HoliSurface® 2024

HS www.holisurface.com

DRAFT MANUAL

Software for the holistic analysis of surface waves and vibration data according to a series of very efficient *active* and *passive* methods that require a very limited field equipment

The HS technique is protected by an international patent

KEEP IT SIMPLE, KEEP IT HOLI

The more you know, the less you need

Yvon Chouinard

LESS IS MORE
LUDWIG MIES VAN DER ROHE

The methodologies implemented in the *HoliSurface®* software allow you to analyze surface waves and vibration data recorded according to a series of very efficient methodologies based fundamentally on just one 3-component geophone (HS active data and HVSR passive data) or 4 vertical geophones arranged according to a very small radius (MAAM and SPAC techniques).
Vibration data recorded on a building or bridge using a single 3-component geophone are used to determine both the eigen frequencies, the modes (torsional or flexural) and the damping.
There are several tools for a myriad of applications (2D V_S sections, data editing and comparison and much more).

A new set of tools makes the software perfectly suited for the efficient management of continuous data recorded by cableless systems such as the SmartSolo nodes.

Please, take some time to go through the manual and see by yourself how can be easy your field work and how precise can be your analyses.

our social media

https://www.facebook.com/HoliSurface [public]

https://www.facebook.com/winMASW [for *friends*]

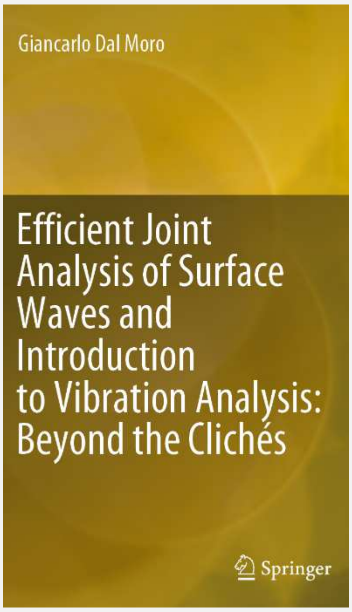
https://twitter.com/winmasw

https://www.youtube.com/user/winMASW/videos

https://www.researchgate.net/profile/Giancarlo_Dal_Moro

In particular, we recommend our *Facebook* page, which is frequently updated with case studies, news and various useful tips.

Efficient Joint Analysis of Surface Waves and Introduction to Vibration Analysis: Beyond the Clichés



Springer

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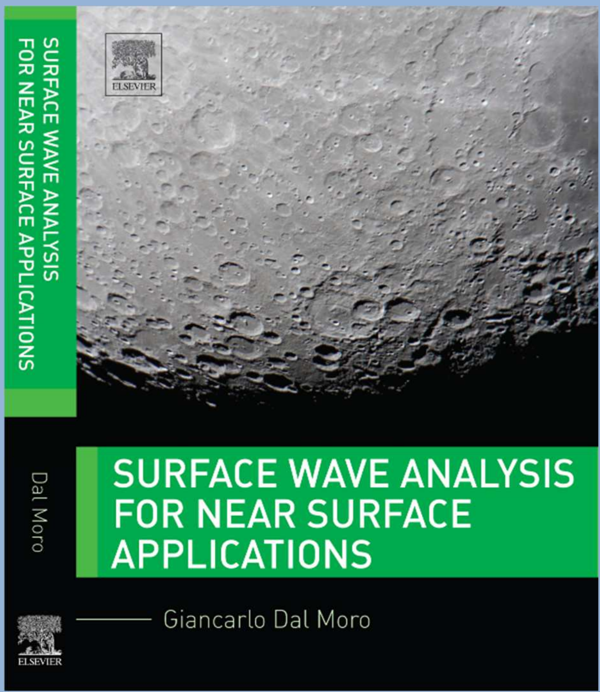

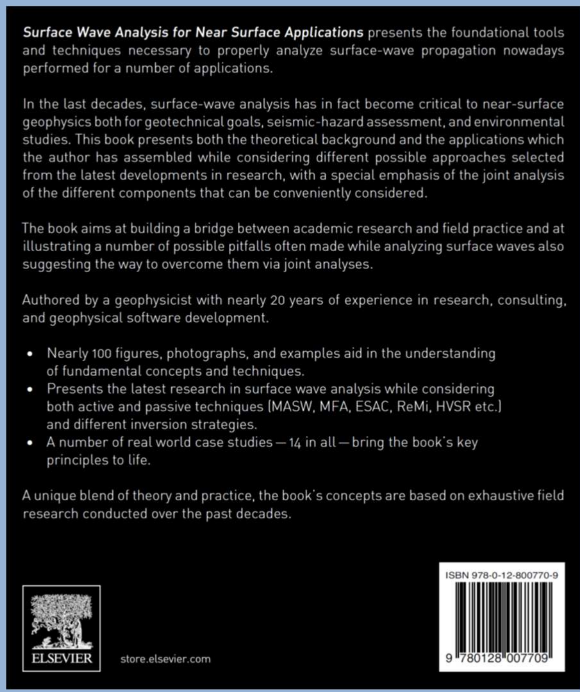

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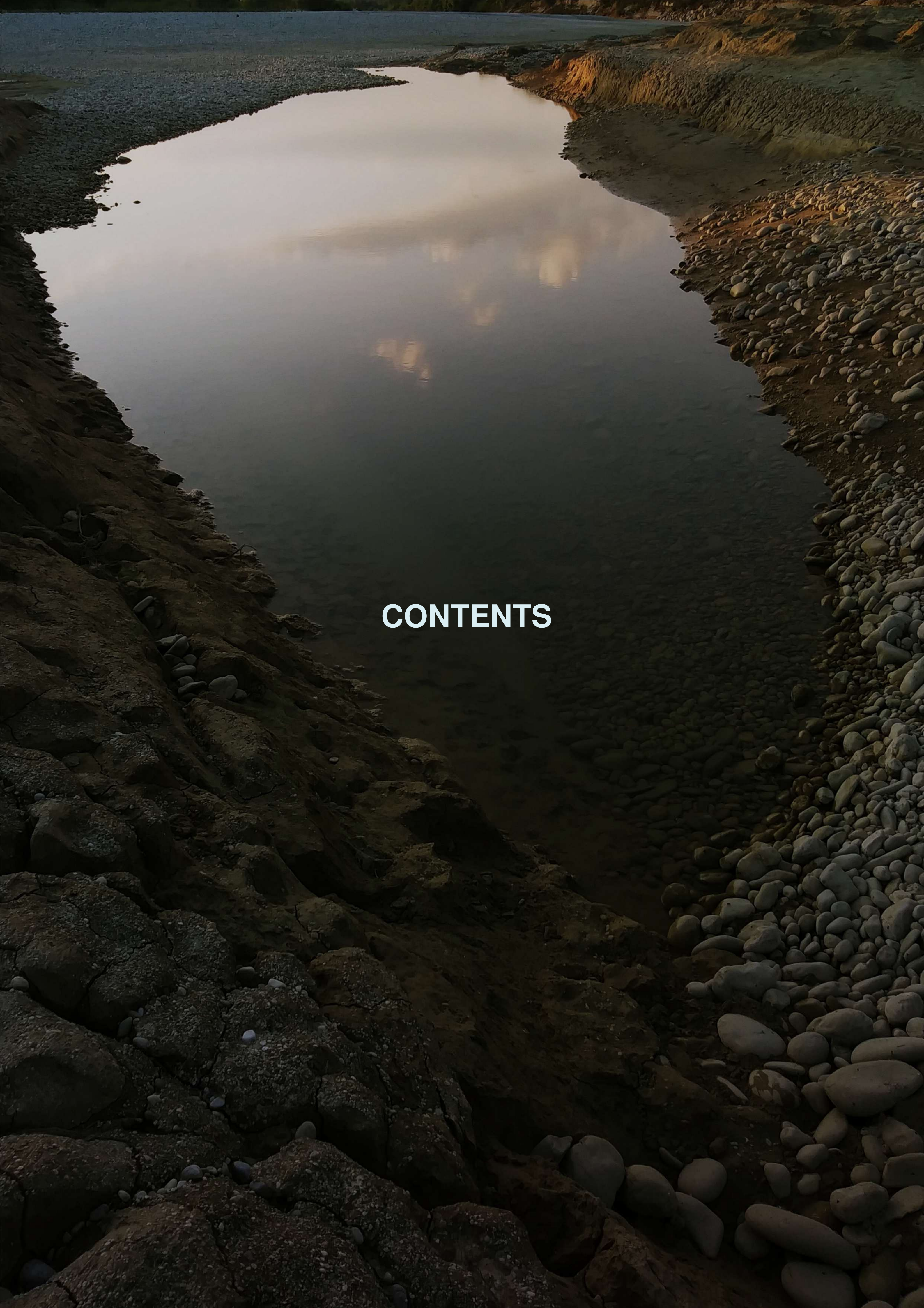

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The *HoliSurface®* system in brief

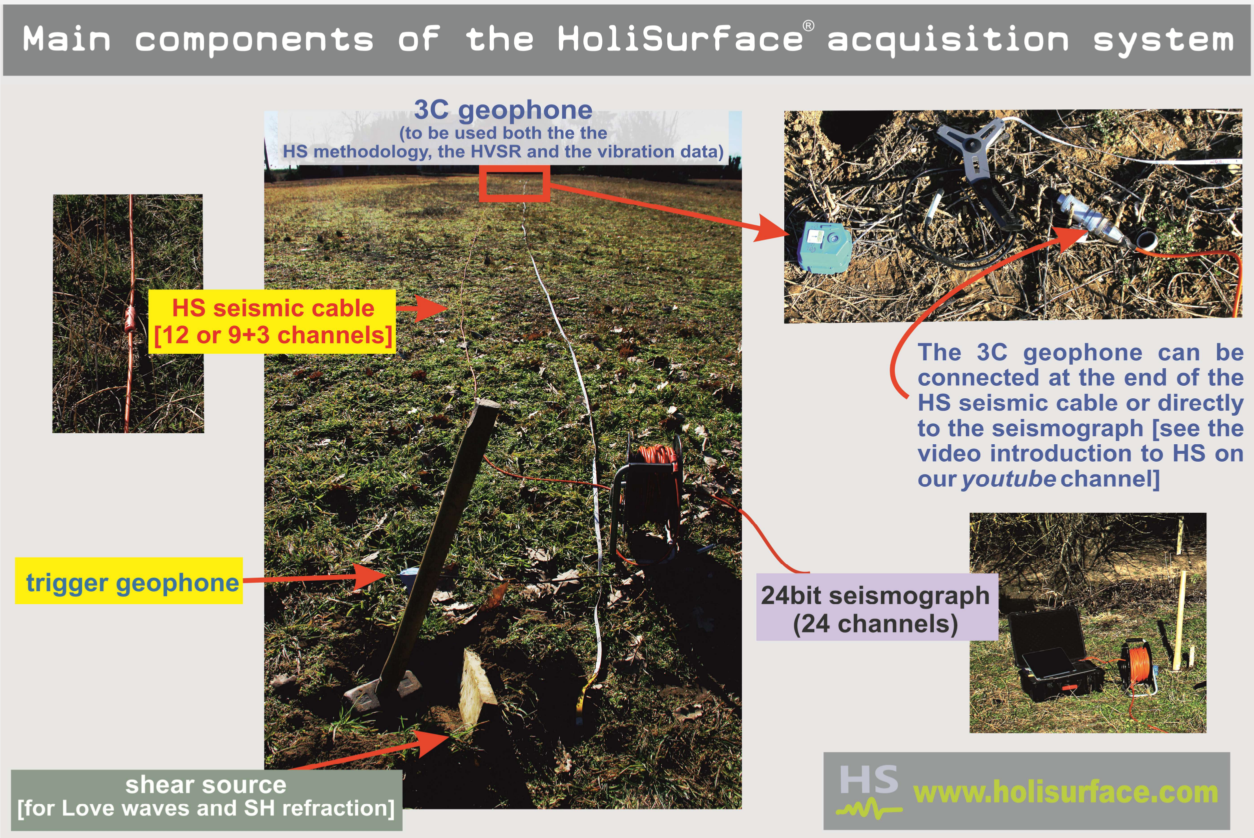
HoliSurface® (or **HS**) is a software that allows you to take full advantage of a whole series of methodologies by simply using a 4-channel seismograph (of excellent quality and properly designed and engineered).
From a practical point of view, using **HS** combined with a suitable *acquisition system* makes it possible to carry out an extensive series of analyses that require very simple (active and passive) acquisition procedures.

Fundamentally, what you need is:

- ✓ **high-quality (24 or 32 bit) seismograph**
- ✓ **a suitable seismic cable that makes possible a series of useful connections**
- ✓ **one 3-component geophone (for a wide range of active and passive techniques)** **[in case you have two of them, the number of possible techniques dramatically increases]**
- ✓ **four (4) or six (6) high-quality vertical geophones (for MAAM and some attenuation analyses)**
- ✓ **trigger geophone [optional in case you have two 3-component geophones]**

This equipment must be of the highest quality and any attempt to patch together a *do-it-yourself* HS system risks yielding poor results.

The *basic* system (that can be easily upgraded/expanded so to also handle MASW/ESAC/SPAC/ReMi/PS-MuCA/refraction studies) we provide together with the HS software is summarized by the previous list and shown in the following scheme.



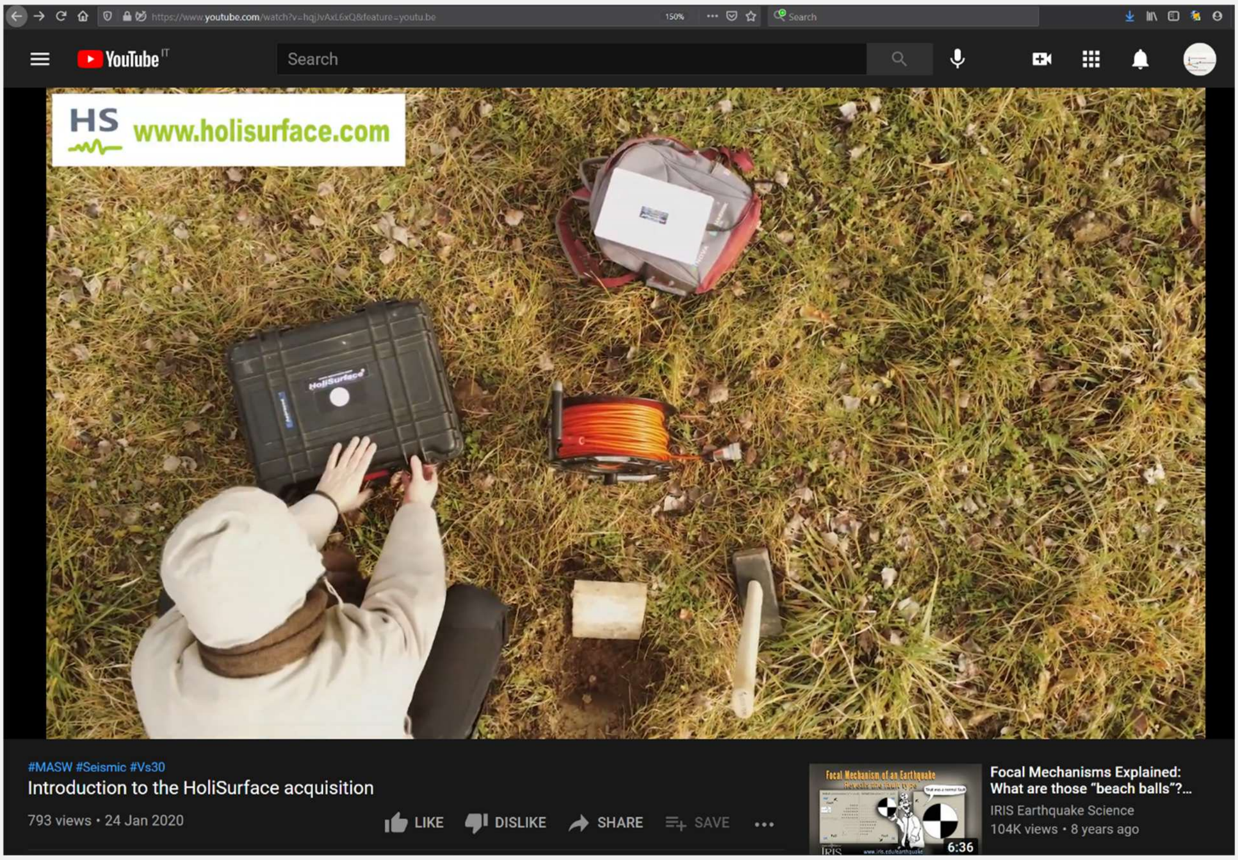
The keyword is ***system***, meaning a well-defined ***combination of elements*** that, properly designed and combined, make the field procedure easy and the data quality high.

This is why we invite anyone interested in joining the *HoliSurface*® universe to contact us in advance so to define the best solution for your professional needs.
When the *system* is set up according to our instructions, the following acquisitions/analyses can be carried out in a simple and logical way—and expanded over time by adding new modules that are capable of better carrying out existing analyses and introducing new ones:

Active seismology:
1) joint analysis of group velocities, RVSR ratio and *Rayleigh-wave Particle Motion* (RPM frequency curve): the *HoliSurface* approach to surface wave analysis

Passive seismic data and engineering applications:
1) HVSR, SSR (Standard Spectral Ratio), multi-channel SR and MAAM (Miniature Array Analysis of Microtremors) analysis
2) DIN/UNI/ISO, SSR (*Standard Spectral Ratio*) and SD (*Spectral Difference*) analysis
3) vibration analysis of a building to identify flexural and torsional eigenmodes

At the following link a short video introduction to the HS data acquisition:
https://youtu.be/hqjJvAxL6xQ



The **HS integrated system** is a flexible system designed to make ***sense*** of all acquisition and analysis operations and to establish **perfect congruence between data acquisition and analysis methods**, making the dream of a compact and accurate system a reality with respect to a vast range of application methods.
The **basic configuration** allows you to carry out in an ideal way all the acquisitions/analyses possible with the ***HoliSurface®*** software, while leaving also the possibility to work in active and passive multichannel mode [multi-component MASW, ESAC, ReMi, refraction/reflection] consisting in the **advanced configuration**, which is available with an extremely limited additional cost (9 horizontal and/or vertical geophones are sufficient depending on the techniques of interest).

It is a **modular system** where the function and purpose of each element has been carefully studied keeping in mind a wide range of possible survey methods. For example, the *HoliSurface®* composite cable (9+3 channels) [one of the crucial features of the HS system] can be used as an "extension" connecting the seismograph to the 3C geophone so that active data can be acquired for the *HoliSurface®* analysis (in this case no other geophone is connected to the 9 channels). The same cable can also be used for other types of multi-offset acquisition and then, in this case, you will also acquire the intermediate channels (connecting additional geophones).

This cable is therefore both an extension cable in the case of HS acquisition, and a "normal" seismic cable (in the case of acquisitions with 9 single component geophones). A second cable with 12 additional channels can also be connected to the seismograph.
We cannot illustrate all the details that make the **HS integrated system** unique: come and visit us and you will see with your own eyes what you can do and how to do it. Our offer does not only cover one aspect (acquisitions or analyses), but the entire acquisition and analysis process according to all the techniques related to surface waves and vibration data.

The **HS integrated *system*** is a compact system designed **to work effectively while optimizing space, time and energy**. For instance, the HS system also lets you work easily on your own. For example, when you need to record data for the *HoliSurface®* technique (active seismic), the seismograph and the source are in the same point, while the 3C geophone is at a certain distance (*offset*). In this way, after a first "blow", users can verify the quality of the data directly on the monitor on the spot and proceed without having to go up and down between the source and the recording system, as you need to do with other acquisition systems.
The integrated HS *system* is the only one which, included in the price, provides qualified training on all aspects of acquisition and analysis.
We will show you how to carry out acquisitions and analyses using all possible methodologies.
Before throwing money away for inadequate equipment, come visit us and we will show you our integrated HS acquisition system.

Choose the equipment for your actual needs

Eliosoft supplies and recommends its *integrated acquisition system HoliSurface®*.

24-bit (24 channel) seismograph to be used initially with just one 3-component geophone (for all methodologies implemented in HS) but that can then be easily and affordably increased to up 24 channels (for all the standard multi-channel multi-offset seismic methodologies).

***HoliSurface®* composite seismic cable** (9+3 channels).

4.5 Hz **vertical and horizontal high-sensitivity geophones** (for MASW and ESAC acquisitions): bear in mind that for active acquisitions (MASW), Rayleigh waves (their radial component) and Love waves can only be acquired using horizontal geophones.

Optimized **3-component geophone equalized via software down to about 0.2 Hz** (see also HS 9+3 seismic cable) for HS, HVSR and vibration data also in combination with MAAM and ESAC/SPAC (or ReMi). Some more info at the following link: http://download.winmasw.com/documents/Holi3C_geophone_Eliosoft.pdf.

Vertical and horizontal geophones (also with the supports to work on asphalt)

Your clips: when ordering your geophones for your seismic cable, remember to tell us if your seismic cable fits *Split Spring* or *Mueller* connectors.

Split Spring

Müller (or Mueller)

AREA51 device and accessories for MAAM acquisitions on asphalt and soil

Polyethylene plate (for active seismic acquisition): lightweight, sturdy and efficient

The acquisition system: seismograph, cables and geophones

Eliosoft also supplies geophones (of all types) and can recommend the tools that best fit and optimize the available procedures with the *HoliSurface®* software. Considering our ongoing upgrading efforts, we suggest that you contact us in advance for updated information and advice on the "ideal" hardware to take full advantage of the power and compactness of the *HoliSurface®* software (which is a set of various analysis methodologies).

***winMASW®* software**

Simply everything you could ever want to do in surface wave analysis using multi-channel techniques: multi-component MASW and MFA (Rayleigh and Love), ReMi, ESAC/SPAC, Rayleigh wave attenuation, 1D refraction of P and SH waves, HVSR and a countless series of tools for processing seismic traces.

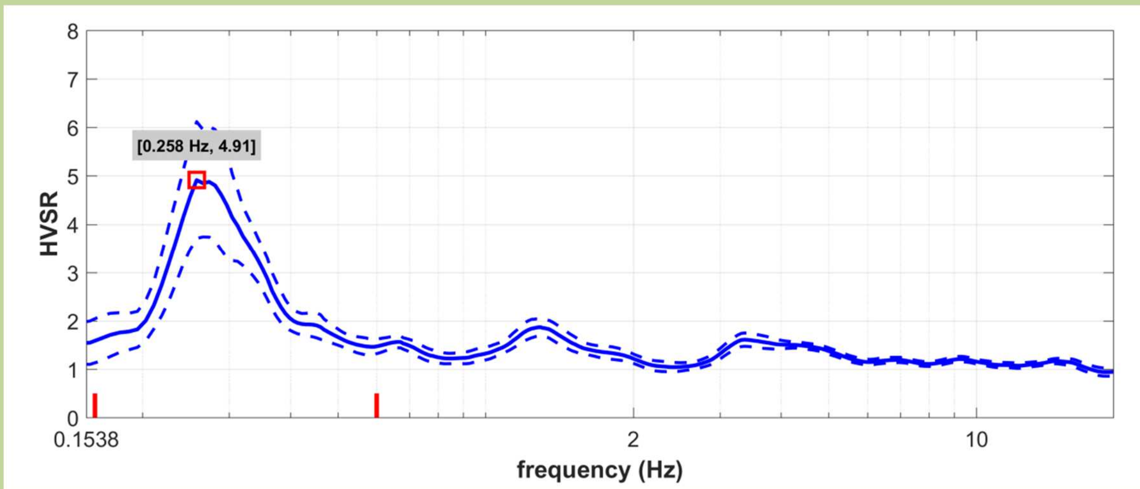
Moreover, to avoid buying useless, redundant and/or inadequate equipment, before purchasing a seismograph or a PC, please contact us and we will give you full support.
The mistake that is made too often is to buy instruments (field equipment), which do not allow you to work in optimal conditions and are perhaps even more expensive than those that we propose and suggest. Never underestimate the wisdom and common sense embodied summarized in Chouinard's quotation (*The more you know, the less you need*).

Something more about our HOLI3C geophone

The ***Holi3C*** geophone is a three-component velocimeter designed by *Eliosoft* and realized by *Geospace* with the aim of fully meet the requirements necessary to acquire active and passive data useful for a large number of applications.

The basic model is equipped with a **Cannon NK-27 connector** (on the left) but it is also possible to have a model with **three split spring connectors** (on the right).

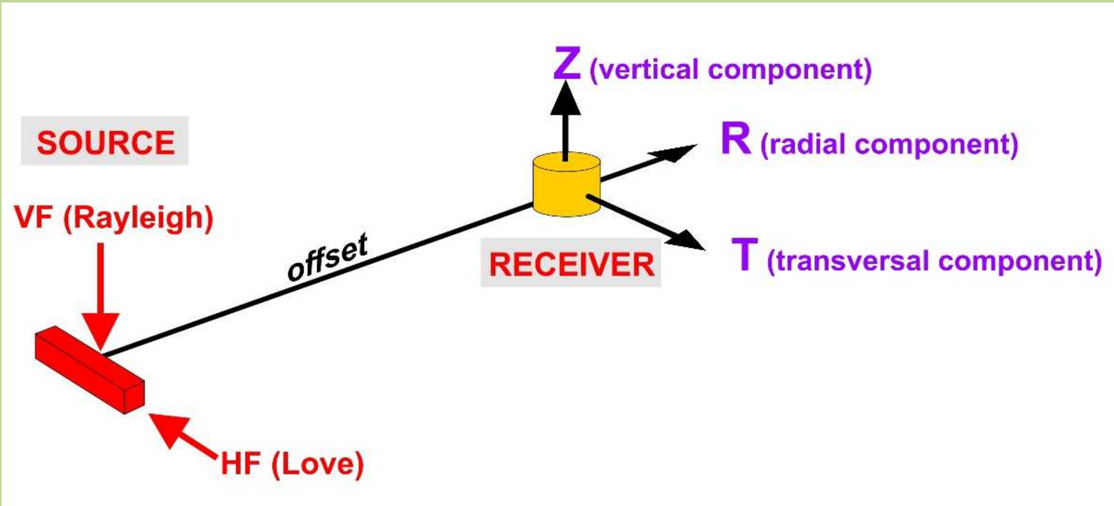
While recording microtremor data with your *acquisition system*, do not forget to activate the "high-gain all geos" option. In the following image an example of HVSR peak identified at a very low frequency (0.258 Hz) using HOLI3C.



The NK-27 connector can be connected directly to the seismograph we recommend (see photo on the left) or to the final connector or the 9 channel cable we provide in particular (but not only) for the *HoliSurface®* method (see section "Holi3C for the acquisition of active data").

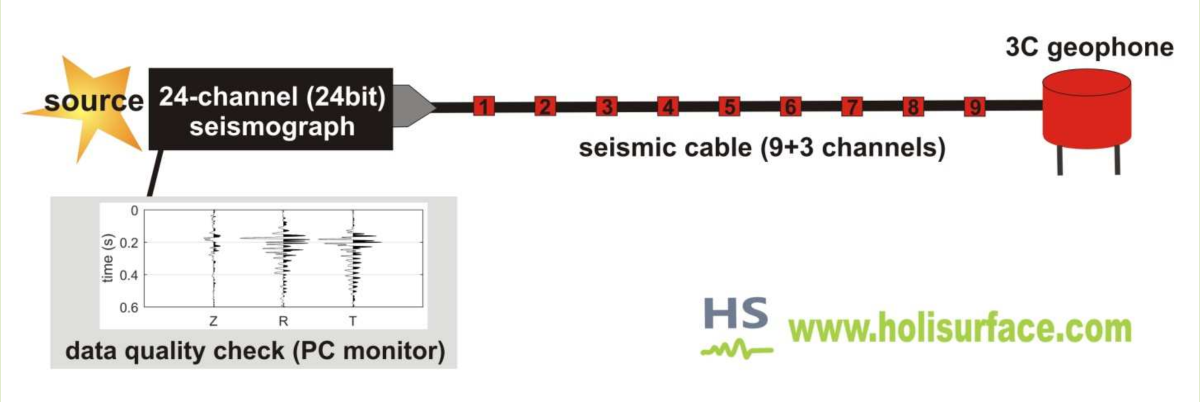
Holi3C for the acquisition of active data (*HoliSurface®* method) and synchronized vibration data

A 3-component geophone can be used for several purposes and HVSR is only one of them. It can be used for the analysis of vibrational data (see e.g. Dal Moro et al., 2018) as well as for the analysis of dispersion according to the HS (*HoliSurface®*) method (e.g. Dal Moro, 2018).



Setting of the source and geophone during an HS acquisition: just one source and one 3-component geophone.

This way we can jointly analyze up to five "objects" also adding the HVSR (joint analysis of six objects so to significantly reducing the non-uniqueness of the solution).

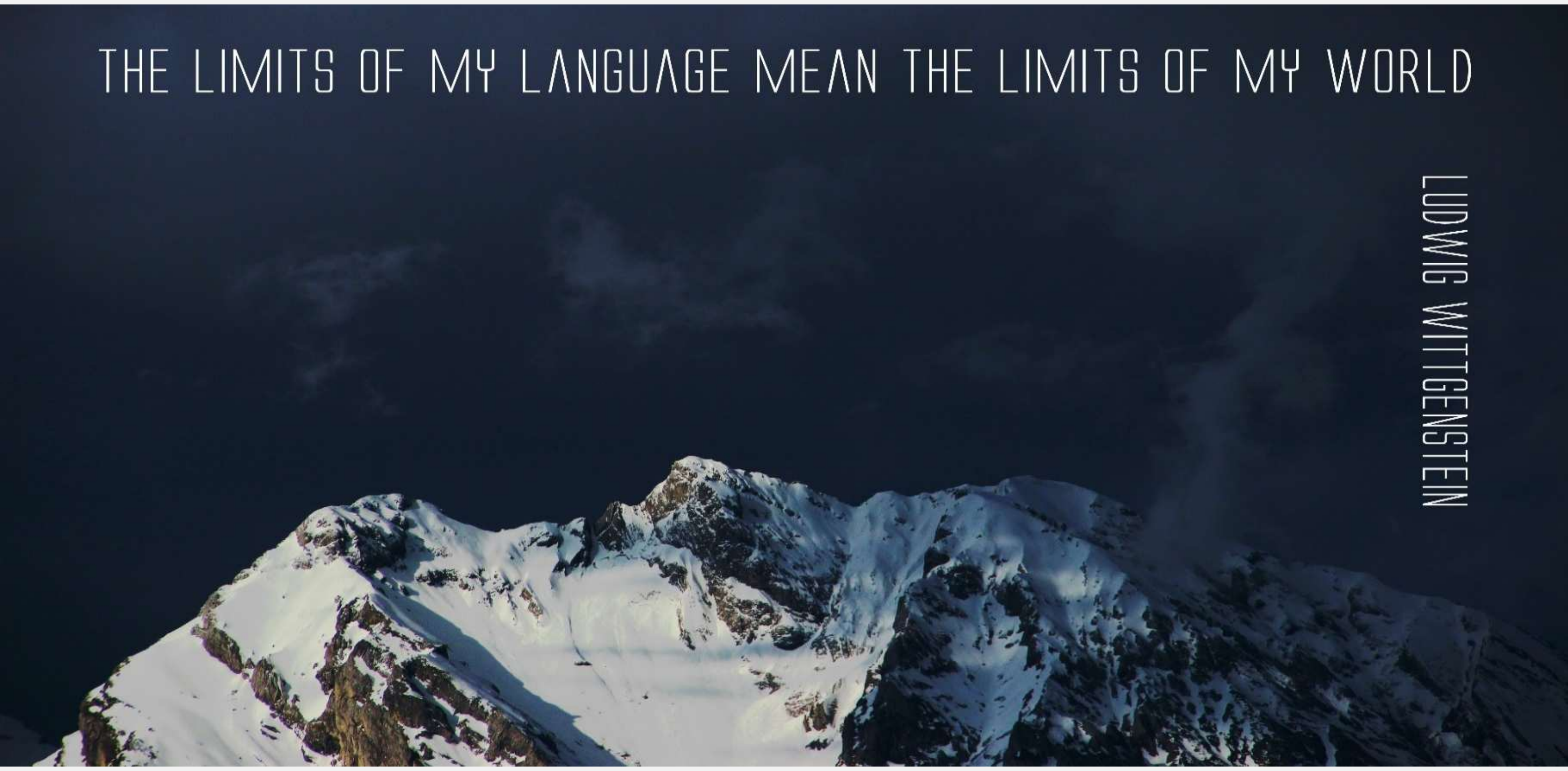


The orange cable is the 9-channel cable that ends with a Cannon connector that can be used to connect the **Holi3C** geophone.

If you have two **HOLI3C geophones** (please, visit our web pages) and one of our HS seismic cables, you can also record synchronous data useful for the classical approach to the building vibration characterization (see [Dal Moro et al., 2018]) and perform the “hybrid (active + passive) seismic acquisition” (extremely useful to obtain more field data in just a very efficient way – see the “**The HS technique: data acquisition**” section).

DownHole seismics: our hardware and software solution

Twin borehole geophone: two 3-component geophones placed at 1 m one from the other so to halve the field effort. For details, please see the ELIOVSP manual, our software application for the joint analysis of downhole seismic data (P and SH arrivals) together with the HVSR.



Seismic techniques and main abbreviations

	definition	notes
MASW	Multi-channel Analysis of Surface Waves	Methodology for the determination of the phase velocity spectrum (dispersive properties) from multi-offset active data. Mathematics can have a series of possible variants: *fk* analysis, τ-p or *phase shift* (this latter is surely the best one). In order to solve the inevitable non-uniqueness issues, it is recommended to analyze multi-component data
MFA / FTAN	Multiple Filter Analysis / Frequency-Time ANalysis	Methodology for the determination of the group-velocity spectrum from the data of one single trace [MFA and FTAN are equivalent]
FVS	Full Velocity Spectrum	Methodology for the dispersion analysis carried out *not* through the interpretation of the modal dispersion curves but through the inversion / modeling of the entire (full) velocity spectrum (hence the entire velocity-frequency matrix). In this way it is not necessary to give any *interpretation* of the velocity spectra. Possible both for phase-velocity spectra [multi-offset approach] and group-velocity spectra [single-offset approach]; both for single-component data and multi-component data [joint analysis].
HS	HoliSurface [Holistic Analysis of Surface Waves]	Improved MFA/FTAN methodology that considers multi-component data (recorded at one single offset from the source) and analyzed together with the RPM and/or RVSR curves [dispersion is analyses according to the FVS [*Full Velocity Spectrum*] approach. See our *HoliSurface®* application software
RPM	Rayleigh-wave Particle Motion	Curve that represents the retrograde-prograde motion due to the Rayleigh wave as a function of the frequency (useful to better constrain the subsurface model).

RVSR	Radial-to-Vertical Spectral Ratio	Spectral ratio of the radial and vertical components from active data (Rayleigh-wave ellipticity). Useful, especially in the low-frequency range in the joint analysis of dispersion data
HVSR	Horizontal-to-Vertical Spectral Ratio	Ratio of the horizontal components with respect to the vertical one from passive (microtremor) data. It depends on the amount of Rayleigh and Love waves in the microtremor field (α factor)
ReMi	Refraction Microtremors	Determination of the dispersive properties from passive data using a mathematics pretty similar to the one usually used from active (MASW-style) data.
SPAC	SPatial AutoCorrelation	Methodology for the determination of the dispersive properties of passive data recorded according to a circular geometry. Less flexible compared to ESAC (this latter is preferable cause provides better results and works with any geometry)
ESAC	Extendend SPatial AutoCorrelation	Methodology for the determination of the dispersive properties of passive data recorded according to *any* geometry, included the linear one (that we often recommend - see winMASW® manual). It's the "generalization" of the SPAC approach (*E* stands for *Extended*)
PS-MuCA	Passive Seismics – Multi-Components Analysis	Joint analysis of multi-component passive data used to define dispersive properties for all the considered components and the HVSR at each point (so to possibly define 2D V_S sections)
MAAM	Miniature Array Analysis of Microtremors	Determination of the phase velocities [*effective* dispersion curve] from passive data recorded considering a circular geometry [e.g. equilateral triangle] with a very limited radius (*miniature* array). The mathematics is different compared to the ESAC & SPAC approaches and the radius necessary to investigate a similar frequency range is considerably smaller (see details in this manual)
SSR	Standard Spectral Ratio	Spectral Ratio (SR) of the amplitude spectra obtained at one site with respect to the amplitude spectra at a *reference* (rocky) site while considering the data recorded during one or more earthquake(s). It represents the actual site amplification (with respect to the rocky outcrop site).
SSRn	Standard Spectral Ratio - *noise*	As for the SSR but considering microtremor data (*n* stands for *noise*)
GHM	Gaussian-filtered Horizontal Motion	Methodology for the determination of the eigen-frequencies and the respective mode (flexural, torsional or mixed) from vibration (microtremor) data recorded at two (or more) points of the structure itself. Details in this manual.

Refraction seismics

The need (or usefulness) of the various techniques depends on the goals and on the technical characteristics (pro and cons) of the methodologies although, unfortunately, inertia and bad habits often dominate. **When do we "need" to use refraction seismics?** When we need to try to reconstruct the 2D structure of the most superficial layers in case significant lateral variations occur. On the field this can be easily and quickly verified by comparing the HVSR curves at 2 or 3 points along the section we need to investigate [see also our **HS-QC software**]. If, in the pertinent frequency range, they are different then refraction can be useful otherwise not. Remember that refraction has **limited penetration depth**: in the lucky cases, you can reconstruct the velocity profile down to almost 1/3 of the length of the array (and just in the central part of it). When needed, using less than 16/24 channels is not recommended because you would not collect the data needed for that objective. **P or SH waves?** If you are working on soft sediments with the presence of water (even far from saturation conditions) P waves are not recommended because you risk seeing just the water table.

Main news in the recent *HoliSurface®* releases

- Compatible with Windows 11
- User manual highly improved with more and more information and case studies
- A new **tool for managing hybrid datasets** (hybrid = dataset containing both passive and active data) recorded with two 3-component geophones: active data are extracted and stacked [perfect in case you have **SmartSolo nodes**]
- New panel for the **automatic inversion of one or more HVSR curve(s)** (also for the reconstruction of 2D sections)
- Tool to define the Local Seismic Response
- Automatic batch processing of multiple HVSR data: do you have a large series of HVSR data and want to process them according to a batch (automatic) procedure? Now you can do it (see "Batch processing of multiple HVSR data" Appendix)
- Improved the *Standard Spectral Ratio* (SSR) panel [seismic zoning studies]
- Optimization of the tool for 2D profiling (starting from different Vs profiles along a line)
- Statistical evaluation of the results of joint inversions
- Improvements in the conversion module from seg to SAF format (addition of a multiplier, unit of measurement, notes and GPS data).
- **Vibration analysis for buildings/structures/bridges** according to advanced procedures (synchronized [dynamic] acquisitions on the vertical axis or on the horizontal plane) and also **according to our GHM (Gaussian-filtered Horizontal Motion) method** - Dal Moro, Weber and Keller, 2018.
- **MAAM and SPAC analysis.** Several significant improvements. While all other HS instruments use the data collected with only one 3C (three-component) geophone, in this type of acquisition it is necessary to use a multi-channel seismograph (of excellent quality) and 4 (or 6) high-sensibility vertical geophones.
- **HVSR panel:**
  1) tools for the management of industrial components
  2) upload SEG2 files without the need to transform them as SAF files (this is very useful for those who acquire microtremors with a passive 3-channel geophone connected to the seismograph). Possibility of setting an arbitrary sequence of channels in the upload phase and the unit of measurement
  3) additional tools for automatic removal of transients (time domain) and outlier HVSR curves (frequency domain)
  4) automatic saving of the Google Earth location file (.kmz file) [if clearly available from the field SAF/seg file]
  5) calculation of coherence between the various pairs of sensors (an extremely useful tool to determine the presence of peaks/signals of an industrial nature)
  6) equalization (recovery of the real amplitudes) in case of use of one of our 3C geophones (HOLI3C)
  7) HVSR modelling with our proprietary codes that allow taking into account attenuation and Love waves

warning

Science and technology do not allow shortcuts and evolve very quickly.

Would you ever buy a computer or smartphone designed and built more than 10 years ago? So, why rely on methodologies and approaches that have been superseded by the most recent methods and advances?

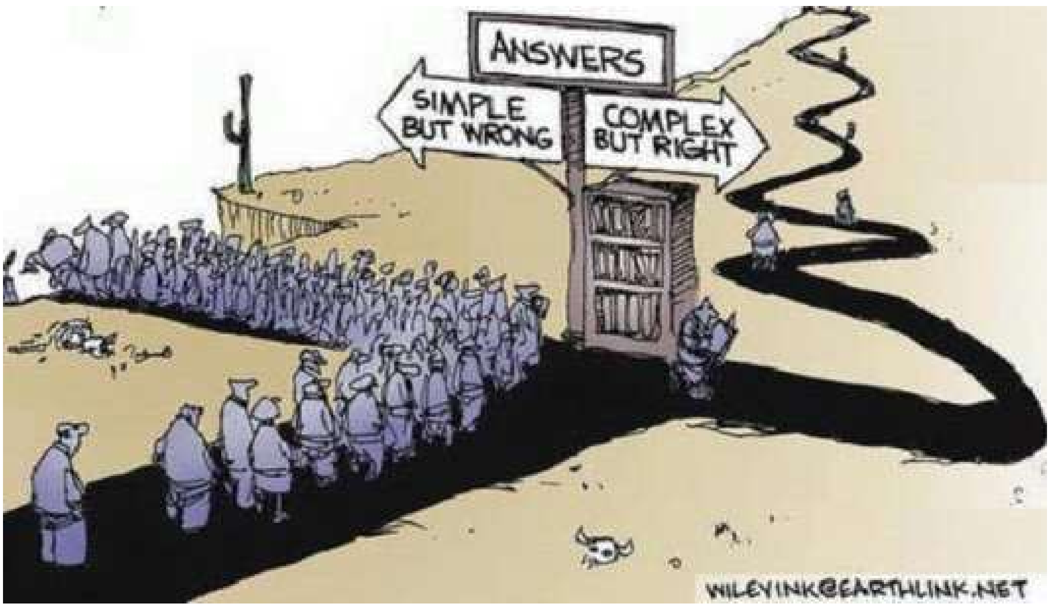
In order to fully tap the potential of *HoliSurface®*, keep in mind some elements without thinking though that the very low field effort in data acquisition (a single calibrated 3C geophone is all you need) involves very little "intellectual" effort in data analysis.

Working with group velocities (unlike all other methodologies, the *HoliSurface®* technique is based on group velocities) offers significant opportunities but requires mastery of a set of aspects that are all but trivial.

Whoever wishes to master these techniques needs to attend dedicated workshops, also considering that one training day cannot make a *beginner* an *expert*.

For these reasons, the software is only proposed in combination with and at rather advanced workshops (it is assumed that the concepts presented in the book "*Surface Wave Analysis for Near Surface Applications*" are fully understood).

For those who cannot or wish to devote themselves in a conscious and rigorous way to these new issues but still want to obtain V_S profiles with a very small field effort and a reduced cost of the equipment, a second approach is advisable: take advantage of dealing with very simple field operations (in the *HoliSurface®* method only one 3-component geophone is used) and use our data processing service (this also saves the cost of the software).



Ideal logical sequence of texts to read in order to understand methodologies implemented in *HoliSurface®*:

The book published by Elsevier (2014) and the one by Springer in 2020

Dal Moro G., Coviello V., Del Carlo G., 2014. Shear-Wave Velocity Reconstruction via Unconventional Joint Analysis of Seismic Data: Two Case Studies in the light of Some Theoretical Aspects, Extended Abstract for the IAEG (International Association for Engineering Geology and the Environment) XII CONGRESS - Turin, September 15-19, 2014: http://download.winmasw.com/documents/Surface_Waves_Joint_Inversion_Dal_Moro_Coviello_Del_Carlo_DISSEMINATION.pdf **[Introduction to the FVS dispersion analysis]**

Dal Moro G., 2016. Four Geophones for seven objective functions: active and passive seismics for tricky areas. Invited presentation and Extended Abstract for the *Urban Geophysics* workshop at the 22nd *EAGE Near Surface Geoscience* conference (Barcelona - Spain, 4-8 September 2016) **[introduction to the HS technique]**

Dal Moro G., Ponta R., Mauro R., 2015. Unconventional Optimized Surface Wave Acquisition and Analysis: a Geotechnical Application in a Perilagoon Area. *J. Appl. Geophysics,* 114, 158-167 **[the HS and MAAM method explained and used for a case study]**

Dal Moro G., Keller L., Poggi V., 2015. A Comprehensive Seismic Characterization via Multi-Component Analysis of Active and Passive Data. *First Break*, 33, 45-53 **[an important comparative case study]**

Dal Moro G., Keller L., Moustafa S.R., Al-Arifi N., 2016. Shear-wave velocity profiling according to three alternative approaches: a comparative case study. *Journal of Applied Geophysics*, 134, 112-124 **[comparative case study: classical HS method, MAAM and multi-channel MASW with FVS processing]**

Dal Moro G., 2015. Joint Inversion of Rayleigh-Wave Dispersion and HVSR of Lunar Seismic Data from the Apollo 14 and 16 sites. ICARUS, 254, 338-349 **[an extraterrestrial case study]**

Dal Moro G., Al-Arifi N., Moustafa S.R., 2017. Analysis of Rayleigh-Wave Particle Motion from Active Seismics. *Bulletin of the Seismological Society of America*, 107, 51-62 **[the RPM curve, its meaning and possible use]**

Dal Moro G., Al-Arifi N., Moustafa S.R., 2017. Improved Holistic Analysis of Rayleigh Waves for Single- and Multi-Offset Data: Joint Inversion of Rayleigh-wave Particle Motion and Vertical- and Radial-Component Velocity Spectra. *Pure and Applied Geophysics*, on-line version available from this link **[joint analysis of velocity spectra of components Z and R in combination with RPM data for both multi-offset (MASW) and single-offset (HS) data)]**

Dal Moro G. and Puzzilli L.M., 2017. Single- and multi-component inversion of Rayleigh waves acquired by a single 3-component geophone: an illustrative case study. Acta Geodyn. Geomater., vol. 14, No. 4(188), 431-444. On-line version available here **[commented HS case study]**

Dal Moro G., Weber T., Keller L., 2018. Gaussian-filtered Horizontal Motion (GHM) plots of non-synchronous ambient microtremors for the identification of flexural and torsional modes of a building, Soil Dynamics and Earthquake Engineering, 112, 243–255 **[building vibrations by means of the GHM methodology]**

Dal Moro G., Stemberk J., 2022. Tools for the efficient analysis of surface waves from active and passive seismic data: exploring an NE-Italy perilagoon area with significant lateral variations, Earth Planets Space 74, 140. https://doi.org/10.1186/s40623-022-01698-z

Dal Moro G. and Mazanec M., 2024. Determination of the Vs profile at a "noisy" industrial site via active and passive data: the critical role of Love waves and the opportunities of multi-component group velocity analysis, GEOPHYSICS, 0: 1-77. https://doi.org/10.1190/geo2022-0540.1

A software application is just a tool

The accuracy of the results depends solely on the user's skill and experience.

A key rule should be: "do it only if you know what you are doing."

Data are not ***interpreted*** (as unfortunately many say often say) but are ***understood*** as a whole.

This is only possible if you have adequate training (also theoretical).

In seismics (as a whole) there is no concept of ***lab testing*** as in geotechnics.

The term ***test*** refers to a series of completely standardized procedures that ensure that the numbers obtained can be "simply" compared. Laboratory *tests* in geotechnics are/can be done by normal technicians following standardized procedures/protocols that are the same for all.
In geophysics none of this is possible because:

1) nothing can be standardized;

2) data must be analyzed by a qualified professional specialized in that *specific* technique

Just as one cannot speak of "*reflection-seismic test*" (never heard of and it would be just blasphemous), one cannot speak of *MASW tests* or the like (here, unfortunately, blasphemies abound daily).

A ***test*** refers to an objective data item, while the analysis of any seismic data item is instead (as we unfortunately know very well) something in which a person puts in all his or her *know-how-and-what*.

winMASW® Academy and *HoliSurface®*

If you want to make full use of the potential of *winMASW® Academy* and/or *HoliSurface®*, the entire system is needs to be consistent.

The field equipment (seismograph, geophones, 3 channels for HVSR analysis and *HoliSurface®*, etc.), the acquisition and analysis software, the computers used for data acquisition and analysis make up a system that must be absolutely consistent.

The system's performance depends on the weak link (this system also includes the user's theoretical and practical knowledge).

It is therefore essential to study the system in detail based on your professional needs, avoiding, due to inappropriate choices, to turn a good investment into a useless cost.

In this regard, we would like to remind you of our data processing and consulting services. In particular, the latter are recommended for those who, approaching the world of geophysics, want to do so as consistently as possible by acquiring the most suitable hardware and software tools to work as best as possible considering the quality/cost ratio.

For more documents, visit our website and attend one of our workshops/webinars.

helps

Many *tips* can be visualized by simply moving the cursor over the button: a text on a yellow background will appear with some basic information.
It is also recommended to take a look at our video tutorials.

Assistance and video tutorials

The only way to properly use HS is to attend one of our workshops, where you receive the necessary theoretical background which is otherwise presented in all the papers reported in the reference list and in the Springer book.

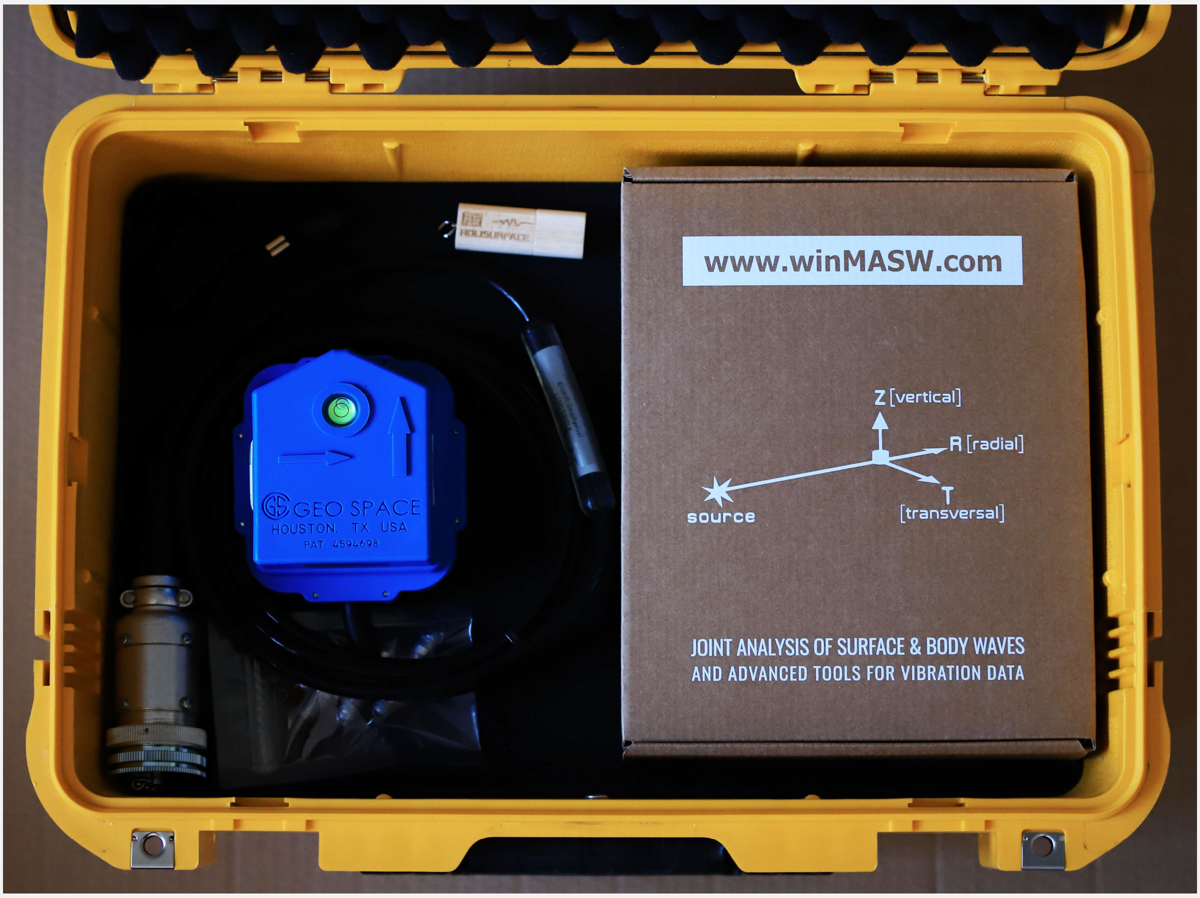
The only parties authorized to provide information and assistance on *HoliSurface®* and *winMASW®* are reported in our website (winmasw@winmasw.com).

In addition to this manual, the **www.holisurface.com** website reports several case studies and video tutorials.

New video tutorials are occasionally made public at the following *YouTube* channel (which we invite you to subscribe to together with our *Facebook* page, where case studies and recommendations are presented)

HoliSurface® www.winmasw.com

SUMMARY TABLE OF THE MAIN TOOLS



HoliSurface® analysis A set of highly-automated and "holistic" procedures with joint analysis of up to 7 components (describing the entire propagation of surface waves)	√
MAAM (*Miniature Array Analysis of Microtremors*) analysis	√
SPAC (*SPatial AutoCorrelation*) analysis	√
HVSR (Horizontal-to-Vertical Spectral Ratio): advanced processing & modelling	√
Tons of tools for editing your active and passive data: resampling, filtering, cleaning, etc.	√
Determination of Vs30 and equivalent Vs (mean Vs down to the bedrock)	√
Spectral analysis (amplitude and phase spectra) and spectrograms (limited variation in frequency over time)	√
1D modeling of P and SH wave refraction (also with low velocity channels)	√
Elastic modulus calculation	√
Joint inversion of HV + group velocity spectrum/spectra	√
Tool for creating 2D sections	√
Vibration analysis (DIN-4150, UNI-9614 and ISO-2631 standards)	√
Tool for the *Standard Spectral Ratio* [SSR] and SD [*Spectral Difference*] (site amplification studies)	√
Vibration analysis on buildings/structures according to the GHM methodology	√
Tool to compute the local Seismic Response	√

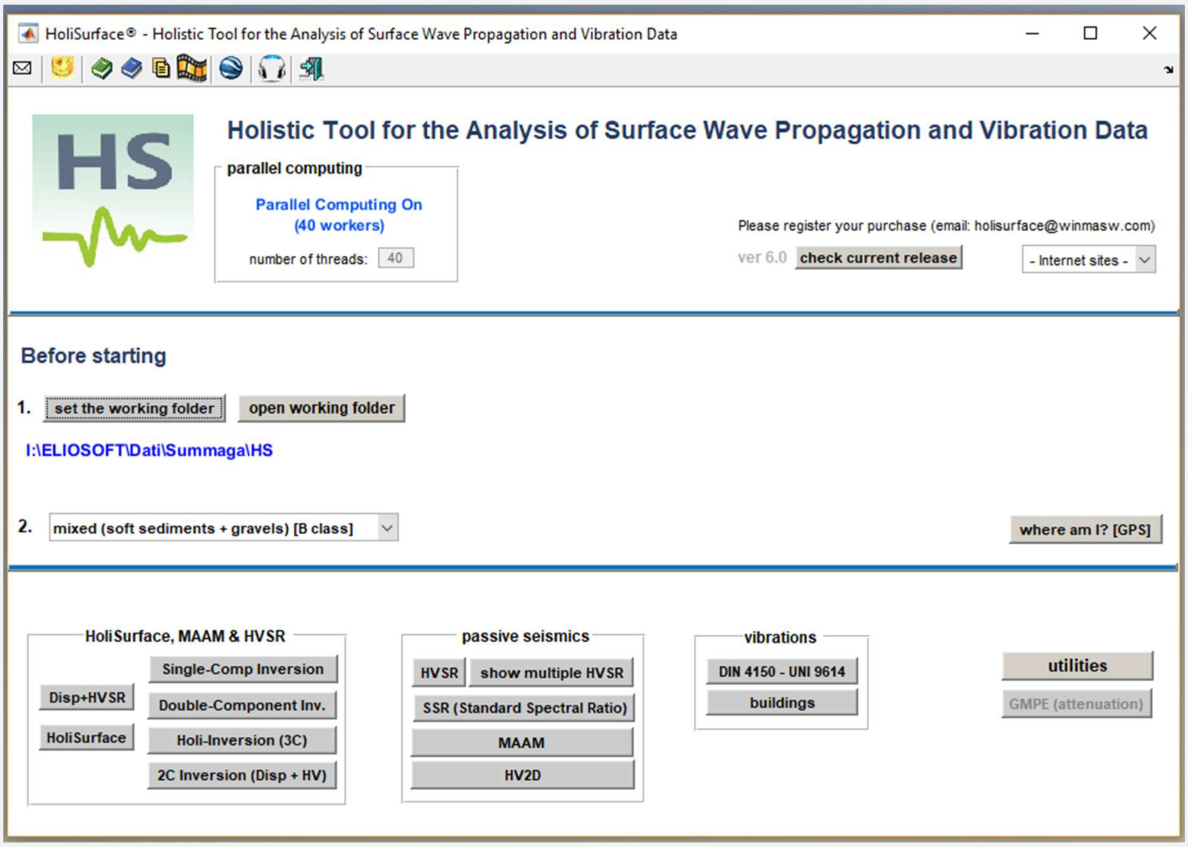
What is *HoliSurface®*?

HoliSurface® was developed as software (and then as an integrated *acquisition system*) to exploit a multitude of seismic and vibration methodologies starting from a very limited (<u>but precise and very well studied</u>) field equipment with minimal field effort.

The *HoliSurface®* software allows analyzing seismic data to obtain a vertical profile of V_s (shear wave velocity) in a very robust way according to different active and passive methods/approaches. This is done through both active (*HoliSurface®* method) and passive (MAAM and HVSR) data.

In addition, it is possible to analyze data for dynamic vibration analyses on buildings, for purposes linked to UNI/DIN/ISO standards and for determining the *Spectral Ratio Standard* (SSR) [site amplification studies].

Make sure not to confuse the <u>*HoliSurface®* method</u> (patented) with the <u>*HoliSurface®* software</u>: the *HoliSurface®* software implements various analysis modules that share the fact that data acquisition can be carried out with a limited set of instruments (essentially a 4-channel acquisition system is sufficient).



A few key points:

1. The *HoliSurface® software* implements various methodologies that share the fact that the acquisition procedures require a limited (but carefully designed) equipment.

2. The computer to be used for a smooth and fast analysis should be sufficiently powerful (see “System requirements” section).

3. Our offer includes the *HoliSurface® software* as well as an optimized *acquisition system* Is it possible to use other acquisition systems? Yes, of course, but needs to be explicitly tested/verified for all the methodologies implemented in the HS software. The one we are proposing is capable of optimizing ***everything***.

4. *Training* is crucial: without a training day on the entire *HoliSurface®* system, it is absolutely impossible to fully (and correctly) the HS software application.

HoliSurface®: methodologies for a wide range of applications

HoliSurface® is an innovative (patented) technique to analyze the propagation of surface waves in order to determine the Vs vertical profile. In practice, it is an improvement compared to the classic technique used by all the seismologists for over fifty years (MFA - *Multiple Filter Analysis*). Note that the acronym FTAN (Frequency Time ANalysis) is sometimes used by other researchers to indicate the same technique.

The crucial aspect characterizing the *HoliSurface®* methodology is that wave propagation is analyzed based on the data acquired with a single 3C geophone while using a multi-component approach.

The *HoliSurface®* technique should not be mistaken with the *HoliSurface®* software. This latter includes many methodologies, all of which have in common the fact that they require limited equipment and a small field effort.

For a complete list of the modules currently implemented in the *HoliSurface®* software, see the "**Summary table of the main features**"

The *HoliSurface®* method is particularly effective for the identification of the *bedrock* in areas where there is a strong contrast between the covering sediment and the underlying *bedrock* (see for example *case study #1* available on the website and the *HoliSurface* DVD). In this case, we recommend using the three basic components: ZVF, RVF and RPM (and if necessary HVSR if the depth of the *bedrock* is greater than 20 m).

Below follows a small table indicating the most appropriate method for the analysis of surface wave propagation in order to determine the V_S profile.

stratigraphic conditions	most suitable method
Several dozens of meters of fine sediment (silt, clay, sand)	HS (VF and HF) + HVSR
Small basins (soft or sloping sediments) on solid rock a few dozen meters away	HS (VF + HF) or MAAM/SPAC + HVSR
Fast sediment / rock already at the surface (or almost)	HS (HF)

equivalent V_S (VsE) and Italian seismic-hazard regulations

Some national regulations adopt the **V_S equivalent** value defined according to the following equation:

$$V_{S,eq} = \frac{H}{\sum_{i=1}^{N} \frac{h_i}{V_{S,i}}}$$

where the depth H is that at which the velocity V_S is equal to or greater than 800 m/s (seismic bedrock).

In practice, it is a variation on the subject with respect to the parameter Vs30 (in that case the value of H was and is set at 30 m).
If the seismic bedrock is deeper than 30 m (from the foundation depth) the V_S equivalent (which in our software is referred to in short as **VsE**) is equal to Vs30.

Do you know that we analyzed the surface waves recorded on the Moon during the Apollo missions (active [group-velocity spectra] & passive [HVSR] data)? Would you like to know what we found out? Have a look here:
https://www.sciencedirect.com/science/article/abs/pii/S0019103515001177

1. System requirements

HoliSurface® runs only under 64bit operating systems (*Windows 11* included and, indeed, highly recommended).

If you are using a Mac, there are several possibilities to run a windows software: https://www.howtogeek.com/187359/5-ways-to-run-windows-software-on-a-mac/

It is important to frequently update your operating system ("windows update" button) in order to provide all the tools that *HoliSurface®* assumes to be present in your PC.

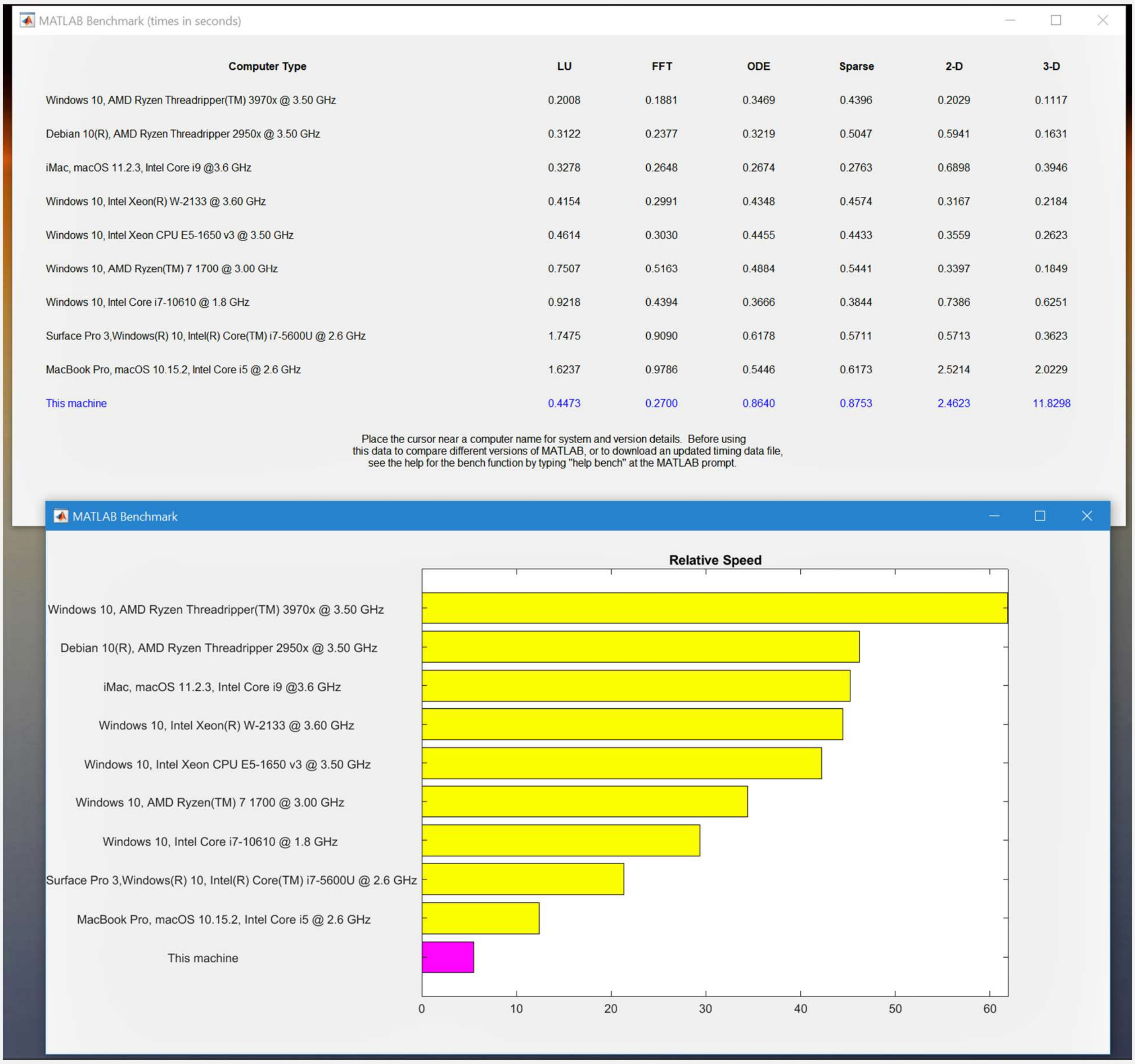
If we want to exploit the parallel computing potential and multi-objective automatic inversion procedures of *HoliSurface®* (joint multi-component analysis of FVS, RPM, etc.), it is necessary to use a computer (workstation) with excellent CPUs.
We might for instance consider the *Intel i9-13980HX* (24 cores, 32 threads) or the AMD Ryzen Threadripper 7960X (24 *cores*, 48 threads) CPUs. On the other side, if we plan to analyze (almost daily) a massive amount of data, you can set up a real *workstation* with a motherboard capable of handling **two Xeon CPUs** (with a sufficiently-large number of cores), thus doubling the number of cores.
In this case, if you buy the right **motherboard**, you can initially install just one (Xeon) CPU and, in case in future you decide to further increase the computational power of your ***workstation***, you can then install a second CPU.
This is the solution we recommend **in case you plan to analyze a large amount of data according to the more advanced procedures** possible in **winMASW® Academy** and/or **HoliSurface®** (so this is not necessary for "standard" MASW/ReMi/HVSR/ESAC analyses): buying a *workstation* with a motherboard capable of handling two CPUs. Initially you can install just one (not less than 8 physical cores) but you will be able to install a second CPU (in case your needs grow). The cost will be surely higher compared to an ordinary computer but your work will significantly benefit from it and your workstation will continue to be an excellent tool for many more years.

Minimum **RAM** recommended: 16 GB

Monitor/screen resolution: 1920x1080 (or higher), recommended the 21:9 ultra-widescreen monitors

We would also like to point out that the field equipment (seismograph, cables, geophones etc.), the software for the data acquisition and analysis, and the computer used for data analysis represent a *system*, which, taken as a whole, must be absolutely consistent. The *HoliSurface®* system allows extremely efficient field procedures at a very affordable cost while the computational load can be heavy (a high-performance PC is therefore important).

Thanks to the "**current releases & benchmarks**" button (from the main panel of the software), you can get an idea of the performance of your processor (the power of one single core) compared to a set of reference systems.
Here is an example for an old CPU composed or pretty slow cores which is nevertheless still quite powerful since the total number of cores is pretty large (in this case 36).



MATLAB Benchmark (times in seconds)

Computer Type	LU	FFT	ODE	Sparse	2-D	3-D
Windows 10, AMD Ryzen Threadripper(TM) 3970x @ 3.50 GHz	0.2008	0.1881	0.3469	0.4396	0.2029	0.1117
Debian 10(R), AMD Ryzen Threadripper 2950x @ 3.50 GHz	0.3122	0.2377	0.3219	0.5047	0.5941	0.1631
iMac, macOS 11.2.3, Intel Core i9 @3.6 GHz	0.3278	0.2648	0.2674	0.2763	0.6898	0.3946
Windows 10, Intel Xeon(R) W-2133 @ 3.60 GHz	0.4154	0.2991	0.4348	0.4574	0.3167	0.2184
Windows 10, Intel Xeon CPU E5-1650 v3 @ 3.50 GHz	0.4614	0.3030	0.4455	0.4433	0.3559	0.2623
Windows 10, AMD Ryzen(TM) 7 1700 @ 3.00 GHz	0.7507	0.5163	0.4884	0.5441	0.3397	0.1849
Windows 10, Intel Core i7-10610 @ 1.8 GHz	0.9218	0.4394	0.3666	0.3844	0.7386	0.6251
Surface Pro 3,Windows(R) 10, Intel(R) Core(TM) i7-5600U @ 2.6 GHz	1.7475	0.9090	0.6178	0.5711	0.5713	0.3623
MacBook Pro, macOS 10.15.2, Intel Core i5 @ 2.6 GHz	1.6237	0.9786	0.5446	0.6173	2.5214	2.0229
This machine	0.4473	0.2700	0.8640	0.8753	2.4623	11.8298

Place the cursor near a computer name for system and version details. Before using this data to compare different versions of MATLAB, or to download an updated timing data file, see the help for the bench function by typing "help bench" at the MATLAB prompt.

2. Installation

To run the installation procedure, simply click on the installation file.

Updated details on the installation procedure can be found in the README.PDF file on the *HoliSurface®* DVD.

Pay attention

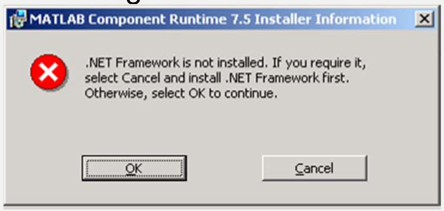
In some operating systems (Windows Vista in particular) managing installation privileges and writing in some files is quite restrictive.
It has sometimes been noticed (especially with Windows Vista) that installing the software outside the "system" folders (*C:\Program Files, C:\Programs* and *C:\Windows*) and inside ad hoc folders (such as *C:\HoliSurface* or *C:\geofisica\HoliSurface*) there are fewer constraints for users and are no possible problems related to lack of privileges.
If you have problems when launching *HoliSurface* (we only checked it with *Windows Vista*), check first the privilege settings ("properties" set by right-clicking on the *HoliSurface®* icon on your desktop).
It is important that the user who is using *HoliSurface®* has the write privilege in the "*HoliSurface*/output" folder (this may not happen if you have installed the software as an *Administrator* but run it with a different user this may not happen).
If using *Windows Vista,* we strongly recommend installing the software in an external folder, e.g., "*C:\ HoliSurface.*"

If you install *HoliSurface®* in a folder where there were previous versions of the software, all data and analysis files, if any, will be deleted. Therefore, use different folder and/or back up your data first.

The software relies on *Matlab* libraries, which are installed along with the software (choose English as the language of installation):

Should the *Matlab* libraries already be installed on your Computer, in following window choose the option "*Modify*"

When installing the libraries, a message such as the one below may appear:



Just click on “OK” and ignore it.

Firewalls and parallel computing

If your firewall is particularly restrictive, it may happen that when you run the software a message like the following one appears:

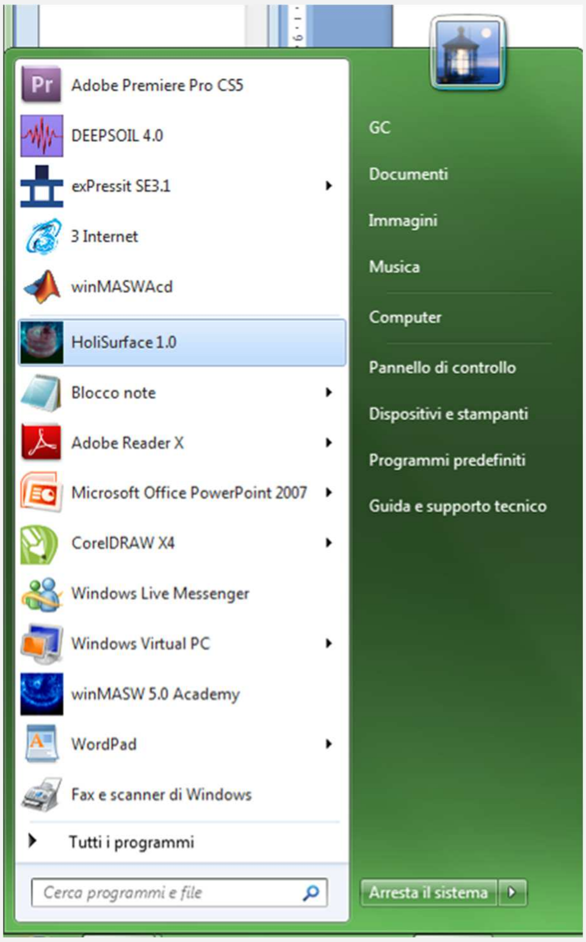
This happens because, in order to take advantage of parallel calculation procedures, your computer needs to be able to do some operations that require the express permission of the user/administrator. Don’t worry and “unlock" the application

Anti-virus systems

Some anti-virus systems that are unable to handle envelope-based protection systems (such as, FEITIAN), they may report the HS.exe application as a Trojan. If this happens, ignore the report and tell the anti-virus software to ignore the *HoliSurface* installation folder. The latest anti-virus systems (we suggest AVG, an excellent free software) do not have this type of problem, which at the moment is reported at times by AVAST, AVIRA and Panda.

Once installation is complete, the *HoliSurface* icon will appear on the Desktop (as usual, double-clicking it will run the application):

Similarly, the *HoliSurface* group is created among the programs that can be accessed from the Windows Start menu → *all programs* (in addition to running *HoliSurface*, you can consult the *HoliSurface* website, the manual, etc., from the group).



3. License and USB dongle

The *HoliSurface®* software works by means of a hardware key (USB dongle) and can be installed on an unlimited number of computers. The License is perpetual.

If the dongle is damaged, you can obtain a new one by sending us the damaged one and paying the cost of the new USB dongle and shipping costs. In the event of theft or loss, a copy of the report made to the relevant authorities is required.

In case you need an additional USB dongle, there is a discount set on a case-by-case basis. The two USB dongles will constitute a single License and may not be sold to any third party separately.

In order to obtain software updates released after the date of purchase, a maintenance fee is required.

ELIOSOFT does not assume any responsibility for results obtained from inappropriate use of the software due to negligence or lack of knowledge of the methodologies.

Unless otherwise stated, no data processing is carried out free of charge.
A seismic data processing service is available (please, see the pertinent section of this manual).

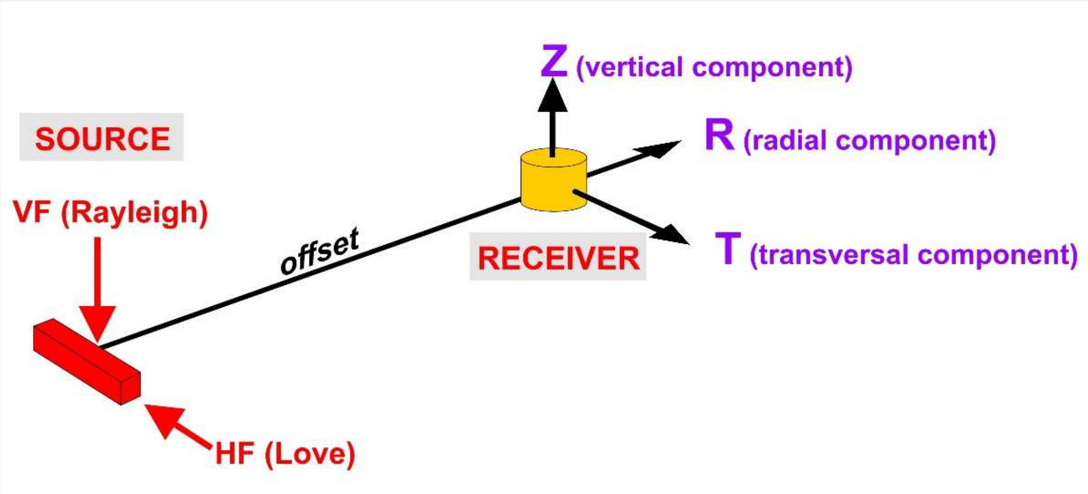
Educational License

Universities and scientific institutions that **do not** carry out work for third parties may request an Educational License at special terms and conditions.

info@winmasw.com

4. The HS technique: data acquisition

The term *HoliSurface®* comes from the combination of the words *Holistic* and *Surface*. It expresses the fact that the purpose of the method/software is to analyze the propagation of surface waves in a complete, holistic way.
Acquiring data for *HoliSurface®* analysis is not very different from traditional active seismic acquisition, e.g., MASW or refractive analysis (zero time [also said *origin time*] is fixed by the trigger).
The main difference is that in this case we use a single three-component geophone (3C - often also referred to as 3D because it is a geophone with 3 sensors oriented in three orthogonal spatial directions), whose orientation is, however, crucial. The decisive aspect is that the second trace of the output file must represent the *radial* component (i.e., the direction that represents the axis that connects the *source* and the *geophone*).

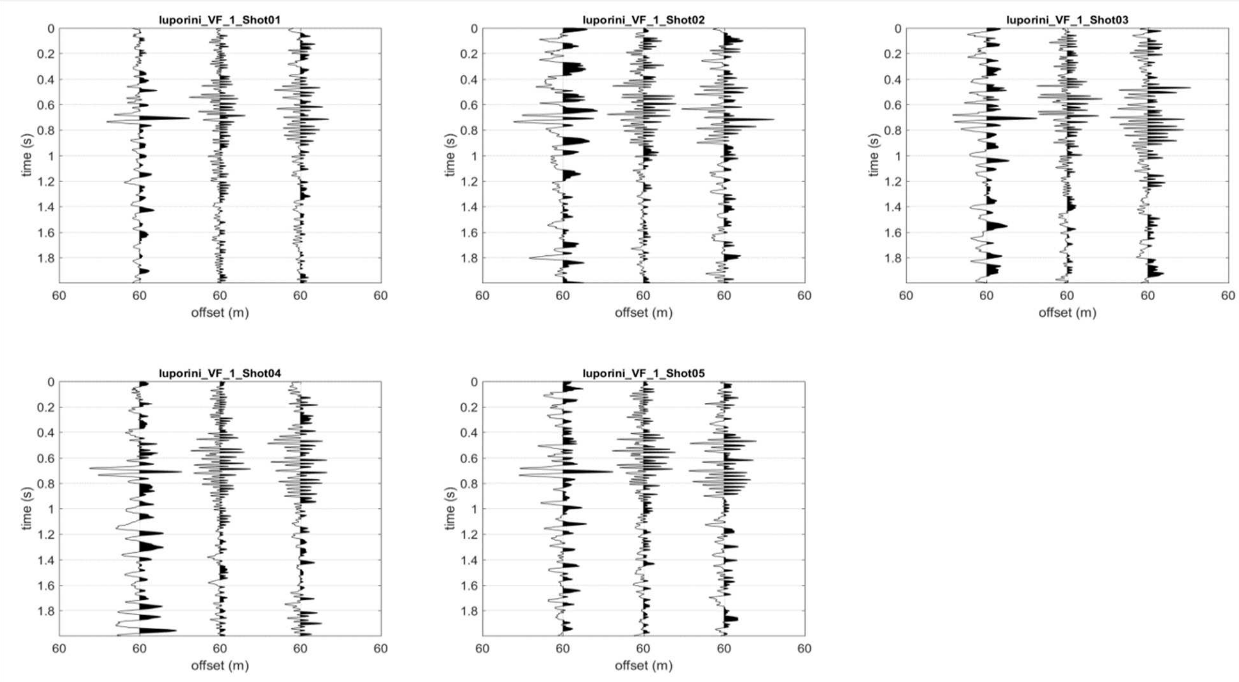


What we can define as the "*HoliSurface®* acquisition (and analysis) method" is nothing more than active seismic acquisition and, therefore, quality depends entirely on the operator engaged in the data acquisition.
In particularly noisy environments (e.g., urban or industrial areas), the only way to get good traces is to increase the *stack*.

How is possible that you can define the V_S profile using the active data obtained from one single 3-component geophone?
Simply because the HS methodology is an improvement of *the* most classical seismological approach: **the analysis of the group velocities. To define the group velocities one geophone is sufficient while for defining the phase velocities you need several traces.**
Most of the seismological crustal studies are in fact based on the group velocities obtained while considering the data from a single recording station. The literature is infinite and any introductory course about seismology should provide the basic elements necessary to understand the basic facts. Just google for “seismology group velocity shear-wave velocity” and you will find hundreds of studies about it.

The **HoliSurface technique** is an improvement of the classical MFA/FTAN (Multiple Filter Analysis / Frequency Time ANalysis) method. See for instance the following paper: ***On the efficient acquisition and holistic analysis of Rayleigh waves: Technical aspects and two comparative case studies***
Dal Moro et al, 2019, Soil Dynamics and Earthquake Engineering 125 (2019) 105742, https://doi.org/10.1016/j.soildyn.2019.105742

In order to analyze the group velocities, it is important to deal with **high-quality data**. If during the field acquisition you notice noisy traces like the ones in the following example (an acquisition made while considering stack 5), it means that the background noise is pretty high and there are only two possibilities:
- reduce the *offset* (but this way you will also decrease the investigated depth)
- the stack needs to be considerably increased (the performance of the stack increases "slowly" as the square root of the number of shots: from 5 to 7 does not lead to any significant improvement; so, you will have to try a stack of 12, for example, or more).

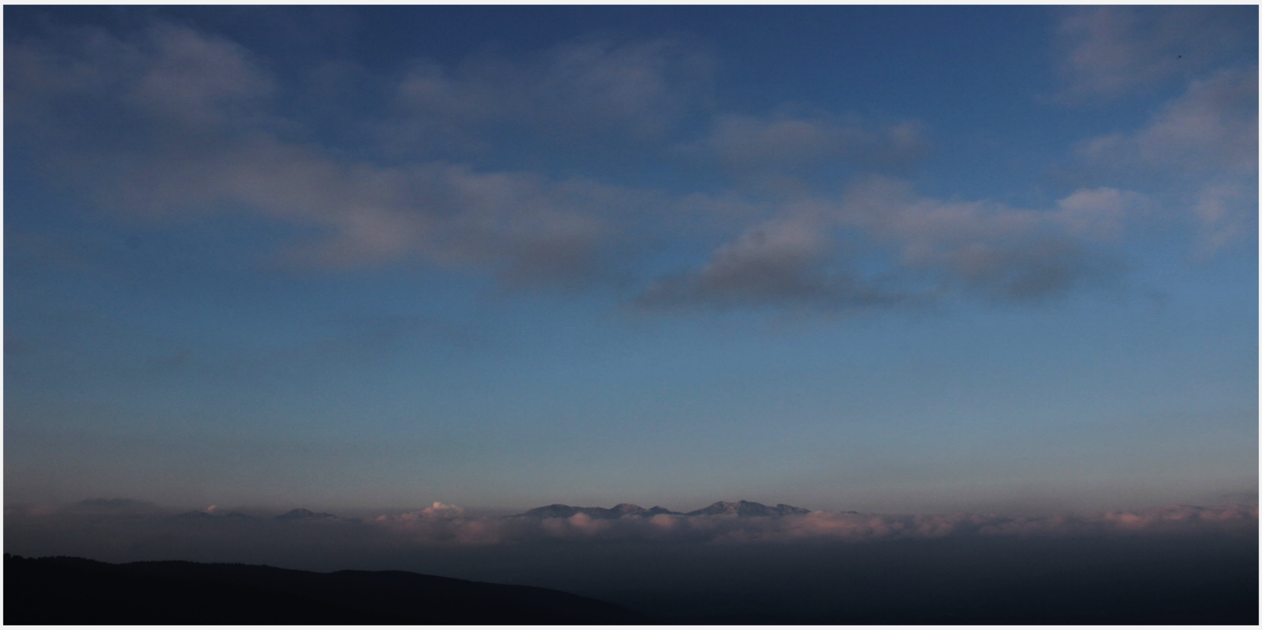


We have not considered here the case in which the problem lies in the equipment (not optimized) or in the operator's inability (which cannot always be ruled out).

Finally, consider that if you acquired a first dataset with a stack 5, you could actually take it up to 15 simply by acquiring a second dataset of 10 shots and then summing up all the 5+10 shots once you are in your studio (see "vertical stack" tool).

For further details about the acquisition procedures see the pdf specifically dedicated to the HS acquisitions. You can find it among the documents of the HS software (folder "documents", file "**Acquisitions-HoliSurface-EN.pdf**").

In particular, remember that the arrow of the HS sticker placed on our 3C geophone must point towards the source:



DATA ACQUISITION FOR THE HS+HVSR PROCEDURE

If you decide to send us your *HoliSurface®* data for analysis (we do not recommend that you try analyzing using methods whose principles and procedures are not thoroughly mastered), remember to send us (in a single email) **all** the following data (using the nomenclature mentioned on the previous page):

1. *HoliSurface®* data for Rayleigh waves (VF)
2. *HoliSurface®* data for Love waves (HF)
3. passive datasets for computing the HVSR at two different points of the array (e.g. one at the end and one in the middle)
4. a couple of (possibly geo-referenced) photos of the site/acquisition (see “GPS data in our software applications (*winMASW®*, *HoliSurface®* & ELIOVSP®)GPS data in our software applications (winMASW® HoliSurface® & ELIOVSP®)” section)
5. Any available information about the stratigraphy

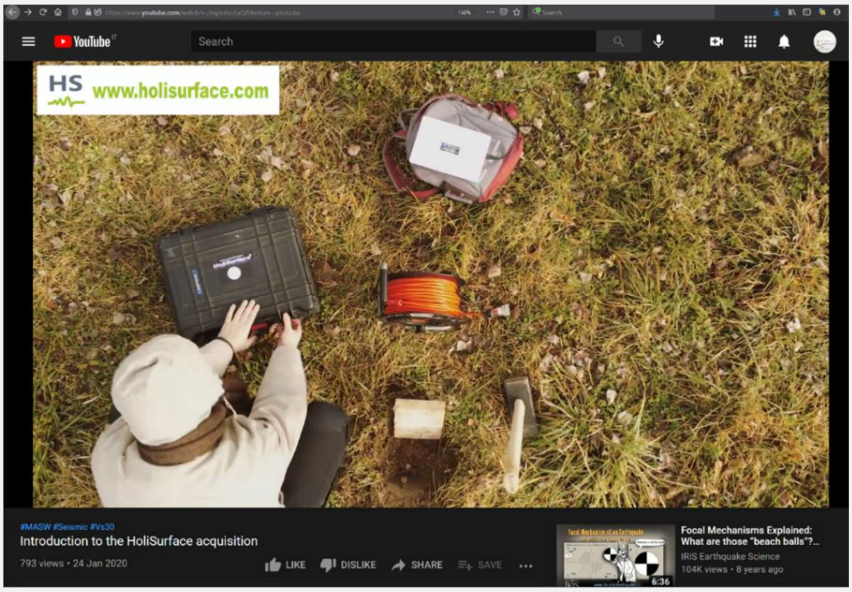
If you suspect lateral variations or, similarly, if you do not know much about the site, it is also a good idea to perform a direct and a reverse acquisition (simply by inverting the geophone and source). In this case, we will add the words "*direct*" and “*reverse*" to the name of the file (e.g., HF_off60_direct.SAF; HF_off60_reverse.SAF).
This may not be very important if you are working in the middle of an alluvial plain (with soft sediments and lateral variations with very long wavelengths), but if you are working in areas with loose gravel or in the hills/mountains, then this is strongly recommended.

Stack (*vertical stack* to be more precise) **is a key operation to properly implement on the field. The number of shots is proportional to the offset and to the noisy level of the site (*never* less than 6 shots, but *the more the better*).**

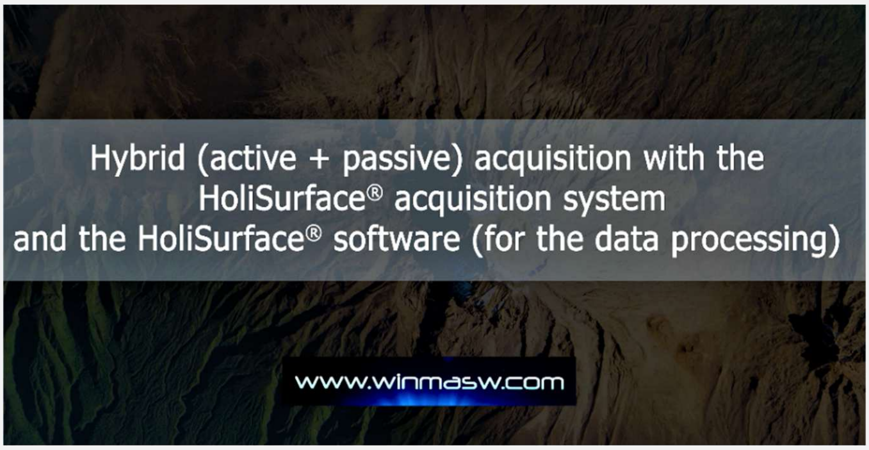
Bear in mind that, speaking about the field operations, the difference between a good acquisition (see the points listed above) and a bad one is just a couple of minutes.

Two ways to record your HS + HVSR data on the field

1) **Standard acquisition**: record the active data according to the very classical fashion, i.e. using your trigger geophone and the "active setting" of your seismograph: **https://youtu.be/hqjJvAxL6xQ**



2) In case you have two 3-component geophones (see our **HOLI3C** geophones), you can go for the **hybrid acquisition (hybrid = dataset containing both passive and active data)**. This way you will obtain a single 6-trace dataset to use both to extract the data for two HVSRs (at the two extreme points of the HS array), both the active data for the HS processing (see later on this manual): **https://www.youtube.com/watch?v=ED_gVpokZ6g**



This way to handle **hybrid data** is particularly important (**necessary**) in case you are using a **wireless acquisition system** where the data are continuously recorded. In order to identify (and stack) your active shots, the hybrid tool is clearly extremely useful.

Incidentally this is the same kind of setting used for the acquisition of synchronized vibration data (see the "Vibration analysis for structural characterization" chapter).

Three ways to produce Love waves

The acquisition and analysis of Love waves in a ***crucial point*** in surface wave analysis (please see our Elsevier and Springer books and references therein mentioned).

You can produce SH (and therefore Love) waves by using a classical wooden beam as in the following photo:

In order not to damage the wood, you can also cover the beam with the polyethylene plate used for the VF acquisitions:

Finally, when working on soft soils, you can dig a small hole in the soil and place the polyethylene plate (almost) vertically like in the following picture: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VSP
ELIOSOFT
8 and 10-kg sledgehammer and polyethylene plate
In the beginning...
... after some months of hammering
using the plate to generate Love waves
HS

5. Supported file formats and general procedures

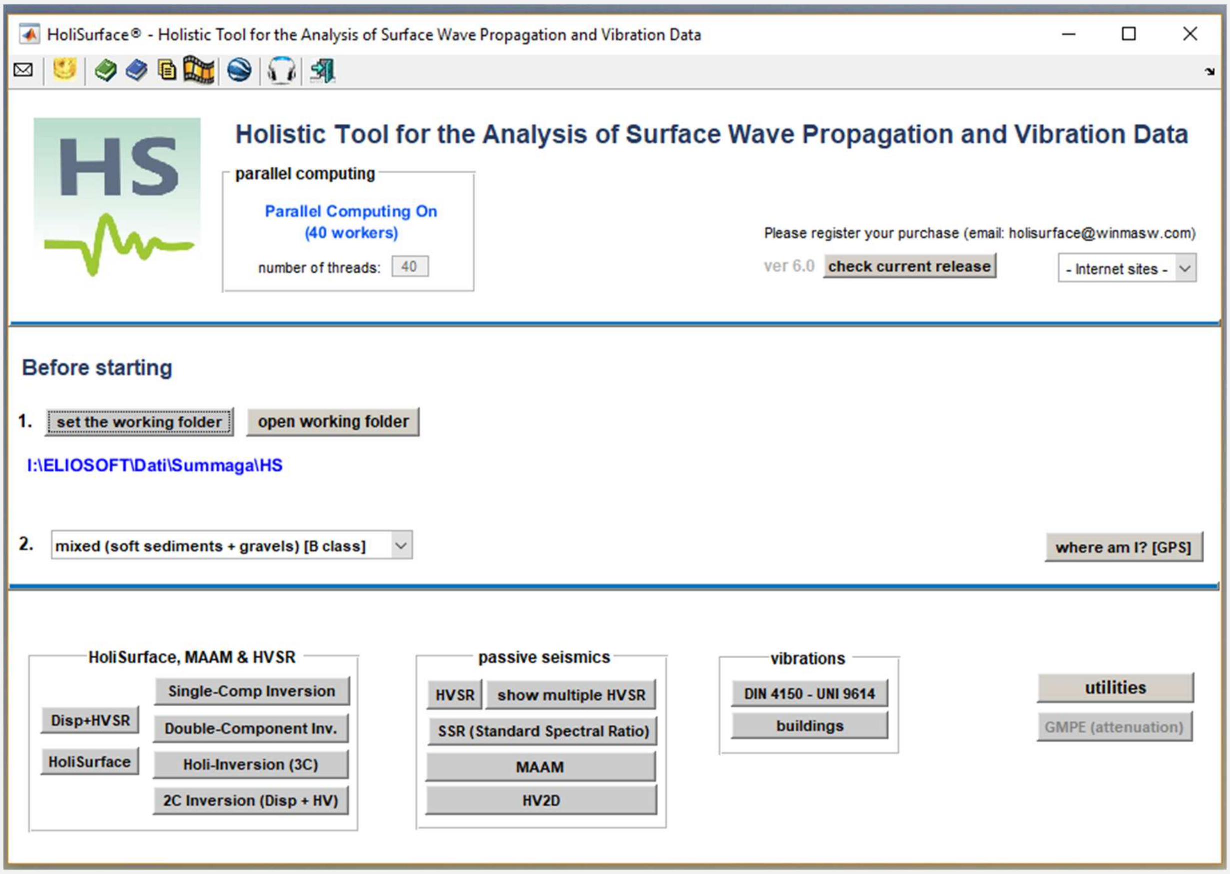
Which format are supported by *HoliSurface®*? Or, in other terms, can my data be read and analyzed by *HoliSurface®*?

In general terms HS handles data in three different formats: **SAF** (a very well-known ASCII file typically used for HVSR (i.e. passive) data but that we also use for the active HS data. In addition to this HS also supports the very classical **seg2** data. For the active HS data is supported also the **segy** format.

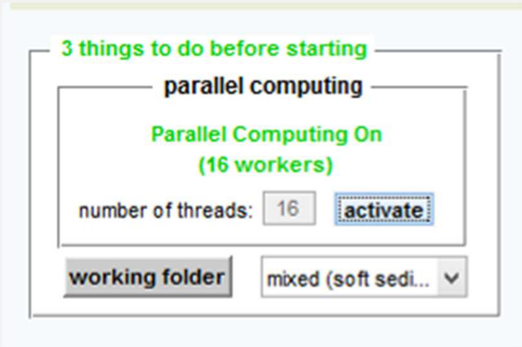
General procedures

When *HoliSurface®* is launched, in addition to the main window, a DOS window will remain open in the background displaying information on the progress of the operations and analysis.

The main screen of the software highlights (on the right) the "parallel computing" area. Since all newly manufactured computers are equipped with multi-core CPUs, it is essential to activate all the cores that will then be exploited by the software.
The number of cores that can be activated depends on your PC (more precisely on the installed CPU).
Considering the computational effort for some of the possible methodologies, we recommend using a CPU with at least six physical cores (see *system requirements*).

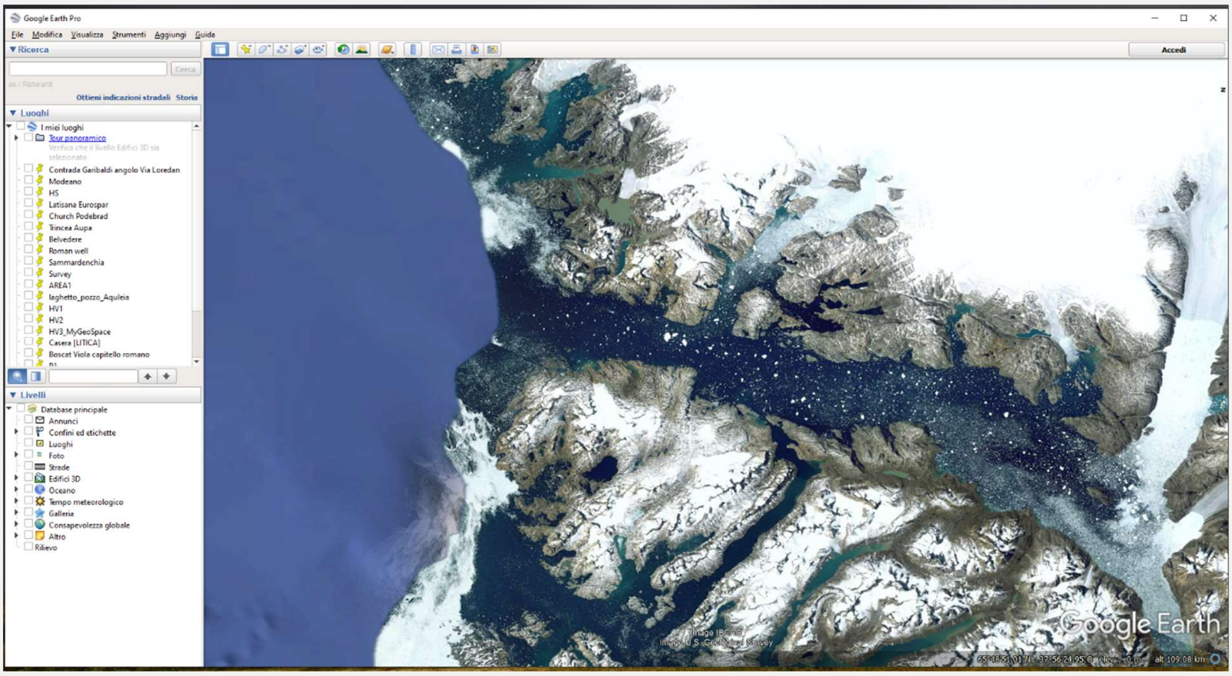


Above the main screen before activating parallel computing (note the red text). Below the screen after activating the parallel computing procedure (now the text is green).



<u>The first thing to do is to choose your *working folder*, inside which the data will have been saved. The output files will be automatically saved in the same folder (or subfolders, depending on the specific operation).</u>

From the main screen you can also run *Google Earth Pro* (icon) (clearly if the software is already installed on your PC):



We suggest downloading the video tutorials (as they are made available) in the folder *HoliSurface/Documents/videos* (then accessible from any panel - icon).

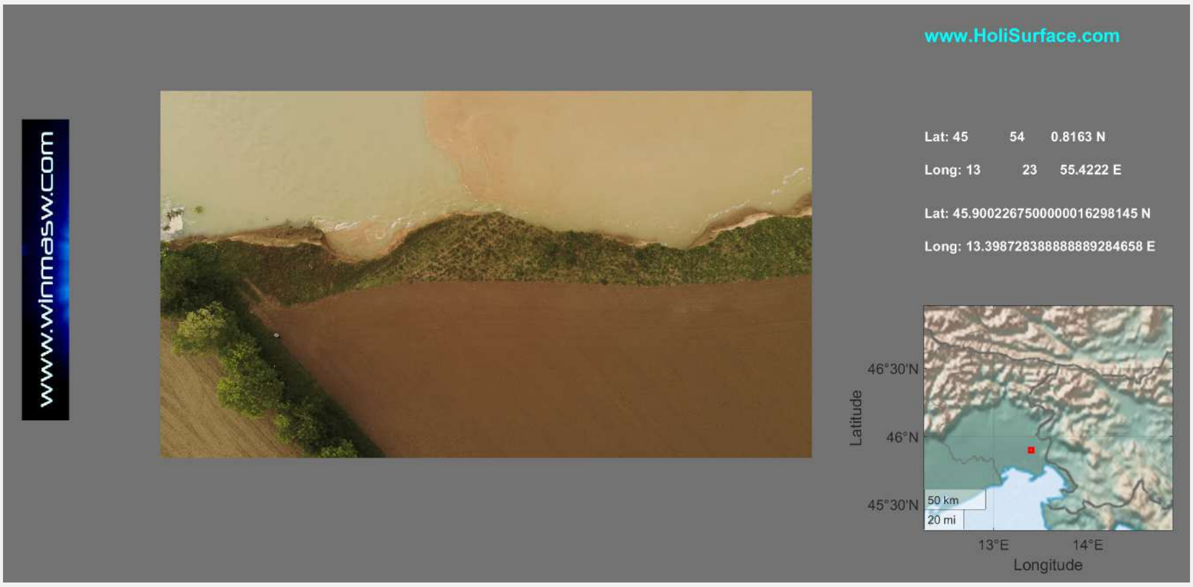
The manuals can be opened from any panel (icons - for the Italian and English versions).

GPS data in our software applications (*winMASW*®, *HoliSurface*® & ELIOVSP®)

In most of the panels, it is possible to upload an image (to include in the report) and, in case such an image contains GPS information (several APPs of your mobile can do that [e.g. *MapCam* or *GPS Map Camera*] as well as all the Action Cameras [e.g. GoPro] and *drones*), **the GPS information (Latitude, Longitude, Altitude and number of satellites) will be reported and shown in the output report.**
Of course, it is possible to upload any photo you want to automatically insert in your report, even without the GPS information.

MapCam | **GPS Map Camera** | **Action cameras**

Drones



Modeling the HVSR

If you cannot attend our workshops, we recommend that you read the following works (and clearly also know the works mentioned there):

Arai, H., Tokimatsu, K., 2004. *S-wave velocity profiling by inversion of microtremor H/V spectrum*. Bull. Seismol. Soc. Am. 94, 53–63.

Dal Moro, G., 2014. *Surface Wave Analysis for Near Surface Applications*. Elsevier, 9780128007709.

Dal Moro G., 2011. *Some Aspects about Surface Wave and HVSR Analyses: a Short Overview and a Case Study*, BGTA (Bollettino di Geofisica Teorica e Applicata), *invited paper*, 52, 241-259 (see "paper section" at www.holisurface.com)

Albarello D. and Lunedei E., 2010. *Alternative interpretations of horizontal to vertical spectral ratios of ambient vibrations: new insights from theoretical modeling*. Bulletin of Earthquake Engineering 8, 519–534.

Dal Moro G., 2010. *Insights on Surface Wave Dispersion and HVSR: Joint Analysis via Pareto Optimality*, J. Appl. Geophysics, 72, 29-140

This is the only way to understand when (in which situations and for which frequencies) it is possible to consider the HV deriving from the body waves as valid (essentially this is valid only for the fundamental period of the site) and when it is necessary instead to consider the surface waves.

File and component names

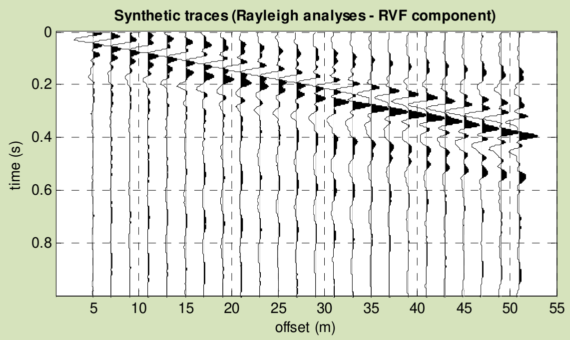
ZVF, RVF, ZEX, REX or THF?

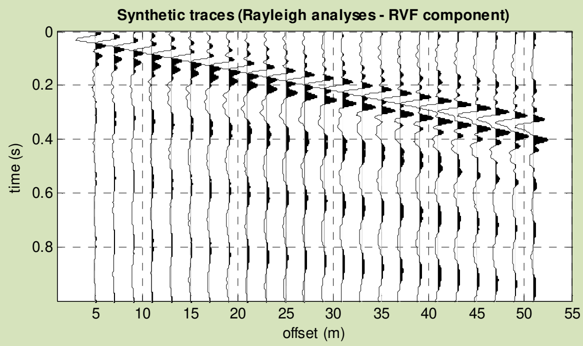
As for the type of source, in Prof. Herrmann's coding convention VF stands for "*Vertical Force*" (the classic vertical sledgehammer), while EX indicates an explosive source (*Explosive*). As far as the analyzed component is concerned, it can be Z or R for the "Vertical" or "Radial" component, respectively.
To analyze Love waves, instead, it is advisable to consider a shear source (i.e. horizontal - HF=Horizontal Force) and geophones placed perpendicular to the positioning (T=transversal).

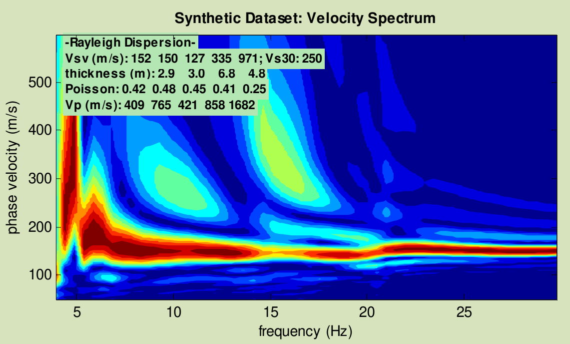
Here is a summary of the meaning of the components that can be simulated through synthetic seismograms (bear in mind that the first letter refers to the recorded component - which clearly depends on the type of geophone used and its direction - while the last two letters indicate the type of source used):

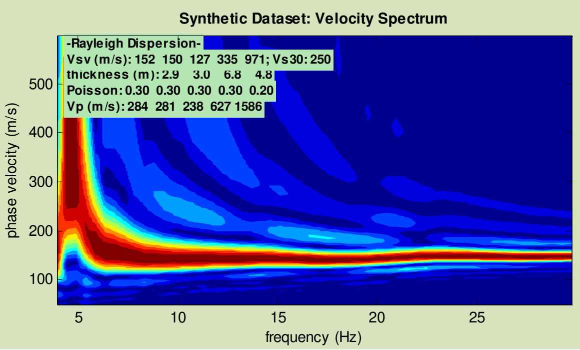
ZVF: vertical force (e.g., sledgehammer or fall of a weight) and vertical component
RVF: vertical force and radial component
ZEX: explosion (sub-surface) and vertical component
REX: explosion (sub-surface) and radial component
THF: horizontal/transverse force (e.g., shear-wave source) and transverse component (e.g., Love waves).

Below the same models shown in the box "Poisson's ratio and energy distribution between modes" (different values of the Poisson's ratio) but for the Radial component.
Note that energy distribution between the modes is a bit different (and in this case the field data were acquired with vertical geophones and therefore the most appropriate comparison is with the ZVF component - see in the previous box the excellent match between the observed data and the first synthetic model characterized by high Poisson values).









Seismic components

What is a *seismic component*?

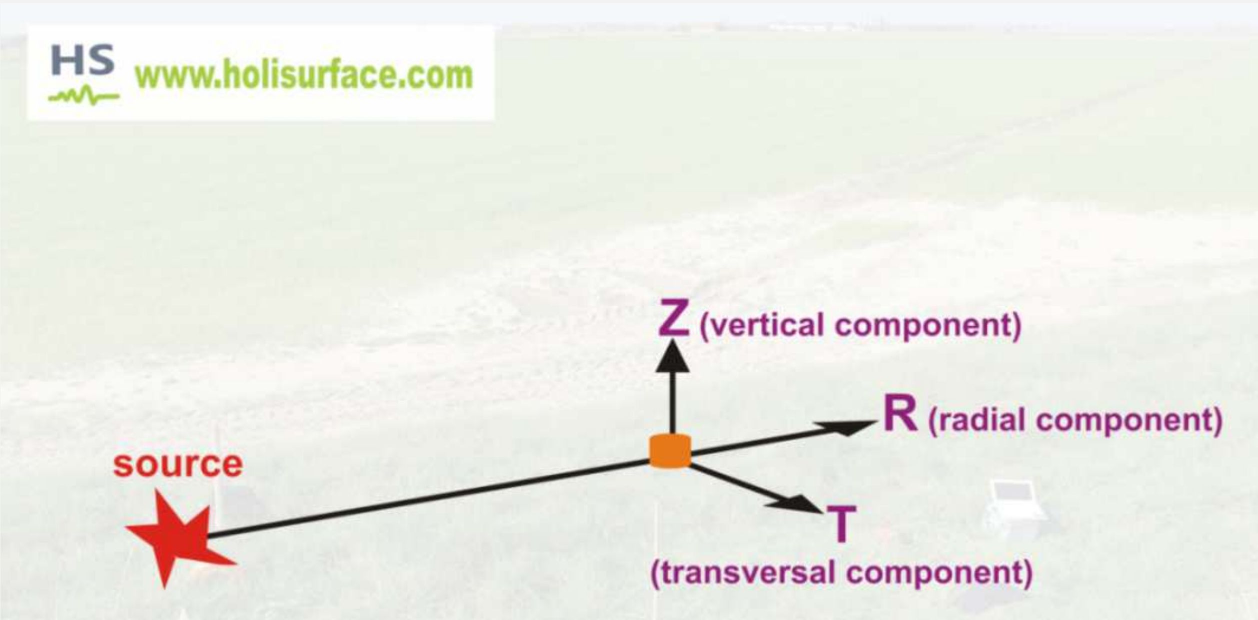
Put shortly, we can define the *component* as the direction along which a certain particle motion takes place.

Fundamentally (see image below):
Love waves move only along the T (transversal) component [as well as the reflected/refracted SH waves];
Rayleigh waves move along the vertical (Z) and radial (R) components [as well as the reflected/refracted P waves].

Needless to say that, in order to define the seismic components, the location of the source must be known (and properly considered).

Multi-component analysis means the analysis of what happens along two or more of the indicated components (note that for the sake of completeness we should also record the rotational components and not only those related to *displacements* along the three Cartesian axes).

In short, the *HoliSurface®* approach aims at jointly (i.e., holistically) analyzing everything that happens along all three components Z, R and T.



Assembling Rayleigh- and Love-wave files: the "Assemble VF/EX with HF" utility

Both in the *HoliSurface®* utilities panel and in the various modules available (icon with the Greek letter sigma capitalized, Σ), it is possible to access the module for "assembling" files (the first relating to Rayleigh waves, the second to Love waves - see Chapter on data acquisition).

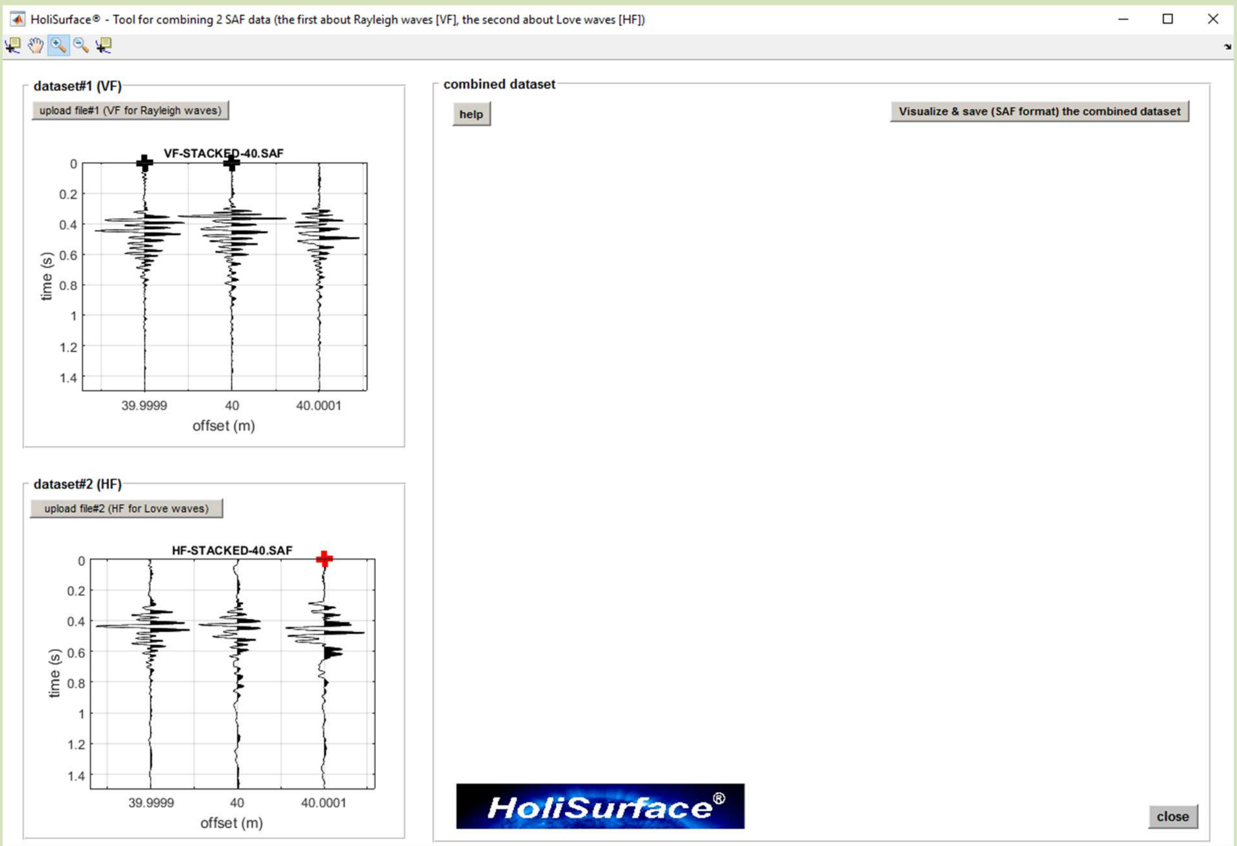
Among the utilities, the module is called "*VF/EX with HF assembly*" while the icon used in the modules is an Σ (the *sigma* Greek letter).

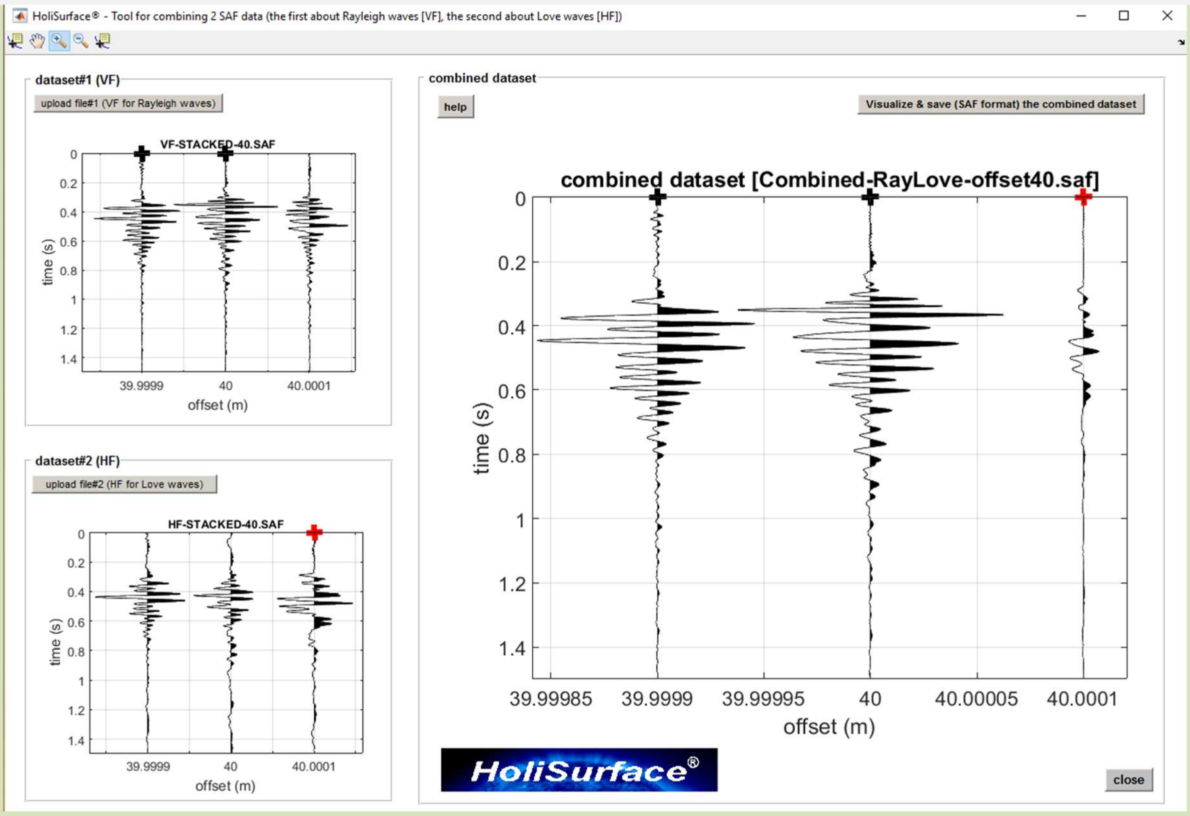
Here you can assemble the two acquisitions (therefore the two files) to obtain a single SAF file with the following characteristics: the first two columns/traces show/represent the vertical and radial components of the Rayleigh waves, while the third column/trace is about Love waves.

Please, note that the joint Rayleigh + Love analysis is highly recommended.

File #1 (**VF** - Vertical Force) concerns the Rayleigh waves (vertical component = first trace from the left; radial component = second trace from the left - see black crosses in the images below) while file #2 (**HF** - Horizontal Force) contains the Love waves (component T which must be on the third trace - see red cross in the images below).

Below is an example of an assembly of 2 files (the first one is the VF file about Rayleigh waves while the second one is the HF file about Love waves). Note the two energy distributions that (of course) do not have exactly the same frequency (this is not very important anyway - but it is one of the reasons why vertical stack acquisition mode is preferable)





The resulting file will then be loaded into the "*Disp+HVSR*" or "*HoliSurface*" panels allowing for easy joint (Rayleigh + Love + RPM or HVSR) analysis.

6. Data pre-processing and forward modelling

There are currently two modules for loading data and preparing them for data modelling (with reconstruction of the vertical profile of V_S).

The first ("Disp+HVSR" module) is used to process surface wave dispersion data (group velocity) + HVSR, while the second ("*HoliSurface*") gives more emphasis to the active HS data (although it is possible to add the HVSR also in such a panel).

TYPICAL V_S VALUES FOR COMMON MATERIALS

As extensively explained in the book published by Elsevier (*Surface Wave Analysis for Near Surface Applications*), instead of an *automatic inversion* procedure, *direct* (or *forward*) *modelling* is often recommended.

Consider that the typical values of V_S for the most common materials are roughly:

Material	V_S (m/s)
Incompetent soils and peats	50 – 130
Competent soils	130 – 300
Very competent soils and gravel	300-600
Conglomerates, weathered rock	600-1000
Solid rock	> 1000

Do not forget to consider meaningful values for the Poisson's ratio (high values in case of saturated sediments and low in the opposite case).

HS DATA CLEANING: A KEY OPERATION

In both panels ("*Disp+HVSR*" and "*HoliSurface*") are available a series of tools to clean the data. This is a crucial point while you work with group velocities.
The goal is to get rid of late arrivals or high-amplitude refraction events (first arrivals).

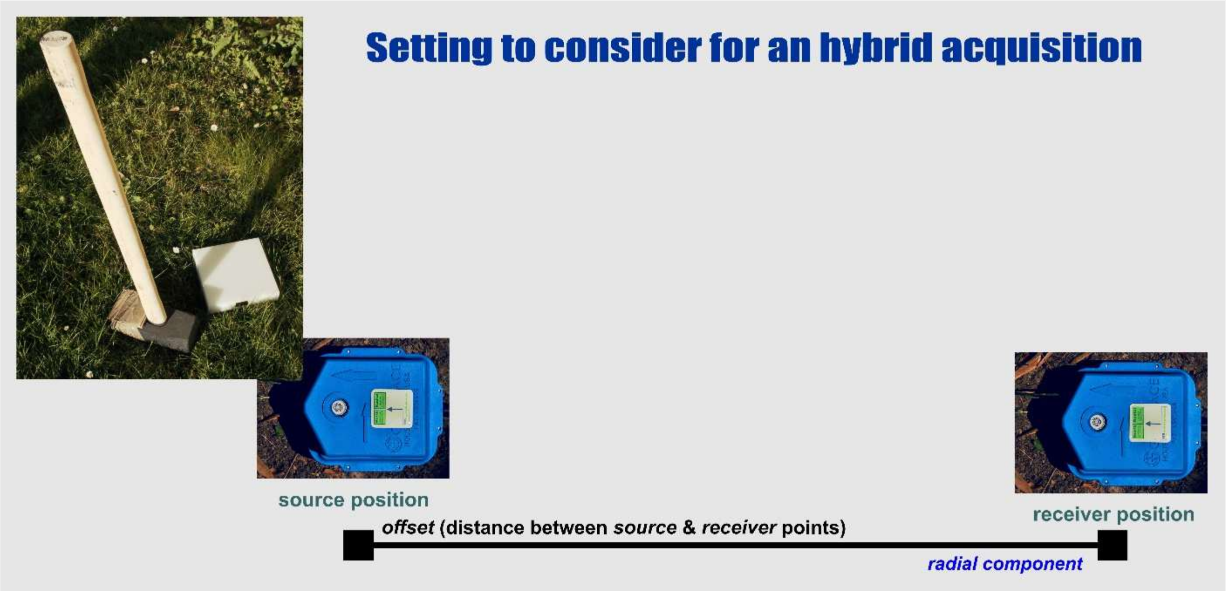
During the acquisition, in order to avoid large-amplitude body waves, we should fix an offset as large as possible (this is important also to increase the investigated depth).

During data analysis (pre-processing), it is then possible (and necessary) to clean the data using two tools:

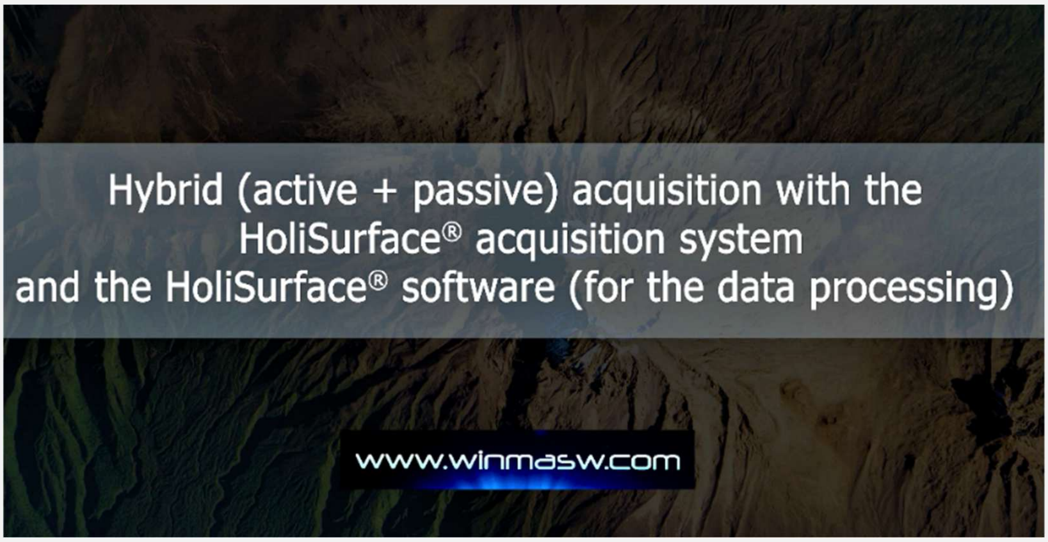
1) Removing the useless part of the traces: if you recorded 4 seconds by the surface waves are limited in the first 1.5 seconds, it is necessary to remove the data after 1.5 seconds (use the "time to visualize", "done" and "cut" tools just below the seismic traces);
2) To perform a "surgical cleaning", use the tools in the "select data" group on the right of the seismic traces (see also *video tutorials*).

6.1 Hybrid data: active data extraction and processing of HVSR passive data

First of all have a look at the video where we illustrate the "hybrid (active + passive) acquisition procedure" from a very practical point of view. You need two 3C geophones and a long – "passive" - acquisition time (ranging from 10 to 30 minutes depending on the site and on your objectives).
The two HOLI3C geophones need to be deployed in such a way that the *Radial component* (which corresponds to the line that connects the two geophones) and the *verse* (i.e. the geophone orientation) is the same. As usual, the arrow on the HS sticker of the geophone at the *receiver* position points to the source:



Here the video: https://www.youtube.com/watch?v=ED_gVpokZ6g



If you properly perform this operation (using an *acquisition system* explicitly designed and tested for this sort of acquisition procedures), you obtain a hybrid seismic *dataset* with 6 traces: the first three refer to the 3C geophone away from the source (receiver position) while the trace#4, #5 and #6 refer to the 3C geophone nearby the source. The data contain *both* the background microtremors (for the HVSR), *both* your hammering/shooting (at the beginning of the acquisition).

The data are then used ***both*** to compute the HVSR curves at the two extreme points, ***both*** to extract the active shots to use for the dispersion analysis (HS technique).

Computation of the HVSR curves at the two extreme points

The only point we intend to underline here is that the 6 traces of the obtained dataset are processed to obtain the HVSR curves at the two extreme positions. The computation of the HVSR curves is made following the procedure shown in the "**HVSR: analysis, modelling and inversion**" section. Dealing with two HVSR curves you can verify the overall consistency of them. If the two curves are very similar, that means that data are fine and no significant lateral variations are present. In case the curves are different there are two possible reasons: a) significant lateral variations occur; b) one of the two curves is (for some reason) not reliable [for a wider discussion about it, please see the Springer 2020 book].

Data processing:

1) create two subfolders: **HVSRrcv** (rcv=receiver) and HVSRsrc (src=source)
2) in the HVSR panel, set the *working folder* for the first HVSR [e.g. **HVSRrcv**]
3) upload the 6-trace (hybrid) field dataset
4) a dialog box will pop up to select the 3 traces (UD, NS and EW) pertinent to the 3C geophone deployed at the *receiver station* [if you are using our *acquisition system* and properly set up the acquisition setting, you should for instance choose the traces 1 2 and 3]
5) process the selected data as usual (see the "HVSR: analysis, modelling and inversion" section of this manual)

We can now select and process the data about the second 3C geophone (at the source position).

6) in the HVSR panel, modify the *working folder* for the second HVSR [e.g. **HVSRsrc**]
7) re-upload the 6-trace (hybrid) field dataset
8) the same dialog box will pop up to select the 3 traces (UD, NS and EW) pertinent to the 3C geophone deployed at the *source position* [if you are using our *acquisition system* and properly set up the acquisition setting, you should for instance choose the traces 6 5 and 4]
9) process the selected data as usual

At this point we have defined the HVSR curves at the two extreme points (to verify the overall congruency and the possible presence of significant lateral variations).

Active shot extraction

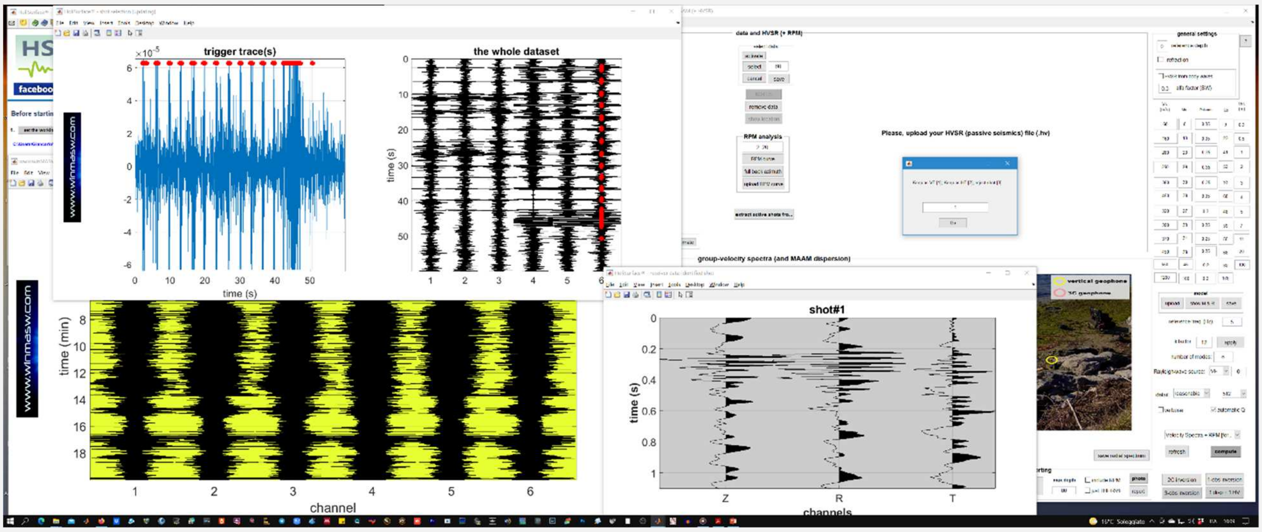
The 6-trace dataset also contains the active shots that we can easily extract, save and use for our HS (dispersion) analysis.
Both in the "**disp + HVSR**" and "**HoliSurface**" panel (from the main HS panel), you can find the "**extract active shots from hybrid data**" button.
Stay tuned with our **YouTube channel** to see a ***video tutorial*** where you can see how to extract the shots (which can be both VF and HF – imagine for instance that your first 10 shots are VF while the next 10 shots are HF).

When you click the "**extract active shots from hybrid data**" button, you are asked to upload the 6-trace hybrid field dataset and choose/define the 3 channels (Vertical, Radial and Transversal) of the receiving 3C geophone (the one away from the source), the *offset* (i.e. the distance between the source and the distant 3C receiver/geophone) and the trace to use as *trigger trace* (to choose from the 3 traces of the 3C geophone nearby the source).
The software will automatically identify the shots (your hammer blows) and show you the identified signals/shots.
For each single identified signal you are then invited to choose among three possible options:

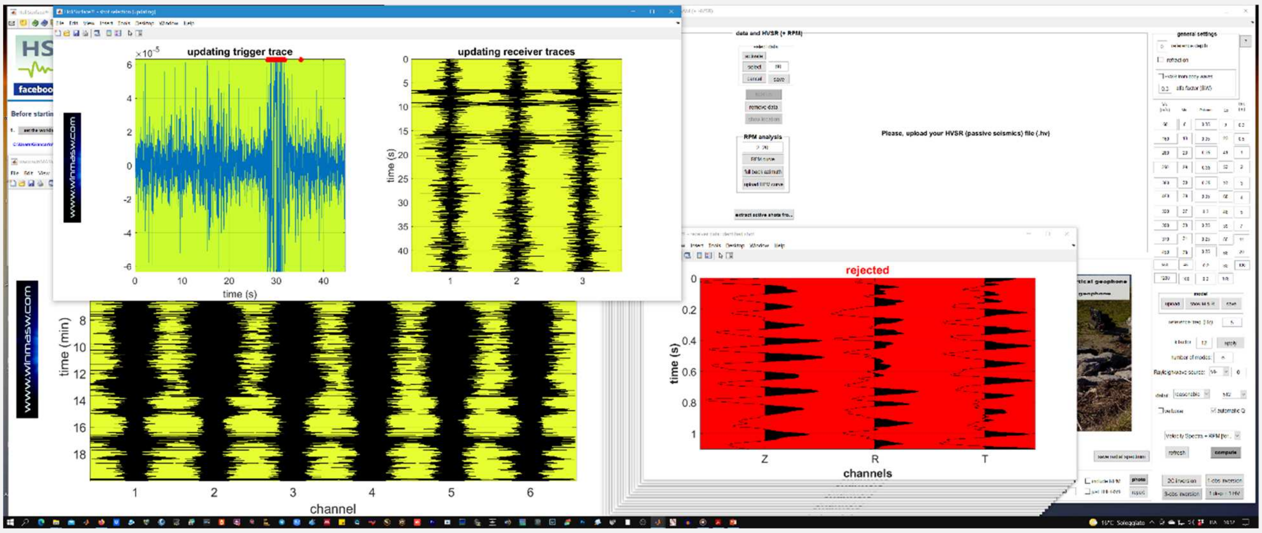
1) the identified signal refer to a VF shot [option#1]
2) the identified signal refer to a HF shot [option#2]
3) the identified signal is too poor/week and must be rejected [option#3]

Of course you should remember that your first 10 (for instance) shots were made as VF [to generate Rayleigh waves] and the next 10 (for instance) shots as HF [to generate Love waves].
See carefully the snapshots reported in the following (which refer to a dataset recorded in an *extremely* noisy industrial area).

At the end of the procedure, the software will save each single shot (as VF or HF file according to your decision) and will also *stack* all the VF and HF shots [all the files are automatically saved in the working folder].



For each identified shot you are invited to define whether it is a VF (1) or HF (2) acquisition. In case the quality is poor (see next snapshot), you simply write 3 (in order to reject such a shot).



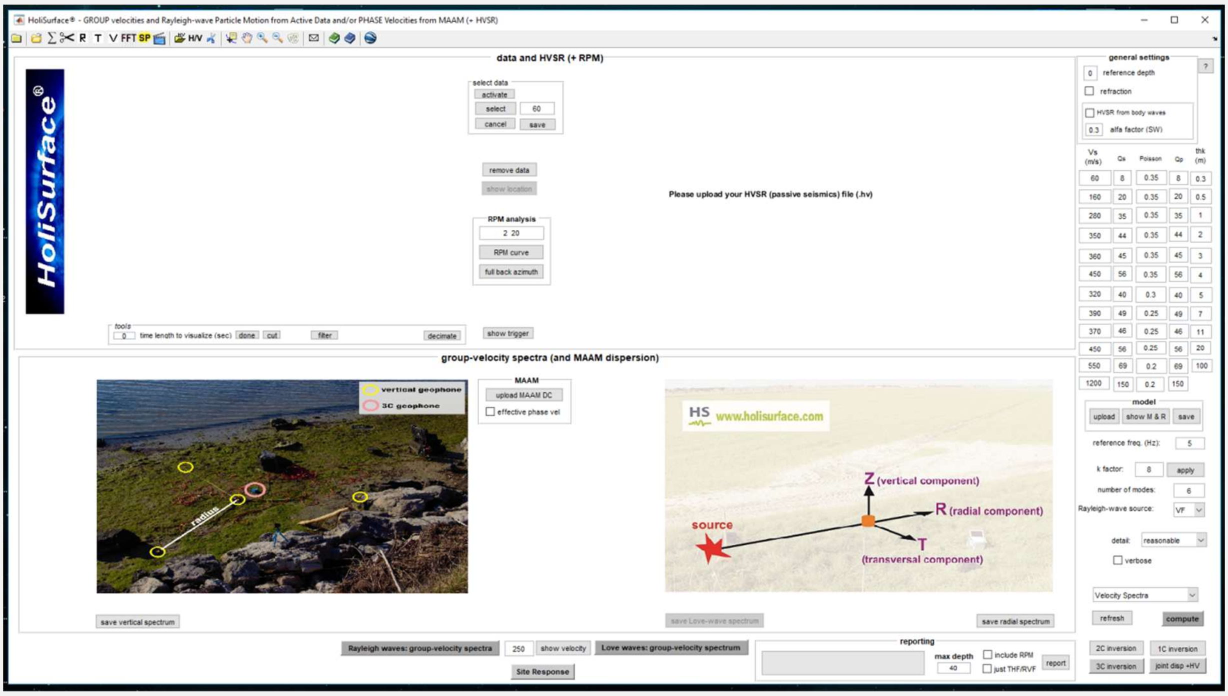
See for instance the paper “**Determination of the V_S profile in a noisy industrial site: further evidences about the importance of Love waves and the opportunities of the group velocity analysis**” available from our web site.

6.2 The *Disp+HVSR* panel

This is the panel we suggest for most common professional works: it allows the joint analysis of *dispersion* (group velocity spectra of two components) together with the RPM and HVSR in the simplest way

In this panel (as from the similar "*HoliSurface*" panel) the data of the active seismic field (SAF/seg data file) and the previously calculated HVSR curve (see Chapter on HVSR analysis and relative tutorial video available in the "Documents" folder) are loaded for joint modelling.

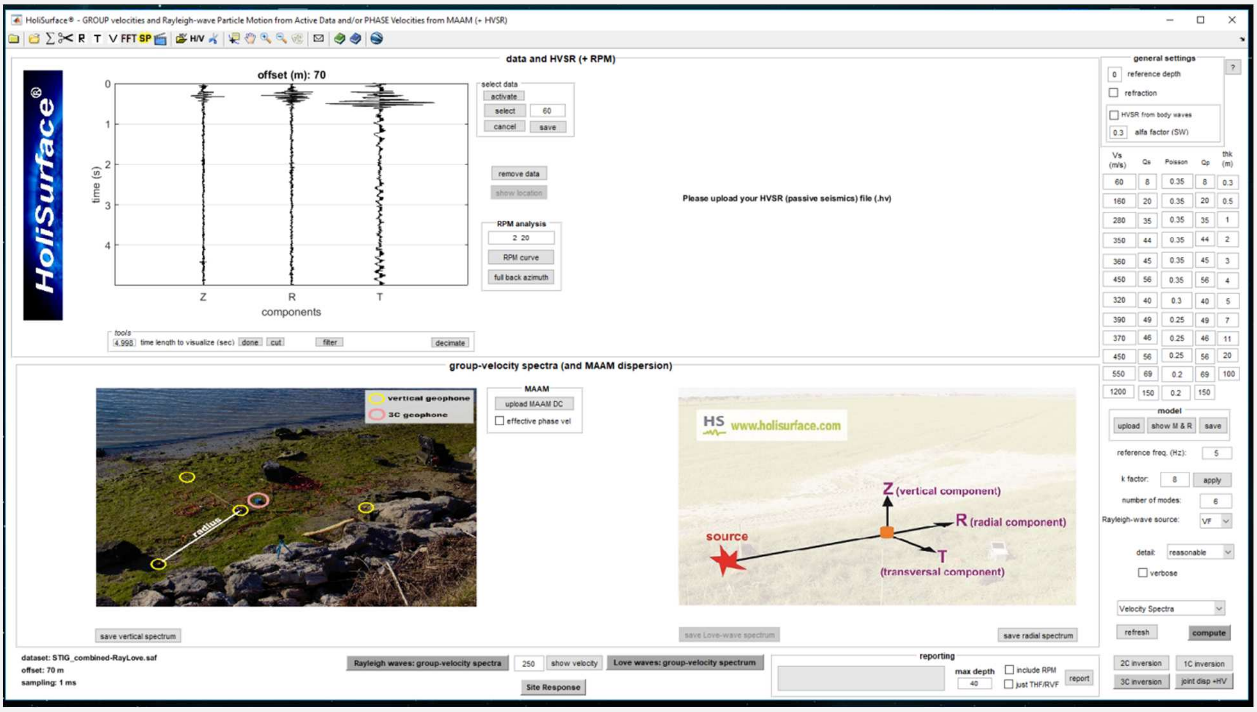
In this panel/module you can also model the HVSR curve alone. To do this, simply load the previously calculated HVSR curve (see the chapter dedicated to calculating the HSVR curve) without forgetting to load active seismic data. Modelling is then carried out simply by varying the parameters of the model (mainly V_S and thickness values) based on the available stratigraphic information and then calculating ("**compute**" button) the synthetic HVSR until you get a good match with the observed/experimental HVSR curve. At the end, you just have to click on the *Report* button.
Bear in mind that the HVSR curve is highly non-unique: you can derive various models of the subsoil from a single curve (see all the literature). Analysis of the HVSR curve alone is therefore not recommended.



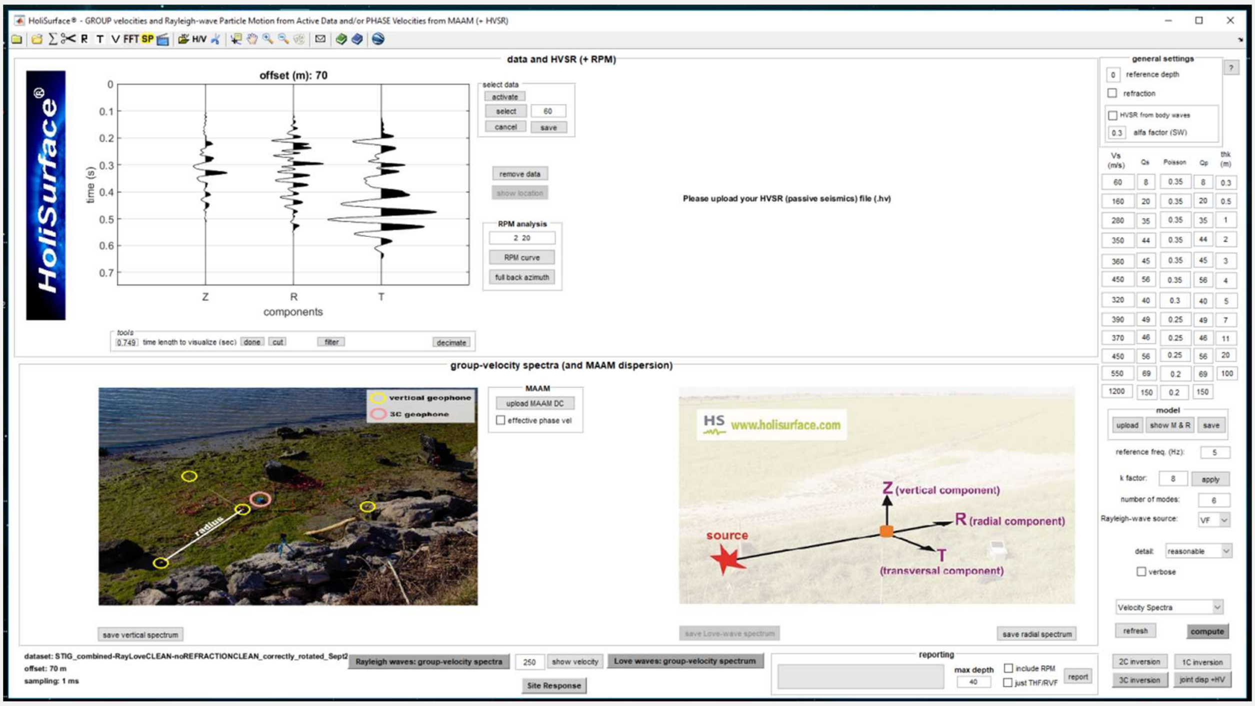
The *Disp+HVSR panel* before data loading ("disp+HVSR" panel)

Step-by-step procedure:

1. uploading of the field SAF/seg2 file (second icon from the left on the toolbar) of the *HoliSurface®* active seismic (see Chapter on *HoliSurface®* acquisitions).

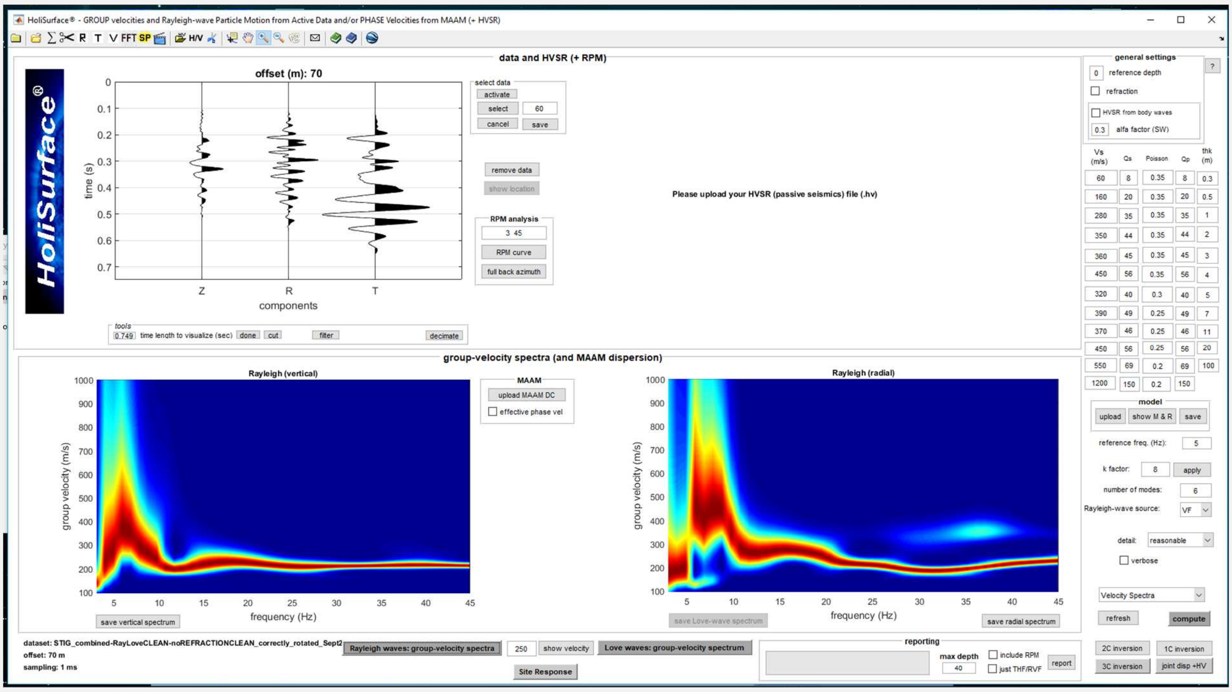


Uploading the field active data (HS) (note the three components: Z, R and T)

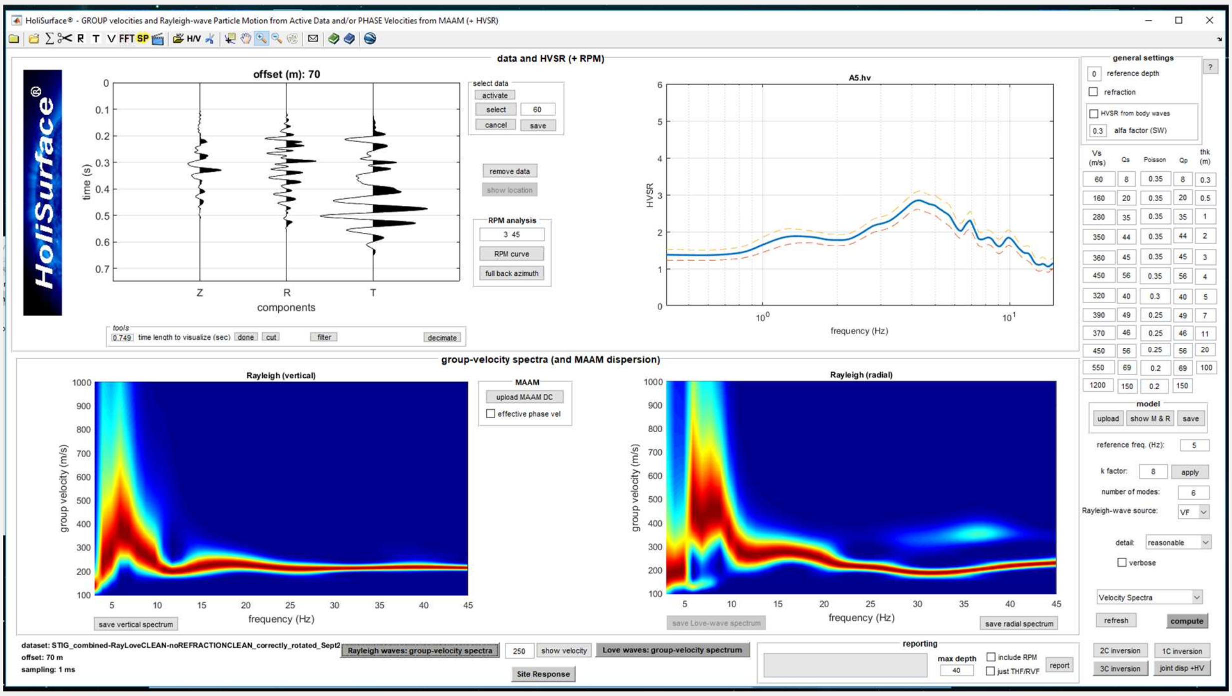


Data cleaning with 2 tools: "**cut**" (removal of useless part of the traces where late arrivals can pollute your analysis) and "**select data**" to remove refraction events, etc.

2. If this data is an acquisition for Rayleigh waves, click on the "*Rayleigh waves: group velocity spectra*" button. In this way you will obtain the velocity spectra of the vertical and radial components of the Rayleigh wave.

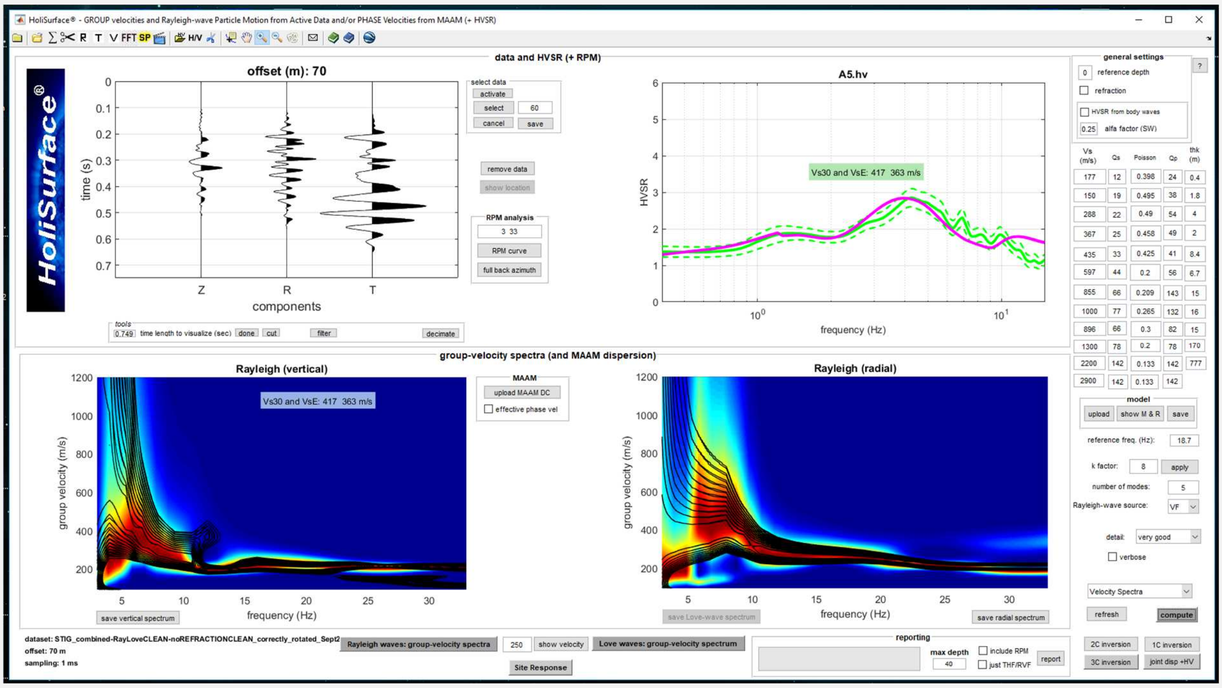


3. upload the previously-computed HVSR curve (see toolbar - with various *helps*)

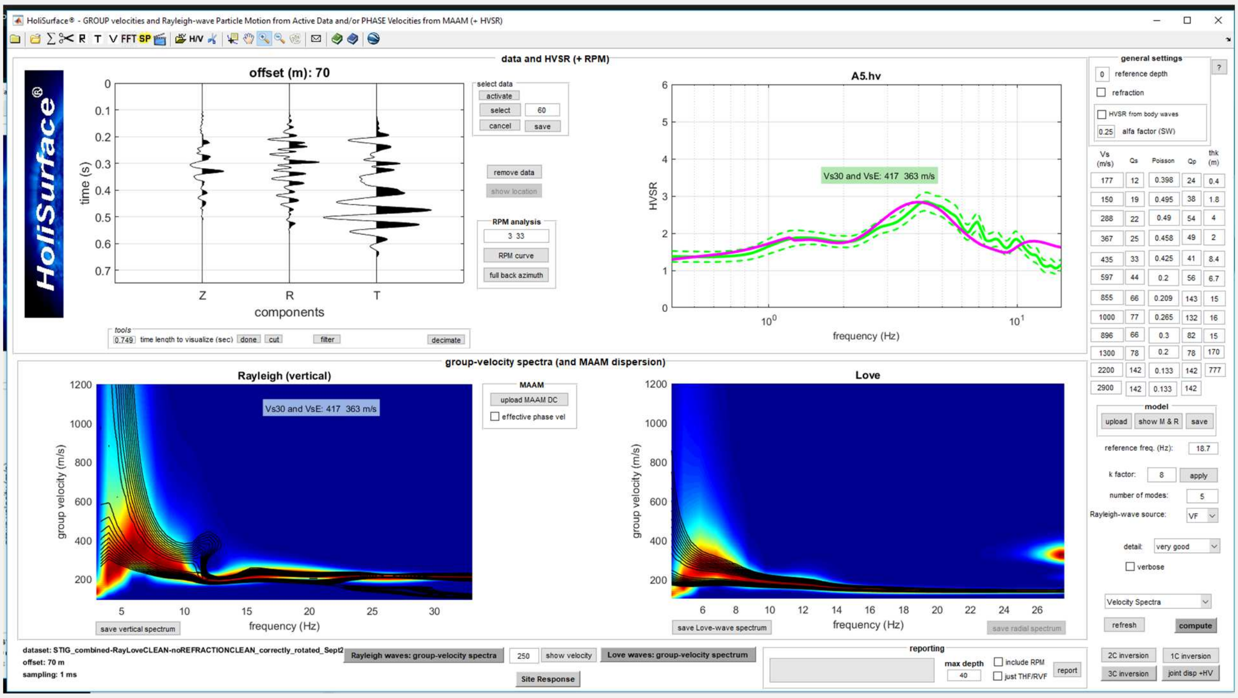


We are now ready for data **modelling** (done in a similar way to any other method - see for example video tutorials on direct modelling in *winMASW®* and the upcoming *HoliSurface®* video tutorials).

In practice, V_S and thickness values must be modified until a satisfactory agreement between observed and modelled data is obtained. In case the agreement you obtain by forward modelling is not completely satisfactory, you can use the automatic inversion tools (in any case it is important to start from a reasonable *start model* that you must identify through the forward modelling).



If the loaded data also contains data about Love waves (see box "Assemble the files of the Rayleigh and Love waves"), you can also consider those. To do so, click on the button "*Love waves: group velocity spectrum.*" At this point, instead of the radial component of the Rayleigh wave (in the left bottom hand of the panel), you will get the group velocity speed for the Love waves:



Screenshot showing data related to: HVSR, vertical (Z) component group-velocity spectrum (Rayleigh wave) and Love-wave group-velocity spectrum.

“Verbose" button (in "*forward modelling*")

When this option is activated, two possible results are obtained, depending on which modelling option is currently activated:

1. "**Vel Spectra & RVSR**": in this case on an external plot you will get the synthetic traces and the relevant group velocity spectra (and/or RVSR)

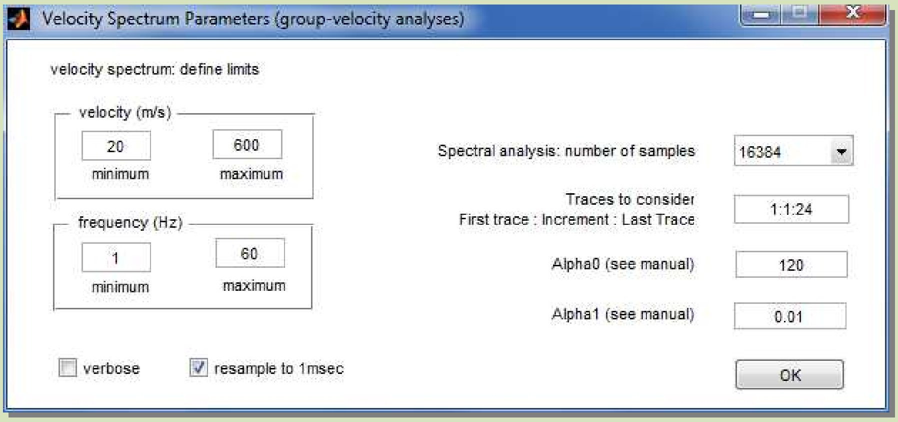
2. "**Modal Disp Curves**": in this case, in an external plot, the phase velocity dispersion curves will be obtained (group curves will be plotted on the velocity spectra of the field data)

Example - case study

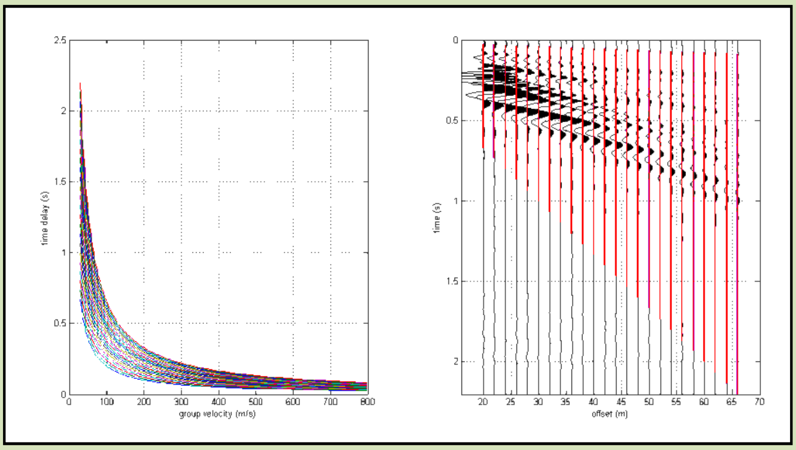
An example of this type of approach is available among the case studies in the *HoliSurface* DVD (“Natissa_case_study_8_Elsevier_Natissa”).

***Alpha0 & Alpha1* parameters**

The shape of the filters used to determine the group velocity spectra depends on 2 parameters (Alpha0 and Alpha1): there are no good values for such analyses; everything depends on the type of data (therefore on the dispersive characters) of the specific dataset.

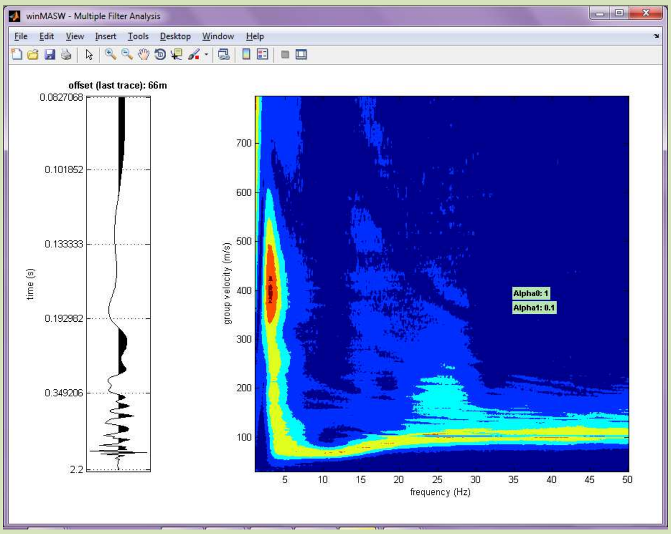


Activating the *verbose* option will give you the 2 screens shown here.



The first shows the delays as a function of the *offset*

While the second shows the last trace considered on the left, establishing a relationship between the delays and the group velocities (spectrum on the right).



6.3 RPM (Rayleigh-wave Particle Motion) Analysis

It consists in analyzing the motion determined by the passage of the Rayleigh wave. To understand this kind of analysis it is absolutely necessary to attend a training course specifically dedicated to the *HoliSurface®* software (and/or *winMASW® Academy*) and all the methodologies implemented in it.

6.3.1 Correct Data Acquisition

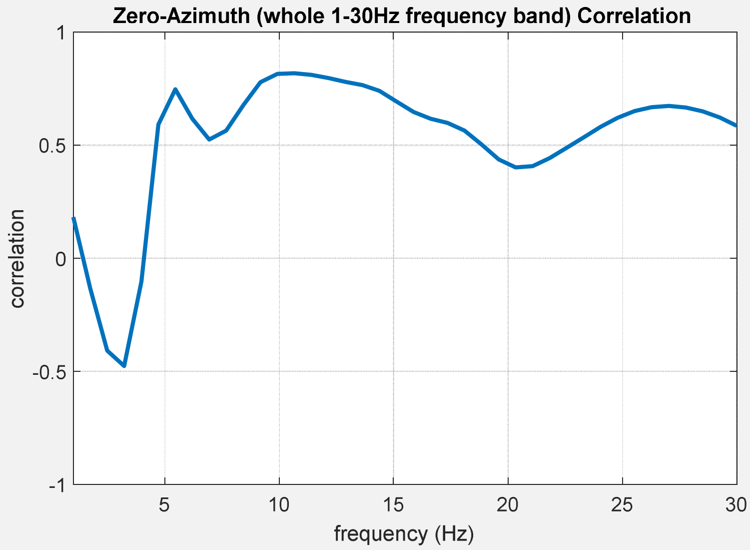
In order to carry out these analyses, it is essential to acquire the data in an absolutely punctual and rigorous manner. In this case, it is not only the *direction* that matters, but also the *orientation*. To make sure that you are acquiring the data correctly, make your acquisitions with instruments that we have expressly approved (i.e., tested in order to verify the correctness of the orientation of your 3C geophone).
That is, make sure to use 3C geophones with the HS sticker like the one shown below and point the arrow in the direction of the source (VF) used.

Below follows some basic information (consider that for each action/analysis the resulting images and data are automatically saved in the working folder).

RPM data calculation

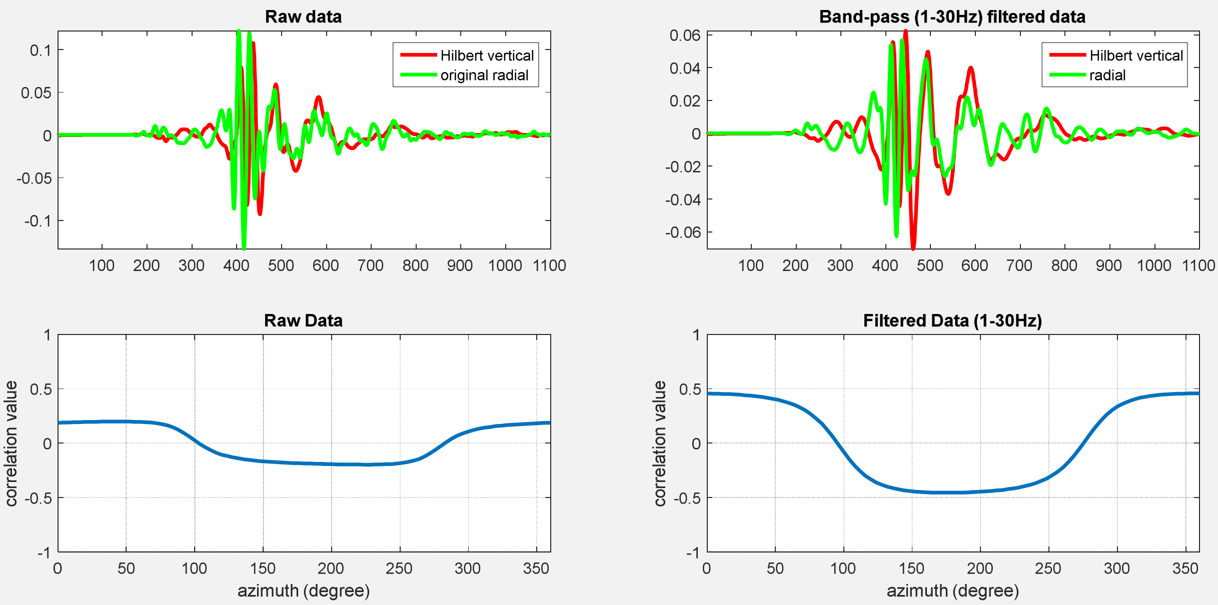
Immediately to the right of the loaded seismic traces there is the box "RPM analysis". There are three buttons:

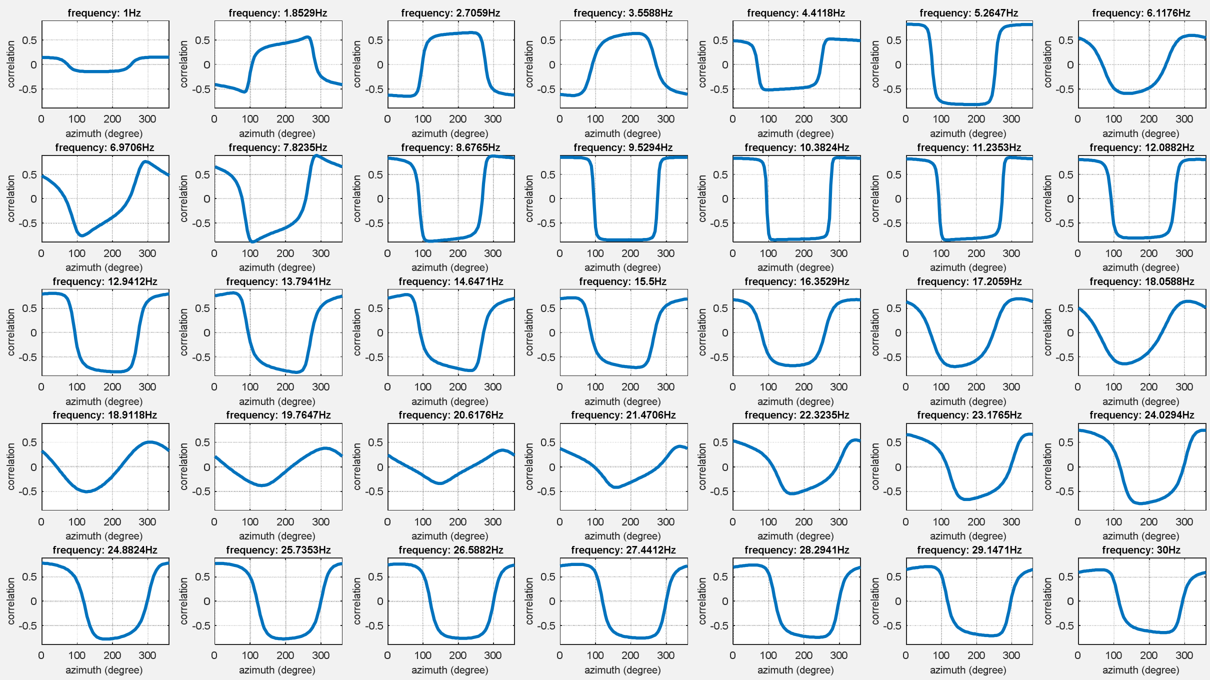
1. **"RPM curve" button:** it computes the RPM curve (which is automatically saved in the working folder- see .RPM file). **<u>Such a curve can be used during the inversion process so to further constrain the subsurface model.</u>**



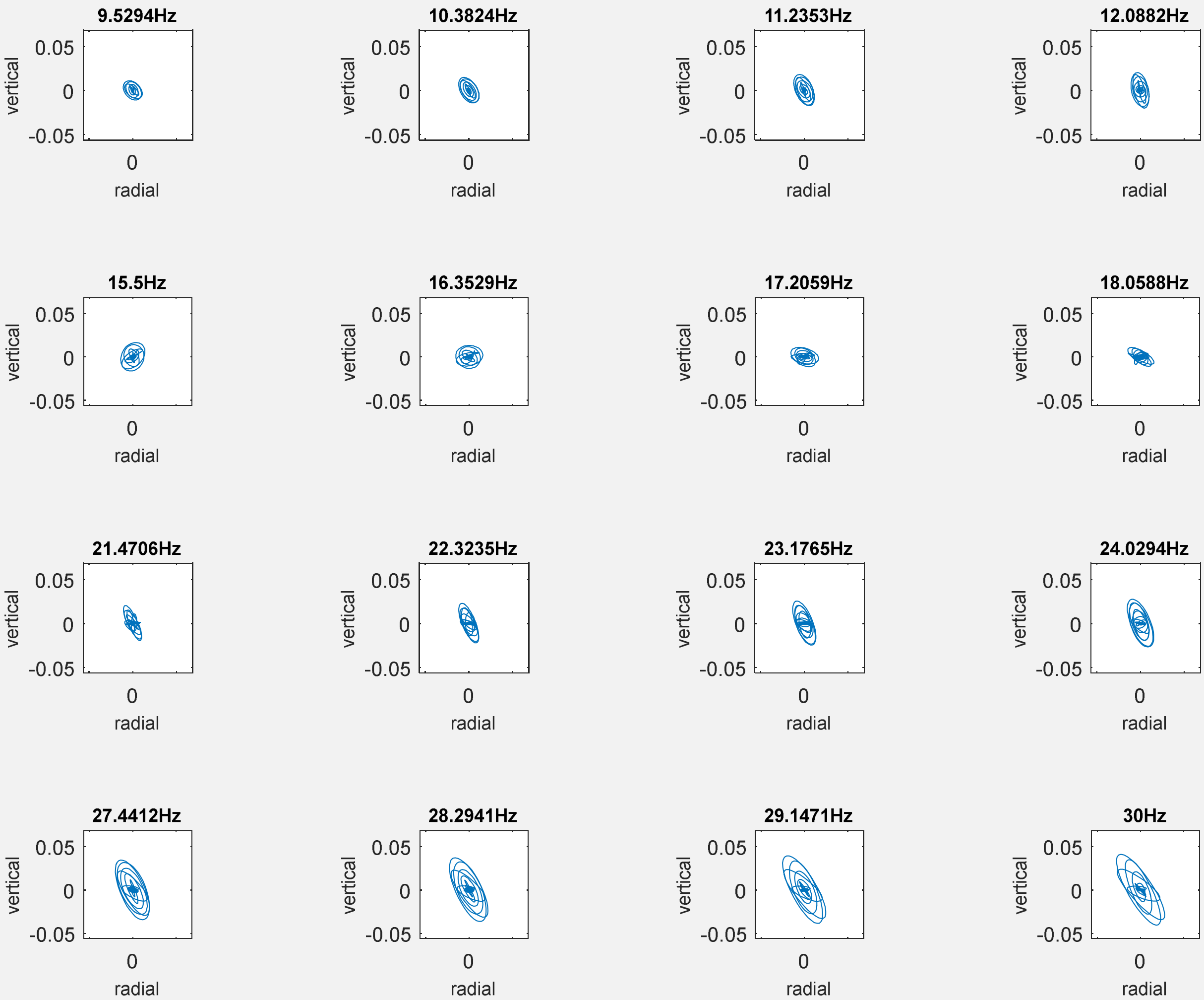
Example of RPM curve: +1 means *retrograde* motion while -1 *prograde* (see related literature)

2. **"Full analysis" button:** calculates many other quantities useful for very advanced studies illustrated during our training sessions (as always, the graphs are automatically saved in the working folder). The azimuth is calculated clockwise starting from the instrumental "North."

