EXAMIN

Impact of soil spatial variability on high frequency site response and surface waves

Irmela Zentner, Aurélie Gosset EDF R&D
Kristel Meza-Fajardo BRGM

Plan

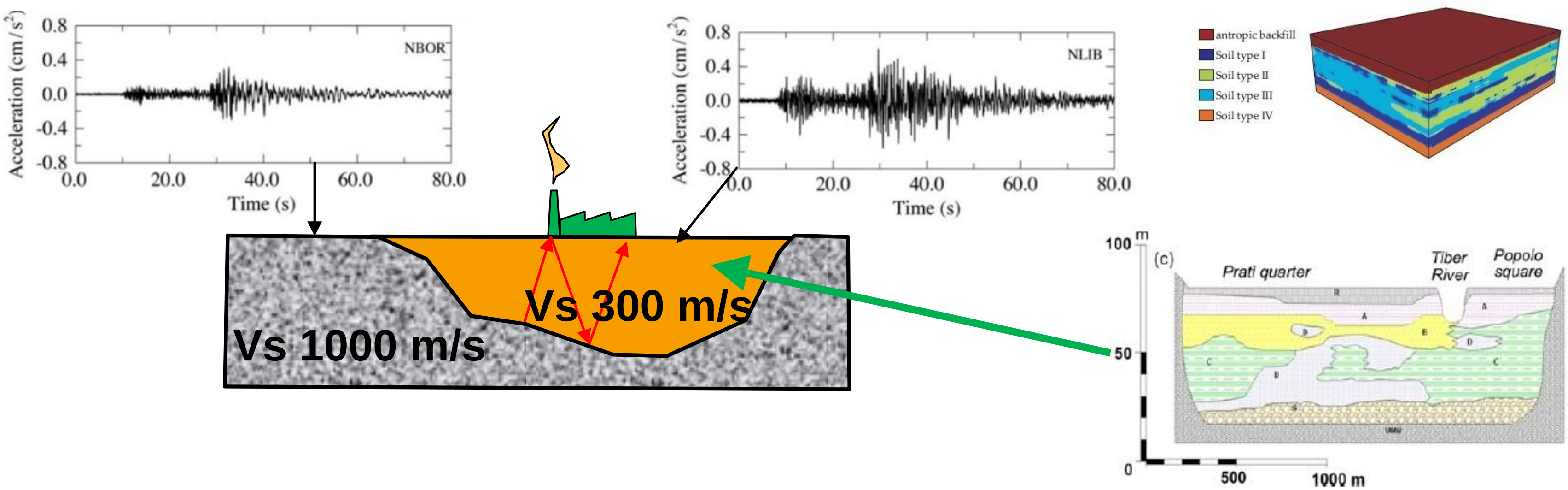
1. Introduction
   - Context an objectives

2. Impact of wave scattering on site response
   - Random field modelling
   - High frequency decay and kappa
   - Surface waves and 1D-2D site response

3. Conclusion & perspectives

Introduction

- Site effect: layering, basin, topography, subsoil configuration
- Local Spatial variability of soil properties: variability of soil properties and seismic motion on ground surface even at local scale (< 100m)



Martino et al BSSA 2015

Introduction

- Impact of local spatial variability on surface ground motion
  - Incoherence of ground motion (coherency functions, …) -> Afifas talk
  - High frequency decay
    - Damping drives high frequency attenuation
    - Decay more important for higher frequencies, not fully explained by soil intrinsic damping (Thompson et al 2012, Sato 2018, …)
    - Comprehensive analyses of impact of scattering and intrinsic damping on kappa
  - 1D versus 2D site response,
    - Are 1D soil column analyses enough?
    - Creation and properties of surface waves

Random field modelling

- Lognormal random field for Young's modulus

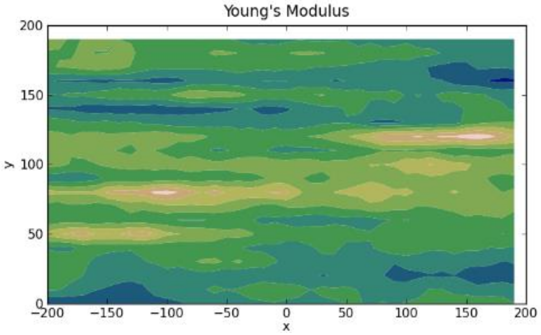
$$E(x) = E_m(x)exp[\beta_E U(x)]$$ ← Gaussian random field

- Centered standard Gaussian random field U(x) entirely characterized by its correlation function

$$R_U(x,x') = \boldsymbol{E}(U(x)U(x'))$$

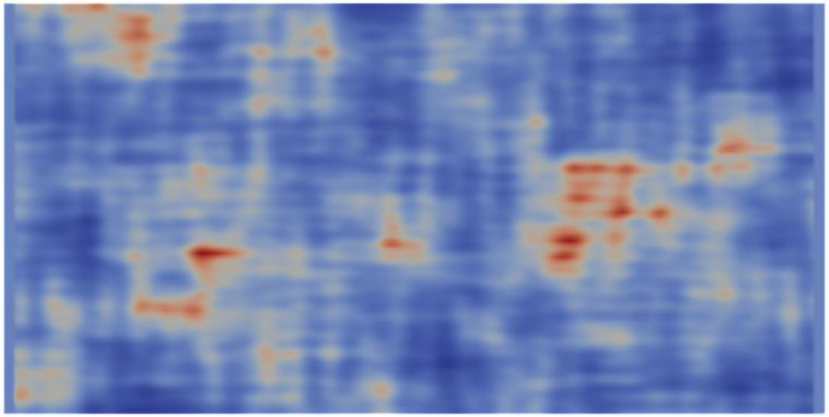
Depends only on distance $\zeta = x - x'$ for a homogeneous random field and on parameters Lc and cov

