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)

Using Ambient Vibration Array Techniques
SESARRAY PACKAGE

GEOPSY

array tools

H/V | damping | FK | Capon | MSPAC | MASW

figue
figures

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

Post-processing

max2curve

spac2disp

build_array
Array response

DINVER
inversion

(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

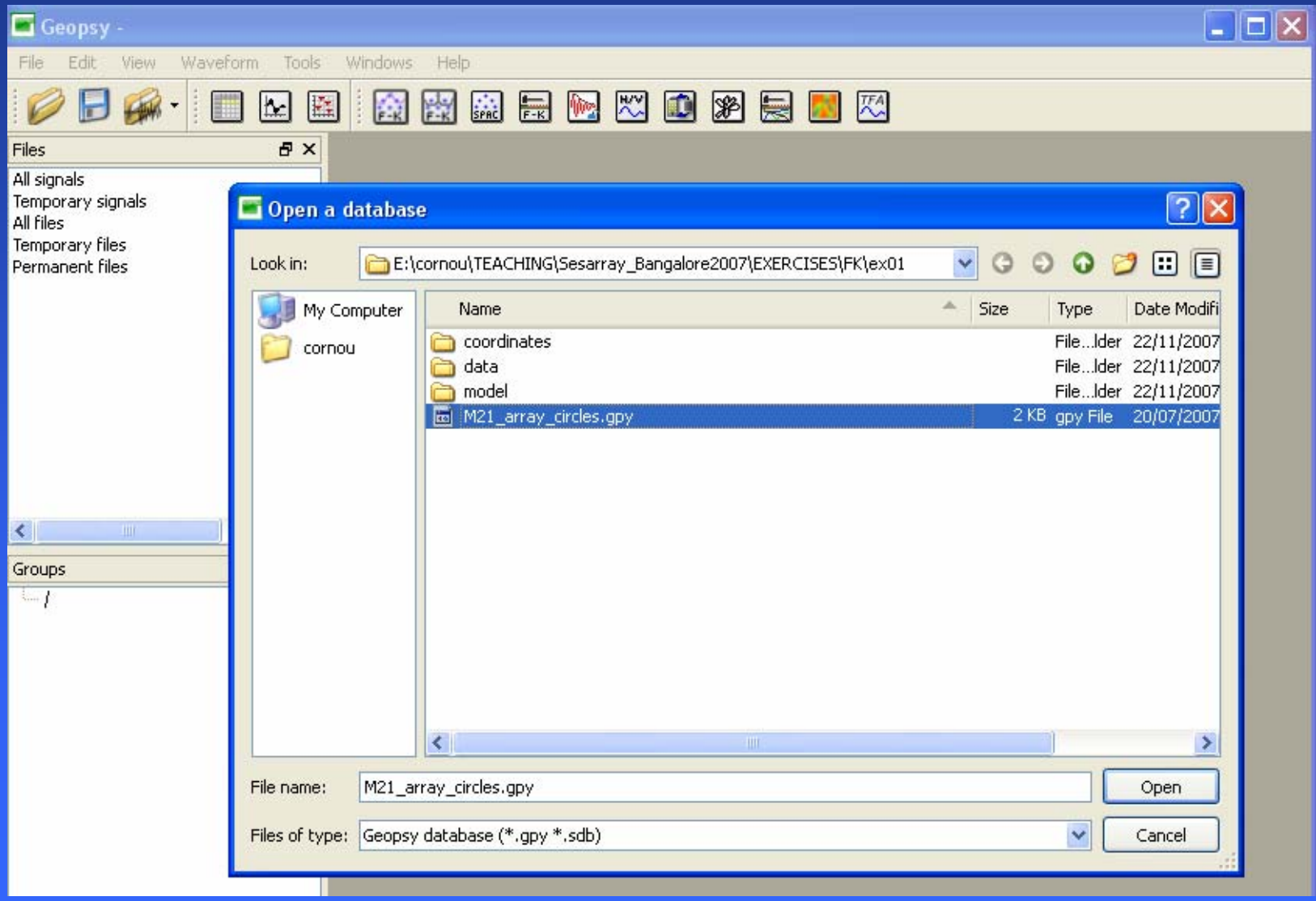
(3) We will then provide quantitative criteria for choosing the processing parameters which are related to the array layout

(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

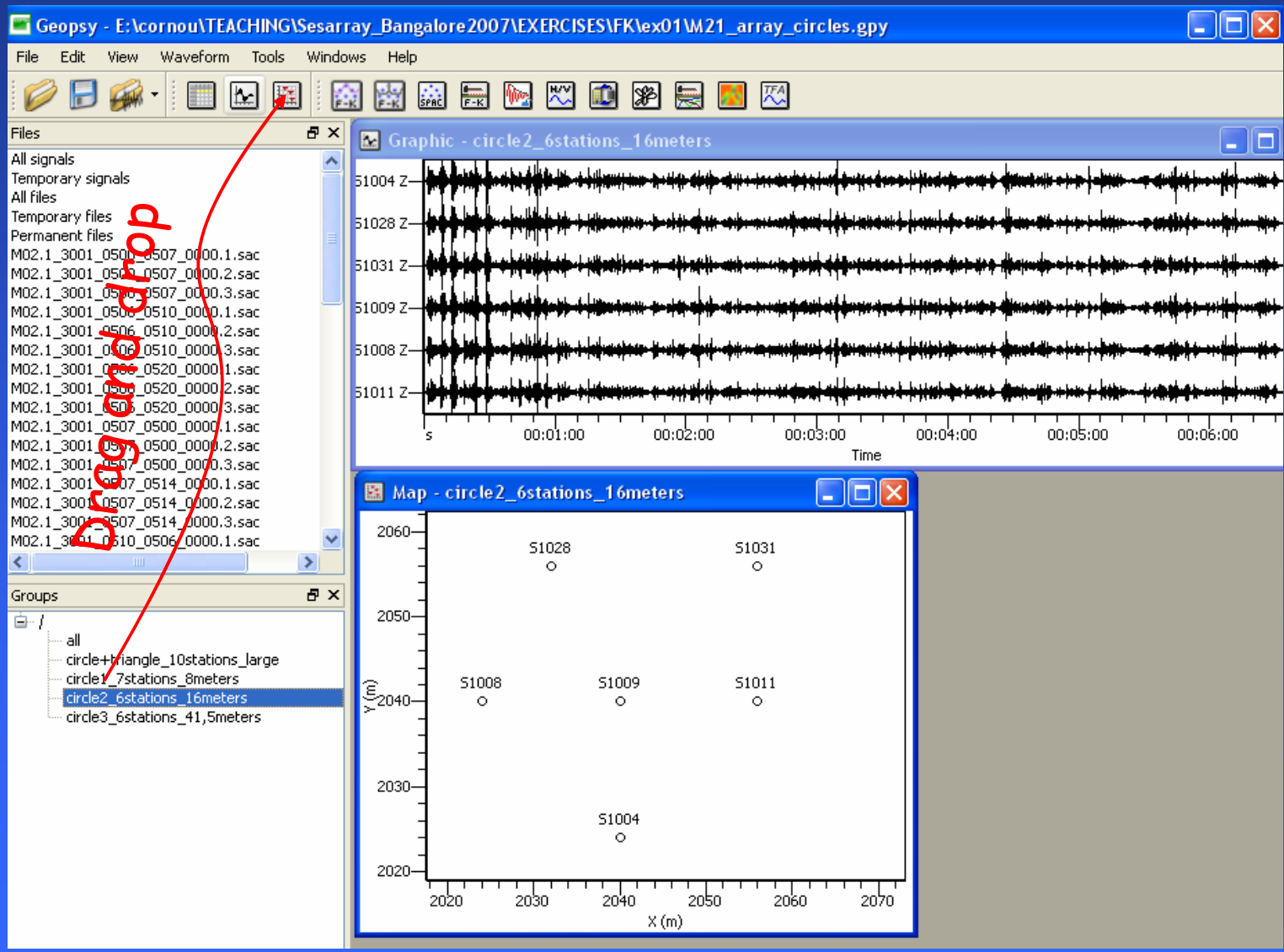
Loading geopsy database

~/data/EXERCISES_FK/EX01/.gpy*



Using Ambient Vibration Array Techniques for Site Characterisation

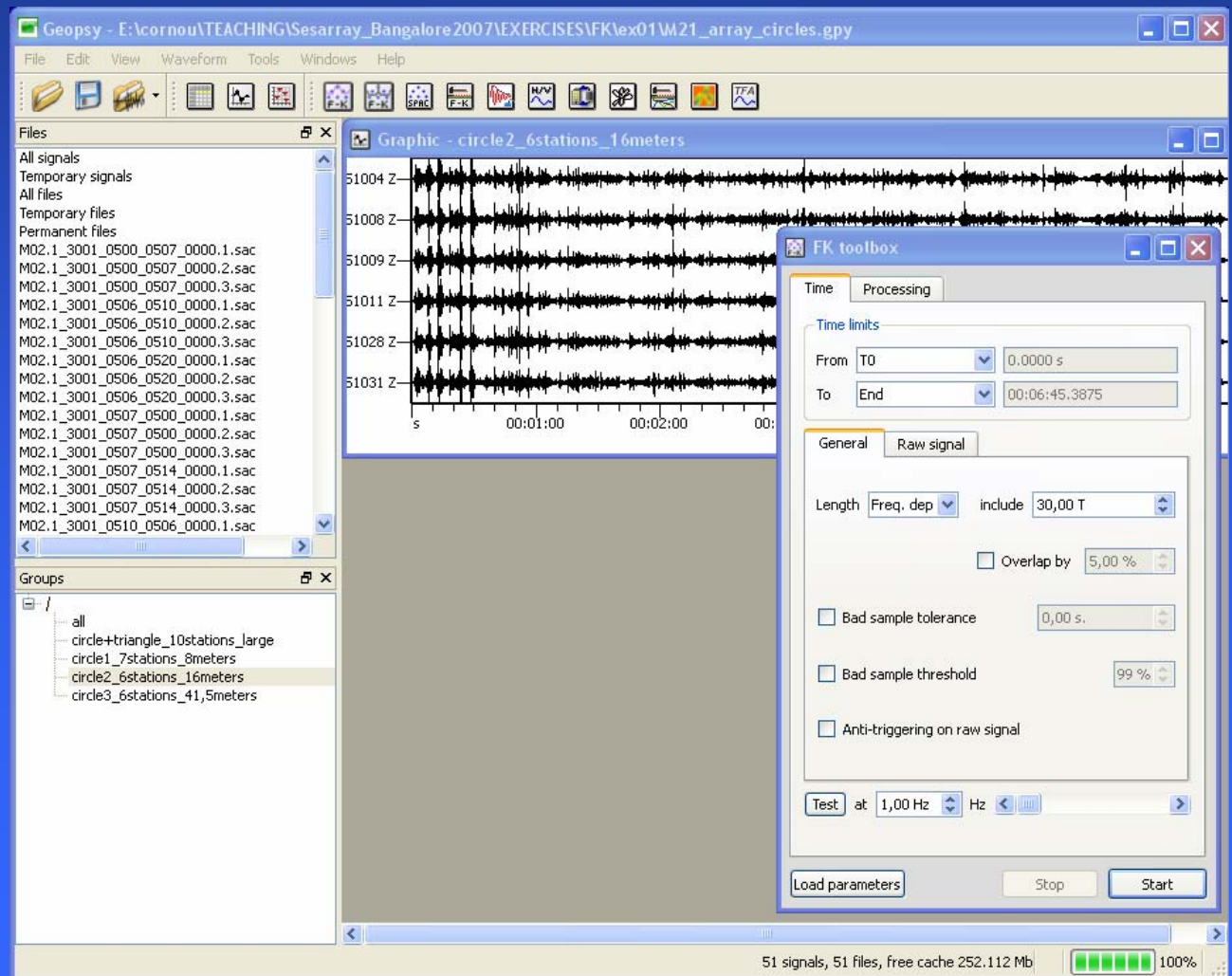
Display signals and array layout



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



Using Ambient Vibration Array Techniques for Site Characterisation

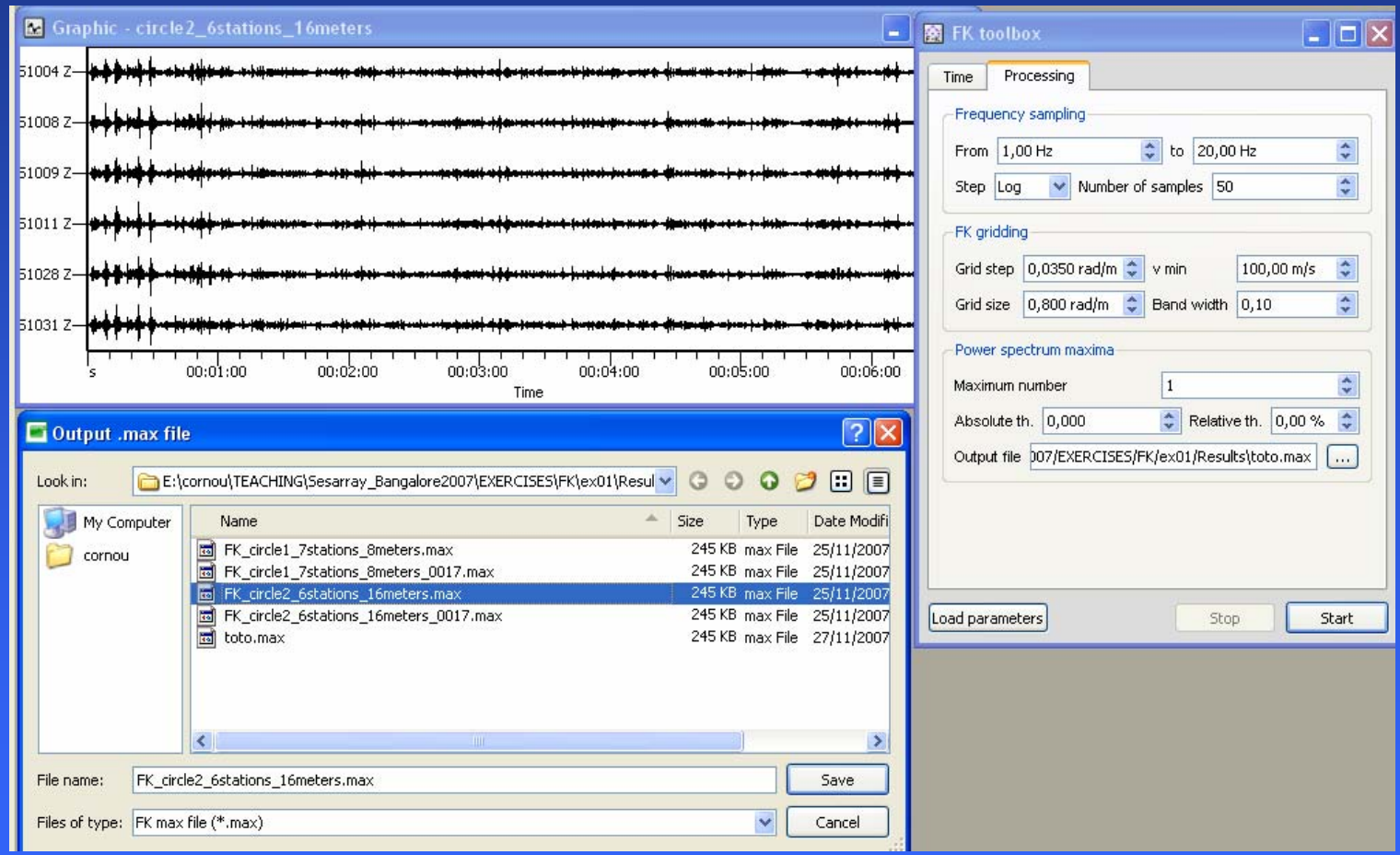
- Set processing parameters
- Set name of output file (.max extension)

Fmin=1 Hz
Fmax=20 Hz
Nb samples = 50

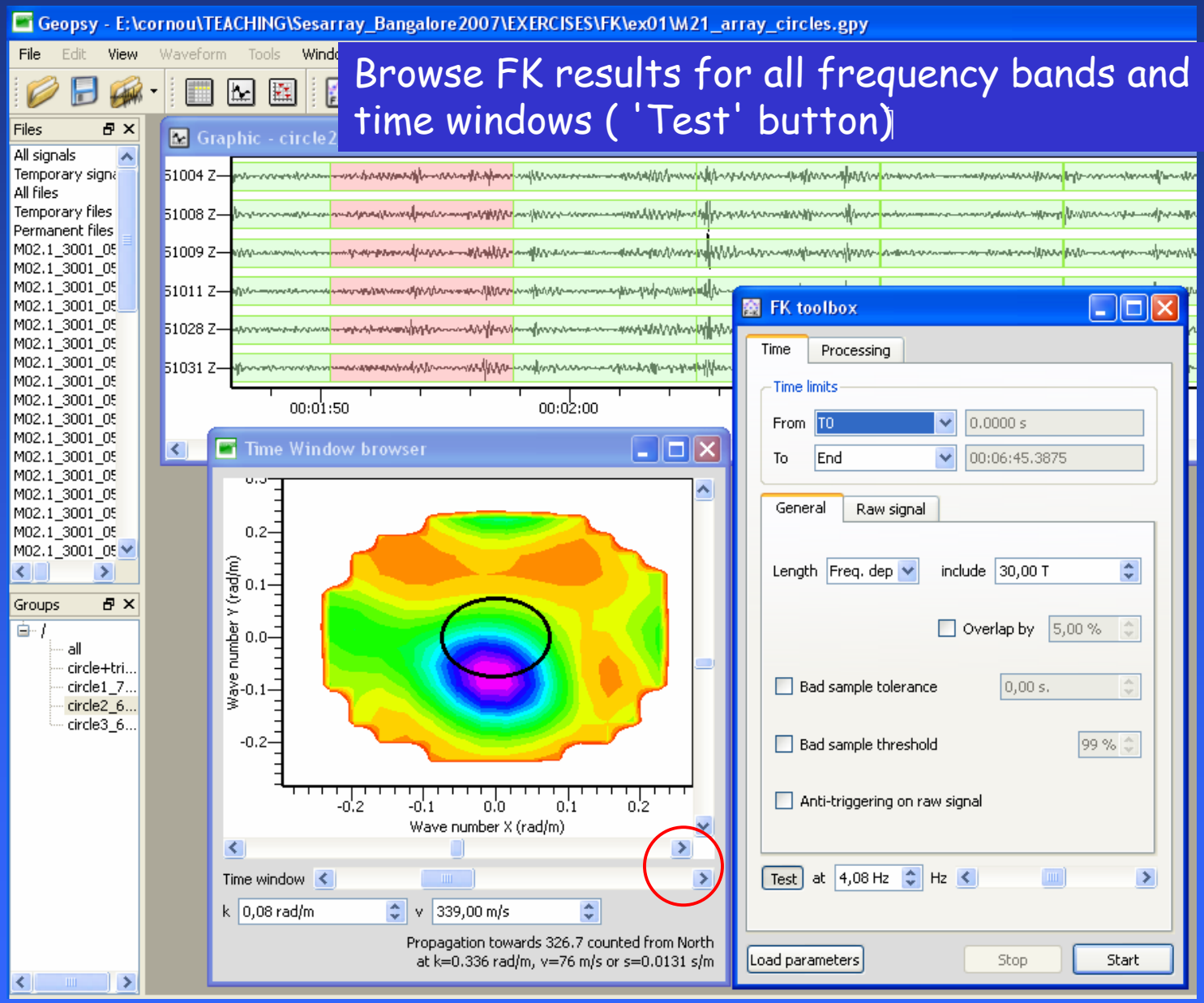
Grid_step=
0.035 rad/m

Grid_size=
0.8 rad/m

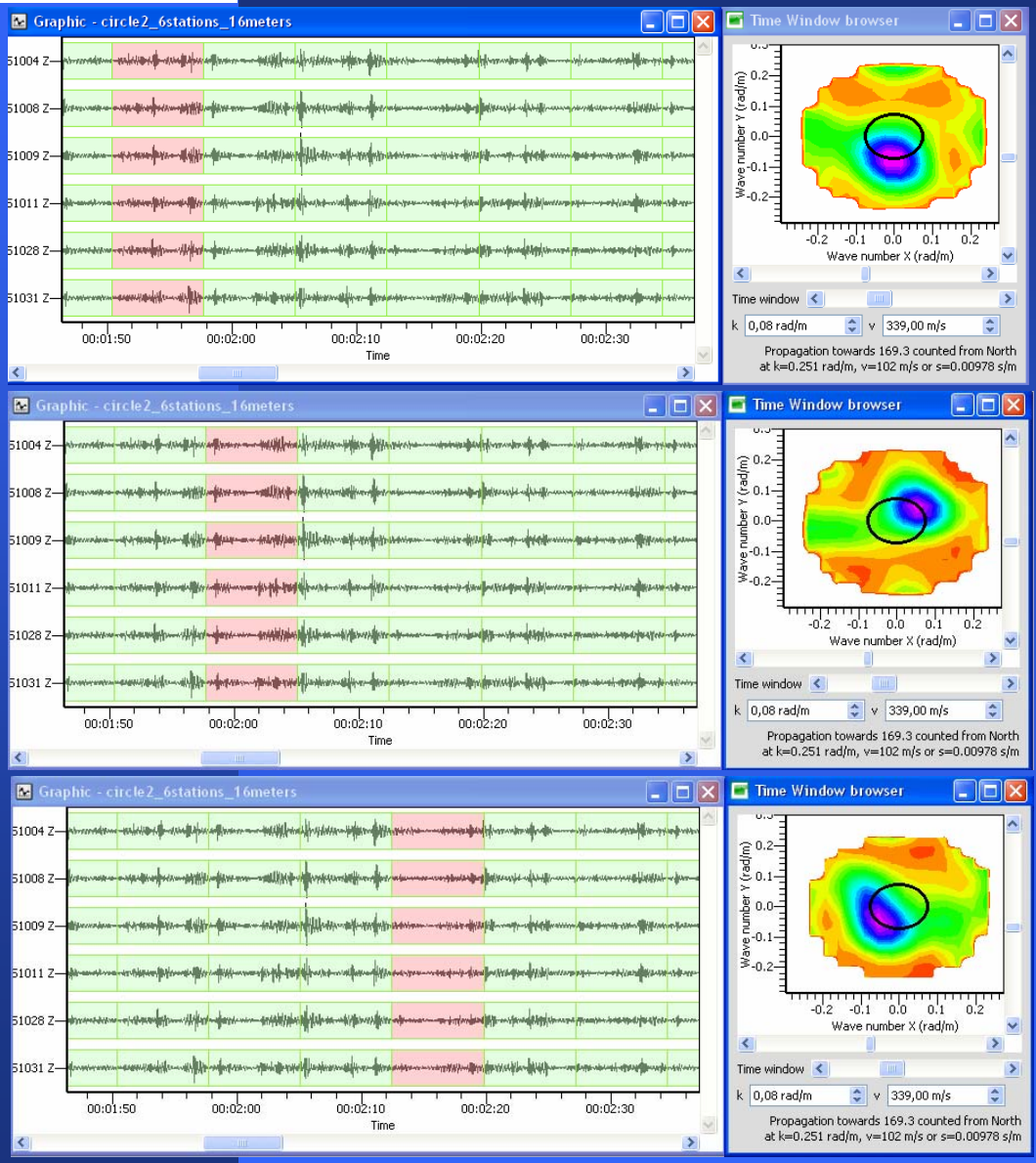
Vmin=100 m/s



Using Ambient Vibration Array Techniques for Site Characterisation



Using Ambient Vibration Array Techniques for Site Characterisation



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.