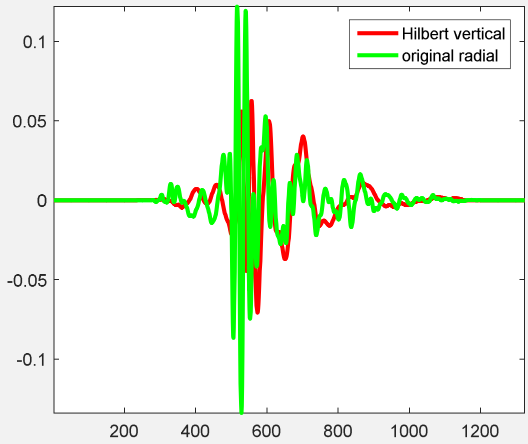


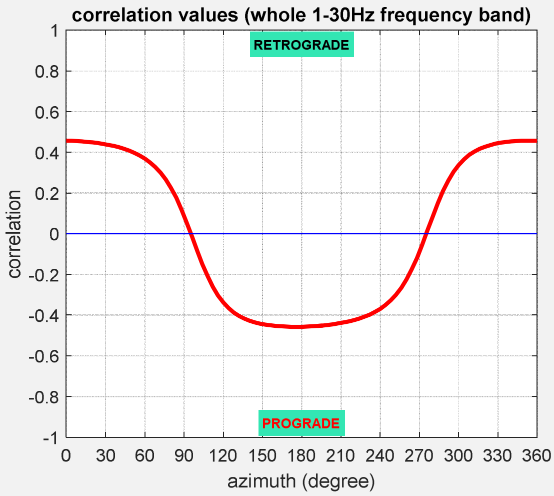


Frequency-by-frequency azimuth correlation curves

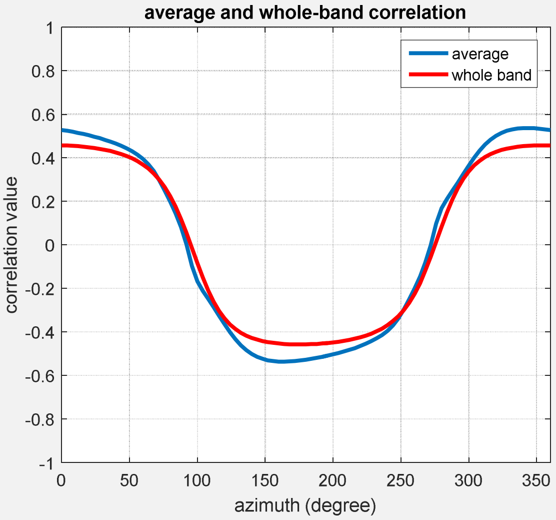


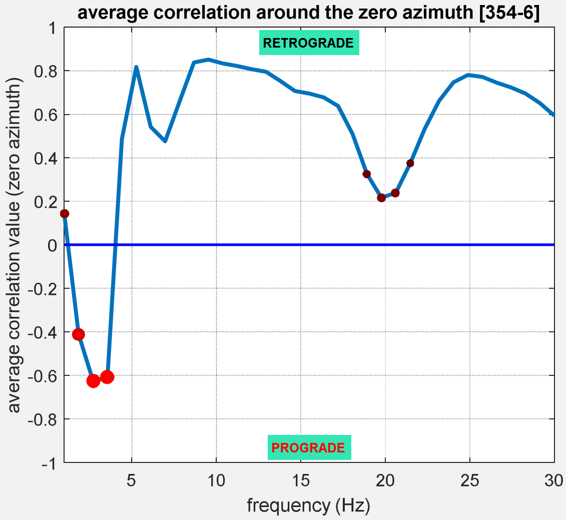
Particle motion on the Z-R plane frequency by frequency



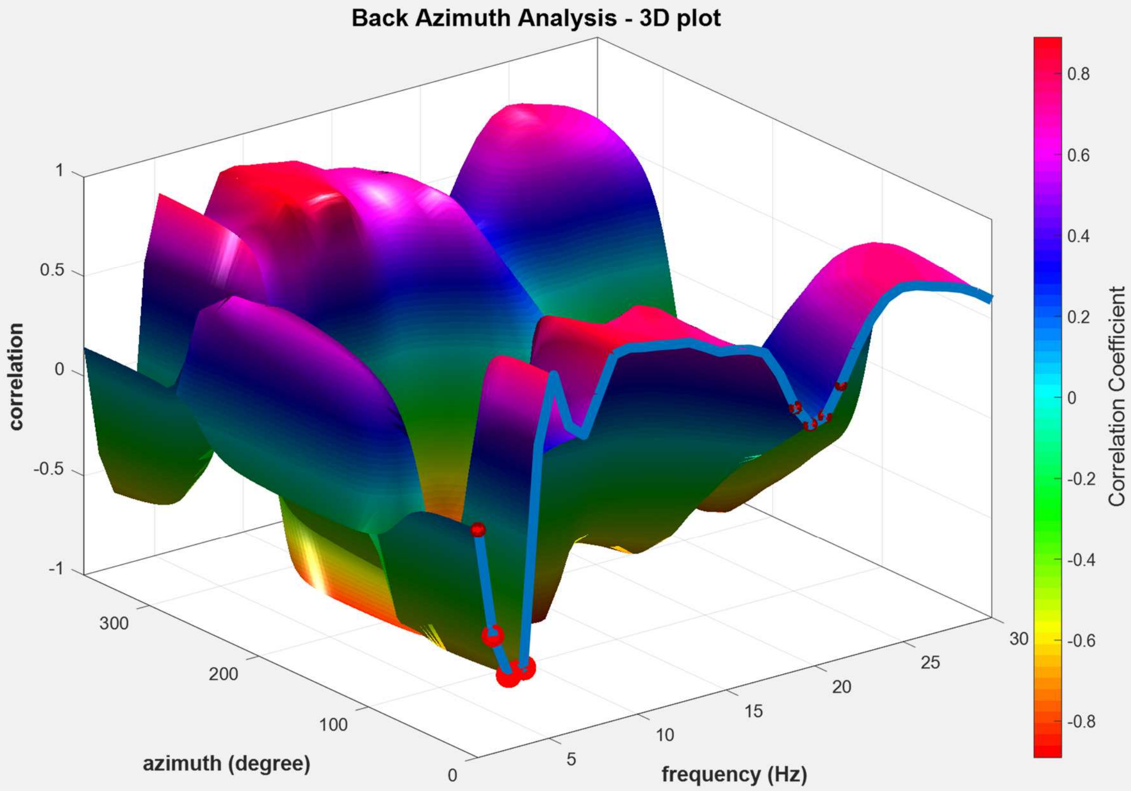


Vertical trace after application of the Hilbert transform and radial trace with correlation curve as a function of azimuth (in the frequency range specified by the user). Remember that +1 means *retrograde* motion while -1 is *prograde.*



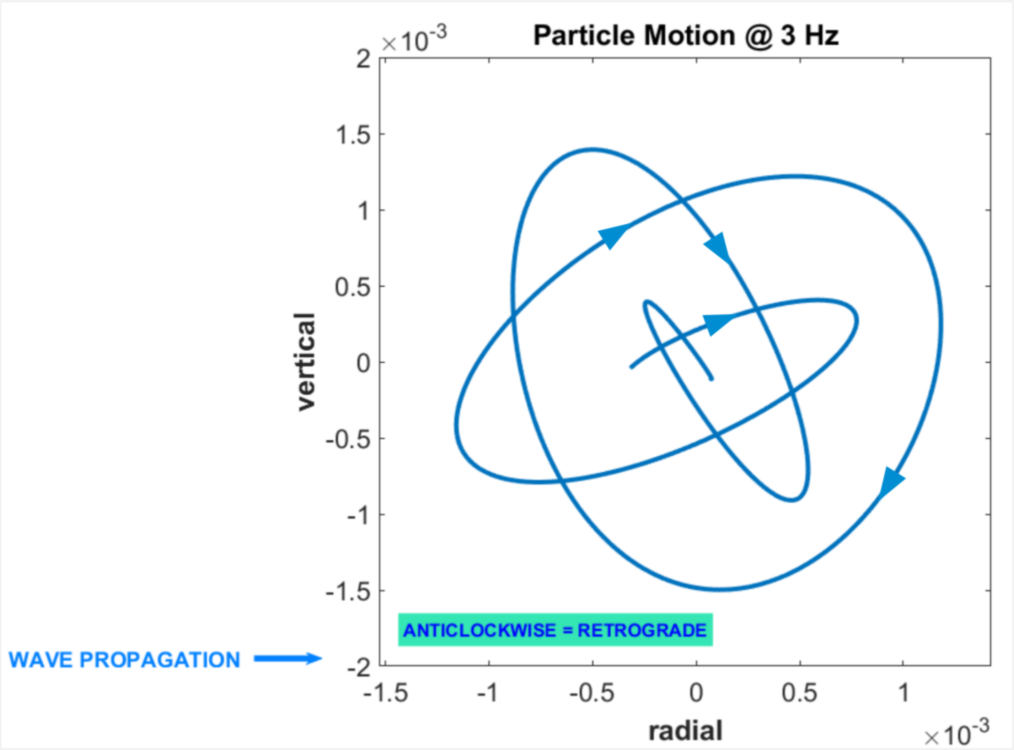


Correlations as a function of azimuth (within the frequency range indicated by the user) and as a function of frequency (considering the Z-R plane, therefore azimuth zero).



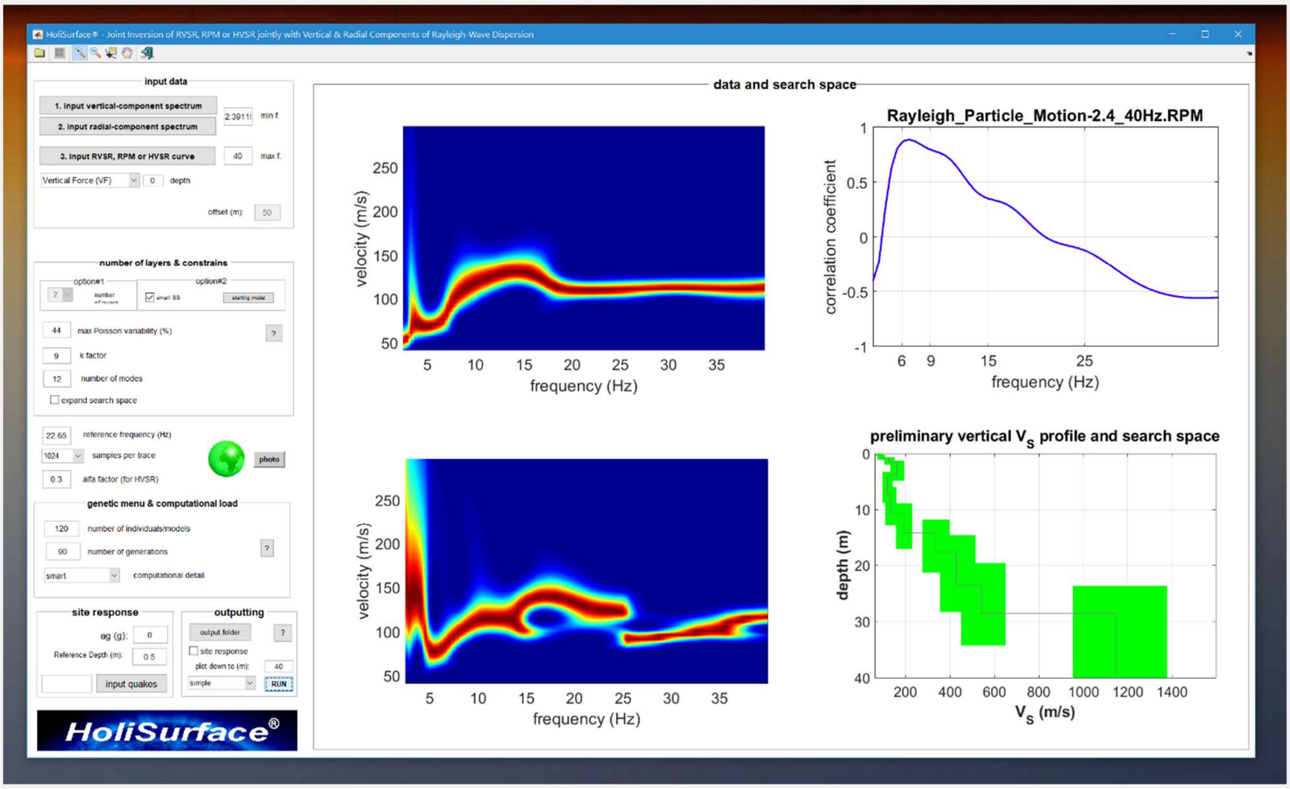
3D representation of the correlation factor as a function of frequency and azimuth.

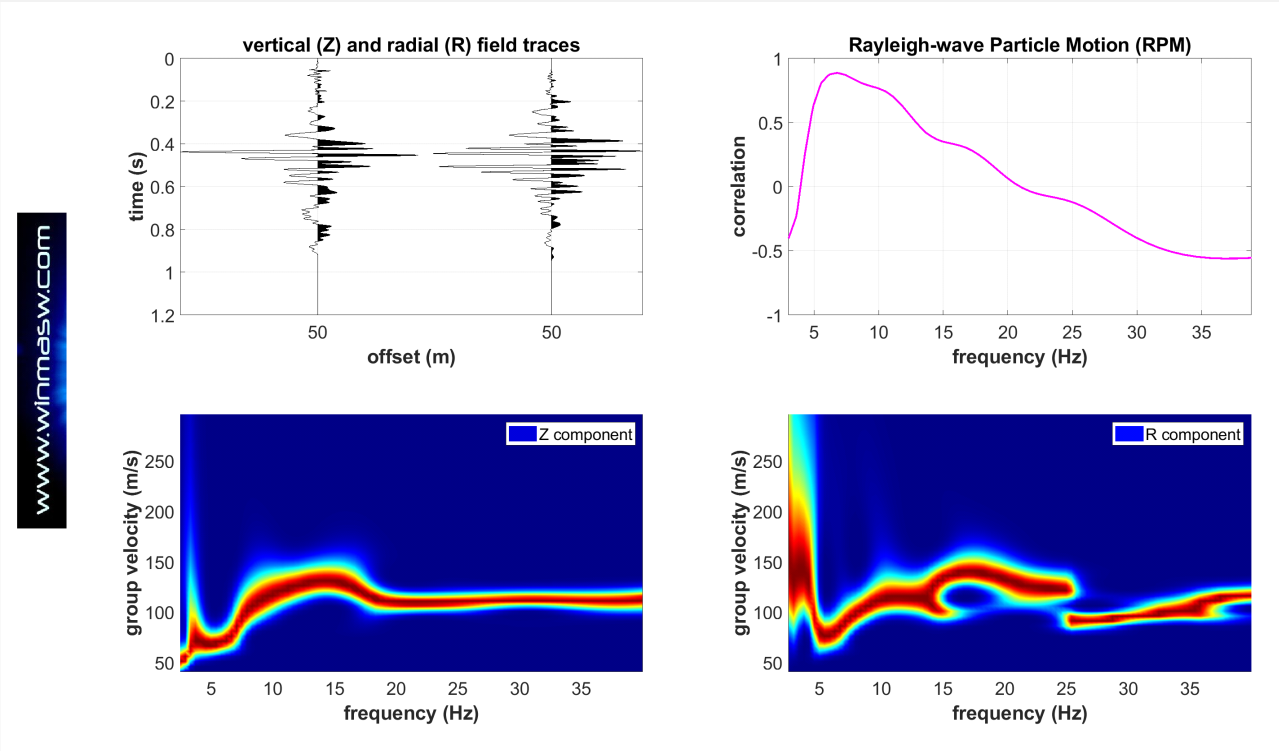
3. **"Particle Motion" button**: a video representing the motion of the particle on the Z-R plane is also automatically saved in the working folder at the frequency indicated by the user in the respective field.

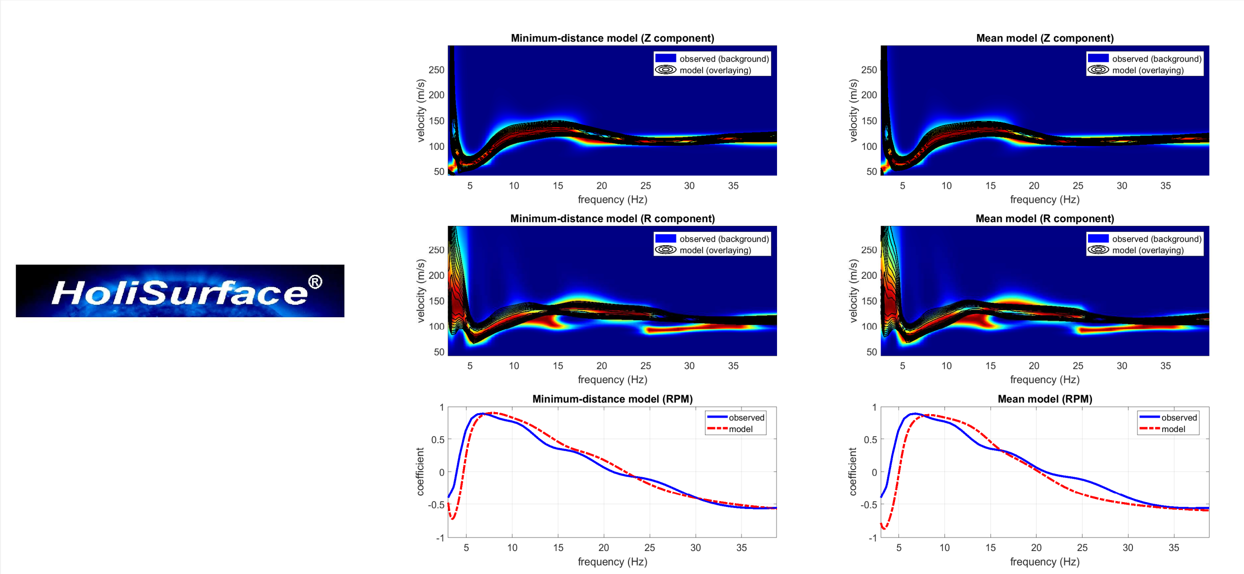


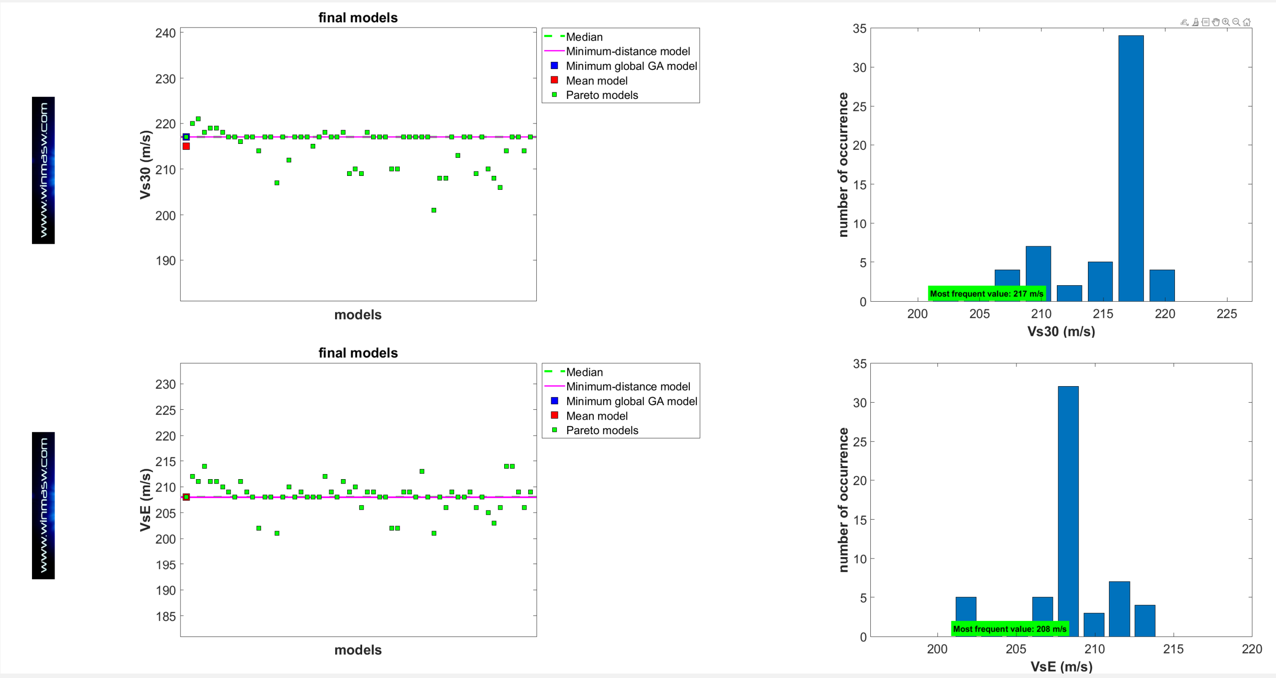
6.3.2 Joint inversion ZVF+RVF+RPM (or RVSR or HVSR)

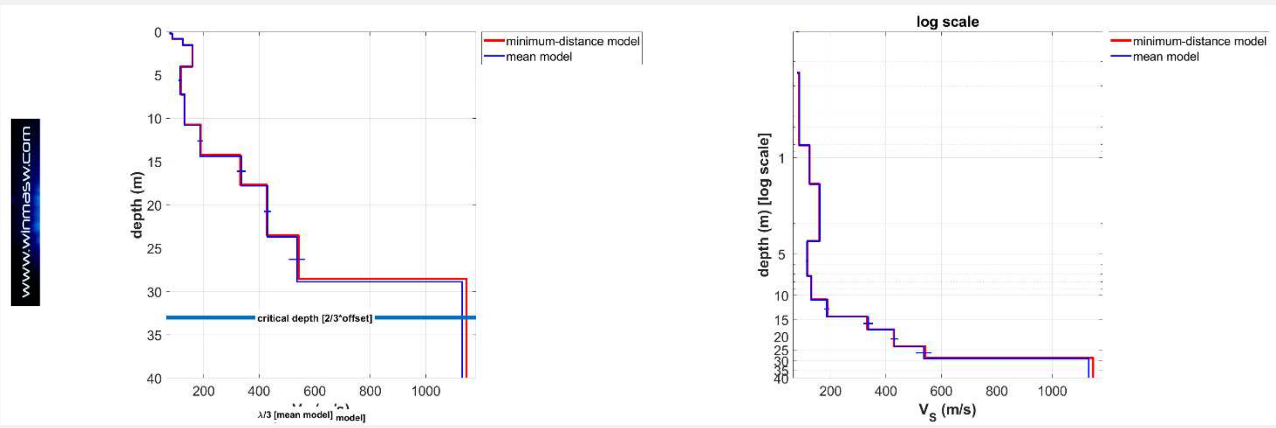
If you keep the summary window of the "Rayleigh-wave Particle Motion" (RPM) open from the "*HoliSurface*" panel and click on the three-observable joint inversion module ("3-obs inversion" button at the bottom right corner). You will jointly invert the two Rayleigh-wave group-velocity spectra (Z and R) and the RPM curve (see figures below).







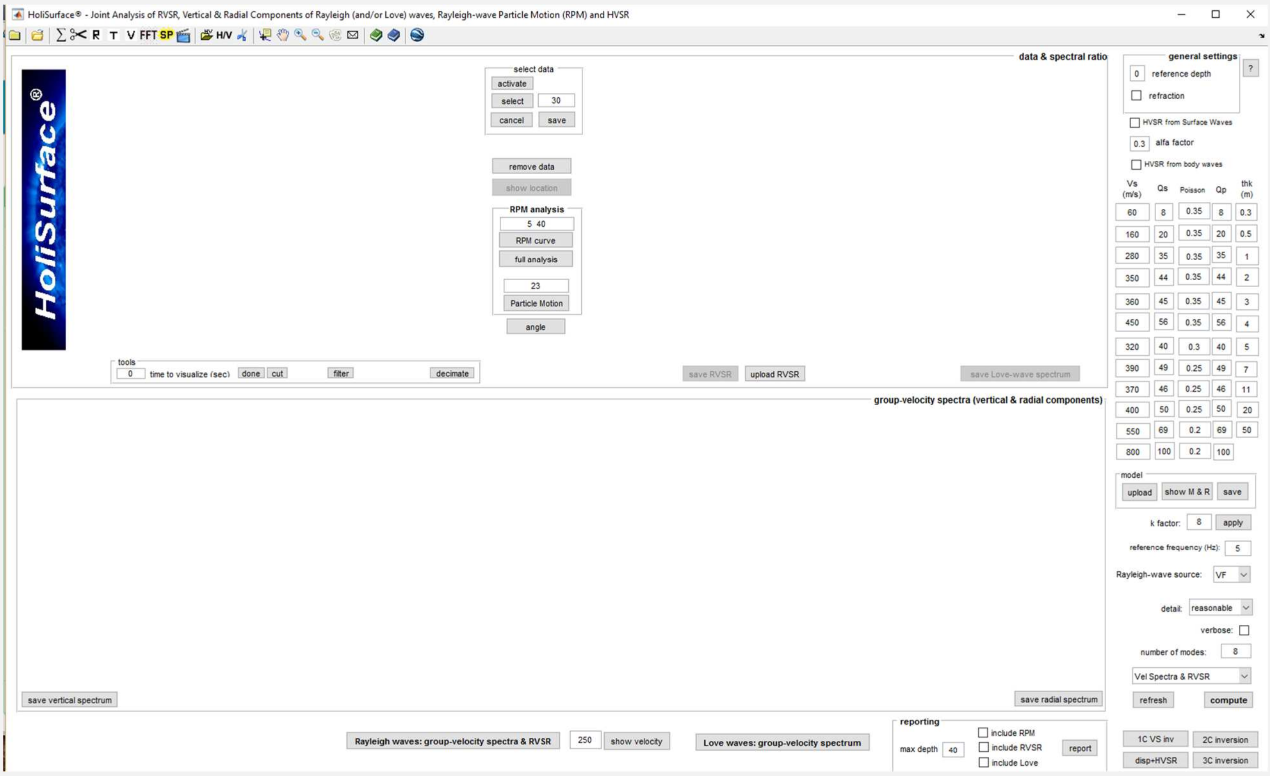




For further information on the various possibilities inherent in the "3C inversion" module, see section "**3-obs Inversion**" module.

6.4 *HoliSurface®* panel

In this module you can load data and determine group velocity spectra of Rayleigh waves and RVSR + the group velocity spectrum of Love waves. Then proceed with direct data modelling (always to be preferred to automatic inversion).

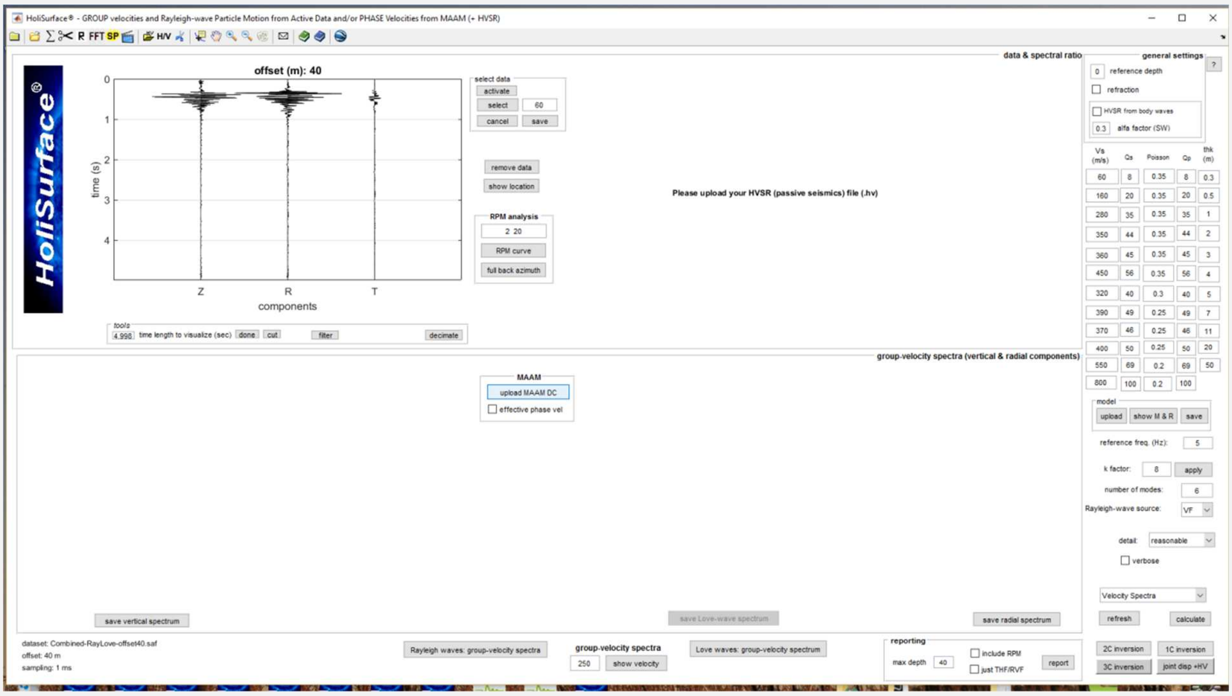


"Virgin" panel when opening the module

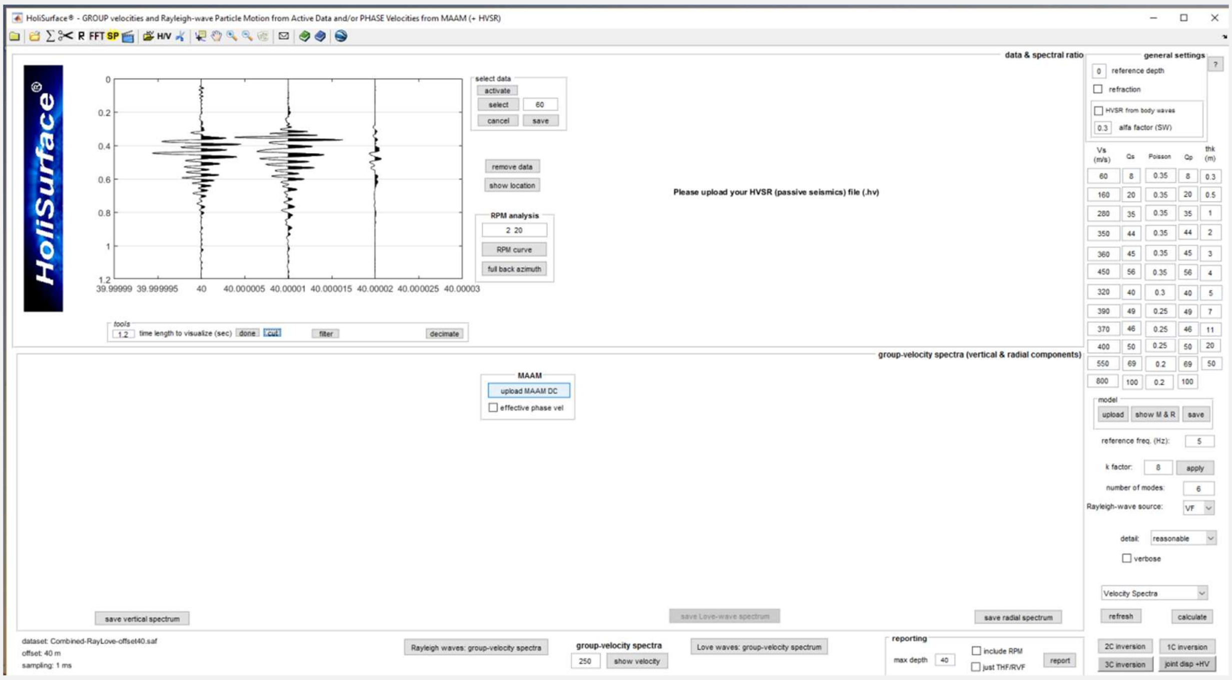
Below is the procedure (recommended) to be carried out if you have previously assembled a file (single) with the Rayleigh and Love waves (see box "Assemble the files of the Rayleigh and Love waves").

Procedure

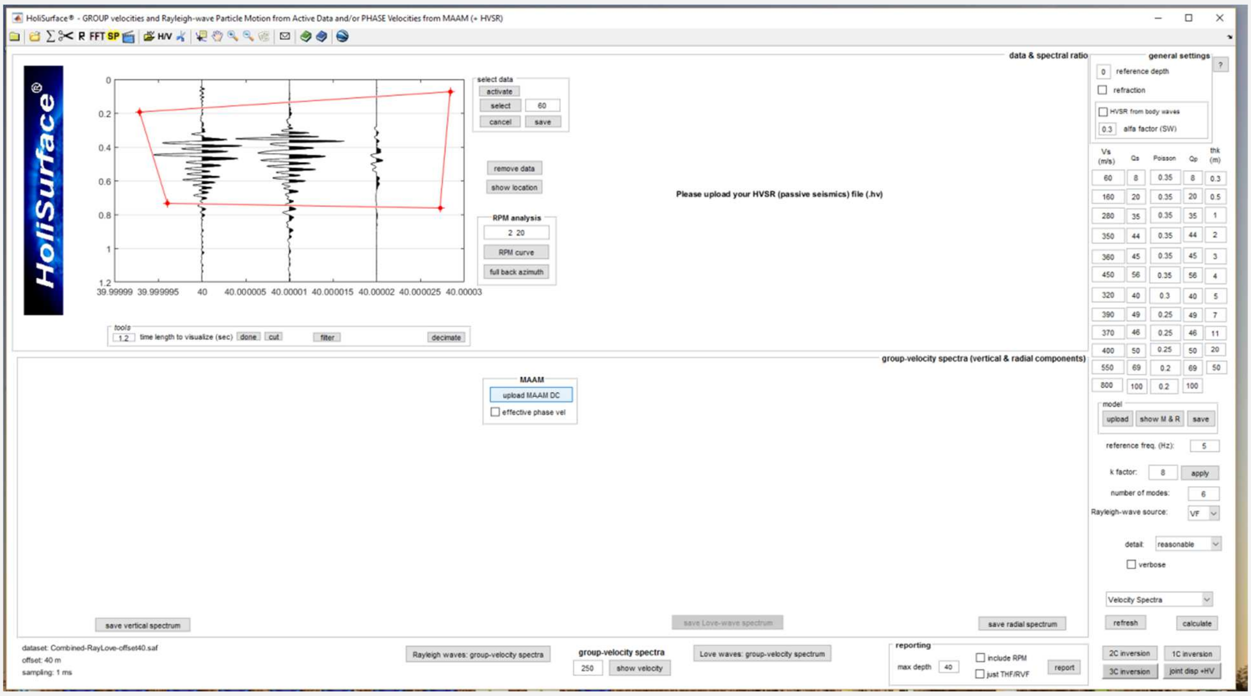
1. Load the data (second button from the left on the toolbar - the first button is used to define the working folder):

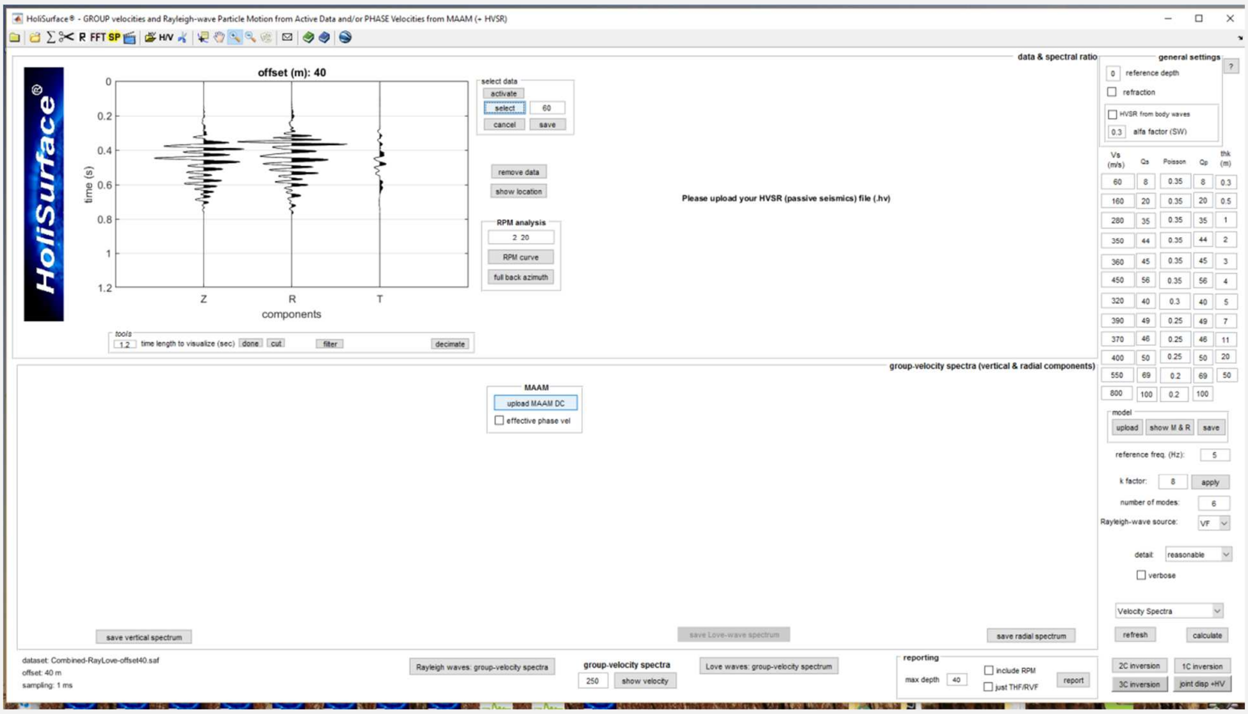


You can see that the useful data certainly does not exceed (indicatively) 1.2 seconds and, entering this value in the field at the bottom left [*tools* group] we display the times up to only 1.2 s. At this point, if this value is good for us (we are sure that over 1.2 seconds there is no useful signal), we remove the data with the **"cut" button**.



At this point, we can further clean the data with the tools of the **"*select data*" group** (to the right of the seismic traces). The red polygon must be activated [**activate**] (the objective is to keep only the data within the polygon). Moving the corners of the polygon changes the shape and once we have defined what we want to keep, we click the **"select" button** [at that point the data outside the polygon are zeroed].





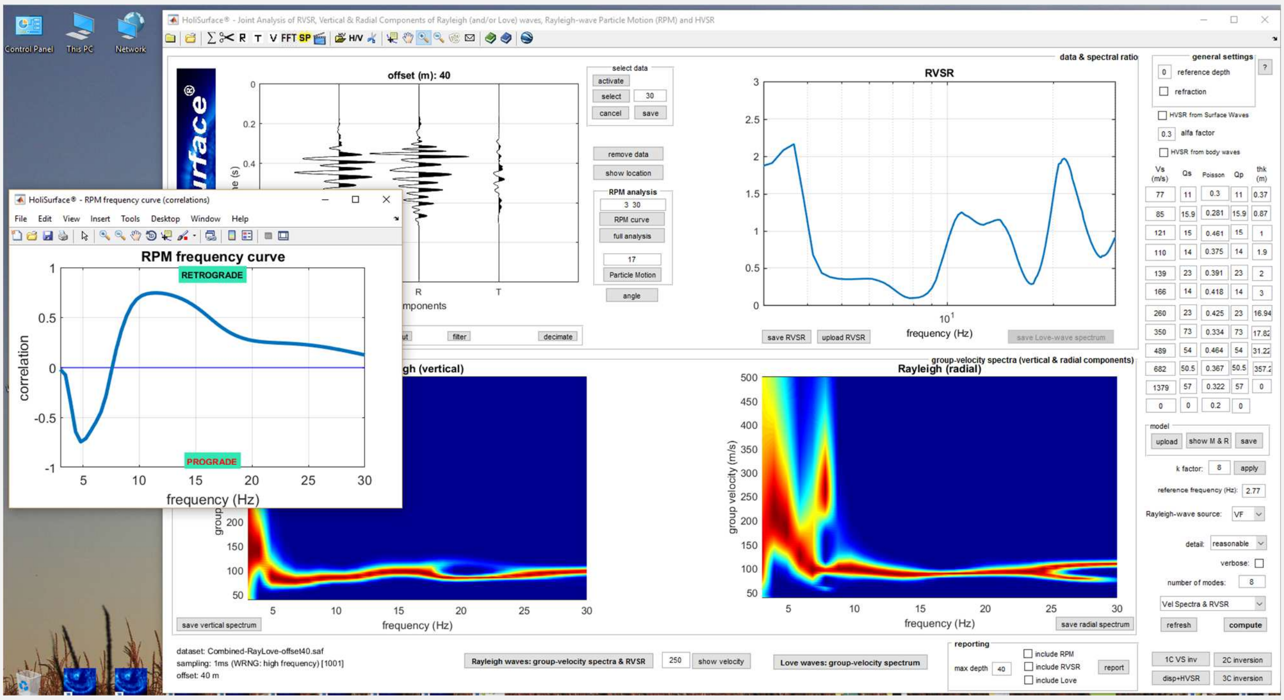
The "cancel" button lets you undo in case you regret having cut badly the dataset while the **"save" button** lets us you save the cleaned dataset according to our assessments.

2. Determine the group velocity spectra of Rayleigh waves (and RVSR) [**"*Rayleigh waves: group-velocity spectra (& RVSR)*" button**]

How to choose the minimum and maximum frequencies? Knowing the fundamentals of surface wave propagation and the general characteristics of the site. In general terms, we can say that:

1. for the minimum frequency: do not go below half of the frequency of the supplied geophone (unless dealing with electronically equalized geophones).

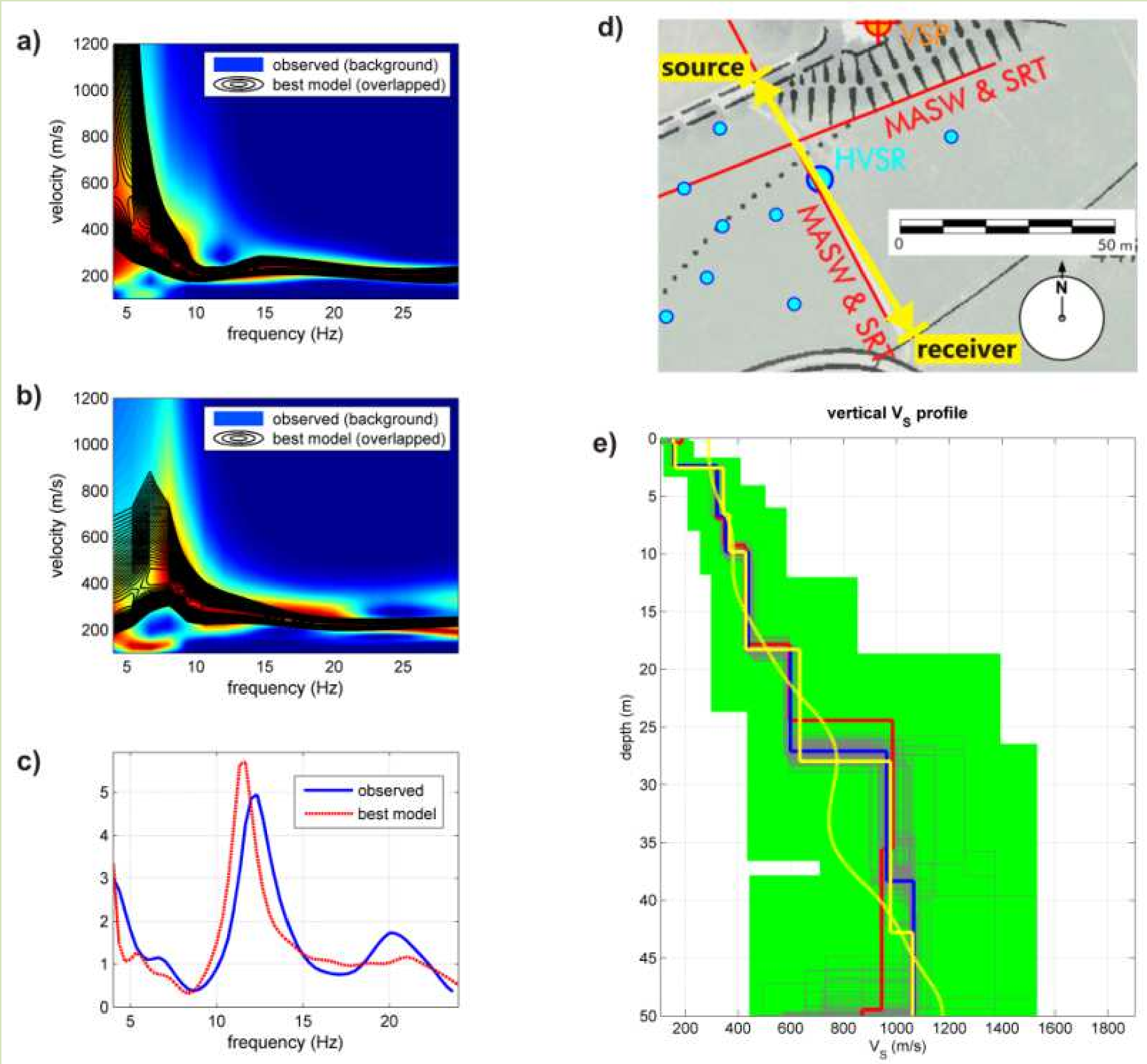
2. the maximum frequency depends very much on the site: on flood plains it may be enough to work <u>approximately</u> between 3 and 20Hz, on gravel between 10 and 40, etc. [see workshops and case studies].



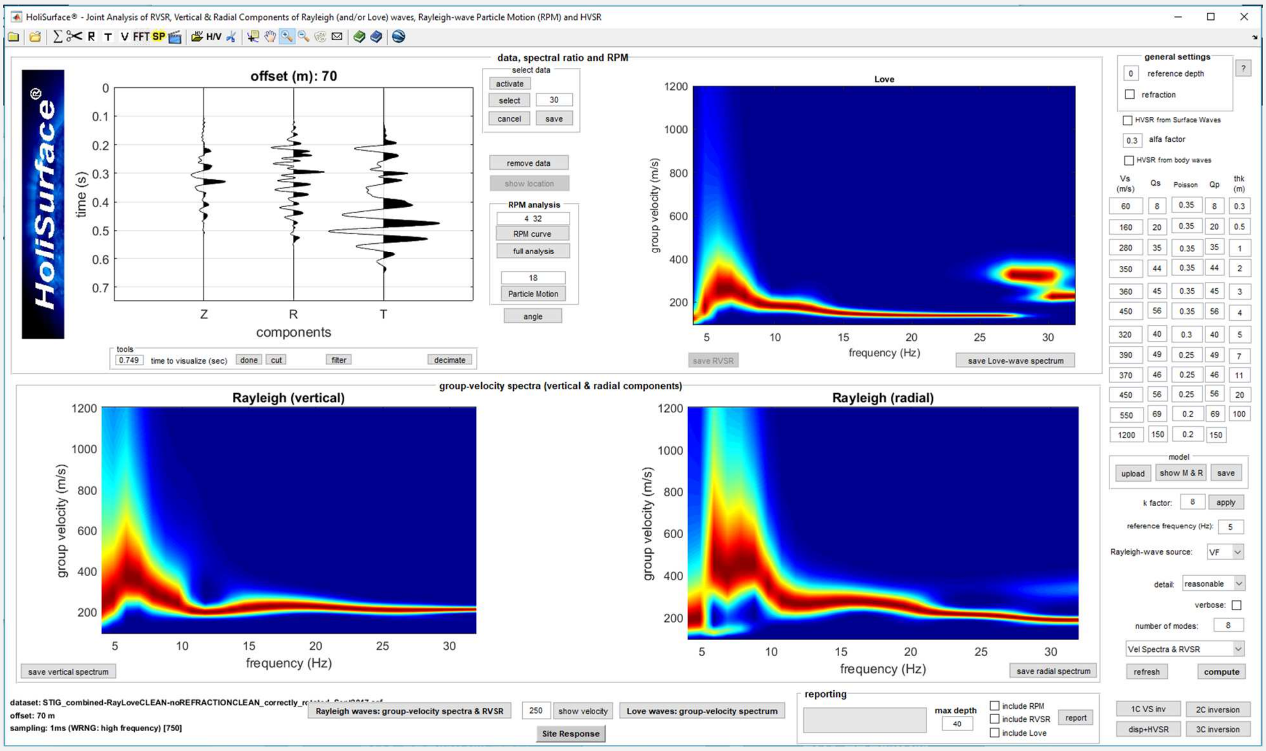
Pay attention: The RVSR curve is a very sensitive "object". The calculation depends, among other things, on how we "clean up" the data. It is therefore recommended to use it only in case of <u>perfect</u> mastery of <u>everything</u> related to the propagation of surface and body waves and everything related to the signal analysis.

The RPM curve is more "stable" and therefore typically preferable (e.g., **Dal Moro and Puzzilli, 2017**).

Below is an example of a "classic" *pure* HS analysis: a) and b) show the group velocity spectra of the field data (background colors) and the synthetic model) (black contour lines); c) the field and synthetic RVSR curve. On the right is the V_S profile, which is also compared with the one obtained from downhole data (VSP). From "*A Comprehensive Seismic Characterization via Multi-Component Analysis of Active and Passive Data*" - Dal Moro et al. (2015).



3. If you have also acquired data for Love waves, determine the velocity spectrum of the Love waves ["*Love waves: group-velocity spectrum*" button]. This will replace the RVSR:



We can now proceed with the direct modelling (joint Rayleigh + Love) considering the problem of anisotropies of Vs (a subject of which unfortunately very little is known at present and which has been neglected by the world of research).

First we will understand the data using the modal dispersion curves ("*Modal Disp Curves*" option in the pop-up menu above the calculation button "*calculate*").

Once we have gained adequate confidence, we will move on to the "*Velocity Spectra*" mode (with which we will plot the peaks of the velocity spectra of the synthetic data.

It should be noted that it is also possible to load the experimental HVSR curve ("HV" button in the toolbar). Activating HVSR modelling (number of modes greater than zero and/or HVSR from body waves) will model then the HVSR too.

Reporting **("include RVSR" button)**

Once sufficient consistency is achieved, the model is identified and we can move on to the final report ("report" button).

As you can see, next to the "report" button there is the option "*include RVSR*" which clearly includes or not the RVSR in the final report.
This option has been added because in case of lateral variations the group velocity spectra show an "average" value that is not affected very much by these variations while

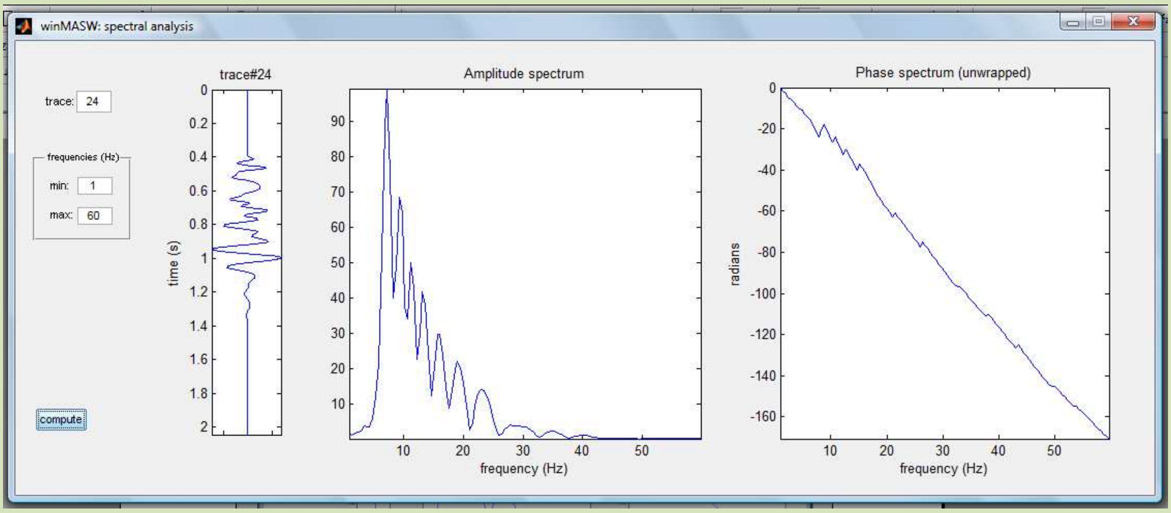
the RVSR is greatly affected (we will show our findings during our workshops and in the next dissemination works that we are preparing).
In these cases (presence of significant lateral variations) it is therefore impossible to obtain good coherence of all three of these quantities (the two velocity spectra and the RVSR) and it is therefore necessary to exclude the RVSR from modelling (therefore from the final report).

Example - case study

An example of this type of approach is available among the case studies in the "Documents" folder: see the file “*HoliSurface-CaseStudy1-Purgessimo.pdf*."

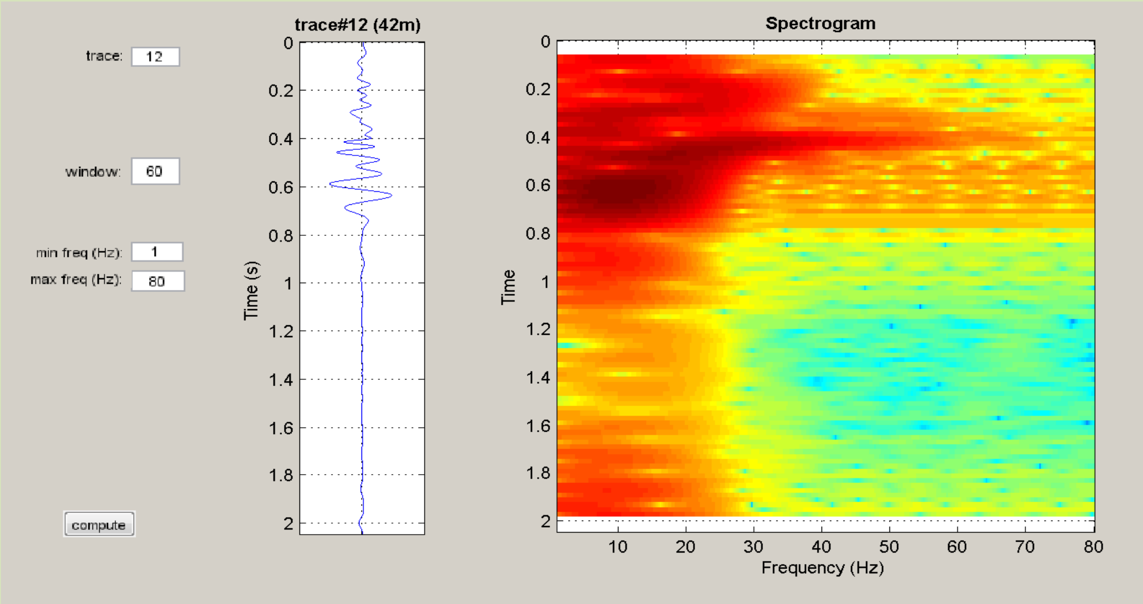
Spectral analysis and spectrogram

In the "*HoliSurface*" panel, you can carry out spectral analyses (phase and amplitude spectrum) of the loaded traces ("FFT" button).



Spectrogram

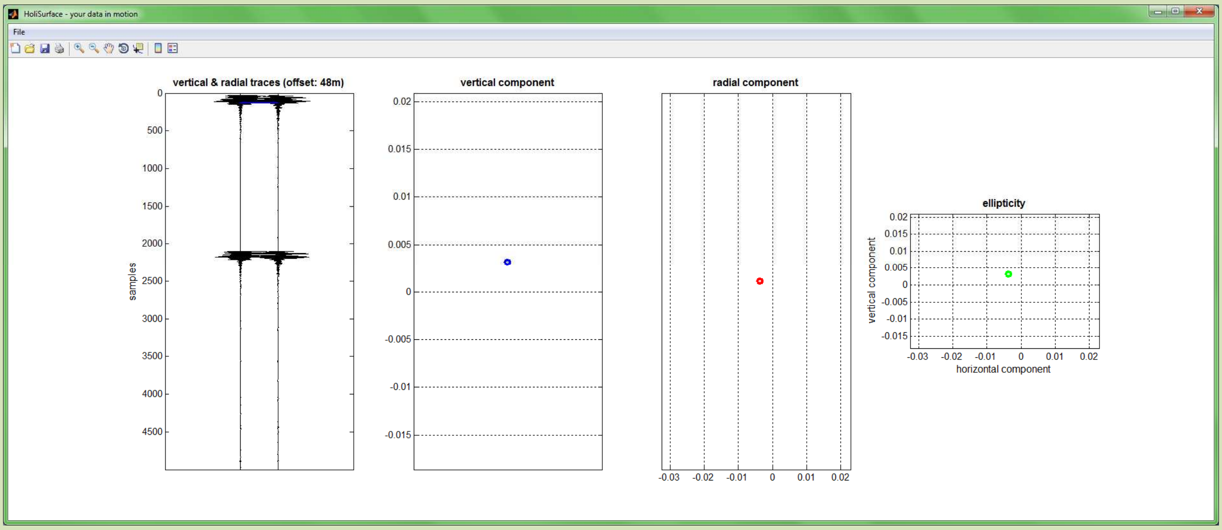
The "SP" button (on the toolbar) allows you to calculate the spectrogram (amplitude spectrum as a function of time).



Data decimation

The "decimate" button allows you to reduce (halve) the sampling of the data. If we have data acquired for example with a sampling interval of 0.5msec, clicking on "decimate" will give data with a sampling interval of 1 msec. By clicking again, the sampling will become 2 msec.

Movie BUTTON



You can view the data in a video animation (movie button in the "*#1 uploading & processing*" box).

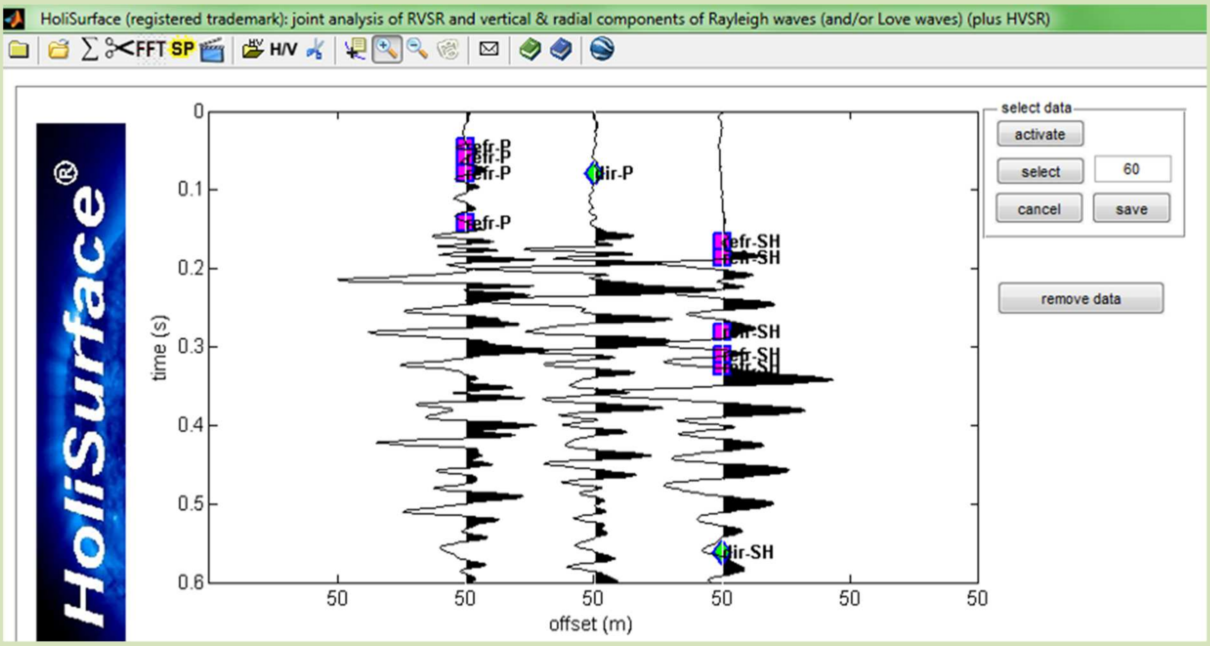
Save current snapshot

With the small camera icon (on the toolbar) you can save the current screen.
There are 4 possible formats: jpg, png, tiff and bmp.
The ones that ensure the best definition (quality) of the image are png and tiff.

Body-wave refraction in *HoliSurface*®

In the panels "*Disp+HVSR*" and "*HoliSurface*" it is also possible to consider the arrival times of the refracted waves P and SH.
To do so, simply activate the "*refraction*" option (top right button).
When we calculate the dispersion curves or the velocity spectra ("calculate" button), the arrival times of the refracted waves P and SH (as well as the respective direct waves) will also be displayed.

In accordance with the adopted convention (the first two traces refer to VF acquisitions and the third to HF acquisitions - see box "Assemble the Rayleigh and Love waves files") the display of all times are distributed between the three traces as shown (by way of example) in the following figure:



The refracted P waves are shown along the first trace, the direct P wave along the second, while the third trace (referred to the T component) refer to SH waves.

It goes without saying that, since we are dealing with a single offset, this type of data can be useful in stratigraphically simple situations and/or to evaluate the maximum Poisson coefficient to understand if and how much a certain sediment is saturated with water (see for example case study#2 of the Elsevier book "*Surface Wave Analysis for Near Surface Applications*" or the paper "*Unconventional Optimized Surface Wave Acquisition and Analysis: Comparative Tests in a Perilagoon Area*").

7. Automatic inversion panels

So far, there are (at least) three ways to proceed with automatic inversion in *HoliSurface®*. As always, there is no *one* correct way and only a good knowledge of the method and related issues allows you to work correctly.

Basically there are 3 possible (automatic) inversions (but remember that direct modelling is always the best way to proceed and still represents a fundamental step before accessing any type of automatic inversion).

Below are the 3 possible automatic inversions available in *HoliSurface®*.

A few key points

The method of managing velocity spectra is based on the generation of synthetic seismograms using *modal summation*.

Calculation times are heavy (therefore a high performance PC is recommended) and it is therefore recommended to start from an already significant model (option#2) considering a .mod model previously identified and saved through direct modelling).

It is **essential** to use a *velocity spectrum* that contains information related to surface waves only.
Therefore, before computing (and saving) the spectrum, clean-up your data (e.g., by removing refracted signals and late arrivals not related to your hammering).
Fix a minimum and maximum frequency that includes the frequency range of the surface waves (which vary from site to site). On alluvial soils these are typically between 4 and 30-40 Hz, while on stiffer (and less attenuating) soils they can rise up to even 60 Hz and over.
The correct determination of the velocity spectra is clearly essential for a successful inversion.

The fact that it is not necessary to *pick* the velocity spectra does not mean that the method is a "shortcut" that does not require an understanding of what you are doing.

Expand search space

In the automatic inversion modules, by activating this option, the software will be able to search for solutions outside the search space (V_S and maximum and minimum thickness values) indicated by the user. The reason for this is to allow better fitting in case the user has not correctly parameterized search space. If you are not too experienced, we suggest to activate this option.

Recommended inversion parameters

Parameter	Meaning	Recommended values
Minimum frequency of the velocity spectrum(a) and maximum frequency of the RVSR or RPM curves	*With regard to the maximum frequency of the RVSR*: frequencies that are too high risk contamination due to lateral variations of the very first decimeters of the soil; *With regard to the minimum frequency of the velocity spectrum/a*: very low frequencies can only be used if the offset and source used are adequate in that sense. It is a good idea to cut frequencies for which there is no longer a clear coherence signal of the spectrum.	It is impossible to recommend "universal" values (they depend on the site) but, roughly speaking, we can say: 2-6 Hz as minimum frequency 20-25 Hz as maximum frequency for the RVSR curve. The RPM curve can be usually considered up to the same maximum frequency of the velocity spectra
Number of layers	Number of layers used to reconstruct the vertical profile. Consider that it is highly recommended to perform automatic inversion from a previous starting model identified by "direct modelling" (*option #2*).	The *HoliSurface®* method can define more stratigraphic details than the MASW and HVSR methods. An adequate number of layers must therefore be considered: usually 6-8 layers but, in case of extremely complex situations, (or in case you need to reach deep layers) 12 layers are necessary.
K factor	Value of the K factor that regulates the relationship between V_S and Q_S: $Q_S=V_S/K$	Suggested values: 10 when working on non-consolidated sediments; 14 (or more, even much more) on rock. See also "Max Poisson and *K* factor variability"
Max Poisson and K factor variability	Value that regulates the variability of the Poisson ratio and K factor values initially adopted.	Suggested value: 30%

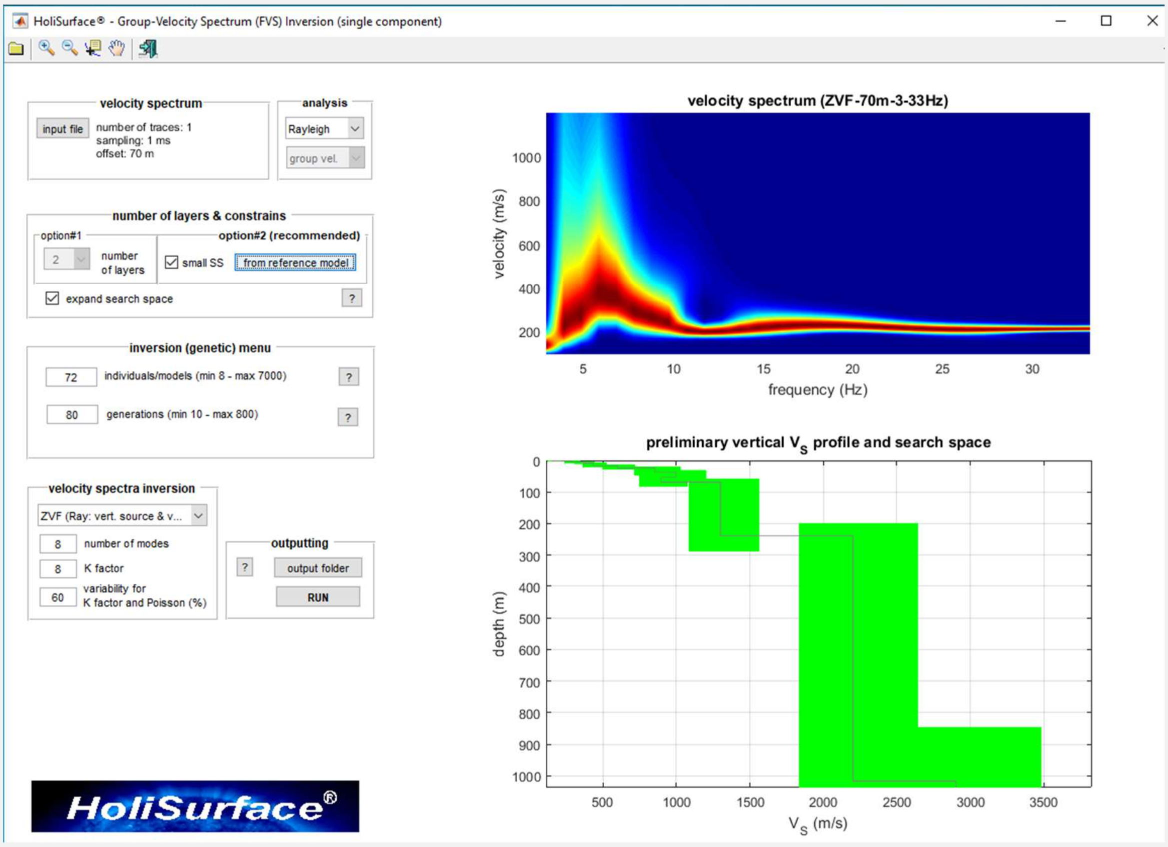
Search space	Minimum and maximum values for each variable (thickness and V_S of each layer)	*HoliSurface®* proposes values (the suggested values are rather large) that the user **must** modify based on the geological knowledge of the area.
Number of individuals/models	Number of models constituting the number of individuals evolving to better solutions. The greater the number of layers, the greater the number of models to be considered is.	Minimum 60
Number of generations	Number of generations after which better and better models are explored	Minimum 50
Computational detail	Degree of "mathematical precision" of the dispersion computation	It is perfectly sufficient for normal and "reasonable" stratigraphic situations. Highly complex situations (abrupt V_S variations) may require a "good" (or very rarely a "very high") level of detail. This parameter has a significant influence on the computational load.

7.1 Single-Component Inversion panel

Automatic inversion procedure which, in summary, takes place according to the steps summarized below.

1. Load the previously saved velocity spectrum; in this case, the file is "ZVF-70m-3-33Hz.mat" (i.e., it is the vertical component of an acquisition made with offset 70 m, in the 3-33 Hz range - see snapshots below)

2. Set the search space (starting from a previously identified and saved starting model)



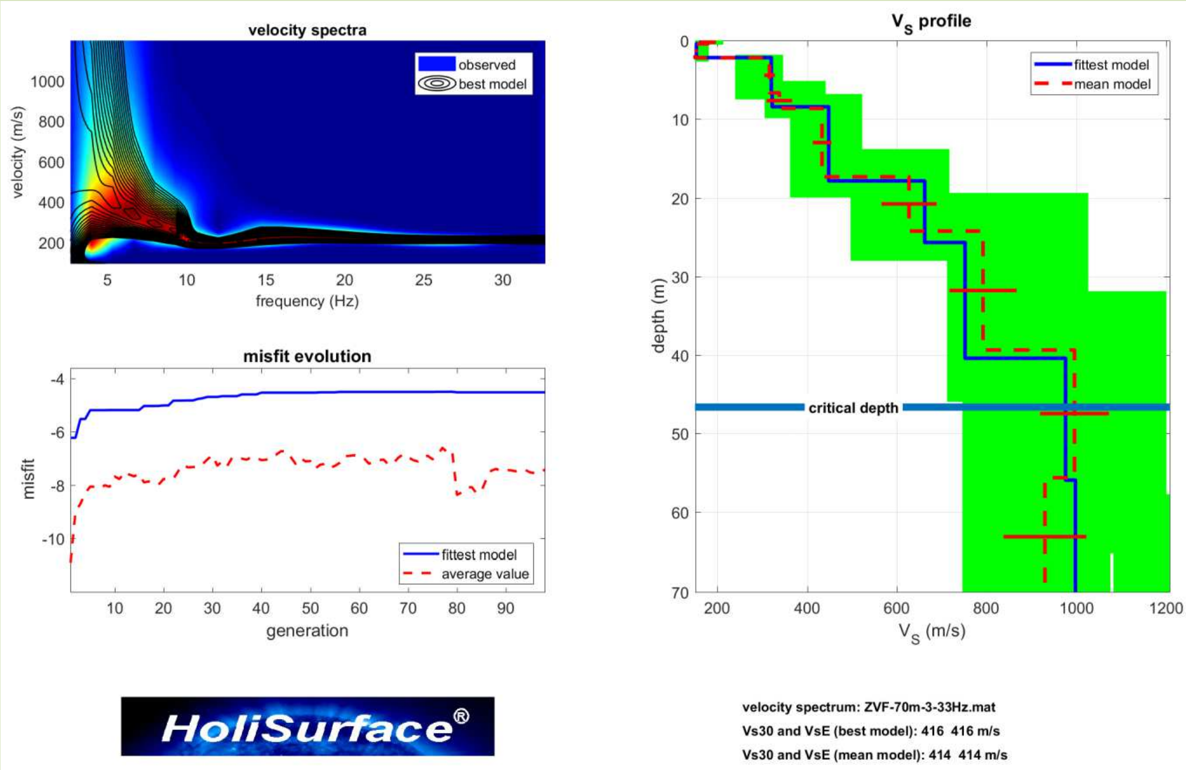
3. Carefully set all the inversion parameters and then click the "RUN" button.

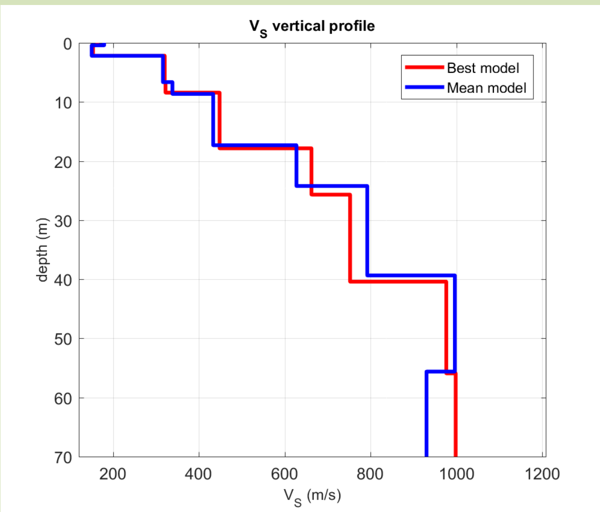
Once inversion has been launched, a "status bar" will appear showing the elapsed time and the remaining time:

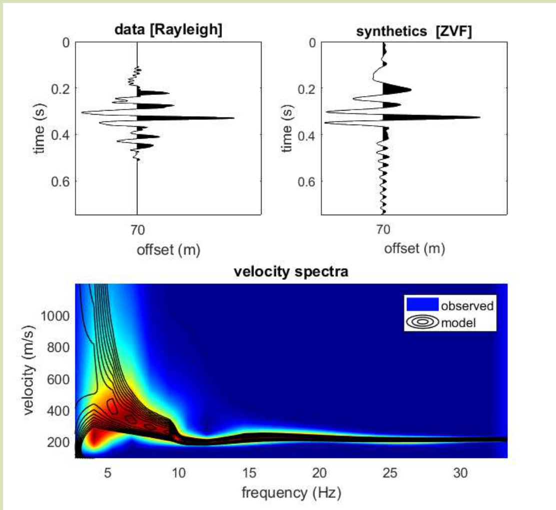
The inversion procedure is complete when the following window appears:

At the end of the inversion process, a series of outputs (automatically saved in the chosen output folder) will be created. Among these files you will notice the report file with .html extension that will open automatically in your browser.

some outputs







Critical depth

In the graphs showing the V_S profile as a function of depth, a "*Critical Depth*" is also indicated.
This indicates the depth beyond which the determined V_S values can no longer be considered sufficiently constrained and clearly depend on the offset adopted during acquisition.
In practice (and in a necessarily semi-quantitative perspective), if you have carried out all the operations correctly, the V_S profile that can be determined by means of automatic *HoliSurface®* inversions is to be considered reliable up to a depth of about 2/3 of the offset considered. Beyond this depth and up to a depth equal to the offset used, the V_S values are to be understood as "approximate" in relation to the precise V_S value. However, it is nonetheless of a certain relevance in relation to the identification of a possible strong leap of V_S.
An example will clarify the concept.
Let us assume that we performed a *HoliSurface®* acquisition with an offset of 50 m at a site where a 40-metre sedimentary cover is present above a massive *bedrock*.
Two-thirds of 50 m is 33 m.
The final result of this situation will be that through the analysis of the active *HoliSurface®* data we will be able to "feel" the presence of the *bedrock* (and we will be able to identify the approximate depth), but we will not be able to precisely define the V_S value which, on the other side, will be defined by also considering the HVSR curve - see the *Holi-Inversion (3C)* panel.

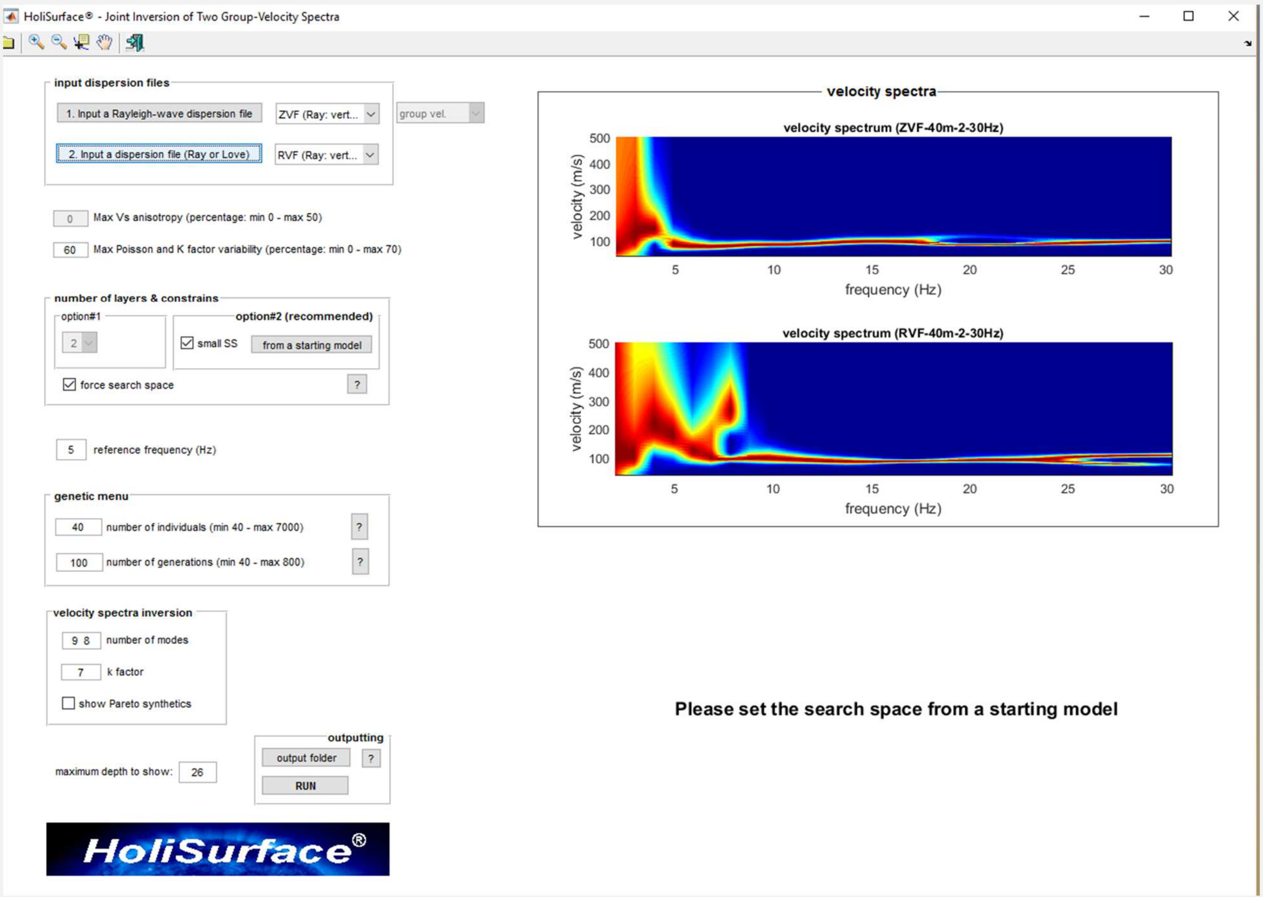
7.2 2C inversion module (joint inversion of 2 components)

Module for the joint inversion of the velocity spectra of group 2 components selected from ZVF, RVF, REX, ZEX and THF.
This module is aimed at the joint inversion of two previously-saved group-velocity spectra. A very useful approach for reconstructions of the most superficial part of the ground (approximately up to about half of the adopted offset), for example for geotechnical purposes.

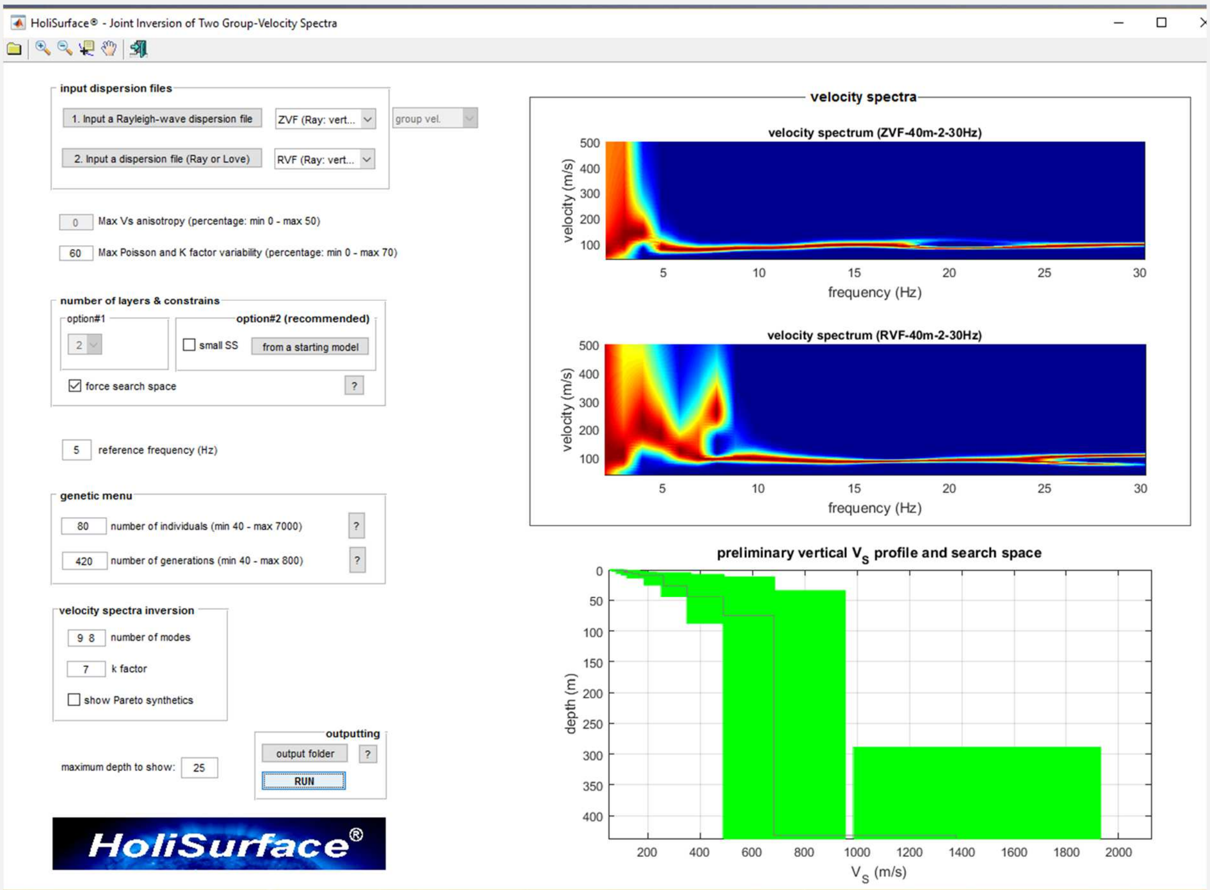
Below is an example of ZVF+RVF joint inversion (joint inversion of group velocities with respect to both the *vertical* and *radial* components of the Rayleigh wave).

Sequence of operations to accomplish:

1. upload the two (previously-saved) group-velocity spectra



2. Set the search space from a previously assessed/modeled model (to be considered as starting model) in the data loading, cleaning, and direct modelling panel.

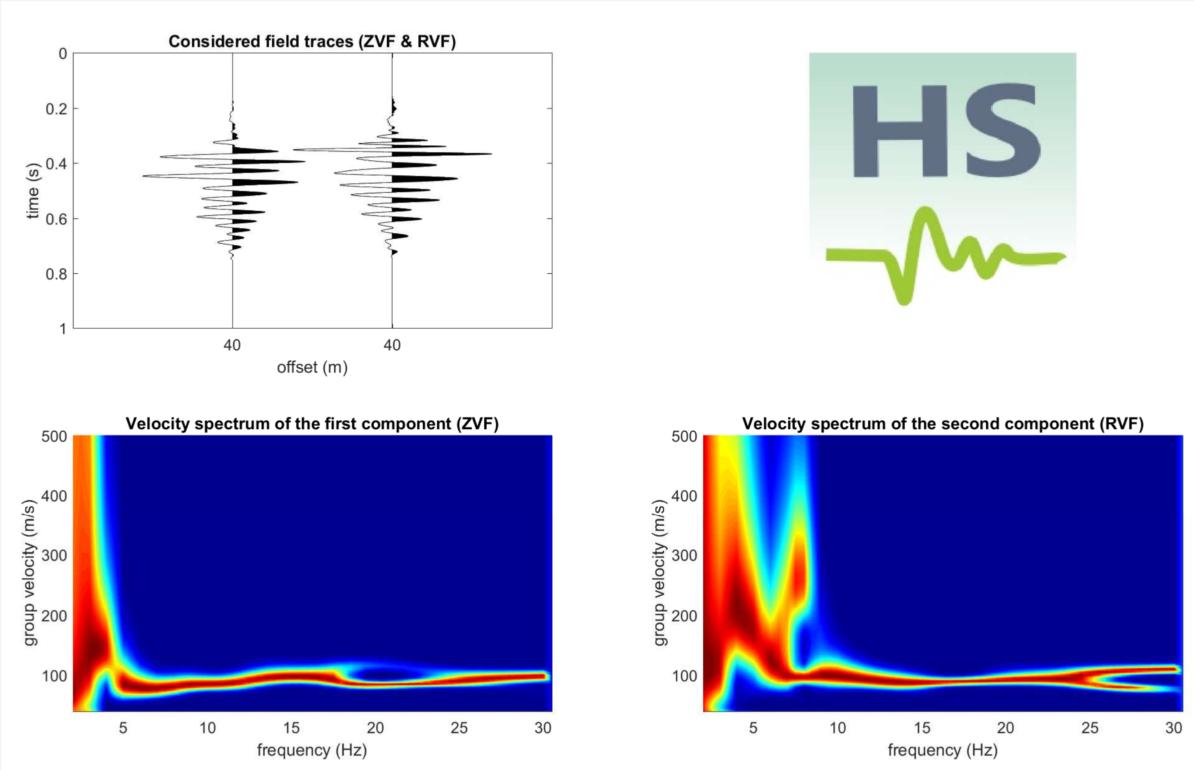


3. Set the number of models and generations to consider (the time needed to perform the inversion depends on these 2 values and on the power of your PC - CPU in particular - see recommendations on "system requirements")

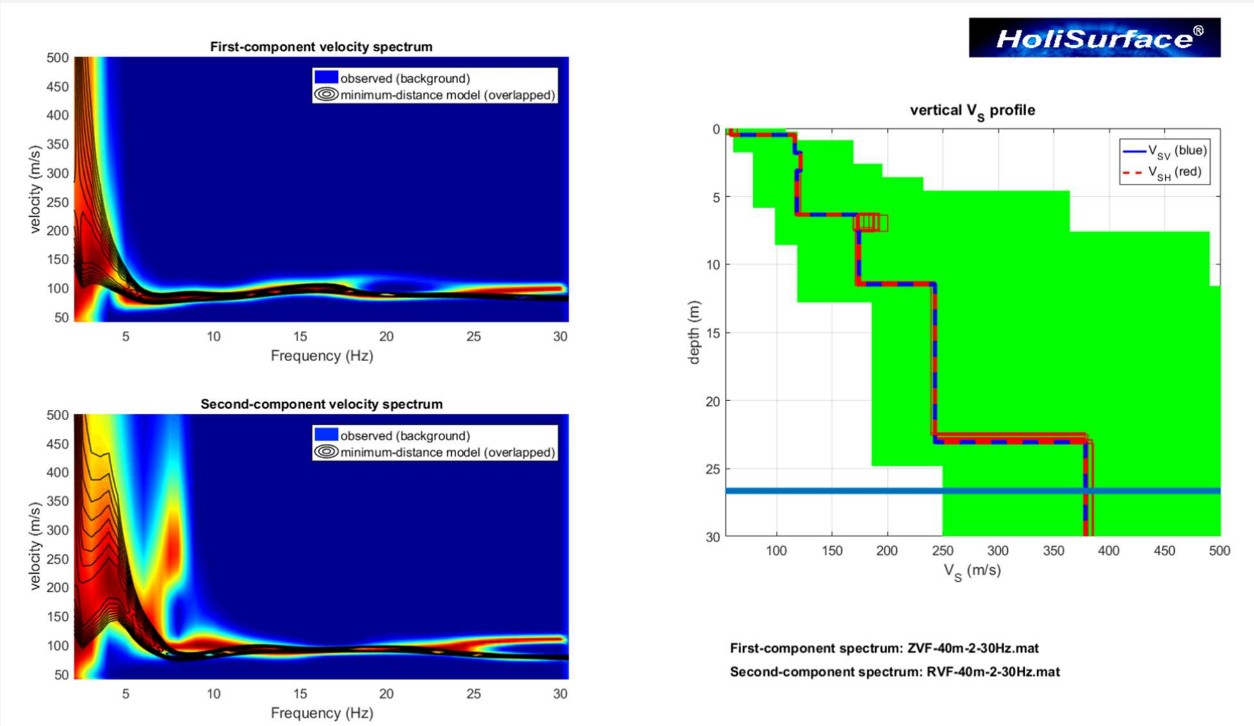
4. Set the depth to which we want to show the result (Vs profile), remember that - if the data have been taken and pre-processed correctly - for this kind of inversion, the V_S values are reliable indicatively up to about half or 2/3 of the *offset*.

5. Run the inversion (RUN).

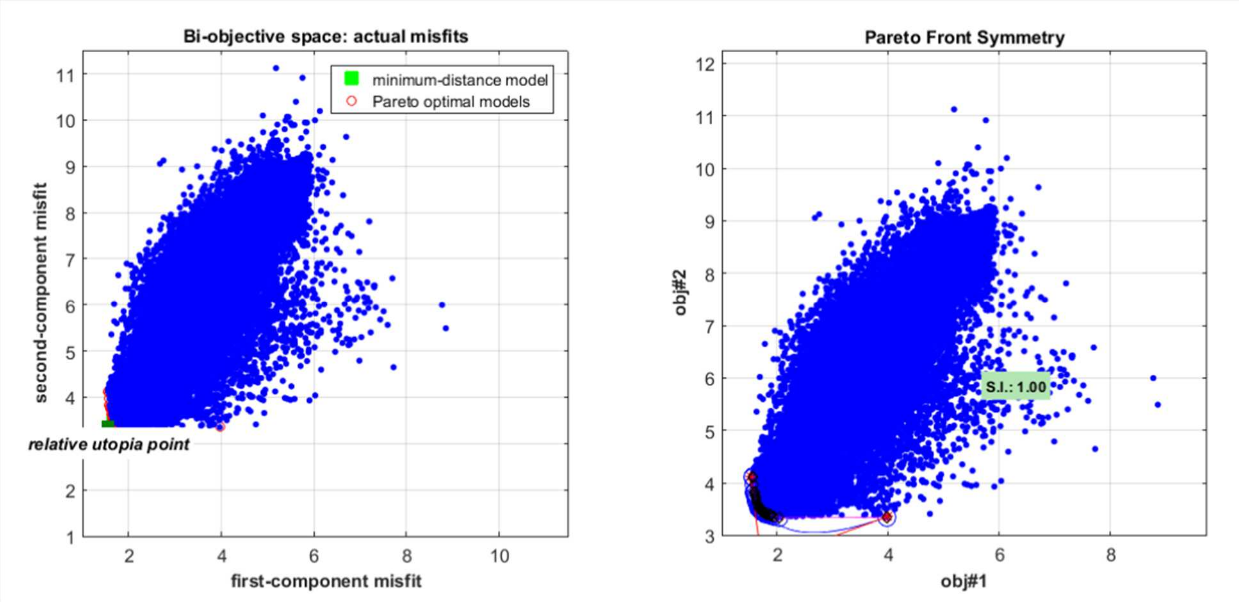
Here an example of the output eventually obtained:



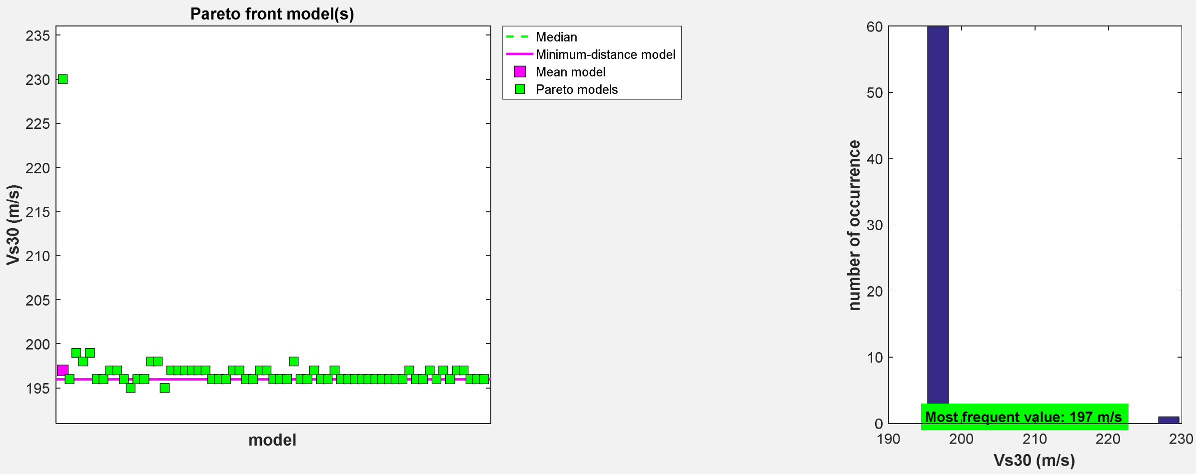
Summary of the considered data (components Z and R)



Main panel summarizing the results.



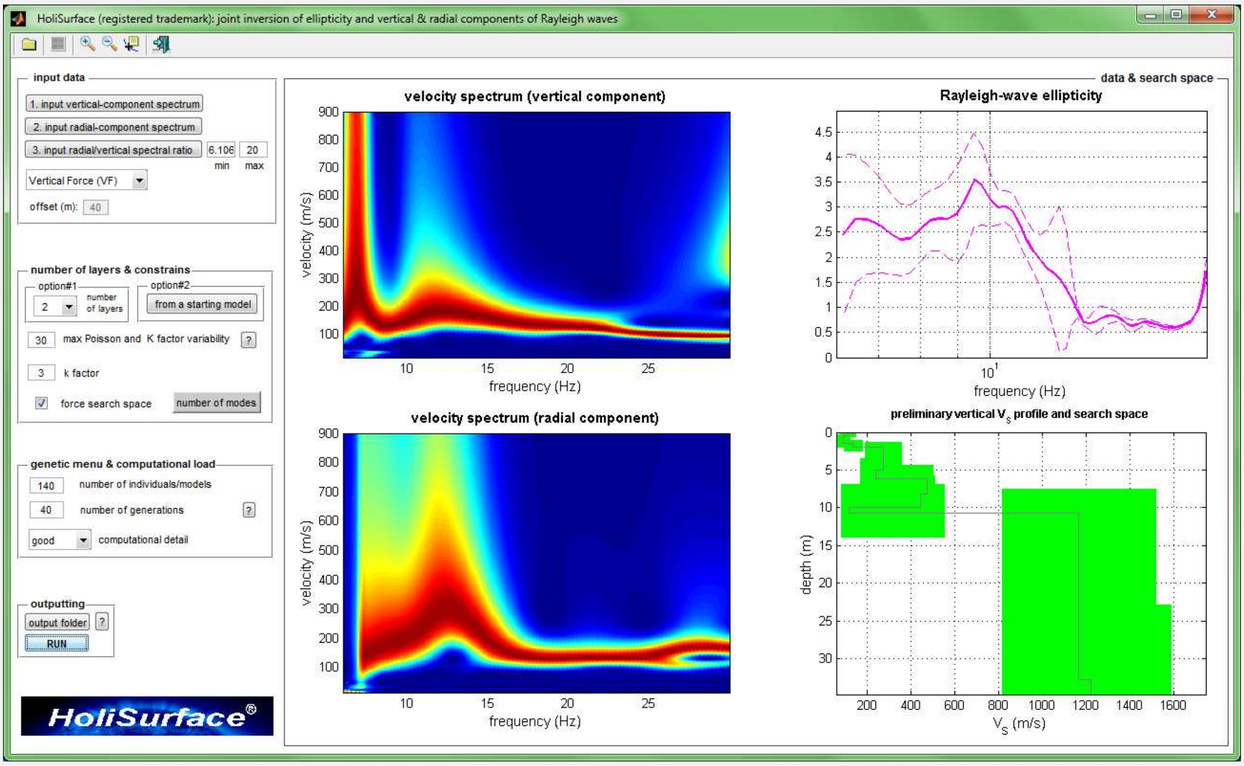
Distribution of models in the bi-objective space (good symmetry).



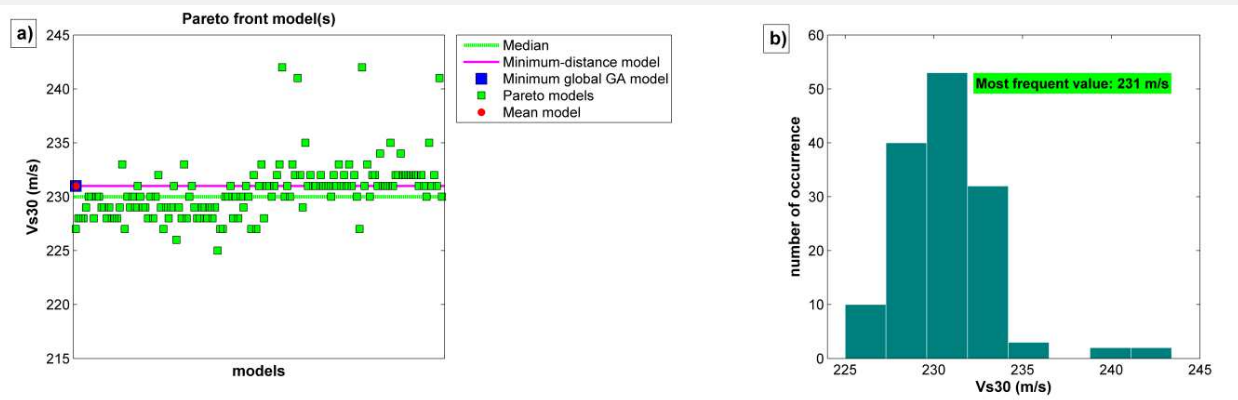
Statistics on Vs30 values of Pareto front symmetry models.

7.3 Holi Inversion (3-obs inversion): joint inversion of 3 observables

In this module, the radial and vertical components of the Rayleigh waves are inverted together with the RVSR, the RPM or the HVSR curve. The recommendations/precautions are obviously the same as those of the "*Joint Dips. - RVSR*" module.



Screenshot with the three observables considered in this inversion: group-velocity spectra of the Z and R components + HVSR

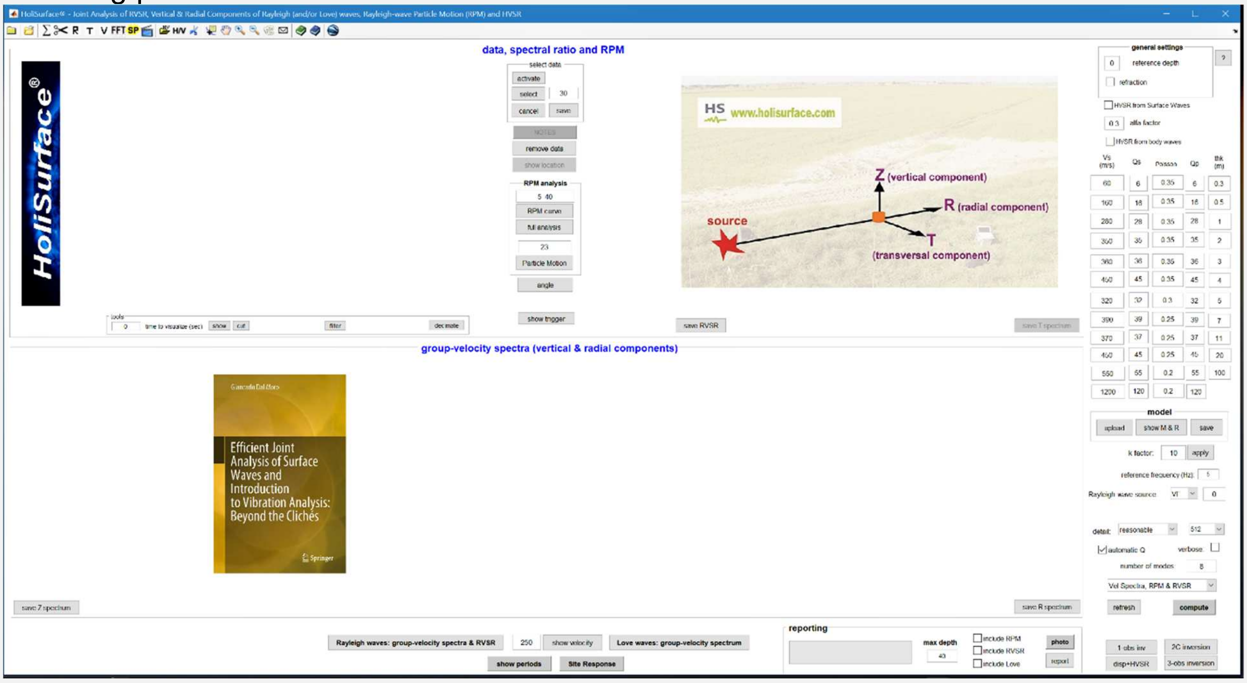


7.4 An example of data processing for the joint inversion of three observables while considering just active data [Z + R + RPM]

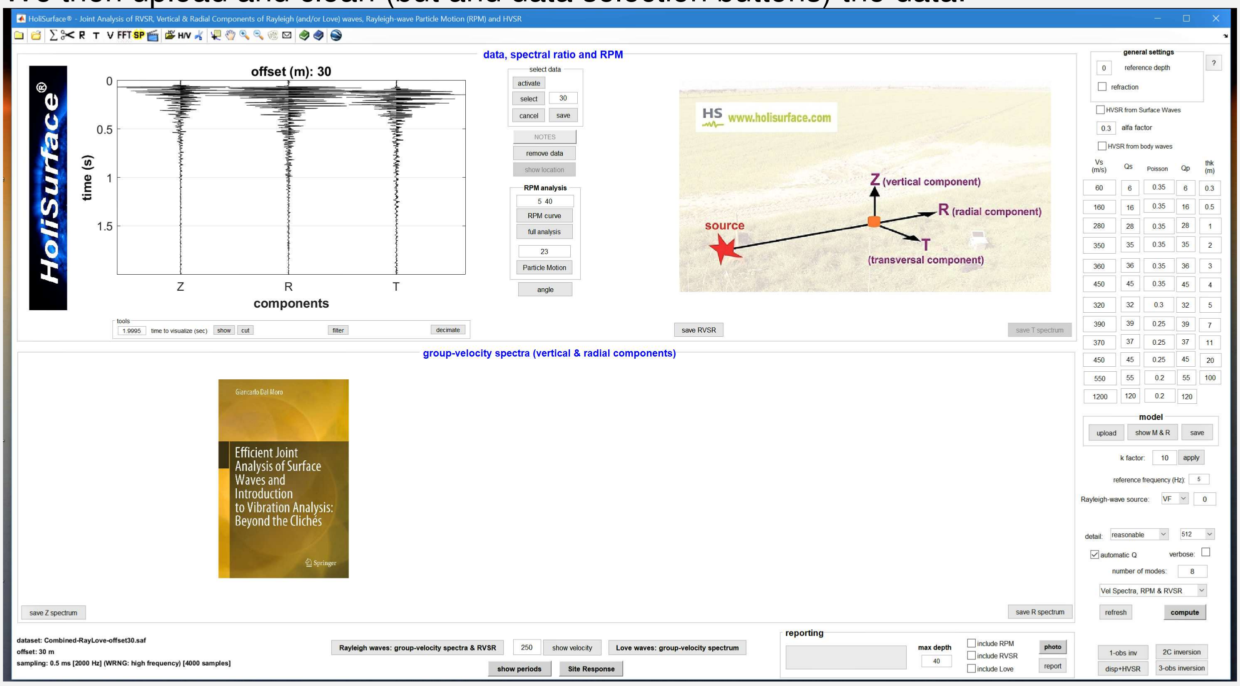
In this section we consider the upload, pre-processing and automatic joint inversion of purely-active data: the two Rayleigh-wave components [i.e. the group-velocity spectra of the Z & R components] and the RPM curve. Of course we assume that data were properly recorded [RPM curve is correct only if our acquisition system is explicitly tested for it].

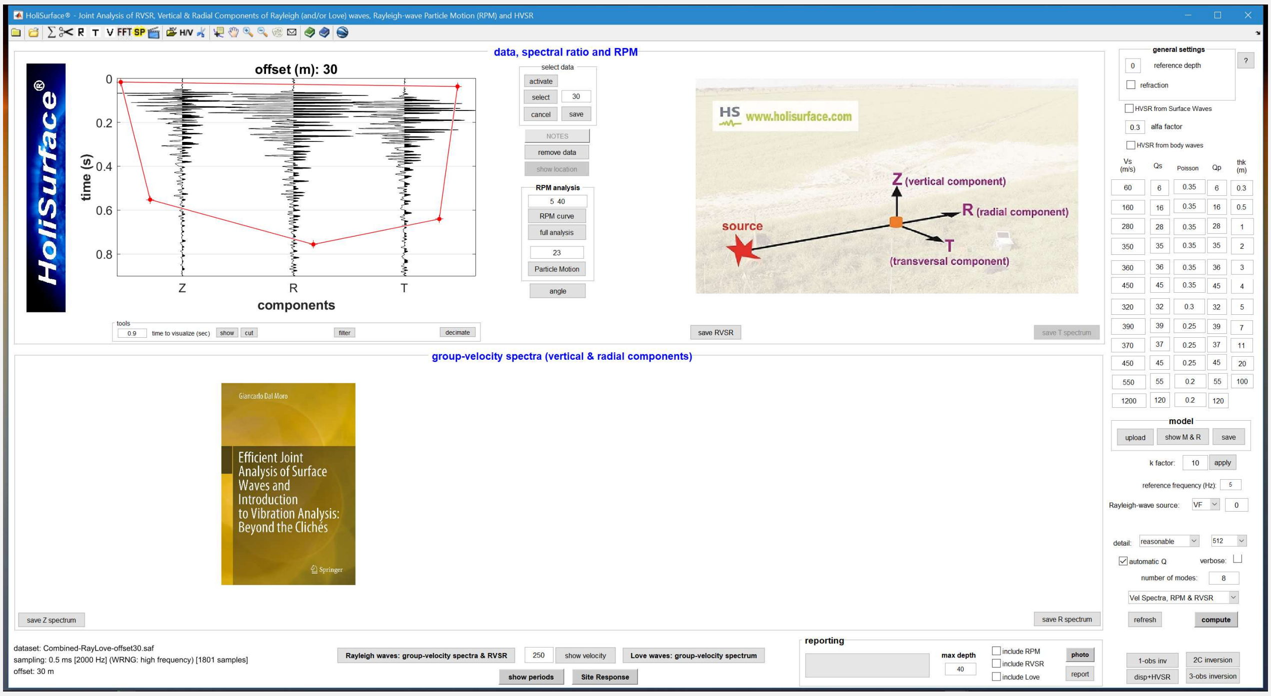
step#1: data upload and cleaning

From the main panel of the software, we click the "HoliSurface" button so to open up the following panel:



We then upload and clean (but and data selection buttons) the data:

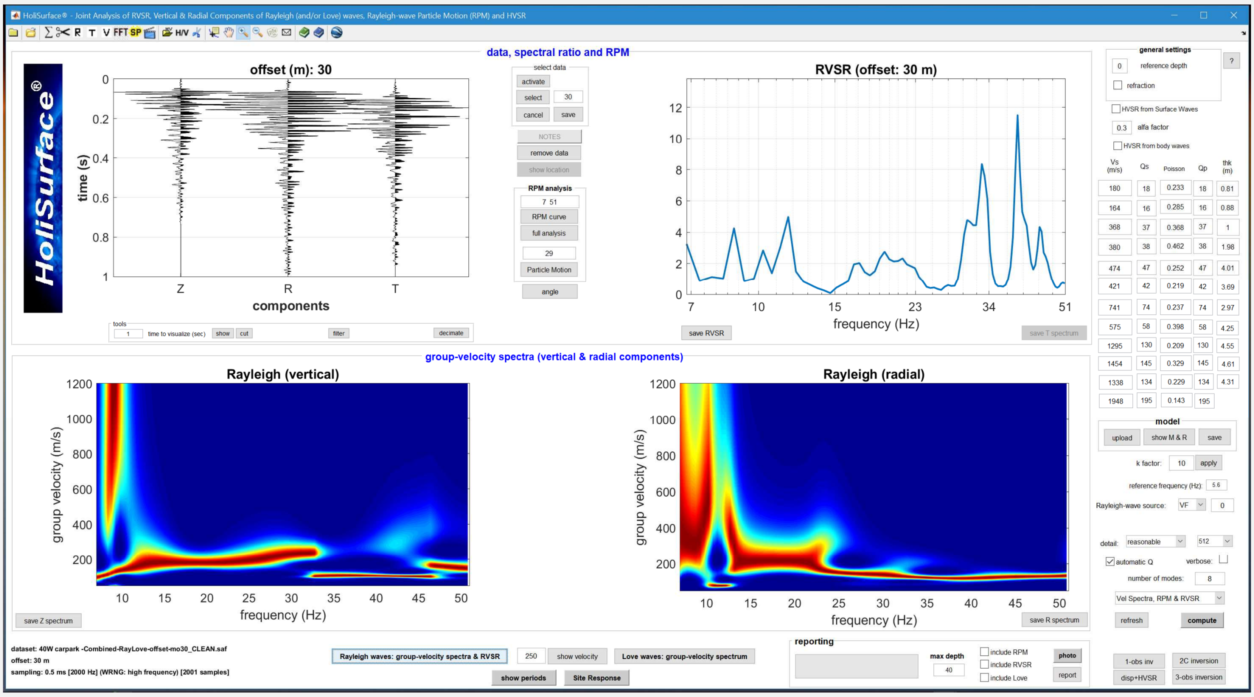




step#2: group-velocity spectra computation

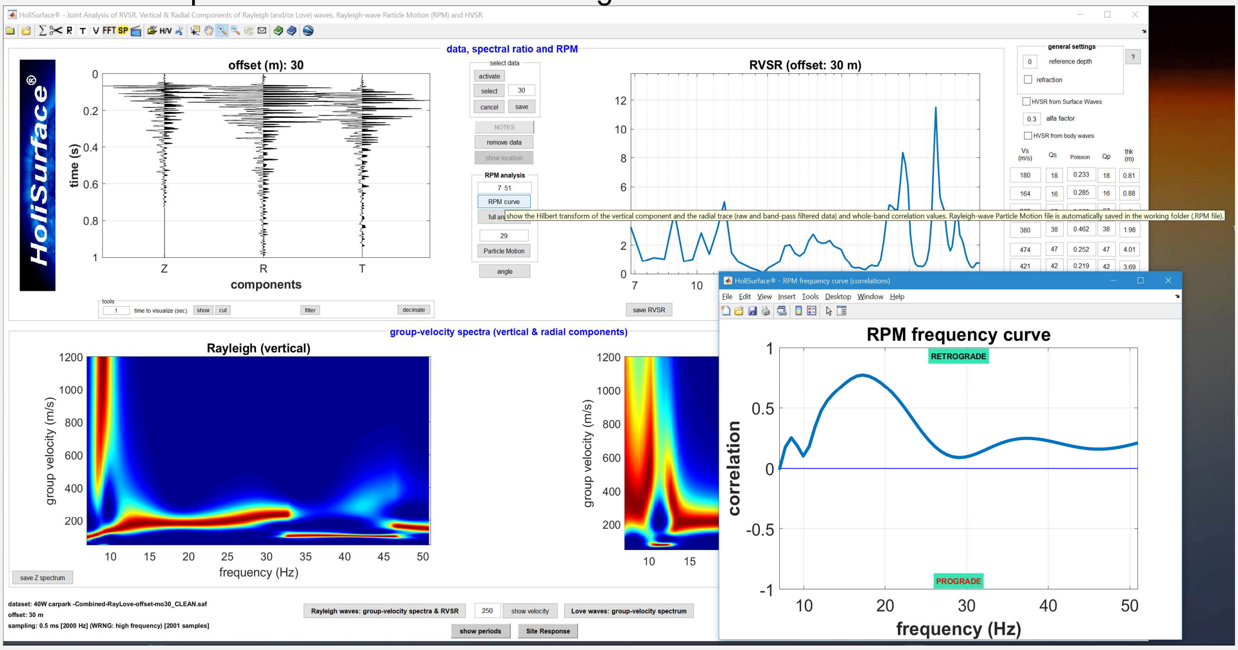
Now, we can compute the group-velocity spectra of the two components we intend to consider (in this case the Z and R components, i.e. just Rayleigh waves) ["Rayleigh waves: group-velocity spectra & RVSR" button in the central-lower part of the panel].
Please, consider that

1) It is important to properly choose the frequency and velocity ranges that are appropriate for the considered site/data [this is possible by carefully considering the theoretical aspects of the dispersion analysis];
2) In this case we are not going to work with the RVSR curve [see next step].



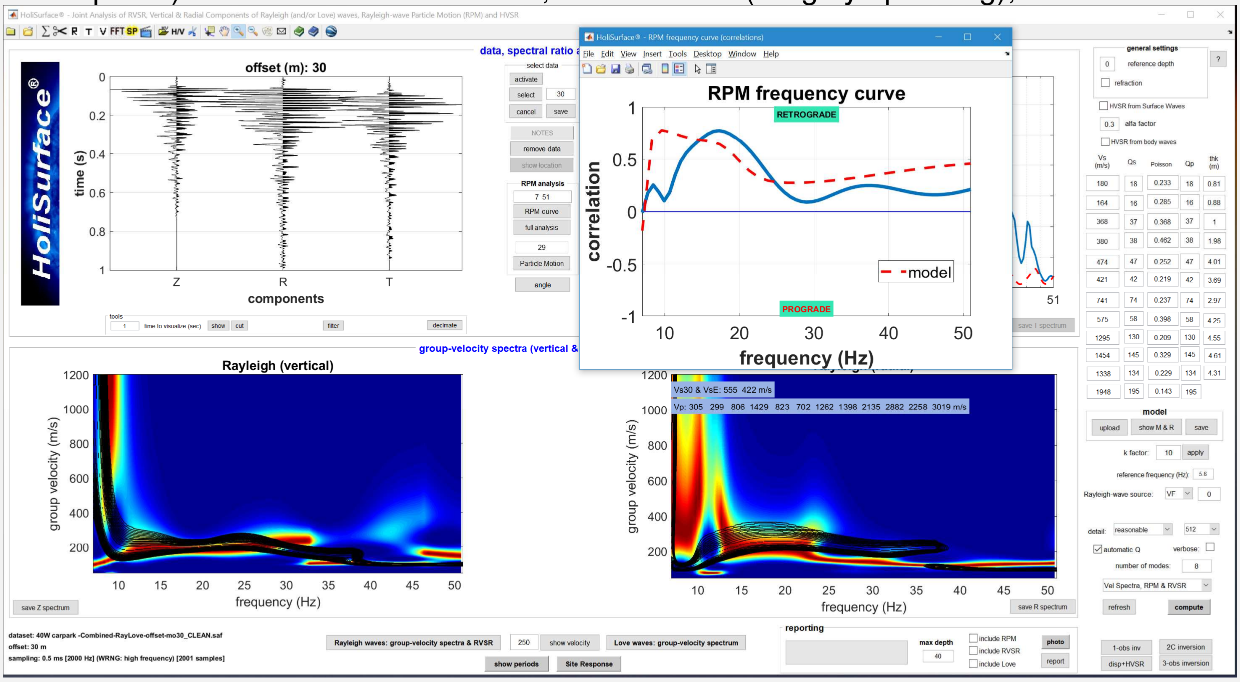
step#3: RPM computation

We then click the “RPM curve” button in the “RPM analysis group” more or less at the center of the panel and obtain the following outcome:



step#4: some preliminary modelling

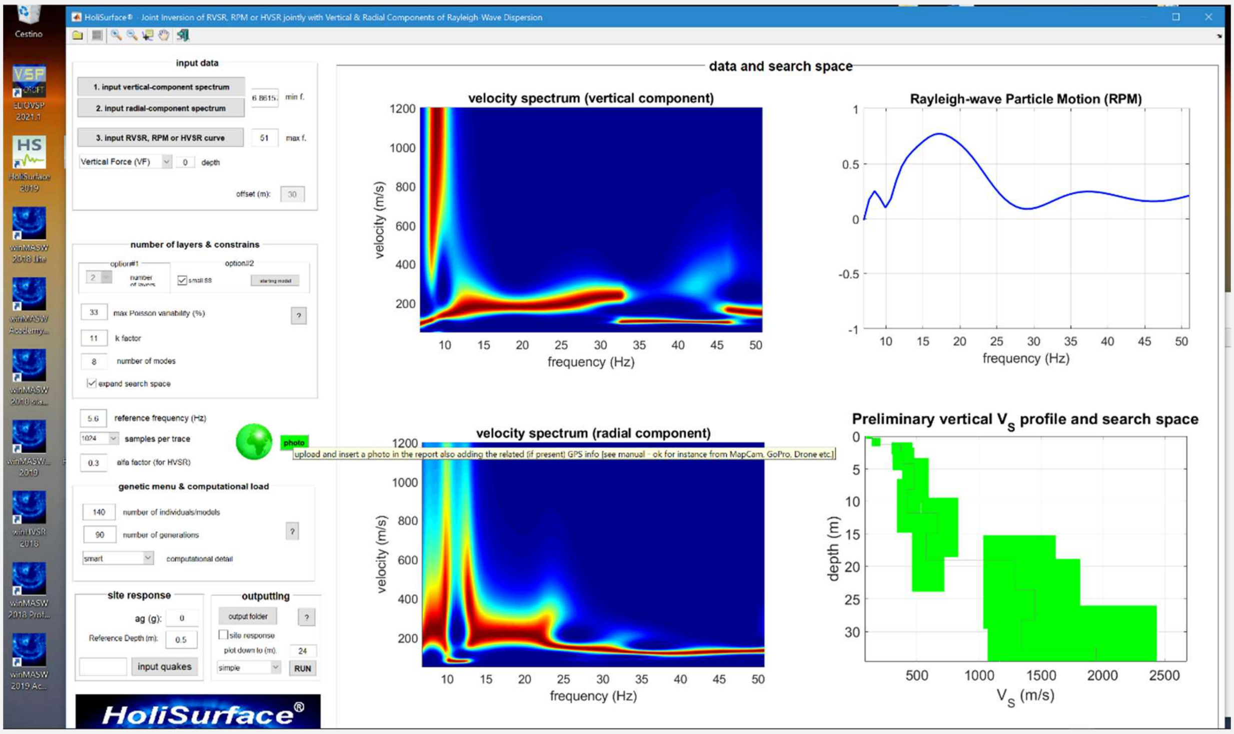
The 3 observables we intend to analyze (and invert) are now ready and we can do some forward modelling (i.e. variation of the Vs and thickness values listed along the right part of the panel) so to obtain a model that, more or less (roughly speaking), fits the data:



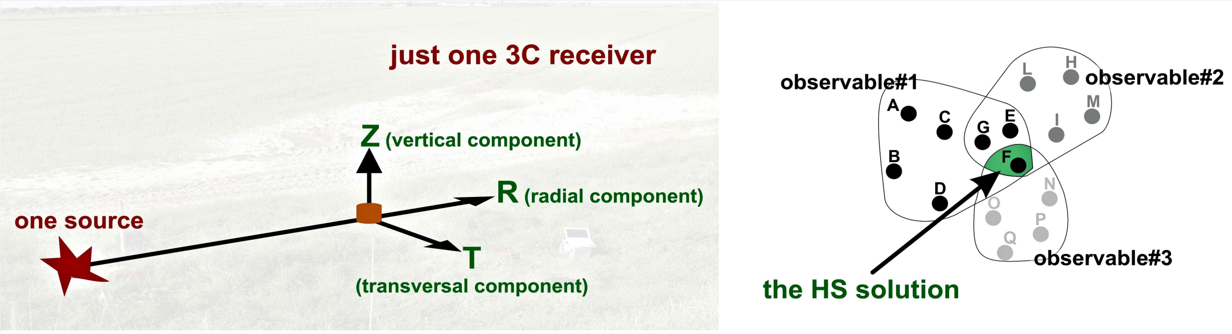
As you can see, the synthetic data (i.e. the model) is not too far from the field data but still not perfect.

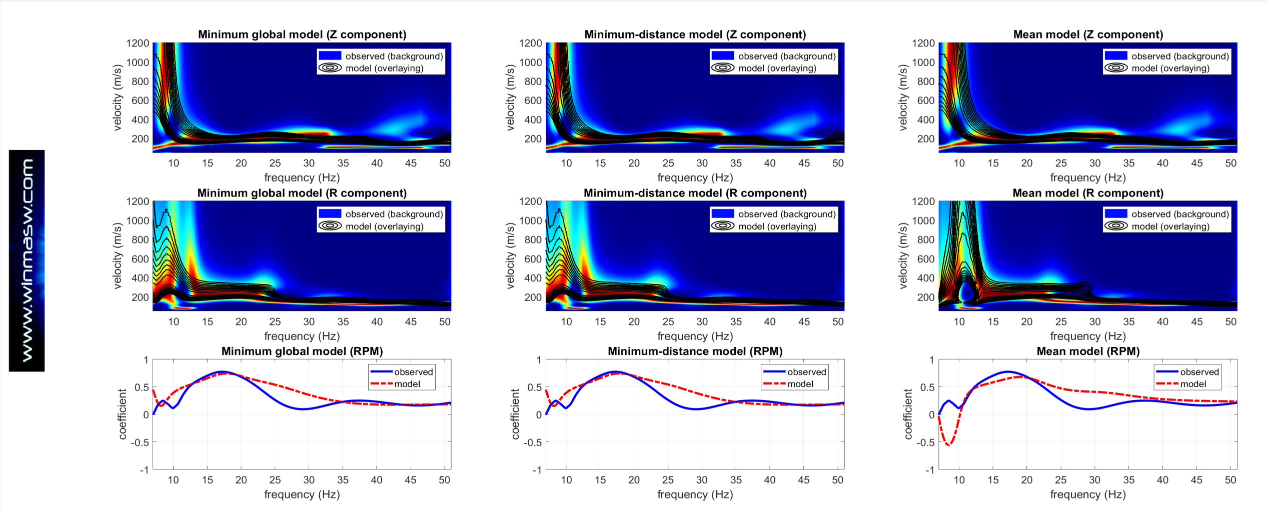
In order to improve the solution we click the “3-obs inversion” button (lower-right corner) and open up the automatic-inversion panel.

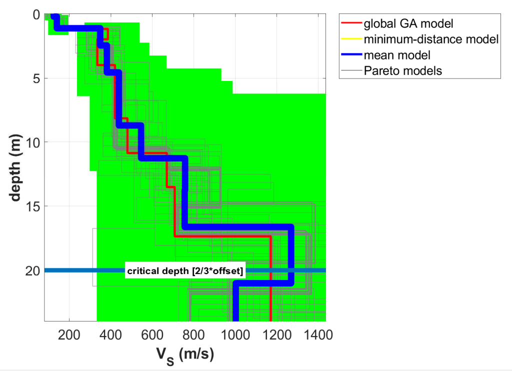
step#5: automatic 3-observable joint inversion

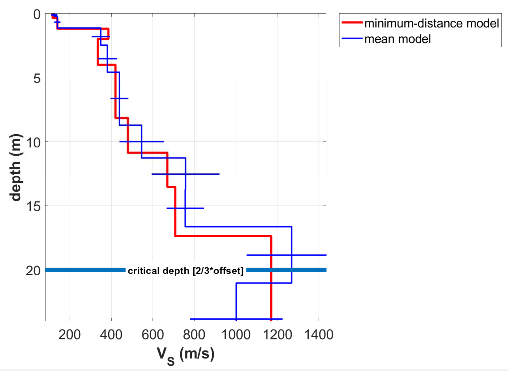


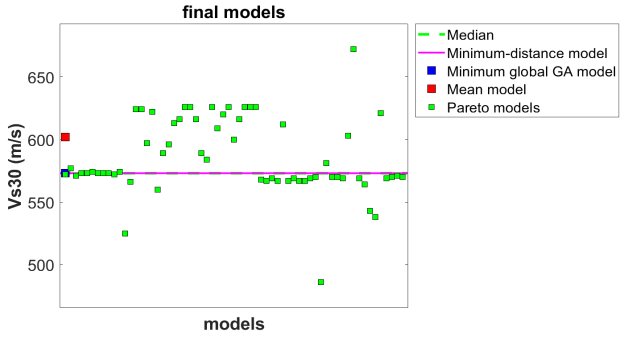
We must now set up the inversion parameters (that depend on several aspects – see the section about the details of this panel) and launch the inversion process ("RUN" button). In the following an example of outcome obtained for this dataset (all the figures and the report is automatically saved in the output folder):

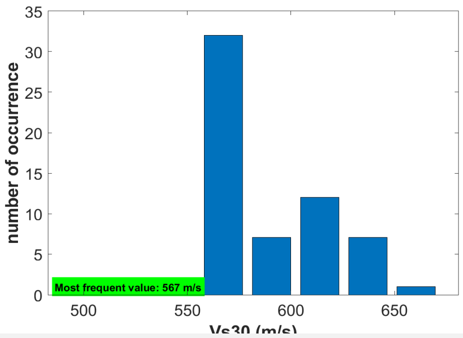





global GA model
minimum-distance model
mean model
Pareto models
critical depth [2/3*offset]
depth (m)
V_S (m/s)


minimum-distance model
mean model
critical depth [2/3*offset]
depth (m)
V_S (m/s)


final models
Median
Minimum-distance model
Minimum global GA model
Mean model
Pareto models
Vs30 (m/s)
models


Most frequent value: 567 m/s
number of occurrence
Vs30 (m/s)

8. Few recommendations

<u>Tip #1</u>: Number of models and generations

The number of individuals and generations to be adopted must be proportional to the effort required to identify a good solution. These parameters must therefore go hand in hand with the number of layers adopted (more layers = greater degree of freedom of the system = greater computational effort) and the dimension of the "seach space" (the larger the search space, the larger the computational load).
The *search space* to be adopted can be set by the user based on the available geological information (and considering the V_S for the most common lithological types).
On the other hand, users with a deeper understanding of the velocity-spectra behavior (and the HVSR) can easily understand the approximate V_S values directly from the velocity spectra (and the HVSR curve).

<u>Tip #2</u>: search space

The search space has to be fixed on the basis of the geological knowledge of the site. If these are limited, it is necessary to fix a wide search space and a large number of individuals/models and generations.
The "expand search space" option allows the software to search solutions even outside the search space initially fixed by the user.

<u>Tip#3</u>: get familiar with the method, its potential and its limits

Upload one of the datasets we provide to train yourself and compute the velocity spectra. Try to model the observed data by changing the model parameters in the "direct modelling" section. Modify one parameter at a time and verify how the dispersion changes. What happens if you increase the depth of some fast layer? What happens when you insert a Low-Velocity Layer? What is the relationship between the V_S of the layer, its depth and the obtained velocities?
These kind of exercises (forward modelling) are very helpful to become familiar with the actual sensitivities of surface-wave analysis.

<u>Tip #4</u>: number of layers to consider

Compared to phase velocities (MASW, ReMi, ESAC, SPAC and MAAM tecniques), <u>group</u> velocities are typically more sensitive to variations of the V_S values.
This is both a good opportunity and a "problem": an opportunity because with just one trace/channel we can have a valuable "object" (velocity spectrum) for our analyses; a "problem" because its FVS analysis requires a significant computational effort (which is why it is important to work with computers with <u>excellent</u> characteristics - see *system requirements*).
However, **<u>never</u>** use less than 4 layers (not even when you think you are dealing with a 2-layer geological situation): even the most seemingly-trivial site is certainly (from a seismic point of view) more complex.

9. HVSR: analysis, modelling and inversion

Analysis: HVSR computation

The few parameters to be set are clearly readable (see also SESAME, 2005): if you are not sure of the value and weight of the parameters involved, it is worth attending a few workshops; of course, this tip applies to any method you decide to use.

The basic format used is the official SESAME project format (SAF = *SESAME* ASCII data format) but you can also upload seg2 data/files.

SAF data format/file

The SAF format (*SESAME* ASCII data format) is an ordinary ASCII file that can be opened with any word editor.

The *winMASW®* and *HoliSurface®* software assume that the 3 columns represent respectively:

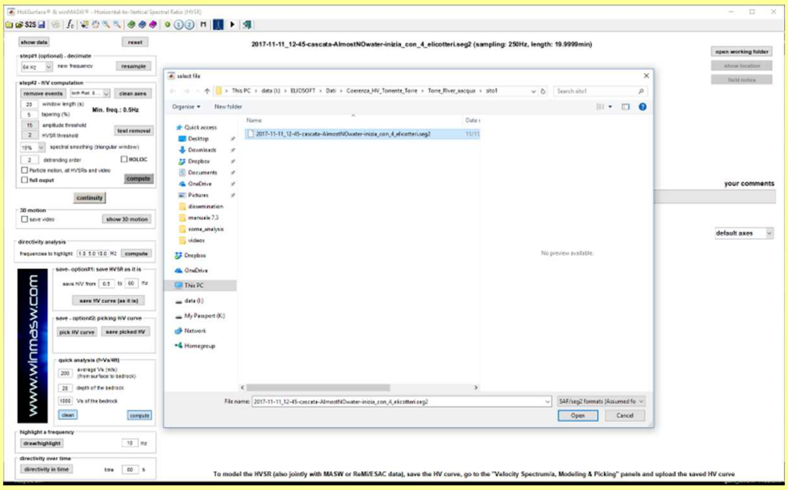
first column: vertical component
second column: NS component
third column: EW component

by the way, while uploading the data you can specify any other possible format/sequence.

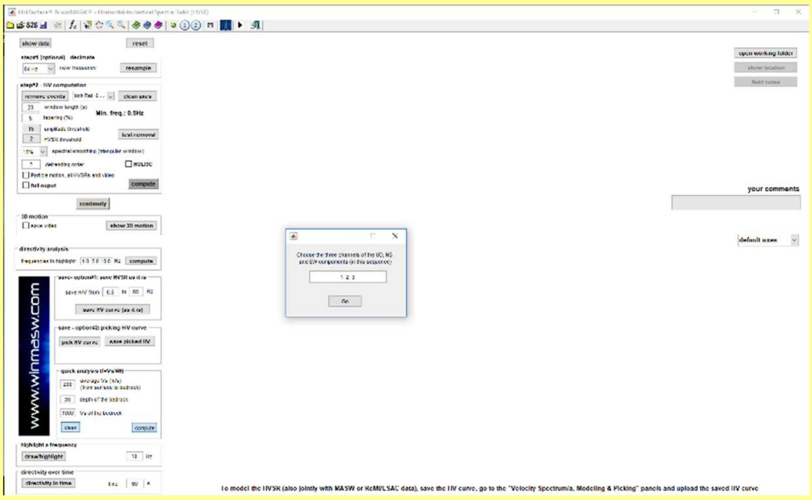
Moreover:
Two parameters are by the *header*:
the sampling frequency (“SAMP_FREQ =”)
the date (“START_TIME = ”)

As you can guess, it is absolutely necessary to have the sampling frequency ("SAMP_FREQ =").
On the other hand, the date ("START_TIME = ") is not a necessary parameter and in case of its absence a simple "warning" will be displayed that lets you proceed with the analysis anyway.

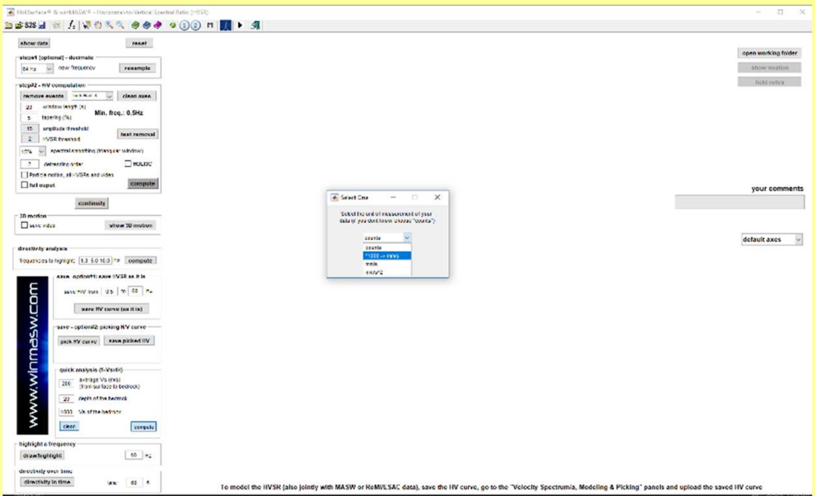
Reading SEG2 data



Open/select the file (seg2 format)

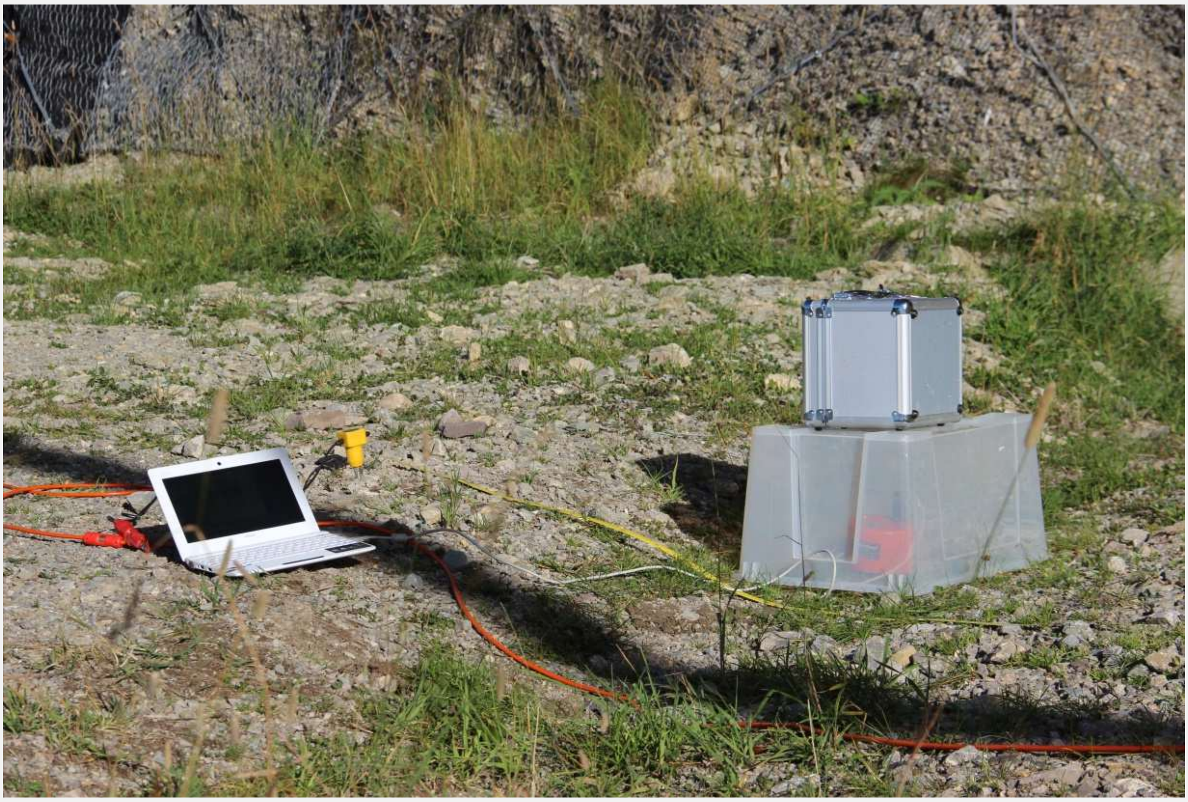


Define the sequence of channels containing, in order, the UD, NS and EW components



Define the unit of measurement of the data (if you are using our *HoliSurface®* acquisition system following the correct acquisition procedures, select the option highlighted in the snapshot above and you will get the data in mm/s).

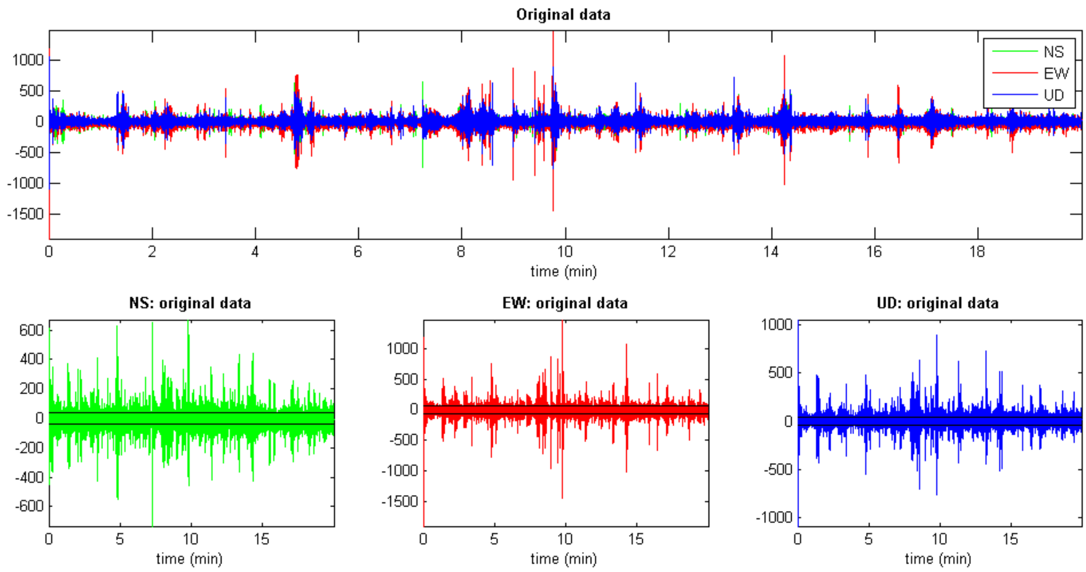
Protecting the 3C geophone against the wind



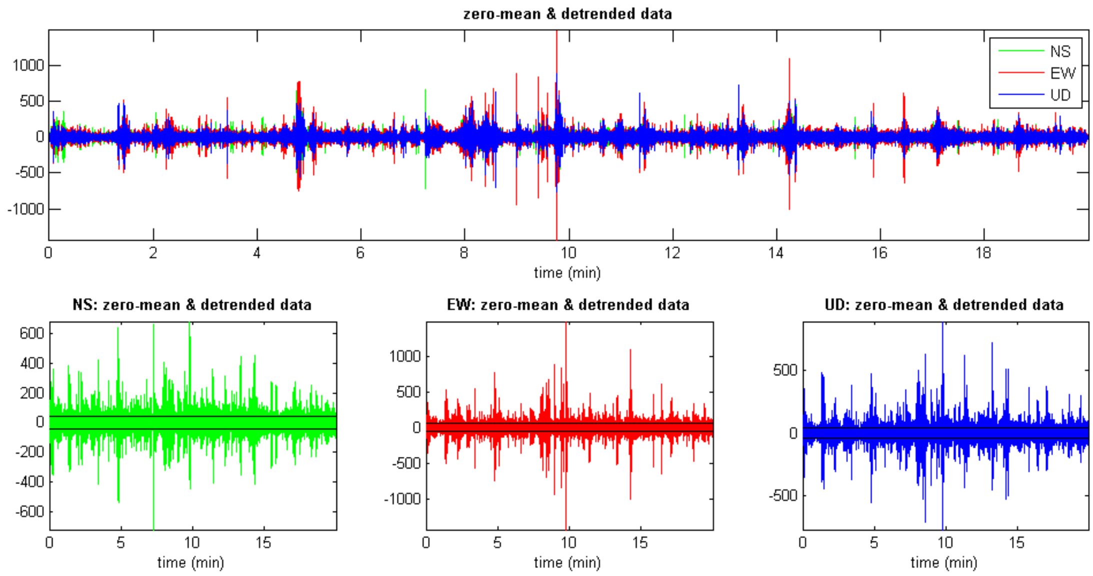
Data display

If the option "*show data*" is activated, the following 2 windows will be shown.

Original data



Data after basic processing (zero mean and de-trending)



"Show location" button

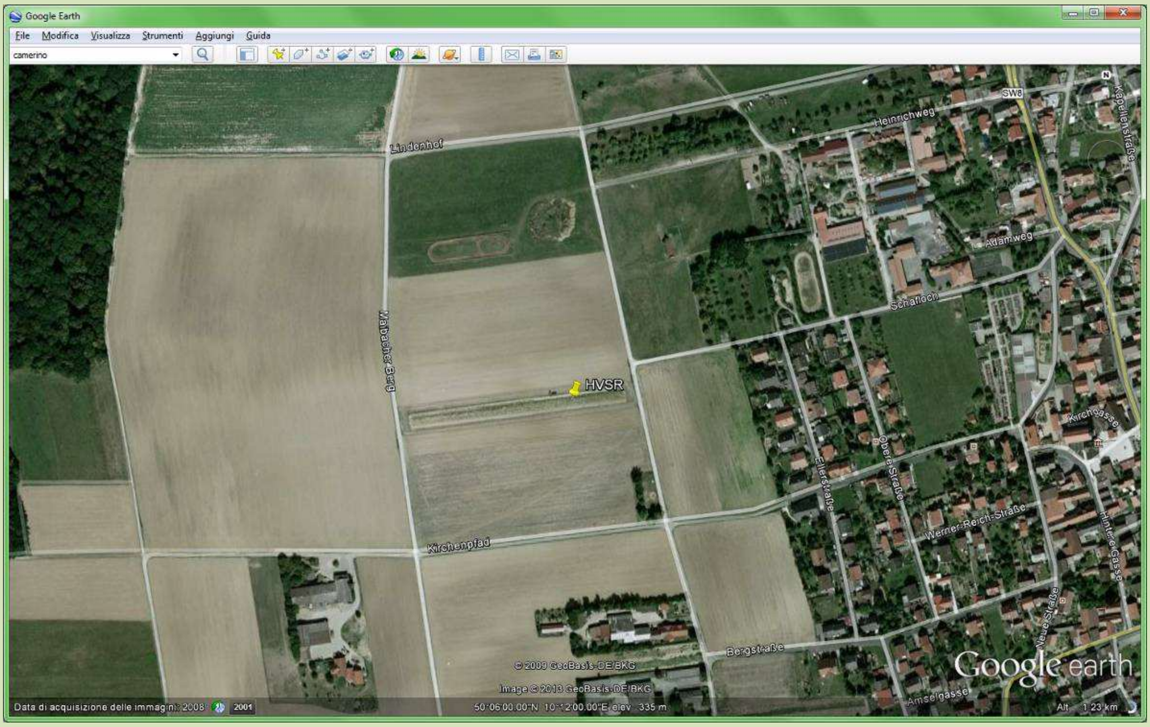
If you have a GPS-equipped 3-channel geophone, you can now view the location of the measurement on *Google Earth* (which clearly must have been installed beforehand) with a simple click.

Geographical data are those indicated in the SAF file (according to the SAF format) in the fields EVT_X (longitude), EVT_Y (latitude) and EVT_Z (altitude)

Example of geographical data in the SAF file:

EVT_X = 10.2
EVT_Y = 50.1
EVT_Z = 0

If these data are present, the "show location" button is activated and it is therefore possible to quickly and automatically obtain a screen like the one shown below



To find out if your 3-channel geophone (and the related acquisition software) are equipped with this option, consult the manufacturer of the 3-channel geophone.

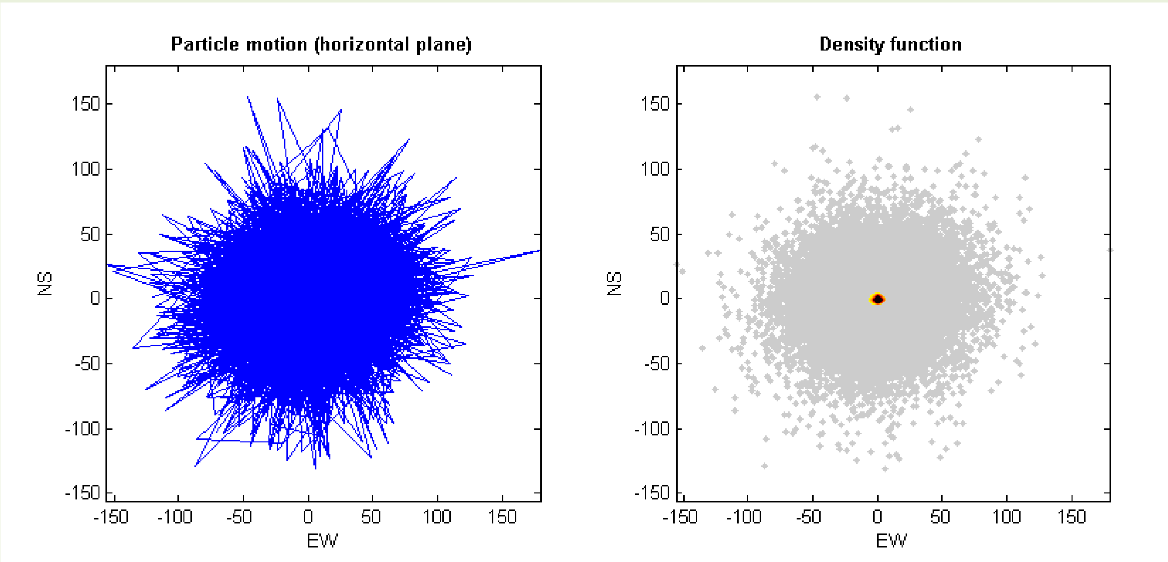
Sampling and re-sampling

What are the most interesting frequencies from a geological and engineering point of view? Generally speaking, from 0.5 to 20 Hz.
Since it is necessary to sample at least twice that frequency in order to identify a certain frequency, it goes without saying that by sampling a signal of at least 40Hz we should be able to bring home sufficiently detailed data for the main geological purposes.
A series of other considerations that cannot be made here in full suggest acquiring at least 128 Hz.
According to some, it is even advisable to acquire data at even higher frequencies (256 or 512 Hz) and then resample them (decimate them) at a lower frequency.
In order to avoid unnecessarily large computation time, it is important to remove (decimate/resample) uselss data (we usually recommend to resample the data to 64 Hz).

For geological/engineering purposes, it is completely useless to analyze data at a sampling rate higher than 64 Hz: we strongly recommend **re-sampling at 64 Hz** - which still allows you to see up to 32 Hz (which is much more than what we actually need).

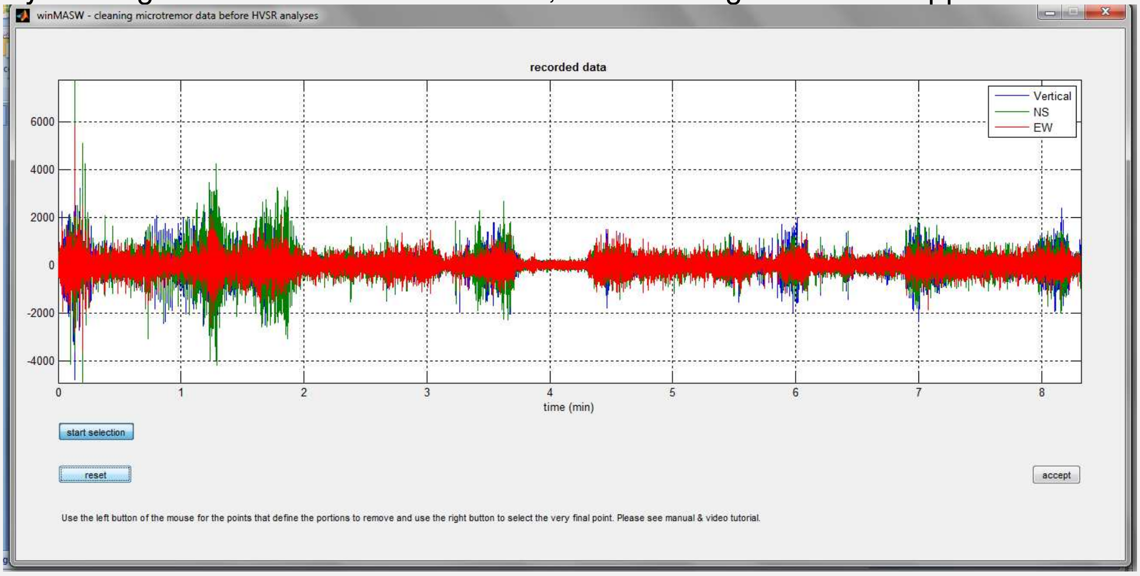
Particle motion

If the option "*show particle motion (of the original data)*" is selected, the plot of the soil motion will be obtained along the three sections *vertical-NS*, vertical-EW and *horizontal* (NS-EW) (clearly of the original data).

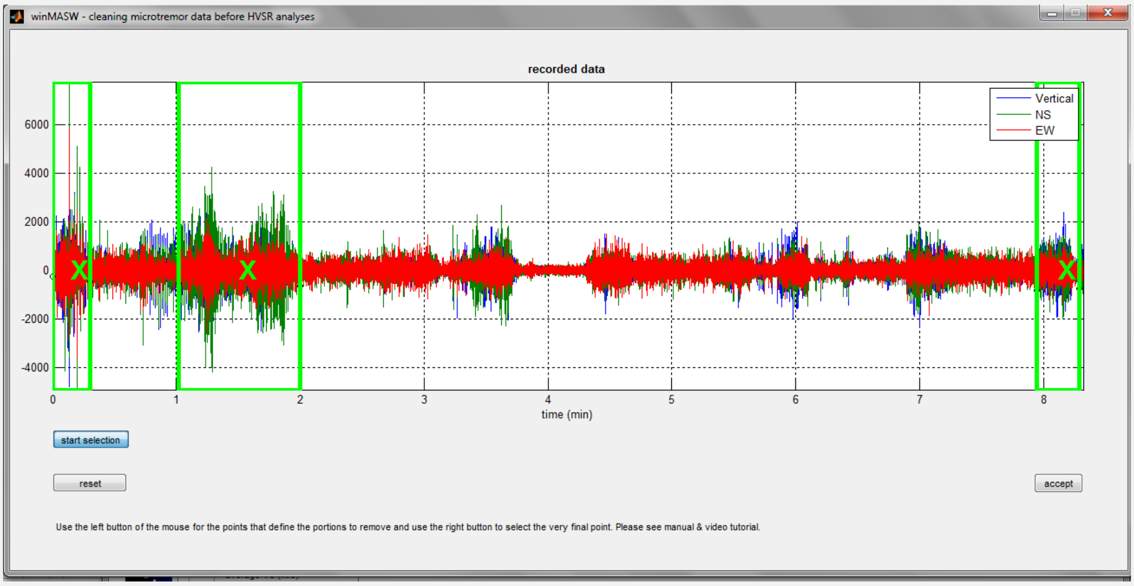


Removing events (transients) before calculating the H/V spectral ratio

By clicking the "remove events" button, the following screen will appear:

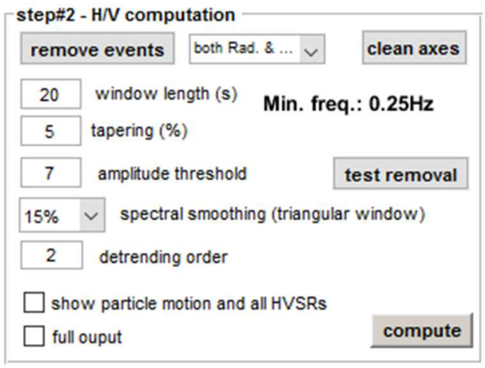


The user can now select specific events (signals) to be removed. To do so, click on the "start selection" button and use the left mouse button to define each point (note that each event is defined by a start point and an end point). To select the last point, use the right button. In the example below there are 3 selected events (to be removed). These events are clearly defined by 6 points. The first 5 must be identified using the left button and the last (in this case almost at the end of the dataset) with the right button.
If the selection works, we will click at this point the "accept" button to return to the main screen; otherwise we can make a new selection resetting the previous one ("reset" button).

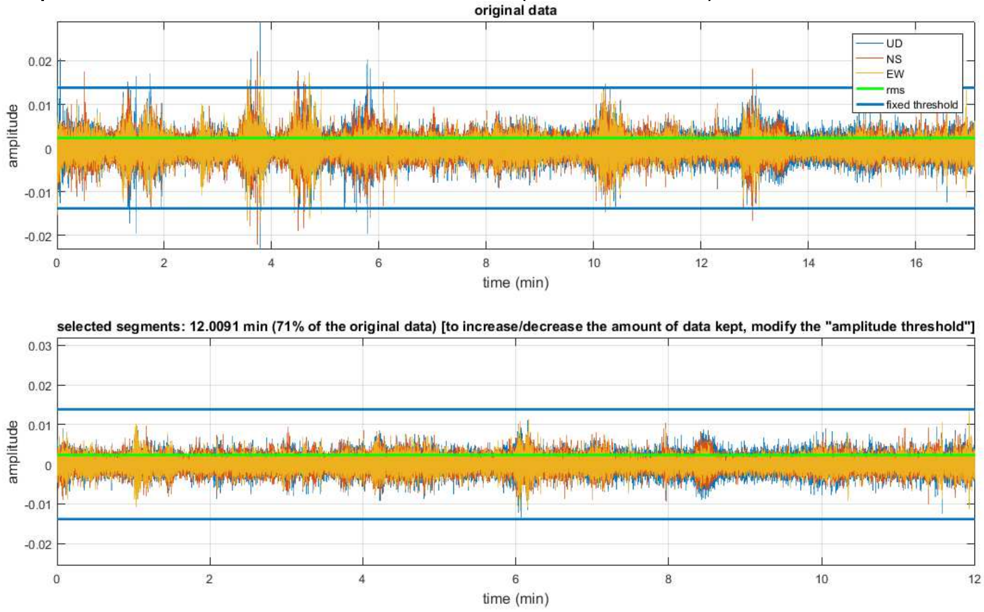


<u>Automatic</u> removal of events with amplitude above an amplitude threshold set by the user

Among the parameters to be set for HVSR processing, there is also the amplitude threshold used to automatically remove all those windows within which there are events with amplitude.
In summary, the root mean square amplitude of the traces is calculated and then multiplied by the amplitude threshold set by the user.
If a window contains an event with a larger amplitude, this window is deleted from the analyses.
Clearly, the lower that value, the more data/windows will be removed.



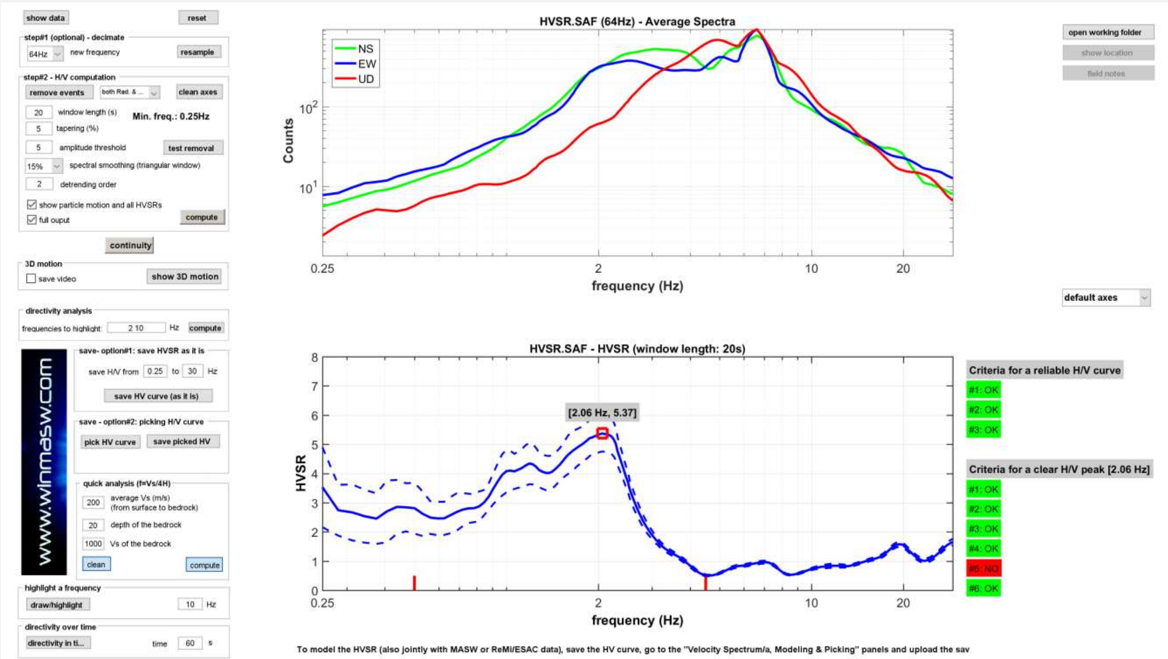
With the "test removal" button, you can check how this automatic cleaning of the data works and we can increase or decrease the automatic cleaning of the traces before proceeding with the final calculation (done by ticking the option "*full output*").
Below is an example of data before and after removing windows in which the amplitude exceeds the set threshold (see blue line).



Main panel

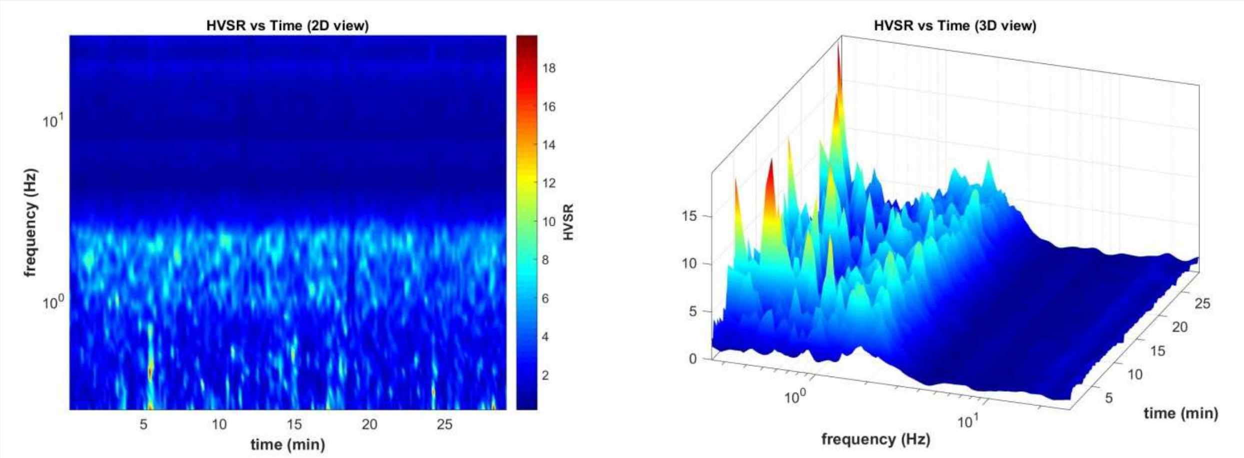
The screen is easy to read. As a first step, load the dataset you want to analyze (classic icon at the top left end of the toolbar).

Then set the various parameters as needed and launch the analysis with the "compute" button. Once the analysis is complete, the screen shows the spectra of the three components and the H/V ratio:



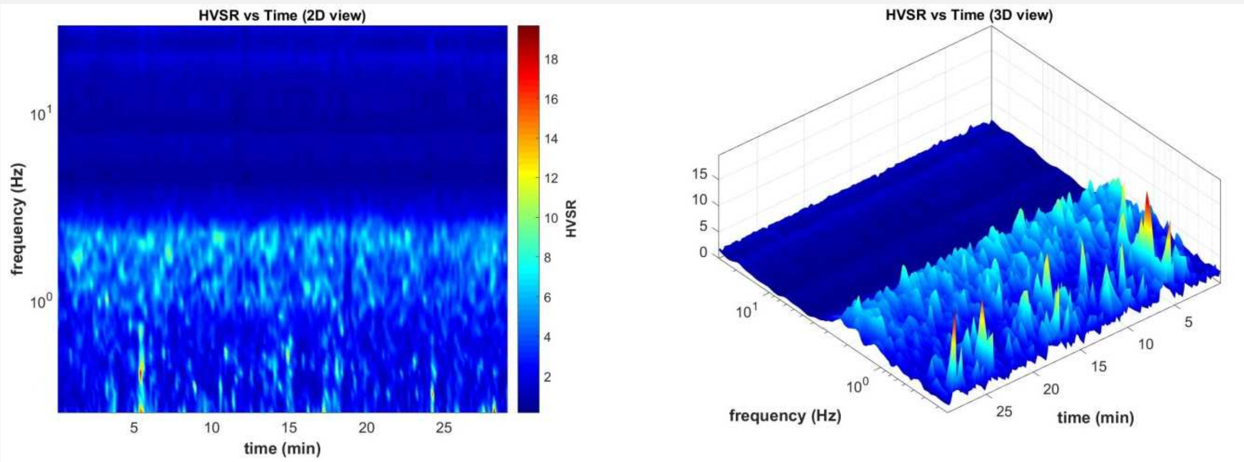
If the 3-channel geophone used also included a GPS and the SAF file obtained contains the geographical indications of the site (fields "EVT_X", "EVT_Y" and "EVT_Z"), it is possible ("show location" button) to get the automatic display of the site on Google Earth (which must clearly have been previously installed).
Once a good HVSR curve has been obtained by changing the processing parameters, at that point it is possible to carry out the "complete" calculation of everything that can be calculated. To do so, simply activate the "full output" option. As a result, a series of outputs (images and text) will be saved in the working folder. The main one is an HTML file (an ordinary file in web format manageable with any browser): clicking on it opens the analysis report.
The red dots (see screenshot above) indicate HVSR values below the unit (*possible* velocity inversion index).

The various outputs also include the "continuity" of the HVSR during acquisition (in this case a little less than 18 min), i.e., the value of the HVSR on each window considered:

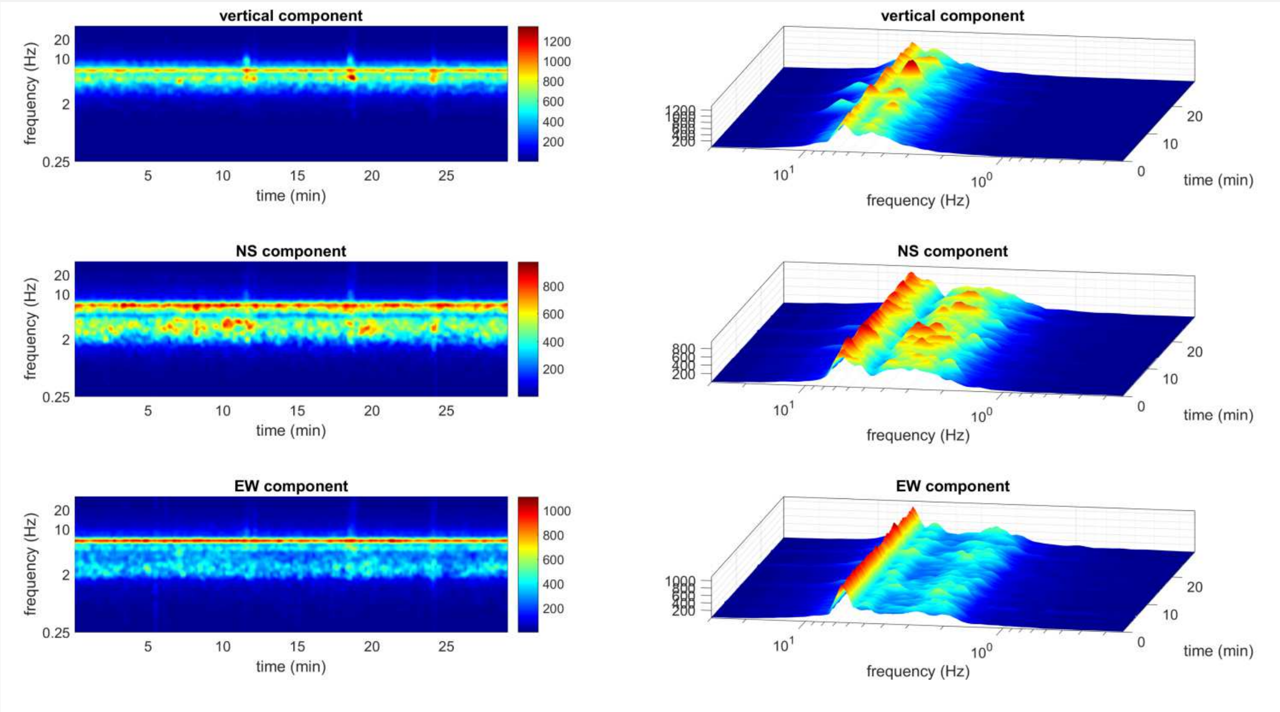


Continuity is presented both in the classic two-dimensional (on the left) and three-dimensional (on the right) visualization.

A series of tools is as always present in the bar. For example, it is possible to display the color scale (which in this case represents the values of the H/V spectral ratio - see image below).



Amplitude spectra of the individual components as a function of time.



Minimum frequency of the HVSR curve

In accordance with SESAME guidelines, the minimum frequency that can be displayed depends on the value of the analysis window. Since at least 10 cycles are required, the minimum frequency that can be determined in a robust way is therefore equal to f=10 / l_w (10 divided by the length of the window in seconds).

If you want to go down to 0.1 Hz, for example, you need to set the analysis window to 100 seconds and write 0.1 in the field relating to the minimum frequency in the group "**save - option#1: save HVSR as it is**"

HVSR Report and SESAME criteria

At the end of the calculation of the HVSR curve a report (.html file) summarizing all the parameters used and the results of the analysis is provided (the file is automatically saved in the working folder).
SESAME criteria regarding the reliability of the H/V curve and its peak are also evaluated. Analyses using SESAME criteria are carried out considering the data in the 0.5-15 Hz range (engineering) but this range can be modified using the f_c button in the toolbar at the top. The complexity of this kind of evaluation is such that it is necessary to have a "critical" look by the user who must be well aware of the subject. It is therefore necessary that the user has well assimilated the SESAME guidelines (considered as a minimum prerequisite) and all subsequent literature.

Among other things, the output provides the following outcomes:

```
=================================================================
In the following the results considering the data in the 0.5-15Hz frequency range
Peak frequency (Hz): 3.2 (±0.3)
Peak HVSR value: 5.5 (±0.5)

= Criteria for a reliable H/V curve ====================================
#1. [f0 > 10/Lw]: 3.2 > 0.25 (OK)
#2. [nc > 200]: 6314 > 200 (OK)
#3. [f0>0.5Hz; sigmaA(f) < 2 for 0.5f0 < f < 2f0] (OK)

= Criteria for a clear H/V peak (at least 5 should be fulfilled) ===============
#1. [exists f- in the range [f0/4, f0] | AH/V(f-) < A0/2]: yes, at frequency 2.0Hz (OK)
#2. [exists f+ in the range [f0, 4f0] | AH/V(f+) < A0/2]: yes, at frequency 4.2Hz (OK)
#3. [A0 > 2]: 5.4 > 2 (OK)
#4. [fpeak[Ah/v(f) ± sigmaA(f)] = f0 ± 5%]: (OK)
#5. [sigmaf < epsilon(f0)]: 0.313 > 0.157 (NO)
#6. [sigmaA(f0) < theta(f0)]: 0.642 < 1.581 (OK)

Please, be aware of possible industrial/man-induced peaks or spurious peaks due
to meaningless numerical instabilities.
```

Few tips in this regard:

- do not consider the SESAME criteria as, so-to-speak, the Bible
- changing the processing parameters (analysis window length, transient removal, etc.) necessarily leads to changes that can also be reflected in the SESAME criteria.
- criterion#5 (among the "*Criteria for a clear H/V peak*") is often among the most restrictive. Beyond its rigorous formulation, the data should be evaluated using common sense (always necessary for any method).
- by default the criteria are calculated in the 0.5-15 Hz range (usually the one of greatest engineering interest), but this range can be changed with the fc button in the toolbar.

- pay attention because possible anthropic/industrial peaks (Various Authors - Report SESAME project) 2005; Dal Moro, 2012; 2014) cannot be automatically recognized but must not be considered for geological purposes.

