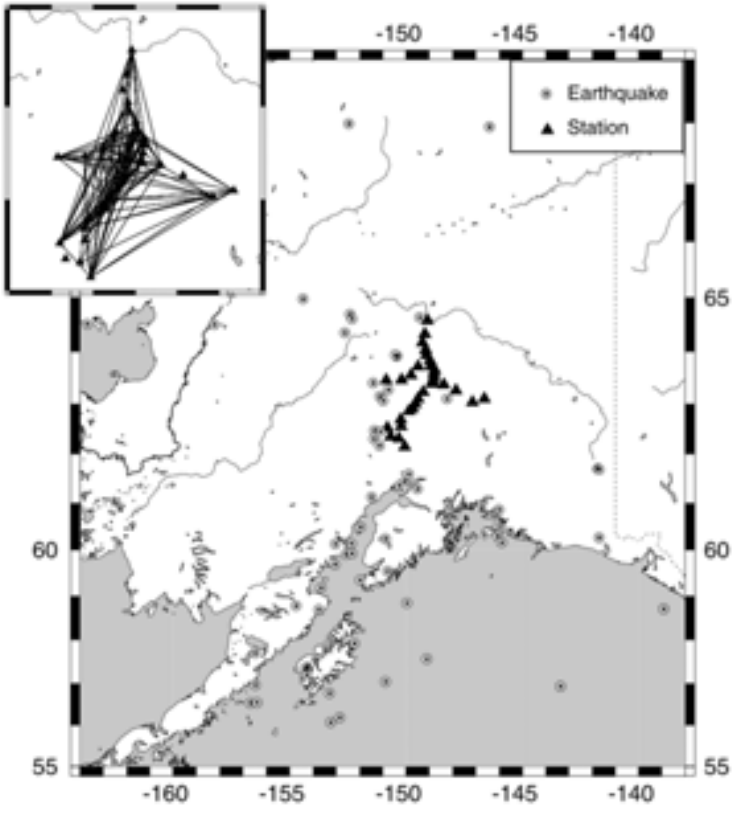




[Campillo and Paul, 2003]

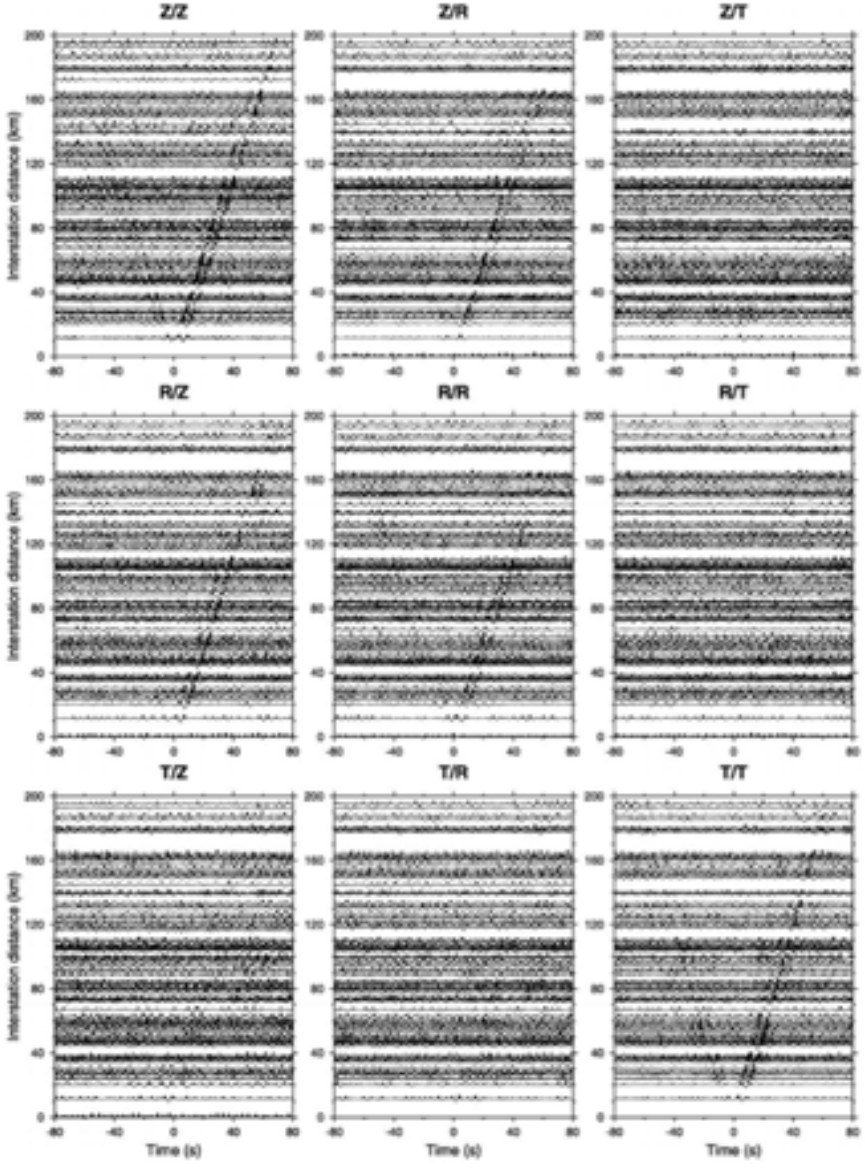
retrieve surface waves from earthquake coda

