Manual of Multi-Channel Analysis of Surface Waves (MASW)

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Contents

Note: : This version was developed on Linux: Ubuntu 19.10 (Eoan Ermine) on VirtualBox version 6.1. on Windows10 Home 64bit (Build 14393) for 64bit PC, using gfortran compiler.

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Operation on other OS may require additional revision or modification by users themselves.

Execution of commands is conducted as

./bin/*executable_file_name*.exe
or
sh *shell_script_file_name*.sh

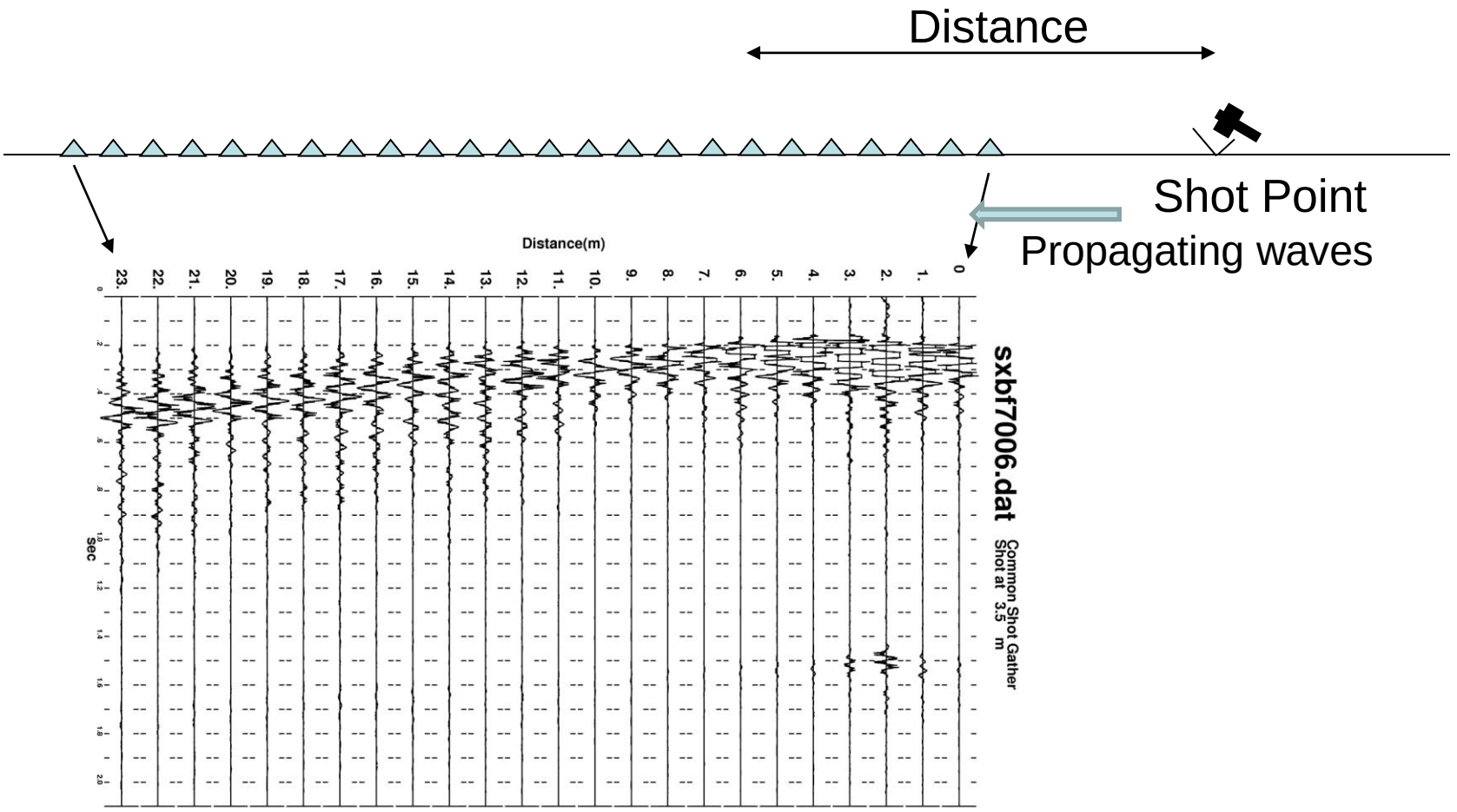
If it is necessary to leave log file of execution

./bin/*executable_file_name*.exe 2>&1 |
tee ./spacwkf/log/*log_file_name*.log
or
sh *shell_script_file_name*.sh 2>&1 |
tee ./spacwkf/data/log/*log_file_name*.log

1. Instruction Manual of Programs for Analysis

Glossary: Common Shot Gather

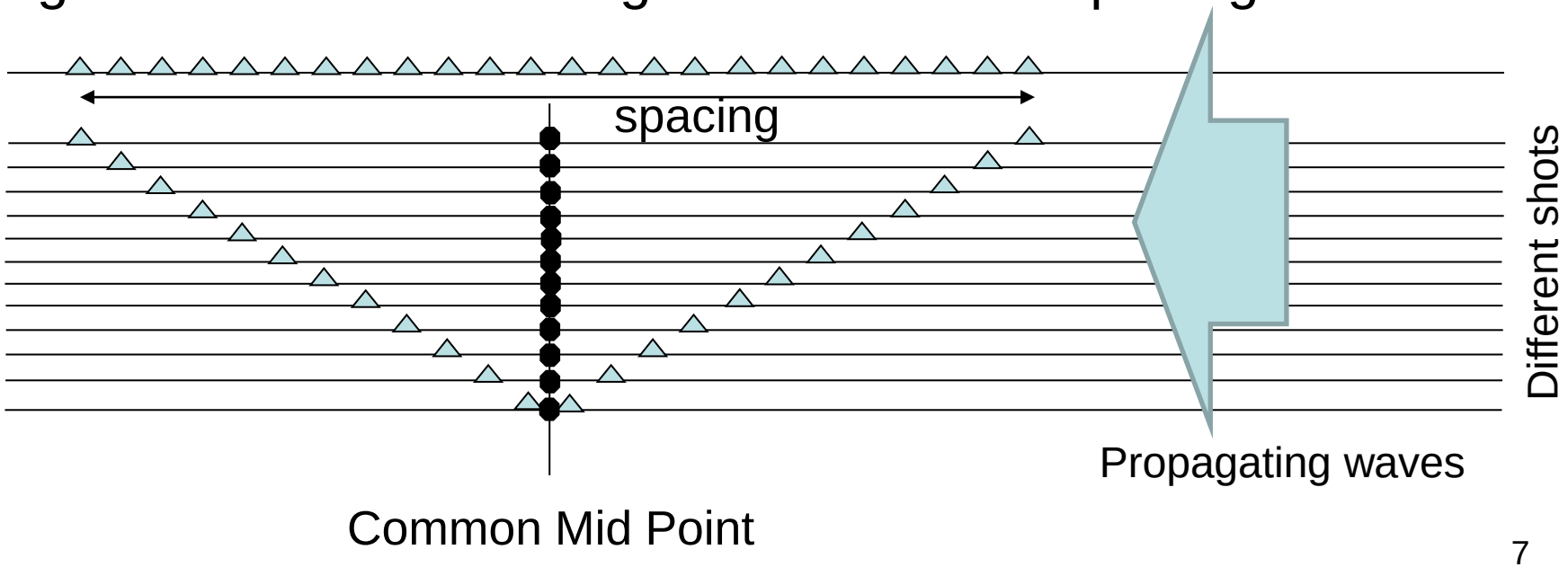
A group of seismic traces having the same shot point



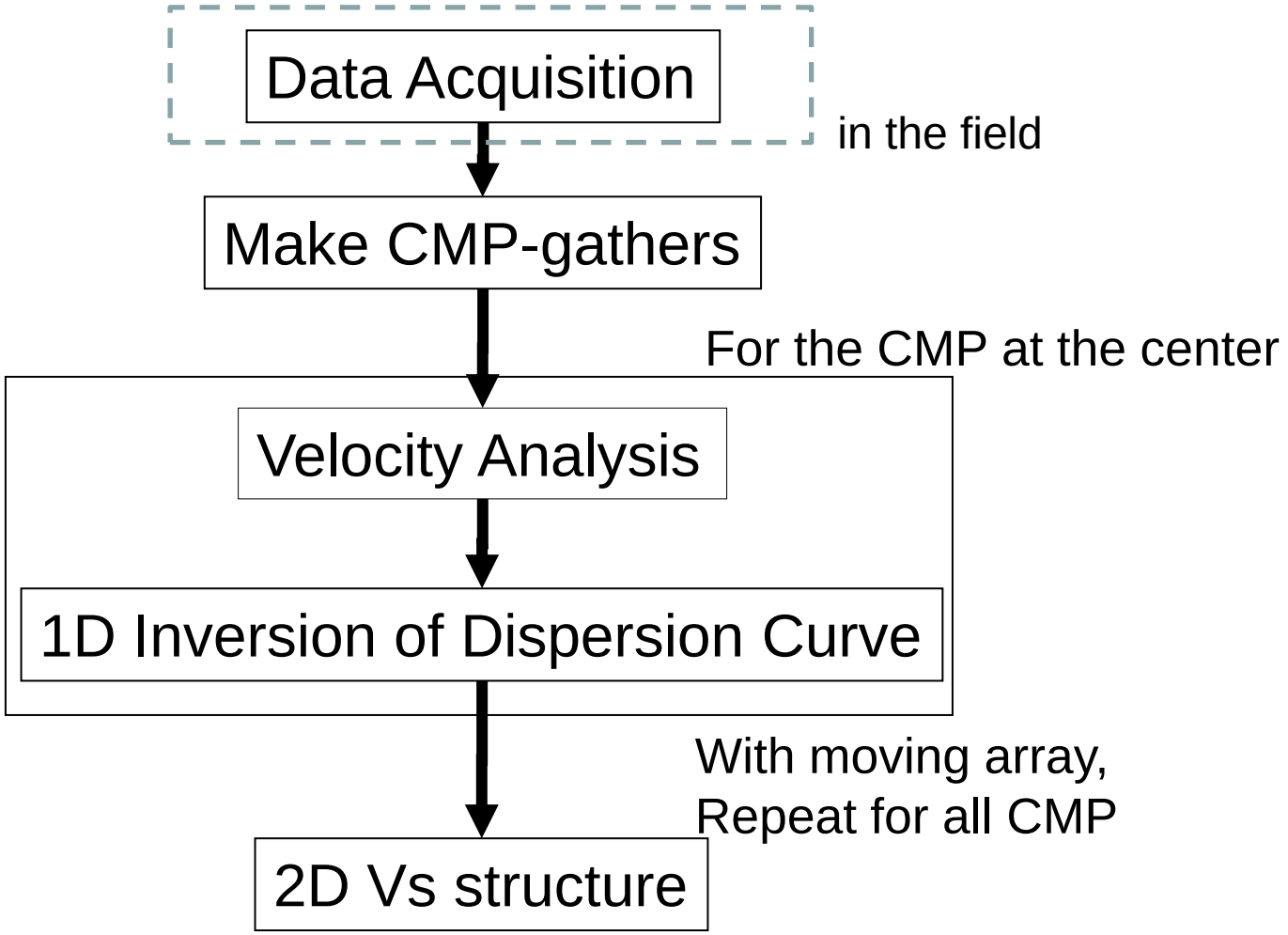
Glossary: Common Mid Point Gather

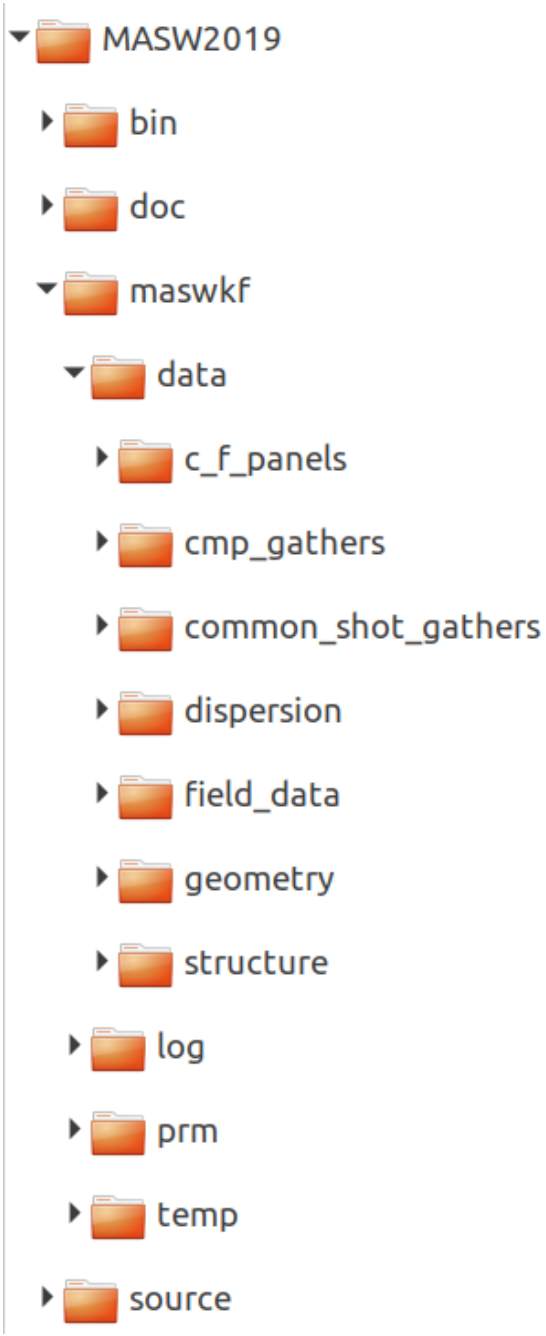
Usual definition: A group of seismic traces having the same mid point between shot and detector (geophone)

For MASW: A group of correlograms having the same mid point between a pair of detectors (geophone). A CMP gather includes correlograms of various spacing.



Task Flow of MASW





Folder Structure

Every necessary programs and files are stored under the folder “MASW2020”. The command operation must be conducted in this folder.

The source codes of the programs are stored in the subfolder “source”, document files including this instruction manual in “doc”, executable ones in “bin”.

The subfolder of work space “maswkf” contains the subfolder “prm” for parameter files that includes script files of GNUPLOT and the subfolder “data” for data files including graphic ones.

The compressed file “maswkf.tar.gz” keeps subfolder structure of “maswkf” and all parameter files in “maswkf/prm”.

Note: GNUPLOT scripts files

Some files of GNUPLOT scripts are stored under the subfolder

"./maswkf/prm/gnuplt_scripts"

These can be loaded on GNUPLOT as load '????'
Some programs create the scripts of GNUPLOT that include the command

'set terminal x11' ,

This works on the GNUPLOT on Ubuntu and may be that on Windows.

If any problem on Windows, it is worth to try to replace it with

'set terminal wxt' .

Note: Executable files

The folder “MASW2020” includes several executable files. Their source code files are stored in the subfolder “./source”. Then, the following command is required to re-compile them if necessary. In the folder MASW2020, type in the following command.

gfortran ./source/???.for –o ./bin/???.exe

In case of problems caused by the incompatibility between Fortran77 and Fortran95,

gfortran -ff2c ./source/???.for –o ./bin/???.exe

Executable files are stored in the subfolder “MASW2020/bin”.

Note: Shell script files

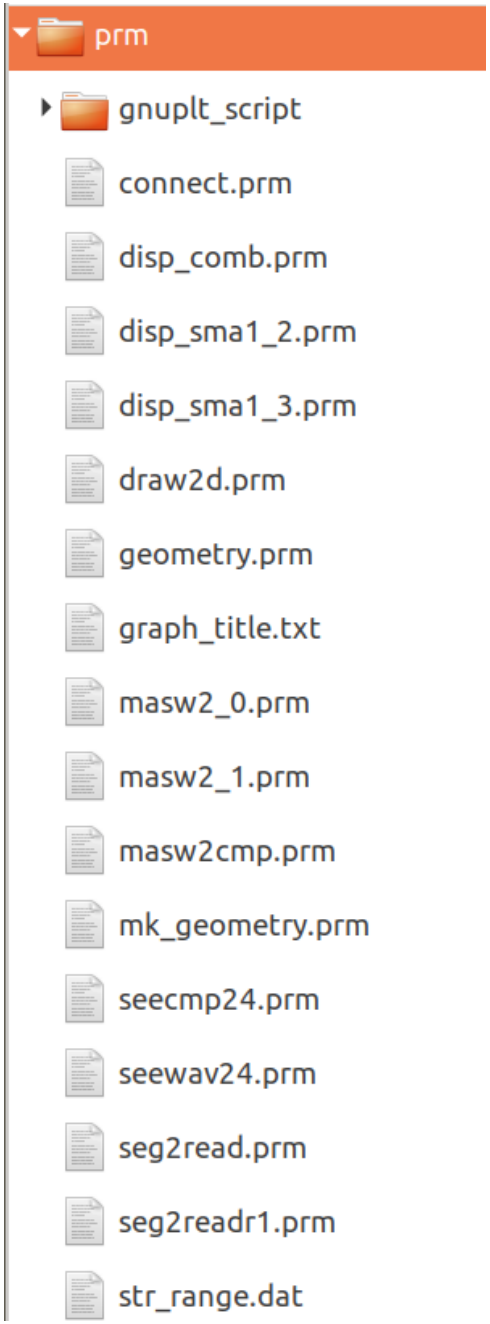
The folder “MASW2020” includes several shell script files.
They are composed of few executing commands to reduce the typing tasks in data processing.
The following command can execute the shell script files.

sh *shell_script_file_name*.sh

As the contents of the shell script files contained in this program package are simple, they can work as batch files. However, it is necessary to activate batch files using the following.

chmod u+x *shell_script_file_name*.sh

For execution as a batch file,
shell_script_file_name.sh



Note: Parameter files

All parameter files are stored in the subfolder "./maswkf/prm" and have their extension ".prm" except "str_range.dat".

It is often required to modify these parameter files in the analysis explained in the following slides. Any text editor can be used, e.g., "gedit" on Ubuntu and/or "nedit" on Cygwin, notepad.exe on Windows etc..

Note: Cleaning up the subfolders

- Use
  sh clean_all.sh
  in the folder "MASW2020" to delete all files of input data, interim outputs and results for a new processing task.
- Use
  sh clean_field_data.sh
  in the folder "MASW2020" to delete all input files of sg2 format under "./maswkf/data/field_data".

Build MASW2020

makefile:

```
FC = gfortran
store= 2>&1 | tee -a ./maswkf/log/make_all.log

all:          clean_log
              ${FC} ./source/connect.for      -o ./bin/connect.exe ${store}
              ${FC} ./source/disp_comb.for    -o ./bin/disp_comb.exe ${store}
              ${FC} ./source/disp_sma1_2.for  -o ./bin/disp_sma1_2.exe ${store}
              ${FC} ./source/disp_sma1_3.for  -o ./bin/disp_sma1_3.exe ${store}
              ${FC} ./source/draw2d.for       -o ./bin/draw2d.exe ${store}
              ${FC} ./source/geometry_plt.for -o ./bin/geometry_plt.exe  ${store}
              ${FC} ./source/inv_plt.for      -o ./bin/inv_plt.exe  ${store}
              ${FC} ./source/masw2_0.for      -o ./bin/masw2_0.exe ${store}
              ${FC} ./source/masw2_1.for      -o ./bin/masw2_1.exe  ${store}
              ${FC} ./source/masw2cmp2D.for   -o ./bin/masw2cmp2D.exe ${store}
              ${FC} ./source/masw2cmp.for     -o ./bin/masw2cmp.exe  ${store}
              ${FC} ./source/mk_geometry.for  -o ./bin/mk_geometry.exe ${store}
              ${FC} ./source/mk_title.for     -o ./bin/mk_title.exe ${store}
              ${FC} ./source/seecmp24.for     -o ./bin/seecmp24.exe ${store}
              ${FC} ./source/seewav24.for     -o ./bin/seewav24.exe ${store}
              ${FC} ./source/seg2read.for     -o ./bin/seg2read.exe ${store}

clean:
              cd ./bin/; rm *.exe; cd ..

clean_log:
              rm -f ./maswkf/log/make_all.log 2>/dev/null
```

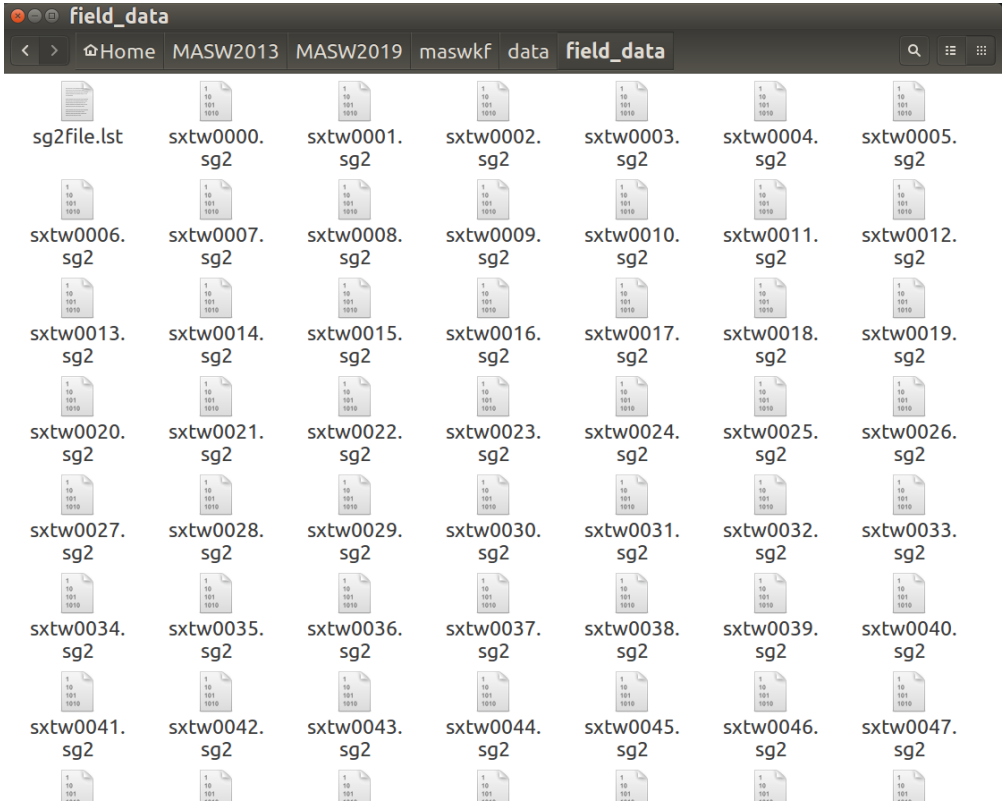
1. Instruction Manual of Programs for Analysis

1.1 Data Format Conversion

The data acquisition equipment/software usually provides binary format files. It is necessary to convert them in ASCII text format. In this package, the format converter from seg2 standard is prepared. Note: this program can not process the data that includes AUX channel and/or more than 24 channels. Don’t use AUX channel in the field, or exclude it when the binary data files are converted to seg2 format.

seg2read.for + seg2read.prm

Copy the field data files in seg2 format into the subfolder ./maswkf/data/field_data



File name must consist of 4 alphabetic character, 4 integers with the extension ".sg2". These integers are used to represent the numbering of the shots applied in the field. Consecutive numbers are required for the convenience of the latter processing.

In the example above, the data set consists of 68 shot gathers (0000-0067)

```
seg2read.sh:

#! /bin/sh -x
cd maswkf/data/sg2_files
ls *.sg2 > sg2file.lst
cd ../../..
./bin/seg2read.exe | tee cca_wkf/log/seg2read.log
cd maswkf/data/multiplexed_files
ls *.dat > mltfile.lst
cd ../../..
./bin/mk_title.exe
```

Shell script executes "ls *.sg2 > sg2file.lst" in this sub-folder and existing sg2 files are listed in the newly created file "sg2file.lst".
All the files listed in it that have the extension specified in the 3rd line of the parameter file “seg2read.prm”.

Finally, the first line of “seg2read.prm” is copied to “graph_title.txt” and “vel_model_plt.prm” in the subfolder “./maswkf/prm”.

Example: seg2read.prm

All the files listed in "sg2file.lst" that have the extension specified in the 3rd line are converted to the output files that have the extension given in the 4th line.
Edit the file "sg2file.lst" using “gedit” or other text edior if necessary.

seg2read.prm

```
MASW,LINE1,Iwaki City Office, Dec. 22, 2012.                          :comm(a70)
 0.159      :(A12) scaling factor (for output files in mkine(1.e-3cm/s))
sg2         : extension of input seg2 format files(a3)
dat         : extension of output ascii text files(a3)
0 3 0.1 1.0 1.5  :nfilter(=1:apply),nchara=3:bandpass),fl,fh,fs
normal      : Channel Pivoting
```

Explanation: seg2read.prm

All the files listed in "sg2file.lst" that have the extension specified in the 3rd line are converted to the output files that have the extension given in the 4th line.
Edit the file "sg2file.lst" using “gedit” or other text edior if necessary.

seg2read.prm

1st line : comment (a70)
2nd line : scaling factor (use the value that makes the unit of the output files "mkine" (1.e-3 cm/s))
3rd line : extension of input seg2 format files(a3)
4th line : extension of output ascii text files(a3)➔Fix it “.dat”
5th line : nfilter(=0:pass, =1:apply, =2:DC & Trend removal), ncharacter(=2:lowpass,=3:bandpass),fl,fh,fs
6th line : Channel Pivoting
'normal' : no pivoting, all channel used
'rev_al' : all channel used but in reversed order
'rev_fh' : all channel used but former half in reversed order
'rev_lh' : all channel used but latter half in reversed order
'pvlist' 2 1 3 4 6 23 24 : Pivoting list.

Examples of the 6th line of seg2read.prm

Use all channels without pivoting:

normal : Channel Pivoting

Use all channels but reversed order:

reverse : Channel Pivoting

Use the first 7 channels of the input files without changing order:

pvlist 1 2 3 4 5 6 7 : Channel Pivoting

The same as above but 7th channel moved to the first:

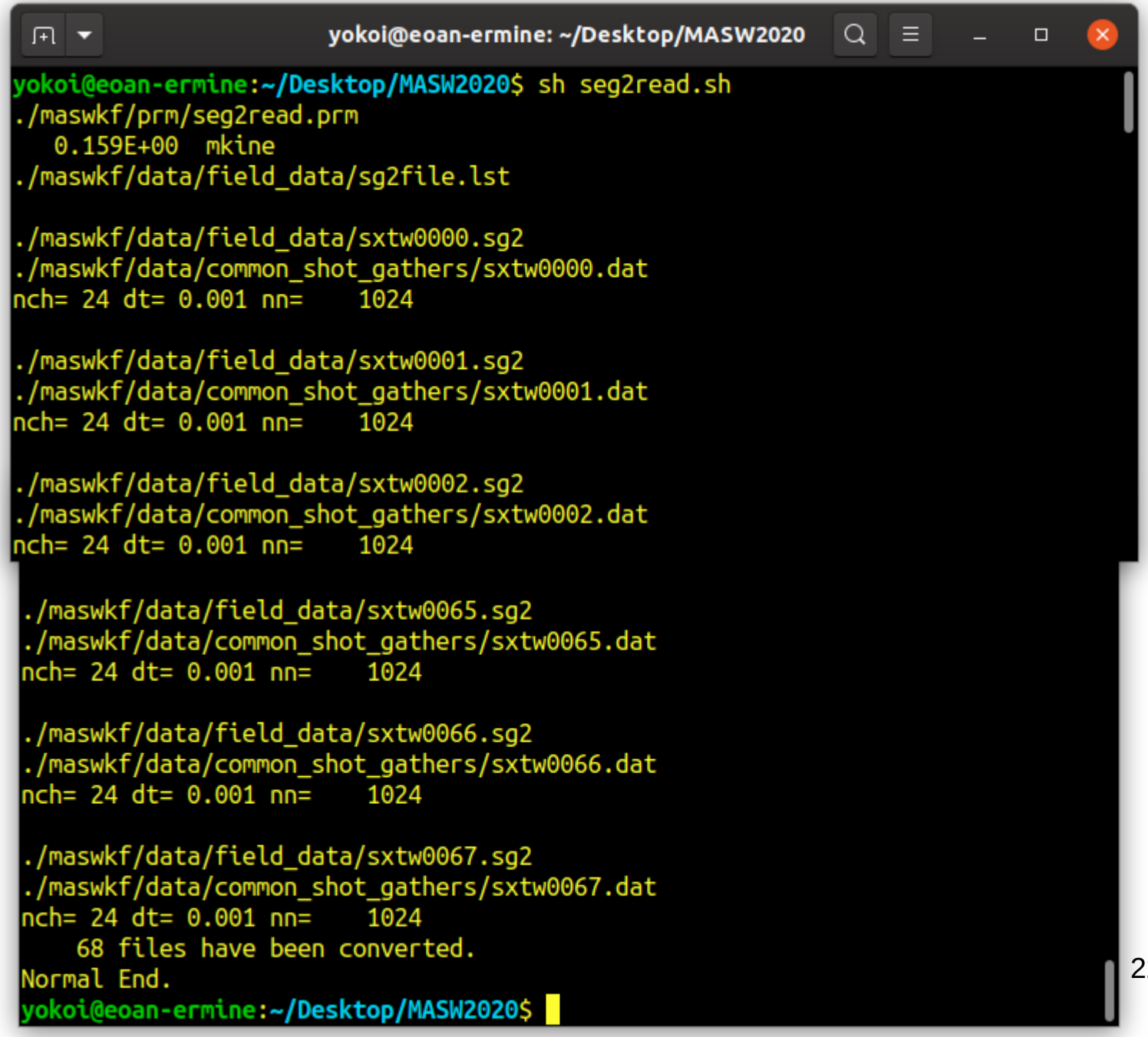
pvlist 7 1 2 3 4 5 6 : Channel Pivoting

Use only odd numbered channels among 24 without changing order:

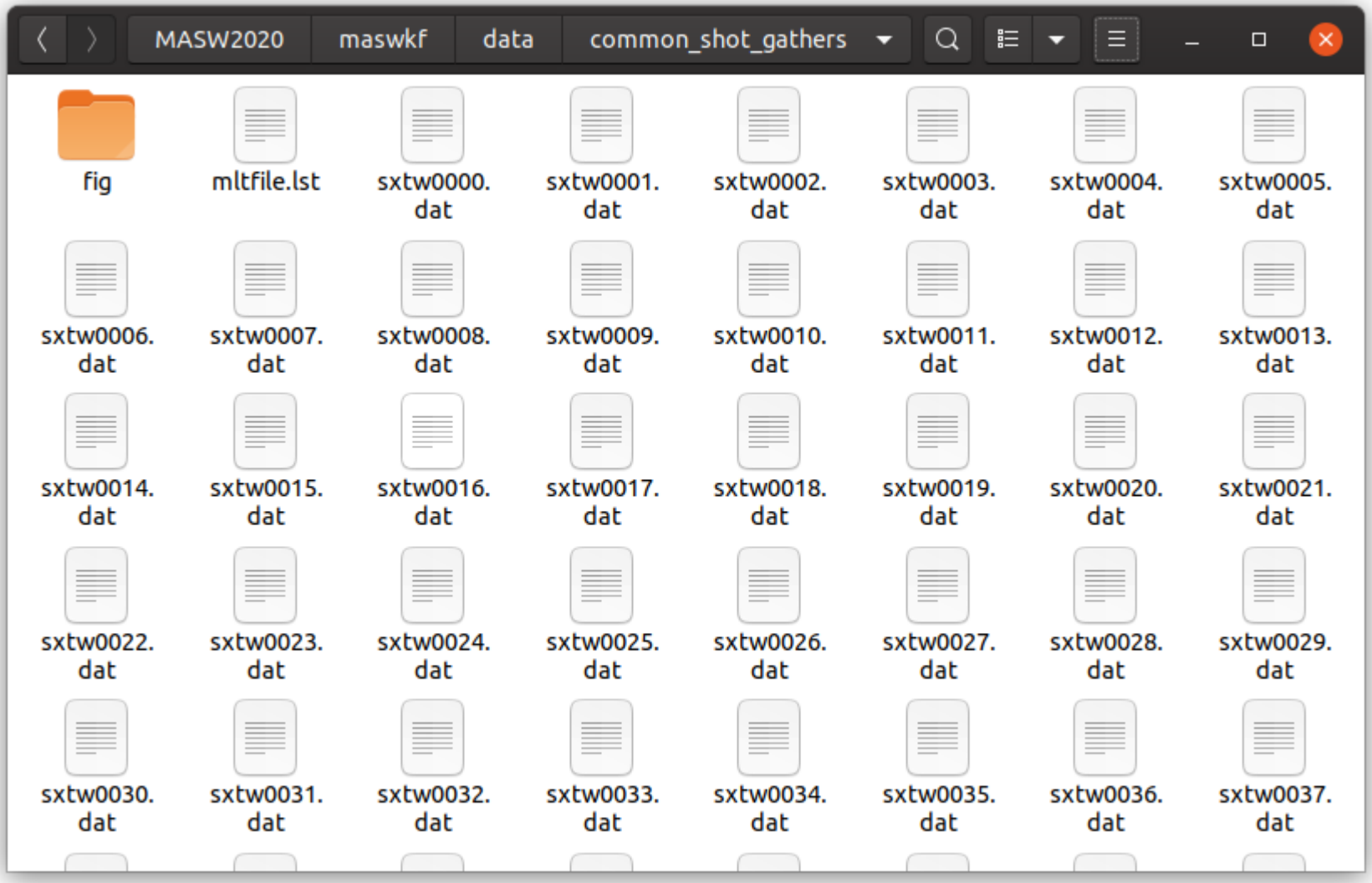
pvlist 1 3 5 7 9 11 13 15 17 19 21 23 : Channel Pivoting

Note: Be sure to put ‘ ‘(blank) before ‘:’(colon), otherwise the program can have an error in detecting the end of line.

