

Relation between array response and array analysis

Tutorial

Relation between array response and array analysis

1. Relation between array response and FK estimates
 - ⇒ Introduction to *fk* tool
 - ⇒ Introduction to *build_array* tool

2. FK computation
 - ⇒ Input parameters
 - ⇒ *fk* gridding
 - ⇒ Post-processing (use of *max2curve* tool)



figue
figures

gp tools
*Dispersion curves
Ellipticity curves
Autocorr. Curves
...*

Post-processing

max2curve **spac2disp**

DINVER
inversion

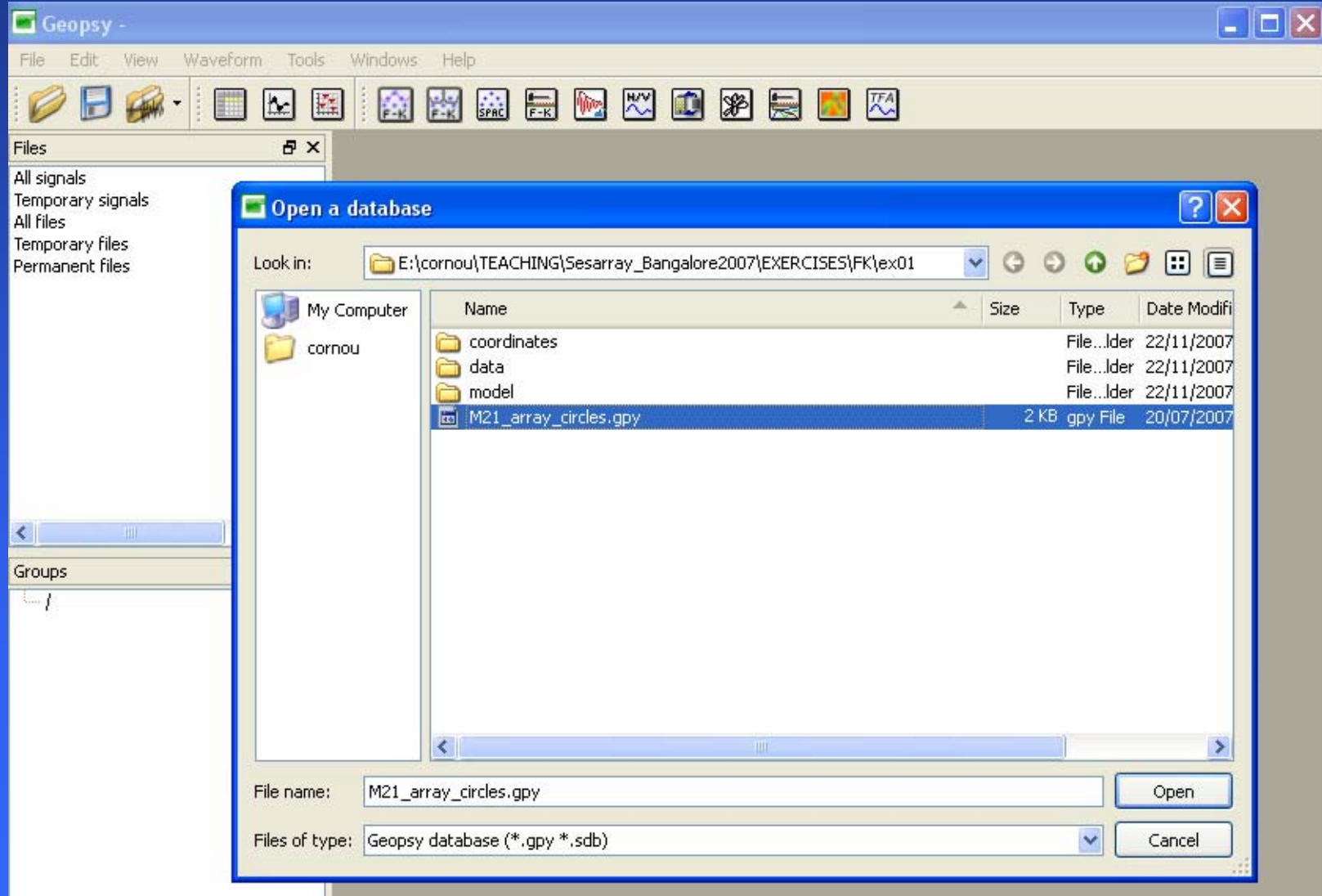
build_array
Array response

- (1) You will be given the processing parameters
- (2) we will see the link between the observed phase velocities estimates and the array response for different array size
- (3) We will then provide quantitative criteria for choosing the processing parameters which are related to the array layout
- (4) We will show you how to use the post processing tools for improving phase velocity estimates

Using Ambient Vibration Array Techniques for Site Characterisation

Loading geopsy database

~/data/EXERCISES_FK/EX01/.**



Geopsy -

File Edit View Waveform Tools Windows Help

Files

- All signals
- Temporary signals
- All files
- Temporary files
- Permanent files

Open a database

Look in: E:\cornou\TEACHING\Sesarray_Bangalore2007\EXERCISES\FK\ex01

Name	Size	Type	Date Modifi
coordinates		File...lder	22/11/2007
data		File...lder	22/11/2007
model		File...lder	22/11/2007
M21_array_circles.gpy	2 KB	gpy File	20/07/2007

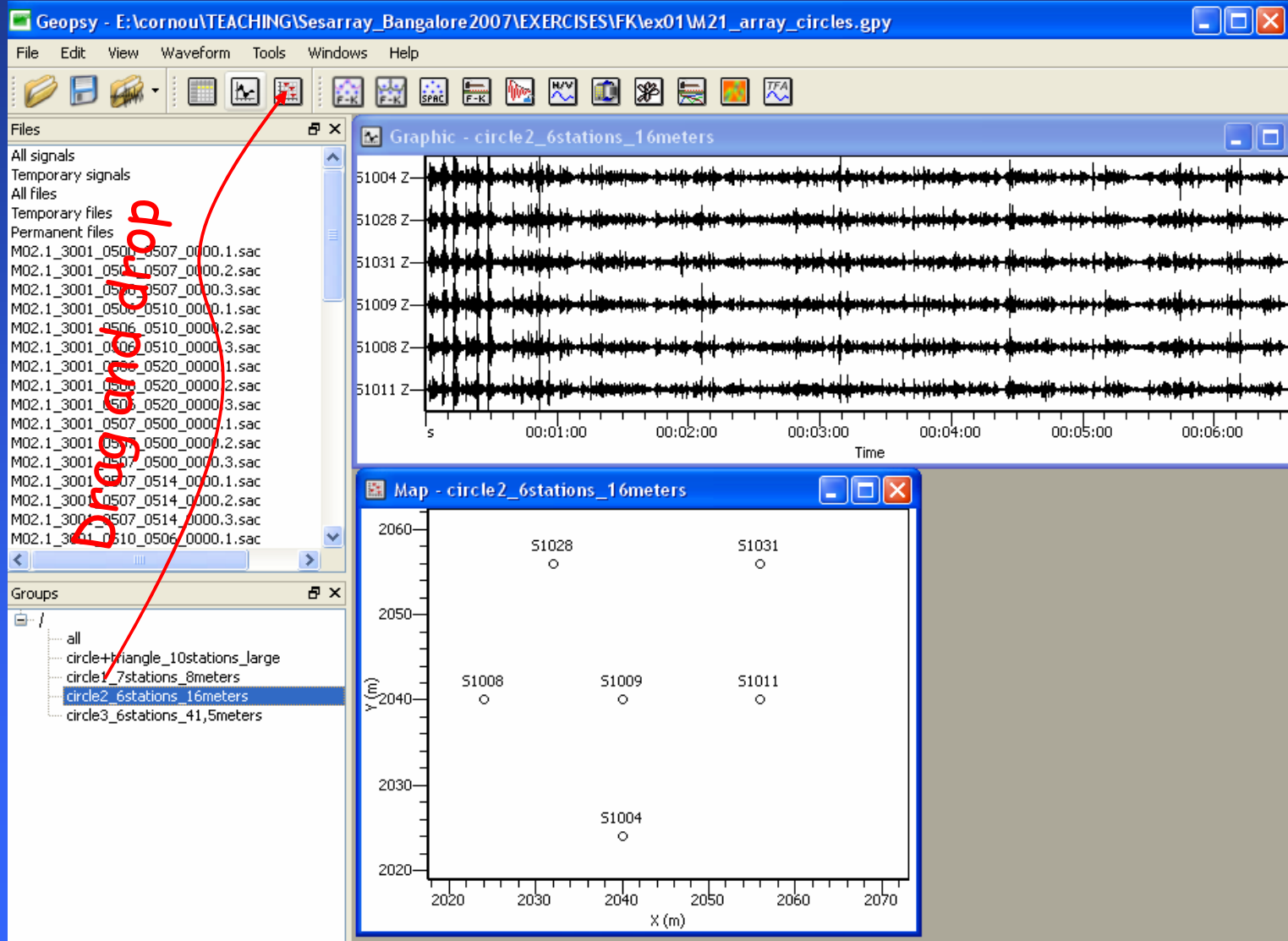
File name: M21_array_circles.gpy

Files of type: Geopsy database (*.gpy *.sdb)

Open Cancel

Using Ambient Vibration Array Techniques for Site Characterisation

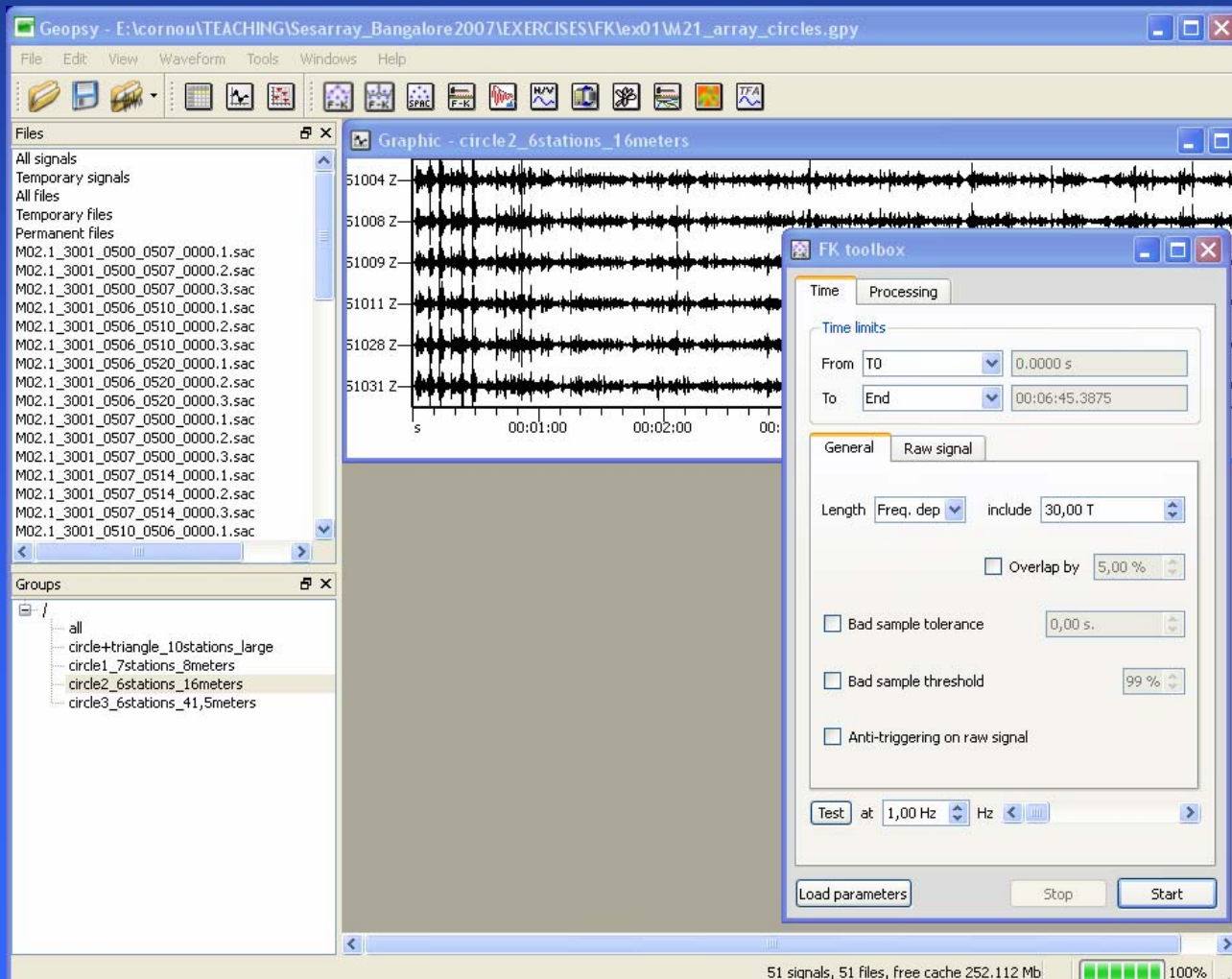
Display signals and array layout



Using Ambient Vibration Array Techniques for Site Characterisation

- Activate signals graphic of group *circle2_6stations_16meters*
- Launch the fk tool
- Set time parameters (limits, window length)

Window length=30T



The screenshot shows the Geopsy software interface. The main window displays a graphic of seismic signals for the group *circle2_6stations_16meters*. The signals are stacked vertically, with time markers on the left (51004 Z, 51008 Z, 51009 Z, 51011 Z, 51028 Z, 51031 Z) and a time axis at the bottom (00:01:00, 00:02:00). The **FK toolbox** is open, showing the **Time** tab. The **Time limits** section is set to **From TO** (0.0000 s) and **To End** (00:06:45.3875). The **General** tab is selected, showing the **Raw signal** section. The **Length** is set to **Freq. dep** include **30,00 T**. Other options include **Overlap by 5,00 %**, **Bad sample tolerance 0,00 s**, **Bad sample threshold 99 %**, and **Anti-triggering on raw signal** (unchecked). The **Test** section is set to **at 1,00 Hz**. The **Load parameters**, **Stop**, and **Start** buttons are visible at the bottom of the toolbox. The status bar at the bottom indicates **51 signals, 51 files, free cache 252.112 Mb** and **100%** processing.

Using Ambient Vibration Array Techniques for Site Characterisation

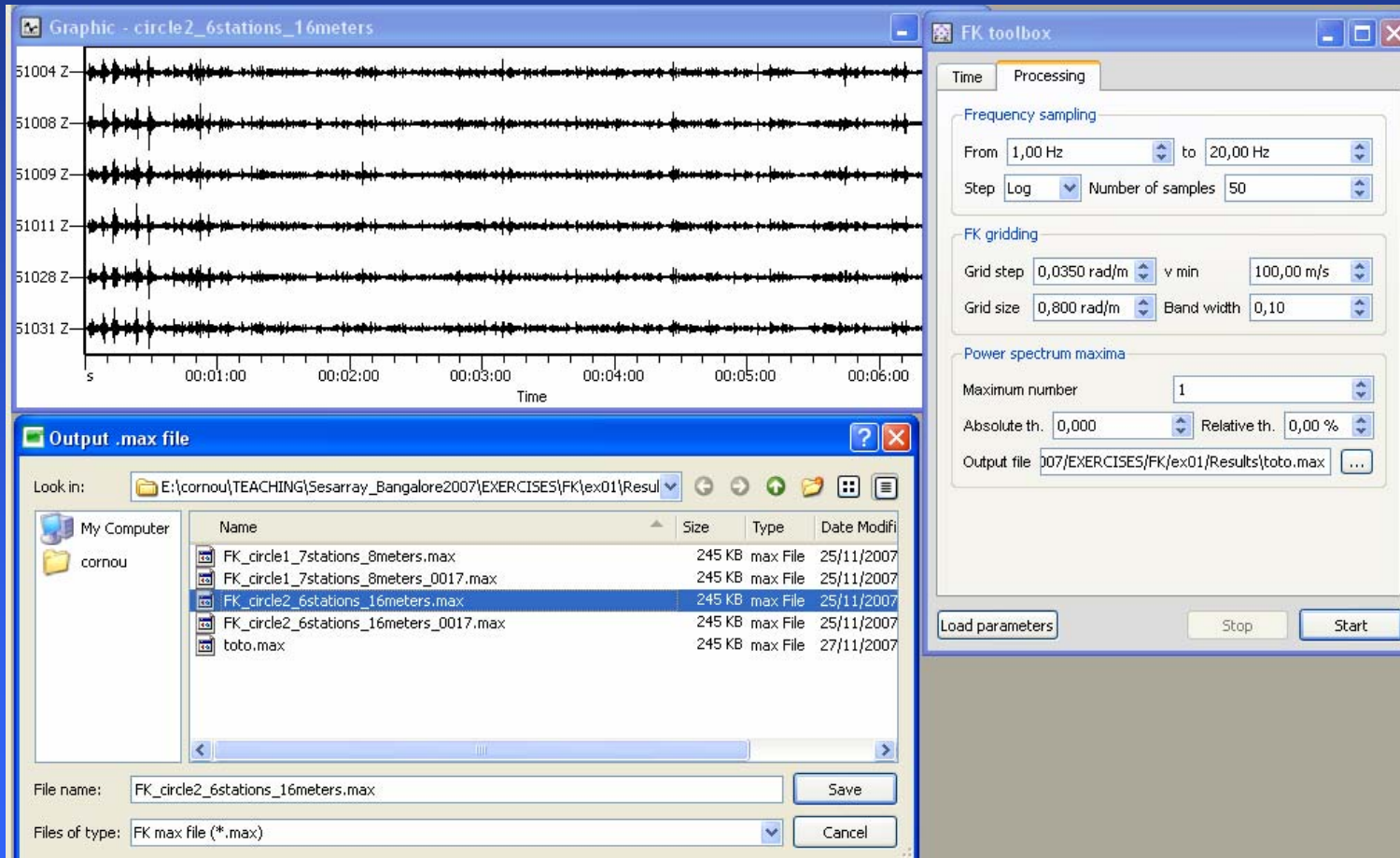
- Set processing parameters
- Set name of output file (.max extension)

$F_{min}=1$ Hz
 $F_{max}=20$ Hz
 Nb samples = 50

Grid_step=
 0.035 rad/m

Grid_size=
 0.8 rad/m

$V_{min}=100$ m/s



Graphic - circle2_6stations_16meters

51004 Z
 51008 Z
 51009 Z
 51011 Z
 51028 Z
 51031 Z

s 00:01:00 00:02:00 00:03:00 00:04:00 00:05:00 00:06:00

Time

FK toolbox

Time Processing

Frequency sampling

From 1,00 Hz to 20,00 Hz

Step Log Number of samples 50

FK gridding

Grid step 0,0350 rad/m v min 100,00 m/s

Grid size 0,800 rad/m Band width 0,10

Power spectrum maxima

Maximum number 1

Absolute th. 0,000 Relative th. 0,00 %

Output file 007/EXERCISES/FK/ex01/Results/toto.max

Load parameters Stop Start

Output .max file

Look in: E:\cornou\TEACHING\Sesarray_Bangalore2007\EXERCISES\FK\ex01\Resul

Name	Size	Type	Date Modifi
FK_circle1_7stations_8meters.max	245 KB	max File	25/11/2007
FK_circle1_7stations_8meters_0017.max	245 KB	max File	25/11/2007
FK_circle2_6stations_16meters.max	245 KB	max File	25/11/2007
FK_circle2_6stations_16meters_0017.max	245 KB	max File	25/11/2007
toto.max	245 KB	max File	27/11/2007

File name: FK_circle2_6stations_16meters.max Save

Files of type: FK max file (*.max) Cancel

Using Ambient Vibration Array Techniques for Site Characterisation

Geopsy - E:\cornou\TEACHING\Sesarray_Bangalore2007\EXERCISES\FK\ex01\W21_array_circles.gpy

File Edit View Waveform Tools Window

Files

Graphic - circle2

Time Window browser

FK toolbox

Time Processing

Time limits

From TO 0.0000 s

To End 00:06:45.3875

General Raw signal

Length Freq. dep include 30,00 T

Overlap by 5,00 %

Bad sample tolerance 0,00 s

Bad sample threshold 99 %

Anti-triggering on raw signal

Test at 4,08 Hz Hz

Load parameters Stop Start

51004 Z

51008 Z

51009 Z

51011 Z

51028 Z

51031 Z

00:01:50 00:02:00

Wave number Y (rad/m)

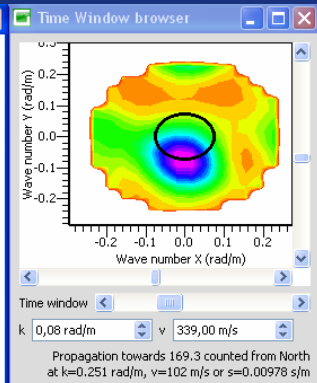
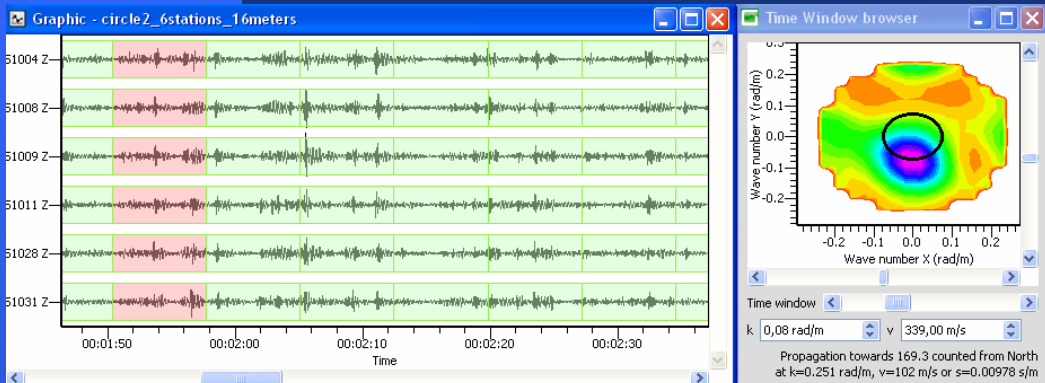
Wave number X (rad/m)

Time window

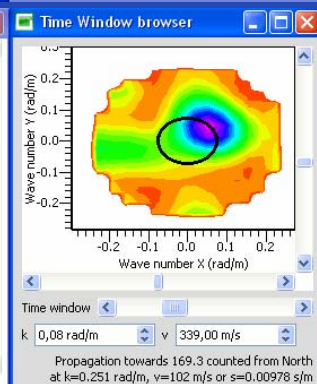
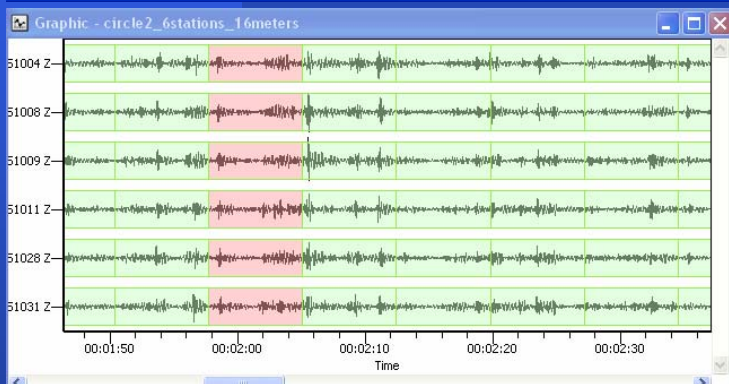
k 0,08 rad/m v 339,00 m/s

Propagation towards 326.7 counted from North
at k=0.336 rad/m, v=76 m/s or s=0.0131 s/m

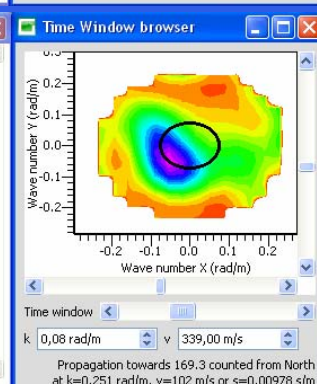
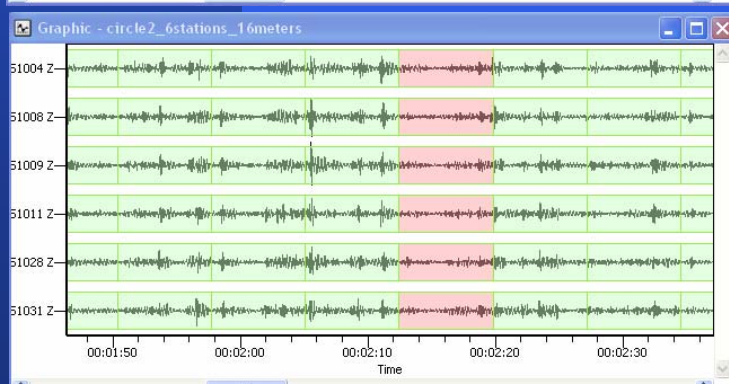
Browse FK results for all frequency bands and time windows ('Test' button)



The FK time windows browser allows to provide information on the noise wave field structure.



