Site Effect estimation

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DI TRIESTE

Site effect estimation

1) ***<u>Direct methods</u>:***

Earthquake based:

<u>With reference site</u>: Standard Spectral Ratio (SSR), Generalised Inversion Technique (GIT),

<u>Without a reference site</u>: Horizontal-to-Vertical Spectral Ratio (H/V)

Seismic noise based:

<u>With reference site</u>: Standard Spectral Ratio (SSR), Spectra analysis,

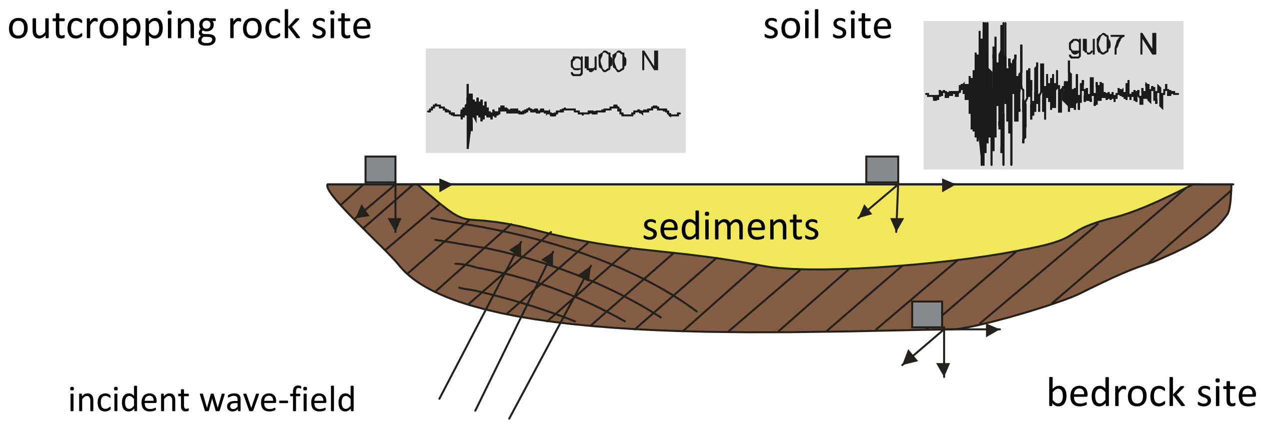
<u>Without a reference site</u>: Horizontal-to-Vertical Spectral Ratio (H/V)

2) ***<u>Indirect methods</u>***: active (SASW, MASW) and passive (seismic noise) array analysis. Numerical simulations

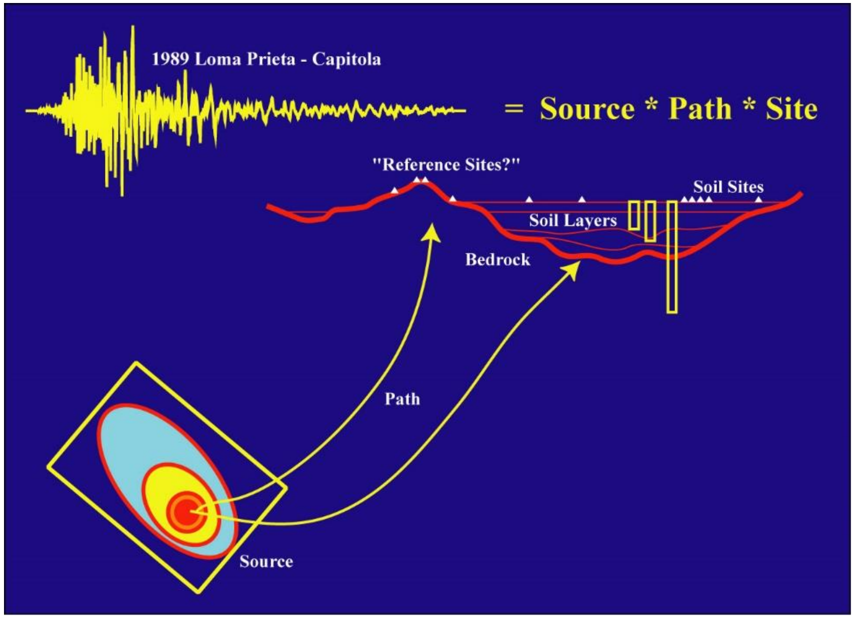
Earthquake based Reference Site methods

1) *Standard spectral ratio*: spectral ratio between the same ground motion components of 2 close stations

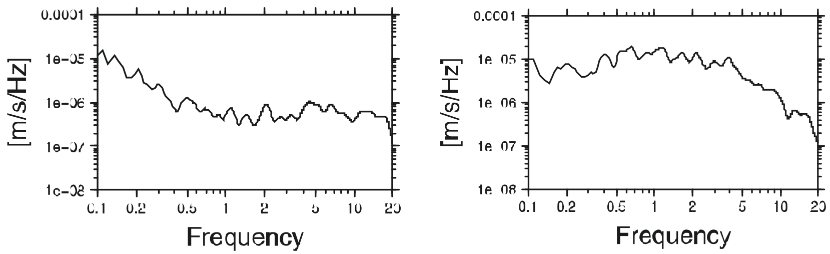
2) *Generalized inversion techniques*: a spectral inversion is performed in order to correct for the path effects if the reference station is faraway from the actual one.



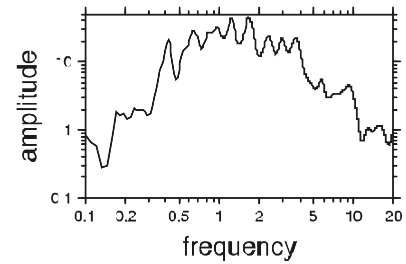
Fourier Amplitude Spectra A(f)



Amplitude



Amplification function



$$\frac{A_{soil}(f)}{A_{rock}(f)} = \frac{\cancel{Source_{soil}}\; Path_{soil}\; Site_{soil}}{\cancel{Source_{rock}}\; Path_{rock}\; Site_{rock}} = \frac{\cancel{Path_{soil}}\; Site_{soil}}{\cancel{Path_{rock}}} = Site_{soil}$$

=1 (reference)

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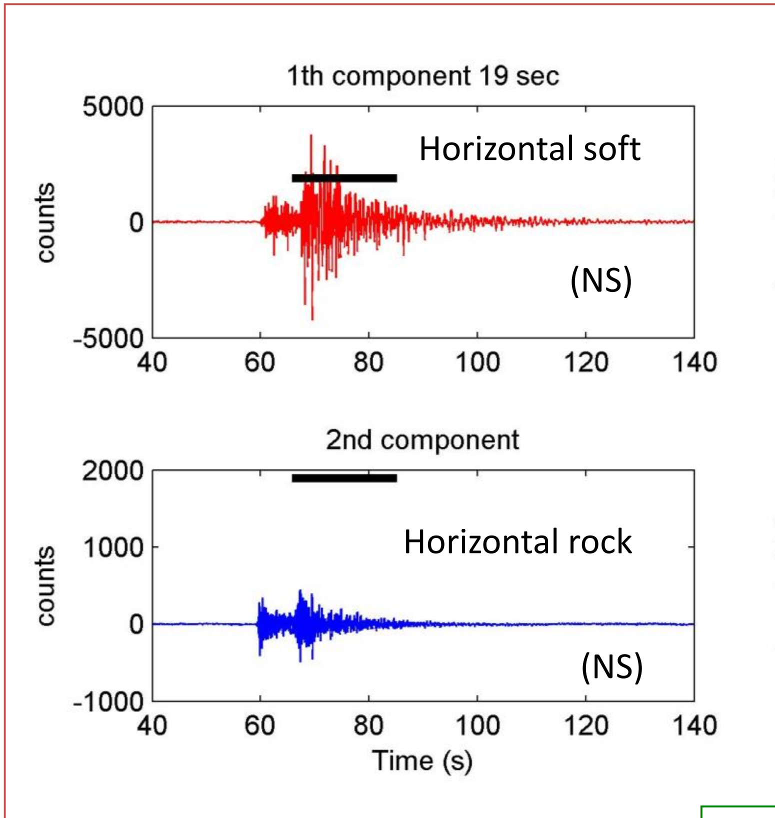
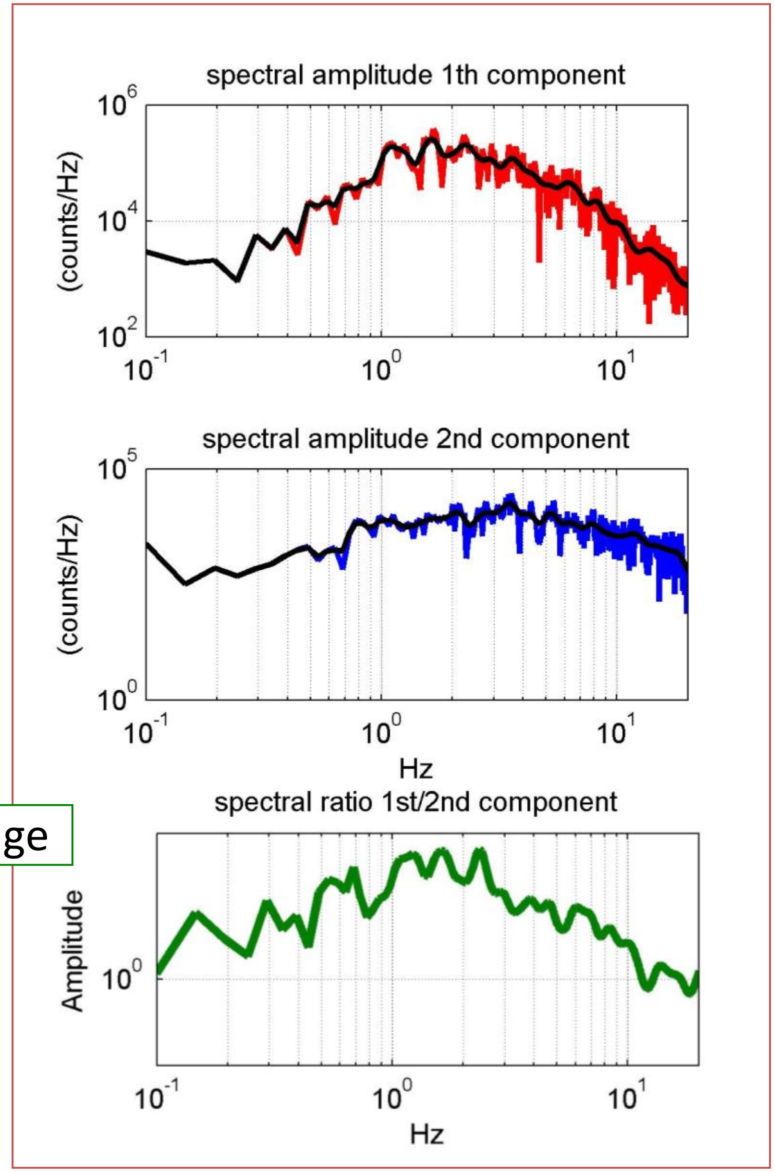
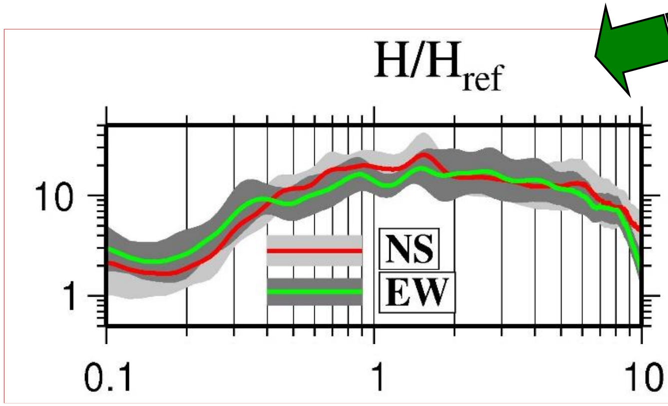
Window selection in time domain → Fourier amplitude and smoothing