Using Ambient Vibration Array Techniques for Site Characterisation

FK results: output .max and .log files

MINGW32:/e/cornou/TEACHING/Sesarray_Bangalore2007/EXERCISES/FK...

```
cornou@LGIT-1229 /e/cornou/TEACHING/Sesarray_Bangalore2007/EXERCIS
ES/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/EXERCIS
ES/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

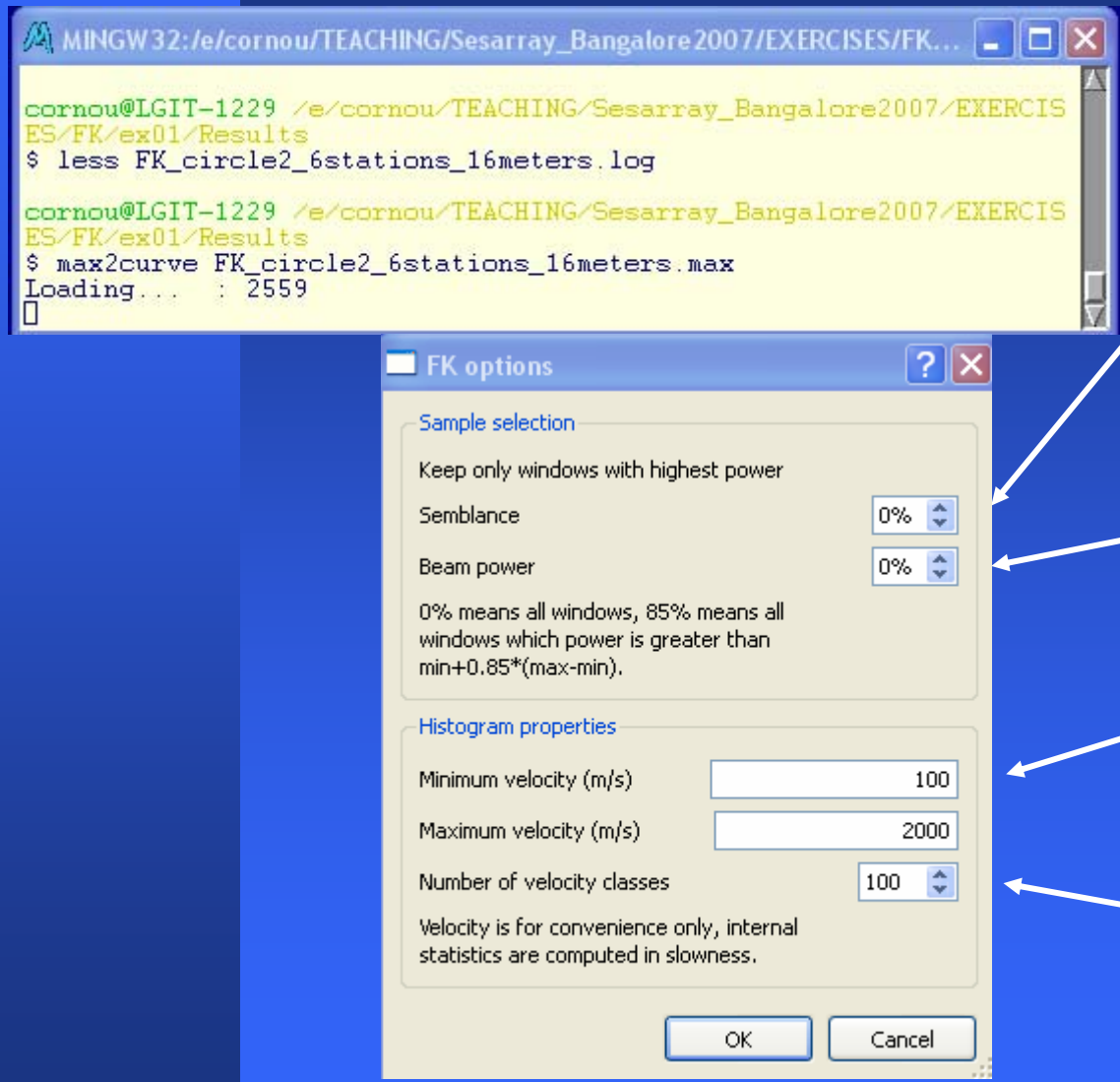
MINGW32:/e/cornou/TEACHING/Sesarray_Bangalore2007/EXERCISES/FK...

```
cornou@LGIT-1229 /e/cornou/TEACHING/Sesarray_Bangalore2007/EXERCIS
ES/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



FK histograms: max2curve

Computed from semblance estimates

Computed from beampower estimates

Histograms computed within this velocity range

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

Using Ambient Vibration Array Techniques for Site Characterisation

max2curve - FK - E:\cornou\TEACHING\Sesarray_Bangalore2007\EXERCISES\FK\ex01\Results\FK_circle2_6station...

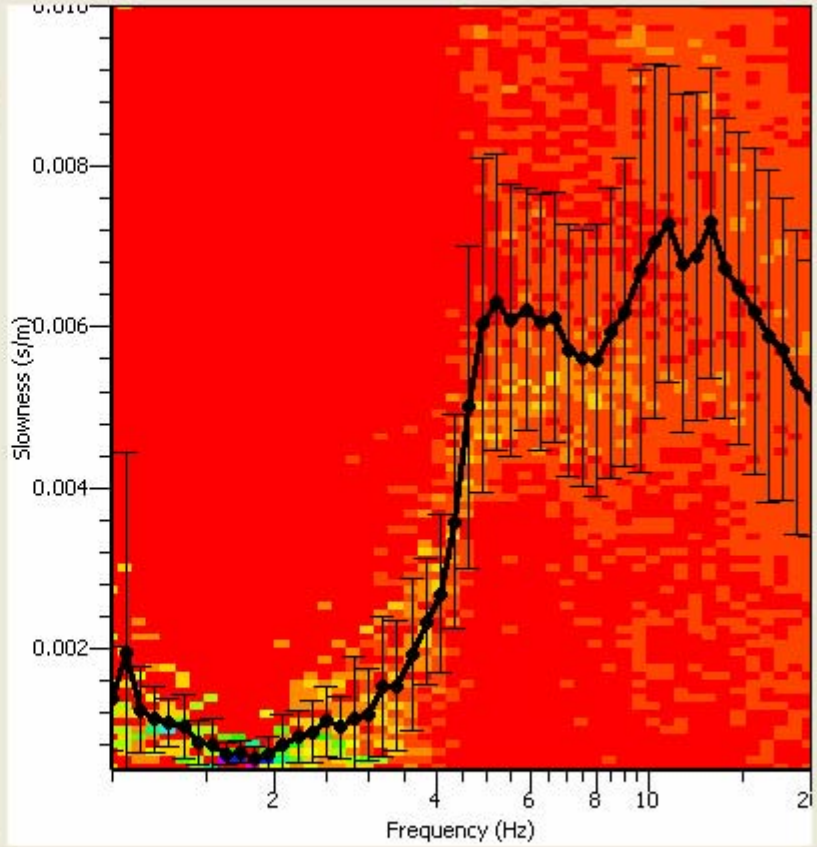
Load | Clear | Legend | Average

Curve data

Curve 1 of 1

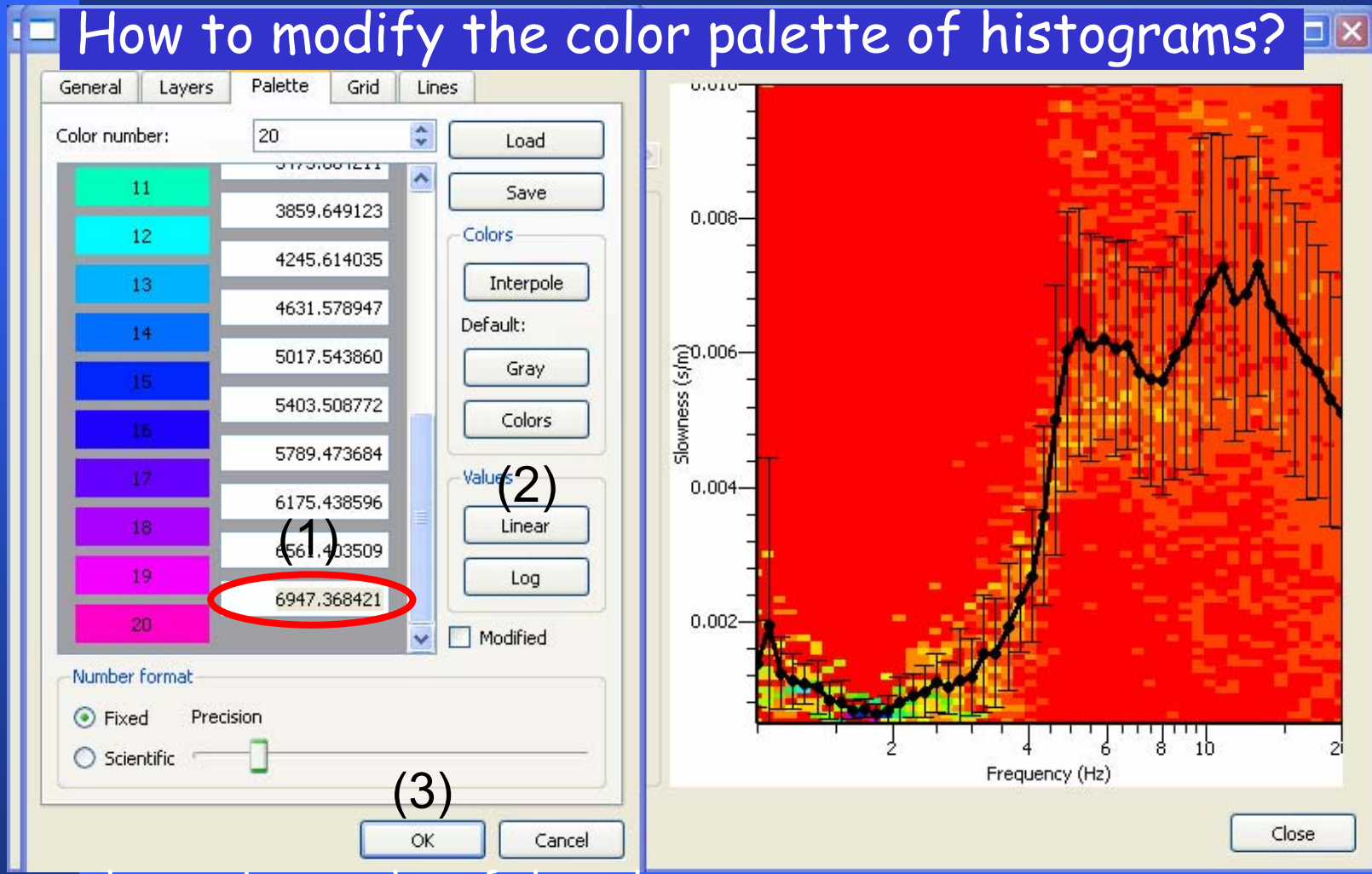
	Frequency	Period	Valid	Average	Std dev	Weight
1	1	1	☑	0,0013...	0,0006...	12
2	1,06304	0,94...	☑	0,0019...	0,0024...	13
3	1,13006	0,88...	☑	0,0012...	0,0005...	14
4	1,20131	0,83...	☑	0,0011...	0,0004...	15
5	1,27705	0,78...	☑	0,0010...	0,0002...	10
6	1,35756	0,73...	☑	0,0010...	0,0003...	9
7	1,44314	0,69...	☑	0,0008...	0,0002...	6
8	1,53413	0,65...	☑	0,0008...	0,0003...	6
9	1,63085	0,61...	☑	0,0006...	0,0001...	5

Name: Curve #1 | ☑ Visible | Actions



Filter | Smooth | Save | Close

How to modify the color palette of histograms?



(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 ?

max2curve - FK - E:\cornou\TEACHING\Sesarray_Bangalore2007\EXERCISES\FK\ex01\Results\FK_circle2_6station...

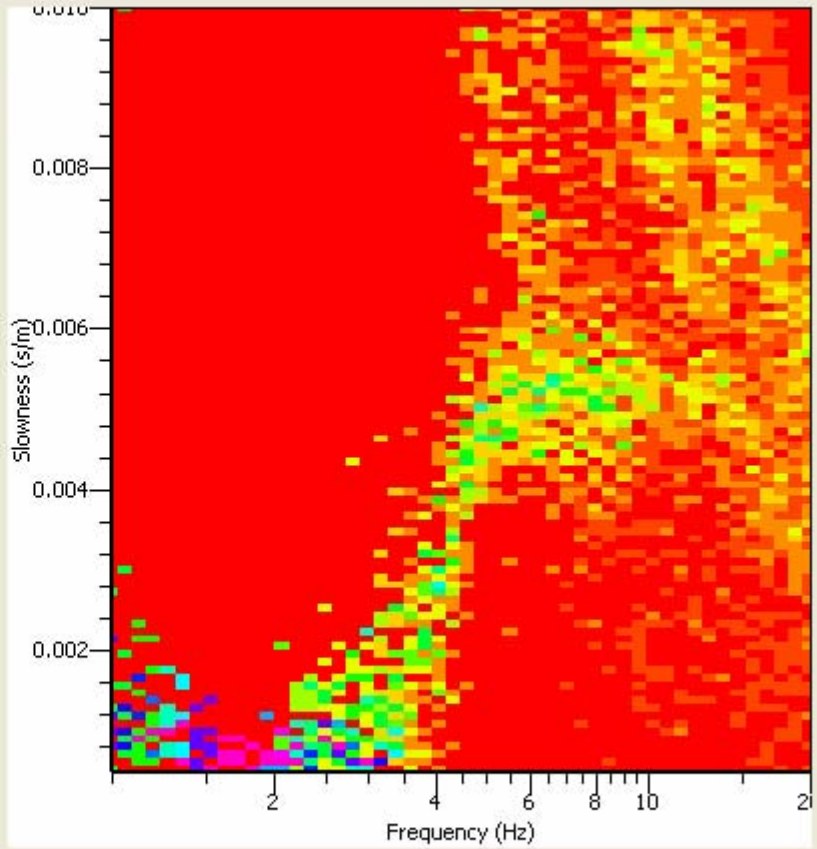
Load | Clear | Legend | Average

Curve data

Curve 1 of 1

	Frequency	Period	Valid	Average	Std dev	Weight
1	1	1	☑	0,0013...	0,0006...	12
2	1,06304	0,94...	☑	0,0019...	0,0024...	13
3	1,13006	0,88...	☑	0,0012...	0,0005...	14
4	1,20131	0,83...	☑	0,0011...	0,0004...	15
5	1,27705	0,78...	☑	0,0010...	0,0002...	10
6	1,35756	0,73...	☑	0,0010...	0,0003...	9
7	1,44314	0,69...	☑	0,0008...	0,0002...	6
8	1,53413	0,65...	☑	0,0008...	0,0003...	6
9	1,63085	0,61...	☑	0,0006...	0,0001...	5

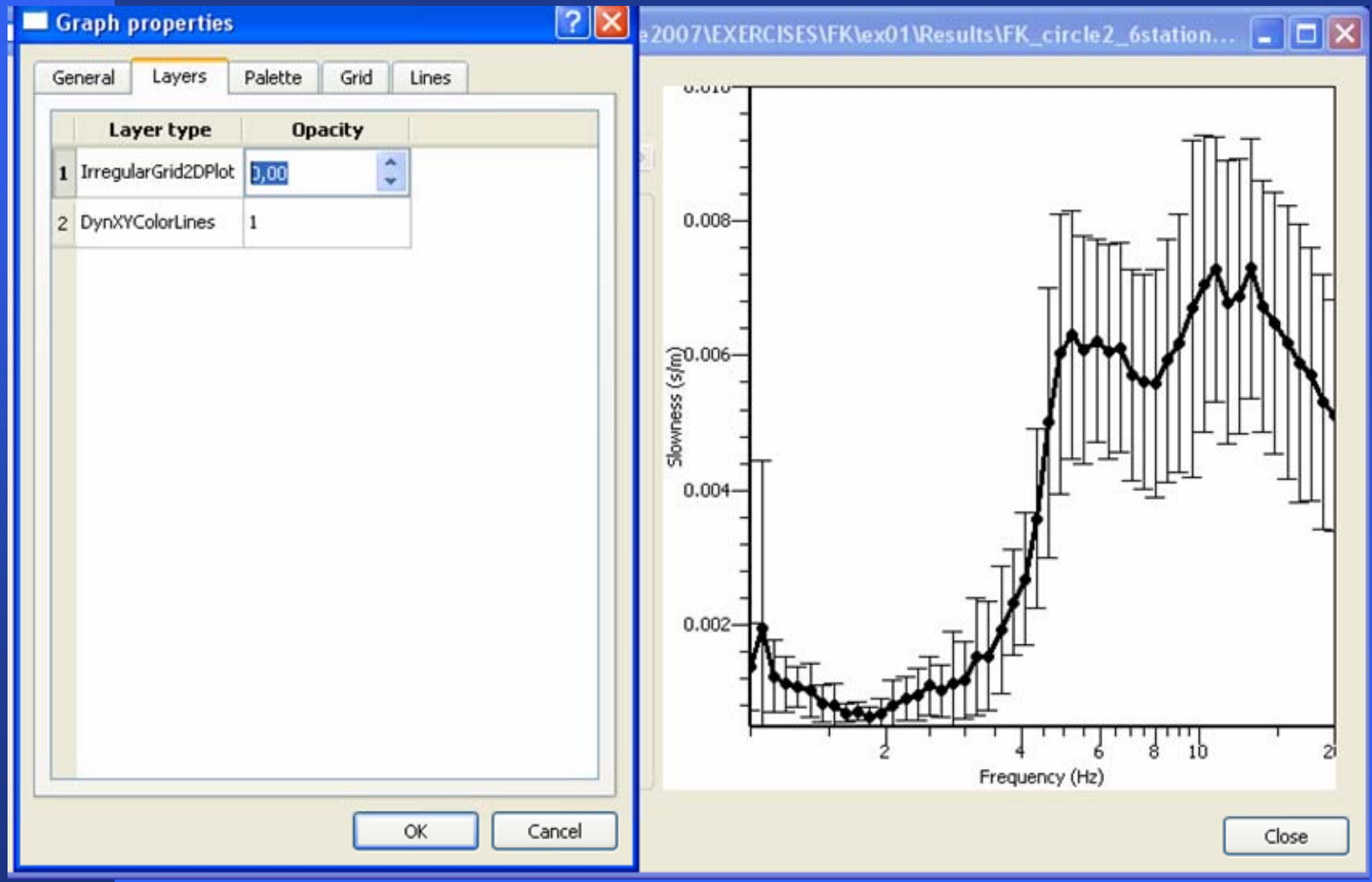
Name: Curve #1 | Visible | Actions



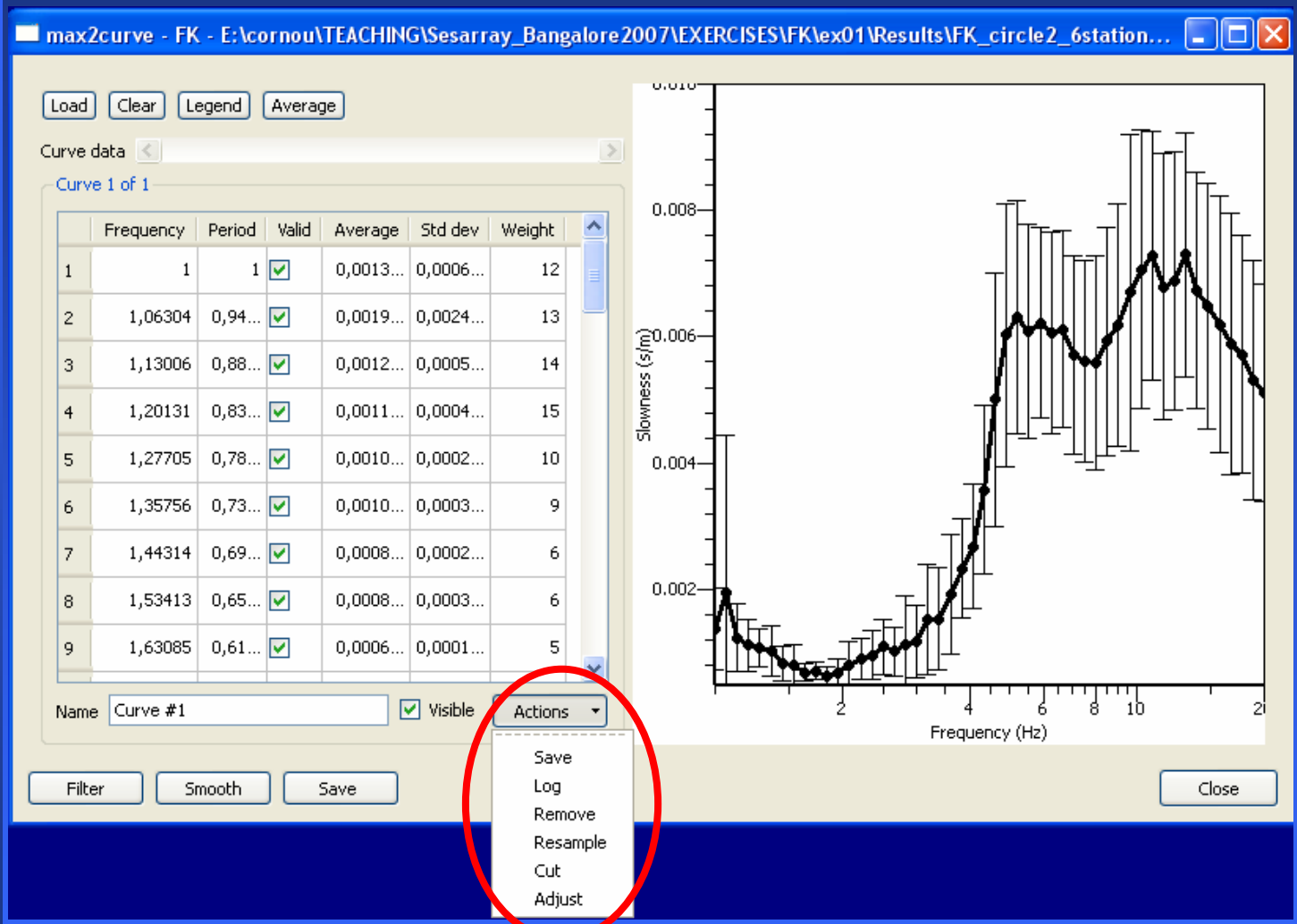
Filter | Smooth | Save | Close

Using Ambient Vibration Array Techniques for Site Characterisation

How to hide histograms ?