In this example, the azimuth of the most energetic arrivals is varying from time to time: noise sources are thus spatially randomly distributed.



Directionality of noise sources can be useful/necessary when interpreting dispersion curve estimates.

FK results: output .max and .log files

```
MINGW32:/e/cornou/TEACHING/Sesarray_Bangalore2007/EXERCISES/FK...
cornou@LGIT-1229 /e/cornou/TEACHING/Sesarray_Bangalore2007/EXERCISES/FK/ex01/Results
$ ls FK_circle2_6stations_16meters.*
FK_circle2_6stations_16meters.log
FK_circle2_6stations_16meters.max
```

```
MINGW32:/e/cornou/TEACHING/Sesarray_Bangalore2007/EXERCISES/FK...
cornou@LGIT-1229 /e/cornou/TEACHING/Sesarray_Bangalore2007/EXERCISES/FK/ex01/Results
$ less FK_circle2_6stations_16meters.max
```

```
TEACHING/Sesarray_Bangalore2007/EXERCISES/FK/ex...
6689 center 10.8521 upper 11.9373
3826 center 11.5363 upper 12.6899
0372 center 12.2636 upper 13.4899
7331 center 13.0367 upper 14.3404
4728 center 13.8586 upper 15.2445
2591 center 14.7323 upper 16.2056
095 center 15.6611 upper 17.2273
9836 center 16.6485 upper 18.3133
9283 center 17.6981 upper 19.4679
9325 center 18.8139 upper 20.6953
center 20 upper 22
```

```
# seconds from start | cfreq | slow | baz | math-phi | semblance | be
ampow
0 1 0.829805 16.467 73.533 0.720848 -57.6781
30.0125 1 0.959312 279.914 170.086 0.878759 -52.5059
60.025 1 2.72924 259.757 190.243 0.625953 -60.4831
90.0375 1 0.542245 326.81 123.19 0.888618 -58.2561
120.05 1 0.829619 36.809 53.191 0.649696 -63.9876
150.063 1 1.5958 156.292 293.708 0.758928 -60.1918
180.075 1 0.991335 9.17086 80.8291 0.821155 -62.6515
210.088 1 1.21758 65.1324 24.8676 0.766642 -59.5914
240.1 1 2.11548 324.673 125.327 0.894959 -59.1921
270.113 1 1.15502 13.7 76.3 0.65543 -61.9761
300.125 1 0.407093 160.9 289.1 0.94574 -56.3375
330.138 1 1.29649 228.905 221.095 0.8181 -60.3799
360.15 1 2.13867 358.877 91.1229 0.850065 -58.5761
0 1.06304 1.29124 158.759 291.241 0.602574 -59.2413
28.2275 1.06304 0.826952 260.886 189.114 0.943489 -51.0378
56.455 1.06304 9.99999 328.434 121.566 0.43589 -62.9523
84.6825 1.06304 0.303693 328.735 121.265 0.928455 -57.1999
112.91 1.06304 0.885679 26.2076 63.7924 0.890801 -59.149
141.138 1.06304 1.19067 191.331 258.669 0.77391 -65.3658
169.365 1.06304 1.30636 81.5274 8.4726 0.855961 -59.4472
197.593 1.06304 3.0173 126.63 323.37 0.779682 -59.9411
225.82 1.06304 1.92692 283.782 166.218 0.873034 -58.2451
:
```

The output columns are:

- start starting time (s)
- cfreq center frequency (Hz)
- slow slowness (s/m)
- Baz backazimuth (radian)
- math-phi azimuth (radian)
- array-out semblance
- array-out beampower

Using Ambient Vibration Array Techniques for Site Characterisation

```
MINGW32:/e/cornou/TEACHING/Sesarray_Bangalore2007/EXERCISES/FK...
cornou@LGIT-1229 /e/cornou/TEACHING/Sesarray_Bangalore2007/EXERCISES/FK/ex01/Results
$ less FK_circle2_6stations_16meters.log

MINGW32:/e/cornou/TEACHING/Sesarray_Bangalore2007/EXERCISES/FK/ex...
RAW LTA (s) = 30
RAW MIN SLTA = 0.2
RAW MAX SLTA = 2.5
MINIMUM FREQUENCY = 1
MAXIMUM FREQUENCY = 20
INVERSED FREQUENCY = n
SAMPLES NUMBER FREQUENCY = 50
SAMPLING TYPE FREQUENCY (0=log, 1=linear)= 0
FROM TIME TYPE = 1
FROM TIME TEXT = 0.0000 s
TO TIME TYPE = 1
TO TIME TEXT = 00:06:45.3875
MIN K = 0.035
MAX K = 0.8
MIN V = 100
FREQ BAND WIDTH = 0.1
N MAXIMA = 1
OUTPUT FILE = E:\cornou\TEACHING\Sesarray_Bangalore2007\EXERCISES\FK\ex01\Results\FK_circle2_6stations_16meters.max
### End Parameters ###
### Process Log ###
Frequency 1/50 1
Min Window length 30 seconds
Max Window length 30 seconds
13 Time windows
Frequency 2/50 1.06304
Min Window length 28.2208 seconds
Max Window length 28.2208 seconds
14 Time windows
Frequency 3/50 1.13006
Min Window length 26.5472 seconds
Max Window length 26.5472 seconds
15 Time windows
Frequency 4/50 1.20131
Min Window length 24.9727 seconds
:
```


Using Ambient Vibration Array Techniques for Site Characterisation

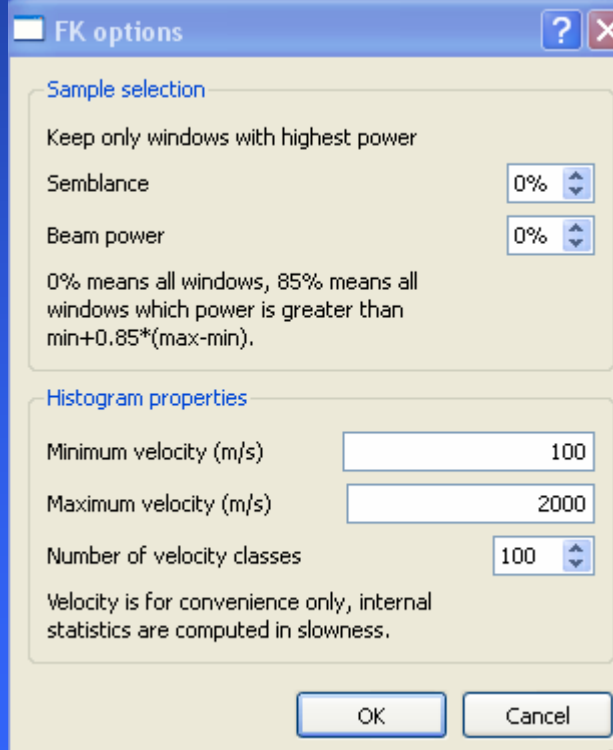
```

MINGW32:/e/cornou/TEACHING/Sesarray_Bangalore2007/EXERCISES/FK...
cornou@LGIT-1229 /e/cornou/TEACHING/Sesarray_Bangalore2007/EXERCISES/FK/ex01/Results
$ less FK_circle2_6stations_16meters.log

cornou@LGIT-1229 /e/cornou/TEACHING/Sesarray_Bangalore2007/EXERCISES/FK/ex01/Results
$ max2curve FK_circle2_6stations_16meters.max
Loading... : 2559
    
```

FK histograms: max2curve

Computed from semblance estimates



FK options

Sample selection

Keep only windows with highest power

Semblance: 0%

Beam power: 0%

0% means all windows, 85% means all windows which power is greater than $\min + 0.85 * (\max - \min)$.

Histogram properties

Minimum velocity (m/s): 100

Maximum velocity (m/s): 2000

Number of velocity classes: 100

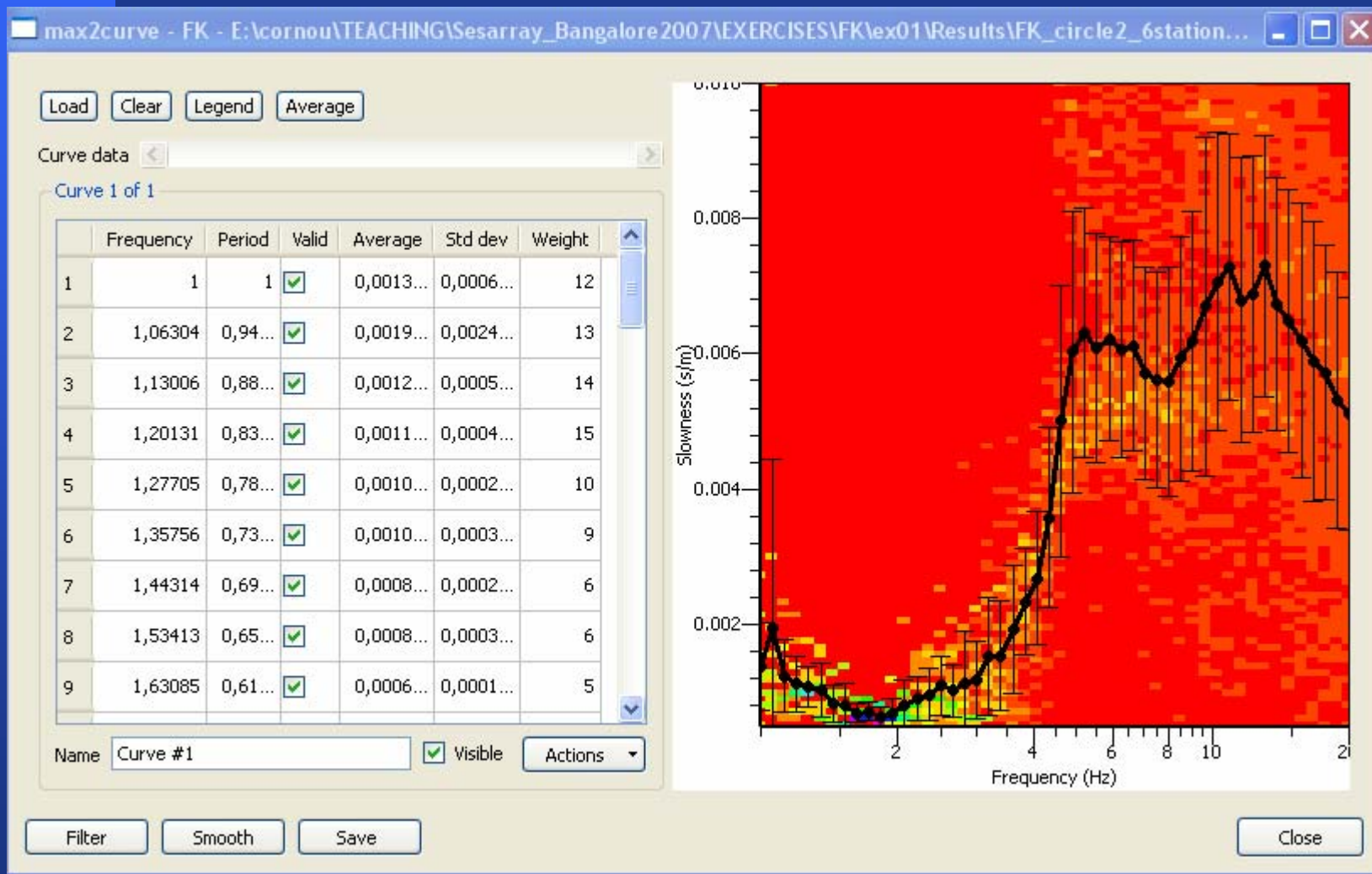
Velocity is for convenience only, internal statistics are computed in slowness.

OK Cancel

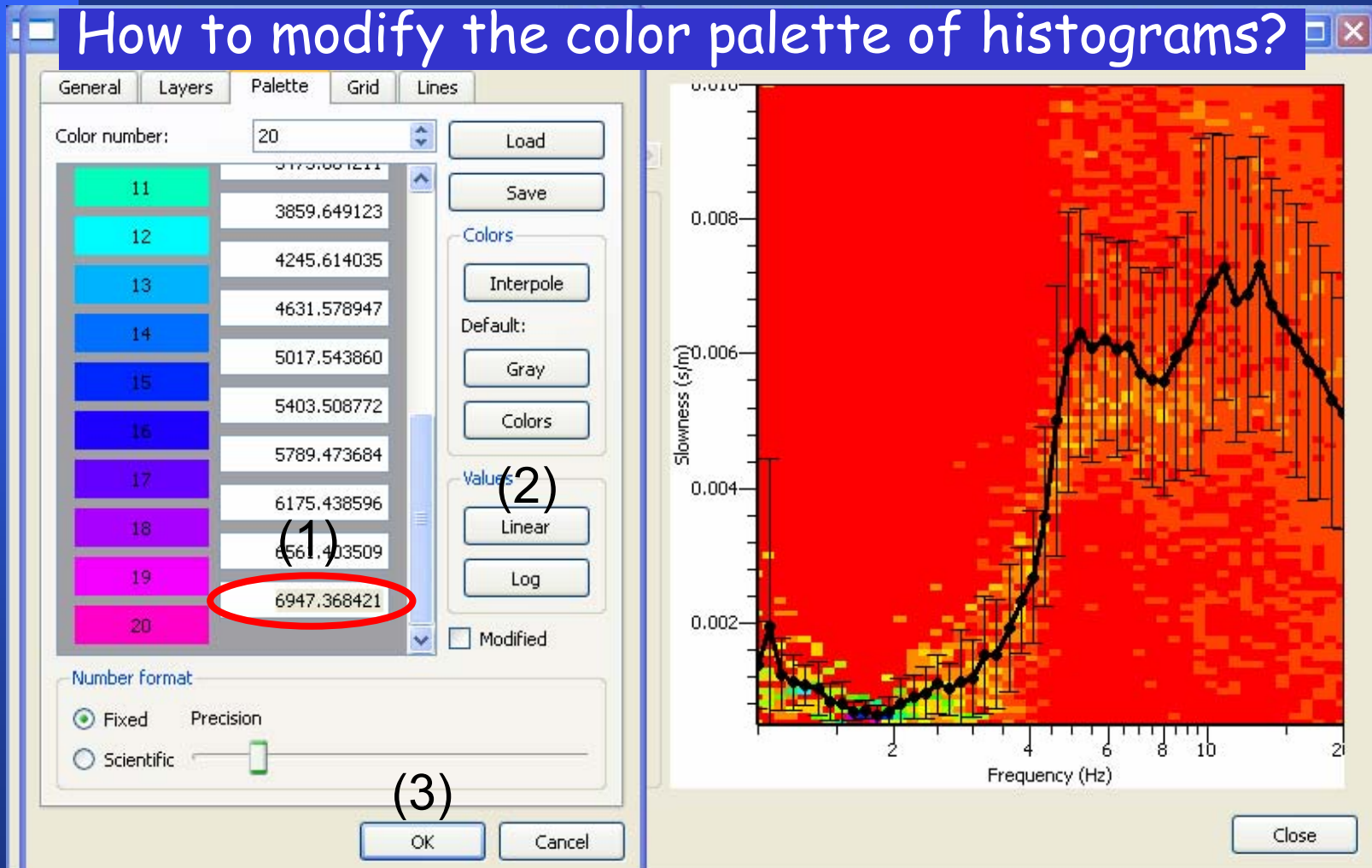
Computed from beampower estimates

Histograms computed within this velocity range

Number of slowness (velocity) cells within $[V_{\min} V_{\max}]$.



How to modify the color palette of histograms?



Color number: 20

11	3173.001211
12	3859.649123
13	4245.614035
14	4631.578947
15	5017.543860
16	5403.508772
17	5789.473684
18	6175.438596
19	6561.403509
20	6947.368421

Colors: Interpolate, Default, Gray, Colors

Values: Linear, Log

Number format: Fixed, Scientific

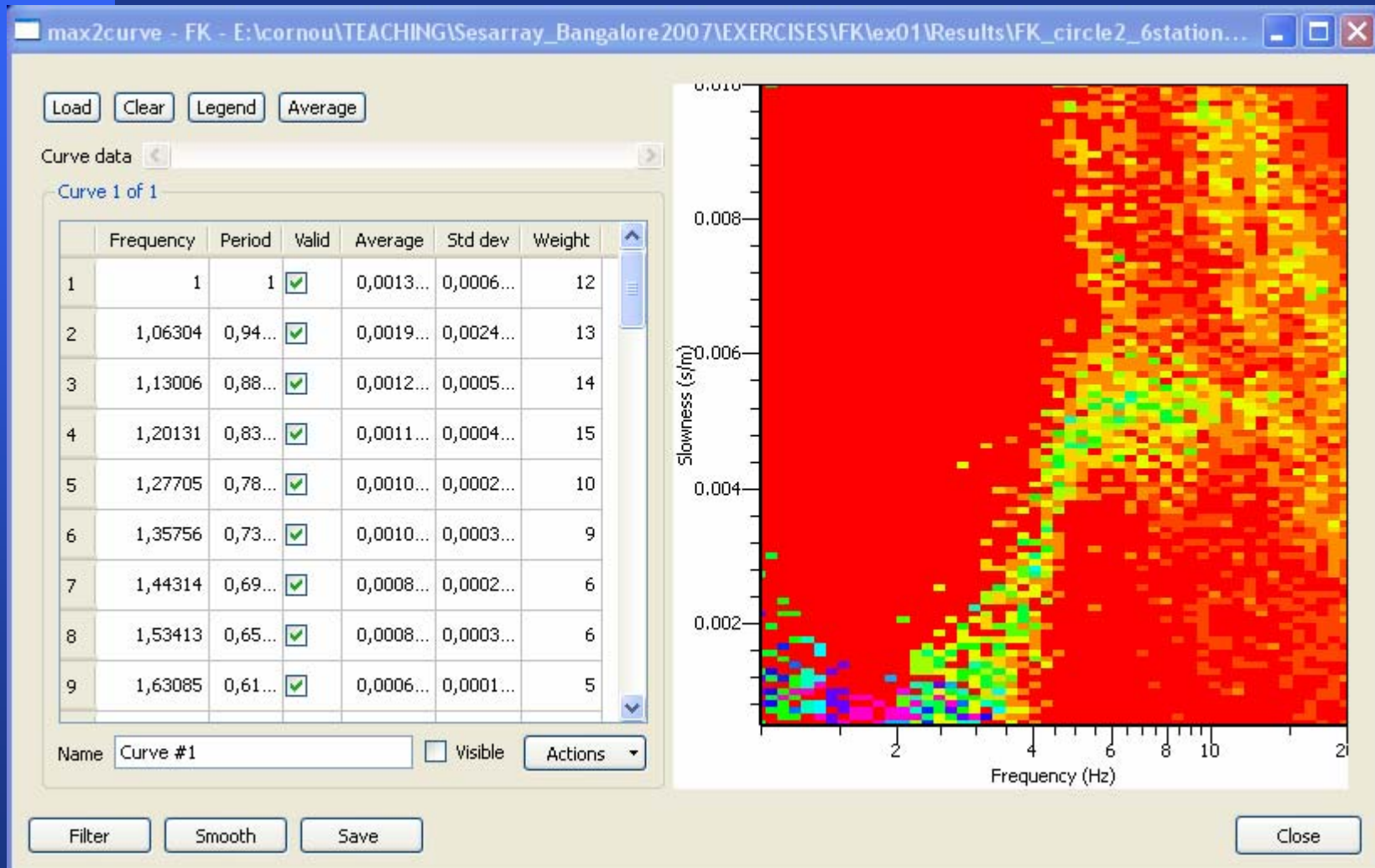
OK Cancel

Close

- (1) Change the maximum value of the palette
- (2) press on linear to adjust the color scale from the first to the last color number
- (3) press on OK

