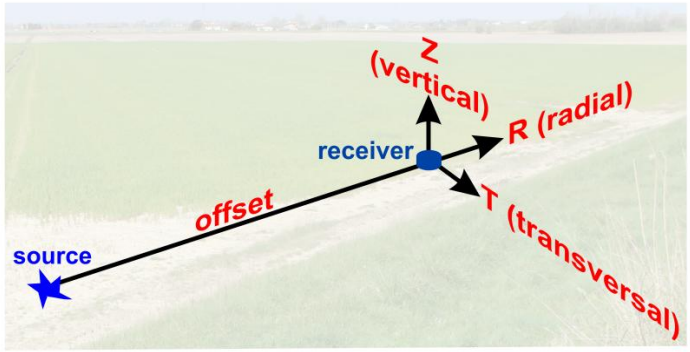
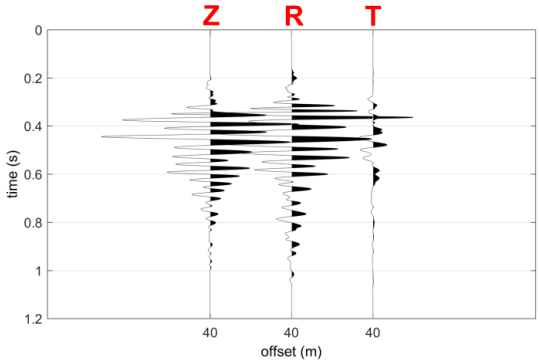
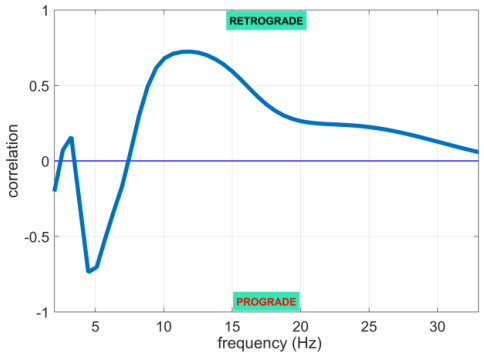
Ma chi l'ha detto che le onde di Rayleigh sono retrograde?







Giancarlo Dal Moro

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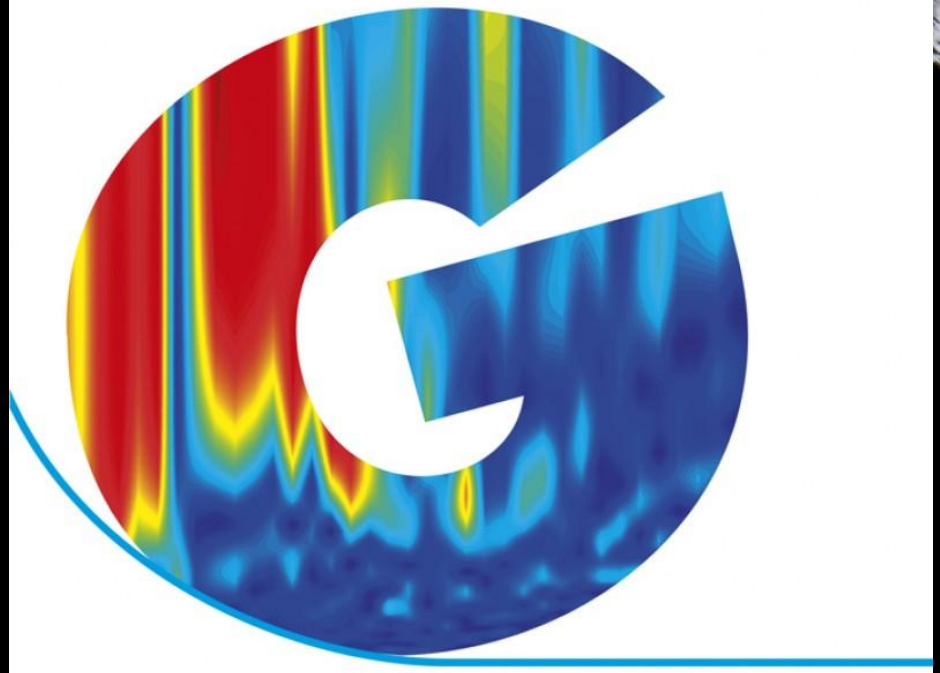
dalmoro@irsm.cas.cz; gdm@winmasw.com

Giancarlo Dal Moro

Onde di superficie in geofisica applicata

Acquisizione e analisi di dati secondo tecniche MASW e HVSR

Dario Flaccovio Editore



Onde di Rayleigh e onde di Love ✓
Acquisizione dati ✓
Analisi MASW, ReMi e HVSR ✓
Raccolta di casi studio ✓

SURFACE WAVE ANALYSIS FOR NEAR SURFACE APPLICATIONS

ELSEVIER

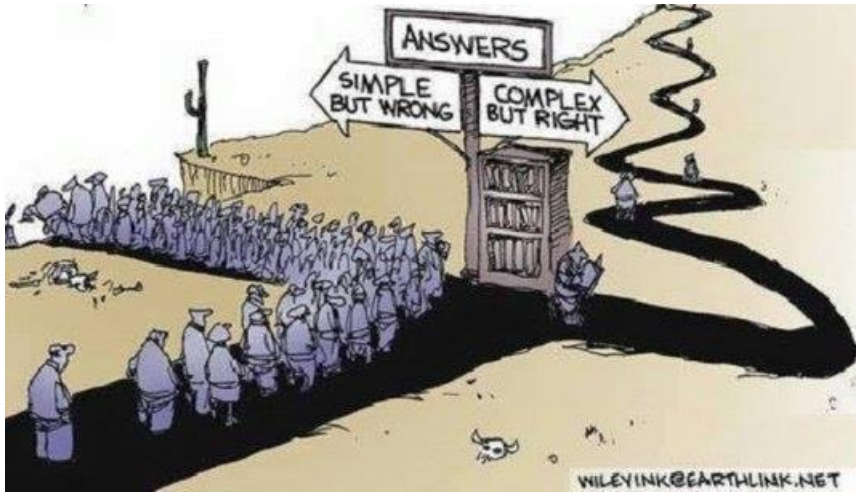
Dal Moro

SURFACE WAVE ANALYSIS FOR NEAR SURFACE APPLICATIONS

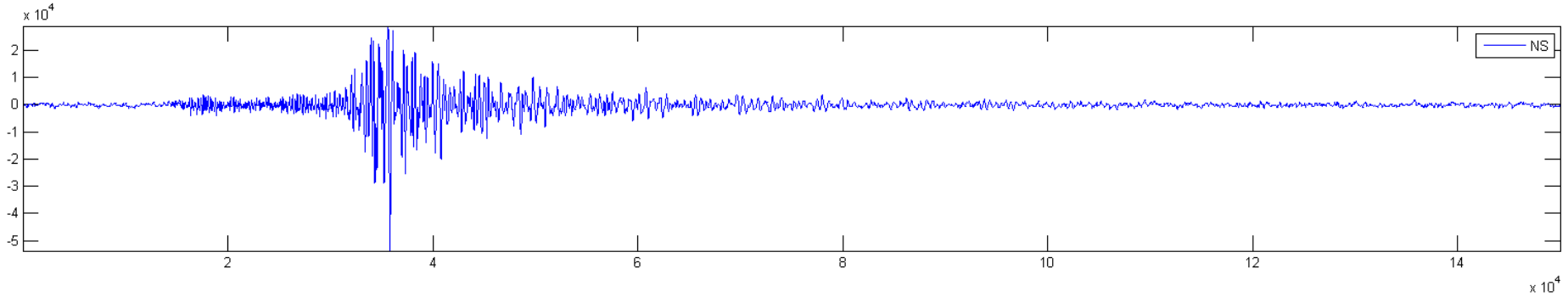
Giancarlo Dal Moro

ELSEVIER

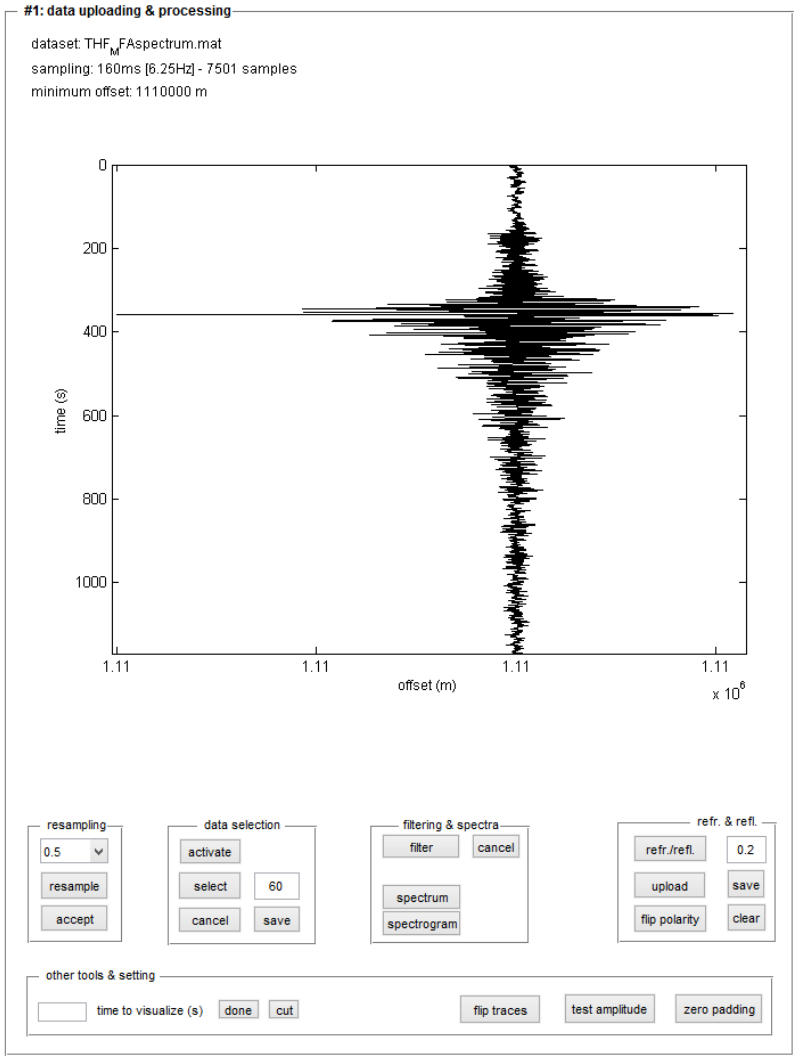
recruiting

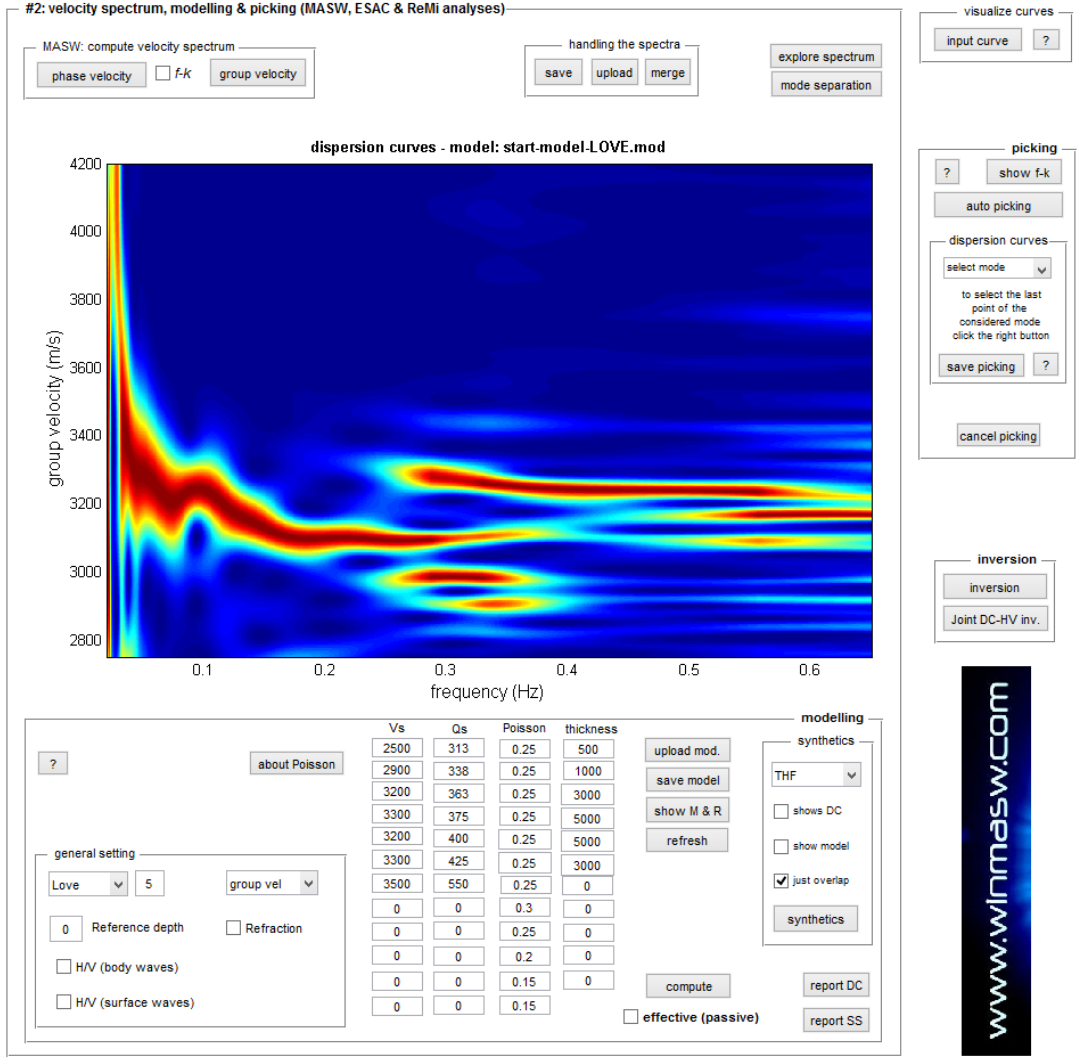

ANSWERS
SIMPLE BUT WRONG
COMPLEX BUT RIGHT
WILEYINK@EARTHLINK.NET

Some Garage Seismology



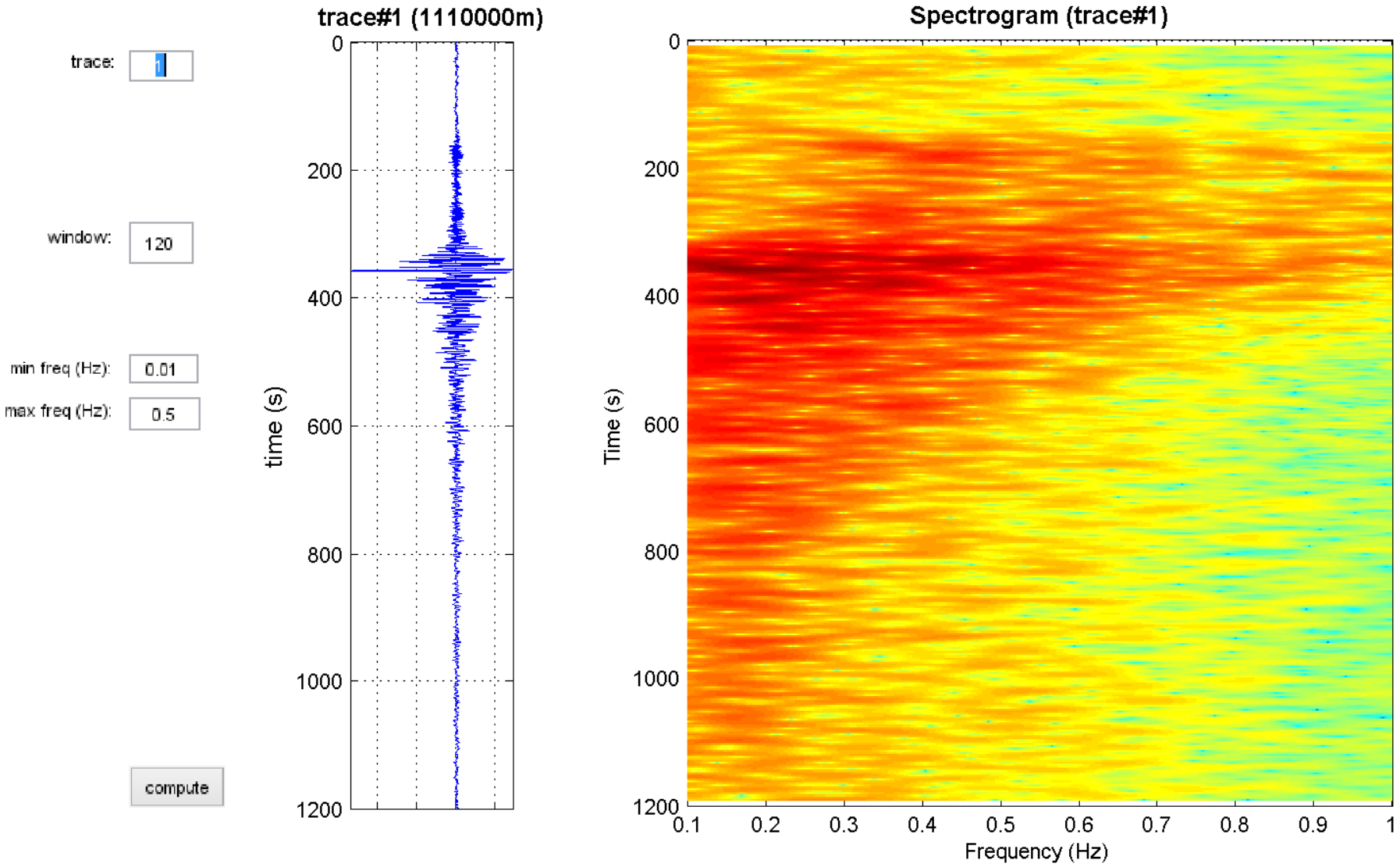
Some Garage Seismology





www.winmasw.com

Some Garage Seismology



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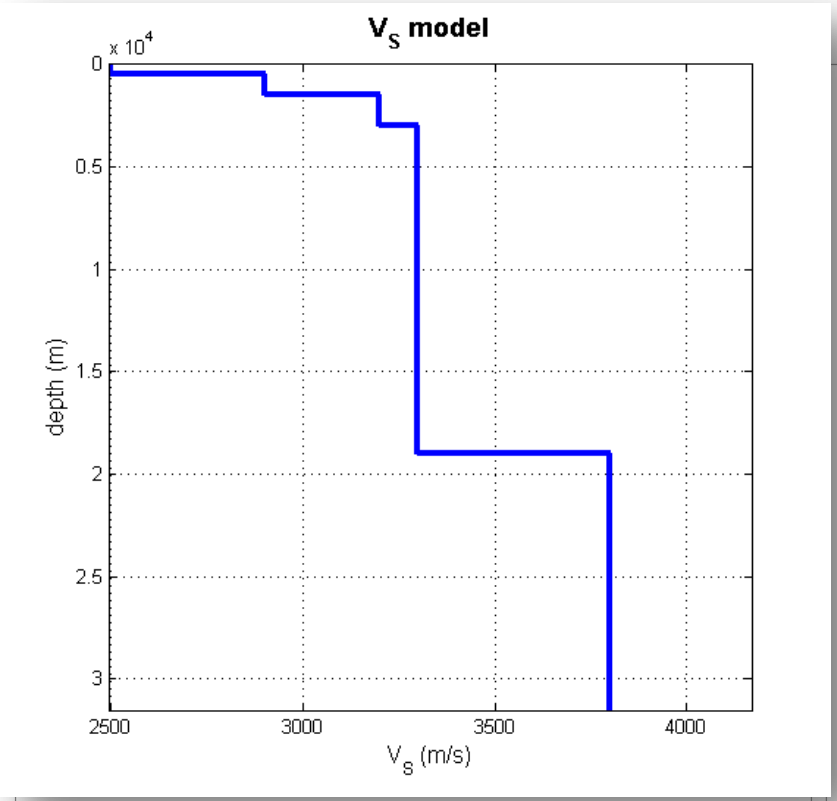

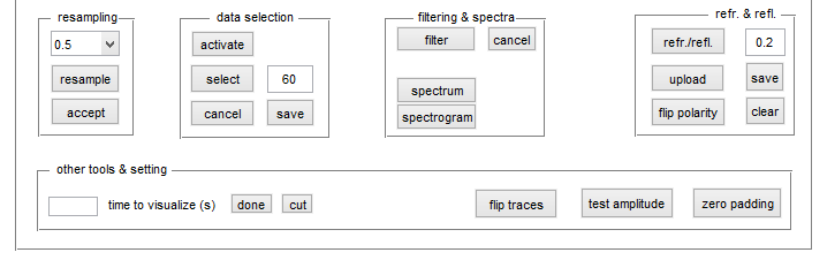

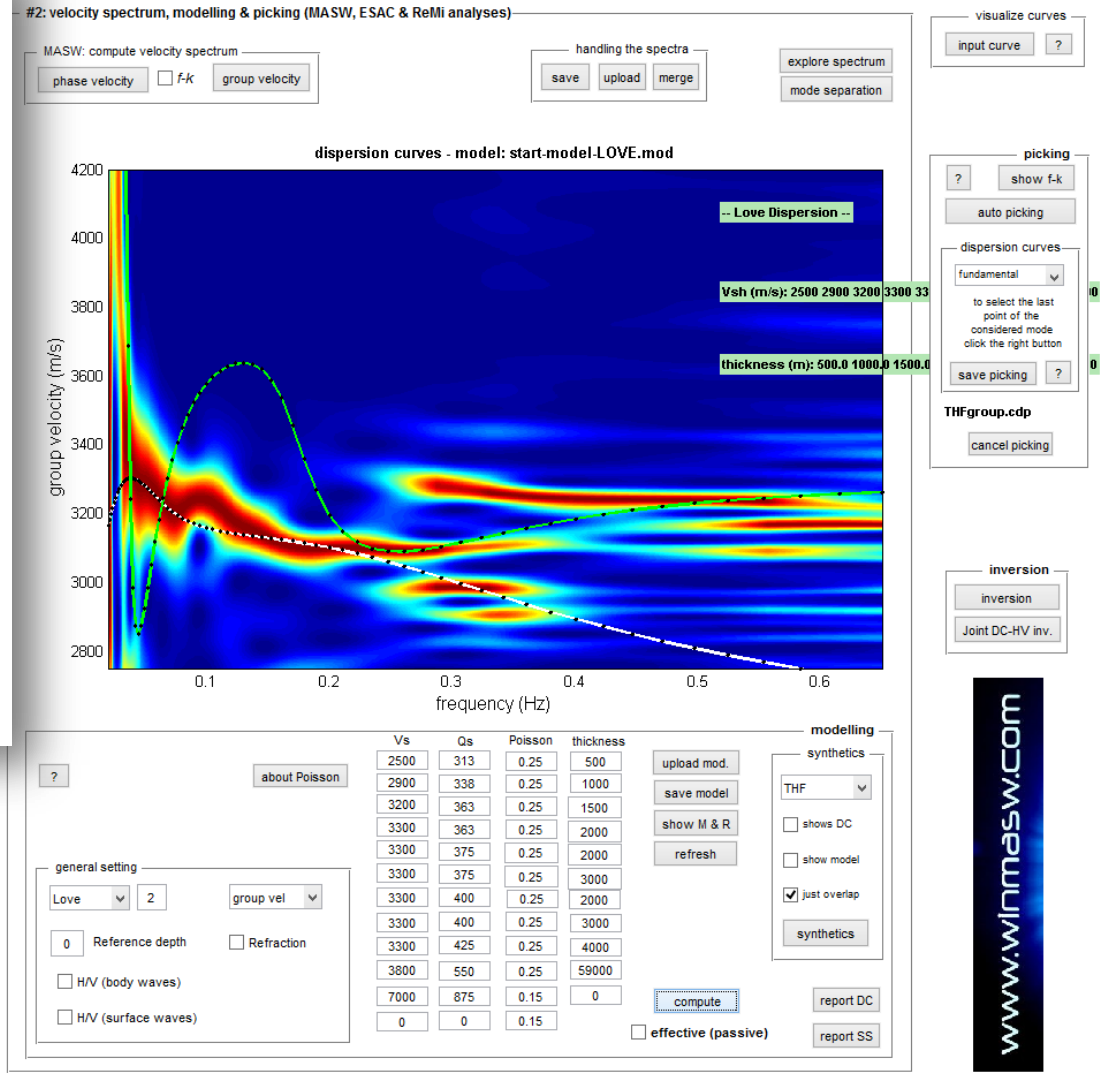

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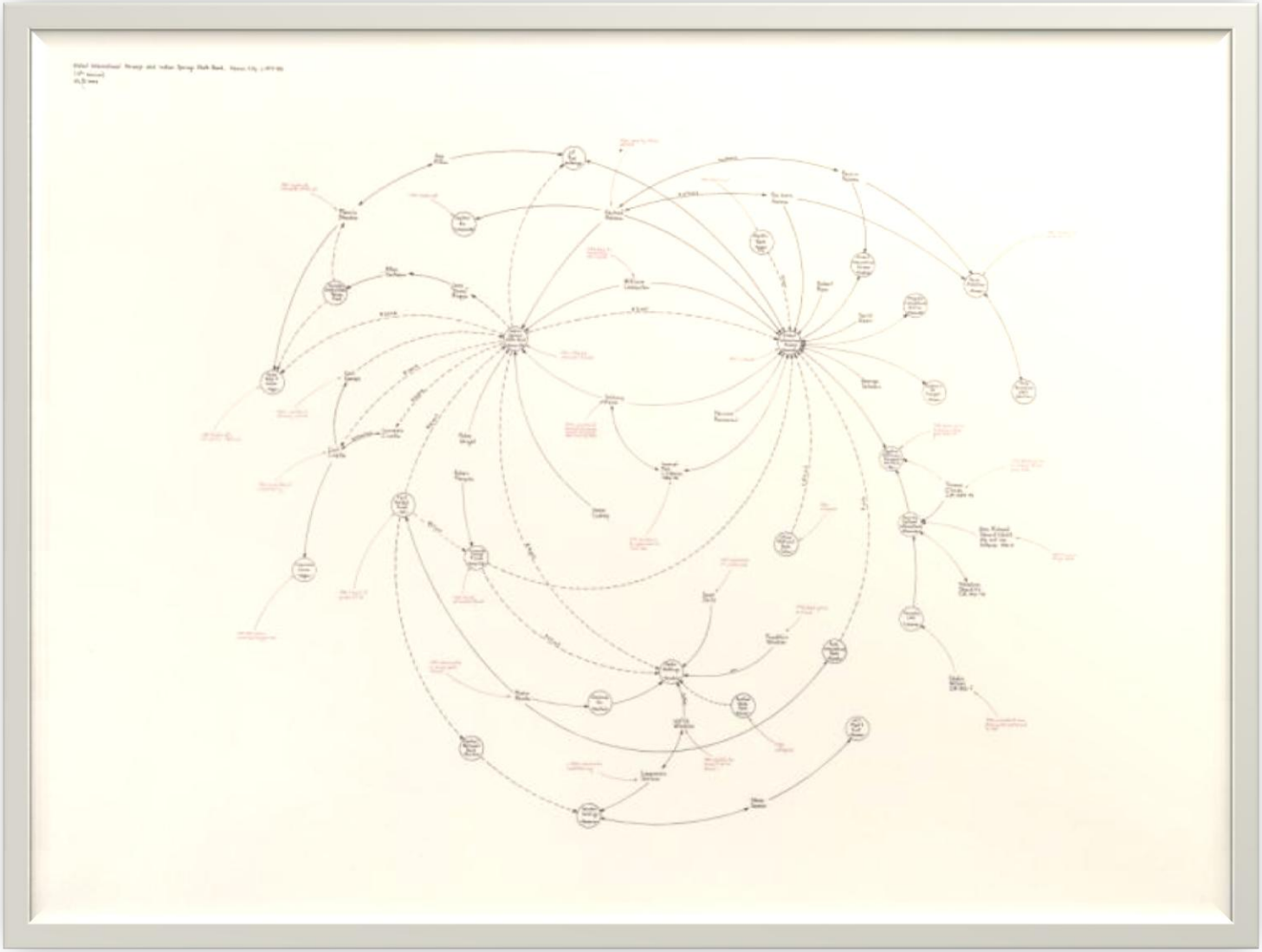
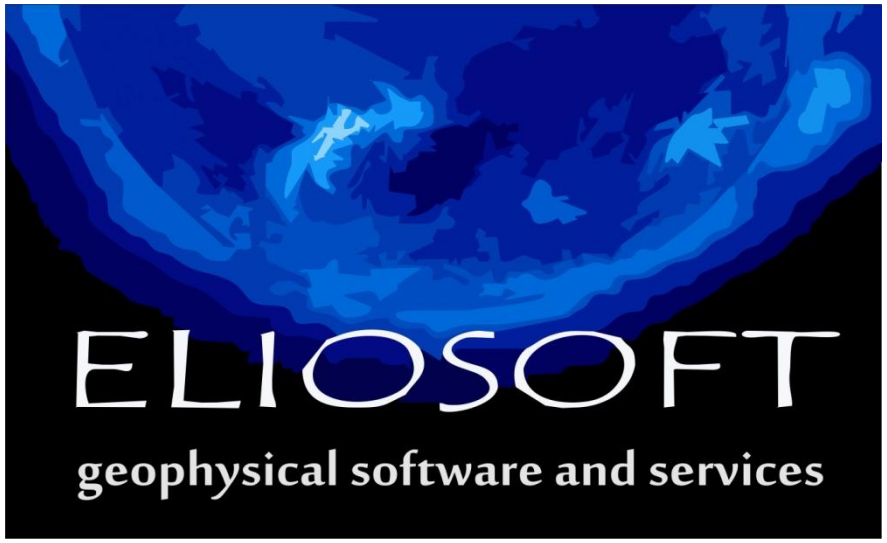
Tutoring

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



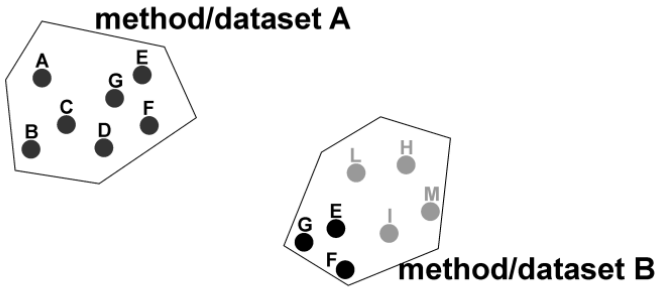


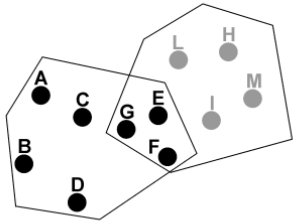
Two R&D lines

Classical (improved) methodologies

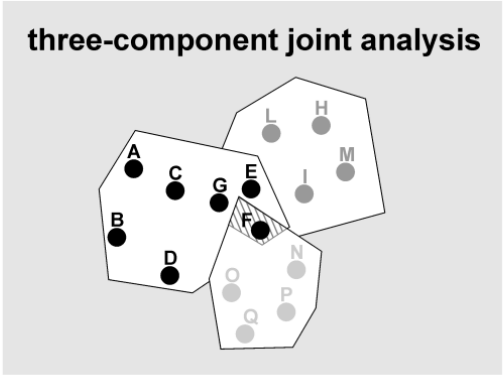
Unconventional (particularly effective) methodologies