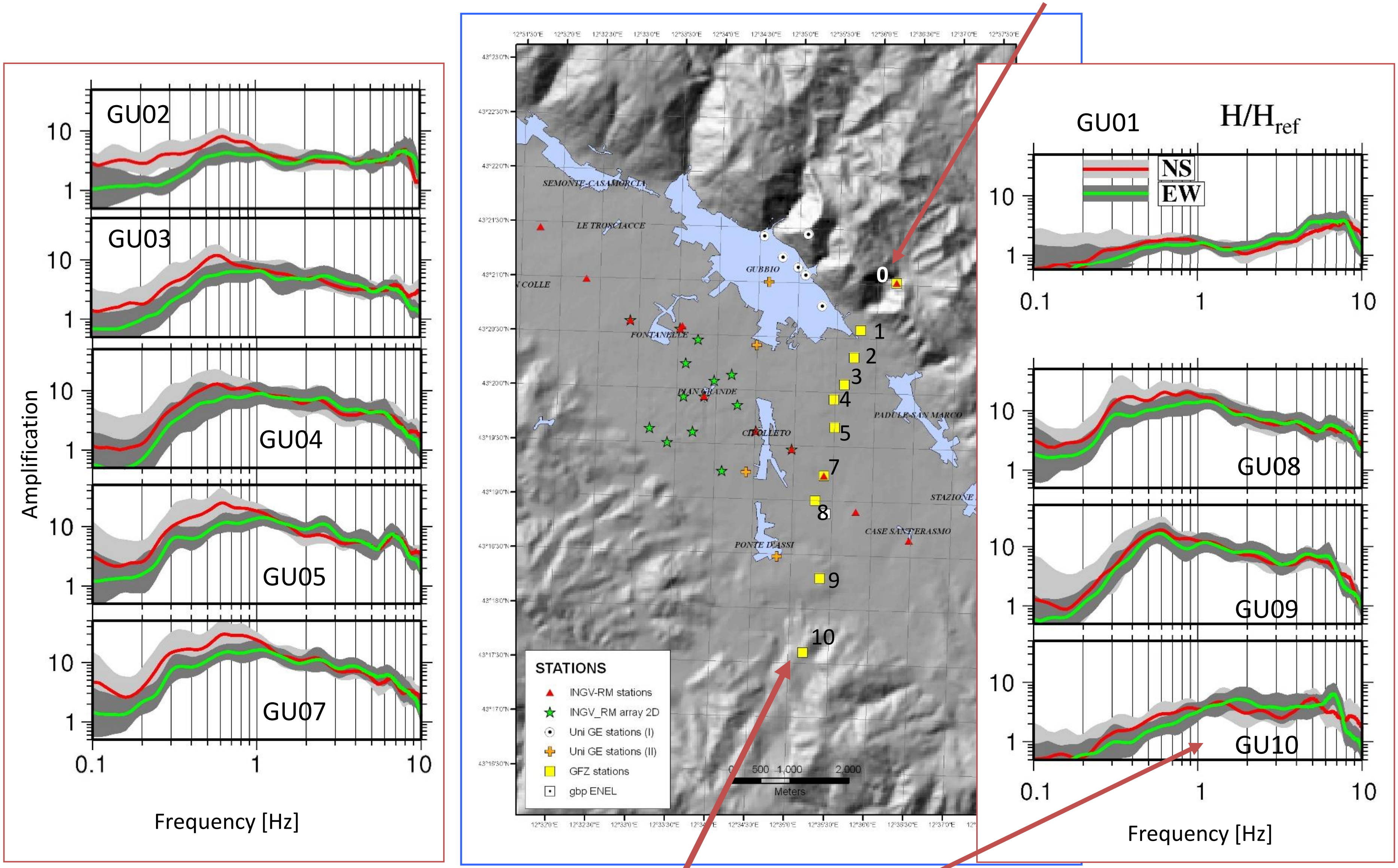
$$\frac{H(f)}{H(f)} = |SSR(f)|$$

Average



Standard spectral ratios: the example of Gubbio basin (Italy)

"Good" reference site



another rock station but ......

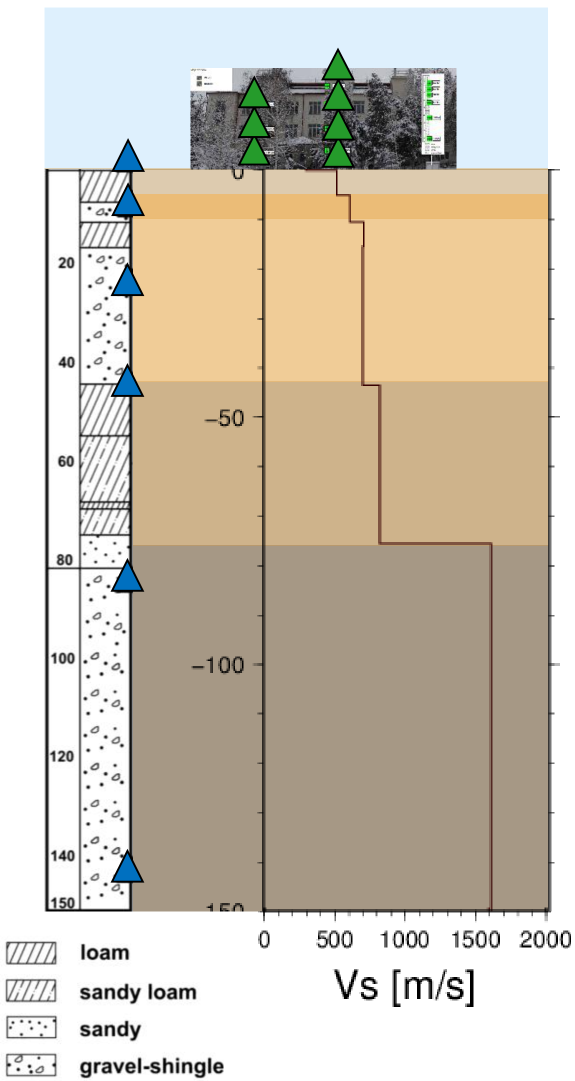
Bindi et al. (2009)

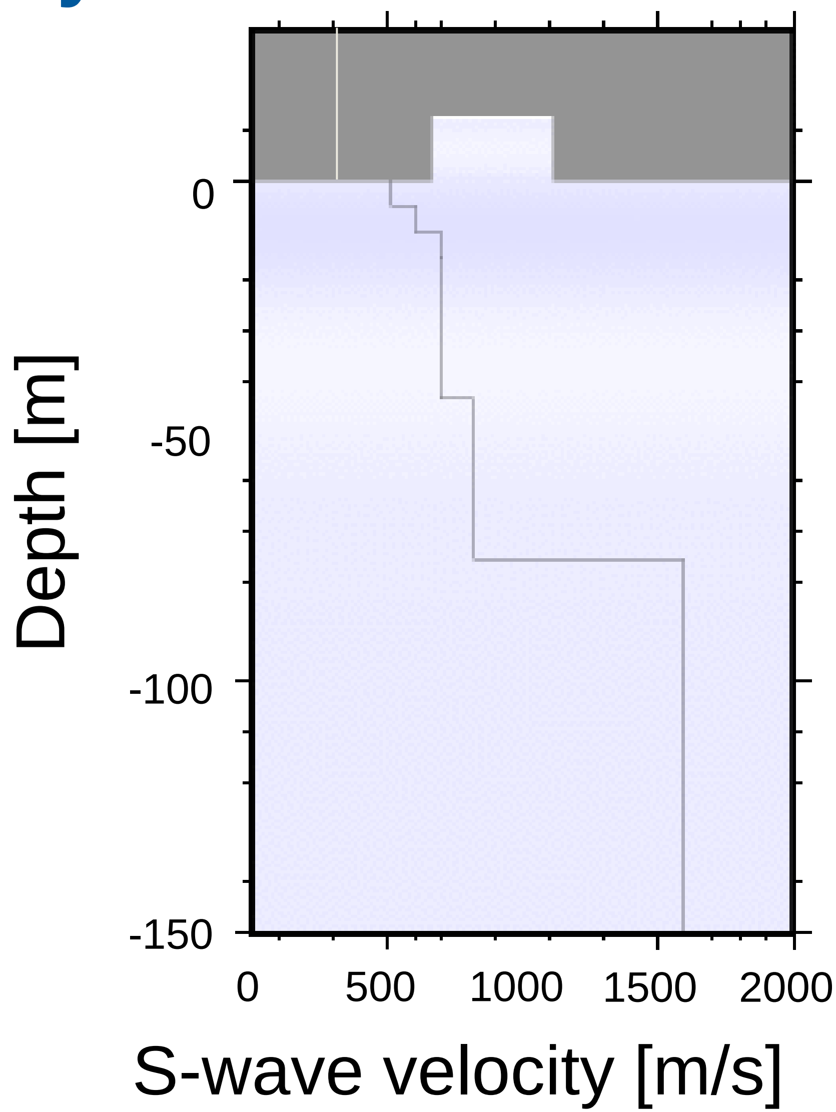
For standard spectral ratio, the distance between the 2 stations should be at least 5 time smaller than the hypocentral distance in order to assume that the path is the same.

A close good reference site might not be available.

Also rock site may have their own site response

Wave propagation through building-soil-layers





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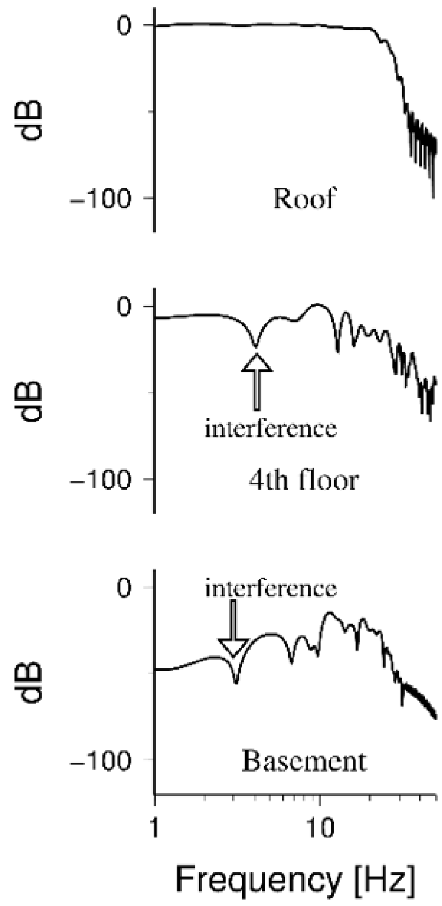
Deconvolution



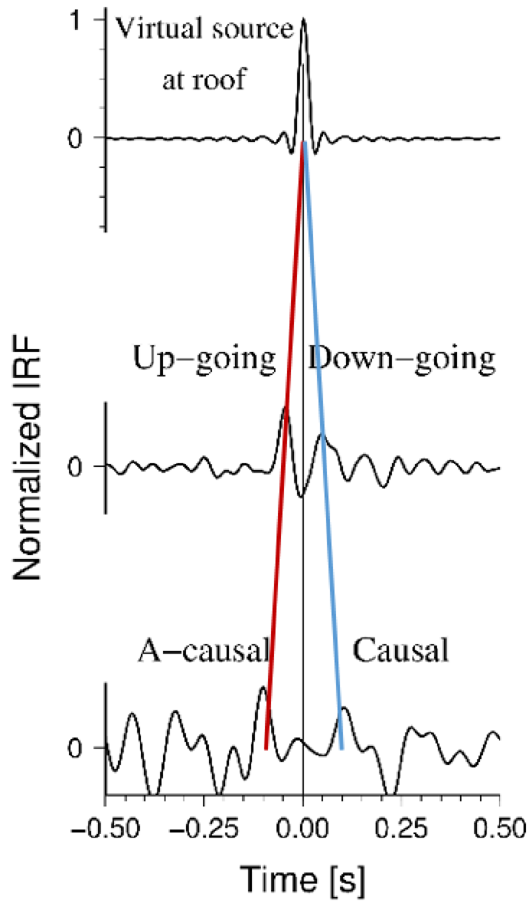
Deconvolution

$$D(\omega) = \frac{\hat{u}(\omega)}{\hat{u}_{ref}(\omega)}$$

Regularized deconvolution

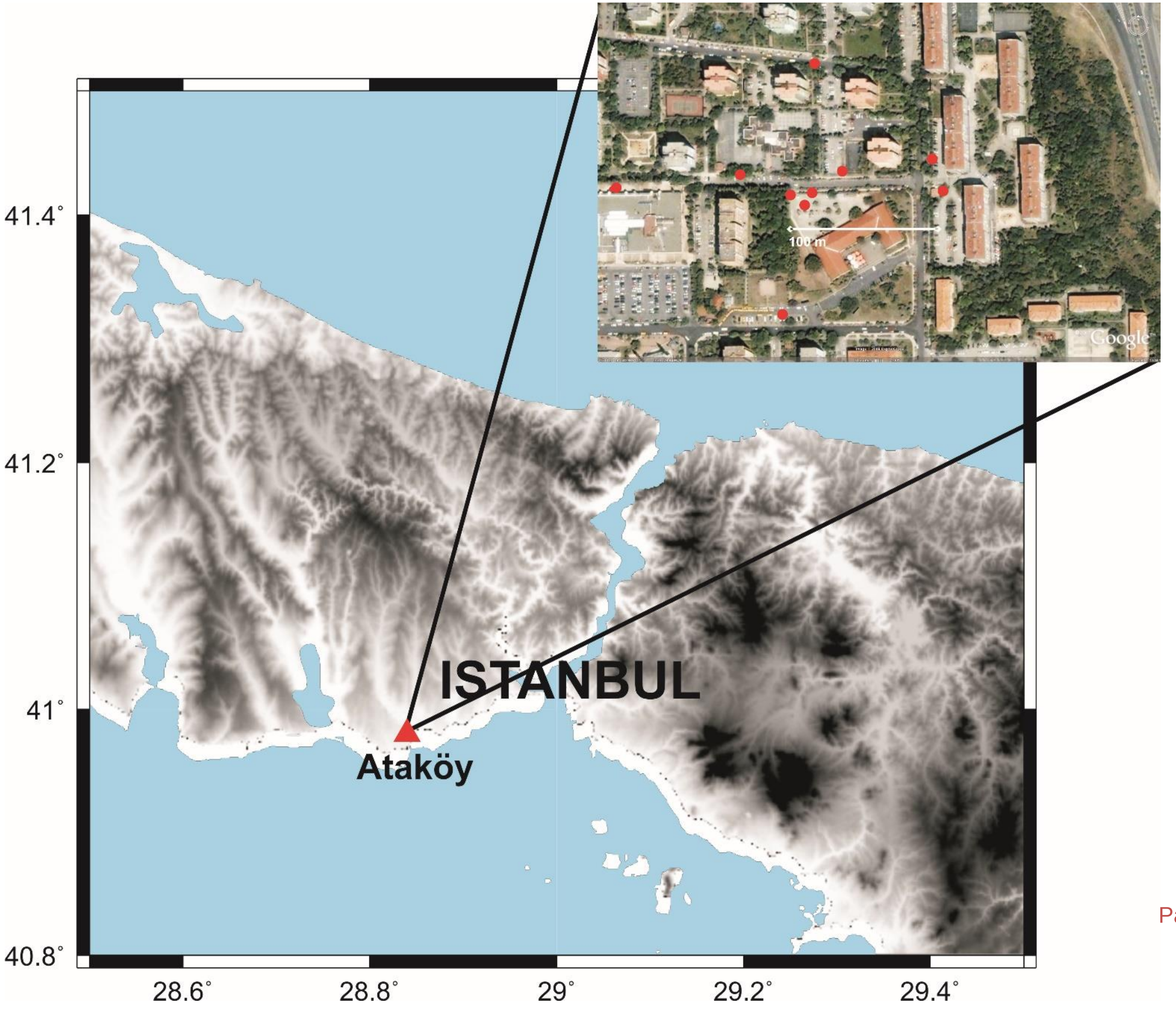
$$D(\omega) = F(\omega)\hat{u}(\omega)$$

$$F(\omega) = \frac{\hat{u}^{*}_{ref}(\omega)}{|\hat{u}_{ref}(\omega)|^2 + \varepsilon}$$