Execution:


yokoi@eoan-ermine: ~/Desktop/MASW2020
yokoi@eoan-ermine:~/Desktop/MASW2020$ sh seg2read.sh
./maswkf/prm/seg2read.prm
0.159E+00 mkine
./maswkf/data/field_data/sg2file.lst
./maswkf/data/field_data/sxtw0000.sg2
./maswkf/data/common_shot_gathers/sxtw0000.dat
nch= 24 dt= 0.001 nn= 1024
./maswkf/data/field_data/sxtw0001.sg2
./maswkf/data/common_shot_gathers/sxtw0001.dat
nch= 24 dt= 0.001 nn= 1024
./maswkf/data/field_data/sxtw0002.sg2
./maswkf/data/common_shot_gathers/sxtw0002.dat
nch= 24 dt= 0.001 nn= 1024
./maswkf/data/field_data/sxtw0065.sg2
./maswkf/data/common_shot_gathers/sxtw0065.dat
nch= 24 dt= 0.001 nn= 1024
./maswkf/data/field_data/sxtw0066.sg2
./maswkf/data/common_shot_gathers/sxtw0066.dat
nch= 24 dt= 0.001 nn= 1024
./maswkf/data/field_data/sxtw0067.sg2
./maswkf/data/common_shot_gathers/sxtw0067.dat
nch= 24 dt= 0.001 nn= 1024
68 files have been converted.
Normal End.
yokoi@eoan-ermine:~/Desktop/MASW2020$

The converted files are stored in the subfolder ./maswkf/data/common_shot_gathers



Fortran statements used to write the output multi-channel files (Common Shot Gathers):

```
      write(kbn,'(i8,f8.4,e16.4,i8,2x,a5)')nnch,dt,scale,nn,cunit
      write(kbn,'(a70)')comment
      do i=1,nn
       write(kbn,cform2)real(i-1)*dt,(xx(i,ich)*scale,ich=1,nnch)
      enddo
```

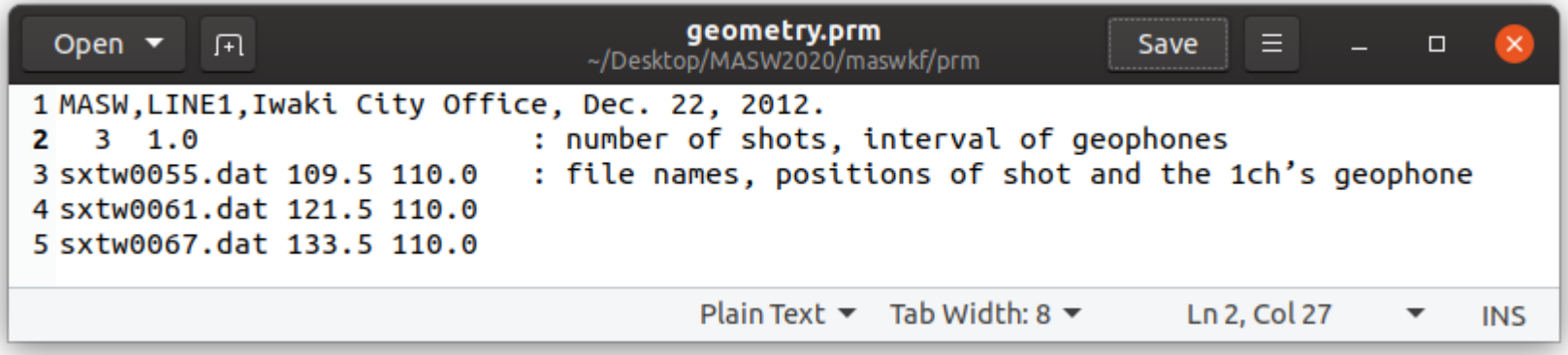
```
  24  0.0010      0.1590E+00    1024  mkine
MASW,LINE1,Iwaki City Office, Dec. 22, 2012.
    0.000000  0.4784059E-04  0.2323320E-04  0.5452908E-05 -0.6335467E-05 -0.6702706E-05 -0
    0.001000  0.5317741E-04  0.2754530E-04  0.1113682E-04 -0.3327660E-05 -0.5908996E-05 -0
    0.002000  0.5590208E-04  0.3997457E-04  0.1326325E-04 -0.1536481E-05 -0.5446985E-05 -0
    0.003000  0.5680241E-04  0.4159161E-04  0.1950750E-04 -0.1824349E-06 -0.5180441E-05 -0
    0.004000  0.5680834E-04  0.4268740E-04  0.2061514E-04  0.1234397E-05 -0.4937589E-05 -0
    0.005000  0.5657141E-04  0.4368250E-04  0.2176425E-04  0.2676107E-05 -0.3404662E-05 -0
...
```

1. Instruction Manual of Programs for Analysis (1D: conventional MASW)

1.2 Input manually the information of Field Geometry

Geometry

Edit the parameter file “geometry.prm” for geometry configuration.



1st line: Comment copied from graph_title.txt
2nd line: number of shots, interval of geophones
3rd & latters: file names, positions of shot and the 1ch’s geophone.

Above example shows: two shots were applied at 109.5 m and 133.5 m and data were acquired by the 24 geophones’ string spread from 110 m with 1.0 m interval.

mk_geometry.sh

Support to make the parameter file ‘geometry.prm’ for complicated cases.

mk_geometry.sh

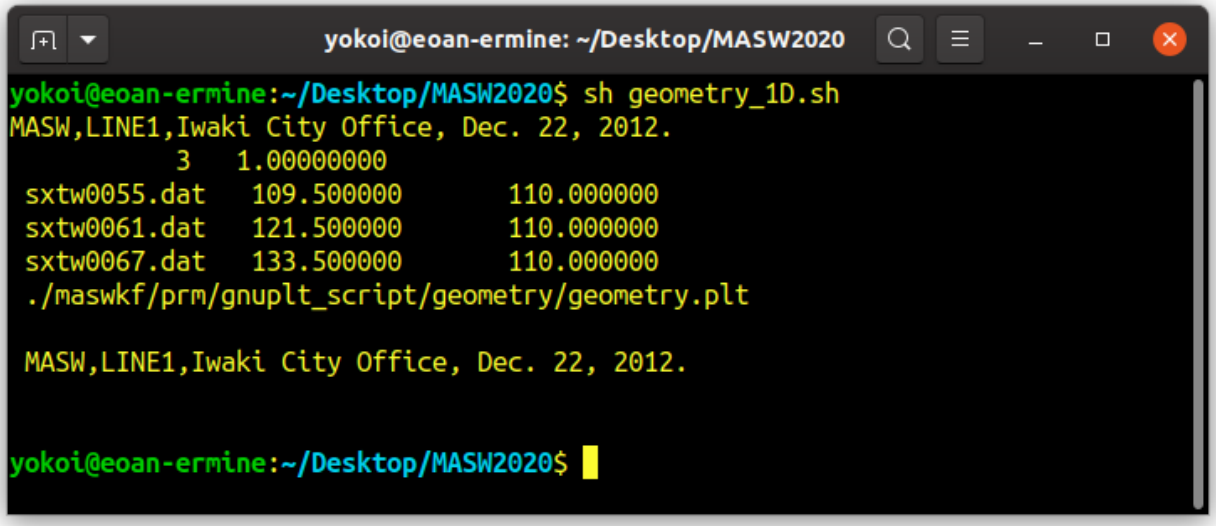
```
#!/bin/sh -x
./bin/mk_geometry.exe | tee maswkf/log/mk_geometry.log
```

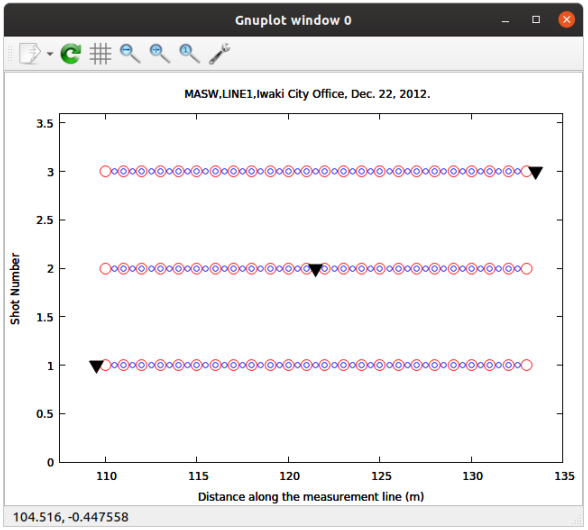
mk_geometry.prm

```
68  sxtw00  00  55  67   : no. of shots,cname(A6),cst(A2),cit(A2),ced(A2)
 -0.5 2.0 0.0 1.0        : 1st position & Interval of shots, 1st position of 1ch, dx(geopone interval)
```

Then, execute
sh geometry_1D.sh

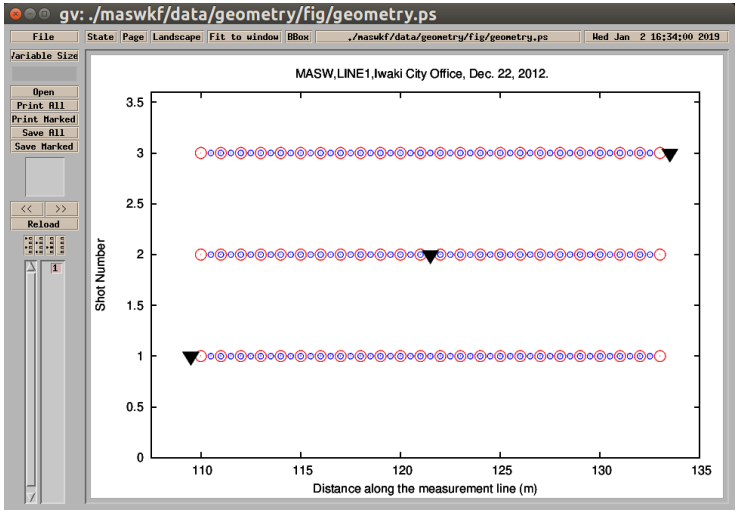
```
sh geometry_1D.sh

#!/bin/sh -x
./bin/geometry_plt.exe | tee maswkf/log/geometry_plt.log
gnuplot -e "
load ./maswkf/prm/gnuplt_script/geometry/geometry.plt' ;
pause -1
"
```





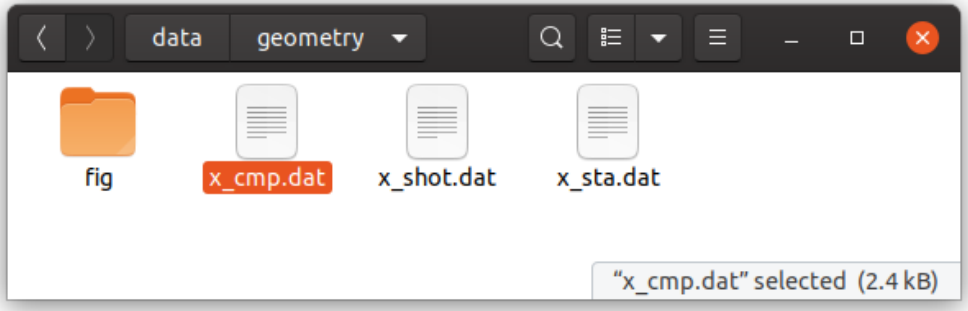
When the program is run, the drawing of geometry appears in a X-windows as shown below. Simultaneously, the same image is stored in the Postscript file ./maswkf/data/geometry/fig/geometry.ps

Use Ghostview to plot these PostScript files: gv &

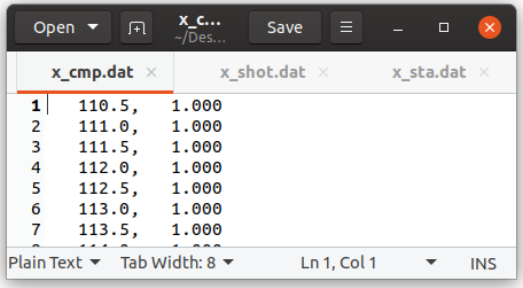


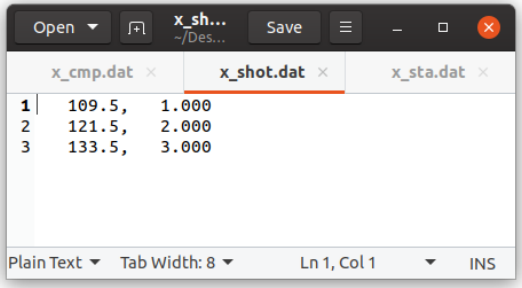
Triangles: shot points,
Red circles: geophone locations,
Blue circles: locations of mid points of shot & receivers.
Modify "./maswkf/prm/gnuplt_script/geometry/geometry.plt" and load it again to change marks, titles, fonts sizes etc..

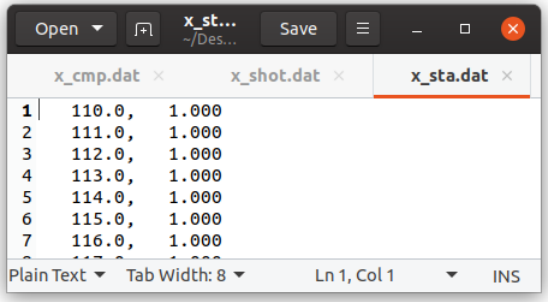
Three files are created in ./maswkf/data/geometry



x_cmp.dat: position of CMPs
x_shot.dat: position of shot points
x_sta.dat: position of geophones







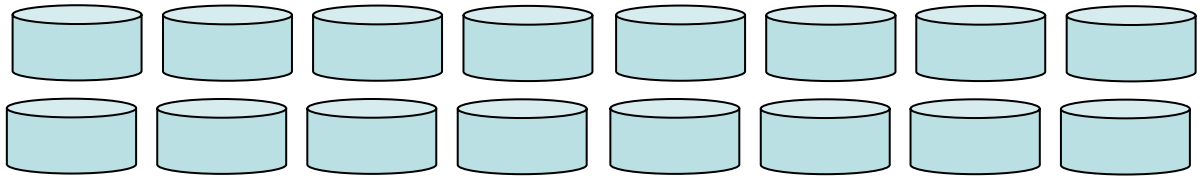
1. Instruction Manual of Programs for Analysis (1D: conventional MASW)

1.3 Plotting Common Shot Gathers

sh seewav24.sh

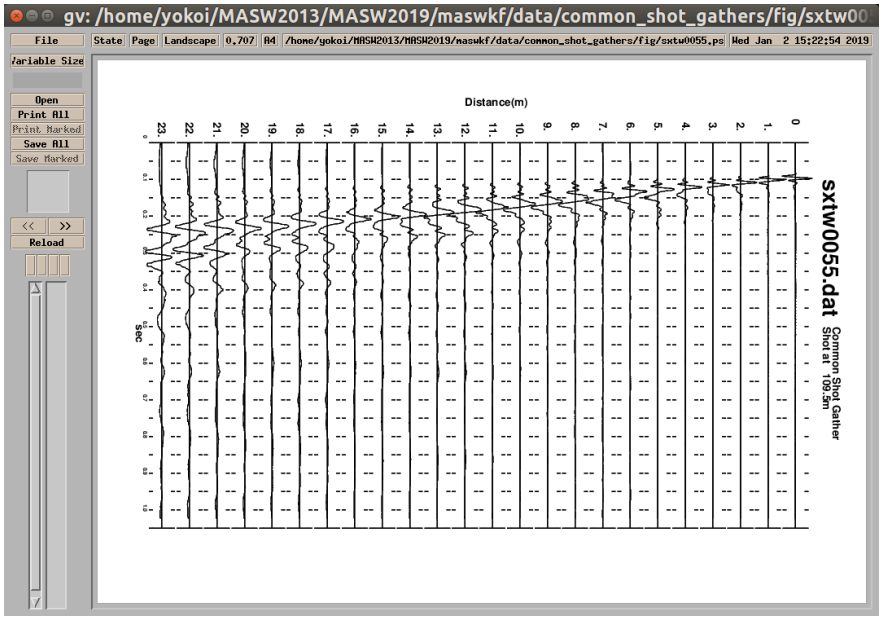
seewav24.for + seewav24.prm

Field Data = Common Shot Gathers



seewav24.for

+ seewav24.prm



Plot the paste-up of 24 Channel traces

Draw paste-up of common shot gathers by
"sh seewav24.sh"

```
#! /bin/sh -x
./bin/seewav24.exe | tee
maswkf/log/seewav24.log
```

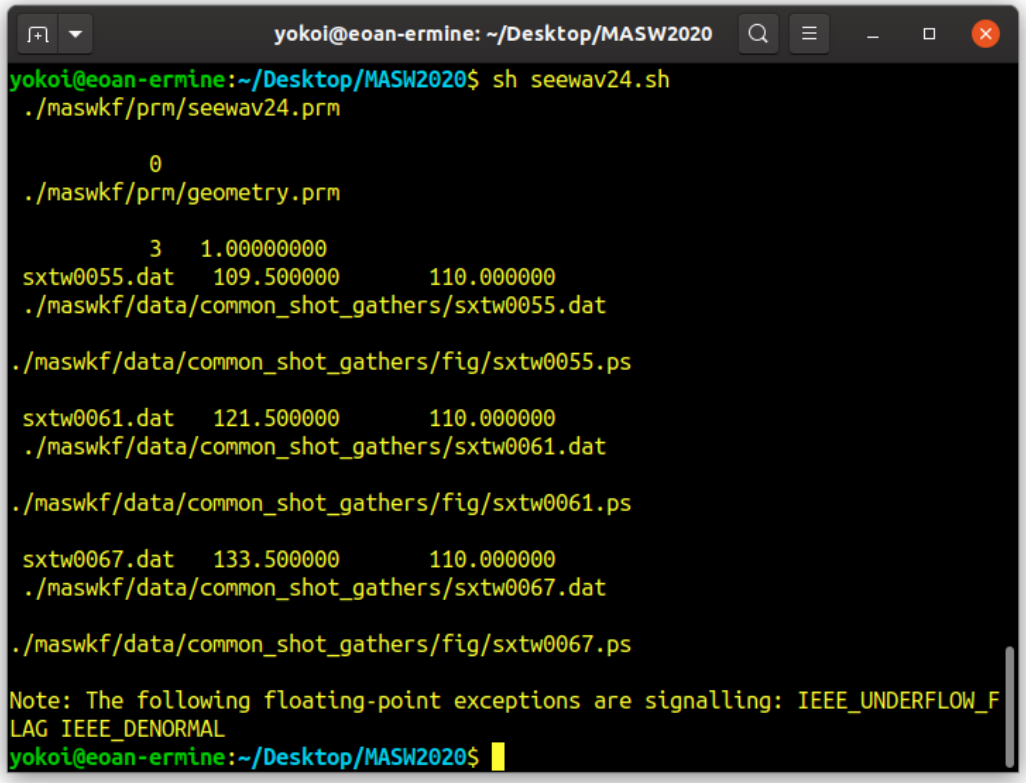
This program uses the parameter file
./maswkf/prm/seewav24.prm
and the geometry information
./maswkf/prm/geometry.prm
to draw the paste-up of all common shot gathers in the PostScript files stored in the subfolder
./maswkf/data/common_shot_gathers/fig

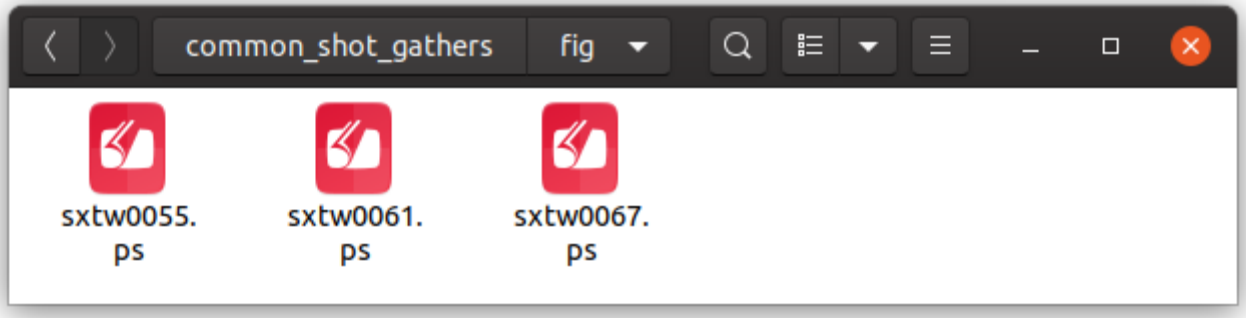
Use Ghostview to plot these PostScript files: gv &

Parameter File: seewav24.prm

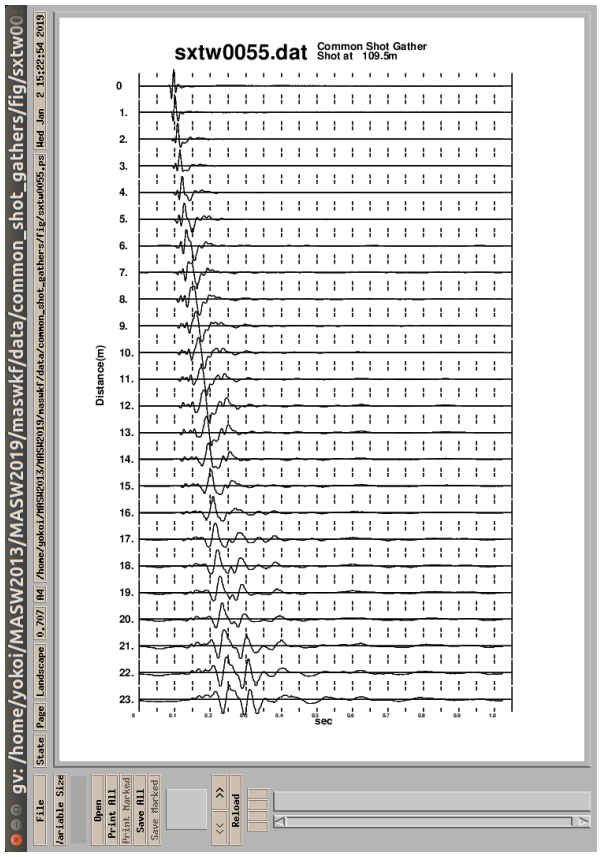
0	:Flag for normalizing(=0; by max. of each ch, =1: by max. of all chs)

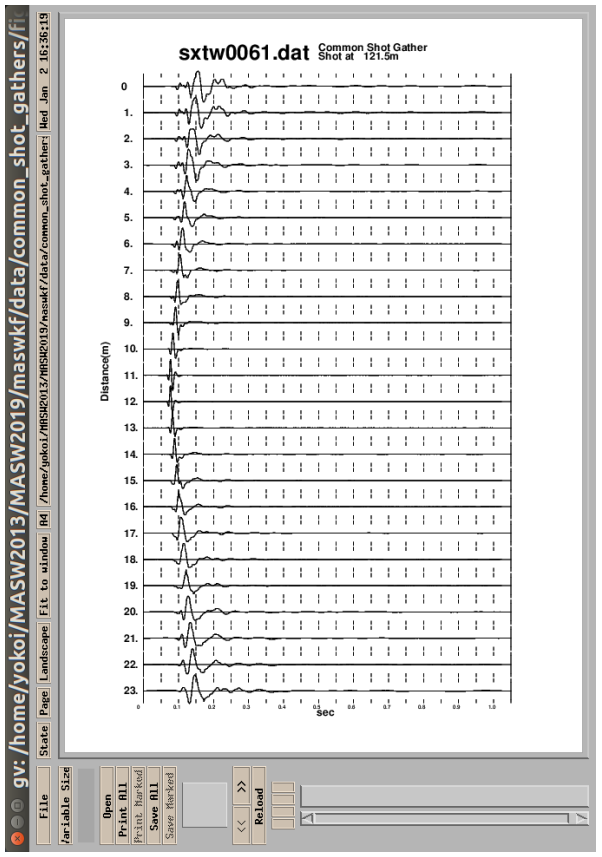
Execution:

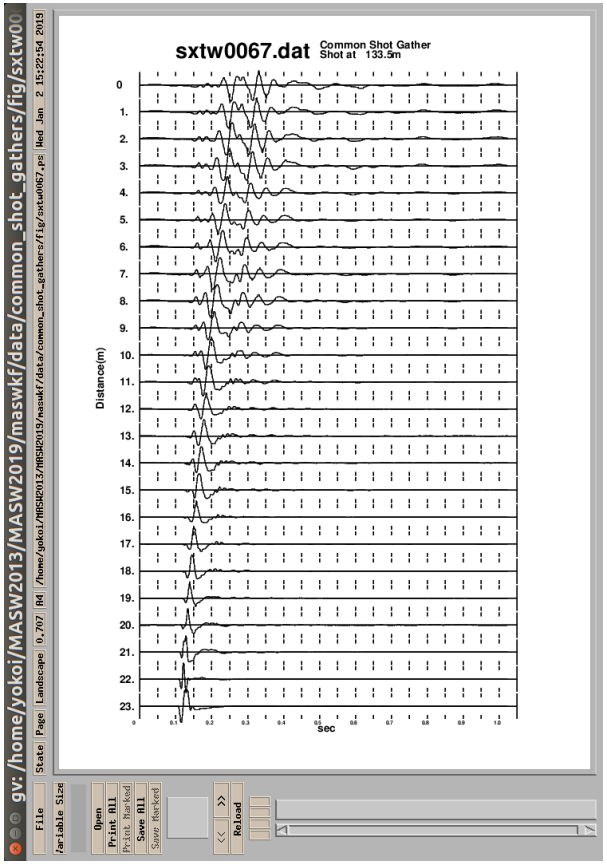




Example of Common Shot Gather Plot







1. Instruction Manual of Programs for Analysis (1D: conventional MASW)

1.4 Making & Plotting the gathers of the stacked Correlogram of the Common offset traces.

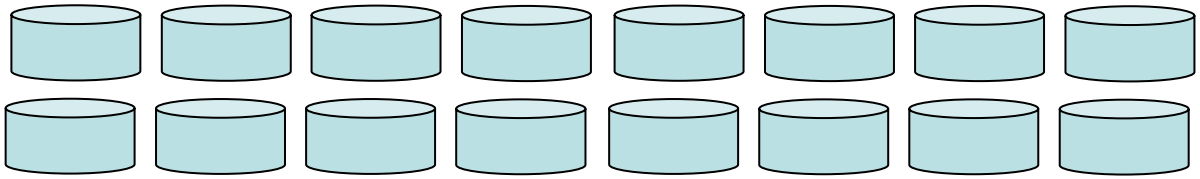
sh masw2_0.sh

masw2_0.for + masw2_0.prm

When the number of shots is small, for example, only at two ends of a fixed measurement line, CMPCC technique sometimes does not show a good performance.
The program “masw2_0.for” is prepared for the conventional MASW method. It provide more stacks at each points on the measurement line in comparison with CMPCC, but under the assumption of 1D velocity structure.

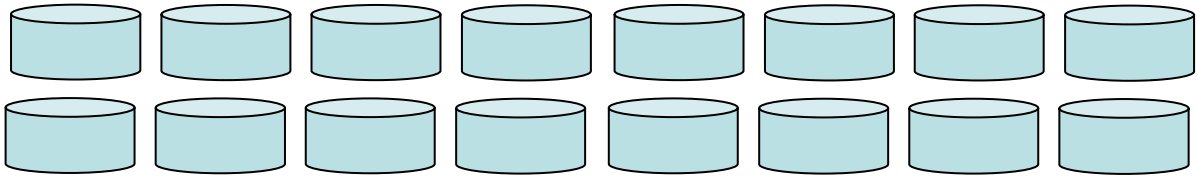
Use
sh masw2_0.sh
instead of “masw2_1.sh”.
masw2_0.sh refers its own parameter file “masw2_0.prm” in the subfolder “./maswkf/prm”.

Field Data = Common Shot Gathers



masw2_0.for + masw2_0.prm

Stacked Correlogram of the Common offset traces for various offsets



Execute
sh masw2_0.sh
This program uses the parameter file
./maswkf/prm/masw2_0.prm
and
./maswkf/prm/geometry.prm
to create the files of CMP gathers in the subfolder
./maswkf/data/cmp_gathers
with file name
cmp???.dat
, where ??? denotes the numbering of CMPs.