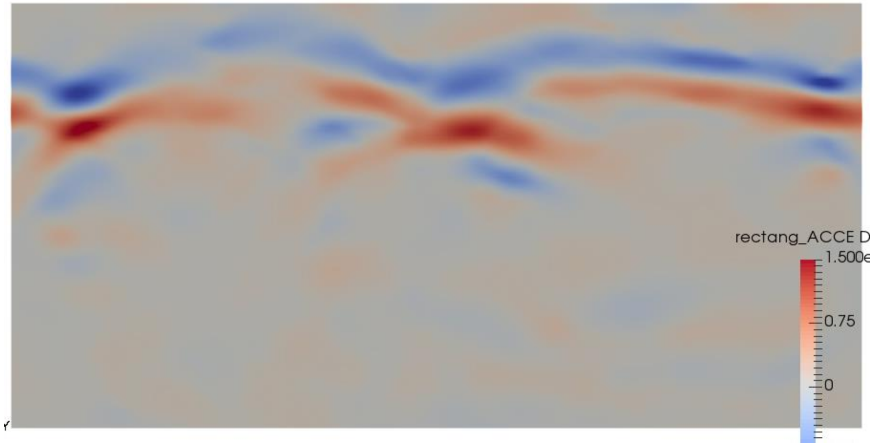
Correlation Model	Expression
Markov	$R(\zeta) = exp\left(-\frac{\lvert\zeta\rvert}{a}\right)$
Gaussian	$R(\zeta) = exp\left(-\pi(\frac{\zeta}{a})^2\right)$
von Karman	$R(\zeta) = \frac{2^{1-\kappa}}{\Gamma(\kappa)}(\frac{\zeta}{a})^{\kappa}K_{\kappa}(\frac{\zeta}{a})$



Random field modelling

- 2D site response
  - Numerical investigation of impact of wave scattering using code_aster





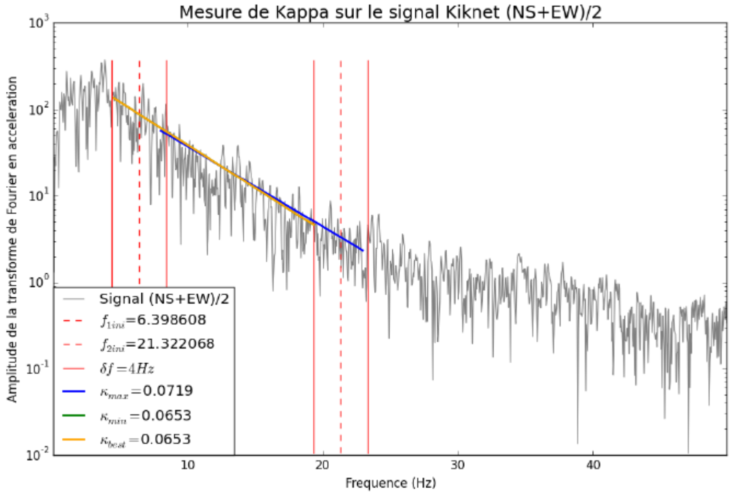
Random field modelling

- Animation

High frequency decay

- Spectral amplitude of ground motion

  Decay as defined by (Anderson & Hough 1984)



$$A(f) = A_0 e^{-\pi\kappa f}, f > f_{max}$$

slope $$-\pi\kappa = \frac{dln(A(f))}{df}$$

FAS $$A(f) = \Omega(f) D(r, f) S(f)$$

High frequency decay

- Kappa
  - Contribution to high frequency decay from site and path
    $$\kappa(R) = \kappa_0 + \kappa_{path}(\mathrm{R})$$
  - Considerable variations of κ_0 due to different site conditions, represents attenuation due to rock subsoil properties → “site kappa”
  - Site transfer function S(f)
- Site response
  - Velocity profile and damping $\xi = \frac{1}{2Q}$
  - Intrinsic damping and wave scattering effect $Q_{ef}^{-1} = Q_i^{-1} + Q_{sc}^{-1}(f)$
- Q & kappa represent attenuation $\kappa_0 = \int_0^z \frac{dz}{V_s(f)Q_{ef}(f)}$

→ Study impact of intrinsic damping and scattering separately

High frequency decay

- Transfer function with and without damping
  - Relation between soil damping and kappa

Vs=600m/s,
fcoup=50Hz

Ration of transfer functions with and without intrinsic soil damping ⇒ $\Delta\kappa=\kappa_i$

AH	0.03	0.05	$\Delta\kappa$	0.01042	0.0160
t^*	0.0086	0.0143	AH	0,037	0,056
$\Delta\kappa$	0.01042	0.0160			

$$Q_i = \frac{1}{AH}$$

$\Delta\kappa \sim t^*=H/Q_i\,Vs$

$$S(f) = \exp(-\pi H f / Q_i V_s)$$

(no contrast)

High frequency decay

Vs=600m/s,
fcoup=50Hz
AH = 0.01

- Transfer function with and without spatial soil variability

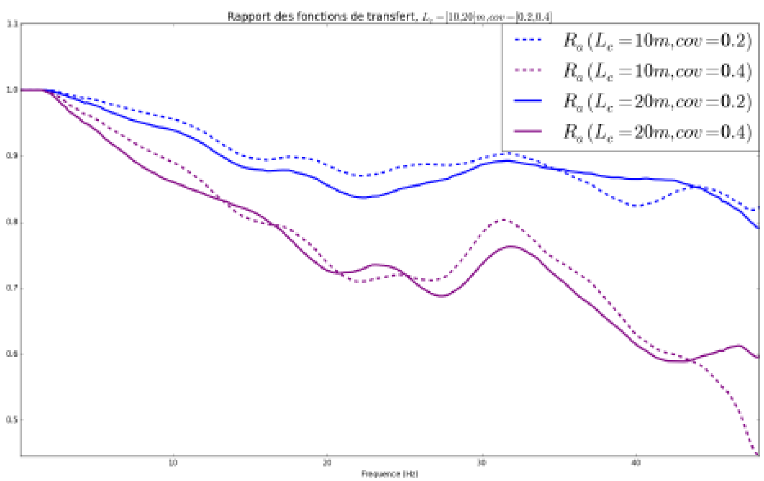
κ en fonction de L_c et *cov* :

cov \ L_c (m)	10	20	30
0.2	0.00970	0.00969	0.00941
0.4	0.0118	0.0105	0.00992

↑ cov ⇒ ↑ kappa

- Separate κ_{sc} and κ_i

Ratio of transfer functions with (mean over 10 realizations) and without soil heterogeneities