[Bindi et al., 2015]

Studying wave propagation in the shallowest crustal layers including non-linear behaviour: the vertical array in Ataköy



Parolai et al. (2009)

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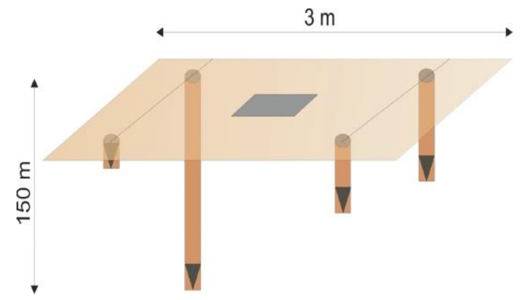
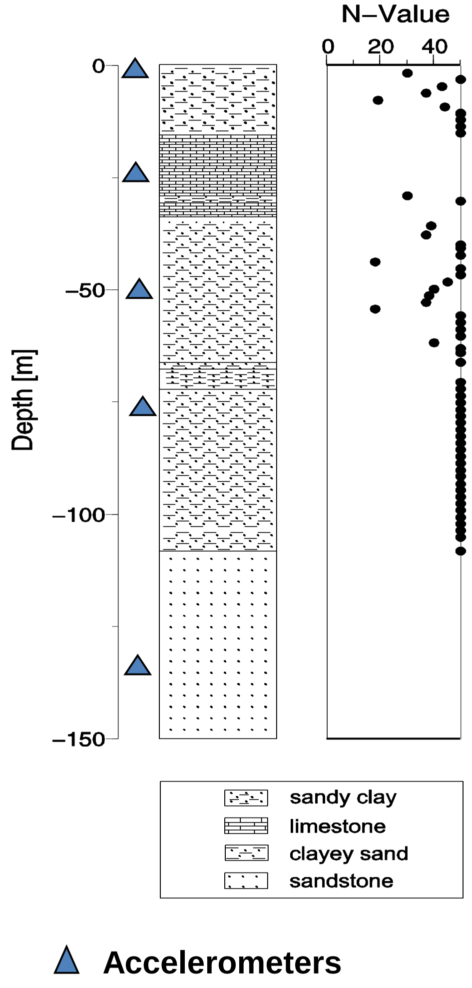
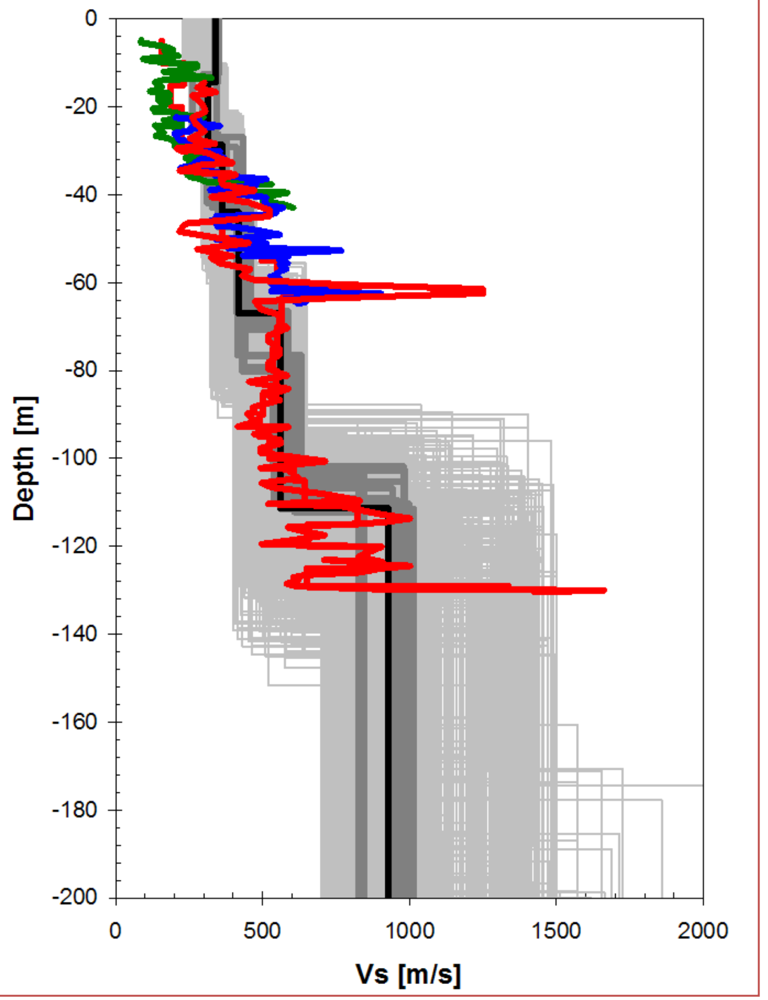
Studying wave propagation in the shallowest crustal layers including non-linear behaviour: the vertical array in Ataköy

Vertical array:
PS logging and array measurements

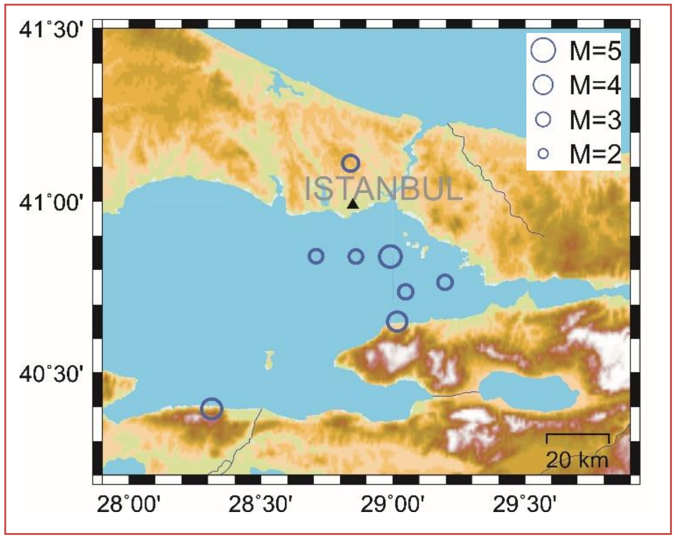


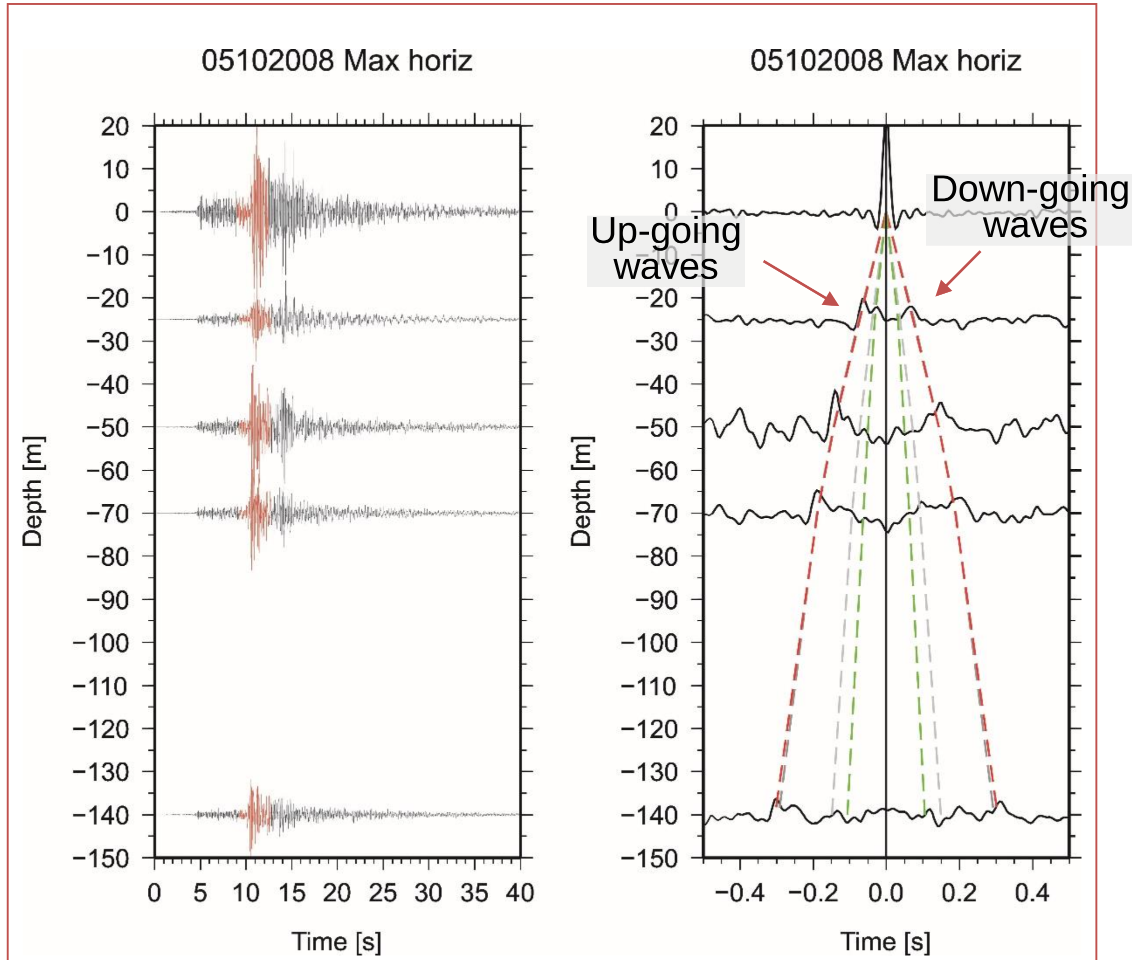




Parolai et al. (2009)

Studying wave propagation in the shallowest crustal layers including non-linear behaviour: the vertical array in Ataköy





Ts
Tp (Vp=1290+1.1*Vs from Kitsunezaki *et al.* (1990)
Ts
Tp (inverting also for the poisson's ratio)

Parolai et al. (2009)

Surface to bottom spectral ratio might be misleading in identifying the resonance frequency

The deconvolution results do not depend on the selected window but on the used component