# Application 2: coda correlation in an array

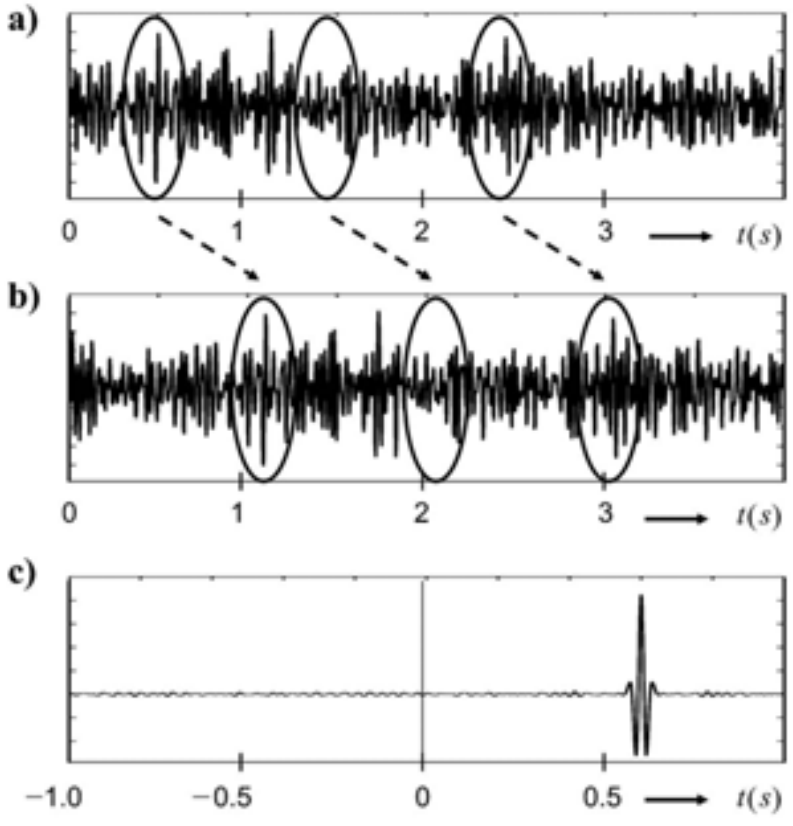
Green's tensor




[Paul et al., 2005]



