Unambiguous determination of the Vs profile via joint analysis of multi-component active and passive seismic data

EAGE
EUROPEAN ASSOCIATION OF GEOSCIENTISTS & ENGINEERS

Giancarlo Dal Moro, Eliosoft.it (gdm@winmasw.com)
Lorenz Keller, roXplore.ch (lorenz@roxplore.ch)

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Project and goals

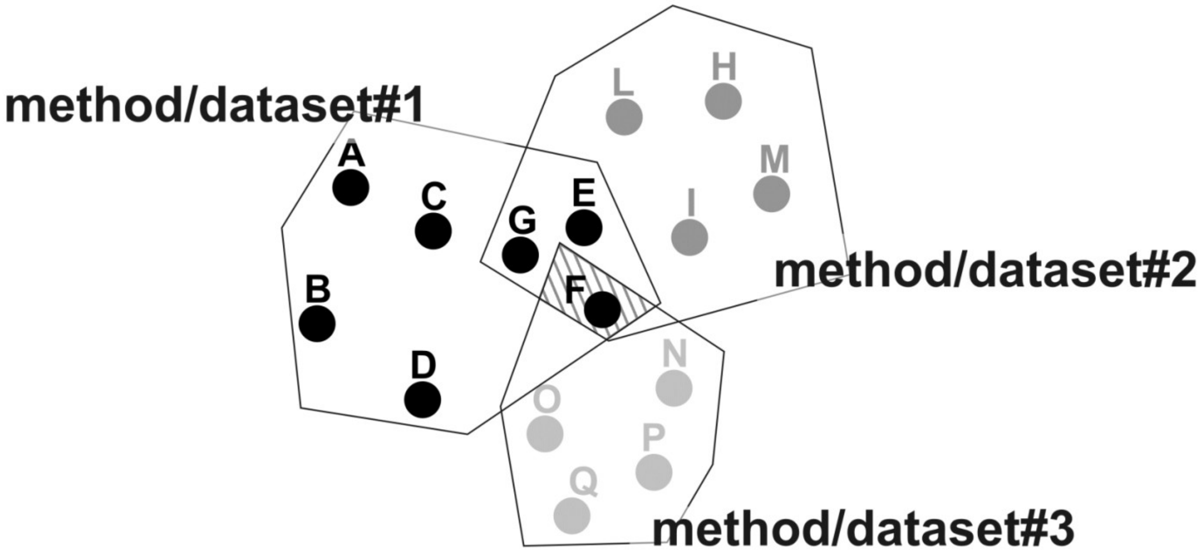
- **Characterizing the site in terms of compressional- and, most of all, shear-wave velocities**

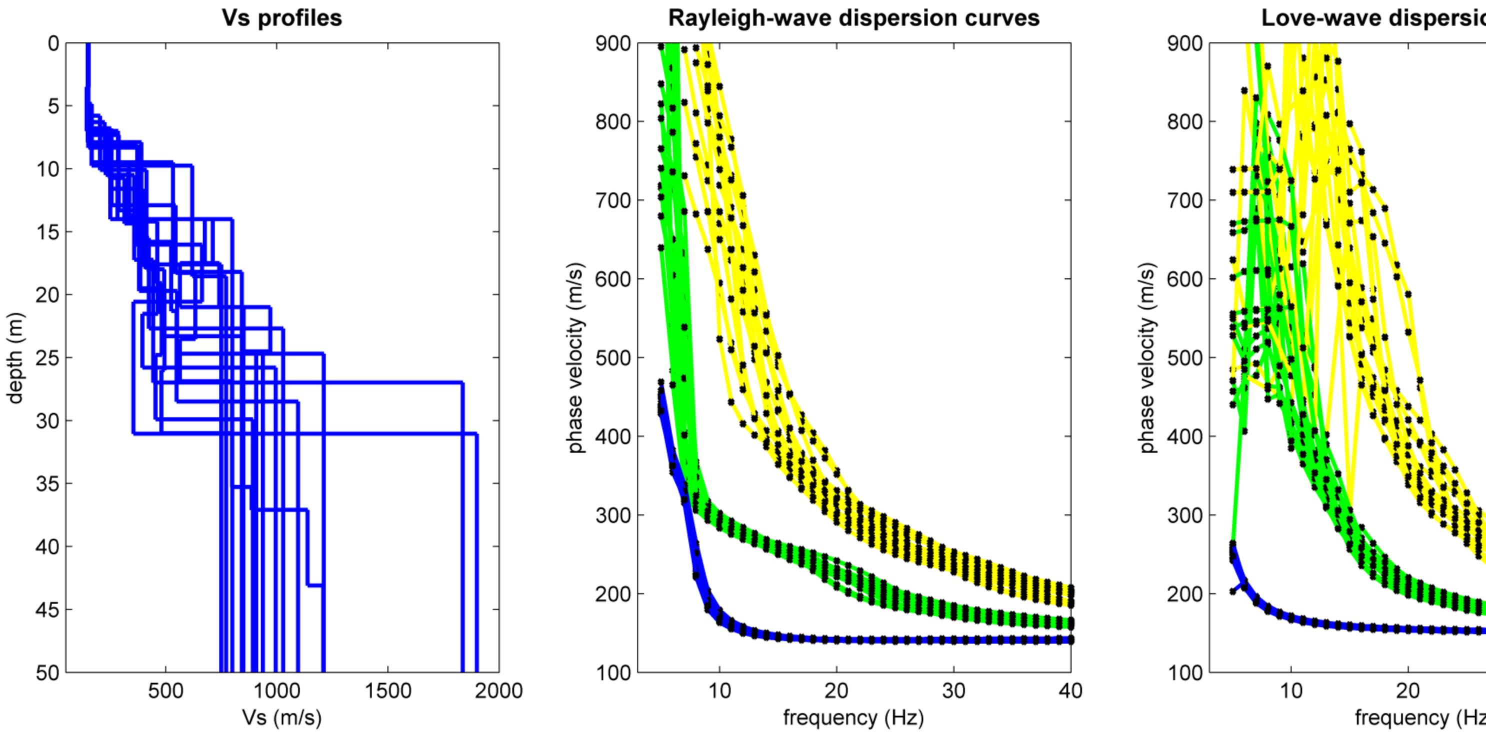
- **Assessing the local seismic response for a newly installed seismological borehole observation station (~130 m below surface): requested to map the Vs distribution down to 100 m (seismic-hazard study)**

- **The seismological station is (will be) operated by the *Swiss Seismological Survey* on behalf of *Nagra* (*Nationale Genossenschaft für die Lagerung radioaktiver Abfälle*), the Swiss cooperative for the disposal of radioactive waste**

The approach: motivations (1/2)

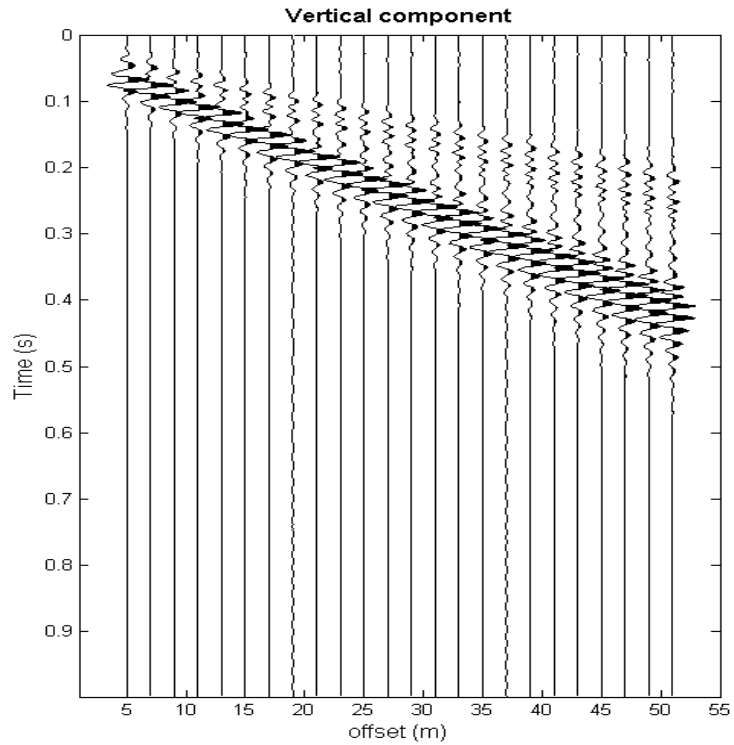
Non-uniqueness

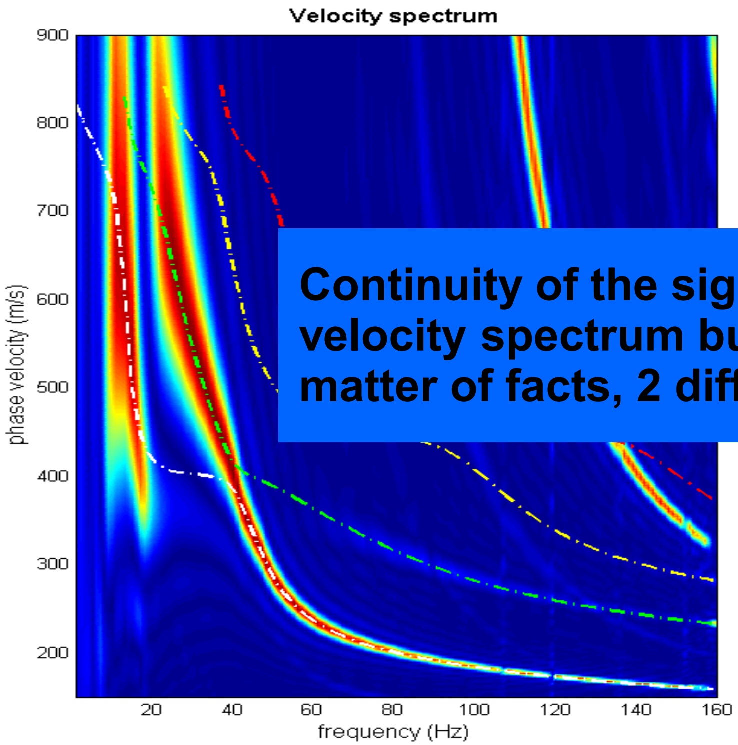




The approach: motivations (2/2)

Interpretative issues (1/2)





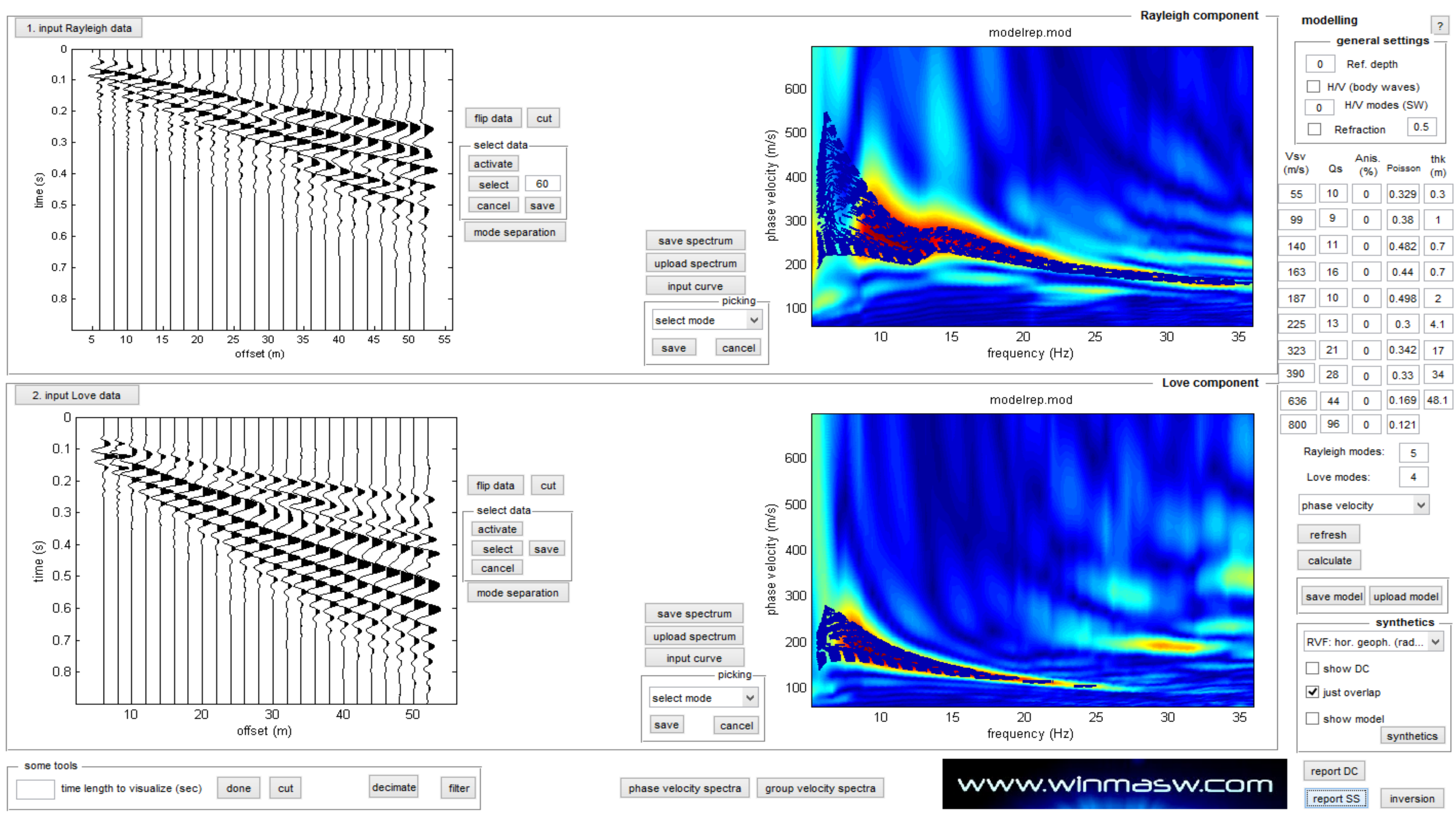
Continuity of the signal in the velocity spectrum but, as a matter of facts, 2 different modes

