MISS – Project

Minderung der Störwirkung von Windenergieanlagen auf seismologische Stationen

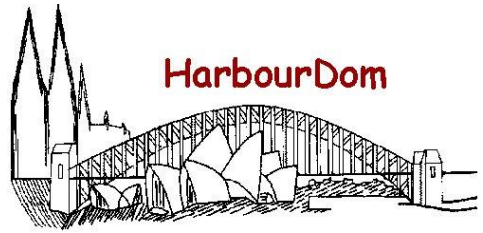
Gefördert durch:

EFRE.NRW
Investitionen in Wachstum und Beschäftigung

EUROPÄISCHE UNION
Investition in unsere Zukunft
Europäischer Fonds für regionale Entwicklung

Teilprojekt WWU:
Mitigation of effects on the travel path – a theoretical approach

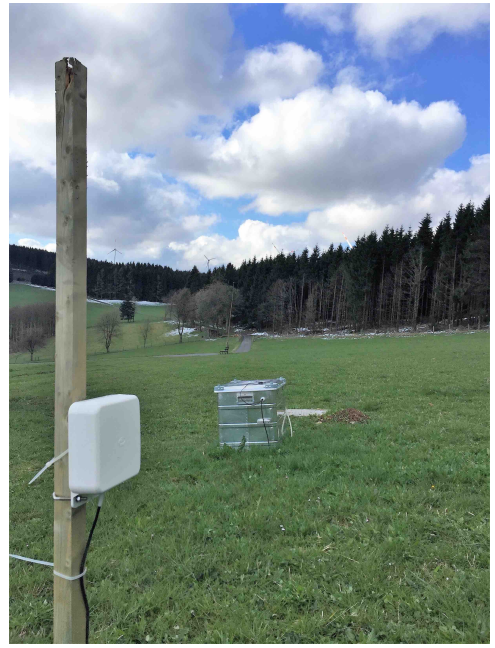
Rafael Abreu, Christine Thomas



MISS: Mitigation of induced seismic signals

Trying to avoid or reduce windturbine noise

- at the station (filters)
- at the source (metamaterials)
- on the way (metamaterials)



Photos from Simon Kremers

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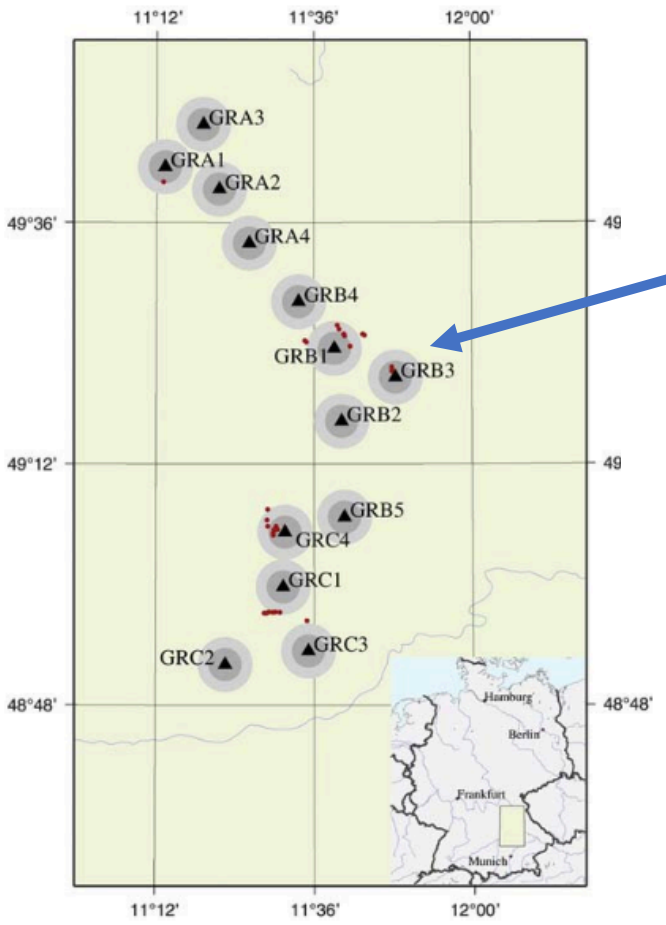
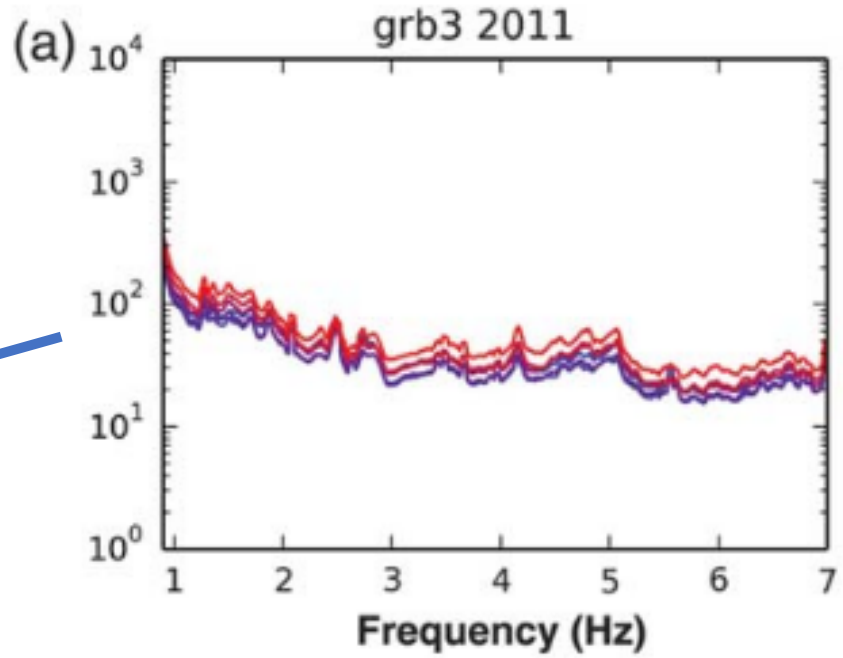
Windturbine noise in Germany

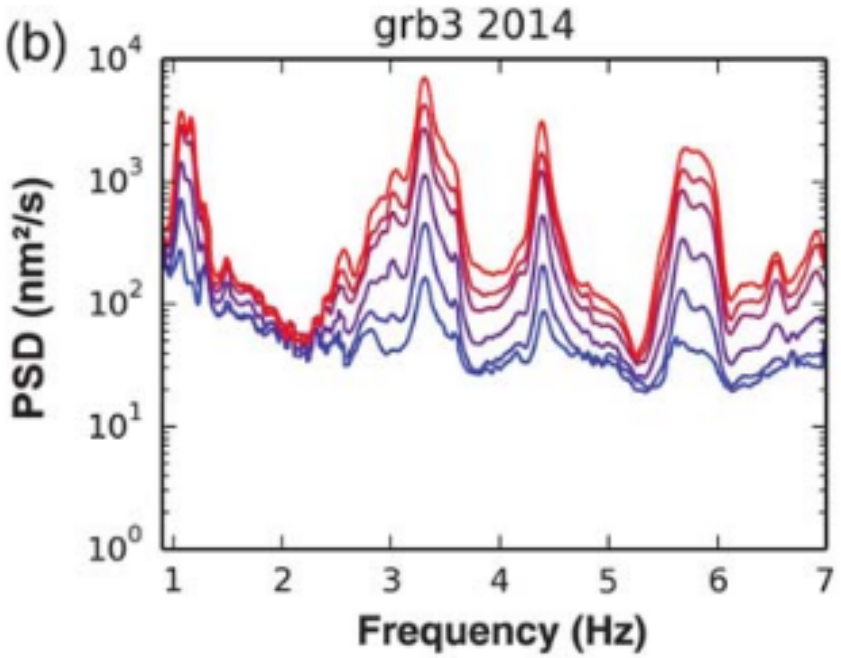
Gräfenberg
seismic array



Before installation of WT



After installation of WT



Colors of the lines for different wind speeds.

Seismometers show strong noise dependence on wind strength

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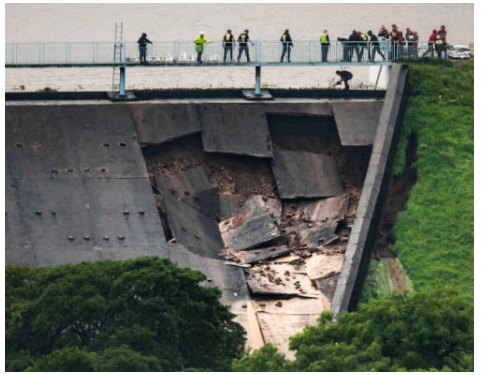
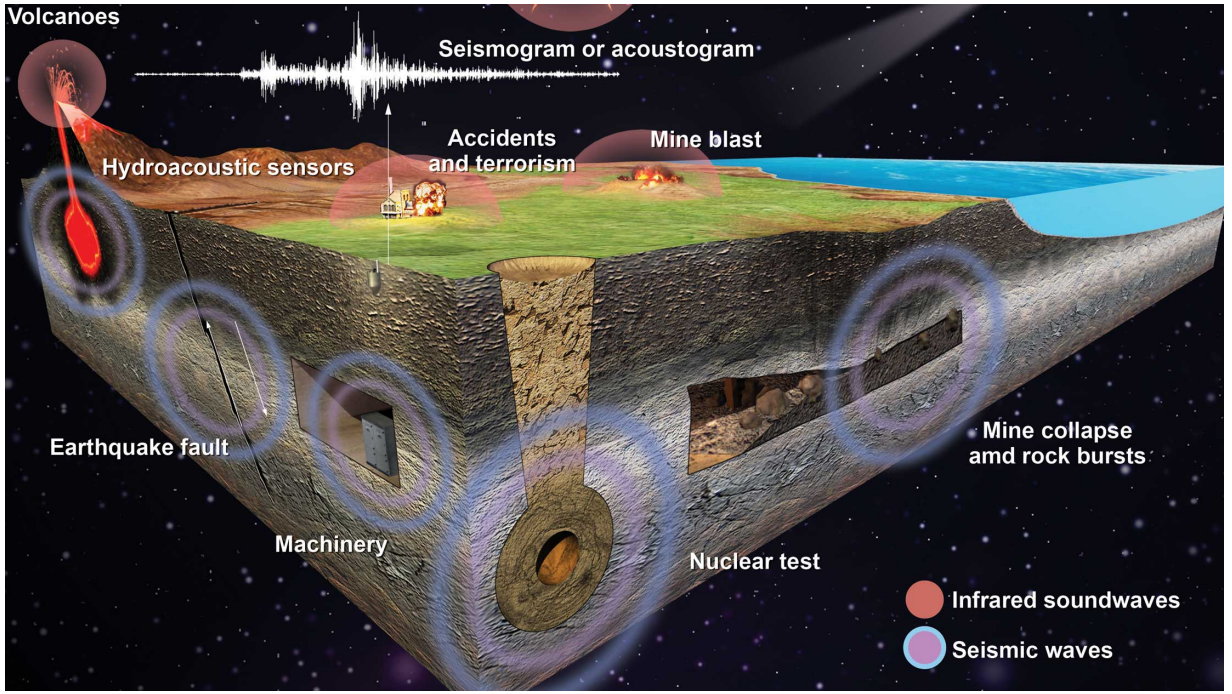
Applications of seismic monitoring

- Seismic monitoring of water dams

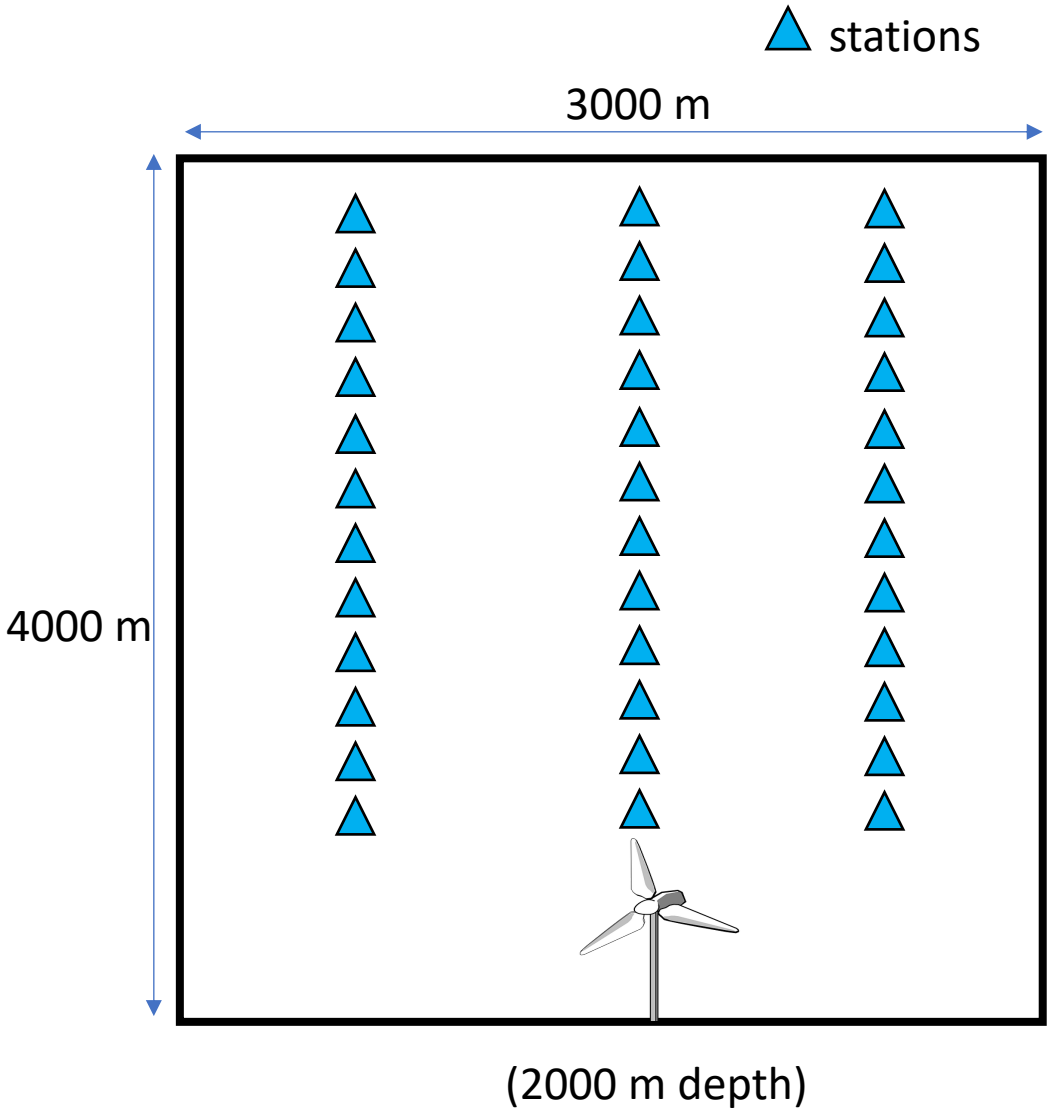


Seismometers are used for monitoring purposes amongst other applications.
Seismometers need to have low noise conditions



- Storage of radioactive waste
- Nuclear test ban treaty
- Mining collapse
- Many more

Numerical experiments: setup



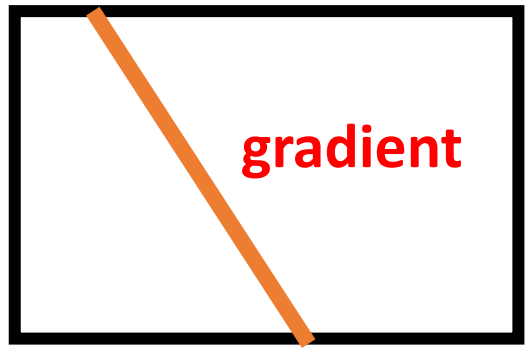
Test models

homogeneous

Vp = 1500 m/s
Vs = 900 m/s

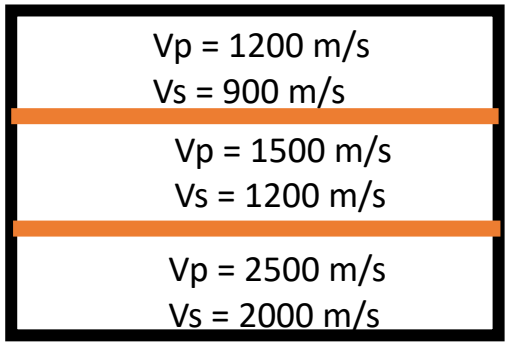
Simulation of data using 3D models with one source and different model set-ups: homogeneous, velocity increase and 3 layers

