Effect of shallow heterogeneities on wavefield gradients measurements

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How sensitive are the wavefield gradients to shallow localized velocity changes?

In this study we **investigate the sensitivity of the wavefield and the wavefield gradient measurements** to shallow localized velocity changes.

Seismic simulation software	Spectral element simulation software (SEM46[1]) modified: rotations and strains as a direct output

Experiments performed

Seismic array placed above a velocity anomaly

Weak anomaly
(10% velocity drop)

Strong anomaly
(70% velocity drop)

[1] Brossier et al. 2019, “Efficient time-domain 3D elastic and viscoelastic full-waveform inversion using a spectral-element method on flexible Cartesian-based mesh”

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We performed each experiment two times, the first time considering a fully homogeneous medium, the second time including the seismic anomaly.

How a seismic anomaly interacts with the wavefield and its observables?

Phase shift

The seismic phases acquire a delay or advance with respect to the homogeneous case.

↓

Very precise methods to measure it by frequency-time decomposition, adapted to slight velocity variation, the continuous wavelet transform[2]

Amplitude variations

The normalized waveform changes its amplitude when the anomaly is placed in the medium

↓

Comparison of the amplitude in the time domain

Necessary for seismic monitoring, our goal!

[2]Mao et al 2019, "On the measurement of seismic traveltime changes in the time-frequency domain with wavelet cross-spectrum analysis"

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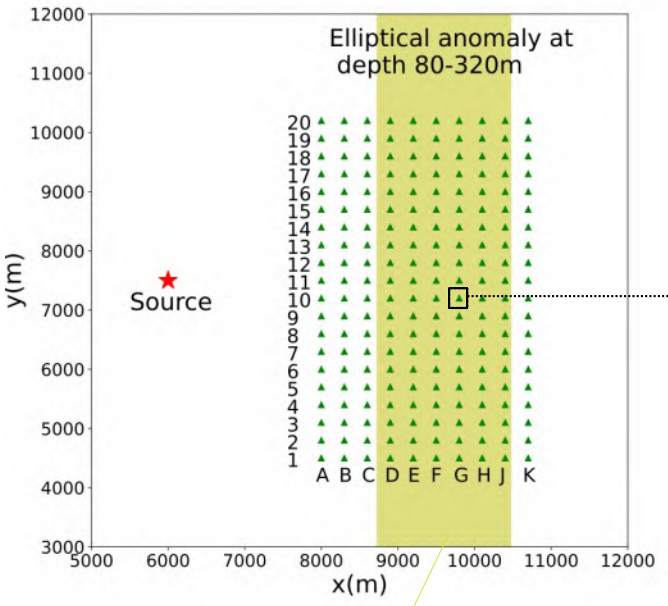
Weak anomaly experiment

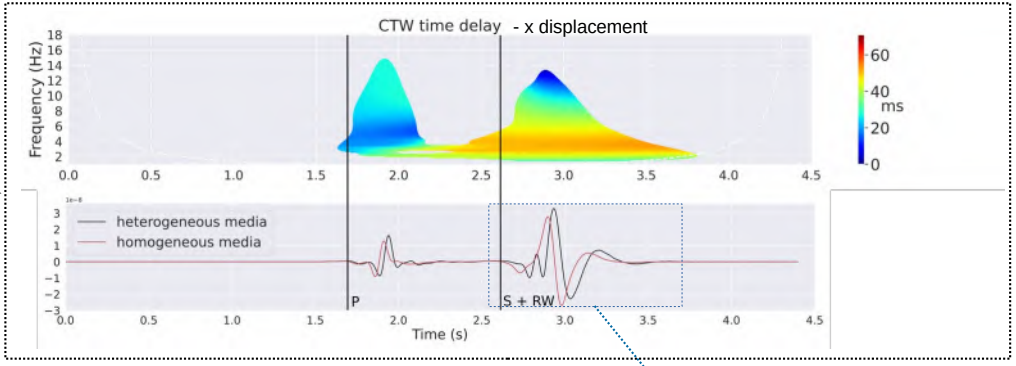
Continuous wavelet analysis

Experiment configuration



10% velocity drop

Cross wavelet transform. UP: delay observed in the time frequency domain.
BOTTOM: waveforms in the time domain