Non-uniqueness of the solution





What could be these methods/datasets/components?
[Elsevier pdf]



Waves and components (Elsevier book)

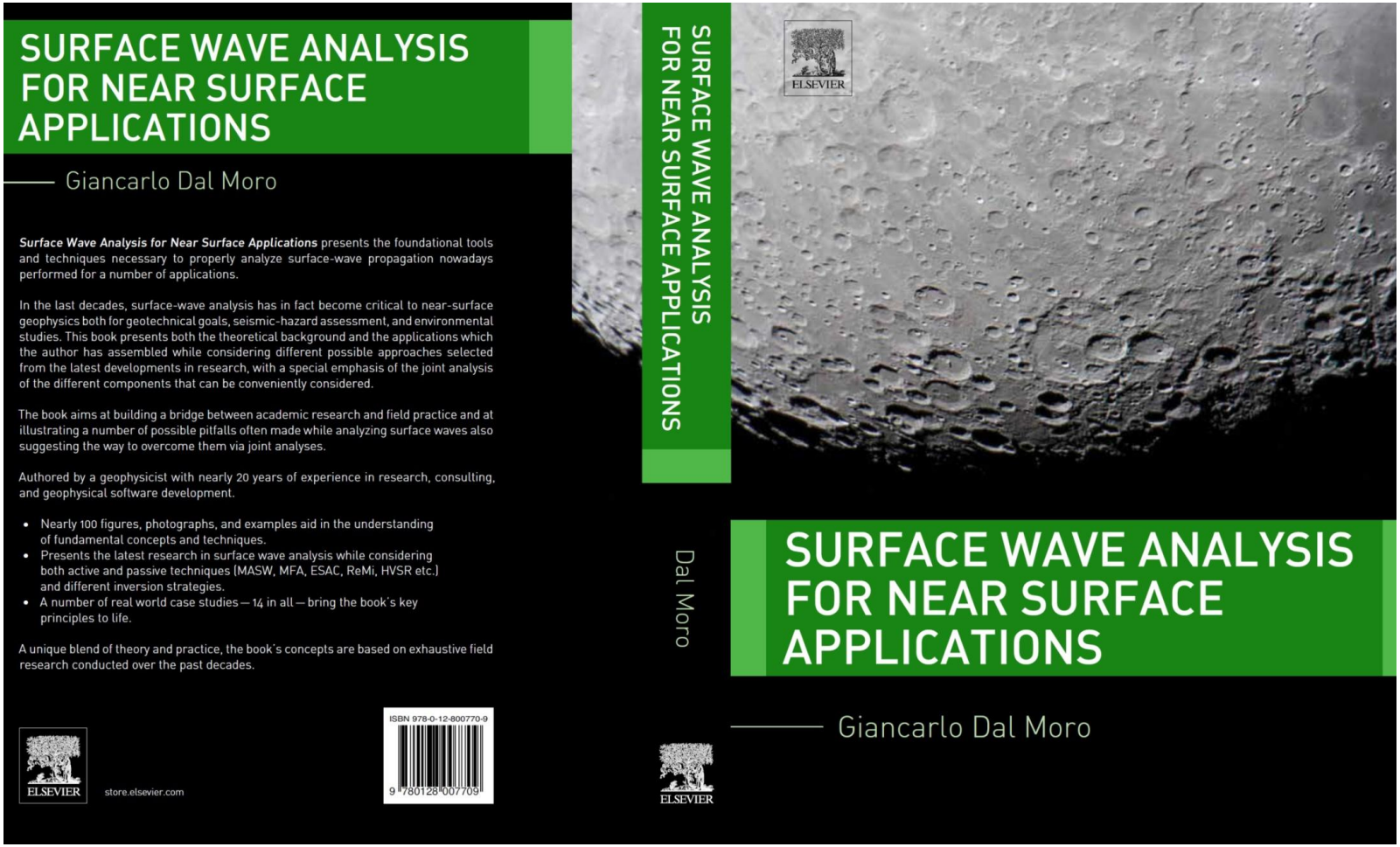
Waves and nomenclature
(file names and multi-component data)

ZVF-ZEX
RVF-REX
THF

See Flaccovio and Elsevier books

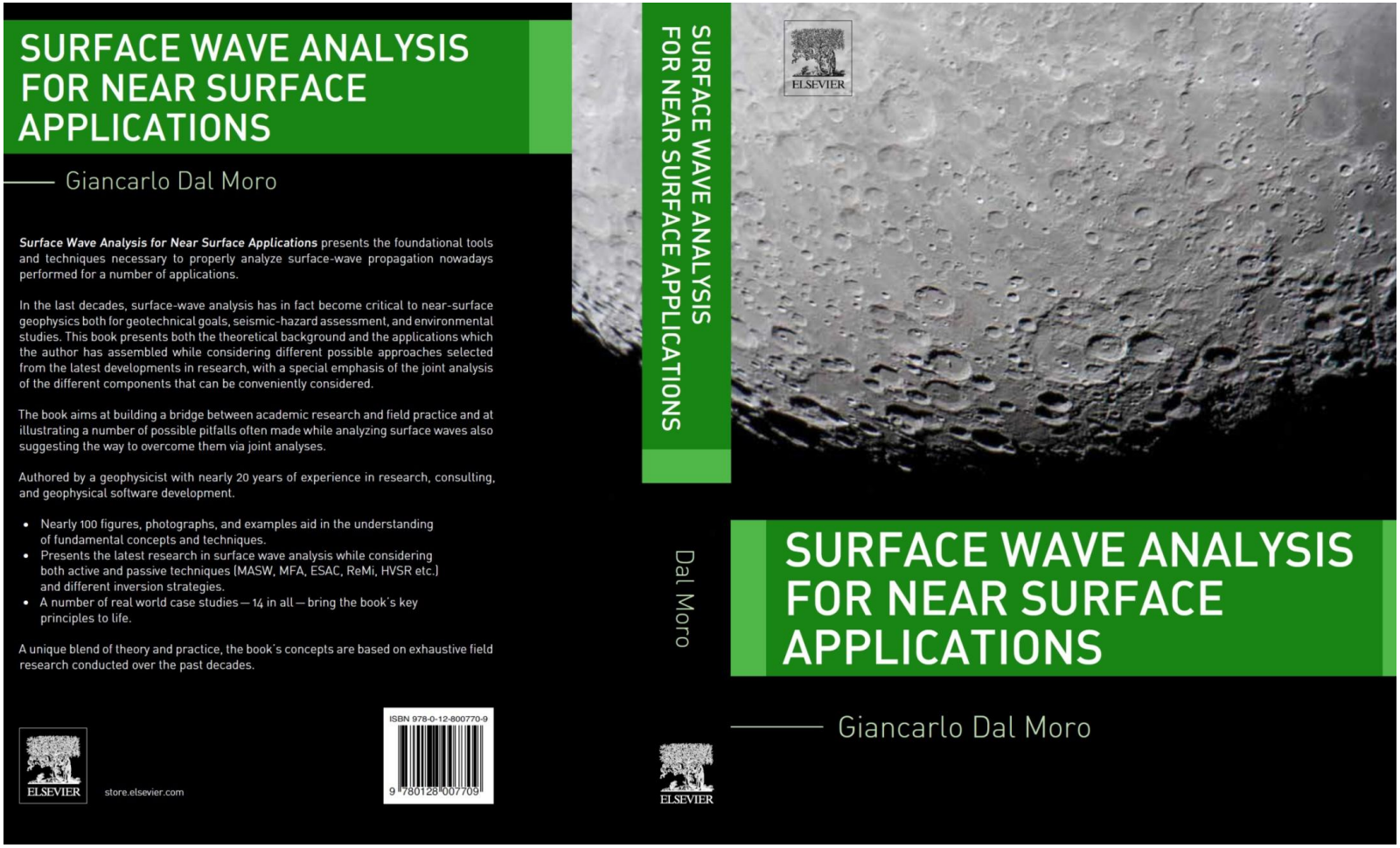
dx and the vertical resolution

The number of channels: an issue?



See paragraph: "2.2.1 Multichannel Acquisition (MASW)"

ReMi versus ESAC

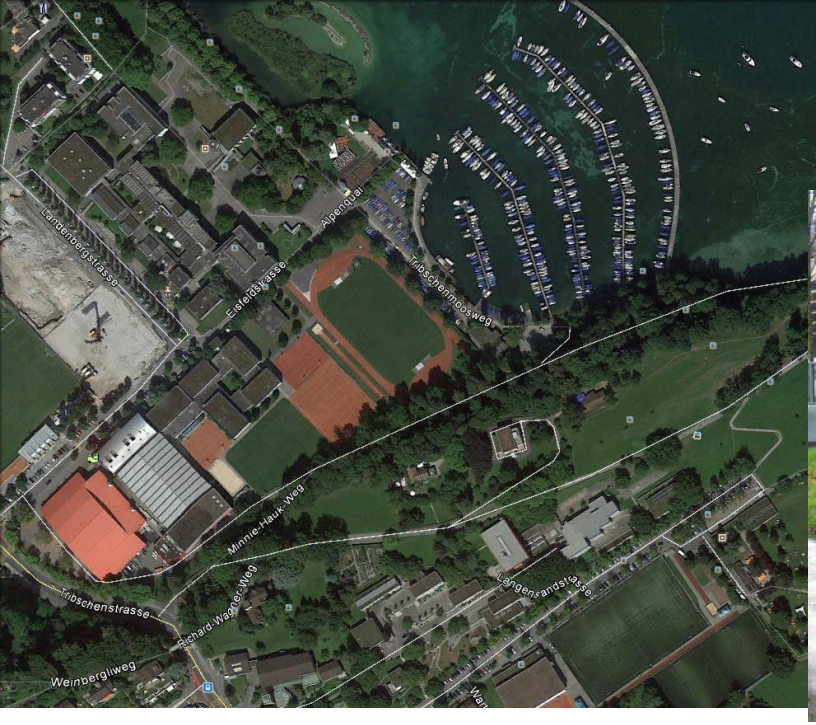


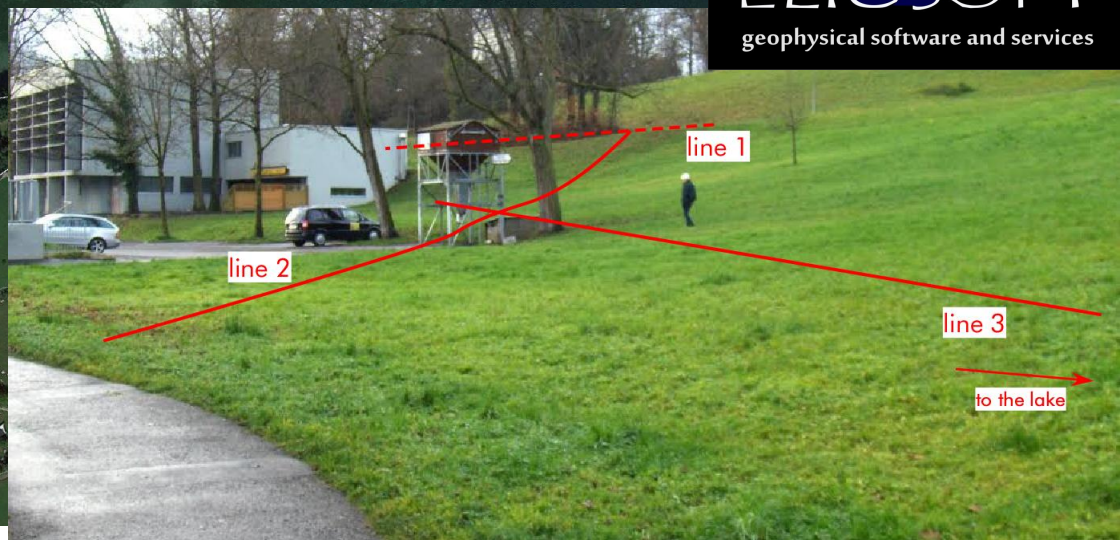
See paragraphs: "2.3 PASSIVE METHODOLOGIES" and "3.3 ABOUT PASSIVE METHODS"

drifting and HVSR

Done *live* during the lecture

Not *what*, but *how*





ELIOSOFT
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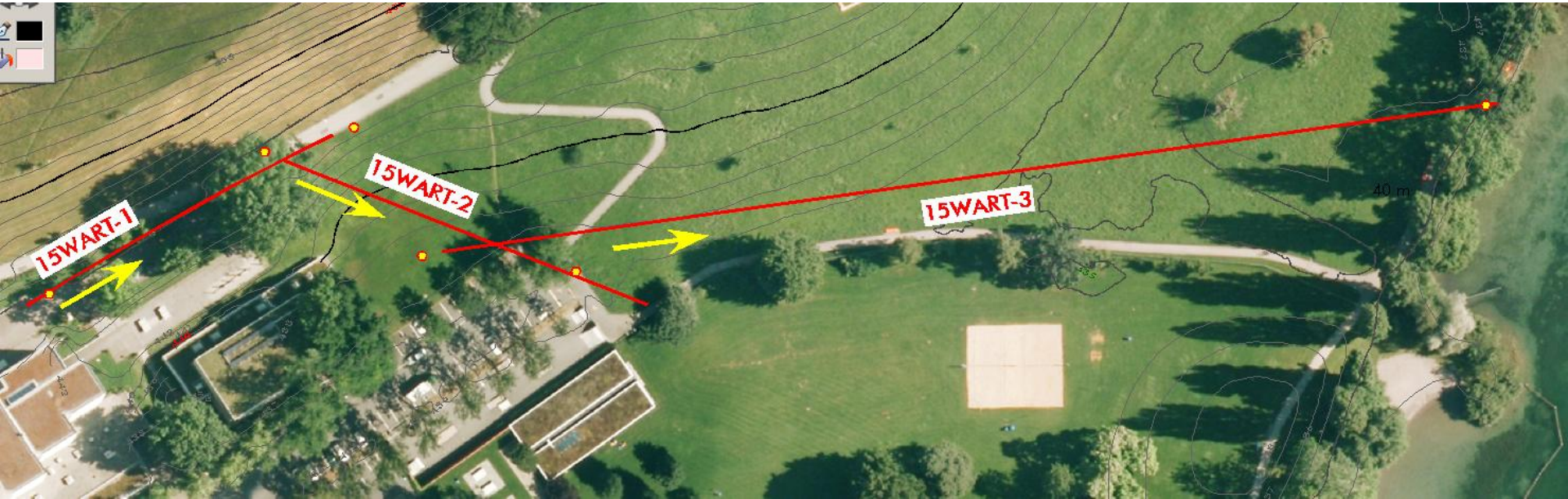
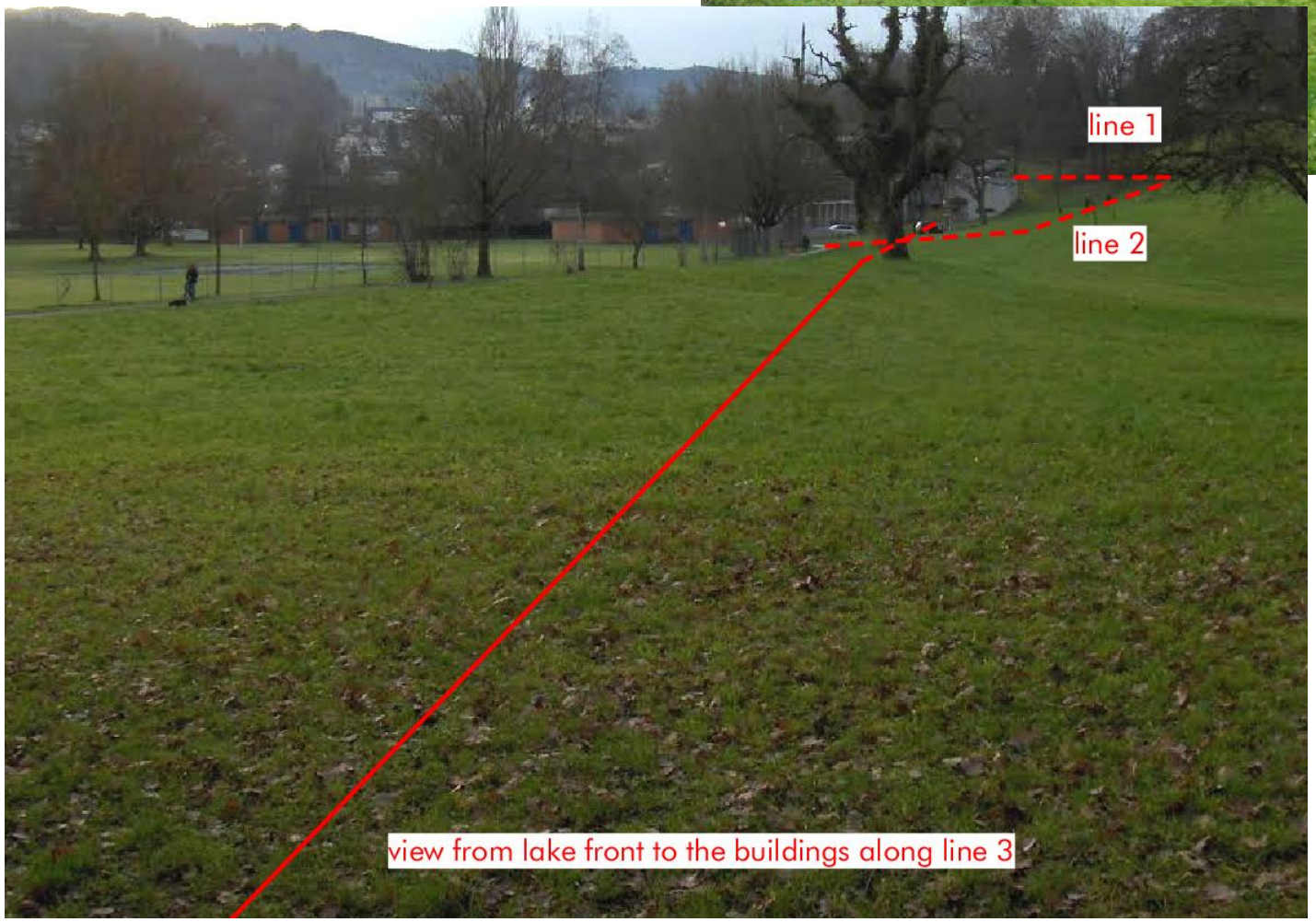
Esempio di efficienza: “Vierwaldstättersee” survey



Vierwaldstättersee survey



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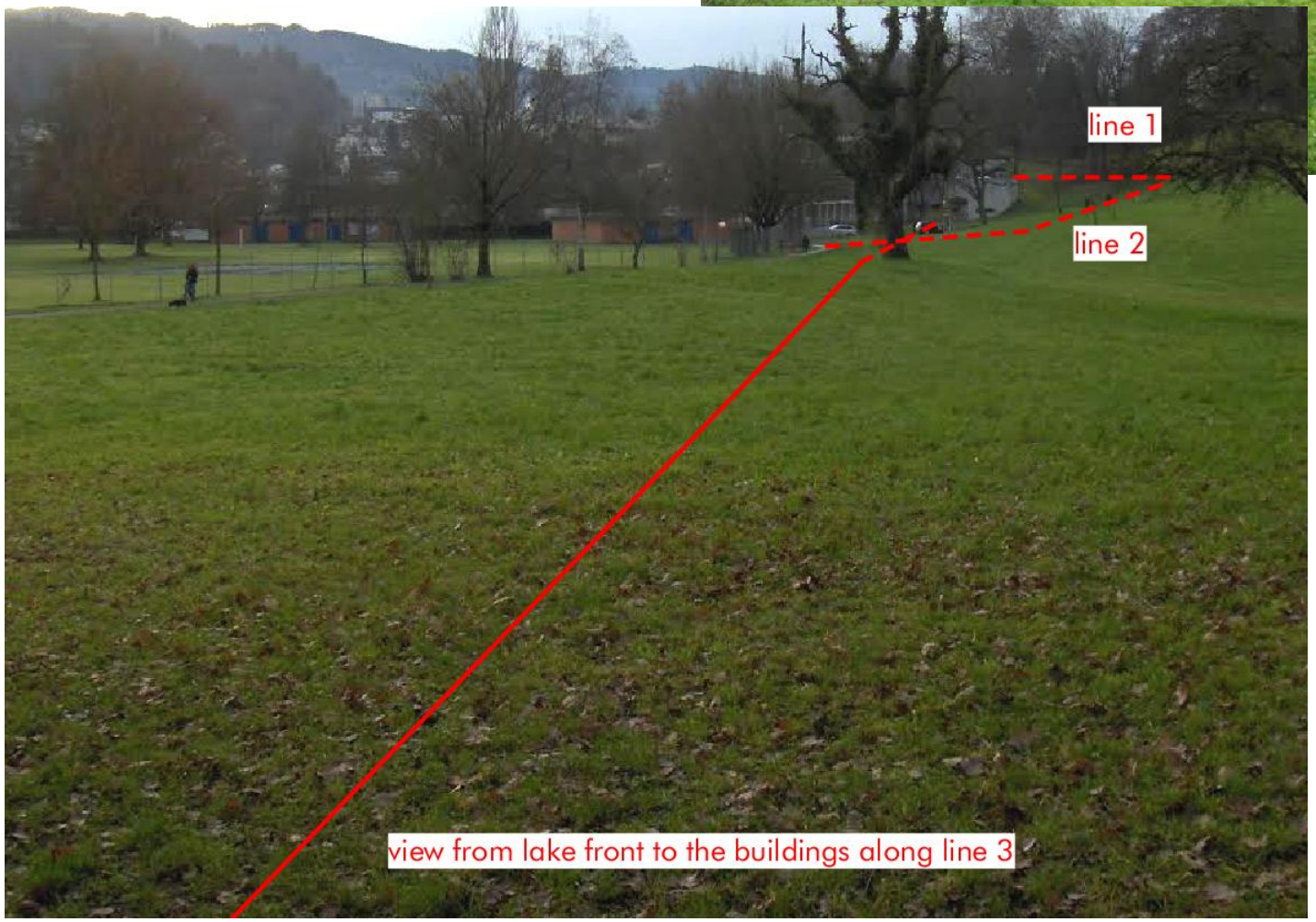
Vierwaldstättersee survey



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ADAM-2D

Apparent-**D**ispersion **A**nalysis of **M**ulticomponent Data – **2D**

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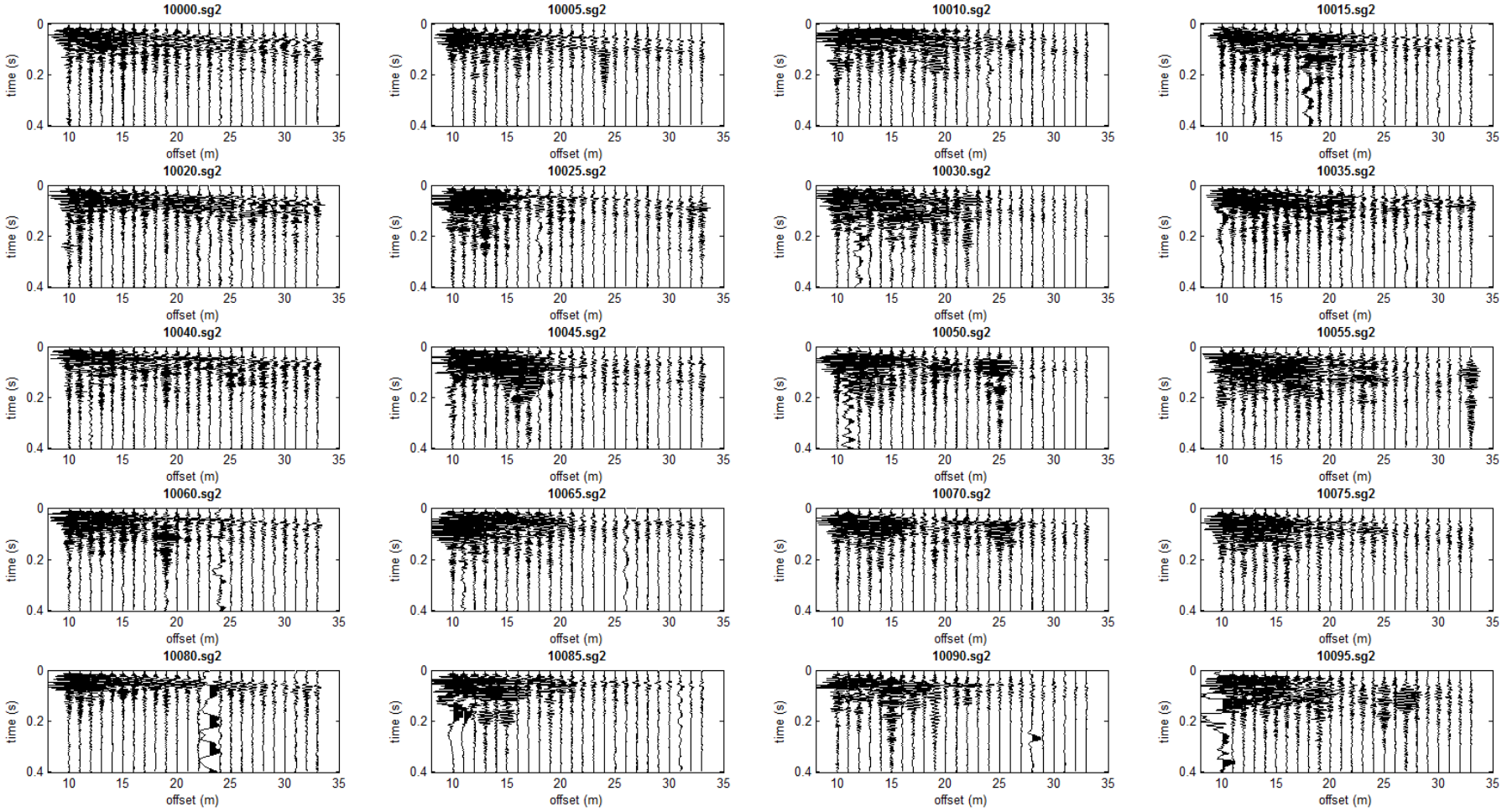
ADAM-2D

Apparent-**D**ispersion **A**nalysis of **M**ulticomponent Data – **2D**

Qatar survey

Automatic upload and pre-processing of the data

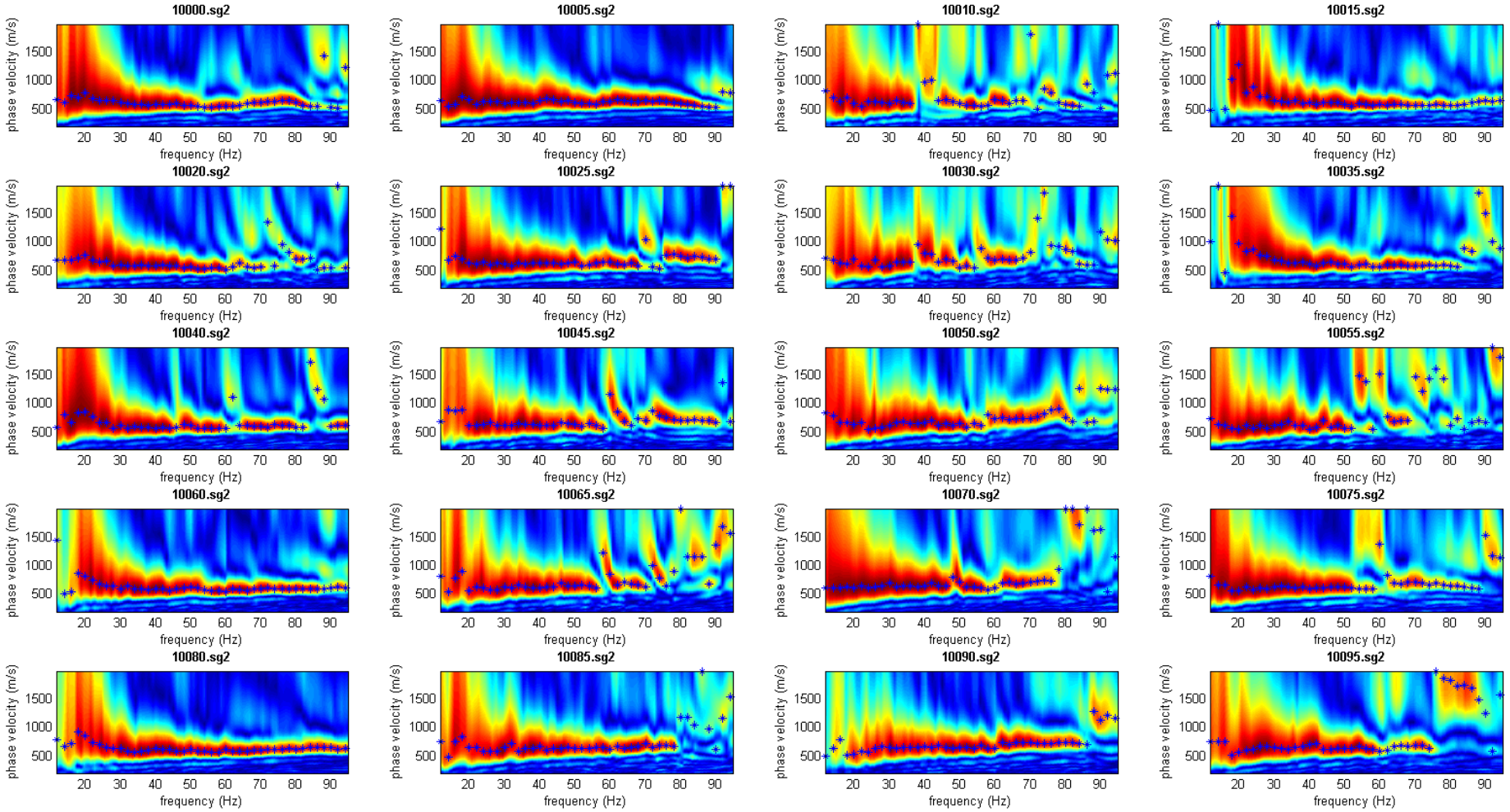


ADAM-2D

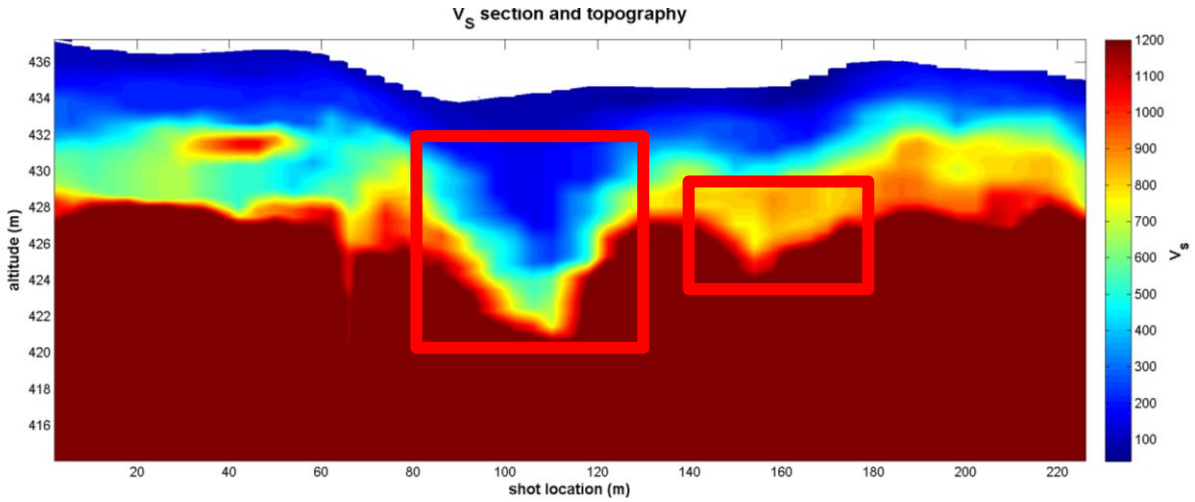
Apparent-**D**ispersion **A**nalysis of **M**ulticomponent Data – **2D**