Vp = 1200 m/s
Vs = 900 m/s



Vp = 2500 m/s
Vs = 1400 m/s

2 layers / half space



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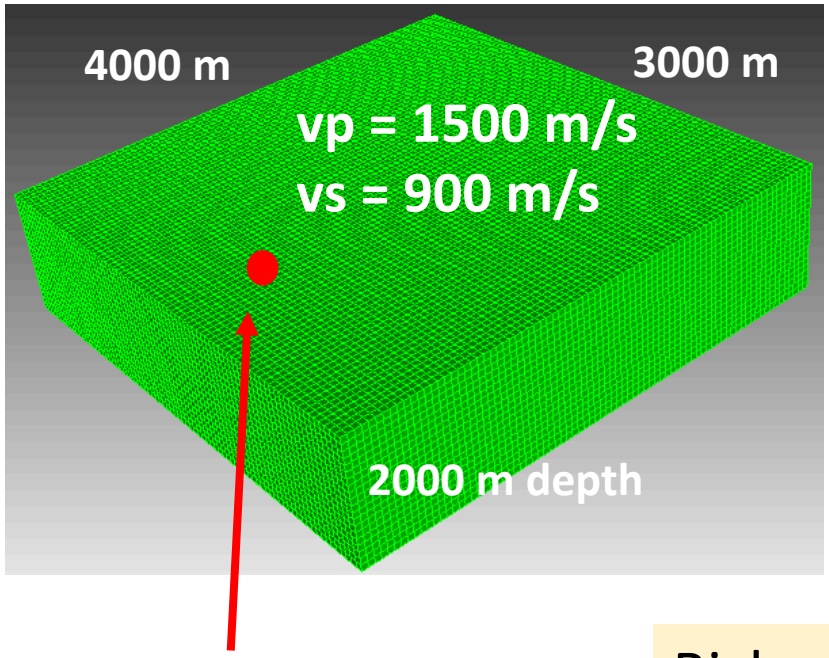
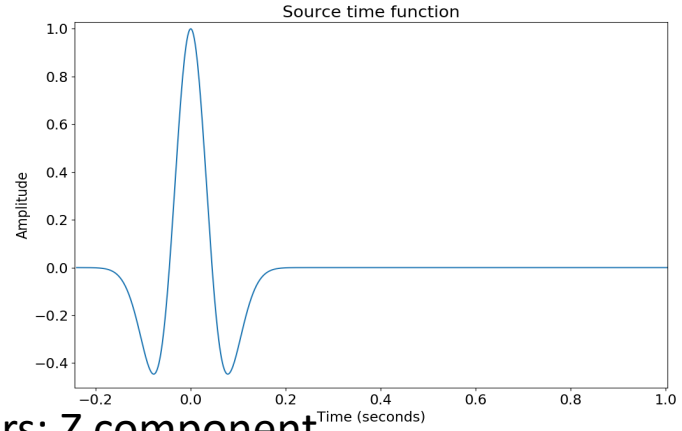
Homogeneous model



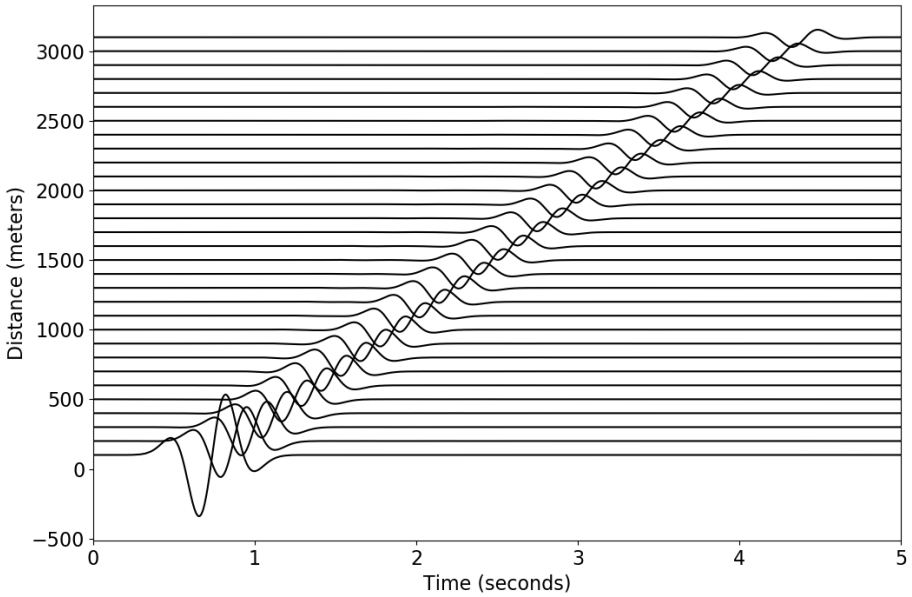
Vertical source

Ricker source time function.

✓ Behavior agrees with predictions for homogeneous model

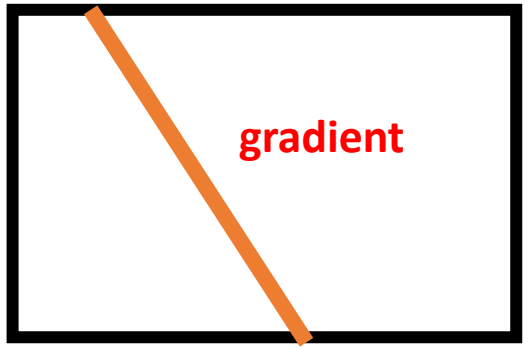


Receivers: Z component



Gradient model

Vp = 1200 m/s
Vs = 900 m/s

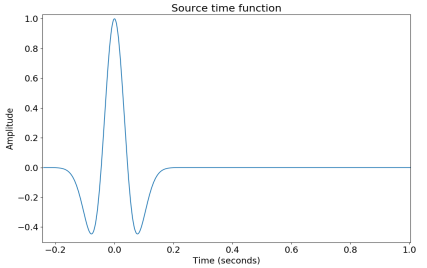


2 km depth

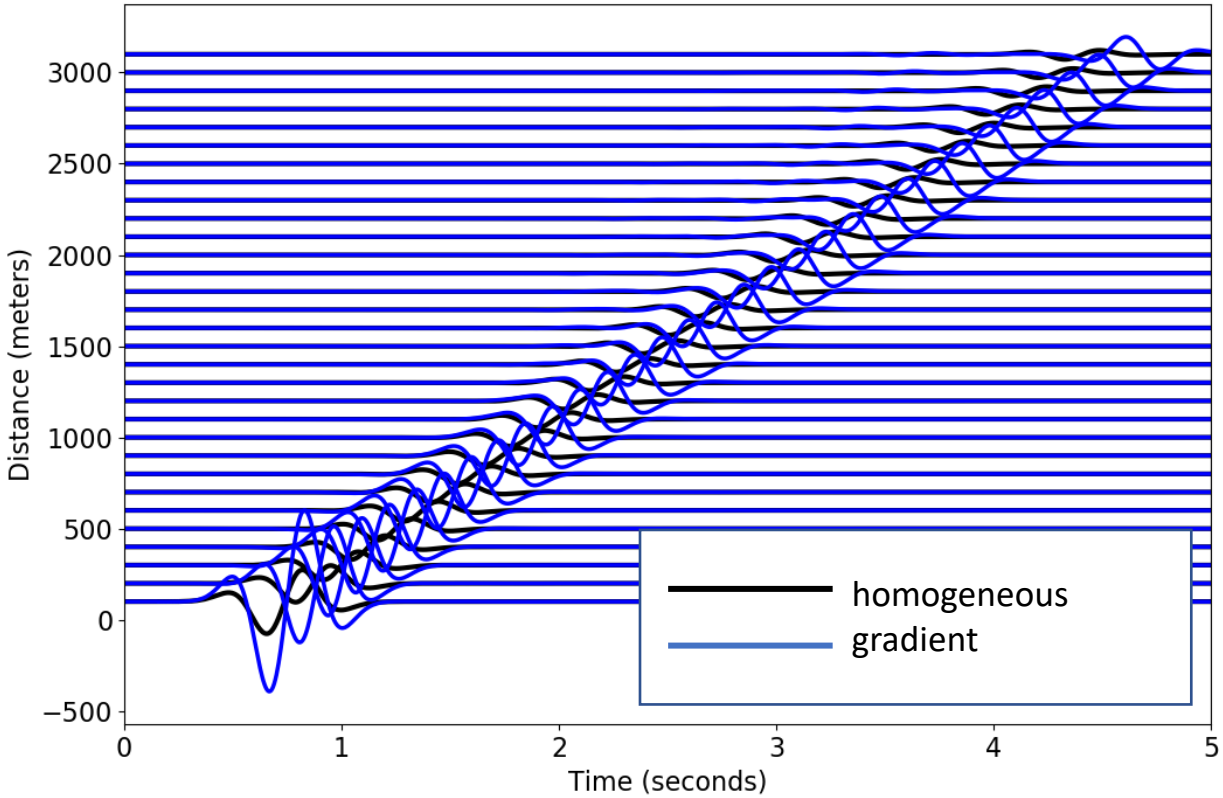
Vp = 2500 m/s
Vs = 1400 m/s

Amplitude changes compared with homogenous model. Travel time nearly the same

Vertical source



Receivers: Z component



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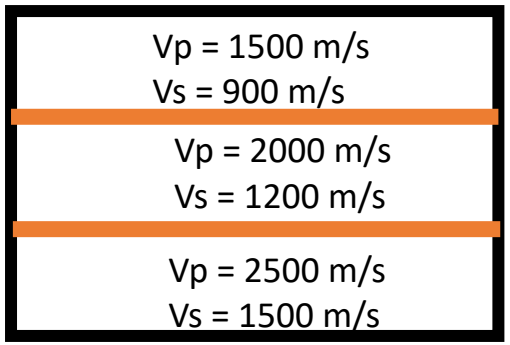
2 layers + half space model

2 layers + half space



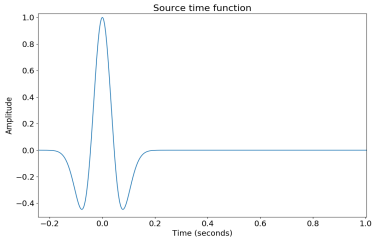
100m

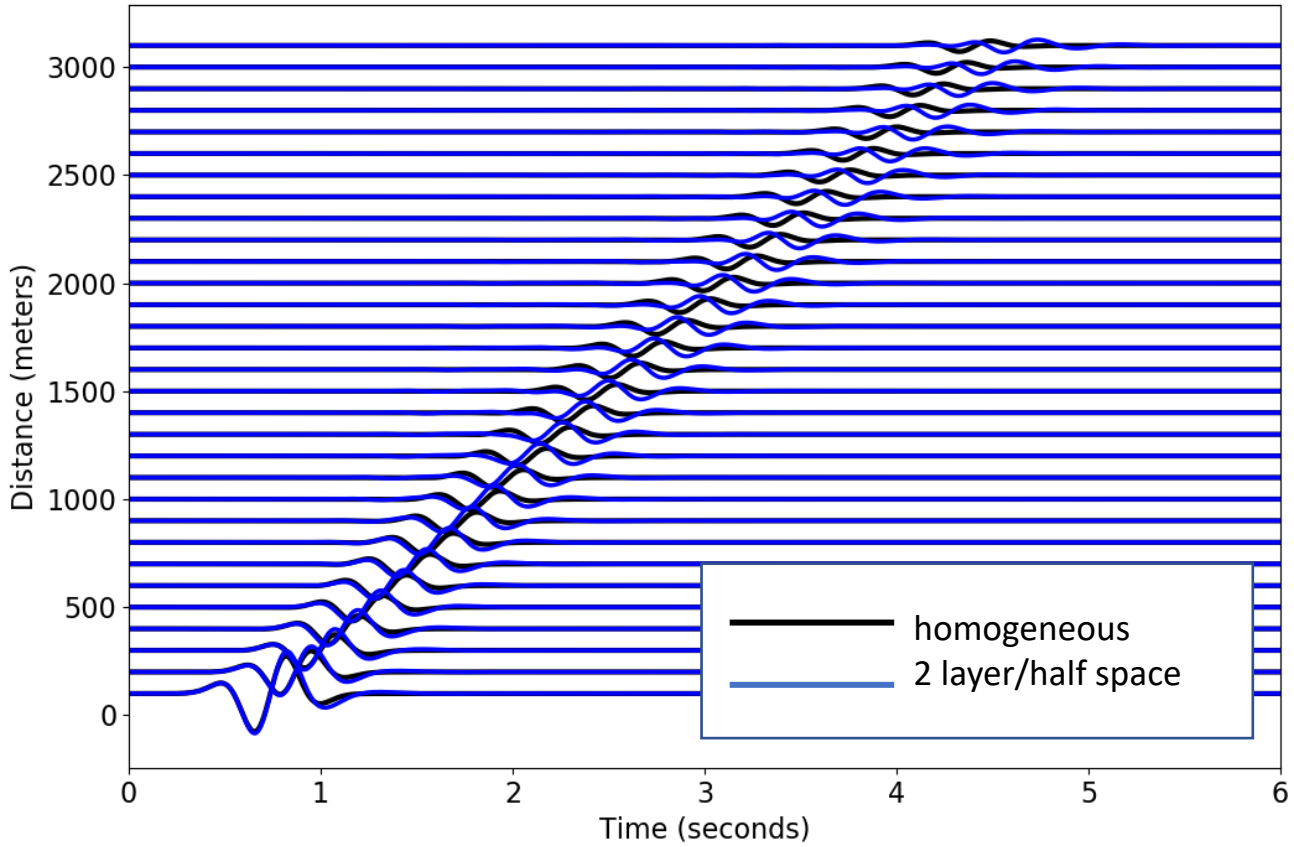
200m

Vertical source

Same amplitudes compared with homogenous model. Small travel time changes

Receivers: Z component





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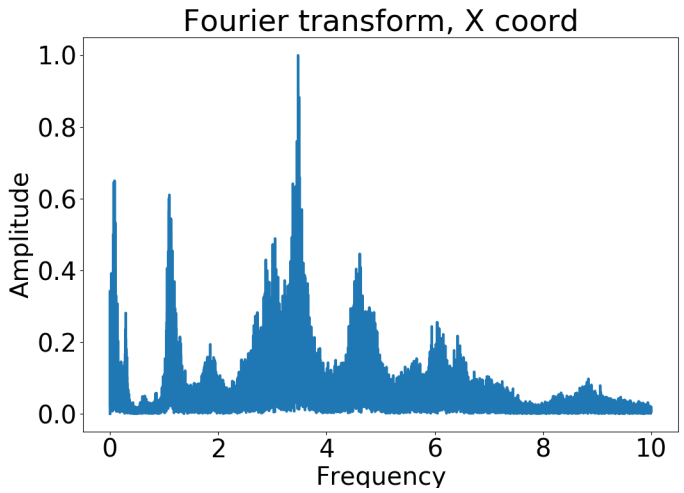
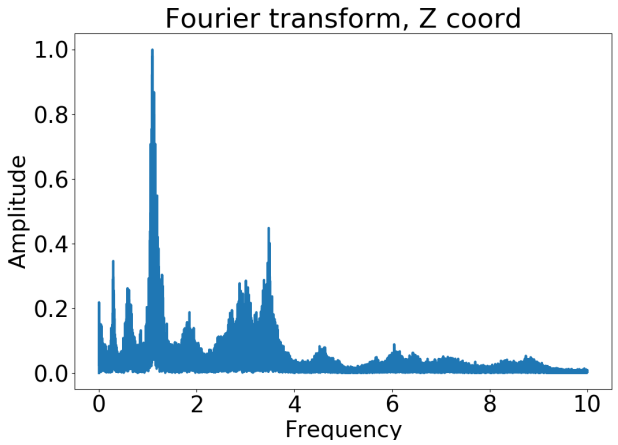
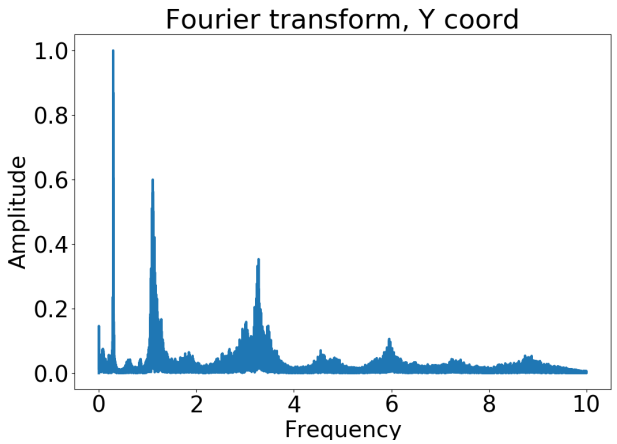
BHM collected data

