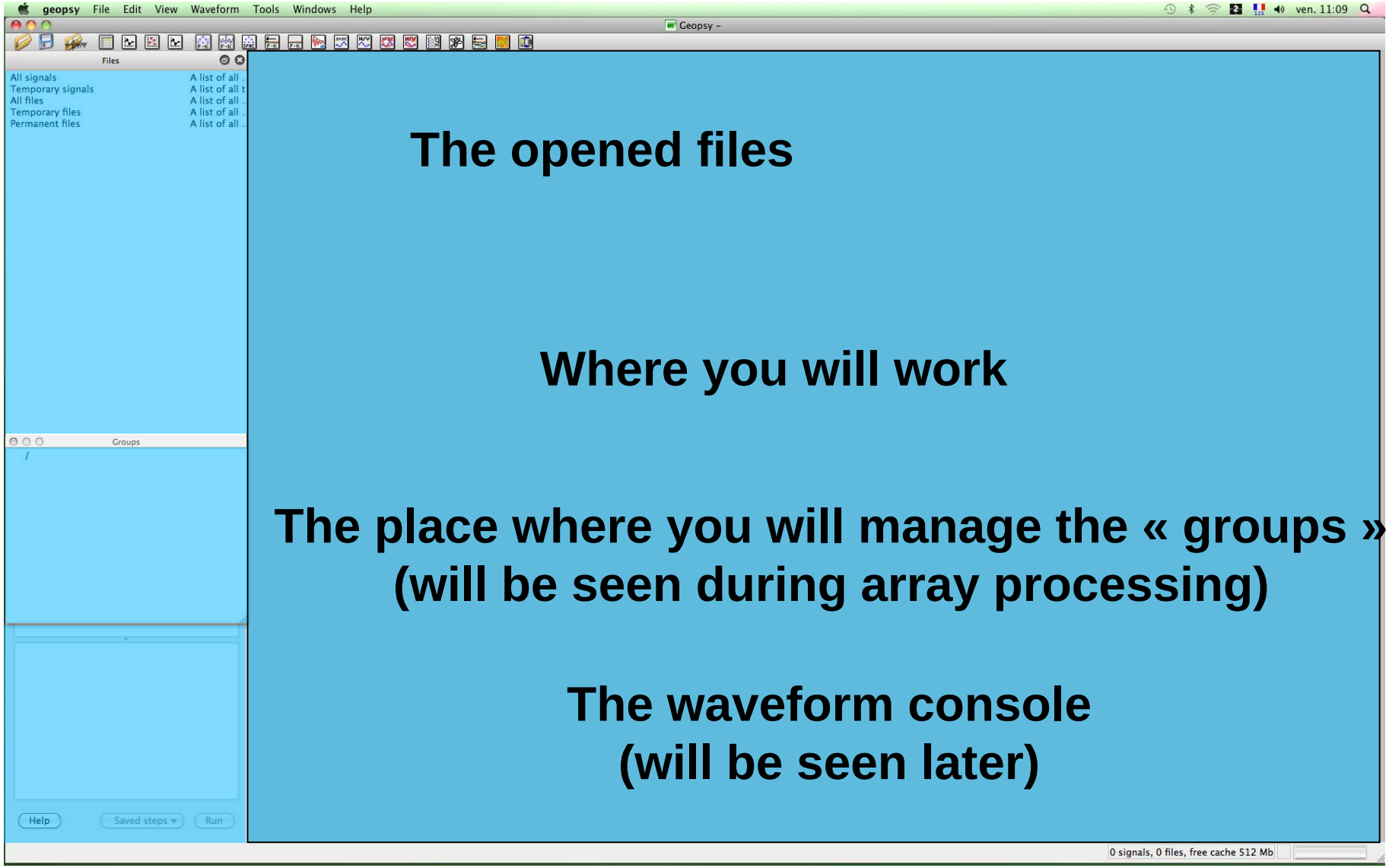
Using Ambient Vibration Techniques for Site Characterisation

Single station measurement: H/V

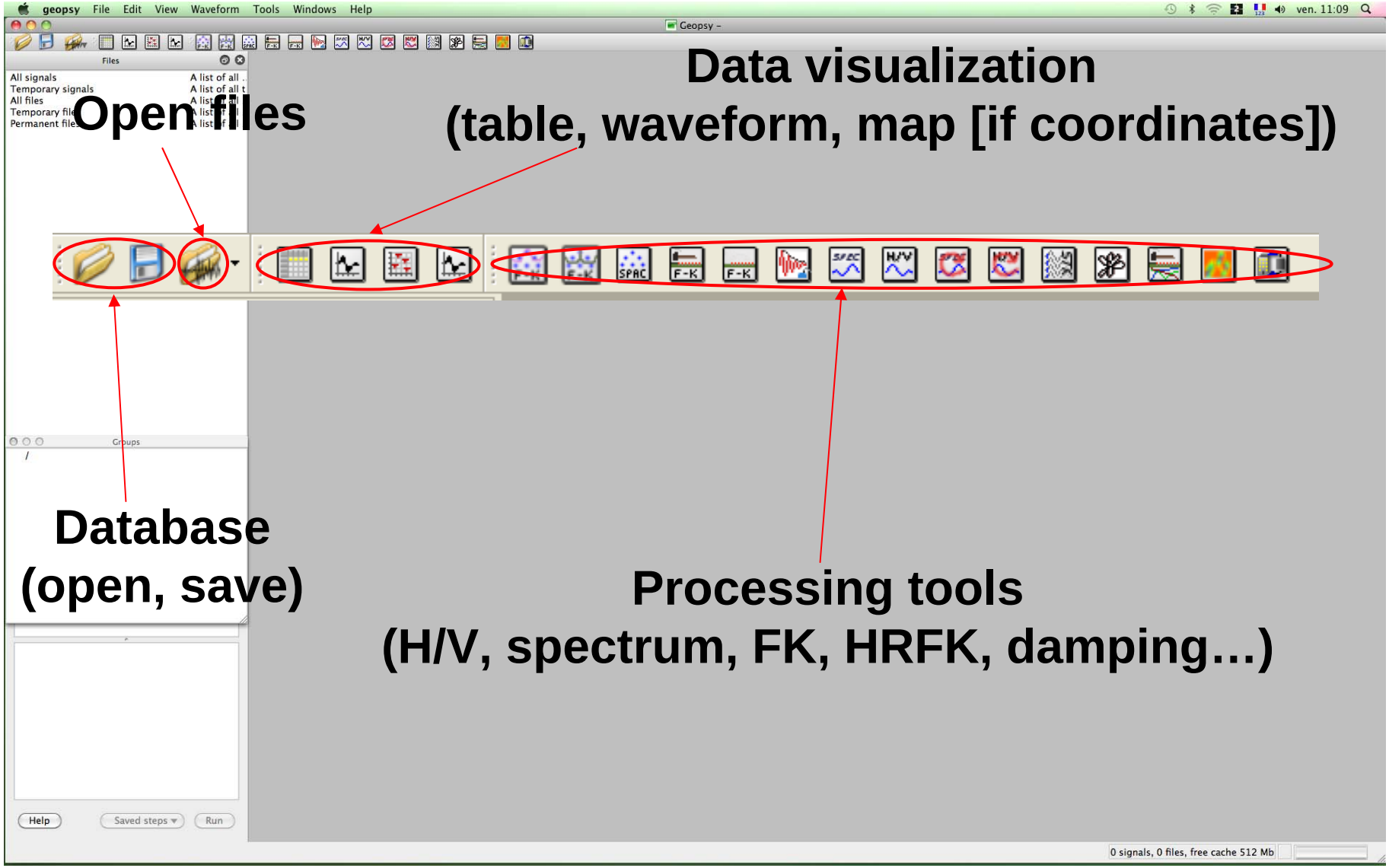
TUTORIAL

February, 2010, Thessaloniki, Greece

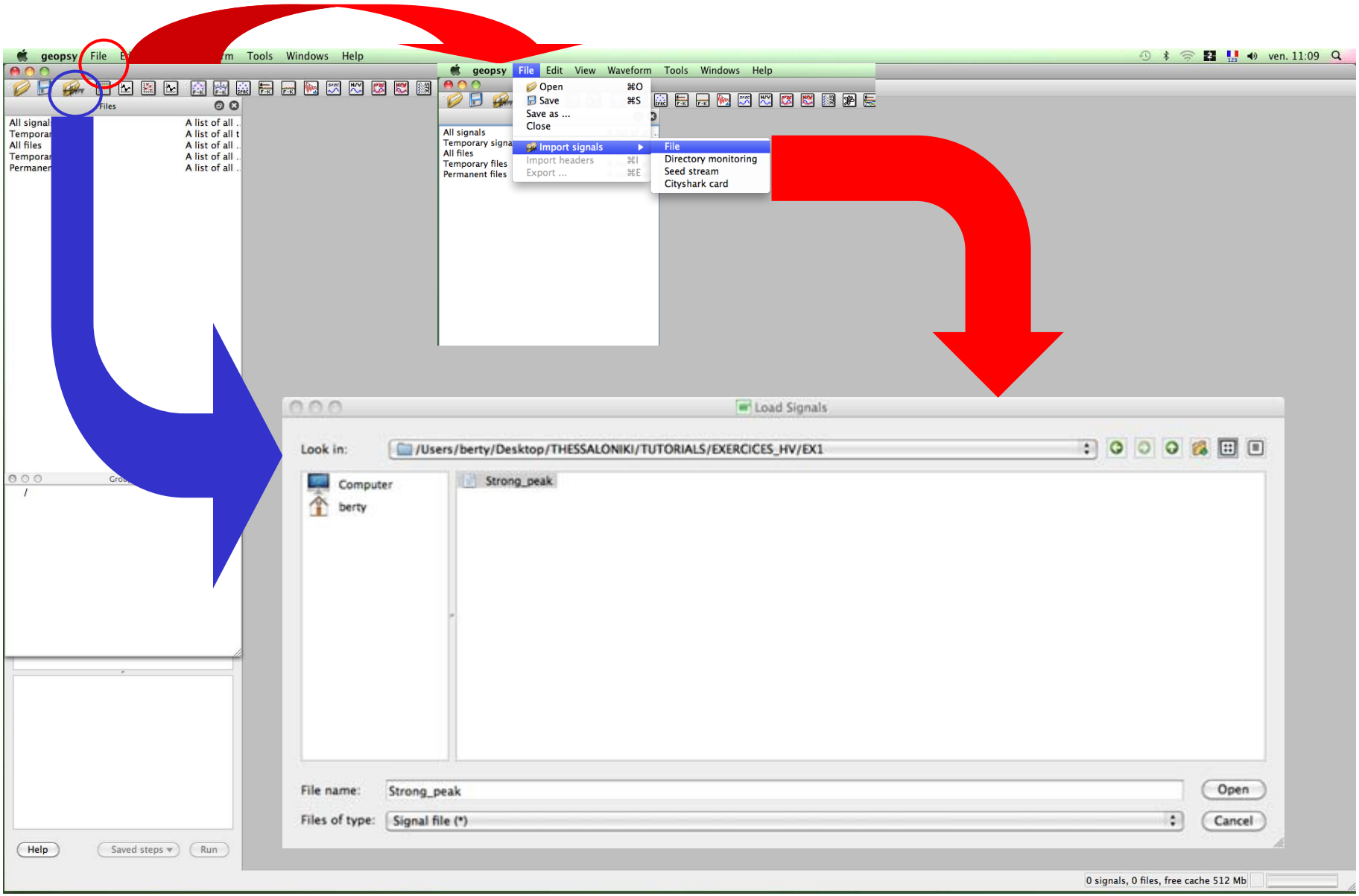
Start Geopsy



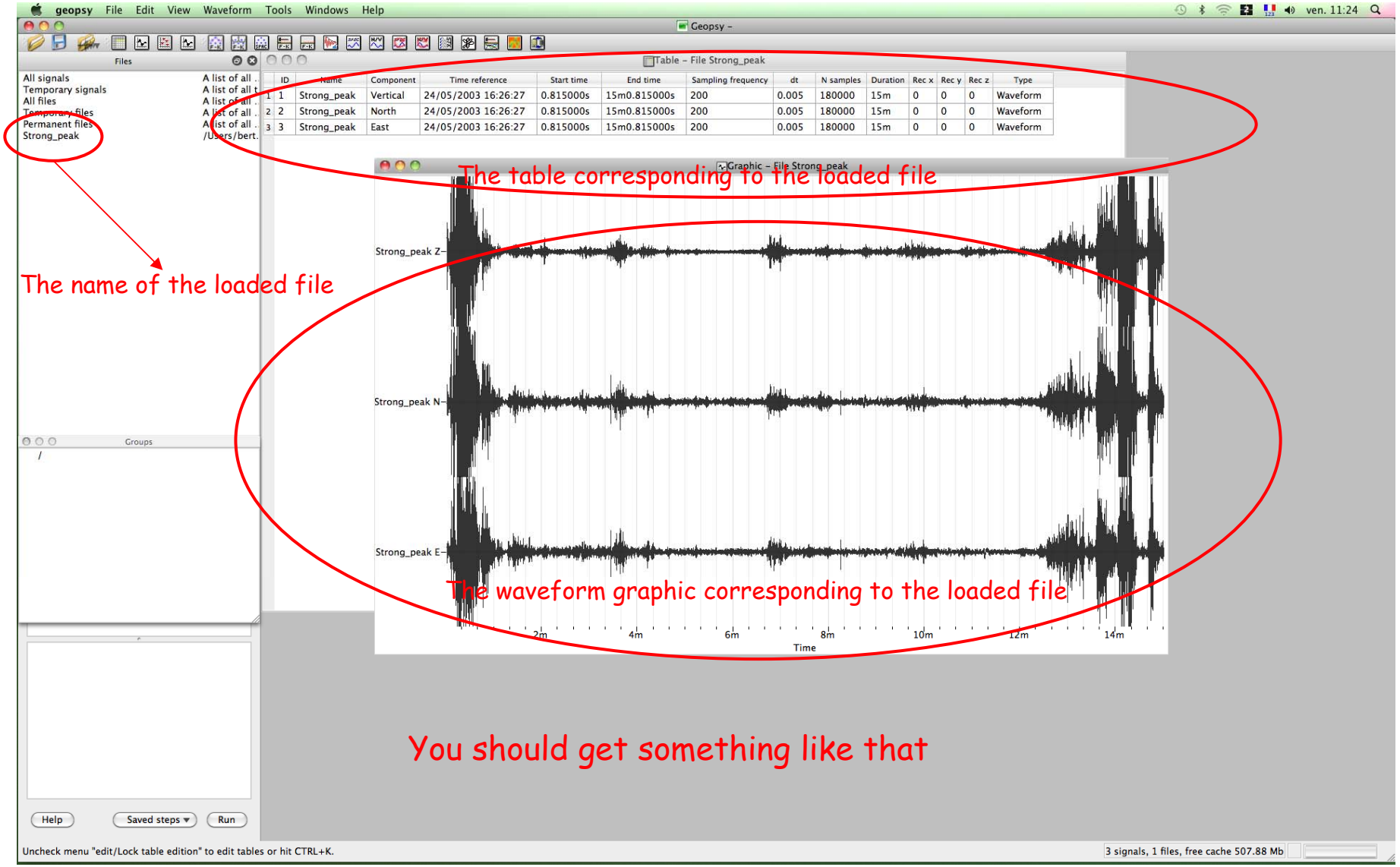
Start Geopsy



Loading signals
Directory EXERCISES_HV/EX01



Loading signals
Directory EXERCISES_HV/EX01



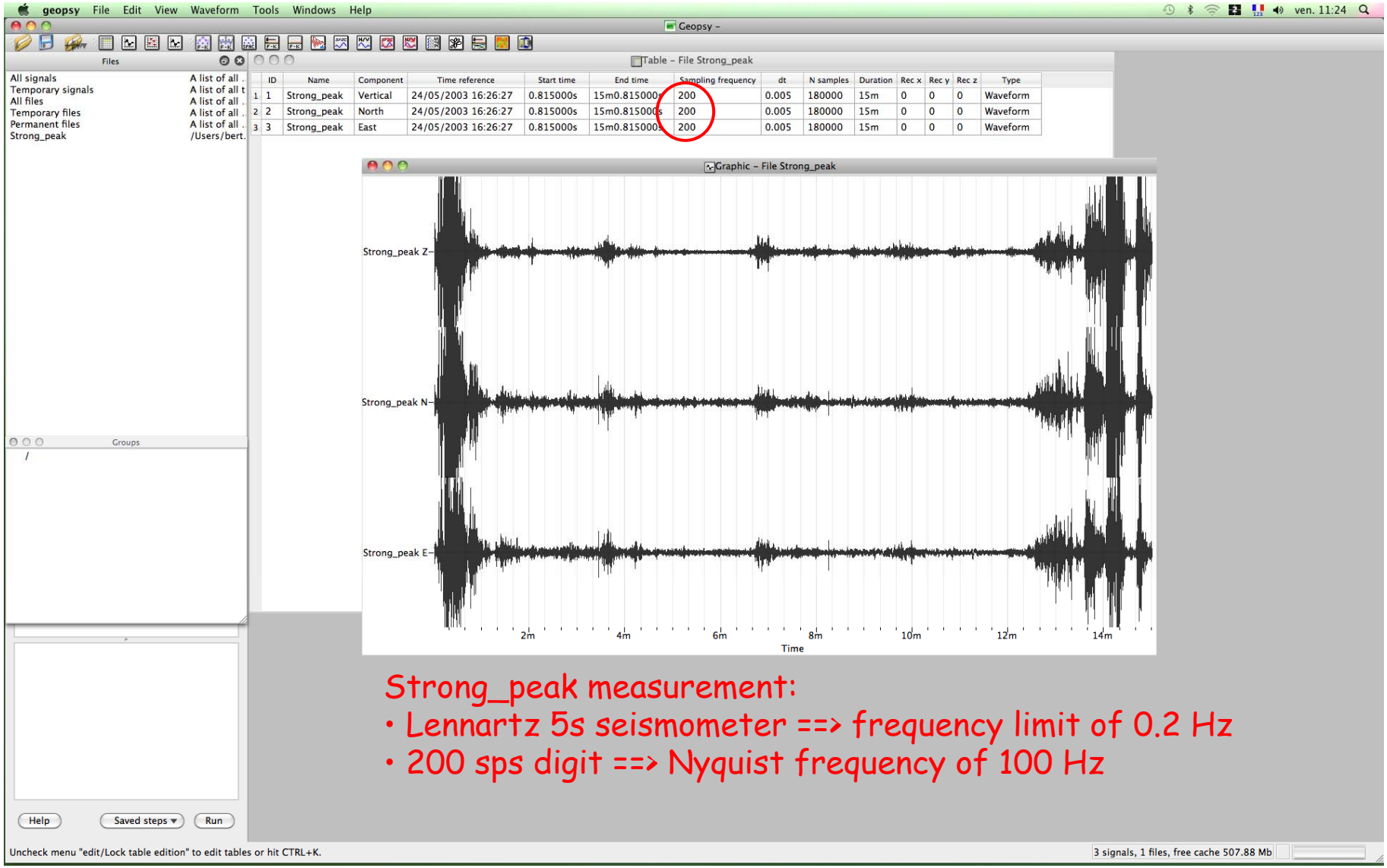
The table corresponding to the loaded file

The name of the loaded file

The waveform graphic corresponding to the loaded file

You should get something like that

Loading signals
Directory EXERCISES_HV/EX01

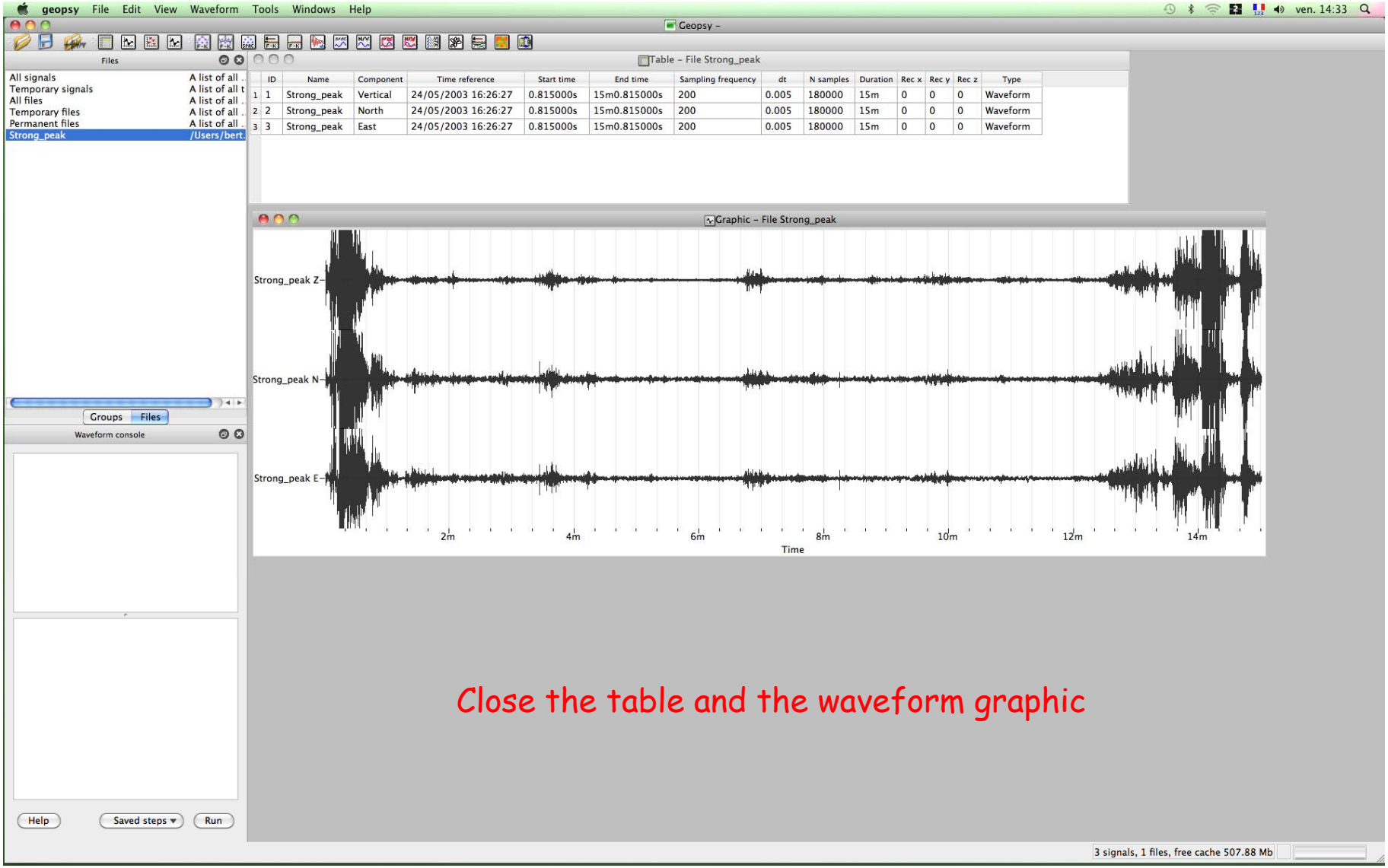


Strong_peak measurement:

- Lennartz 5s seismometer ==> frequency limit of 0.2 Hz
- 200 sps digit ==> Nyquist frequency of 100 Hz

Manipulating the data

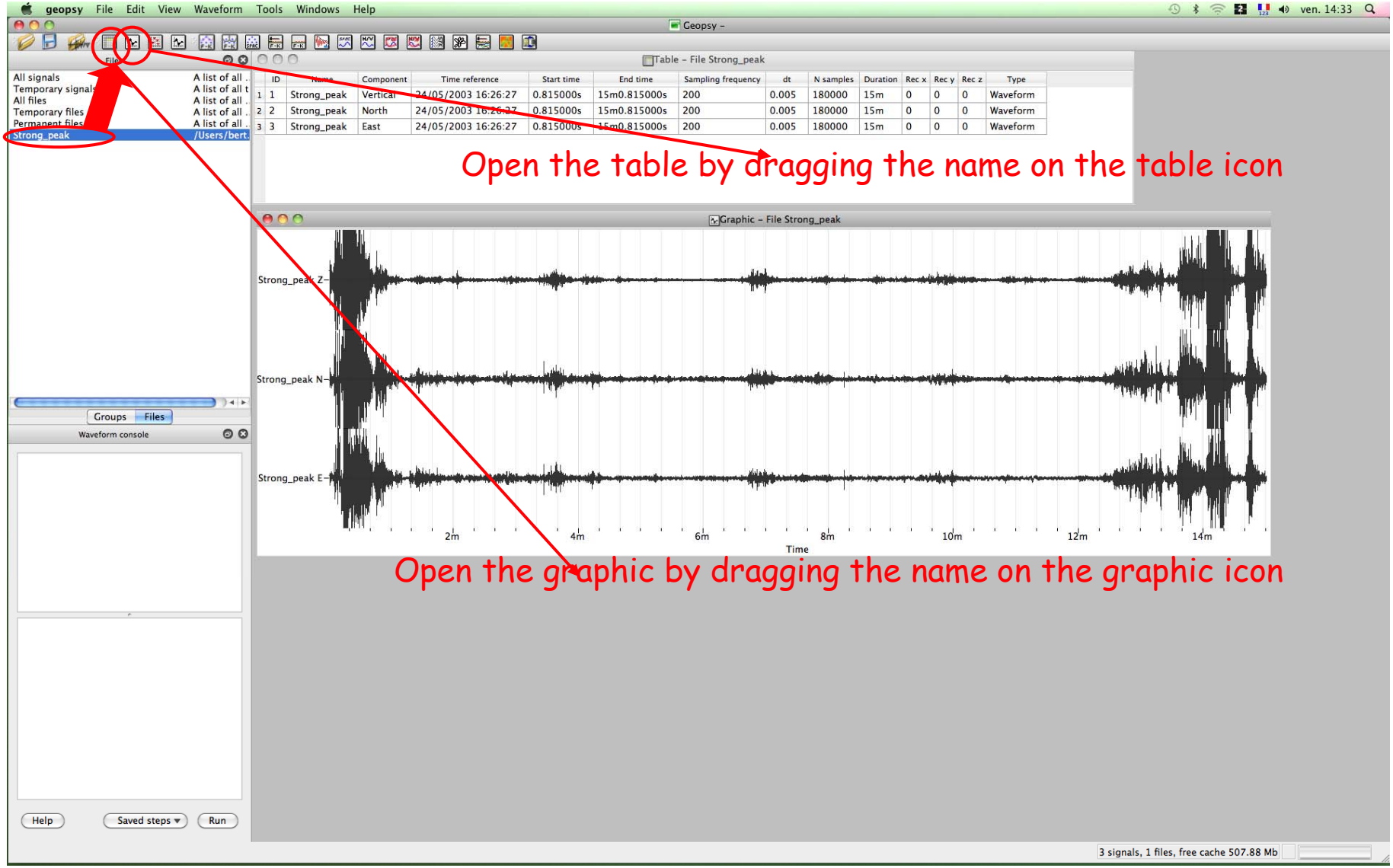
Possibility to open table and graphic



Close the table and the waveform graphic

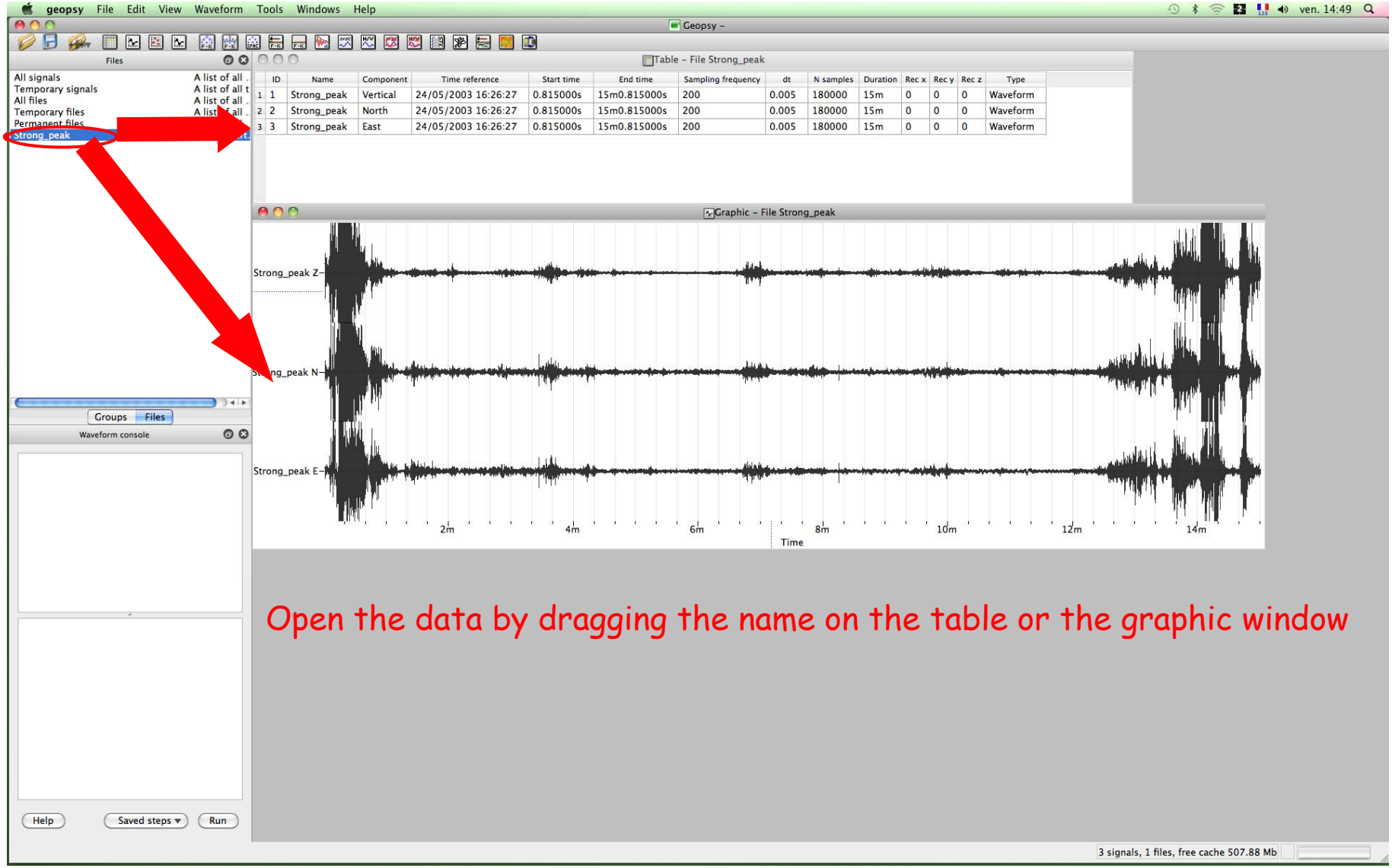
Manipulating the data

Possibility to open table and graphic 1



Manipulating the data

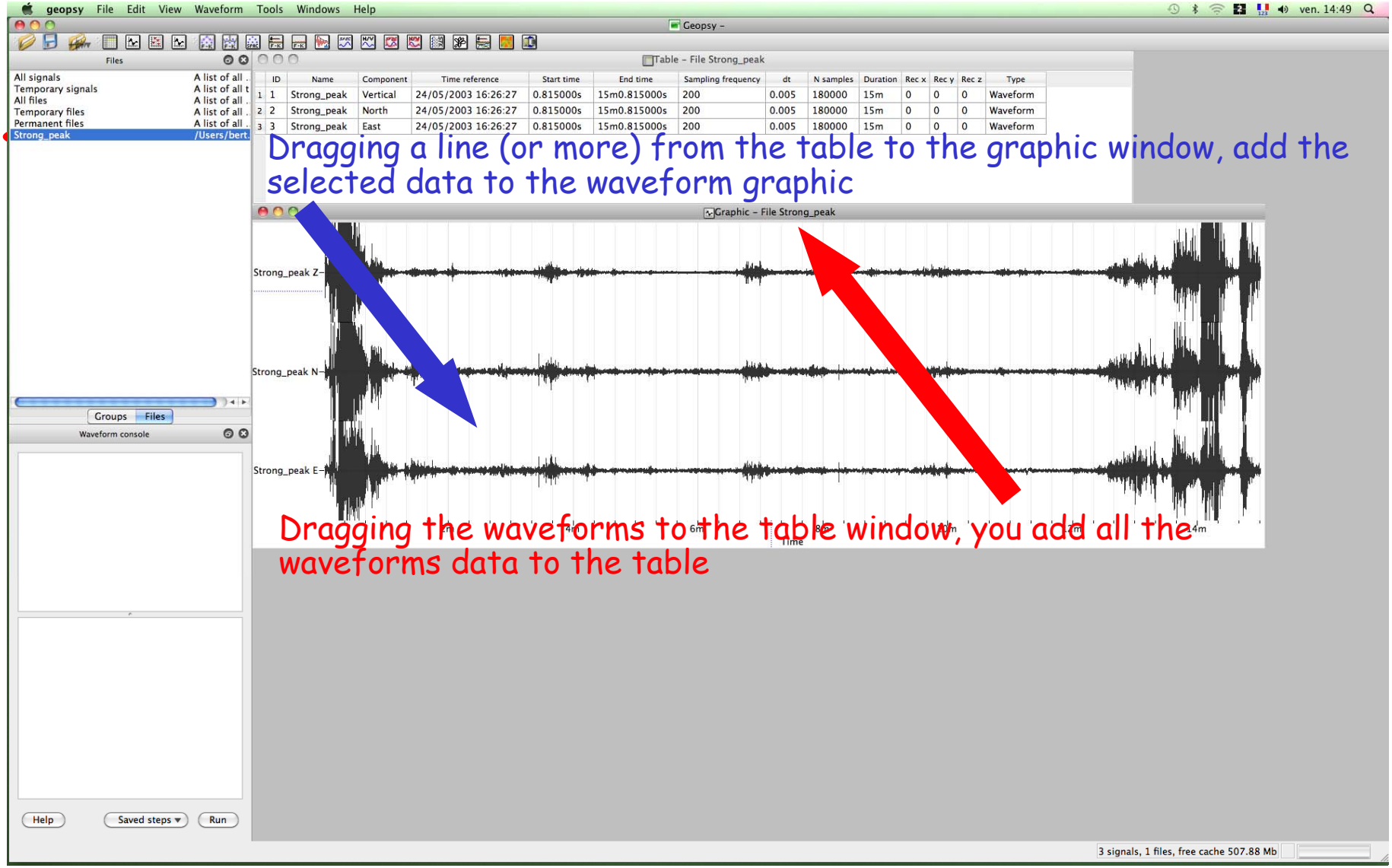
Possibility to open table and graphic 1 2