A problem especially for Rayleigh waves

The approach: motivations (2/2)

Interpretative issues (2/2)

Field dataset (Rayleigh + Love waves): background colours the observed velocity spectra, blue contour lines the velocity spectra of the identified model (*Full Velocity Spectra* approach – an improvement of the "effective dispersion curve" approach); please notice the very good agreement



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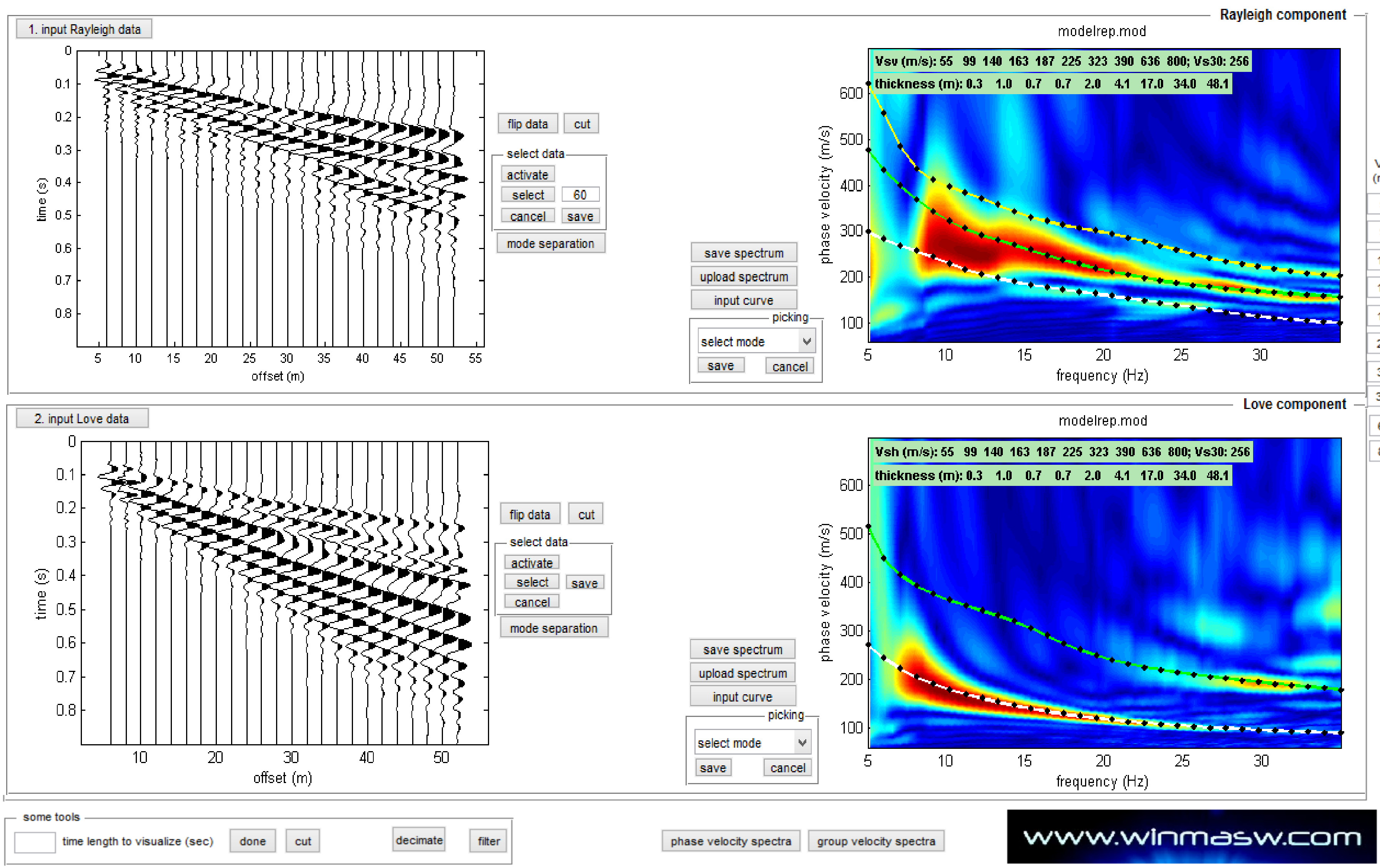
The approach: motivations (2/2)

Interpretative issues (2/2)

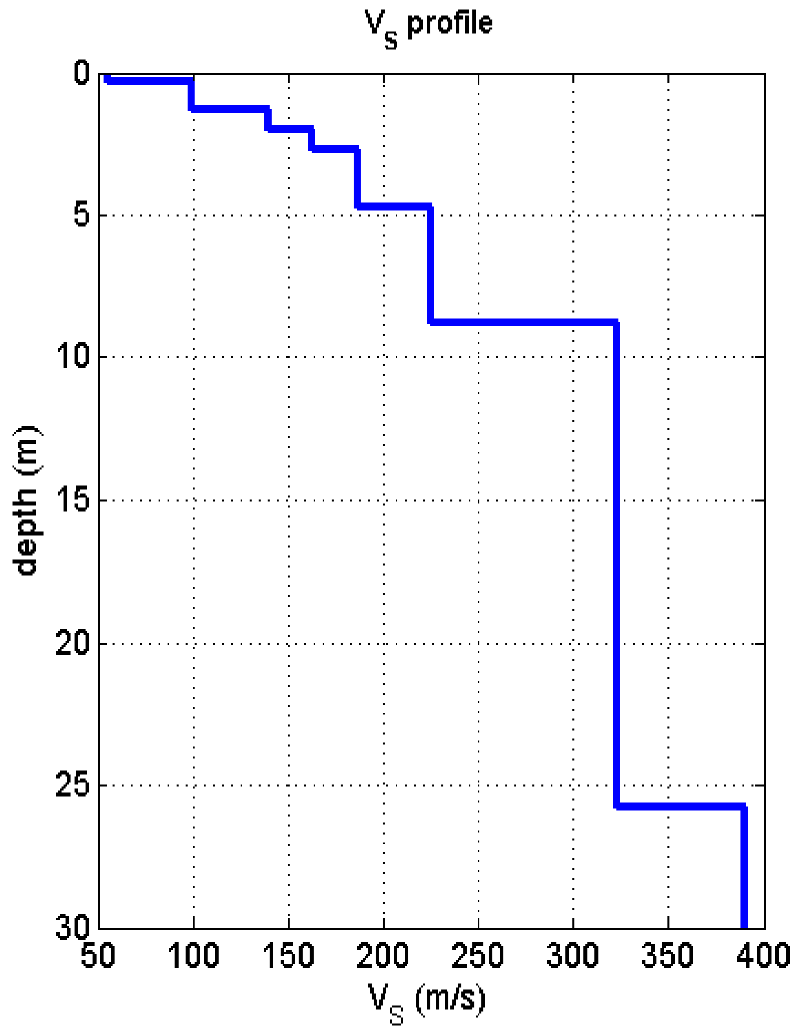
Field dataset (Rayleigh + Love waves): shown the modal dispersion curves of the identified model (<u>same</u> of the previous slide). Please notice that the fundamental mode of Rayleigh waves is missing.

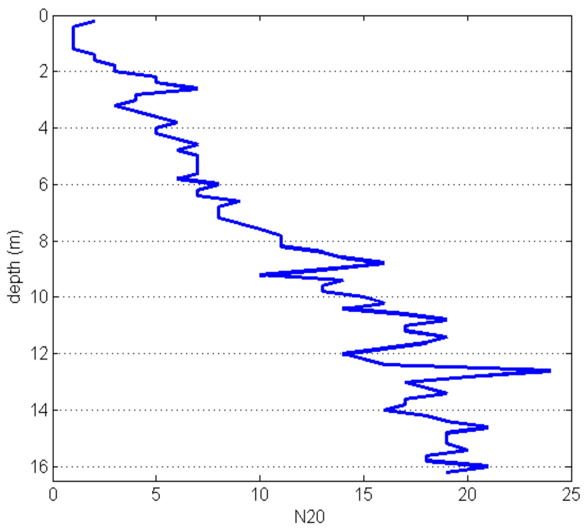


Vsv (m/s)	Qs	Anis. (%)	Poisson	thk (m)
55	10	0	0.329	0.3
99	9	0	0.38	1
140	11	0	0.482	0.7
163	16	0	0.44	0.7
187	10	0	0.498	2
225	13	0	0.3	4.1
323	21	0	0.342	17
390	28	0	0.33	34
636	44	0	0.169	48.1
800	96	0	0.121	

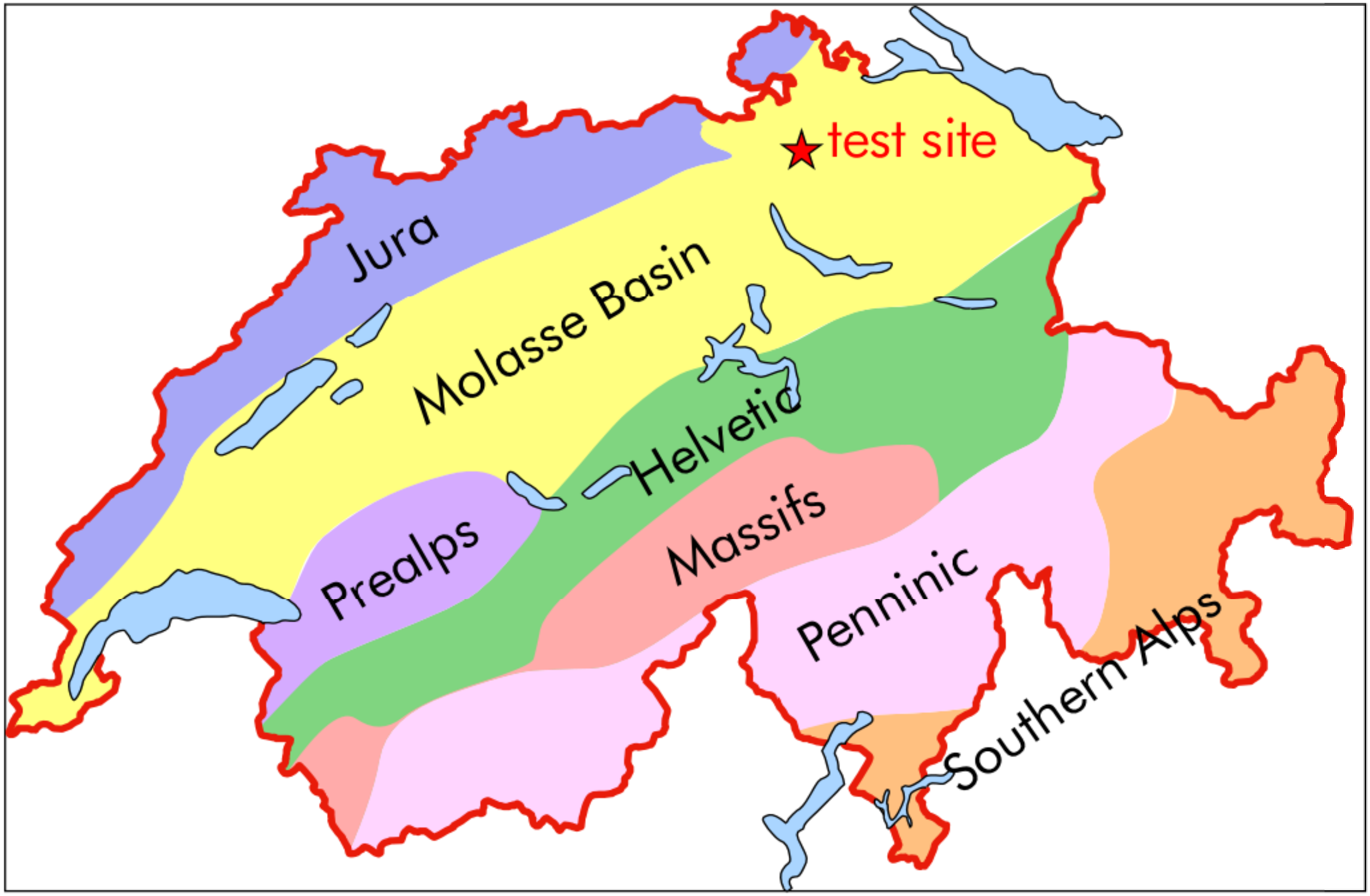
Rayleigh waves: fundamental mode almost completely missing