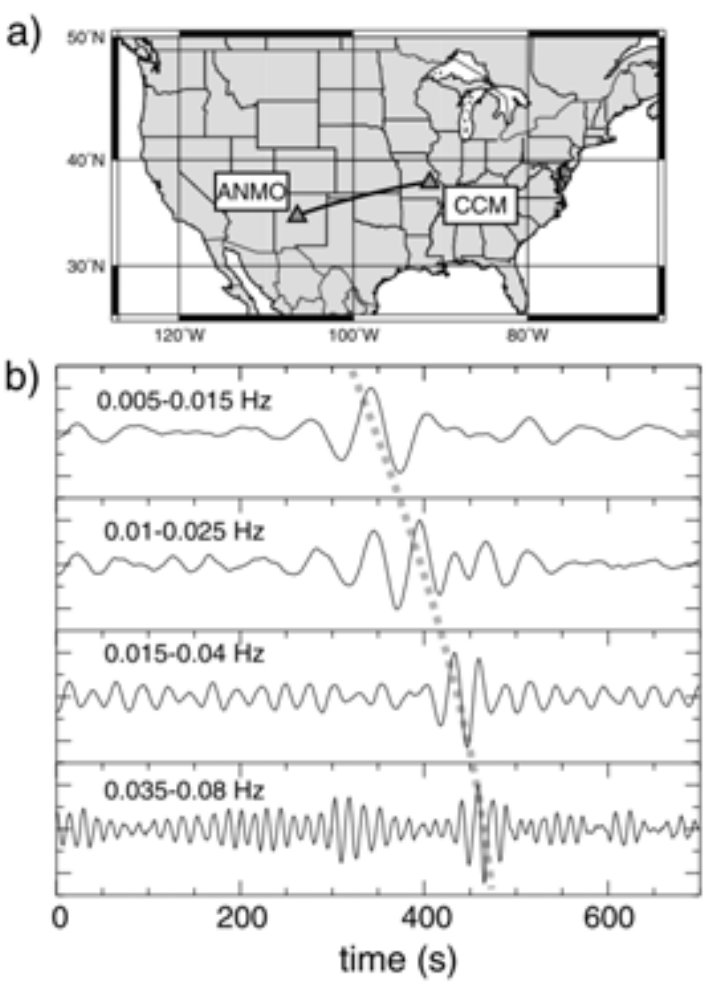
# Application 3: noise correlation

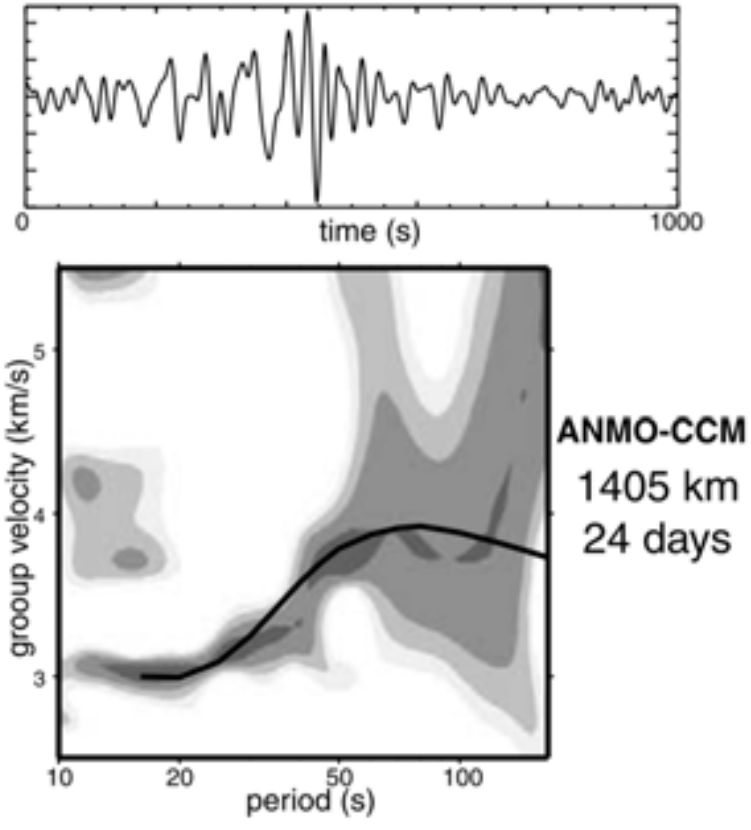



[Wapenaar et al., 2010]

# Application 3: noise correlation

dispersion




[Shapiro and Campillo, 2004]

# First summary

Seismic interferometry

- uses records of a random wavefield that contains the required waves
- waves propagating between receivers are extracted from the random field by cross correlation
- allows to retrieve surface waves traveling between seismic stations

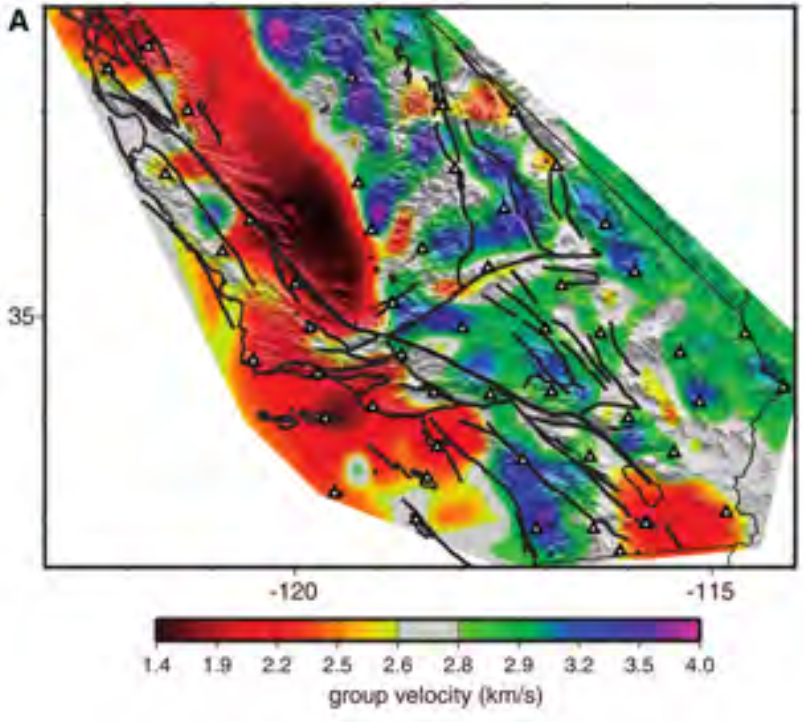
Some review papers on SI:

- [Snieder, 2004]
- [Campillo, 2006]
- [Curtis et al., 2006]
- [Wapenaar et al., 2010]
- [Snieder and Larose, 2013]

