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A parametric analysis on the behaviors of seismic waves interacting with geologic metamaterials

Abstract

The idea of developing seismic invisibility cloaks that render geologic targets invisible to seismic waves has recently received increased attention for earthquake hazard reduction. Using the concept of invisibility cloaks, previous field experiments that considered sets of air-filled boreholes (seismic metamaterials, [1]) and forests of trees (above-surface resonators, [2]) as seismic cloaks successfully demonstrated the feasibility of both for seismic energy suppression at specific bandwidths for earthquake protection. While the experiments provide a strong motivation for the applicability of seismic cloaking to real world applications, designing optimal seismic metamaterials specific for a given field of interest requires a better understanding of how the design parameters and geologic factors affect the response of a passing seismic wavefield at geophysical scales.

Here, we investigate the behaviors of seismic waves through geologic metamaterials with different design parameters by conducting a thorough numerical modeling study. An in-house, finite difference modeling code is used to simulate elastic wave propagation in 3D geologic media. Our analysis particularly focuses on the interactions of a passing seismic wavefield with geologic media that are transformed into seismic metamaterials via borehole implantations. We systematically test the influence of geologic metamaterial design parameters (density and geometry of boreholes) and the complexity of the host geologic media on wave propagation.

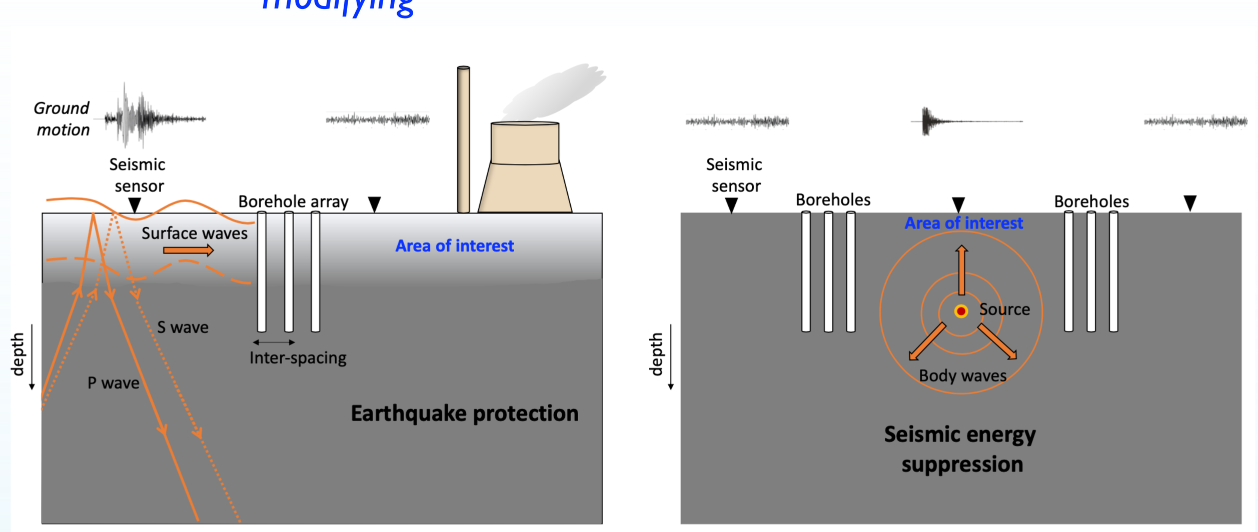
Seismic cloaking

The concept of cloaking has only been investigated in a few field-scale tests (i.e., [1,2]). Designing seismic cloaks for real world applications requires a better understanding of the physics of metamaterials at geophysical scales.