High frequency decay

- Transfer function with and without spatial soil variability
  - Determine additional damping due to scattering as a function of cov and Lc

$$\kappa_{sc} = \Delta\kappa = \kappa_0 - \kappa_a$$

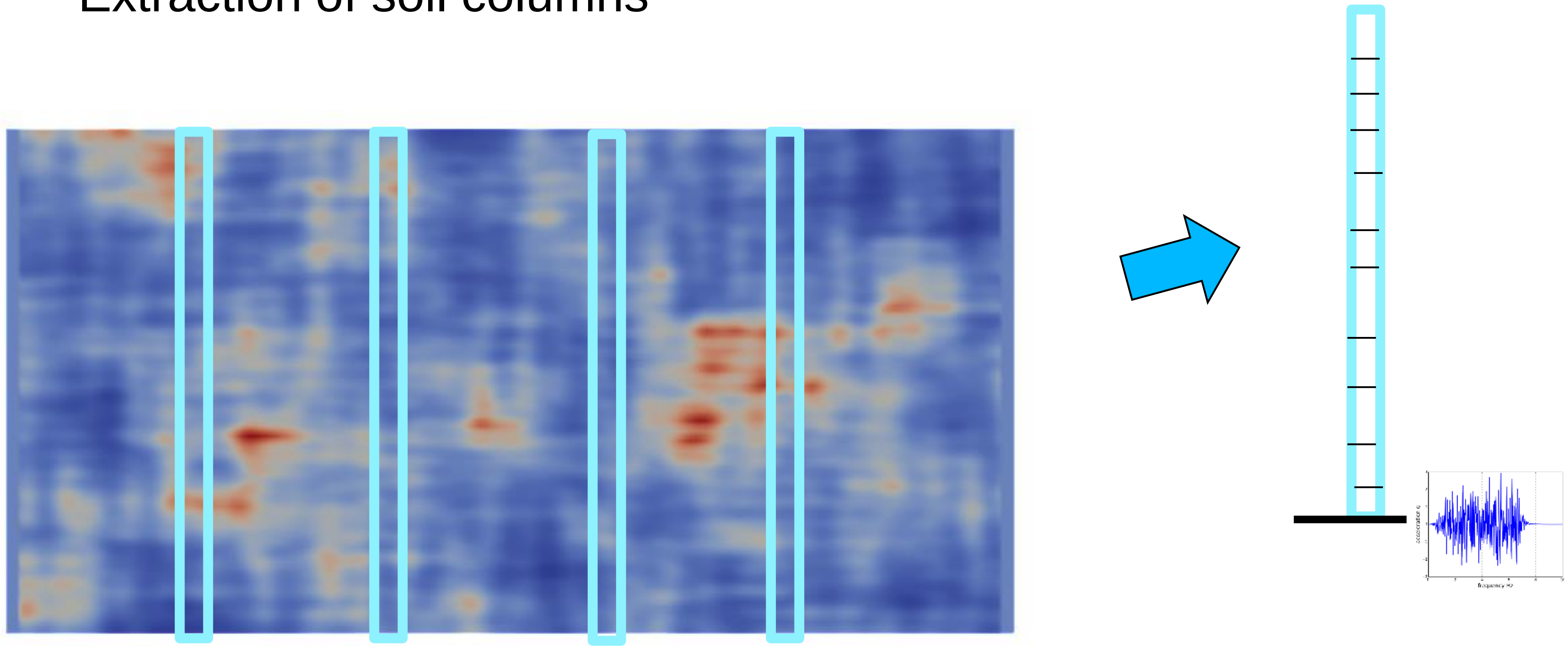
cov \ L_c (m)	10	20	30
0.2	0.00175	0.00174	0.00146
0.4	0.00385	0.00255	0.00197

AH = 0.01

$\uparrow$ cov $\Rightarrow \uparrow$ kappa

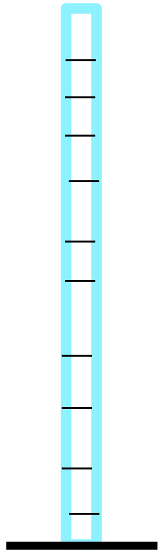
1D vs 2D site response

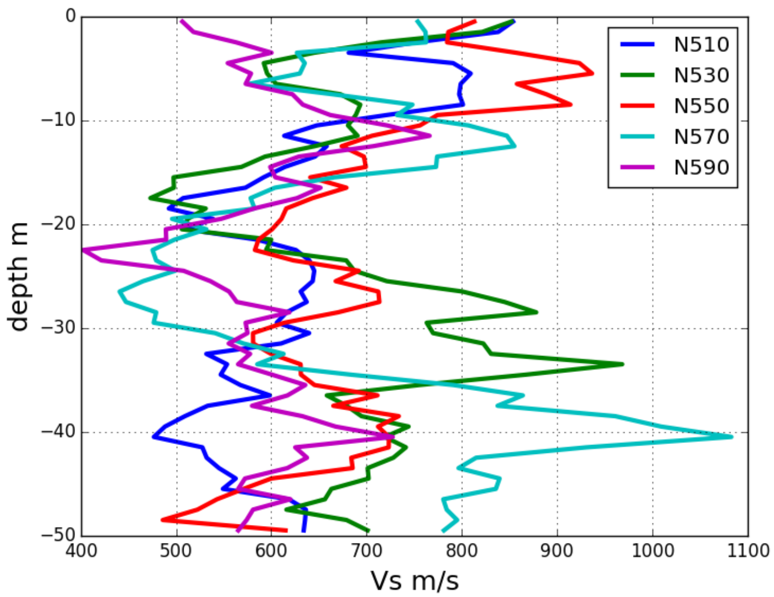
- Impact of 2D scattering
  - Classical approach consists in constructing 1D site response by soil column analyses
  - Extraction of soil columns

