

Using Ambient Vibration Array Techniques for Site Characterisation

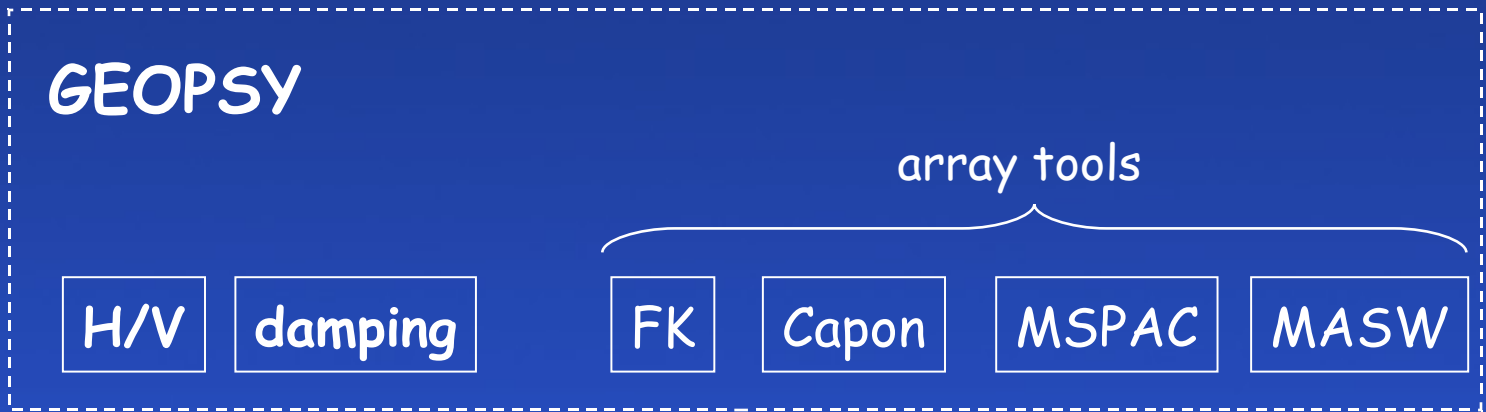
Dispersion Curve Inversion with Dinver

Tutorial

Dispersion Curve Inversion with Dinver

1. Calculating a theoretical dispersion curve
 - ⇒ Introduction to gpdc
 - ⇒ Playing with gplivemodel
2. Inversion of dispersion curves
 - ⇒ Targets
 - ⇒ Parameterization
 - ⇒ Running inversion processes
 - ⇒ Viewing results

SESARRAY PACKAGE

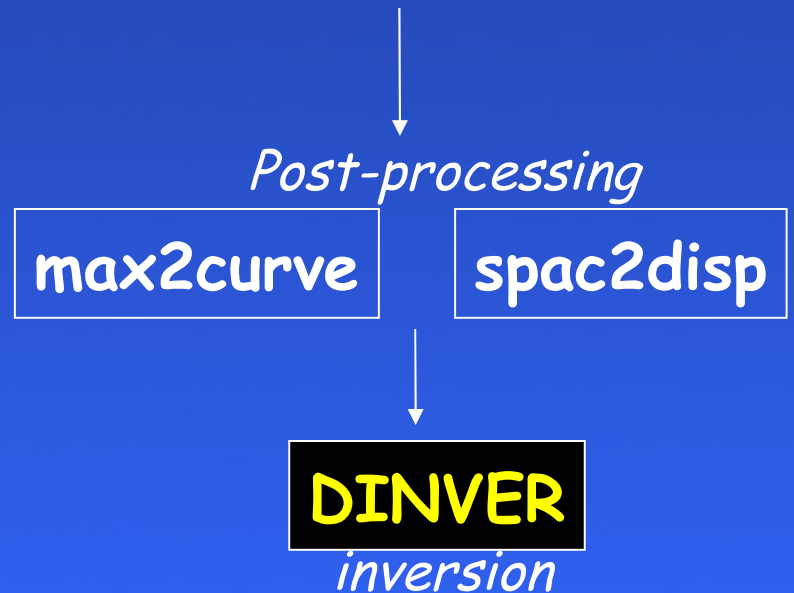


figue
figures

gp tools
*Dispersion curves
Ellipticity curves
Autocorr. Curves*

build_array
Array response

...



1. Calculating a theoretical dispersion curve

Create a text file with model parameters

(vi, notepad,... any text editor)

```

MINGW32:/e/cornou/TEACHING/Sesarray_Algiers2007/TUTORIA
cornou@LGIT-1229 /e/cornou/TEACHING/Sesarray_Algiers
$ vi test.model
    
```

```

MINGW32:/e/cornou/TEACHING/Sesarra...
2
25 1350 1000 1900
0 2000 1000 2500
2
2
2
2
2
2
2
2
    
```

Number of layers →
Thickness →

V_p **V_s** **Density**

gpdc: a command line tool for dispersion curve computation

```

MINGW32:/e/cornou/TEACHING/Sesarray_Algiers2007/TUTORIALS
cornou@LGIT-1229 /e/cornou/TEACHING/Sesarray_Algiers2007/TUTORIALS
$ gpdc --help
Usage: gpdc [OPTIONS] [FILE]

Compute dispersion curve for layered models given through stdin or FILE.

Format for layered models:
Line 1 : <number of layers including half-space for first model>
Line 2 : <thickness (m)> <Vp (m/s)> <Vs (m/s)> <Density (kg/m3)>[ <Qs> <Qp>]
...
Line n : 0 <Vp (m/s)> <Vs (m/s)> <Density (kg/m3)>[ <Qs> <Qp>]
Line n+1: <number of layers including half-space for second model>
...

Quality factors are not mandatory. If not specified, pure elastic computation is
performed. Any number of models can be given as input.

Generic options:
  -help           Show help about options
  -version        Show version information
  -reportbug      Start bug report dialog, information about bug is
                  passed through stdin. This option is used internally to
                  report bugs if option -nbugreport is not
                  specified.
  -nbugreport     Do not generate bug report in case of error

Gpdc options:
  -n <count>      Number of samples (default=100)
  -L <n modes>    Number of Love modes (default=0)
  -R <n modes>    Number of Rayleigh modes (default=1)
  -group          Switches to group slowness (default=phase)
  -s <sampling>  Defines the sampling type:
                  period      regular sampling in period
                  frequency   regular sampling in frequency
                  log          regular sampling in log(frequency)
                  (default)
  -min <min>     Minimum of range for dispersion curve (default=0.2)
  -max <max>     Maximum of range for dispersion curve (default=20)
  -n <count>     Number of samples (default=100)

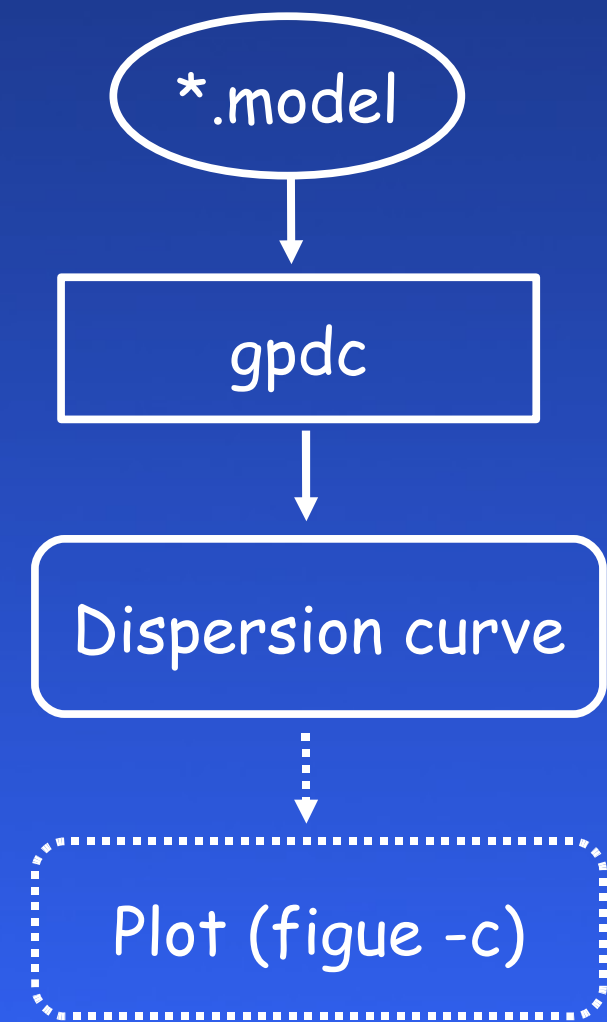
Examples:
  gpdc < test.model

Calculate fundamental Rayleigh dispersion curve from 0.2 Hz to 20 Hz for
model 'test.model'.

  gpdc -L 1 -R 2 < test.model

Calculate fundamental Love mode and fundamental and first higher mode for
Rayleigh.

  gpdc < test.model | figure -c
    
```



```
gpdc < test.model
```

Calculate fundamental Rayleigh dispersion curve from 0.2 Hz to 20 Hz for model 'test.model'.

```
gpdc -L 1 -R 2 < test.model
```

Calculate fundamental Love mode and fundamental and first higher mode for Rayleigh.

```
gpdc < test.model | figure -c
```

Calculate the same dispersion curve and plot it.

```
gpdc < test.model | figure -c -m dc.mkup
```

Show the same dispersion curve on a log-log plot. 'dc.mkup' is a tar.gz file containing an xml description of the graphic format, it can be generated from figure's interface.

```

MINGW32:/e/cornou/TEACHING/Sesarray_Algers2007/TUTORIALS
cornou@LGIT-1229 /e/cornou/TEACHING/Sesarray_Algers2007/TUTORIALS
$ gpdc -R 2 < test.model > target.dc
    
```

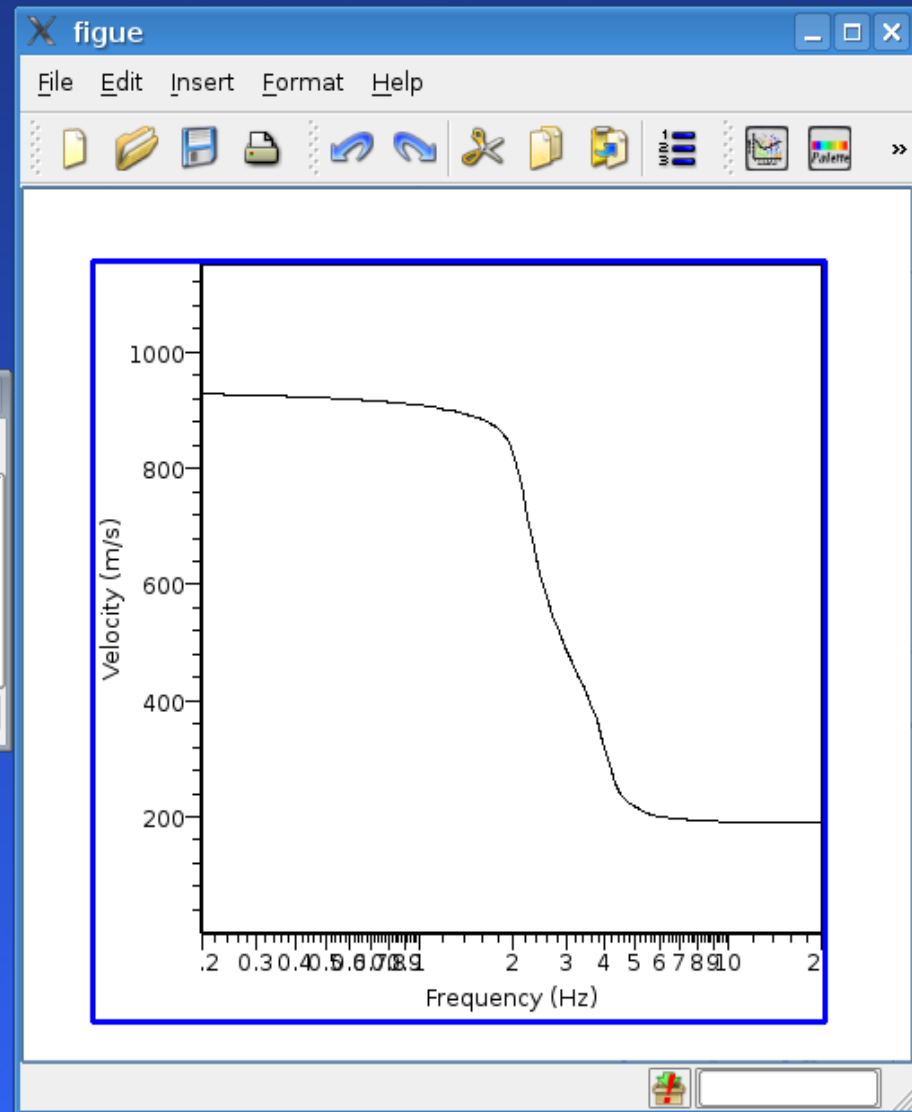
```

MINGW32:/e/cornou/TEACHING/Sesarray_A...
# 2 Rayleigh dispersion modes
# Mode 0
0.2 0.00107739331509553
0.209523150557933 0.00107763758157074
0.219499753098611 0.00107789409424396
0.229951399079547 0.00107816323021893
0.240900708051756 0.00107844578444416
0.252371376613204 0.0010787424664883
0.264388229693206 0.0010790540286263
0.276977274278775 0.0010793812691111
0.290165755699188 0.00107972503579373
0.303982216590587 0.00108008623014239
0.318456558668219 0.00108046581172061
0.333620107440012 0.00108086480319564
0.349505680001537 0.00108128429596249
0.366147656059074 0.00108172545648591
0.383582052334498 0.00108218953348406
0.401846600513009 0.00108267786610392
0.420980828902404 0.00108319189327193
    
```

```

MINGW32:/e/cornou/TEACHING/Sesarray_A...
17.3949800523557 0.00524099612354591
18.2232551223098 0.00524117200283951
19.0909691332367 0.00524129289654945
20.0.00524137441070279
# Mode 1
2.24664806595606 0.0010322920874912
2.35362390487 0.00106091110454442
2.46569347888413 0.00107854340076219
2.58309933002977 0.00109059866066247
2.70609554915962 0.001099722720448
2.83494832585361 0.00110721447007284
2.96993652450893 0.00111376540442095
3.11135228786095 0.00111977851655673
3.25950166924129 0.00112551170920067
3.41470529494138 0.0011311500807528
3.57729905811487 0.00113684443785493
3.74763484572077 0.00114274232371332
3.92608130008054 0.00114901694885534
4.1130246166973 0.00115591068556711
    
```