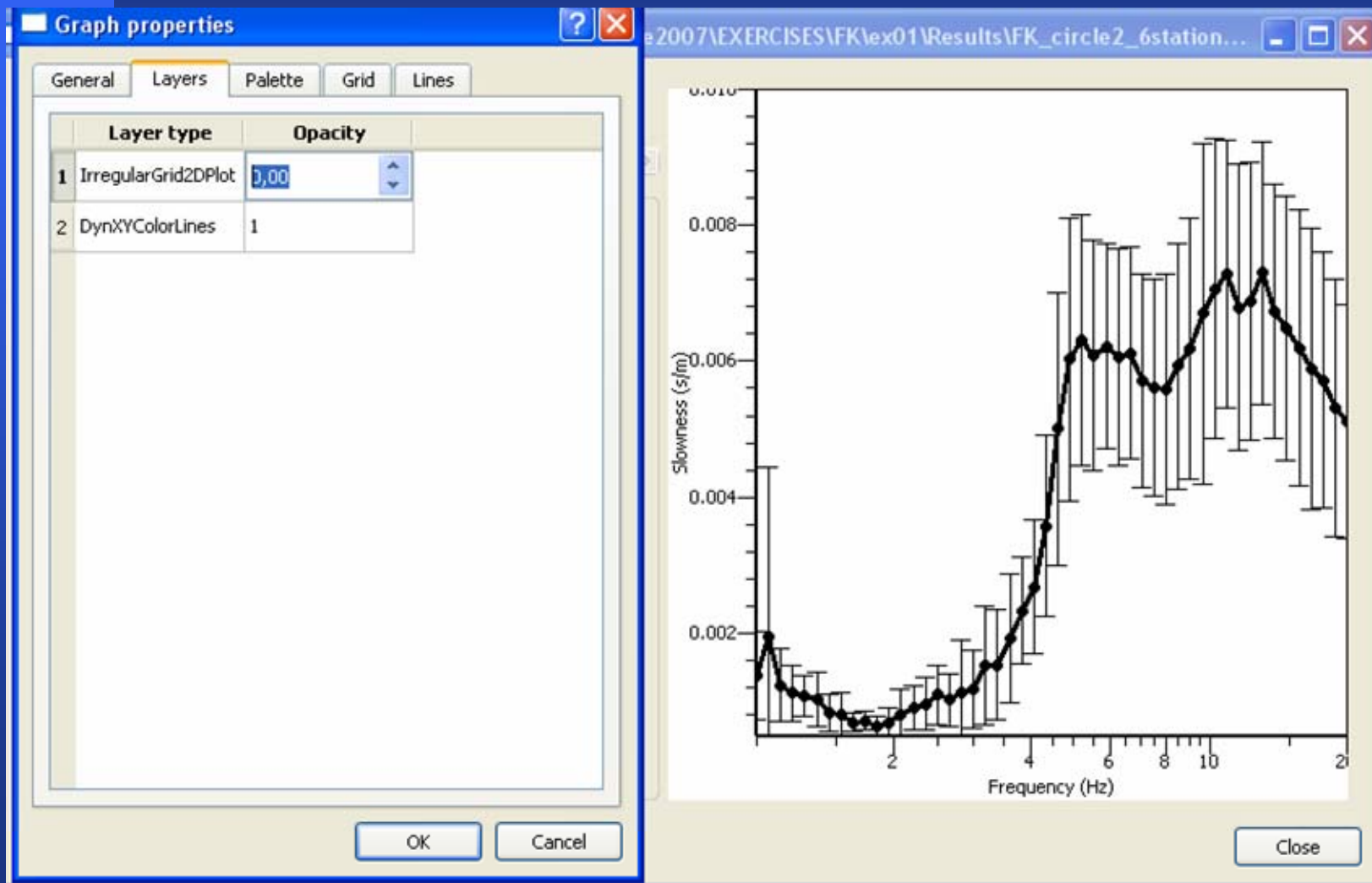
Using Ambient Vibration Array Techniques for Site Characterisation

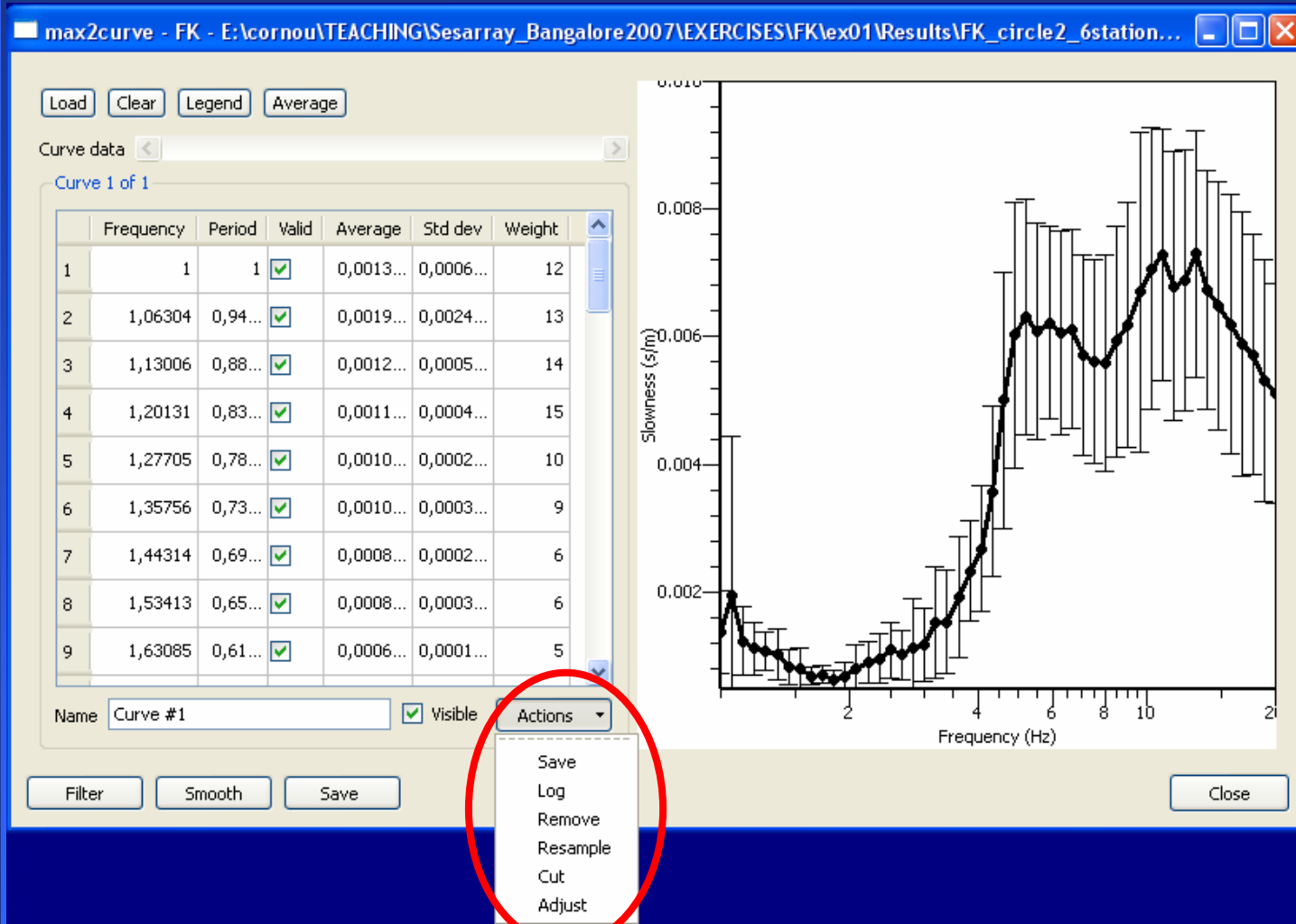
How to hide mean curve ?



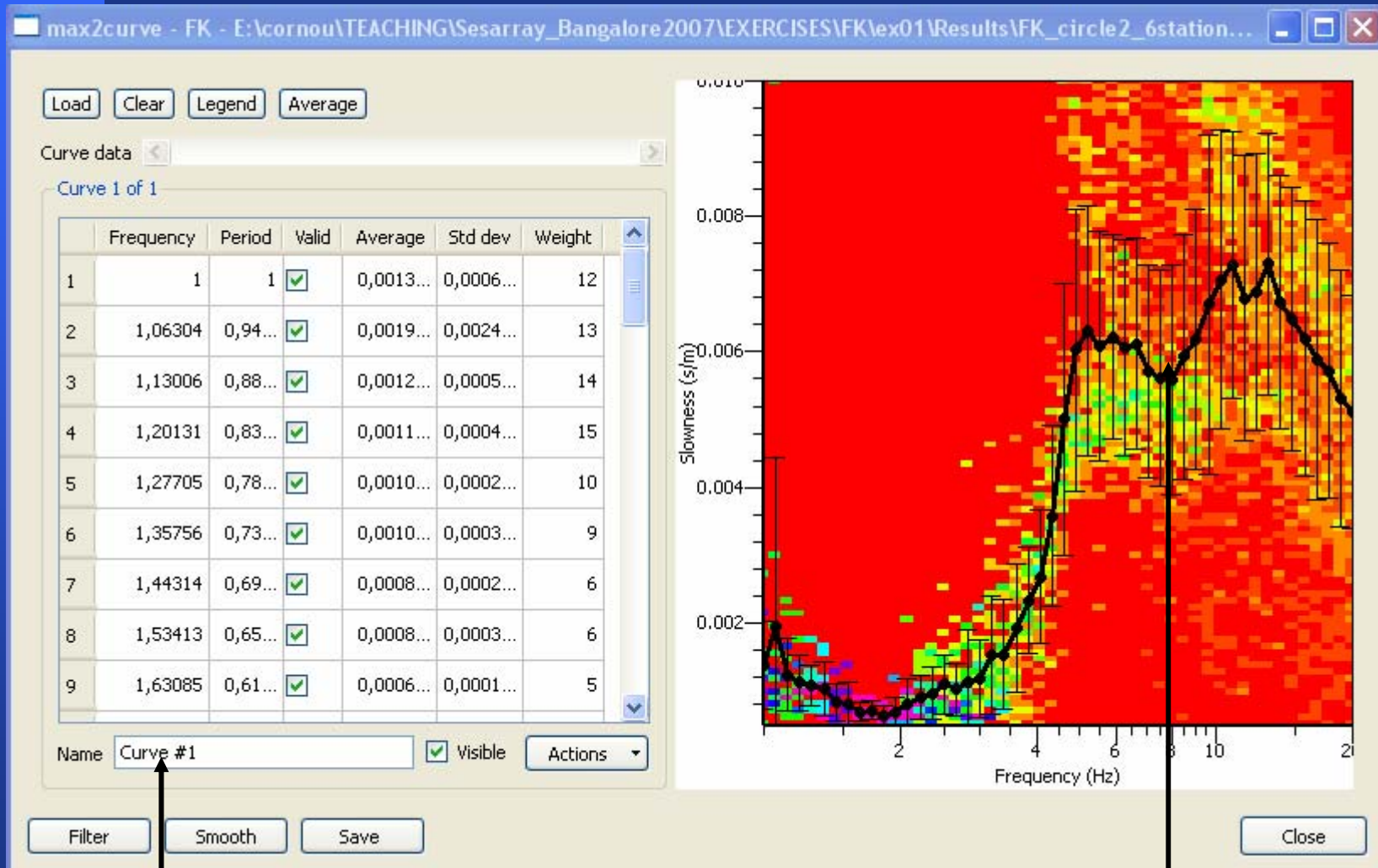
Using Ambient Vibration Array Techniques for Site Characterisation

How to hide histograms ?





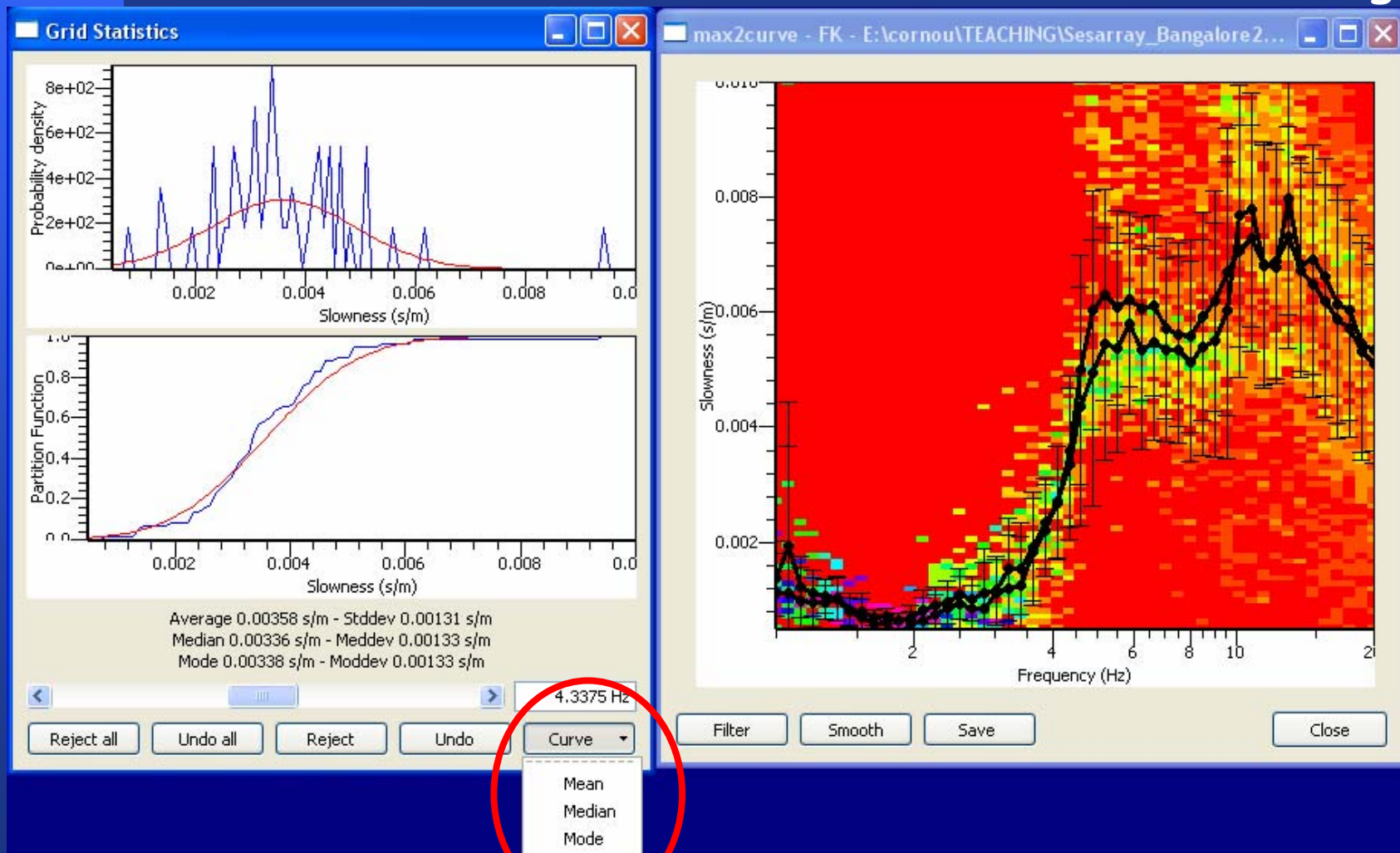
Actions button for curves: save / remove / resample / cut / adjust
Note: applies to selected curve only (there may be more than one!)



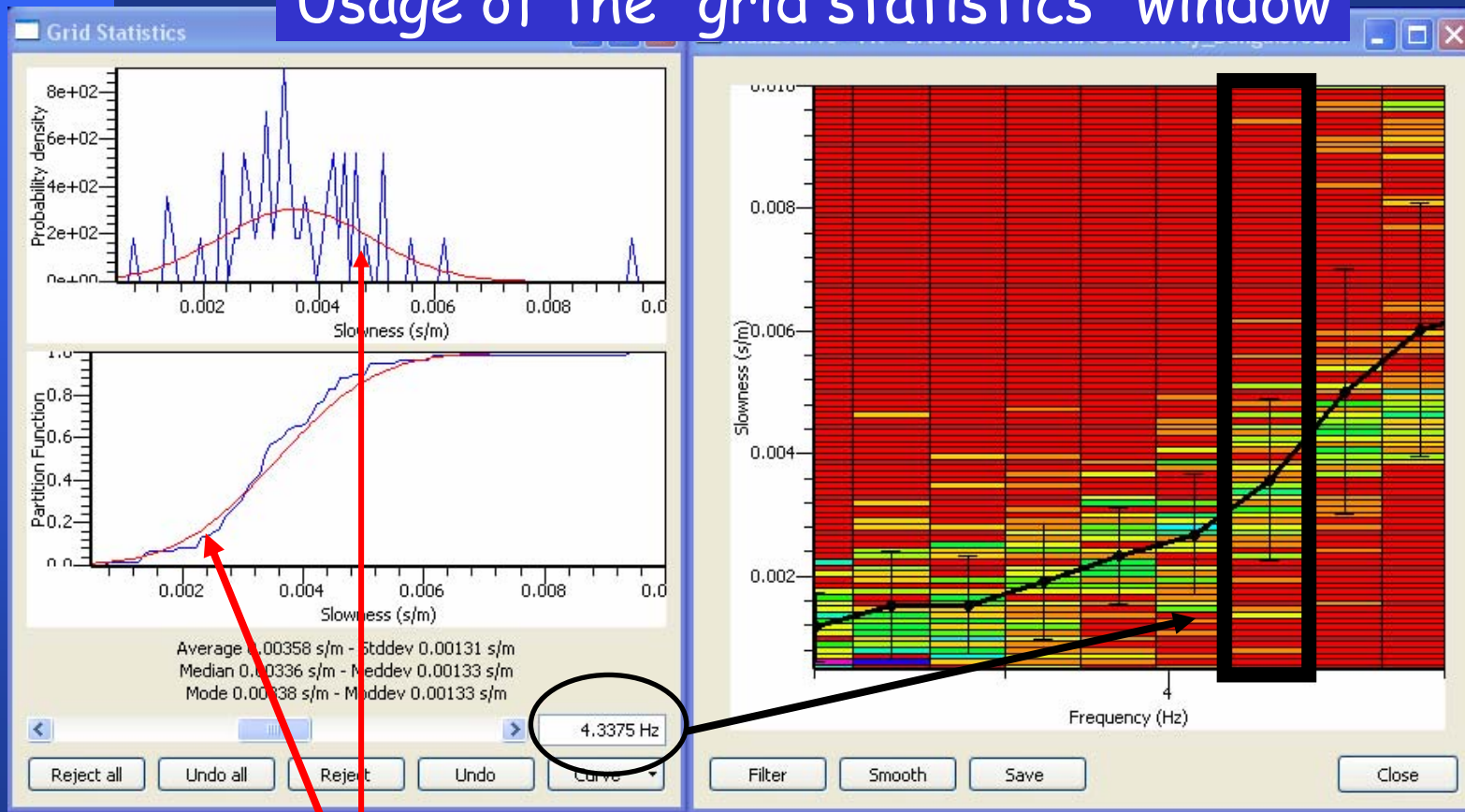
Curve identification (number/name)

Mean +/- std (by default)

How to re-calculate mean/median or mode after editing?



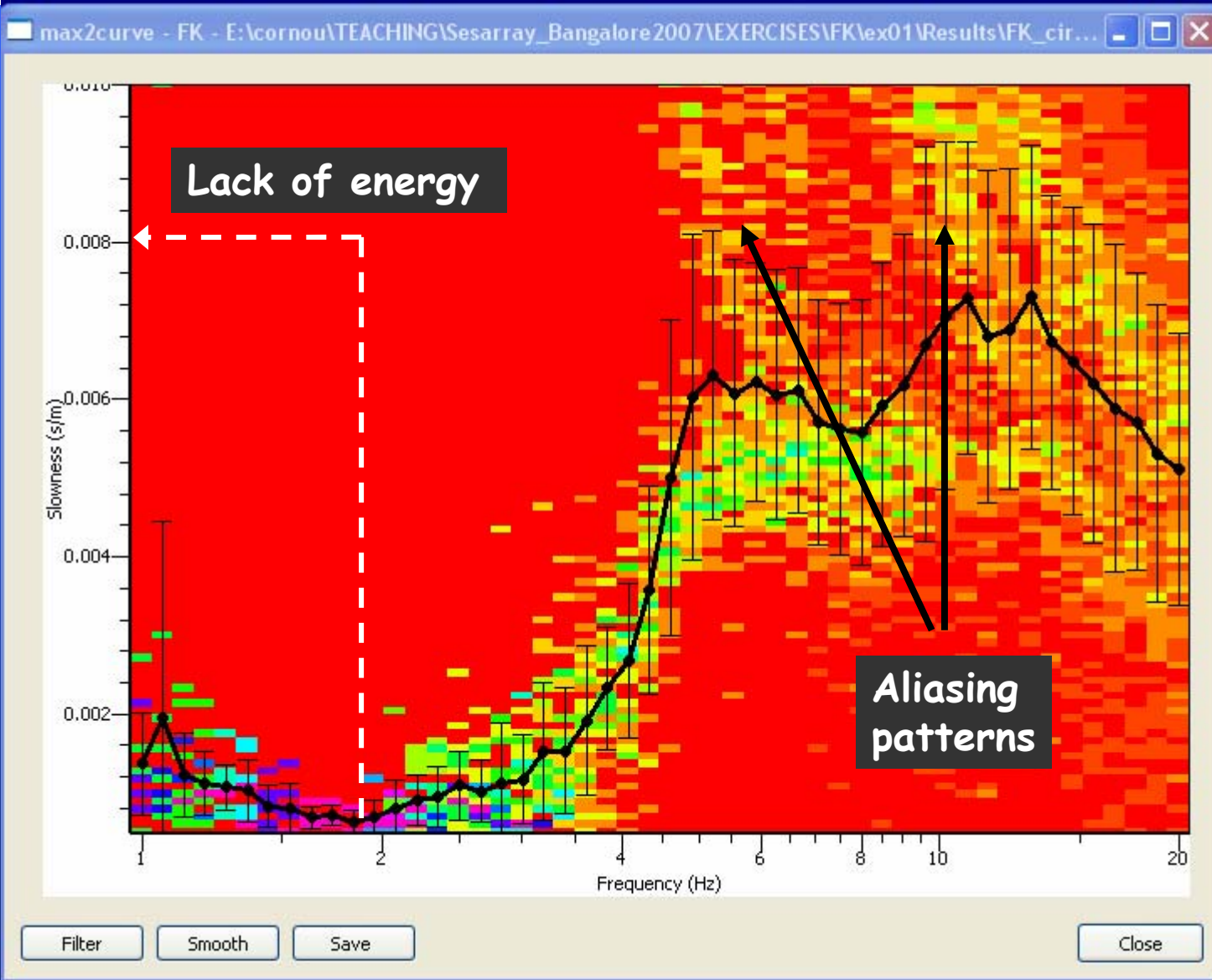
Usage of the "grid statistics" window

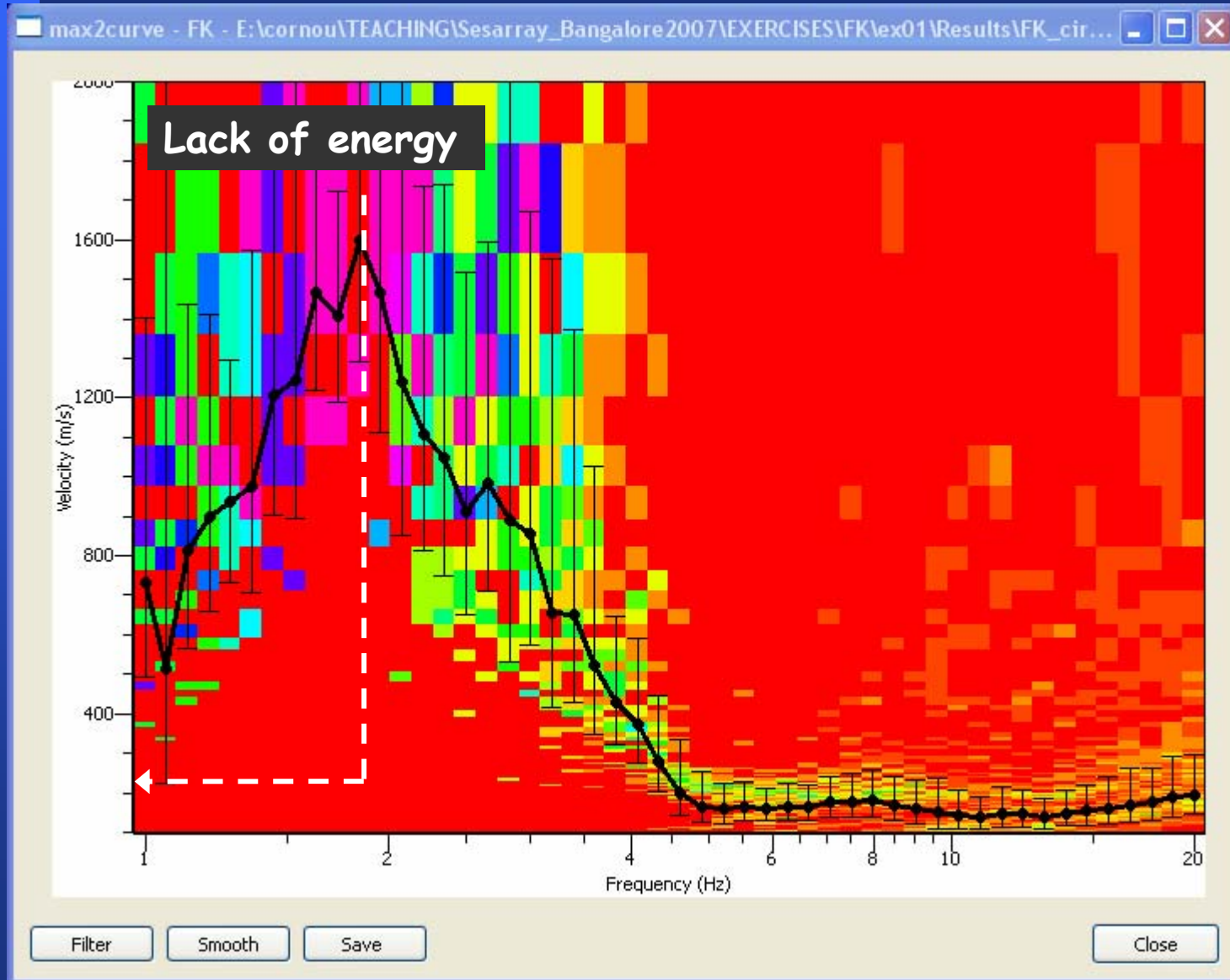


Gaussian distribution computed from the observed mean and standard deviation

The grid statistics toolbox can be used for 'cleaning' the histograms from outliers. Also useful for separating individual modes.