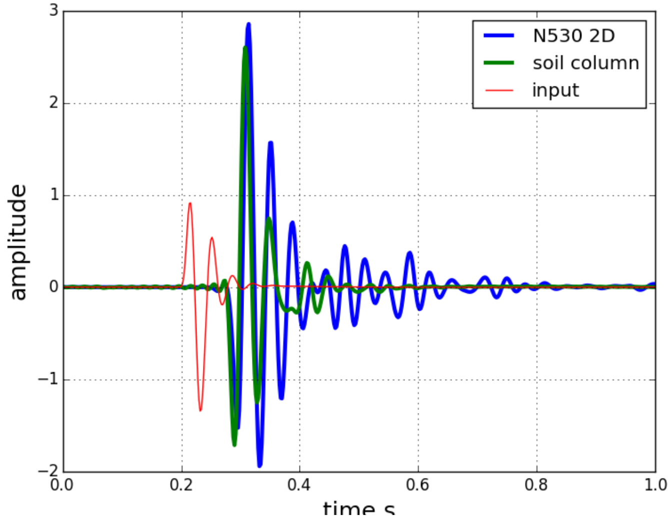


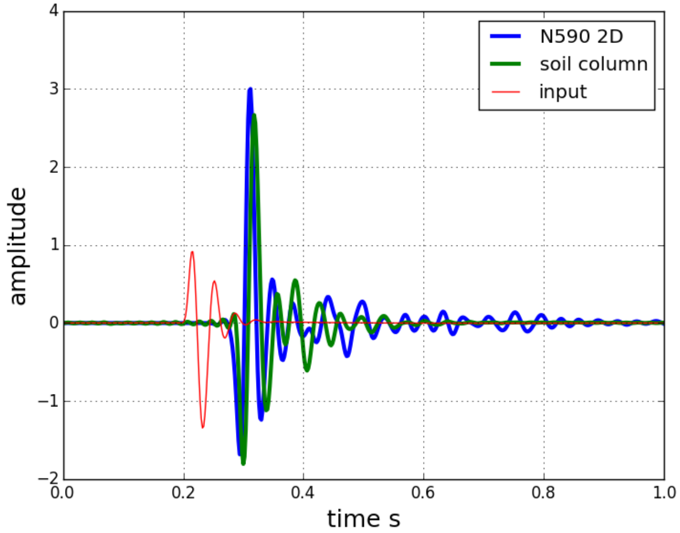
1D vs 2D site response

- Comparison of 1D – 2D response









- Elongation of wave path – strong motion duration increased
- Surface waves

Surface waves

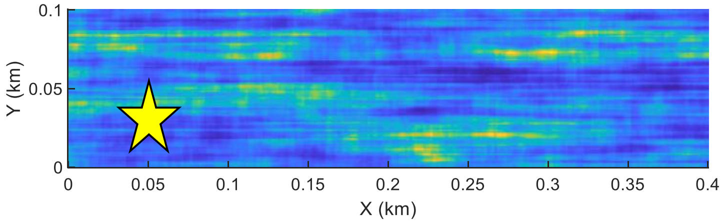
- Comparison of 1D-2D site response
  - Scattering : the path of the waves is impacted by the random velocity heterogeneities, late arrivals
  - Creation of surface waves