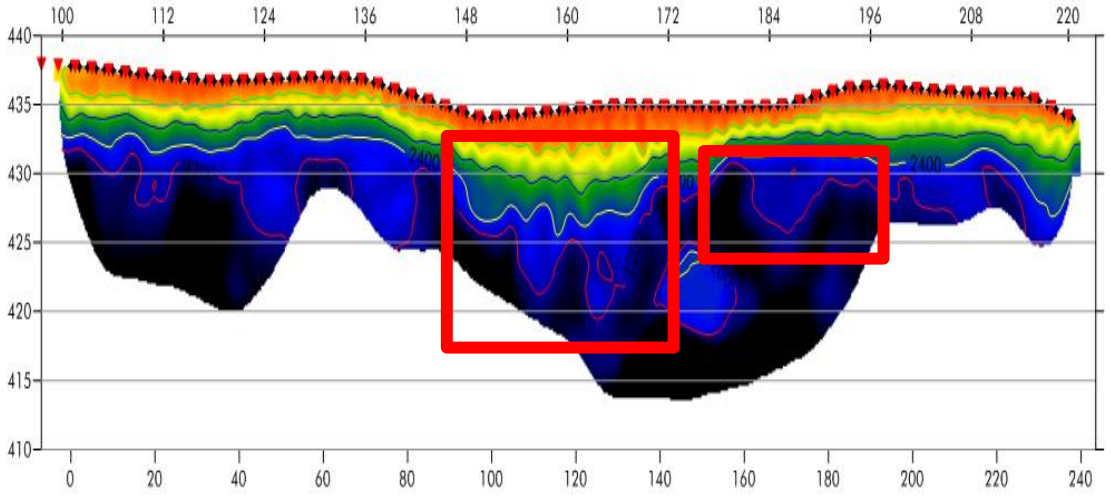
Qatar survey

Automatic computation of velocity spectra and <u>apparent dispersion curves for multi-component data</u>



ADAM-2D





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

L. Keller[1*], G. Dal Moro[2], C. Lacave[3]

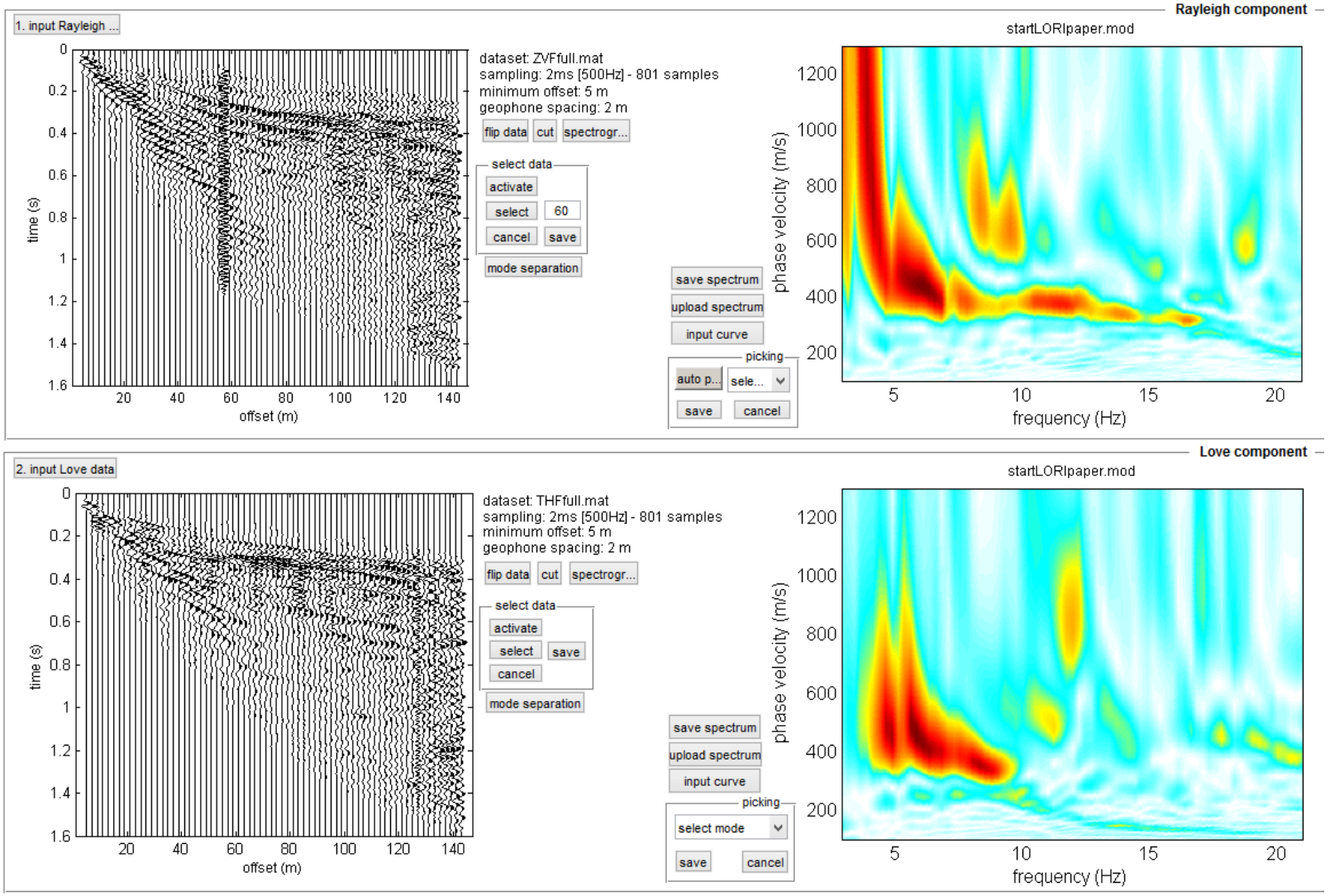
([1]) roXplore gmbh, seismic service provider, Amlikon (Switzerland)
[*]e-mail: lorenz@roxplore.ch

([2]) Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic, Prague (Czech Republic)

([3]) Résonance Ingénieurs-Conseils SA, dynamic engineering, Carouge (Switzerland)

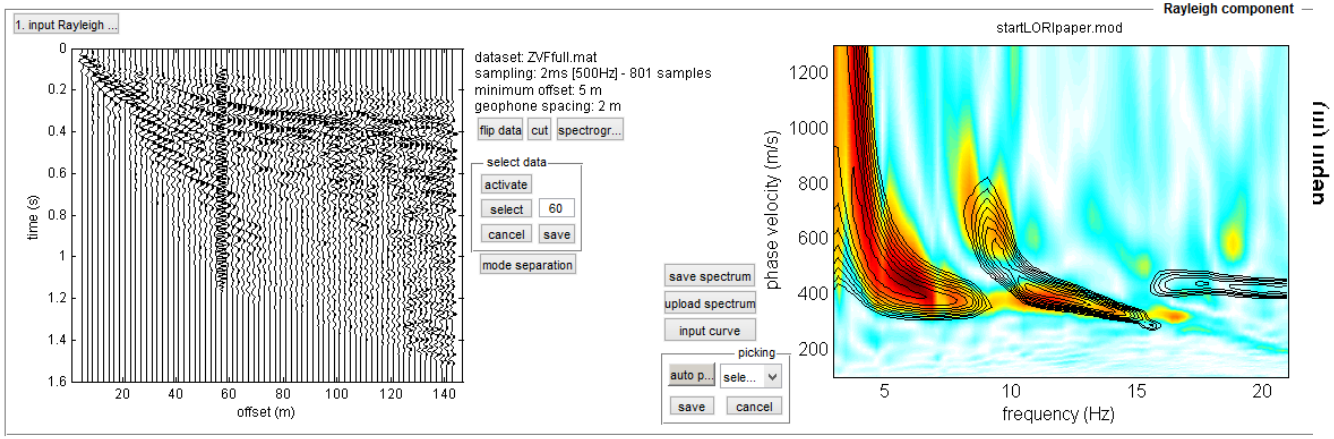
Oberflächengebundene Bestimmung eines robusten Vs-Modells als Eingangsparameter zu bodendynamischen Berechnungen an einer historischen Klosterkirche

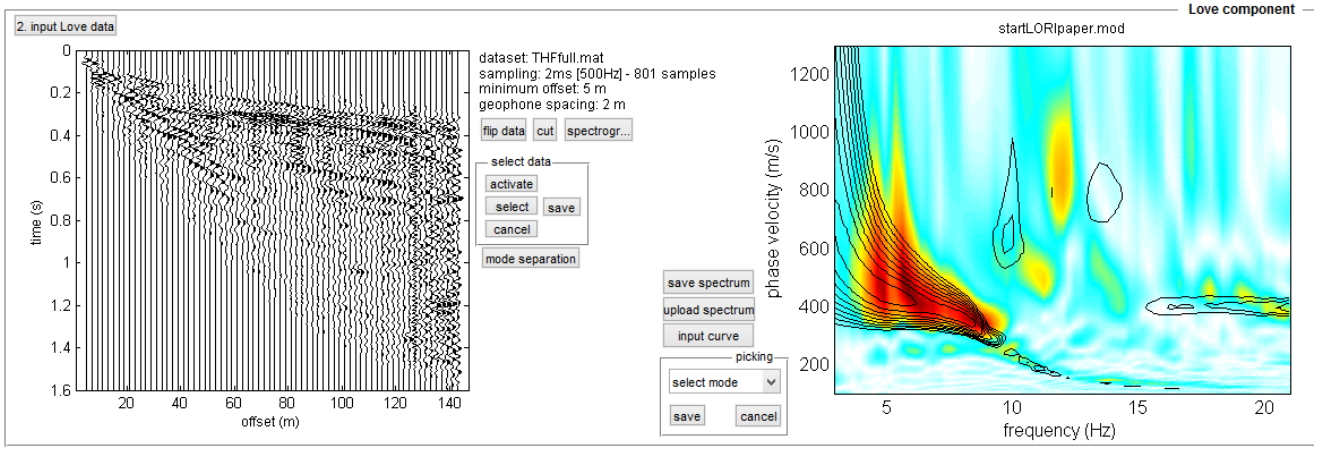
The “ordinary” multi-channel approach

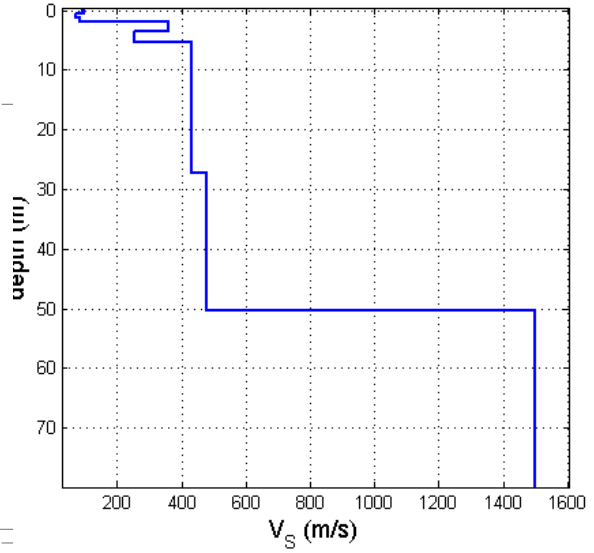


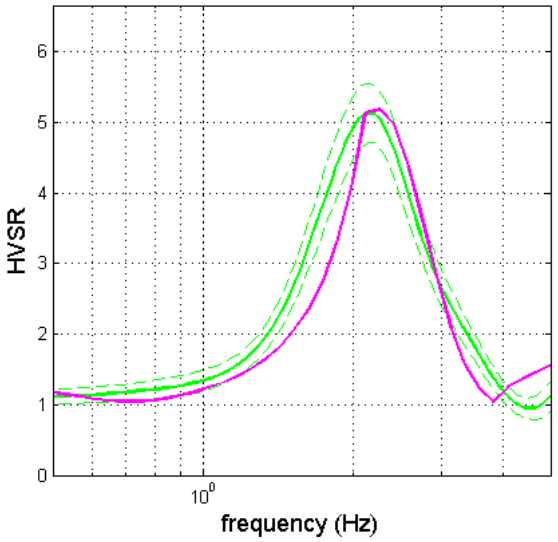
Oberflächengebundene Bestimmung eines robusten Vs-Modells als Eingangsparameter zu bodendynamischen Berechnungen an einer historischen Klosterkirche

The “ordinary” multi-channel approach







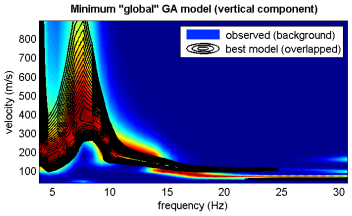


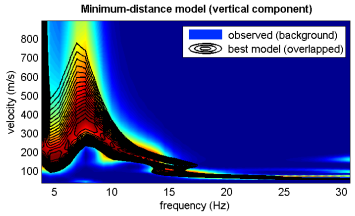
the unordinary approaches

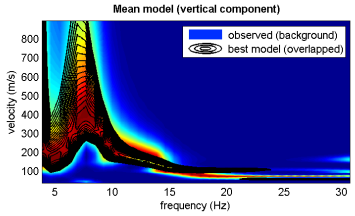
The more you know,
the less you need.

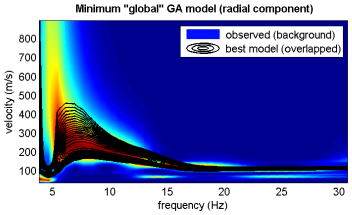
Yvon Chouinard

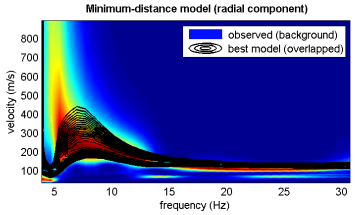
Oberflächengebundene Bestimmung eines robusten Vs-Modells als Eingangsparameter zu bodendynamischen Berechnungen an einer historischen Klosterkirche

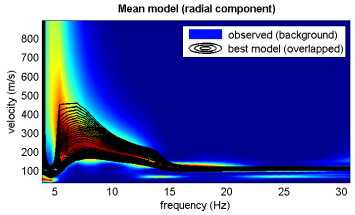


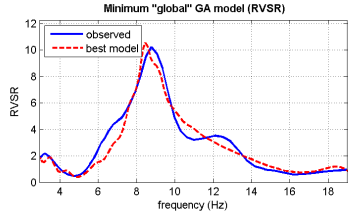


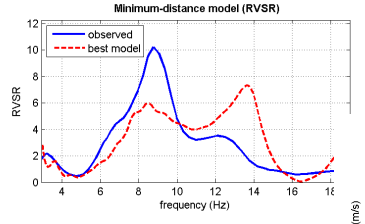


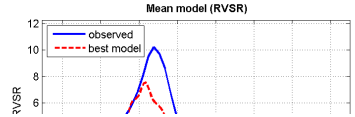


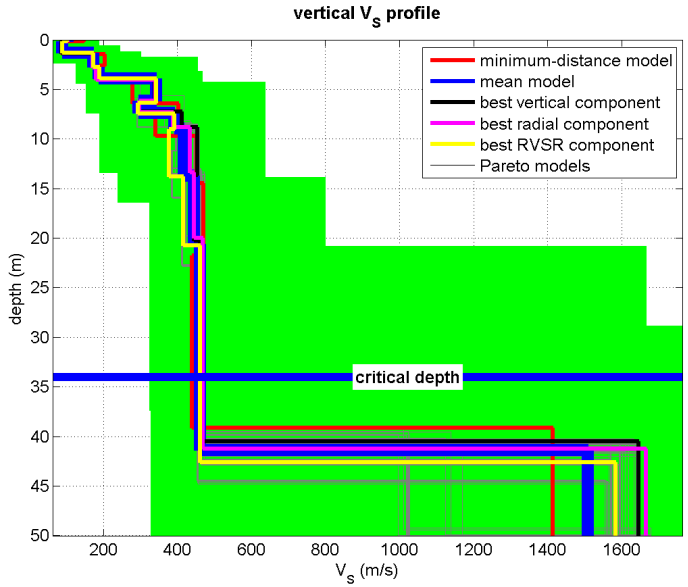


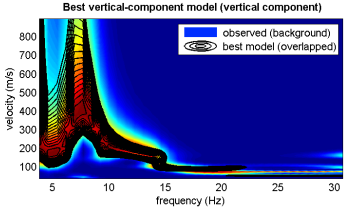


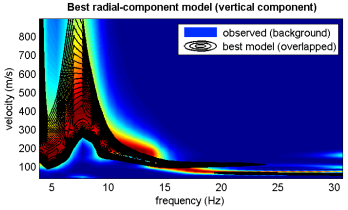


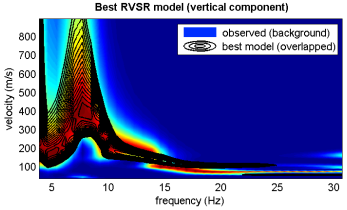


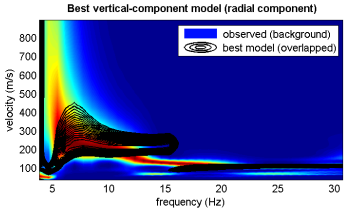


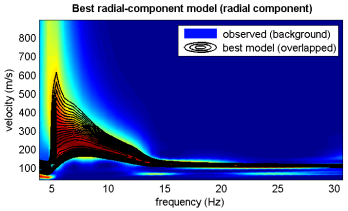


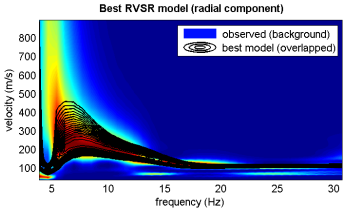


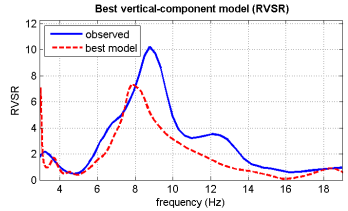


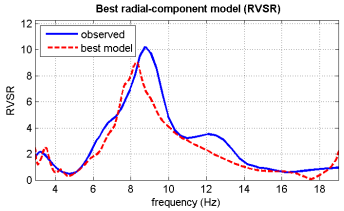


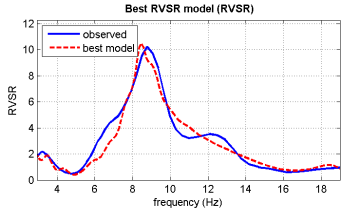






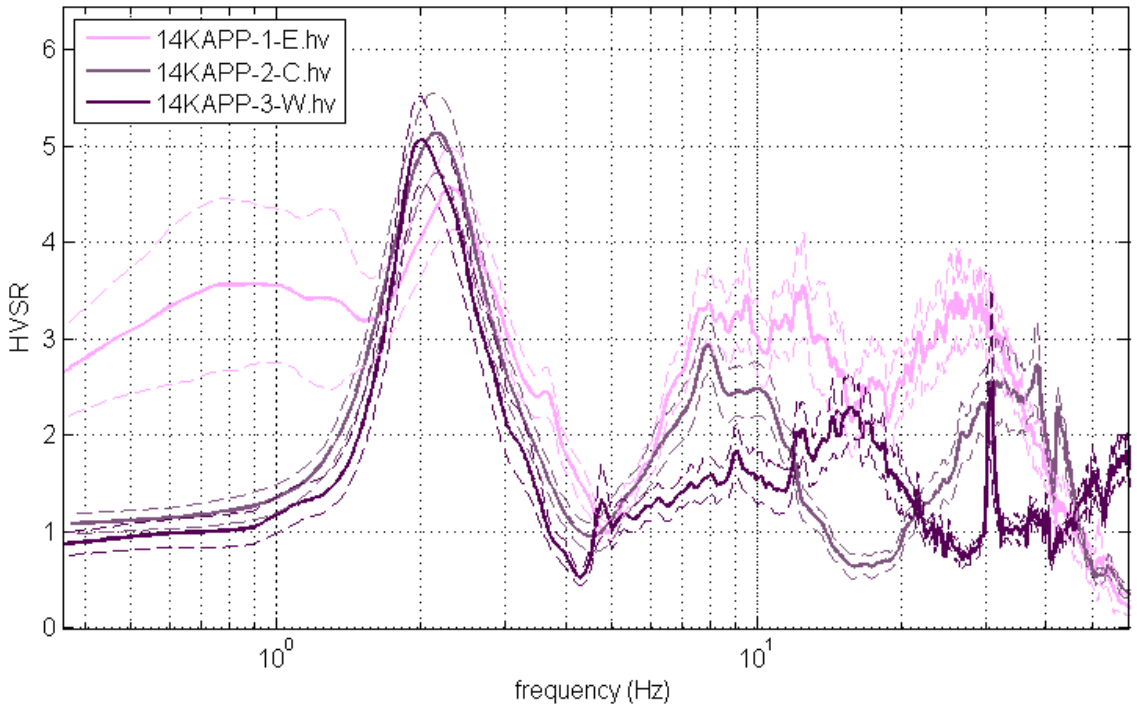




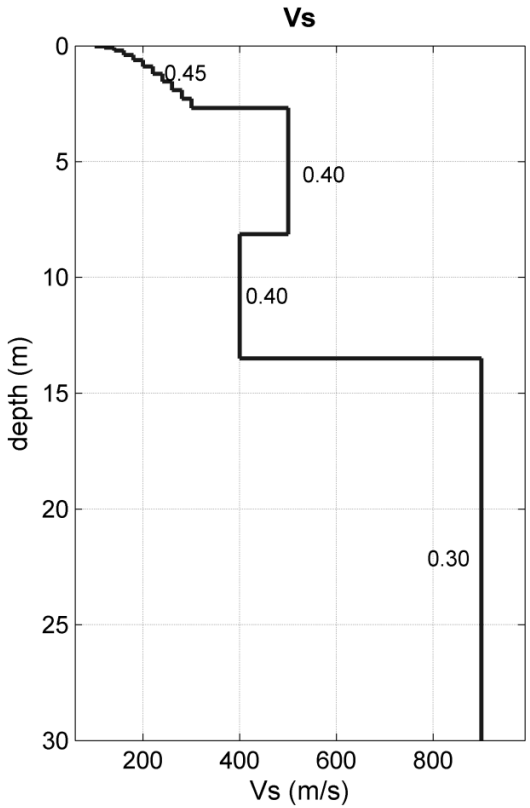


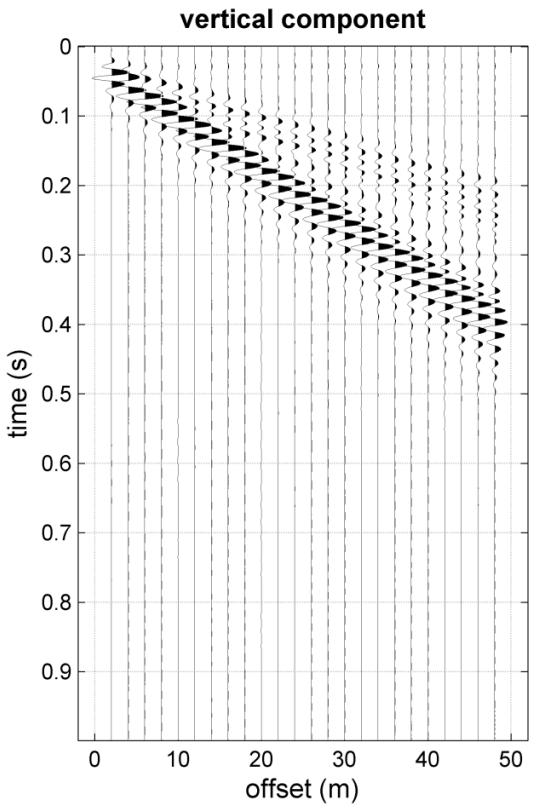
Pure *HoliSurface*

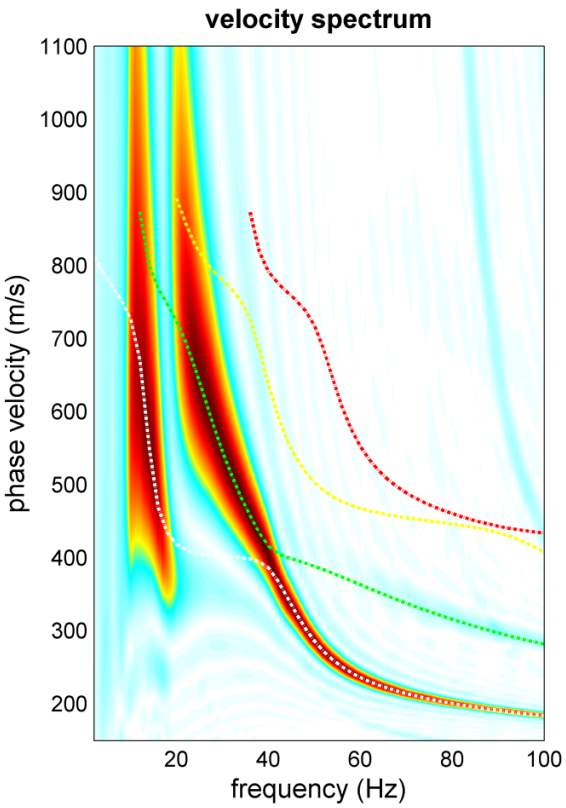
Oberflächengebundene Bestimmung eines robusten Vs-Modells als Eingangsparameter zu bodendynamischen Berechnungen an einer historischen Klosterkirche



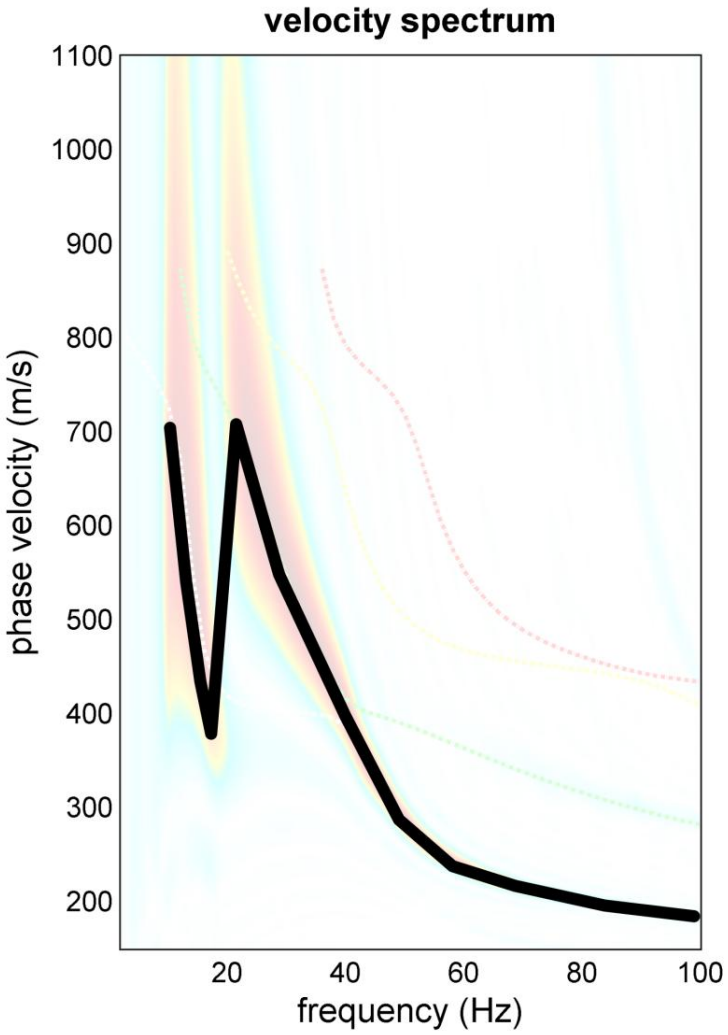
Modal and effective dispersion curves: problems and solutions