It takes time…

masw2_0.sh

```
#!/bin/sh -x
./bin/masw2_0.exe | tee maswkf/log/masw2_0.log
cd ./maswkf/data/cmp_gathers
ls *.dat > cmpfile.lst
cd ../../..
./bin/seecmp24.exe | tee maswkf/log/seecmp24.log
```

Parameter File: masw2_0.prm

```
 1.0 40.0 0.001                :fmin,fmax,dt
  5. 23.                       :rrmin,rrmax
24  133. 1.0 1024              :# of channel for a Common Shot Gather,
                                 length of measurement line,dx,nn
23                             :Coverage of distance window
```

Explanation:

1st line: (fmin, fmax) the minimum and maximum frequencies for analysis and the sampling interval(dt)

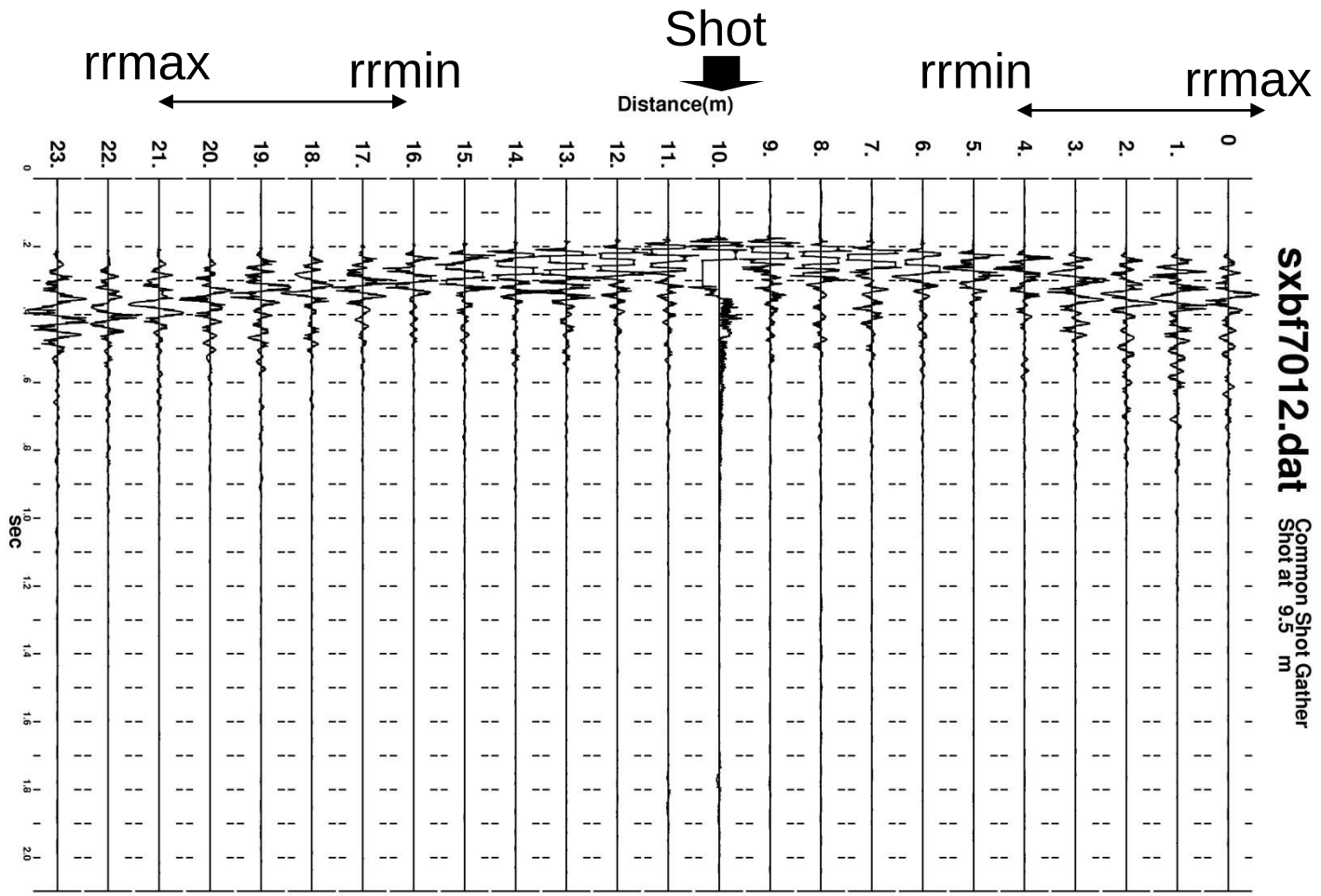
2nd line: (rrmin, rrmax) the minimum and the maximum offset from shot point to geophones. See next slide.

3rd line: Number of channels for a Common Shot Gather, length of measurement line, interval of geophones, number of samples in a file

4th line: Coverage of distance window

2nd line: (rrmin, rrmax) minimum and maximum distance from shot point to geophones

The traces nearby the shot point may be clipped and those far from may have the problem of low signal-to-noise ratio. Then CMP gather is made from the traces of which offset from the shot point is between rrmin and rrmax.



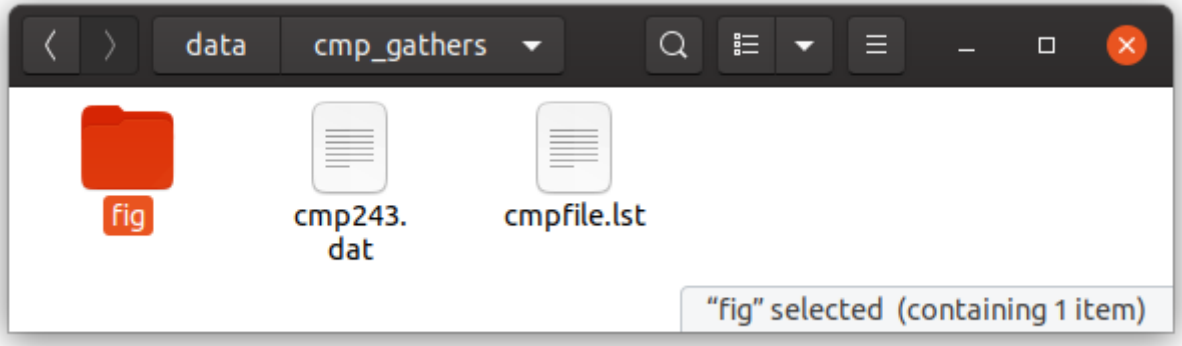
Input Files

- Common Shot Gather Files of the same measurement line that are stored in the subfolder ./maswkf/data/common_shot_gathers

Execution:

```
yokoi@eoan-ermine: ~/Desktop/MASW2020
yokoi@eoan-ermine:~/Desktop/MASW2020$ sh masw2_0.sh
 Program masw2_0.for
./maswkf/prm/masw2_0.prm
  4.5000 40.0000  0.0010
   3.00000000       23.0000000
          24   133.000000       1.00000000           1024
          23
  nn=         1024
./maswkf/prm/geometry.prm
 sxtw0055.dat    109.500000       110.000000
 sxtw0061.dat    121.500000       110.000000
 sxtw0067.dat    133.500000       110.000000
 xmin=    110.000000      xmax=    133.000000
 x_c_p_min=    121.500000      x_c_p_max=    121.500000            265
 Interval    x_s      c_p      x_e     stack          243
   1.000 110.000 121.500 133.000      54
   2.000 110.000 121.500 133.000      50
   3.000 110.000 121.500 133.000      46
   4.000 110.000 121.500 133.000      42
   5.000 110.000 121.500 133.000      38
   6.000 110.000 121.500 133.000      34
   7.000 110.000 121.500 133.000      30
   8.000 110.000 121.500 133.000      26
```

Output files:



Output File: Correlograms Stacked over Common Offset Gather

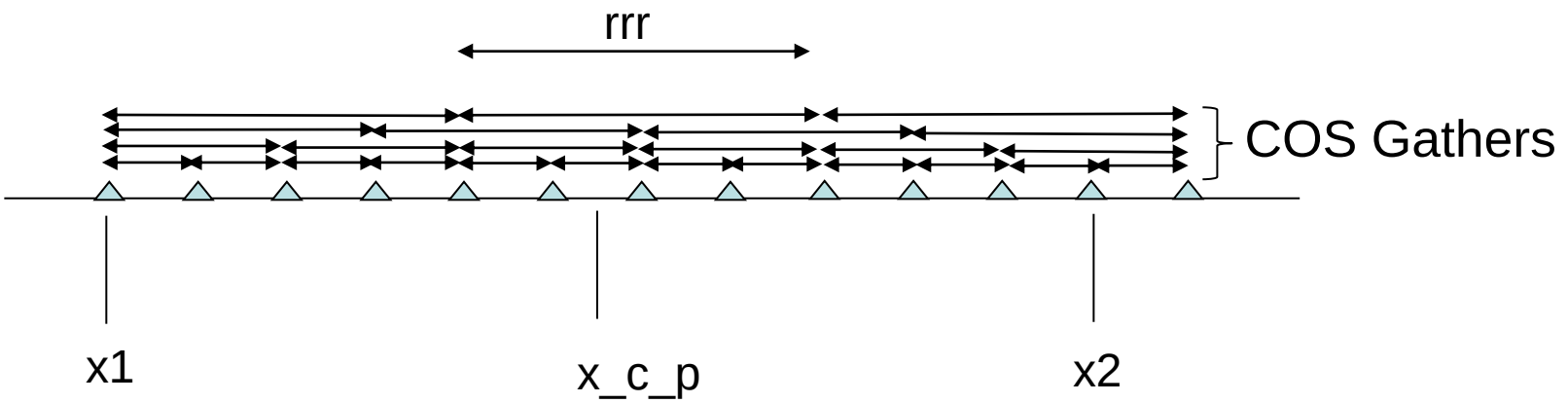
```
243121.5000  0.0010    1024      17
     1   1.000 110.000 121.500 133.000      46
0.344648E-06 0.446964E-06 0.542811E-06 0.626689E-06 0.692931E-06
0.736664E-06 0.755654E-06 0.750093E-06 0.721534E-06 0.673631E-06
0.610467E-06 0.537231E-06 0.458561E-06 0.378502E-06 0.300101E-06
0.224897E-06 0.154016E-06 0.879233E-07 0.262336E-07-0.308933E-07
....
```

Writing sentences of the program:

```
write(13,'(i8,2f8.4,2i8)')icmp,x_cmp,dt,nn,n_trace
      do irr=1,nsegment
        rrr=real(irr)*dx
        if(irr.eq.1) write(6,*)'Interval','   x_s  ','   c_p  ','   x_e  ','  stack ',icmp
        write(6,'(4f8.3,i8)')rrr,x_s,x_cmp,x_e,nstack(irr)
        write(13,'(i8,4f8.3,i8)')irr,rrr,x_s,x_cmp,x_e,nstack(irr)
        write(13,'(5e13.6)')(cr(i,irr),i=1,nn)
      enddo
```

Output File: Stacked Correlograms of Common Offset Gather (Conventional MASW)

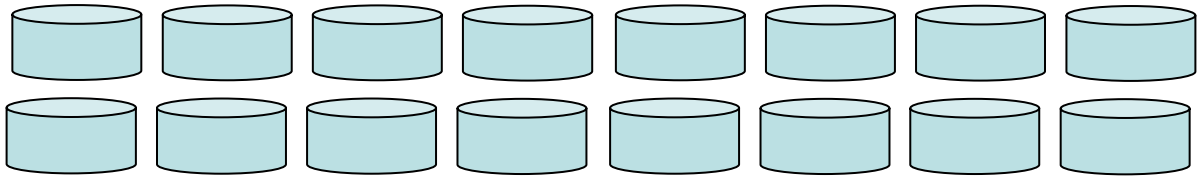
icmp,x_cmp: Numbering, and position of Center Point of measurement line
dt,nn,n_trace: sampling interval, number of sampling, number of correlograms
irr,rrr: Numbering of trace, spacing of common offset gather
x1,x_cmp,x2,nstack(irr): x1, Position of C_P,x2, number of stack
(cr(i,irr),i=1,nn): samples of the correlograms



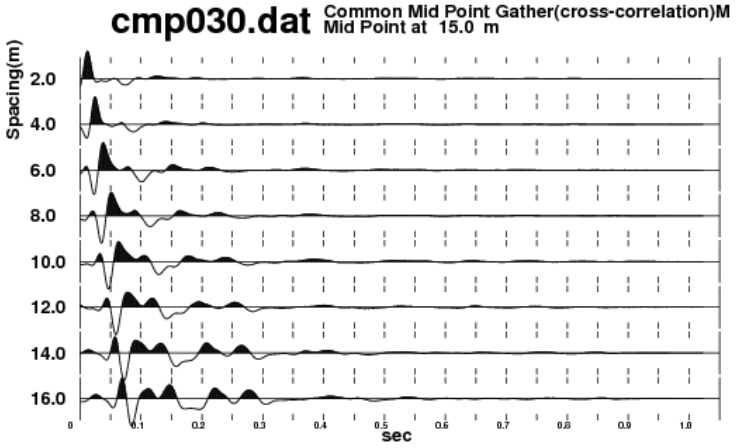
The correlograms having the same offset are stacked together. The gather is composed of the stacked Correlograms of Common Offset with various spacing rrr. This not a CMP gather, but hereafter called CMP gather because being dealt in the same way as the CMP gathers for 2D analysis.

Plotting Common Offset Gathers

Common Offset Gathers cmp???.dat



seecmp24.for
+ see2cmp24.prm



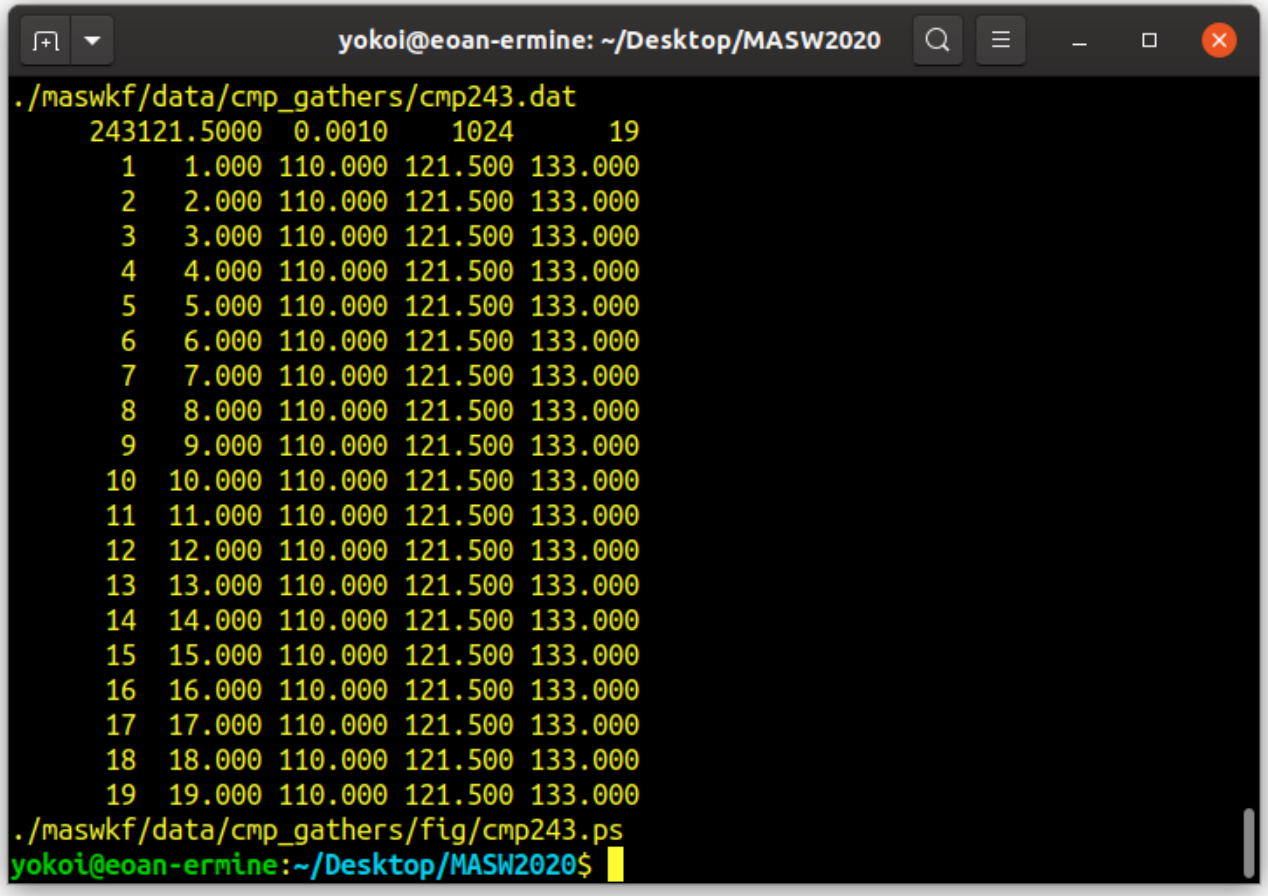
Plot Common Offset traces cmp???.ps

Parameter File

243 243 1 0 :ncmps, ncmpe, ncmpd, Flag for normalize(=0; by max. of each ch,=1: by max. of all channels)

Executed by the 3rd line of masw2_0.sh

The program searches cmp-gather files from ncmps-th cmp to ncmpe-th one with increment ncmpd.



Input files: the output files of masw2_0.exe, that are Common Offset Gathers. These are stored in ./maswkf/data/cmp_gathers

The program looks for the Common Offset Gather files from cmp"ncmps".dat to cmp"ncmpe".dat with increment ncmpd denoted as parameters in the 1st line of seecmp24.prm.

Output files:
in Post Script (PS) format
A file is created for each Common Mid Point Gather and stored in ./maswkf/data/cmp_gathers/fig
These files can be opened, for example, using Ghostview: gv &

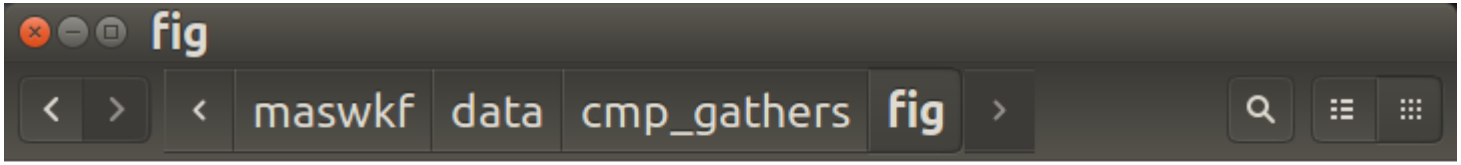
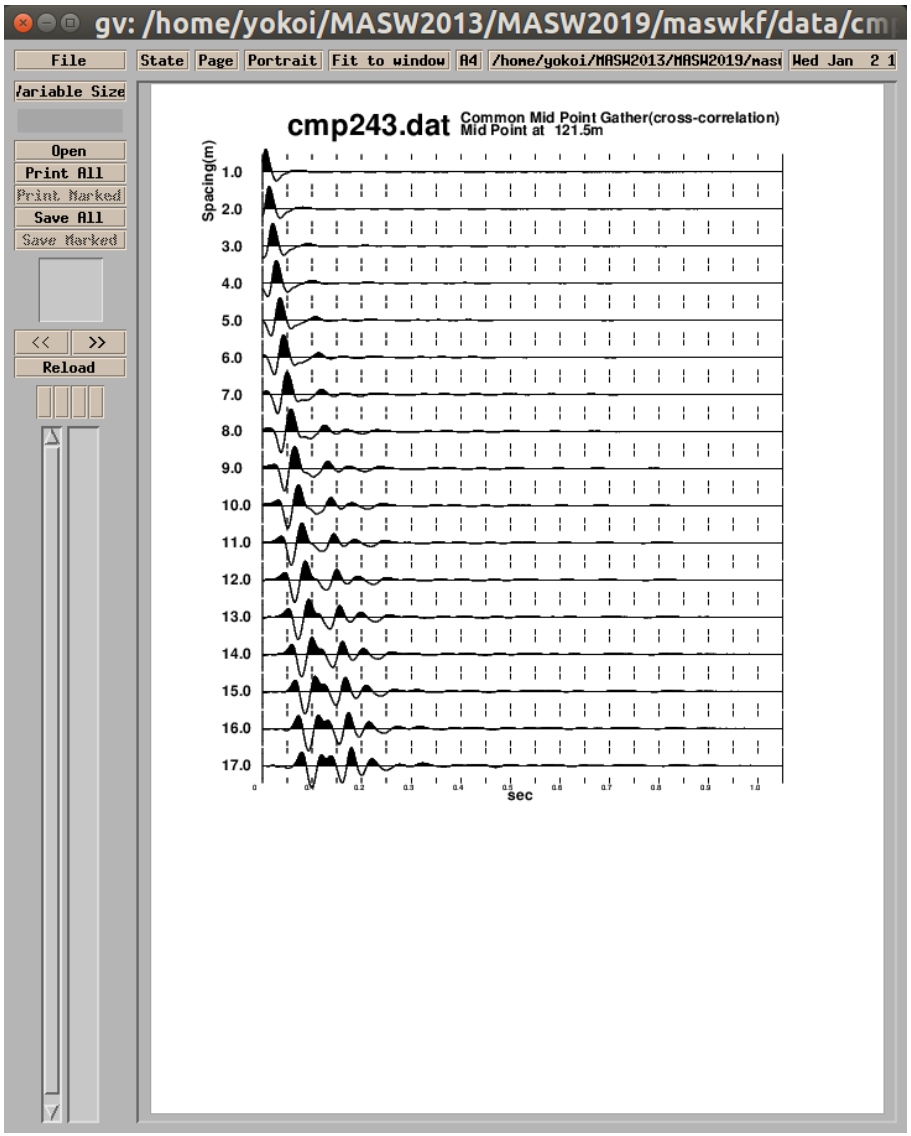
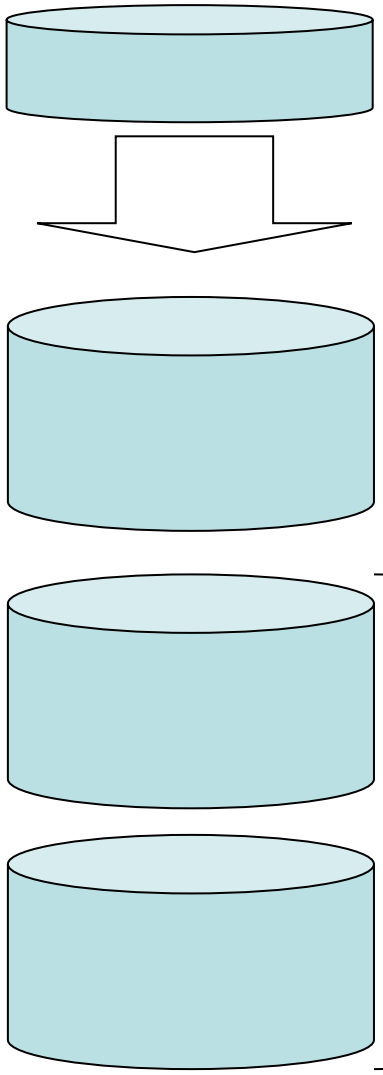


fig
maswkf
data
cmp_gathers
fig

cmp243.ps


gv: /home/yokoi/MASW2013/MASW2019/maswkf/data/cm
File
State
Page
Portrait
Fit to window
A4
/home/yokoi/MASW2013/MASW2019/mas
Wed Jan 2 1
Variable Size
Open
Print All
Print Marked
Save All
Save Marked
<<
>>
Reload
cmp243.dat
Common Mid Point Gather(cross-correlation)
Mid Point at 121.5m
Spacing(m)
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
Sec

Common Offset Gathers cmp???.dat



masw2cmp.sh=
masw2cmp.for
+ masw2cmp.prm
+ geometry.prm

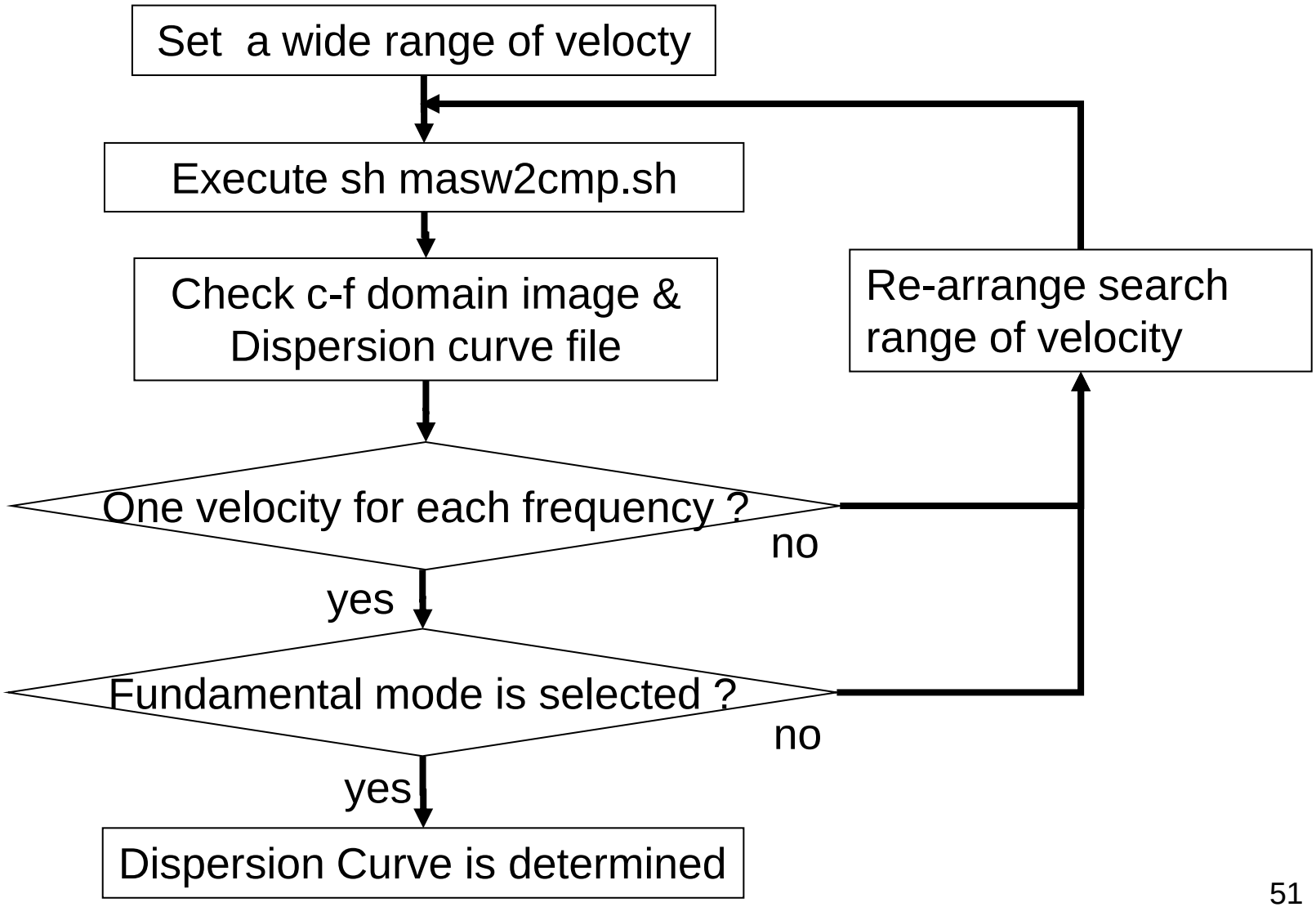
Output: dispersion Curve Files for each CMP gather

GNUPLOT script files for drawings

Interim output files for the c-f domain image and peaks

PostScript files for images in the c-f domain

Task Flow of Velocity Analysis



masw2cmp.sh

```
#!/bin/sh -x
./bin/masw2cmp.exe | tee maswkf/log/masw2cmp.log
gnuplot -e "
load ‘./maswkf/prm/gnuplt_script/c_f_panels/multi_cf.plt';
pause -1
"
```

Parameter File: masw2cmp.prm in ./maswkf/prm

```
1.0 40.0 0.001  1          :fmin,fmax,dt,n_parzen(=0, No, =1, Yes)
 1   0                     :n_cf_domain,normalize(=0 all, =1 each
                            freq.)
 50.  400. 1.0   1          :vmin,vmax,dv,ndisplay
 5. 80  10.  80. 15.  80. :(f1,v1),(f2,v2),(f3,v3) for lower limit
 4. 400  5. 400. 10. 200. :(f1,v1),(f2,v2),(f3,v3) for upper limit
```

(f1,v1),(f2,v2),(f3,v3) for lower and upper limits are explained in the slide of output file. They control the search range for peaks on the result of the velocity analysis.

cmp files are handled by the following do loop.

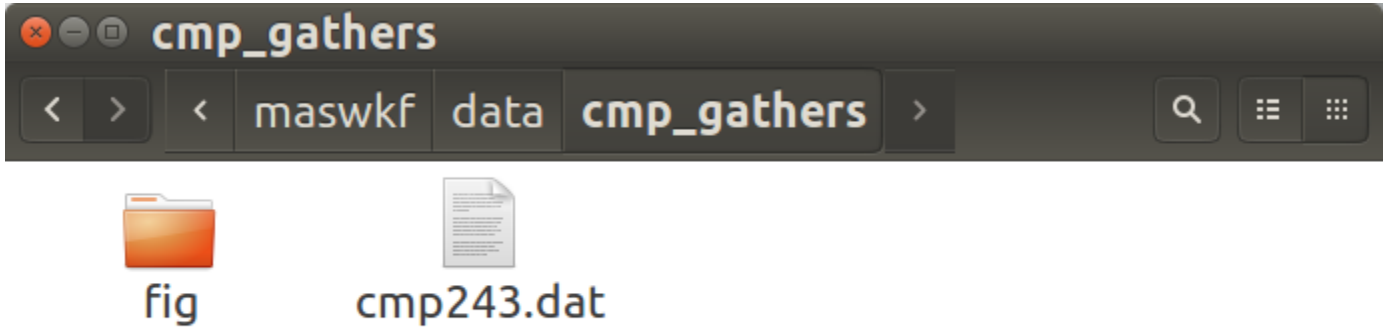
“do icmp=ncmps,ncmpe,ncmpd
…
enddo”

It is recommendable to use the same values of (fmin, fmax, dt) as those used in “masw2_0.prm” or a larger fmin & a smaller fmax than them.

./maswkf/prm/geometry.prm is also read.