Measurement of the
Rayleigh waves delay

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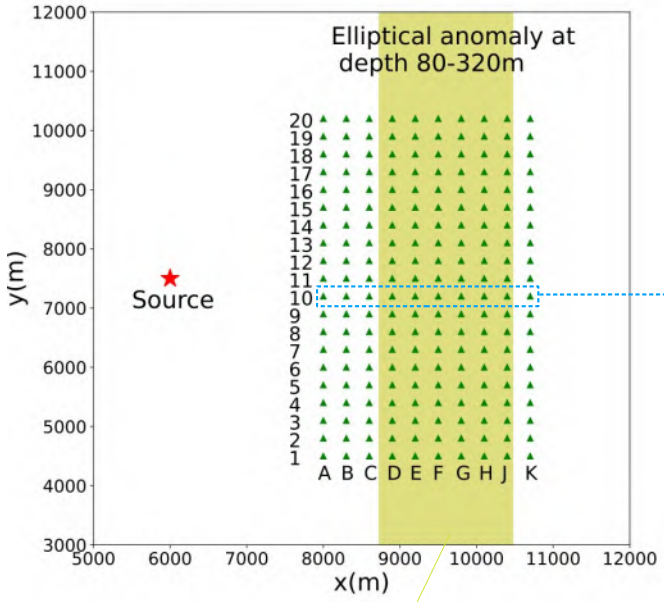
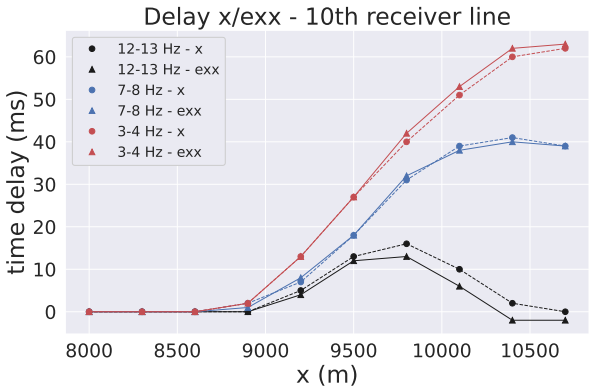
Weak anomaly experiment

Delay measured at the 10th line of receivers in three frequency bands, 3-4Hz, 7-8Hz, 12-13Hz

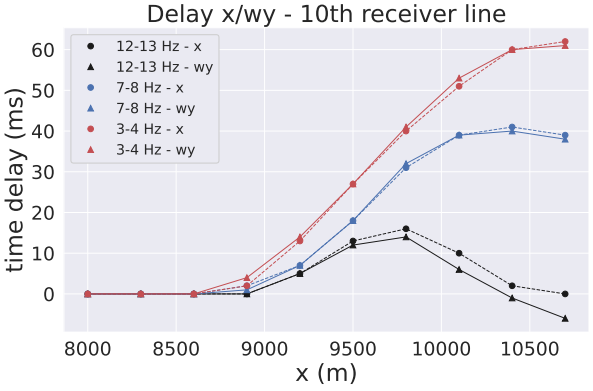
Experiment configuration



10% velocity drop



Displacement versus strain



Displacement versus rotation

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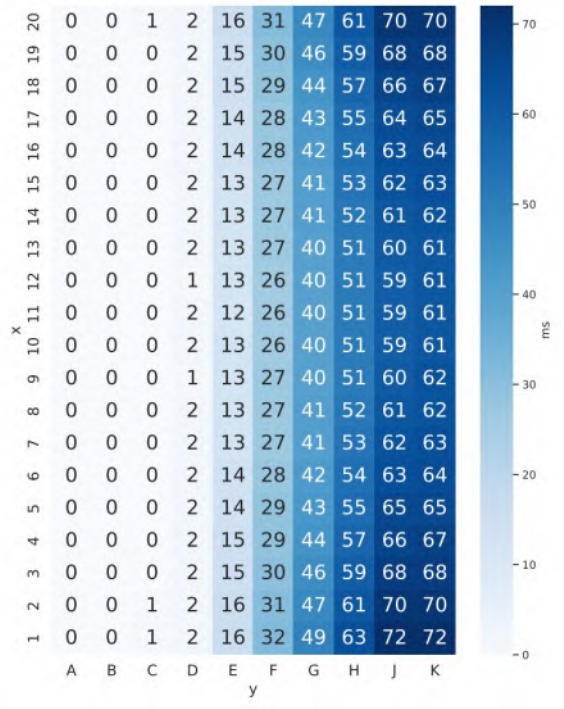
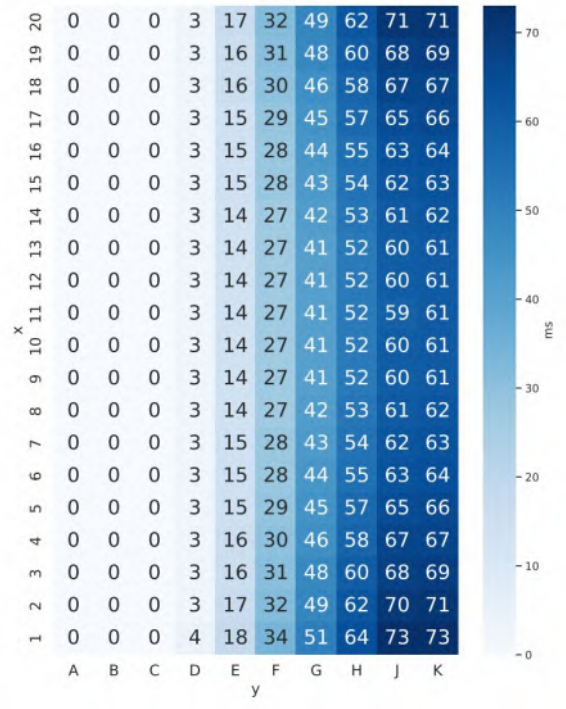
Observables sensitivity comparison