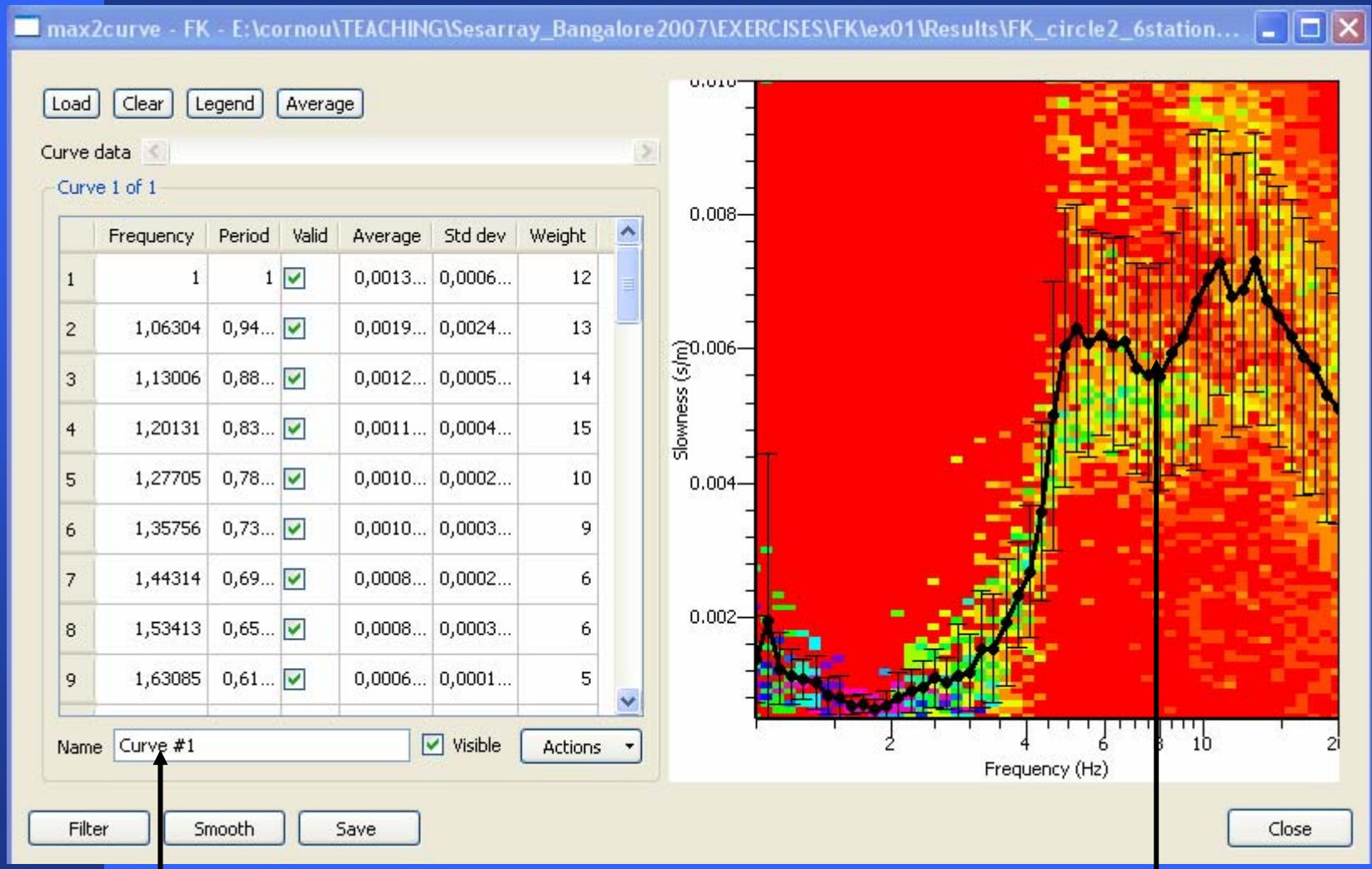


Using Ambient Vibration Array Techniques for Site Characterisation



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

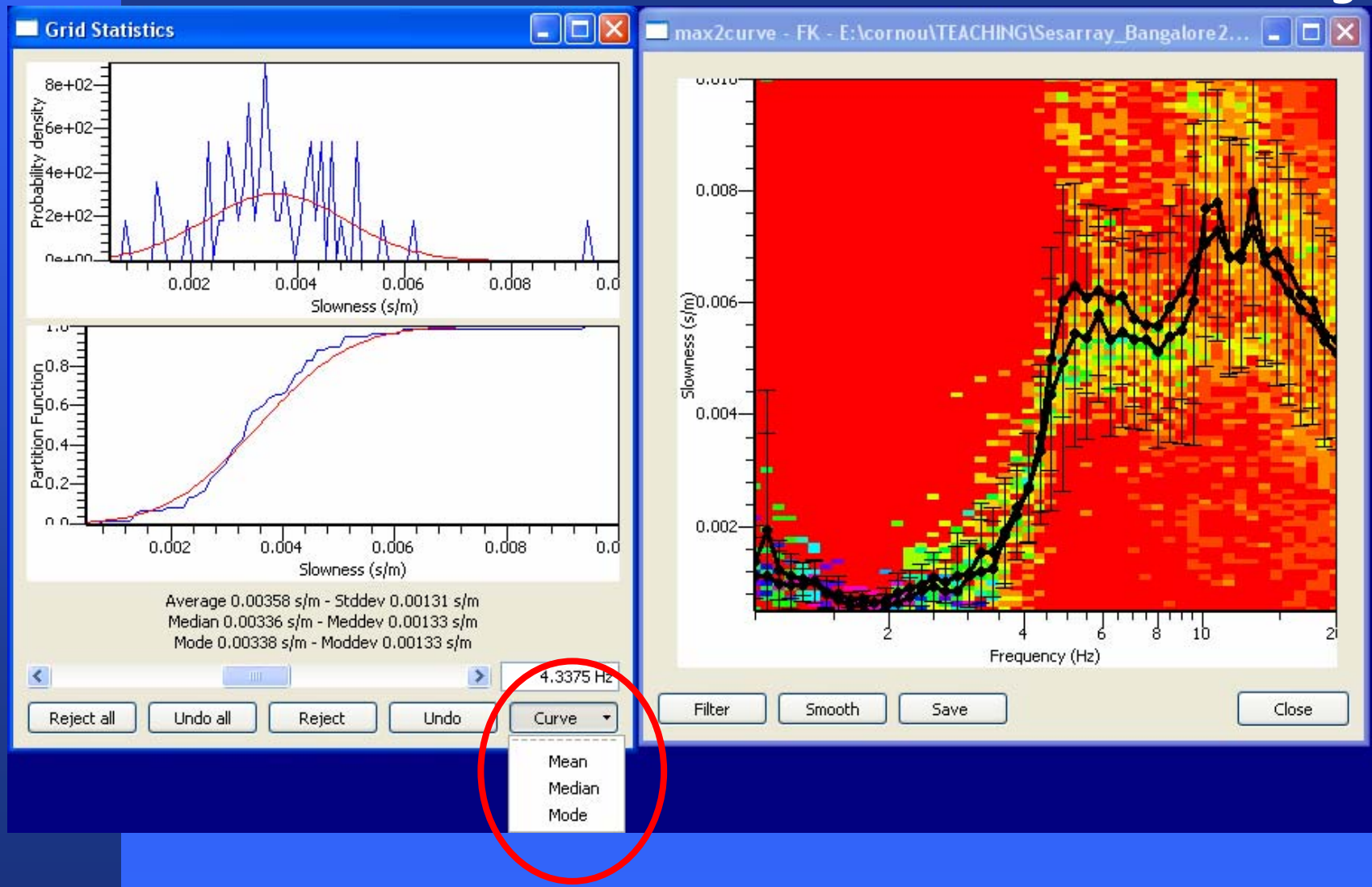
Using Ambient Vibration Array Techniques for Site Characterisation



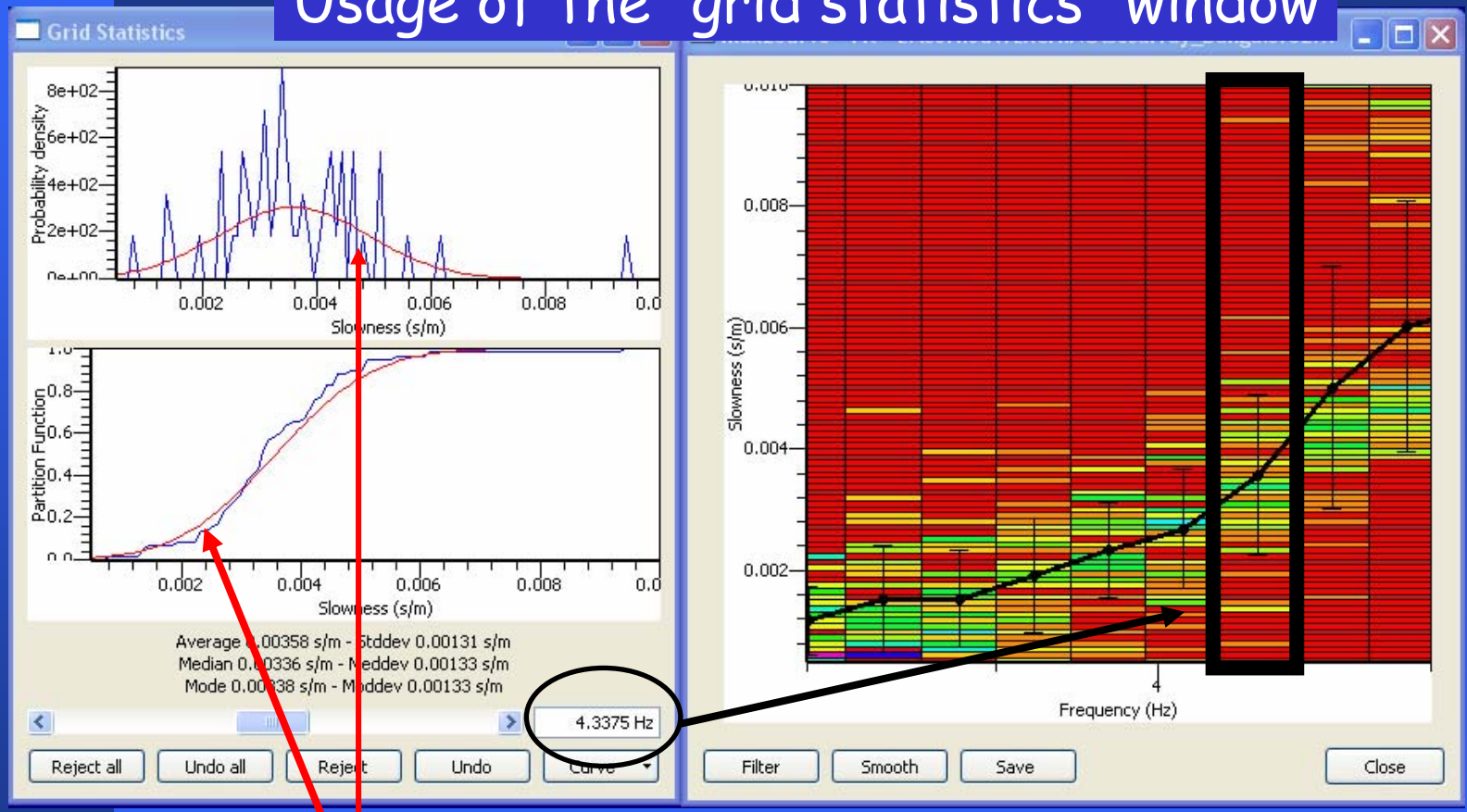
Curve identification (number/name)

Mean +/- std (by default)

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



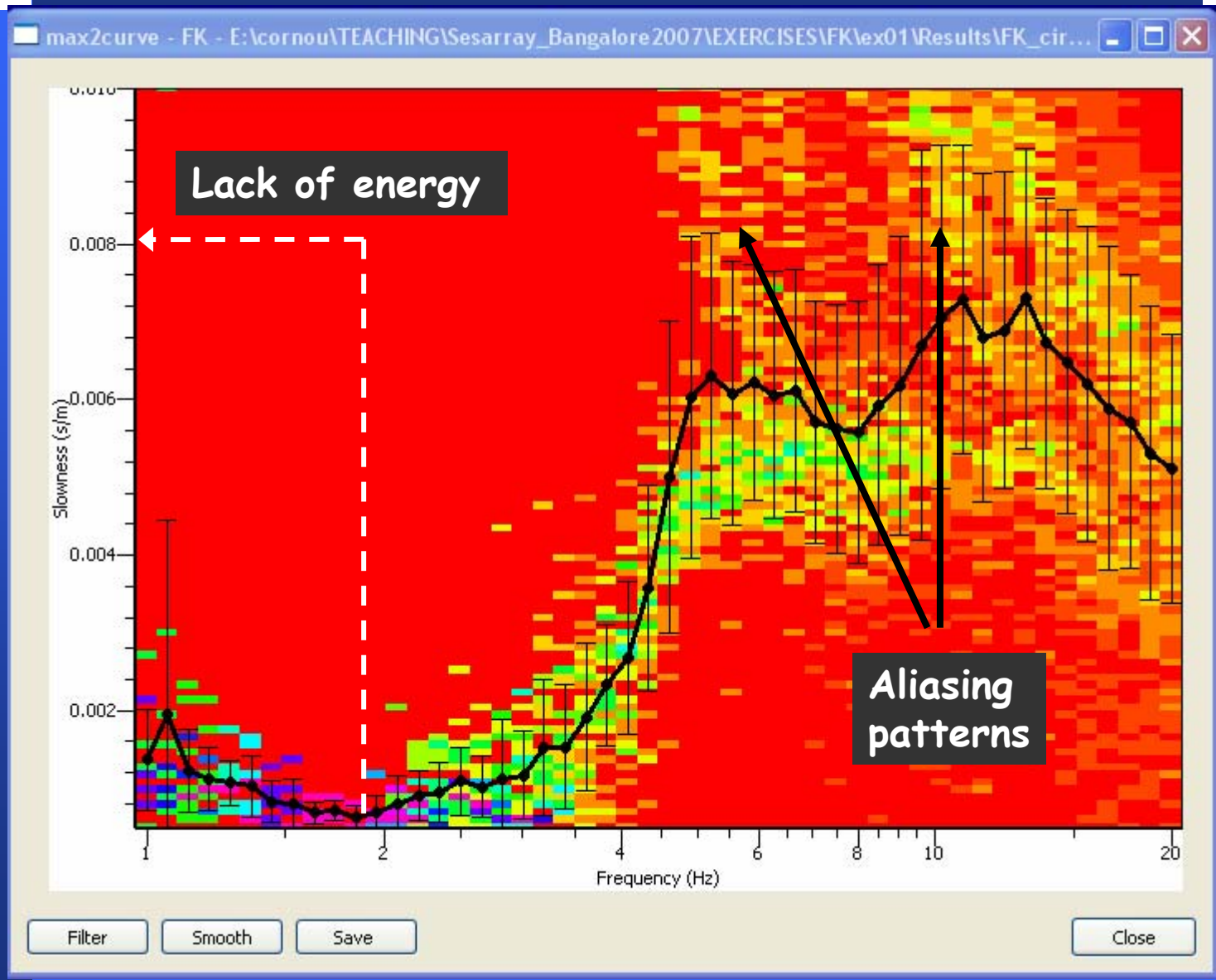
Usage of the "grid statistics" window



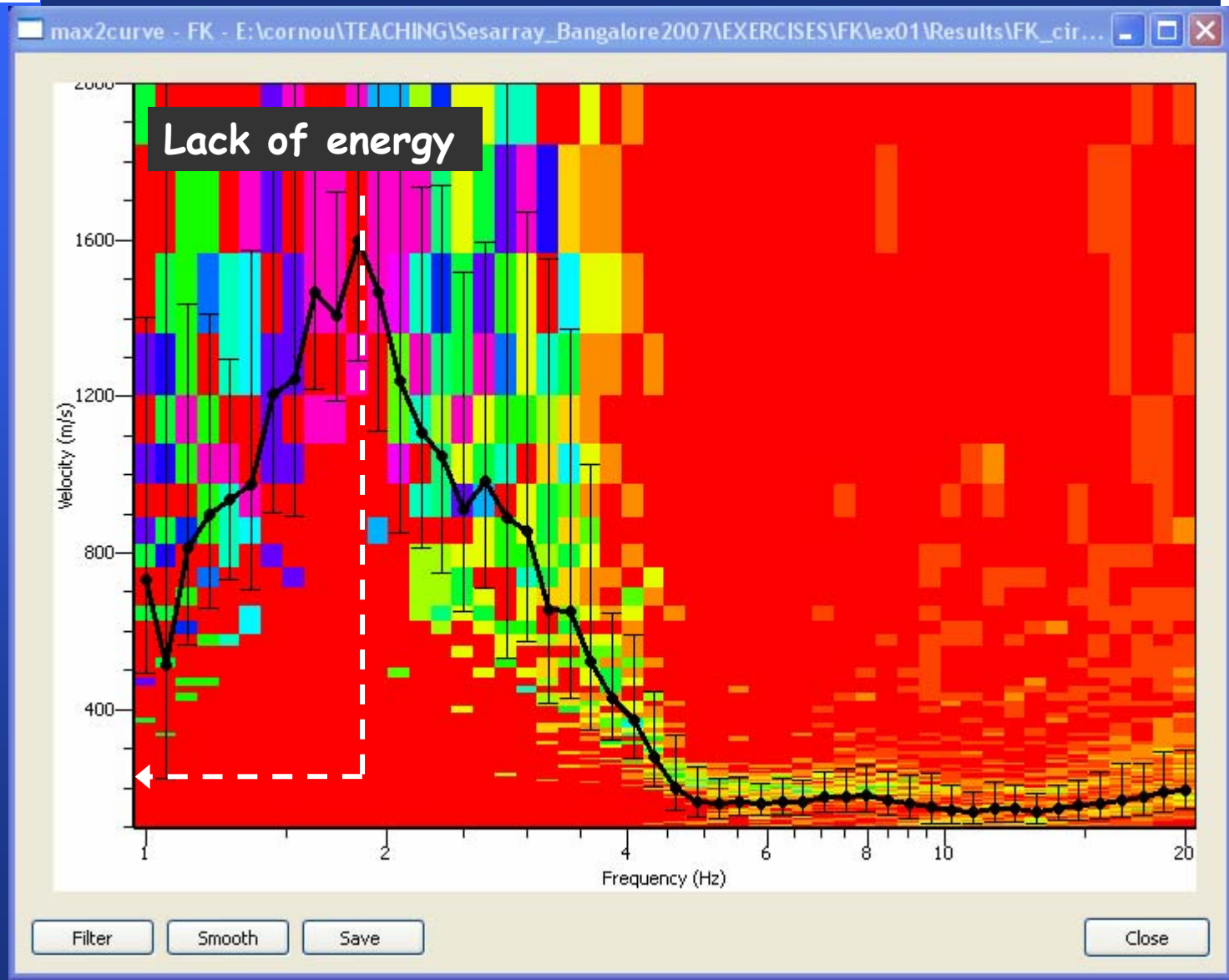
Gaussian distribution computed from the observed mean and standard deviation