Input File: cmp???.dat

Input files: the output files of “sh masw2_0.sh” that are Common Offset Gathers stored in the subfolder ./maswkf/data/cmp_gathers



Output File

Interim output files:
./maswkf/data/c_f_panels/crs_cf243.dat
(graphic output of stacked seismograms in C-F domain)
./maswkf/data/c_f_panels/coh_pk???.dat
(data files for the peak locations in the c-f domain image)

Dispersion curve files:
./maswkf/data/dispersion/cmp???ds.dat

GNUPLOT script files:
./maswkf/prm/gnuplt_script/c_f_panels/masw???.plt

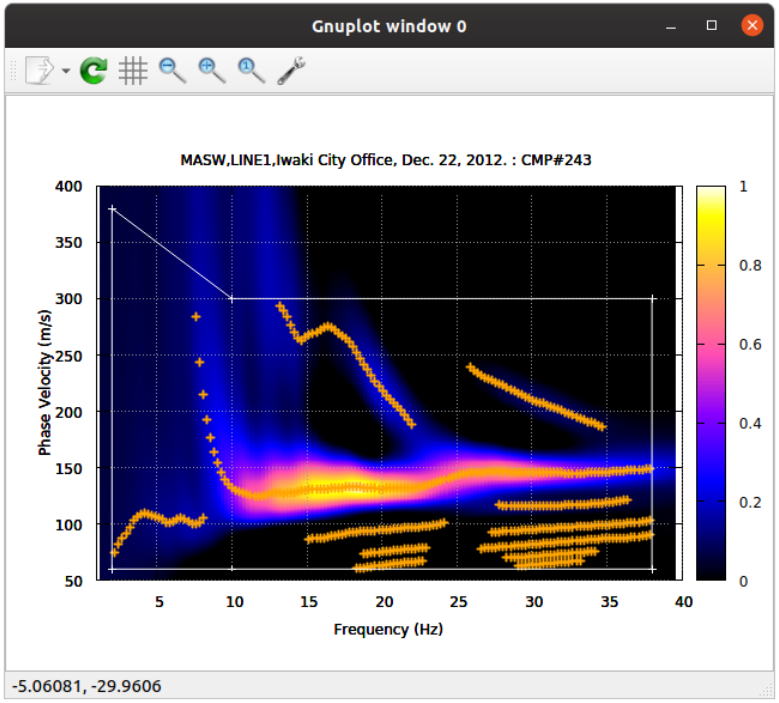
, where ??? denotes the numbering of CMP.

Execution (example): 1st trial

```
yokoi@eoan-ermine:~/Desktop/MASW2020$ sh masw2cmp.sh
 Program masw2cmp.for
 ./maswkf/prm/masw2cmp.prm
   1.00000000       40.0000000       1.00000005E-03          1
            1                0
   50.0000000       400.000000       1.00000000              1
cmp243.dat
            1
 ./maswkf/data/cmp_gathers/cmp243.dat
    243121.5000  0.0010    1024
      1   1.000 110.000 121.500 133.000
      2   2.000 110.000 121.500 133.000
      3   3.000 110.000 121.500 133.000
      4   4.000 110.000 121.500 133.000
      5   5.000 110.000 121.500 133.000
      6   6.000 110.000 121.500 133.000
      7   7.000 110.000 121.500 133.000
      8   8.000 110.000 121.500 133.000
      9   9.000 110.000 121.500 133.000
     10  10.000 110.000 121.500 133.000
     11  11.000 110.000 121.500 133.000
     12  12.000 110.000 121.500 133.000
     13  13.000 110.000 121.500 133.000
     14  14.000 110.000 121.500 133.000
     15  15.000 110.000 121.500 133.000
     16  16.000 110.000 121.500 133.000
     17  17.000 110.000 121.500 133.000
     18  18.000 110.000 121.500 133.000
     19  19.000 110.000 121.500 133.000
 ./maswkf/data/c_f_panels/crs_cf243.dat
 Interim output (peaks of C-F spectra):./maswkf/data/c_f_panels/coh_pk243.dat

 ./maswkf/data/dispersion/cmp243ds.dat
 ./maswkf/prm/geometry.prm
MASW,LINE1,Iwaki City Office, Dec. 22, 2012.
 ./maswkf/prm/gnuplt_script/c_f_panels/masw243.plt
Hit return to end the process
yokoi@eoan-ermine:~/Desktop/MASW2020$
```

masw2cmp.prm

```
1.0 40.0 0.001  1          :fmin,fmax,dt,n_parzen(=0, No, =1, Yes)
 1   0                     :n_cf_domain,normalize(=0 all, =1 each freq.)
 50.  400. 1.0  1          :vmin,vmax,dv,ndisplay
 2.0 60  10.  60. 38.  60. :(f1,v1),(f2,v2),(f3,v3) for lower limit
 2.0 380 10. 380. 38. 380. :(f1,v1),(f2,v2),(f3,v3) for upper limit
```

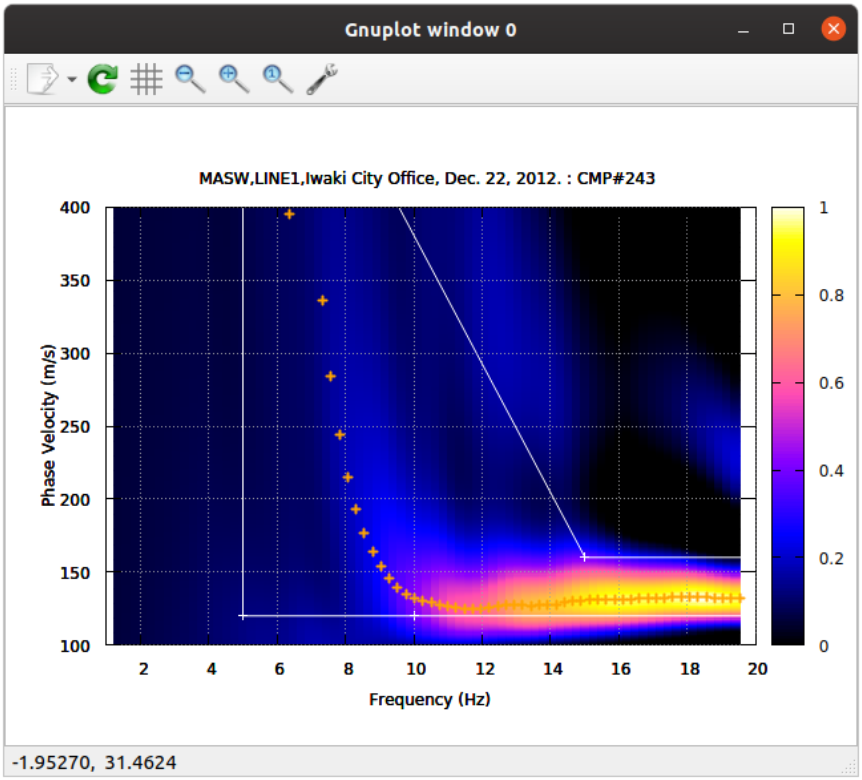


Peaks within the white hexagon (+) are detected to create the dispersion curve. Therefore, the contents of the red rectangle above should be modified to select (+)s on the highest peaks colored yellow-orange.

Execution (example): After few trials

masw2cmp.prm

```
1.0 20.0 0.001  1          :fmin,fmax,dt,n_parzen(=0, No, =1, Yes)
 1   0                     :n_cf_domain,normalize(=0 all, =1 each freq.)
 100.  400. 1.0  1         :vmin,vmax,dv,ndisplay
 5. 120 10. 120. 20. 120.  :(f1,v1),(f2,v2),(f3,v3) for lower limit
 5. 600 15. 160. 20. 160.  :(f1,v1),(f2,v2),(f3,v3) for upper limit
```



If only a few data points should be removed from the file of dispersion curve, direct editing by gedit can be faster.

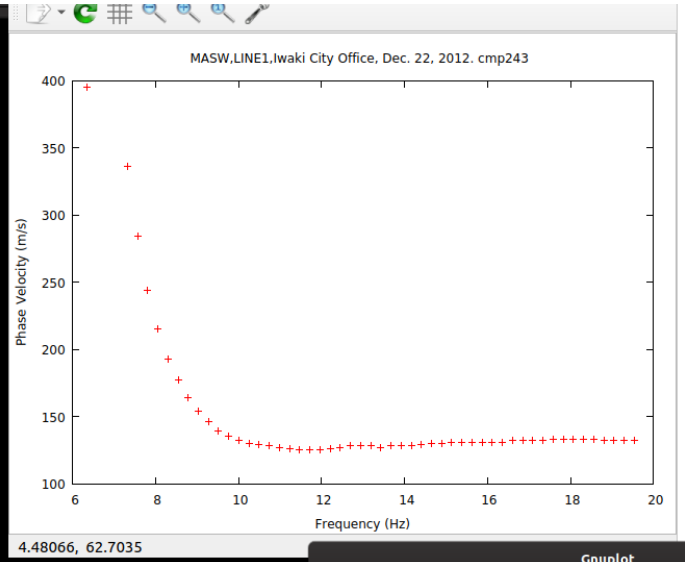
Dispersion curve files:
./maswkf/data/dispersion/cmp???ds.dat

Peaks within the white hexagon (+) are detected to create the dispersion curve.

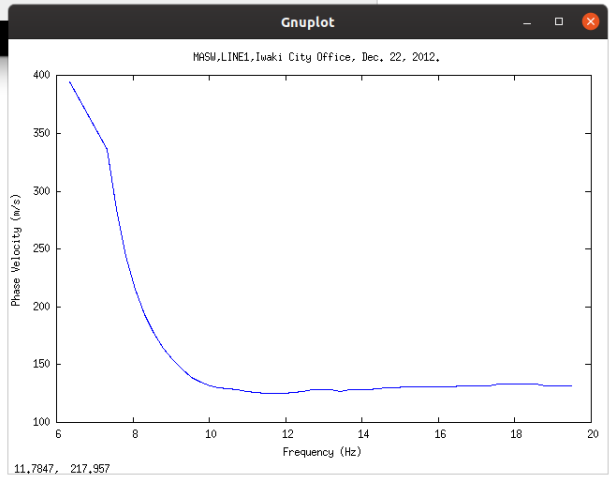
Plot Dispersion Curve: sh disp_comb.sh

```
yokoi@eoan-ermine: ~/Desktop/MASW2020
yokoi@eoan-ermine:~/Desktop/MASW2020$ sh disp_comb.sh
 Program disp_comb.for
 ./maswkf/data/dispersion/disp_all.csv

ncmp=   1 icmp=  1
          1         243  (f8.3,a1,f4.0)
 ./maswkf/data/dispersion/disp_all.dat

 ./maswkf/prm/gnuplt_script/dispersion/disp_all.plt

MASW,LINE1,Iwaki City Office, Dec. 22, 2012.
 ./maswkf/prm/gnuplt_script/dispersion/disp243.plt



yokoi@eoan-ermine:~/Desktop/MASW2020$
```

Individual Curve

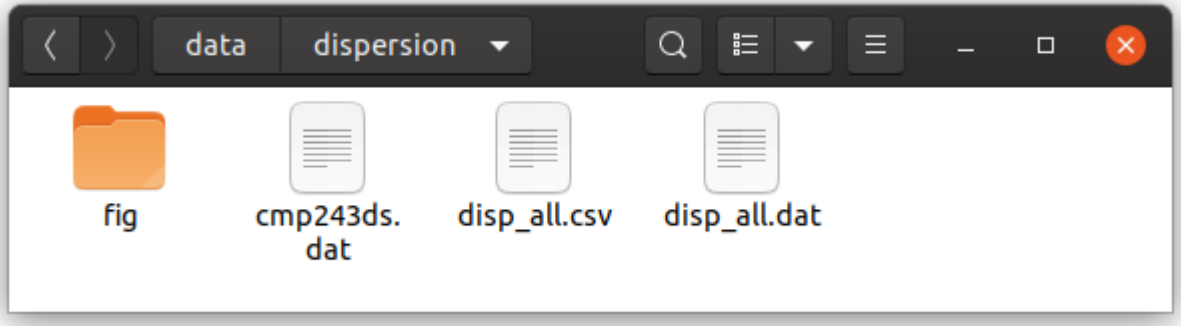


All curves

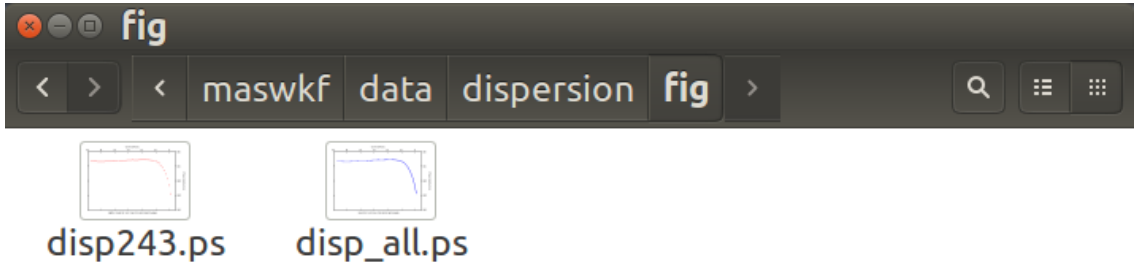



```
cd ./maswkf/data/dispersion
ls -1 cmp*ds.dat > ../../prm/disp_comb.prm
cd ../../..
./bin/disp_comb.exe | tee maswkf/log/disp_comb.log
gnuplot -e "
load './maswkf/prm/gnuplt_script/dispersion/disp_all.plt' ;
pause -1
"
```

For 1D analysis, in this example, only one dispersion curve is determined and two almost identical figures are given.



The data for the determined dispersion curves are stored in ./maswkf/data/dispersion/cmp???ds.dat and used in the next process.
A csv format file ./maswkf/data/dispersion/disp_all.csv is created for drawing using Excel.
The PostScript files that contain the same figures as shown in the previous slide are stored in "./maswkf/data/dispersion/fig/".



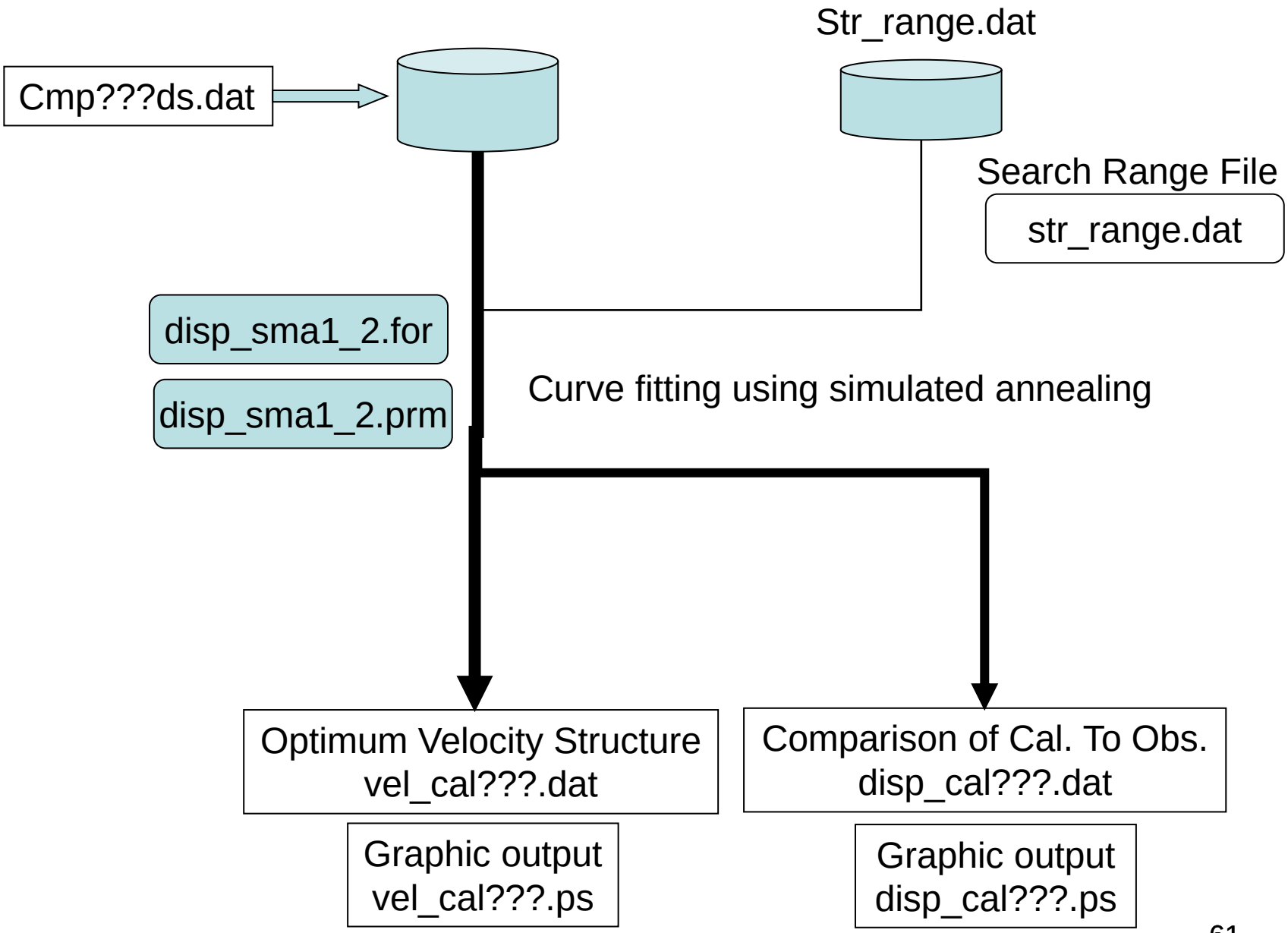
disp???.ps contains the image of an individual curve, whereas disp_all.ps all curves together. In this example, both contain only one curve.

1. Instruction Manual of Programs for Analysis (1D: conventional MASW)

1.6 Inversion of dispersion curve

sh inversion_1D.sh

disp_sma1_2.for + disp_sma1_2.prm


Str_range.dat
Cmp???ds.dat
Search Range File
str_range.dat
disp_sma1_2.for
disp_sma1_2.prm
Curve fitting using simulated annealing
Optimum Velocity Structure
vel_cal???.dat
Comparison of Cal. To Obs.
disp_cal???.dat
Graphic output
vel_cal???.ps
Graphic output
disp_cal???.ps

Conduct inversion and plot the results.

sh inversion_1D.sh

inversion_1D.sh

```
#!/bin/sh -x
./bin/disp_sma1_2.exe | tee ./maswkf/log/inversion_1D.log
sh inversion_1D_plt.sh
```

inversion_1D_plt.sh

```
#!/bin/sh -x
./bin/inv_plt.exe | tee -a ./maswkf/log/inversion_1D.log
gnuplot -e "load './maswkf/prm/gnuplt_script/dispersion/disp_cal.plt' ; pause -1 "
gnuplot -e "load './maswkf/prm/gnuplt_script/structure/vs_structure.plt' ; pause -1 "
rm ./maswkf/temp/temp*.dat 2>/dev/null
```

inversion_1D_plt.sh can be executed solely to plot the results.
sh inversion_1D_plt.sh

Parameter File: disp_sma1_2.prm

```
 1 1. 0.6 1.3 5000  5  :idum,t0,a,c,ntemp,j0
 0.0007                :eps0
    1    1             :n_roh,n_vp
    1    0    1        :ini_flg,ndsp_flg,n_err
    0    1             :kflg,jflg
    0    0             :n_vs,n_th
str_range.dat          :File name for the initial velocity model (a25).
cmp243ds.dat           :File name for the obseved dispersion relation (a25).
vel_cal.dat            :File name for the estimated velocity structure (a25)
disp_cal.dat           :File name for the calculated dispersion relation (a25)
```

```
Control parameter for the simulated annealing method
idum      :Random seed (integer). As the result may
          depend on the initial velocity model given by
          random number, it is strongly recommended for
          users to apply this program several times with
          various values of random seed and tograsp the
          scatter of result.
t0        :Initial Temperature
a,c       :Coefficients for T=T0*exp(-c*k**a), where k is
          iteration number
ntemp     :Maximum number of temparature change
j0        :Number of iteration for each temperature

Threshold for conversion
 eps0     : averaged deviation
```

```
flags of empirical relations for roh and vp
 n_vp     : 1=by Ludwig et al(1970),
            vp=1.11*vs+1.29
            0=fixed to the initial values
 n_roh    : 1=by Kitzunezaki et al(1990),
            roh=1.2475+0.399*vp-0.026*vp**2
            0=fixed to the initial values
 n_initial: 1=Initial model is set to the given value
            0=Initial model is set using random seed
flags for output to Display
 ini_flg  : Initial Velocity Structure Model 1=yes
 ndsp_flg : Observed Dispersion Relation     1=yes
 n_err    : Error at each iteration          1=yes
 kflg     : Missfit at each temp. change     1=yes
 jflg     : Missfit at each itration with the same temp.
                                             1=yes
 n_vs     : Vs value  (n_vs=layer number, 0=no output)
 n_th     : Thickness (n_th=layer number, 0=no output)
 n_err    : errors
```

Input File

- “str_range.dat” is the file in “./maswkf/prm/”, that includes the initial structure model and the search range.
- “cmp???ds.dat” the file in “./maswkf/data/dispersion/”, that includes the observed dispersion curve.

Format of “str_range.dat”

```
MASW_1D,LINE1,Iwaki,Dec22,2012:Model                                    :comments(a70)
         6                        :IL(I5),Layer Number
1.9   1.5    0.001  0.010  0.140 0.300 :density,Vp,hmin,hmax,vmin,vmax
1.9   1.5    0.001  0.010  0.080 0.200 :density,Vp,hmin,hmax,vmin,vmax
1.9   1.5    0.001  0.010  0.150 0.250 :density,Vp,hmin,hmax,vmin,vmax
1.9   1.5    0.001  0.010  0.200 0.300 :density,Vp,hmin,hmax,vmin,vmax
1.9   1.5    0.001  0.010  0.300 0.350 :density,Vp,hmin,hmax,vmin,vmax
2.0   1.70   900.0  999.0  0.350 0.600
```

(hmin, hmax): the minimum and maximum of the serach range of layers thickness. For the deepest layer they must be (998.0, 999.0).

(vmin, vmax): the minimum and maximum of the search range of shear wave velocity Vs.

(hini,vini):given initial values of the thickness and Vs of each layer.

Format of the file for Dispersion curve

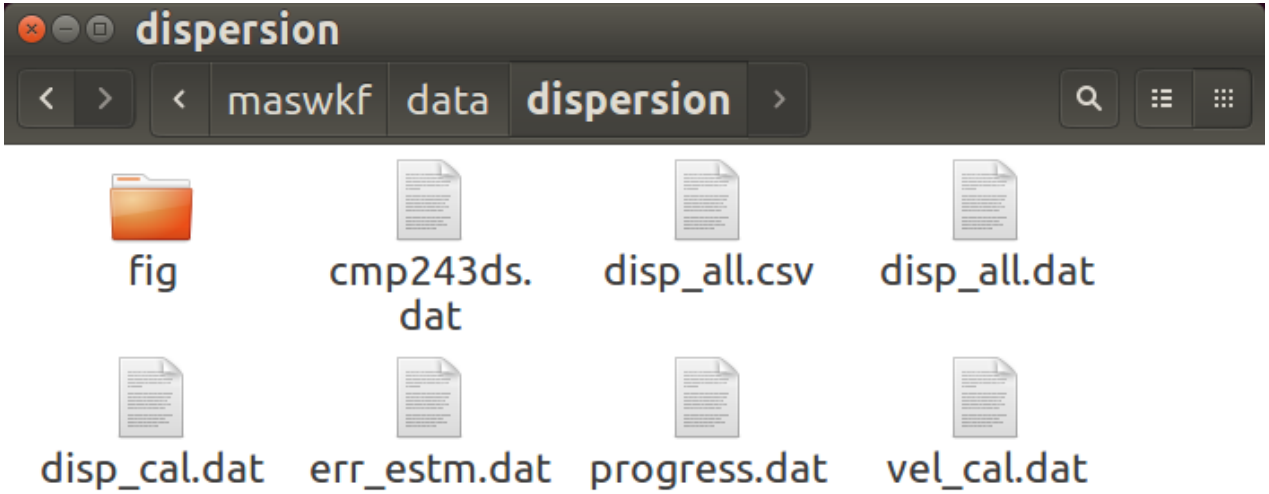
output file “cmp???ds.dat” from “sh masw2cmp.sh”

cmp243ds.dat

```
 #  Freq.  V.m/s
    6.348  395.000
    7.324  336.000
    7.568  284.000
    7.812  244.000
….
```

Output file

- Stored in “./maswkf/data/dispersion/”
- “vel_cal.dat” of the example of the parameter file shown above. File for the estimated velocity structure by the heuristic search.
- “disp_cal.dat” of the example of the parameter file shown above. File that includes the observed and calculated dispersion curve together.
- Both can be read by Excel.



Format of output file “vel_cal.dat”

Thicknes(Km)	Density(g/cm^3)	Vp(Km/sec)	Vs(Km/sec)
1	0.001691	1.802829	1.547940	0.232378
2	0.002879	1.750138	1.384686	0.085303
3	0.002804	1.784682	1.491226	0.181285
4	0.002716	1.804126	1.552014	0.236048
5	0.002051	1.840045	1.665922	0.338669
6	999.000000	1.927524	1.952819	0.597134

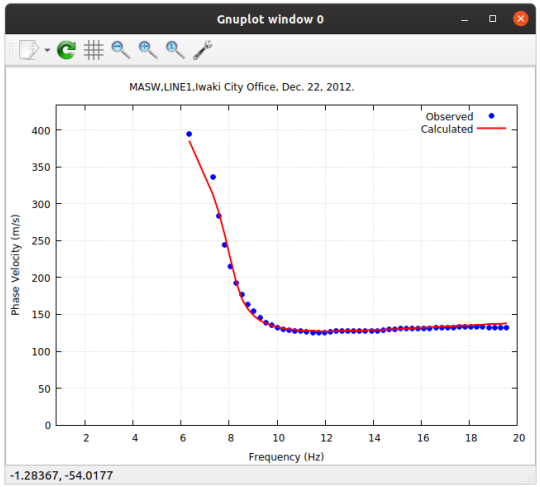
Format of output file “disp_cal.dat”

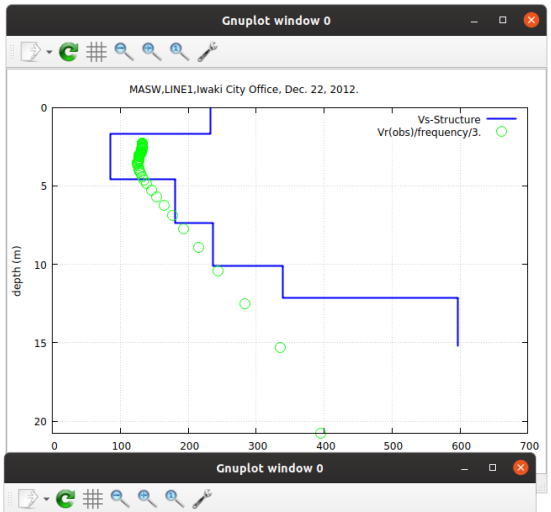
# Frequency(Hz)	Observed Velocity	Calculated Velocity	
6.348	0.395	0.385	0.001
7.324	0.336	0.313	0.001
7.568	0.284	0.289	0.001
7.812	0.244	0.259	0.001
8.057	0.215	0.225	0.001
8.301	0.193	0.193	0.001
8.545	0.177	0.170	0.001
…			

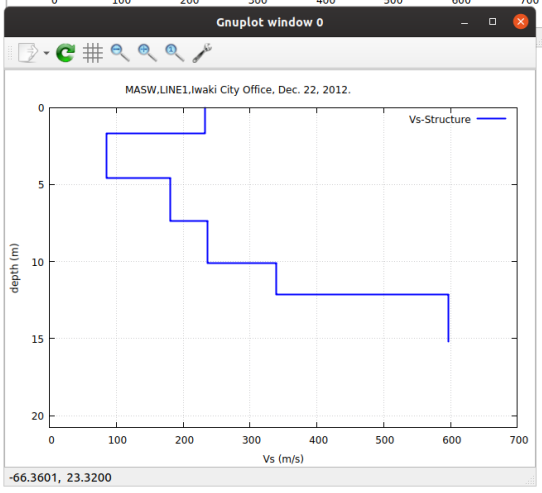
Execution: Example.

```
yokoi@eoan-ermine: ~/Desktop/MASW2020

yokoi@eoan-ermine:~/Desktop/MASW2020$ sh inversion_1D.sh
 +-------------------------------------------------+
 +                                                 +
 +                   Disp_sma1                     +
 +                                                 +
 + Program to obtain the optimum undeground velocity +
 + structure for the given dispersion relation of  +
 + Rayleigh wave.                                  +
 +                                                 +
 + The used method is a combination of the down hill +
 + simplex method (Nelder & Mead (1965)) and the   +
 + very fast simulated annealing method (Ingber    +
 + (1989)).                                        +
 +                                                 +
 + The subroutine DSPRAY and DSPMRX published in   +
 + "Seismological Algorithm" are used directly.    +
 + AMOEBA and AMOTRY published in "Numerical Recipe" +
 + are also used, but with significant modification +
 + for the adaptation with the very fast simulated +
 + annealing method.                               +
 +                                                 +
 + By the combination with the down hill simplex   +
 + method, the very fast simulated annealing method +
 + is gotten much faster.                          +
 +                                                 +
 +                                  July 6, 2005+
 +    CopyRight by Toshiaki Yokoi, IISEE, BRI, Japan.+
 +-------------------------------------------------+
 ./maswkf/data/dispersion/progress.dat
 ./maswkf/prm/disp_sma1_2.prm
 ./maswkf/prm/str_range.dat
  Initial values randomly produced
                                Range of random fluctuation
Thicknes Density      Vp      Vs   Thickness          Vs
   0.006   1.774   1.459   0.152   0.001   0.010   0.140   0.300
   0.009   1.765   1.431   0.127   0.001   0.010   0.080   0.200
   0.008   1.803   1.548   0.233   0.001   0.010   0.150   0.250
   0.005   1.823   1.613   0.291   0.001   0.010   0.200   0.300
```