Comparison of the Vs identified model (on the left) and the DPSH (Dynamic Probing – Super Heavy) data (available only down to 16m)





Geological setting



- **The Mesozoic-Cenozoic Swiss foreland basin**
- **The site is located on a Miocenic terrace (Upper Fresh-water Molasse) constisting of clay and sandstones.**
- **Thin (<2 m) moraine cover possibly locally present.**

Overview on considered methods/datasets

- SRT: Seismic Refraction Tomography (SH- and P-waves)
- MASW: Multichannel Analysis of Surface Waves
- VSP: Vertical Seismic Profiling
- HVSR: *Horizontal-to-Vertical Spectral Ratio* (Nakamura)
- ZVF/RVF/REX/THF:
  - 1st char refers to receiver: Z = vertical, R = radial, T = transversal
  - 2nd + 3rd chars refer to source type: VF = Vertical Force, HF: Horizontal Force
- ZVF: vertical component of Rayleigh waves
- RVF: radial component of Rayleigh waves
- THF: Love waves

Field Measurements

Passive data

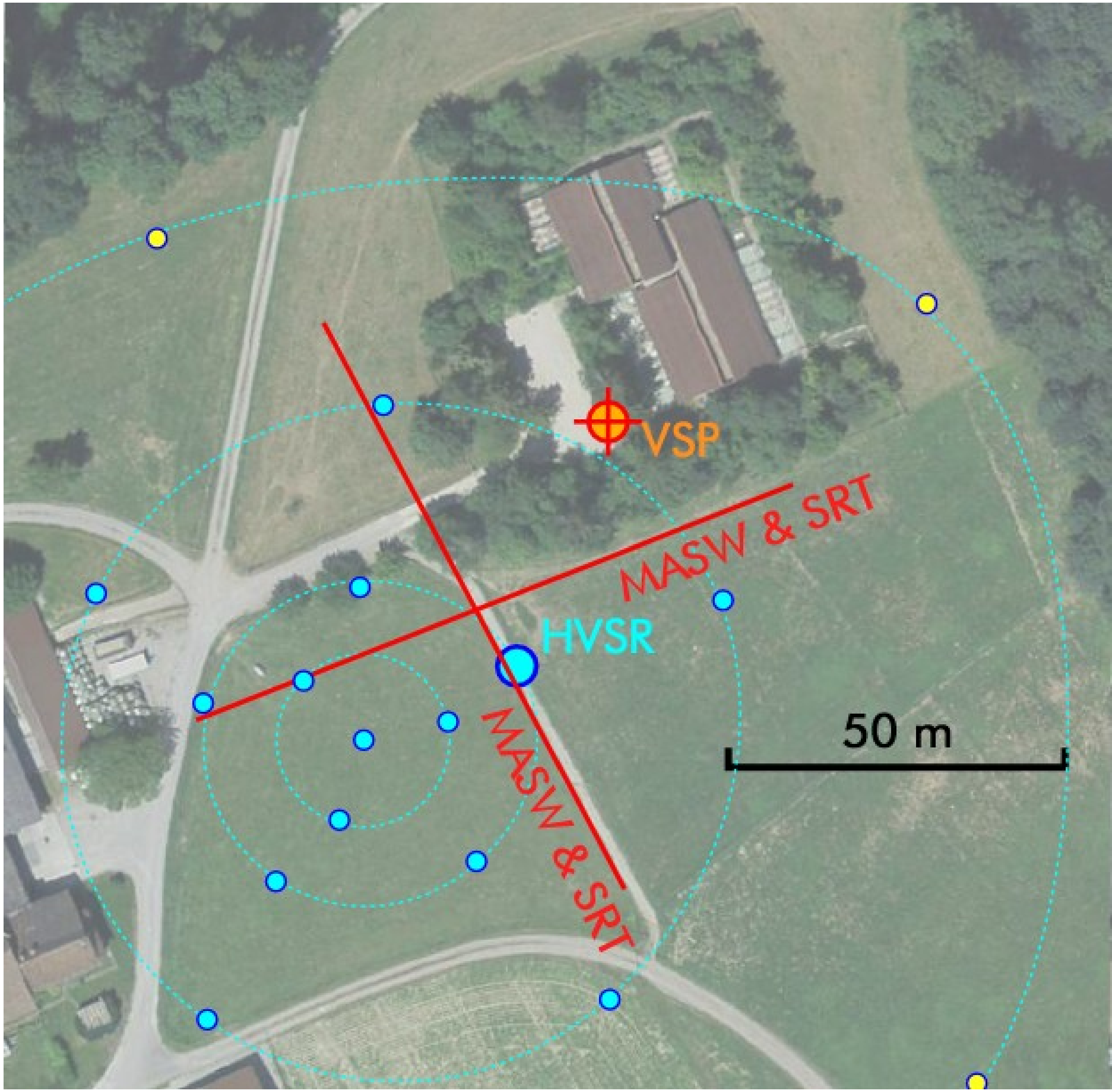
- array measurement of ambient vibrations for *f-k* (dispersion) analisis and HVSR (ETH team – Donat Fäh & Valerio Poggi)

Active data

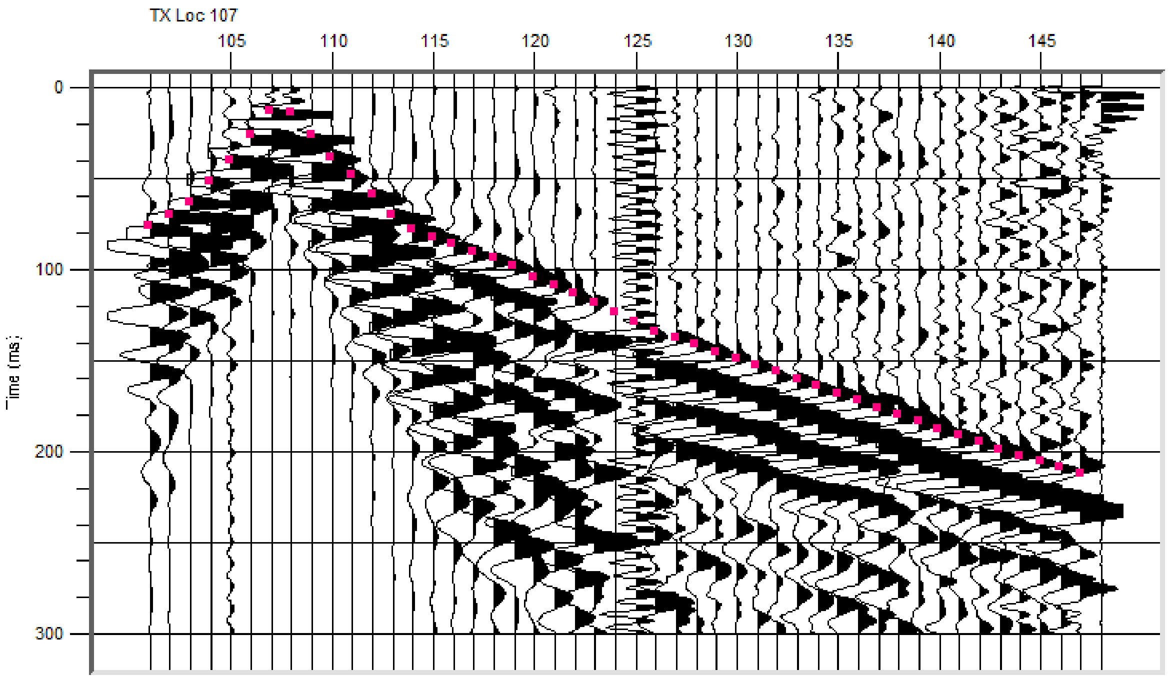
- Rayleigh- and Love-wave MASW: ZVF + RVF + THF components
- pSRT (sledgehammer)
- sSRT (shear-component vibroseis)
- VSP (SH- and P-waves): sledgehammer for Vertical and Horizontal Force

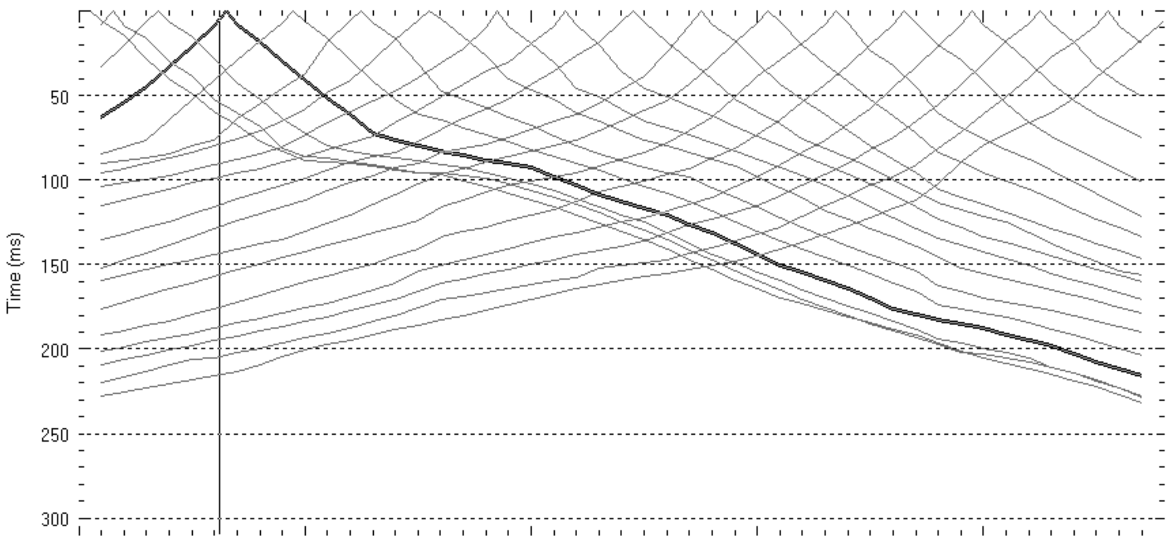
Field setup

- 4 +/- concentric circles (30 – 200 m diam.) of 3 to 5 Lennartz 3/5s seismometers
- 2 perpendicular active arrays of 94 m length, 2 m geophone interval, 4.5 Hz vertical, 10 Hz horizontal
- 100 m VSP with 1.0 [0-20 m] and 2.0 m [20-100 m] depth interval



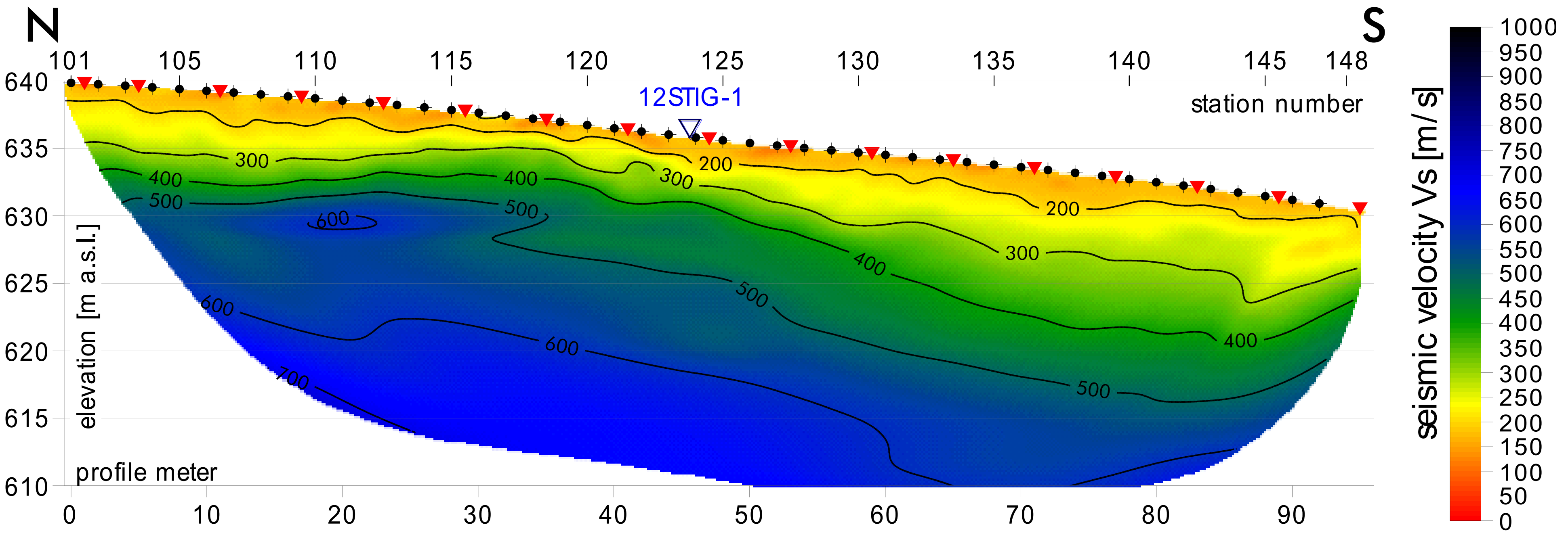
Refraction tomography sSRT (and pSRT)

