

# Unconventional and Optimized Surface-Wave Acquisition and Analysis

giancarlo dal moro  
gdm@winmasw.com

## ***Keywords:***

**Seismic data, data acquisition, MASW, multi-component MASW, *Full Velocity Spectrum (FVS)* analysis, HVSR, ESAC (Extended Spatial AutoCorrelation), ReMi (Refraction Microtremors), seismic data inversion, joint analysis, joint inversion, *Miniature Array Analysis of Microtremors (MAAM)*, *winMASW*, *HoliSurface (HS)*, *Multiple Filter Analysis (MFA)*, body waves, surface waves, Rayleigh waves, Love waves, Scholte waves, refraction, seismology, vibrational analyses, building resonance.**

Tutti gli argomenti presenti in questo documento sono trattati nel seguente volume edito dalla Elsevier (molto più aggiornato rispetto il volume della Flaccovio e con numerosi nuovi casi studio).

Per info: [gdm@winmasw.com](mailto:gdm@winmasw.com)

## SURFACE WAVE ANALYSIS FOR NEAR SURFACE APPLICATIONS

— Giancarlo Dal Moro

*Surface Wave Analysis for Near Surface Applications* presents the foundational tools and techniques necessary to properly analyze surface-wave propagation nowadays performed for a number of applications.

In the last decades, surface-wave analysis has in fact become critical to near-surface geophysics both for geotechnical goals, seismic-hazard assessment, and environmental studies. This book presents both the theoretical background and the applications which the author has assembled while considering different possible approaches selected from the latest developments in research, with a special emphasis of the joint analysis of the different components that can be conveniently considered.

The book aims at building a bridge between academic research and field practice and at illustrating a number of possible pitfalls often made while analyzing surface waves also suggesting the way to overcome them via joint analyses.

Authored by a geophysicist with nearly 20 years of experience in research, consulting, and geophysical software development.

- Nearly 100 figures, photographs, and examples aid in the understanding of fundamental concepts and techniques.
- Presents the latest research in surface wave analysis while considering both active and passive techniques (MASW, MFA, ESAC, ReMi, HVSr etc.) and different inversion strategies.
- A number of real world case studies — 14 in all — bring the book's key principles to life.

A unique blend of theory and practice, the book's concepts are based on exhaustive field research conducted over the past decades.

SURFACE WAVE ANALYSIS  
FOR NEAR SURFACE APPLICATIONS



## SURFACE WAVE ANALYSIS FOR NEAR SURFACE APPLICATIONS

Dal Moro

— Giancarlo Dal Moro

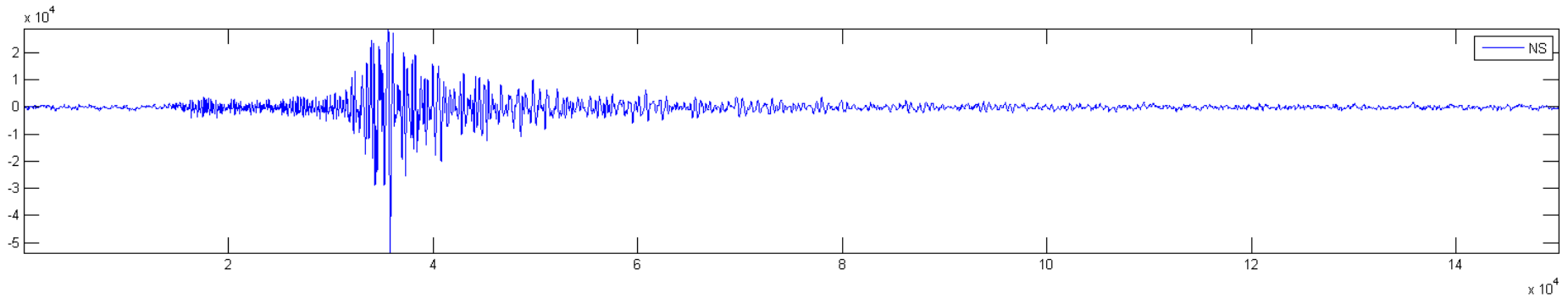


store.elsevier.com



# Some Garage Seismology

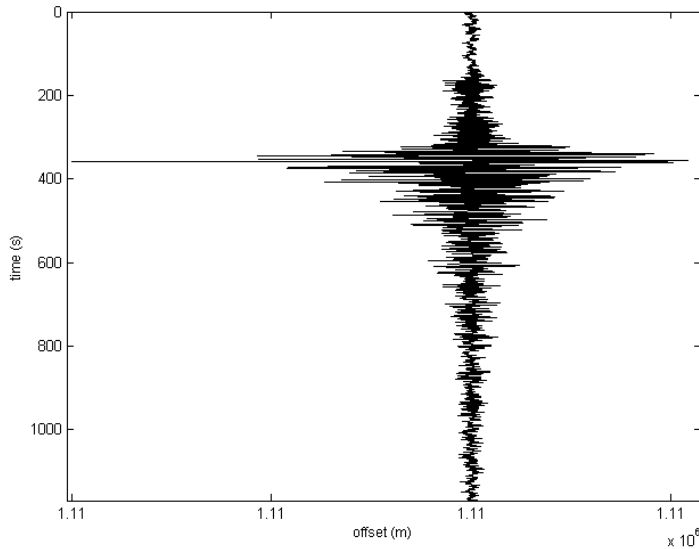
Definiamo la struttura crostale media dell'Adriatico in modo rapido e economico.



# Some Garage Seismology

## #1: data uploading & processing

dataset: THF\_M\_FAspectrum.mat  
 sampling: 160ms [6.25Hz] - 7501 samples  
 minimum offset: 1110000 m



resampling

0.5

resample

accept

data selection

activate

select 60

cancel save

filtering & spectra

filter cancel

spectrum spectrogram

refr. & refl.

refr./refl. 0.2

upload save

flip polarity clear

other tools & setting

time to visualize (s) done cut

flip traces test amplitude zero padding

## #2: velocity spectrum, modelling & picking (MASW, ESAC & ReMi analyses)

MASW: compute velocity spectrum

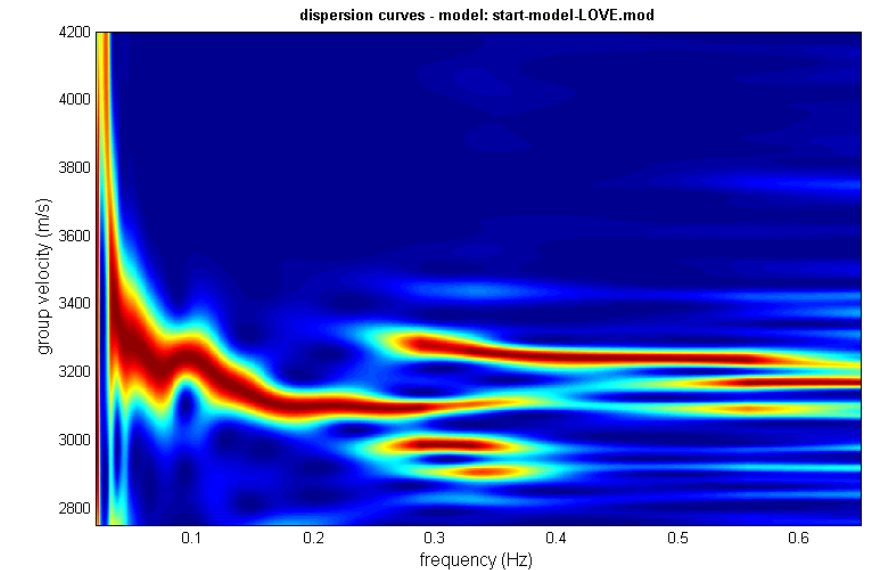
phase velocity  f-k  group velocity

handling the spectra

save upload merge

explore spectrum

mode separation



general setting

Love 5 group vel

0 Reference depth  Refraction

H/V (body waves)

H/V (surface waves)

Vs	Qs	Poisson	thickness
2500	313	0.25	500
2900	338	0.25	1000
3200	363	0.25	3000
3300	375	0.25	5000
3200	400	0.25	5000
3300	425	0.25	3000
3500	550	0.25	0
0	0	0.3	0
0	0	0.25	0
0	0	0.2	0
0	0	0.15	0
0	0	0.15	0

modelling

synthetics

THF

shows DC

show model

just overlap

synthetics

compute report DC report SS

effective (passive)

visualize curves

input curve ?

picking

? show f-k

auto picking

dispersion curves

select mode

to select the last point of the considered mode click the right button

save picking ?

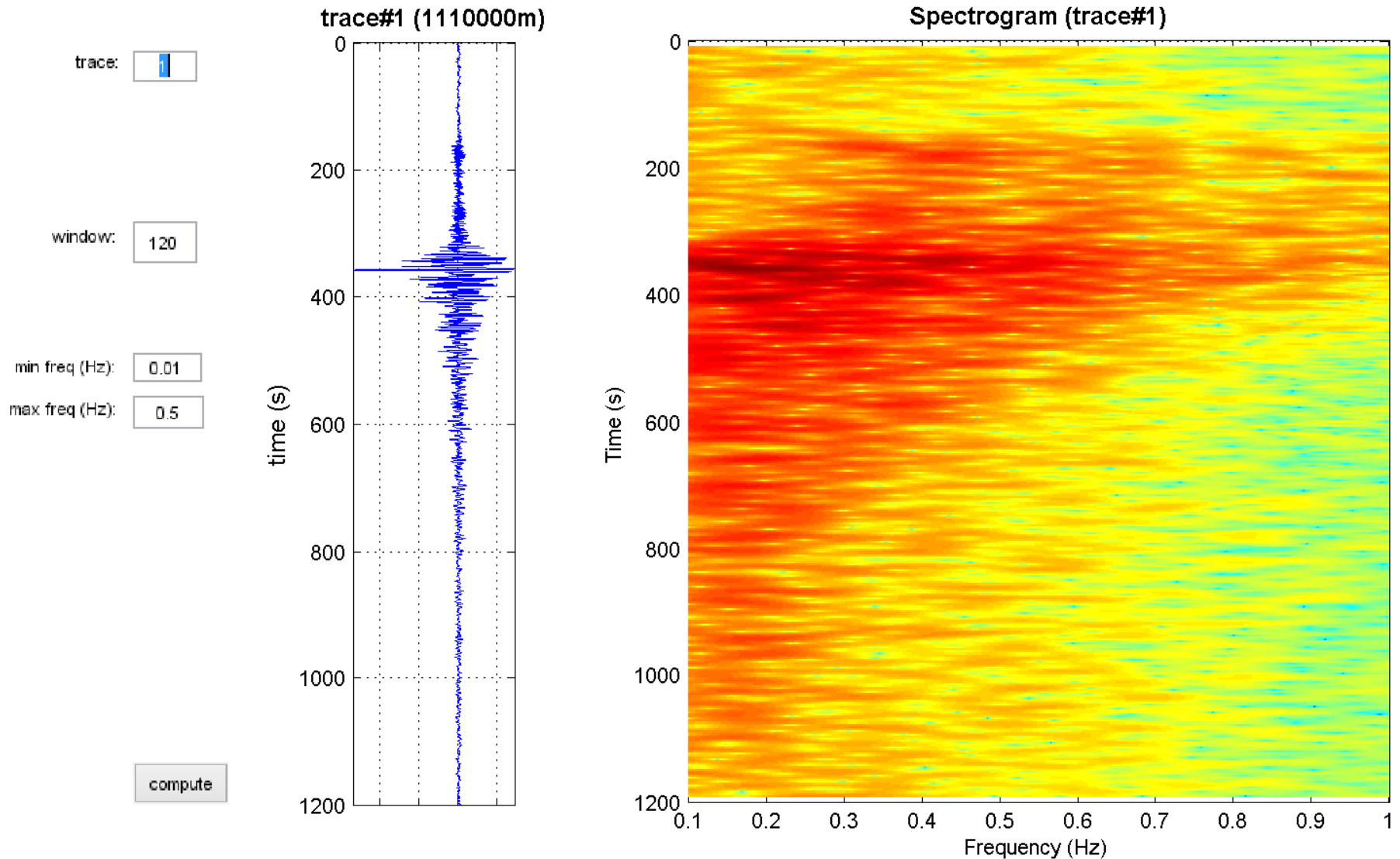
cancel picking

inversion

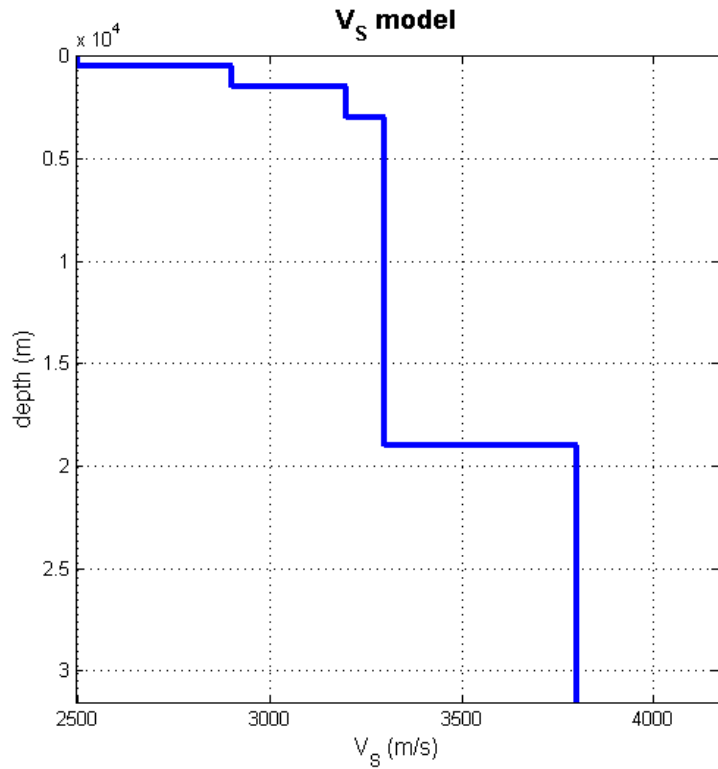
inversion

Joint DC-HV inv.

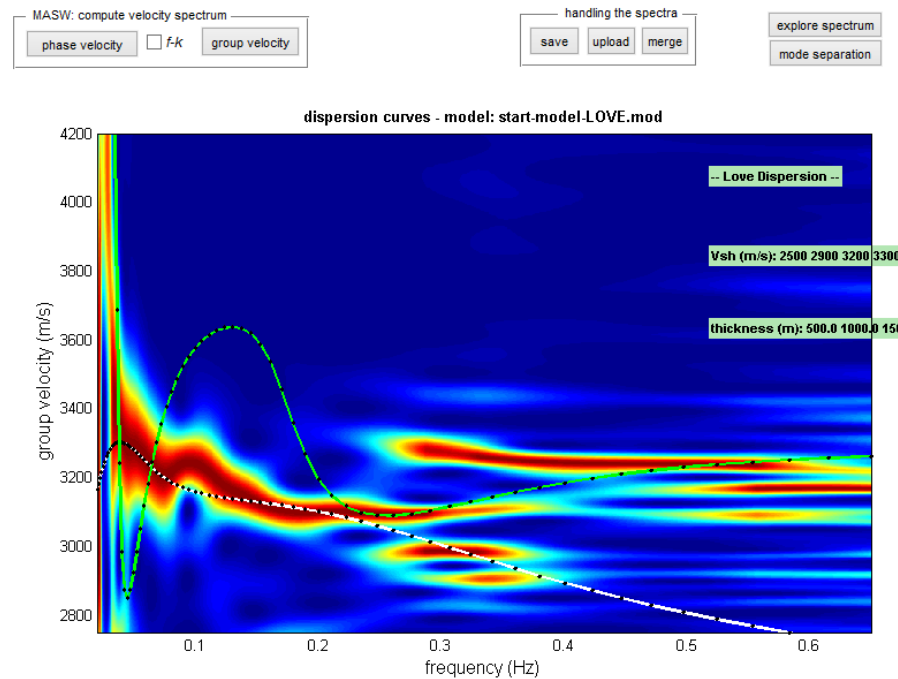
# Some Garage Seismology



# Some Garage Seismology



#2: velocity spectrum, modelling & picking (MASW, ESAC & ReMi analyses)



visualize curves  
input curve ?

picking  
? show f-k  
auto picking  
dispersion curves  
fundamental  
to select the last point of the considered mode click the right button  
save picking ?  
THFgroup.cdp  
cancel picking

inversion  
inversion  
Joint DC-HV inv.

resampling: 0.5  
resample  
accept

data selection: activate  
select 60  
cancel save

filtering & spectra: filter cancel  
spectrum spectrogram

refr. & refl.: refr./refl. 0.2  
upload save  
flip polarity clear

other tools & setting  
time to visualize (s) done cut  
flip traces test amplitude zero padding

about Poisson

Vs	Qs	Poisson	thickness
2500	313	0.25	500
2900	338	0.25	1000
3200	363	0.25	1500
3300	363	0.25	2000
3300	375	0.25	2000
3300	375	0.25	3000
3300	400	0.25	2000
3300	400	0.25	3000
3300	425	0.25	4000
3800	550	0.25	59000
7000	875	0.15	0
0	0	0.15	

general setting: Love 2 group vel

0 Reference depth Refraction  
 HV (body waves)  
 HV (surface waves)

modelling synthetics: THF  
 shows DC  
 show model  
 just overlap  
 synthetics

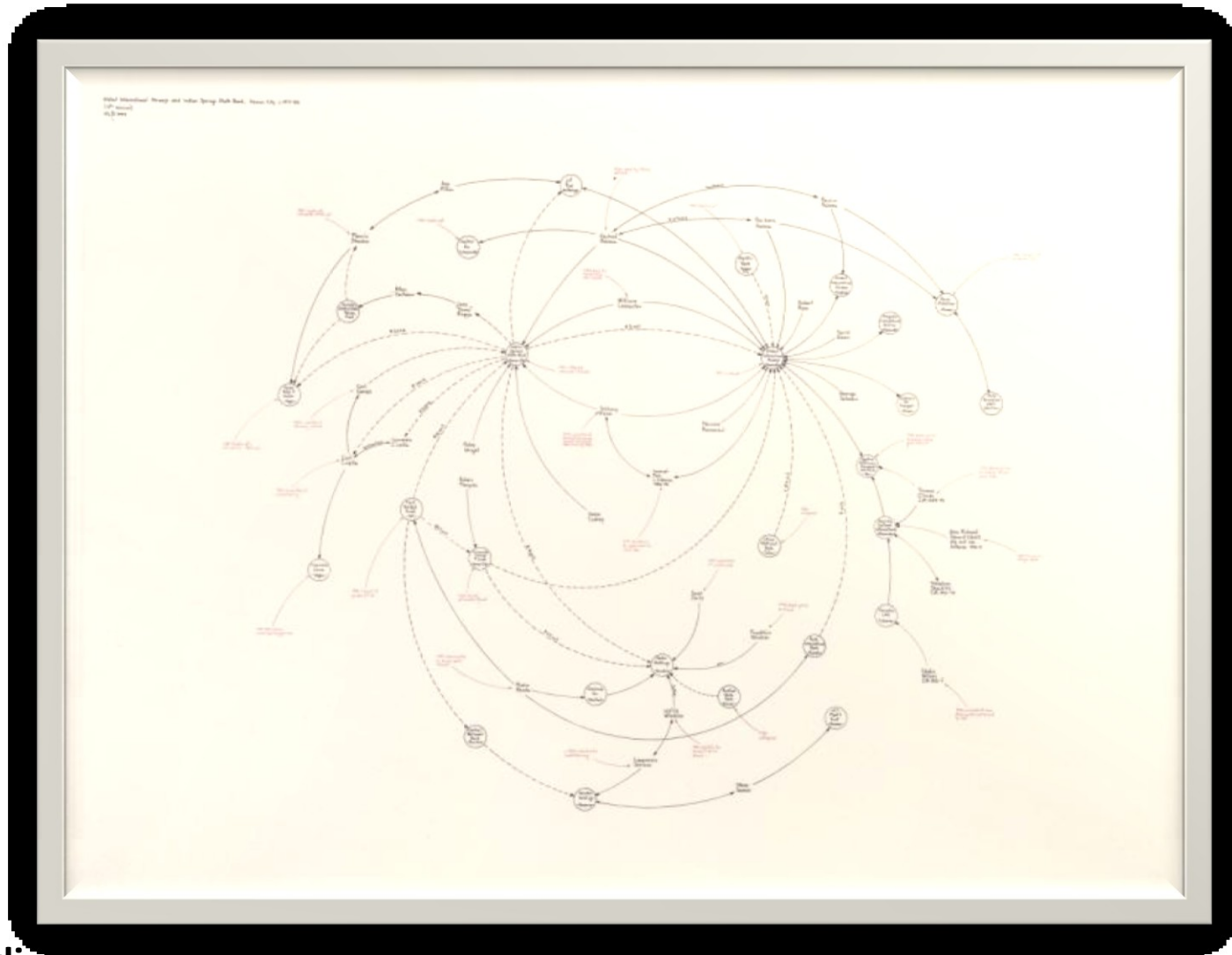
compute report DC report SS  
 effective (passive)

# Tutoring

*It's not what you look at that matters, it's what you see.*

**Henry David Thoreau**

# Le due alternative: *comprendere tutto o non capire nulla*



L'opera di Mark Lombardi



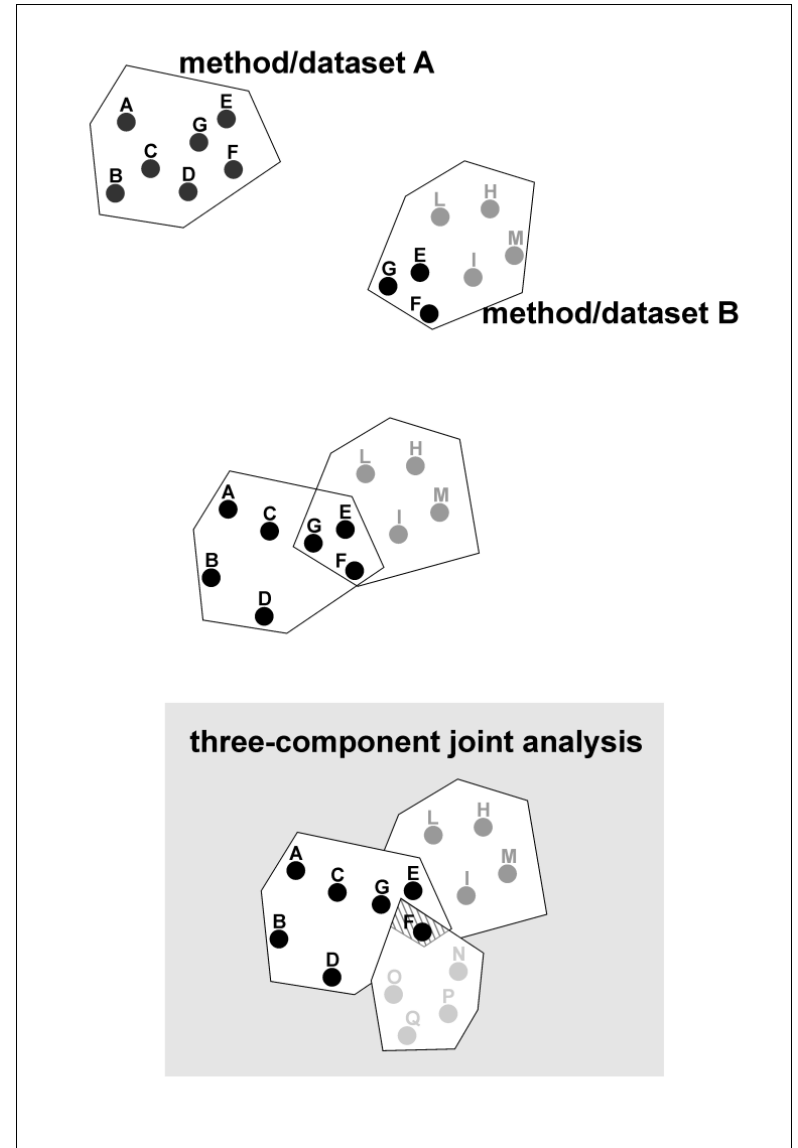


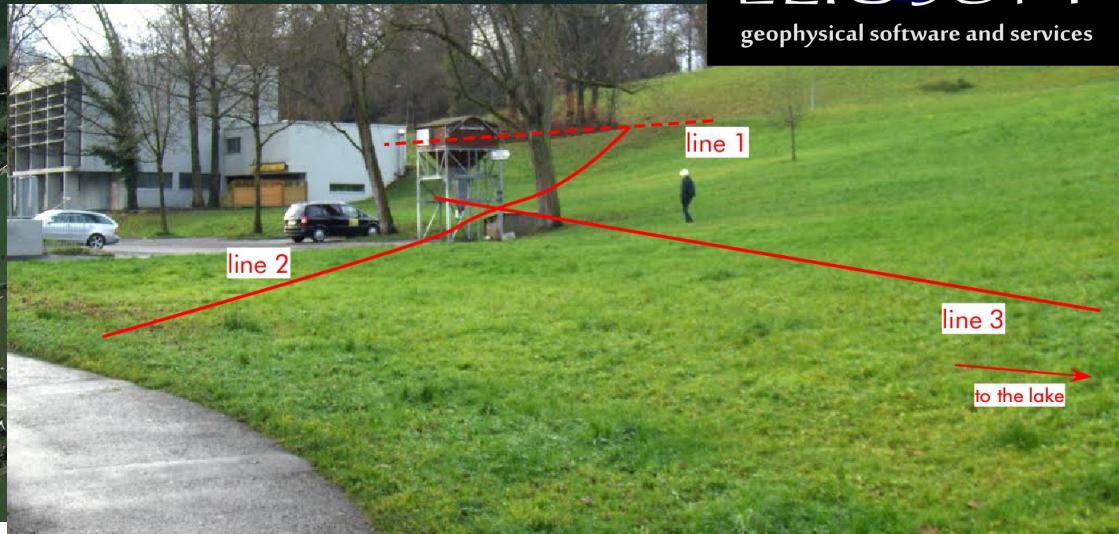
## Two R&D lines

**Classical (improved) methodologies:  
e.g., multi-component MASW analyses according to FVS**

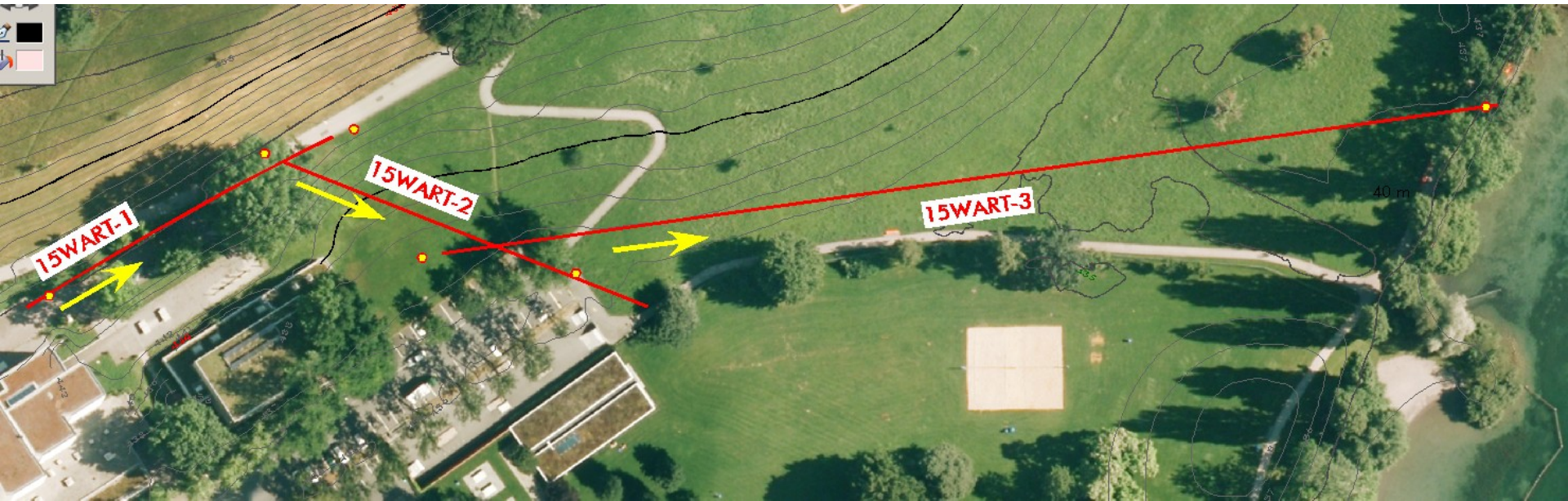
**Unconventional (particularly effective) methodologies: *HoliSurface* & MAAM**

