Effect of shallow heterogeneities on wavefield gradients measurements

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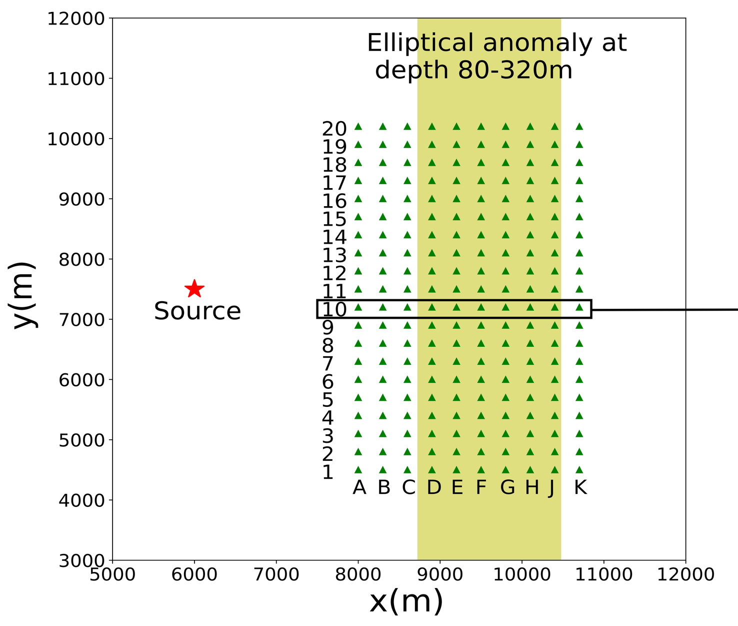
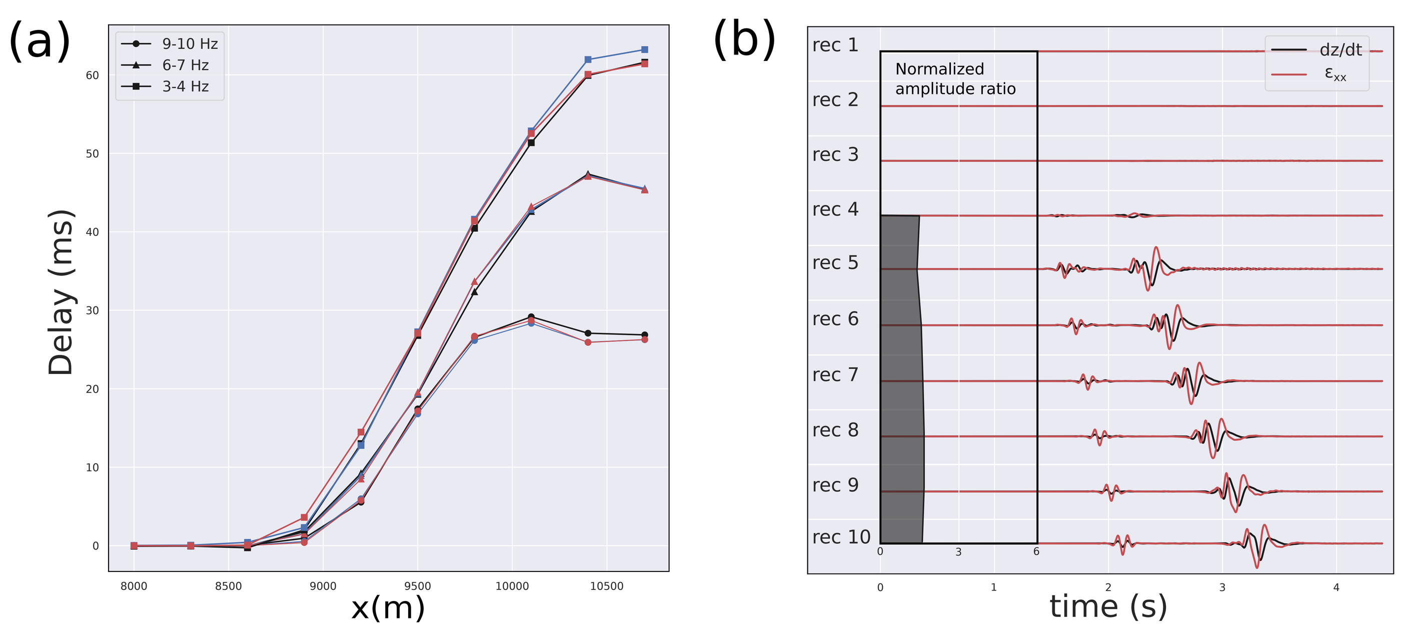
Motivation