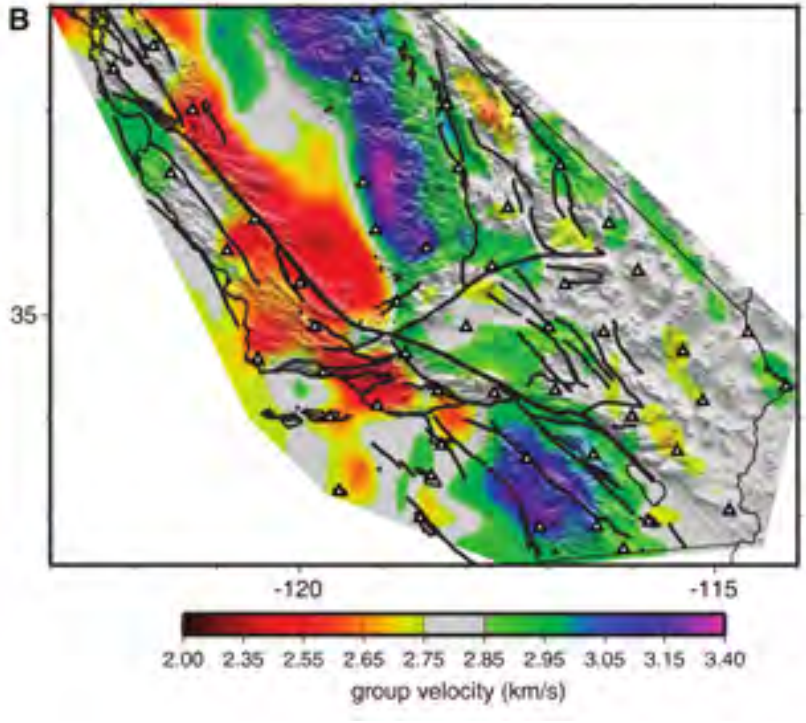
# Application 4: ambient noise surface wave tomography

group velocity maps of Southern California

7.5 s



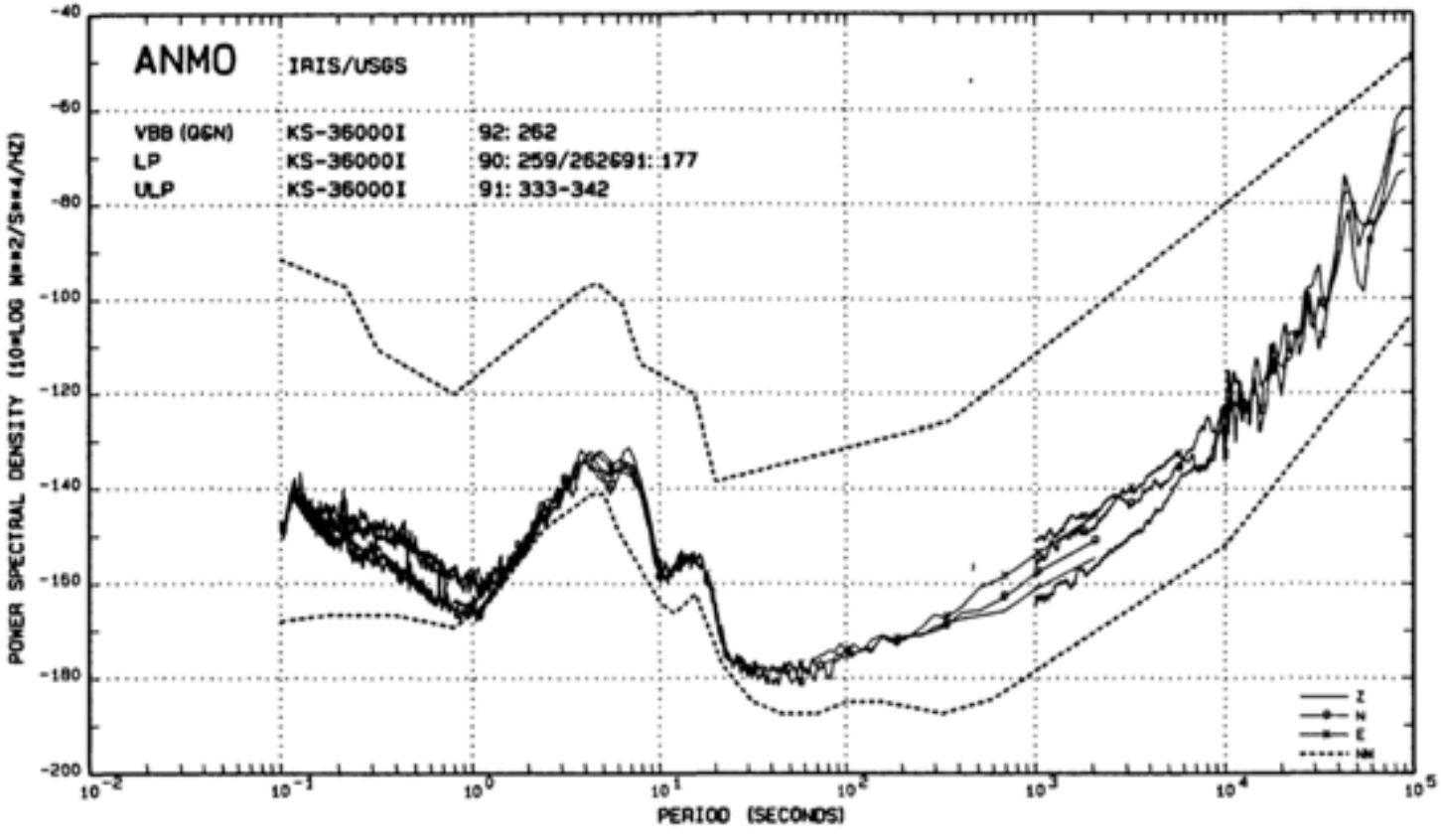

15 s




[Shapiro et al., 2005]