# Non-uniqueness of the solution

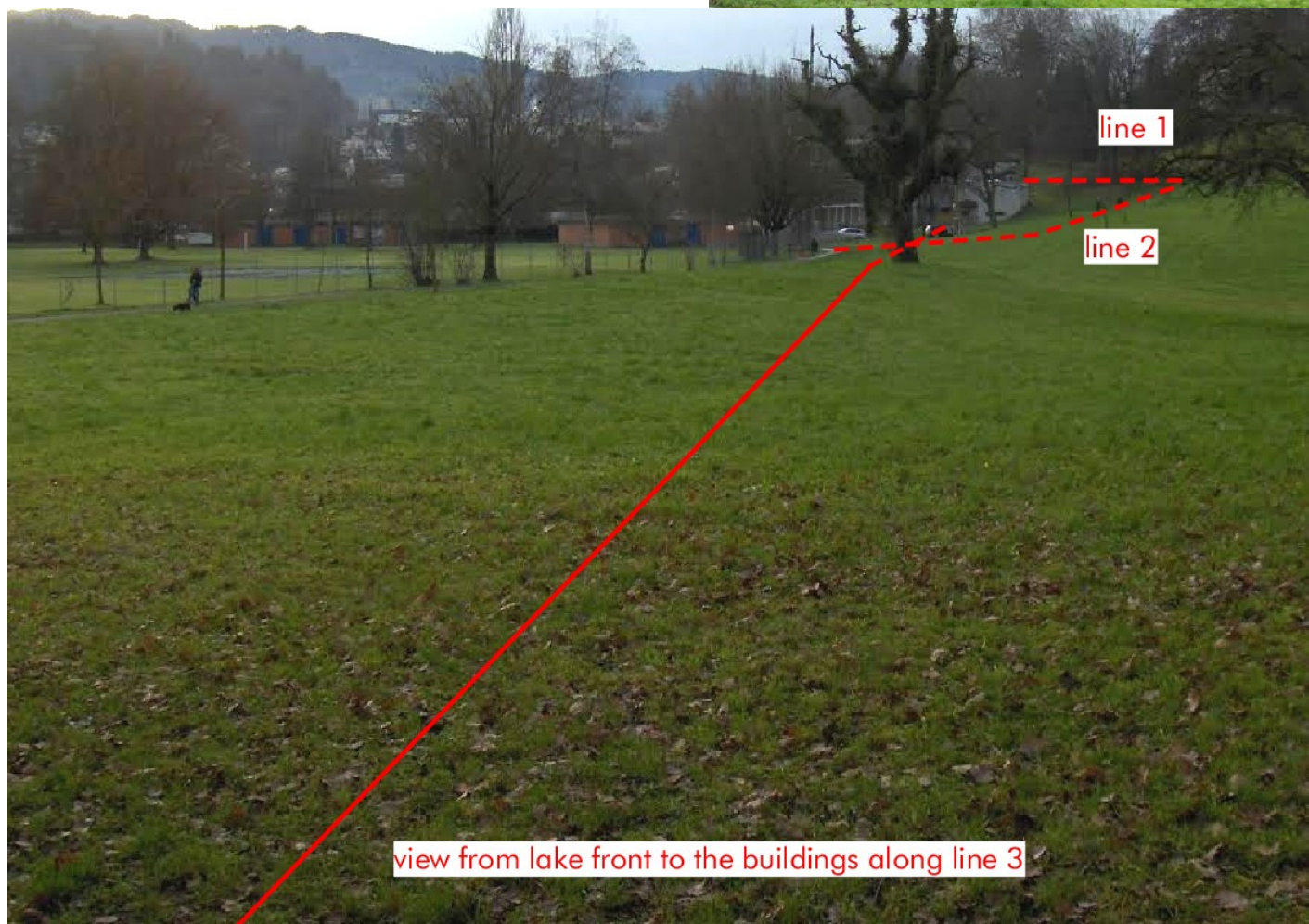




## Esempio di efficienza: "Vierwaldstättersee" survey



# Vierwaldstättersee survey



# ADAM-2D

## Apparent-Dispersion Analysis of Multicomponent Data – 2D

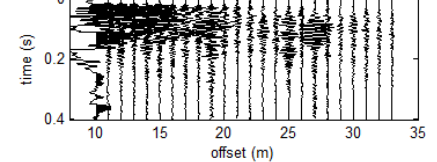
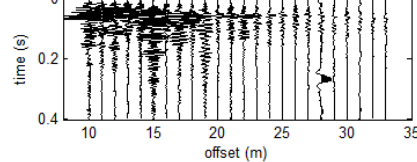
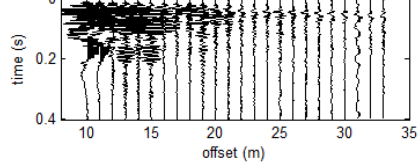
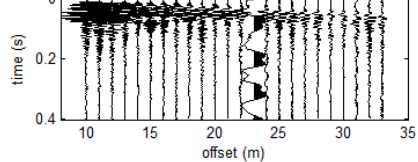
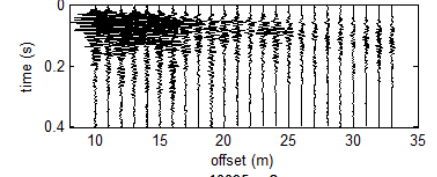
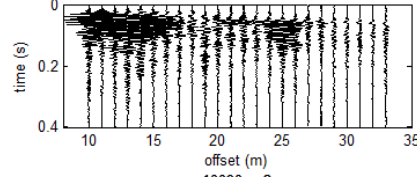
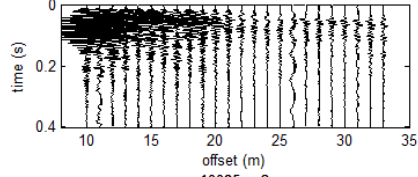
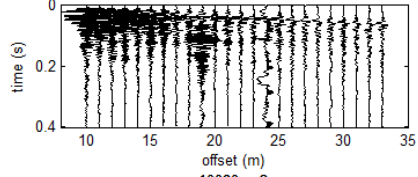
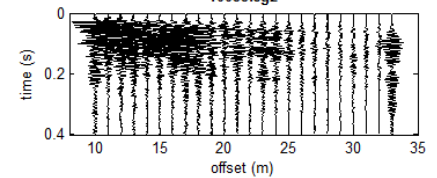
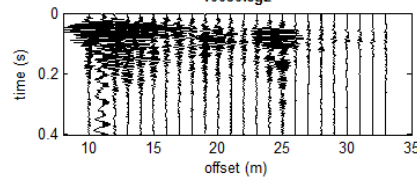
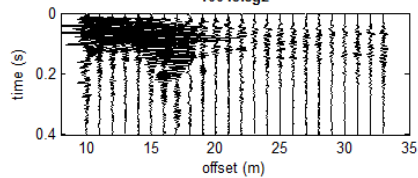
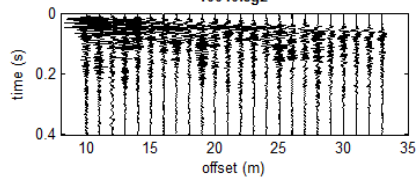
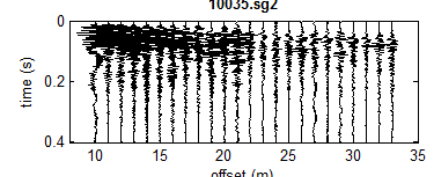
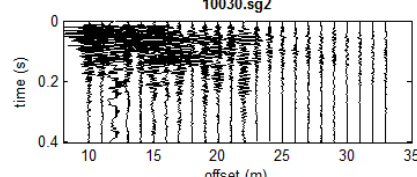
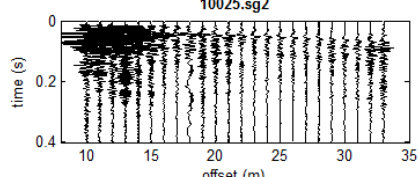
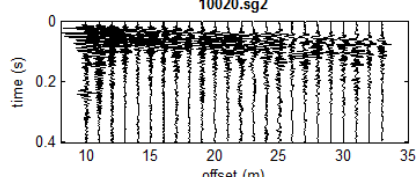
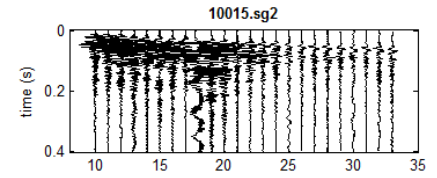
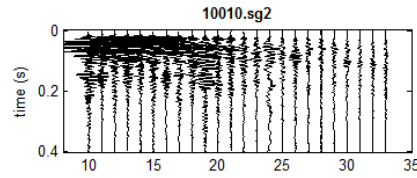
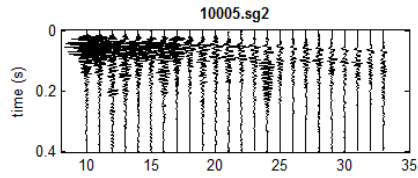
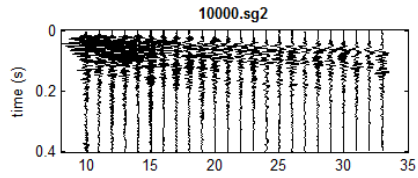


# ADAM-2D

## Apparent-Dispersion Analysis of Multicomponent Data – 2D

Qatar survey

Automatic upload and pre-processing of the data

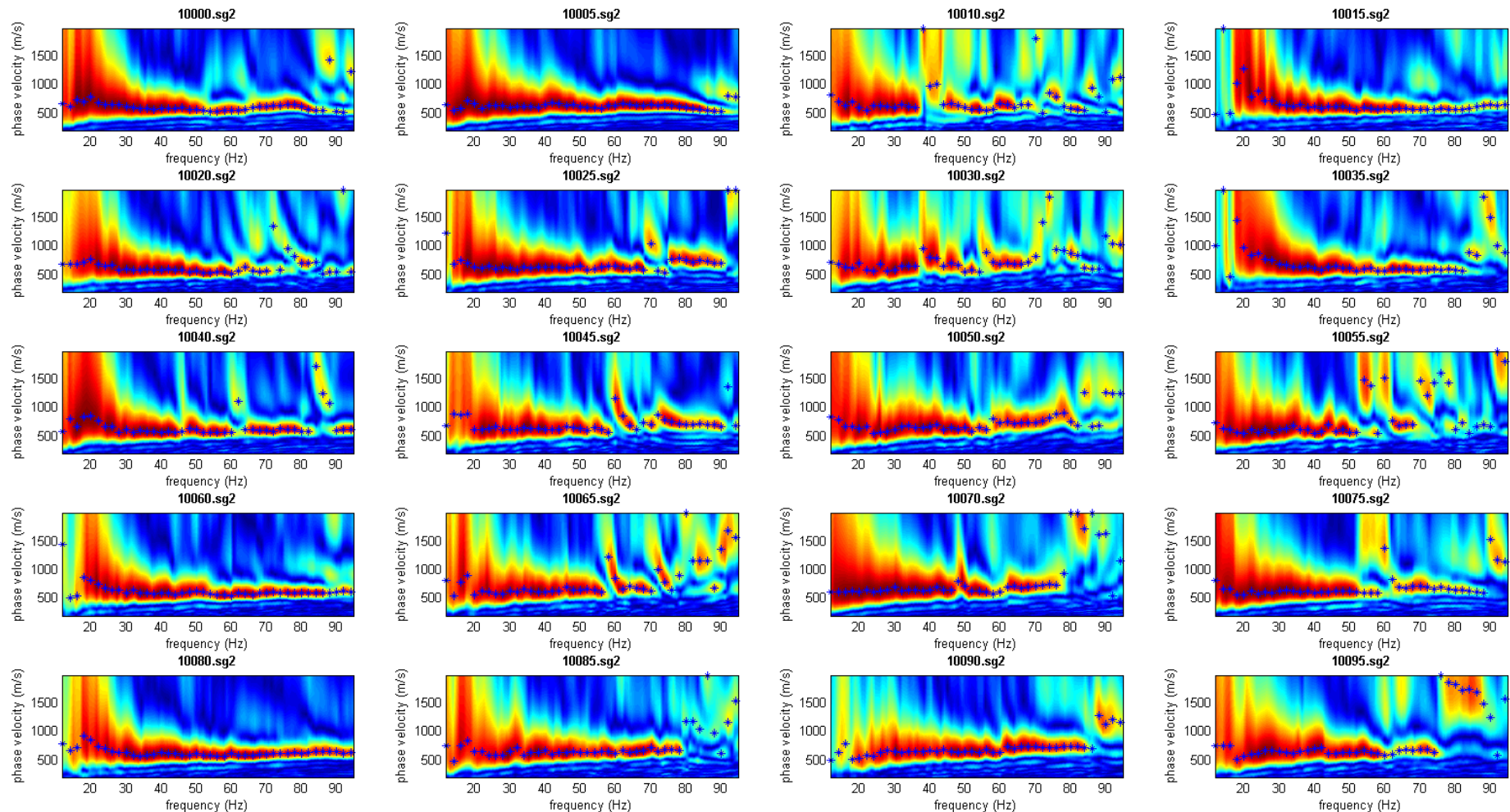


# ADAM-2D

## Apparent-Dispersion Analysis of Multicomponent Data – 2D

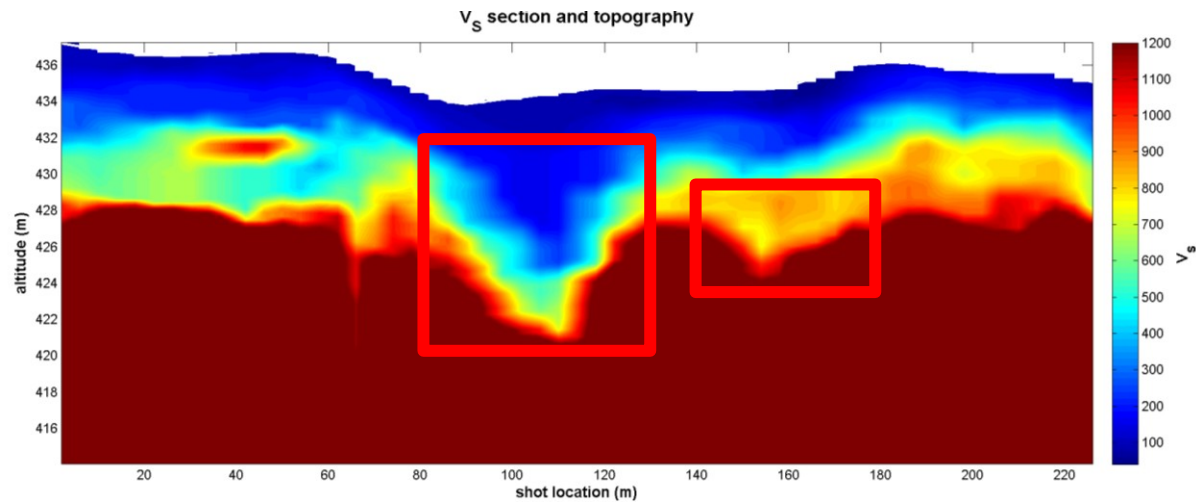
Qatar survey

Automatic computation of velocity spectra and apparent dispersion curves for multi-component data

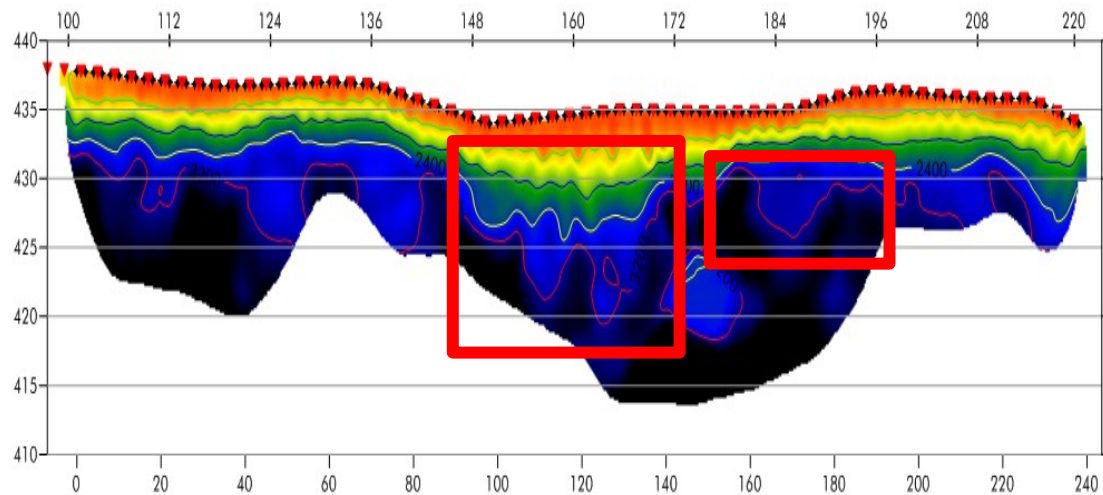


# ADAM-2D

$V_s$



$V_p$





# Oberflächengebundene Bestimmung eines robusten Vs-Modells als Eingangsparameter zu bodendynamischen Berechnungen an einer historischen Klosterkirche

L. Keller<sup>1\*</sup>, G. Dal Moro<sup>2</sup>, C. Lacave<sup>3</sup>

(<sup>1</sup>) roXplore gmbh, seismic service provider, Amlikon (Switzerland)

\*e-mail: [lorenz@roxplore.ch](mailto:lorenz@roxplore.ch)

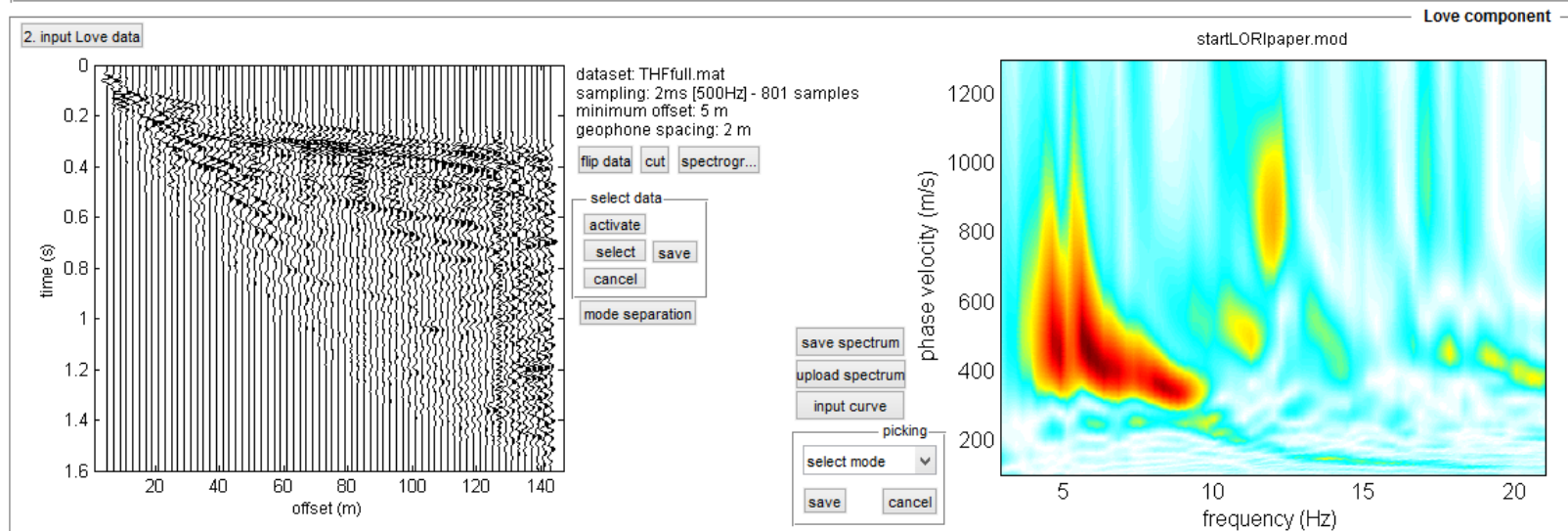
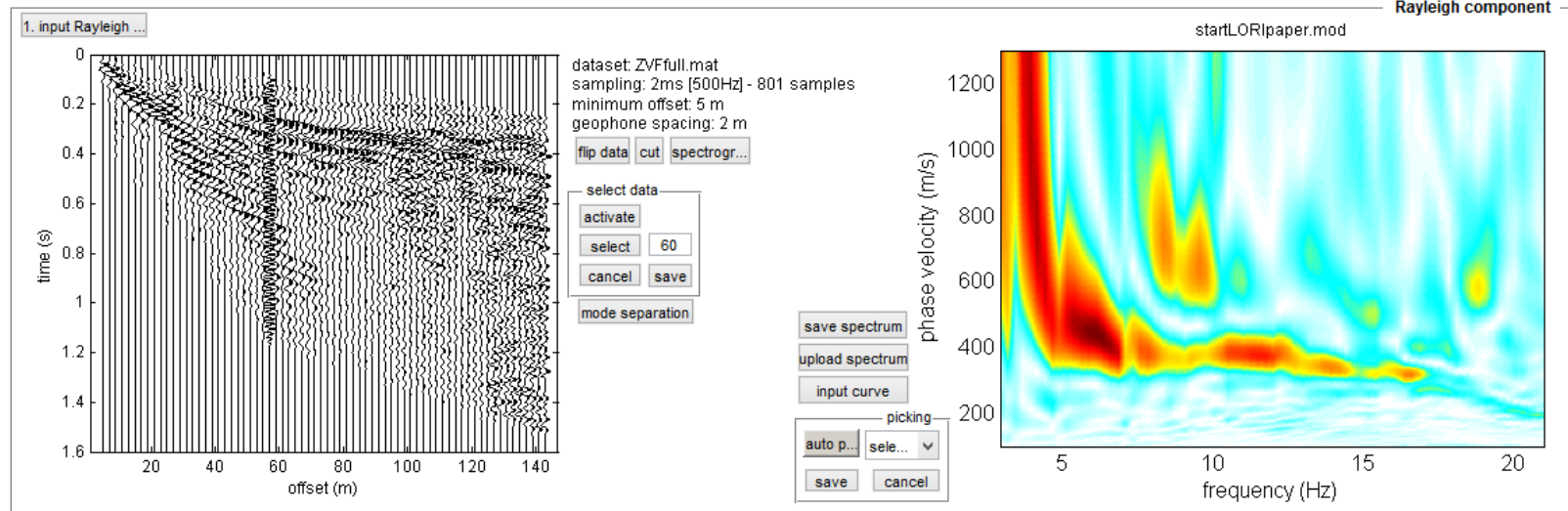
(<sup>2</sup>) Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic, Prague (Czech Republic)

(<sup>3</sup>) Résonance Ingénieurs-Conseils SA, dynamic engineering, Carouge (Switzerland)