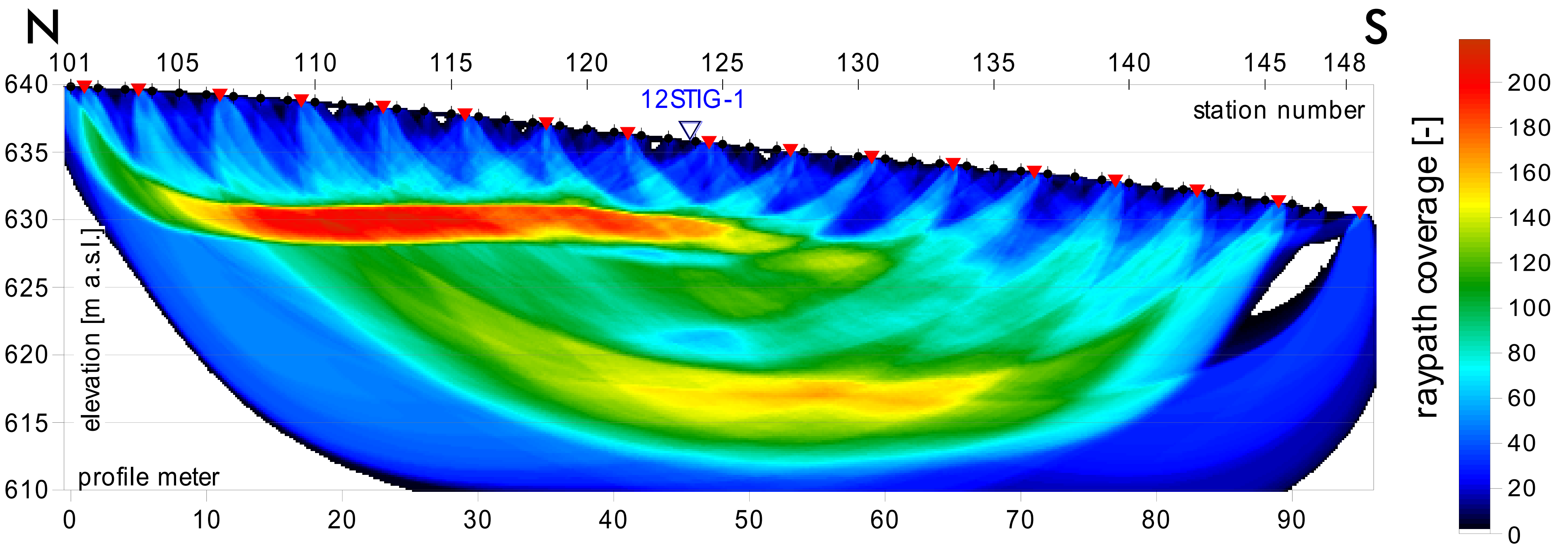




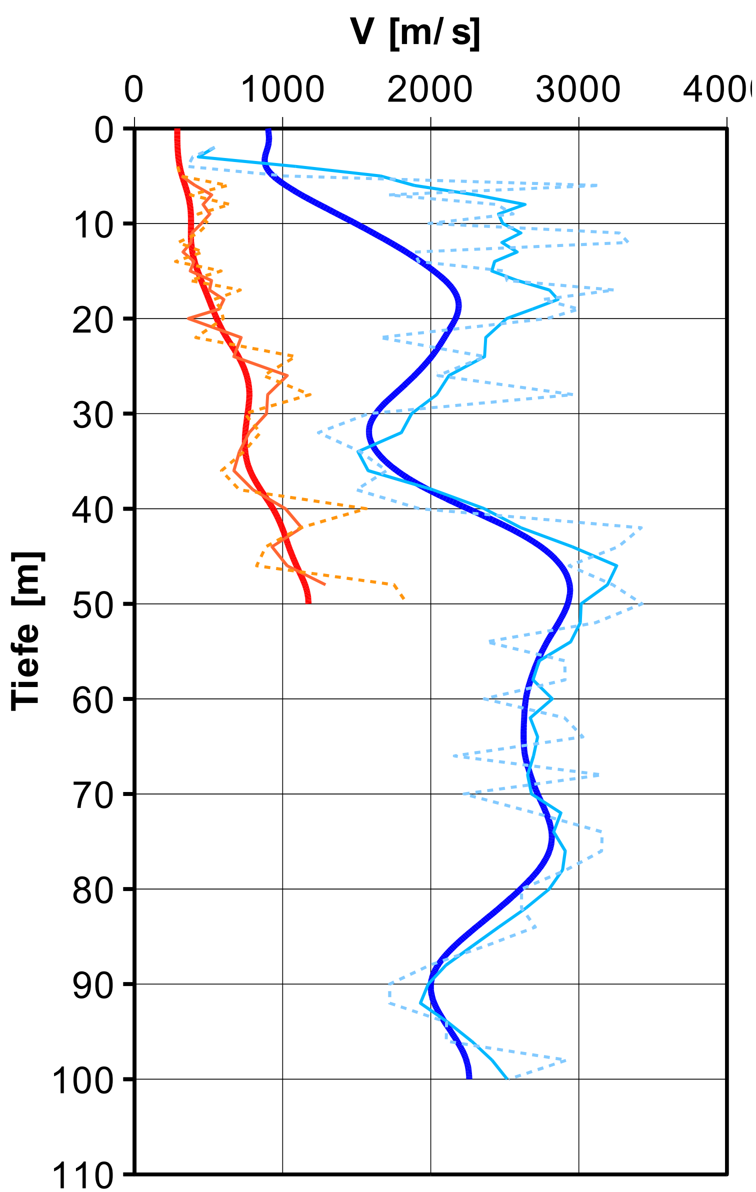
Vs: vibro source ElViS
(450N peak force; 20-160Hz)
Rx interval: 2.0 m
Tx interval: 6.0 m

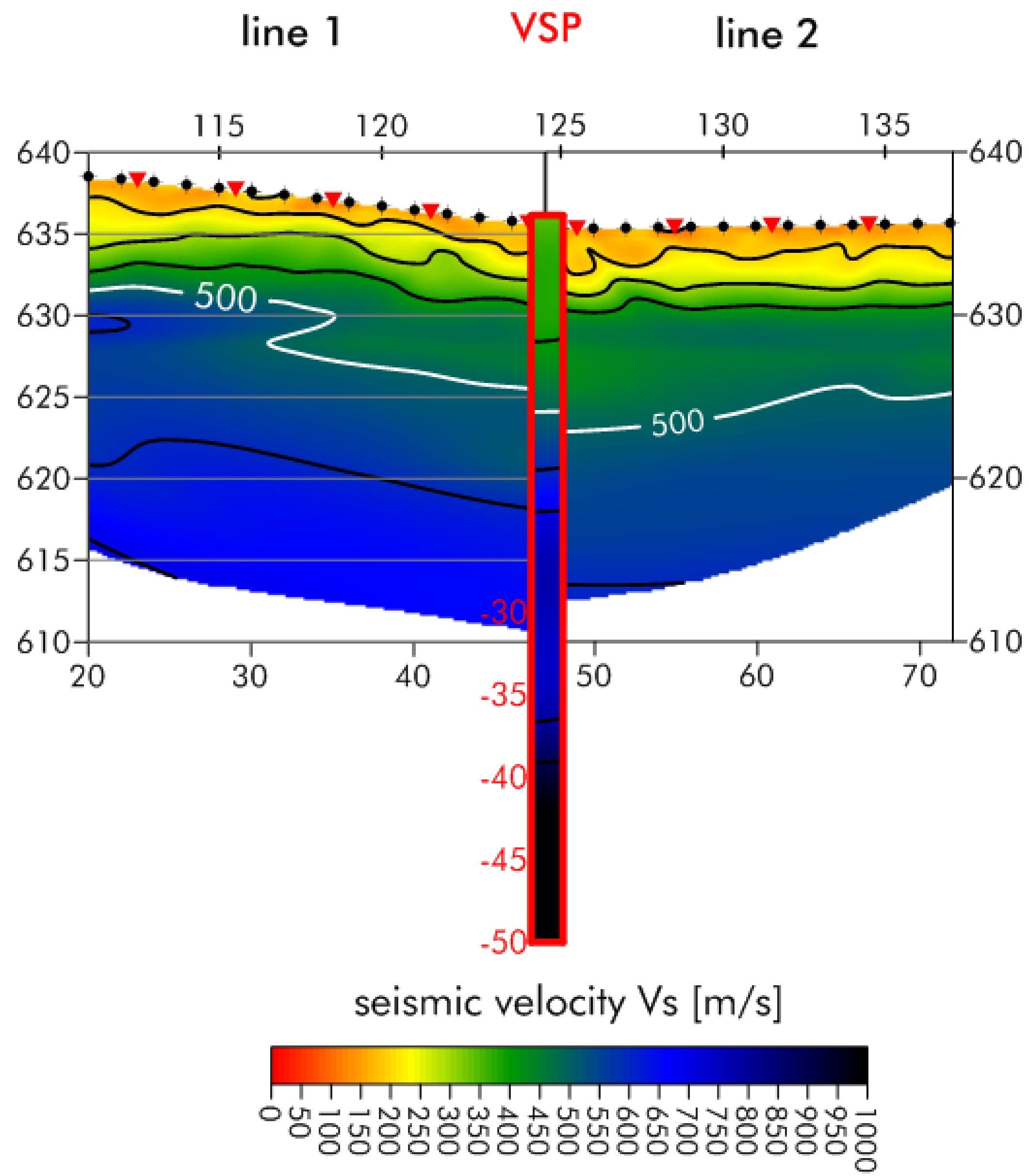
sSRT results of one line





sVSP & pVSP results





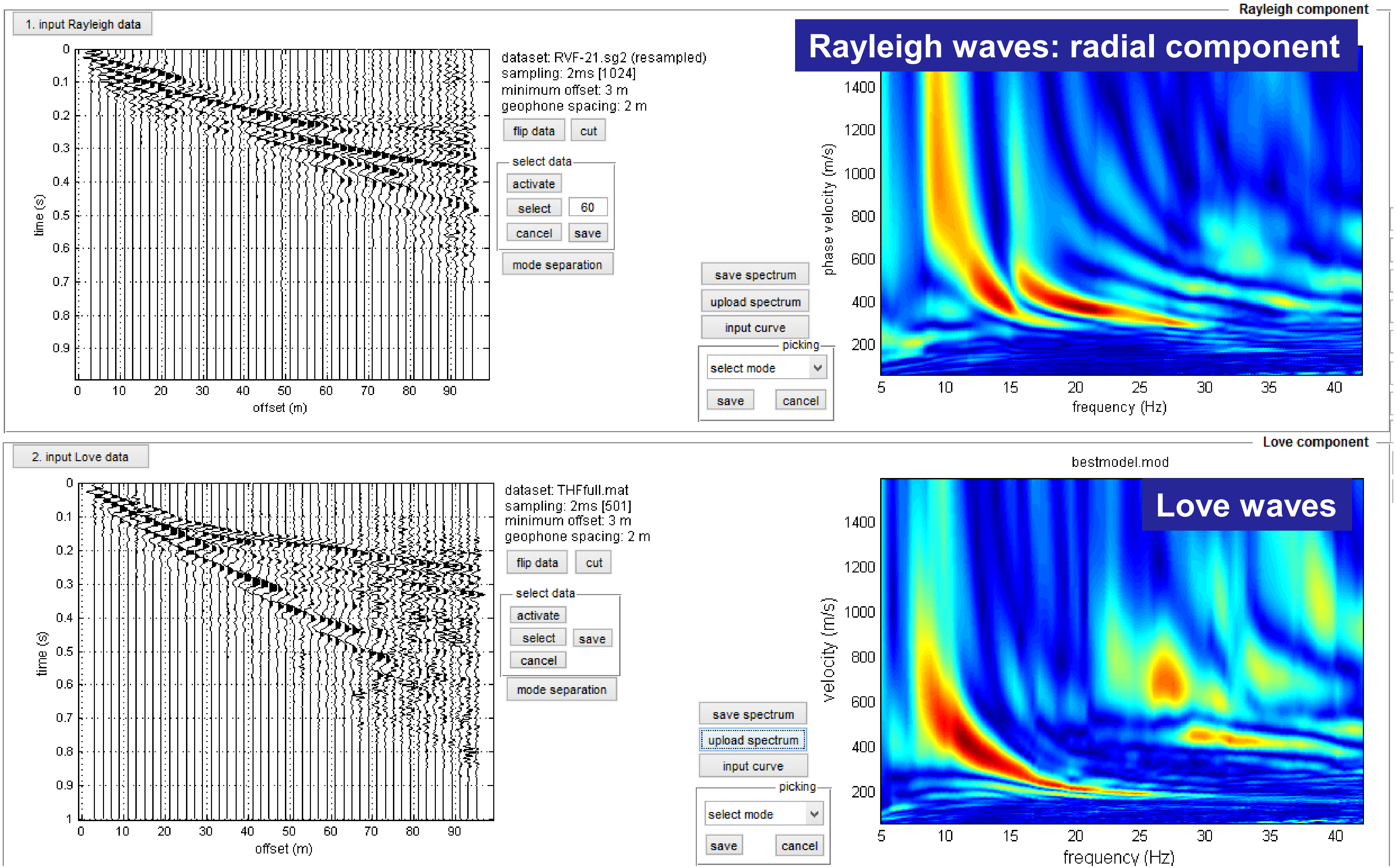
MASW (Rayleigh & Love waves)