Seismic ***invisibility*** cloaks

shielding
attenuating
absorbing
modifying

? → at geophysical scales (10s to 1000s of meters)

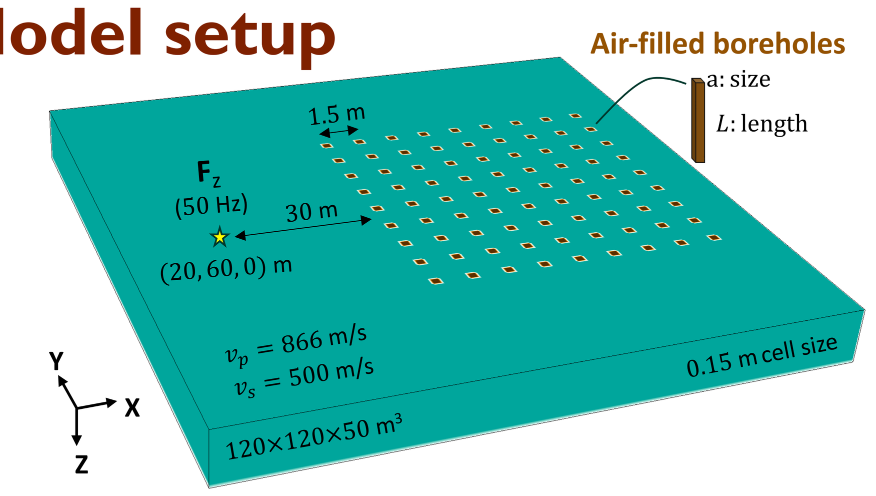


Strategies for cloaking seismic wavefields *include*

- Seismic metamaterials (borehole implantations)
- Above-surface resonators (rods, trees, etc.)
- Buried mass-resonators (dampers, scatters, absorbers, etc.)

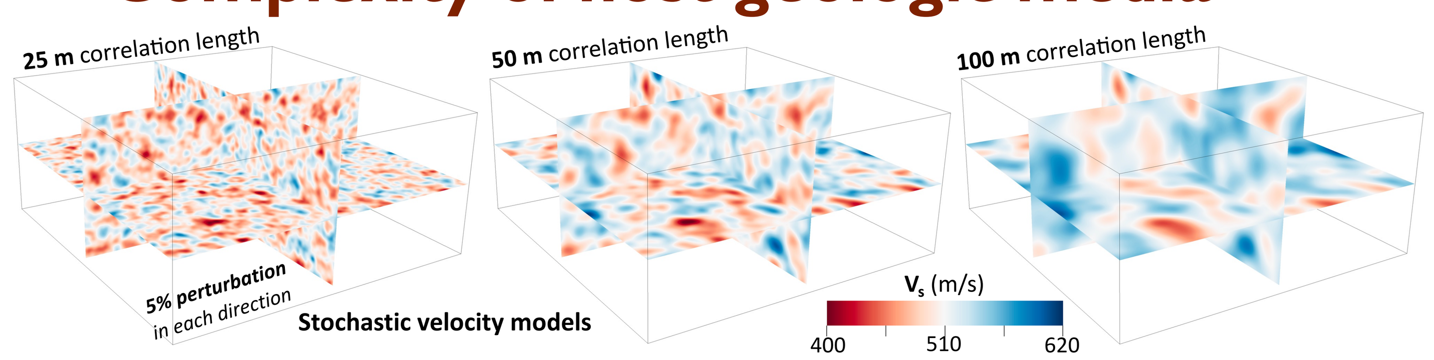
Cloaking seismic waves via geologic metamaterials