# What is the ambient noise?

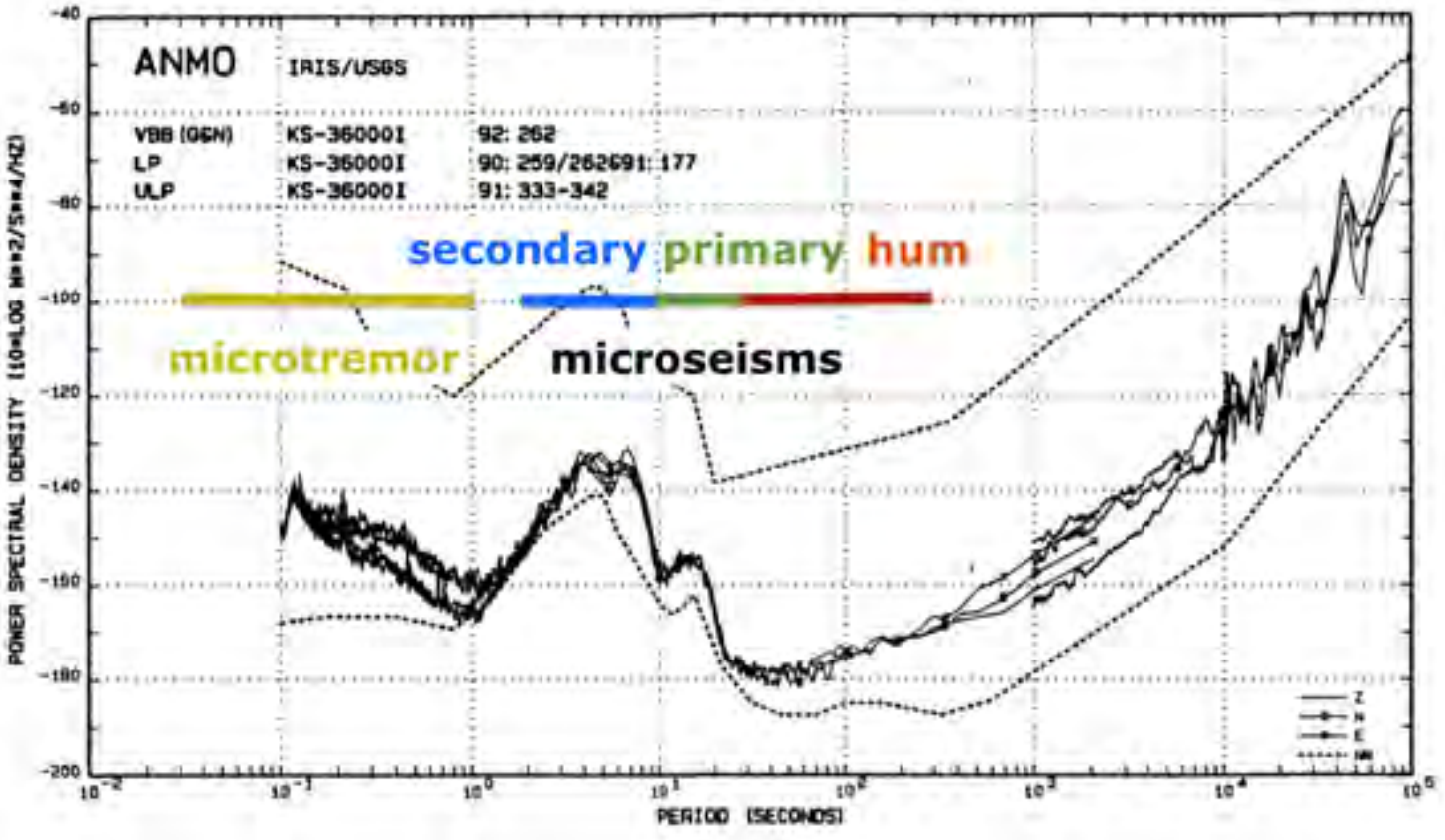
power spectrum of a typical noise record (New Mexico)




[Peterson, 1993]

