Relation between array response and array analysis

Tutorial

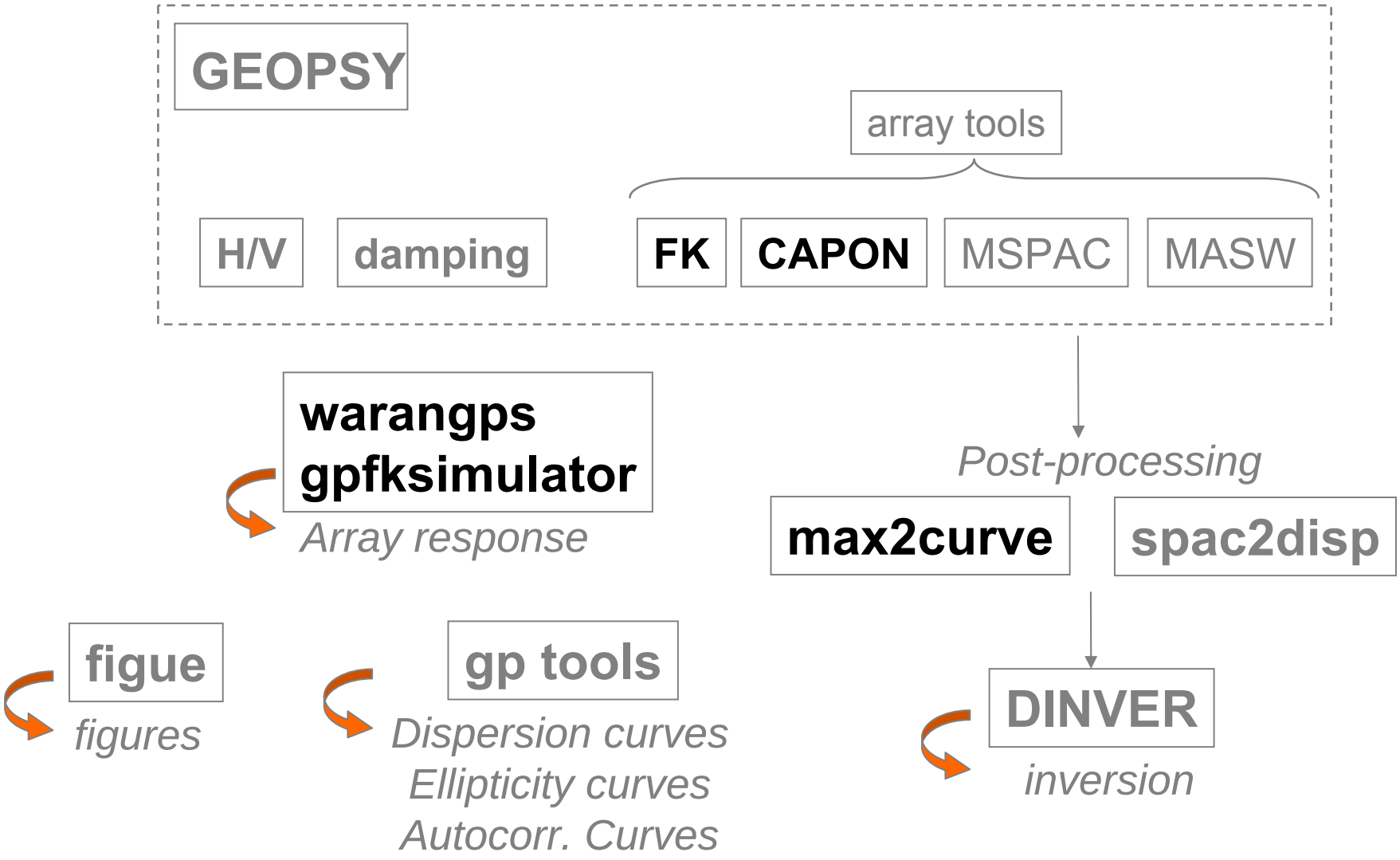
Relation between array response and FK estimates

- Introduction to ***fk / hrfk*** tool
- Introduction to ***warangps*** and ***gpfksimulator*** tool

FK computation

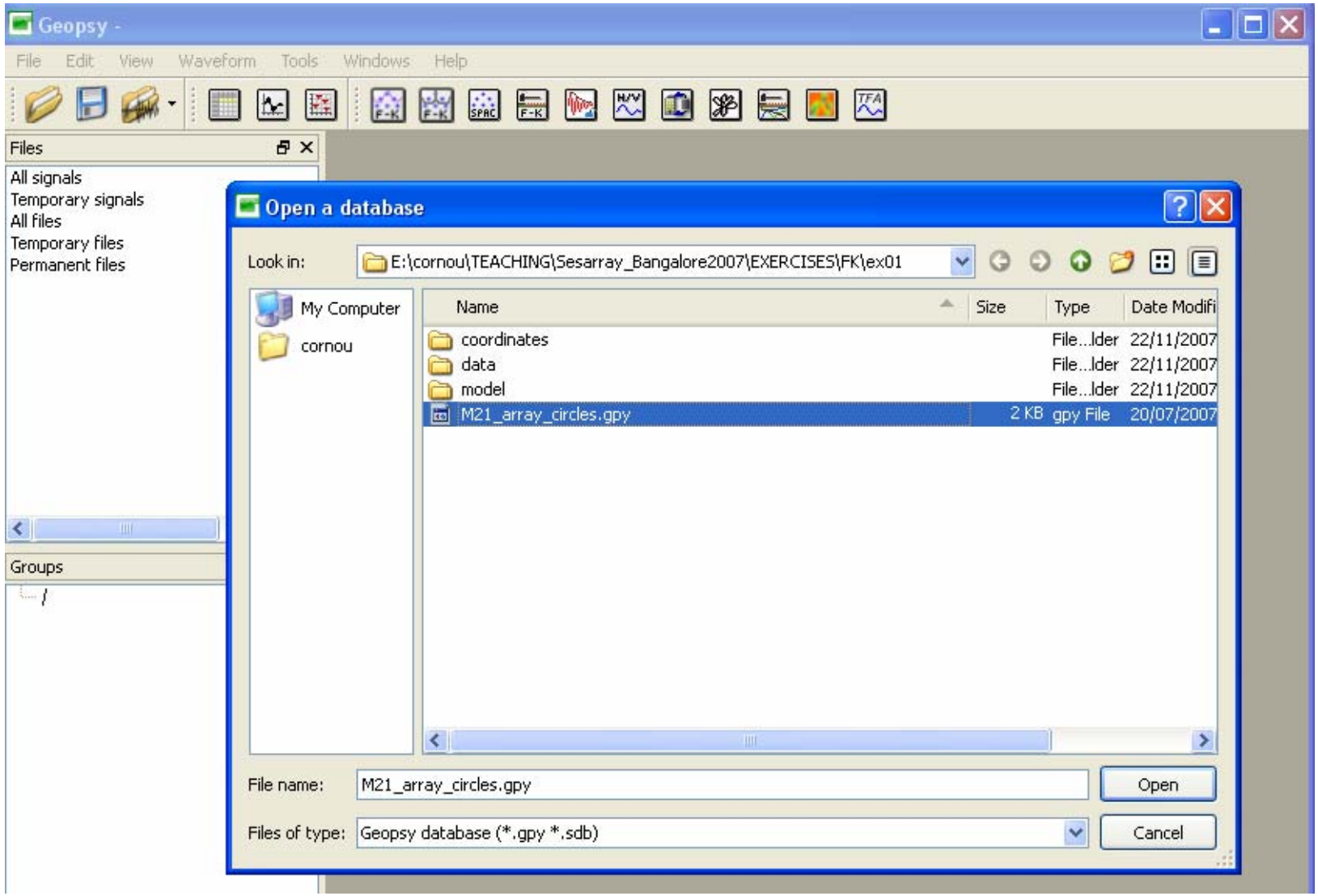
- Input parameters
- fk gridding (optimized grid search)
- Post-processing (use of *max2curve* tool)

SESARRAY PACKAGE

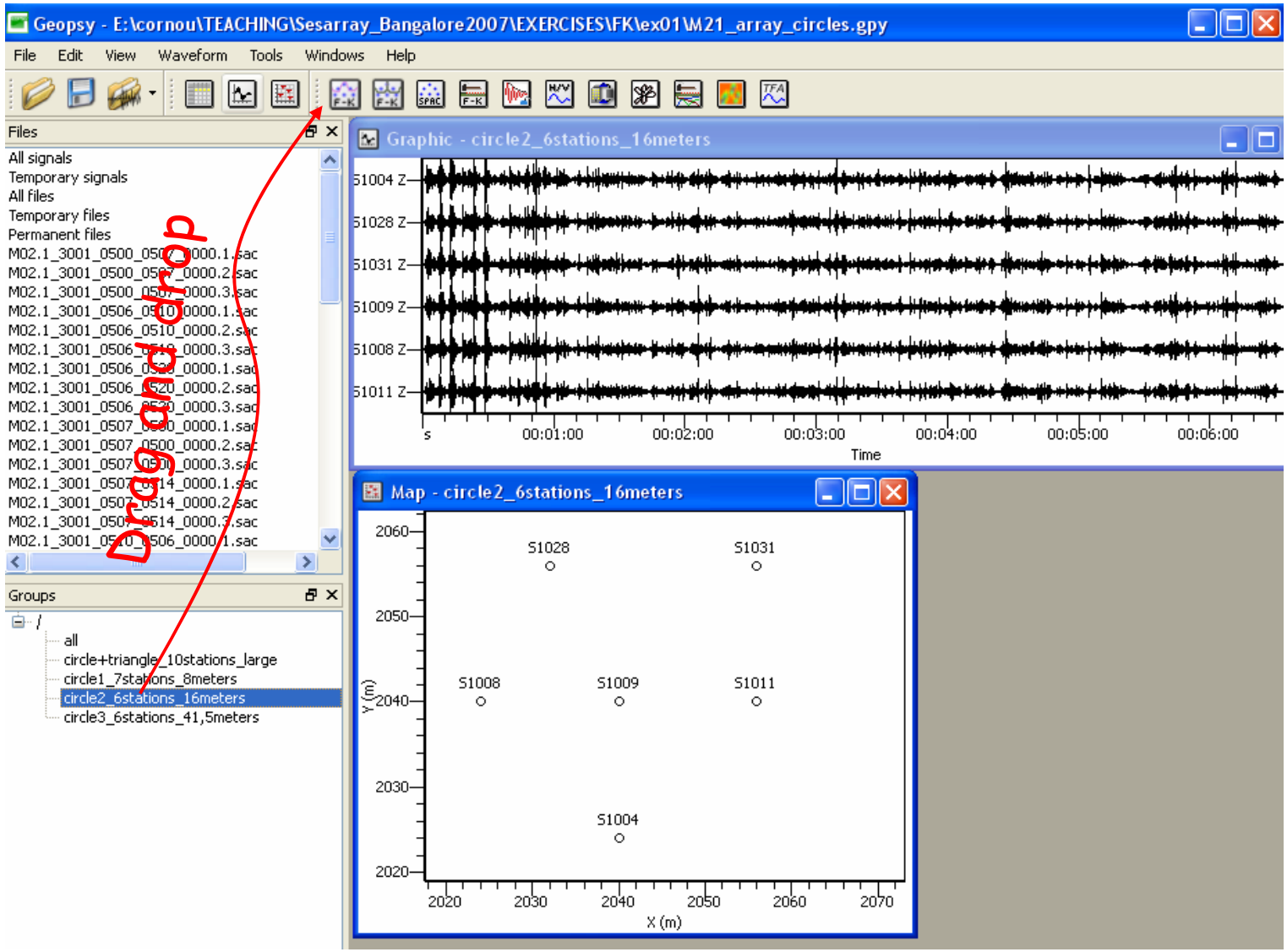


Loading geopsy database

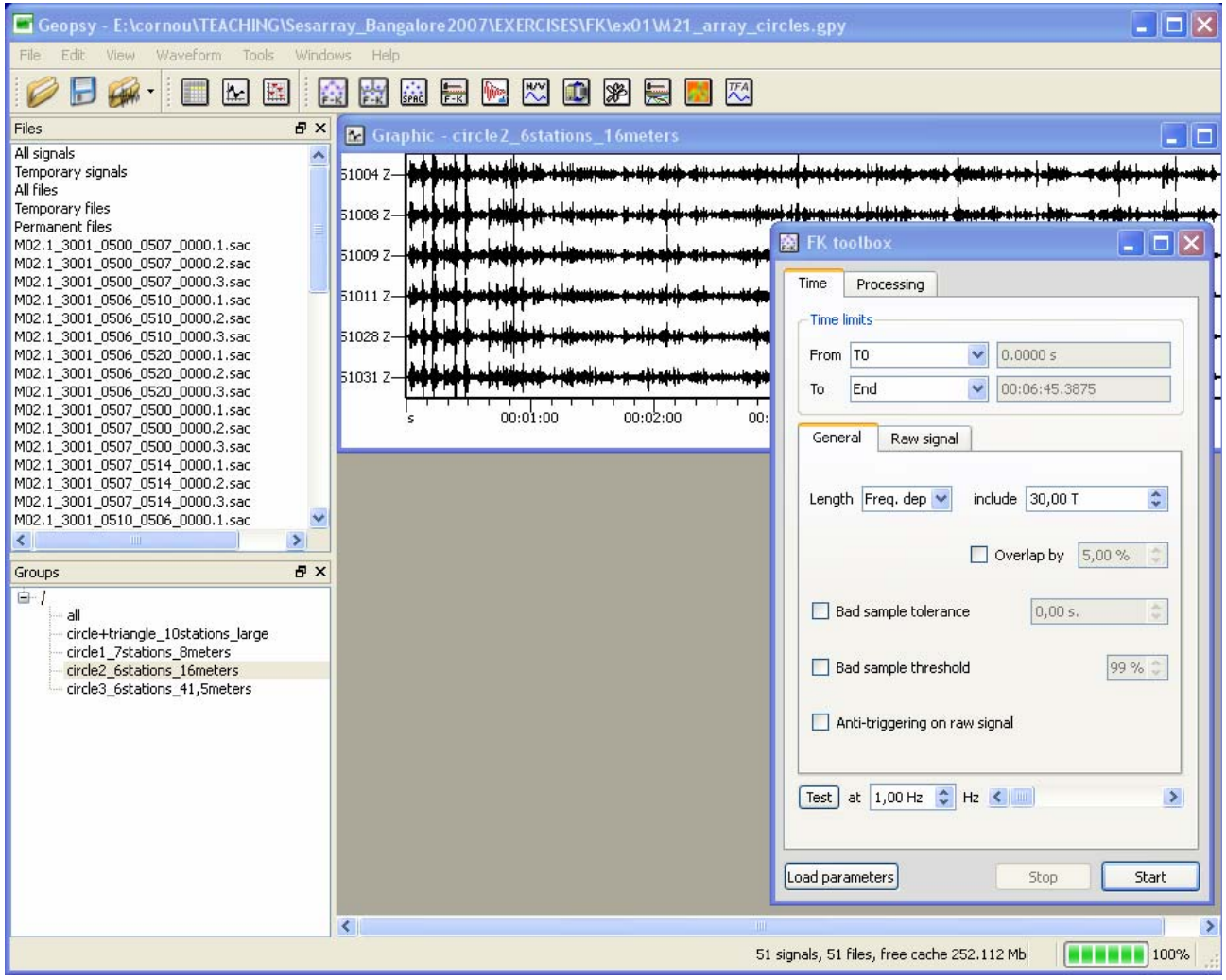
~/data/EXERCISES_FK/EX01/.gpy*



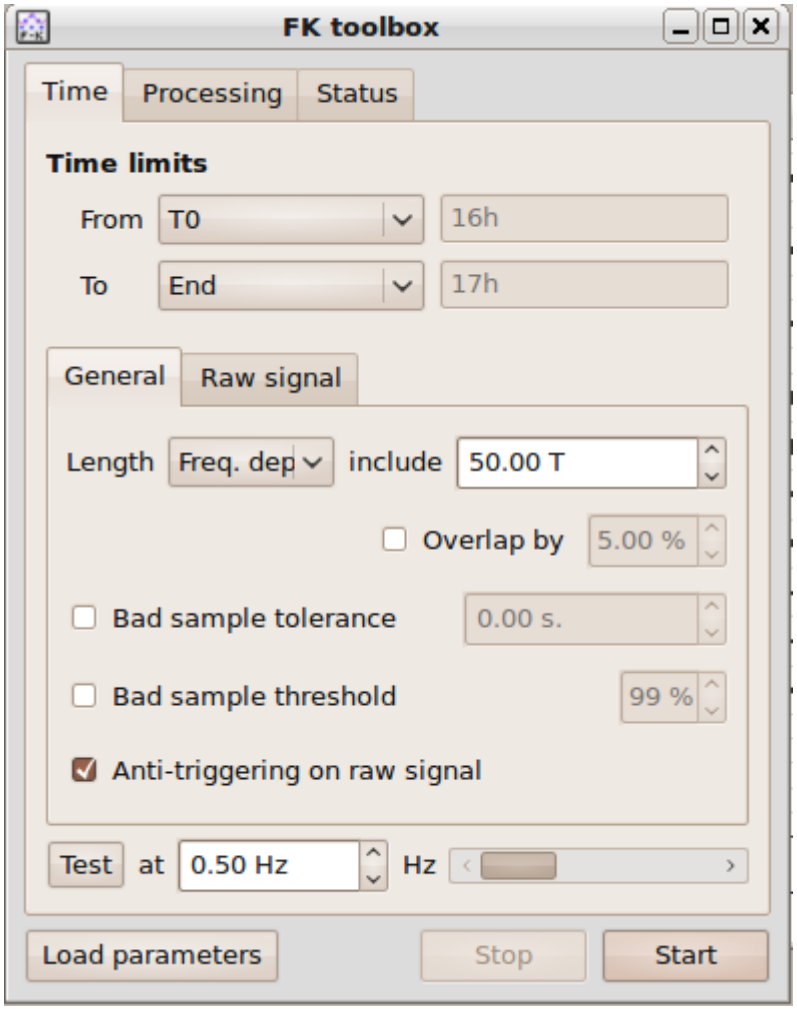
Display signals and array layout

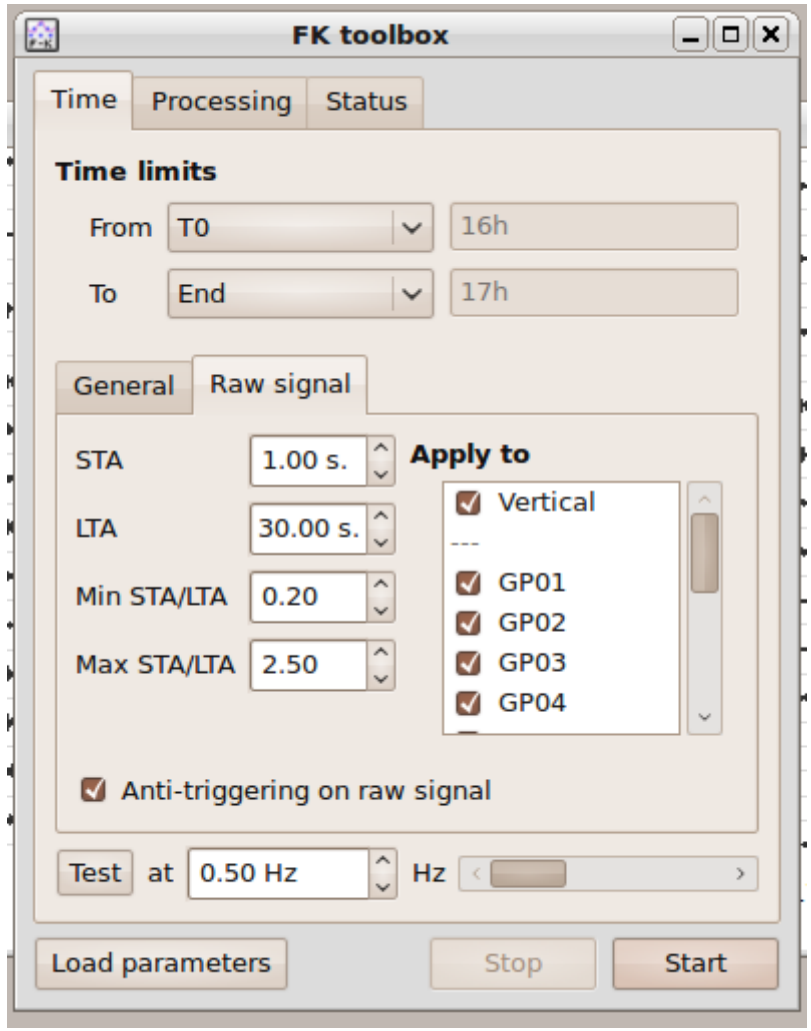


- Activate signals graphic of group *circle2_6stations_16meters*
- Launch the fk tool
- Set time parameters (limits, window length) Window length=30T

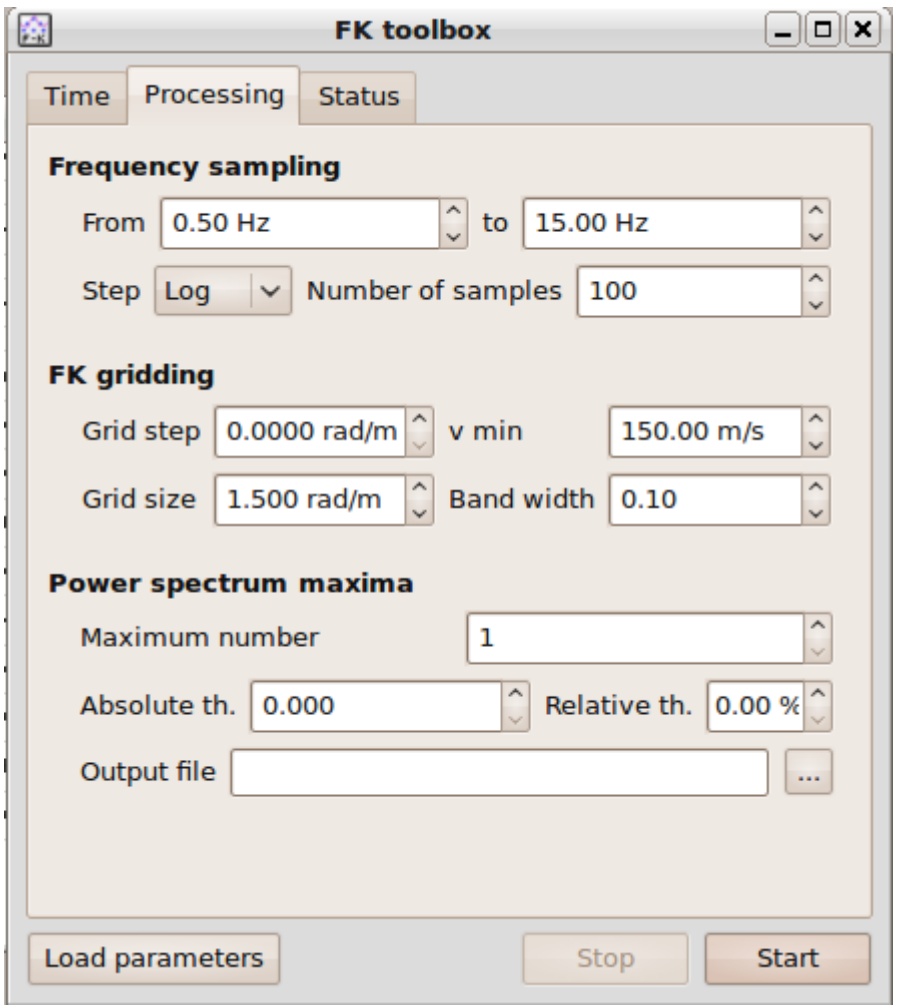


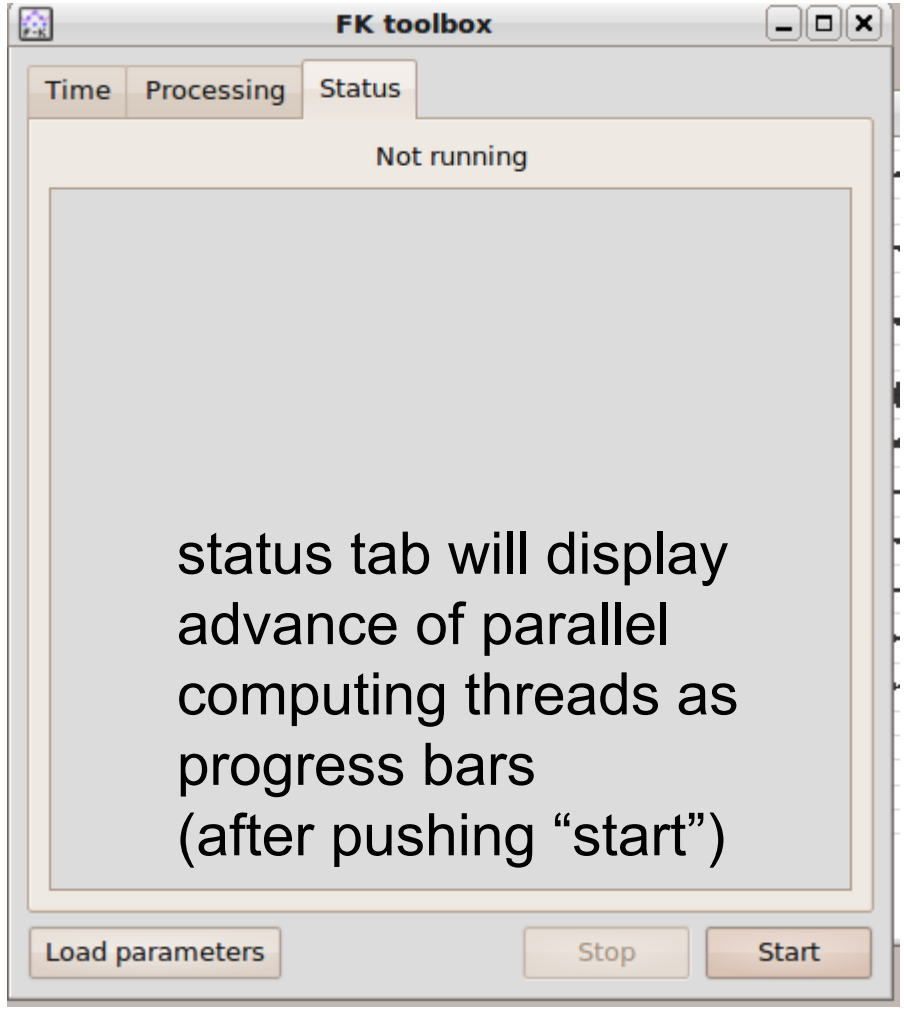
FK-toolbox – tab contents – overview (I)