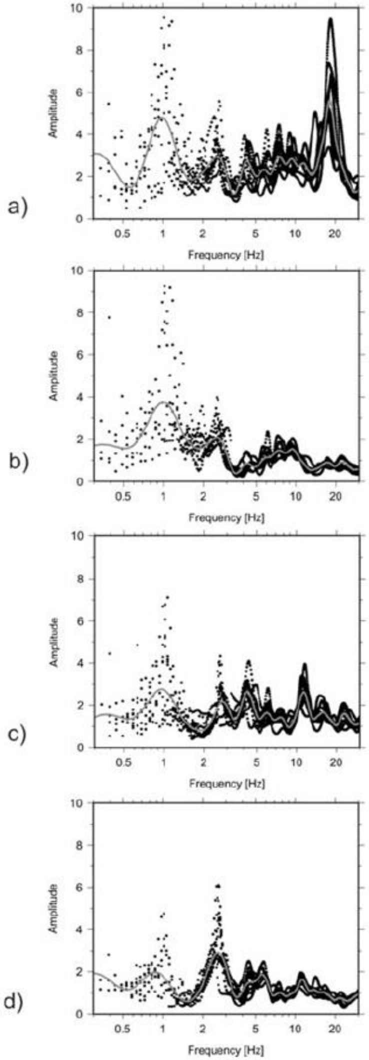
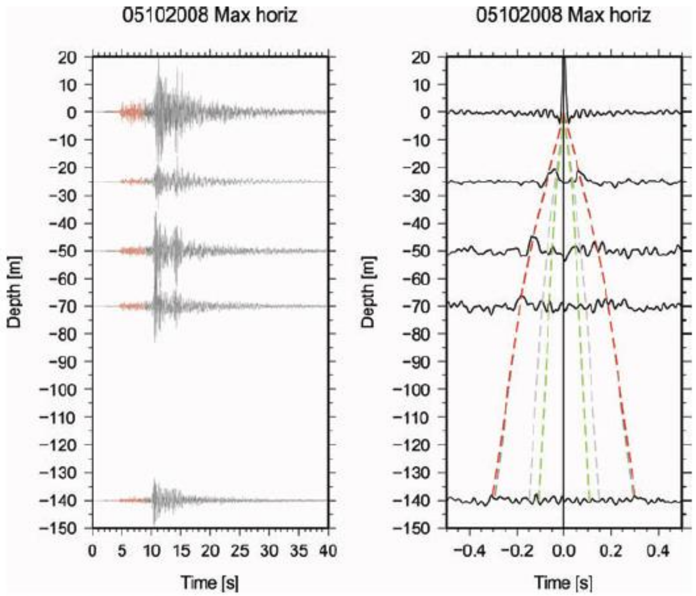
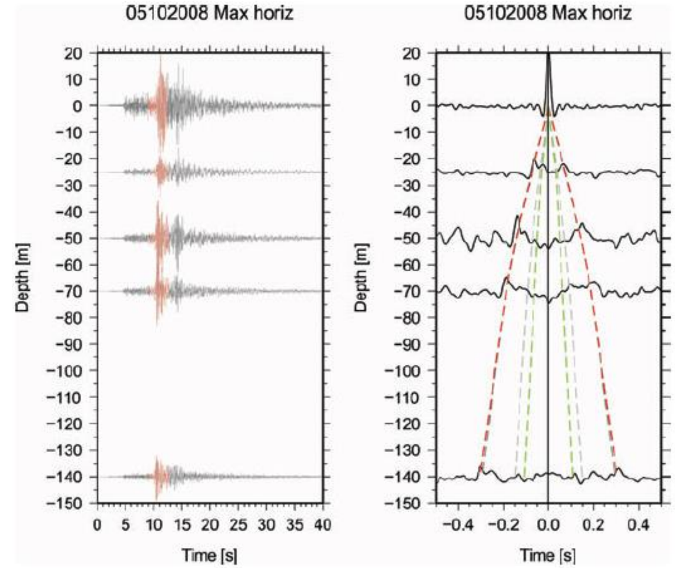


Figure 6. The spectral ratio results, using the station at 140 m depth as the reference, for the station located at the surface (a), at 25 m depth (b), 50 m depth (c) and 70 m depth (d). Black dots indicate spectral ratio values calculated for frequencies with signal-to-noise ratios larger than 3. Due to the limited number of event used, a 1-D trend interpolation (Wessel & Smith 1991) is used to highlight the behaviour of the data.



s Fig 8, but for the horizontal component.



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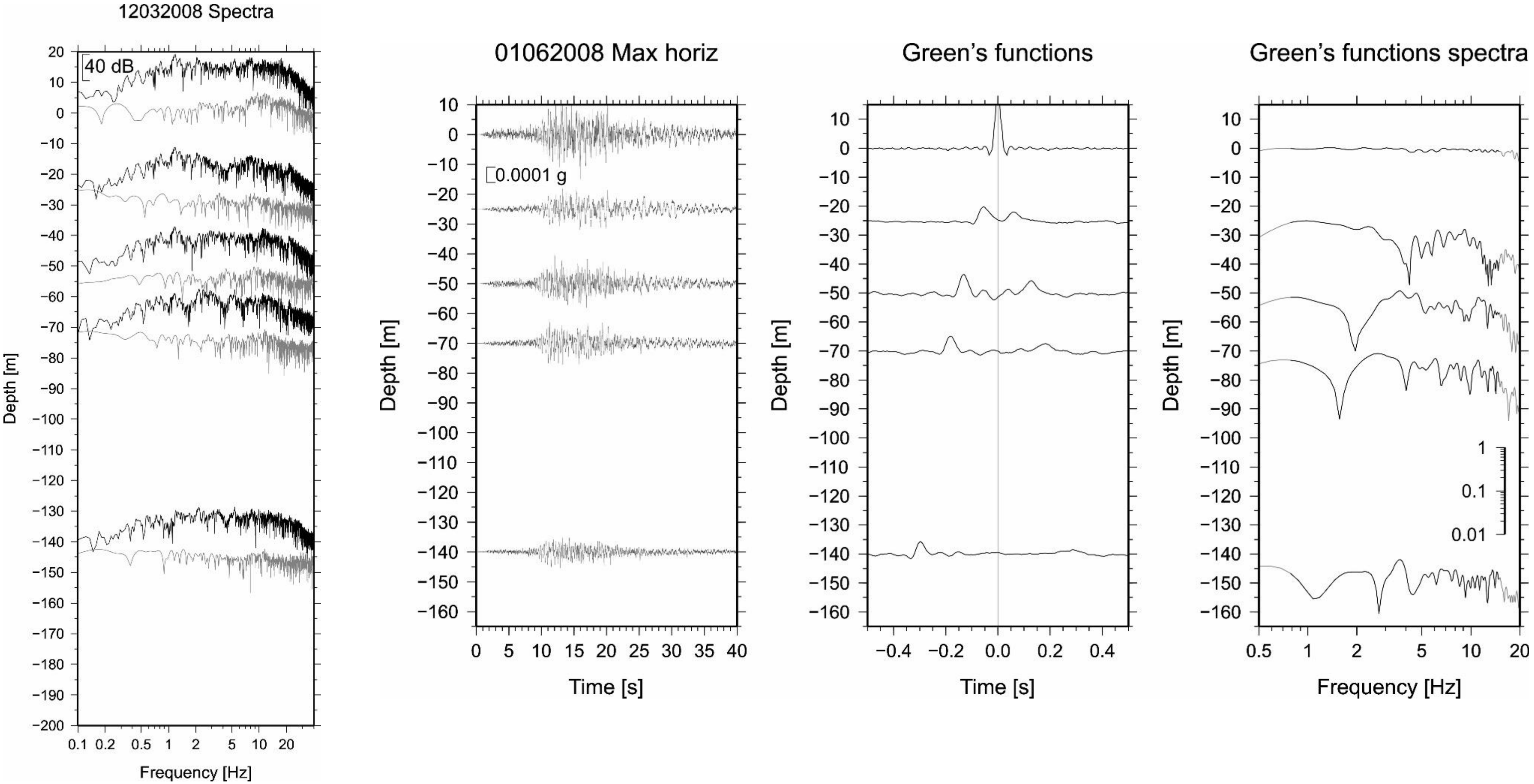
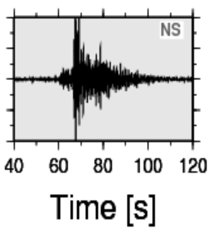
Estimation of the deconvolved wavefield



Parolai et al., 2011

Site A (for example an accelerometric station of a national network)

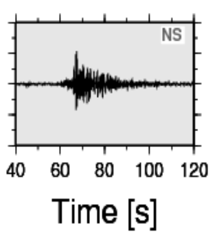
Site B (site where a building must be designed)



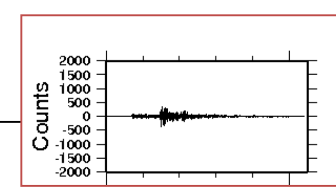
????

depth

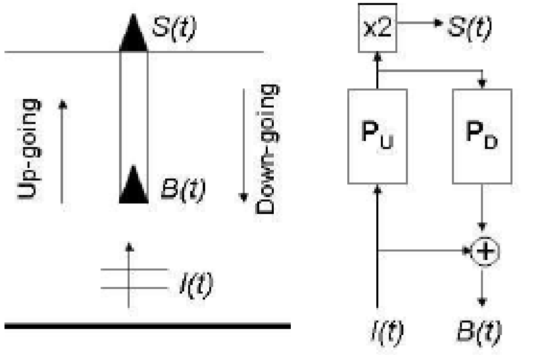
The task is to provide a seismic input that can be used elsewhere for design!

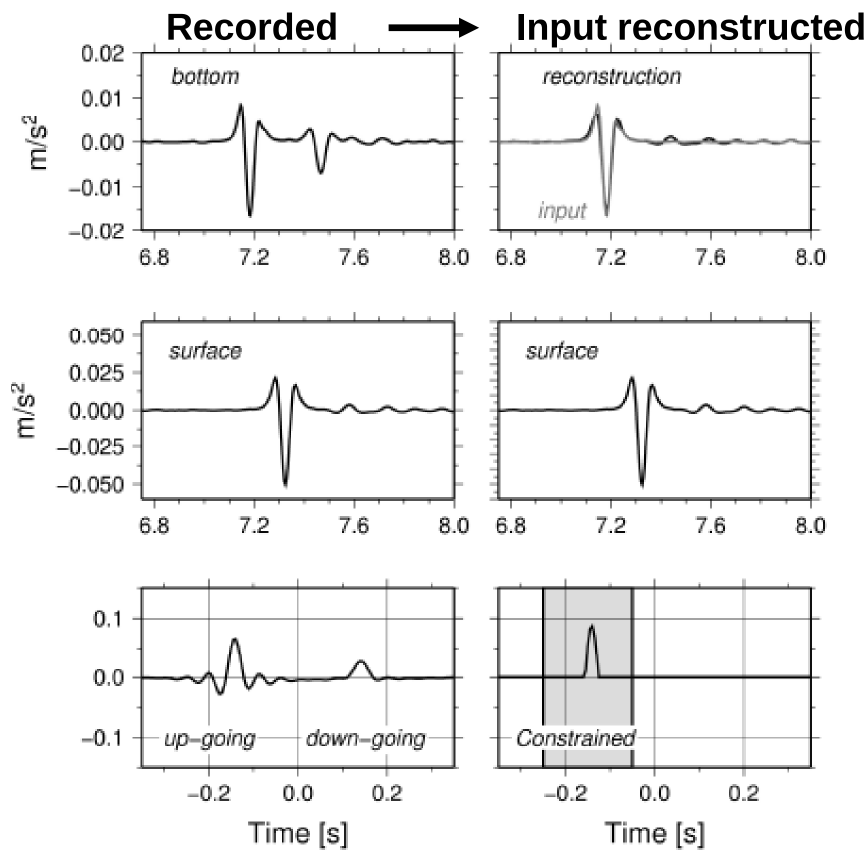


Wave Propagation



The input ground motion at depth is reconstructed from that at the surface without requiring the knowledge of the borehole velocity structure





$$S_n(\omega) = W_n(\omega)\frac{u(z1,\omega)}{u(z2,\omega)}$$

where

$$W_n(\omega) = 1-(1-\tau\,|\,u(z2,\omega)\,|^2)^n$$

is the Landweber filter

Bindi et al., 2010

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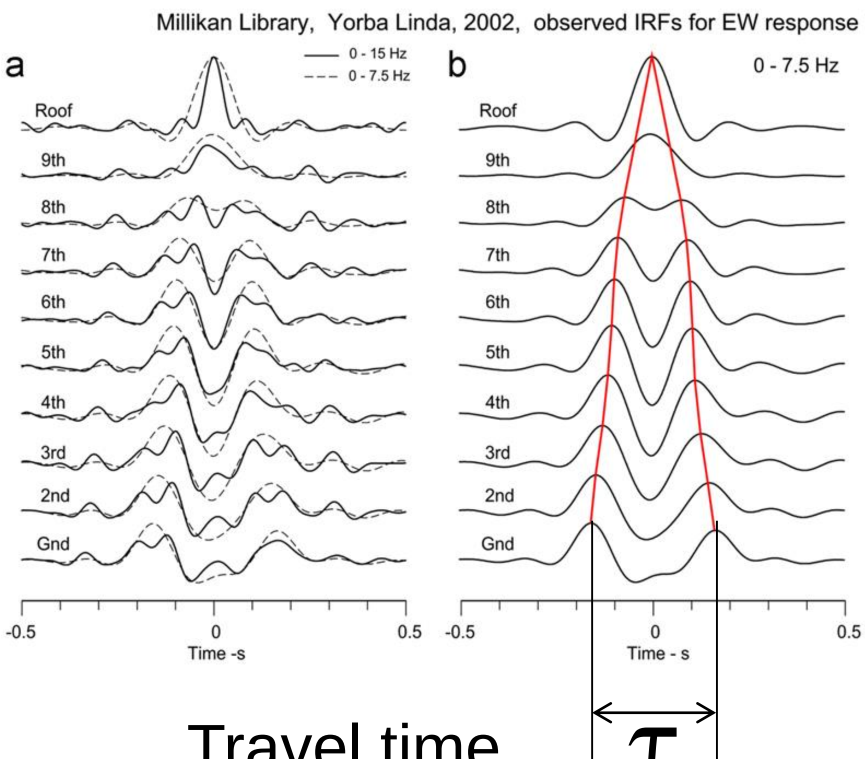
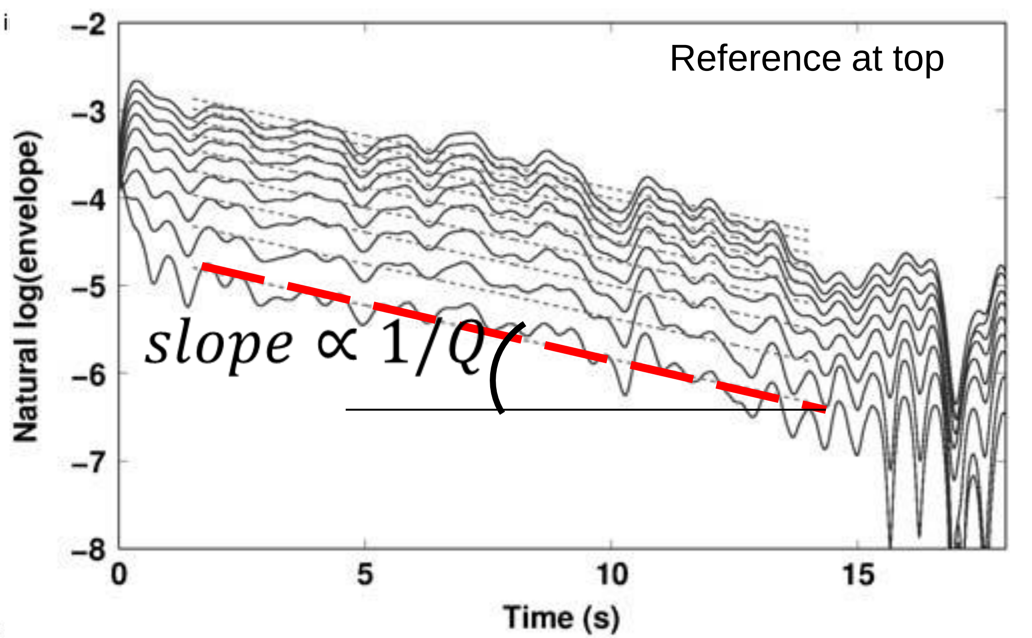
Seismic interferometry - Earthquakes