Modal and effective dispersion curves: problems and solutions



Modal and effective dispersion curves: problems and solutions

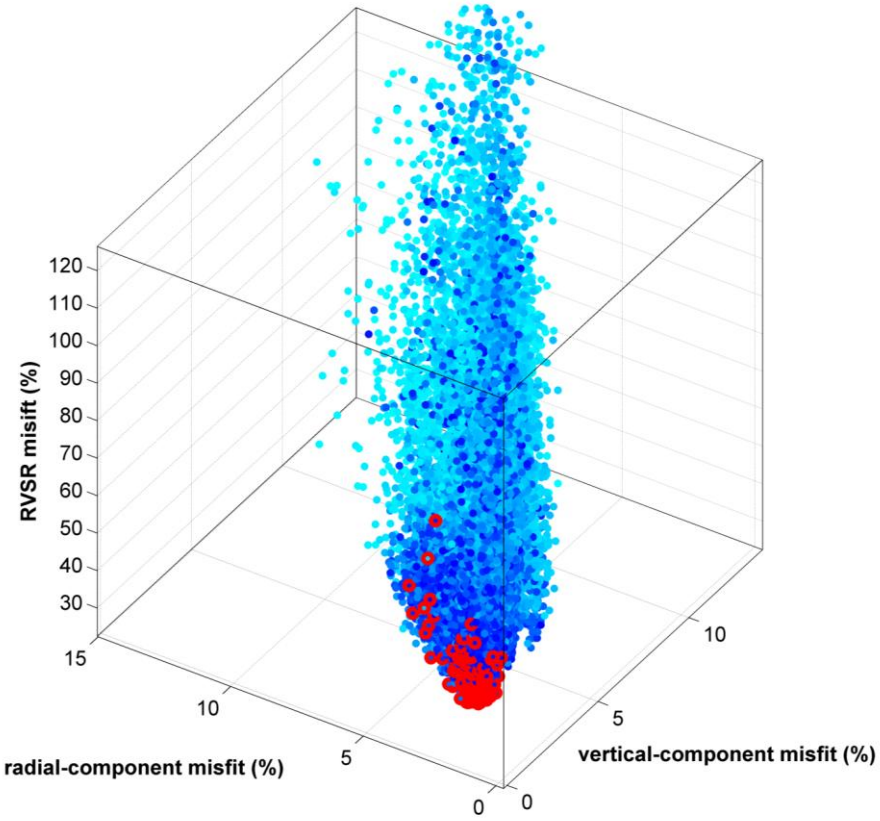
From (11) and (12), the relative powers of the vertical and horizontal motions of mth mode can be expressed as $A_m^2 c_m$ and $(A_m[\dot{u}/\dot{w}]_m)^2 c_m$, respectively. Hence, by knowing A_m, c_m, and $[\dot{u}/\dot{w}]_m$ of each mode for a frequency f, the apparent phase velocities of vertical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

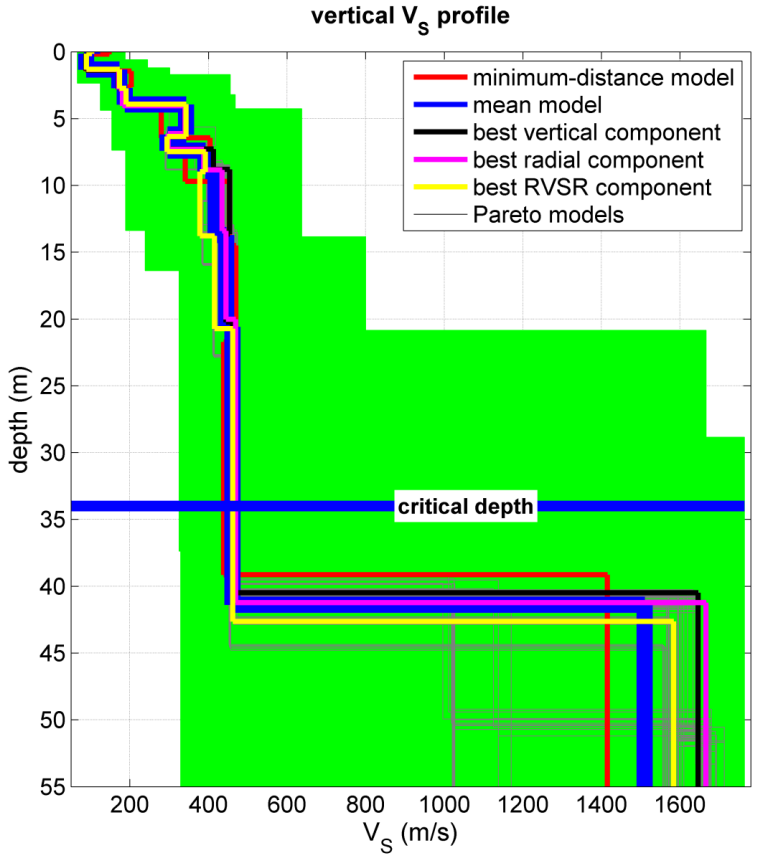
$$c_{sv} = \frac{2\pi f D}{\cos^{-1}\left[\dfrac{\sum_{m=1}^{M} A_m^2 c_m \cos\left(\dfrac{2\pi f D}{c_m}\right)}{\sum_{m=1}^{M} A_m^2 c_m}\right]} \qquad \text{(20)}$$

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

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

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

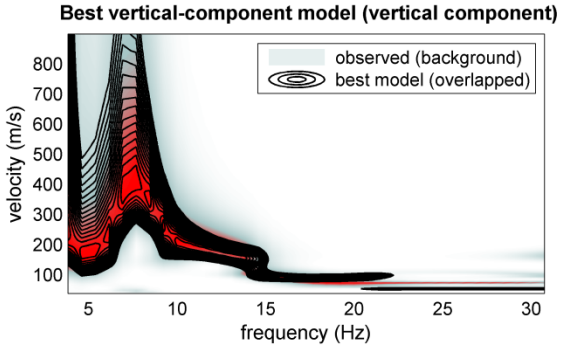


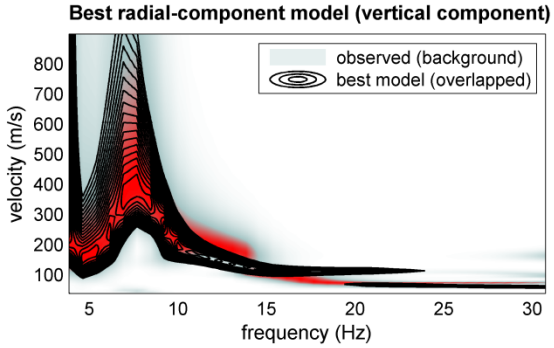


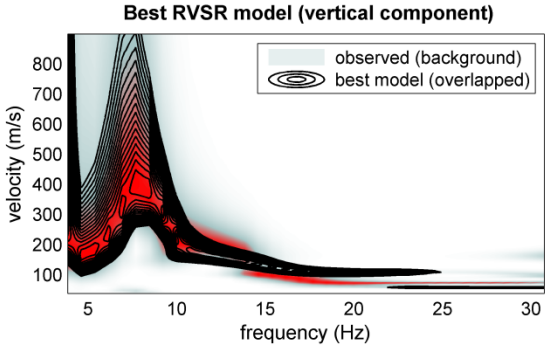
The unordinary *HoliSurface* approach

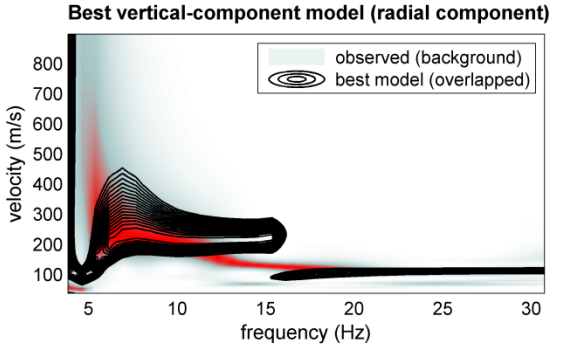
Oberflächengebundene Bestimmung eines robusten Vs-Modells als Eingangsparameter zu bodendynamischen Berechnungen an einer historischen Klosterkirche

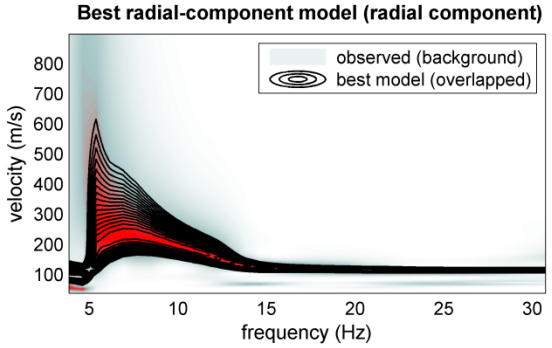
The unordinary *HoliSurface* approach

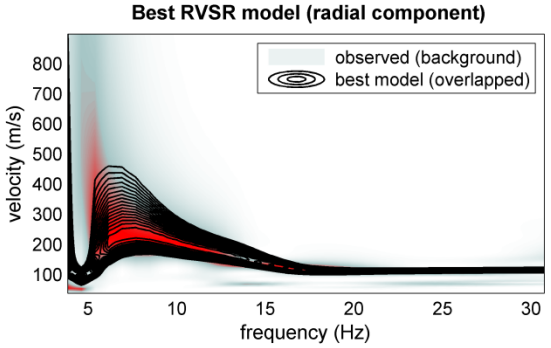


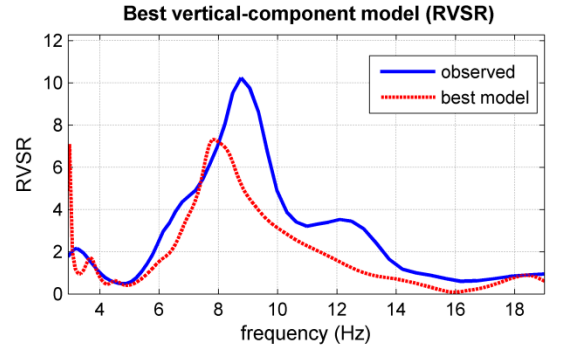


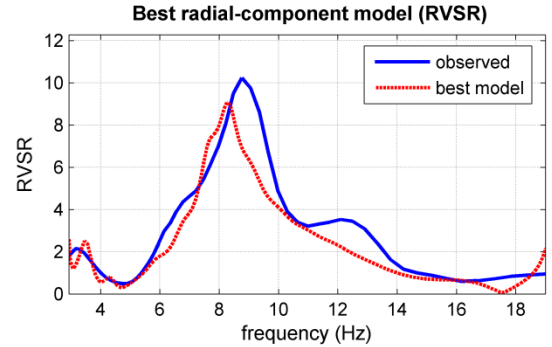


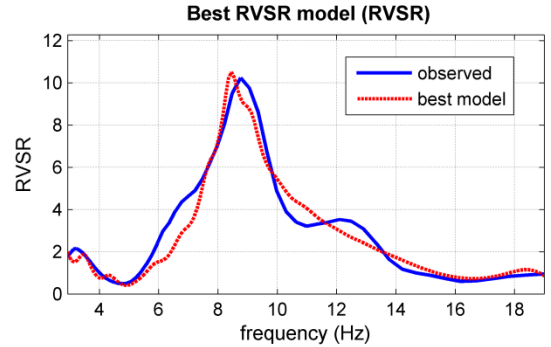






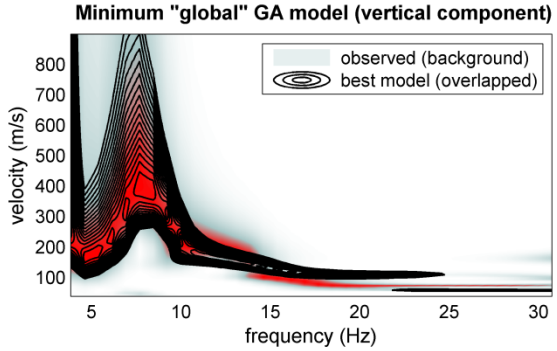


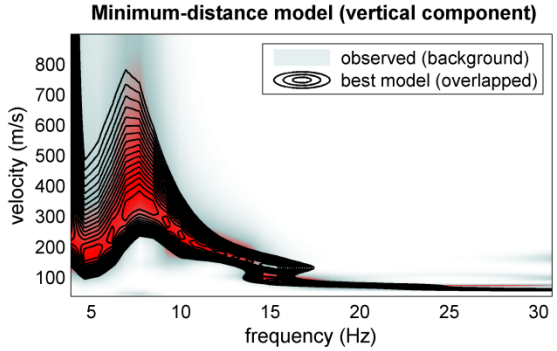


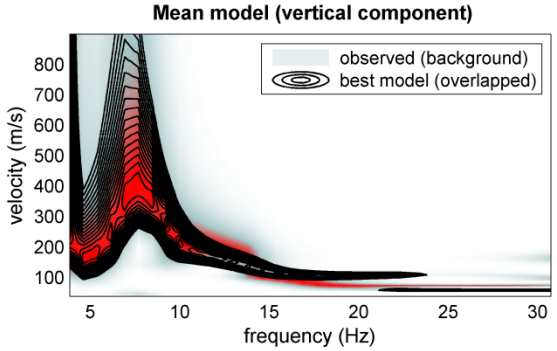


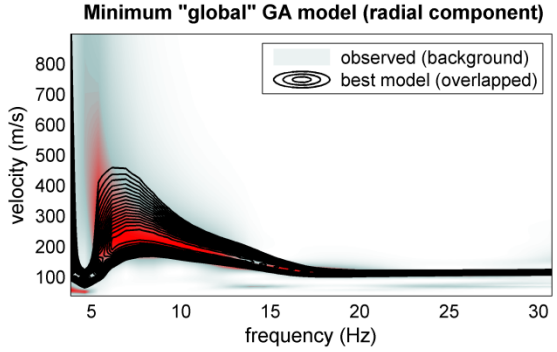
Oberflächengebundene Bestimmung eines robusten Vs-Modells als Eingangsparameter zu bodendynamischen Berechnungen an einer historischen Klosterkirche

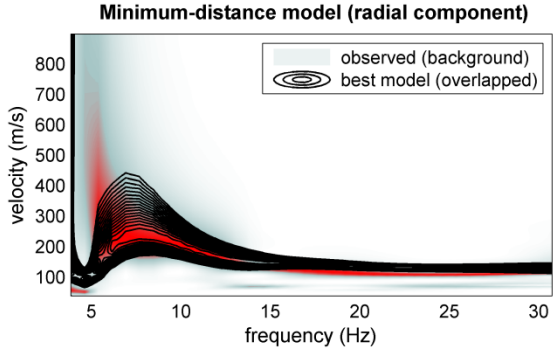
The unordinary *HoliSurface* approach

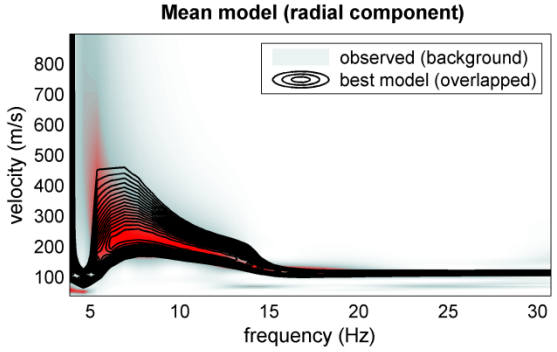


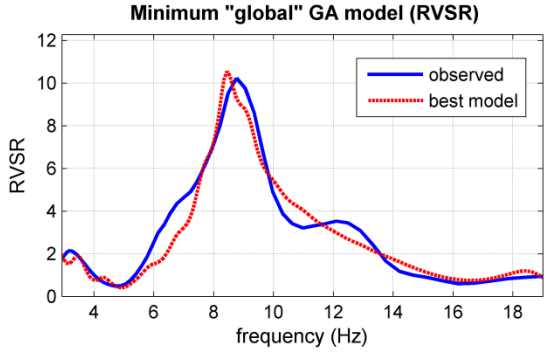


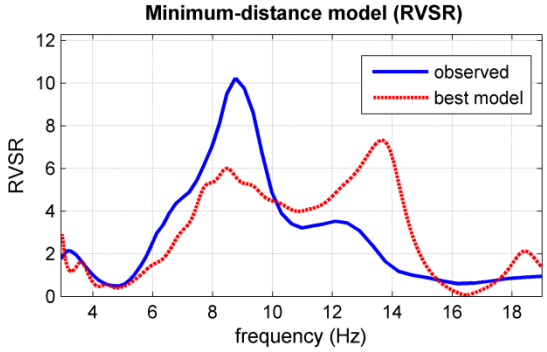


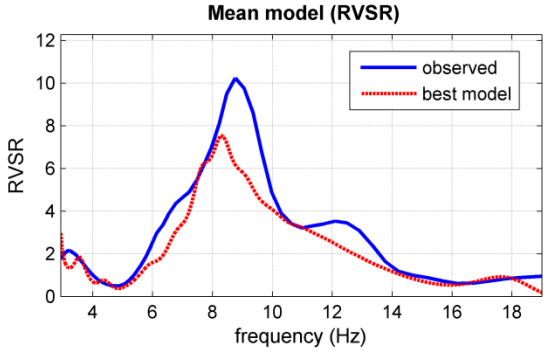










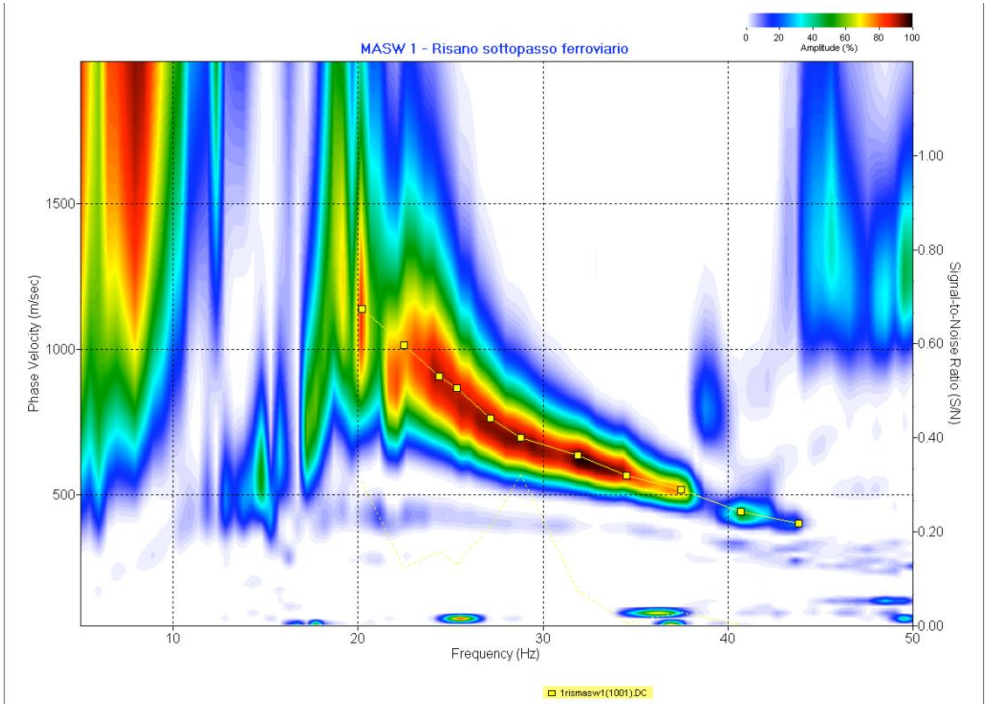


Modal and effective dispersion curves: problems and solutions

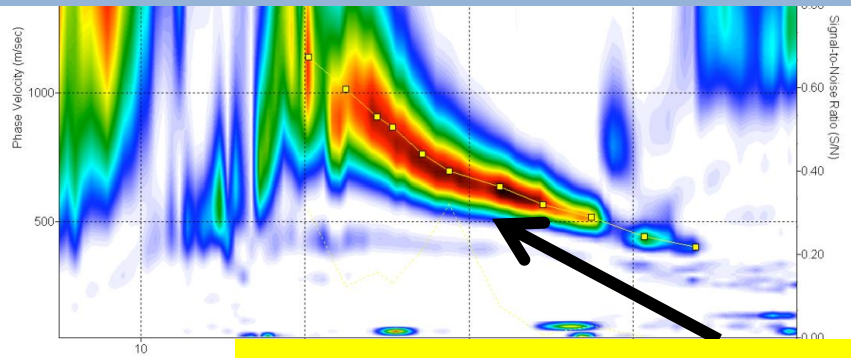
"MASW"

Downhole

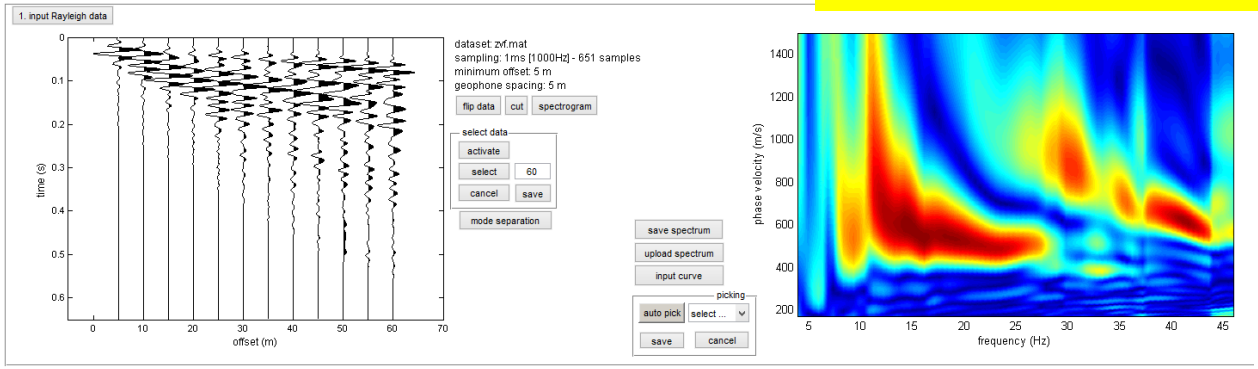
P-wave refraction

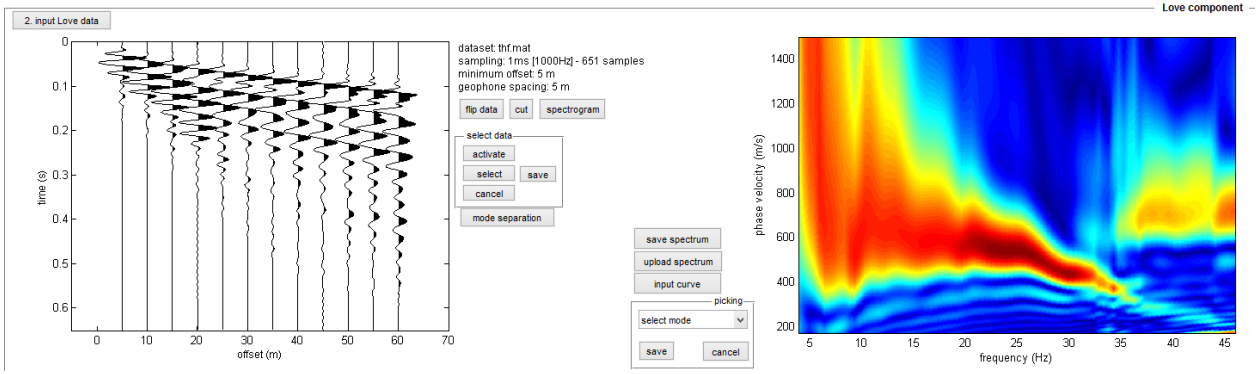


Modal and effective dispersion curves: problems and solutions

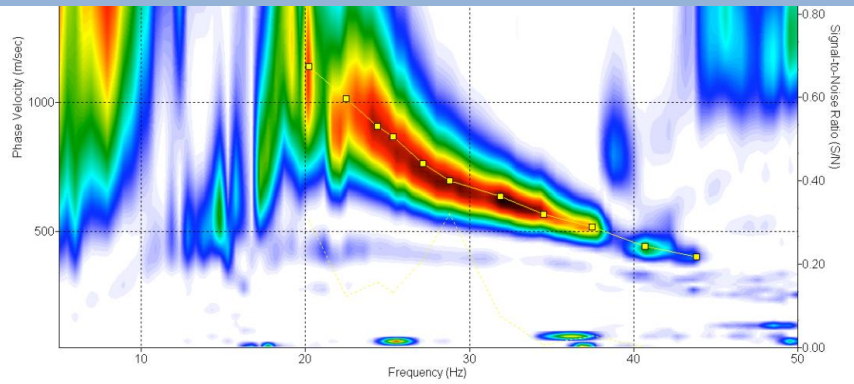


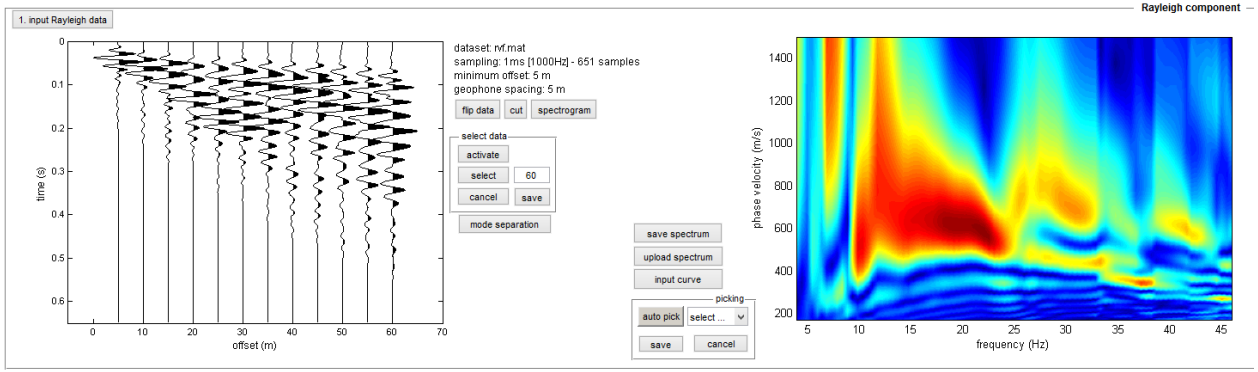
Dies ist nicht der Fundamentalmodus!

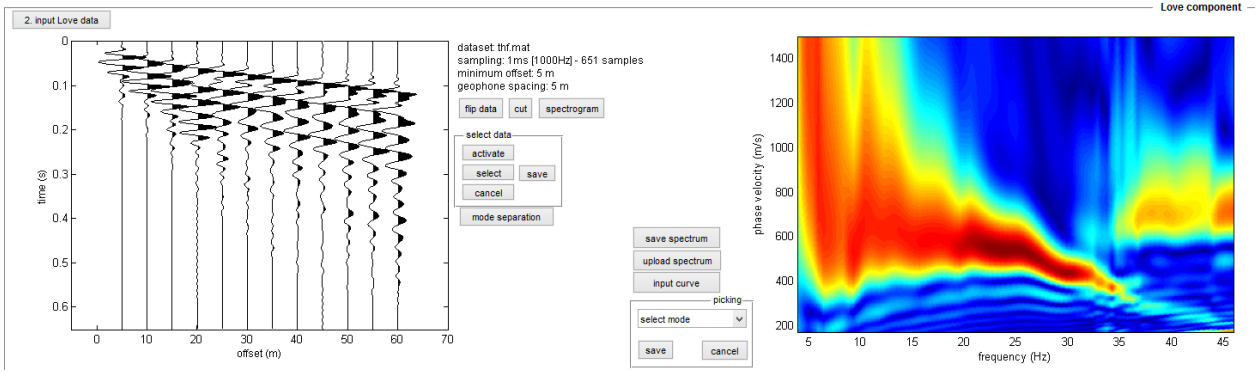




Modal and effective dispersion curves: problems and solutions

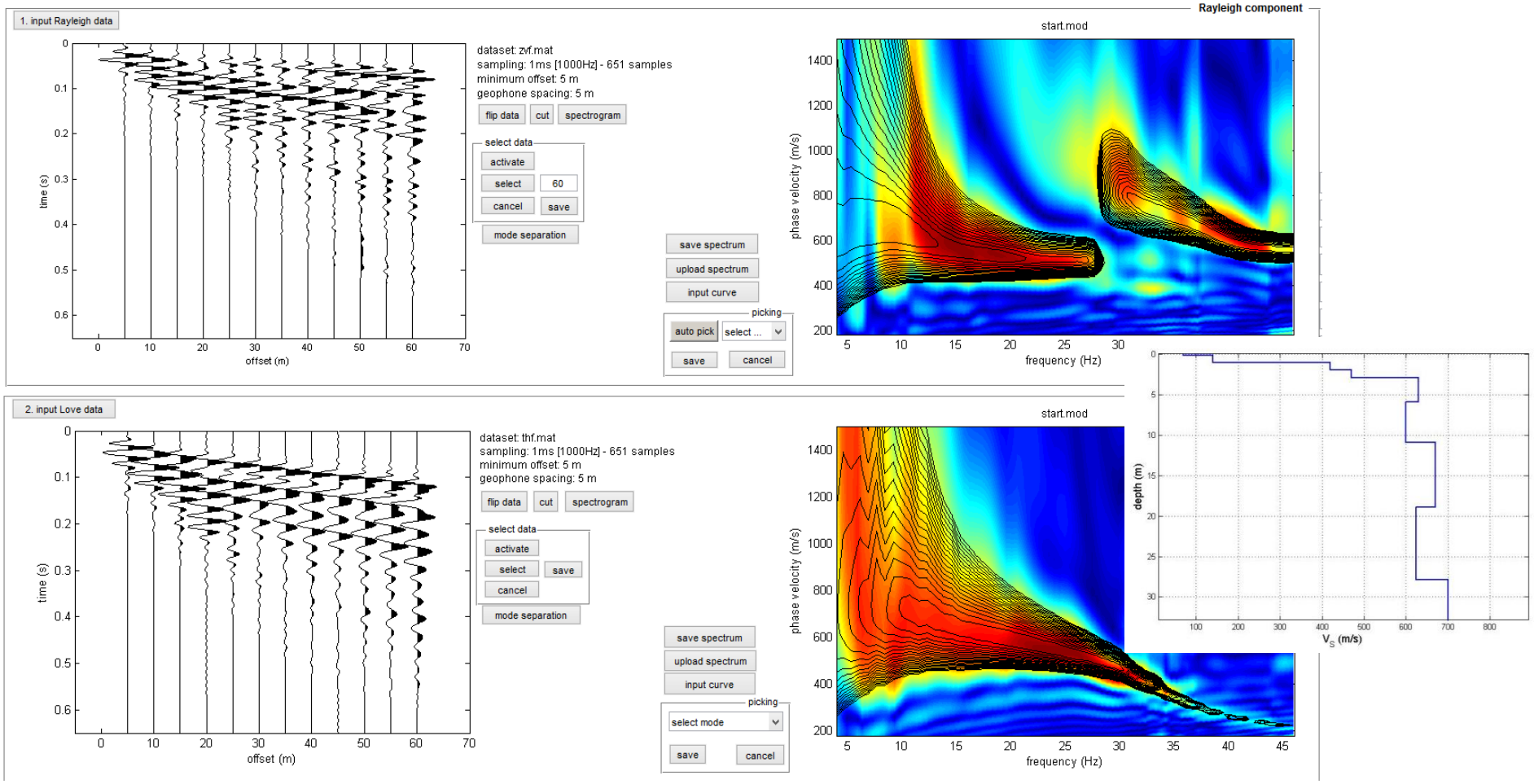






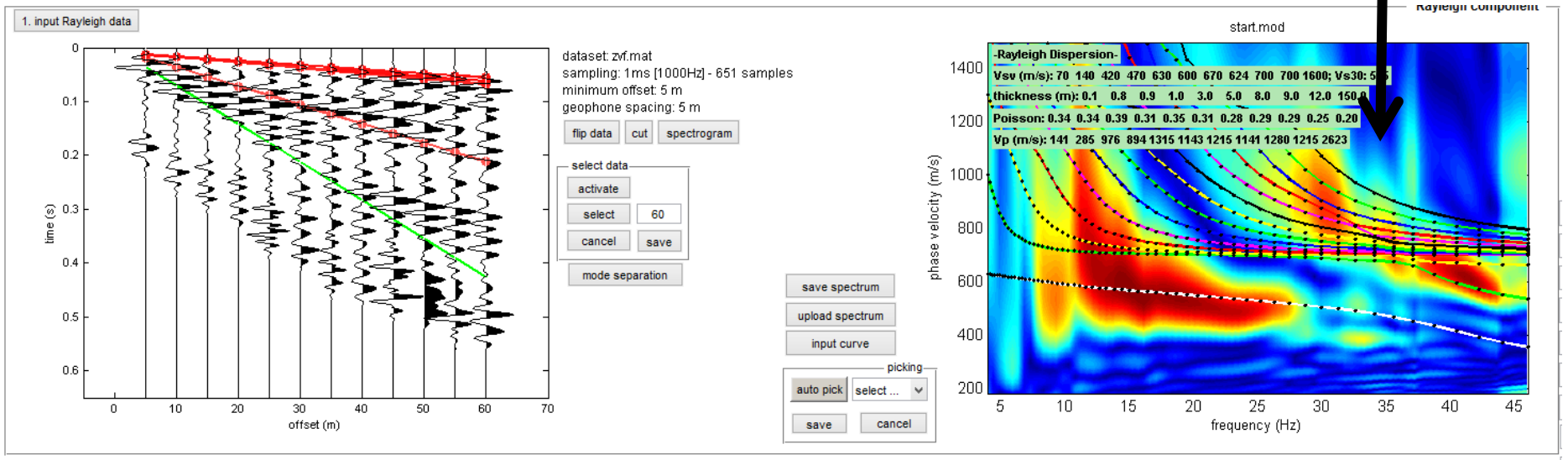
Modal and effective dispersion curves: problems and solutions

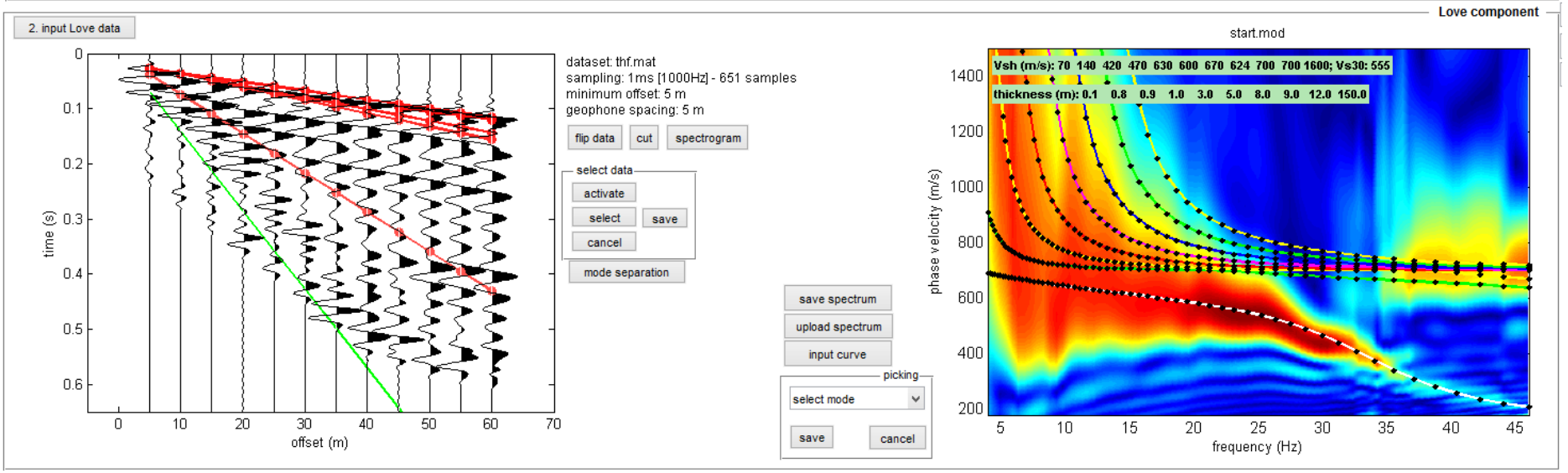
Our joint FVS solution



About modes (and refraction)

Dies ist nicht ein einziger Modus!