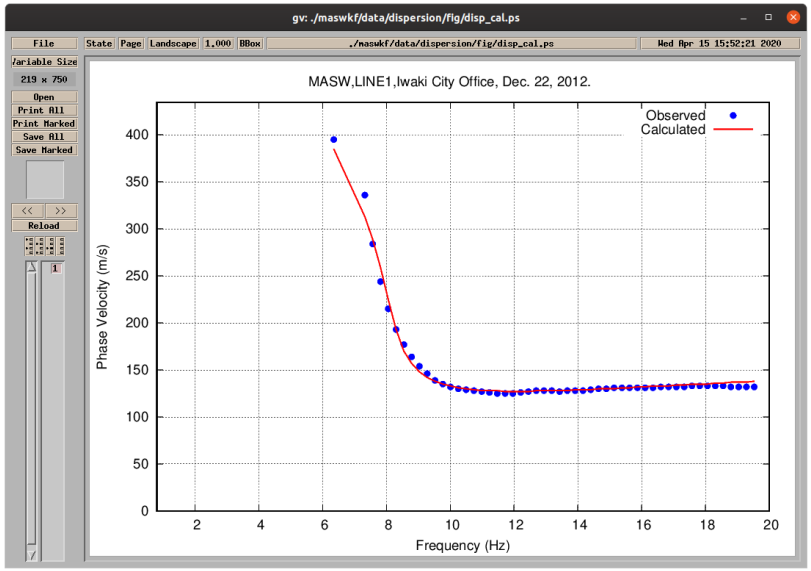
```
yokoi@eoan-ermine: ~/Desktop/MASW2020

 3560    0.0007001944
 3570    0.0007001248
 3580    0.0006974395
 ./maswkf/data/structure/vel_cal.dat
      Thicknes(Km) Density(g/cm^3)     Vp(Km/sec)     Vs(Km/sec)
    1     0.001691       1.802829       1.547940       0.232378
    2     0.002879       1.750138       1.384686       0.085303
    3     0.002804       1.784682       1.491226       0.181285
    4     0.002716       1.804126       1.552014       0.236048
    5     0.002051       1.840045       1.665922       0.338669
    6   999.000000       1.927524       1.952819       0.597134
 ./maswkf/data/dispersion/disp_cal.dat
 ./maswkf/data/dispersion/err_estm.dat
Note: The following floating-point exceptions are signalling: IEEE_UNDERFLOW_FLA
G IEEE_DENORMAL
Note: The following floating-point exceptions are signalling: IEEE_DENORMAL

Hit return to continue.
Hit return to continue.

yokoi@eoan-ermine:~/Desktop/MASW2020$
```

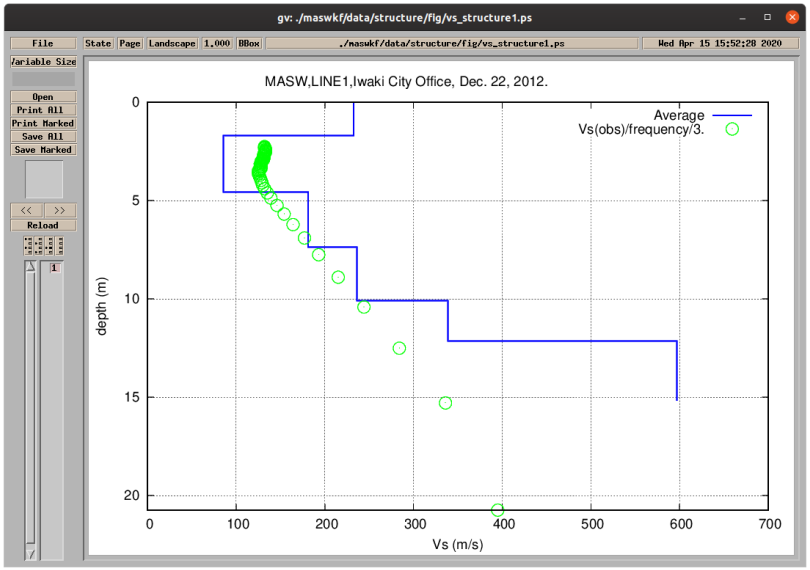


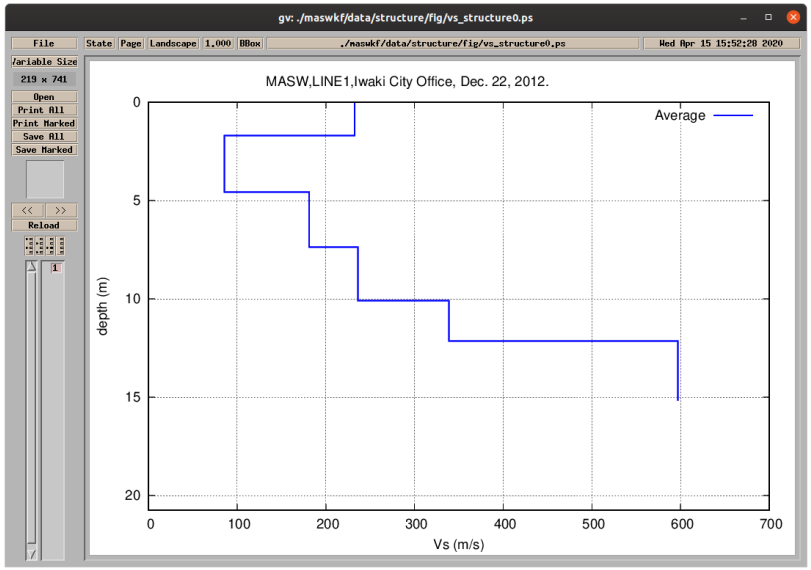




Three output figures are stored as PostScript files in ./maswkf/data/dispersion/fig and ./maswkf/data/structure/fig



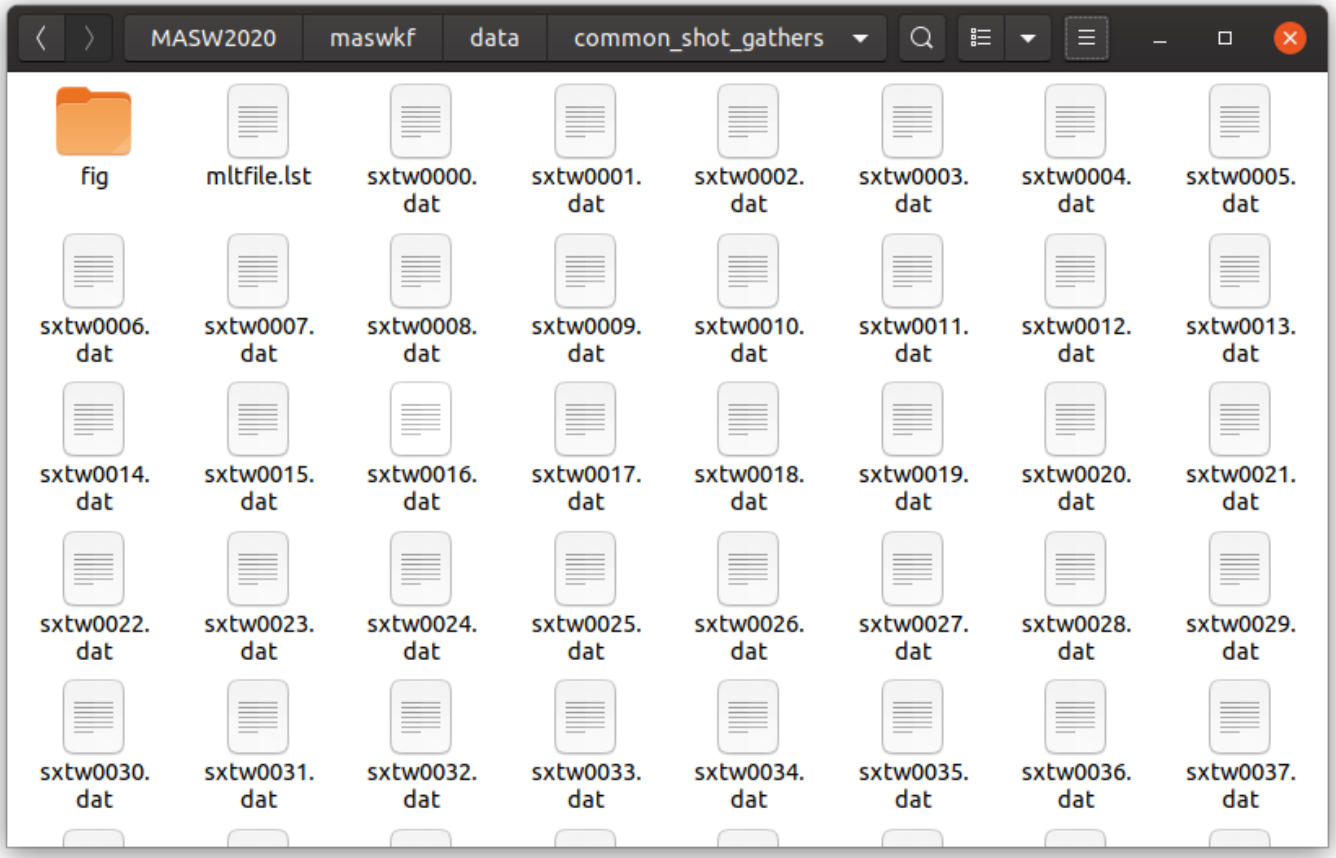




2. Instruction Manual of Programs for Analysis (2D: CMPCC-MASW)

2.1 Semi-automatic input of the information of Field Geometry

Copy all sg2 field data files to ./maswkf/data/sg2_files, and edit "./maswkf/prm/seg2read.prm" as sown in the next slide.
Then, execute "sh seg2read.sh".
The converted files are stored in the subfolder
./maswkf/data/common_shot_gathers
as shown below



Example: seg2read.prm

All the files listed in "sg2file.lst" that have the extension specified in the 3rd line
are converted to the output files that have the extension given in the 4th line.
Edit the file "sg2file.lst" using “gedit” or other text edior if necessary.

seg2read.prm

```
MASW,LINE1,Iwaki City Office, Dec. 22, 2012.                          :comm(a70)
 0.159      :(A12) scaling factor (for output files in mkine(1.e-3cm/s))
sg2         : extension of input seg2 format files(a3)
dat         : extension of output ascii text files(a3)
0 3 0.1 1.0 1.5  :nfilter(=1:apply),nchara=3:bandpass),fl,fh,fs
normal      : Channel Pivoting
```

Geometry

Edit the parameter file “mk_geometry.prm” for geometry configuration.

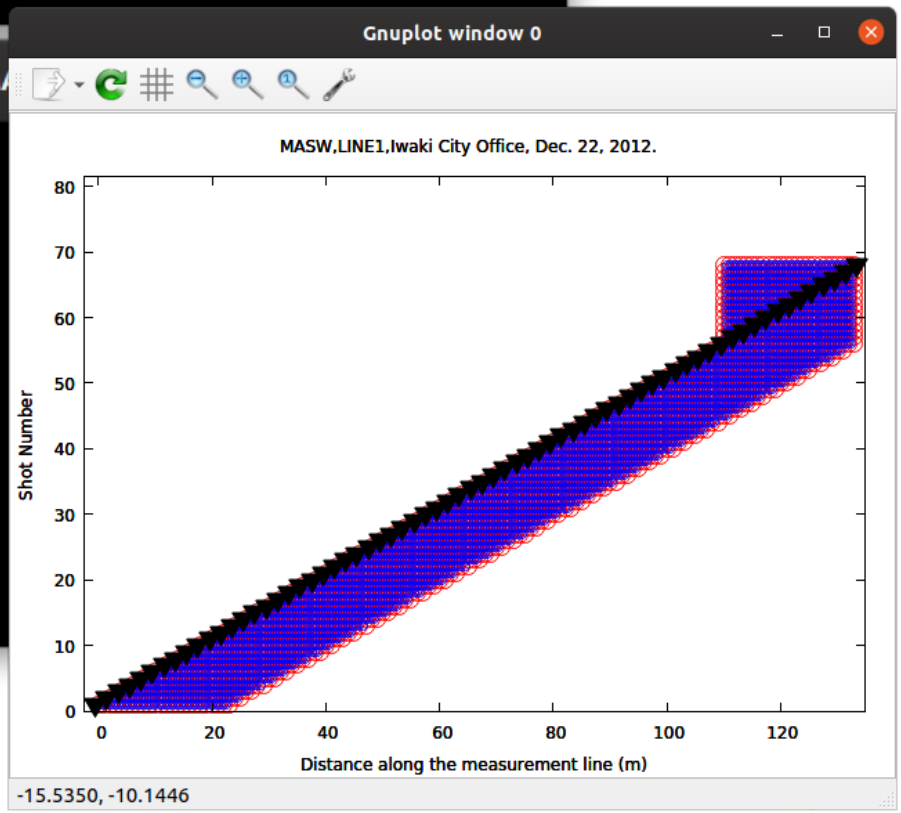
```
mk_geometry.prm

68  sxtw00  00  55  67   : no. of shots,cname(A6),cst(A2),cit(A2),ced(A2)
 -0.5 2.0 0.0 1.0   : 1st position & Interval of shots, 1st position of 1ch, dx(geopone
                     interval)
```

68 seg2 format files from sxtw0000.sg2 to sxtw0067.sg2 are processed. Shot position was moved 68 times from -0.5 m with the interval 2.0 m. The geophone string composed of 24 geophones ,with the interval 1.0 m and the initial position of the 1st channel 0.0 m, followed the moving shot from sxtw0000.sg2 to sxtw0054.sg2. However from sxtw0055.sg2 to sxtw0067.sg2 the geophone string was not moved, only shot position was moved.
Then, execute
sh geometry_2D.sh

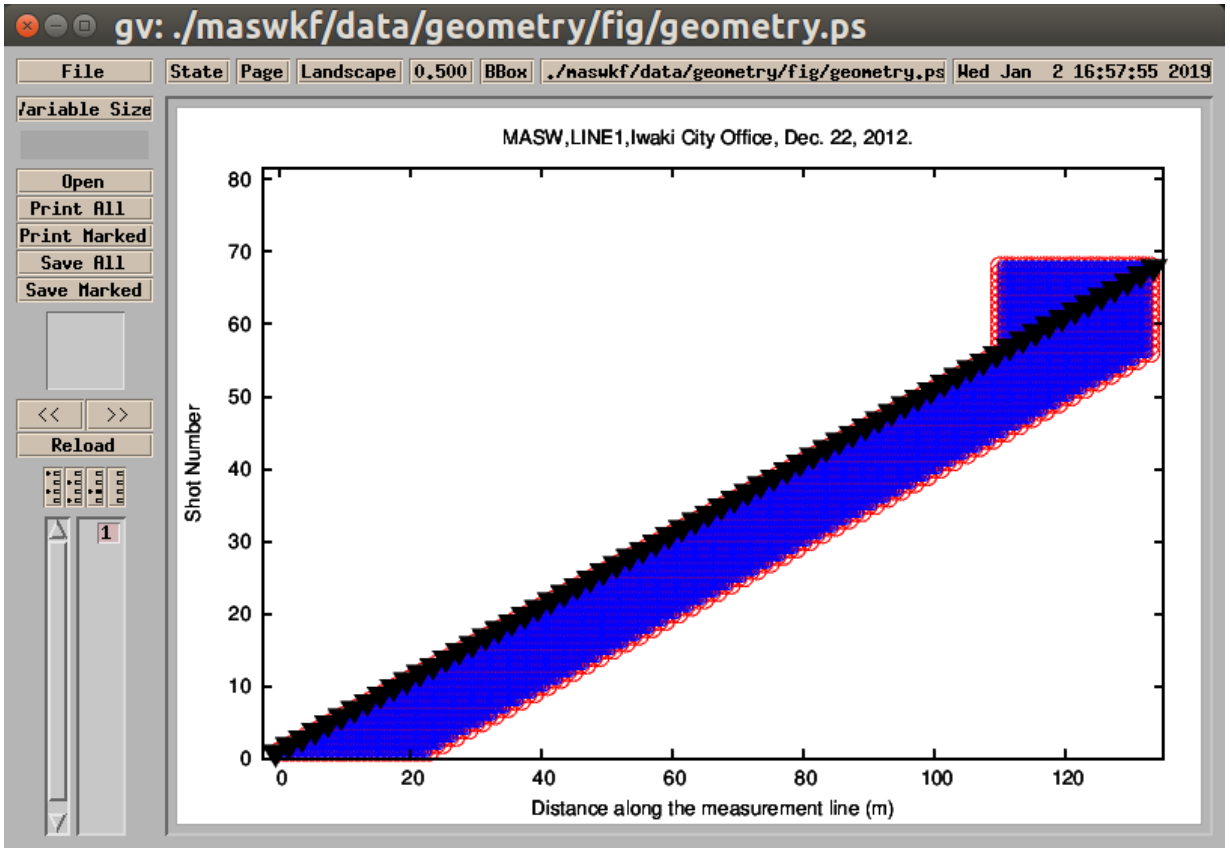
```
sh geometry_2D.sh

#! /bin/sh -x
./bin/mk_geometry.exe | tee maswkf/log/mk_geometry.log
./bin/geometry_plt.exe | tee maswkf/log/geometry_plt.log
gnuplot -e "
load './maswkf/prm/gnuplt_script/geometry/geometry.plt' ;
pause -1
"
```

```
yokoi@eoan-ermine: ~/Desktop/MASW2020
yokoi@eoan-ermine:~/Desktop/MASW2020$ sh geometry_2D.sh
sxtw0000.dat sxtw0055.dat sxtw0067.dat
 -0.500000000       2.00000000       0.00000000       1.00000000
MASW,LINE1,Iwaki City Office, Dec. 22, 2012.
 68  1.0
sxtw0000.dat  -0.5   0.0
sxtw0001.dat   1.5   2.0
sxtw0002.dat   3.5   4.0
sxtw0003.dat   5.5   6.0
sxtw0004.dat   7.5   8.0
sxtw0005.dat   9.5  10.0
```

```
yokoi@eoan-ermine: ~/Desktop/MA
 sxtw0061.dat   121.500000       110.000000
 sxtw0062.dat   123.500000       110.000000
 sxtw0063.dat   125.500000       110.000000
 sxtw0064.dat   127.500000       110.000000
 sxtw0065.dat   129.500000       110.000000
 sxtw0066.dat   131.500000       110.000000
 sxtw0067.dat   133.500000       110.000000
 ./maswkf/prm/gnuplt_script/geometry/geometry.plt

 MASW,LINE1,Iwaki City Office, Dec. 22, 2012.


yokoi@eoan-ermine:~/Desktop/MASW2020$
```



When the program is run, the drawing of geometry appears in a X-windows as shown in previous slide. Simultaneously, the same image is stored in the Postscript file “./maswkf/data/geometry/fig/geometry.ps”



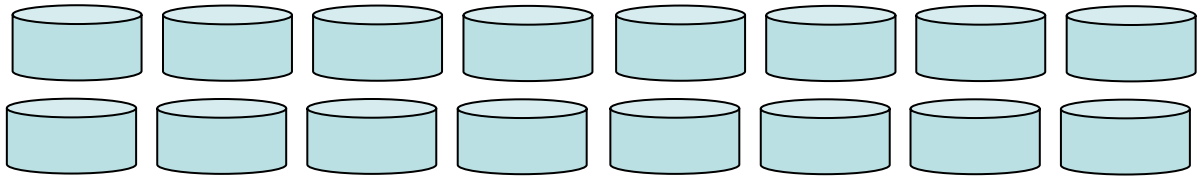
Triangles: shot points,
Red dots: geophone locations,
Blue dots: CMP location.
Modify ./maswkf/prm/gnuplt_script/geometry.plt and load it again to change marks, titles, fonts sizes etc..

2. Instruction Manual of Programs for Analysis (2D: CMPCC-MASW)

2.2 Plotting Common Shot Gathers

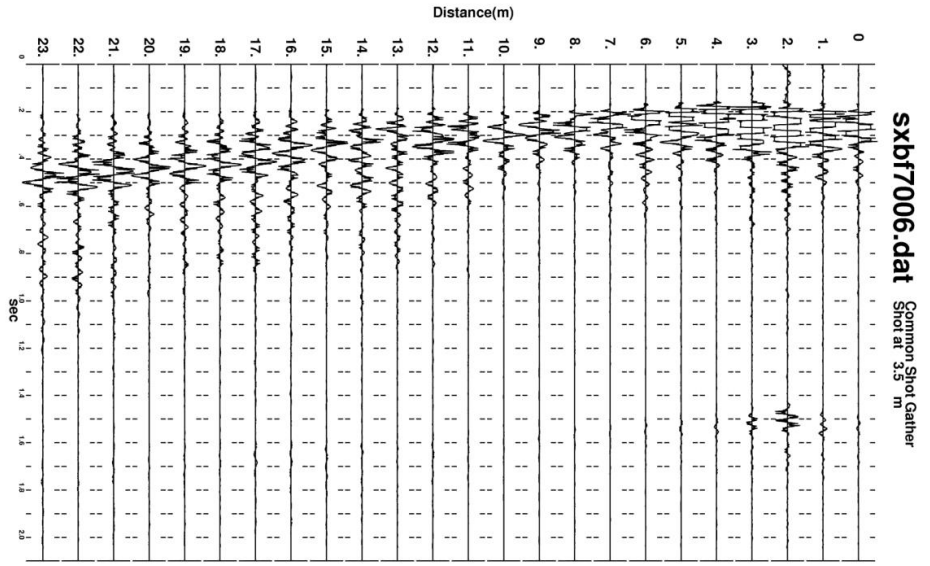
seewav24.for + seewav24.prm

Field Data = Common Shot Gathers



seewav24.for

+ seewav24.prm



Plot the paste-up of 24 Channel traces

Draw paste-up of common shot gathers by
"./seewav24.exe"

This program uses the parameter file
./maswkf/prm/seewav24.prm
and the geometry information
./maswkf/prm/geometry.prm
to draw the paste-up of all common shot gathers in the PostScript files stored in the subfolder
./maswkf/data/common_shot_gathers/fig

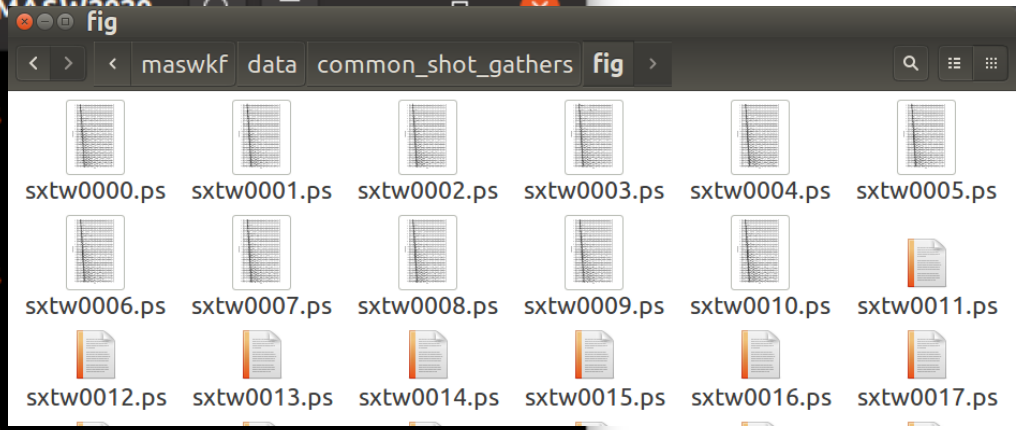
Use Ghostview to plot these PostScript files: gv &

Parameter File: seewav24.prm

0 :Flag for normalizing(=0; by max. of each ch,=1: by max. of all chs)

```
yokoi@eoan-ermine: ~/Desktop/MASW2020

yokoi@eoan-ermine:~/Desktop/MASW2020$ sh seewav24.sh
 ./maswkf/prm/seewav24.prm

          0
 ./maswkf/prm/geometry.prm

         68   1.00000000
 sxtw0000.dat -0.500000000       0.00000000
 ./maswkf/data/common_shot_gathers/sxtw0000.dat

./maswkf/data/common_shot_gathers/fig/sxtw0000.ps
 sxtw0001.dat   1.50000000       2.00000000
```

```
yokoi@eoan-ermine: ~/Desktop/M

./maswkf/data/common_shot_gathers/fig/sxtw0065.ps
 sxtw0066.dat   131.500000       110.000000
 ./maswkf/data/common_shot_gathers/sxtw0066.dat

./maswkf/data/common_shot_gathers/fig/sxtw0066.ps
 sxtw0067.dat   133.500000       110.000000
 ./maswkf/data/common_shot_gathers/sxtw0067.dat

./maswkf/data/common_shot_gathers/fig/sxtw0067.ps
Note: The following floating-point exceptions are signalling: IEEE_UNDERFLOW_FLA
G IEEE_DENORMAL
```



Input File Format

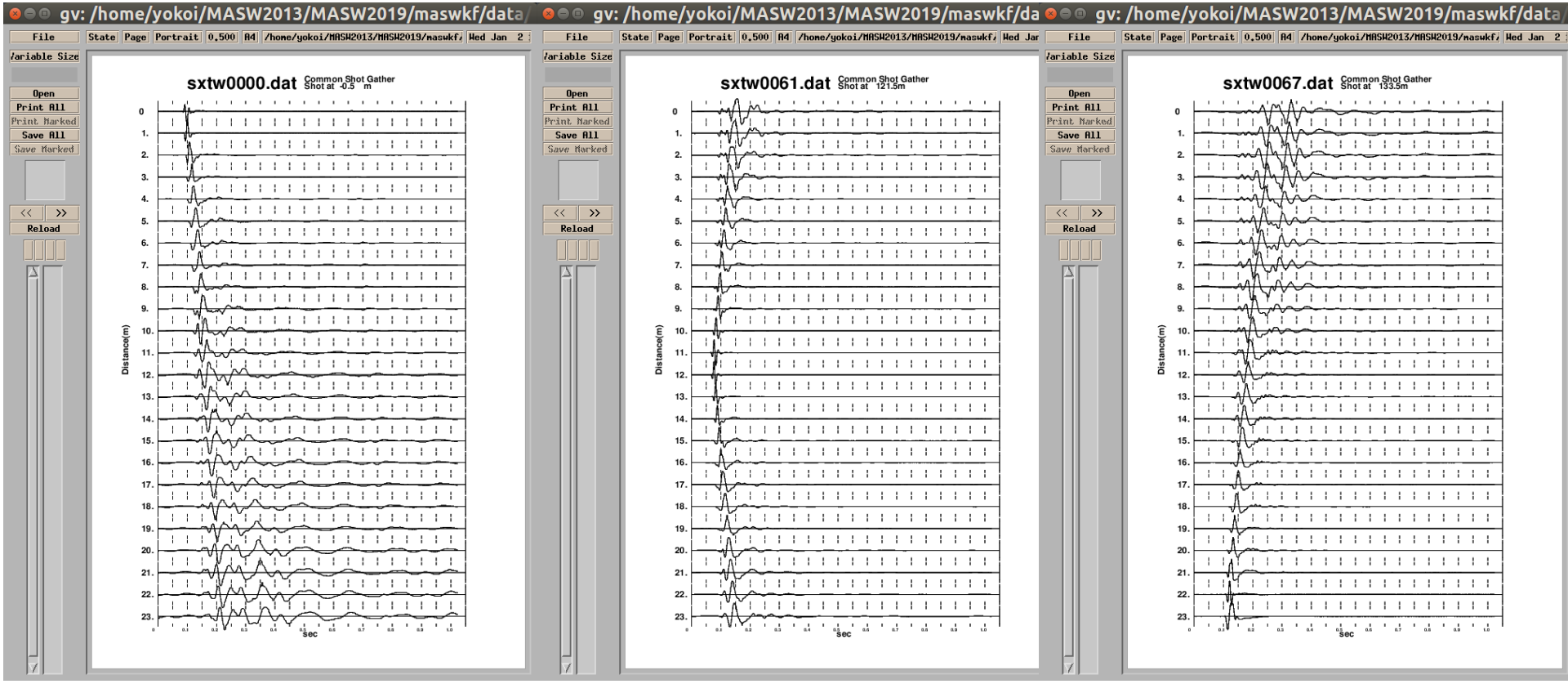
```
 24 0.00100    1024       0.100E+01
         1
0.300884E-03 0.334449E-03 0.351585E-03 0.357248E-03 0.357285E-03 0.355795E-03
0.354305E-03 0.352852E-03 0.349760E-03 0.345215E-03 0.339180E-03 0.331730E-03
0.322863E-03 0.312544E-03 0.300996E-03 0.288330E-03 0.274733E-03 0.260390E-03
…
```

1st line: Number of channels, dt, number of samples, scale factor
2nd line: channel number
3rd line: data
Below:

Writing sentences in the program (seg2read.for) used when these files were created.

```
write(2,'(i8,f8.5,i8,e16.3)')nch,dt,nn,scale
      do ich=1,mch
       write(2,'(i12)')ich
       write(2,'(6e13.6)')(xx(i,ich)/scale,i=1,nn)
      enddo
```

Example of Common Shot Gather Plot



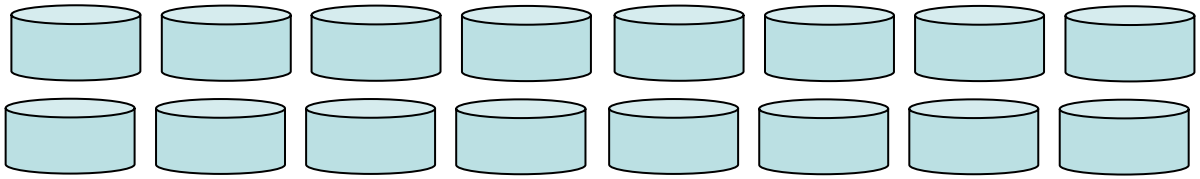
2. Instruction Manual of Programs for Analysis (2D: CMPCC-MASW)

2.3 Making Common Mid Point Gather of correlograms & Plotting Common Mid Point Gathers

sh masw2_1.sh

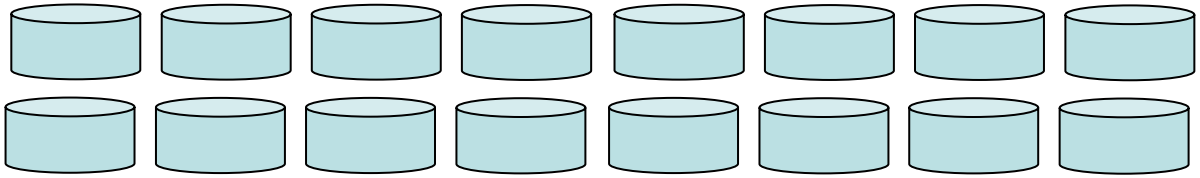
masw2_1.for + masw2_1.prm

Field Data = Common Shot Gathers



masw2_1.for + masw2_1.prm

Common Mid Point Gathers for various mid points



Run by
sh masw2_1.sh
This program uses the parameter file
./maswkf/prm/masw2_1.prm
and
./maswkf/prm/geometry.prm
to create the files of CMP gathers in the subfolder
./maswkf/data/cmp_gathers
with file name
cmp???.dat
, where ??? denotes the numbering of CMPs.

Have a coffee break during the processing, as it takes time.

masw2_1.sh

```
#!/bin/sh -x
rm ./maswkf/data/cmp_gathers/cmp*.dat 2> /dev/null
./bin/masw2_1.exe | tee maswkf/log/masw2_1.log
cd ./maswkf/data/cmp_gathers
ls *.dat > cmpfile.lst
rm ./fig/cmp*.ps 2> /dev/null
cd ../../..
./bin/seecmp24.exe | tee maswkf/log/seecmp24.log
```

Parameter File: masw2_1.prm

```
 1.0 20.0 0.001              :fmin,fmax,dt
  5.0 128.                   :dmin,dmax (min & max distance)
 1.0 24.0 1                  :rrmin,rrmax (min & max spacing),ngroup
 1  5                        :min_stack_number,min_trace_number
24 133. 1.0 1024             :# of channel for a Common Shot Gather,length
                                 of measurement line,dx,nn
```

Explanation:

1st line: (fmin, fmax) the minimum and maximum frequencies for analysis and the sampling interval(dt)

2nd line: (dmin,dmax) the minimum and maximum distance along the measurement line. CMPs between them will be processed.