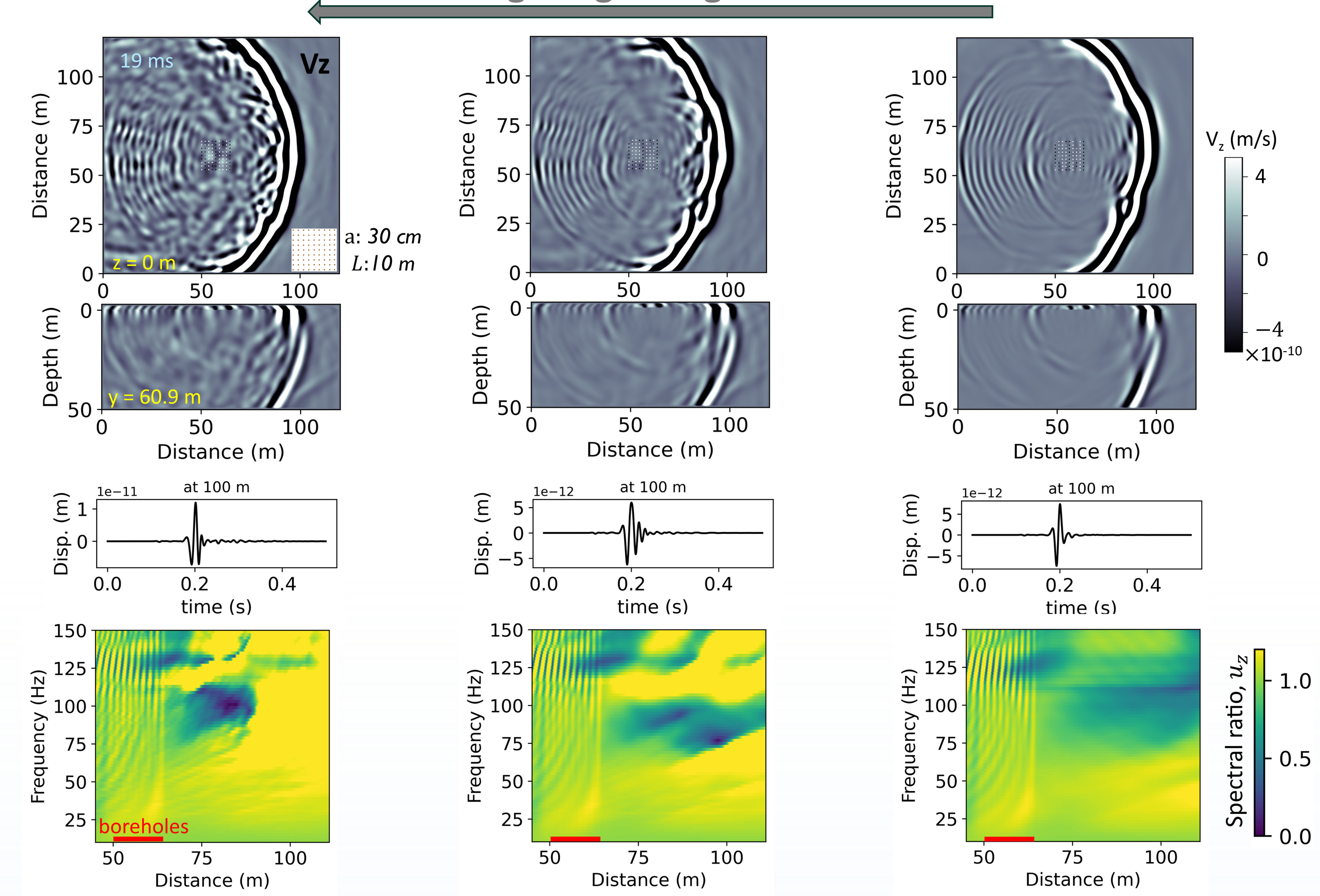
Model setup



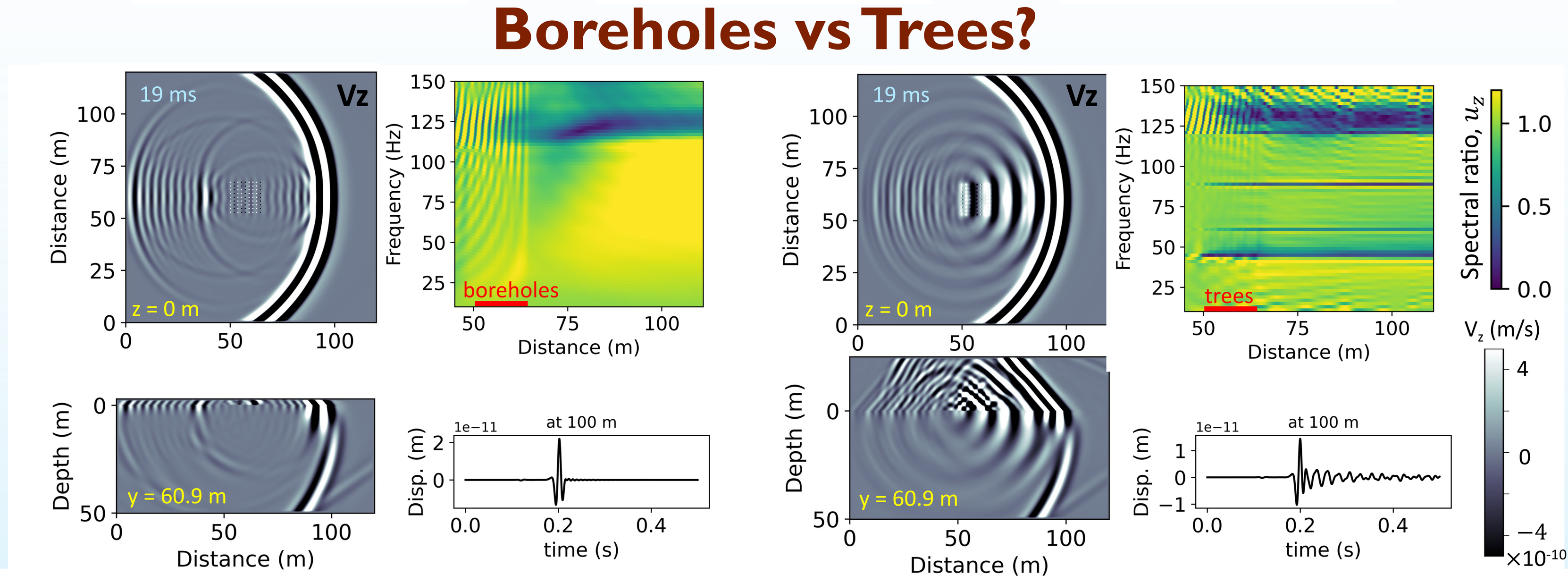
Seismic wave propagation is simulated by using an in-house, parallel 3D wave simulation code (finite difference solver).