# What is the ambient noise?

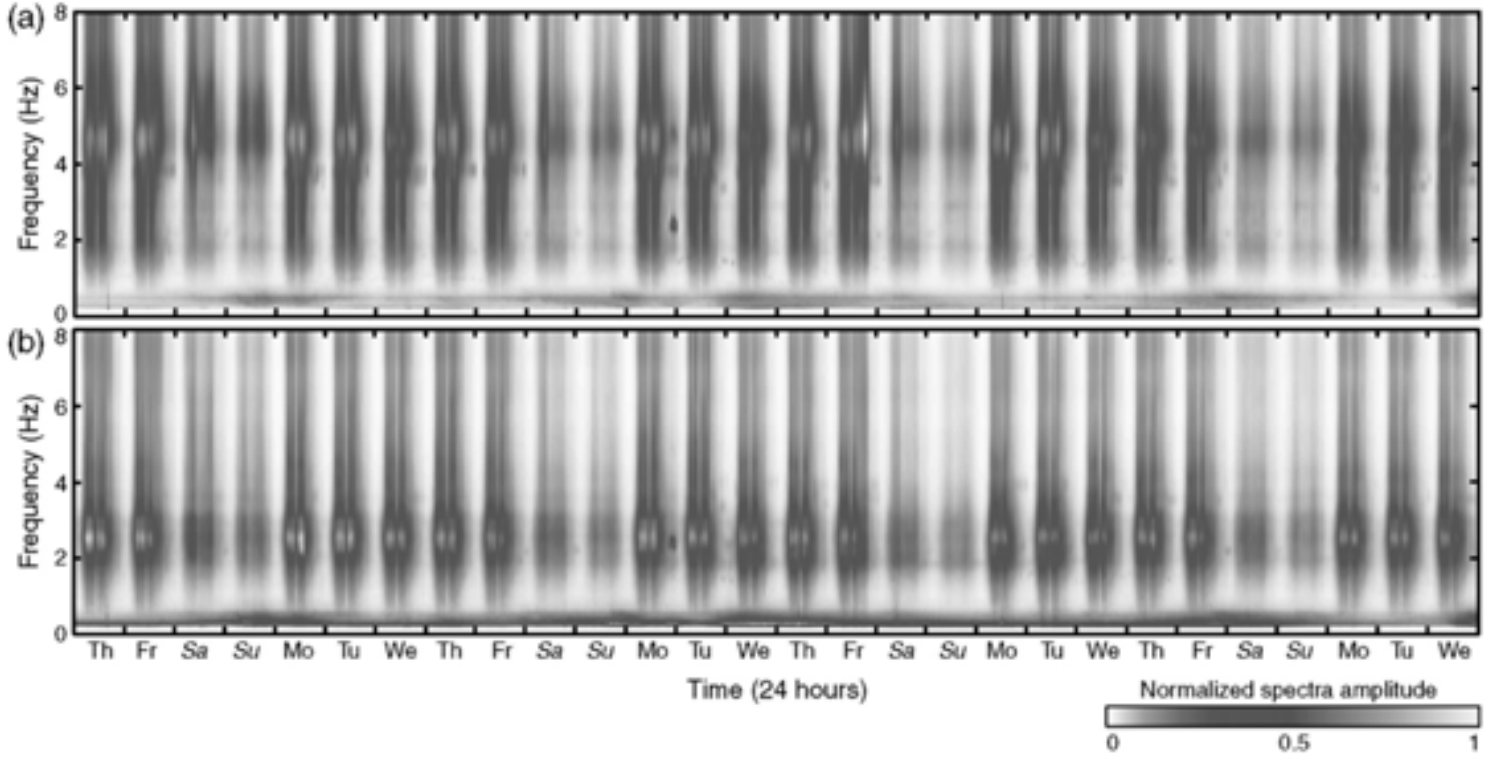
power spectrum of a typical noise record (New Mexico)




[Peterson, 1993]

# Microtremor

vibrations with $f > 1Hz$ mostly of cultural origin (traffic, industry, wind turbines)




[Bonnefoy-Claudet et al., 2006]