STATION MP1

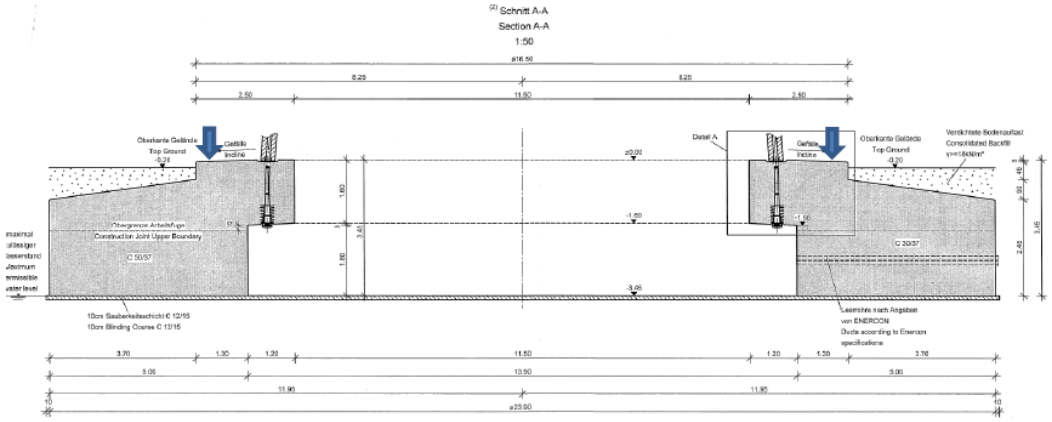


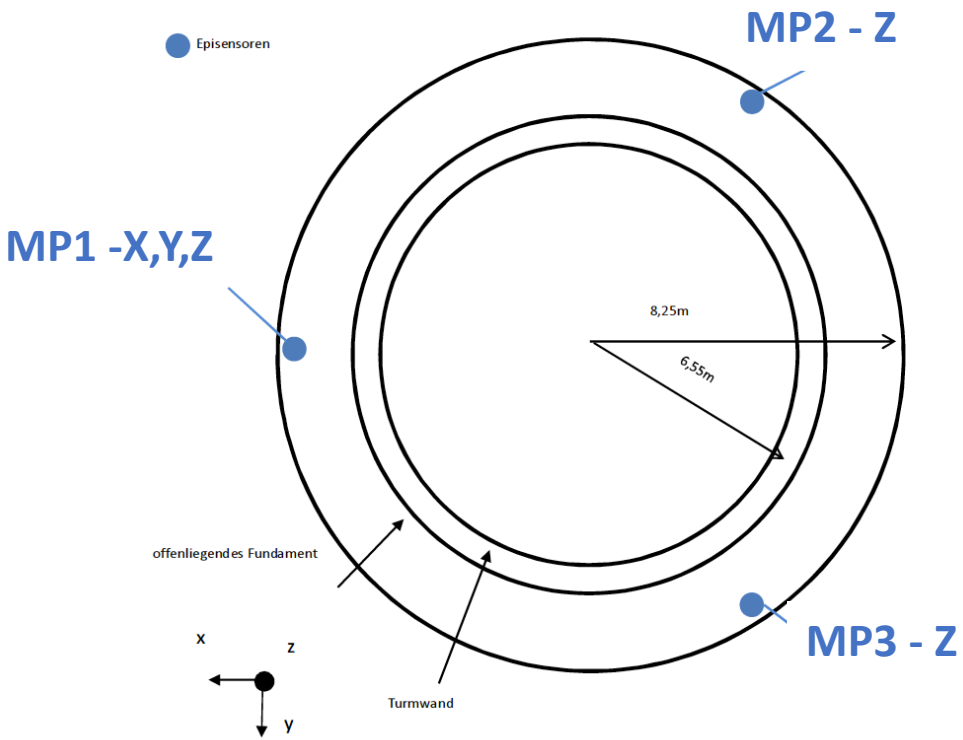




Velocity spectra entire trace

Layout of measuring points:





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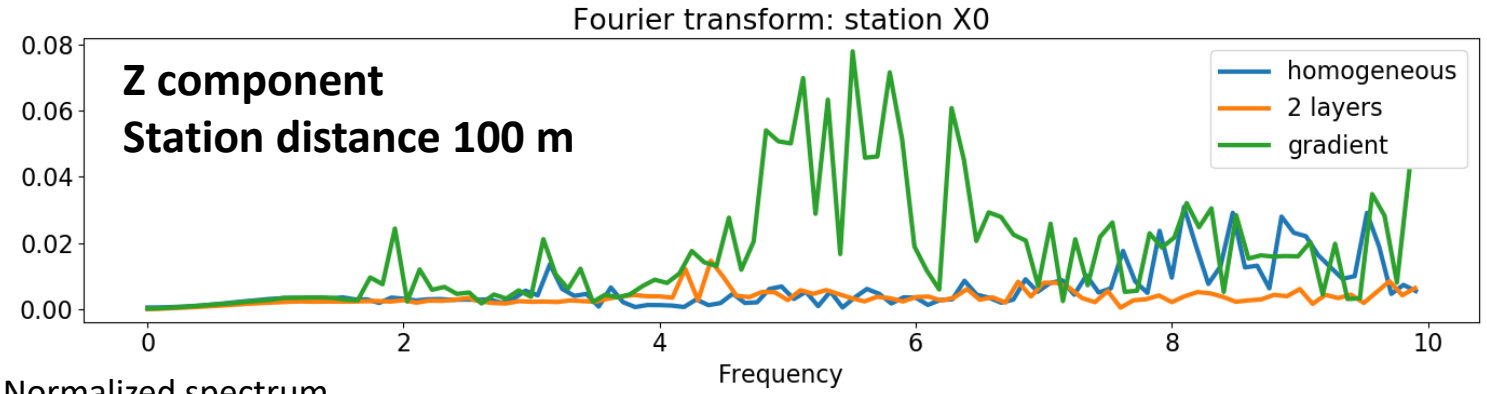
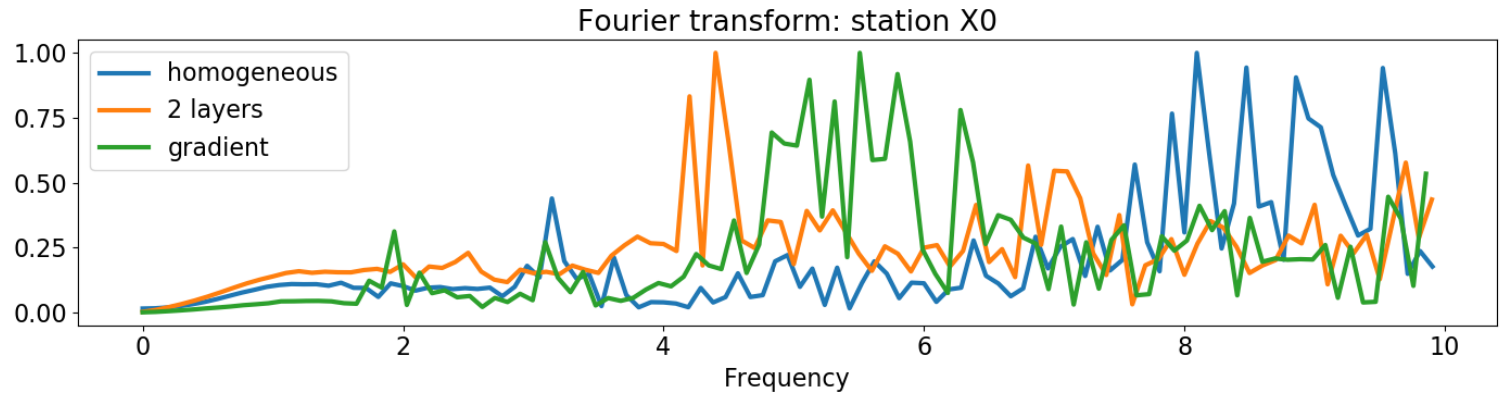
BHM data and simulations: spectra comparison

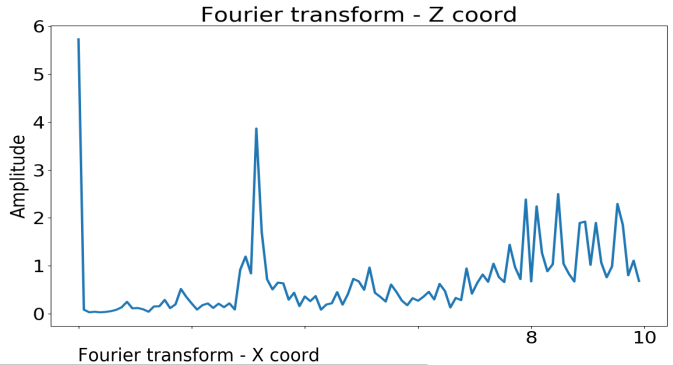


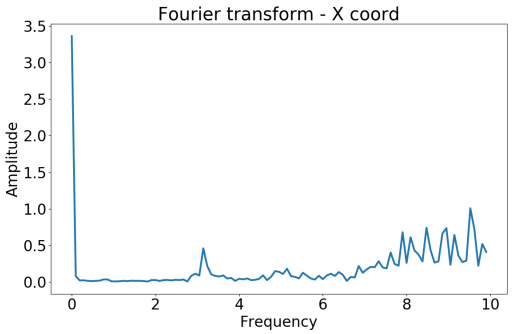
Normalized spectrum

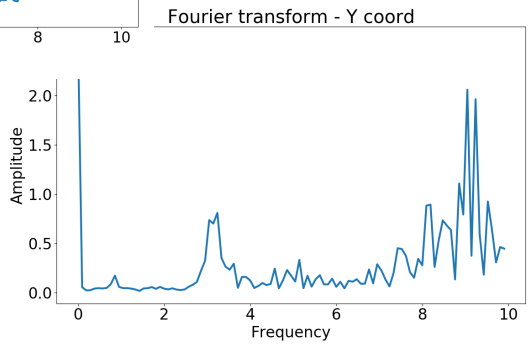


Spectra show peaks, they are different from z-comp measured spectra due to combination of 3 spectra for source.
Peaks seem to have large amplitudes at different frequencies for different models – effect of surface waves?

Combined source time functions in 3 directions, measured at MP1







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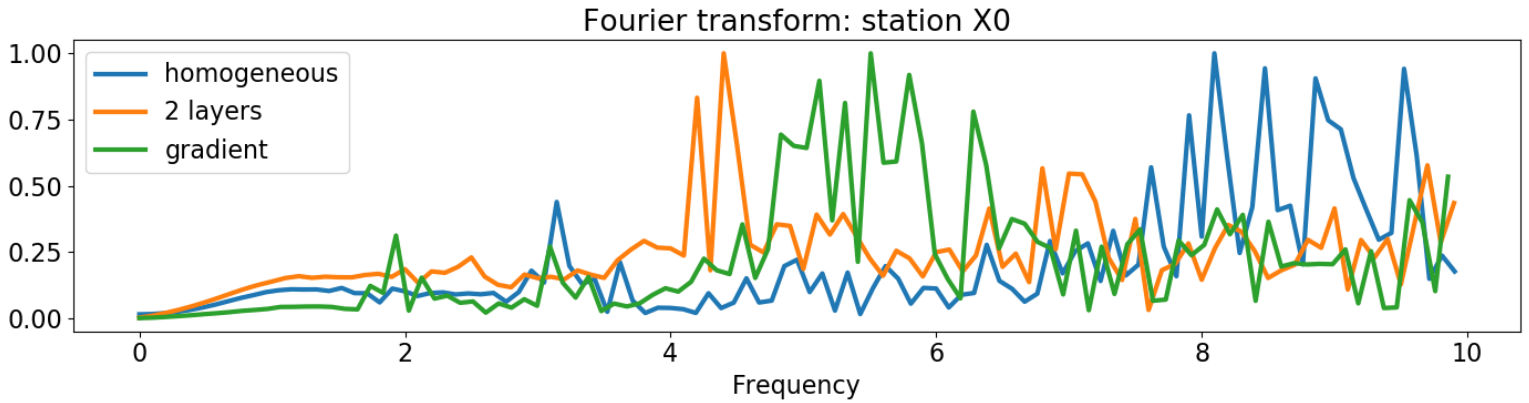
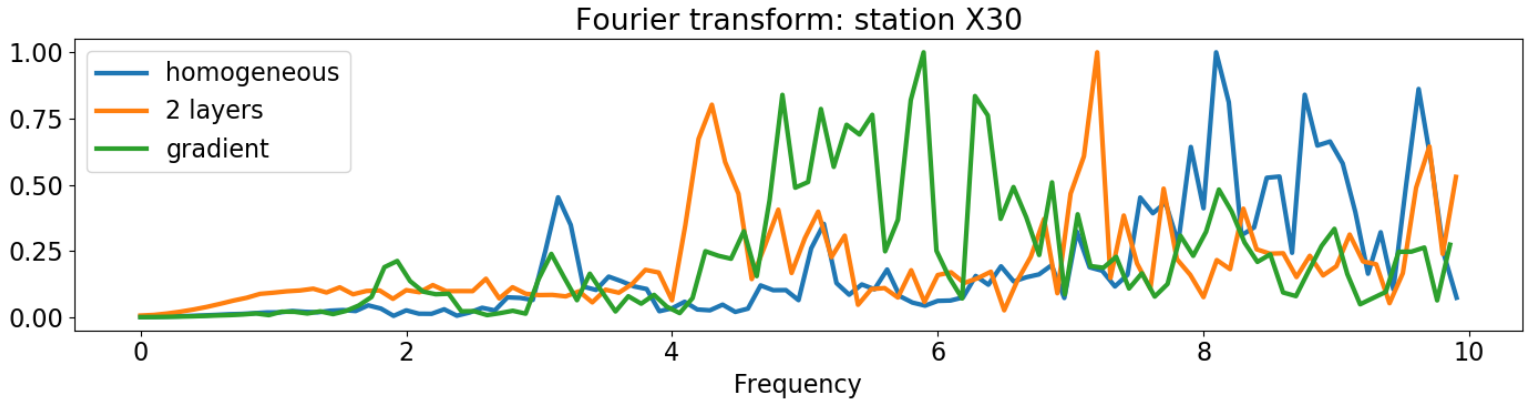
BHM data: spectrum comparisons

Z component
Station distance 100 m



Z component
Station distance 3500 m



No strong difference in the spectra for different distances.
Reason: model are 1D models

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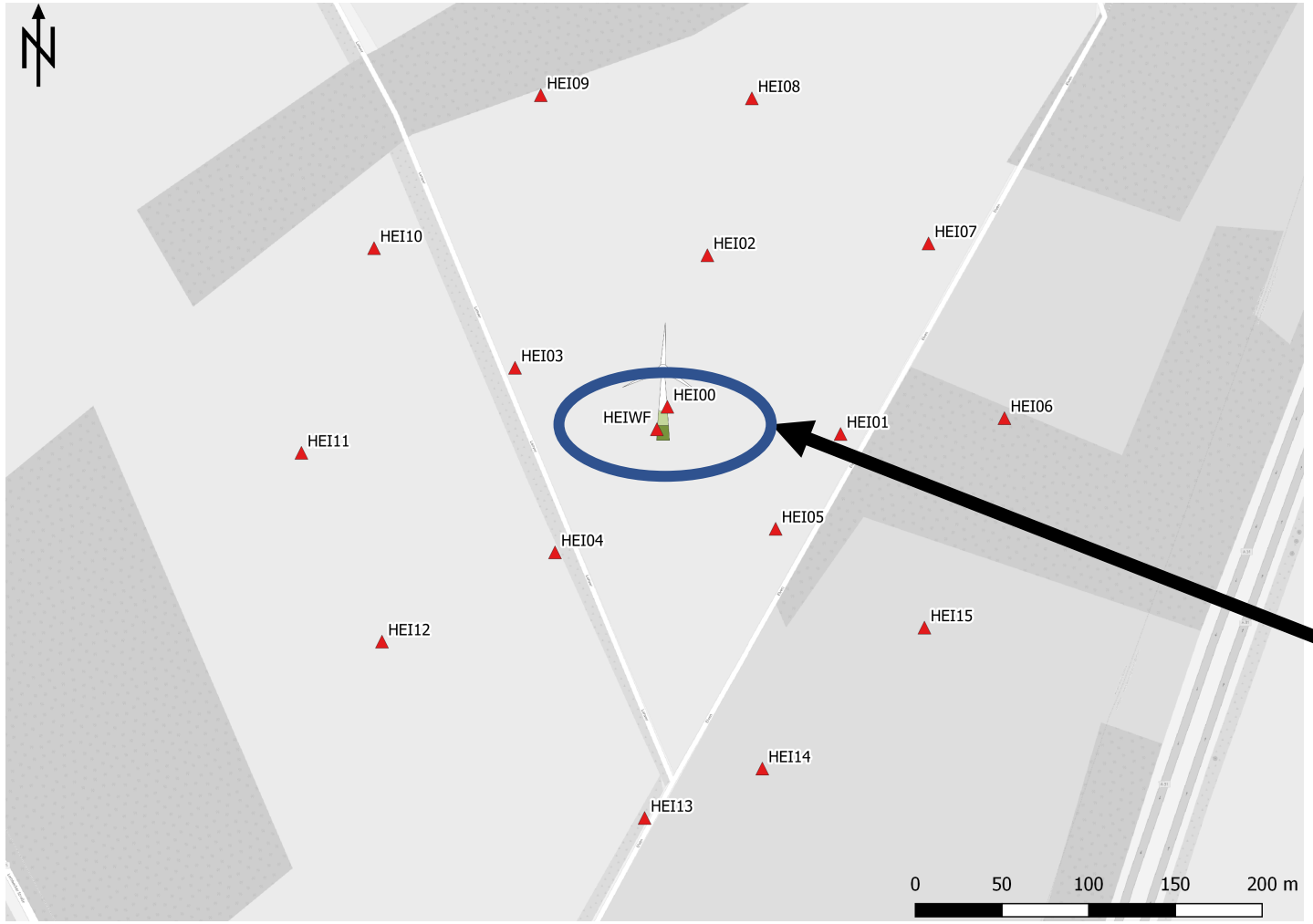
Data from DMT



BHM have only stations at foundation of WEA.
To compare path effects, we use measured data from DMT.