Complexity of host geologic media

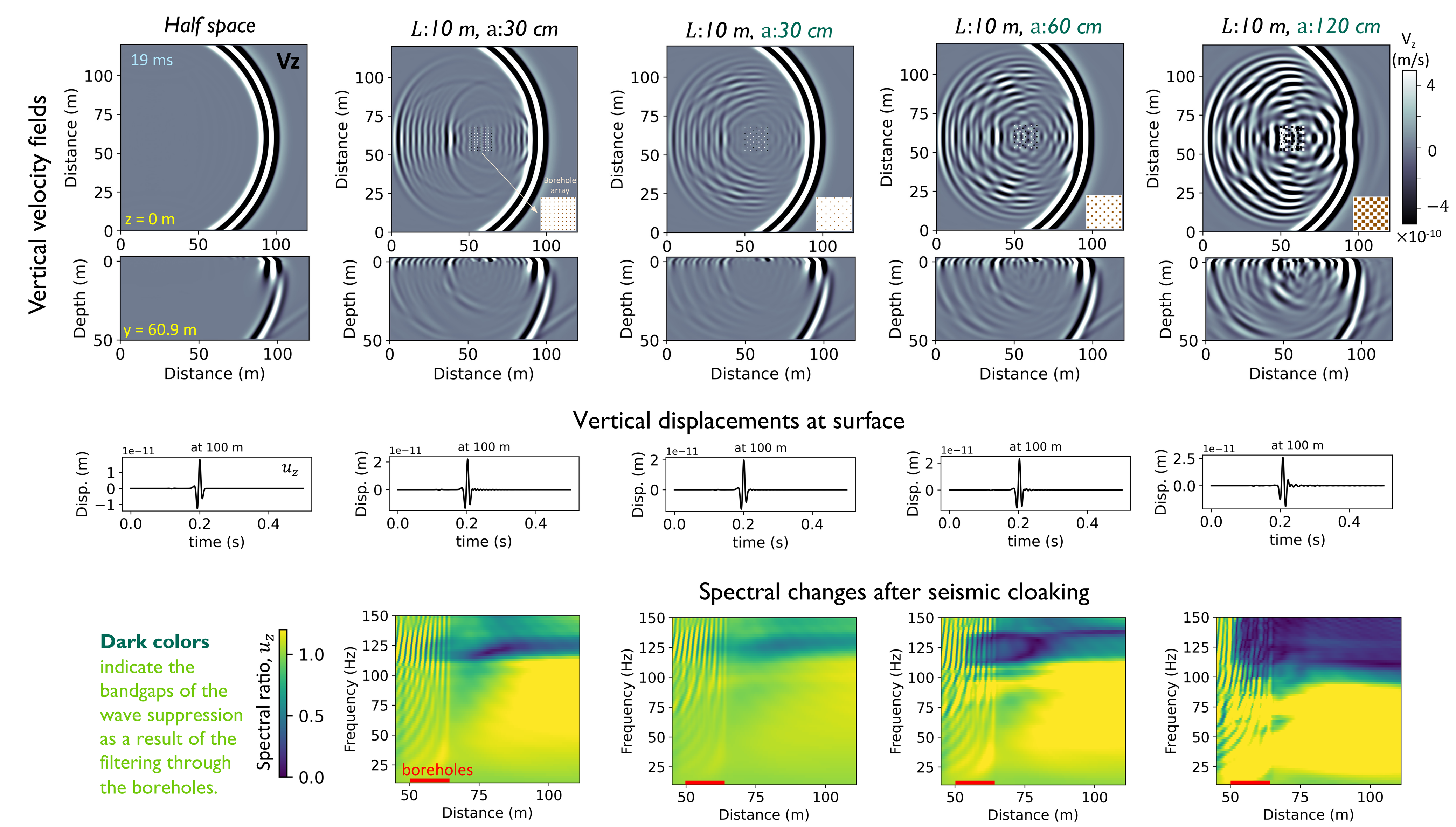




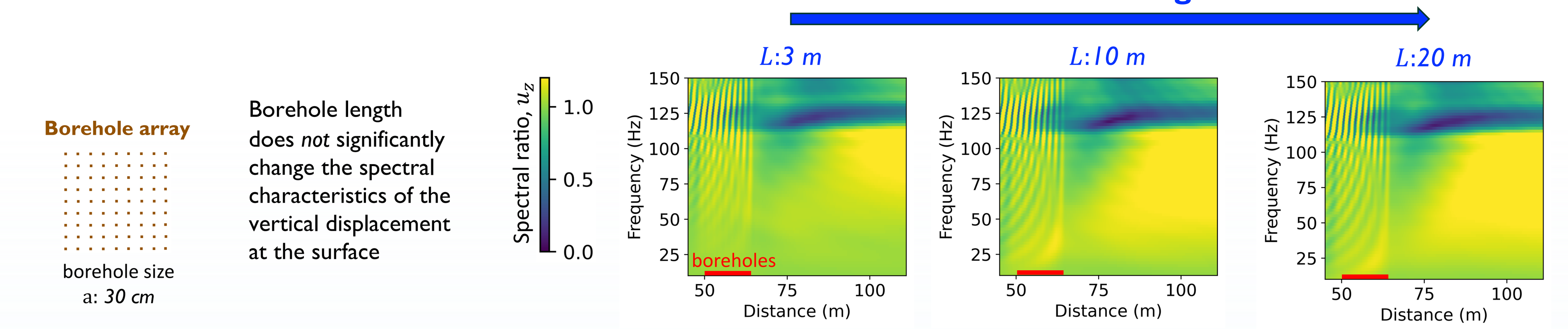
Boreholes vs Trees?



Geometric properties of metamaterials



Dark colors indicate the bandgaps of the wave suppression as a result of the filtering through the boreholes.



Borehole length does *not* significantly change the spectral characteristics of the vertical displacement at the surface

Conclusions

- Our spectral analysis indicates that sparser borehole arrays as geologic metamaterial result in less efficient cloaking against seismic waves while the borehole length does not affect the performance of the wave suppression of surface waves generated by a vertical point source located at surface.
- Sparser arrays with larger borehole size can suppress waves at broader bandgaps compared to dense arrays with smaller borehole size.
- The variations in seismic velocity significantly impact the bandgaps at that the waves can be attenuated suggesting that the host geologic medium needs to be well characterized while designing seismic metamaterials.
- Considering the same source and the field conditions, the above-surface resonators (trees) perform more efficiently suppressing waves at much lower bandgaps compared to seismic metamaterials (boreholes).

References

[1] Brûlé, S., E.H. Javelaud, S. Enoch, and S. Guenneau (2014), Experiments on seismic metamaterials: molding surface waves, Phys. Rev. Lett. 112, 133901.

[2] A. Colombi, P. Roux, S. Guenneau, P. Gueguen, and R.V. Craster (2016), Forests as a natural seismic metamaterial: Rayleigh wave bandgaps induced by local resonances, Sci. Rep. 6, 19238.

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