Open the data by dragging the name on the table or the graphic window

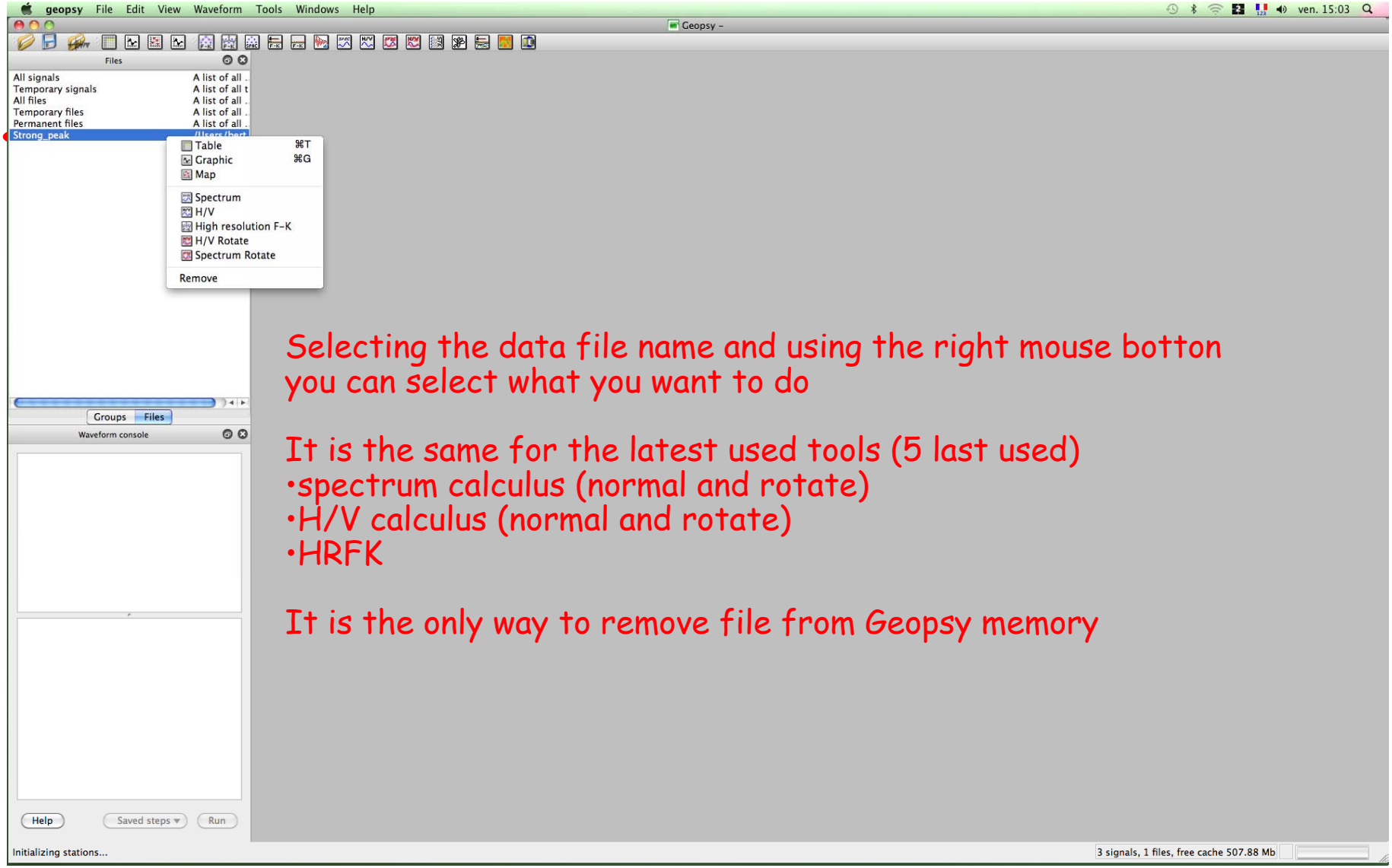
Manipulating the data

Possibility to open table and graphic 1 2 3



Manipulating the data

Possibility to open table and graphic 1 2 3 4

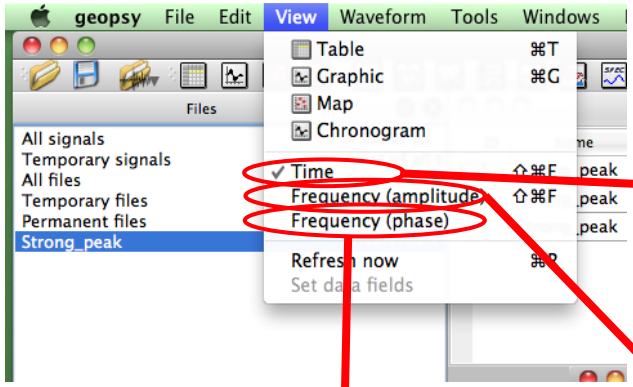


Selecting the data file name and using the right mouse botton you can select what you want to do

It is the same for the latest used tools (5 last used)
- spectrum calculus (normal and rotate)
- H/V calculus (normal and rotate)
- HRFK

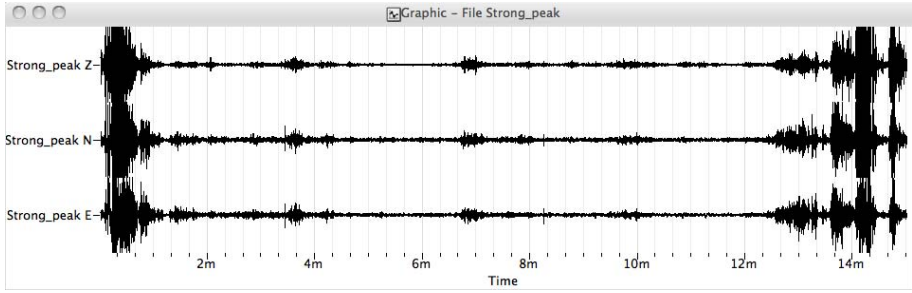
It is the only way to remove file from Geopsy memory

VIEW Menu
HOW TO PRESENT THE DATA

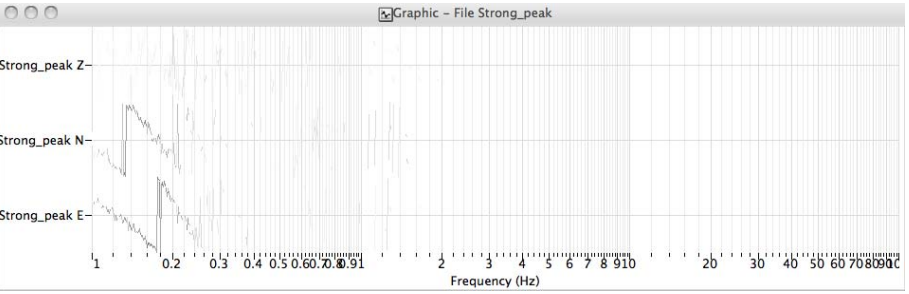


No distortion of the signal, only various ways to present the same thing

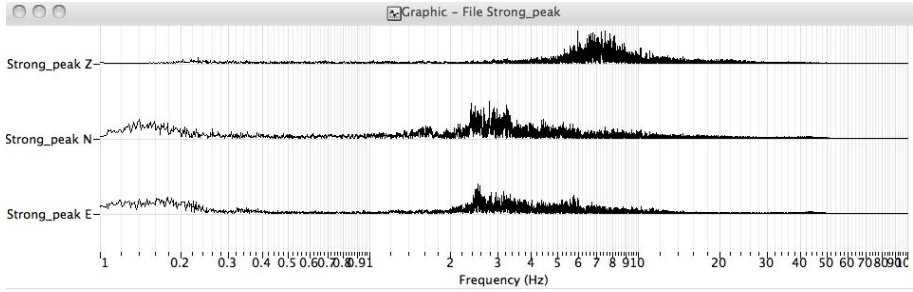
presents the data
•in time serie (normal)



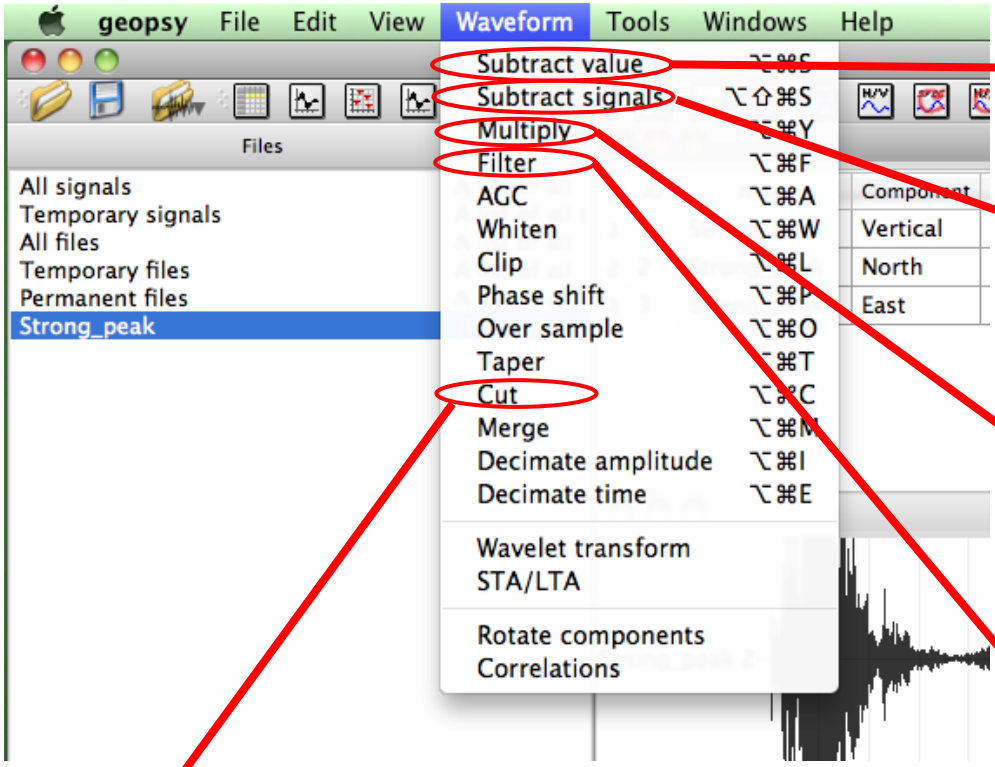
presents the data
•in frequency-phase content



presents the data
•in frequency-amplitude content



WAVEFORM TOOLS (main)



Substract value: Offset removal
- given value
- mean value (of the whole waveform)

Substract a signal to other signal
Can be useful for building purposes
Do the substraction sample to sample

Multiply the signal amplitude by a given value

Cut: allow you to cut the signal useful to select specific part of the waveform

Frequency *filter*:
- high pass
- low pass
- band pass
- band reject

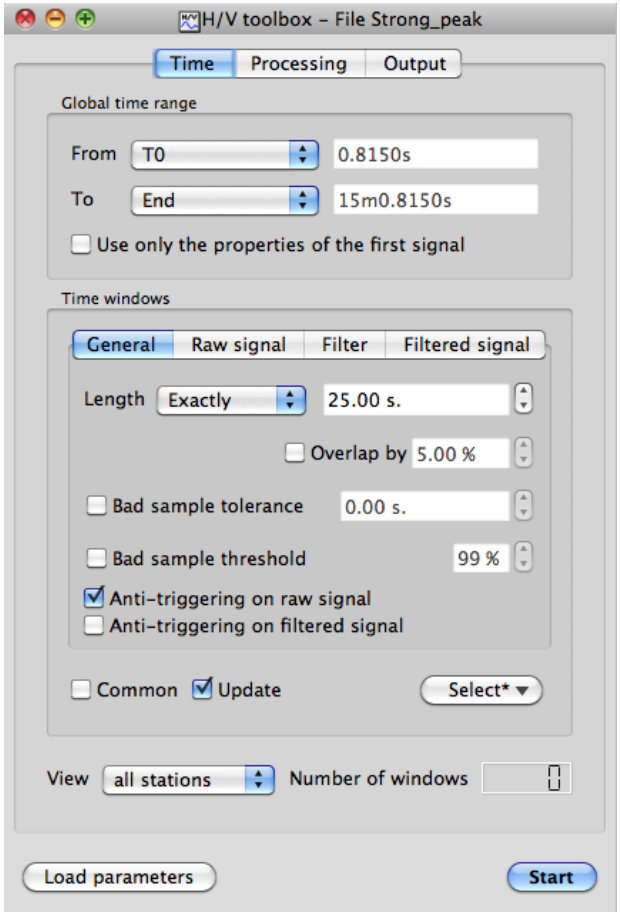
Never forget to use the waveform console

H/V
(WINDOWING - GENERAL)

Close all the windows opened

PLot the « Strong_peak » waveform

Select H/V graphic icon => a « H/V toolbox » opens (followed by the file name)



Time (windowing)
Processing (smoothing/type of HV)
Output (graphic/files)

Global time setting tool

Works like the « waveform/Cut » tool

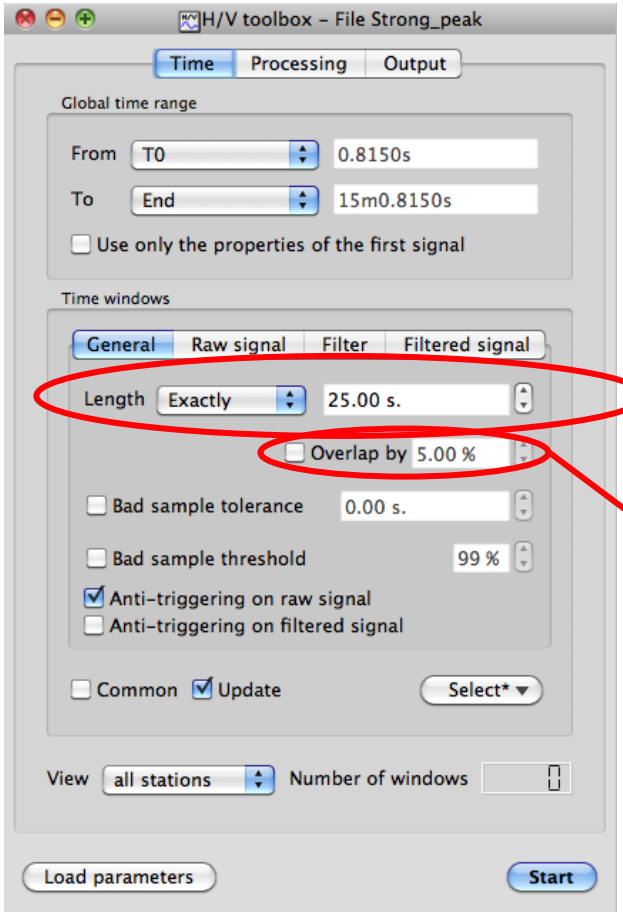
Allows you to reject parts of the signal (beginning and end)

Windowing setting

Windowing results

Start the computation

H/V
(windowing-general)



Time window length (idea of the geology)

EXACTLY: you give the time window length

AT LEAST: you give a minimum and a maximum time window length. So a window has the minimum fixed length and increases its length until the maximum fixed length or a sample rejected by the anti-trigger

This option forces the program to define the windows with an overlap (useful if you are short in time recording)

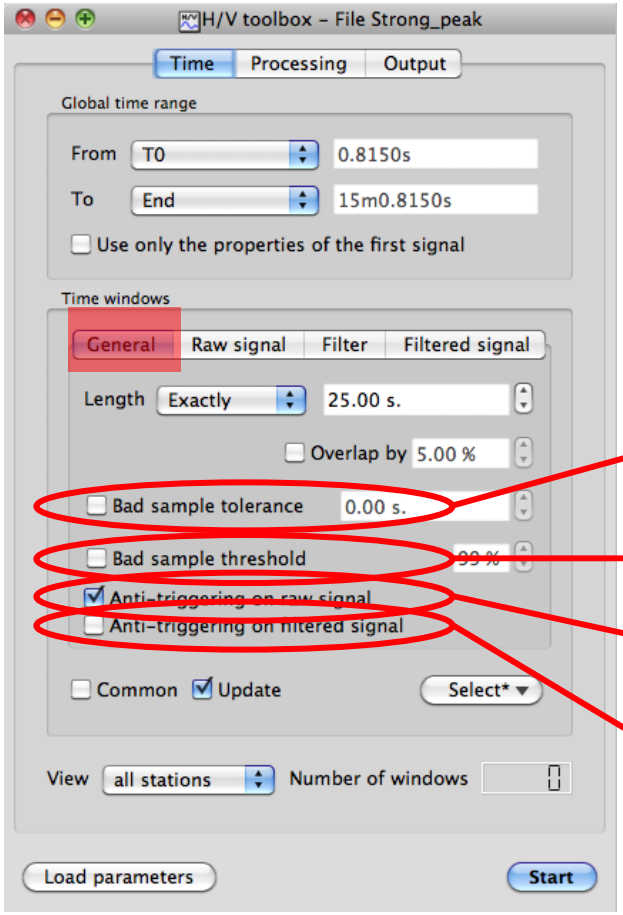
But (10/window length) could not be lower than the natural frequency of the seismometer

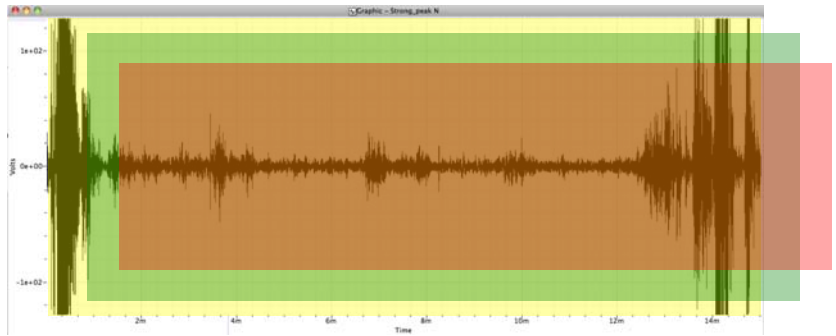
➔ 25 s time window length allows to analyze until 0.4 Hz

➔ 5 s cut-off period seismometer allows to use time window of 50 s maximum length.

$10/w_l > f_{seismometer}$

H/V
(windowing-general)





You allow the anti-trigger to accept some « bad » samples (problem of « glitch » for example)

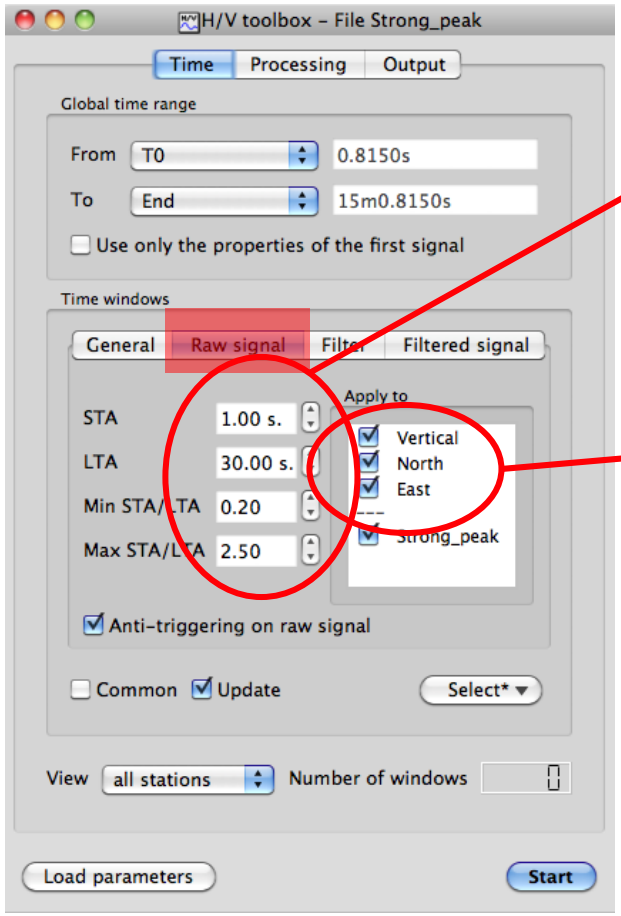
You force the anti-trigger to consider some samples as « bad », introducing a limit in amplitude

The anti-trigger algorithm is applied on the original signal (as fixed)

You apply an anti-trigger algorithm on a filtered signal (as fixed), but the H/V computation is done on the unfiltered signal

All the options can be used at the same time

H/V
(WINDOWING - ANTI-TRIGGER)



Define the anti-trigger parameters (STA, LTA, minumum ratio, maximum ratio) Here, the values of 1, 30, .2 and 2.5 are the commonly used values. They can be changed when you want. Do not hesitate to use these parameters, but beware !!!!!!

The anti-trigger is applied on the 3 components

Can be useful if you have too heavy noise on one or two components.

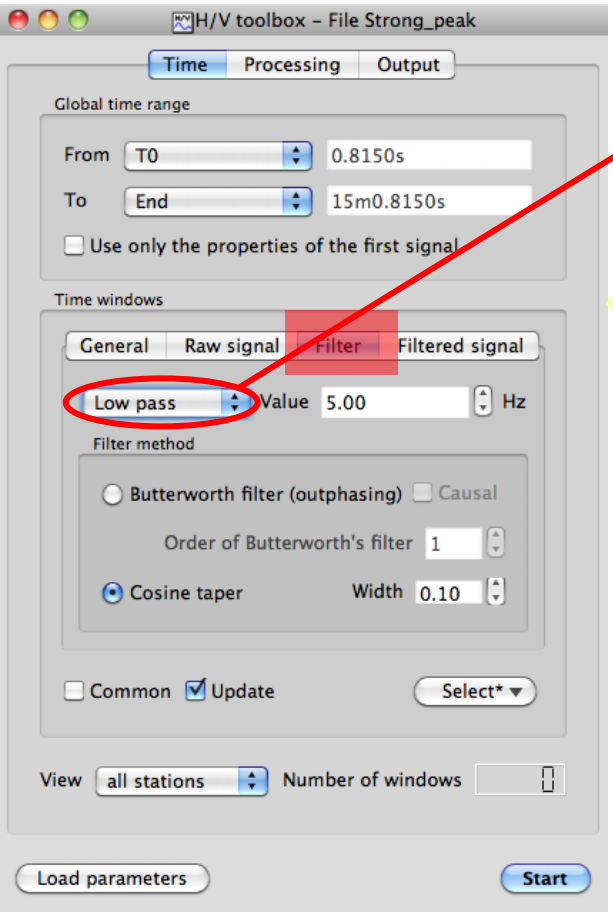
Beneath, you can define where this anti-trigger will be applied (file name)

H/V (WINDOWING - ANTI-TRIGGER USING FILTER OPTION)

Filter and Filtered signal

- allow to use an anti-trigger algorithm on a filtered signal
- can be done with or without normal anti-trigger (on raw signal)

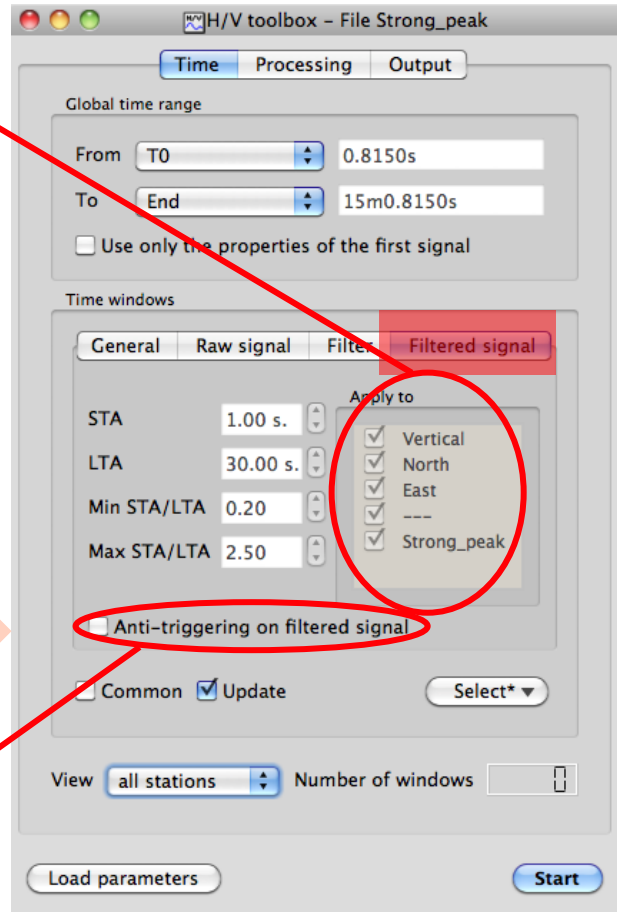
Can be used when the signal presents bursts of energy



If these parts are grayed, the anti-trigger on filtered signal is not used

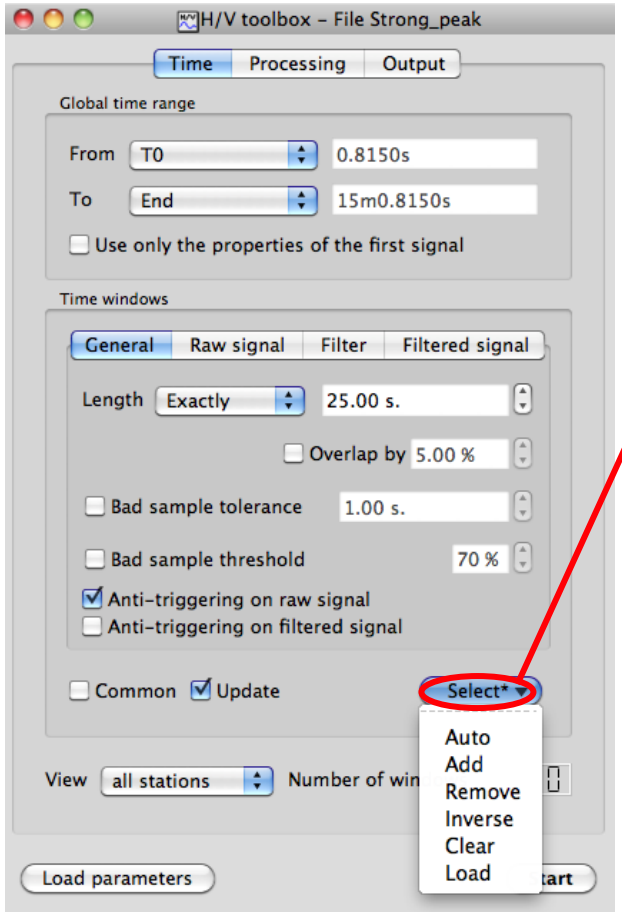
The filter options are the same that on « Waveform-Filter » menu

The « filtered signal » is equal to the LTA/STA options of the raw signal



You can activate the filter option from here

H/V
(basic use)



If you clic on « Select », a menu appear with 6 possibilities

- « Auto »: to apply the active windowing options
- « Add »: will be seen later on
- « Remove »: will be seen later on
- « Inverse »: to inverse the windowing
- « Clear »: to clear the windowing (no more windows)
- « Load »: to load a windowing from a file (external file)

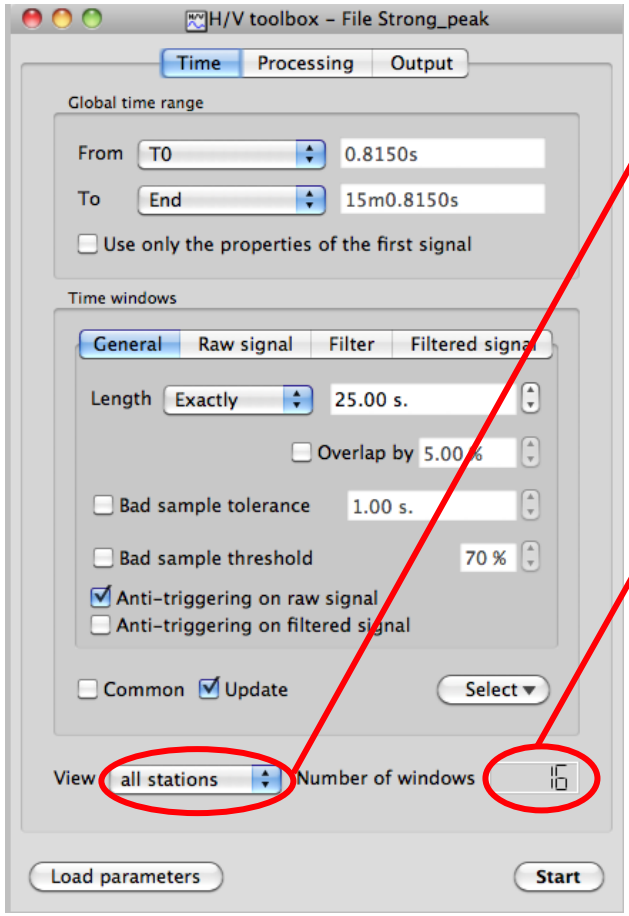
If « Select » is followed by a star (*), that means:
- no windowing has been applied (at the beginning for example)
- you have already applied a windowing but you have changed some options without using them

For now, there is only windowing processing, no H/V computation

CLIC ON « AUTO »

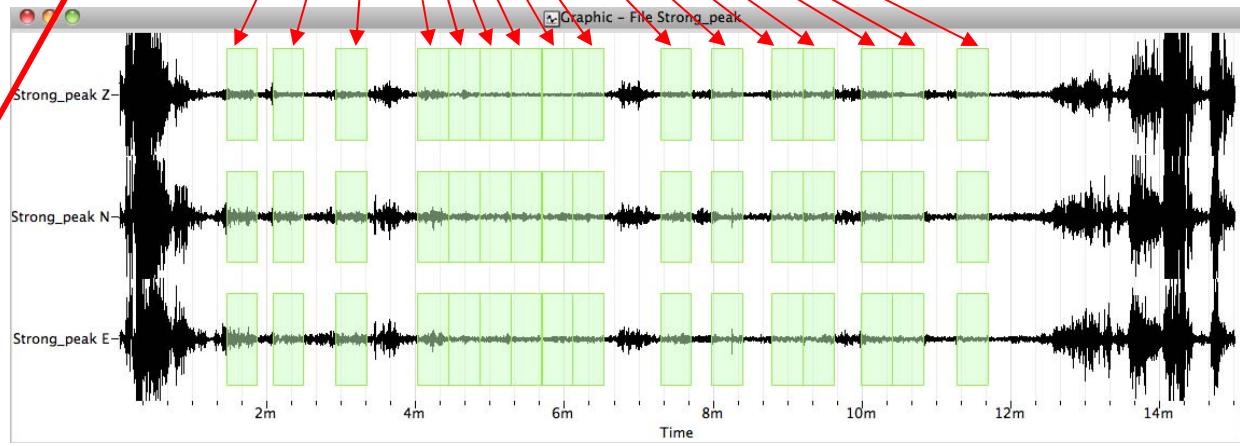
H/V (windowing)

For the moment, there is only windowing processing, no H/V calculus



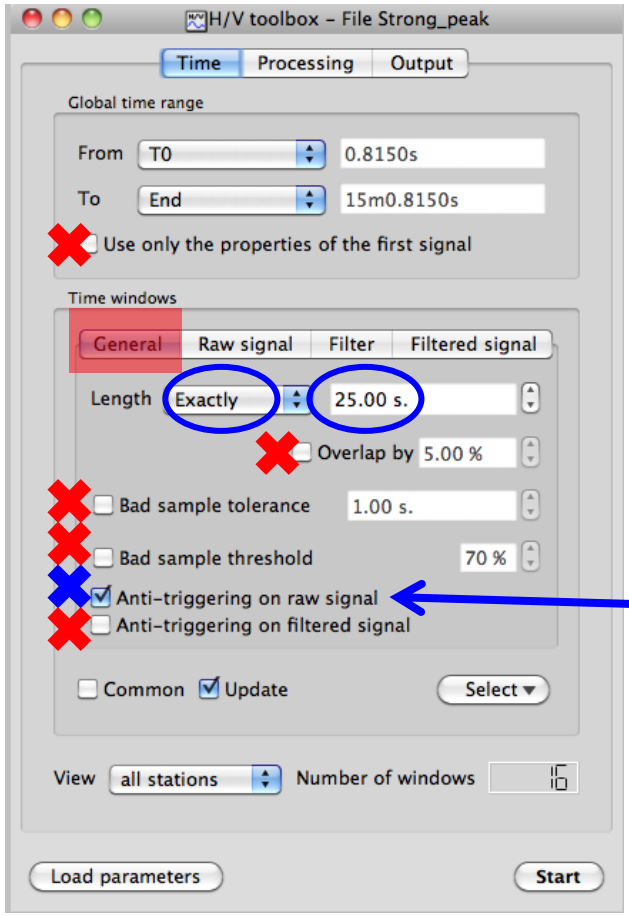
It is basically for all the stations (3 components rec.)
It can be checked for each record (pop-up menu)

Number of windows



H/V (windowing)