ZVF (Vertical component of Rayleigh waves)

RVF (Radial component of Rayleigh waves)

THF (Love)

MASW data (line#2dir) – comparing radial and vertical components



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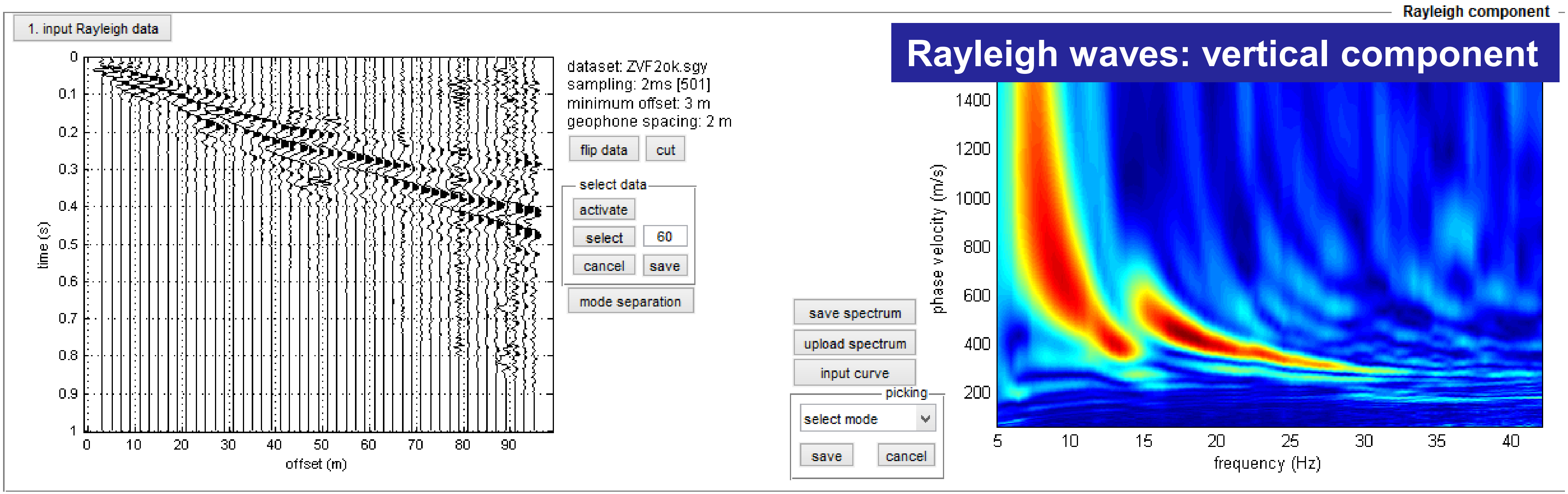
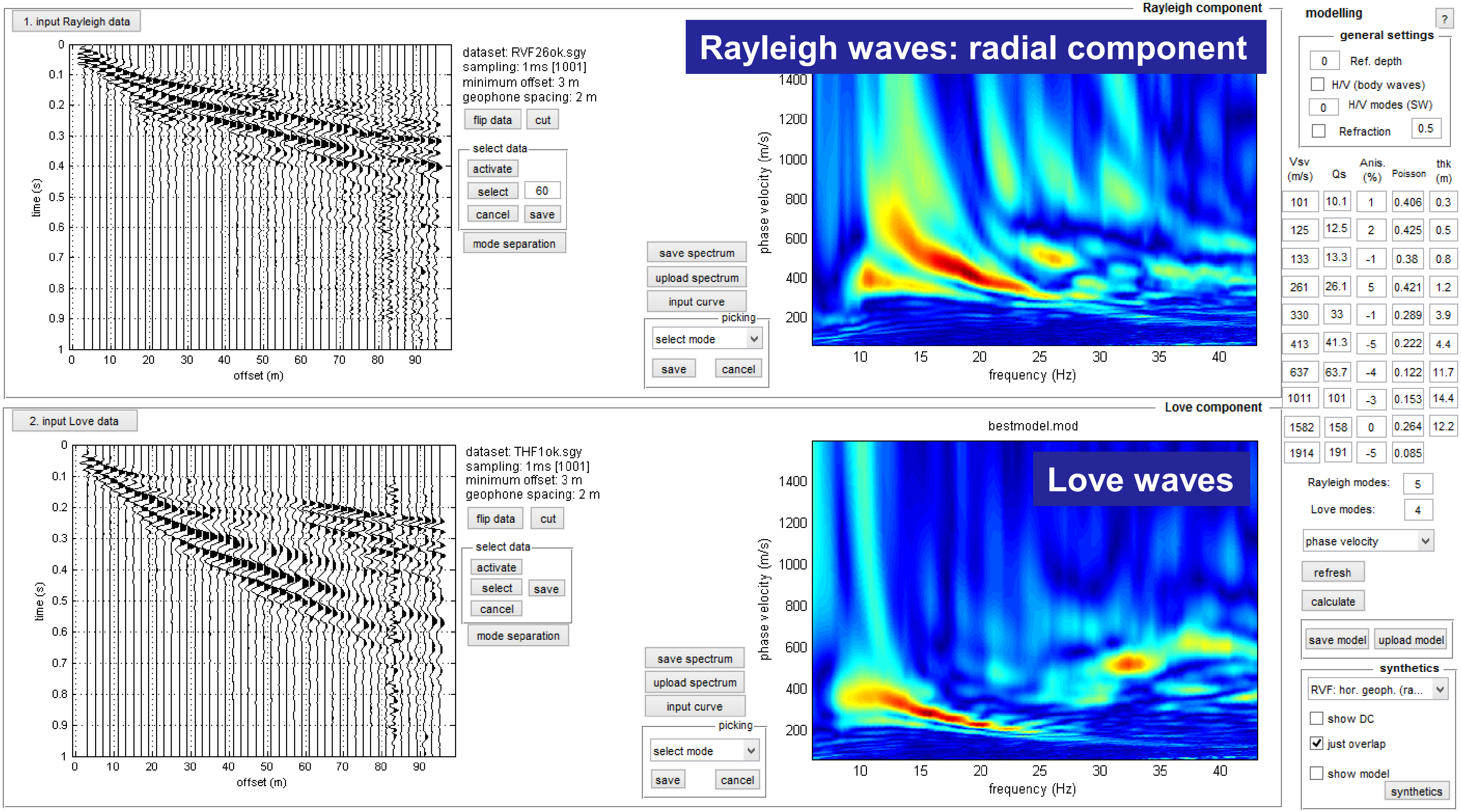
MASW data (line#2dir) – comparing radial and vertical components

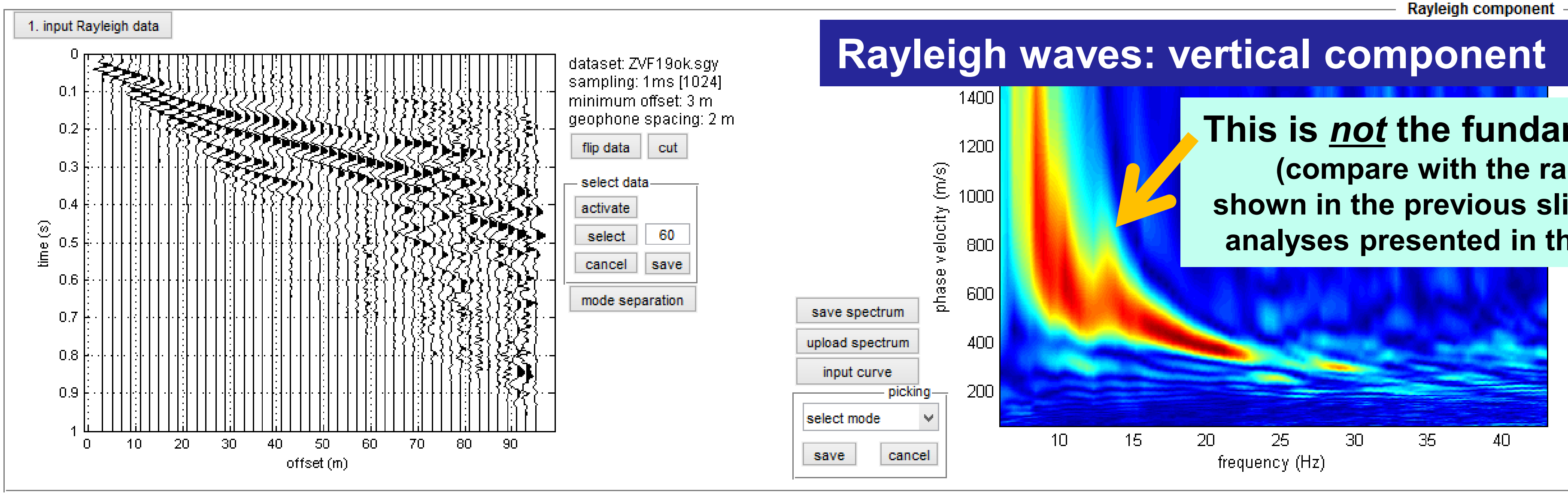


MASW data (line#2rev) – comparing radial and vertical components



Please notice the lack of low frequencies in the radial component of Rayleigh waves and in the Love waves: this is simply due to the use of 10Hz horizontal geophones (ZVF was instead acquired using 4.5Hz vertical geophones)

MASW data (line#2rev) – comparing radial and vertical components



Rayleigh waves: vertical component

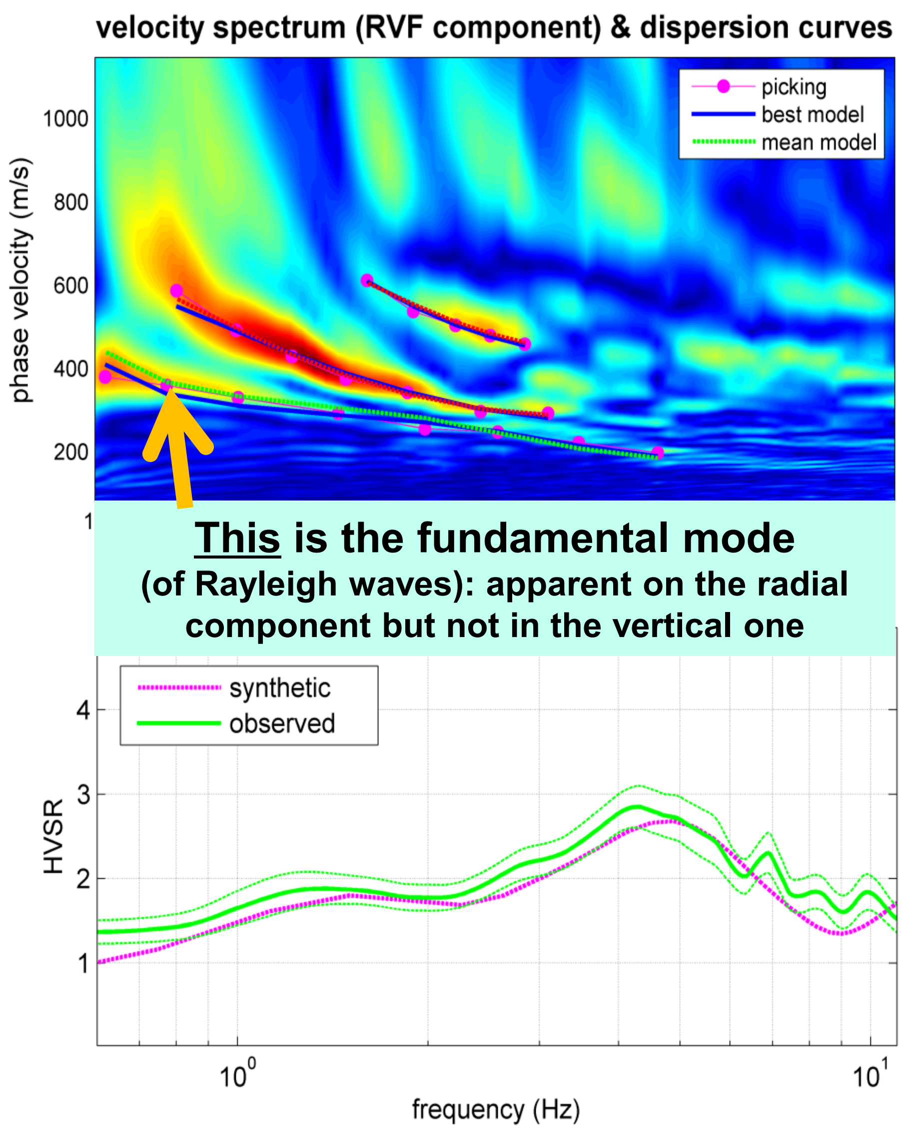
This is *not* the fundamental mode
(compare with the radial component shown in the previous slide and with the analyses presented in the next 2 slides)