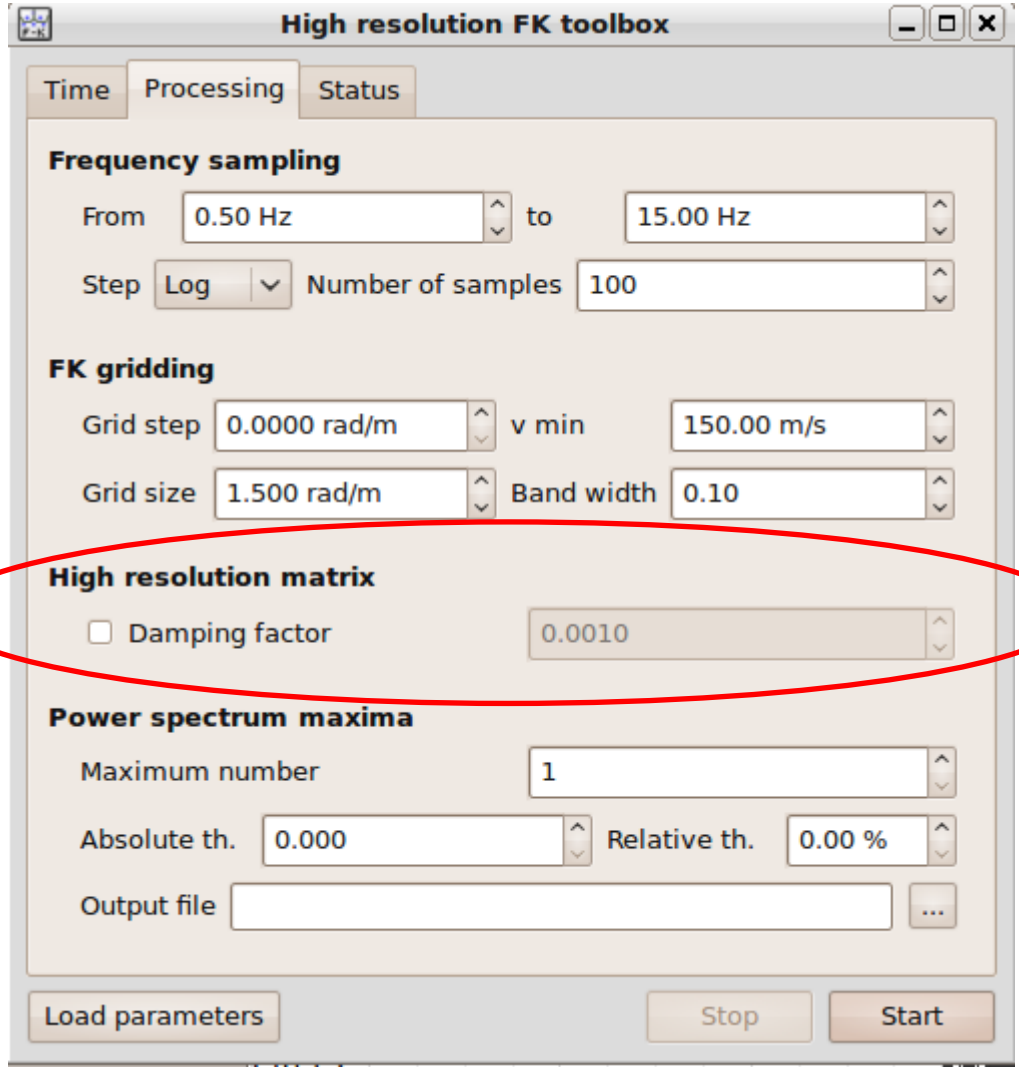


FK-toolbox – tab contents – overview (II)





HRFK-toolbox = FK-toolbox with minimal addition



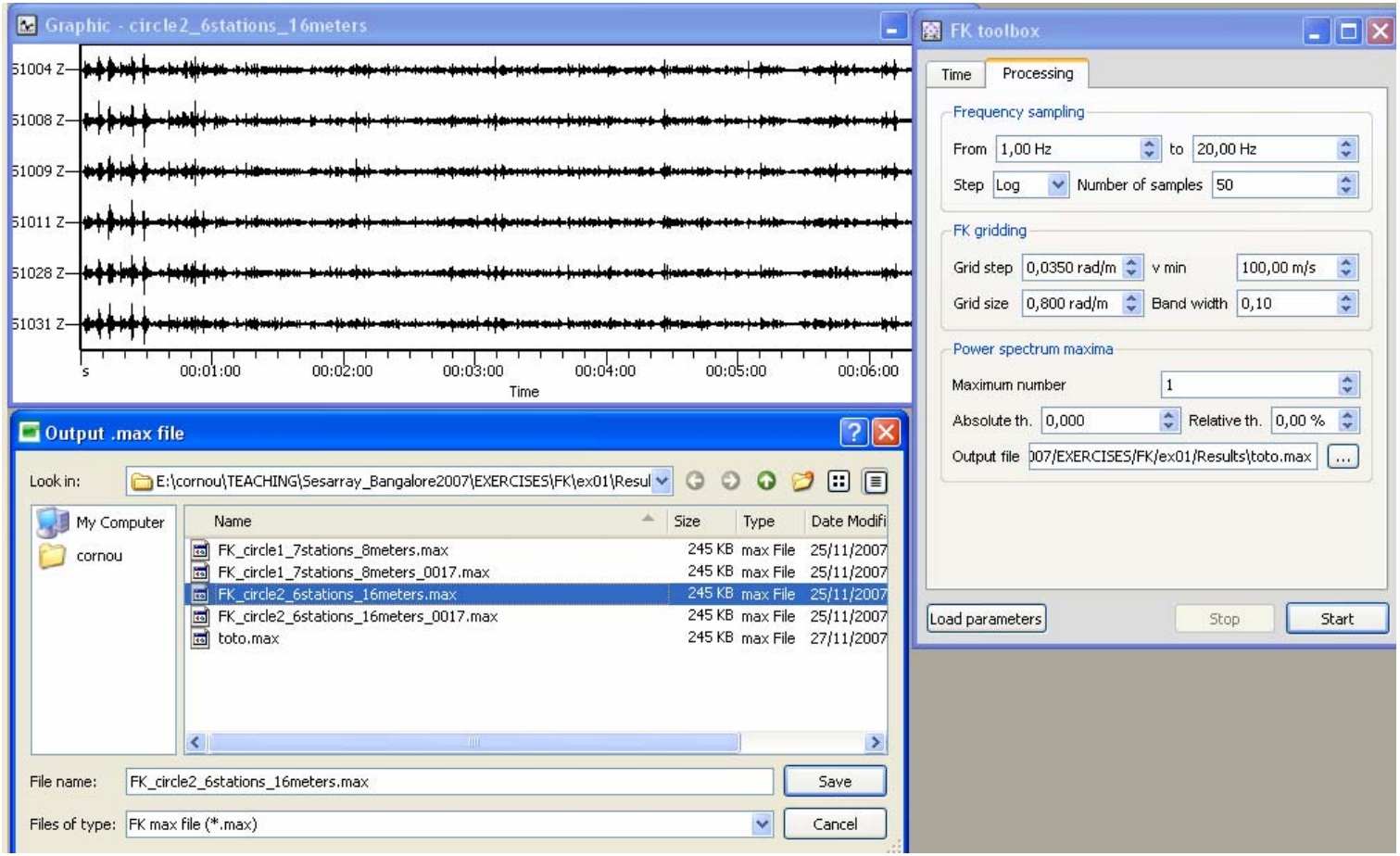
- Set processing parameters
- Set name of output file (.max extension)

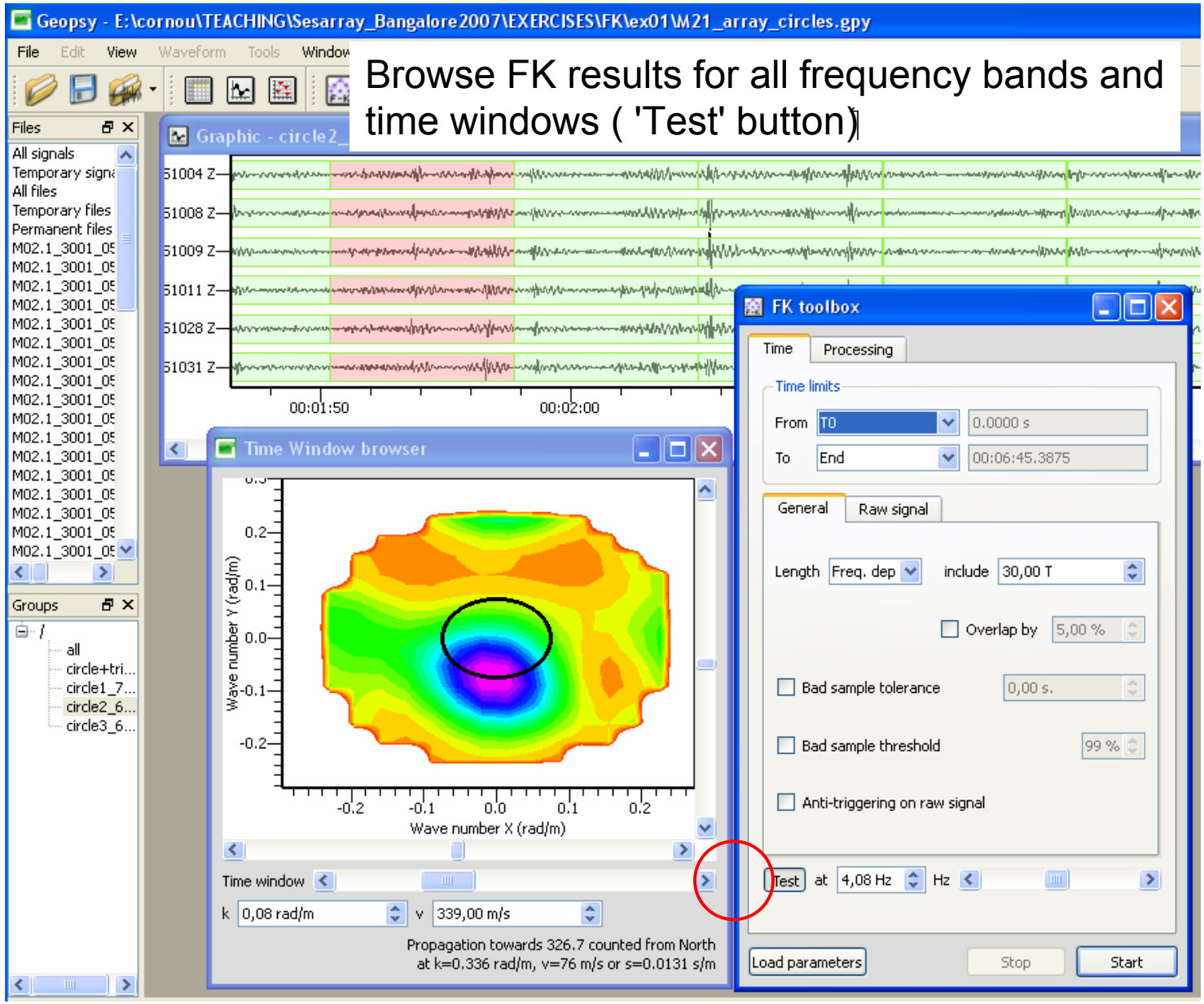
Fmin=1 Hz
Fmax=20 Hz
Nb samples = 50

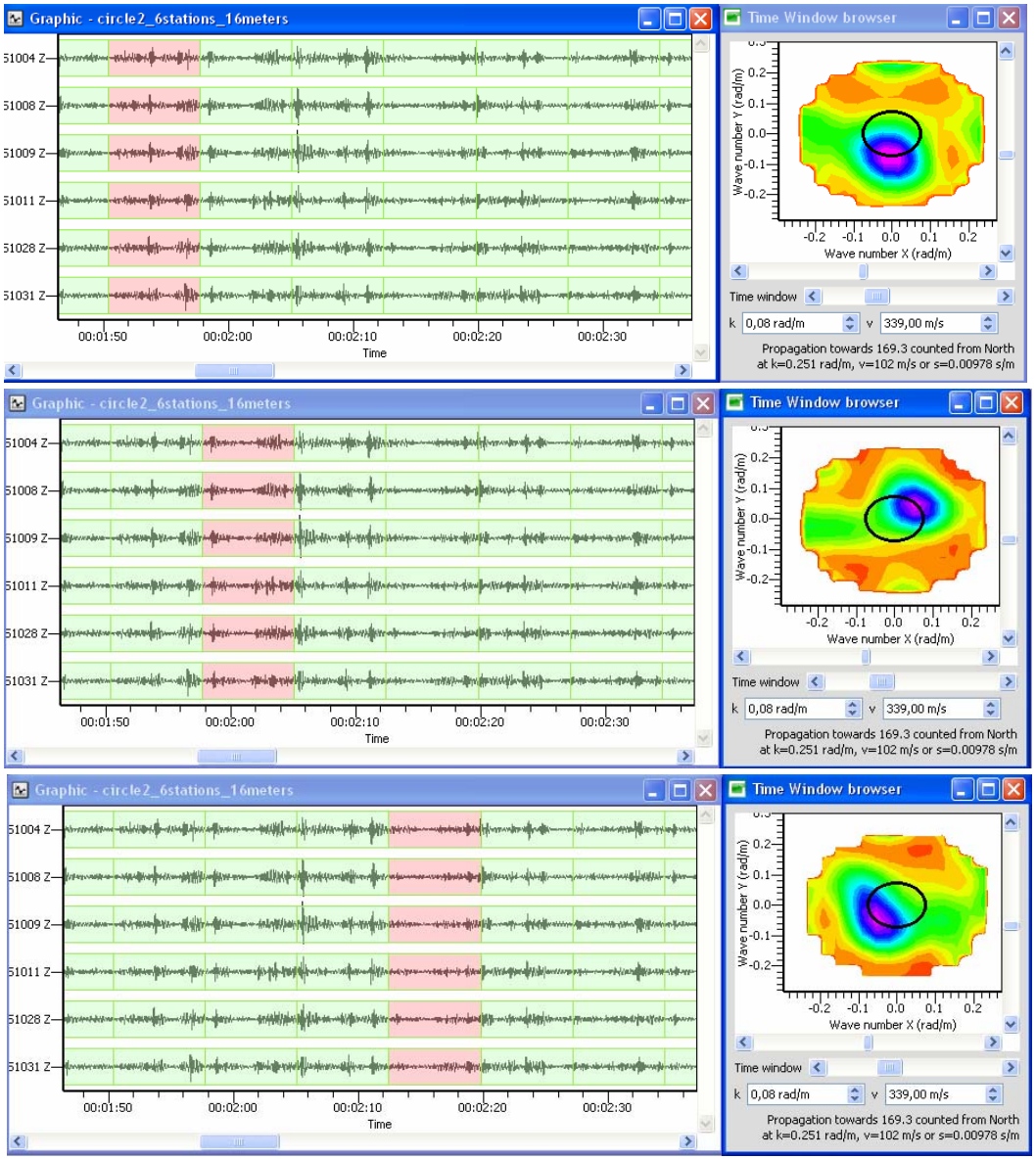
Grid_step=
0.035 rad/m

Grid_size=
0.8 rad/m

Vmin=100 m/s
Bandwidth = 0.1




Geopsy - E:\cornou\TEACHING\Sesarray_Bangalore2007\EXERCISES\FK\ex01\M21_array_circles.gpy
File Edit View Waveform Tools Window
Browse FK results for all frequency bands and time windows ('Test' button)
Files
All signals
Temporary files
All files
Temporary files
Permanent files
Groups
all
Graphic - circle2_
51004 Z
51008 Z
51009 Z
51011 Z
51028 Z
51031 Z
00:01:50
00:02:00
Time Window browser
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
FK toolbox
Time
Processing
Time limits
From T0 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



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/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
:
```

.max

The output columns are:

start	relative starting time [s]
cfreq	center frequency [Hz]
slow	slowness [s/km]
Baz	backazimuth [degree]
math-phi	azimuth [degree]
array-out	semblance
array-out	beampower (Db-scale)

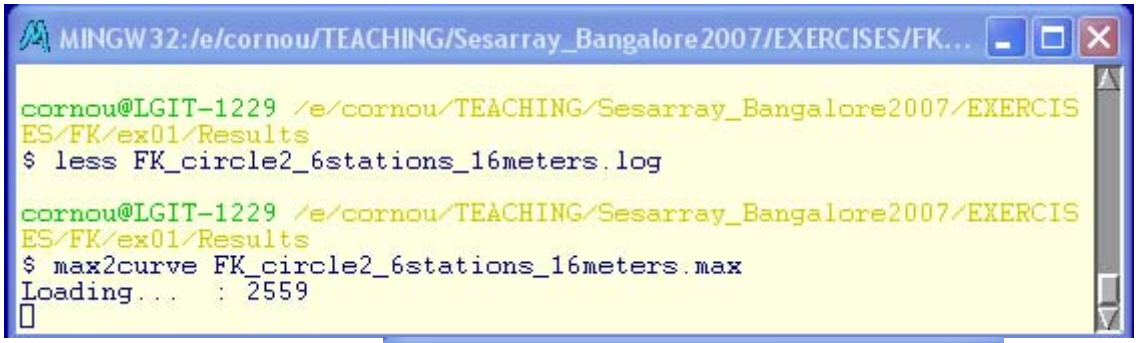
MINGW32:/e/cornou/TEACHING/Sesarray_Bangalore2007/EXERCISES/FK...

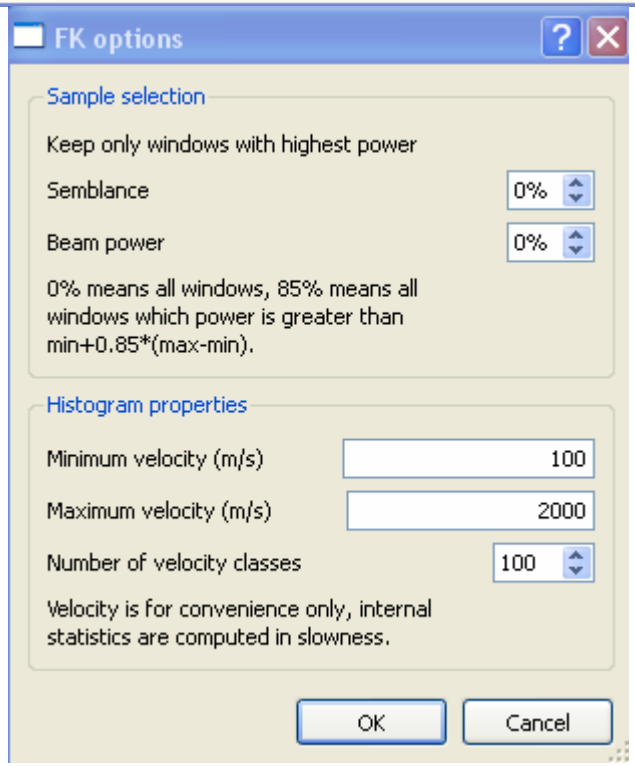
```
cornou@LGIT-1229 /e/cornou/TEACHING/Sesarray_Bangalore2007/EXERCIS
ES/FK/ex01/Results
$ less FK_circle2_6stations_16meters.log
```

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
:
```

.log





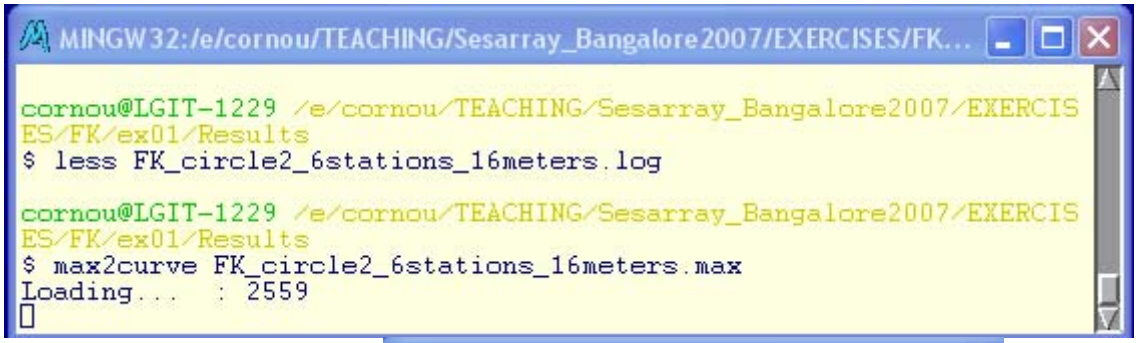
FK histograms: max2curve

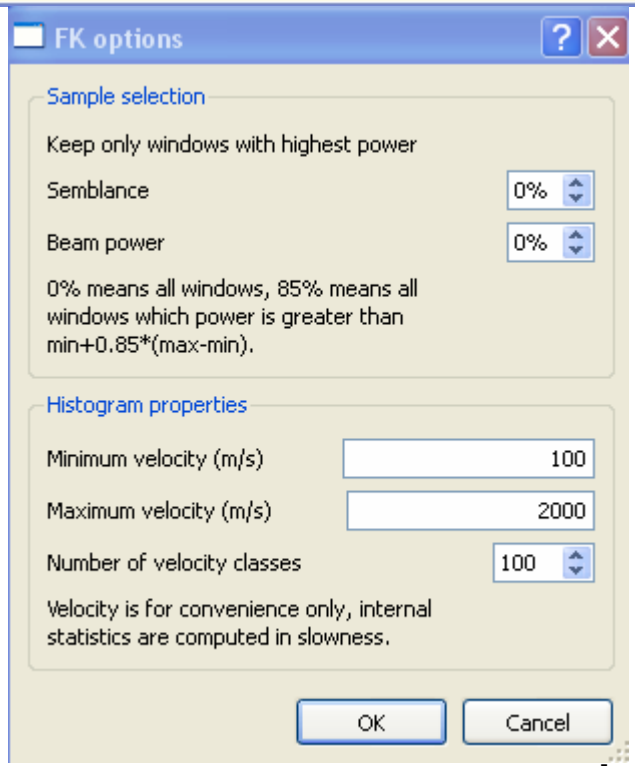
Computed from overall set of fk-estimates (optional filtering possible)

Filtering is performed via logical AND condition on both semblance and beampower estimates

Histograms computed within this velocity range

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

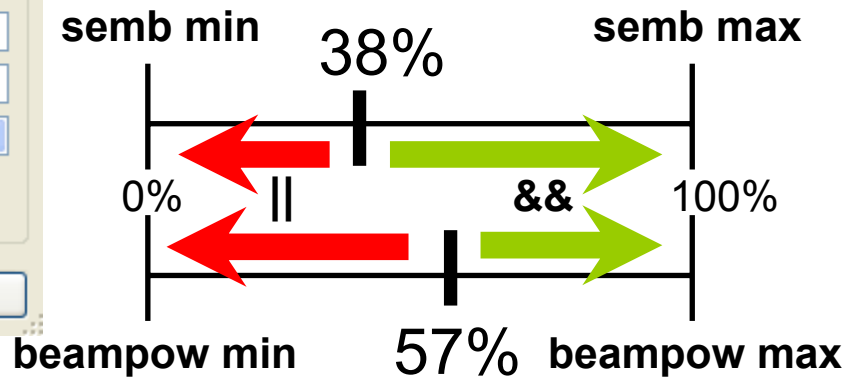


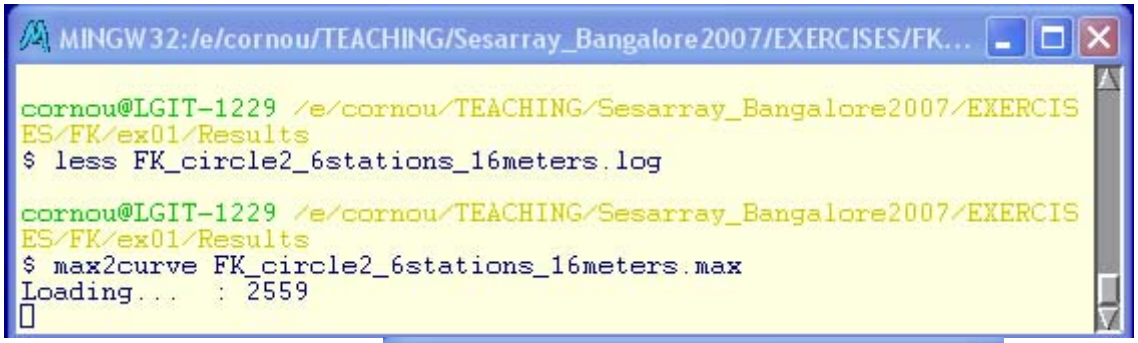


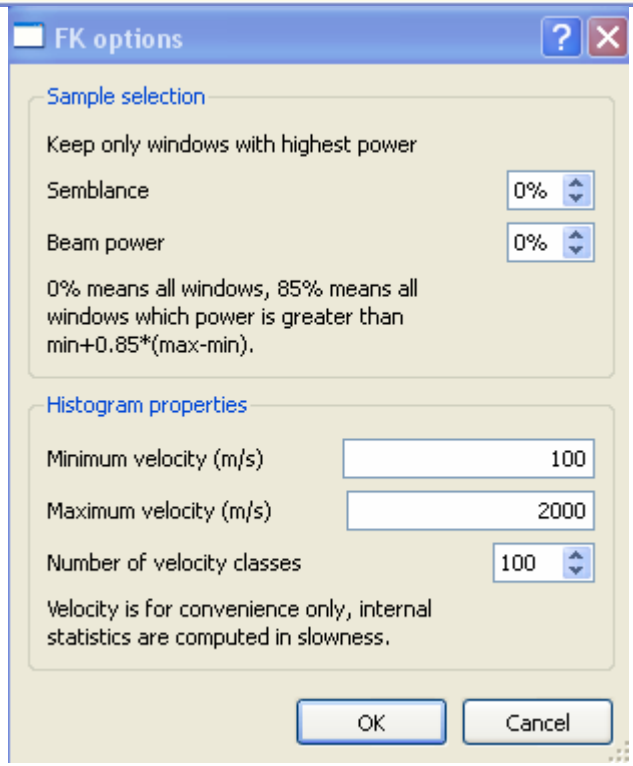
FK histograms: max2curve

Computed from overall set of fk-estimates (optional filtering possible)

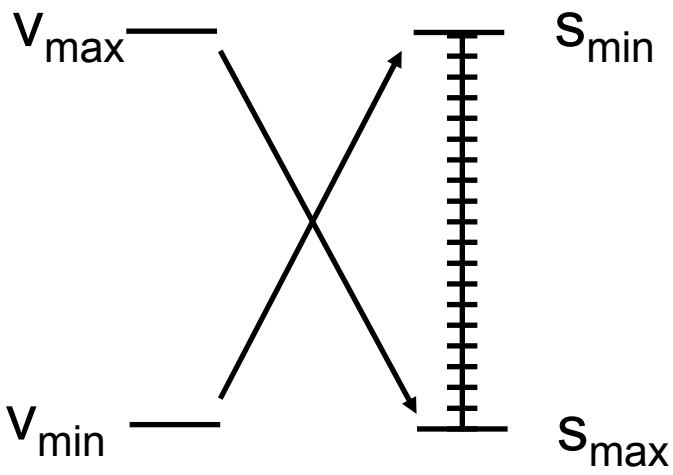
Filtering is performed on logical AND condition on both semblance and beampower estimates







FK histograms: max2curve



Histograms computed within this velocity range

Number of equidistantly distributed slowness cells within limits [V_{min}, V_{max}].