# Microseisms

seismic waves excited by the action of ocean waves

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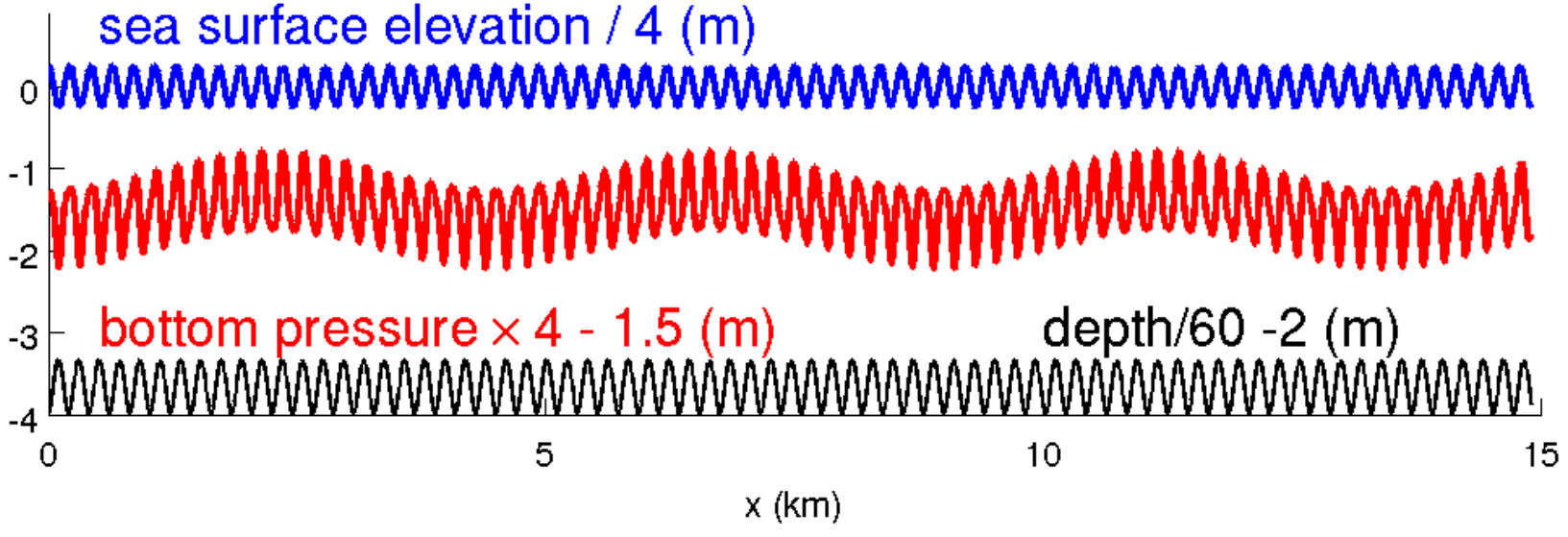
seismic waves excited by the action of ocean waves

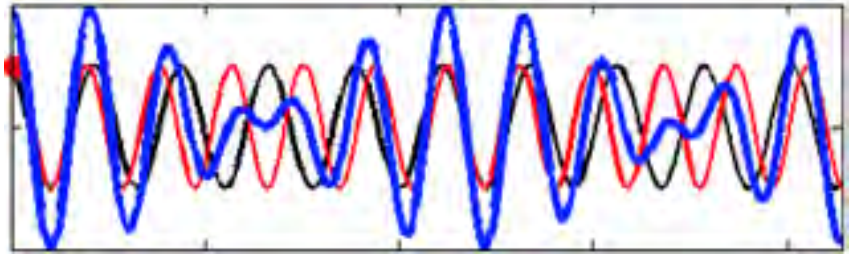
- hum and primary microseisms around 12 s period: interference of waves with ocean bottom topography



# Microseisms

seismic waves excited by the action of ocean waves

- hum and primary microseisms around 12 s period: interference of waves with ocean bottom topography
- secondary (double frequency) microseism around 6 s period: wave-wave interaction



# Microseisms

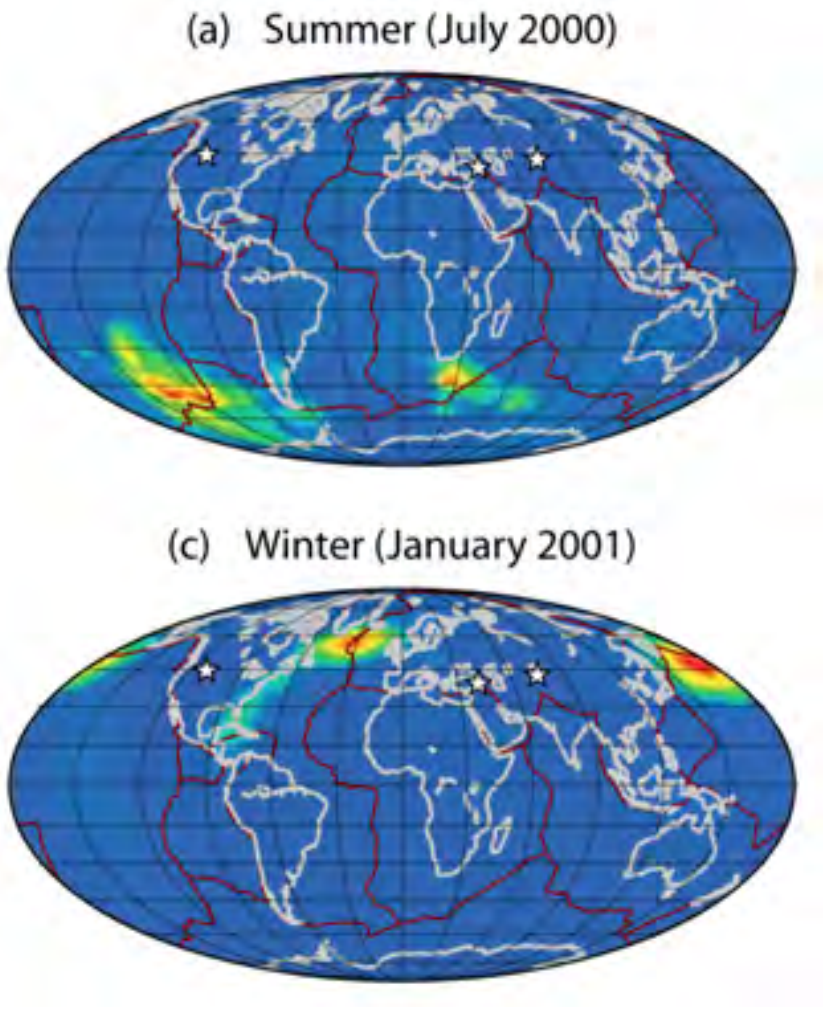
seismic waves excited by the action of ocean waves