Lesson:

1) DO NOT use modal dispersion curves;
2) DO NOT use (only) Rayleigh waves.

So:

1) Use FVS (*Full Velocity Spectrum*) analysis and/or the *effective* dispersion curves;
2) Use (also) Love waves.

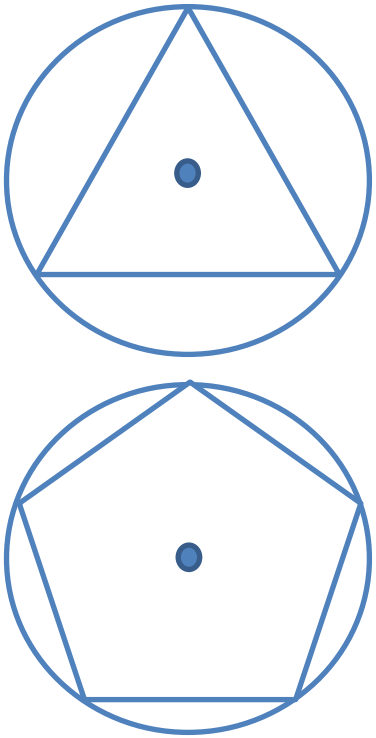
What's in common?

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

HS

HVSR

MAAM



Noise

Two volunteers, please

HoliSurface®

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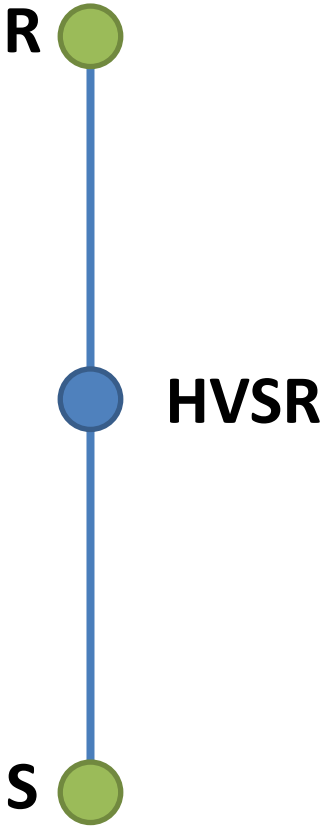
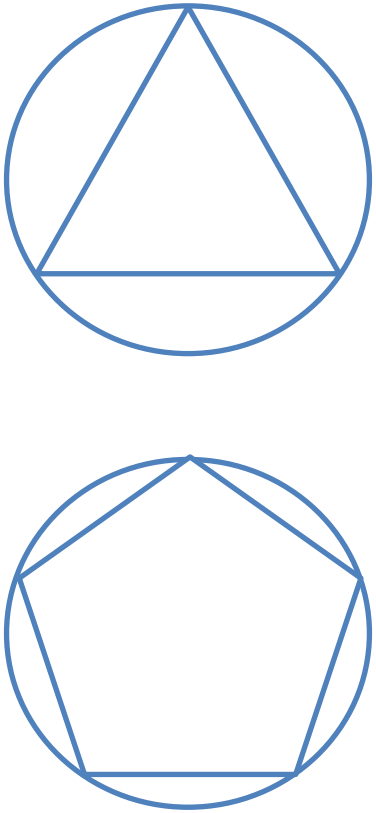
Richard Long

HS

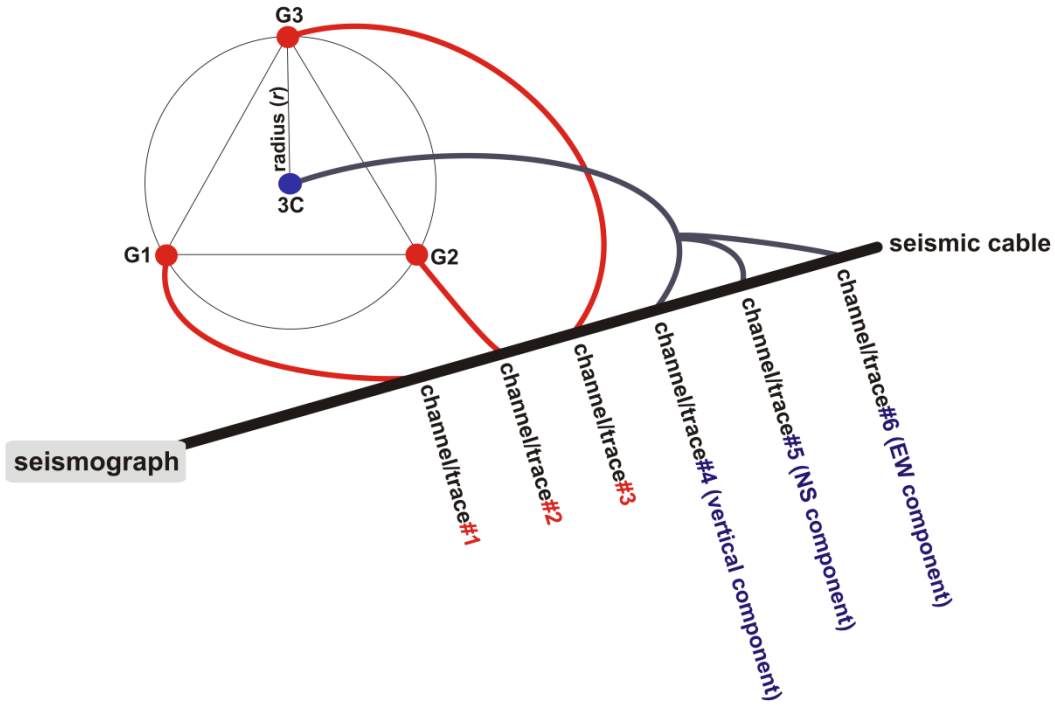


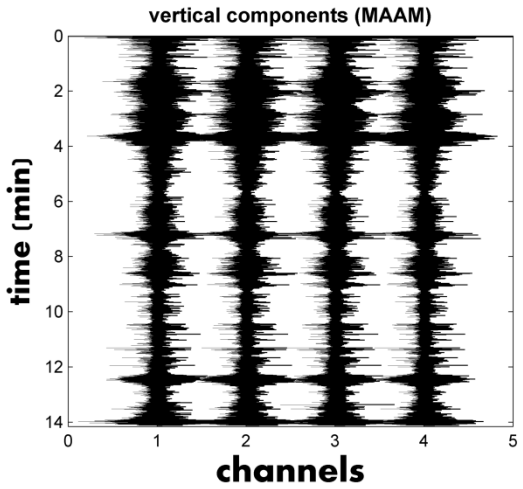
MAAM

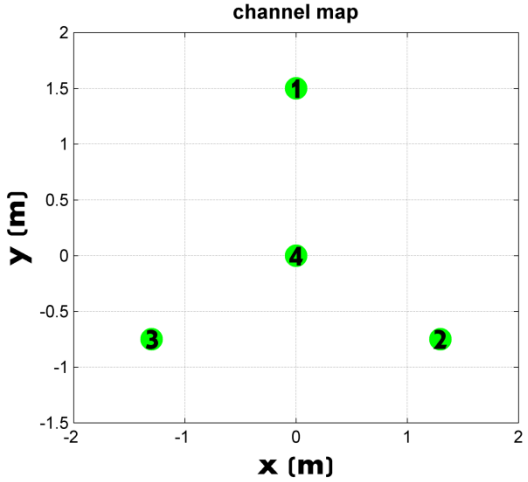


An efficient urban palindrome

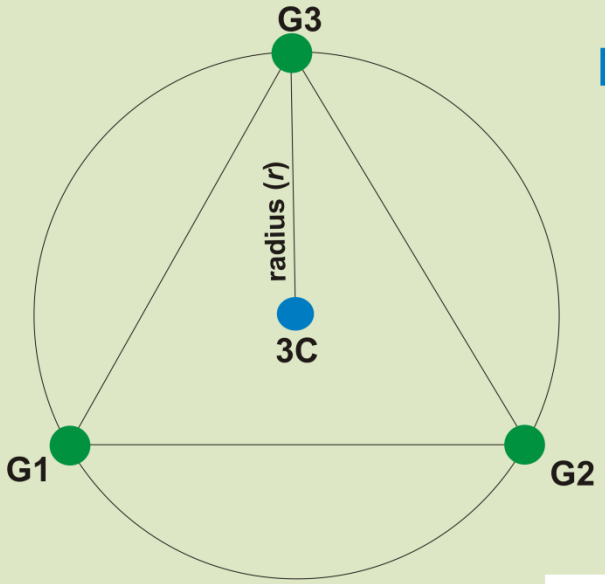
HoliSurface®

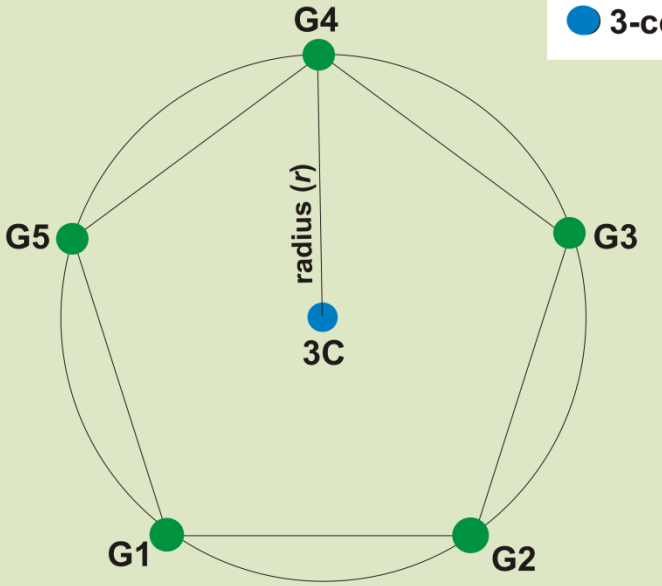




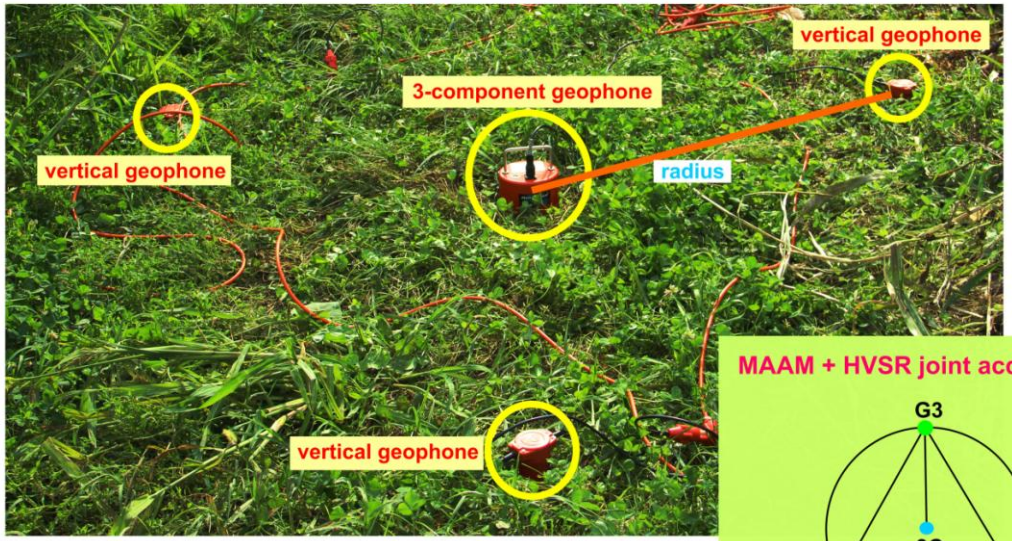


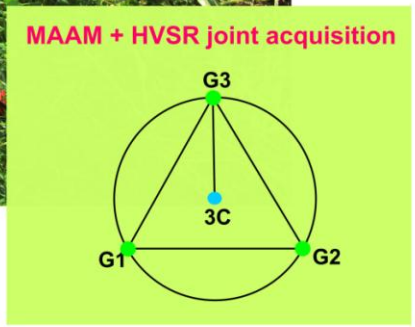
MAAM + HVSR joint acquisition





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





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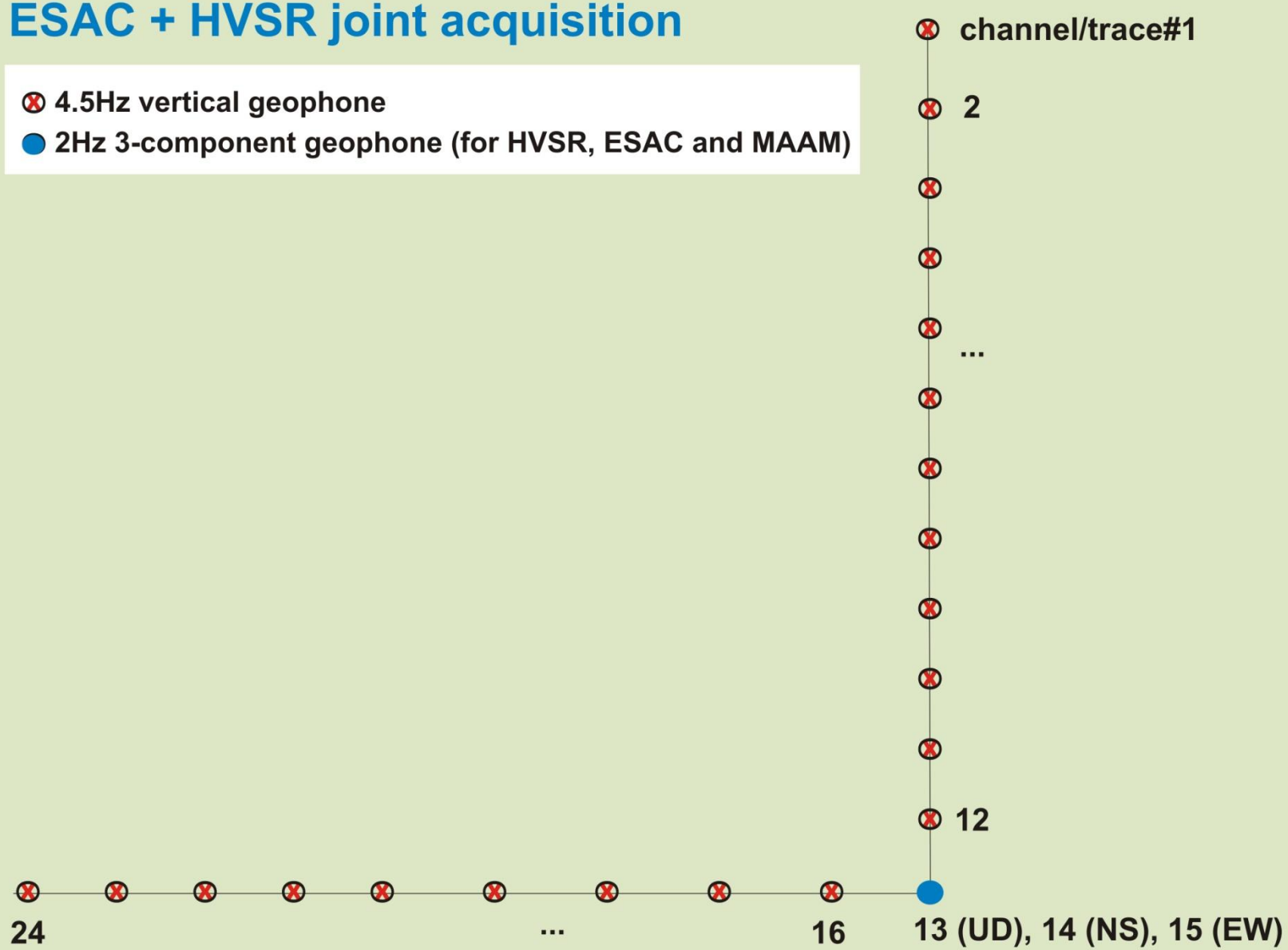
ESAC + HVSR joint acquisition



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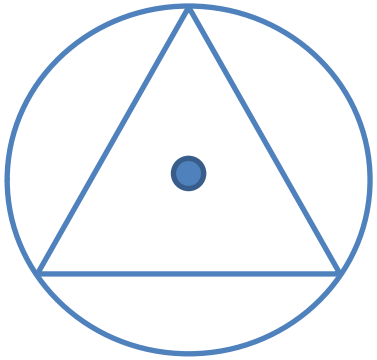
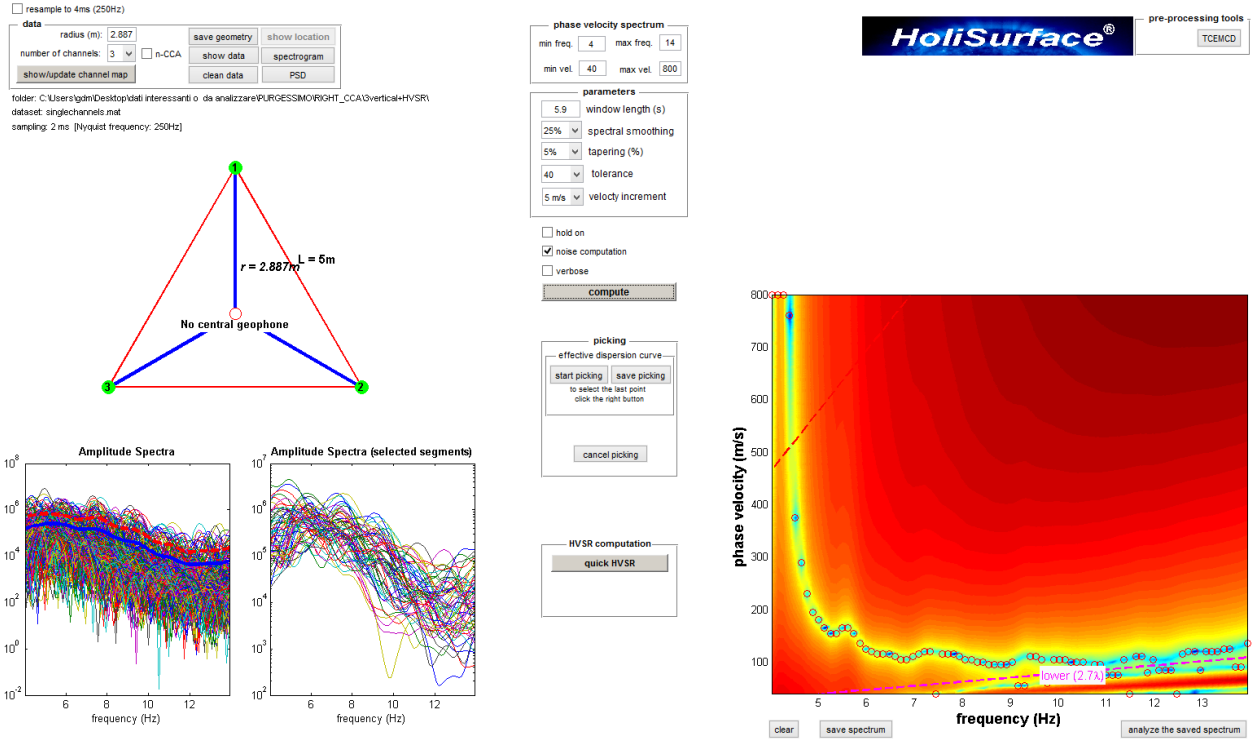
MAAM





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

HoliSurface®

Scavo 2 – (corrispondente H/V2)

0-45/50 terreno agrario

45/50-270 limo da debolmente sabbioso a sabbioso

270-370 sabbia fine limosa

370-410 ghiaia e ciottoli in scarsa matrice limosa

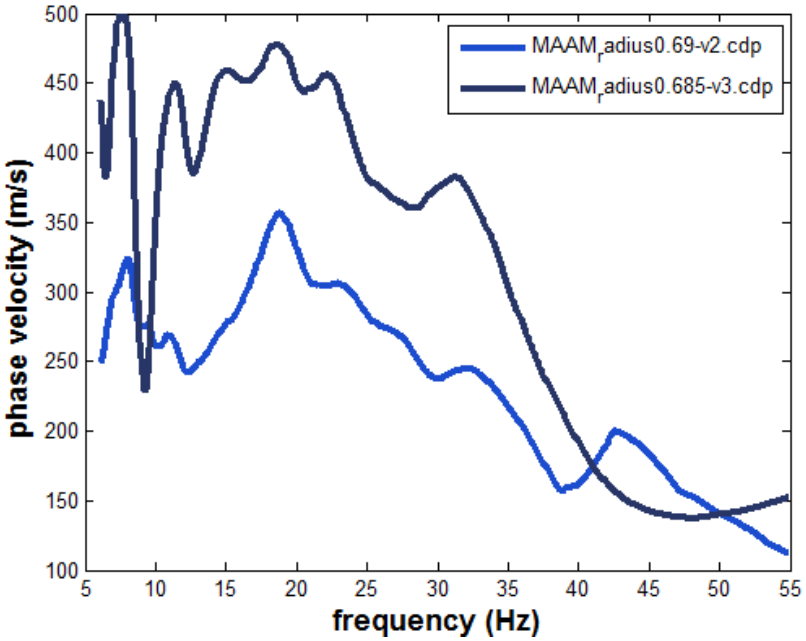
Scavo 3 – (corrispondente H/V3)

0-40/45 terreno agrario

40/45-110 limo da debolmente sabbioso a sabbioso

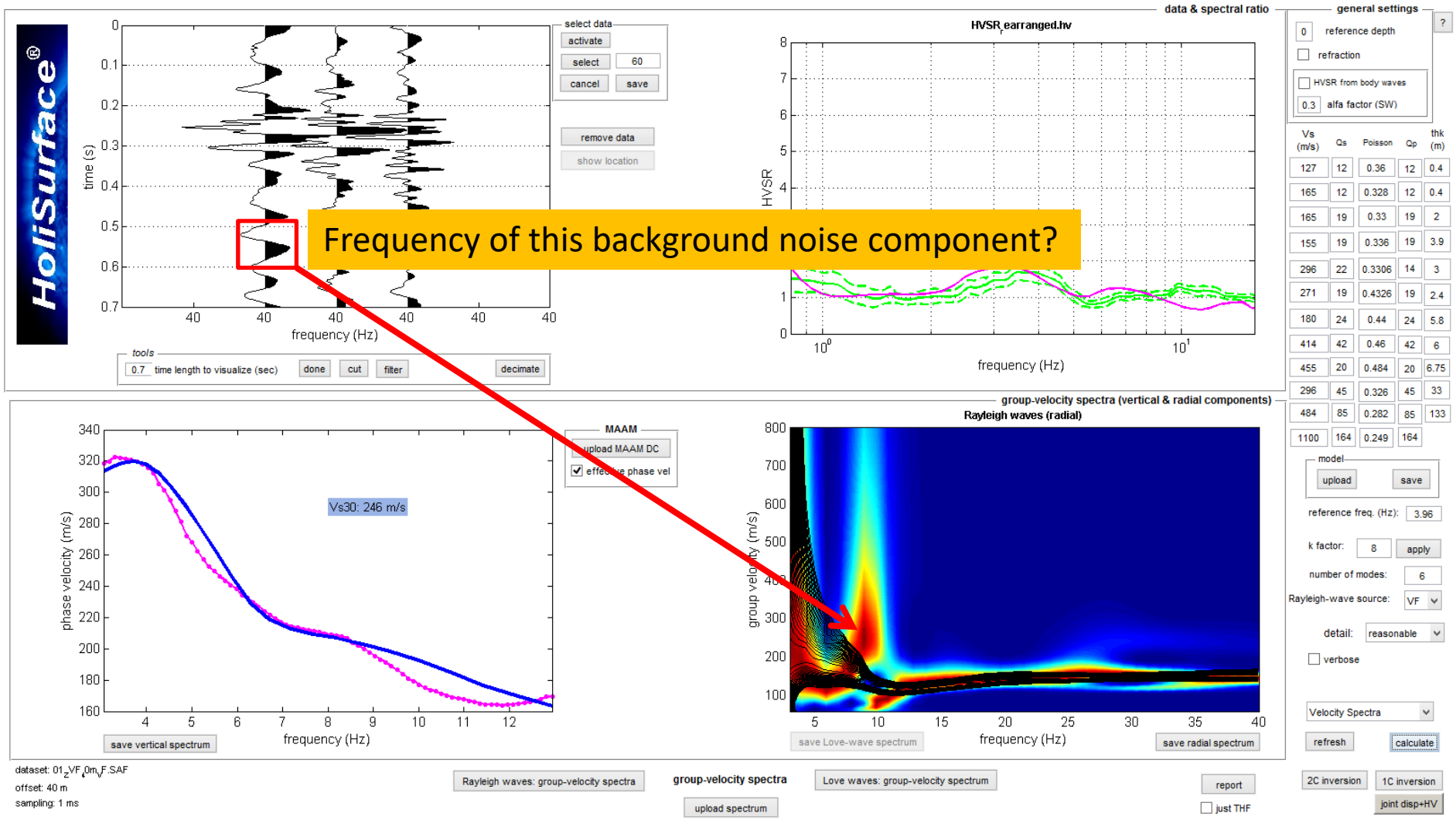
110-180 ghiaia e ciottoli in matrice limosa

180-300 ghiaia sabbia con ciottoli



Comparing the effective dispersion curves at site#2 and #3

A “noisy” desperate case



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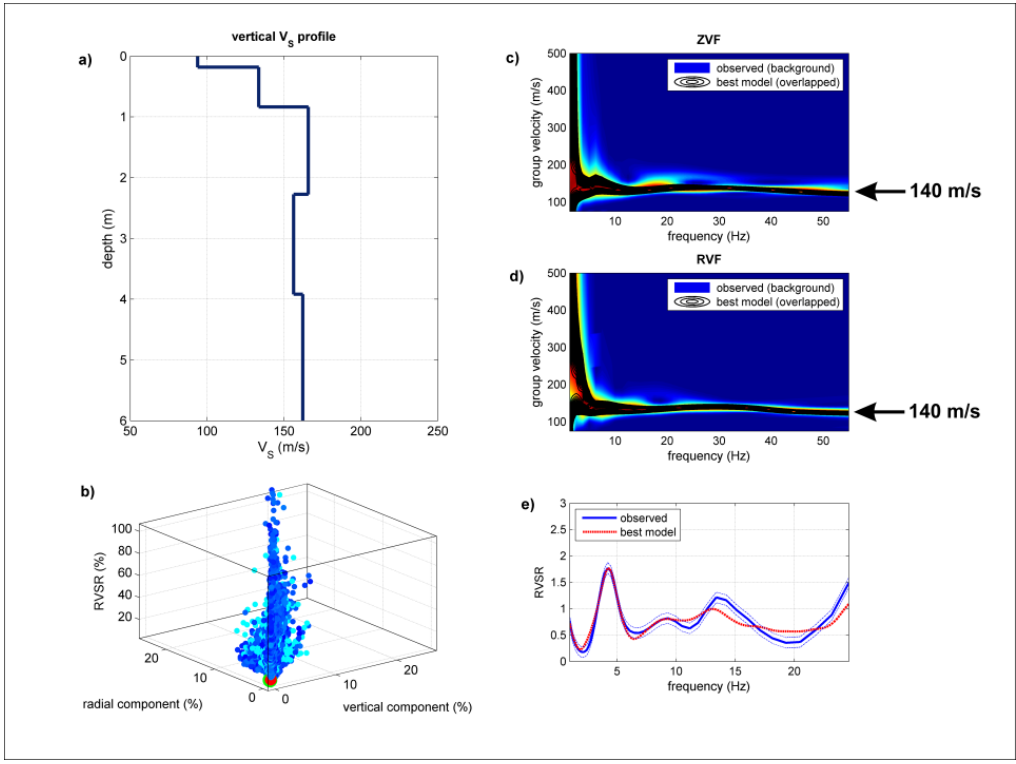
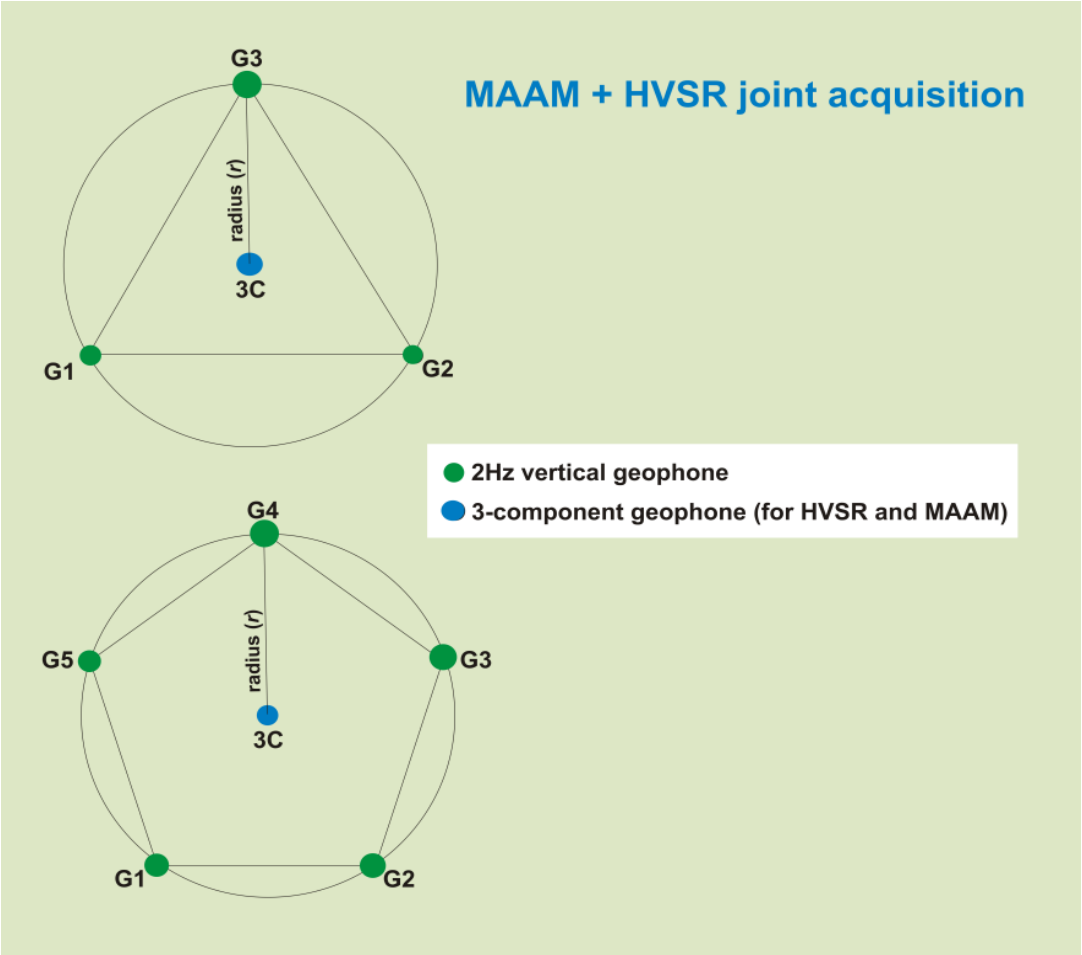
What's in common?