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

Interpretation of FK histograms



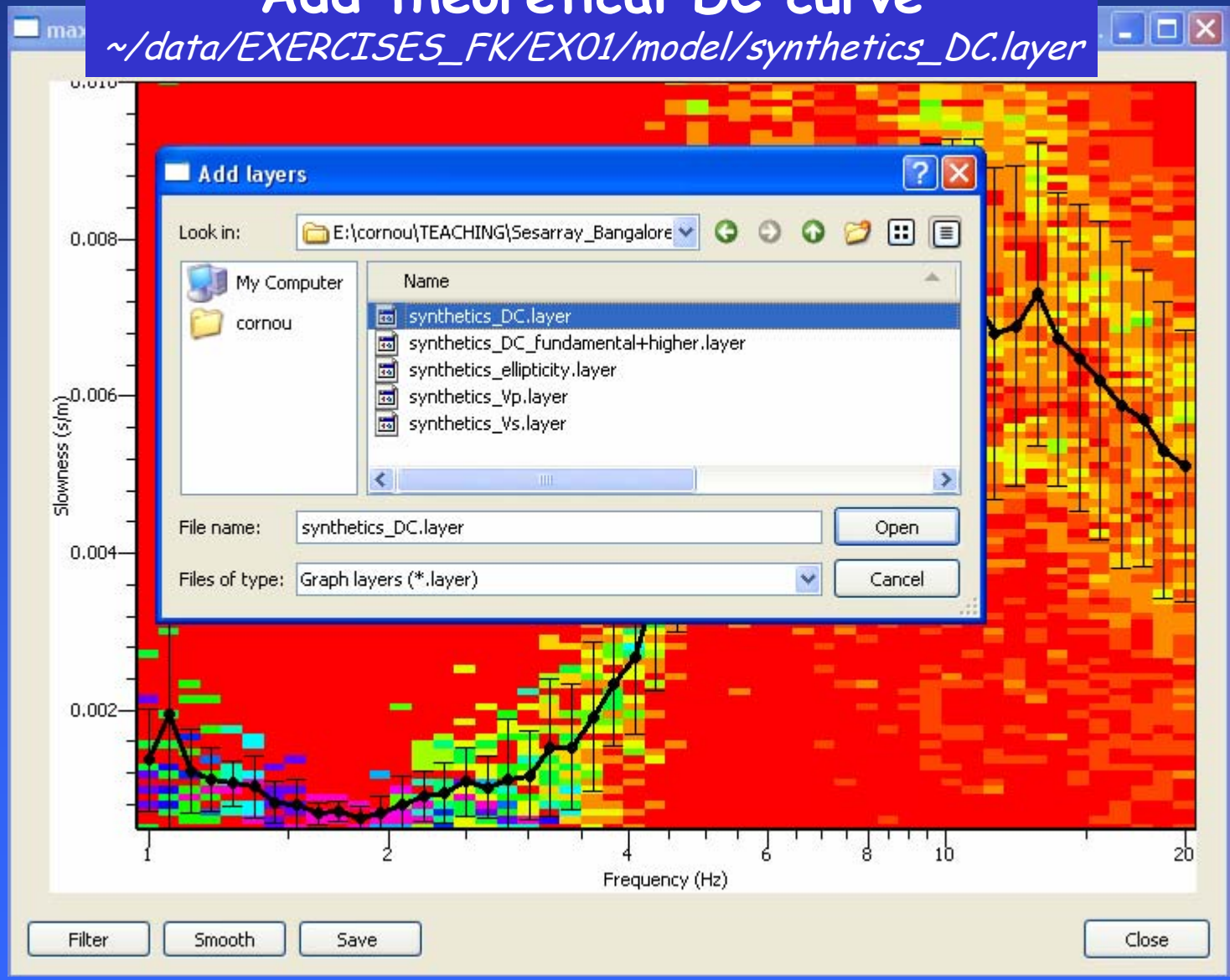
Using Ambient Vibration Array Techniques for Site Characterisation



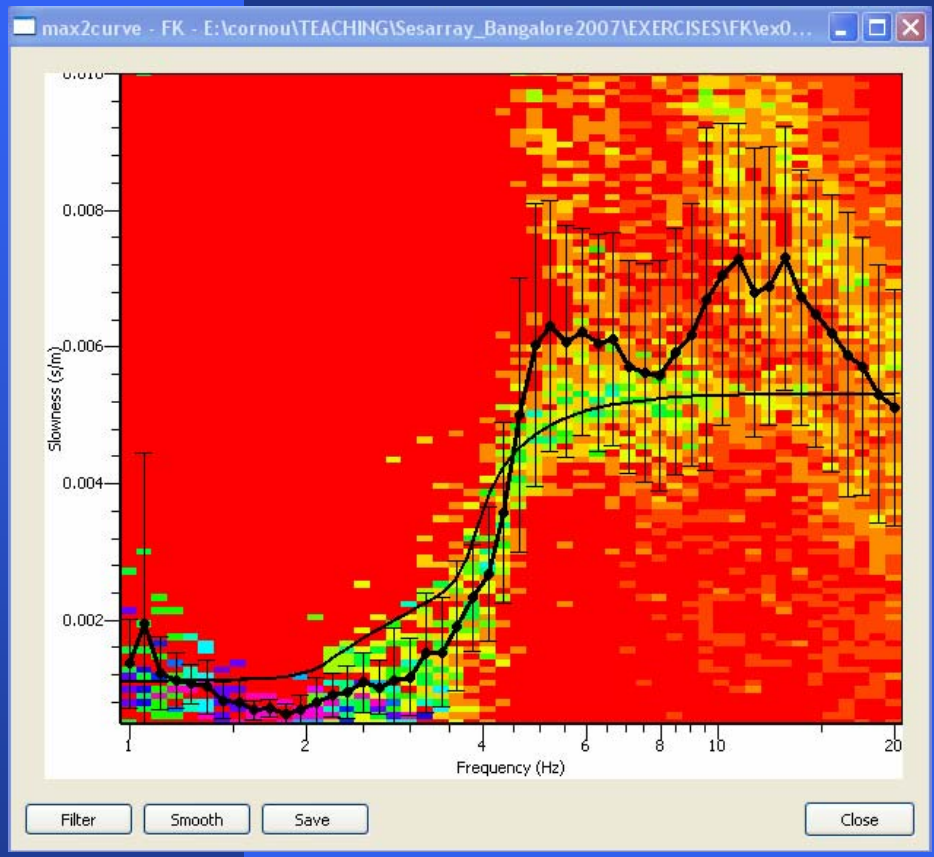
Using Ambient Vibration Array Techniques for Site Characterisation

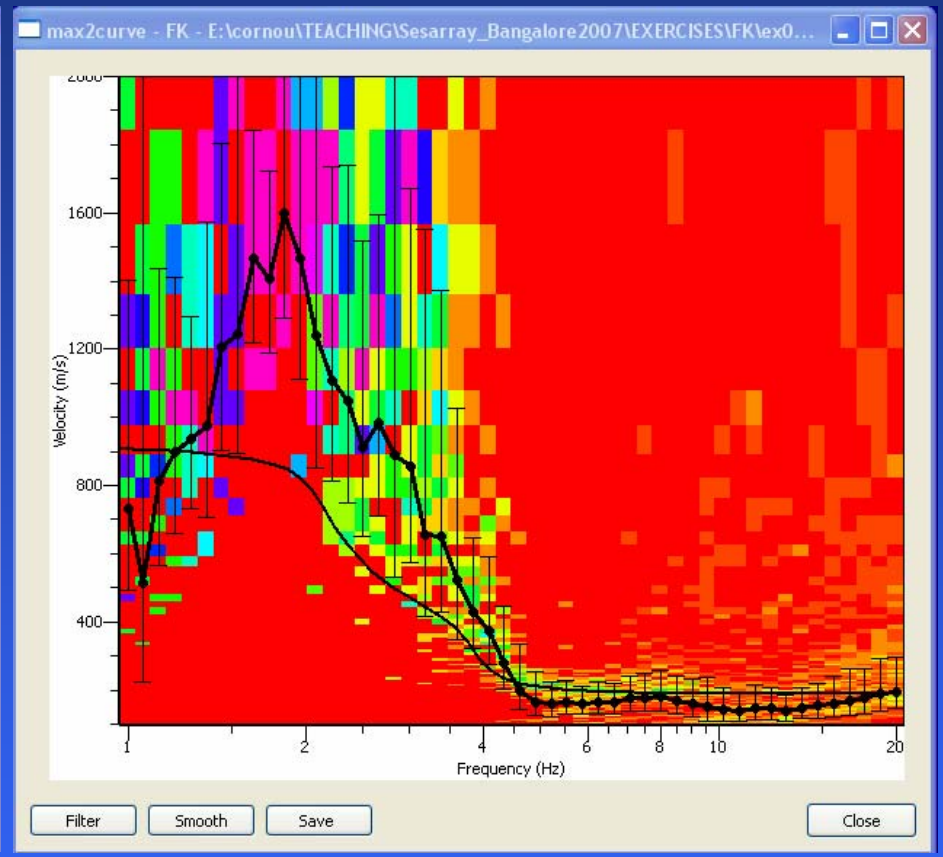
Add theoretical DC curve

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



Using Ambient Vibration Array Techniques for Site Characterisation





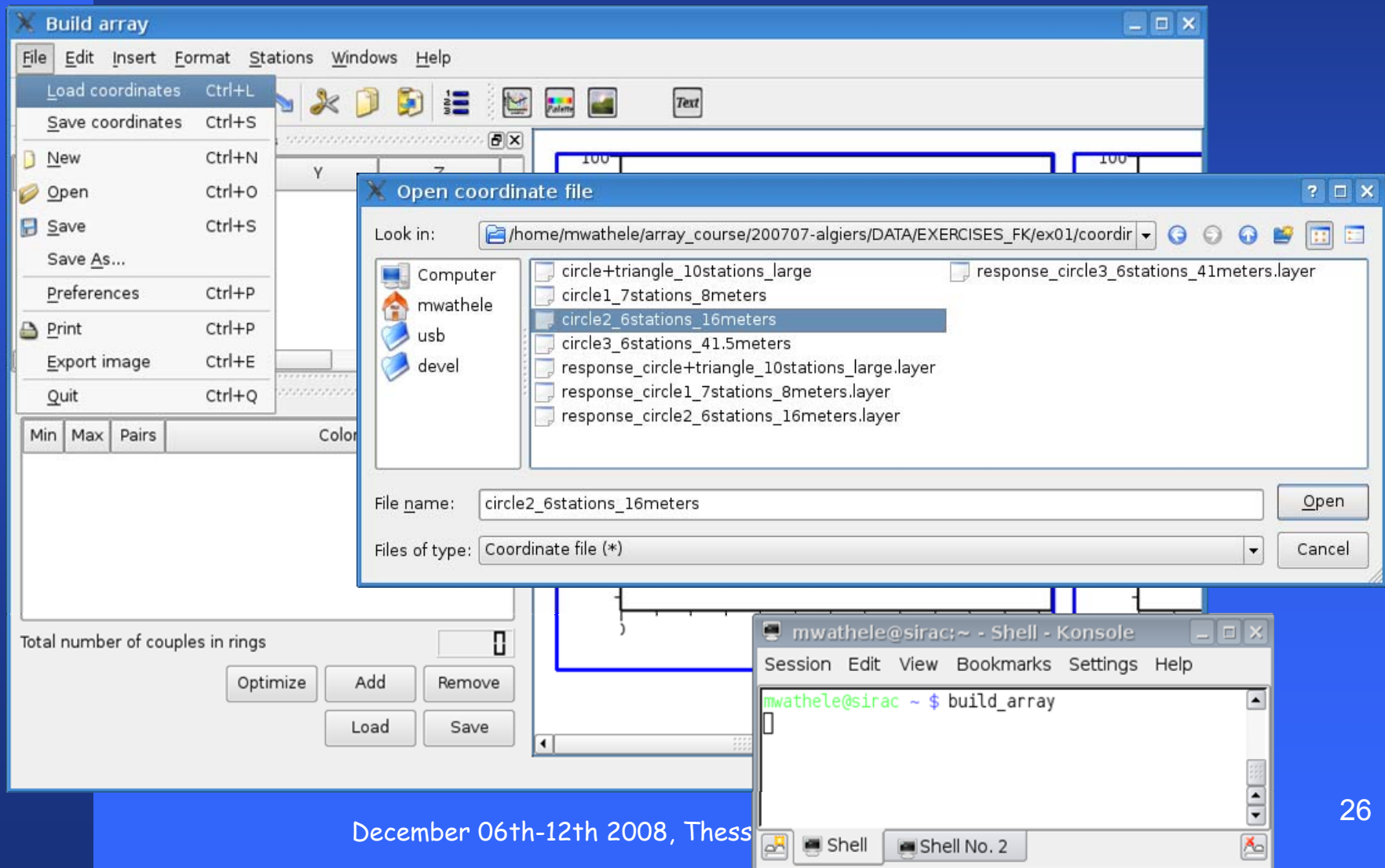
Above 4 Hz, mean curve is not representative of actual distribution which fits better the true dispersion curve

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

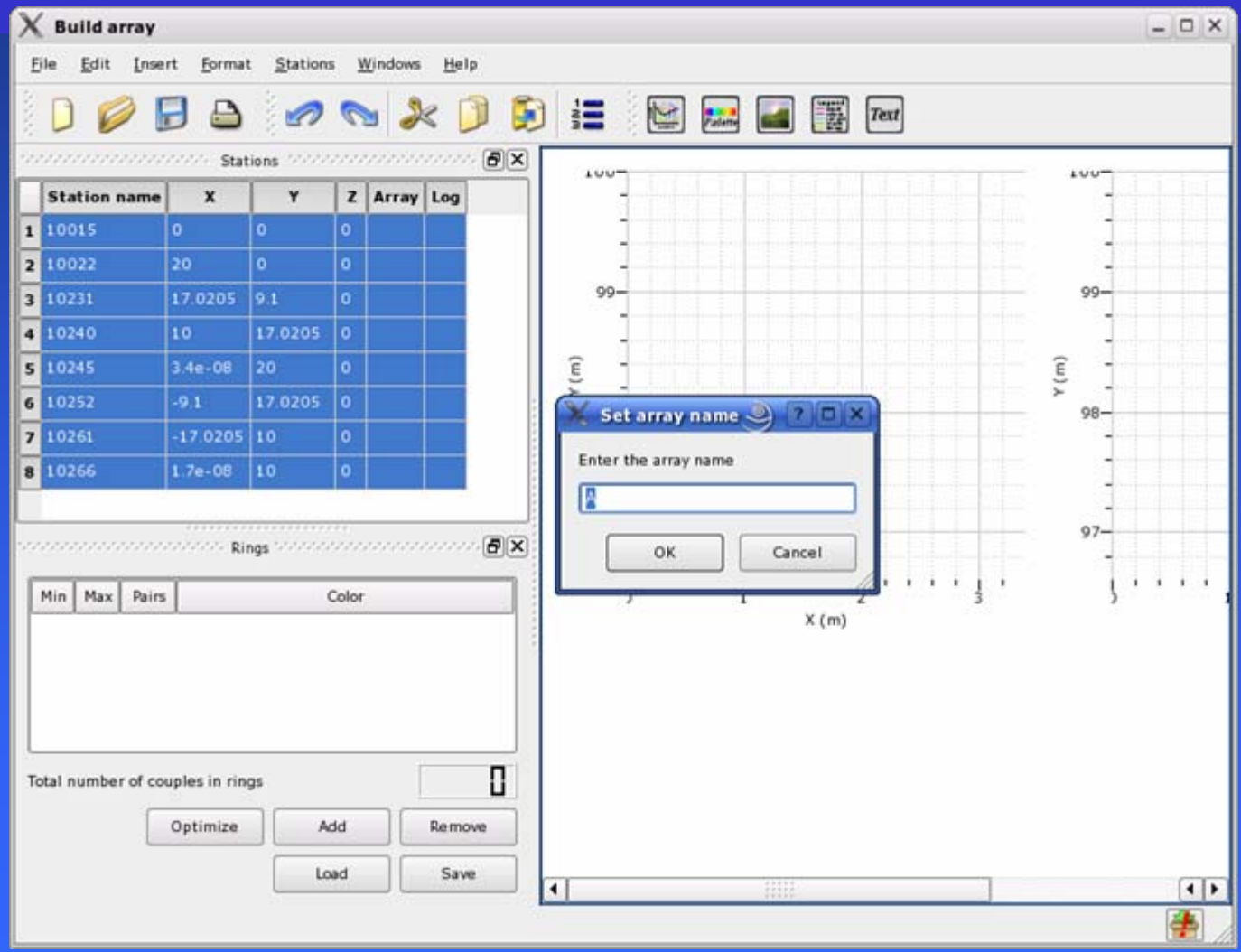
Using Ambient Vibration Array Techniques for Site Characterisation

Computing array response with *build_array*

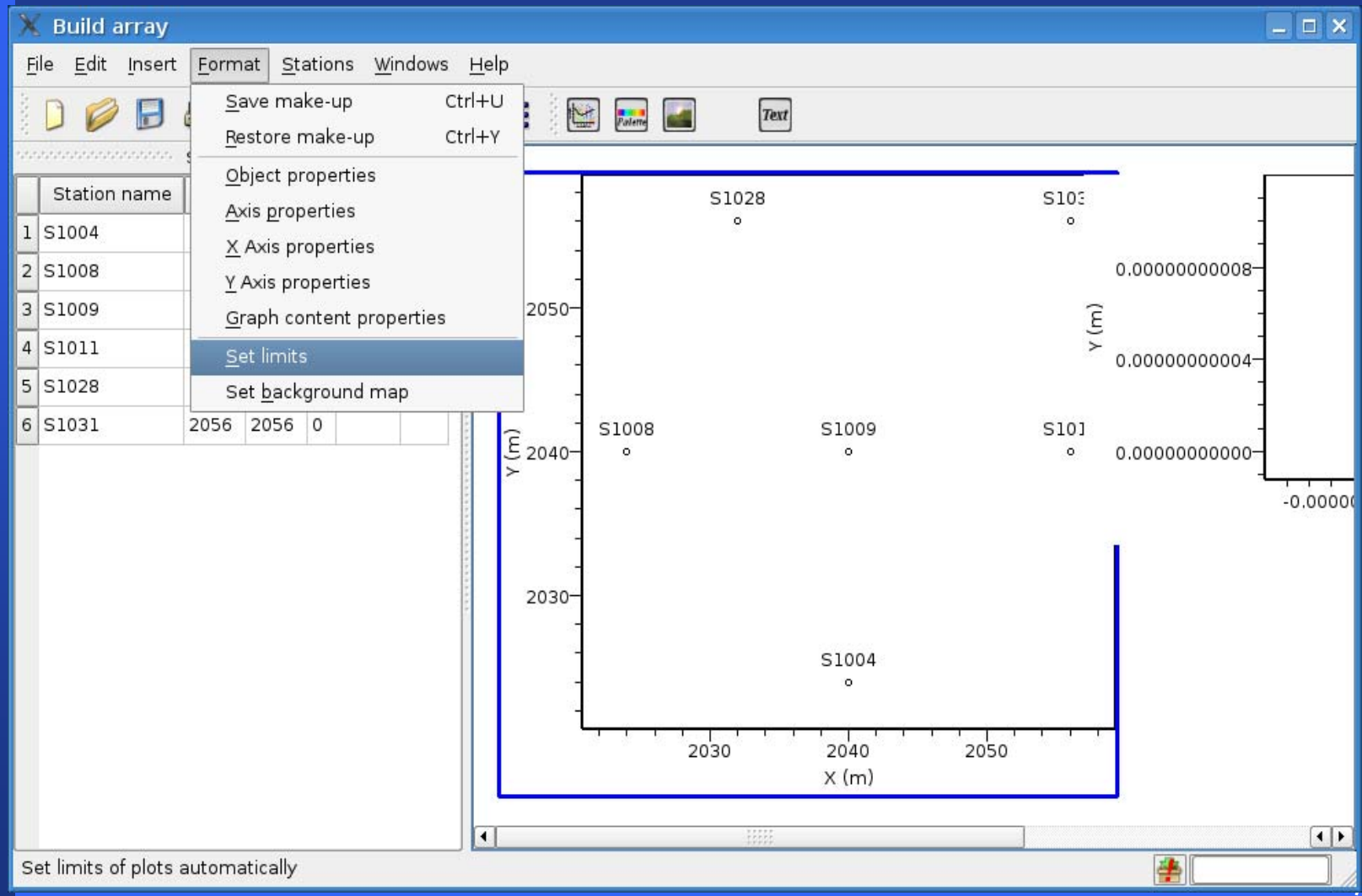
~/data/EXERCISES_FK/EX01/coordinates/circle2_6stations_16meters



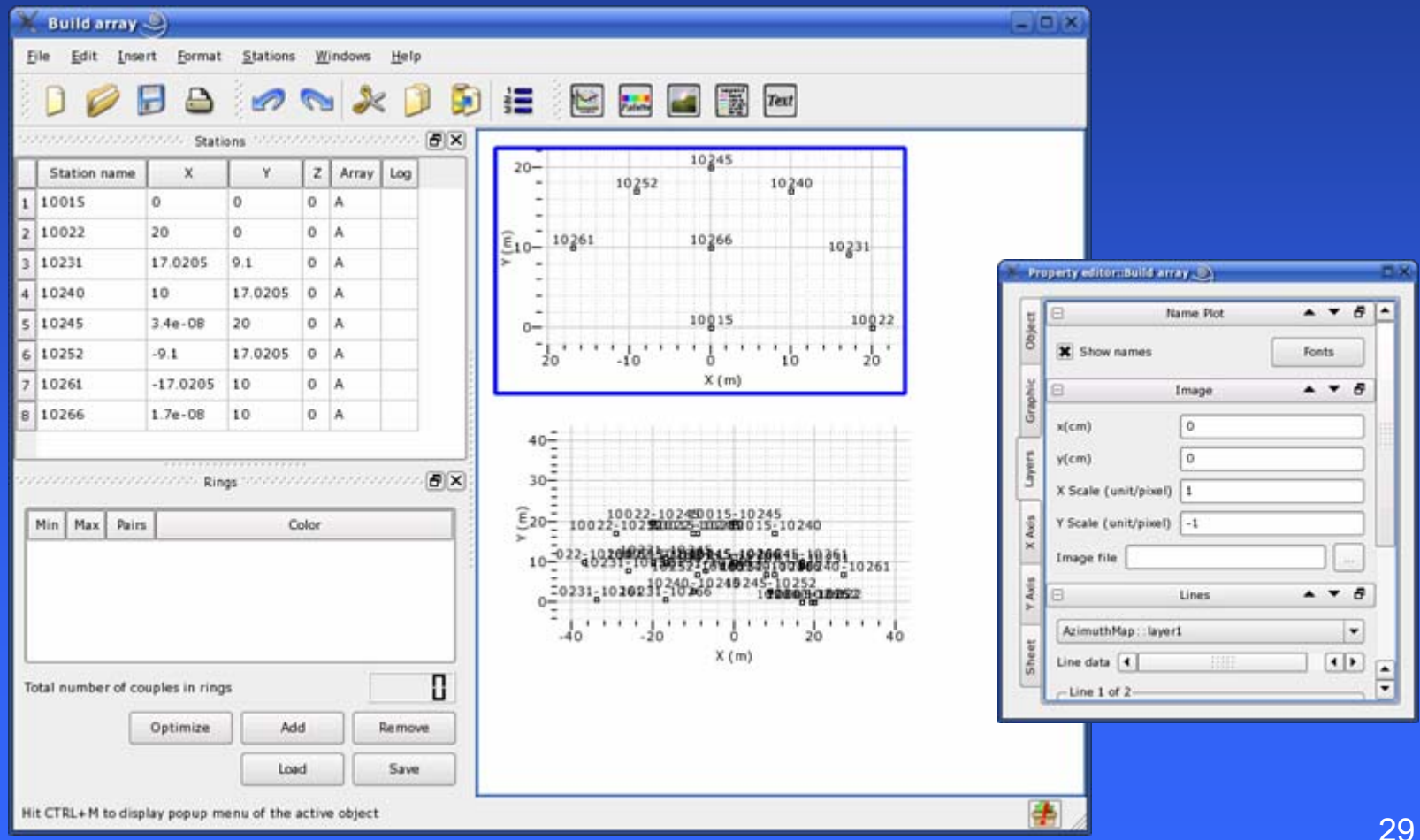
After loading coordinates – set some array name