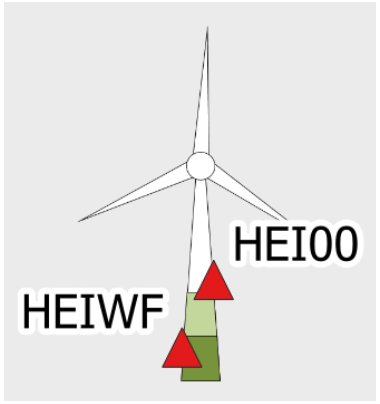
Stations at the Wind-turbine:

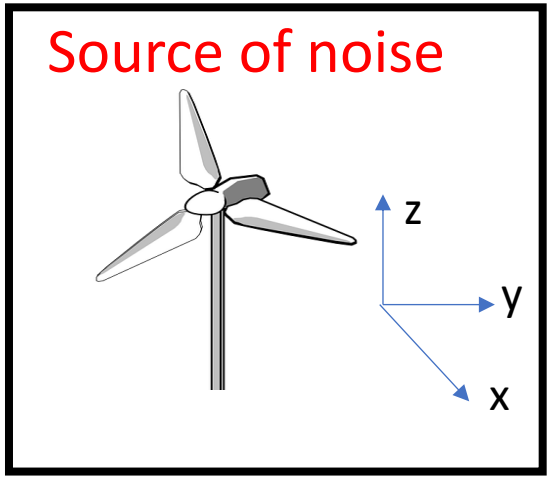
- HEI00
- HEIWF

Low and high wind speeds velocity measurements

Different types of noise sources from DMT

Seismic stations at the wind turbine





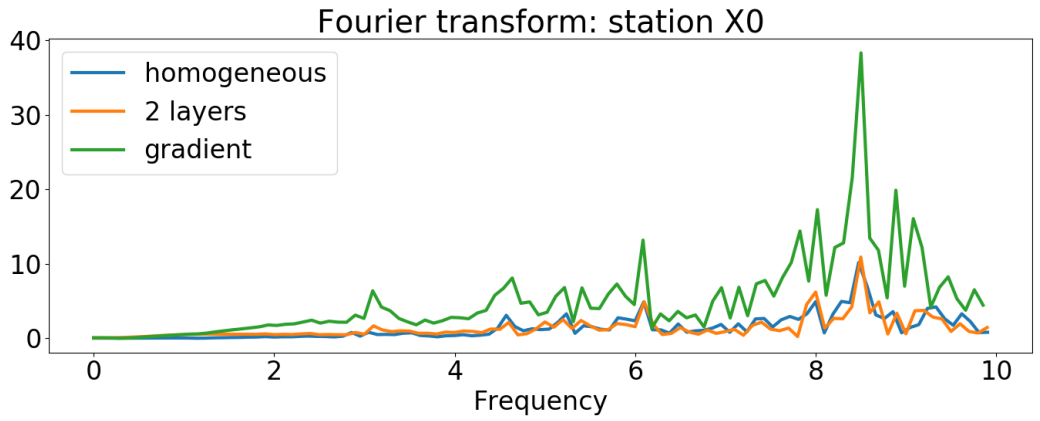
High wind + 3 components measurements (X,Y,Z) + **Low wind**

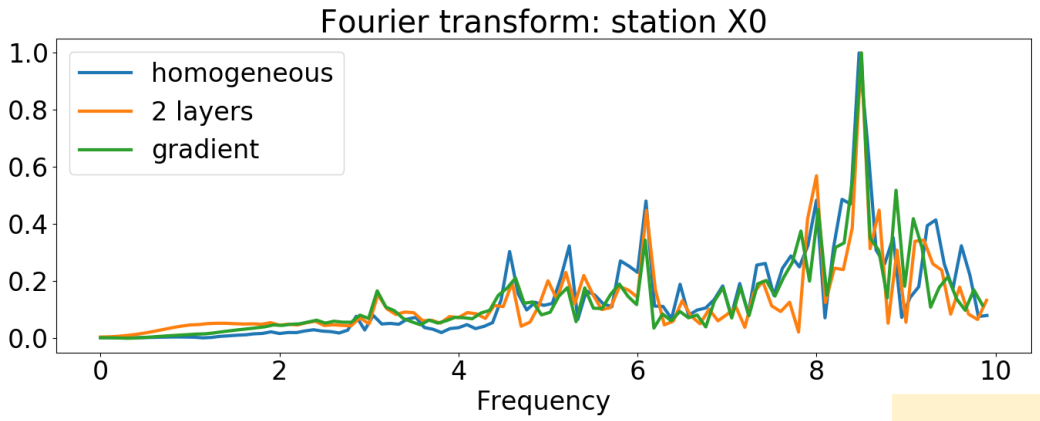
TOTAL of measurements: 3 (comp) x 2 (sta) x 2 (scenarios) = 12 source time functions

DMT data simulation: spectrum comparisons

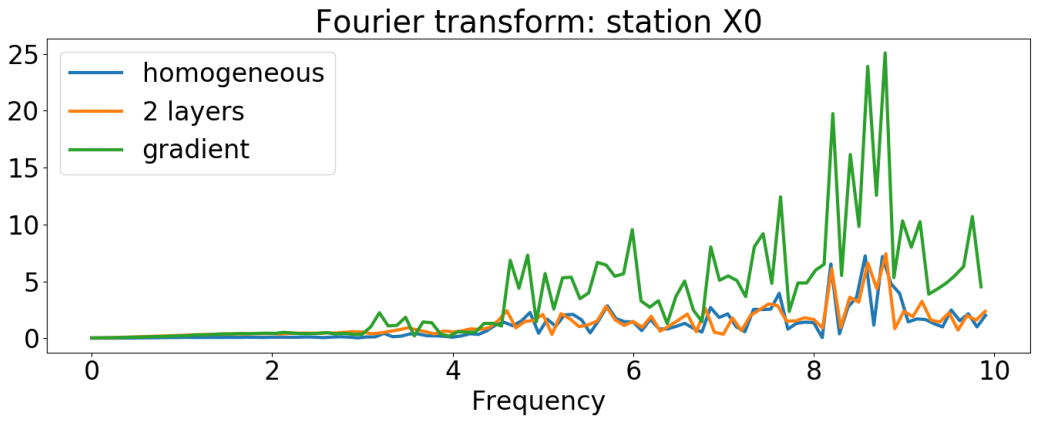
Calculated
Station HEI00

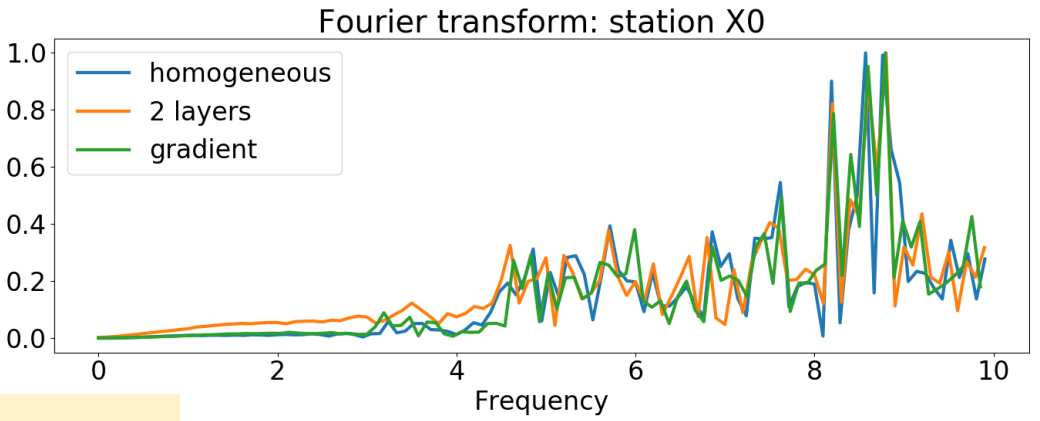
high wind speed





low wind speed





Not-normalised amplitudes

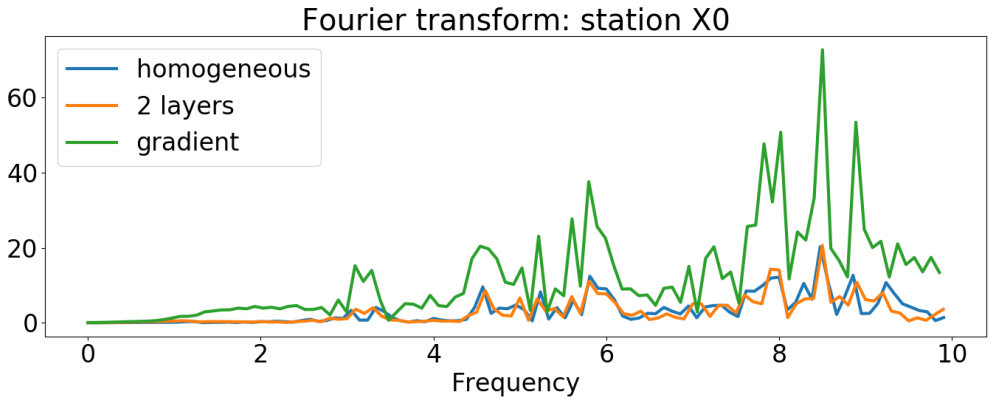
Normalised amplitudes

Station distance of 100 m

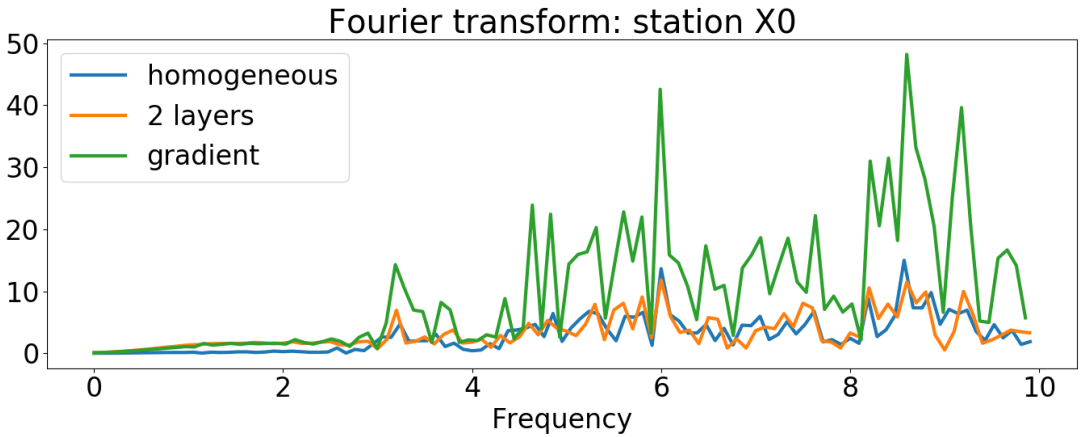
DMT data simulation: spectrum comparisons

Calculated Station HEIWF (foundation)

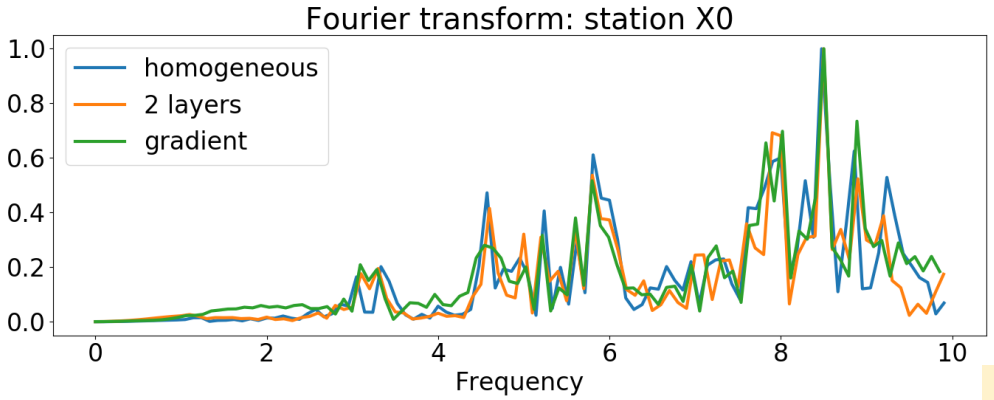
high wind speed



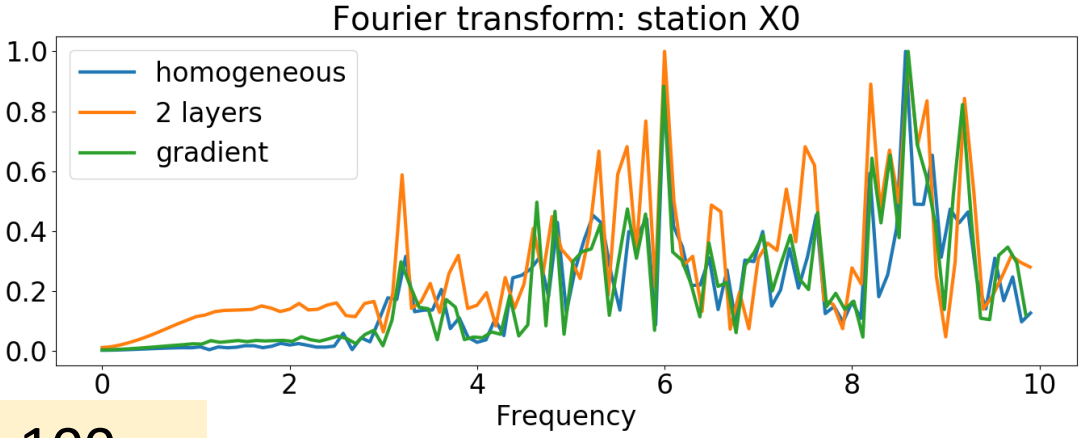
low wind speed



Not-normalised amplitudes



Normalised amplitudes



Station distance 100 m

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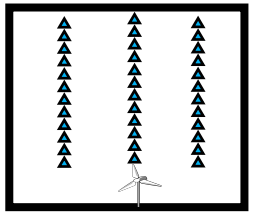
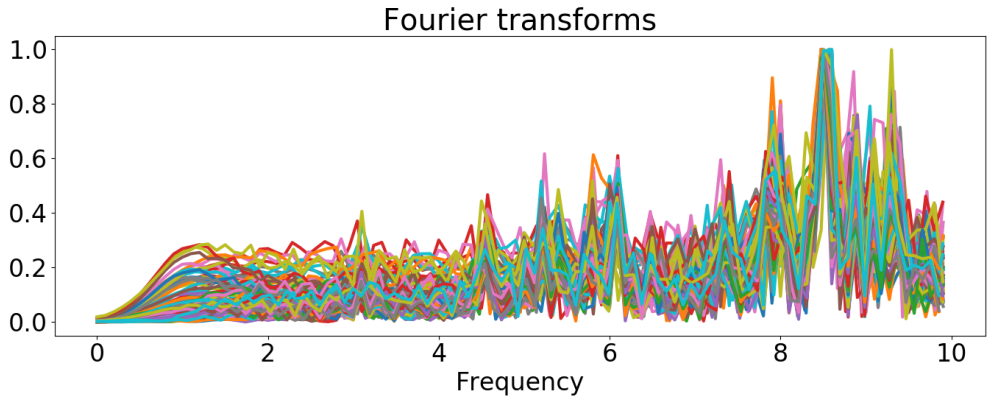
Comparison with distance- stack of all simulated spectra