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

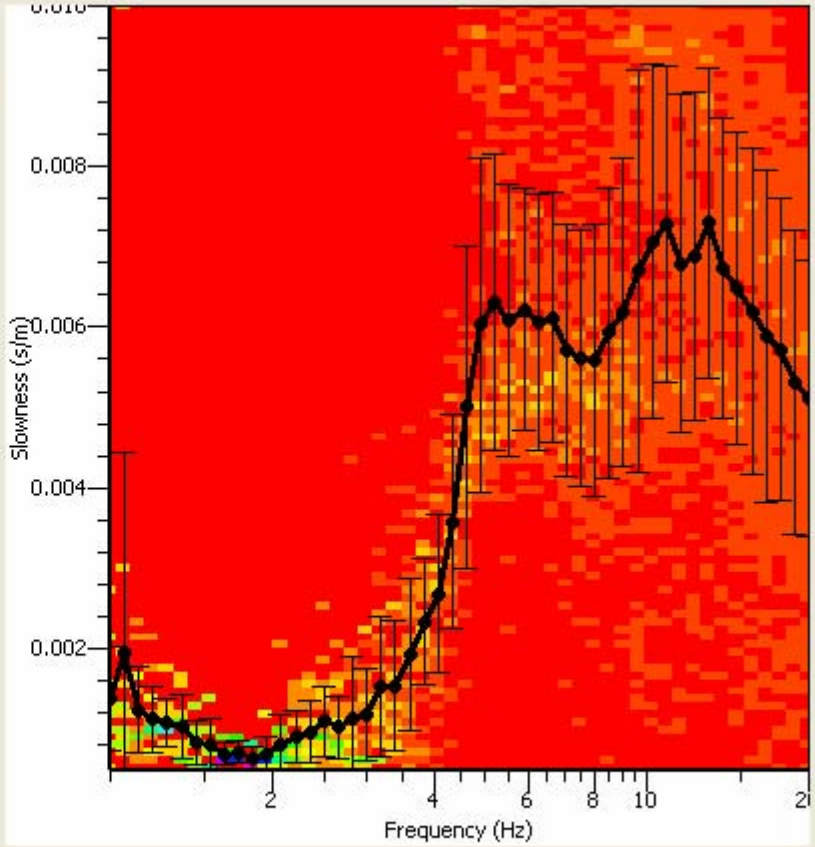
Load | Clear | Legend | Average

Curve data

Curve 1 of 1

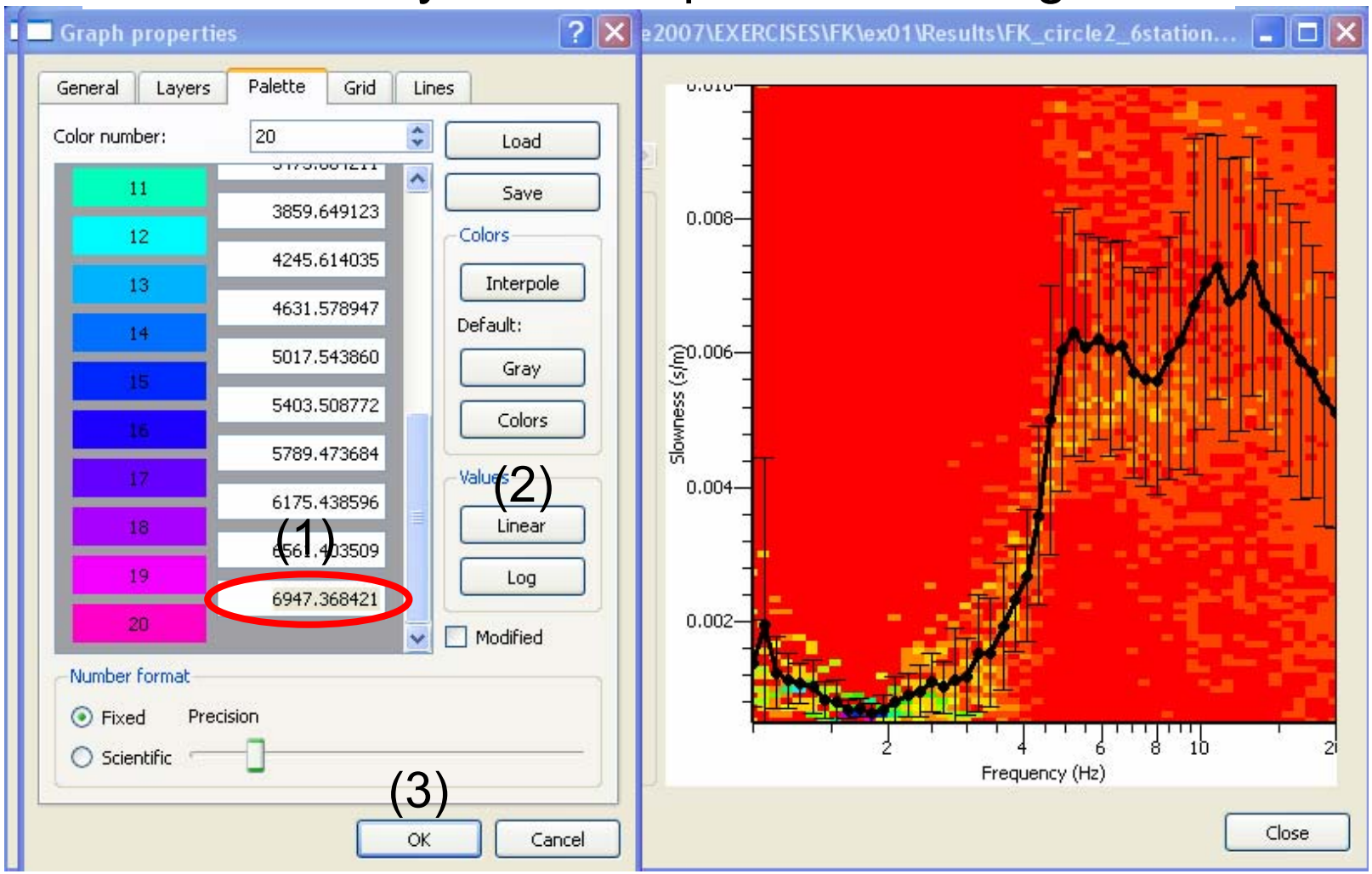
	Frequency	Period	Valid	Average	Std dev	Weight
1	1	1	☑	0,0013...	0,0006...	12
2	1,06304	0,94...	☑	0,0019...	0,0024...	13
3	1,13006	0,88...	☑	0,0012...	0,0005...	14
4	1,20131	0,83...	☑	0,0011...	0,0004...	15
5	1,27705	0,78...	☑	0,0010...	0,0002...	10
6	1,35756	0,73...	☑	0,0010...	0,0003...	9
7	1,44314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



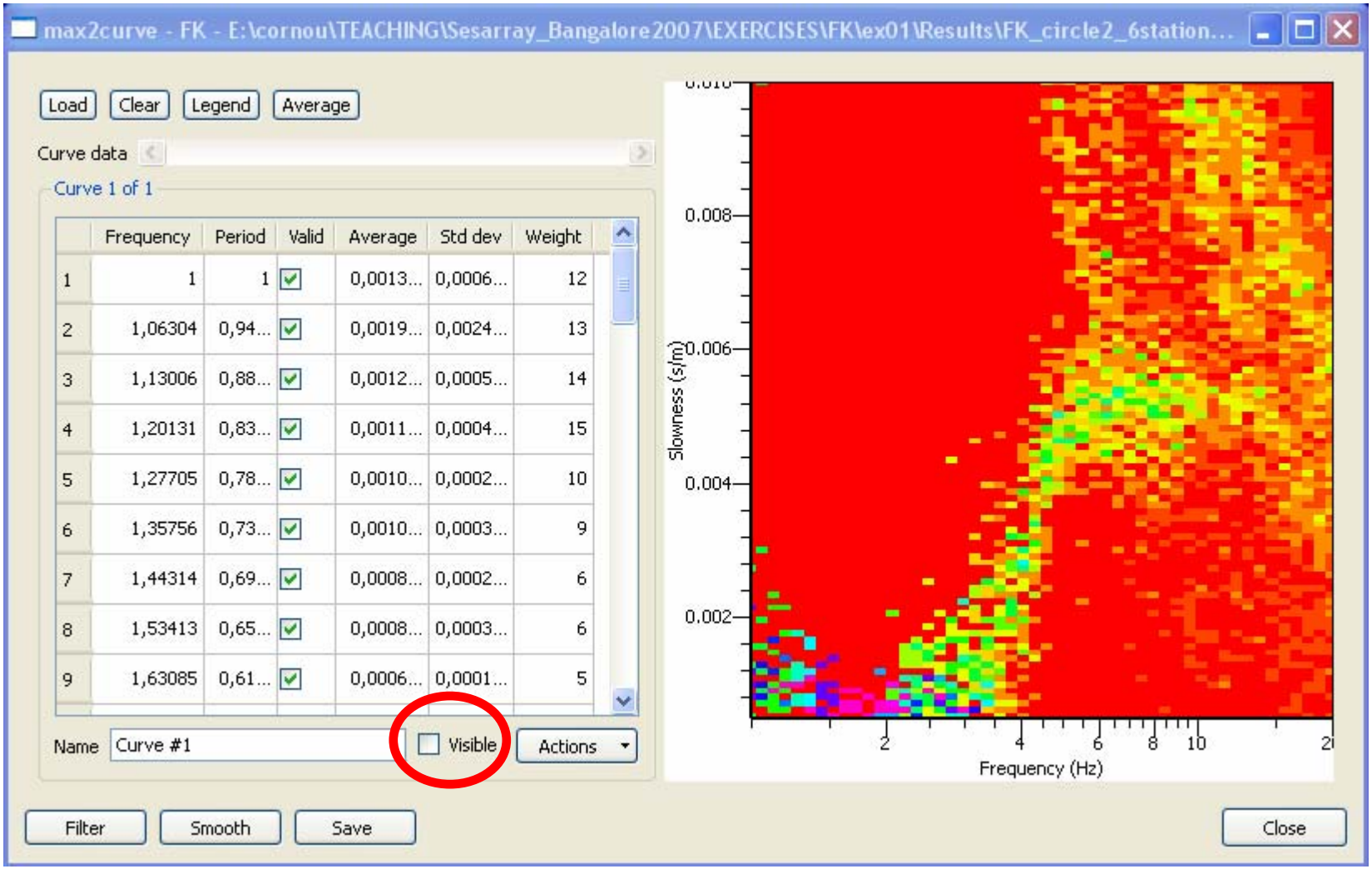
Filter | Smooth | Save | Close

How to modify the color palette of histograms?

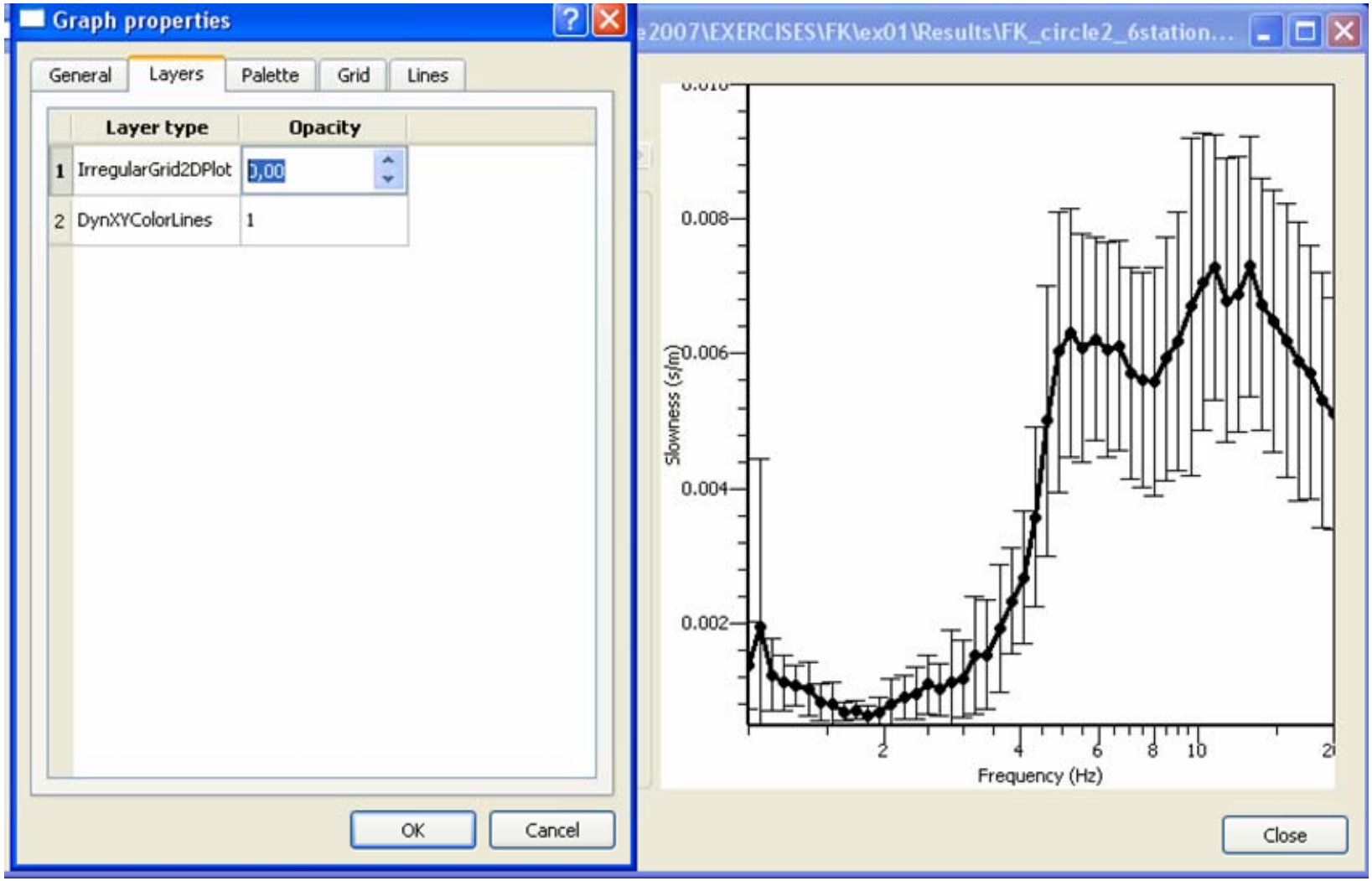


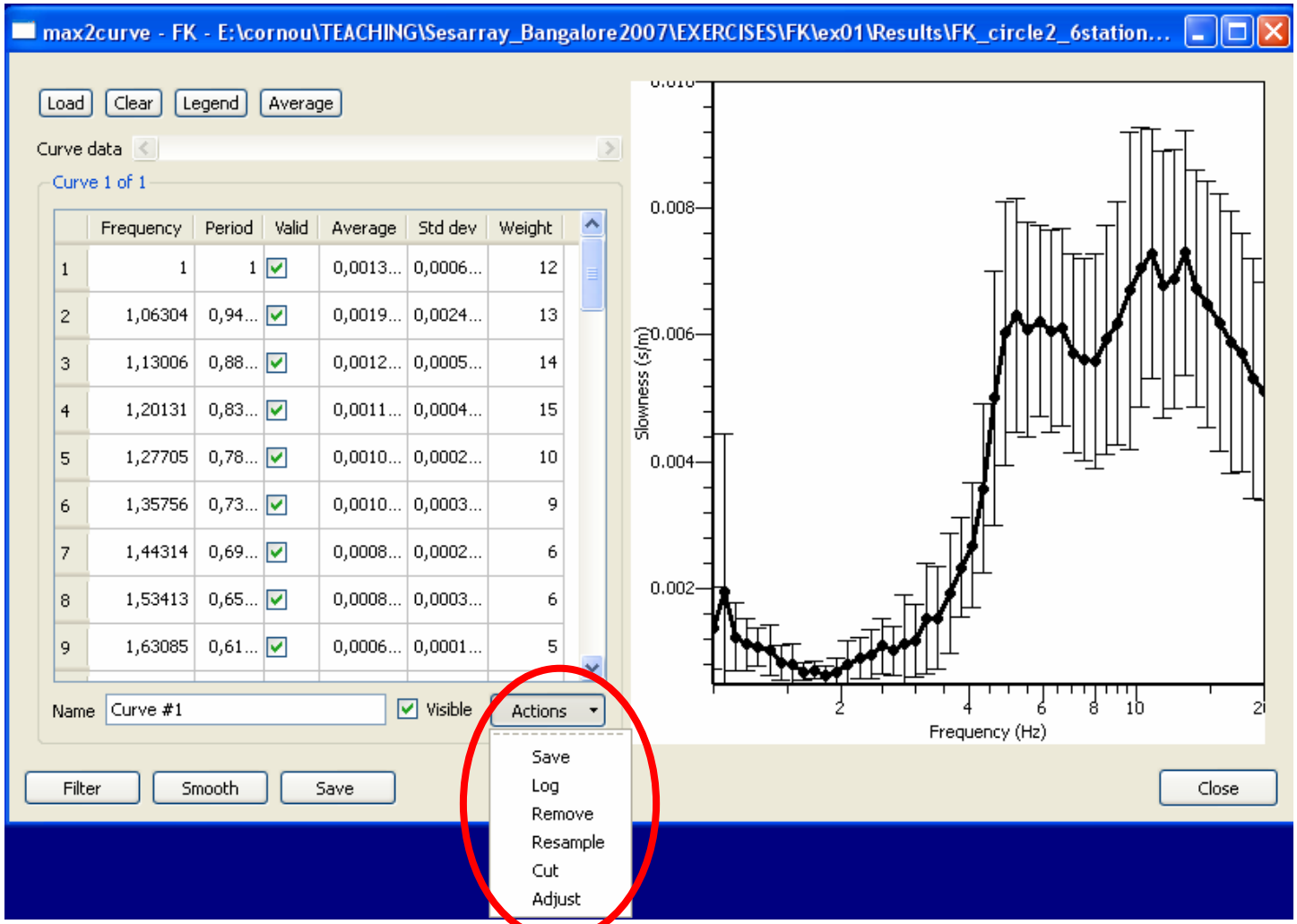
Change the maximum value of the palette
press on linear to adjust the color scale from the first to the last color number
press on OK

How to hide mean curve ?



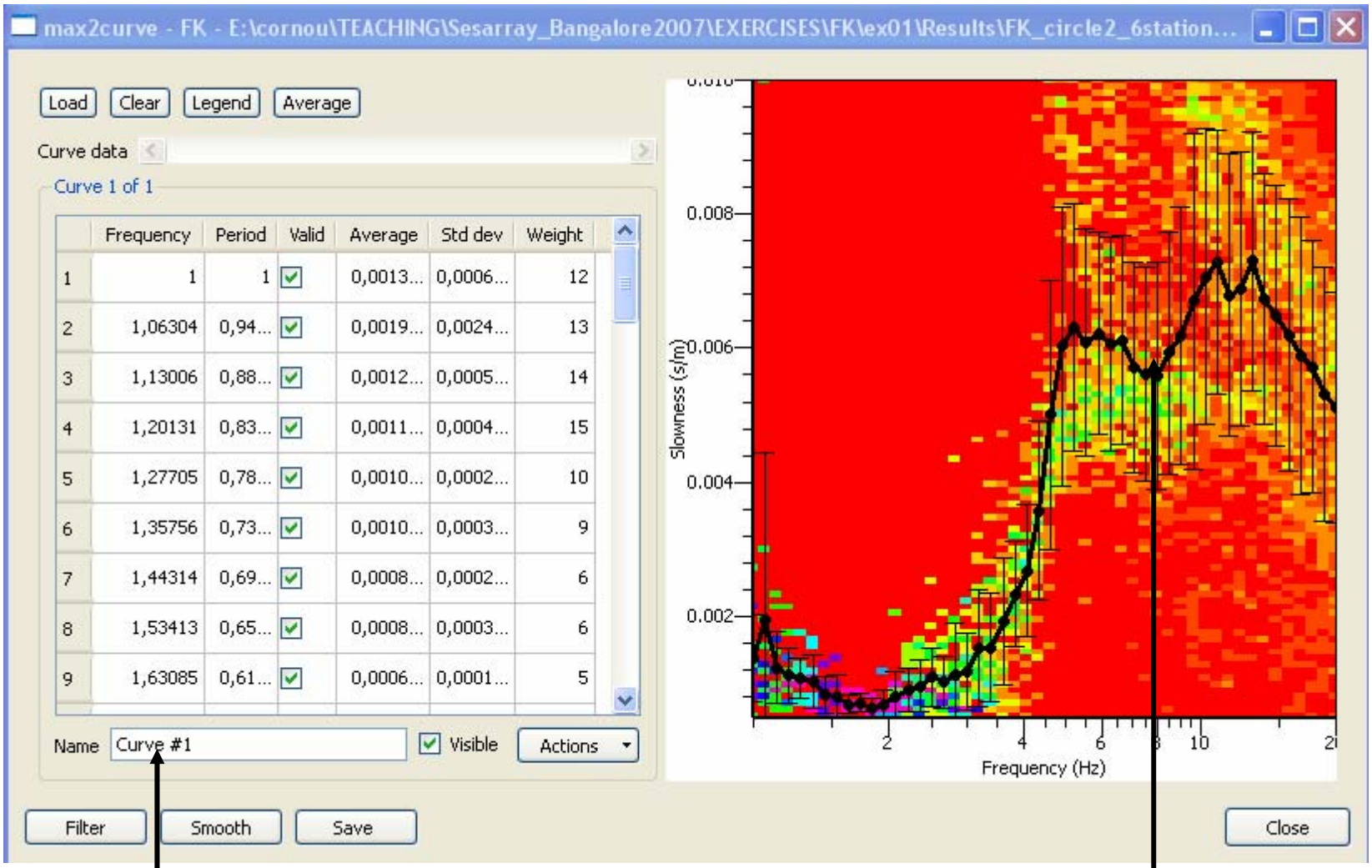
How to hide histograms ?





Actions button for: save / remove / resample / cut / smooth /adjust

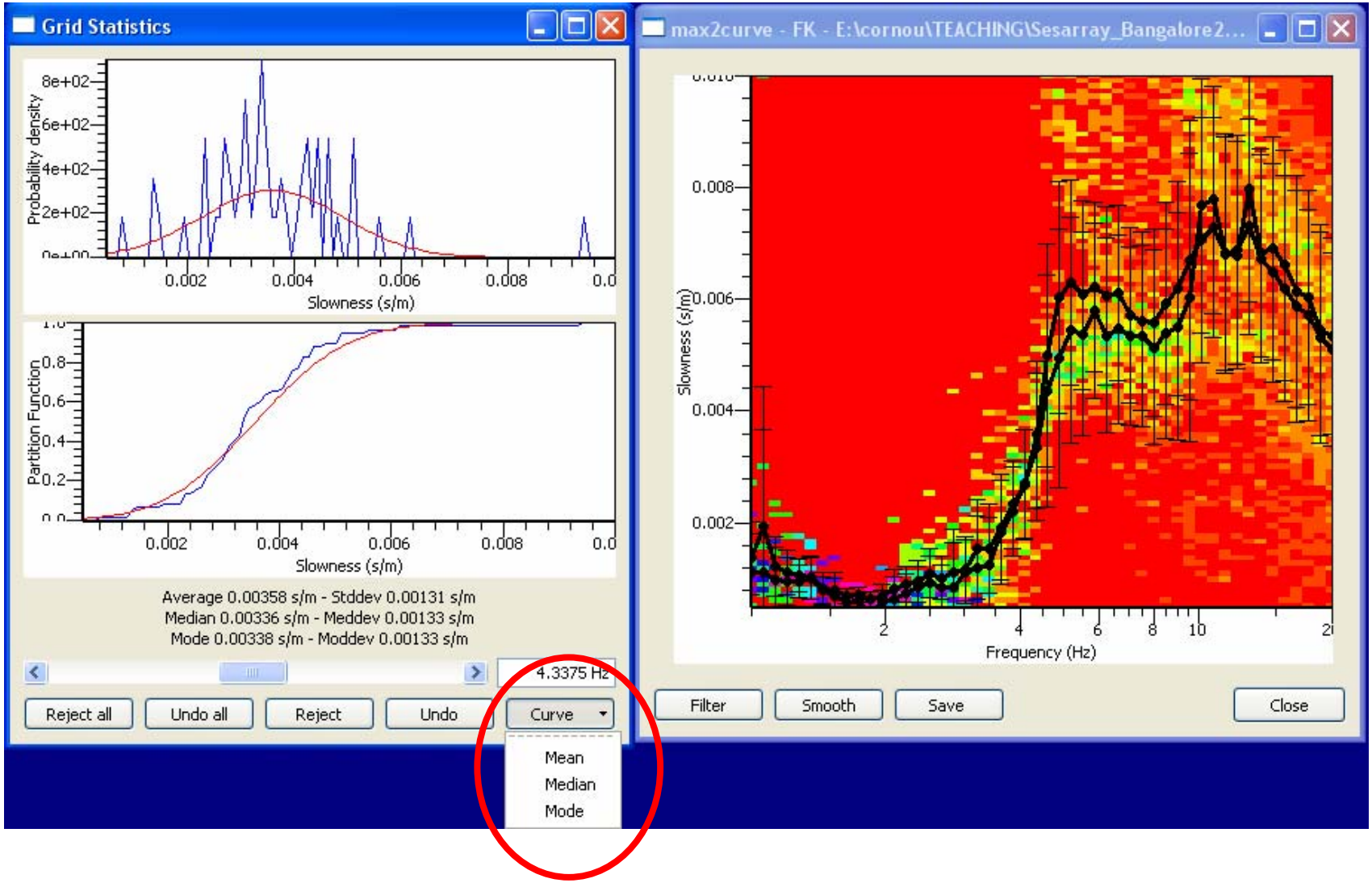
Note: applies to selected curve only (there may be more than one!)