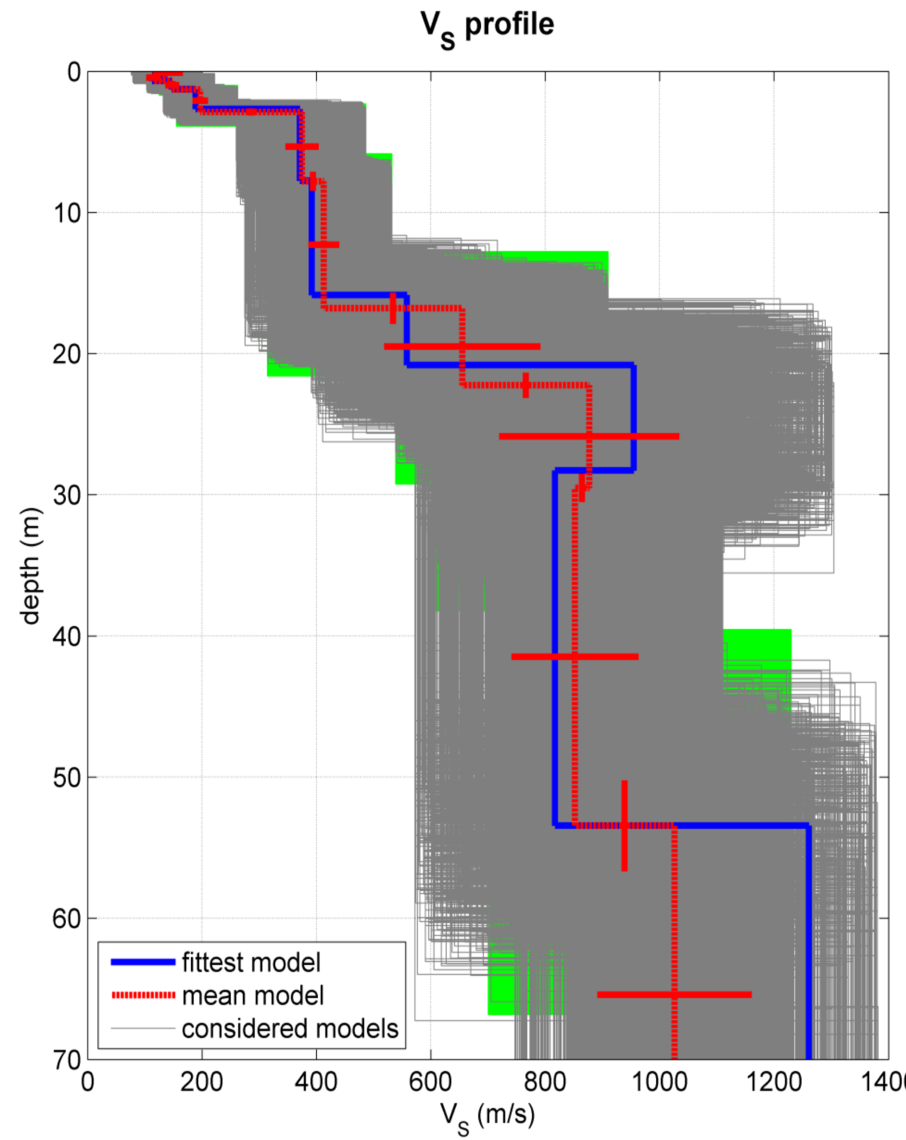
Note that, in this case, the *Vertical Component* completely lacks of the fundamental mode so if you would use only the vertical component (the "classical" MASW analysis) you would easily misinterpret the data (velocity spectrum).

The *Radial Component* (of Rayleigh waves) and the Love waves appear much clearer, thus simpler to interpret and invert.

Joint MASW (Rayleigh+Love) + HVSR analysis

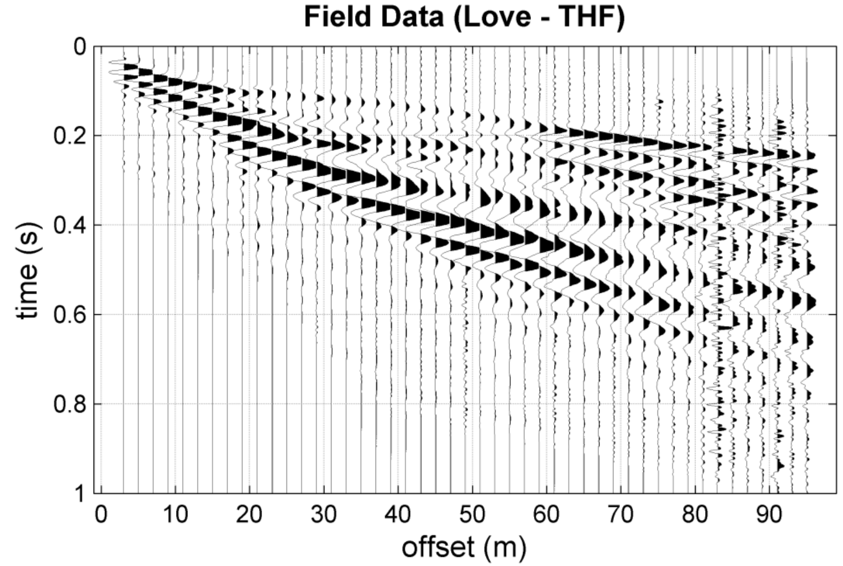
In this case the radial component of Rayleigh waves allows to better identify modal dispersion curves (three modes at least)

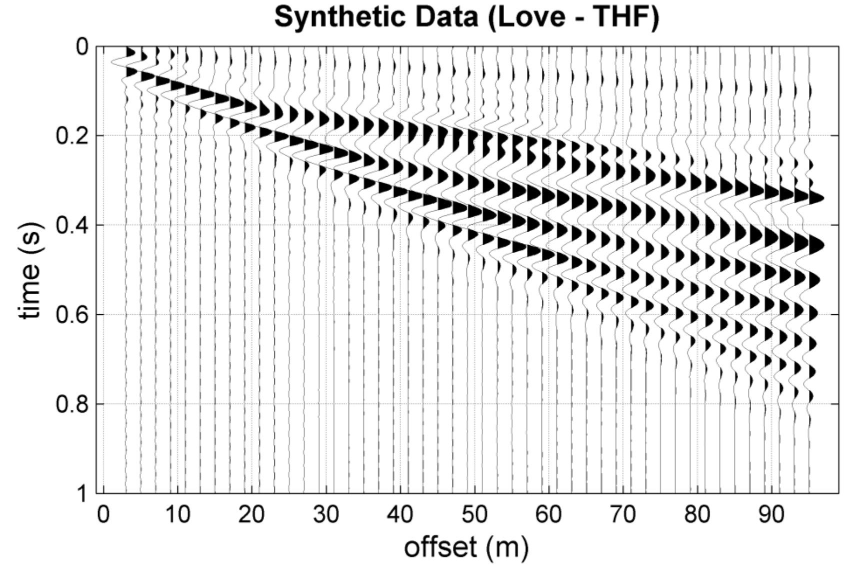


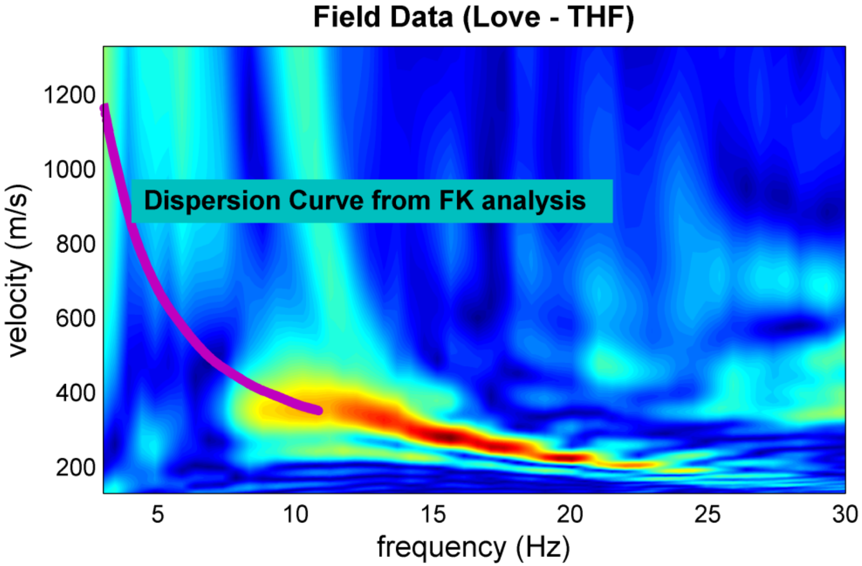


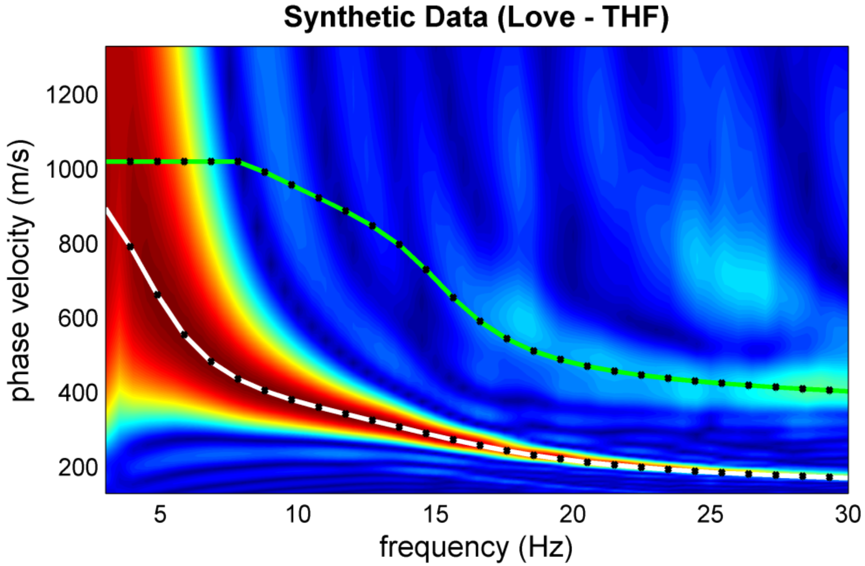
MASW (Love waves – THF component)