Saving the H/V curve

At the end of the analysis you can save an H/V curve (here too in the standard format of the SESAME project). There are 2 possible options:

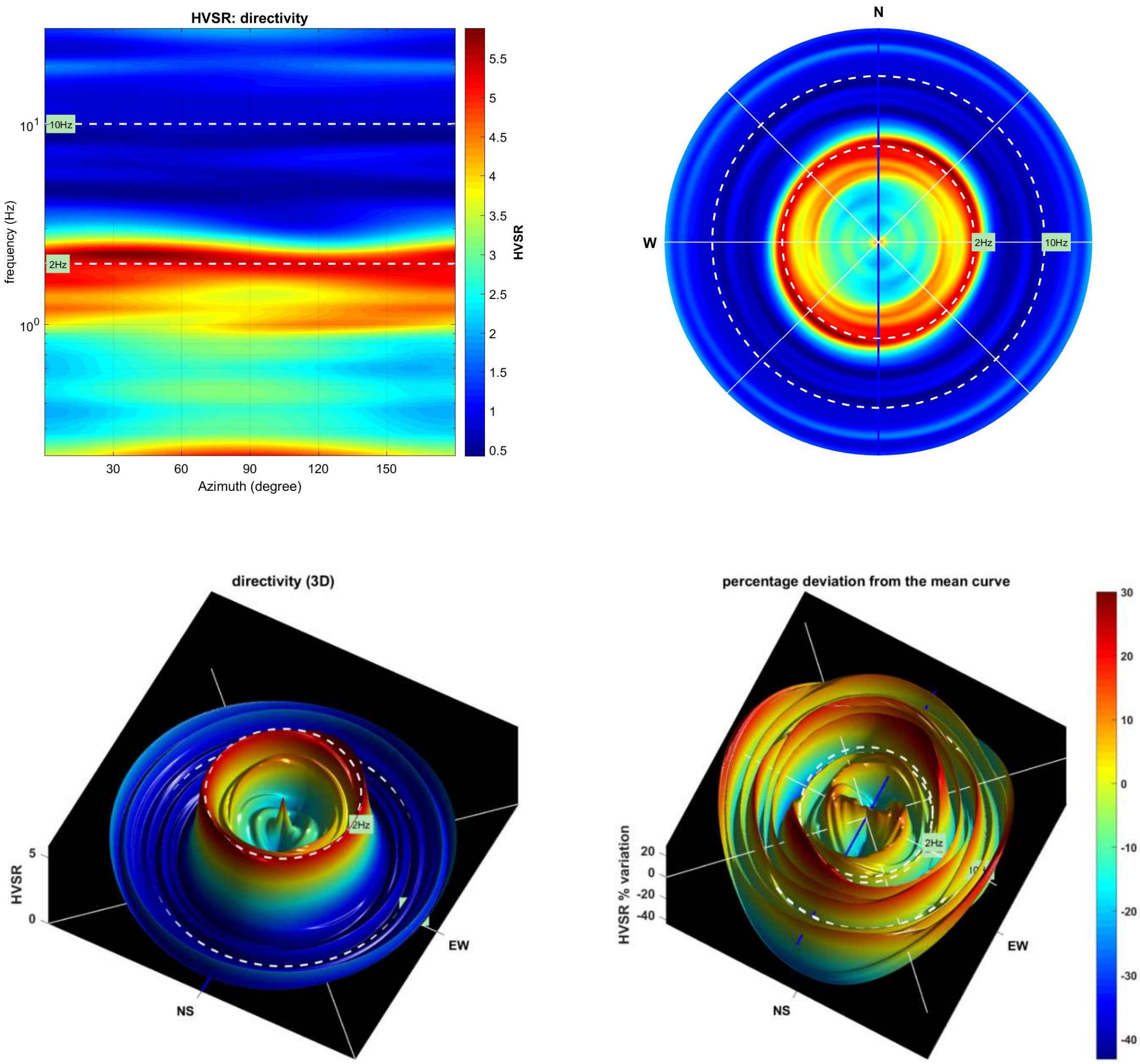
“option#1 - save HVSR as it is”
“option#2 – picking H/V curve”

In the former case you save the calculated H/V curve (visible at the bottom of the screen) in the frequency range indicated.

In the second case, it is possible to pick the H/V curve, thus making it possible to eliminate possible peaks due to anthropic "artifacts" not linked to lithological amplification signals.
winMASW® and *HoliSurface®* users who are subscribers of our mailing list will receive further information.

Directivity

Once the mean H/V curve has been calculated, it is also possible to calculate the directivity of the signal up to a specified frequency (see above for the relevant frequencies).

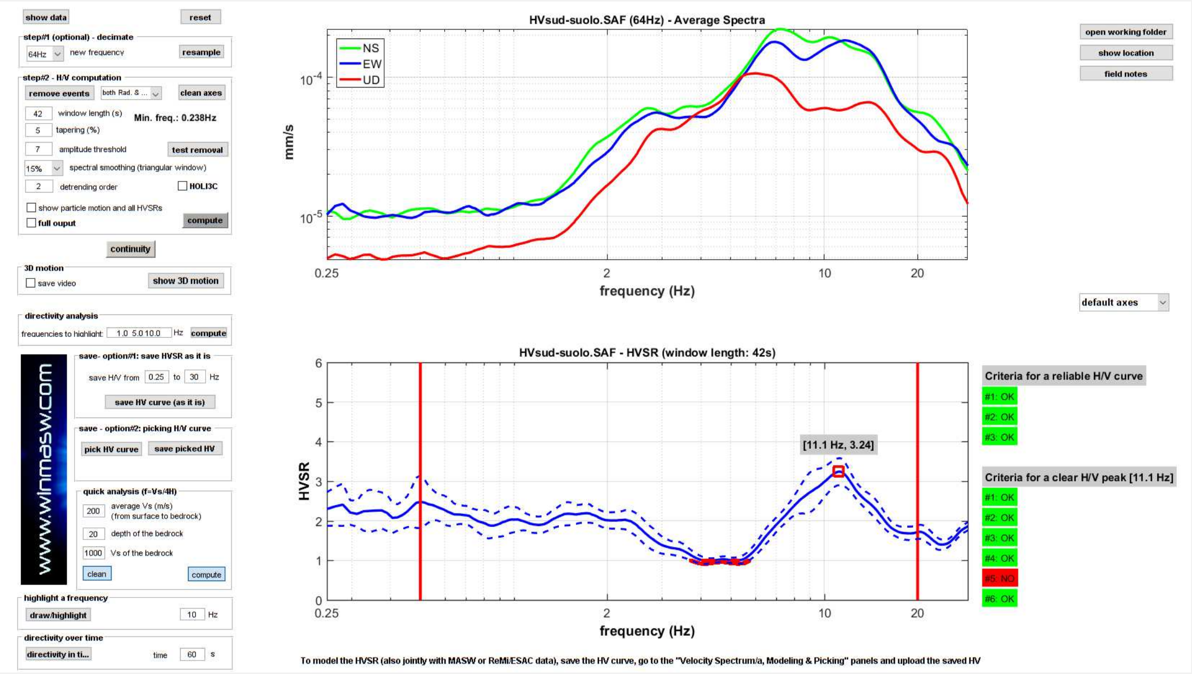


Consider that while in one case (left) the frequency scale is logarithmic, in the other case (right) it is linear. The figure is automatically saved in the previously indicated working/output folder ("working folder") but can also be saved manually by the user in any of the many possible formats.

The HVSR analysis in <u>two steps</u>

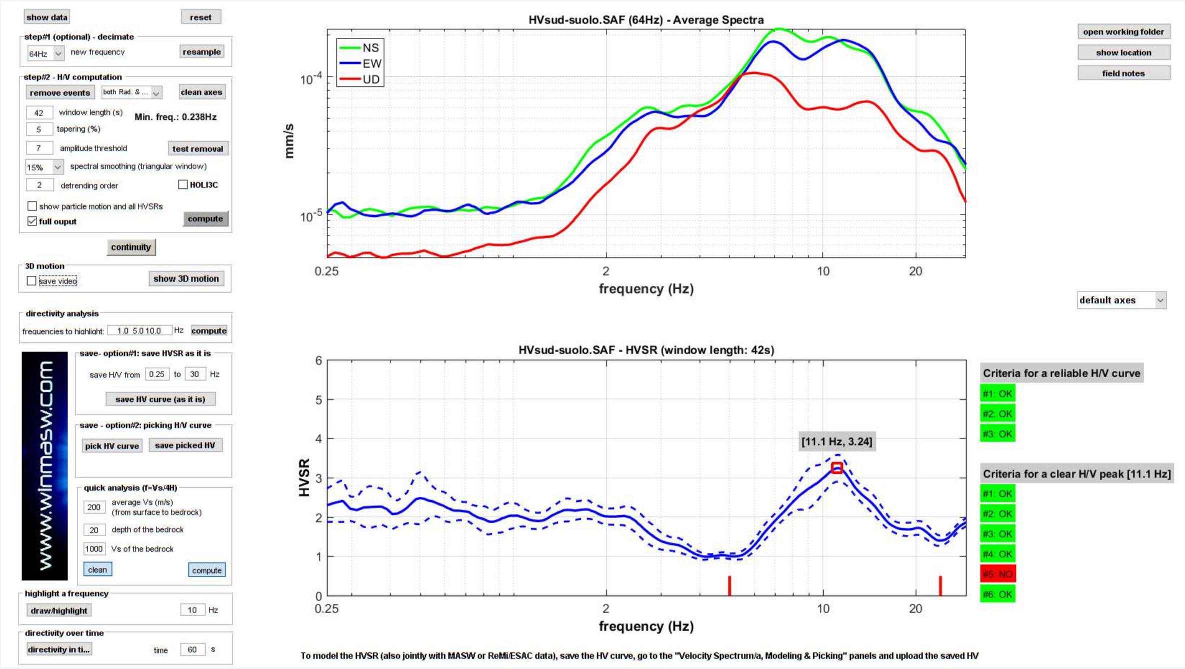
In a **<u>first step</u>** (clicking on "compute" without having activated any particular option) we calculate only the HVSR curve to understand which parameters (*smoothing*, window length, etc.) are most suitable for the dataset considered.

In this phase, two vertical red bars are also highlighted, indicating the minimum and maximum frequency within which the SESAME criteria are calculated:



It is the user's responsibility to modify these limits ("*fc*" button on the toolbar) to include the peak to be evaluated based on the SESAME criteria.

In the **<u>second step</u>**, once the limits have been modified and the "full output" option has been activated (to carry out all the possible directivity, continuity analyses, etc.), we obtain a graph like the one below (in which the limits are now indicated in a more "discreet" way and the values below the unit are not highlighted):

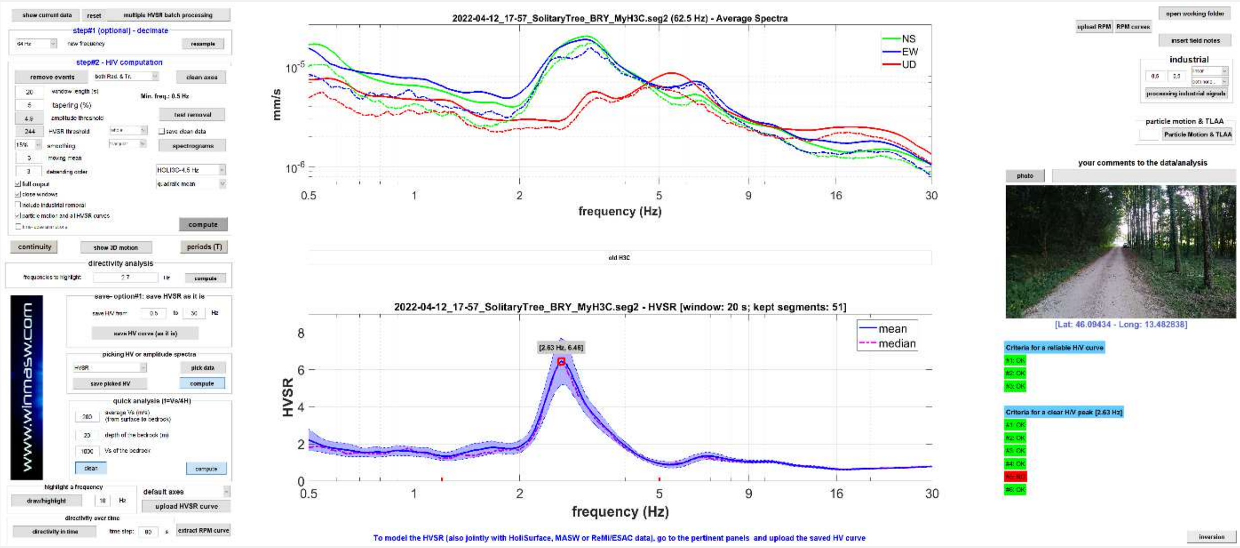


In fact, if there is more than one peak in a curve, they will have to be evaluated (based on the SESAME criteria) individually/separately (see the *winMASW-HVSR-SESAME.rar* "package" in the "Documents" folder in the *winMASW*® and *HoliSurface*® installation folder and refer to our workshops and the book that should be published by Springer in February 2020).

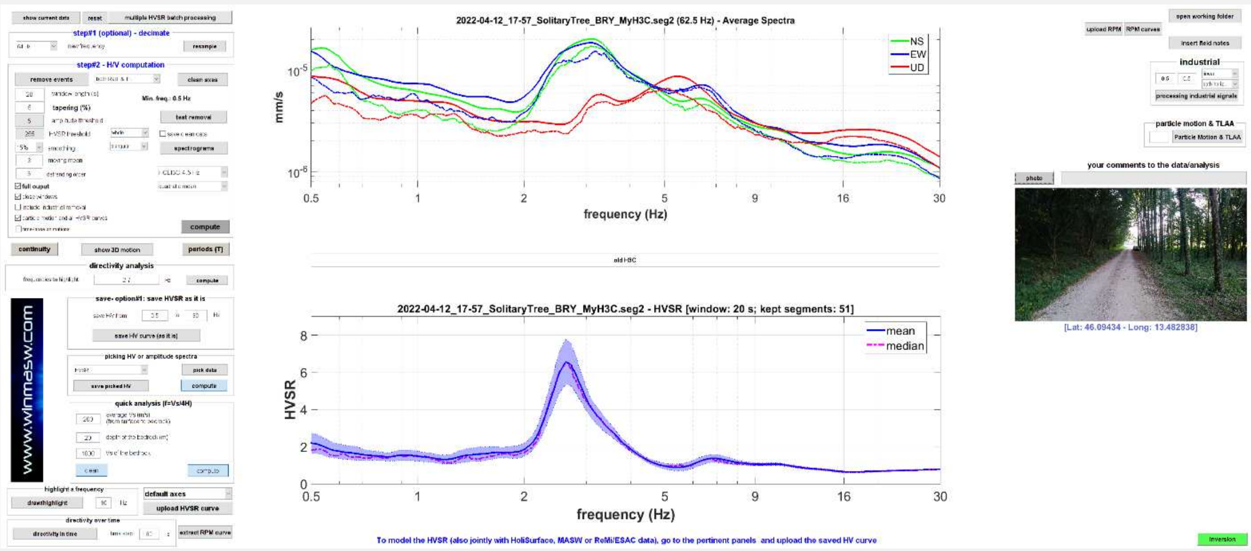
So (in case of multiple peaks) the SESAME criteria should be considered for each peak (having to launch the calculation for each individual peak - after having clearly modified the *fc* limits to include the peak you want to consider from time to time).

SESAME or not SESAME?

By default, the software computes the SESAME criteria in the frequency range specified by the user - see previous pages and the article Dal Moro & Panza (2022). A plot similar to the following is obtained:



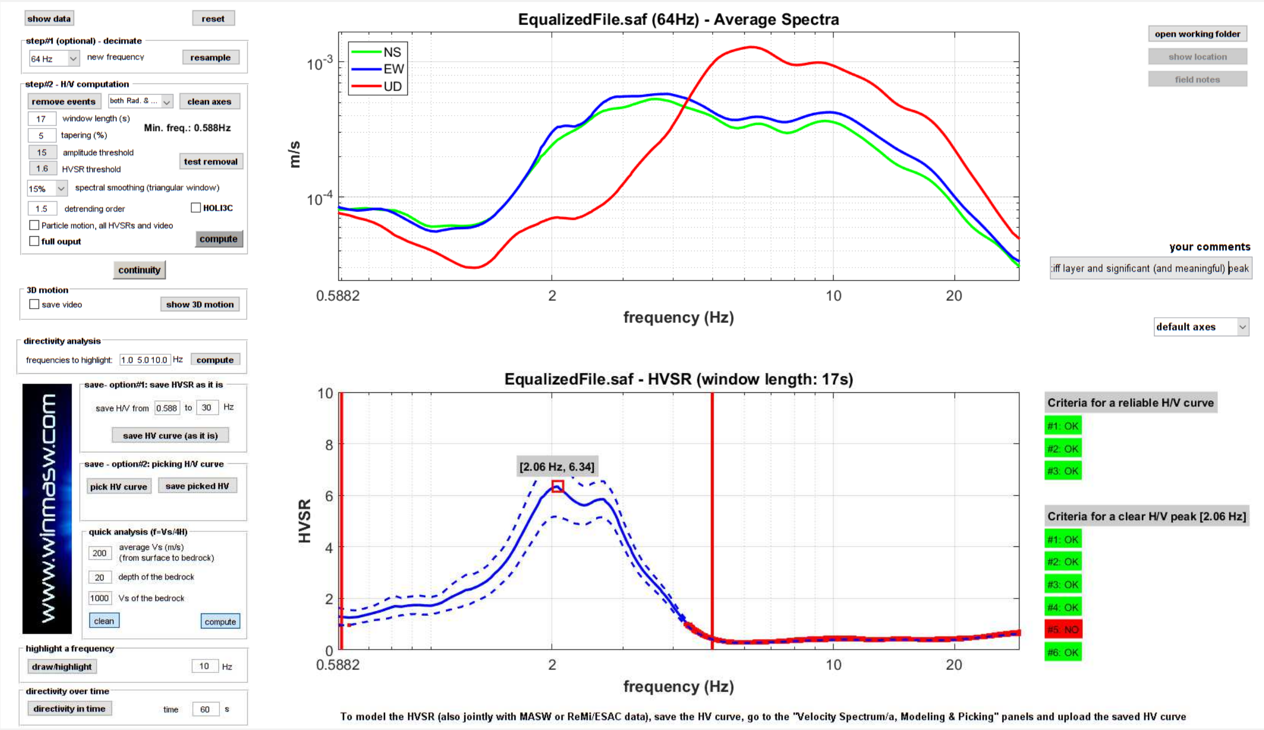
In case you do not want to compute and show the SESAME criteria (and the indication of the "peak" – see red square in the upper plot), you can disable the SESAME criteria calculation by simply "cancelling" (inserting null values) the two f_c values. This way you will then get a plot like the one shown below.



Your comments

It is also possible to add comments to the data and analysis (see the grey box "your comments" to the right of the amplitude spectra graph).

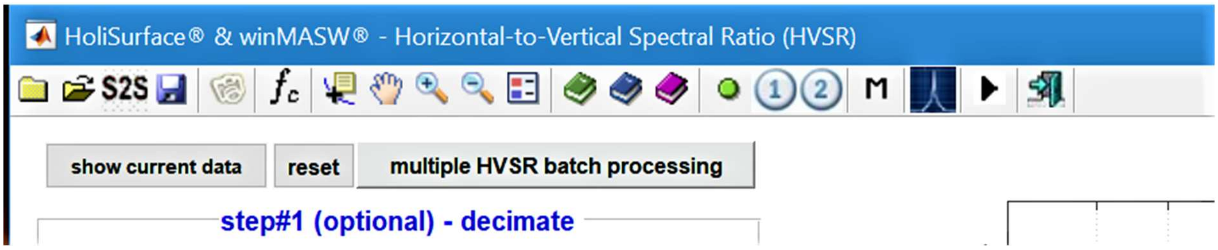
The comments will be automatically reported at the bottom of the final report obtained by computing the HVSR having activated the "**full output**" option.



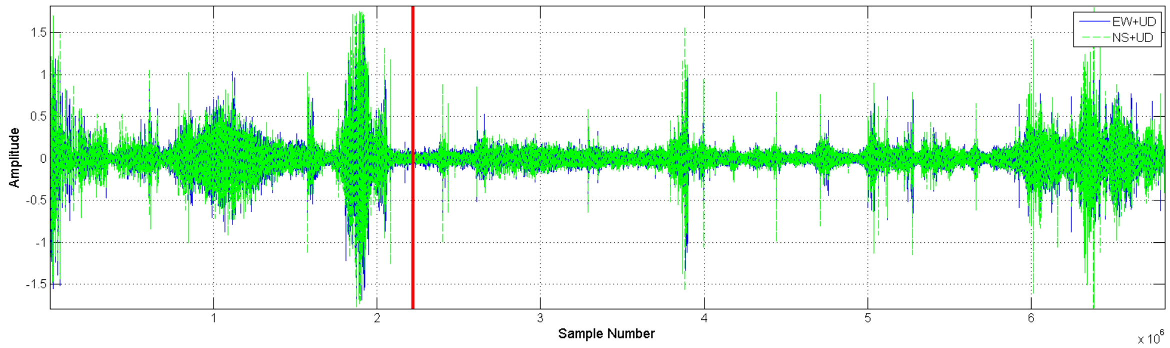
Listen to visualize (and save) your microtremor data

From the HVSR panel (► button along the toolbar) it is possible to listen to your microtremor. Click that button and choose one of the two possible options: 1) just listen to the audio version of your microtremors [“**simple**” **option**] or 2) show the time lapse spectrogram animation [**visualization [longer]” option**].

Data are reproduced with a velocity about 10 times faster than the actual data (a 10-minute dataset will be then played in just 1 minute).



Just a funny curiosity? Not necessarily. Attend one of our workshops and discover that our ears can help us also in the assessment of the microtremor data.

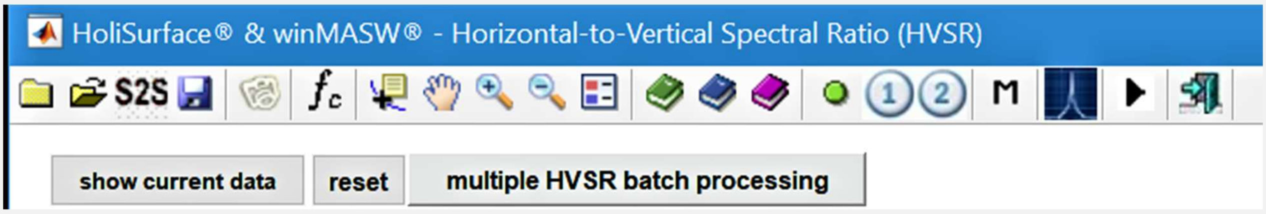


The audio is also automatically saved as *flac* file in the working folder and can therefore be played on any device.
IN order to appreciate the sound of our *Mother Earth*, we would like to recommend you to use a good sound system or your headphones.
Consider that in order to preserve the high frequencies, you should perform this operation before resampling the data.

The same tool is also available in the ESAC panel ("**play & save audio data**" button).

Time Lapse of your microtremor data in the frequency domain

From the HVSR panel (► button along the toolbar) it is also possible to visualize a time lapse animation of the spectr4igrams of the three components and of the HVSR itself.

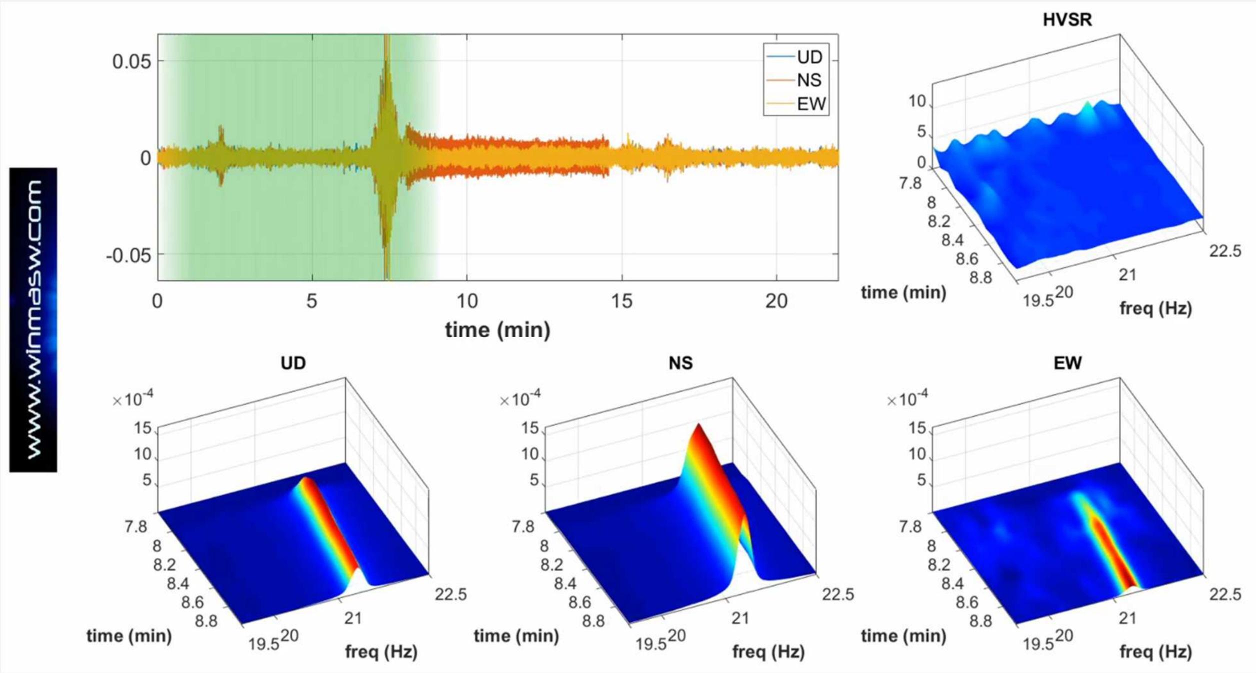


Click the same button and, instead of choosing the "simple" option (see previous section), choose the "**visualization [longer]" option.**
This can be useful in case you want to monitor/visualize the persistence of a specific industrial component.
The minimum and maximum frequency (i.e. the frequency range shown) are the same specified for the minimum and maximum values for the HVSR (see the two values to specify in the "**save – option#1**" group).

In case you also select the "time-lapse animation" option (in the "step#2" group), the shown video will be saved in the working folder as **mp4 file**.

An example of data characterized by a clear industrial component (that also changes its frequency) is shown here: https://www.youtube.com/watch?v=NW1e_q09g-c

Such example is analyzed in detail in the paper "*On the identification of industrial components in the Horizontal-to-Vertical Spectral Ratio (HVSR) from microtremors*" (Dal Moro, 2020).



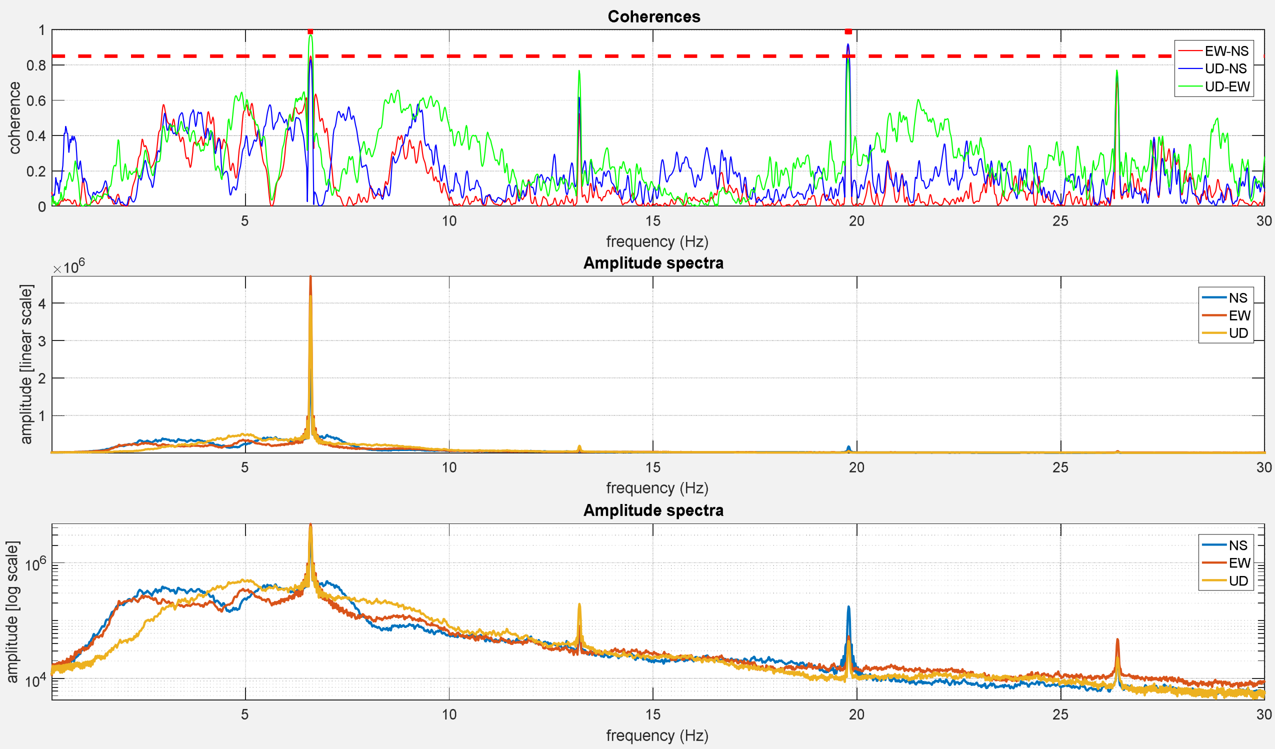
Industrial components

The amplitude spectra of the three components with linear frequency scales (both log and linear amplitude scale) and the coherences between the various pairs of sensors (EW versus NS, EW versus UD and NS versus UD) are also shown.

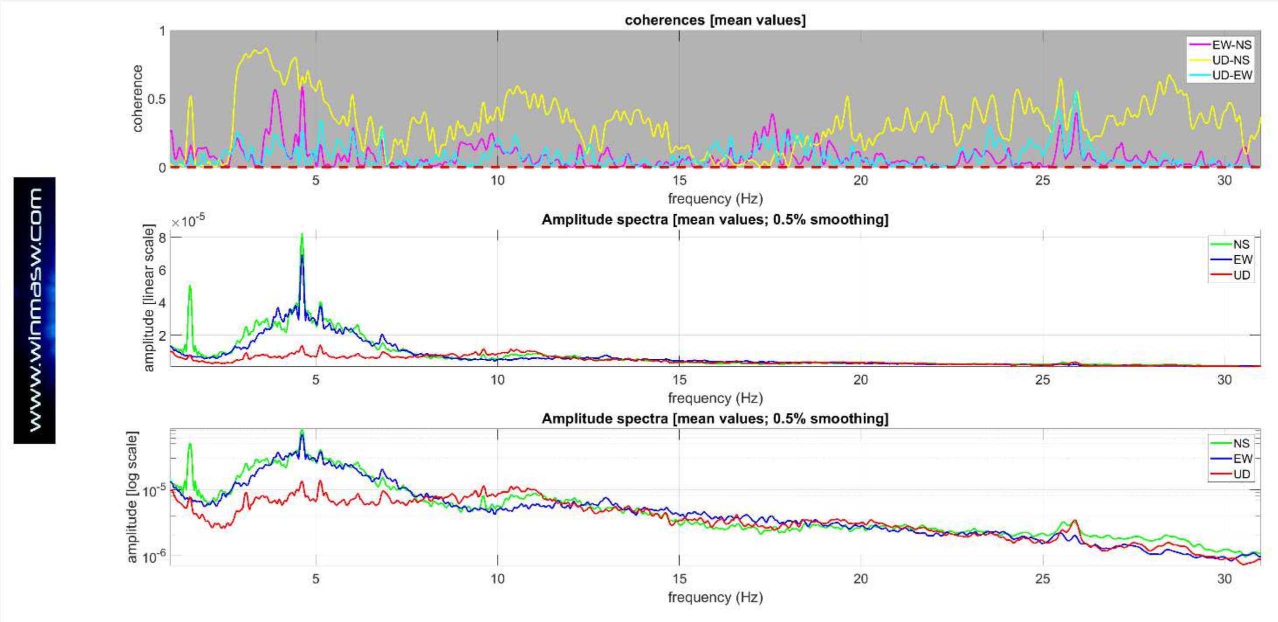
<u>This way it is possible to better highlight possible industrial components.</u>

We would strongly recommend to study the paper *On the identification of industrial components in the Horizontal-to-Vertical Spectral Ratio (HVSR) from microtremors* (Dal Moro, 2020 – Pure and Applied Geophysics – **https://doi.org/10.1007/s00024-020-02424-0**

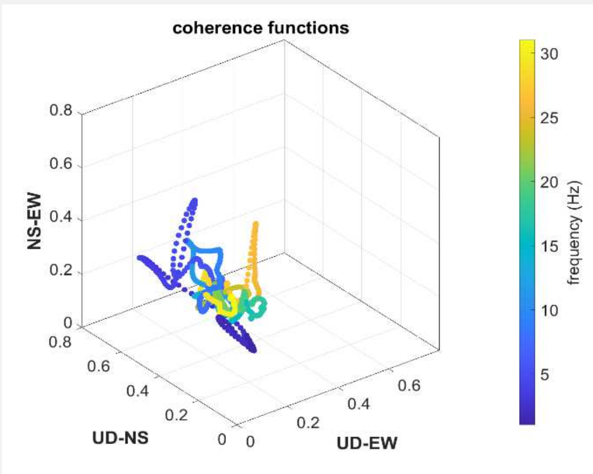
In the example below the presence of a series of "artificial" (industrial) peaks at 6.6, 13.2, 19.8 and 26.4 Hz is evident (note that - in this very peculiar case - you can see the fundamental frequency of an industrial component [at 6.6 Hz] with a series of higher harmonics).



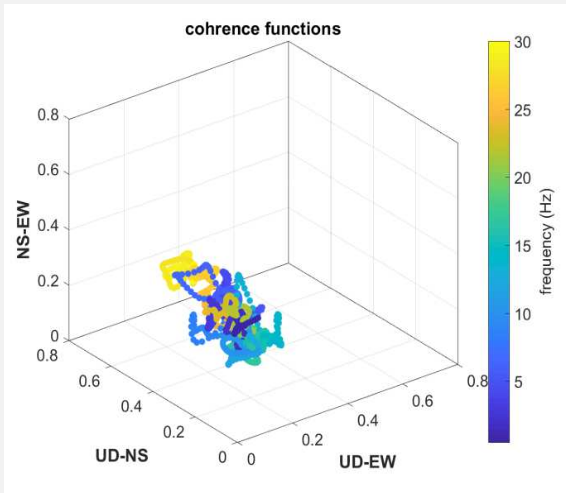
In the next example you can note the presence of a couple of industrial signals at about 1.56 and 4.63 Hz.



a)



b)



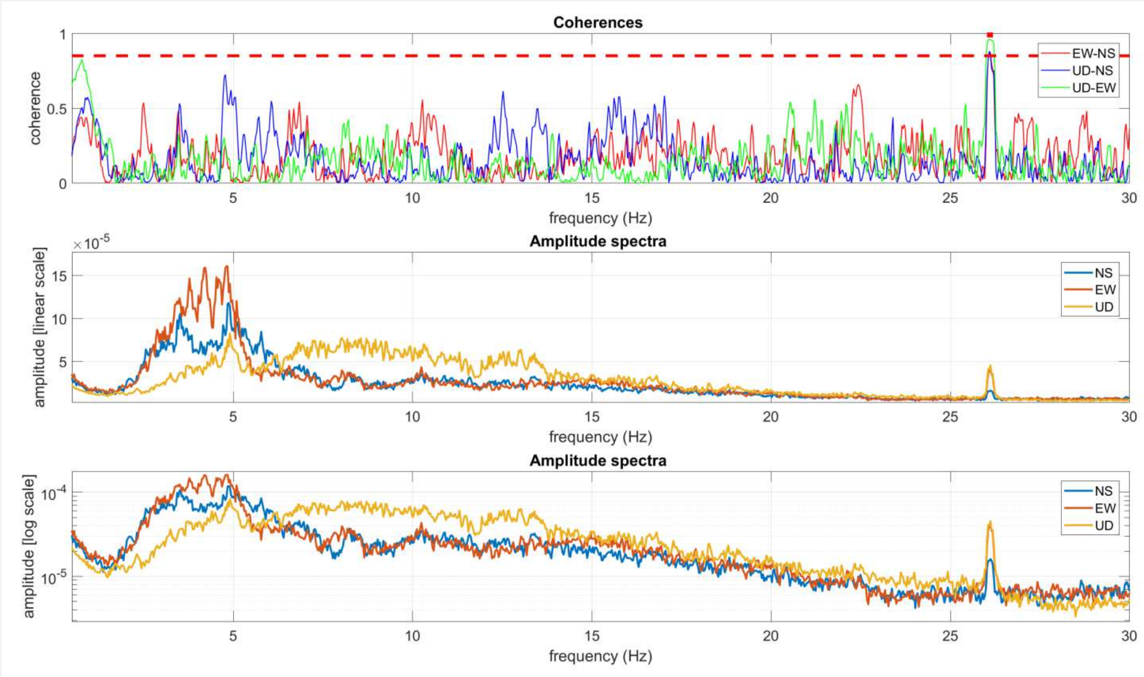
Two examples of coherence functions displayed in 3D mode with the color scale representing their frequency: on the right a case where no significant industrial components are evident, on the left a complex dataset with a couple industrial components.

With regard to the data in the left plot see also the two images below related to:

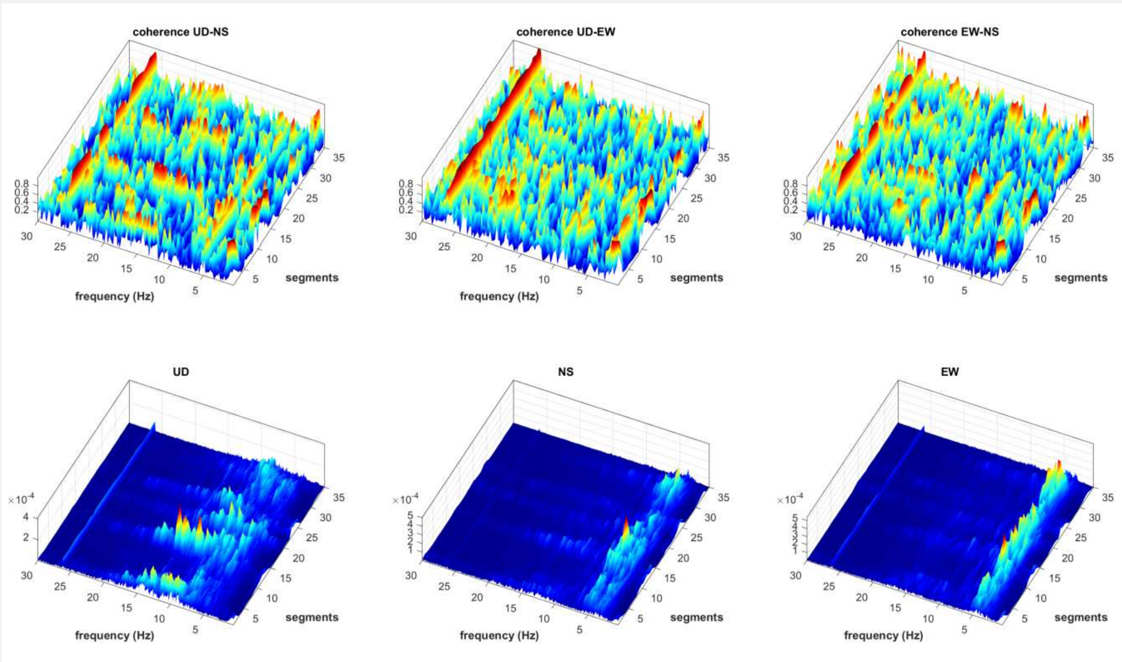
1) frequency coherence functions (for all three combinations NS-EW, EW-UD, and NS-UD) and linear and logarithmic amplitude spectra (smoothed by only 3%);

2) coherence functions and spectrograms (time-dependent).

1)


Coherences
coherence
frequency (Hz)
EW-NS
UD-NS
UD-EW
Amplitude spectra
amplitude [linear scale]
NS
EW
UD
amplitude [log scale]

2)


coherence UD-NS
coherence UD-EW
coherence EW-NS
UD
NS
EW
frequency (Hz)
segments

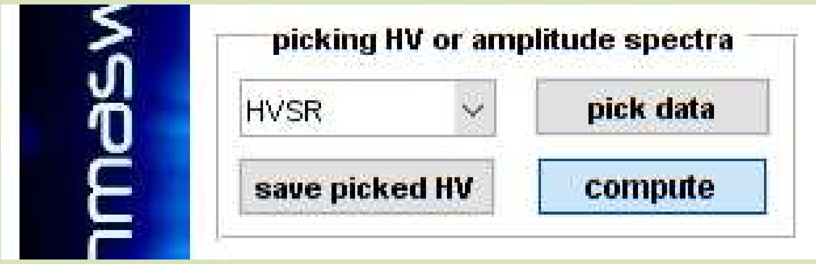
Managing (manually) the industrial components

There are two ways to attenuate/reduce/delete industrial signals:
1) massively smooth the spectra (50% and more [see parameter *spectral smoothing*]);
2) manually picking the HVSR curve or, if the situation is complex, the amplitude spectra of the UD, NS and EW components.

The first approach does not require much clarification and is therefore not discussed here.
Let us see some details on the other two approaches, it being understood that in order to implement them seriously it is necessary to attend our training courses.
It should be emphasized that the quality of this type of operation depends entirely on the level of theoretical knowledge of those who carry them out.

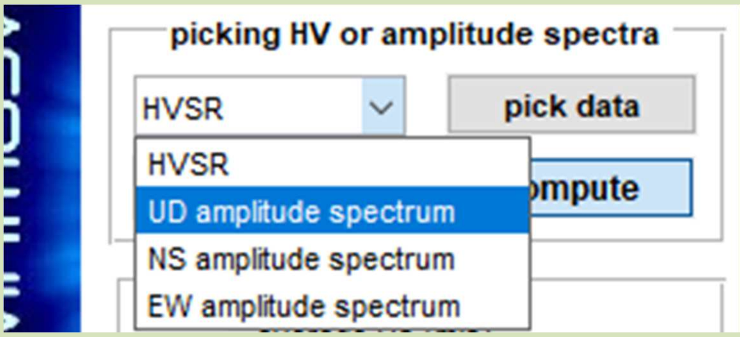
a) picking of the HVSR curve

In this case, the HVSR curve potentially "contaminated" by industrial signals is picked directly.



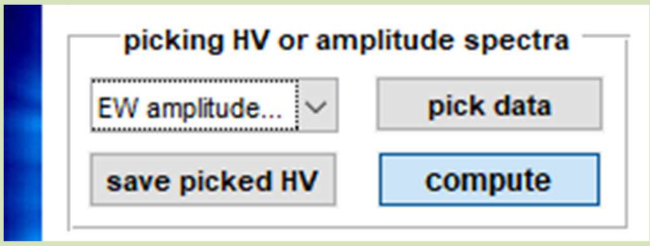
1) In the drop-down menu, select the "HVSR" option;
2) Click the "pick data" button;
3) Start picking the desired curve (to close picking, use the right mouse button);
4) Save the picked curve by clicking on the "save picked HV" button.

b) picking of the amplitude spectra of the three components and related recalculation of the HVSR curve:



1) HVSR calculation with limited smoothing (approximately 2-3%)
2) In the drop-down menu, select the component to be picked (all three components must be picked in sequence);
3) Once the component has been selected, click on the "pick data" button;
4) Start picking the selected amplitude spectrum (we recommend that you always follow the same order): UD, NS and EW; to close picking, use the right mouse button);

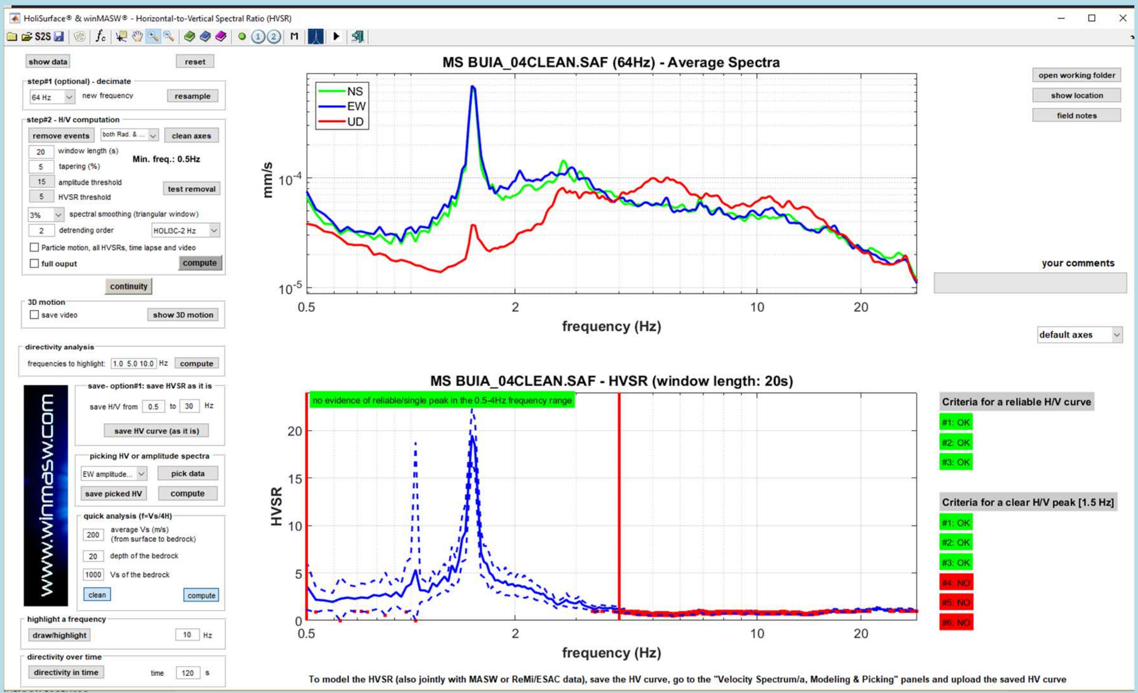
Points 2, 3 and 4 are repeated so to pick the amplitude spectra for all the three components (UD, NS and EW).



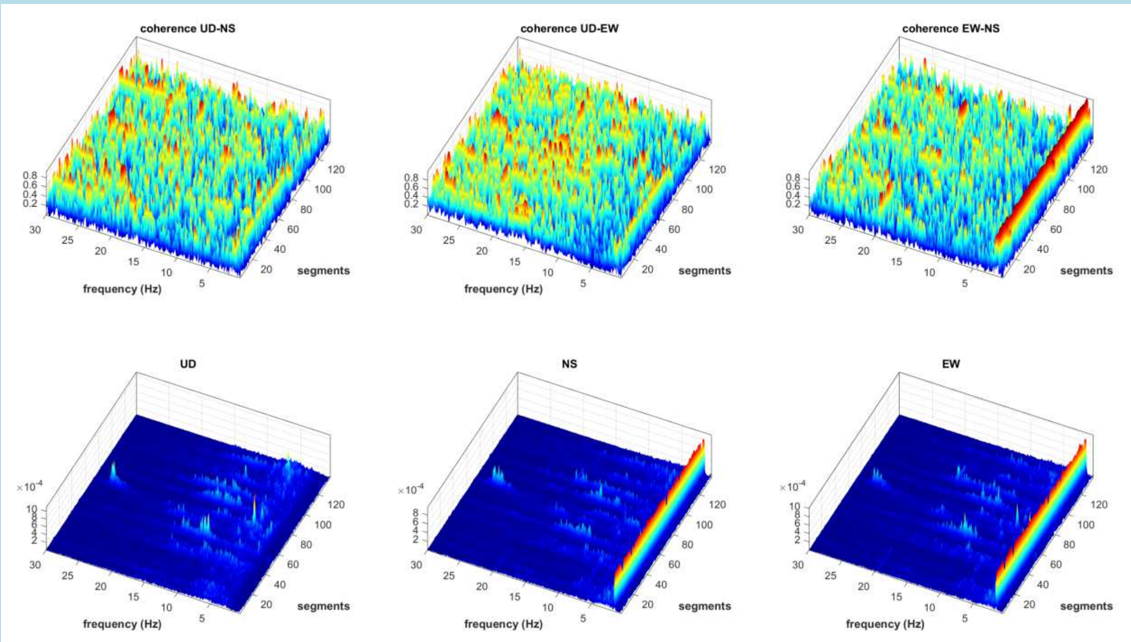
5) Once the last component has been picked, the use must (re)compute the H/V ratio based on the amplitude spectra of the picked three components. To do so, press the "compute" button. At this point, a summary screen will be displayed and the re-computed HV curve will be automatically saved in the working folder as a file with the same name as the field datafile with the additional suffix "_reconstructed.hv".

An example

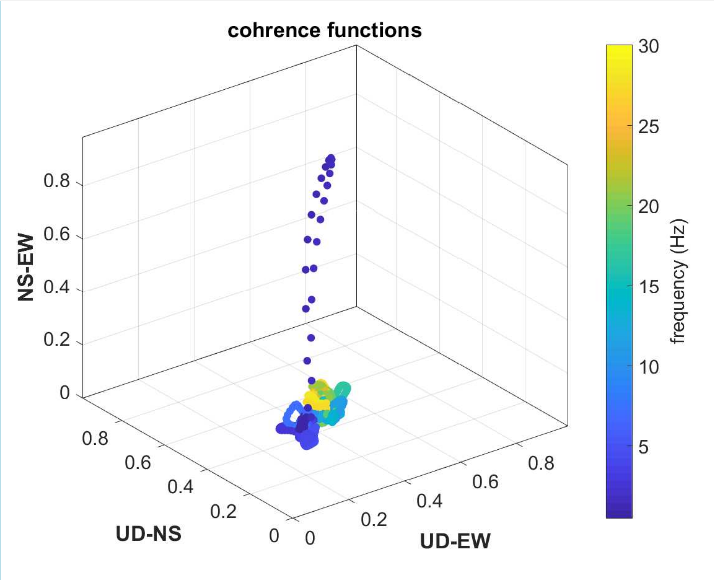
1) computation with 3% smoothing (incidentally, in this way the SESAME criteria are completely out of sync). The well-known 1.5 Hz industrial component is evident (common throughout Friuli and beyond).



During this first phase you will get, among other things, also the following two graphs:

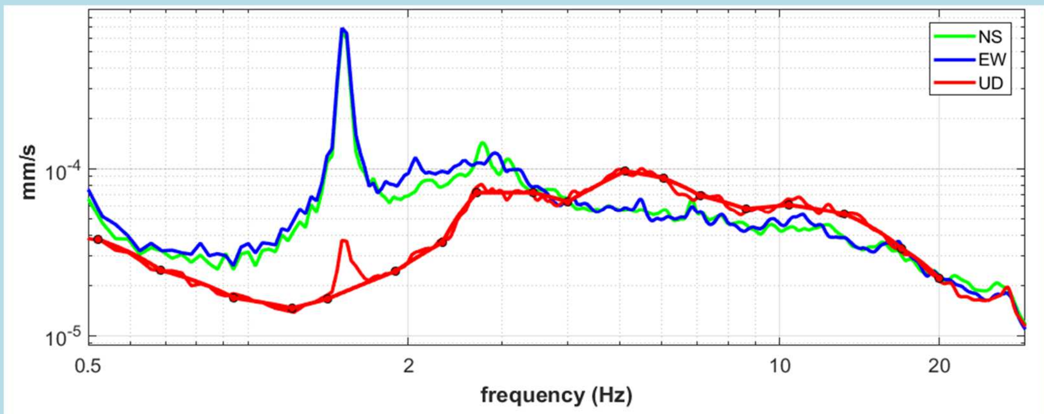


Top: graph of the coherence functions of the three possible combinations as a function of time; **bottom**: amplitude spectra as a function of time (spectrograms). The industrial signal at 1.5 Hz is clear.

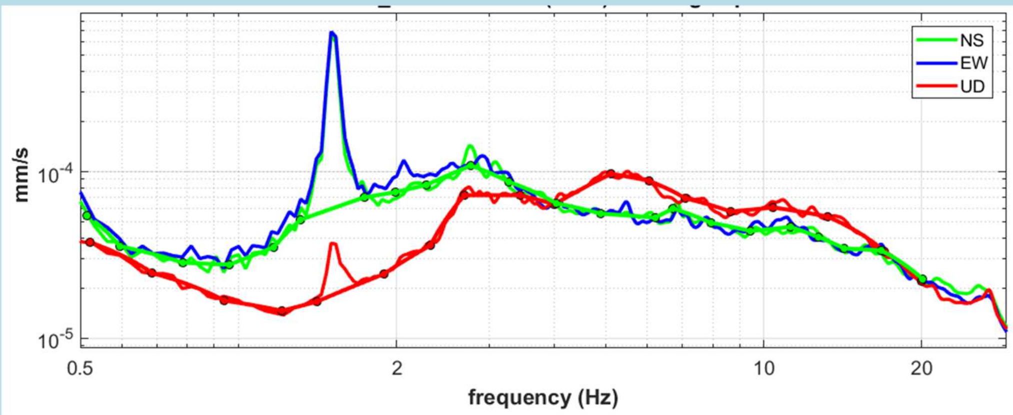


Coherence functions (3D view): colors relate to the frequency of each point. The industrial signal at 1.5 Hz is apparent.

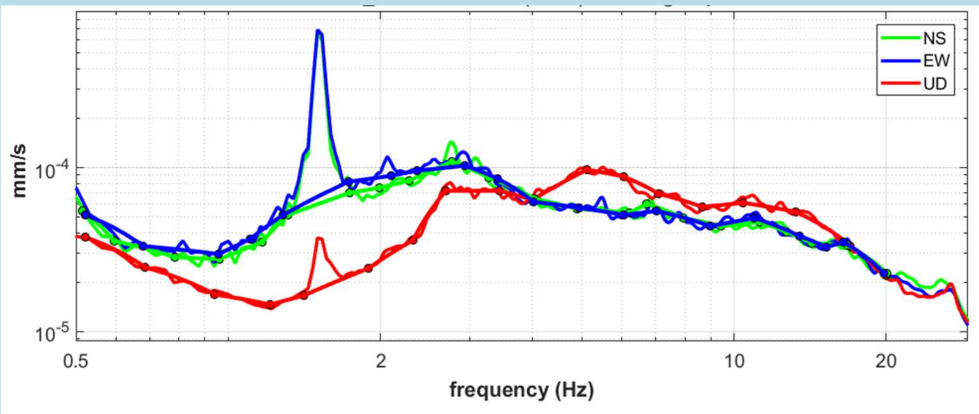
2) picking of UD component



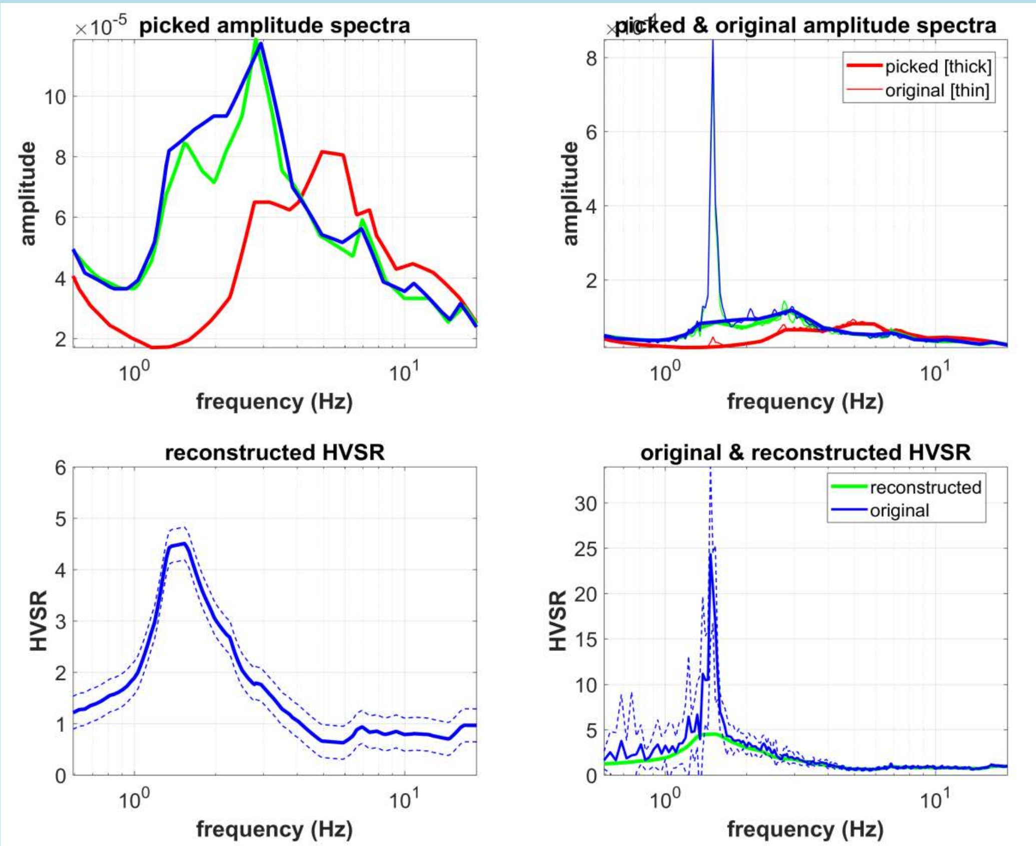
3) picking of NS component



4) picking of EW component



5) calculation of HVSR from the peak amplitude spectra to obtain the following graph and its .hv file



Please note and bear in mind that, for statistical reasons, the average of the HVSR curves is not identical to the HVSR calculated from the average of the amplitude spectra. This means that at low frequencies (more "unstable") the two curves may differ slightly. If all the operations involved in the analyses have been carried out correctly, the two curves fall within the margins of uncertainty (see curves relating to standard deviations). You should also bear in mind that for these picking operations we are working and need to work with very little smoothed data (about 2-3%) and therefore with non-ideal curves.

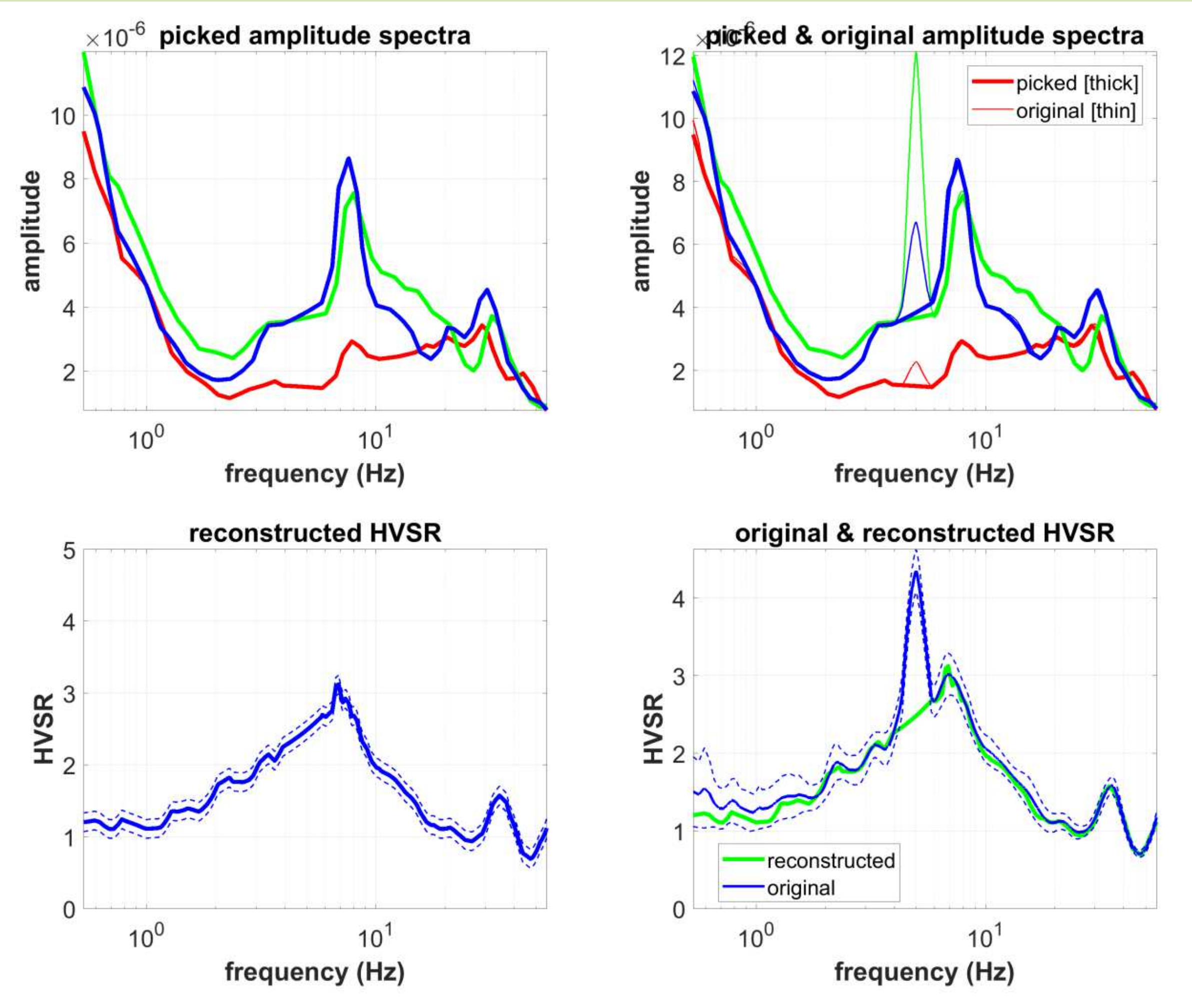
SESAME criteria of the reconstructed HVSR curve

Clearly, with this type of processing/reconstruction, we work with the final mean curves (of the amplitude spectra and of the HV).
Since the first 3 SESAME criteria (for the whole curve) and the criteria 4, 5 and 6 for the evaluation of a "peak" work instead (according to "statistical" criteria) considering **all** the HVSR curves of each window, it is not possible to calculate all the SESAME criteria of the reconstructed curve (since we only have the final mean curves available here).

Only the first 3 criteria for a reliable peak can be "calculated" (at sight).

The first two require that the value of the curve drops to at least half of the value of the peak in the $f_0/4$ - $4*f_0$ frequency range (f_0 being the frequency of the peak considered). The third is even more trivial (the value of the peak must exceed the value of 2).

If we consider the following example (the 5 Hz signal is clearly of an industrial nature), we can see that (also considering the standard deviations) all the first three criteria for a "reliable peak" and relating to the reconstructed curve (green curve in the lower right box) are certainly met [f0 equal to about 7 Hz and frequency range to be considered equal to 1.75-28 Hz].



Automatic removal of industrial signals

In the upper right corner of the HVSR panel there is the “**INDUSTRIAL**” group. By setting the appropriate parameters you can use the “**process industrial signals**” button to automatically remove (or attenuate) possible industrial components that alter the HVSR curve. Always remember that the “right” parameters are data dependent and it is impossible to define universal values.

The procedure basically consists of three steps: a) identification of the industrial signals; b) removal from the data; c) interpolation from the surrounding data.

There are four “parameters” to set up:

1) the <u>threshold value for the coherence function</u> (values higher than the specified value are considered expression of an artificial/industrial signal);

2) the <u>threshold value for the derivative of the amplitude spectra</u> (values higher than the specified value are considered expression of an artificial/industrial signal);

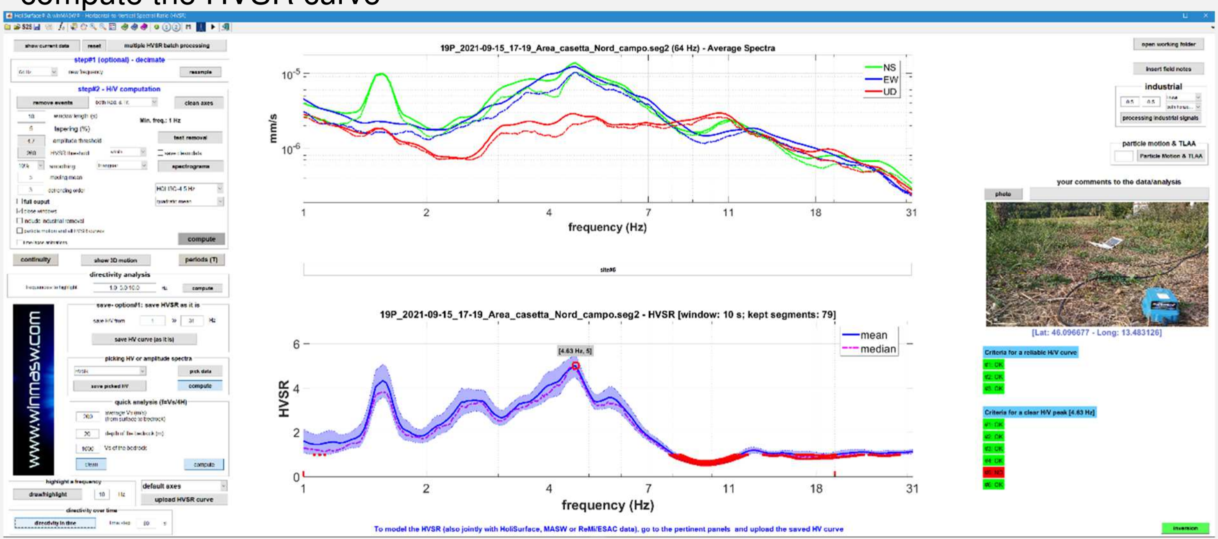
3) the components (Z, NS and/or EW) to use for the computation of the (average) amplitude-spectra derivatives;

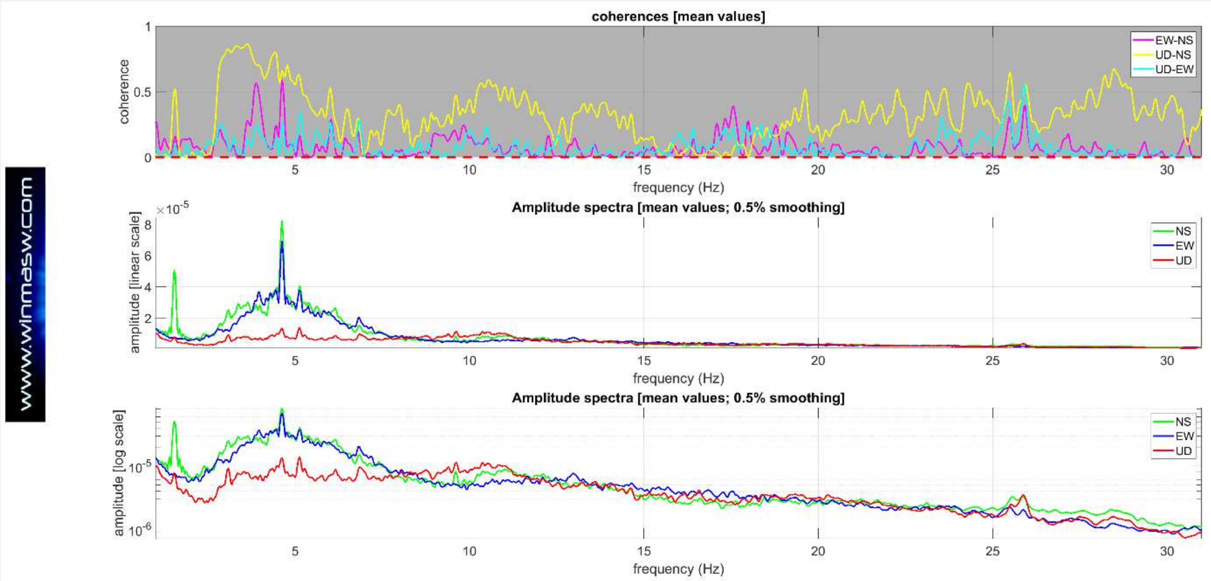
4) the <u>type of interpolation</u> to use to interpolate between the points removed cause attributed to an industrial component.

Here an example that should clarify how it works:

a) upload the microtremor data and the georeferenced photo

b) compute the HVSR curve

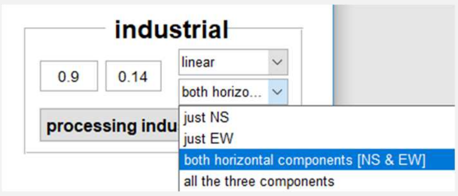




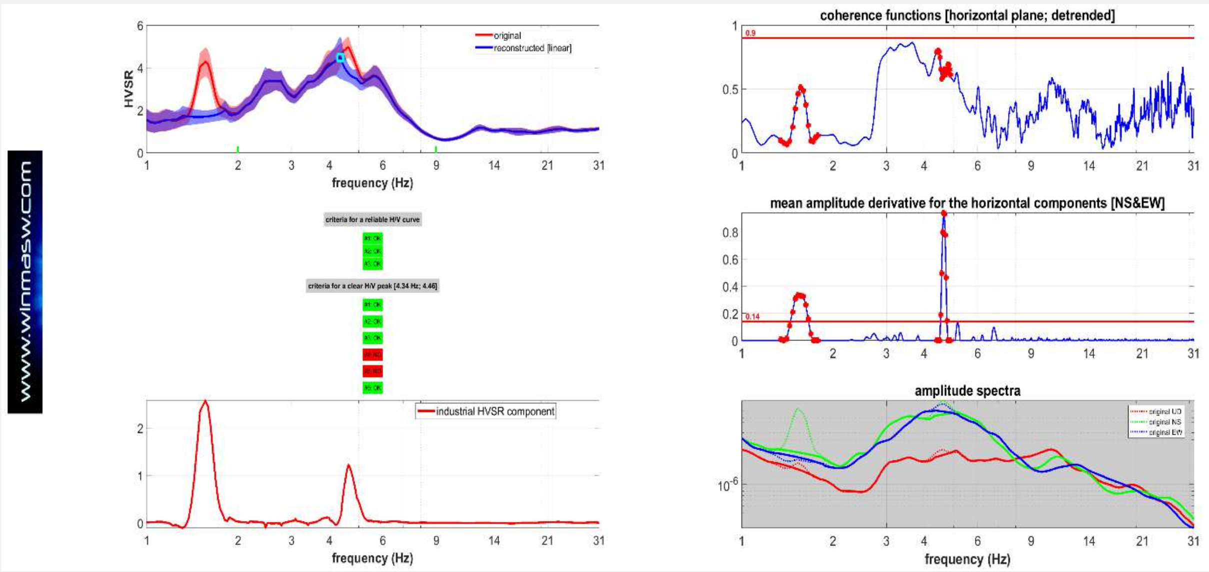
In this case the presence of **two industrial components at about 1.5 and 4.6 Hz** is pretty clear especially in the almost-unsmoothed (5%) amplitude spectra while the coherence functions are, in this case, pretty complex and can just confirm the 1.5 Hz signal (while are otherwise extremely complex – this is actually a pretty unusual dataset).

In order to try to remove the influence of these signals on the HVSR, we:

1) set a very high value for the **coherence functions threshold** (since, in this case, we do not want to use the coherence function to identify the industrial components) and a low value for the derivative; since the 4.6 Hz industrial component is clear especially along the NS and EW components – see amplitude spectra reported in the previous figure) we choose to consider the average derivative from **both the horizontal components**

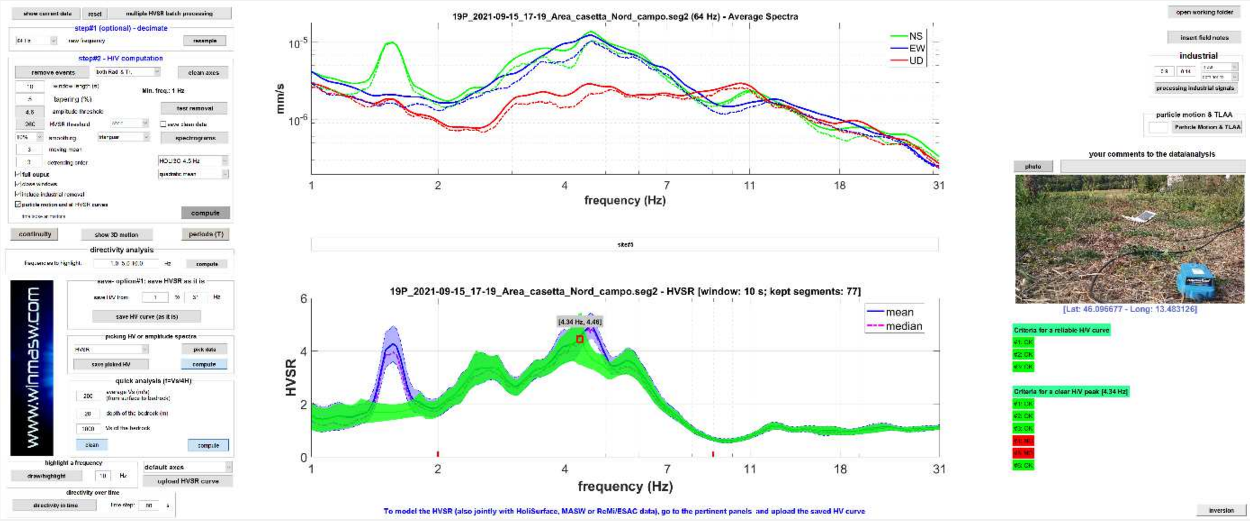


We can now click the "**processing industrial signals**" button and obtain this result:



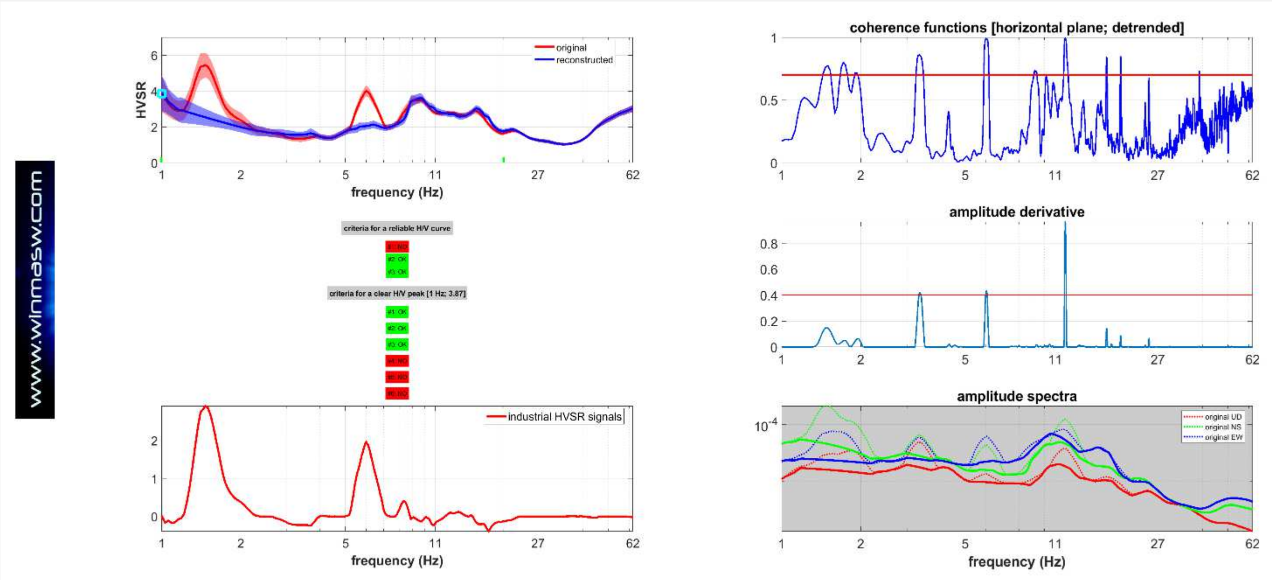
Two quick notes: a) since we decided to fix a very large (0.9) threshold for the coherence functions, the selection of the industrial signals is not based on the coherence functions;

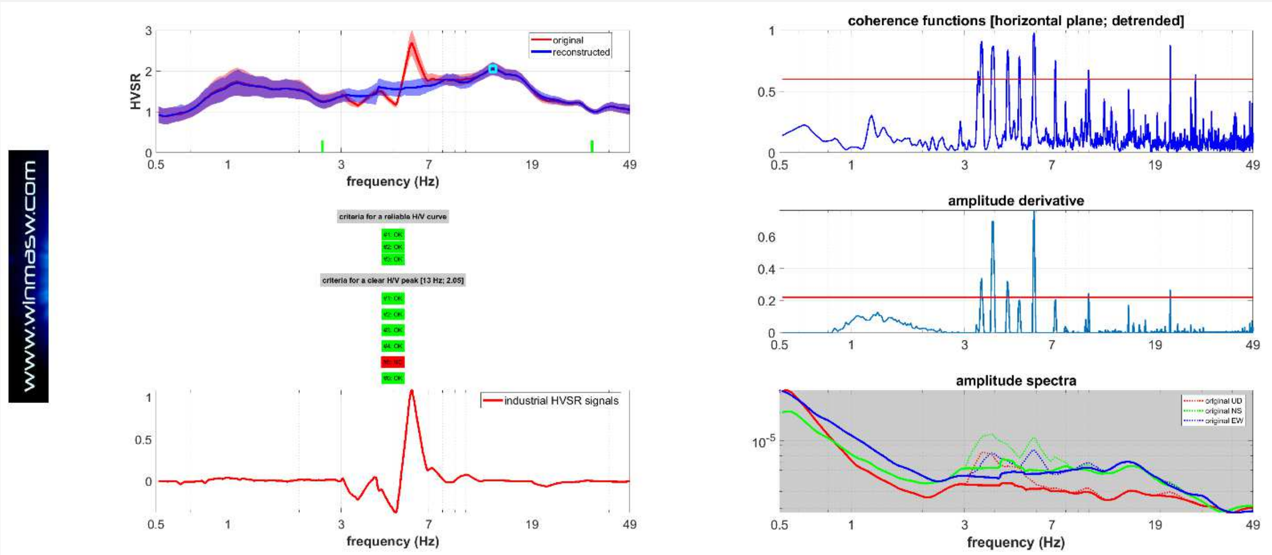
b) since we fixed a very small threshold value for the amplitude derivative, the two industrial signals were properly identified by means of them (the amplitude-spectra derivatives – see the “mean amplitude derivative for the horizontal components [NS&EW]” plot).



The green curve represents the “cleaned” HVSR curve free from the industrial components identified through the correct parameters above described. Once again we need to underline that the correct parameters are data dependent and need to be properly set by the user (who need to understand how the procedure works).
See a further example reported in the Appendix “**Few examples of what you can do with HS® (small case studies)**”.

In the following, few more examples of the performance of the tool for the automatic removal/attenuation of the industrial signals (in the upper left corner are reported the original HVSR curve [in red] and the “cleaned” one [in blue]). As you can see, the parameters used to remove the industrial signals are different for each dataset.


www.winmasw.com
HVSR
original
reconstructed
frequency (Hz)
industrial HVSR signals
frequency (Hz)
coherence functions [horizontal plane; detrended]
amplitude derivative
amplitude spectra
original UD
original NS
original EW
frequency (Hz)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HVSR
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frequency (Hz)
industrial HVSR signals
frequency (Hz)
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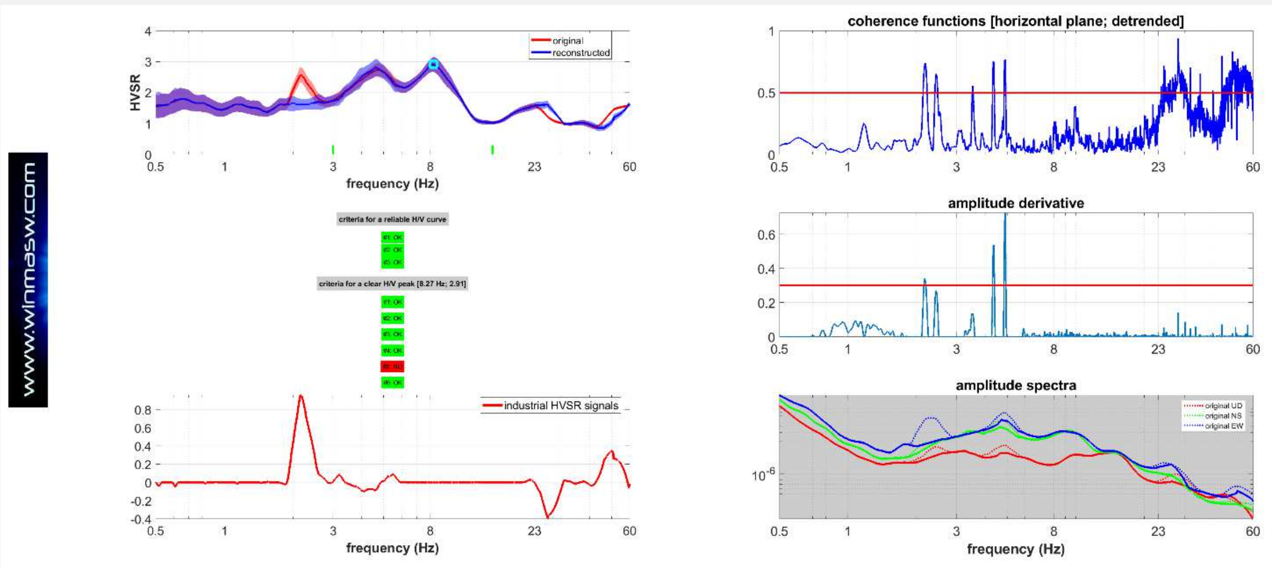
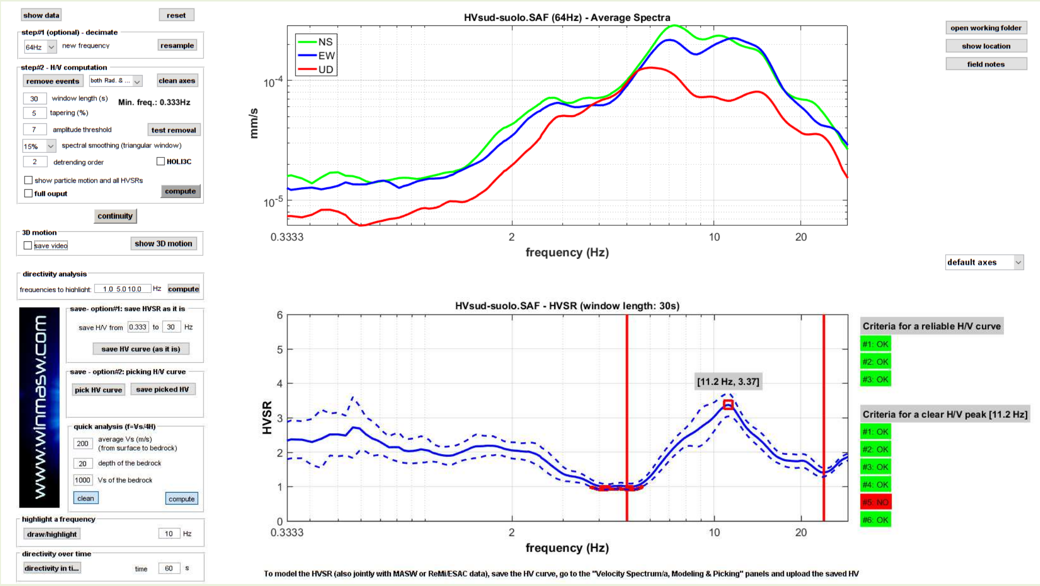
amplitude derivative
amplitude spectra
original UD
original NS
original EW
frequency (Hz)

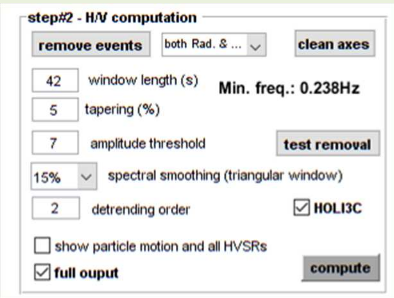

www.winmasw.com
HVSR
original
reconstructed
frequency (Hz)
industrial HVSR signals
frequency (Hz)
coherence functions [horizontal plane; detrended]
amplitude derivative
amplitude spectra
original UD
original NS
original EW
frequency (Hz)

“HOLI3C" option (equalization of our 2 and 4.5 Hz geophones)

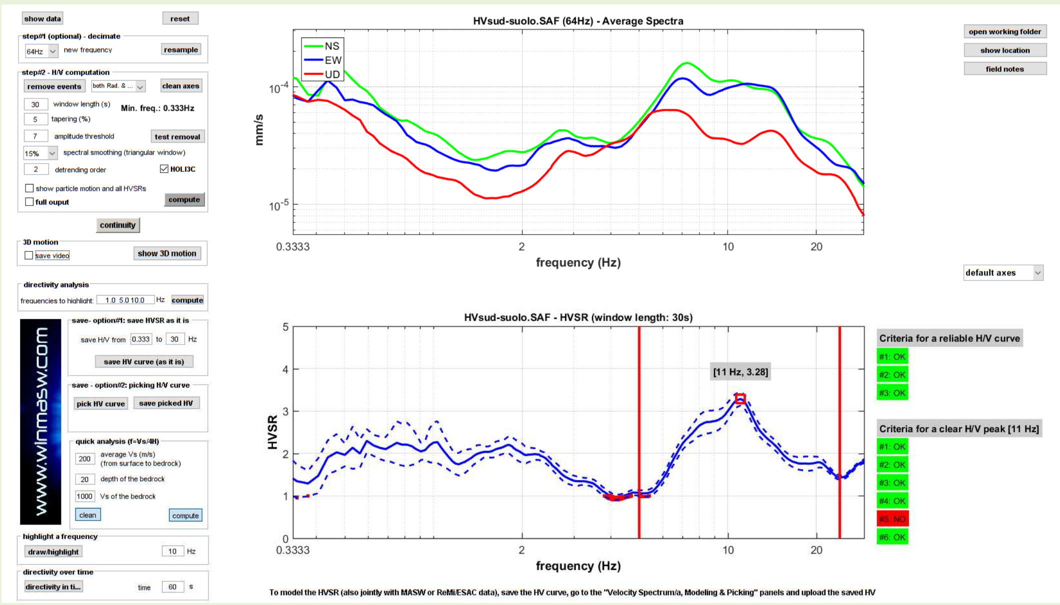
If you have acquired the data using one of our three-component geophones [HOLI3C geophone], activating the HOLI3C option, you obtain the equalization of the traces with recovery (at their real amplitude) of the very low frequencies.



HVSR analysis without trace equalization (HOLI3C option not activated)



Activating the HOLI3C option (from release 2018 you can choose between 2 options depending on the purchased HOLI 3C geophone).

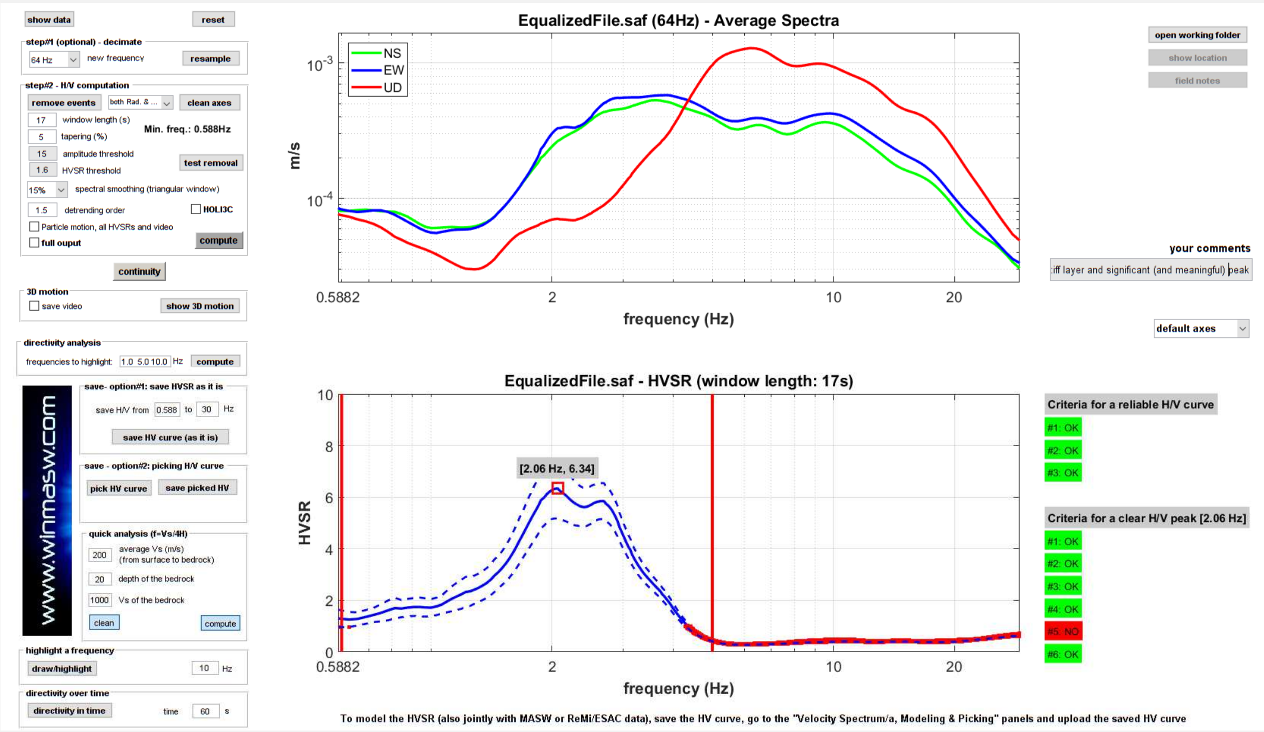


HVSR analysis with trace equalization (HOLI3C-2Hz option activated): note the recovery of real amplitudes

Enter your comments

It is now also possible to enter comments on the data and analysis (see the grey box "your comments" to the right of the amplitude spectra).

The comments will be automatically reported at the bottom of the final report obtained by calculating the HVSR having activating the "full output” option.

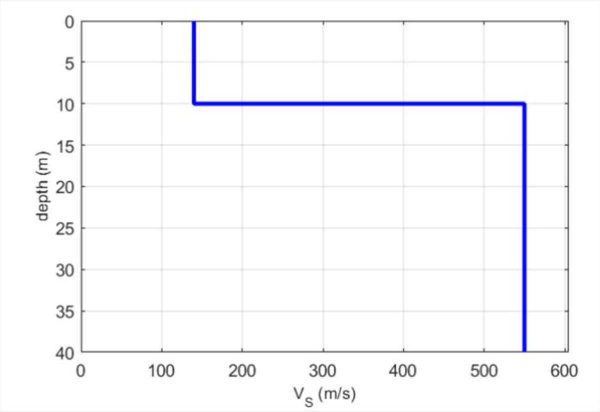


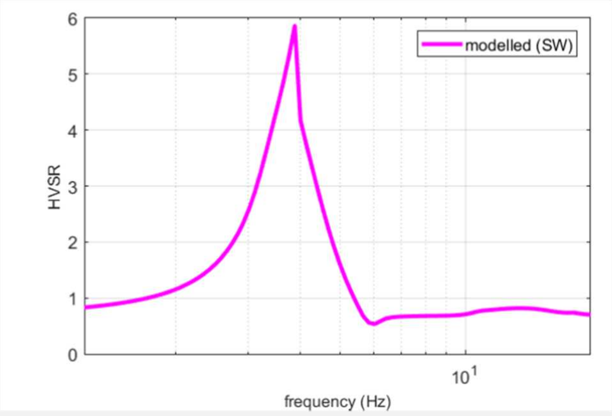
HVSR modelling

Both during direct modelling and automatic inversion it is good practice (we would say absolutely recommended) to always insert a very deep and very fast layer that serves to stabilize the mathematics behind the HVSR calculation.
In practice, this means that the actual situation must be reproduced in the most correct way.
If in your area there are, for example, (let's simplify things) 10 meters of clay and then several meters of gravel, to correctly simulate the peak related to this contact it is also necessary to introduce a deep contact between the gravel and what there must be below it even if this deep contact is of no interest to you and is not actually "visible/identifiable" with your data.

Therefore, a model that for you might be:
10 m of silt (V_S: 140 m/s)
gravel half-space (V_S: 550 m/s - for several dozens or hundreds of meters)

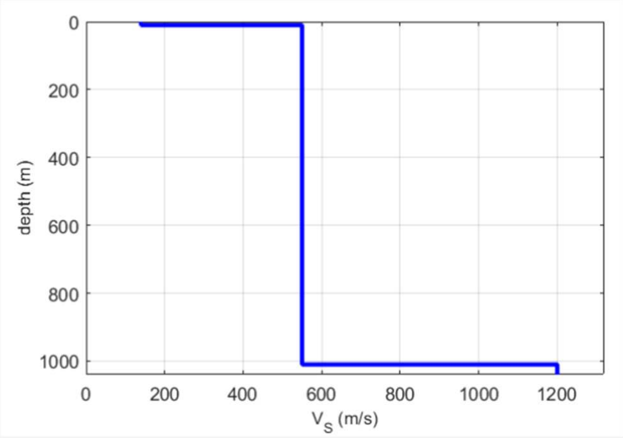
should be rather considered/modelled as:
10 m of silt (V_S: 140 m/s)
1000 m of gravel (V_S: 550 m/s)
rocky half-space (V_S: 1200 m/s)

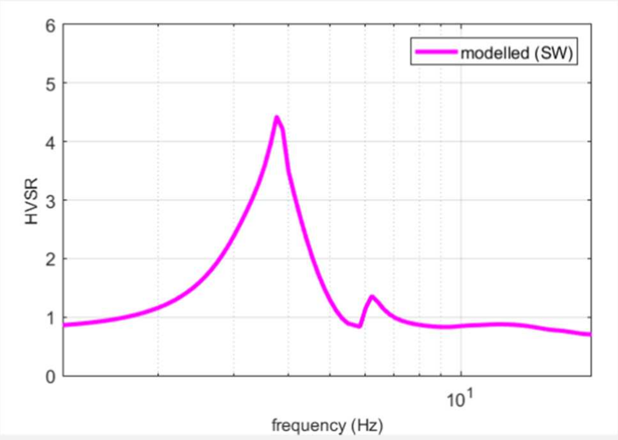




Adding a fast deep layer (actually "invisible") will produce the following result:

layer	Vs (m/s)	thickness (m)	depth (m)
1	140	10	10
2	550	1000	1010
3	1200	0	0



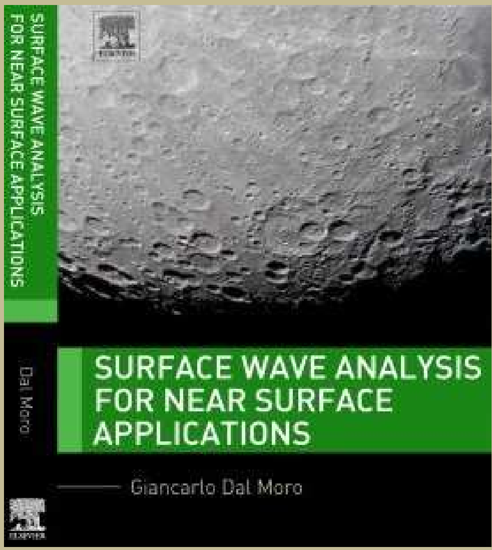


As you can see, now the peak relating to the silt-gravel contact is smaller (it was about 6 and now is about 4.4) and the shape of the HVSR curve is slightly different.

It should be stressed that this is related to the mathematics of the HVSR (in the final report you do not have to include this deep level if there is no evidence of it in the data - evidence should be at very low frequencies).

Also bear in mind the role of the alpha (α) factor (gradually lower values make the HVSR curve lower).

The H/V spectral ratio and the Love waves: the α factor

Extracted from 

The experimental HVSR is basically the result of the joint action of the Rayleigh and Love waves according to the following equation:

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

being H_R and V_R the contribution of Rayleigh waves (in terms of power spectra - see Arai and Tokimatsu, 2004) on the horizontal (H) and vertical (V) component, and H_L the contribution related to Love waves (the parameter α can therefore be considered as the contribution of Love waves to the experimental HVSR).

For a complete modelling of the observed HVSR, the value of the parameter α must be considered appropriately, i.e., the relative quantity of Love waves which, incidentally, is probably a function of the specific weather/seasonal conditions

The modelling presented in Figure A shows the effect of Love waves: the same V_S profile is used to compute the HVSR considering two different (extreme, α = 0.2 and α = 0.9) values of the parameter α.

Two consequences are straightforward:

1. The relative amount of Love waves (expressed by the α – *alpha* - factor) should be considered as one of the variables in the inversion/modelling of the HVSR curve (experience teaches that this value usually takes a value between 0.3 and 0.5).

2. The HVSR curve alone is absolutely insufficient to limit the definition of a V_S profile even when stratigraphic/geological information is available and the only solution is provided by joint analysis with other geophysical data (such as surface wave dispersion).

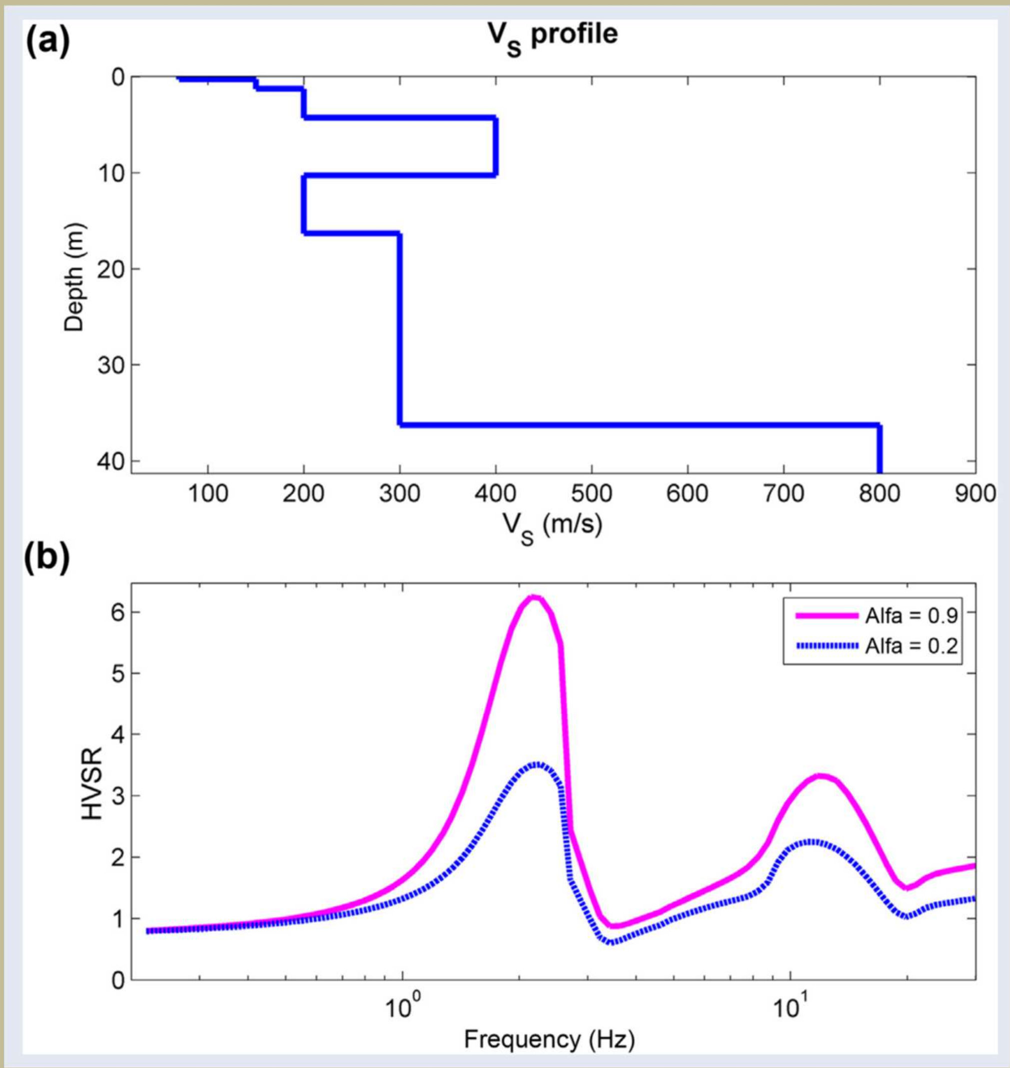


Figure A Effect of Love waves on the HVSR curve: (a) V_S profile considered; (b) HVSR curves obtained considering a different "quantity" of Love waves (α factor).

More details in *Surface Wave Analysis for Near Surface Applications* (Dal Moro G., 2014 - Elsevier, 252 pp).

HVSR and site resonance frequency: almost an hoax

The topic is actually extremely complex and this manual is not meant to be a text book.

Here we just recall the fundamental equation regarding the HVSR peak (that surely cannot be used in a simplistic way):

$$T_o = \frac{4\mathrm{H}}{\mathrm{V_S}}$$

where:
V_S = mean V_S down to the horizon responsible for a HVSR peak
H = thickness of the sediments over the considered horizon/contact

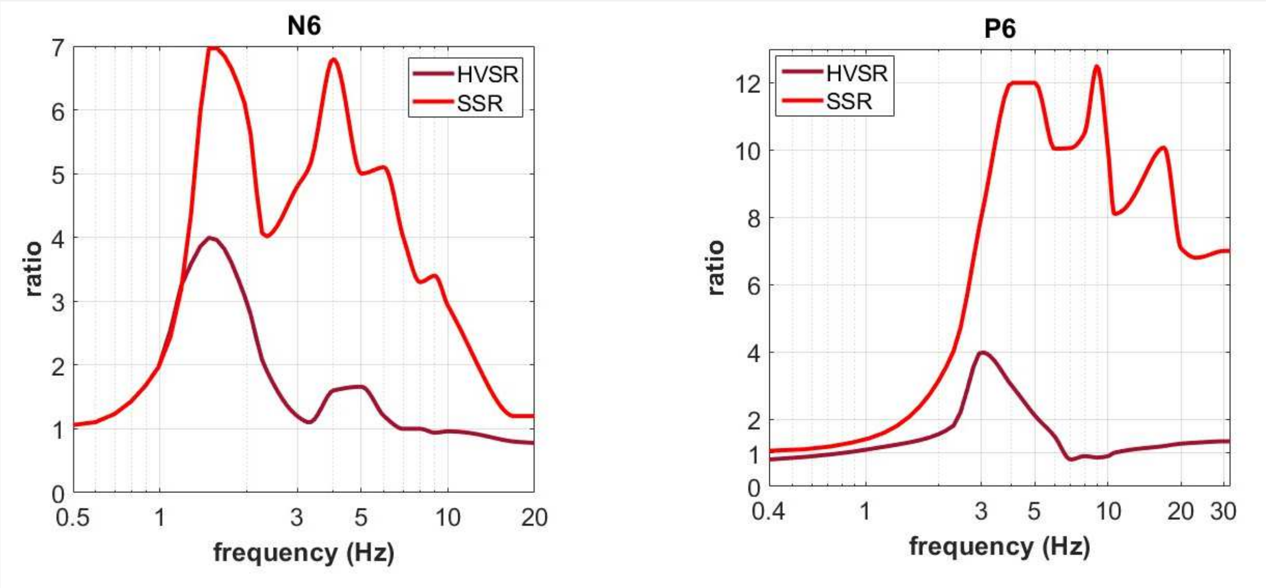
For instance, in case there is a strong V_S increment at a depth of 37 m (e.g. 37 meters of unconsolidated sandy materials [average V_S value equal to 250 m/s] over a thick gravel layer), we should obtain a HVSR peak at about 1.7 Hz.

Remember that an HVSR peak does not necessarily means *bedrock* (see e.g. Dal Moro 2018 - *Effective Active and Passive Seismics for the Characterization of Urban and Remote Areas: Four Channels for Seven Objective Functions*).

But, does the peak in the HVSR represents the resonance frequency?

No. See for instance Perron et al (2018) and the few evidences summarized also in our 2020 Springer book mentioned throughout this manual.

The HVSR has been in use in seismology since about the late 1960s (e.g. Mark and Sutton, 1975). In the 1980s, in Japan, some studies were carried out in order to evaluate its possible use in the seismic-hazard assessment (see Nakamura's papers in the References). As a matter of fact, the relationship between the amplification during a quake and the HVSR curve has never been clearly demonstrated and theoretical considerations and experimental data do not support this idea which is unfortunately very popular.
Several studies (e.g. Perron et al., 2018 and references therein) have shown that the amplification actually recorded during an earthquake significantly deviates from the HVSR curve; see for instance the data in the following Figure.



Comparison between the HVSR curve and the actual amplification curve obtained from SSR (Standard Spectral Ratio) analysis from a series of accrual earthquakes (after Perron et al., 2018). Note the significant difference between the HVSR curve and actual measured amplification.

Therefore, the HVSR represents a valid observable to estimate the V_S of the deeper layers (e.g. Arai & Tokimatsu, 2005; Dal Moro, 2015; 2020), but it should not be considered as an estimate of site amplification.

Automatic inversion of the HVSR curve

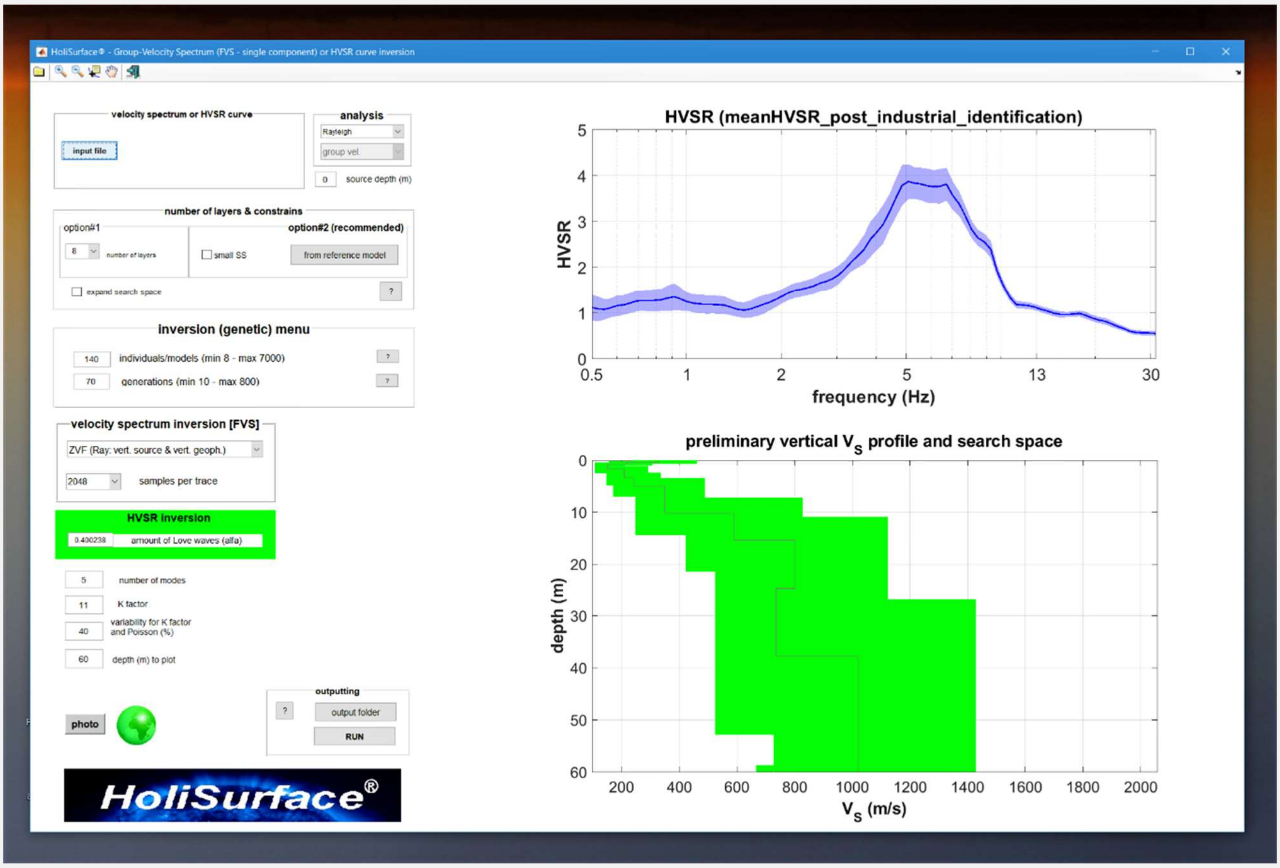
The **single-observable inversion panel** (“single obs inv: disp or HVSR”) available from the main panel (as well as from others) allows you to automatically invert a previously-computed HVSR curve.
As always, you just need to define the *search space* (minimum and maximum thickness and shear-wave velocity for each layer [you can consider up to 12 strata]).

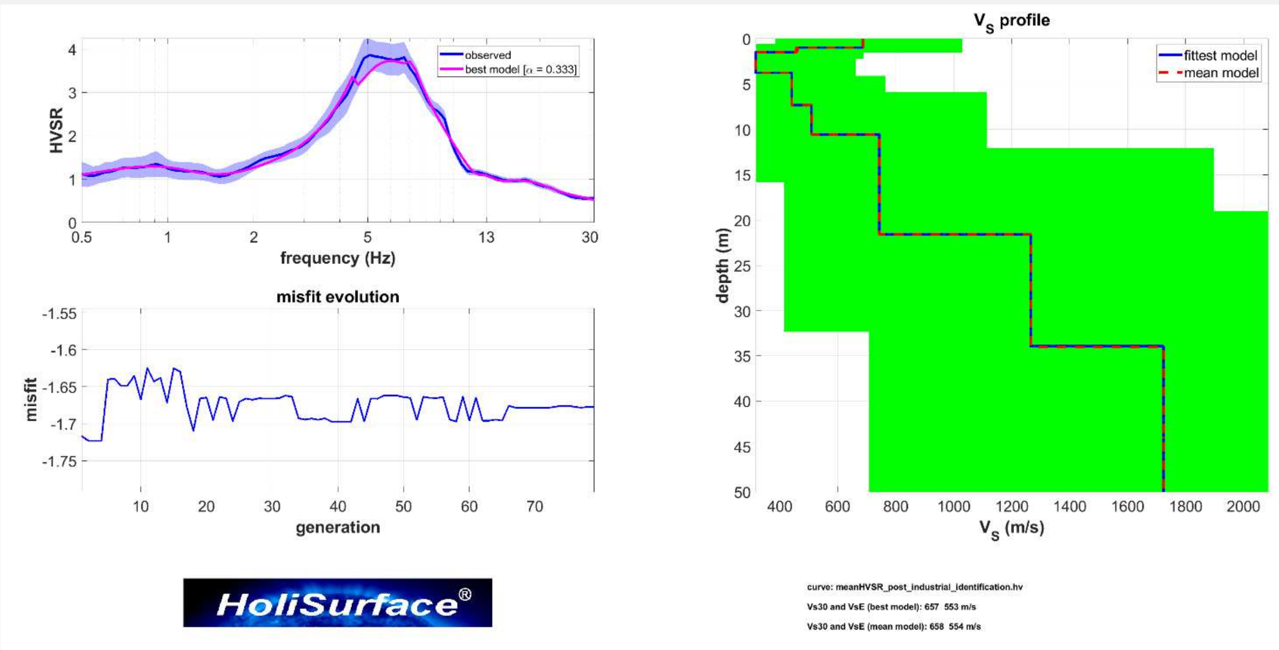
Before the modeling or the inversion of the HVSR curve, remember to carefully identify and remove possible industrial signals (see previous sections of the manual).

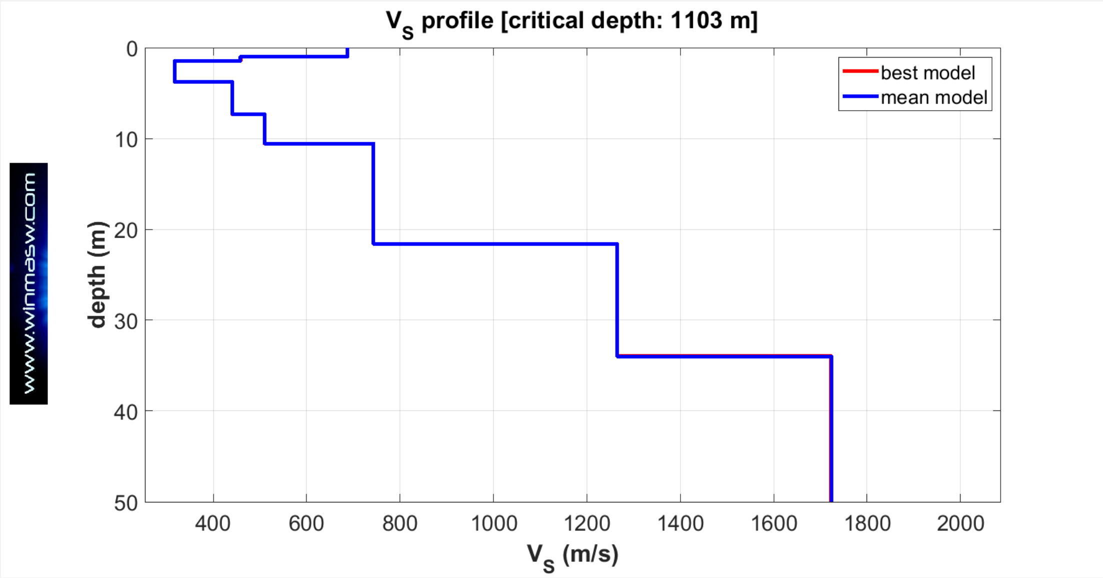
Procedure:

1) upload the previously-computed HVSR curve (.hv file);
2) define the limits of the *search space* (Vs and thicknesses) by choosing a previously saved starting model (option # 2 - recommended) or considering the option # 1 (fixing the number of layers and the search space limits which need to be accurately defined based on the geological knowledge of the site);
3) choose the number of models and generations, the α (alpha) factor value (usually around 0.3) and the other parameters (number of modes to use, variability of the Poisson values, etc.) [see previous sections of the manual];
4) If we are considering a curve in a very-high frequency range, it can be useful to increase the number of "samples per trace" (the useful limits for common geological-geotechnical applications are generally between 0.5 and 15 Hz and if your curve is in this frequency range you do not need to increase the default 512 value);
5) upload a (possibly geo-referenced) photo of the survey (optional);
6) choose the maximum depth to be displayed for the final V_S profile;
7) launch the inversion (RUN button).

In the following snapshots an example of HVSR automatic inversion.


HoliSurface® - Group-Velocity Spectrum (FVS - single component) or HVSR curve inversion
velocity spectrum or HVSR curve
input file
analysis
Rayleigh
group vel.
source depth (m)
number of layers & constrains
option#1
number of layers
option#2 (recommended)
small SS
from reference model
expand search space
inversion (genetic) menu
individuals/models (min 8 - max 7000)
generations (min 10 - max 800)
velocity spectrum inversion [FVS]
ZVF (Ray: vert. source & vert. geoph.)
samples per trace
HVSR inversion
amount of Love waves (alfa)
number of modes
K factor
variability for K factor and Poisson (%)
depth (m) to plot
photo
outputting
output folder
RUN
HoliSurface®
HVSR (meanHVSR_post_industrial_identification)
HVSR
frequency (Hz)
preliminary vertical V_S profile and search space
depth (m)
V_S (m/s)

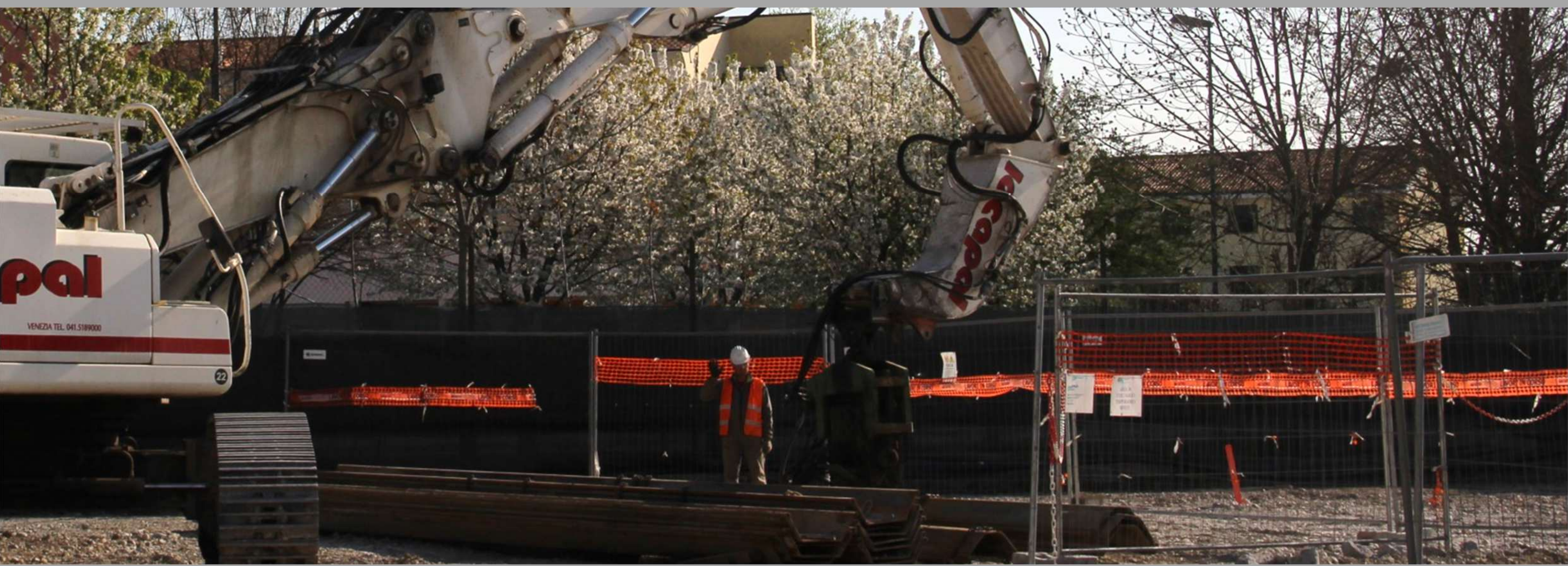

observed
best model [α = 0.333]
HVSR
frequency (Hz)
misfit evolution
misfit
generation
HoliSurface®
V_S profile
fittest model
mean model
depth (m)
V_S (m/s)
curve: meanHVSR_post_industrial_identification.hv
Vs30 and VsE (best model): 657 553 m/s
Vs30 and VsE (mean model): 658 554 m/s



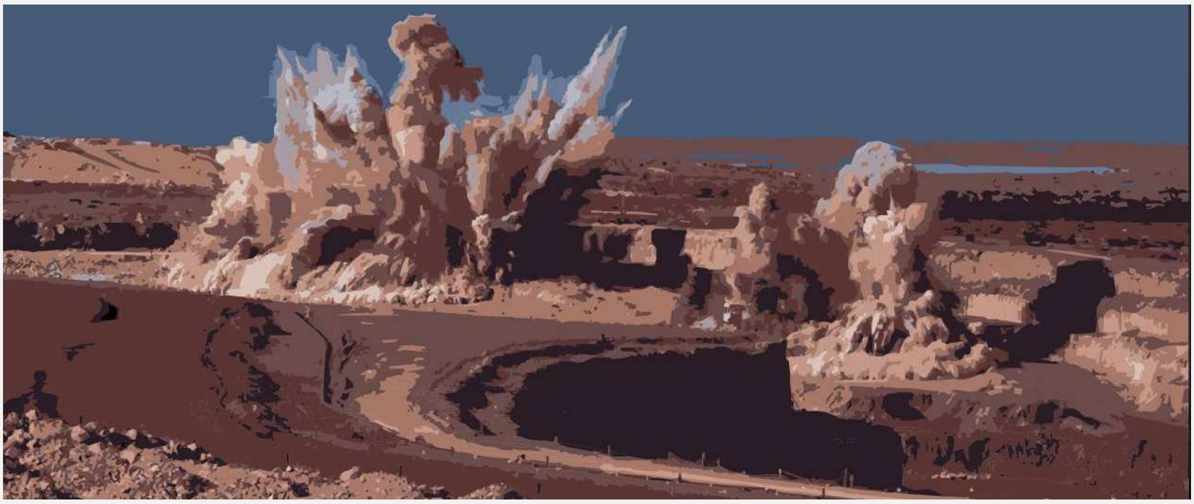
Obviously, the problem of the HVSR is always the same: the **non-uniqueness of the solution**. This is why the *search space* must be fixed with great care (based on your hypotheses / knowledge of the local stratigraphy) and prefer the joint inversion together with dispersion data (velocity spectra).

A "peculiarity" of this panel. If at the end of the inversion procedure the result is not too bad (not too far from the field data) but you are still not completely satisfied, you can re-launch the inversion without changing any parameters and the new inversion will start from the model just identified (in the previous inversion).

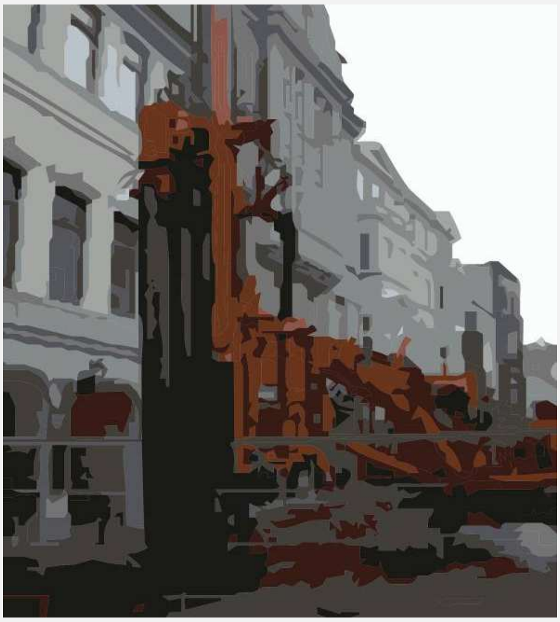
The “*critical depth*” for the HVSR is estimated based on the procedure reported in the ***On the efficient acquisition and holistic analysis of Rayleigh waves: Technical aspects and two comparative case studies*** (Dal Moro et al. 2019) paper [please, note that the frequency of the possible peak has nothing to do with the investigated depth which, instead, depends on the minimum frequency of the considered curve].

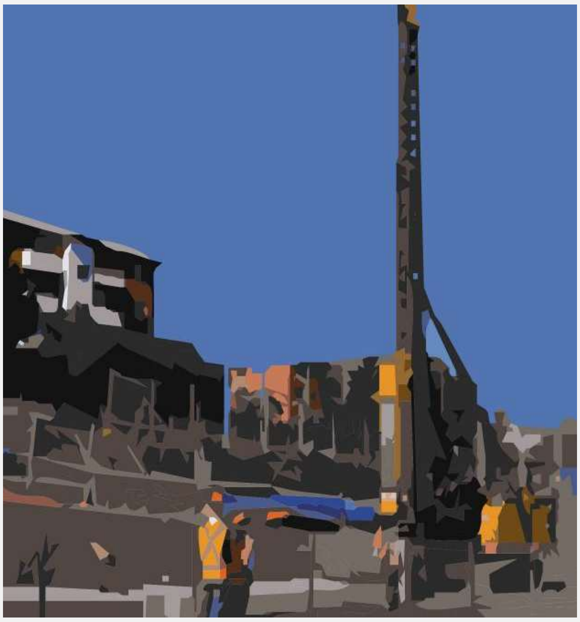


10. Vibration analysis (DIN-4150, UNI-9614 and ISO-2631)



The "DIN-4150, UNI-9614, ISO-2631" module lets you analyze a dataset in order to verify whether or not the vibrations exceed certain threshold values set by three well-known standards (DIN-4150, UNI-9614 and ISO-2631).
The most common applications are related to the analysis of vibrations induced by quarry breakaways, passing trains or metros in urban areas and so on.





To perform these analyses, the data need to have been acquired with instruments that return the data expressed in *physical units* (mm/s or m/s) and not in "counts" (units per se devoid of physical meaning because they are linked to the electronics of the instruments used).
The data format should be the usual SAF format (i.e., the format commonly used for passive acquisitions useful for HVSR analysis).

Recommendation:
avoid using accelerometers and use velocimeters (geophones)

In a nutshell: obtain the accelerations from the velocities is a trivial operation (*derivation*), while the opposite (from acceleration to velocity) is something that has always been carefully avoided by all researchers/seismologists because the *integration* operation is in itself "unstable" and almost necessarily provides non-fully reliable velocities values.

Data acquisition for DIN/UNI/ISO analysis with our HS integrated system

The essential point is that the data we enter in the software is not in "counts" but in physical units (in our case mm/s).

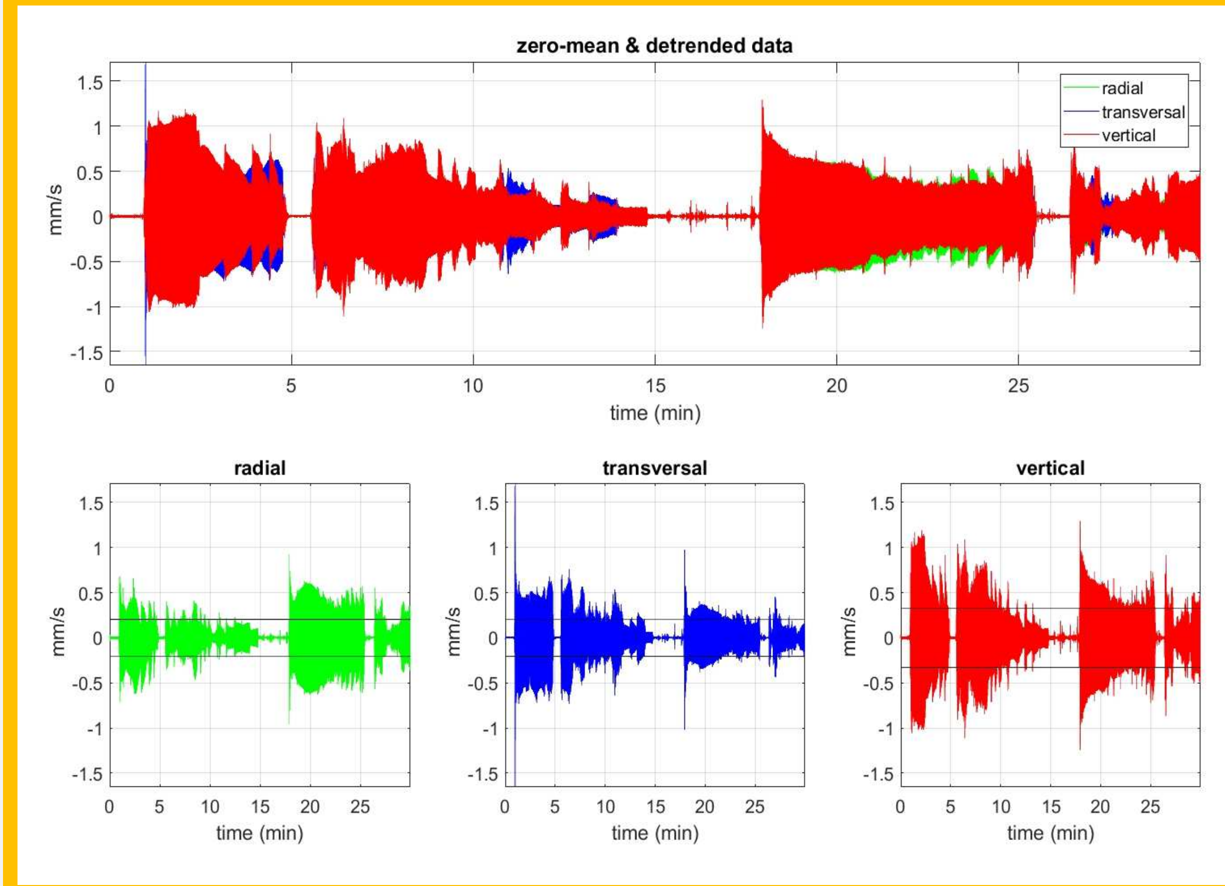
If you use our *HoliSurface®* acquisition system, there are two things you need to know for sure during the acquisition process:

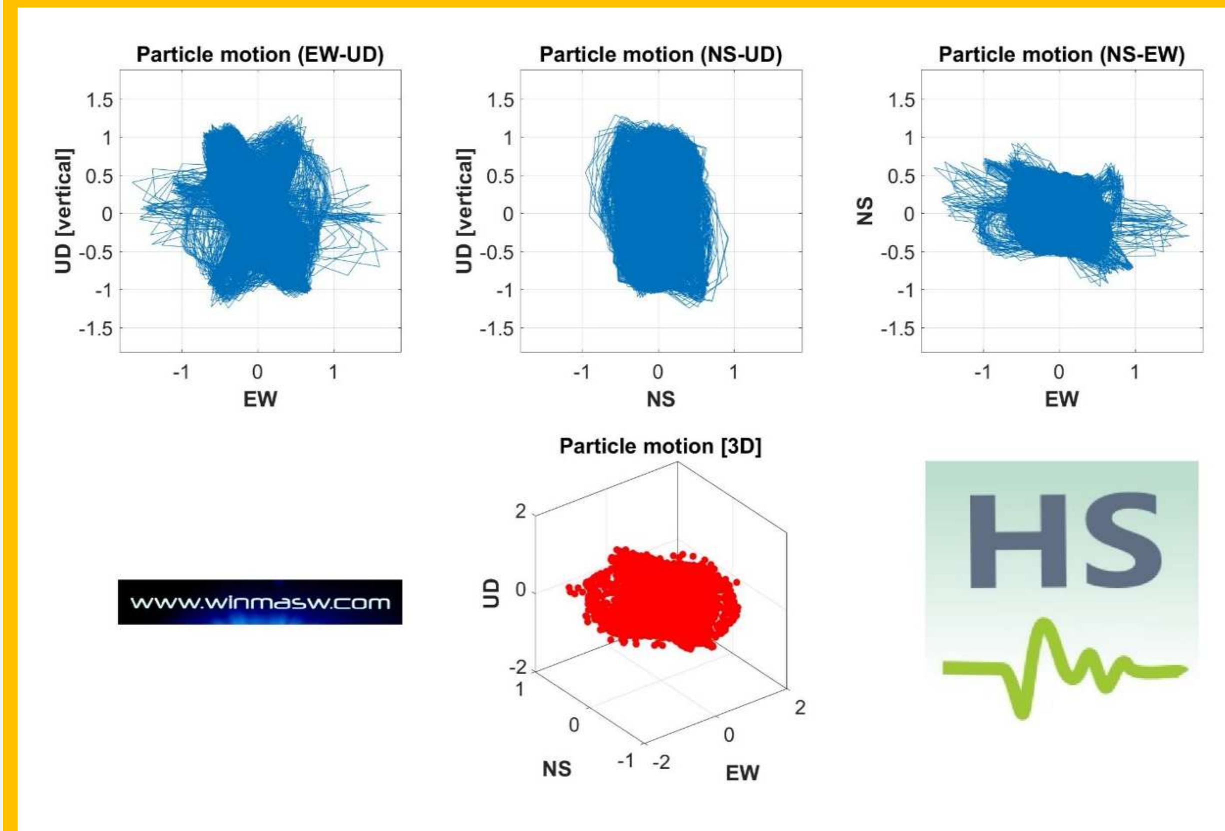
1. you have entered the correct sensitivity of the geophone (the HOLI3C geophone is supplied with the sensitivity value)

2. during acquisition, you must avoid activating the option "High Gain for all geos".

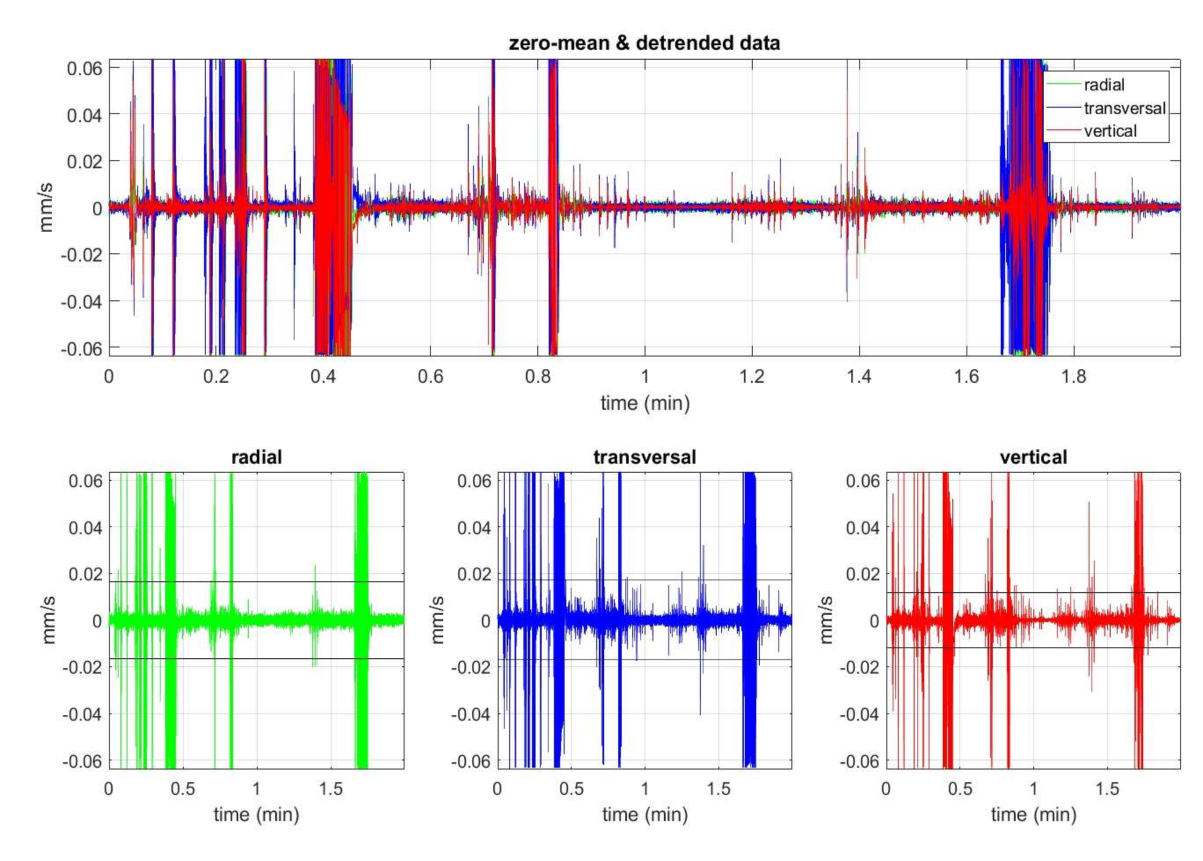
If the gain is erroneously set and/or the signal has an excessive amplitude with respect to the *dynamic range* of your *acquisition system*, the signal could be clipped (saturation) and the data would be unsuitable for this vibration analyses.

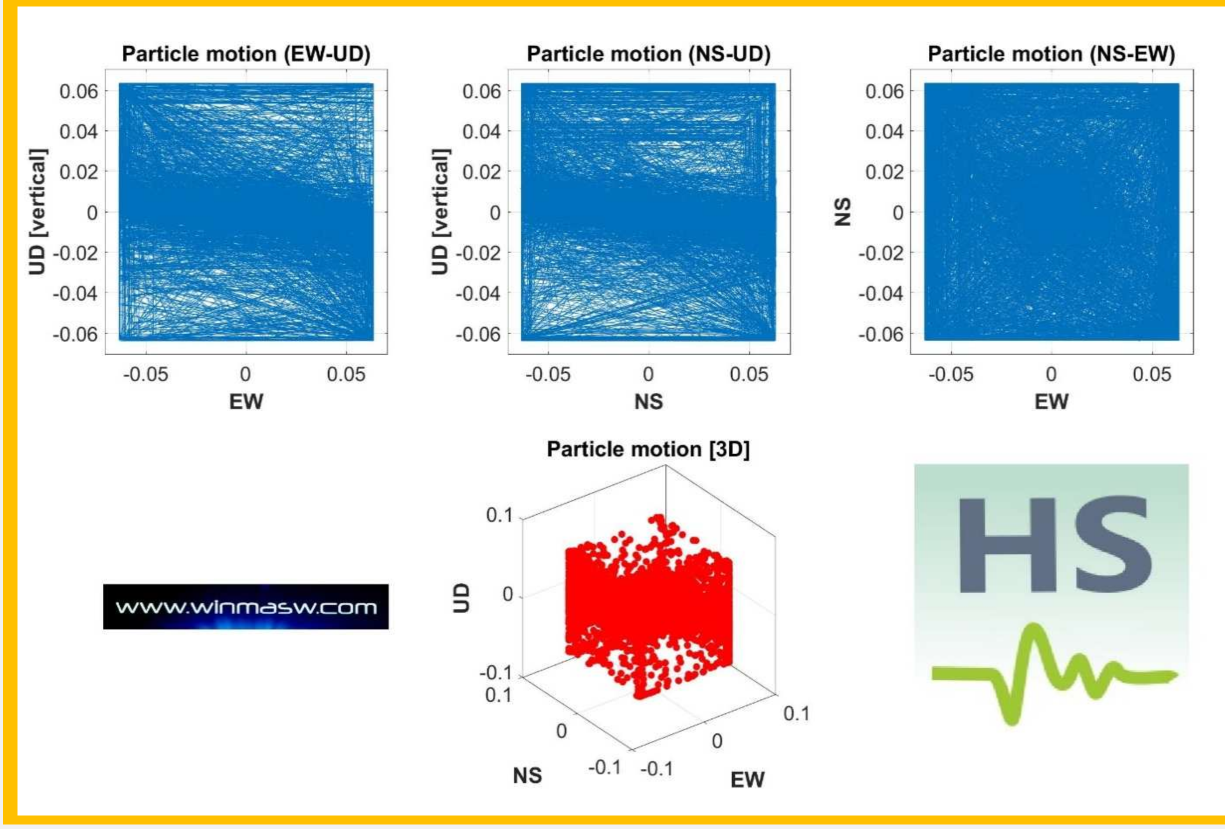
Correct (non-clipped) signal:





Clipped signal (data cannot be used for this sort of analysis):





Main panel

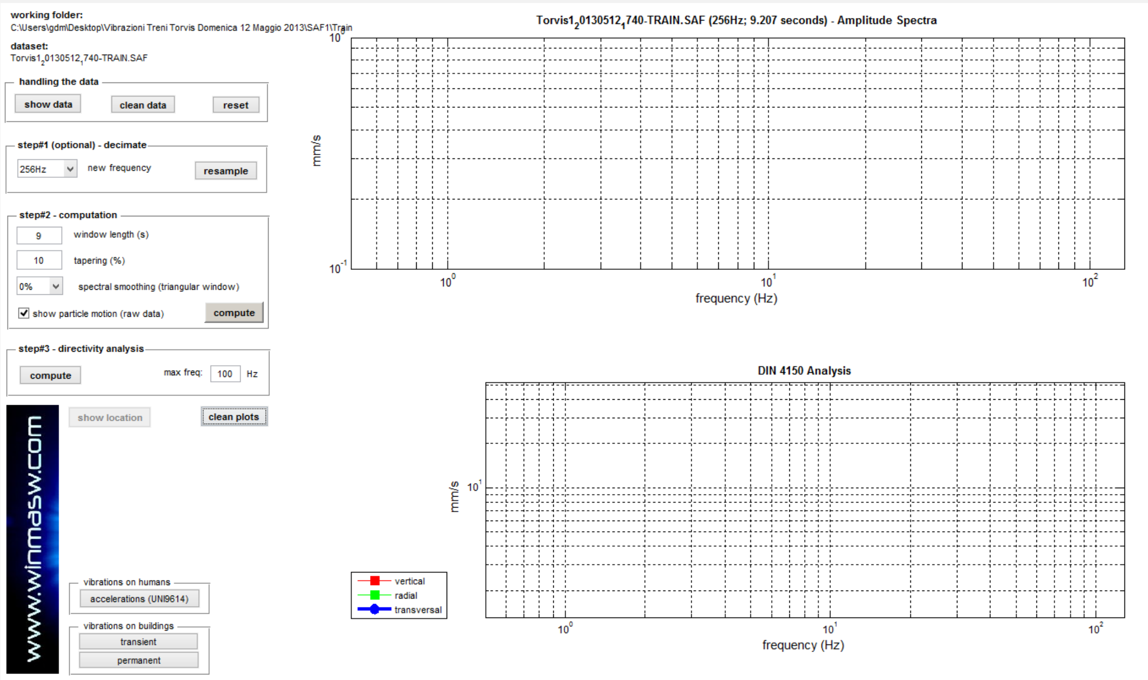
The main screen of this module is very similar to the one used for HVSR analysis. In a nutshell, you need to (see also case studies):

1. upload the field SAF/seg2 file (second icon from the left on the toolbar);

2. remove (if desired) part of the recorded seismic traces (you can remove part of the data where nothing happens/occurs);

3. proceed with the calculation of the vibration levels in relation to buildings (DIN4150 standard and limits) with the "compute" button.

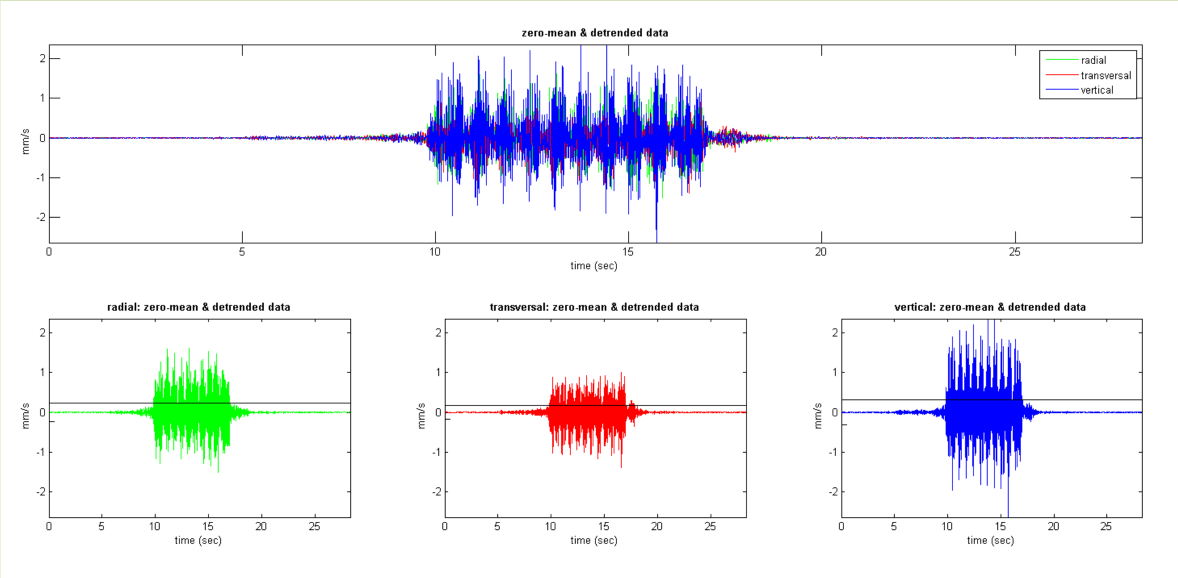
By default, the analyses are carried out on the entire dataset (i.e., a single window), but you can change this criterion by acting on the parameter "*window length*." If, for example, the signal we want to analyze is very long (e.g., 1 minute) and we want to have an average of its intensity, you can divide the signal into a series of windows of length equal to the "*window length*" (option not recommended for non-experts).



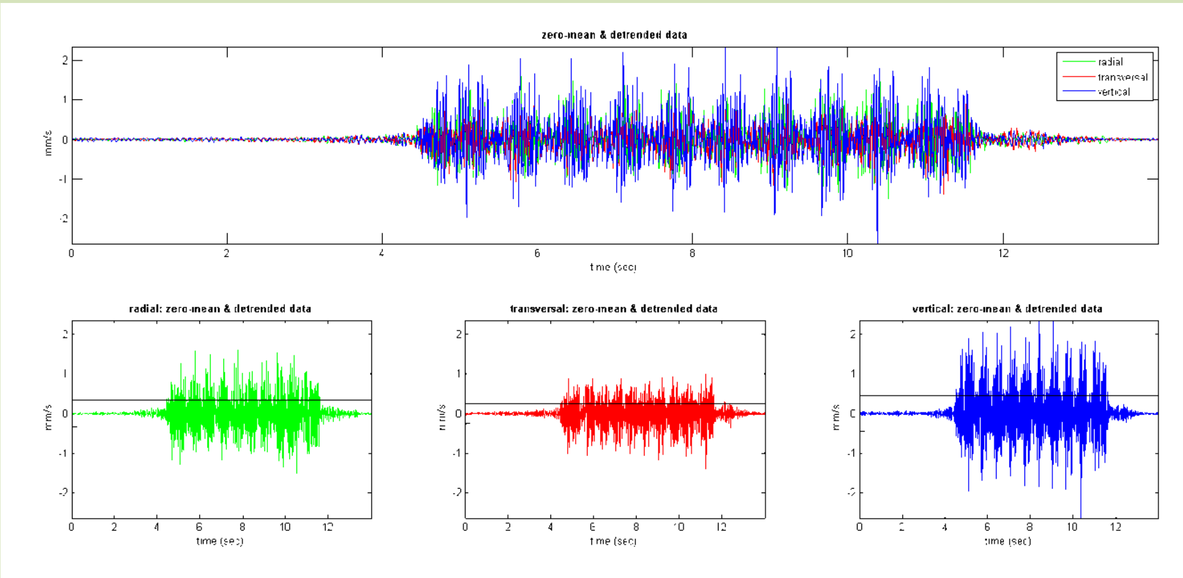
If you later want to evaluate the effects on humans (UNI9614 and ISO2631), just do the computation for accelerations ("accelerations" button).

Example of computation of vibrations at the railway line when trains pass

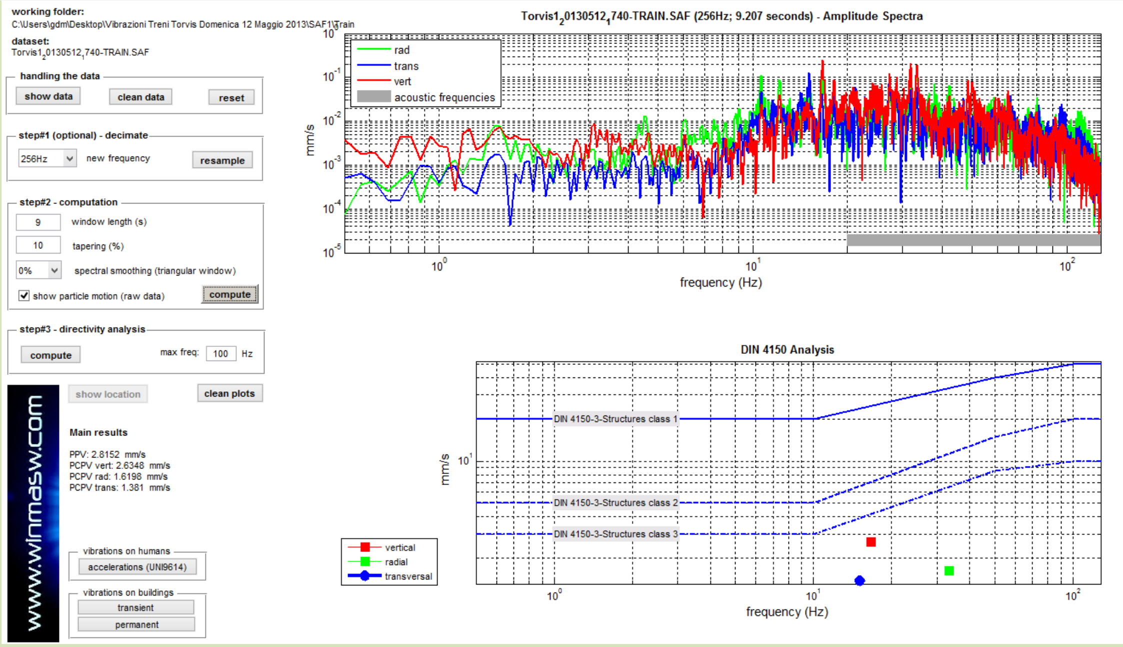
Field data with passing trains:



We remove some data before and after a train passes (optional operation - "*clean data*" button):

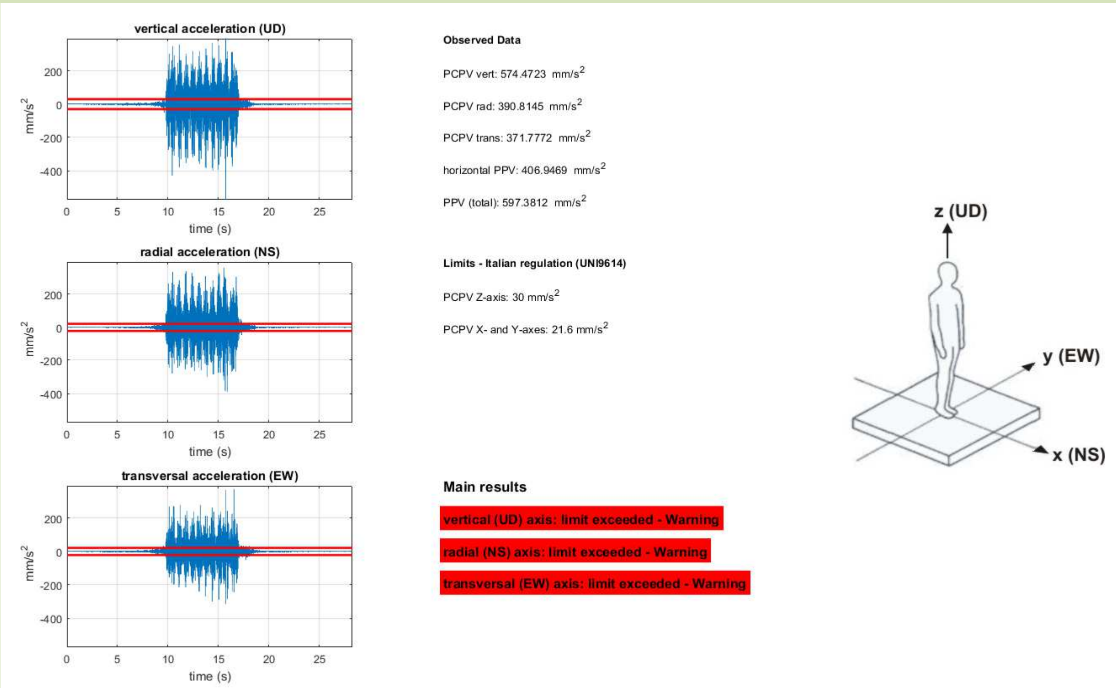


With the "compute" button we can evaluate the danger with respect to structures/buildings (DIN4150) determined by considering the velocity (bear in mind that the software assumes that the data represent precisely the velocity in mm/s - standard units for calibrated geophones):



It should be noted that in this case the vibrations induced by a passing train do not exceed any of the thresholds set by the regulations.

We now evaluate the value of a passing train with regard to the effects on humans (UNI9614 and ISO2631), which are determined considering the accelerations and no longer the velocity.



It should be noted that, in this case, a passing train (which did not represent a problem for the buildings) is able to generate a disturbance on humans exceeding the limits set by the regulations.

This situation (vibrations not exceeding the limits for the buildings but exceeding those of about the effects on the human body) is quite common and should not come as a surprise.

Some useful documents

http://www.civil.ist.utl.pt/~luisg/textos/REGC.pdf

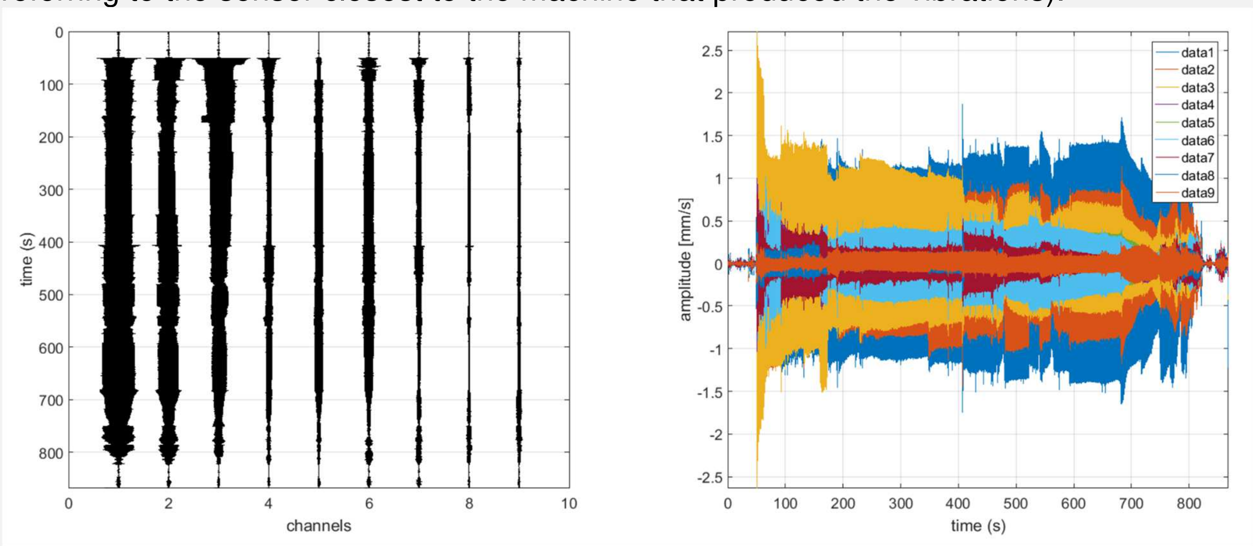
http://www.nzta.govt.nz/projects/completing-wrr/docs/docs-enquiry/application/g19-assessment-of-vibration-effects-report.pdf

https://uwaterloo.ca/centre-of-research-expertise-for-the-prevention-of-musculoskeletal-disorders/resources/position-papers/whole-body-vibration-overview-standards-used-determine

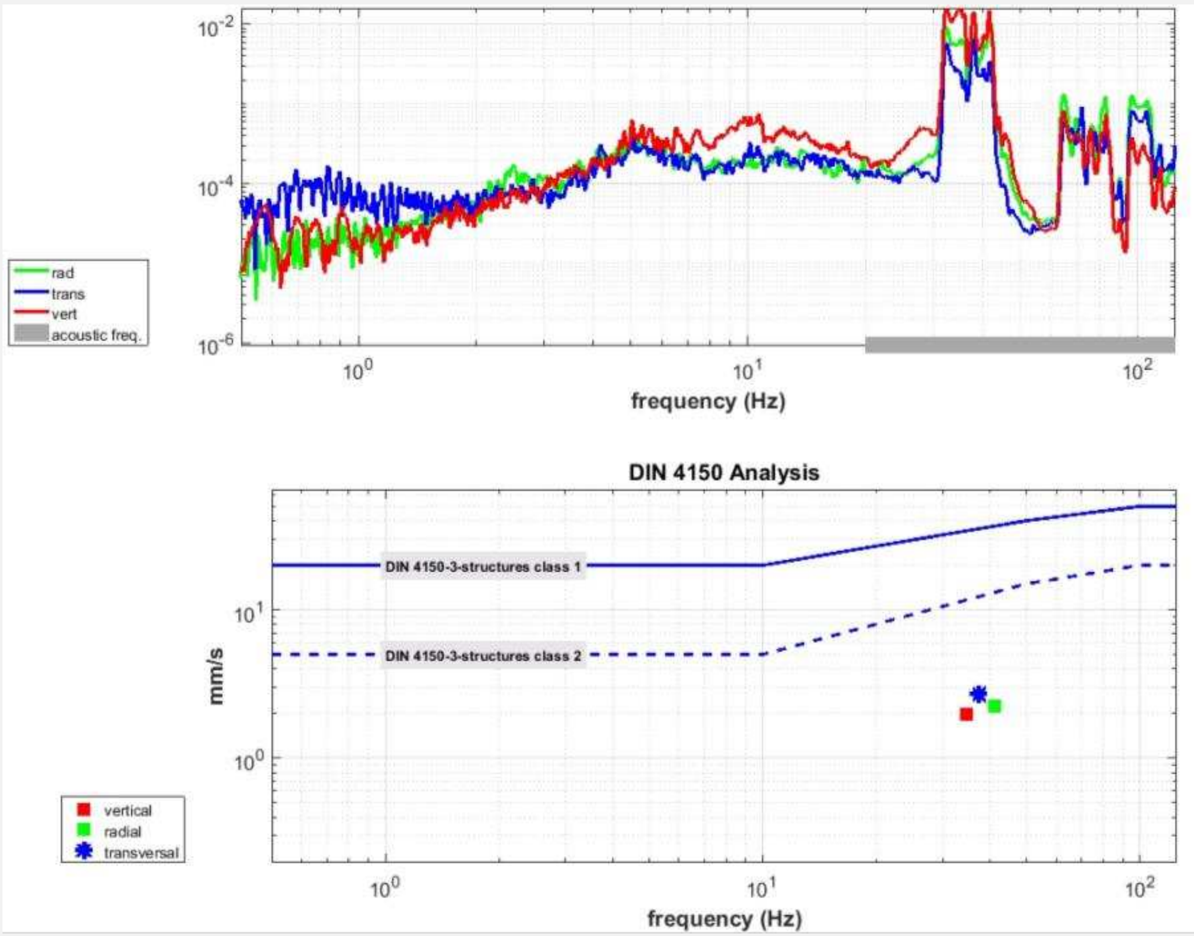
The NEOWISE comet from the Eliosoft headquarter [July 2020]

Example (case study)

It is possible to load a "composite" dataset in which, for example, the first three traces refer to a 3C geophone and the following ones to *n* single-component geophones) [see sequential data shown].
It is possible to note that in this case, the maximum trace width is about 2.6 mm/s (clearly referring to the sensor closest to the machine that produced the vibrations).



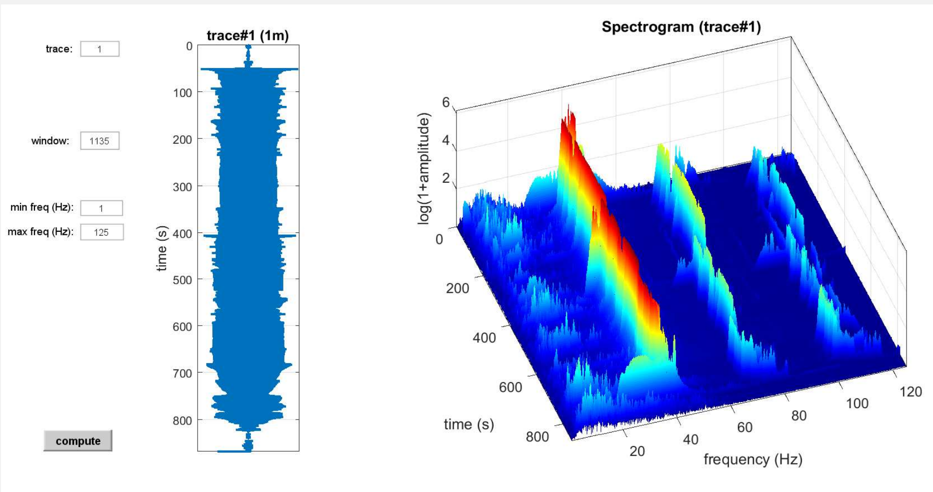
The following is the DIN4150 analysis for sensor P1 (the one with the largest amplitudes since it is the closest to the vibration source).

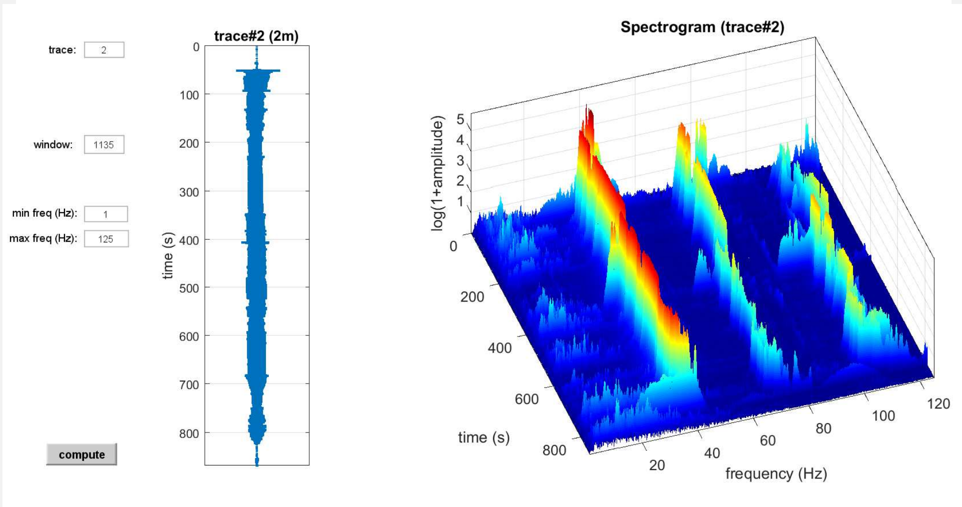


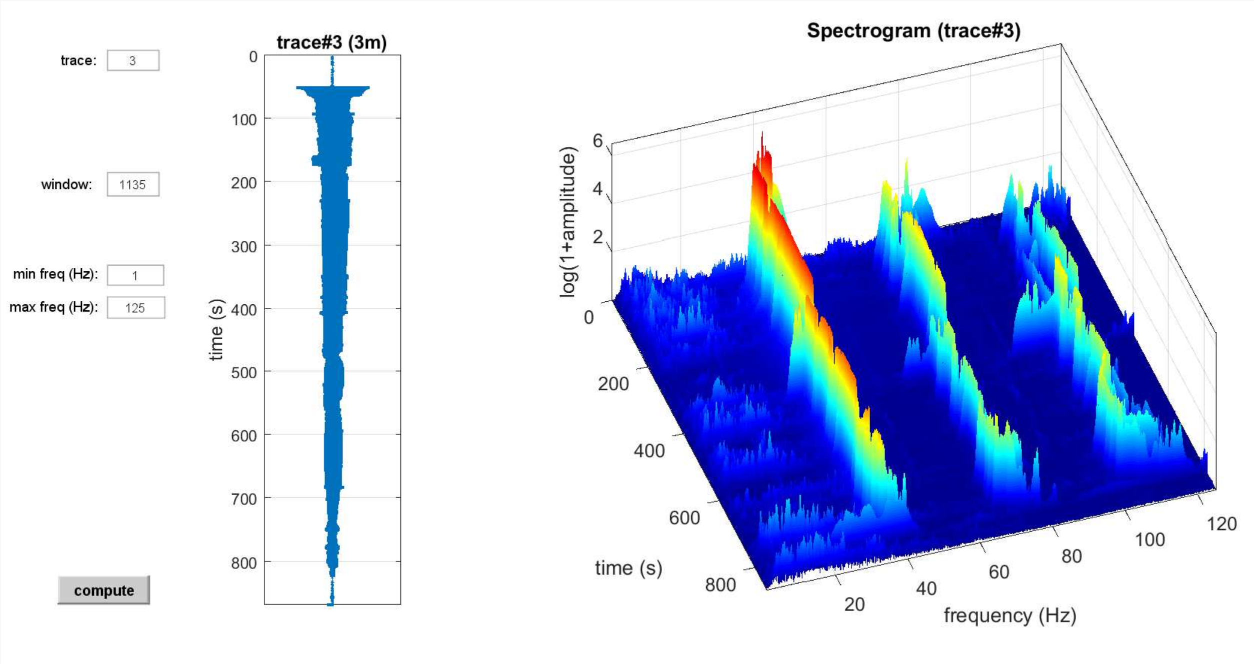
Common question:
Is there a strict correspondence between the frequencies of the maximum amplitudes (indicated by the amplitude spectra shown in the upper part of the screen) and those of the maximum speed peaks (lower part of the screen, frequency-speed graph)?

Answer:
Yes and no.
The frequencies of the amplitude spectra are computed by considering/supposing a periodic signal (see the Fourier bottom-line theory) while the velocity peaks necessarily refer to a specific and isolated point/value (which does not have a specific frequency). This fact becomes particularly important when we are considering transient events (for example quarry blasts).
When, on the other hand, we are analyzing "continuous" vibrations (for instance from constructions sites), these two things (frequencies of the peak velocity and maximum amplitude of the amplitude spectra) are clearly more closely related and the frequencies of the velocity peaks are usually practically the same as the maxima of the amplitude spectra are (see for instance previous figure).

The three spectrograms shown below (for the vertical, radial and transverse components, respectively) show the very high frequencies used (around 40Hz, very far from the frequencies typical of any type of building).



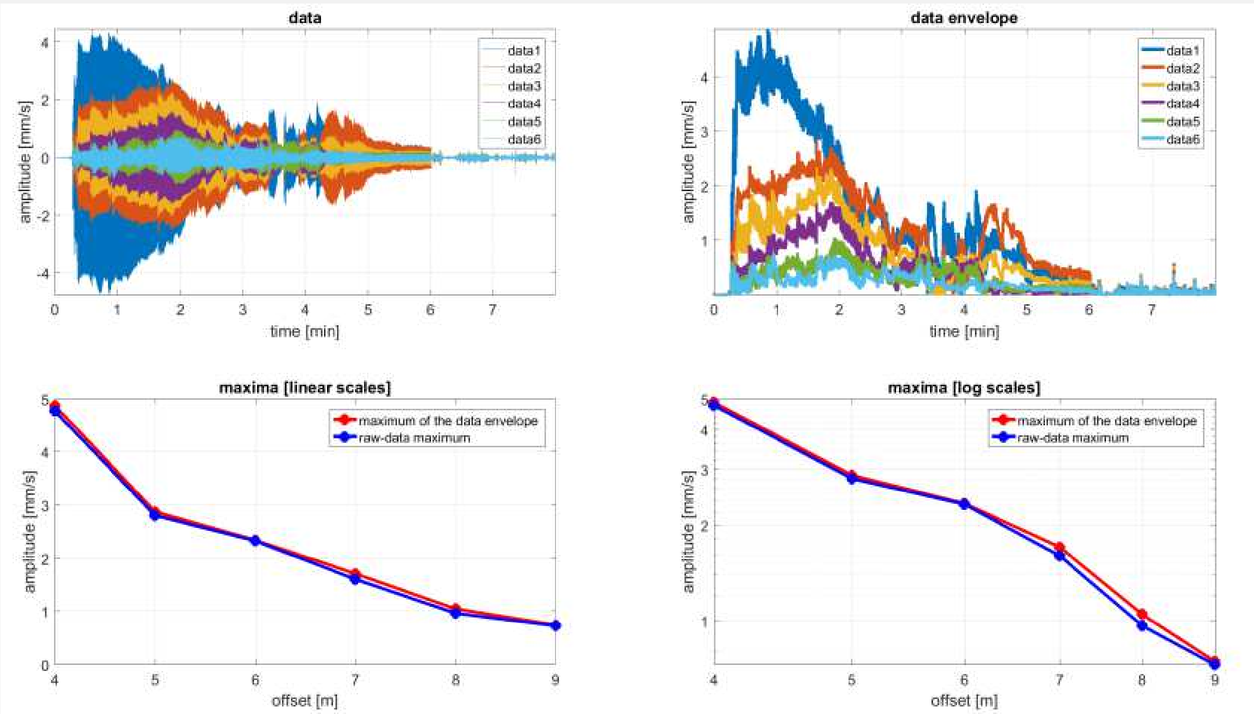




As is clear from the data and analyses illustrated, the maximum vibration value (around 2.6 mm/s, at a frequency of around 40 Hz) is well below the limits suggested by the standard.

Signal attenuation

The analysis of the amplitude decrease as a function of the distance from the source (offset) is useful for various reasons (illustrated in detail during our training sessions).

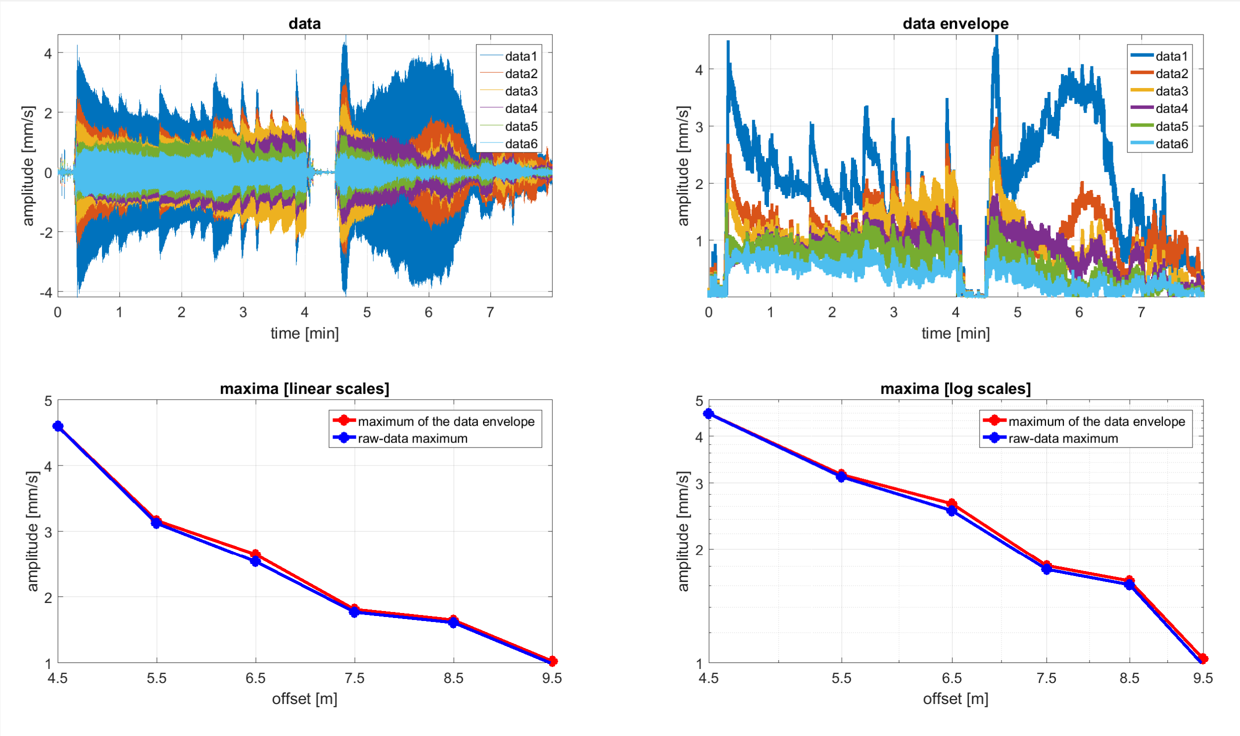


In the case reported here, the analysis of the decrease in amplitude as a function of the distance from the source (offset) shows that at about 4.5 m from the source the peak velocity observed was 4.6 mm/s (40% of the regulatory limit at 30 Hz [working frequency of the machine used]), then decreasing to 1 mm/s (9% of the regulatory limit) at 9.5 from the source.