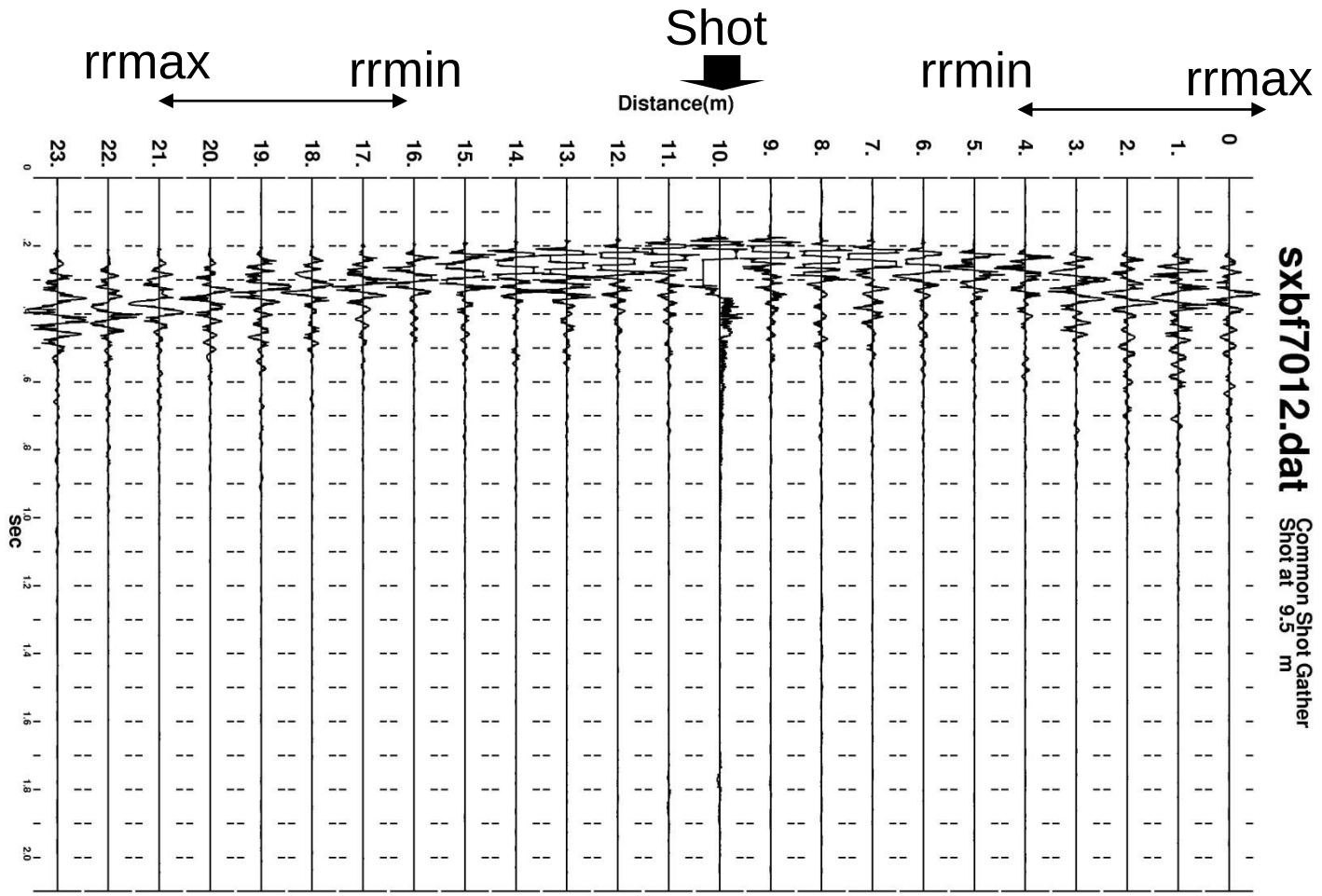
3rd line: (rrmin, rrmax) the minimum and the maximum spacing, ngroup.

4th line: the minimum stack number, minimum trace number

5th line: Number of channels for a Common Shot Gather, length of measurement line, interval between geophones, number of samples in a file

3rd line: (rrmin, rrmax) minimum and maximum distance from shot point to geophones

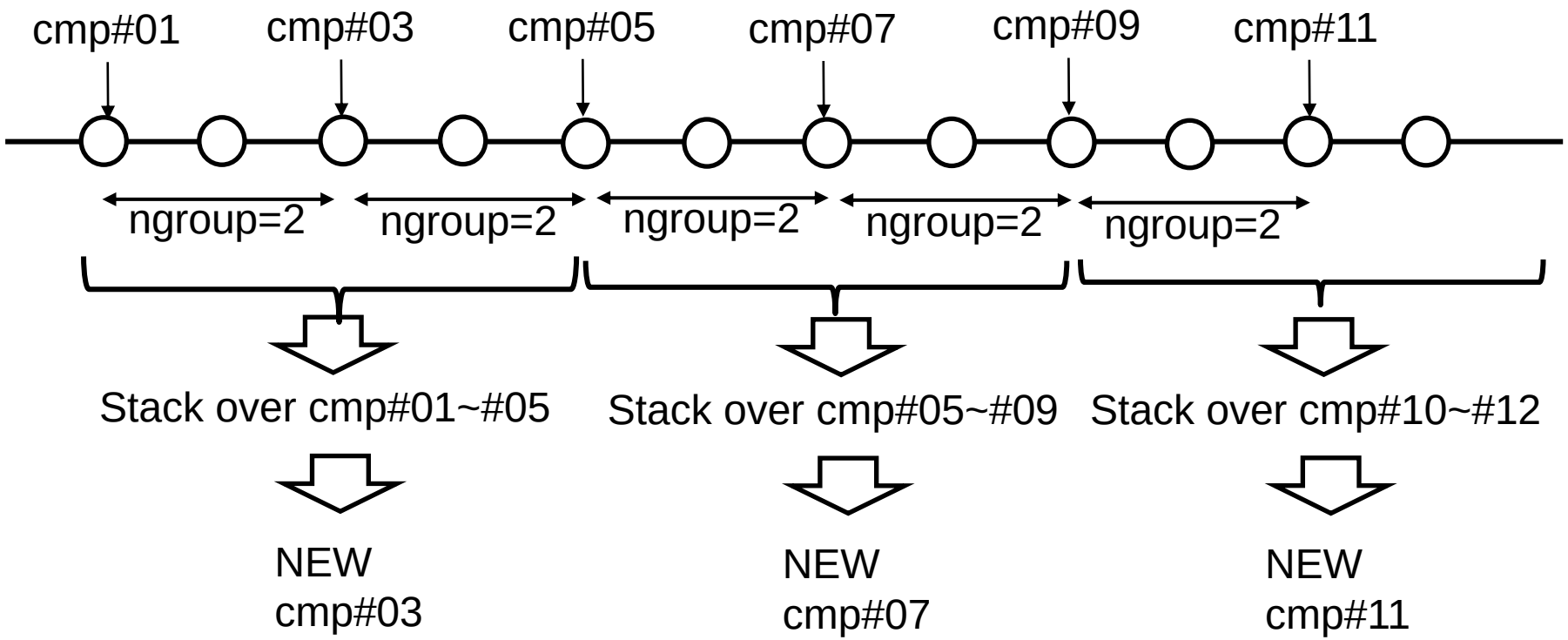
The traces nearby the shot point may be clipped and those far from may have the problem of low signal to noise ratio. Then CMP gathers are made from the traces of which distance from the shot point is between rrmin and rrmax.



3rd line: ngroup

This parameter controls the grouping of neighboring CMPs.

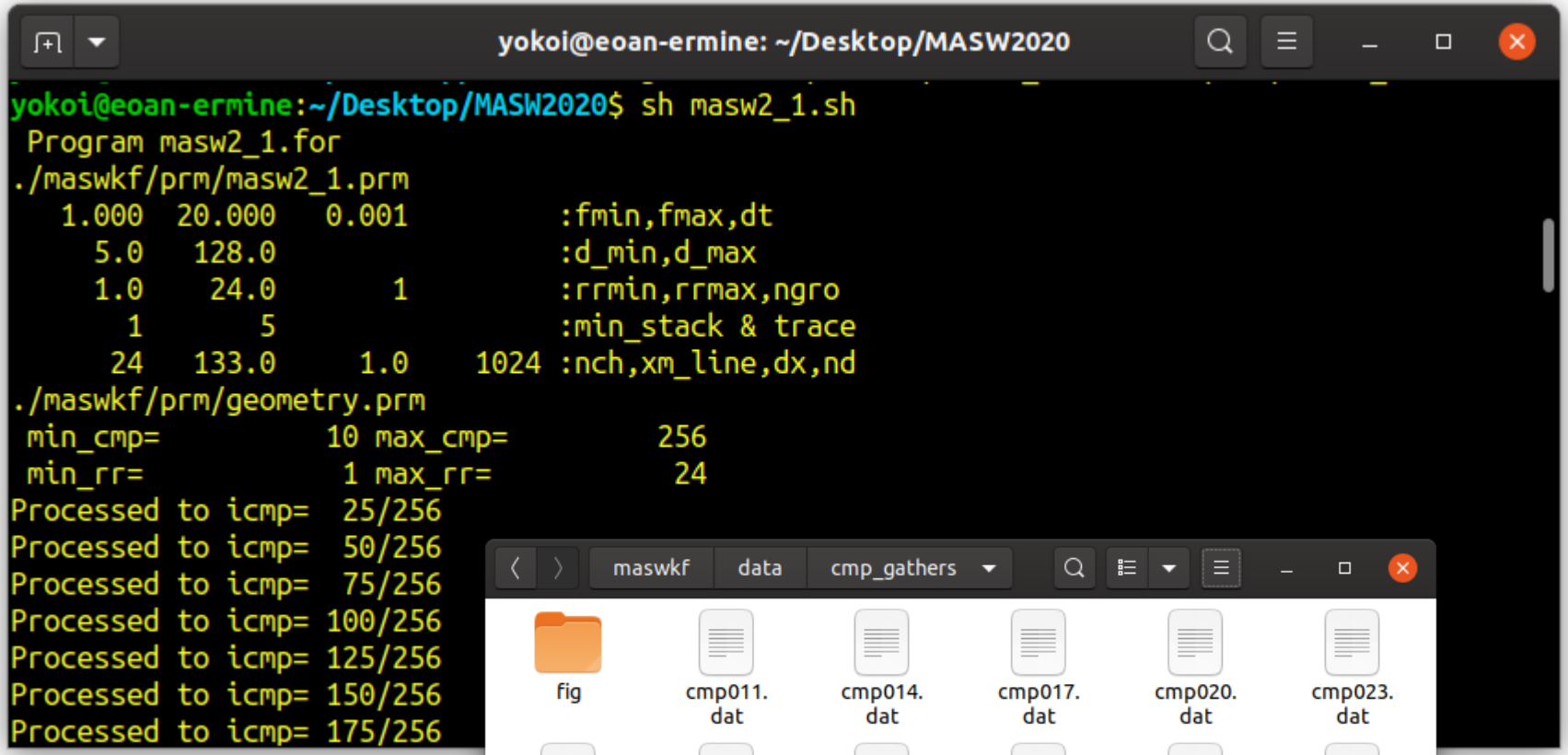
For example: if ngroup=2,

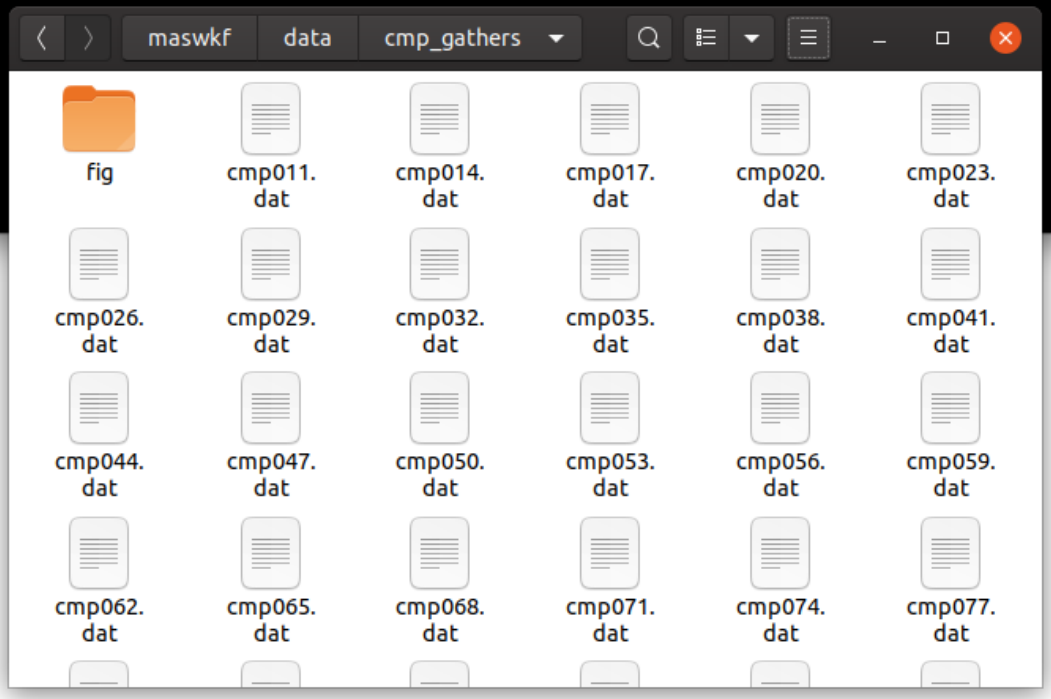


Input Files

- Common Shot Gather Files of the same measurement line that are stored in the subfolder ./maswkf/data/common_shot_gathers
- Their file name is cmp???.dat, where ??? denotes the numbering of CMP.

Execution:





Output files:

Input File Format

```
 24 0.00100    1024       0.100E+01
         1
0.300884E-03 0.334449E-03 0.351585E-03 0.357248E-03 0.357285E-03 0.355795E-03
0.354305E-03 0.352852E-03 0.349760E-03 0.345215E-03 0.339180E-03 0.331730E-03
0.322863E-03 0.312544E-03 0.300996E-03 0.288330E-03 0.274733E-03 0.260390E-03
…
```

1st line: Number of channels, dt, number of samples, scale factor
2nd line: channel number
3rd line: data
Below:

Writing sentences in the program (seg2read.for) used when these files were created.

```
write(2,'(i8,f8.5,i8,e16.3)')nch,dt,nn,scale
      do ich=kch,mch
       write(2,'(i12)')ich
       write(2,'(6e13.6)')(xx(i,ich)/scale,i=1,nn)
      enddo
```

Output File: Correlograms of Common Mid Point Gather

File names are automatically given as “cmp???.dat” , where ??? is the numbering of CMP.

```
 27  13.500   0.001    1024       9
      1   1.000  13.000  13.500  14.000       5
0.146614E-06 0.226895E-06 0.304618E-06 0.372445E-06 0.424314E-06
0.456951E-06 0.466428E-06 0.453546E-06 0.421210E-06 0.373336E-06
0.315429E-06 0.250940E-06 0.186377E-06 0.124637E-06 0.683129E-07
....
```

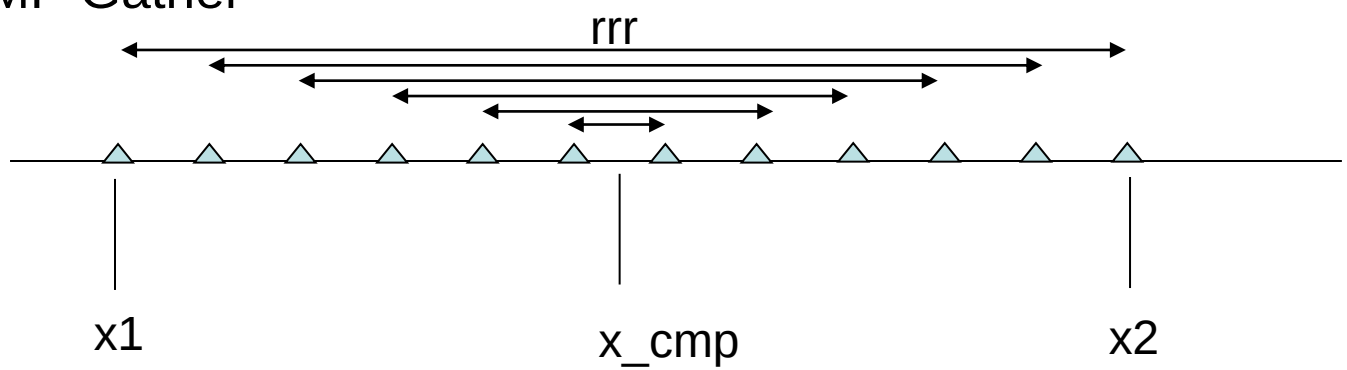
Writing sentences of the program:

```
open(13,file=filen,status='unknown')
write(13,'(i8,2f8.3,2i8)')icmp,x_cmp,dt,nn,n_trace
do irr=1,nch
 write(13,'(i8,4f8.3,i8)')irr,rrr,x1,x_cmp,x2,nstack(irr)
 write(13,'(5e13.6)')(cr(i,irr),i=1,nn)
enddo
close(13)
```

Output File: Correlograms of Common Mid Point Gather

icmp,x_cmp: Numbering and position of Common Mid Point
dt,nn,n_trace: sampling interval, number of sampling, number of correlograms
irr,rrr: Numbering of trace, spacing of CMP gather
x1,x_cmp,x2,nstack(irr): x1, Position of CMP,x2, number of stack
(cr(i,irr),i=1,nn): samples of the correlograms

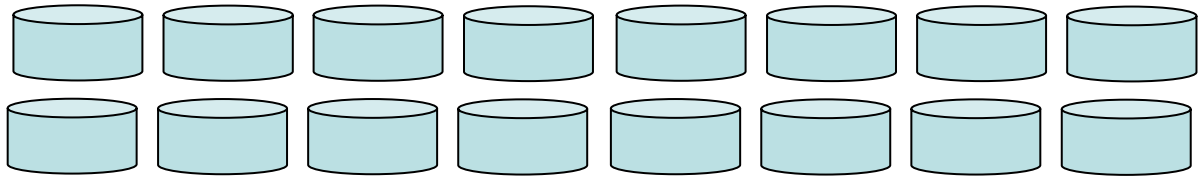
CMP Gather



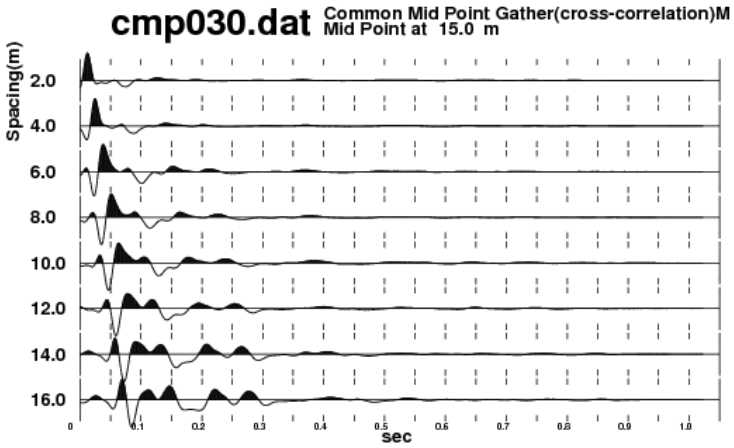
The correlograms having the same mid point and the same spacing are stacked together.

Plotting Common Mid Point Gathers

Common Mid Point Gathers cmp???.dat



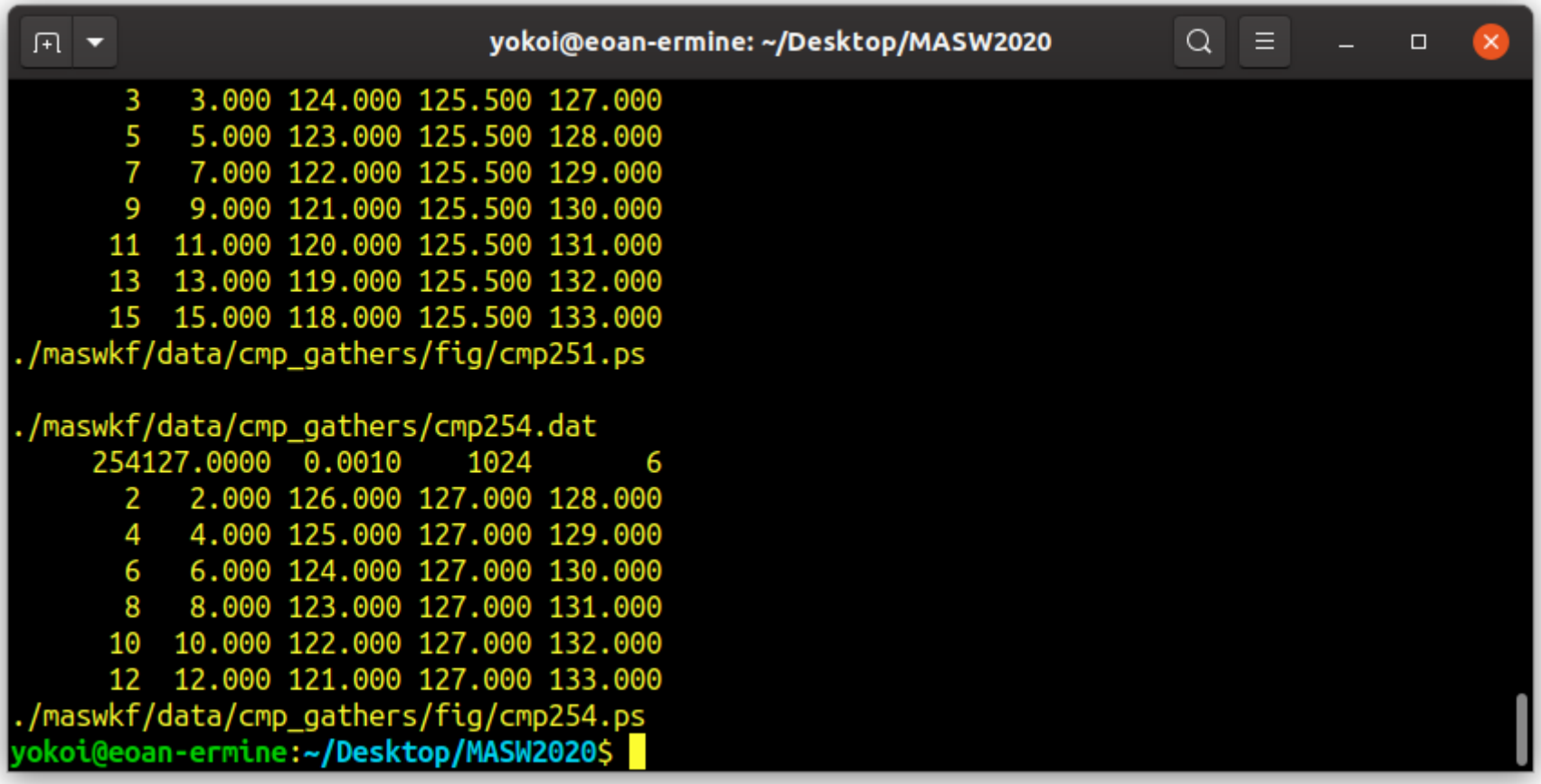
seecmp24.for
+ see2cmp24.prm



Plot CMP traces
cmp???.ps

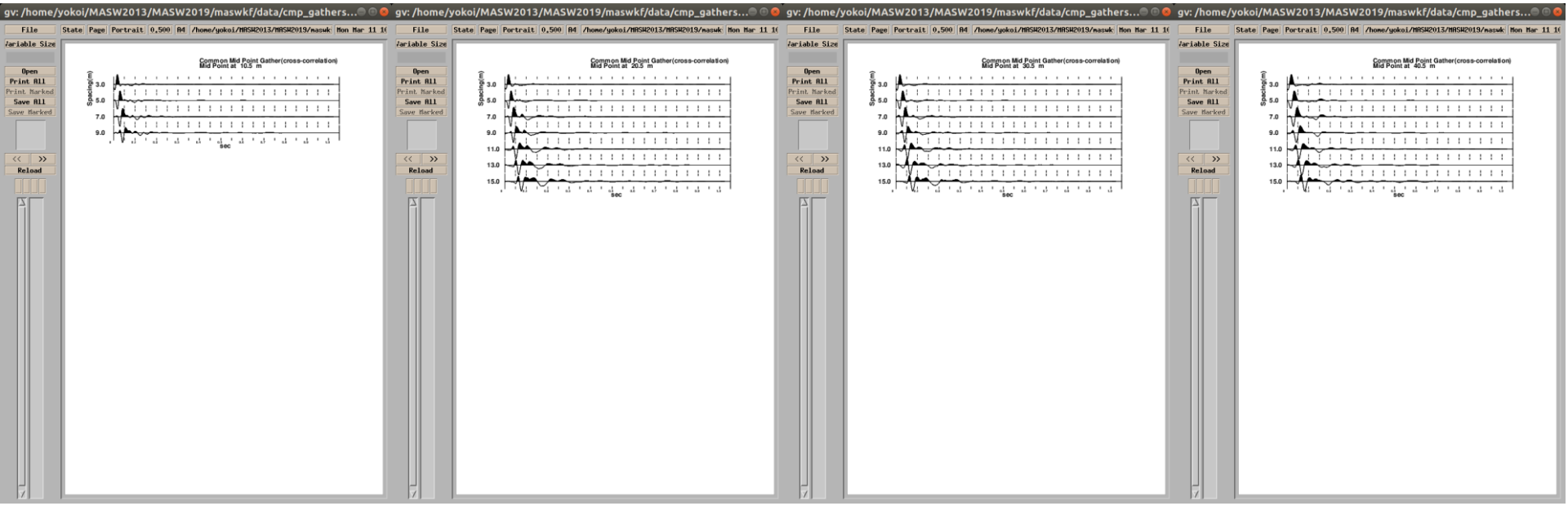
Parameter File

0	:Flag for normalize(=0; by max. of each ch,=1: by max. of all channels)



Input files: the output files of masw2_1.exe, that are Common Offset Gathers. These are stored in ./maswkf/data/cmp_gathers

Output files:
in Post Script (PS) format
A file is created for each Common Mid Point Gather and stored in ./maswkf/data/cmp_gathers/fig
These files can be opened, for example, using Ghostview: gv &



Note: Sufficient number of correlograms can not be obtained at close to the ends of measurement line.

3. Instruction Manual of Programs for Analysis

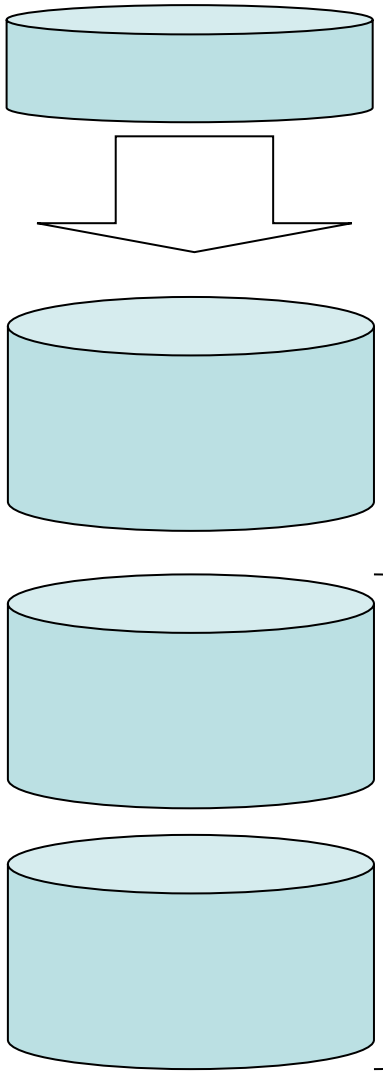
3.1 Velocity Analysis using CMP Gathers

masw2cmp.for + masw2cmp.prm

and

masw2cmp2D.for + masw2cmp2D.prm

Common Mid Point Gathers
cmp???.dat



masw2cmp.for
+ masw2cmp.prm
+ geometry.prm

Output: dispersion Curve Files for each CMP gather

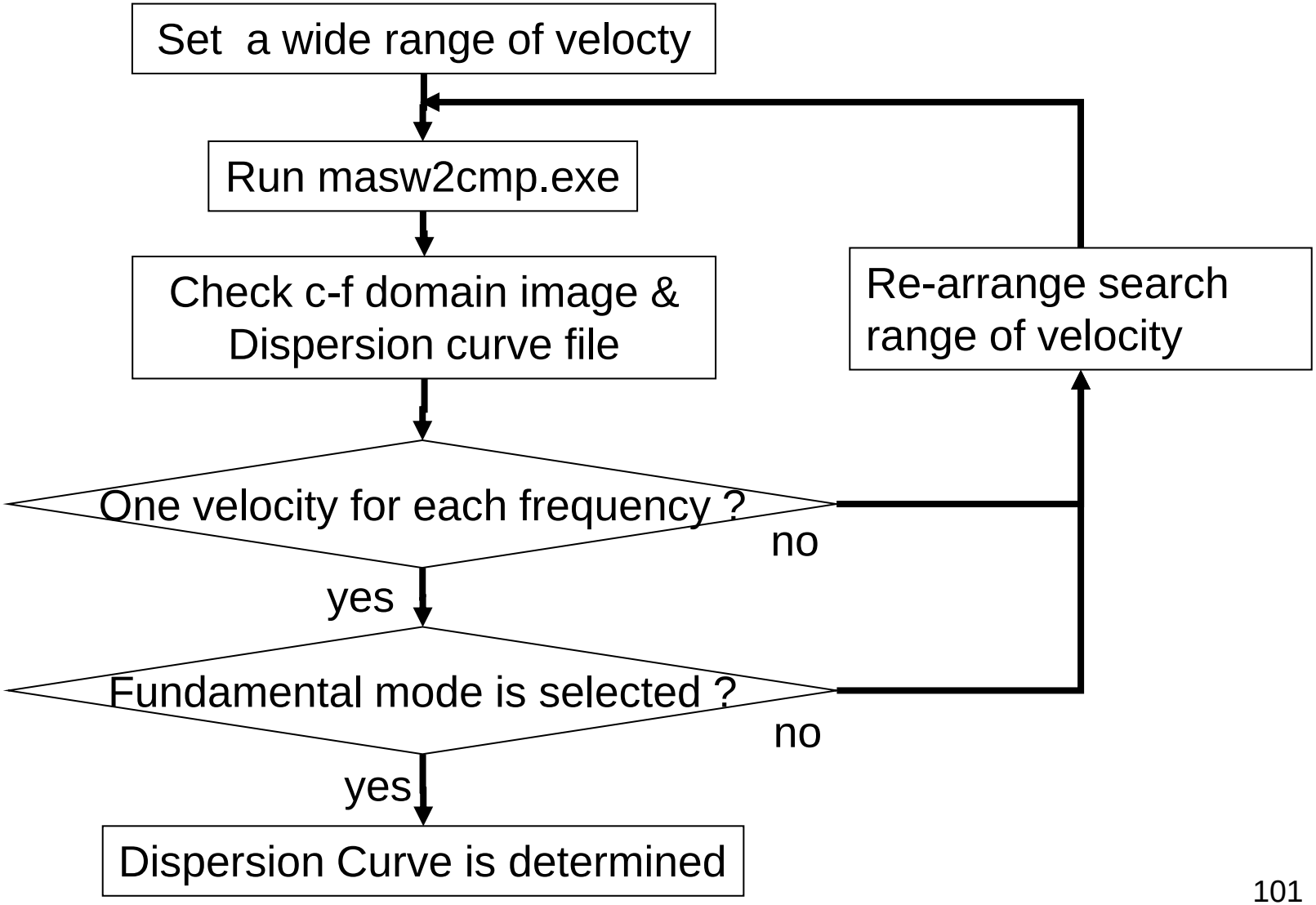
GNUPLOT script files for drawings

Interim output files for the c-f domain image and peaks

PostScript files for images in the c-f domain

Interactive Task between man (the operator) and machine (the programs) is required, because it is necessary to change the values of the control parameters due to the gradual changes of the dispersion curve CMP by CMP.