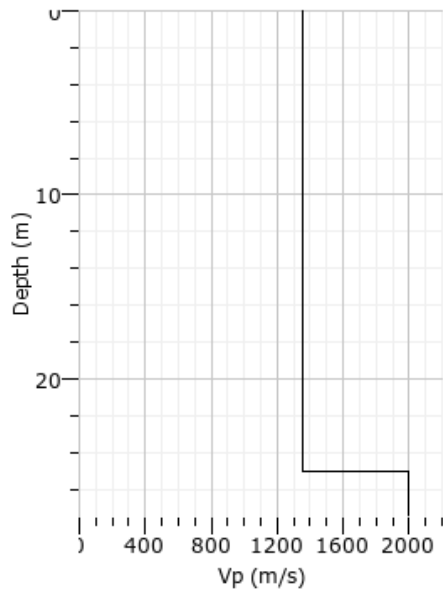
```
mwathele@sirac:~/tmp - Shell - Konsole <2>  
Session Edit View Bookmarks Settings Help  
mwathele@sirac ~/tmp $ gpdc < test.model | figure -c -m dc.mkup
```



Gplivemodel : background models

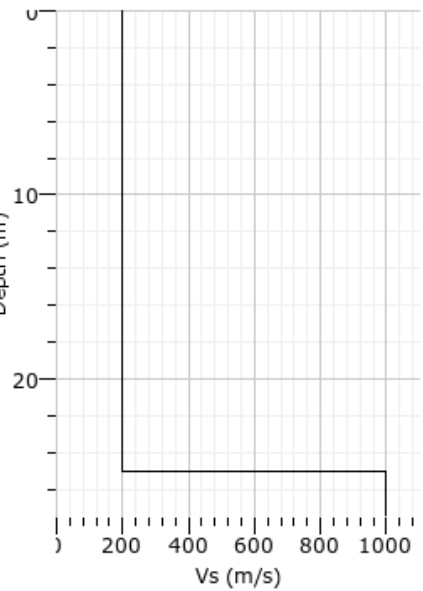
gplivemodel

File Edit Insert Format Tools Help



Depth (m)

Vp (m/s)

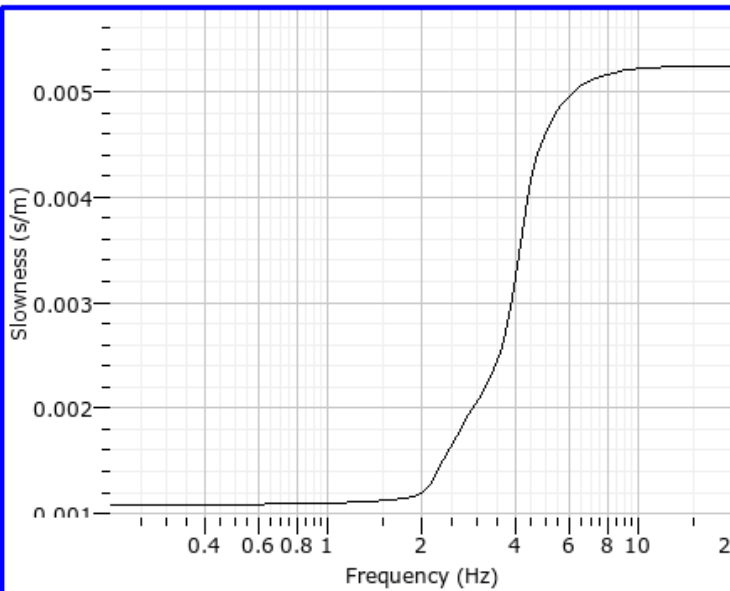


Depth (m)

Vs (m/s)

Background models

Foreground models



Slowness (s/m)

Frequency (Hz)

Background models

```

2
25 1350 200 1900
0 2000 1000 2500
          
```

Background models Reference model Foreground model

Control Panel

Unnamed

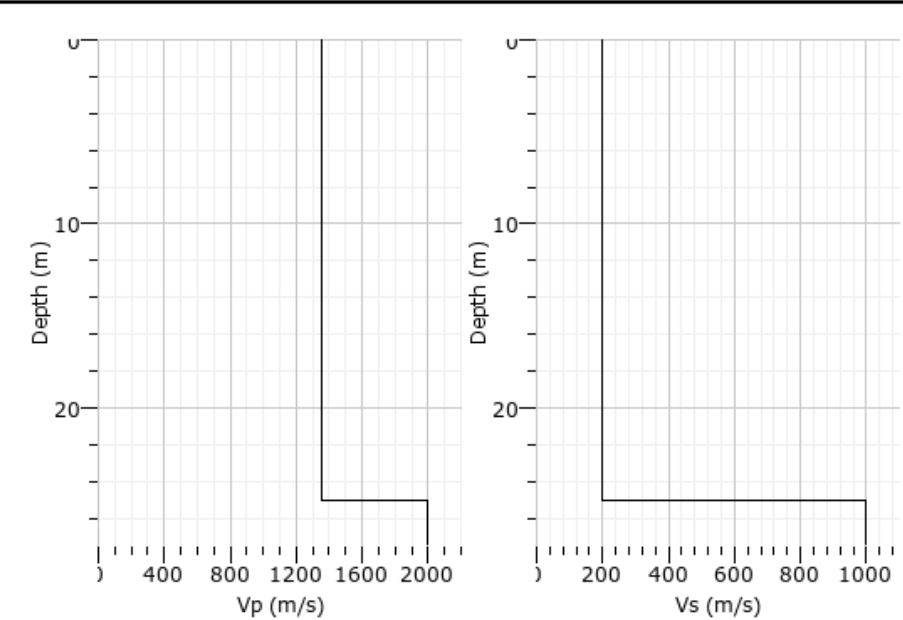
Add Load Save

Gplivemodel : reference model

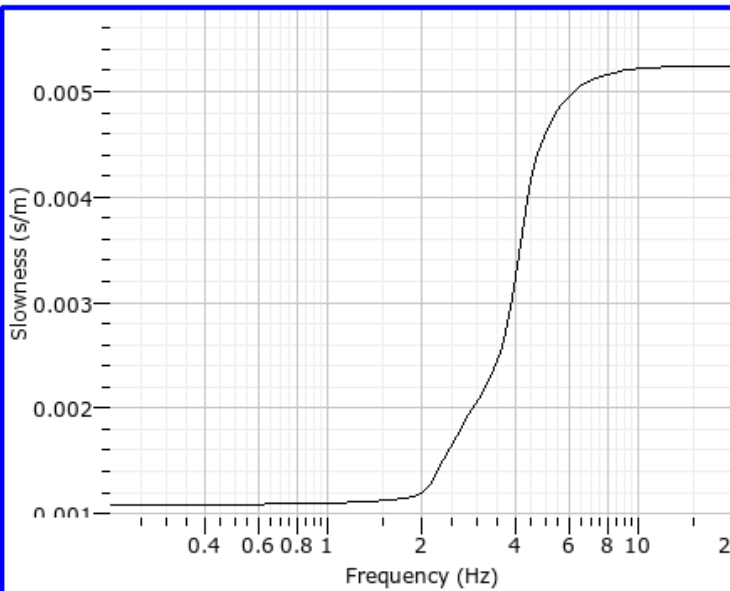
gplivemodel

File Edit Insert Format Tools Help

Background models



Foreground models



Reference model

```

2
25 1350 200 1900
0 2000 1000 2500
          
```

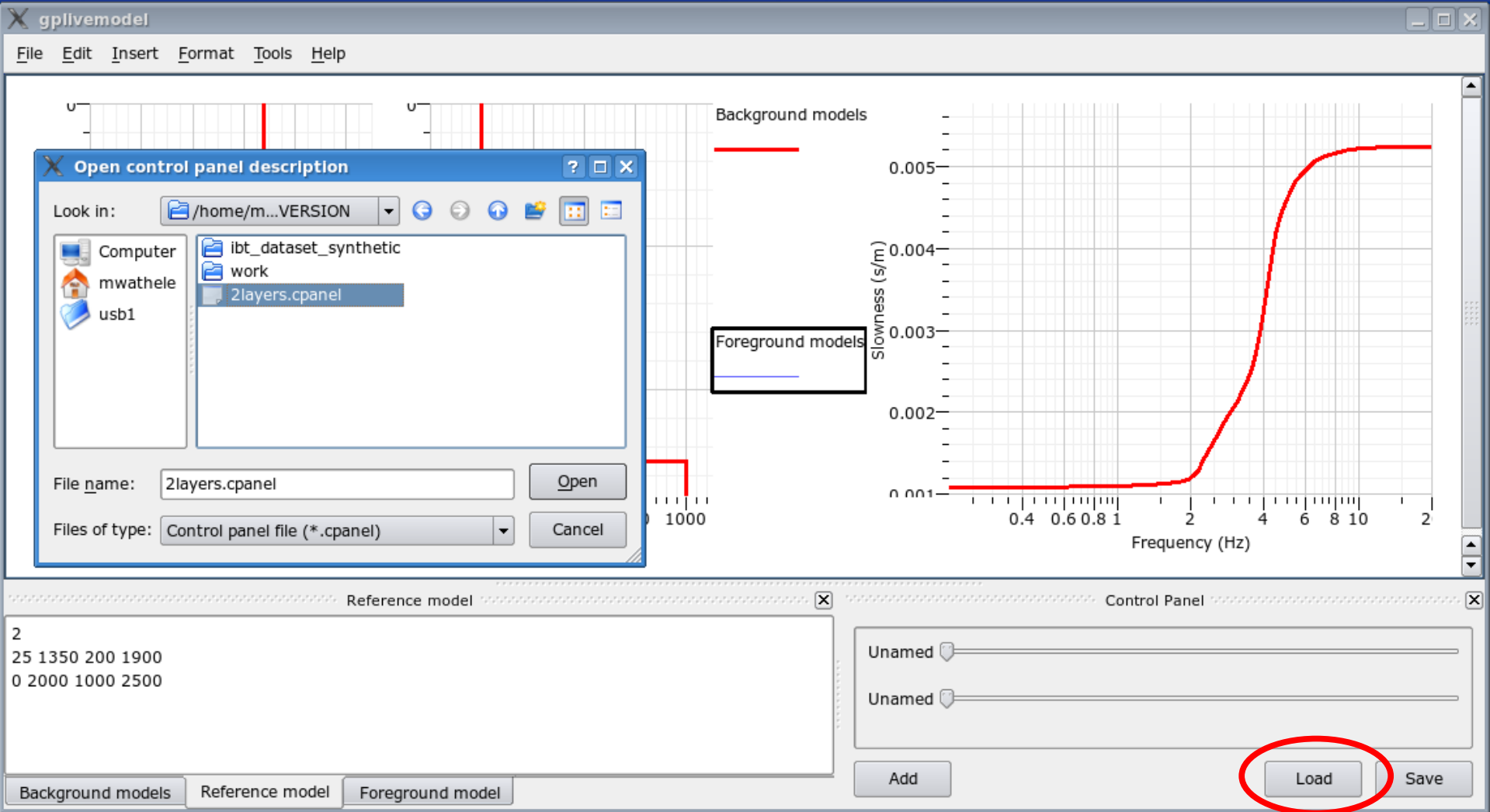
Background models Reference model Foreground model

Control Panel

Unnamed

Add Load Save

Gplivemodel : legends & control panel



The screenshot displays the **gplivemodel** application window. At the top, there is a menu bar with **File**, **Edit**, **Insert**, **Format**, **Tools**, and **Help**. The main workspace is divided into several sections:

- Open control panel description dialog:** A file selection window showing the directory `/home/m...VERSION`. It lists folders like `Computer`, `mwathele`, and `usb1`, and files like `ibt_dataset_synthetic`, `work`, and `2layers.cpanel`. The `2layers.cpanel` file is selected. The **File name:** field contains `2layers.cpanel` and the **Files of type:** dropdown is set to `Control panel file (*.cpanel)`. Buttons for **Open** and **Cancel** are visible.
- Graphs:**
 - Background models:** A plot showing a red horizontal line at a slowness value of approximately 0.005.
 - Foreground models:** A plot showing a blue horizontal line at a slowness value of approximately 0.001.
 - Slowness (s/m) vs Frequency (Hz):** A plot showing a red curve that starts at a slowness of ~0.001 at 0 Hz and increases to ~0.005 at 10 Hz.
- Reference model:** A text area containing the following data:


```

      2
      25 1350 200 1900
      0 2000 1000 2500
      
```
- Control Panel:** A panel with two sliders labeled **Unnamed** and two buttons: **Add**, **Load** (circled in red), and **Save**.

At the bottom, there are tabs for **Background models**, **Reference model**, and **Foreground model**.

Gplivemodel : play with cursors

gplivemodel

File Edit Insert Format Tools Help

Background models

Foreground models

Depth (m)

Vp (m/s)

Vs (m/s)

Slowness (s/m)

Frequency (Hz)

Reference model

```

2
25 1350 200 1900
0 2000 1000 2500
  
```

Control Panel

Sediment Vs

Thickness

Bed-rock Vs

Travel time

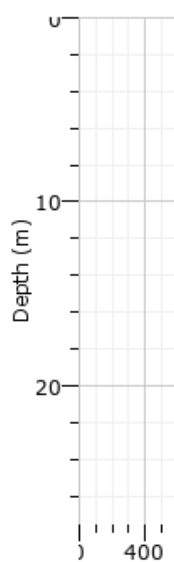
Add Load Save

Background models Reference model Foreground model

Gplivemodel : editing cursors

gplivemodel

File Edit Insert Format Tools Help



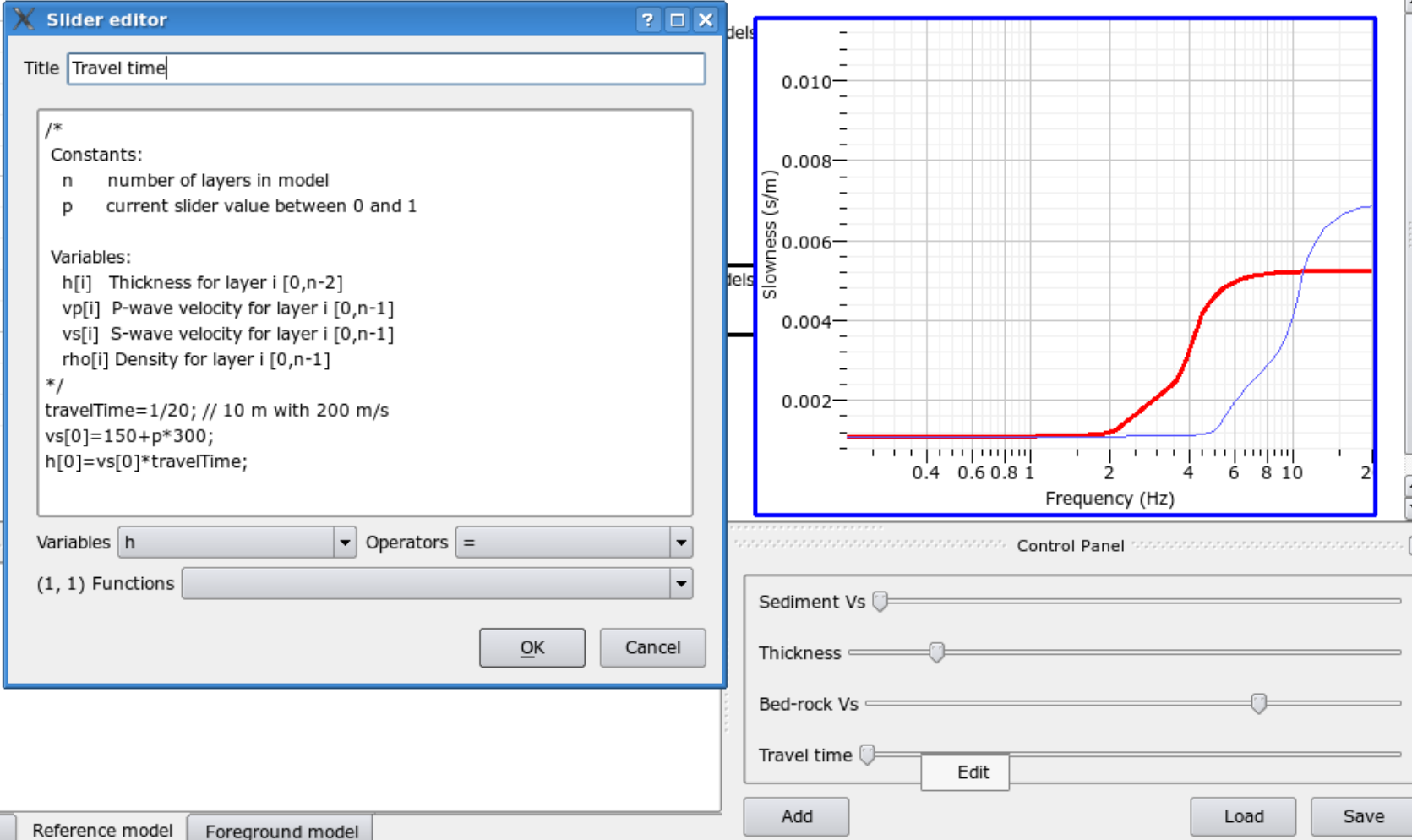
Depth (m)