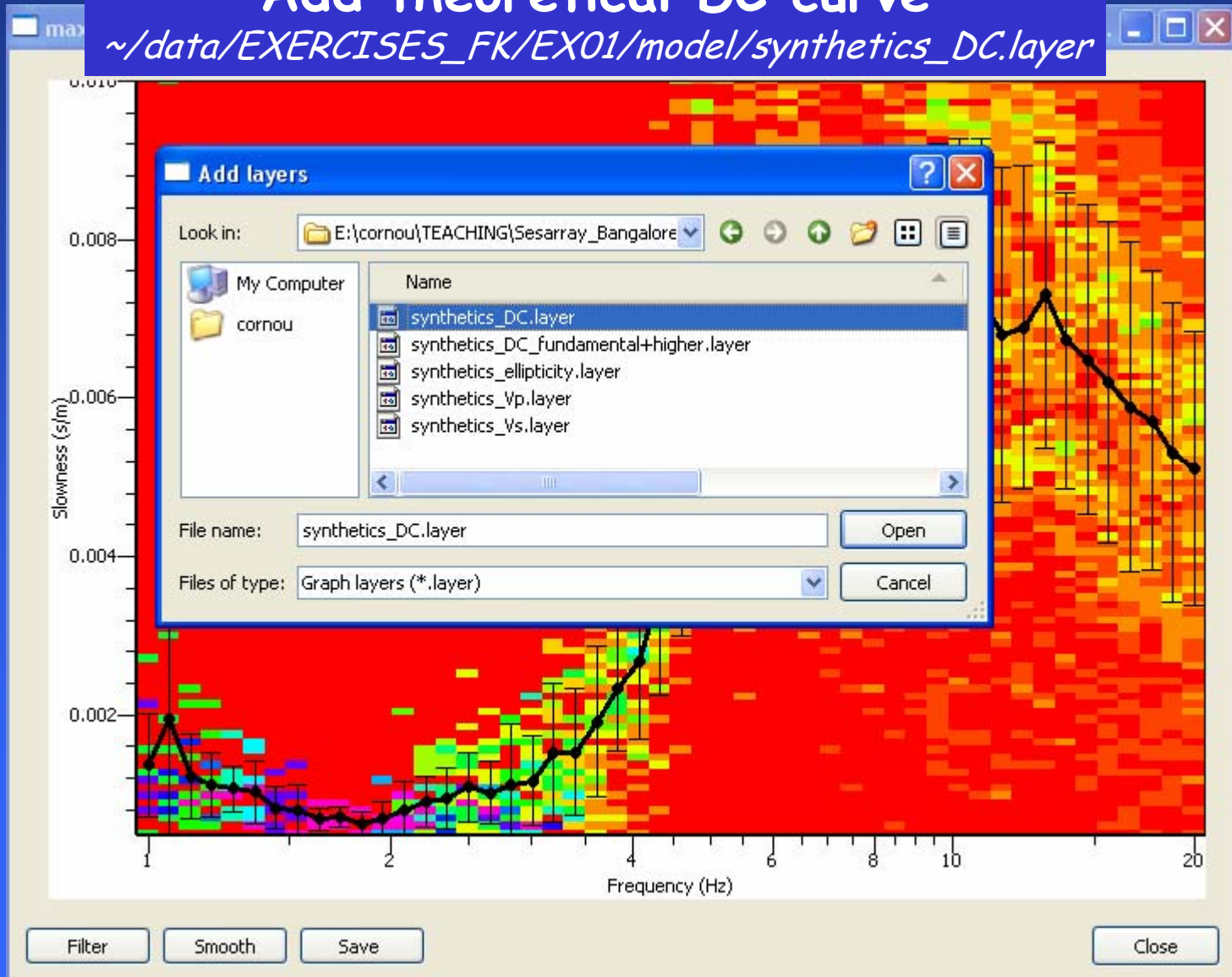
Using Ambient Vibration Array Techniques Interpretation of FK Histograms for Site Characterisation

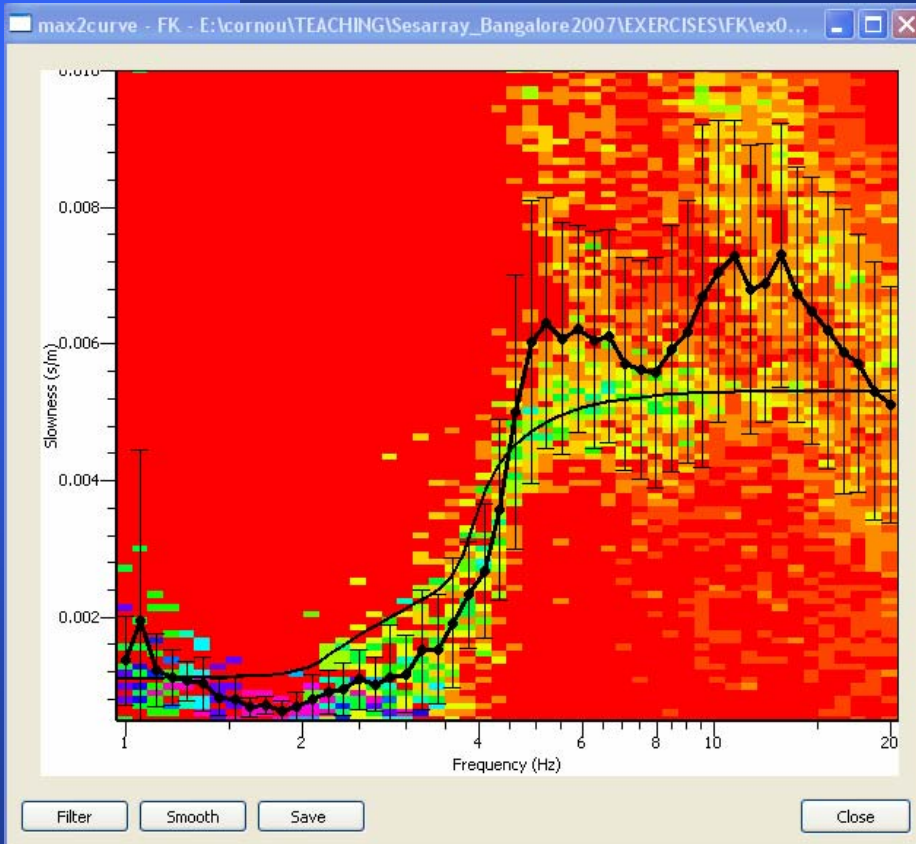




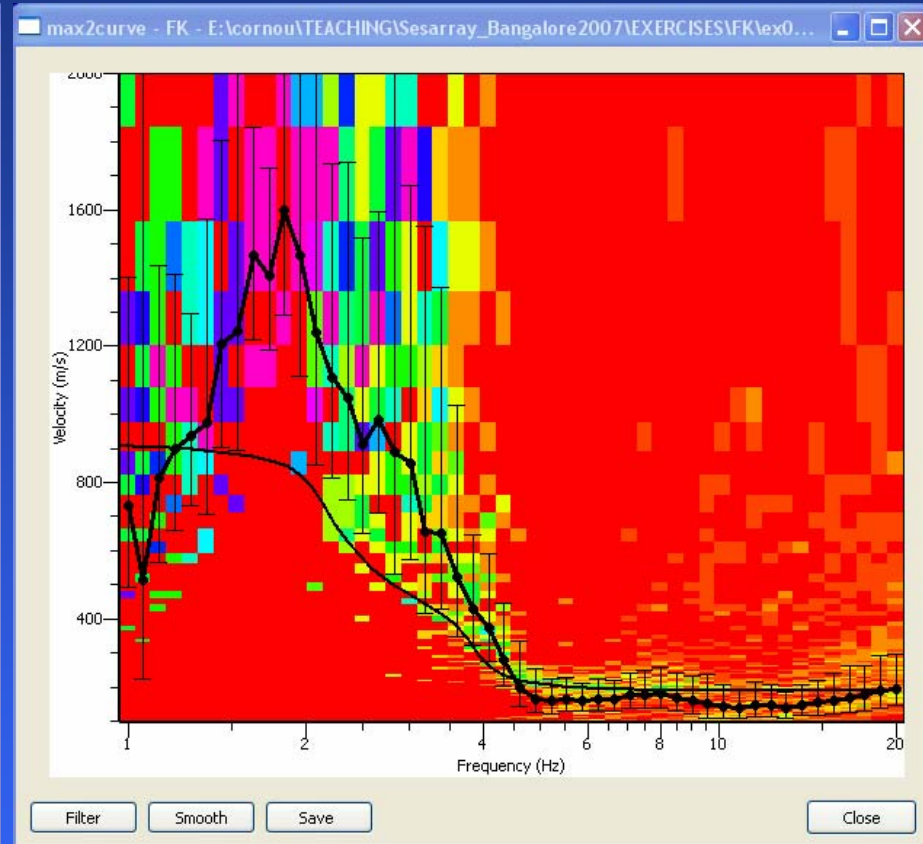
Add theoretical DC curve

~/data/EXERCISES_FK/EX01/model/synthetics_DC.layer



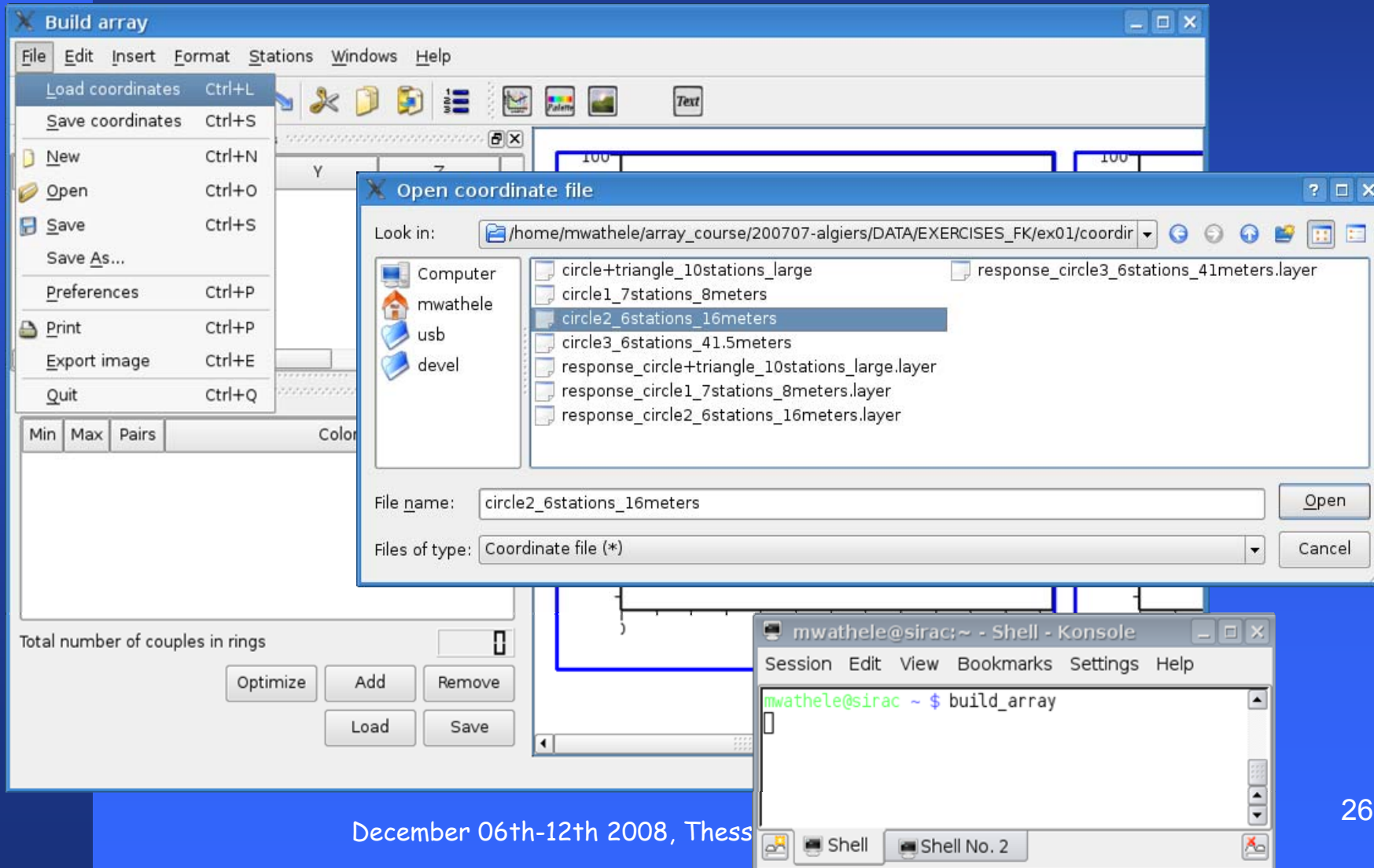


Above 4 Hz, mean curve is not representative of actual distribution which fits better the true dispersion curve



Below 4 Hz, phase velocities are overestimated: is it related to array response ???

Computing array response with *build_array* ~/data/EXERCISES_FK/EX01/coordinates/circle2_6stations_16meters



The screenshot displays the 'Build array' software interface. The 'Open coordinate file' dialog box is open, showing the file list with 'circle2_6stations_16meters' selected. The file name field contains 'circle2_6stations_16meters' and the file type is set to 'Coordinate file (*)'. Below the dialog, a terminal window shows the command 'build_array' being executed.

Build array (File Edit Insert Format Stations Windows Help)

- Load coordinates Ctrl+L
- Save coordinates Ctrl+S
- New Ctrl+N
- Open Ctrl+O
- Save Ctrl+S
- Save As...
- Preferences Ctrl+P
- Print Ctrl+P
- Export image Ctrl+E
- Quit Ctrl+Q

Open coordinate file (Look in: /home/mwathele/array_course/200707-algiers/DATA/EXERCISES_FK/ex01/coordir)

- circle+triangle_10stations_large
- circle1_7stations_8meters
- circle2_6stations_16meters
- circle3_6stations_41.5meters
- response_circle+triangle_10stations_large.layer
- response_circle1_7stations_8meters.layer
- response_circle2_6stations_16meters.layer

File name: circle2_6stations_16meters

Files of type: Coordinate file (*)

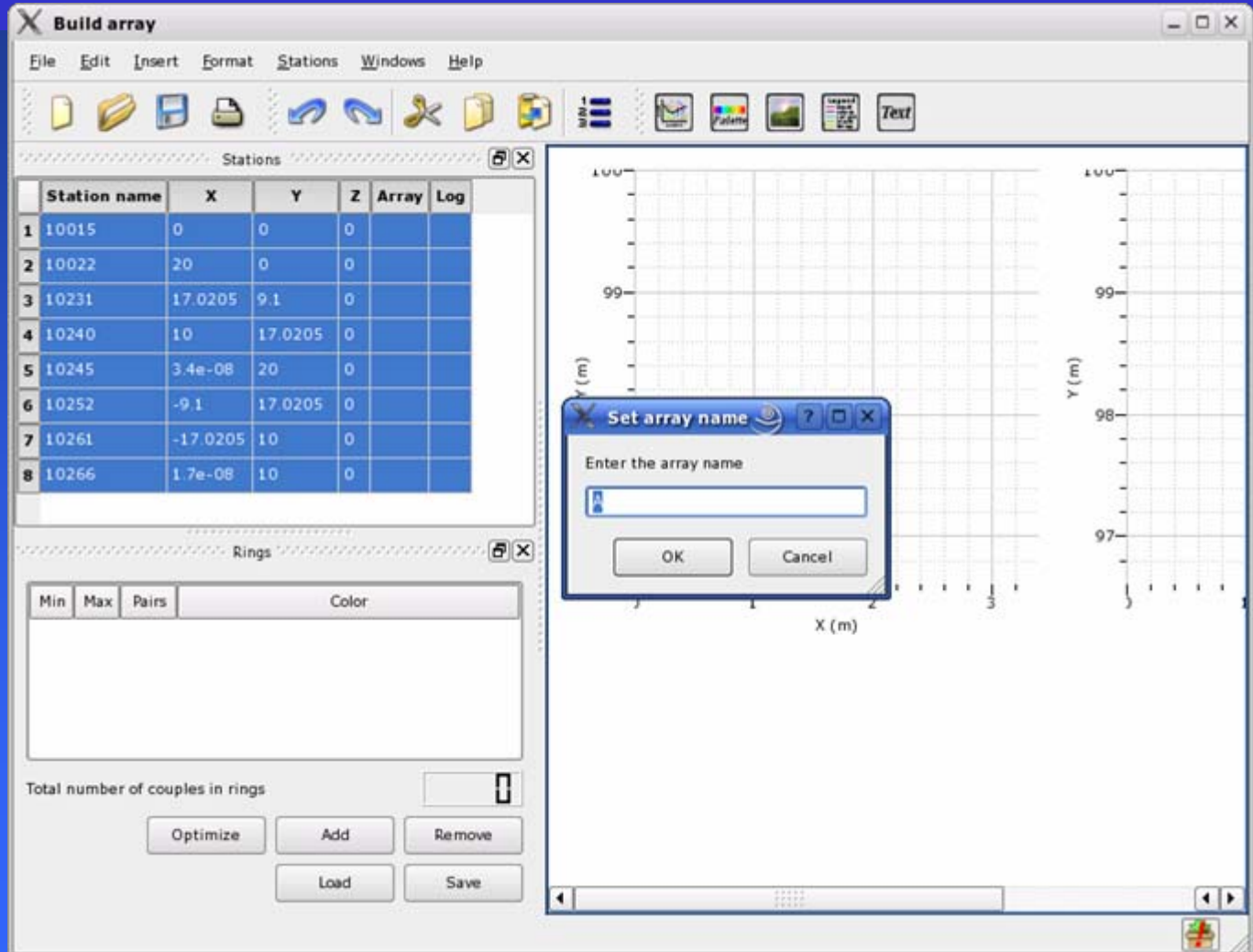
Terminal (mwathele@sirac:~ - Shell - Konsole):

```
mwathele@sirac ~ $ build_array
```

Total number of couples in rings: [input field]

Buttons: Optimize, Add, Remove, Load, Save

After loading coordinates - set some array name



Build array

File Edit Insert Format Stations Windows Help

Stations

	Station name	X	Y	Z	Array	Log
1	10015	0	0	0		
2	10022	20	0	0		
3	10231	17.0205	9.1	0		
4	10240	10	17.0205	0		
5	10245	3.4e-08	20	0		
6	10252	-9.1	17.0205	0		
7	10261	-17.0205	10	0		
8	10266	1.7e-08	10	0		

Rings

Min	Max	Pairs	Color

Total number of couples in rings:

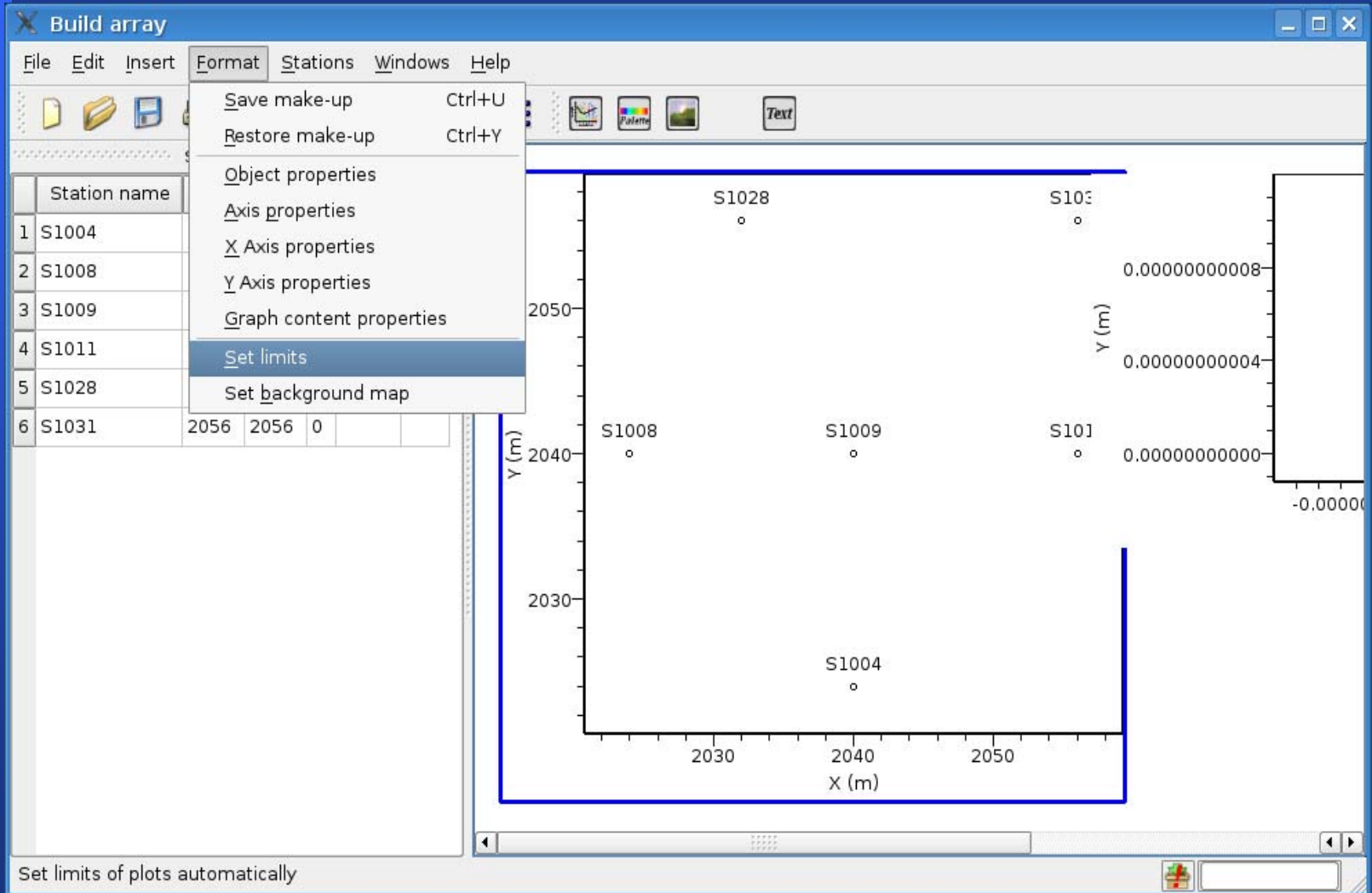
Optimize Add Remove Load Save

Set array name

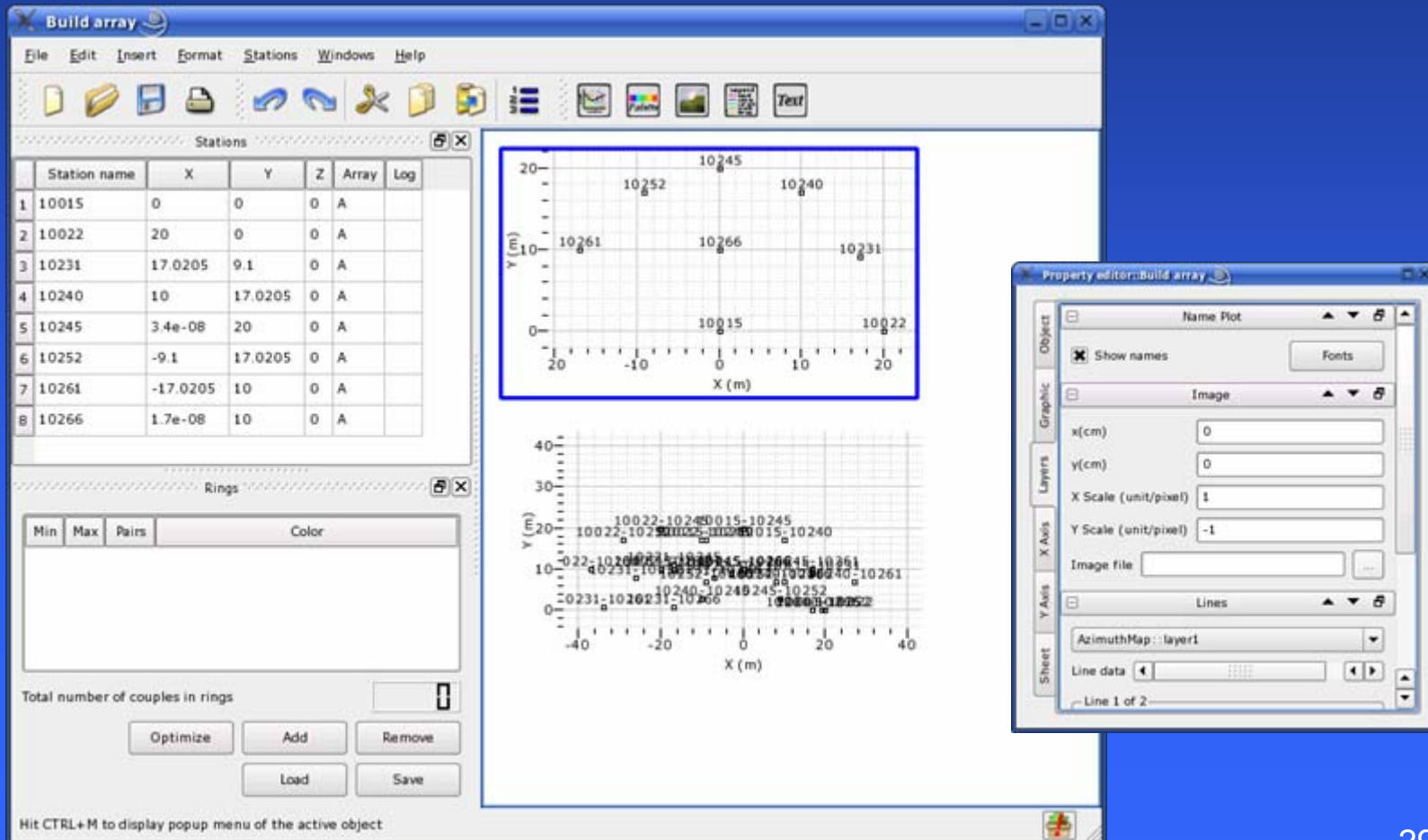
Enter the array name

OK Cancel

Viewing array geometry



For better viewing geometries (array + coarray) remove names from plot using property editor



The screenshot displays the 'Build array' software interface. On the left, a 'Stations' table lists 8 stations with their names, X, Y, Z coordinates, and array types. Below it is a 'Rings' section with a table for defining ring pairs and colors, and buttons for 'Optimize', 'Add', 'Remove', 'Load', and 'Save'. The main area contains two plots: a top plot showing station locations with names and a bottom plot showing the resulting coarray geometry. A 'Property editor' window is open on the right, showing settings for the 'Name Plot' object, including a checked 'Show names' option and various scaling parameters.

	Station name	X	Y	Z	Array	Log
1	10015	0	0	0	A	
2	10022	20	0	0	A	
3	10231	17.0205	9.1	0	A	
4	10240	10	17.0205	0	A	
5	10245	3.4e-08	20	0	A	
6	10252	-9.1	17.0205	0	A	
7	10261	-17.0205	10	0	A	
8	10266	1.7e-08	10	0	A	

Compute theoretical array response for the given station geometry

Stations Windows Help

- Add
- Circle
- Cartesian
- Remove
- Clear
- Set station names
- Set array names
- Array list
- Set coordinates
- Recalculate
- Rotate
- Translate
- Relative positions
- Theoretical response**
- Simulate response

Build array

File Edit Insert Format Stations Windows Help

Stations

	Station name	X	Y	Z	Array	Log
1	10015	0	0	0	A	
2	10022	20	0	0	A	
3	10231	17.02				
4	10240	10				
5	10245	3.4e-0				
6	10252	-9.1				
7	10261	-17.02				
8	10266	1.7e-0				

Array response - transfer function

Select an array ...

Dispersion plot sampling

From 0.50 Hz to 15.00 Hz

Step Log Number of samples 100

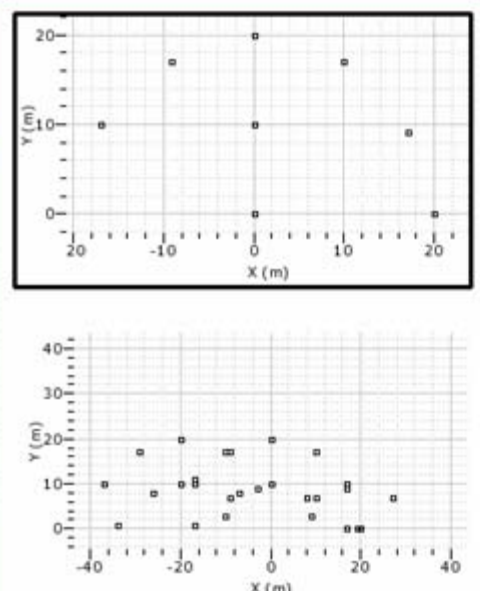
Grid definition

k max factor 3

OK Cancel

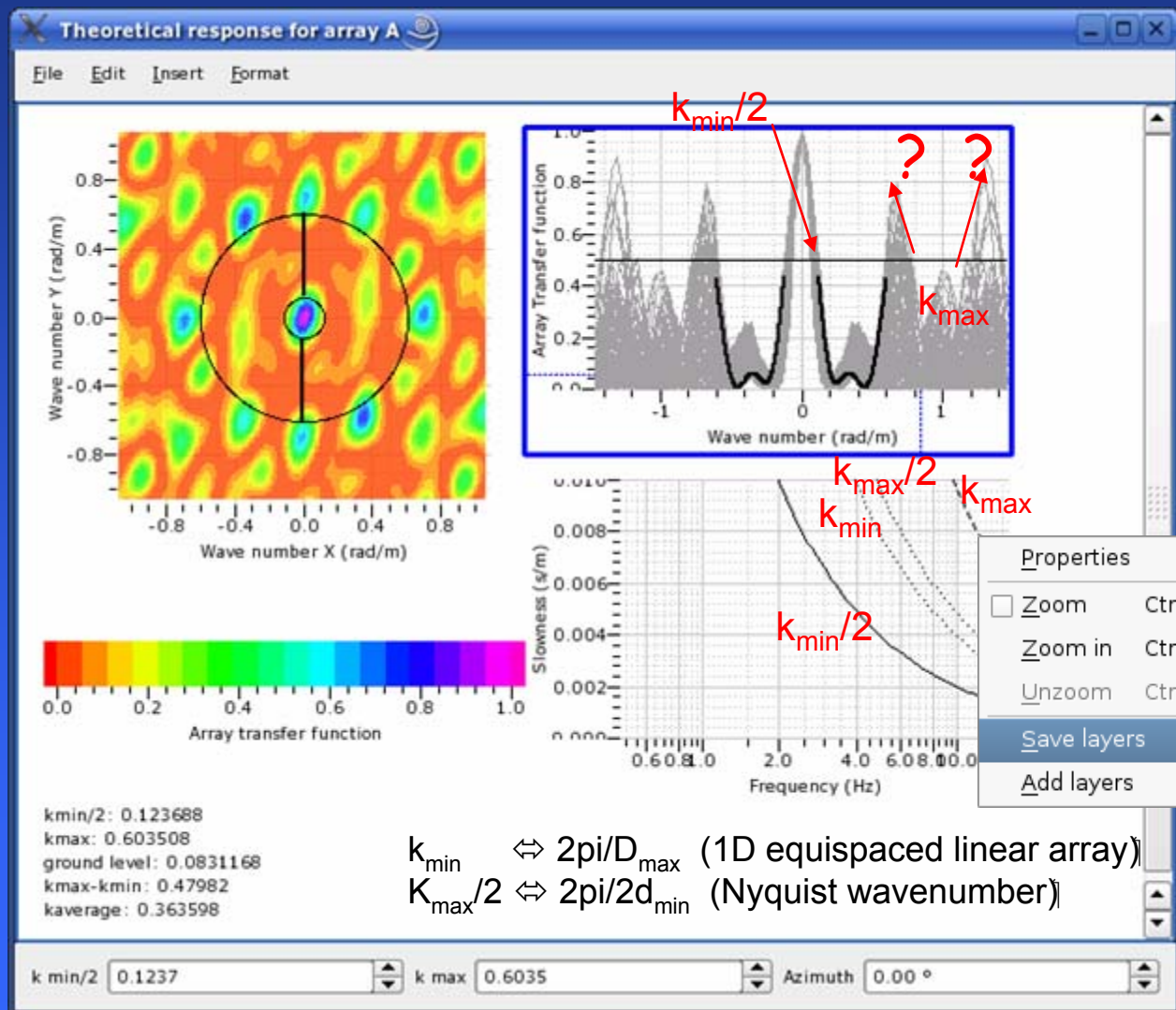
Total number of couples in rings

Optimize Add Remove Load Save

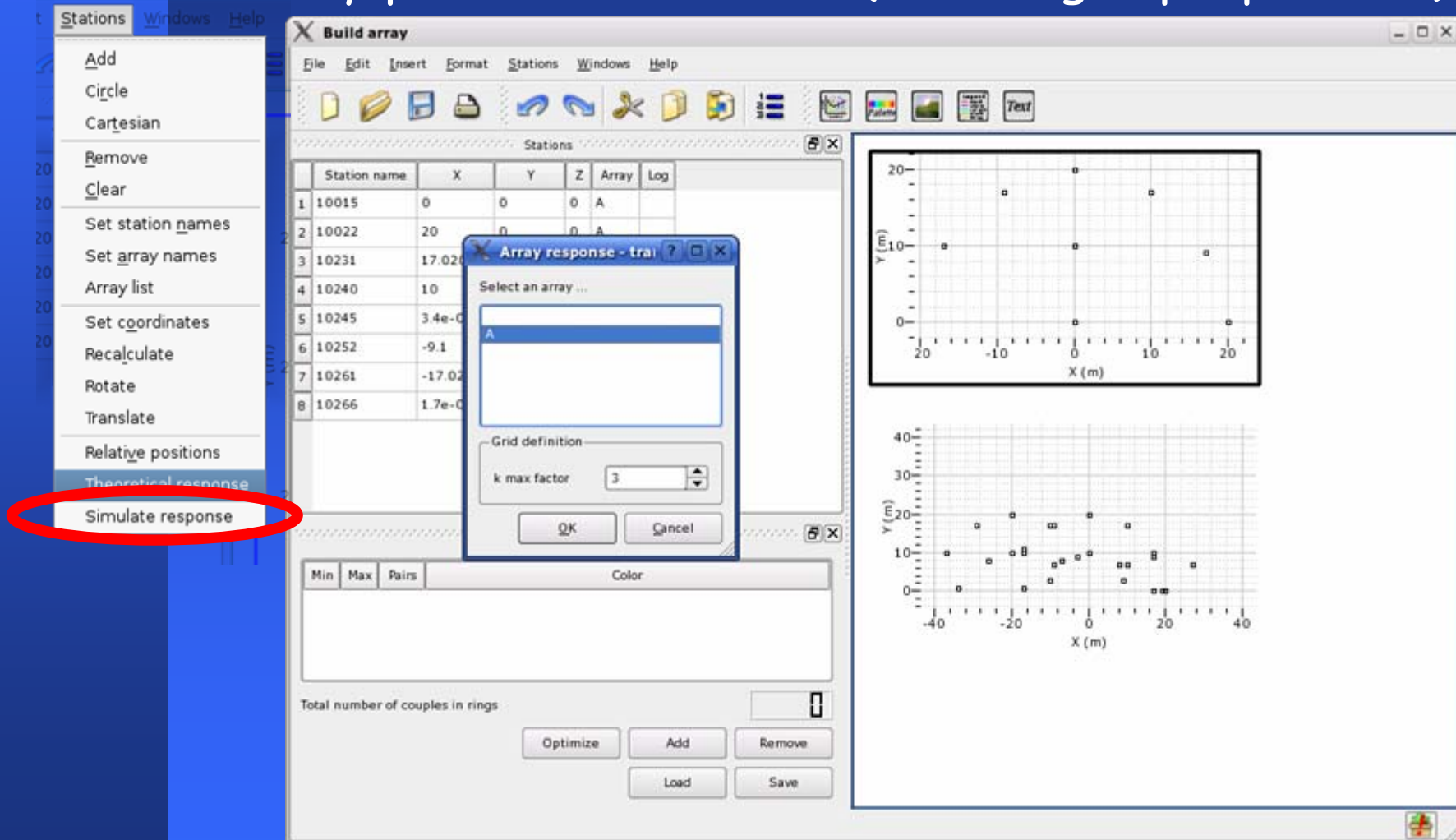


Using Ambient Vibration Array Techniques for Site Characterisation

Where is k_{max} ?



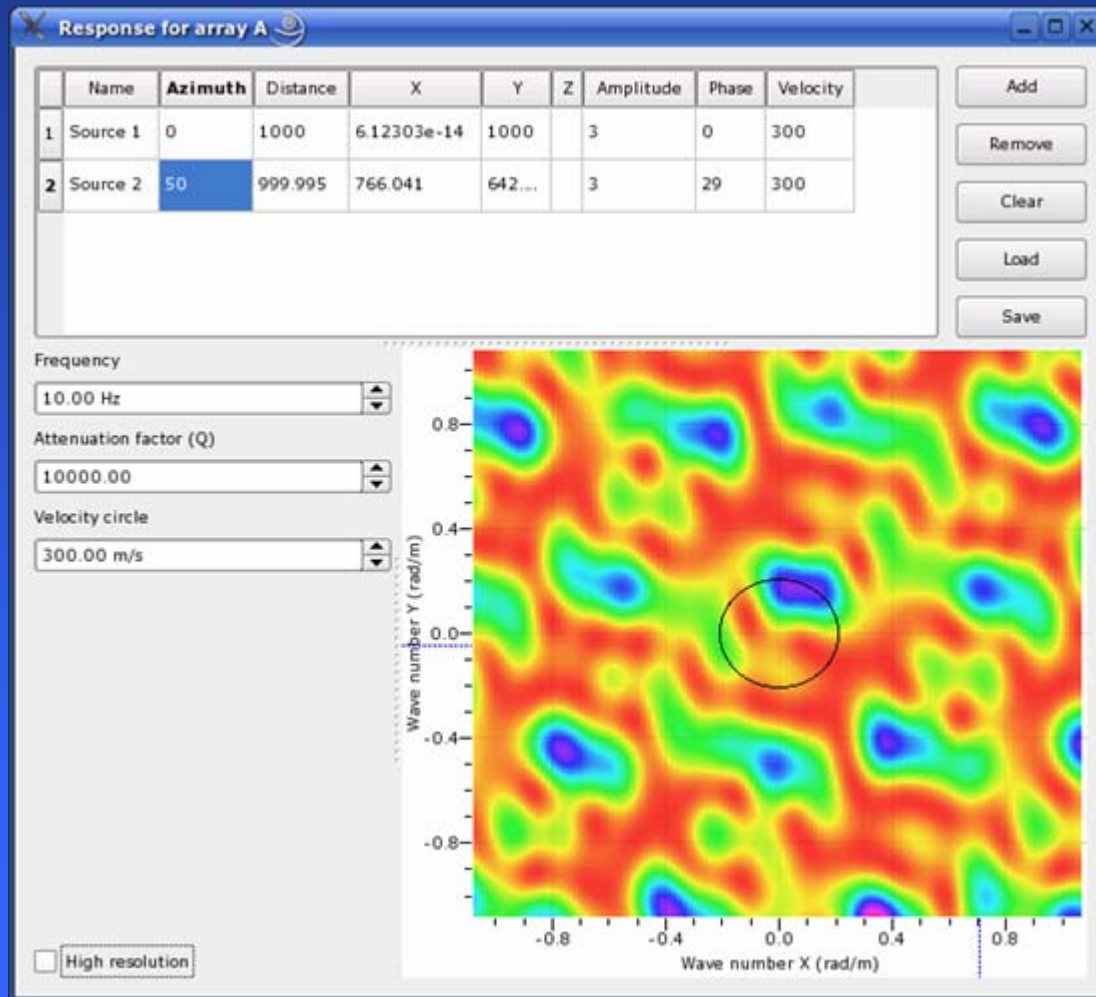
What do we mean by k_{max} ? - simulate array response for arbitrary plane wave arrivals (including superposition)



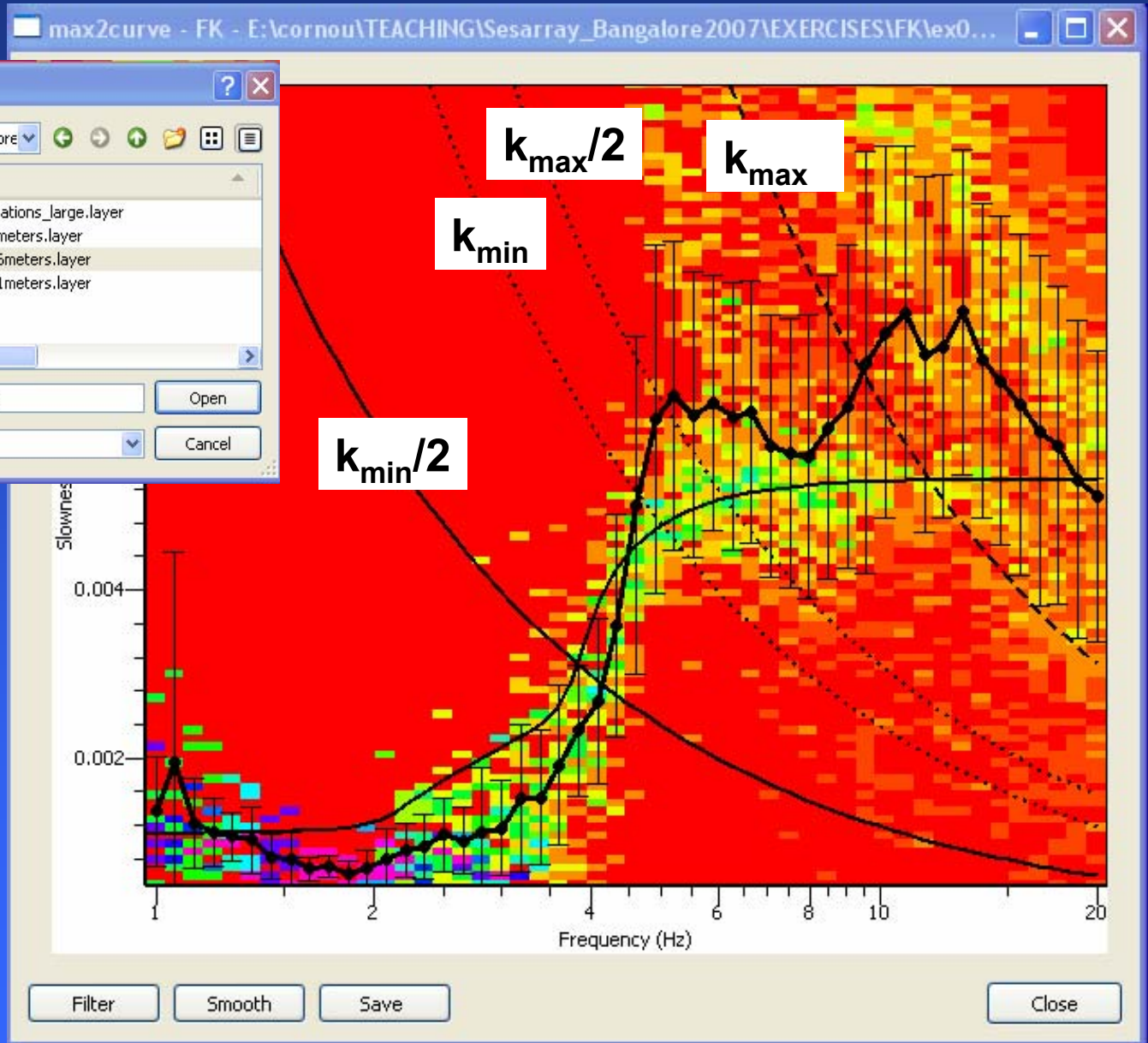
The screenshot shows the 'Build array' software interface. The 'Stations' menu is open, with 'Simulate response' circled in red. A 'Build array' dialog box is open, showing a table of stations and a 'Grid definition' section with 'k max factor' set to 3. Two plots show the station layout and the resulting grid.