Velocity estimation



Travel time τ

Attenuation estimation



$\zeta = 1/2Q$

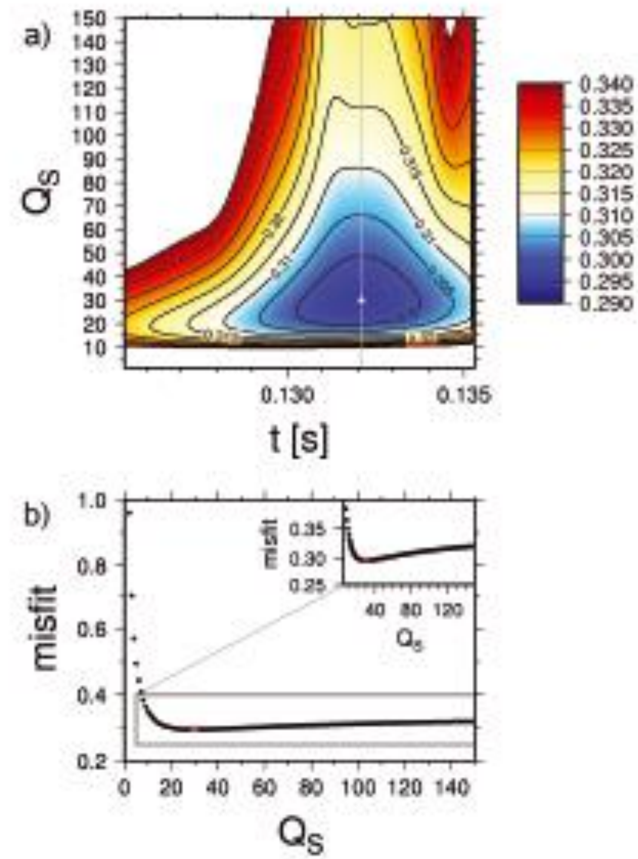
[e.g.Rahmani and Todorovska, 2013; Newton and Snieder, 2012]

Estimation of attenuation using a deconvolution approach

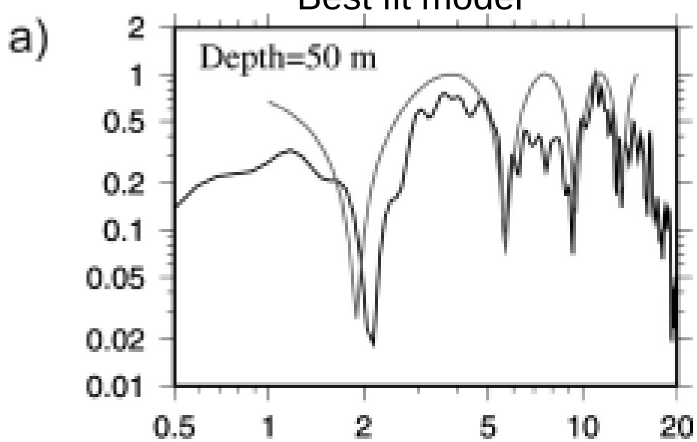
Simplified analytical model to described propagation between different depth ranges

$$\left|\tilde{S}(0,h;\omega)\right| = \frac{\sqrt{1+\mathrm{e}^{\frac{-4\pi f \tau}{Q_S}} + 2\mathrm{e}^{\frac{-2\pi f \tau}{Q_S}}\cos(4\pi f \tau)}}{2\mathrm{e}^{\frac{-\pi f \tau}{Q_S}}}.$$

Grid search procedure

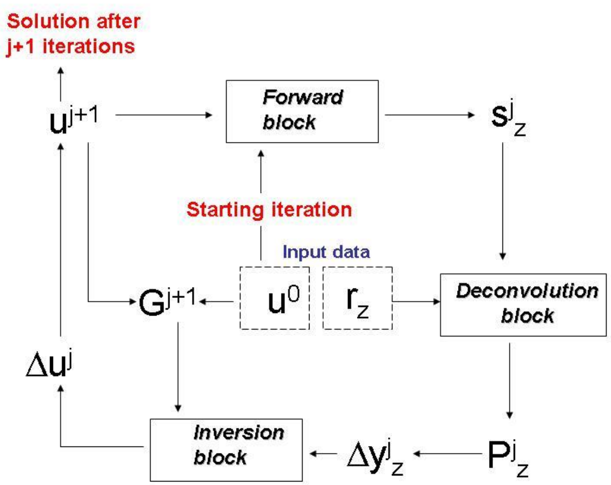


Best fit model



Parolai et al., 2010

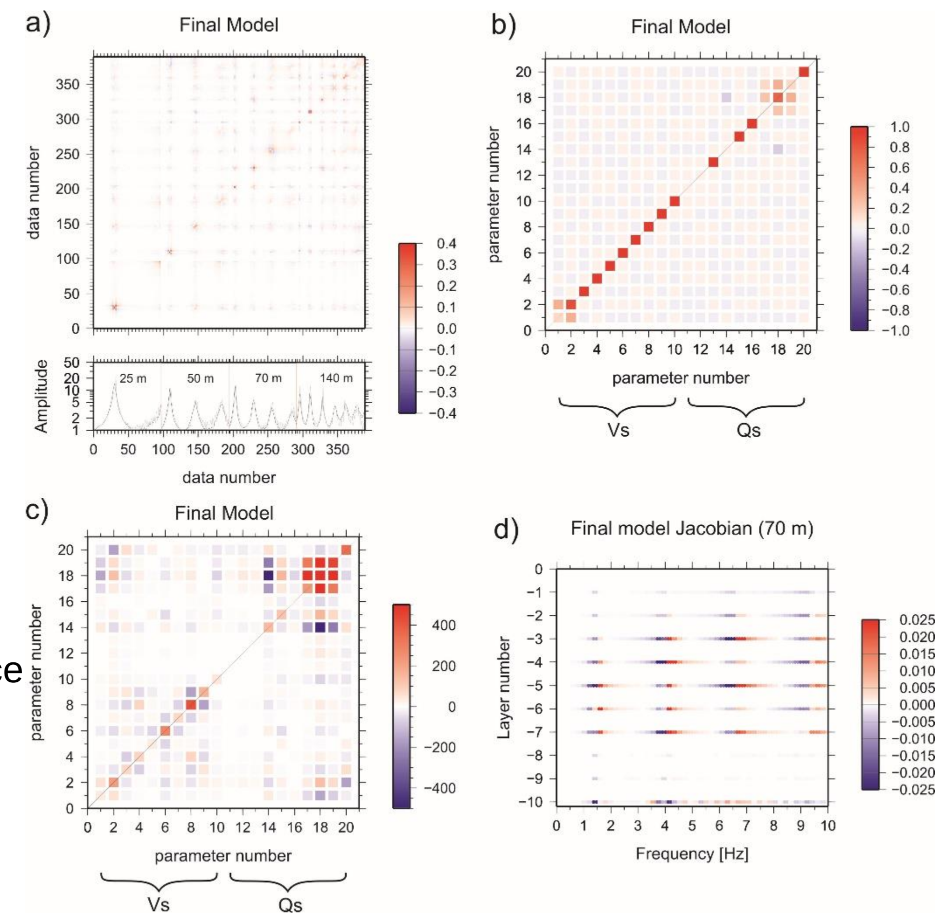
Deconvolved wavefield inversion: VS velocity structure



Data Resolution matrix

Model Resolution matrix

Covariance matrix



Parolai et al., 2011

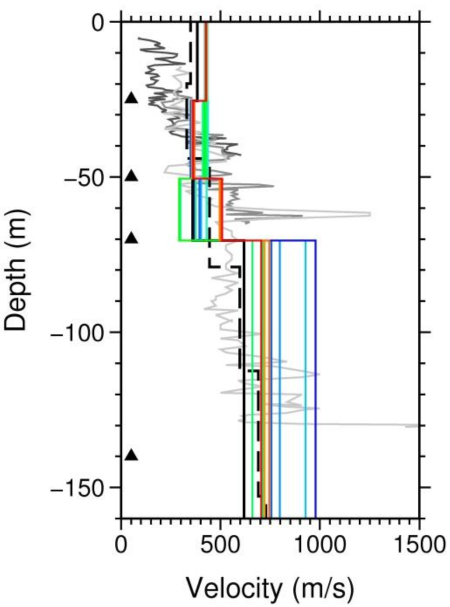
Borehole data inversion

Inversion of weak motion data allow to fix the range of uncertainty in the VS and QS estimation

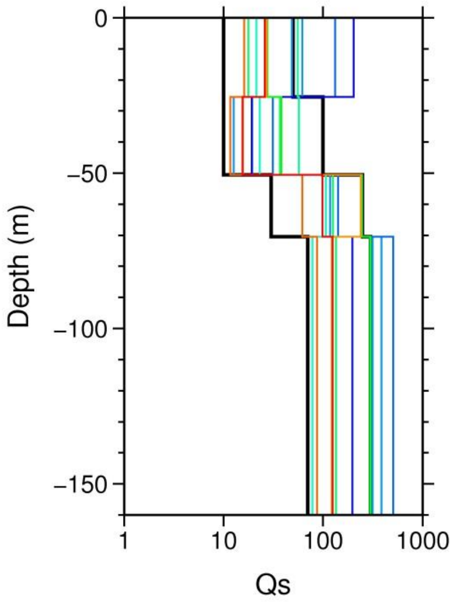
Tools for the inversion of strong motion data are ready

Open question: When is soil non linear behaviour starting? Important influence on damages.