Task Flow of Velocity Analysis



Input File: cmp???.dat

Input files: the output files of masw2_1.exe, that are Common Mid Point Gathers. These are stored in the subfolder ./maswkf/data/cmp_gathers

Output File

Interim output files:
./maswkf/data/c_f_panels/coh_pk???.dat
(data files for the peak locations in the c-f domain image)

Dispersion curve files:
./maswkf/data/dispersion/cmp???ds.dat

GNUPLOT script files:
./maswkf/prm/gnuplt_script/c_f_panels/masw???.plt

PostScript files
./maswkf/data/c_f_panels/fig/cmp???.ps

, where ??? denotes the numbering of CMP.

Parameter File: masw2cmp.prm in ./maswkf/prm

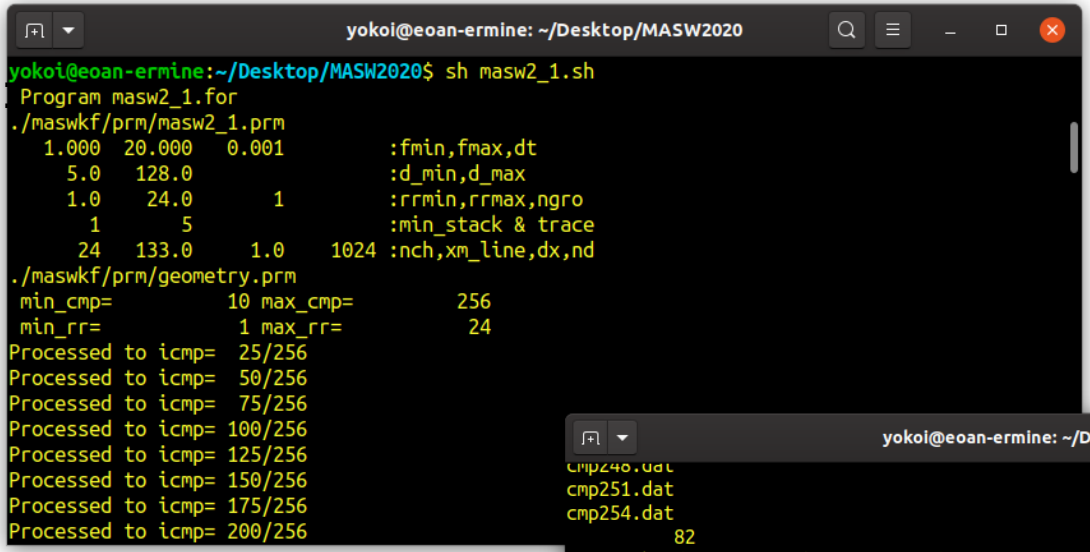
```
1.0 20.0 0.001  1         :fmin,fmax,dt,n_parzen(=0, No, =1, Yes)
 1   0                    :n_cf_domain,normalize(=0 all, =1 each freq.)
  50.  300. 1.0  0        :vmin,vmax,dv,ndisplay
 2.0  90.0 12.0 100.0 20.0 110.0 : ! lower limit
 2.0 250.0 10.0 150.0 20.0 150.0 : ! upper limit
```

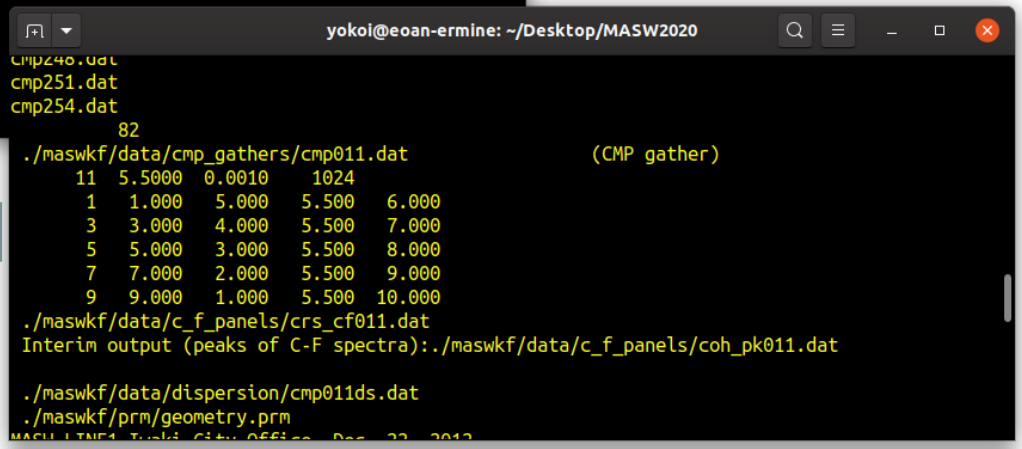
(f1,v1),(f2,v2),(f3,v3) for lower and upper limits are explained in the slide of output file. They control the search range for peaks on the result of the velocity analysis.

(fmin,fmax,dt) must be the same as those used in “masw2_1.prm”.

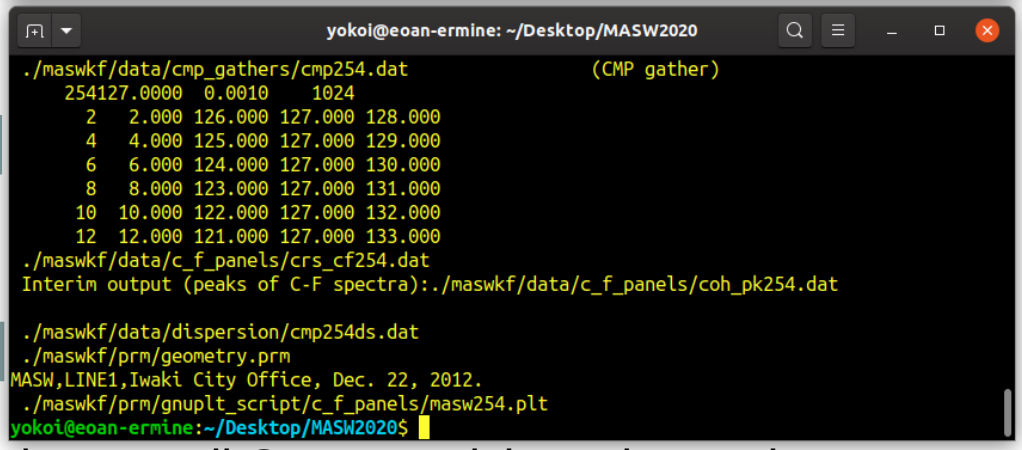
./maswkf/prm/geometry.prm is also read.

Execution





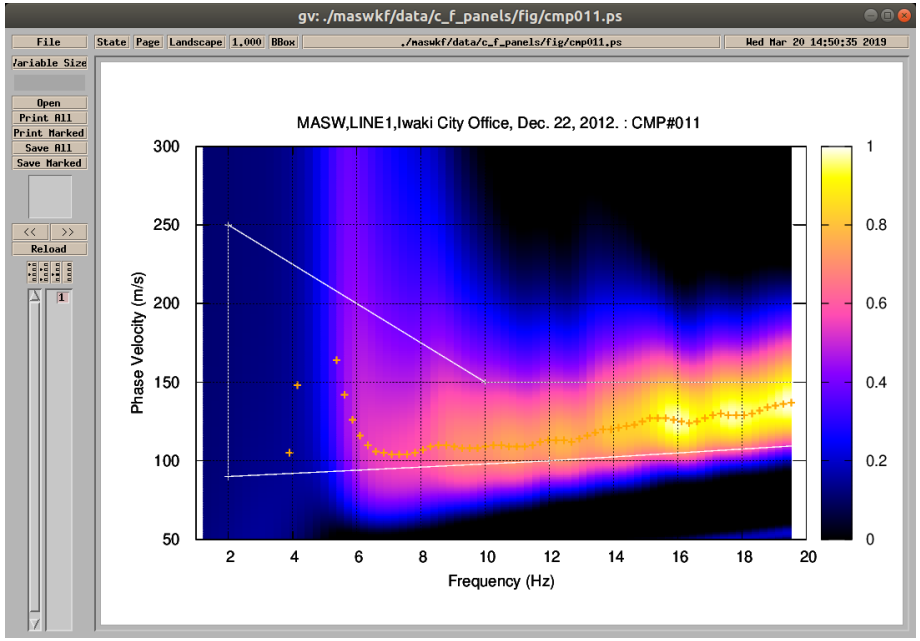
The 1st CMP:
cmp011.dat
crs_cf011.dat
coh_pk011.dat
cmp011ds.dat



The last CMP:
cmp254.dat
crs_cf254.dat
coh_pk254.dat
cmp254ds.dat

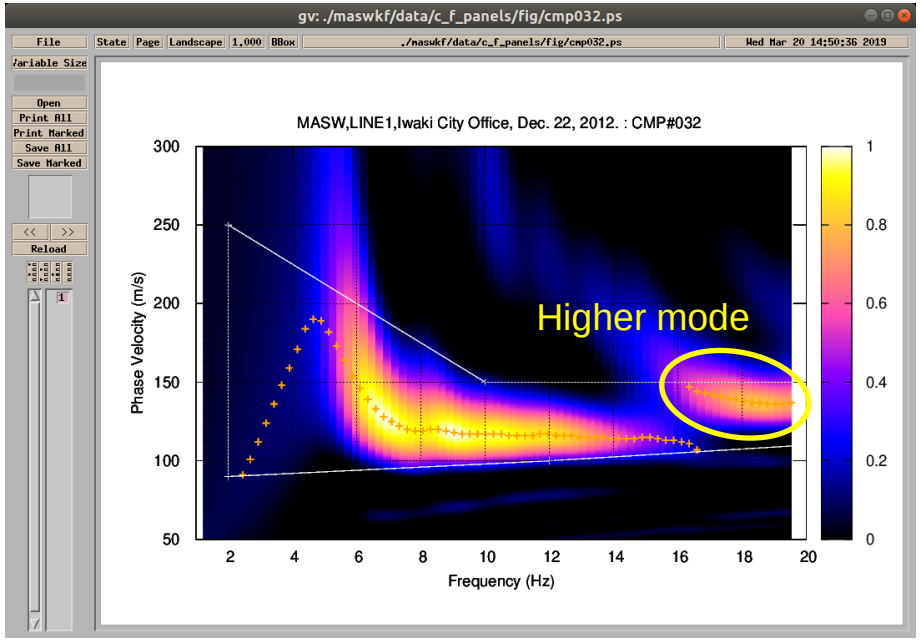
PostScript file:
cmp011.ps……cmp254.ps

masw2cmp.sh applies the same C-F windows to all CMPs to pick up the peaks.
With “gv &” PostScript files can be browsed.



Example: CMP#011

For some CMPs the applied C-F window can pick up the peaks of C-F spectra at each frequency, i.e., the phase velocity as a single valued function.



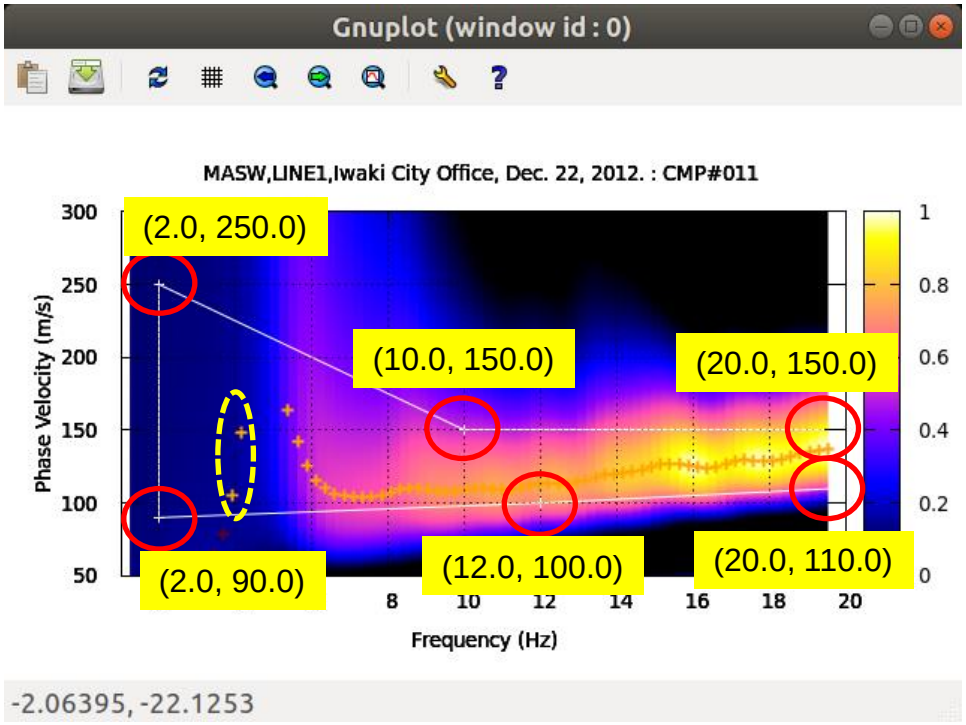
Example: CMP#032

However, for other CMPs the applied C-F window erroneously pick up the peaks of C-F spectra at each frequency, but from the higher order mode or noises.

Individual arrangement is needed.

C-F window limits the search range for peaks of C-F spectra to exclude peaks of higher modes and accidentally appearing ones by noises. CFW shown by the white polygon on C-F panel is defined upper and lower limit lines independently composed of three pairs of frequency-phase velocity, of which values are given in the fourth and fifth lines of "masw2cmp.prm". Some of these points can be selected outside the C-F panel. Peaks in the common range of the given CFW and the C-F panel are selected for the analysis in next steps.

For example, two strange peaks are observed in yellow broken ellipse. These can be eliminated by re-setting CFW in the next steps.




```
masw2cmp.prm
1.0 20.0 0.001  1          :fmin,fmax,dt,n_parzen(=0, No, =1, Yes)
 1   0                     :n_cf_domain,normalize(=0 all, =1 each freq.)
  50.  300. 1.0  0         :vmin,vmax,dv,ndisplay
 2.0  90.0 12.0 100.0 20.0 110.0 : ! lower limit
 2.0 250.0 10.0 150.0 20.0 150.0 : ! upper limit
```

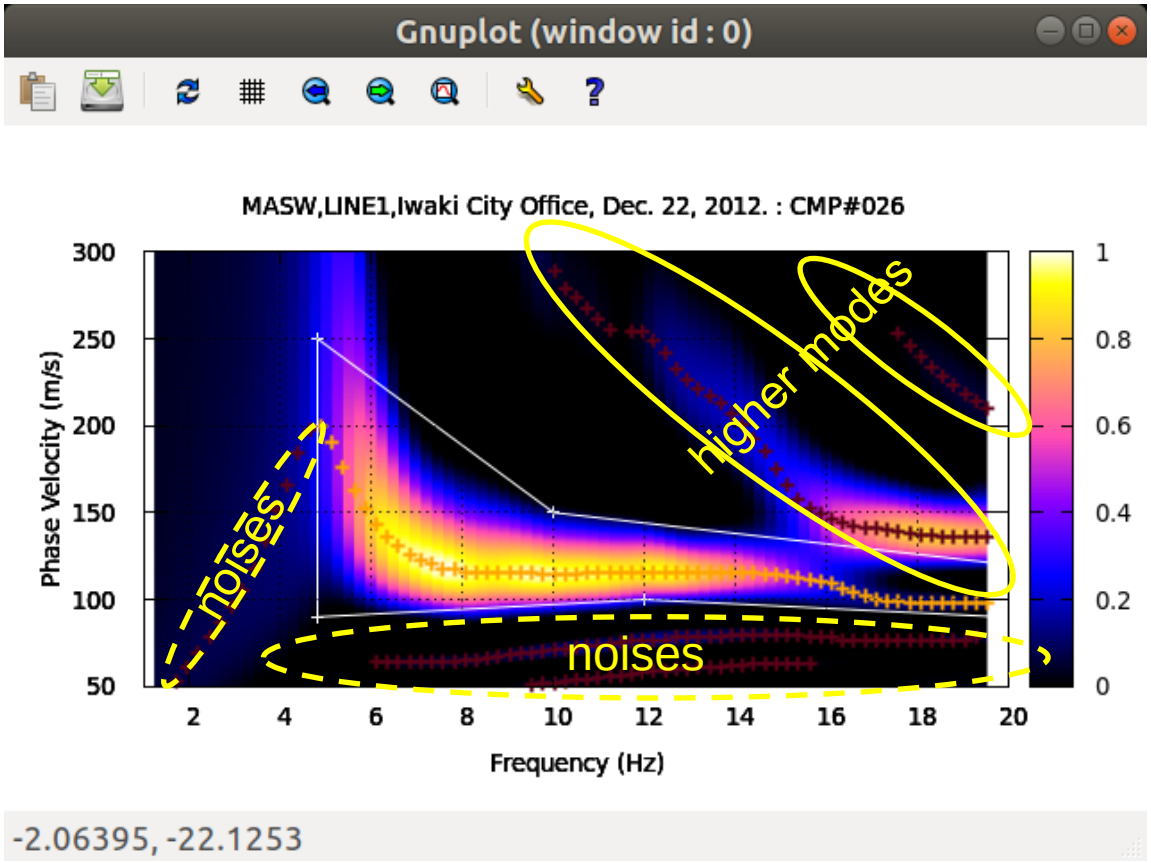
3. Instruction Manual of Programs for Analysis

3.2 Individual Arrange of Dispersion Curve for each CMP

masw2cmp2D.sh

masw2cmp2D.for + masw2cmp.prm

“masw2cmp.sh” sometimes pick up the peaks of C-F spectra of the higher modes and also those caused by unknown but un-desirable noises included in observed records or generated during data processing.
“masw2cmp2D.sh” is for the individual arrangement of dispersion curves estimated using “masw2cmp.sh”.

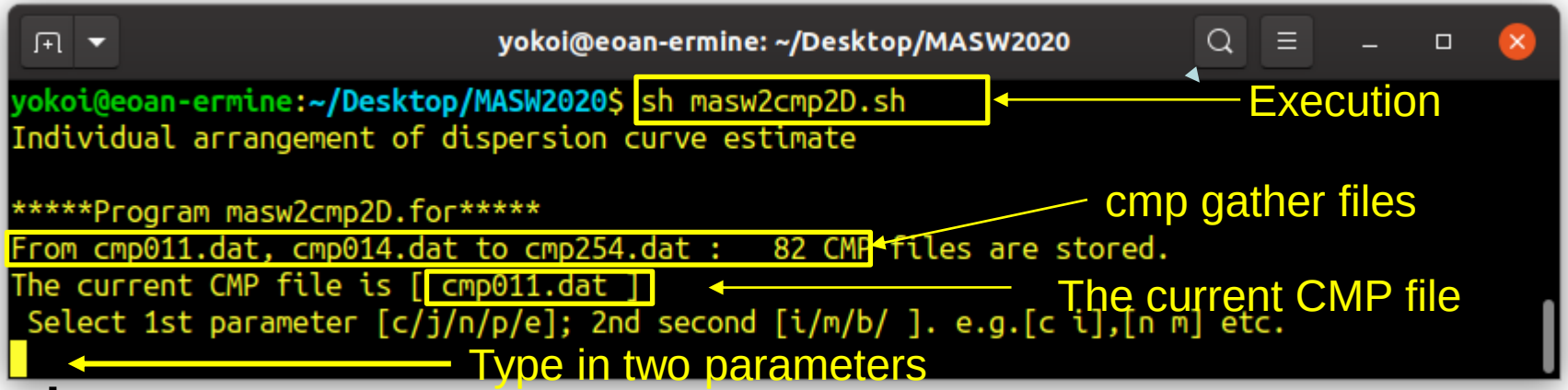


Check and better the individual dispersion curve one by one using

sh masw2cmp2D.sh

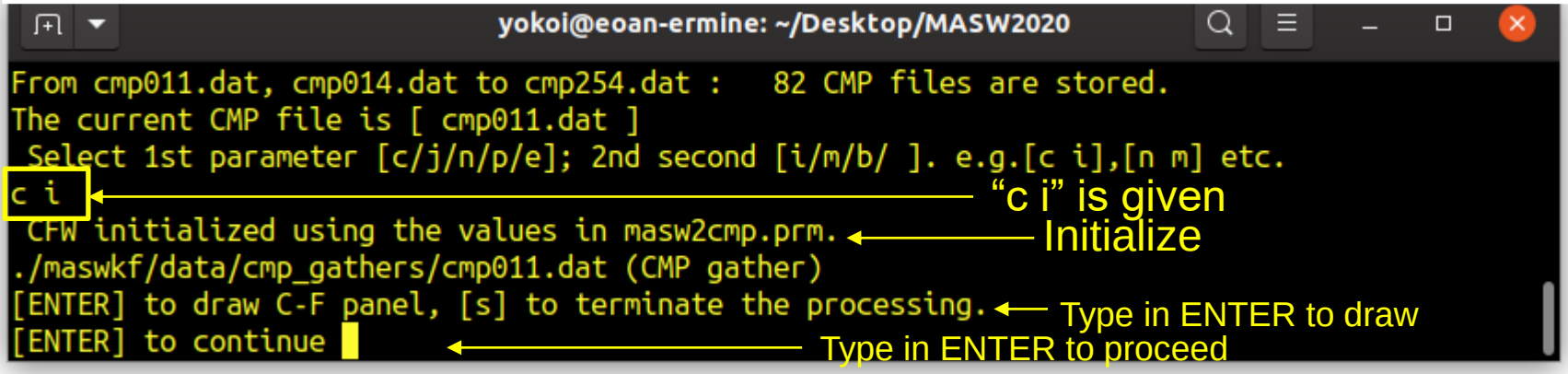
```
#!/bin/sh -x
echo "Individual arrangement of dispersion curve estimate"
while [ "$key" != "s" ]
do
  ./bin/masw2cmp2D.exe | tee maswkf/log/masw2cmp2D.log
  echo -n "[ENTER] to draw C-F panel, [s] to terminate the processing. "
  read key
  if [ "$key" != "s" ] ; then
  gnuplot -e "
  load './maswkf/prm/gnuplt_script/c_f_panels/multi_cf.plt';
  "
  fi
done
rm ./maswkf/temp/temp20.dat 2> /dev/null
rm ./maswkf/temp/temp33.dat 2> /dev/null
```

Execution:



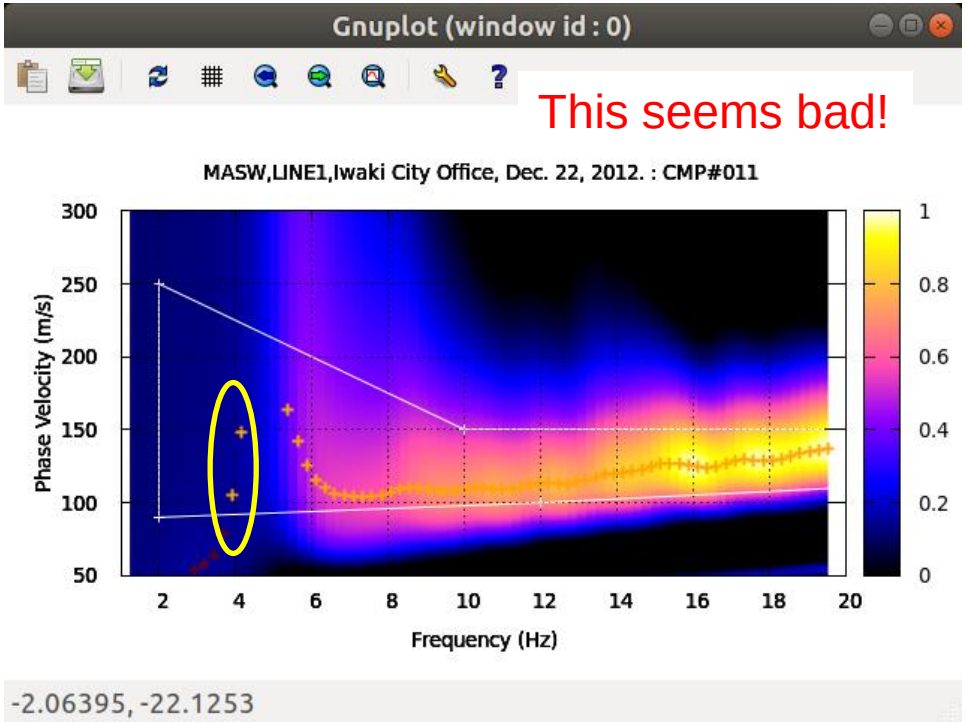

```
[c]: Process [current]   CMP with current C-F window
[j]: [jump] to specified CMP with current C-F window
[n]: Proceed to [next]   CMP with current C-F window
[p]: Back to [previous]  CMP with current C-F window
[e]: end/terminate the processing
Additional command (use as [c i], [n m] etc.)
[i]: [initialize] C-F win. with that of masw2cmp.prm
[m]: [modify] C-F win. by typing in the parameters
[b]: C-F win. used previously for the specified CMP
[ ]: Default: to use the current C-F window. It is not
     necessary to type-in a space.
```

How to start processing?:



"masw2cmp2D.sh" usually used after the execution of "masw2cmp.sh". Then, at the beginning the current CMP is set at the first file. In case of re-starting other files can be selected as the initial one.

The given dispersion curve has some inappropriate data due to noise.
It is necessary to exclude them by arranging the C-F window indicated with white polygon.



As the dispersion curve in the previous slide shows an inappropriate feature, we try to modify the C-F window using “c m” as shown in this slide.


```
yokoi@eoan-ermine: ~/Desktop/MASW2020
 Select 1st parameter [c/j/n/p/e]; 2nd second [i/m/b/ ]. e.g.[c i],[n m] etc.
c m
 Input the new parameters.
    2.0   250.0    10.0   150.0    20.0   150.0 : ! upper limit
    5.0   250.0    10.0   150.0    20.0   150.0
    2.0    90.0    12.0   100.0    20.0   110.0 : ! lower limit
    5.0    90.0    12.0   100.0    20.0   110.0
 CFW renewed using the typed-in values.
./maswkf/data/cmp_gathers/cmp011.dat (CMP gather)
[ENTER] to draw C-F panel, [s] to terminate the processing.
[ENTER] to continue
```

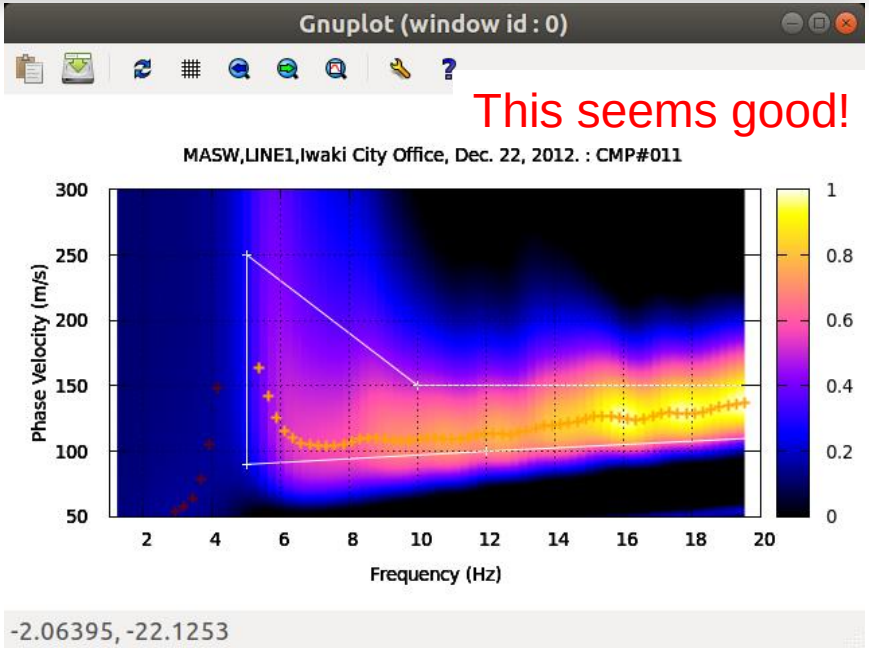
“c m” is given

Replaced C-F window

Type in ENTER to draw

Type in ENTER to proceed

Inappropriate data are removed by new C-F window (white polygon). Then Move to the next.



yokoi@eoan-ermine: ~/Desktop/MASW2020

```
*****Program masw2cmp2D.for*****
From cmp011.dat, cmp014.dat to cmp254.dat :   82 CMP files are stored.
The current CMP file is [ cmp011.dat ]
 Select 1st parameter [c/j/n/p/e]; 2nd second [i/m/b/ ]. e.g.[c i],[n m] etc.
n
 CFW of the default values in cmpfcntl.prm.
./maswkf/data/cmp_gathers/cmp014.dat (CMP gather)
[ENTER] to draw C-F panel, [s] to terminate the processing.
[ENTER] to continue

*****Program masw2cmp2D.for*****
From cmp011.dat, cmp014.dat to cmp254.dat :   82 CMP files are stored.
The current CMP file is [ cmp014.dat ]
 Select 1st parameter [c/j/n/p/e]; 2nd second [i/m/b/ ]. e.g.[c i],[n m] etc.
c m
 Input the new parameters.
    5.0  250.0   10.0  150.0   20.0  150.0 : ! upper limit
    4.8  250.0   10.0  150.0   20.0  150.0
    5.0   90.0   12.0  100.0   20.0  110.0 : ! lower limit
    4.8   90.0   12.0  100.0   20.0  110.0
 CFW renewed using the typed-in values.
./maswkf/data/cmp_gathers/cmp014.dat (CMP gather)
[ENTER] to draw C-F panel, [s] to terminate the processi
[ENTER] to continue
```

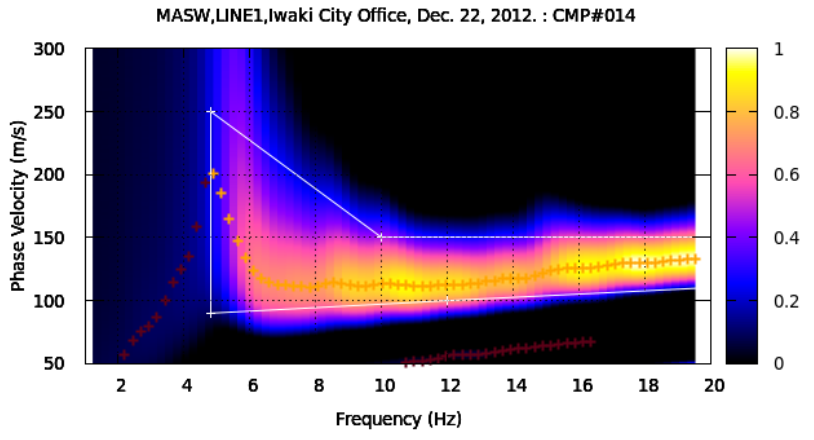
"n" is given

Type in ENTER to draw

Type in ENTER to proceed

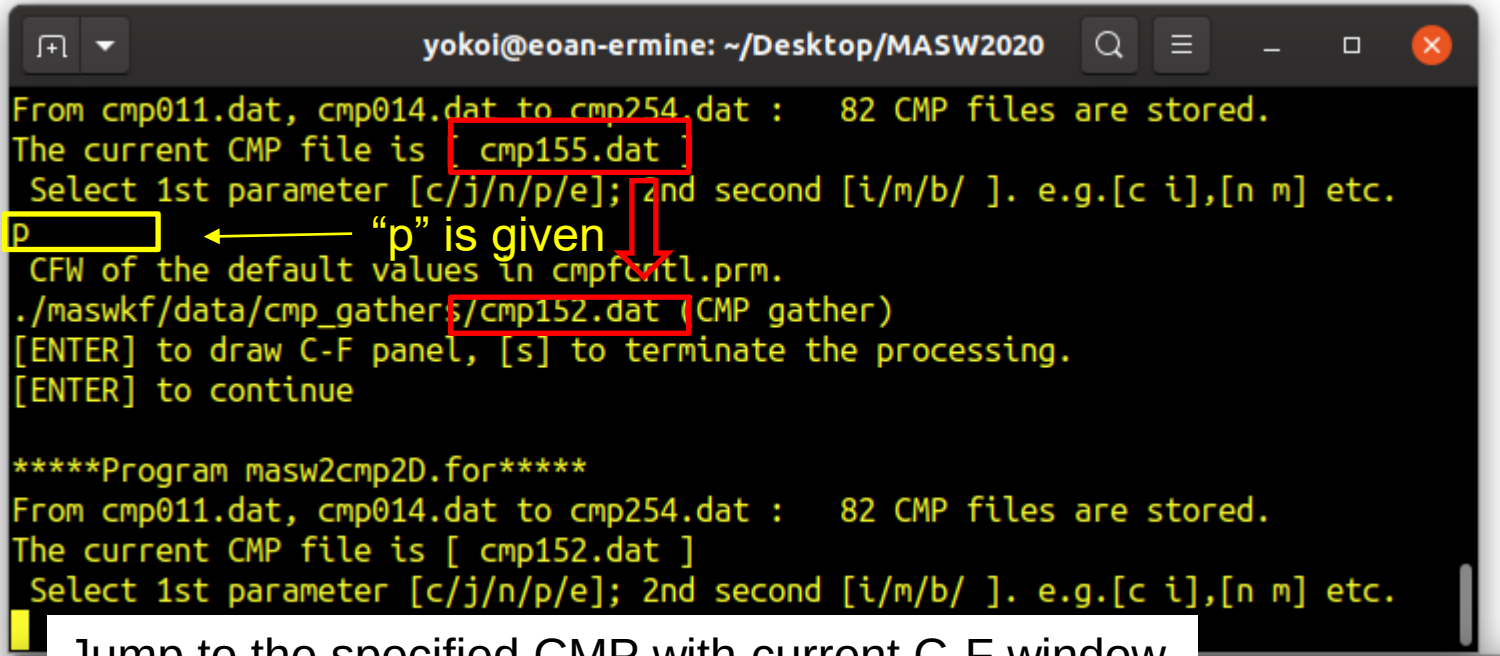
Gnuplot (window id : 0)

This seems good!