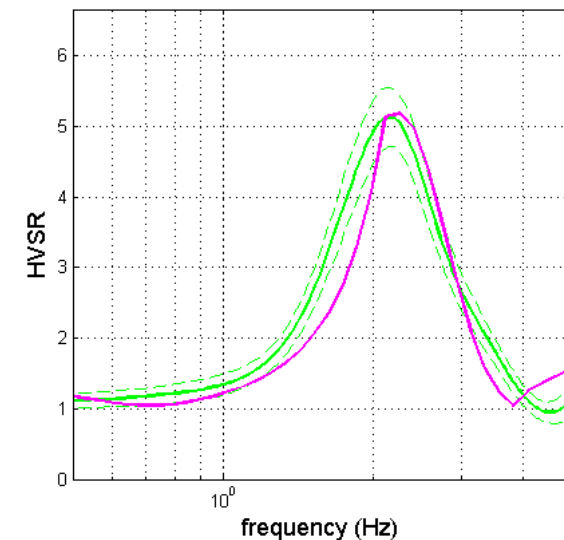
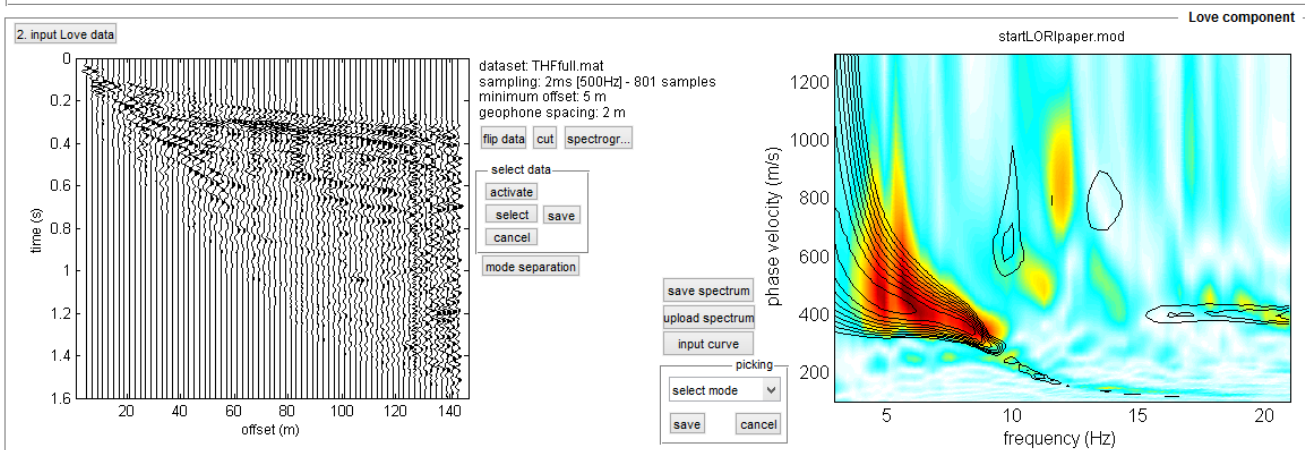
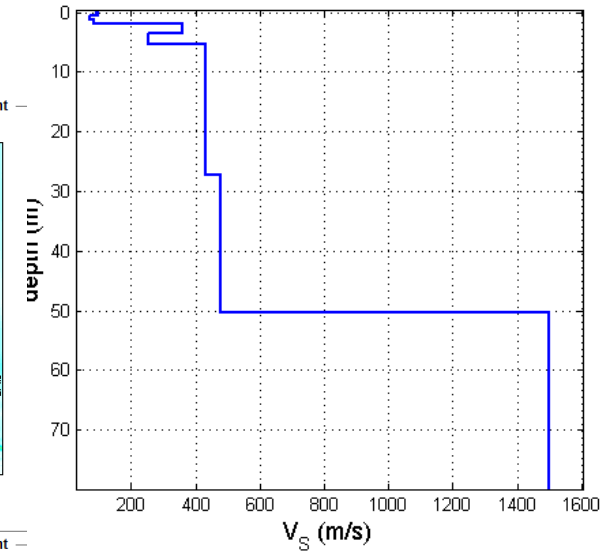
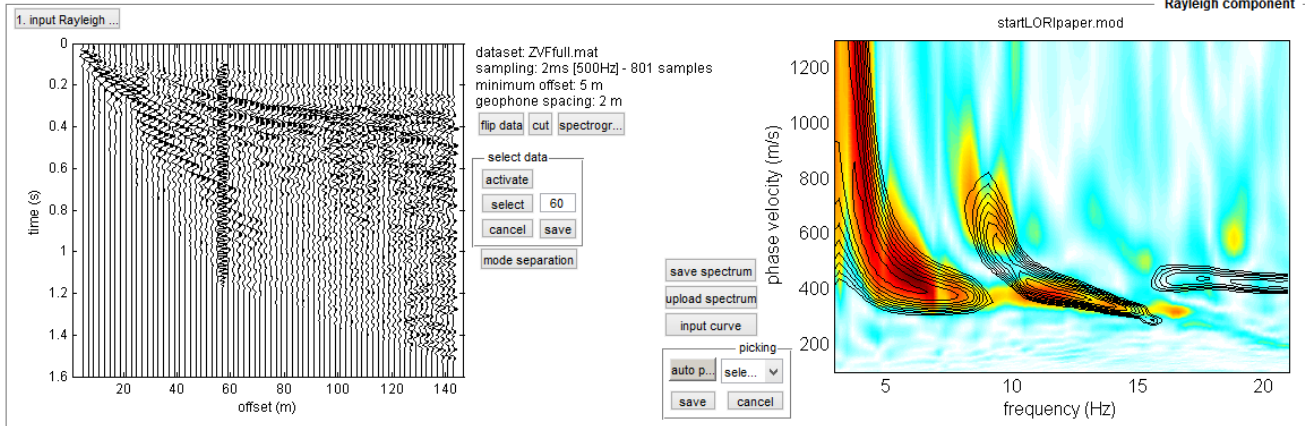
# Oberflächengebundene Bestimmung eines robusten Vs-Modells als Eingangsparameter zu bodendynamischen Berechnungen an einer historischen Klosterkirche

## The “ordinary” multi-channel approach



# Oberflächengebundene Bestimmung eines robusten Vs-Modells als Eingangsparameter zu bodendynamischen Berechnungen an einer historischen Klosterkirche

## The “ordinary” multi-channel approach



the unordinary approaches



*The more you know,  
the less you need.*

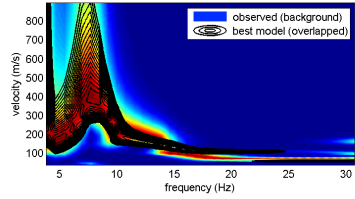
Yvon Chouinard

# Oberflächengebundene Bestimmung eines robusten $V_s$ -Modells als Eingangsparameter zu bodendynamischen Berechnungen an einer historischen Klosterkirche

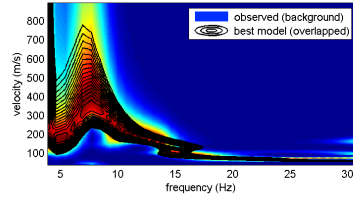
Pure HoliSurface



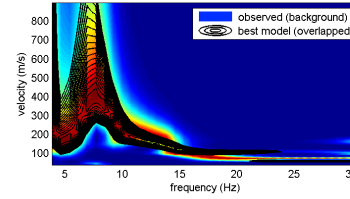
Minimum "global" GA model (vertical component)



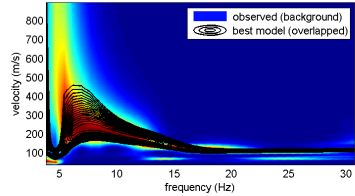
Minimum-distance model (vertical component)



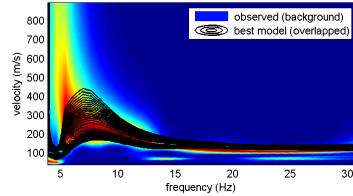
Mean model (vertical component)



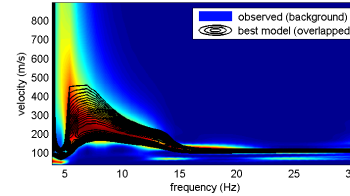
Minimum "global" GA model (radial component)



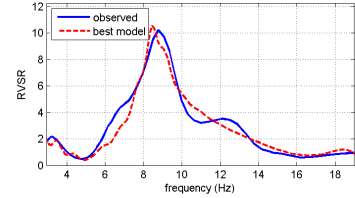
Minimum-distance model (radial component)



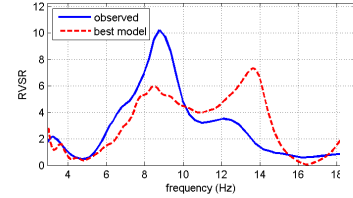
Mean model (radial component)



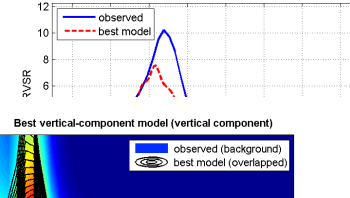
Minimum "global" GA model (RVSr)



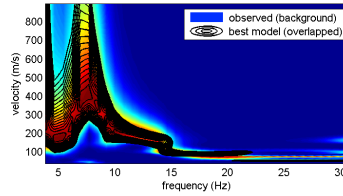
Minimum-distance model (RVSr)



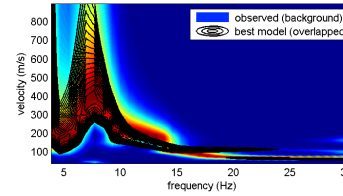
Mean model (RVSr)



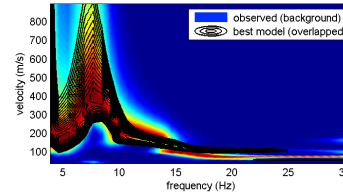
Best vertical-component model (vertical component)



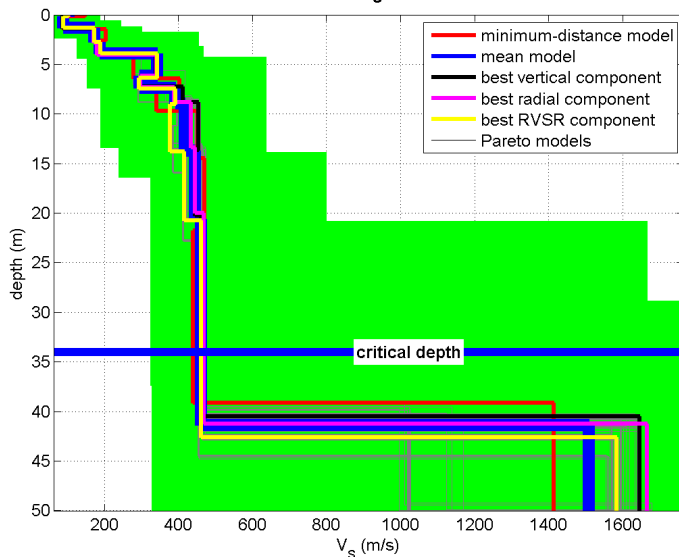
Best radial-component model (vertical component)



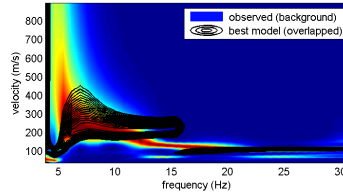
Best RVSr model (vertical component)



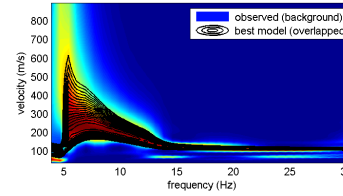
vertical  $V_s$  profile



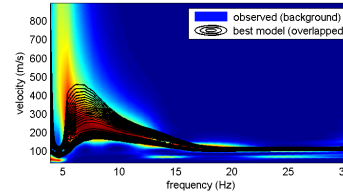
Best vertical-component model (radial component)



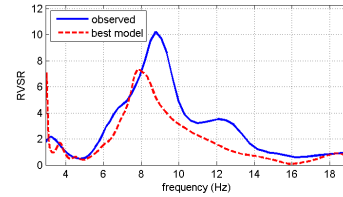
Best radial-component model (radial component)



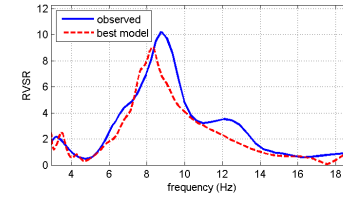
Best RVSr model (radial component)



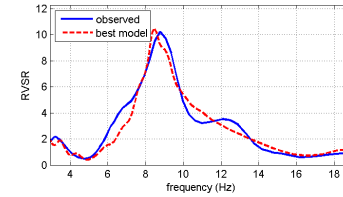
Best vertical-component model (RVSr)



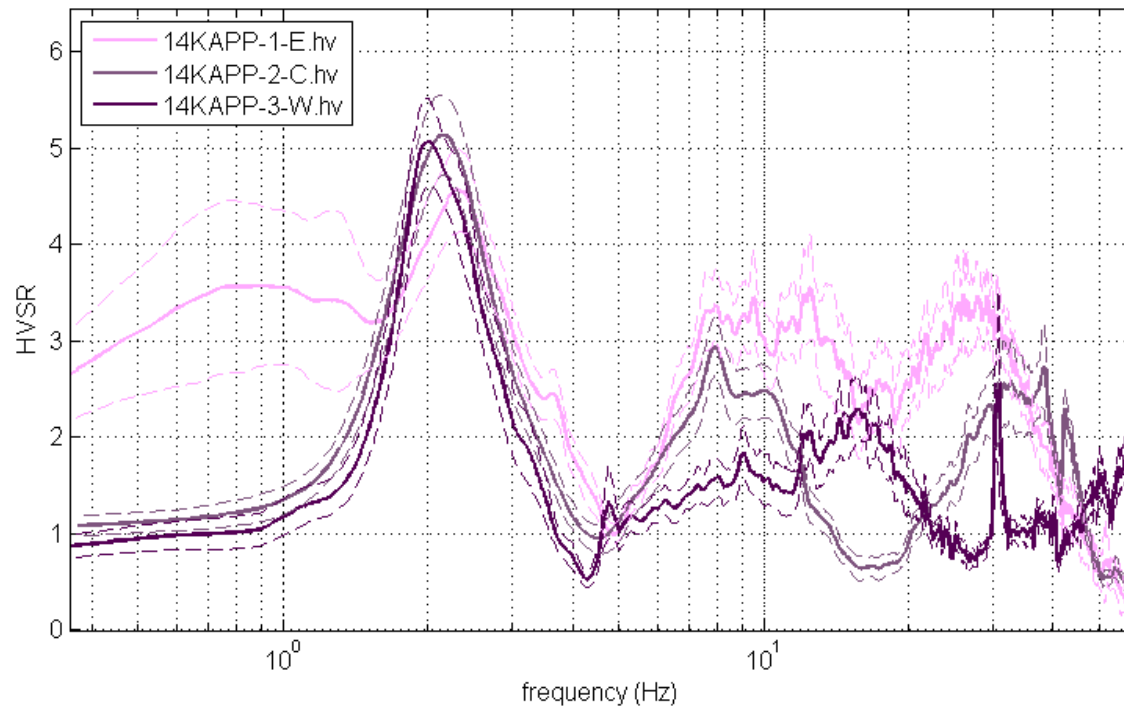
Best radial-component model (RVSr)



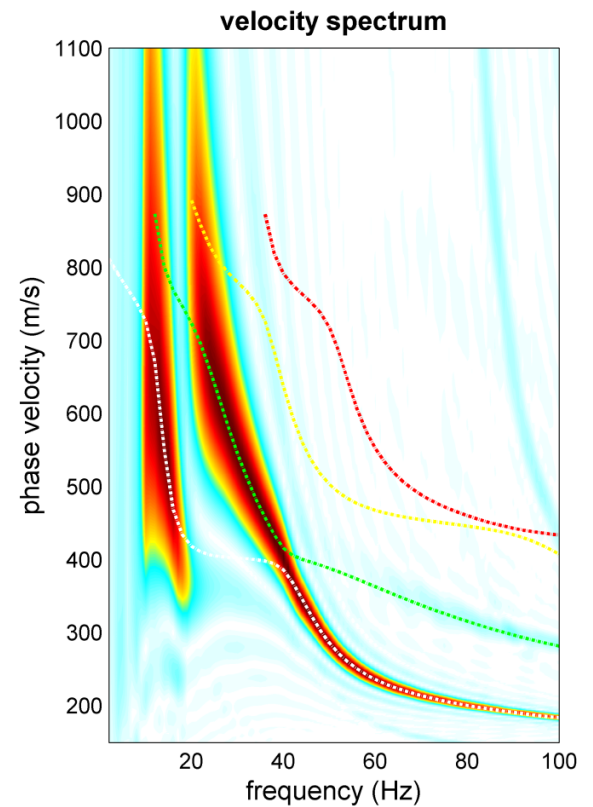
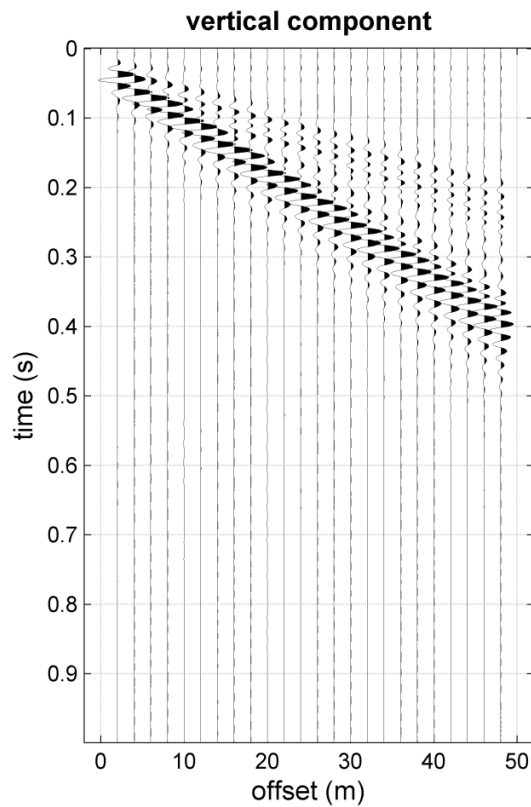
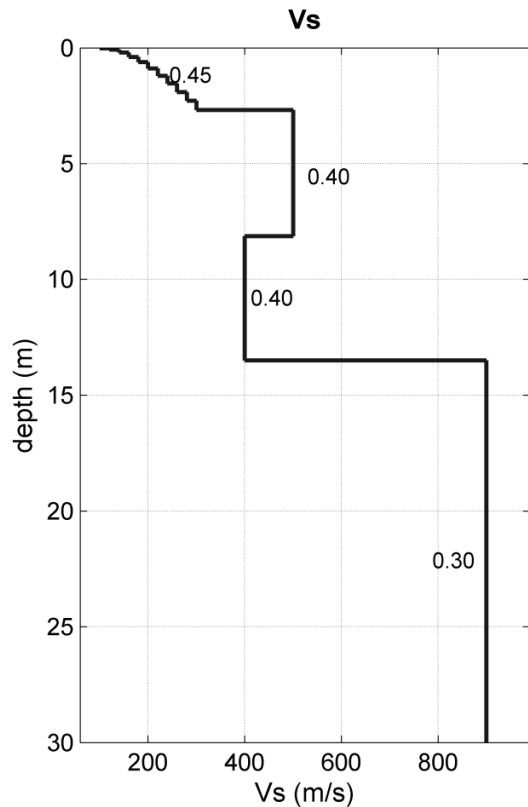
Best RVSr model (RVSr)



# Oberflächengebundene Bestimmung eines robusten Vs-Modells als Eingangsparameter zu bodendynamischen Berechnungen an einer historischen Klosterkirche



# Modal and effective dispersion curves: problems and solutions

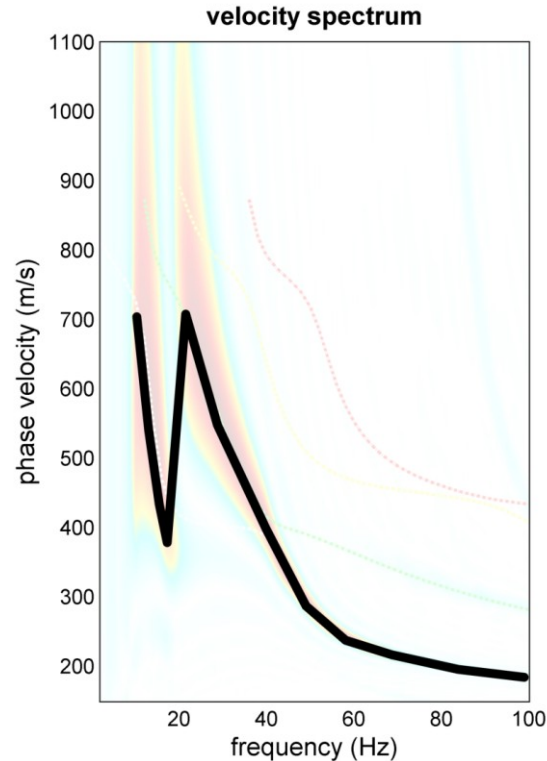


**Onde di Rayleigh:**

**La continuità di un segnale non significa che quel segnale appartiene ad un unico/singolo modo.**

**Soluzione: analisi congiunte con le onde di Love!**

# Modal and effective dispersion curves: problems and solutions



**Onde di Rayleigh:**

**La continuità di un segnale non significa che quel segnale appartiene ad un unico/singolo modo.**

**Soluzione: analisi congiunte con le onde di Love!**



# Modal and effective dispersion curves: problems and solutions

From (11) and (12), the relative powers of the vertical and horizontal motions of  $m$ th mode can be expressed as  $A_m^2 c_m$  and  $(A_m [\dot{u}/\dot{w}]_m)^2 c_m$ , respectively. Hence, by knowing  $A_m$ ,  $c_m$ , and  $[\dot{u}/\dot{w}]_m$  of each mode for a frequency  $f$ , the apparent phase velocities of vertical and horizontal motions for a given sensor distance can be determined as

$$c_{sv} = \frac{2\pi f D}{\cos^{-1} \left[ \frac{\sum_{m=1}^M A_m^2 c_m \cos \left( \frac{2\pi f D}{c_m} \right)}{\sum_{m=1}^M A_m^2 c_m} \right]} \dots \dots \dots (20)$$

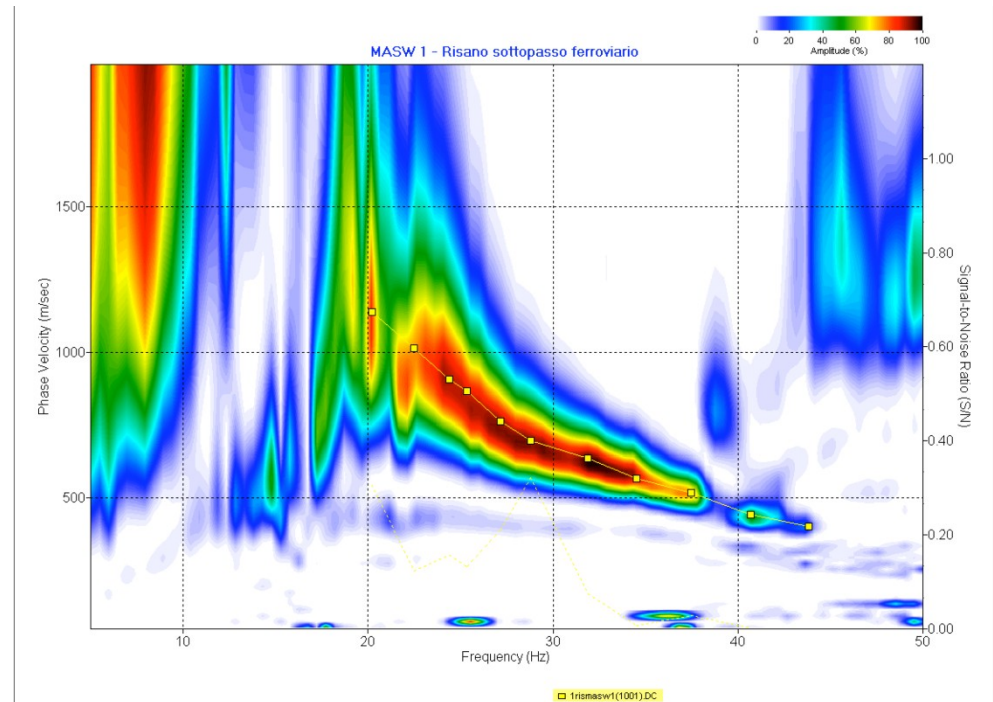
$$c_{sh} = \frac{2\pi f D}{\cos^{-1} \left[ \frac{\sum_{m=1}^M \left( A_m \left[ \frac{\dot{u}}{\dot{w}} \right]_m \right)^2 c_m \cos \left( \frac{2\pi f D}{c_m} \right)}{\sum_{m=1}^M \left( A_m \left[ \frac{\dot{u}}{\dot{w}} \right]_m \right)^2 c_m} \right]} \dots \dots \dots (21)$$