400

2

25 1350 200 1900

0 2000 1000 2500



Slider editor

Title

```

/*
Constants:
n   number of layers in model
p   current slider value between 0 and 1

Variables:
h[i] Thickness for layer i [0,n-2]
vp[i] P-wave velocity for layer i [0,n-1]
vs[j] S-wave velocity for layer i [0,n-1]
rho[i] Density for layer i [0,n-1]
*/
travelTime=1/20; // 10 m with 200 m/s
vs[0]=150+p*300;
h[0]=vs[0]*travelTime;
          
```

Variables Operators Functions

Control Panel

Sediment Vs

Thickness

Bed-rock Vs

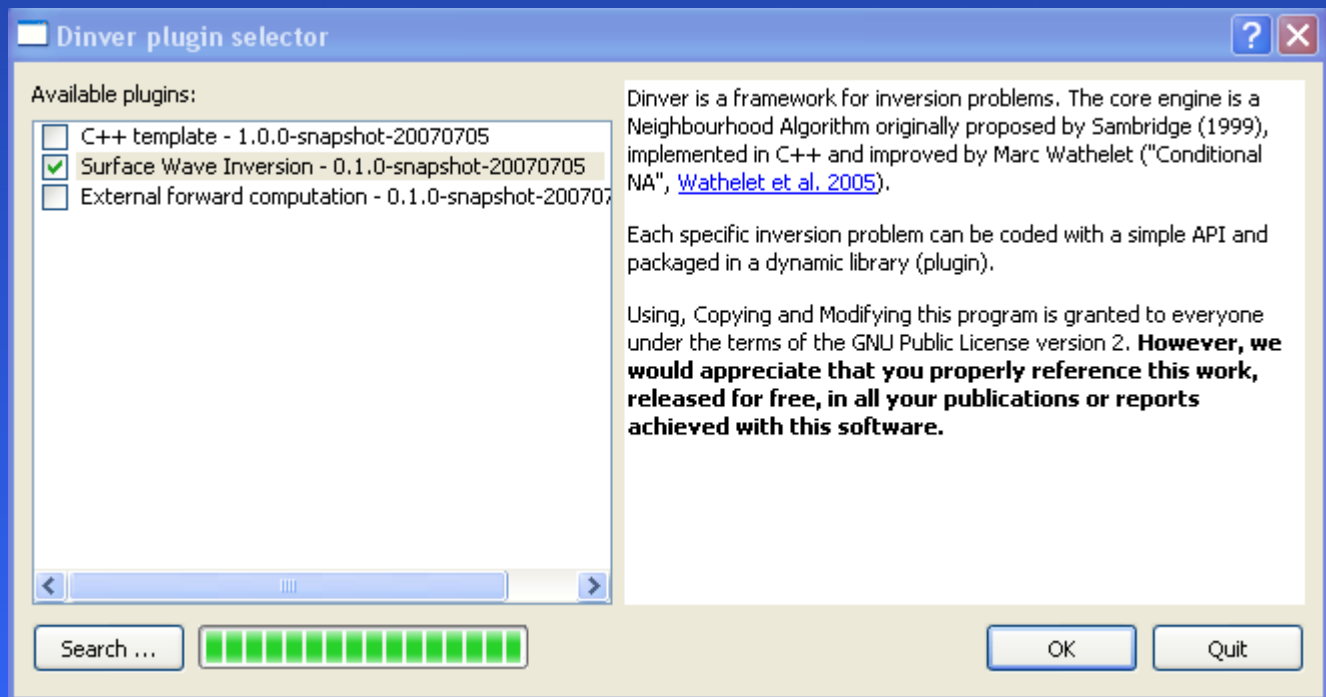
Travel time

Background models Reference model Foreground model

2. Inversion dispersion curves

Starting Dinver: plugin selection

```
MINGW32:/e/cornou/TEACHING/Sesarray_Algiers2007/TUTORIALS  
  
cornou@LGIT-1229 /e/cornou/TEACHING/Sesarray_Algiers2007/TUTORIALS  
$ dinver
```

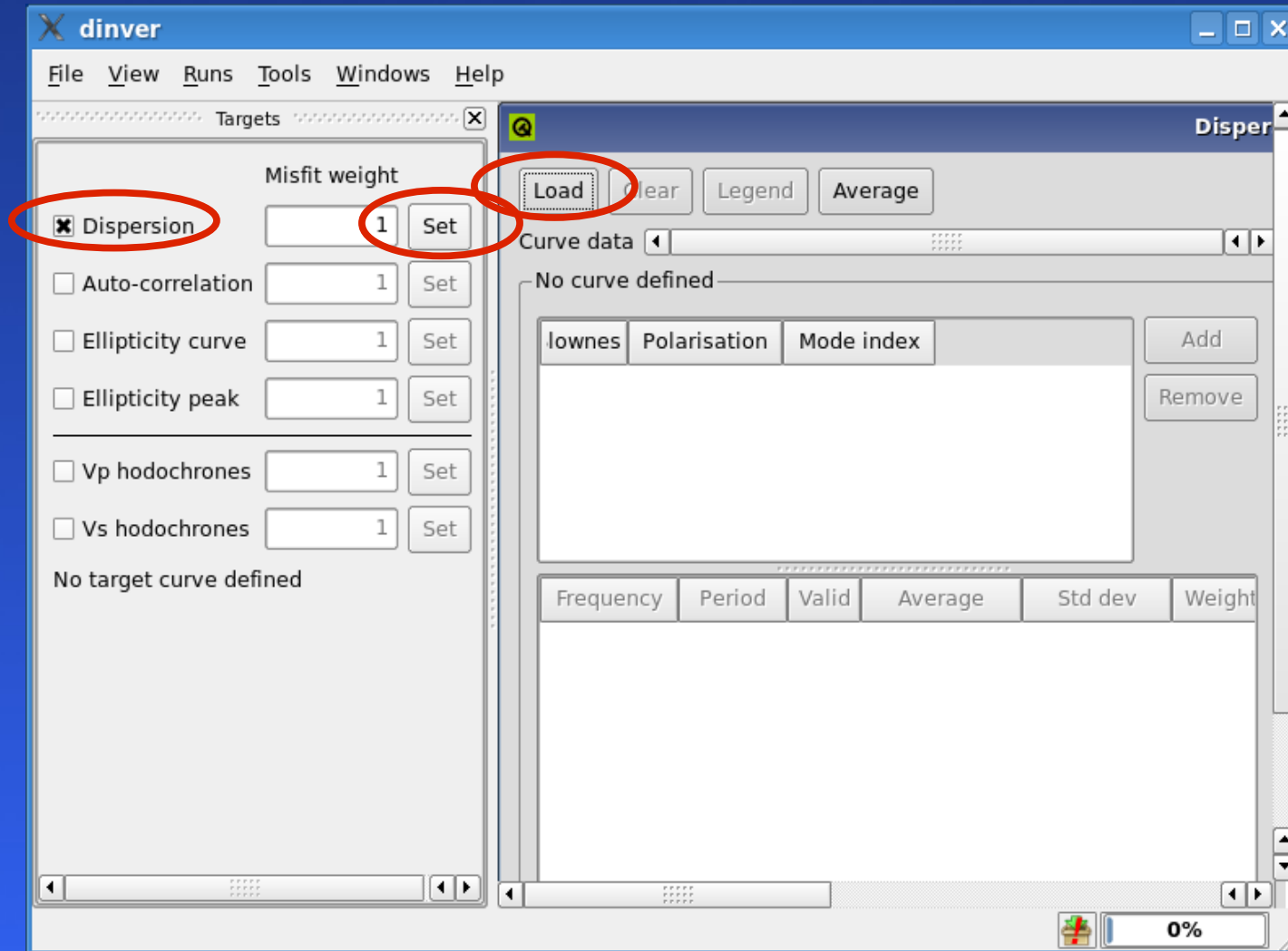


Surface Wave Inversion: Dinver's workspace

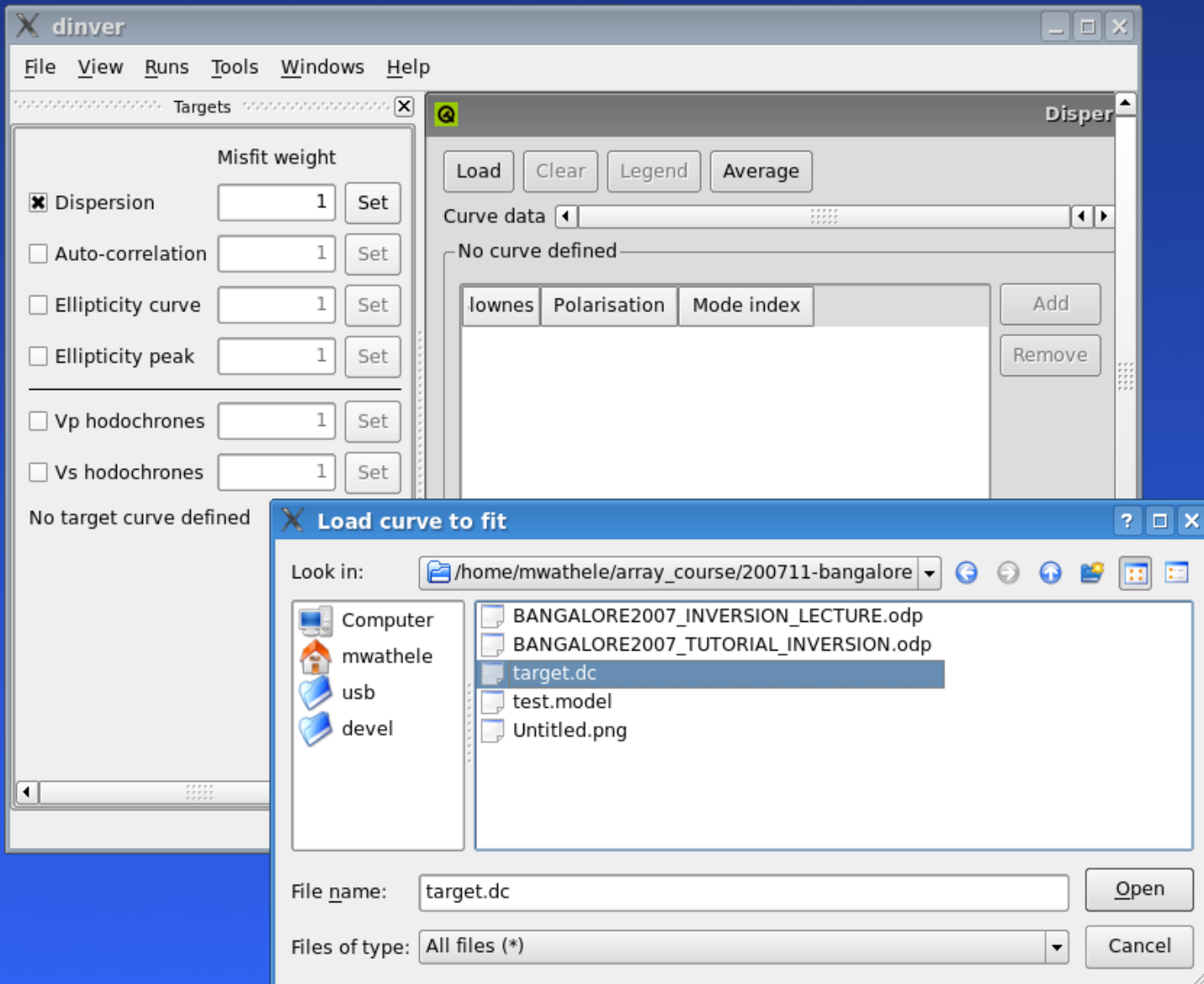
The screenshot shows the Dinver software interface with the following components and annotations:

- 1. Targets:** A panel titled "Targets" with a "Misfit weight" section. It contains several options with input fields and "Set" buttons:
 - Dispersion (value: 1)
 - Auto-correlation (value: 1)
 - Ellipticity curve (value: 1)
 - Ellipticity peak (value: 1)
 - Vp hodochrones (value: 1)
 - Vp hodochrones (value: 1)
- 2. Parameterized ground model:** A "Parameters" panel at the bottom right with controls for:
 - Compression-wave velocity (m/s)
 - Poisson's Ratio
 - Shear-wave velocity (m/s)
 - Density (kg/m³)
- 3. Inversion processes:** A "Runs" panel at the bottom left showing a table with columns: Run name, lmax, Ns0, Ns, Nr, S.
- 4. Processes status:** A "Status" panel at the bottom left showing a graph of "Minimum misfit" vs "Generated models" and a table with columns: Pen, Run name, Min misfit, M.
- 5. Logs:** A "Log" panel on the right side of the main workspace.