- Numerical experiments
  - 2D soil domain with point source

Surface waves

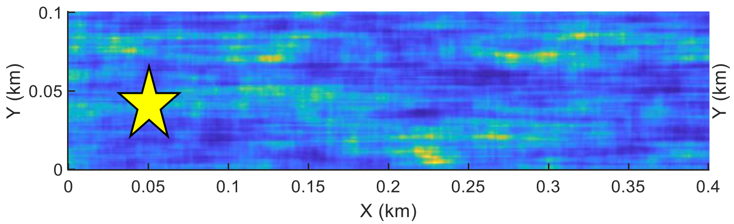
- Numerical experiments

Lc = 80

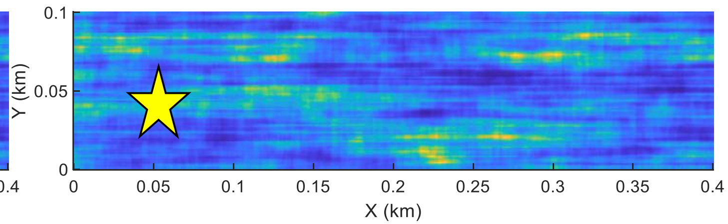


Vs=600ms
Lcv = 10m

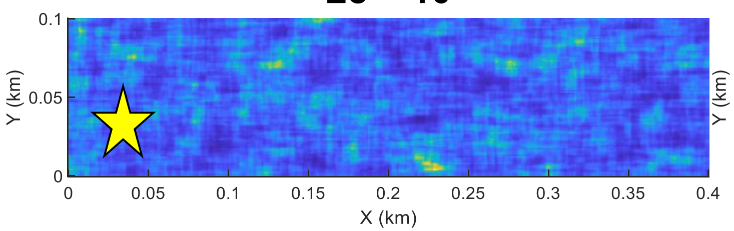
Lc = 40



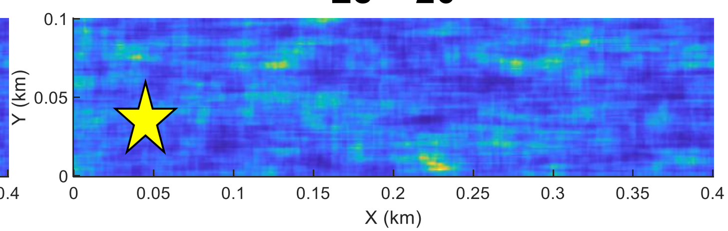
Lc = 60



Lc = 10

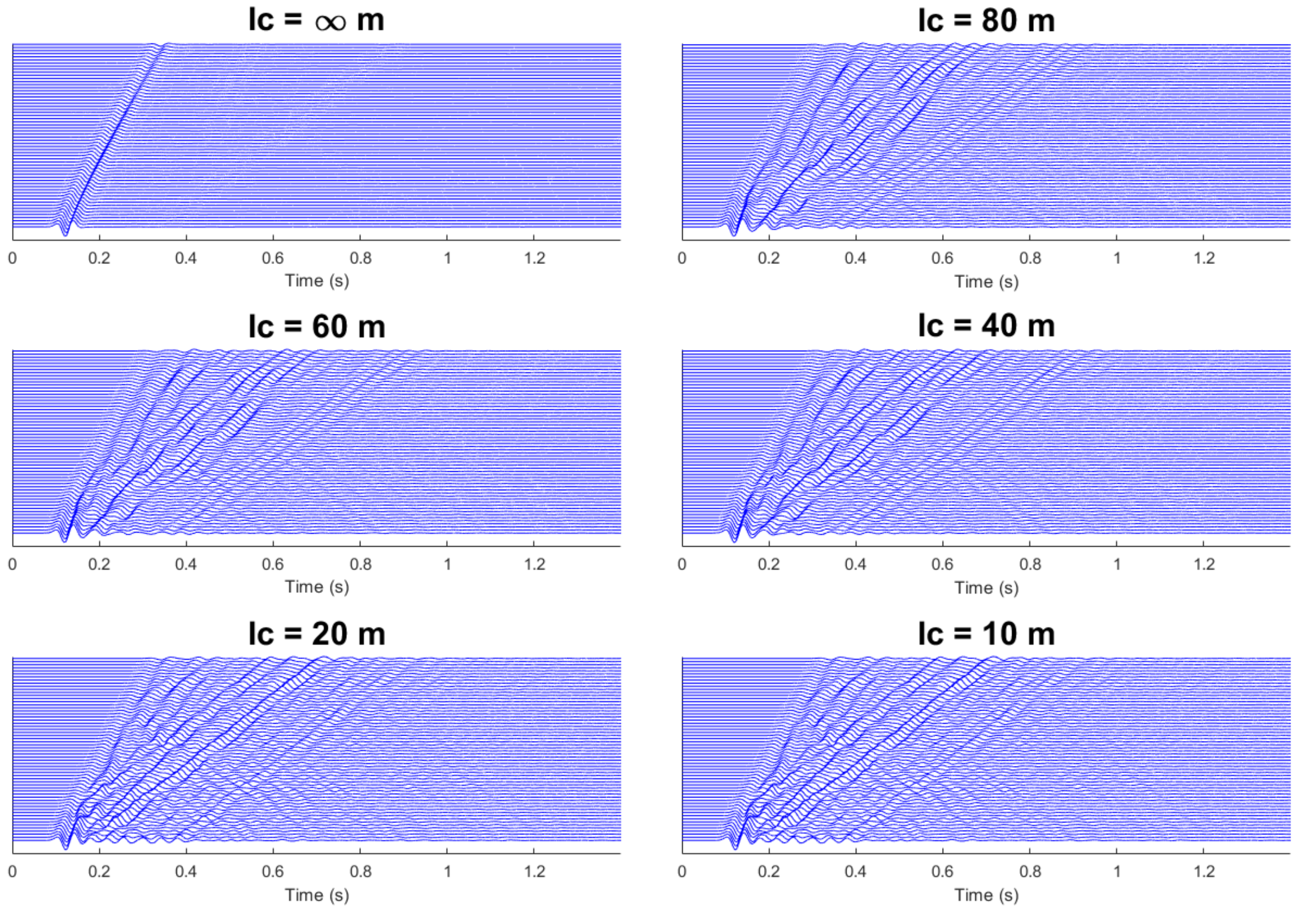


Lc = 20



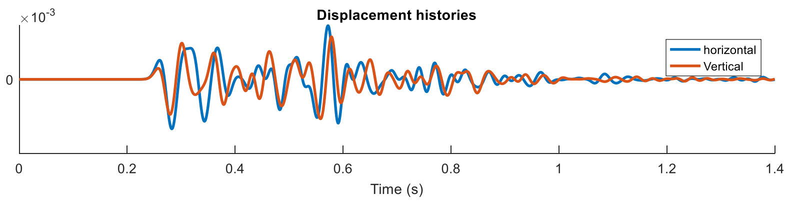
Surface waves

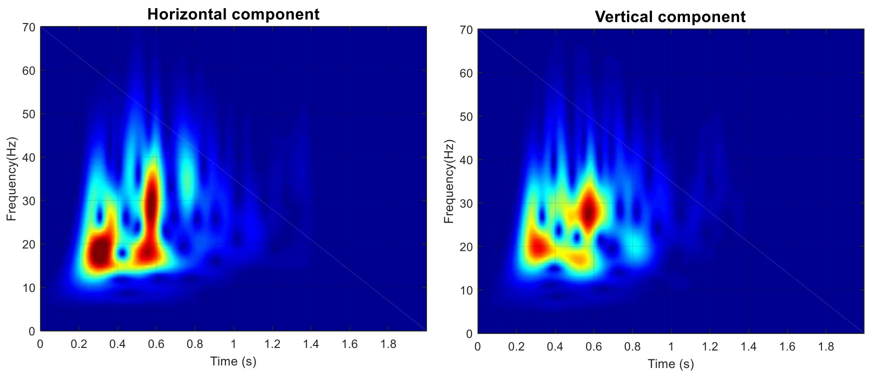
- Total wavefied



Surface waves

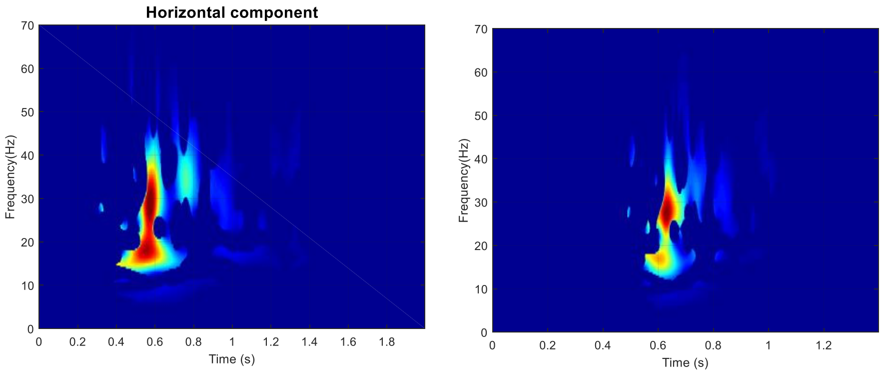
- Extraction of Rayleigh waves (K. Meza-Fajardo et al 2015)