A further dataset

Multi-offset data for checking the vibration attenuation and predicting the amplitude at any additional distance/offset.

In this case: minimum offset 5.5 m and geophone distance 1 m.



Please note that, in accordance with the theory, by adopting a logarithmic amplitude scale, the curve (amplitude vs offset) tends to follow a linear trend.

The maximum of the raw data is the maximum of data as uploaded (i.e., raw data).

The maximum envelope is the maximum envelope of the uploaded data.

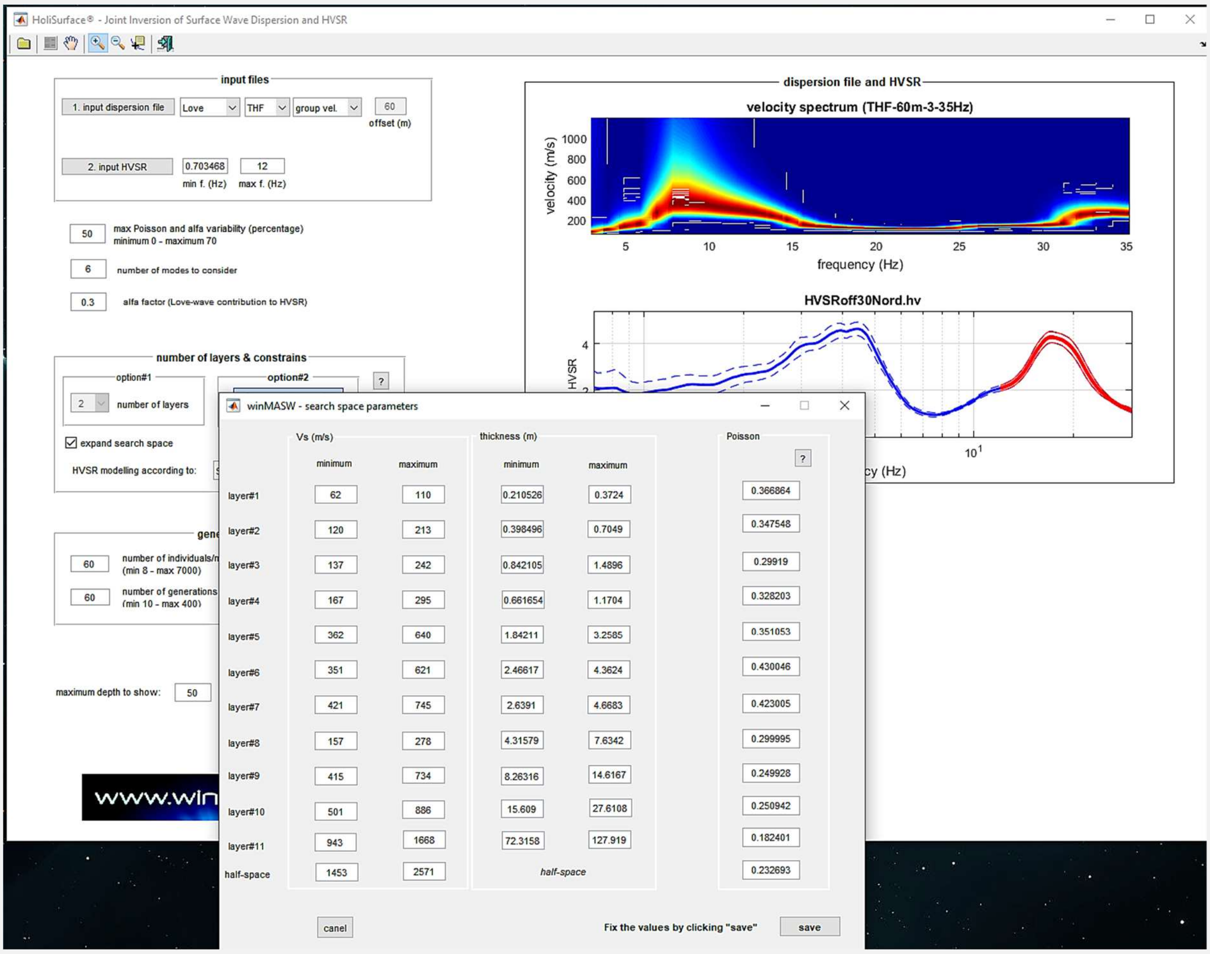
Both values should be very similar although, by the very nature of the envelope, it is normal that the maximum of the envelope may be slightly higher (depending on the nature of the data and the sampling used - there should be no major difference [see images above where the red (maximum envelope) and blue (maximum raw data) curves practically overlap]).

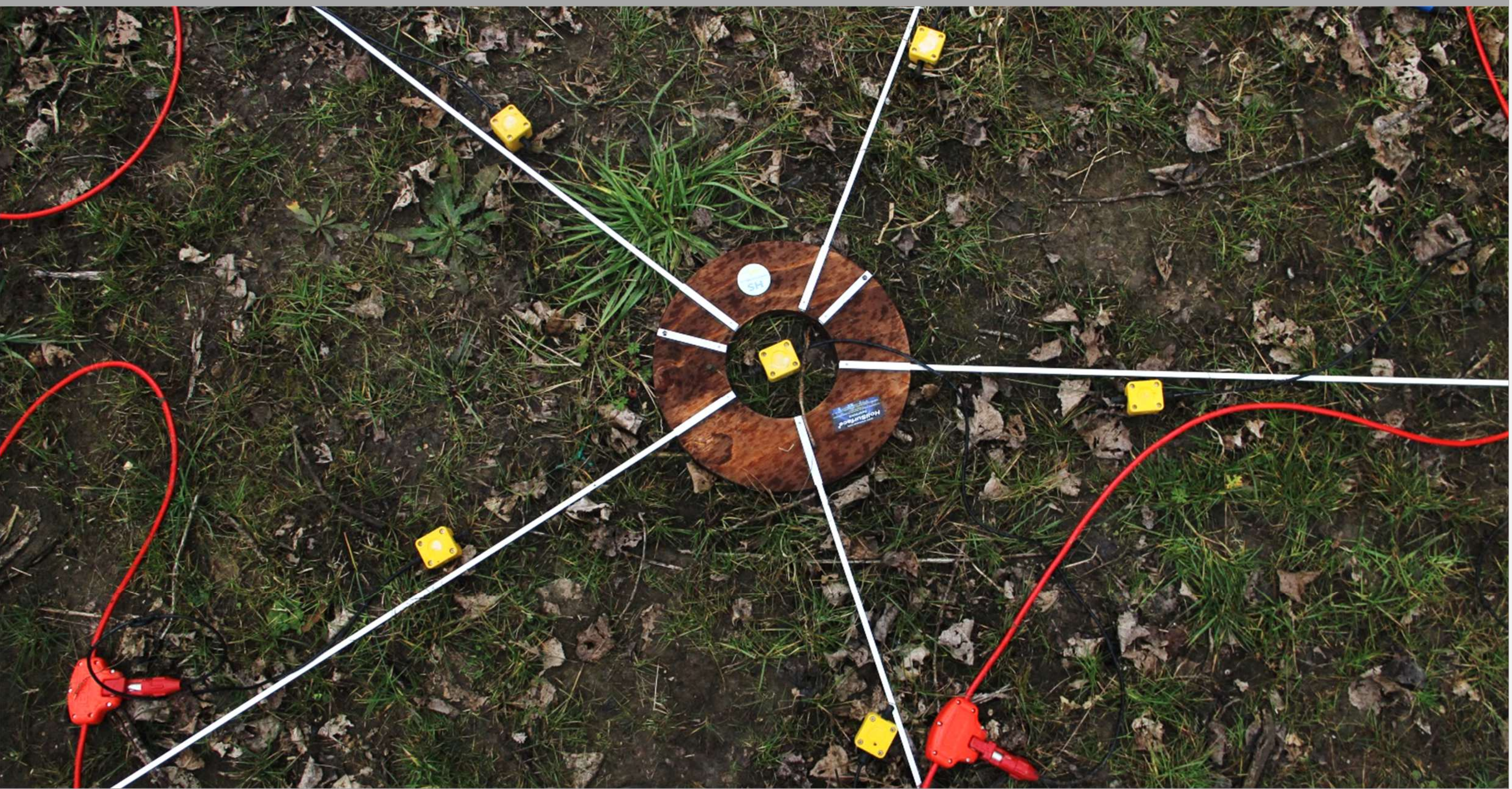
11. Joint inversion of group velocity spectrum + HVSR

A procedure/panel for inverting the velocity spectrum and the HVSR spectral ratio is also available ("Joint Inversion MFA+HVSR” module).
An example of a reasoned approach to the problem is presented in the article *Insights on Surface Wave Dispersion and HVSR: Joint Analysis via Pareto Optimality* (Dal Moro G., 2010), J. Appl. Geophysics, 72, 29-140

The procedure is very similar to the previous ones:

1. upload a previously-saved velocity spectrum (group)
2. upload a previously-computed HVSR curve (we suggest removing frequencies higher than 15 Hz)
3. set the inversion parameters (including the "search space" from a previous starting model identified during the direct modelling phase) and run the inversion.





12. MAAM: acquisition and analysis

MAAM stands for *Miniature Array Analysis of Microtremors* (Cho et al., 2013). It is, in short, a sort of mini-ESAC capable of detecting the dispersion of the Rayleigh wave (vertical component) at rather low frequencies (approximately from 3 Hz and over - it depends on the equipment and radius) even when the available space is limited.

This is therefore a particularly effective and sophisticated technique which, for this very reason, requires particular care and attention from all points of view (theoretical knowledge, excellent *acquisition system* [= seismograph + cables + geophones] and care during the data acquisition and processing).

Some tips

To do so, four or six high-quality vertical geophones (specifically tested for MAAM) are required, coupled with the 3C geophone (HOLI3C) we offer for HVSR, *HoliSurface®* and MAAM acquisitions.
Is it possible to use 4.5 Hz geophones? Only if the seismograph we have is of excellent quality (excellent signal-to-noise ratio) and you are using high-sensitivity geophones specifically tested for this type of acquisitions.
It is essential to stress that the signal-to-noise ratio (S/N) is an absolutely central fact in the case of MAAM acquisitions: seismographs without excellent characteristics cannot be used because this method is heavily influenced by the S/N ratio of the instrument (the top is theoretically represented by seismographs with 24bit digitization already at the geophone and 2Hz geophones but it is not possible to determine in advance - without specific tests - the quality of a seismograph).
It is the combination of the "seismograph+geophone" system that determines the quality of the signal and at least one of these two elements must be excellent (of course better if both).
In any case, it is only through specific tests on your equipment that you can be sure that our system works.
Eliosoft declines any responsibility for the use of hardware solutions (geophones and seismographs) not specifically tested for MAAM acquisitions/analyses.

Best weather conditions for passive seismics

The amplitude of the signals (microtremors) used during MAAM (but also HVSR) analysis is important.

If possible, carry out the acquisitions on **cloudy (but not windy) days**.

In short

Use a field equipment explicitly tested for this specific type of acquisitions.

We (*Eliosoft*) can provide the field equipment or test your *acquisition system*. Clearly, we cannot analyze or provide assistance if your data has been recorded with an inadequate (untested) *acquisition system*.

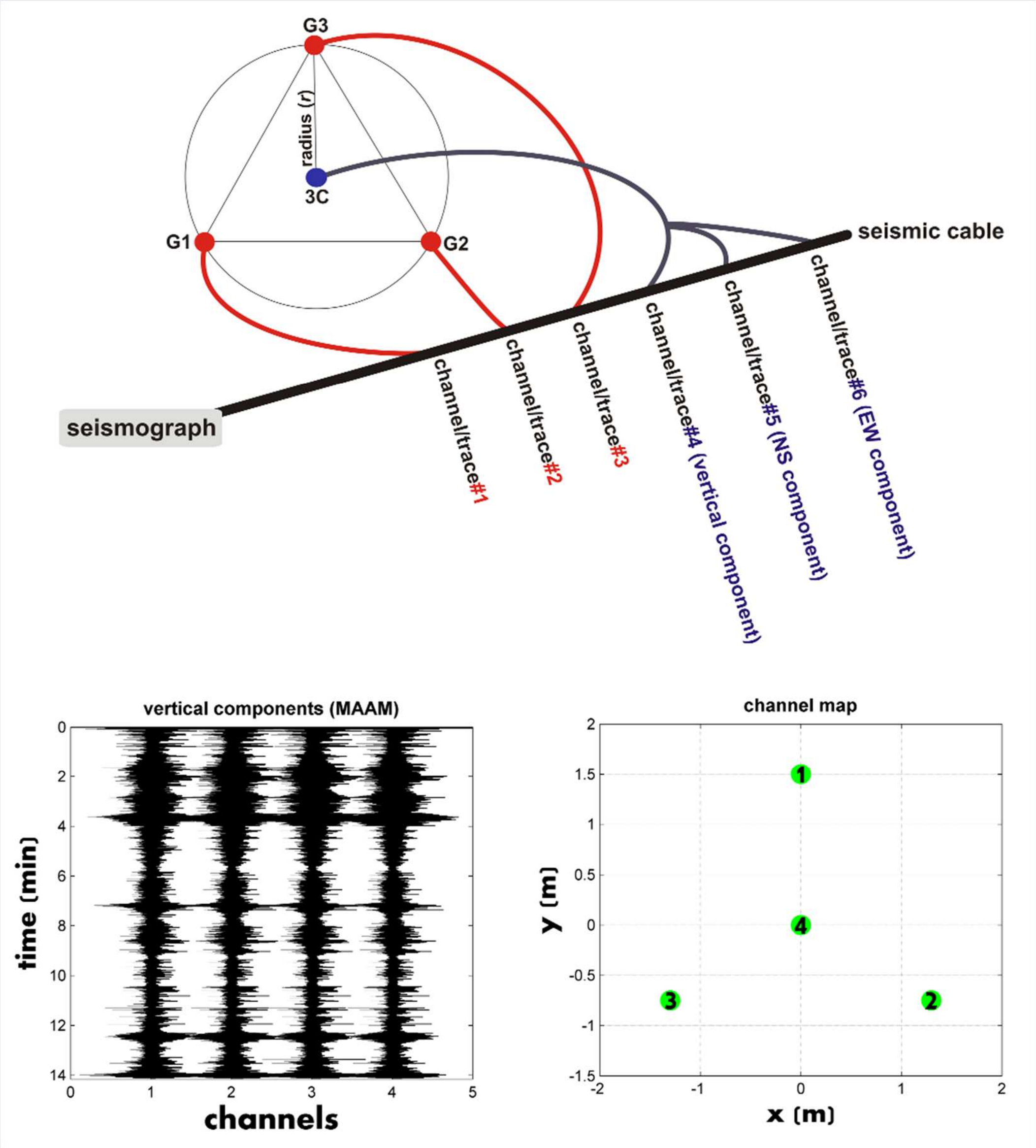
12.1 Data Acquisition

The acquisition is passive and is done using a triangle or pentagon geometry: the vertical geophones (with excellent characteristics and perfectly identical response curves) are placed at the vertices and at the center.

Acquisition geometry in the case of joint MAAM+HVSR acquisitions

In this case, at the center of the triangle or pentagon there is a 3-component geophone which must have the same characteristics (response curves) as the vertical geophones present at the vertices of the triangle/pentagon.
It is important to follow carefully the recommendations shown in the following images, which, in summary, can be summarized as follows:

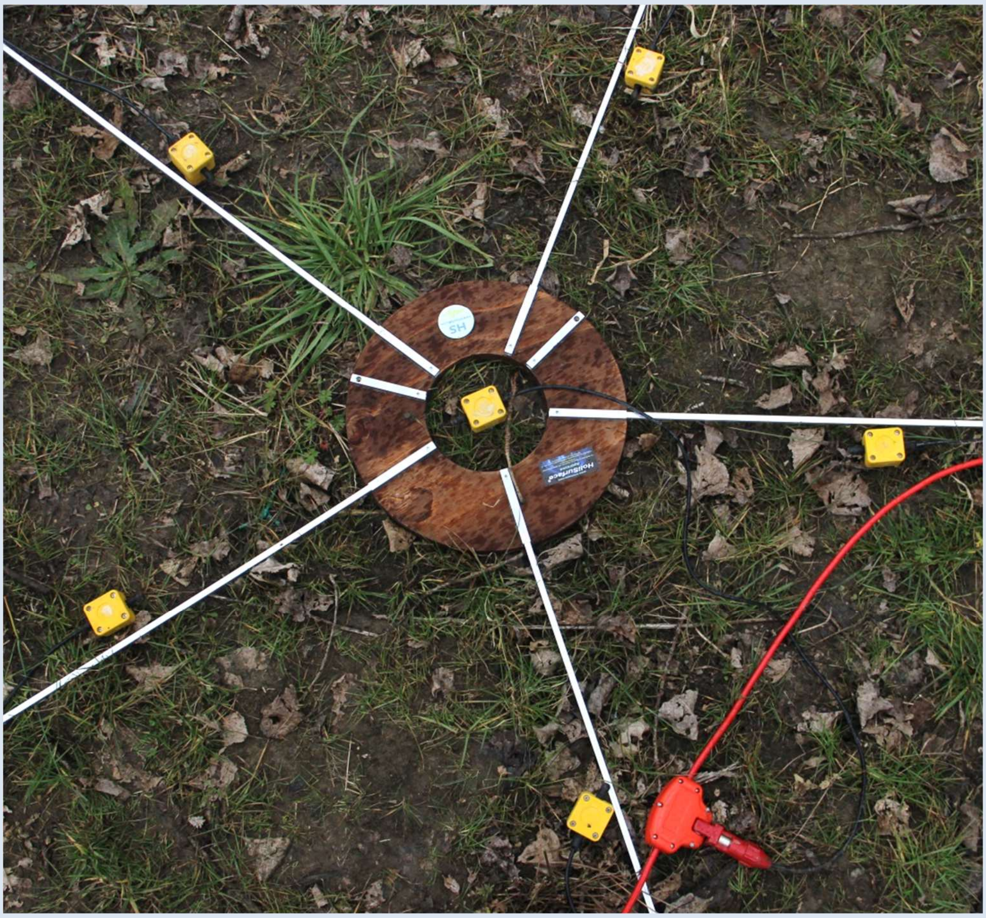
1. The first 3 (or 5) channels are those relating to the geophone at the top, while channels 4, 5 and 6 (or 6, 7 and 8 in the case of pentagon geometry) are those relating to the central 3C geophone.



It is also possible to use three vertical geophones at the vertices and a 3C one at the center, but to do so, it is necessary that the response curves of all the geophones used are identical.

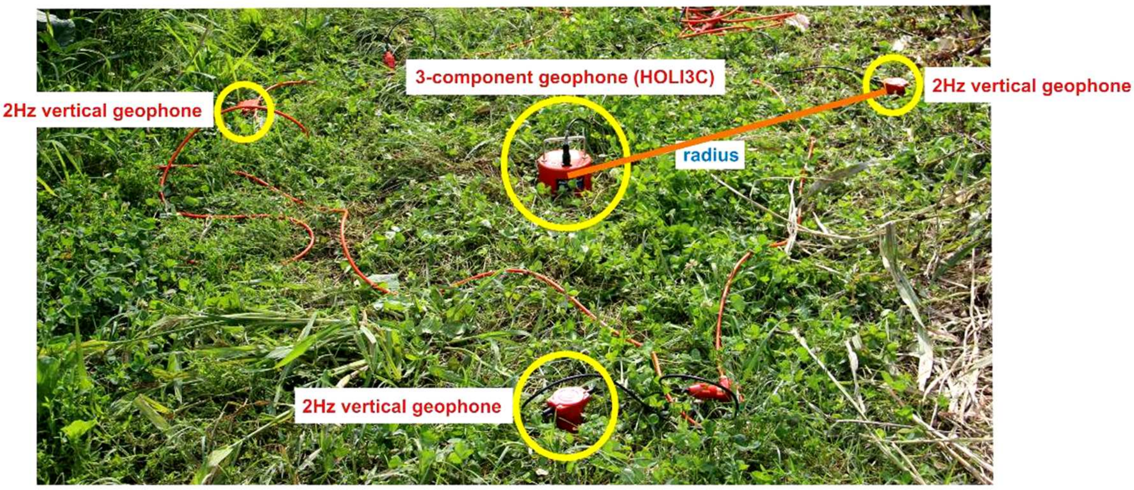
This way, the dataset will have 6 traces.

2. In some cases it may be useful/interesting to record two datas4ets with two different radii. In this case the difference must be relevant, for instance 2 m abd 12 m (it makes little sense to record two datasets with similar radii such as 2 and 5)



In this case, were used six (previously tested!) 4.5 Hz geophones

Optimized joint MAAM+HVSR acquisition



Radius (m)	The best thing is to acquire two datasets (each at least 15/20 minutes) with **2 different rays**: **60 cm and 2/4 meters.** If for some reason you do not have time to perform this double acquisition, a single useful radius can be **1.5 m** (but it is of course risky to have a single dataset).

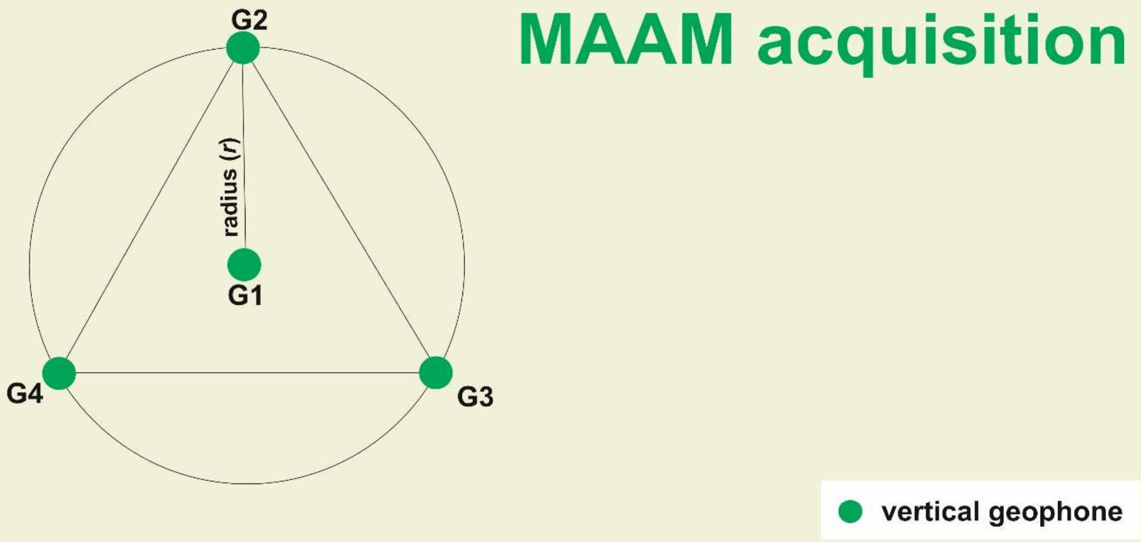
In some cases it can be useful to protect the geophones against the wind.

2Hz HS vertical geophone

geophone protection from the wind

If you use 2 Hz geophones, because of their *delicacy*, when they are not used you should keep them *short circuited* with a metal thread wrapped around the copper of the connector.

MAAM acquisition



Please strictly follow these general rules:

1) the central geophone is the first one

2) the G1-G2 direction should point toward the area from which most microtremors are supposed to come (e.g., an industrial area, a busy highway, etc.)

3) In case you are using a *nodal system* (a series of cableless 3C sensors), the *serial number* of the sensors should increase from the central point to the last point (following a clockwise spiral)

4) in case you are using a *nodal system*, do not orientate the 3C sensors accoring to the geographical North. Your North is the G1-G2 direction.

HS www.holisurface.com

In general terms we also recommend

For the data acquisition (HVSR+MAAM):

✓ connect your 3C geophone to the first three channels;

✓ connect the four vertical geophones (explicitly tested for MAAM) to next four channels (you need to carefully check the channel of the central vertical geophone);

[in this case the resulting file will have 7 traces: the first three about the 3C geophone - for HVSR analysis – and the next four channels for MAAM analysis];

✓ run a **short test acquisition** (1-2 minutes) to check the data quality (see **HS-QC software** to be used during the field acquisition): if the quality is good, proceed with the final/real (long) acquisition (15-20 minutes depending on the site and goals);

The choice of **file name** is, as always, crucial. In the considered example (let us imagine the radius is 2 m) the file name could be something like:

Z_N_E_MAAMradius2_centralFIRST.seg2

or

HVSR_and_MAAMradius2_centralFIRST.seg2

Once at home (for the analysis):

1) **open the HVSR panel of the HoliSurface® software and upload the 7-trace file** (e.g. “Z_N_E_MAAMradius2_centralFIRST.seg2”).
In the dialog box that will pop up, indicate channels 1 2 and 3 [for the Z, NS and EW traces to be used for the HVSR computation];

2) Once the HVSR computation is done go to the MAAM panel and load the same file. In the dialog box that will pop up, indicate the channels related to the 4 vertical geophones (in our case the channels 4 5 6 and 7);

3) Once these traces are loaded you have to enter the radius of the acquisition and indicate to the software which one is the central geophone (in our case it is the first one since in loading only the four traces related to the MAAM we excluded the first three traces pertinent to the 3C geophone).

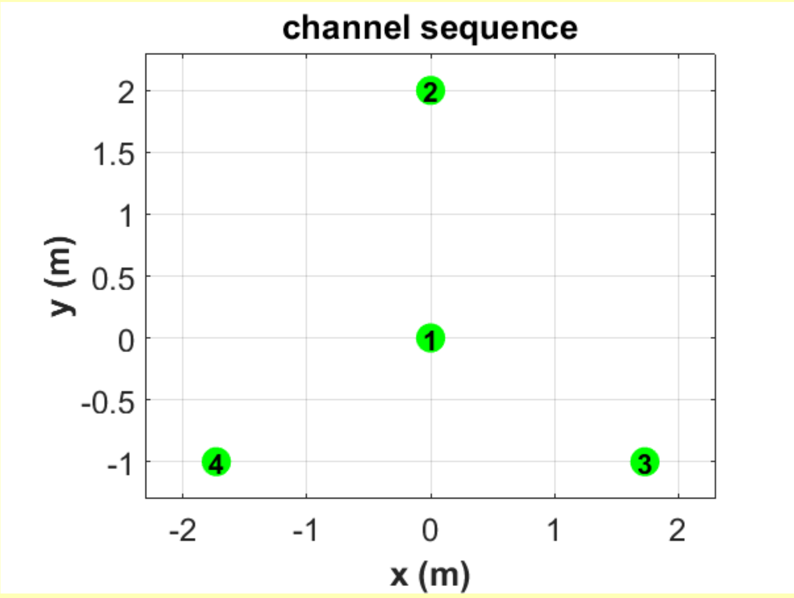
Recommendations for the data acquisition

Please, avoid making acquisitions and analyses without first following specific advanced training courses on these issues and without first verifying the quality of your equipment (the quality depends not only on the seismograph but also on the geophones - it is the whole *acquisition system* that determines data quality).

To acquire data useful for a MAAM analysis, it is essential to be sure which is the central channel (be very careful about it).

Our recommendation is to set the central geophone as the first channel. We can then follow a clockwise rotation and set the second channel that we might call *the north channel* (we do not care about the real North and everything is merely “relative”). The third channel will be the East channel and the forth channel the West channel.

first channel = central geophone
second channel = the “north” geophone
third channel = the “east” geophone
forth channel = the “west” geophone



To be sure, the best thing is to run the acquisition (passive) and tap a few times on the central geophone with your and then move away.
When you load the data, check on which channel/geophone those initial taps appear. This way you can be sure that the central channel indicated is the right one.

Most appropriate values for radius and acquisition time

Radius: Never go below 60 cm (0.6 m). On very slow soils use "large" radii (3-5 m), on "fast" soils (mainly gravel) use a radius of approximately 1.5-2 m.

Time: for the most common type of surveys (a couple of meters in radius), at least 20 minutes of data

Sampling frequency: 500 Hz (2 ms) to 200 Hz (5 ms).

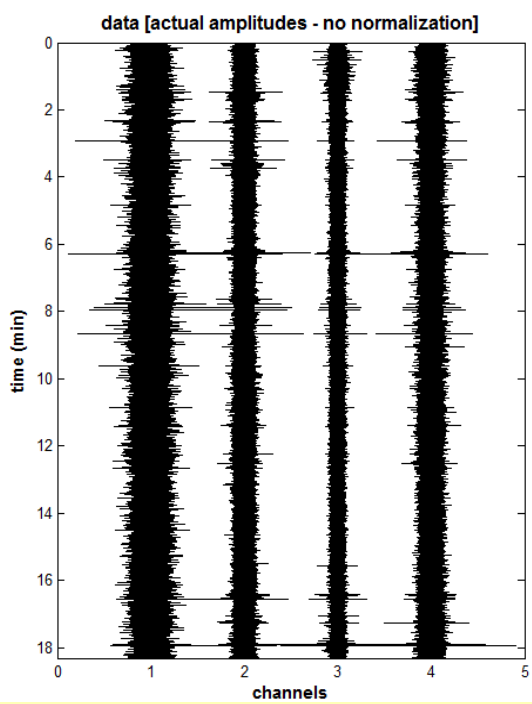
And what about the geophones?

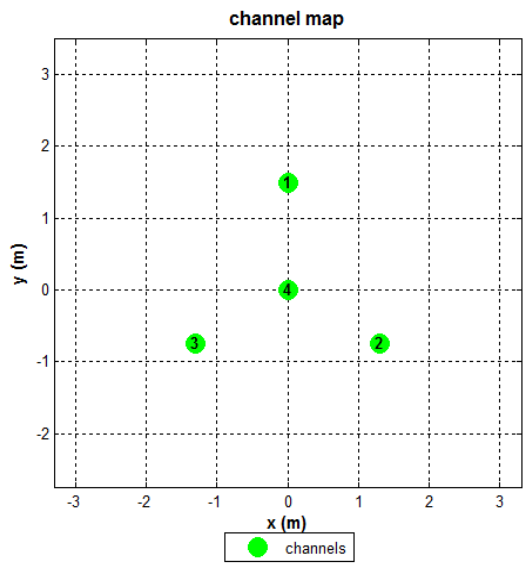
All geophones must have the same characteristics (response curve). If the amplitude of one or more acquired tracks differs too much from the mean value (see image below - the first trace has a high amplitude compared to the second and third traces; the fourth trace too has an abnormal amplitude). This means that something has not gone well and this could lead to an insignificant analysis.

Consider that the distance between the channels is extremely small and, if the instruments and the coupling of the geophones are OK, the average width of the traces must be absolutely comparable/similar (almost identical).

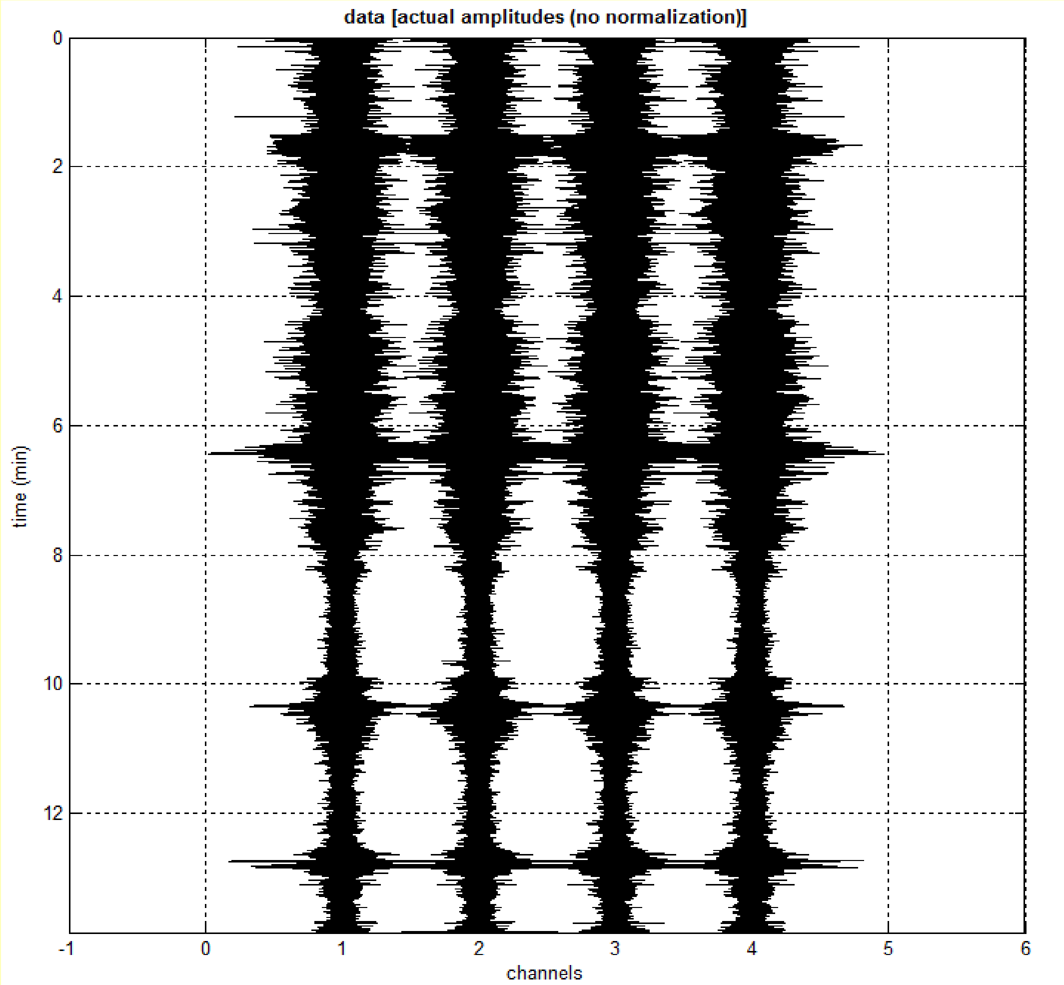
It is essential to place the geophones perfectly vertically (use a spirit level to check it in an absolutely accurate and rigorous way).

For this type of acquisition, the expression "more or less" is absolutely forbidden.





Here below is instead a case in which the 4 traces acquired show the same amplitude (a sign that the instruments and setting of the seismograph are "in order"):



Therefore, use identical geophones (excellent quality) and set the gains of the channels to the same value.

How to name your field dataset

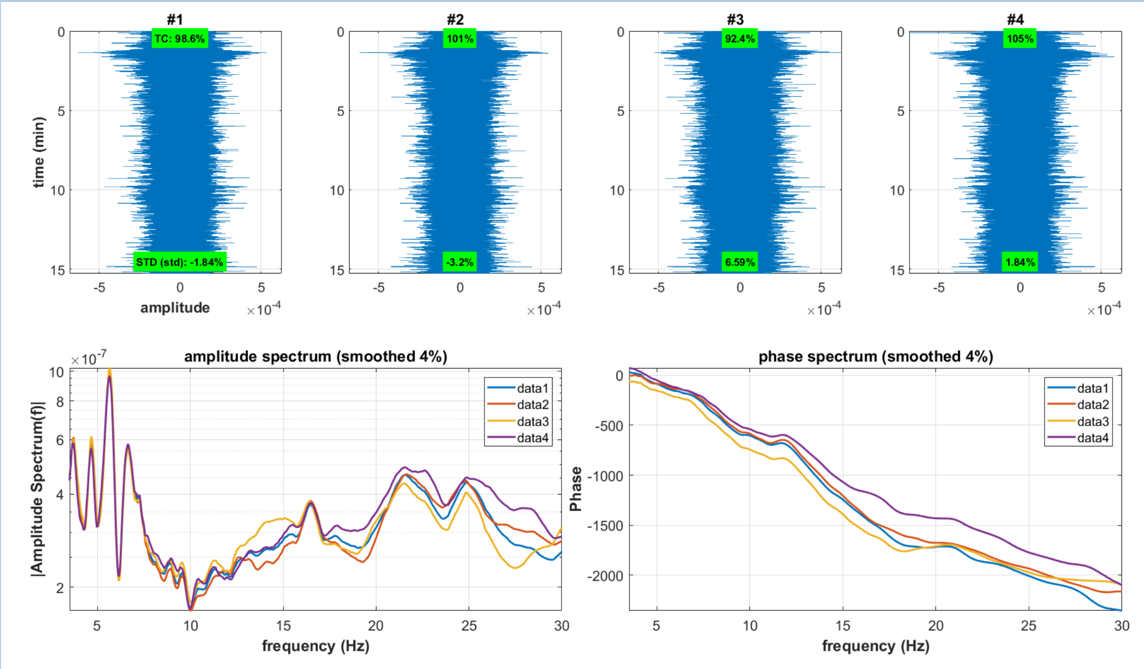
Avoid meaningless file names such as "Monday_13e15_PortoCervo.seg2". The file names must provide **information about the geometry**.

For a simple MAAM acquisition (with 4 vertical geophones) it may, for example, make sense to give a file name such as the following:

MAAM_radius3m_FirstTraceCentral.seg2

Quick check of data quality

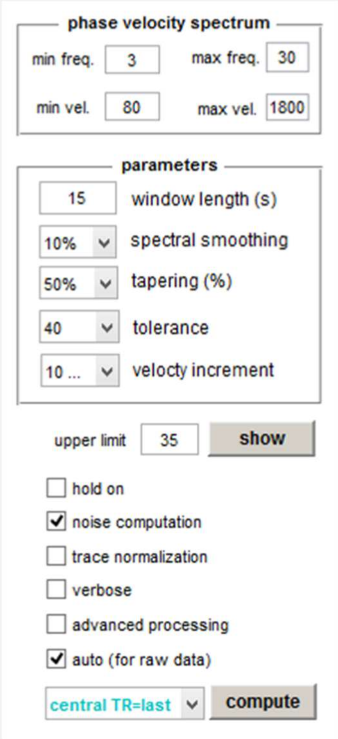
An initial check of the data quality is possible by clicking on the "**data check**" button (in the MAAM panel this button is in the top left corner - "**check data**"). This operation consists simply in computing the root-mean-square of the data. If one of the values deviates too much from the median value, the data may not be of sufficient quality for MAAM analysis (a warning message is displayed).



Needless to say, this operation should in fact be carried out during the field operations: just acquire 1 minute of data and run the quality analysis and in case everything is fine record the long dataset to be actually used for the MAAM. Since it would be extremely cumbersome to carry out such a control using the *HoliSurface®* software during the field acquisition, **it would be advisable for the instrument/seismograph used to carry out the analyses for this simple operation.**
You should then ask the manufacturer of your seismograph to add this tool to the seismograph acquisition software.

Computation options

Several options are available while computing the dispersion curve via MAAM:

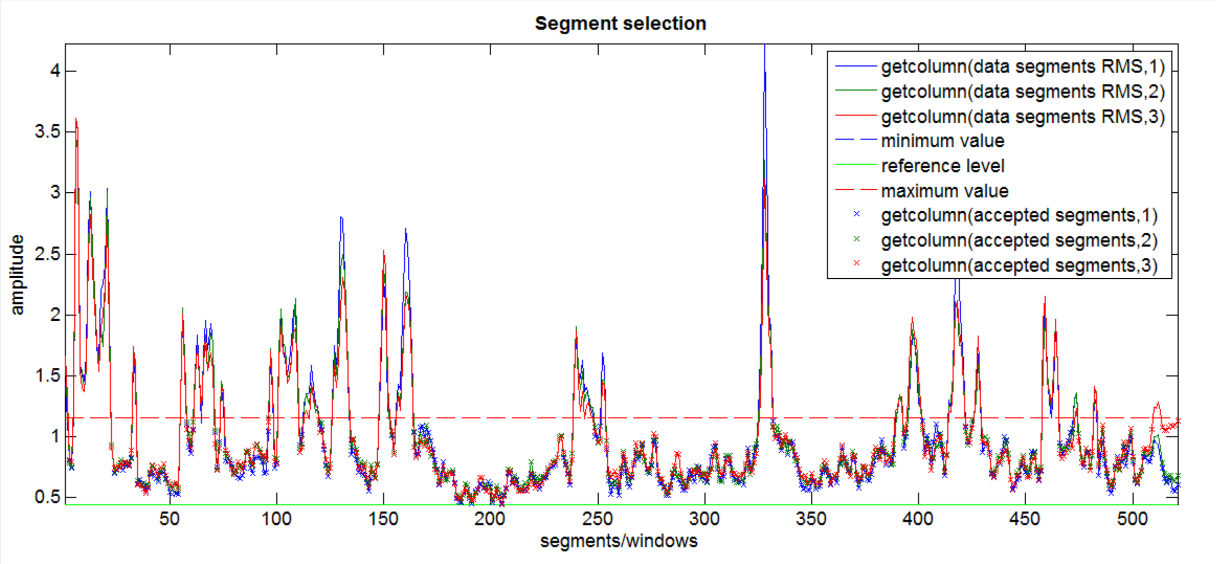


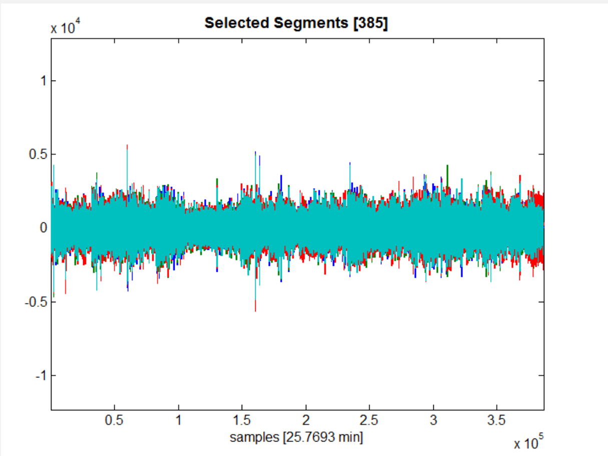
Here are some general information about the meanings

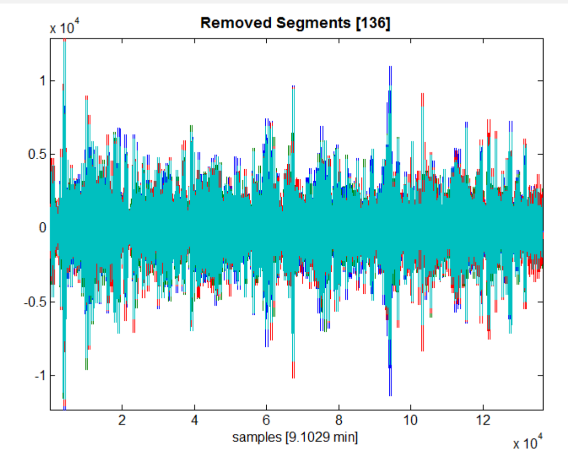
option	meaning	note
Noise computation	It computes the *Noise-to-Signal ratio* and uses it to compensate the dispersion	It must be always activated ("mandatory")
Trace normalization	If the seismic traces do not have the same mean amplitude (see box "*additional recommendations*"), you can force their "normalization" by using this option	Try to use it only if necessary (when the amplitude of the traces is not uniform). It is just a "desperate attempt" that cannot solve a serious acquisition problem.
Verbose	Shows a range of additional technical outputs	Useful to fully understand the processing and enrich your report.
Advanced processing	This option tries to solve problems related to large signal directionality.	Recommended (in order to be fully understood it requires a deep knowledge of the considered phenomena)

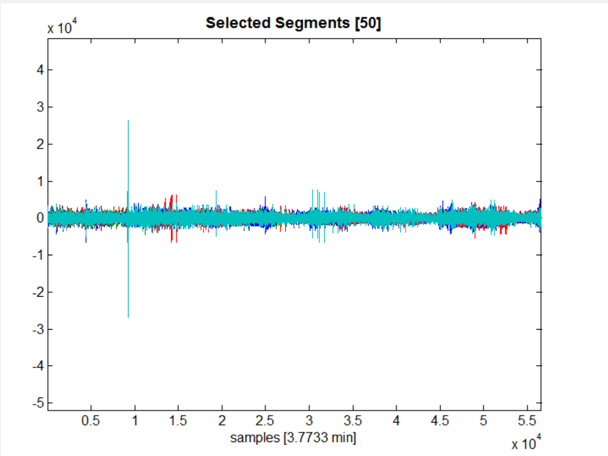
When you start the processing ("**compute**" button), among the many things done by the software, there is the selection of data below a certain amplitude that depends on the parameter "**tolerance**".
Incidentally, in the working folder, the two related data files are also saved automatically: the one with the selected segments ("clean" - file FileSelectedSEGMENTS.mat) and the one with the removed segments (FileRemovedSEGMENTS.mat).

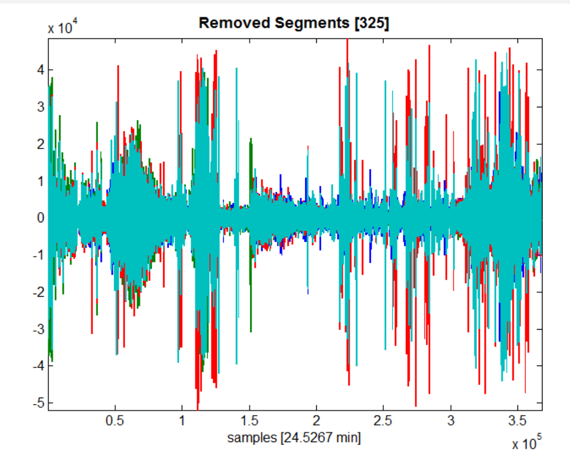
Tolerance


Segment selection
amplitude
segments/windows
getcolumn(data segments RMS,1)
getcolumn(data segments RMS,2)
getcolumn(data segments RMS,3)
minimum value
reference level
maximum value
getcolumn(accepted segments,1)
getcolumn(accepted segments,2)
getcolumn(accepted segments,3)


Selected Segments [385]
samples [25.7693 min]


Removed Segments [136]
samples [9.1029 min]


Selected Segments [50]
samples [3.7733 min]


Removed Segments [325]
samples [24.5267 min]

Processing parameters: important note

Reaffirming that MAAM is an acquisition/analysis technique that should be reserved for those who have solid, serious and "sincere" seismological bases, it is important to underline that there are two parameters that most influence the processing (therefore the phase velocity spectra obtained):

1. **Window length**
2. **Maximum tolerance**

What values to use? It is impossible to give immutable and absolute values. The window length depends to a great extent on the adopted radius (values around 20-25 seconds are often the ones to be adopted in case of radii around 2 m, but they decrease for very small radii and increase for much larger radii).
How to do that? Try a few different values and, by assessing the spectra obtained, choose the most appropriate value.

The tolerance (remember to choose the "below" option to keep only signals with an amplitude below the "maximum tolerance" set) depends on the nature of the data and in particular on the type and quantity of transient events (generally related to traffic or various industrial activities).

Lambda (λ) lines

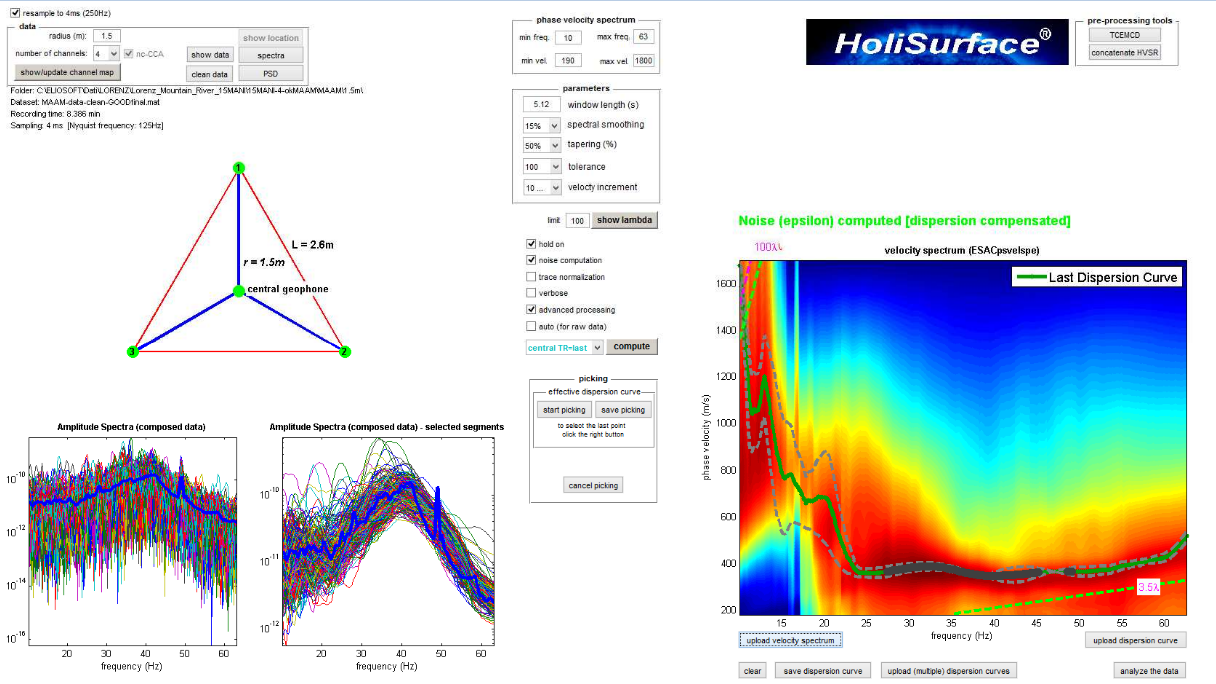
3 lambda lines appear (but with the "show lambda" button you can display any other value). They represent the frequency range within which, if the processing operations have been carried out correctly, the dispersion curve obtained (actual/apparent) is to be considered reliable and representative.

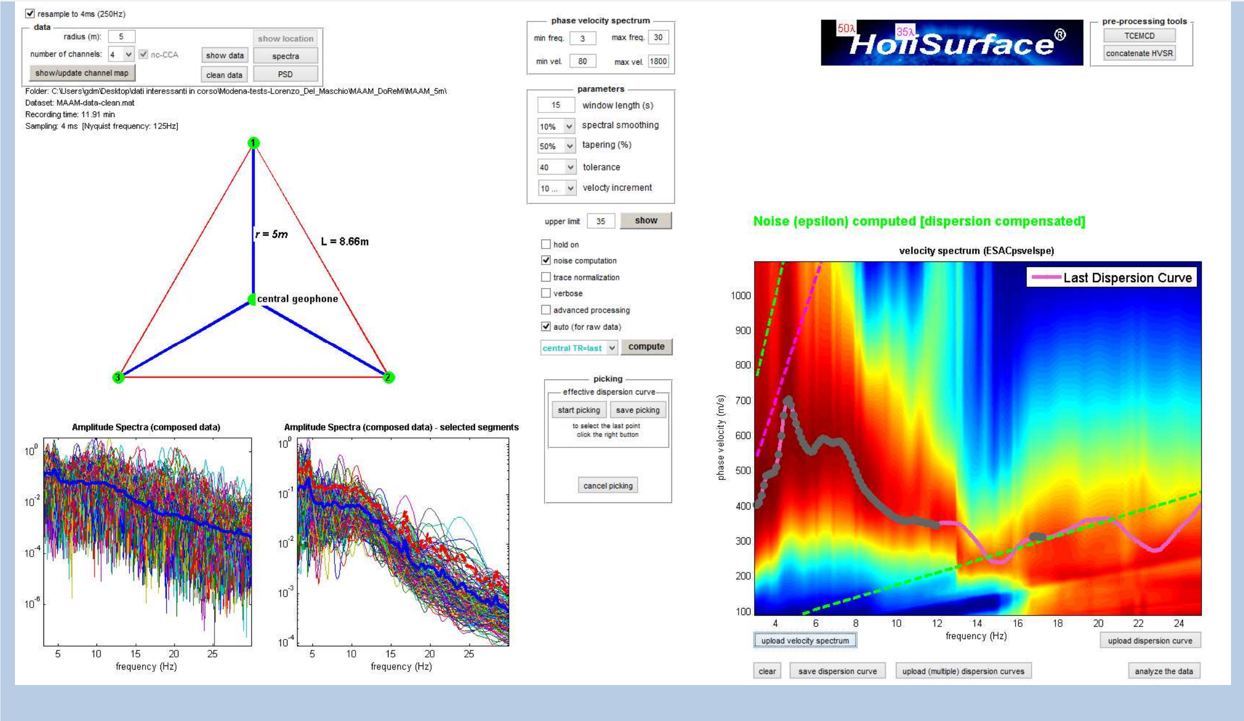
The "lower" line (3.5 λ): represents the limit of spatial aliasing. Under this line it is not possible to obtain information on dispersion. The exact value/number is in fact a function of various things and cannot be considered as absolute and universal (which in general does not differ much from the values of 3-3.5).

40 λ: can be considered the upper limit in case you are using a good instrument/system without compensating noise. In less fortunate cases, instead, it represents the upper limit for a low efficiency system for which noise compensation procedures are used by means of the option described above ("**noise computation**")

The "upper" line (80-90 λ): is reached under two conditions: 1) use a good acquisition system; 2) consider noise compensation (always recommended).

Never forget that in passive seismic acquisition, "luck" (in the sense given to the combination of randomness, accuracy of the field operations and specific conditions/situations that can "alter" the actual significance of the data acquired) always has some weight.





phase velocity spectrum
parameters
window length (s)
spectral smoothing
tapering (%)
tolerance
velocity increment
picking
effective dispersion curve
start picking
save picking
cancel picking
pre-processing tools
TCEMCD
concatenate HVSR
central geophone
r = 5m
L = 8.66m
Amplitude Spectra (composed data)
Amplitude Spectra (composed data) - selected segments
frequency (Hz)
Noise (epsilon) computed [dispersion compensated]
velocity spectrum (ESACpsvelspe)
Last Dispersion Curve
phase velocity (m/s)
upload velocity spectrum
upload dispersion curve
save dispersion curve
upload (multiple) dispersion curves
analyze the data

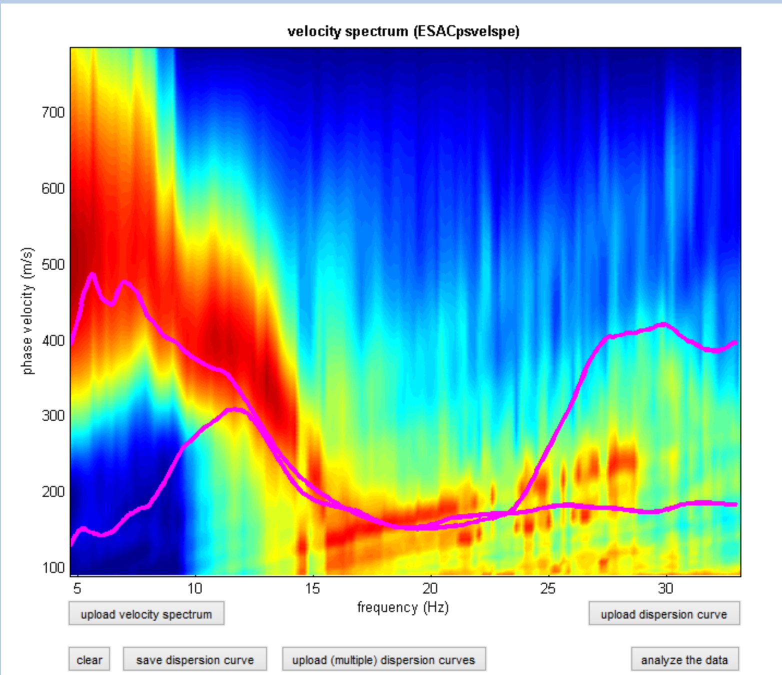
12.2 Analyses

The most important parameters to be set during data analysis are the **window length** (which for the datasets commonly considered in the most common jobs ranges from a minimum of 2 seconds to a maximum of 6), ***smoothing*** (i.e., the smoothing of the dispersion curve) and **tolerance** (which defines the threshold to be used in the automatic removal phase of signals that exceed a certain threshold and that are eliminated to avoid contaminating the analysis with signals of excessive amplitude - a bit as commonly done in the removal of transient events during HVSR analysis).

Finally, it is also essential to develop the correct "sensitivity" necessary to understand the frequency range within which the dispersion curve obtained is sufficiently significant and reliable (to do so, it is essential to follow our workshops dedicated to *HoliSurface* and a regular study of the various commented case studies that will be made available and published from time to time).

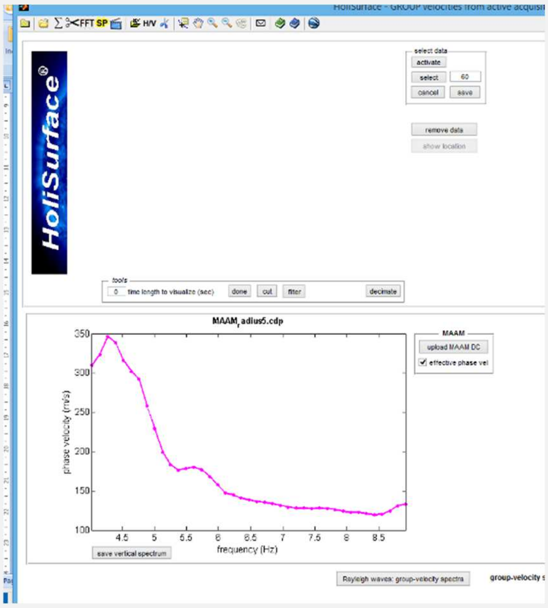
Double MAAM acquisition

The figure below shows two dispersion curves defined by considering two MAAM acquisitions with radii of 0.5 and 2 meters respectively, performed with an "old-fashioned" instrument (16bit digitized "downstream") and in a site particularly rich in “man-made noise" (state road + crematorium in action).
The high frequencies are those defined by the acquisition carried out with a radius of 0.5m and the low frequencies with a radius of 2 m.
The velocity spectrum in the background is derived from ESAC acquisition/processing.

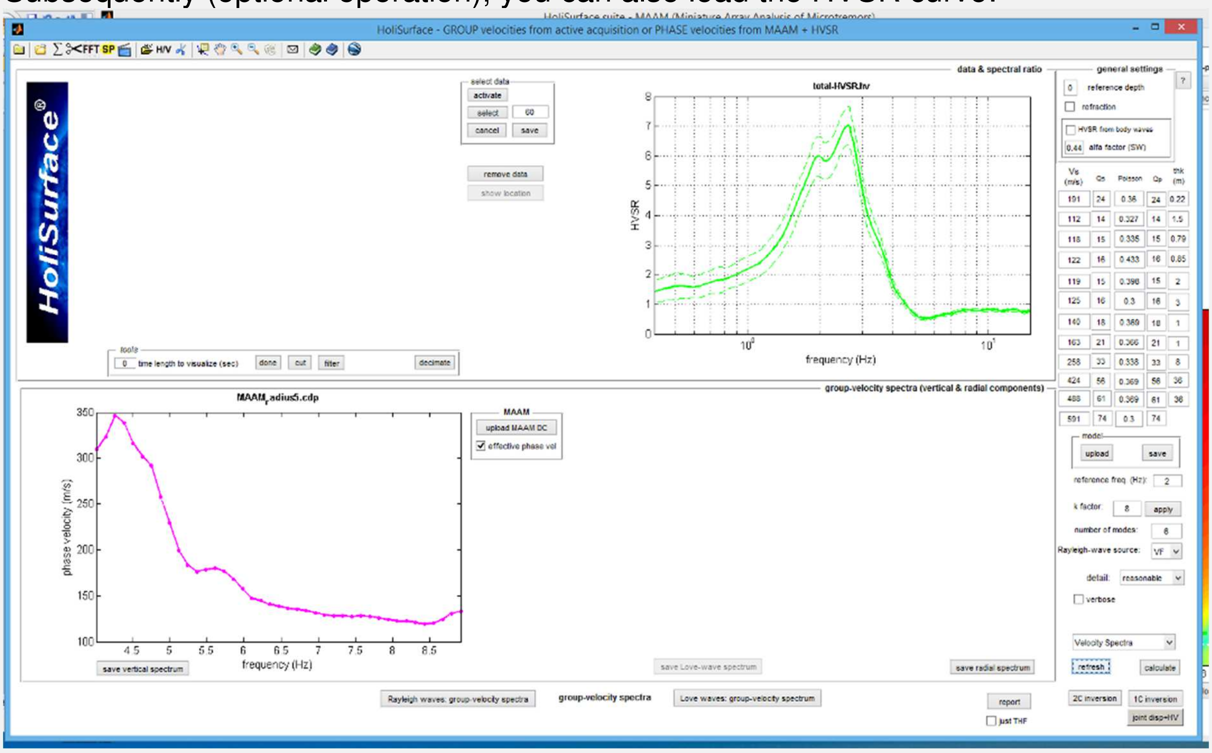


The analyses are carried out in the "Disp+HVSR" panel in "HoliSurface, MAAM & HVSR (modelling)" group.

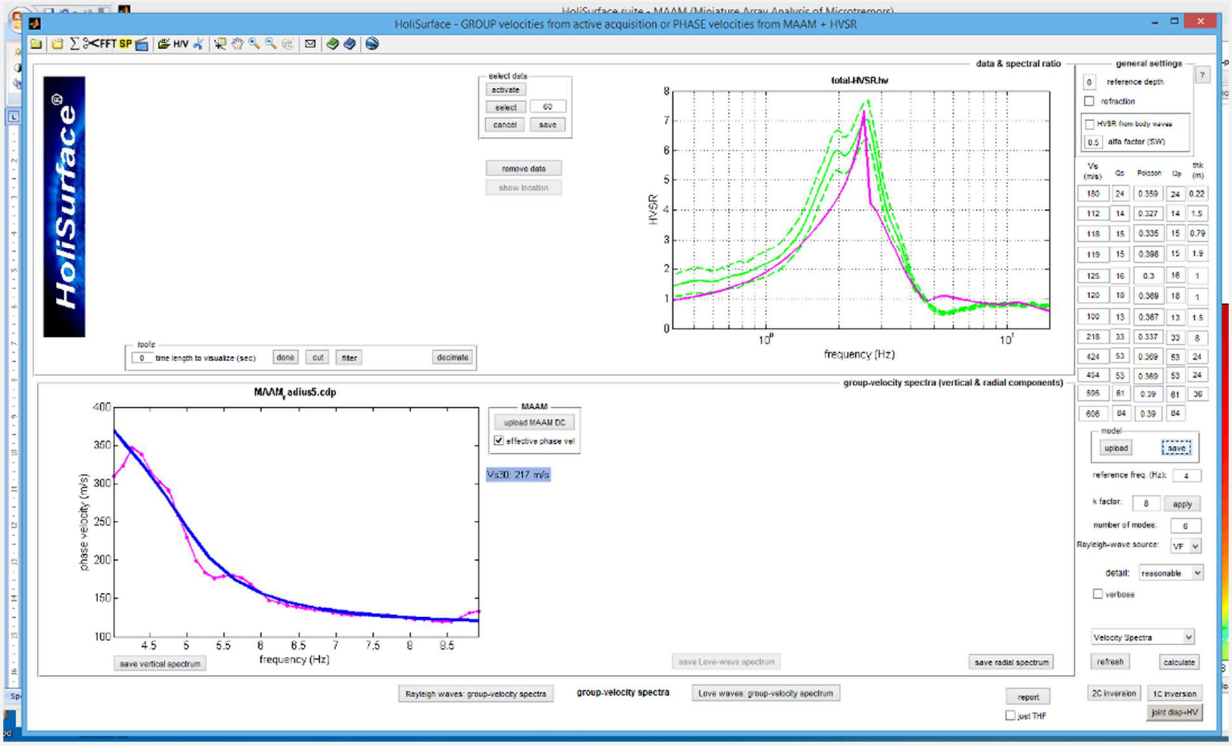
The actual dispersion curve is loaded (see screenshot below):



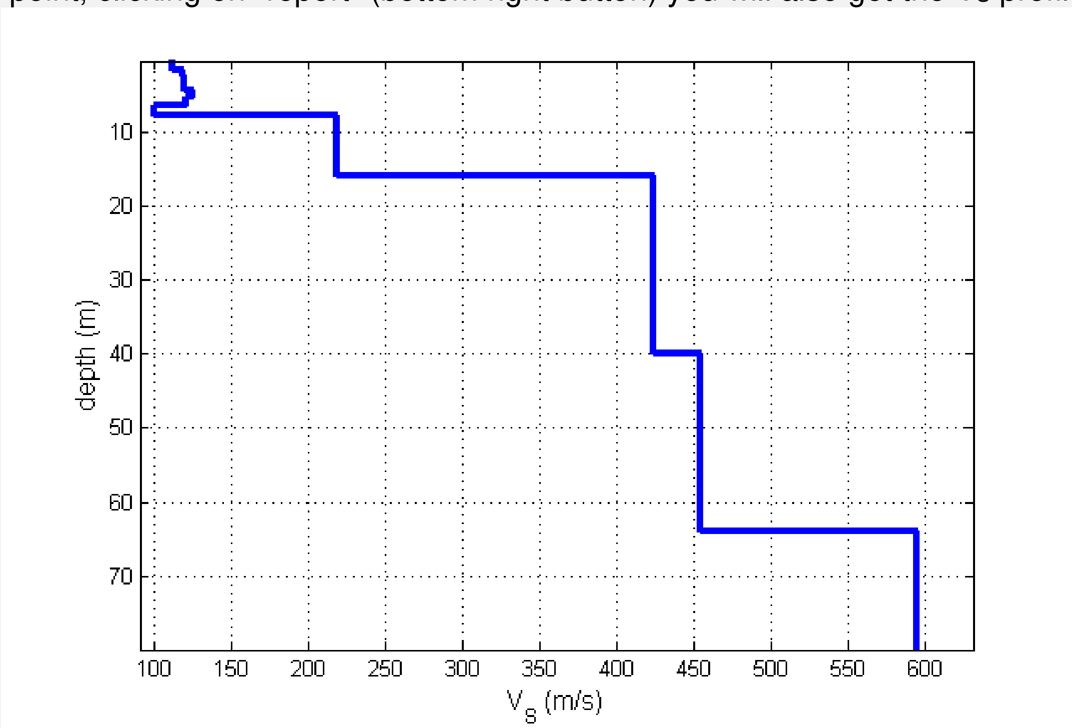
Subsequently (optional operation), you can also load the HVSR curve:



By acting on the Vs and model thickness values (direct modelling) it will be possible to find a solution that satisfies both observations:

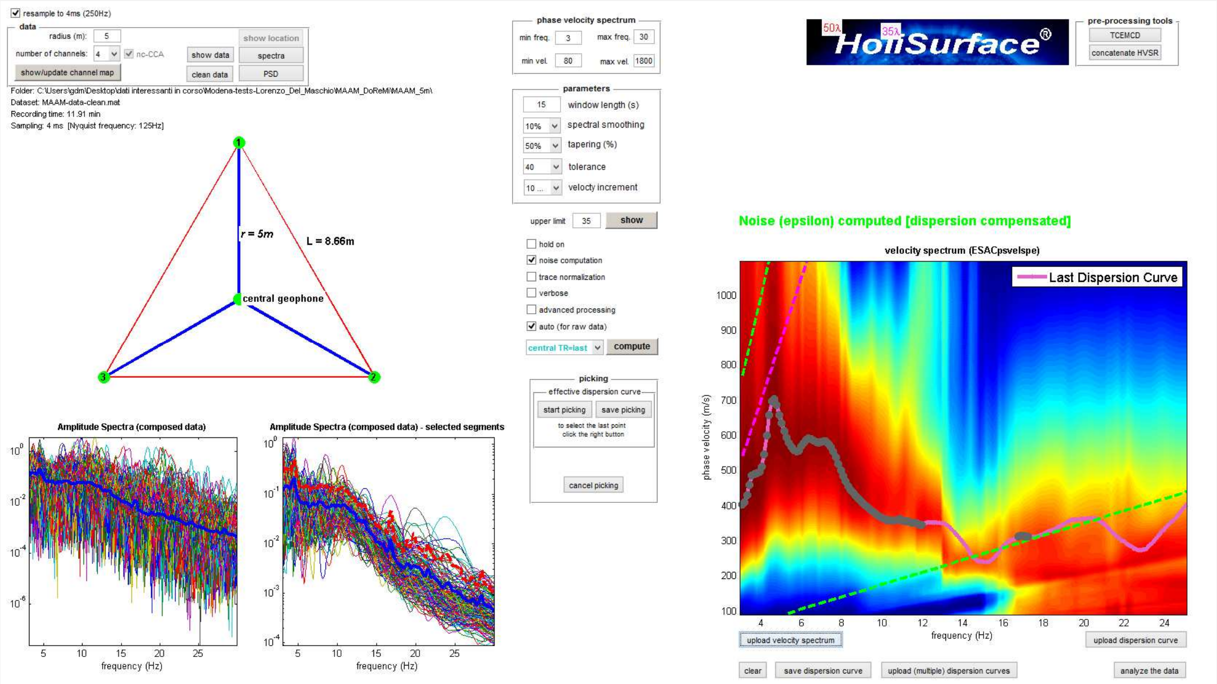


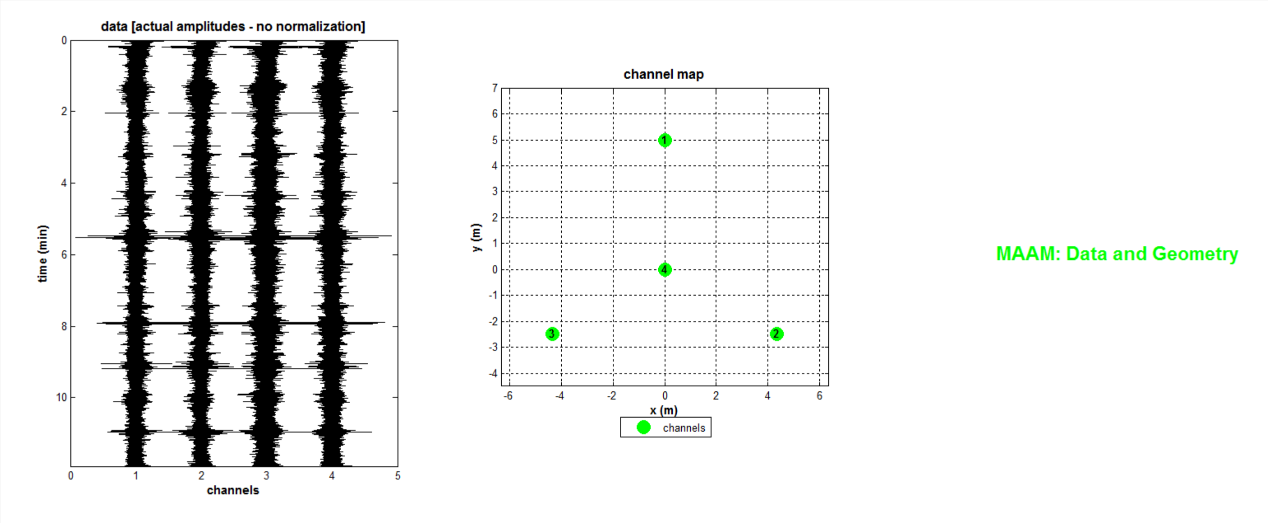
At this point, clicking on "report" (bottom right button) you will also get the Vs profile:



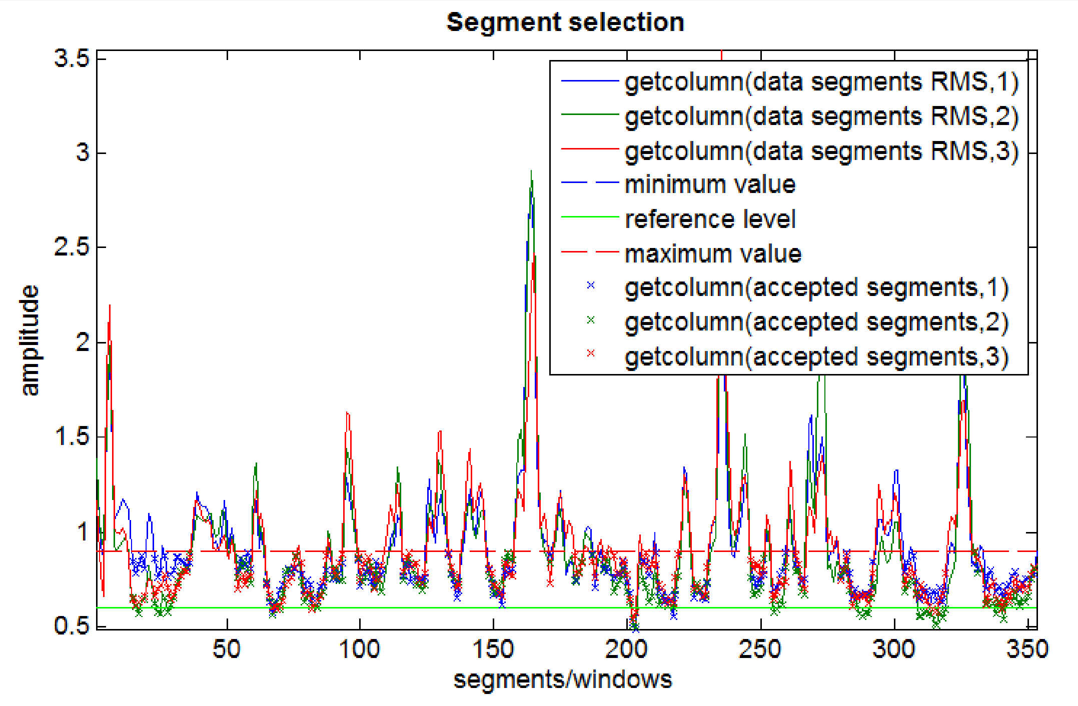
12.3 MAAM processing examples

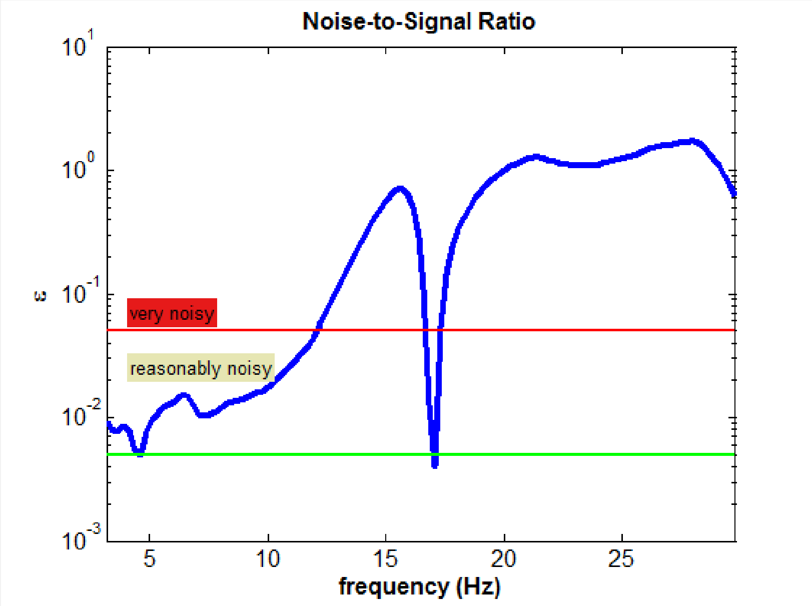
Acquisition with 4.5 Hz geophones (high sensibility) (both for MAAM and ESAC).





This slight difference in trace amplitude should not worry you (do not activate the "*trace normalization*" option).


Segment selection
amplitude
segments/windows
getcolumn(data segments RMS,1)
getcolumn(data segments RMS,2)
getcolumn(data segments RMS,3)
minimum value
reference level
maximum value
getcolumn(accepted segments,1)
getcolumn(accepted segments,2)
getcolumn(accepted segments,3)
3.5
3
2.5
2
1.5
1
0.5
50
100
150
200
250
300
350

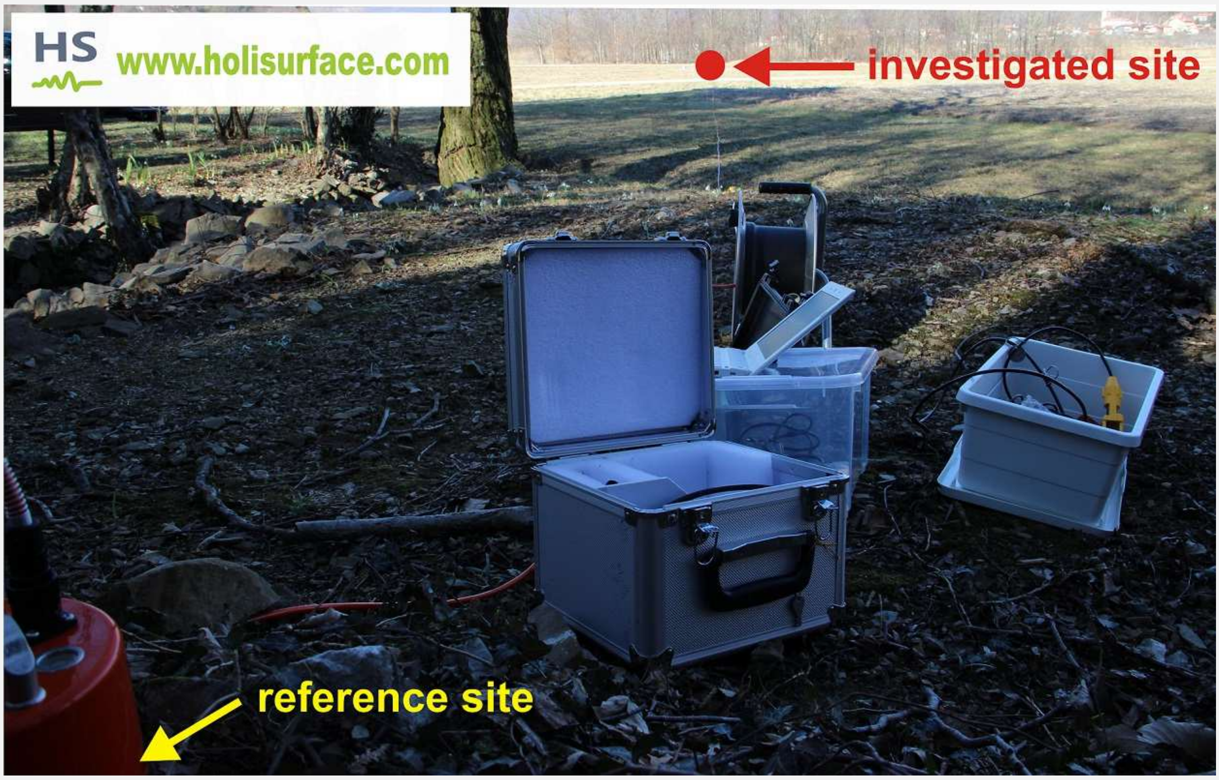

Noise-to-Signal Ratio
ε
frequency (Hz)
very noisy
reasonably noisy
10^1
10^0
10^-1
10^-2
10^-3
5
10
15
20
25

13. SSR (Standard Spectral Ratio) and SD (Spectral Difference)

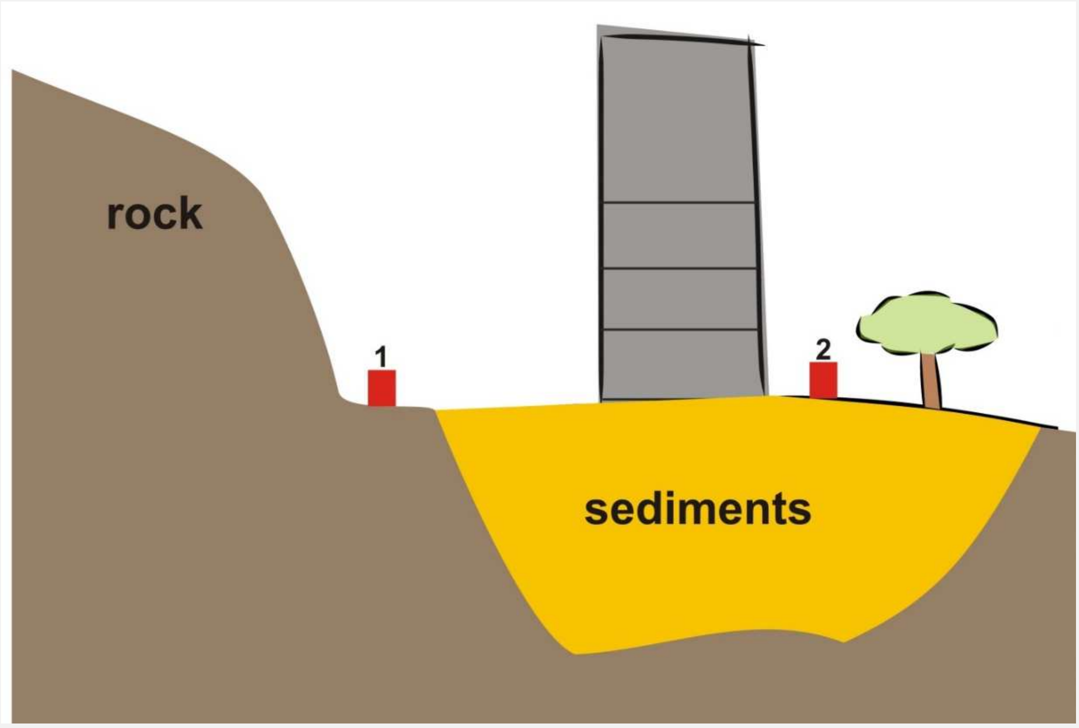
Standard Spectral Ratios (SSR and SSRn)

SSR is one of the most classic methods for estimating site effects: seismic traces acquired at the point whose amplification is to be assessed are compared with seismic traces collected at bedrock (assuming that this is not too far from the point with respect to which we want to define site effects - the point on the rock is called "*reference*").
The topic is taught in detail during our workshops and only a few essential points are reported here.
Data must be acquired (possibly synchronously) at the two points (the rocky *reference* point and the point whose amplification must be assessed). In case of SSRn (see Perron et al. 2018): sampling frequency 100-200 Hz and recording time 30 minutes (at least).

Synchronous acquisition of useful data for SSR analysis (as for synchronous vibration analysis on buildings).



Example of synchronous acquisition of data useful for SSR analysis: the "reference site" is on rock, while the “surveyed" point is about one hundred metres away (in the middle of a small basin).



Conceptual scheme about the SSR (and/or SD) data acquisition

An example of SSRn is shown in Appendix H [Example#2 [small basin surrounded by calcarenite hills] but we recommend to attend our workshops and read the pertinent papers.

Data acquisition for the determination of the SSRn: synchronous data?

For SSRn you do not necessarily need synchronous data because we analyse microtremors. You can record the two datasets one immediately after the other. Of course you cannot compare measurements taken on different days or in case the weather conditions have changed in the meantime, but if you record the second dataset just after the first one, that's fine.

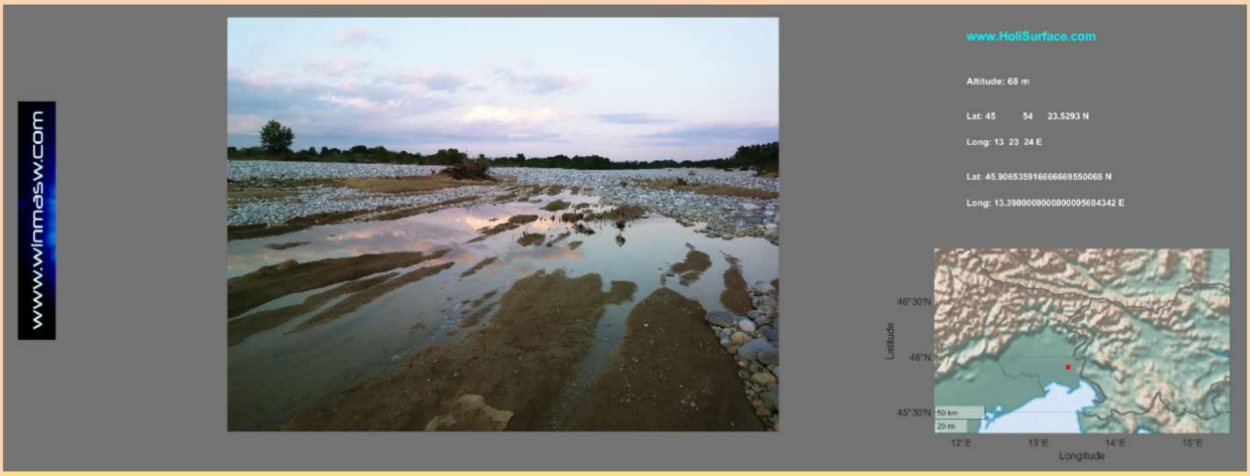
Decisive point: for the SSRn we analyse microtremors (not earthquakes!), so you just record the data, carefully remove all the transients so to get a steady time series just about the background microtremors, and at that point whether the data are synchronous or not changes absolutely nothing.

Fundamentally:
1) we acquire the data at point#1 (the usual 15-30 minutes depending on the site/goals)
2) we immediately move to site#2 and acquire the data at this new point
3) we clean the two time series (either by hand or with the panel's "automatic" tool)

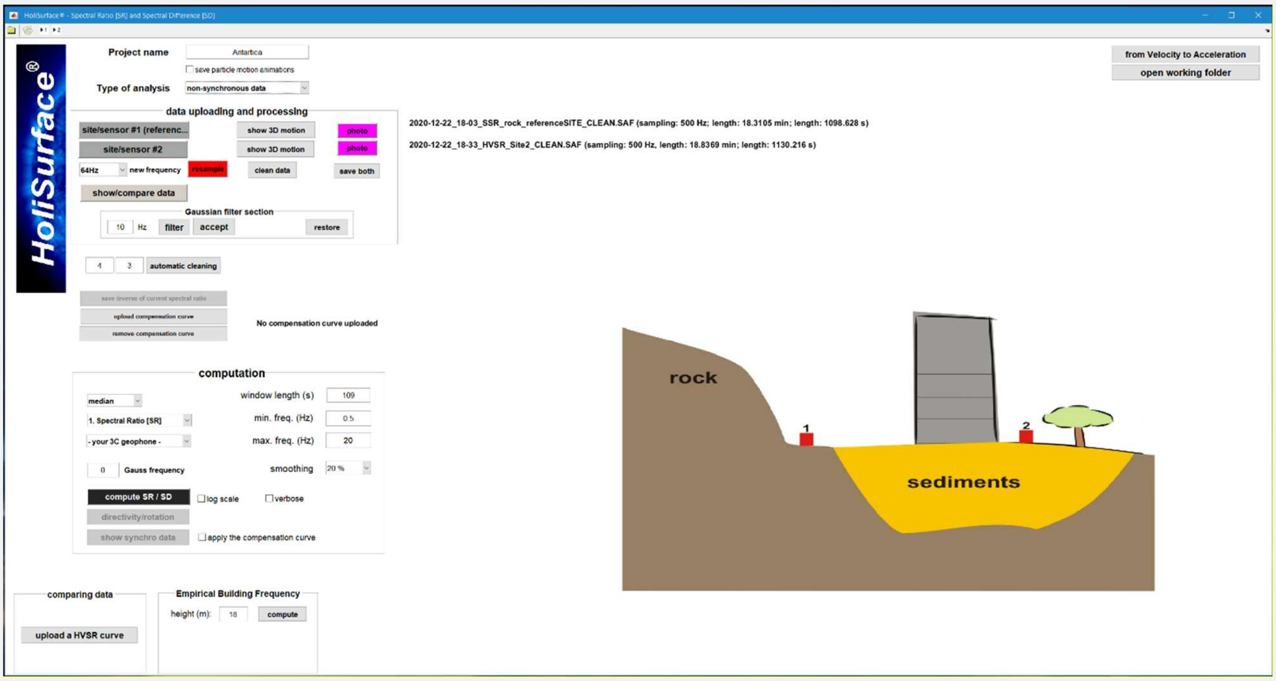
The series are now comparable for spectral ratio analysis.

Field photos in *HoliSurface®*

Please note that, in order to obtain a comprehensive report, during the acquisition procedures it is good practice to take some photos using for instance the *MapCam* app (see the "GPS data in our software applications" section in the fifth chapter of this manual). In the case of SSR or SSRn analyses, it is recommended to photograph both sites/points.



Here below is reported the SSR (and SD) panel once the two files (for the two sites) have been uploaded.



Few notes (while considering a real **SSRn** case):

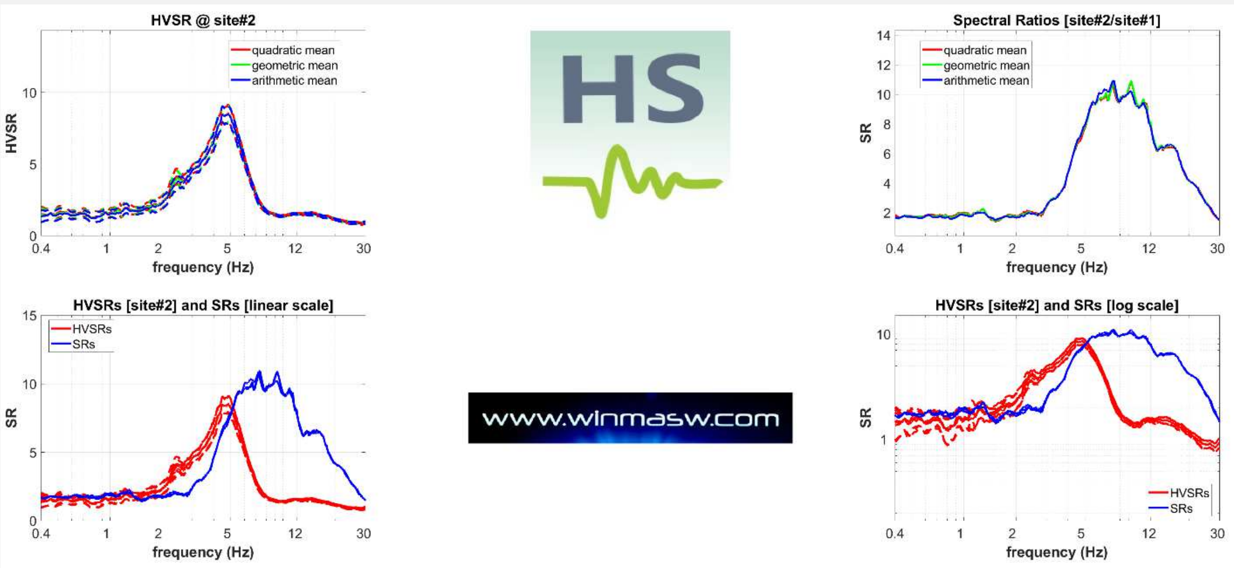
1) It is possible/useful to upload the geo-referenced photos for both the sites;

2) it is recommended to upload data already cleansed by transient events in order to keep only the steady (low-amplitude) microtremor data/field [this can be done, for example in the HVSR panel, saving the clean data as a SAF file);

3) since frequencies higher than 20 Hz are useless from a seismological / engineering point of view, it is always useful to re-sample the data at (usually) 64 Hz (see Nyquist-Shannon theorem);

3) the minimum frequency of interest depends on the type of study / application you are interested in; the general rules are the same to adopt while analyzing the HVSR and, therefore, also the length of the window to be used must be chosen with the same logic [typically: 20 second window and minimum frequency of 0.5 Hz];

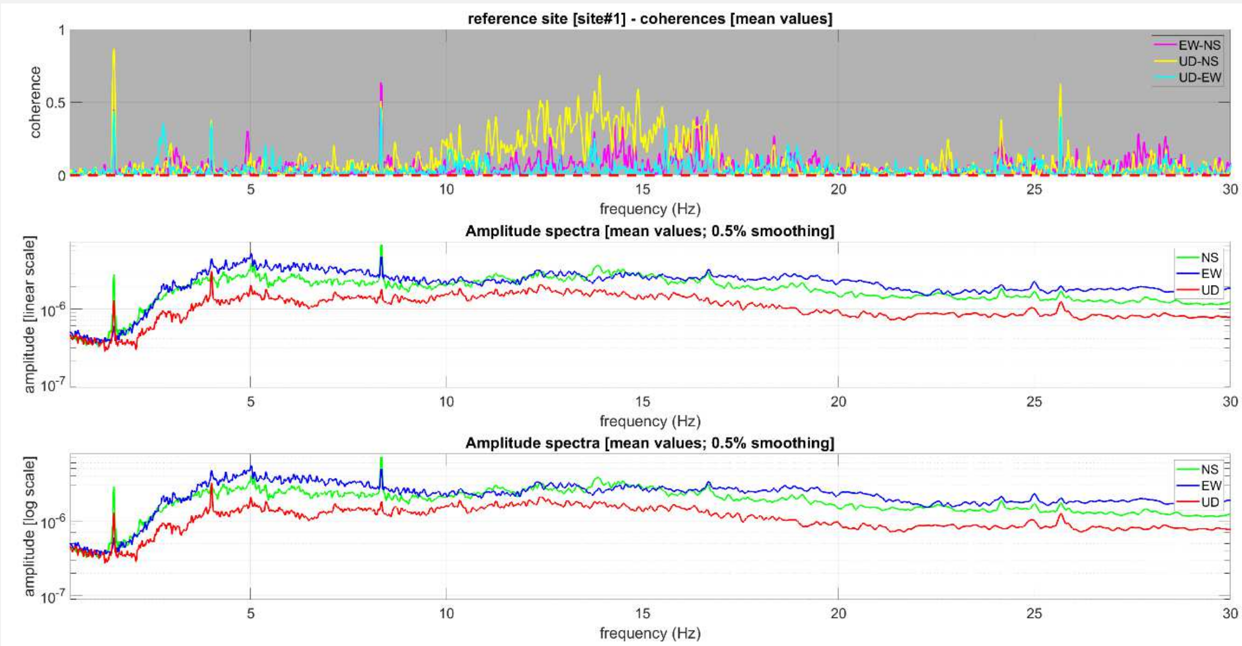
4) the difference between HVSR (at the site#2) and the spectral ratio (SSRn) is generally considerable. In the snapshot shown here below, it can be seen that the amplification of microtremors between, for example, 8 and 11 Hz, is equal to about 10 while the HVSR does not significantly deviate from the value of 1;



5) the actual amplification (which can be verified during actual earthquakes through the SSR) is generally halfway between the HVSR and the SSRn (see book *Efficient Joint Analysis of Surface Waves and Introduction to Vibration Analysis: Beyond the Clichés* and the therein references);

6) Among the various outputs provided by the software, we can mention the comparison between the density functions (in the frequency range considered) of the particle motion along the horizontal plane at the reference site and at the investigated site (see snapshot here below);

6) In order to avoid "misunderstandings" generated by the possible presence of industrial signals, the ***coherence functions*** (and the un-smoothed amplitude spectra) of the data are also computed for both the sites (an example is shown below): the aim is to help avoiding the mis-interpretation of an industrial signal (see the Springer 2020 book and Dal Moro, 2020 [*On the identification of industrial components in the Horizontal-to-Vertical Spectral Ratio (HVSR) from microtremors*]).



Spectral Difference (SD)

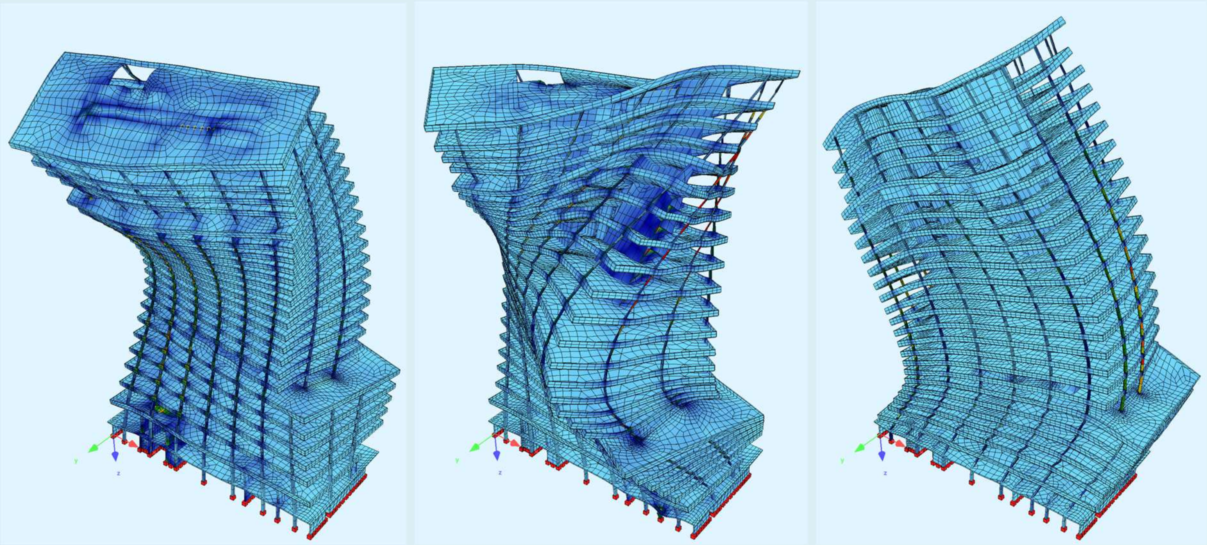
To put it in simple terms, SD represents a variation on the subject compared to the SSR.

If in the case of SSR the amplitude spectra are compared by analyzing their **ratio** (spectrum sensor #2 / spectrum sensor #1), in the case of SD the spectra are compared by making the difference (spectrum sensor #2 - spectrum sensor #1).

This can be useful in some geotechnical studies if you want to quantify how much a certain site "amplifies" the signal in terms of mm/s (and not merely in relation to the reference site).

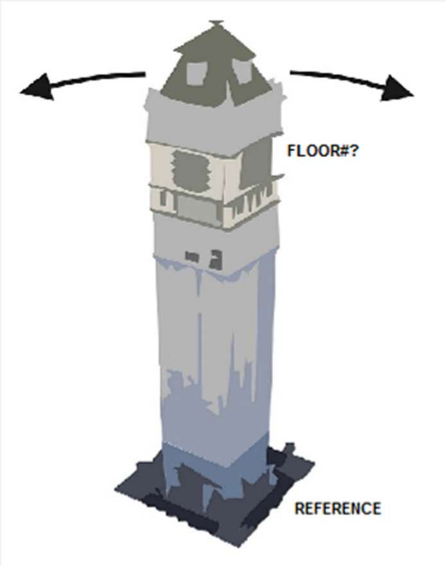
Clearly, bear in mind that this comparison (by subtraction and not by ratio) only makes sense when we are analyzing data expressed in physical units (mm/s) and not in "counts".

Inside the "documents" folder (a subfolder inside the HoliSurface installation folder) there is an example of an application that refers to the analysis of the effects of vibrations induced by passing railway trains (see "Eliosoft_Tarvisio_Trains_Vibrations_Dissemination.pdf").



15. Vibration analysis for structural characterization

Acquiring and analyzing data useful for defining the vibration frequencies of a building (possibly to be compared with the amplifications highlighted by a Local Seismic Response or - in the first instance - by an HVSR measured near the building) is certainly not the most difficult thing among those possible with a calibrated 3-channel geophone (i.e., with a 3C geophone).
The important thing is not to exaggerate in the "interpretation" of the data by giving names (modes and type of oscillation), which, to be given in a serious and reasoned way, require skills typical of a structural engineer rather than a geologist.
Below we consider the case of acquisitions made with a single sensor (in this case a geophone) placed on gradually higher floors.
Different (and more articulated) is the case in which at various floors the measures are carried out simultaneously (this allows a much more rigorous analysis and therefore much more stringent and complete analysis).



Orientation of the 3C geophone during the data acquisition

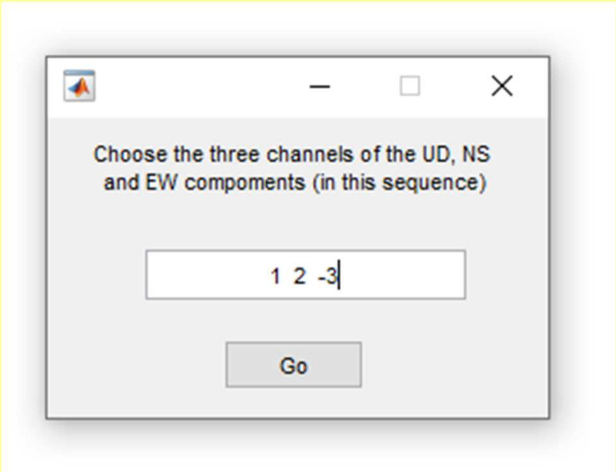
Few important notes

1) The geophone must be positioned near the bearing walls (avoid area in the middle of the rooms or near the stairs, elevator shafts, etc.);

2) The NS direction of the 3C sensor must be set considering the axes of the investigated structure and not the geographic North.
Once the two measurement points have been chosen, the orientation to adopt in order to obtain GHM plots that can be easily interpreted is to set the EW axis as the direction that connects the two points. In other words, the NS direction of the geophone(s) should be the axis perpendicular to the (imaginary) line connecting the two measurement points.

Data format and change in the data polarity

By default, the program assumes that the data are sorted (from left to right) in the following order: vertical trace (UD), north-south trace (NS) and east-west trace (EW).
In order to achieve this, in case the data has been acquired according to other conventions, while uploading the data it is also possible to modify the position/meaning of the traces (by considering that we must work with data organized according to the sequence **UD, NS and EW**).
If your *acquisition system* provides seismic traces with an erroneous polarity, it is possible to invert it when loading the data. To do this, simply insert the minus sign (-) in front of the respective trace.
Example (we want to invert the polarity of the EW trace - third trace): when uploading the data, in the dialog window we simply add a minus (-) in front of the third trace:



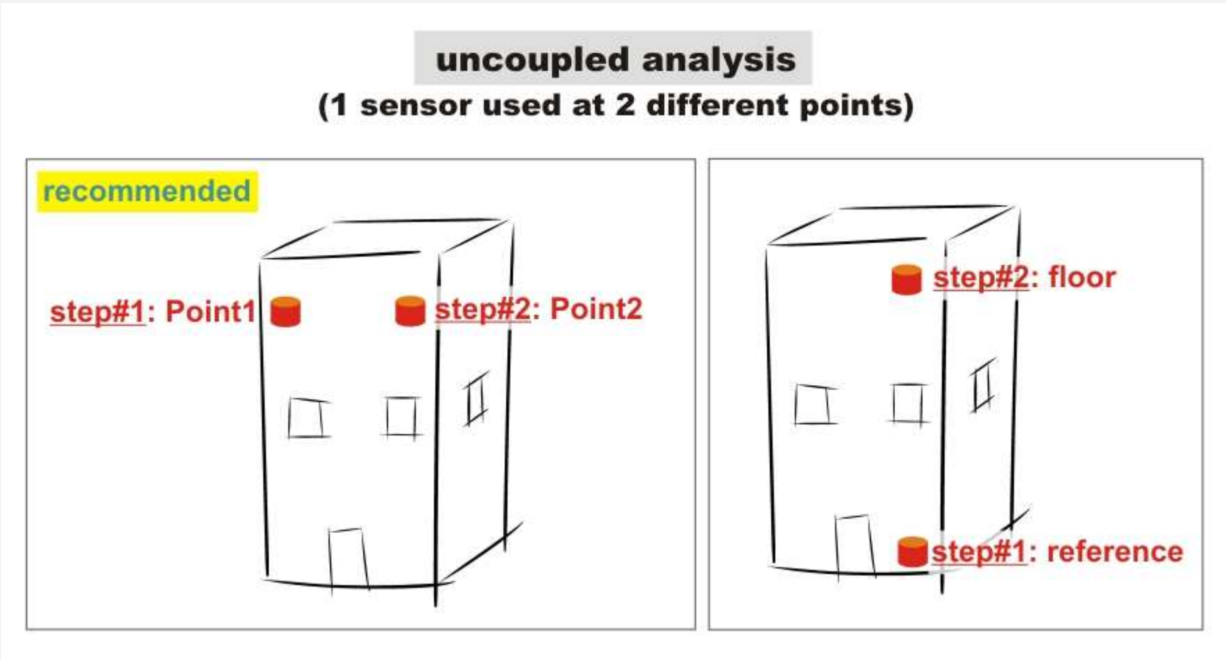
How to know if our acquisition system provides data with the correct polarity? You can send us your *acquisition system* and we will test it for you. During our workshops we teach how to test your *acquisition system*.

Warning: the test for the correct determination of the RPM curve concerns only the UD and NS traces (and not the EW one) while for the analysis of vibration data for building characterization, it is instead necessary to check the EW trace as well.

15.1 Types of acquisitions and analyses

There are at least three ways to carry out acquisitions and vibration analyses useful for studying the resonance frequencies of a building.

1- Simplified procedure (uncoupled):
with only one 3-channel geophone, 10 minutes of data must be acquired on the lowest floor (foundation) and then (with the same 3-channel geophone) 10 minutes on X floor (ideally on a point along the vertical line with respect to the previous measurement).
The data is then "compared" to obtain information whose clarity depends on the complexity of the building's motions.
To summarize this kind of procedure (simplified), it is useful to use a synthetic expression such as US1 and US3 (*Uncoupled Sensors*, with the two numbers that indicate the floors at which the measurements were made, in this case the basement and the third floor).
In the case of particularly tall buildings, it is possible and useful to make a measurement every 2 or 3 floors (i.e., at floor “zero," at the second floor, at the fourth floor, and so on).

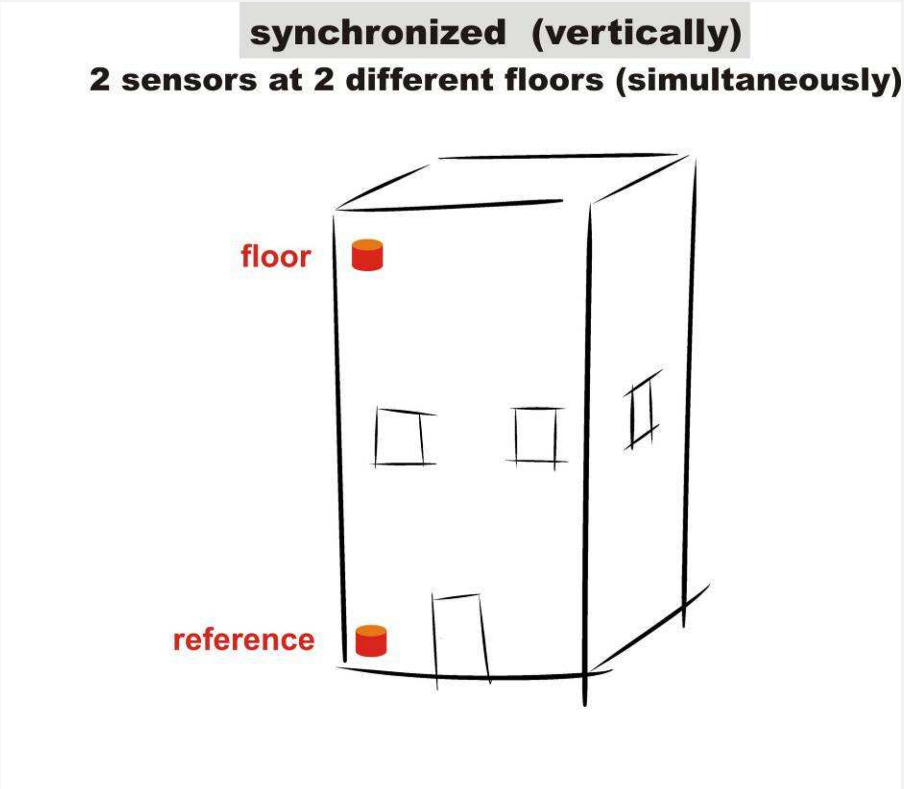


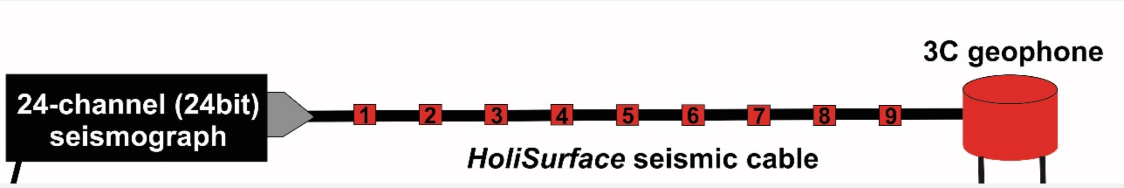
Floor zero

It is the floor which the measures are then referred to for the upper floors. It ideally represents the foundation level. So make sure you get as far down as possible (usually cellars or underground car parks).

2- Synchronized sensors placed in different floors (on the same vertical line):

I would call it SS-V_-1_4 (*Syncro Sensors - Vertical*, followed by the two numbers expressing the two floors at which the data are taken).
The second type of acquisition/analysis is carried out by considering two sensors, which are synchronized and acquire simultaneously to two different floors. We will call this type of acquisition and analysis *synchronized vertically*. Clearly, in order to carry out this type of analysis it is necessary to use 2 3-channel geophones that have identical characteristics and are perfectly synchronized.



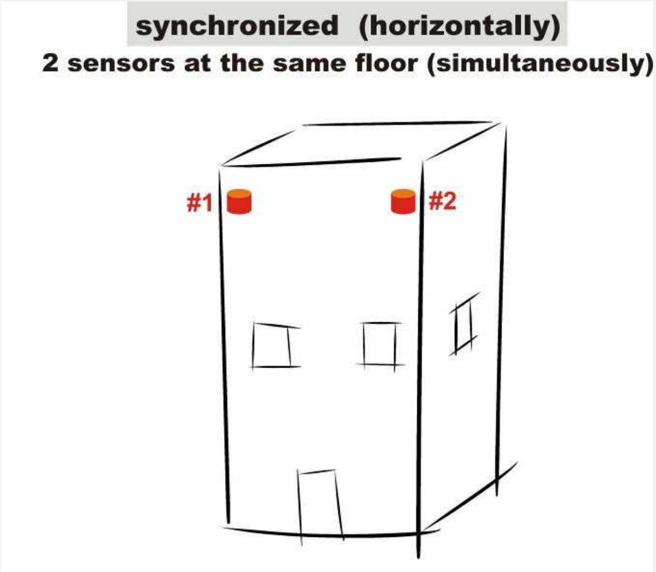


3- Synchronized sensors placed on the same floor (recommended):

[needed to separate torsional and flexural eigenmodes – see GHM technique]

I would call it SS-H3 (*Syncro Sensors* - *Horizontal* with the number indicating the floor number on which the measurements were carried out)

A last type of acquisition/analysis is carried out by considering two sensors, which are synchronized and acquire simultaneously on two different floors. We will call this type of acquisition and analysis *synchronized vertically*. Clearly, in order to carry out this type of analysis it is necessary to use two 3-channel geophones that have identical characteristics and are perfectly synchronized.

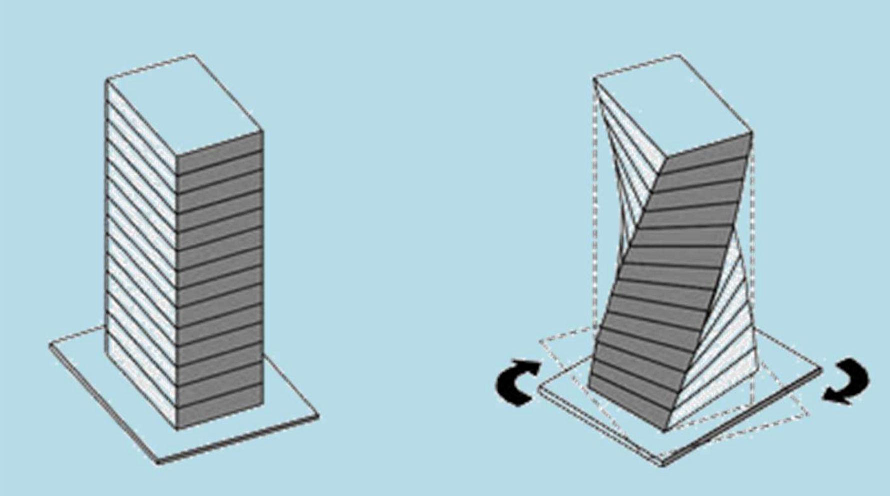


Below is a schematic diagram of synchronized acquisition carried out with the *HoliSurface®* acquisition system: two 3-channel (3C) geophones, 24-bit seismograph, a small cable that connects the 3C geophone directly to one of the seismograph connectors and the *HoliSurface®* seismic cable that connects the seismograph to the second 3C geophone (positioned away from the seismograph).

Even if having to remember these little "rules" may seem challenging at the beginning, with practice you will realize how much this type of naming helps to visualize (objectively and for all) the type of situation from time to time considered.

GHM

The GHM method (see Dal Moro et al. 2018) allows not only to identify in a clear way all the modes of vibration (with the respective frequency) but to discern even if a certain way is **torsional**, **flexural** or **mixed**.



Torsional motion

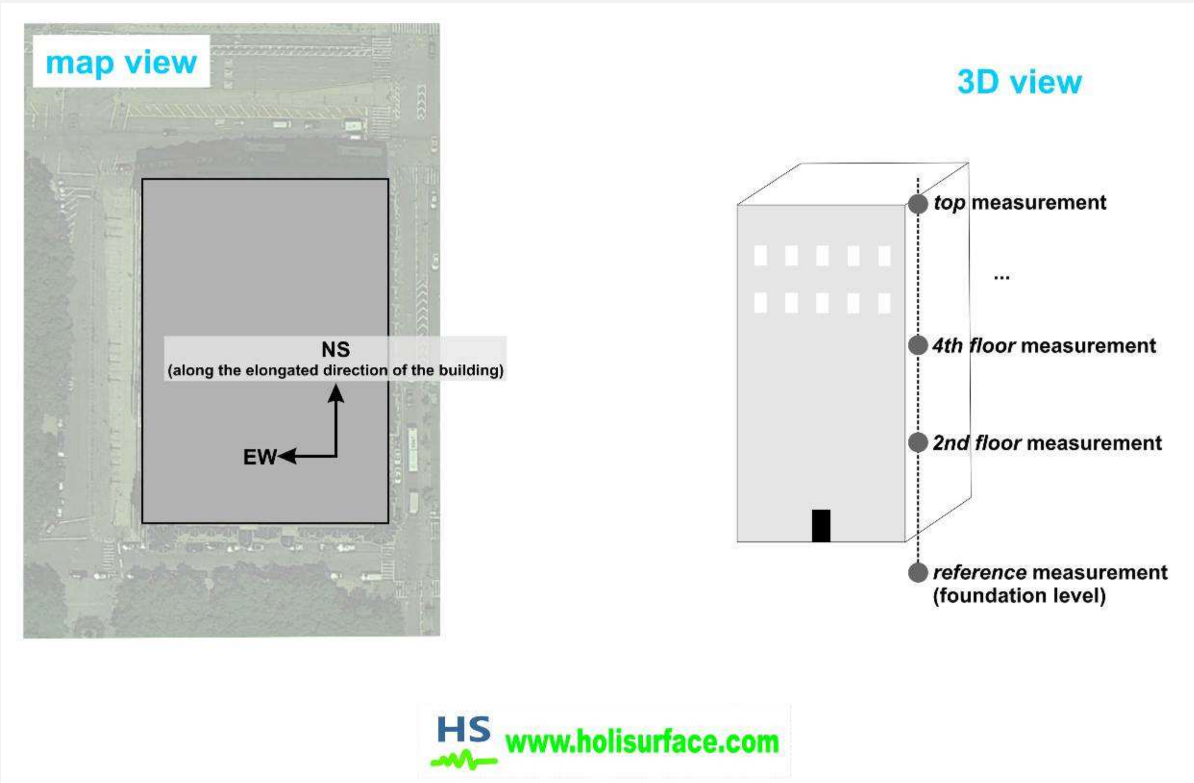
Some videos on flexural and torsional components are available at YouTube

https://www.youtube.com/user/winMASW/playlists

15.2 Acquisition

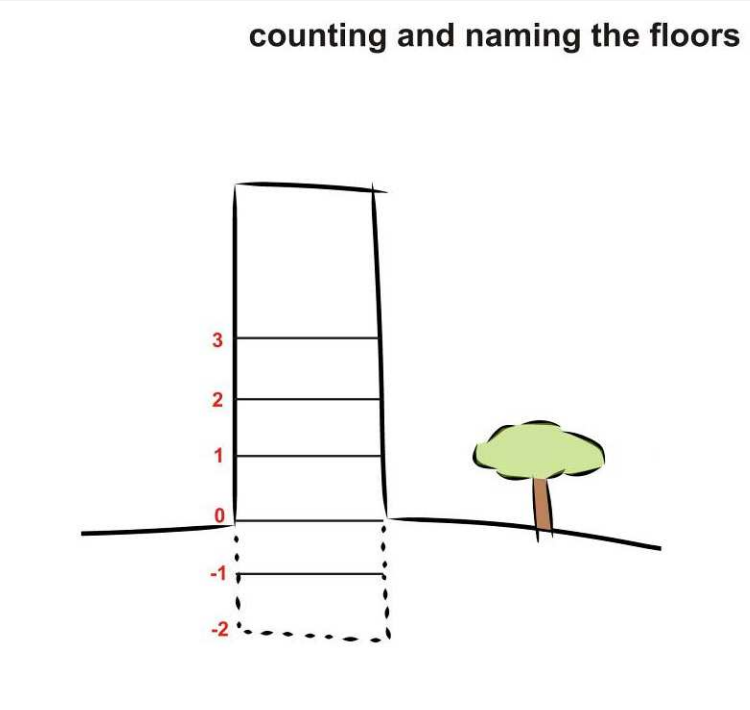
Below is a simple sequence of operations to be carried out in order to collect data and then estimate the oscillations of a building. In order to create a "protocol" to follow always in the same way (thus avoiding "errors of distraction"), it is recommended to always follow the same procedure:

1. Go to the deepest floor of the building. The "level" that represents the foundation (the place where the building rests on the ground) can be a garage, a basement, or a cellar. Arrange the 3-channel geophone with the two axes (NS and EW) according to the axes of the building. In the software, this floor/level is referred to as ***reference***.
It is good to always arrange the NS of the instrument along the same axis as the axis of major elongation of the building (if this is not exactly square) [see "**map view**" in the image below]. This is only a general rule and therefore helps avoid forgetting how the measurements were made.
It is important (as far as possible) to make all the measurements trying to maintain the same vertical axis [see "**3D view**" in the image below].



So if, for example, we are carrying out measurements in a building in a typical Italian city (where all the buildings are "connected" to each other almost creating a single built-up structure along a road), the NS is placed parallel to the road itself.

2. Go to the upper floors (making sure to follow as much as possible an ideal vertical axis (see "**3D view**") and place the geophone in the same way. It is not essential to take measurements one by one on all floors. For example, if you are dealing with a 6-storey building, you can only take measurements on the second, fourth and last (floor) floors (for quick measurements, you could also acquire data only on the last floor - in addition to the "reference" floor).



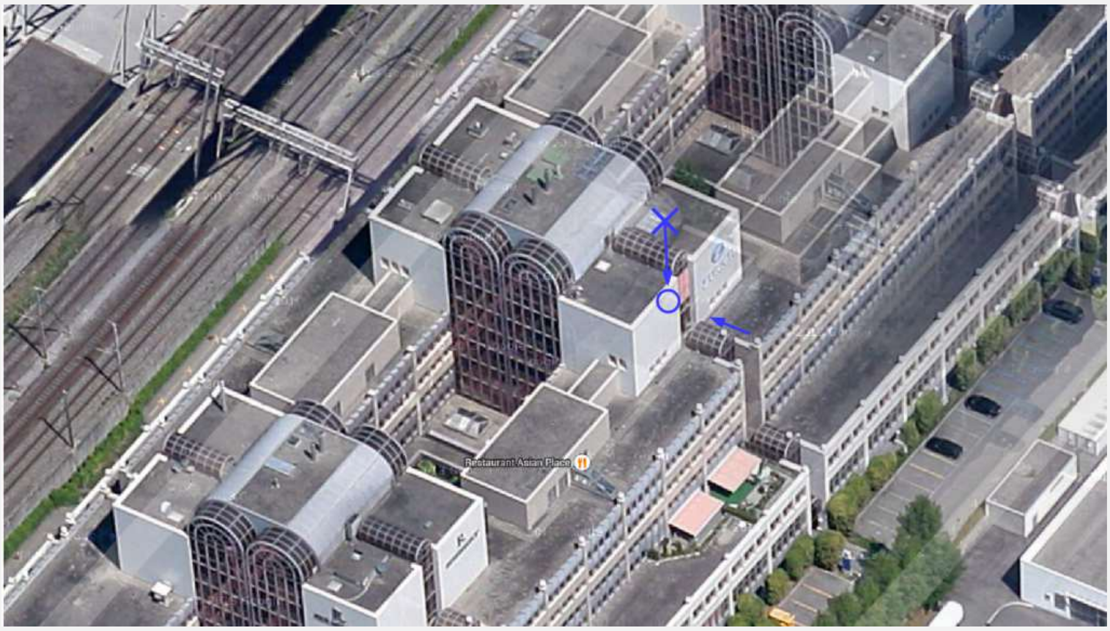
Basic recording parameters

Recording length	10-20 minutes (even less may suffice, but it is better not to exaggerate)
Sampling frequency	50-60 Hz is enough (but 100 Hz is fine) (from the engineering point of view we are interested in maximum frequencies of about 20 Hz)

How to name files

It is always good to give names that are informative and easy to understand even for those who have not personally taken the measurements and therefore help in the analysis. Below is an example of meaningful and therefore useful names.

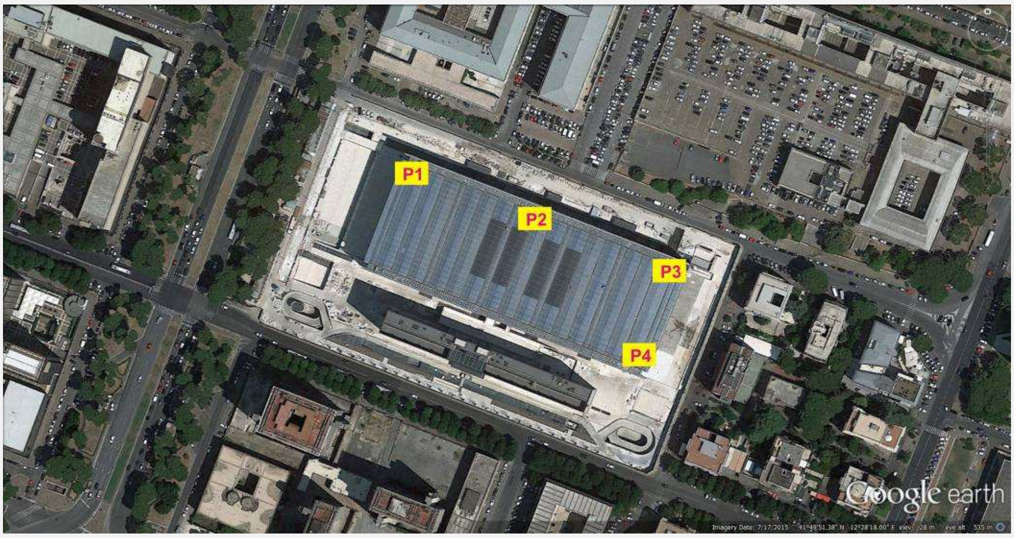
BUILDING_ViaLAMPO3_reference.SAF (or BUILDING_ViaLAMPO3_floor0.SAF)
BUILDING_ViaLAMPO3_floor2.SAF
BUILDING_ViaLAMPO3_floor4.SAF
BUILDING_ViaLAMPO3_floor6.SAF
BUILDING_ViaLAMPO3_floor8.SAF



If, out of curiosity or necessity, you carry out vibration acquisitions on different days (characterized by different weather conditions - a quiet and windless day and a day when there is strong wind instead) it will be interesting to see (in relative and comparative terms) the increase in the amplitude of the oscillation.

If you are measuring on several points/vertical axis, we recommend specifying it directly in the file name:

thus obtaining for point/vertical axis 1
BUILDING_ViaLAMPO3_floor0_VerticalPoint1.SAF
BUILDING_ViaLAMPO3_floor4_VerticalPoint1.SAF
BUILDING_ViaLAMPO3_floor6_VerticalPoint1.SAF



thus obtaining for point/vertical axis 2
BUILDING_ViaLAMPO3_floor0_VerticalPoint2.SAF
BUILDING_ViaLAMPO3_floor4_VerticalPoint2.SAF
BUILDING_ViaLAMPO3_floor6_VerticalPoint2.SAF

The aim is always the same: to be able to provide a colleague with data in a clear and straightforward way without verbose and complicated "field notes": in the name of the file there must be all—or almost all—the information necessary to understand what it is about.

Some further recommendations for the data acquisition

1. Use equalized sensors and instruments that allow you to obtain data in mm/s (not in counts);

2. Always acquire one more data item rather than one less:

3. In addition to an acquisition at the "reference floor," always take one also externally (on the ground or asphalt);

4. Inside the building, pay attention to washing machines, dishwashers, loud stereo systems, pumps (including those of the heating system, radiators), etc.

5. In the case of synchronized measurements (sometimes called dynamic measurements), first check the polarities of the data (depending on the sensor-cable-acquirer combination)

6. If possible, make acquisitions in periods of "absolute calm" (when there is little human or industrial activity inside the building - to avoid possible spurious signals that can be misinterpreted/misunderstood). Consider therefore the evening hours and/or the weekends.

7. In order for this to happen, it is always necessary to ask for the cooperation of those who live/work in the building (who must avoid carrying out the above activities). If this is not possible, the data collected can be contaminated by signals that have nothing to do with the building vibrations (see case studies in the "*Efficient Joint Acquisition and Analysis of Surface Waves and Introduction to Vibration Analysis: Beyond the Clichés*" book [G. Dal Moro, 2020, Springer, ISBN 978-3-030-46303-8].

In the analysis of building vibrations, the analysis of HVSR has no meaning (what matters are the amplitude spectra and not the HVSR).

15.3 GHM and GVM Analyses

The GHM method is presented in the article *Gaussian-filtered Horizontal Motion (GHM) plots of non-synchronous ambient microtremors for the identification of flexural and torsional modes of a building* (Dal Moro, Weber, Keller, 2018). A further case study is available in the paper *Influenza della modellazione degli edifici sulla determinazione della loro vulnerabilità sismica* (Sancin, Dal Moro, Amadio, Romanelli, Vaccari, 2018).

This method allows identifying the vibration frequencies of a building as well as its mode (flexural, torsional or mixed) from the data collected on two points (angles) of the same plane.

The power and elegance of this method lies in the fact that, unlike the classical approach, to distinguish the type of mode it is not necessary for the data (in the two points A and B) to be synchronous. That is to say, it is possible to record the data first in point A and then in point B.

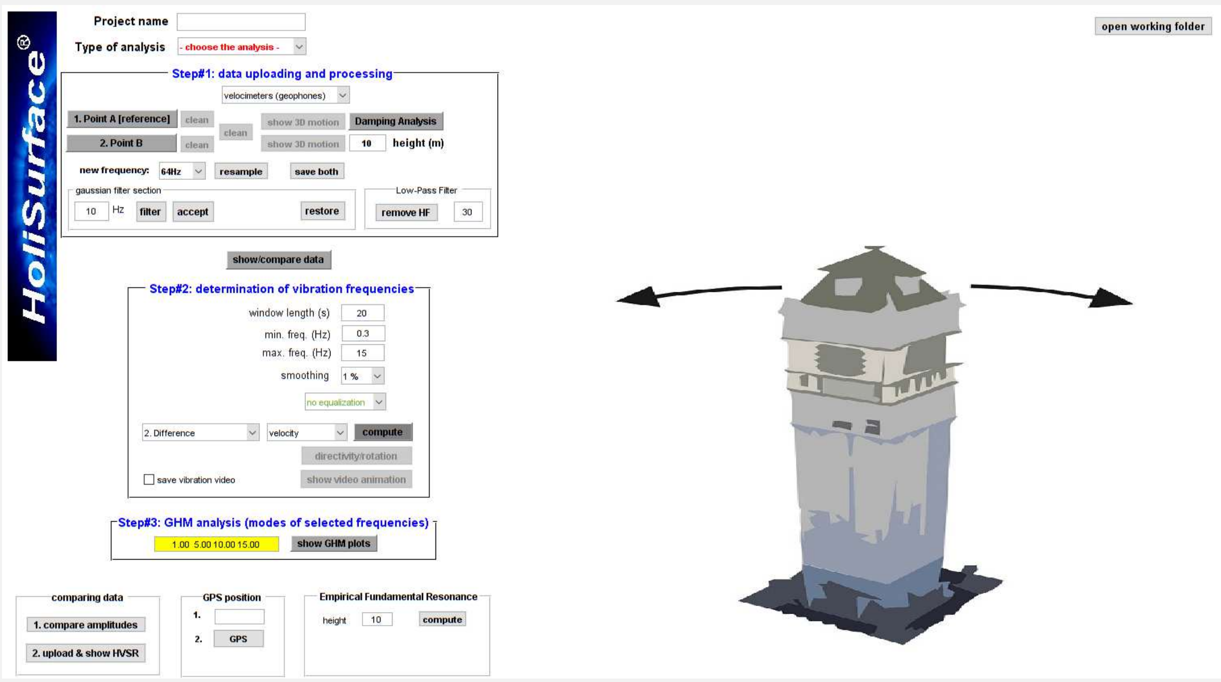
In the first instance, we recommend summarizing **what are the three steps** to be taken in order to characterize the vibrations of a building.

After setting the *working folder*, the project name and the type of analysis (uncoupled or horizontally synchronized data), here is the sequence of steps:

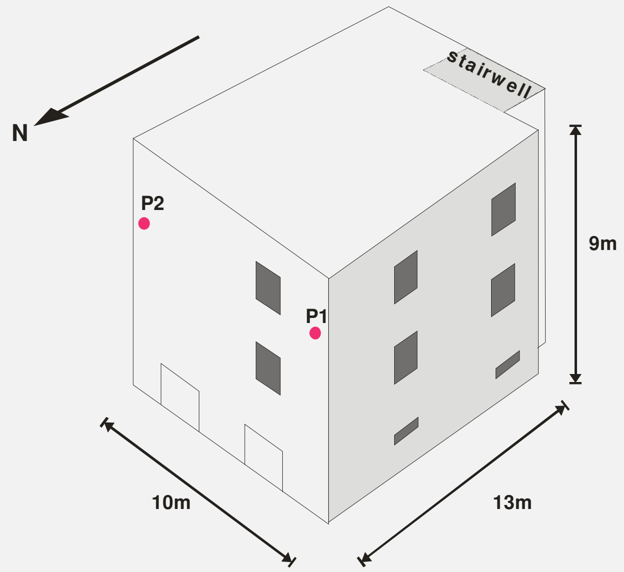
1) step #1: upload the data and perform the data pre-processing as you would do for the HVSR analysis (possible re-sampling, cleaning of the transient signals, etc.);

2) step #2: carry out the analysis of the amplitude spectra useful to identify the vibration frequencies of the building;

3) step #3: carry out the GHM (*Gaussian-filter Horizontal Motion*) **analysis** that allows (if the data have been acquired appropriately) to obtain information on the type of motion (flexural or torsional) associated with the frequencies previously identified.



Example



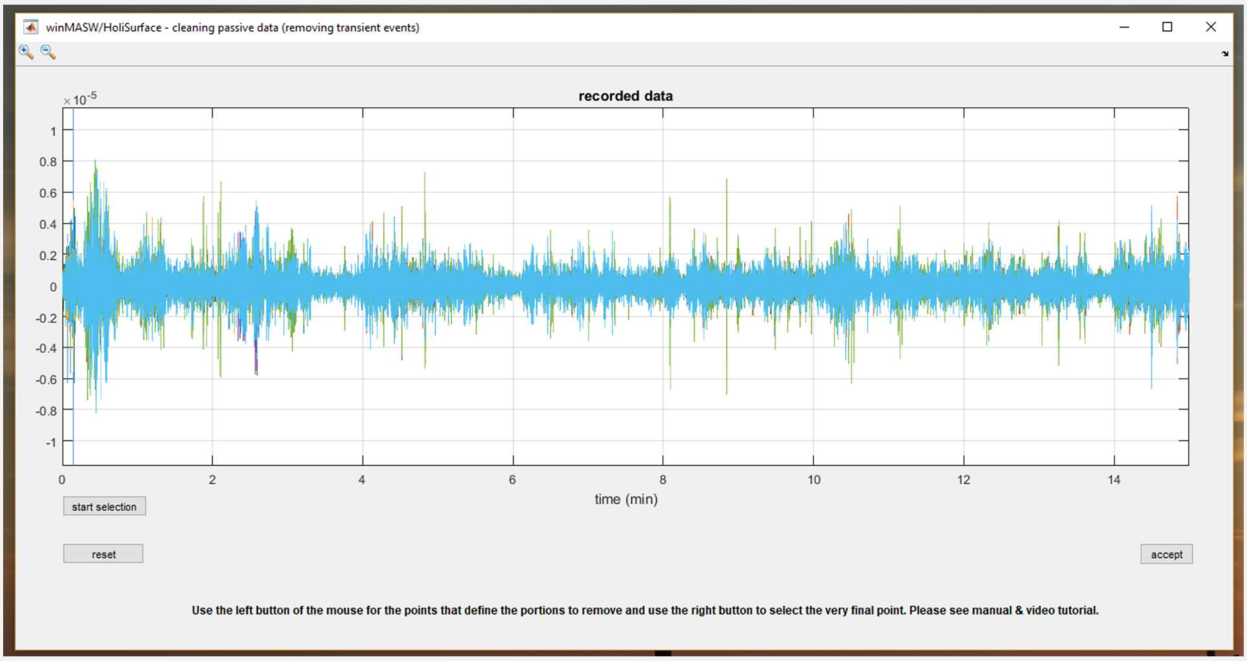
The following is an example carried out for a building like the one in the figure above and considering data taken in sync by two 3-channel geophones at points P1 and P2.

Step #1 – data uploading

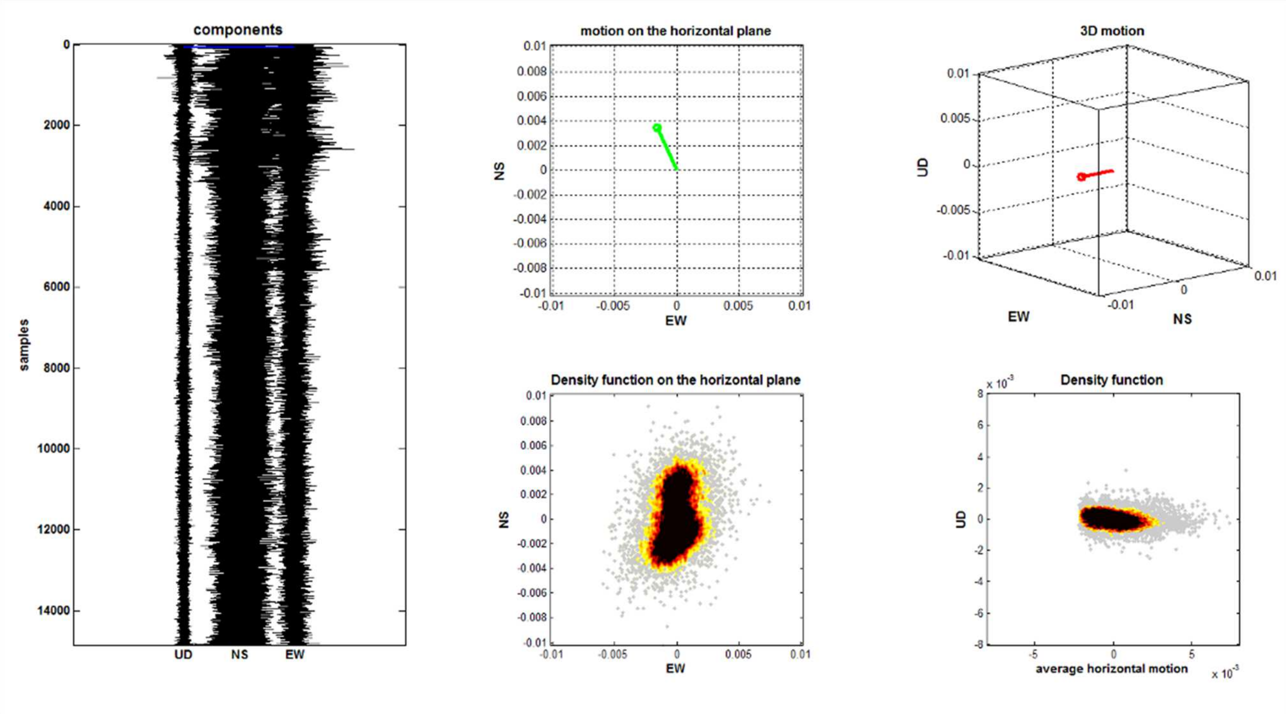
First we need to upload the data (and in case resample them). A few operations can then be applied.

Data cleaning

To clean the data (the same way as when you compute the HVSR), click the "**clean**" button:



By clicking on the "**show 3D motion**" button, you can view the data and obtain "visual" information about motion in the point considered:

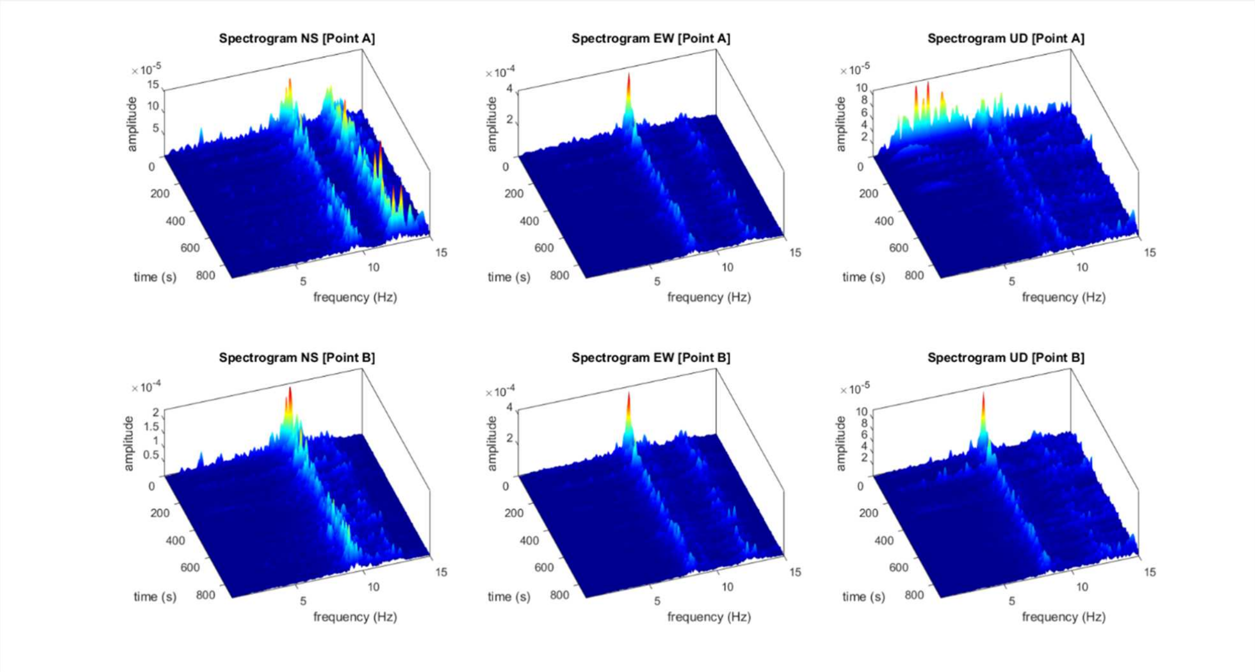


Step #2 - determination of the eigen frequencies

Analysis on synchronized data (vertical or horizontal)

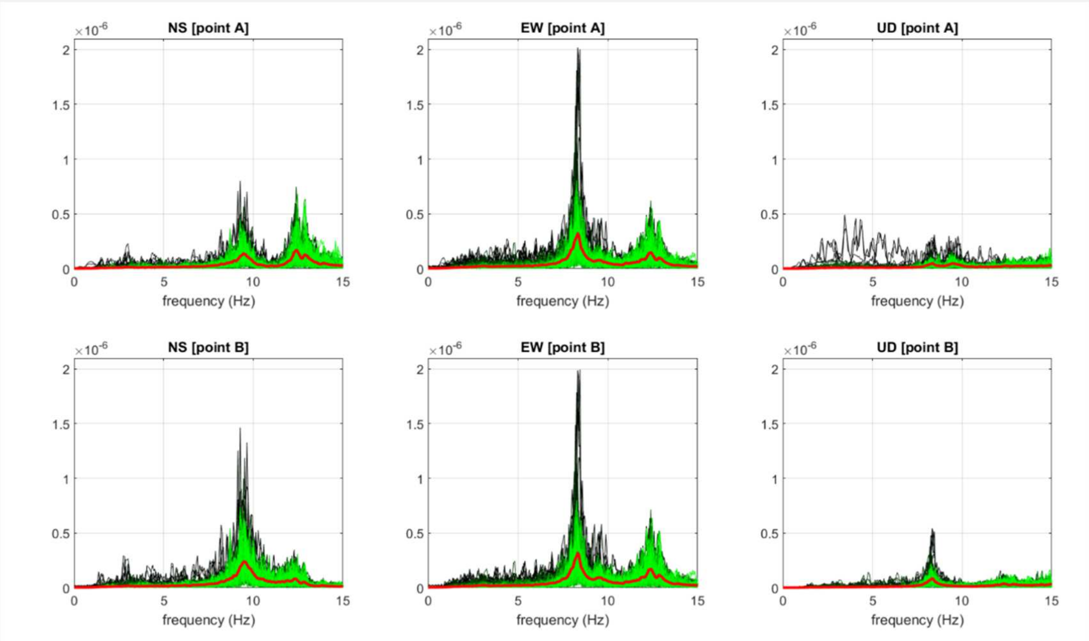
This is the synchronous case without distinguishing whether it is horizontal or vertical (the difference is merely in the reasoning to be followed when reading the results).
Once the data are uploaded and cleaned, just click the "compute" button within the group "**Step#2: determination of vibration frequencies**”.

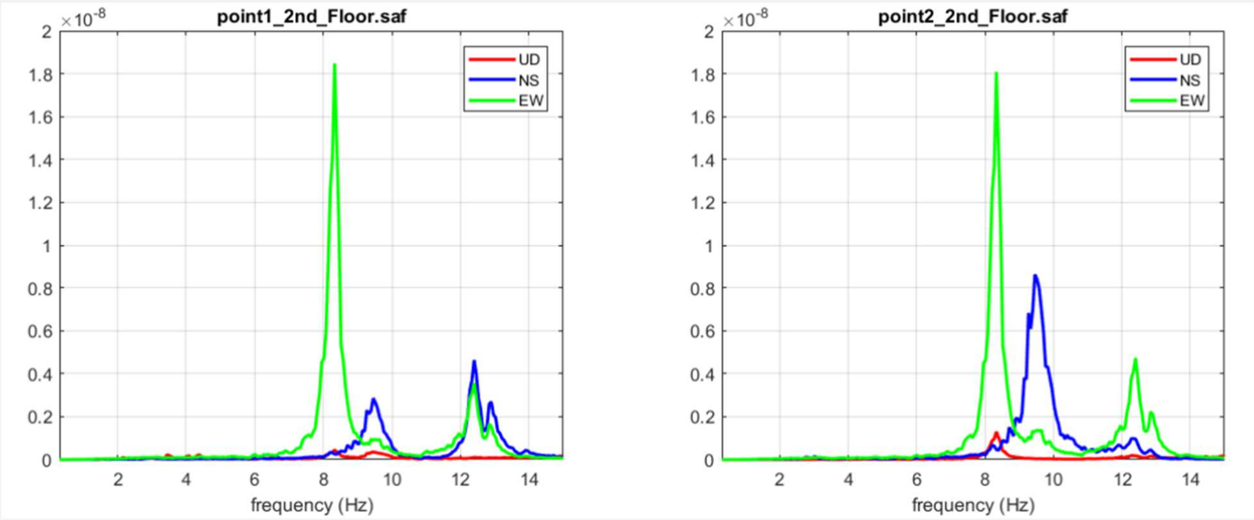
Among the various output data, these are the most important ones:



Spectrograms of the three components (for both measuring points).

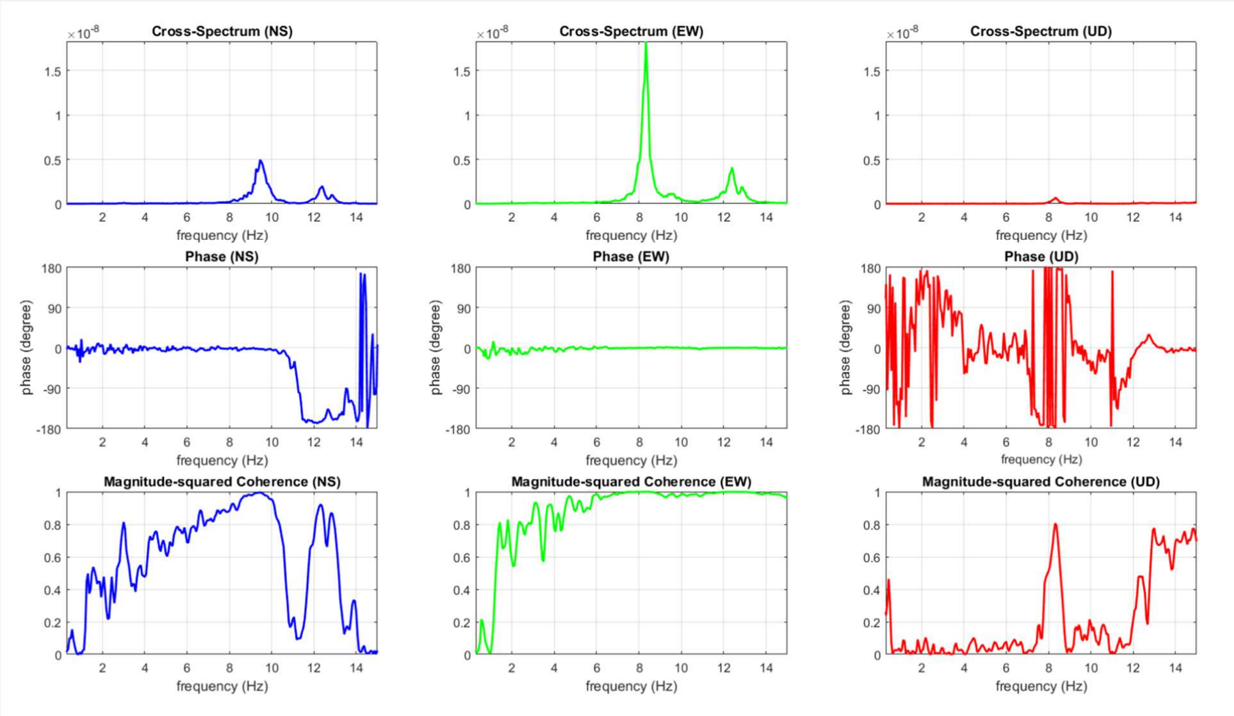
Amplitude spectra of the various segments (the quantity clearly depends on the window length) and, in red, the mean amplitude spectra.

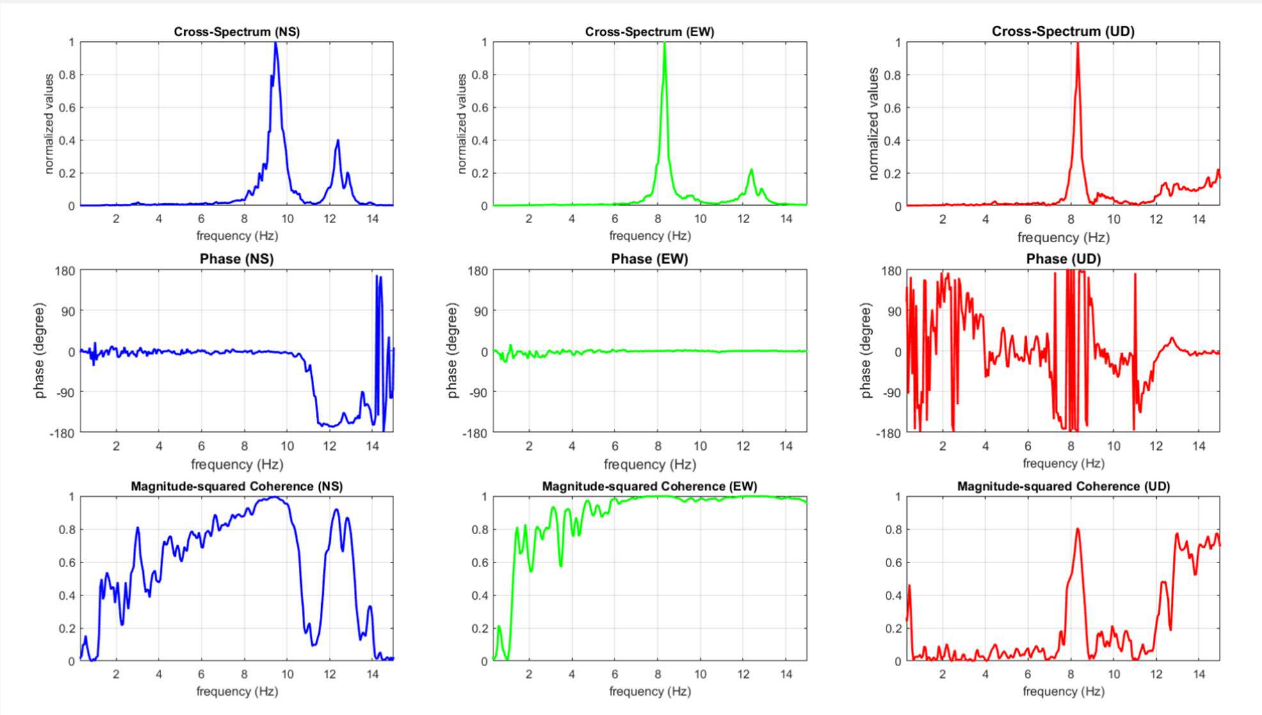


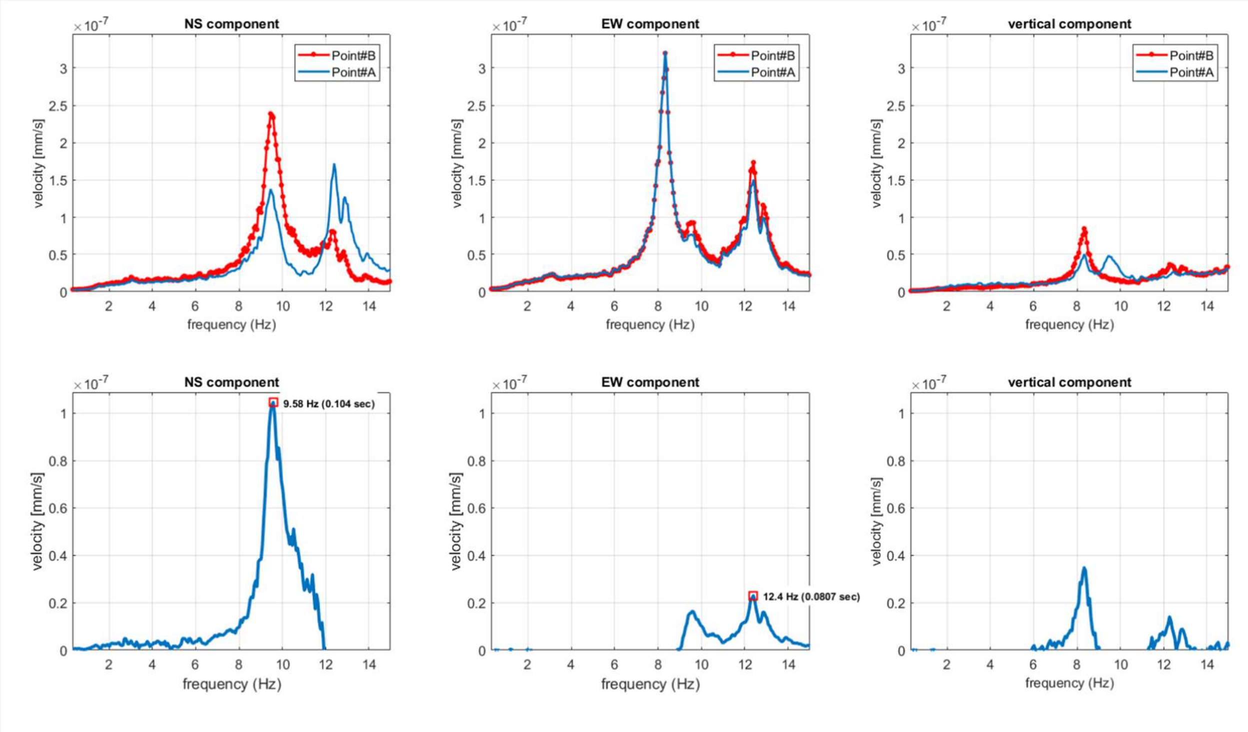


Autospectra (also normalized) of the three components (for both measuring points): three clear vibration frequencies (about 8.3, 9.5 and 12.4 Hz).

Here below are the cross-spectrum, the phase and coherence functions for the three components (bear in mind that the vertical component is not of usually interest) [both the graph of the actual values and the one with the normalized ones are shown].







Comparison of the amplitude spectra of the two points considered (for the three components) and their difference.

The set of these data/analyses allows you to clearly define three vibration frequencies: 8.3, 9.5 and 12.4 Hz

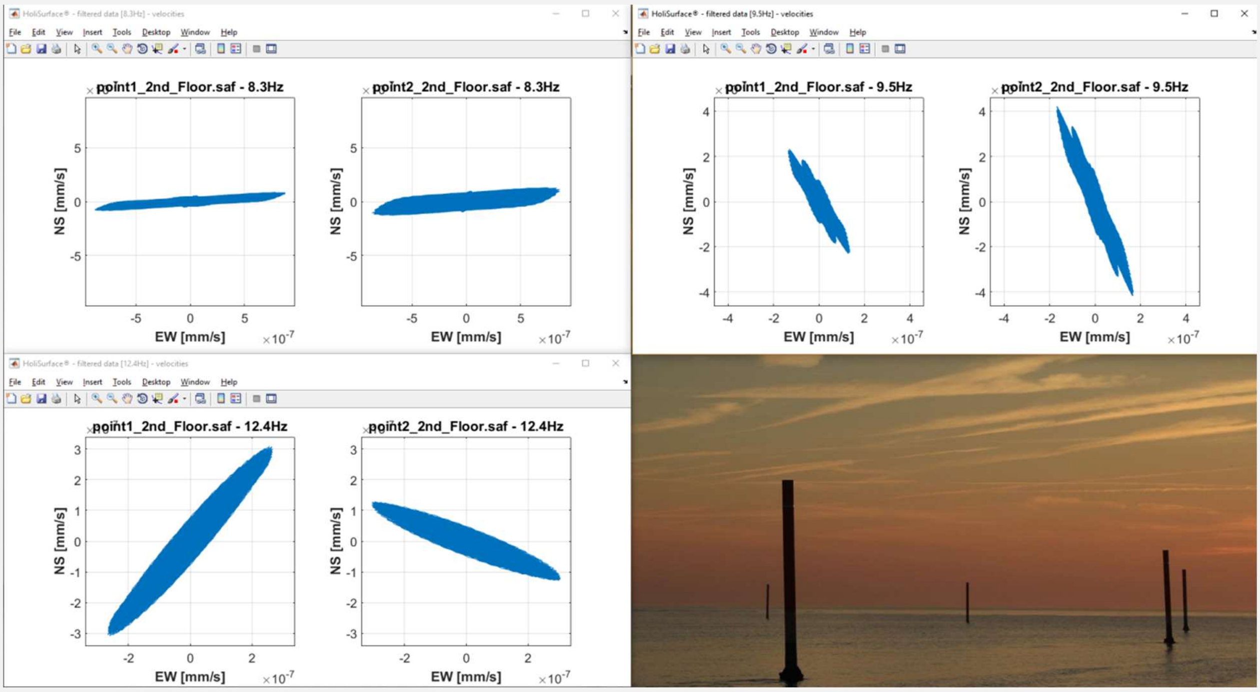
Step #3 - GHM analysis (mode identification of selected frequencies)

This third step is aimed at understanding the type of mode (flexural or torsional) for each of the identified frequencies.

This procedure is only applicable in the case of measurements collected on a single floor (typically high) in two different points (typically two opposite corners of the building, for example the north-east (NE) corner and the north-west corner of the top floor).

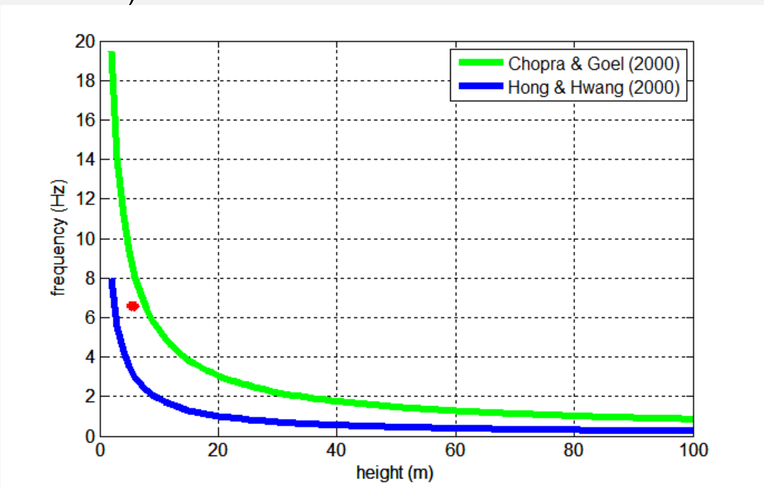
Enter the frequencies previously identified in the field (yellow background) and click the "show GHM plots" button.

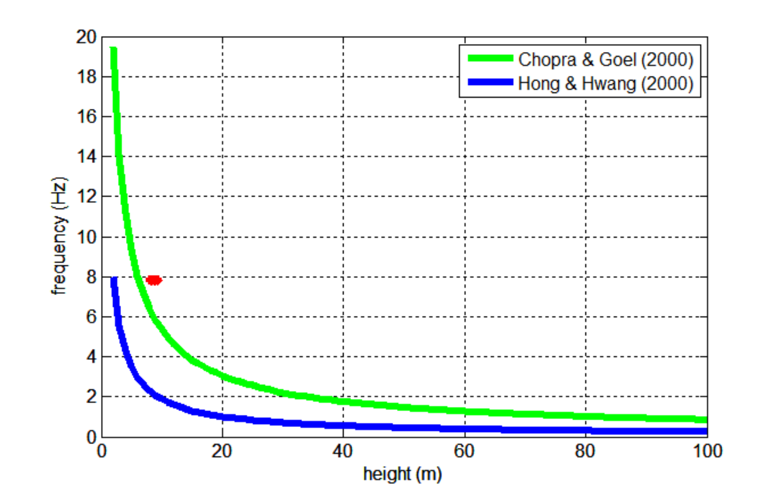
This is what you get in the case of the dataset considered for this example (in which we identified three vibration frequencies):



These plots show how the mode for the frequencies 8.3 and 9.5 Hz is flexural (both points move in the same direction), while the mode for the frequency 12.4 Hz is torsional (the directions of motion show a torsion/rotation) [see article "***Gaussian-filtered Horizontal Motion (GHM) plots of non-synchronous ambient microtremors for the identification of flexural and torsional modes of a building***" (Dal Moro et al., 2018)].

By entering the height of the building (button "compute" in the section "*Theoretical Fundamental Resonance*") you are given the theoretical resonance periods compared with the empirical curves indicated by Chopra and Goel (2000) and Hong and Hwang (2000).
Here are two example images: in the first case, the red point (representing the resonance frequency with the maximum amplitude of the analyzed data) is in an area (between the two empirical curves) that could indicate that this vibration is the one relative to the fundamental period.
In the second case, on the other hand, the frequency identified is higher, as it may indicate some "anomalies" (error in the analyses? particularly rigid building? frequency not related to the fundamental mode?)



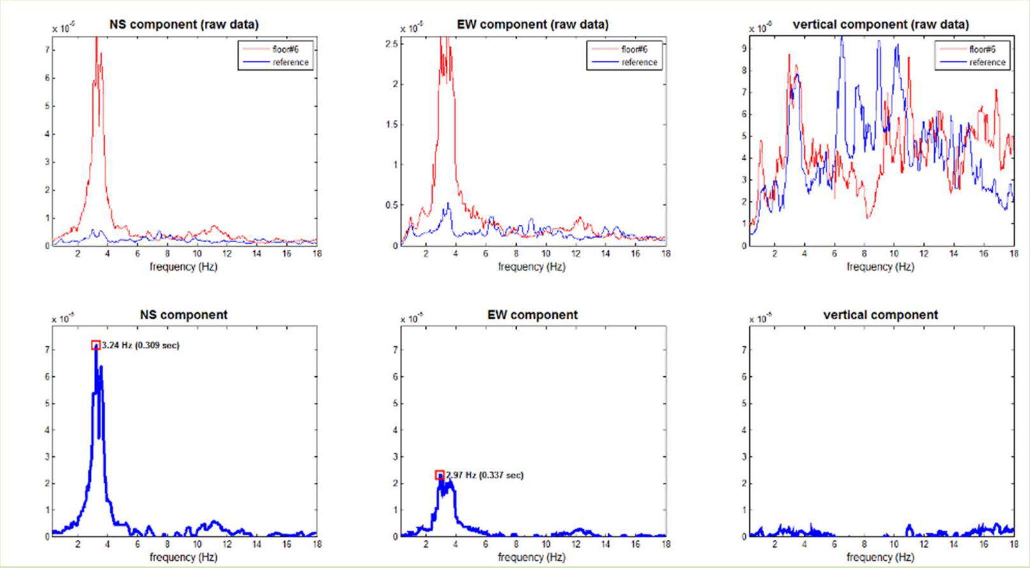


Chopra A.K. and Goel R.K., 2000. *Building Period Formulas for Estimating Seismic Displacements* Technical Note, Earthquake Spectra, Earthquake Engineering Research Institute, 16, 533-536.

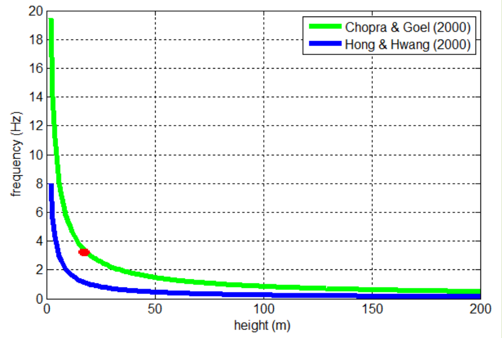
Hong L-L and Hwang W-L., 2000. Empirical formula for fundamental vibration periods of reinforced concrete buildings in Taiwan. Earthq. Engin. and Struct. Dyn., 29, 327–337.

Example of analysis on a 6-storey building

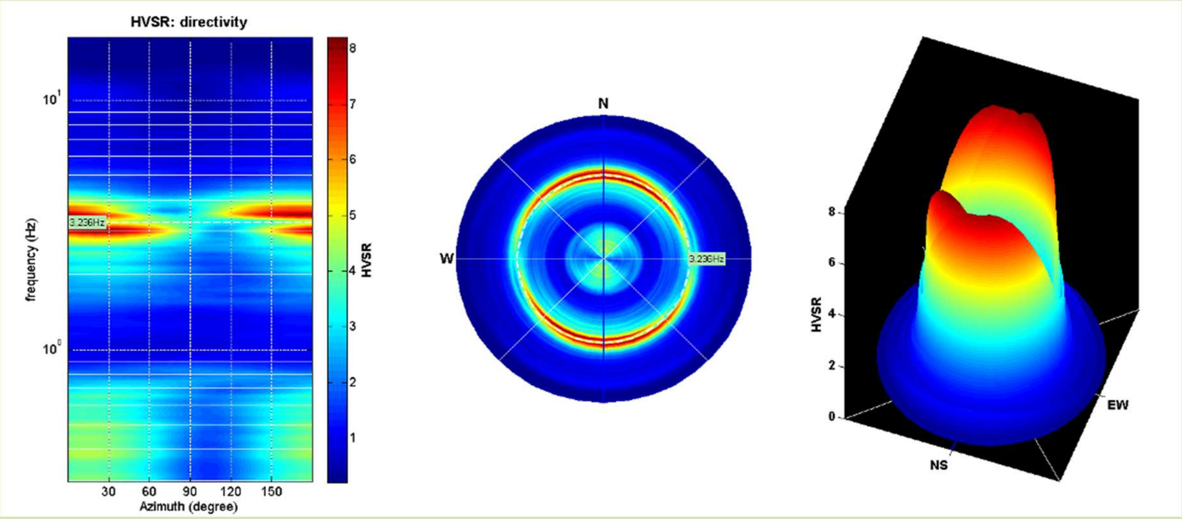
It is possible to see that along the NS axis (the building's major elongation axis) the building "resonates" on 2 frequencies that are slightly different from those of the EW axis, showing different and uncoupled (translational?) modes along the 2 axes.



If we plot these frequencies on a graph that also shows the curves according to Chopra and Goel (2000) and to Hong and Hwang (2000) we see that the frequencies of the building approximate the values indicated by the former authors.



Finally, it is also possible to calculate the directivity of the HVSR (at the topmost floor): you can see the largest amplitude (and the "duplicity of the peak") of the HV along the NS axis (confirming what was observed in the graphs above).



15.3.1 Bridges: GVM analysis

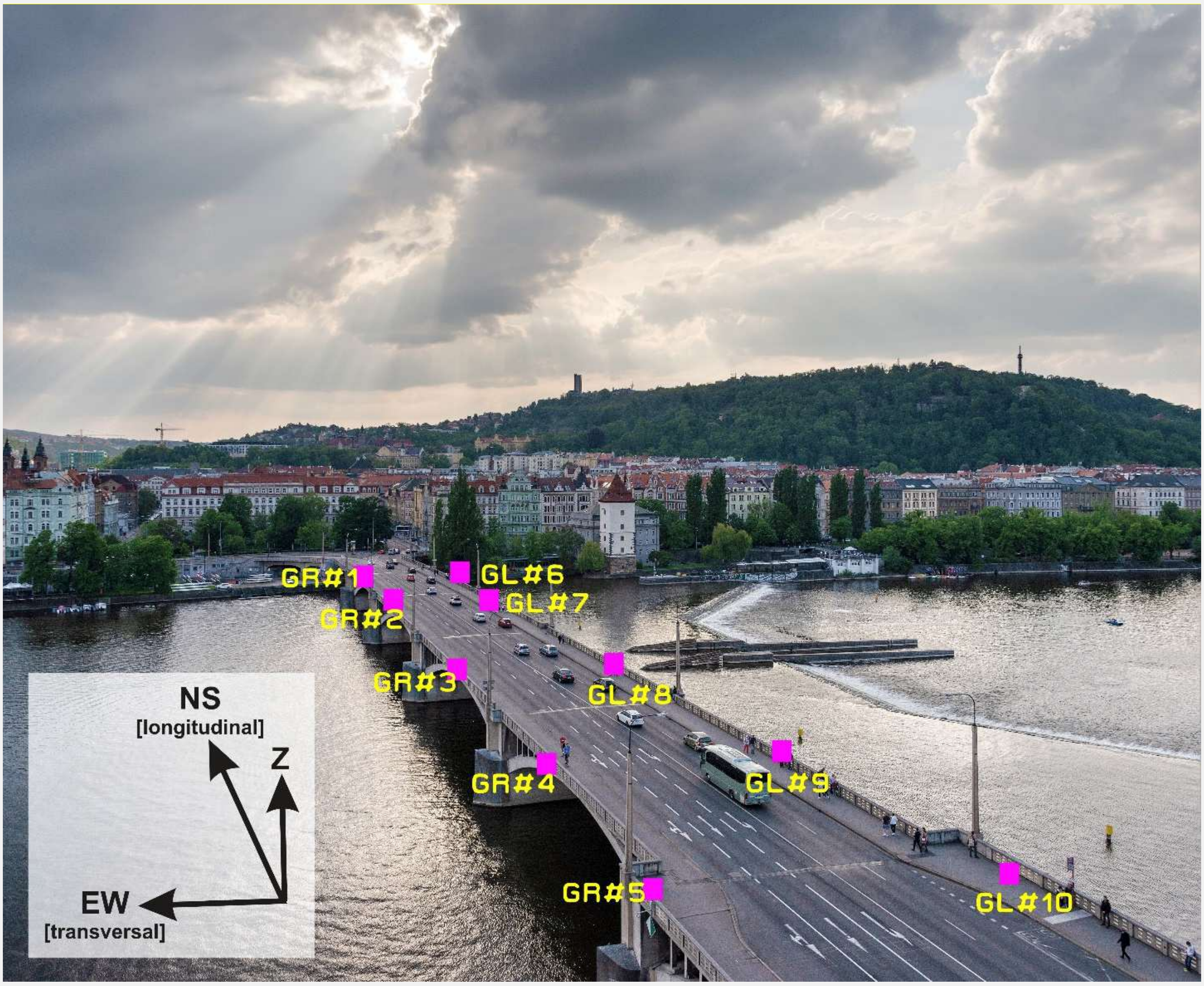
And in case we are analyzing data collected on a bridge?