1. Selection of target curve



1. Selection of target curve



Import text file with dispersion curves

dinver - [Dispersion target]

Qt File View Runs Tools Windows Help

Targets

Load Clear Legend Average

Curve data

Load curves

Parser Save Load

Lines Columns Sections

	1	2
Type	Frequency (Hz)	Slowness (s/m)
Factor	1	1
RX		
After		
4	0.2	0.00107739...
5	0.20952315...	0.00107763...
6	0.21949975...	0.00107789...
7	0.22995139...	0.00107816...
8	0.24090070...	0.00107844...
9	0.25237137...	0.00107874...

Use the same parser for next files

Ok Cancel

Misfit w

Dispersion

Auto-correlation

Ellipticity curve

Ellipticity peak

Refraction Vp

Refraction Vs

0 dispersion curves

Targets Log Runs

Minimum misfit

Generated models

Legend

Parameters Status

frequency (Hz)

Rate Eff. Nr Re

0%

Resampling the target curve

Usually: between 30 to 50 samples

Dispersion curve target

Load Clear Legend Average

Curve data

Curve 1 of 2

	lownes	Polarisation	Mode inde:	Add
1	Phase	Rayleigh	0	Remove

	Frequency	Period	Valid	Average
1	0.2	5	✘	928.
2	0.209523	4.77274	✘	927.
3	0.2195	4.55581	✘	927.
4	0.229951	4.34875	✘	927.
5	0.240901	4.15109	✘	927.

Name target.dc Visible Actions

Save
Log
Remove
Resample
Cut

Resample

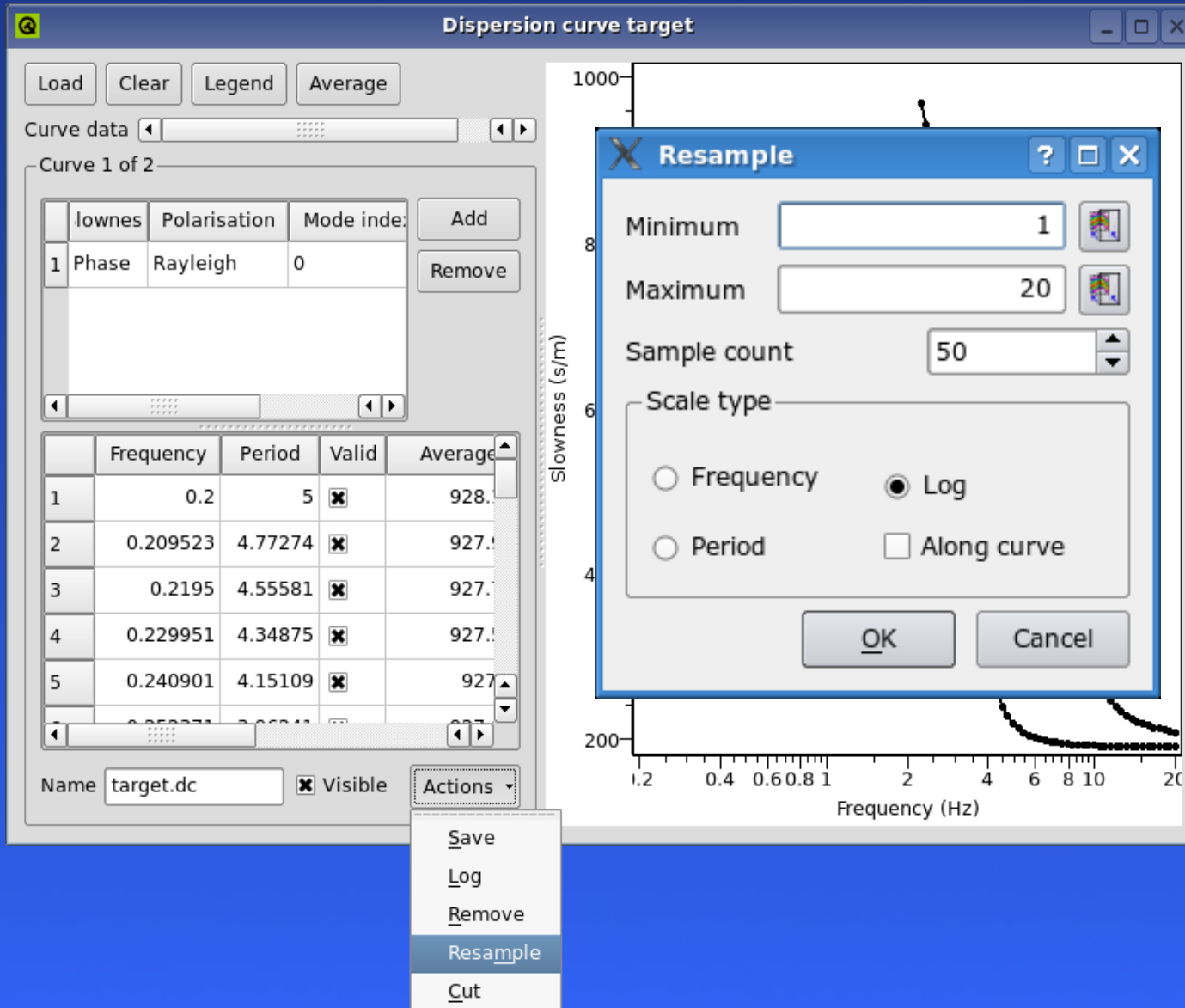
Minimum 1
Maximum 20
Sample count 50

Scale type
 Frequency
 Log
 Period
 Along curve

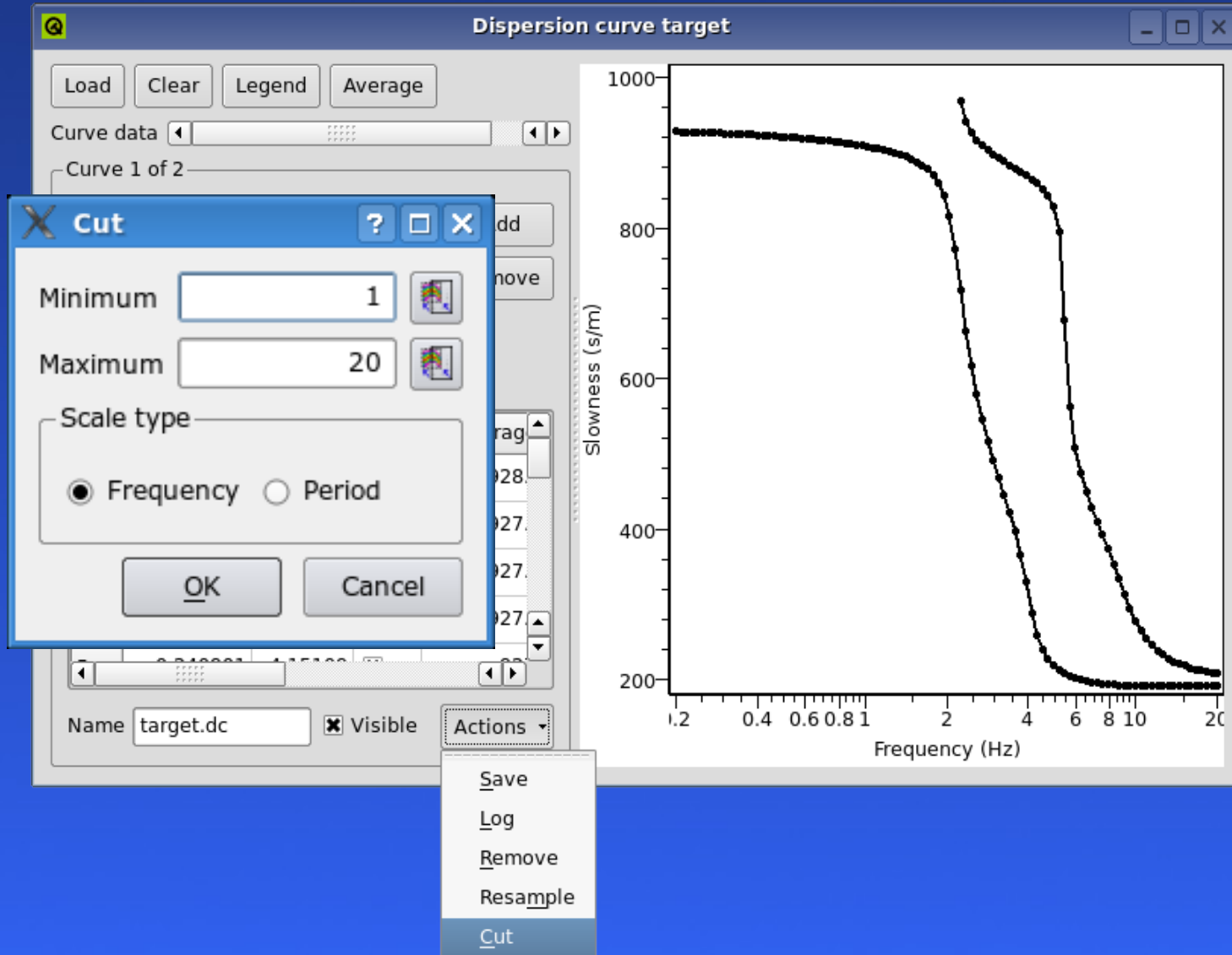
OK Cancel

Slowness (s/m)

Frequency (Hz)