Station name	X	Y	Z	Array	Log
1 10015	0	0	0	A	
2 10022	20	0	0	A	
3 10231	17.02				
4 10240	10				
5 10245	3.4e-0				
6 10252	-9.1				
7 10261	-17.02				
8 10266	1.7e-0				

What do we mean by k_{\max} ? - simulate array response
 For arbitrary plane wave arrivals (including superposition)

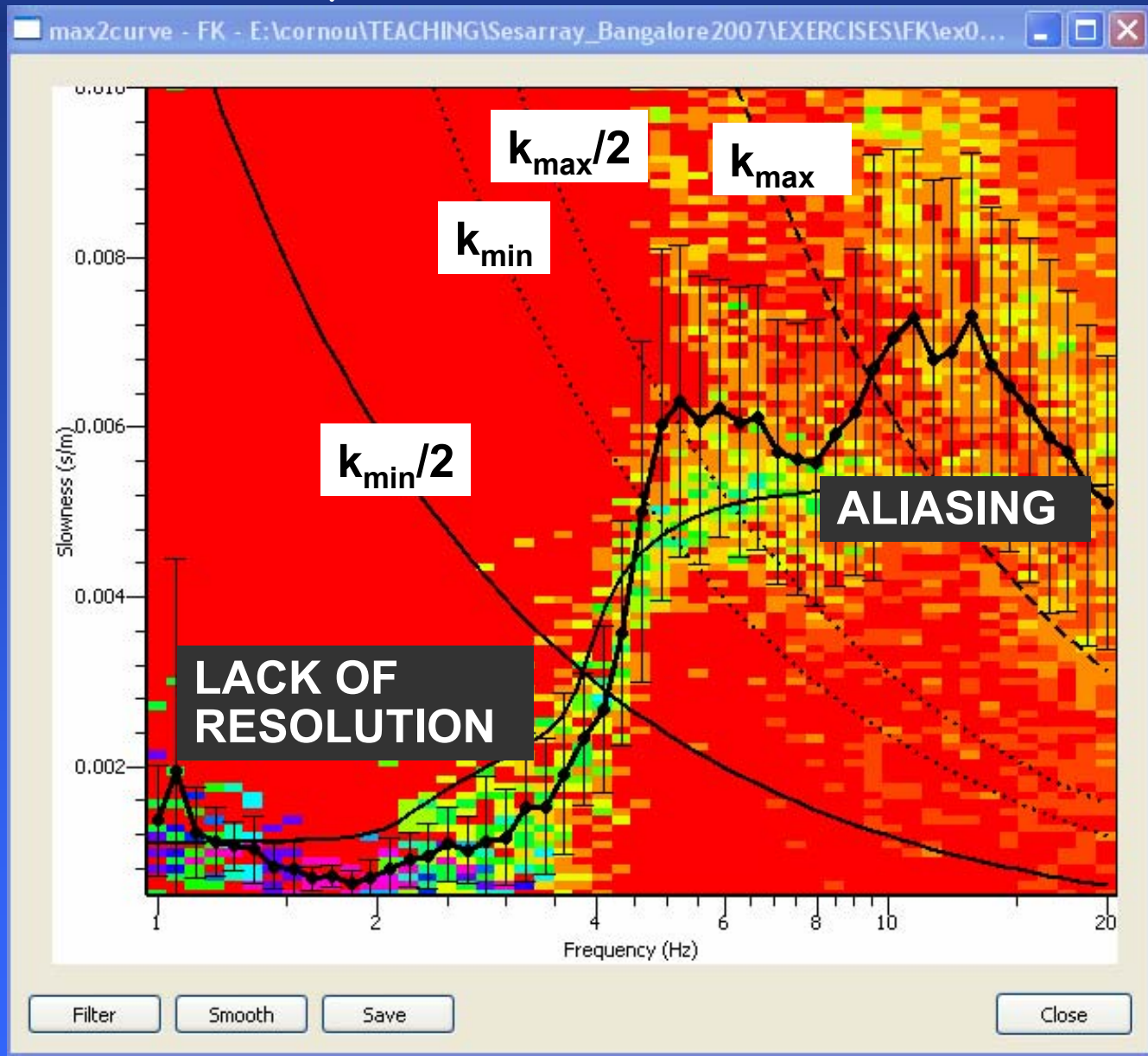


play around
and observe ...



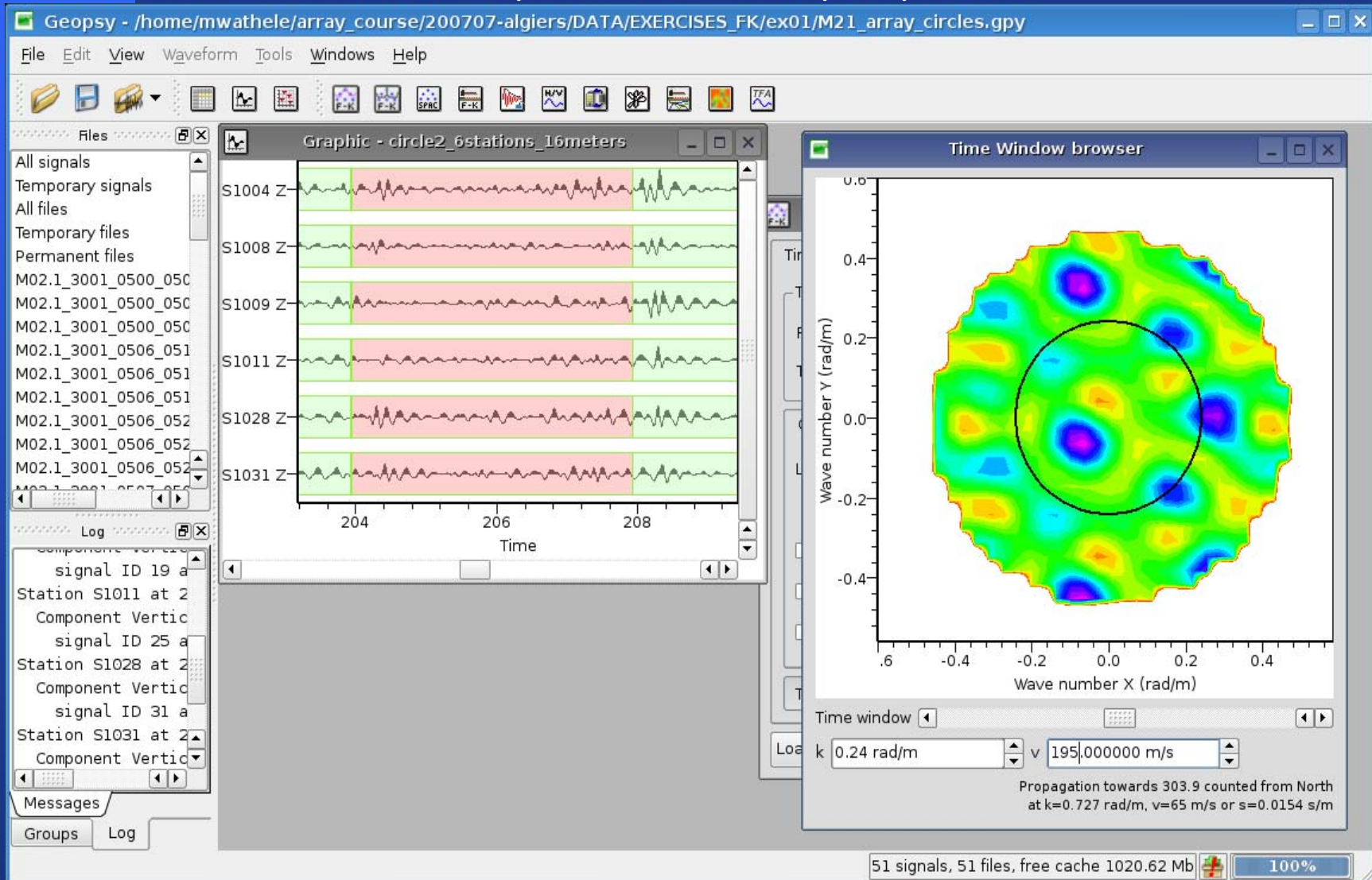
Add the array response layer on the fk histogram plot

Using Ambient Vibration Array Techniques for Site Characterisation

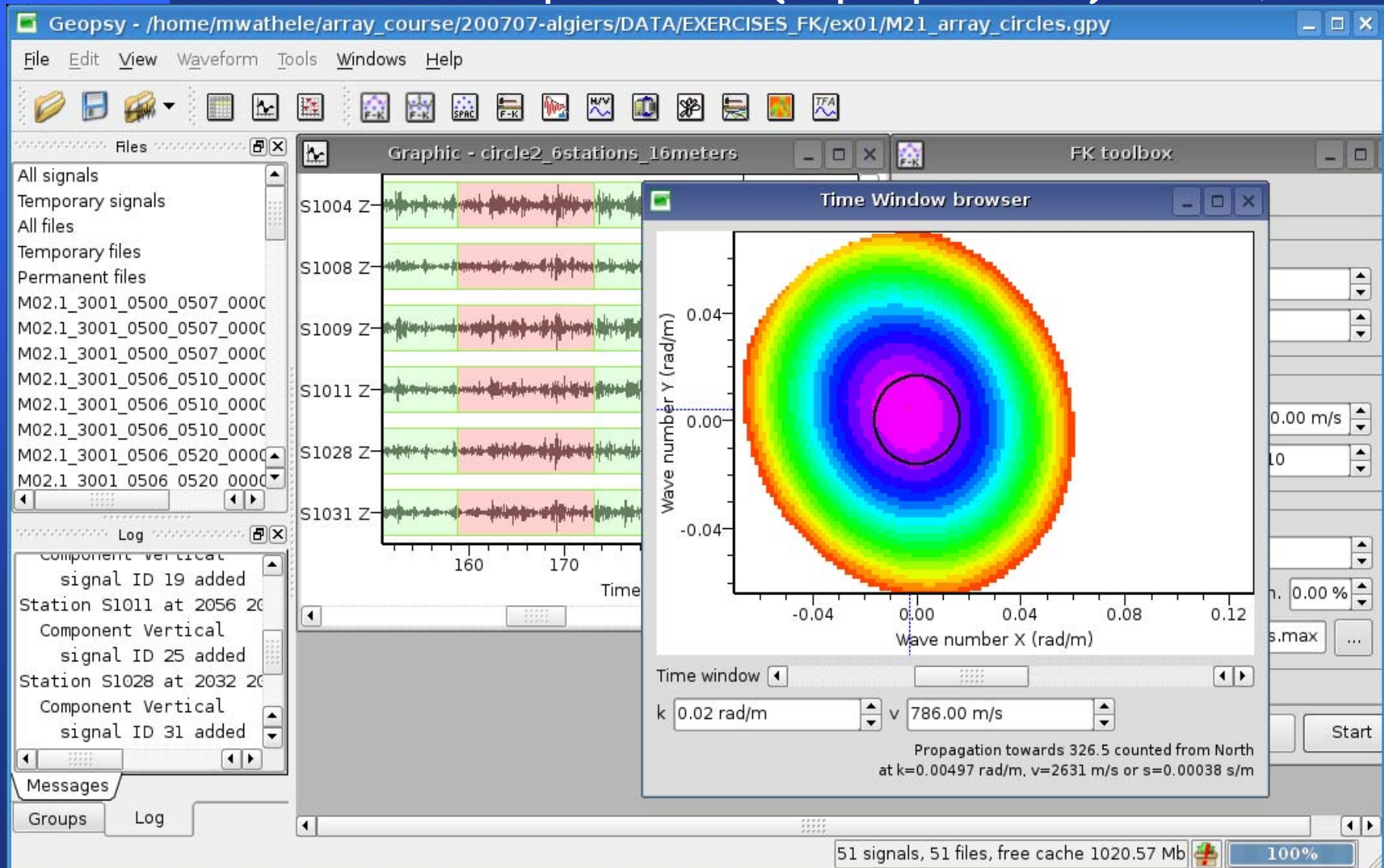


Using Ambient Vibration Array Techniques for Site Characterisation

FK misinterpretation (superposition) 7.5 Hz



Using Ambient Vibration Array Techniques for Site Characterisation FK misinterpretation (superposition) - 2 Hz