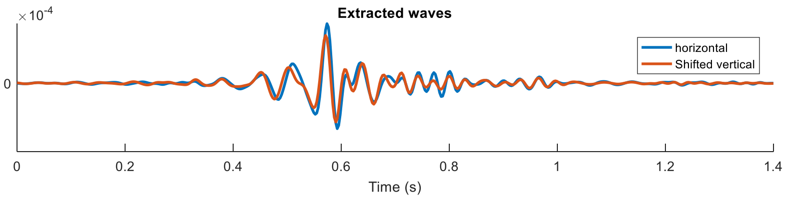




S-transforms

S-transforms filtered based on polarization properties

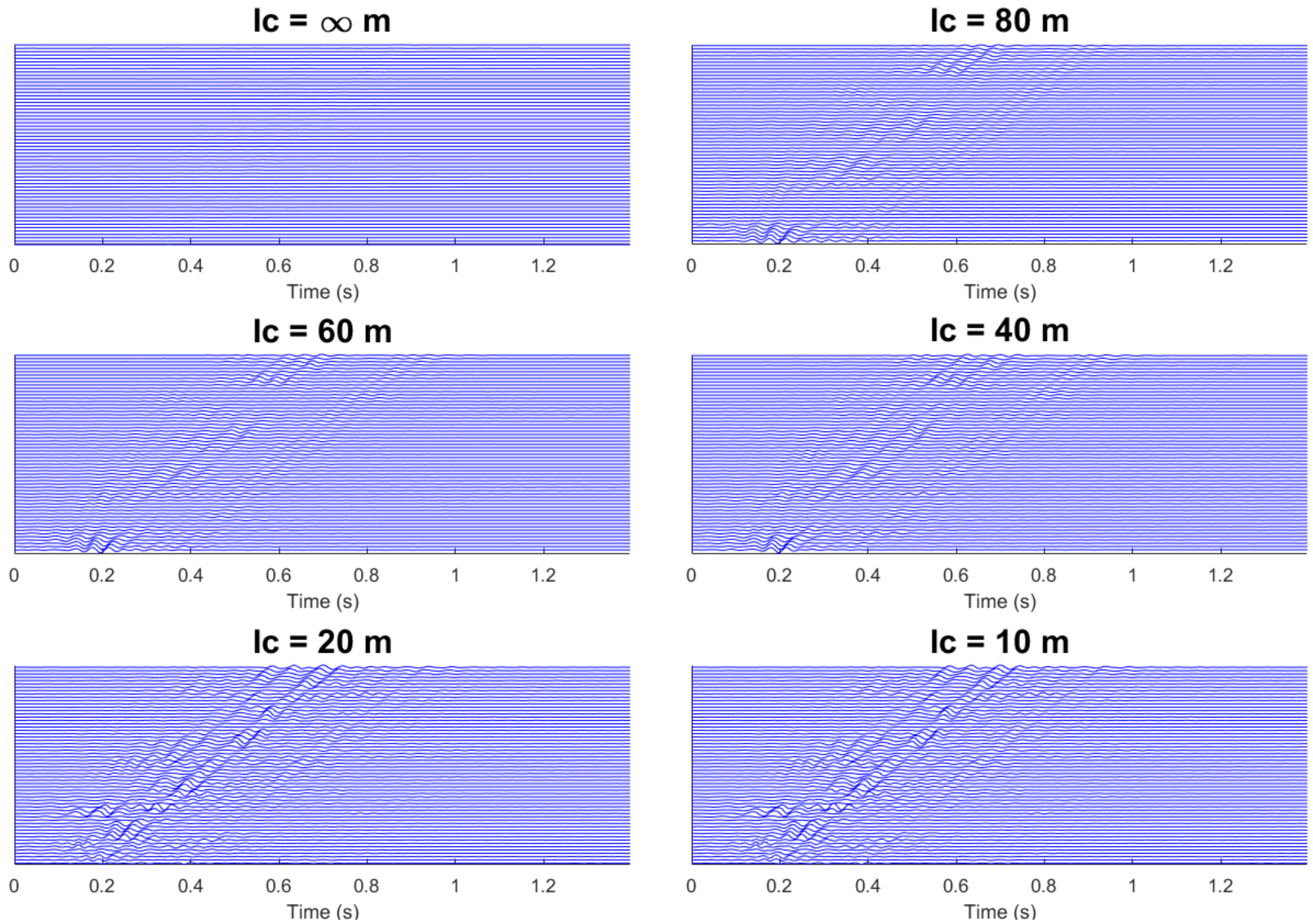




Extracted Rayleigh waves

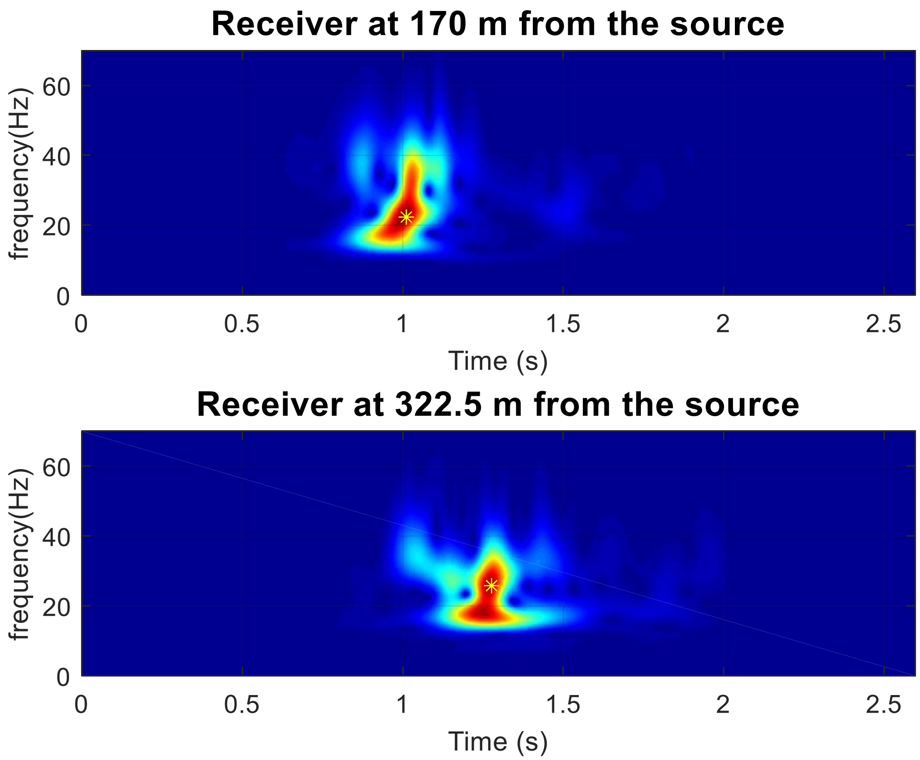
Surface waves

- Extraction of Rayleigh waves (K. Meza-Fajardo et al 2015)