# Modal and effective dispersion curves: problems and solutions

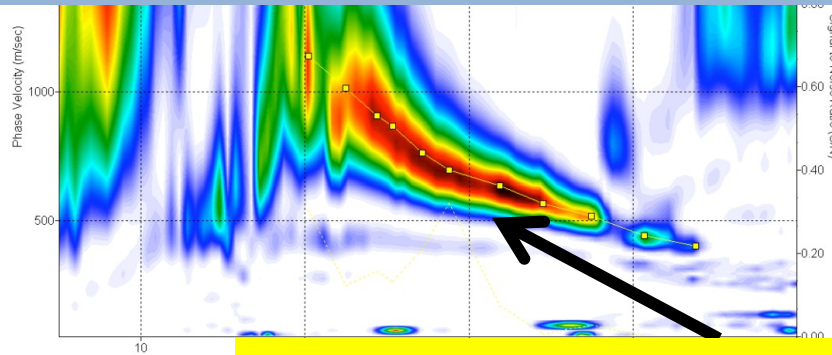
**“MASW”**

***Downhole***

***P-wave refraction***

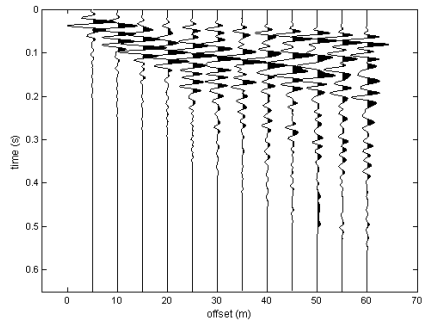


# Modal and effective dispersion curves: problems and solutions



**Dies ist nicht der Fundamentalmodus!**

1. input Rayleigh data



dataset: zvf.mat  
sampling: 1ms [1000Hz] - 651 samples  
minimum offset: 5 m  
geophone spacing: 5 m

flip data   cut   spectrogram

select data

activate

select   60

cancel   save

mode separation

save spectrum

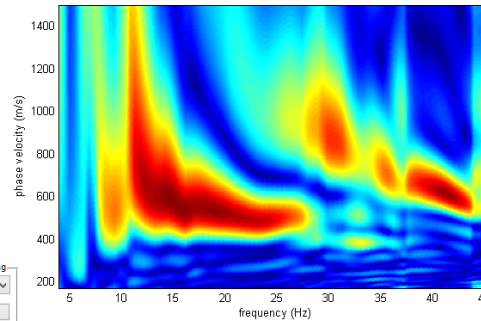
upload spectrum

input curve

picking

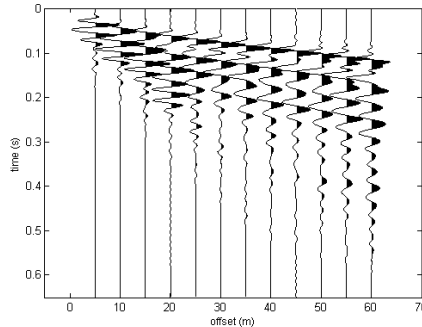
auto pick   select ...

save   cancel



Love component

2. input Love data



dataset: thf.mat  
sampling: 1ms [1000Hz] - 651 samples  
minimum offset: 5 m  
geophone spacing: 5 m

flip data   cut   spectrogram

select data

activate

select   save

cancel   save

mode separation

save spectrum

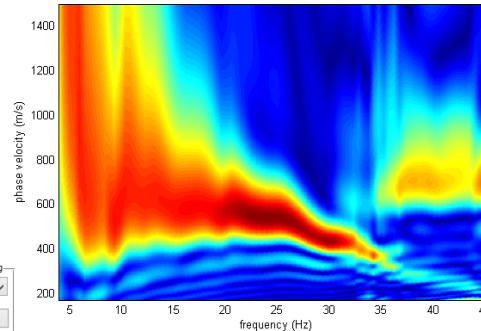
upload spectrum

input curve

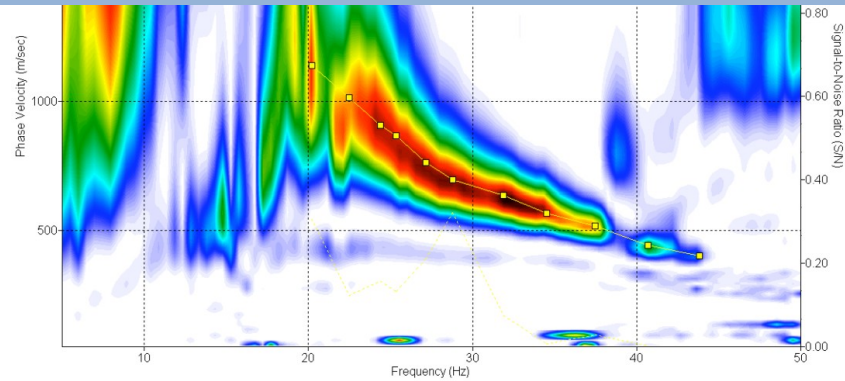
picking

select mode

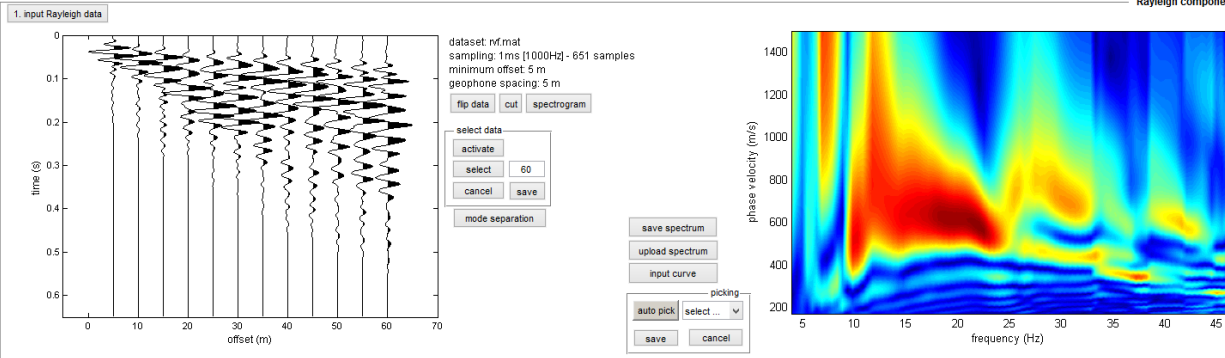
save   cancel



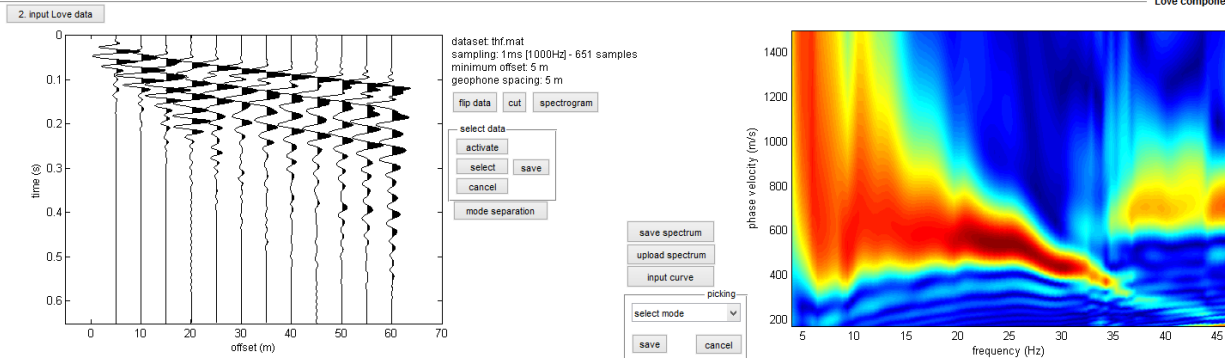
# Modal and effective dispersion curves: problems and solutions



Rayleigh component

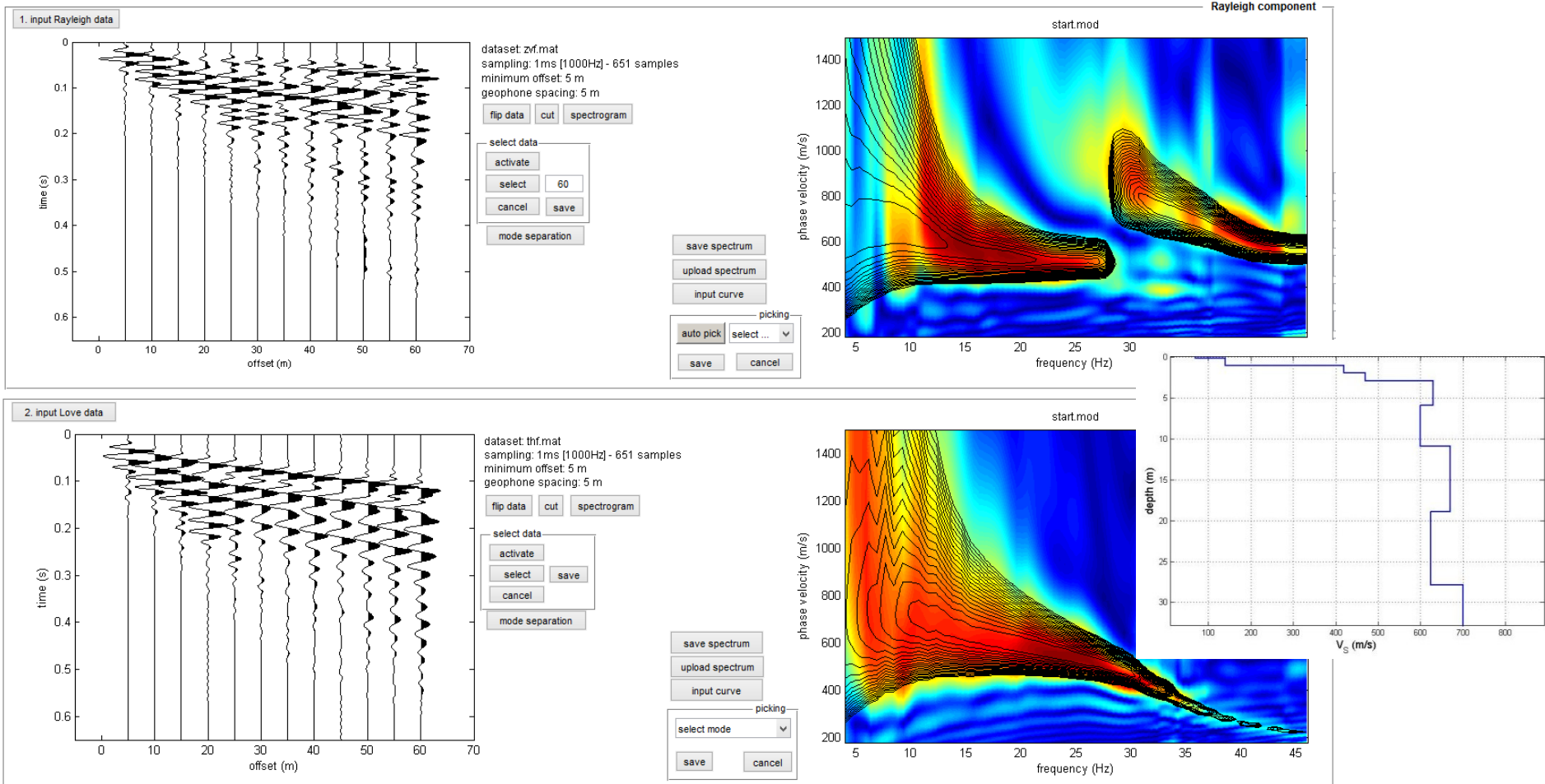


Love component



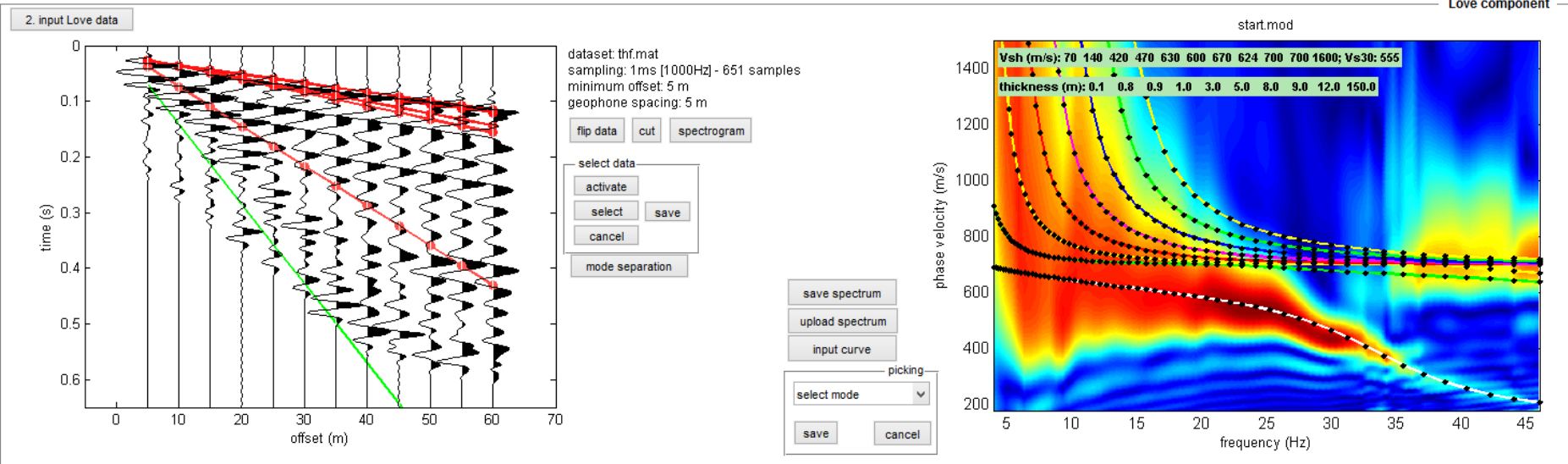
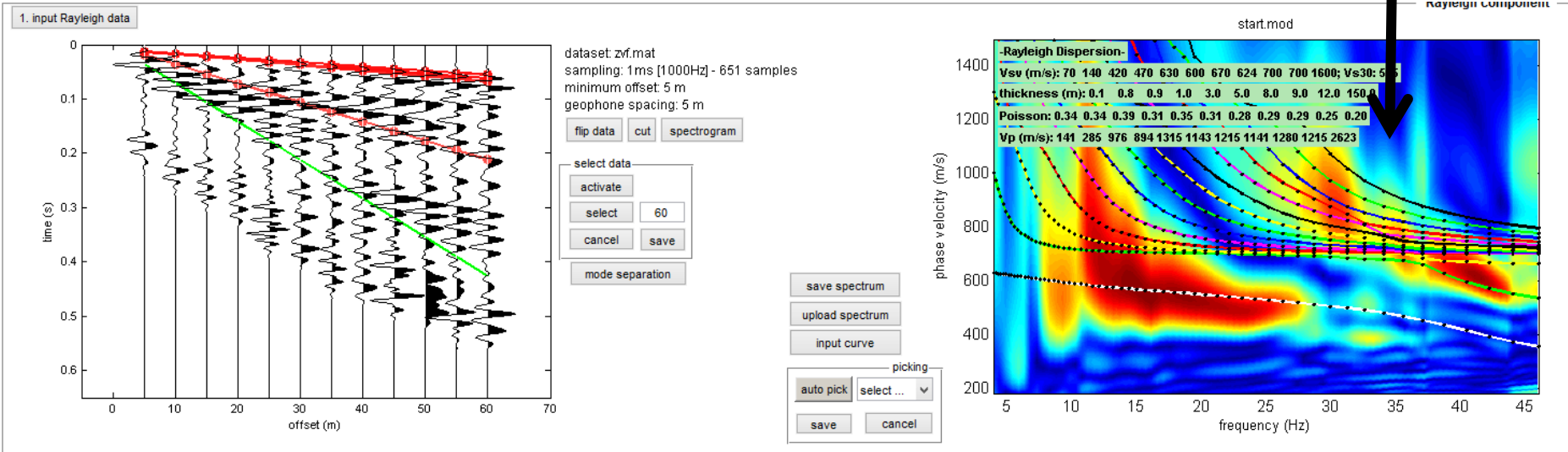
# Modal and effective dispersion curves: problems and solutions

Our joint FVS solution: our synthetic velocity spectra perfectly overlap with the observed ones



# About modes (and refraction)

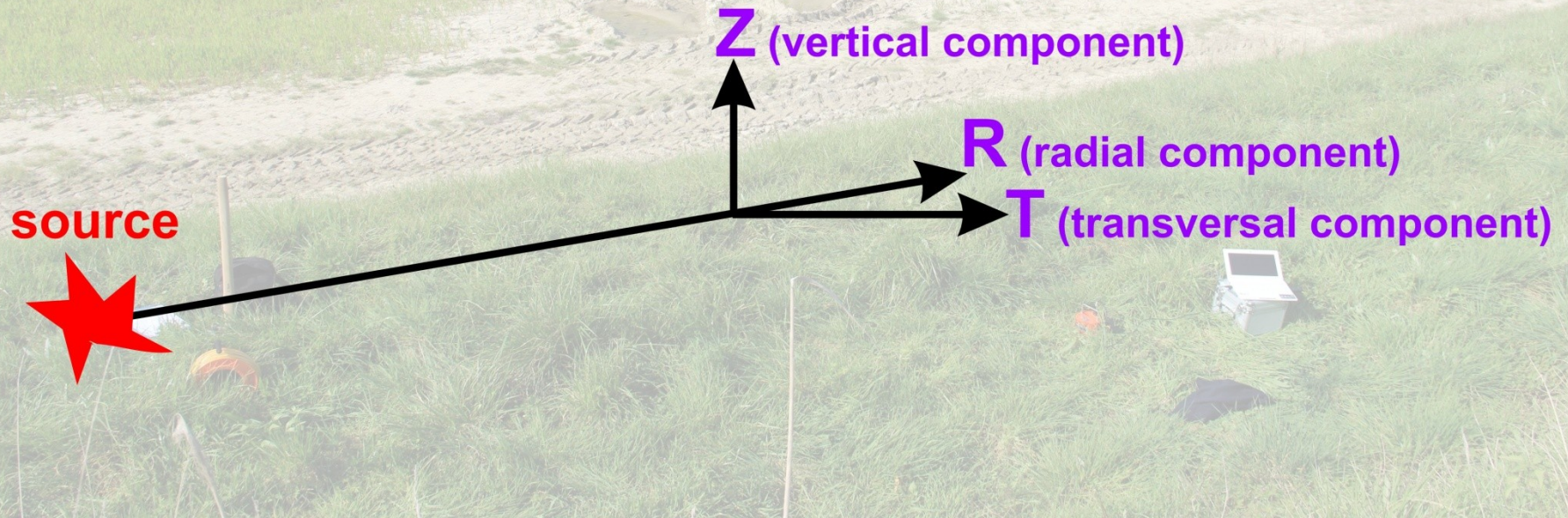
Dies ist nicht ein einziger Modus!



**just recruiting**



**HS** [www.holisurface.com](http://www.holisurface.com)





*A circle, a line: they look good, they are abstract, they are common knowledge. They belong to everyone and equally to the past, the present and the future.*

Richard Long

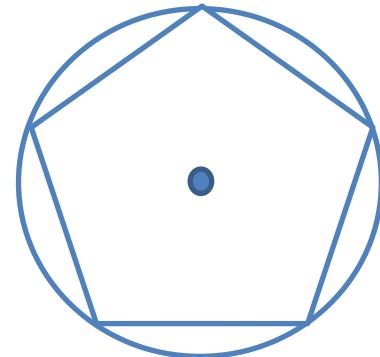
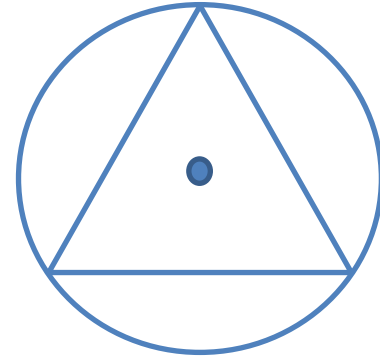
# What's in common?



HS

HVSR

MAAM

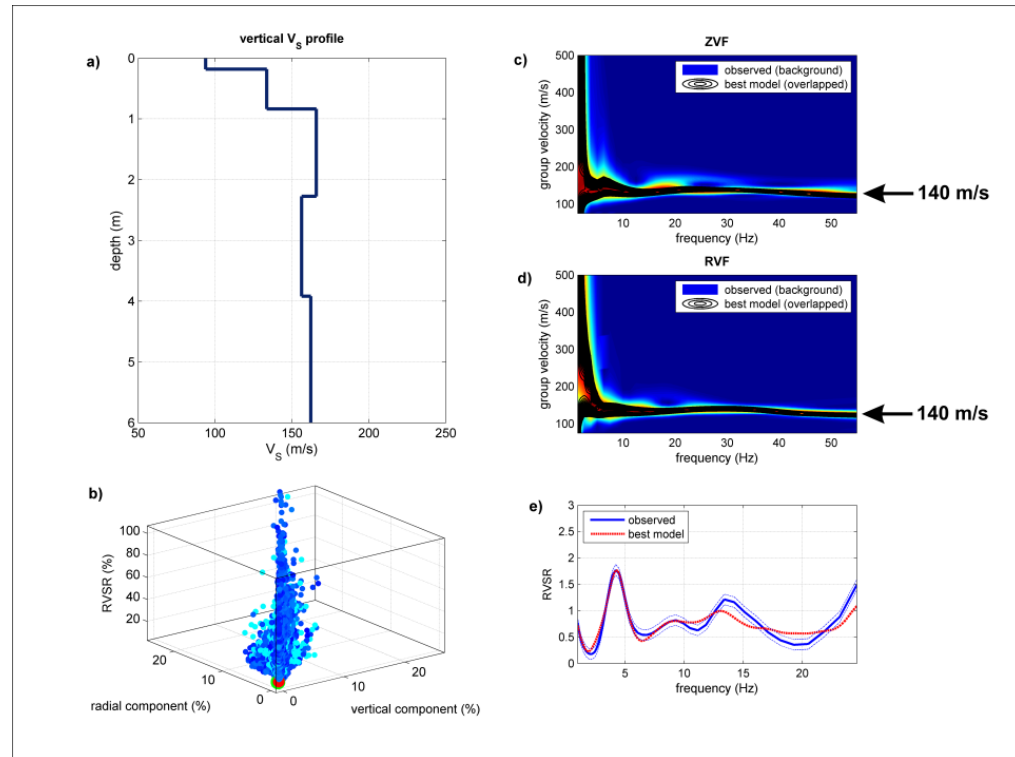




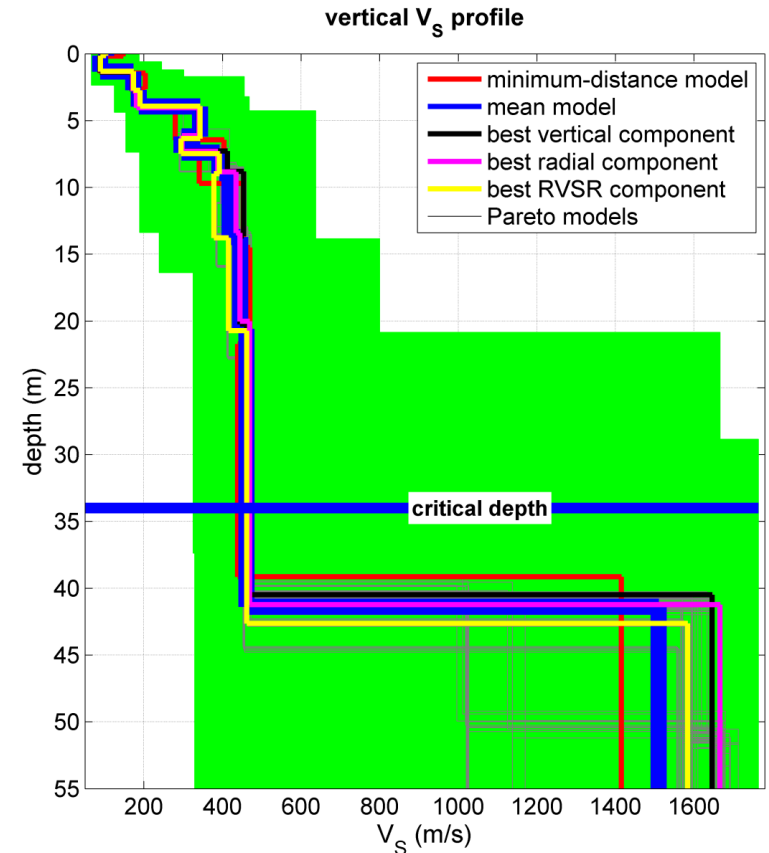
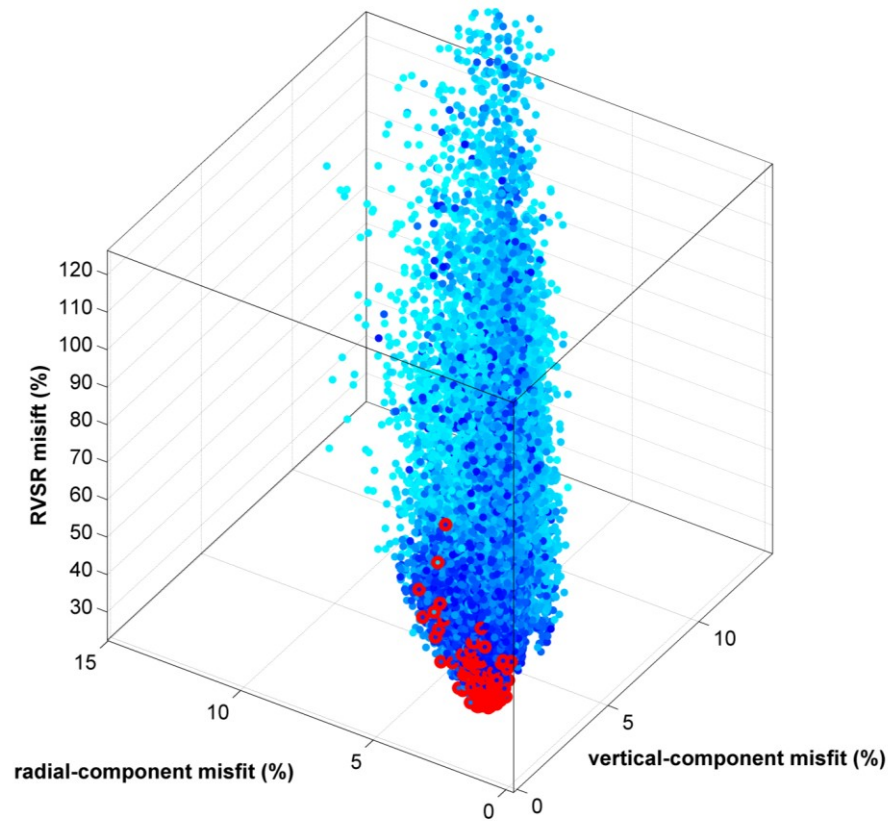
A LINE MADE BY WALKING