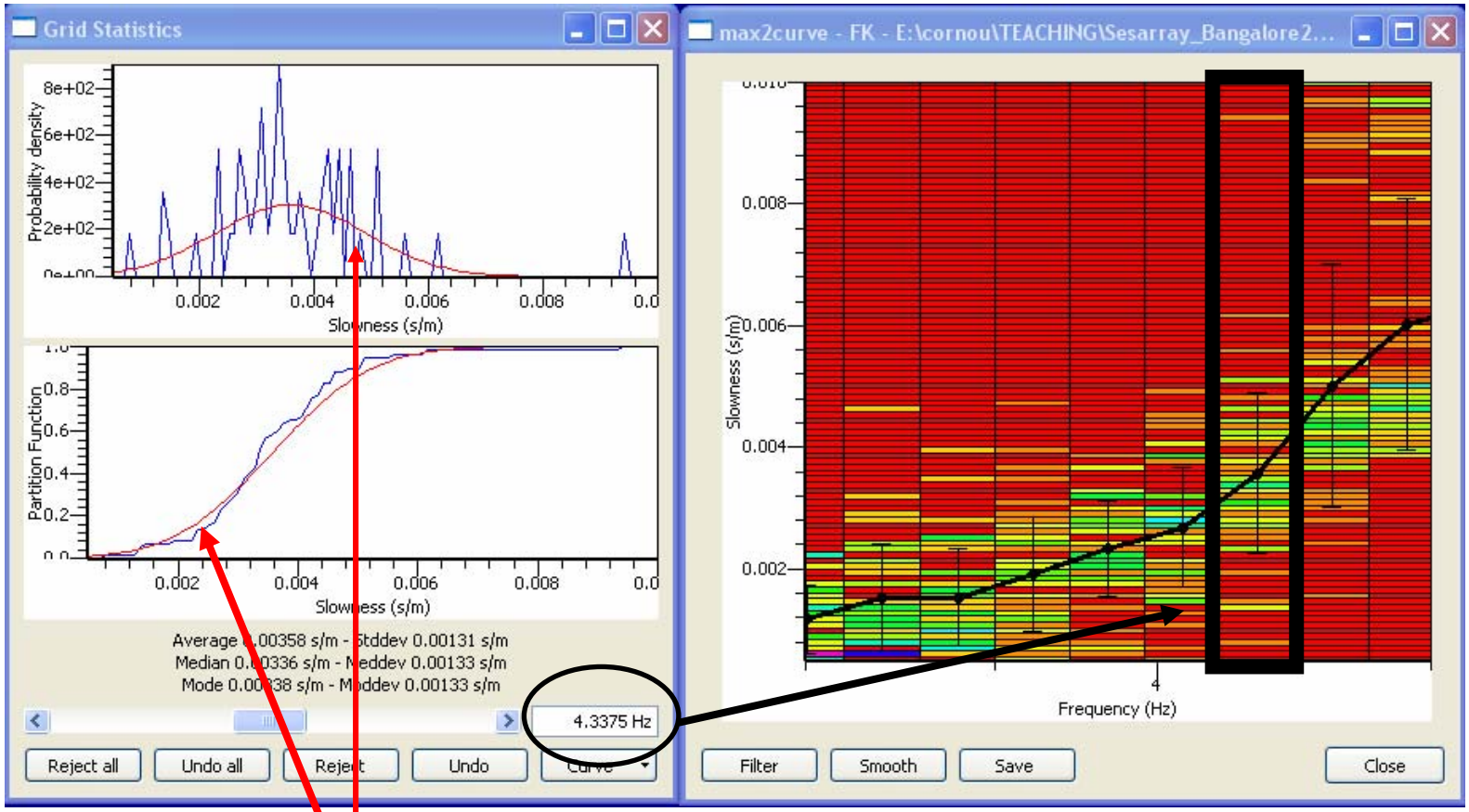
Curve identification (number/name)

Mean +/- std (by default)

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



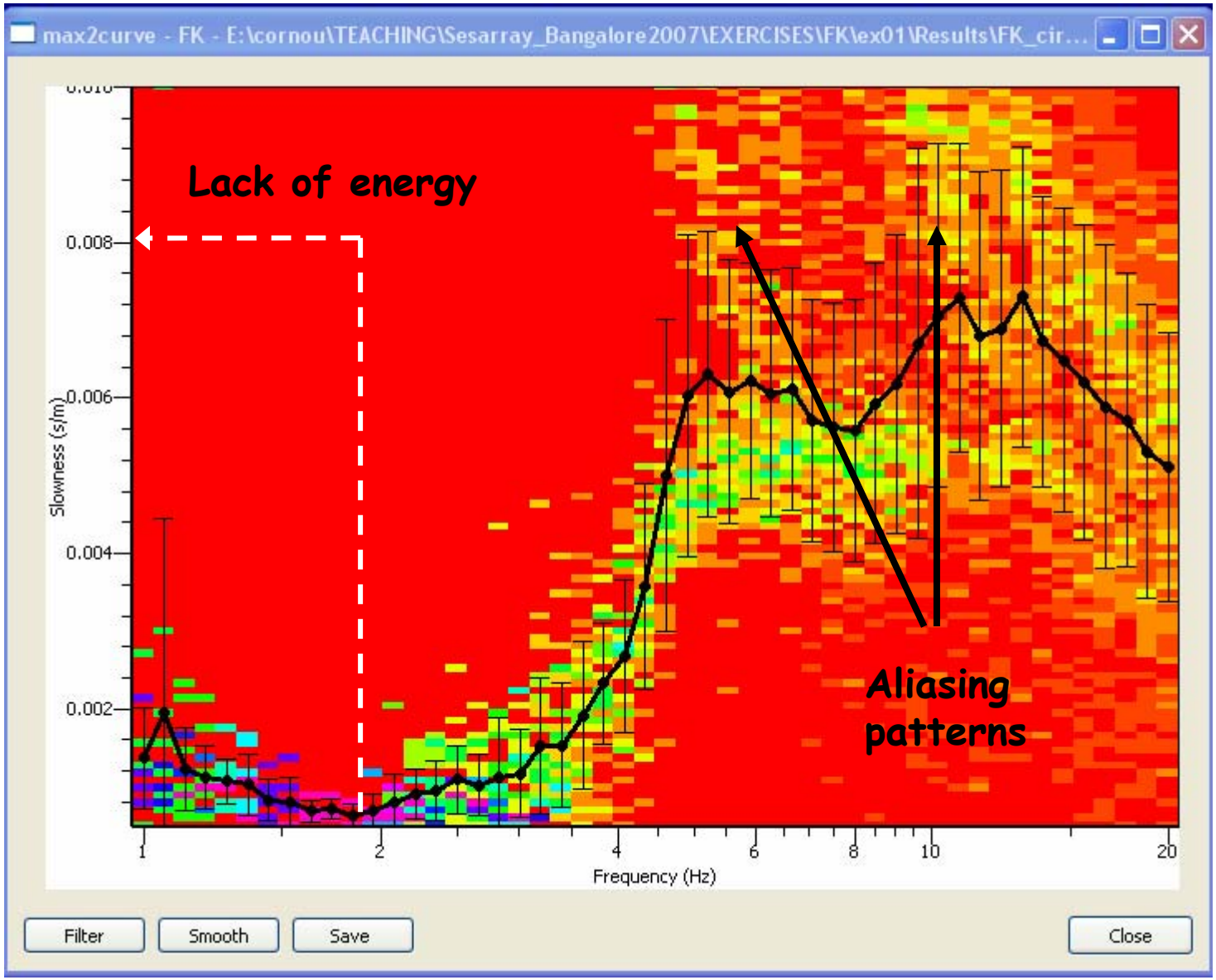
Usage of the “grid statistics” window

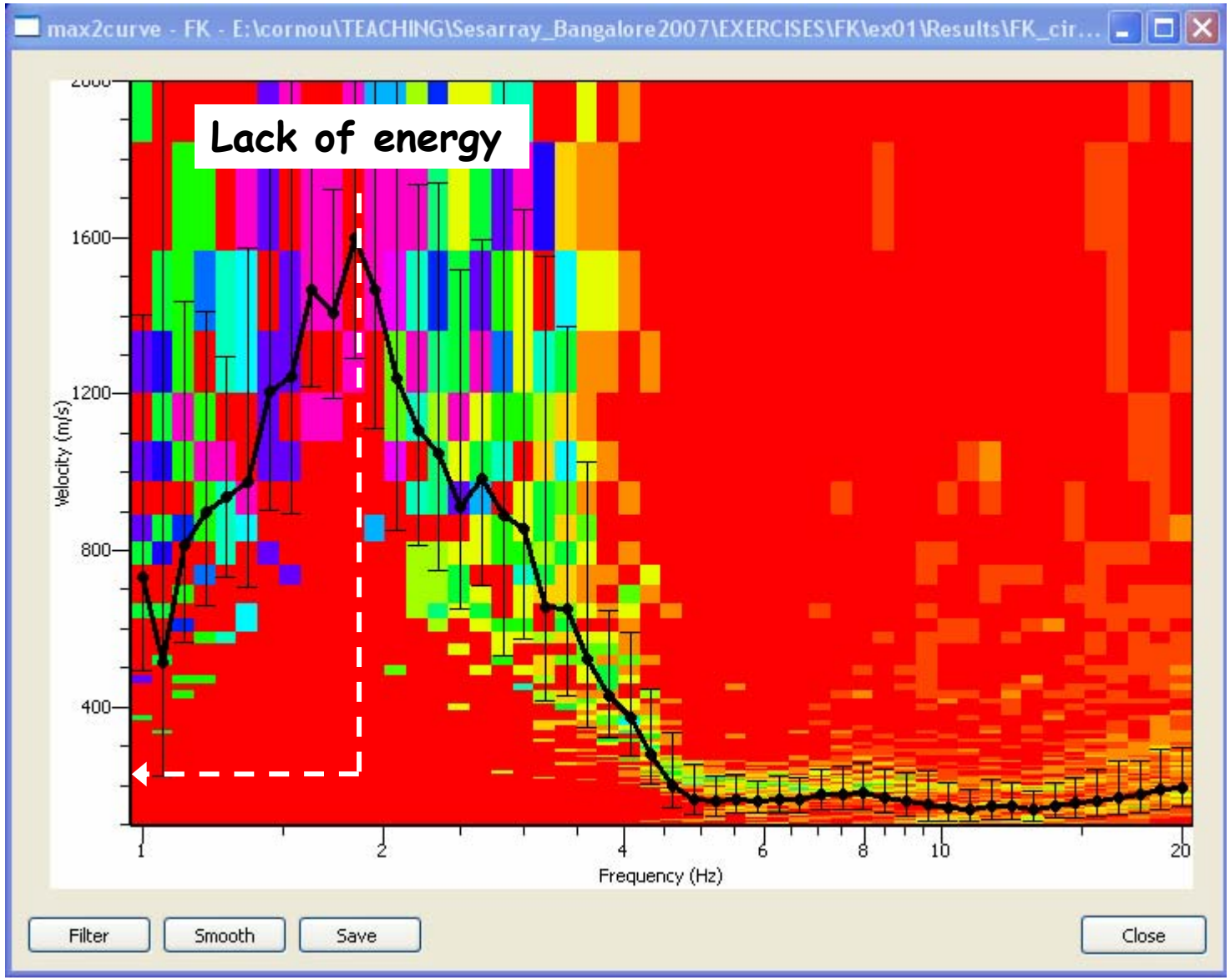


Gaussian distribution computed from the observed mean and standard deviation

The grid statistics toolbox can be used for ‘cleaning’ the histograms from outliers. Also useful for separating individual modes.
WARNING: be careful!!

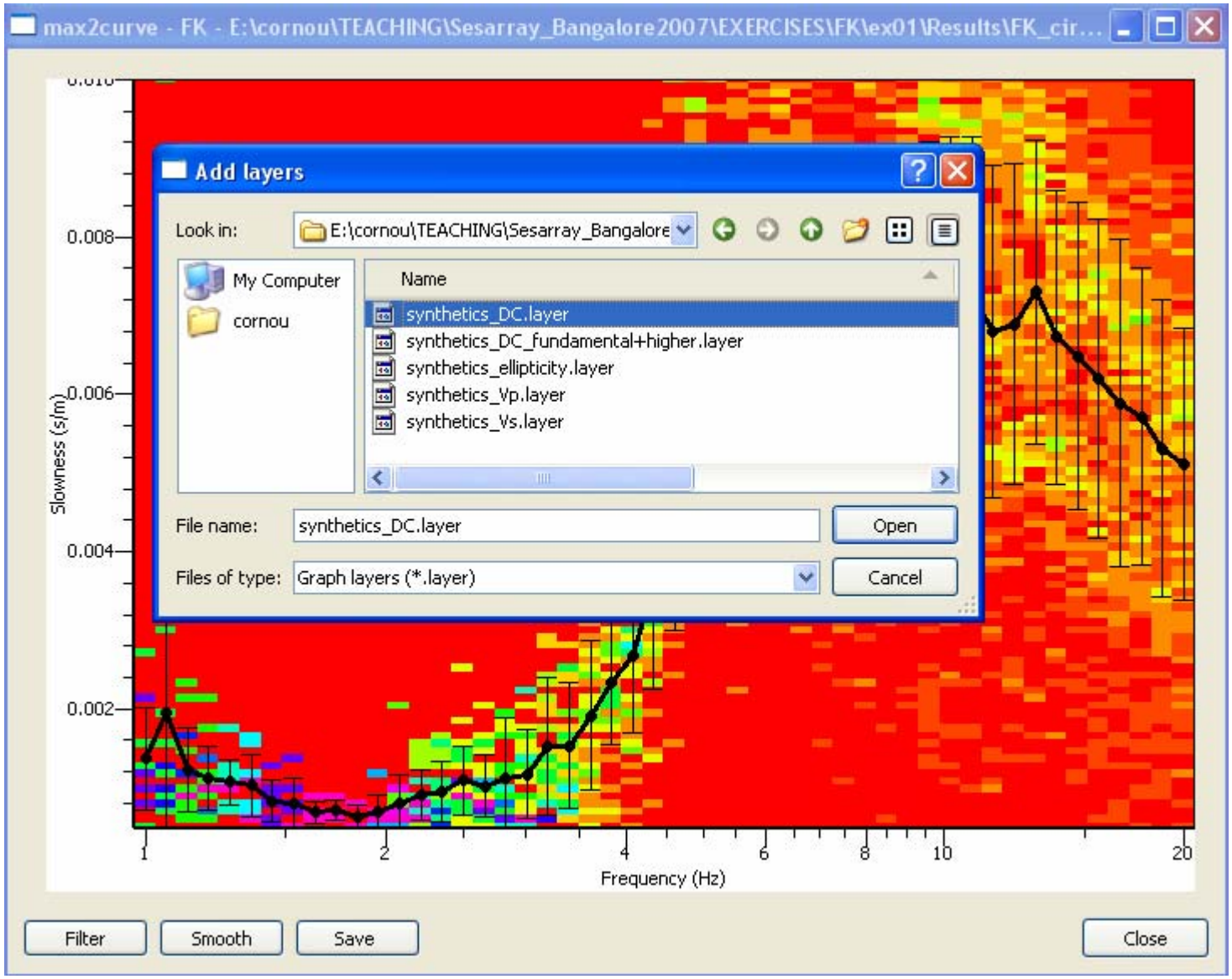
Interpretation of FK histograms

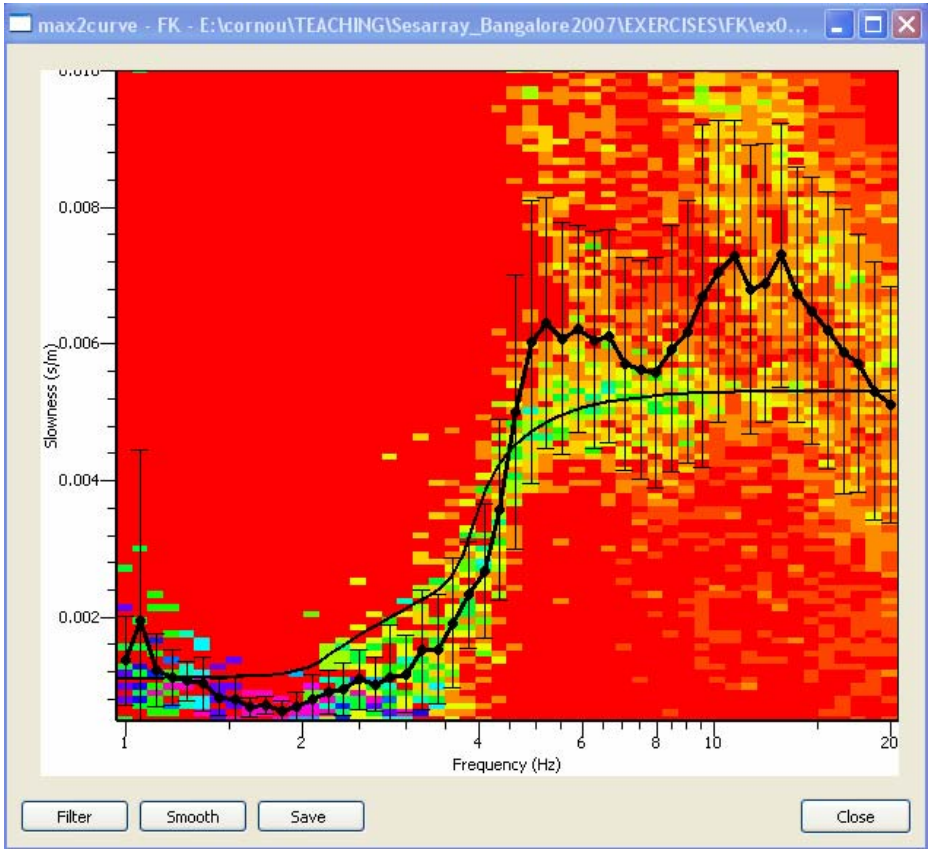


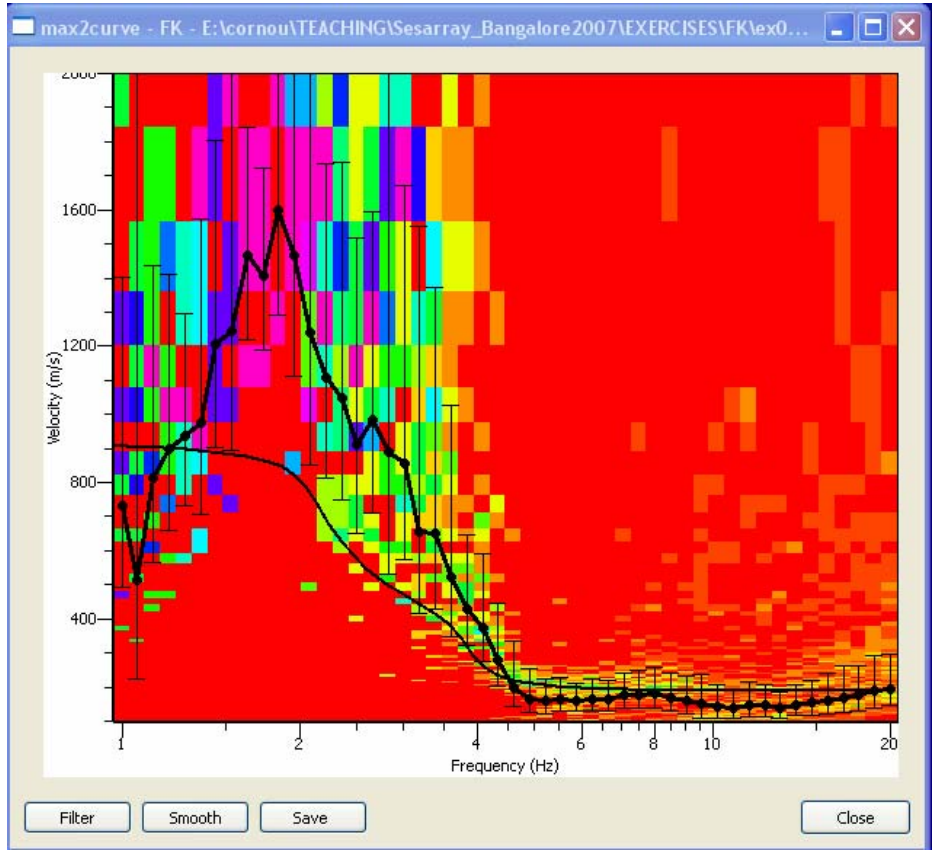

max2curve - FK - E:\cornou\TEACHING\Sesarray_Bangalore2007\EXERCISES\FK\ex01\Results\FK_cir...
Lack of energy
1600
1200
800
400
Velocity (m/s)
1
2
4
6
8
10
20
Frequency (Hz)
Filter
Smooth
Save
Close

Add theoretical DC curve

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





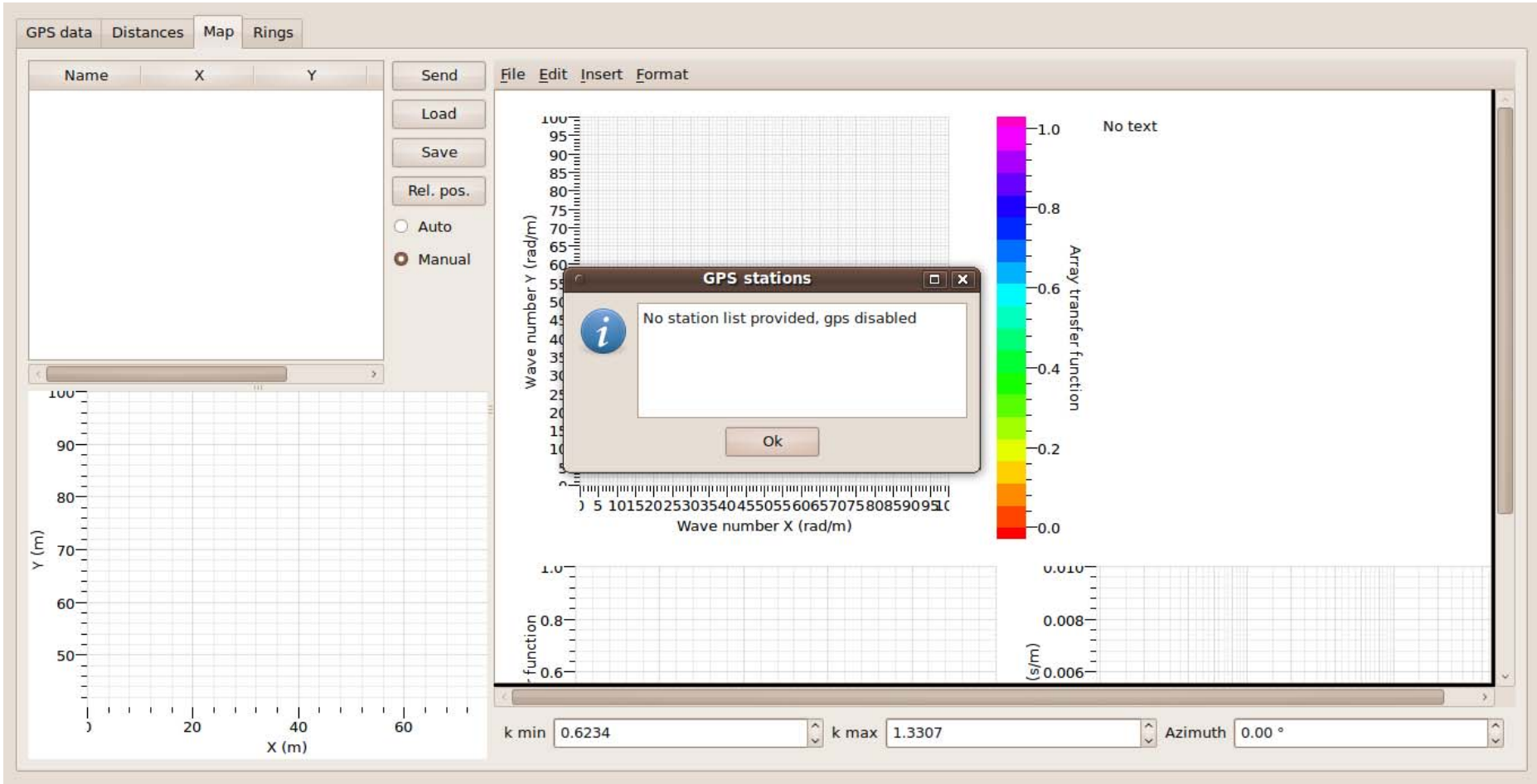


Above 4 Hz, mean curve is not representative of actual distribution which fits better the true dispersion curve