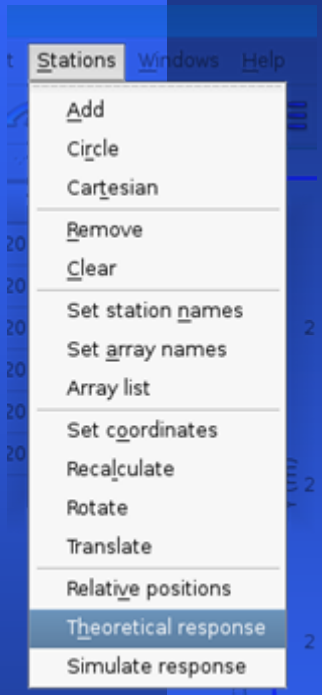
Viewing array geometry

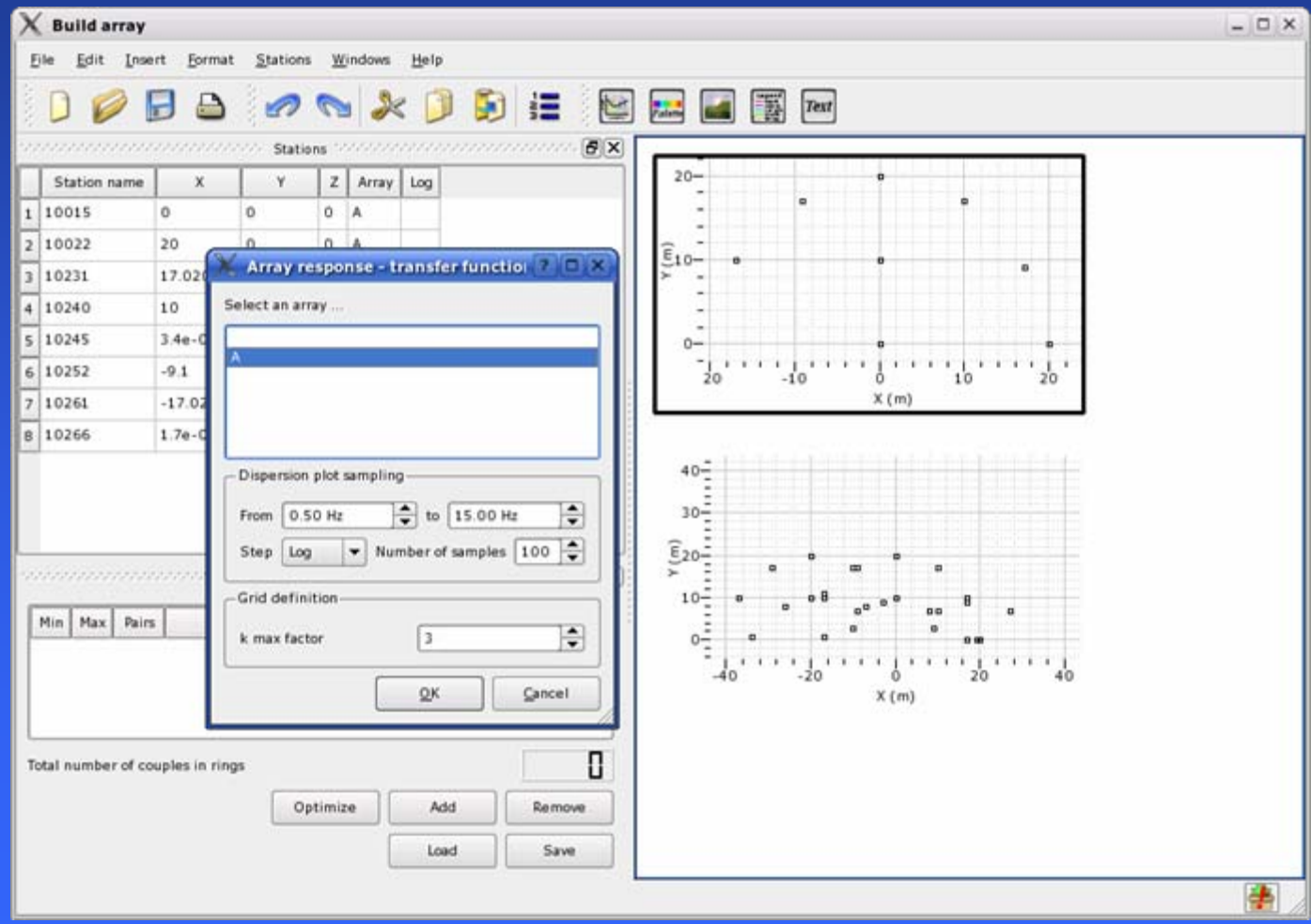


For better viewing geometries (array + coarray) remove names from plot using property editor



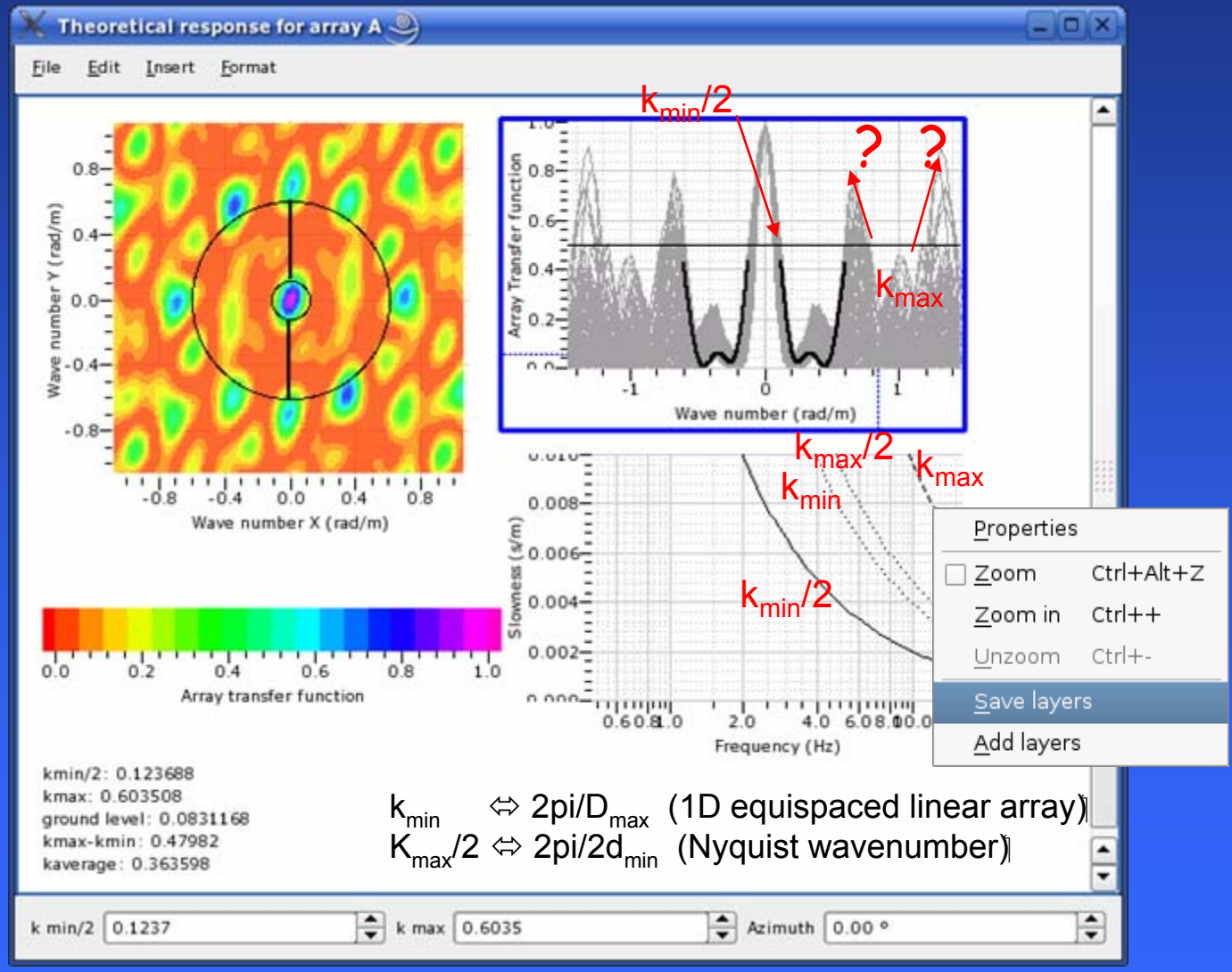
Compute theoretical array response for the given station geometry



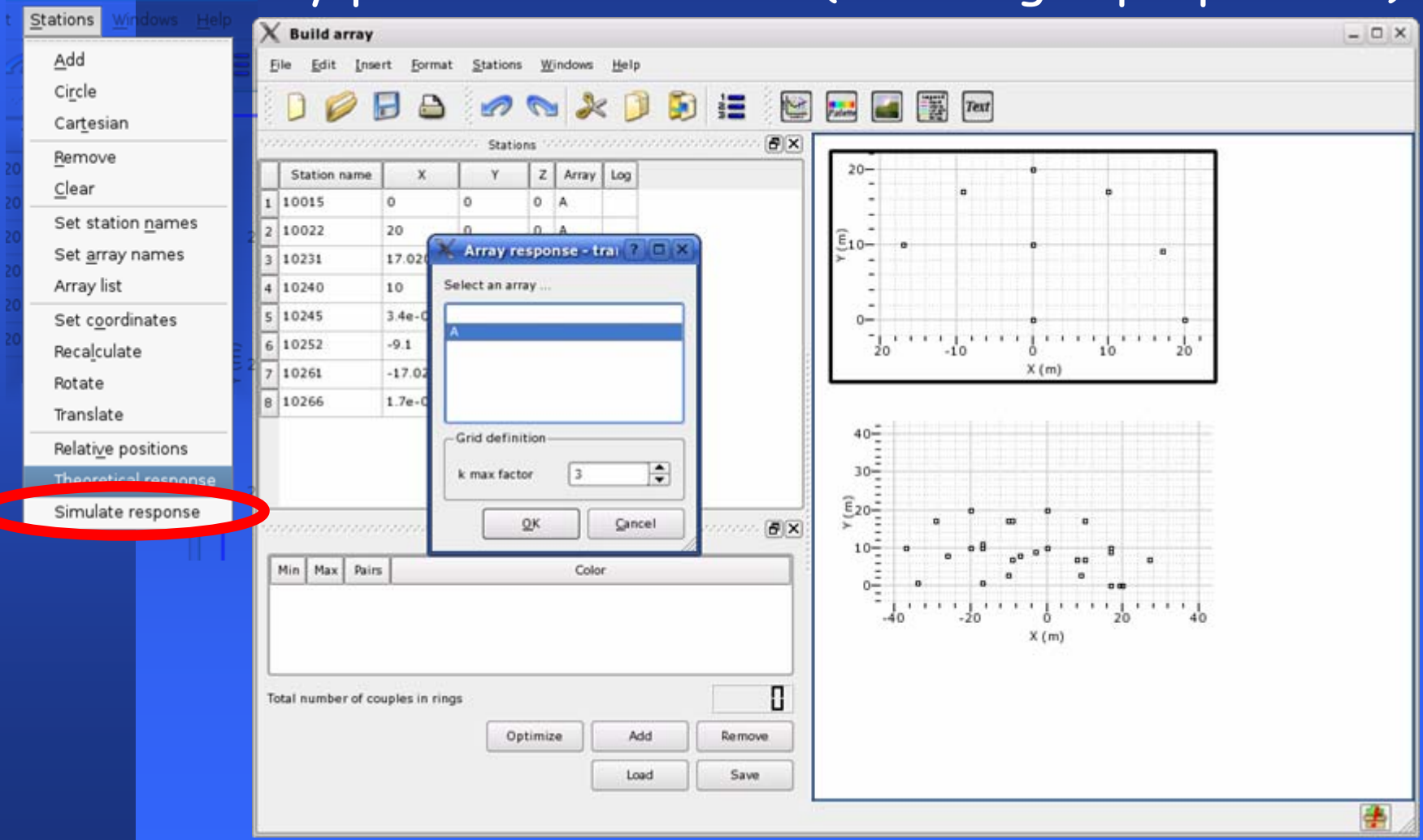


Using Ambient Vibration Array Techniques for Site Characterisation

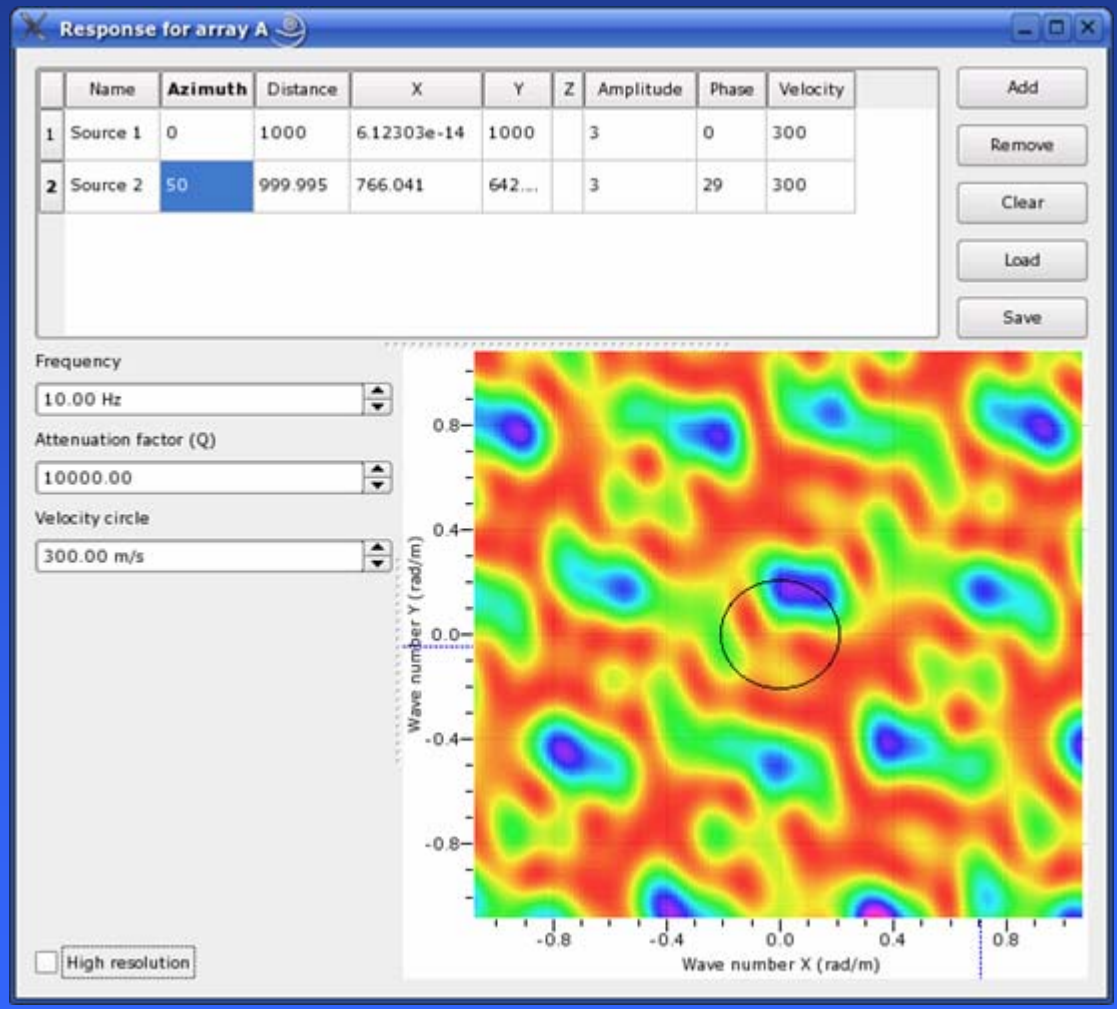
Where is k_{max} ?



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

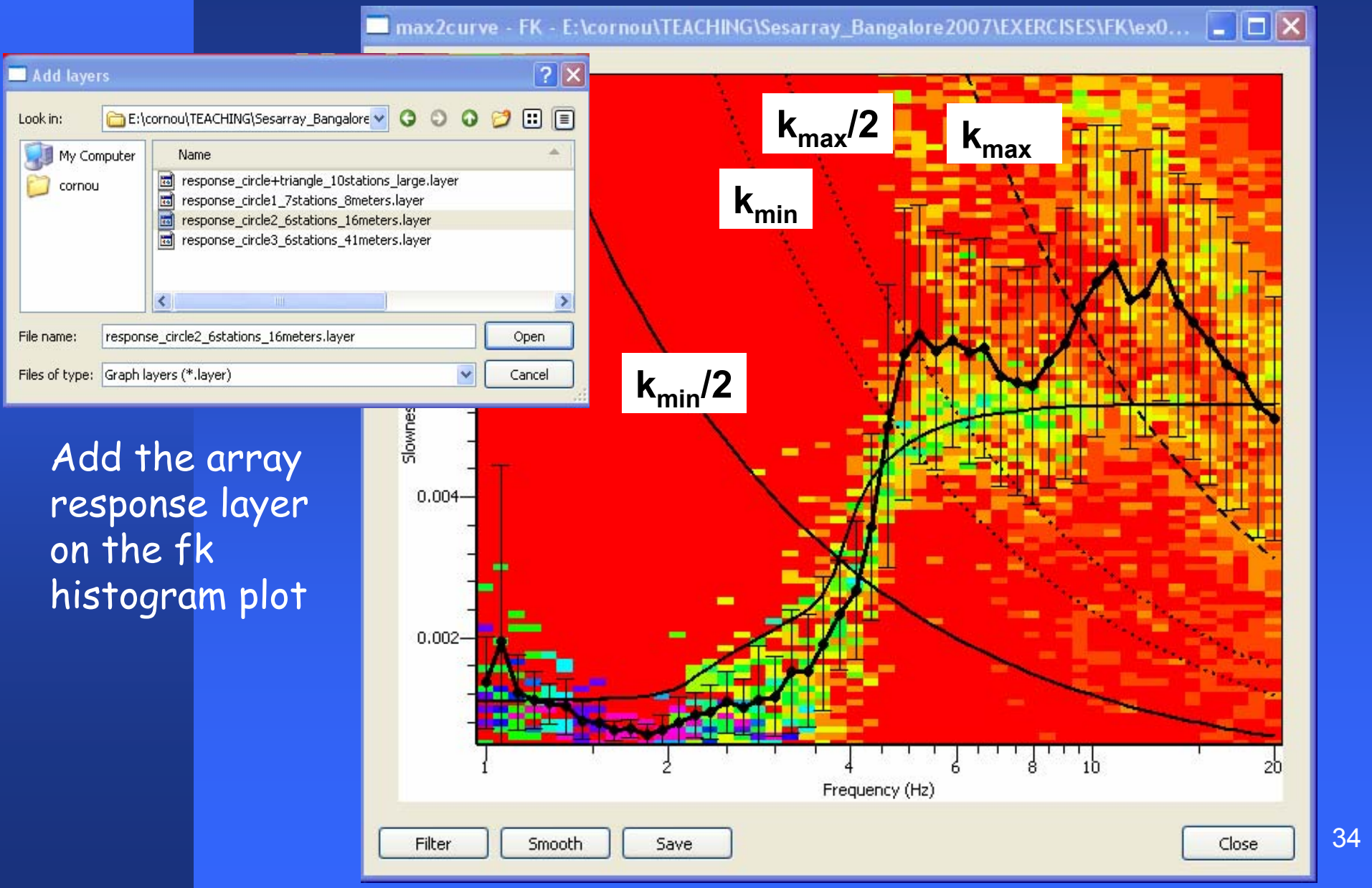


What do we mean by k_{max} ? – simulate array response For arbitrary plane wave arrivals (including superposition)