Using Ambient Vibration Array Techniques for Site Characterisation

Do the same exercise using the two
other predefined arrays

Circle3_6stations_41.5meters

Grid_step = 0.015 rad/m

Grid_size = 0.34 rad/m

Vmin = 100 m/s; window length = 30 T

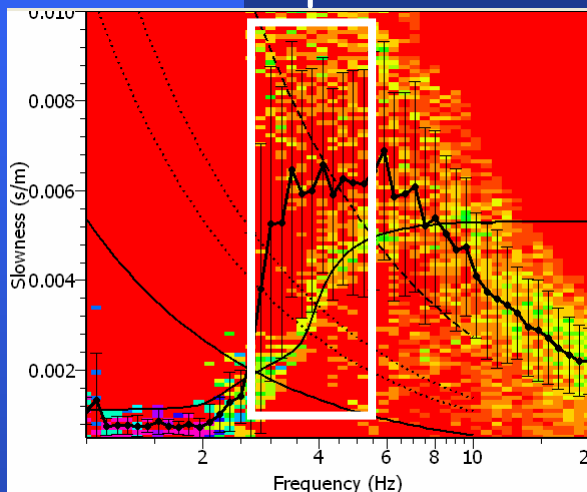
Circle1_7stations_8meters

Grid_step = 0.065 rad/m

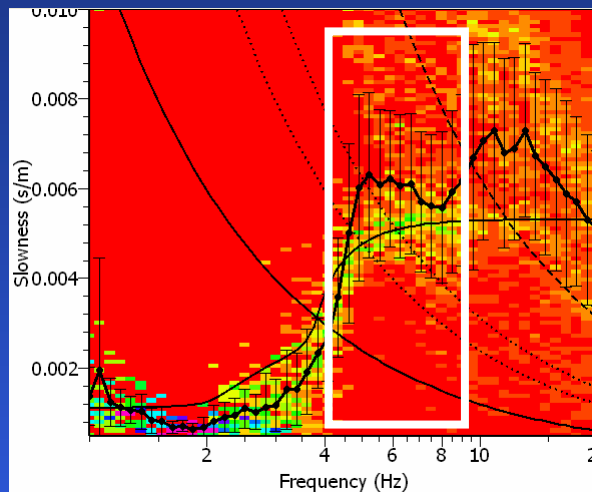
Grid_size = 1.6 rad/m

Vmin = 100 m/s; window length = 30 T

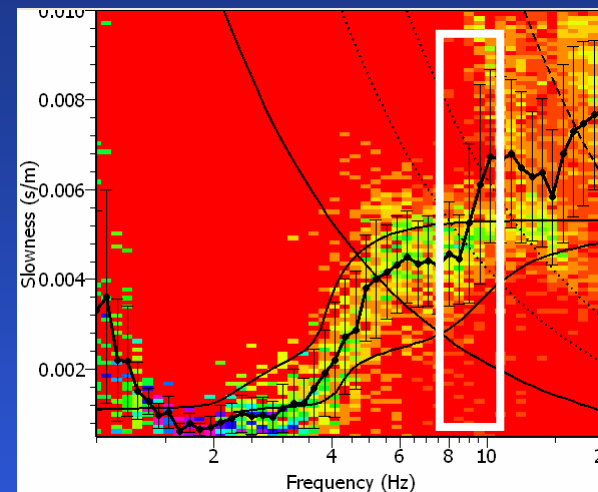
41 m aperture



16 m aperture

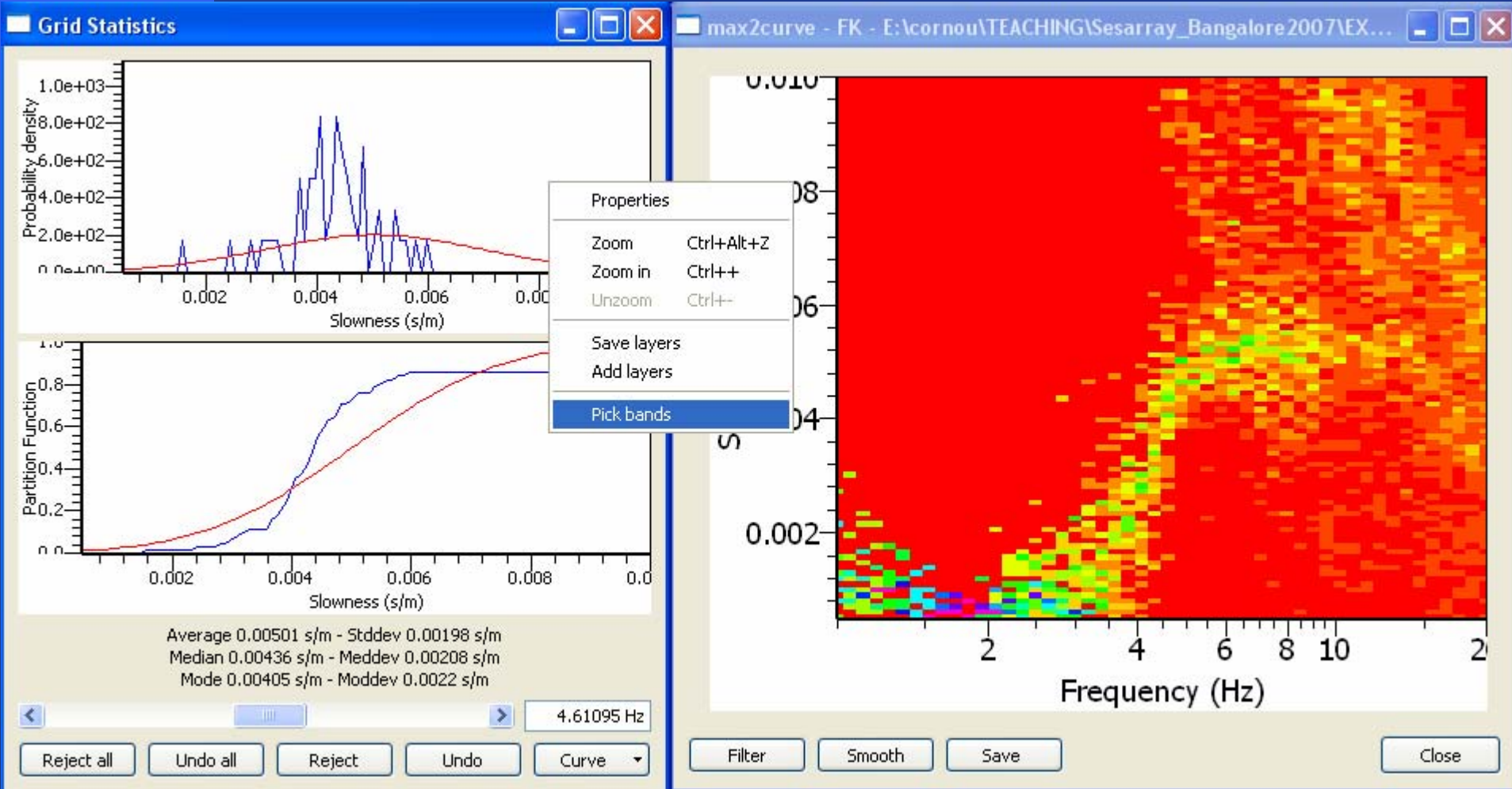


8 m aperture

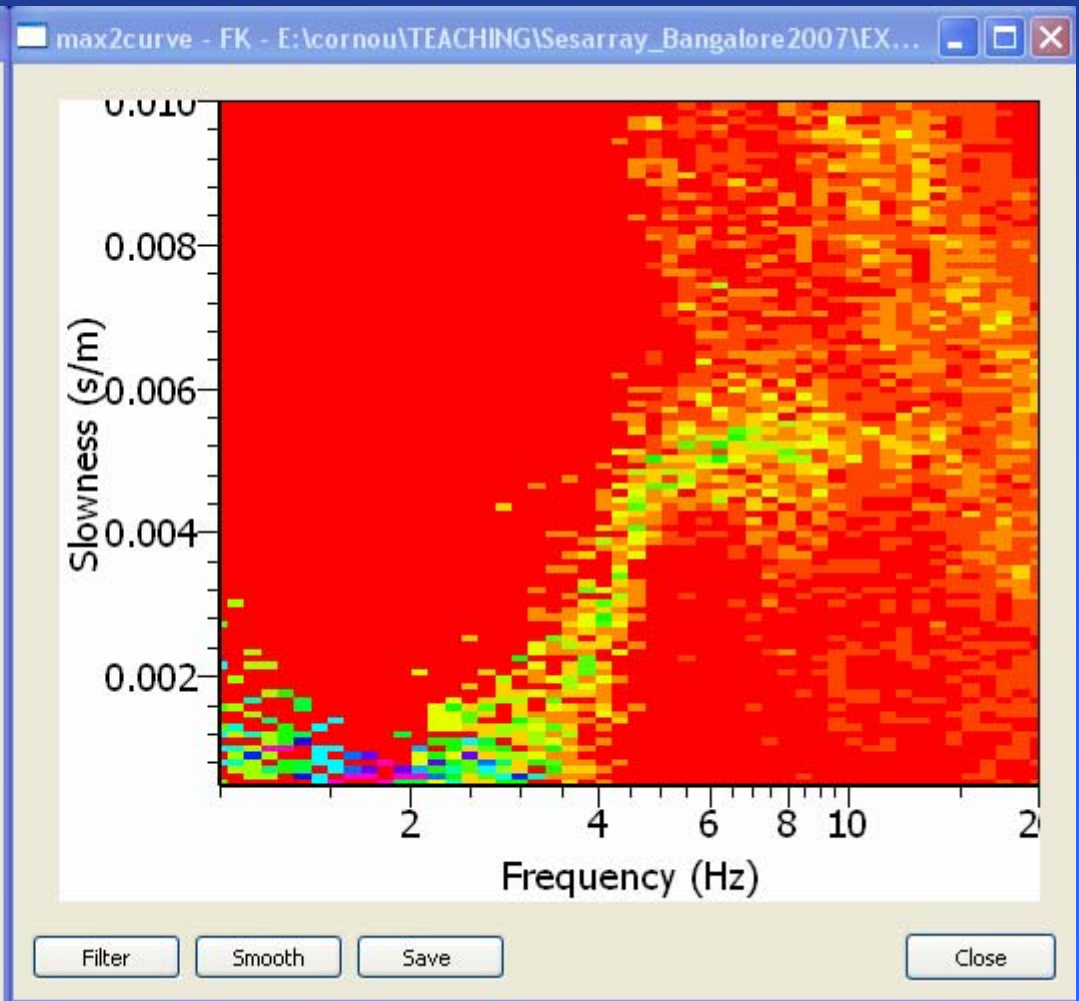
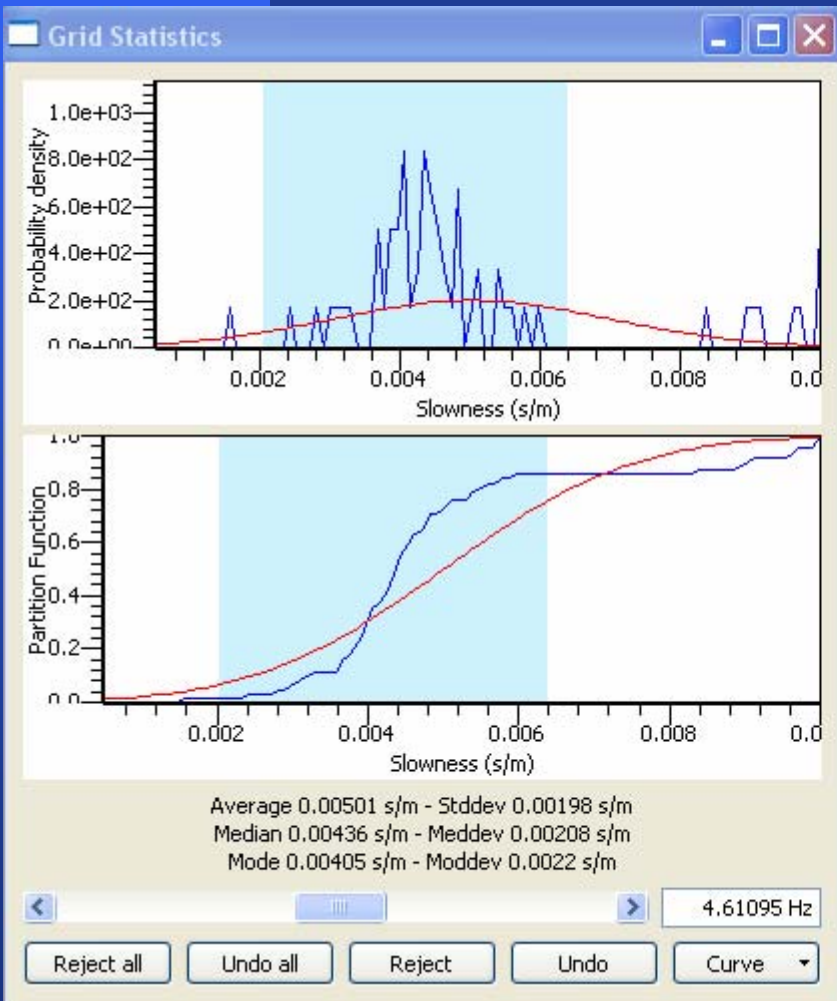


- Larger (smaller) aperture, better resolution at LF (HF)
- In this example, smallest aperture array provides phase velocities deviating (overestimation) than true ones.
- Histograms should be cleaned in order to remove outliers or estimates which can be clearly attributed to aliasing effects.

FK histograms: outlier removal

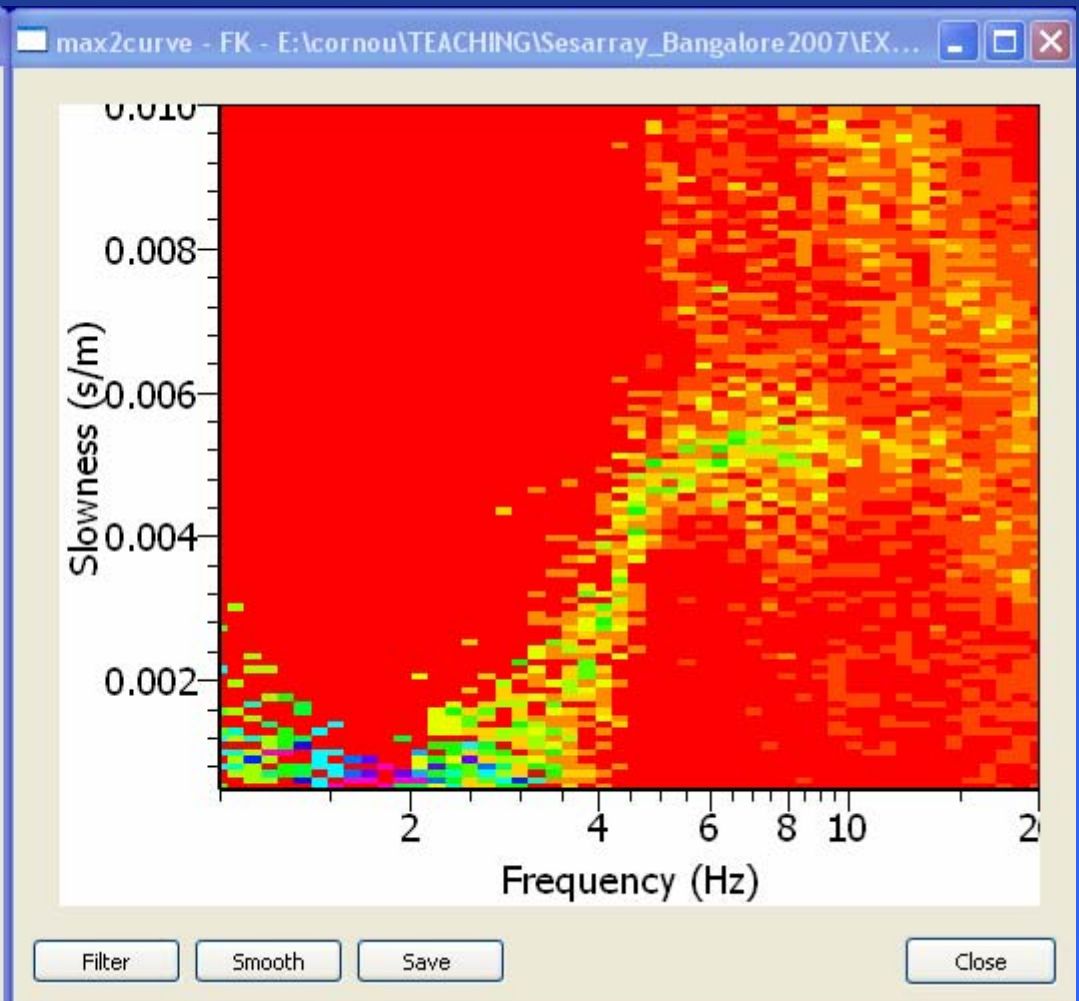
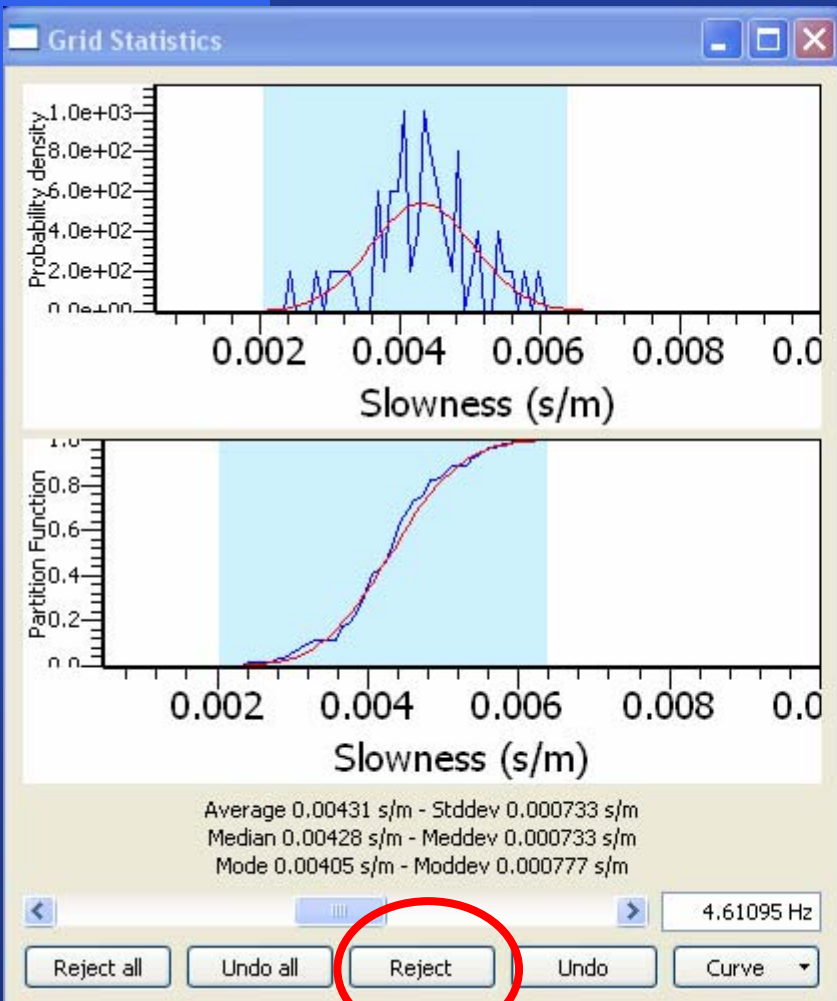


Select the slowness band you want to keep (pick band)



Using Ambient Vibration Array Techniques for Site Characterisation

Press on "reject" to remove the samples **outside** selected band from the distribution



Use of the keyboard's arrows to facilitate the removing of bad samples

To increase frequency



SHIFT + : to apply selection
and go to next frequency

To modify the left limit of the pick band



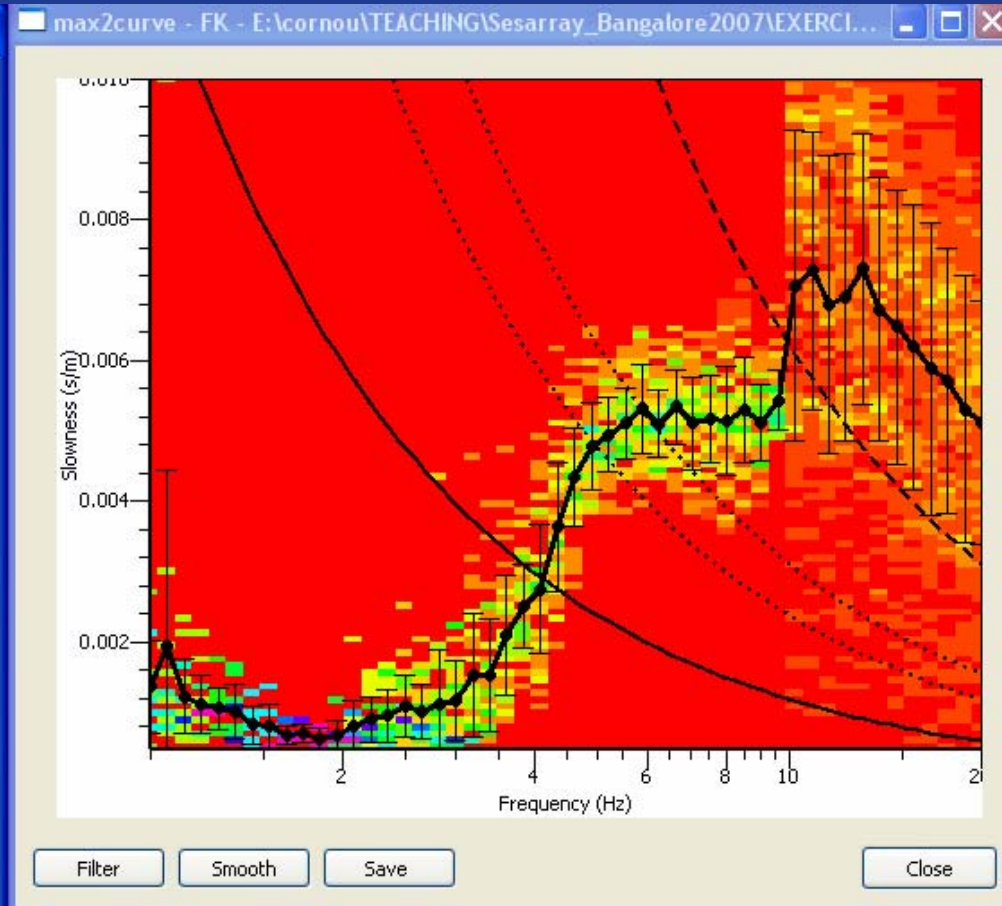
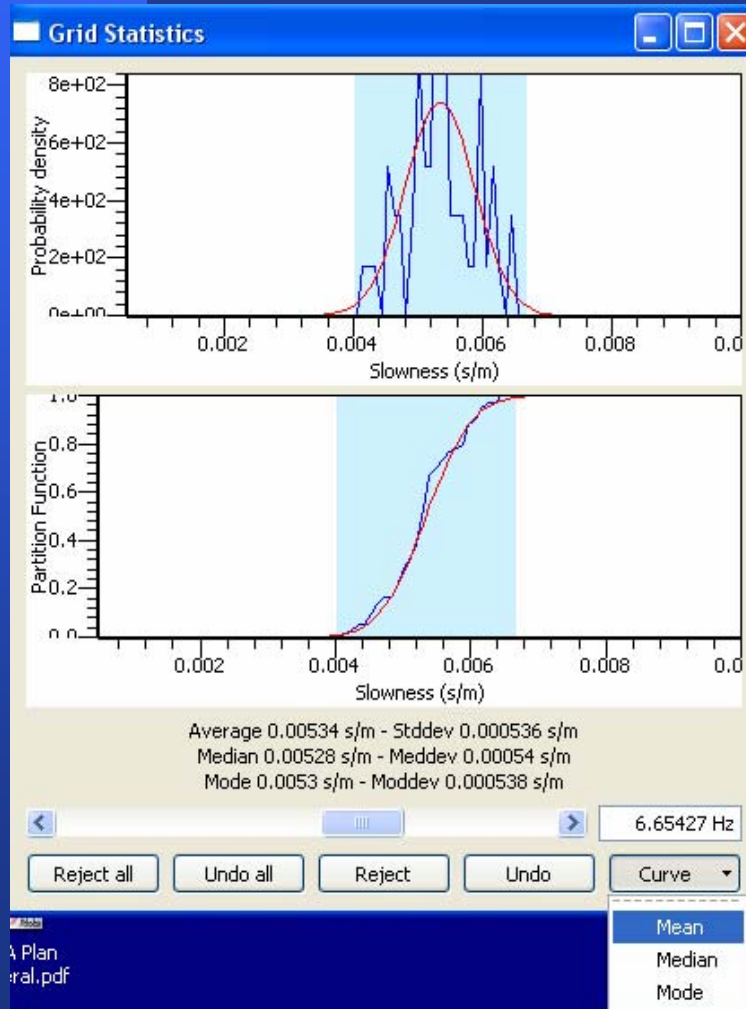
+ SHIFT: to move the right limit of the pick band

SHIFT + : to apply selection
and go to previous frequency

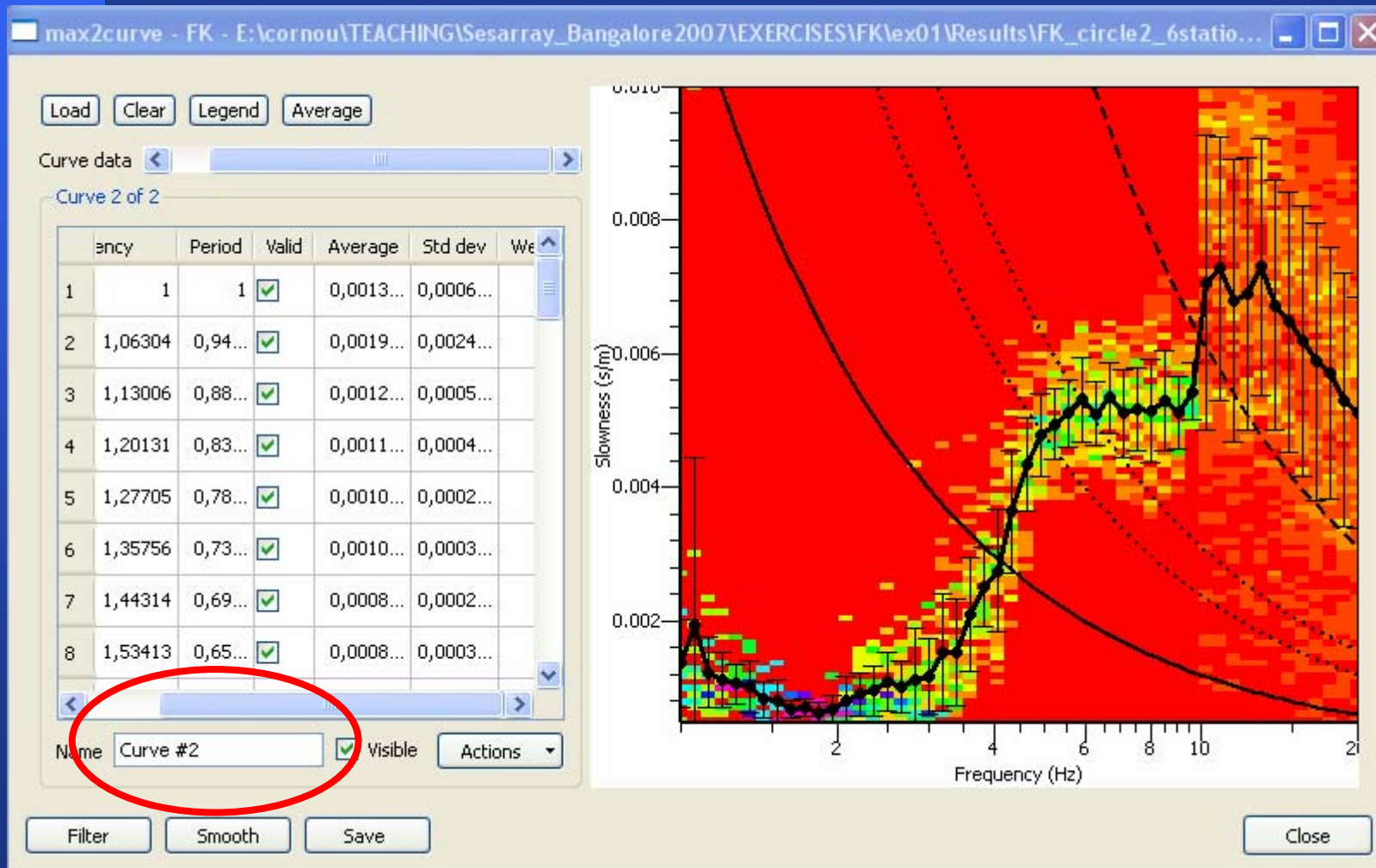


To decrease frequency

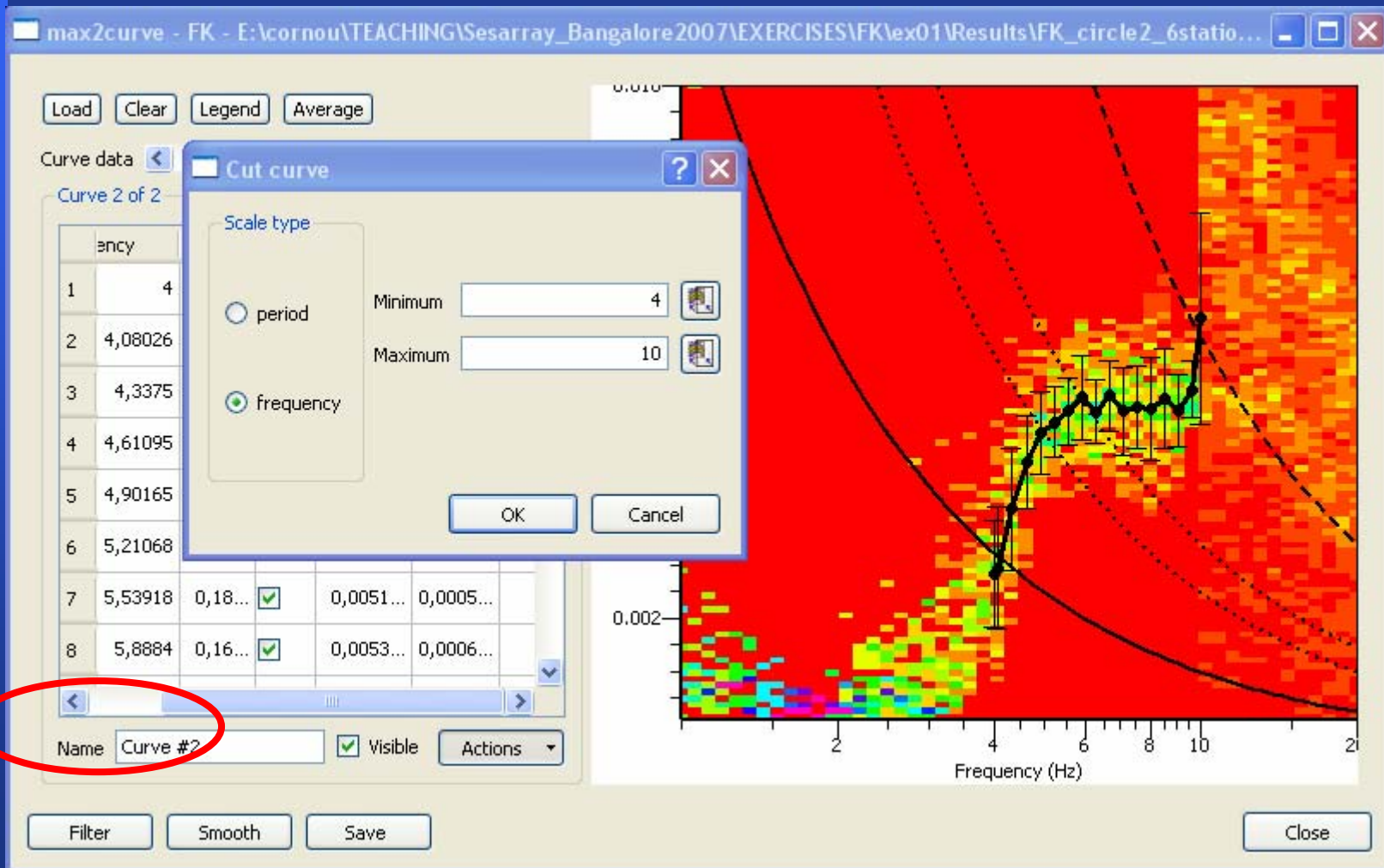
Computation of new mean/median/mode curve