Delay recorded at each receiver of the array (3-4Hz)



Displacement x



Rotation ω_y

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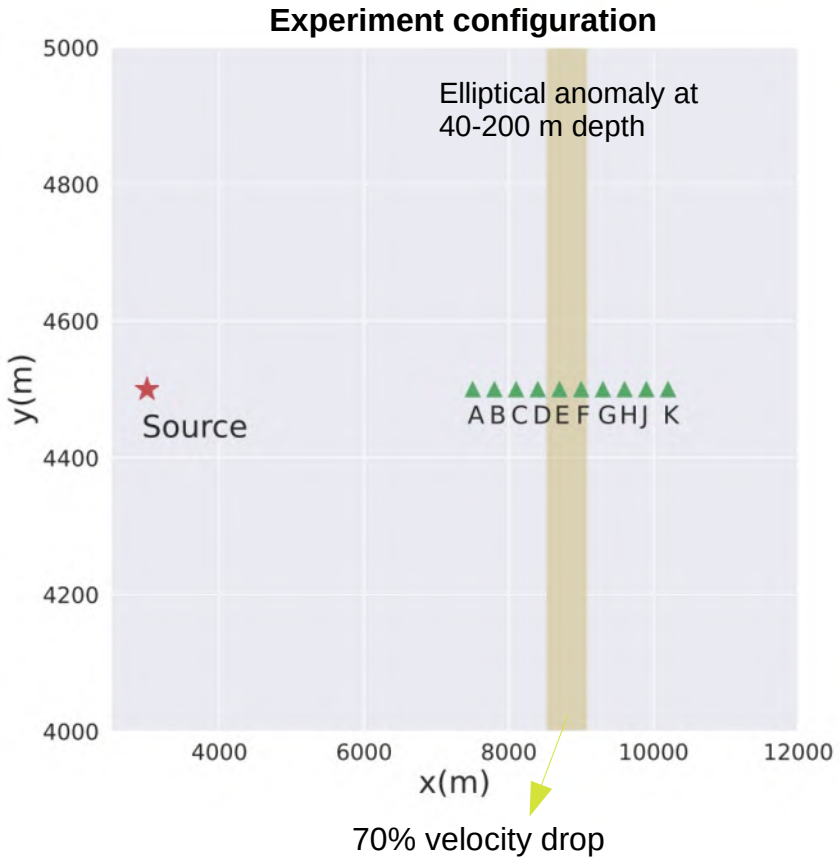
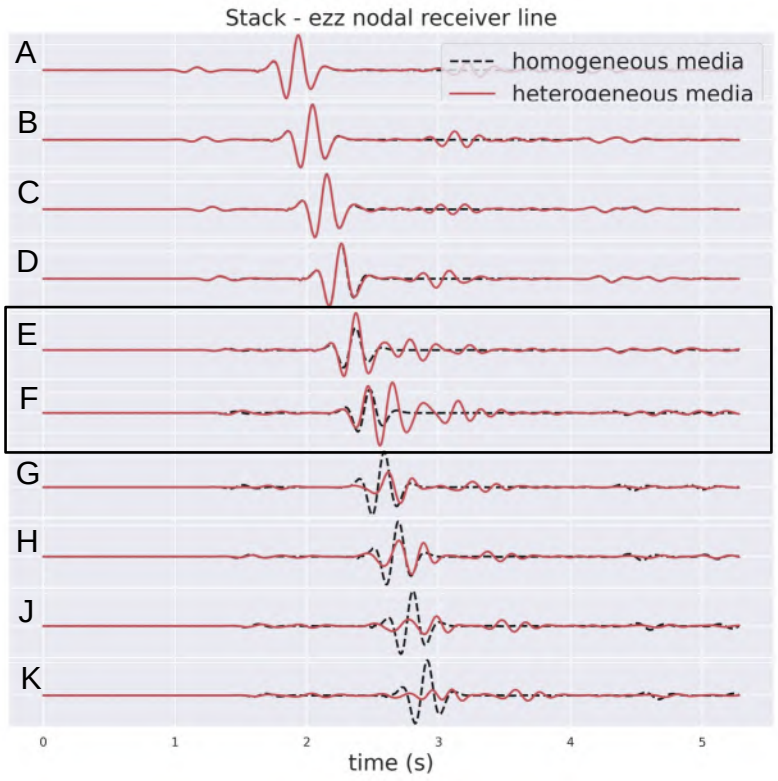
Strong anomaly experiment