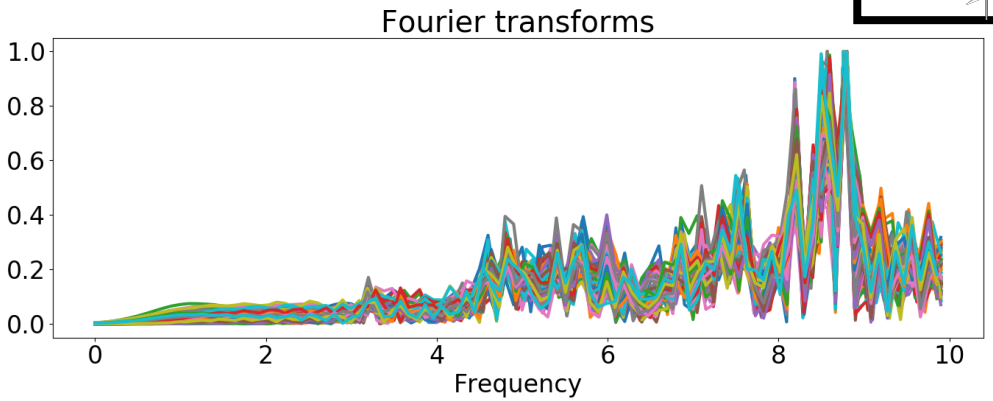


high wind speed

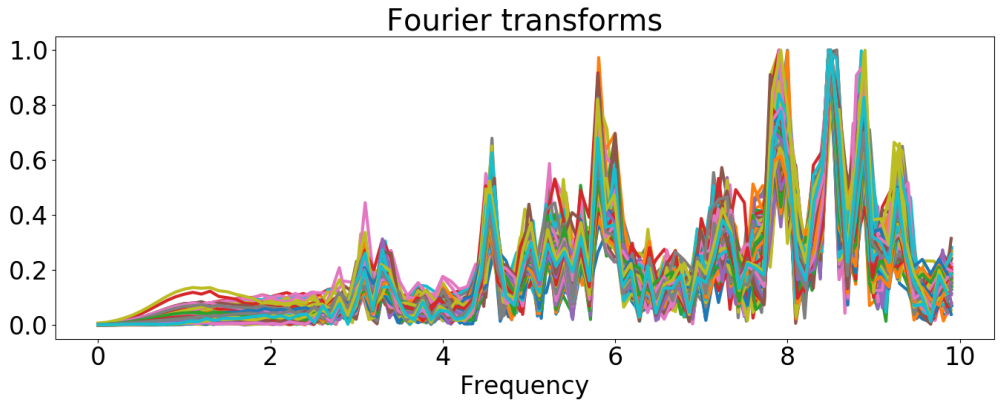


Station HEI00 as source

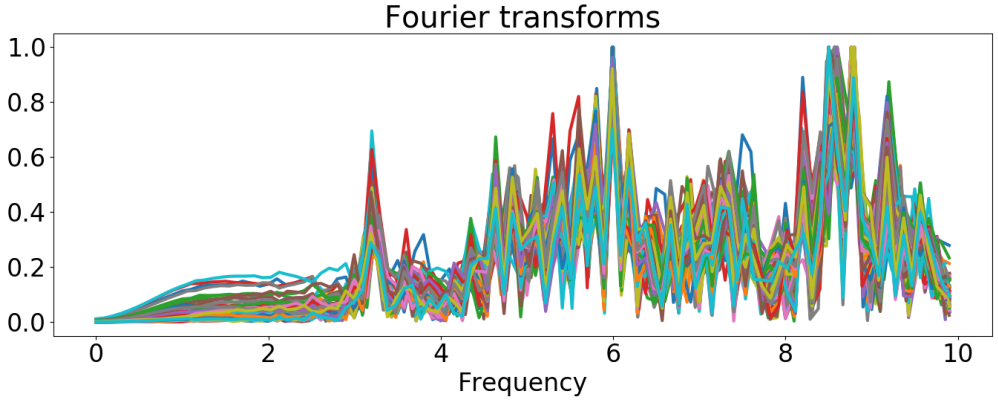
low wind speed



Spectra for all distances are similar



Station HEIWF as source



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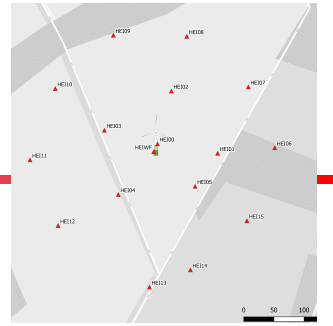
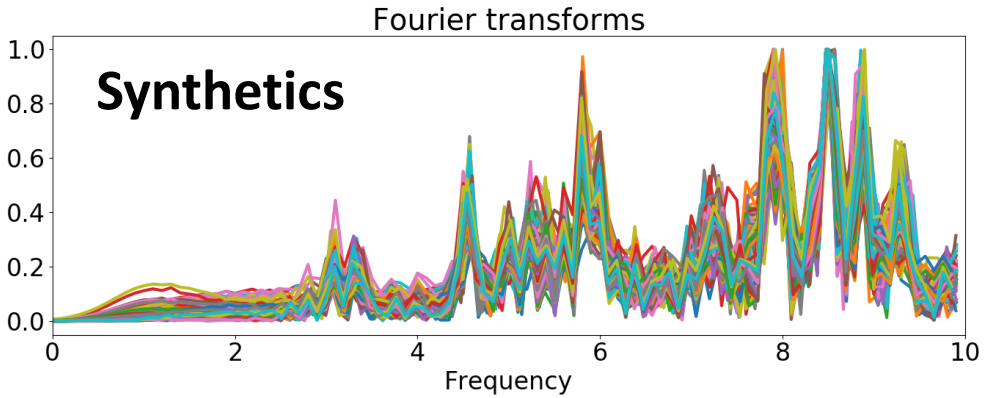
DMT data: spectra comparison data and simulations

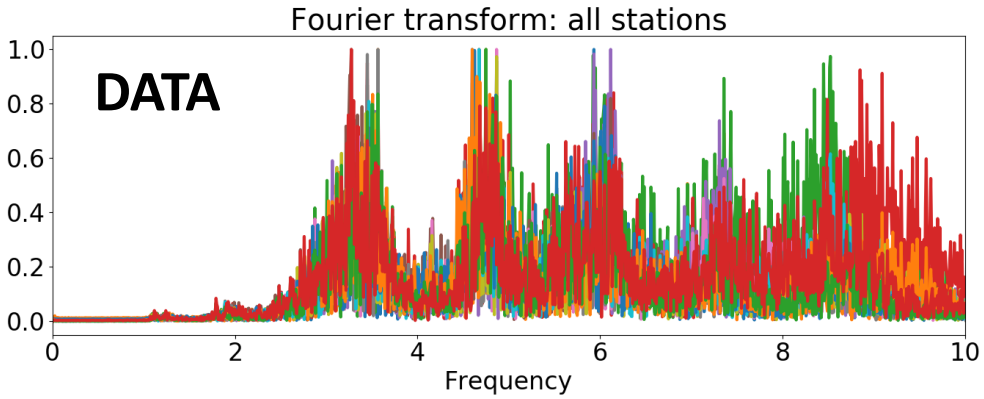


high wind speed

low wind speed

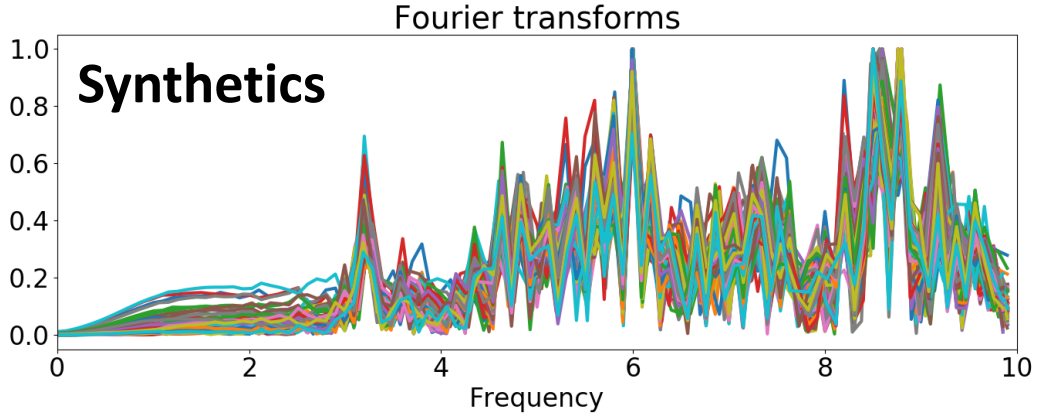
Station HEIWF

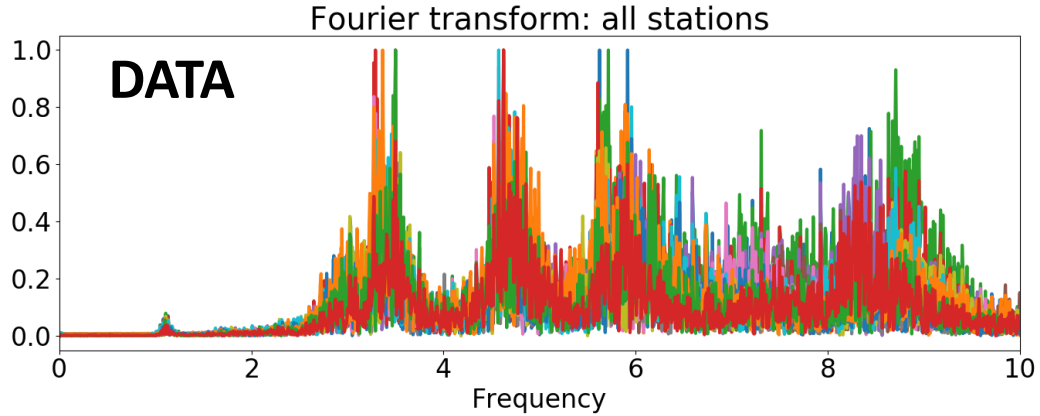




Spectra for simulations and data are similar

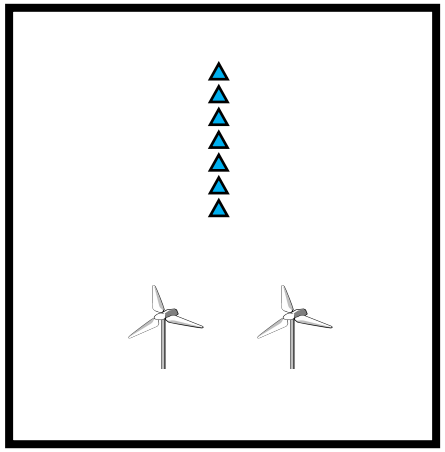
Station HEIWF



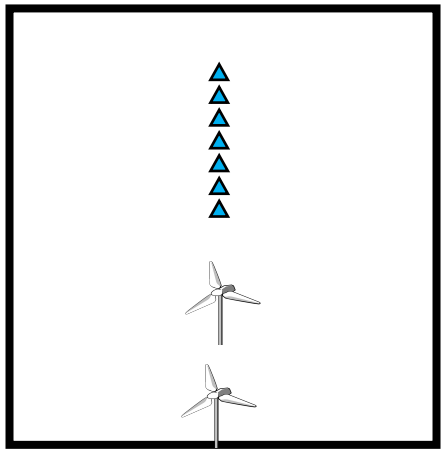


Influence of wind-turbine locations

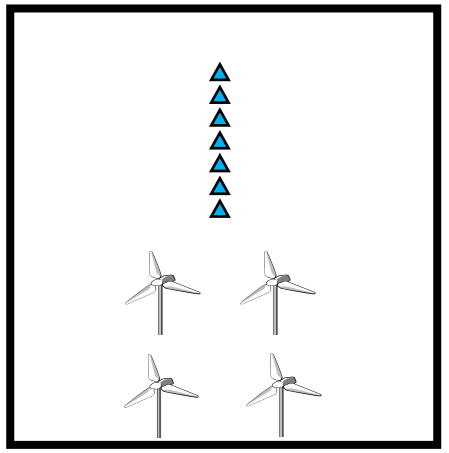
2 windturbines – horizontally aligned



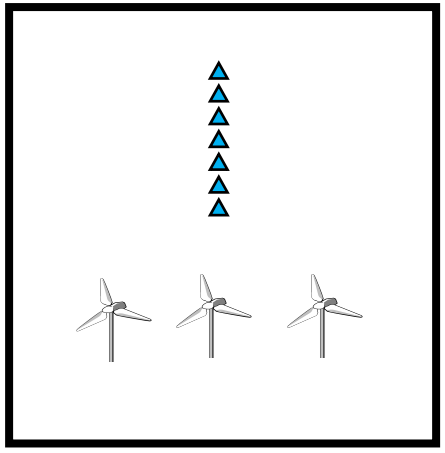
2 windturbines – vertically aligned



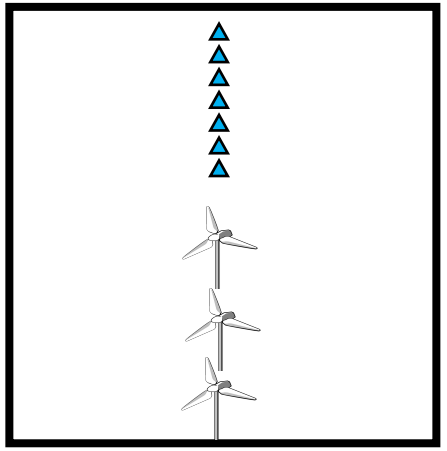
4 windturbines



3 windturbines – horizontally aligned



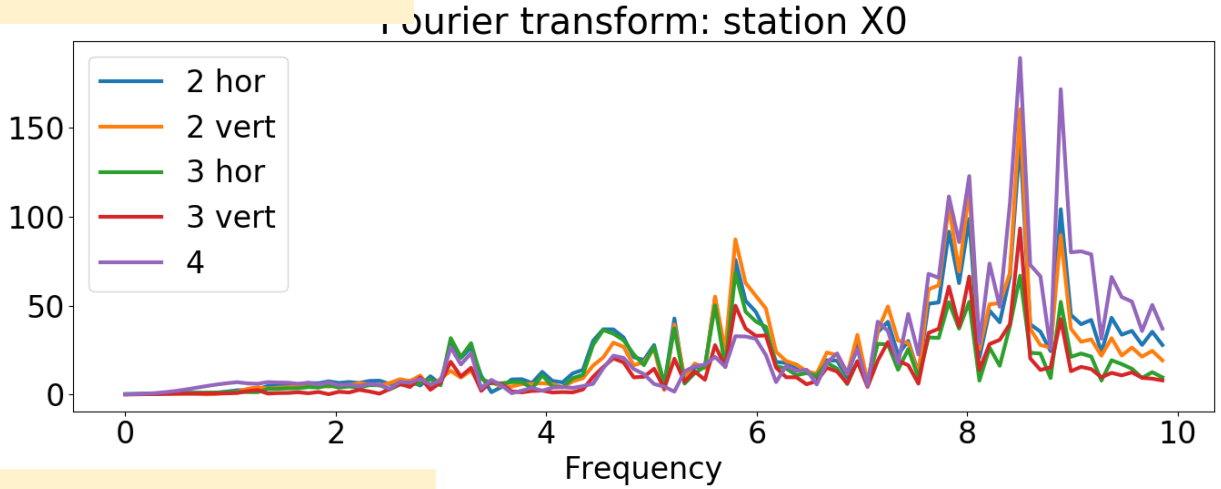
3 windturbines – vertically aligned



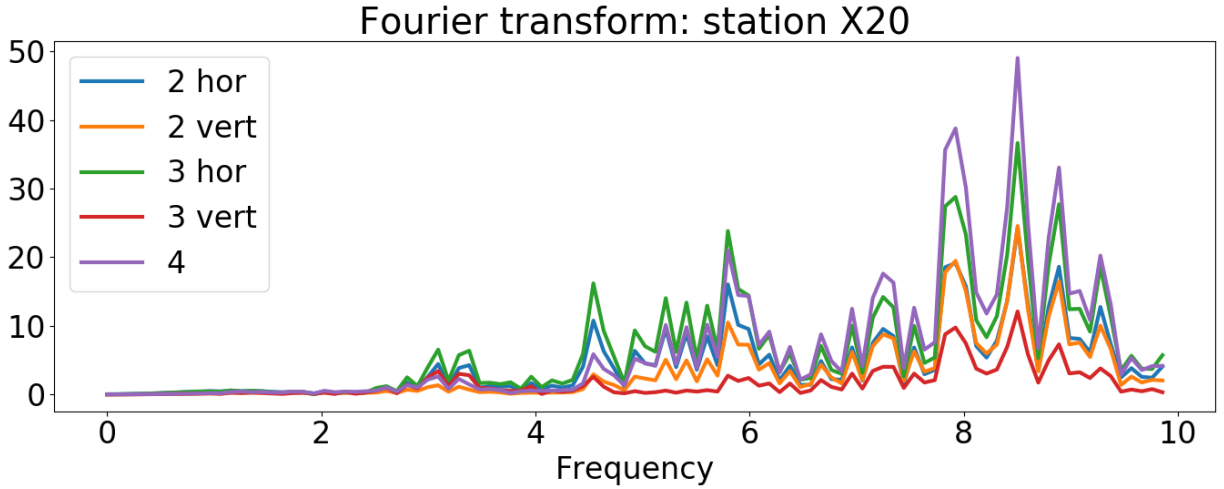
We test 5 different scenarios in order to study the influence of wind turbine arrangement on the amplification and frequency of the noise

Influence of wind-turbine locations

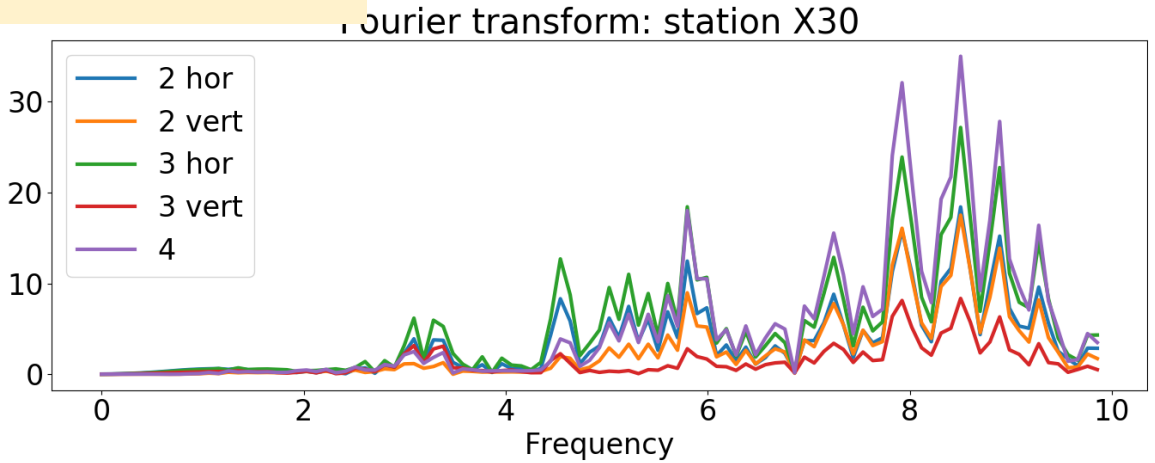
distance 100 m



distance 2300 m



distance 3500 m



Arrangement of turbines seems to help to reduce some frequencies, especially at higher frequencies.
Need to explore further!