If you do not obtain that, check the options you have

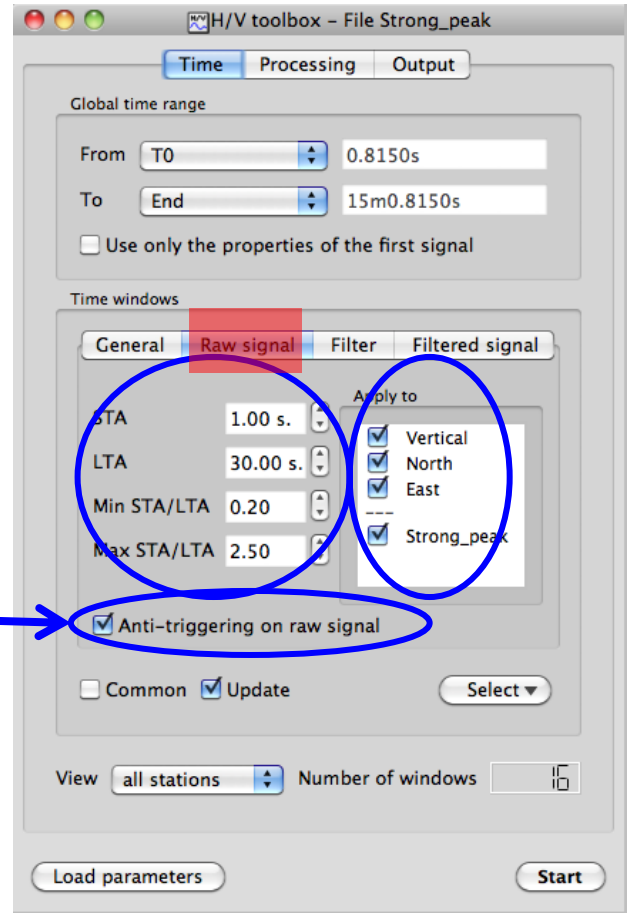


In red: not active option

In blue: active option

Check the values and in which component they are applied

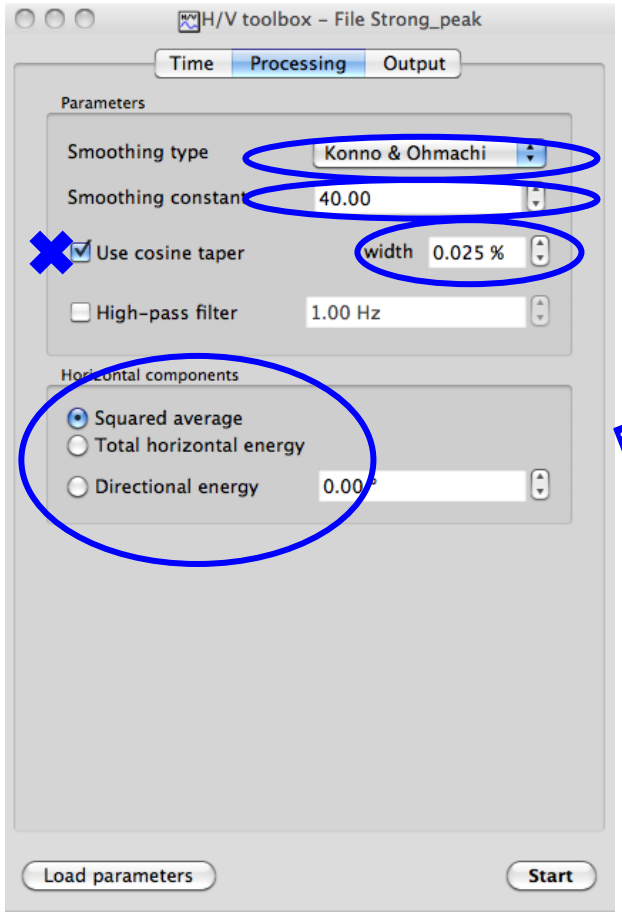
the same



ON « GENERAL » PANEL

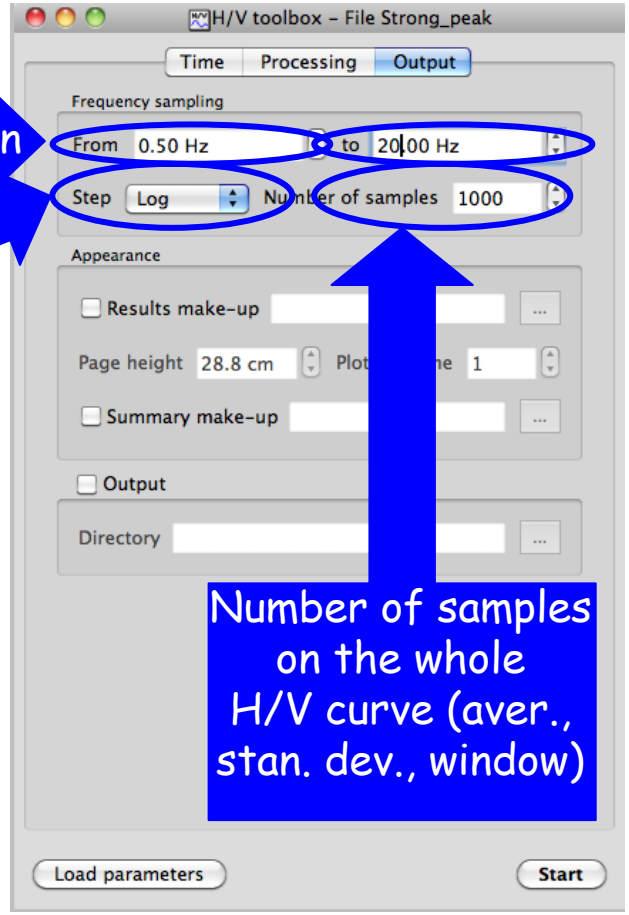
ON « RAW SIGNAL » PANEL

H/V
(processing and output)



Range for the H/V computation

Type of sampling step: lin - log



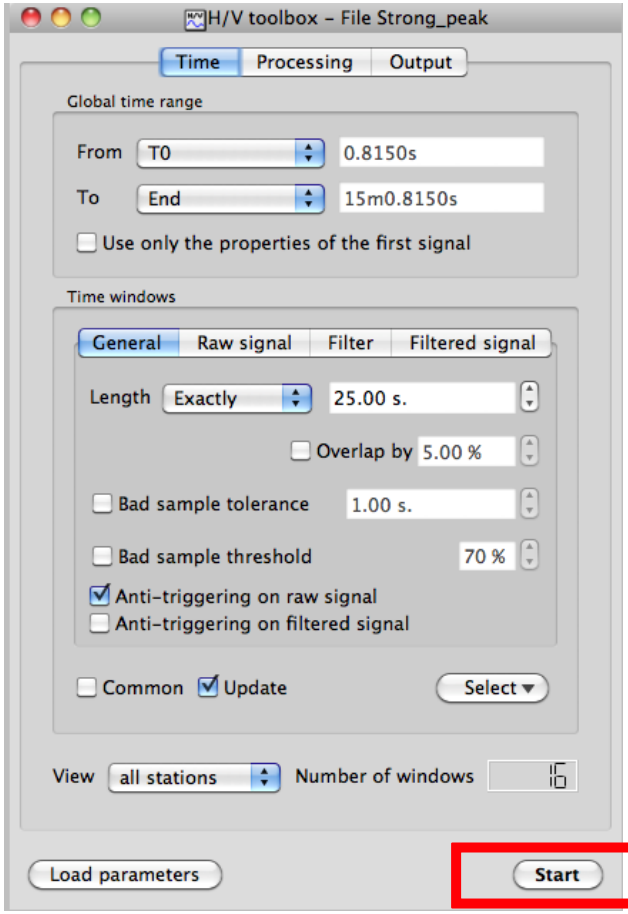
Number of samples on the whole H/V curve (aver., stan. dev., window)

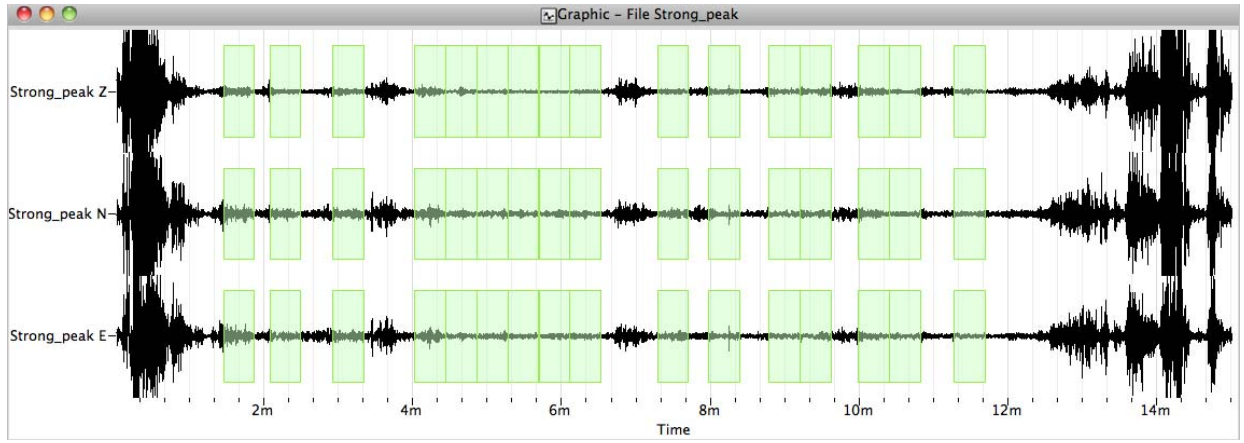
Parameters generally used

The frequency range for the H/V computation is varying upon the window length (seismometer and geology) and the sample frequency acquisition

H/V (computed)

If all is fine

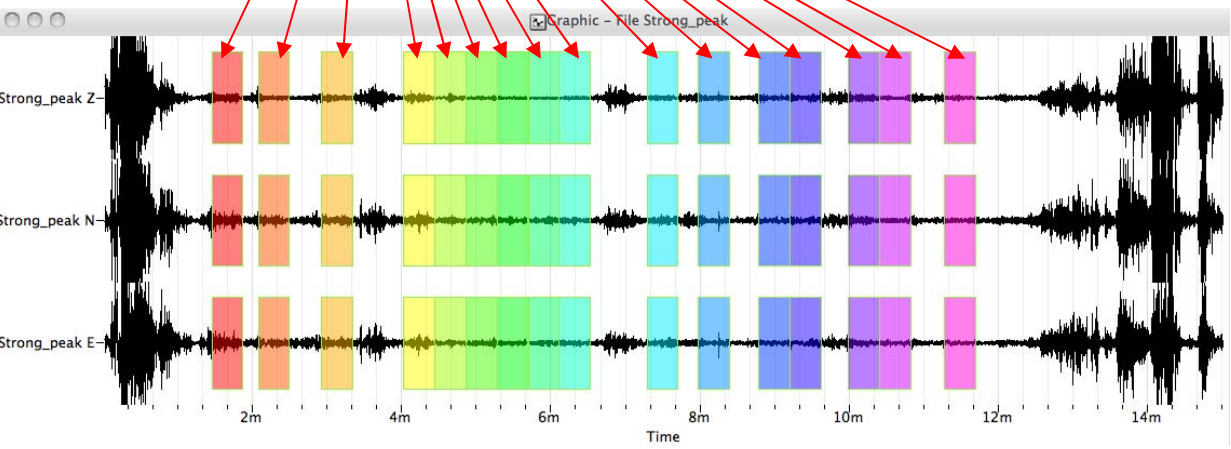


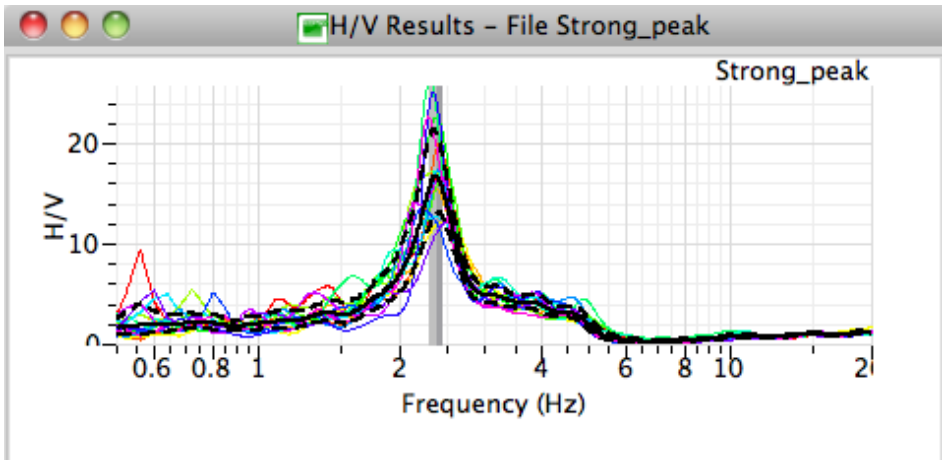


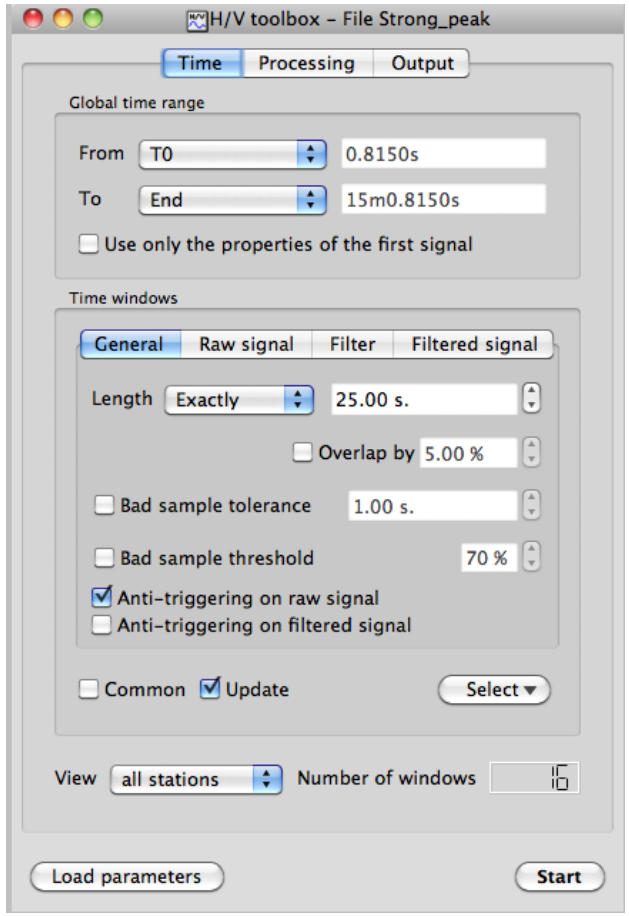
Click on « Start »

Colored windows

H/V (computed)

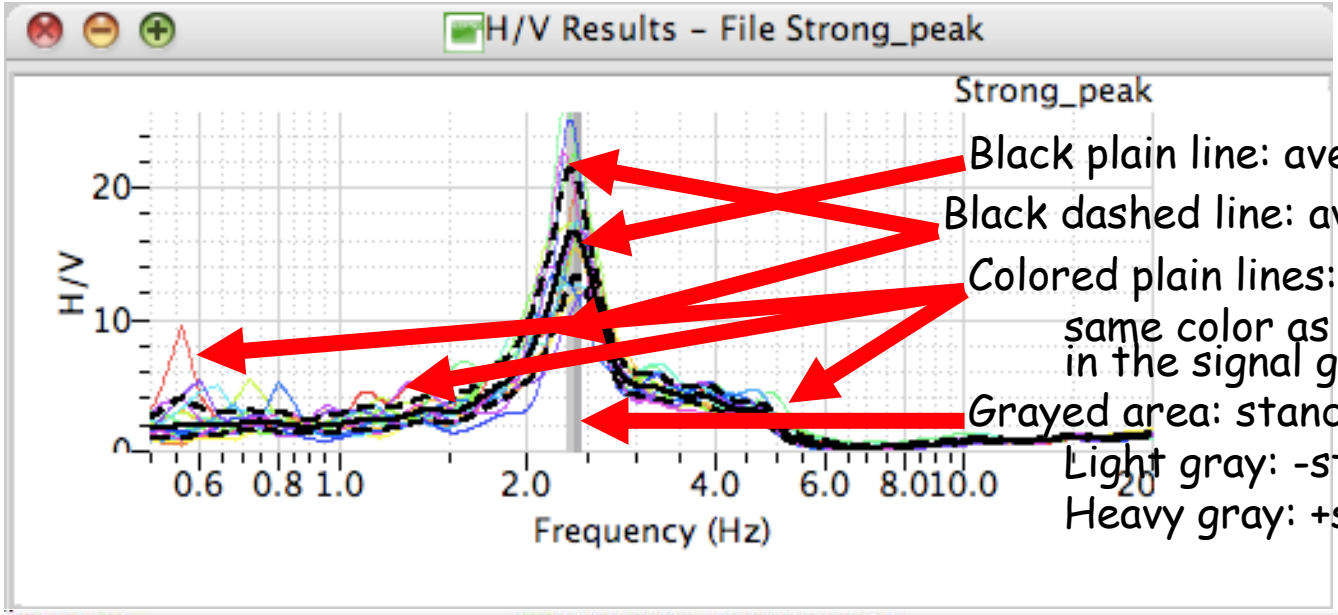






THE H/V CURVE !!!!!

H/V (computed)

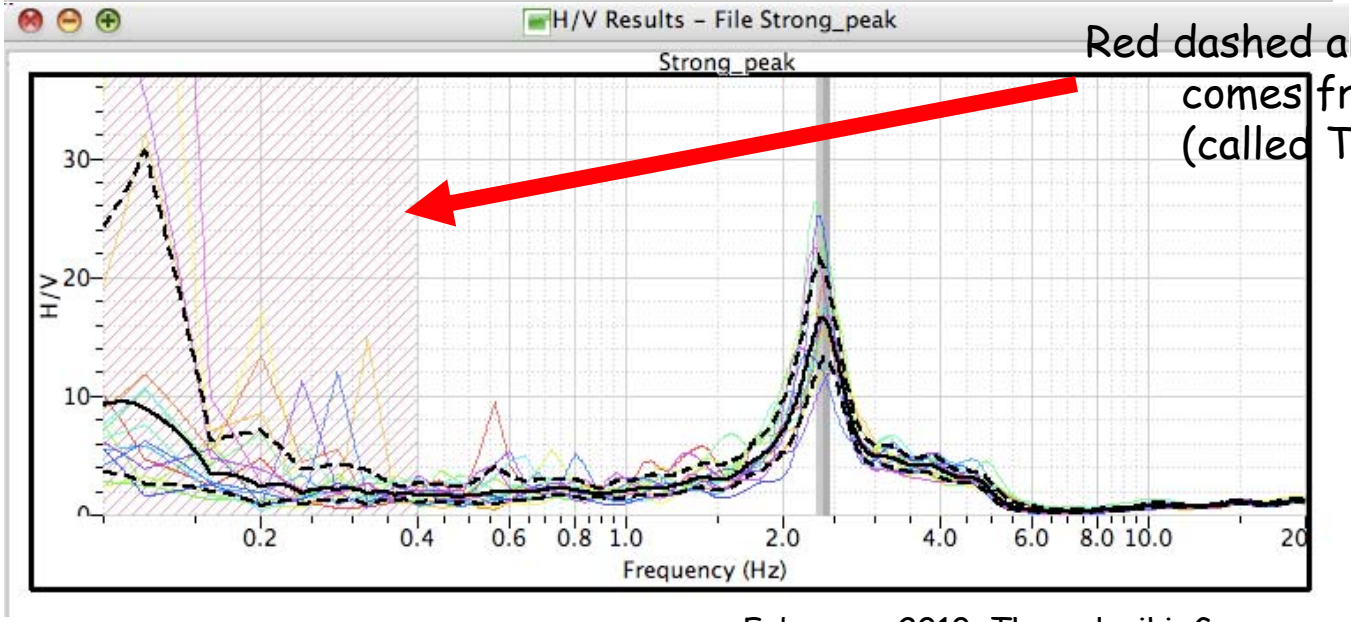


Black plain line: averaged H/V curve

Black dashed line: average + standard deviation

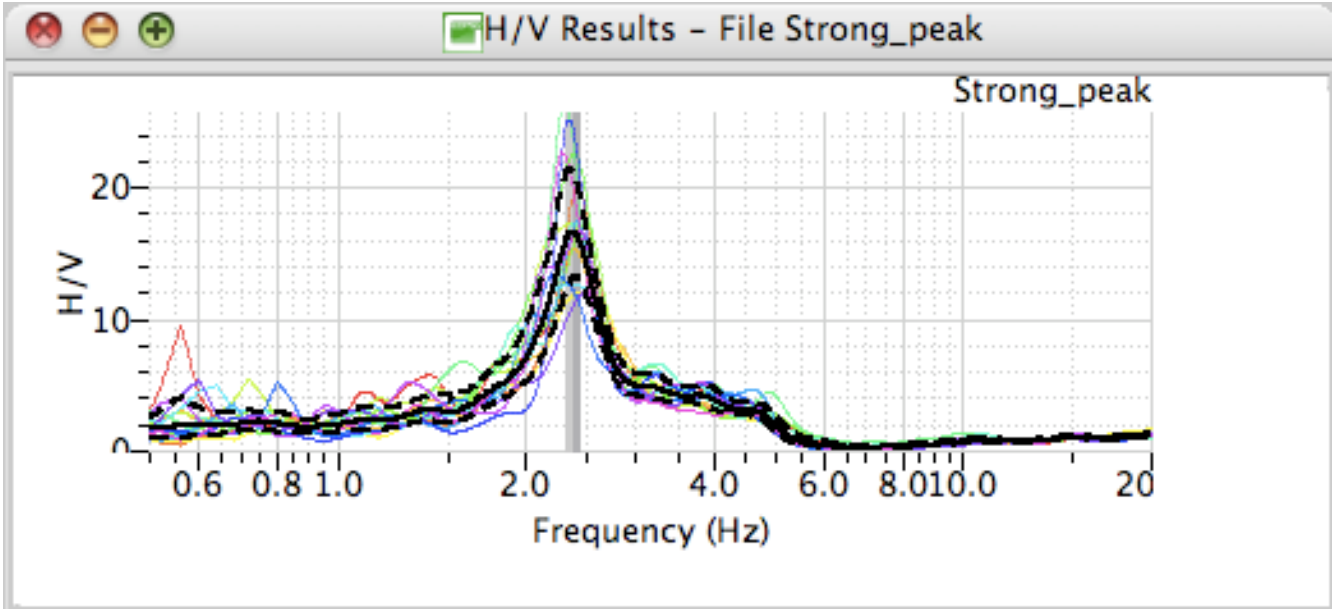
Colored plain lines: window H/V curves
same color as the time window in the signal graph

Grayed area: standard deviation on H/V peak
Light gray: -stand. dev. (from windows)
Heavy gray: +stand. dev. (from windows)



Red dashed area: unreliable results
comes from 10/window_length
(called T10)

H/V
(computed)



f_0 = 2.38 Hz

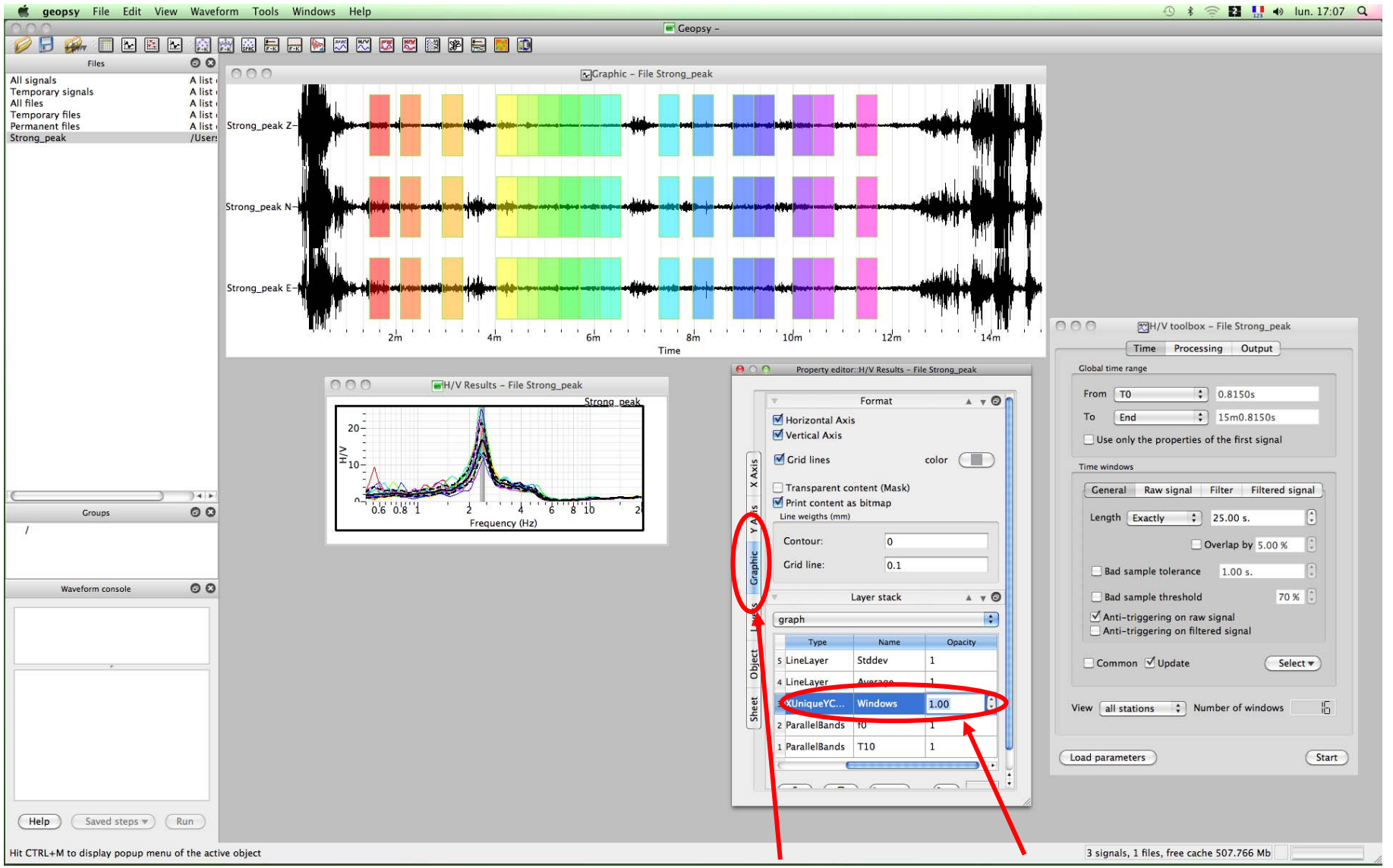
$A_0 \approx 16$

WARNING !!!!!!!!

This type of H/V curve (so strong, so nice)

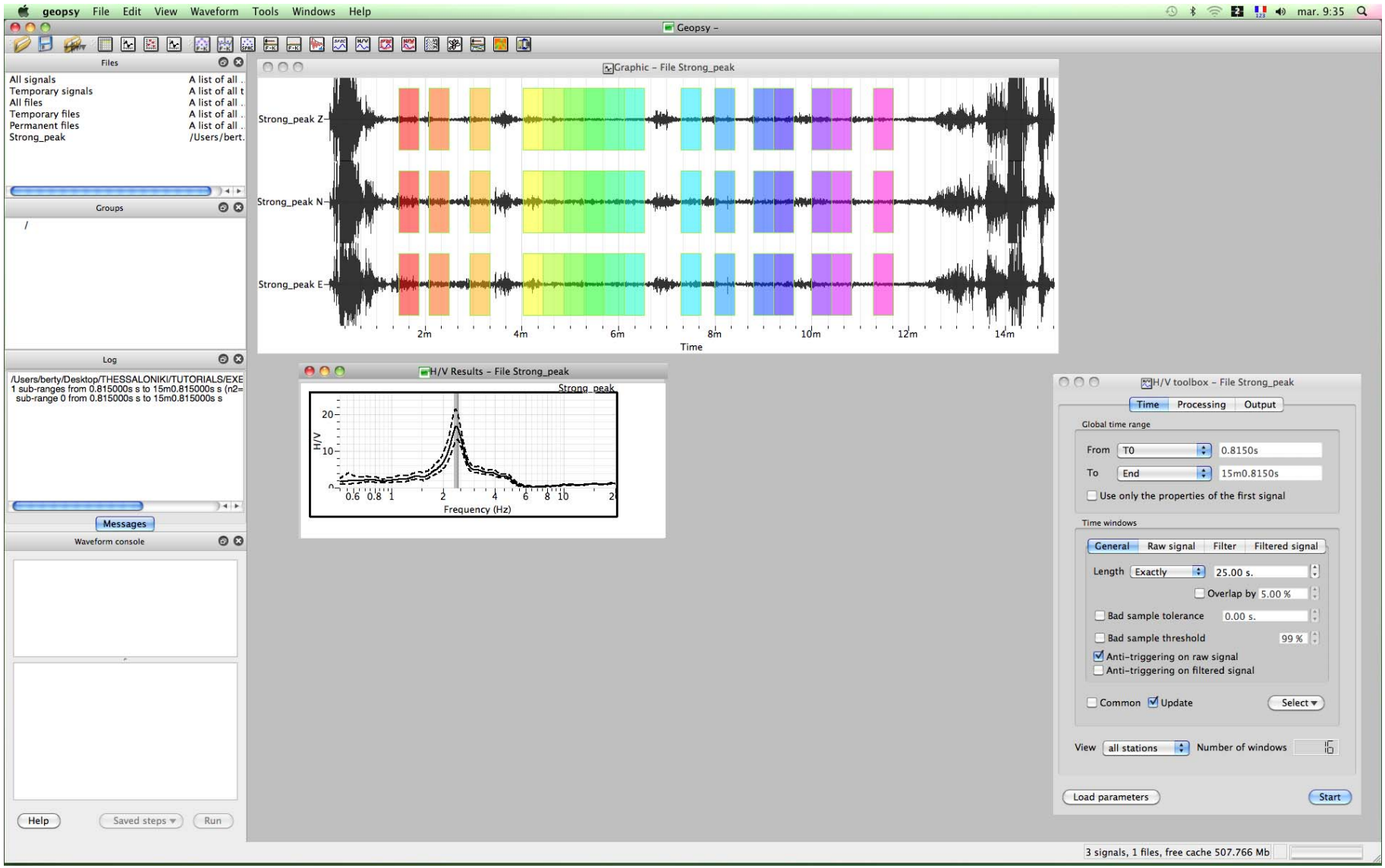
VERY RARE

H/V (solution 1)
(computed: remove window curves displaying)



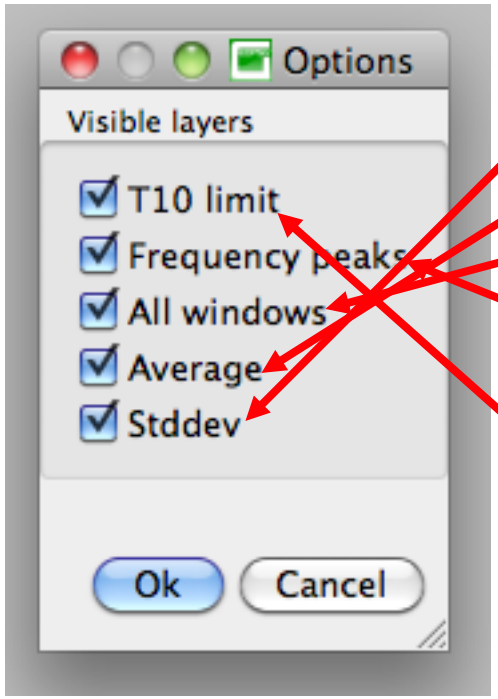
Right click mouse and select « properties » Graphics: Put « windows » at 0
or « double-click » on the H/V graph

H/V (solution 2)
(computed: remove window curves displaying)



H/V presentation

We show you how to remove the window H/V curves
But you can do much more, on both menus…..