ENGLAND 1967

# What's in common?



# Oberflächengebundene Bestimmung eines robusten $V_s$ -Modells als Eingangsparameter zu bodendynamischen Berechnungen an einer historischen Klosterkirche



HS

The unordinary *HoliSurface* approach

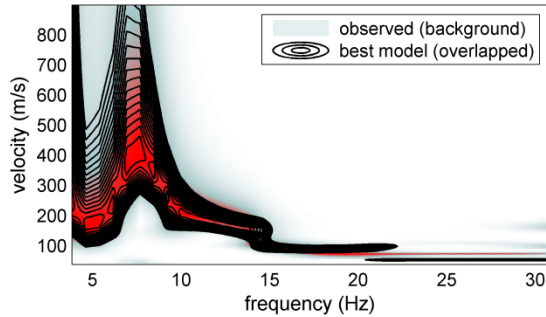


# Oberflächengebundene Bestimmung eines robusten Vs-Modells als Eingangsparameter zu bodendynamischen Berechnungen an einer historischen Klosterkirche

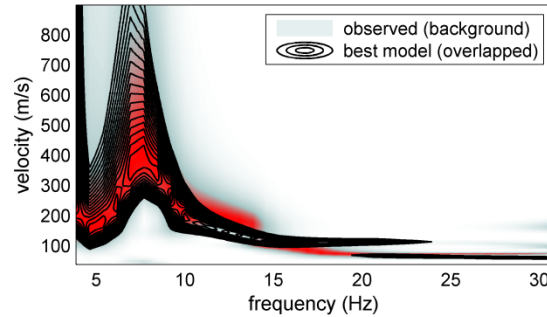


The unordinary *HoliSurface* approach

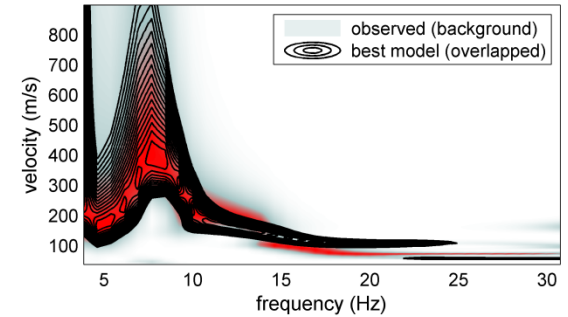
Best vertical-component model (vertical component)



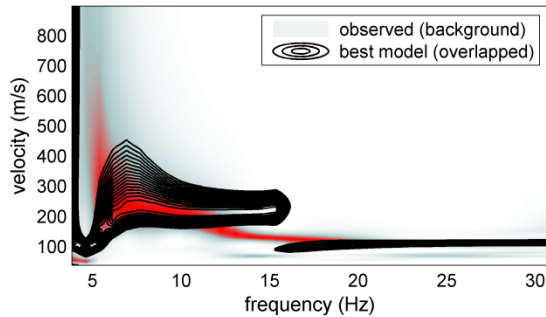
Best radial-component model (vertical component)



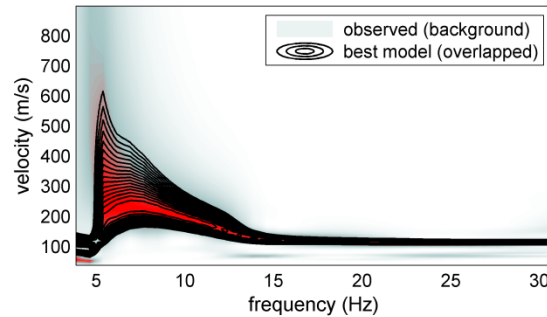
Best RVSr model (vertical component)



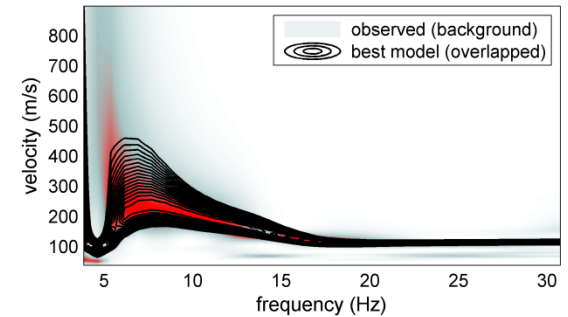
Best vertical-component model (radial component)



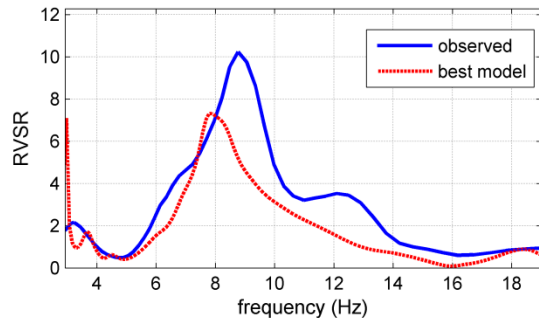
Best radial-component model (radial component)



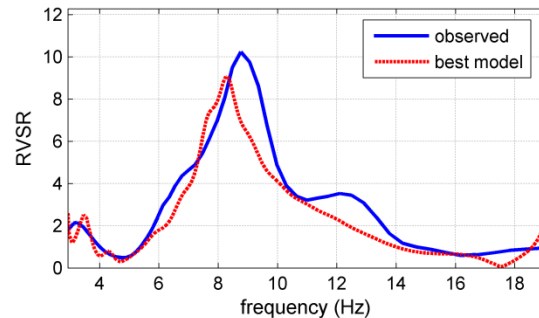
Best RVSr model (radial component)



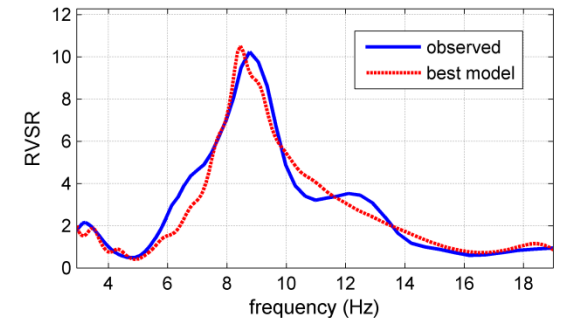
Best vertical-component model (RVSr)



Best radial-component model (RVSr)



Best RVSr model (RVSr)

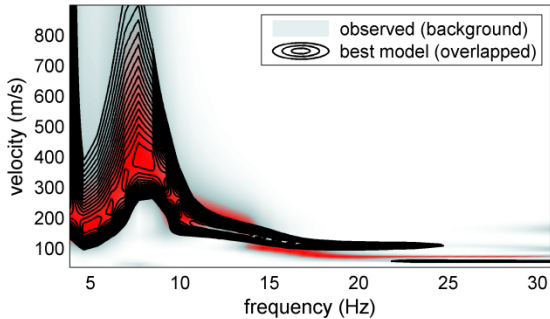


# Oberflächengebundene Bestimmung eines robusten Vs-Modells als Eingangsparameter zu bodendynamischen Berechnungen an einer historischen Klosterkirche

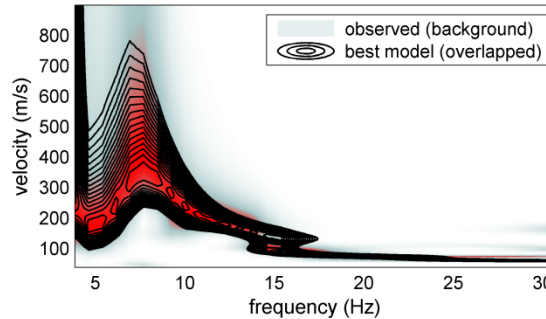


The unordinary *HoliSurface* approach

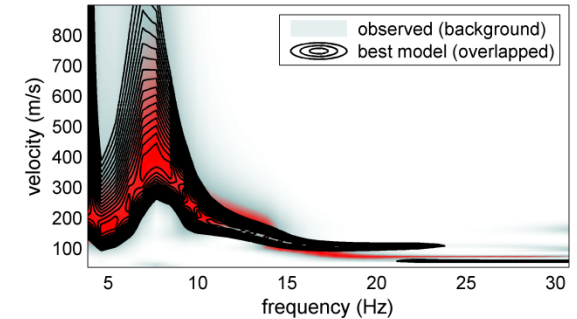
Minimum "global" GA model (vertical component)



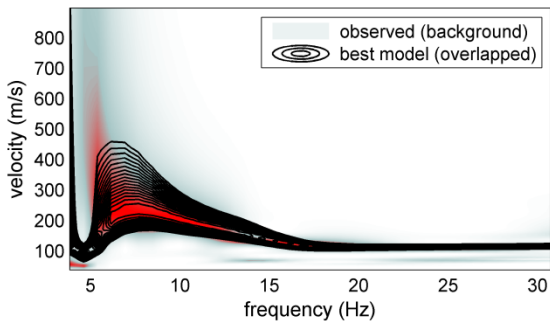
Minimum-distance model (vertical component)



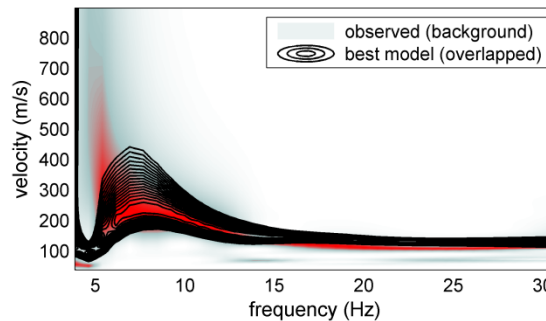
Mean model (vertical component)



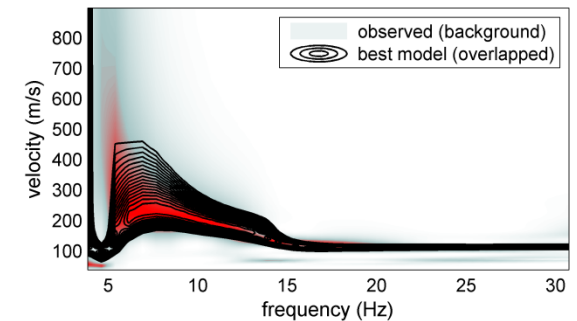
Minimum "global" GA model (radial component)



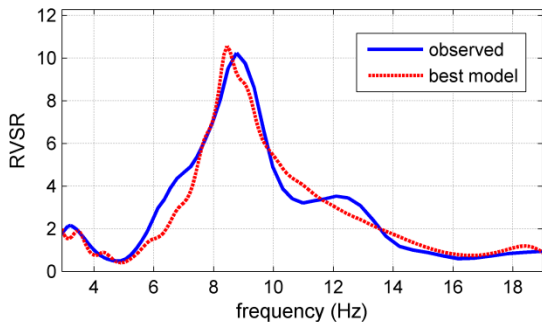
Minimum-distance model (radial component)



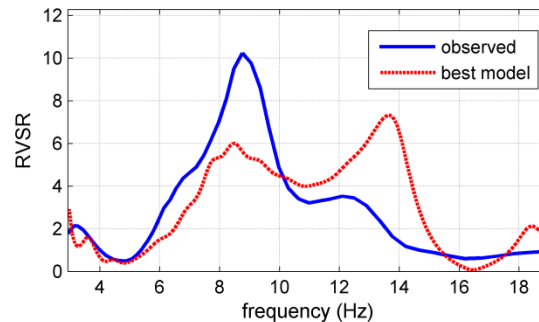
Mean model (radial component)



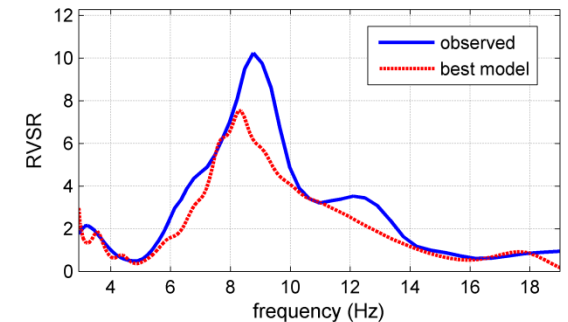
Minimum "global" GA model (RVSR)



Minimum-distance model (RVSR)



Mean model (RVSR)





# *HoliSurface* results compared to VSP (Vertical Seismic Profiling)

A Comprehensive Seismic Characterization via Multi-Component Analysis of Active and Passive Data  
(Dal Moro G., Keller L., Poggi V.), *First Break* (September, 2015)

*first break* volume 33, September 2015

technical article



## A comprehensive seismic characterisation via multi-component analysis of active and passive data

G. Dal Moro<sup>1\*</sup>, L. Keller<sup>2</sup> and V. Poggi<sup>3</sup>

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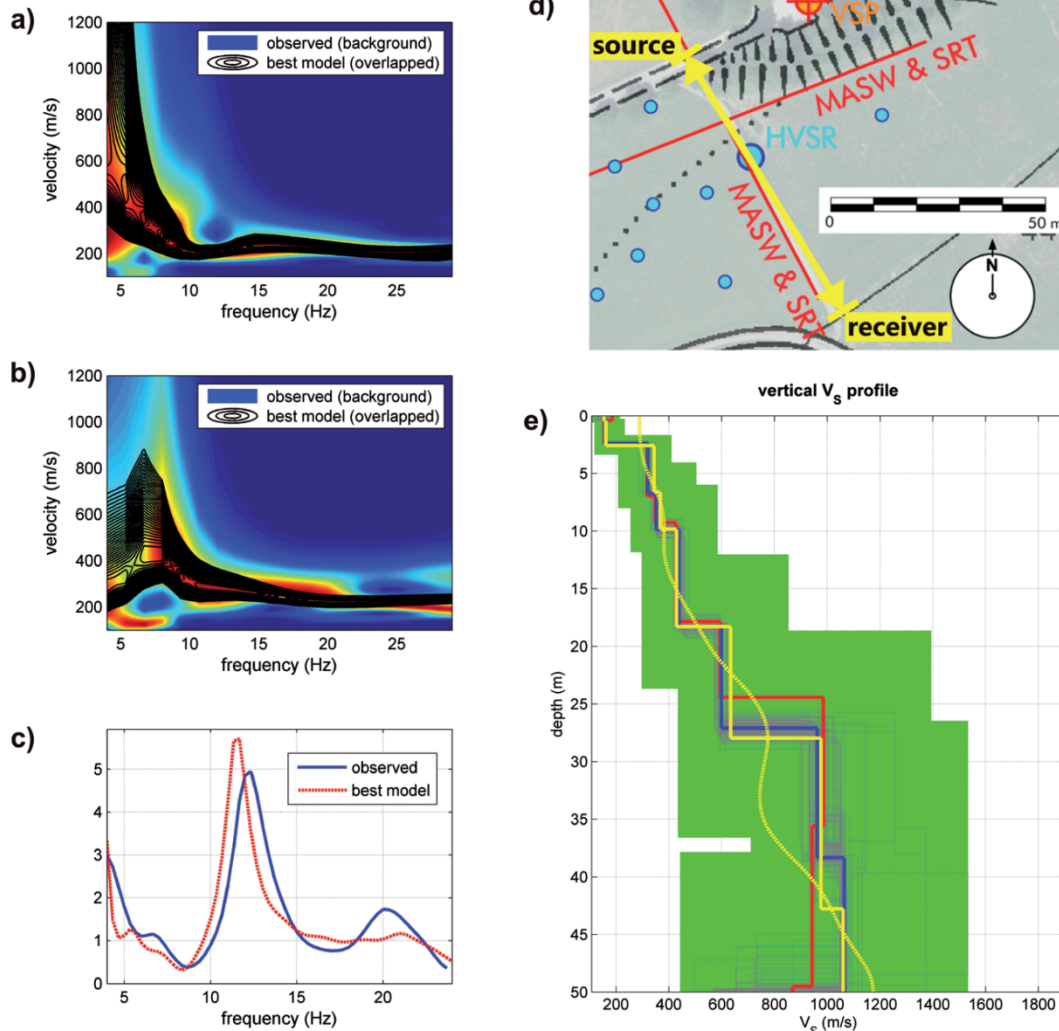
### Abstract

A comprehensive seismic survey was conducted with the aim of characterising one of the *Swiss Digital Seismic Network* stations in Northern Switzerland. Both active (P- and S-wave refraction tomography, surface-wave analysis, vertical seismic profiling) and passive methodologies (wavelet decomposition, Horizontal-to-Vertical Spectral Ratio, three-component frequency-wavenumber analysis) were jointly considered in order to solve the intrinsic non-uniqueness of the solution and determine a consistent subsurface model free from ambiguities, eventually used for the assessment of the local site amplification.



# HoliSurface results compared to VSP (Vertical Seismic Profiling)

A Comprehensive Seismic Characterization via Multi-Component Analysis of Active and Passive Data  
(Dal Moro G., Keller L., Poggi V.), *First Break* (September, 2015)



**Figure 10** Holistic analysis of the vertical and radial-component group-velocity spectra jointly with the Radial-to-Vertical Spectral Ratio (RVSR): a) and b) the observed velocity spectra (background colours) and, overlaying (black contour lines), the synthetic ones; c) observed and computed RVSRs; d) map reporting the position of the source (in this case a simple vertical-impact sledgehammer) and receiver (a single 3-component calibrated geophone – offset 70 m); e) the retrieved  $V_s$  profile and the one obtained by means of VSP analysis.

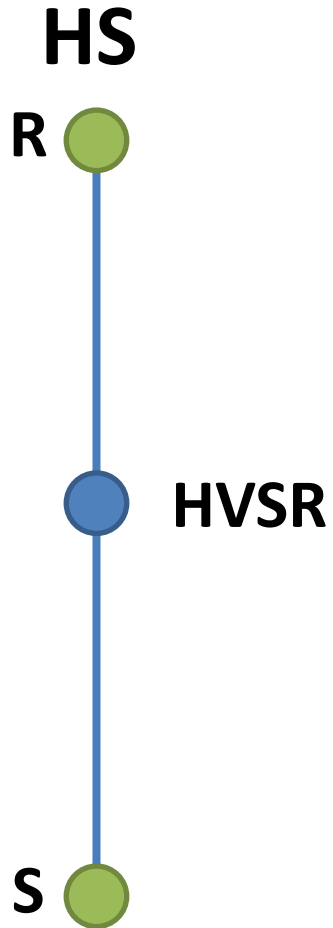
# Noise

Two volunteers, please

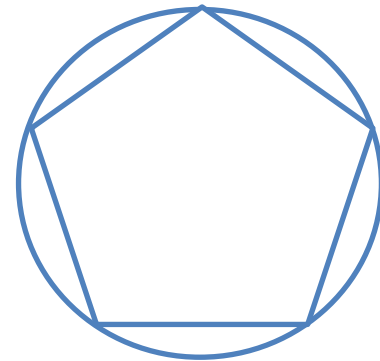
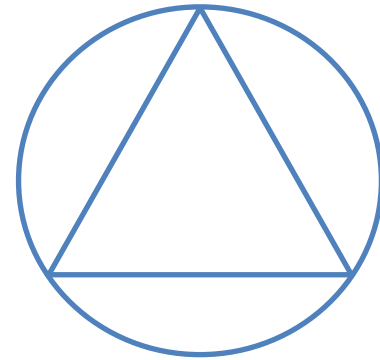






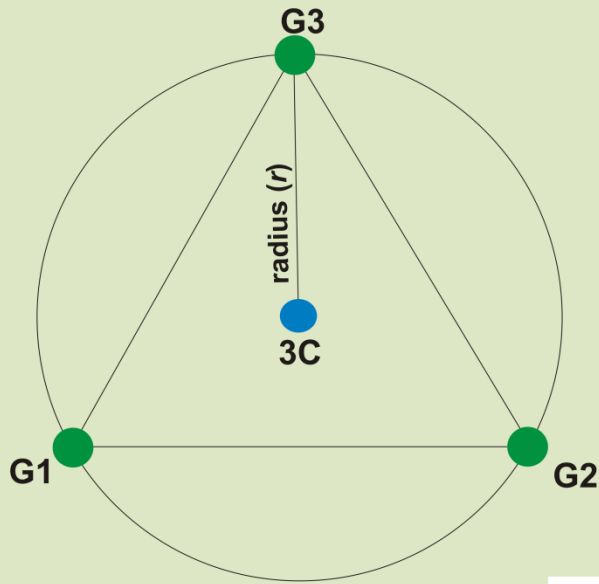


**MAAM**

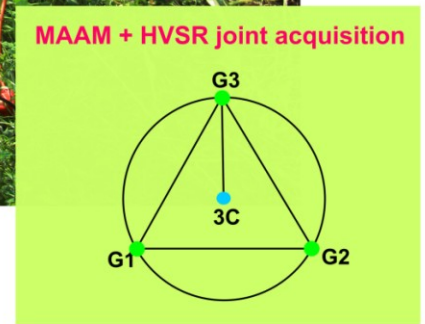
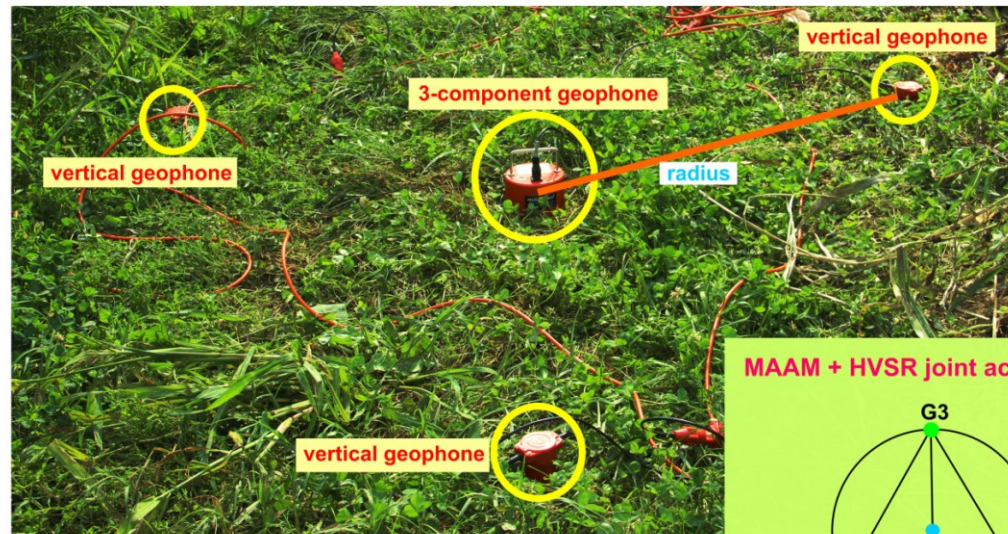
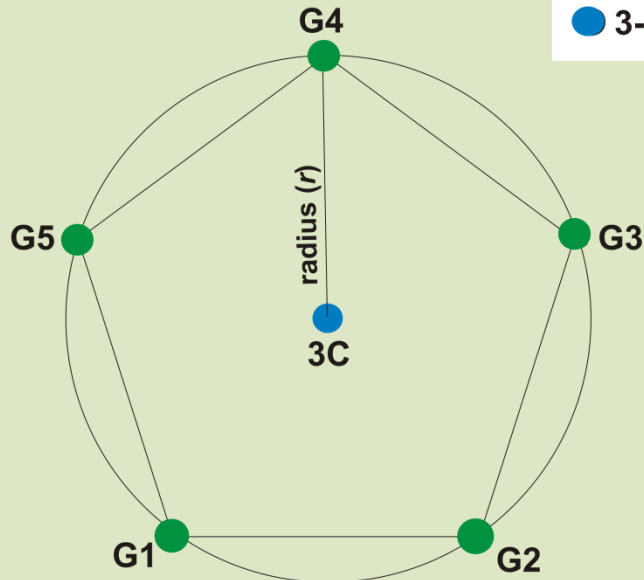