- hum and primary microseisms around 12 s period: interference of waves with ocean bottom topography
- secondary (double frequency) microseism around 6 s period: wave-wave interaction

The source site effect due to the water depth modulates the efficiency of seismic wave generation.

Seismic sources are neither simply below wind systems nor at the shore!

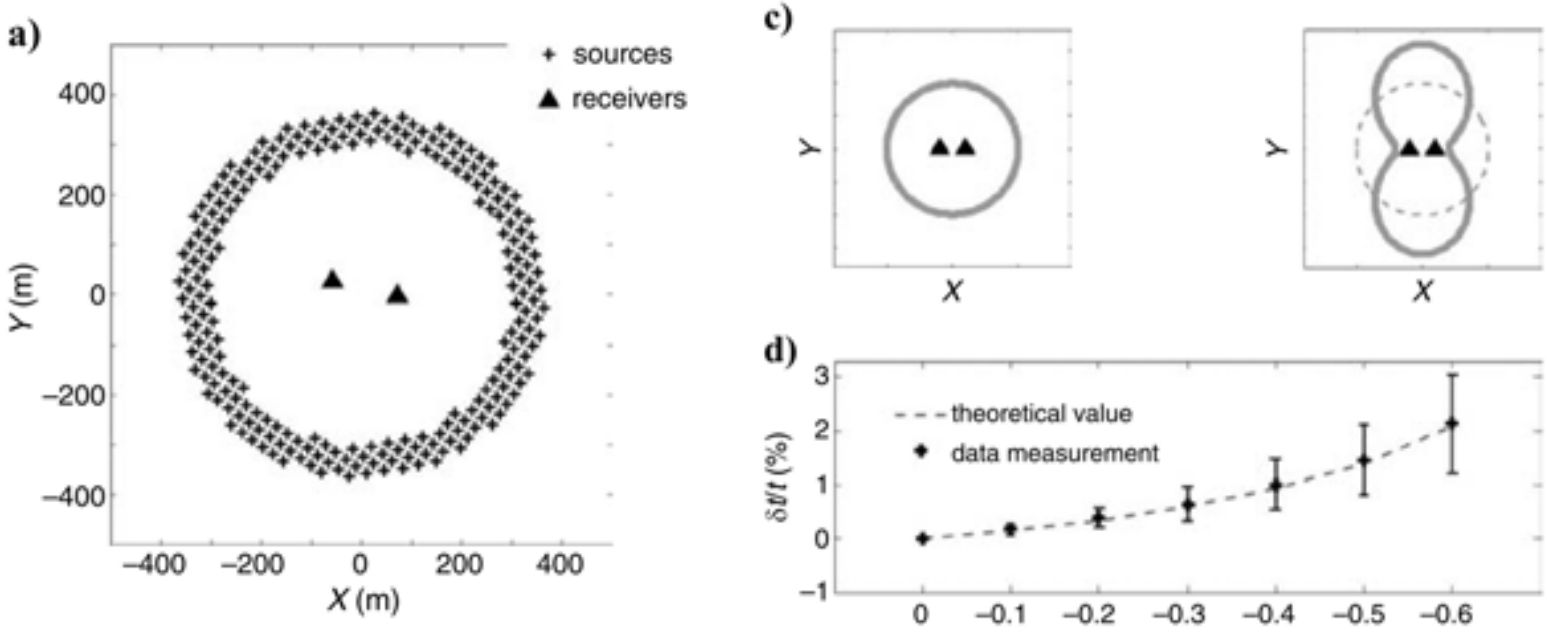
# Source regions of secondary microseisms




[Landès et al., 2010]

# Consequences for tomography

- source distribution is variable $\Rightarrow$ potenial for estimates of wave velocities




[Froment et al., 2010]

$\Rightarrow$ long time averaging required to reduce the effect of non-uniform source distributions.

# Summary

- seismic interferometry allows to retrieve the Green's function from random seismic fields (e.g. ambient noise)
- the ambient field below 0.3 Hz is generated in the oceans (microseisms)
- high frequency cultural noise above 1 Hz

$\Rightarrow$ allows for surface wave tomography without individually identified sources

- uneven source distribution can bias velocity estimates

# References



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