Calibrated and triggered geophone



MAAM (Miniature Array Analysis of Microtremors)



MAAM

Preliminary equipment test

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

radius/radii

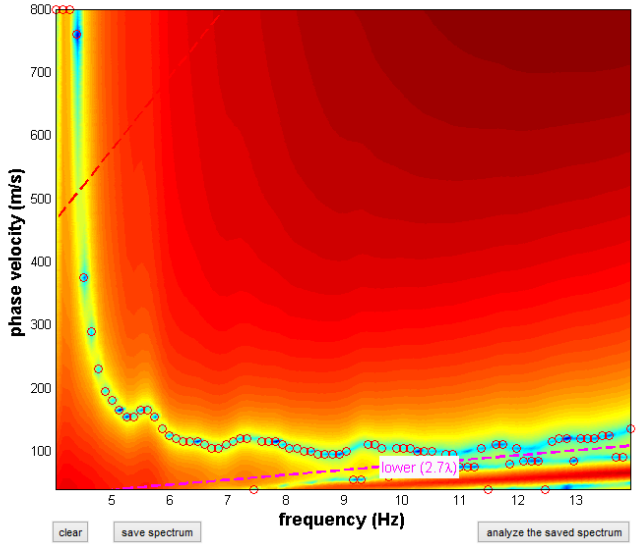
Tolerance & smoothing

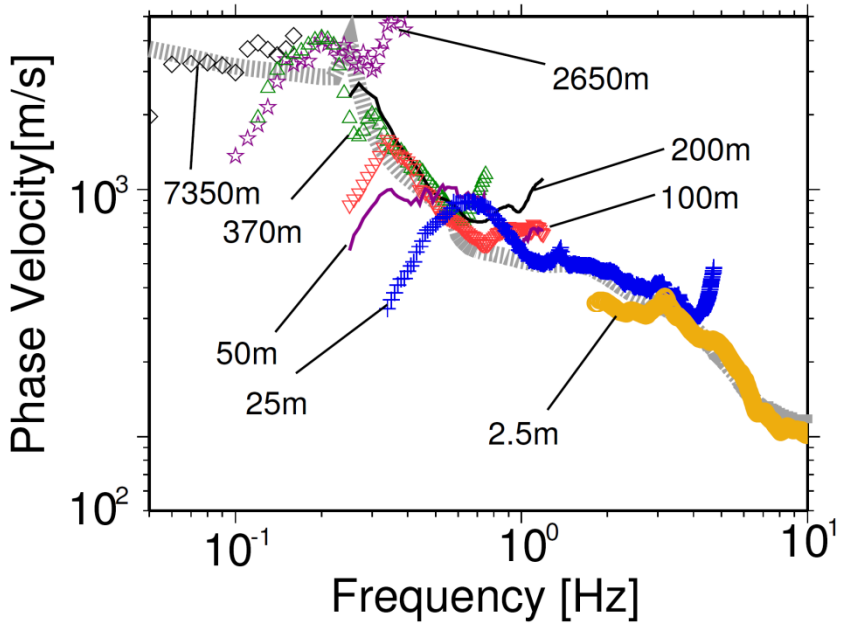
window length

data cleaning

MAAM

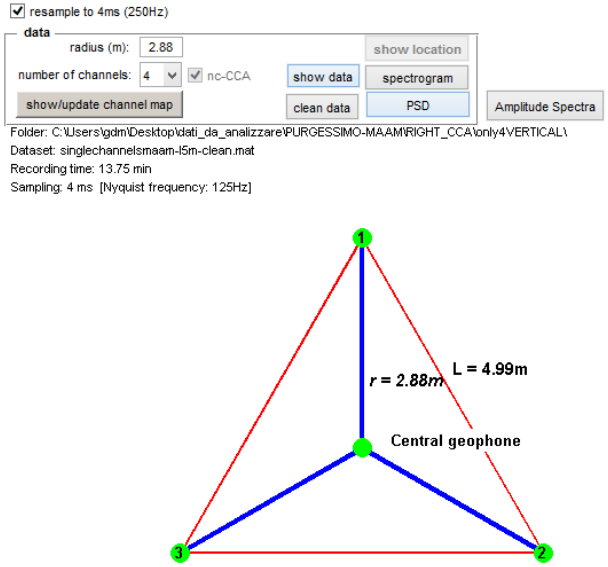
MAAM

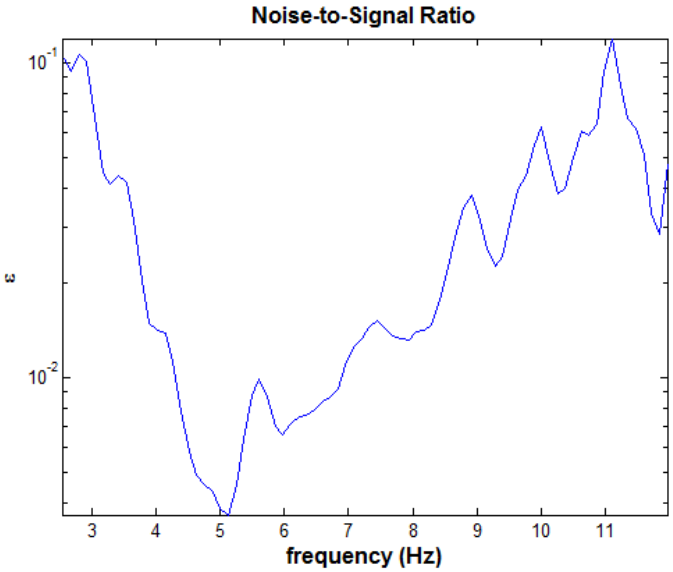

phase velocity (m/s)
frequency (Hz)
lower (2.7λ)
clear
save spectrum
analyze the saved spectrum

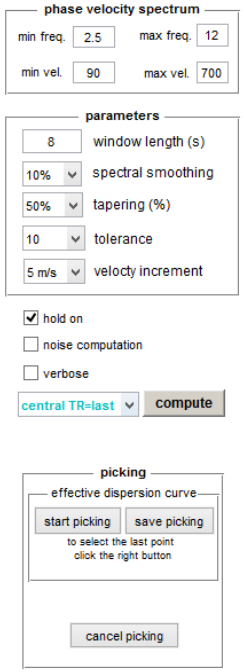

Phase Velocity[m/s]
Frequency [Hz]
2650m
7350m
370m
200m
100m
50m
25m
2.5m

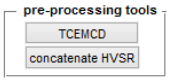
MAAM Comparing MASW-ZVF

1. Purgessimo

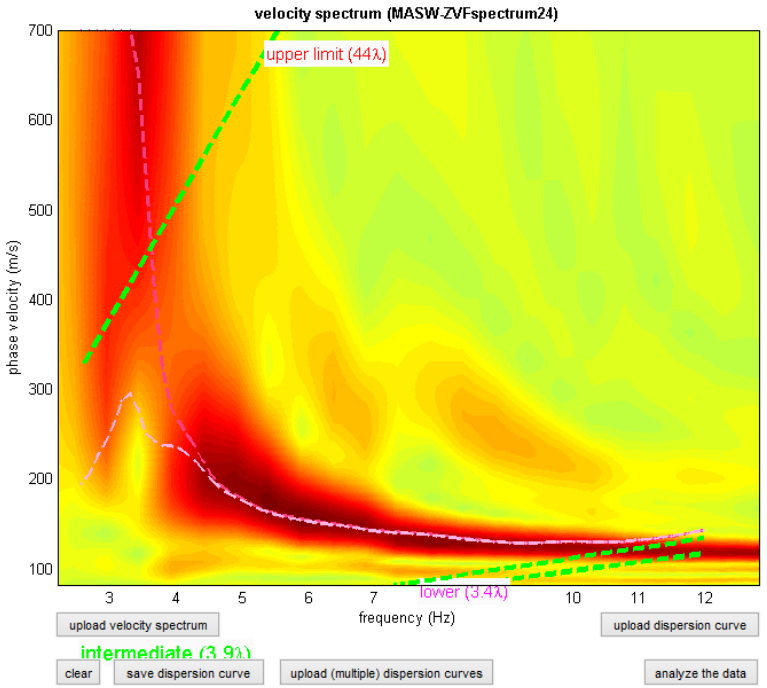








No noise computation/compensation



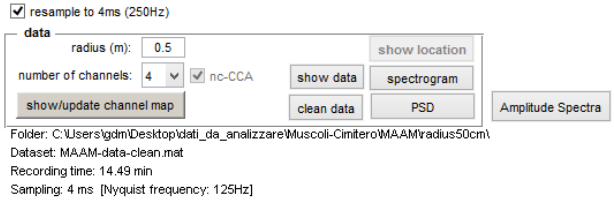
MAAM

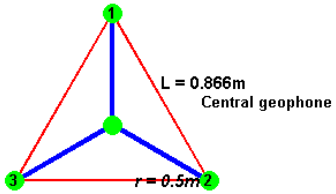
Comparing ESAC

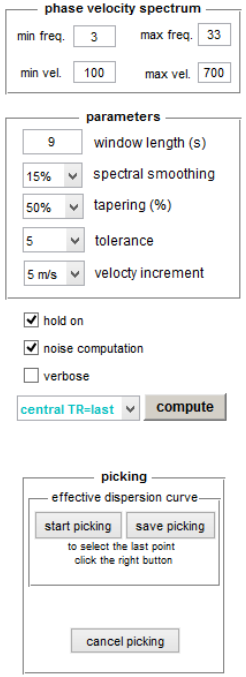
Equipment quality (N/S ratio)

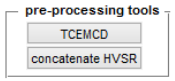
6. Muscoli

Two radii (2 and 0.5m)

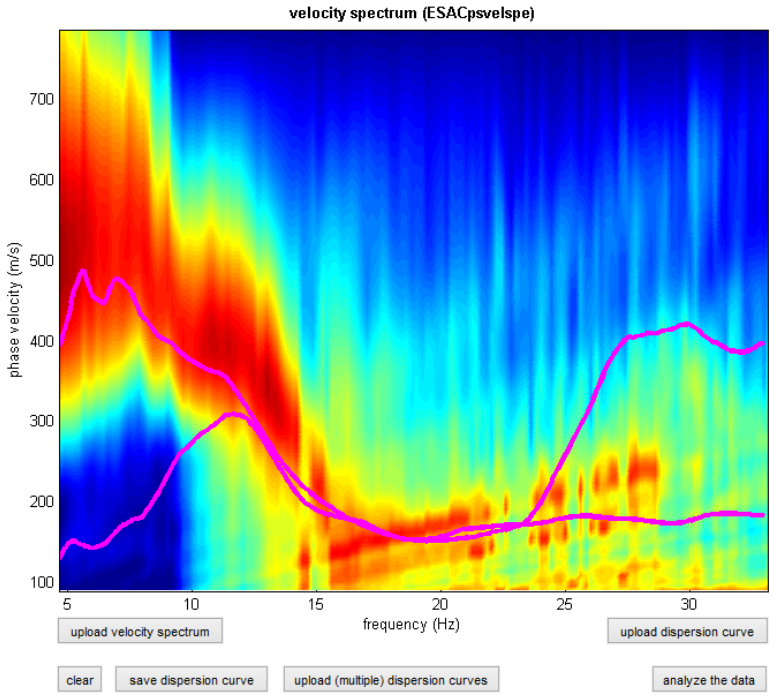






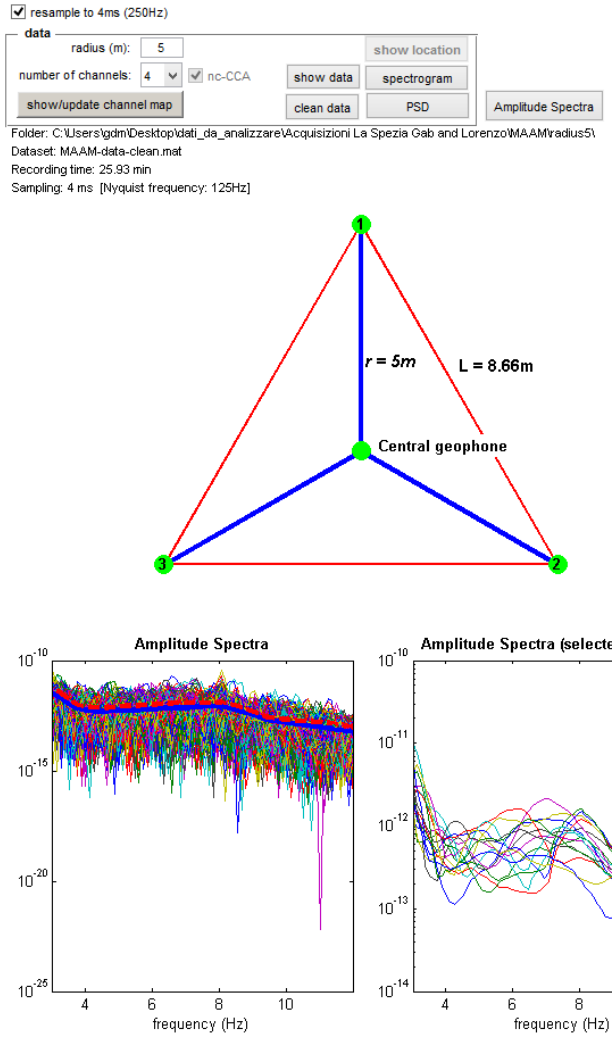


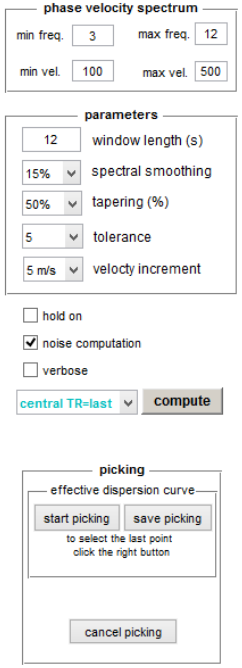
Noise (epsilon) computed [dispersion compensated]



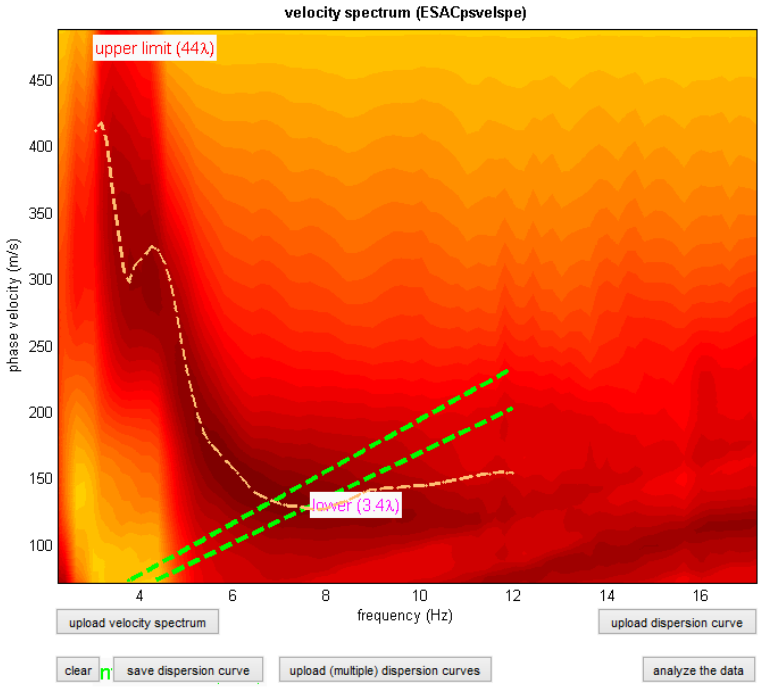
MAAM Comparing ESAC

7. La Spezia





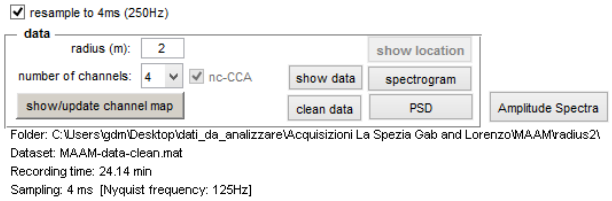
Noise (epsilon) computed [dispersion compensated]

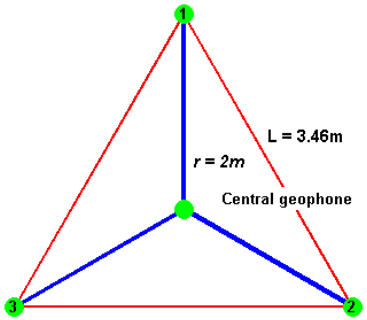


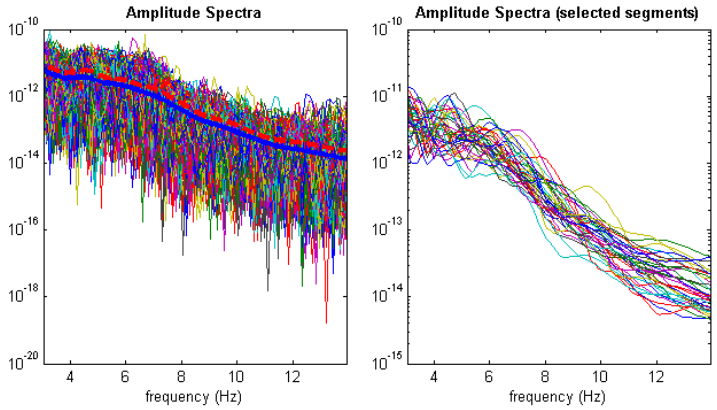
MAAM Comparing ESAC

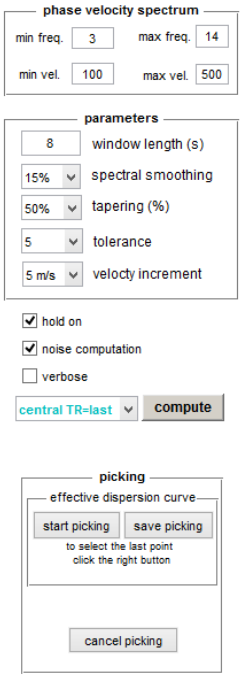
7. La Spezia

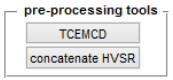
Two radii (5 and 2m)



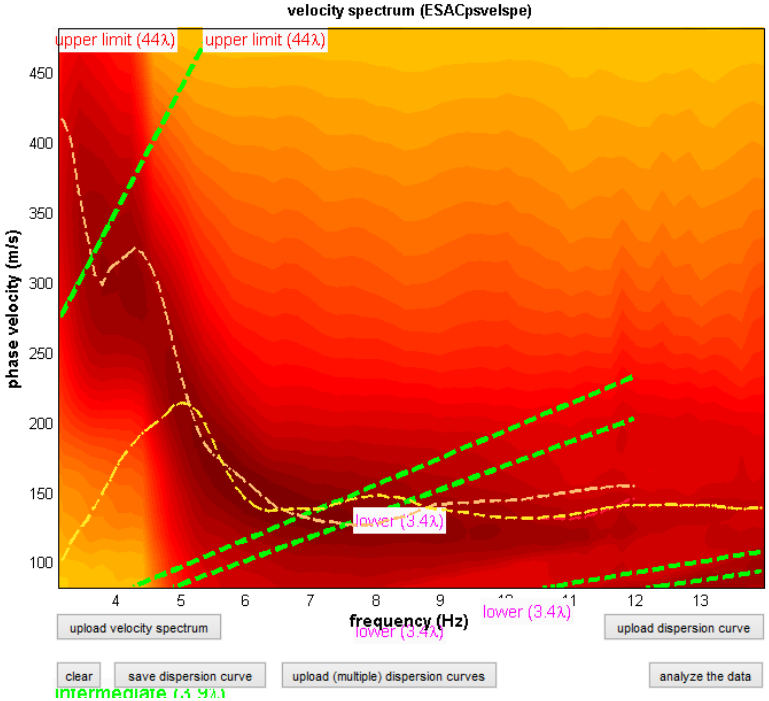








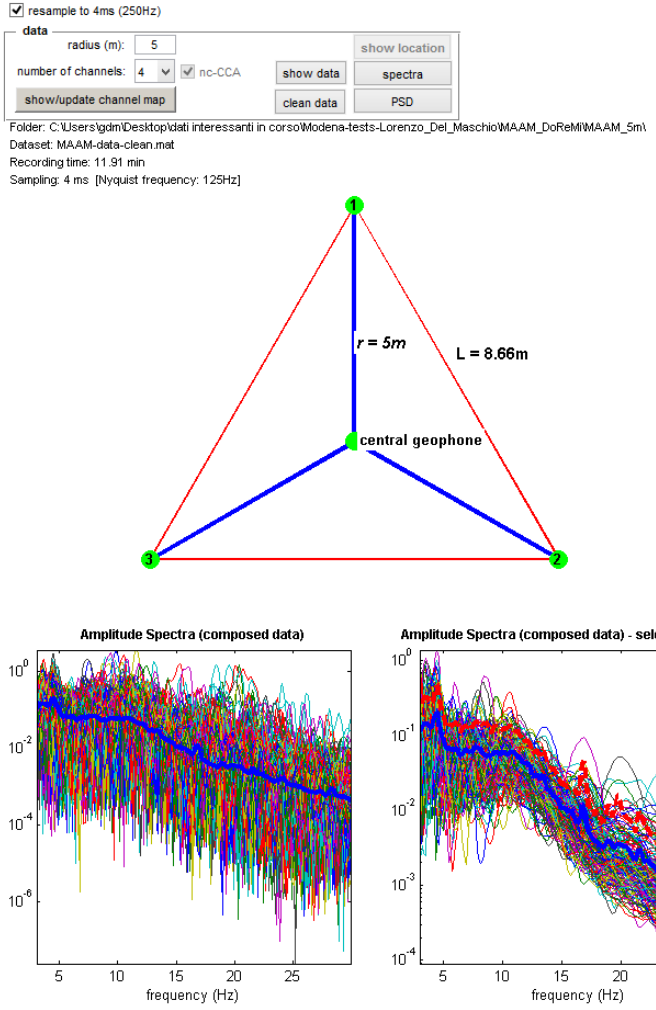
Noise (epsilon) computed [dispersion compensated]

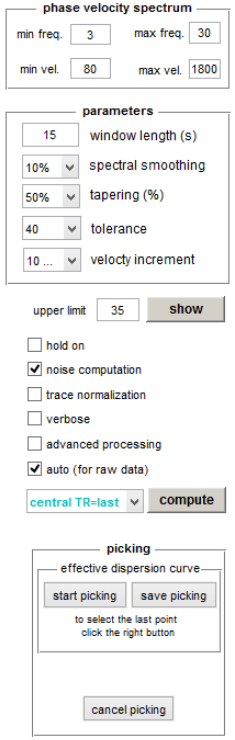


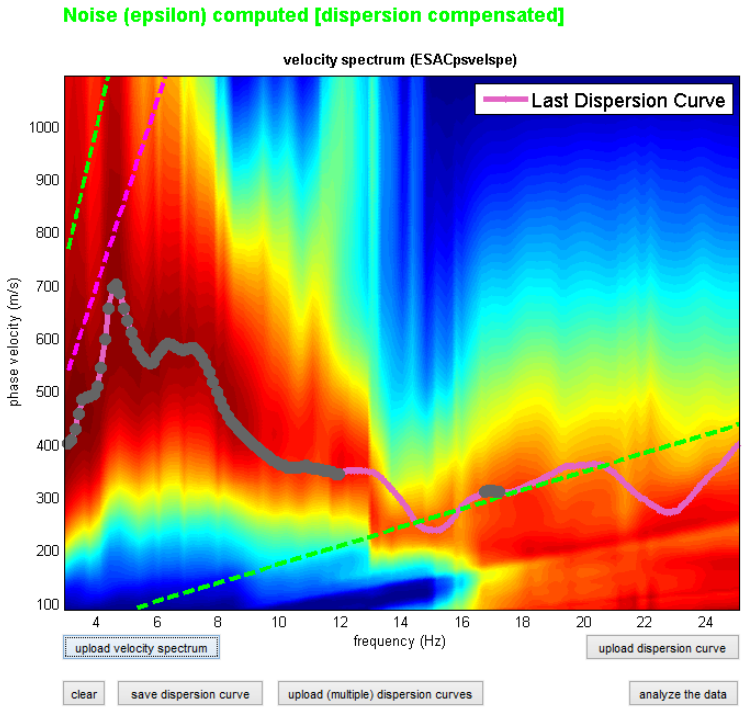
MAAM Comparing ESAC

8. Modena

Radius (5m)







MASW:
are you sure to know everything you need to know?