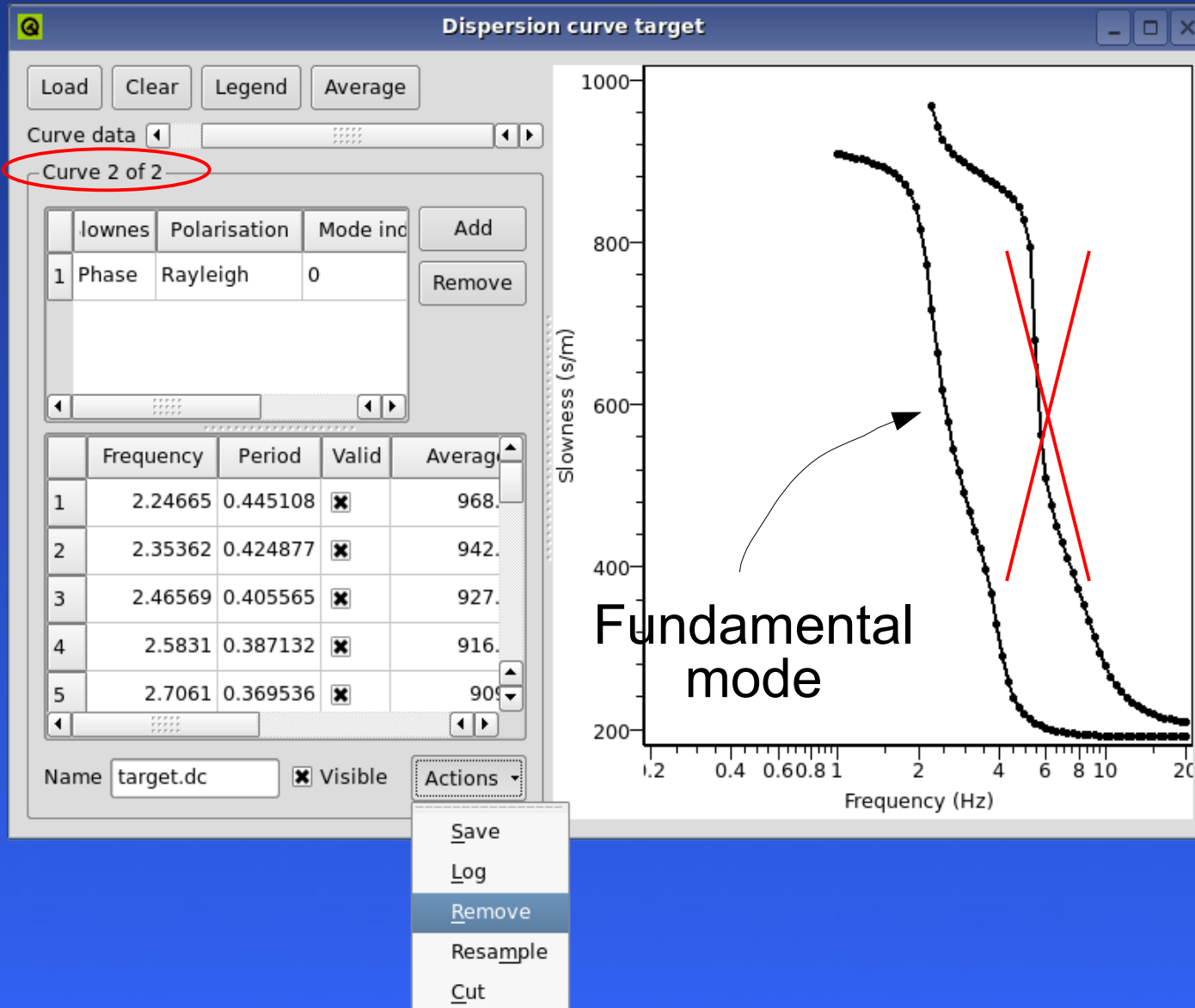


Cutting the target curve

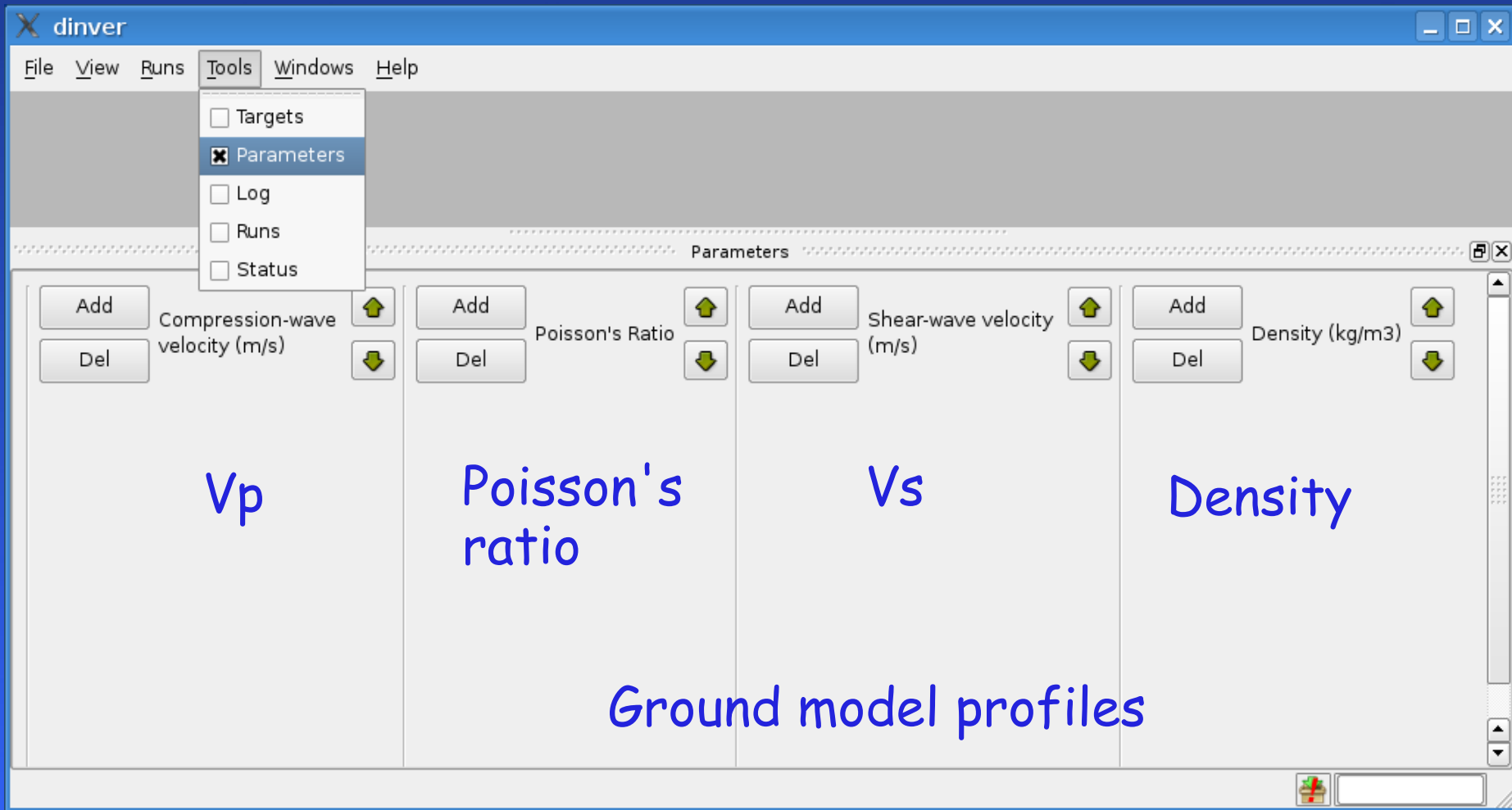


All available curves are included in misfit

Remove the higher mode

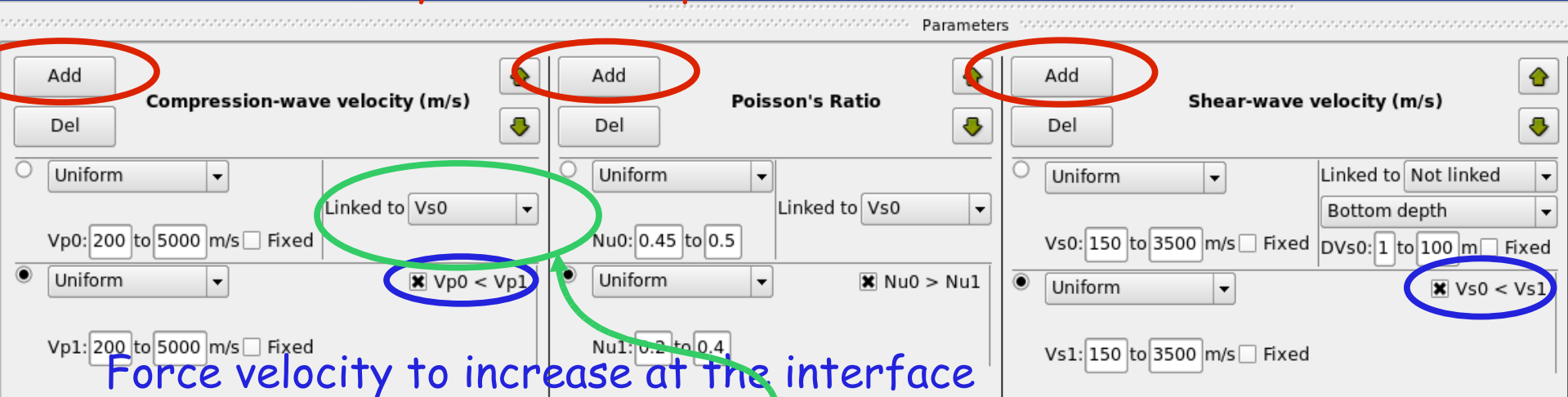


2. Definition of parameter space



Parameterized ground model with two layers and a positive velocity contrast

Add new layers to each profile



Parameters

Compression-wave velocity (m/s)

Add Del

Uniform

Linked to Vs0

Vp0: 200 to 5000 m/s Fixed

Uniform Vp0 < Vp1

Vp1: 200 to 5000 m/s Fixed

Poisson's Ratio

Add Del

Uniform

Linked to Vs0

Nu0: 0.45 to 0.5

Uniform Nu0 > Nu1

Nu1: 0.3 to 0.4

Shear-wave velocity (m/s)

Add Del

Uniform

Linked to Not linked

Bottom depth

Vs0: 150 to 3500 m/s Fixed

DVs0: 1 to 100 m Fixed

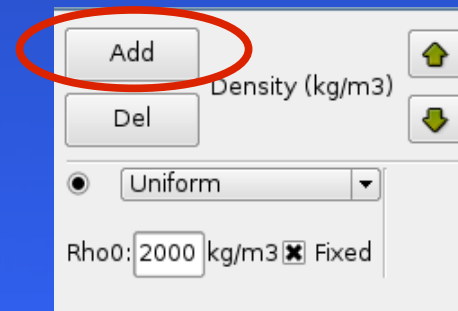
Uniform Vs0 < Vs1

Vs1: 150 to 3500 m/s Fixed

Force velocity to increase at the interface

Force Vp, Poisson and Vs profiles to have a common interface

Density generally fixed to a constant



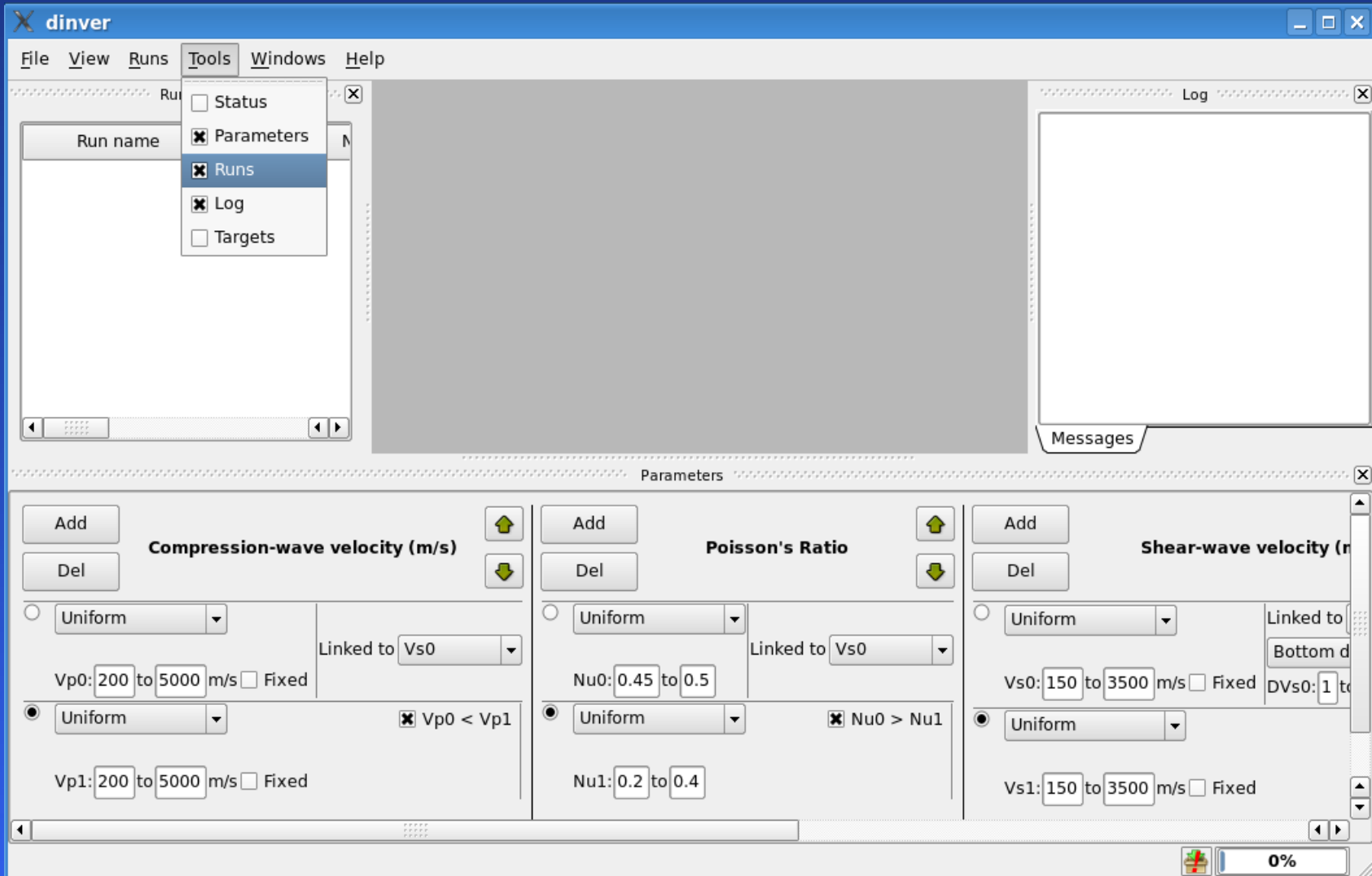
Add Del

Density (kg/m3)

Uniform

Rho0: 2000 kg/m3 Fixed

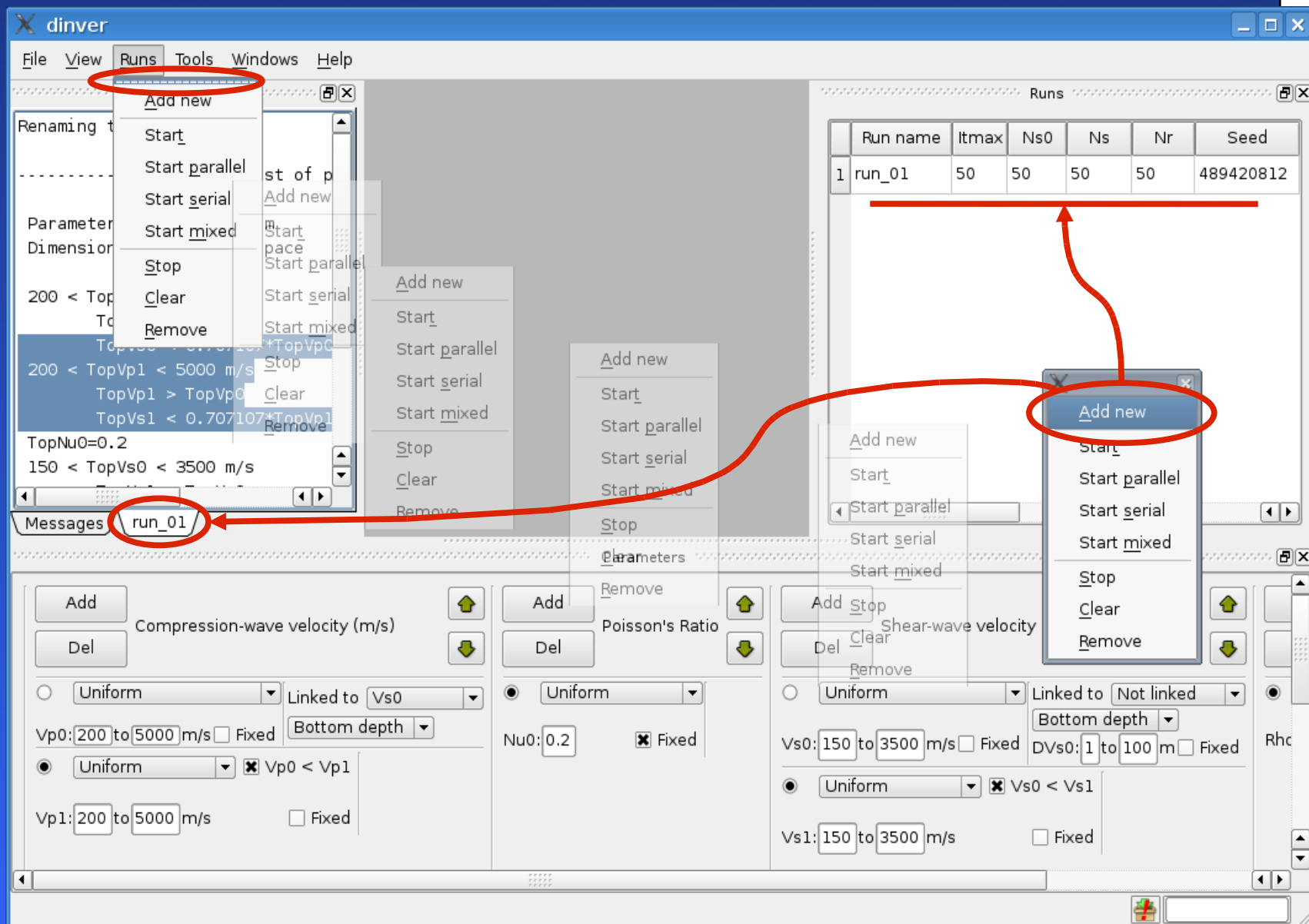
3. Create inversion processes



Show "Runs" & "Log" windows

December 6th-12th, Thessaloniki, Greece

Add a new inversion run

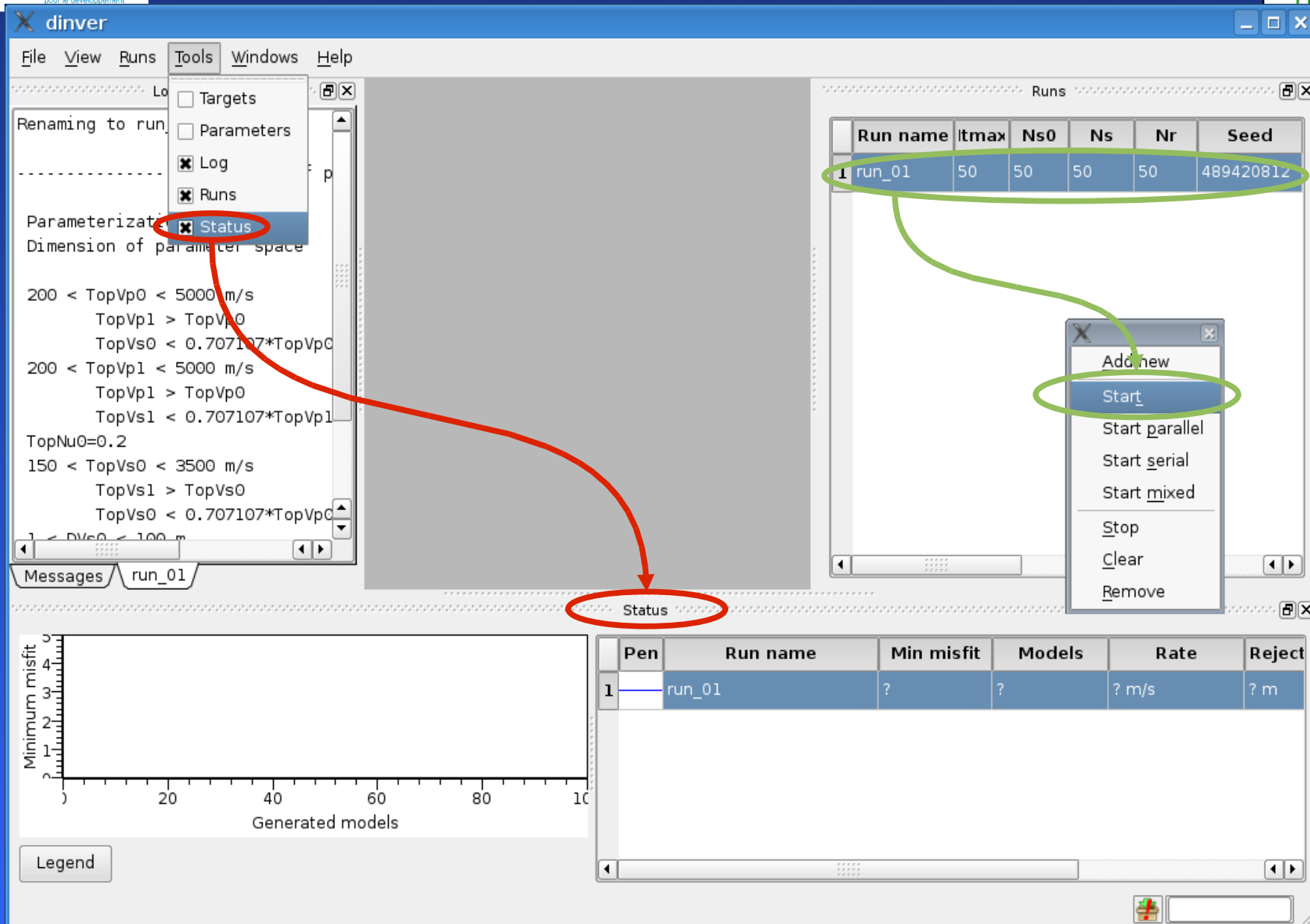


The screenshot shows the 'dinver' software interface. The 'Runs' menu is open, and the 'Add new' option is highlighted. A table in the 'Runs' panel shows the following data:

	Run name	ltmax	Ns0	Ns	Nr	Seed
1	run_01	50	50	50	50	489420812

Red annotations highlight the 'Add new' menu item, the 'run_01' entry in the table, and the 'Add new' button in the 'Parameters' section.

Start inversion run

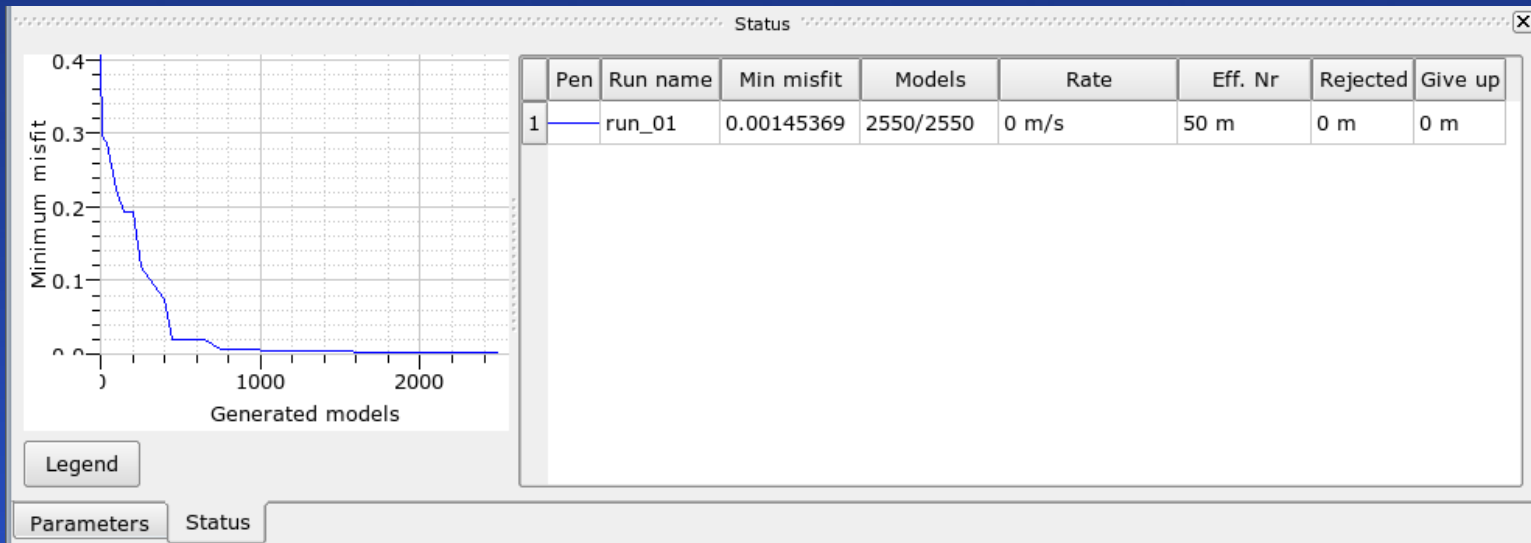


The screenshot shows the 'dinver' software interface. On the left, a 'Tools' menu is open with 'Status' selected. A red arrow points from 'Status' to the 'Status' label at the bottom of the main window. On the right, a 'Runs' table is visible with one entry: 'run_01'. A green oval highlights this entry, and a green arrow points from it to a context menu where 'Start' is selected. Below the main window, a 'Status' window is open, showing a table with columns: Pen, Run name, Min misfit, Models, Rate, and Reject. The table contains one row for 'run_01' with question marks in the other columns. To the left of the table is a graph of 'Minimum misfit' vs 'Generated models'.

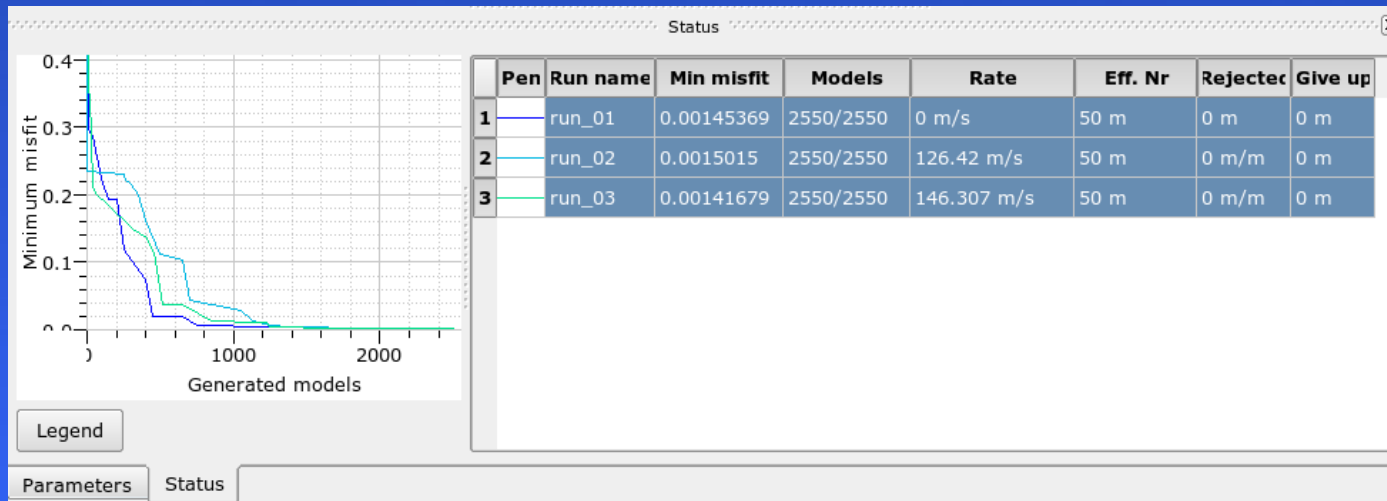
Run name	Itmax	Ns0	Ns	Nr	Seed
1 run_01	50	50	50	50	48942081z

Pen	Run name	Min misfit	Models	Rate	Reject
1	run_01	?	?	? m/s	? m

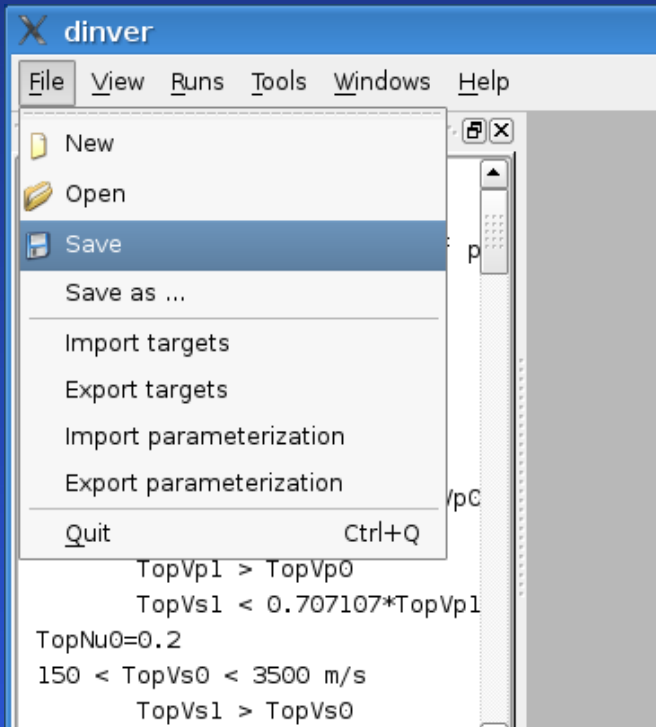
Misfit history & processes statistics



Start at least 2 or 3 runs with distinct seed values



New/Open/Save a Dinver project



When no project is saved,
 all .report files are saved in
[YOUR HOME]/.dinvertemp/

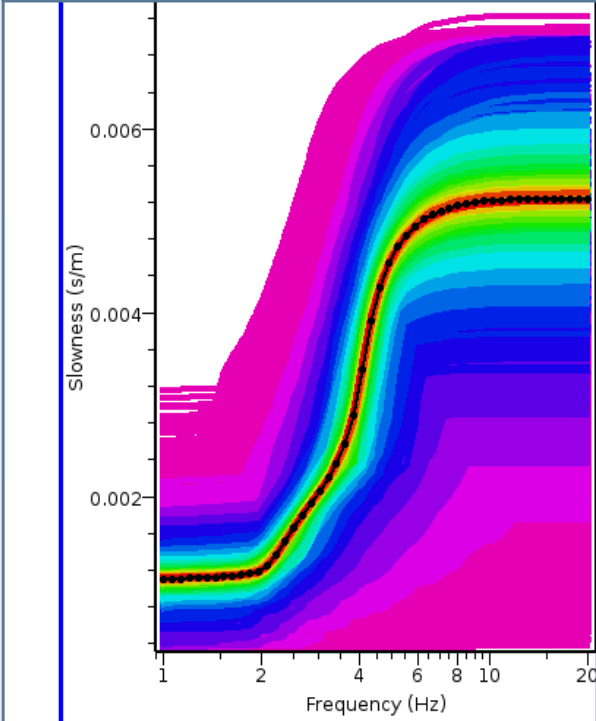
When project is saved,
 all .report files are saved in
[YOUR PROJECT]_report/

Viewing velocity profiles & dispersion curves

dinver - [Dispersion curves (Phase Rayleigh): run_01 run_02 run_03 run_04 run_05]

View | Parameter Space | Ground profiles | Dispersion | Autocorrelation | Ellipticity

Run	Ns
1 run_01	50
2 run_02	50
3 run_03	50
4 run_04	50
5 run_05	50



Dispersion viewer

Maximum misfit: 1.0000
 Maximum number of modes: 1
 Mode: Slowness (Phase), Polarisation (Rayleigh)