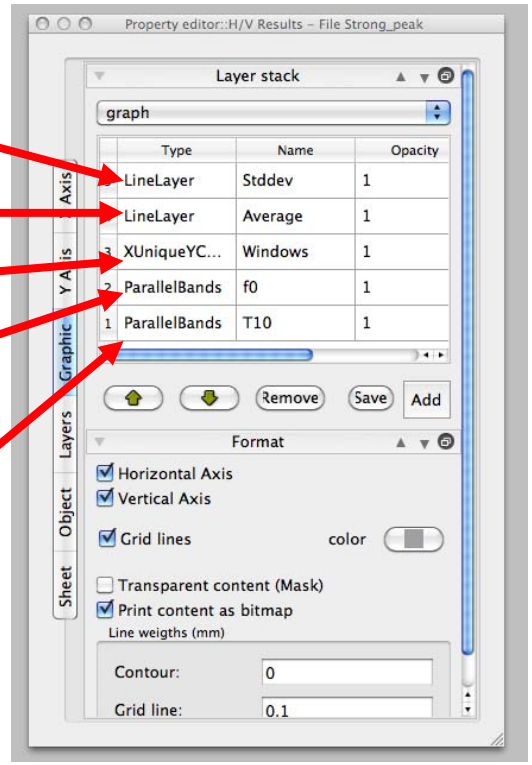
Remove the standard deviation of the averaged H/V curve

Remove the averaged H/V curve

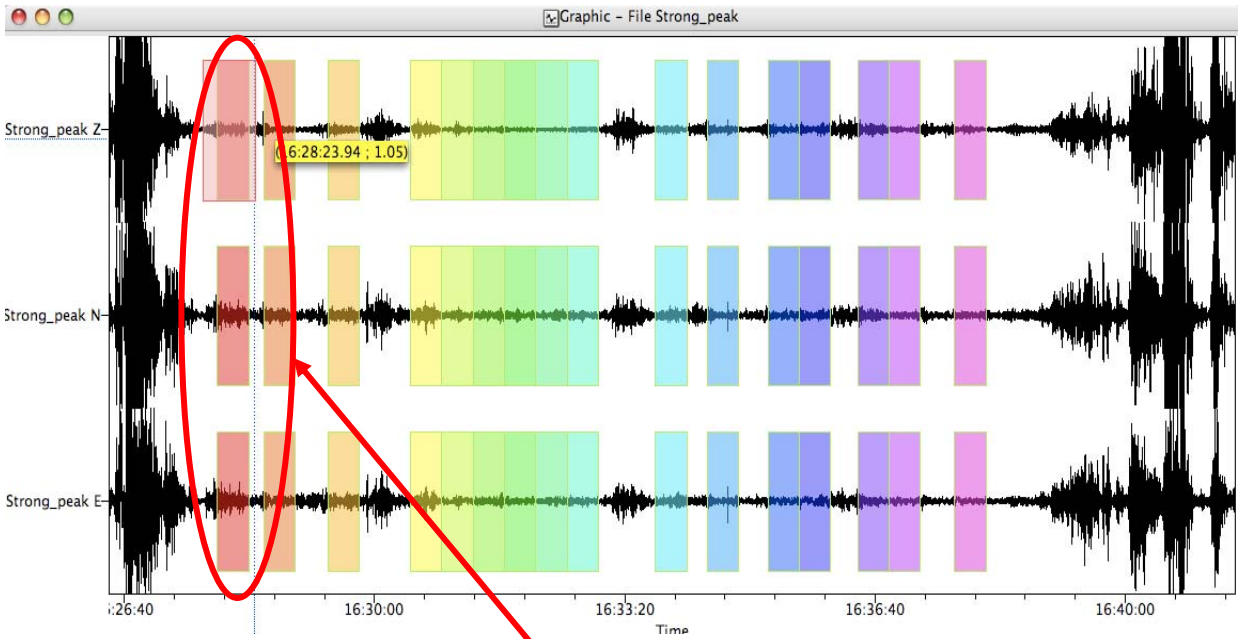
Remove the window H/V curves

Remove the averaged f_0 and its standard deviation

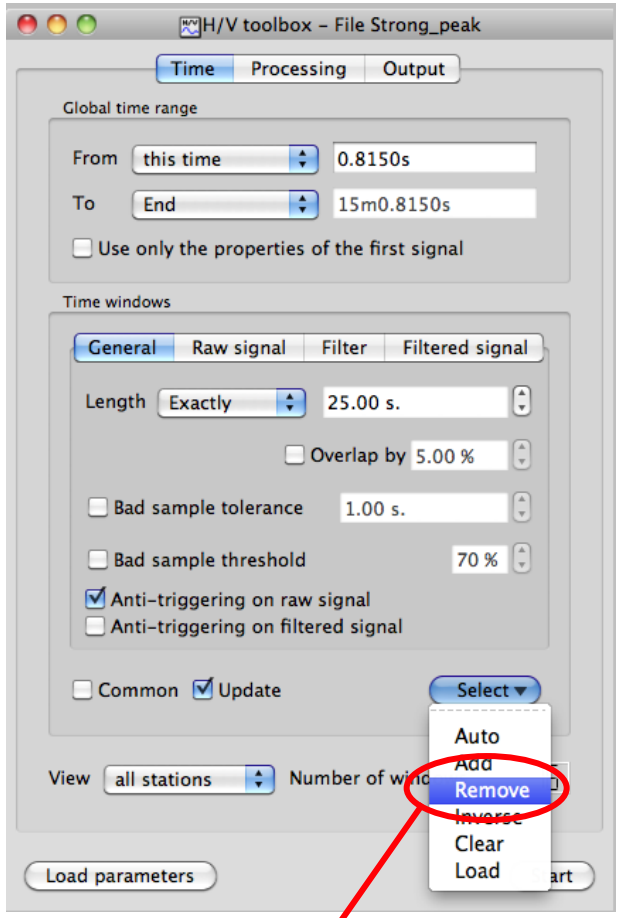
Remove the lower frequency of your processing (time window or natural frequency of your seismometer)

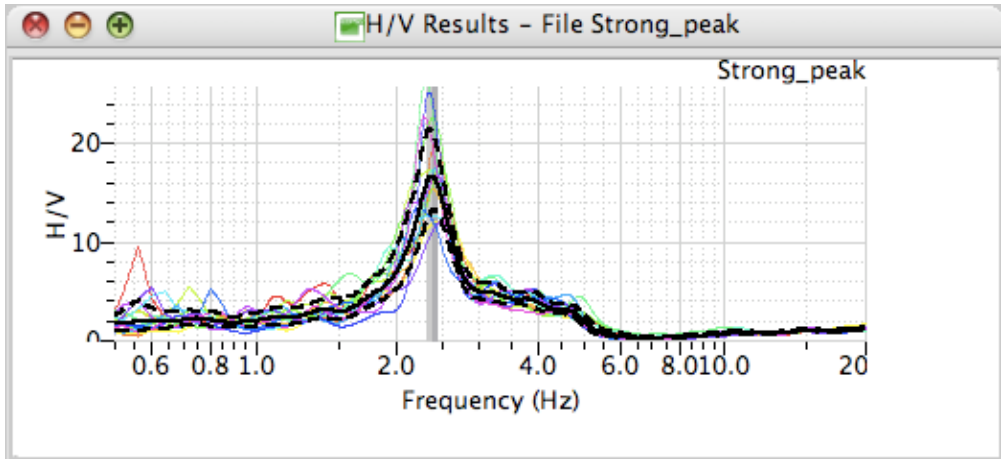


H/V
(computed remove window - 1)



Then click on the graphic window and select the window(s) you want to remove



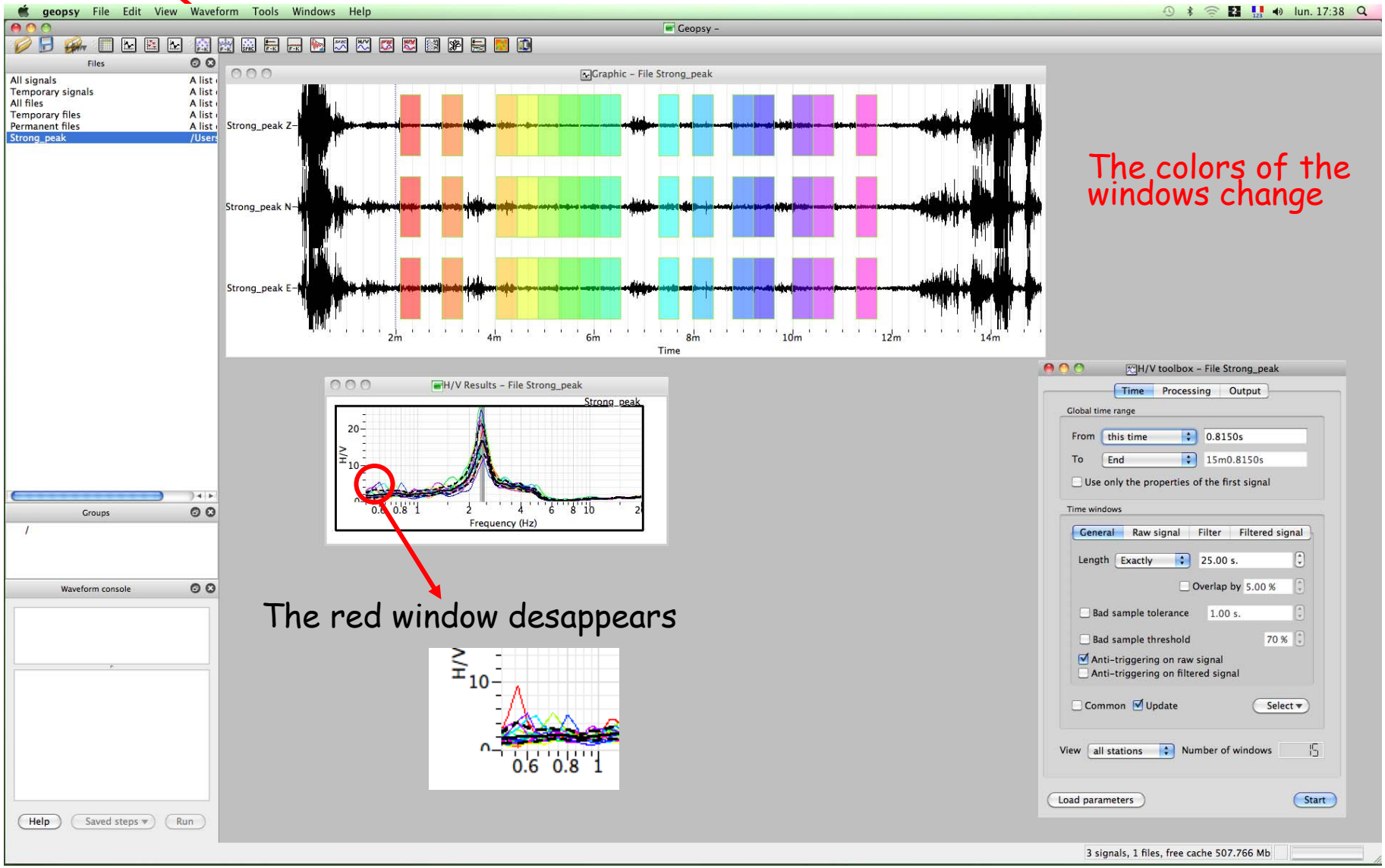


On the « Select » pop-up menu, click on « remove ». From now, you are in « remove » mode

THE H/V curve doesn't change !!!!!

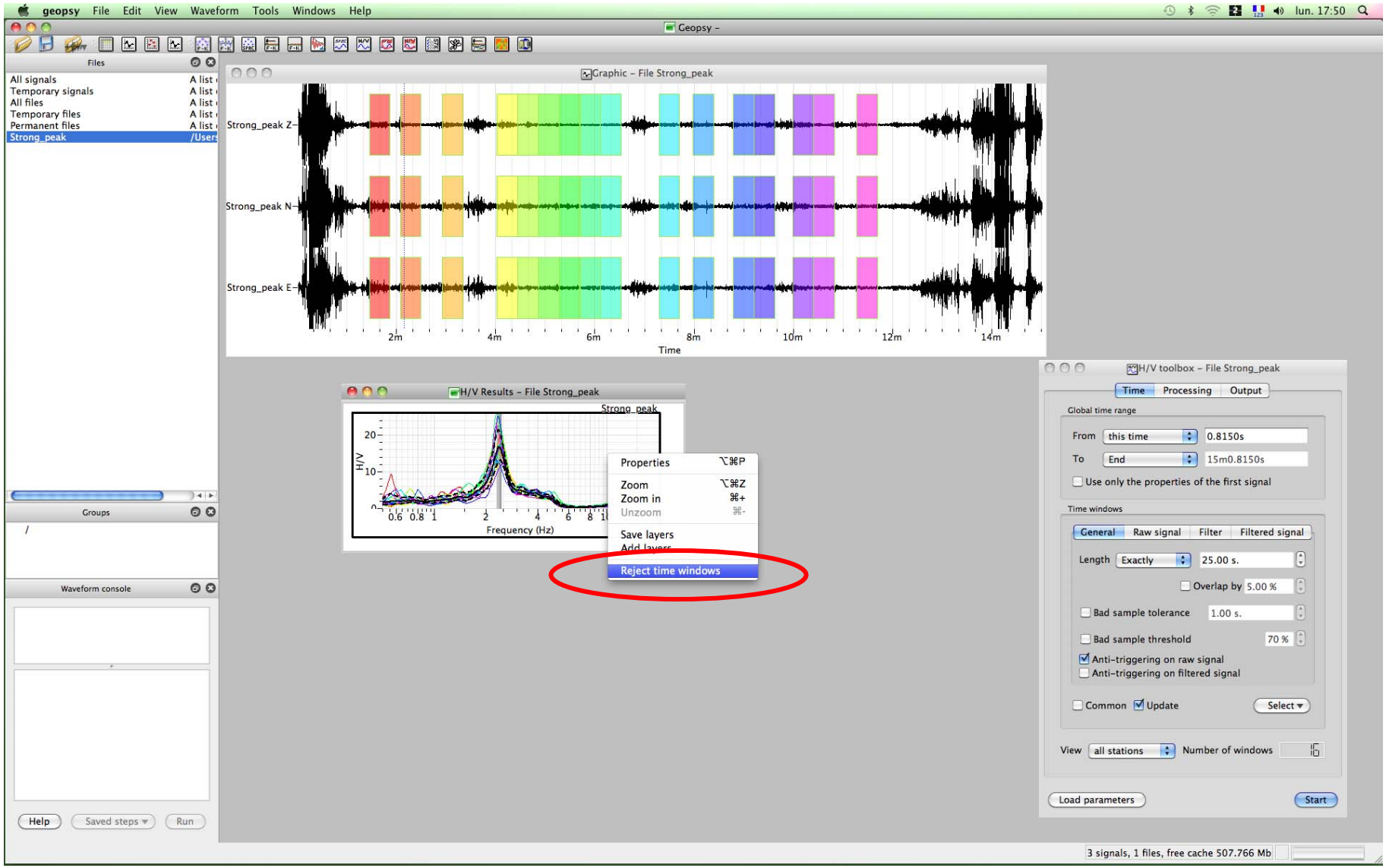
H/V
(computed remove window - 1)

The selected window disappears



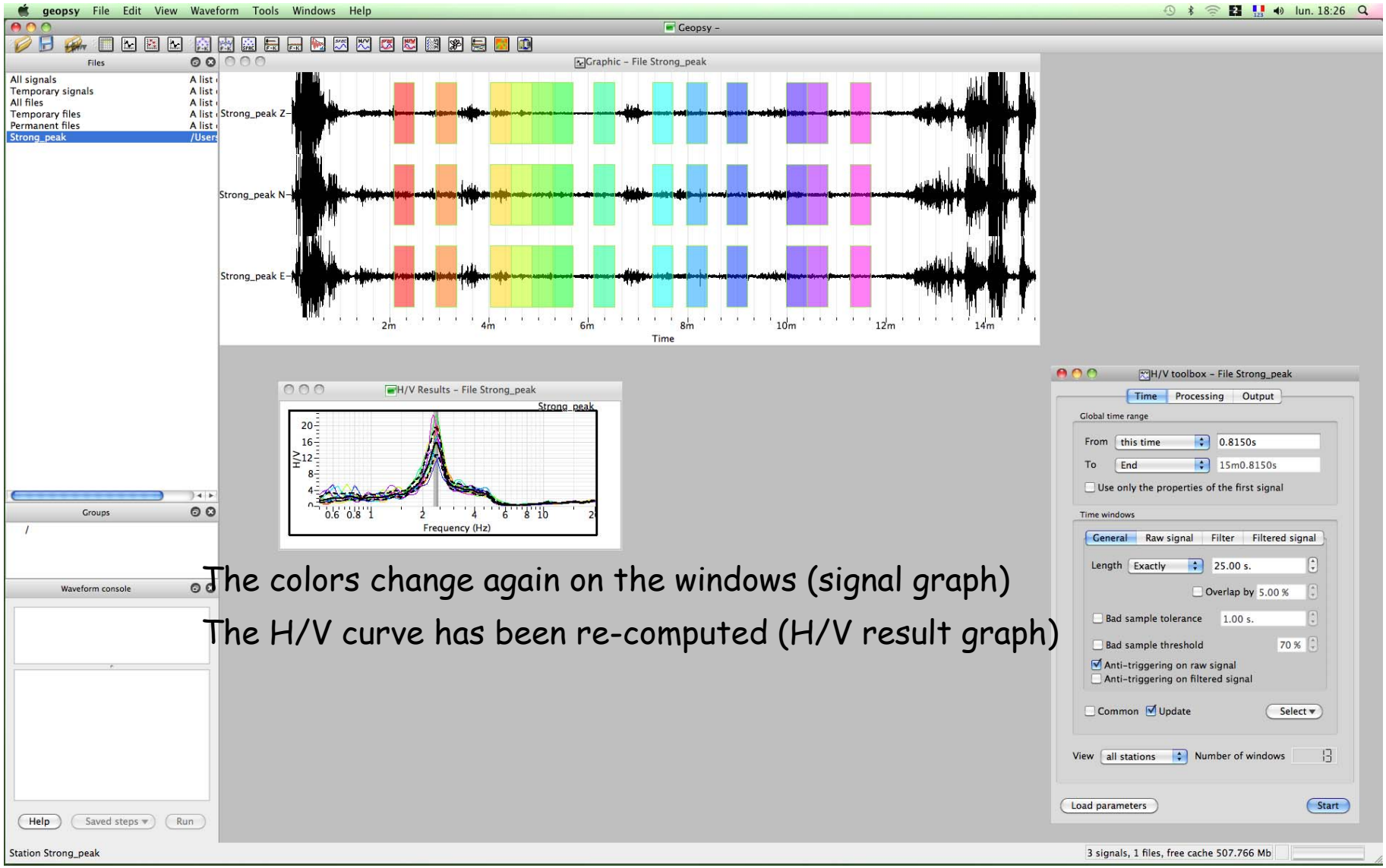
The red window desappears

H/V
(computed remove window - 2)



Click on the rigth button of the mouse and select « reject time windows »

H/V
(computed remove window - 2)



The colors change again on the windows (signal graph)

The H/V curve has been re-computed (H/V result graph)

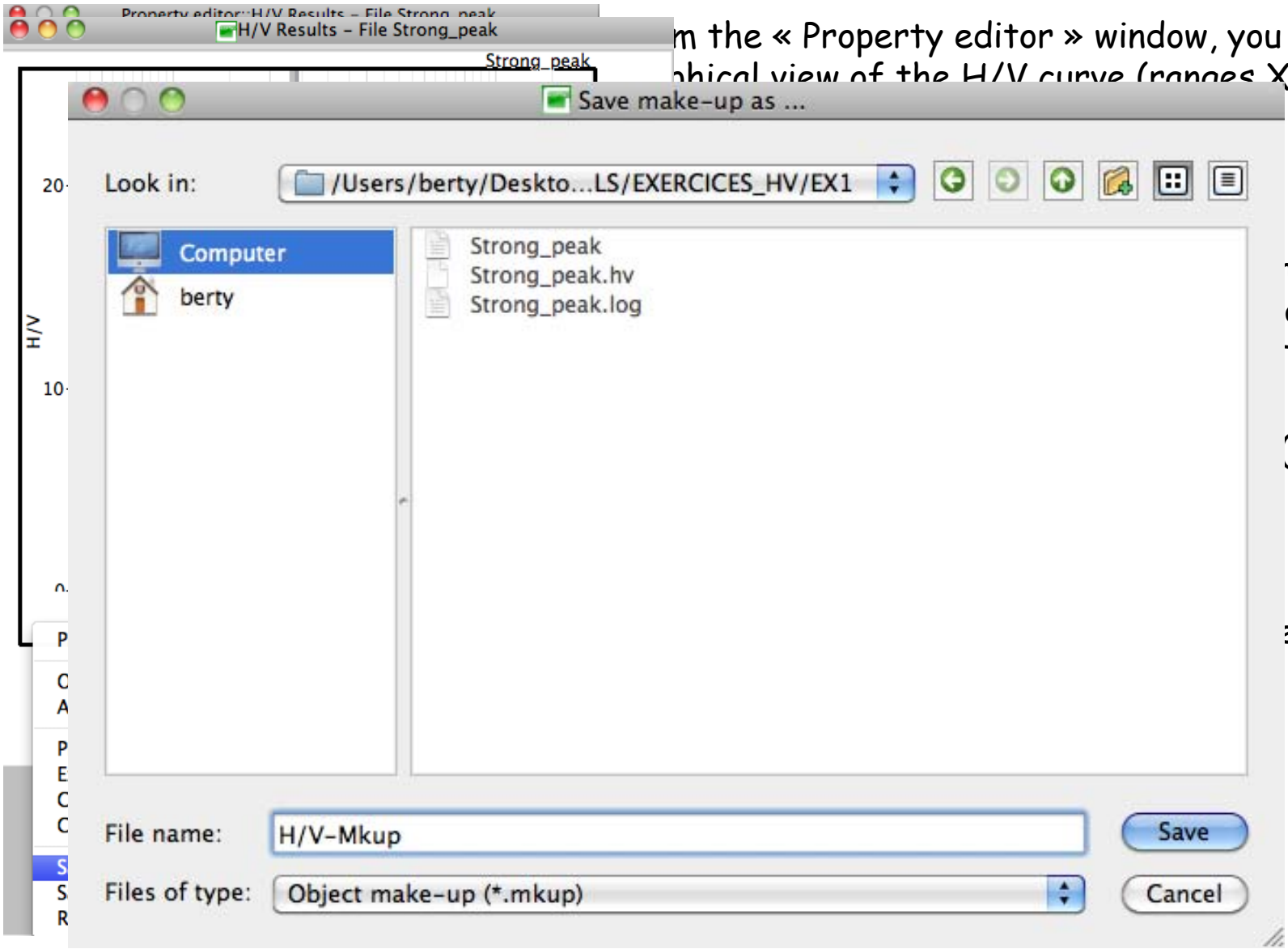
H/V MAKE-UP
(program the graphics-1)

m the « Property editor » window, you can modify the
hical view of the H/V curve (ranges X and Y, type of

n save its
aded when you
t

(inside graphic)

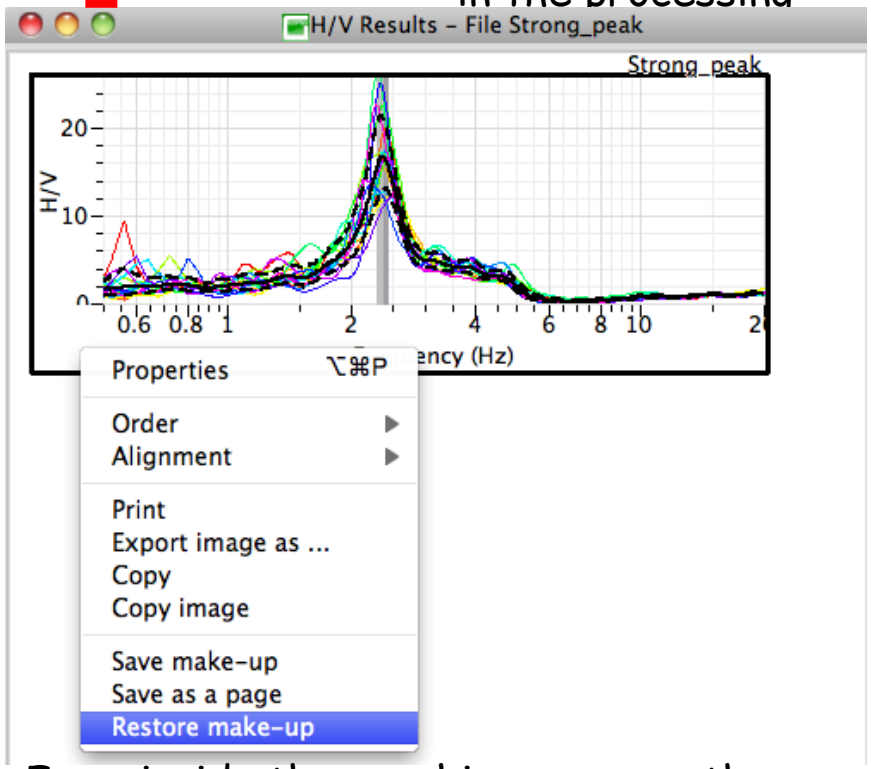
ers



H/V MAKE-UP
(program the graphics-2)

When your make-up file is saved, you can call it:

- manually
- automatically as an input in the processing

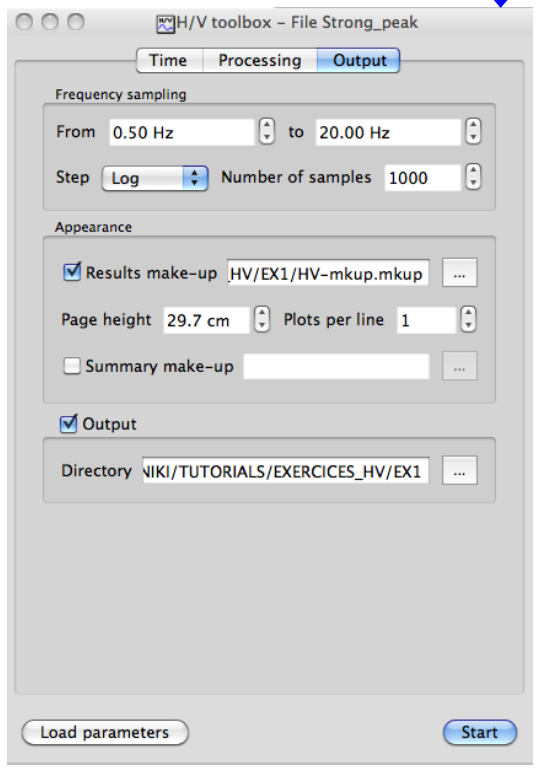


From inside the graphic, you open the pop-up menu and you choose the « Restore make-up » option

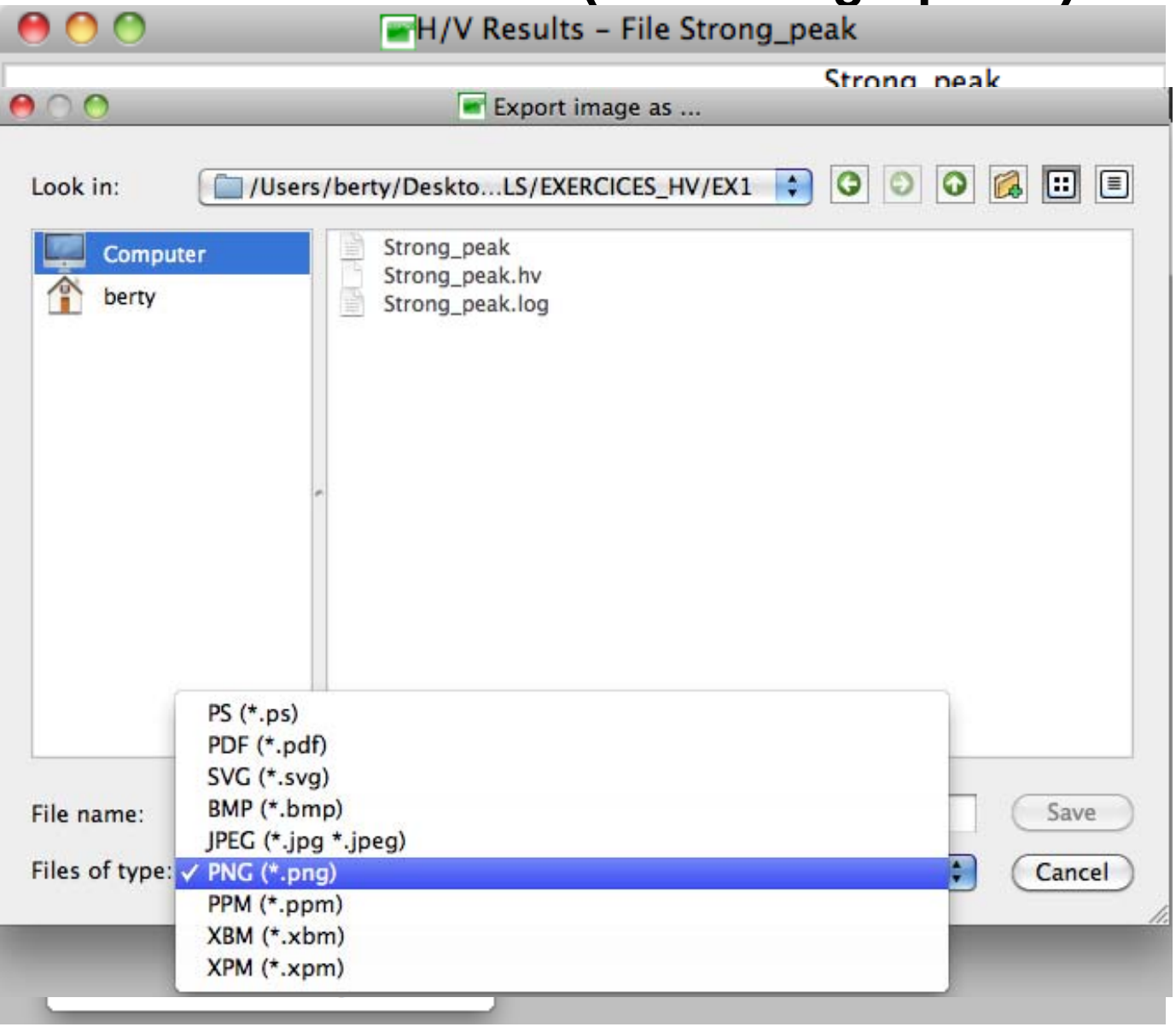
- a new window opens allowing you to choose the file
- the make-up is directly applied

In the H/V toolbox, choose the « output » window

- check the « Results make-up » option
- choose the make-up file
- the make-up will be directly applied during the processing



H/V OUTPUT
(save the graphics)

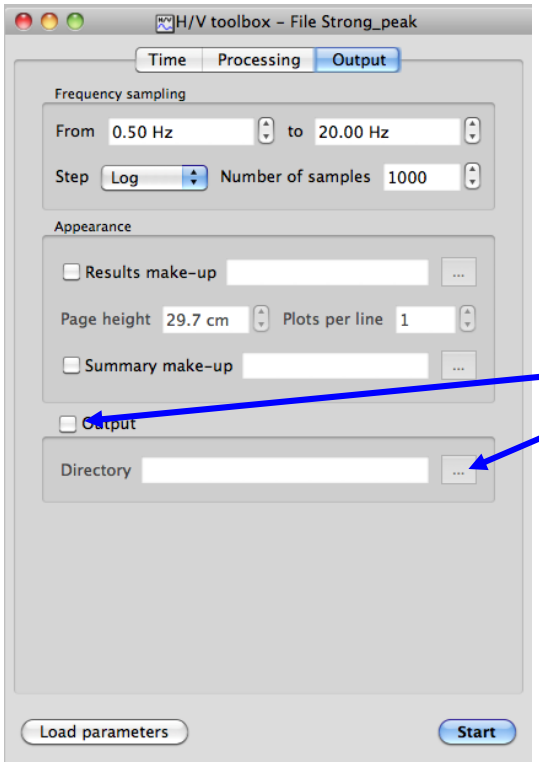


Click on the right button inside the yellow part.

- A pop-up menu appears
- Select
  « Export image as… »

- a new window appears
  - ➔Give the name for the file
  - ➔Choose the type of graphic file you want

H/V OUTPUT



Until now, we have checked the graphic part, but the processing and the results can be saved in files:

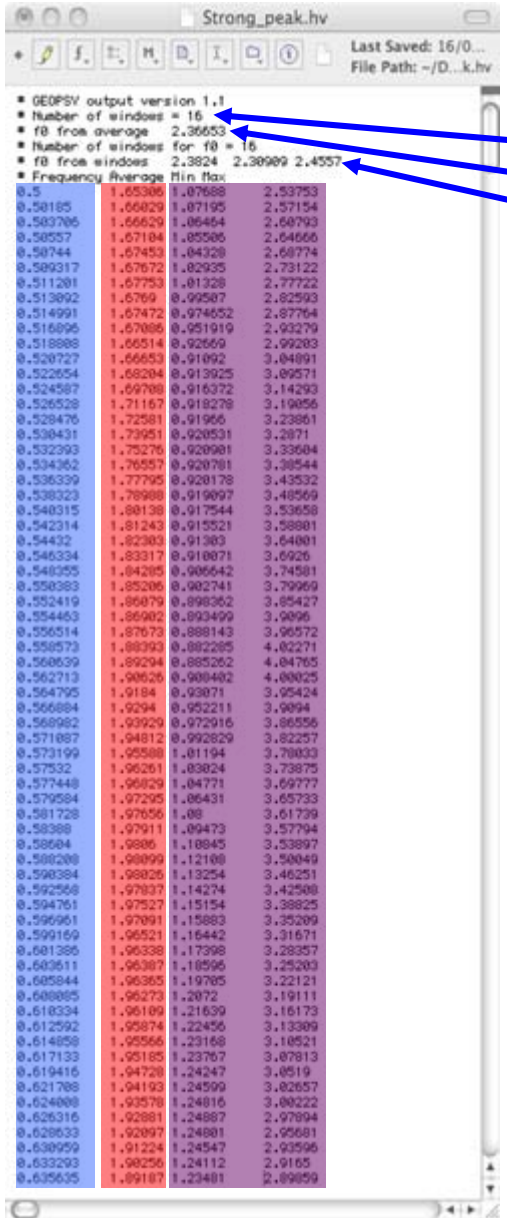
- H/V results → «station_name».hv
- the H/V processing parameters → «station_name».log

You need to define where (in your HD) the files can be saved

- select the « Output » option
- choose the file to save the results

For this practice, select the « EXERCICES_HV/EX1 » folder

H/V OUTPUT (HV file)



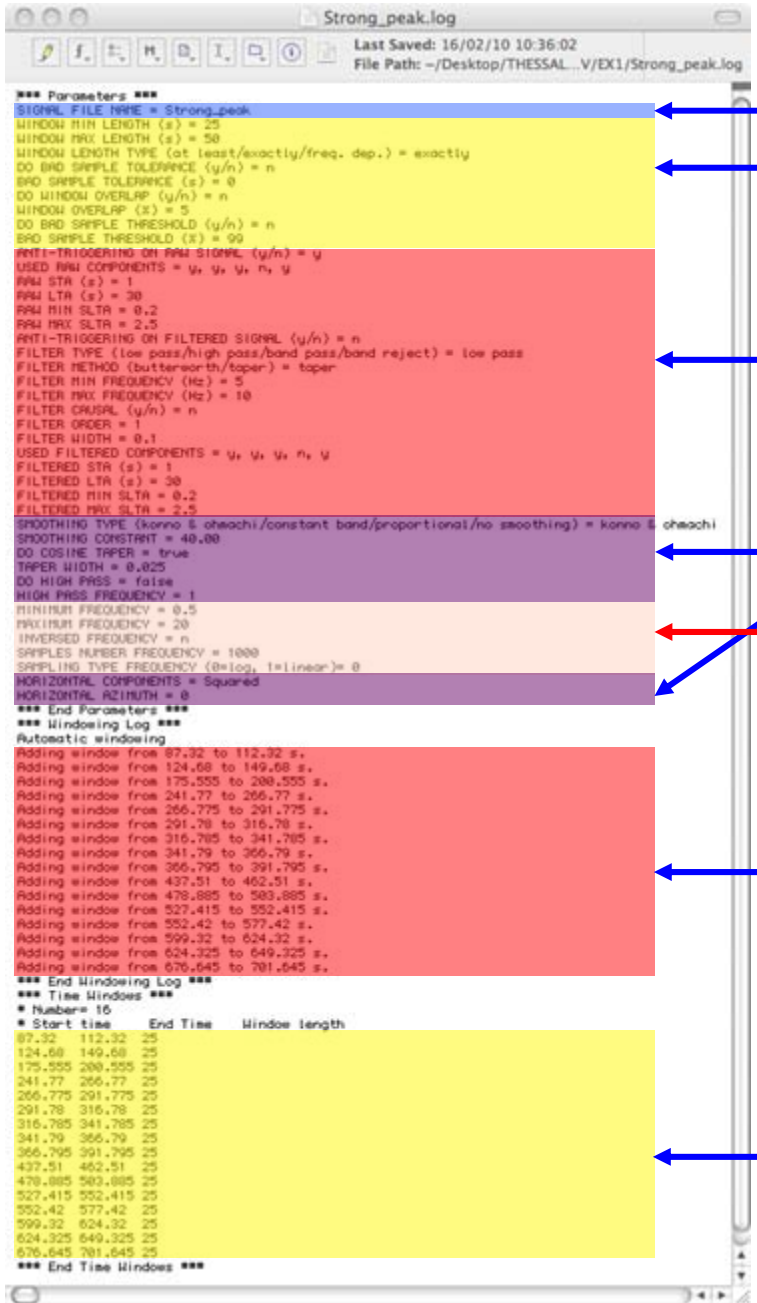
Lines with « # » indicating no data set.