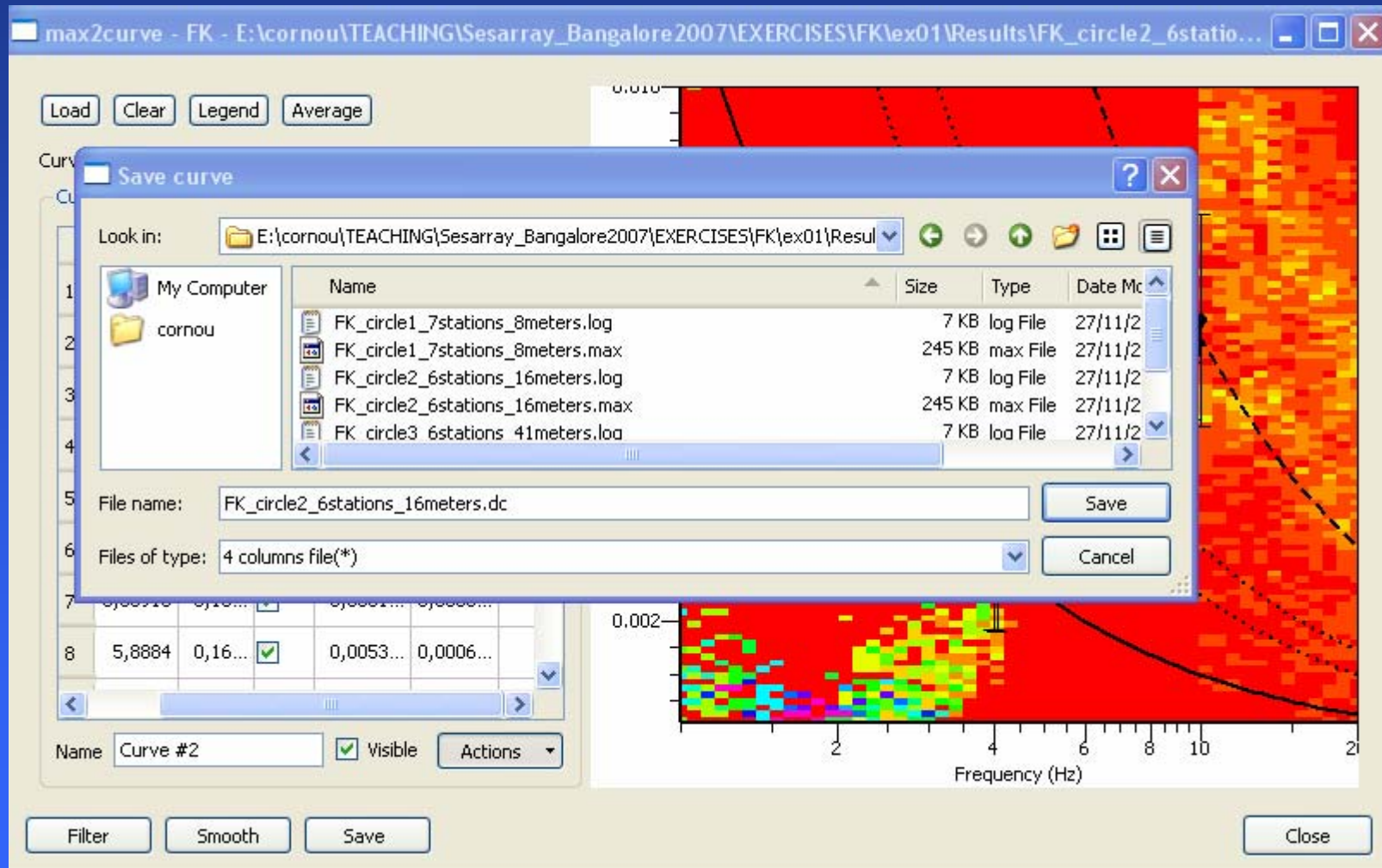
The new mean curve appears as Curve #2



Cut curve in order to keep estimates only for reliable f.-band



Saving the dispersion curve



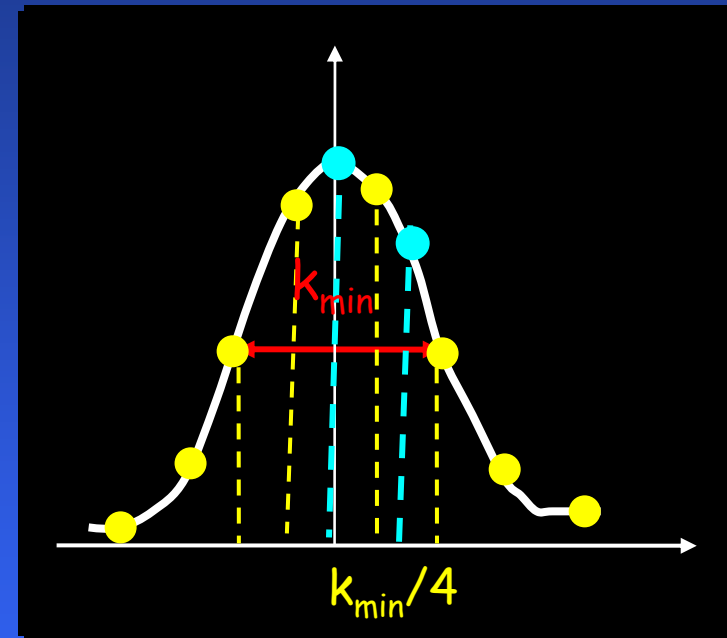
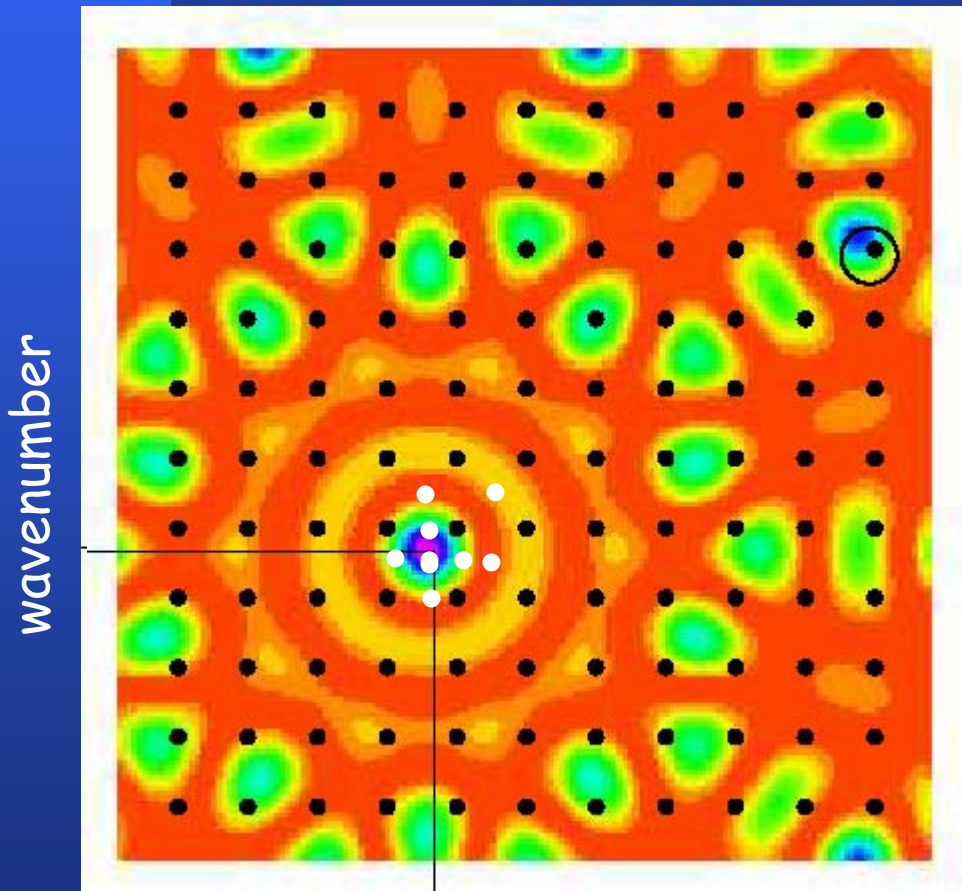
The screenshot shows the 'max2curve' software interface. A 'Save curve' dialog box is open, displaying a file explorer view of the directory 'E:\cornou\TEACHING\Sesarray_Bangalore2007\EXERCISES\FK\ex01\Resul'. The dialog shows a list of files with columns for Name, Size, Type, and Date Modified. The file 'FK_circle2_6stations_16meters.dc' is selected in the 'File name' field. The 'Files of type' is set to '4 columns file(*)'. The background shows a dispersion curve plot with Frequency (Hz) on the x-axis (ranging from 2 to 10) and a y-axis with values 0.010 and 0.002. The plot area is filled with a color-coded heatmap, and a dashed line represents the dispersion curve. At the bottom of the software window, there are buttons for 'Filter', 'Smooth', 'Save', and 'Close'.

Name	Size	Type	Date Modified
FK_circle1_7stations_8meters.log	7 KB	log File	27/11/2
FK_circle1_7stations_8meters.max	245 KB	max File	27/11/2
FK_circle2_6stations_16meters.log	7 KB	log File	27/11/2
FK_circle2_6stations_16meters.max	245 KB	max File	27/11/2
FK_circle3_6stations_41meters.log	7 KB	log File	27/11/2

Some issues on $f-k$ processing as implemented in sesarray

- What reasonable values should be chosen for fk analysis ? (k_{\min} , k_{\max} , window length T)
- How is the fk gridding performed ?

adaptive grid search technique (from coarse to fine grid)
 Important: What initial *grid_step* to choose ?



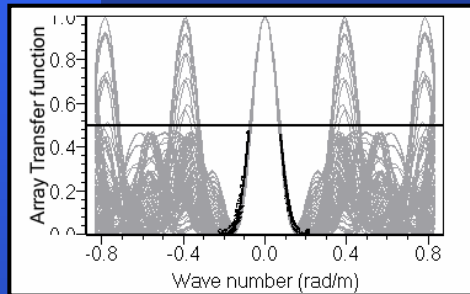
Peak refinement until numerical relative precision of 10^{-5} in wavenumber

wavenumber

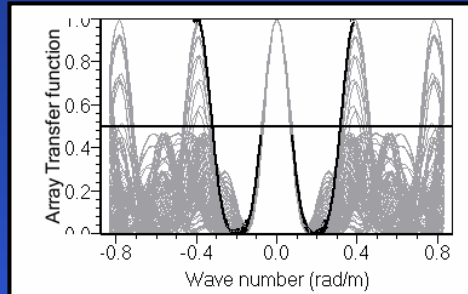
$$\text{grid_step} < k_{\min}/4$$

What *grid_size* to choose ?

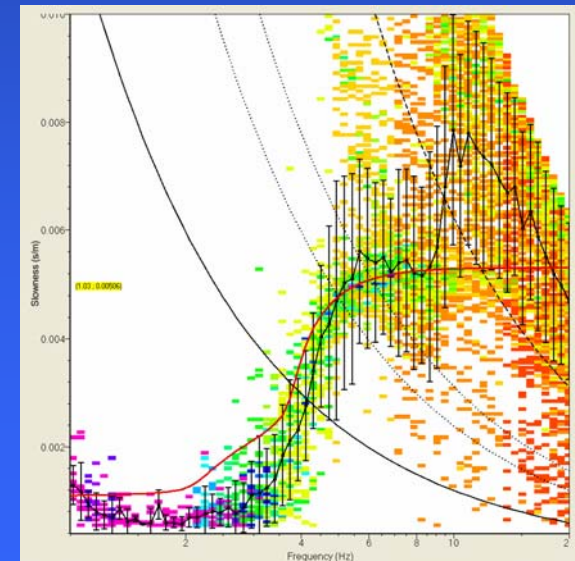
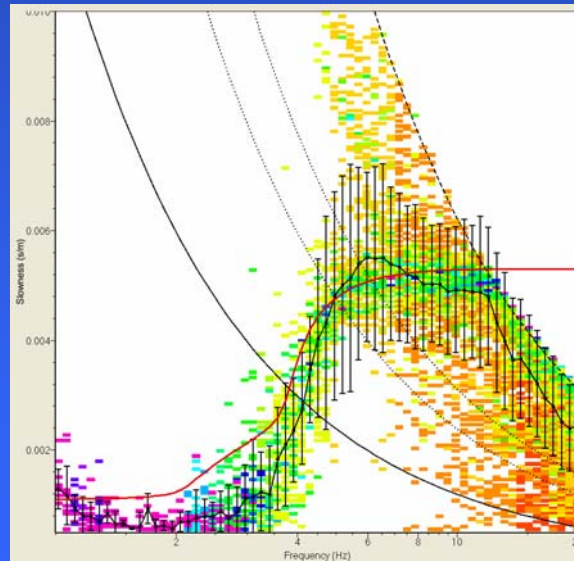
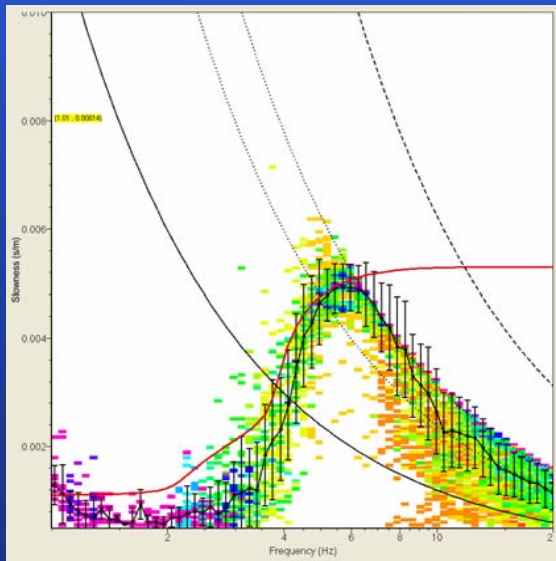
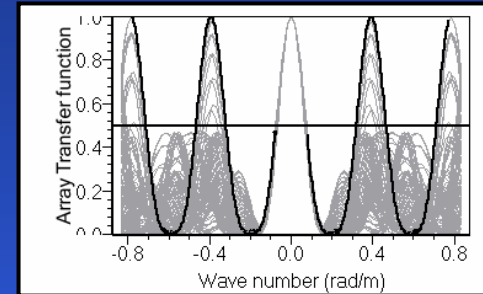
$k_{max}/2$



k_{max}

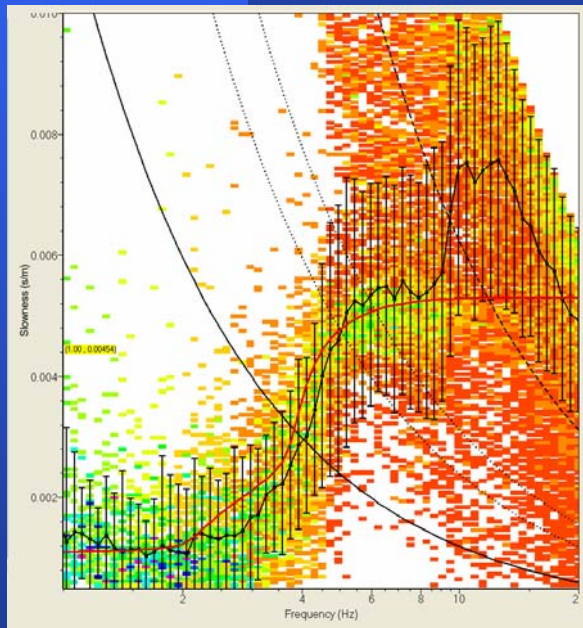


$2*k_{max}$

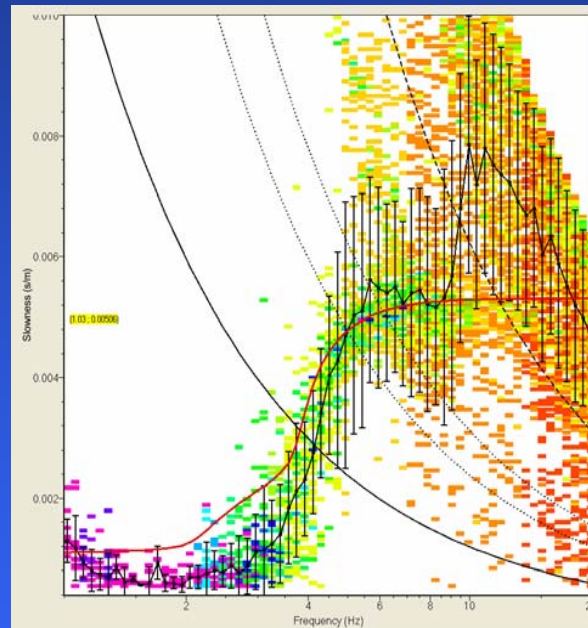


What *window_length* to choose ?

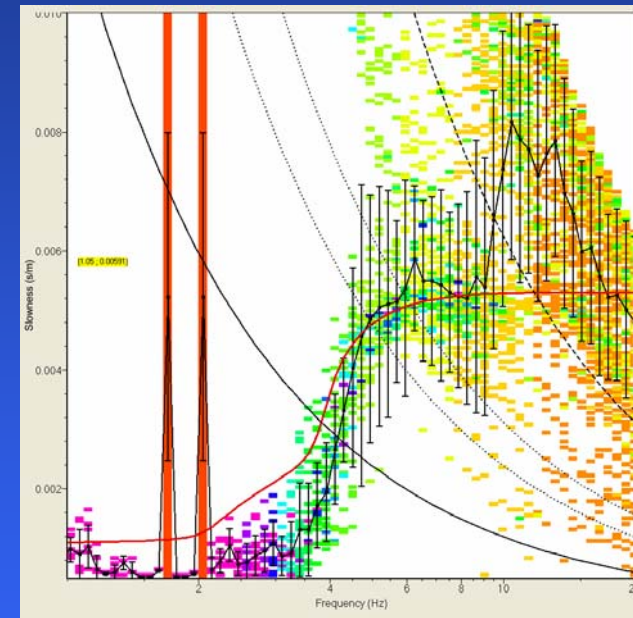
10 T



30 T



50 T



Window_length T : 20 - 50 T (and even more!)

Recommended parameters

- $\text{grid_step} < k_{\min}/4$ (maximum value)
($< k_{\min}/20$ for hrfk!)
- $\text{grid_size} > k_{\max}/2$ ($\rightarrow 2 k_{\max}$)
- $T = 20 - 50$ seconds (and even more !)

And do tests !!!

Don't feel confident yet?

* So, we have to practice 😊

Here is another (very nice) data set for you:

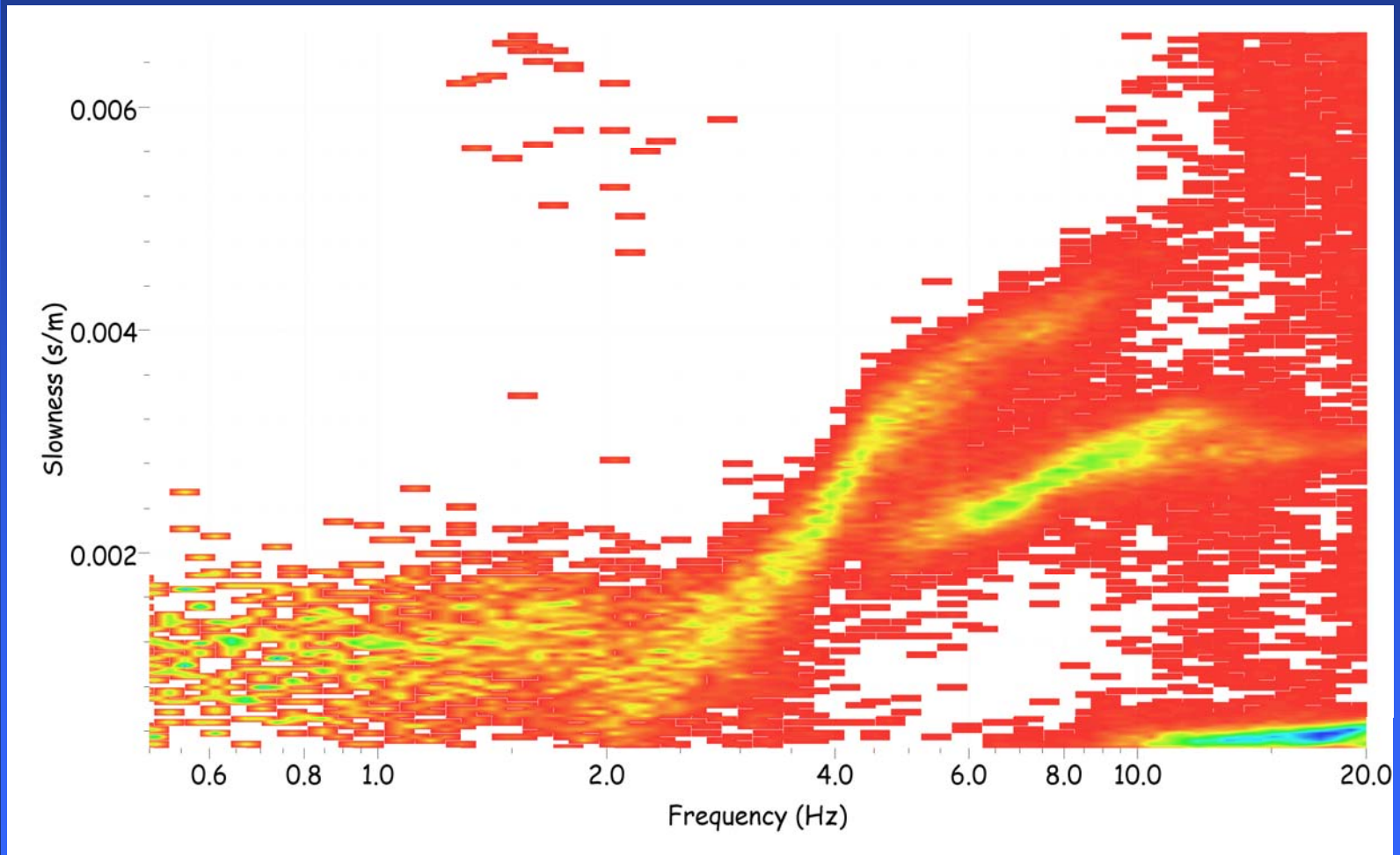
~/data/EXERCISES_FK/EX03/.gpy*

However, this time you won't be given the
processing parameters 😊😊😊

- Compute array response for full array
- Process all station together - look at max-file
- Select small and large array (eventually also a middle size one) - compute array responses
- Process individual arrays - then combine max files and compare to results from (2)

Using Ambient Vibration Array Techniques for Site Characterisation

Which result do you like more? This one



Using Ambient Vibration Array Techniques for Site Characterisation

or this one ... ?