In this case, the particle motion on the vertical planes (Z-NS and/or Z-EW) are extremely important to define the types of modes (*eigenmodes*) of the considered bridge/structure.

Therefore, the GVM (Gaussian-filtered Vertical Motion) plots are of paramount importance (Z-NS and/or Z-EW depending on the type of structure and eigenmodes).

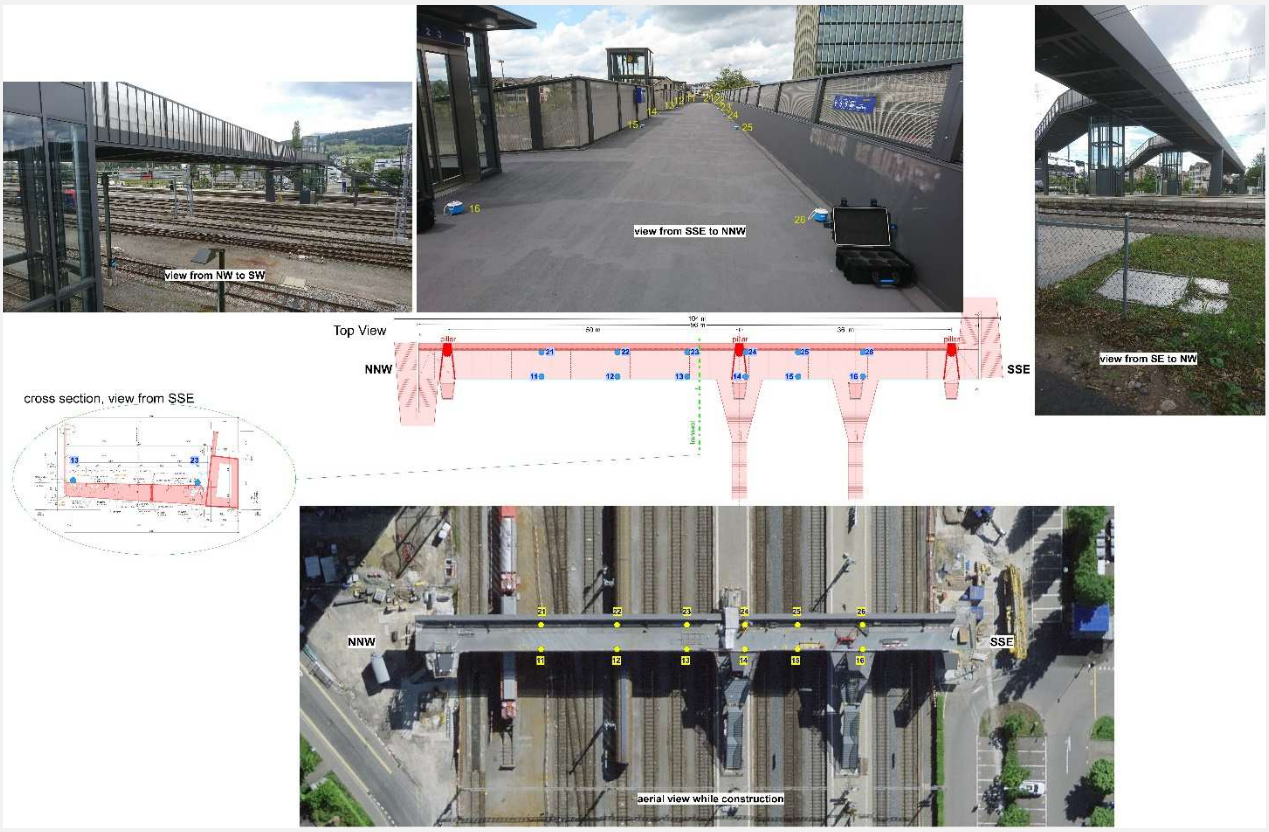
Remember that in seismics and vibration analysis there are **<u>no geographical directions</u>** (N, S, E & W): in seismics we deal and speak about *components* (Vertical, Radial and Transverse) and while analysing vibration darta there we must consider the *structural axes*.
In the case of "elongated" structures, we often speak of *longitudinal axis* (the one with the maximum elongation) and *transversal axis* (perpendicular to it). <u>Usually, the instrumental NS is by convention the one that corresponds to the longitudinal axis</u>.

Study carefully the image below. When a properly oriented 3C geophone is used to record vibration data, it is important to choose a meaningfull and clear file name such as Point1_Z_Long_Transv.seg2 (meaning that the first trace is about the vertical component, the second about the longitudinal axis and the third abot the transversal axis).



First example: pedestrian metal bridge(typical of several railway stations)

In this case, twelve 3C geophones were used, recording synchronously (so the type of analysis to be selected is "synchro horizontal"): 6 along one side and 6 along the opposite side (see images below).
In this case, the NS (second trace of the dataset) is the main direction/axis of the bridge [the first trace is the vertical and the third the transversal].



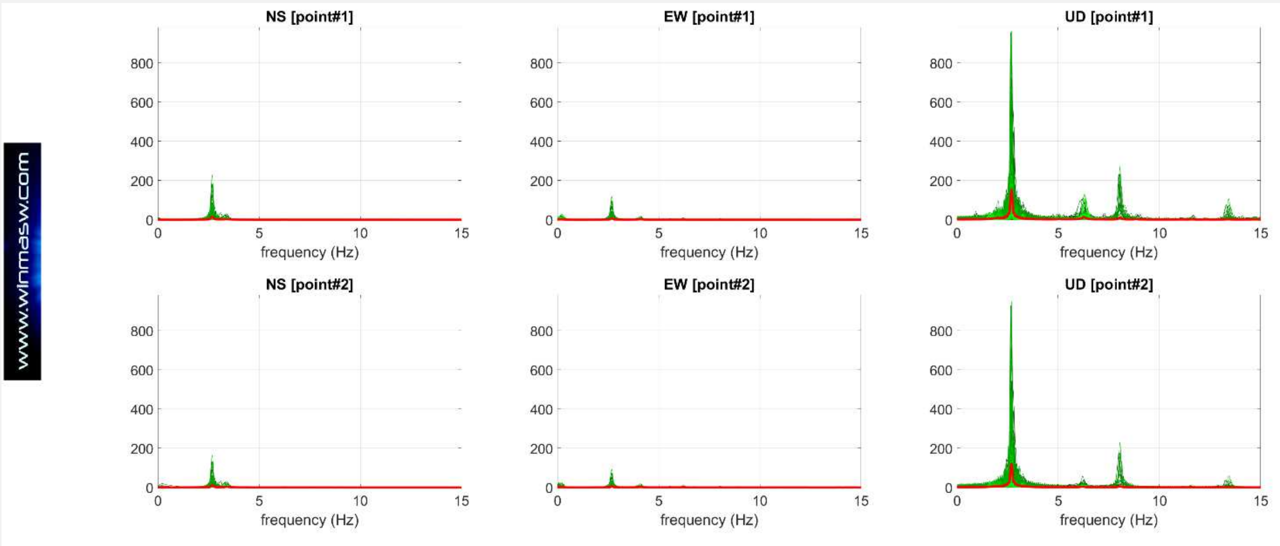
The goal is to characterize the vibration modes of the bridge (eigenfrequencies and type of particle motion).
Let us briefly see how to work in order to be able to tell the structural engineer what are the eigenmodes of this structure.

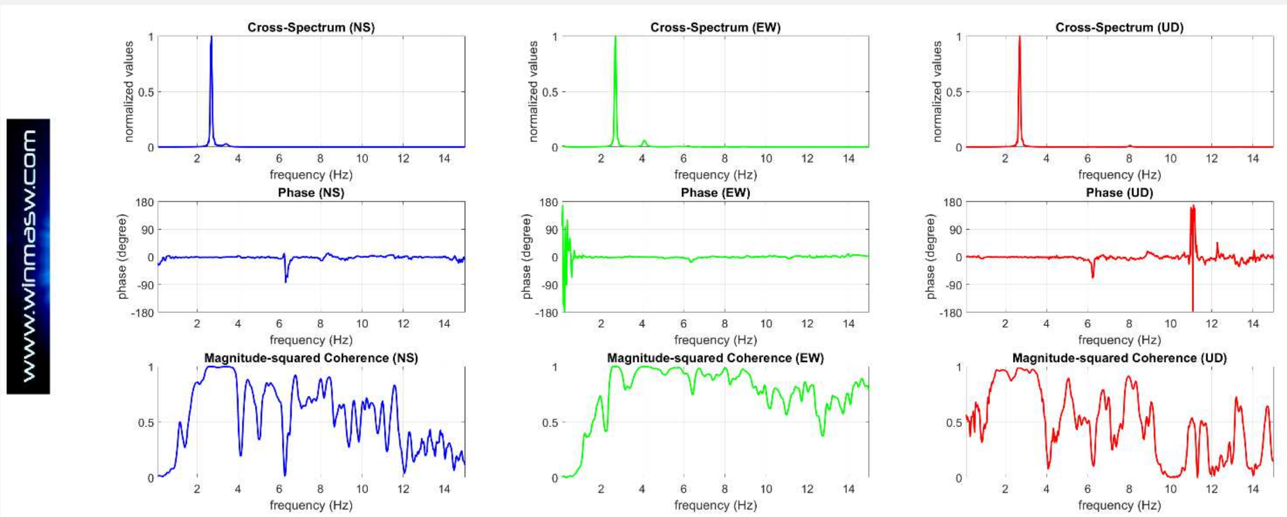
For the sake of brevity, let us consider two (particularly significant) combinations of sensors: 11-21 and 11-14 [looking at the images and sketches shown in the above figures, you can see that sensor #14 is located exactly at a pylon/junction while sensors 11 and 21 are at a very "unconstrained" point of the bridge.

First step: data analysis for the points #11 and #21

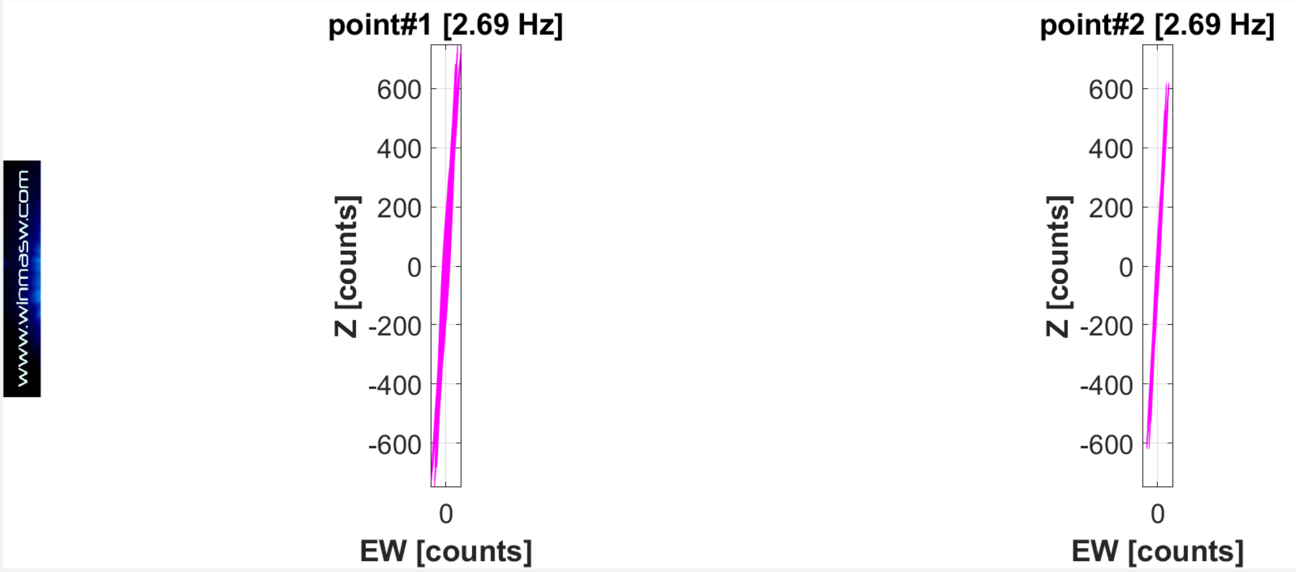
These points (see images) are located on the opposite sides of the bridge in a segment quite far from any structural constrain.

The two images shown below indicate that the particle motion at the two points is basically identical (same amplitude and synchronized - see amplitude spectra and phase functions: at 2.69 Hz the motion of the particle is exactly the same [no phase shift]) and, neglecting lower-amplitude modes, the characterizing mode is at 2.69 Hz.





The **GHM and GMV plots** reported in the following show the type of motion: the amplitude along the vertical axis is far greater than the limited vibration/oscillation/motion along the horizontal plane (compare with the amplitude spectra reported above).



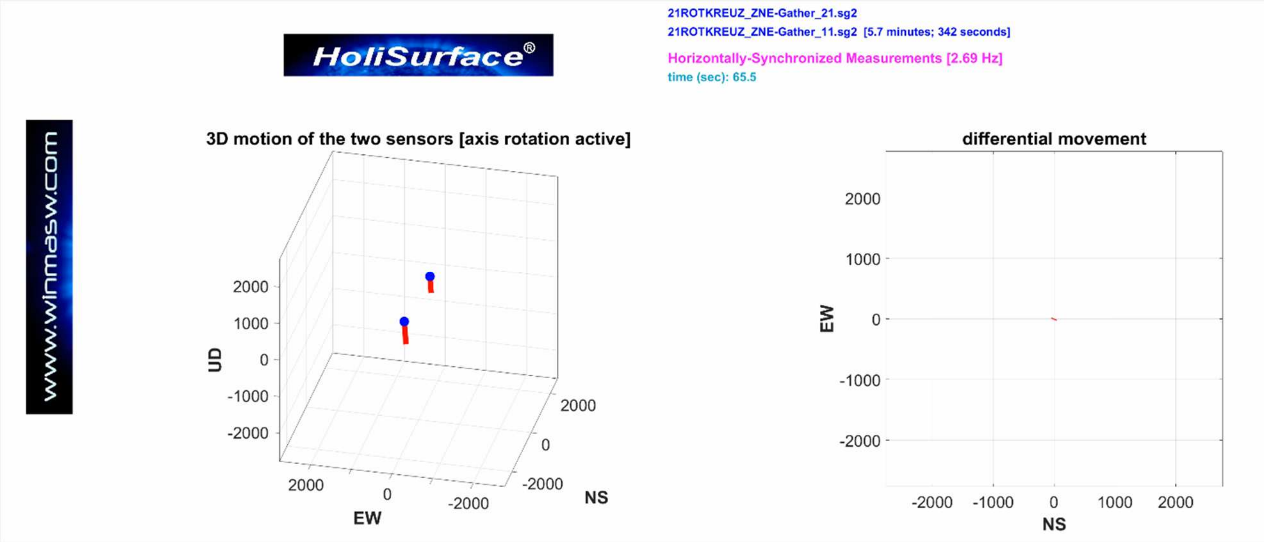
These facts are also clearly and easily verified by the animation of the data ("show 3D video animation" button). In particular, if we want to visualize the motion of the particle at 2.69 Hz (the main mode) we need to perform a **Gaussian filtering** cantered at that frequency.

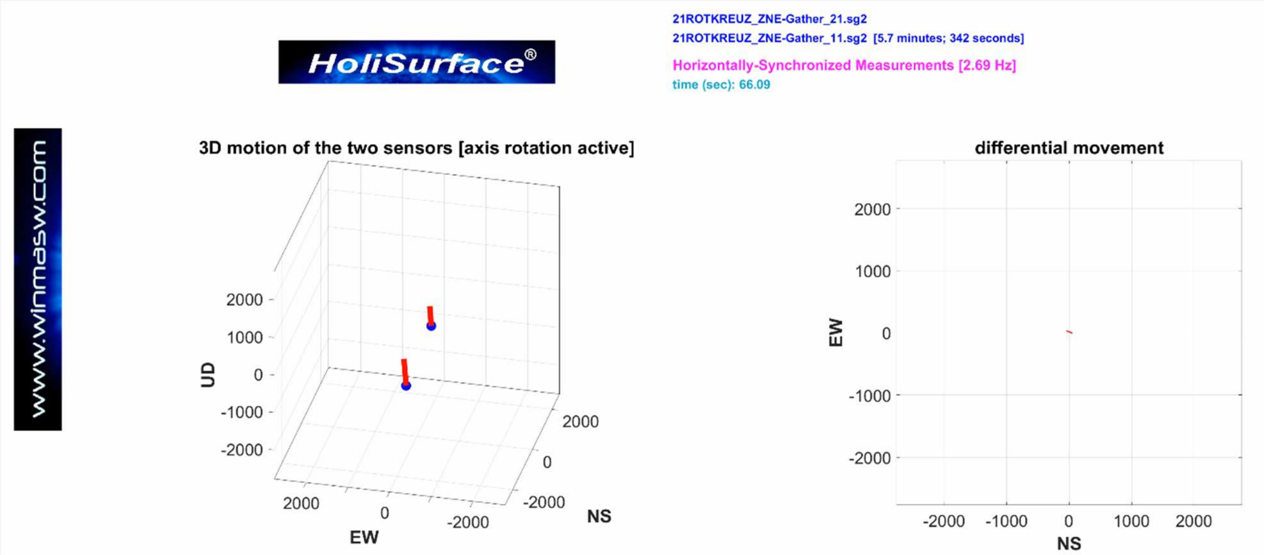
To do this we go to the **"Gaussian filter section" group**, fix the frequency of interest (2.69 Hz), filter the data ("1. filter" button), and if everything looks good we confirm/accept such a filtering ("2. accept").
At this point the data are those Gaussianally filtered at the specified frequency.

At this point we can show the **video animation** (“show 3D video animation” button) that will confirm that the two points are moving at once (perfectly synchronized).

Below are presented two snapshots that clearly show the (almost perfectly) identical motion even through the differential motion shown on the right (close to zero).

Remember that, during the video animation, you can rotate the *viewpoint* (with the mouse), adapting it to the type of motion and the components you wish to highlight.
If you enabled the "**save vibration video**" option, the video will be automatically saved in the working folder.
For computational/graphical issues, it is recommended to work with data re-sampled at the lowest possible frequency (which is usually 32 Hz - Nyquist frequency equal to 16 Hz).

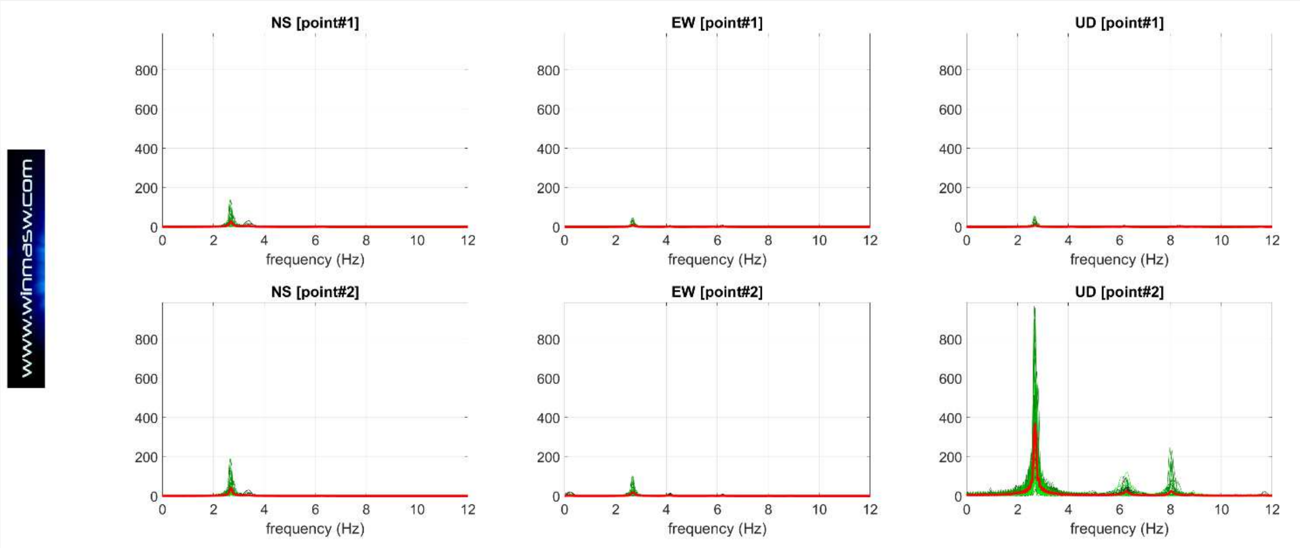




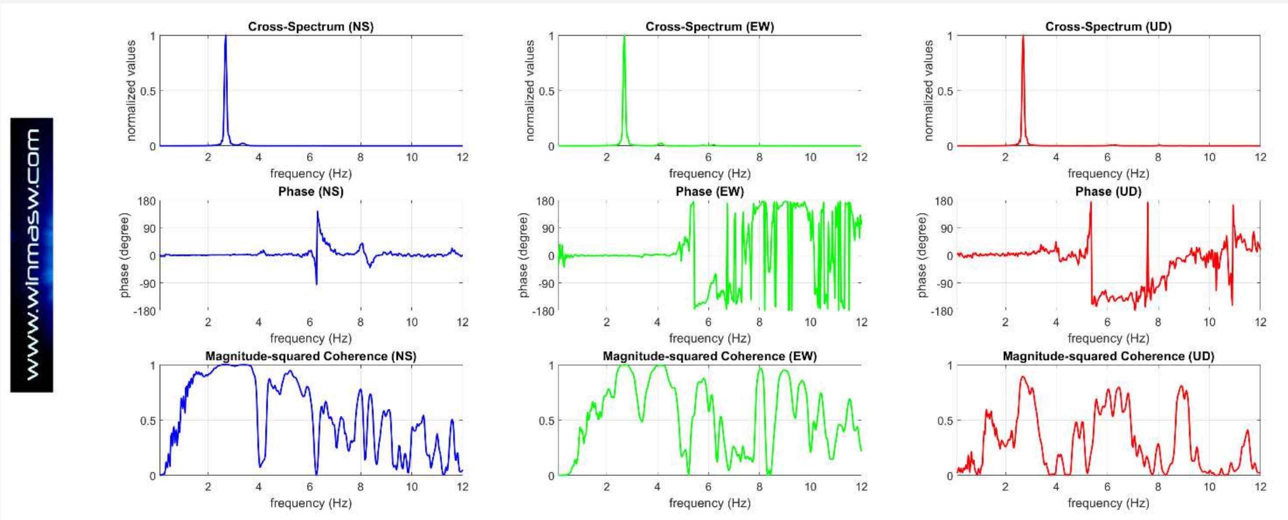
Remember that you can get back to the raw (unfiltered) data just clicking the "restore" button (in the “Gaussian filter section” group).

Step two: data analysis for the points #11 and #14

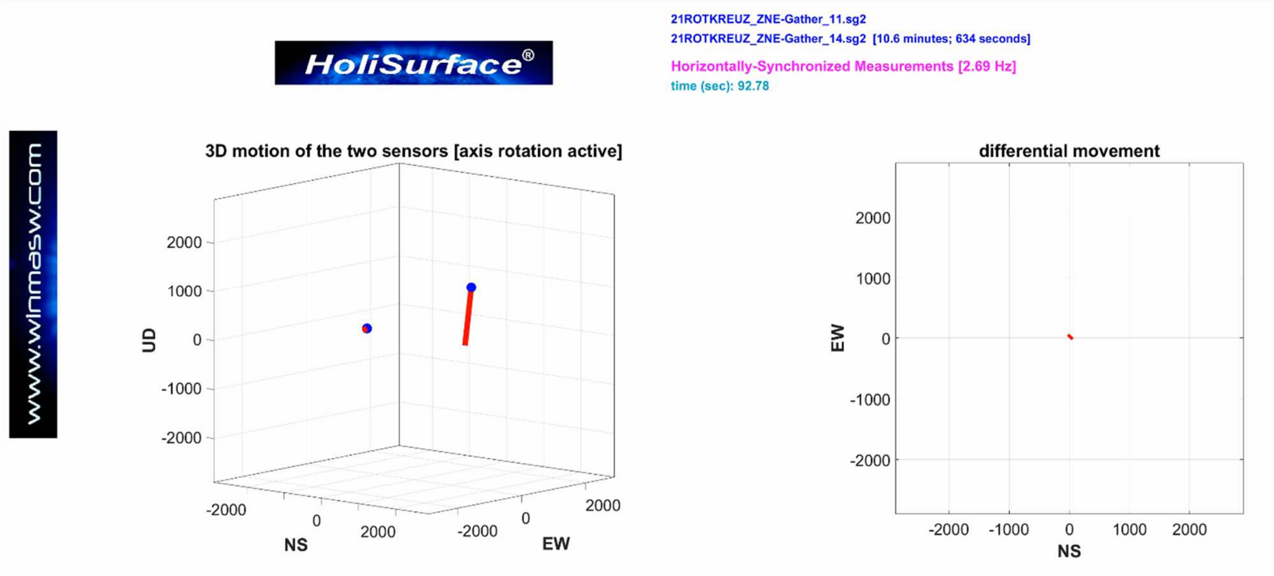
Let us now consider two points which are profoundly different in terms of structural arrangements. While at point #11 there is in fact no structural constrain, point #14 corresponds instead to a pylon (see photos and schemes).

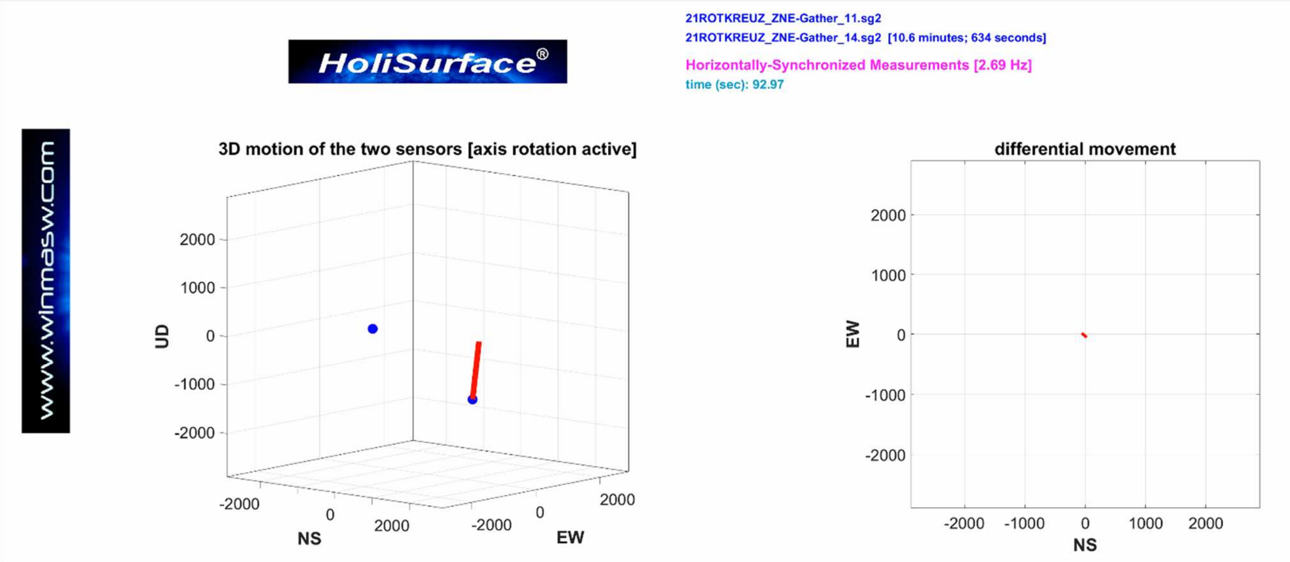


Also for points 11-14, the phase functions (see image below) indicate that at 2.69 Hz the two points move synchronously with the same direction (thus no torsional component).



We can also visualize the *video animation* that highlights that the pylon at point#14 constrains the structure (no particle motion) while at point#14 the structure clearly moves (we are still focusing on the 2.69 Hz mode):





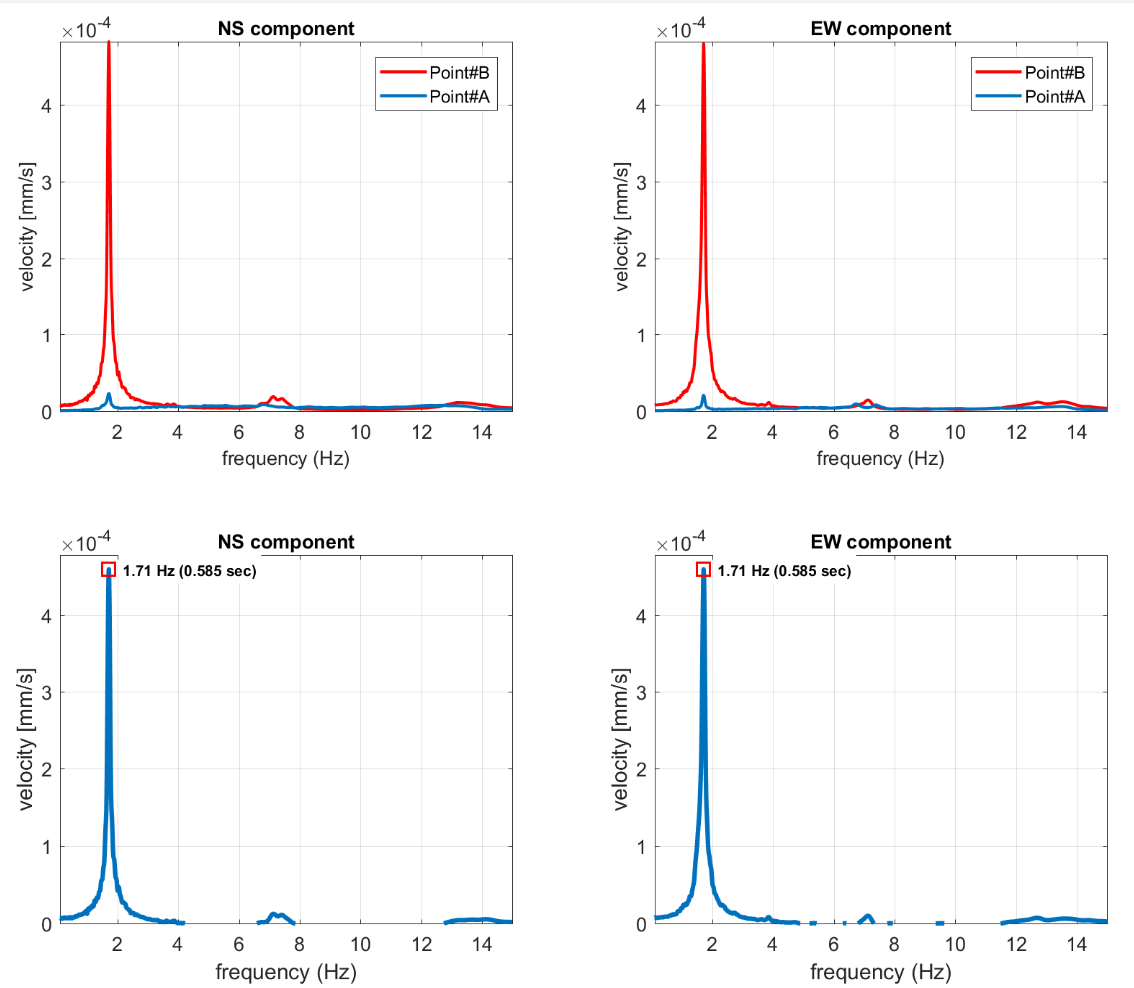
Please consider that the outputs you obtain from this panel allow you to points out several facts and our recommendations is first of all to get familiar with the fundamentals of vibration and structural analysis.

15.4 Damping analysis from passive (microtremor) data

Once the analyses useful for defining the vibration frequencies of a building (see previous pages) have been carried out, it is possible to experimentally determine the damping of each identified mode.
Attention: Damping changes depending on the amplitude of the stresses. Analyzing (as is commonly done) the microtremors, you will get very low damping values, but in case of data collected during an earthquake the values you would get would be higher (see for example Ceravolo et al., 2017).
For customers and jobs of particular importance, it is possible that knowledge of real/experimental damping (even from simple microtremors) can still be useful information to an engineer.

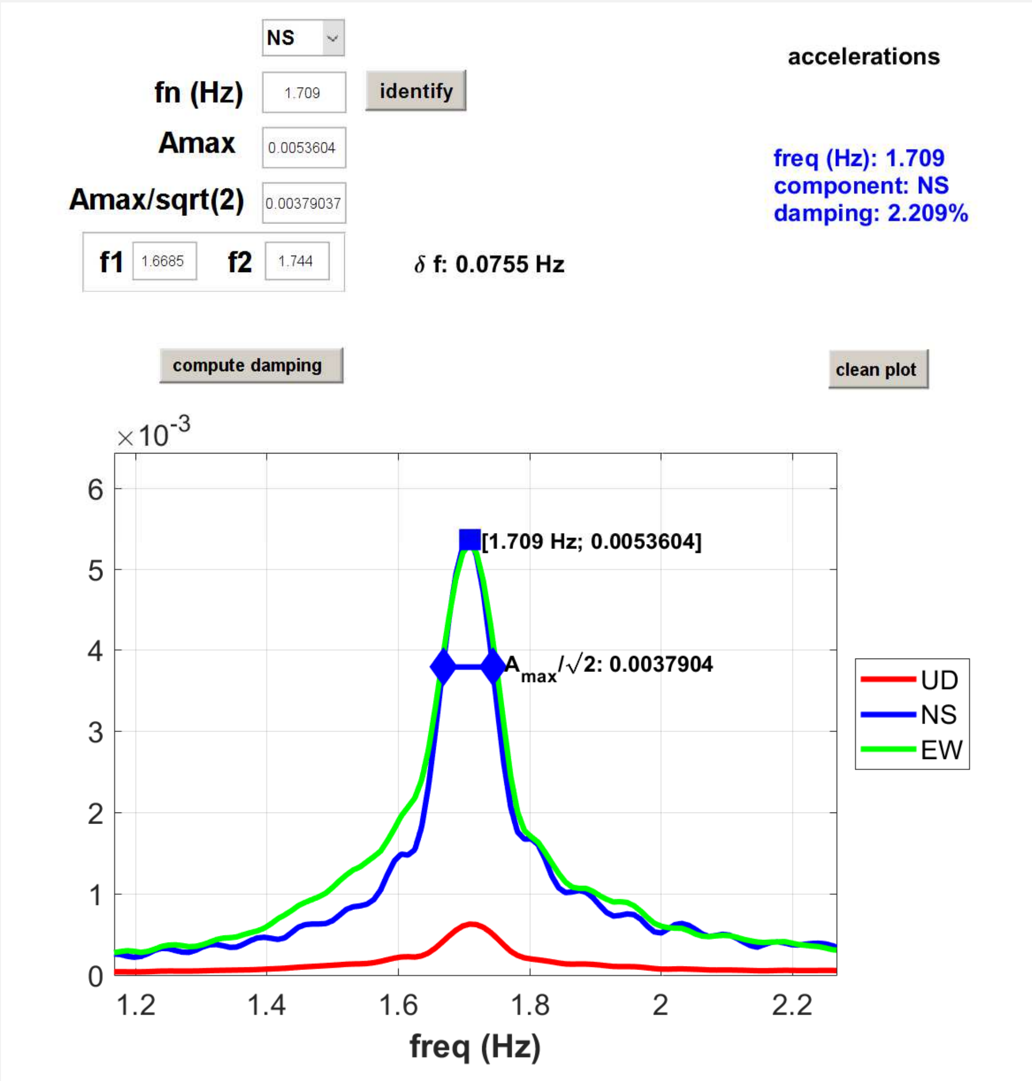
Once the analysis to define the frequencies of the modes that characterize the structure in question is completed, click the "**compute damping**" button, having also chosen for which dataset/point the analysis has been performed ("Point A" or "Point B").
If GHM analyses have been carried out (i.e., having positioned both 3-channel geophones in two points on the same plane), choosing one point or the other does not generally make a difference.

Let us remember that for these analyses, HS assumes that the loaded data come from geophones (therefore velocimeters).

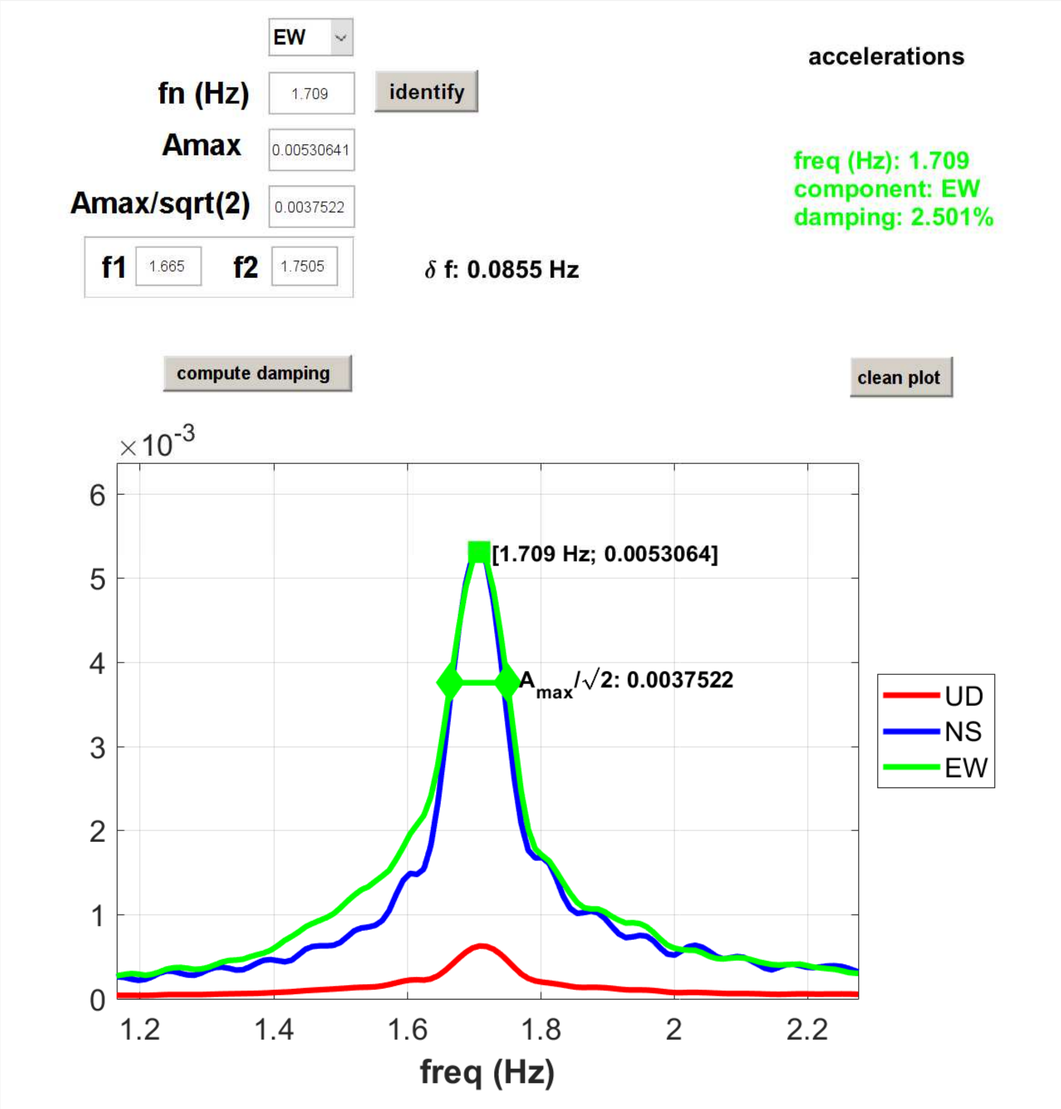


At this point choose the component to consider (NS, EW or UD) and in the field "**fn**" enter the frequency of the mode you want to assess. <u>It is essential to be very accurate in doing so, using three decimals after the decimal point.</u>

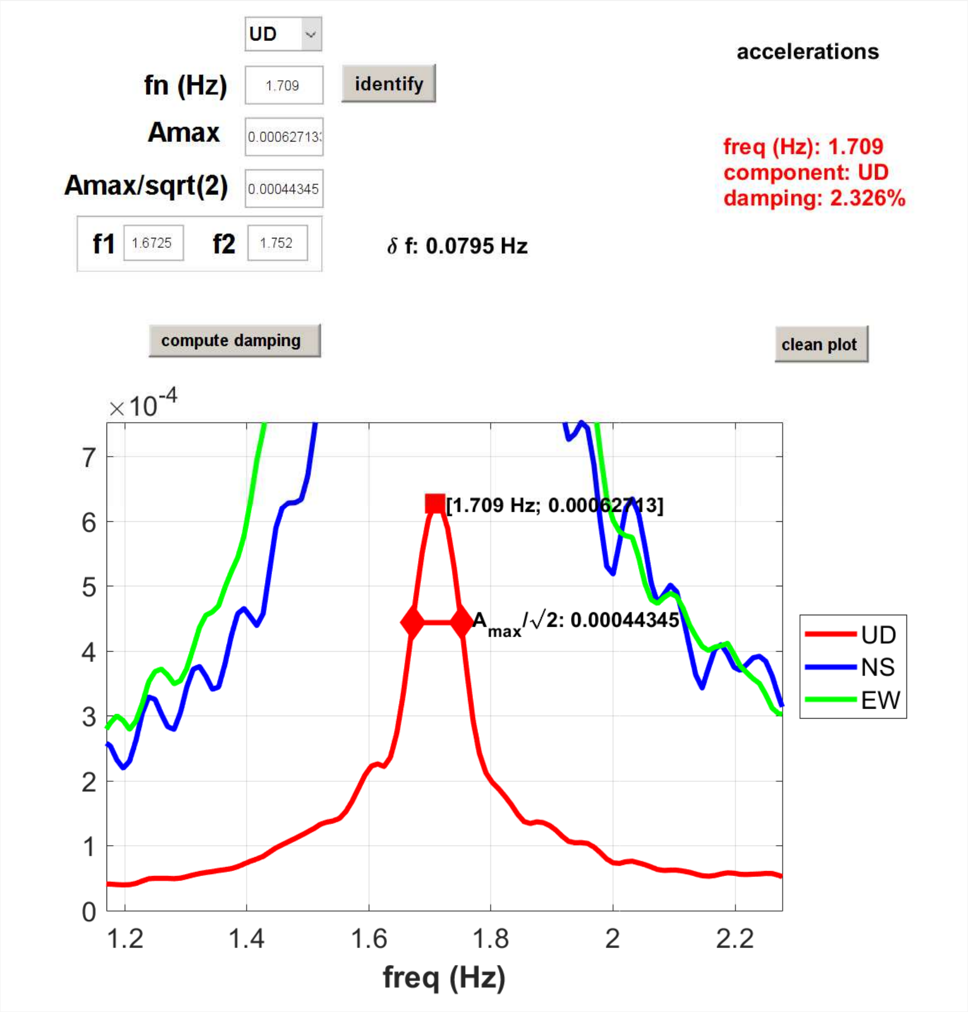
Now click the "identify" button. This will optimize the search for the peak of the signal around the frequency **fn** indicated by us and will return the damping value. In case we were too vague in defining the fn frequency, you can enter a new (more accurate) fn value and re-do the calculation of the damping by clicking the "**compute damping**" button.



Damping computation for the NS component (1.709 Hz mode).



Damping computation for the EW component (1.709 Hz mode).

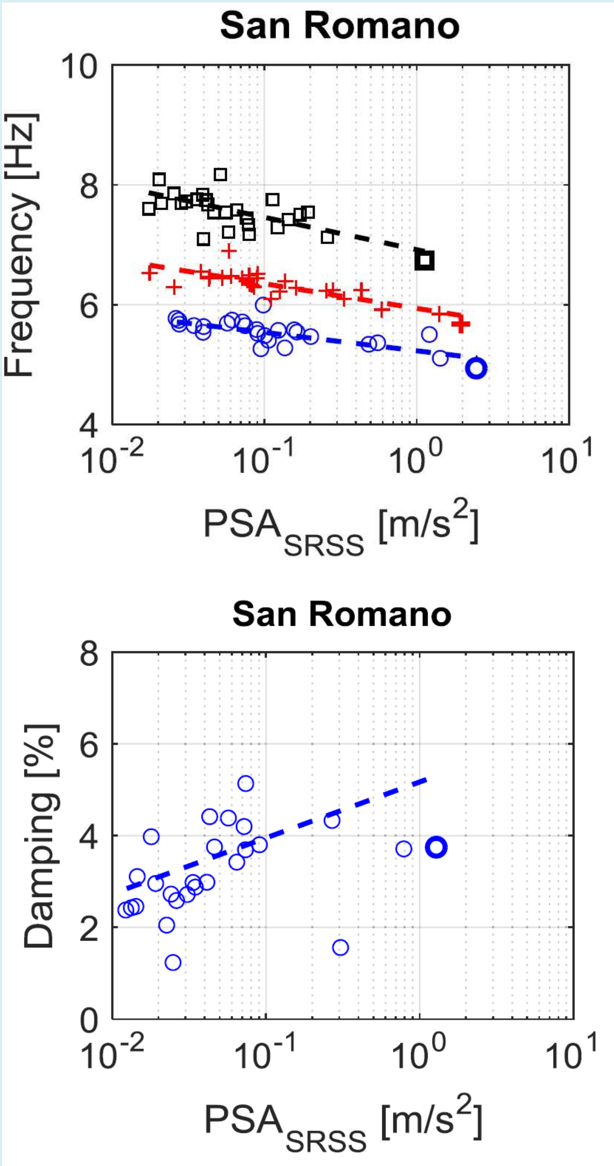


Damping computation for the UD component (1.709 Hz mode).

We can see that, in the above case (but that is normal), the damping values are in fact the same for all three components. They can change from mode to mode instead.
For details on the meaning of damping obtained by analysing various types of data, see for example Ceravolo et al. (2017) and attend one of our training courses.

Note to the identified eigenmode frequency and the related *damping*

When carried out with microtremor data in mind, the results for the frequencies of the different modes and their damping clearly refer to small "stress" amplitudes.
What happens (typically) in the case of high stresses such as those that occur during an earthquake?
In general terms, there is an increase in damping (which can increase indicatively from 2% [range of microtremors] to about 5%) and a decrease in the frequencies of the different modes typical of the building for a value of 10% of the value identified using the microtremors.
An article that addresses these issues is for example Ceravolo et al. (2017).



Municipality of San Romani in Garfagnana (IT). Upper plot: frequency variation for the first 3 modes as a function of the PSA. Lower plot: damping variation for the first mode. From Ceravolo et al. (2017). PSA = Peak Structural Acceleration recorded on the building.

15.5 Analysis of *damping* from active data

Future release

Some links and basic information

http://mceer.buffalo.edu/infoservice/reference_services/EQaffectBuilding.asp

http://mceer.buffalo.edu/infoservice/reference_services/buildingRespondEQ.asp

http://en.wikipedia.org/wiki/Earthquake_engineering

http://www.steelconstruction.info/Floor_vibrations

To transform the number of floors into building height, consider that, typically and on average, a floor is about 3 m.

16. Seismic Site Response

Brief and informal introduction

The two main problems can be summarized as it follows:

1. The V_S profile must be accurate (and many V_S profiles determined via simplistic procedures are not);

2. The probabilistic approach (PSHA) used to select input earthquakes is strongly criticised by a large part of the scientific community.

Given these bottom-line problems, it is completely useless to follow sophistry on, for example, the G/Go curves and the biblical saying returns: "you filter out the gnat, yet swallow a camel!"

Two further reasons on why not to dwell on secondary or ill-definable aspects:

1. the response spectra are defined for a model of SDOF (Single Degree Of Freedom) linear oscillator, which is a first approximation valid only for buildings with a simple answer;

2. the damping factor of the structure (monolithically fixed at 5%) is an additional question mark (i.e., a variable). Trying to vary the damping of the structure (not the damping of the layers of the geological model - in turn parameter to be set) from, for example, 3 to 7% you can see how it also has a weight in determining the final response spectra. To realize how much the damping of a structure can vary in relation to the amplitude of the input, see for example Naito & Ishibashi (1996).

It is therefore recommended to do everything that can and should be done without wasting time in negligible specific and often secondary aspects.

How it works (in brief)

The site response analysis requires the following three operations to be done with extreme care:

1) accurate determination of the V_S profile

2) determination of a series of "reference quakes" at the bedrock for the surveyed site

3) simulation of the shaking effect

Errors in only one of these phases (to be kept conceptually well separated) inevitably leads to the definition of response spectra without meaning or validity.

With regard to the **first and third points**, please refer to the considerations made in the introduction to this section of the manual.
With respect to **point#2**, we recommend that you attend the meetings we have recommended and read the petinent literature about the disputes between the PSHA (*Probabilistic Seismic Hazard Assessment*) and the NDSHA (*NeoDeterministic Seismic Hazard Assessment*).

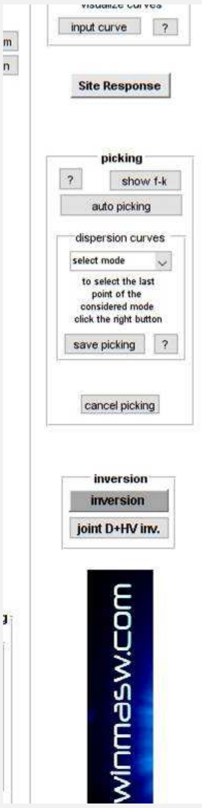
The instruments available in *winMASW® Academy* and *HoliSurface®* refer to the operations described in point #3 (and of course point #1).
To simplify, it is as if *winMASW® Academy* and *HoliSurface®* were carrying out software operations such as *Strata* or *Deepsoil* with the advantage of not having to "move" from *winMASW®* and *HoliSurface®* to those software and being able to do everything in a few simple and immediate clicks.
The discussion is rather complicated on quake selection — see debate on the correctness of the probabilistic approach (PSHA) compared with the physical approach (NDSHA).

Many choose the input quakes using according to the PSHA approach, but this procedure is subject to serious and reasoned criticism.
Clearly, we cannot deal here with these aspects and it is the responsibility of the professional to determine in the most accurate and punctual way the reference seismic events to be loaded to determine the final response spectrum.

Let us see below how to proceed and what parameters to set.

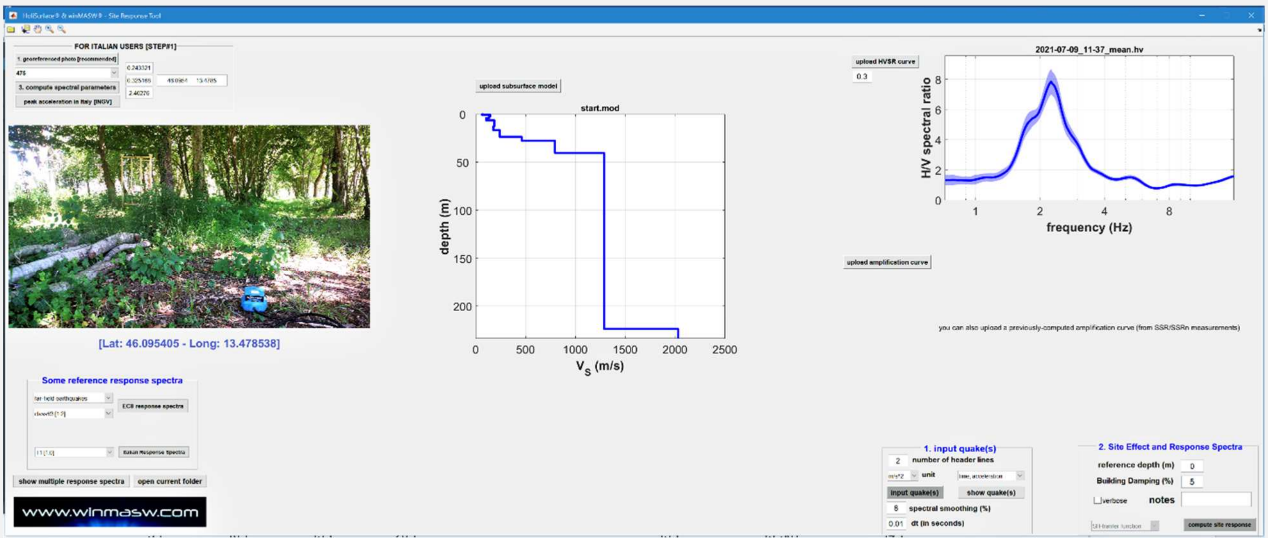
Setting the parameters

Once defined the right Vs profile (which must be consistent with all the available data) you can access to the panel by clicking the **Site Response** button:



The following panel will show up:

By default the model uploaded is the one active in the moment you click the "Site Response" button, but it can be modified by uploading a different (previously-saved) model by clicking the "**input subsurface model**" button.



Parameters to set up:

reference depth (m)

Depth of the foundation of the building (output results are computed while considering such a depth as the free surface).

"input quake(s)"

Specify the unit of measurements (m/s^2 or cm/s^2).
Fix the number of ***header lines*** in the data (accelerograms) you are going to upload.
You can upload **two kinds of time series**:

1) with **two columns** the first one represents the time (in seconds), the second one the accelerations)
2) with just **one column** (just the accelerations)

In case you have only the acceleration column (this is the case of the format used by REXEL LITE), you must specify the sampling interval (in seconds). You can find the sampling interval in the header lines (for instance “SAMPLING_INTERVAL_S: 0.005000” means that the sampling intervals is 5 ms or 0.005 s).

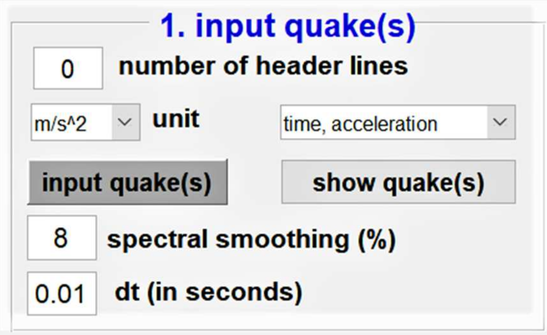
Also fix the *smoothing* to apply while processing the spectra.

In the following are reported some example of possible file format. Fixing the correct parameters is clearly crucial.

Example#1

Example of acceleration history/file with no *header line* (header value: 0) and acceleration expressed in m/s^2:

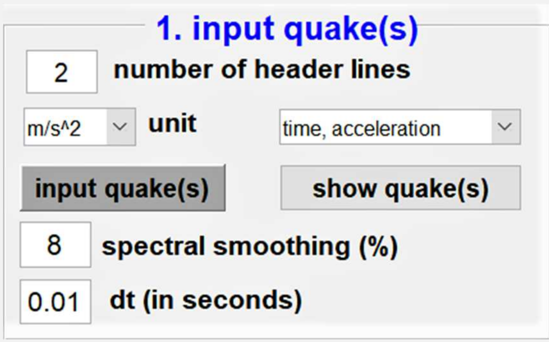
0.0000000e+000 0.0000000e+000
5.0000000e-003 -3.2748000e-004
1.0000000e-002 -6.6074000e-004
1.5000000e-002 -6.6930000e-004
2.0000000e-002 -6.7780000e-004
2.5000000e-002 -6.8632000e-004
3.0000000e-002 -6.9493000e-004
3.5000000e-002 -7.0372000e-004
4.0000000e-002 -7.1276000e-004
4.5000000e-002 -7.2215000e-004
5.0000000e-002 -7.3195000e-004
...



Example#2

In case, for instance, the first line would report the site name and the second its coordinates (or any other information), we should indicate "2" *header lines*.

Berlin
52°31′00″N 13°23′20″E
0.0000000e+000 0.0000000e+000
5.0000000e-003 -3.2748000e-004
1.0000000e-002 -6.6074000e-004
1.5000000e-002 -6.6930000e-004
2.0000000e-002 -6.7780000e-004
2.5000000e-002 -6.8632000e-004
3.0000000e-002 -6.9493000e-004
3.5000000e-002 -7.0372000e-004
4.0000000e-002 -7.1276000e-004
4.5000000e-002 -7.2215000e-004
...



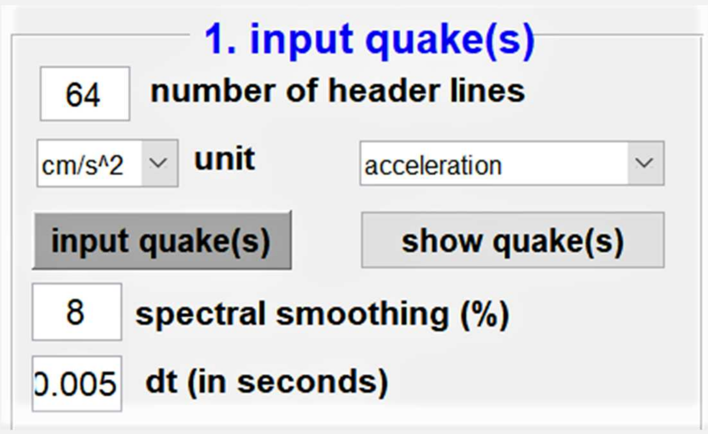
Example#3 [REXEL lite]

In this case we have 64 header lines, just one column with the accelerations, the accelerations expressed in cm/s^2 and the sampling interval equal to 5 ms

EVENT_NAME: CENTRAL_ITALY
EVENT_ID: EMSC-20161030_0000029
EVENT_DATE_YYYYMMDD: 20161030
EVENT_TIME_HHMMSS: 064018
EVENT_LATITUDE_DEGREE: 42.8322
EVENT_LONGITUDE_DEGREE: 13.1107
EVENT_DEPTH_KM: 9.2
HYPOCENTER_REFERENCE: INGV-CNT_Seismic_Bulletin
MAGNITUDE_W: 6.5
MAGNITUDE_W_REFERENCE: INGV-webservice
MAGNITUDE_L: 6.1
MAGNITUDE_L_REFERENCE: INGV-CNT_Seismic_Bulletin
FOCAL_MECHANISM: NF
NETWORK: IT
STATION_CODE: MMO
STATION_NAME: Montemonaco
STATION_LATITUDE_DEGREE: 42.899300
STATION_LONGITUDE_DEGREE: 13.326800
STATION_ELEVATION_M: 1030
LOCATION:
SENSOR_DEPTH_M: 0.0
VS30_M/S:
SITE_CLASSIFICATION_EC8: A*
MORPHOLOGIC_CLASSIFICATION:
EPICENTRAL_DISTANCE_KM: 19.2
EARTHQUAKE_BACKAZIMUTH_DEGREE: 247.2
DATE_TIME_FIRST_SAMPLE_YYYYMMDD_HHMMSS: 20161030_064005.480
DATE_TIME_FIRST_SAMPLE_PRECISION: milliseconds
SAMPLING_INTERVAL_S: 0.005000
NDATA: 12000
DURATION_S: 60.000
STREAM: HGN
UNITS: cm/s^2
INSTRUMENT: sensor = Unknown [Unknown] | digitizer = Unknown [Unknown]
INSTRUMENT_ANALOG/DIGITAL: D
INSTRUMENTAL_FREQUENCY_HZ:
INSTRUMENTAL_DAMPING:
FULL_SCALE_G:
N_BIT_DIGITAL_CONVERTER:
PGA_CM/S^2: -185.085632
TIME_PGA_S: 22.245000
BASELINE_CORRECTION: BASELINE REMOVED
FILTER_TYPE: BUTTERWORTH
FILTER_ORDER: 2
LOW_CUT_FREQUENCY_HZ: 0.050
HIGH_CUT_FREQUENCY_HZ: 30.000
LATE/NORMAL_TRIGGERED: NT
DATABASE_VERSION: DYNA 1.0
HEADER_FORMAT: DYNA 1.2
DATA_TYPE: ACCELERATION
PROCESSING: manual (Paolucci et al., 2011)
DATA_TIMESTAMP_YYYYMMDD_HHMMSS: 20170711_162914.567
DATA_LICENSE: CC-BY3_0-IT (http://creativecommons.org/licenses/by/3.0/deed.en)
DATA_CITATION: Luzi L, Puglia R, Russo E & ORFEUS WG5 (2016). Engineering Strong Motion Database. Istituto Nazionale di Geofisica e Vulcanologia, Observatories & Research Facilities for European Seismology. doi: 10.13127/ESM
DATA_CREATOR: ESM working group

ORIGINAL_DATA_MEDIATOR_CITATION: Ufficio Rischio Sismico e Vulcanico del Dipartimento della Protezione Civile (http://www.protezionecivile.gov.it/)
ORIGINAL_DATA_MEDIATOR: Rete Accelerometrica Nazionale - RAN Download (http://www.mot1.it/randownload/)
ORIGINAL_DATA_CREATOR_CITATION: Italian Strong Motion Network, Italian Civil Protection Department http://www.protezionecivile.gov.it
ORIGINAL_DATA_CREATOR: network: IT (Italian Strong Motion Network); owner: Dipartimento Della Protezione Civile
USER1: /home/dyna/processing-itaca/processing.py /var/www/processing//tmp/Lucia//IT.MMO..HGE.D.20161030.064018.X.ACC.ASC /var/www/processing//tmp/Lucia//IT.MMO..HGN.D.20161030.064018.X.ACC.ASC /var/www/processing//tmp/Lucia//IT.MMO..HGZ.D.20161030.064018.X.ACC.ASC --tmp /var/www/processing//tmp/Lucia/ --le 0.050 --he 30.000 --ln 0.050 --hn 30.000 --lz 0.050 --hz 30.000 --fo 2 --ca -10 --cz 130 --ta 5 --tz 5 --mf 1 --rf 0.005 --tr NT
USER2:
USER3:
USER4:
USER5:
0.000000
0.033719
0.067431
0.067420
0.067407
0.067392
0.067376
0.067357
0.067337
0.067316
0.067292
…

Therefore you will you have to fix the following parameters:
Number of header lines: 64
Unit: cm/s^2 (see header lines)
Data format: just acceleration (one column)
dt (sampling interval in seconds): 0.005 (see header lines)



"peak acceleration" button

In the PSHA approach, the input quakes are scaled to a fixed value of the peak ground acceleration (indicated by the national regulation). Italian users can refer to the INGV site (http://esse1-gis.mi.ingv.it).

ag (g) [peak acceleration in Earth gravity unit]

In the PSHA approach, the quakes must be normalized/scaled to the peak acceleration value defined by your national regulations (see for instance the INGV site). Such a peak value depends on the kind of building you are considering and on the return period.

If you specify a "ag" value higher than zero, the input quakes (which must be in m/s^2) will be scaled so that the peak acceleration will be equal to the ag value (which is in g - earth gravity - unit).

In case you do not want your quakes to be scaled (as for instance in the NDSHA approach), just let zero (0) the ag value

.

building damping (%)

Damping of the building (Response Spectra are computed while considering such a value.

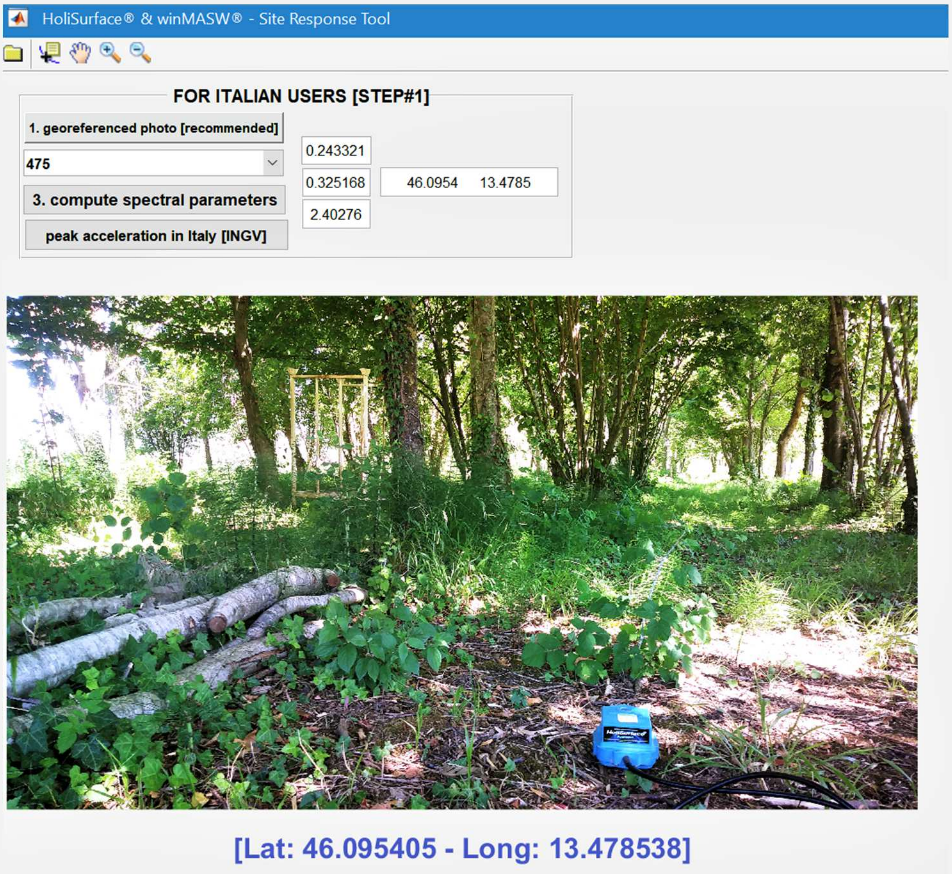
Usually the value is fixed to 5% but the structural engineer might ask for a different value which better expresses the characteristics of the building under study (see e.g. Naito and Ishibashi, 1996).

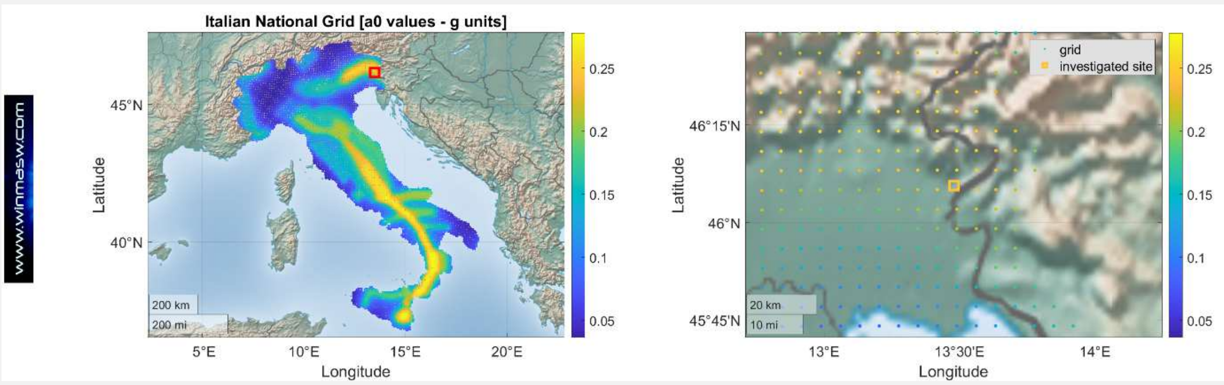
For Italian users that follow the PSHA approach:

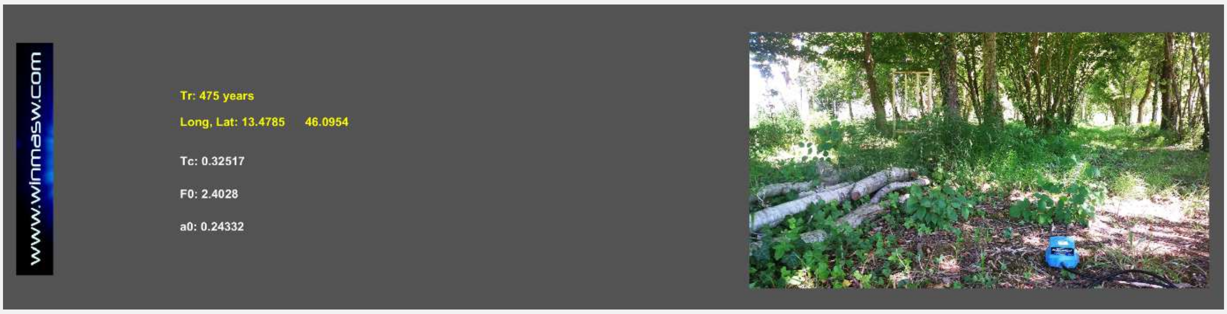
1) upload a georeferenced photo [button in the upper left corner]

2) fix the return time [tempo di ritorno], which depends on the structure you are going to assess and the local regulations

3) click the “compute spectral parameters” button so to obtain the **ag Tc** and **F0** values necessary for the computation of the final response spectra (based on the PSHA approach).

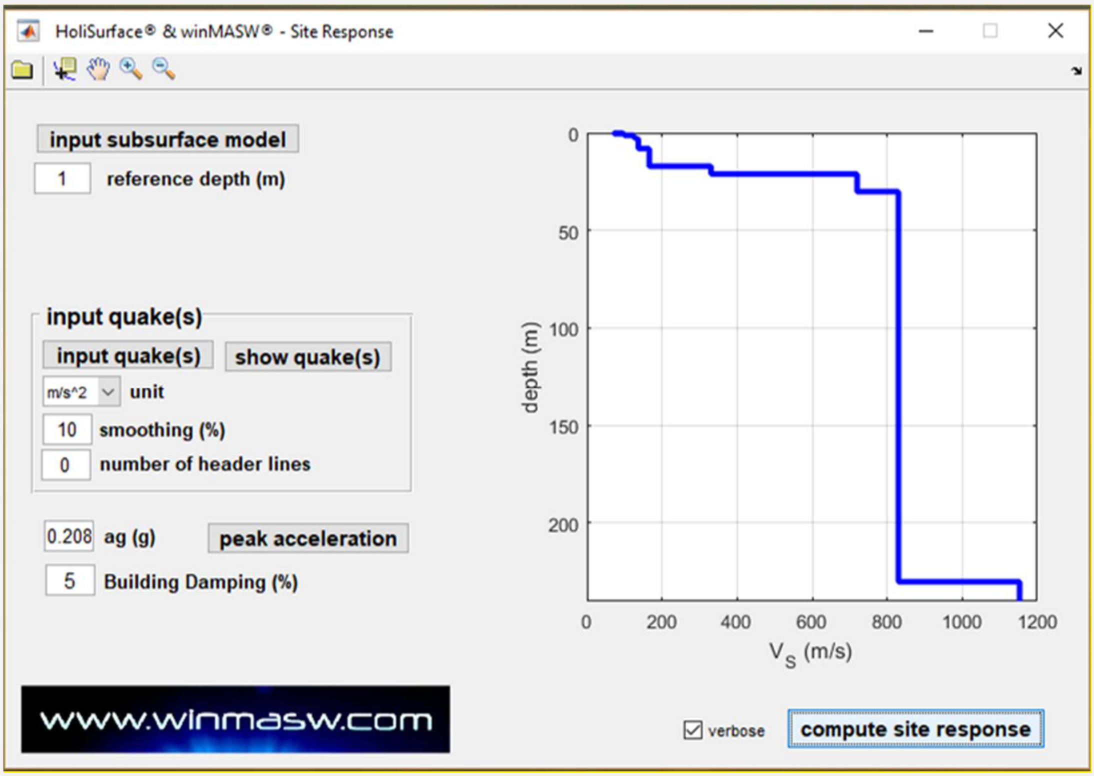




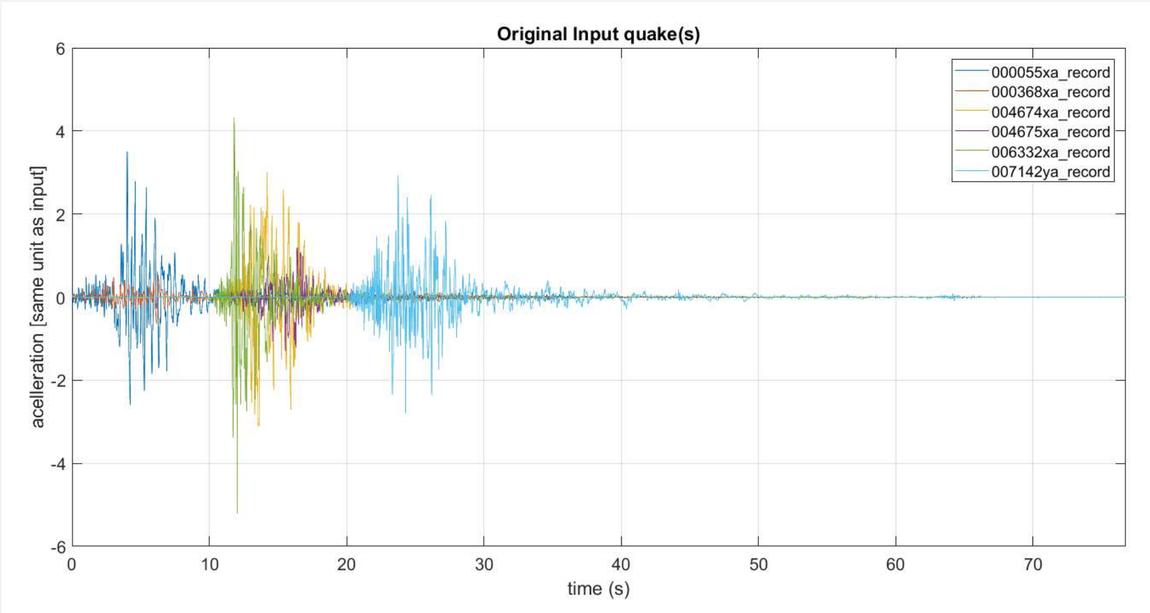


An old example

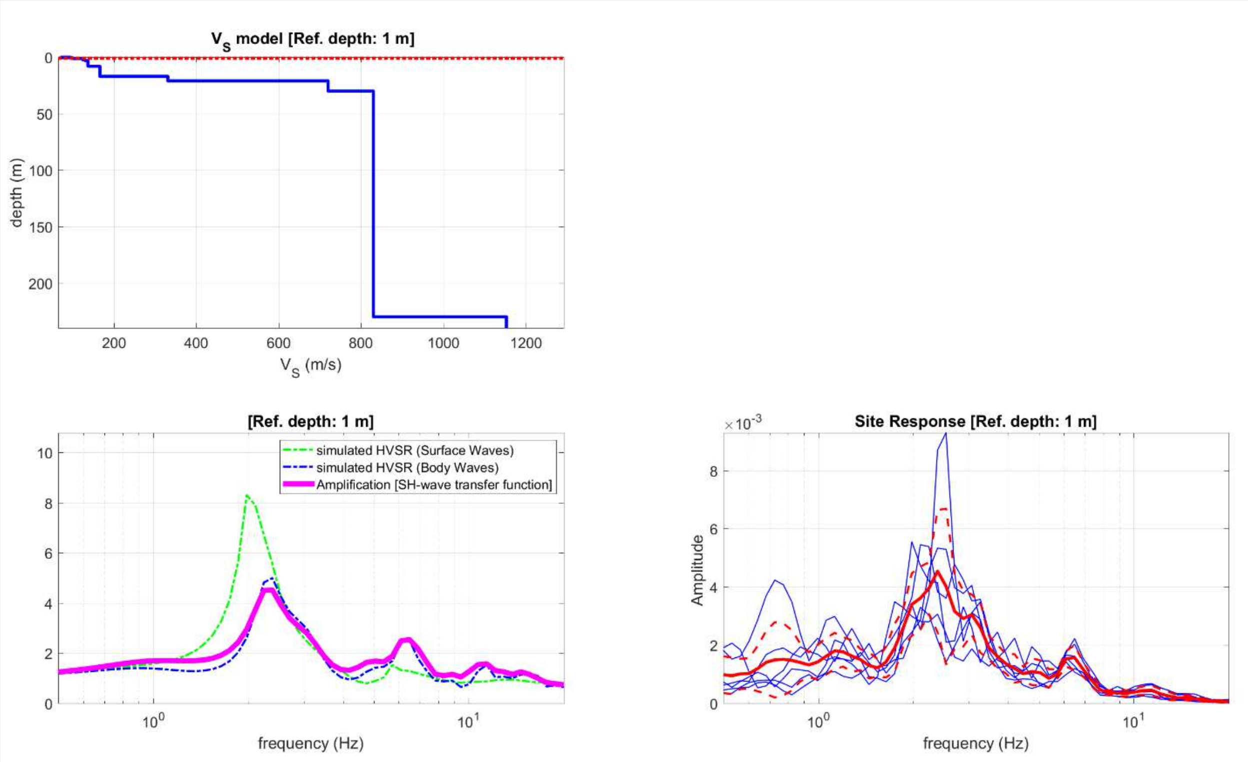
Please, notice that several data/spectra are reported both as a function of frequency and period. As usual, all the figures are automatically saved in the *working folder*.



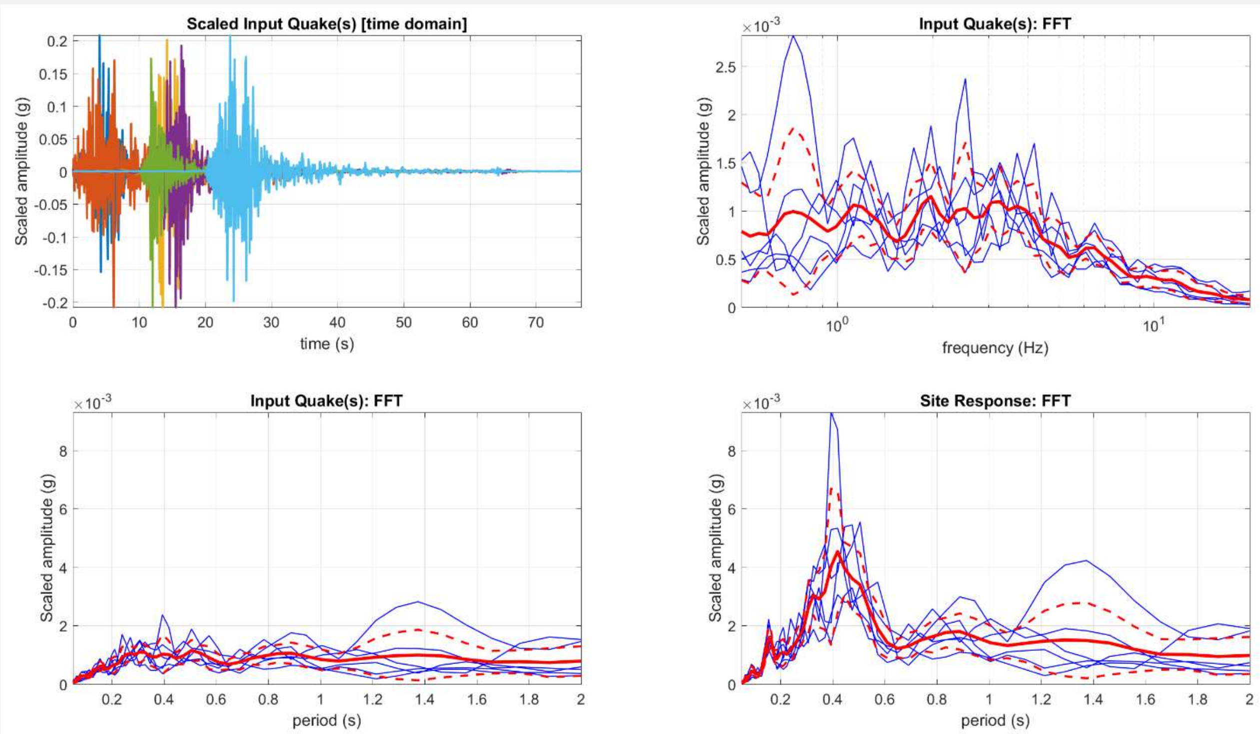
Uploaded quakes (with their original amplitudes):



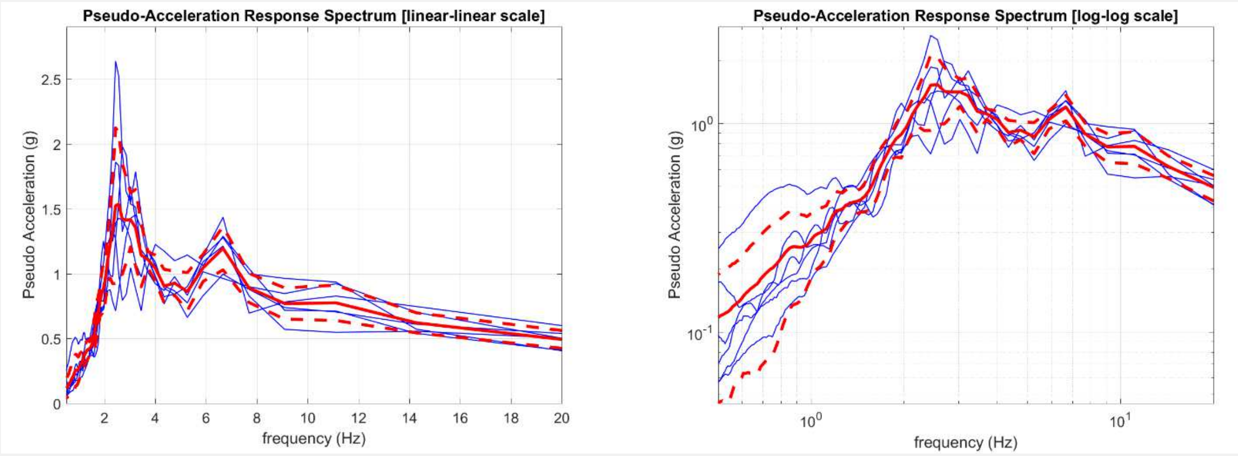
Uploaded V_S model, modelled HVSR (from surface and body waves) together with the SH-wave transfer function [often improperly considered the “amplification curve”] and, in the lower right corner, the amplitude spectra at the chosen reference depth (see “reference depth (m):” in the main panel):



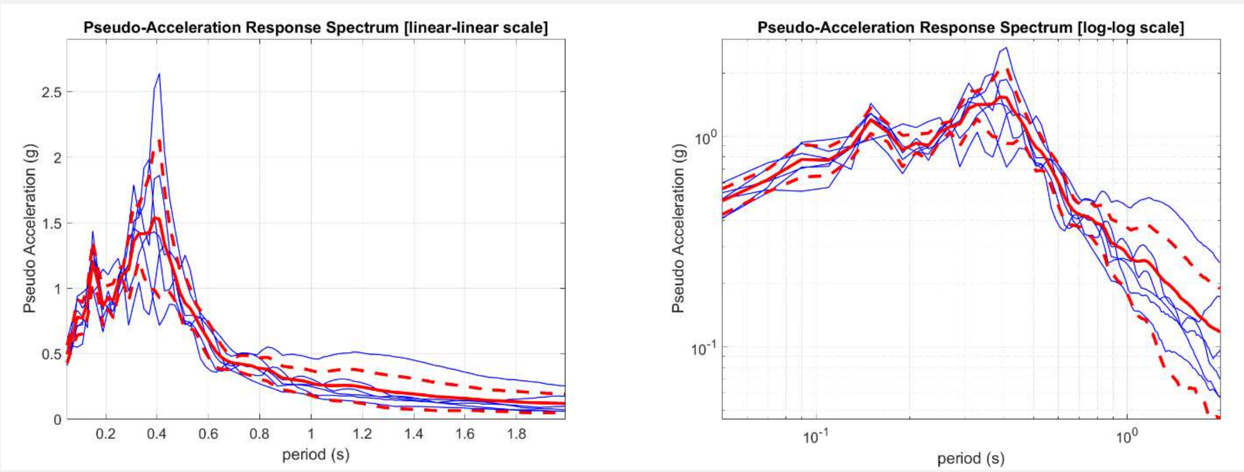
Normalized quakes (time series are multiplied so that the maximum value is set equal to the specified **ag** value – standard PSHA approach), FFT of the input quakes (normalized) as a function of both frequency and period, amplitude spectra at the reference depth:



Response spectra at the reference depth (in this case 1 m from the surface) as a function of the frequency (linear and logarithmic scales).



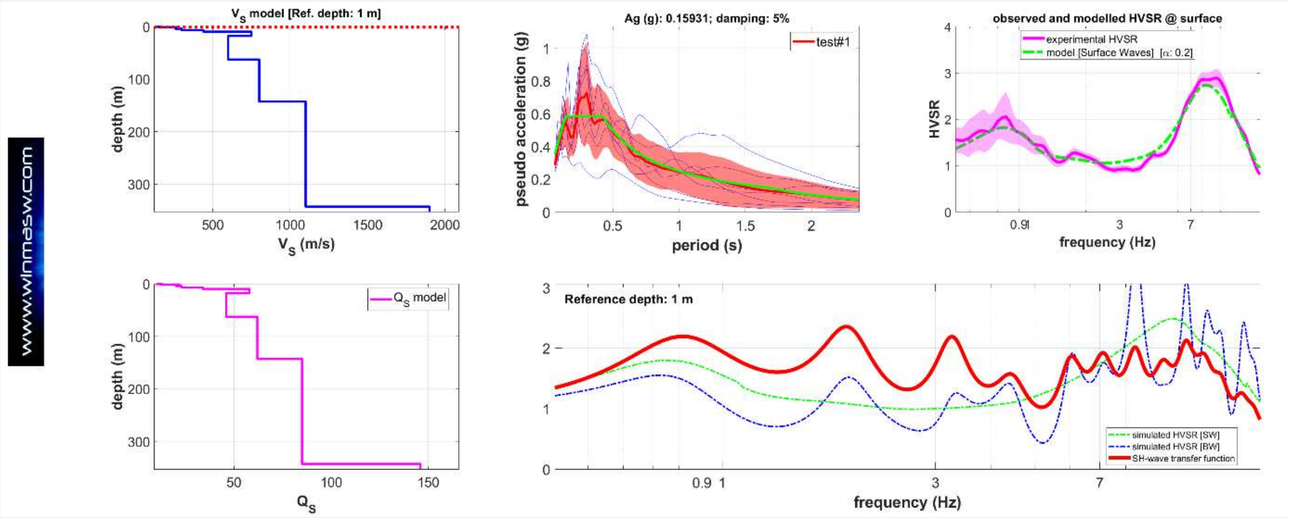
Response spectra at the reference depth (in this case 1 m from the surface) as a function of the period (linear and logarithmic scales).



The response spectra are automatically saved as ASCII files in the *working folder* with file names that clearly indicate the content:

All_Response_Spectra_Frequency.txt
All_Response_Spectra_Period.txt
Mean_Response_Spectrum_Frequency.txt
Mean_Response_Spectrum_Period.txt

The following snapshot reports an example of the verey final figure summarizing the main facts (from another site/silutation). Each plot clearly reports the meaning/labels of the shown curves/functions.



Shown:

1) the V_S and Q_S values of the upload model;
2) the uploaded and modelled HVSR curves [upper right graph];
3) the SH-wave transfer function [red line] together with the uploaded and modelled [according to both surface and SH waves] HVSR curves;
4) the response spectra for all the uploded input quakes together with the mean curve and the regularized one (see “spectra regularization” box in the next pages) [central upper plot].

Site Response in the recent *releases* of *winMASW®* Academy & *HoliSurface®*

Once the correct V_S profile has been obtained (a model can be considered correct onòy if it is in agrrement with multi-component data – see all the examples shonw in this manual), click the "Site Reponse" button and access the **Site Response tool**.

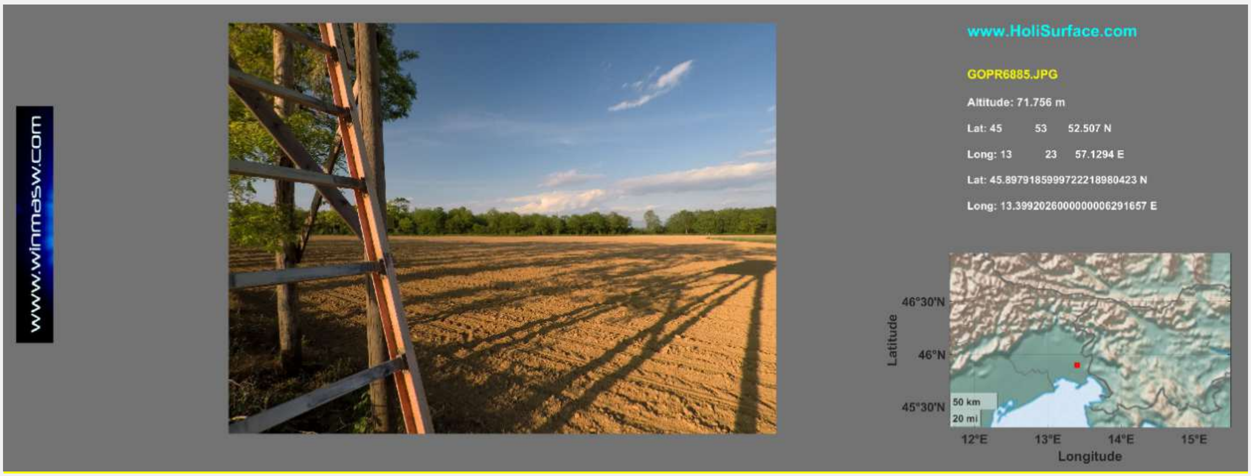
In case you click the “Site Response” button from the analysis panels, the subsurface model and the HVSR curve are automatically uploaded but it is possible to (re)upload both ("upload subsurface model" and "upload HVSR curve" buttons in the Site Response panel).

Remember that by simply hovering the mouse over a button, a brief description/help shows up.

Sequence to follow:

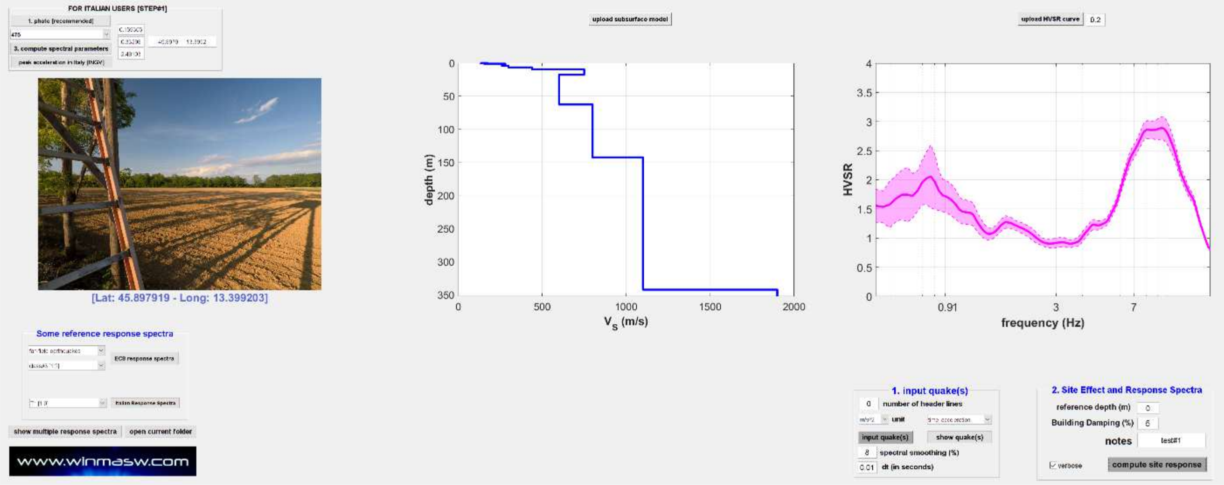
The first three operations can be performed only by Italian users (since, so far, the table data are availbale only for Italy). In case you are working in a different country, you must sset the **ag**, **Tc** and **F0** value by yourself (following your national building codes).

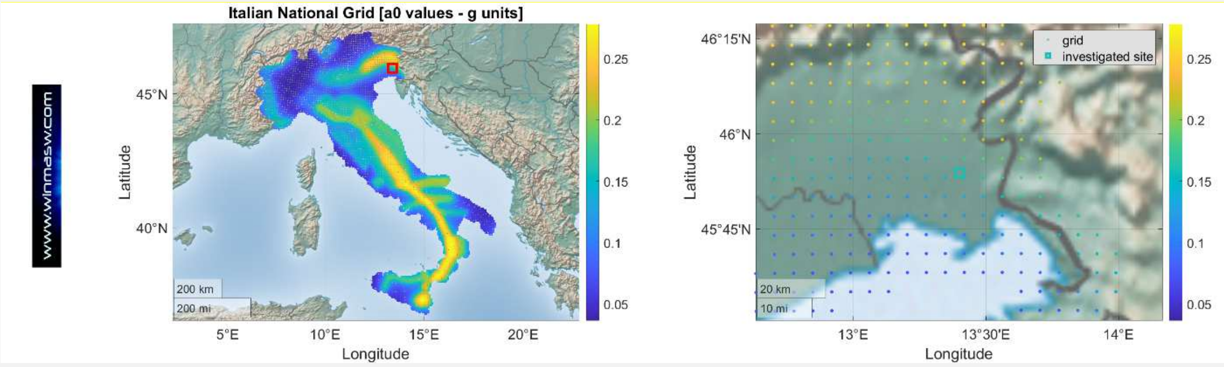
1) Optional but recommended: upload the georeferenced photo [button "photo [recommended]" top left] so that the software can automatically obtain the latitude and longitude [alternatively, if you do not have a georeferenced photo, enter these values manually];

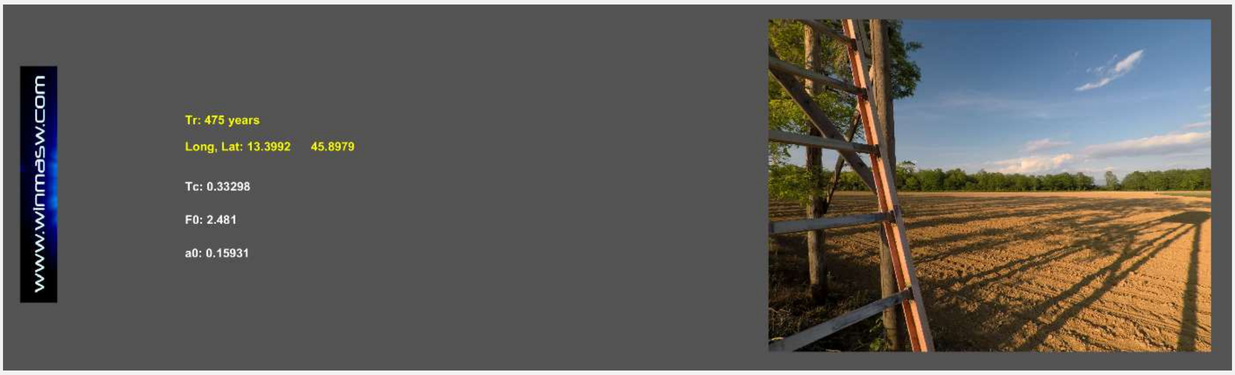


2) set the value of the ***return time*** (which depends on the type of work under study);

3) Click the "**compute spectral parameters**" button (top left), thanks to which we will obtain the parameters (**ag, Tc and F0**) used for the following operations;





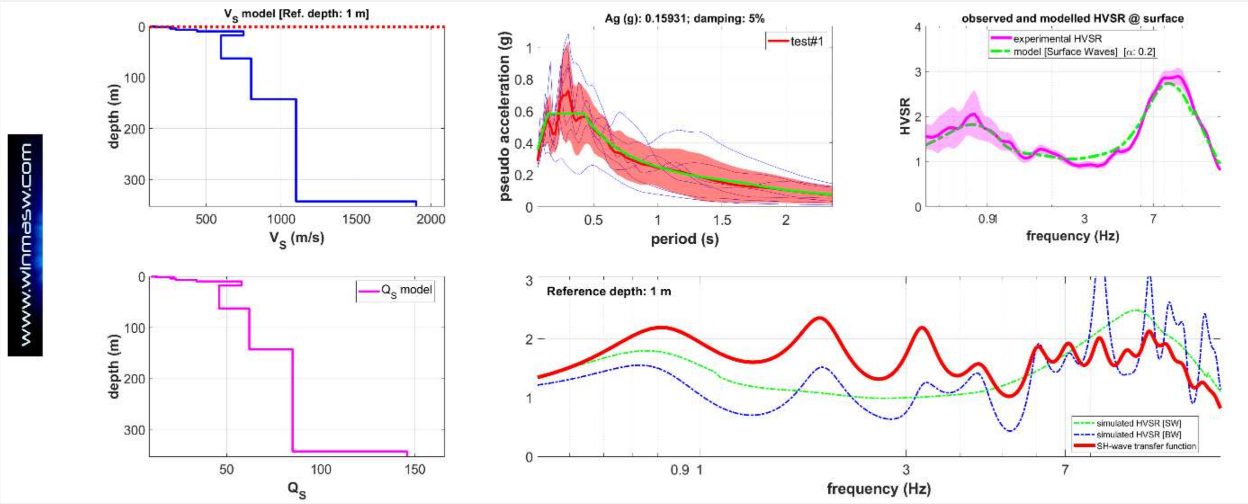


Spectral parameters determined on the basis of the site (latitude and longitude) and return time. So far this operation can be done automatically only for Italian users. For studies outside the Italian territory, the ag, Tc and F0 parameteres need to be fixed manual (based on the values tabled the local national building codes).

4) Now, after checking the correctness **ag, Tc and F0** parameters, you can upload the reference earthquakes (referred to the local *bedrock*) [use the "input quakes" button in the "1. Input quake(s)" group box];

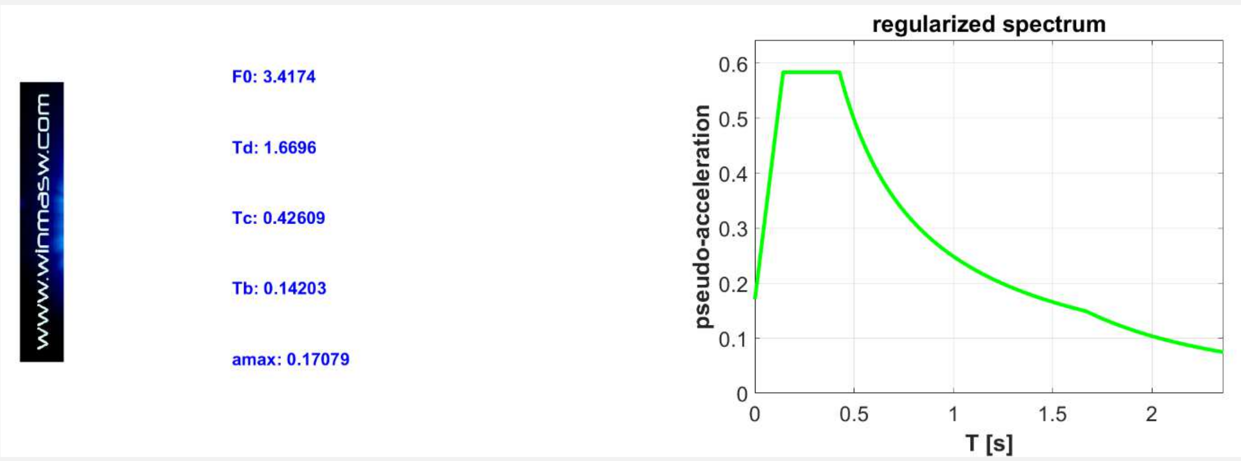
We are now ready for the final computation: click the **"compute site response" button** in the "2. Site effect and Response Spectra" group of the panel.

An example of what you get in the end:



Seismic Response Spectra and computation of the SH wave transfer function (red curve in the bottom right plot - this curve is usually improperly considered as the *amplification curve*). In this case the foundation (reference) depth was 1 m.

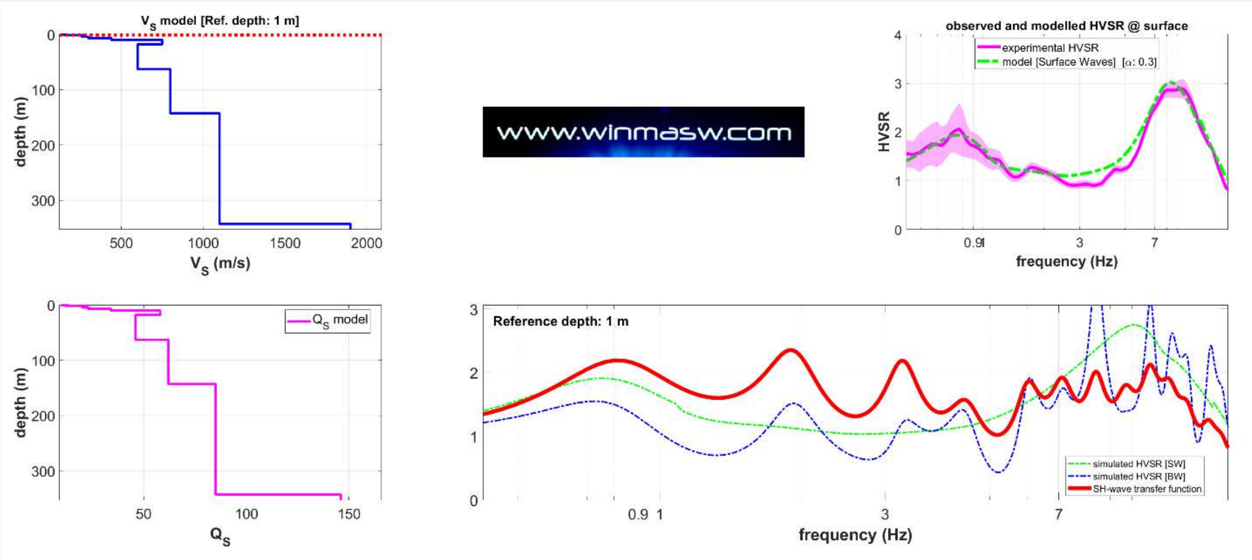
Note how the response spectrum/a is/are also provided after regularisation (see box in the following pages).



Some 'guidelines' require that such simulations are carried out for a number of so-called *limit states* which depend on the structure we are considering. The specific *limit state* can be reported in the 'notes' field so that it appears in the legend of the obtained plots. For details refer to your national building codes.

A few important notes

In case you do not upload any quake, the tool will provide you just the outcomes shown in the following snapshot, i.e. the uploaded and modelled HVSR curves and the *SH-wave transfer function*. Compare the following snapshot with the one shown in the previous page (obtained while having uploaded a series of quakes).



As a matter of fact, the *SH-wave transfer function* does not represent what happens during a real earthquake since the actual wave phenomena are much more complex and depends on the kinds of quakes, the azimuth with respect to the source and much more. The wave distortion due to the local site effects are different for the body and surface waves (and, clearly, the *SH-wave transfer function* cannot consider the surface waves - see Bowden and Tsai, 2017);

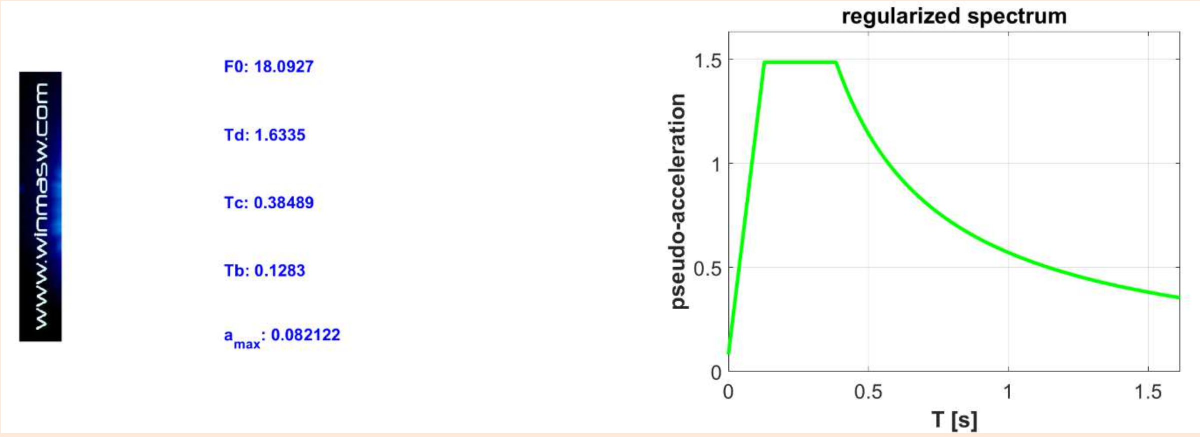
Remember that the final **accuracy of the obtained response spectra** depends on the accuracy of two key "parameters":

- ➔ the subsurface model (Vs and Qs values – these latter determine the attenuation)
- ➔ the accuracy of the input (reference) quakes [i.e. the quakes at the local *bedrock*]

You should also always consider that the "unknown variables" are innumerable and it is therefore pretty naïve to put too much emphasis on singular/specific aspects. So just be sure that your V_S (and Q_S) model is well constrained and invest some of your time in studying all the problems and ambiguities of the PSHA approach (i.e. on the way you choose the reference quakes).

If you attend a course/lecture/workshop about the computation of the local site effect (and the response spectra) be careful and try to understand whether it is a serious course about *the physics* of the considered wave phenomena or if it is a meeting about the *national regulations* about it. This is a crucial point: do they want to teach you how seismic waves propagates (and modify their amplitudes) or do they want to tell you the “legal” aspects and the “practical steps” to perform in order to obtain some curve to sell to your final client without let you understand *what* and *why* from a scientific point of view?

Spectra regularization



The final mean response spectrum is also “regularized” so to obtain the standard F0, Td, Tc, Tb and a_{max} values. This is done according to the schemes presented in:

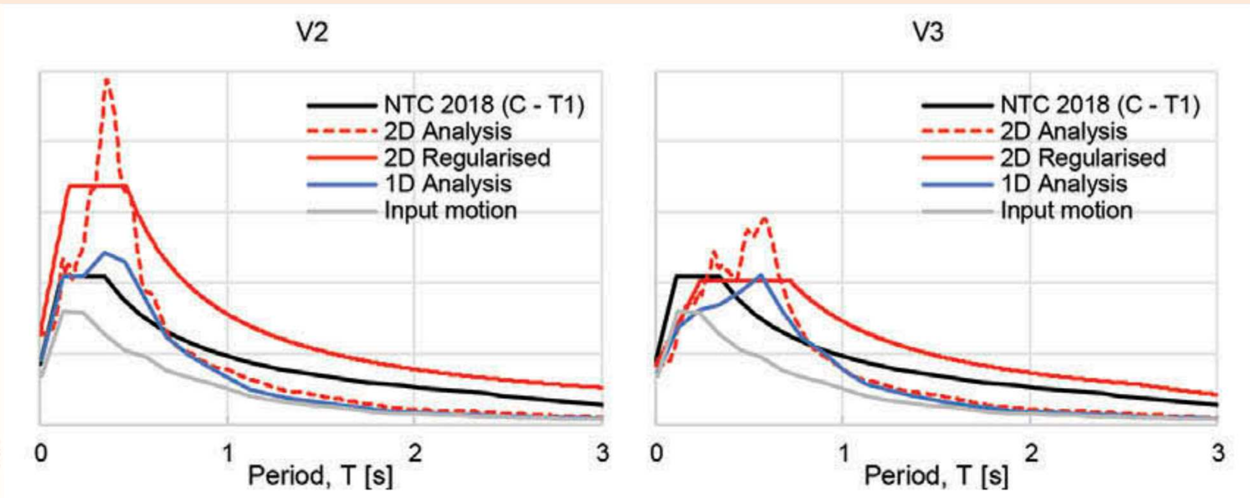
Newmark N.M. and Hall W.J., 1982. Earthquake spectra and design. EERI Research Report, 82-71183, 103 pp.

Liberatore D. and Pagliaroli A., 2014. Verifica della sicurezza sismica dei Musei Statali. Applicazione O.P.C.M. 3274/2003 s.m.i. e della Direttiva P.C.M. 12.10.2007. Convenzione Arcus – DG PaBAAC Rep n. 113/2011 del 30/09/2011

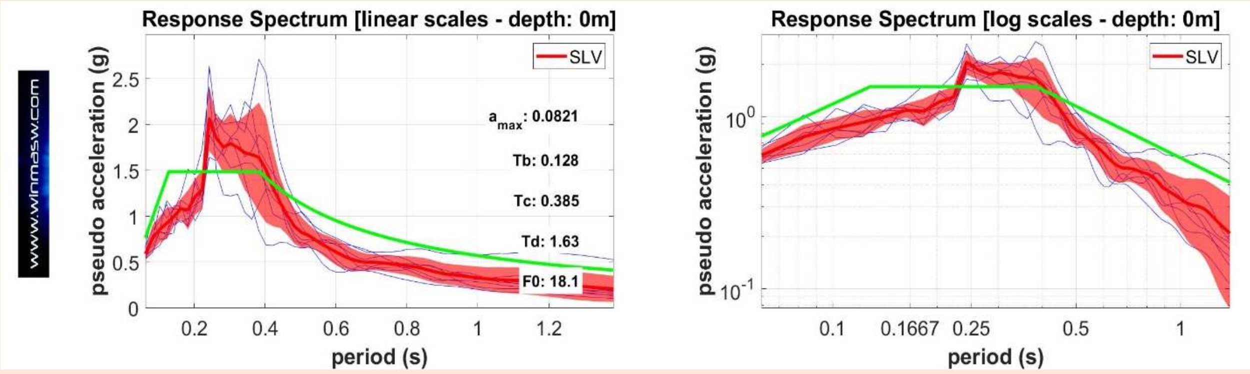
Italian users can also refer to:
Decreto n. 55 (April 24 2018) and NTC 2018 (Italian seismic regulations)

Chapter 2.5.4.3.1 of the “Indirizzi e criteri per la Microzonazione Sismica” volume of the *Dipartimento di Protezione Sismica* (*Editors* Bramerini, Di Pasquale, Naso, Severino).

Please, note that *regularization* is questionable because it alters the response spectra that you computed while considering the actual V_S profile and the input reference quakes. It is done to facilitate the work of the engineers that are not able to consider the actual shape of the computed response spectrum but its cogency is questionable.
Note that when the actual shape of the mean response spectrum is particularly complex irregular and sharp, the regularized spectrum can significantly differ from the original computed spectrum.

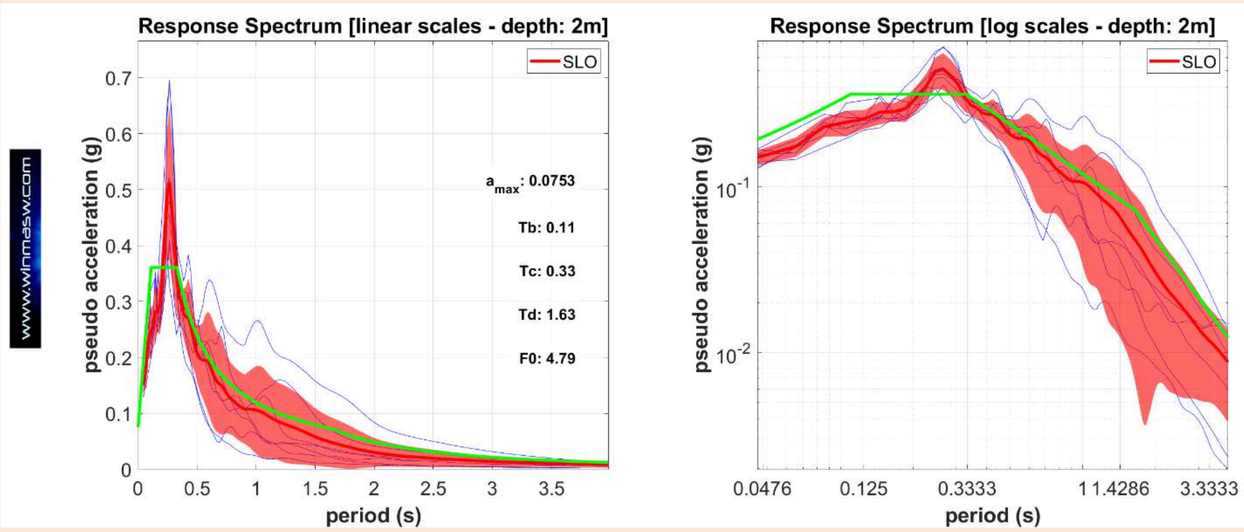


Example of regularised response spectrum [continuous red line] (see the significant difference with the Analysis [dashed red line]). From Pagliaroli et al. (2019).



A further example of regularised response spectrum [green line] (see the significant difference with the mean response spectrum obtained through the analysis [red thick line]).

Below, a final example where the regularized spectrum is not too far from the computed one [red thick line]: this happens cause the computed spectrum has a pretty “simple” shape not far from the one expected on the basis of the regulation assumptions.



Few final recommendations

Remember that the final **accuracy of the obtained response spectra** depends on the accuracy of the two key parameters:

1) the subsurface model (Vs and Qs values – these latter determine the attenuation)
2) the accuracy of the input (reference) quakes

You should also always consider that the "unknown variables" are innumerable and it is therefore pretty naïve to put too much emphasis on specific aspects. So just be sure that your V_S (and Q_S) model is well constrained and invest some of your time in studying all the problems and ambiguities of the PSHA approach (i.e. on the way you choose the reference quakes).

If you attend a course/lecture/workshop about the computation of the local site effect (and the response spectra) be careful and try to understand whether it is a serious course about *the physics* of the considered wave phenomena or if it is a meeting about the national regulations about it. This is a crucial point: do they want to teach you how seismic waves propagates (and modify their amplitudes) or do they want to tell you the "legal" aspects and the "practical steps" to perform in order to obtain some curve to sell to your final client without let you understand *what* and *why* from a scientific point of view?

17. Demo and provided data (for your self-training)

Demo version?

The *HoliSurface®* [HS] application (as well as *winMASW® Academy*) is a highly-sophisticated tool that, in order to be fully and properly used, requires a robust theoretical background.
If you try to use *HoliSurface®* without considering a series of bottom-line theoretical facts you risk not to be able to understand the necessary workflow.

Below are few things you could consider for a self-assessment of your theoretical background (which should be provided in any good university course):

- the meaning and practice of **multi-component** seismics (Z, R and T components)
- how **group velocities** work (compared to **phase velocities**)
- what are the consequences of **non-uniqueness and ambiguities in geophysical data**
- how to solve those problems (setting up a **joint analysis based on several *observables***)
- what is an ***effective*** (not *modal*!) **dispersion curve** and what is the **FVS analysis**
- what is the **RPM frequency curve(s)** and why is useful to work with it
- **HVSR does not** represent the site amplification

Once these things are clear, you'll be able to go on the field with the very limited equipment (see the HS backpack in the picture below) necessary for the methodologies implemented in HS and obtain V_S profiles which are *necessarily* more accurate than those that you can obtain using 24 vertical geophones.
There is a vast literature about all those points but we would like to recommend the two books published by Elsevier in 2014 and Springer in 2020. The first one is an introduction to (multi-component) surface-wave analysis while the second is specifically about the methodologies implemented in the *HoliSurface®* software.

A series of video tutorials, papers and case studies are available from our web site but the best way to learn to efficiently and jointly acquire and analyze surface waves is visiting us.

For all these reasons, no *demo* version is currently provided. In fact, a *demo* software is something people quickly download just to have the chance to randomly click a series of buttons without taking the trouble to study the theory necessary to understand what we are actually doing.

On the other side, the methodologies implemented in HS are the optimization of very classical techniques (published in a long series of papers in the best international journals) and were used all over the world since 2010 also, for instance, for the assessment of important nuclear sites…

"Quality is never an accident; it is always the result of intelligent effort."

John Ruskin

Provided data

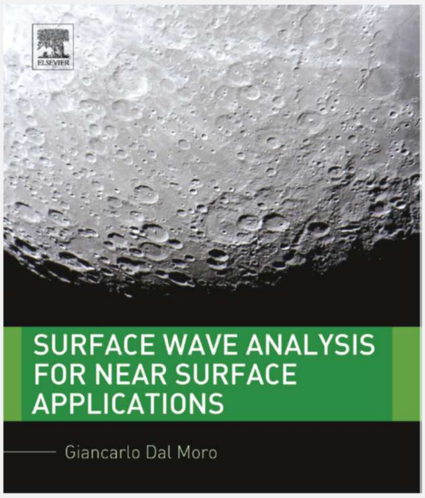
Together with the software, in the HS USB, a series of datasets are available for your own self-training in the following subfolders of the "**Data_ Self_Training_Data_Dissemination**" main folder:

1) About the Springer 2020 book: "**Chapter5_Building_Vibrations_GHM_Case_Study1_3floor_building**", i.e. the vibration data presented in the mentioned chapter of the book

2) "**Natissa_case_study_8_Elsevier_Natissa**" case study#8 from the Elsevier book

3) "**Elsevier_book_case_study12_HS_HV_ESAC_MASW_Aquileia**" from the Elsevier 2014 book (case study#12)

4) "**Dissemination_HS_Eliosoft_SummerLab**" folder: a HS+HVSR dataset from one of our workshops (with shown also the results)



For further case studies and documents about the methodologies implemented in *HoliSurface*®, we recommend you to regularly visit our www.holisurface.com web site.

“A mistake is always forgivable, rarely excusable and always unacceptable.”

Robert Fripp

18. Some tips: recommended procedures

The HS software allows such a variety of analyses that it risks being confusing and intimidating for those who do not have a solid background in geophysics. Here are some practical suggestions aimed in particular at professionals who often face problems related only to NTCs.

In order to determine in a sound and rigorous way the vertical profile of shear wave velocity (up to at least 30 m of depth - and even deeper) the approach that we strongly recommend is given by the joint analysis of Love waves (active seismic) and HVSR.

To do so, from the main screen, **access the "Disp + HVSR" panel** and proceed as follows:

1. carry out the two preliminary operations from the main panel: a) set the working folder (where the field data are present and where the output files will be automatically saved); b) choose the type of site (general indication) being studied.

2. upload the file related to the Love waves (which, if the operations were carried out as recommended, could have a name like HF-50m-direct.SAF/seg2);

3. compute the group velocity spectrum ("**Love waves: group-velocity spectrum**" button at the bottom) [the frequency and velocity ranges should be set with good sense];

4. upload the previously calculated **HVSR curve;**

5. carry out some direct modelling until you identify a model that accounts for both dispersion and the HVSR curve;

6. click on "report" to get a report on the identified model.

Of course, the THF+HVSR inversion is also possible (and often recommended).
To do so, save the group velocity spectrum of the Love waves ("save Love-wave spectrum" button, open the "disp+HVSR" module (bottom left), load both the spectrum of the Love waves and the HVSR curve. At this point, set the search space starting from the model that best adhered to the data during the direct modelling phase (and that you made sure to save). This model is loaded ("starting model" button) and, if necessary, the limit values of Vs and thicknesses are modified. At this point, the inversion is launched (details in the relevant section of the manual).

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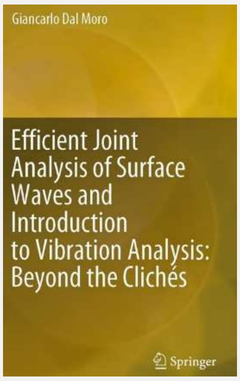
Springer (book), ISBN 978-3-030-46303-8

266 pages, over 200 illustrations in colour



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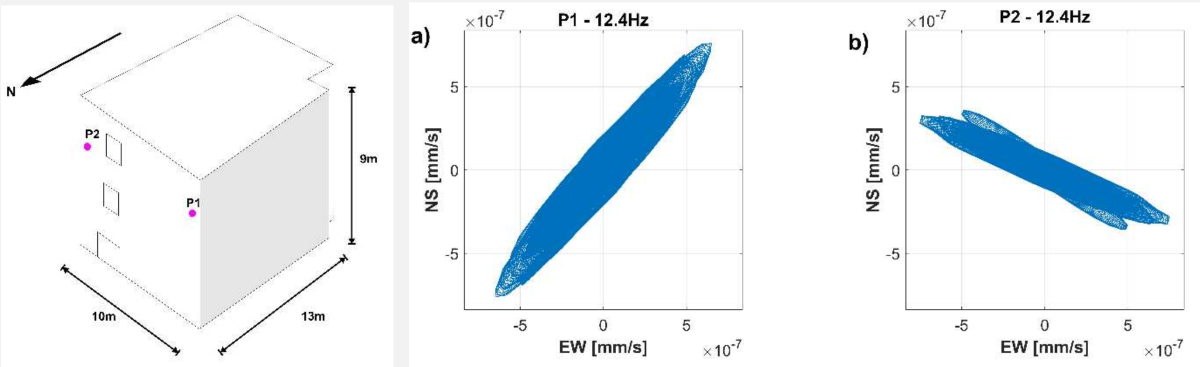

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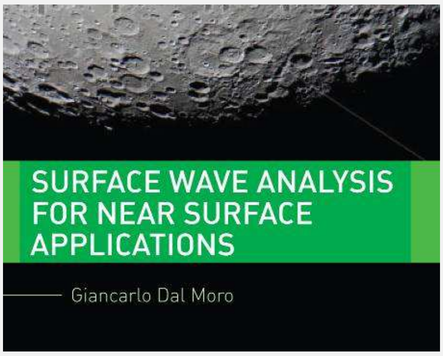

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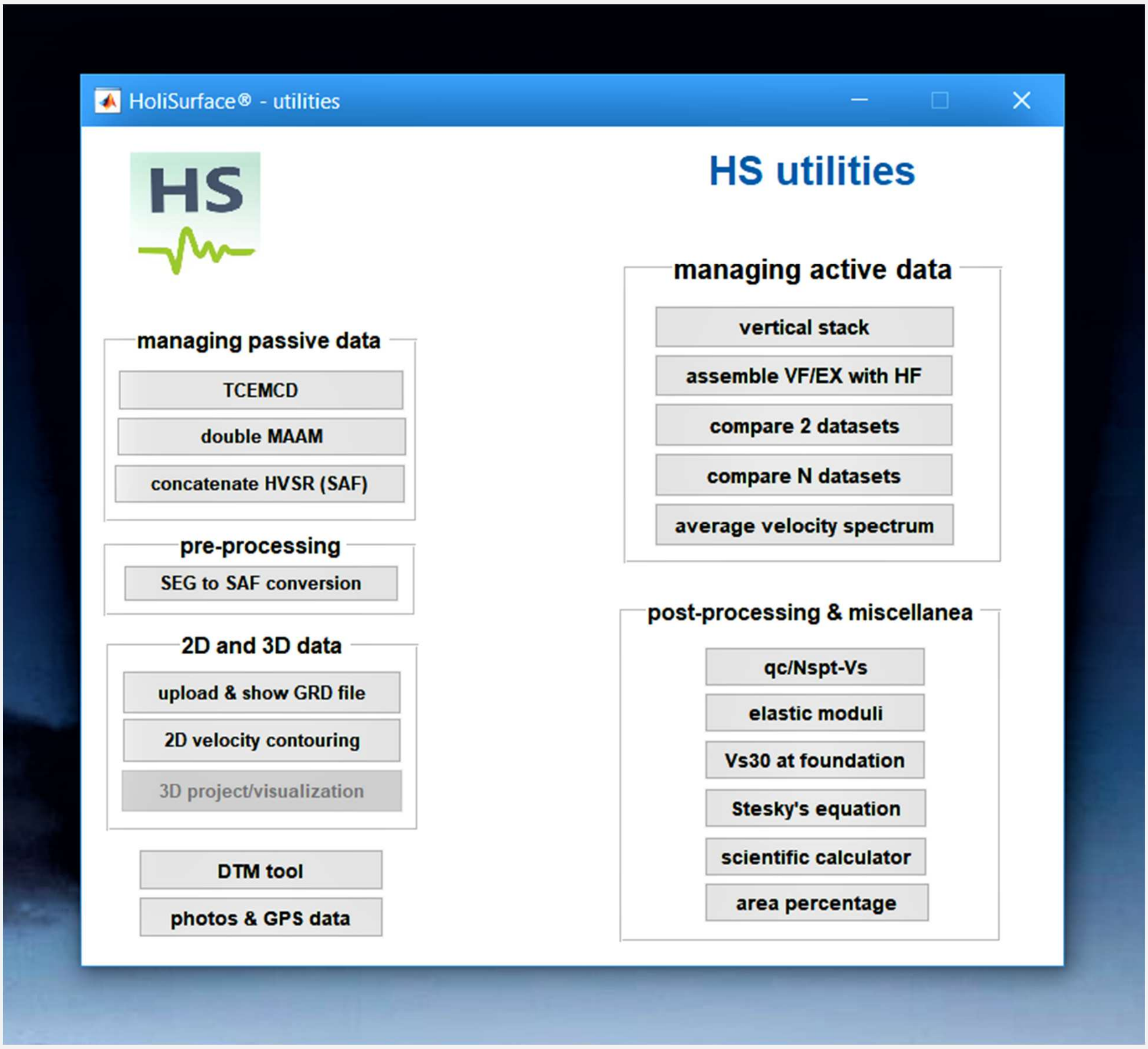
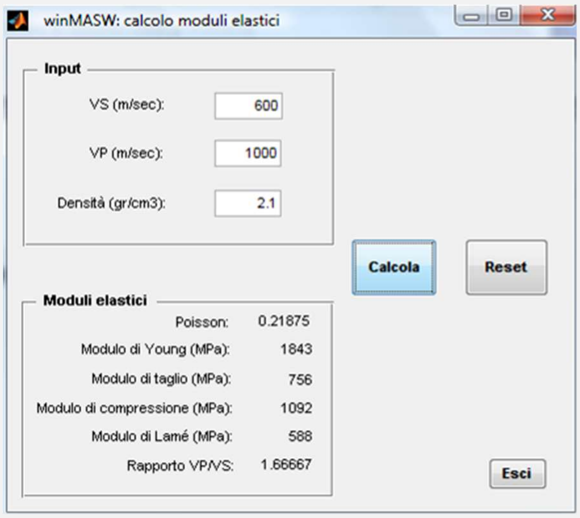
APPENDICES


HoliSurface® - utilities
HS
HS utilities
managing passive data
TCEMCD
double MAAM
concatenate HVSR (SAF)
pre-processing
SEG to SAF conversion
2D and 3D data
upload & show GRD file
2D velocity contouring
3D project/visualization
DTM tool
photos & GPS data
managing active data
vertical stack
assemble VF/EX with HF
compare 2 datasets
compare N datasets
average velocity spectrum
post-processing & miscellanea
qc/Nspt-Vs
elastic moduli
Vs30 at foundation
Stesky's equation
scientific calculator
area percentage

Appendix A: Elastic moduli

In the main screen of *HoliSurface®* a utility is available to compute a series of elastic moduli from the values of V_S, V_P and density. The velocities speeds must be expressed in m/s, the density in gr/cm³ while the calculated modules (Young modulus, shear modulus, compression modulus and Lamé λmodulus) are in MPa (MegaPascal) (Poisson's modulus and VP/VS ratio are dimensionless).
Bear in mind that from surface wave analysis you cannot determine the V_P values. The only modulus we can consider as a good estimation of the actual value is the *shear modulus*, (which does not depend on the V_P).
This utility is very useful because considering the V_S obtained by MASW analysis and the obtained V_P by refraction studies we can have an approximate estimation of the various moduli.



Bear in mind that these <u>are all dynamic and *not* static</u> moduli (engineers are generally interested in the latter), since they come from measurements made with seismic methods. While for very rigid materials the difference is not dramatic, on soft materials the difference can reach up to 1 order of magnitude.

Formulas for expressing moduli according to V_S, V_P and density:

Poisson modulus (dimensionless)	$(V_P^2 - 2V_S^2)/[2(V_P^2 - V_S^2)]$
Young modulus (in Pa)	$\rho V_S^2 (4 - 3k^2)/(1 - k^2)$
Shear modulus (in Pa)	ρV_S^2
Lamé λ modulus (in Pa)	$\rho V_S^2 (k^2 - 2)$
Compression modulus (in Pa)	$\rho V_S^2 (k^2 - 4/3)$

where:

$k = V_P/V_S$ (dimensionless)
ρ = density (Kg/m³)
V_S and V_P = velocity of shear and compression waves in m/s

Clearly, to convert values expressed in Pascal (Pa) to values in MegaPascal (MPa) just divide the number by 10^6 (Mega = 1 million)

Appendix B: Stesky's equation

Through the formula considered, which for simplicity we will call Stesky's, as it is reported in one of his publications (Stesky, 1978), allows you to determine the "actual" velocity (results) if you are dealing with a medium composed of 2 materials (e.g., gravel made up of pebbles immersed in a sandy matrix).

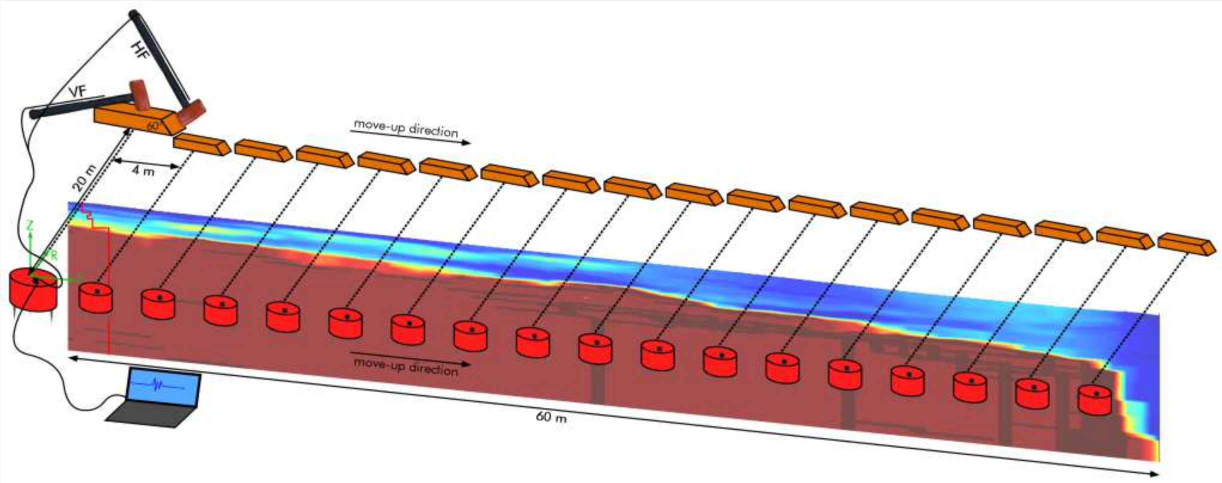
The formula is simply the following (and can be called up from the "Stesky's equation" module in the main panel among the utilities):

$$\frac{1}{V_m} = \emptyset \frac{1}{V_A} + (1 - \emptyset) \frac{1}{V_B}$$

where V_m is the actual "effective" velocity of the "mixed" medium, while V_A and V_B are the velocities of material A and B, being $\emptyset$ the fraction of volume of material A.

Appendix C: Creating 2D sections

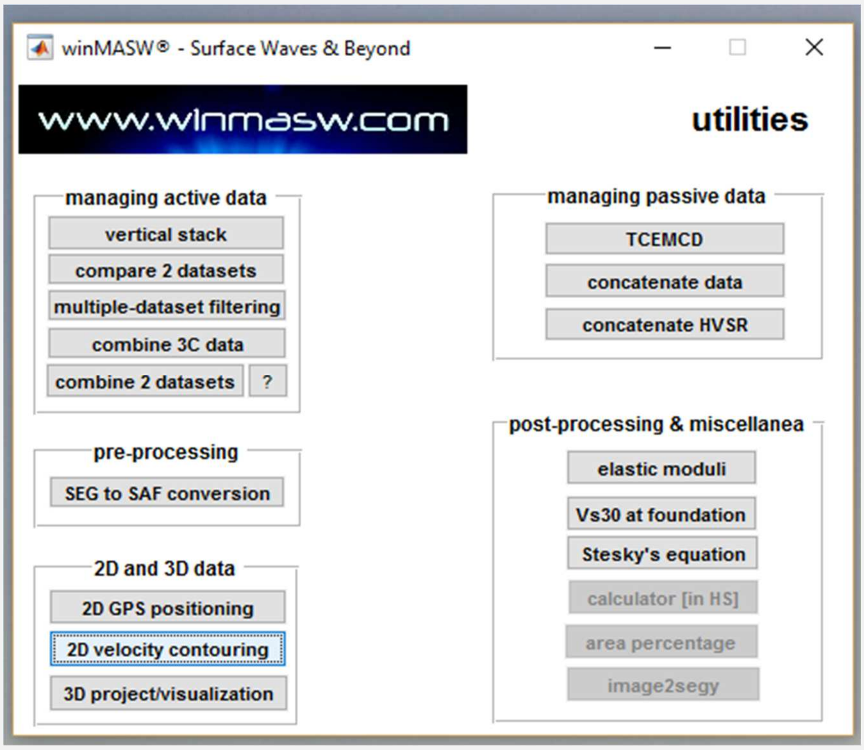
In order to acquire data useful for reconstructing 2D profiles from *HoliSurface* acquisitions, a possible acquisition geometry is shown in the image below (courtesy of www.roXplore.ch).



In this case, the axis of the HS “positioning" is kept perpendicular to the line of the 2D profile that you want to reconstruct.
In other cases it is possible to keep it parallel (classic roll along approach) [to understand which is the best solution you can attend our training seminars].

winMASW® Academy and *HoliSurface®* also offer, among the various utilities, a tool for creating 2D sections from different vertical profiles.

It is used by creating a simple "project file" to be saved as a simple ASCII file (.txt) like the one shown by way of example below



Example of a project file (also downloadable from the internet - see below)

N16 - profile#1
2
404.8000 404.2000 404.4000 405.2000 405.4000 405.8000 405.9000
406.3000 406.7000 407.2000 406.9000 407.6000 409.2000 409.7000 410.4000
411.5000 412.4000 414.5000 417.7000 424.1000
0 50 93 145 194 242 293 348 397 445 492 538 597 647 693 740 785 821 888 933
model1.mod
model2.mod
model3.mod
model4.mod
model5.mod
model6.mod
model7.mod
model8.mod
model9.mod
model10.mod
model11.mod
model12.mod
model13.mod
model14.mod
model15rep.mod
model16.mod
model17.mod
model18.mod
model19.mod
model20.mod

The **first line** contains the name of the project or section in question
The **second line** has no use at the moment (release 2019) (but this value should not be removed at all).
The **third line** shows the topography (the height of each point considered) (if you do not have the topography, simply enter the number 0 (zero))
The **fourth line** shows the position (the point) of each model (below)
All the names of the Vs profiles (saved in the .mod files) are listed **below**

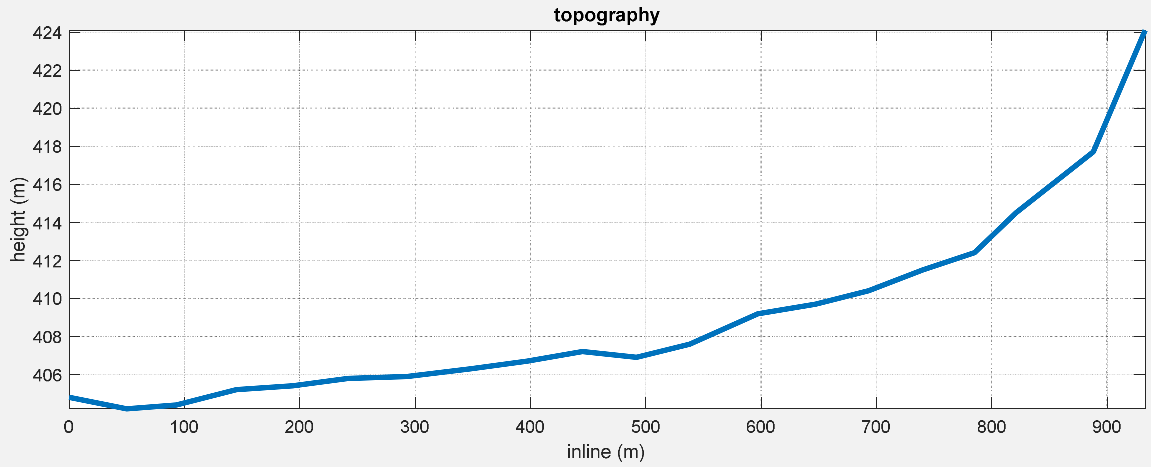
Attention: the models (.mod files) must all have the same number of layers.

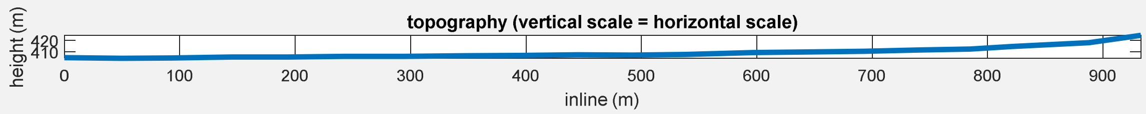
In the example above, for instance, we are dealing with a 2D section built on the basis of 20 points (the first profile Vs is relative to point 0, the second to point 50 and so on).

All these files must be in the same folder as the project itself.

The project and the above data (which refer to the images below) can be downloaded from the following address: http://download.winmasw.com/data/2Dsection.rar

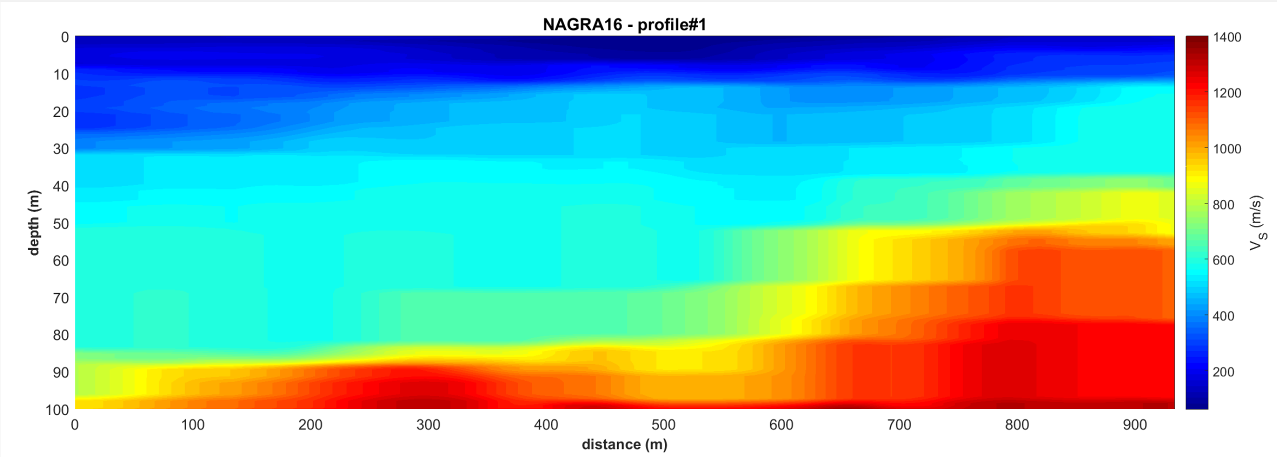
The project file to open and the file " NAGRA16_2Dprofile.txt"

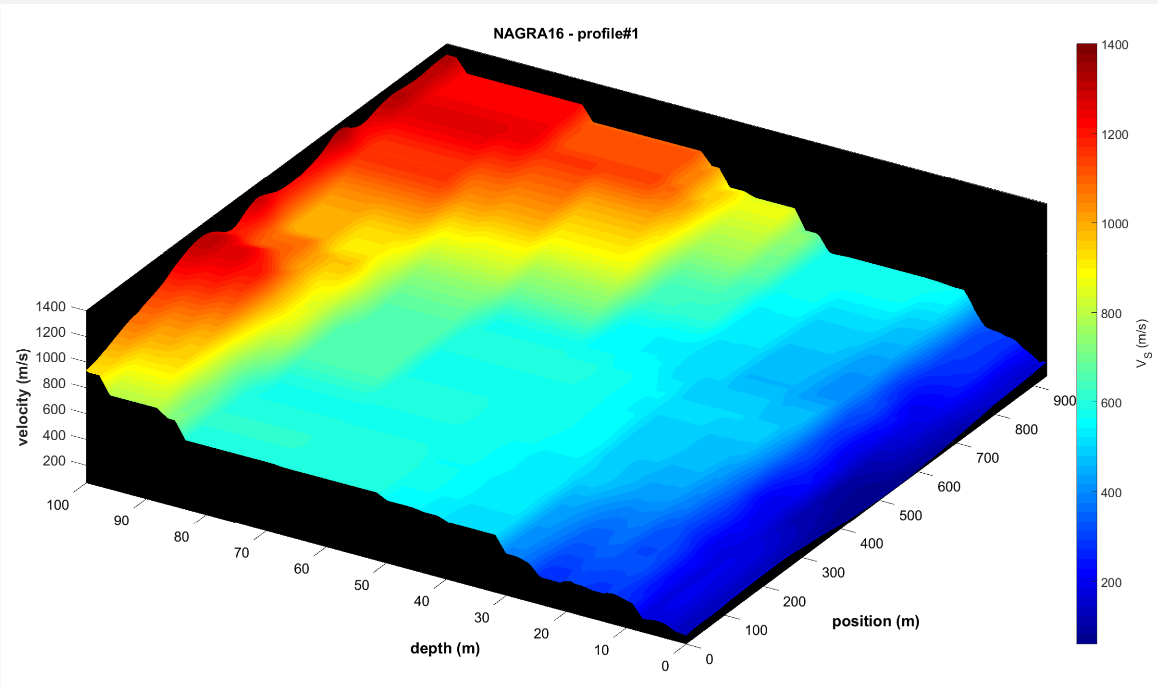


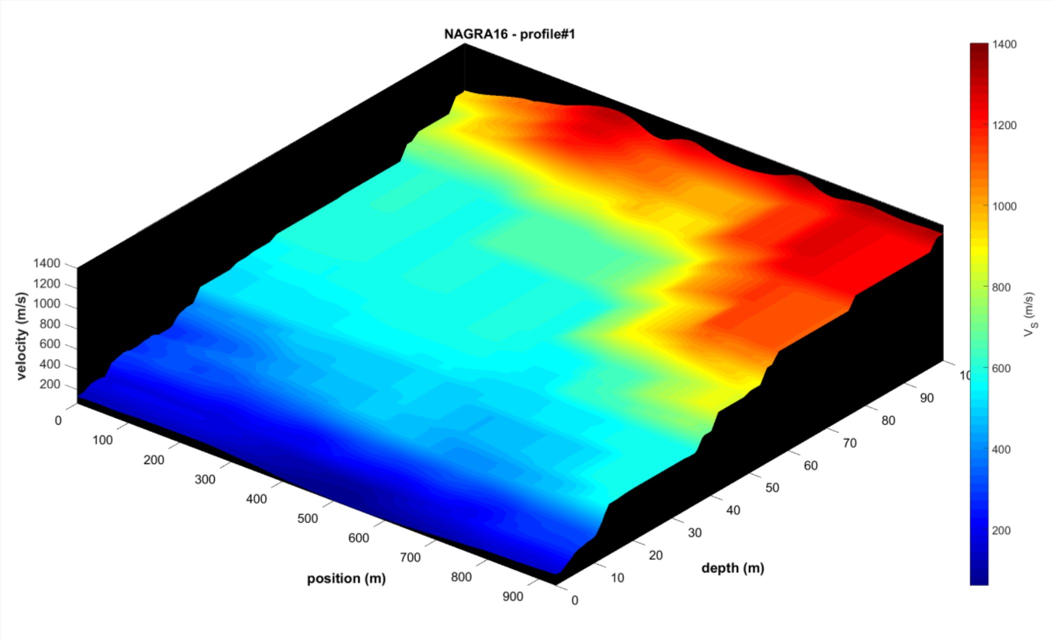


Once the file with the profile data has been loaded, the depth of the deepest interface (horizon) appears within the depth group. **The user must then select the maximum depth to be used in the 2D profile display (by default a value equal to the depth of the deepest interface + 2 meters is proposed) and the maximum velocity with respect to which to define the colour scale.**
The % of lateral smoothing should also be defined.

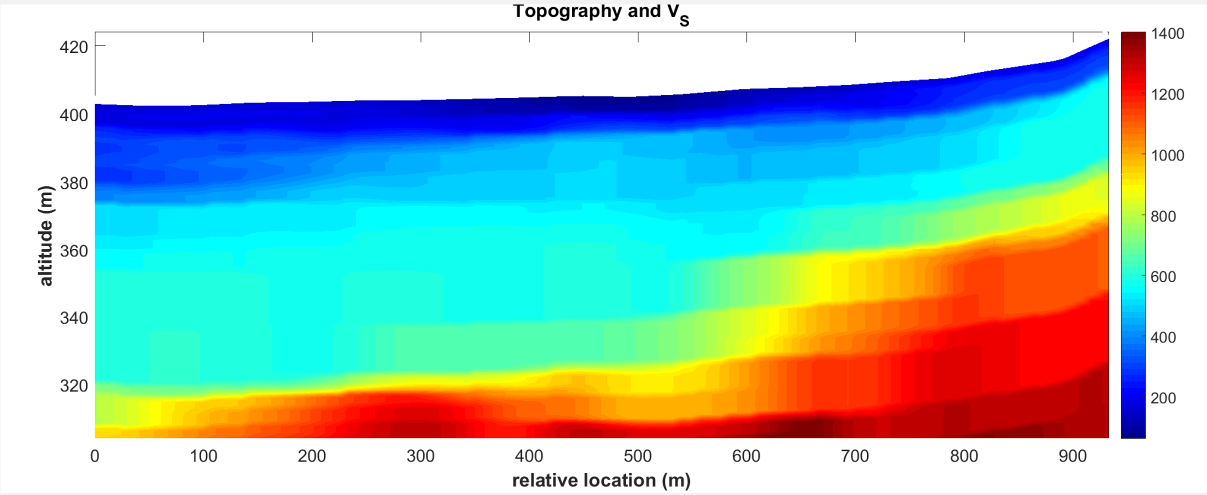
It is suggested that you play with these three parameters a little and see what effect you get.
You can then define whether or not to display individual profiles (enable or disable the checkbox "*show profiles*" (see images below) and whether the profile refers to V_S or V_P.
Note that in the file to be fed you can actually specify <u>any</u> quantity to be "contoured" in the section. You can then construct 2D sections of any data (as long as it is organized according to the format indicated in the "File Format" box).



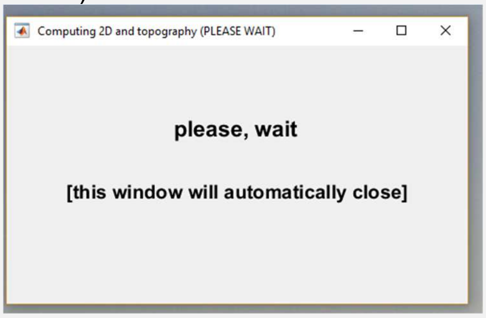


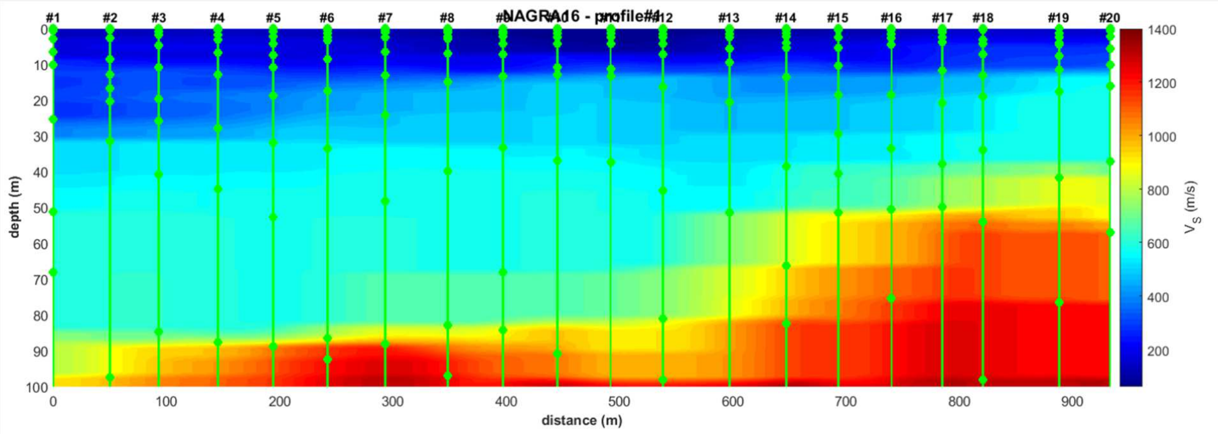


If you activate the option "*show also topography*" and the project file shows the height for each measurement point (see third and fourth line of the project file), an image like the following will be shown:



During the necessary calculations, a window will appear that should not be removed (wait until the calculations are finished):





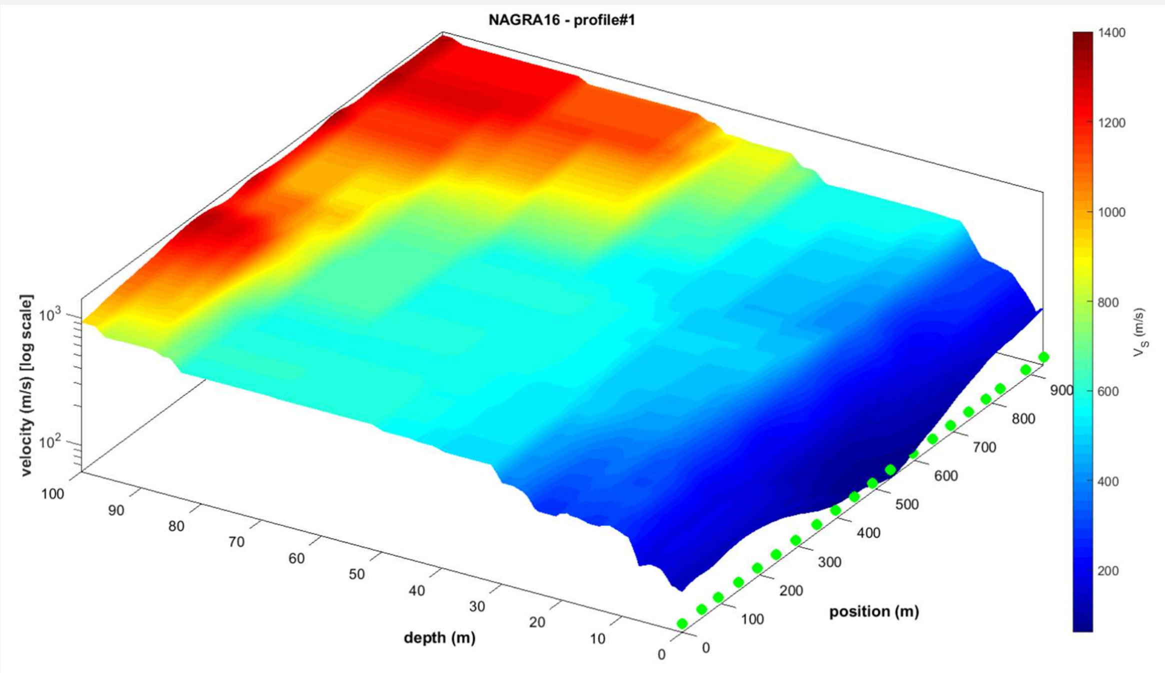
If you activate the **option "*show positions of the single profiles*"**, you will highlight the individual vertical profiles from which the intermediate values are then interpolated.

Regarding the positioning of the individual profiles. There are 2 possible circumstances:

- profiles are equidistant. In this case it is possible/sufficient to enter only the value of the distance between profiles (e.g., 30 m);
- profiles are not equidistant. In this case it is necessary to insert the positions of all the profiles (inside square brackets). In the example above, for instance, the following positions have been specified: 20, 30, 50, 80, 100.

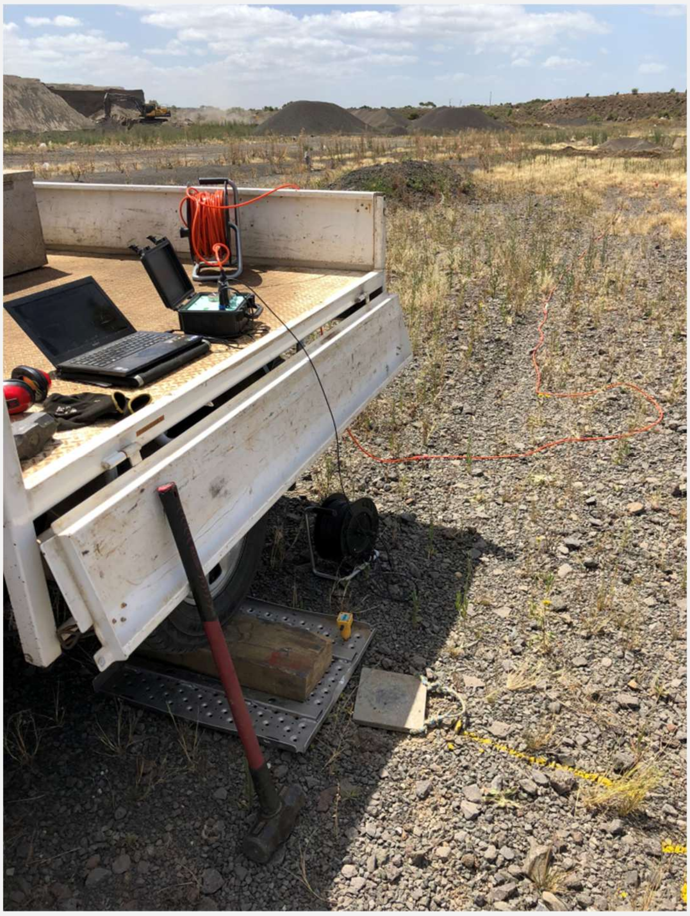
All the images shown are automatically saved (in the working folder) but it is also possible to manually save any image in different graphic formats from the toolbar: "File -> Save".

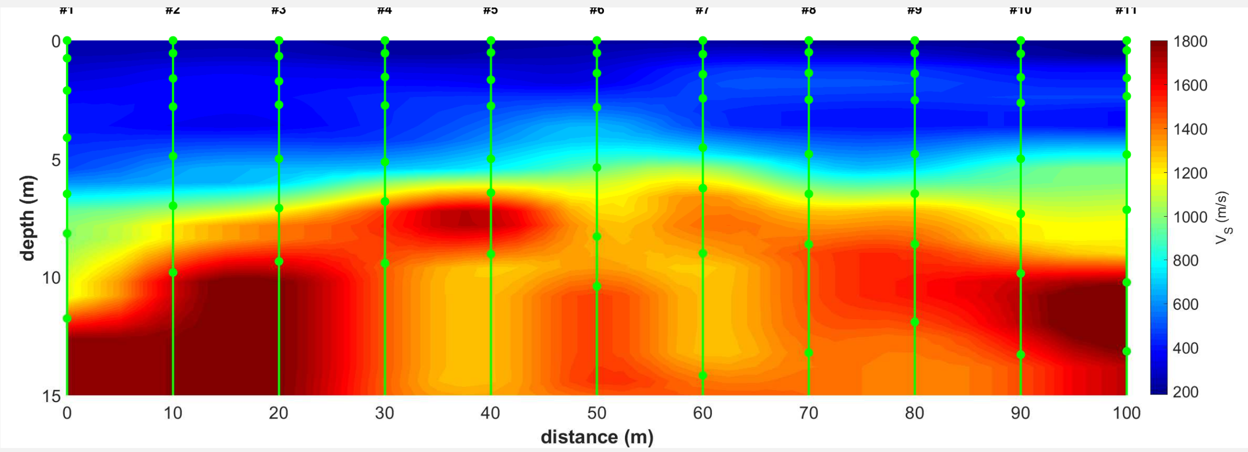
Activating the "log scale (3D plot)" option, you will plot the velocities according to a **logarithmic scale** (this allows you to highlight some lateral variations. In the example below, at the centre of the section you can see an area of peat with particularly low velocities).
Green dots are the measurement positions.

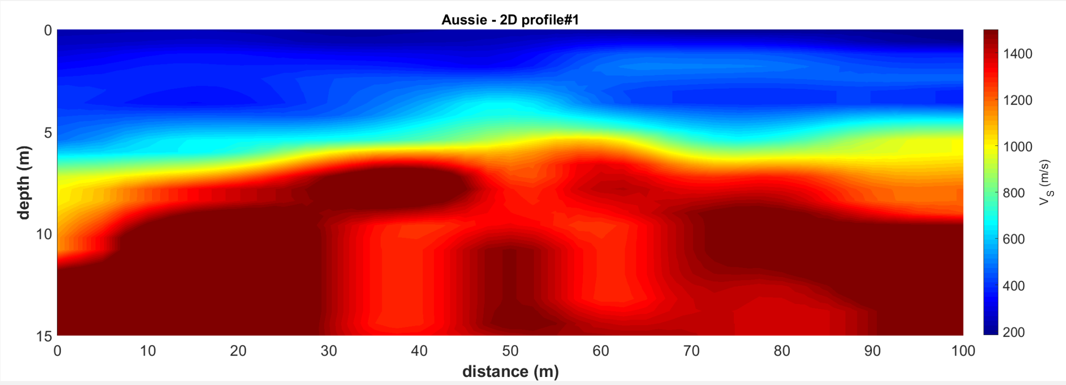


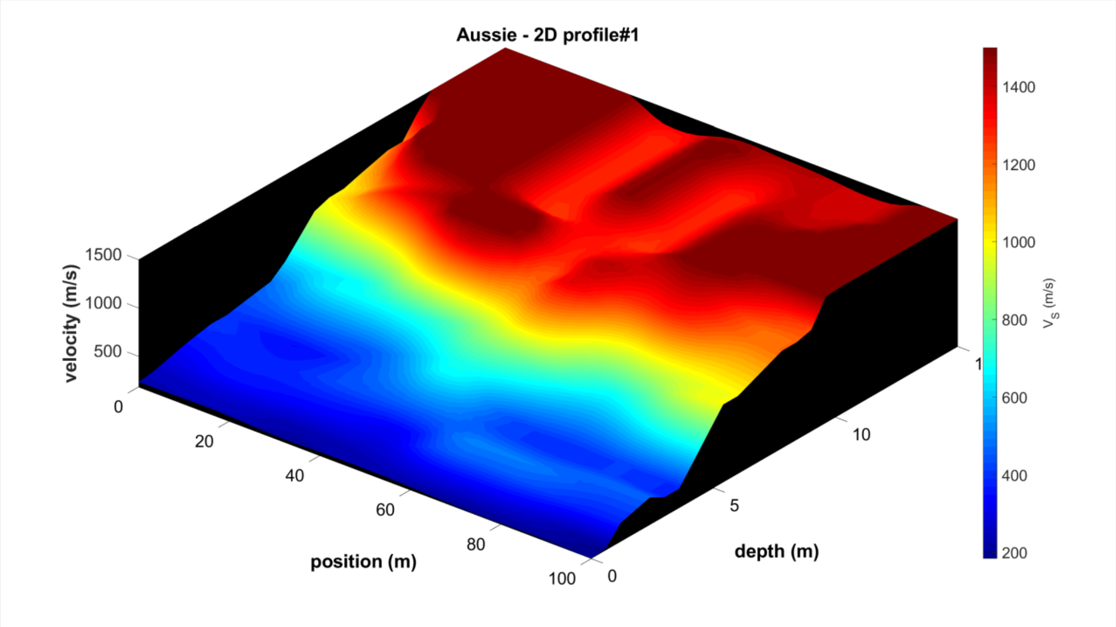
A further example from Australia

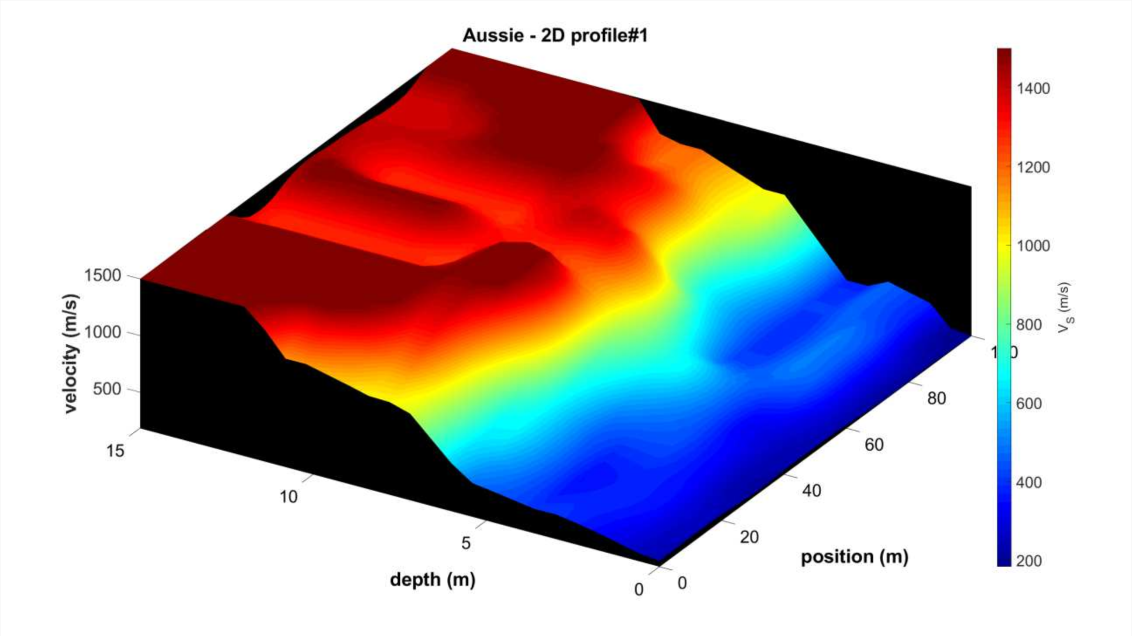
Data kindly provided by Nick Schofield

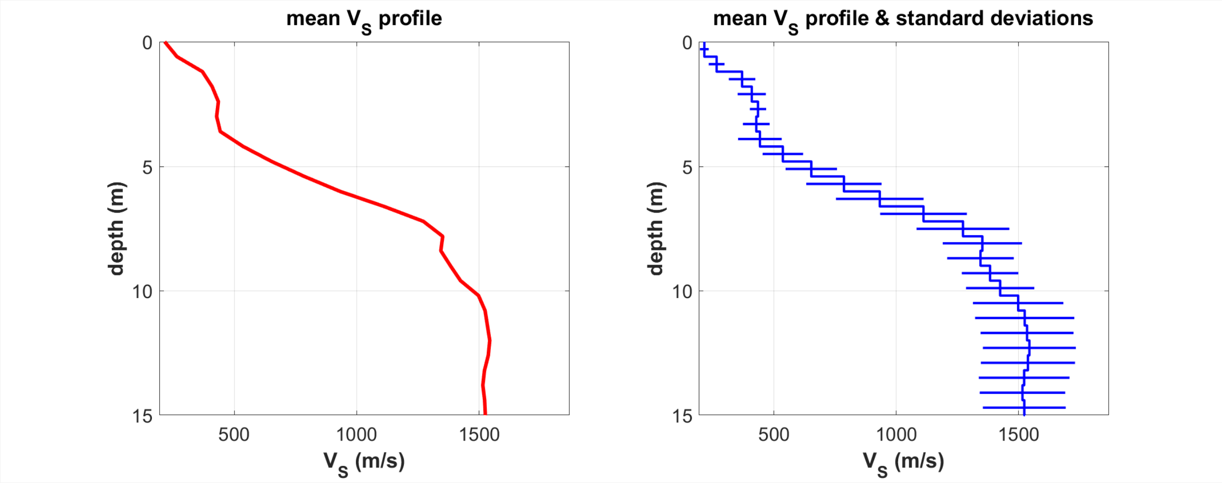




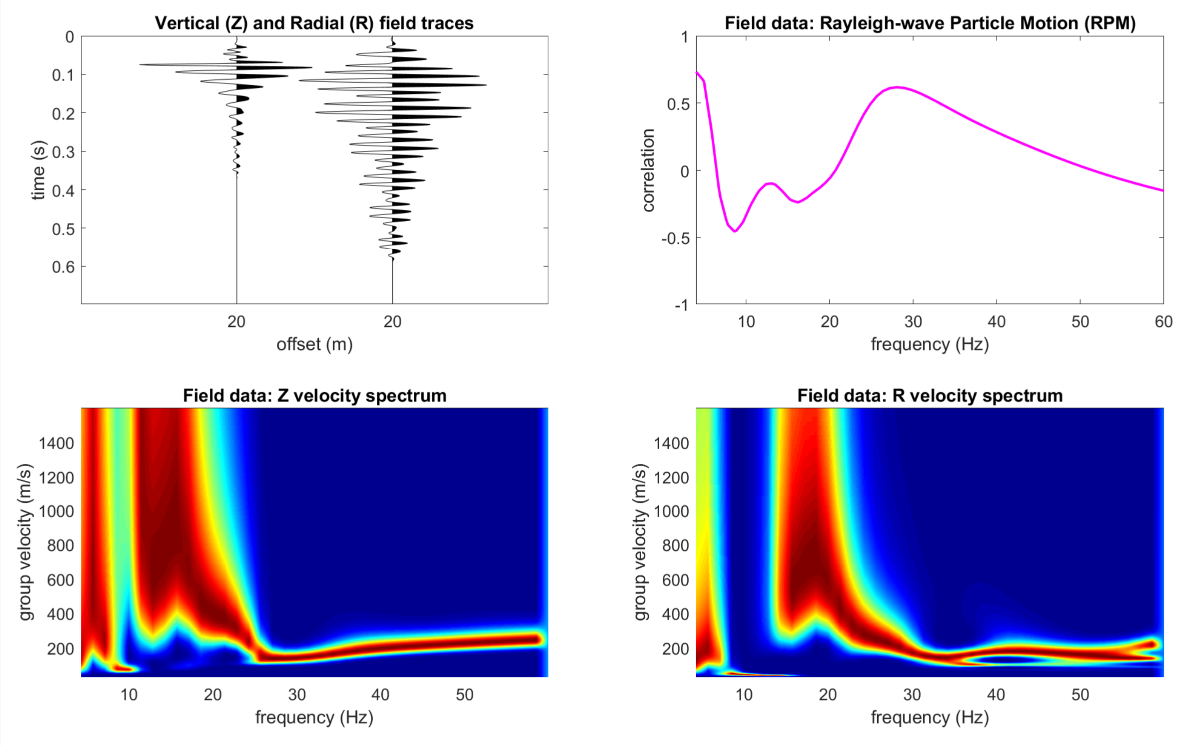

Aussie - 2D profile#1
depth (m)
distance (m)
V_S (m/s)

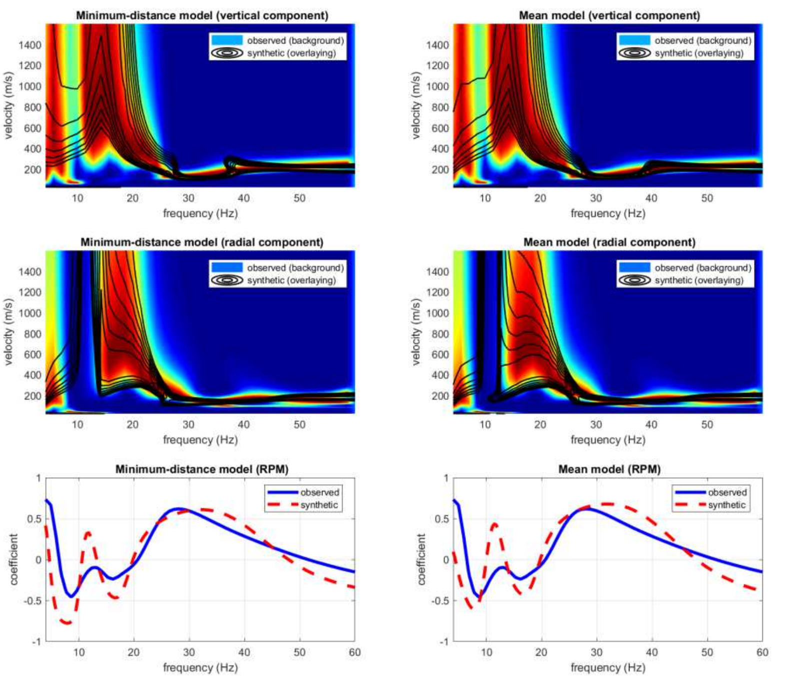

Aussie - 2D profile#1
velocity (m/s)
position (m)
depth (m)
V_S (m/s)

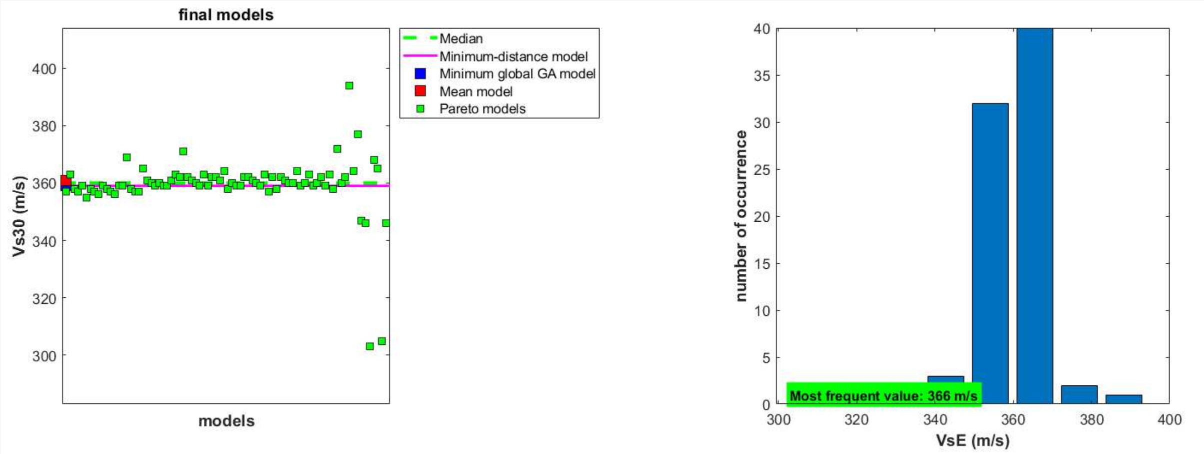

Aussie - 2D profile#1
velocity (m/s)
depth (m)
position (m)
V_S (m/s)

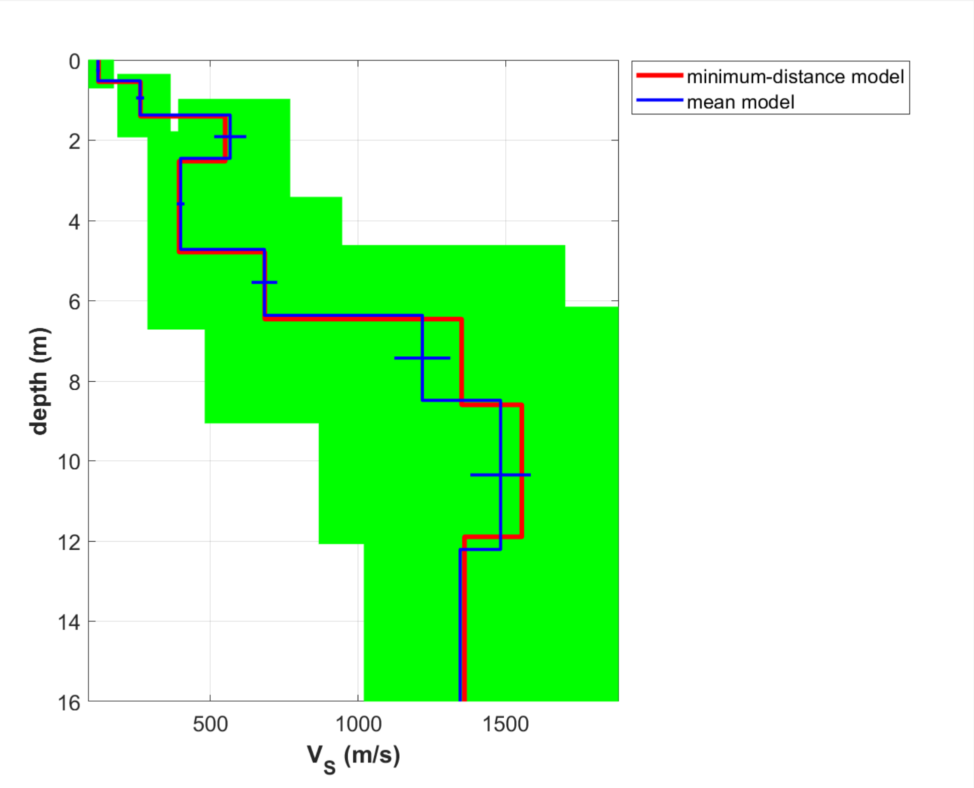

mean V_S profile
mean V_S profile & standard deviations
depth (m)
V_S (m/s)
0
5
10
15
500
1000
1500

The analysis of one of the 11 shots considered in the reconstruction of the 2D profile presented in the previous pages






final models
Median
Minimum-distance model
Minimum global GA model
Mean model
Pareto models
Vs30 (m/s)
models
number of occurrence
Most frequent value: 366 m/s
VsE (m/s)


minimum-distance model
mean model
depth (m)
V_S (m/s)

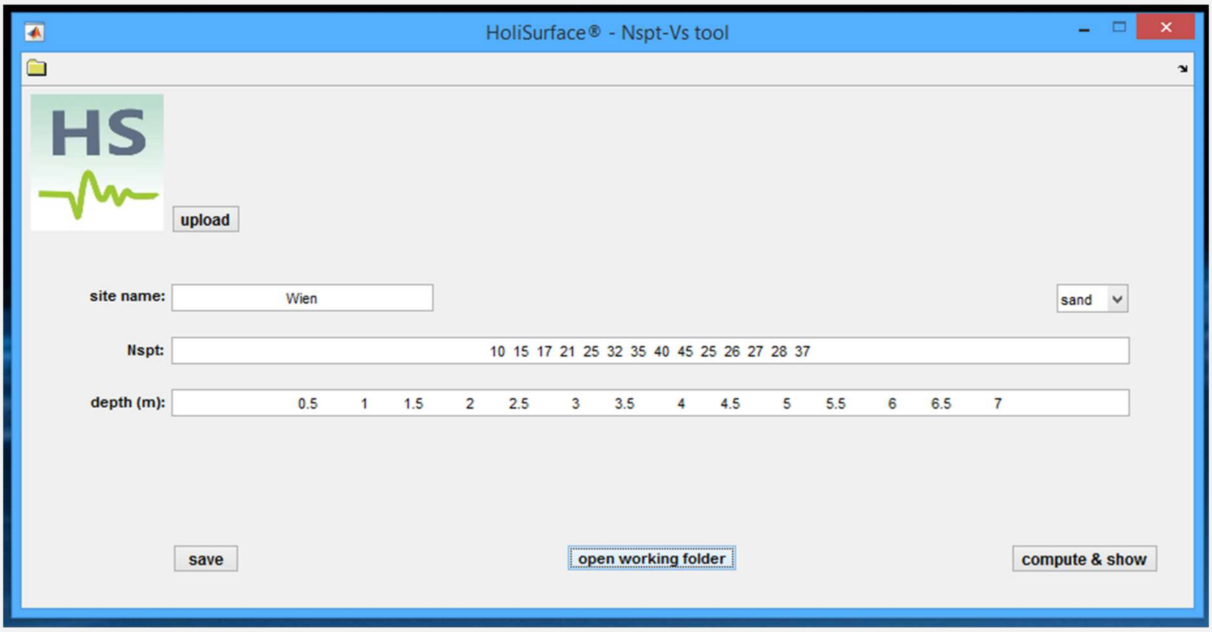
Appendix D: N_{SPT} - V_S tool

Please, notice that, in the near-future release, this tool will be significantly modified/improved

With this tool, you can convert penetrometer data (for now the value of N_{SPT} but in the future also of q_c) in V_S according to some published empirical reports.