- nb windows
- the f_0 coming from the averaged curve
- the f_0 coming from the window curves (+ stand. dev.)

The H/V curve

- frequency (f_{curve})
- value of the averaged H/V curve at f_{curve}
- the standard deviation (+/-) at f_{curve}

H/V OUTPUT (log file)



File name

Global parameters (anti-trigger, bad sample, …)

Values for all parameters (anti-trigger, bad sample, …)

Processing parameters (smoothing, type of H/V…)

Parameters for the H/V curve (frequency limit, nb samples…..)

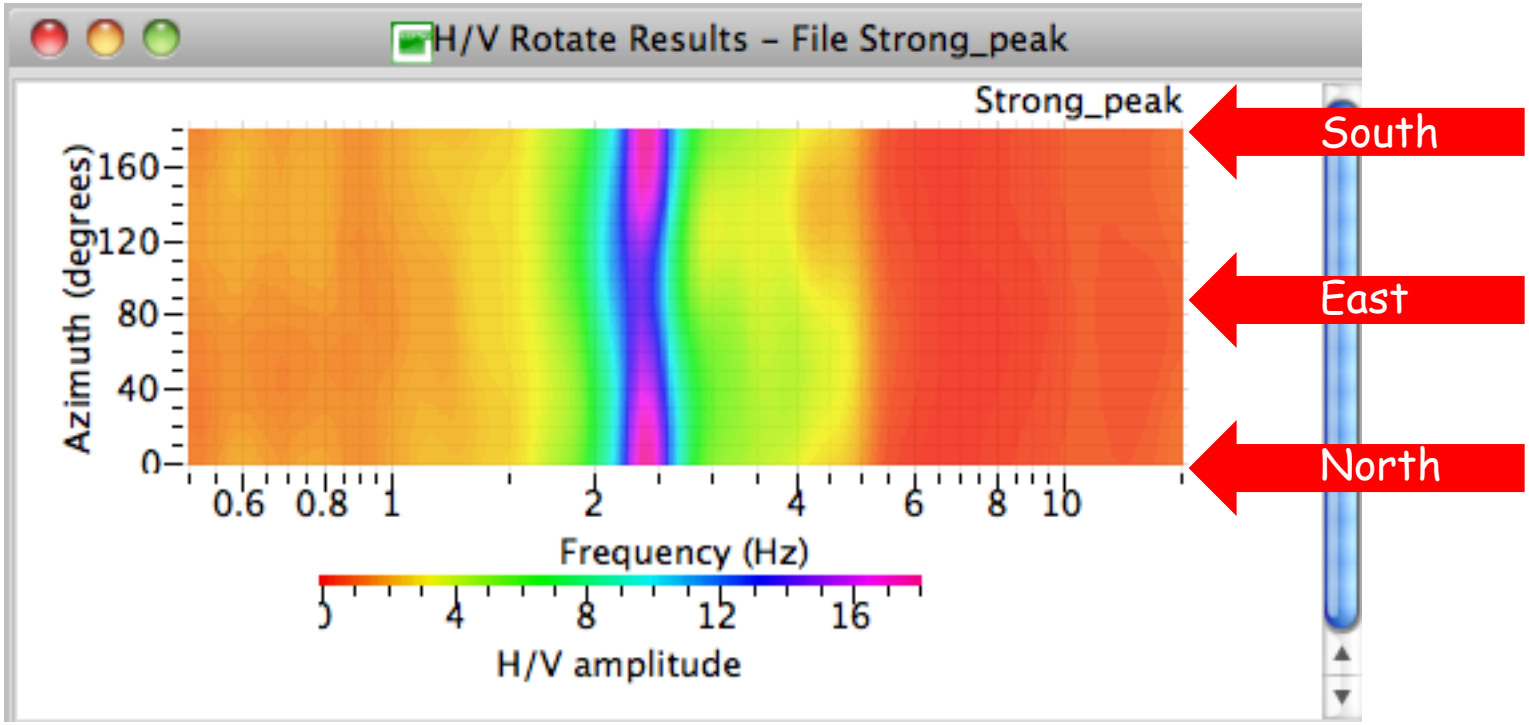
The results of the windowing (i.e. the time wind.)

The used windows

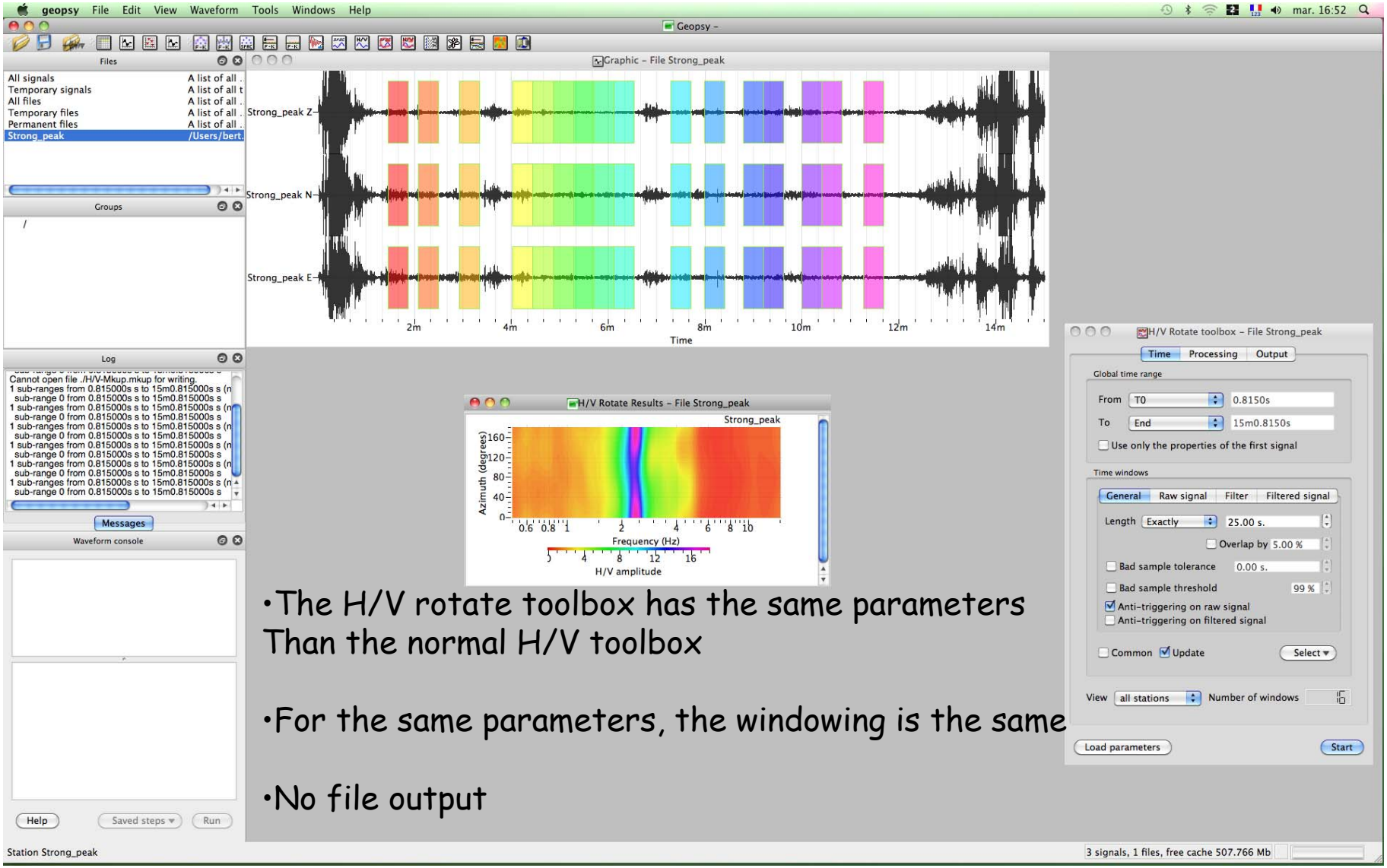
H/V ROTATE

H/V ROTATE

- Compute H/Vs with an horizontal component spanning different azimuths
- Azimuth is counted clockwise from the North (symmetry)
- Useful to check whether a site is 1D



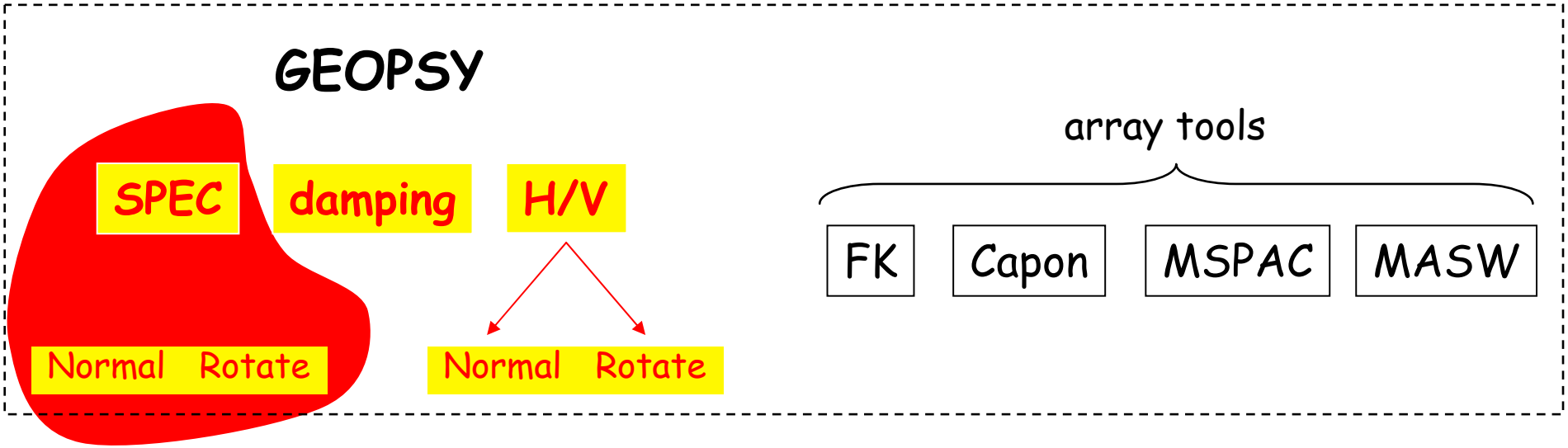
H/V ROTATE



- The H/V rotate toolbox has the same parameters Than the normal H/V toolbox
- For the same parameters, the windowing is the same
- No file output

BEFORE H/V PROCESSING
THE ENERGY SPECTRUM

Verifying the energy spectrum
It is not mandatory, but it is strongly recommended



THE ENERGY SPECTRUM

We will work on EX2: 3 files in a SAC format

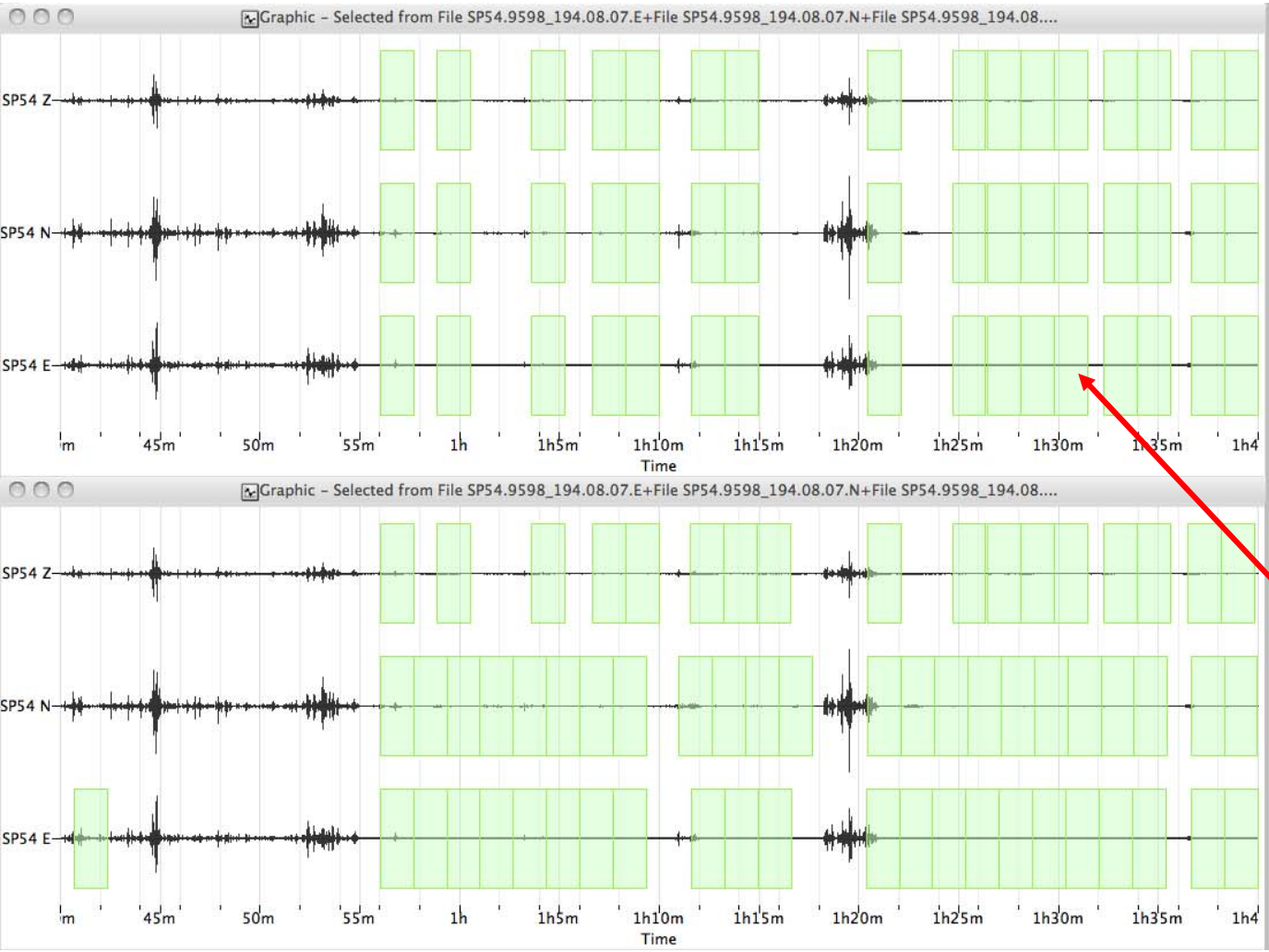
The « Spectrum toolbox » and the « Horizontal Spectrum Rotate toolbox » have the same functionalities as the H/V tools. As you familiarized yourself with H/V toolboxes, it will be very easy for you to use the spectrum tools.

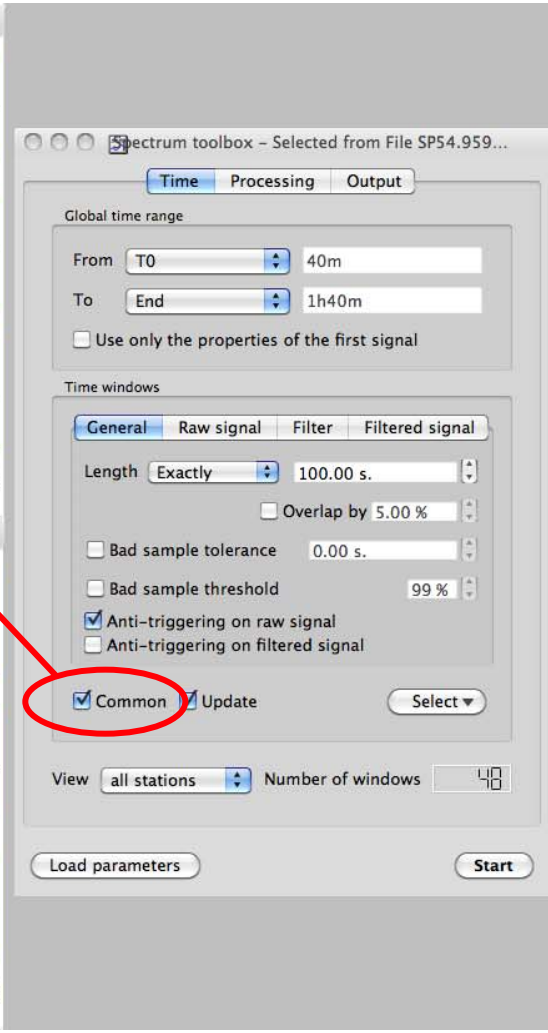
Spectrum toolbox

There is no difference with the « H/V toolbox », except:

- the window definition is not synchronous on the 3 components as in the « H/V toolbox » but you can force the synchronization (check the « Common » option)

THE ENERGY SPECTRUM





THE ENERGY SPECTRUM

The « Spectrum toolbox » and the « Horizontal Spectrum Rotate toolbox » have the same functionalities as the H/V tools. As you familiarized yourself with H/V toolboxes, it will be very easy for you to use the spectrum tools.

Spectrum toolbox

There is no difference with the « H/V toolbox », except:

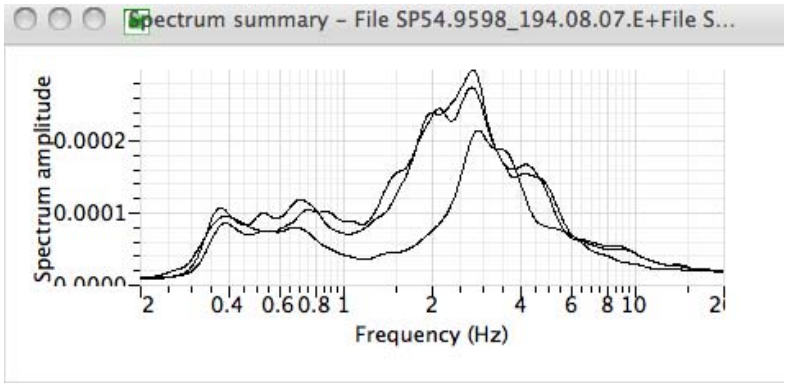
- the window definition is not synchronous on the 3 components as in the « H/V toolbox » but you can force the synchronization (check the « Common » option)
- the output files: 2 files (station_name_ZNE.spec) and (station_name_ZNE.log) are created for each component

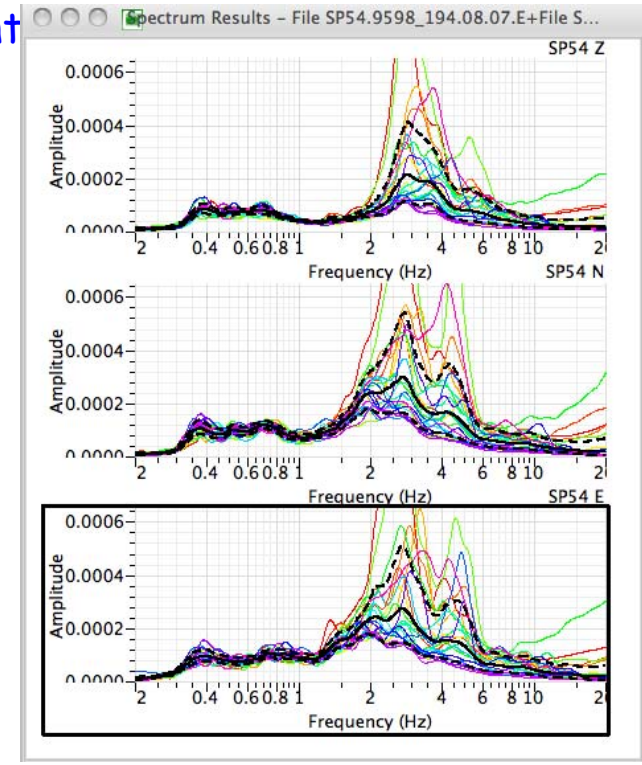
THE ENERGY SPECTRUM

Spectrum toolbox

There is no difference with the « H/V toolbox », except:

- the window definition is not synchronous on the 3 components as in the « H/V toolbox » but you can force the synchronization (check the « Common » option)
- the output files: 2 files (station_name_ZNE.spec) and (station_name_ZNE.log) are created for each component
- 2 graphics are created:
  - ➔a graphic displaying 3 graphs (one for each component
  - ➔a synthetic graph displaying the 3 averaged curves





THE ENERGY SPECTRUM

1- load the 3 files in Geopsy (EXERCISES_HV/EX02)

- very long record (3h50)
- at 100 sps → Upper frequency limit: 50 Hz
- done with a Lennartz LE3D-5s → Lower frequency limit: 0.2 Hz
  Useful window length: 50 s. max

2- As you can observe some strong noise, we will cut the signal to conserve 120'

- cut the signal (in graphic or table) in-between 20' and 2h20'
- open the « Spectral toolbox » by dragging your signal to the spectrum tool 

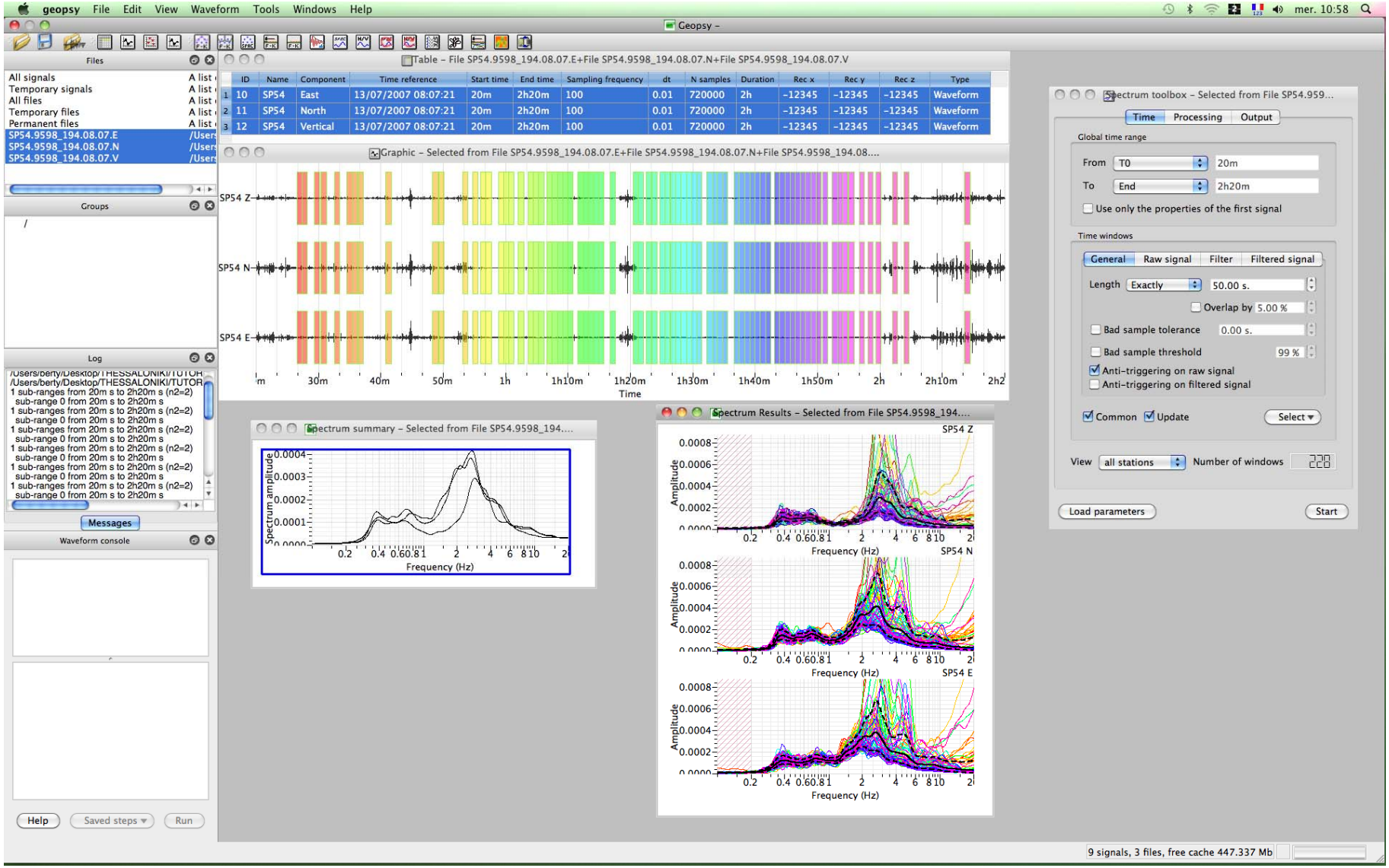
3- We fix:

- the use of an anti-trigger (raw signal, [1 – 30 – 0.2 – 2.5]) with 50 s. windows
- the frequency in a {0.1 – 20} Hz range with 1000 log samples
- normal processing (K&O, 40, cosine taper 5%)
- « Common » option to obtain a windowing identical to the H/V processing

4- « Select – Auto » (you may obtain 228 windows, 76 for each component)

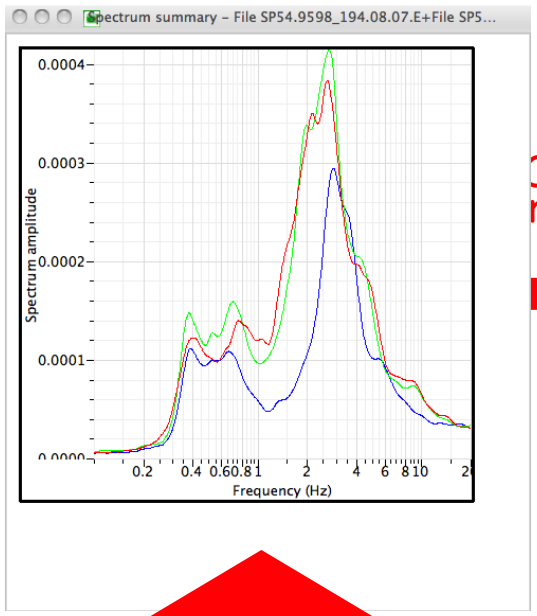
5- « Start »

THE ENERGY SPECTRUM

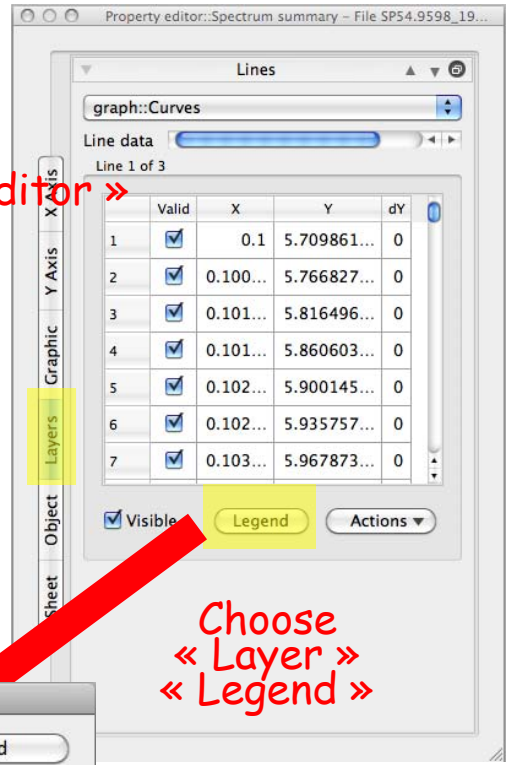


February, 2010, Thessaloniki, Greece

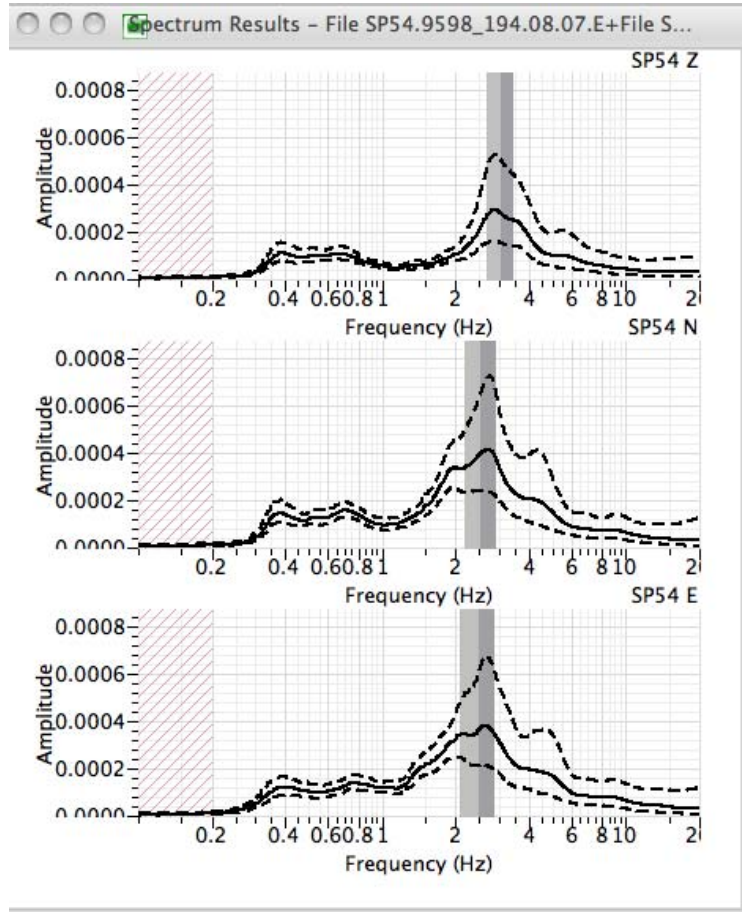
THE ENERGY SPECTRUM

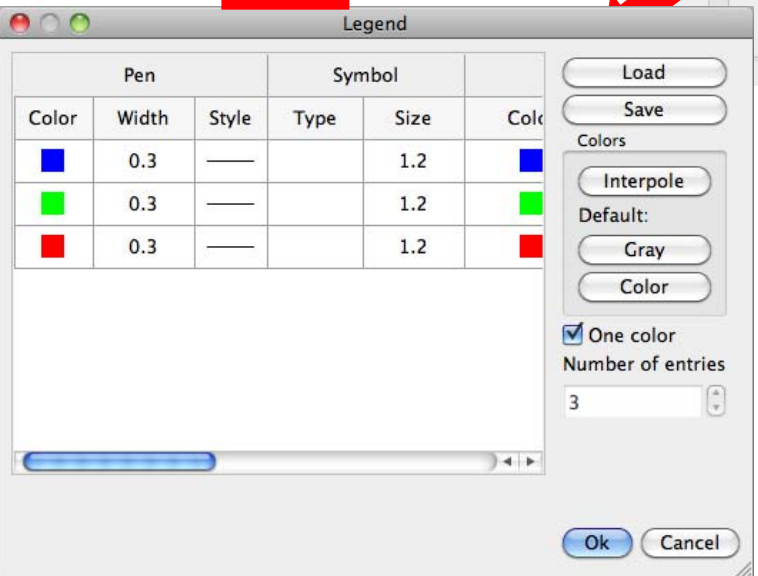


Open
rty editor »