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

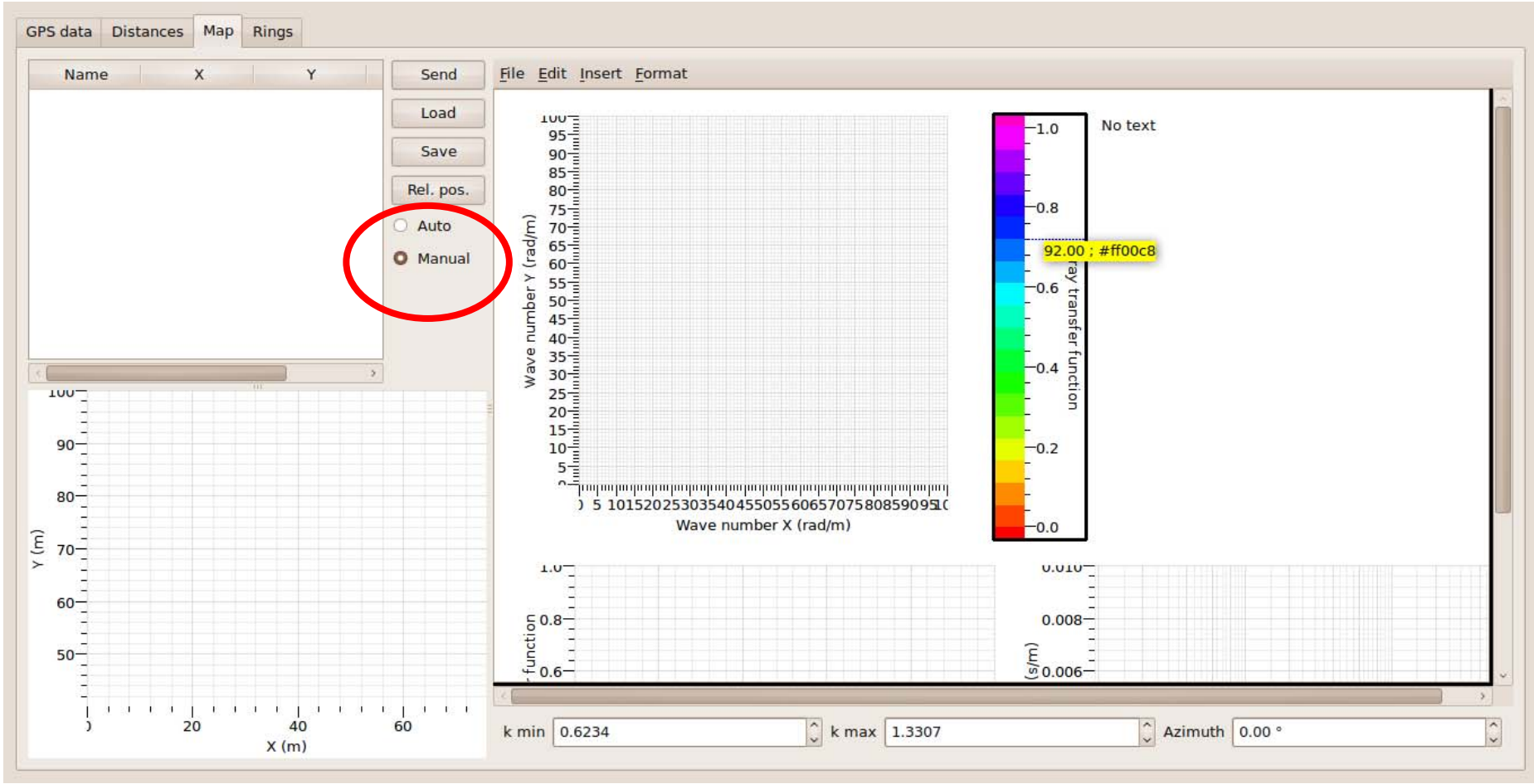
Computing array response with *warangps*

~/data/EXERCISES_FK/EX01/coordinates/circle2_6stations_16meters

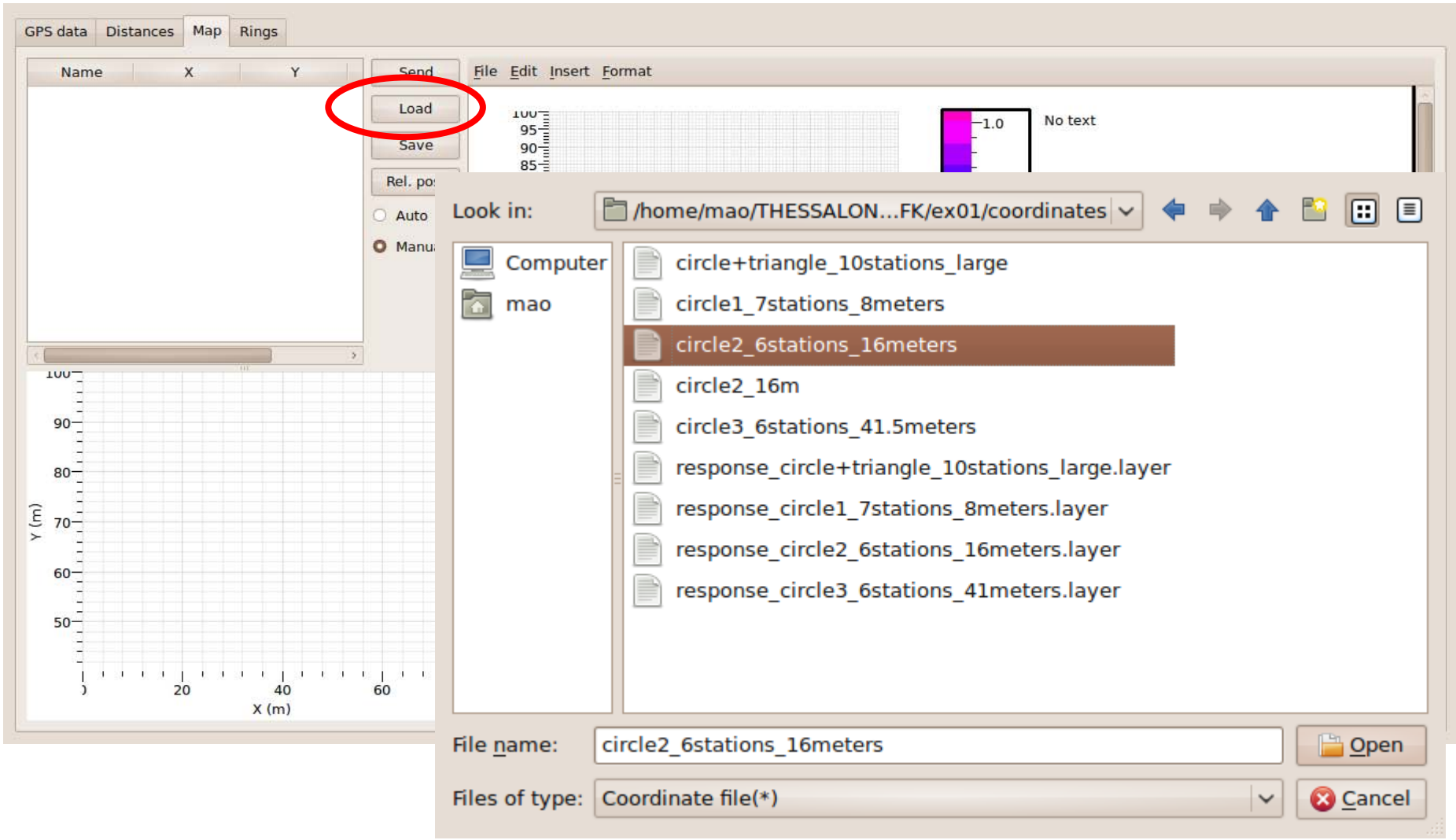


Offline use of realtime tool - switch to map tab for ‘manual’ operation

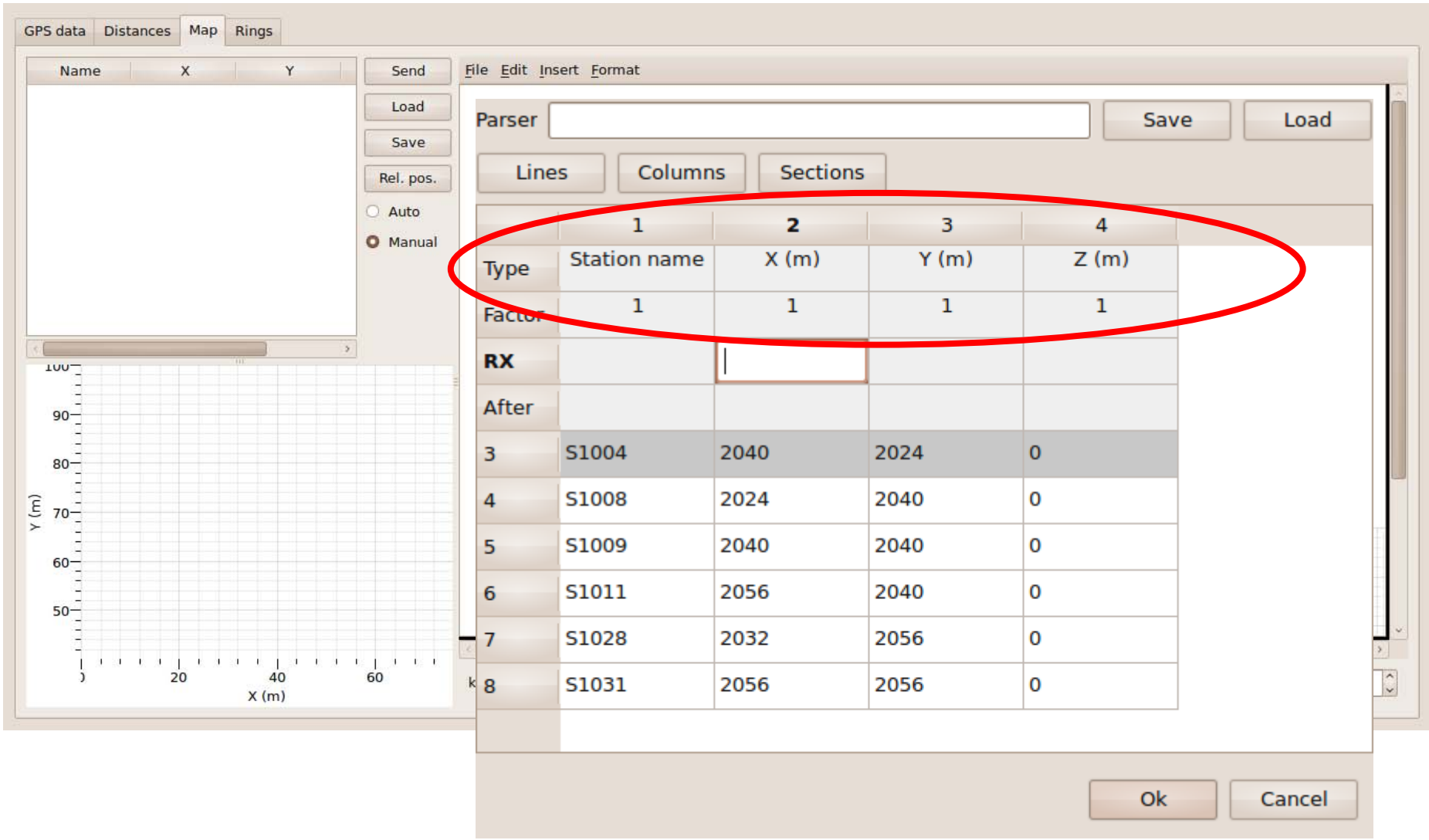
Set coordinate mode to manual! If not, “Load” button is greyed out’



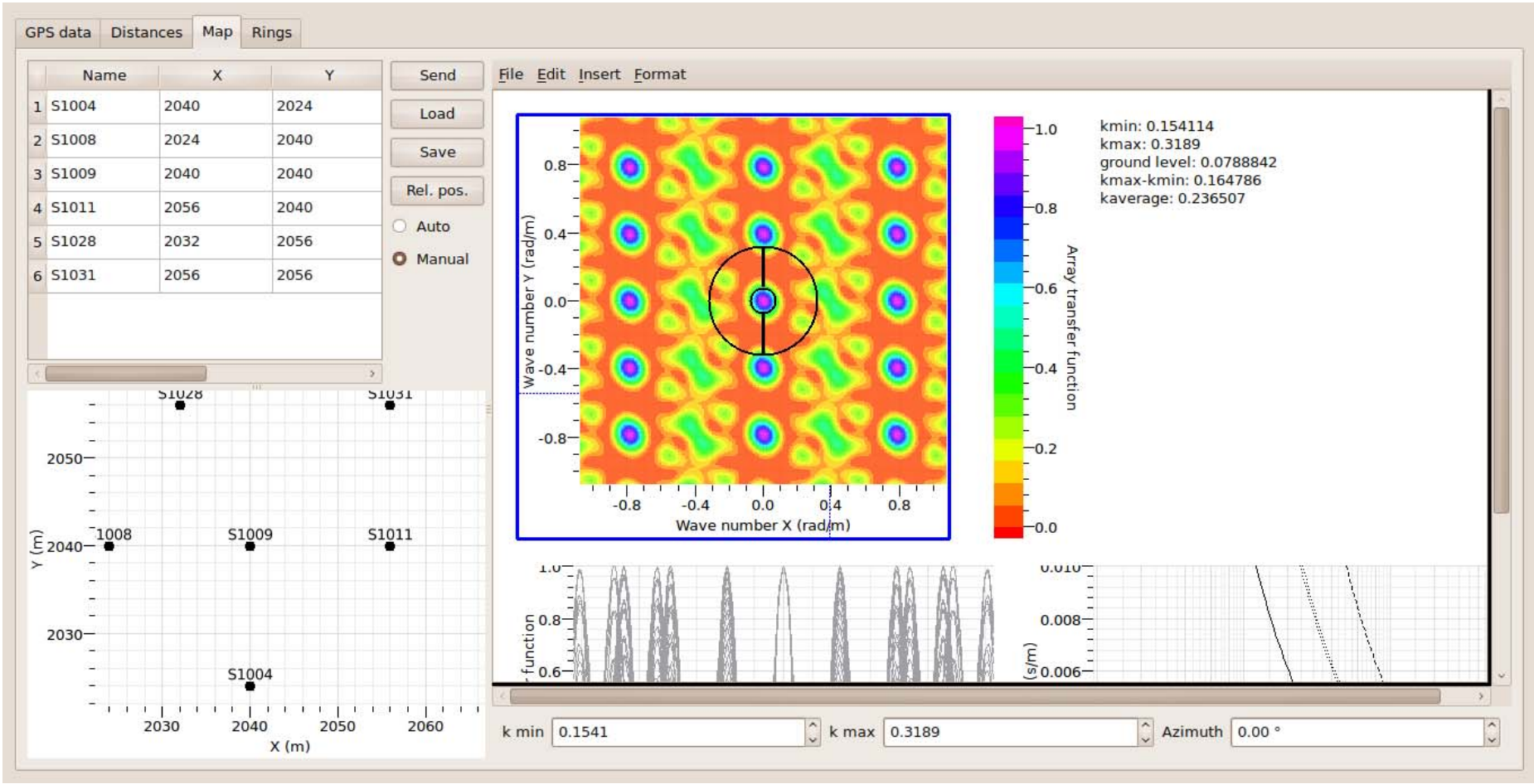
Load coordinates from ….. ex01/coordinates/circle2_6stations_16meters



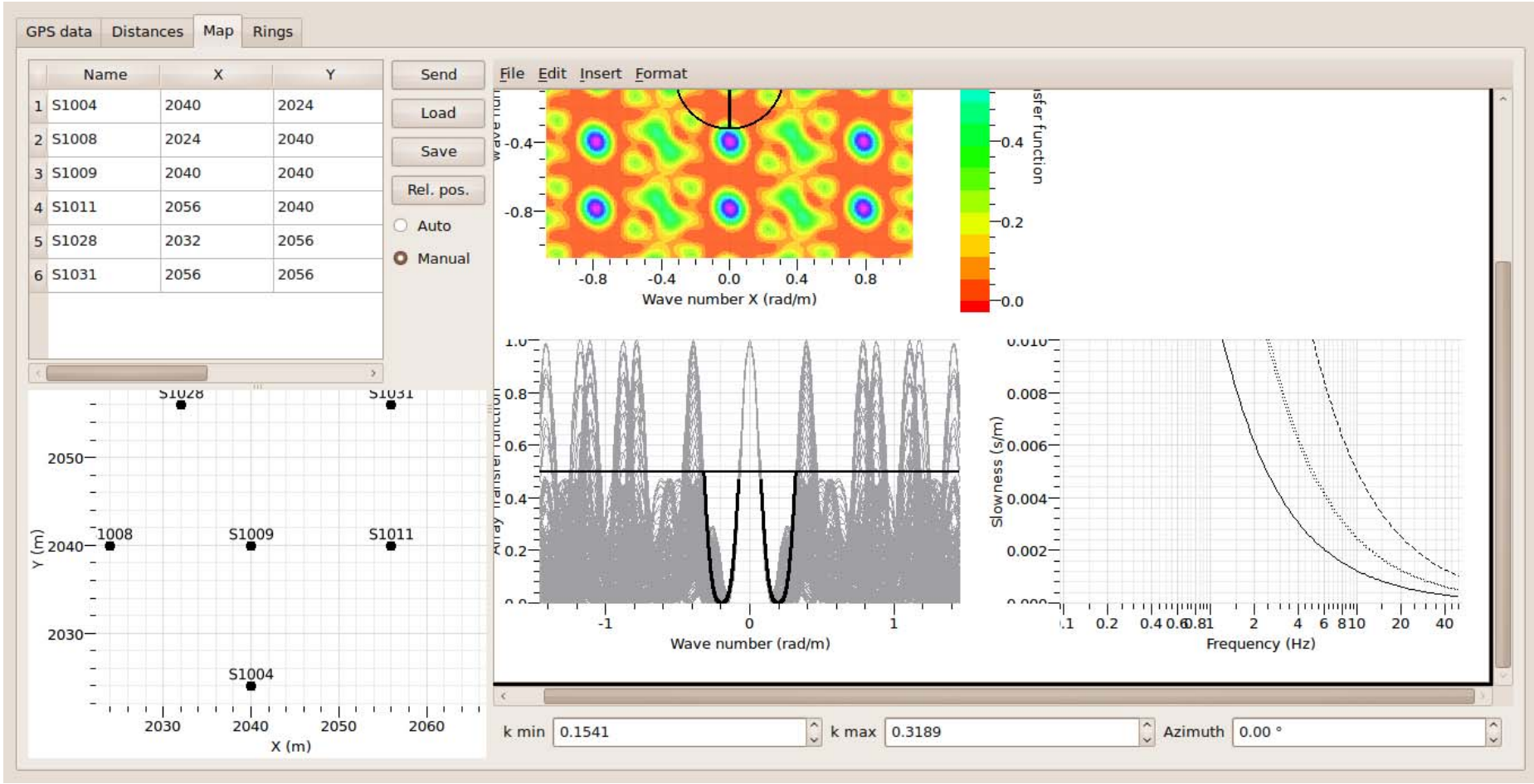
Flexible parser opens for reading coordinate file – explore options



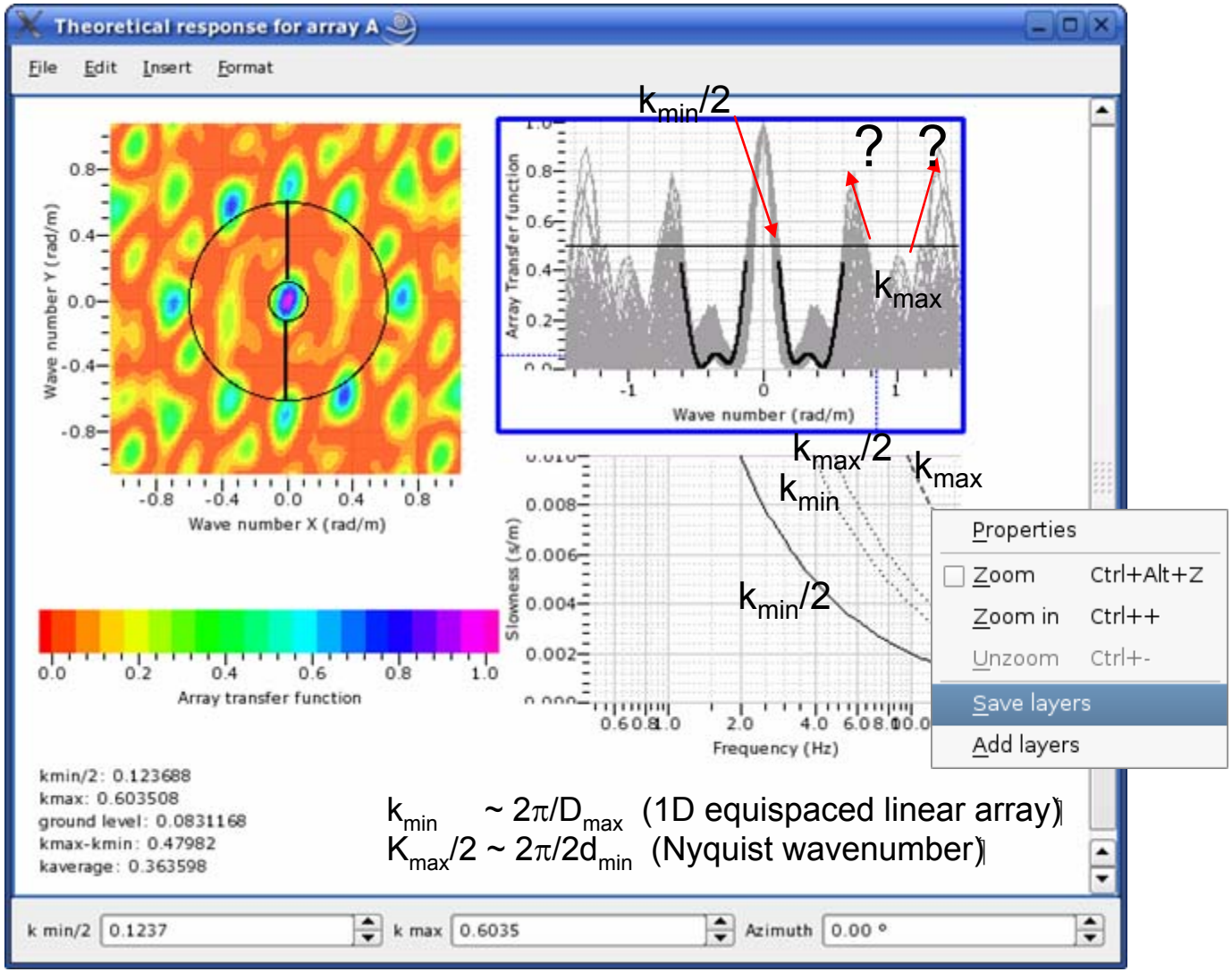
View array response for array geometry



Explore k_{min}, k_{max}, cross-sections through array response topography and save layer for k_{min}/k_{max} curves in freq.-slowness space



Where is k_{max} ?