The tool is quite simple and intuitive (see snapshot below). The four relationships (equation 1, eq.2, eq.4 and eq.4 used) are respectively those of:

eq. 1: Imai (1977)
eq. 2: JRA (1980)
eq. 3: Maheshwari et al. (2010)
eq. 4: Hasancebi and Ulusay (2007)

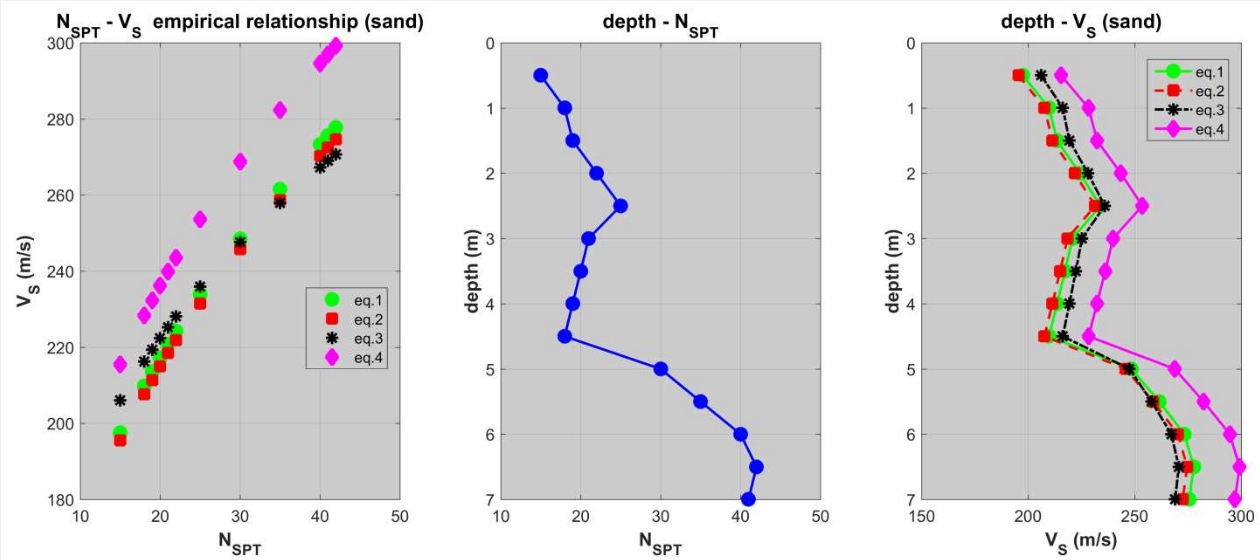


Imai T., 1977, *P-and S-wave velocities of the ground in Japan*. Proc IX Int conf Soil Mech Found Eng 2:127–132

Japan Road Association (JRA), 1980, *Specification and interpretation of bridge design for highway-part V: Resilient design*.

Maheswari R.U., A. Boominathan and G.R. Dodagoudar (2010). *Use of Surface Waves in Statistical Correlations of Shear Wave Velocity and Penetration Resistance of Chennai soils*. Geotechnical and Geology Engineering, 28(2),119-137.

Hasancebi, N. and Ulusay, R., 2007, *Empirical correlations between shear wave velocity and penetration resistance for ground shaking assessments*. Bulletin of Engineering Geology and the Environment, 66(2), 203-213.

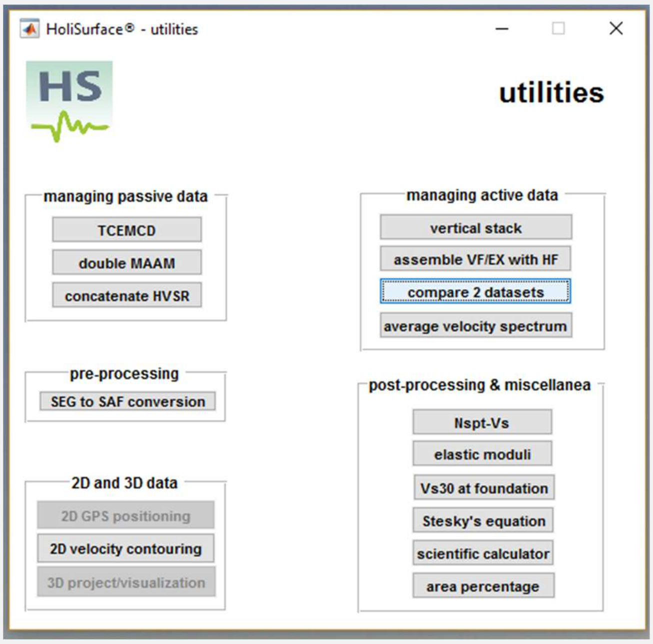


This tool will soon be updated and enriched, giving the user the opportunity to enter their own values useful to establish some relationship between penetrometer data and V_S.

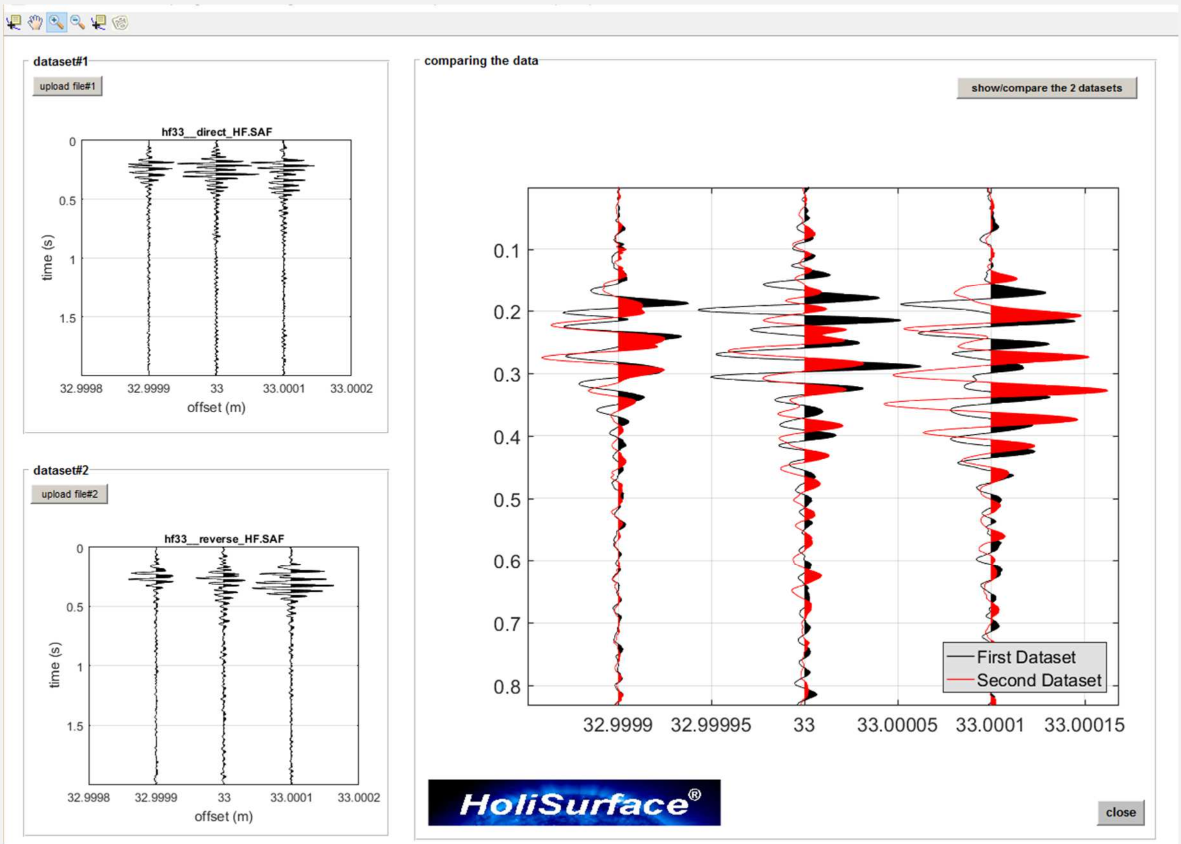
Appendix E: tool for the comparison of active data

The various utilities also include a tool for the comparison of two (active) **HS** datasets ["compare 2 datasets"].

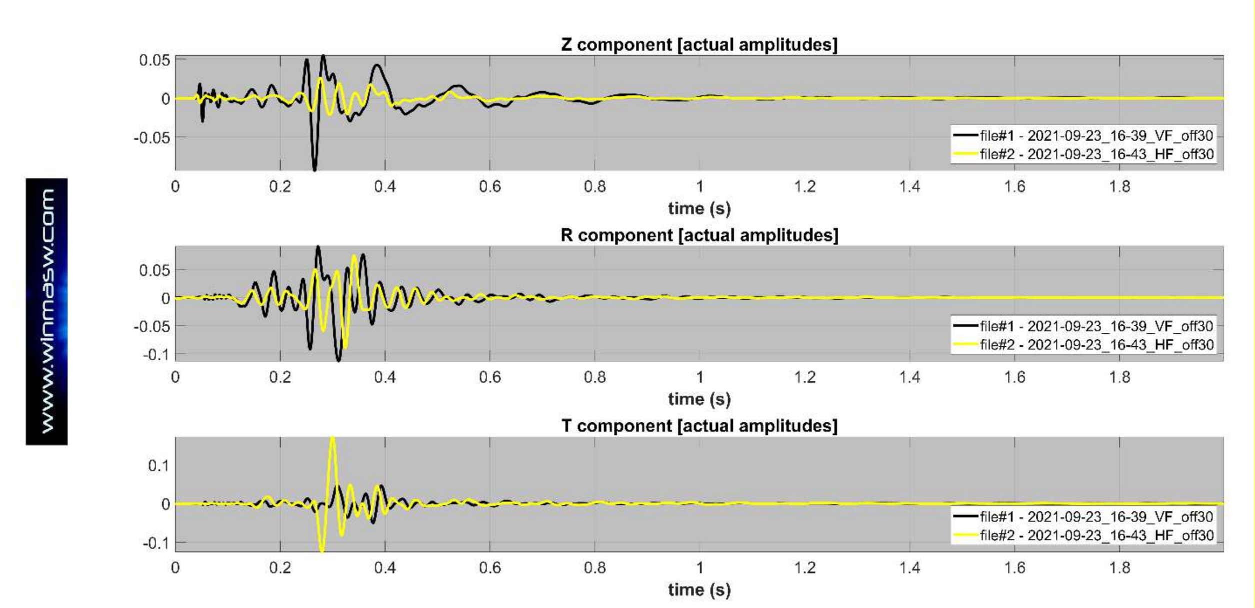
This can be interesting if you want to verify the "similarity" of two datasets (e.g., by reversing the source and the geophone) or verify the similarity of two datasets acquired with identical acquisition parameters but recorded at two different moments (Time Lapse analysis).



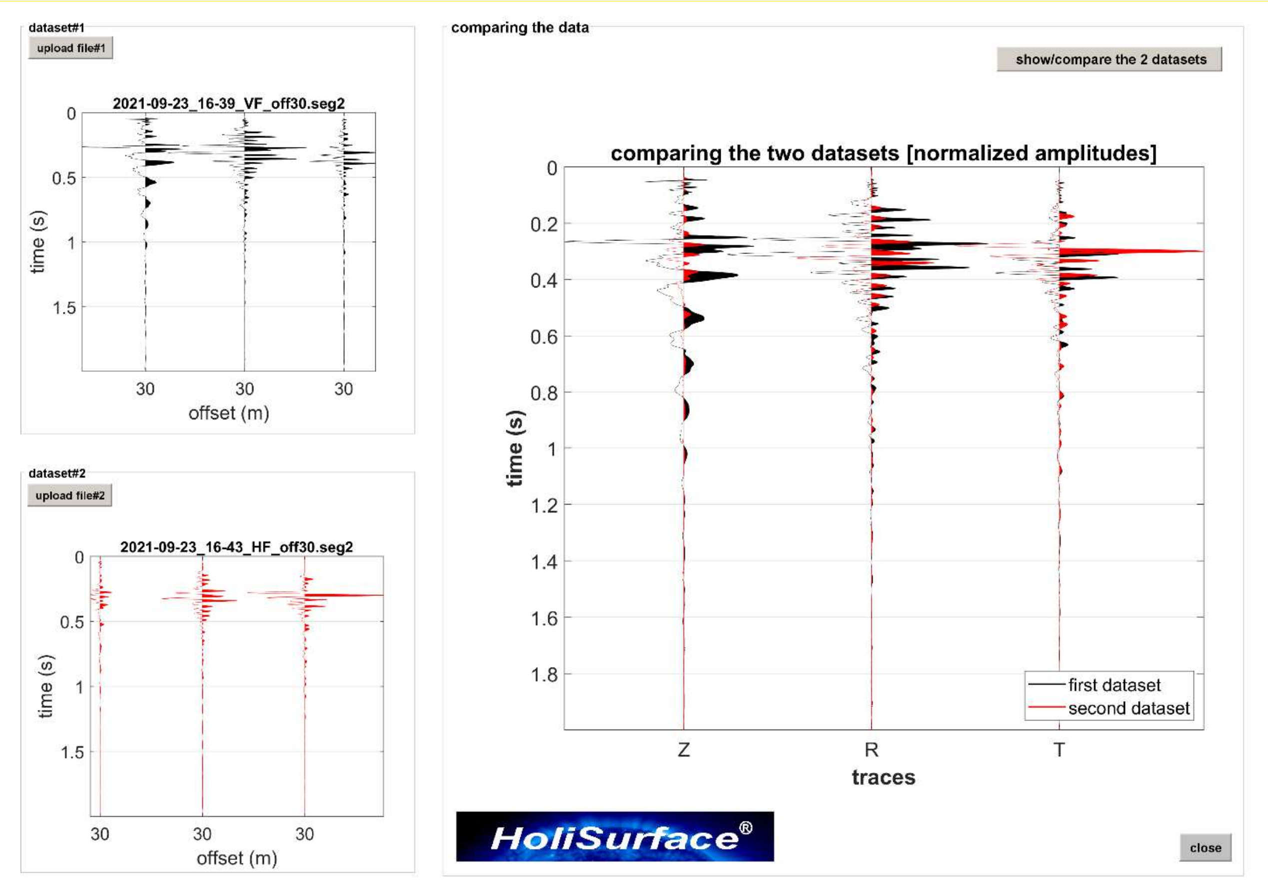
Just load the two datasets and then click "show/compare the 2 datasets."

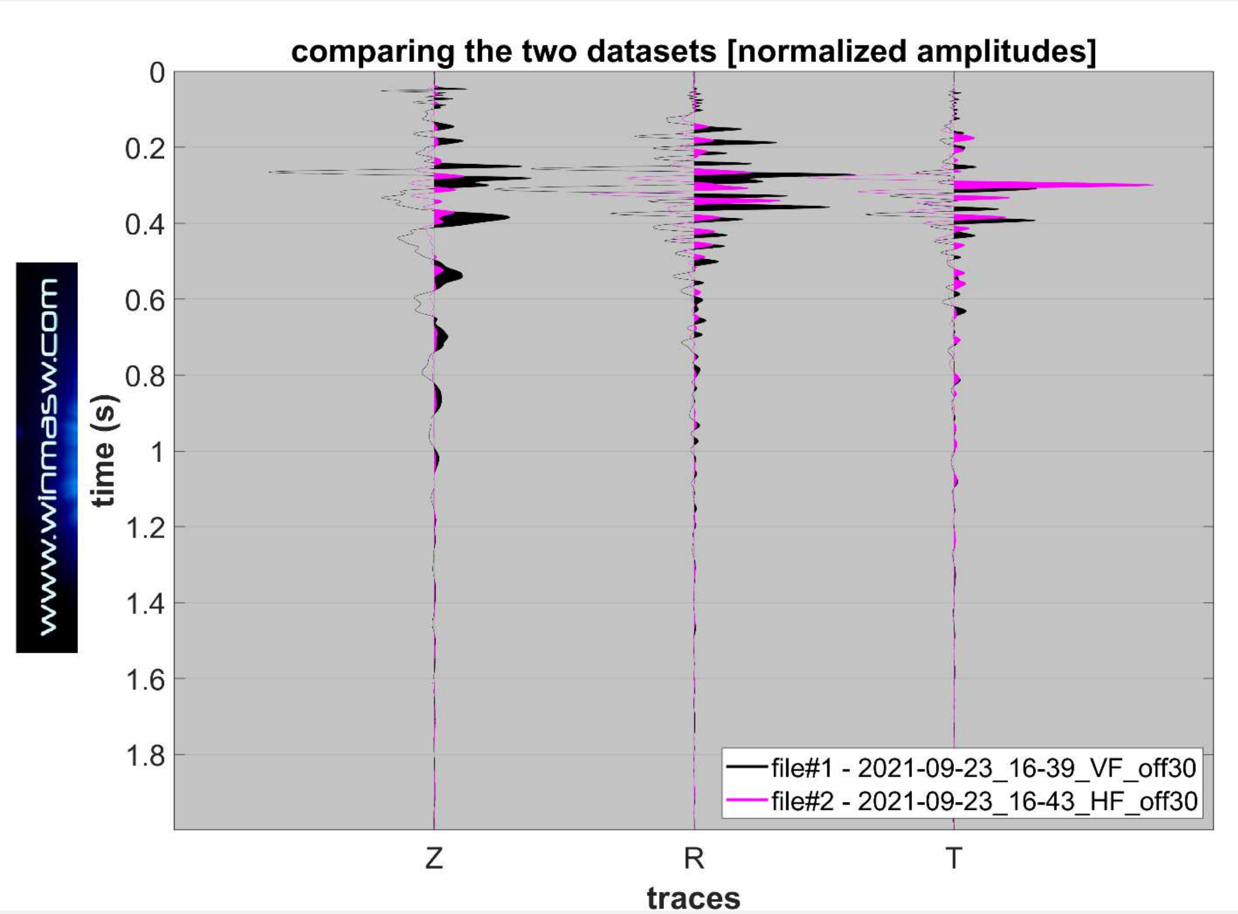


In the following figure a further example: comparison between the VF and HF data. Please, note that this tool produces several graphs, some with the **actual** amplitudes and others with the **normalized** amplitudes (often usefull to better understand the arrival times).



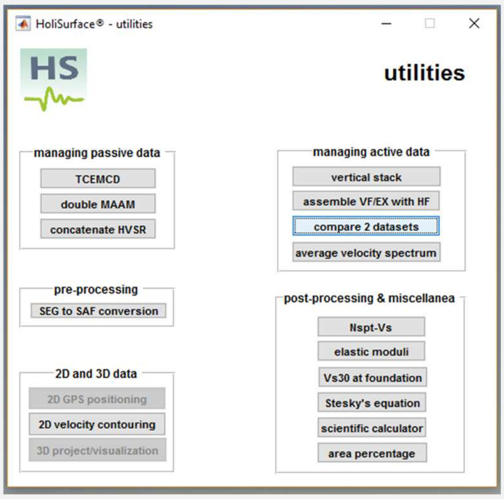
As inevitable, it is clear that the amplitude of the T (transversal) trace is usually significanlty larger in the case of HF acquisitions (accomplished to generate good quality SH waves - and therefore Love waves). Vice versa, during an HF acquisition, the amplitudes of the Z and T traces are ususally smaller.




comparing the two datasets [normalized amplitudes]
time (s)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Z
R
T
traces
file#1 - 2021-09-23_16-39_VF_off30
file#2 - 2021-09-23_16-43_HF_off30
www.winmasw.com

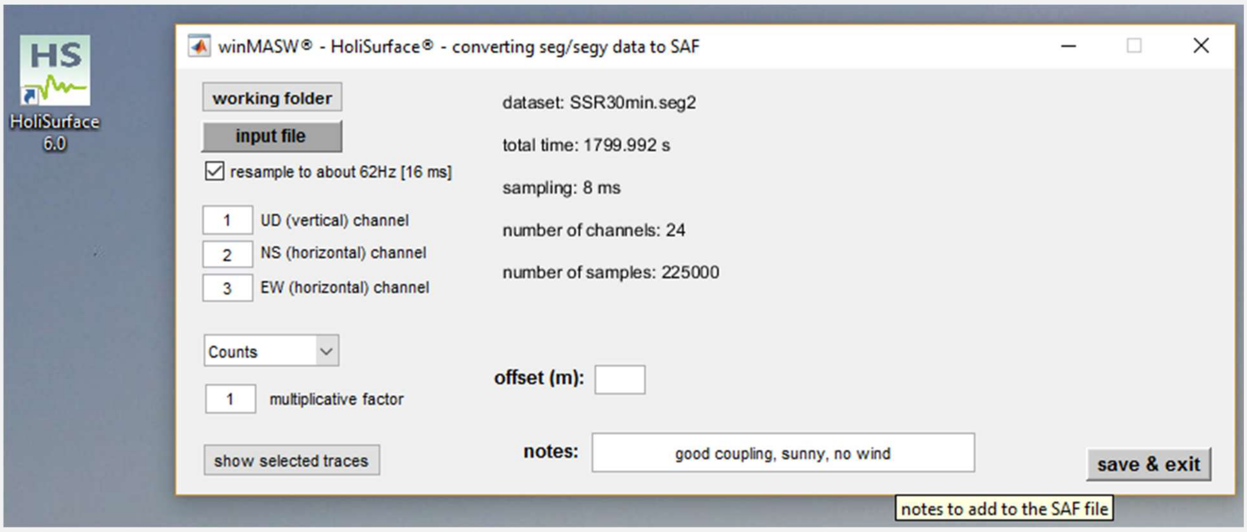
Appendix F: seg to SAF conversion tool

The conversion tool from seg to SAF format (already present in previous releases) has been greatly improved.



Now you can enter:
1) the unit of measurement (see the notes on your seismograph/acquisition system);
2) offset (for active HoliSurface-type acquisition);
3) field notes (useful both for passive acquisitions - HVSR - and for any other type of data) [the notes are clearly included in the SAF file obtained and shown by winMASW/HoliSurface when the SAF file is loaded - for example in the HVSR module].

It is also possible to define a multiplication factor (the data are multiplied by this number and then saved in the SAF file).
Not only: if the acquisitions are made with our *HS acquisition system* (equipped with GPS antenna), the GPS coordinates will be automatically saved in the SAF file and, as soon as loaded in *winMASW®* or *HoliSurface®*, you can view the site directly on Google Earth.



Question: in case I have a seg2 file about microtremor data and need to use it in ordert to compute the HVSR, doI need to convert the data as SAF file?
Answer: No. In the HVSR panel (as well as the SSR and vibration modules) you can upload directly your seg2 file(s).

Appendix G: the stack tool

Among the tools useful for improving the active-data quality, there is the about the (vertical) stack.

It is easy to use. All the shots (related to the same offset and source) need to be uploaded at the same time (multiple selection is obtained by holding the *ctrl key*).

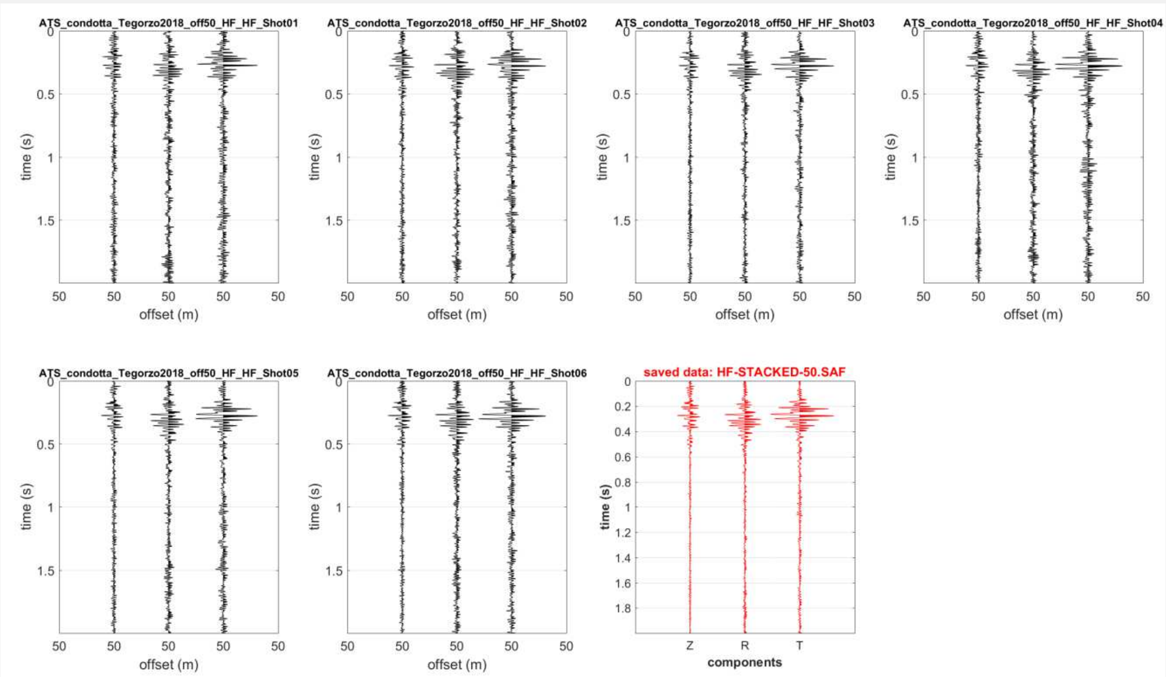
All loaded shots will be “stacked" (averaged sum of the uploaded shots).

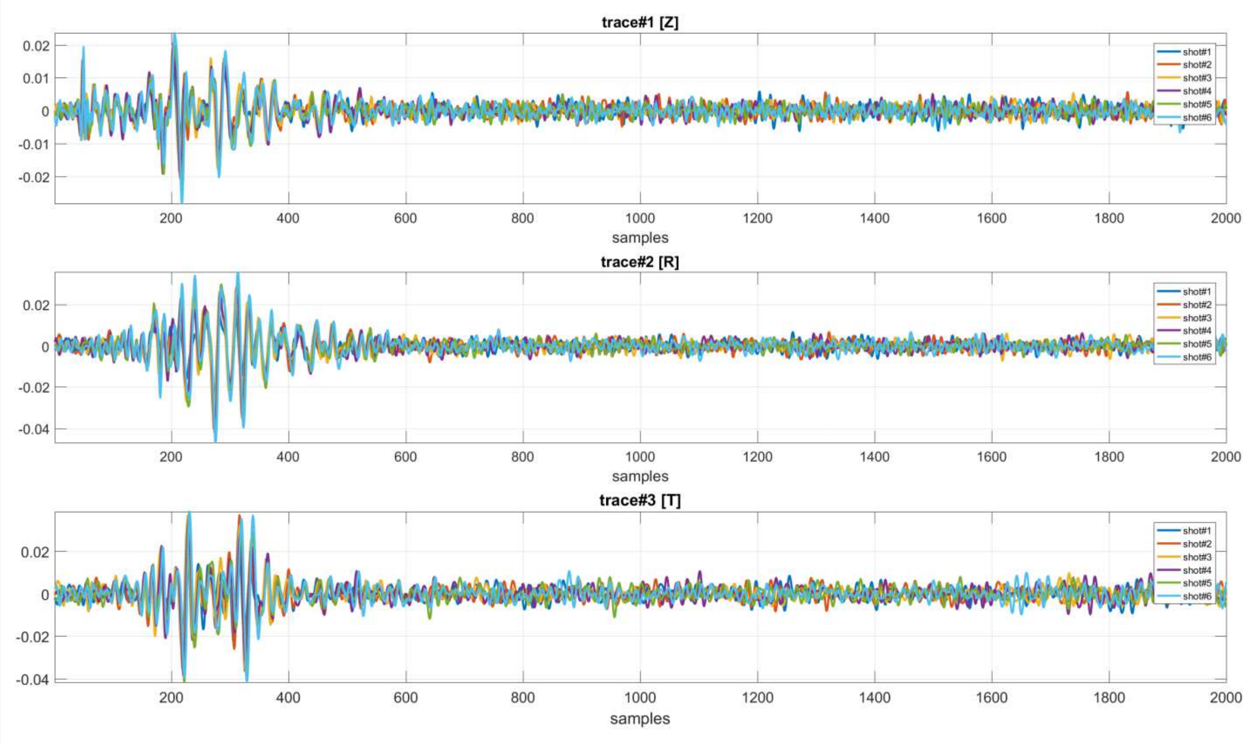
In order to automatically remove shots from the low S/N (Signal-to-Noise) ratio, the value of the correlation coefficient between the average trace and the specific shot is also calculated. If the value is lower than a value indicated by the user (the default value can be clearly modified), this shot is discarded.
This is useful in case you have to handle a large number of shots (several dozen), otherwise it is preferable to choose personally which shots to keep (load).

The higher the value of the correlation coefficient that you will impose, the “clearer” the selection of tge shots will be.
Do not exaggerate and consider that if you have correctly carried out the acquisition process (with an adequate number of shots - never below a value of 5, to be considered as a minimum value), a bad shot generally does not significantly affect the quality of the stack traces.

Remember to always give a name with physical and geometric meaning to the data, as this facilitates all operations (the software recognizes if a data item represents the Love waves - HF file - or Rayleigh waves - VF file).

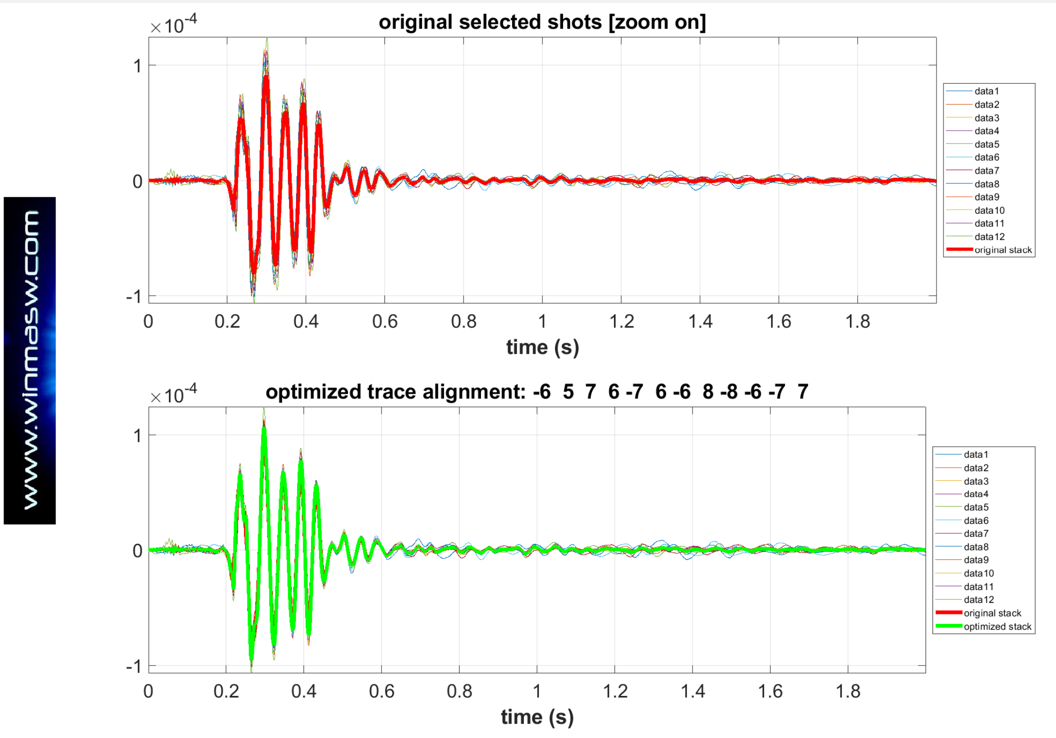
Example of a stack of six shots

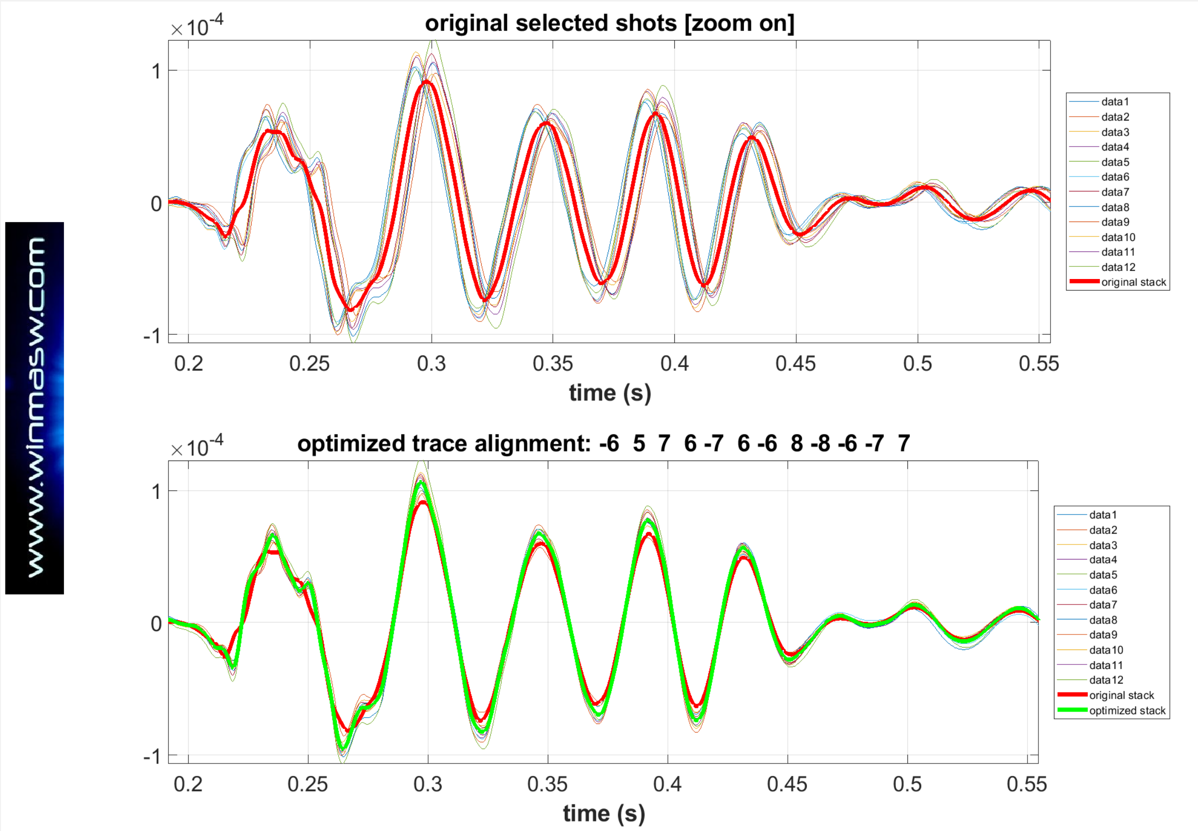




If we had raised the minimum tolerable value, one or more of the traces would have been removed and, together with the data stacked conventionally (i.e., considering all the shots), an "oprimized" file would have been automatically generated (created without taking into account the traces with a correlation coefficient lower than that set by us).

In the recent *release* of the HS software, stack is also optimized though the alignement of the shots. This is done because the “zero time” identified by the trigger signal can be slightly different for different shots. The procedure is aimed at obtained an optimized alignment (see next figures).

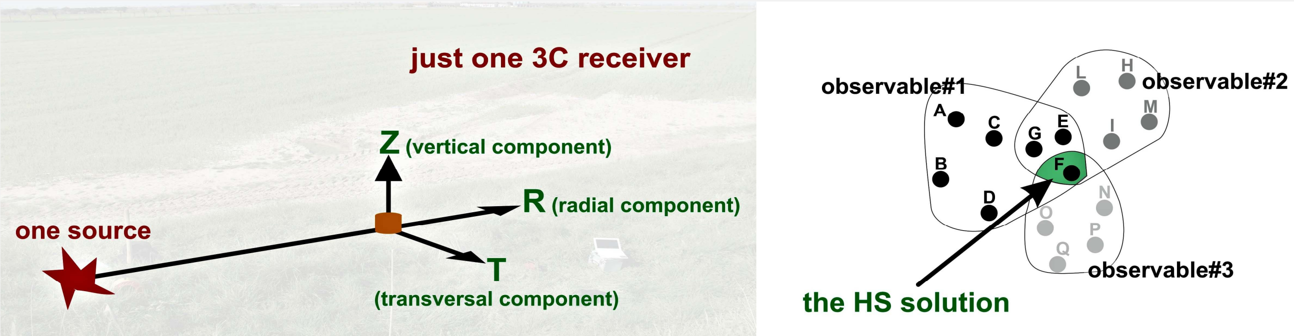




Close up of the singles shots and stacked traces (in this case we are considering the T trace/component): in the upper panel the original traces and the standard stack, in the lower panel the optimized stack after the alignment of the single traces/shots.

This operation is performed also during the extraction and stack of the active shots accomplished in the framework of the ***hybrid acquisition procedure*** (see details in the sections “The HS technique: data acquisition” and “Hybrid data: active data extraction and processing of HVSR passive data”)

Appendix H: few examples of what you can do with HoliSurface® (commented case studies)



Example#1 – an old urban case

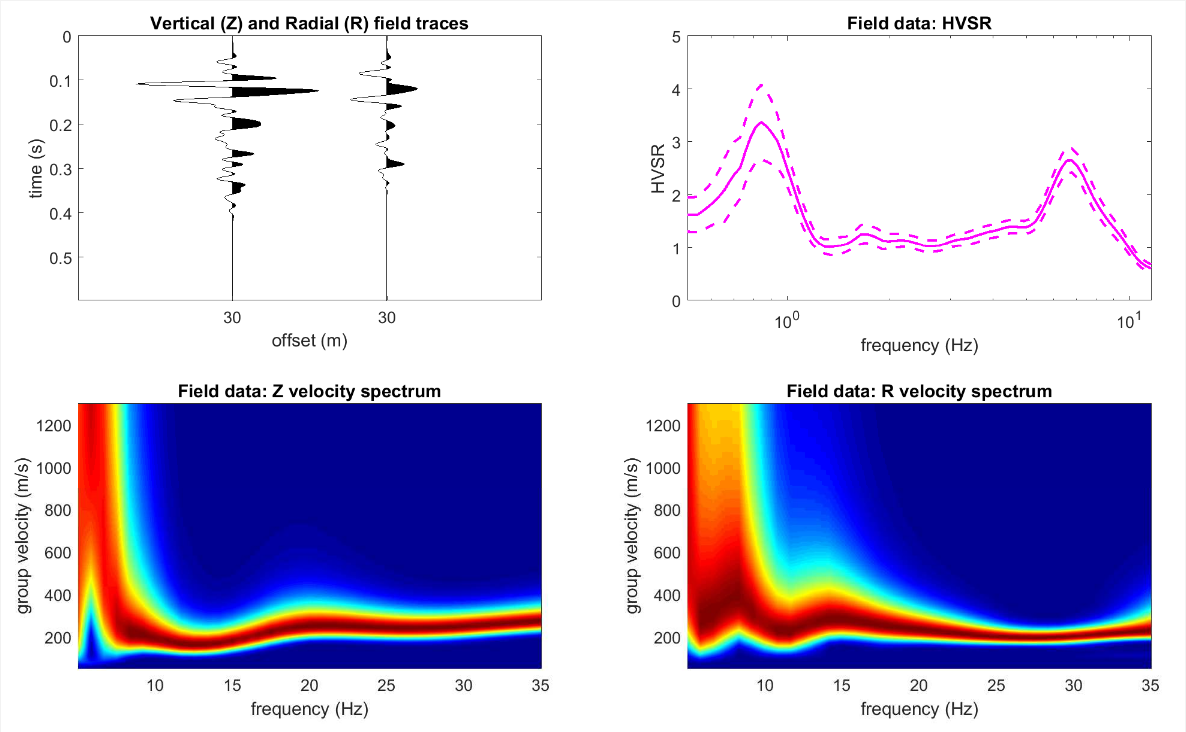
Working in logistically complicated conditions (urban centre with limited possibilities of movement and impossibility to stop the traffic).

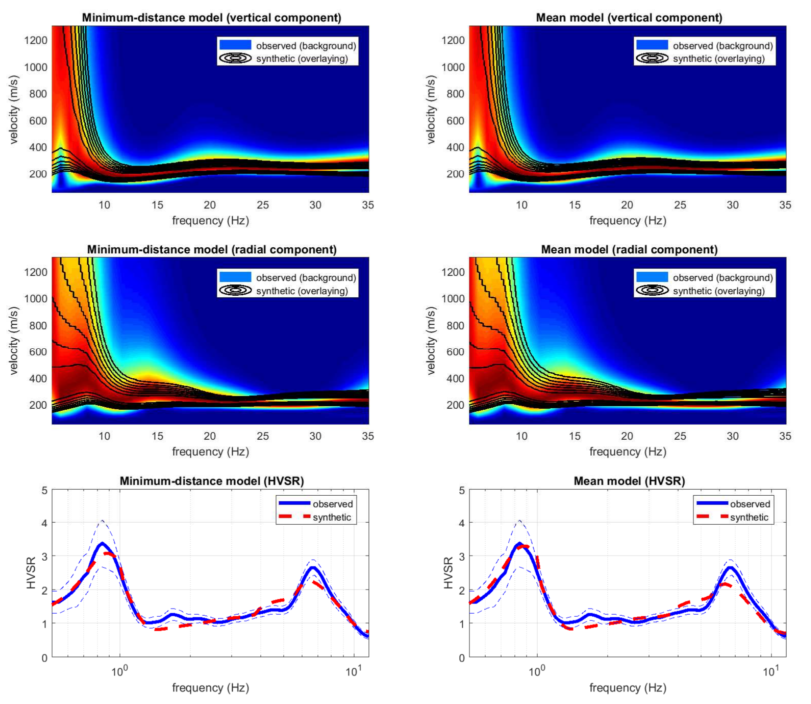
Seismic investigation based on the dispersion of surface waves (group velocity) and its analysis according to the FVS (*Full Velocity Spectrum*) approach [*HoliSurface* - HS].

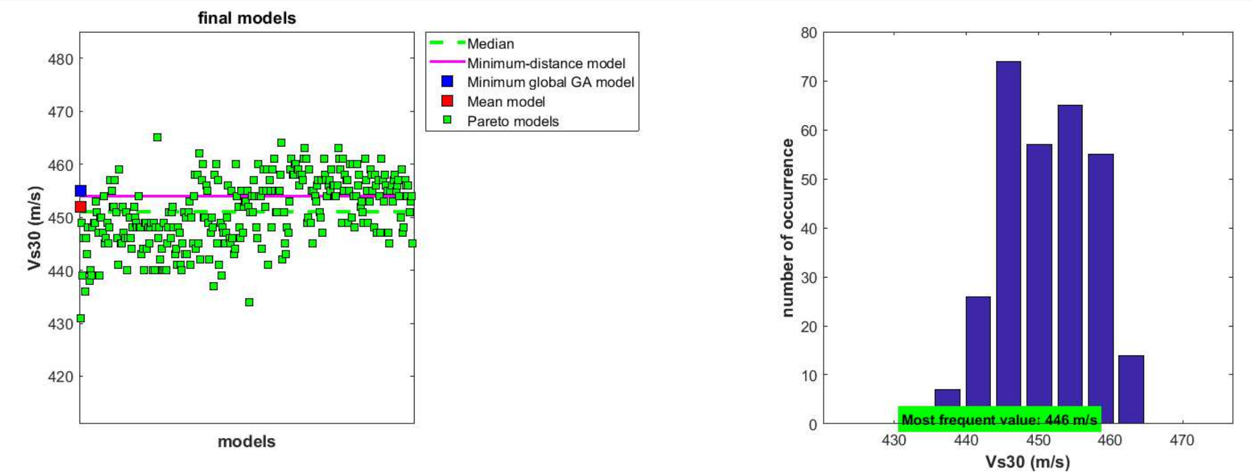
Specifically, both components of the Rayleigh wave (component Z and R) (active acquisition) were analysed together with the H/V spectral ratio (passive acquisition).

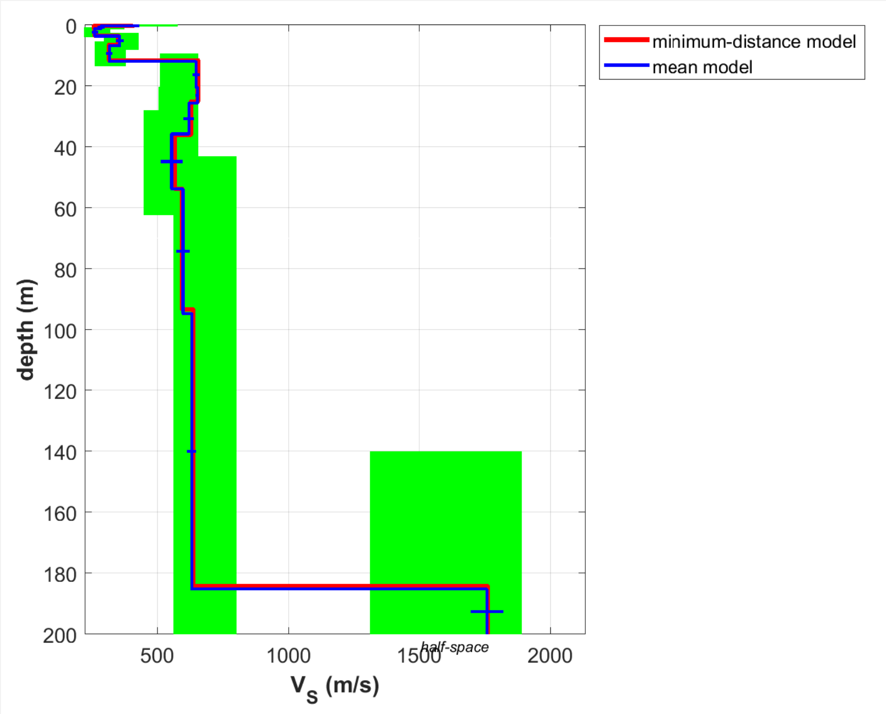
Main HS acquisition parameters:

offset: 30 m; stack: 10


Vertical (Z) and Radial (R) field traces
time (s)
offset (m)
Field data: HVSR
HVSR
frequency (Hz)
Field data: Z velocity spectrum
group velocity (m/s)
frequency (Hz)
Field data: R velocity spectrum
group velocity (m/s)
frequency (Hz)

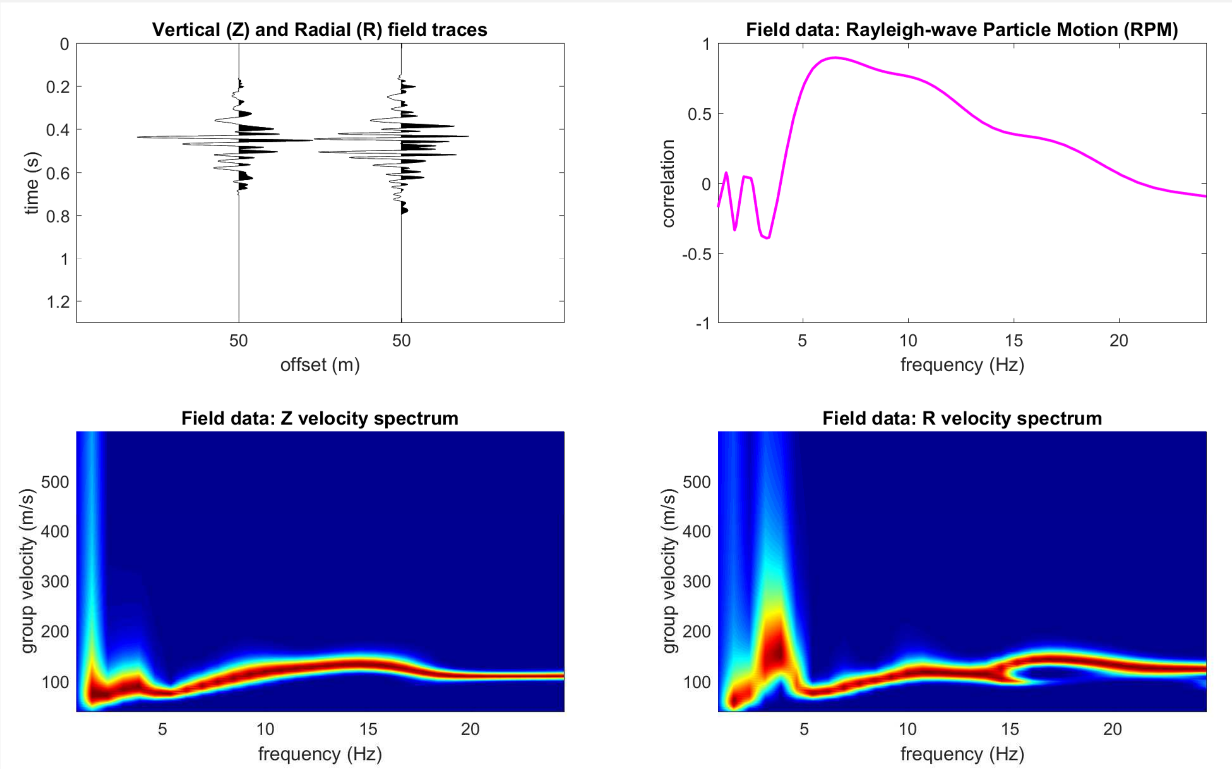

Minimum-distance model (vertical component)
Mean model (vertical component)
observed (background)
synthetic (overlaying)
velocity (m/s)
frequency (Hz)
Minimum-distance model (radial component)
Mean model (radial component)
Minimum-distance model (HVSR)
Mean model (HVSR)
observed
synthetic
HVSR
frequency (Hz)

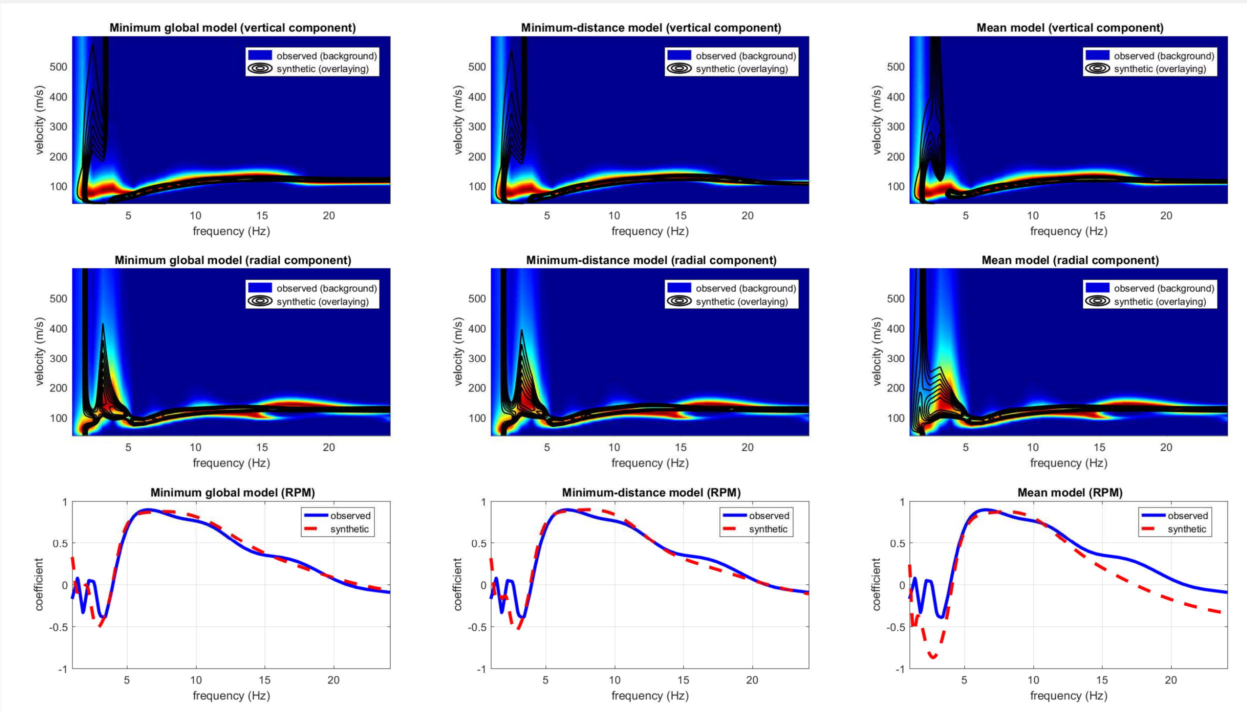

final models
Median
Minimum-distance model
Minimum global GA model
Mean model
Pareto models
Vs30 (m/s)
models
number of occurrence
Most frequent value: 446 m/s
Vs30 (m/s)

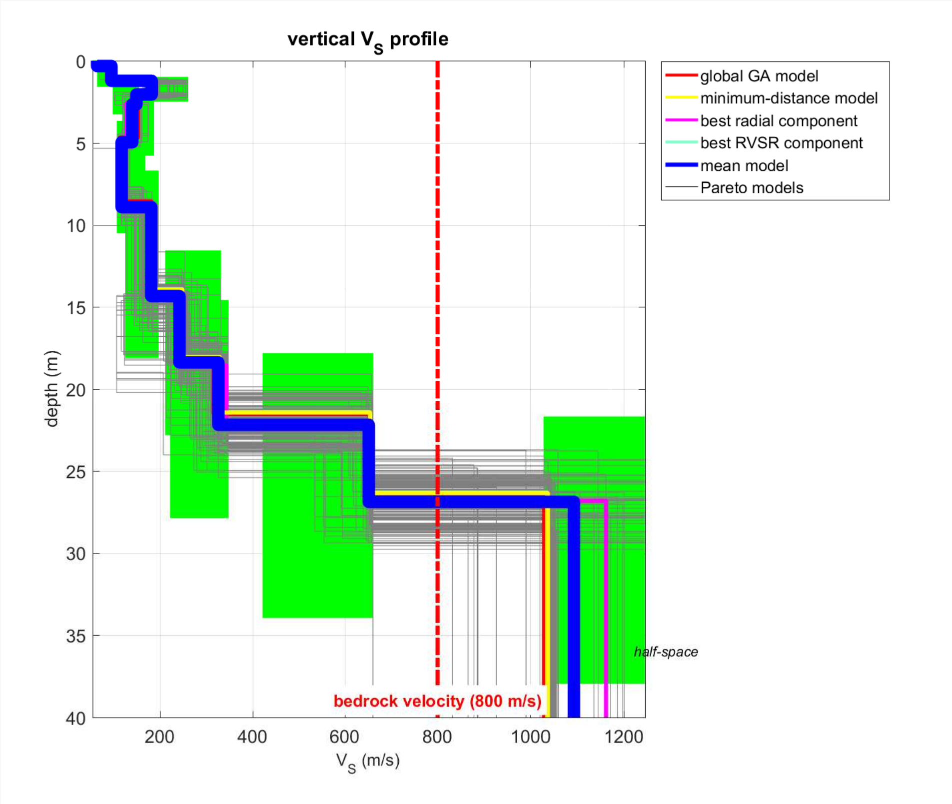

minimum-distance model
mean model
depth (m)
half-space
V_S (m/s)

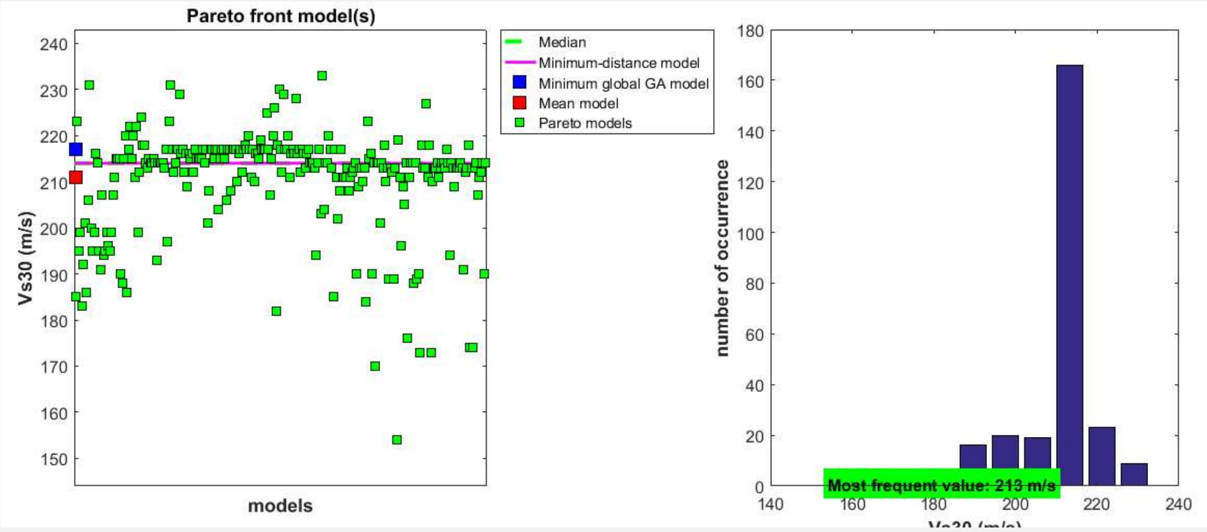
Example#2 – small basin surrounded by calcarenite hills

HS: Z+R+RPM (purely active seismic)

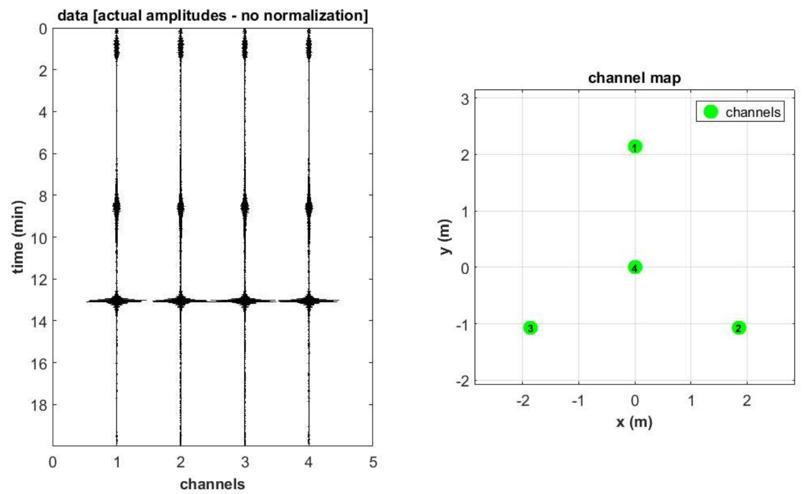


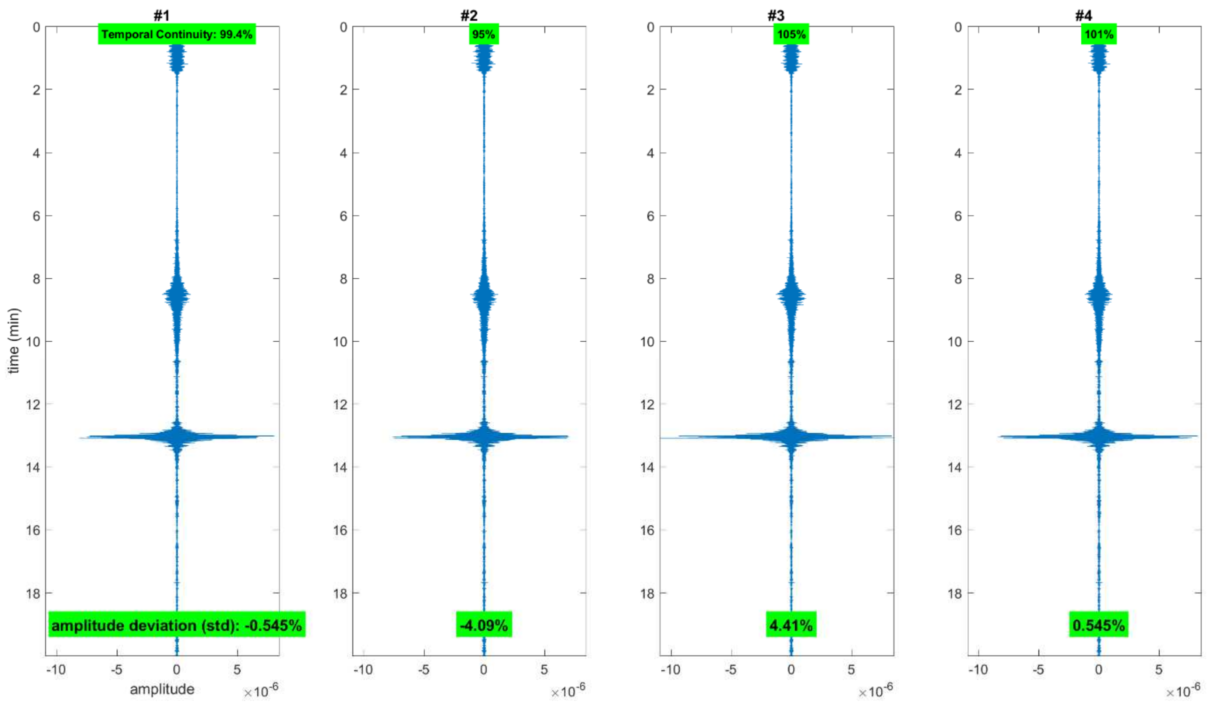


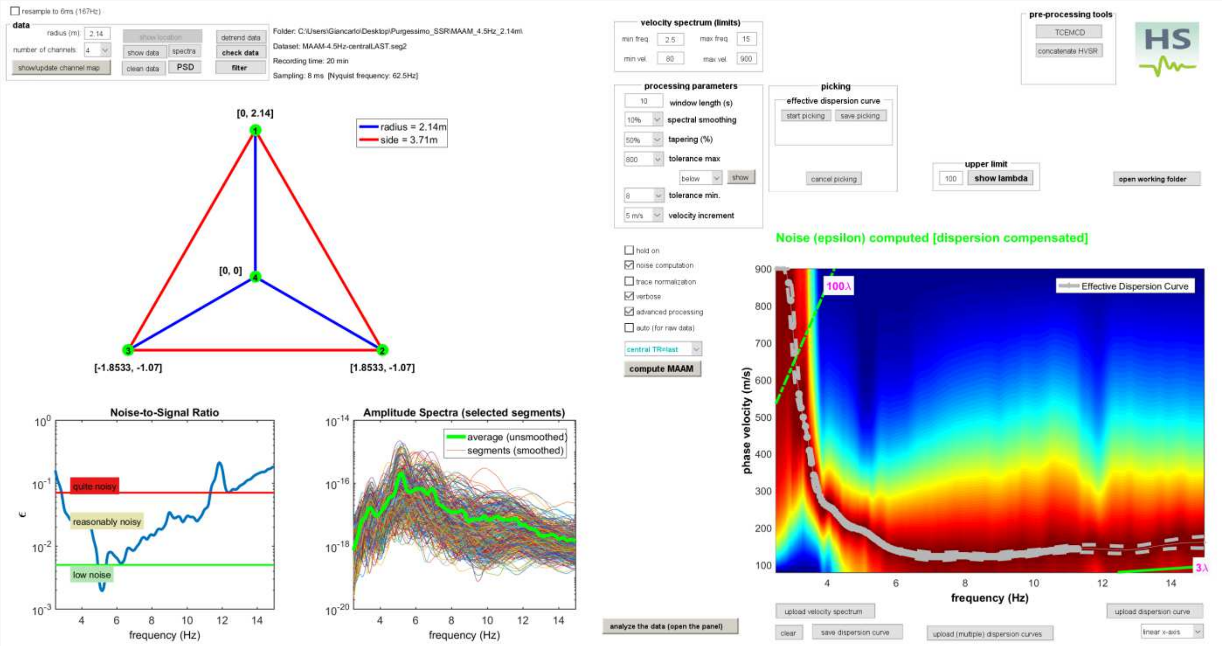

vertical V_S profile
global GA model
minimum-distance model
best radial component
best RVSR component
mean model
Pareto models
depth (m)
half-space
bedrock velocity (800 m/s)
V_S (m/s)

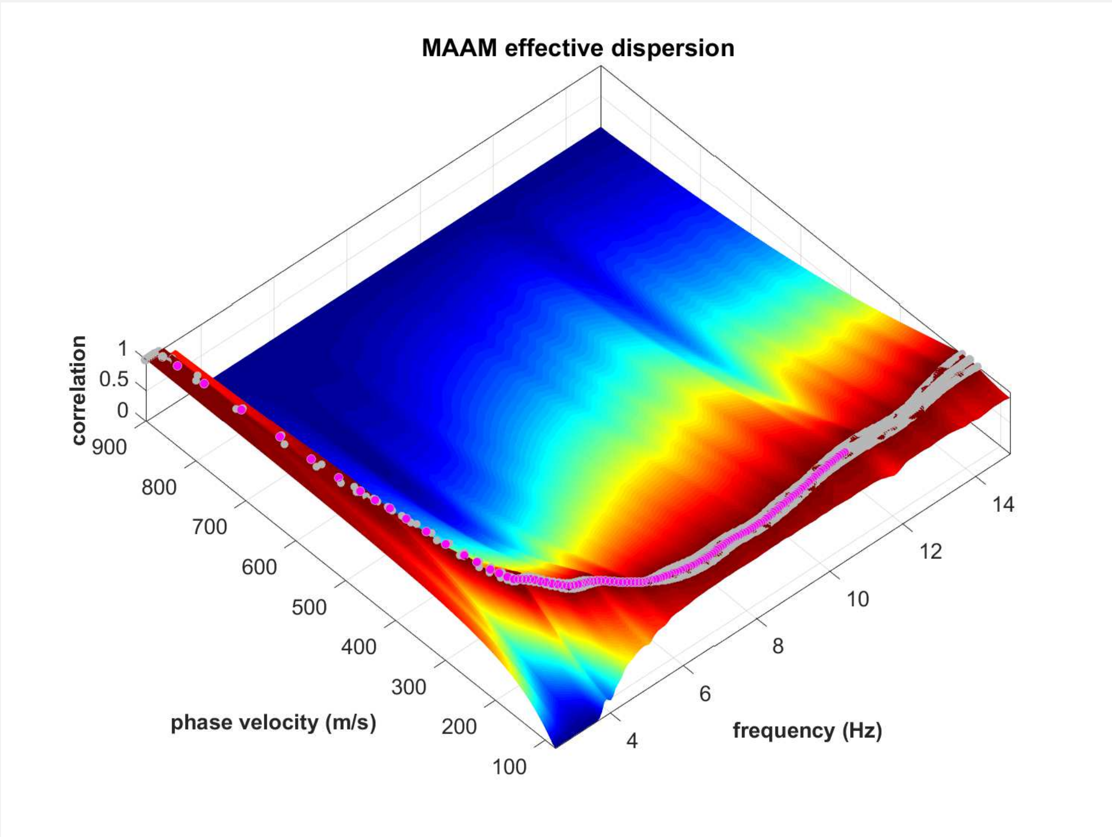

Pareto front model(s)
Median
Minimum-distance model
Minimum global GA model
Mean model
Pareto models
Vs30 (m/s)
models
number of occurrence
Most frequent value: 213 m/s

MAAM


data [actual amplitudes - no normalization]
time (min)
channels
channel map
channels
y (m)
x (m)

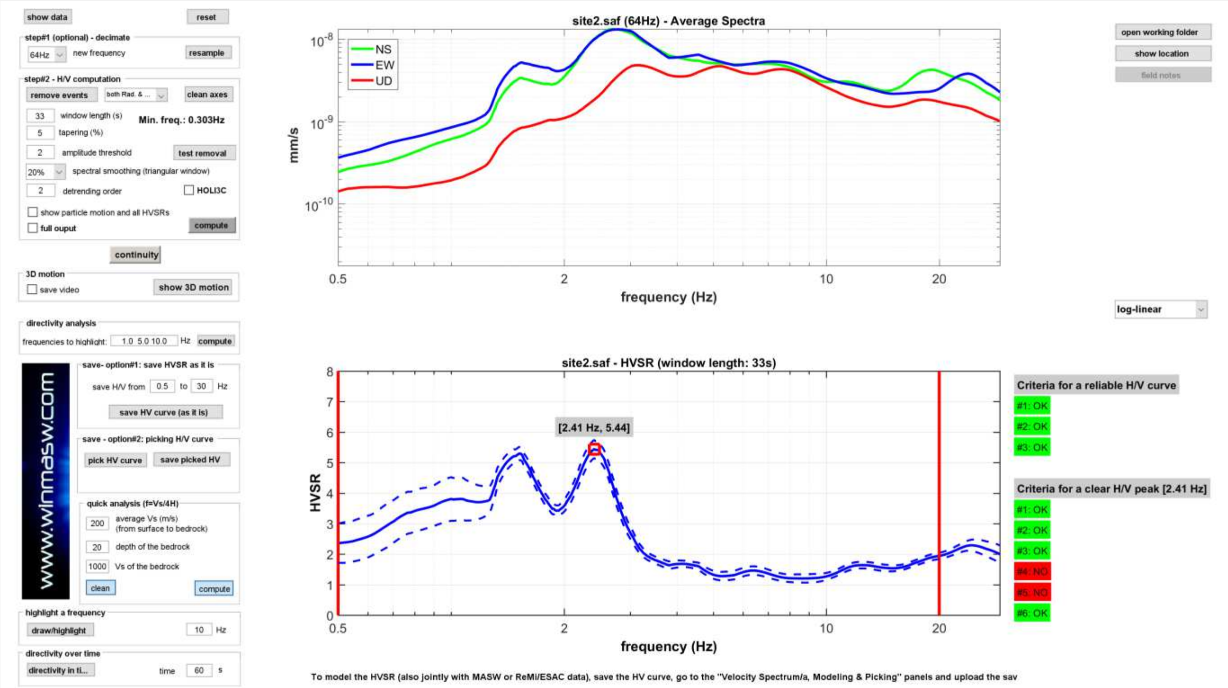

#1
Temporal Continuity: 99.4%
amplitude deviation (std): -0.545%
#2
95%
-4.09%
#3
105%
4.41%
#4
101%
0.545%
time (min)
amplitude
×10^-6



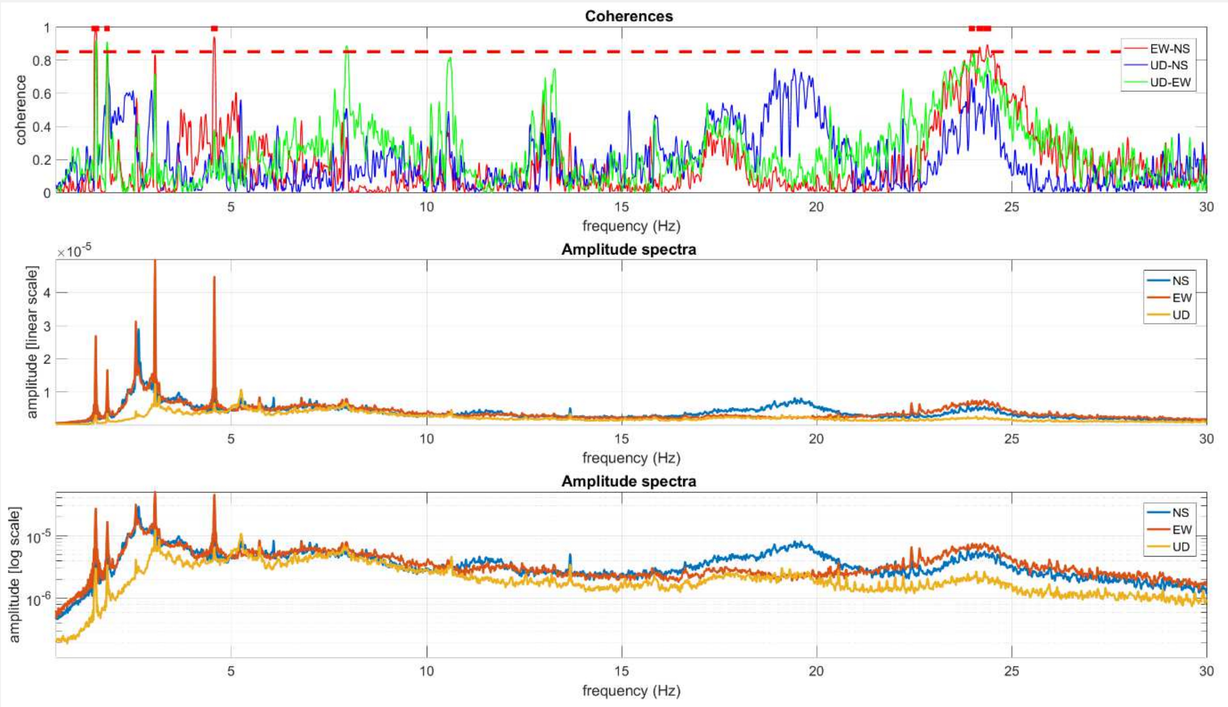


The peak of the dispersion curve below 4 Hz is due to the presence of the bedrock clearly highlighted also by the HS analysis (Z+R+RPM).

HVSR

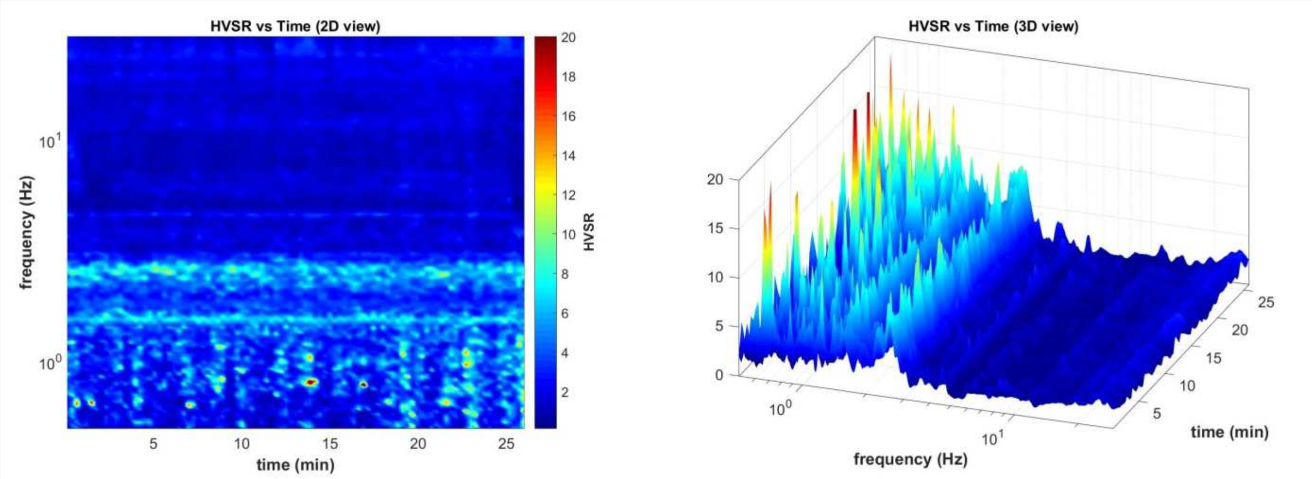


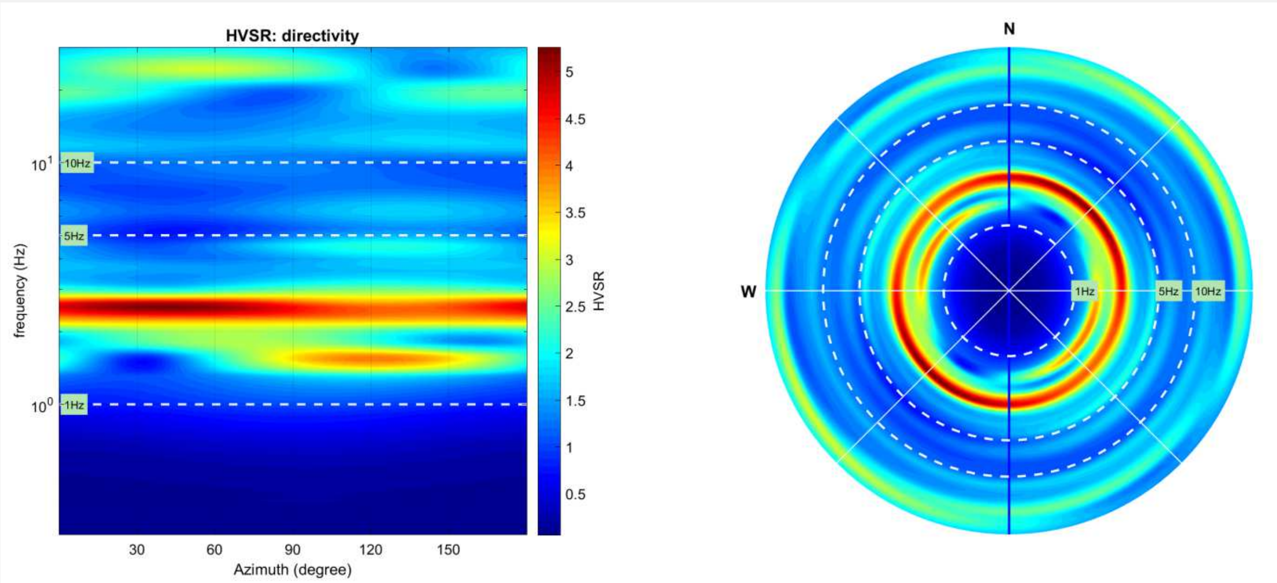
The two "peaks" of the HVSR curve are actually artifacts due to industrial signals that appear very clearly from the analysis of the amplitude spectra and coherence functions shown below:



This means that, due to complex industrial signal interaction phenomena, the HVSR curve in no way represents site amplification (this site and these data are illustrated during our seminars).

How to define the actual site amplification? See the section below about SSR (*Standard Spectral Ratio*).


HVSR vs Time (2D view)
frequency (Hz)
time (min)
HVSR
HVSR vs Time (3D view)
frequency (Hz)
time (min)

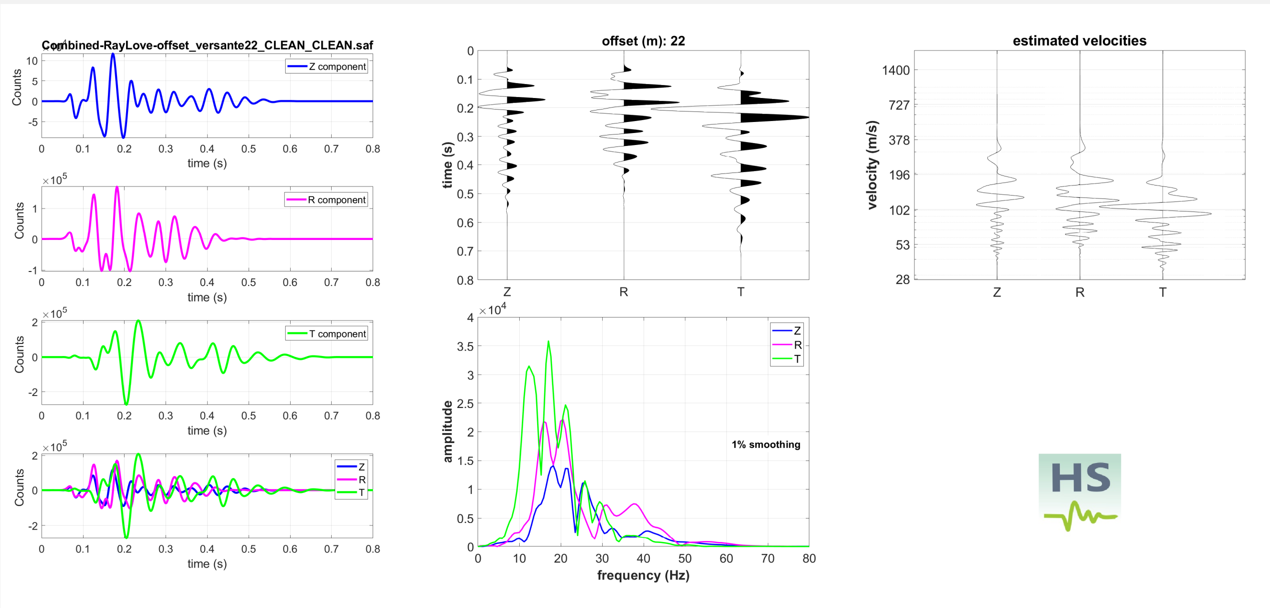

HVSR: directivity
frequency (Hz)
Azimuth (degree)
HVSR
10Hz
5Hz
1Hz
N
W

Example#3 – an hard-to-reach site [a very steep hill]

Working in complicated conditions (along the slope of a hilly area).

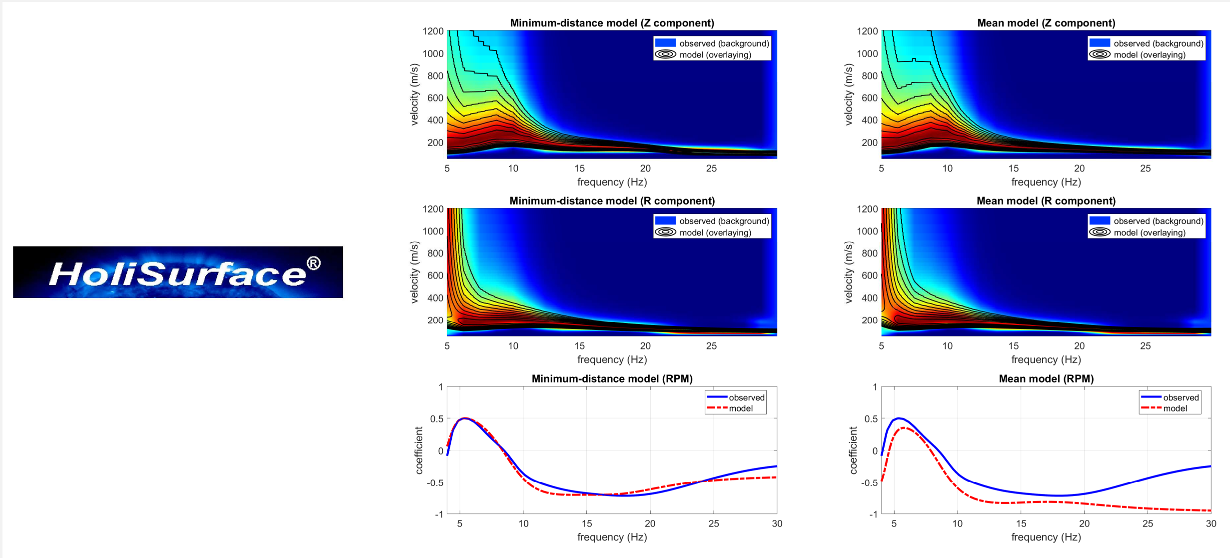
Seismic investigation based on the dispersion analysis (group velocities) according to the FVS (*Full Velocity Spectrum*) approach, also jointly with the HVSR [*HoliSurface* - HS].

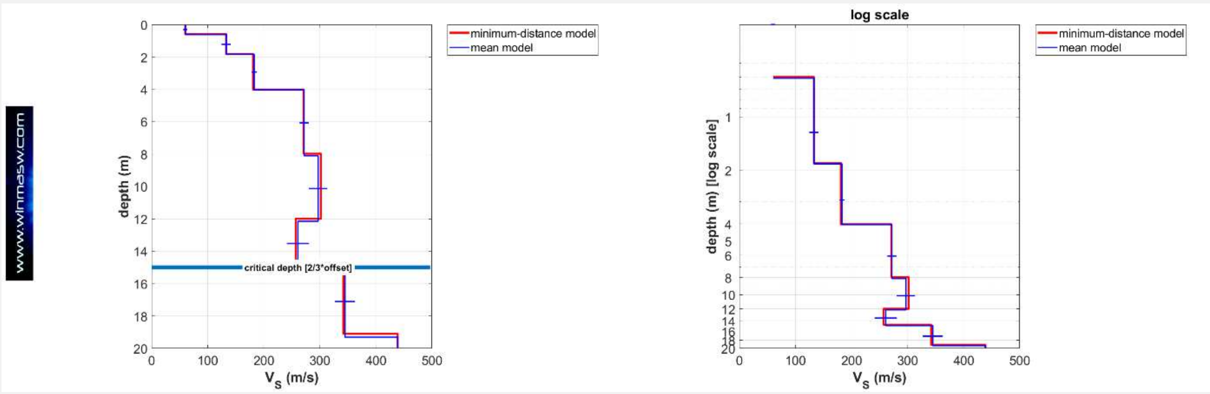
Main HS acquisition parameters: offset: 22 m; stack: 6



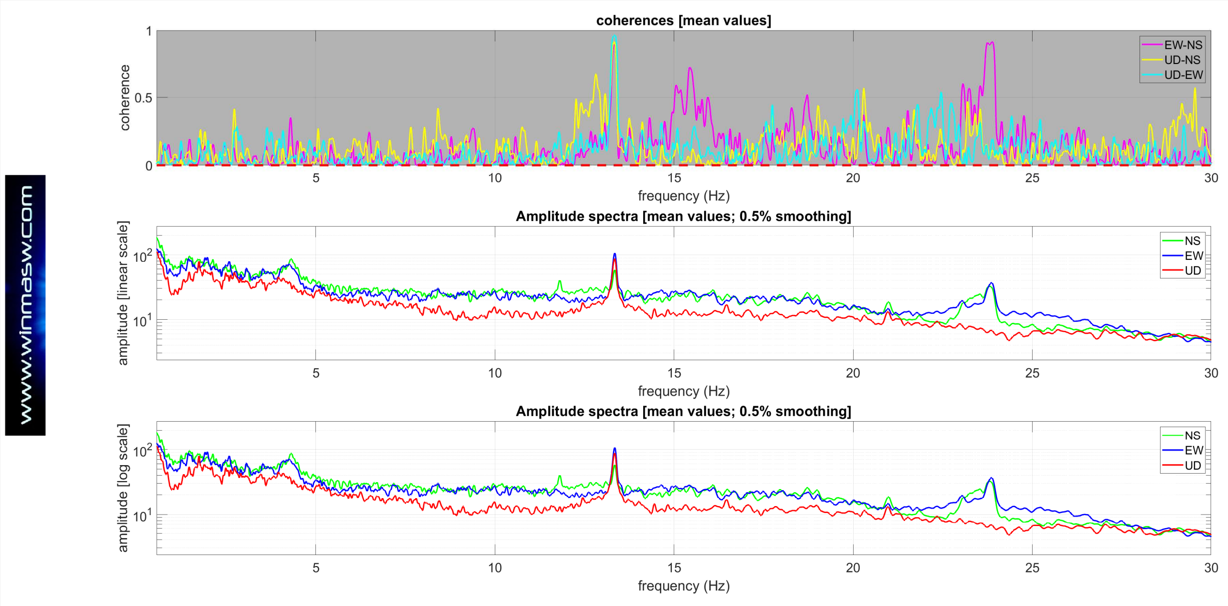
Recorded HS data with the amplitude spectra computed automatically while uploading the data (seg2 or SAF file).

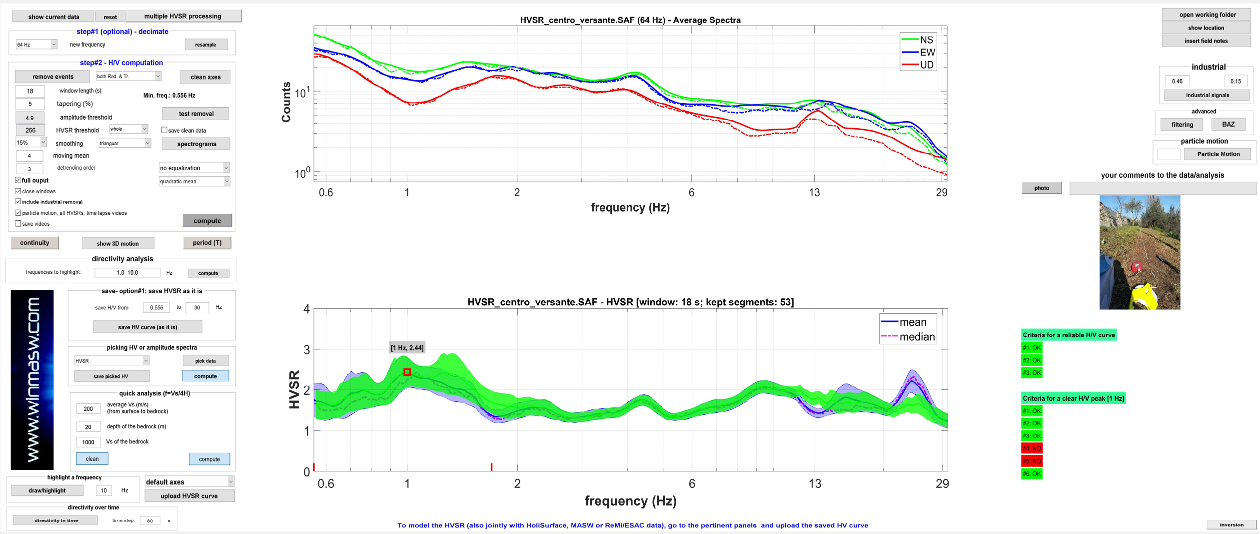
In the following **the joint modelling of the Z and R group-velocity spectra together with the RPM curve (for the detailed investigation of the shallowest layers).**





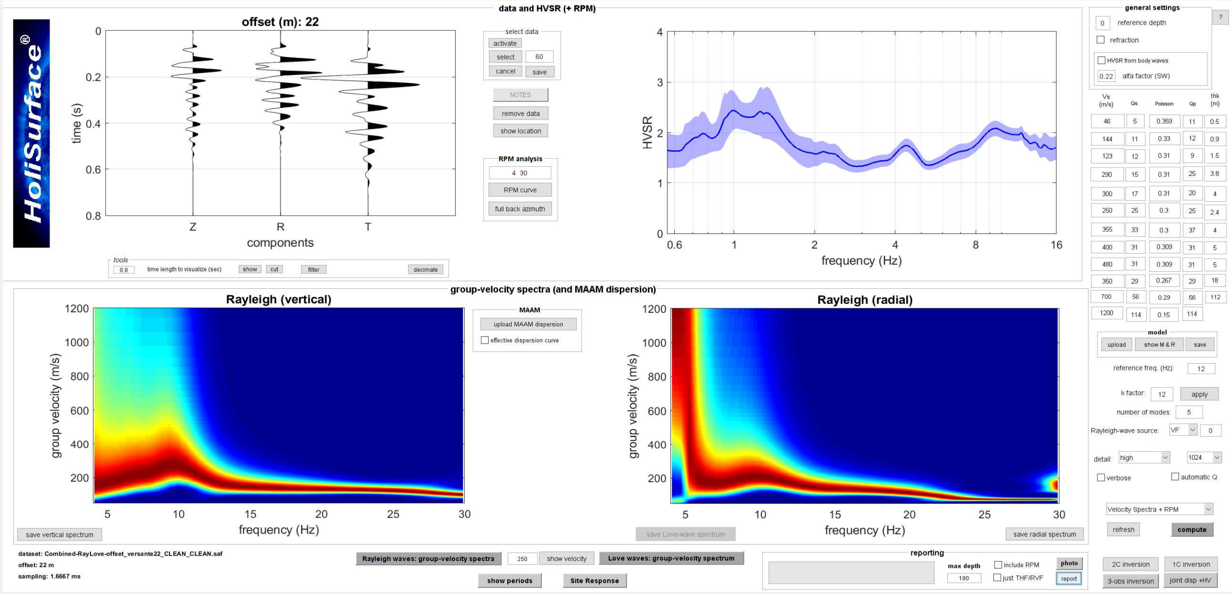
HVSR data

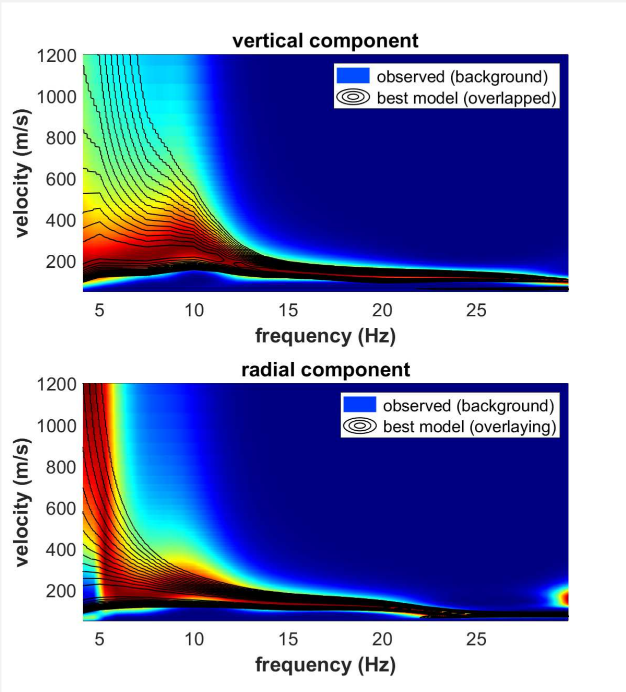


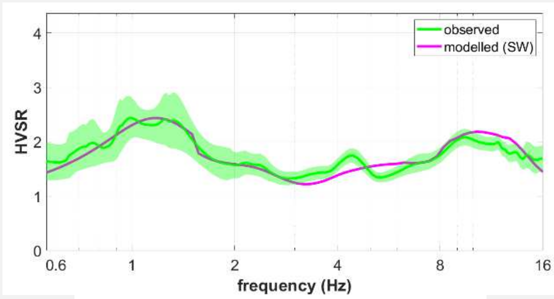


HVSR data: a couple of industrial components are apparent (they are automatically removed/attenuated - see the green curve in the bottom panel).

In the following the joint modelling of the Z and R group-velocity spectra together with the HVSR (for the investigation of the deep layers).

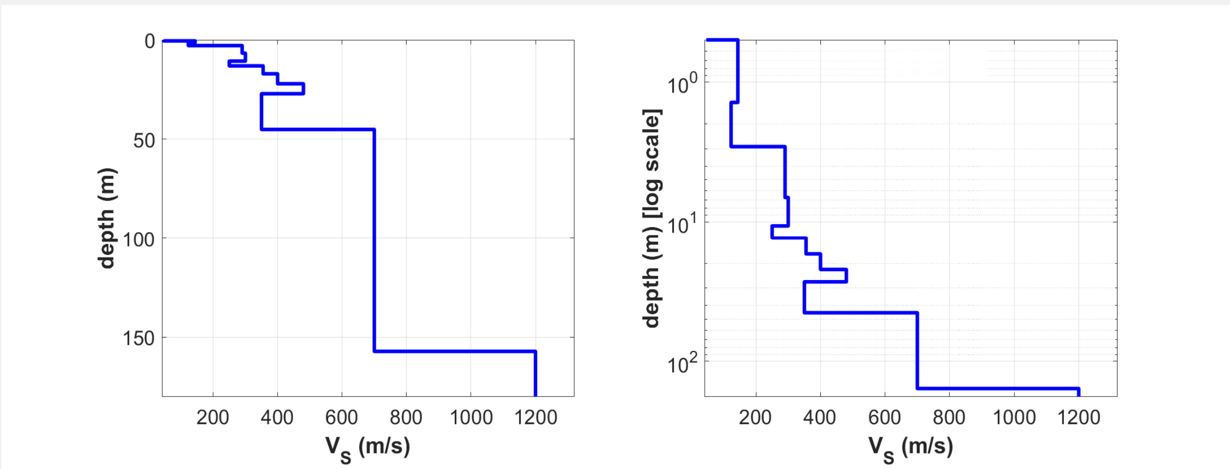






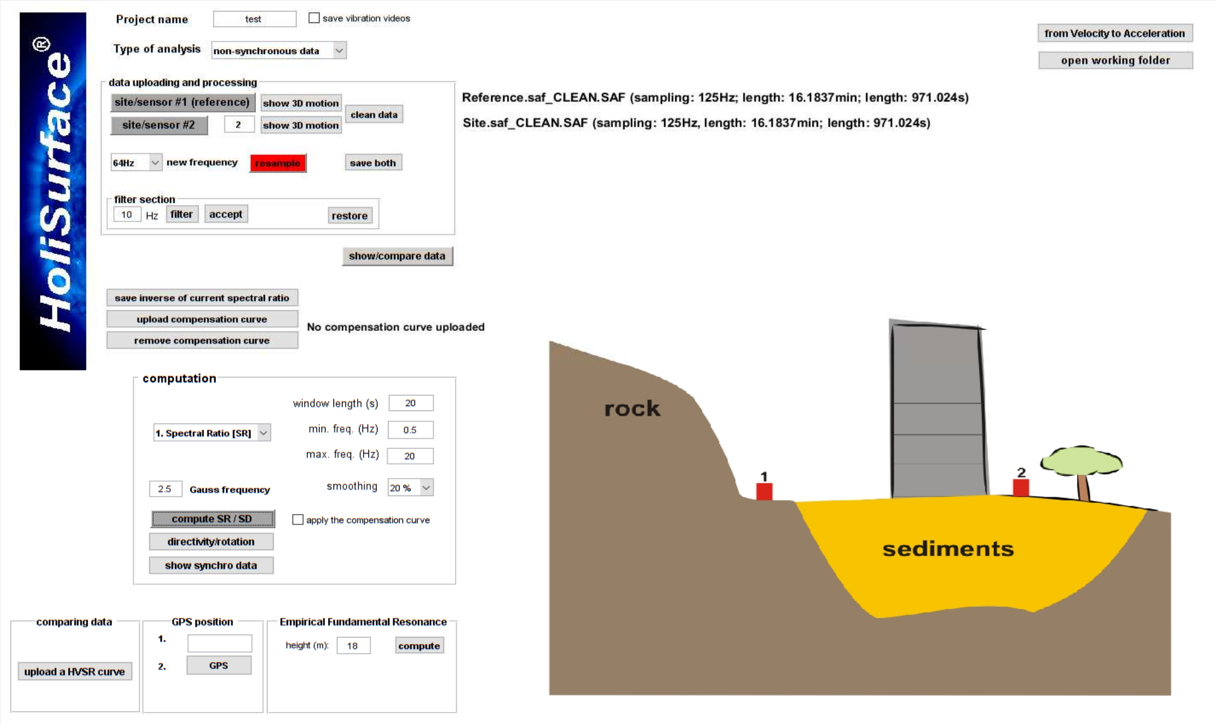
Vs model (Vs30 & VsE @ surface: 278 278 m/s)

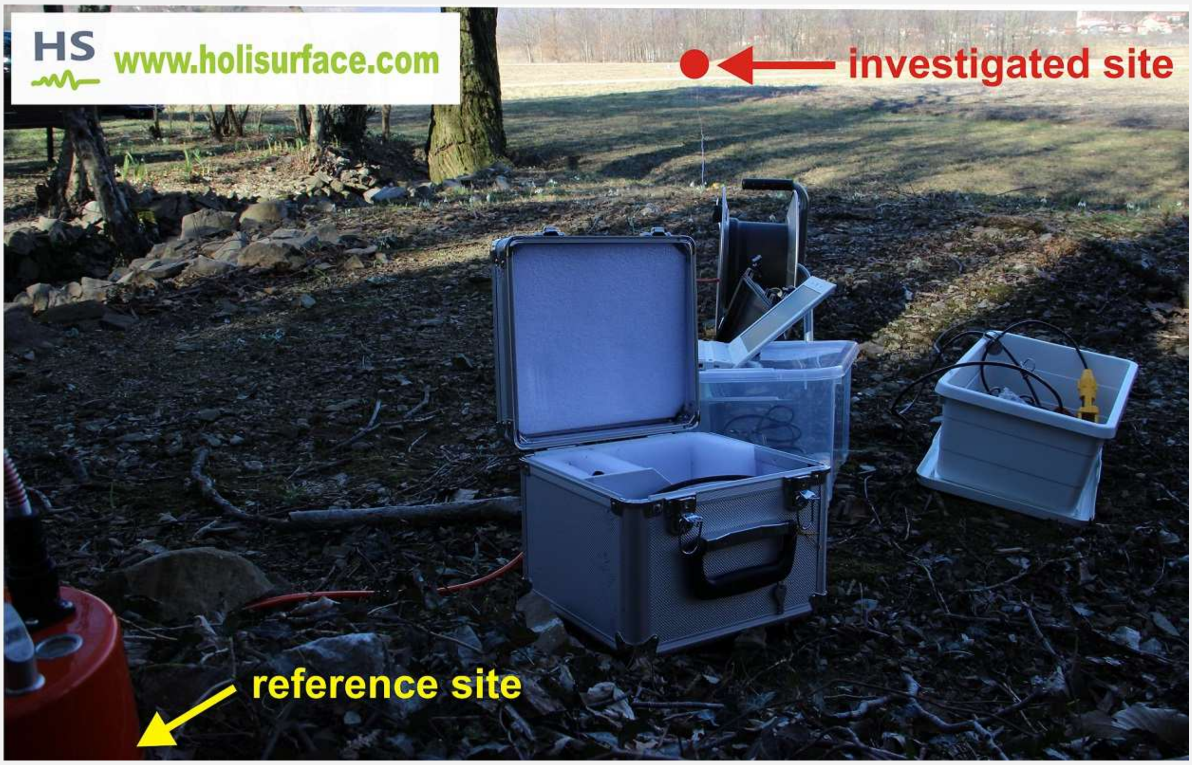
layer	Vs (m/s)	thickness (m)	depth (m)
1	46	0.5000	0.5000
2	144	0.9000	1.4000
3	123	1.5000	2.9000
4	290	3.8000	6.7000
5	300	4	10.7000
6	250	2.4000	13.1000
7	355	4	17.1000
8	400	5	22.1000
9	480	5	27.1000
10	350	18	45.1000
11	700	112	157.10...
12	1200	0	0



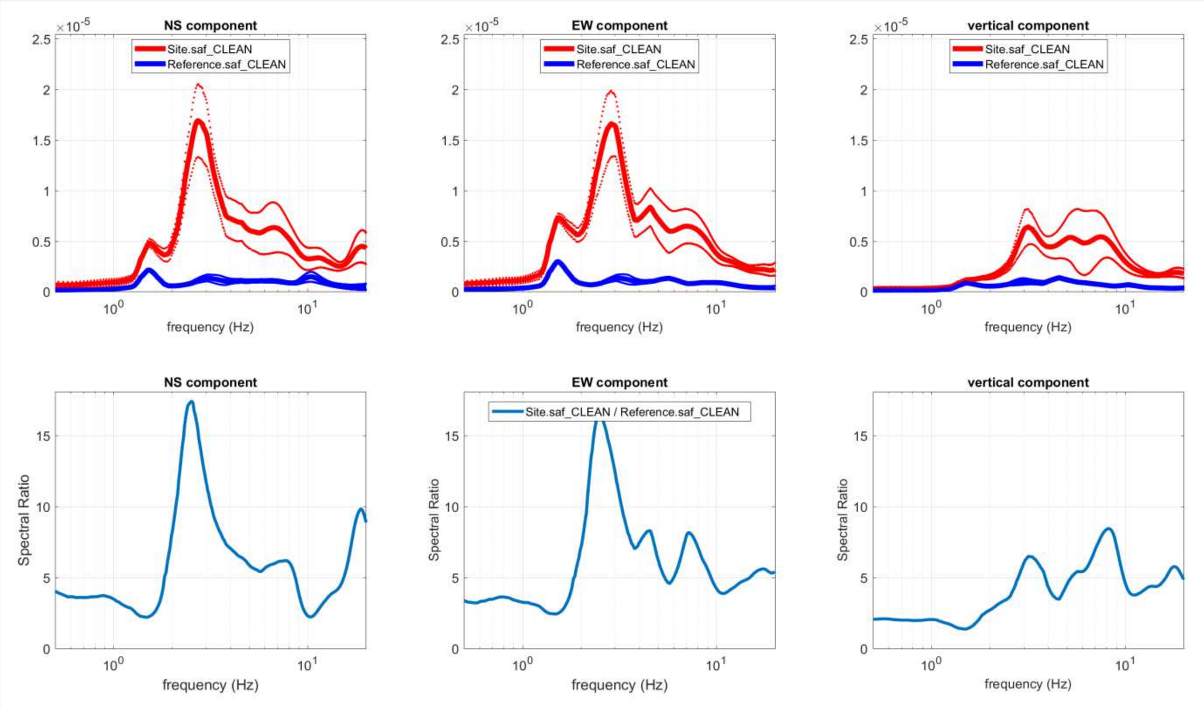
Example#4 – SSRn [first example]

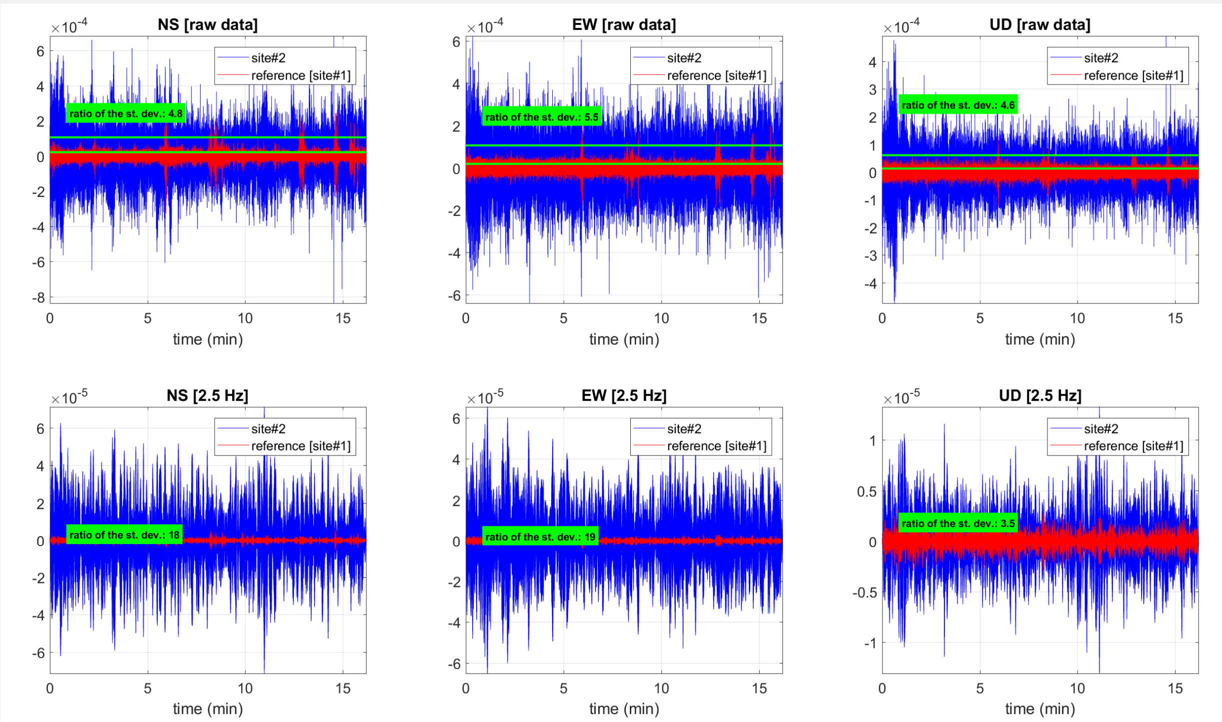
A 3-channel geophone is placed at the center of a small basin whose amplification is to be evaluated (empirically) and the other on the rocky outcrop along the edge of the basin. Since in this case we are evaluating the microtremors, the technique could be actually named SSRn (*n* stands for noise – see Perron et al. 2018).





SSR analysis (the comparison of the data amplitudes at the two considered sites) are carried out in both frequency and time domain:





Clearly, the main amplication occurs at about 2.3 Hz (what happens along the vertical axis is usually not very important).

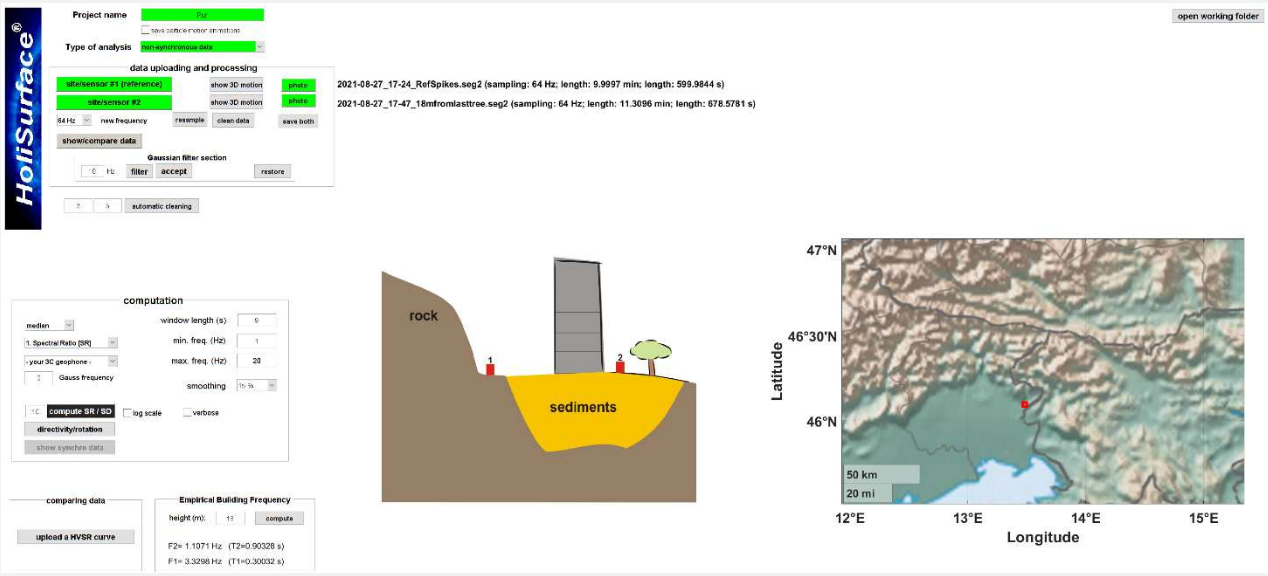
Pay attention: we considerd the microtremors and, therefore (because of non-linearity issues), the amplitude of the spectral ratio (which, along the horizontal axes, in this case is equal to about 16) cannot be directly related to actual amplification in the event of a quake (larger amplitude events).

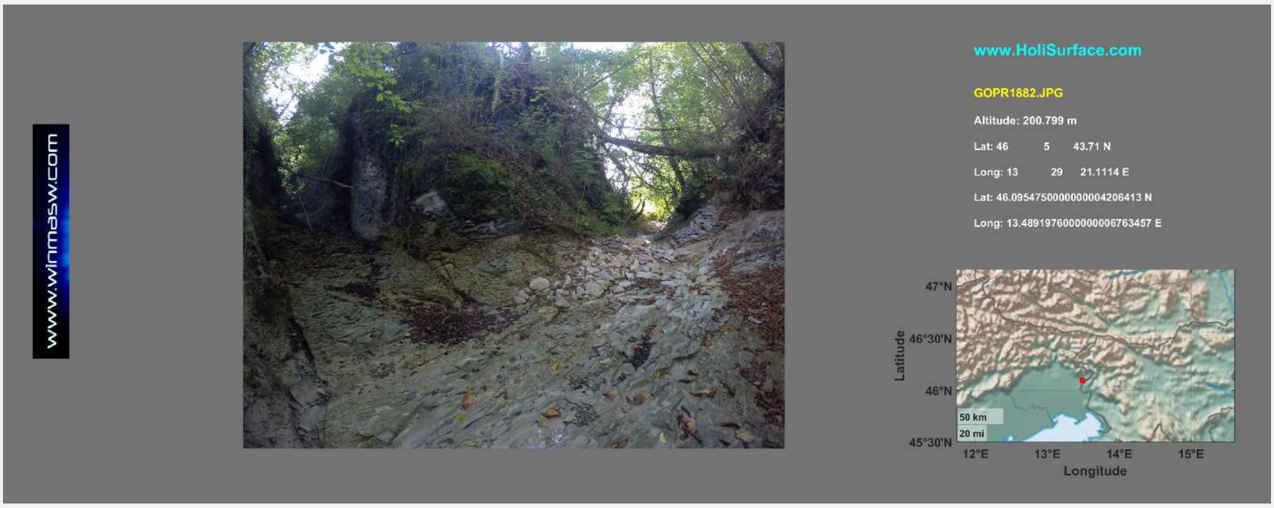
Because of the non-linearity of the site response, the value of amplification in the event of an earthquake is likely to be much lower (see Perron et al. 2018).

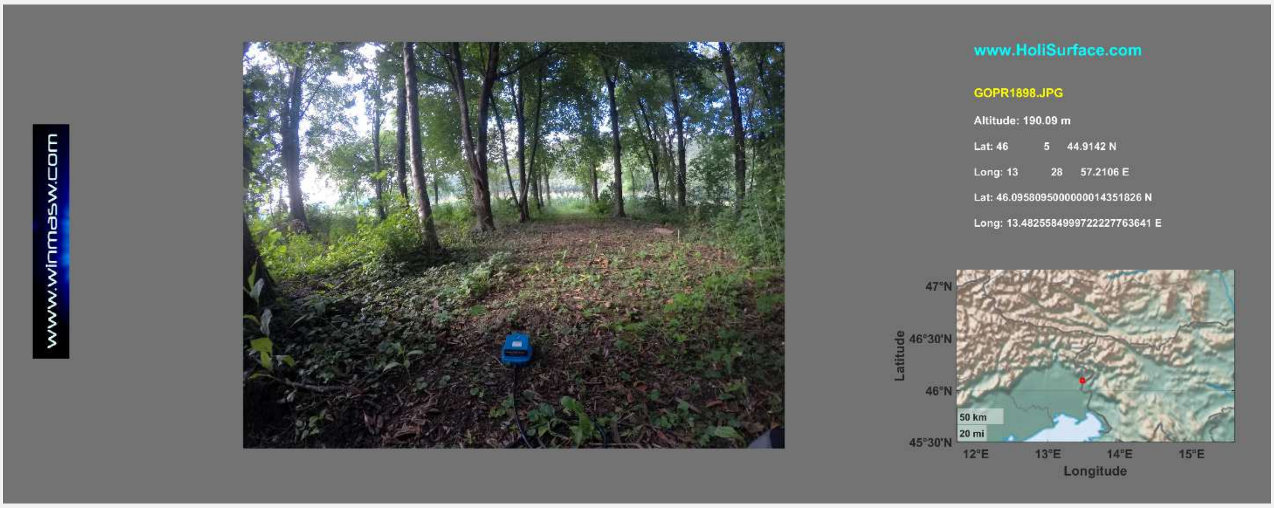
Further examples in the 2020 Springer book.

Example#5 – SSRn [a further example]

The first three figures show the SSR panel and the location of the two sites once the two seismic files (seg2, segy2 or SAF formats) and the two geo-referenced photos taken by the smartphone (see relevant section of this manual) are uploaded. In this case, the data (about ten minutes each) are nonsynchronous: first we recorded the site#1 and *immediately* after the site#2.

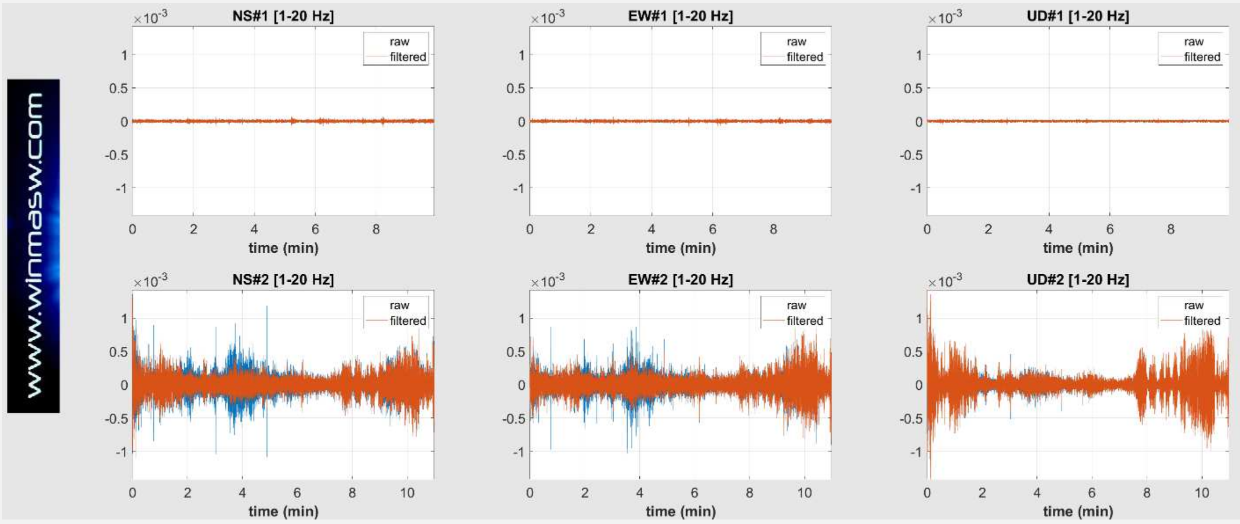


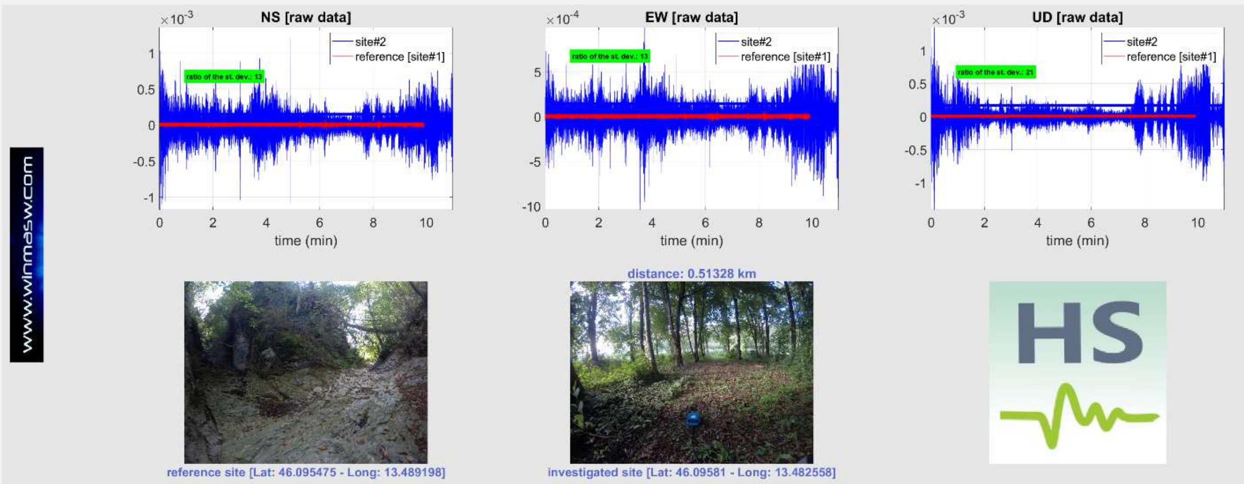


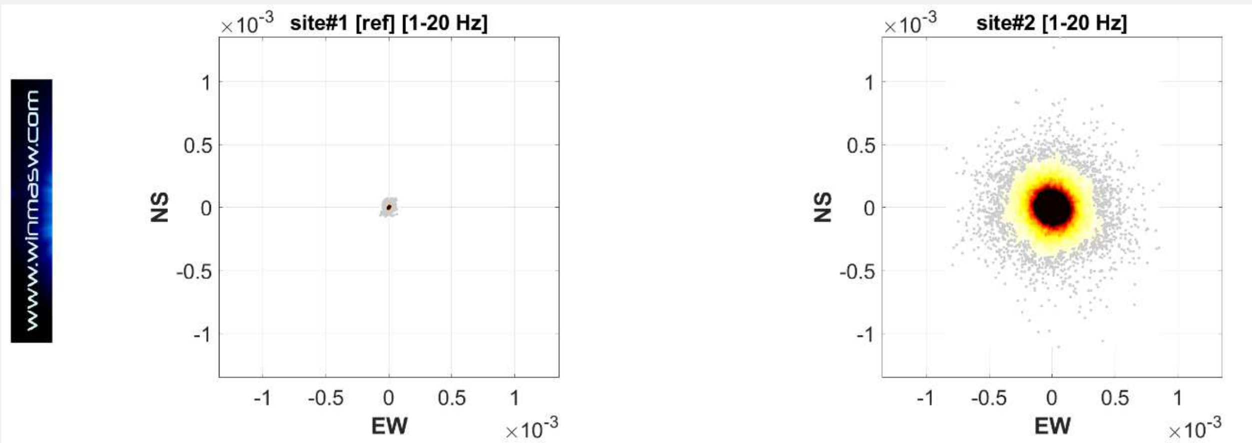


site#2: we intend to verify the microtremor amplification with respect to the reference rocky site (site#1 shown above).

After cleaning the data [so as to obtain time series that represent just the background microtremors without any (local) transient events] and clicked the "compute SR/SD" button (having opted for the SR - i.e. *Spectral Ratio* - option), we obtain a series of figures.
The three images shown in the following represent the **comparison of the data in the time domain** (graphs can be easily understood by considering the quantities indicated in the title and along the axes of each plot – please, take some time to carefully study them). Since we decided to focus in the 1-20 Hz frequency range, shown traces are filtered with a similar band-pass filter.

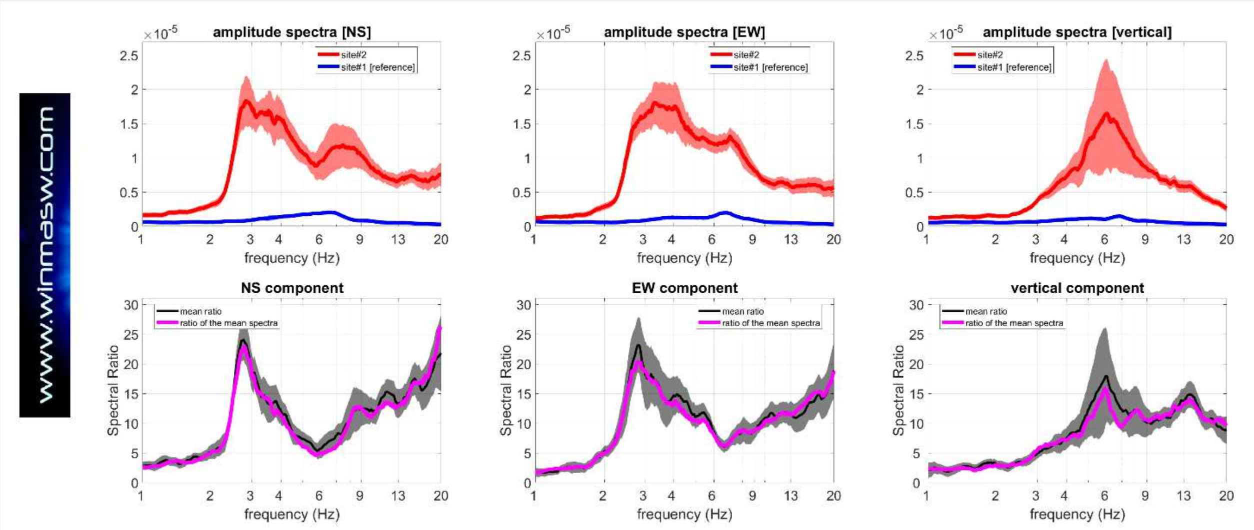




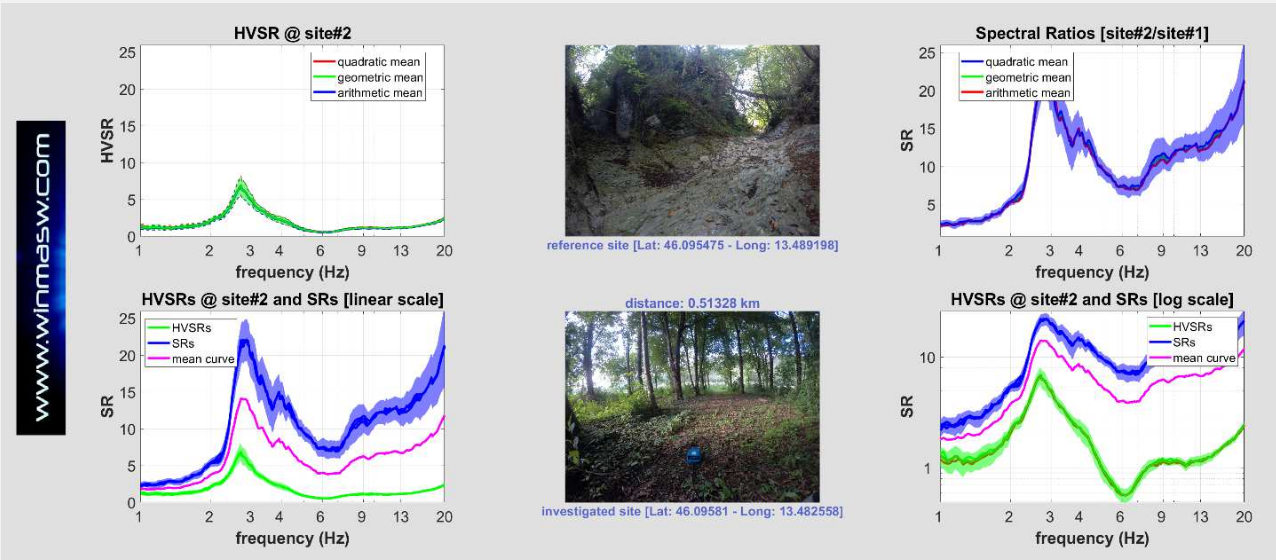


The previous figures show that, in the 1-20 Hz frequency range, the particle motion at site#2 has a far greater amplitude than the one at the site#1 (rocky reference site).

The two following figures represent the **comparison of data in the frequency domain** (in such domain things are tyipically clearer). The amplitude spectra of the three components (for both the sites) are compared and in the last image (the summary of the whole thing), the comparison between the spectral ratio of the H (horizontal) component and the HVSR of site#2 (where we want to assess the microtremor amplification) is shown.



Please, pay attention to the scales and components shown.



The magenta curve is the average/mean curve computed considering the HVSR and the Spectral Ratio (SR). The comparison is made by considering both a linear (bottom left) and logarithmic (bottom right) vertical scale.
The distance between the two points in automatically computed form the GPS coordinates of the uploaded geo-referenced photos.

In order to fully understand all the related issues, it is recommended to study the article by Perron et al. (2018) and our Springer 2020 book ("*Efficient Joint Analysis of Surface Waves and Introduction to Vibration Analysis: Beyond the Clichés*").

Example#6 –V_S profile in case of relatively-shallow *bedrock*

In this case (when we know that the *bedrock* is pretty shallow), we can identify the V_S profile even using just active data.

Always remember to take a geo-referenced photo with your smartphone (see the pertinent section of this manual): your report will be enriched with this type of image.

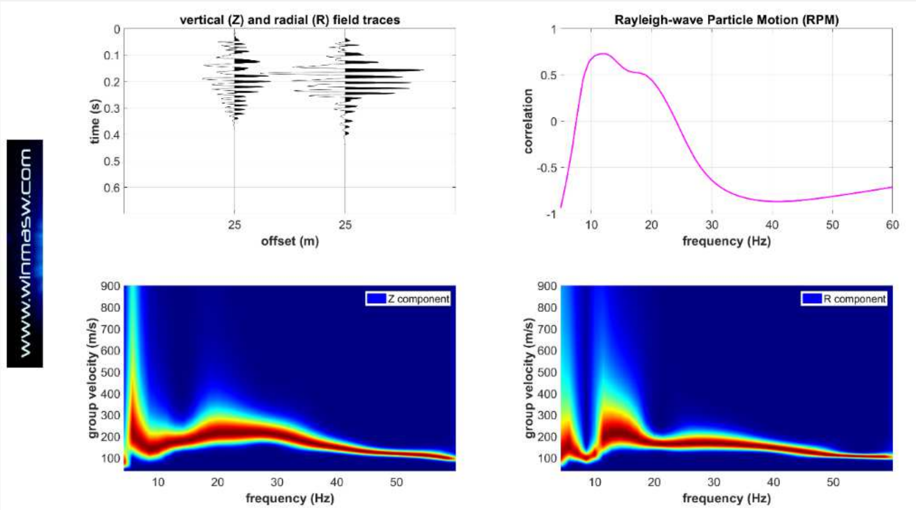
In the following we consider the active data for Rayleigh waves only, analysing the group velocity spectra of the Z and R components together with the RPM curve.

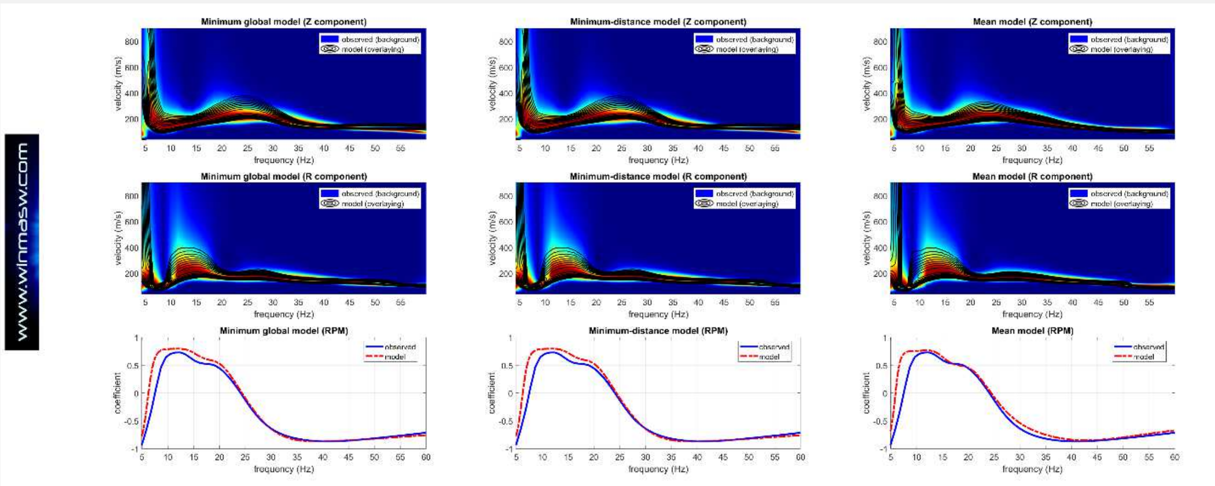
offset: 25 m

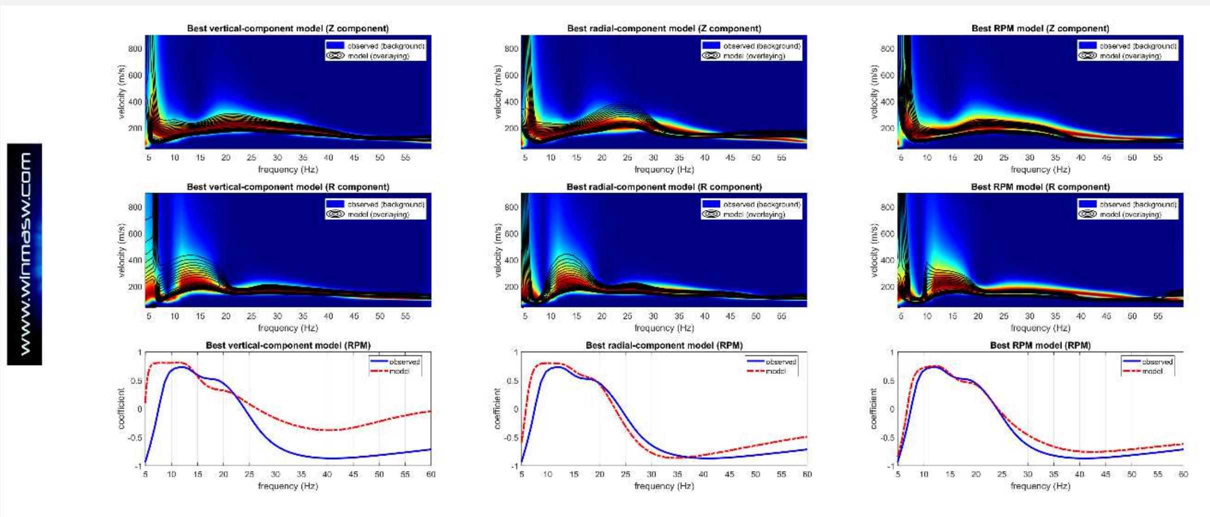
Considering the small offset, it is possible to use small sources: a 2-kg carpenter hammer or even a geologist hammer could be sufficient but in this case it is better to abound with the *stack* (not less than 10).

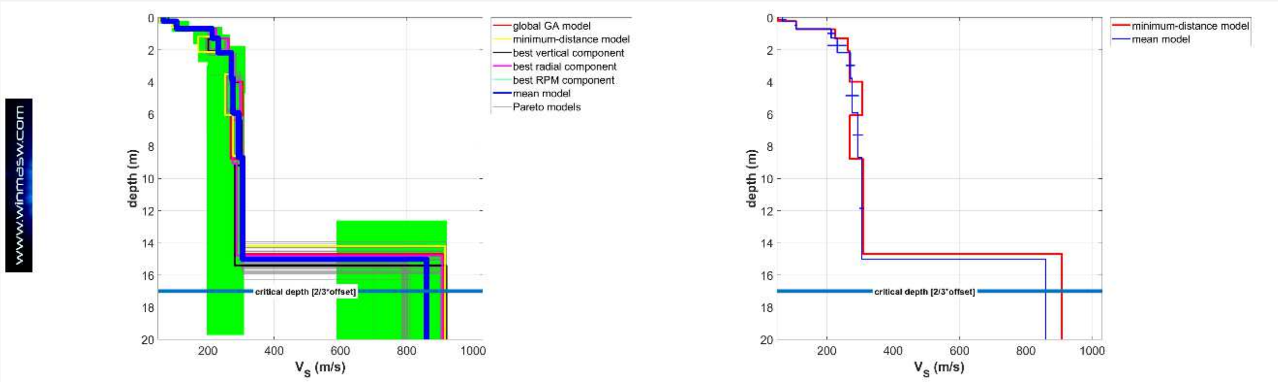
In the following the result of the joint (automatic) Z+R+RPM inversion considering the "full output" option that provides all the six "best" models. For technical details see the following article (open access):

On the efficient acquisition and holistic analysis of Rayleigh waves: Technical aspects and two comparative case studies (Dal Moro G., Al-Arifi N., Moustafa S.R., 2019), Soil Dynamics and Earthquake Engineering 125, 105742, https://doi.org/10.1016/j.soildyn.2019.105742

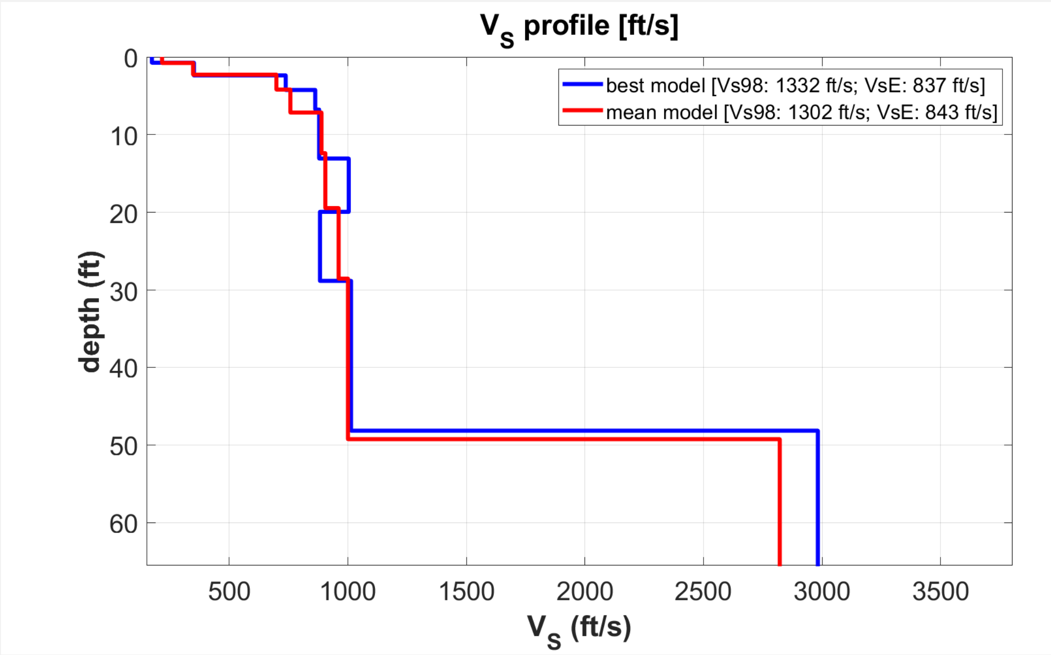








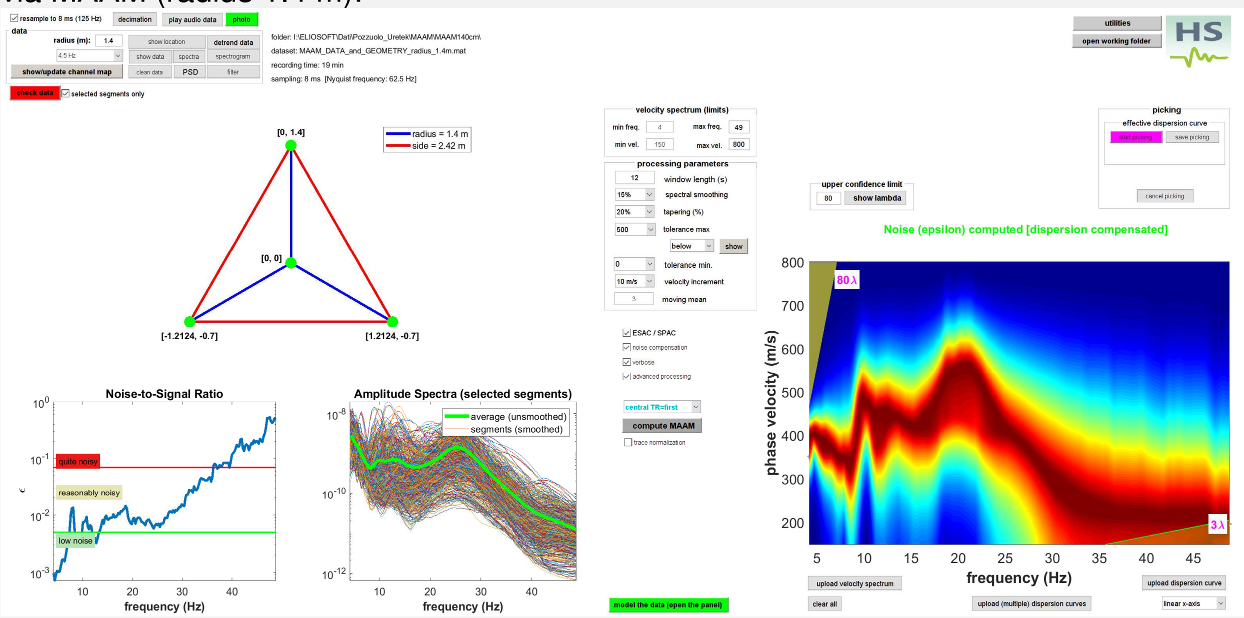
V_S profiles of the six 'best' models (International Units).



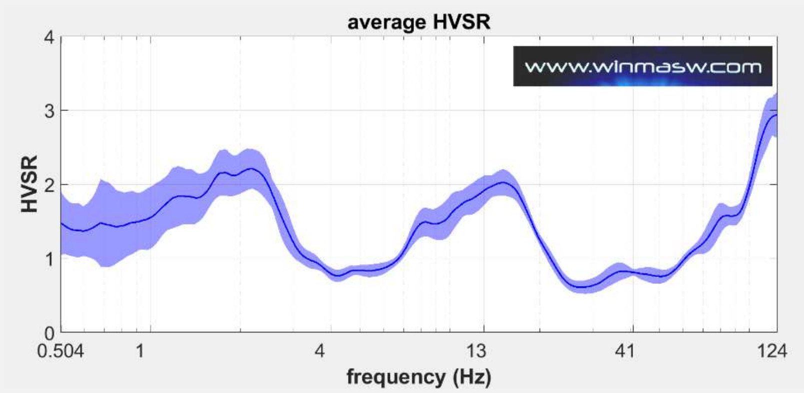
V_S profiles for the mean and "best" (minimum distance) models while considering *feet* instead of *meters*.

Esempio#7 – V_S profile for a site with very limited space available: MAAM + HVSR

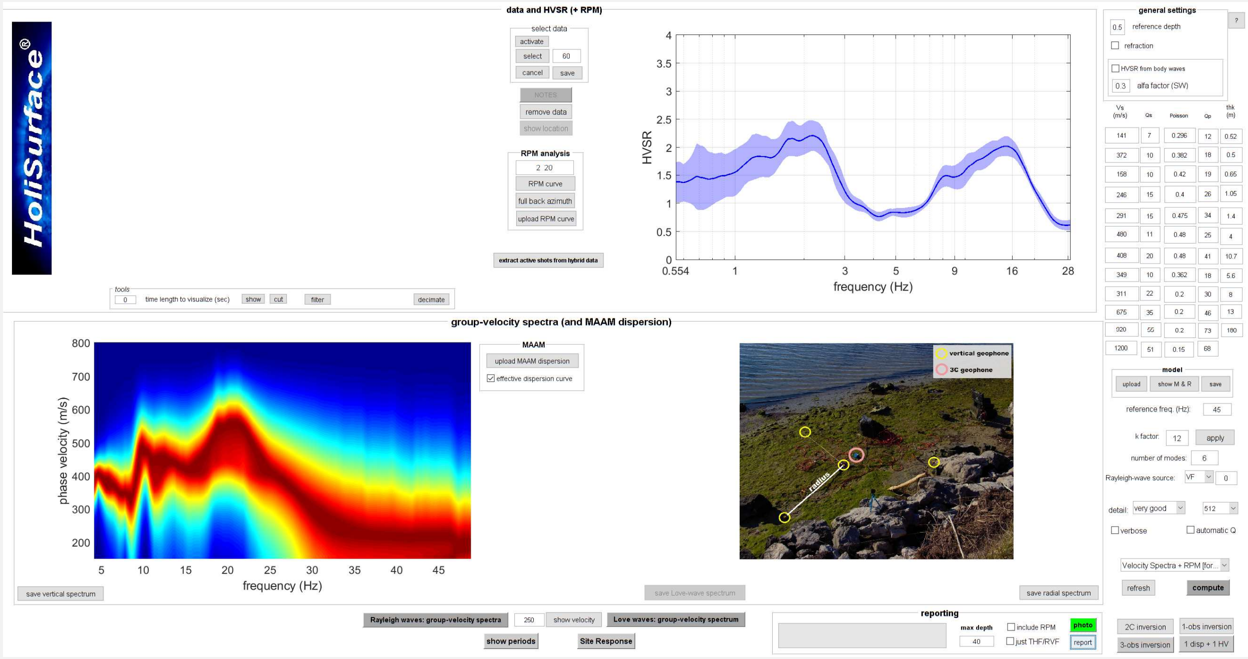
In this case, the very limited space available (see picture) required necessarily the MAAM (Miniature Array Analysis of Microtremors) + HVSR approach (which, incidentally, can be used also in case we have much more space).
The presence of strong lateral variations (highlighted by several penetrometer tests performed around the building) is responsible for a relatively "unstable" velocity spectrum (different channel permutations produce slightly different phase-velocity spectra).
Below the phase-velocity spectrum (mean velocity spectrum) of the Z component obtained via MAAM (radius 1.4 m):

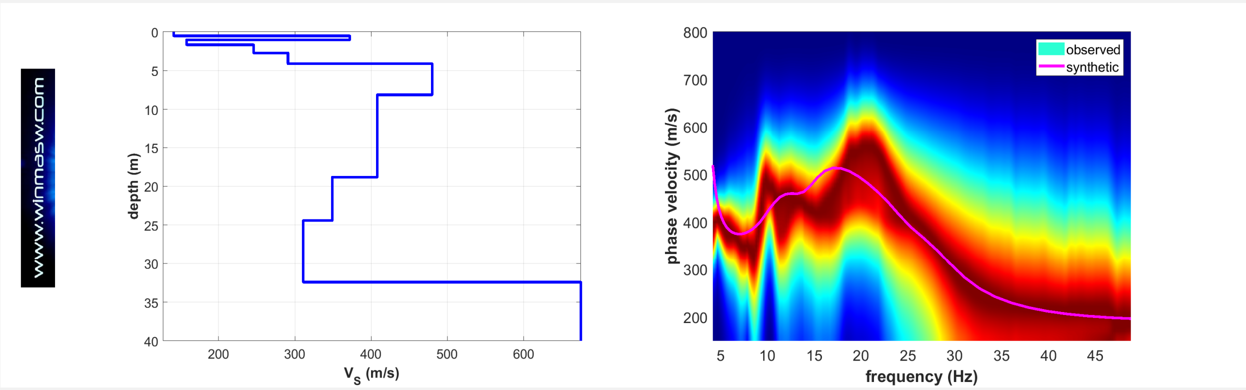


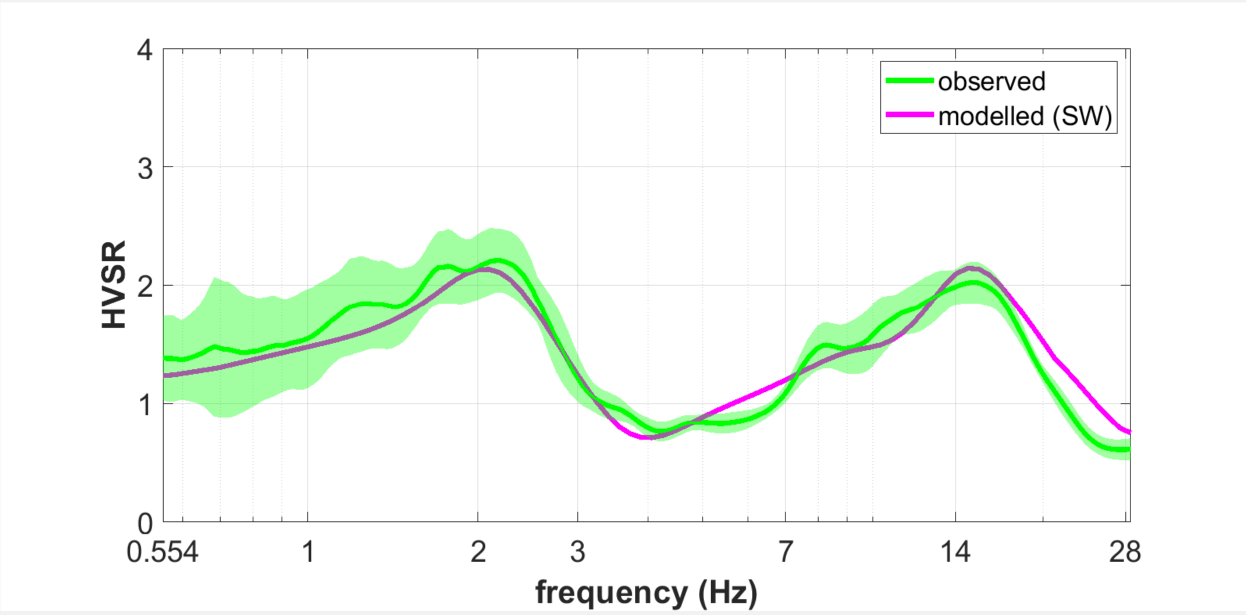
and here the HVSR curve:



Finally, the joint modeling of dispersion (from MAAM) and HVSR:



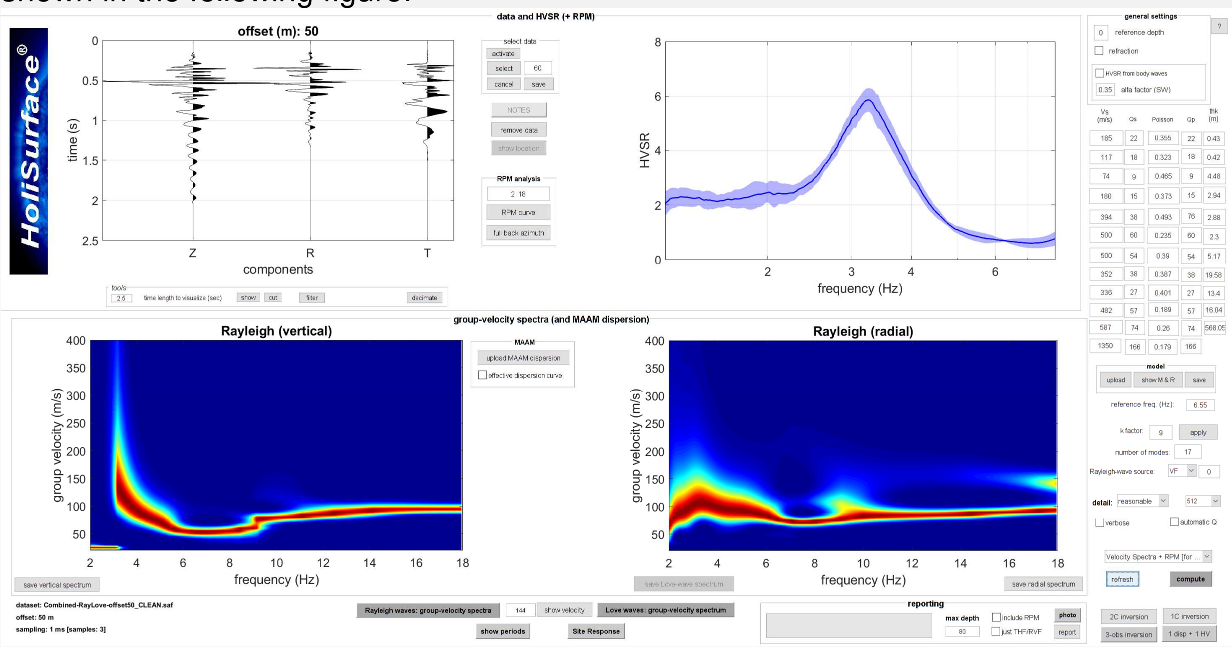




Example#8 –V_S profile in a complex area through the analysis of the Z and R components of Rayleigh waves (group velocities) and the HVSR

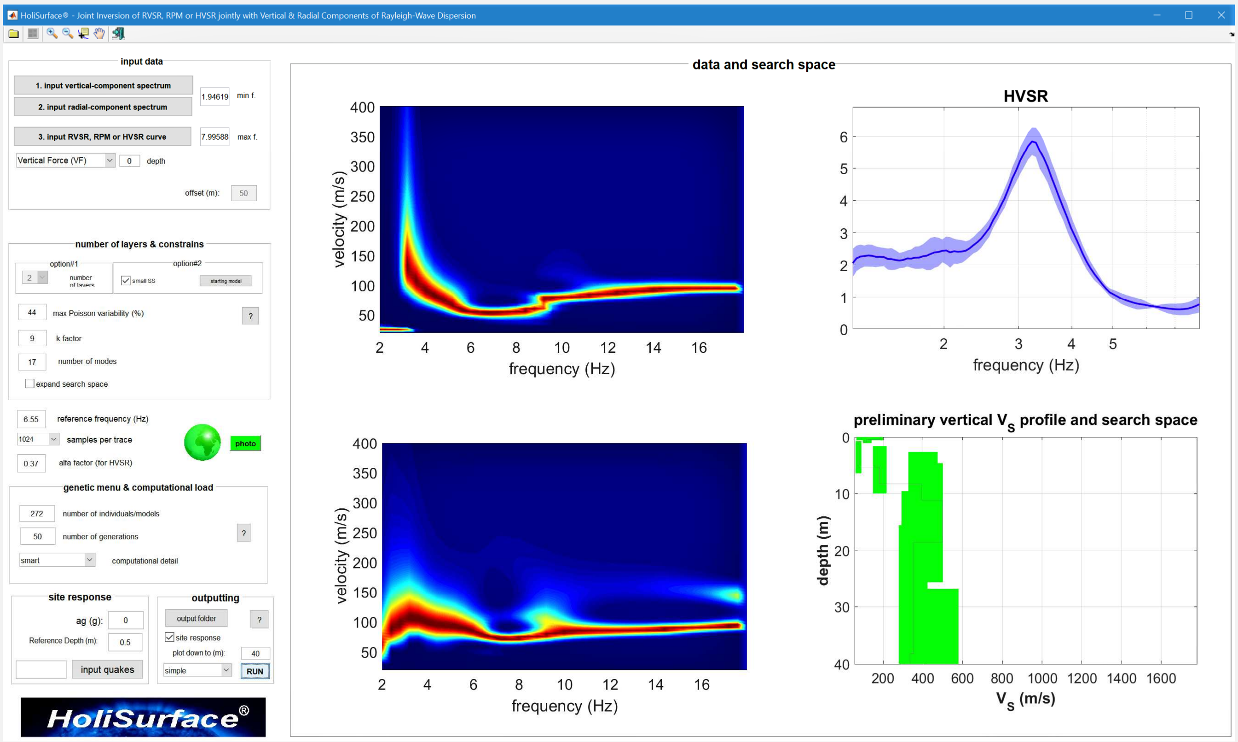
Remember that the HoliSurface methodology consists in the FVS [*Full Velocity Spectrum*] analysis of the group velocity spectra obtained from the active multi-component data recorded by a single 3-component geophone set a certain distance (in this case 50 m) from the source.
The HVSR [*Horizontal-to-Vertical Spectral Ratio*] curve is obtained with the passive data recorded by the same geophone.
Please note that the FVS methodology does not require any personal (i.e. subjective) interpretation of the velocity spectra.
So: just one 3-compoennt geophone for up to six observable useful to fully constrain your Vs profile and overcome the otherwise inevitable ambiguities of just one observable.
In this case we deal with the **vertical (Z) and radial (R) components of Rayleigh waves** together with the HVSR, which is the **mean HVSR curve** from two HVSR curves obtained at two different points, one in the middle of the array and the other at the end of the array [i.e. the same position for the HS active data].

First of all we click the **button "disp + HVSR" from the main panel of the HS software**. We then now upload the HS traces and the mean HVSR curve (previously computed). We then compute the group velocity spectra of the Rayleigh-wave components ("Rayleigh waves: group-velocity spectra" button in the lower part of the panel) and obtain what is shown in the following figure.

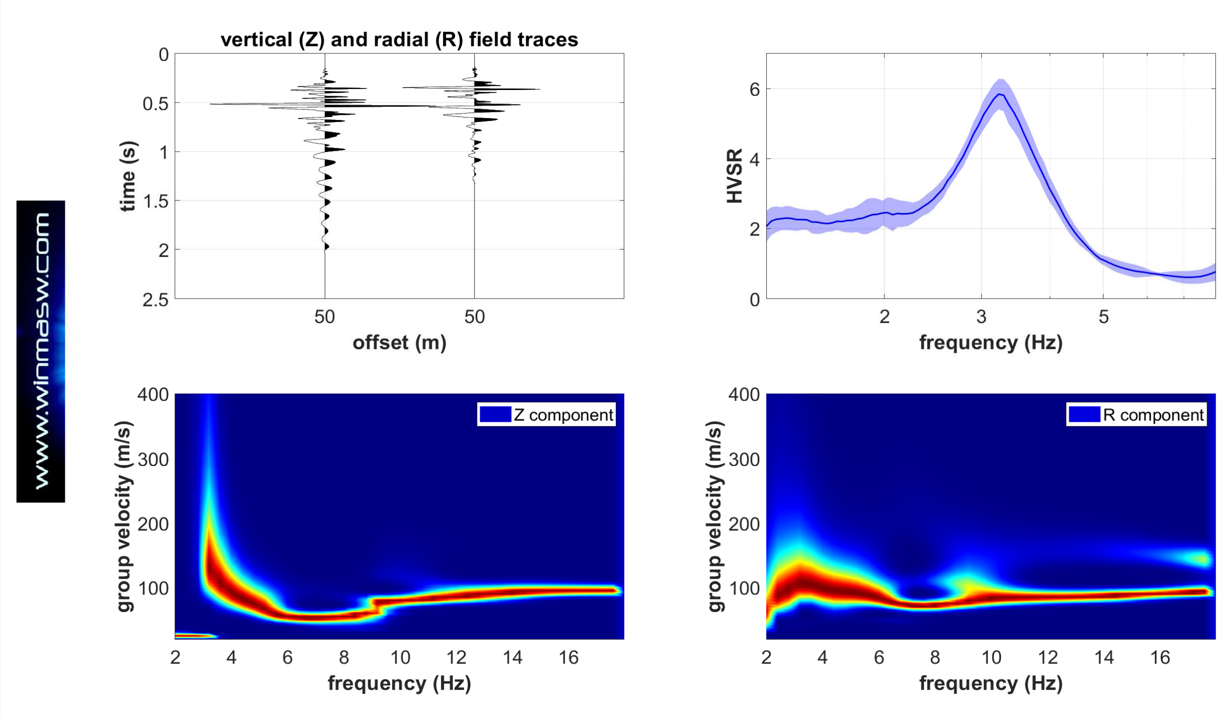


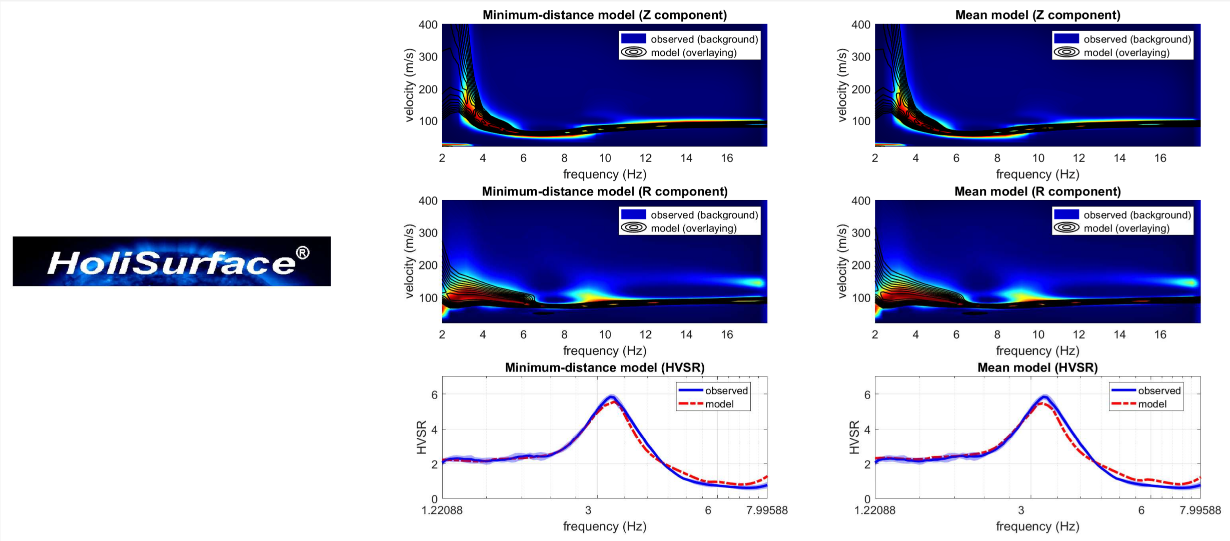
We then play a little bit with the forward modelling and modify the V_S and thickness (and, if necessary, the Poisson) values so to obtain an acceptable consistency between the field and synthetic (modelled) data [see all the tools on the right part of the panel].
Once we obtain a good (but not perfect) model we can enter the 3-observqable automatic-inversion panel by means of the **"3-obs inversion" button** (in the lower-right corner) [see next panel].

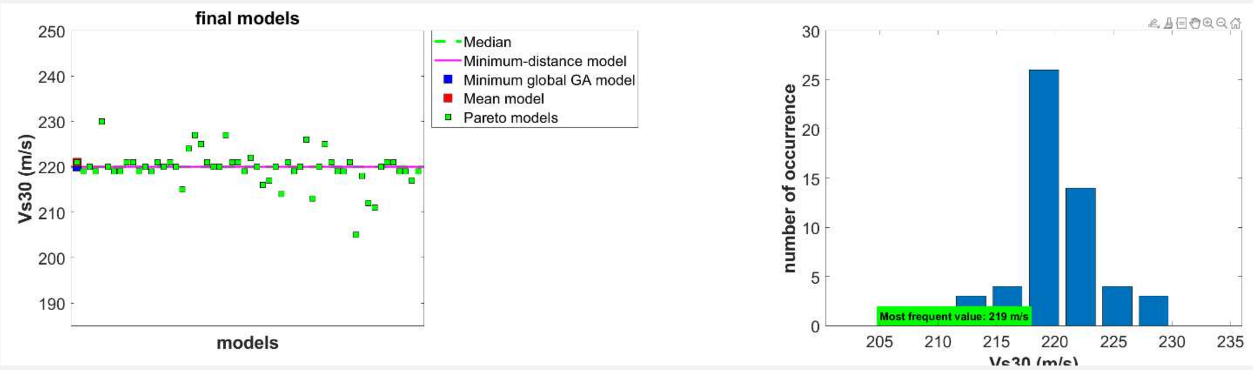
In this panel, we upload the georeferenced survey photo, fix the inversion parameters and then launch the inversion procedure ["RUN" button].

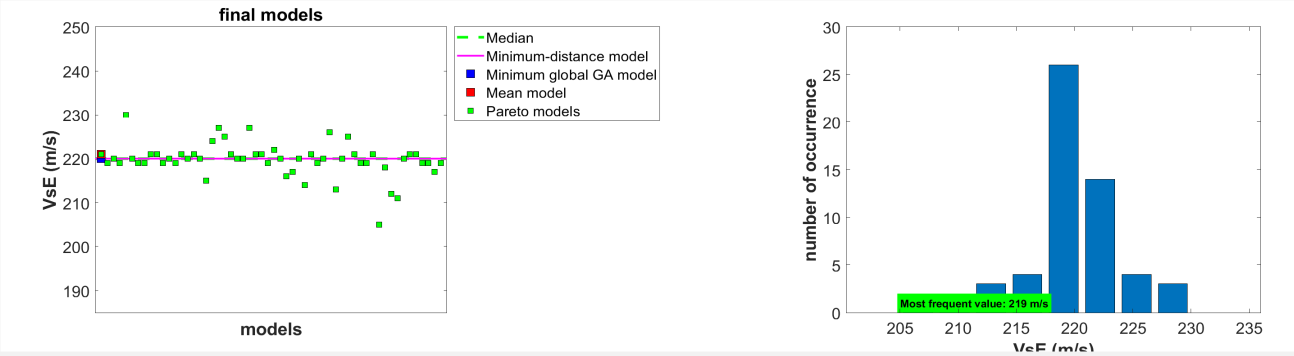


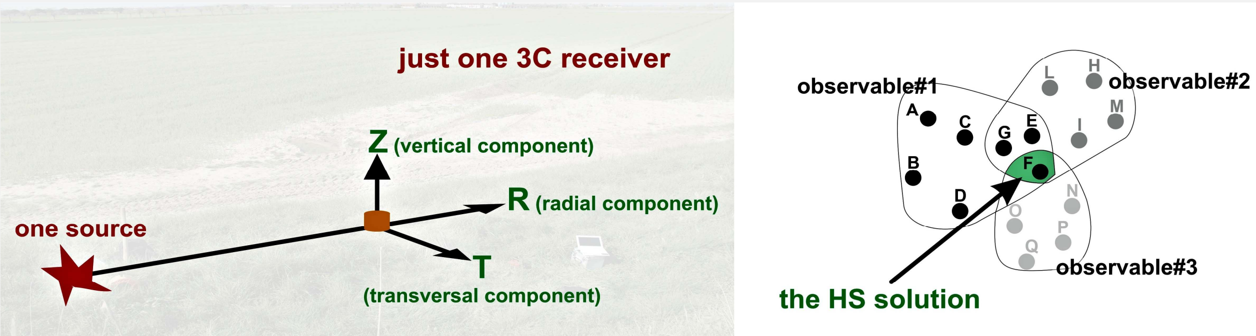
The following figures report the final outcome in case we choose the “simple” option [see “simple-full” pop-up menu in the lower part of the panel].