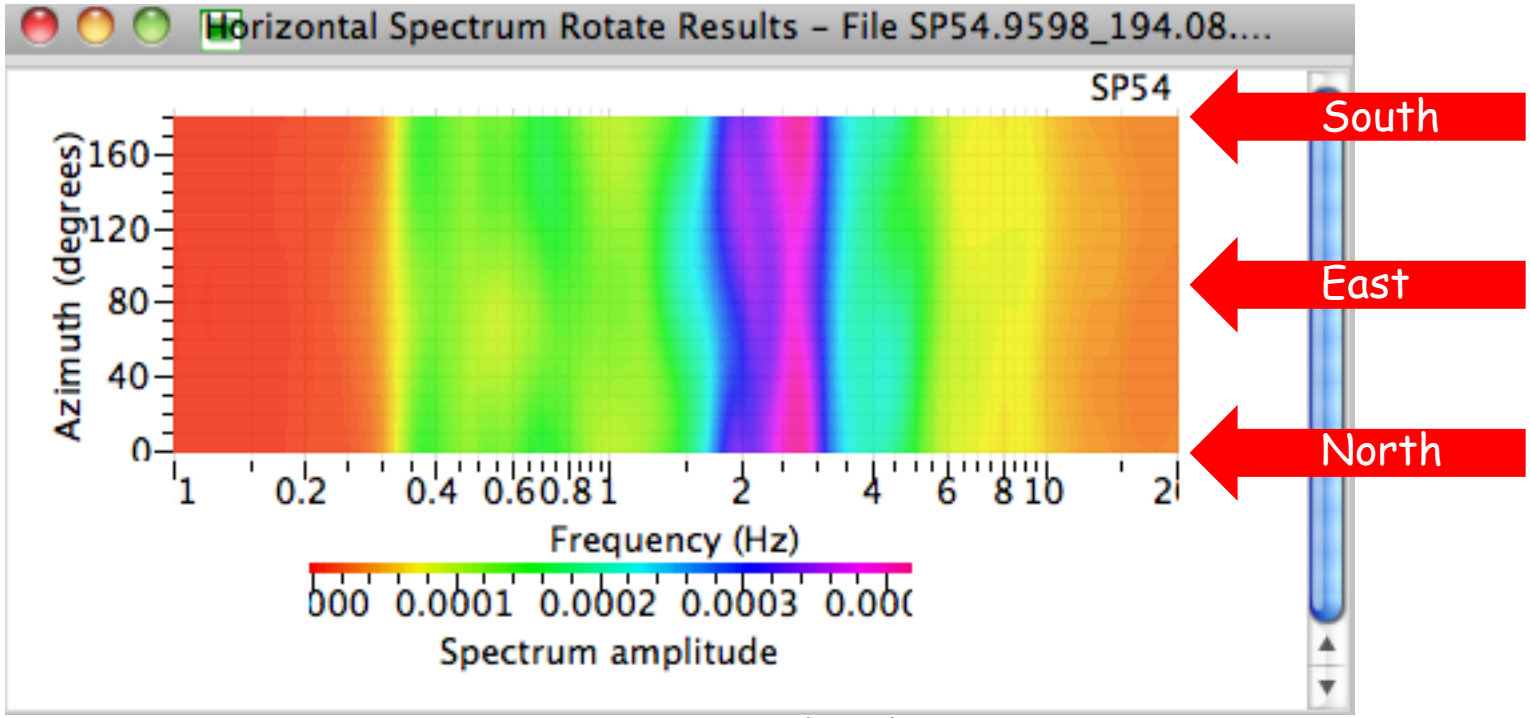
Choose
« Layer »
« Legend »





THE SPECTRUM ROTATE

- This tool works as the "H/V rotate toolbox"
- It computes spectra with horizontal components spanning different azimuths
- Azimuth is counted clockwise from the North (symmetry)
- Useful to check the energy spatial « release »



FEW MOMENTS TO PLAY WITH DATA

Work on data of EX3 (file MECHANICAL)

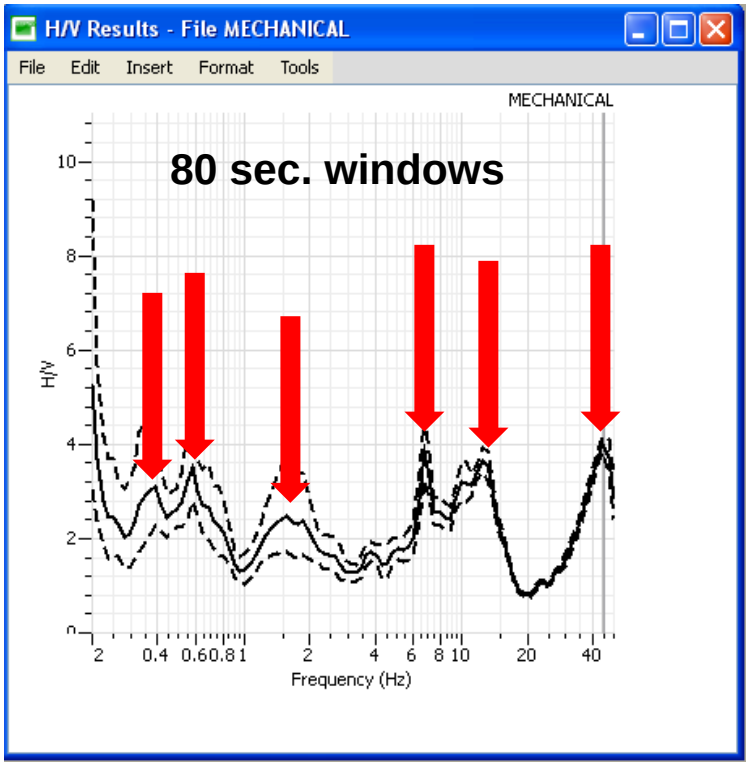
Record made by a CityShark II

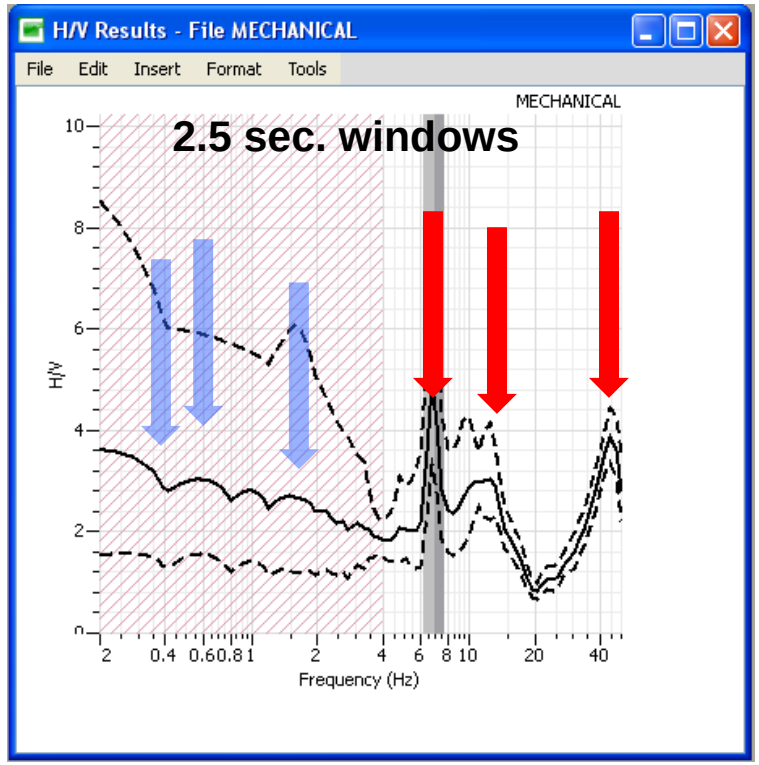
- 200 sps → Nyquist at 100Hz
- Seismometer: Lennartz LE-3D-5s. → Window of 50 s.
  → Lower lim. at 0.2 Hz

- Anti-trigger as usual

Parameters for H/V

FEW MOMENTS TO PLAY WITH DATA
Time windowing





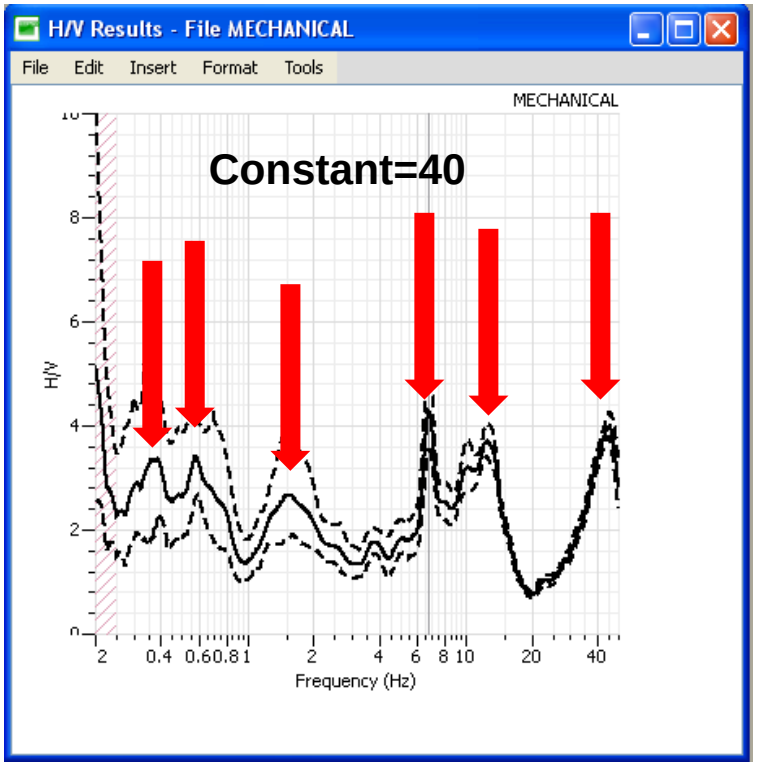
BE CARREFUL!!!!!!

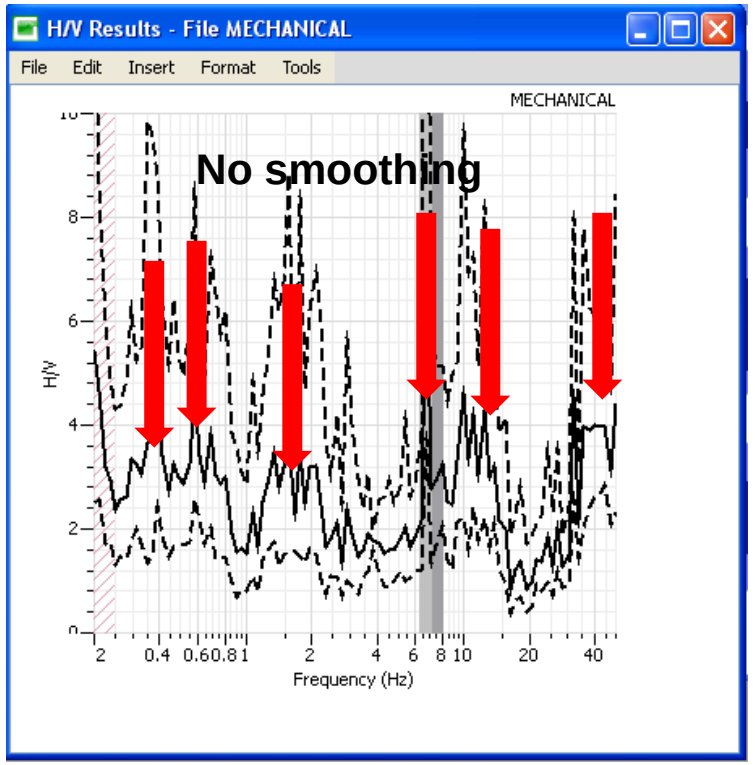
The window time length affects strongly the peaks, especially in the lower frequencies

Even if you are sure (by geology-geotechnical data) of the “presumed” frequency peak

Be secure by increasing the length as much as you can

FEW MOMENTS TO PLAY WITH DATA
Konno and Ohmachi smoothing

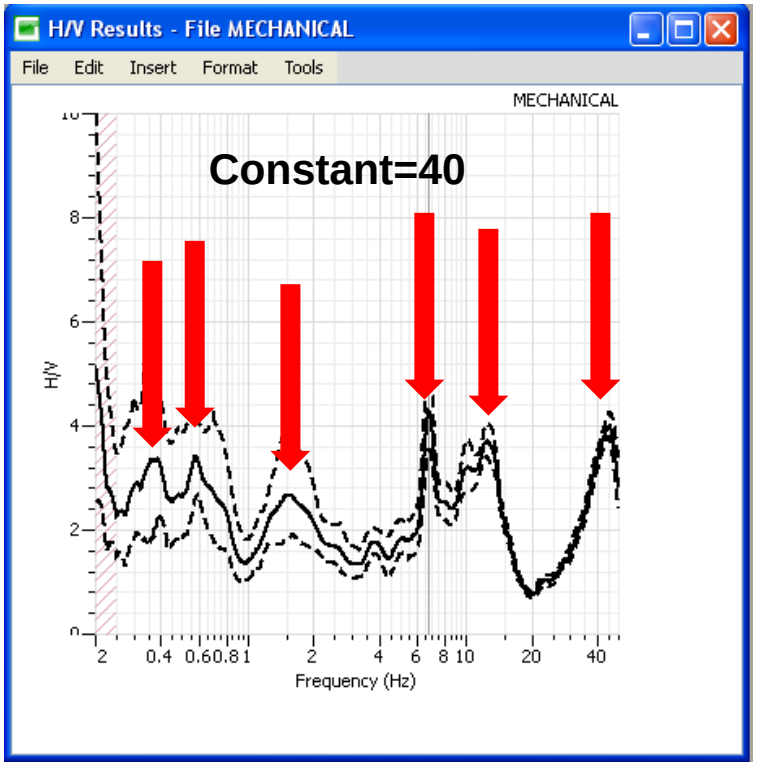


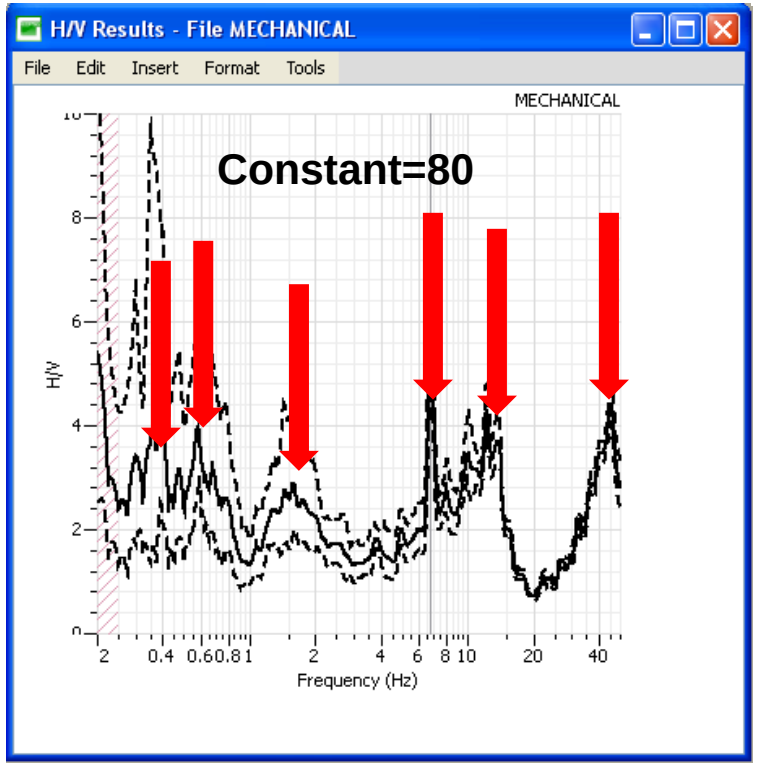


BE CARREFUL!!!!!!

No smoothing makes the H/V curve strongly difficult to interpret

FEW MOMENTS TO PLAY WITH DATA
Konno and Ohmachi smoothing



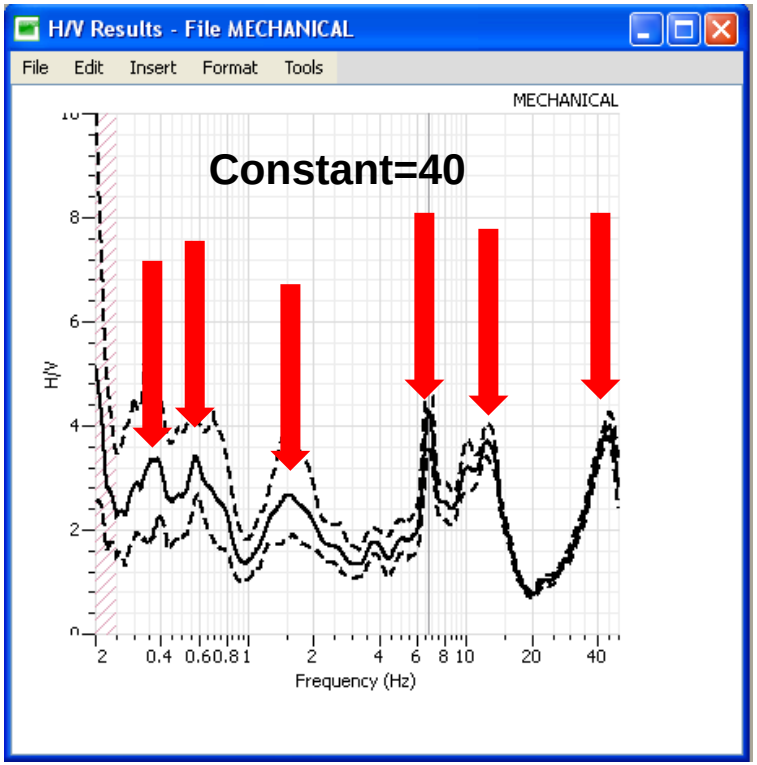


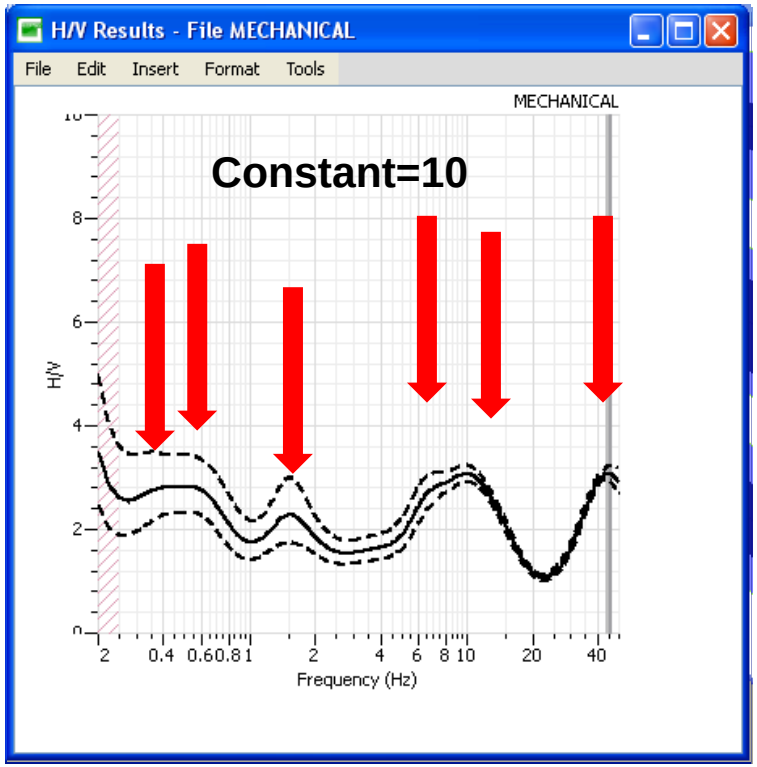
BE CARREFUL!!!!!!

Increasing the K&O constant makes the H/V curve more difficult to interpret

There are too many details.

FEW MOMENTS TO PLAY WITH DATA
Konno and Ohmachi smoothing





BE CARREFUL!!!!!!
Decreasing the K&O constant makes the H/V curve not enough detailed so more difficult to interpret, you can miss some peaks !!!!

THE DAMPING TOOL

Work on data of EX3 (file MECHANICAL)

Record made by a CityShark II

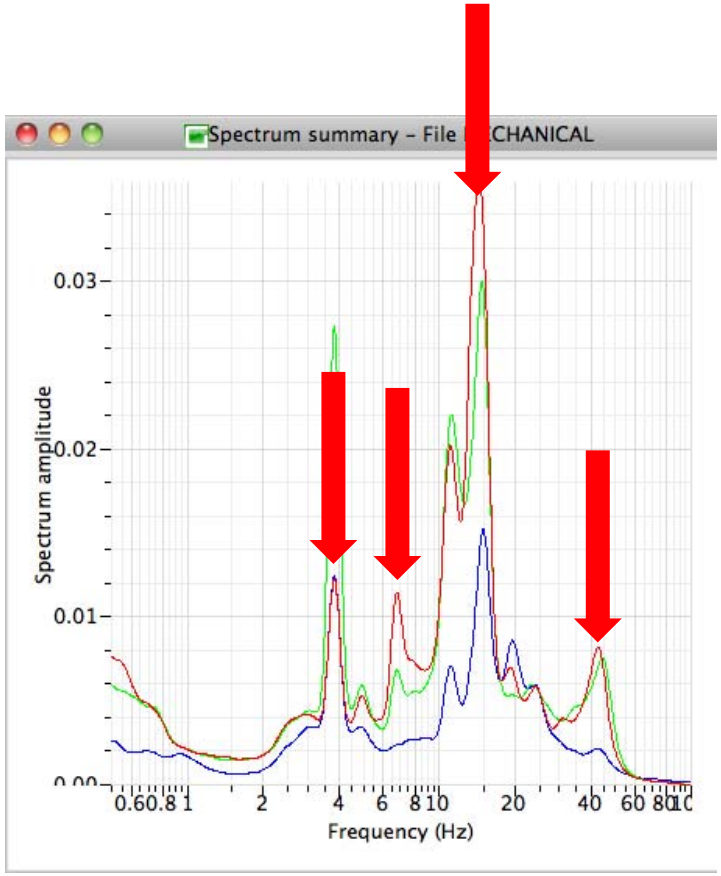
- 200 sps → Nyquist at 100Hz
- Seismometer: Lennartz LE-3D-5s. → Window of 50 s.
  → Lower lim. at 0.2 Hz

- Anti-trigger as usual

Parameters for Spectrum or H/V

THE DAMPING TOOL

Compute the Spectrum and Rotate Spectrum in-between 0.5 and 100 Hz

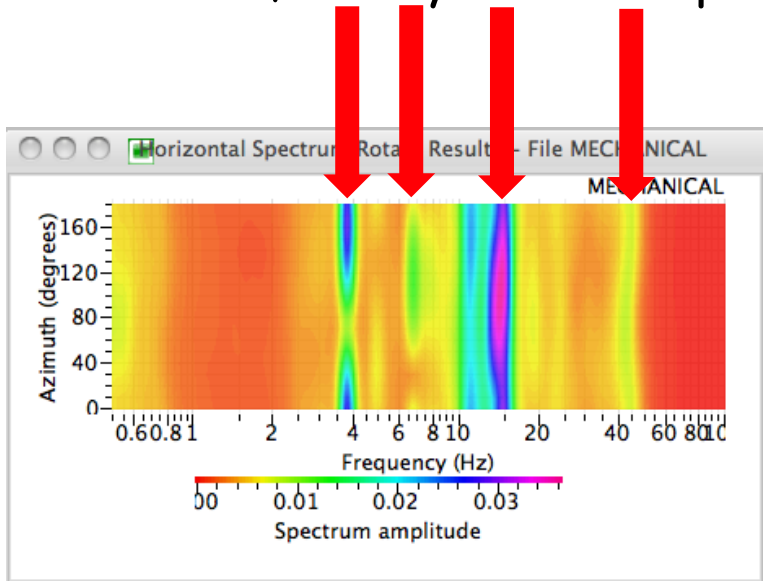


A peak at 3.8 Hz, mainly in N-S direction

A peak at 6.7 Hz, mainly in E-W direction

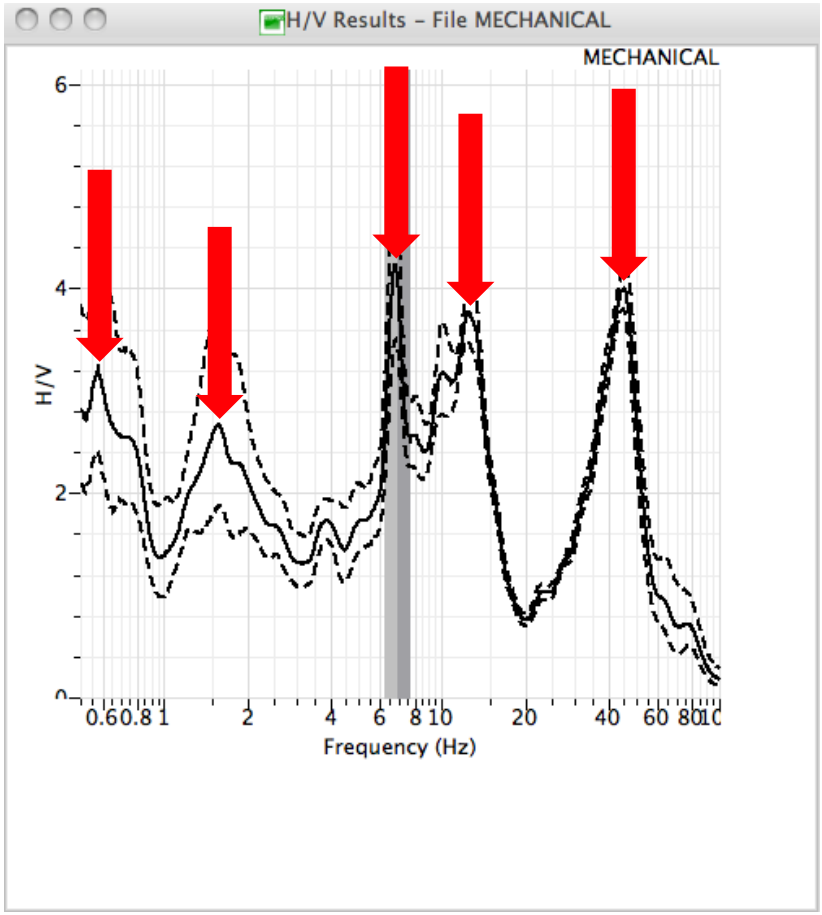
A peak at 14.8 Hz, mainly in E-W direction

A peak at 43.2 Hz, mainly on H comp.

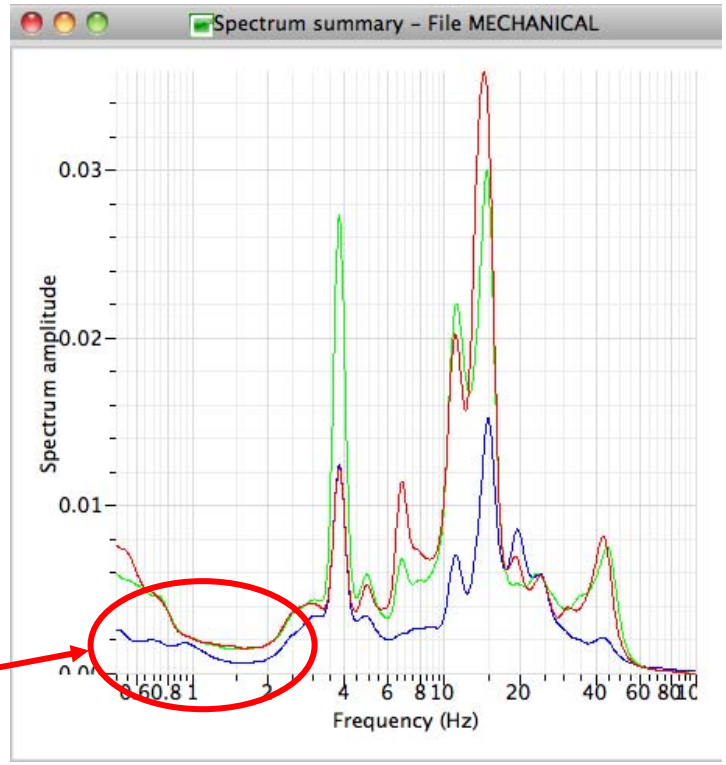


THE DAMPING TOOL

Compute the H/V curve in-between 0.5 and 100 Hz



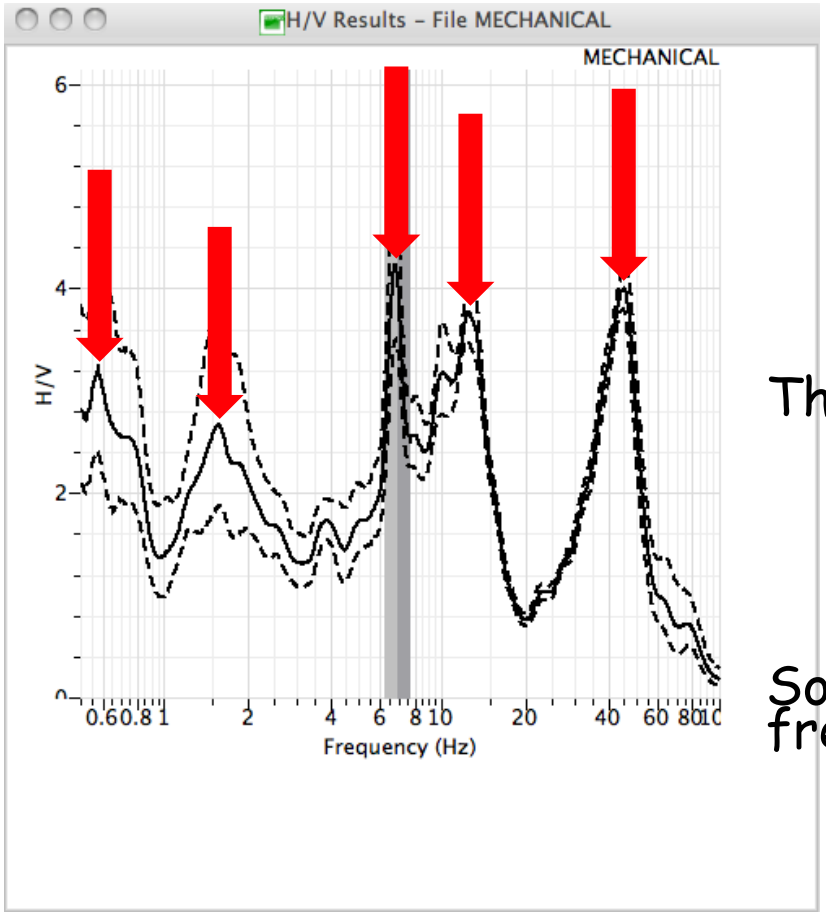
Spectrum	We observe 5 peaks (H/V)
	•0.58 Hz
•3.8 Hz	•1.55 Hz
•6.7 Hz ⟷	•6.75 Hz
•14.8 Hz ⟷	•12.45 Hz
•43.2 Hz ⟷	•45.75 Hz



In these frequencies, there is no peak in energy. So the H/V peaks have a natural origin. But, it is better to confirm the origin.

THE DAMPING TOOL

Compute the H/V curve in-between 0.5 and 100 Hz



Spectrum	We observe 5 peaks (H/V)
	•0.58 Hz
•3.8 Hz	•1.55 Hz
•6.7 Hz ⟷	•6.75 Hz
•14.8 Hz ⟷	•12.45 Hz
•43.2 Hz ⟷	•45.75 Hz

The 2 first peaks:

natural peaks (to be confirmed)

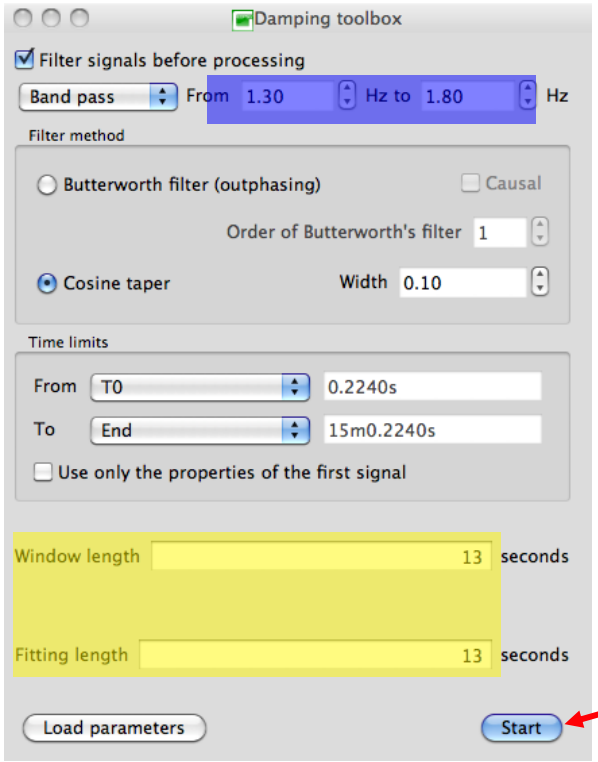
So, we will check the damping for these frequencies to verify their origin

- 1.55 Hz (presumed as natural peak)
- 6.75 Hz ??
- 12.45 Hz ??
- 45.75 Hz ??

THE DAMPING TOOL

Verifying the origin of the « 1.55 Hz » H/V peak

Open the « damping toolbox » by draging the name or signal or table onto this icon:



It will open:

- the « Damping toolbox »
- a signal window (not used)

As we want to check the damping at a defined frequency, we have to isolate a frequency band using a « Band pass » filter.

The frequency band is defined about +/- 0.25 Hz from the target frequency

So, here, we fix the band between 1.3 and 1.8 Hz

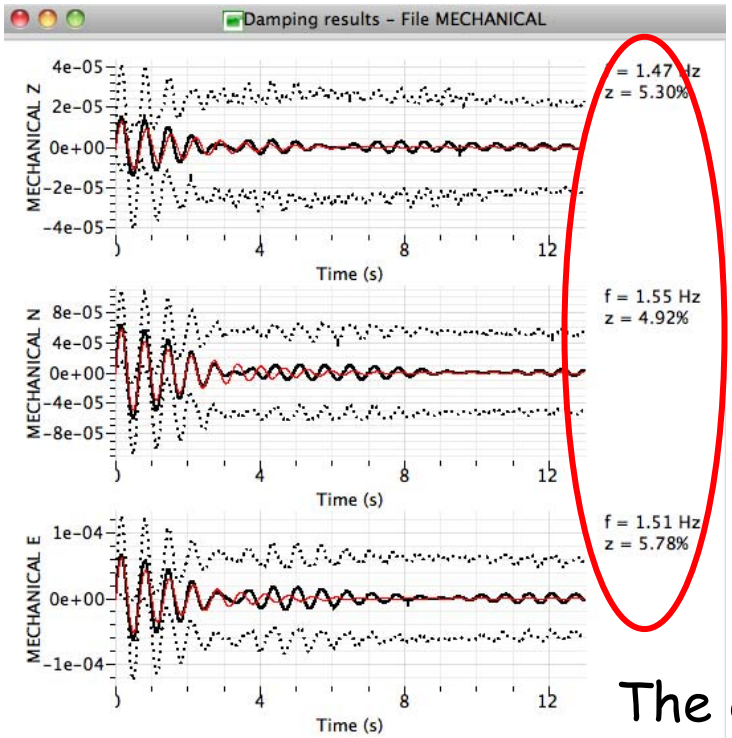
Then click on « Start »

For the « Window length » and « Fitting length »

- we want to check the stability for a time window length of about 20 wavelengths
- here 20/1.55 ≈ 13 sec.