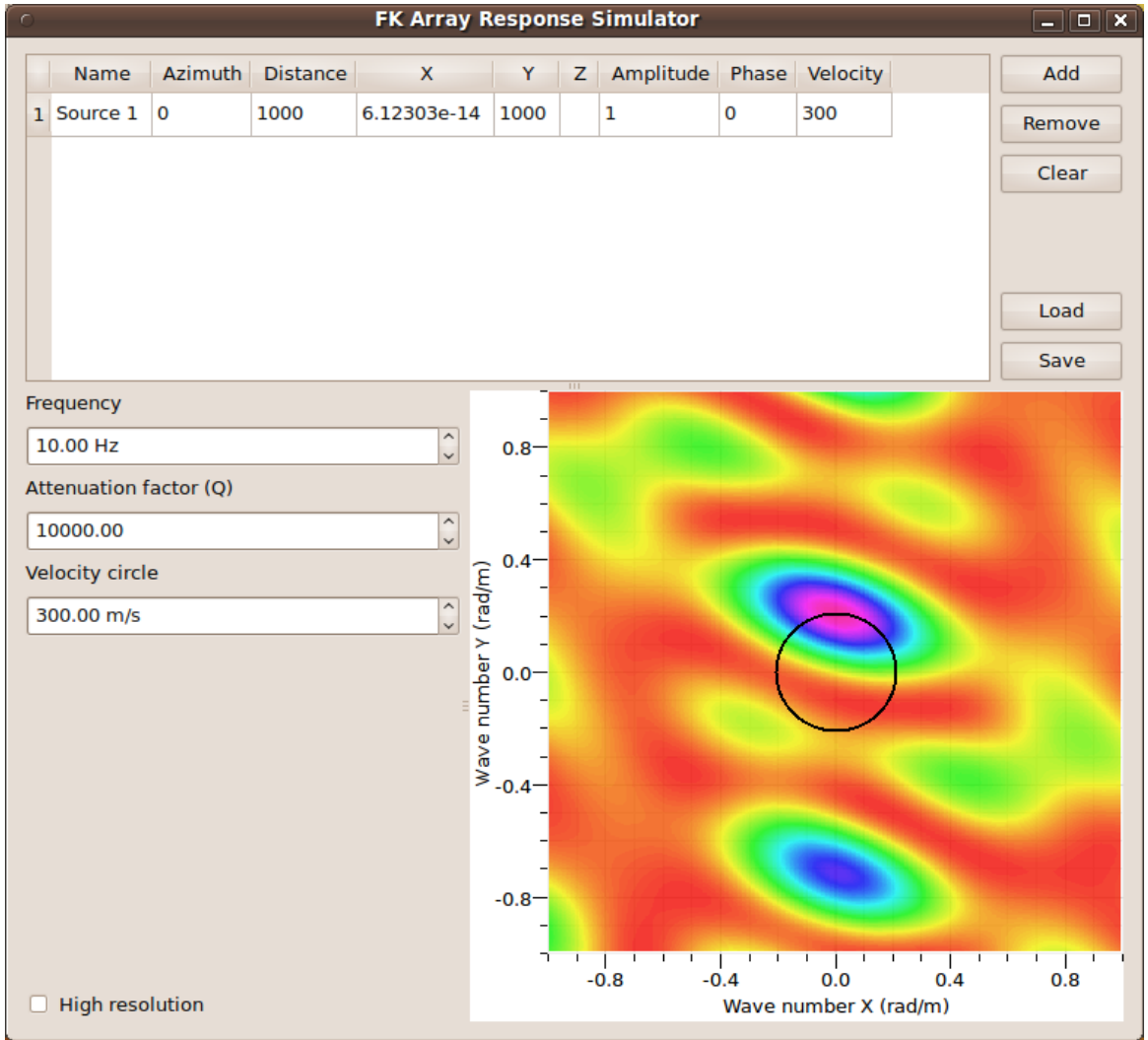


What do we mean by k_{max} ?
Use ***gpfksimulator*** for simulating array response to arbitrary plane wave arrivals (including superposition)

Load one of:

gpfk_ex01.xy
gpfk_ex02.xy
….
gpfk_ex05.xy

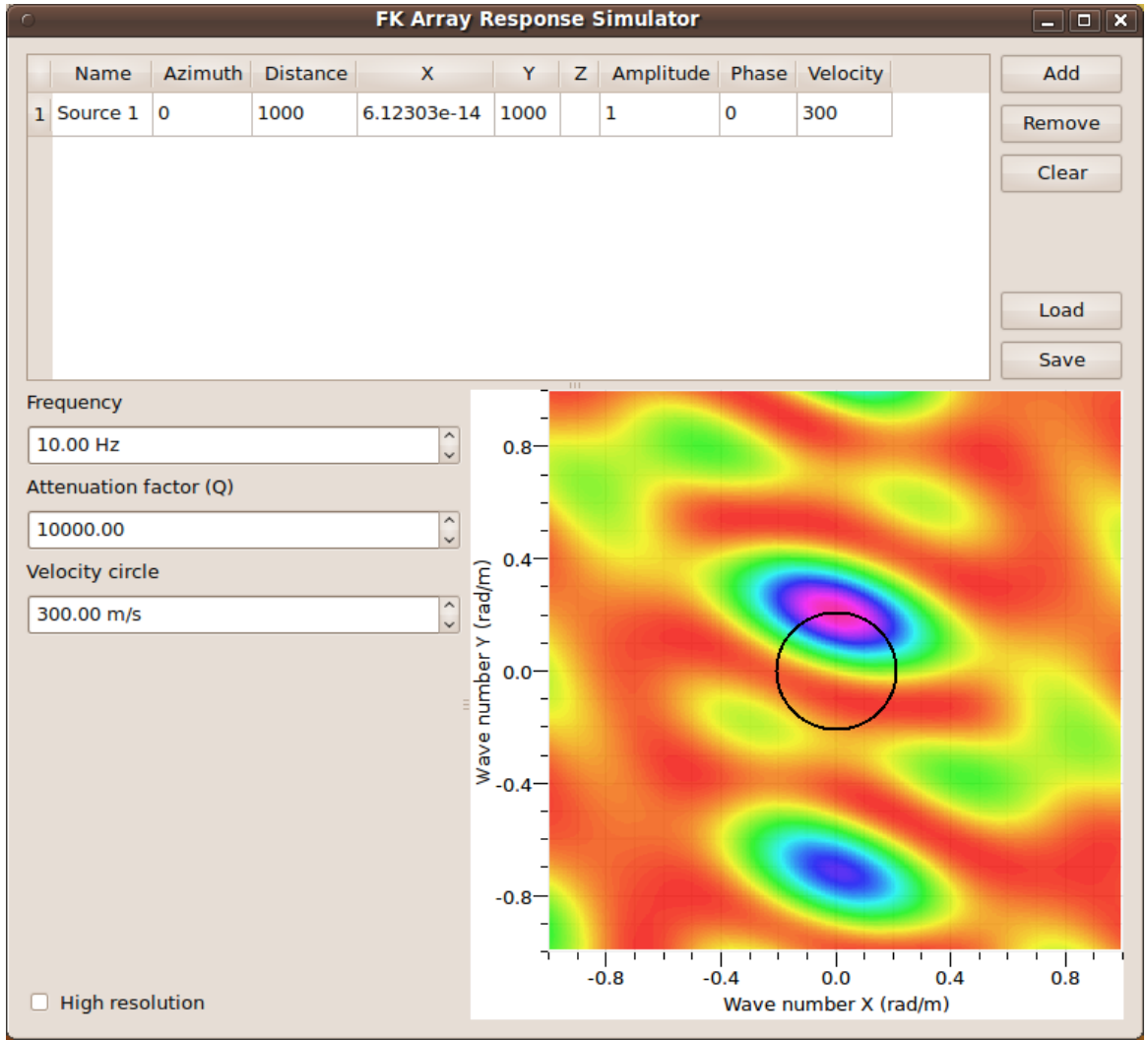
or create your own coordinate file



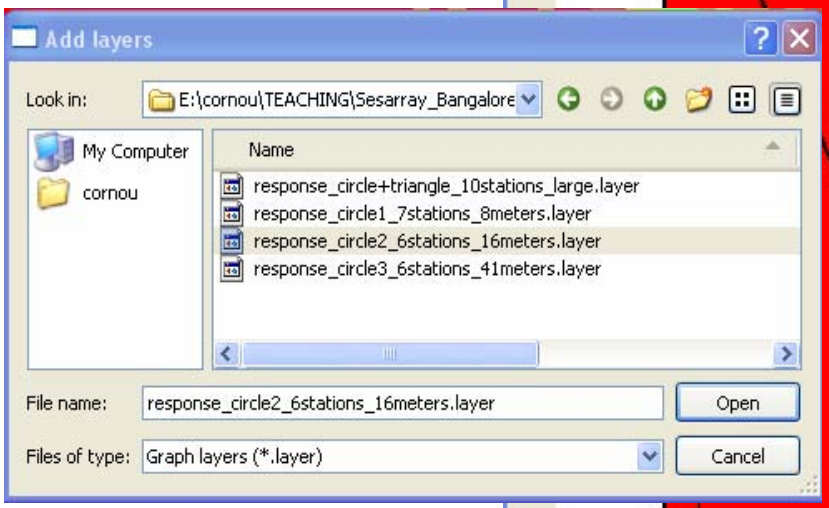
What do we mean by k_{max} ?
Use ***gpfksimulator*** for simulating array response to arbitrary plane wave arrivals (including superposition)

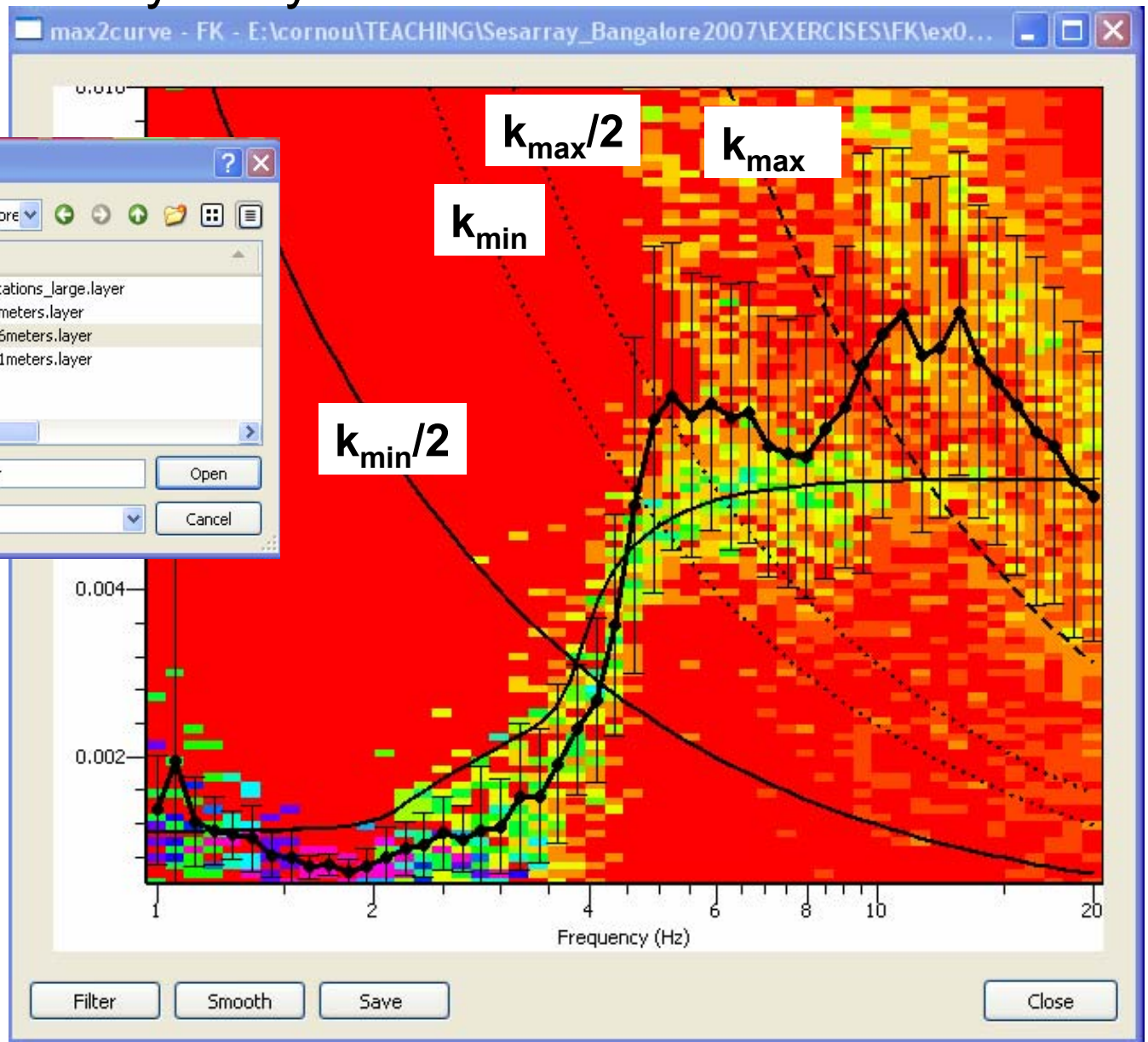
Play with
Azimuth & velocity
for single source

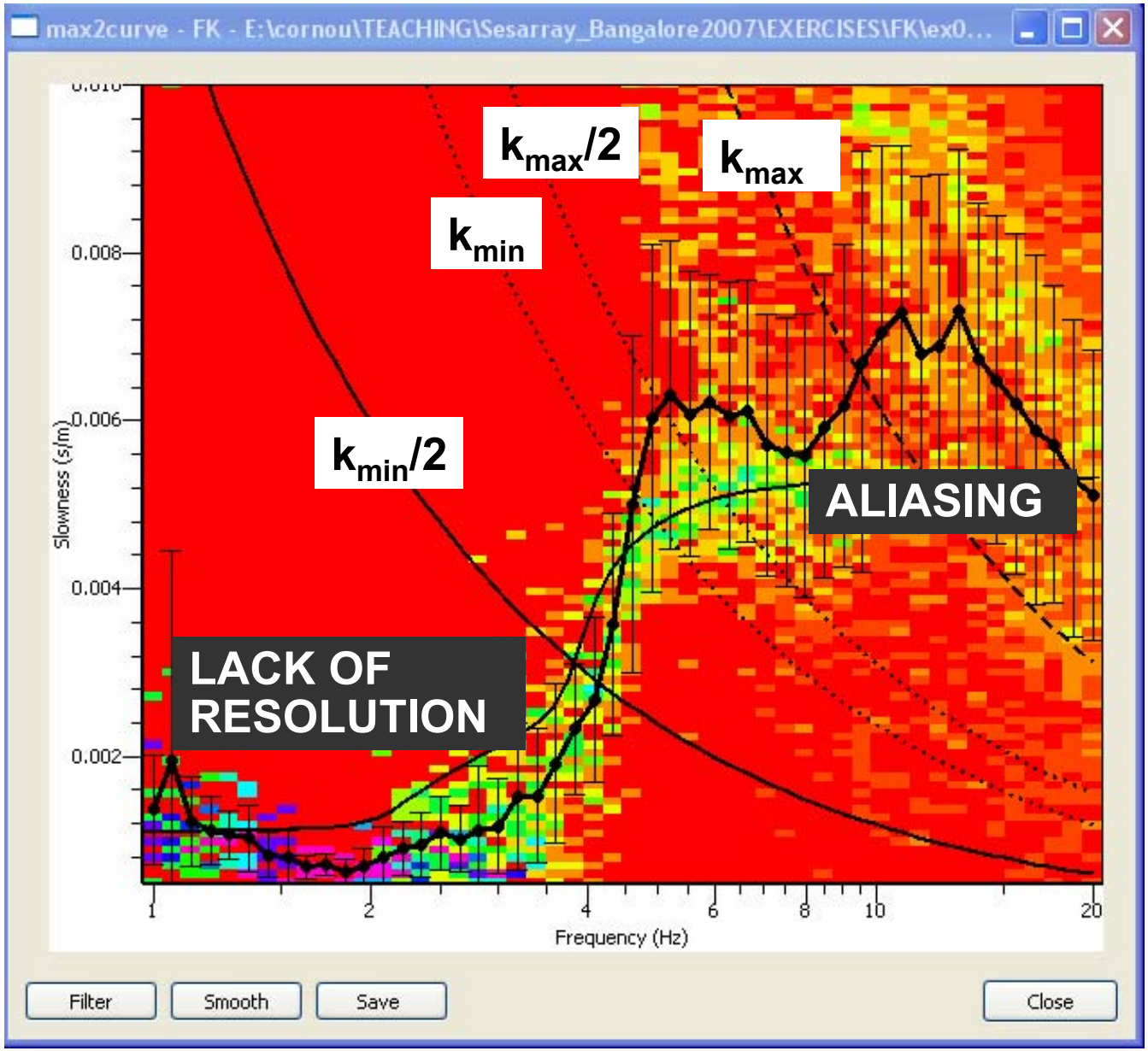
Play with
azimuth, velocity,
amplitudes, phases
for superposition of
more plane waves



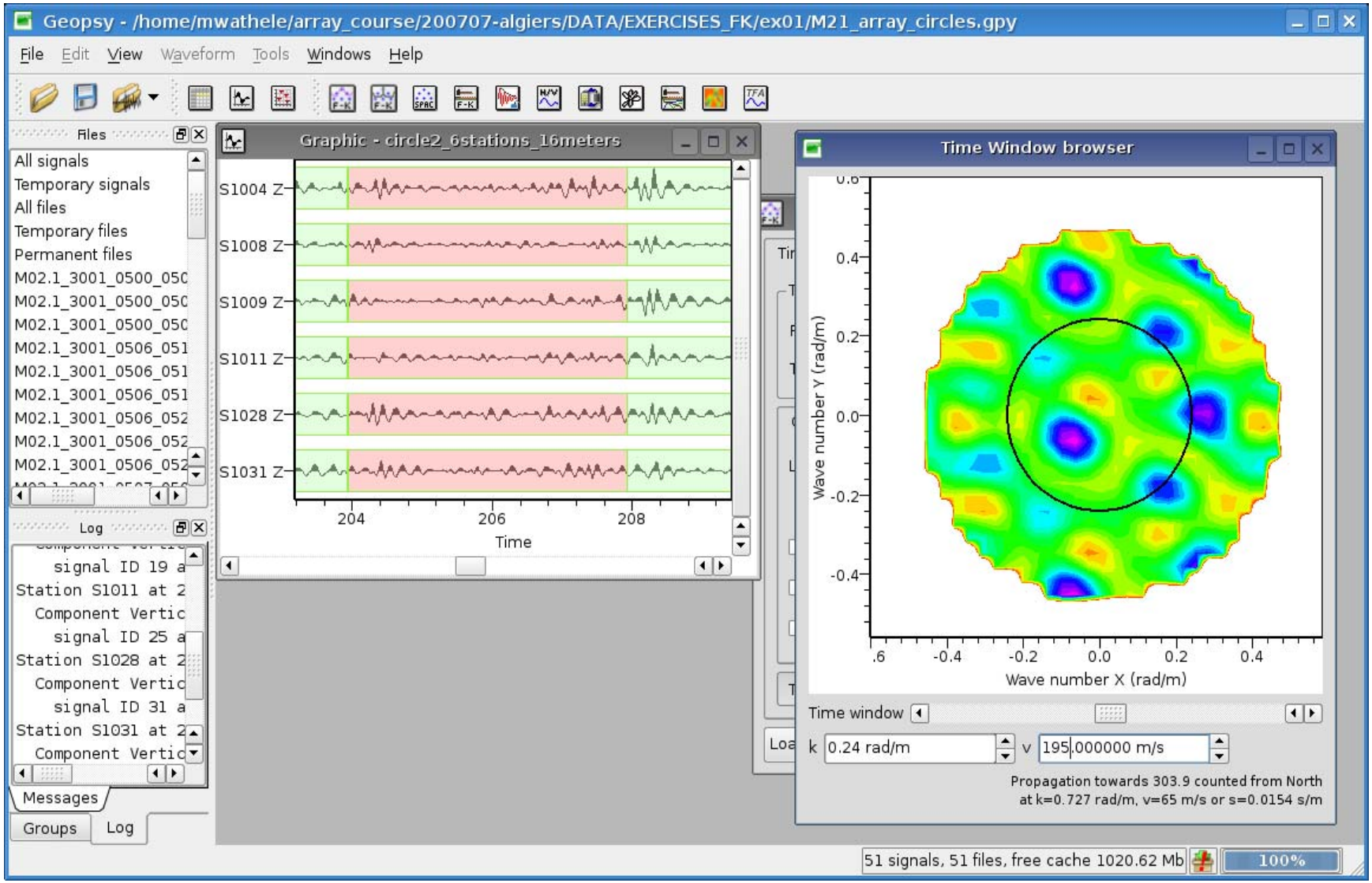
Overlay array-limits in max2curve



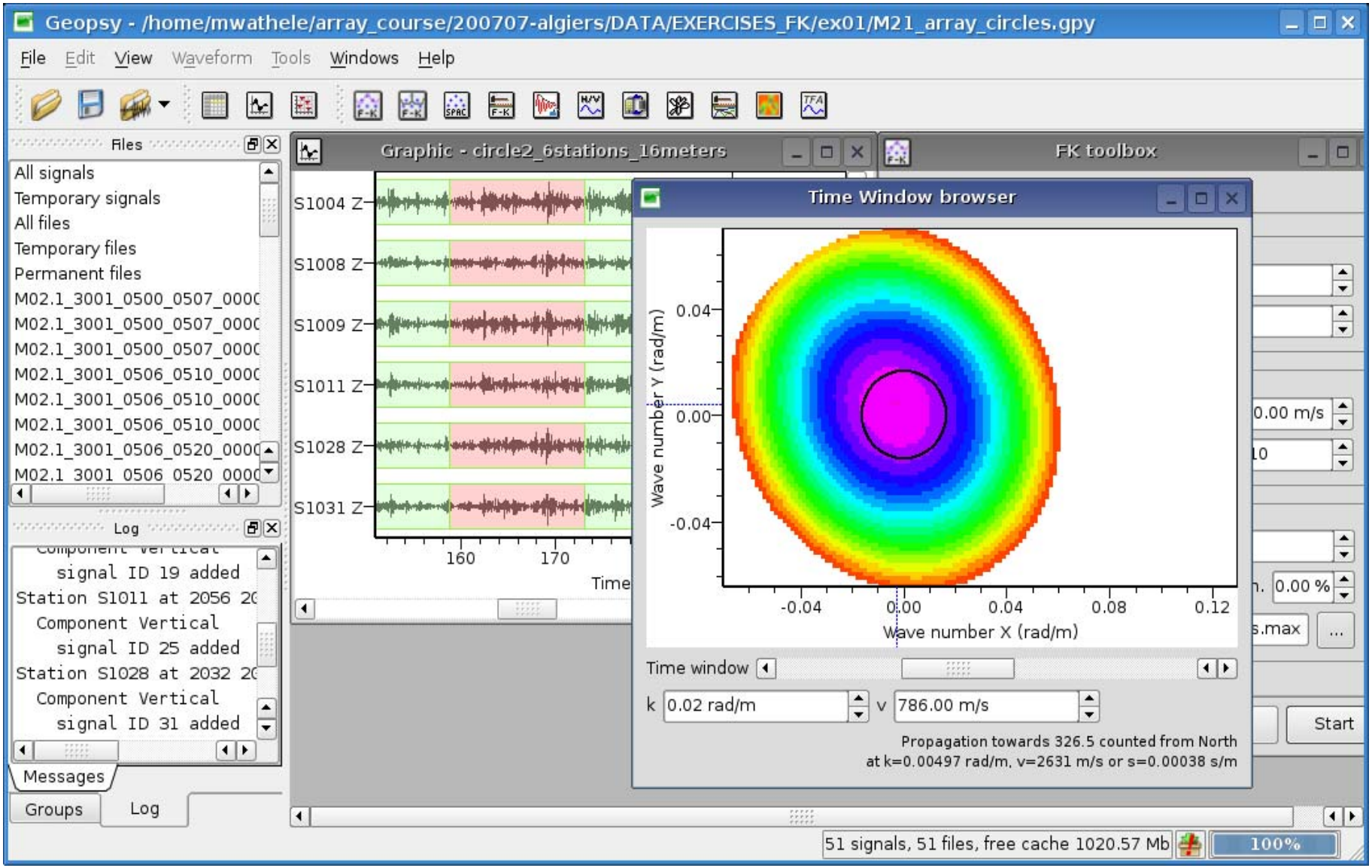



max2curve - FK - E:\cornou\TEACHING\Sesarray_Bangalore2007\EXERCISES\FK\ex0...
$k_{max}/2$
k_{max}
k_{min}
$k_{min}/2$
ALIASING
LACK OF RESOLUTION
0.008
0.006
0.004
0.002
Slowness (s/m)
1
2
4
6
8
10
20
Frequency (Hz)
Filter
Smooth
Save
Close

FK misinterpretation (mainlobe? sidelobe?) 7.5 Hz



FK misinterpretation (superposition) - 2 Hz



Do the same exercise using the two other predefined arrays

Circle3_6stations_41.5meters

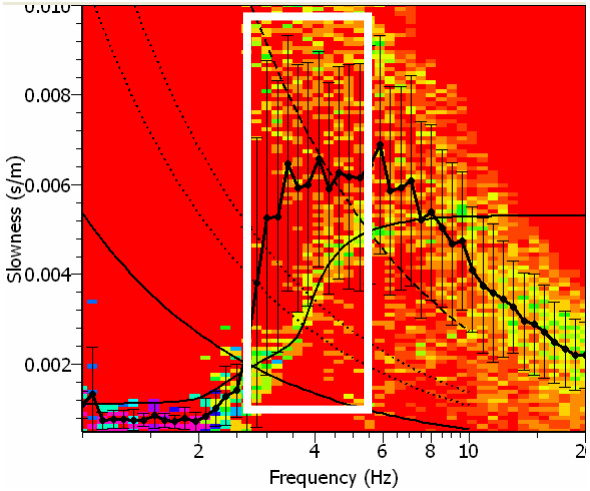
Grid_step = 0.015 rad/m
Grid_size = 0.34 rad/m
Vmin = 100 m/s; window length = 30 T

Circle1_7stations_8meters

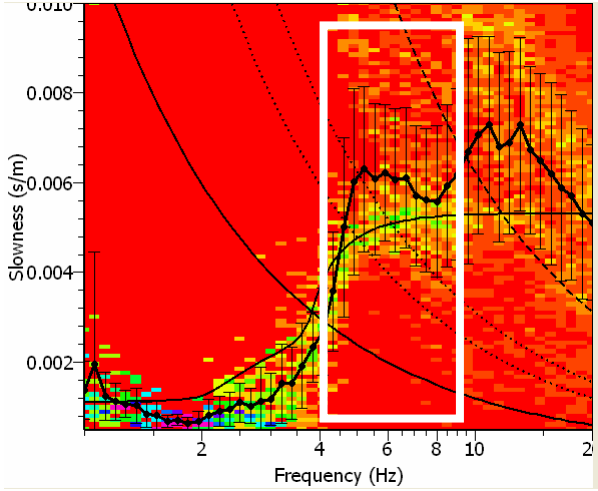
Grid_step = 0.065 rad/m
Grid_size = 1.6 rad/m
Vmin = 100 m/s; window length = 30 T

Summary

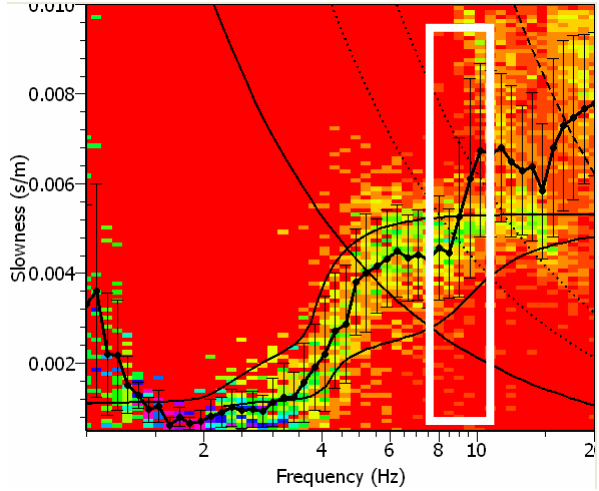
41 m aperture



16 m aperture



8 m aperture



Larger (smaller) aperture, better resolution at LF (HF)

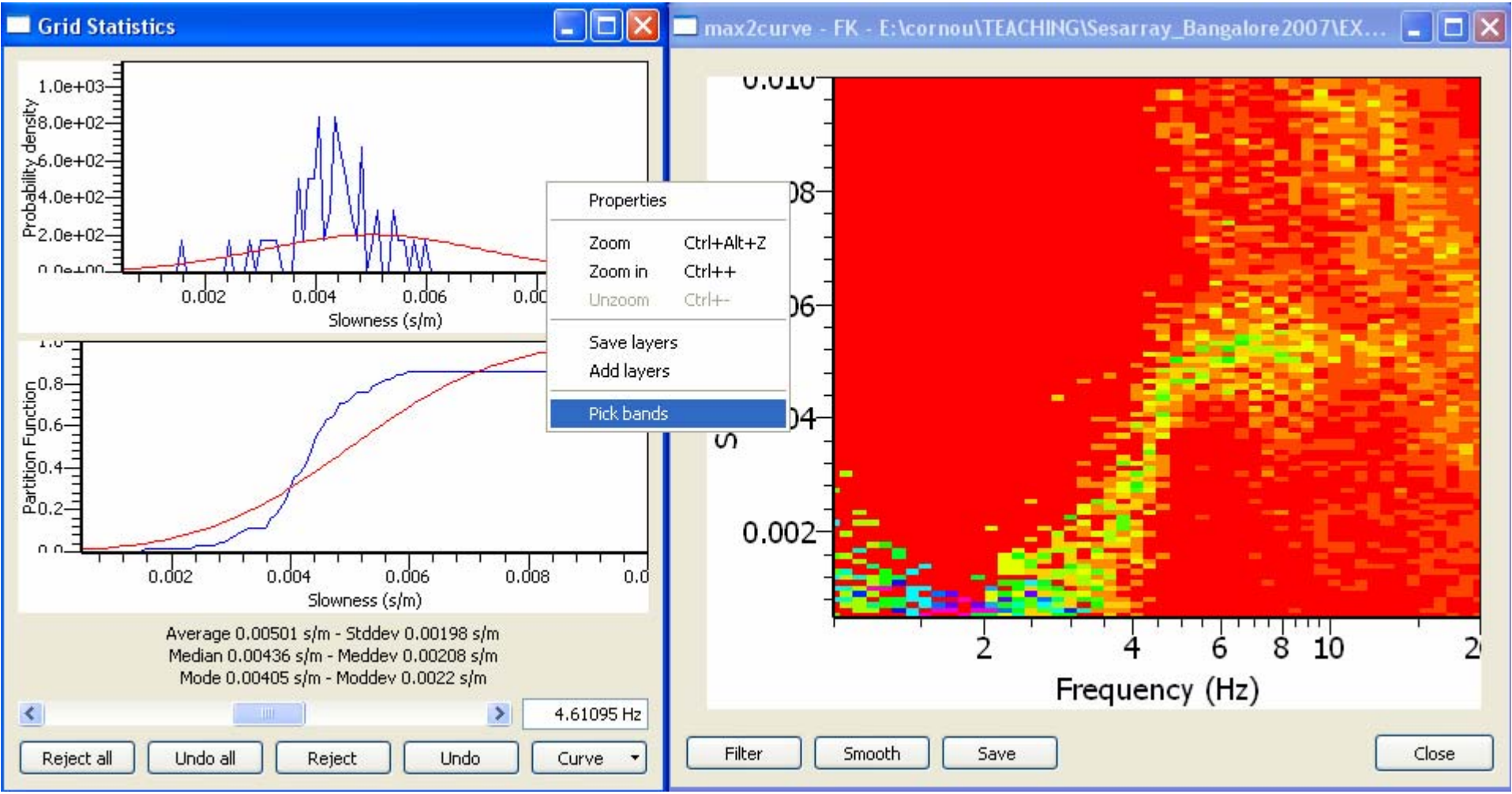
In this example, smallest aperture array provides phase velocities deviating (overestimation) than true ones.