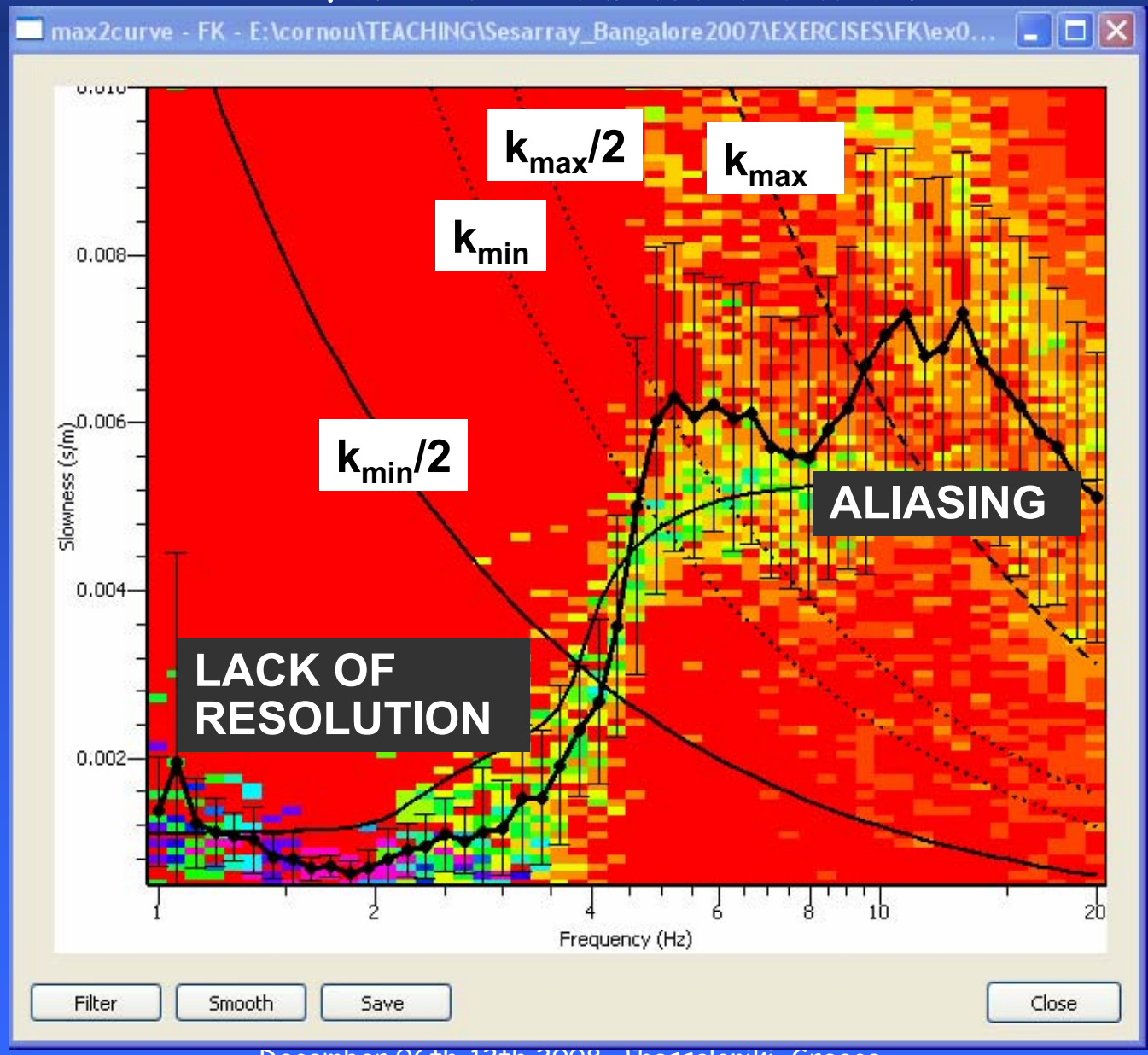
play around and observe …

Using Ambient Vibration Array Techniques for Site Characterisation



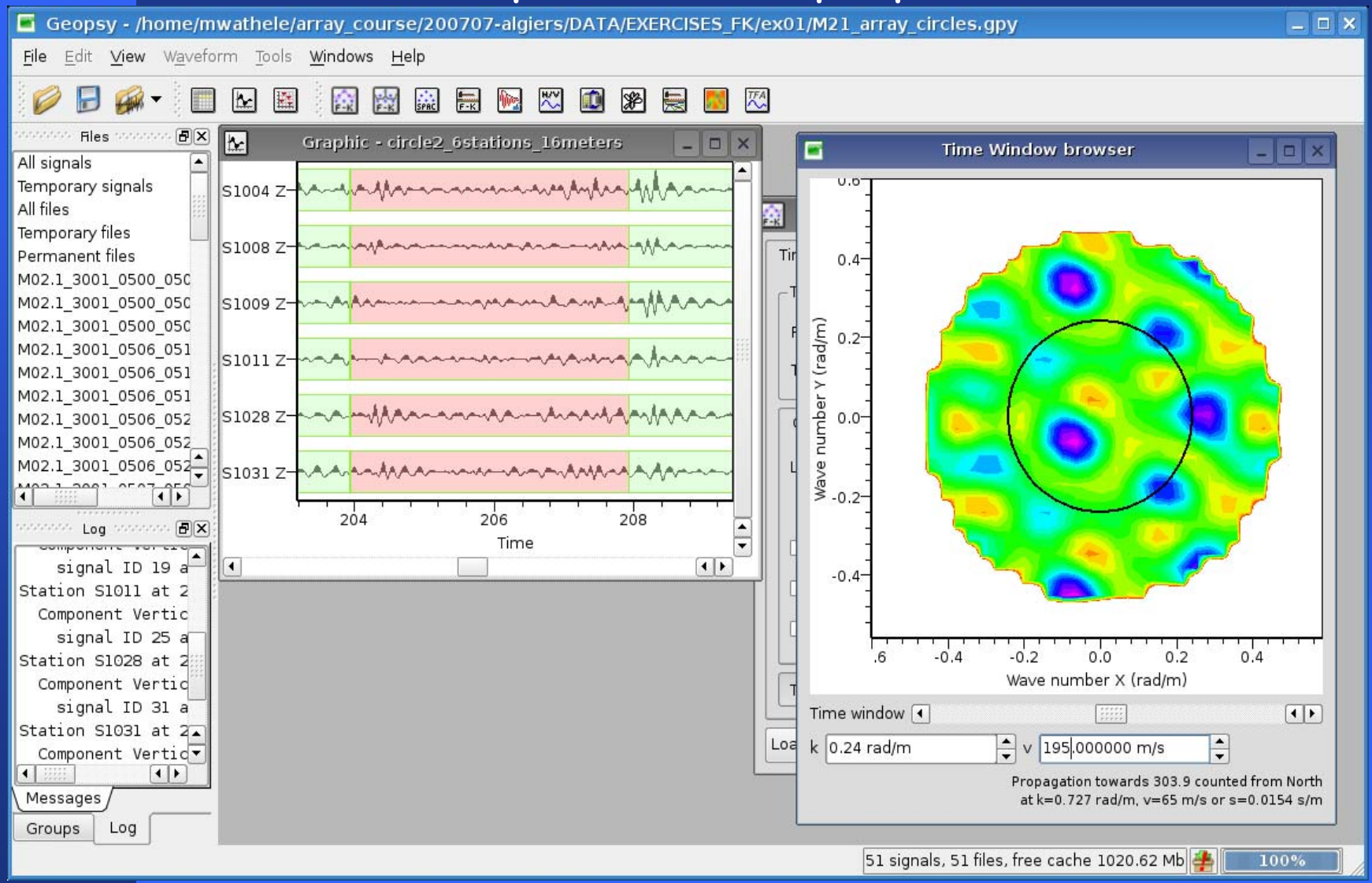
Add the array response layer on the fk histogram plot

Using Ambient Vibration Array Techniques for Site Characterisation

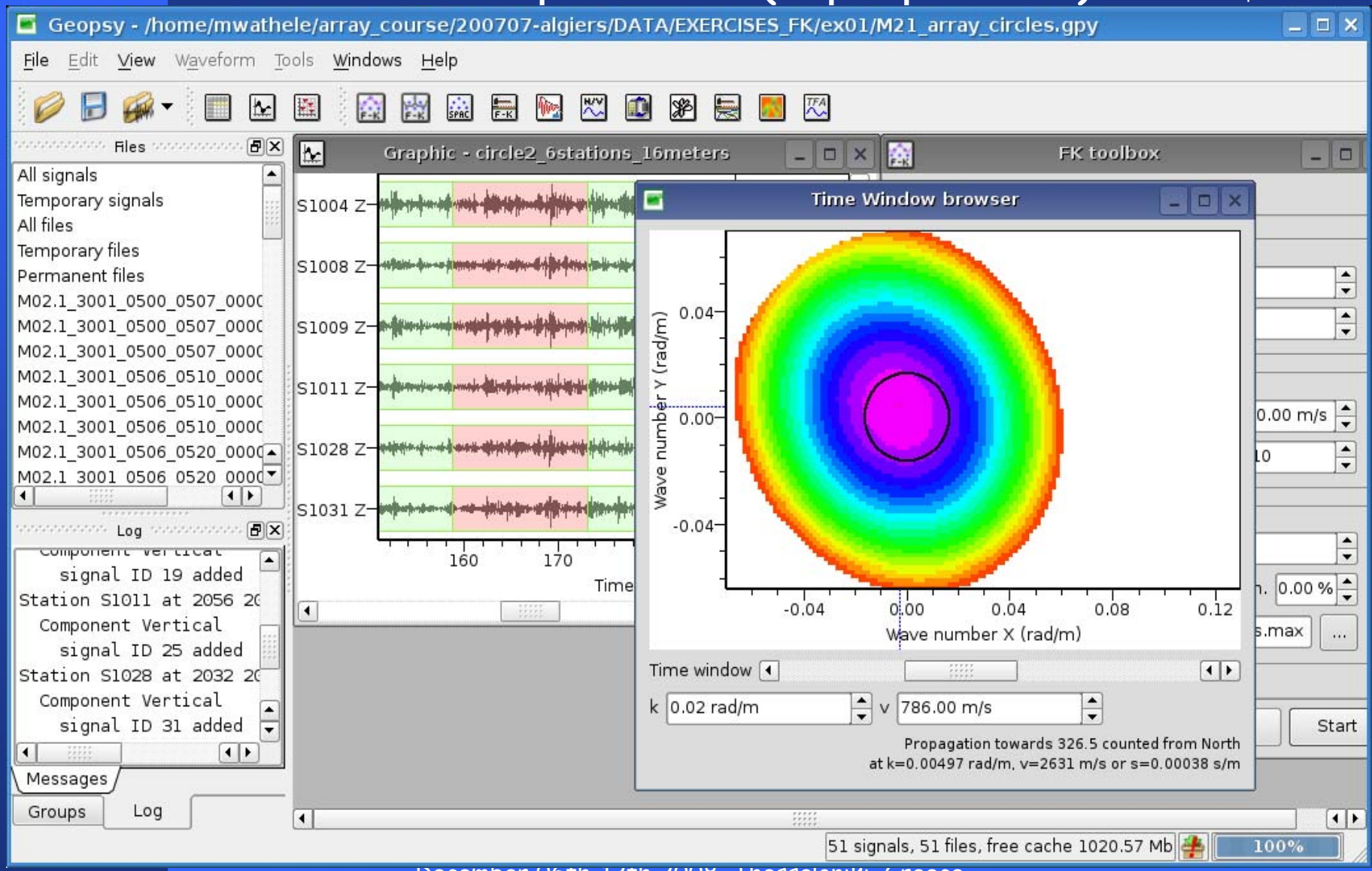


Using Ambient Vibration Array Techniques for Site Characterisation

FK misinterpretation (superposition) 7.5 Hz



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



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

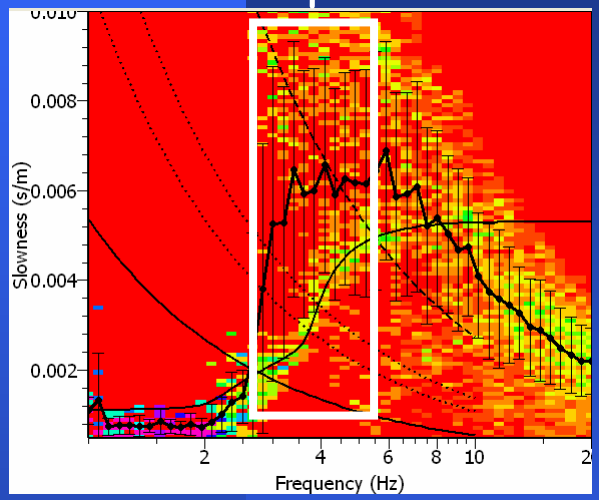
Circle1_7stations_8meters

Grid_step = 0.065 rad/m
Grid_size = 1.6 rad/m
Vmin = 100 m/s; window length = 30 T

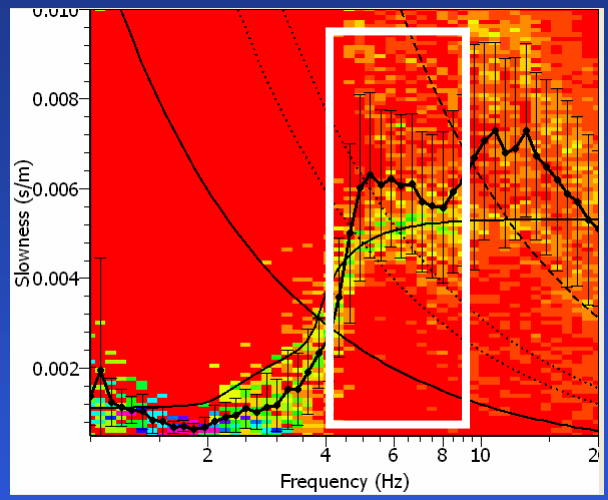
Using Ambient Vibration Array Techniques for Site Characterisation

Summary

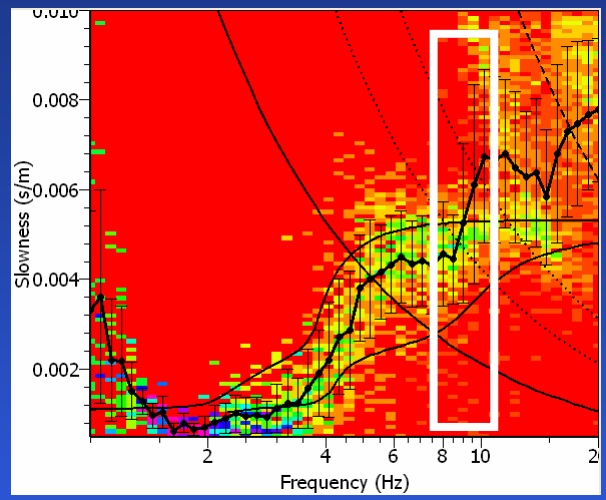
41 m aperture



16 m aperture

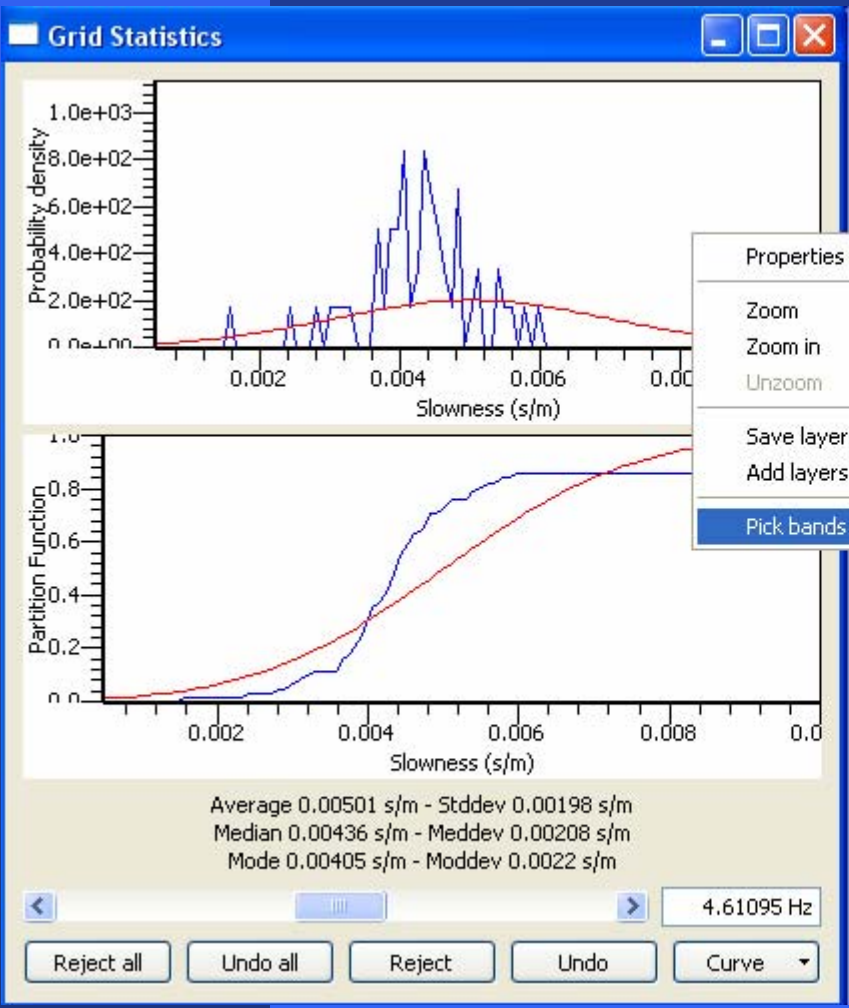


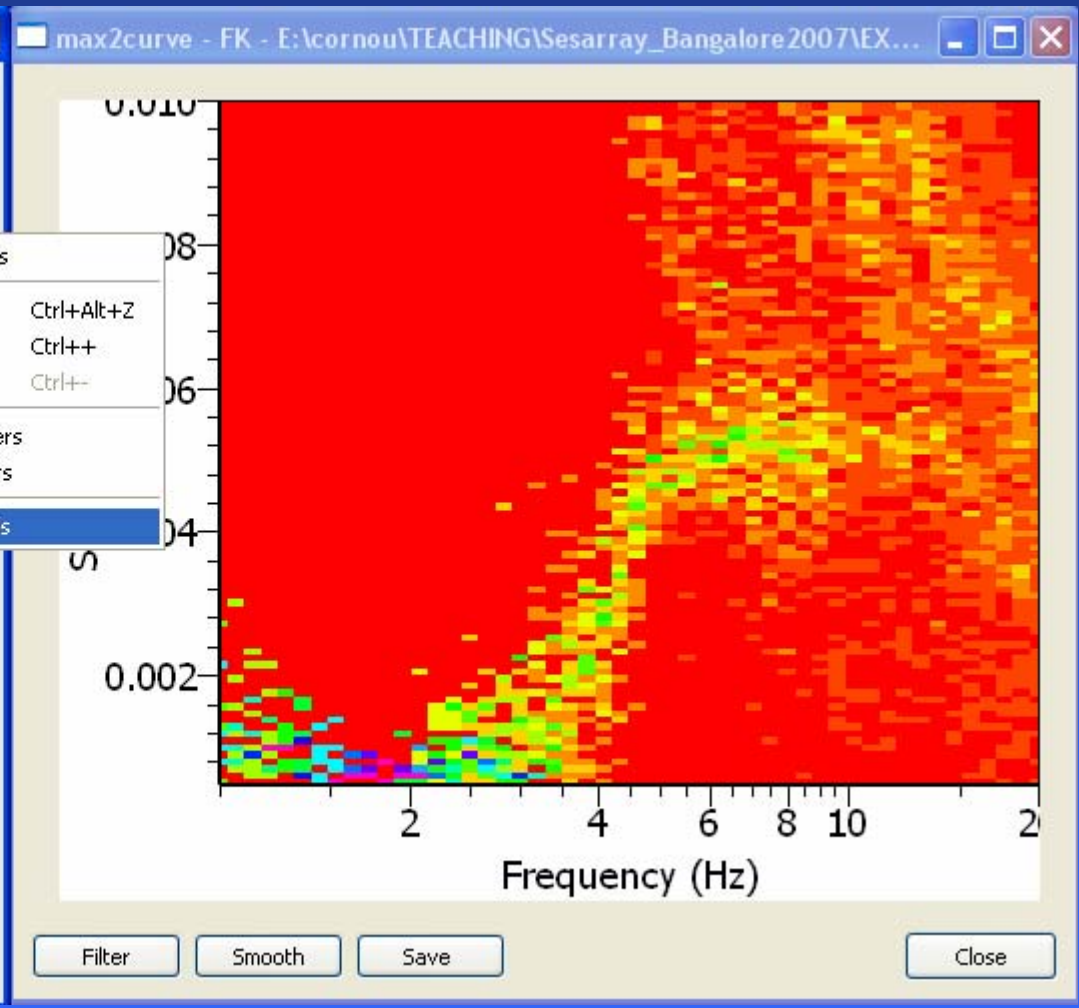
8 m aperture



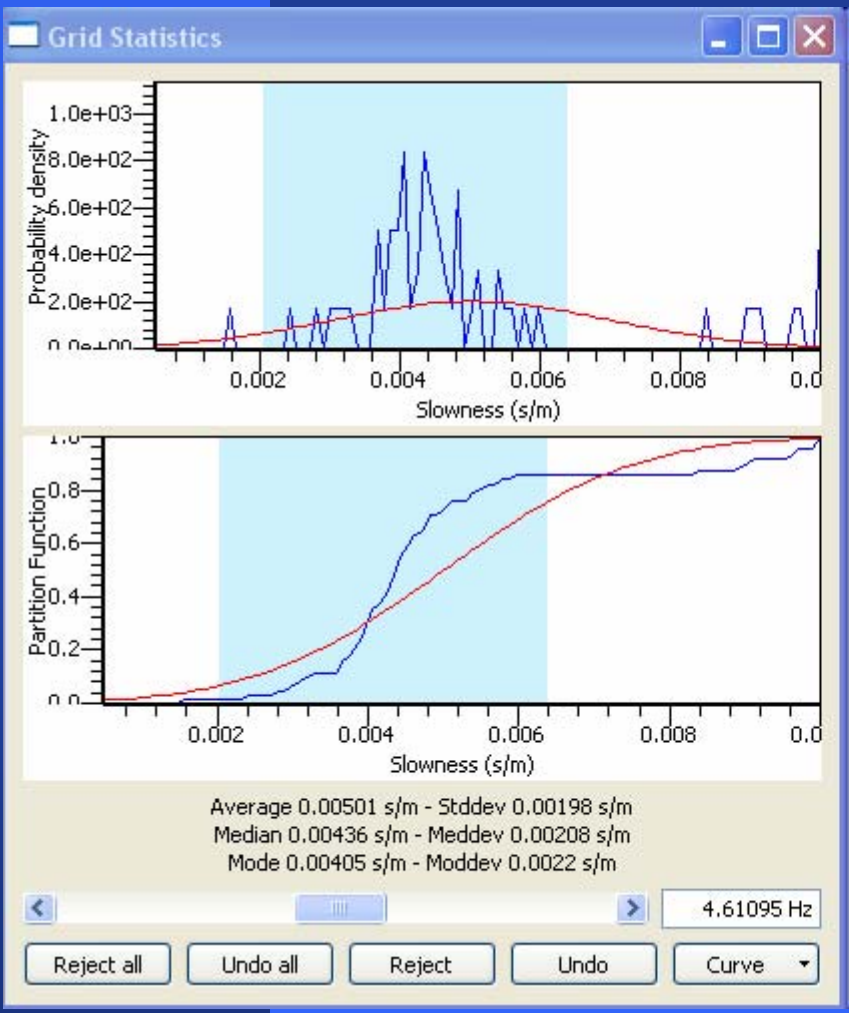
- Larger (smaller) aperture, better resolution at LF (HF)
- In this example, smallest aperture array provides phase velocities deviating (overestimation) than true ones.
- Histograms should be cleaned in order to remove outliers or estimates which can be clearly attributed to aliasing effects.