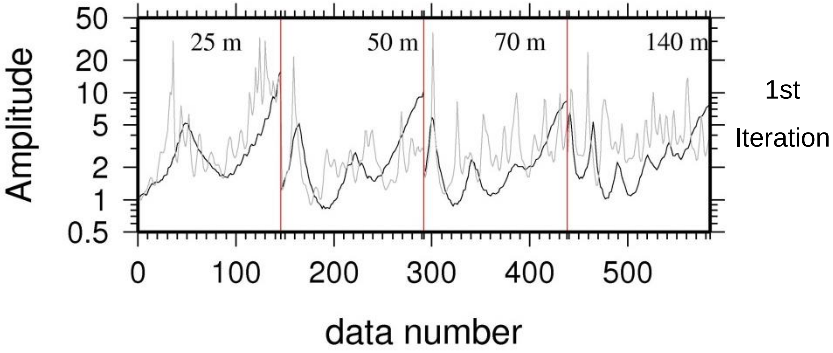
Estimated Vs models



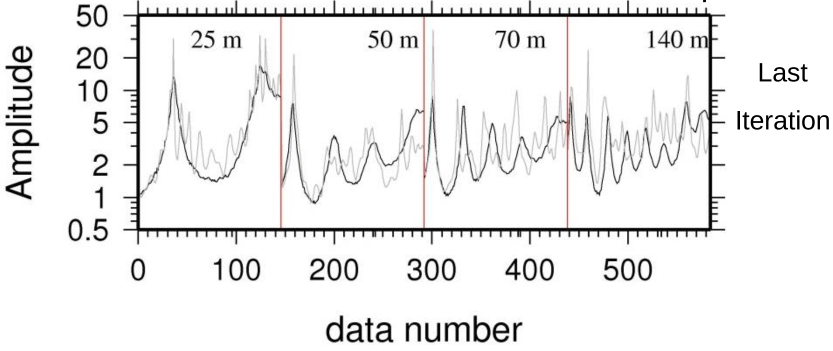
Estimated Qs models



Observed and estimated deconvolved wavefield spectra

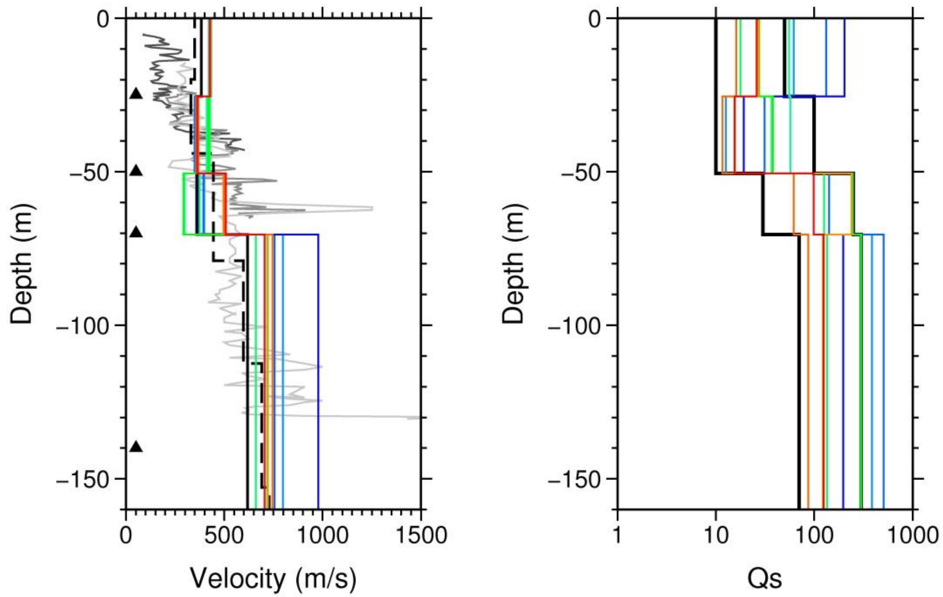


Observed and estimated deconvolved wavefield spectra

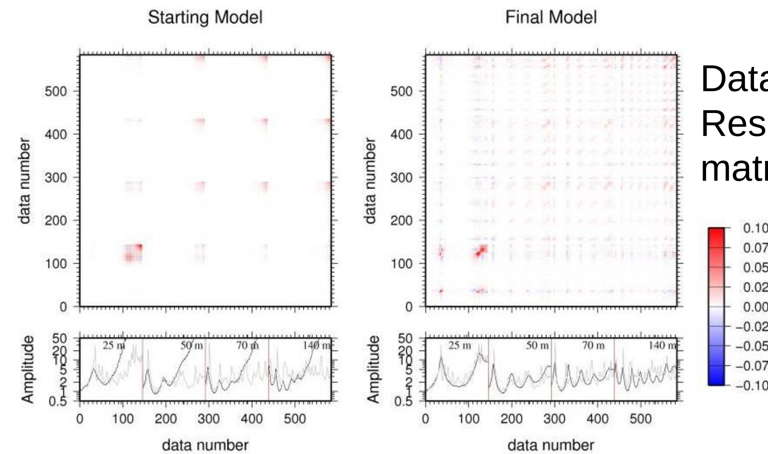


Parolai et al., 2011 .

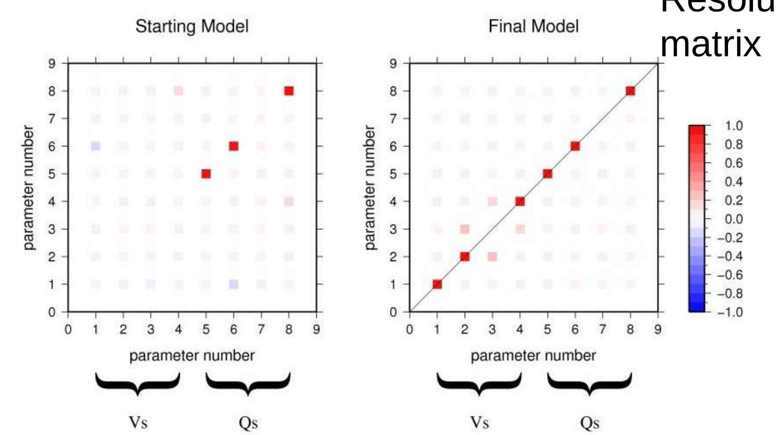
VS velocity structure



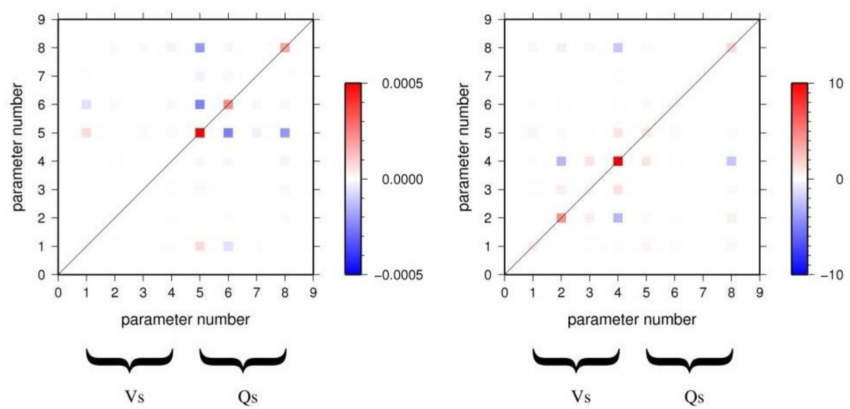
Data Resolution matrix



Model Resolution matrix



Covariance matrix



Parolai et al., 2011

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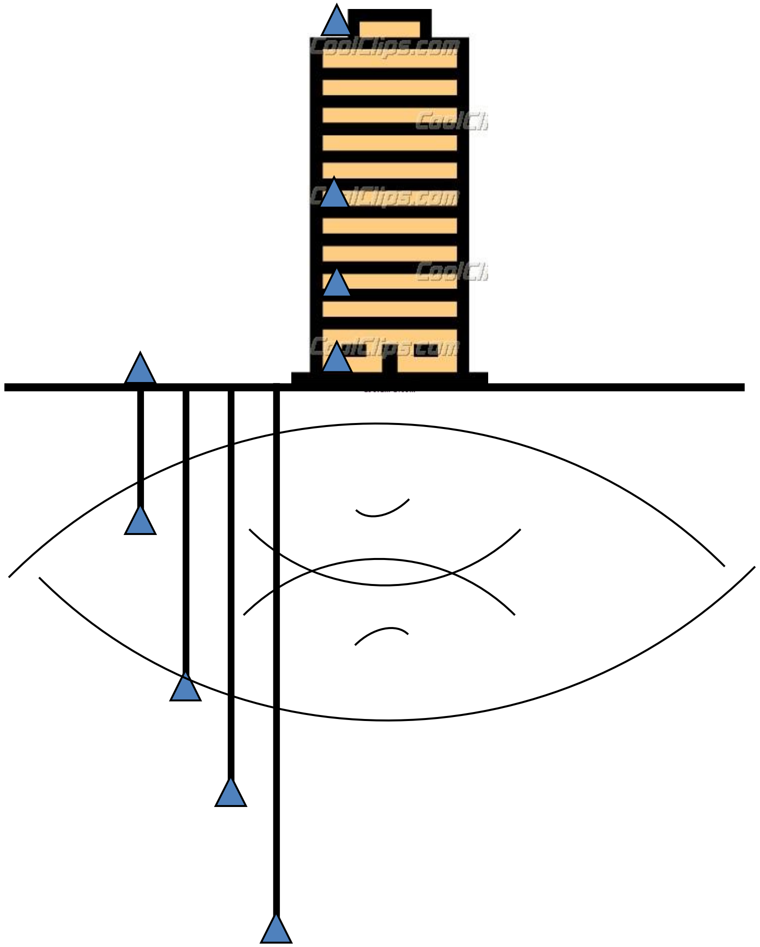


Monitoring soil-structure interaction

Installation of SOSEWIN nodes in the nearby buildings:

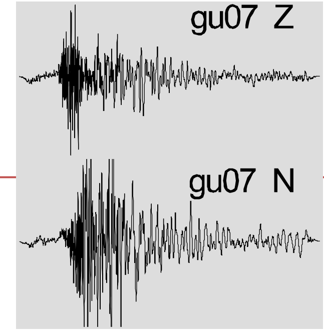
1) Study how energy is propagating from the ground to the structure and vice versa.

2) Understanding how the building (due to the coupling of the structure with soil) is behaving during earthquake ground motion

3) Understanding and quantifying how much energy is released back to the ground, therefore possibly affecting the behaviour of nearby buildings. From this we may gain a better understanding of damage patterns observed during previous earthquake disasters.

EARHQUAKE BASED NON-REFERENCE SITE METHOD:

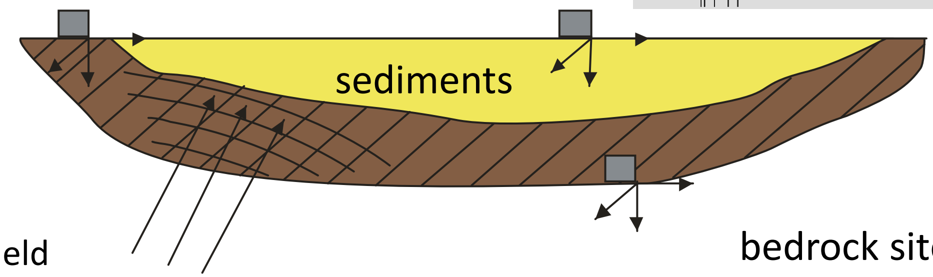
H/V spectral ratio (earthquakes)



horizontal component

outcropping rock site

soil site

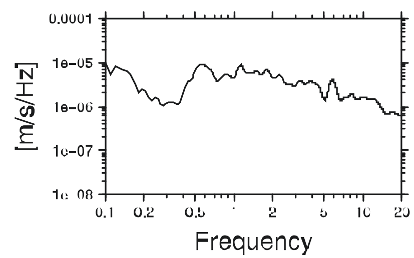


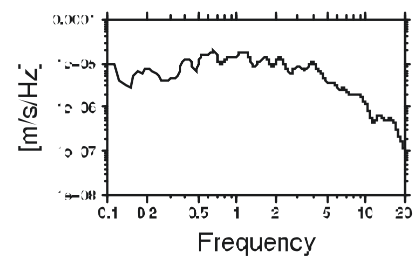
incident wave-field

bedrock site

Fourier Amplitude Spectra A(f)