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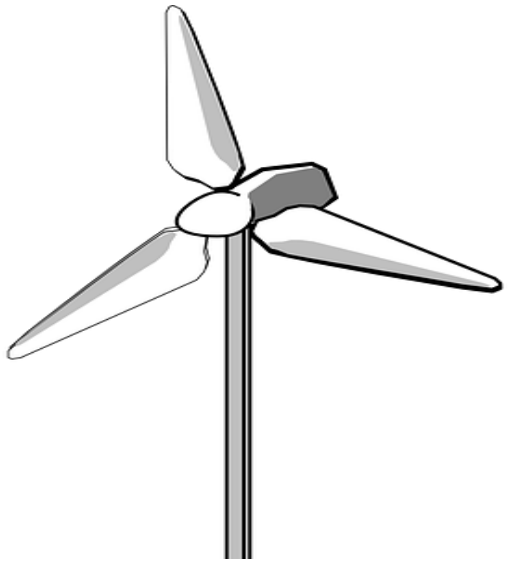
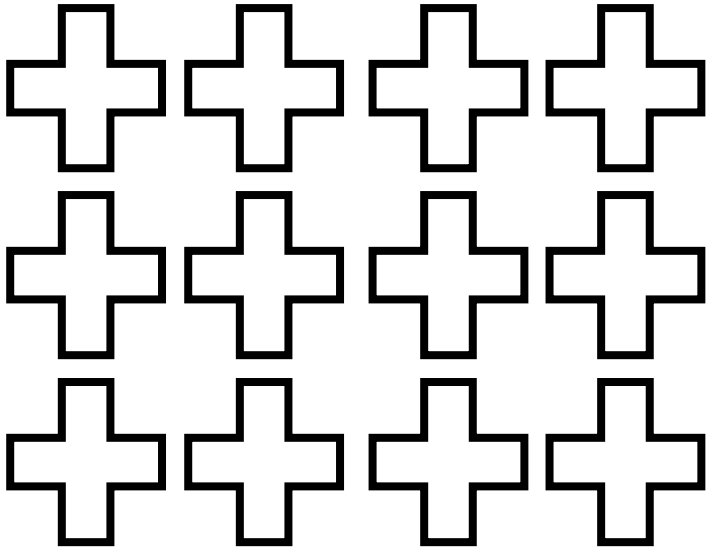
Design of seismic metamaterials



metamaterials



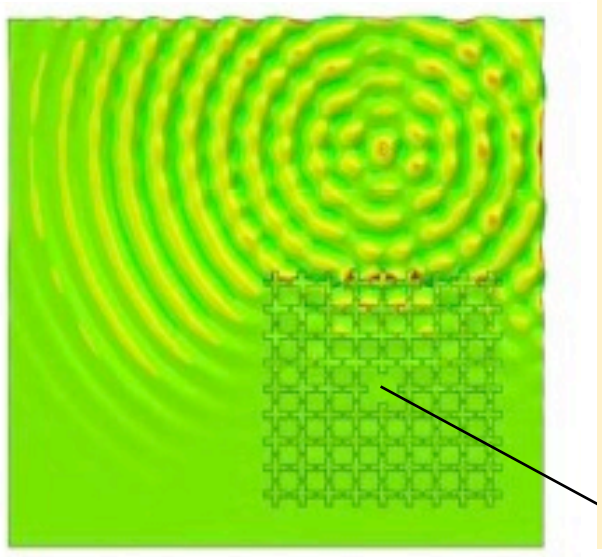
Protected area

Challenges:

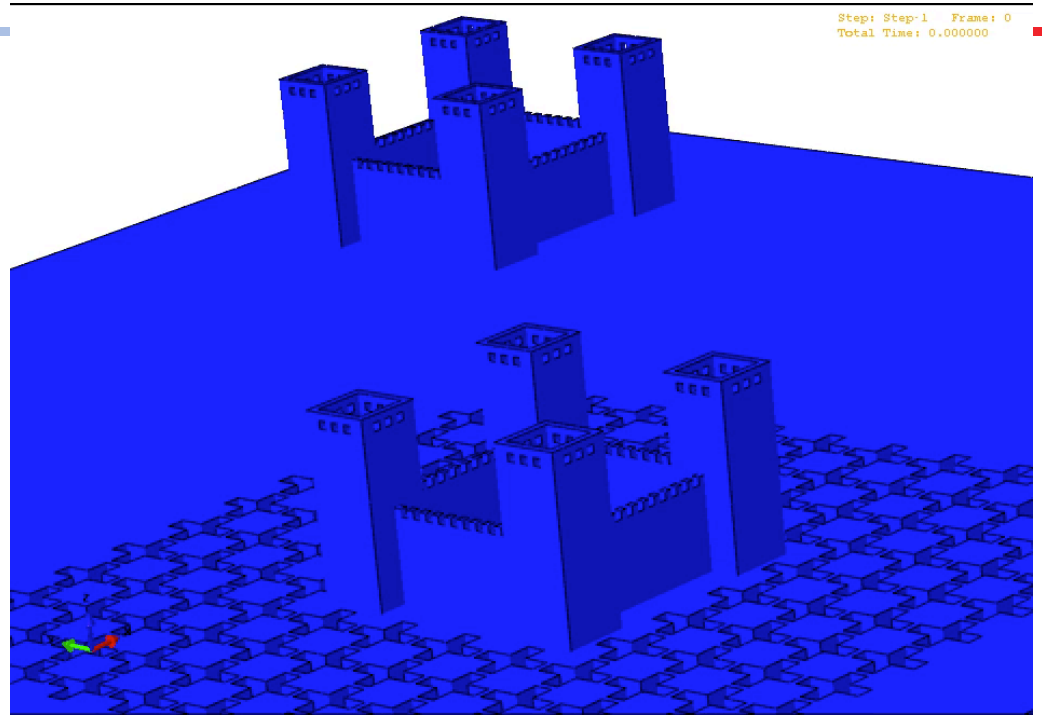
- Simple metamaterials are still far from being applicable for realistic applications
- Numerical design is complicated
- The meshing challenge …

Seismic soil-metamaterials

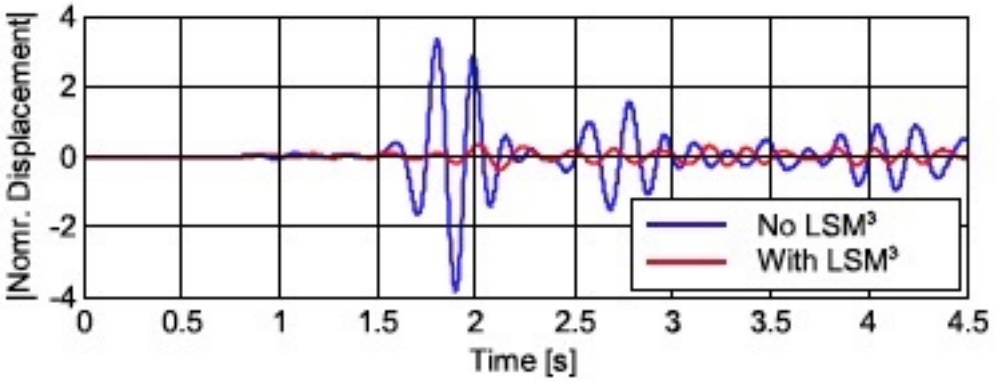
Finite element simulation at 5Hz



Metamaterials have been proposed to protect buildings so far. They reduce frequencies through scattering and attenuation



Miniaci et al. 2016

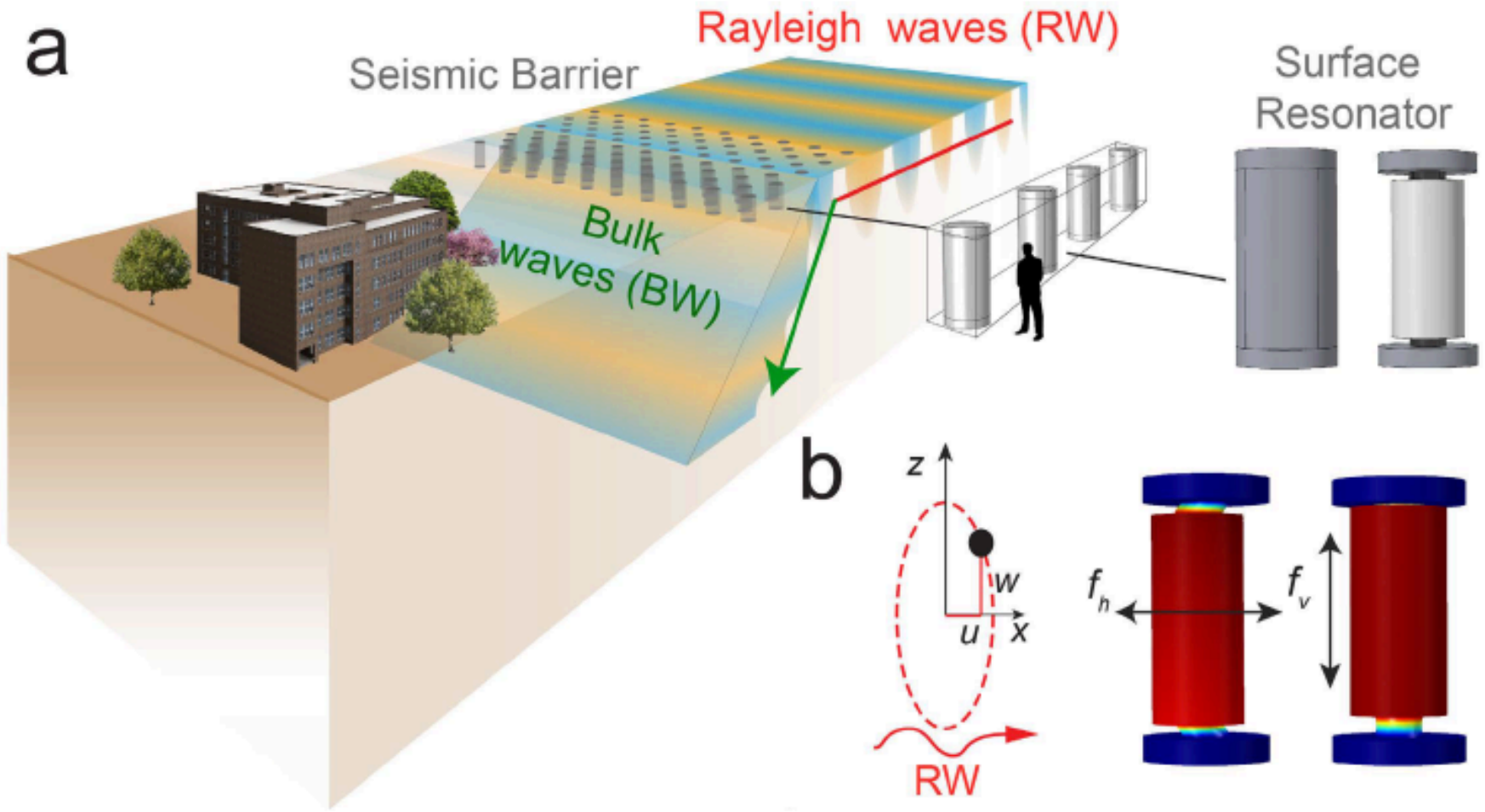


Dimensions of 200 x 200 x 100 m^3

9x9 grid of metamaterials of 10m deep

LSM- Large Scale Metamaterial

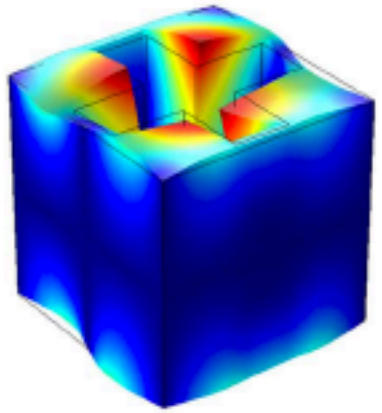
Buried mass resonators

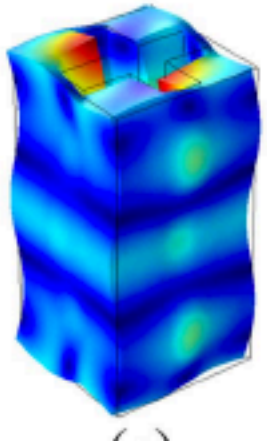


New metamaterial studies include trees, large resonators, holes etc.
Resonators for example not feasible for wind turbines because too expensive

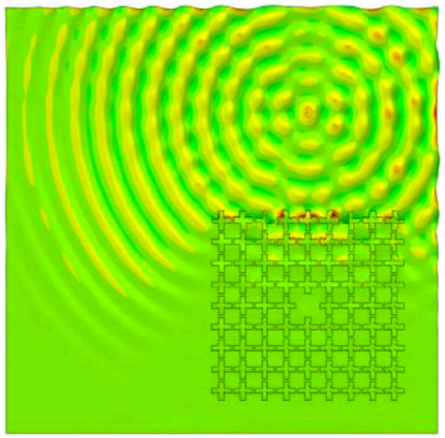
From Palermo et al. 2016

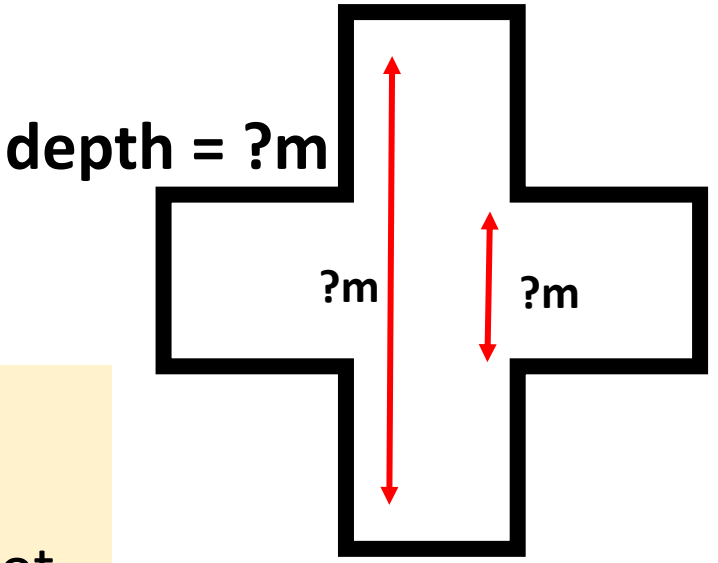
Our metamaterial design: first trials

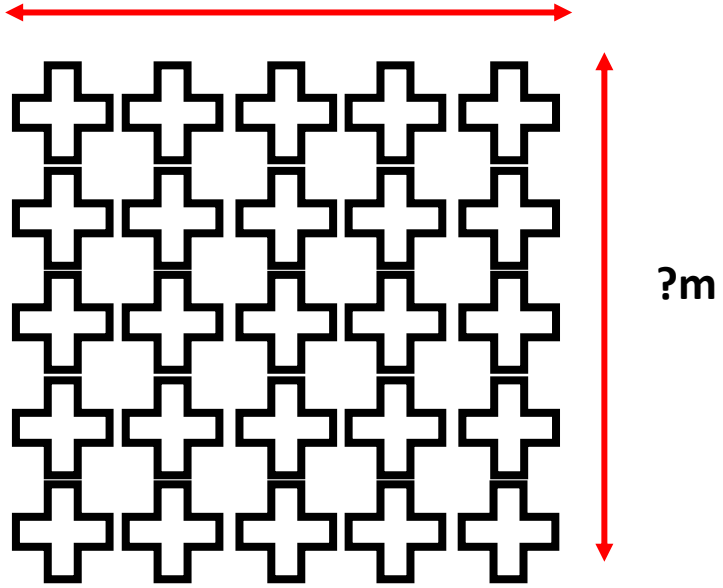




(Miniaci et al. 2016)