Same V_S model presented on the previous slide



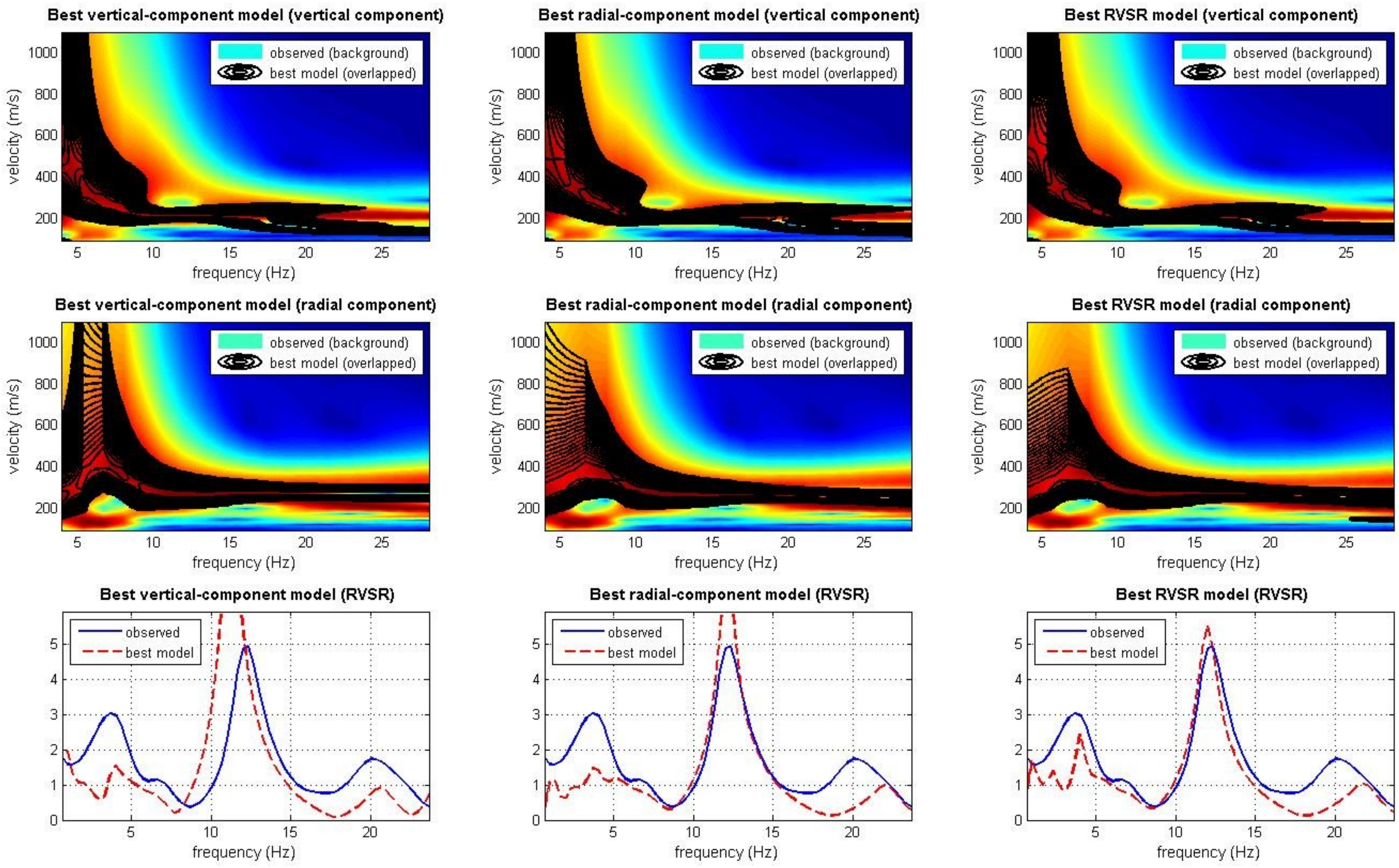






Pure *HoliSurface*® (a patent pending methodology)

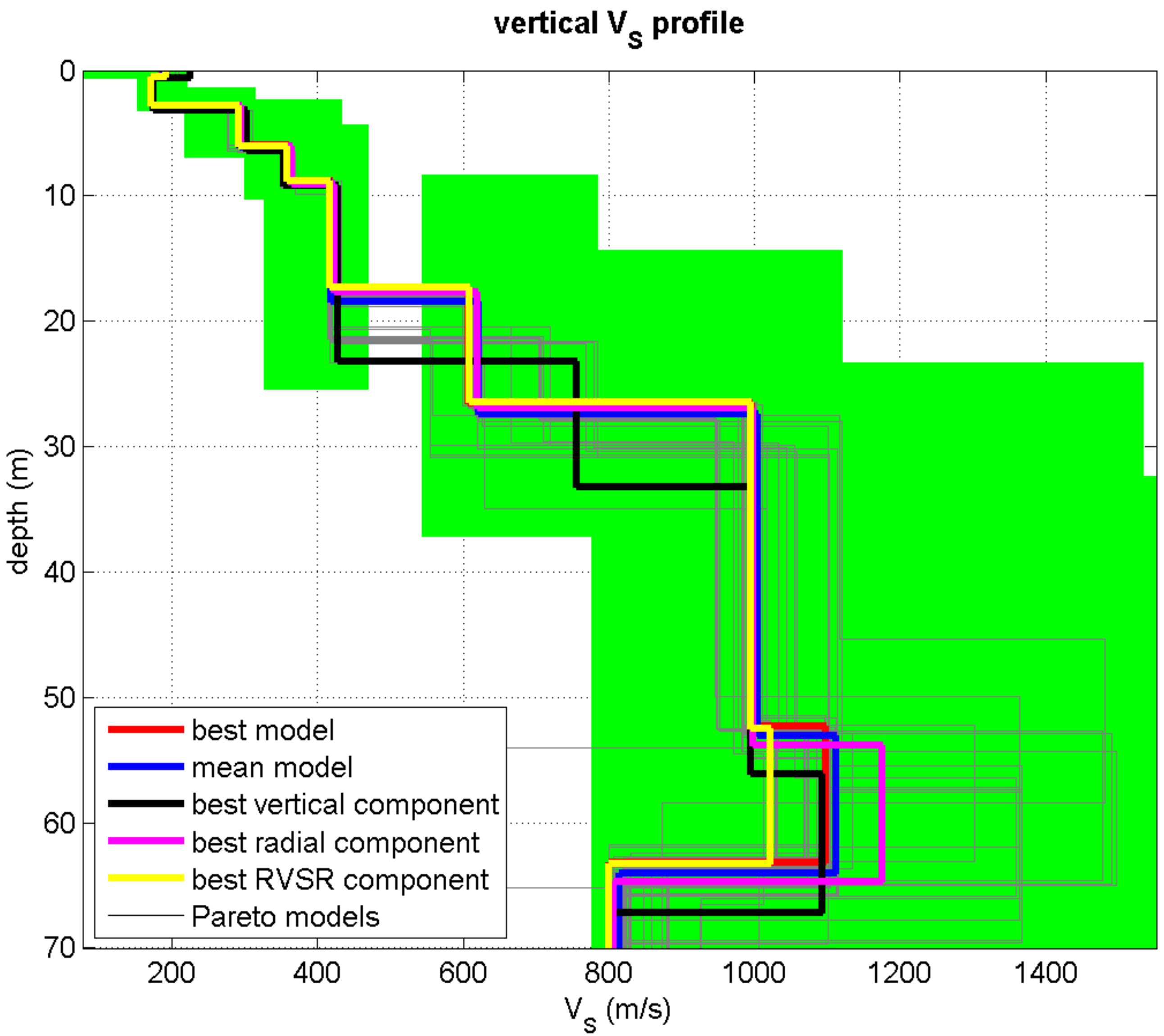
Analyzing dispersion/attenuation through a single 3-component geophone and a single shot (very quick acquisition procedures, analyzing both amplitudes and group velocities, intensive computational load): ***automatic inversion***



Pure *HoliSurface*® (a patent pending methodology)

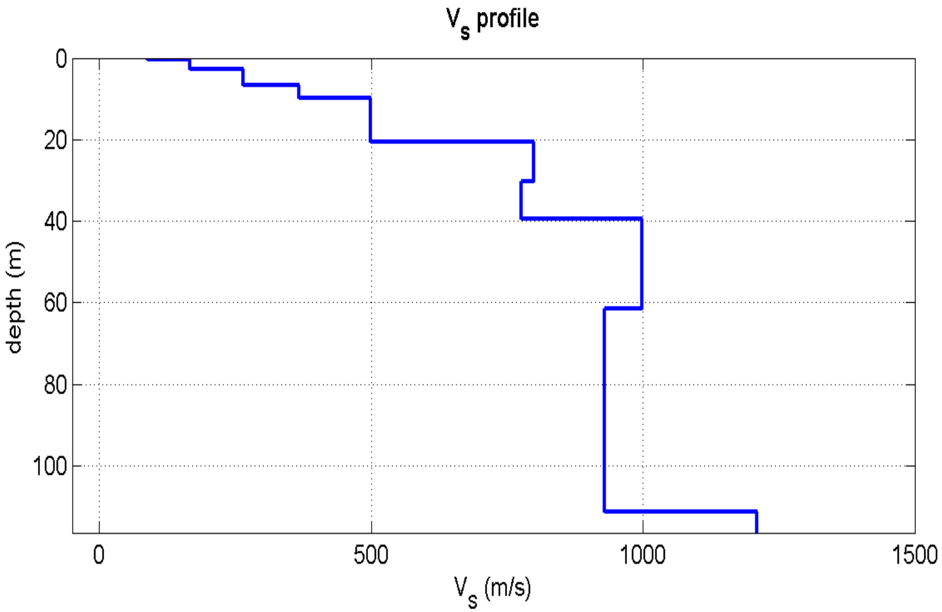
HoliSurface®: analyzing dispersion through a single 3-component geophone