THE DAMPING TOOL

Verifying the origin of the « 1.55 Hz » H/V peak



The results vary slightly:

- the frequencies are close
- the computed damping is over 1.0

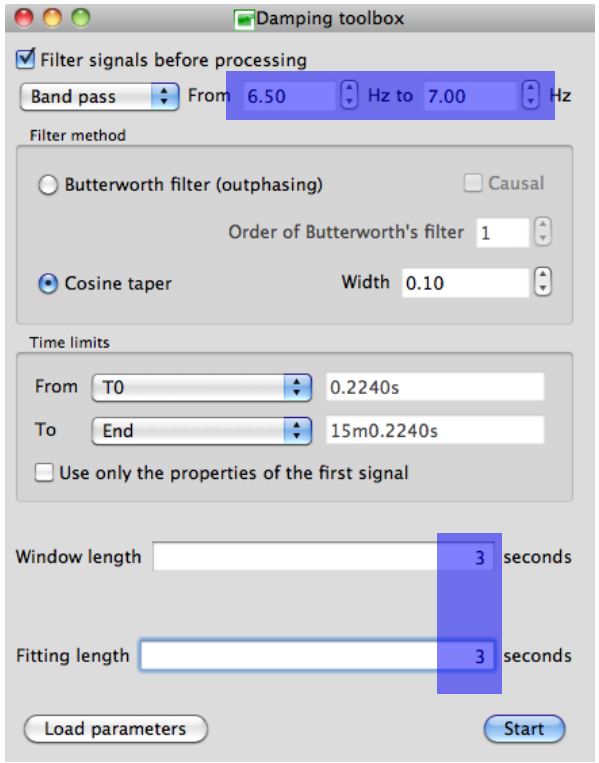
The checked frequency is not SUSTAINED and can be assumed as NATURAL

The « 1.55 Hz » H/V peak is suitable.

THE DAMPING TOOL

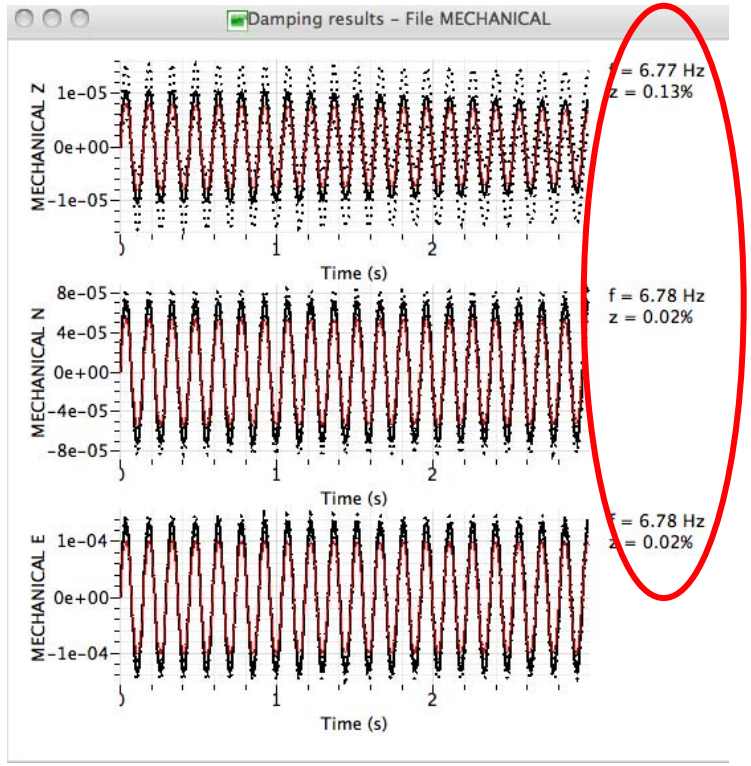
Verifying the origin of the « 6.75 Hz » H/V peak

Open again the « Damping toolbox »
Fix the frequency band between 6.5 and 7.0 Hz
The « Window length » is 20/6.75 ≈ 3 sec.



The results are homogeneous:

- the frequencies are equal
- the computed damping is strongly less than 1.0



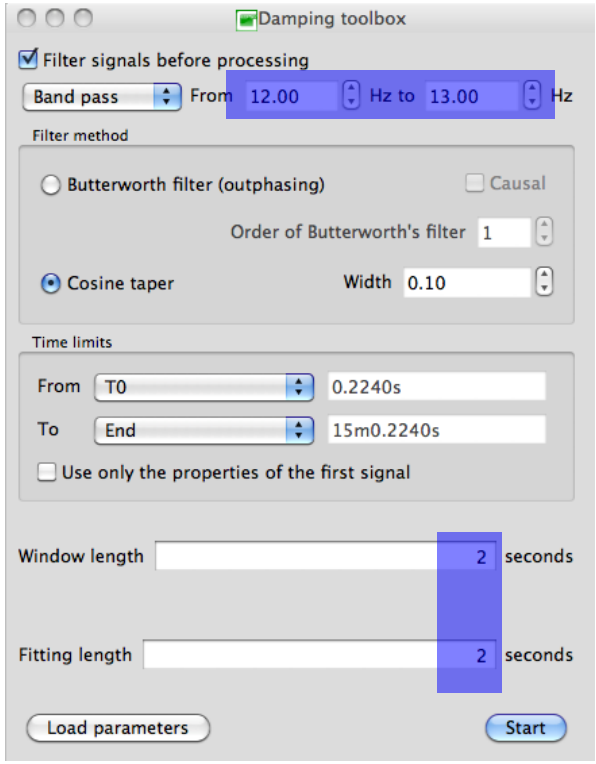
The checked frequency is STRONGLY SUSTAINED and can be assumed as ANTHROPIC and NOT NATURAL

The « 6.75 Hz » H/V peak is an industrial peak

THE DAMPING TOOL

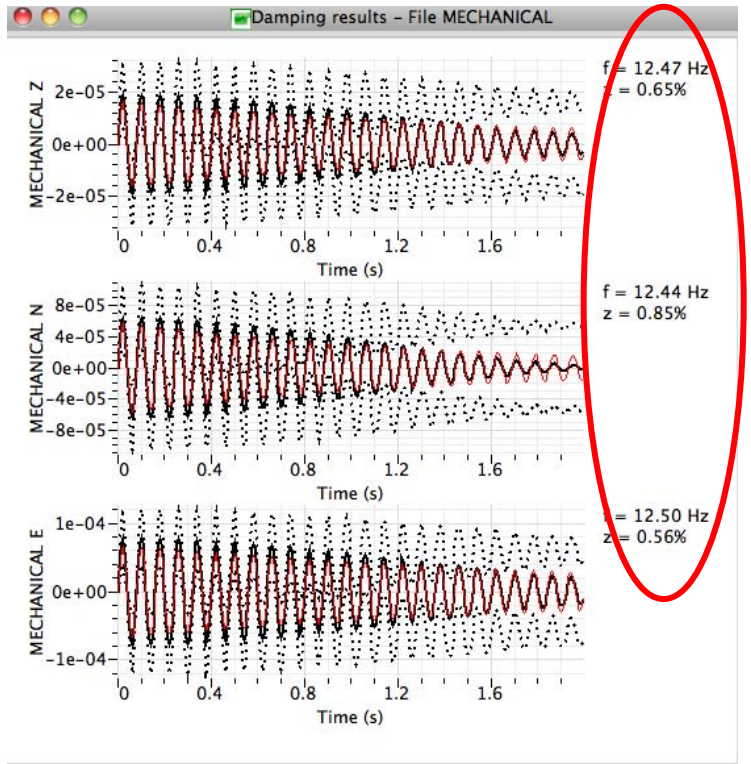
Verifying the origin of the « 12.45 Hz » H/V peak

Open again the « Damping toolbox »
Fix the frequency band between 12 and 13 Hz
The « Window length » is 20/12.45 ≈ 2 sec.



The results are homogeneous:

- the frequencies are equal
- the computed damping is less than 1.0



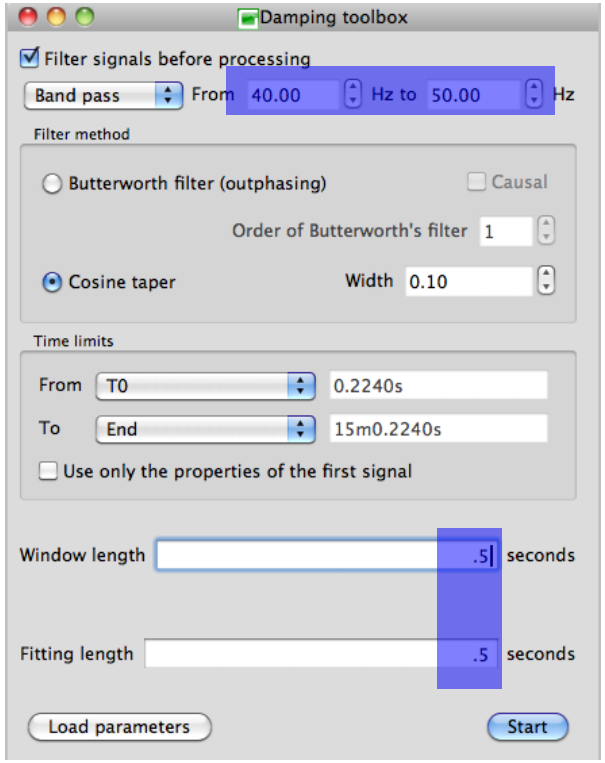
The checked frequency is SUSTAINED
and can be assumed as ANTHROPIC and NOT NATURAL

The « 12.45 Hz » H/V peak has an industrial origin

THE DAMPING TOOL

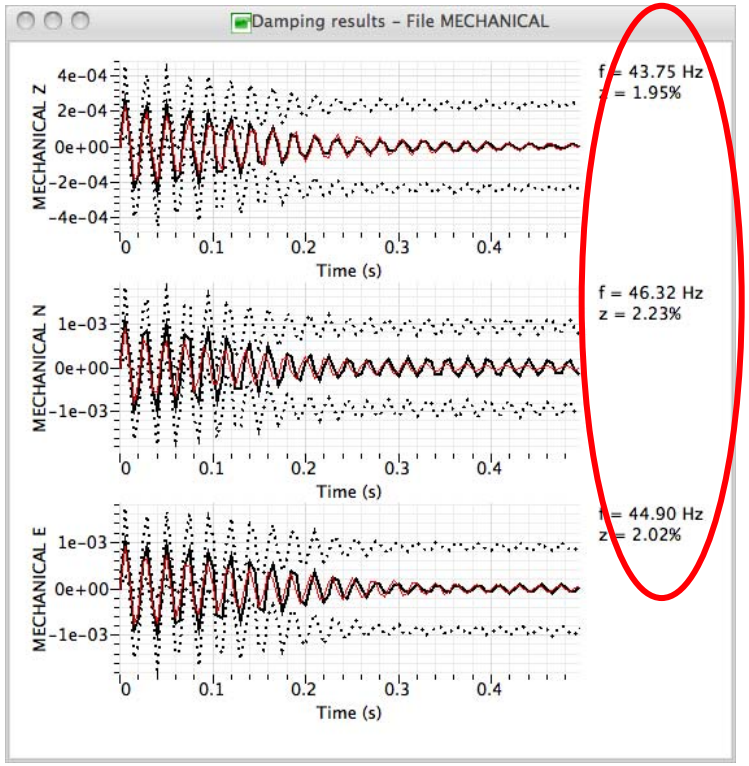
Verifying the origin of the « 45.75 Hz » H/V peak

Open again the « Damping toolbox »
Fix the frequency band between 40 and 50 Hz
The « Window length » is 20/45.75 ≈ 0.5 sec.



The results are NOT homogeneous:

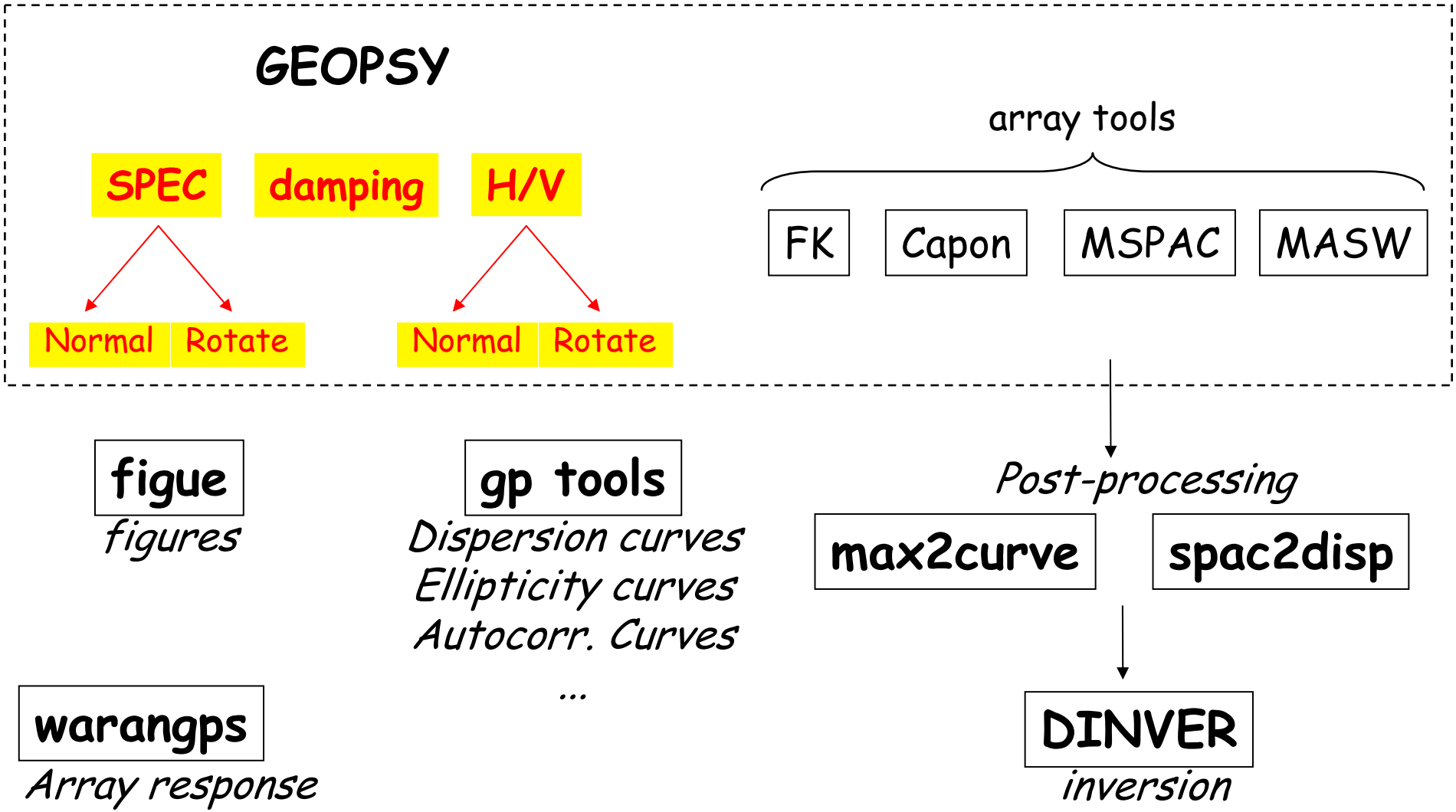
- the frequencies are unstable
- the computed damping is over 1.0



The checked frequency seems to be NOT SUSTAINED and can be assumed as NATURAL, but for me this frequency is doubtful

The « 45.75 Hz » H/V peak seems to be NATURAL (????)

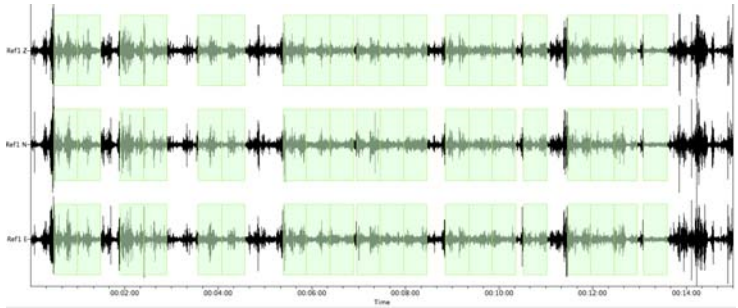
SESARRAY PACKAGES



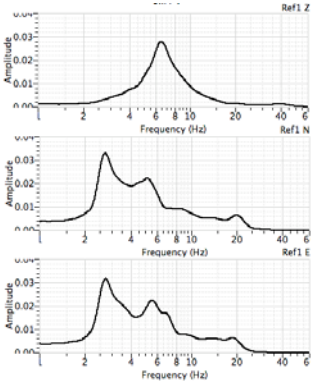
H/V computation (as in Geopsy)

Selection of the *n* most stationary windows

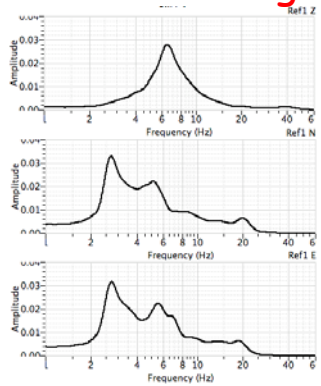
(STA/LTA anti-trigger algorithm)



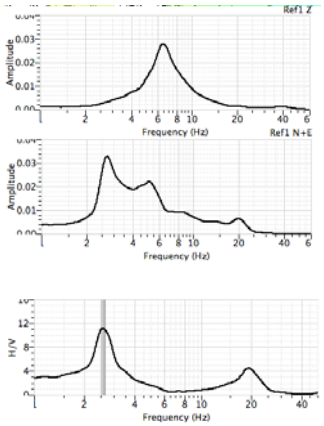
Computation of Fourier amplitude spectra + smoothing



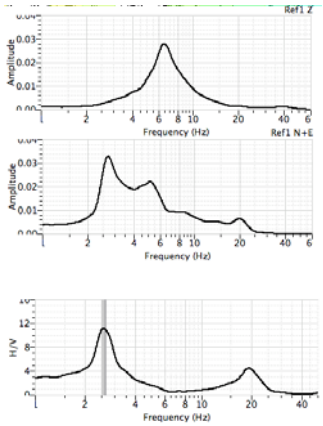
For each window of each component

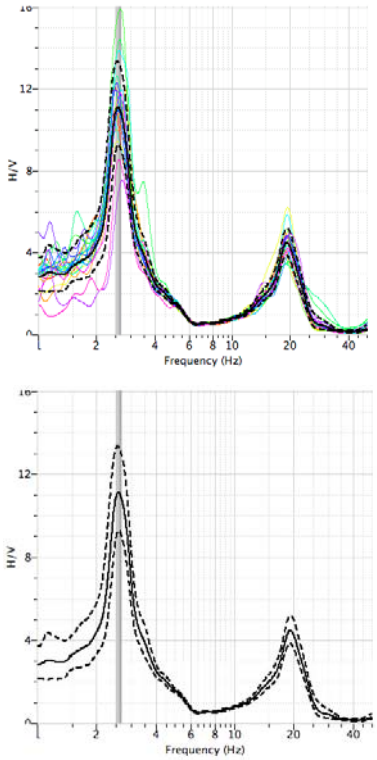


Average of horizontal components



For each window

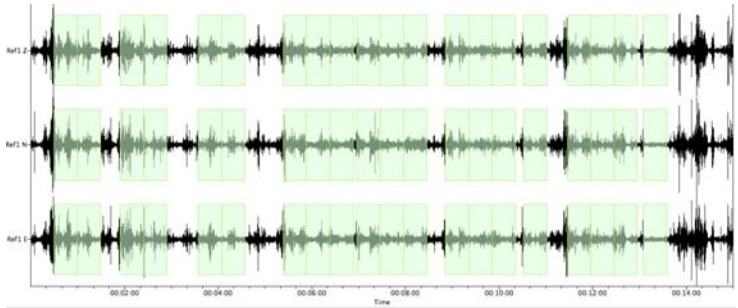




Computation of the average H/V + standard deviation

H/V computation (as in Geopsy)

Selection of the *n* most stationary windows



(STA/LTA anti-trigger algorithm)

1: removal offset for all the waveforms

2: determination of the STA/LTA value for each sample of each component
- 2-1: verification is the ratio fits the STA/LTA given limits
- 2-2: determination of time sample series fullfilling the given time length limits

STA/LTA computation

-2 sliding windows at the same time
- •a short one (STA), with a time length you fix yourself (0.5 - 2 sec): tsta
- •a long one (LTA), with a time length you fix yourself (15 - 60 sec): tlta
- •on each window, you calculate the mean value of the waveform

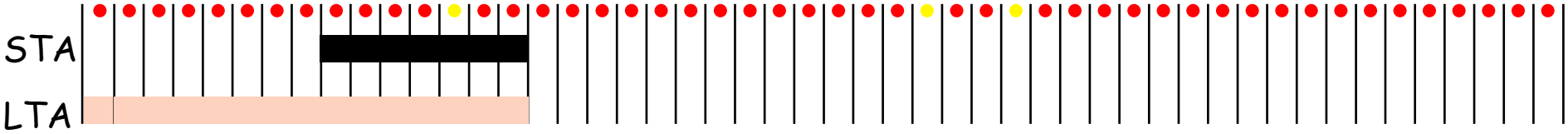
-the ratio STA/LTA is computed and then compared to the fixed boundaries (low and high)
-the calculated ratio (so the sample) is conserved or rejected
-all the process is done for the next sample (for STA and LTA)

STA/LTA ratio calculus

● =1 ● =11

STA average on 2 samples
LTA average on 10 samples

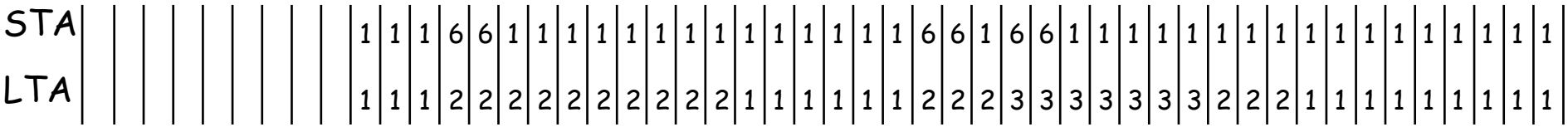
Sample space



Value space

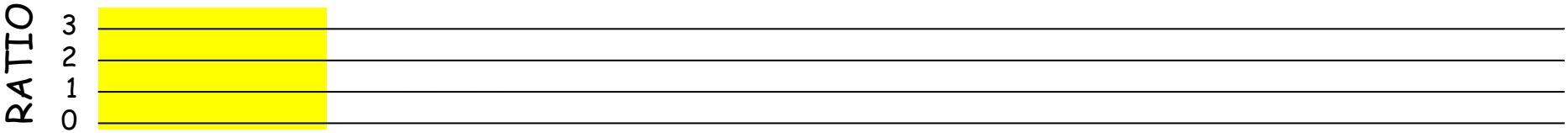
$$V_{10(STA)} = \left(\sum_{i=9}^{10} abs(value(i)) \right) /2$$

$$V_{n(STA)} = \left(\sum_{i=n-1}^{n} abs(value(i)) \right) /2$$



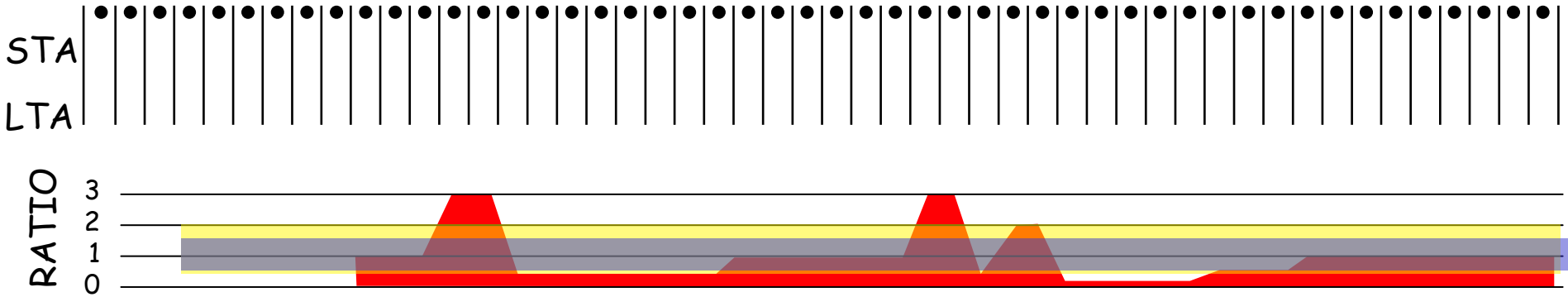
$$V_{10(LTA)} = \left(\sum_{i=1}^{10} abs(value(i)) \right) /10$$

$$V_{n(LTA)} = \left(\sum_{i=n-9}^{n} abs(value(i)) \right) /10$$



STA/LTA ratio calculus

Sample space



Case one: you fix a ratio STA/LTA in-between 0.6 and 1.4

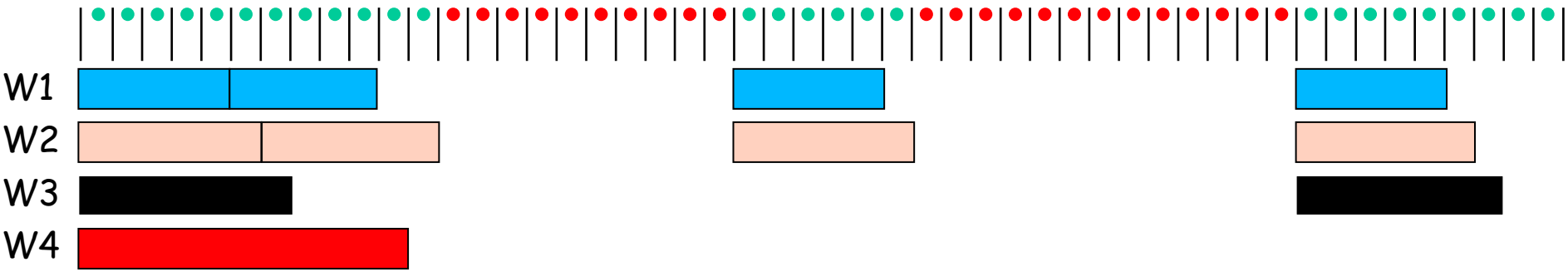
Case two: you fix a ratio STA/LTA in-between 0.5 and 2.0

Larger is the boundaries difference less drastic you are in your selection

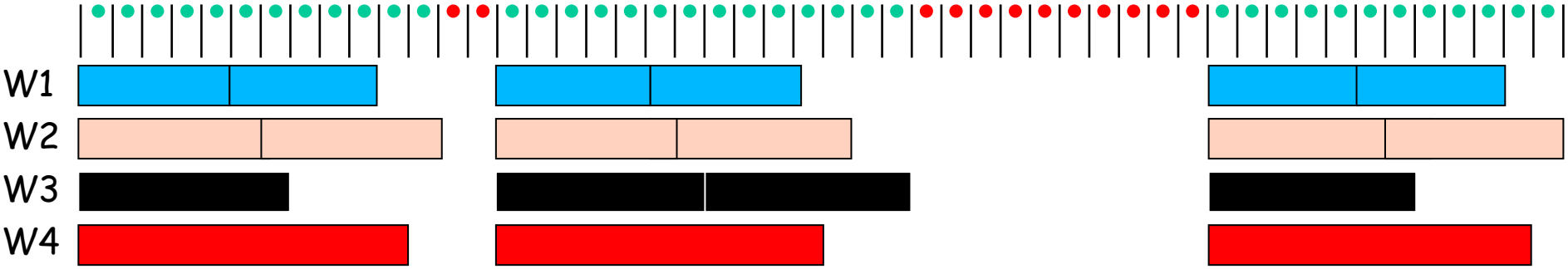
WINDOWING DETERMINATION

W1: 5 samples W2: 6 samples W3: 7 samples W4: 11 samples

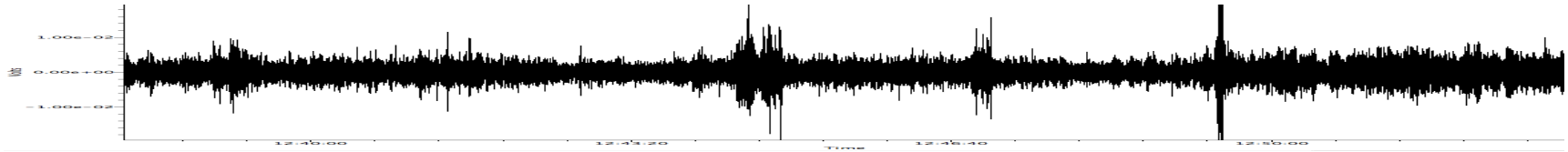
Case one: you fix a ratio STA/LTA in-between 0.6 and 1.4

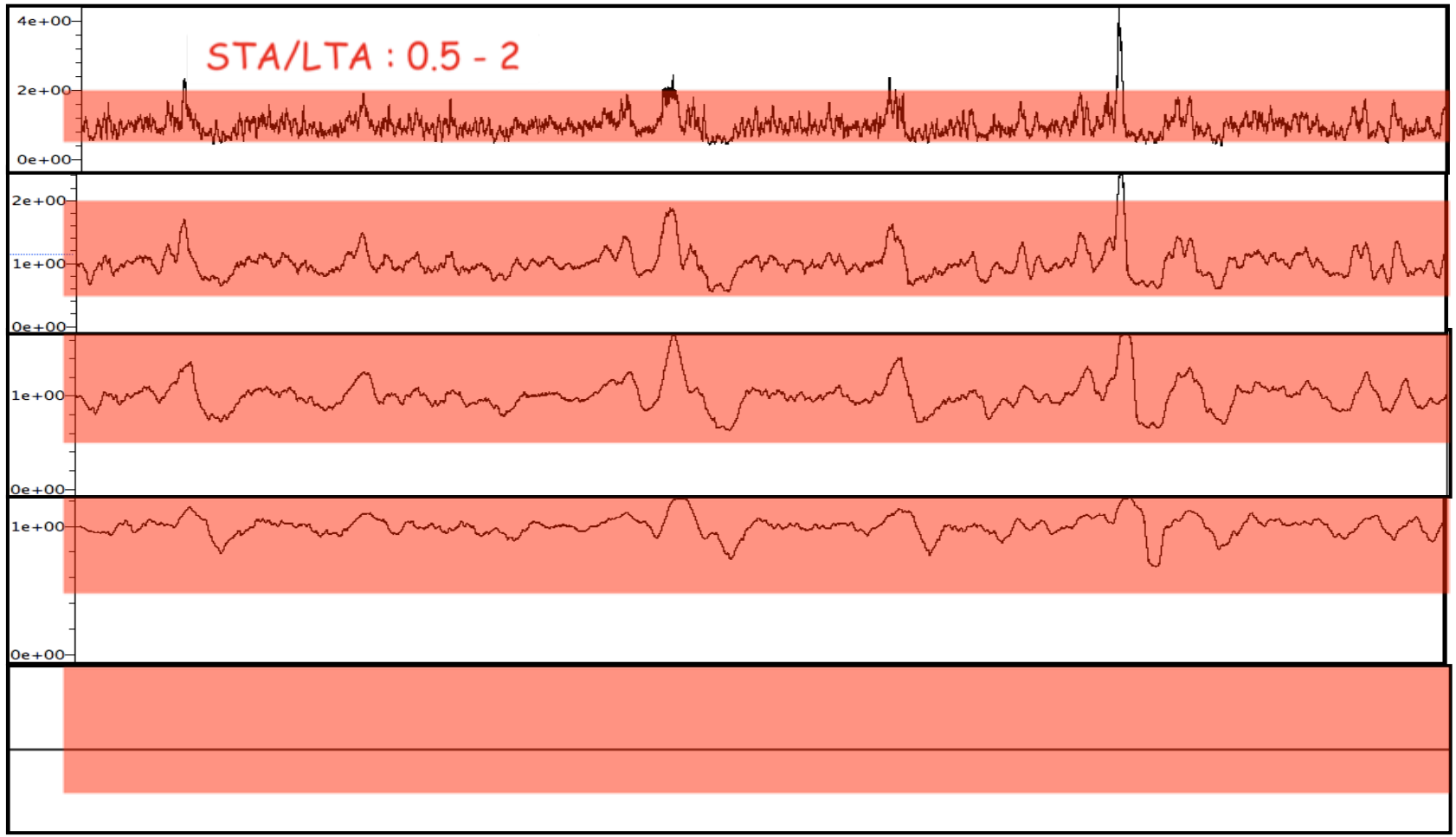


Case two: you fix a ratio STA/LTA in-between 0.5 and 2.0



STA-LTA AND WINDOWING REAL CASE





1-30

5-30

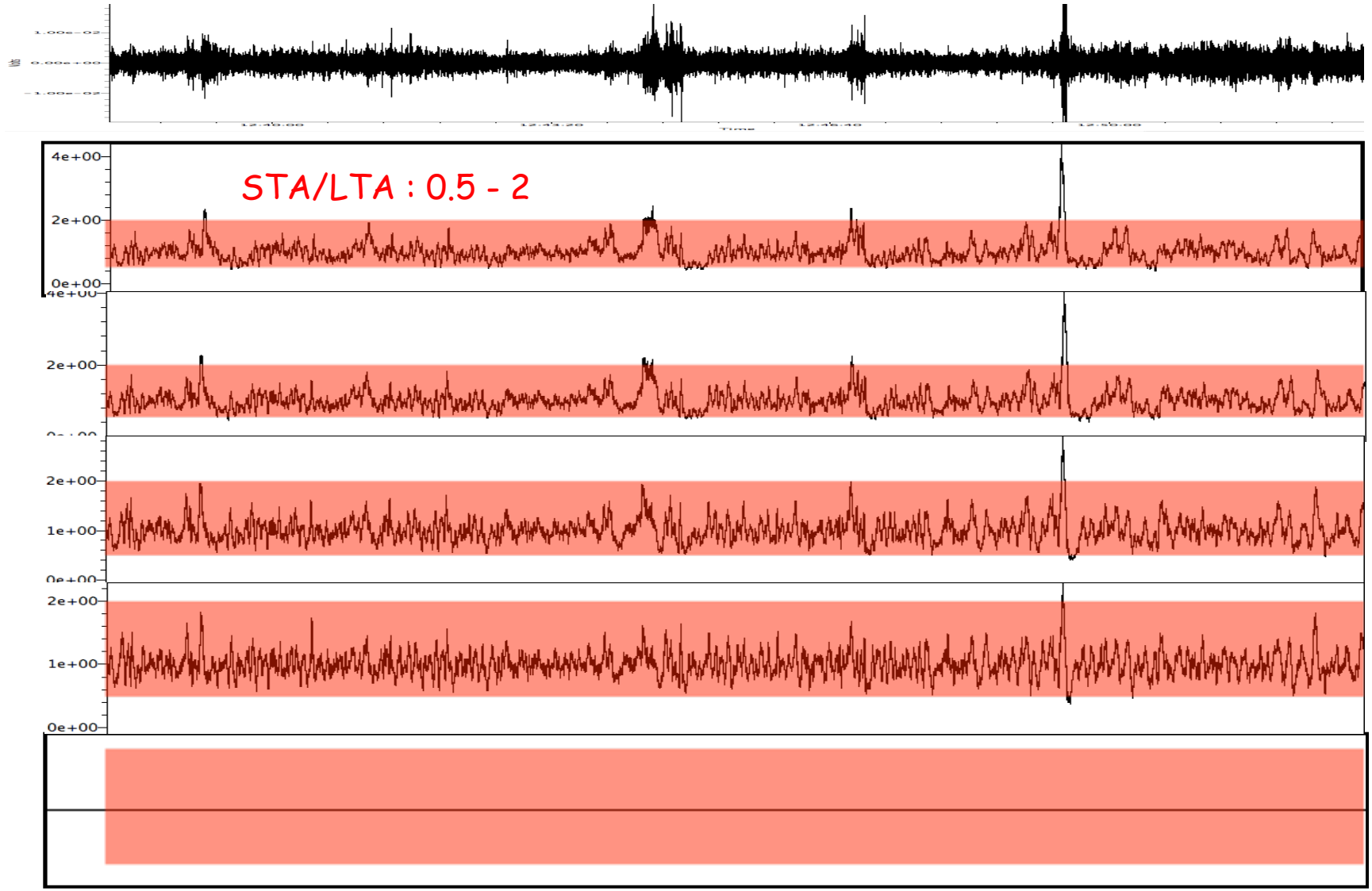
10-30

20-30

30-30

Increasing the tSTA, you smooth and stretch the STA/LTA ratio, until a flat line
You are less selective