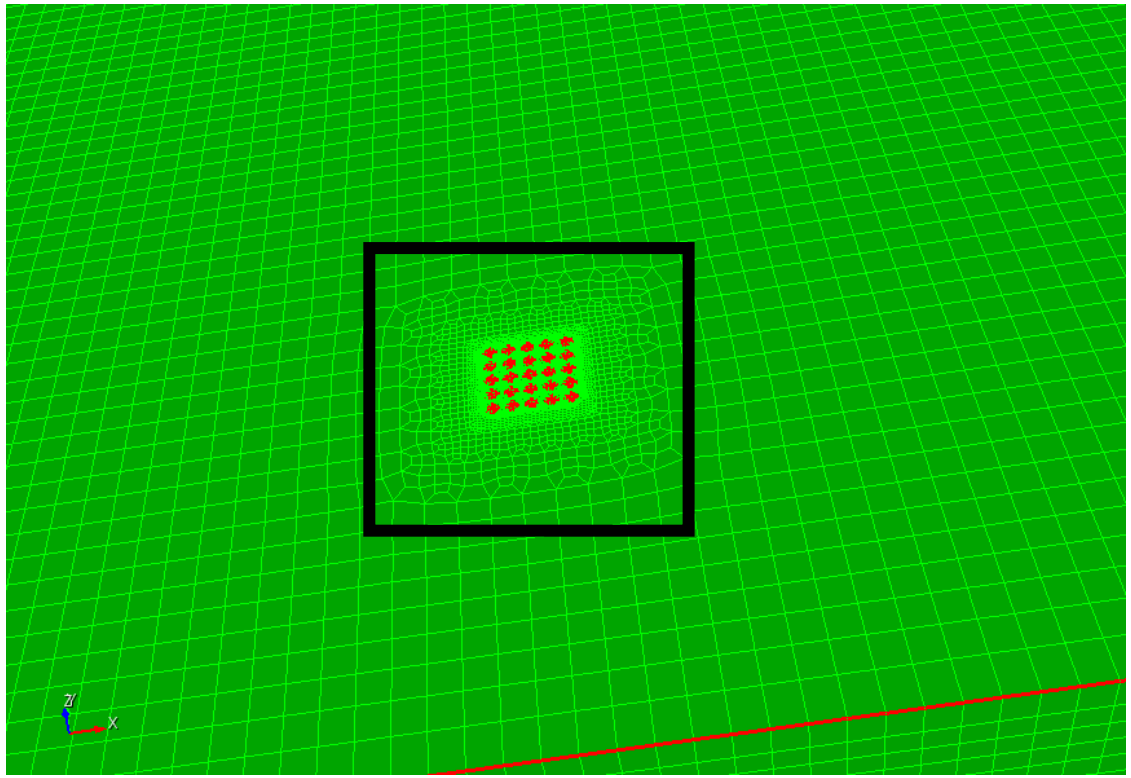


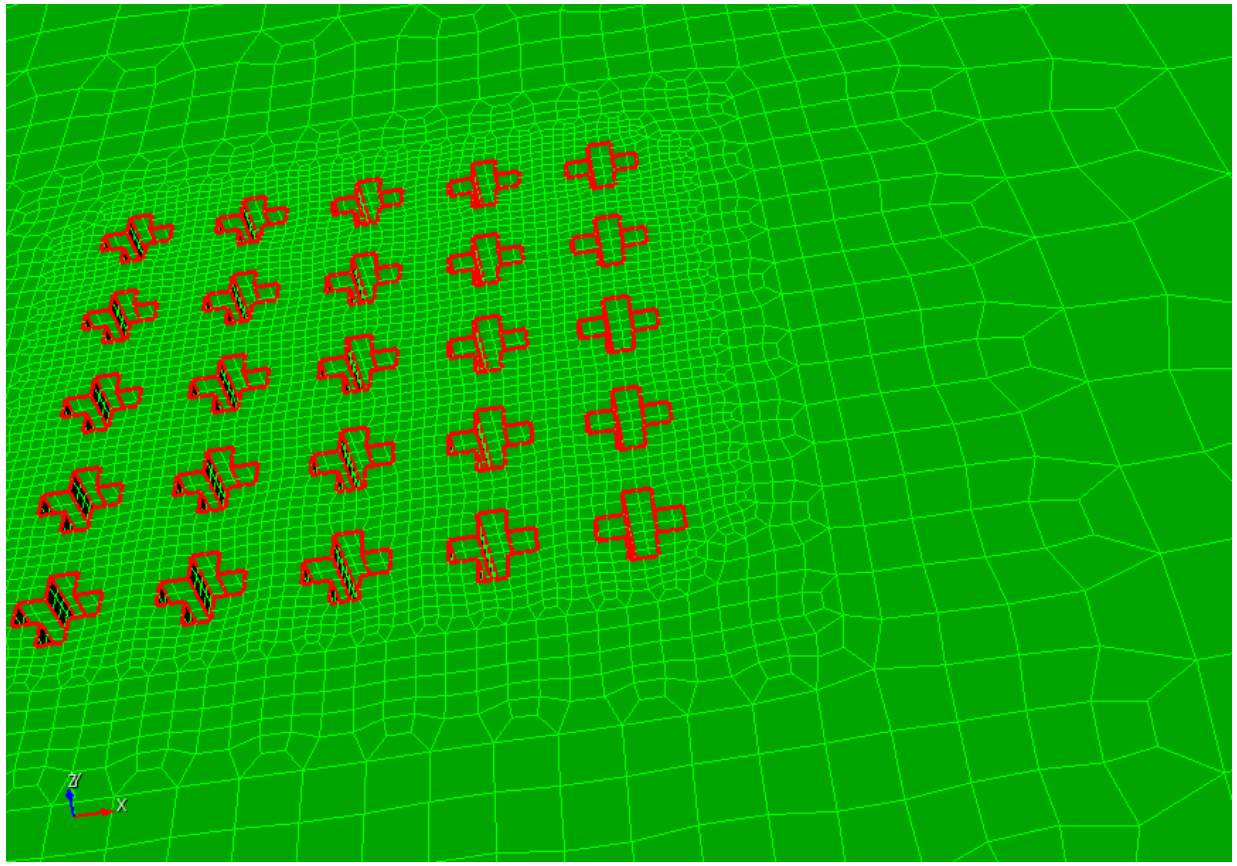


Previous simulation experiment looked at one unit cell with periodic boundary conditions. Not applicable here

We test an array of holes for their effect on seismic waves

The mesh challenge

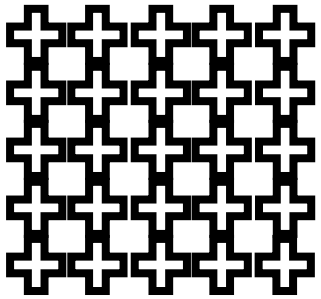


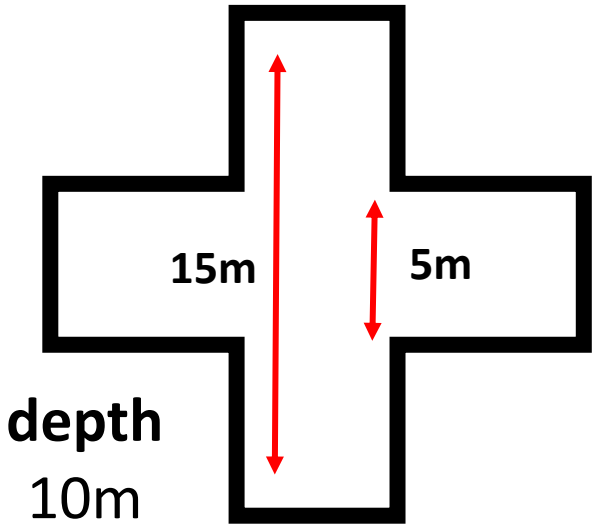


- ✓ The reduction of the element size increases the computer memory requirements
- ✓ Important to build regular meshes

First numerical models

5x5 elements

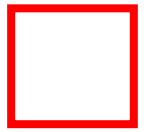




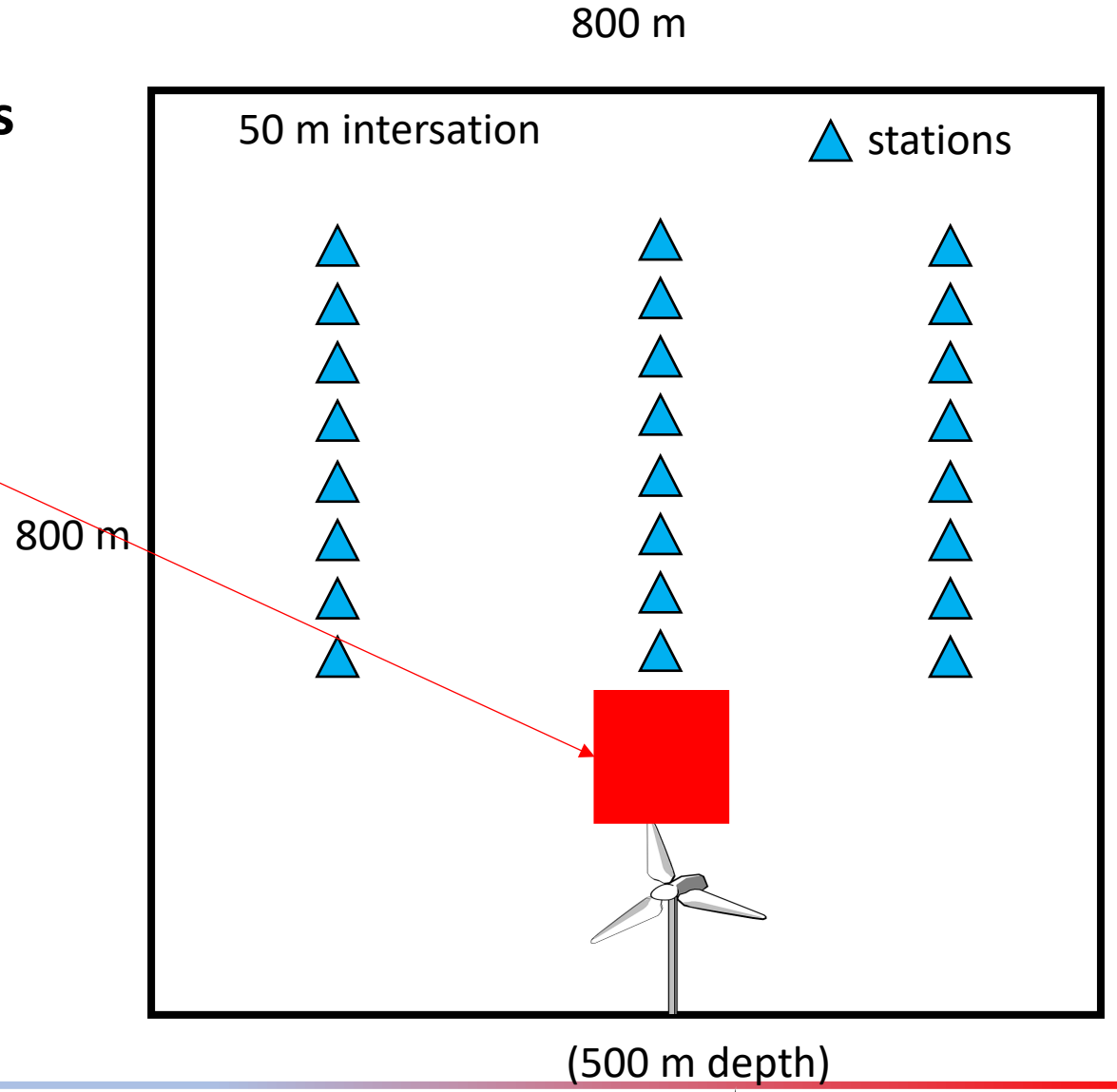
Metamaterials dimensions

60 m X 60 m

80 m X 80 m



We vary the metamaterials aperture of the metamaterias



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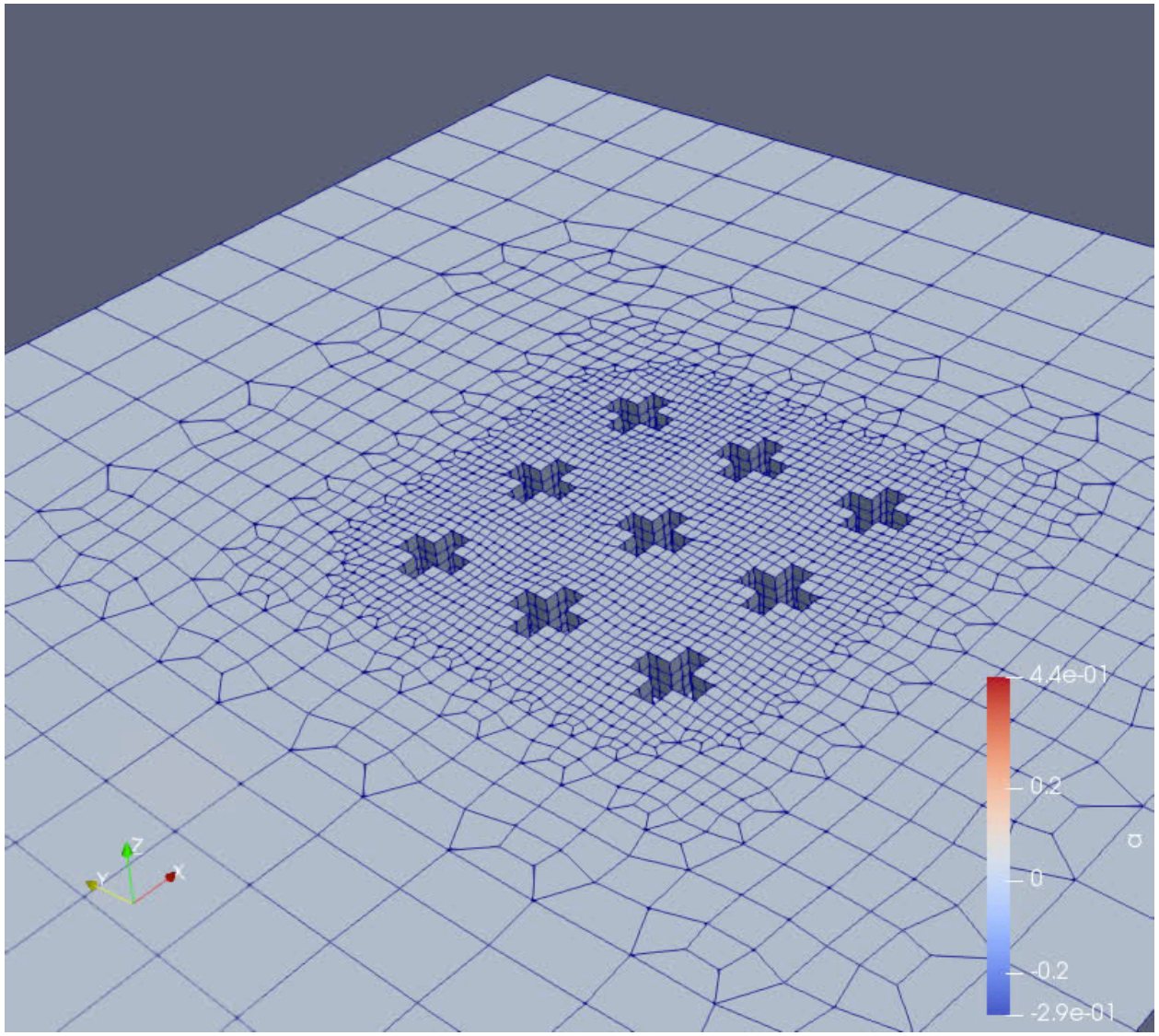
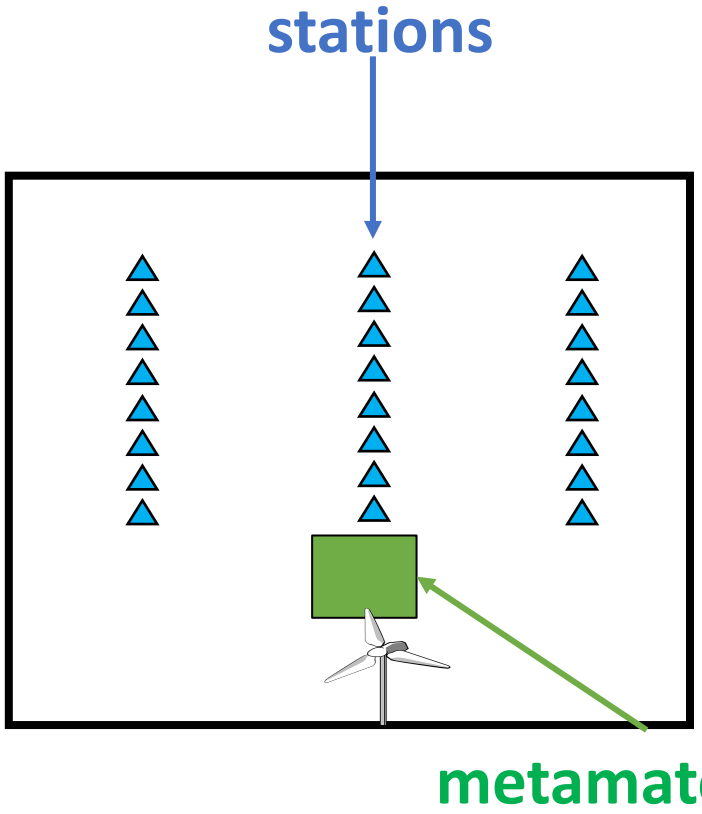
Example simulation

Wave propagation in a toy example mesh designed to test metamaterials' effects

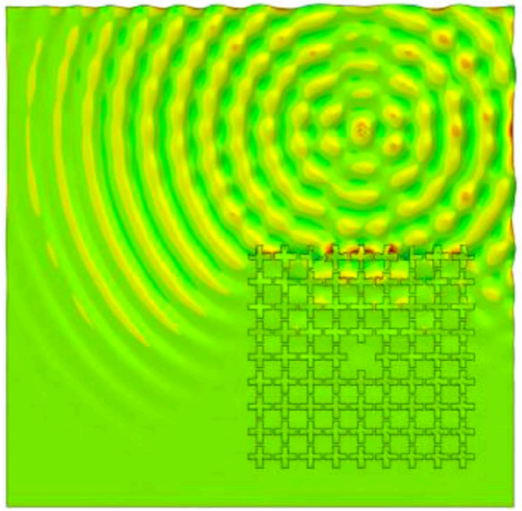


Effects of arrangements?