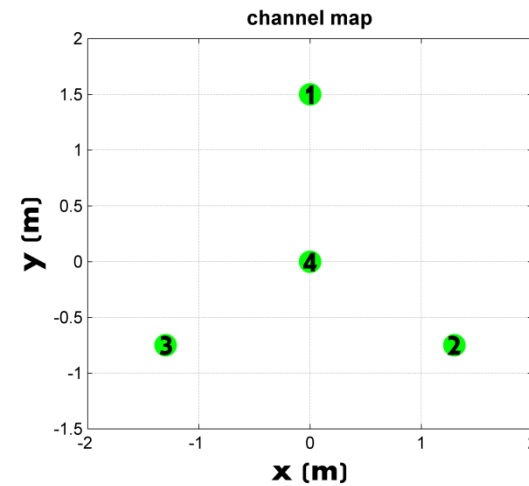
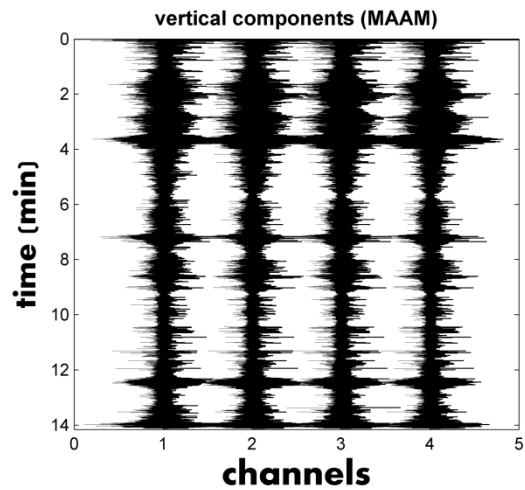
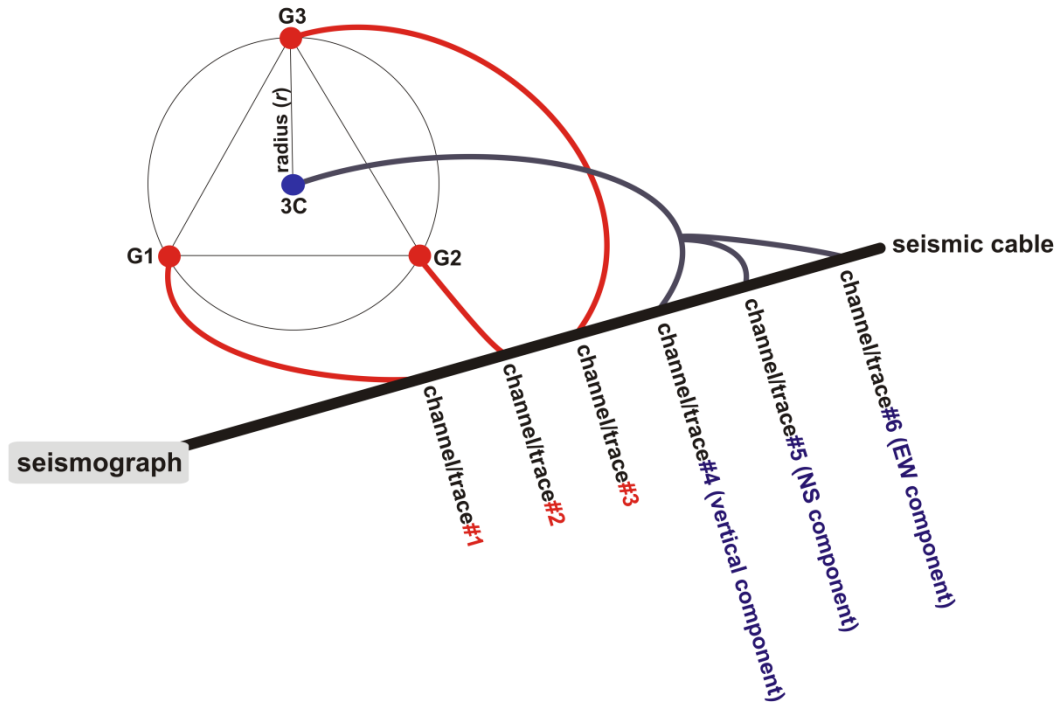
**An efficient urban palindrome**

# MAAM + HVSR joint acquisition



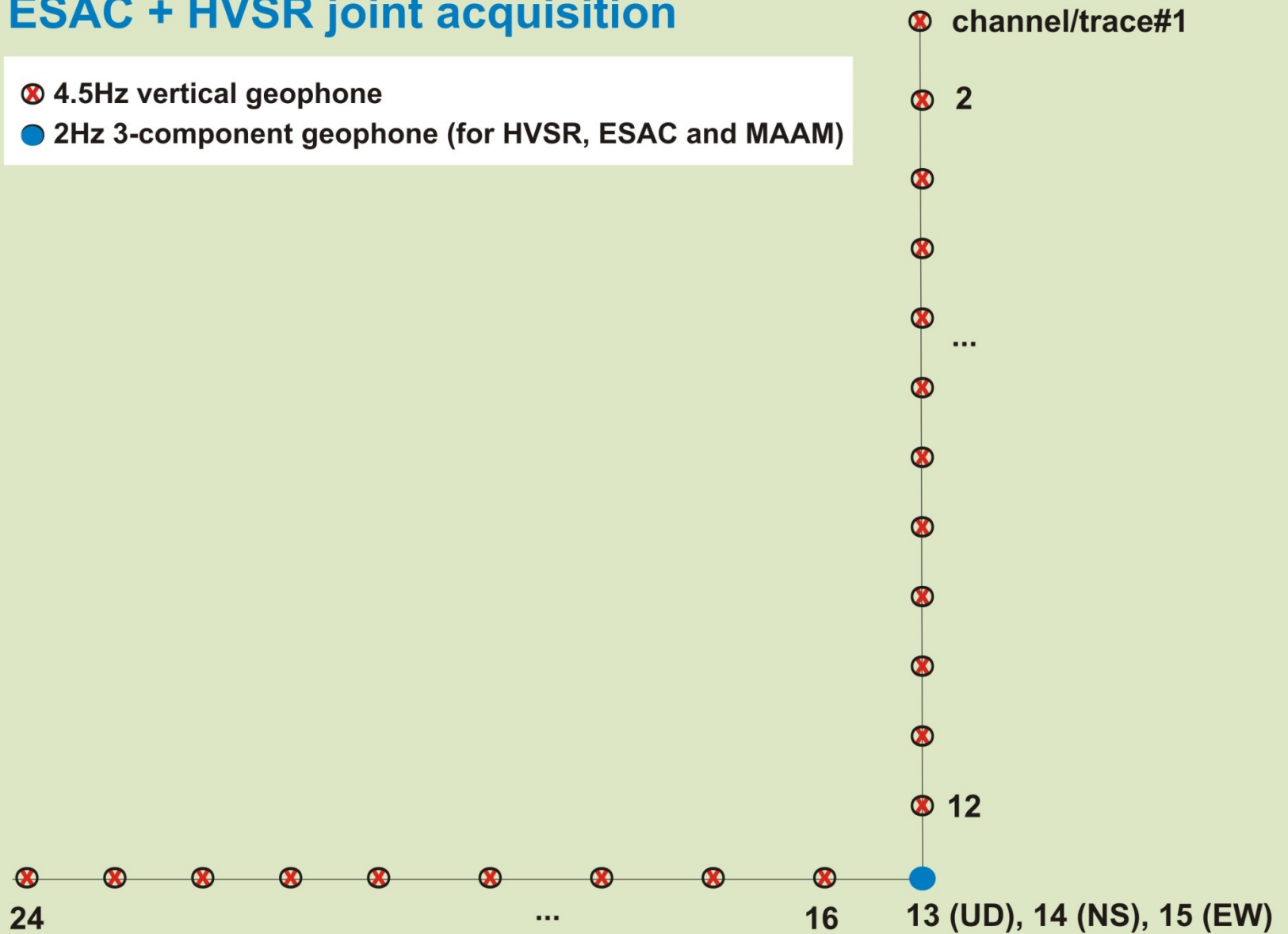
- 2Hz vertical geophone
- 3-component geophone (for HVSR and MAAM)



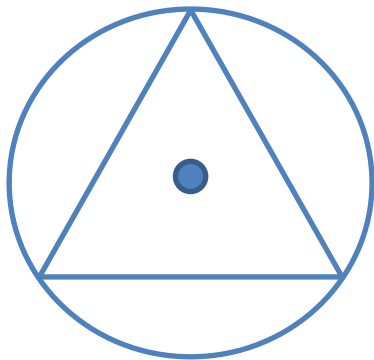


# ESAC + HVSR joint acquisition

- ⊗ 4.5Hz vertical geophone
- 2Hz 3-component geophone (for HVSR, ESAC and MAAM)



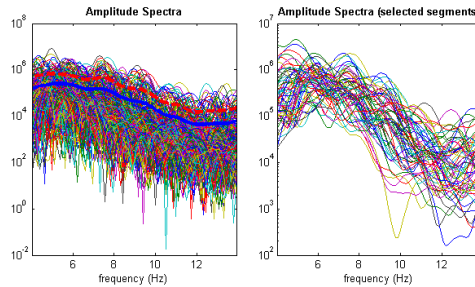
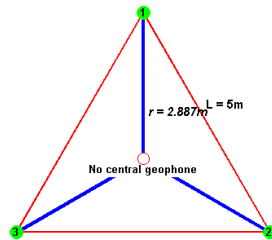
## MAAM



resample to 4ms (250Hz)

<b>data</b>	radius (m): 2.887	save geometry	show location
number of channels: 3	<input type="checkbox"/> n-CCA	show data	spectrogram
show/update channel map		clean data	PSD

folder: C:\Users\gdm\Desktop\ltdl\interessanti o da analizzare\PURGESSMORIGHT\_CCA\vertical+HVSRI  
dataset: singlechannels.mat  
sampling: 2 ms (Nyquist frequency: 250Hz)



**phase velocity spectrum**

min freq: 4 max freq: 14  
min vel: 40 max vel: 800

**parameters**

5.9 window length (s)  
25% spectral smoothing  
5% tapering (%)  
40 tolerance  
5 m/s velocity increment

hold on  
 noise computation  
 verbose  
**compute**

**picking**

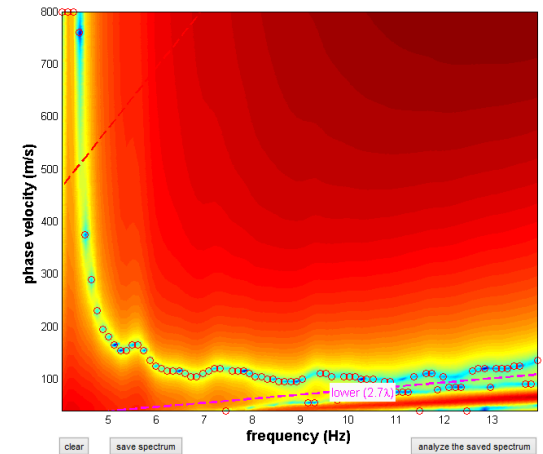
effective dispersion curve

start picking | save picking  
to select the last point  
click the right button

cancel picking

**HVSR computation**


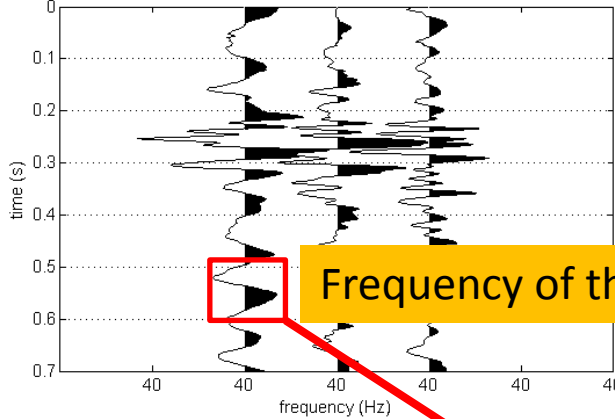
quick HVSR



*A circle, a line: they look good, they are abstract, they are common knowledge.  
They belong to everyone and equally to the past, the present and the future.*

Richard Long

## A “noisy” desperate case

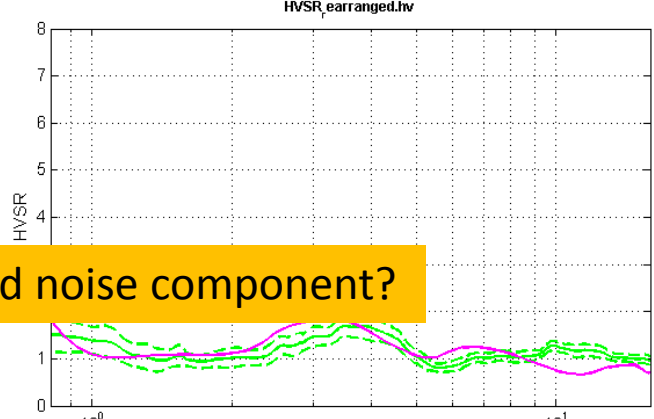
select data  
  
 60

time (s)  
0  
0.1  
0.2  
0.3  
0.4  
0.5  
0.6  
0.7

frequency (Hz)  
40 40 40 40 40 40

tools  
0.7 time length to visualize (sec)

data & spectral ratio



HVSRR  
8  
7  
6  
5  
4  
3  
2  
1  
0

frequency (Hz)  
 $10^0$   $10^1$

general settings

0 reference depth ?  
 refraction  
 HVSRR from body waves  
 0.3 alfa factor (SW)

Vs (m/s)	Qs	Poisson	Qp	thk (m)
127	12	0.36	12	0.4
165	12	0.328	12	0.4
165	19	0.33	19	2
155	19	0.336	19	3.9
296	22	0.3306	14	3
271	19	0.4326	19	2.4
180	24	0.44	24	5.8
414	42	0.46	42	6
455	20	0.484	20	6.75
296	45	0.326	45	33
484	85	0.282	85	133
1100	164	0.249	164	

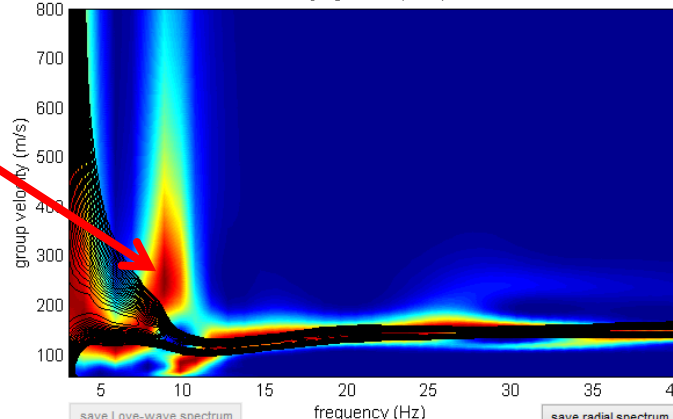
model  
   
 reference freq. (Hz): 3.96  
 k factor: 8   
 number of modes: 6  
 Rayleigh-wave source: VF  
 detail: reasonable  
 verbose

Velocity Spectra

2C inversion  1C inversion  
 joint disp+HV

group-velocity spectra (vertical & radial components)

Rayleigh waves (radial)



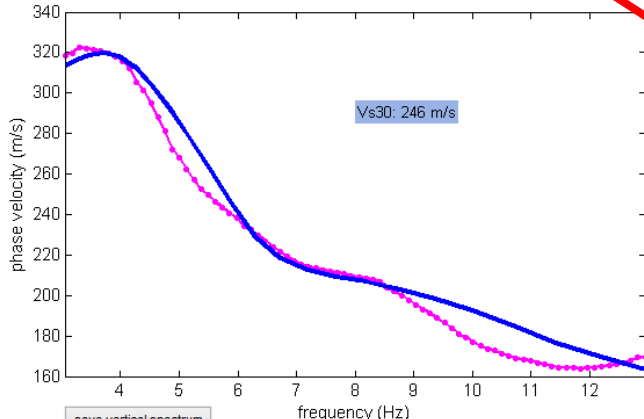
group velocity (m/s)  
800  
700  
600  
500  
400  
300  
200  
100

frequency (Hz)  
5 10 15 20 25 30 35 40

save Love-wave spectrum

MAAM

effective phase vel



phase velocity (m/s)  
340  
320  
300  
280  
260  
240  
220  
200  
180  
160

frequency (Hz)  
4 5 6 7 8 9 10 11 12

save vertical spectrum

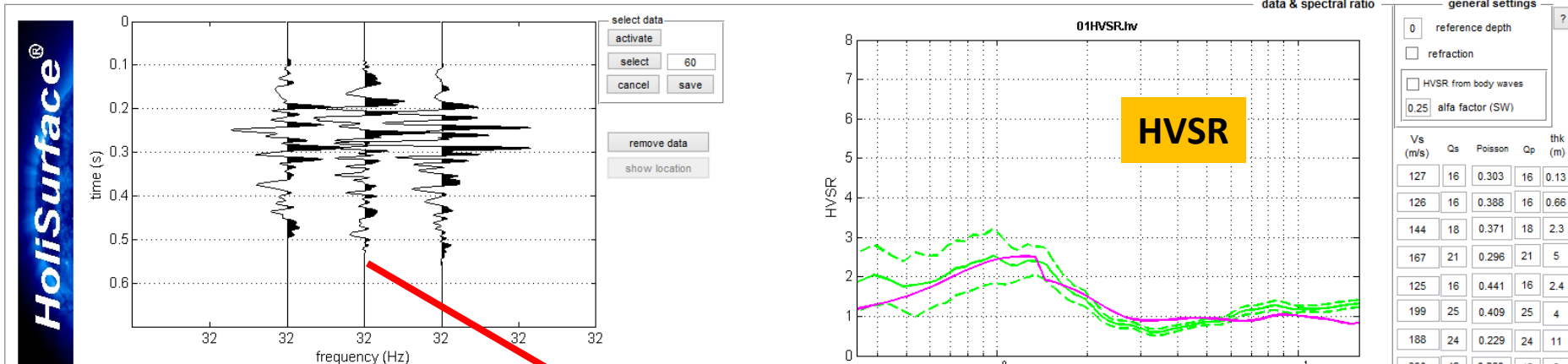
dataset: 01\_VF\_0m\_F.SAF  
 offset: 40 m  
 sampling: 1 ms

Rayleigh waves: group-velocity spectra    just THF

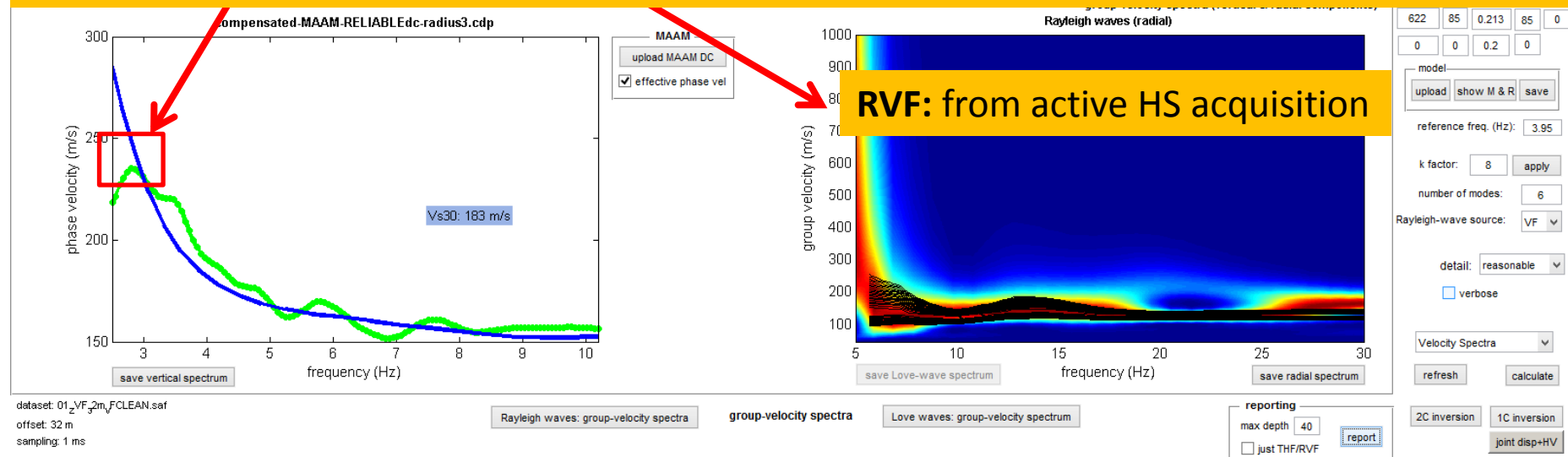
group-velocity spectra

Love waves: group-velocity spectrum

## A further problematic case (little room available and noisy active data)

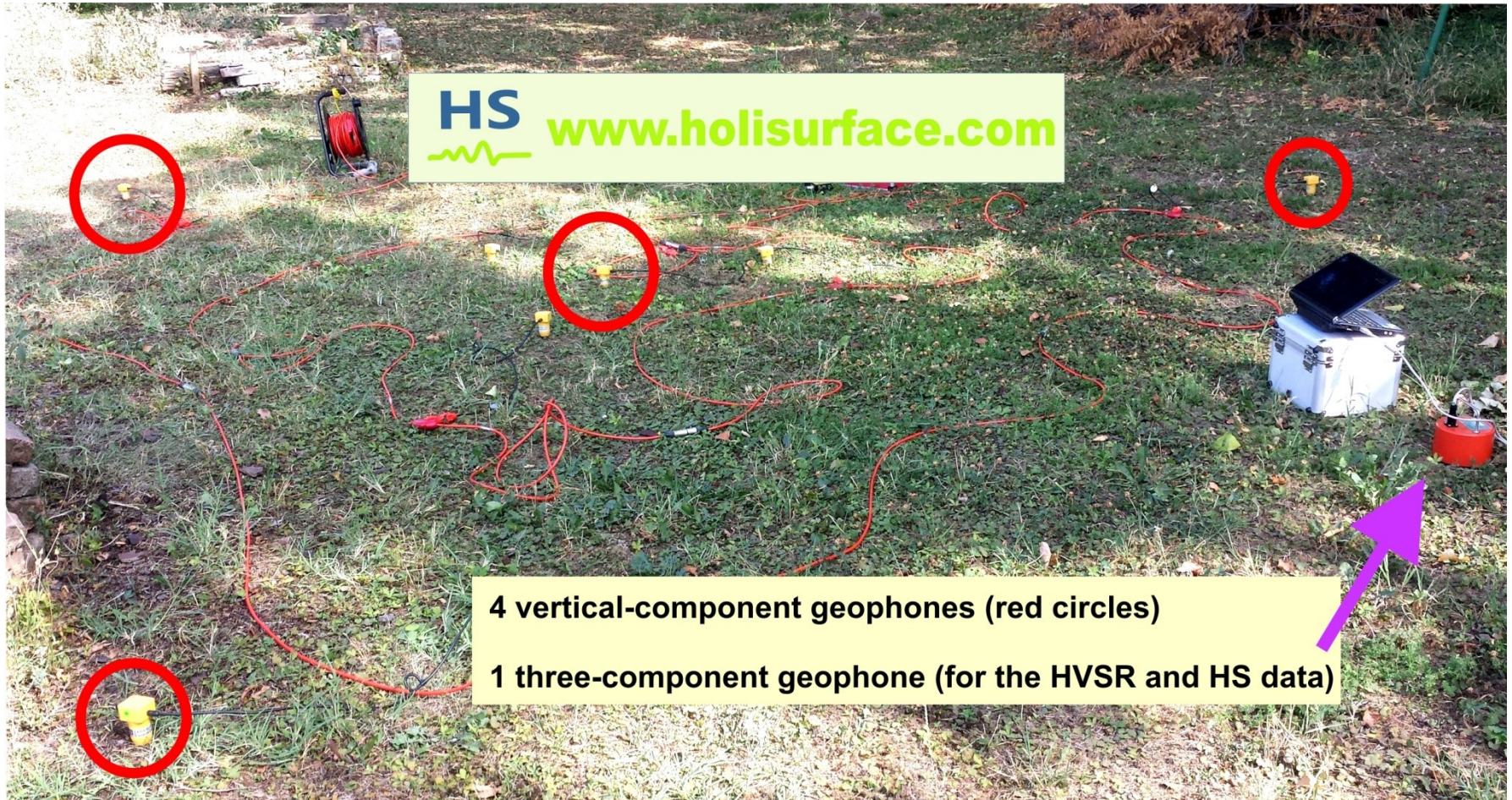


**MAAM:** Used standard 4.5Hz vertical geophones (thus low frequencies not precisely defined)



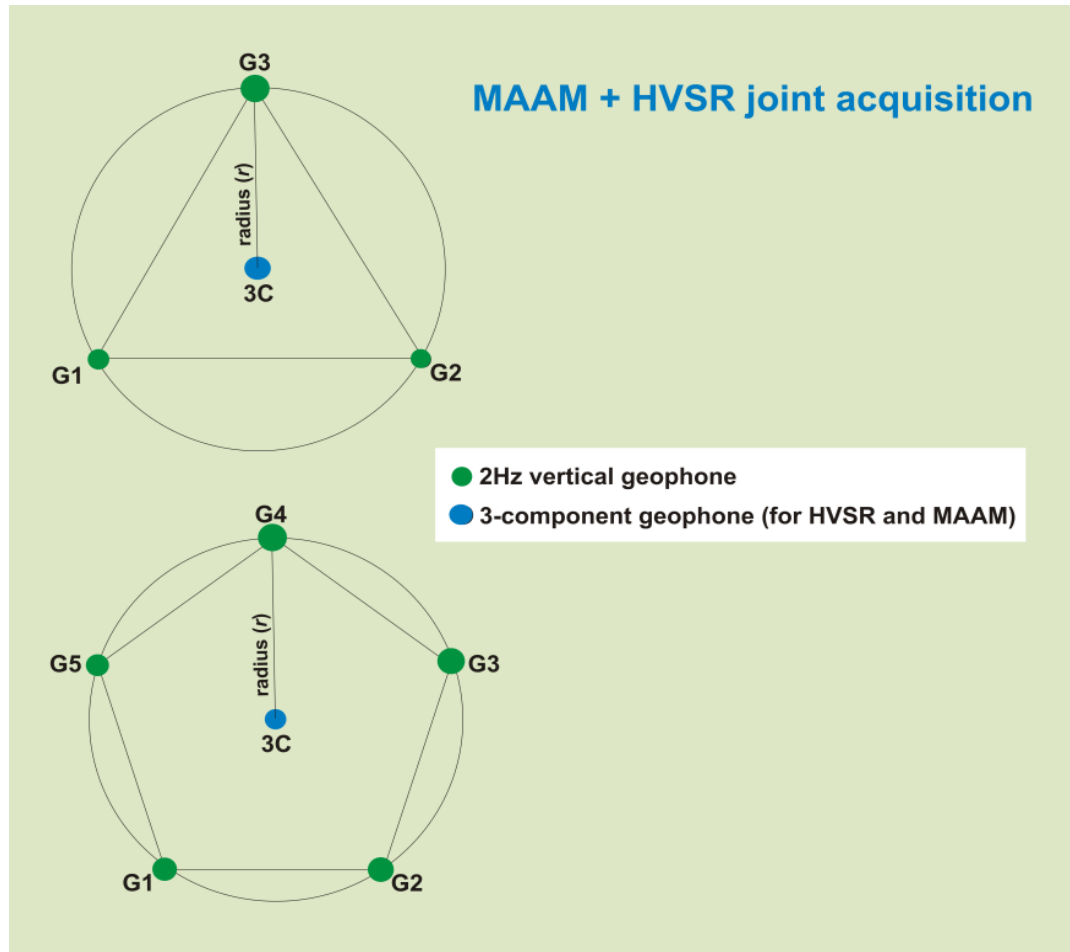


A further problematic case (little room available and noisy active data):  
the acquisition procedures