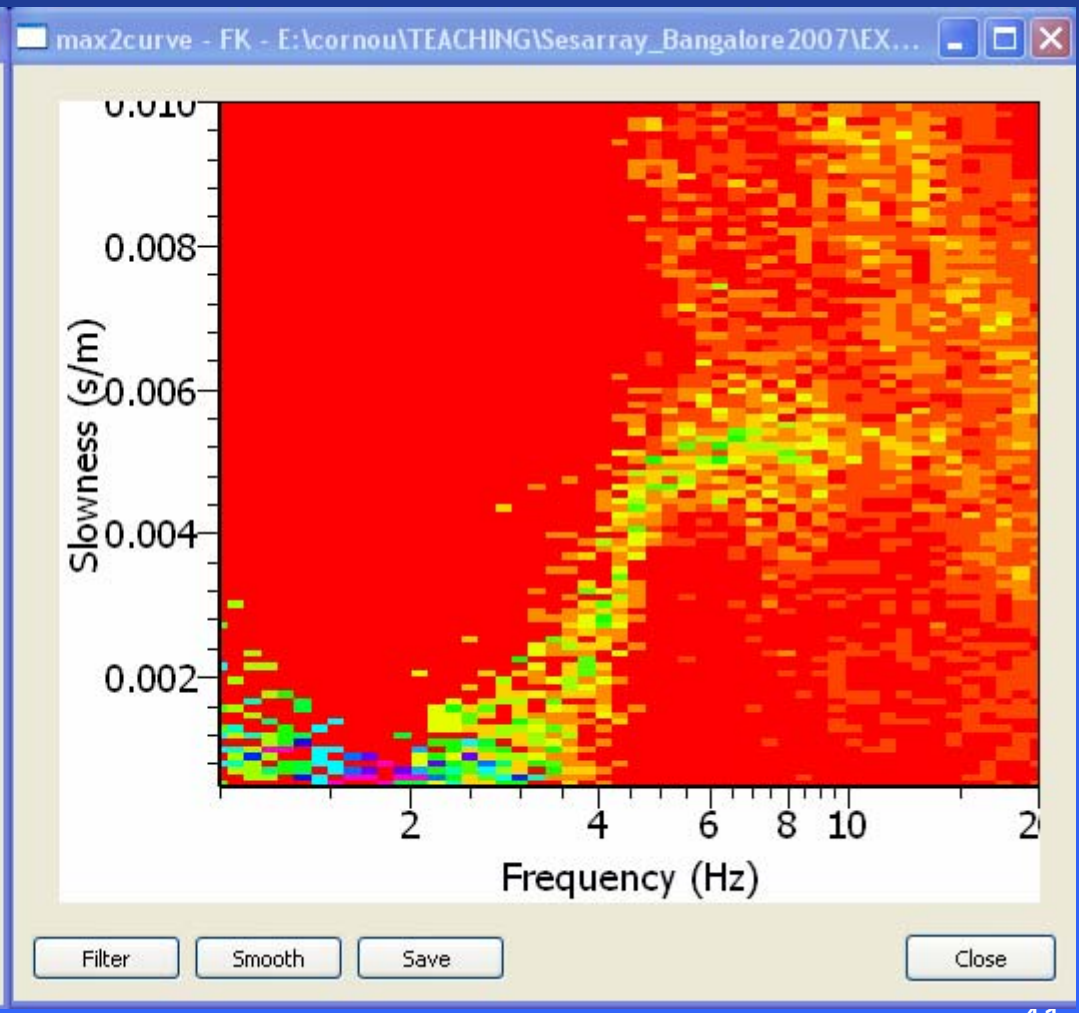
FK histograms: outlier removal





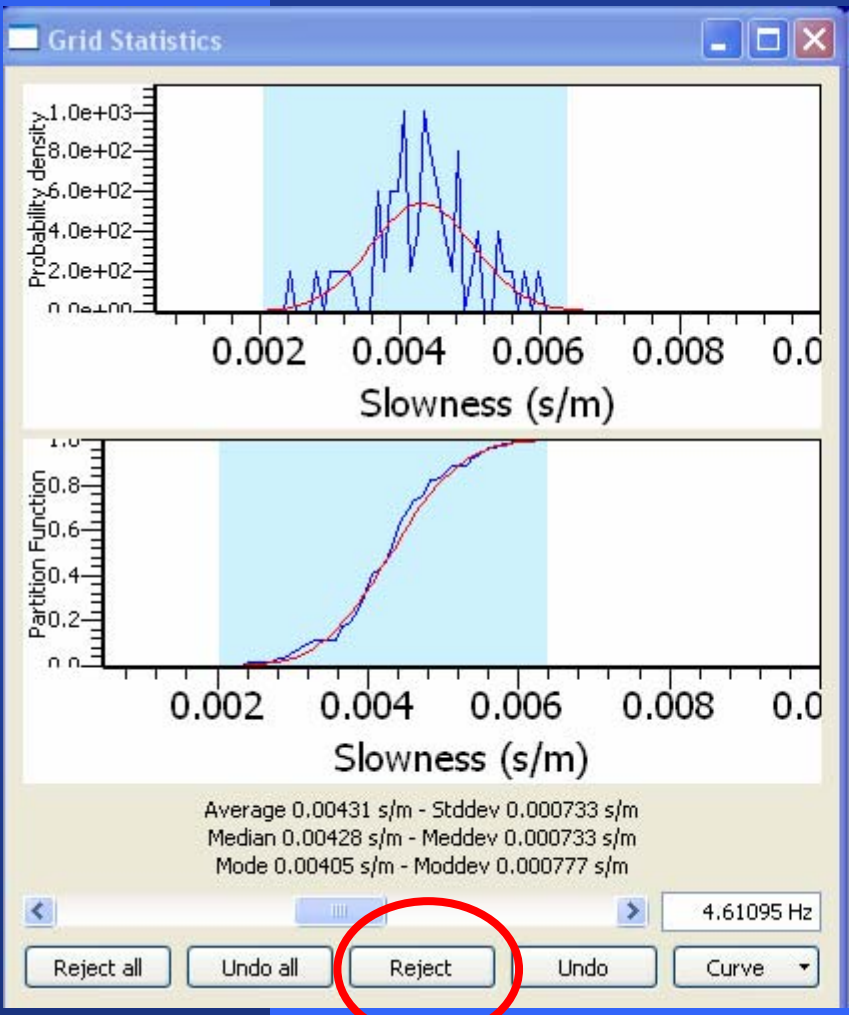
Select the slowness band you want to keep (pick band)

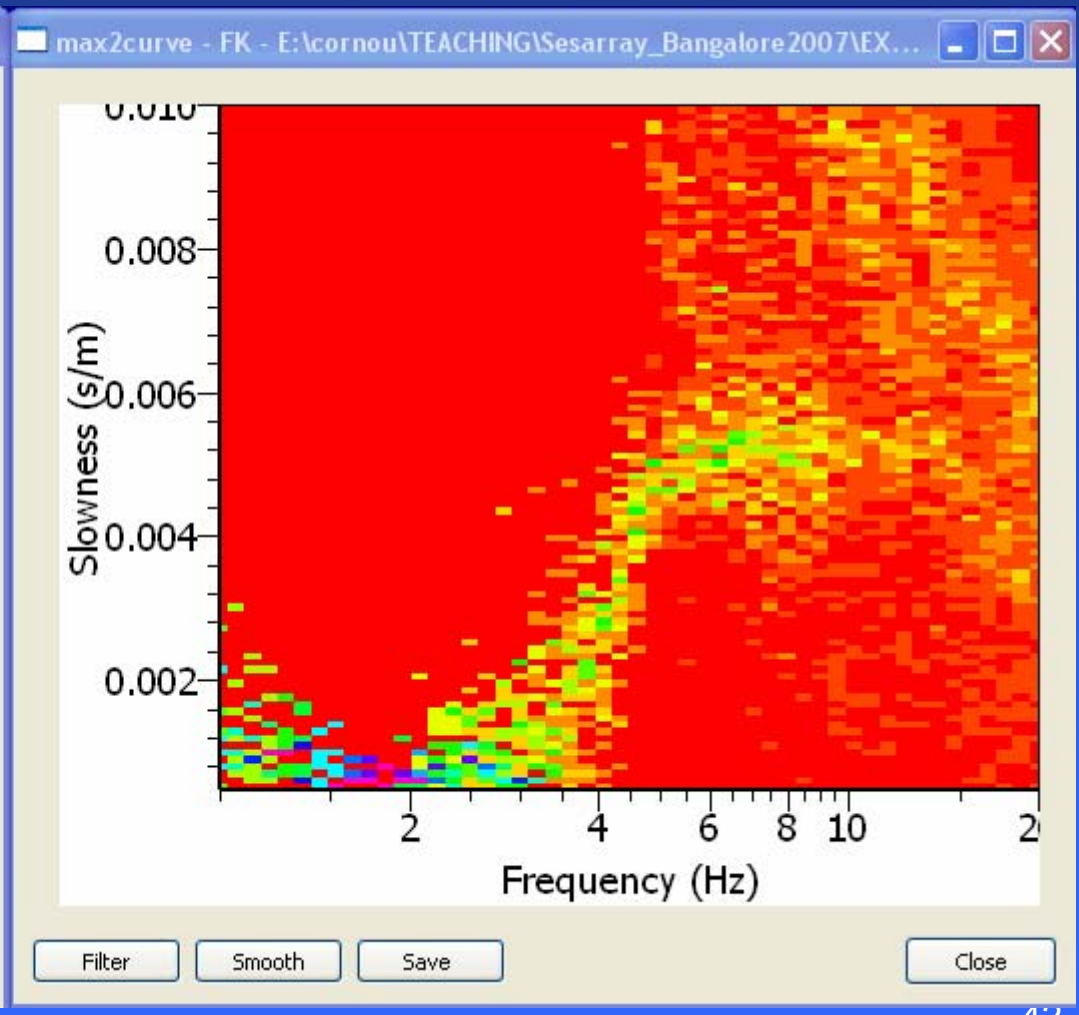




Using Ambient Vibration Array Techniques for Site Characterisation

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

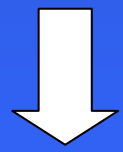
To increase frequency

SHIFT + : to apply selection and go to next frequency

To modify the left limit of the pick band

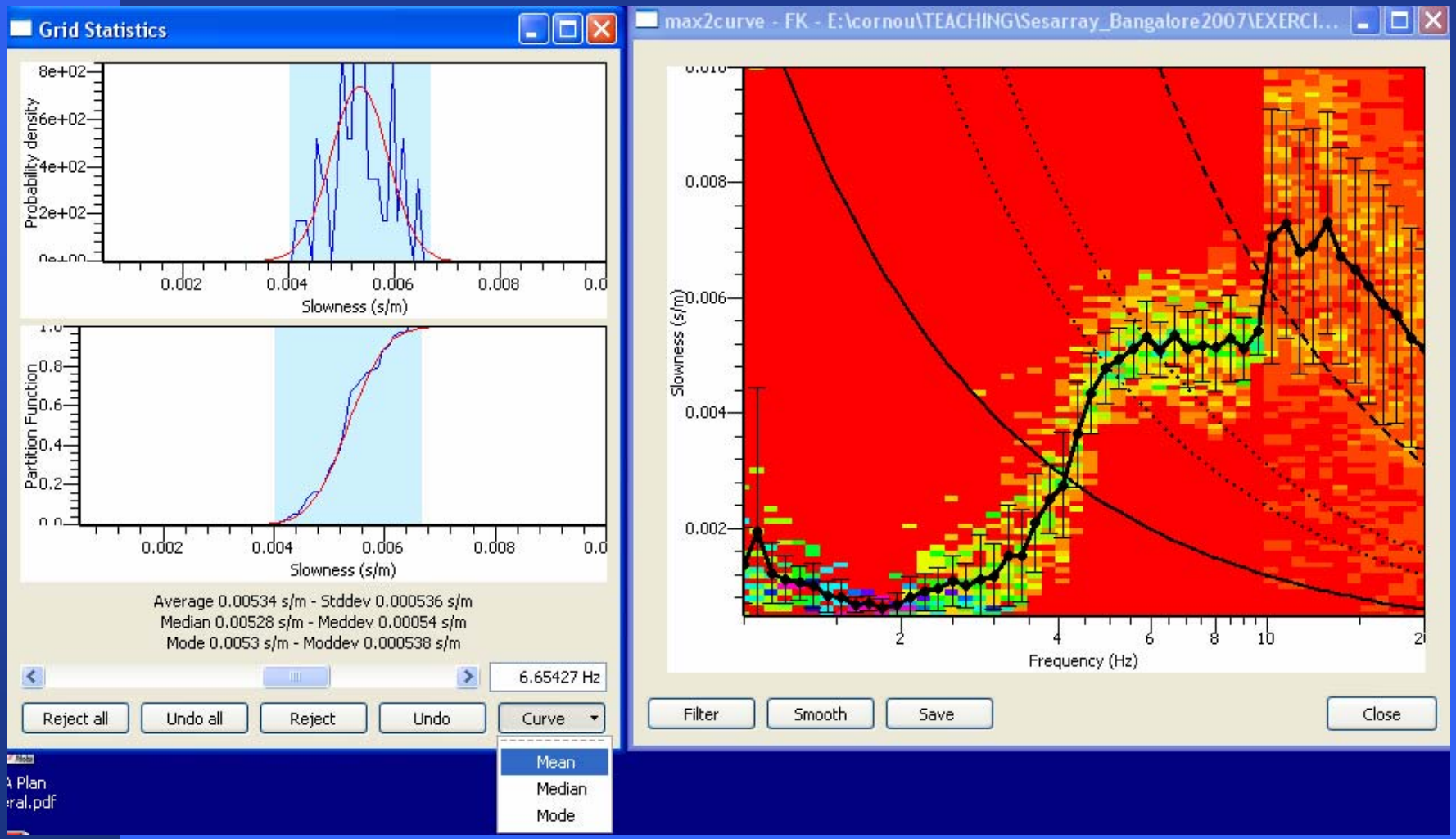
+ SHIFT: to move the right limit of the pick band

SHIFT + : to apply selection and go to previous frequency

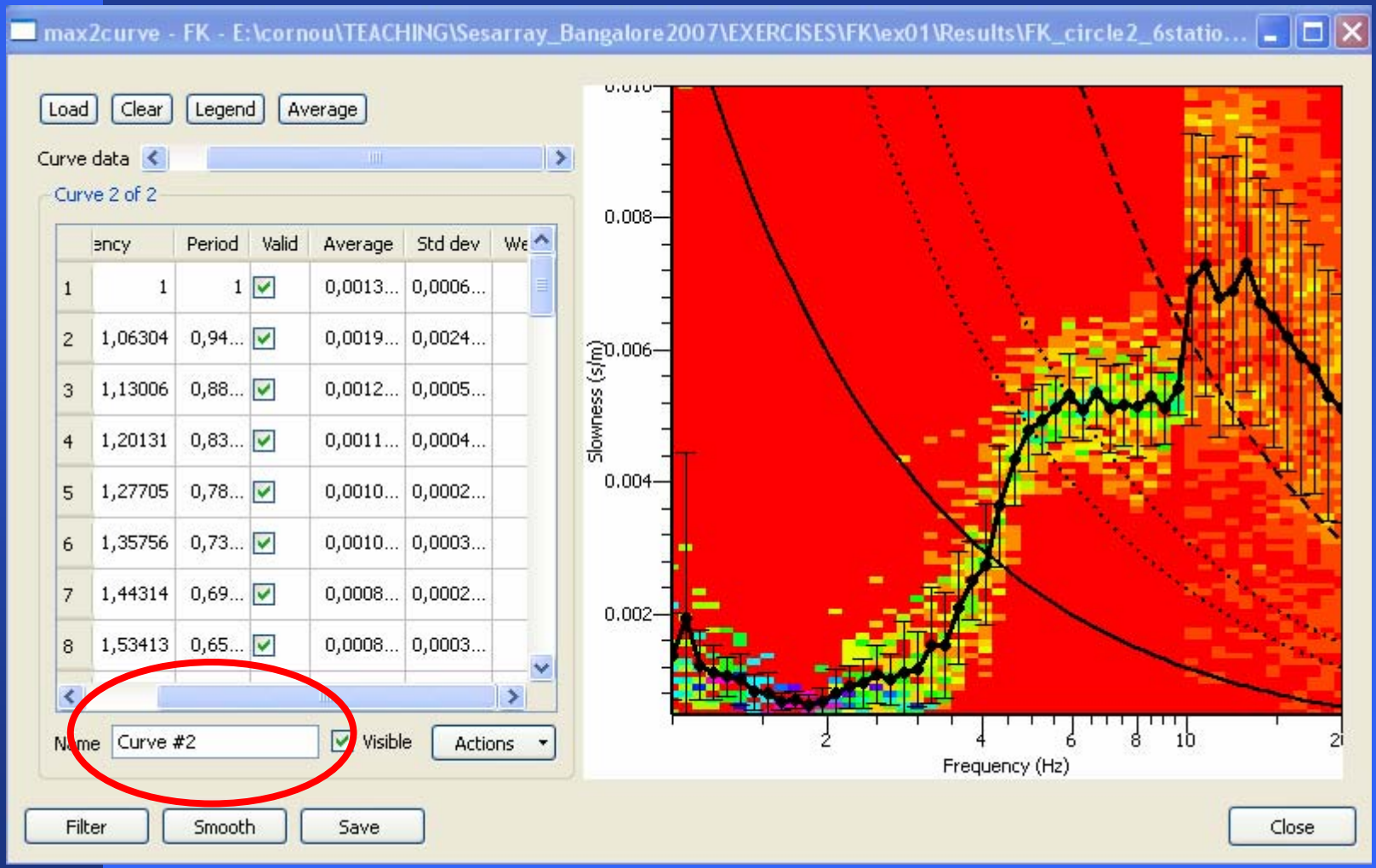


To decrease frequency

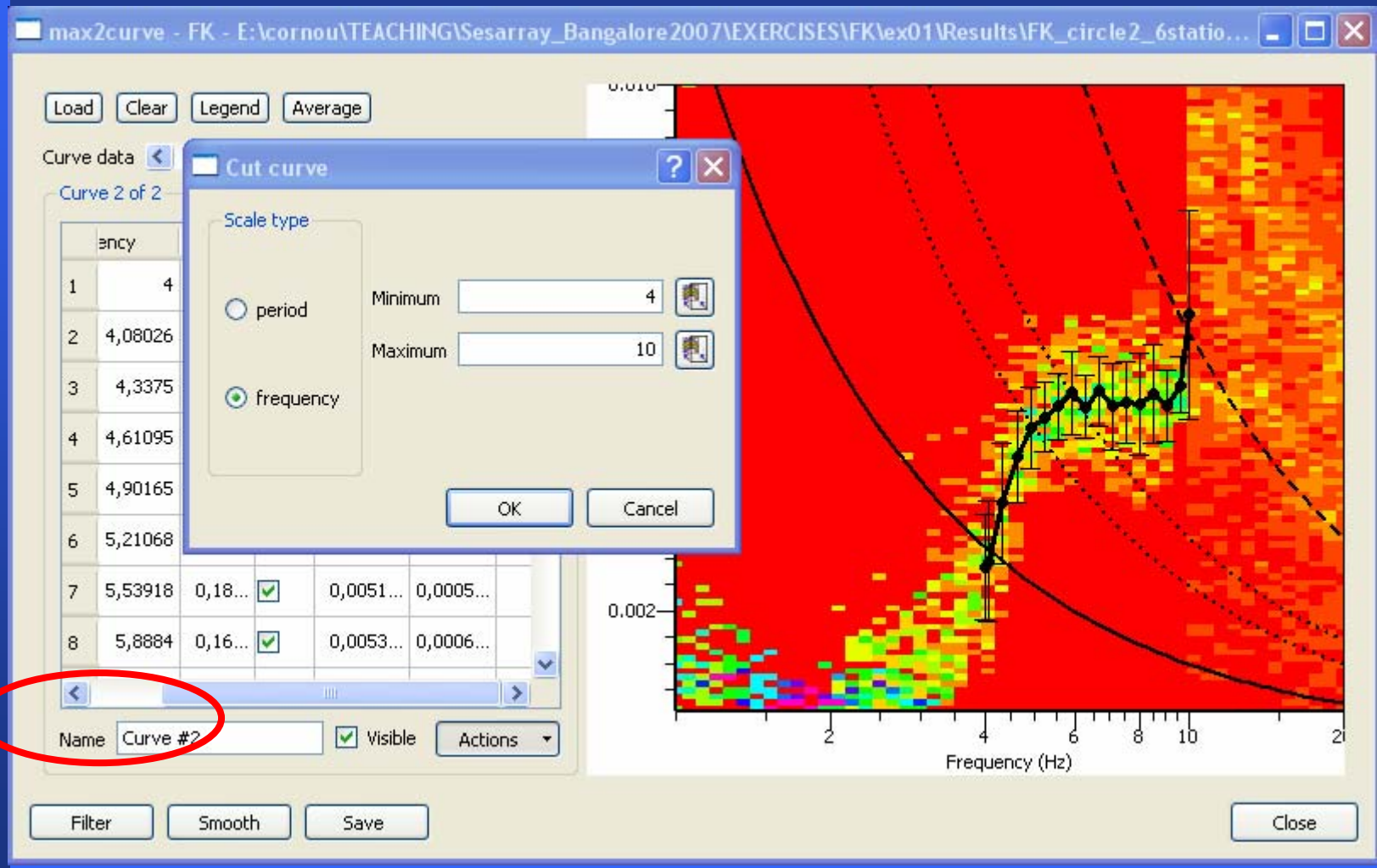
Computation of new mean/median/mode curve