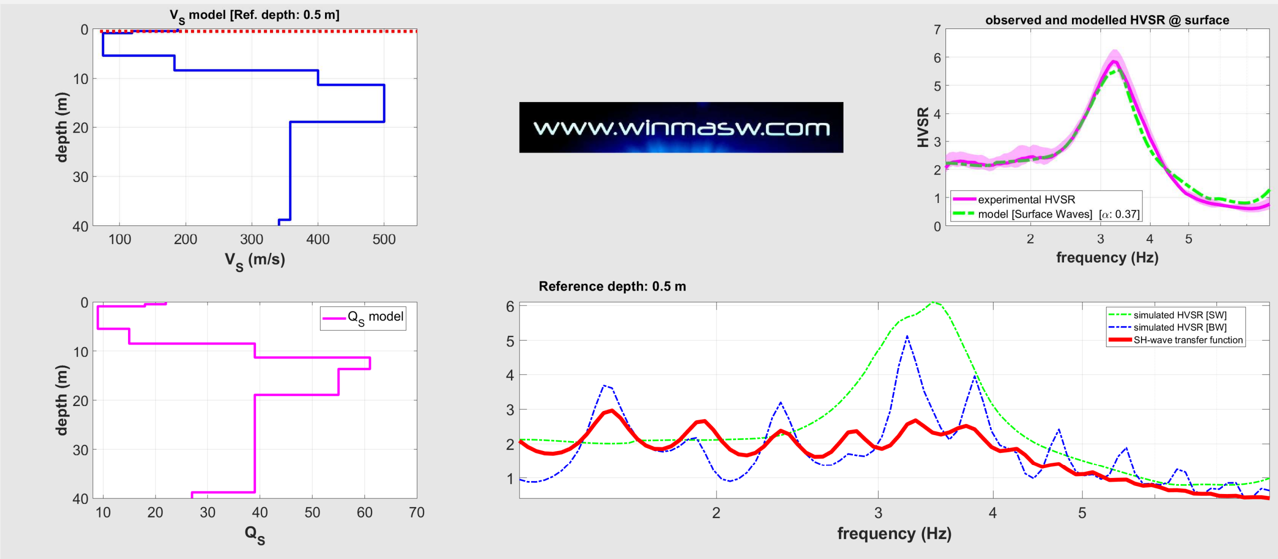

www.winmasw.com
vertical (Z) and radial (R) field traces
time (s)
offset (m)
HVSR
frequency (Hz)
Z component
R component
group velocity (m/s)
frequency (Hz)


HoliSurface®
Minimum-distance model (Z component)
Mean model (Z component)
observed (background)
model (overlaying)
Minimum-distance model (R component)
Mean model (R component)
Minimum-distance model (HVSR)
Mean model (HVSR)
observed
model
velocity (m/s)
frequency (Hz)
HVSR


final models
Median
Minimum-distance model
Minimum global GA model
Mean model
Pareto models
Vs30 (m/s)
models
number of occurrence
Most frequent value: 219 m/s
Vs30 (m/s)


final models
Median
Minimum-distance model
Minimum global GA model
Mean model
Pareto models
VsE (m/s)
models
number of occurrence
Most frequent value: 219 m/s
VsE (m/s)


just one 3C receiver
Z (vertical component)
R (radial component)
one source
T
(transversal component)
observable#1
observable#2
observable#3
the HS solution


Vs model [Ref. depth: 0.5 m]
depth (m)
Vs (m/s)
www.winmasw.com
observed and modelled HVSR @ surface
HVSR
experimental HVSR
model [Surface Waves] [α: 0.37]
frequency (Hz)
Qs model
Qs
Reference depth: 0.5 m
simulated HVSR [SW]
simulated HVSR [BW]
SH-wave transfer function
frequency (Hz)

Example#9 – Comparing Z-component dispersion from ESAC [*winMASW®* Academy] and MAAM [*HoliSurface®*]

In both cases we are dealing with passive data. The mathematics of these two methods is radically different and is reflected in a number of characterizing points:

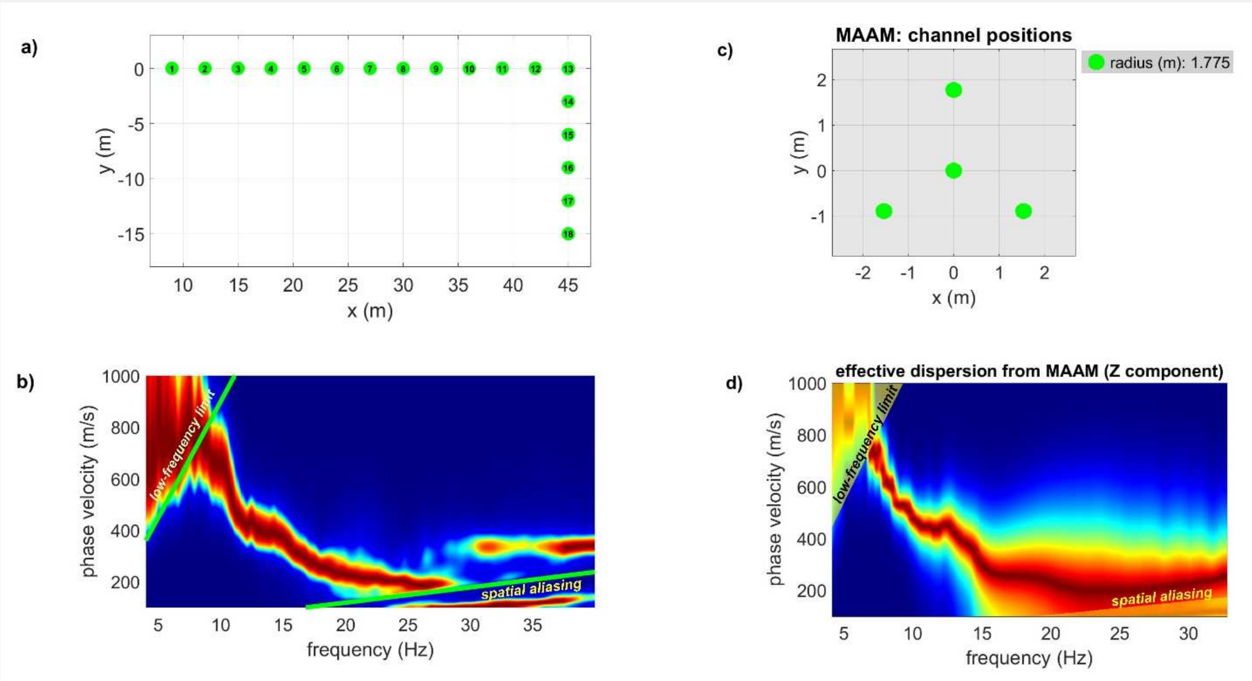
1) ESAC imposes very large arrays (in synthetic terms we can say that “it works with the wavelengths") and a significant number of channels; possible "imperfections" in some of the traces does not significantly affect the result [i.e. a few "noisy" traces do not represent a serious problem];

2) MAAM [implemented in the ***HoliSurface®*** software - HS] requires circular arrays with a limited number of channels (triangle or pentagon with a central geophone) and an extremely-small radius compared to ESAC (just a couple of meters compared to several tens of meters for ESAC). The quality of the **data must be perfect** (see *HoliSurface®* manual and pertinent literature).

The image below reports a comparison between the phase velocity spectra (Z component) obtained from ESAC and the MAAM for a test site. It can be seen that the velocities are fundamentally identical (the validity limits depend on the geometry of the respective arrays and are indicated).

It should be fully understood that (in both cases) we obtain the *effective* dispersion curve (not the fundamental mode). Furthermore, since the areas involved are very different, one should not overlook the fact that while ESAC identifies an average dispersion over a large area (several tens of metres), the MAAM dispersion refers to a very local portion/area (the radius is only a few metres).

The ESAC method is also applicable to the R and T components (see the **PS-MuCA technique in winMASW® Academy**) while so far, the MAAM method can be used just to analyse the Z component of the Rayleigh waves.

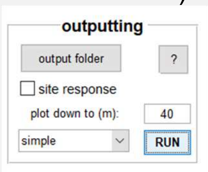


Example of a triangular array for MAAM acquisition: three geophones at the vertices of the triangle and a central one (very high-quality geophones are mandatory). Next to the central geophone you can see the 3C geophone (HOLI3C) used to determine the HVSR (which is then jointly analysed with the dispersion obtained from MAAM). All the geophones are connected to the same seismograph, thus obtaining a dataset with 7 traces efficiently managed by the *HoliSurface®* software.

In ***HoliSurface®***, together with the MAAM analysis, it is also possible to perform the SPAC analysis. Since SPAC follows the same logic/mathematics as ESAC, compared to MAAM it has an extremely limited frequency validity range and, therefore, can be used to verify/compare the phase velocities obtained through the MAAM only at the highest frequencies [see the pertinent section of the *HoliSurface®* manual].

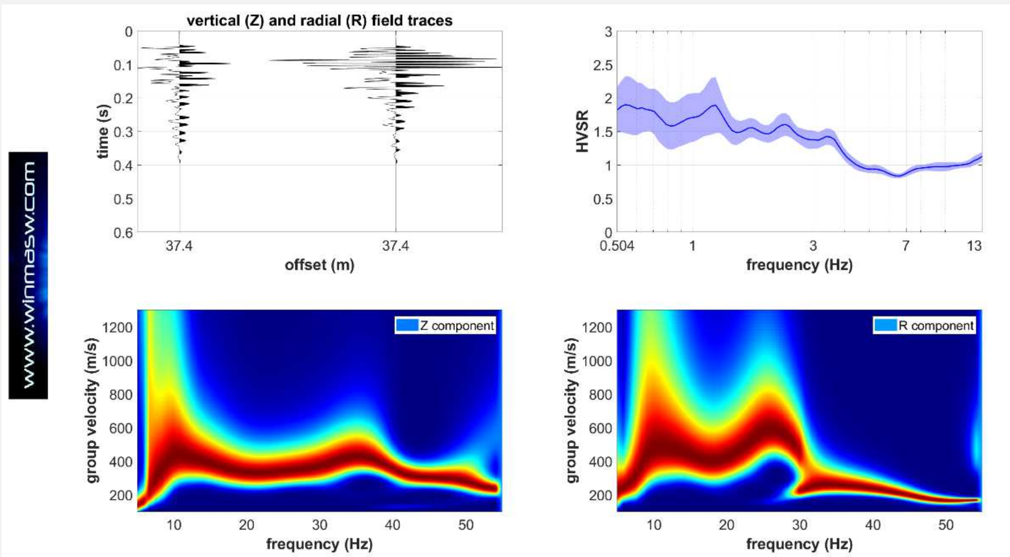
Example#10 – V_S profile in an urban area: joint HS+HVSR analysis

Below it is shown the joint (automatic) Z + R + HVSR inversion for a dataset recorded at a site dominated by gravels and conglomerates that are often responsible for very complex data in case we consider the standard multi-offset MASW approach (based on phase velocities).

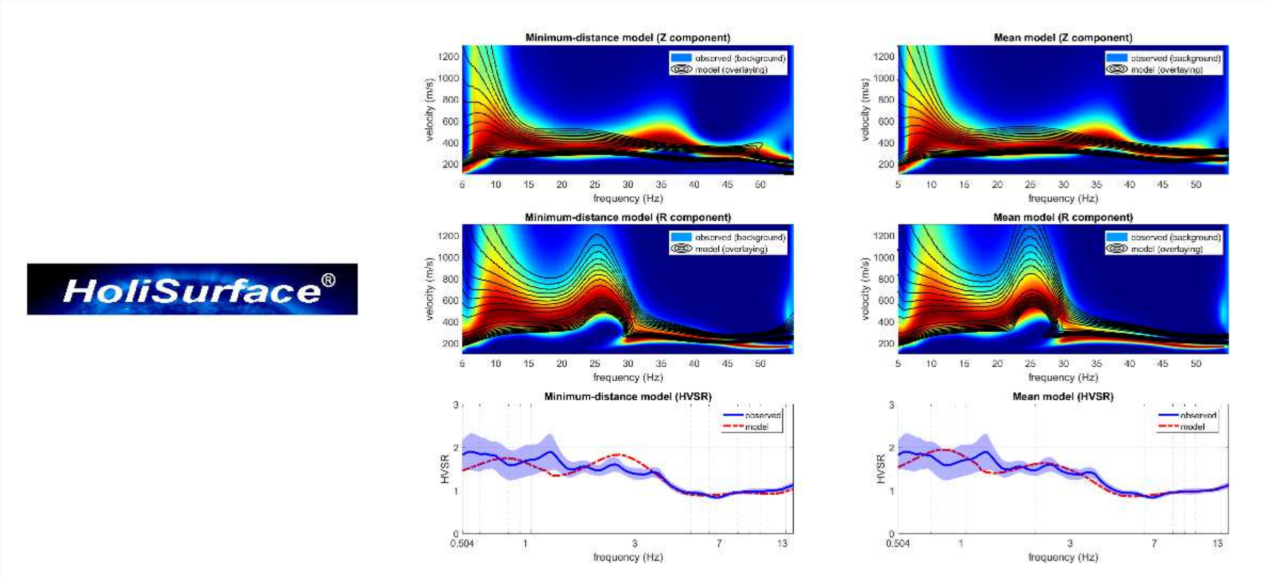


For the joint inversion presented here, the "**simple**" option was selected (the "**full**" option provides many more details that, in order to be properly assessed, require advanced courses).

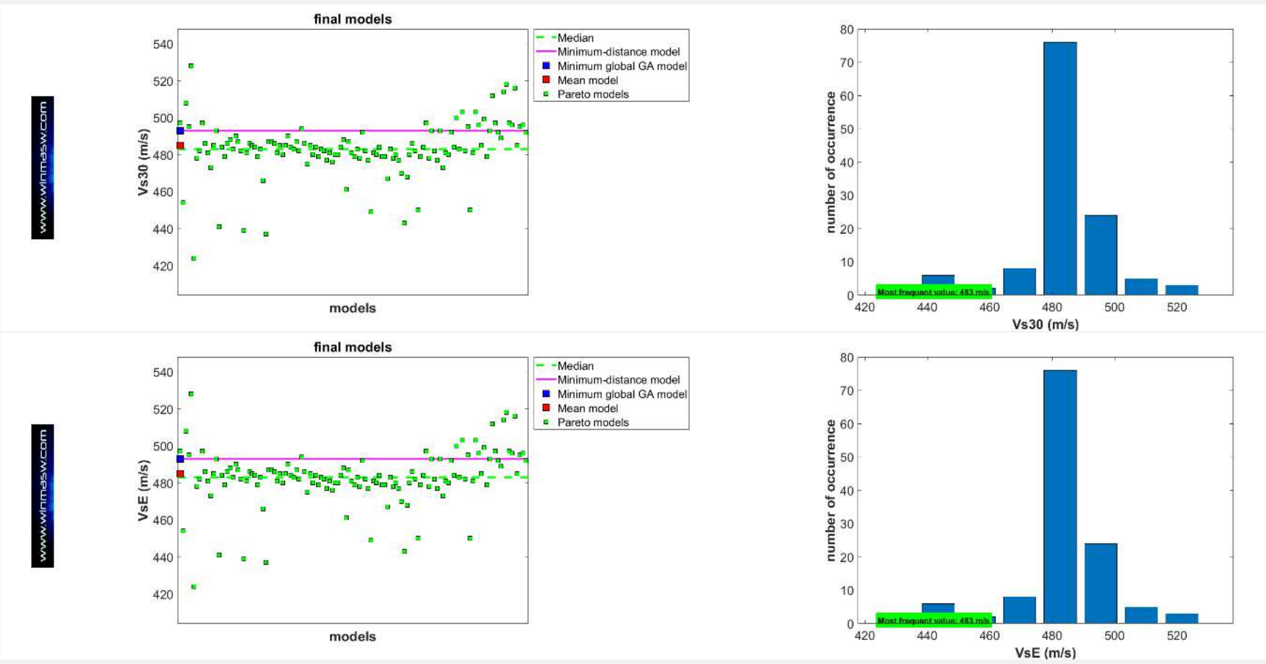
Two geo-referenced photos of the site (a parking lot in the city center)



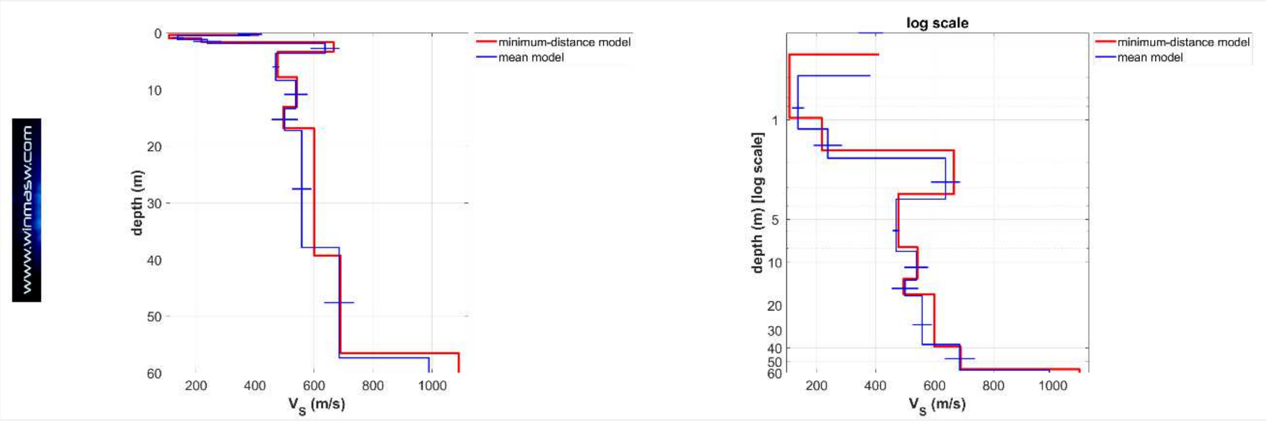
Considered data: HVSR and group velocity spectra for the Z and R components



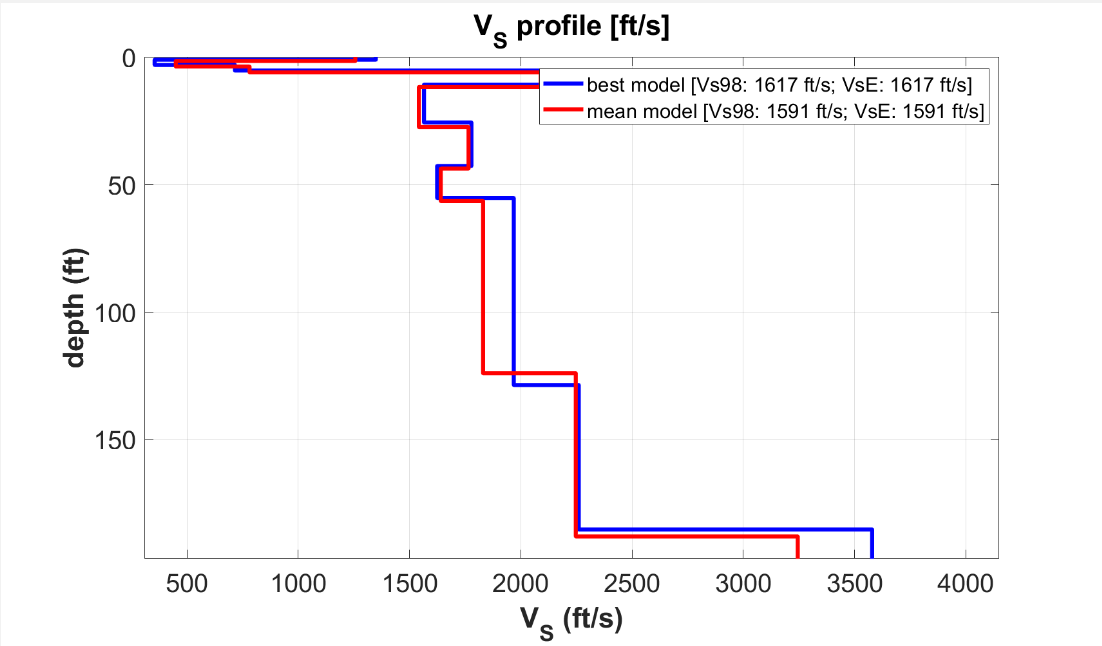
Final result: field data and the two most important models provided when we select the "simple" option output (minimum-distance model and mean model). The overall consistency between field data and retrieved models is apparent (background colors and overlying contour lines match quite well).



Pareto front models: statistical analysis for the Vs30 and Vs equivalent values.



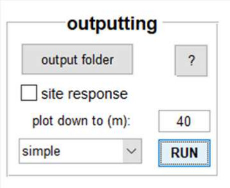
Vs profiles of the two most important models: the *minimum-distance* and the *mean model*. The profiles are shown according to both a linear and logarithmic scale (to emphasize the shallowest layers).



Vs profiles in Anglo-Saxon units (*foot* and *foot/second*).

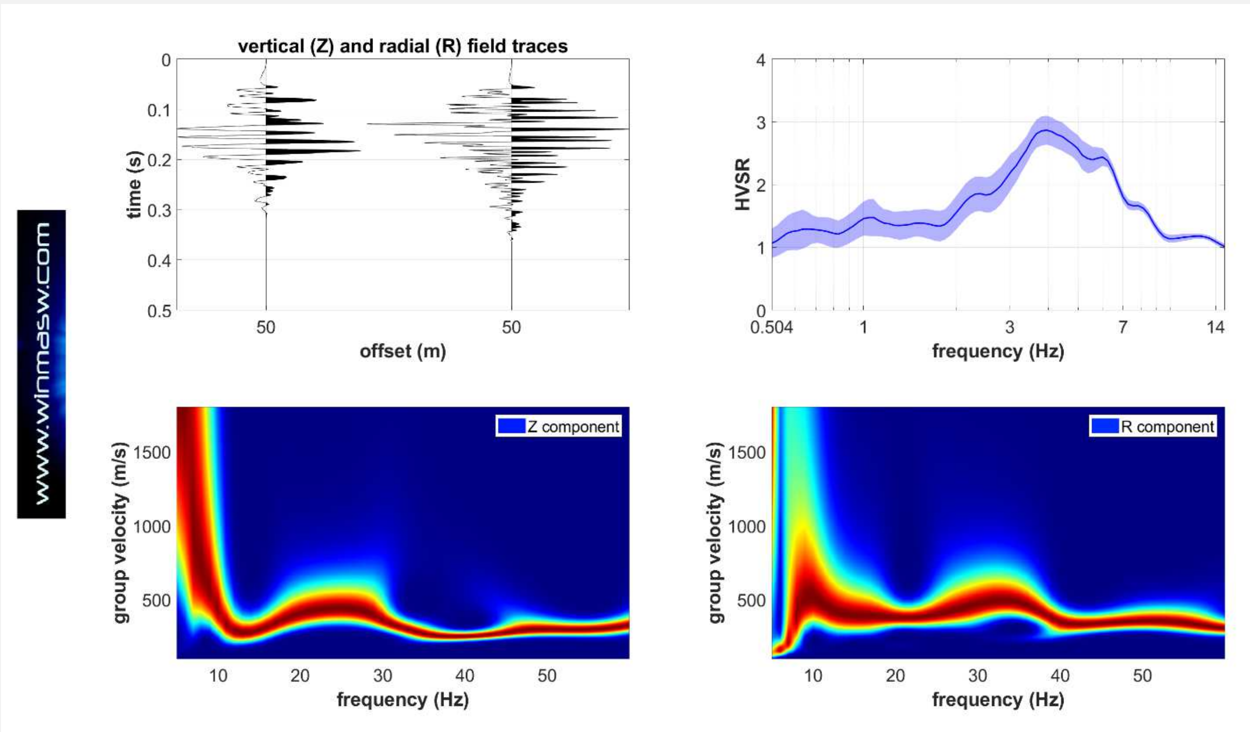
Example#11 – V_S profile at a site dominated by gravel and conglomerates for a university building: a further joint HS+HVSR analysis

Overall stratigraphic conditions were not too different compared to the previous site although in the deeper strata conglomerates were expected to be stiffer.

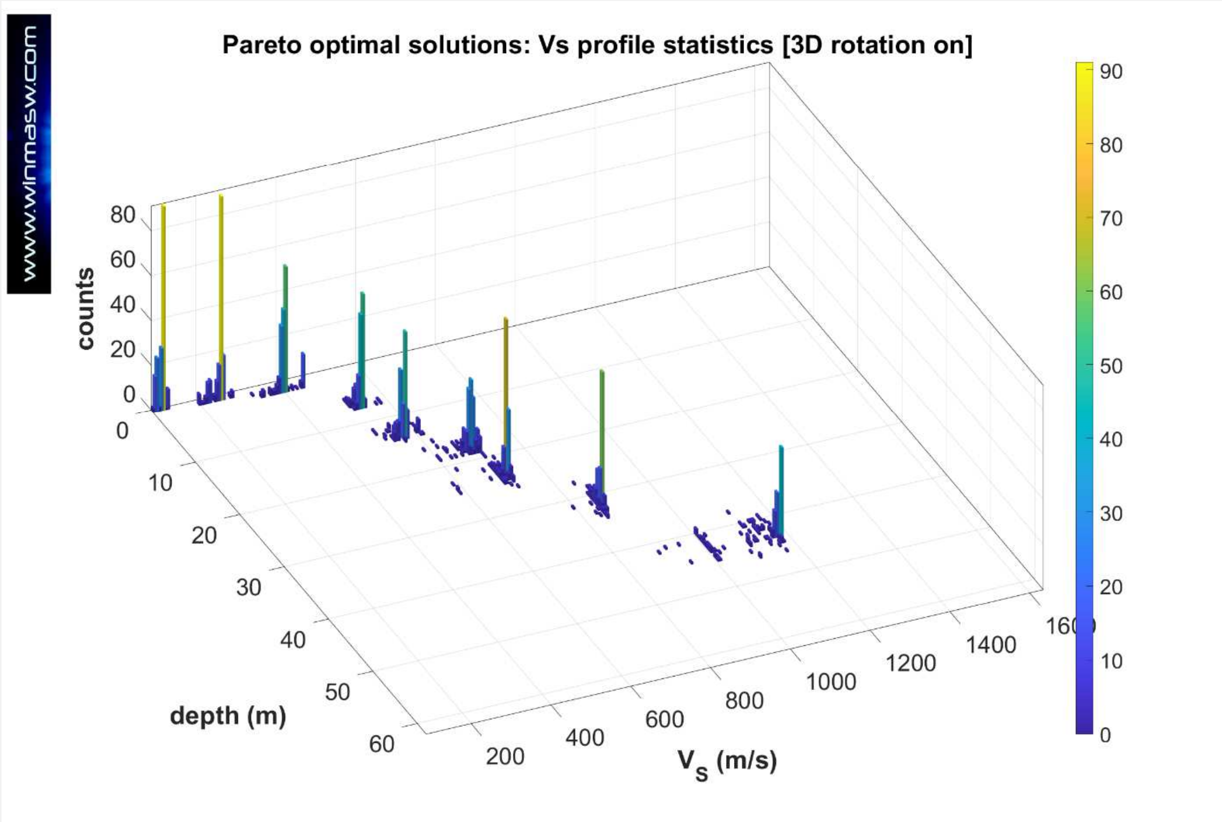


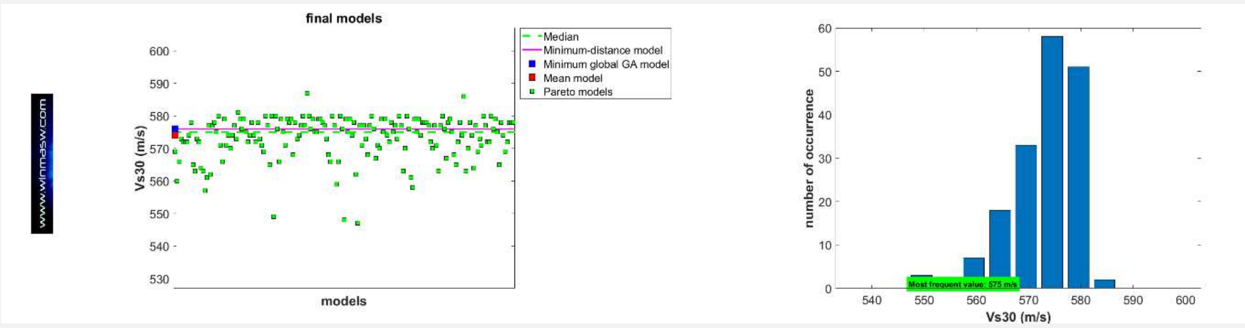
Also for this dataset, during the joint inversion we selected the option “**simple**” (so to obtain just the most important values).

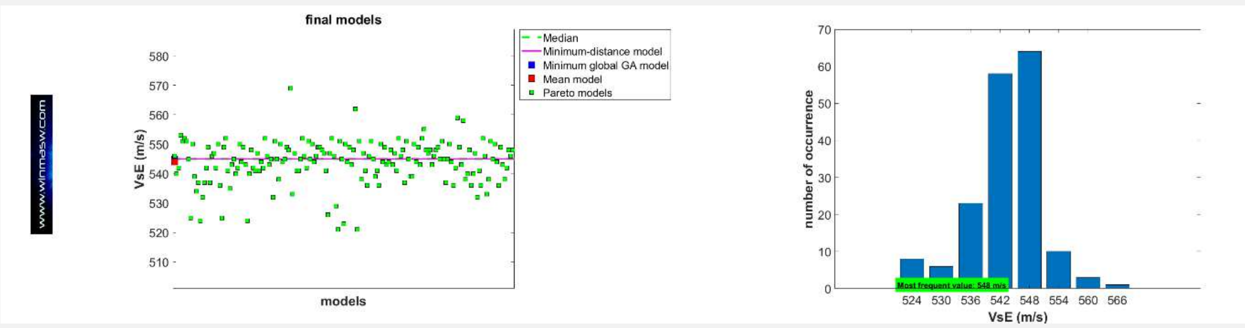
The site



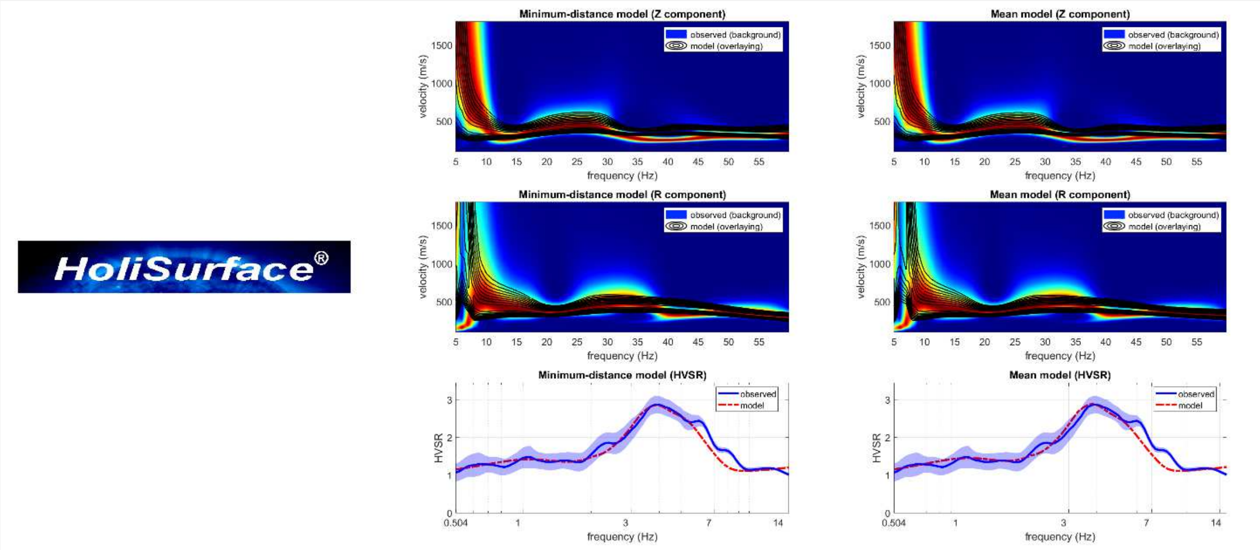
Considered data: HVSR and group velocity spectra for the Z and R components. Two HVSRs were recorded at the site: one at the source and one at the receiver point. The two HVSRs were nearly identical (thus supporting the 1D assumption) and, therefore, it was not necessary to compute the average curve [which can be easily obtained using the “multiple HVSR” tool].



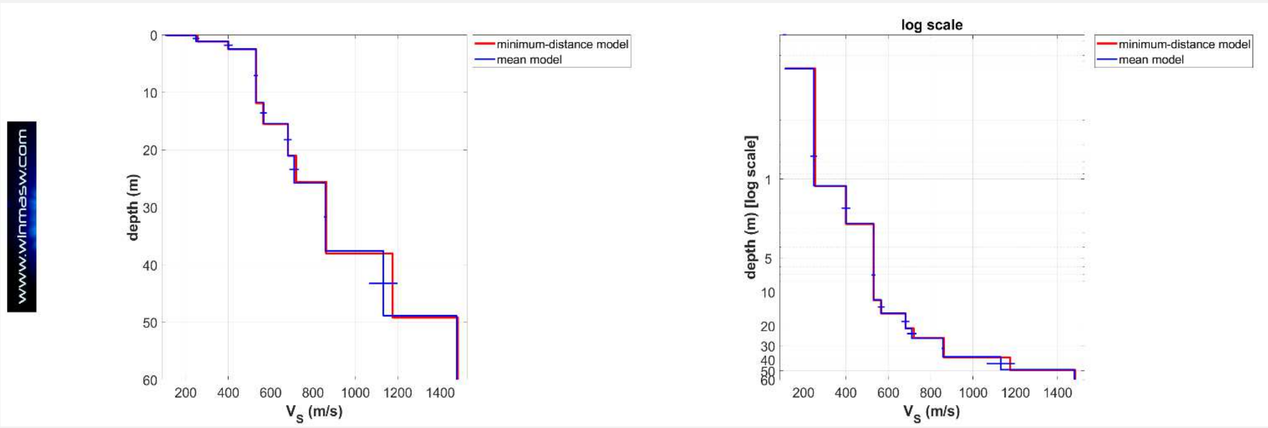




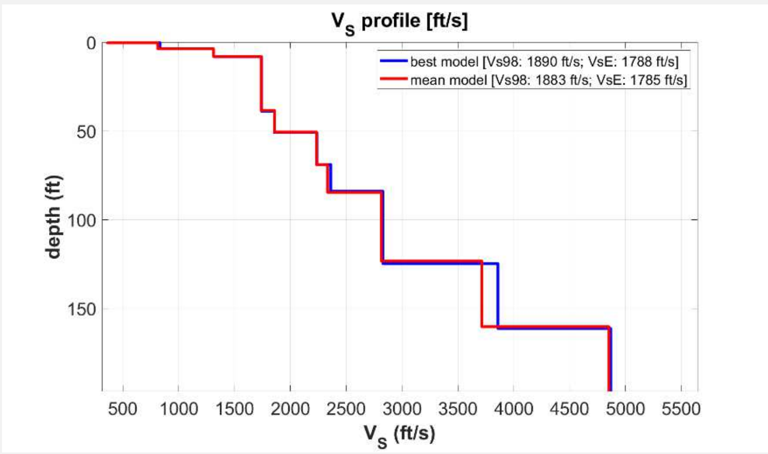
The three figures above represent a summary of the statistical analysis carried out at the end of the joint inversion.



Final result: field data and the two most important models provided when we select the "simple" option output (minimum-distance model and mean model). The overall consistency between field data and retrieved models is apparent.

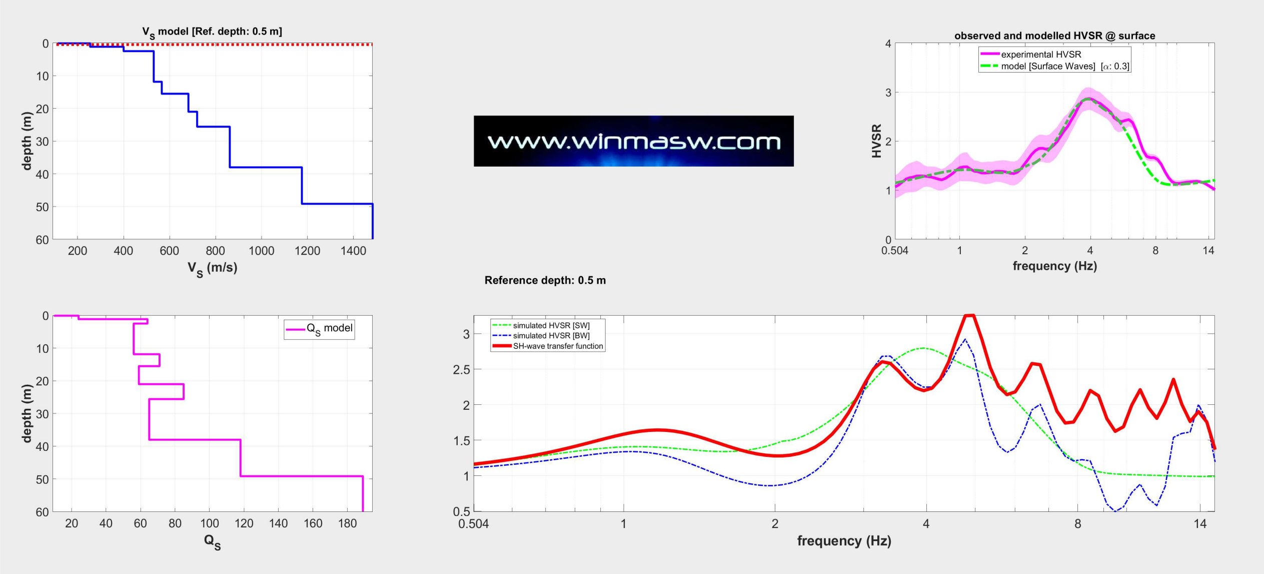


Vs profiles of the two most important models: the *minimum-distance* and the *mean model*. The profiles are shown according to both a linear and logarithmic scale (to emphasize the shallowest layers).



Vs profiles in "Anglo-Saxon" units (*foot* and *foot/second*).

If the "**site response**" option is activated (see first image shown for this case study), the SH-wave transfer function (**red** curve in the bottom left graph of the following image) is also computed:



Example#12 – Eigenfrequencies, eigenmodes and damping for a historical building

A municipal building that will be soon renovated (also from the structural point of view) was characterized through the GHM methodology (Dal Moro et al. 2018; Sancin et al. 2018).

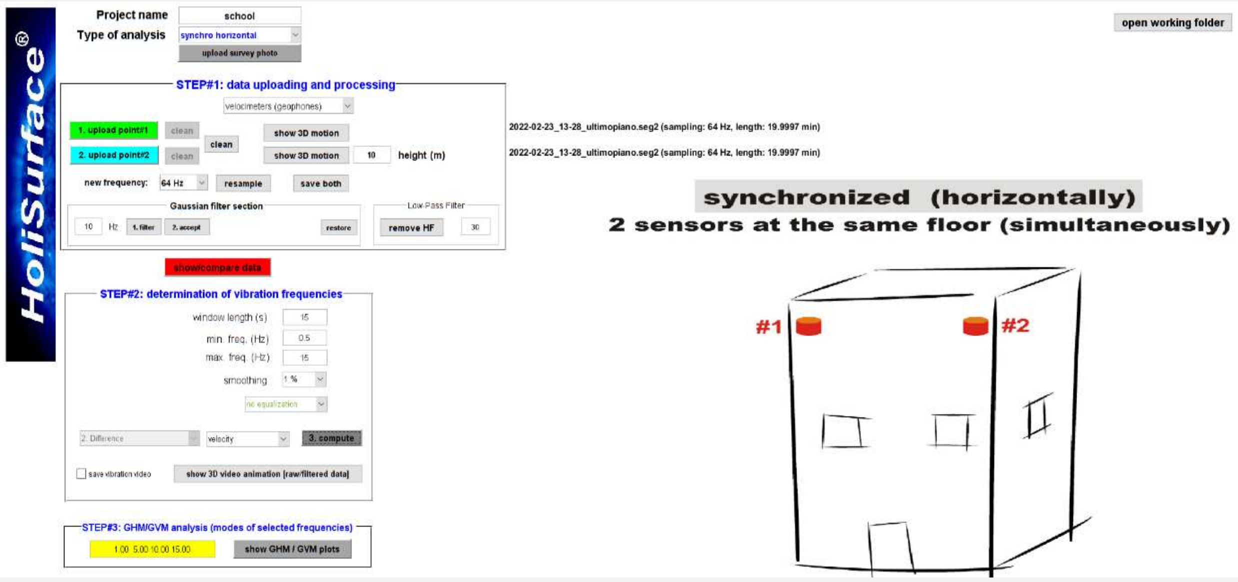
The building has a regular shape and consists of three floors (ground floor + two further floors). In order to record synchronous data, two **HOLI3C** geophones were deployed at two corners on the top floor and connected to the same seismograph (this way we obtained a single 6-trace datasets).

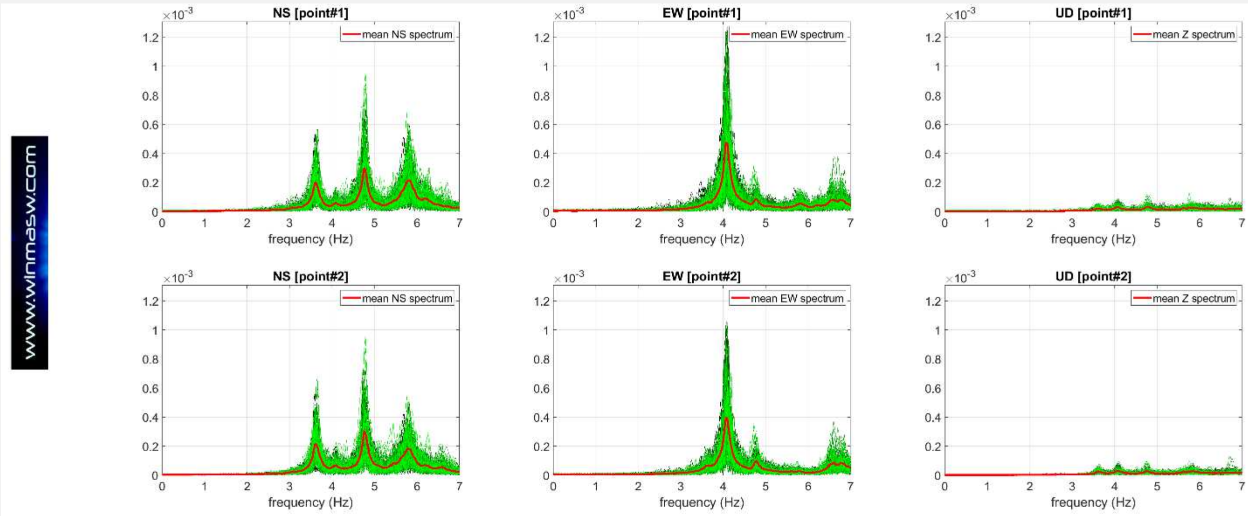
In the following, EW is the axis of greatest elongation of the building (corresponding to the façade shown in the photo below) and NS is the 'short' axis (perpendicular to the previous one).

On the left the **HOLI3C** sensor at one of the two corners of the building.

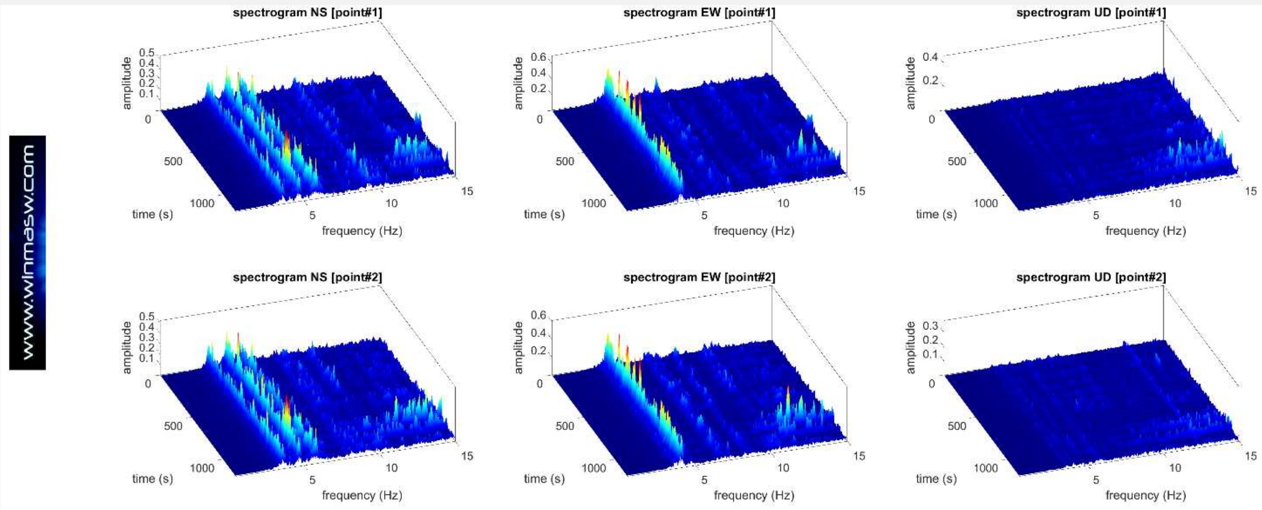
A second (identical) 3C geophone was placed at a second corner (both along the façade shown in the photo).

In other words, the two 3C geophones were deployed according to the scheme shown in the next figure/sketch.

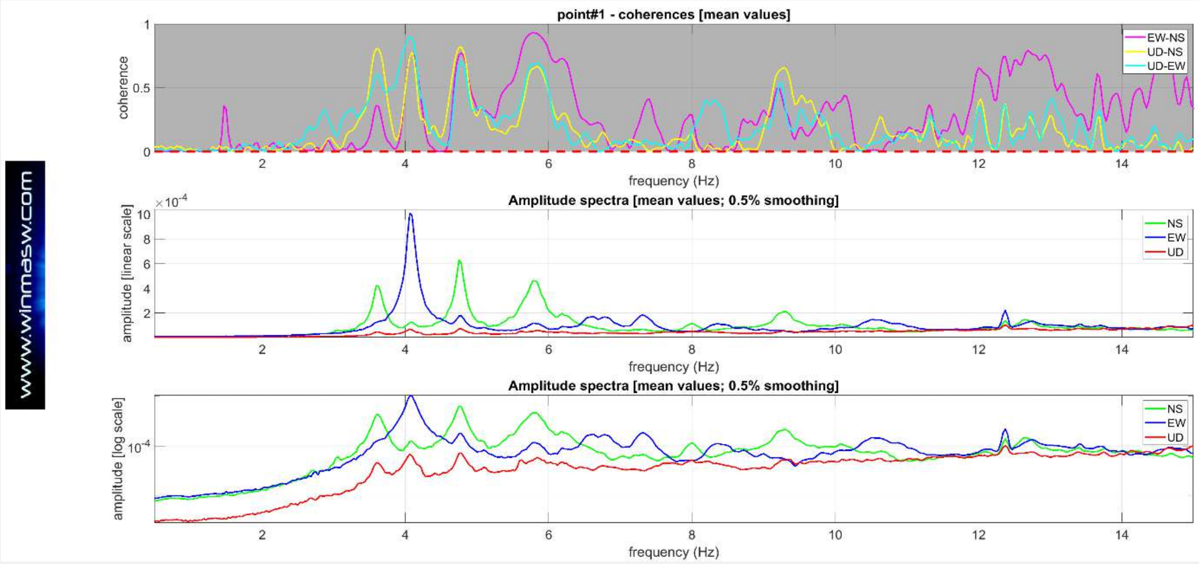




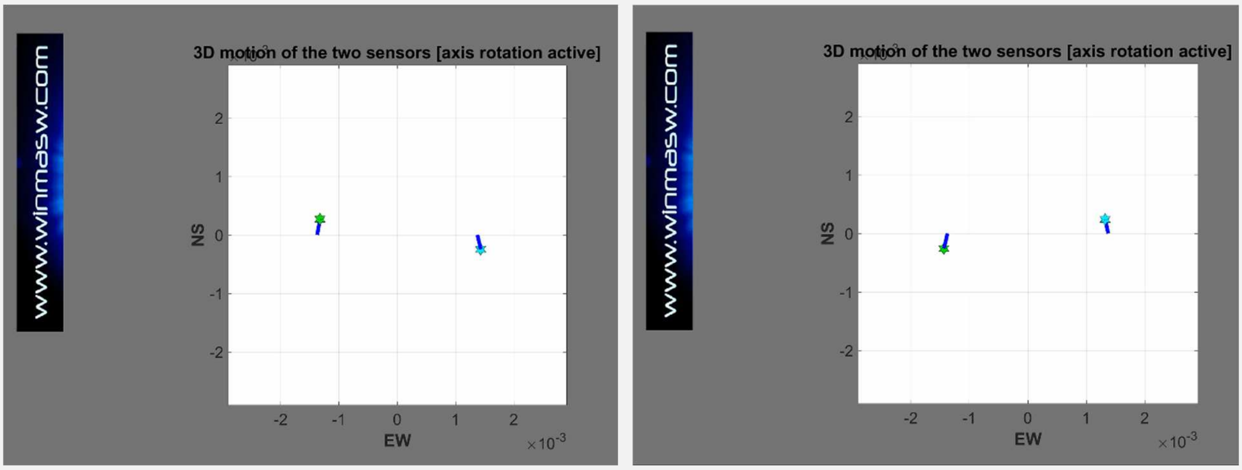
Amplitude spectra for the three components at the two measurement points (#1 and #2): four eigenfrequencies are apparent at 3.62, 4.06, 4.76 and 5.79 Hz.



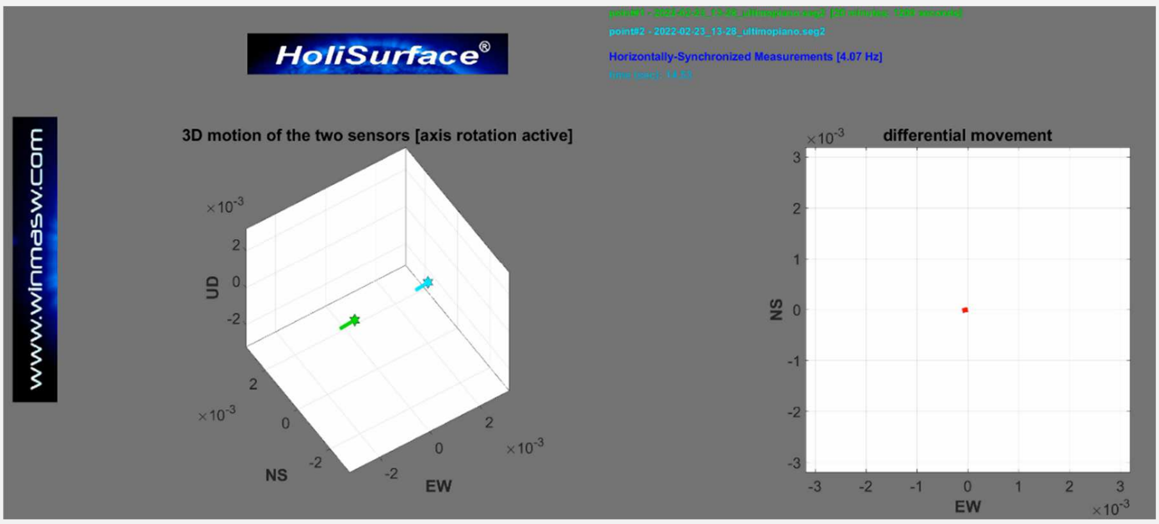
Spectrograms for the three components at the two measurement points: the four frequencies previously highlighted are once again apparent.



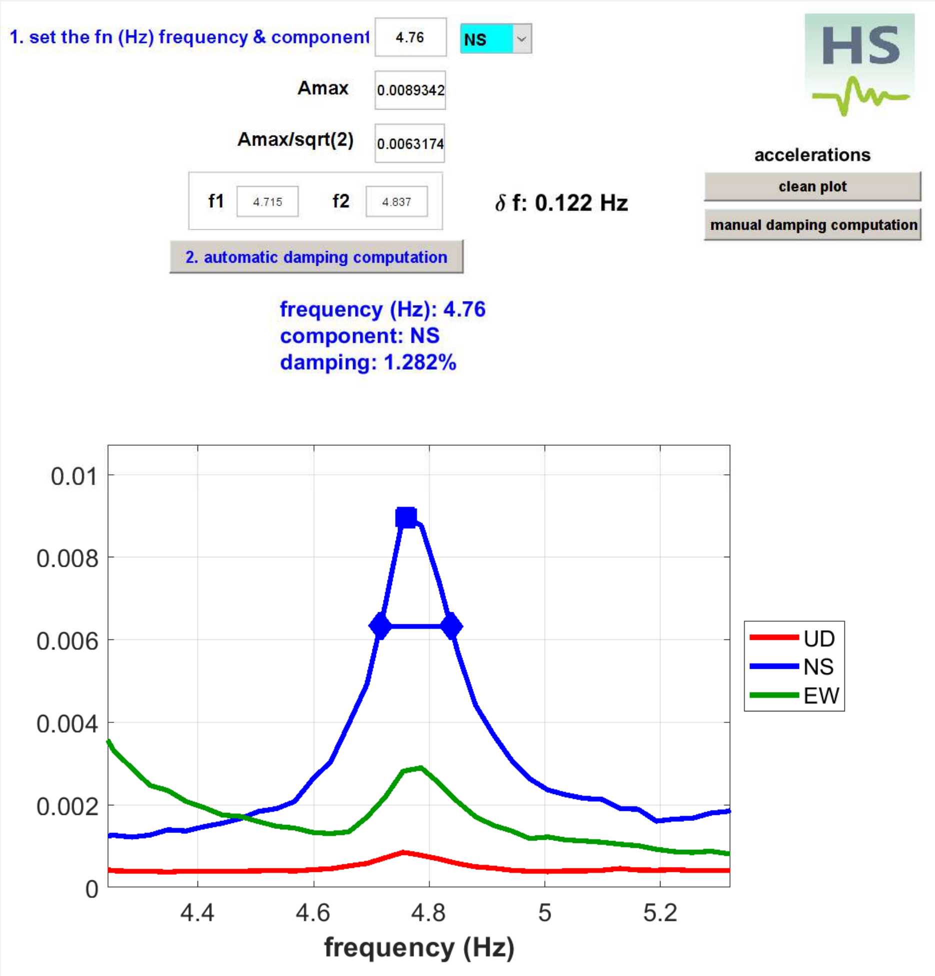
Coherence functions and average amplitude spectra (with linear and logarithmic scales) for point#1: the *eigen frequencies* are once again apparent and the GHM technique allows us to define them as *torsional* or *flexural* (see next two figures and Dal Moro et al. 2018).



Two snapshots of the GHM animation [i.e. the particle motion on the horizontal plane] for the torsional mode at 4.76 Hz (the full video animation is available at our YouTube channel).



Snapshot of the GHM video animation for the *flexural* mode at 4.07 Hz.



Damping computation for the torsional mode at 4.76 Hz (NS component)

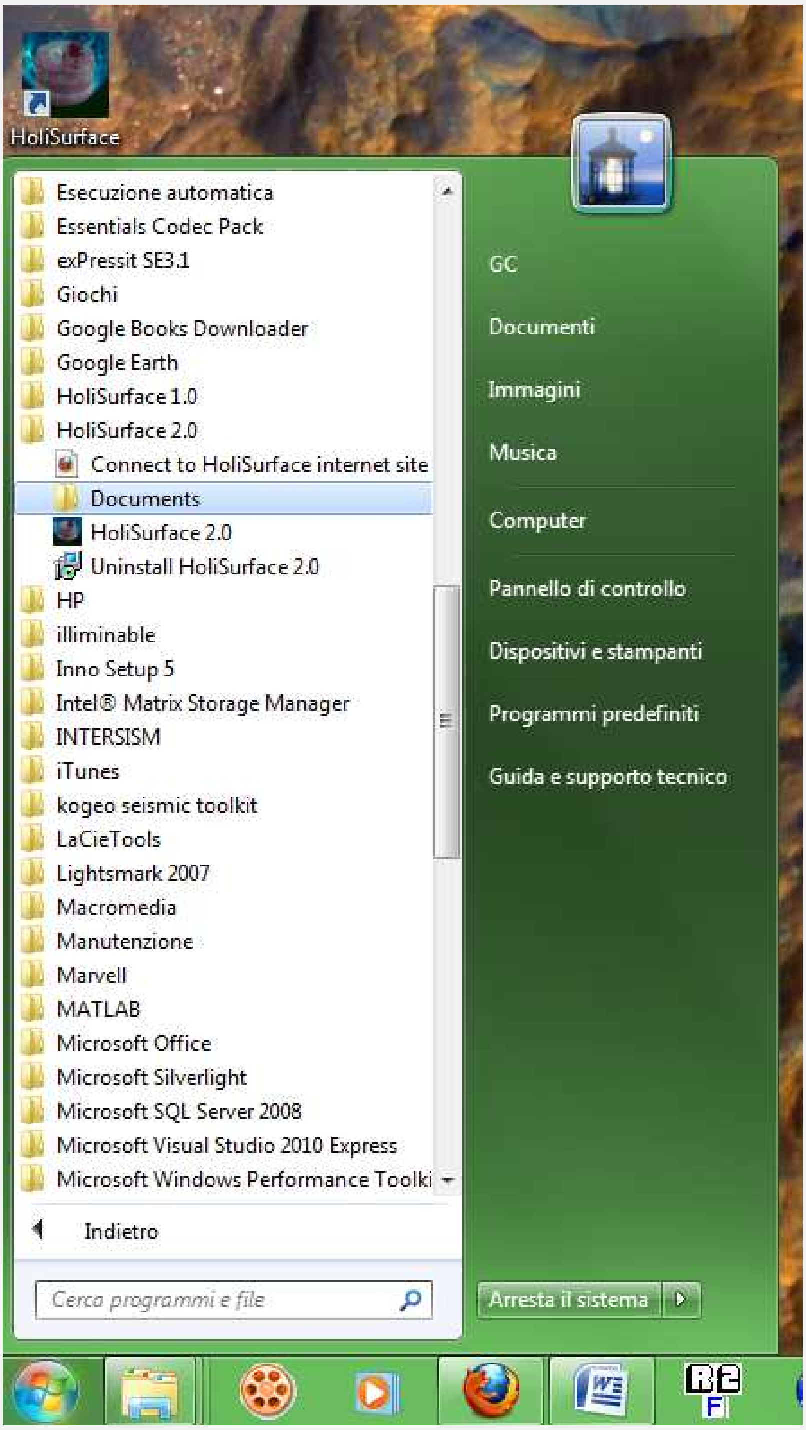
The spectral analysis and the GHM technique allow to define the following *eigen modes*:

frequency (Hz)	eigenmode (mode type)	damping (%)
3.62	flexural (EW axis)	1.88
4.07	flexural (NS axis)	1.57
4.76	torsional	1.28
5.79	flexural (EW axis)	2.16

For further examples of vibration analyses on structures (buildings and bridges), see the pertinent section of this manual and the mentioned papers.

Further case studies can and will be downloaded from the website **www.holisurface.com** in the pages dedicated to *HoliSurface* and in the "publications" area.

Other examples are and will be present in the "Documents" folder inside the *HoliSurface* installation folder:



Appendix I: field equipment - a *checklist*

Below is a checklist of what is needed during field data acquistion.
A and **P** indicate Active (HS method and possible multi-channel and offset acquisitions for MASW data) and Passive (HVSR, MAAM and vibration acquisitions) methods, respectively.

Necessity		
Seismograph or, to be more precise, A/D unit	A+P	√
Seismic cable(s) suggested the *HoliSurface* cable of our HS integrated system	A+P	√
3C geophone	A+P	√
Vertical geophones for MAAM [4 or 6]	A+P	√
Trigger geophone	A	√
Trigger extension (100 m) [for *our* HS system not required]	A	√
Hammer (5 -10 kg, depeding on the site and on the specific goals)	A	√
Plate (for VF acquisitions) and sleeper (for HF acquisition)	A	√
Seismic cable for the trigger [our HS system]	A	√
Field laptop	A+P	√
Power bank (additional power source for the PC)	A+P	√
Tape measure	A+P	√
AREA51 device [for MAAM acquisitions]	P	√

Accessories (optional)	
Second 3C geophone (for vibration and SSR analyses)	√
Metal supports (tripods) for acquisition on asphalt	√
GPS USB antenna	√
USB stick (for transferring acquired data)	√
Field booklet + pens and pencils	√
Camera	√
Swiss Army Knife	√

Remember that our *integrated HS system* is the ideal tool (acquisition system) to do everything you can with *HoliSurface®* and also be able to easily access the multi-channel/offset world (seismic refraction/reflection, multi-component MASW - Rayleigh and Love waves, ReMi, ESAC/SPAC, ReMi, etc.).

For information about our *HS system*: winmasw@winmasw.com

Appendix L: obtaining data in mm/s with our HS system

First of all, it is necessary to understand when it is or is not necessary that the acquired data are in physical units (mm/s is the best solution), always reiterating that acquiring all the data always and in any case in mm/s is a good habit.

HVSR: not necessary (but always useful)

Data for dispersion analysis (MASW, ESAC, ReMi, MFA/FTAN, HS, MAAM): not strictly necessary but always a good habit. For MAAM it is particularly recommended.

Vibration analysis on buildings: extremely useful (highly recommended)

Vibration analysis at construction site (UNI/DIN): absolutely necessary

We need to follow the right procedures in two moments:

1) during data acquisition

2) when uploading the data in the software application (HS or winMASW)

We will see below how to correctly carry out the operations both during acquisition and while loading the data.

1. Acquisition

See documentation provided with the *acquisition system*. Here the information abot the geophones we provide.

The sensitivity of the **3C geophones** we supply is:

- 2-Hz 3C geophone (the red one, metal case): **2 V/cm/s**

- *Geospace-Eliosoft* 3C geophone (blue): **0.89 V/cm/s [equalized down to about 0.2 Hz via software]**

Single-component geophones (see label on their cable):

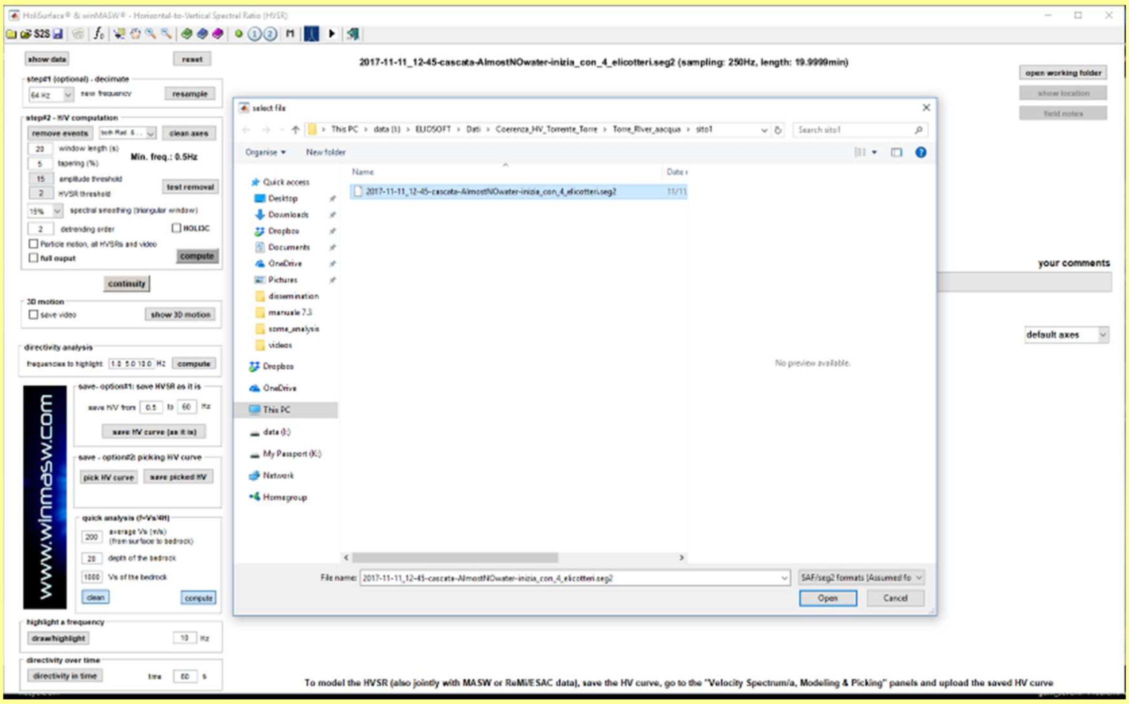
- model C1: **0.82 V/cm/s**
- model C: **0.92 V/cm/s**
- model B1: **0.29 V/cm/s**
- *Geospace-Eliosoft* model (blue) [recommended for MAAM, very useful also for ESAC]: **0.89 V/cm/s**

- model HL-3: **0.6 V/cm/s**

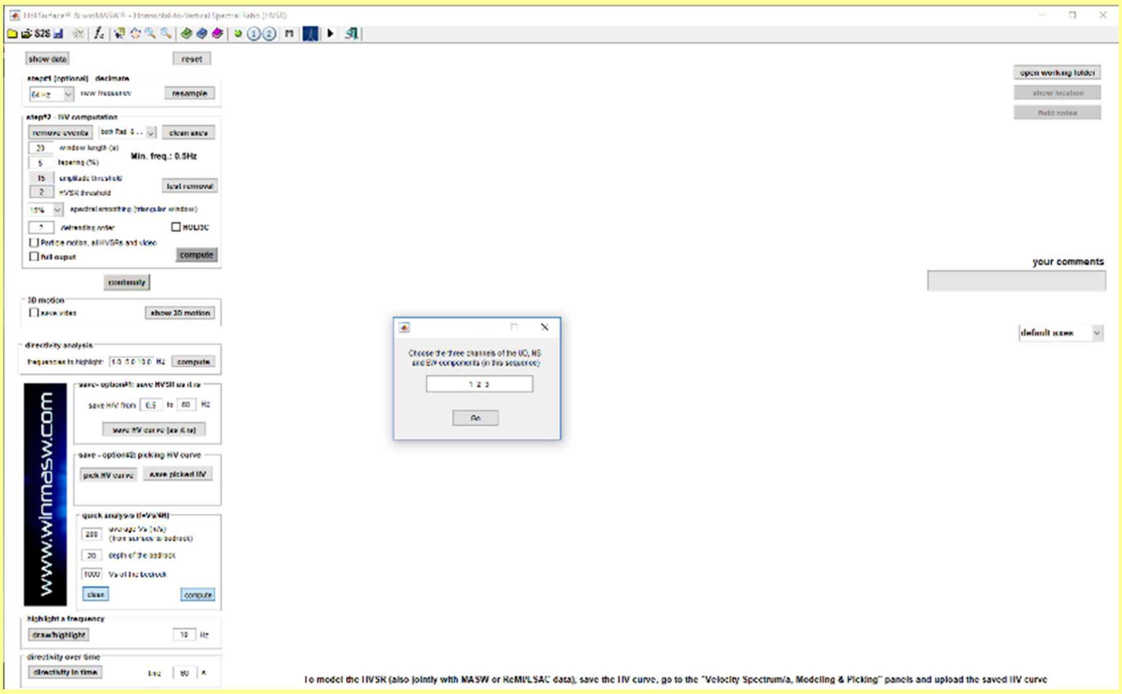
2. Data upload in *HoliSurface®*

If you have acquired the data according to the instructions above, a dialogue box will ask you for the unit of measurement of the data when loading the seg2 file.

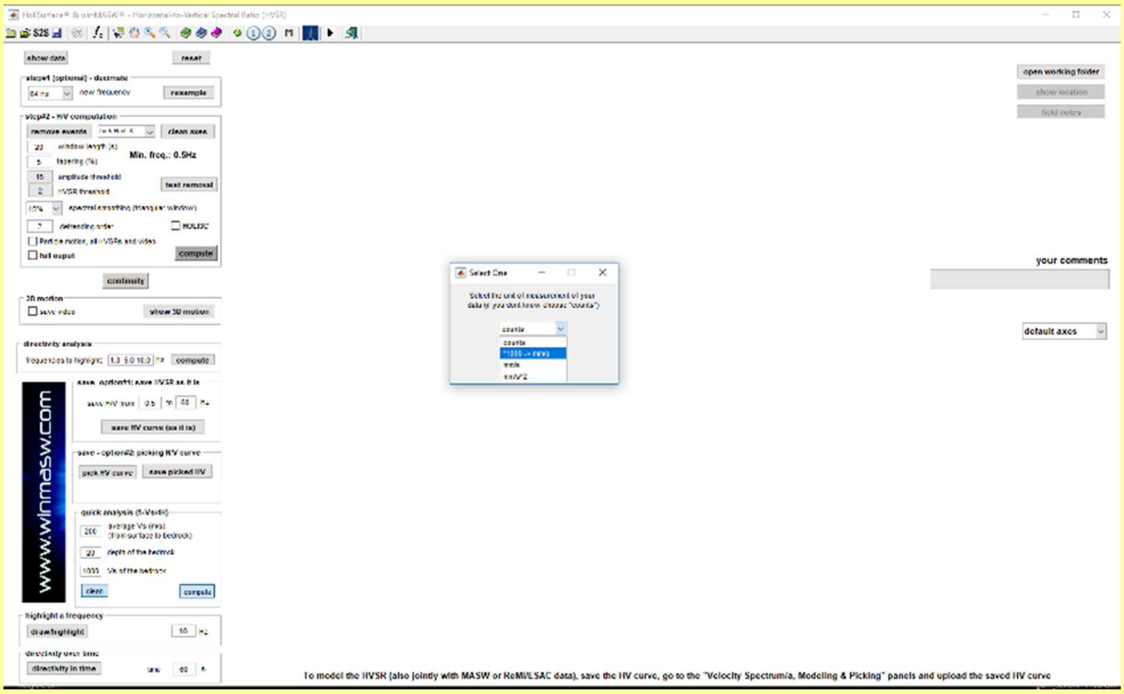
uploading files in SEG2 format



Open/select the file (seg2 format)



Define the sequence of channels containing, in order, the UD (vertical), NS (or radial) and EW (or transverse) component



Define the unit of measurement of the input data.

In case you are using our acquisition system and correctly following the acquisition procedures (see previous section), select the option highlighted in the snapshot above and you will get the data in mm/s.

With this option, data are multiplied by 1000 so to obtain values in mm/s.

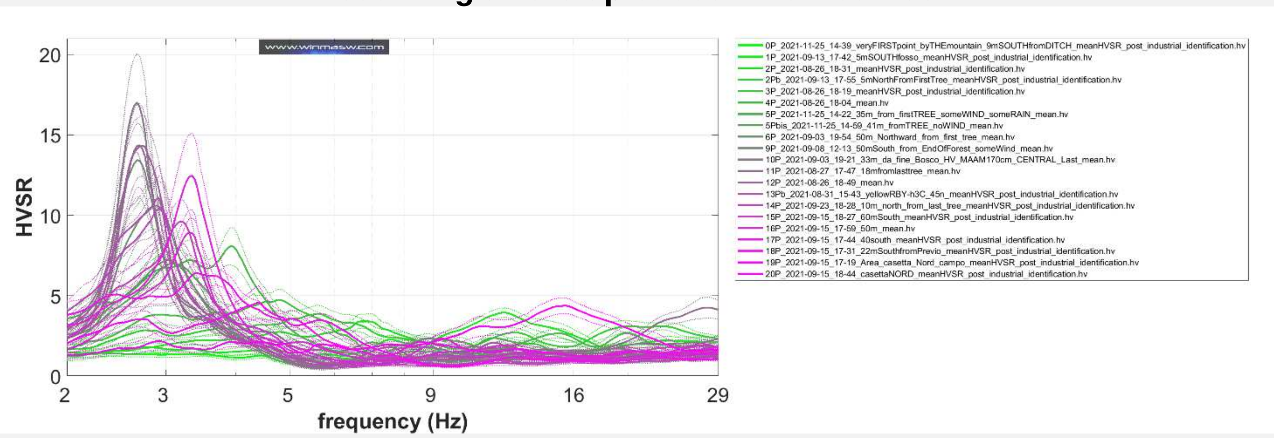
Appendix M: plotting multiple HVSR curves (HVSR 2D sections)

By clicking the "show multiple HVSRs" button <u>you can upload a series of HVSR curves (.hv format) previously saved in the same folder</u> and obtain the following plots (their use and meaning is clearly really wide and it depends on your "fantasy" and needs).
While uploading of the curves, it is possible (through two simple dialogue boxes) to fix the minimum and maximum frequency to plot and the specific positions of each HVSR curve (*inline positions*).

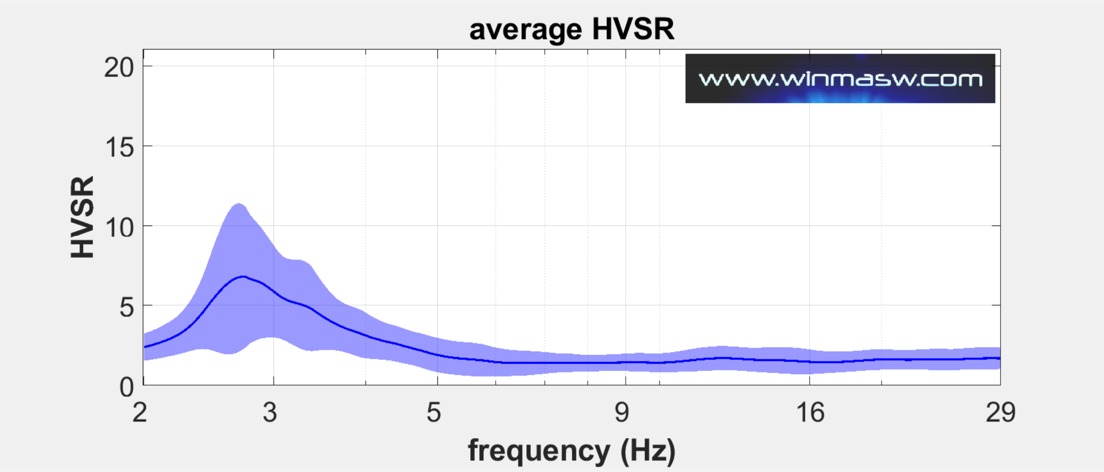
Two possible uses:

1) If we collected several HVSR at the same site, we can compare them using this tool;
2) In case we collected HVSR data at different points (e.g. across a valley), we can have an idea of the overall trend of the subsurface main features (e.g. the *bedrock*) and you obtain a sort of 2D HVSR section.

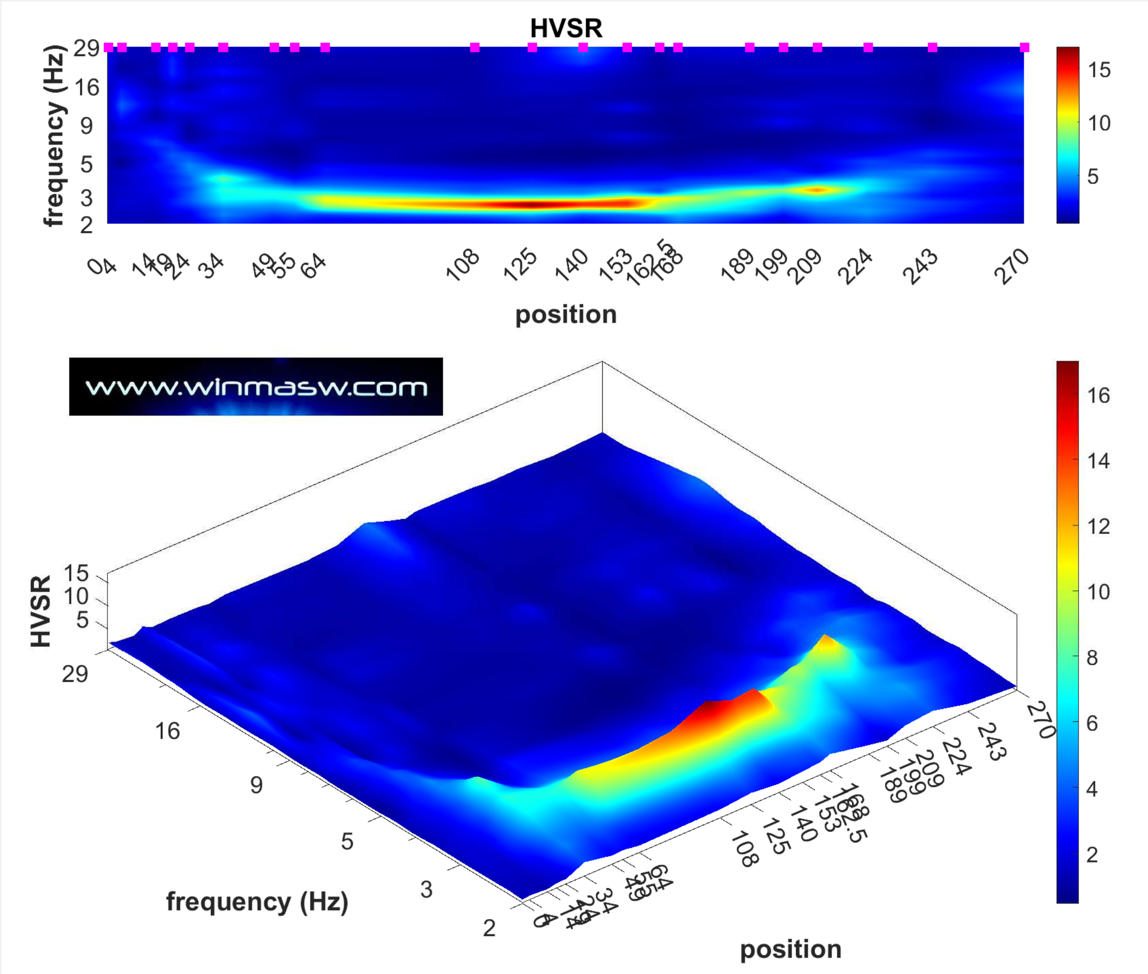
Visualizing all the uploaded HVSR curves:



Average HVSR curve (shown and saved in the working folder)

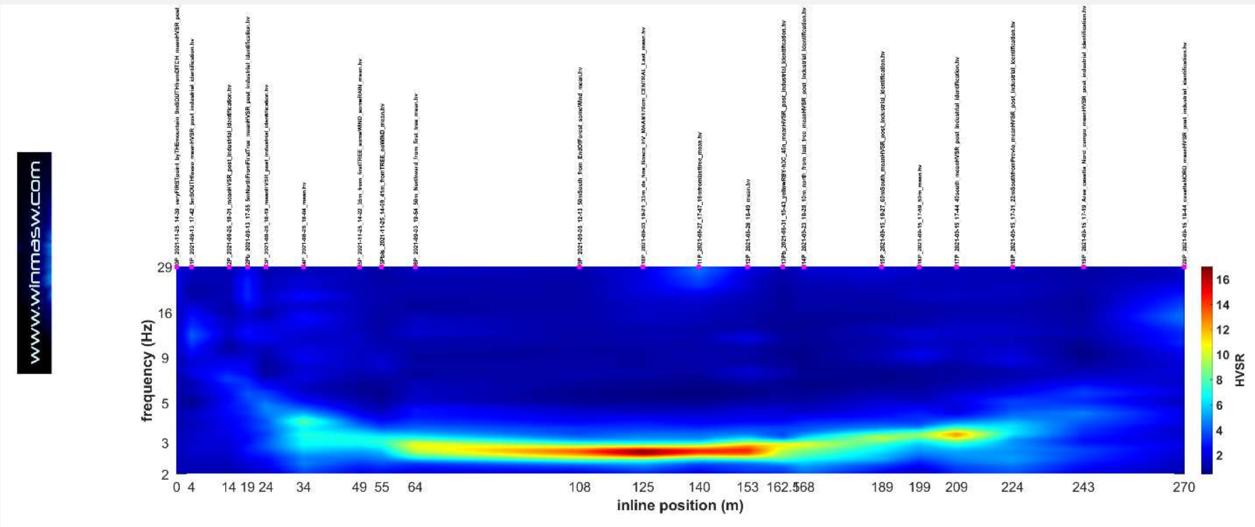


Plotting the original HV curves according to a 2/3D perspective



Small magenta squares report the position of the 21 curves considered for this example.

Summary image where are also reported the filenames of the uploaded curves (so to keep under control everything):



How to obtain the inline positions to use for your 2D HVSR section?

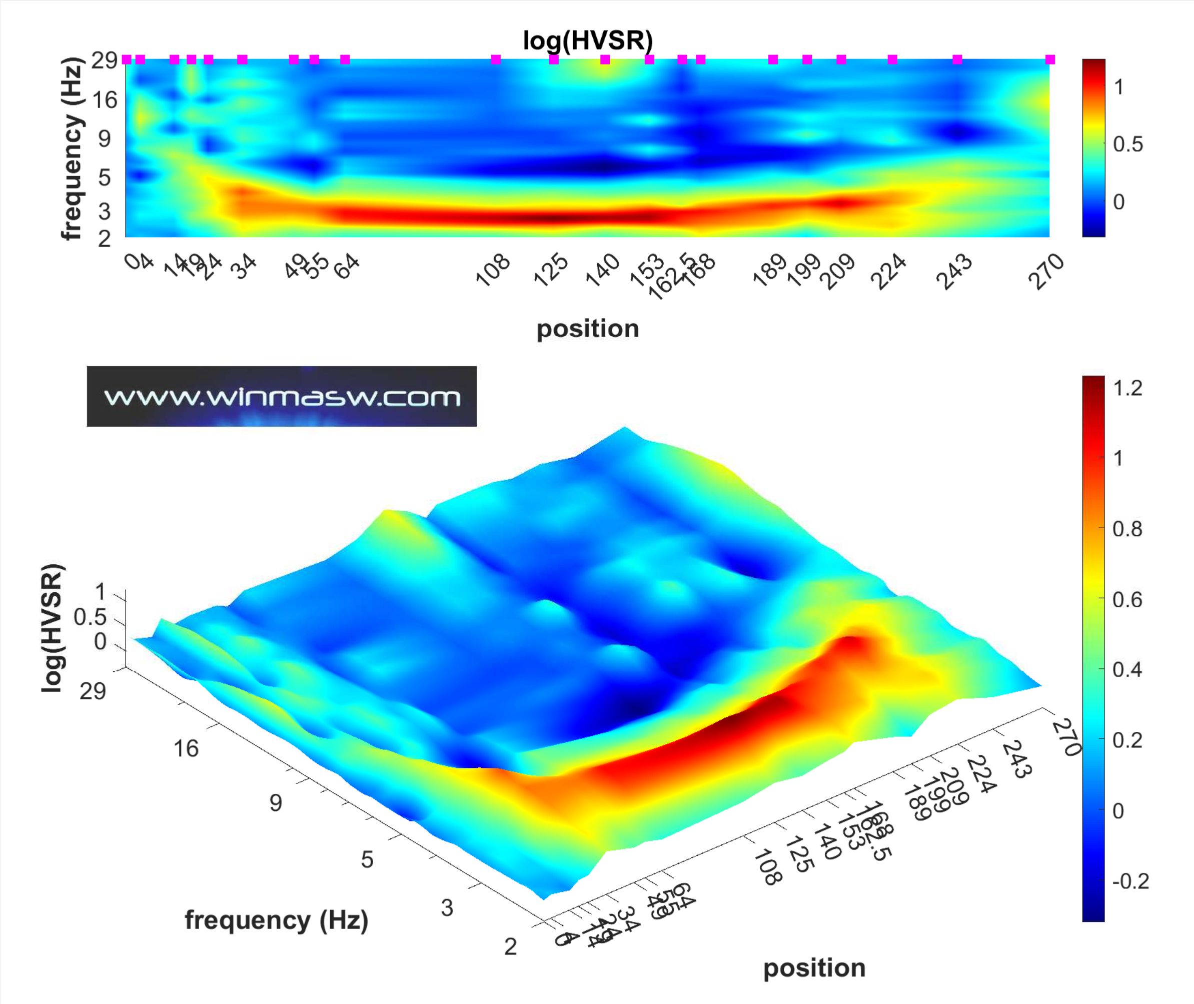
Three possible ways to do it (but you can maybe discover further ways to do it):

1) The most traditional way is the physical measurement on the field of the distances from the zero/reference point for instance with a ***measuring tape***;

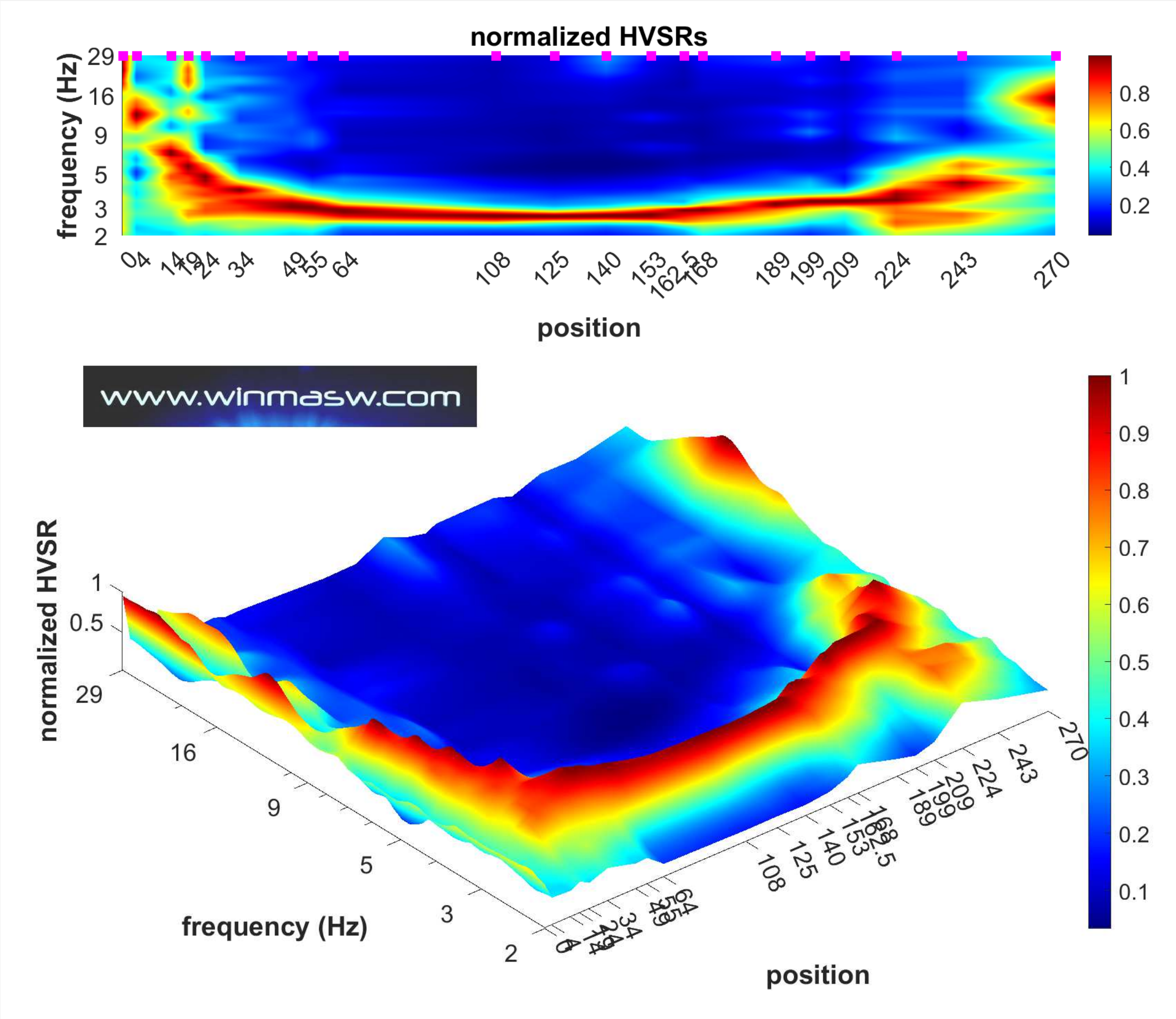
2) **Using Google Earth** and its tool for measuring the distances from one point [of course you need to know the location of each single measuring point];

3) Using the **“multiple geo-referenced photo” tool** available in *HoliSurface®* and *winMASW® Academy* – see relevant Appendix). Of course the precision depends on the device/smartphone you used on the field (and on the satellite cover of the site). Usually this approach is fine in case you are exploring vast areas and there is no need for very-high accuracy.

Plotting the logarithm of the HVSRs (so to better highlight the low amplitudes):

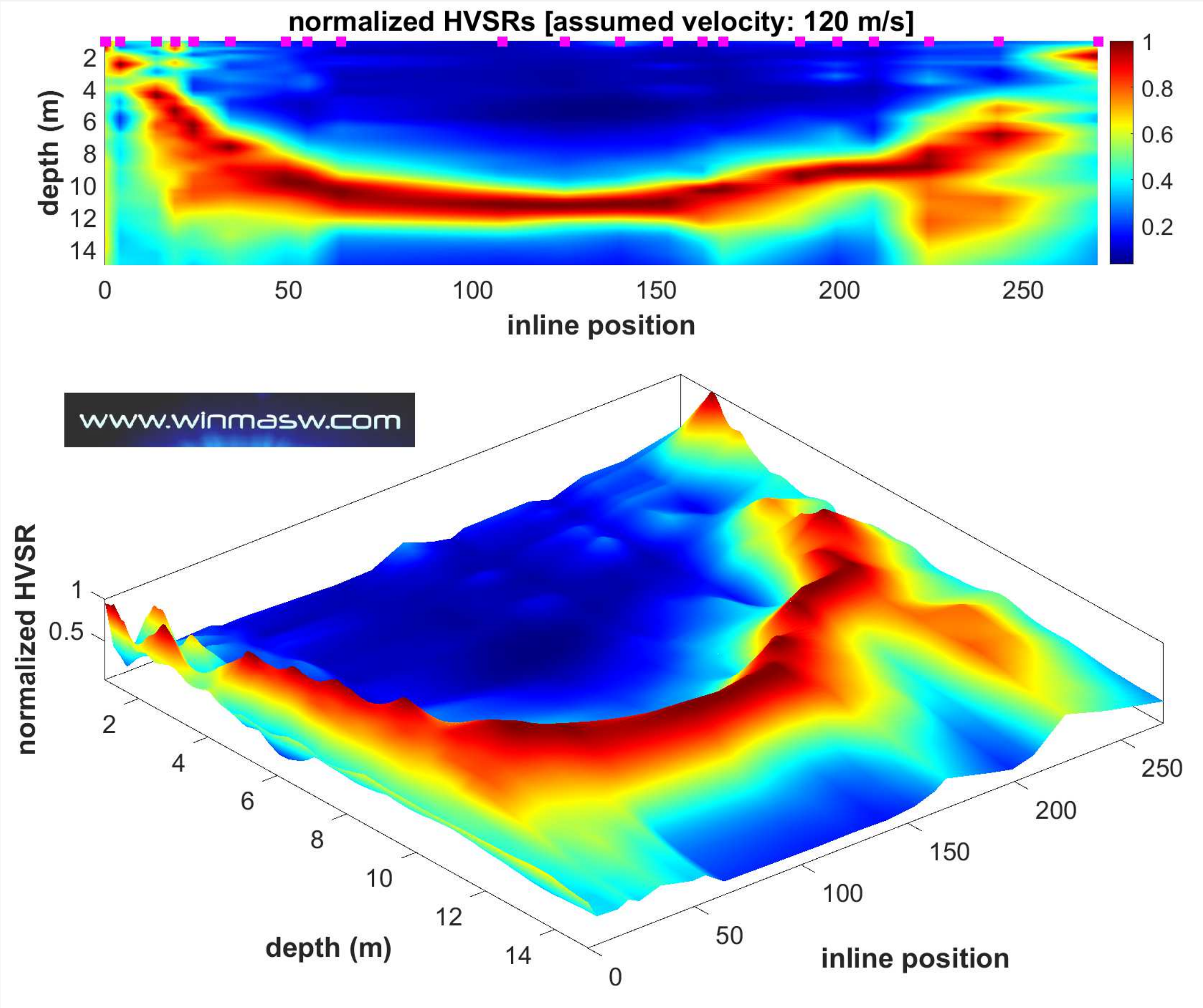


Plotting the normalized curves (to clearly follow the general trend):



Frequency-depth conversion

In order to convert *frequencies* into *depths* (which is useful in the case the subsurface structure is particularly simple and we can believe that a certain "signal" [peak or not] is related to a specific stratigraphic horizon), a dialog box pops up at the end of the processing and the user needs to input the average velocity (V_S) down to the signal we want to focus on.
This can happen for example in case of a valley in which we have a roughly homogeneous coverage characterized by a certain V_S that depends on the nature of the sediments. Using the relation f=Vs/4H it is possible to obtain what is shown in the example shown below, where the *bedrock* is covered by a series of soft sediments with a mean V_S equal to 120 m/s.
The V_S value to input should clearly come from dispersion data (in this case from HoliSurface analysis) and not from mere assumptions.



The image is saved in the working folder with a file name that also includes the input velocity used for the conversion. This is useful, for example, in case we have two or more peaks and, in order to obtain the trend of both the pertinent stratigraphic contacts, we perform two conversions (with two different velocities), the first with the mean V_S above the high-frequency peak and the second with the mean V_S above the low-frequency peak (in the working folder we will then obtain two files, related to two different velocities).

Appendix N: Setting up the HoliSurface acquisition system (seismograph, seismic cable(s) and HOLI3C geophone)

In order to record HS (HoliSurface), HVSR or vibration data with a single 3-component geophone (HOLI3C).

1) Connect the (female) connector of the HoliSurface seismic cable to the (male) connector of the seismograph (channels 1-12)
2) Connect the HOLI3C geophone to the end of the HoliSurface seismic cable (female connector of the HOLI3C geophone to the male connector at the end of the HoliSurface seismic cable).

See also the following video tutorial: **https://youtu.be/hqjJvAxL6xQ**

Remember that, if you want to record the active data for the HoliSurface [HS] technique, the arrow of the HS sticker [on the HOLI3C geophone] must point the source.

3) Now, launch the acquisition software (that you previously installed) and fix the acquisition parameters suitable and necessary for the acquisition you are going to do (remember that, if you properly connected the HOLI3C geophone [for HS, HVSR or vibration data], you just need to activate the channels 1 2 and 3).

This way, the data file you will obtain will have just three traces: the first trace is the vertical component (Z), the second trace is the radial (R) component (or NS direction), then third trace is the transversal (T) component (or the EW direction).

Two short notes

a. in case in just want to record some passive data (for instance to define the HVSR or to record vibration data for a structure/building – please see the "*Efficient Joint Analysis of Surface Waves and Introduction to Vibration Analysis: Beyond the Clichés*" book published for Springer), you can connect the HOLI3C geophone directly to the seismograph (without the HS seismic cable). If you connect it to the 1-12 connector, you need to activate the channels 1 2 and 3 (as we saw before while using the HS seismic cable). The meaning of the obtained traces will be the same: the first, second and third traces will be the Z, R (or NS) and T (or EW) components. On the other side, if you connect the HOLI3C geophone to the 13-24 connector, you need to activate the channels 22, 23 and 24, which (secularly/symmetrically) will be now the T R and Z components, respectively. In other terms, if you connect the HOLI3C geophone to the 13-24 connector, the three traces you will obtain will be: T (first trace), R (second trace) and Z (third/last trace).

b. As a matter of fact, in case we intend to perform an HS acquisition with a limited offset (say 2-4 m) it is possible to connect the HOLI3C geophone directly to the seismograph (without the HS seismic cable). This can be done in case we intend to investigate just the very shallow layers. Please, have a careful look at the following photo/example: the HOLI3C geophone (the blue small case on the left) is connected directly to the seismograph while the source is, together with the trigger geophone on the right (in this case the *offset* is 3.7 m and the joint analysis of the active data together with the HVSR allow to characterize the soil down to about 10-30 m).

c.

Appendix O: our HS seismic cable

Field operations puts any electrical/electronic component and any welding to the test. In the event that your HS cable (the 9+3 or 12 channel cable) shows signs that any channel is “gone," the PIN connection arrangement is shown below.

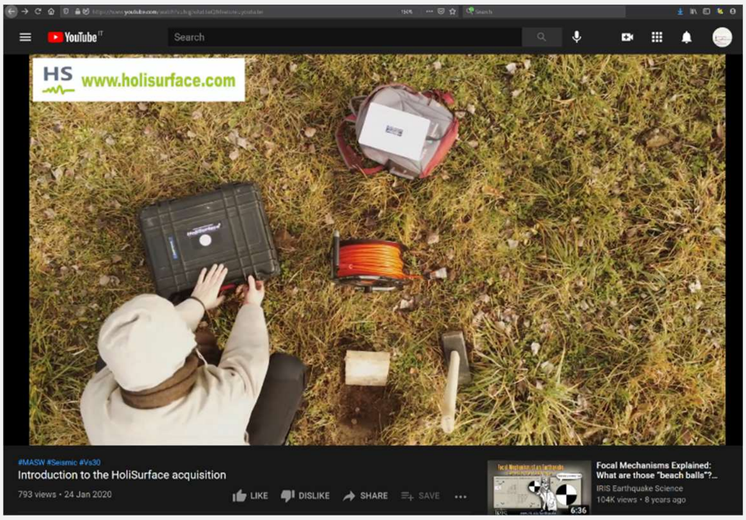
In this way, any electrician will be able to check and fix a possible problem, saving you the time to send it to us. For the 9+3 cable, the PIN sequence is shown in the picture below reported. The meaning should be clear to any electrician/electronics technician: the PINs for the 3C geophone are 24-23 (vertical component/UD), 22-21 (radial component/NS) and 20-19 (transverse component/EW).

If we notice that when we connect the 3C geophone to the terminal connector of the HS 9+3 cable, the EW (transverse) channel does not give signs of life, it is probably due to the fact that PIN 20 and/or 19 are detached.

To fix this, first try to open the end of the cable connector (the one with the male connector) and check if one of the wires (20 and/or 19) is actually detached (in that case just re-weld it). If everything on that connector seems to be fine (all the PINs are ok), the same can happen on the connector on the opposite end of the cable (the female one).

It is clear that, <u>before carrying out these operations on the cable, the 3C geophone will first have been connected directly to the seismograph</u> (without using the HS 9+3 channel cable). If this connection shows that there is a problem on the EW channel, it will be clear that the PIN problem does not concern the seismic cable but the cable/connector of the 3C geophone (with regard to which we will behave in the same way).

At the following link a short video introduction to the HS data acquisition (where you can see how useful is the HS seismic cable): **https://youtu.be/hqjJvAxL6xQ**



PINS of the 9+3 HS seismic cable

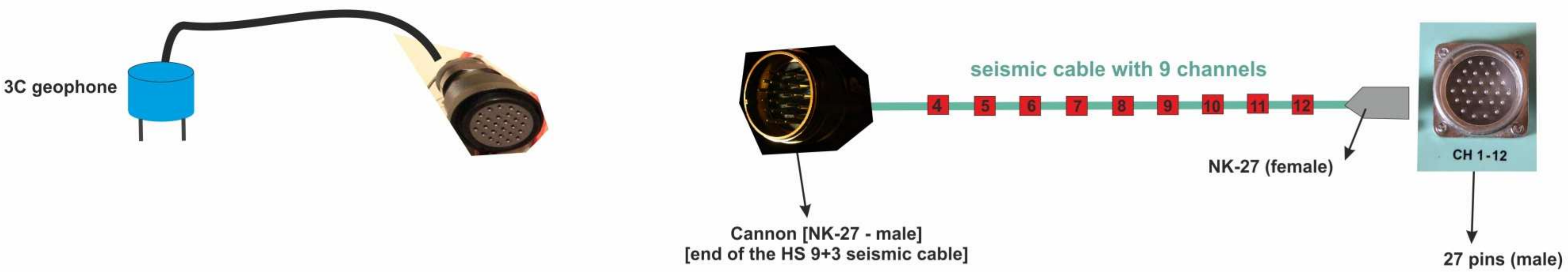
The PINS of the 3C geophone

24-23 (channel#1 - UD [vertical])
22-21 (channel#2 - NS [radial])
20-19 (channel#3 - EW [transversal])

1-12 connectors:

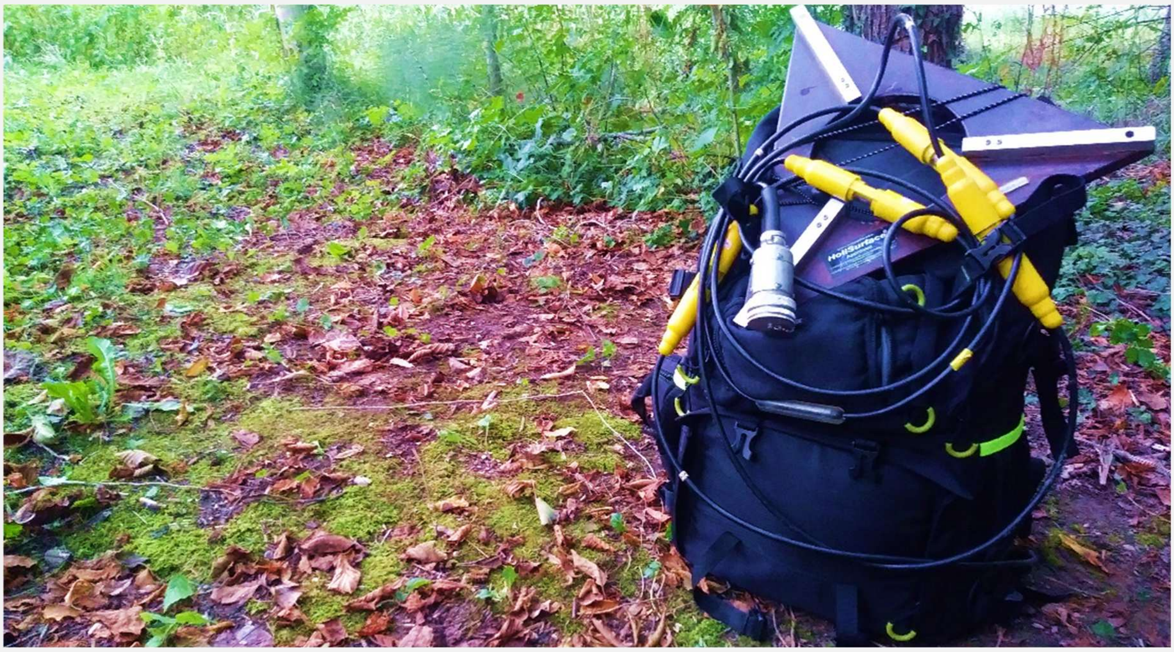
- PIN 24,23 = geophone n°1
- PIN 22,21 = geophone n°2
- PIN 20,19 = geophone n°3
- PIN 18,17 = geophone n°4
- PIN 16,15 = geophone n°5
- PIN 14,13 = geophone n°6
- PIN 12,11 = geophone n°7
- PIN 10,9 = geophone n°8
- PIN 8,7 = geophone n°9
- PIN 6,5 = geophone n°10
- PIN 4,3 = geophone n°11
- PIN 2,1 = geophone n°12

the 3C geophne is connected to the 9-ch seismic cable
(so, all together, we have 12 channels that enter into the seismograph):
the first three channels (pins 24-23; 22-21; 20-19) relate to the 3C geophone while the other 9 channels to the channels of the cable



How to easily obtain a multi-offset dataset (for *phase* velocity analysis - still often called "MASW)" with our *entry-level acquisition system* (4 single-component geophones + one 3C geophone)

The "basic" **HoliSurface® system** includes the HOLI3C 3-component geophone and 4 single-component geophones (the vertical ones are used for MAAM, but we can also work/provide with horizontal geophones, so to acquire the R and/or T components). Everything is easily packed in a backpack (see picture below).



We connect the HOLI3C geophone to the end of the HoliSurface® seismic cable (see, for example, the introductory video tutorial about the HS acquisition - https://youtu.be/hqjJvAxL6xQ) and the 4 single-component geophones (in this case the vertical ones) to 4 channels of the same seismic cable, as in the scheme shown below (for the adopted nomenclature, see our Springer and Elsevier books – **dx** is the geophone spacing and **mo** the minimum offset).
The HoliSurface® seismic cable is then connected to 1-12 block of the seismograph.

Note: if we are using a **9-channel HoliSurface® seismic case** and we connect the HOLI3C to its final connector, we can connect the single-component geophone to any/all of the 9 channels along the cable.
On the other hand, if we are using a **12-channel HoliSurface® cable** and have connect the HOLI3C geophone, the first three channels of the cable cannot be used since the signals from the 3C geophone travels along the first three channels (in this case channels/connectors 4 to 12 will be available, but not the first 3).

If we carry out only the first of the two acquisitions represented in the scheme below reported, we obtain a dataset with 7 traces [the 4 single-component geophones + the 3 traces of the HOLI3C geophone referring to the Z, R and T components].
If we then move the source away by a length equal to dx/2, we obtain a second dataset with similar characteristics but with different offsets/distances.
Let us imagine that we have 4 vertical geophones (the same ones used for the MAAM).

In the example shown below, the geophone distance (**dx**) and the minimum offset (**mo**) of the first datasets are both set equal to 7 m, while for the second acquisition the source is moved to 10.5 m from the first geophone (**mo** = 10.5 m). This value is simply the summation of the previous **mo** value (7 m) + half the geophone distance (7/2 = 3.5).

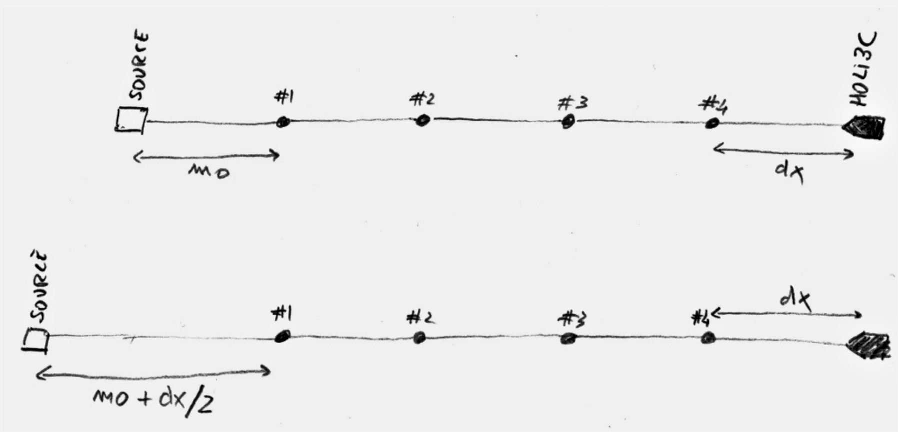
Removing the "wrong" traces

Now, in winMASW® Academy, from the *single-component analysis* panel, we upload the first dataset (where **mo** = 7 m). In order to obtain a homogeneous dataset (remember that now it also contains the R and T traces of the HOLI3C geophone), we have to remove the R and T traces of the 3-component geophone (HOLI3C). If we have recorded the data correctly, the second and third traces have to be removed. The first traces refers to the Z component of the HOLI3C 3-component geophone and must be kept (since along the cable we connected 4 vertical-component geophones). To remove these traces click the "**zeros/flips/remove**" button and follow the procedure aimed at removing the second and third trace.

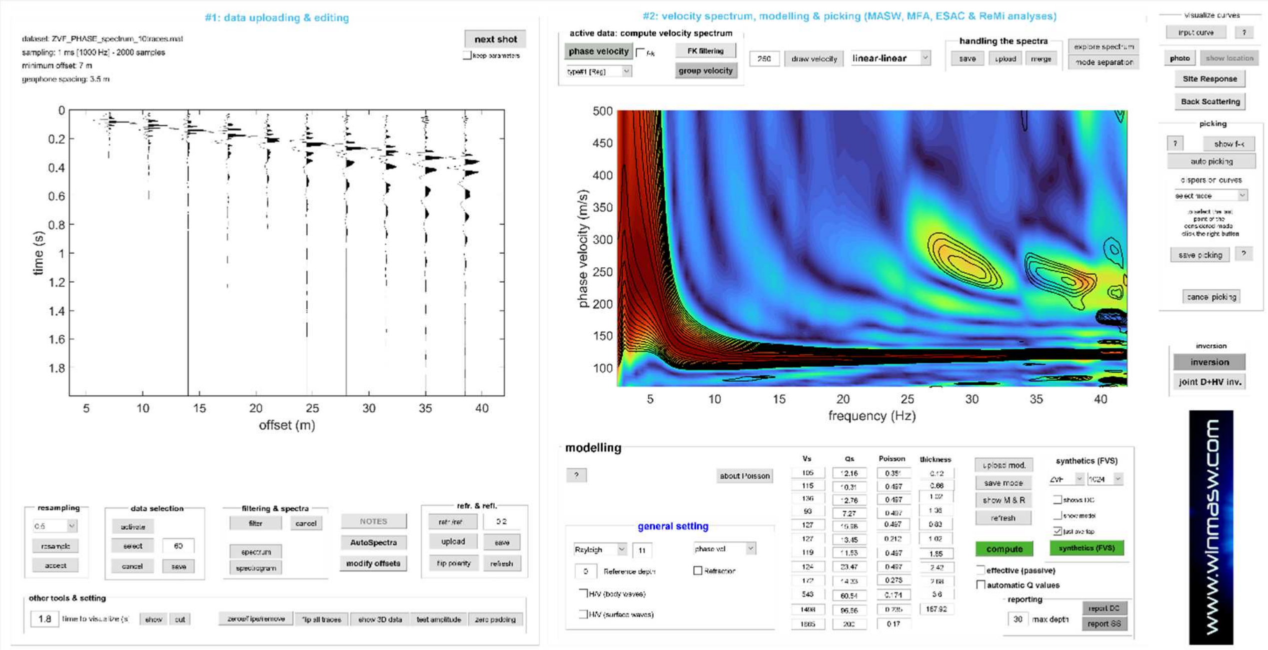
Modifying the offsets

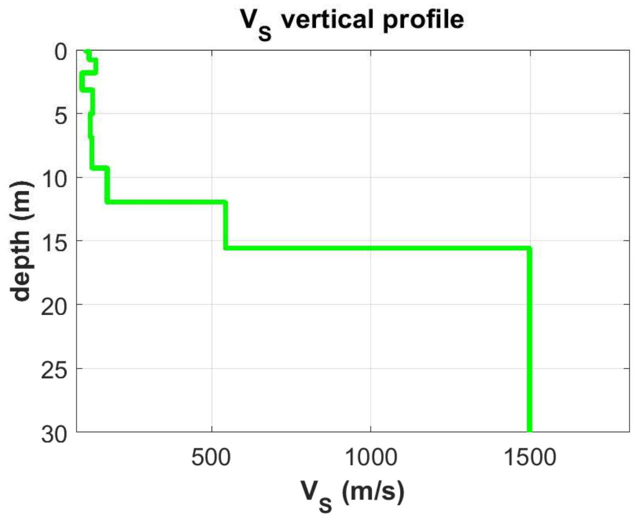
Having removed 2 traces, we must now modify the offsets by entering the correct values ("**modify offset**" button). Once we do it, we obtain a proper 5-trace dataset (referring to the same component) with the correct offsets.

If the array is not particularly long and we are not too interested in high frequencies, a 5-traces dataset may be sufficient (*spatial aliasing* is not a big issue - see e.g. Dal Moro et al., 2003) but if we want to double the number of traces (halving the geophone distance), we must also have recorded the second dataset (see image below) and perform the same operations described above for the first dataset.
At this point we have two 5-trace datasets (in this case all the trace refer to the Z component but we usually recommend to work with the T component, i.e. Love waves) that we can assemble together with the "**combine 2 datasets**" tool available among the winMASW® utilities.



In the following, an example of the 10-trace dataset obtained following this procedure (the dataset is analysed according to the FVS technique – see black contour lines that refer to the V_S model shown below and match very well the field phase-velocity spectrum [colours in background]).



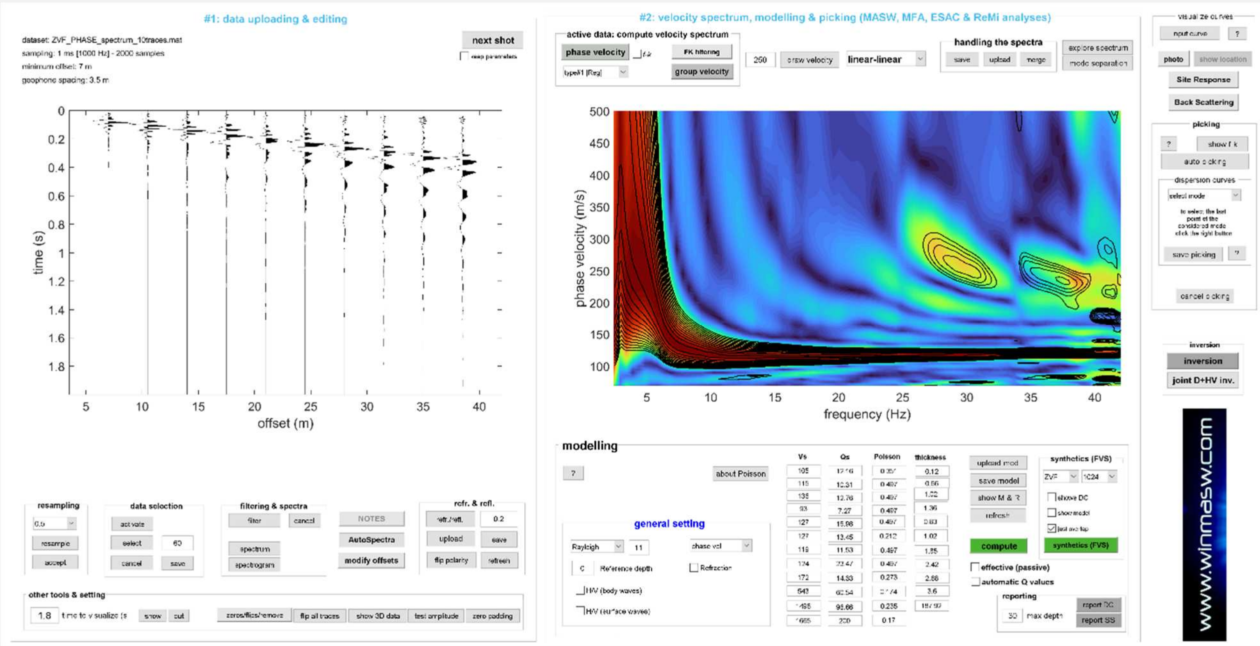


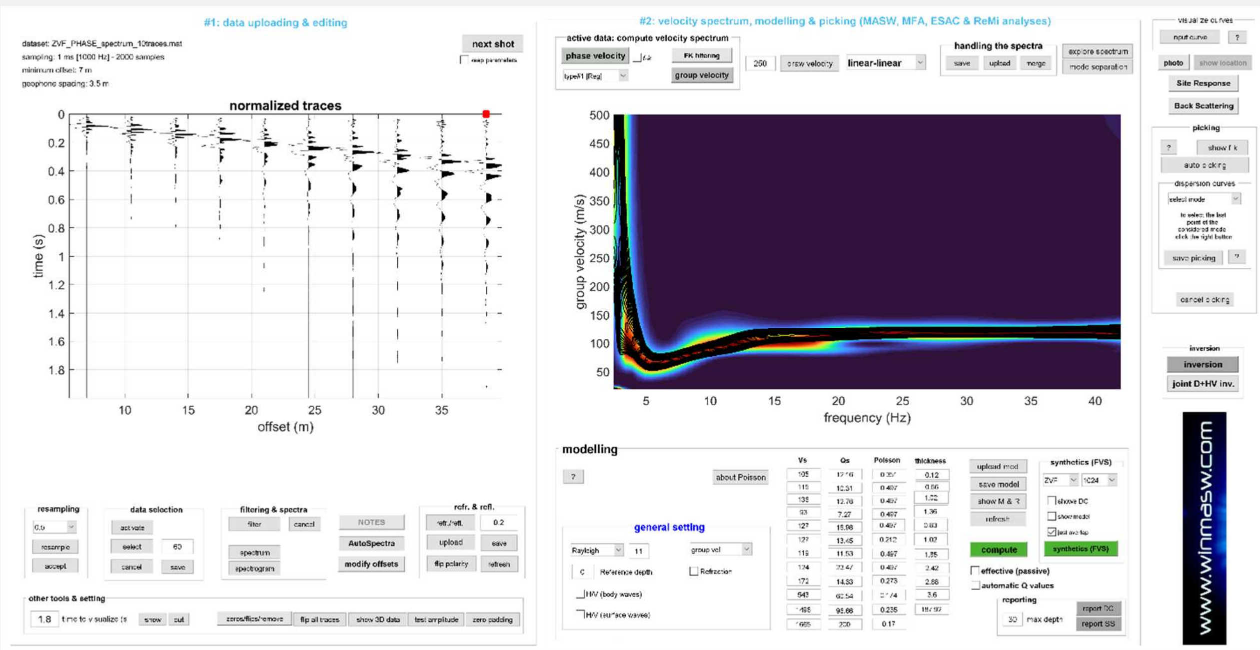
It is important to remember that for the **analysis of phase velocities ("MASW") it is often recommended to use horizontal geophones which allow working with Love waves (as well as the radial component of Rayleigh waves).**

The procedure is the same, with the only difference that if we were working with the T (transversal) component, the traces referred to the HOLI3C geophone to be eliminated would not be the second and third (as in the previous example) but the first and second (which, if the acquisition is performed according to the scheme we recommend, are the Z and R components respectively).

The bottom-line point

Of course, the question to address is always the same: **why working with multi-offset data** (necessary for the determination of ***phase*** velocities) **when the same results can be obtained with the *group* velocities** (which can be computed using a single trace)**?**
Here is the **FVS analysis of the *phase* velocities** (**above**) computed considering all the available **10 traces** and the **FVS analysis of the group velocities** (**below**) computed considering **ONLY the last trace** (see red square at the last trace). The **subsurface model is the same.**

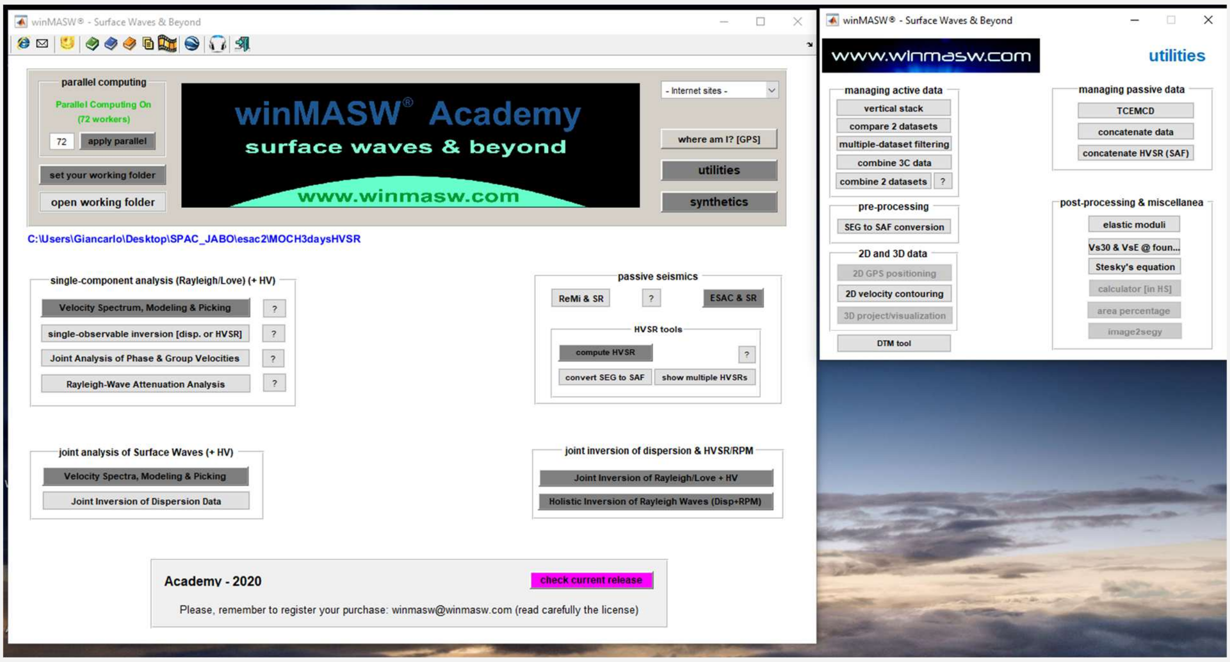




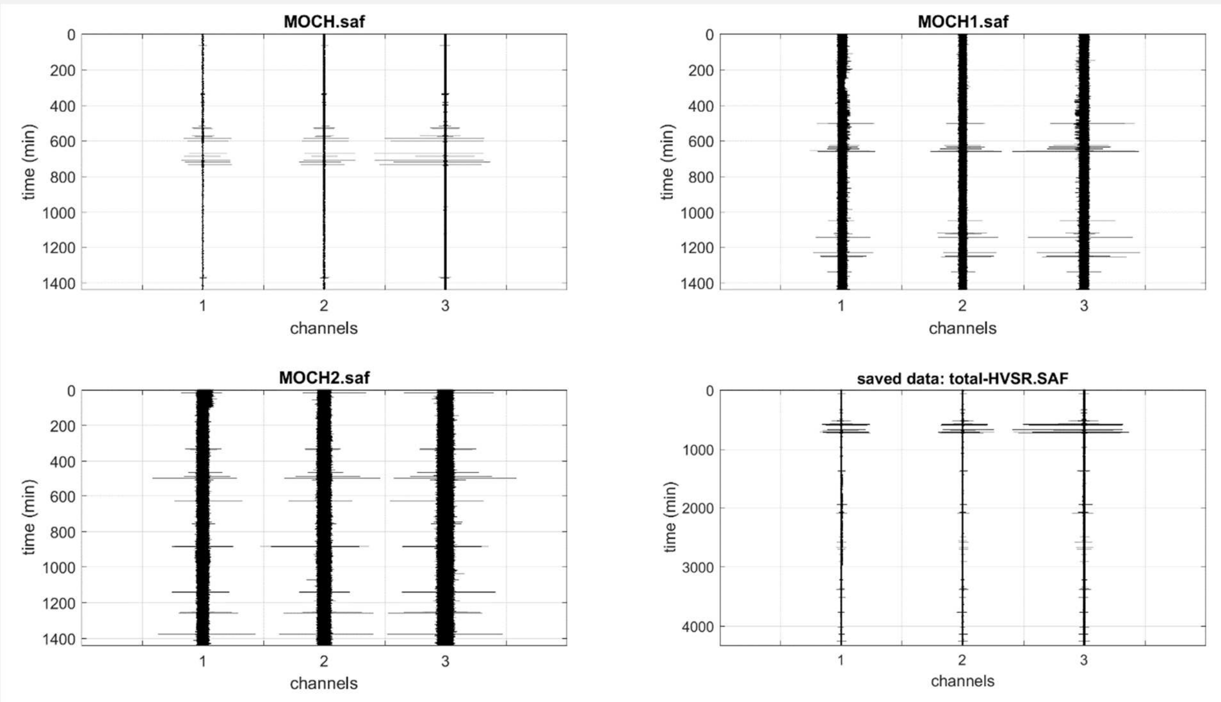
The answer to the bottom-line question cannot therefore be found by following logic and technical-scientific evidences, also considering that a professional/company is not paid to "perform a MASW" but to determine V_S values (following the most appropriate method according to the site and objectives – and there are really several possible methods [see the manual of the HoliSurface® software application]).

Appendix P: 3-component data concatenation (SAF format)

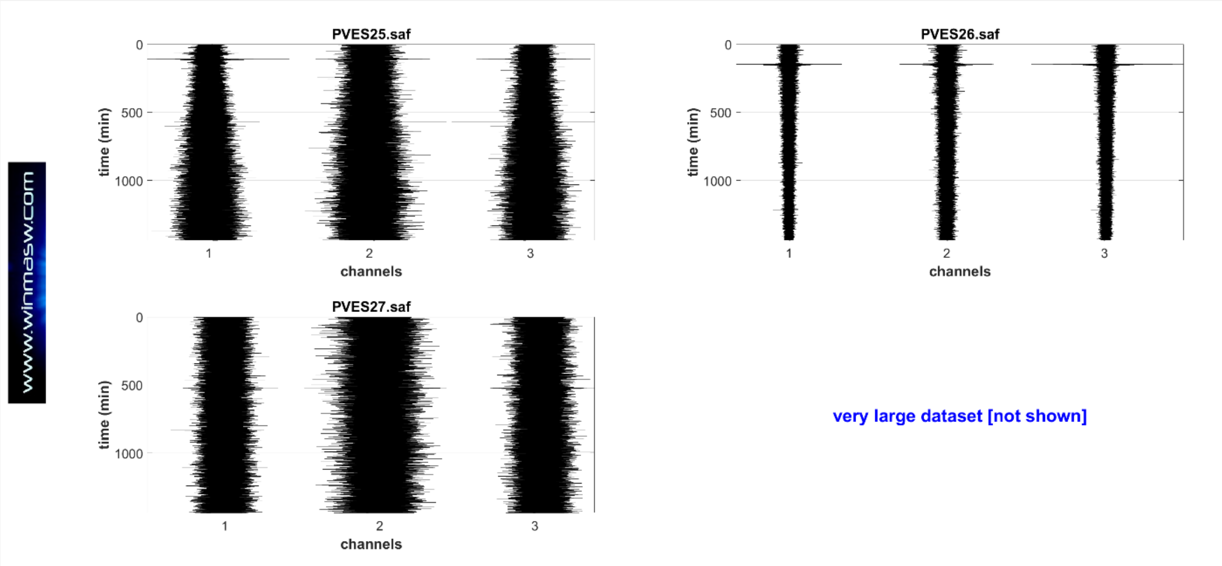
Among the *utilities* (in the "managing passive data" group), you can also find the "concatenate HVSR (SAF)" tool.
By clicking that button you will be able to upload a series of .SAF data (the standard format for microtremor data for the HVSR computation) and you will automatically obtain a (single) "total-HVSR.saf" file with all the uploaded data.
In the example here below, we uploaded three SAF files (each 24h long) so to obtain a single file with 3-day data.



Once the single SAF *files* are uploaded, you can specify the file name for the *total* dataset (again as a SAF file).



In case the *dataset* is exceedingly large (due to a high sampling frequency and/or because of a very long recording) the final (total) *dataset* is not shown (but it is clearly saved with the file name provided by the user):

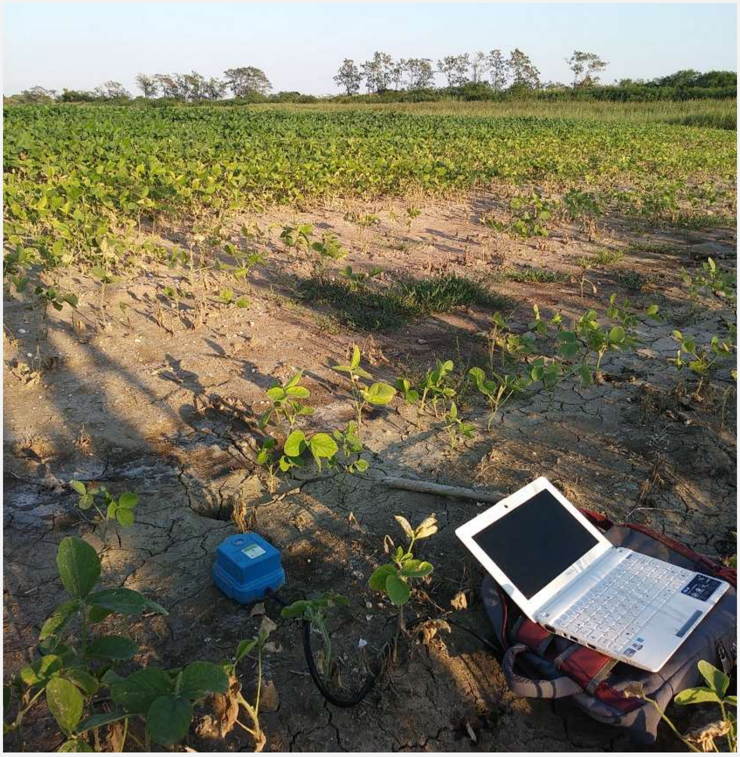


Appendix Q: managing multiple geo-referenced photos [exploration of wide sections]

This *tool* (among the utilities of winMASW® Academy and HoliSurface®) is meant to efficiently manage the exploration (especially via HVSR) of large areas/profiles, where the accuracy of the positioning is not an issue and a relatively-large error (usually 2-4 m) does not represents a real problem.
The point to address through a concrete example. Let us imagine we want to highlight possible lateral variations along a relatively-long profile via passive data (HVSR / ESAC or interferometry). Let's us now here consider the HVSR case.

step#1 (in the field)

At each measurement position of the 3C geophone take a picture with our ***smartphone***, action Camera or whatever - see the section "GPS data in our software applications (winMASW®, HoliSurface® & ELIOVSP®)".



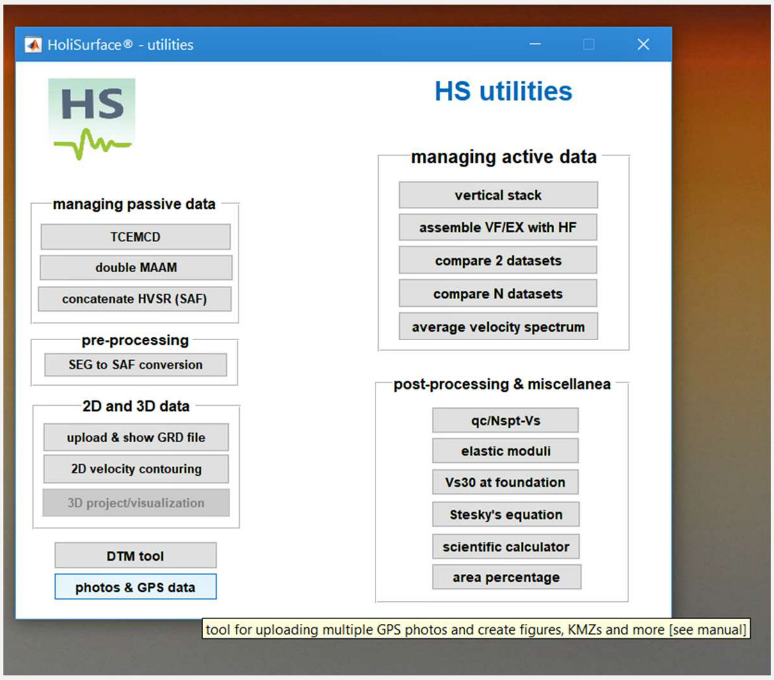
Let's imagine we want to consider 12 points/photos (in this case along a profile more or less 170m long).

step#2 (at home)

First we better **name (re-name) the photo files in a sequential way**. For instance: 1_site1.jpg; 2_site2.jpg; 3_site3.jpg; 4_site4.jpg etc.

step#3

Once we put all the photo files in the same folder (to set as working folder from the main panel of *winMASW®/HoliSurface®*, we can now click the **"photos & GPS data" button** (among the utilities) and upload the twelve (12) photos at once (multiple-file selection possible with the ***ctrl* button**).



As an alternative to uploading the 12 photos, it is also possible to create and upload a **"project file"** in the form of a trivial ASCII file (therefore with the.txt extension) in which the files of each photo are written (one per line).

Here is an **example of a project file** (example "project_file.txt") for uploading 4 photos:
2_20210826_181153_HDR.jpg
4_GPS_2021-09-08_12-07-36-968.jpg
9_2021-09-08_12-12-29-076.jpg
13_20210831_160123.jpg

What is the difference between uploading the *n* images and using a project file?
Only one (but from a practical point of view very important): if the files/images are uploaded directly, they must be re-named as indicated above (in case we want the correct sequence and therefore the correct lengths/distances).
If, on the other hand, we use a project file, it is not necessary to name the image files sequentially because the sequence will be the one indicated in the project file itself. In the latter case, the images may therefore have any name (e.g. sito1.jpg, 2ns_site.jpg, 2021-09-09.jpg etc.).

In any case you will automatically obtain the following figures/outcomes (automatically saved in the working folder):

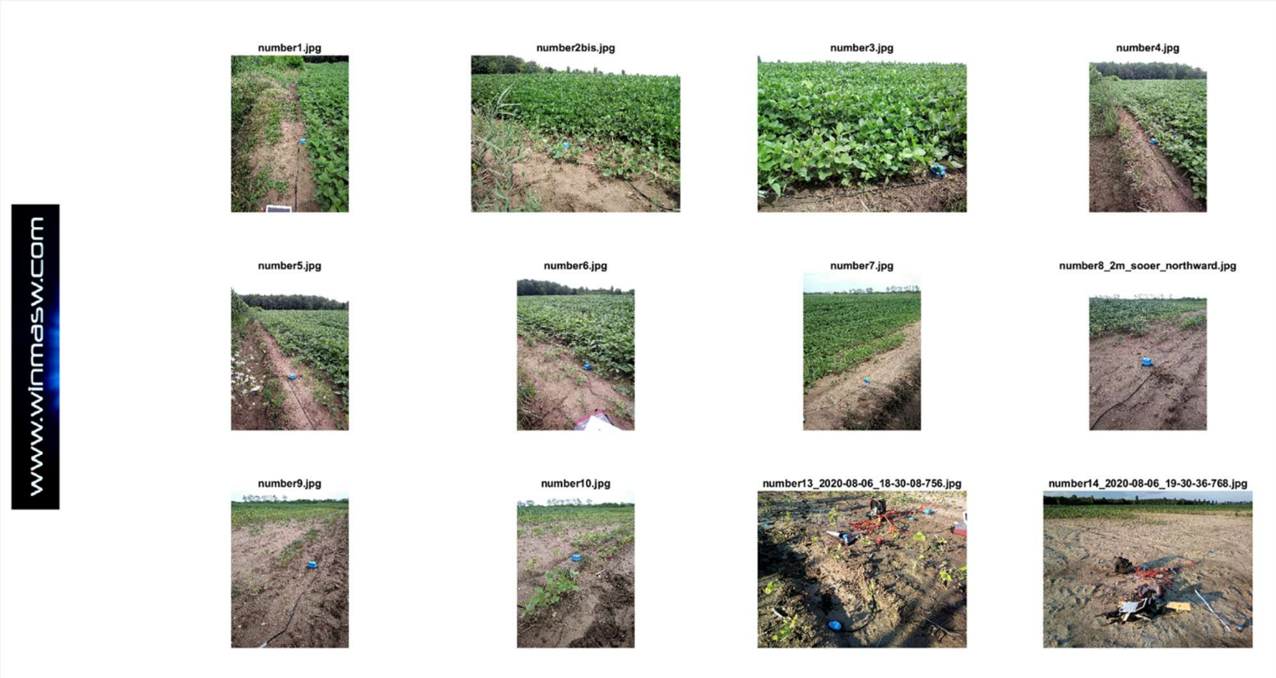
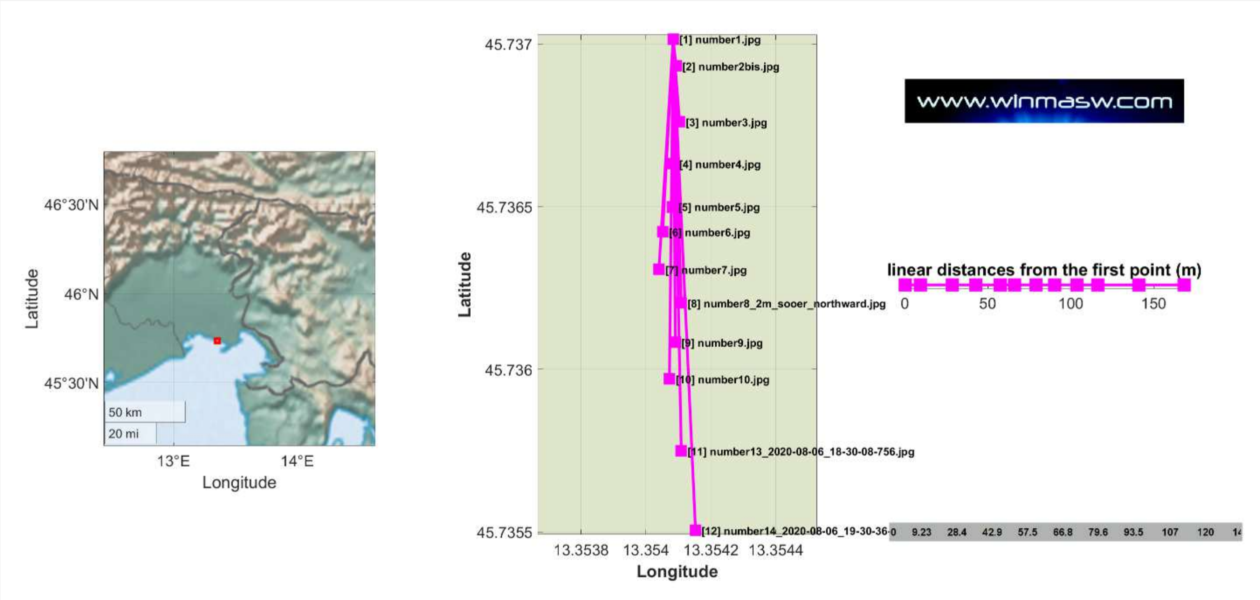


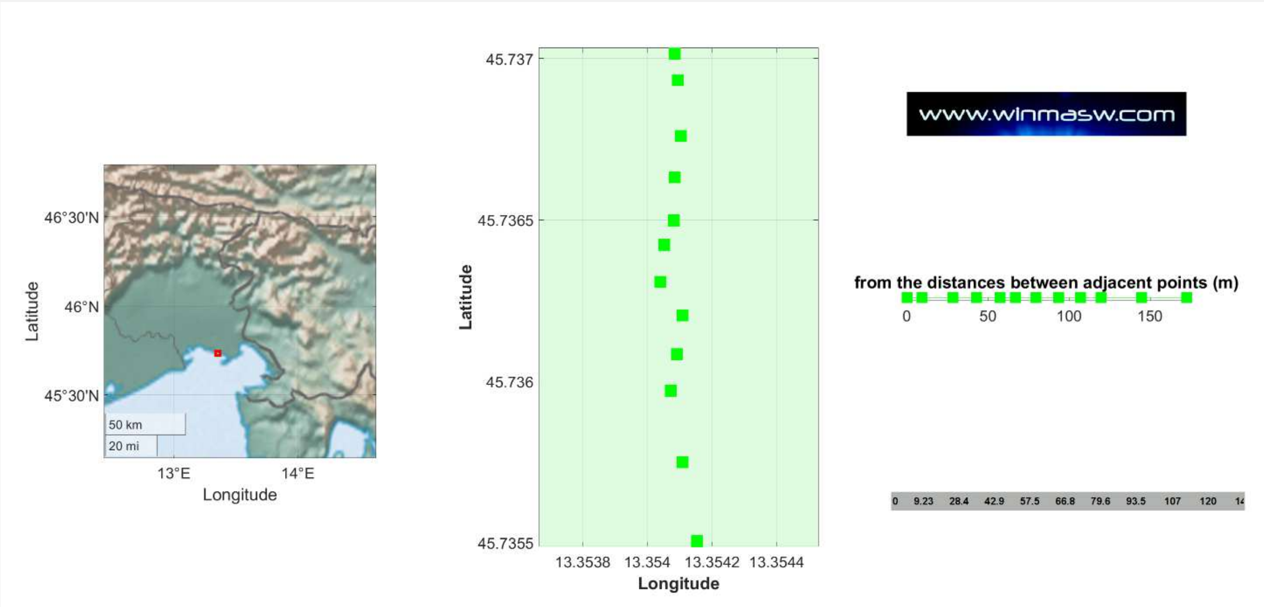
Figure with all the uploaded photos

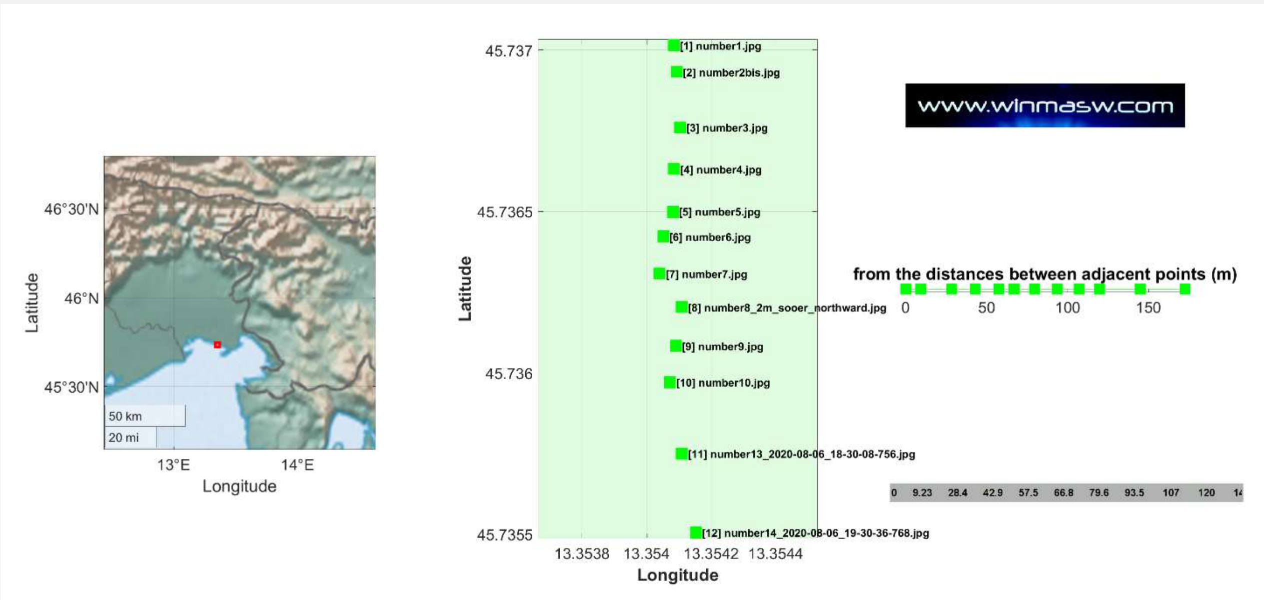
In the working folder, for each photo you will obtain a "**summary figure**" and a **kml file** with the same name as the uploaded photos (e.g. "SiteLocation_4_number4.kml") [of course they can be then easily uploaded/used in **Google Earth**].

Three figures with the same meaning: the position of the twelve sites with three slightly-different ways to visualize such information (you can choose the one that better suits your needs and taste). **In the lower right corner are reported the (editable) linear distances from the first point. You can highlight the whole sequence and copy and paste the obtained values wherever you need to do it.**

For instance you can copy and paste such a sequence (i.e. the inline positions) in the *project file* that can be used to automatically batch processing all the HVSR data (see Appendix "batch processing of multiple HVSR data" – fifth line of the project file). Needless to say that you can modify/correct large errors due to inaccuracy of the device you used to take the snapshots in the field.





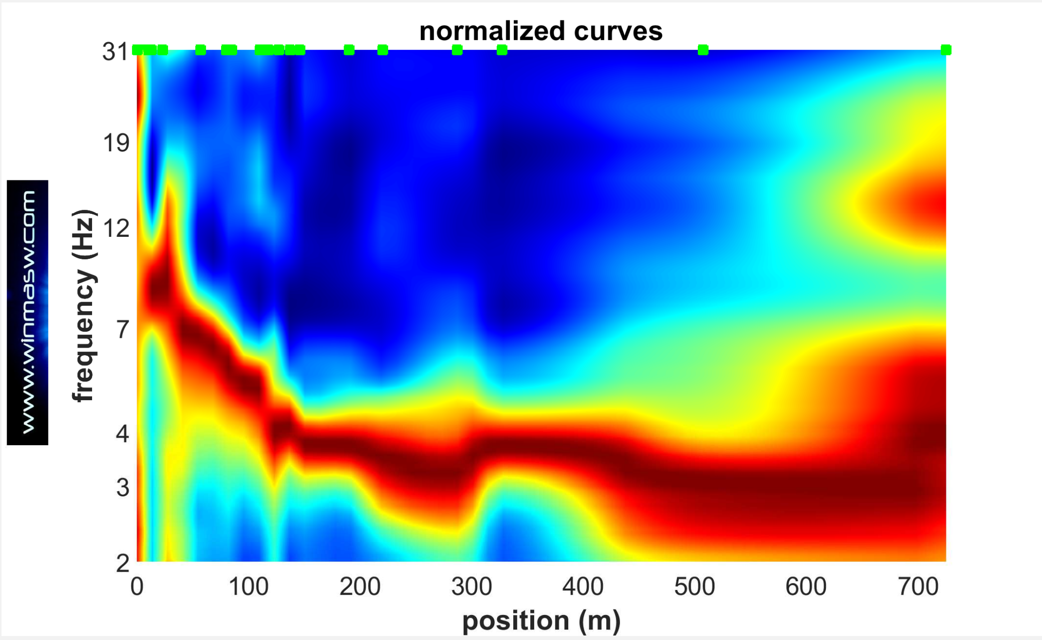


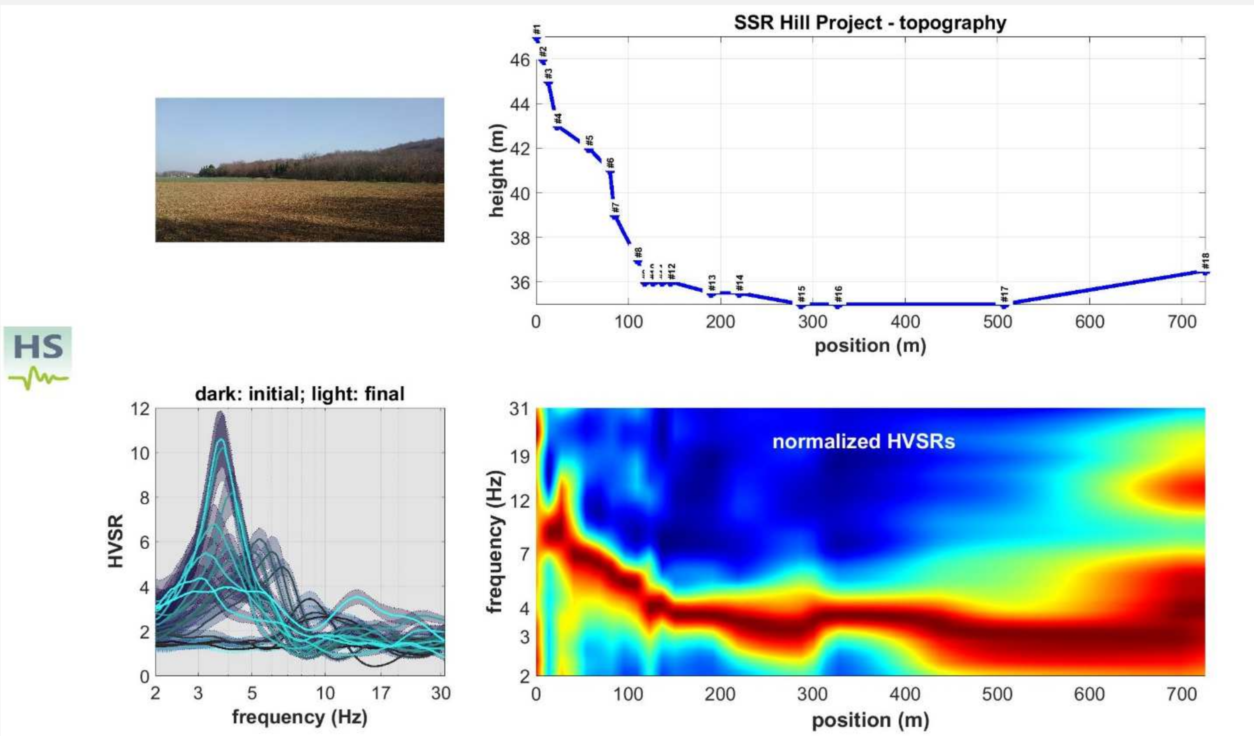
The following HVSR 2D section is just an example of a concrete application of the distances obtained considering the procedure described in the Appendix "**batch processing of multiple HVSR data**".

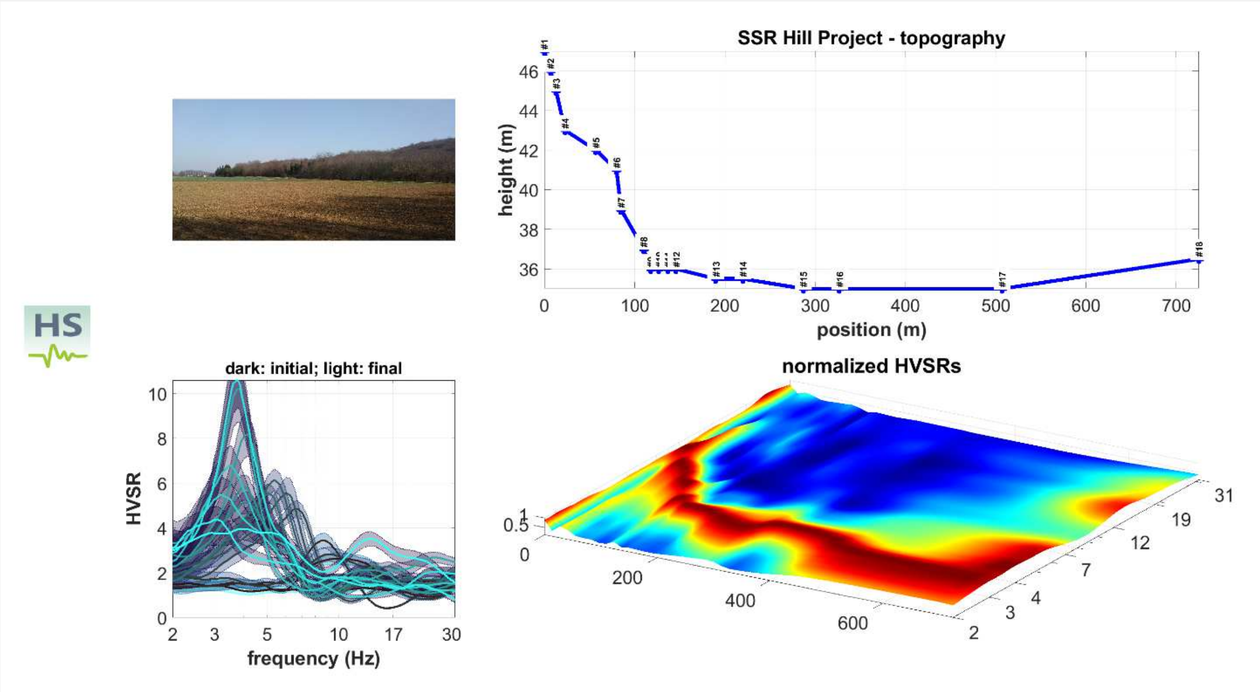
In simple terms: a series of HVSR data were collected along a profile. For each point a geo-referenced picture was taken.

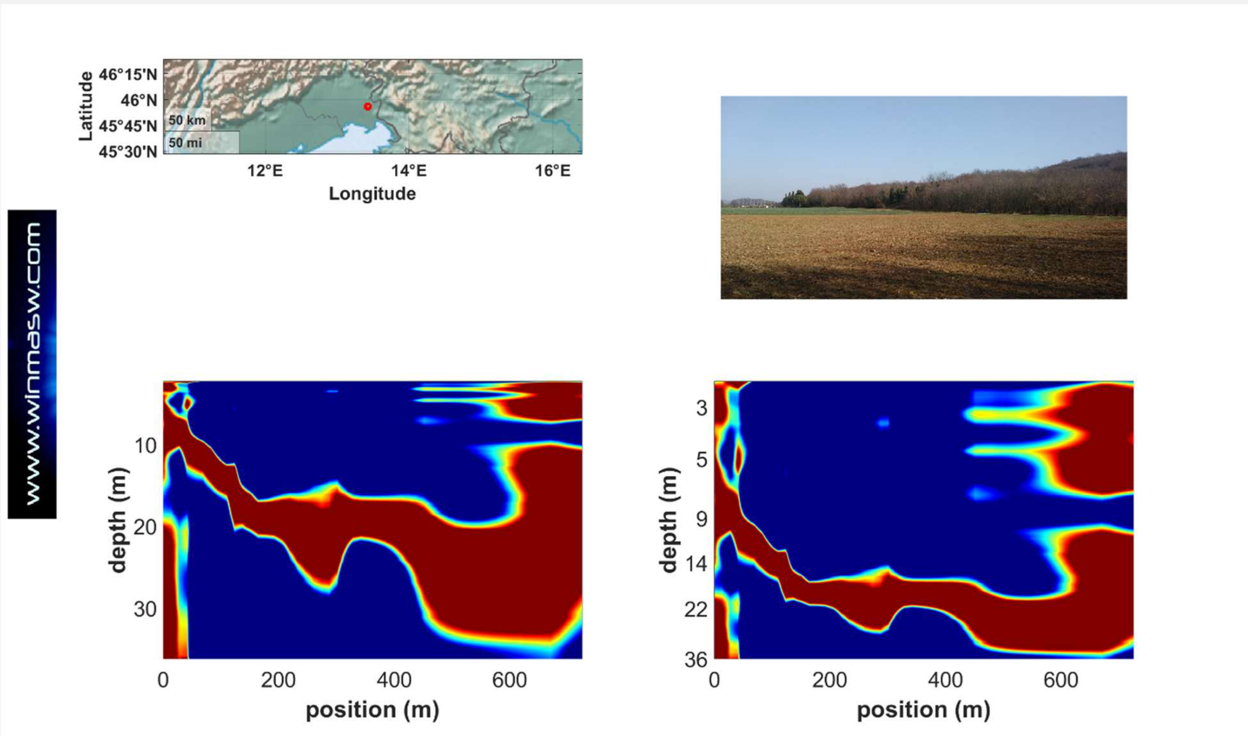
The photos were uploaded with the utility described in this Appendix and the point locations along the profile was therefore obtained (of course a simple straight profile is considered).

In this case the length of the profile is about 700 m and the considered number of points is 18 (with a better focus in the first 350 m [higher point density]).





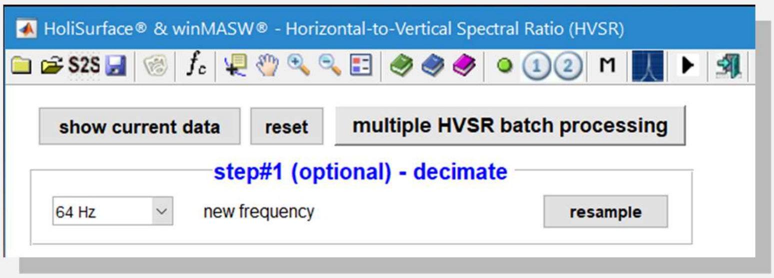




Please, see also the Appendix “**batch processing of multiple HVSR data**”.

Appendix R: batch processing of multiple HVSR data [also for 2D reconstructions]

Processing a large amount of HVSR data can be time consuming. In order to do it automatically (thus saving time and energy) you can use this tool (available in winMASW® Academy and HoliSurface®). A very simple ASCII project file need to be written and saved so to be uploaded using the **"multiple HVSR batch processing" button** in the HVSR panel.



All the files to be processed must be stored in the same folder where you also have your project file.

An example of data and project file is provided together with the winMASW/HoliSurface software in the "**Self_Training_Data_Dissemination**" folder (see subfolder "Automatic_2D_HVSR_section_data_and_projectfile").

The **project file** is a simple ASCII files with the following structure/content (try to open the "project_file_18points.txt"provided file):

```
The Hill Project
2D HVSR section#1
290 350
0
0  7  13  23  57  80  85  110  118  127  137  146  190  220  287  327  507  725
47  46  45  43  42  41  39  37  36  36  36  36  35.5  35.5  35.  35.  35  36.5
firstPOINT.SAF  1 1 2 3  photo_site1.jpg
secondPOINT.seg2 1 1 2 3  photo_site2.jpg
locationTHREE_doubleHOLI3C.seg2 1 1 2 3  photo_site3.jpg
locationTHREE_doubleHOLI3C.seg2 2 6 5 4  photo_site4.jpg
…
```

Meaning of each row

First line: project name

Second line: just a note for you

Third line: the average velocity (VS) between the surface and the horizon/contact you want to follow (equivalent VS). This can be for instance the contact between a shallow soft (e.g. silt) layer and a gravel layer (this kind of contacts can create very large HVSR peaks) or the contact between a quaternary layer and the bedrock. Please, remember that an HVSR peak does not necessarily refer to the *bedrock*. If you insert two (or more) values, the conversion from frequency to depth will be accomplished for all the reported values.

Forth line: this is the "hibernate computer" flag. If "1" (one) at the of the batch processing the computer will automatically hibernate (this can be useful for instance in case you are batch processing a large amount of data and want to launch the procedure and forget about this); in case the value is "0" (zero), at the end of the procedure the computer will not hibernate.

Fifth line: the inline position of each point (in meters) [see also Appendix "*Managing multiple geo-referenced photos [exploration of large areas]*"]

Sixth line: the topography for each point (in meters). In case you are not interested in such a feature, just put one single zero (0) value.

Seventh (and successive) line(s). Along these lines must be provided four (4) information:

1) the filename of your microtremor data (considered both SAF and seg2 formats)
2) the number of the considered 3C geophone (a seg2 file can contain data about more than one 3C geophone! – see later on)
3) the sequence about the vertical, NS and EW traces for the considered geophone
4) the filename of a georeferenced jpg photo (see pertinent section of the manual). In case you do not have it, just write "photo1.jpg" [you *must* write something!]

About the "considered 3C geophone" number the point must be clear

With some acquisition system you can record several "HVSR" data at once, at multiple locations. For instance, with our system, you can easily **connect two HOLI3C (3-component) geophones** and consequently record the data to obtain the HVSR curves at two different locations.

When you are using two (or more) geophones at once, your file will clearly contain more than just 3 traces. Let us here consider the simple case of 2 3-component geophones

recording simultaneously the data. You will clearly have a final **dataset/file with 6 traces (3 about the first geophone/site and 3 about the second geophone/site)**.
In order to easily manage this sort of multiple-HVSR data in your project you can easily specify/define the meaning of your data file in the project file. If, for instance, the file is named "locationTHREE_doubleHOLI3C.seg2", you need to specify the meaning of the traces like this:

locationTHREE_doubleHOLI3C.seg2 **1** 1 2 3 photo_site1.jpg
locationTHREE_doubleHOLI3C.seg2 **2** 6 5 4 photo_site2.jpg

This way we tell the software that the first three traces [1 2 3] are about the first geophone (see the red number) while the traces 6 5 4 are about the second geophone (see the red number).
Of course, in case we are dealing with a single geophone we simply need to write something like "1 1 2 3" (in case the trace sequence is UD NS and EW) or "1 3 2 1" (in case the trace sequence is EW NS UD) [this depends on your *acquisition system*].

A further possible situation is when the HVSR must be computed while considering the data recorded considering a joint HVSR+MAAM set up (like in the following picture). For those who are not familiar with this technique, MAAM stands for *Miniature Array Analysis of Microtremors* (see our *HoliSurface* software application page and this video).

In this case our data file will have 7 traces: 3 about the 3-component geophone and 4 about the 4 vertical geophones used for the MAAM.

Also in this case we need to properly tell the software which ones are the UD NS and EW traces to use for the computation of the HVSR. If, for instance, the 3-component geophone was connected to the first 3 channels of the seismograph the line will be something line:

2020-08-06_18-32_point13_HVSR_MAAM110.seg2 1 1 2 3 photo1.jpg

On the other side, if the 3-component geophone was connected to the last channels (so the first 4 channels were used for the 4 vertical geophones), the line could be for instance something like:

2020-08-06_18-32_point13_HVSR_MAAM110.seg2 1 7 6 5 photo1.jpg

In this case the system and the configuration is such that the 7th channel is about the UD (vertical) component, the sixth channel is connected to the NS component and the fifth channel to the EW component.
It is therefore of paramount importance that you know exactly how your *acquisition system* works (remember we provide all the necessary field equipment and software necessary for any kind of seismic application, please visit our **web site**).

Outputs:

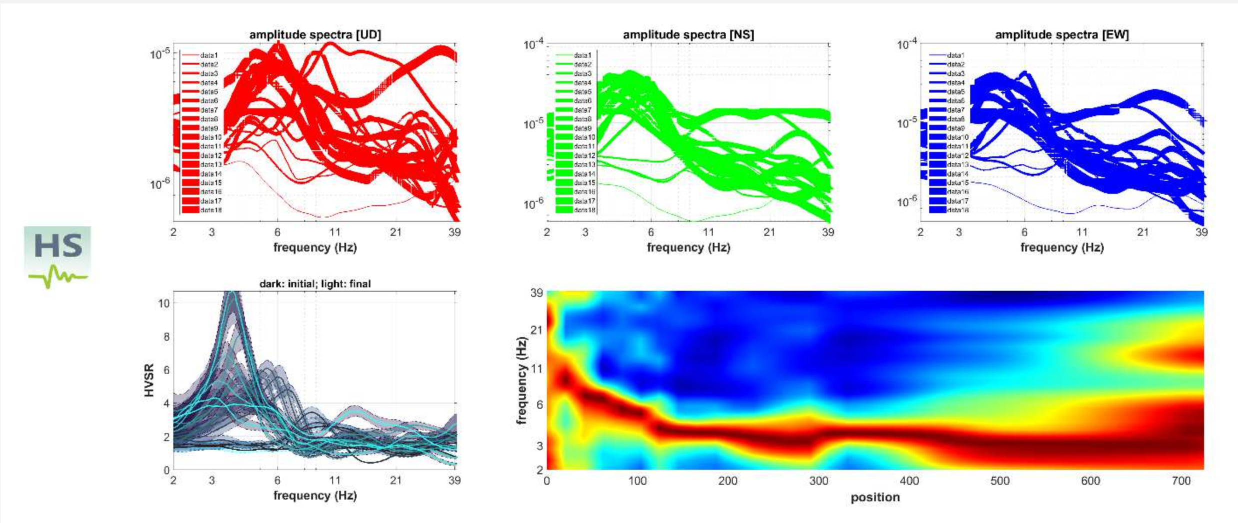
At the end of the procedure you will obtain a series of folders where the full analysis of each dataset is stored. For instance, if the 17th file is named "8_2020-03-03_15-09HUNTERbis" the full analysis will be reported in a new **folder named** "HVSRoutput_17_8_2020-03-03_15-09HUNTERbis".
You will also obtain a series of figures with the reconstructed 2D data (see next pages).

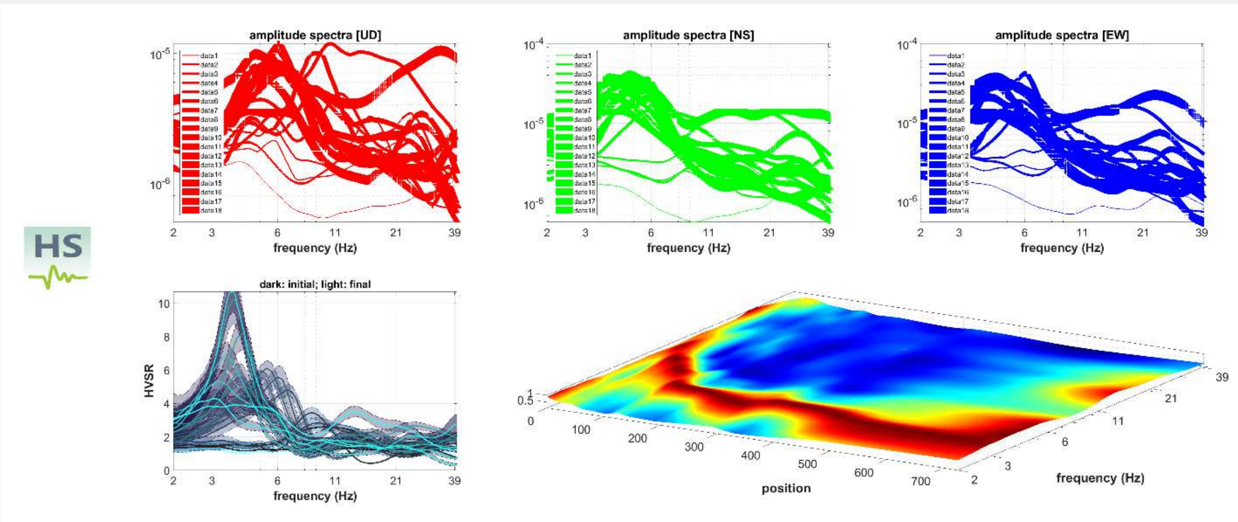
Recommended procedure (try to do it with the provided data):

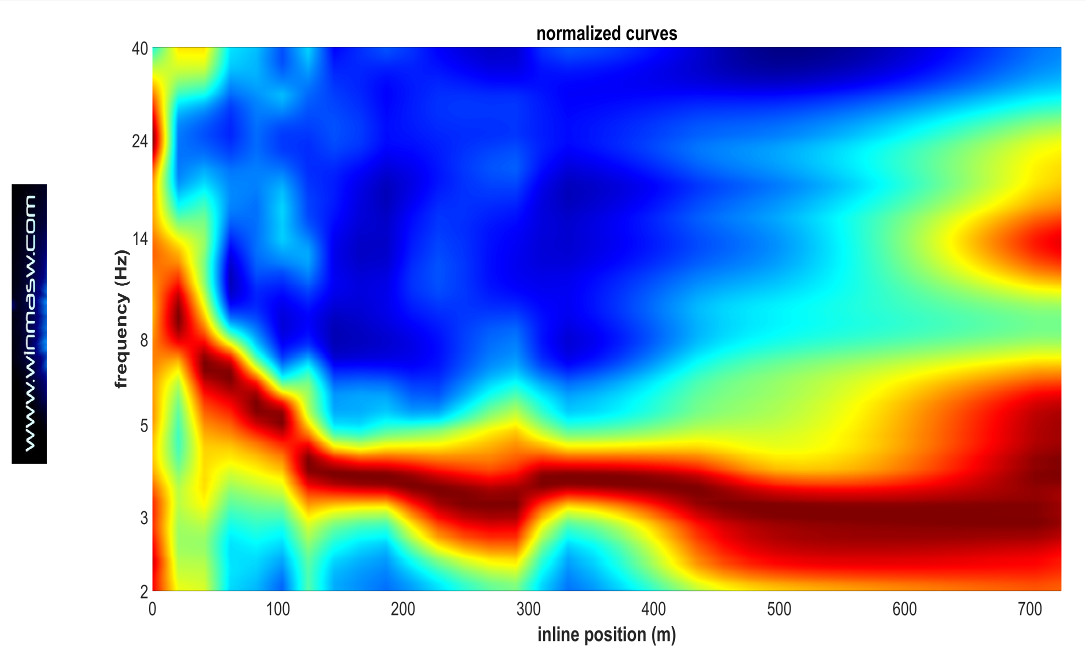
1) **set the working folder** (where all the data and project files are stored)
2) **upload a geo-referenced photo** of the area (this is optional but recommended)
3) **upload the first dataset** and do some processing aimed at defining the best parameters to use during the processing of all the data that will be batched processed
4) once the best processing parameters are chosen (length of the window, minimum and maximum frequency to consider, smoothing, equalization options etc.), activate the "full output" and the "close windows" options and upload the project file with the "**multiple HVSR batch processing**" button.

In the following pages, we report the outcomes you can obtain while adopting such a procedure (with the provided training data & project file).