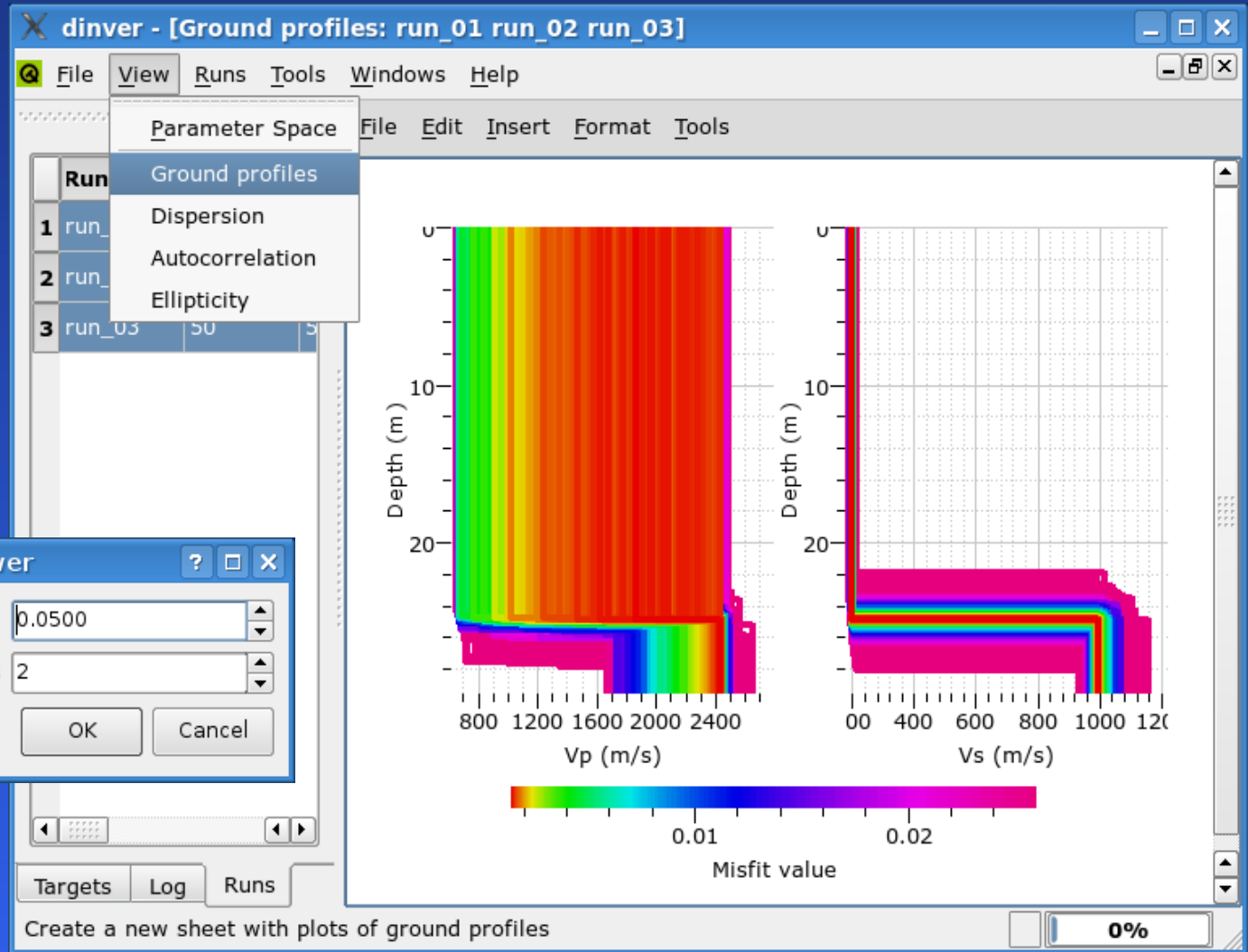
OK Cancel

Pen	Run name	Min misfit
1	run_01	0.00898214
2	run_02	0.0109103

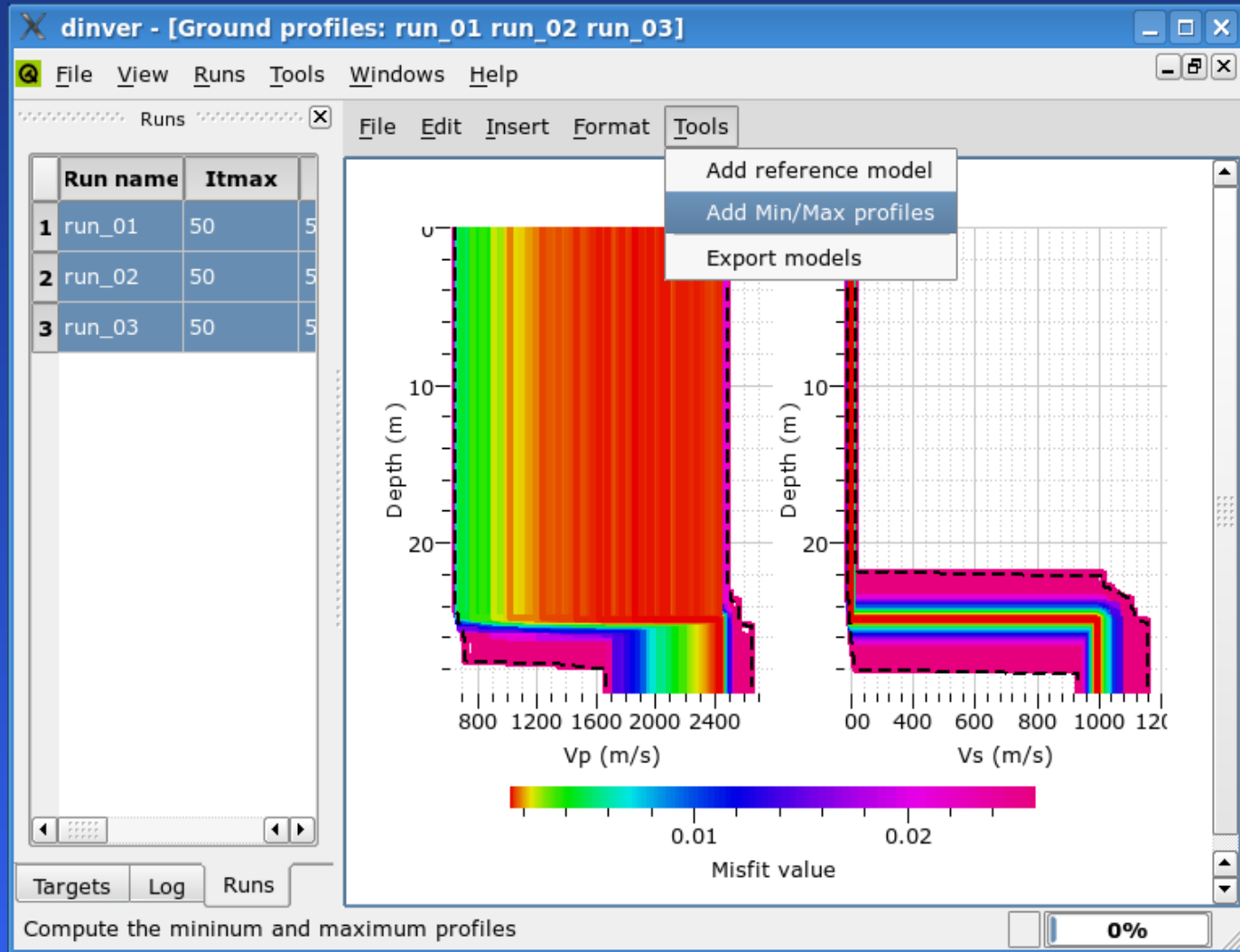
Legend | Parameters | Status | 100%

Create a new sheet with plots of dispersion curves

Viewing velocity profiles & dispersion curves



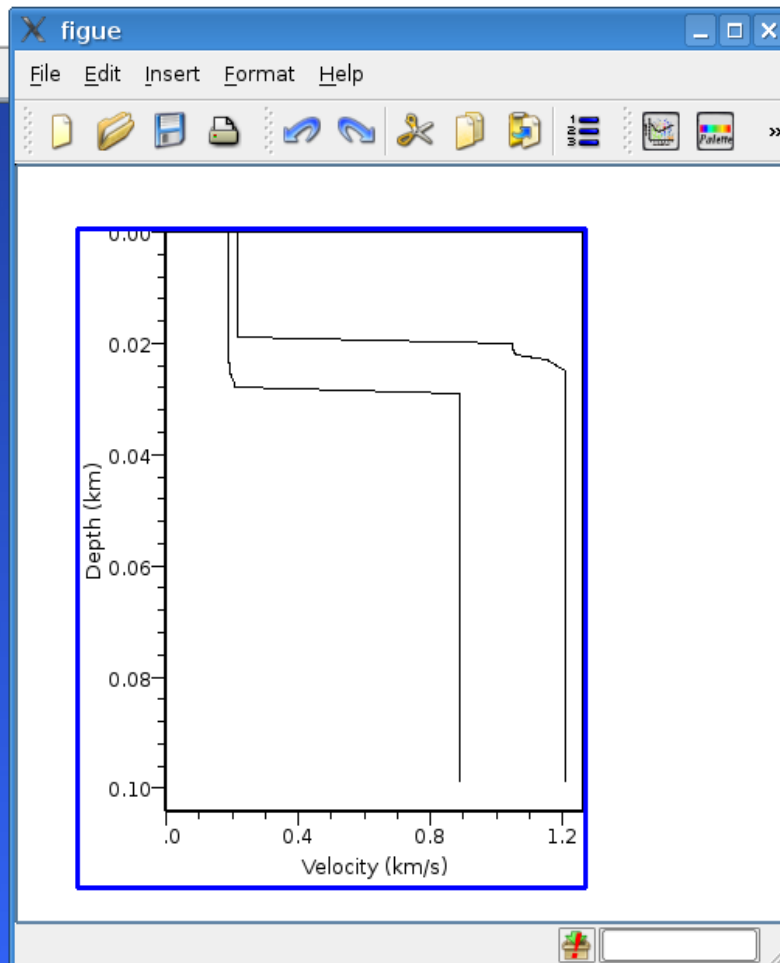
Calculating minimum and maximum profiles

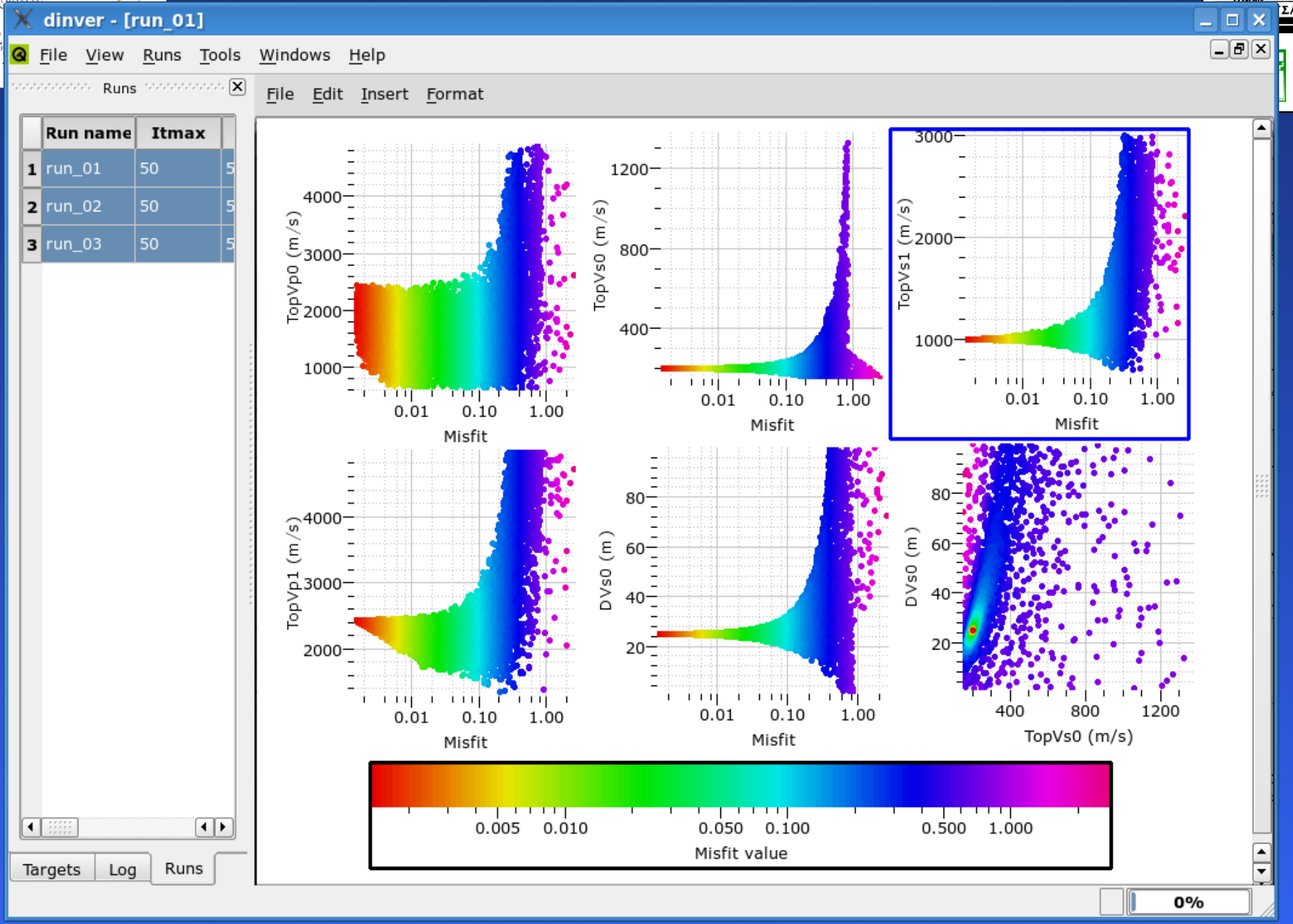


Calculating minimum and maximum profiles

```
mwathele@sirac:~/dinvertemp - Shell - Konsole
Session Edit View Bookmarks Settings Help

mwathele@sirac ~ $ cd ~/.dinvertemp/
mwathele@sirac ~/.dinvertemp $ ls
run_01.report run_02.report run_03.report run_04.report run_05.report
mwathele@sirac ~/.dinvertemp $ gpdcreport *.report -m 0.05 | gpprofile -minmax | figure -c -m ../data/INVERSION/vs.mkup
```



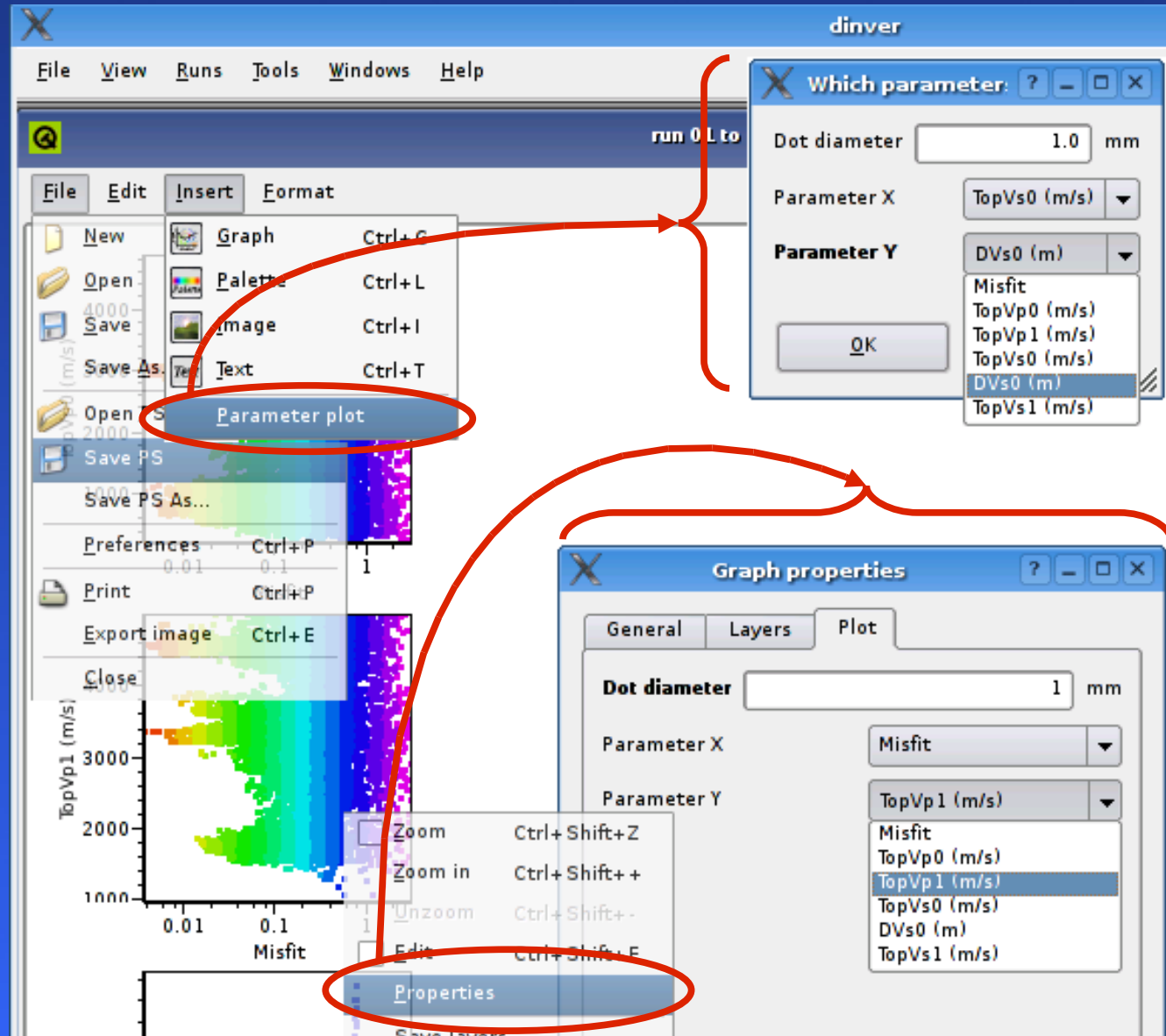


Parameter space viewer: 1D/2D projections

Basic output:
all parameters
vs misfit

Customization:
- Insert new plots
- change parameter
for axis

Save/Open
PS viewer



Analysing .report files produced by inversion

Getting the very best model

```

mwathele@sirac:~/dinvertemp - Shell No. 2 - Konsole
Session Edit View Bookmarks Settings Help

mwathele@sirac ~ $ cd ~/.dinvertemp
mwathele@sirac ~/.dinvertemp $ gpdcreport *.report -m 0.0065
# Report = run_01.report
# N Models = 2550
# Report = run_02.report
# N Models = 2550
# Layered model 2213: misfit=0.006443
2
    24.9084257956825    1538.56959606898    198.84757010434    2000
                        0    3296.21090054071    985.707783525062    2000
# Report = run_03.report
# N Models = 2550
# Report = run_04.report
# N Models = 2550
# Report = run_05.report
# N Models = 2550
# Layered model 2368: misfit=0.005380
2
    25.0600443585102    3261.77736624921    200.935389014041    2000
                        0    3901.0551582349    979.250539654446    2000
mwathele@sirac ~/.dinvertemp $ █