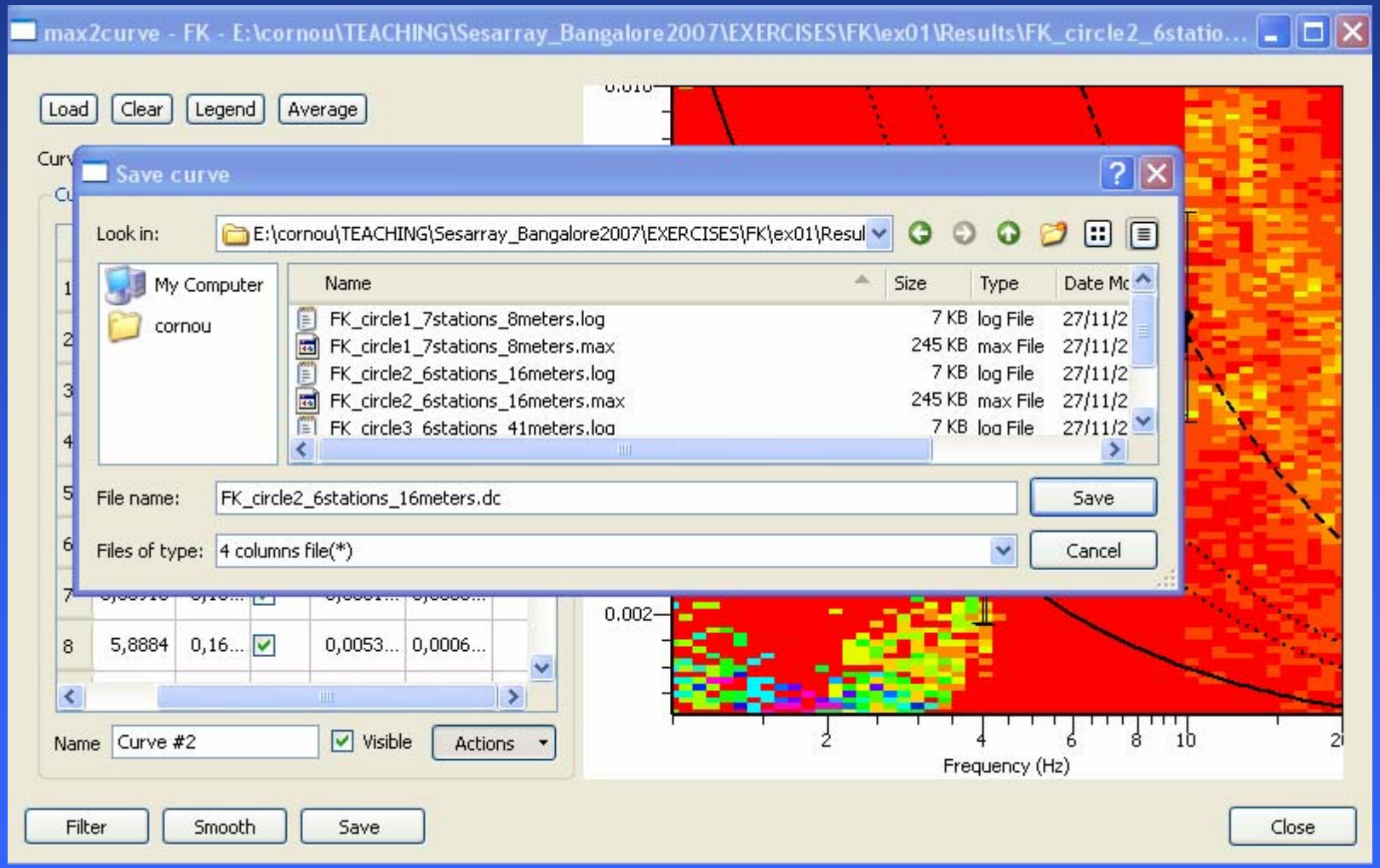
The new mean curve appears as Curve #2



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



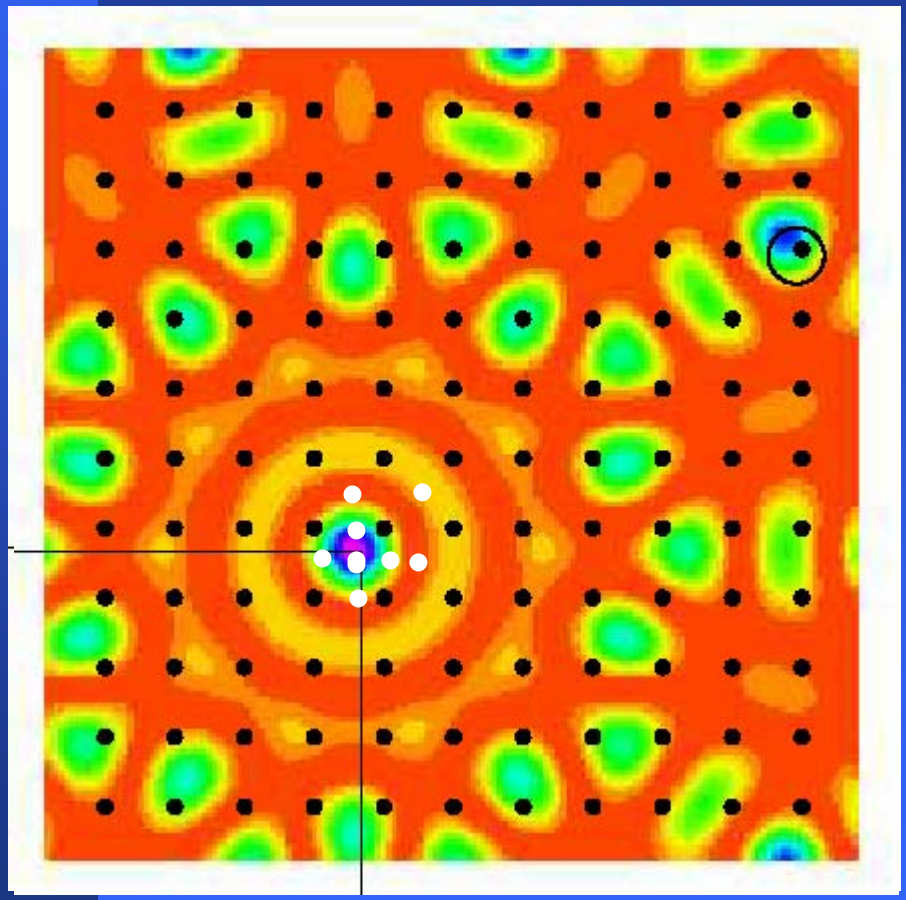
Saving the dispersion curve

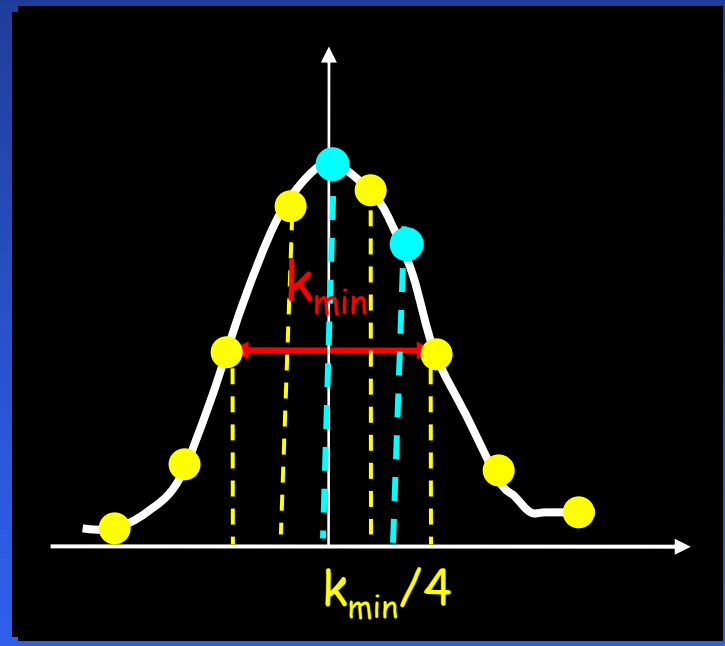


Some issues on *f-k* processing as implemented in sesarray

- 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 ?





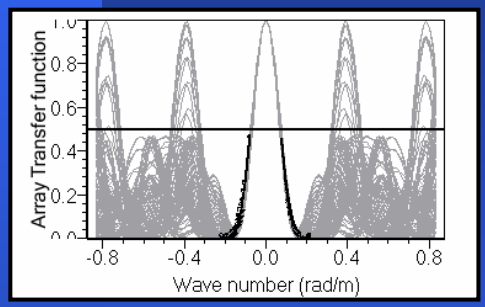
Peak refinement until numerical relative precision of 10^{-5} in wavenumber

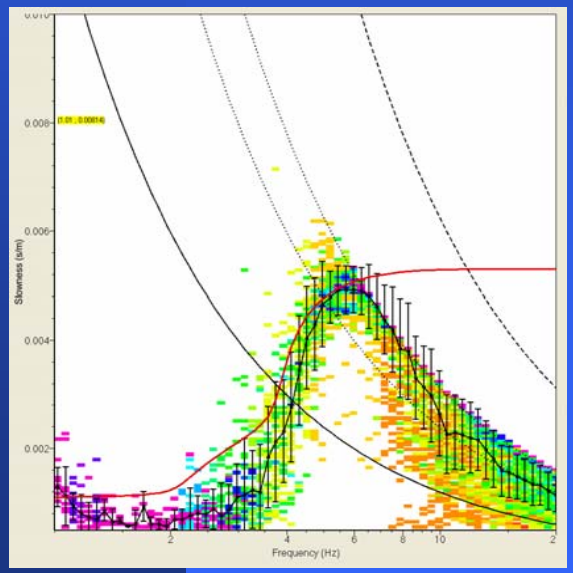
grid_step < $k_{min}/4$

Using Ambient Vibration Array Techniques for Site Characterisation

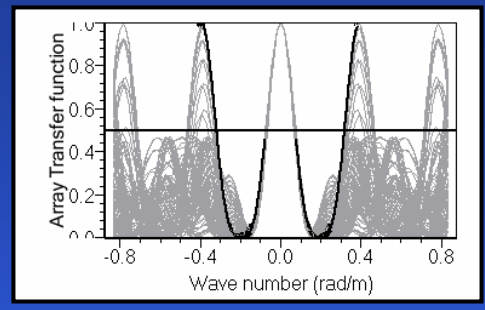
What *grid_size* to choose ?

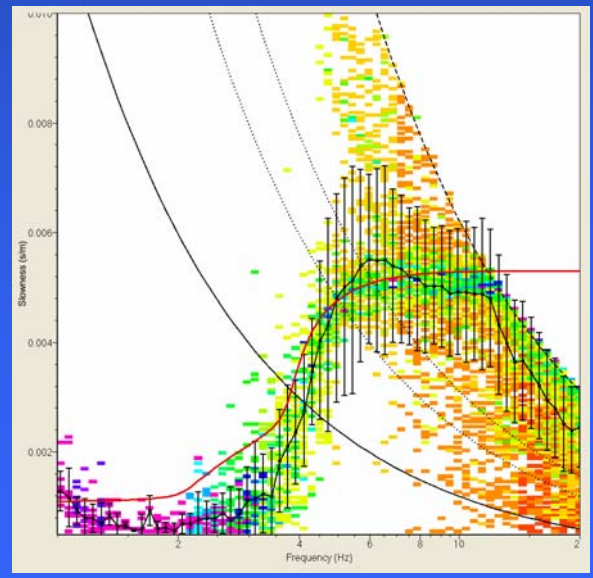
$k_{max}/2$



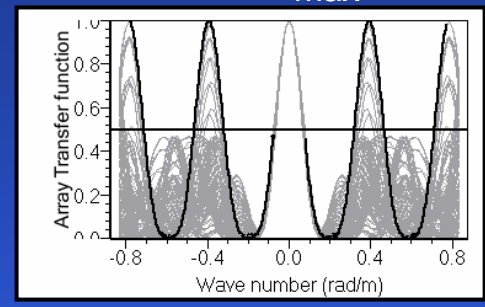


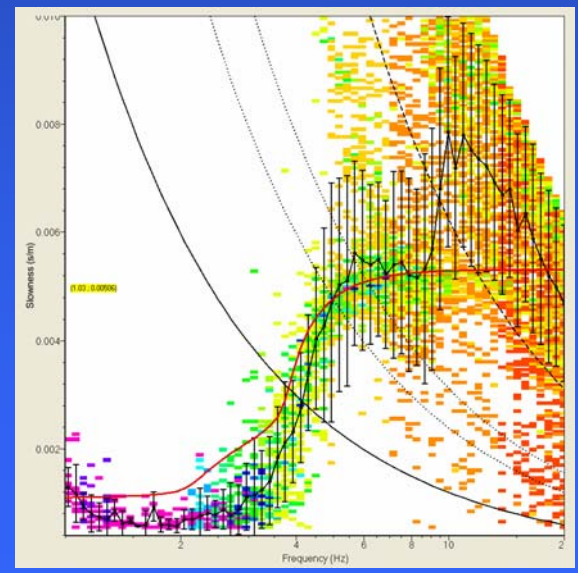
k_{max}





$2*k_{max}$

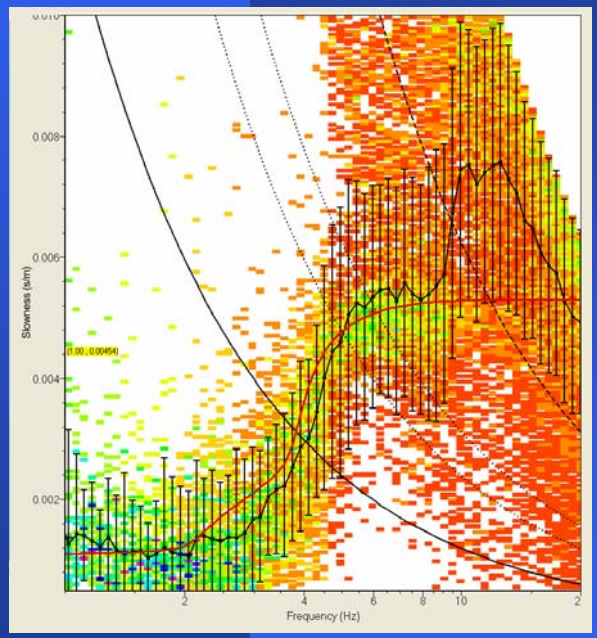




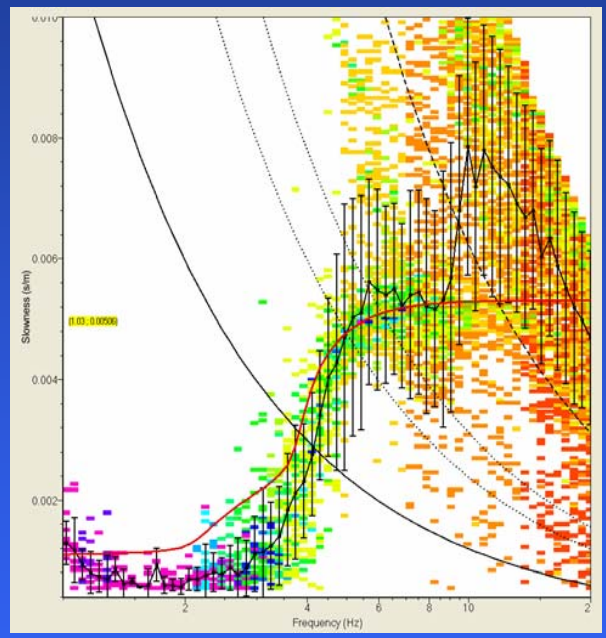
Grid_size > $k_{max}/2$

What *window_length* to choose ?

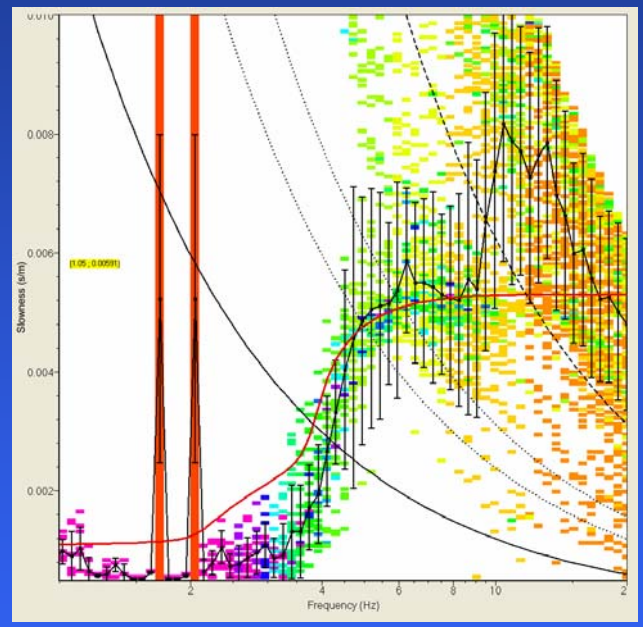
10 T



30 T



50 T



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

Recommended parameters

- grid_step < $k_{min}/4$ (maximum value)
  (< $k_{min}/20$ for hrfk!)
- grid_size > $k_{max}/2$ (→ 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)

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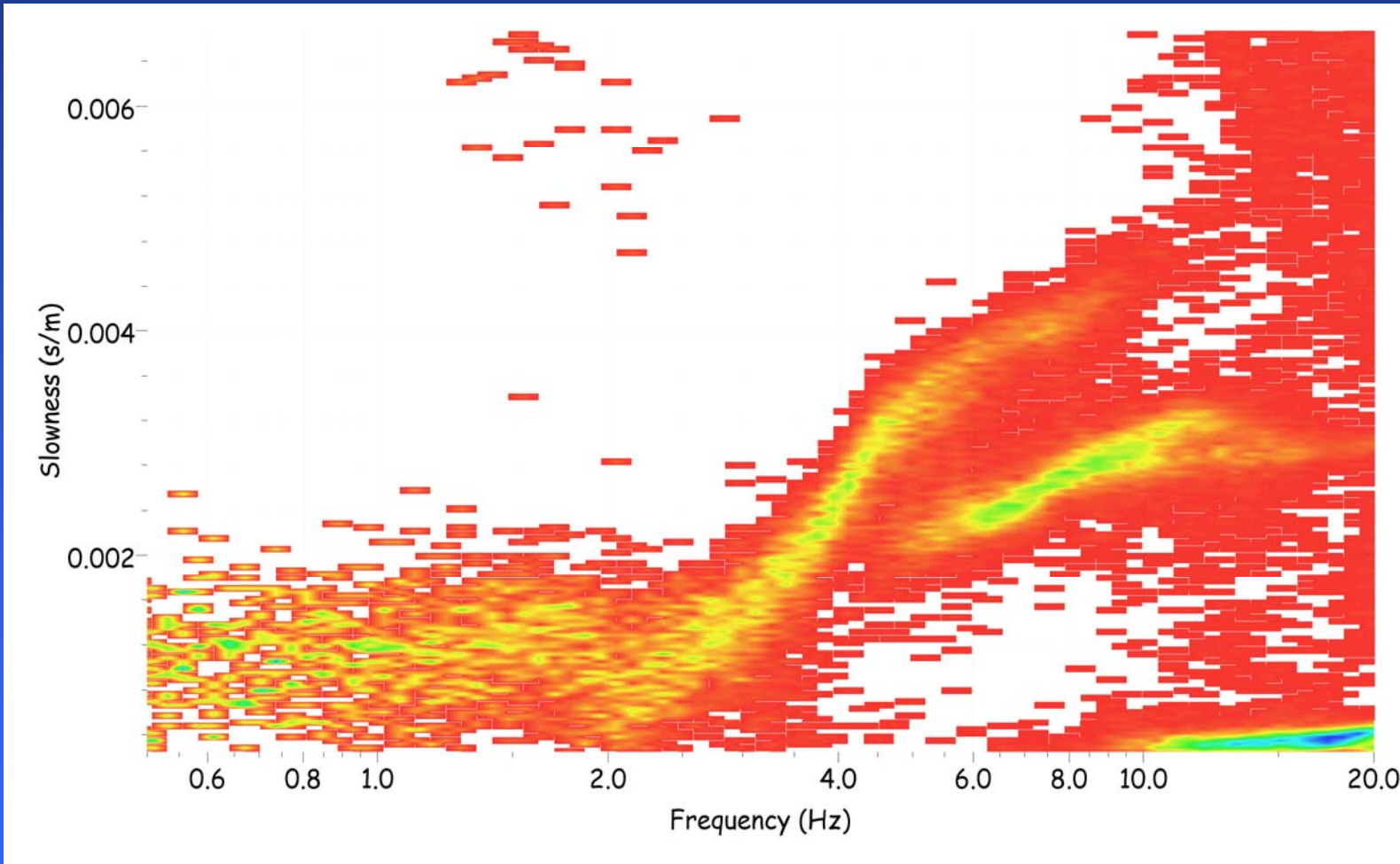
Which result do you like more? This one …..



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or this one … ?