## MAAM (Miniature Array Analysis of Microtremors)



## MAAM

**Preliminary equipment test**

**N+1 identical geophones (2 or 4.5Hz?)**

**radius/radii**

**Tolerance & smoothing**

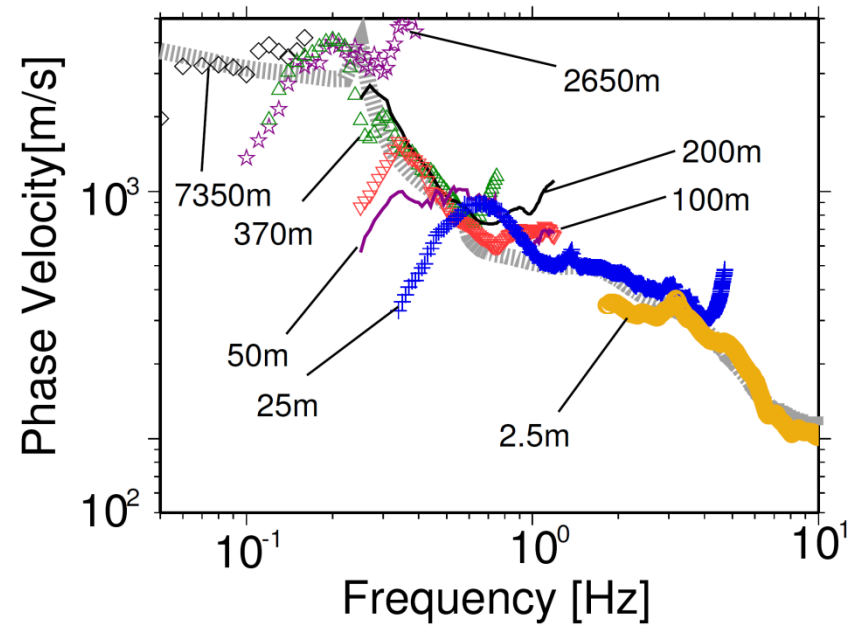
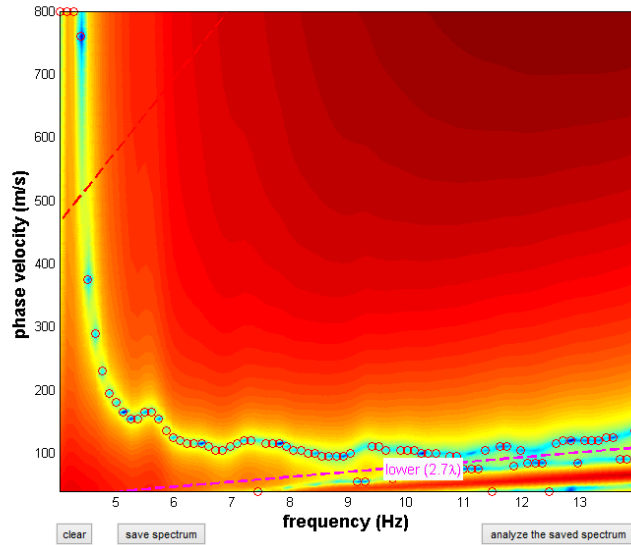
**window length**

**data cleaning**

# MAAM



## MAAM



# MAAM Comparing MASW-ZVF

## 1. Purgessimo

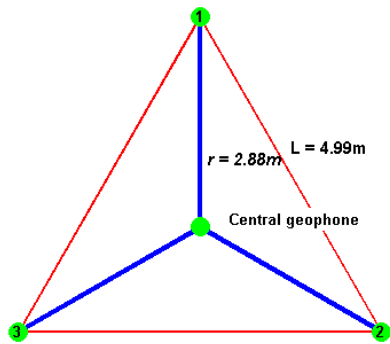
resample to 4ms (250Hz)

**data**

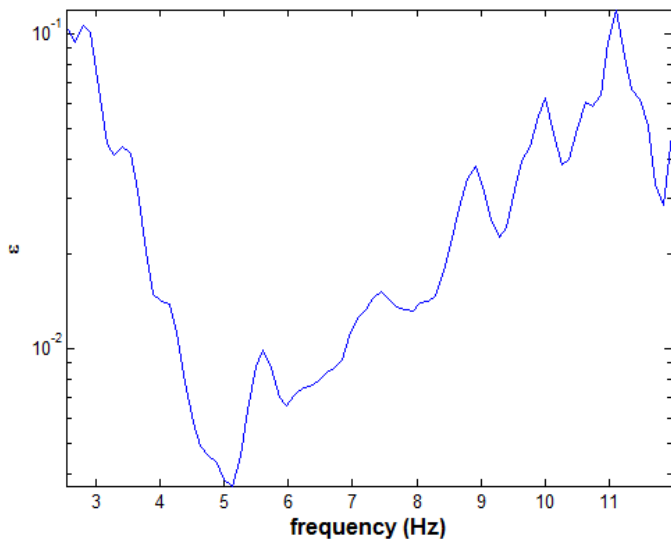
radius (m):

number of channels:   nc-CCA

Folder: C:\Users\gdm\Desktop\kati\_da\_analizzare\PURGESSIMO-MAAM\RIGHT\_CCA\only4VERTICAL\  
 Dataset: singlechannelsmaam-5m-clean.mat  
 Recording time: 13.75 min  
 Sampling: 4 ms [Nyquist frequency: 125Hz]



Noise-to-Signal Ratio



**phase velocity spectrum**

min freq.  max freq.

min vel.  max vel.

**parameters**

window length (s)

spectral smoothing

tapering (%)

tolerance

velocity increment

hold on

noise computation

verbose

**picking**

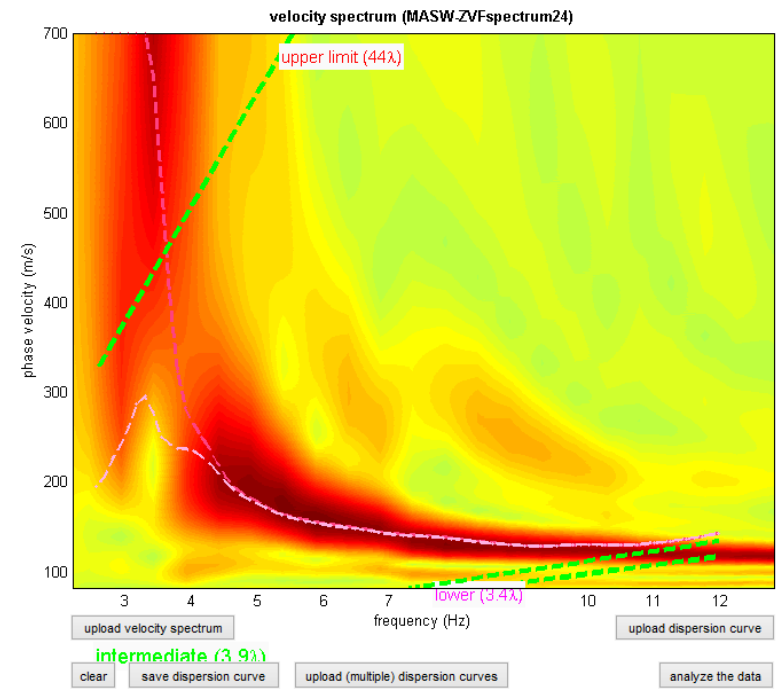
effective dispersion curve

to select the last point  
click the right button



**pre-processing tools**

MAAM with and without *noise* compensation.  
 Colors in the background represent the MASW (ZVF component) velocity spectrum



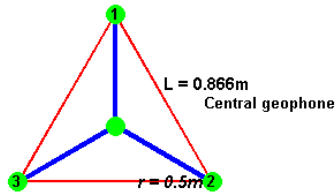
resample to 4ms (250Hz)

**data**

radius (m):

number of channels:   nc-CCA

Folder: C:\Users\gdm\Desktop\data\_da\_analizzare\Muscoli-Cimitero\MAAM\radius50cm\  
Dataset: MAAM-data-clean.mat  
Recording time: 14.49 min  
Sampling: 4 ms [Nyquist frequency: 125Hz]



**phase velocity spectrum**

min freq.  max freq.

min vel.  max vel.

**parameters**

window length (s)

spectral smoothing

tapering (%)

tolerance

velocity increment

- hold on  
 noise computation  
 verbose

**picking**

**effective dispersion curve**

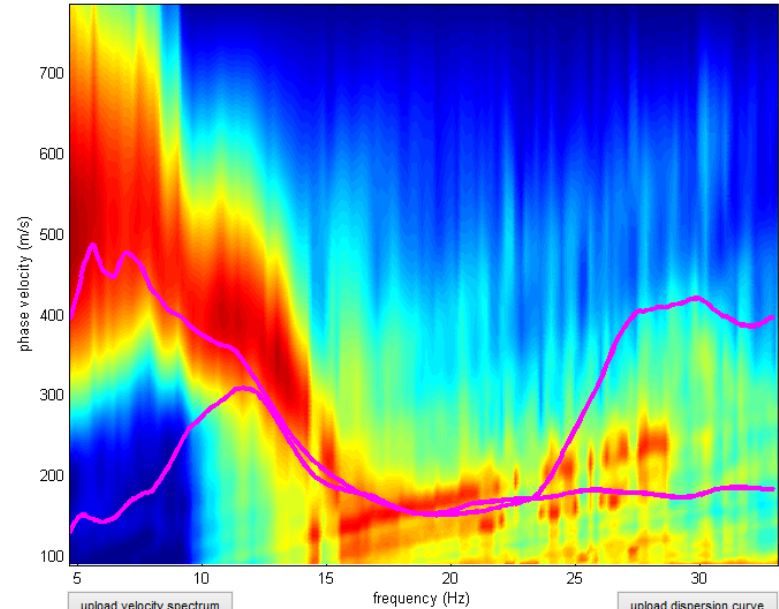
to select the last point  
click the right button



**pre-processing tools**

Colors in the background are the ESAC velocity spectrum! (from large 2D arrays)

velocity spectrum (ESACpsvelspe)





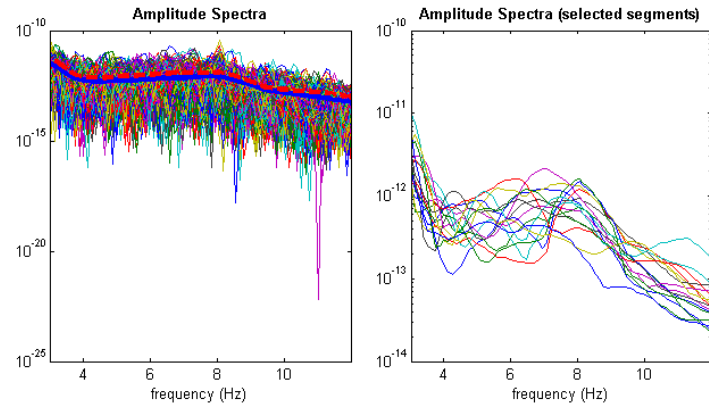
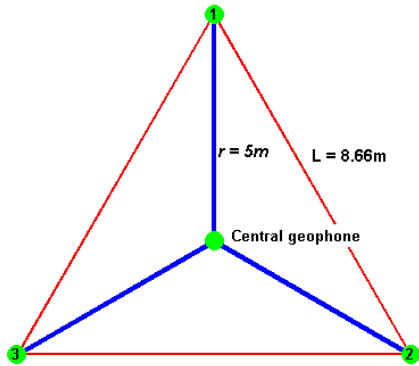
resample to 4ms (250Hz)

**data**

radius (m):

number of channels:   nc-CCA

Folder: C:\Users\gdm\Desktop\data\_analizzare\Acquisizioni La Spezia Gab and Lorenzo\MAAM\radius5\  
Dataset: MAAM-data-clean.mat  
Recording time: 25.93 min  
Sampling: 4 ms [Nyquist frequency: 125Hz]



**phase velocity spectrum**

min freq.  max freq.

min vel.  max vel.

**parameters**

window length (s)

spectral smoothing

tapering (%)

tolerance

velocity increment

hold on

noise computation

verbose

**picking**

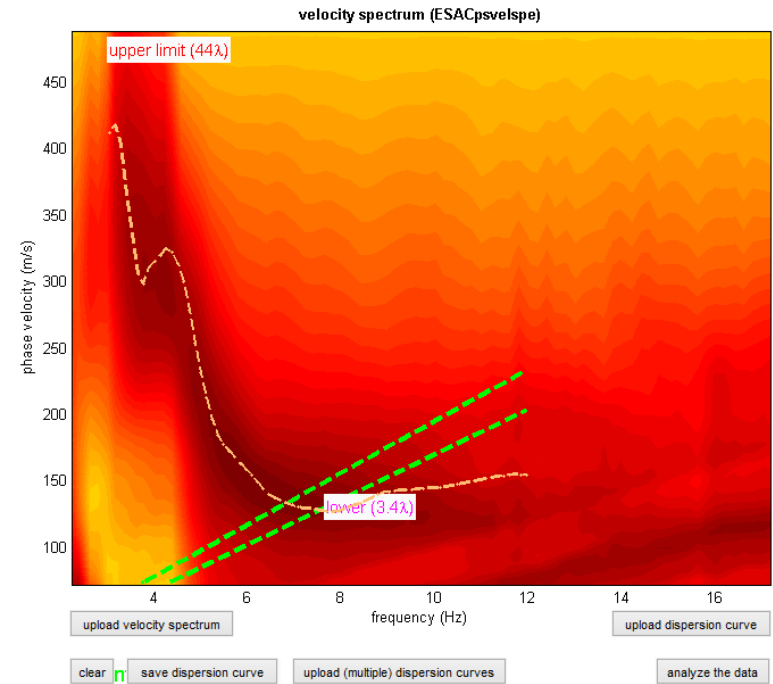
effective dispersion curve

to select the last point  
click the right button



**pre-processing tools**

Colors in the background are the ESAC velocity spectrum! (from large 2D arrays)



### Two radii (5 and 2m)

resample to 4ms (250Hz)

**data**

radius (m):

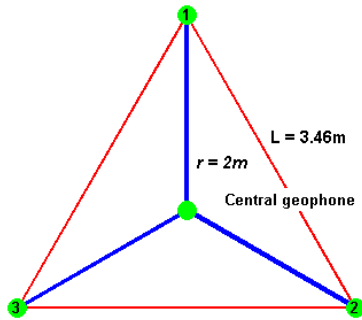
number of channels:   nc-CCA

Folder: C:\Users\gdm\Desktop\data\_da\_analizzare\Acquisizioni La Spezia Gab and Lorenzo\MAAM\radius2\

Dataset: MAAM-data-clean.mat

Recording time: 24.14 min

Sampling: 4 ms [Nyquist frequency: 125Hz]



**phase velocity spectrum**

min freq.  max freq.

min vel.  max vel.

**parameters**

window length (s)

spectral smoothing

tapering (%)

tolerance

velocity increment

hold on

noise computation

verbose

**picking**

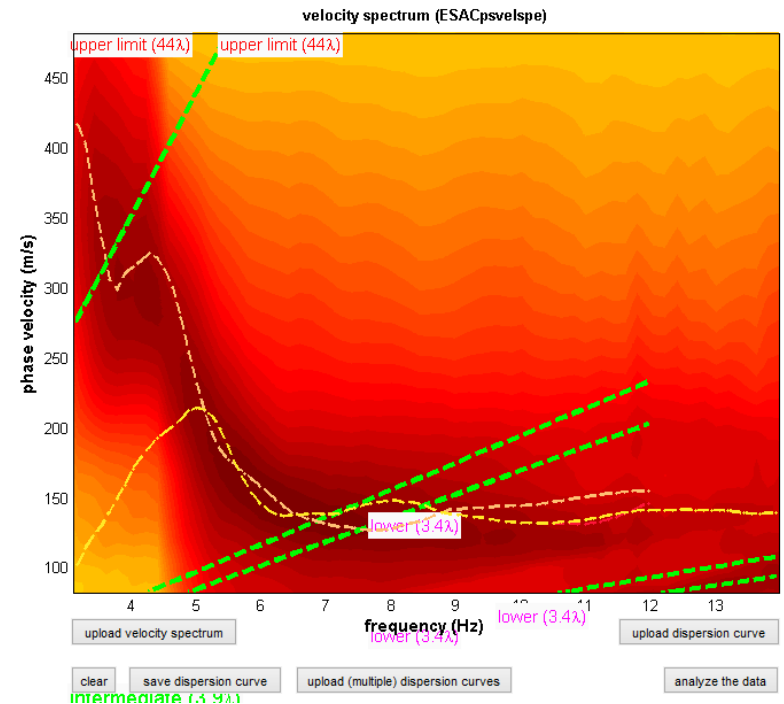
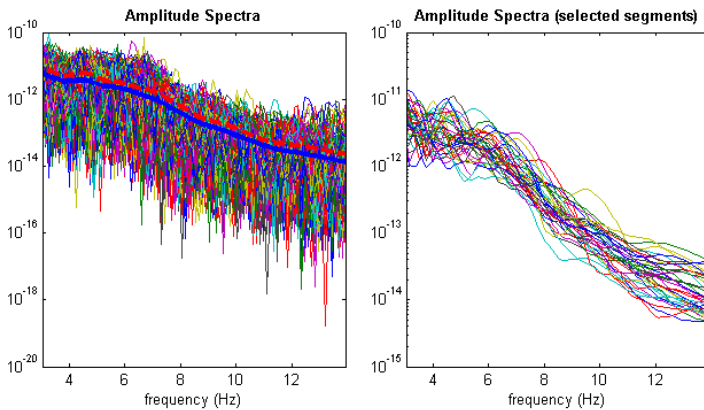
effective dispersion curve

to select the last point  
click the right button



**pre-processing tools**

Colors in the background are the ESAC velocity spectrum! (from large 2D arrays)



intermediate (3.4λ)

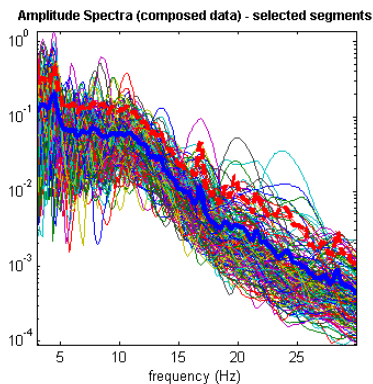
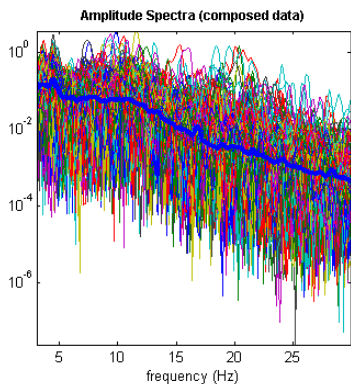
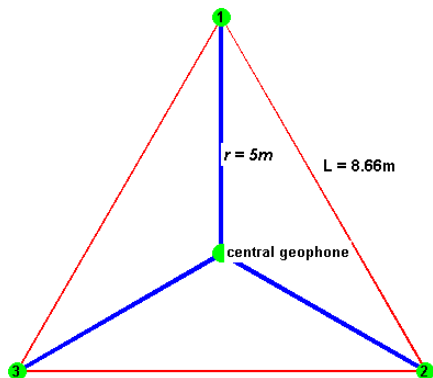
resample to 4ms (250Hz)

**data**

radius (m):

number of channels:   nc-CCA

Folder: C:\Users\gdm\Desktop\dati interessanti in corso\Modena-tests-Lorenzo\_Del\_Maschio\MAAM\_DoReM\MAAM\_5m  
Dataset: MAAM-data-clean.mat  
Recording time: 11.91 min  
Sampling: 4 ms [Nyquist frequency: 125Hz]



**phase velocity spectrum**

min freq.  max freq.

min vel.  max vel.

**parameters**

window length (s)

spectral smoothing

tapering (%)

tolerance

velocity increment

upper limit

hold on

noise computation

trace normalization

verbose

advanced processing

auto (for raw data)

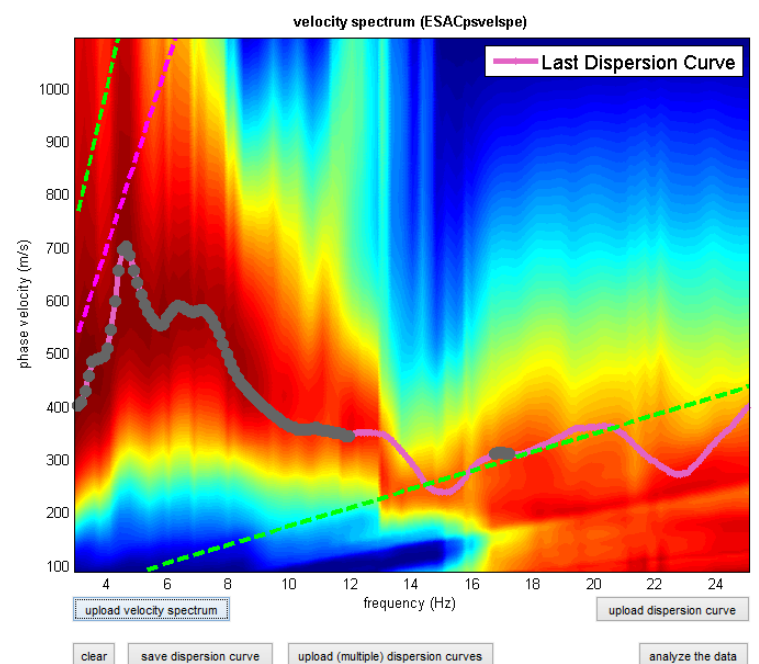
**picking**

effective dispersion curve

to select the last point  
click the right button

**Radius (5m)**  
**Colors in the background are the ESAC velocity spectrum! (from large 2D arrays)**

Noise (epsilon) computed [dispersion compensated]



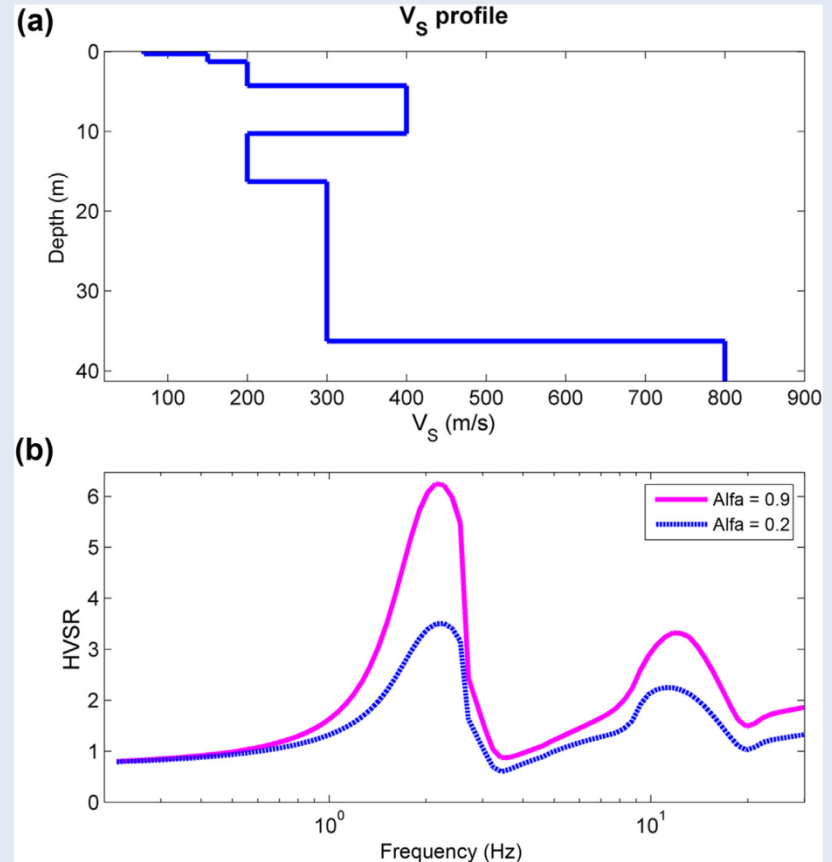
# Love-wave contribution to the observed HVSR

$$\text{HVSR} = \sqrt{\frac{\alpha H_L(f) + H_R(f)}{V_R(f)}}$$

L = contributo delle onde di Love

R = contributo delle onde di Rayleigh

I microtremori sono essenzialmente costituiti da onde di Rayleigh e Love. La quantità di onde di Love (incognita e sintetizzabile con il “parametro alfa”) è essenziale .



**Figure 4.14** Effects of Love waves on the HVSR: (a) considered  $V_S$  profile; (b) the HVSR curves obtained while considering a different amount of Love waves (the  $\alpha$  factor) in the microtremor field. In both cases  $Q_S$  values are fixed according to a simple rule of thumb ( $Q_S = V_S/8$ ).

Two consequences are straightforward:

1. The amount of Love waves (synthetically expressed by the  $\alpha$  factor) should be considered as a further variable in the inversion process aimed at determining the  $V_S$  profile (experience teaches that its value typically ranges from 0.3 to 0.6).
2. The HVSR curve alone is insufficient to properly and precisely define a  $V_S$  profile even when geological/stratigraphical information are available and, consequently, the only viable approach is represented by the joint inversion with further geophysical data (typically the dispersion curves of Rayleigh or Love waves).