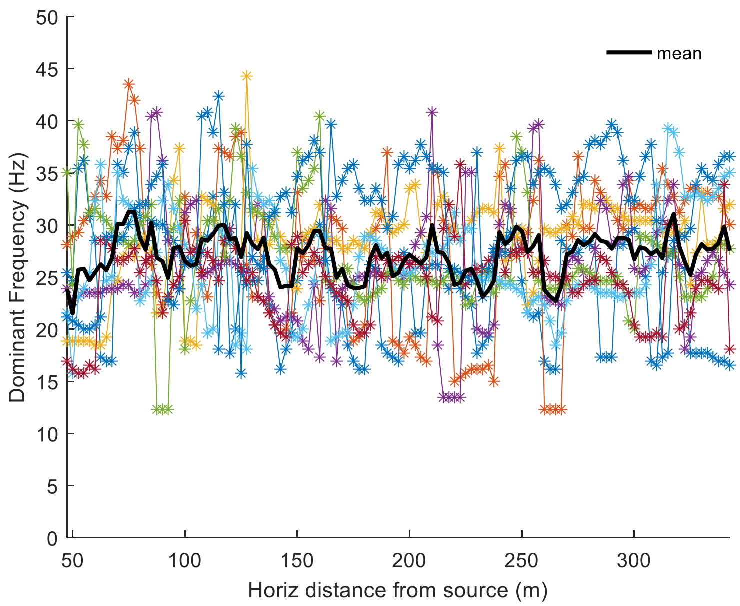
Surface waves

- Analysis of surface waves
  - Dominant frequencies of surface waves from peak ampitude of surface wave S-transform



Surface waves

- Analysis of surface waves
  - Dominant frequencies of surface waves - close to surface waves, large dispersion



Further analyses needed to study link between soil variability and eigenfrequency of surface waves

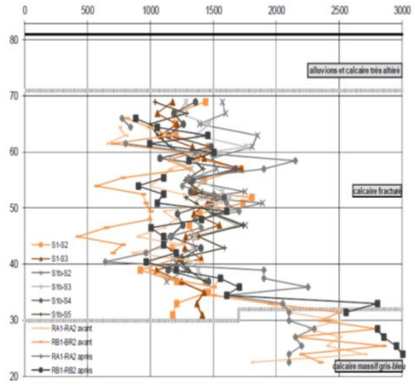
Conclusion

- 2D analyses with Spatial soil variability

- Wave scattering
  - Additional damping (high frequency attenuation)
  - Late wave arrivals (elongation of signals) and creation of surface waves
  - High dispersion of quantities of interest

Perspectives

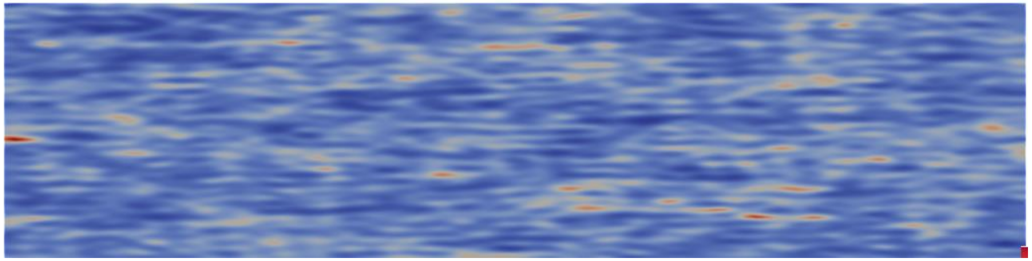
- Quantitative assessment of soil variability's impact
  - on surface waves (eigenfrequency, amplitude ratio)
  - and additional attenuation (kappa)



- Random filed generation: introduce supplementary information in order to avoid not physical configurations (borehole close to site, other geophysical data…)
  - Conditional random fields: soil profiles known at distinct coordinates

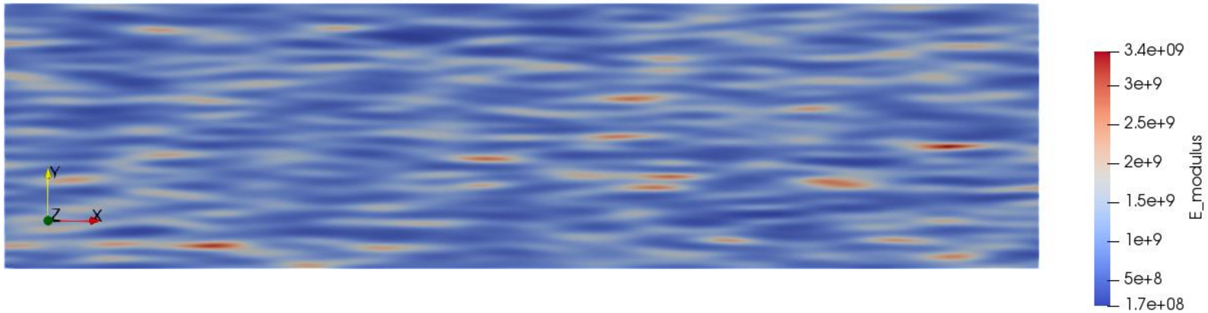
Perspectives

- Assess impact and adequateness of correlation fiunctions
  - Markov model (exponential kernel) represents multi-scale character (Brownian motion)