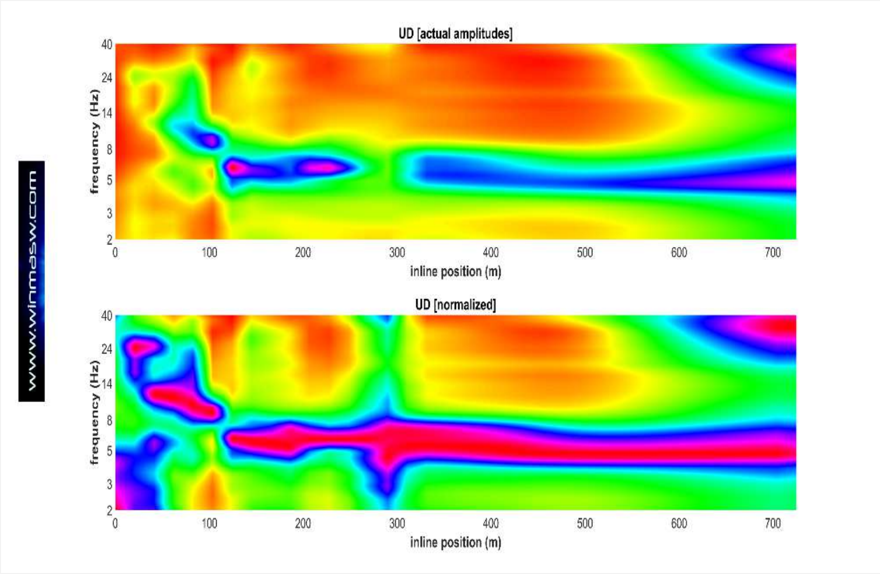
In the following figures are shown the amplitude-spectra curve and the normalized HVSRs (so to better emphasize the HVSR peaks and their continuity over the inline positions)

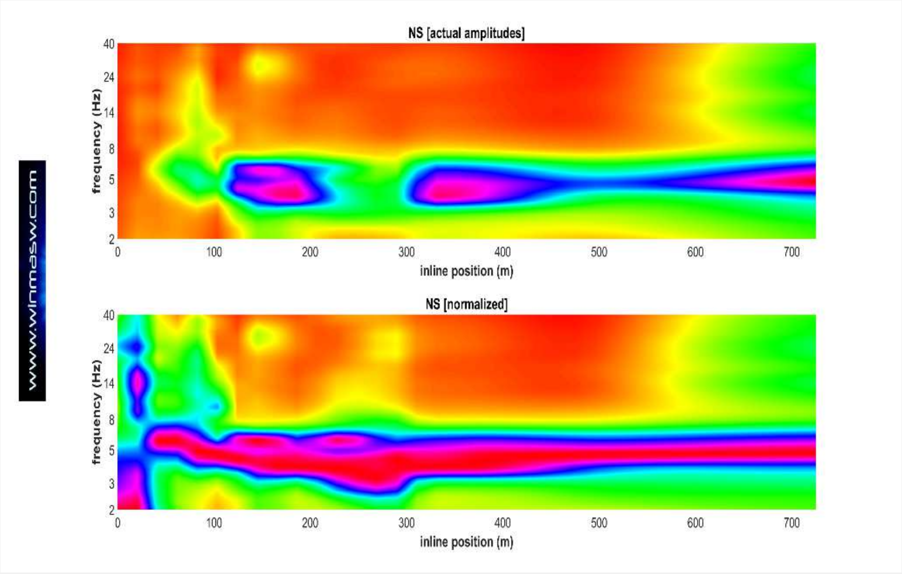


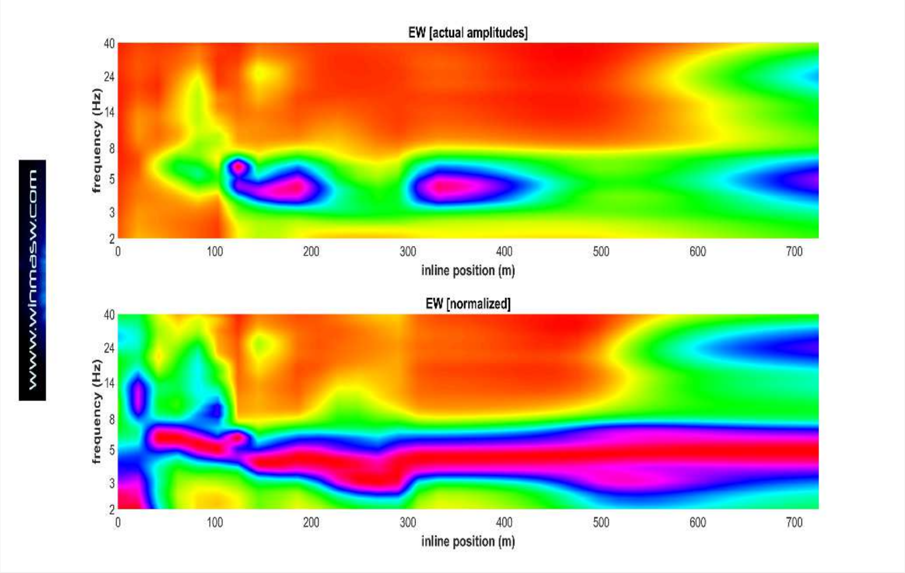



normalized curves
frequency (Hz)
40
24
14
8
5
3
2
0
100
200
300
400
500
600
700
inline position (m)
www.winmasw.com

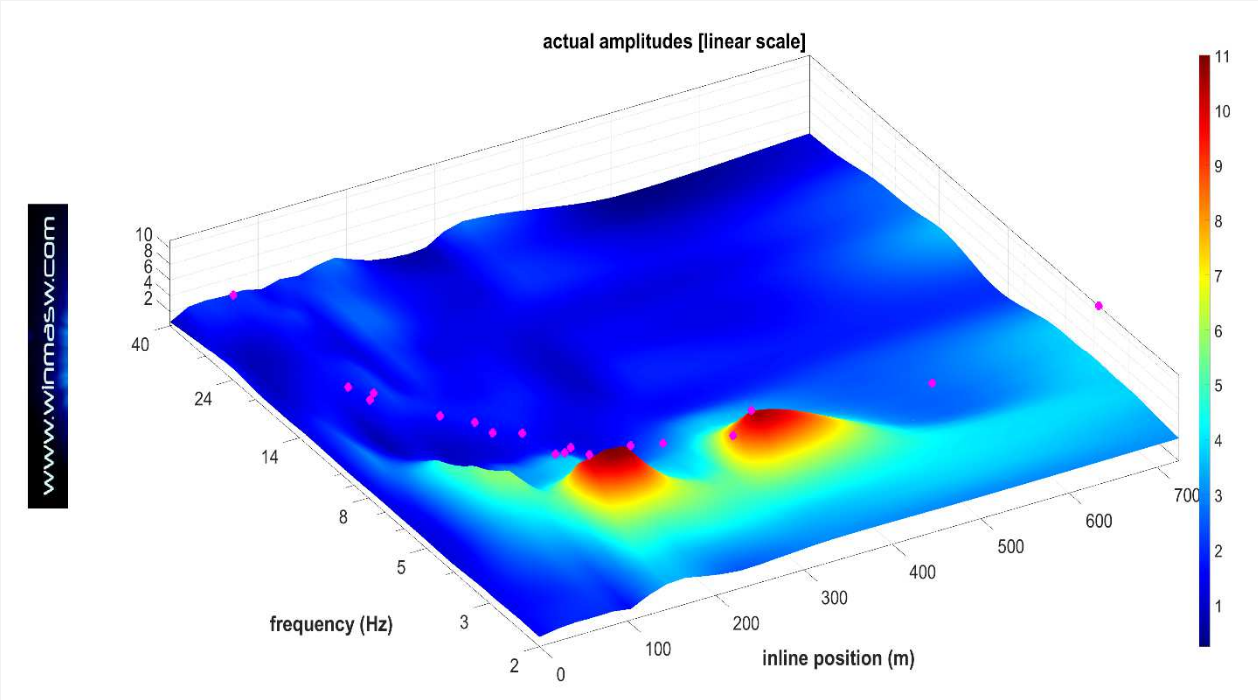
Amplitude spectra (actual and normalized amplitudes) for the three components [vertical, NS and EW].

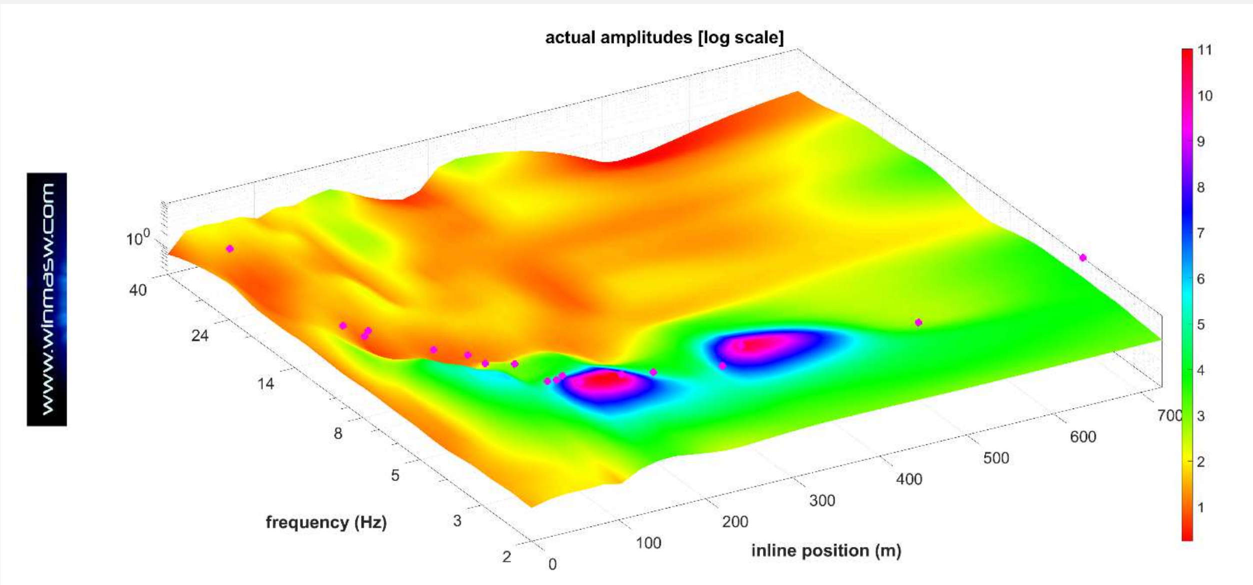




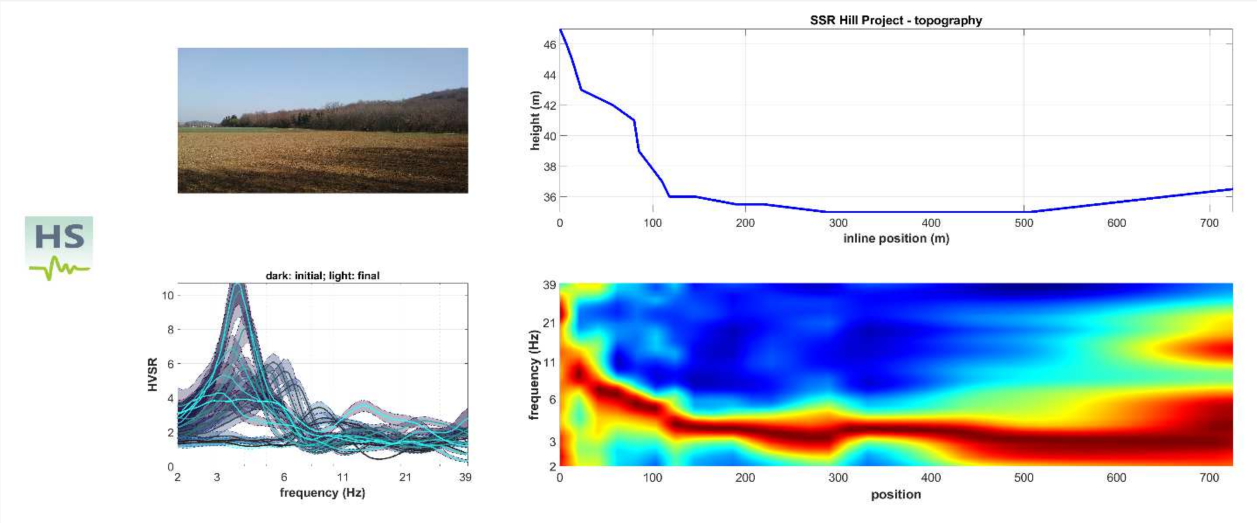


HVSRs (actual amplitudes) using two different color scales:



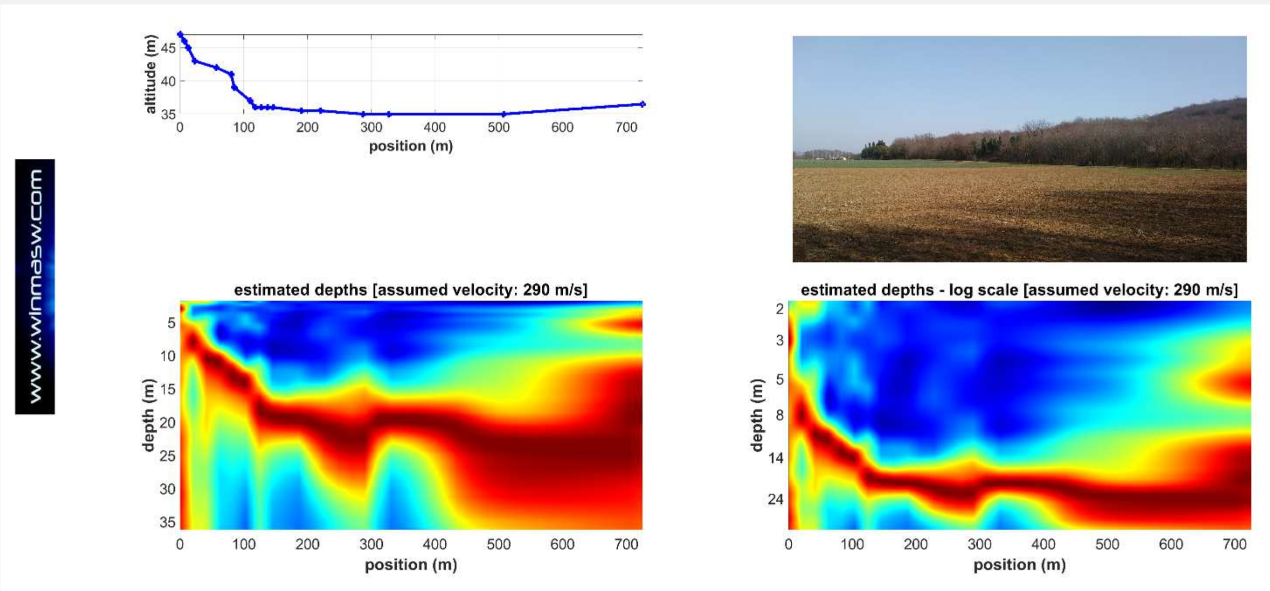


Further (final) figures



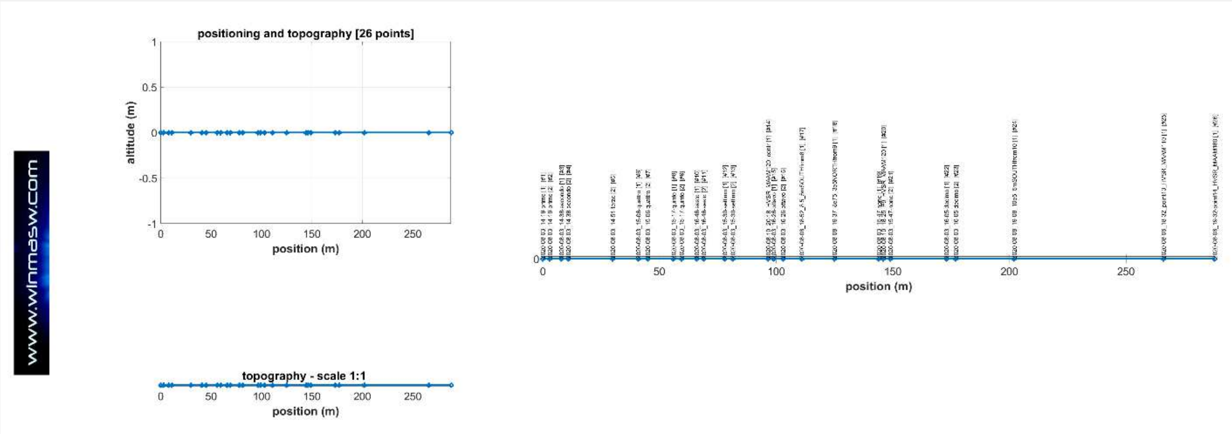
Depth conversion using the velocity reported in the third line of the project file (in this case 290 m/s).

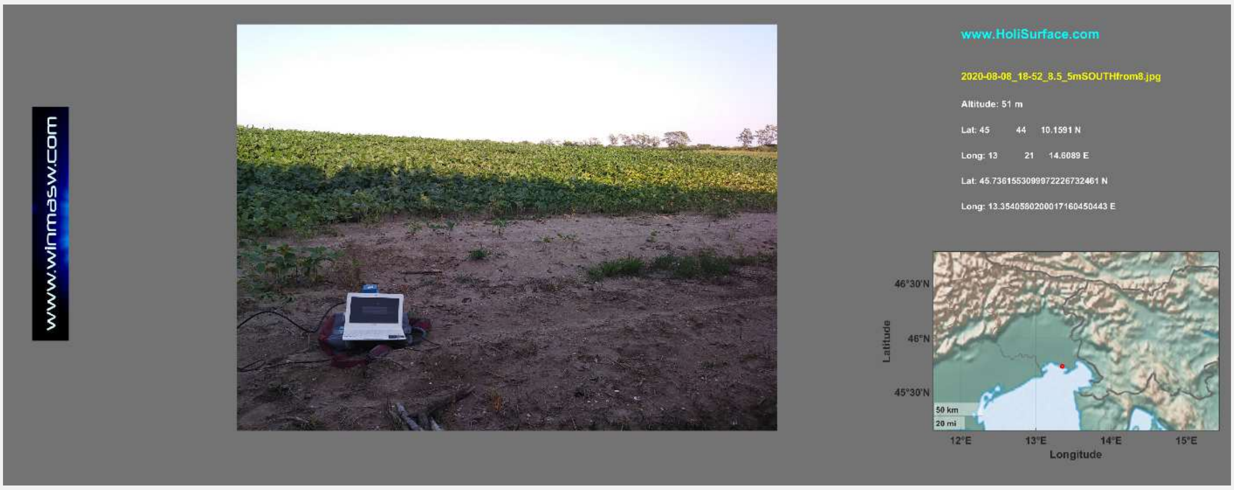
Topography, uploaded picture, depths (having used the average velocity provided in the project file) shown according to linear and log scales.

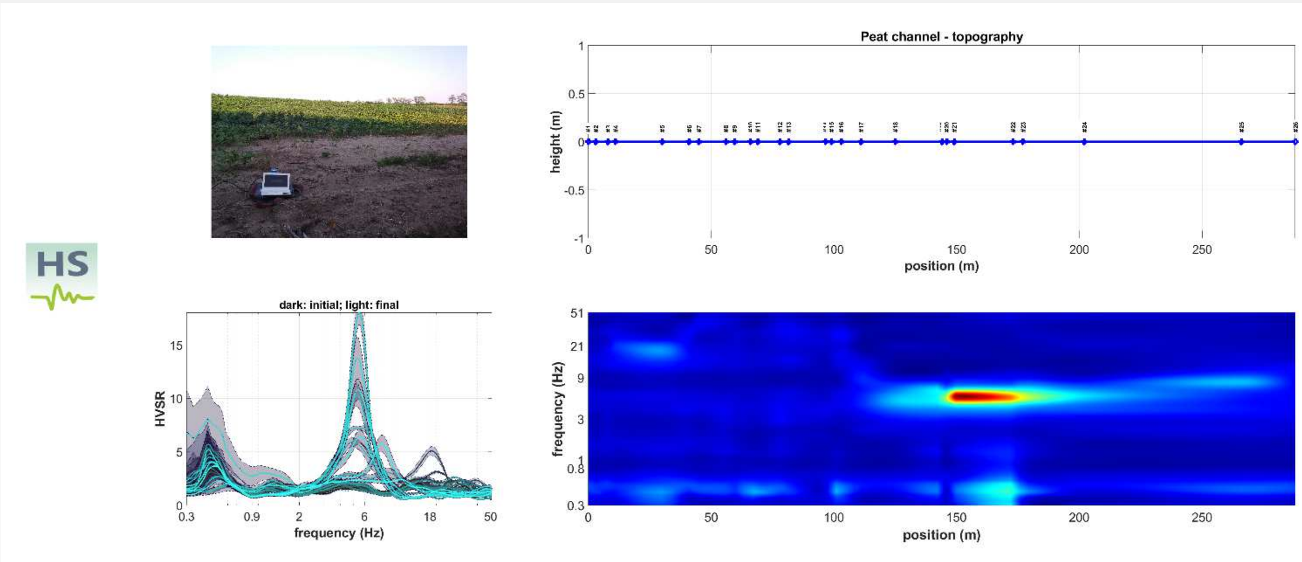


Second example

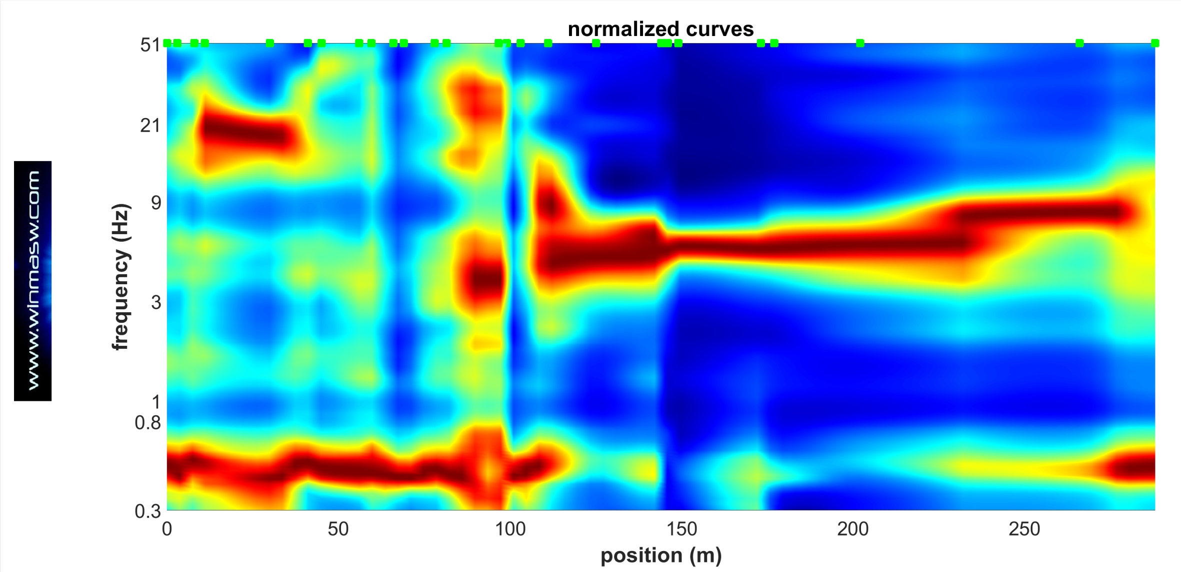
In the following figures, we can see the outcome in case no topography is considered.



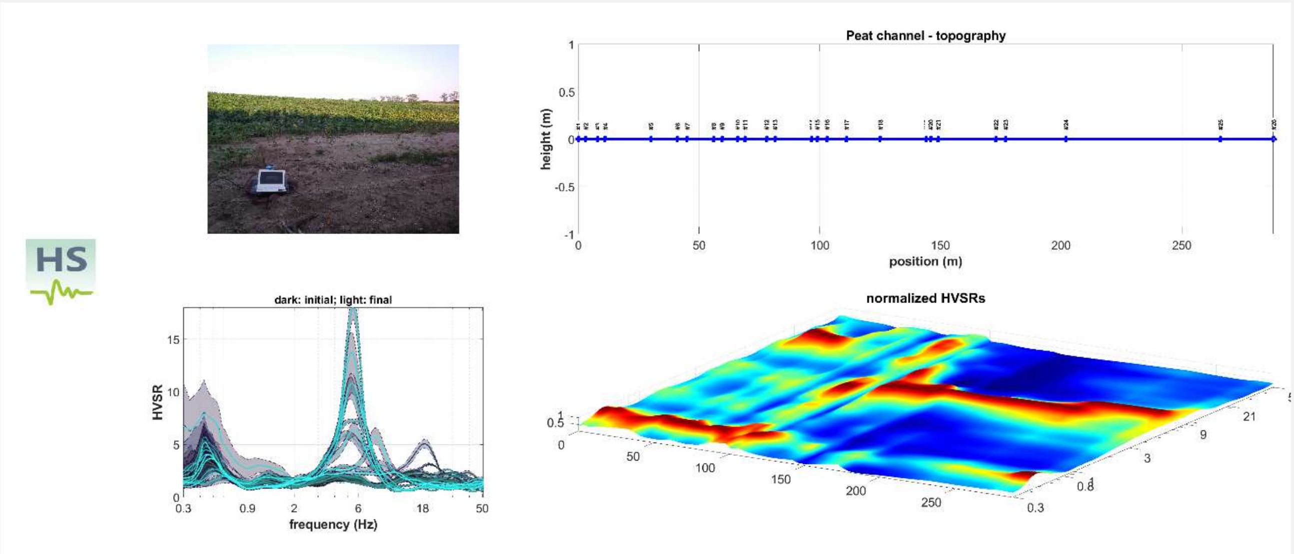




Actual amplitudes: the large peak at about 6 Hz is due to a shallow (local) peat channel while the peak at about 0.5 Hz is due to the deep bedrock



Normalized curves



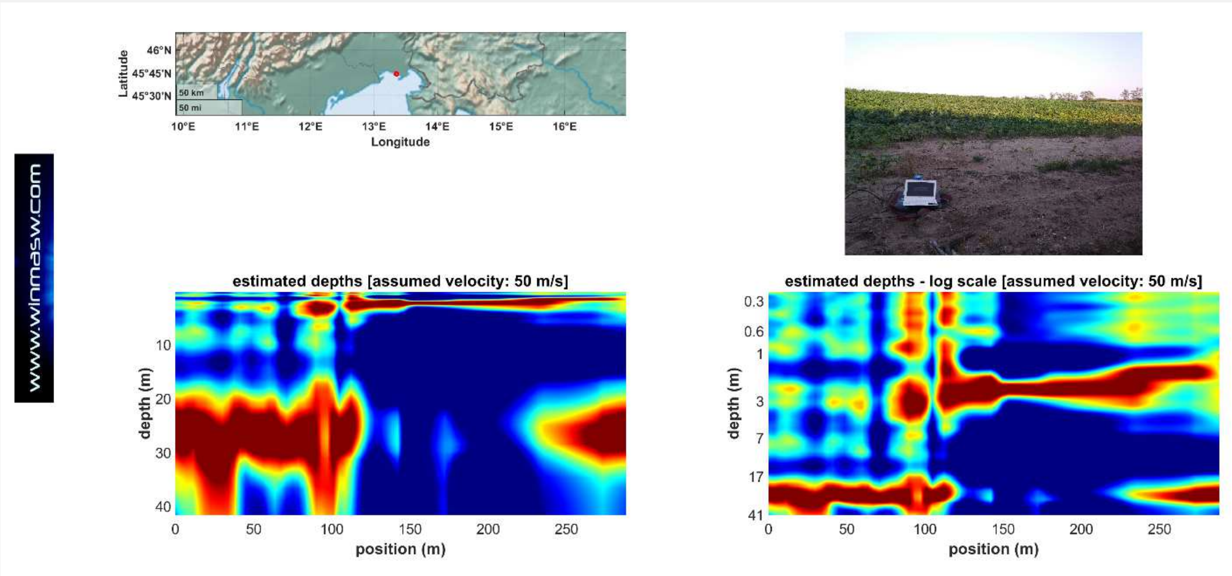
Normalized curves (3D view)

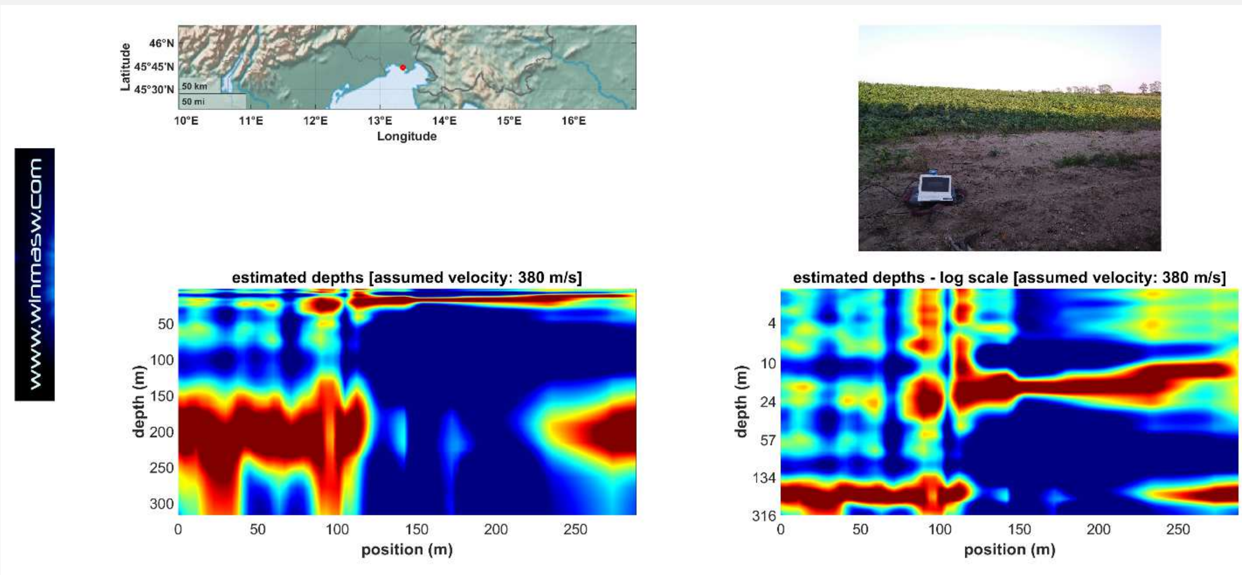
Depth conversion

The two figures shown here are obtained while considering two different mean V_S values (**third line in the project file**): 50 m/s and 380 m/s.

These two values were fixed considering the specific characteristics of the site. While the HVSR peak at about 0.5 Hz is about the deep bedrock, the large peak at 6 Hz is due to a peat channel. The local peats are characterized by a V_S value of about 50 m/s (such a value was obtained through the analysis of surface-wave dispersion – in this case via MAAM) while the average V_S value for the whole stratigraphic column down to the bedrock was estimated while considering ESAC data.

Using these two values (50 and 380 m/s) in the project file (third line) we can obtain the approximated depth of the peat channel (in this case about 3 m) and the depth of the *bedrock*.

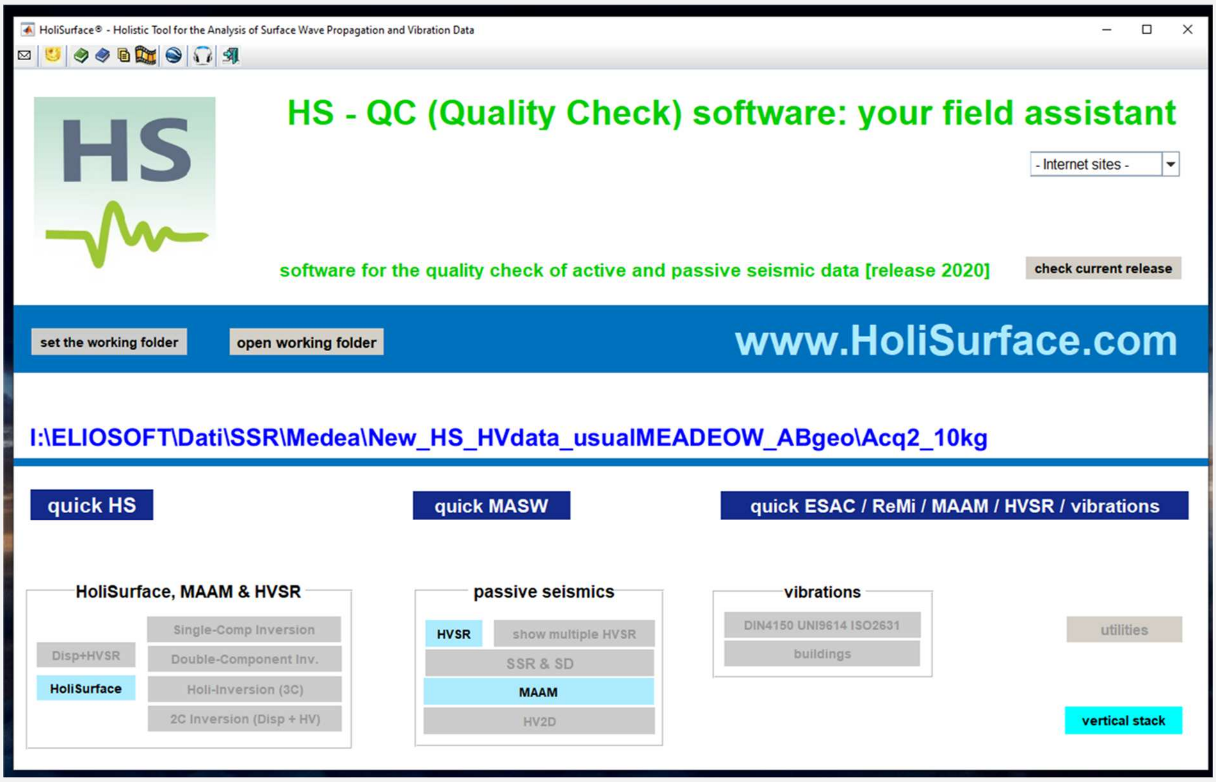




Appendix S: HS-QC [Quality Check] software: your field assistant

Most of the acquisition software applications of the seismographs available on the market lack of tools for the assessment of the data quality. Once your (active or passive) data has been acquired it is in fact impossible to evaluate the actual quality in a clear and "quantitative" way.
For this reason, in order to not bring home poor-quality data, a **QC [Quality Check]** version of our software applications has been implemented.
The data quality can be evaluated **for both active (MASW and HS) and passive (HVSR, ESAC, ReMi, MAAM, vibrational) data**.
The software is clearly also available for those who do not own HS or winMASW ACD (at a small price).
There are two families of panels:
1) **quick analysis [dark blue buttons]**: they allow a very quick and immediate evaluation of the data;
2) **"full" analysis**: they allow you to upload the data and perform broader and more in-depth analyses (these are simplified versions of the analyses possible with HS).

A tool for the **stack** of your active data is also available (see bottom right button in the main panel here below).



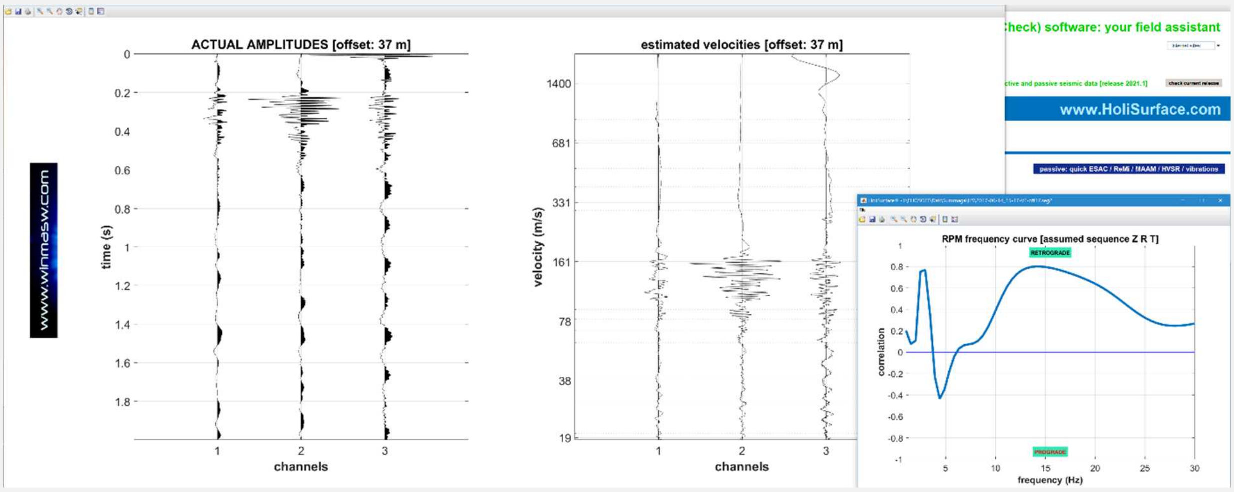
THE THREE QUICK BUTTONS

For the fastest quality check three **QUICK** button are avaialble from the main panel, depending on the type of data you are considering. After you click the pertinent button and upload the recorded dataset you automatically obtain one of the following outcome.

ACTIVE DATA

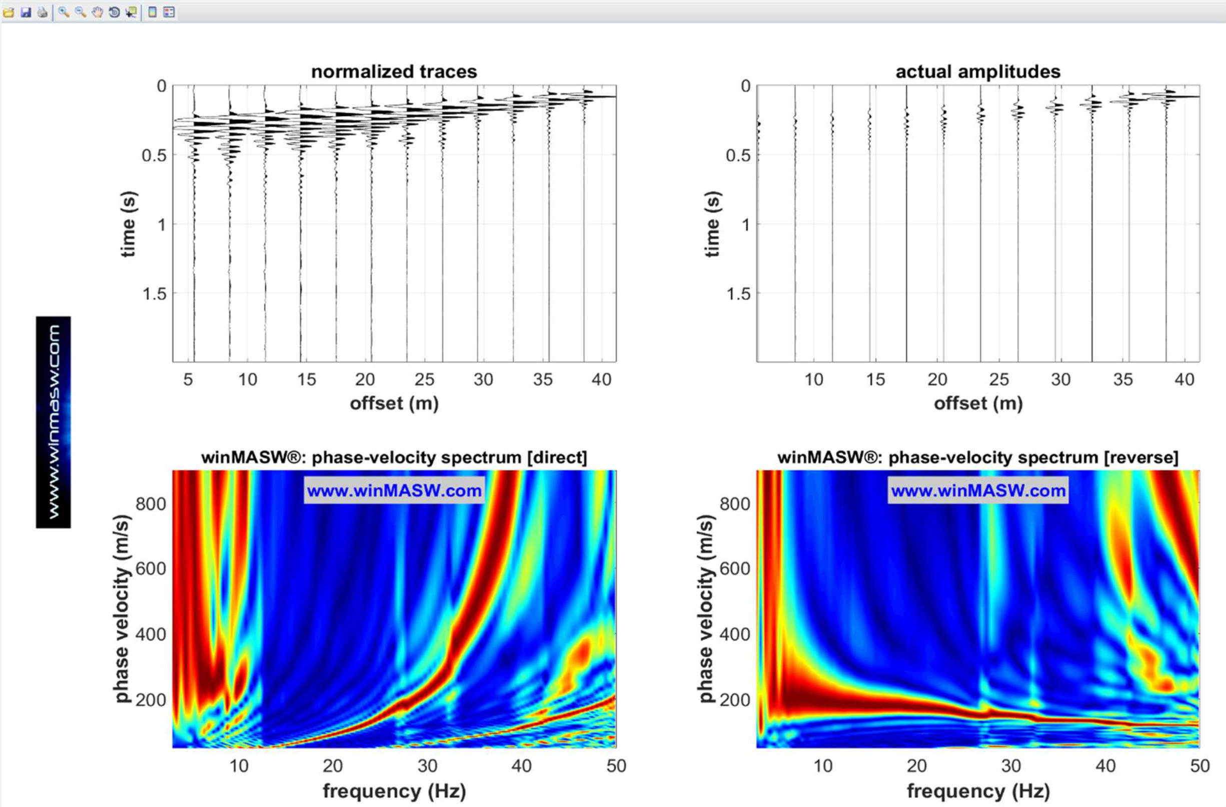
HS data [“quick HS” button]

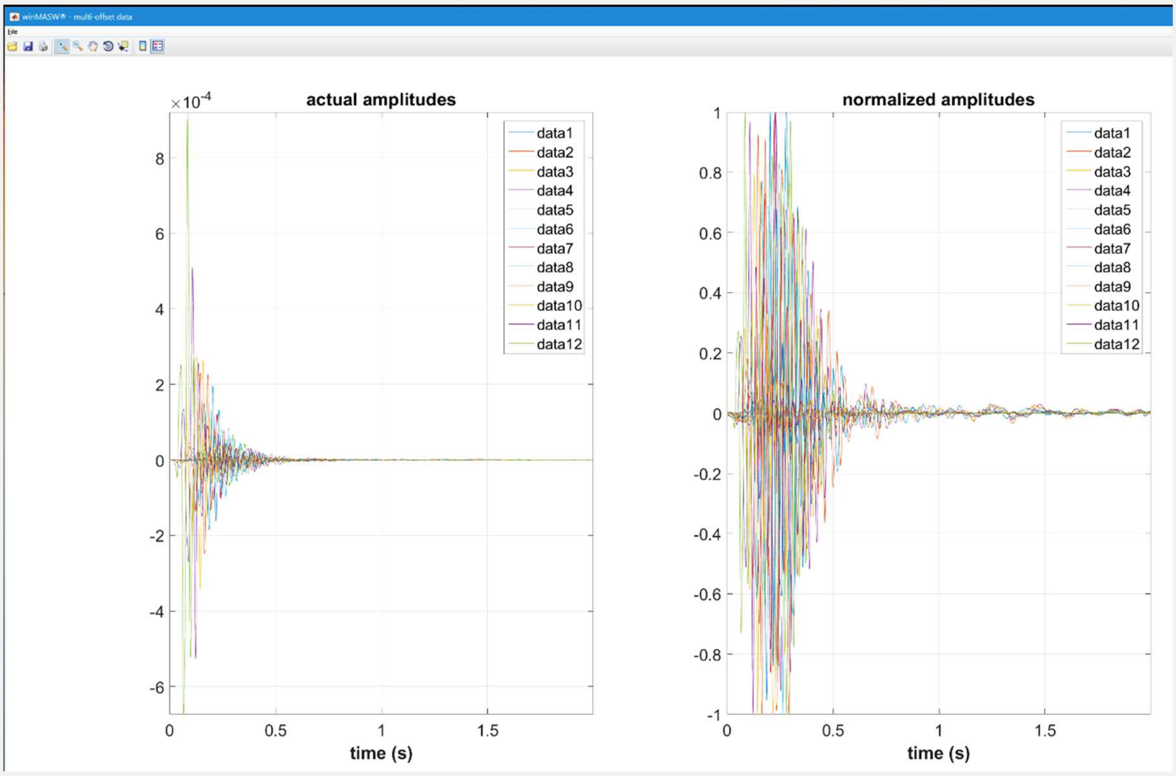
shown the traces, the RPM curve and the “velocity converted” traces



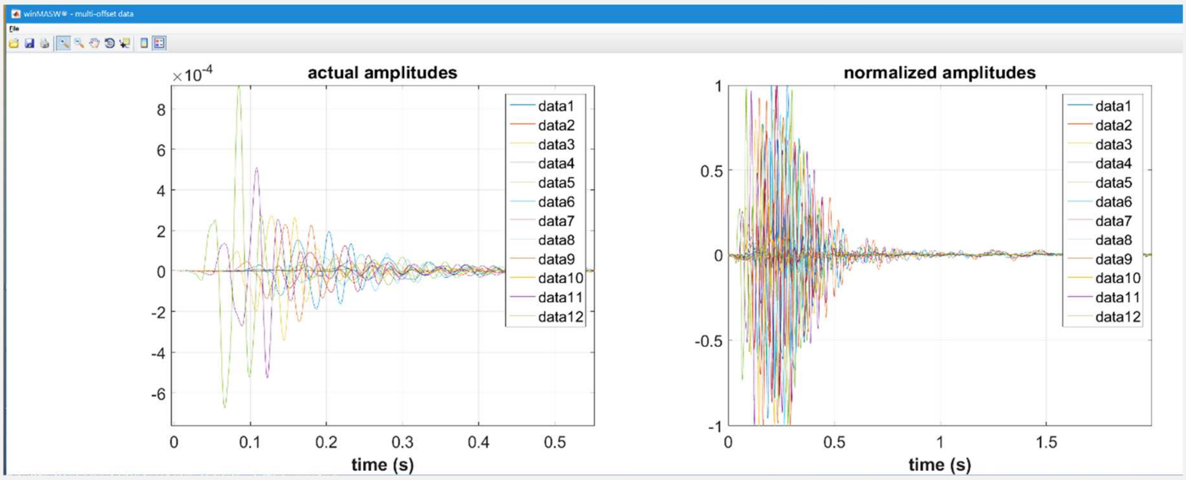
MASW data [“quick MASW” button]

shown the traces (actual and normalized amplitudes) and the phase-velocity spectra





A different way to show the traces

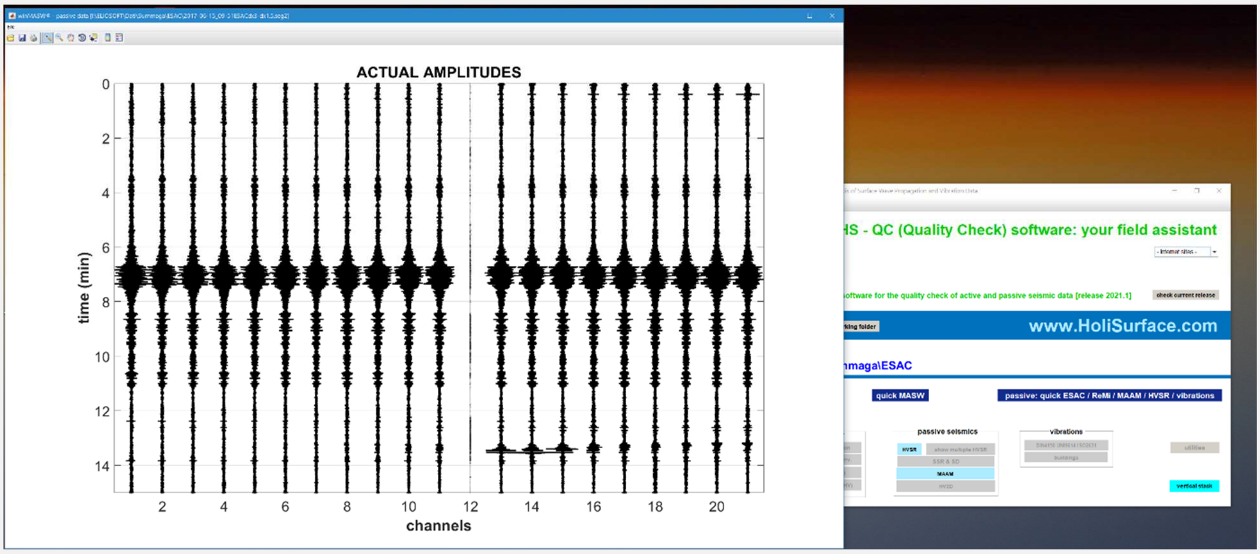


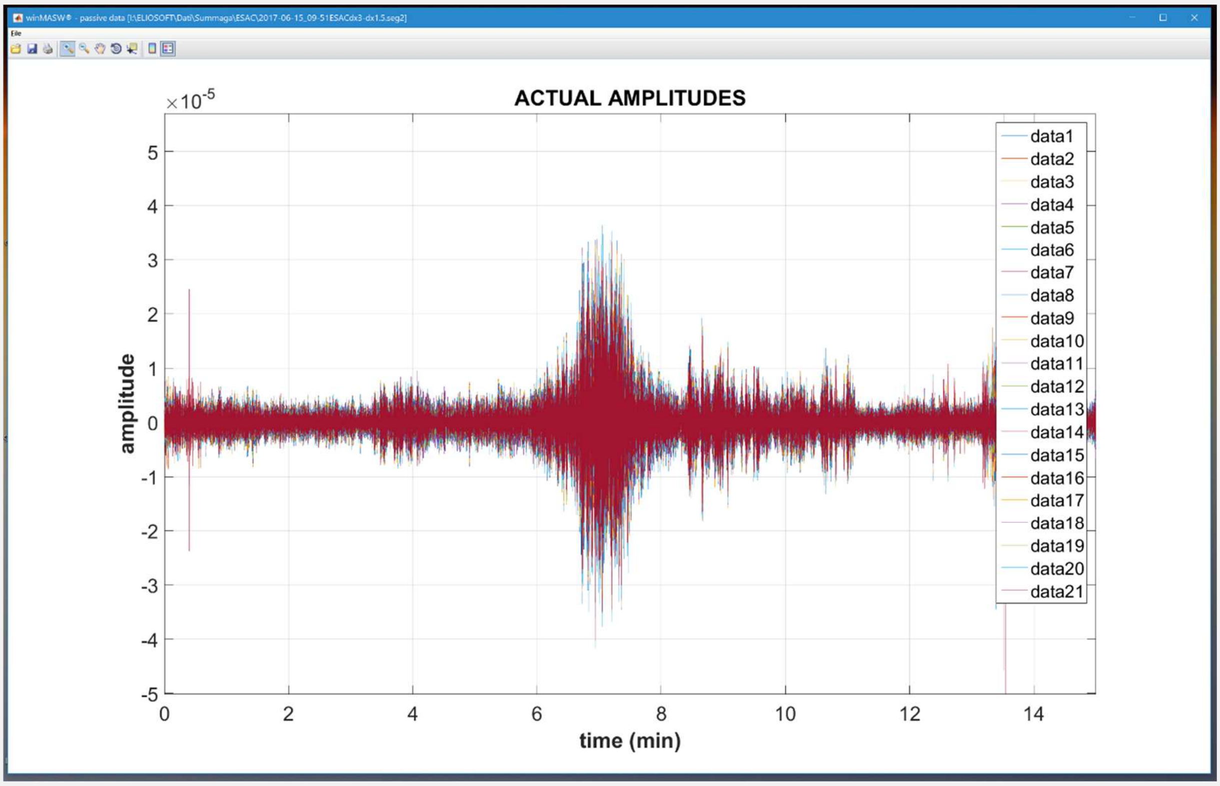
Of course you can zoom in

PASSIVE DATA

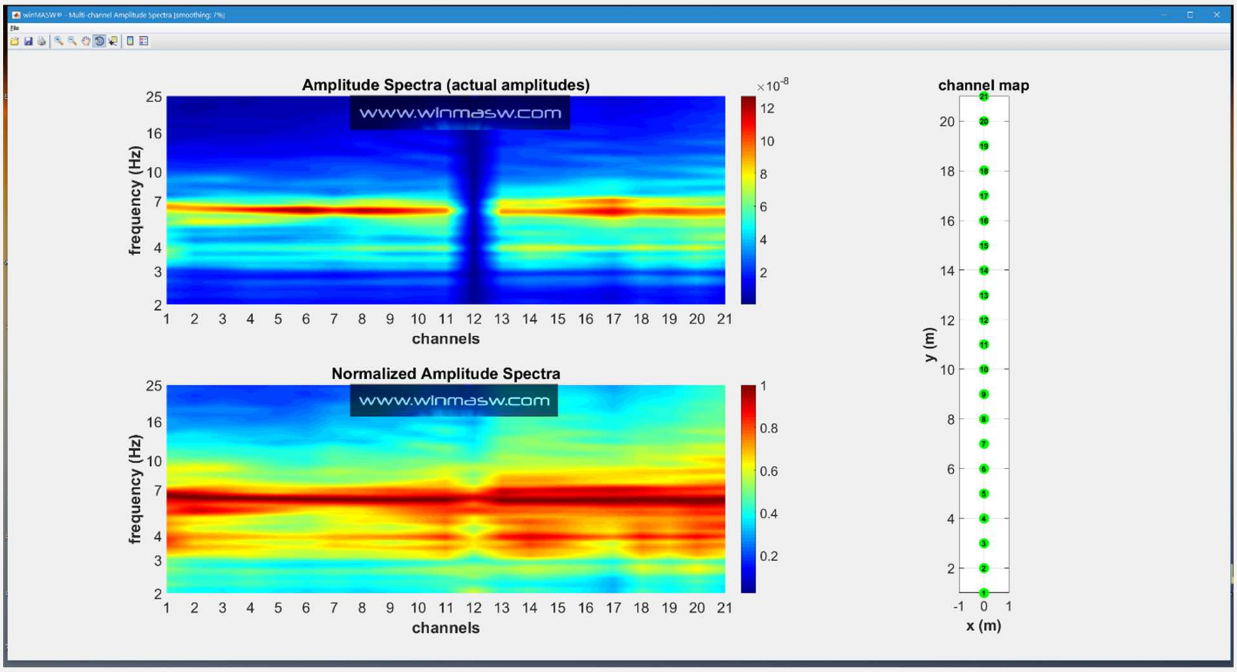
Button “passive: quick ESAC/ReMi/MAAM/HVSR/vibrations”

shown the traces with the actual amplitudes (in the example below there is clearly something wrong with the channel#12)

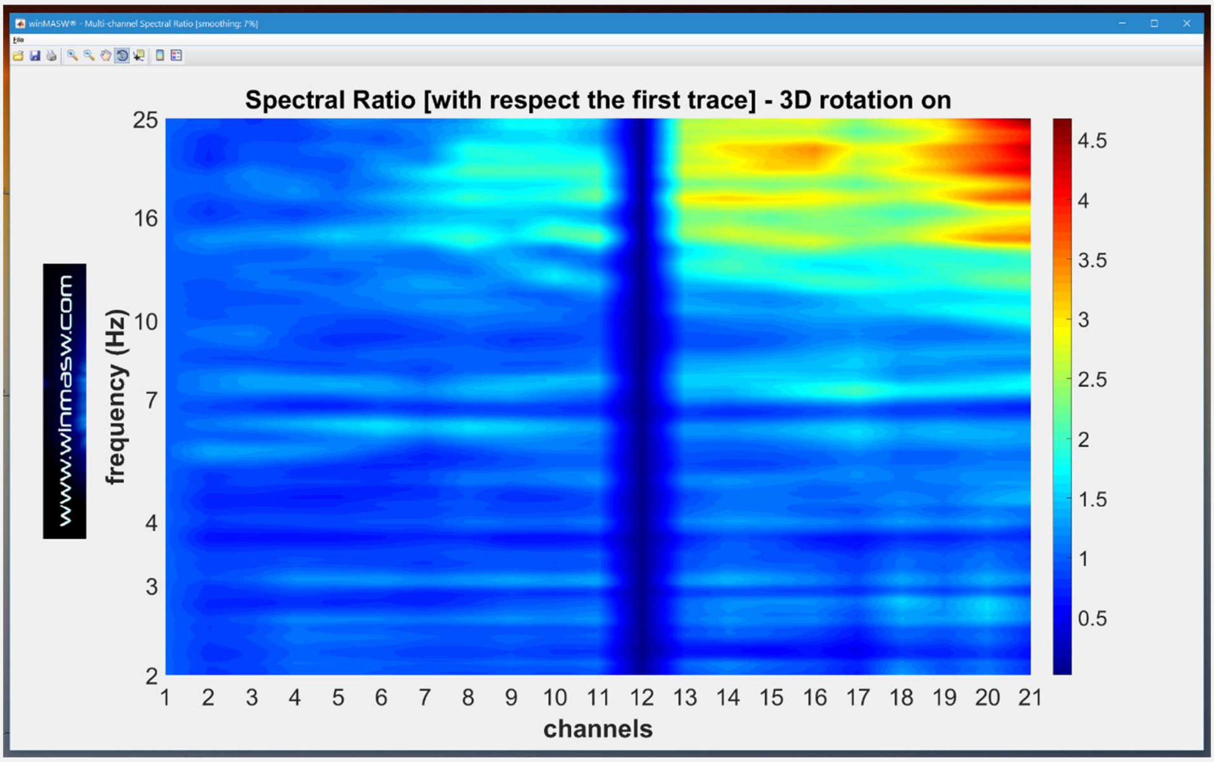




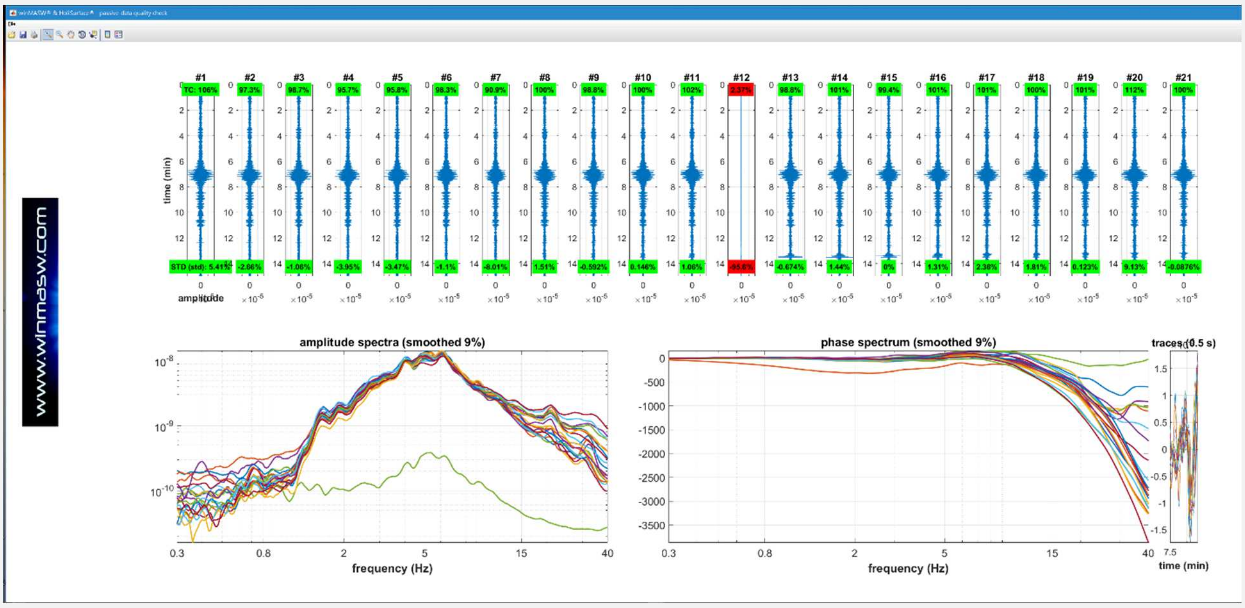
Also shown the amplitude spectra (actual and normalized values – again: the problem with the channel#12 is clear and you need verify the reason on the field: it can be a poorly connected geophone etc.)



A further output is the **Spectral Ratio of each trace with respect to the first trace**.

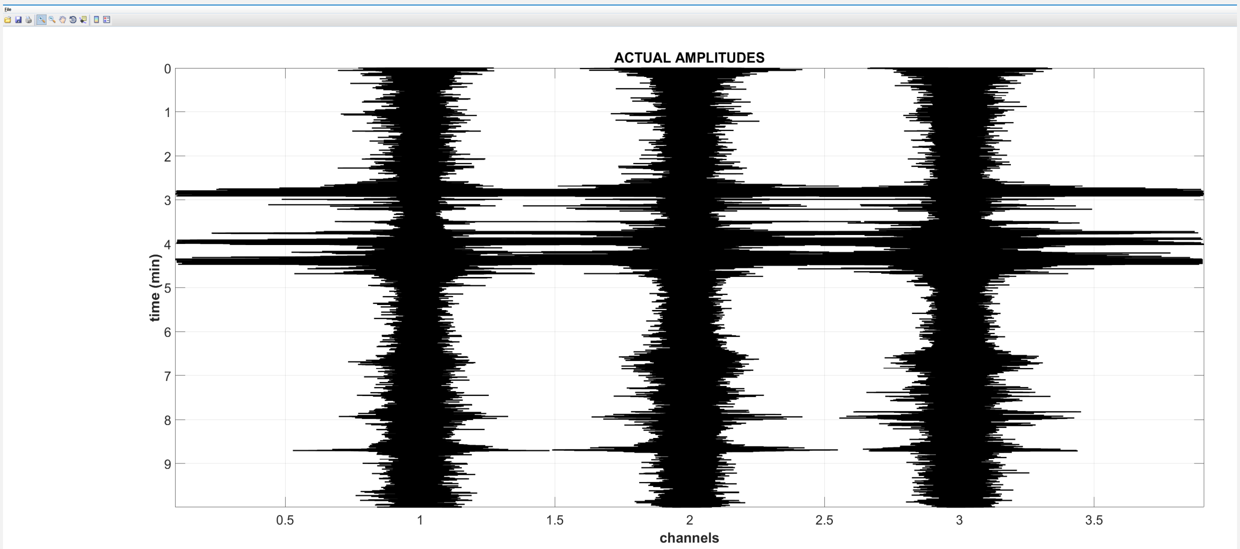


traces, amplitude and phase spectra of the uploaded traces

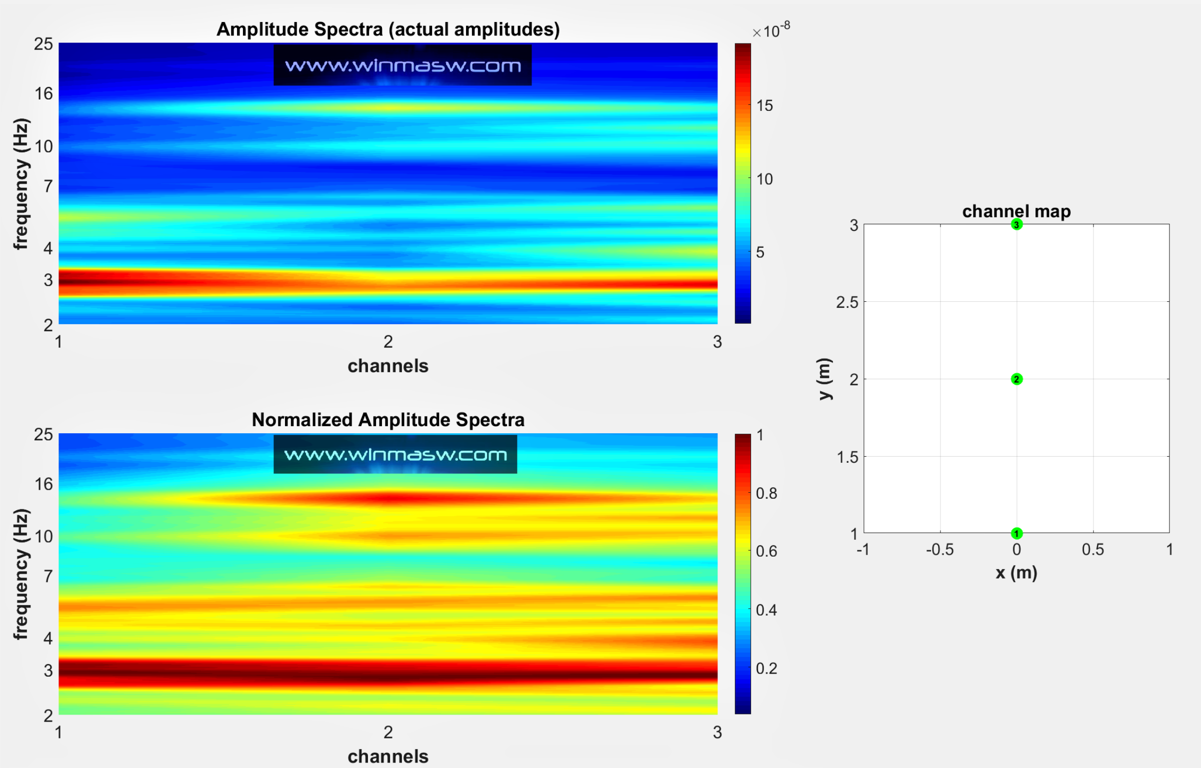


HVSR

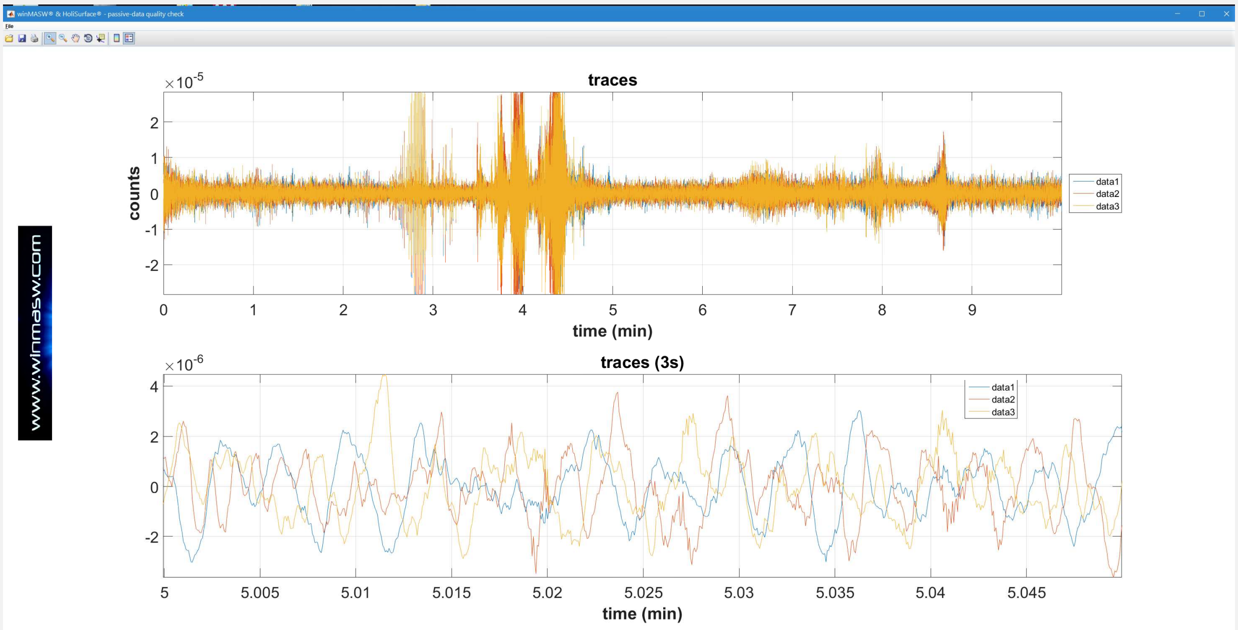
In case the uploaded dataset is composed of just three traces, the software considers the data as microtremor data for the computation of the HVSR and automatically computes and shows the following outputs



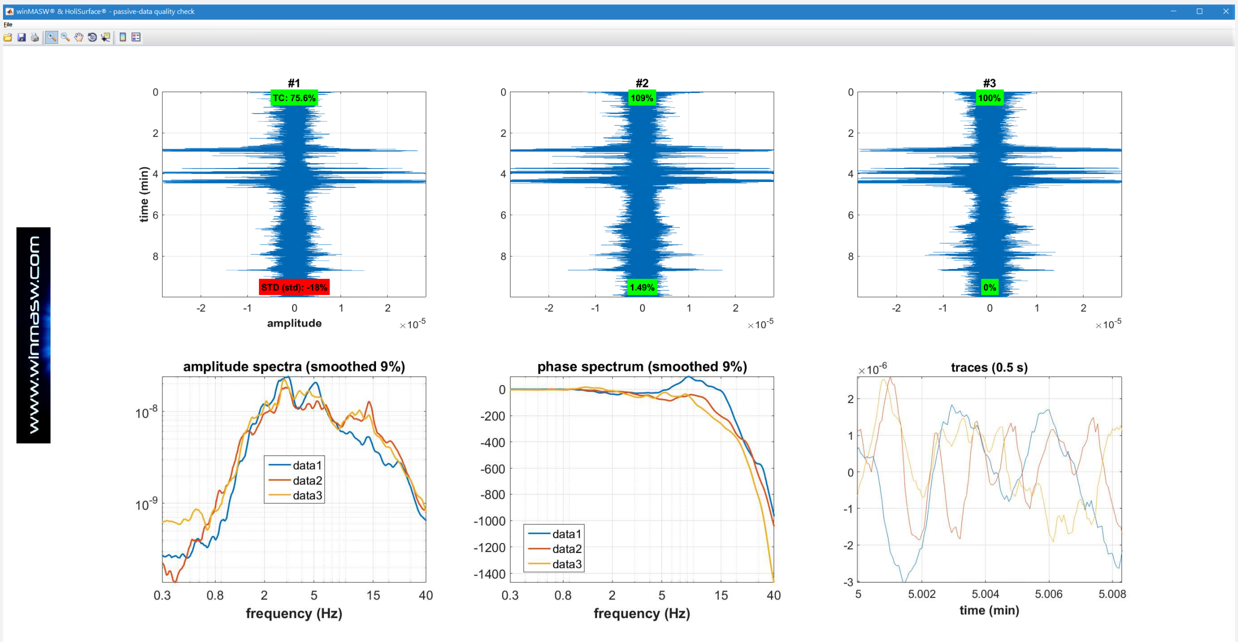
the three uploaded traces (with the actual amplitudes)



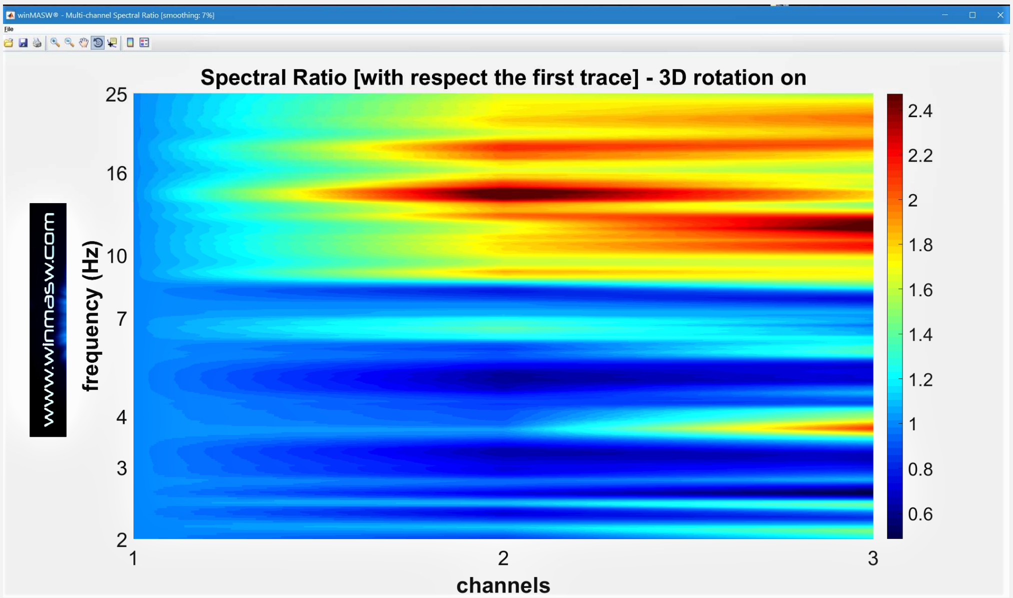
amplitude spectra of the uploaded traces (actual and normalized amplitudes)



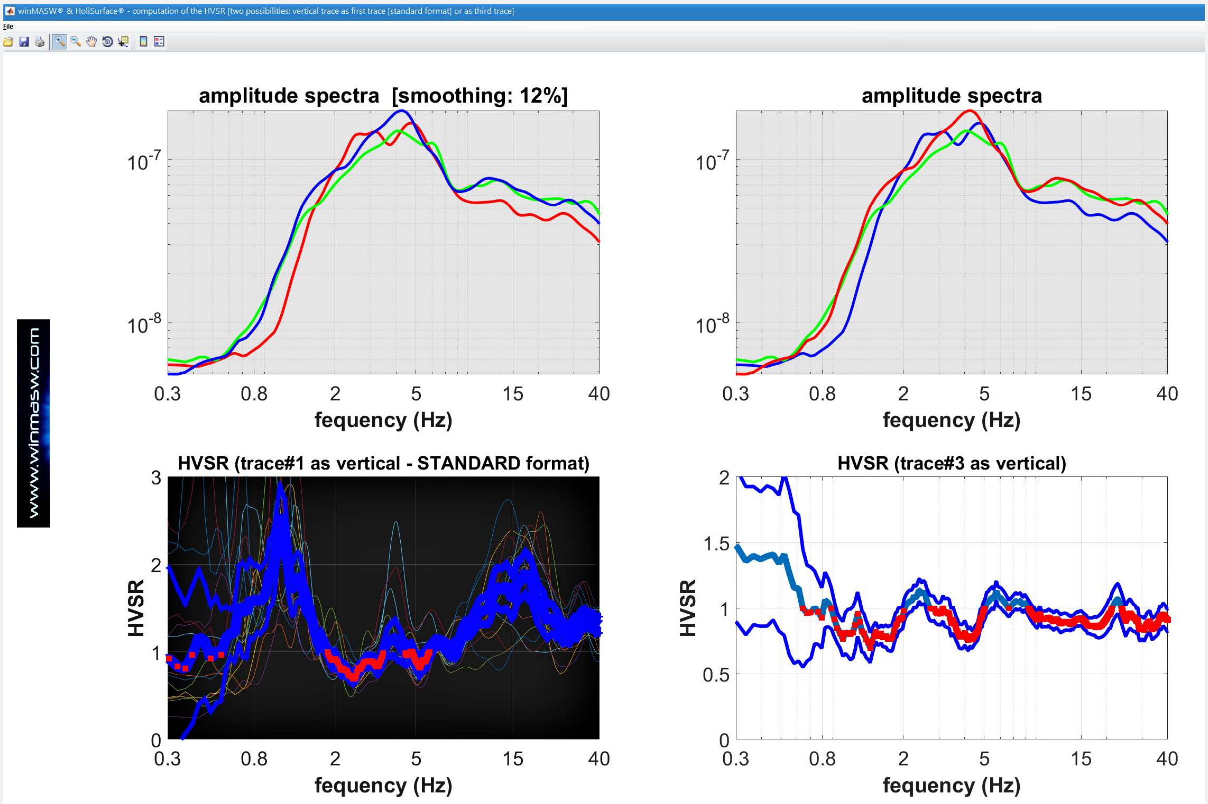
the uploaded traces (in the lower panel a detail/close up)



traces, amplitude and phase spectra of the three traces



Spectral Ratio of each trace with respect to the first trace



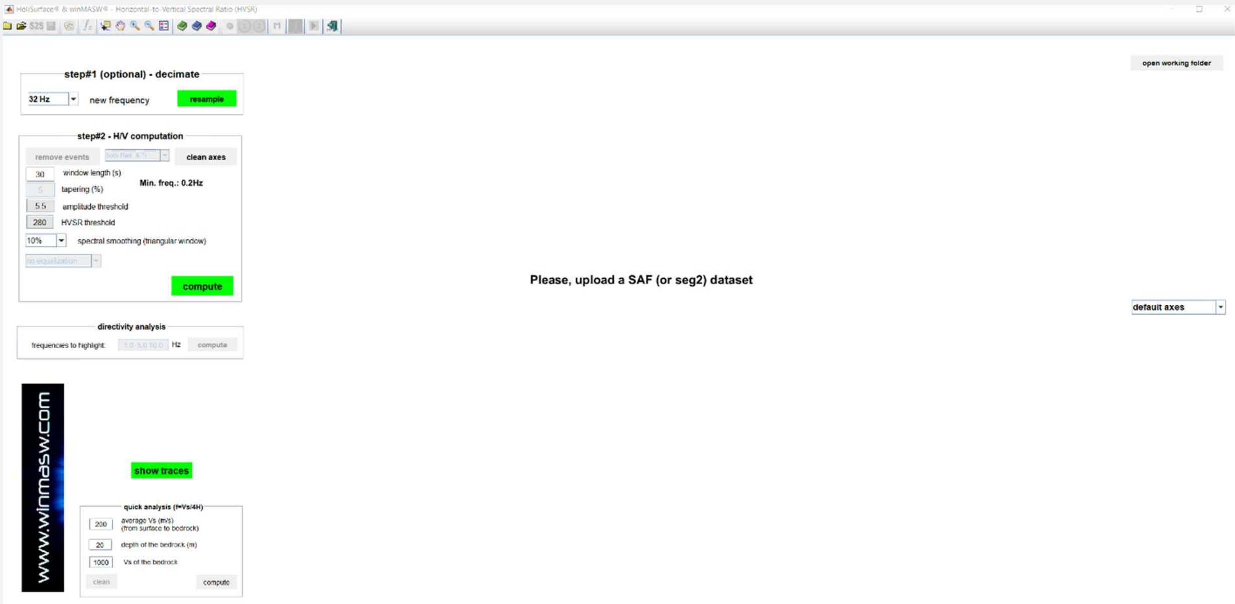
Smoothed (12%) amplitude spectra and HVSR computed considering two possible situations (which depend on the characteristics of your *acquisition system*):

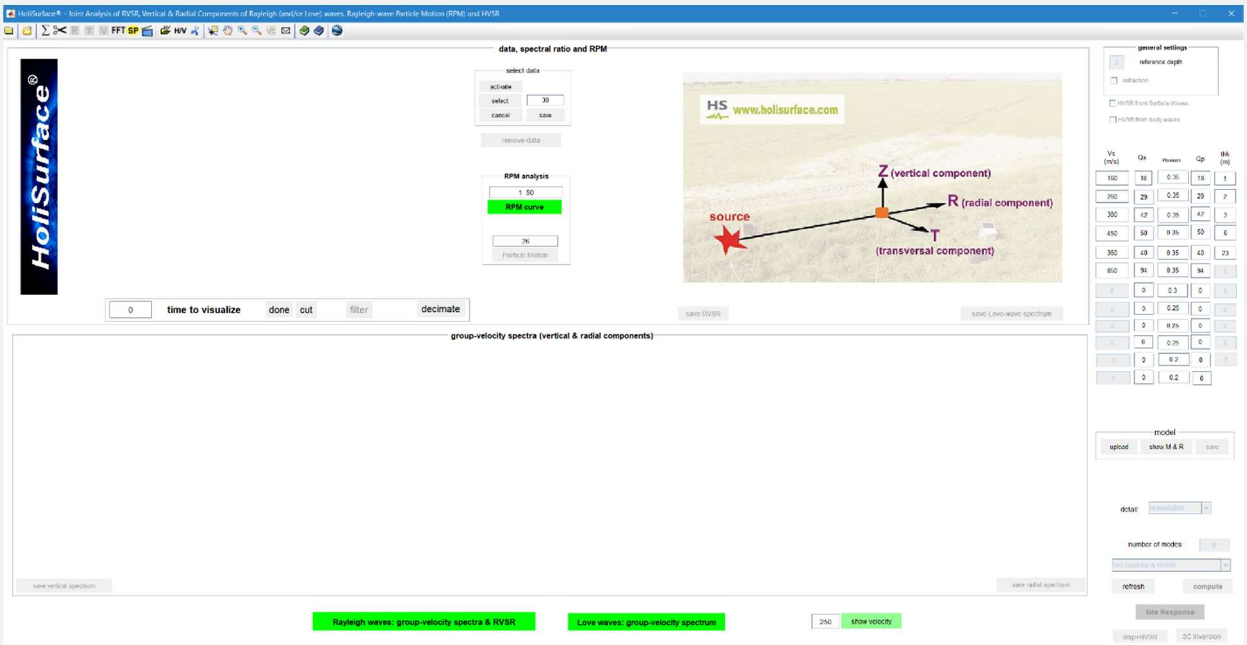
1) **on the left** the results in case the meaning of your traces is vertical, H1 and H2 (i.e. the vertical component is the first trace – standard format);

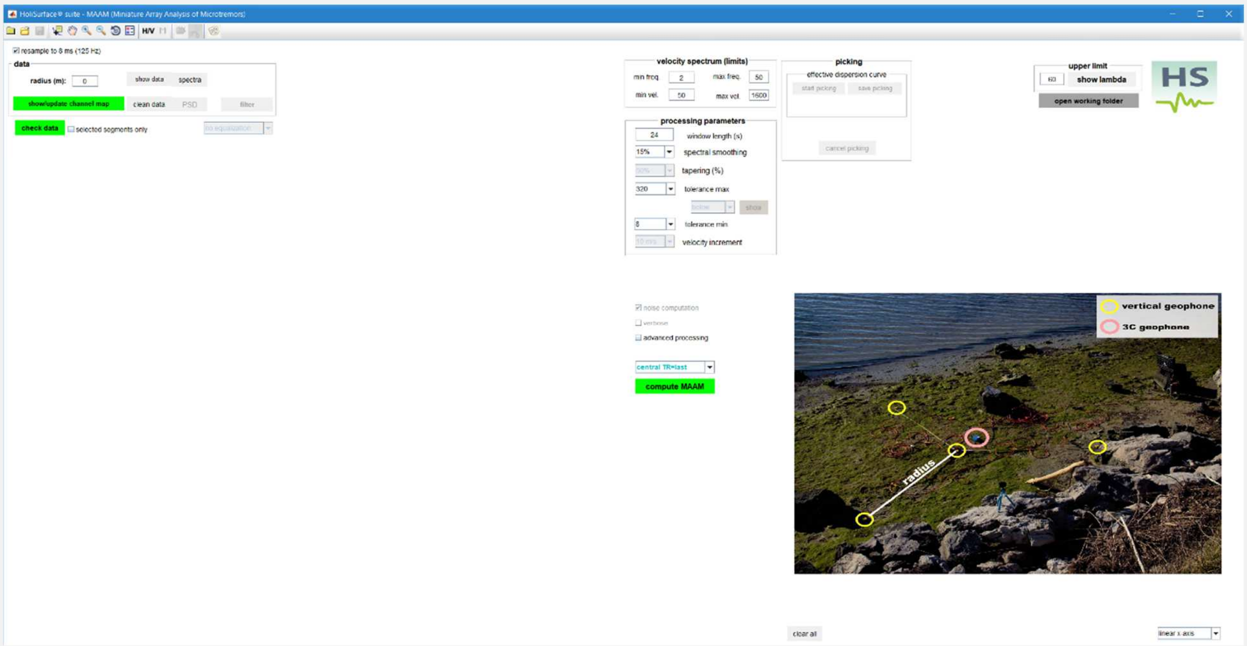
2) **on the right** the results in case the meaning of your traces is H1, H2 and vertical (i.e. the vertical component is the third trace).

THE “ORDINARY” (SIMPLIFIED) PANELS

In addition to the **QUICK** buttons/analyses, a simplified version of the ordinary panels are available, which allow some more detailed – but anyway simple – data analysis to perform already on the field during the data acquisition (in order to simply the field operations the active buttons are highlighted in **green**).







Appendix T: DTM (Digital Terrain Model) tool

Among the utilities, a small tool is available which is useful for viewing DTM data and being able to locate (quickly and effectively) the position of your survey. It is possible to upload up to 4 DTM files (ASC or TIF format) (to complete a larger mosaic) which are then assembled and displayed with the "**show DTM**" button.
It is then possible ("**upload georeferenced photo**" button) to upload a geo-referenced photo of your survey (see section "**GPS data in our software applications (*winMASW®*, *HoliSurface®* & ELIOVSP®)**") and, this way, obtain the positioning of the investigated area as shown in the images reported in the following pages.

Few notes (*release* 2021.1):

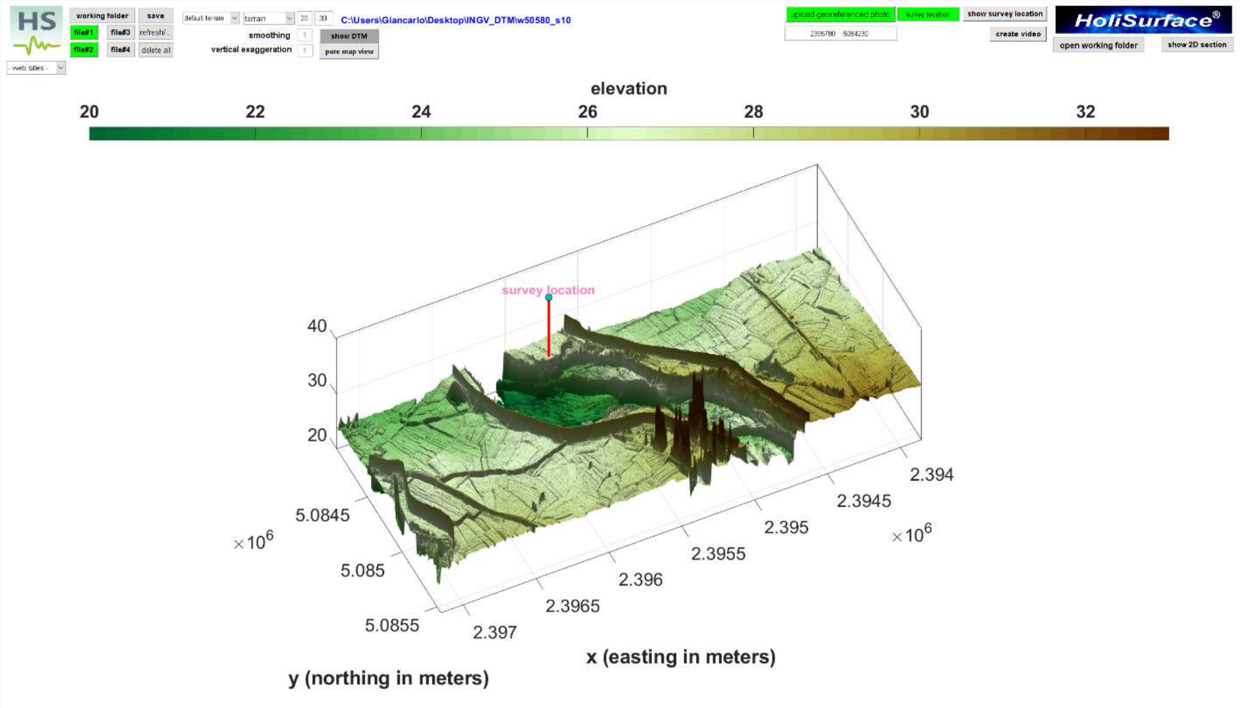
1) as for all the *HoliSurface®* panels, by hovering the mouse over a certain button, a brief description of what type of operation is performed by clicking that button appears

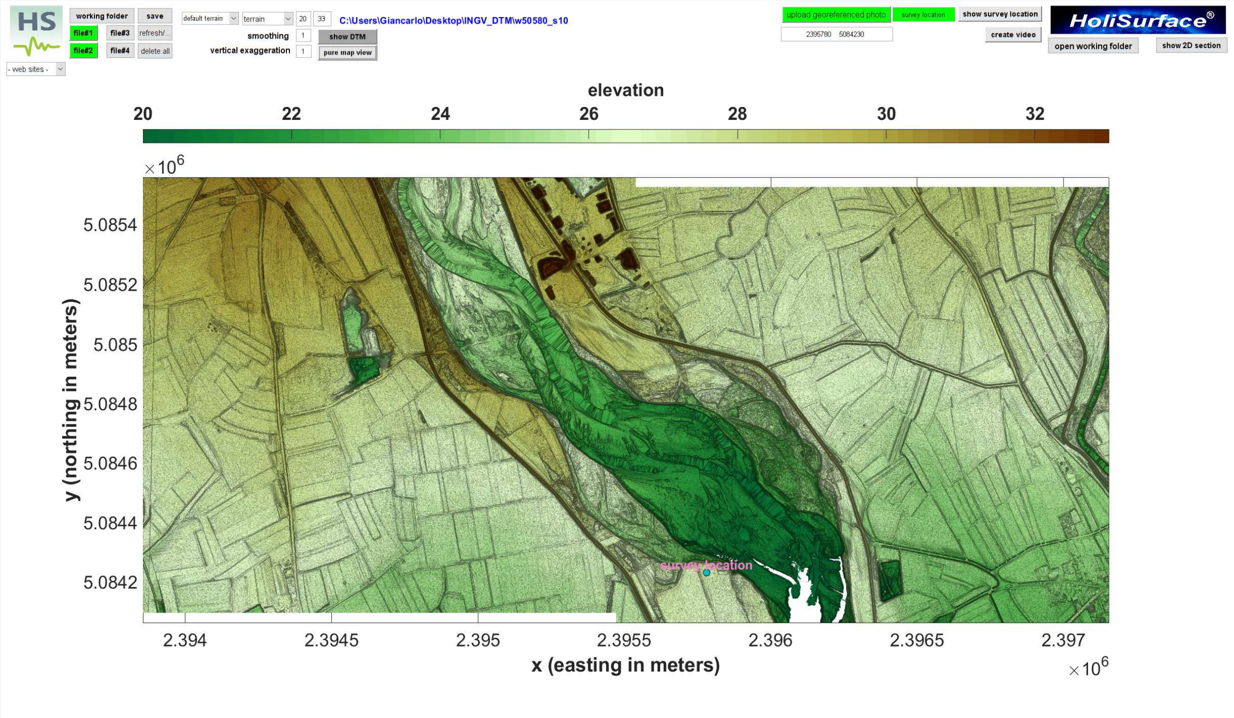
2) the localization of the survey site from an uploaded geo-referenced photo works (properly) only if the uploaded DTM data refers to **WGS84** (World Geodetic System 1984)

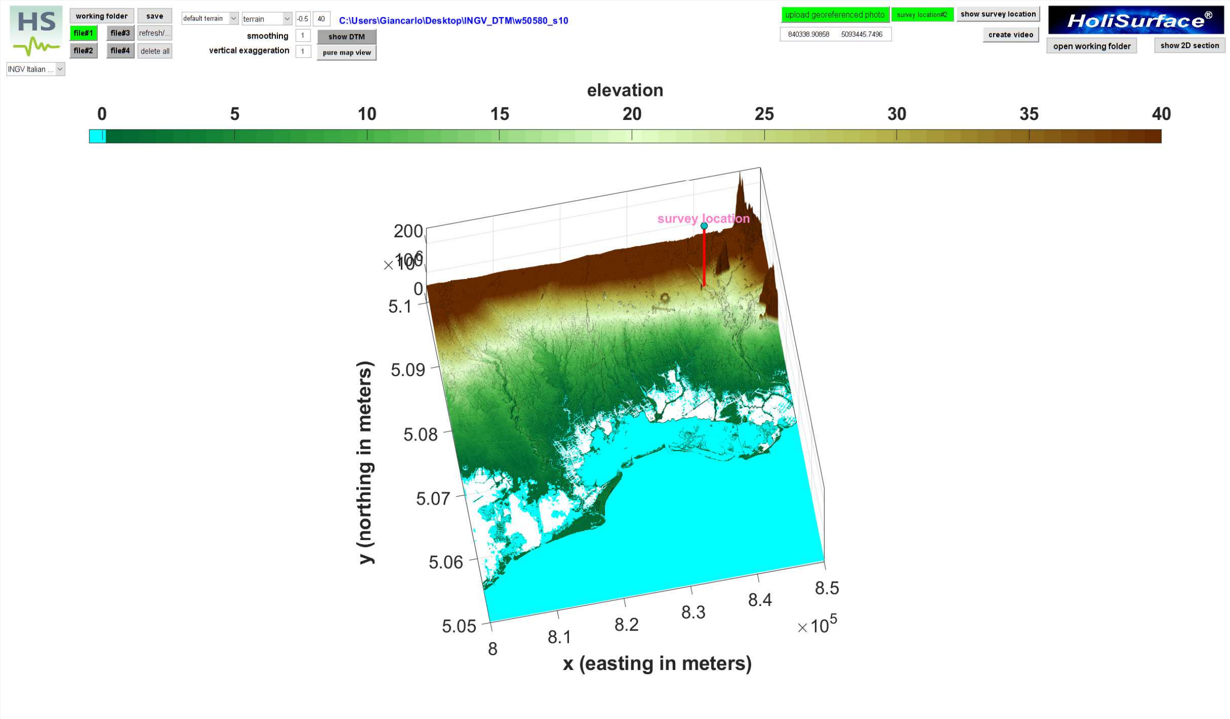
3) if you want to locate the survey site but do not have WGS84 DTM data or geo-referenced photos, you can enter the coordinates of the point to be highlighted manually in the box below the "**upload georeferenced photo**" button

4) in the box on the right of the "**upload georeferenced photo**" button, you can enter the label you want to insert (by default label is "survey location")

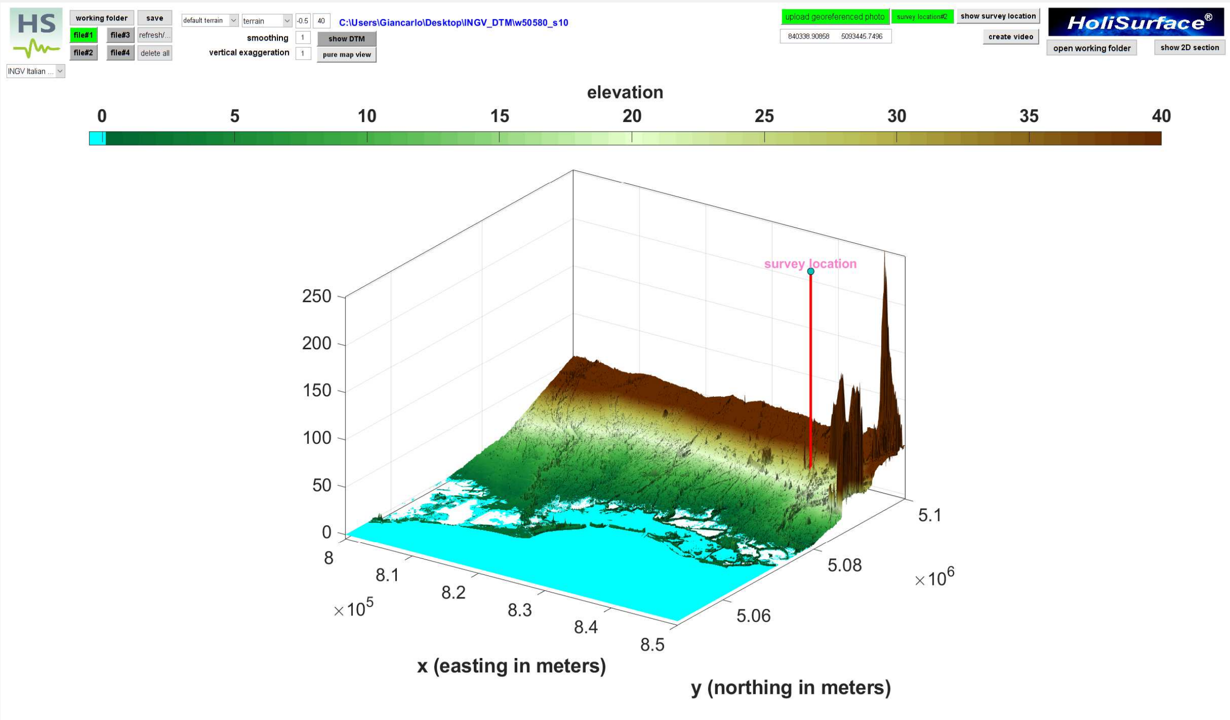
5) the two fields next to the **"color map" pop up menu** are used to indicate the minimum and maximum altitude values to be considered and therefore also serve to modify the range of the chosen color scale


working folder
save
file#1
file#3
refresh/...
file#2
file#4
delete all
- web sites -
default terrain
terrain
20
30
C:\Users\Giancarlo\Desktop\INGV_DTM\w50580_s10
smoothing
1
show DTM
vertical exaggeration
1
pure map view
upload georeferenced photo
survey location
show survey location
2395780 5084230
create video
HoliSurface®
open working folder
show 2D section
elevation
20
22
24
26
28
30
32
survey location
40
30
20
5.0845
$\times 10^6$
5.085
5.0855
2.394
2.3945
2.395
2.3955
2.396
2.3965
2.397
$\times 10^6$
x (easting in meters)
y (northing in meters)


working folder
save
file#1
file#3
refresh/...
file#2
file#4
delete all
- web sites -
default terrain
terrain
20
33
C:\Users\Giancarlo\Desktop\INGV_DTM\w50580_s10
smoothing
1
show DTM
vertical exaggeration
1
pure map view
upload georeferenced photo
survey location
show survey location
2395780 5084230
create video
HoliSurface®
open working folder
show 2D section
elevation
20
22
24
26
28
30
32
$\times 10^6$
5.0854
5.0852
5.085
5.0848
5.0846
5.0844
5.0842
y (northing in meters)
survey location
2.394
2.3945
2.395
2.3955
2.396
2.3965
2.397
x (easting in meters)
$\times 10^6$



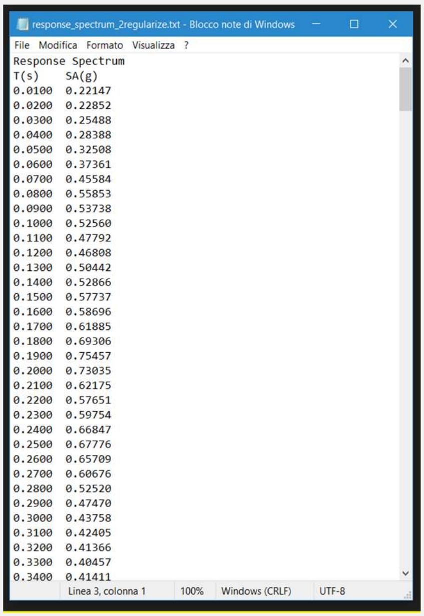
HS
working folder
save
file#1
file#3
refresh/...
file#2
file#4
delete all
INGV Italian ...
default terrain
terrain
smoothing
vertical exaggeration
show DTM
pure map view
C:\Users\Giancarlo\Desktop\INGV_DTM\w50580_s10
upload georeferenced photo
show survey location
create video
HoliSurface®
open working folder
show 2D section
elevation
0
5
10
15
20
25
30
35
40
survey location
y (northing in meters)
x (easting in meters)



HS
working folder
save
file#1
file#3
refresh/...
file#2
file#4
delete all
INGV Italian ...
default terrain
terrain
smoothing
vertical exaggeration
show DTM
pure map view
C:\Users\Giancarlo\Desktop\INGV_DTM\w50580_s10
upload georeferenced photo
show survey location
create video
HoliSurface®
open working folder
show 2D section
elevation
survey location
x (easting in meters)
y (northing in meters)

Appendix U: utility for the regularization of a response spectrum

The regularization of a response spectrum is a questionable operation since it modifies the result of a simulation aimed at representing the real conditions (represented by the actual V_S profile and the input quakes). Spectra regularization (carried out according to the procedures indicated in the *Seismic Site Response* section of this manual) can be applied to any response spectrum saved in a simple ASCII file like the one shown here:



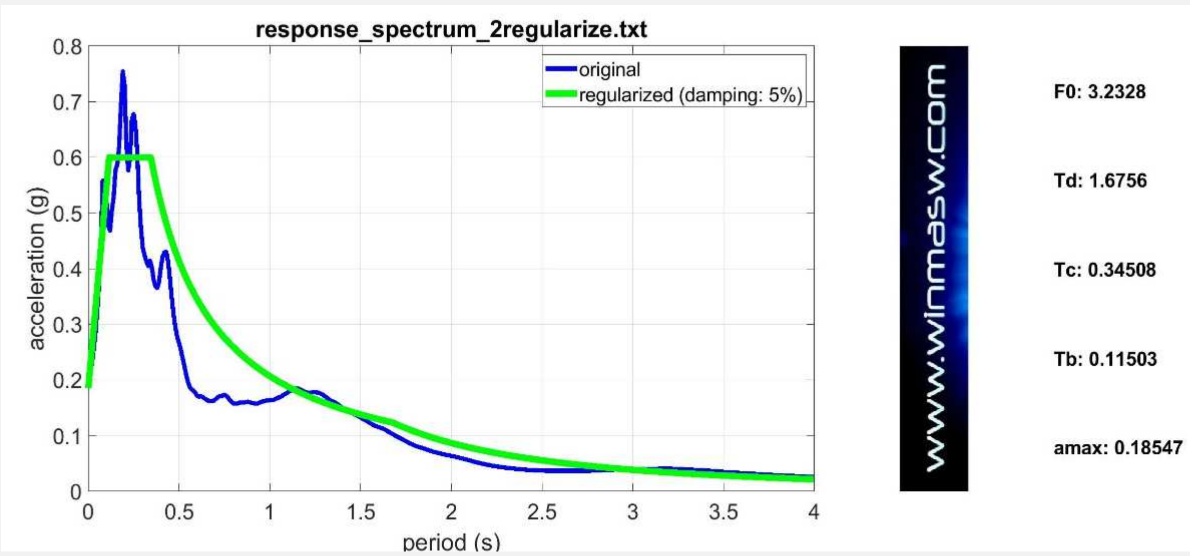
response_spectrum_2regularize.txt - Blocco note di Windows

File Modifica Formato Visualizza ?

```
Response Spectrum
T(s)    SA(g)
0.0100  0.22147
0.0200  0.22852
0.0300  0.25488
0.0400  0.28388
0.0500  0.32508
0.0600  0.37361
0.0700  0.45584
0.0800  0.55853
0.0900  0.53738
0.1000  0.52560
0.1100  0.47792
0.1200  0.46808
0.1300  0.50442
0.1400  0.52866
0.1500  0.57737
0.1600  0.58696
0.1700  0.61885
0.1800  0.69306
0.1900  0.75457
0.2000  0.73035
0.2100  0.62175
0.2200  0.57651
0.2300  0.59754
0.2400  0.66847
0.2500  0.67776
0.2600  0.65709
0.2700  0.60676
0.2800  0.52520
0.2900  0.47470
0.3000  0.43758
0.3100  0.42405
0.3200  0.41366
0.3300  0.40457
0.3400  0.41411
```

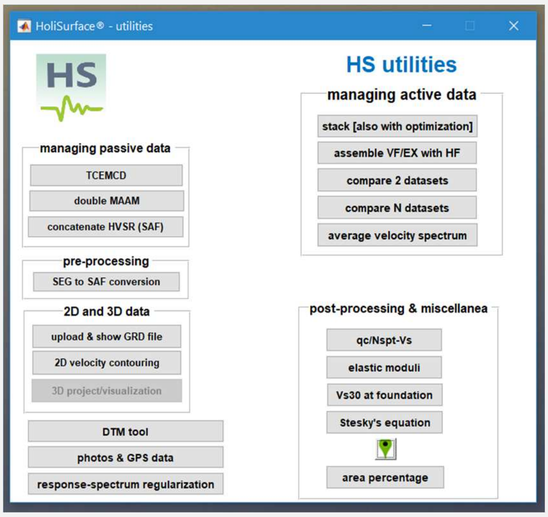
Linea 3, colonna 1   100%   Windows (CRLF)   UTF-8

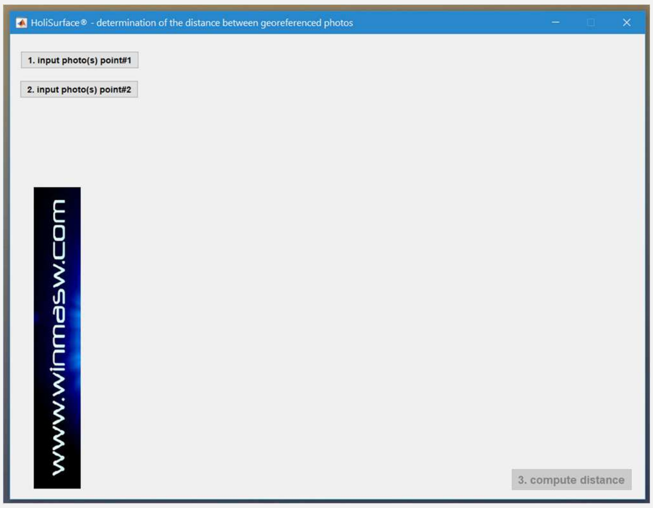
The first column reports the **period (T) in seconds** and the second column the **Accelerations (in units of g)**. When you upload this kind of file in the "**response spectrum regularization**" utility, the software will ask you how many *header lines* are present in your file (in this case there are two) and then what damping value (%) to use (it must be the same as the one used for the computation of the original response spectrum). As usual, the image and ASCII file you will obtain are automatically saved in the working folder (image and regularized curve in an ASCII file having the same format as the one above considered).



Appendix V: computing distances from georeferenced photos

In several panels, it is also present a “GPS icon” ( ) that gives you access to a tool you can use to obtain the distance between two georeferenced photos. This can be useful in several cases where it is not easy or possible to use a measuring tape and we are considering sufficiently-large distances (where GPS uncertainties are acceptable).





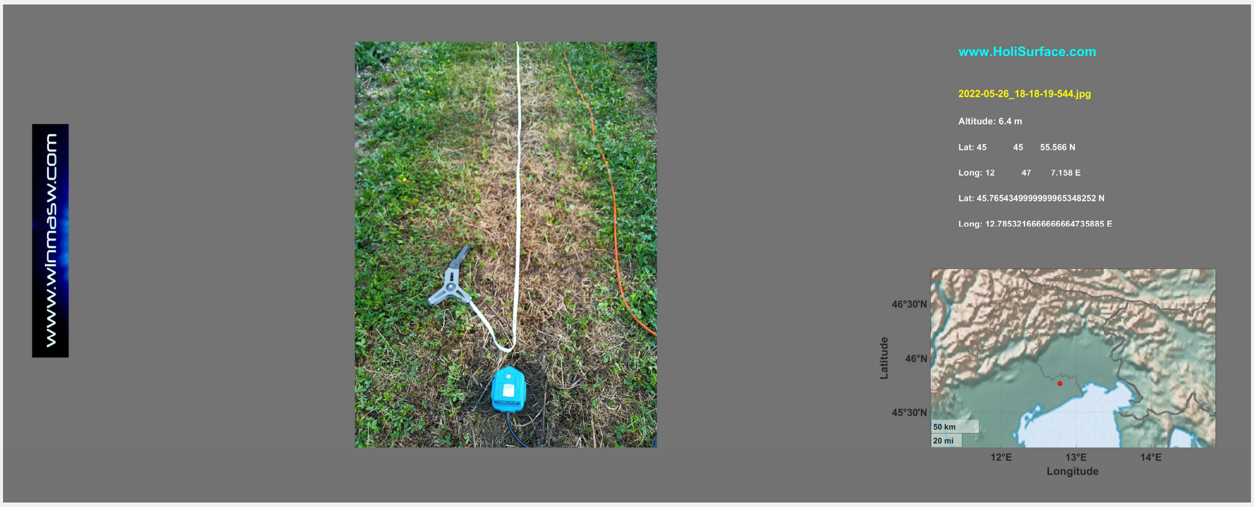
Once you upload the two georeferenced photos [of course, GPS data must be present in both of them], you can click the “compute distance” button and obtain a summary figure with the extracted information and the distance (see following figures).

For each of the two points you can actually upload more than just one photo. In case you upload two or more photos, the software will compute the median GPS position (this can decrease the position errors/uncertainties and you can thus obtain a more robust GPS position).

As always, figures are automatically saved in the current working folder.

Needless to say that the accuracy of the information depends on the device you used to take the pictures.

photo#1



photo#2

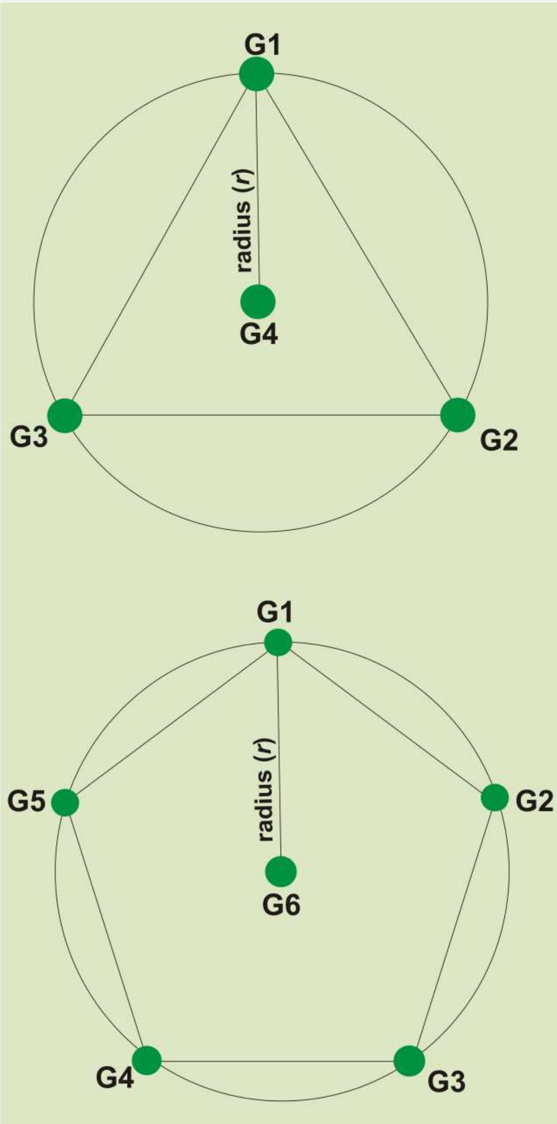
Final outcome

Some accessories for your *HoliSurface®* system

In addition to providing the entire acquisition system you may need, we also point out the following accessories: the *AREA51 device* and the *Solar Power Bank*

AREA51 device

Device for the rapid positioning of geophones during the field data acquisition to be used for MAAM. Available in two versions: triangular (only for triangular geometries) or circular (for both triangular and pentagonal geometries).
The package contains the actual device (circular or triangular - made of polyethylene), the bag in which to insert the rods and the fittings for the rods (now impossible to find). For convenience of shipping, rods that can be easily found in any do-it-yourself store are not sent.



Troubleshooting and support

Any software can inevitably have some issues often due to the application of procedures different from those designed by the programmers.

Before contacting us, please carefully read this section of the manual

Please, report any other problems to *winmasw@winmasw.com* always indicating:

1) **the User ID (UID) and Serial Number (SN) of your USB dongle**
2) **your release (e.g., winMASW Academy 2023)**
3) **the operating system of your computer (e.g. Windows 10 – 64 bit)**

Both the error and the situation in which the error occurs **must** be **clearly** described:

4) **Always include the snapshot of the black (background) DOS window at the time of the error**

Some important notes

1. Many problems are related to the operating system (remember that *winMASW®* and *HoliSurface®* and ELIOVSP only work on 64bit operating systems - we strongly recommend windows-10 and advise against windows-7 [which badly manages certain system privileges]).

2. Update often your operating system ("windows update")

3. Some anti-virus software (currently with AVAST AVIRA and PANDA) may not be able to understand that the hardware protection system used for *winMASW®* and *HoliSurface®* is not a virus. The installer should be able to instruct the antivirus to ignore the contents of a certain installation folder. If you are not able to do so, we recommend a "smarter" anti-virus (e.g. AVG)

4. Pay attention to keep your PC in order with frequent cleaning and optimization operations possible with different software (for example Glary Utilities). A computer is a highly complex machine that must be taken care of (Desktops with dozens of files and folders are usually the first evidence of dangerous deficiencies in this sense).

Some problems originate from the (invasive) influence of some
Antivirus software

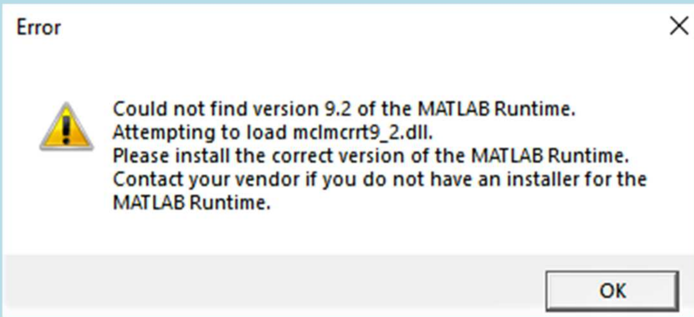
In those cases, before worrying try to disable your antivirus (or to add ELIOVSP to the software that the antivirus should trust and ignore).

Consider installing the AVG anti-virus (free and more discreet/reliable than many others).

Here some possible problems that can be easily solved by the user

First possible problem

If, when launching the software, you get an error window with a message similar to the one shown in the following window (the MATLAB Runtime version number changes over the years), the problem lies in the incorrect software installation; in particular, the Matlab libraries have not been (correctly) installed.
We recommend you to carefully read the "README.PDF" file available in the software DVD/USB and carefully follow the simple instructions (and check that the installation process is fully and properly carried out).



Error "**Undefined function or variable 'matlabrc'**"
(visible at program launch on the DOS window).

Solution:

1) activate (in your Operating System) the display of hidden folders and files (the procedure can be easily found on the internet);

2) manually delete the "temporary" folder of the *Matlab Runtime Compiler*.

Go to the folder *C:\Users [username]\AppData\Local\Temp[username]\mcrCache[version]* and erase it.

3) re-install the file *MCRinstaller.exe* in the "*preHS"* folder of the *HoliSurface* installation CD (i.e., simply run the executable *MCRinstaller.exe*).

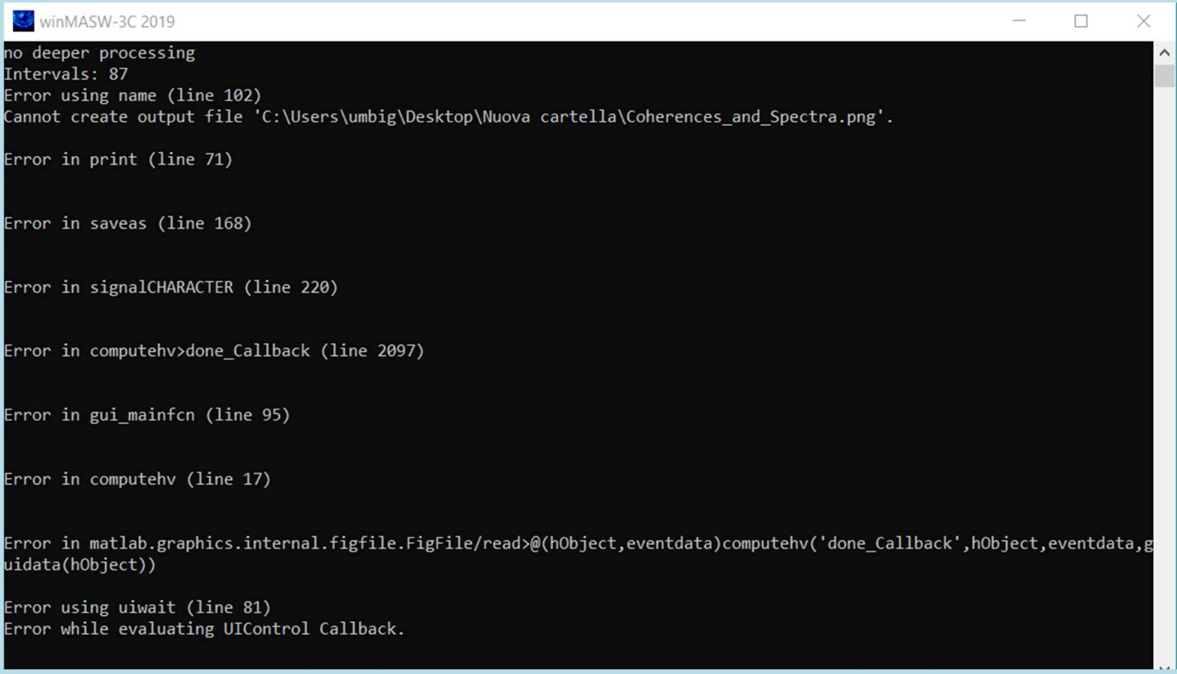
At this point everything should be fixed and you can try to run your *HoliSurface®*.

Error "**Starting parallel pool (parpool) using the 'local' profile** ... Error using parpool (line 103) **Not enough input arguments.**

or

Error "**Cannot create output file**" (or similar)

(visible at program launch on the DOS window).



Solution:

- *search* for the sub-folder "MathWorks" in the folder "users" (or "C:/users") and delete it. Attention, it is not a "C:/user/MathWorks" folder, it is a folder inside one of the "C:/user" folder, so search for "MathWorks".

- do the same for the *mcrCache* folder (always within the folder in C:/users). In some cases / systems, depending on your software release, the folder may also be called (for example) mcrCache9.2.
In some cases this folder is more easily identifiable with a search from C:/ (and not from the sub-folder C:/*users*). For example, you will find the folder "C:\Users\John\AppData\Local\Temp\John\mcrCache9.2", which must be deleted.
At this point everything should be fixed and you can try to launch ELIOVSP (*HoliSurface®* or *winMASW®*).

- if this does not work, re-install the *MCRinstaller.exe* file in the *"preELIOVSP"* folder on the *ELIOVSP* installation DVD (i.e., simply run the MCRinstaller.exe executable).

Remote sessions

In case it is necessary a solution from ELIOSOFT, a remote session via **AnyDesk** is necessary.

In that case:

1) download and install the **Anydesk** software (https://anydesk.com) and provide us with your ID (identification number of your PC)

2) send to winmasw@winmasw.com an appointment request for a remote session [it is important to be on time and carefully follow the provided instructions].

What is **AnyDesk**? You can have a look for instance here: https://www.youtube.com/watch?v=g3W1nBbtqEE

our social media

https://www.facebook.com/HoliSurface [public]

https://www.facebook.com/winMASW [for *friends*]

https://twitter.com/winmasw

YouTube https://www.youtube.com/user/winMASW/videos

ResearchGate https://www.researchgate.net/profile/Giancarlo_Dal_Moro

In particular, we recommend our *Facebook* page, which is frequently updated with case studies, news and tips.

You record, we analyze: our data processing service

Do you need to process your seismic data according to *MASW, MAAM, ReMi, ESAC, downhole, HVSR* or *HoliSurface®* techniques but you don't have the software and want to calmly consider whether to buy it?

You can send us your data and we will take care of the elaboration with reconstruction of the vertical profile V_S (therefore also of the Vs30).

In case you decide to use this service, we need the following data/information:
1. information about local stratigraphy;
2. at least one photo of the array [see the “GPS data in our software applications” section of this manual];
3. Rayleigh (VF) and Love (HF) data;
4. two HVSR measurements (i.e., passive microtremors) with the 3C geophone at two different positions of the array (e.g. at the end and at the center)

Files <u>must</u> be properly and clearly named following the simple rules explained in this manual as well as, for instance, in the 2020 Springer book (“Efficient Joint Analysis of Surface Waves and Introduction to Vibration Analysis: Beyond the Clichés”).
We therefore expect (in general terms) the following *files* (with similar file names):

1) VF_offset50.seg2 (or .SAF) [we also like to have each single shot and not only the stacked data]
2) HF_offset50.seg2 (or .SAF)
3) HVSR_central_Z_NS_EW.seg2 + HVSR_EndArray_Z_NS_EW.seg2
4) photo1.jpg, photo2.jpg, etc.

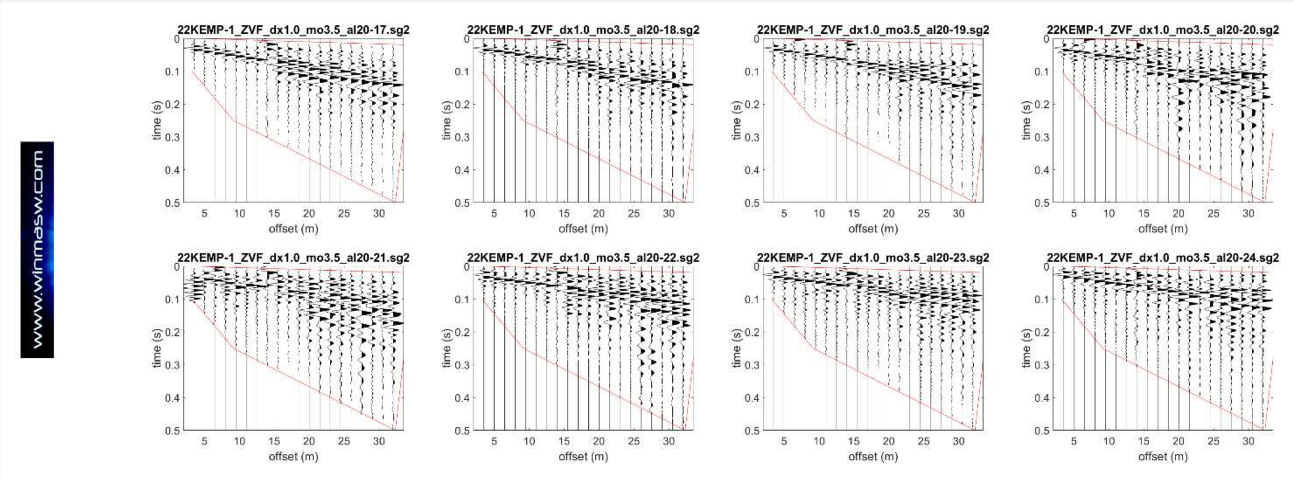
Shear source: the plate is set vertically (in a small hole dug in the ground). The horizontal force (hammer) is applied perpendicularly to the geophone array.

www.winmasw.com

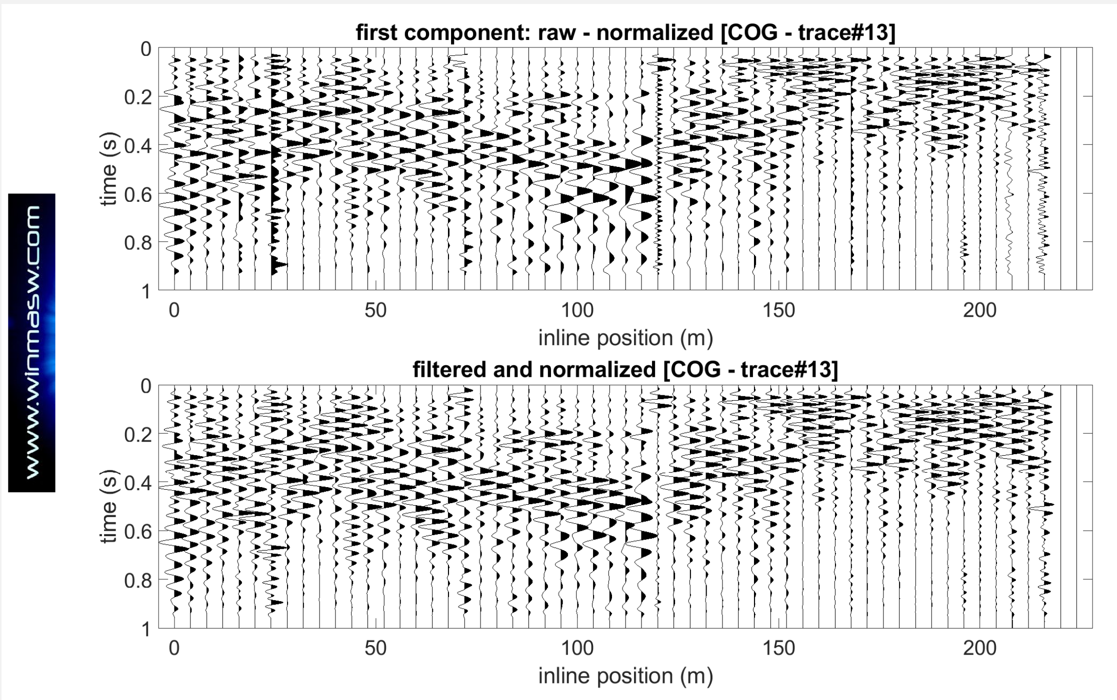
winmasw@winmasw.com

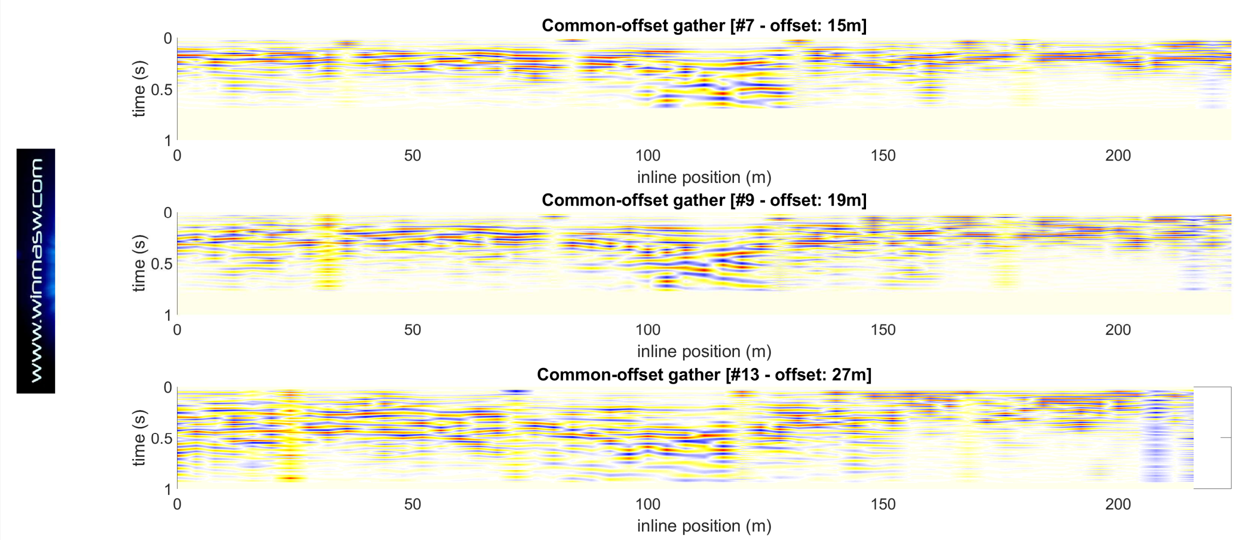
The ADAM-2D data processing service we offer

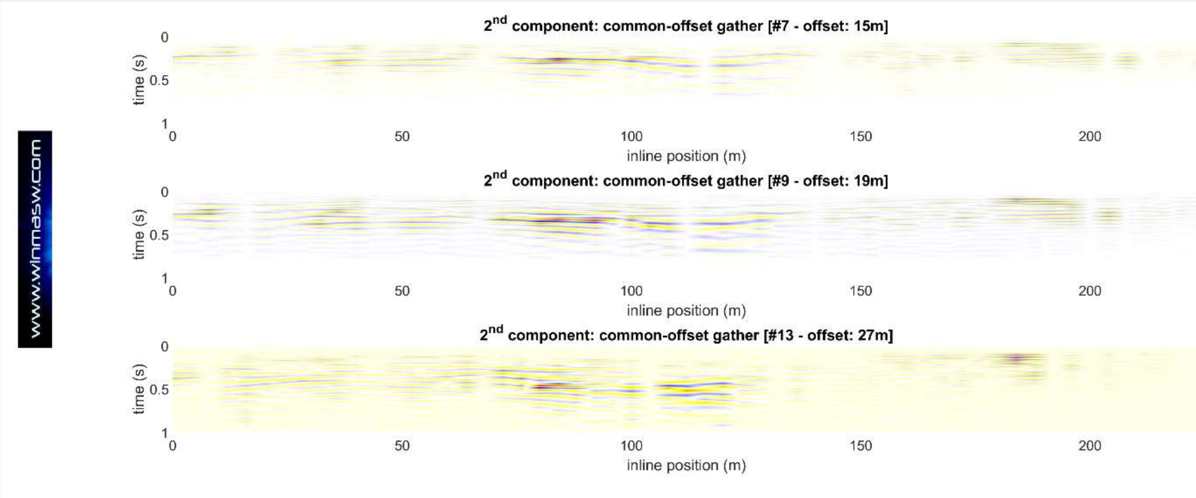
While for short 2D section you can surely use the tools that winMASW® Academy offers you, in case you need to explore larger areas (according to advanced data processing), ADAM-2D is a data-processing service we offer in order to analyse large amount of data and reconstruct the 2D V_S section thanks to the joint analysis of multi-component data (such approach is the only one that can provide reliable V_S values free from ambiguities and/or pitfalls that would inevitably affect any kind of analysis based on just one component- for details, please have a look to our *Elsevier* and *Springer* books).
Here few snaps of what we can do with your (possibly multi-component) data. In order to understand *what is what*, carefully read the title of each figure and the x and y labels.
In this case the goal was to verify the presence of a possible paleo-channel (entering the nearby lake) and which is now completely covered by recent alluvia deposits (flat topography).

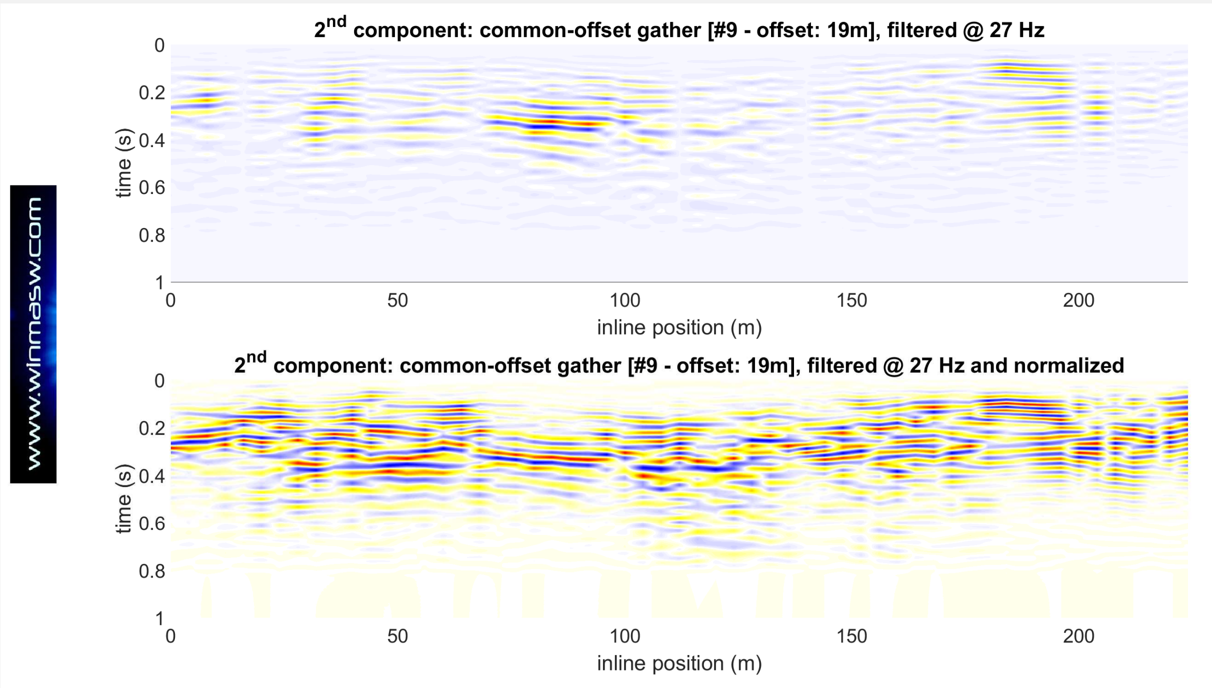


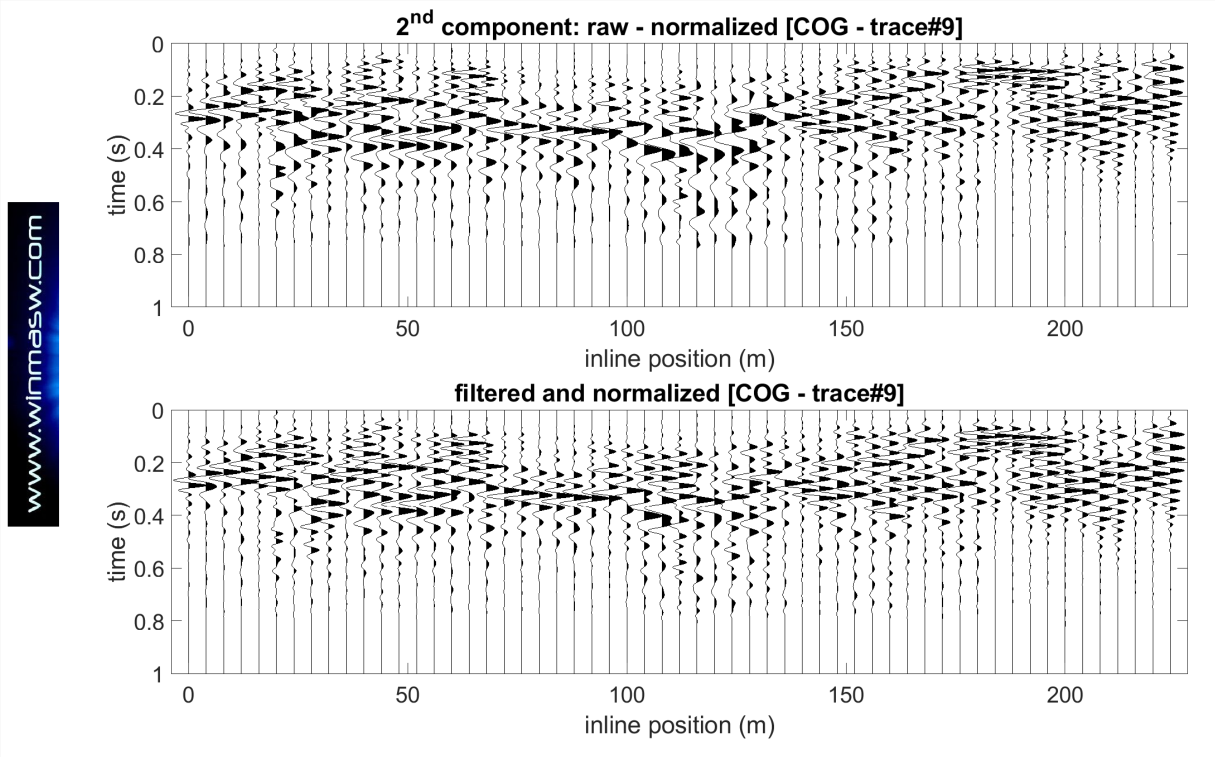
An example of 8 successive shots (Z component) [see the increasing suffix numbers] that can be jointly analysed together with the R (radial) or T (transversal – Love waves) components so to obtain an highly-constrained inversion process.




www.winmasw.com
Common-offset gather [#7 - offset: 15m]
time (s)
inline position (m)
Common-offset gather [#9 - offset: 19m]
time (s)
inline position (m)
Common-offset gather [#13 - offset: 27m]
time (s)
inline position (m)


www.winmasw.com
2nd component: common-offset gather [#7 - offset: 15m]
time (s)
inline position (m)
2nd component: common-offset gather [#9 - offset: 19m]
time (s)
inline position (m)
2nd component: common-offset gather [#13 - offset: 27m]
time (s)
inline position (m)


www.winmasw.com
2nd component: common-offset gather [#9 - offset: 19m], filtered @ 27 Hz
time (s)
inline position (m)
2nd component: common-offset gather [#9 - offset: 19m], filtered @ 27 Hz and normalized
time (s)
inline position (m)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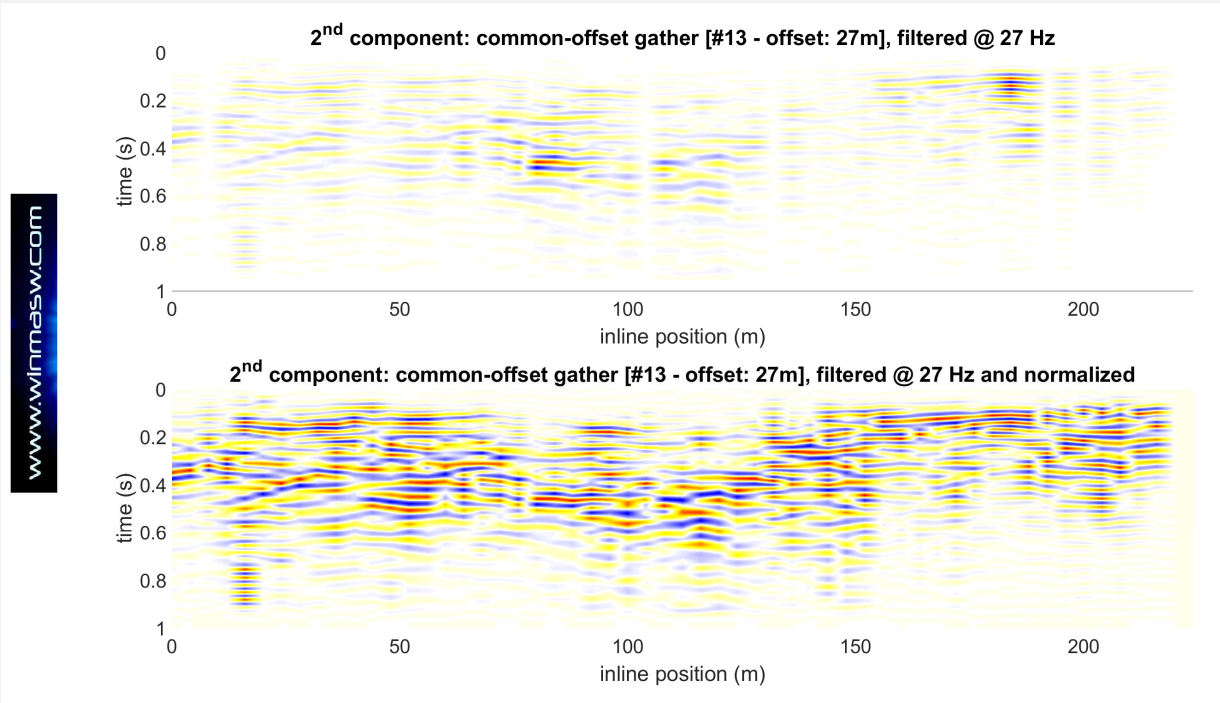
2nd component: raw - normalized [COG - trace#9]
time (s)
inline position (m)
filtered and normalized [COG - trace#9]
time (s)
inline position (m)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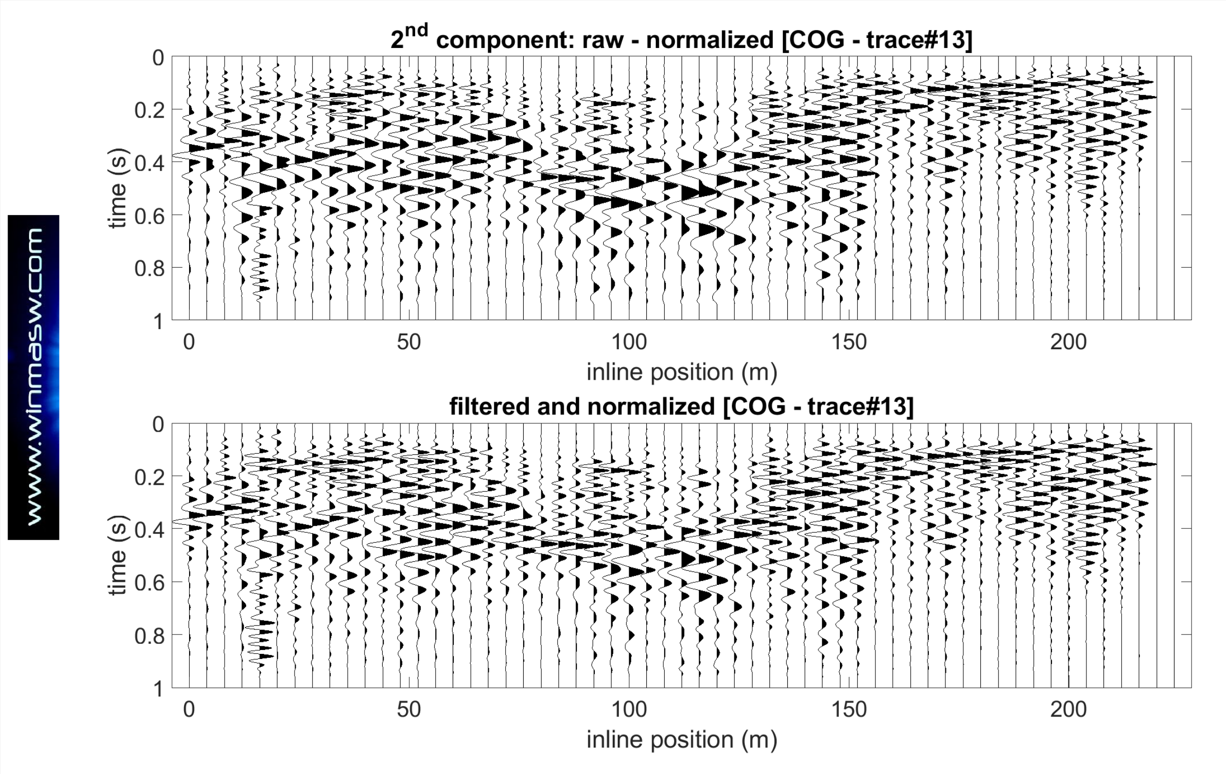
2nd component: common-offset gather [#13 - offset: 27m], filtered @ 27 Hz
time (s)
inline position (m)
2nd component: common-offset gather [#13 - offset: 27m], filtered @ 27 Hz and normalized
time (s)
inline position (m)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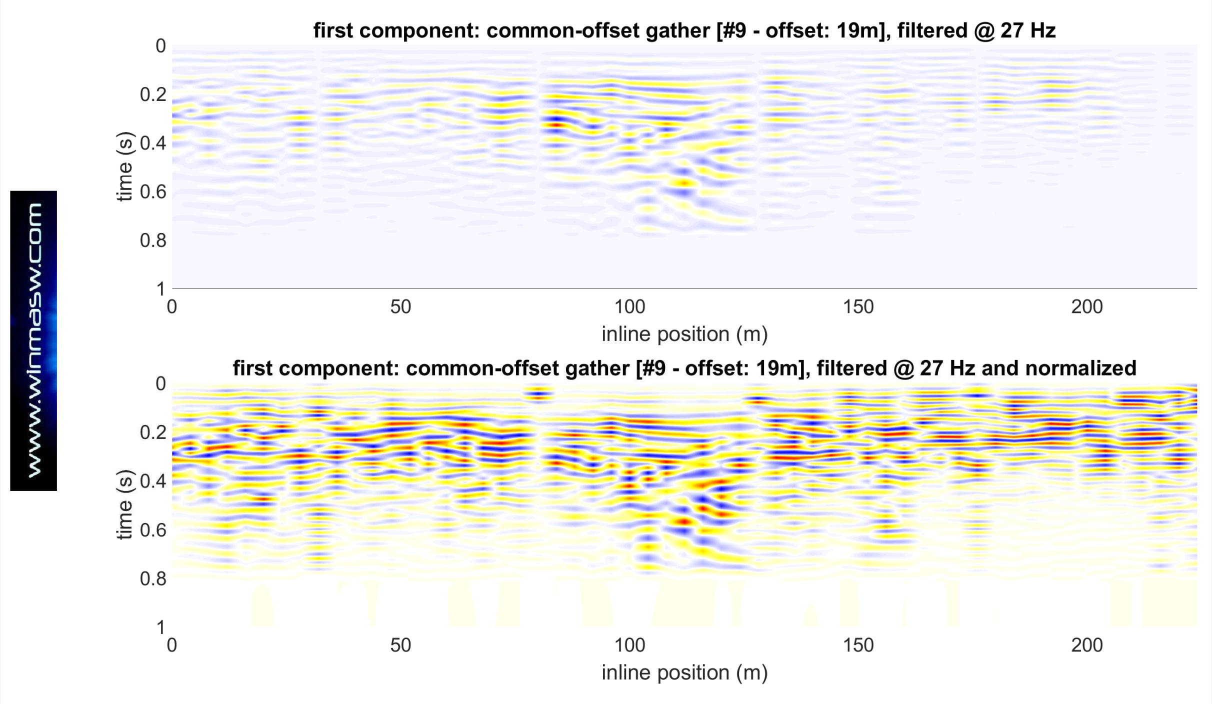
2nd component: raw - normalized [COG - trace#13]
time (s)
inline position (m)
filtered and normalized [COG - trace#13]
time (s)
inline position (m)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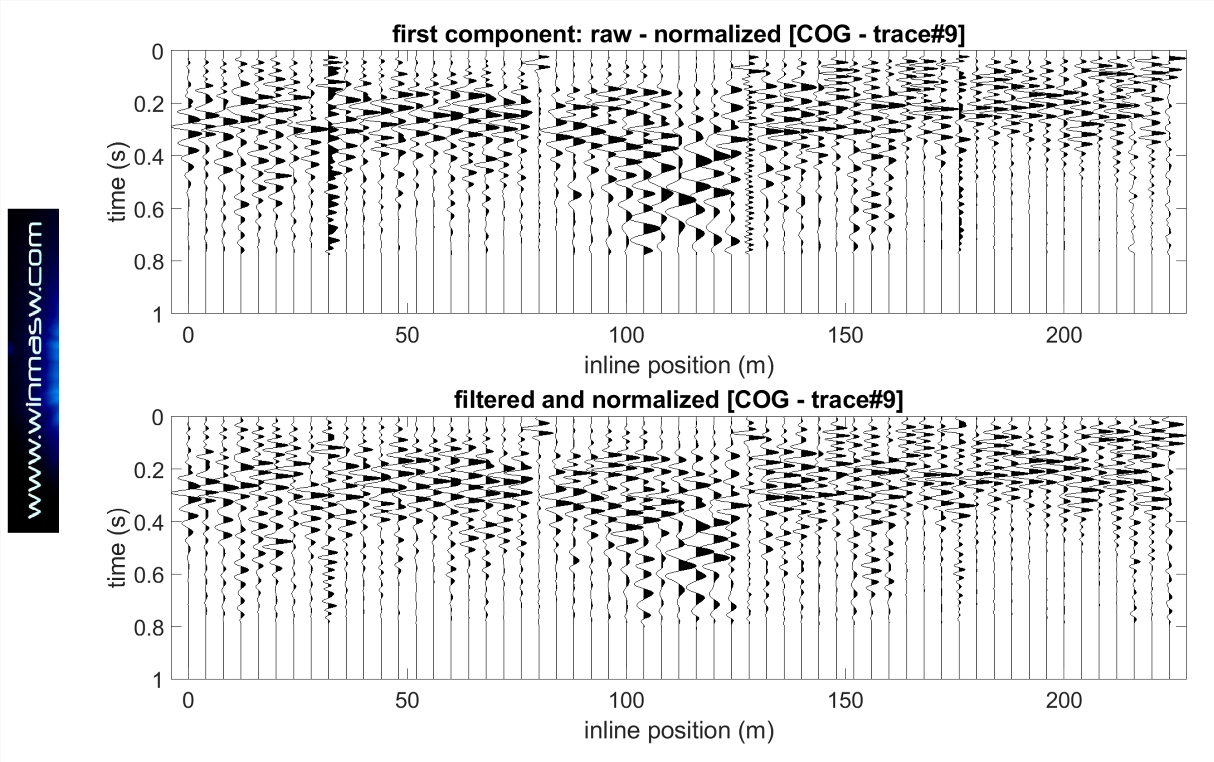
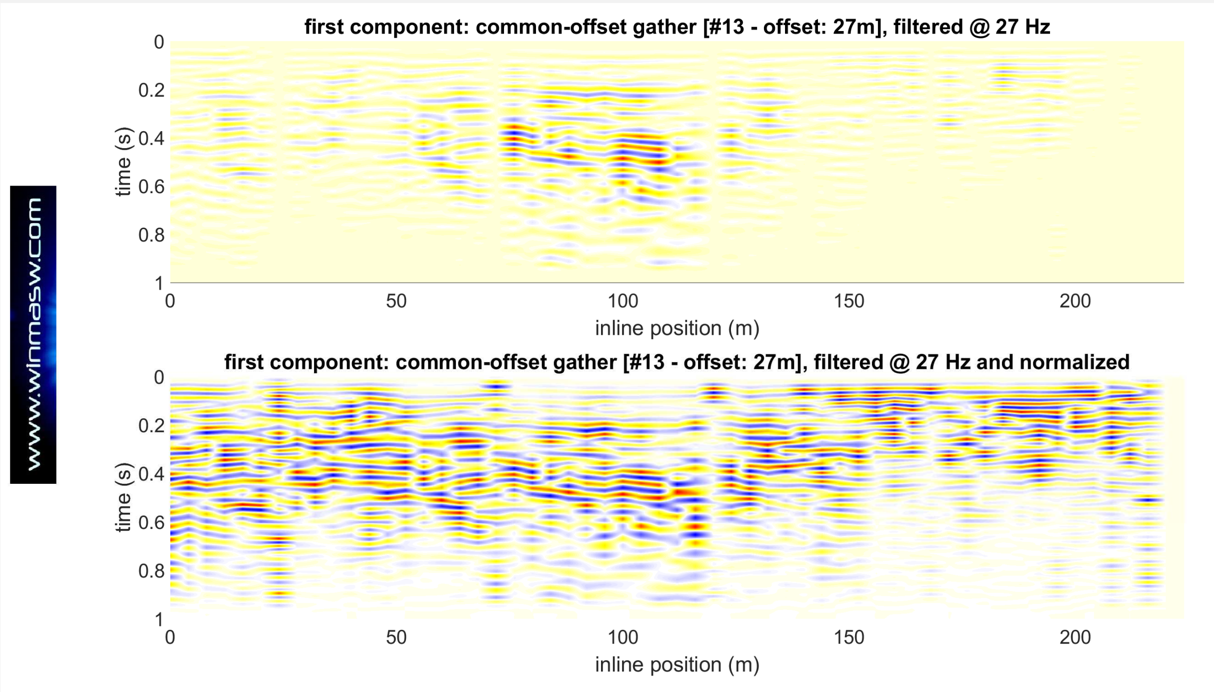
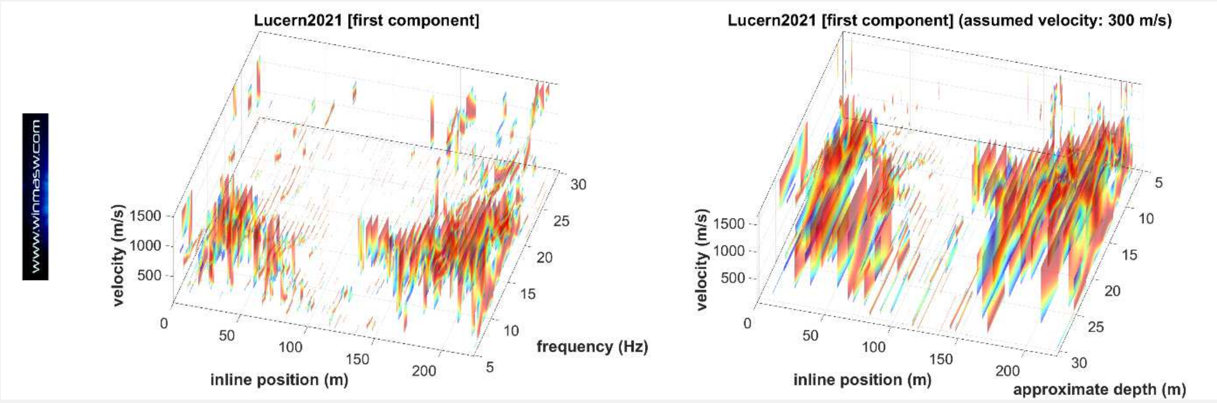
first component: common-offset gather [#9 - offset: 19m], filtered @ 27 Hz
time (s)
inline position (m)
first component: common-offset gather [#9 - offset: 19m], filtered @ 27 Hz and normalized
time (s)
inline position (m)


www.winmasw.com
first component: raw - normalized [COG - trace#9]
time (s)
inline position (m)
filtered and normalized [COG - trace#9]
time (s)
inline position (m)


www.winmasw.com
first component: common-offset gather [#13 - offset: 27m], filtered @ 27 Hz
time (s)
inline position (m)
first component: common-offset gather [#13 - offset: 27m], filtered @ 27 Hz and normalized
time (s)
inline position (m)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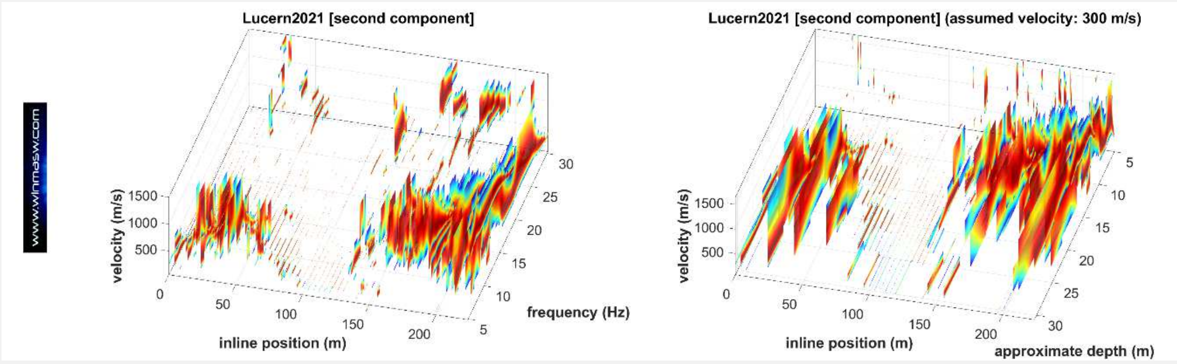
Lucern2021 [first component]
velocity (m/s)
inline position (m)
frequency (Hz)
Lucern2021 [first component] (assumed velocity: 300 m/s)
velocity (m/s)
inline position (m)
approximate depth (m)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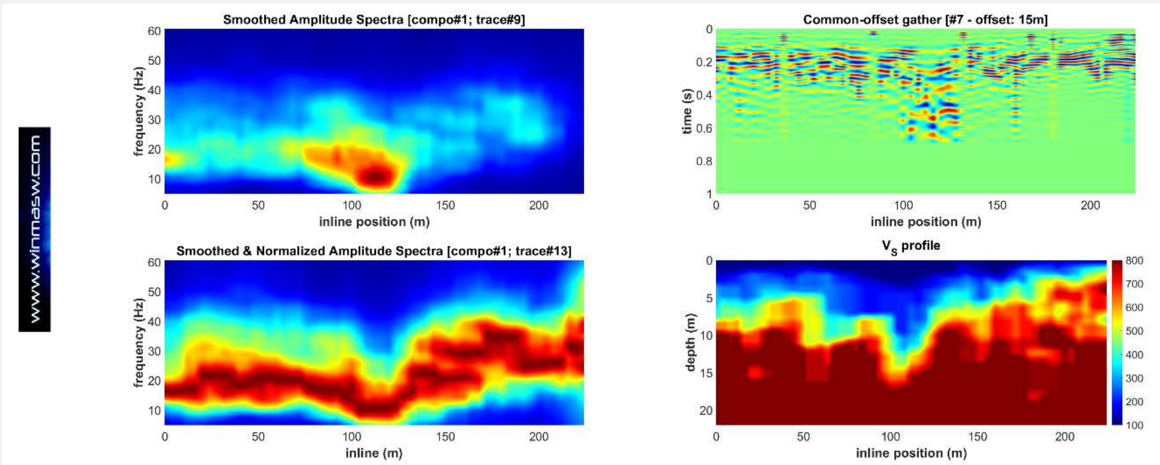
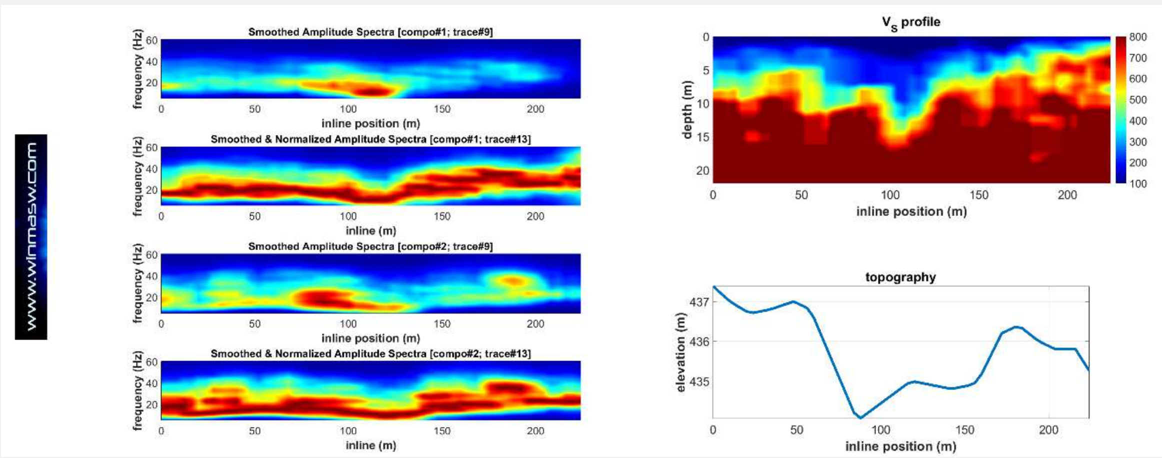
Lucern2021 [second component]
velocity (m/s)
inline position (m)
frequency (Hz)
Lucern2021 [second component] (assumed velocity: 300 m/s)
velocity (m/s)
inline position (m)
approximate depth (m)


www.winmasw.com
Smoothed Amplitude Spectra [compo#1; trace#9]
frequency (Hz)
inline position (m)
Common-offset gather [#7 - offset: 15m]
time (s)
inline position (m)
Smoothed & Normalized Amplitude Spectra [compo#1; trace#13]
frequency (Hz)
inline (m)
V_S profile
depth (m)
inline position (m)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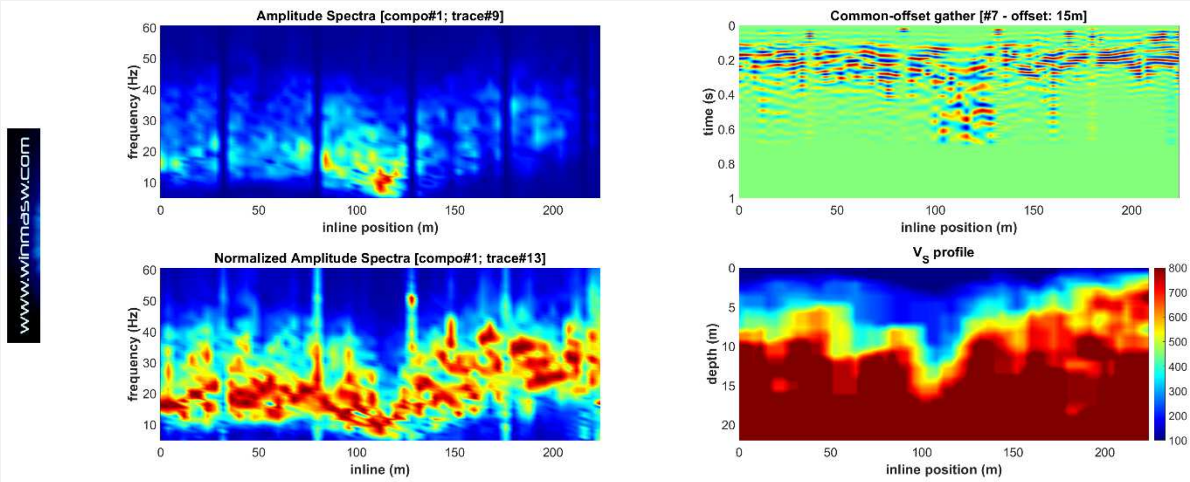
Smoothed Amplitude Spectra [compo#1; trace#9]
Smoothed & Normalized Amplitude Spectra [compo#1; trace#13]
Smoothed Amplitude Spectra [compo#2; trace#9]
Smoothed & Normalized Amplitude Spectra [compo#2; trace#13]
frequency (Hz)
inline position (m)
inline (m)
VS profile
depth (m)
topography
elevation (m)
inline position (m)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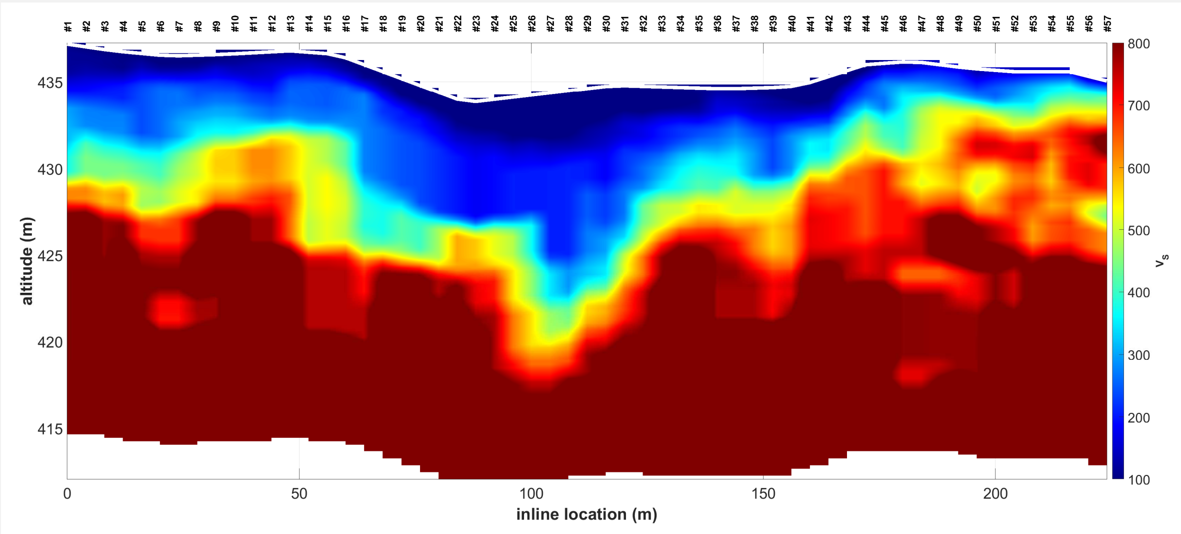
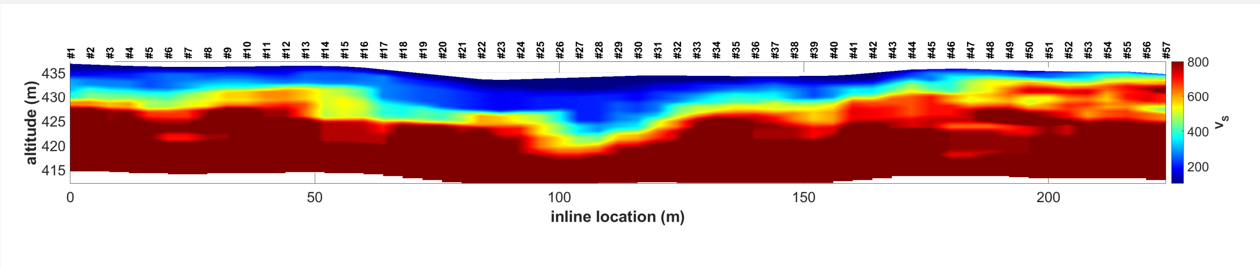
Amplitude Spectra [compo#1; trace#9]
frequency (Hz)
inline position (m)
Common-offset gather [#7 - offset: 15m]
time (s)
inline position (m)
Normalized Amplitude Spectra [compo#1; trace#13]
frequency (Hz)
inline (m)
V_S profile
depth (m)
inline position (m)


altitude (m)
inline location (m)
V_S


altitude (m)
inline location (m)
V_S

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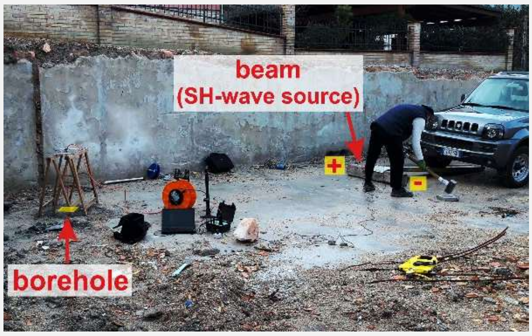
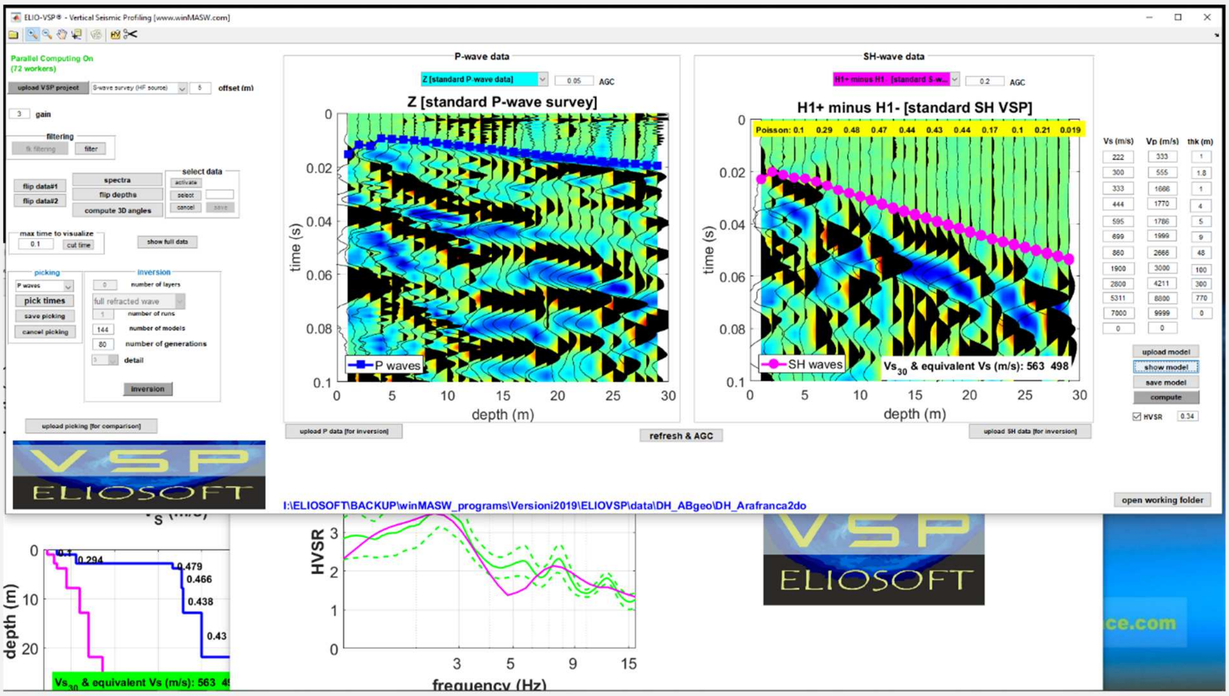
Our software for *DownHole* (DH) seismics:

joint modelling of he P- and SH-wave travel times also jointly with the HVSR (Horizontal-to-Vertical Spectral Ratio), so to increase the investigated depth





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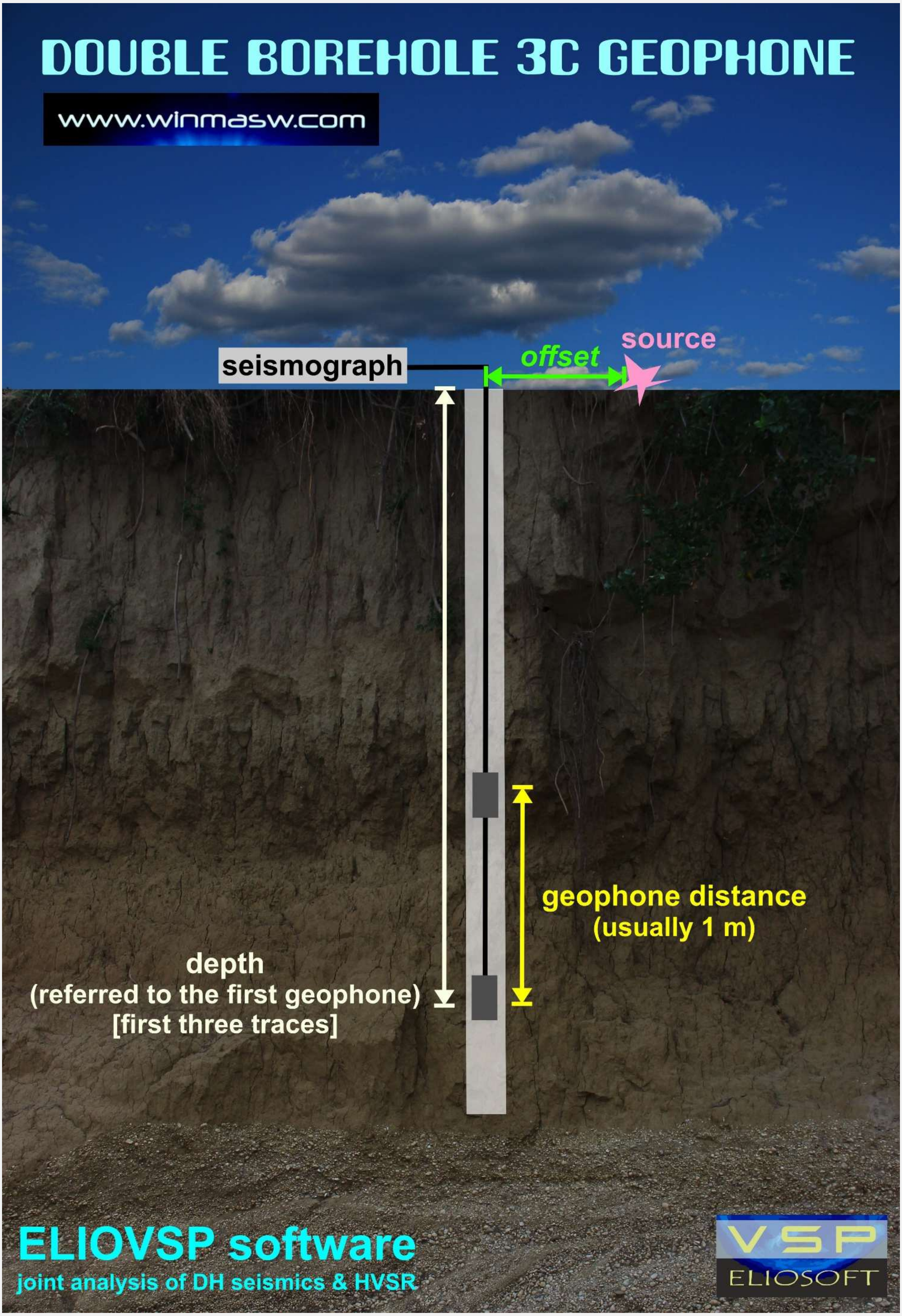

DOUBLE BOREHOLE 3C GEOPHONE
www.winmasw.com
seismograph
offset
source
geophone distance
(usually 1 m)
depth
(referred to the first geophone)
[first three traces]
ELIOVSP software
joint analysis of DH seismics & HVSR
VSP
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