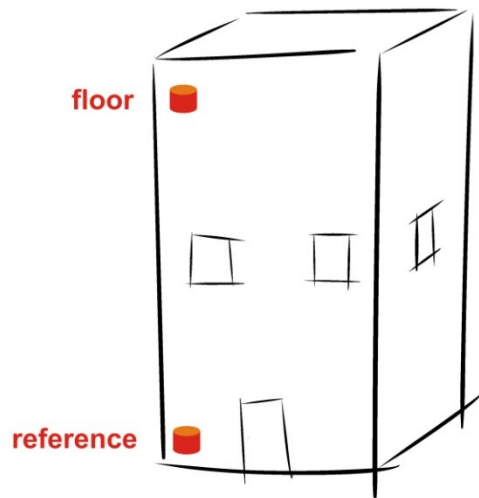
# Vibrational analyses

Allo scopo di analizzare in modo rigoroso le vibrazioni di un edificio, è fondamentale eseguire acquisizioni sincrone sia verticalmente che orizzontalmente (due terne che lavorano perfettamente sincronizzate).

Per un esempio clicca sul seguente link: <https://www.youtube.com/watch?v=6O0SSil1MTo>

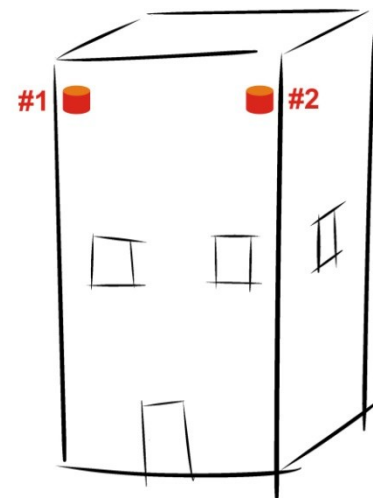
**synchronized (vertically)**

**2 sensors at 2 different floors (simultaneously)**



**synchronized (horizontally)**

**2 sensors at the same floor (simultaneously)**



# The Camerino Data and Analyses

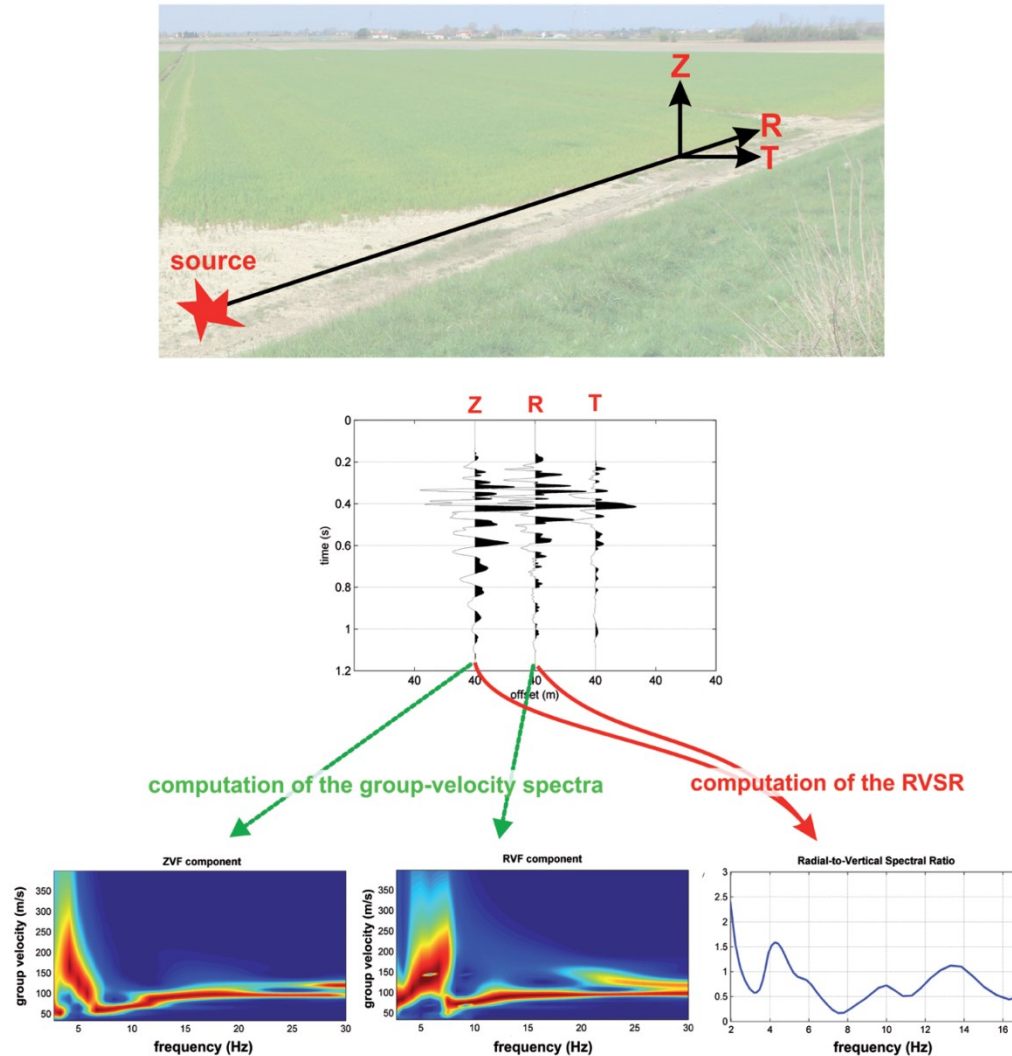
Let's compare the analysis of classical multichannel data (performed according to the FVS approach) and the results obtained via HS (*HoliSurface* – a patented methodology based on the analysis of just a single 3-component geophone) . We will see that the results are practically identical.



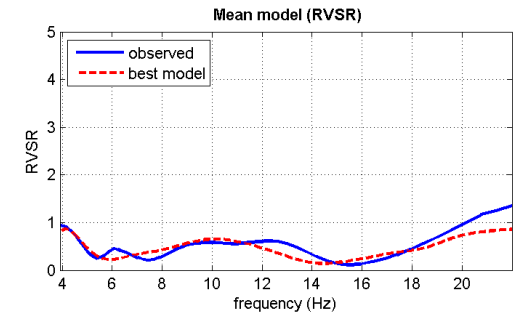
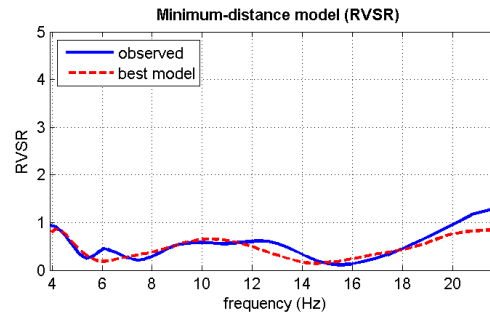
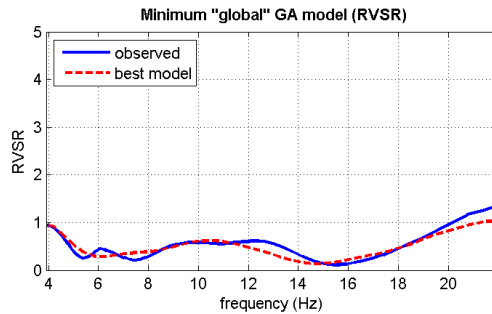
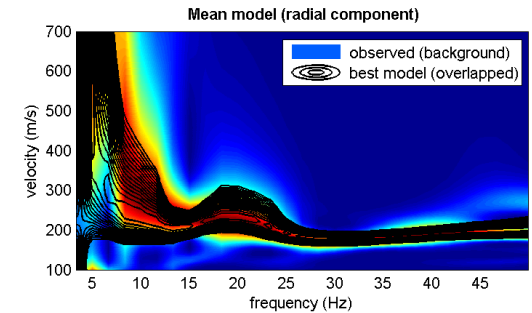
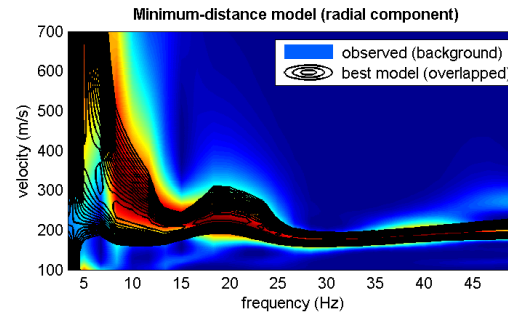
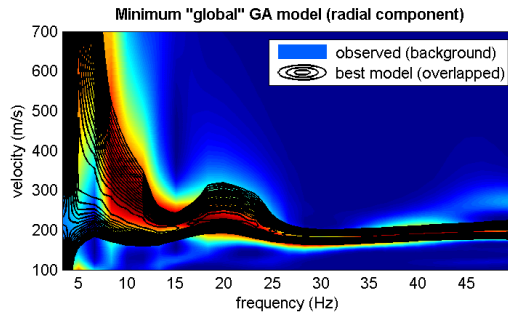
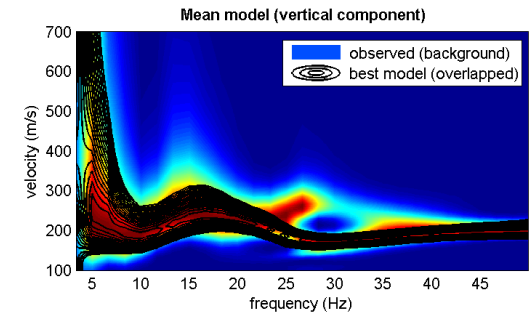
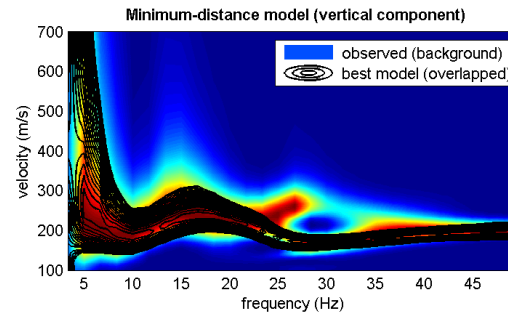
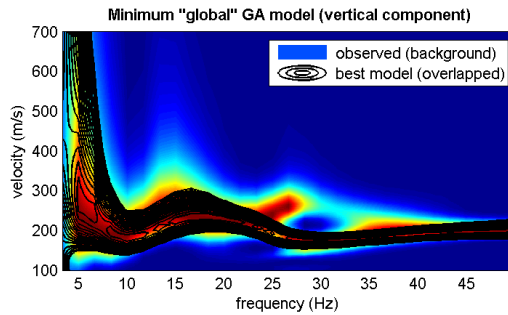
# The Camerino Data and Analyses

The idea of *HoliSurface*<sup>®</sup>.

From: A Comprehensive Seismic Characterization via Multi-Component Analysis of Active and Passive Data (Dal Moro G., Keller L., Poggi V.), *First Break* (September, 2015)

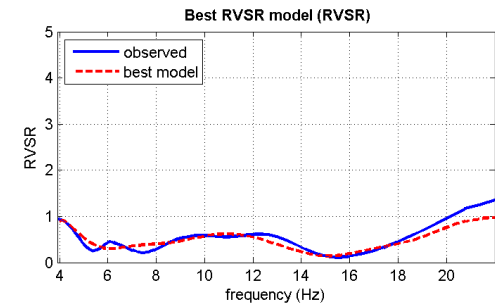
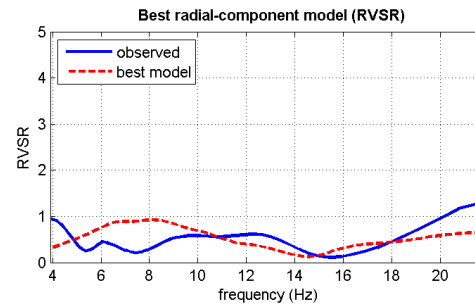
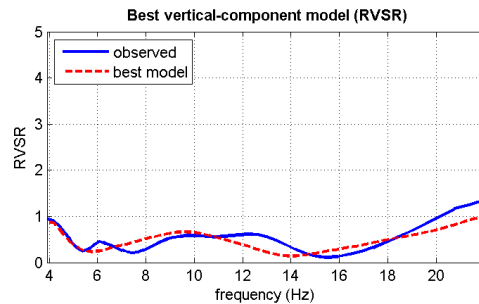
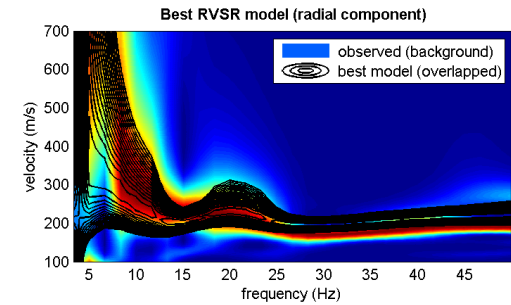
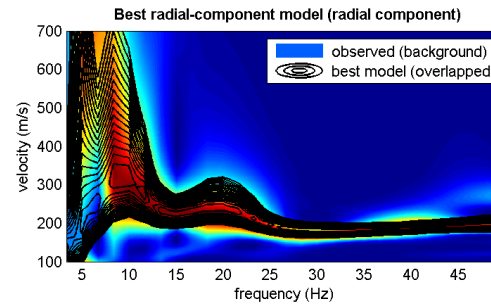
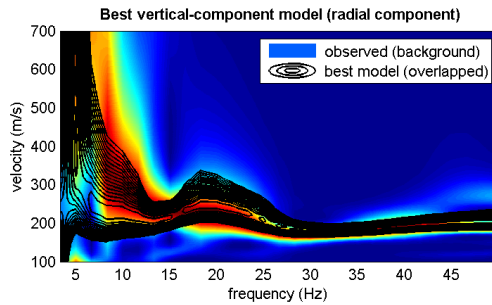
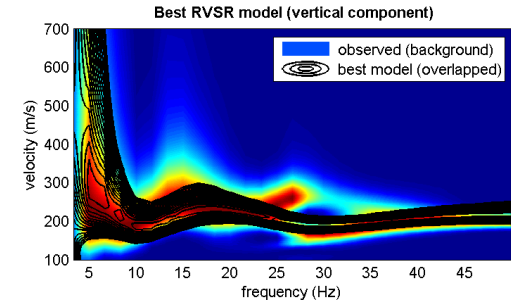
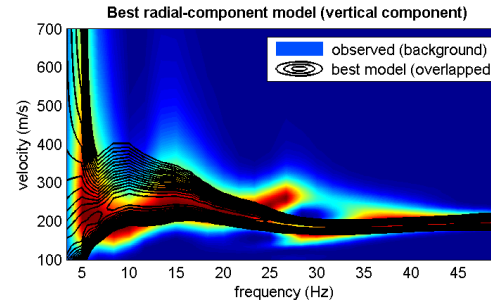
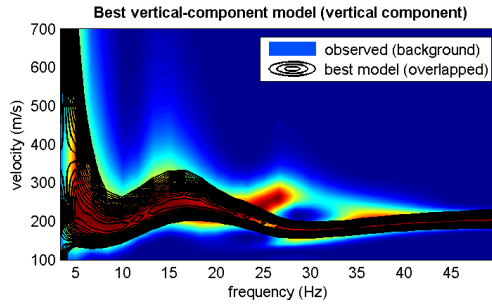


*Figure 9* Data acquisition for the holistic analysis of Rayleigh-wave propagation by means of a single (at least) 2-component geophone recording the vertical and radial components then used to determine the two group velocity spectra and the Radial-to-Vertical Spectral Ratio (RVSR).

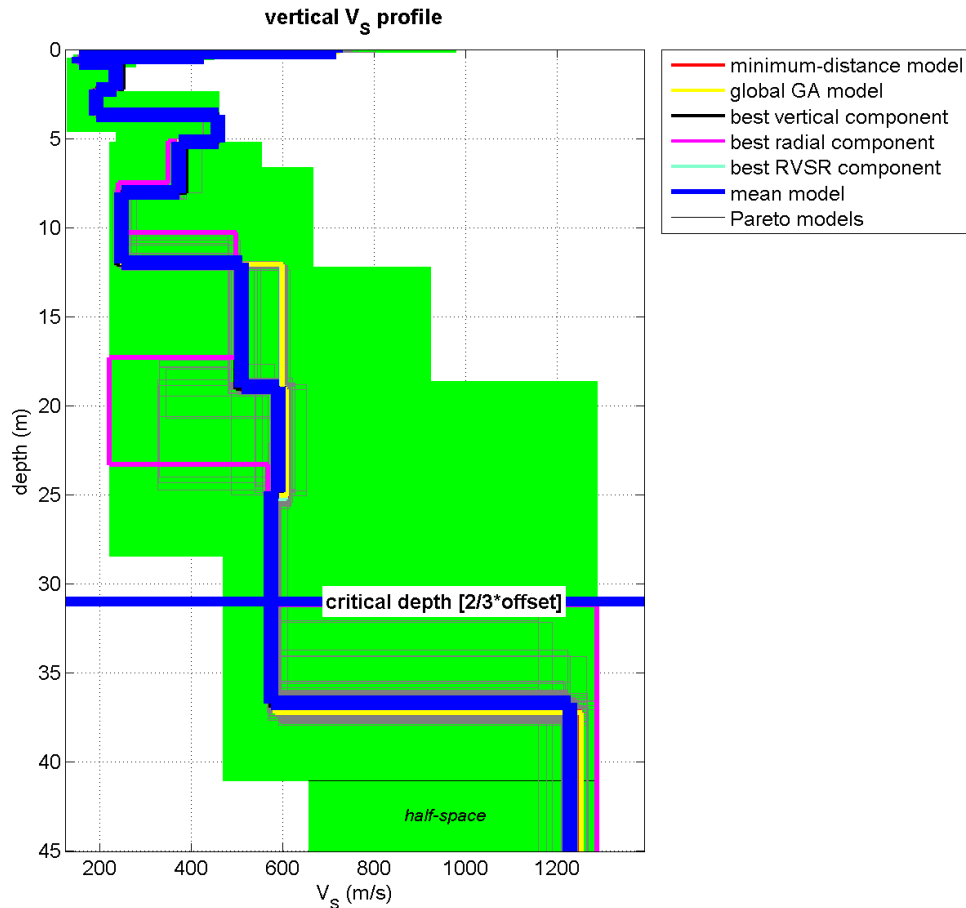


Global models





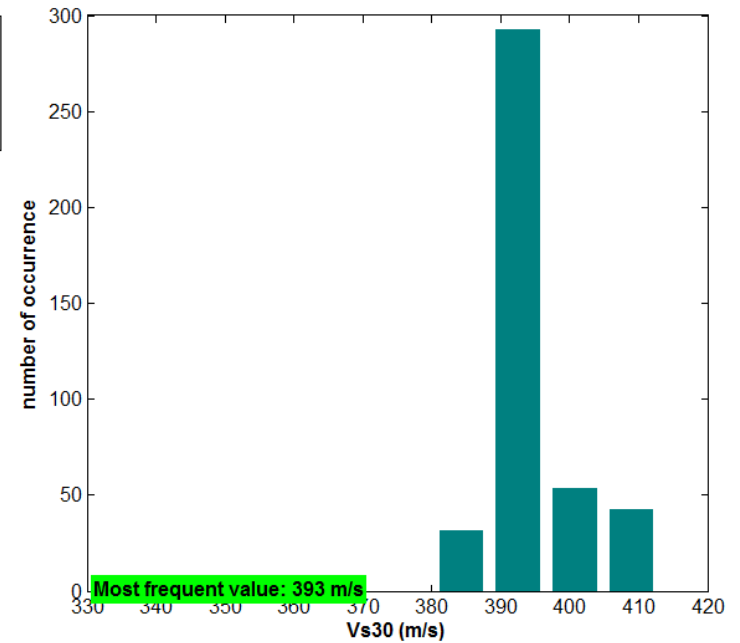
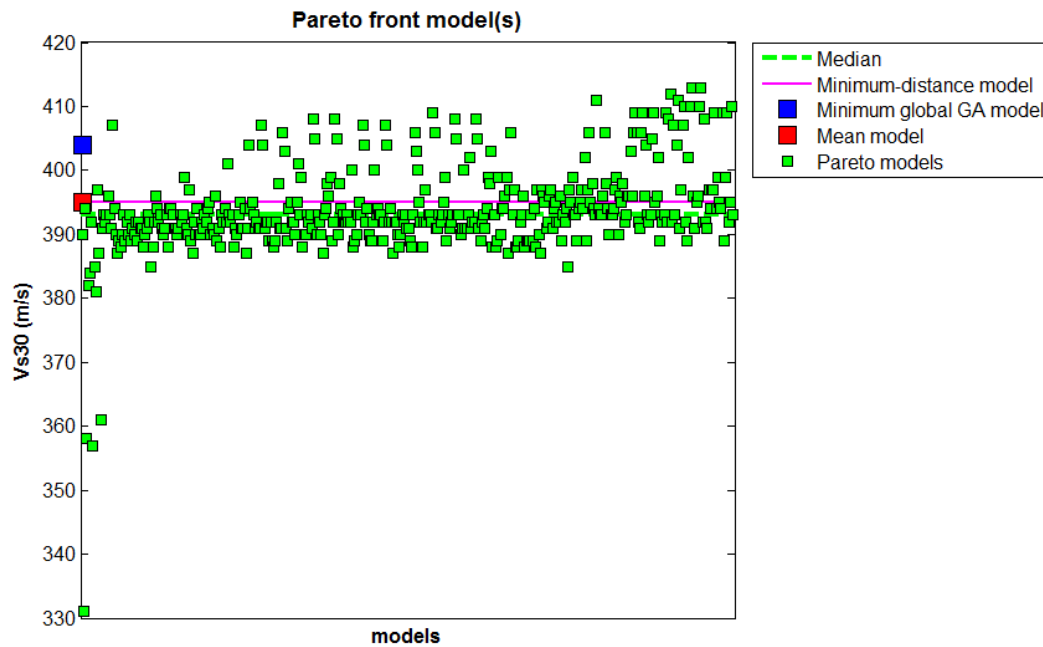
Best single-component models



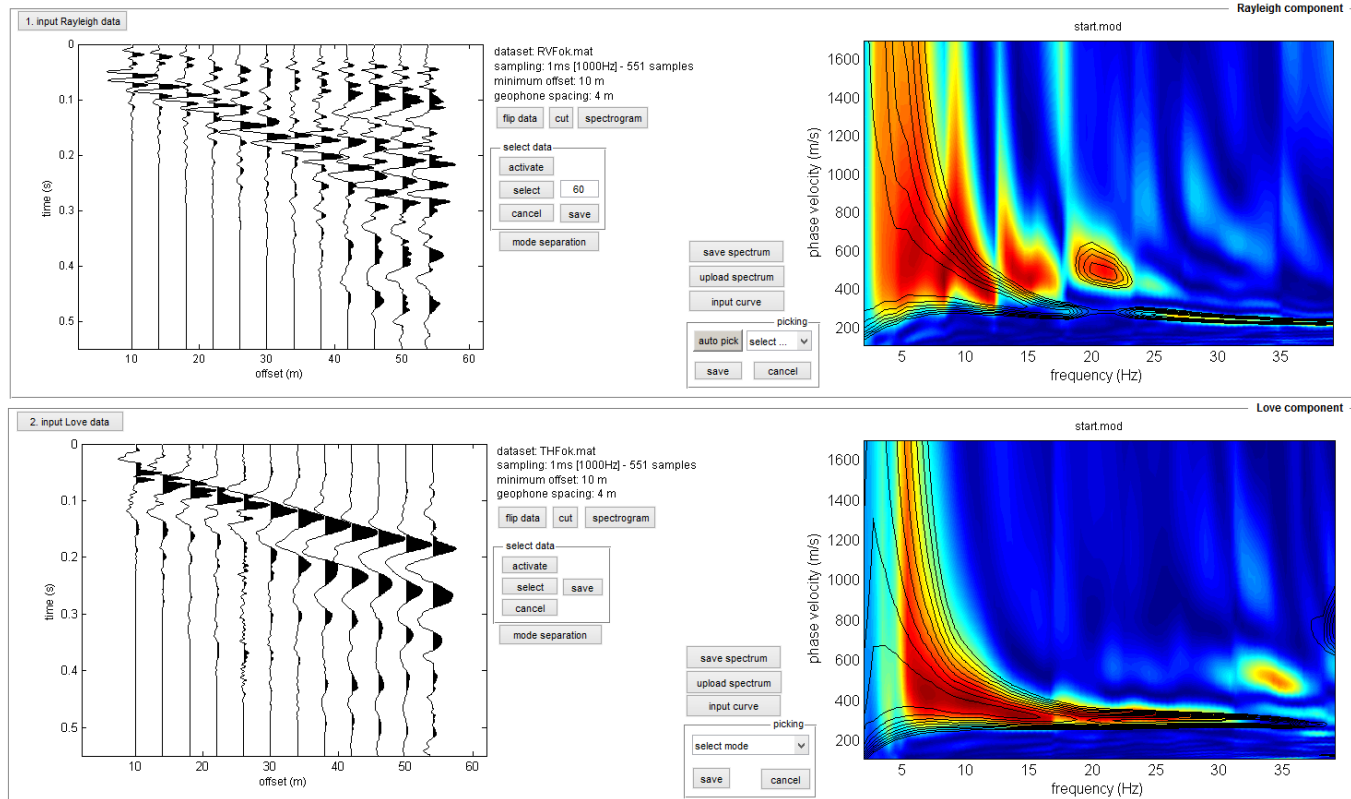
The best RVF model should be not considered (as too far from the rest of the models – which are instead extremely consistent)

## Statistics:

Vs30 values for the Pareto front models (extremely consistent distribution)



Now we take the “best model” from the *HoliSurface* analysis and this is what we obtain:



An extremely good agreement for both the Rayleigh and Love waves, which clearly means that the HS analyses provided extremely good results, which can be considered “equivalent” to the performances possible with the standard multi-channel data.

**RVF (radial component of Rayleigh waves) + THF (Love waves) Full Velocity Spectrum (FVS) joint analysis.** Background color the field phase-velocity spectra, overlaying contour lines the synthetic velocity spectra of the considered Vs model.