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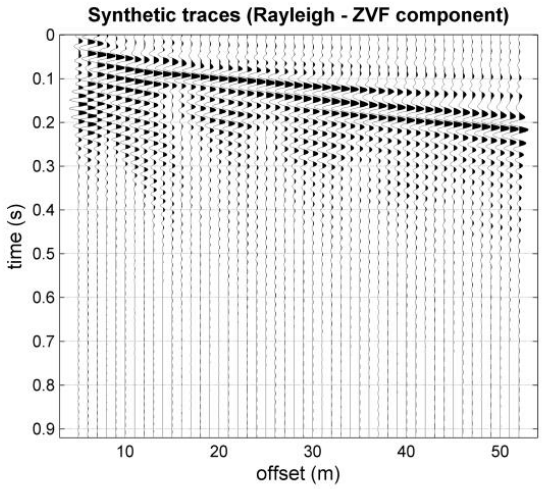

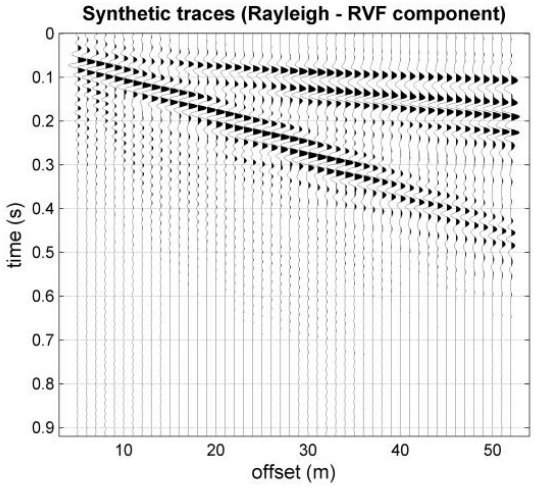

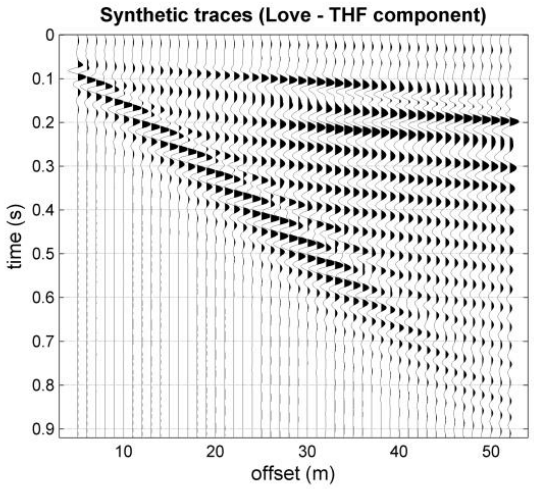

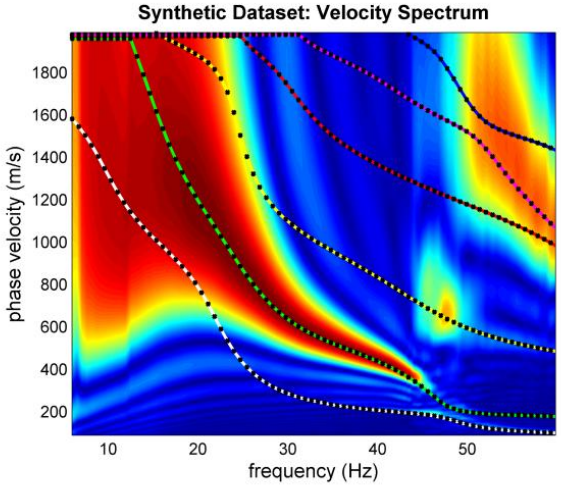

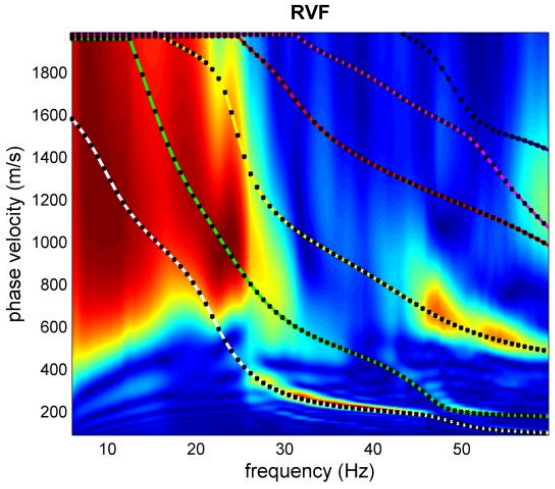

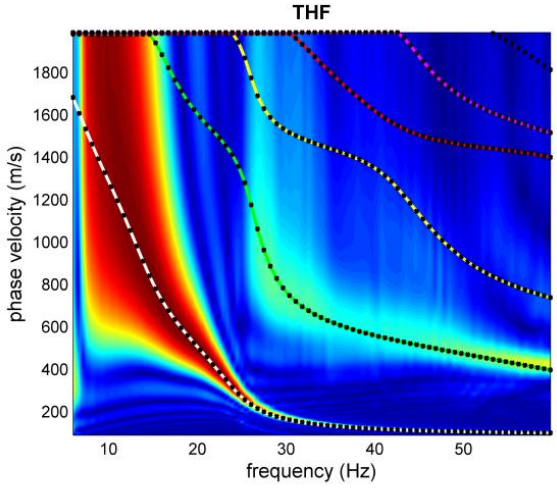

MASW:
are you sure to know everything you need to know?

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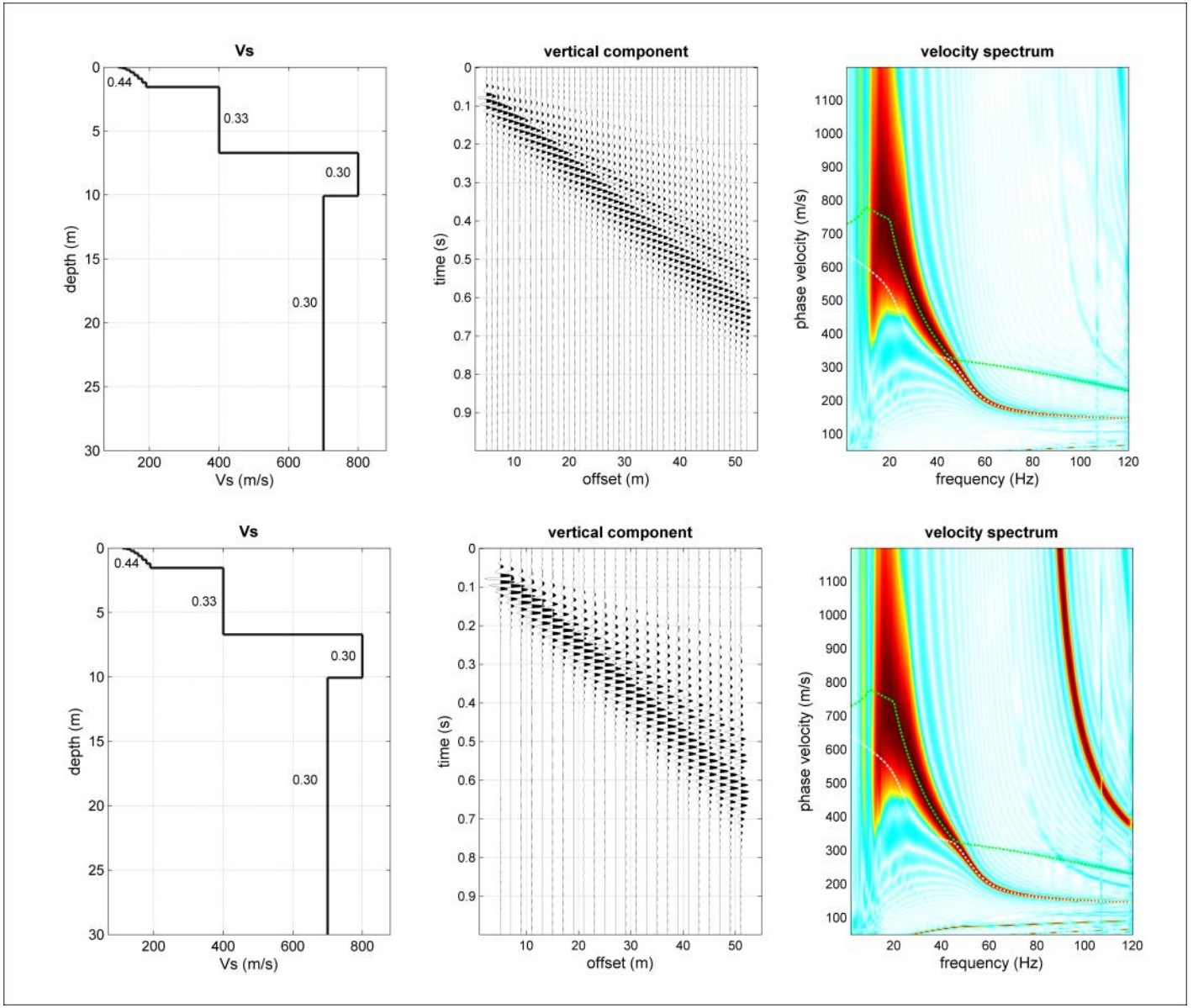

Further exploitation of the HS approaches

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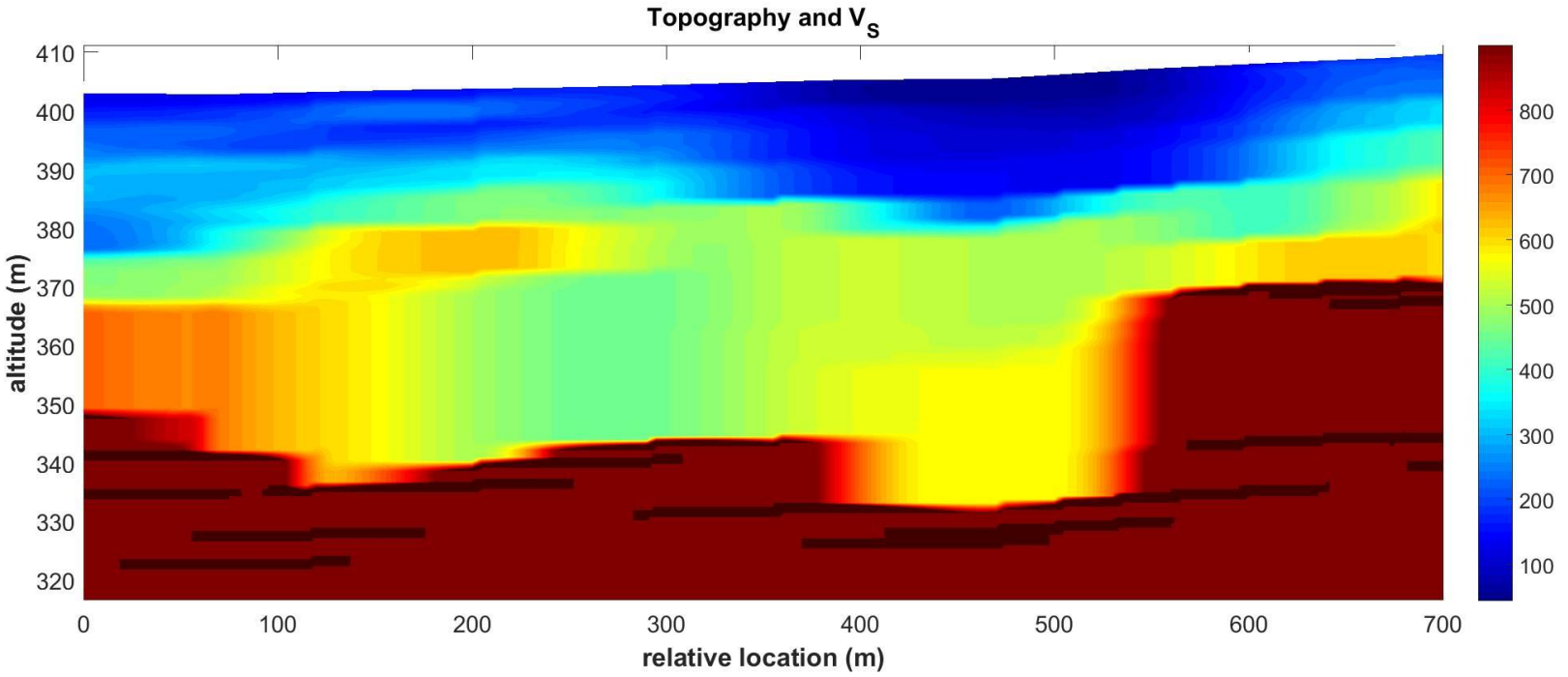
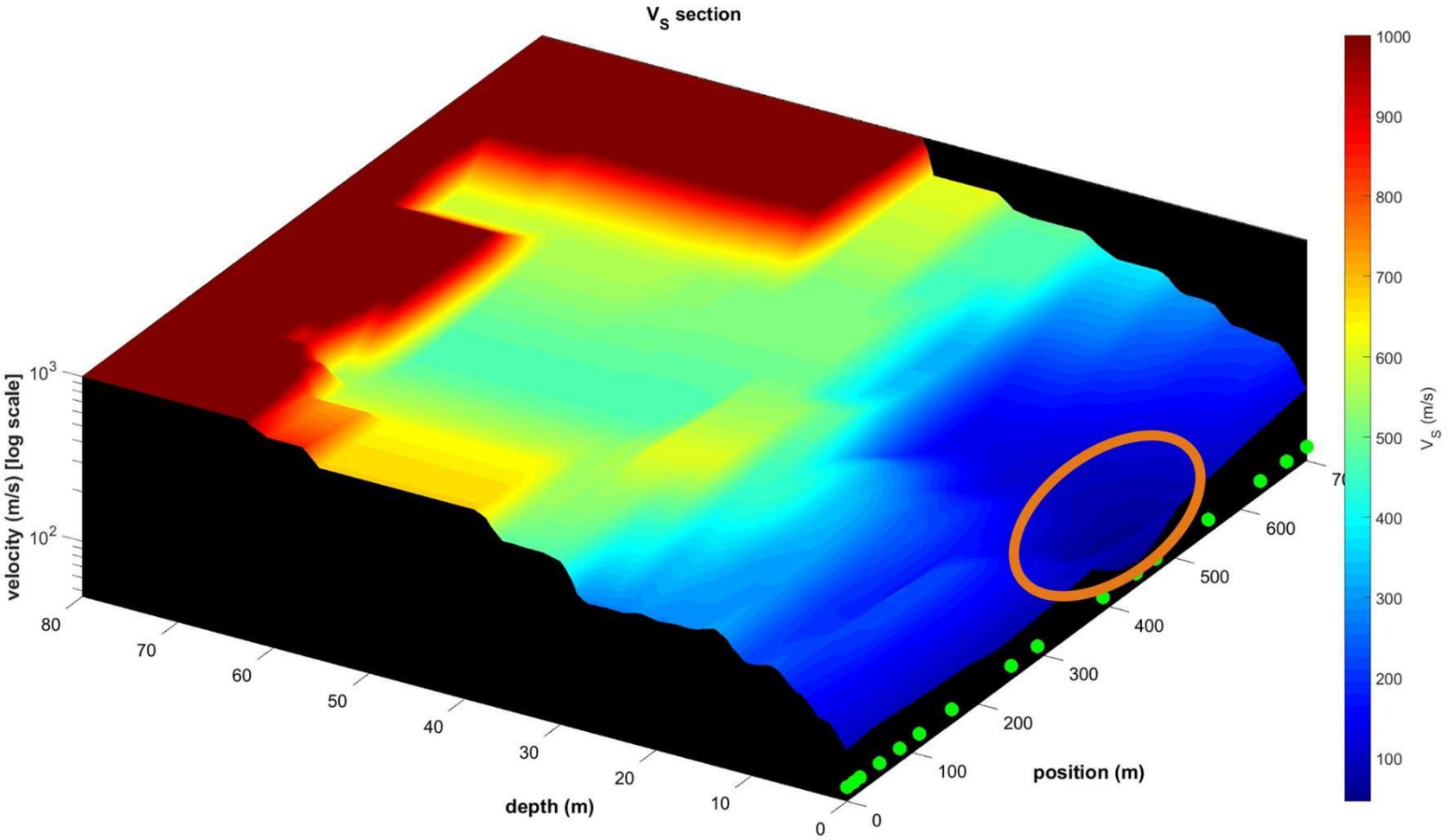
A Swiss work



Further exploitation of the HS approaches

A Swiss work: log scale for the velocities



RPM frequency curve (see Dal Moro et al., 2016 – BSSA): why?

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1. Improved Back-scattering analyses

2. Advanced seismic-vulnerability analyses

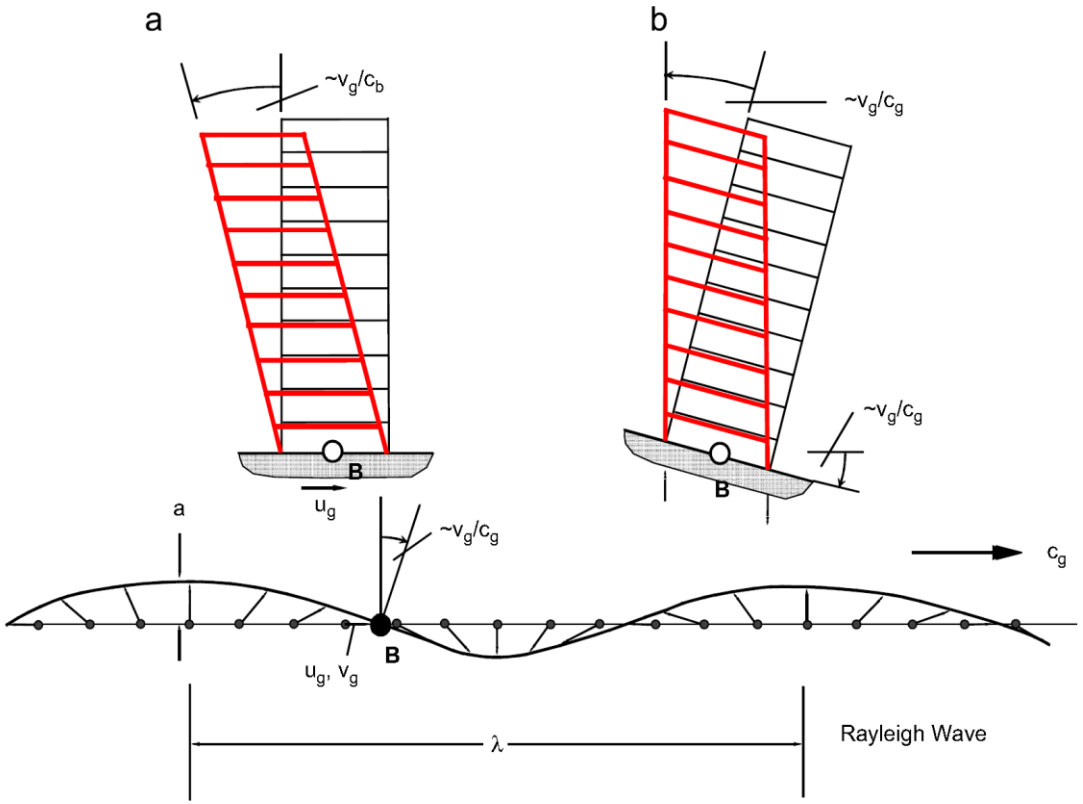

Fig. 8. Geometric interpretation of how horizontal translation and rocking can contribute to the total drift in a simple building during passage of a Rayleigh wave.

3. Exploration of large 2/3D areas

RPM frequency curve: how?

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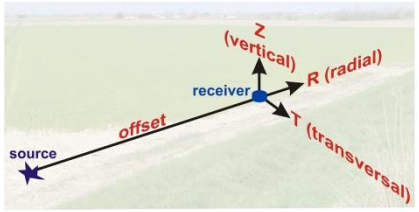
The BSSA paper

More about Joint Analysis of ZVF+RVF+RPM

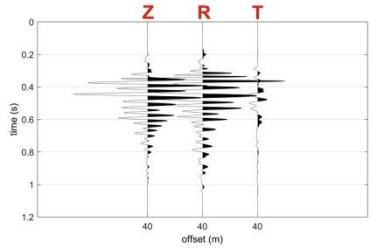
1. Jail dataset (NE Italy): multi- and single-offset data

2. Tuscany (industrial) dataset

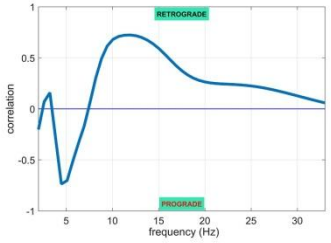
a)

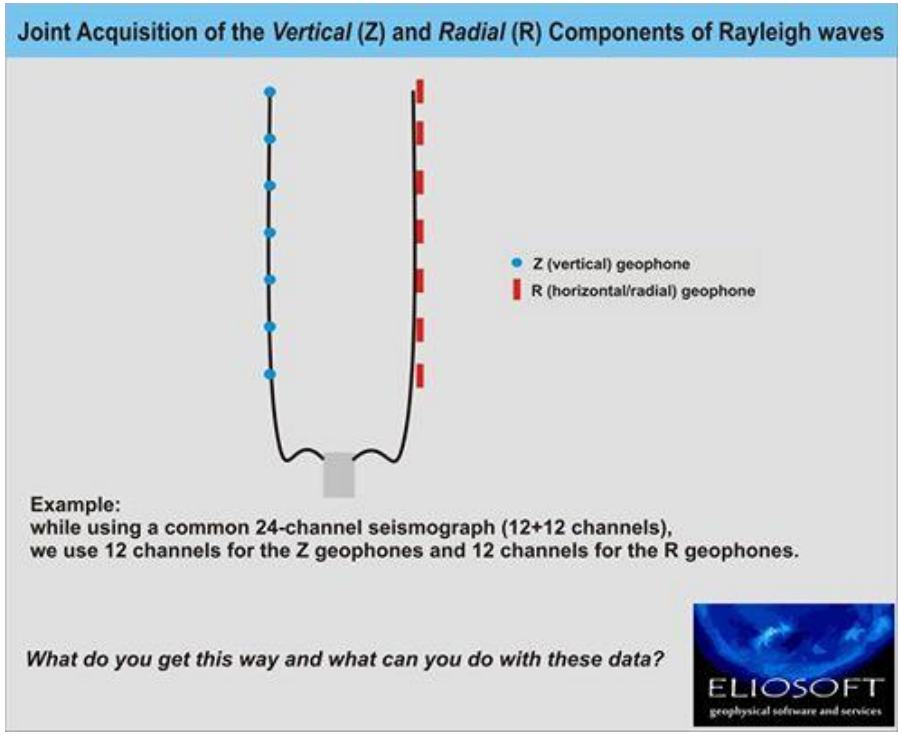


b)



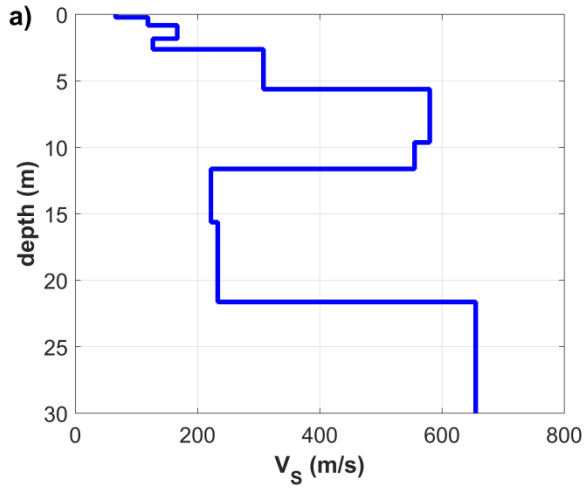
c)

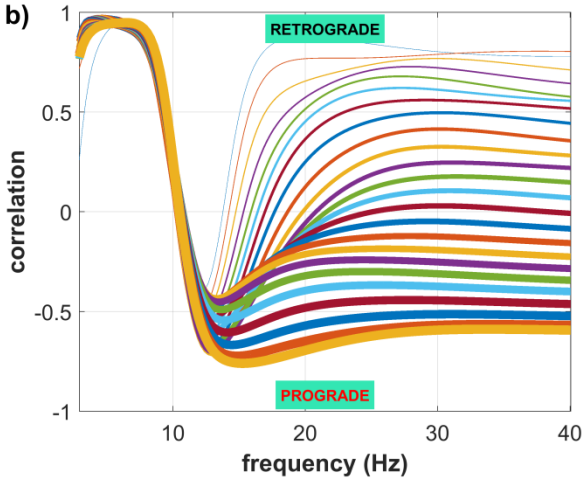


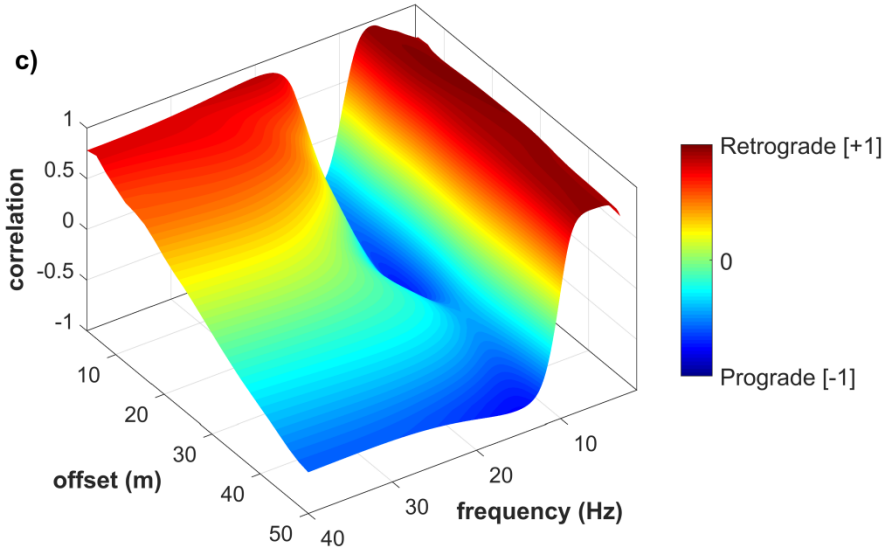


The *Polarity* issue!!!

Do you know your polarity?


a)
depth (m)
0
5
10
15
20
25
30
0
200
400
600
800
V_S (m/s)


b)
RETROGRADE
PROGRADE
correlation
1
0.5
0
-0.5
-1
10
20
30
40
frequency (Hz)


c)
correlation
1
0.5
0
-0.5
-1
offset (m)
10
20
30
40
50
frequency (Hz)
10
20
30
40
Retrograde [+1]
0
Prograde [-1]

The RPM effective frequency curve

1. Compared to other methods for defining the RW polarity (Gribler et al., 2016), the RPM frequency curve describes the Rayleigh motion at each specific frequency (not as a whole gross thing);

To investigate Rayleigh wave particle motion, we convert our vertical (V) and horizontal inline (H) time series from Cartesian coordinates into polar coordinates, using the following equations:

$$A(t) = \sqrt{V(t)^2 + H(t)^2},$$

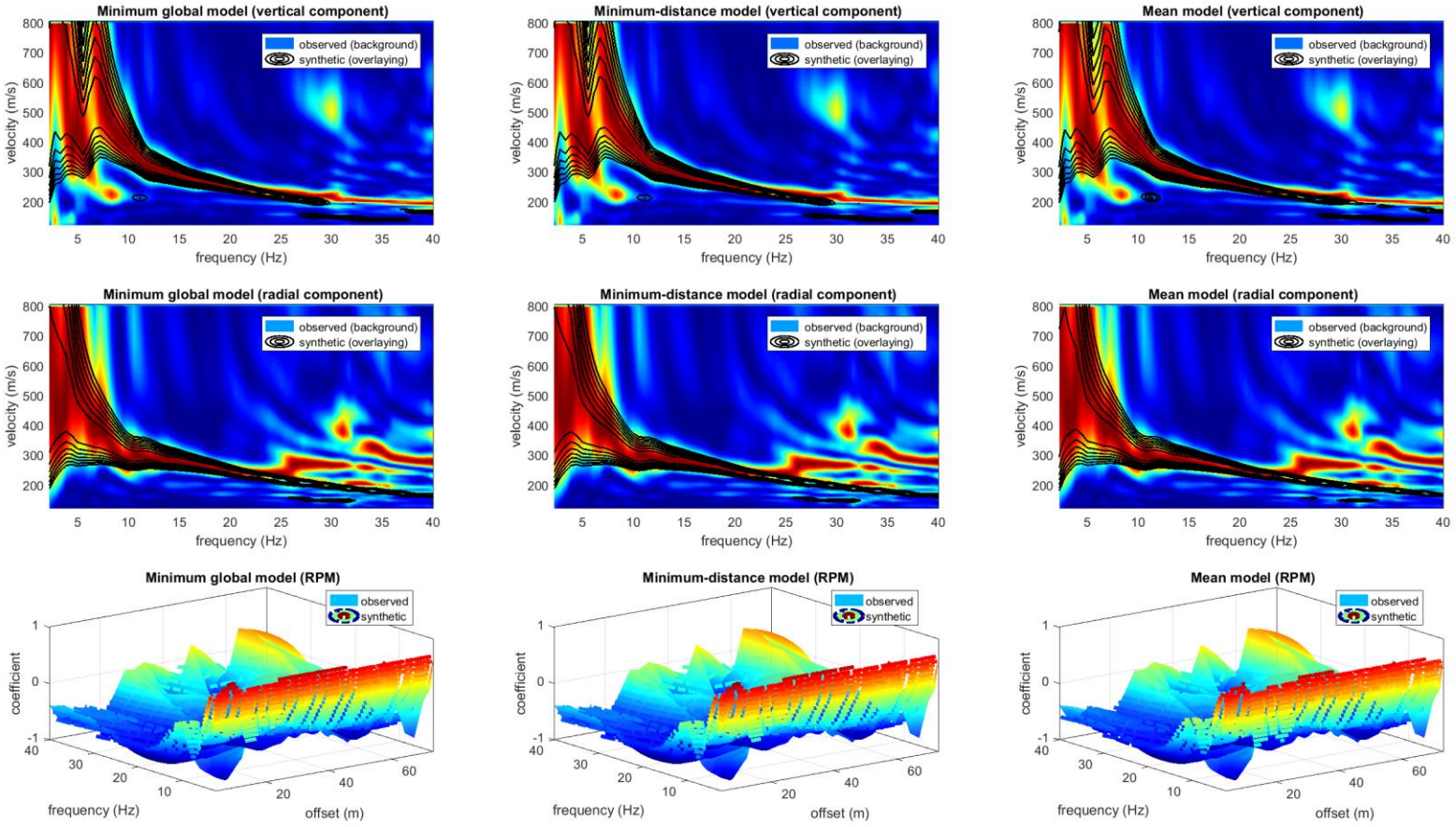
$$\Phi(t) = \tan^{-1}\left(\frac{V(t)}{H(t)}\right),$$

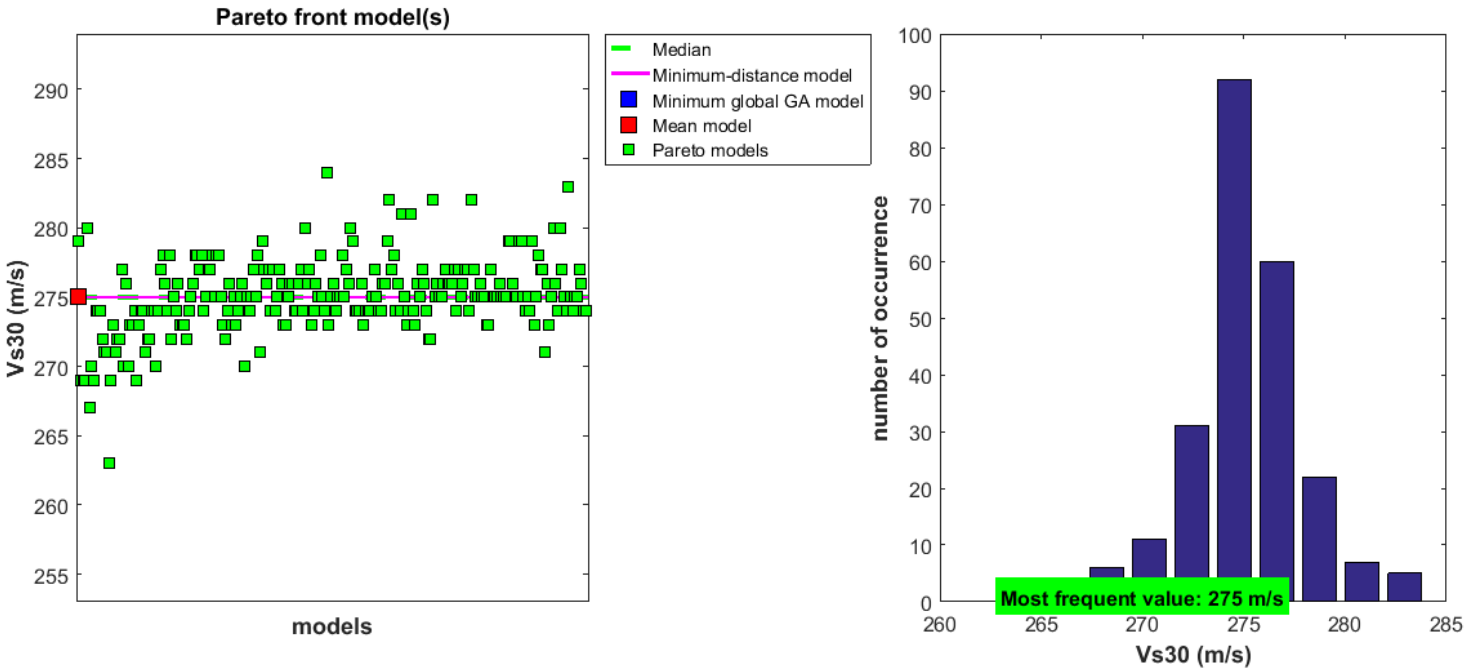
2. It does not require the use of Z and R calibrated geophones.