$$L_{ch} = 10L_{cv}$$

  - Gaussien kernel produces more regular random fields



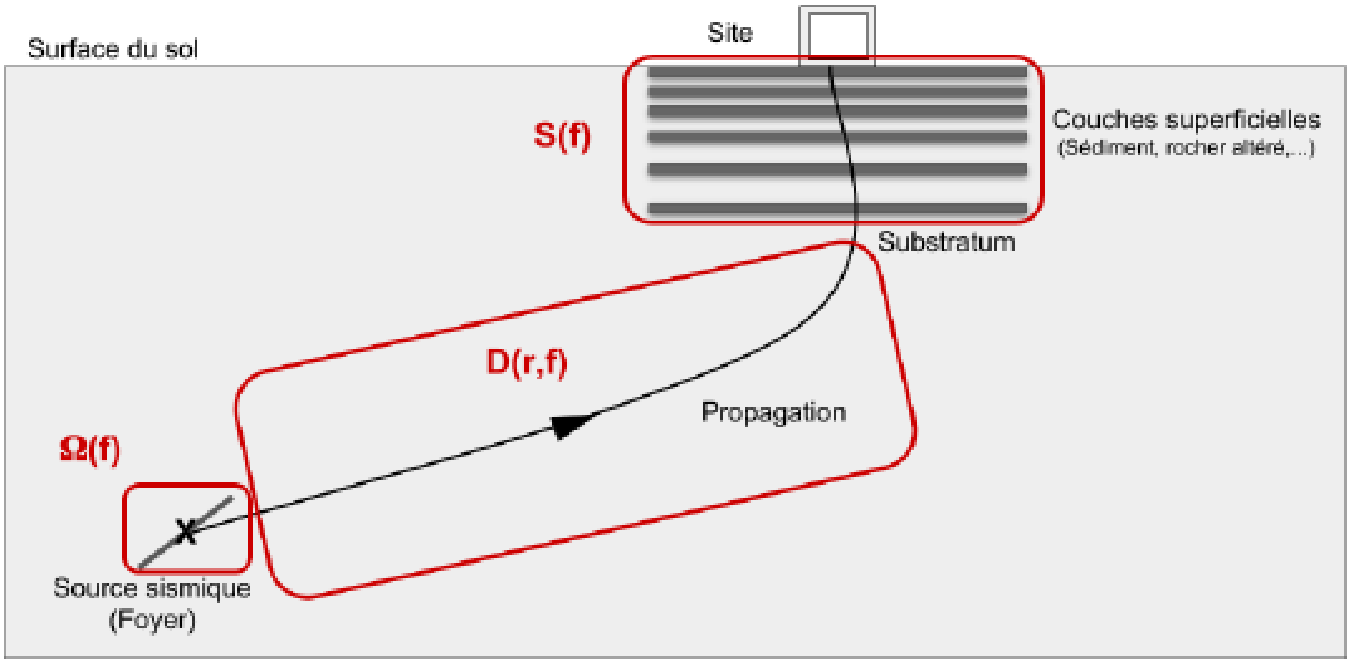
$$L_{ch} = 10L_{cv}$$

THANKS
QUESTIONS?

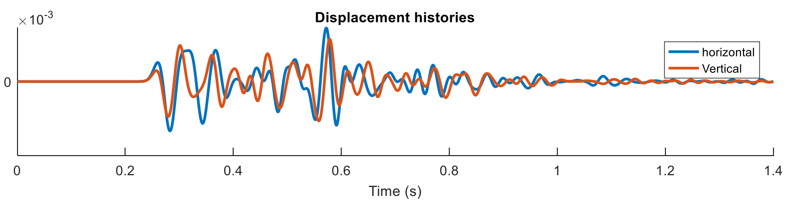
High frequency decay

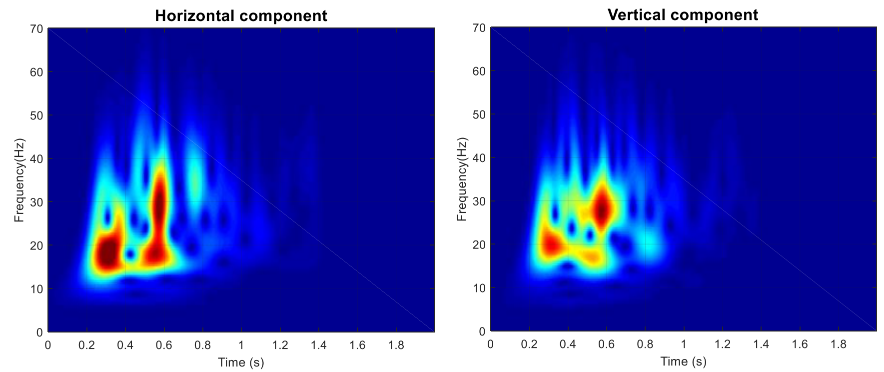
- Global FAS model

$$A(f) = \Omega(f)D(r,f)S(f)$$



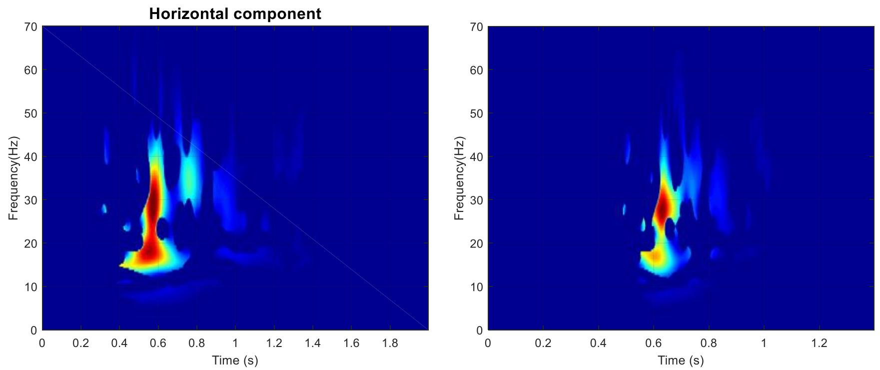
Example of Surface wave extraction. At 270 m from the source



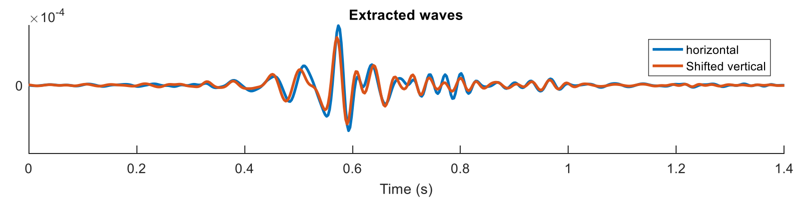


S-transforms

S-transforms filtered based on polarization properties



Extracted Rayleigh waves



Correlation length: 0.8781

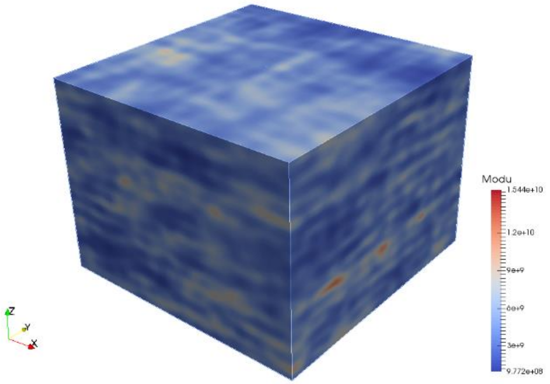
Random field modelling

- 1D, 2D and 3D domains for separable correlation function R_U

$$R_U(\boldsymbol{x}, \boldsymbol{x}') = R_U(x, x')R_U(y, y')R_U(z, z') \qquad \boldsymbol{x} = (x, y, z)$$

$$U(x,y,z) = \sum_{m=1}^{N_m}\sum_{k=1}^{N_k}\sum_{l=1}^{N_l}\sqrt{\lambda_k^{(x)}\lambda_l^{(y)}\lambda_m^{(z)}}\,\phi_k^{(x)}(x)\phi_l^{(y)}(y)\phi_m^{(z)}(z)\,\xi_{klm}$$

- Can account for different length scales in vertical and horizontal direction
- Karhunene Loeve expansion defined on bounding volume



$L_{ch} = 6\, L_{cv}$