Amplitude

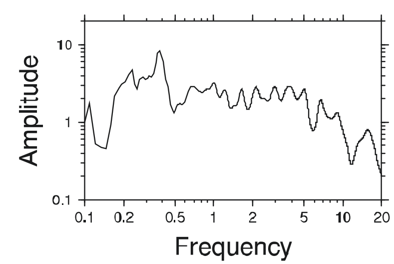




Site response or Spectral ratio

$$S(f) = \frac{H(f)soil}{V(f)soil}$$

Amplification function



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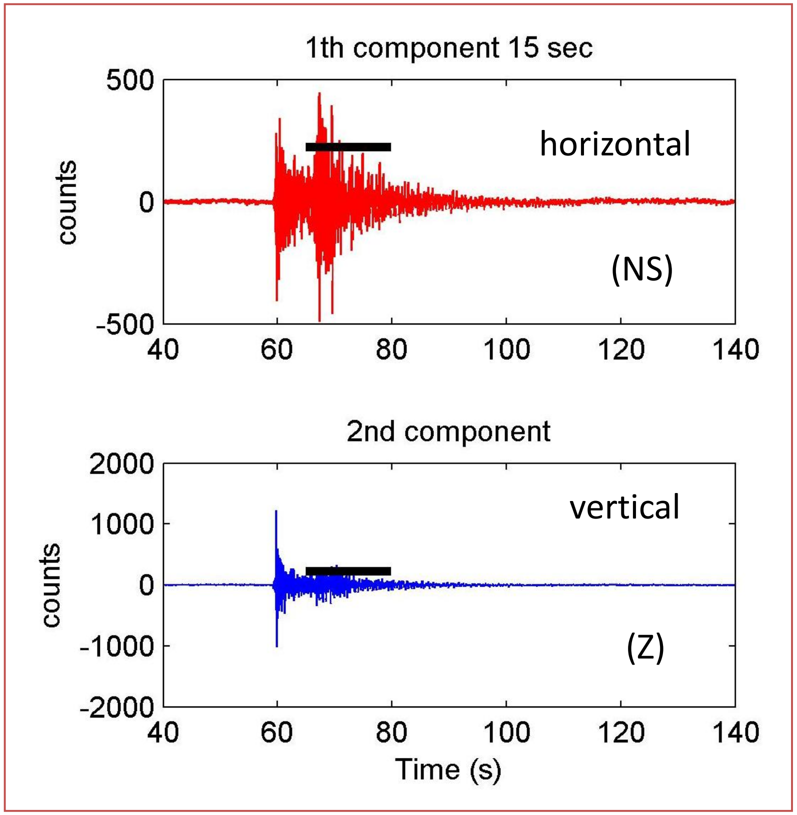
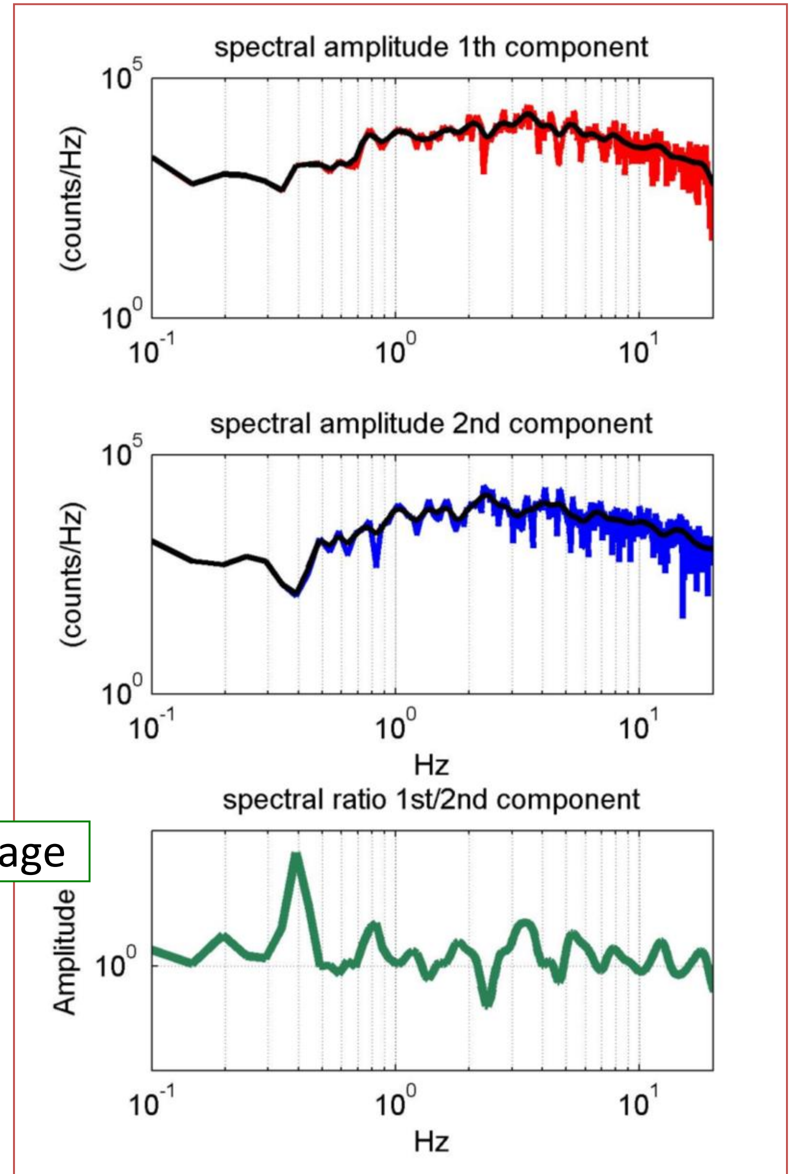
Window selection in time domain → Fourier amplitude and smoothing





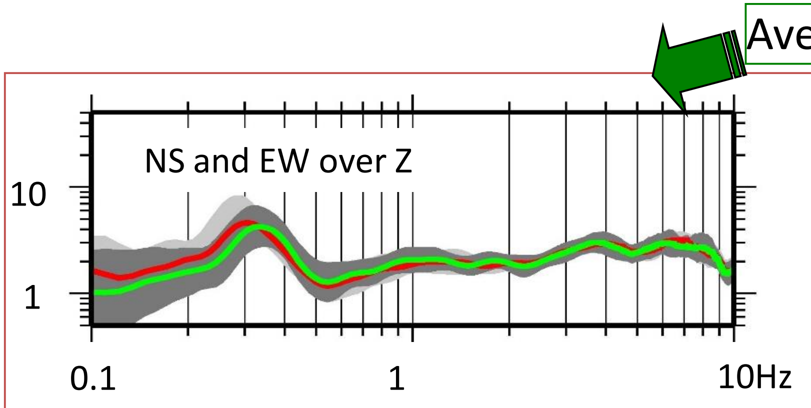
H(f)

Z(f)

=

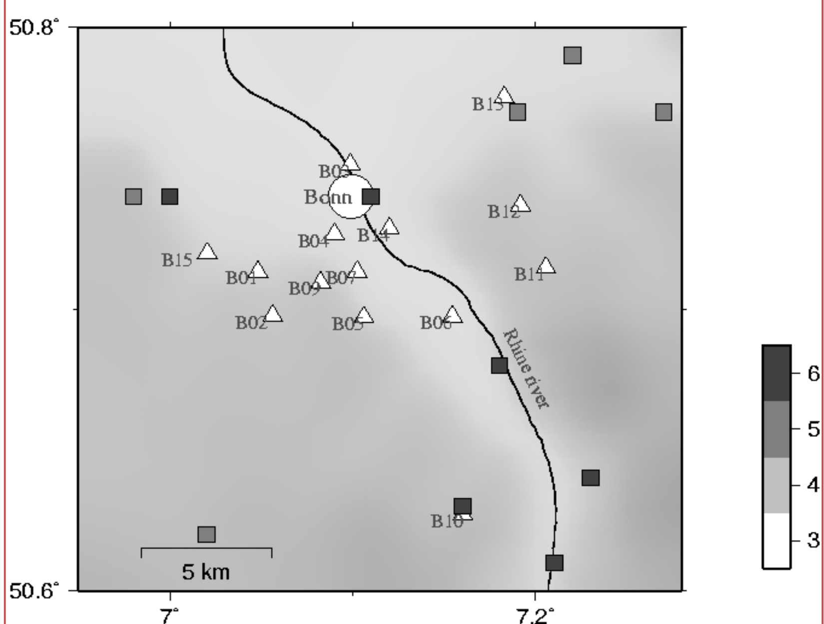
|H/V(f)|

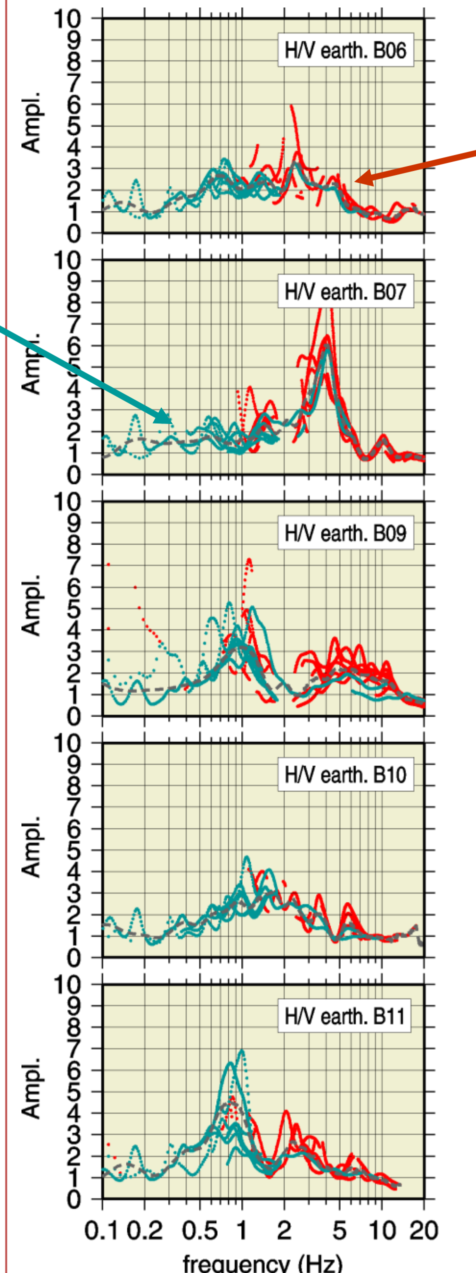
Average



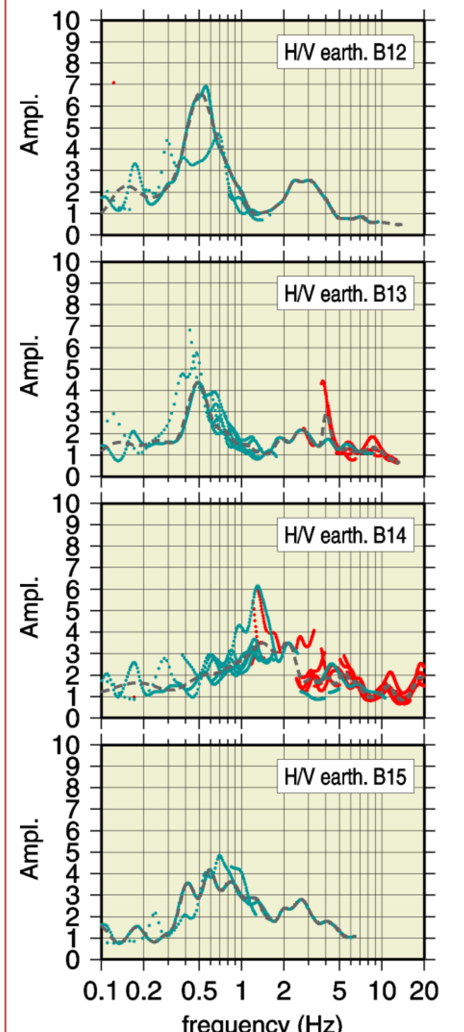
H/V spectral ratios: examples

Regional and teleseisms





Local earthquakes



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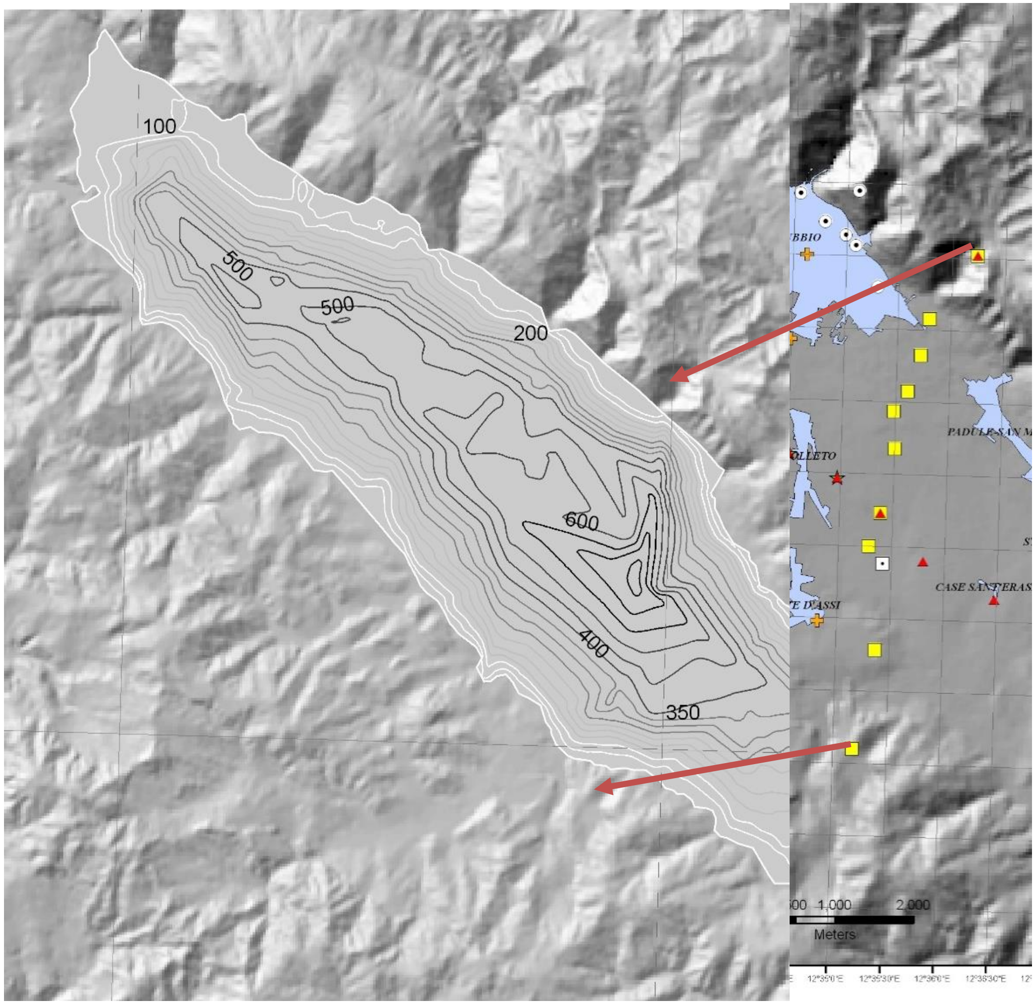
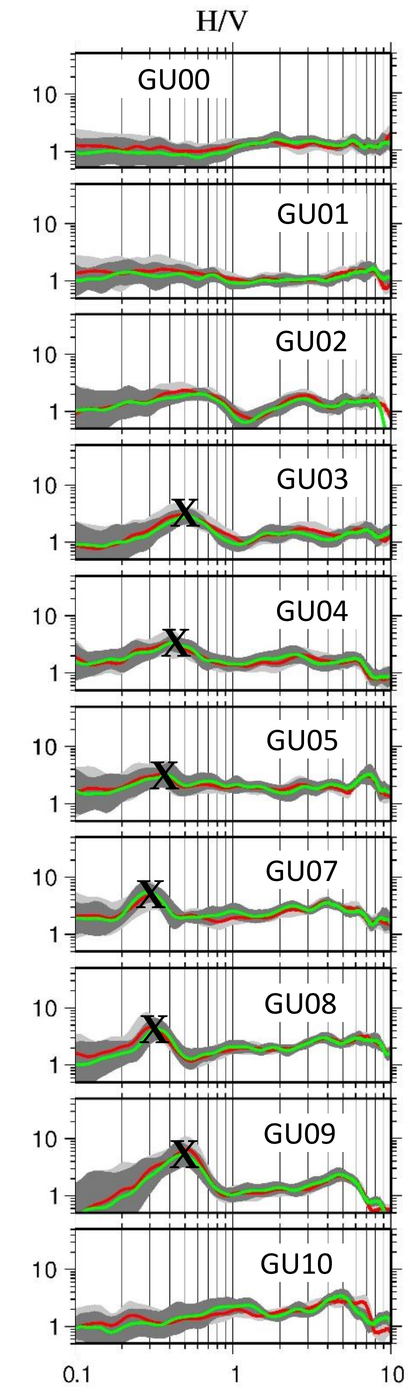
Parolai et al. (2004)