```

Effects of CNA tuning parameters

Itmax: Number of iterations required

Ns0: Initial set of random models

Ns: Number of models generated at each iteration

Nr: Number of "best" cells selected for generation of Ns models

Seed: Any integer number

DynScale: Yes = better exploration

Nw: Number of random walk (Markov chain)

GiveUp: Maximum ratio of rejected/accepted model

Effects of CNA tuning parameters

<u>Behavior</u>	<u>Itmax</u>	<u>Ns0</u>	<u>Ns</u>	<u>Nr</u>
Monte Carlo	0	10000	-	-
Exploration	100	100	100	100
	200	50	50	50
	100	100	100	50
	100	100	100	10
Optimisation	100	100	100	1

Two layers with a gradient

Shear-wave velocity (m/s)

Linear increase

Number of sub-layers: 10

Top Vs0: 150 to 3500 m/s Fixed DVs0: 1 to 100 m Fixed

Bottom Vs0: 150 to 3500 m/s Fixed

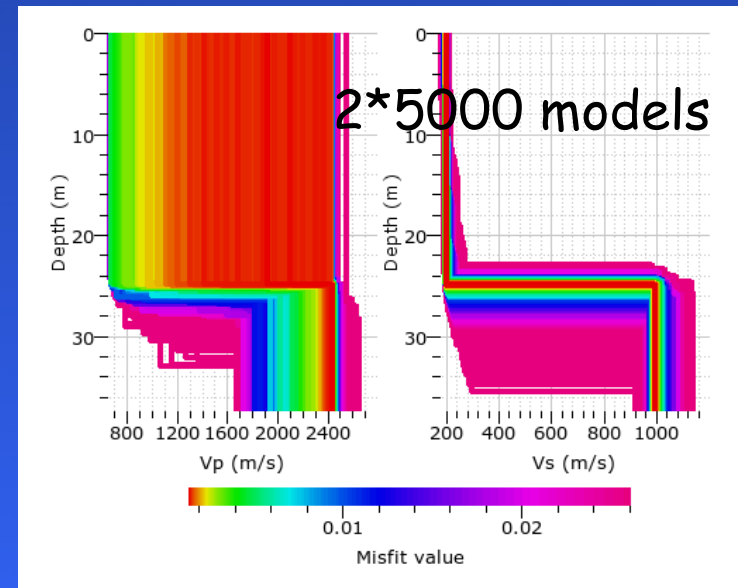
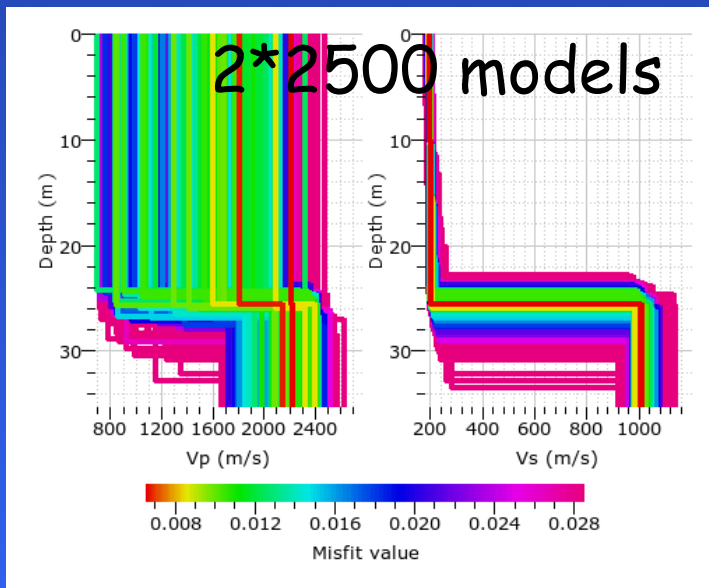
Uniform Vs0 < Vs1

Vs1: 150 to 3500 m/s Fixed

Run 3 runs with 2500 models

View ground models with a misfit < 0.05

What's different?



One more layer

Parameters

Compression-wave velocity (m/s)

Add ↑ Del ↓

Uniform ▼ Linked to Vs1

Vp0: 200 to 5000 m/s Fixed

Uniform ▼ Vp0 < Vp1

Vp1: 200 to 5000 m/s Fixed

Poisson's Ratio

Add ↑ Del ↓

Uniform ▼ Linked to Vs1

Nu0: 0.45 to 0.5

Uniform ▼ Nu0 > Nu1

Nu1: 0.2 to 0.4

Shear-wave velocity (m/s)

Add ↑ Del ↓

Linear increase ▼ Linked to Not linked

Number of sub-layers 5

Top Vs0: 150 to 3500 m/s Fixed

Bottom Vs0: 150 to 3500 m/s Fixed

DVs0: 1 to 100 m Fixed

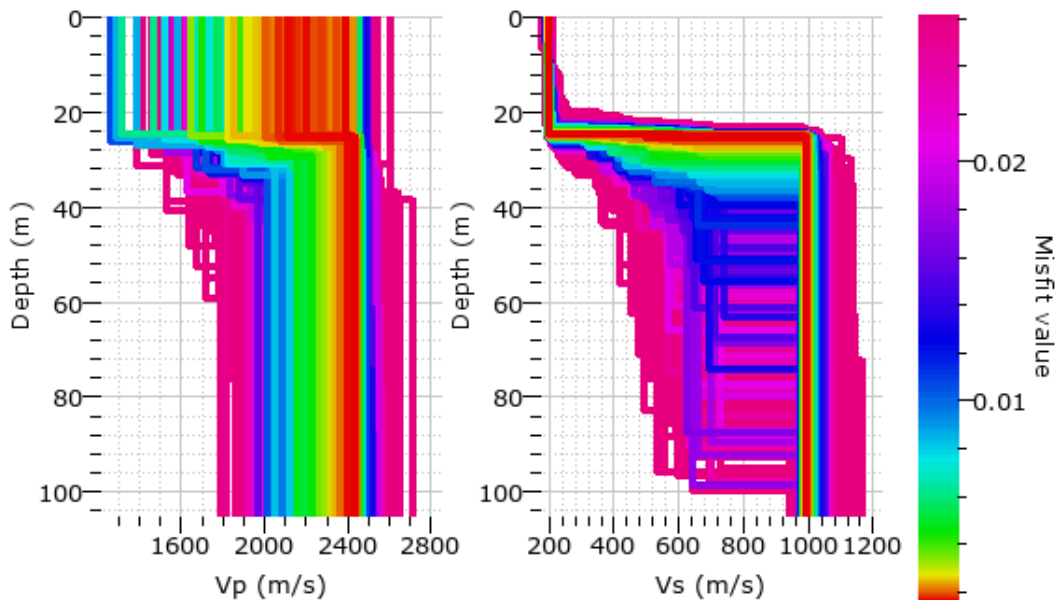
Uniform ▼ Vs0 < Vs1 Linked to Not linked

Vs1: 150 to 3500 m/s Fixed

DVs1: 1 to 100 m Fixed

Uniform ▼ Vs1 < Vs2

Vs2: 150 to 3500 m/s Fixed



2*7650 models

ki, Greece

Force a supplementary layer in sediments

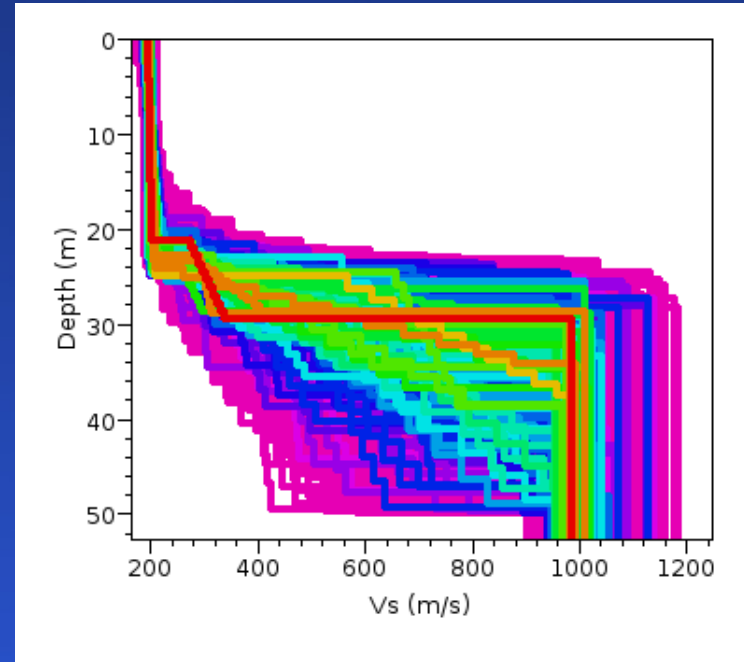
Add ↑
 Del ↓

Shear-wave velocity (m/s)

Linear increase Linked to: Not linked
 Number of sub-layers: 10 Bottom depth: ▾
 Top Vs0: 150 to 3500 m/s Fixed
 Bottom Vs0: 150 to 3500 m/s Fixed
 Vs0: 1 to 25 m Fixed

Linear increase Vs0 < Vs1 Linked to: Not linked
 Number of sub-layers: 10 Bottom depth: ▾
 Top Vs1: 150 to 3500 m/s Fixed
 Bottom Vs1: 150 to 3500 m/s Fixed
 Vs1: 1 to 50 m Fixed

Uniform Vs1 < Vs2
 Vs2: 150 to 3500 m/s Fixed



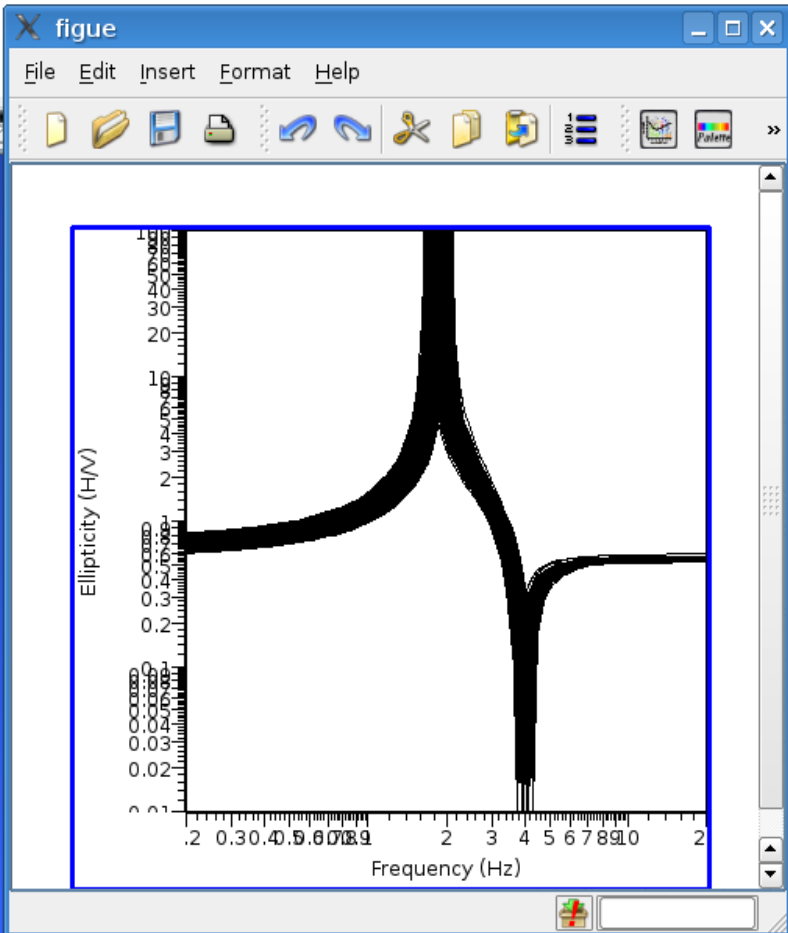
Analysing .report files produced by inversion

Computing ellipticity for the best models

```

mwathele@sirac:~/./dinvertemp - Shell - Konsole
Session Edit View Bookmarks Settings Help

mwathele@sirac ~ $ cd ~/./dinvertemp/
mwathele@sirac ~/./dinvertemp $ ls
run_01.report run_02.report run_03.report run_04.report run_05.report
mwathele@sirac ~/./dinvertemp $ gpdcreport *.report -m 0.05 | gpell | figure -c -m ../data/INVERSION/ell.mkup
  
```



From a model file

gpdc : dispersion curves (Rayleigh, Love, Group)

gpell : ellipticity curves

gpprofiles : Vp, Vs, Poisson profiles

gpspac : spac curves

gpec8 : Eurocode site classes

gpsh : Sh transfer function (coming soon...)

Inversion report post-processing

gpdcreport : any extraction of information

gpdcmisfit : re-computation of misfit

gpviewdcreport : direct access to model plot

Misc.:

gppoisson, gpparam2model, gpmodel2param, gpgroup2phase,
gpcurve

A slightly more complicated inversion problem

Files in EXERCISES_INVERSION/ibt_dataset_synthetic

All curves provided in this test are not real nor simulated.
There are just theoretical curves with some manually added noise.

We provide you with 3 branches of dispersion curves, two pseudo-obtained from a array FK processing (dc1 and dc2) and a third one acquired with an active source experiment with buried explosive sources.

You'll also find a pseudo H/V curve (pseudo obtained with classical processing). hv_average is the average curve and hv_low and hv_high are the one standard deviation curves.

Finally, you have spac curve from 5 rings: 10-12m, 23-27m, 35-41m, 46-57m and 67-88m.

Good luck!