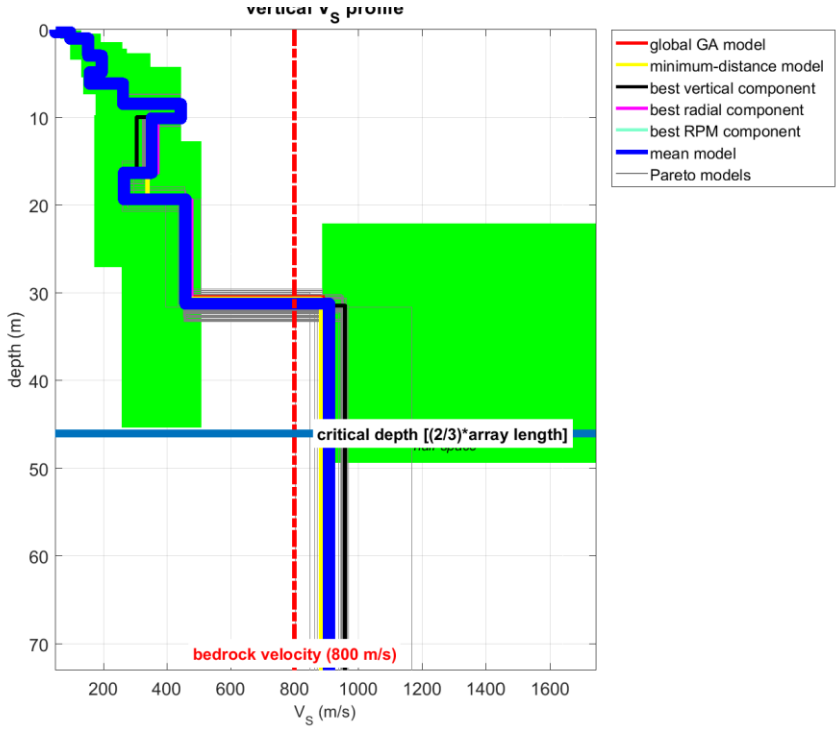
2. Tuscany (industrial) dataset:): multi-offset data

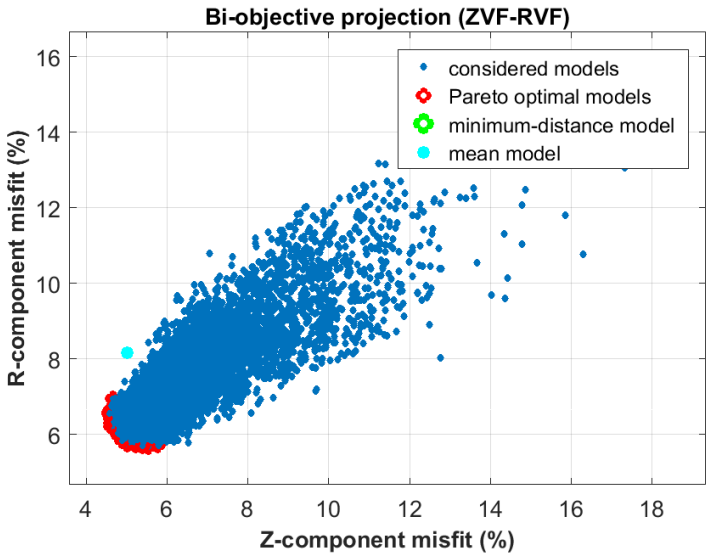
See also:

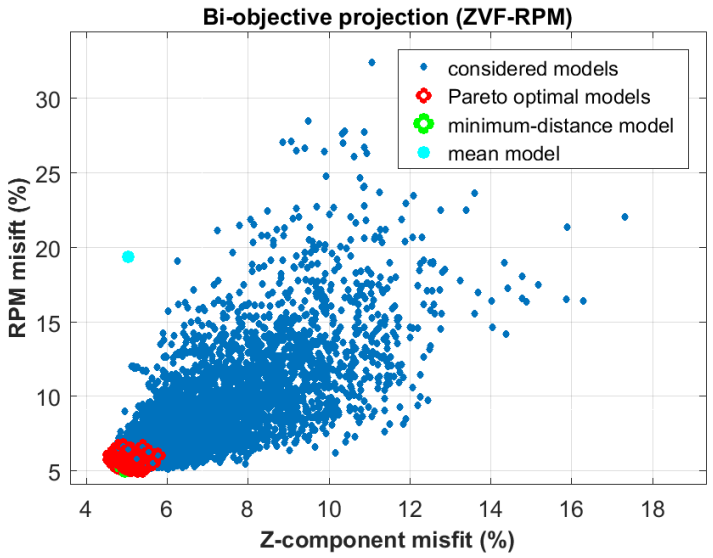
Multi-component Joint Analysis of Surface Waves (Dal Moro G., Moura R.M., Moustafa S.R., 2015), *J. Appl. Geophysics,* 119, 128-138

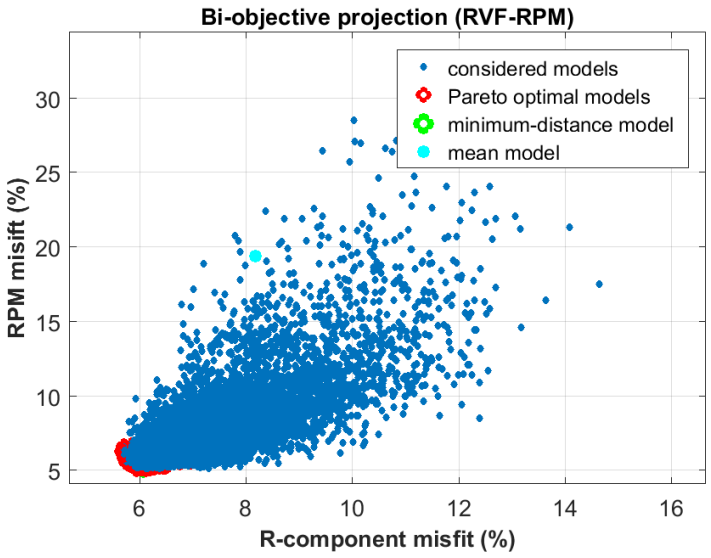


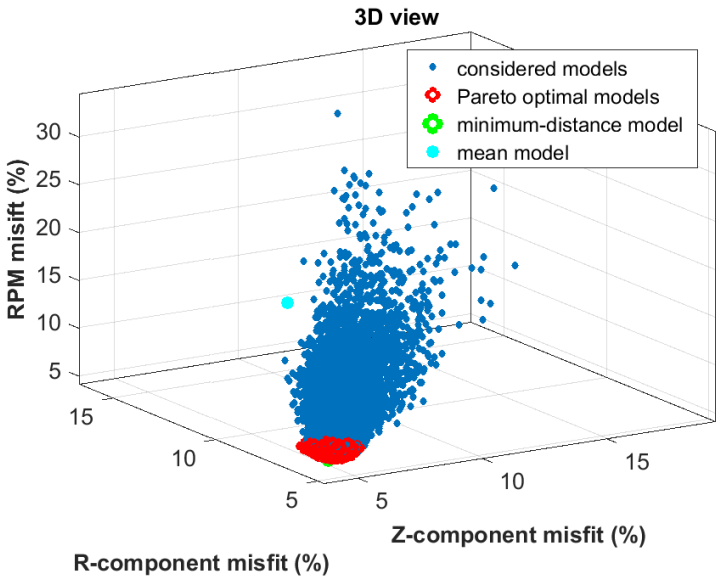

Pareto front model(s)
Median
Minimum-distance model
Minimum global GA model
Mean model
Pareto models
Vs30 (m/s)
models
290
285
280
275
270
265
260
255
number of occurrence
Most frequent value: 275 m/s
Vs30 (m/s)
100
90
80
70
60
50
40
30
20
10
0
260
265
270
275
280
285


vertical V_S profile
global GA model
minimum-distance model
best vertical component
best radial component
best RPM component
mean model
Pareto models
depth (m)
critical depth [(2/3)*array length]
bedrock velocity (800 m/s)
V_S (m/s)
0
10
20
30
40
50
60
70
200
400
600
800
1000
1200
1400
1600

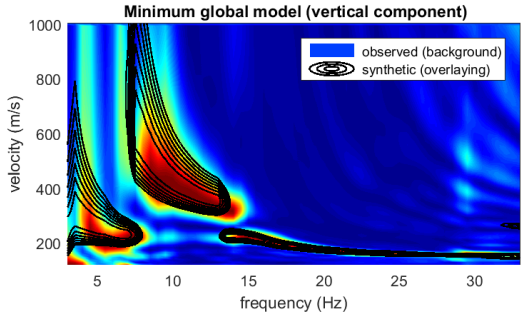

Bi-objective projection (ZVF-RVF)
considered models
Pareto optimal models
minimum-distance model
mean model
R-component misfit (%)
Z-component misfit (%)

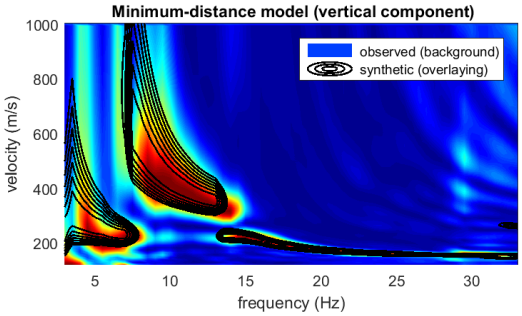

Bi-objective projection (ZVF-RPM)
considered models
Pareto optimal models
minimum-distance model
mean model
RPM misift (%)
Z-component misfit (%)

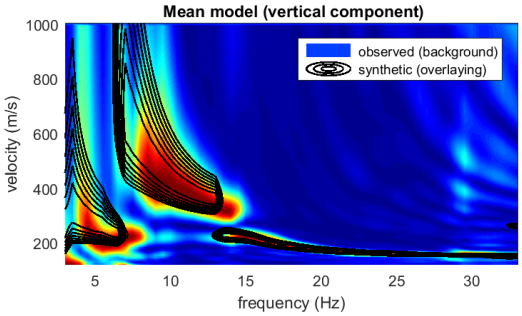

Bi-objective projection (RVF-RPM)
considered models
Pareto optimal models
minimum-distance model
mean model
RPM misift (%)
R-component misfit (%)

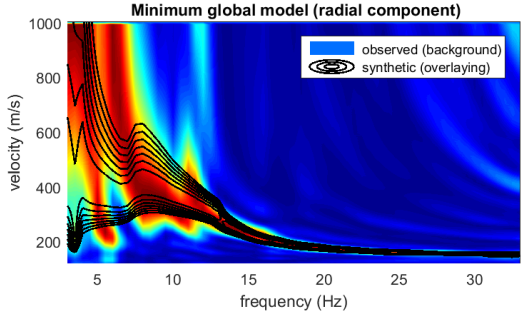

3D view
considered models
Pareto optimal models
minimum-distance model
mean model
RPM misift (%)
Z-component misfit (%)
R-component misfit (%)

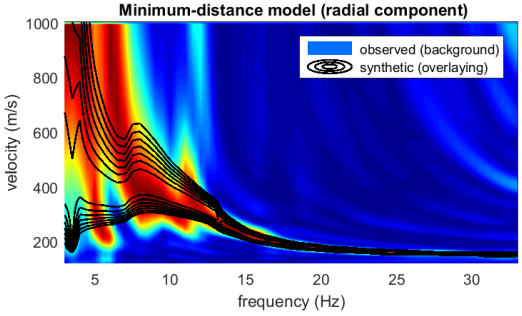
1. Jail dataset (NE Italy): multi-offset data

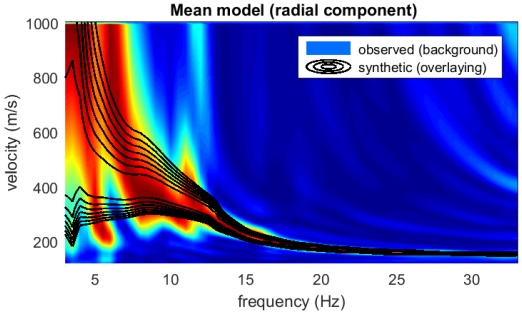


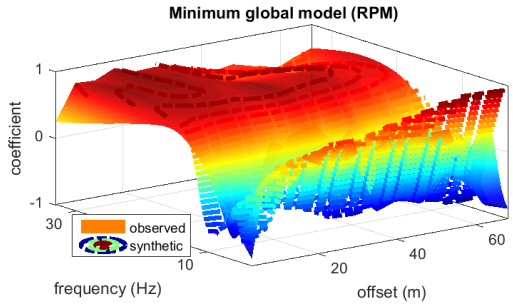


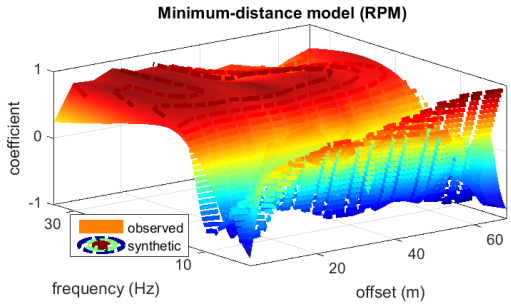


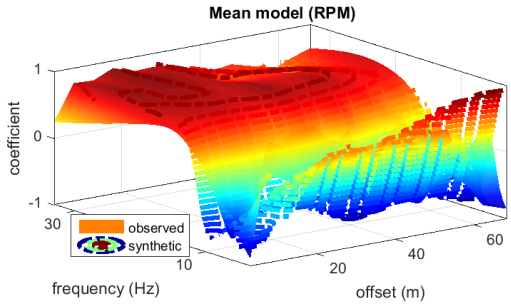


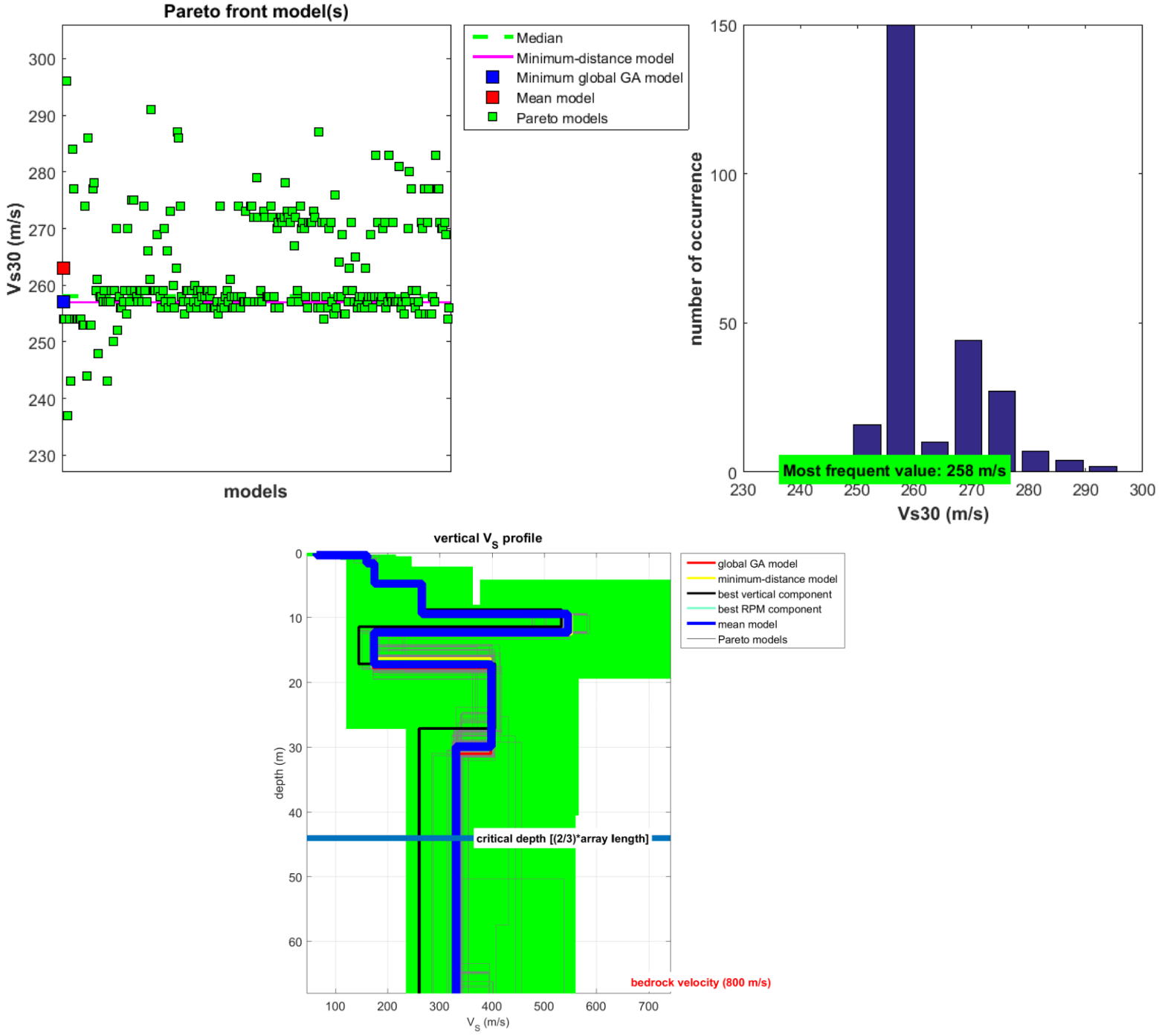




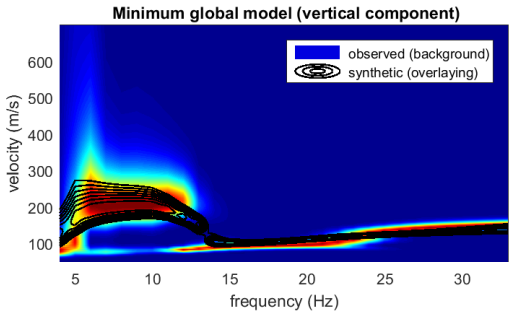


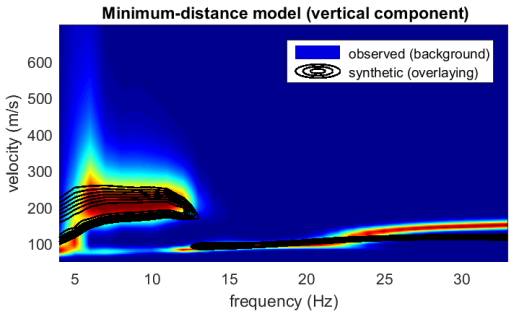


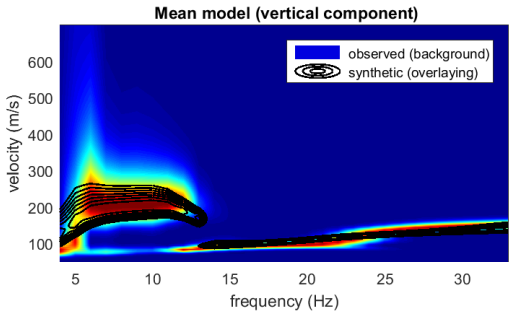


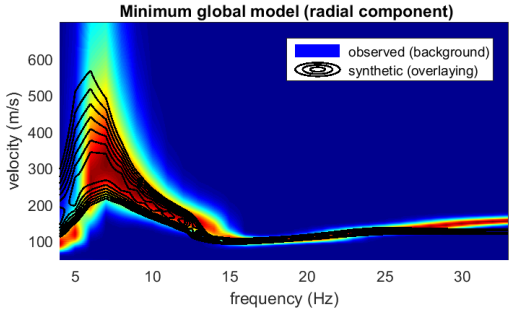

Pareto front model(s)
Median
Minimum-distance model
Minimum global GA model
Mean model
Pareto models
Vs30 (m/s)
models
number of occurrence
Most frequent value: 258 m/s
Vs30 (m/s)
vertical V_S profile
global GA model
minimum-distance model
best vertical component
best RPM component
mean model
Pareto models
depth (m)
critical depth [(2/3)*array length]
bedrock velocity (800 m/s)
V_S (m/s)

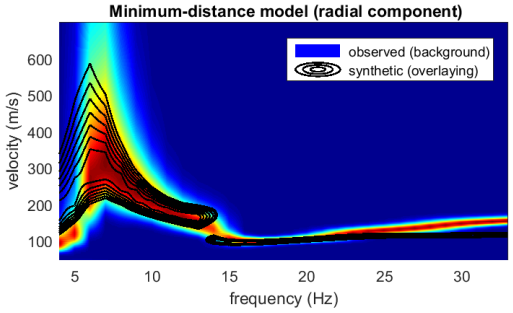
1. Jail dataset (NE Italy): single-offset data

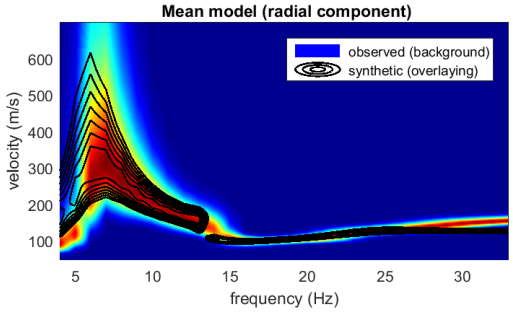


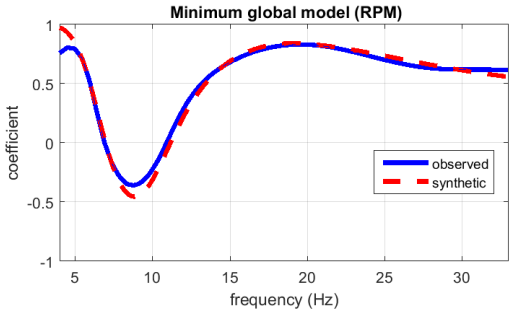


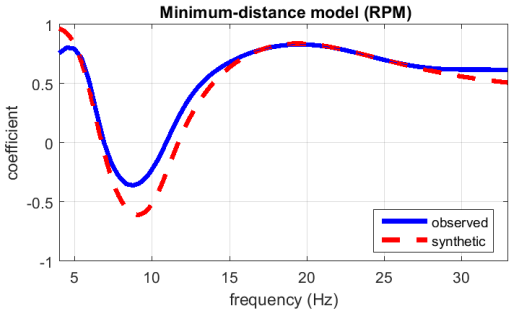


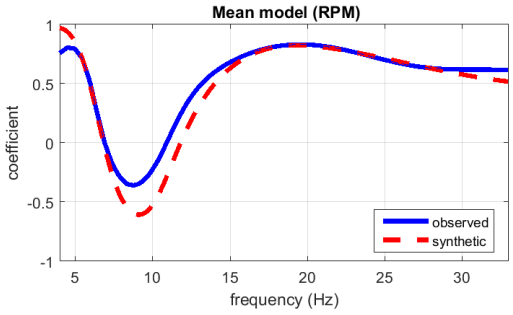












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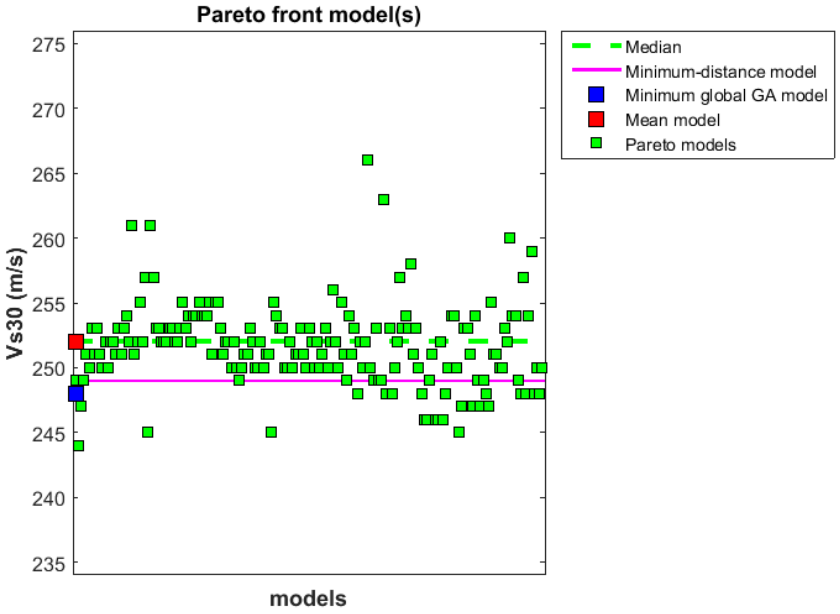
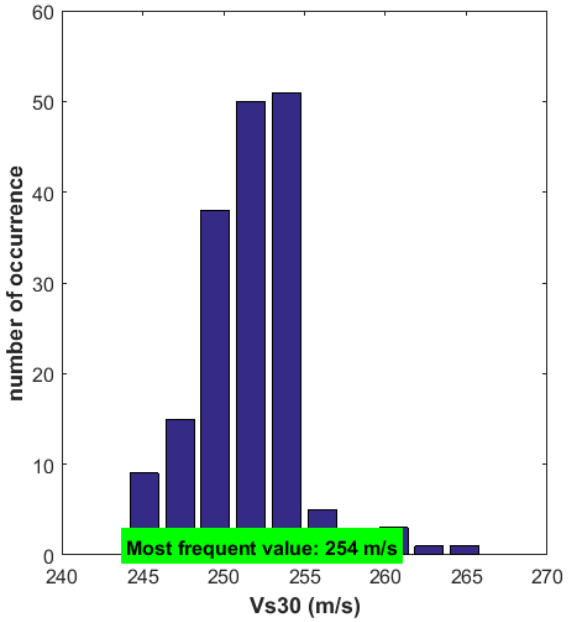
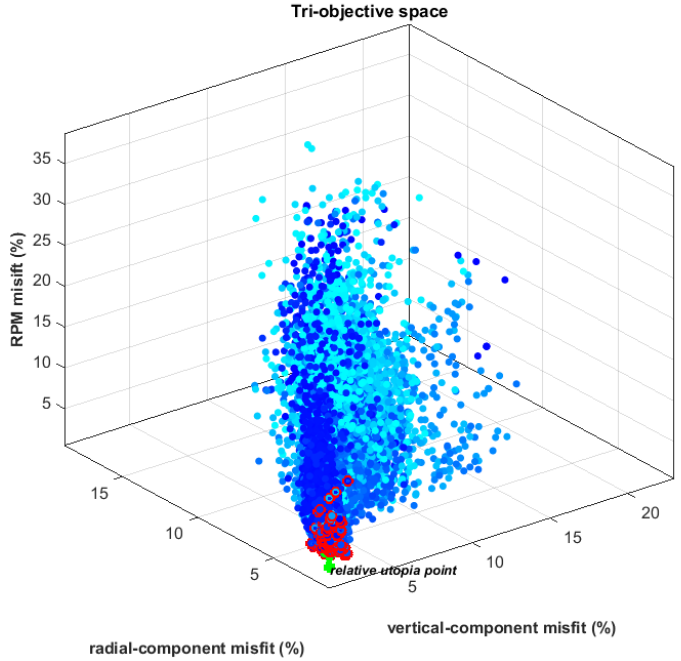
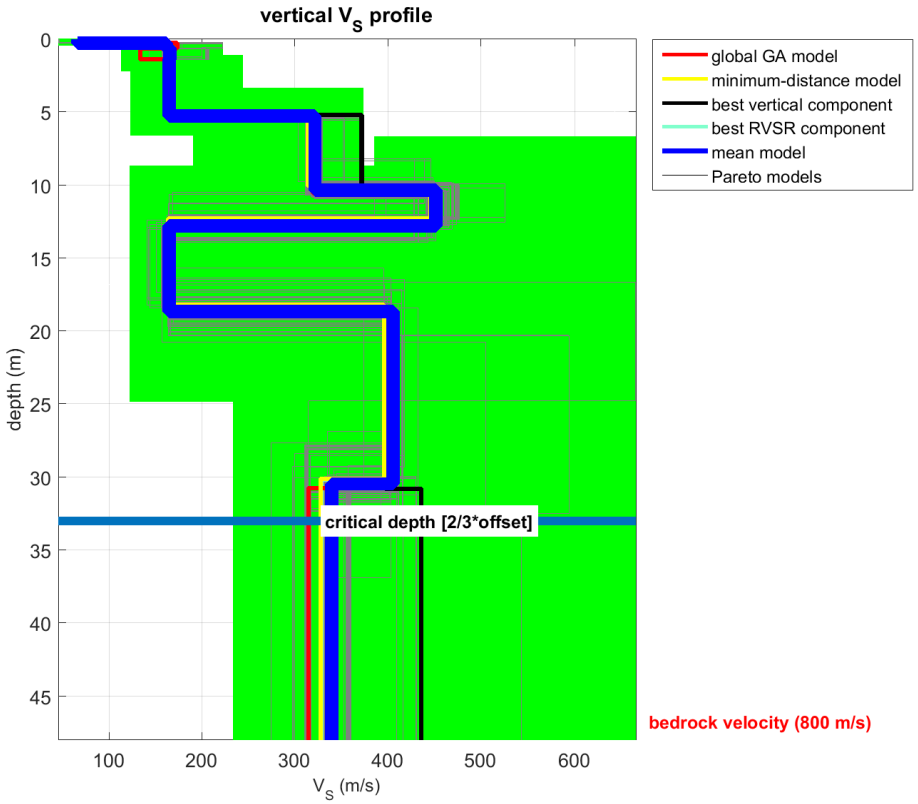






1. Jail dataset (NE Italy): single-offset data



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