Histograms should be cleaned in order to remove outliers or estimates which can be clearly attributed to aliasing effects.

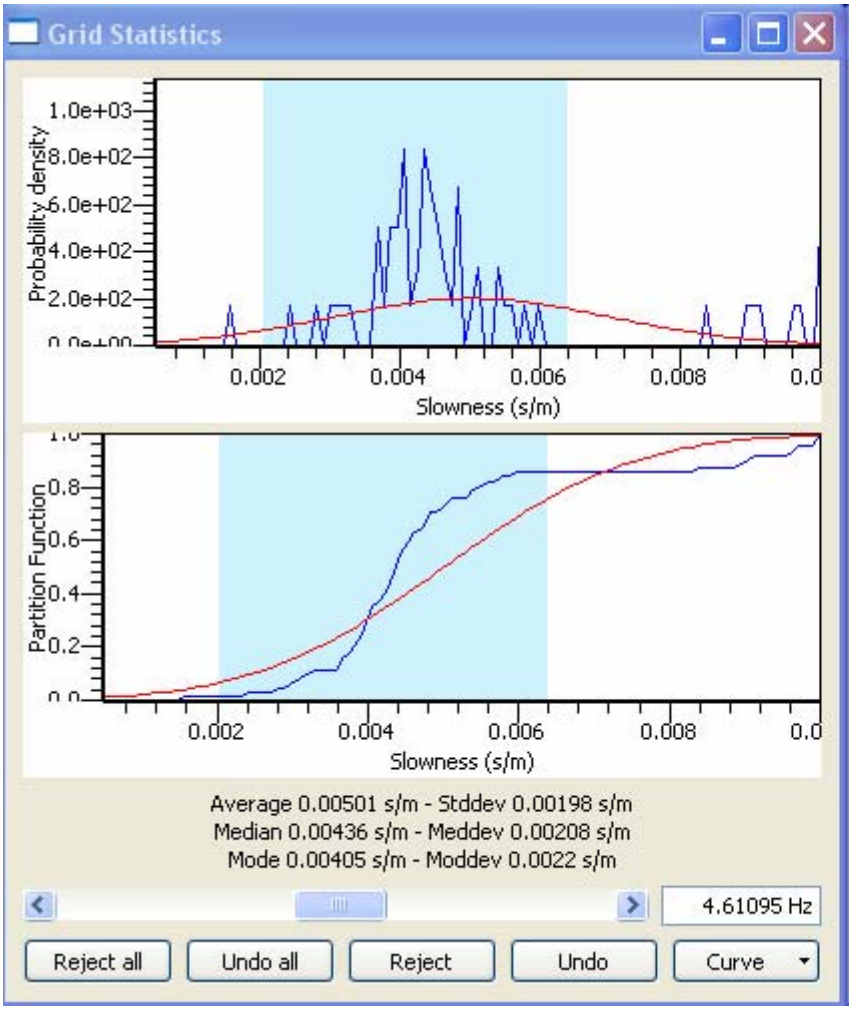
BUT AGAIN: be careful and critical!!!

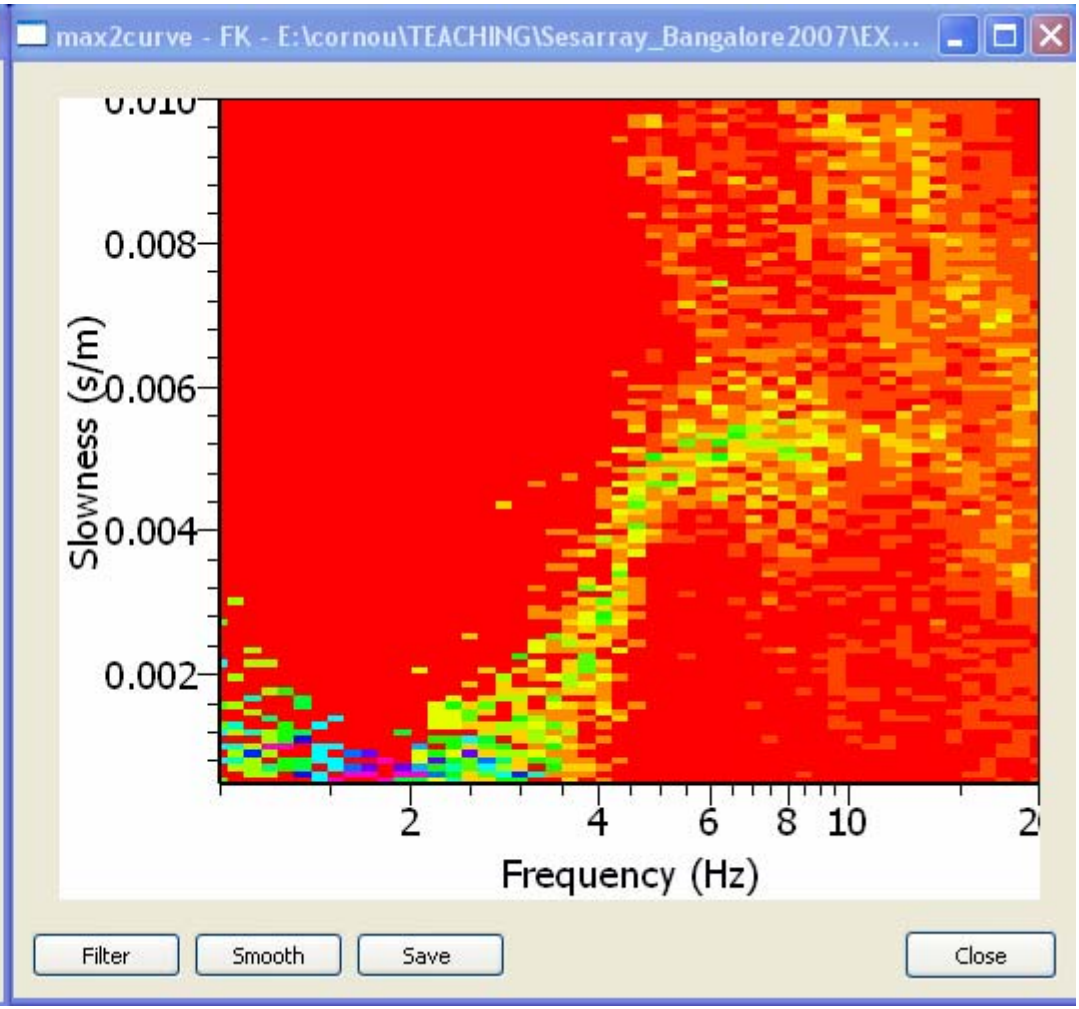
By doing so, you are modifying your data on subjective ground

FK histograms: outlier removal

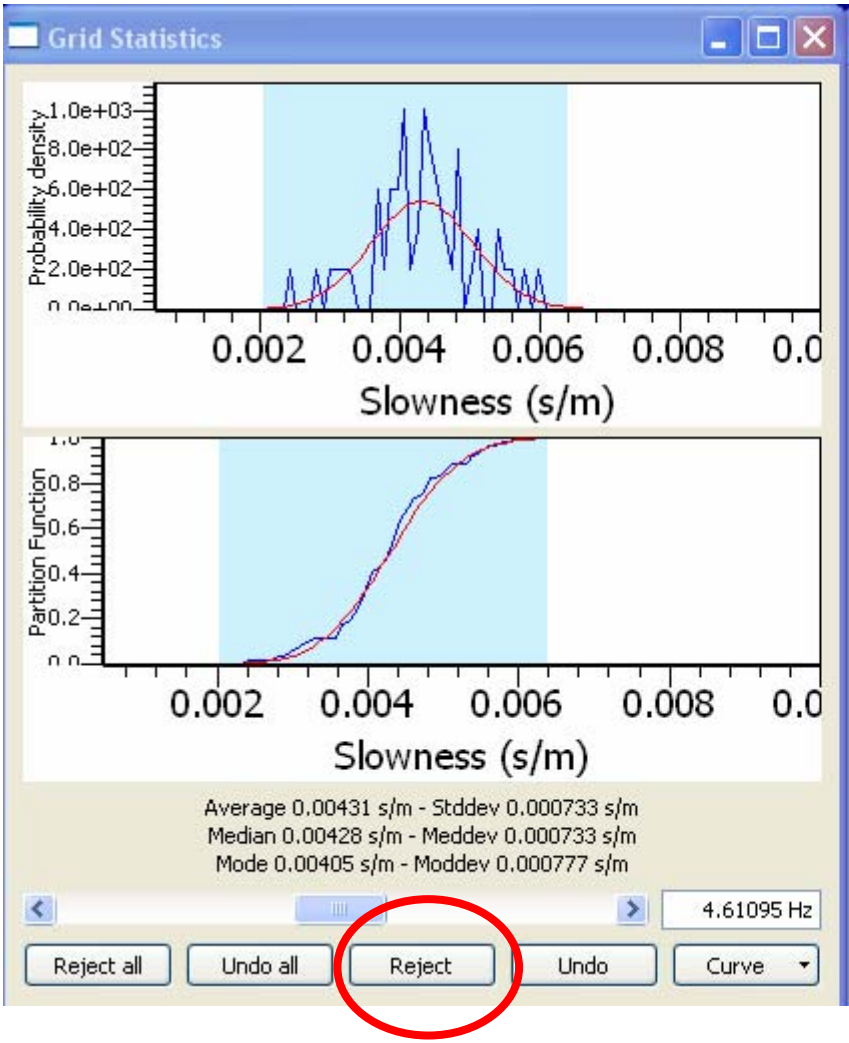


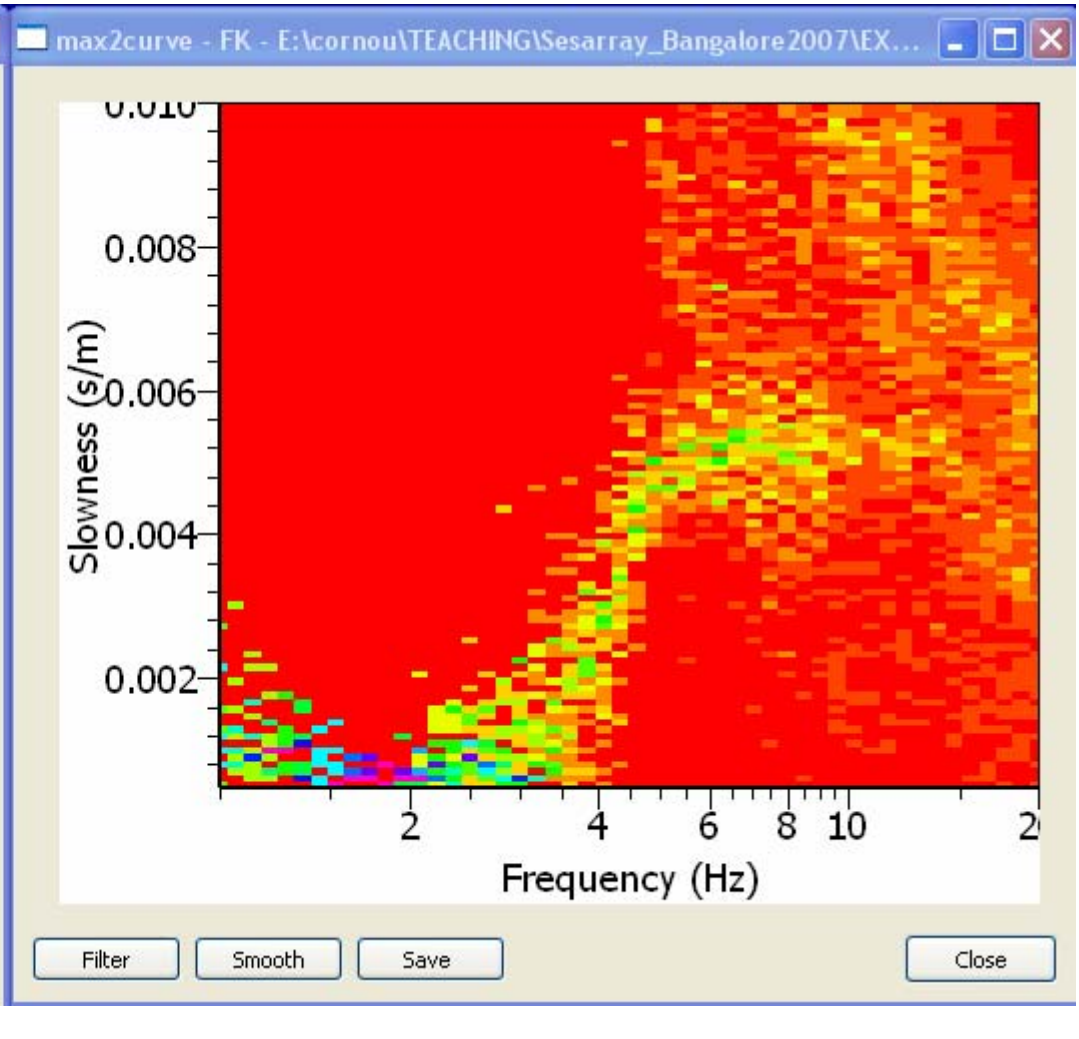
Select the slowness band you want to keep (pick band)





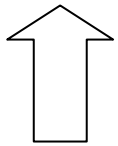
Press on “reject” to remove the samples **outside** selected band from the distribution





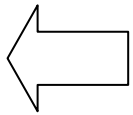
Use of the keyboard's arrows to facilitate the removing of bad samples

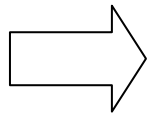
To increase frequency



SHIFT + : to apply selection
and go to next frequency

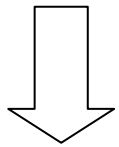
To modify the left limit of the pick band





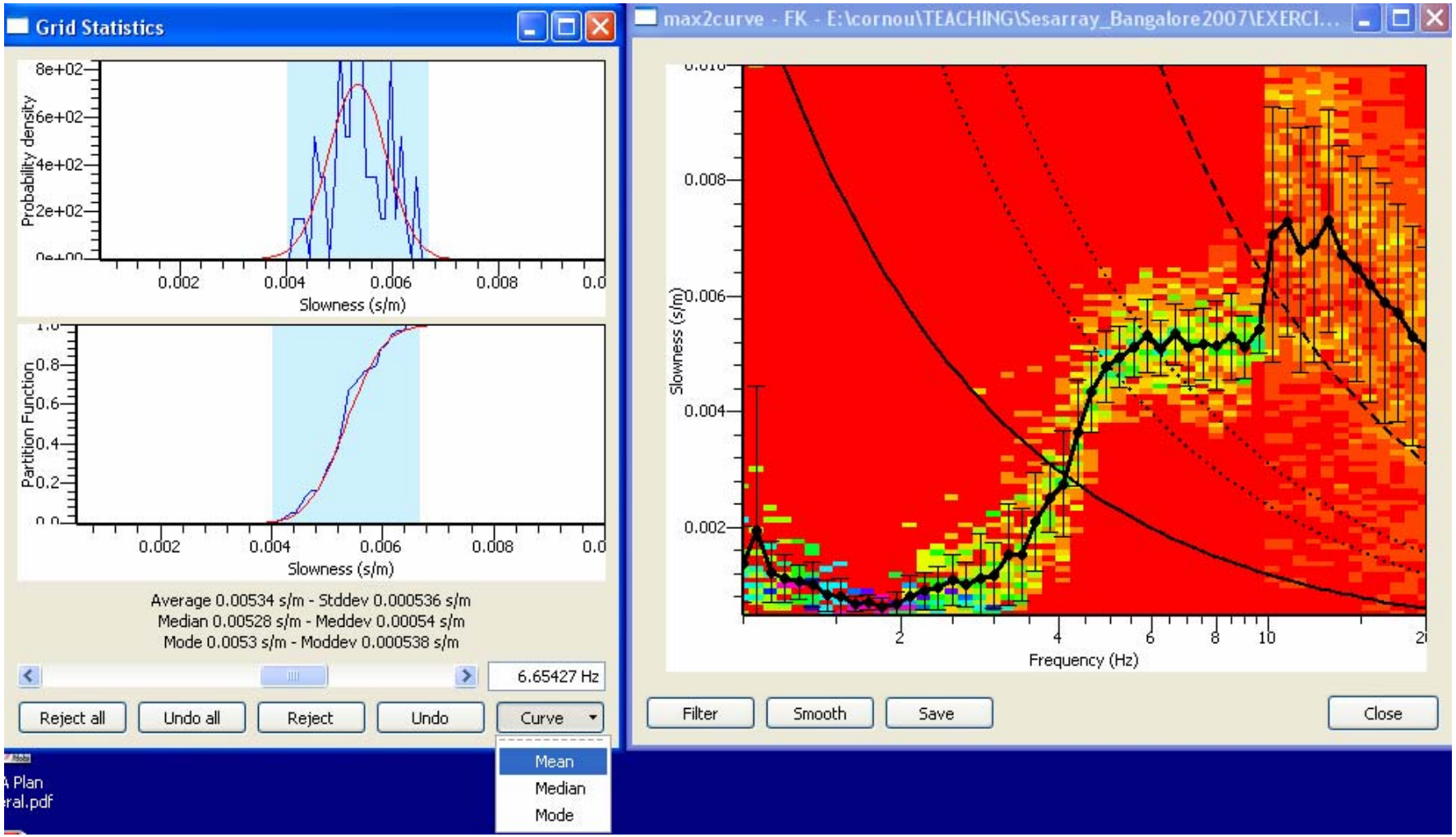
+ SHIFT: to move the right limit of the pick band

SHIFT + : to apply selection
and go to previous frequency

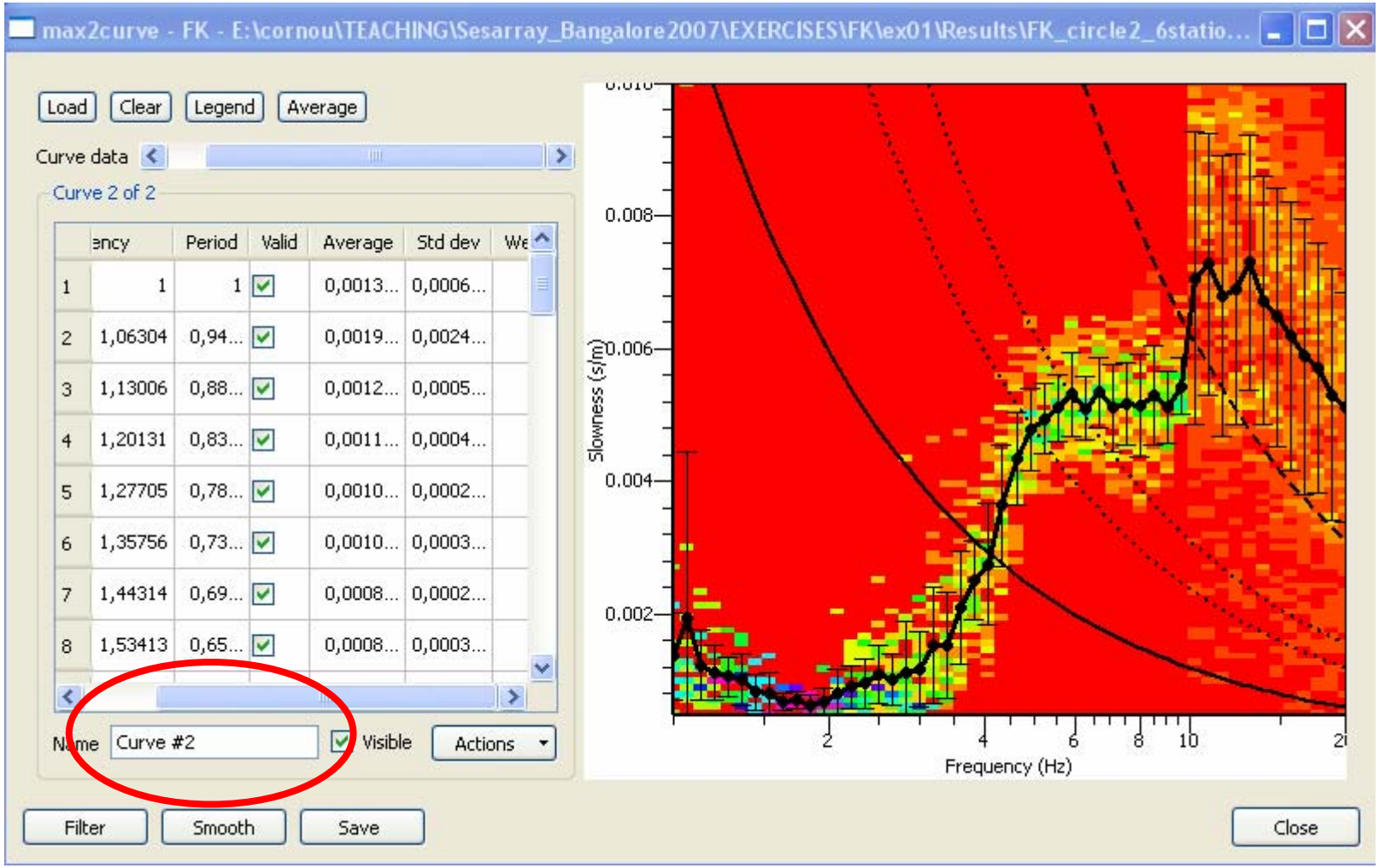


To decrease frequency

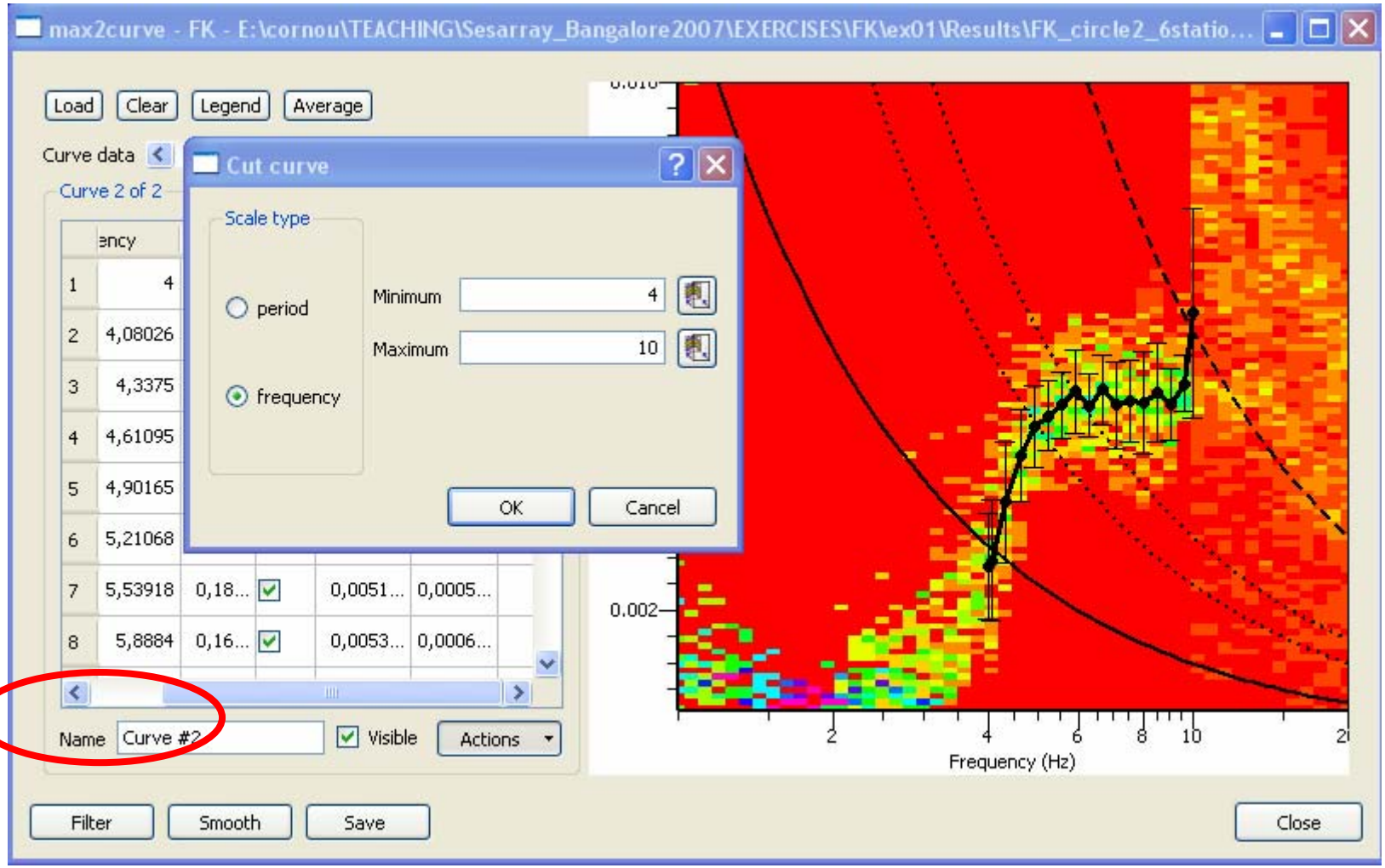
Computation of new mean/median/mode curve