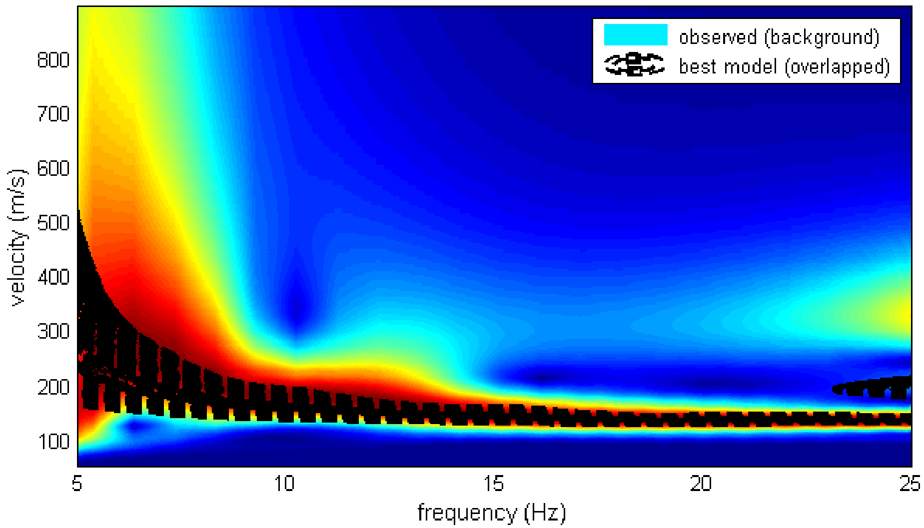
automatic inversion

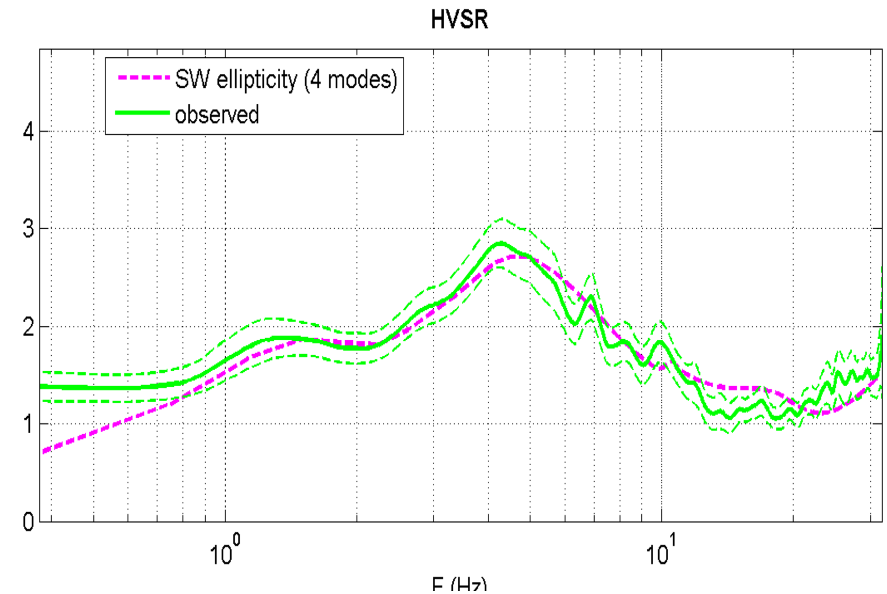


Love-wave group-velocity spectrum + HVSR

Direct modelling approach

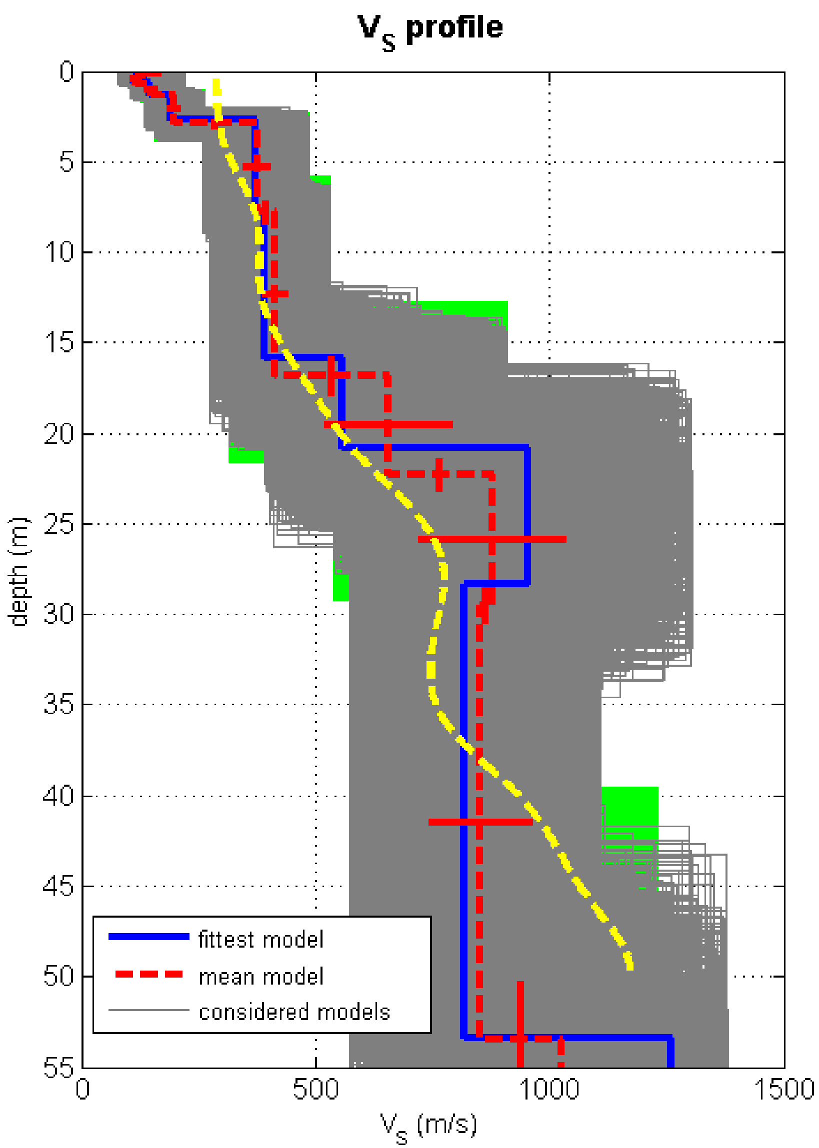




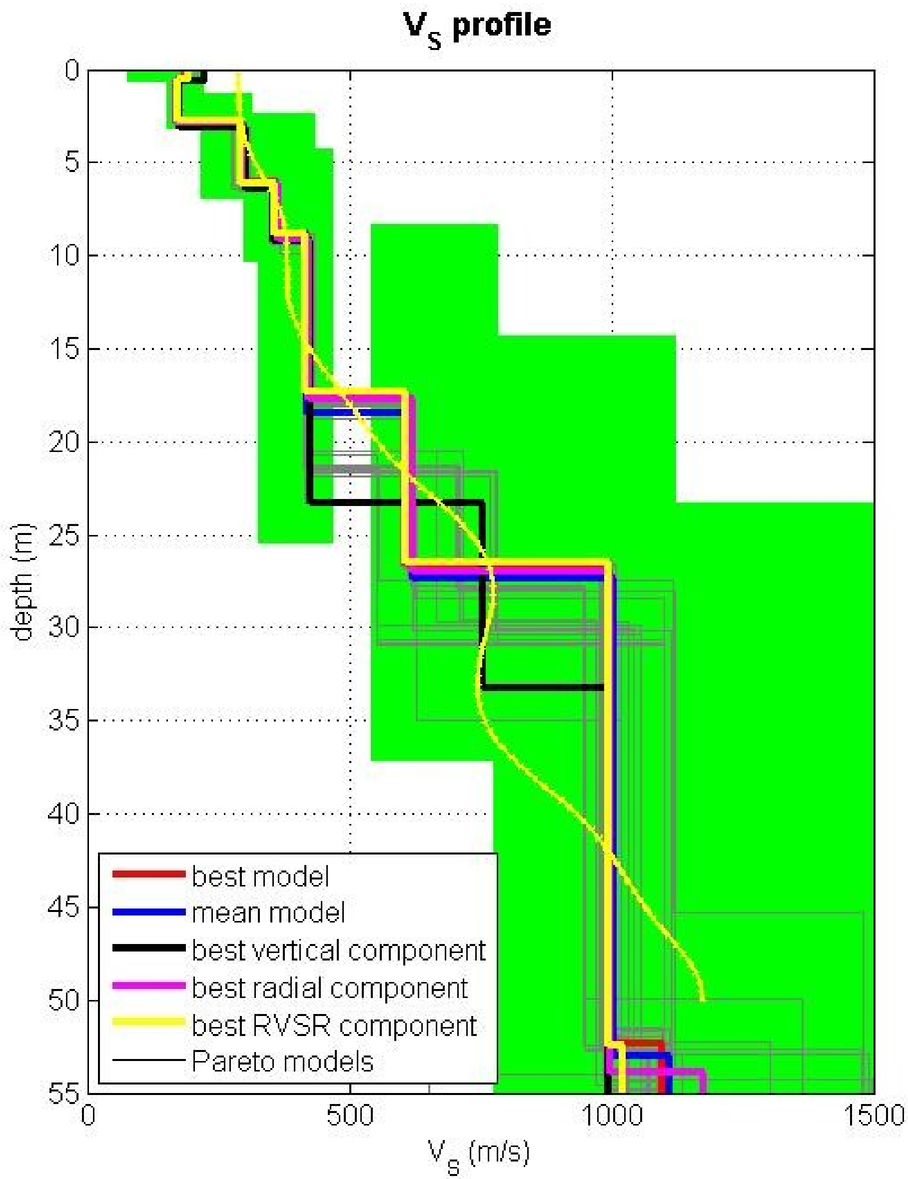


Surface-wave analysis - comparison with VSP data

MASW (Rayleigh + Love + HVSR)

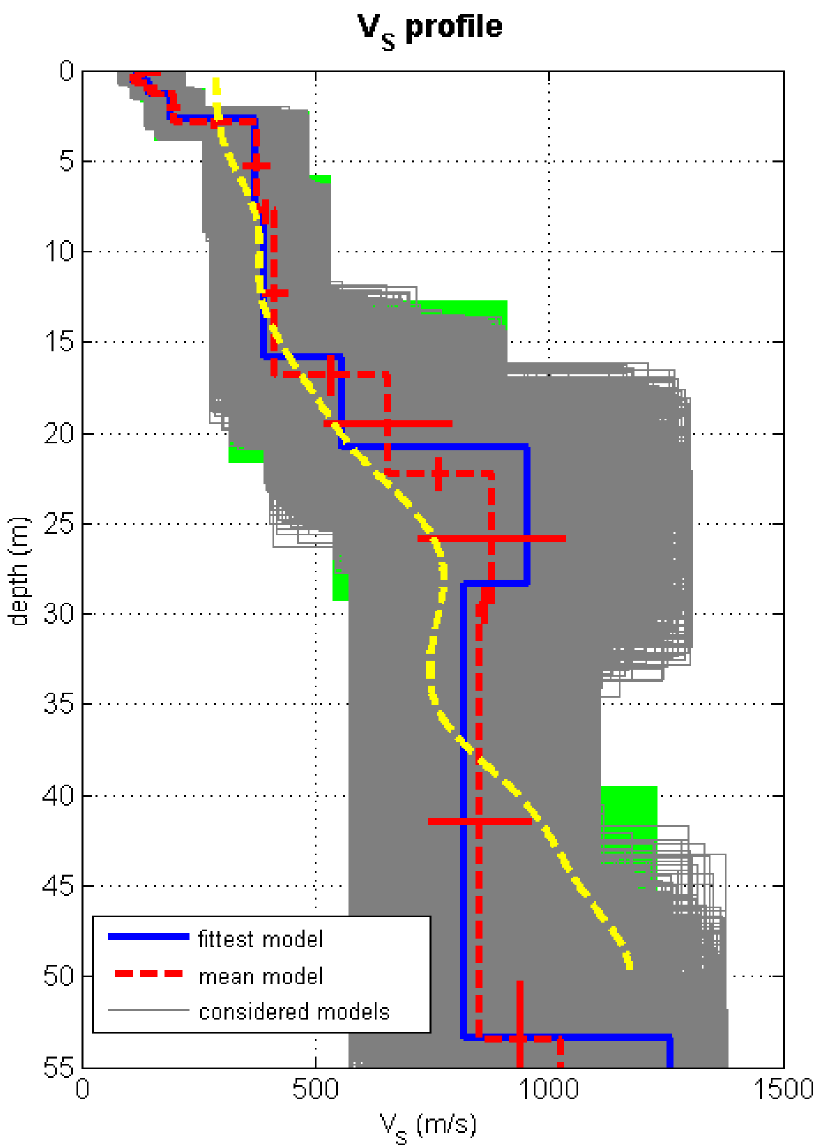


Pure HoliSurface **(just Rayleigh waves)**

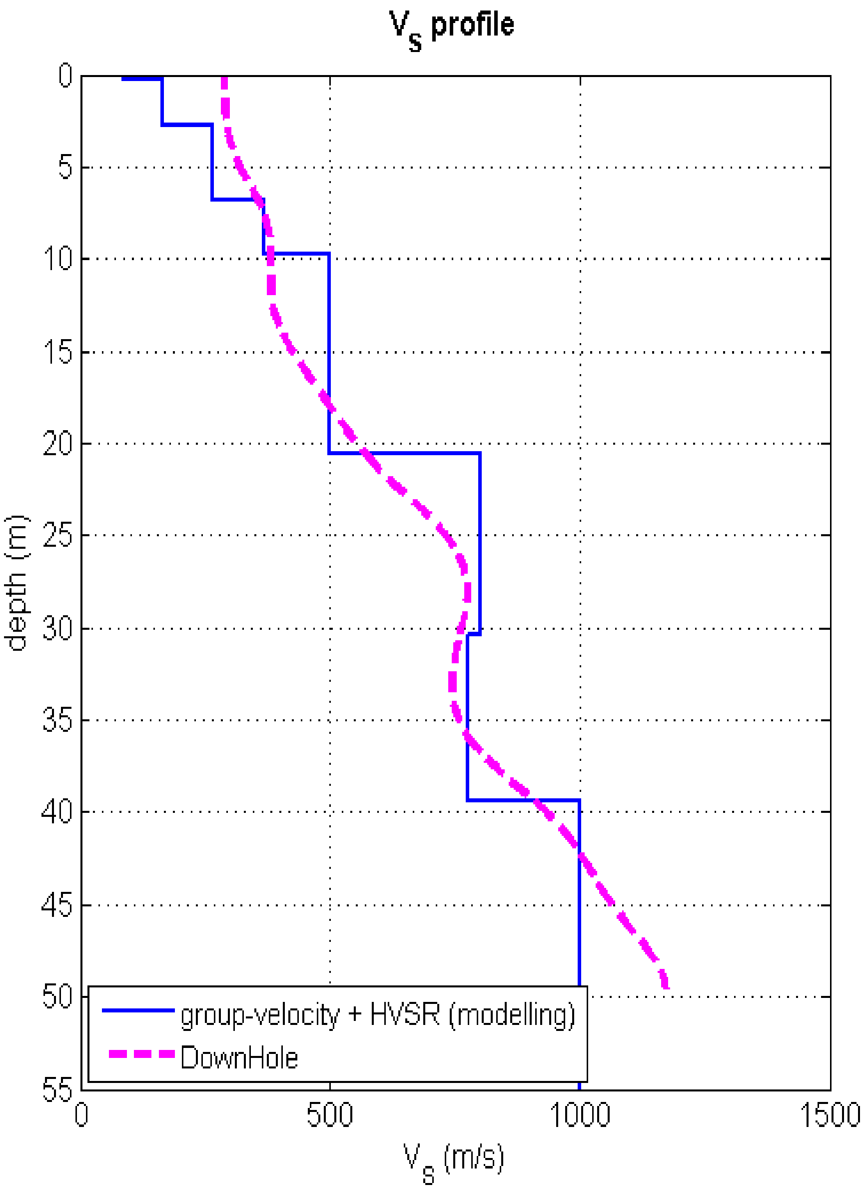


Surface-wave analysis - comparison with VSP data

MASW (Rayleigh + Love + HVSR)



Just group-velocity (Love) + HVSR [direct modelling]



Few conclusions

- As often observed, because of the difficulties in the identification of the shear-wave first arrivals and the consequent erroneous picking, in the first few meters, VSP analysis can overestimate the shear-wave velocities [in this case high velocities from VSP may be partially related to the artificial materials in the parking lot]

- Surface-wave joint analysis of multi-component data (Rayleigh + Love waves) allows to retrieve accurate (unambiguous) Vs profiles which, in the deepest parts, benefit from the joint analysis with HVSR (singularly considered, this method would suffer from a severe ambiguity and non-uniqueness of the solution)

- The analysis of group-velocity spectra obtained from quick acquisitions done through a single 3-component (*HoliSurface*® approach) geophone shows very good results down to at least half the length of the array (to get deeper HVSR can result beneficial)

Acknowledgements

We gratefully acknowledge Nagra (*Nationale Genossenschaft für die Lagerung radioaktiver Abfälle*) for the permission of showing the data. We thank Donat Fäh and Valerio Poggi from the *Swiss Seismological Survey* (ETH - Zürich) for providing the passive data used in this study.

For further documents and case studies

Giancarlo Dal Moro, Eliosoft.it (gdm@winmasw.com)
Lorenz Keller, roXplore.ch (lorenz@roxplore.ch)

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