H/V spectral ratios

Still the frequency of the first H/V peak correlates with the sediment thickness

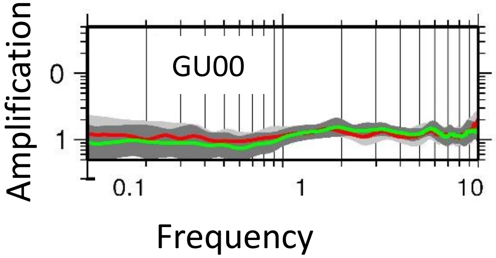




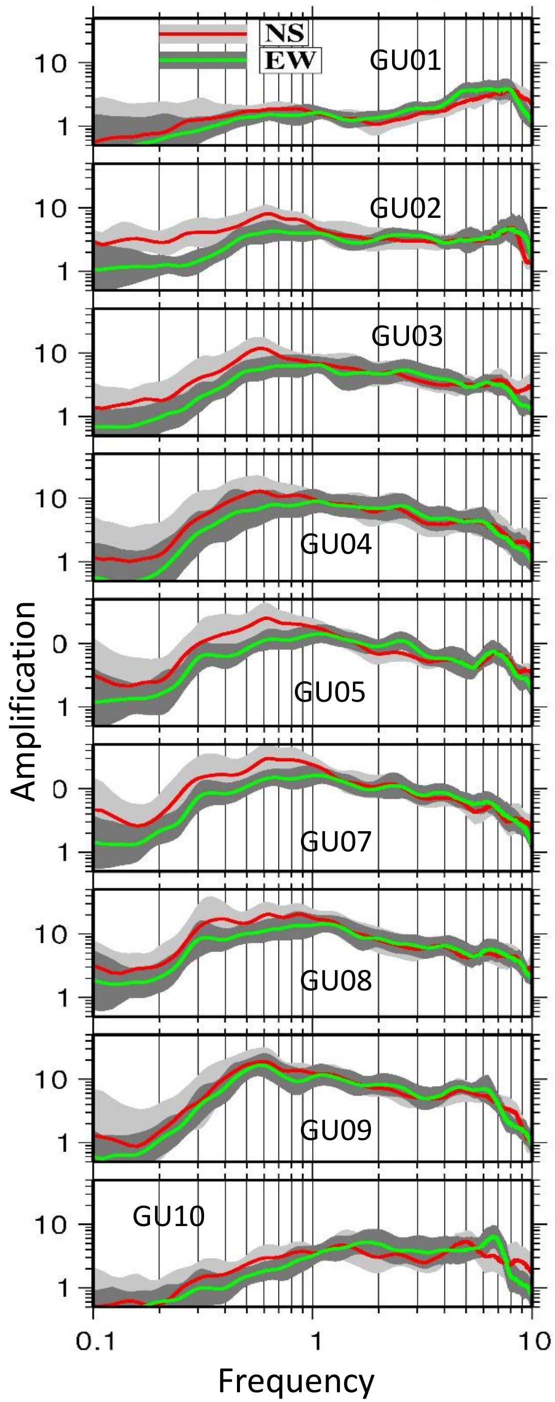
Bindi et al. (2009)

Reference site versus no-reference site methods: comparison for Gubbio

H/V

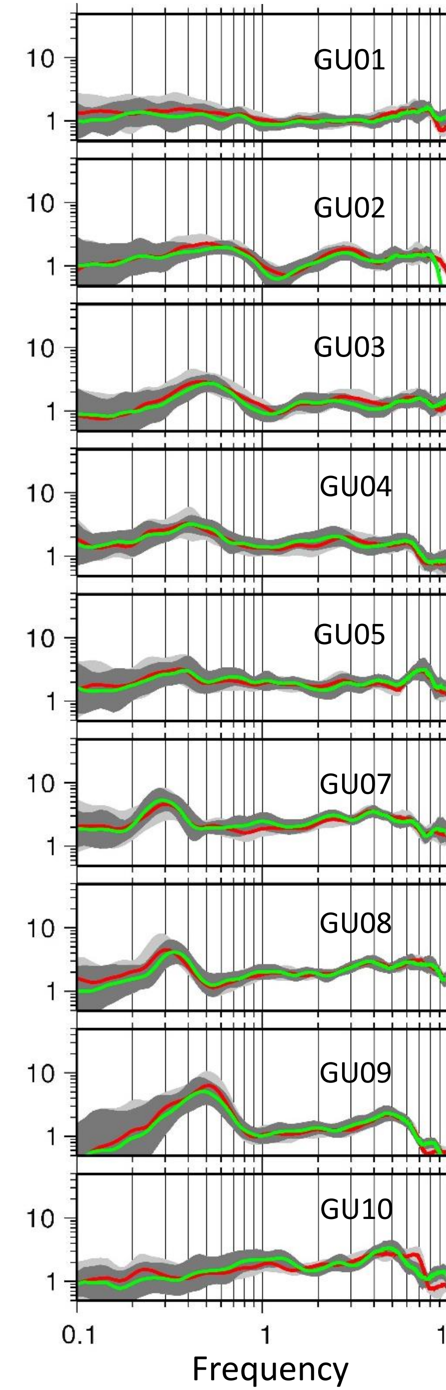


H/H $_{Ref.}$



H/V

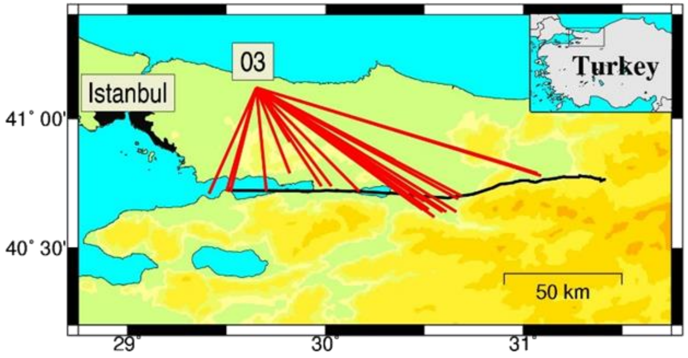
Very different !!!!!

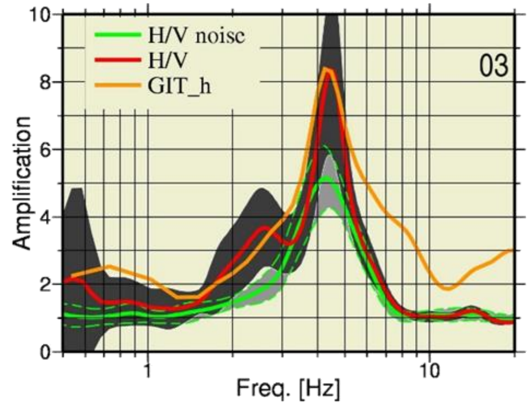


Bindi et al. (2009)

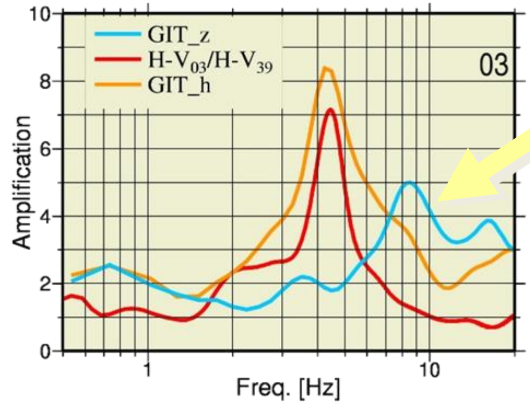
H/V spectral ratios: examples

There is a general good agreement amongst the results obtained with different techniques





H/V provides lower levels of amplifications with respect to GIT at higher frequencies



Amplification of the vertical component

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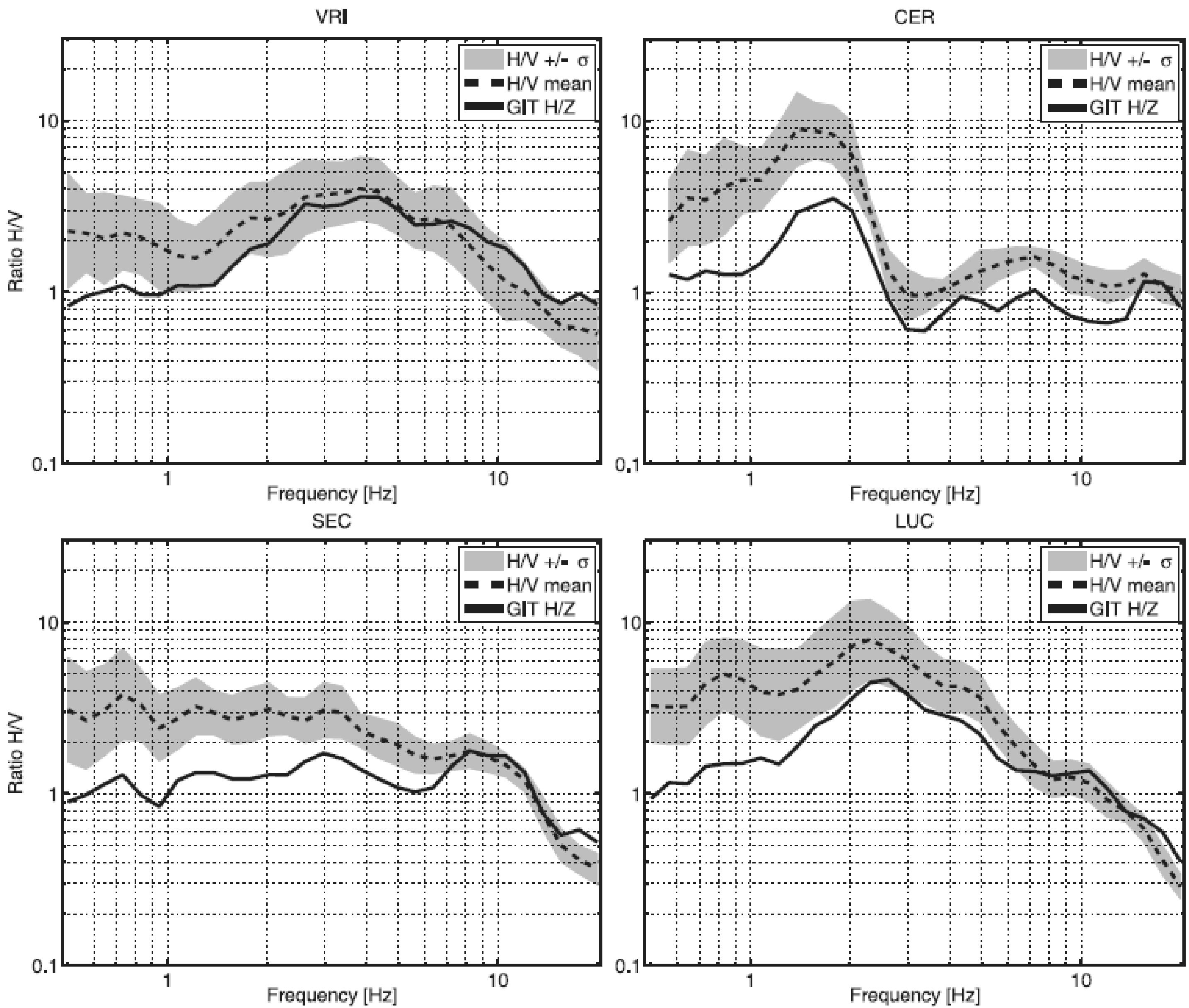
VRI
CER
SEC
LUC
H/V +/- σ
H/V mean
GIT H/Z
Ratio H/V
Frequency [Hz]
0.1
1
10

Reference site versus no-reference site methods

The H/V does not represent the seismic transfer function of the site.

In the case of site amplifications dominated by the vertical resonance, many studies in literature found that:

-the fundamental frequency of resonance estimated by the H/V is in good agreement with the one estimated by the SSR method

-the amplification of the H/V peak is generally a lower bound for the amplification obtained by applying the SSR method

The H/V can fails in determining the amplification at frequencies larger than the fundamental one, due to amplification of the vertical component. In particular, for complex site effects (e.g. 2D-3D site effects), can fail in estimating the site amplification.