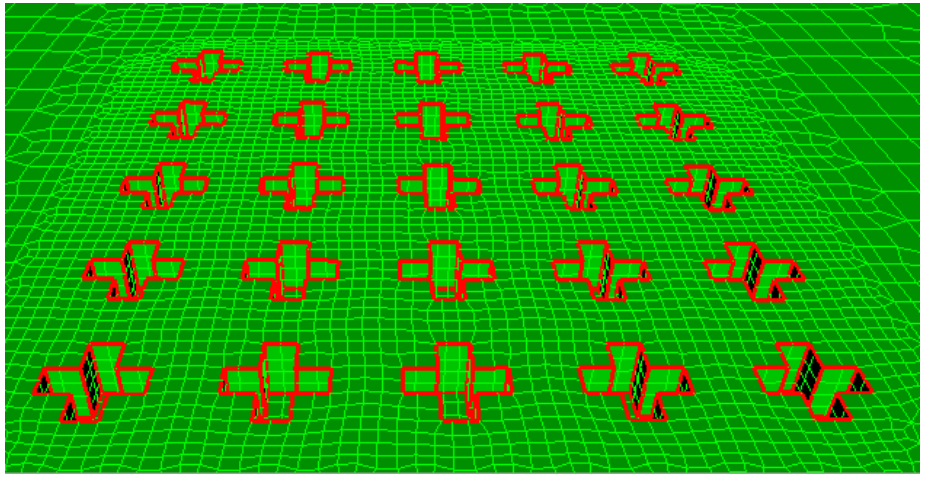
We test two different scenarios in order to investigate the influence of the metamaterials' arrangement (we will test more cases)



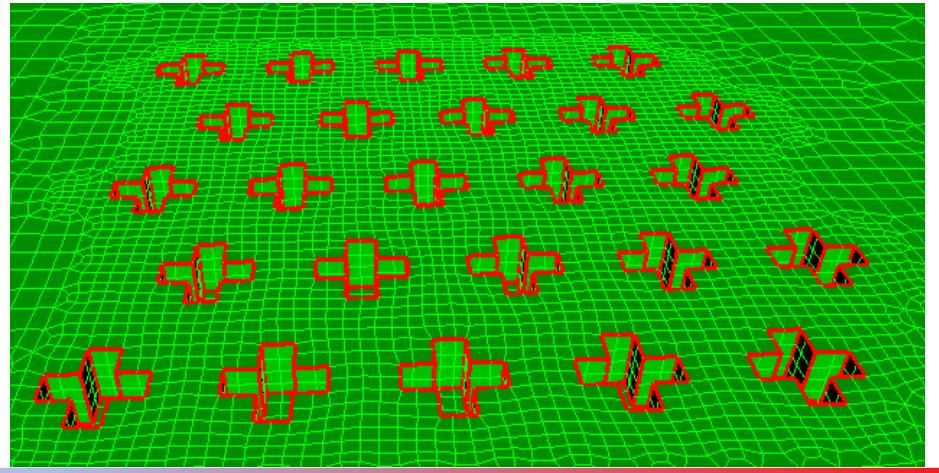
Previously done
(Miniaci et al. 2016)



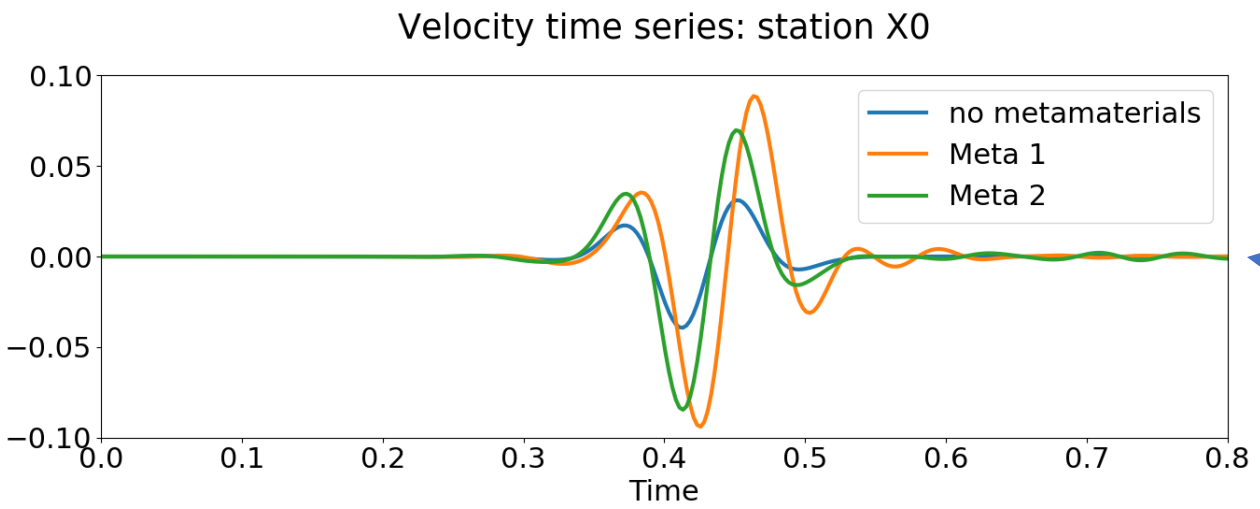
First case **60 m X 60 m**

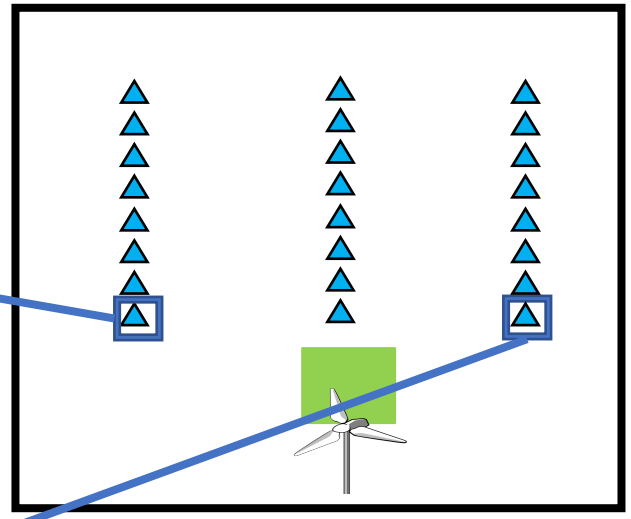


Second case

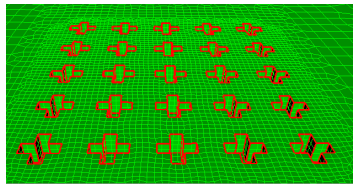


Comparison of wave propagation 1

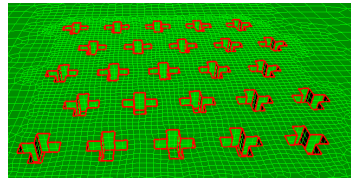


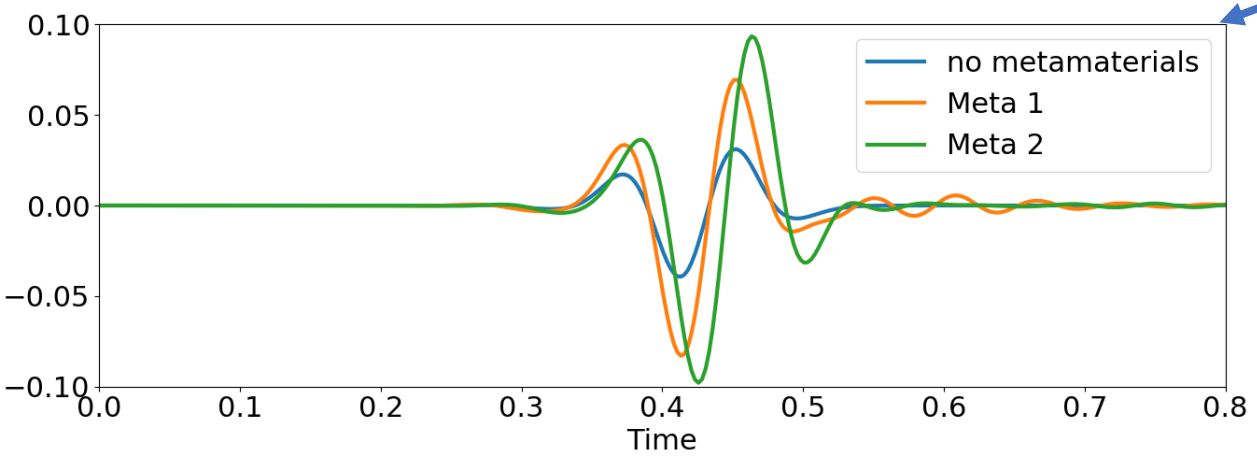


Meta 1



Meta 2





We can observe the presence of anisotropy in the wave propagation (meta 2)
Models with metamaterials show larger amplitude. Why?
Tests needed…

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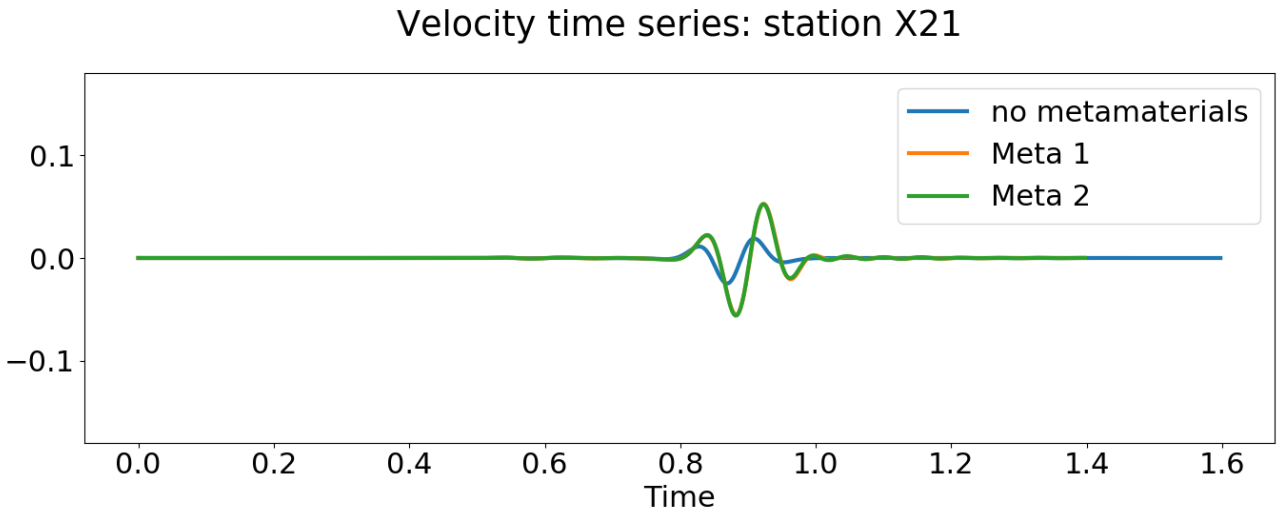
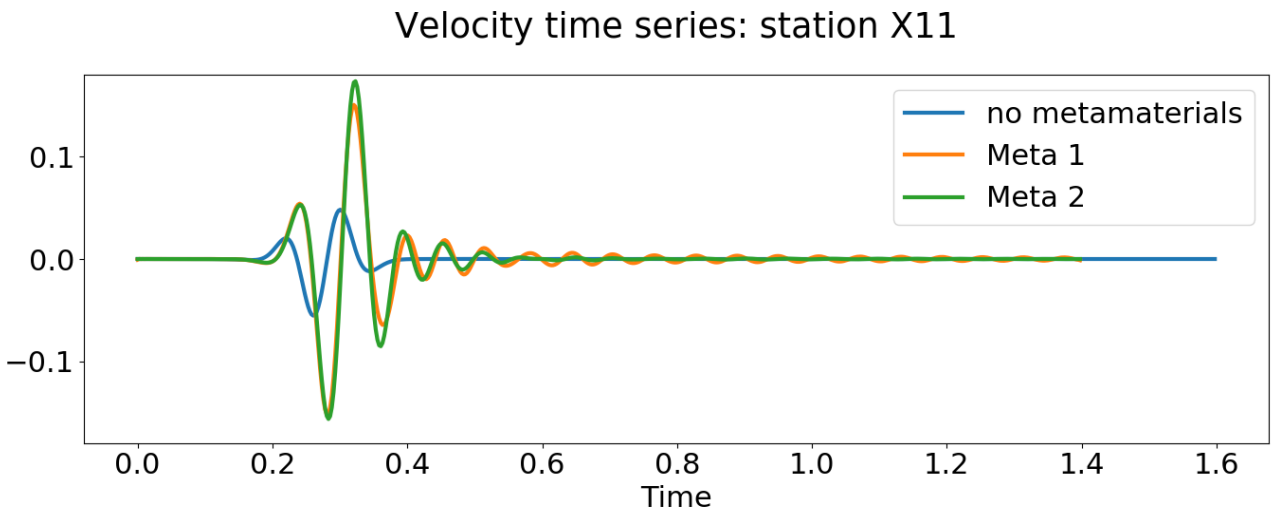
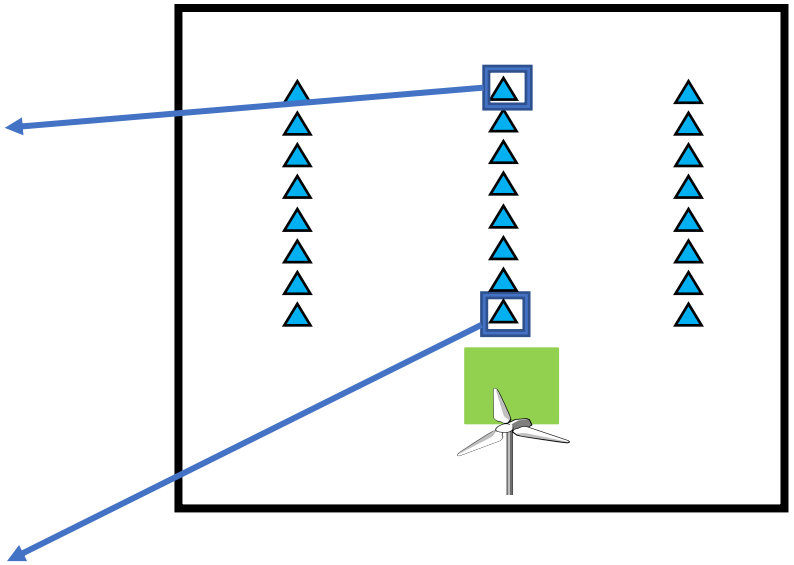
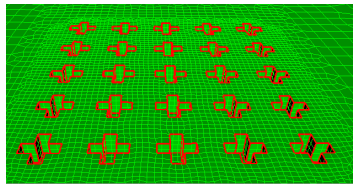
Compasion of wave propagation 2



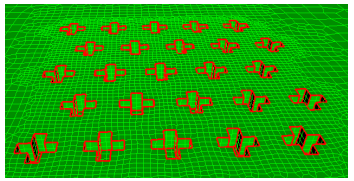




Meta 1



Meta 2



Clear effect of amplification due to scattering produced by the seismic metamaterials (but amplitudes are larger- why?)

Next steps…

- Test different metamaterials in order to determine attenuation (or amplification) effects:
  - Cavities filled with rocks.
  - Cavities filled with sand.
  - Cavities filled with water.

- Test shapes and arrangements of metamaterials

- Test different sizes (problem with computer capacities)

Summary

- ✓ We have performed numerical simulation of wind turbine generated noise through subsurface models
- ✓ 1D models show that spectra for measured DMT data can be reproduced by wave propagation models
- ✓ Effect of different arrangement of wind turbines is large! We need to explore further and compare with measurements (DMT)
- ✓ First numerical simulations of metamaterials. Results show that scattering occurs but amplitudes with metamaterials are larger and it is not clear why yet. Future direction involves exploring different models filled with different materials.