In the last years the use of rotational sensors and DAS became a topic of raising interest between the seismological community, due to their increasing sensitivity and affordability. Many works[1] show the high sensitivity of rotational measurements to shallow heterogeneity in the medium. We modified the spectral element simulation code, SEM46[2], to observe, in addition to the displacement, the rotation and the strain as direct output. We conducted numerical simulations to analyze the sensitivity of the wavefield gradients to localized shallow velocity changes. Furthermore, an experiment is scheduled to take place in May 2023 at the University Campus of Grenoble (UGA).

Weak anomaly in a homogeneous media

A rectangular dense seismic array, composed by 200 receivers was placed above an elliptical section anomaly where the P and S wave velocities decreases by **10%**.



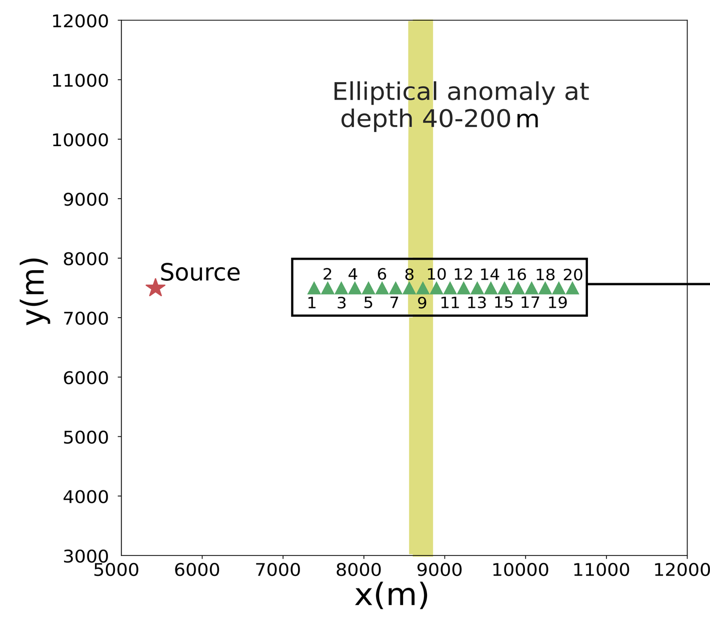


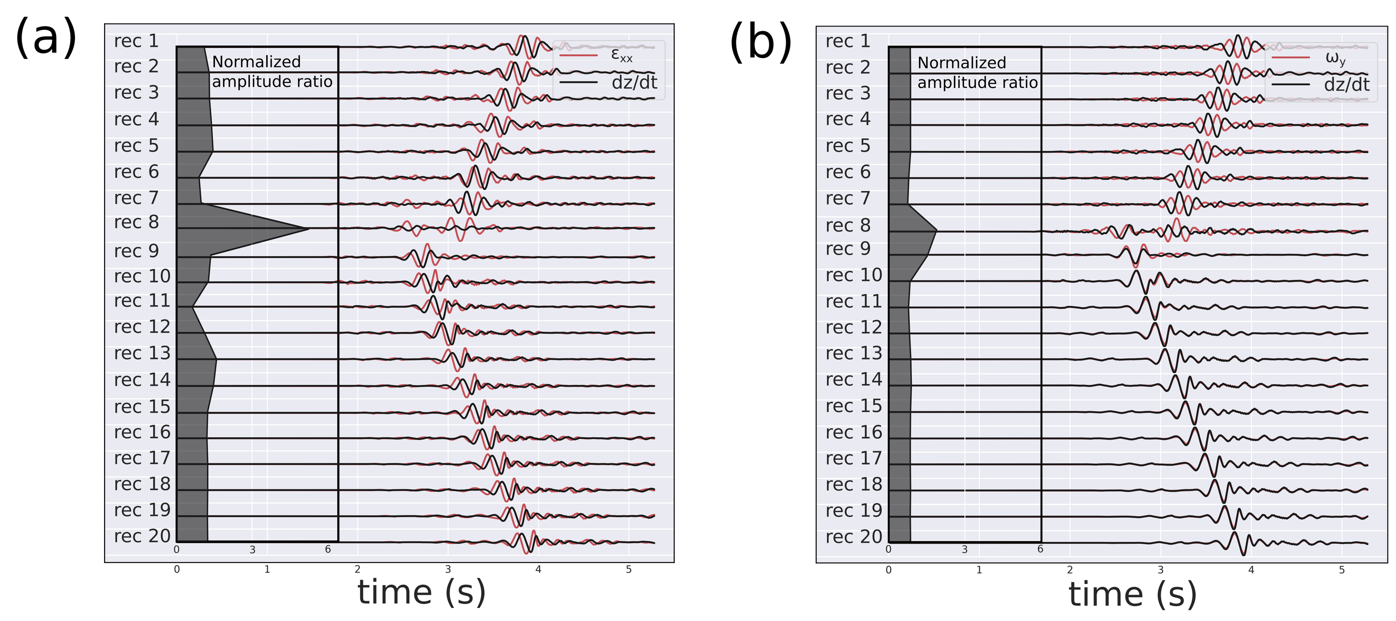
(a) Phase shift measurements.
(b) Normalized amplitude of the scattered field, ε_{xx} vs dz/dt.

The phase shift, induced by the heterogeneity, on the wavefield and its gradients, is the same.
No significant difference is visible in terms of amplitude change.

Strong anomaly in a homogeneous media

A linear seismic array composed by 20 receivers was placed above an elliptical section anomaly, where the velocity of P and S waves decreases by **70%**. In this scenario, the waveforms were too dissimilar to compute the phase shift.



