Ambient Noise Tomography fundamentals

Christoph Sens-Schönfelder

GFZ German Research Centre for Geosciences, Potsdam, Germany

4DMB meeting, 2.2.2018
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 wavefield 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
Seismic records

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

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

How to make use of these random oscillations?
The ambient wavefield

How to make use of these random oscillations?
The ambient wavefield

How to make use of these random oscillations?
The ambient wavefield
The ambient wavefield

How to make use of these random oscillations?
How to make use of these random oscillations?
The ambient wavefield
The ambient wavefield

How to make use of these random oscillations?
The ambient wavefield

How to make use of these random oscillations?
The ambient wavefield

Ho
w to make use of these random oscillations?
The ambient wavefield
The ambient wavefield

How to make use of these random oscillations?
The ambient wavefield

How to make use of these random oscillations?
Seismic Interferometry (SI)

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

Impulsive source

* → ▲
Seismic Interferometry (SI)

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

impulsive source

random sources
Seismic Interferometry (SI)

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

impulsive source

random sources

One can create data for tomography from random fields by correlating records from different locations!
Seismic Interferometry (SI)

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

impulsive source

random sources

One can create data for tomography from random fields by correlating records from different locations!
Seismic Interferometry (SI)

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

impulsive source

random sources

One can create data for tomography from random fields by correlating records from different locations!
Seismic Interferometry (SI)

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

impulsive source

random sources

One can create data for tomography from random fields by correlating records from different locations!
Seismic Interferometry (SI)

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

impulsive source

random sources
Seismic Interferometry (SI)

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

impulsive source

random sources

One can create data for tomography from random fields by correlating records from different locations!
Seismic Interferometry (SI)

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

impulsive source

random sources

One can create data for tomography from random fields by correlating records from different locations!
Seismic Interferometry (SI)

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

impulsive source

random sources

One can create data for tomography from random fields by correlating records from different locations!
Seismic Interferometry (SI)

Green’s functions extraction:

\[ G(x_B, x_A, t) + G(x_B, x_A, -t) \propto \int_S G(x_B, x, t) + G(x_A, x, -t) dS \]
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 $f > 1\text{Hz}$ mostly of cultural origin (traffic, industry, wind turbines)

[Bonnefoy-Claudet et al., 2006]
Microseisms

seismic waves excited by the action of ocean waves
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
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 microseisims 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 $\Rightarrow$ potential for estimates of wave velocities

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

[Froment et al., 2010]

GFZ

HELMHOLTZ GEMEINSCHAFT

Potsdam
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
⇒ allows for surface wave tomography without individually identified sources
▶ uneven source distribution can bias velocity estimates
References