STA-LTA AND WINDOWING REAL CASE

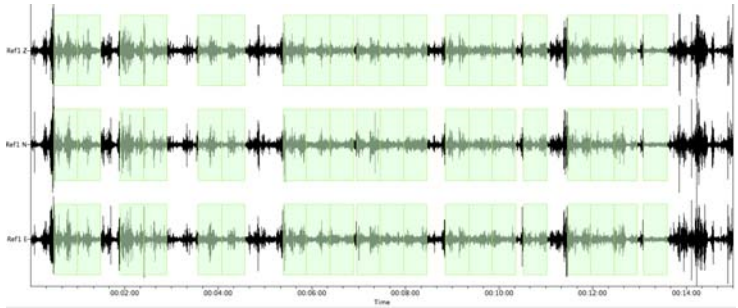


Increasing the tLTA, you only amplify the STA/LTA ratio, from a flat line
You are more selective

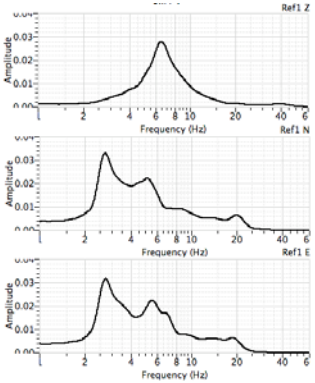
H/V computation (as in Geopsy)

Selection of the *n* most stationary windows

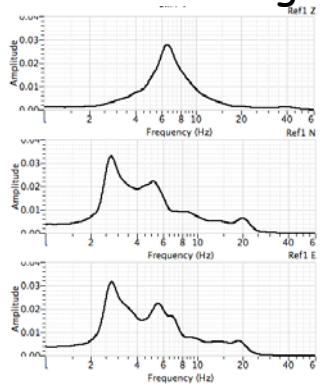
(STA/LTA anti-trigger algorithm)



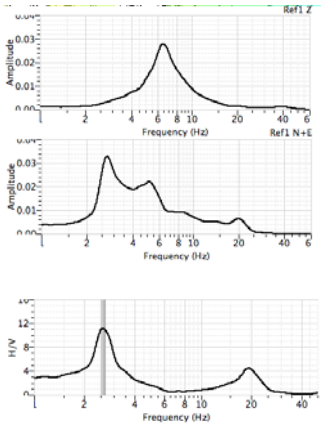
Computation of Fourier amplitude spectra + smoothing



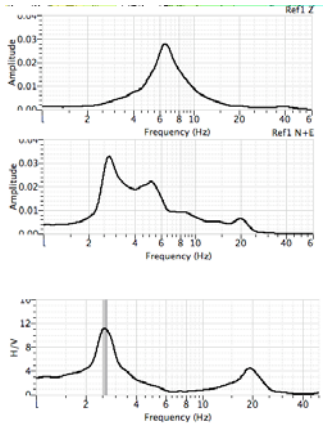
For each window of each component

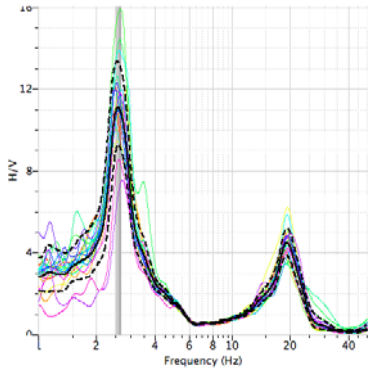


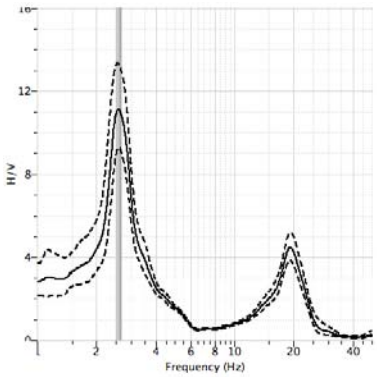
Average of horizontal components



For each window



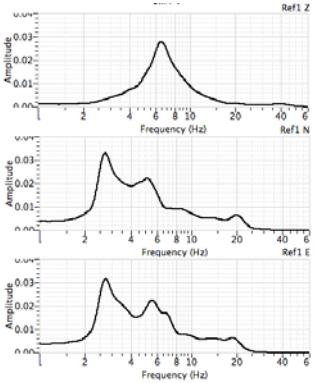


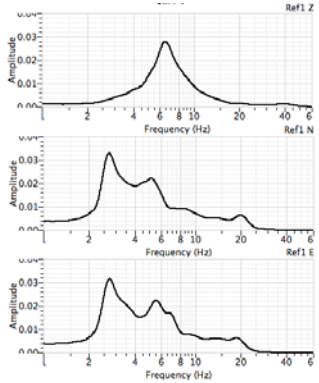


Computation of the average H/V + standard deviation

FFT AND SMOOTHING

Computation of Fourier amplitude spectra + smoothing





For each window of each component

Smoothing with the "Konno-Ohmachi" function

$$\frac{\sin\left(\left(\log_{10}\left(\frac{f}{fc}\right)\right)^{b}\right)}{\left(\left(\log_{10}\left(\frac{f}{fc}\right)\right)^{b}\right)^{4}}$$

f is the frequency,
fc is the central frequency,
b is the bandwidth coefficient.

Constant

The smoothing function has a triangular shape centered on the current frequency and its width is equal to "Band width"

Proportional

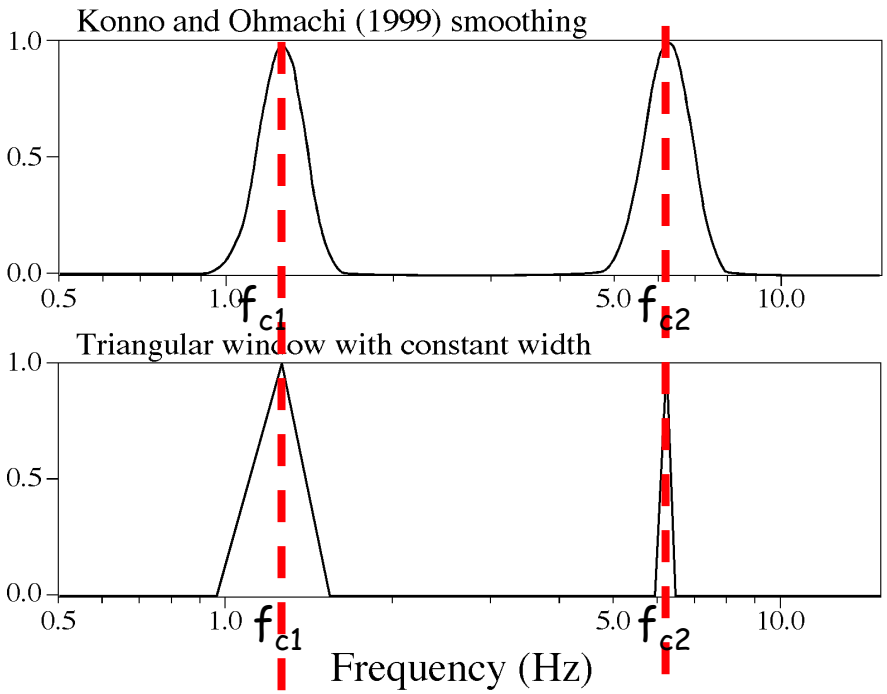
The smoothing function has a triangular shape and its width depends upon the current frequency. The half width is defined by percentage*frequency. The value of "percentage" cannot be greater or equal to 100%.

FFT AND SMOOTHING

$$\frac{\sin\left(\left(\log_{10}\left(\frac{f}{fc}\right)\right)^{b}\right)}{\left(\left(\log_{10}\left(\frac{f}{fc}\right)\right)^{b}\right)^{4}}$$

Konno and Ohmachi smoothing (1999)

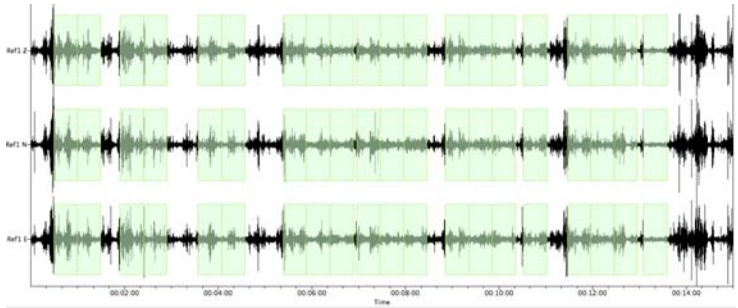
- constant bandwidth in a logarithmic scale
- recommanded because this smoothing function preserves the different number of points at low and high frequency



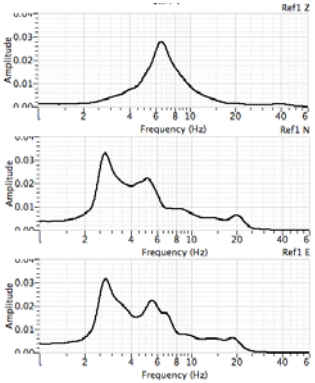
H/V computation (as in Geopsy)

Selection of the *n* most stationary windows

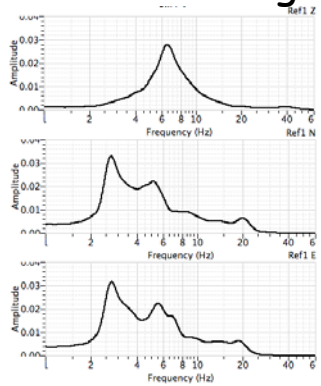
(STA/LTA anti-trigger algorithm)



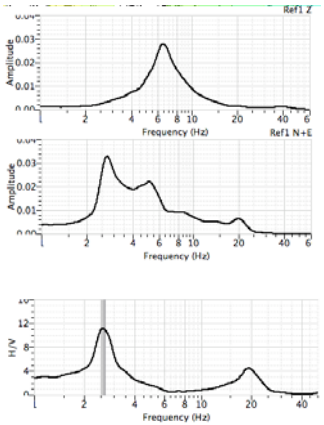
Computation of Fourier amplitude spectra + smoothing



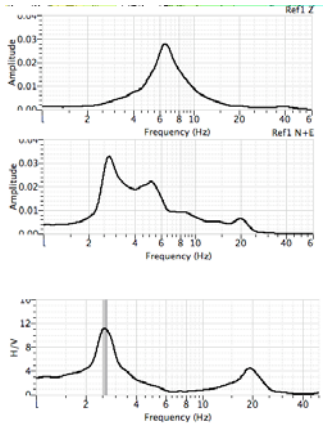
For each window of each component

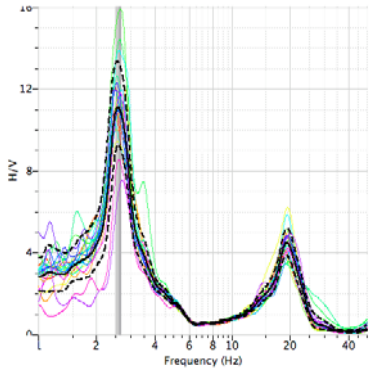


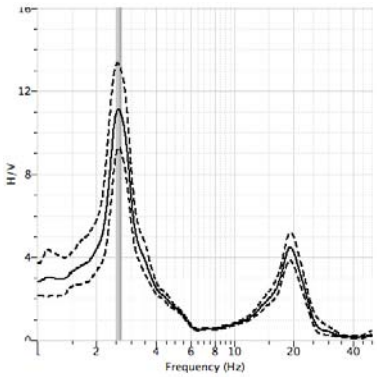
Average of horizontal components



For each window







Computation of the average H/V + standard deviation

H/V COMPUTATION (as implemented in Geopsy)

Squared average

- Fourier amplitude spectra (for each window)
- combination of horizontal spectra (for each window)

$$H(f) = \sqrt{\frac{N^2(f) + E^2(f)}{2}}$$

- smooth of H and V (for each window)
- computation of H/V

Based on total horizontal energy

- Fourier amplitude spectra (for each window)
- combination of horizontal spectra (for each window)

$$H(f) = \sqrt{N^2(f) + E^2(f)}$$

- smooth of H and V (for each window)
- computation of H/V

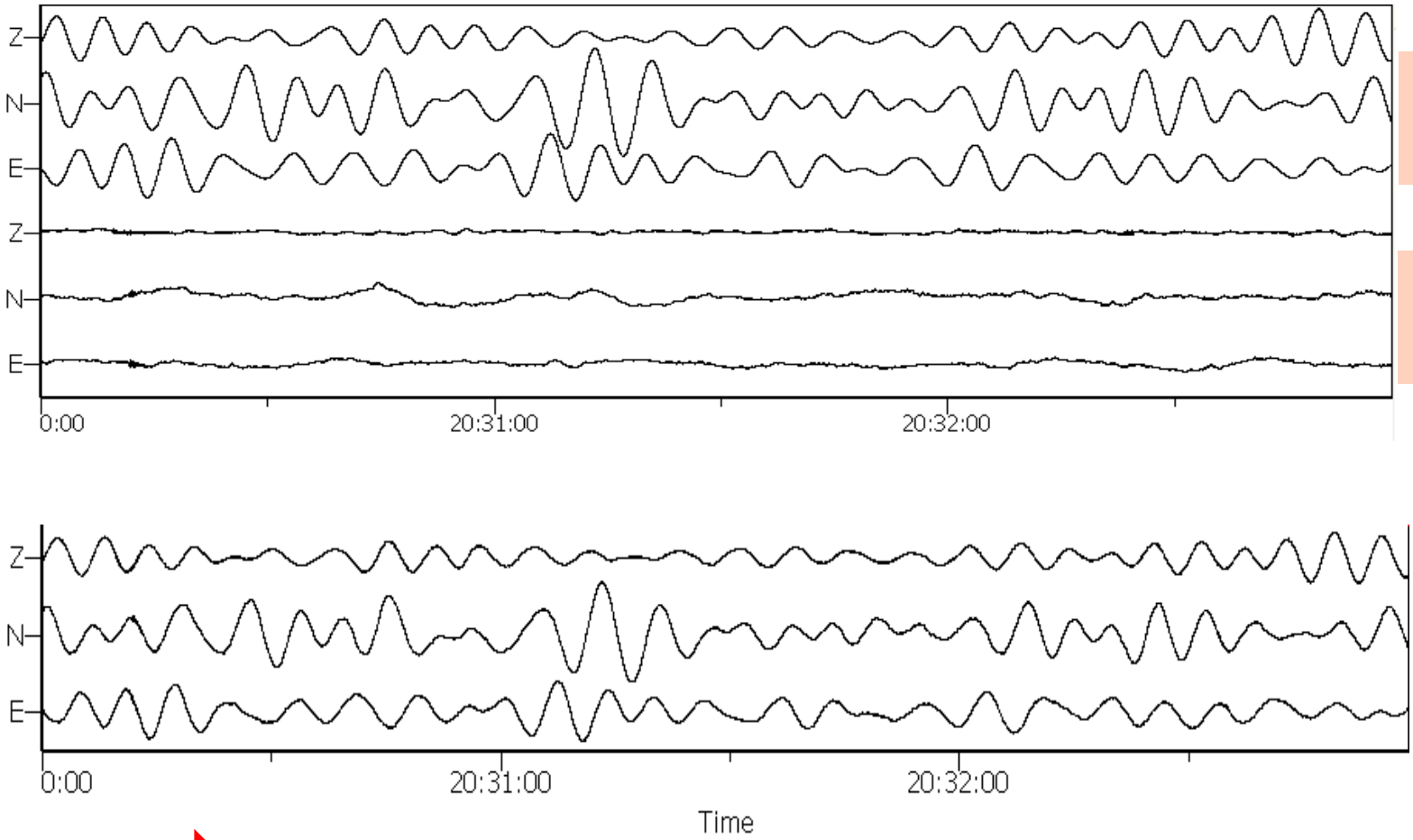
H/V COMPUTATION (as implemented in Geopsy)

Sometimes, the taper size used in the pre-processing has a strong influence at low frequency. If the signal contains a strong and very low frequency component, then cutting into short time windows may strongly distort the observed spectra and H/V. Even when using the minimum window length criteria according SESAME reports (i.e. 10 times the corresponding period for the minimum frequency of interest) may be not enough to ensure a reliable H/V estimation.

In order to avoid such "tapering effects", signals can be high-pass filtered before computing the H/V and spectra curves (Geopsy option).
The higher value for the frequency of the high-pass filter is the minimum 'reliable' frequency, i.e. 10/window_length.

H/V COMPUTATION (taper effects)

- signal at a site having a resonance frequency around 1 Hz
- you add a low frequency component within [0.1-0.2 Hz]



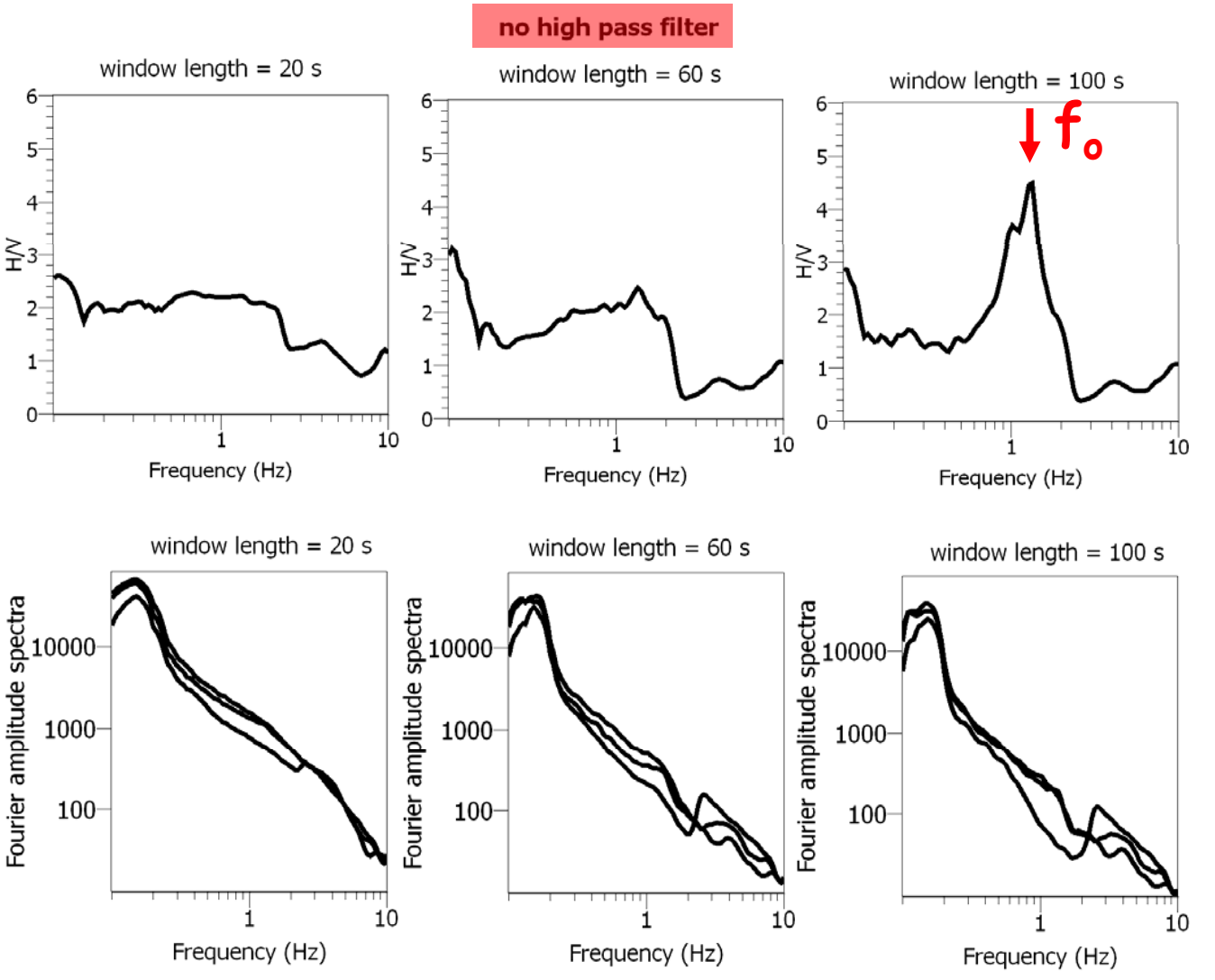
Low freq. content

+

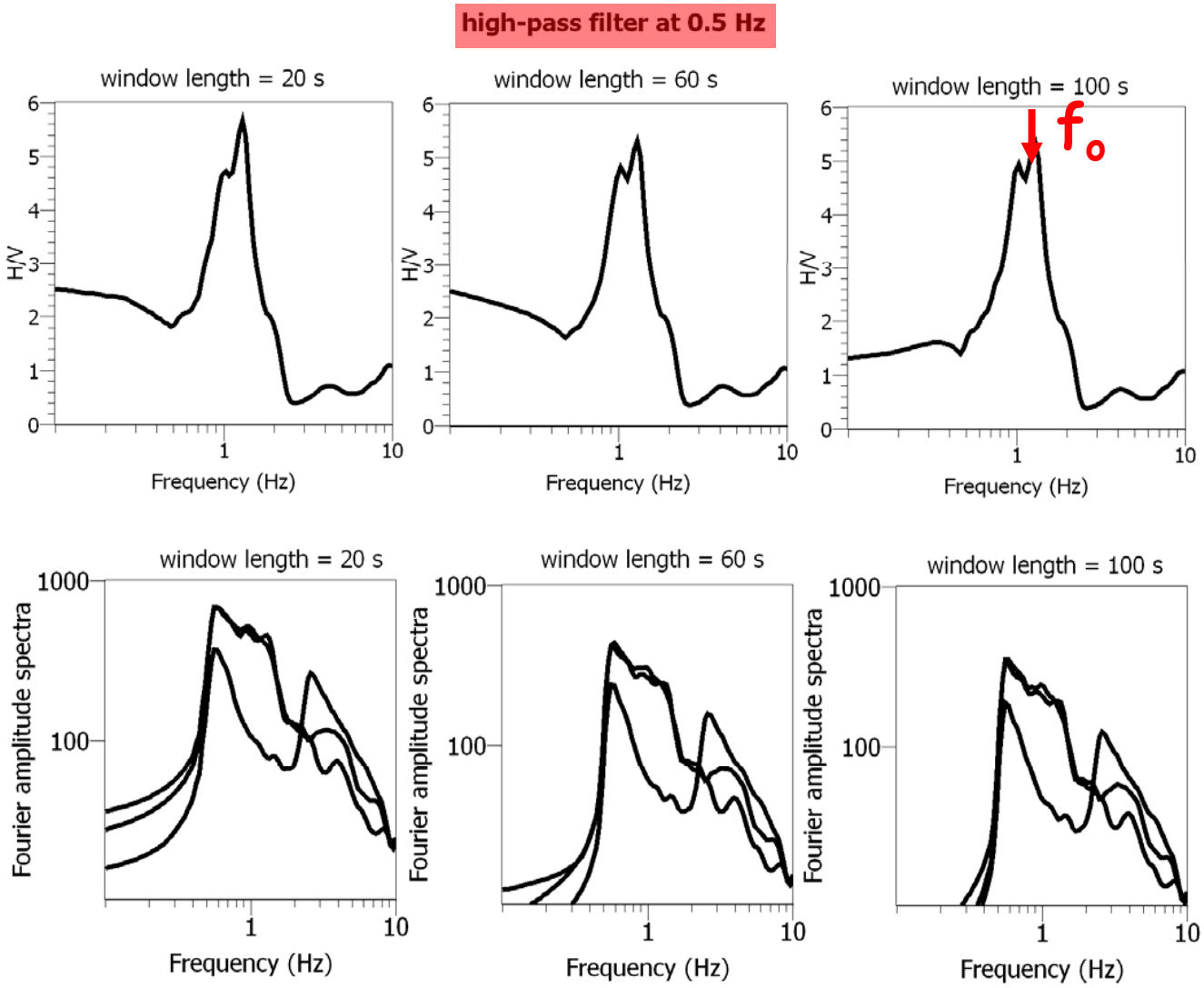
Broad band signal

Normally, with 10 sec. windows, you are able to define the peak

H/V COMPUTATION (taper effects)



H/V COMPUTATION (taper effects)



H/V COMPUTATION (Synthesis)

Signal

----------o----------

Windowing (STA/LTA, window length)

----------o----------

FFT + smoothing of each window of each component +NS-EW averaging

----------o----------

Computing of the H/V curve for each window

==> automatic computing of the main peak (f_0) on each H/V curve (window)

==> error on H/V main peak (f_0) defined in automatic peaking way

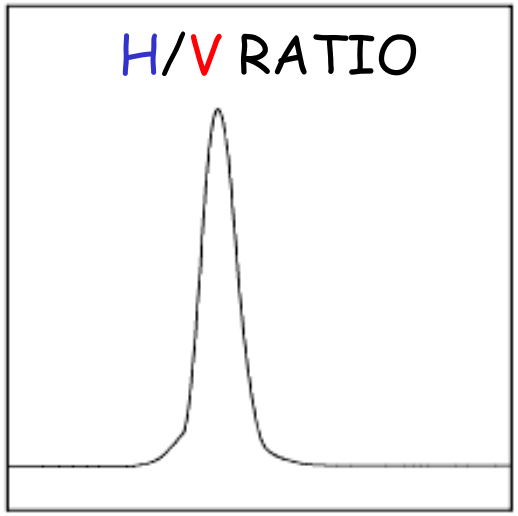
----------o----------

Computing the averaged H/V curve

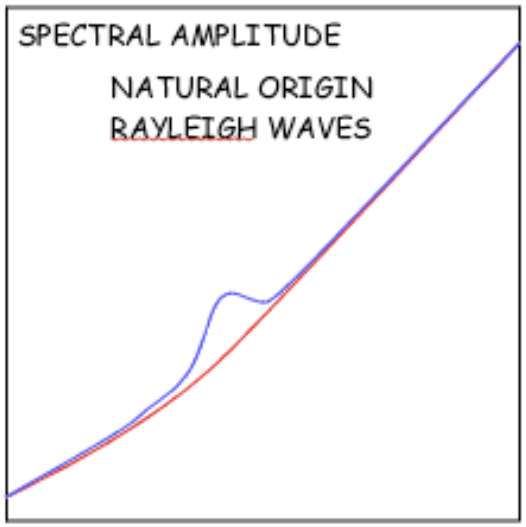
==> averaged H/V curve

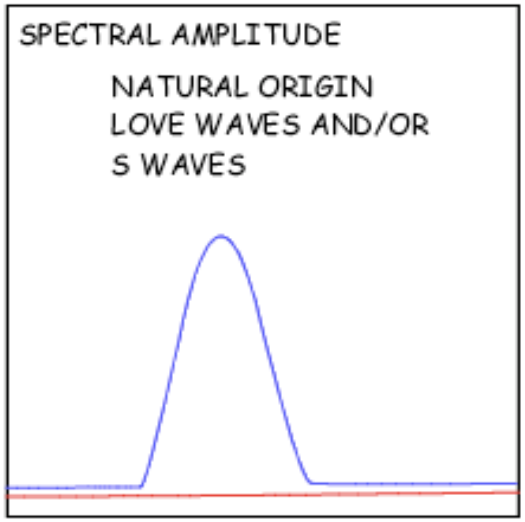
==>computing of the standard deviation

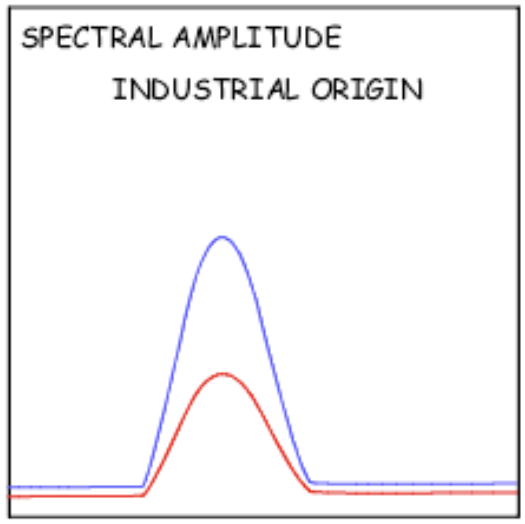
Some keys for H/V interpretation
The probable peak origin ?



Following the spectral amplitude shape, you can define an origin for your peak at least the more probable origin.



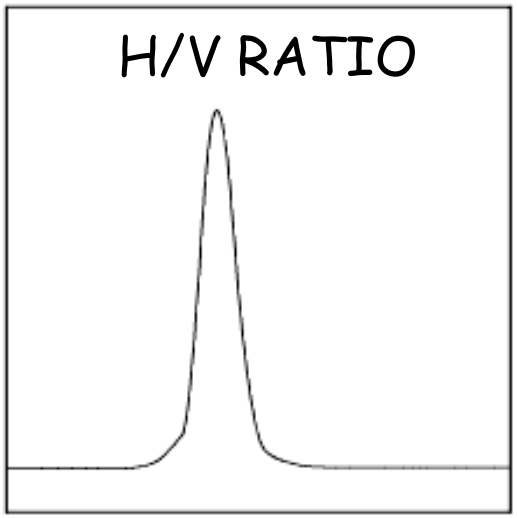




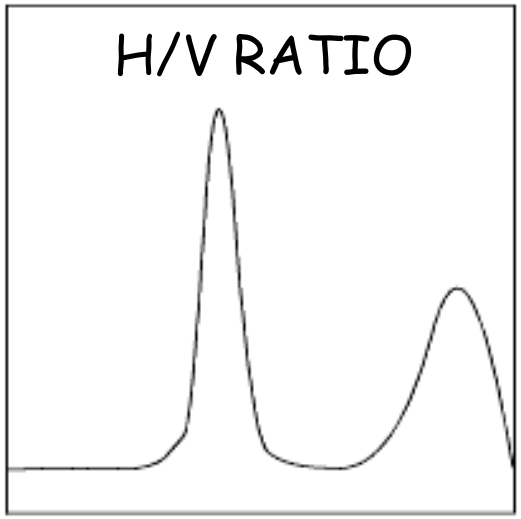
Some keys for H/V interpretation
The structure beneath ?

Following the H/V curve shape, you can « evaluate »
the structure beneath your measurement.

Simple and unique
1D structure with
only one interface



Simple and multiple
1D structure with
various interfaces



Some keys for H/V interpretation
The structure beneath ?

Following the H/V curve shape, you can « evaluate »
the structure beneath your measurement.

Complexe:
2-3D structure with
at least one interface