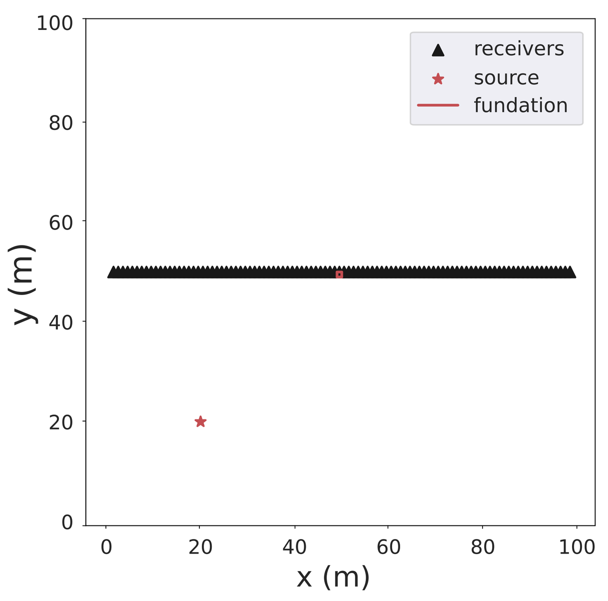


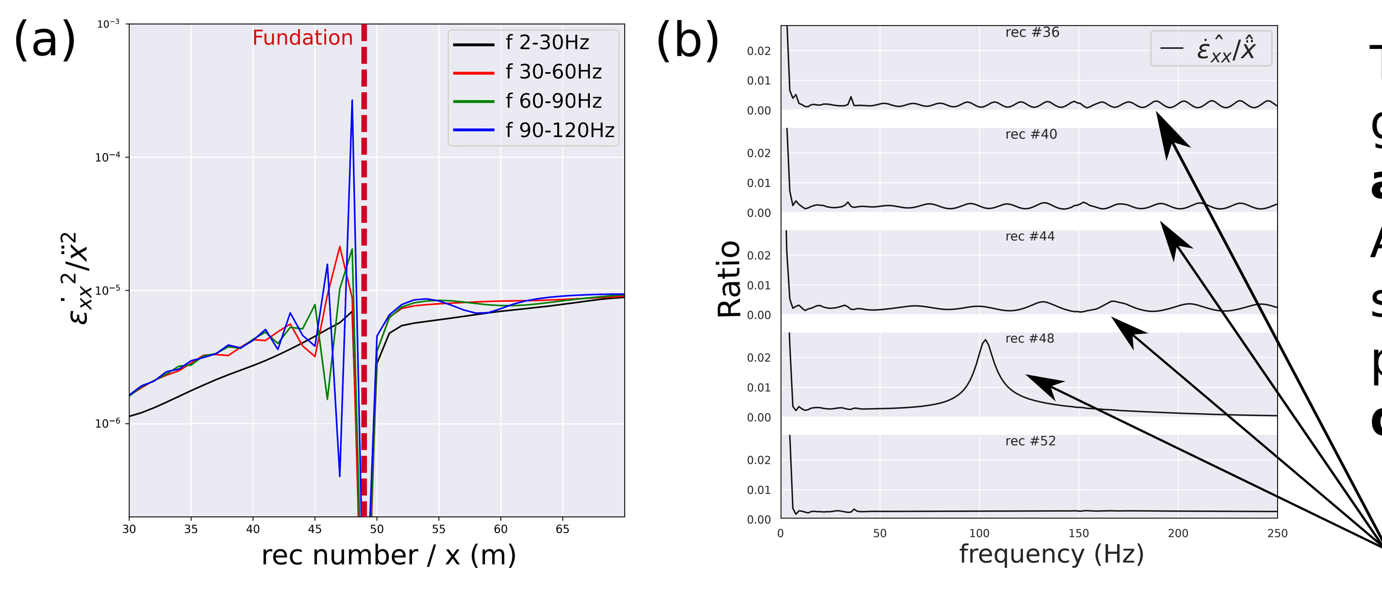
Normalized amplitude of the scattered field observed at the array.
(a) ε_{xx} vs dz/dt. (b) ω_y vs dz/dt.

The strain and the rotation show larger amplitude in proximity of the anomaly.

Experiment at UGA campus

A concrete foundation is located at the surface to a depth of 2 meters, surrounded by soil. In light of the upcoming experiment, where DAS will be deployed in conjunction with seismometers, we are simulating the wavefield and its gradients in a medium with scattering.





The interference between incident and scattered waves generates both **strain rate amplification and acceleration decay in proximity to the anomaly**. At the frequency where the reflection is maximum, the spectrum ratio at the nearest receiver, shows a distinct peak. **Interference fringes can be observed at distances of several wavelengths**.

(a) $(d\varepsilon_{xx}/dt)^2/(d^2x/dt^2)^2$. (b) $F(d\varepsilon_{xx}/dt)/F(d^2x/dt^2)$

Interference fringes

Observations

In mediums where the velocity exhibits changes up to 10%, the wavefield gradients do not show a significant difference in terms of phase shift or amplitude change when compared to the wavefield. However, when there is a strong impedance contraxt, the ratio of amplitudes between the wavefield gradients and the wavefield itself shows larger amplitude near the anomaly. This variation has been interpreted as the combination of two factors: **1.** Interference between incident and scattered waves. **2.** Dominant near-field term in the gradients within a distance of $\lambda/2\pi$.

Conclusion

The comparison between the wavefield gradients and the wavefield itself can provide information about strong subsurface heterogeneities, such as buried objects, faults or cavities.

References: [1]: Fichtner et al. "Sensitivity densities for rotational ground motion" 2009; Singh et al. "Correcting wavefield gradients for the effects of local small-scale heterogeneities" 2019. [2] 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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