Receivers above the anomaly

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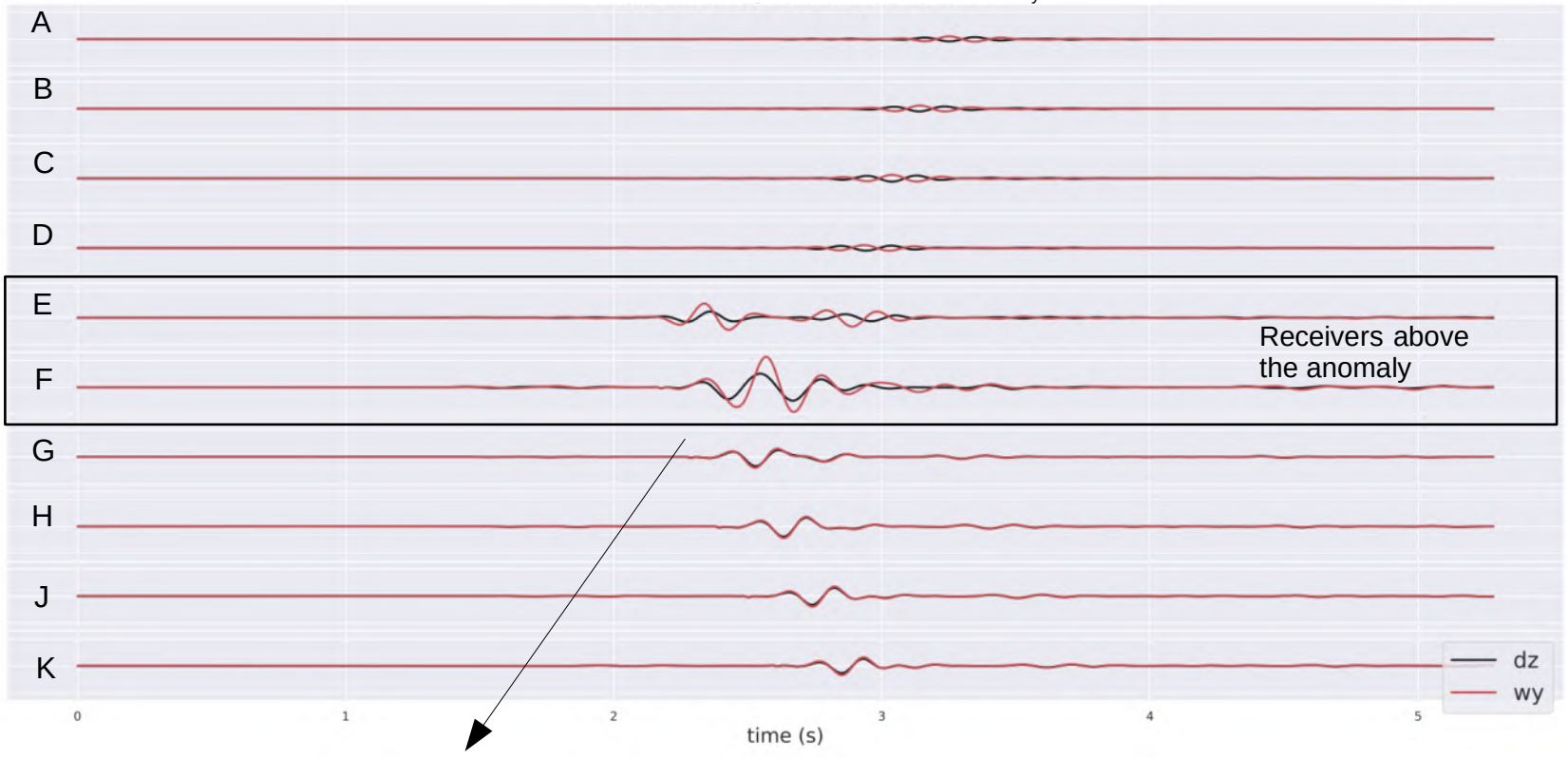
Strong anomaly experiment

Comparison of normalized scattered field dz/dt – ω_y at the array



Local amplification of the rotation

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Conclusions

Weak anomaly experiment

For the purposes related to the seismic velocity monitoring, moderate changes up to 10% of velocity, the wavefield gradients do not show an increased sensitivity compared with the traditional observables

Strong anomaly experiment

- Phase measurements are not effective
- Local amplification of the gradients

The larger sensitivity of the rotations could be used for FWI purposes

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