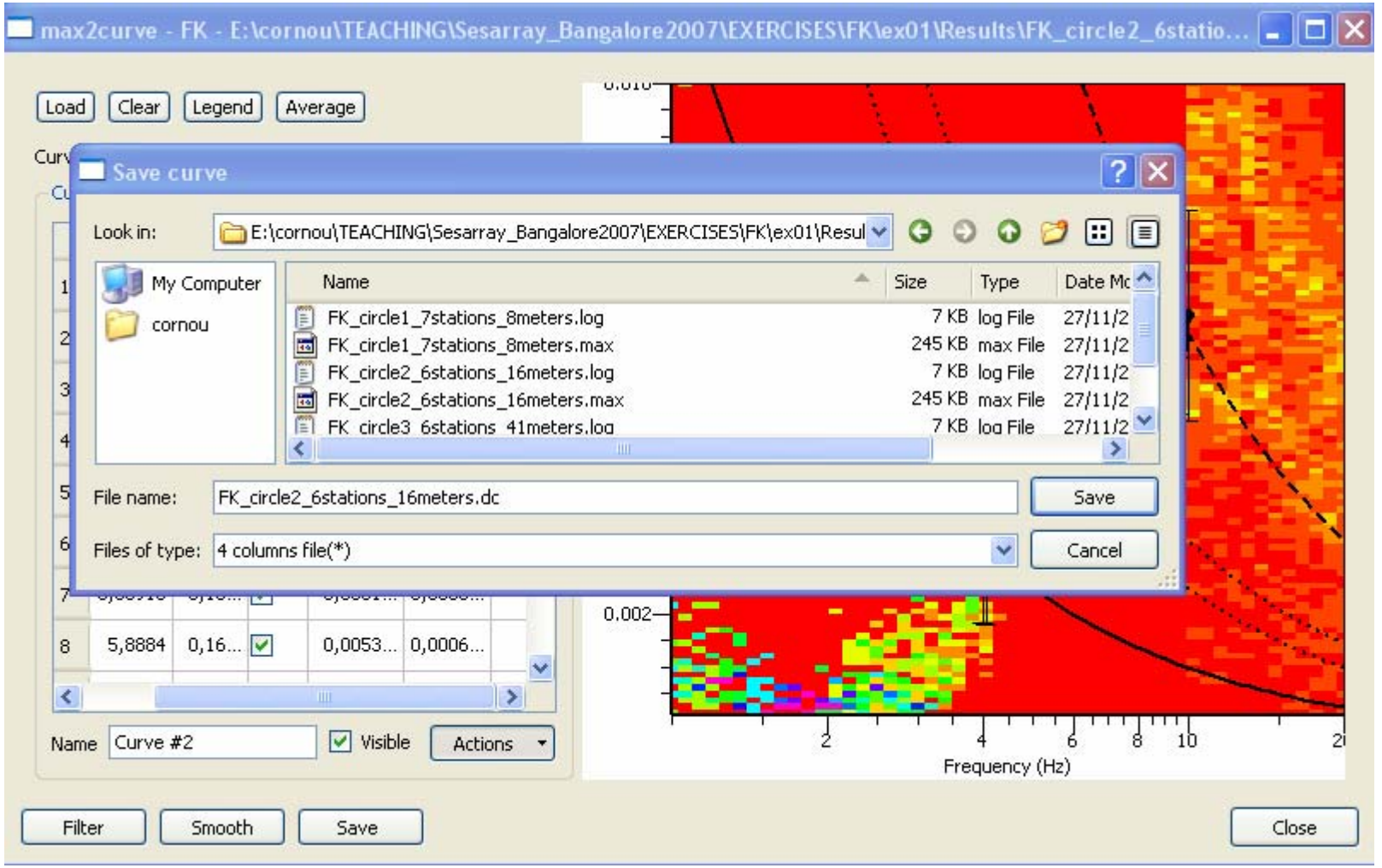
The new mean curve appears as Curve #2



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



Saving the dispersion curve

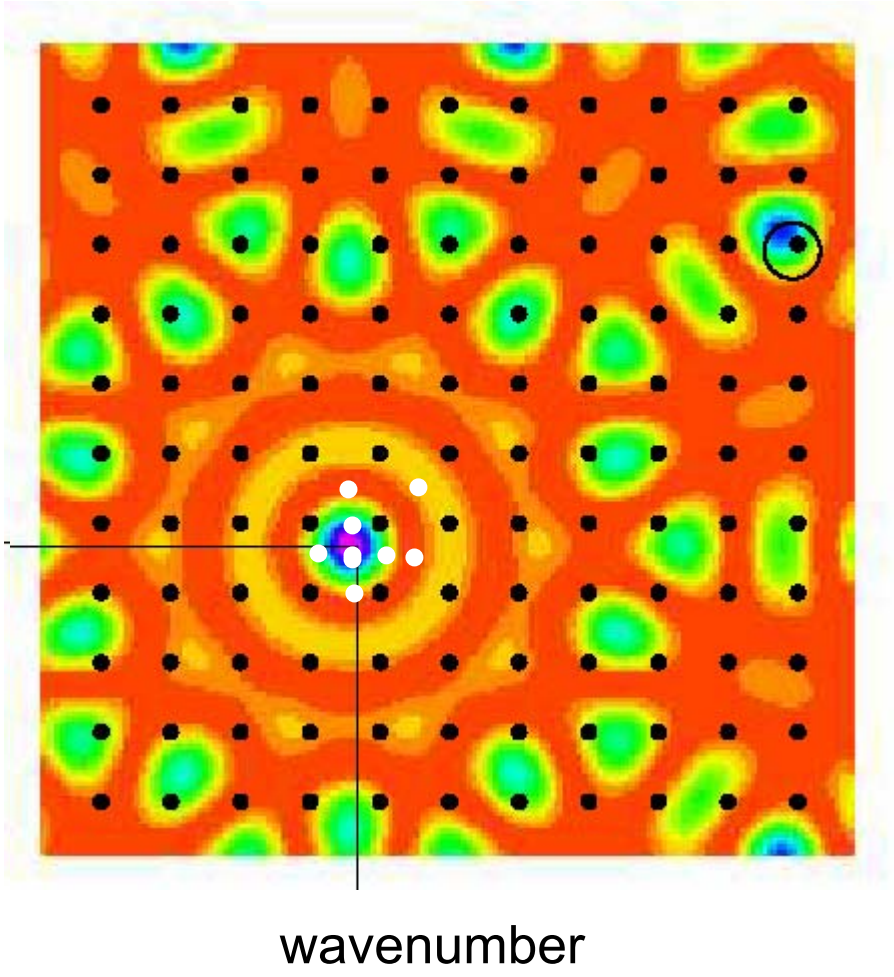


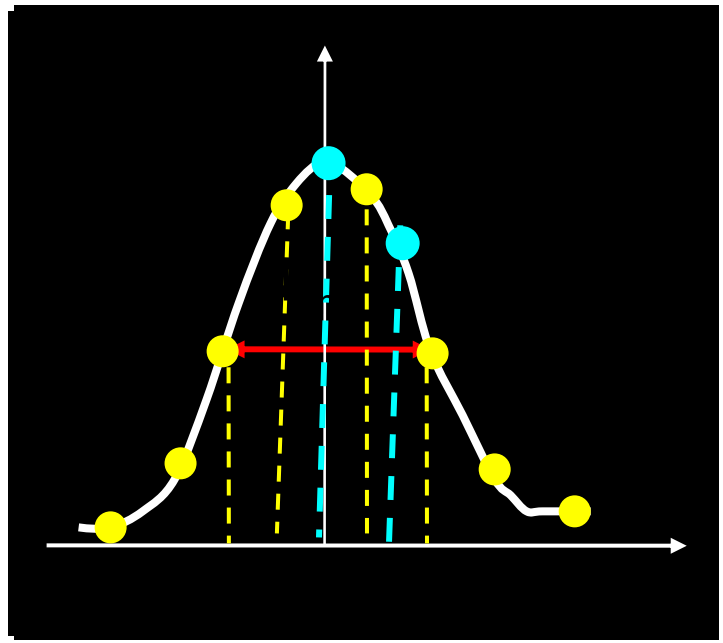
Some issues on *f-k* processing as implemented in sesarray

What reasonable values should be chosen for fk analysis ? (k_{min}, k_{max}, window length T)

How is the fk gridding performed ?
(optimized – non-exhaustive - grid search for computational speed up)

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





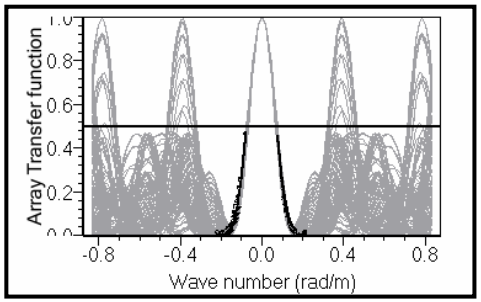
Peak refinement until numerical relative precision of 10^{-5} in wavenumber

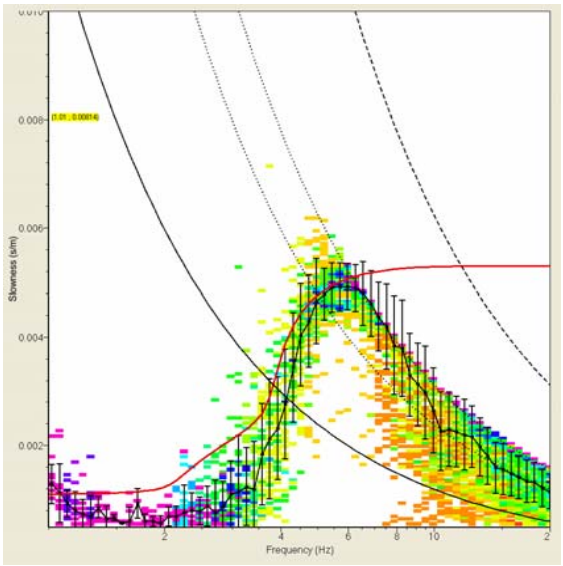
grid_step < k_{min}/4 **fk**

grid_step < k_{min}/20 **hrfk**

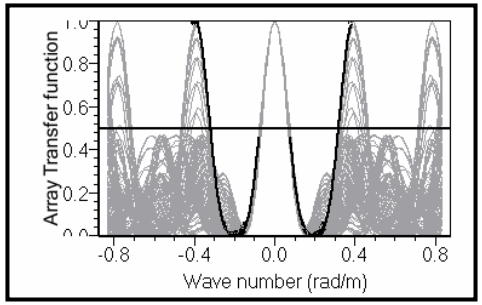
What *grid_size* to choose ?

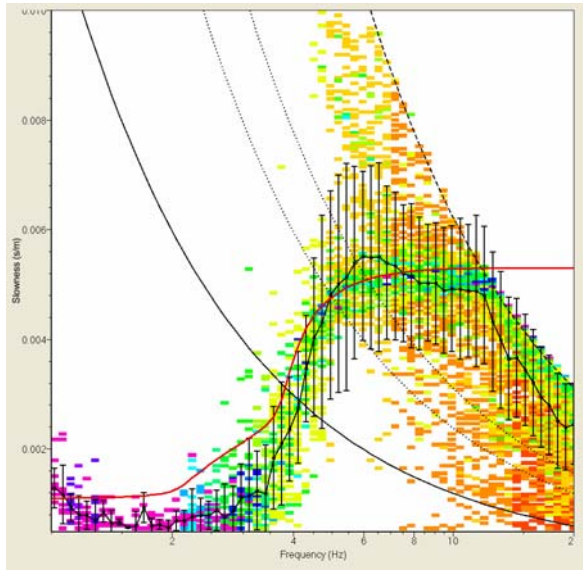
$k_{max}/2$



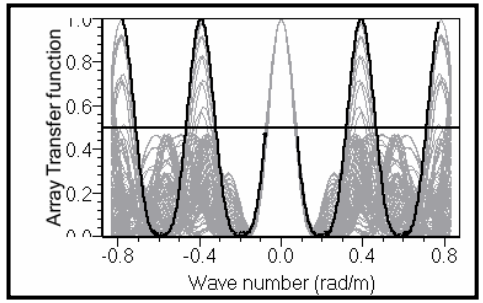


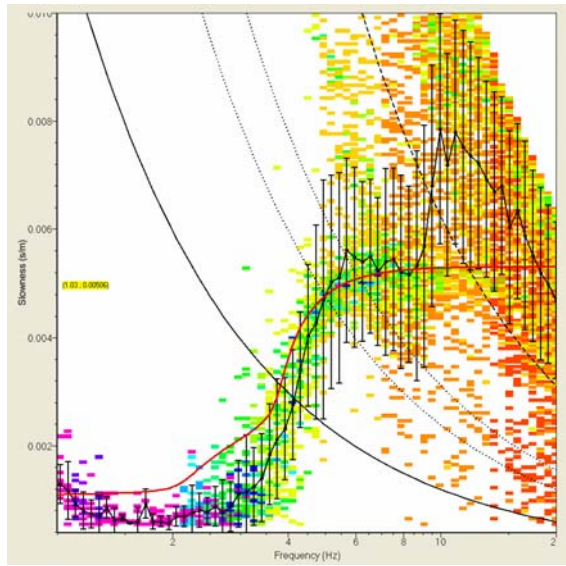
k_{max}





$2*k_{max}$

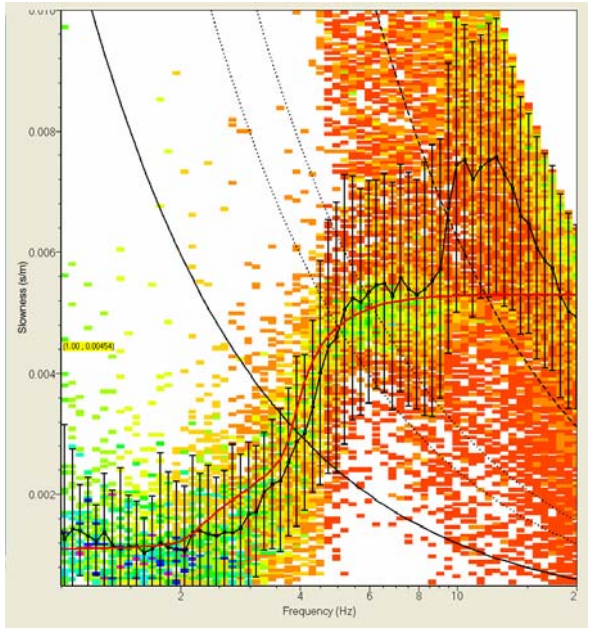




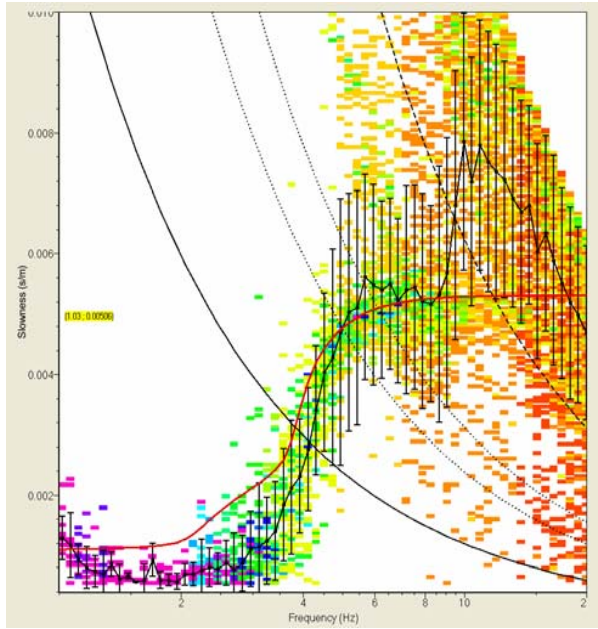
Discuss consequences of different choices!

What *window_length* to choose ?

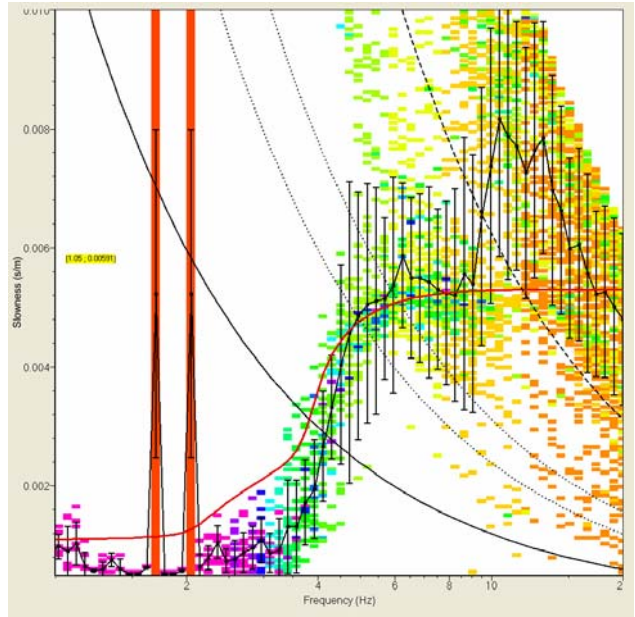
10 T



30 T



50 T



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

Discuss window length selection and find arguments for either choices

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 ☺☺☺

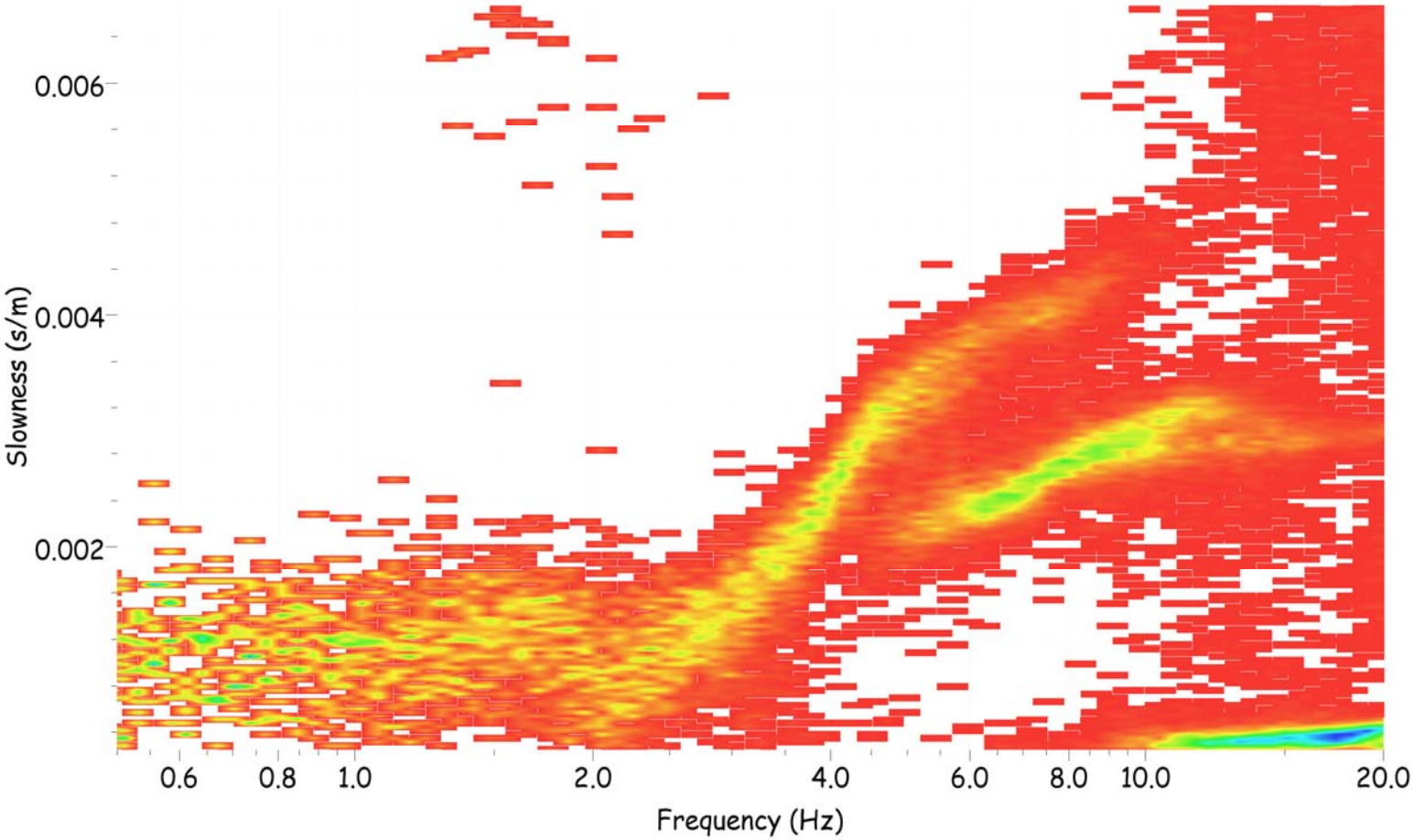
Compute array response for full array

Process all station together – look at max-file

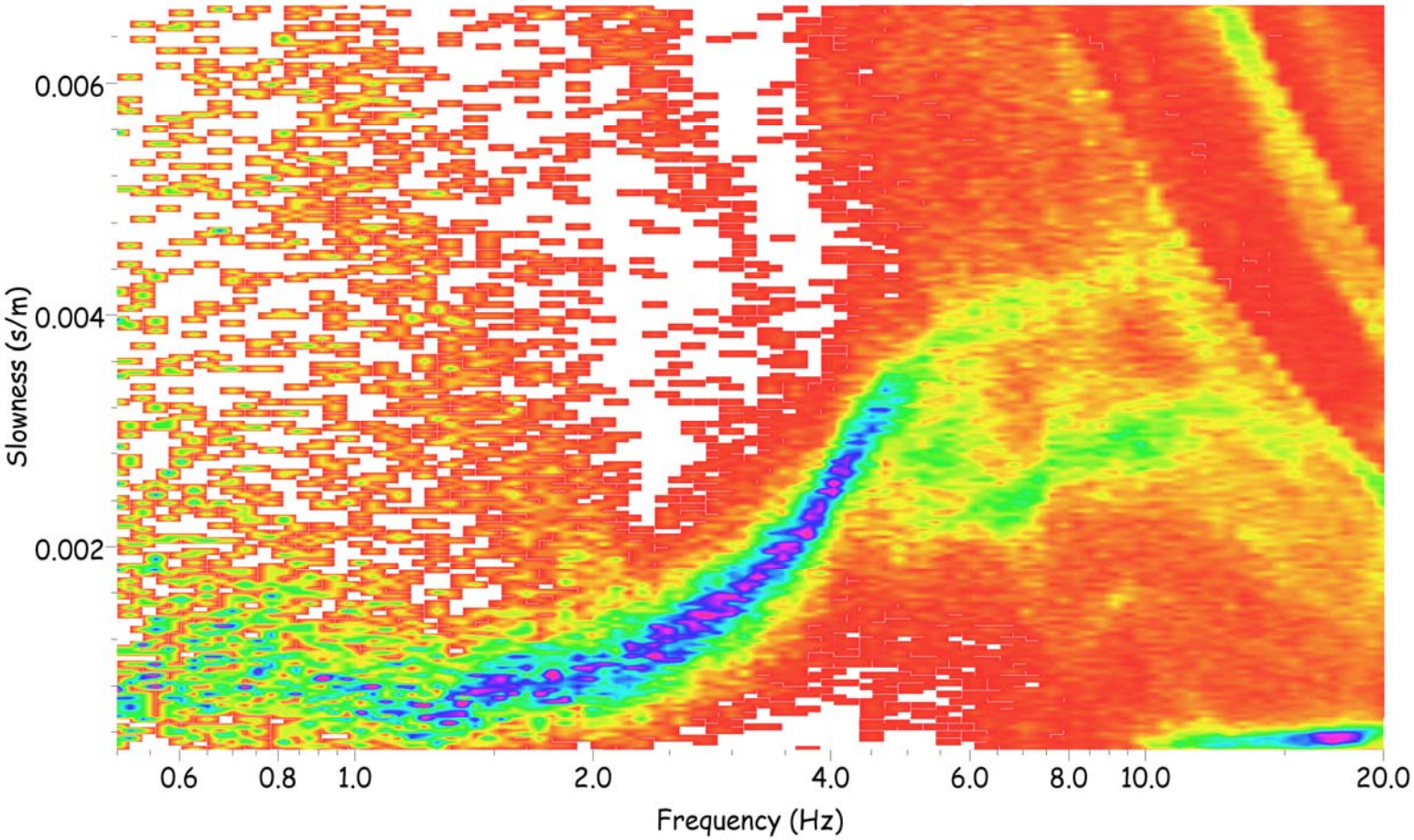
Select small and large array (eventually also a middle size one) – compute array responses

Process individual arrays – then combine max files and compare to results from (2)

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



or this one … ?


0.006
0.004
0.002
Slowness (s/m)
0.6
0.8
1.0
2.0
4.0
6.0
8.0
10.0
20.0
Frequency (Hz)