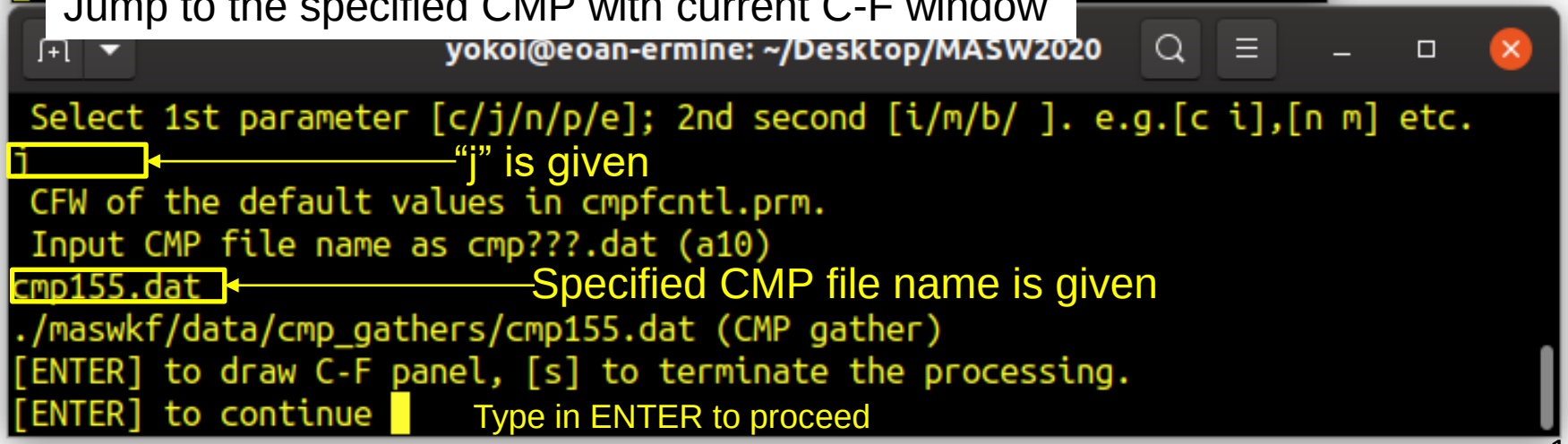


The C-F window is modified at the second trial for the cmg014.dat, and an appropriate dispersion curve is obtained as indicated with Orange "+"s. Dark scarlet "+"s are peaks not selected.

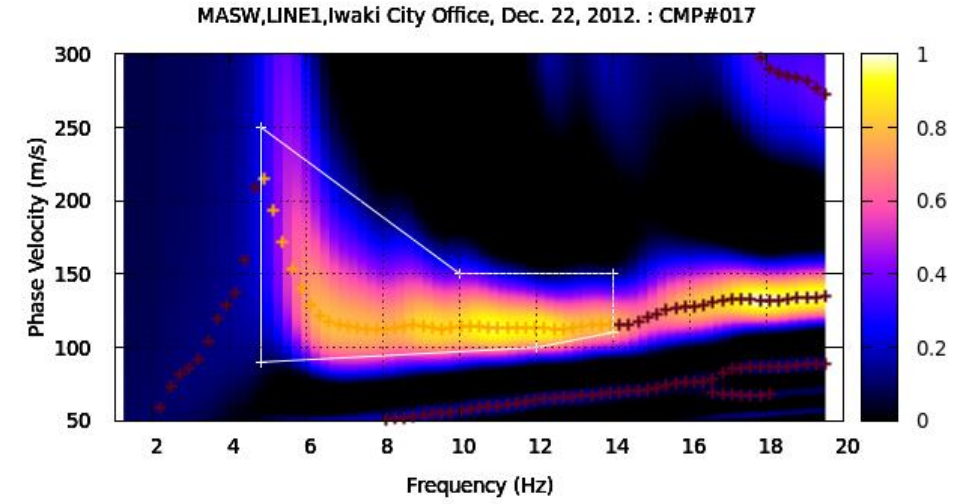
Return to the previous CMP with current C-F window



Jump to the specified CMP with current C-F window

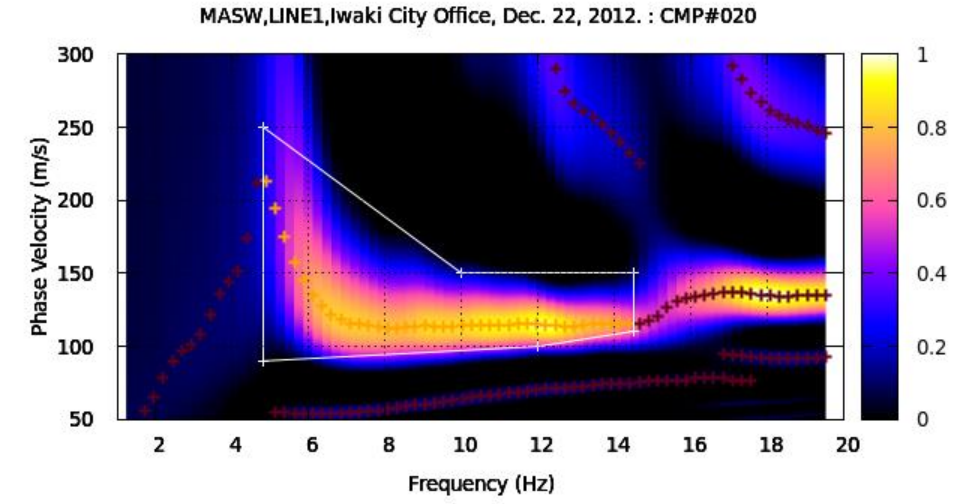


Gnuplot (window id : 0)



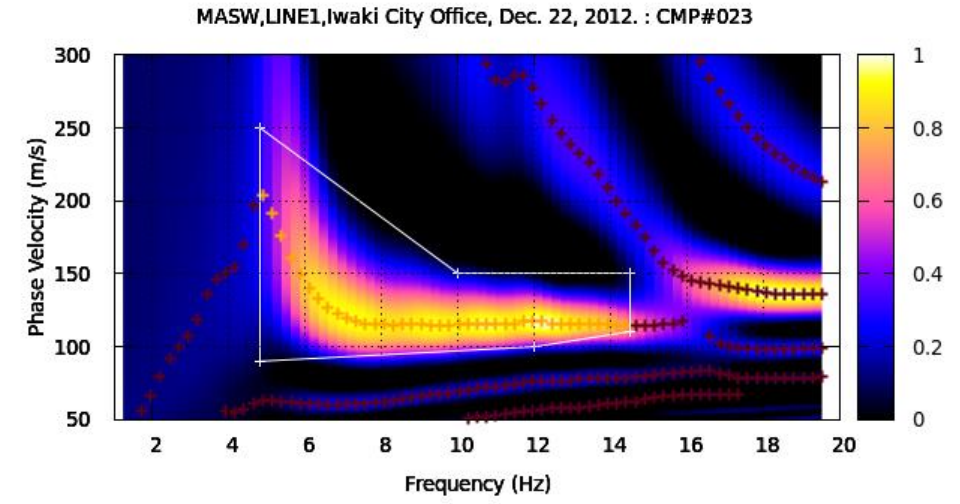
-2.06395, -22.1253

Gnuplot (window id : 0)



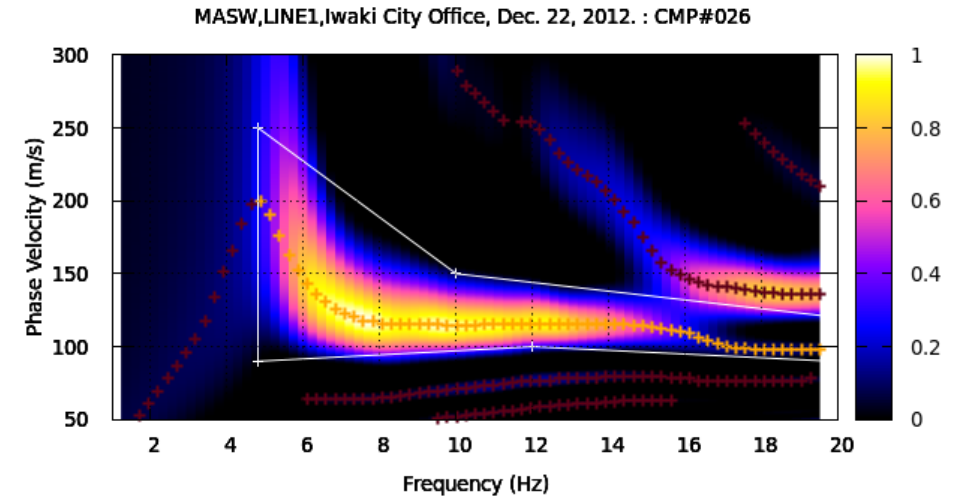
-2.06395, -22.1253

Gnuplot (window id : 0)



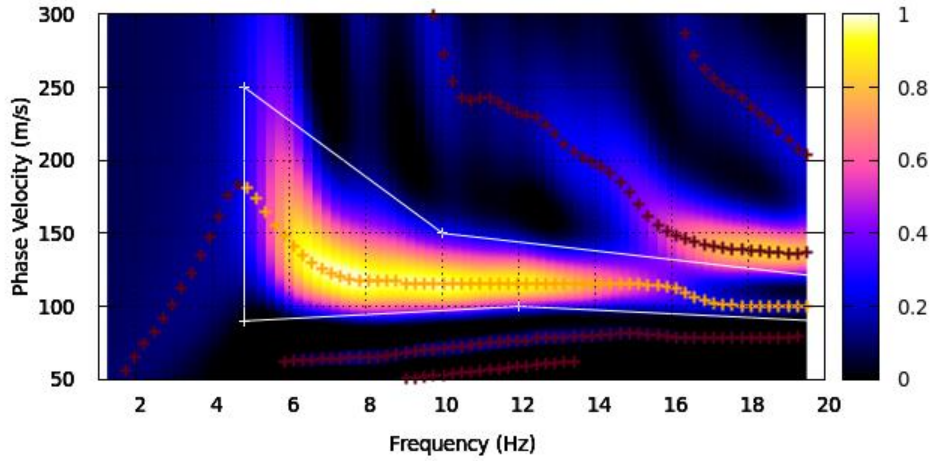
-2.06395, -22.1253

Gnuplot (window id : 0)



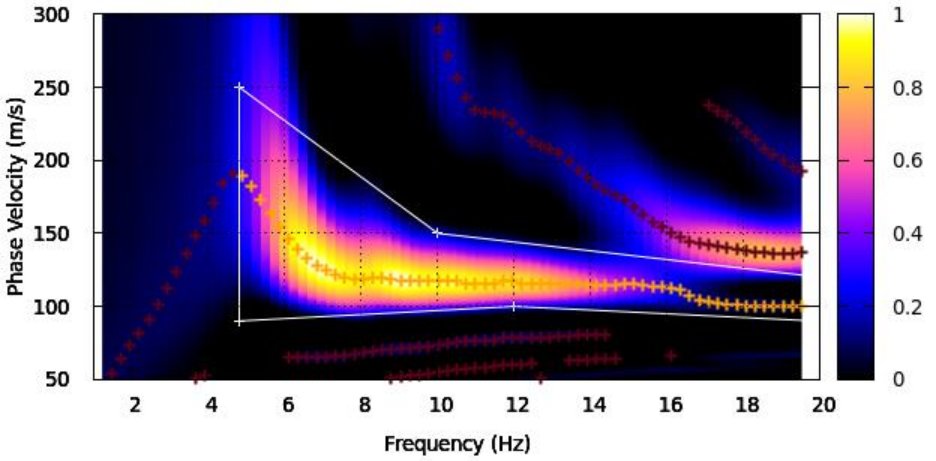
-2.06395, -22.1253

Gnuplot (window id : 0)



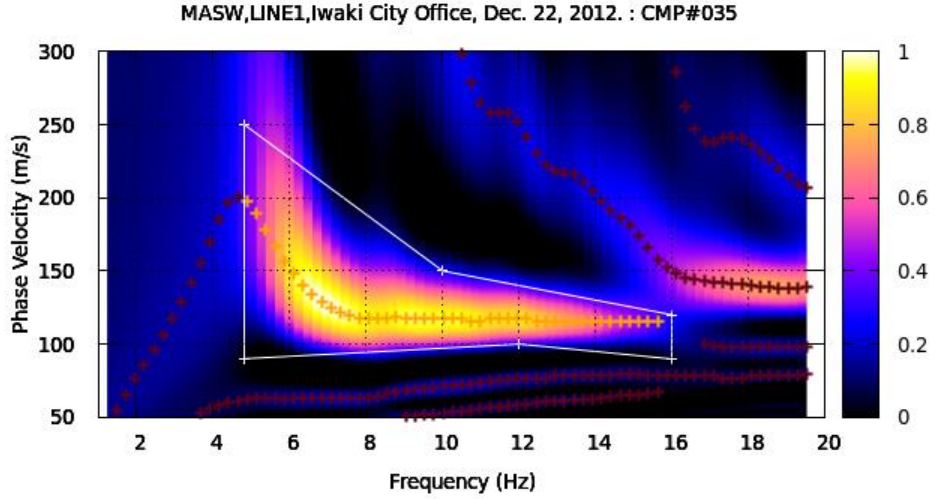
-2.06395, -22.1253

Gnuplot (window id : 0)



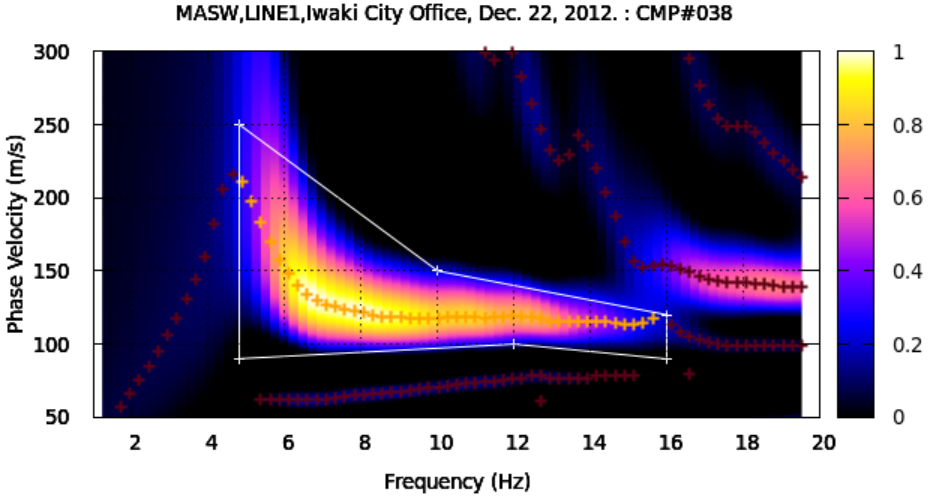
-2.06395, -22.1253

Gnuplot (window id : 0)



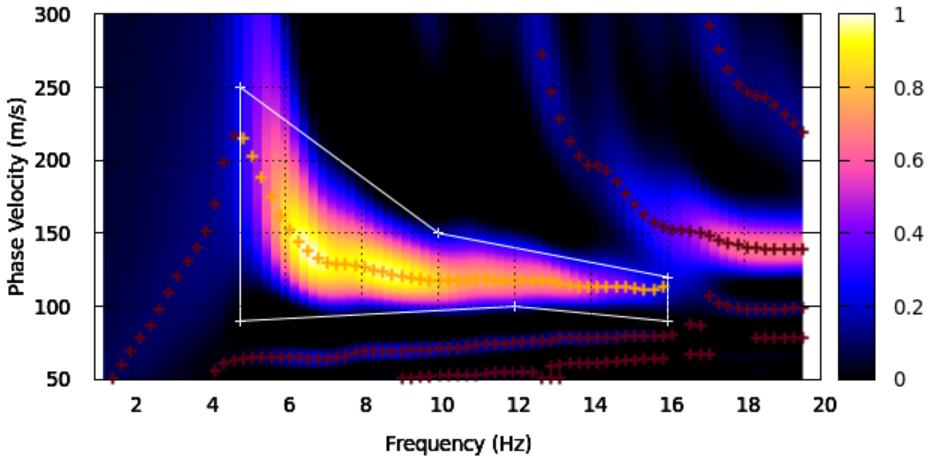
-2.06395, -22.1253

Gnuplot (window id : 0)



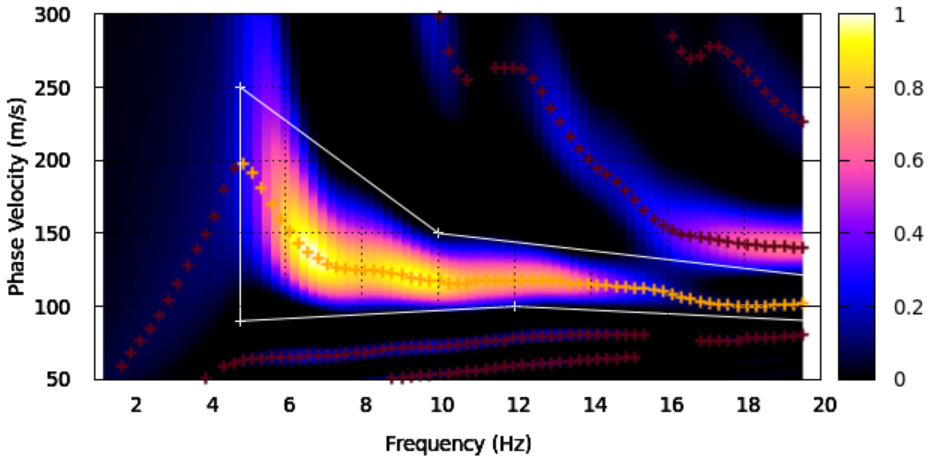
-2.06395, -22.1253

Gnuplot (window id : 0)



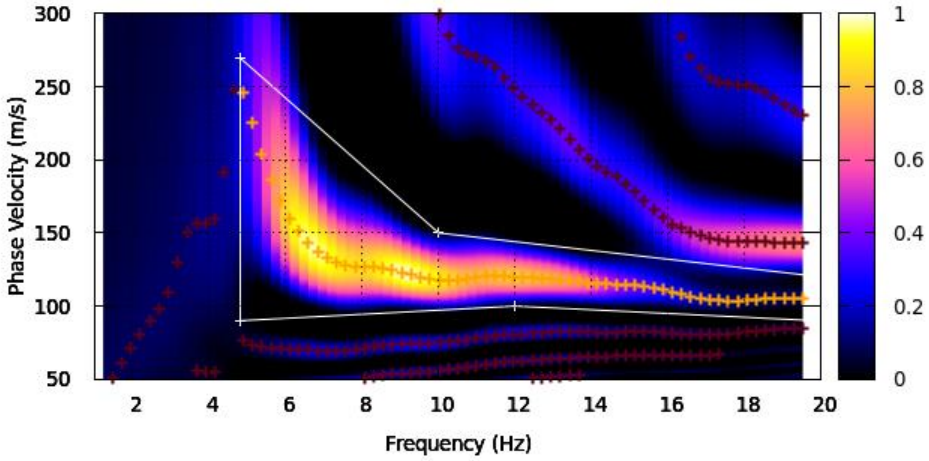
-2.06395, -22.1253

Gnuplot (window id : 0)



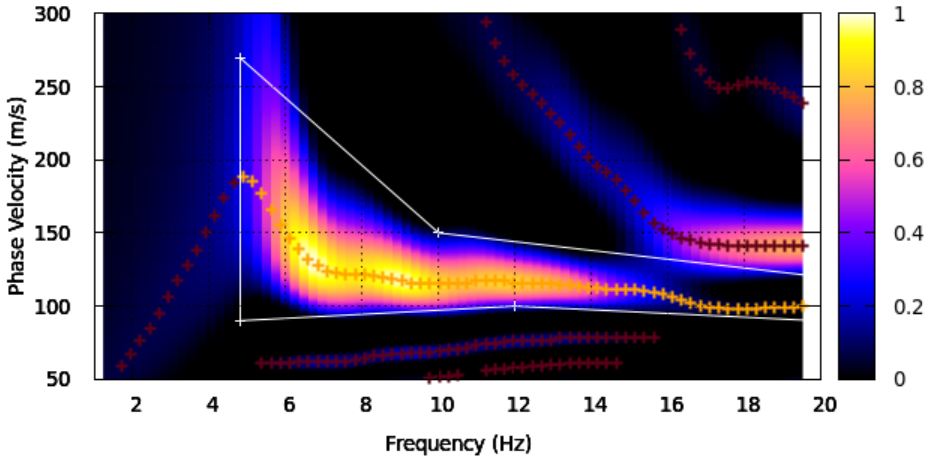
-2.06395, -22.1253

Gnuplot (window id : 0)



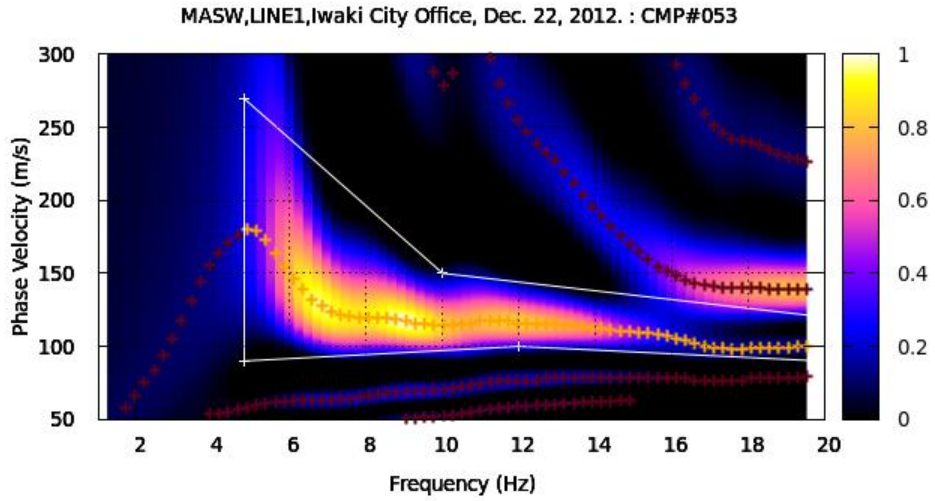
-2.06395, -22.1253

Gnuplot (window id : 0)



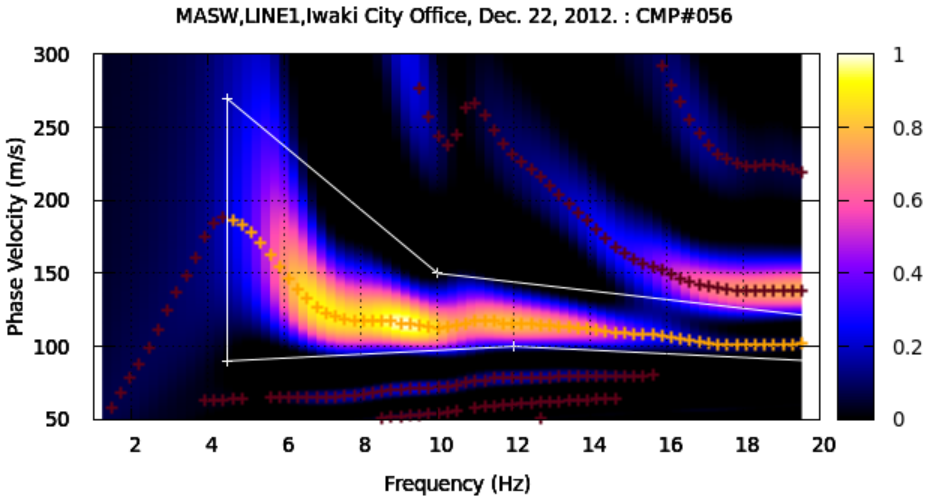
-2.06395, -22.1253

Gnuplot (window id : 0)



-2.06395, -22.1253

Gnuplot (window id : 0)



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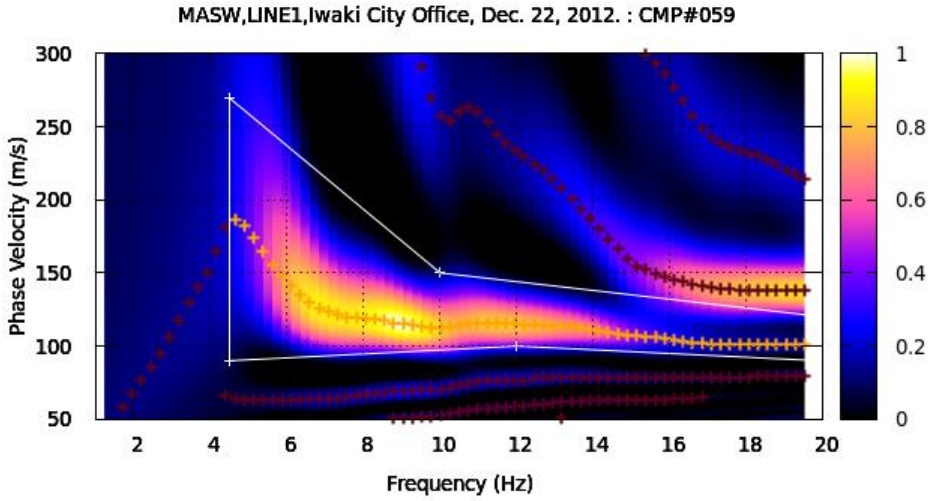

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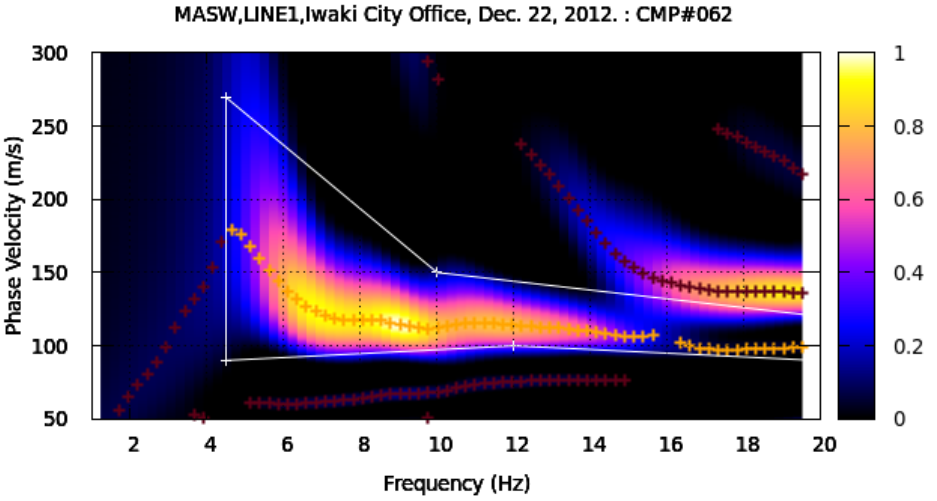

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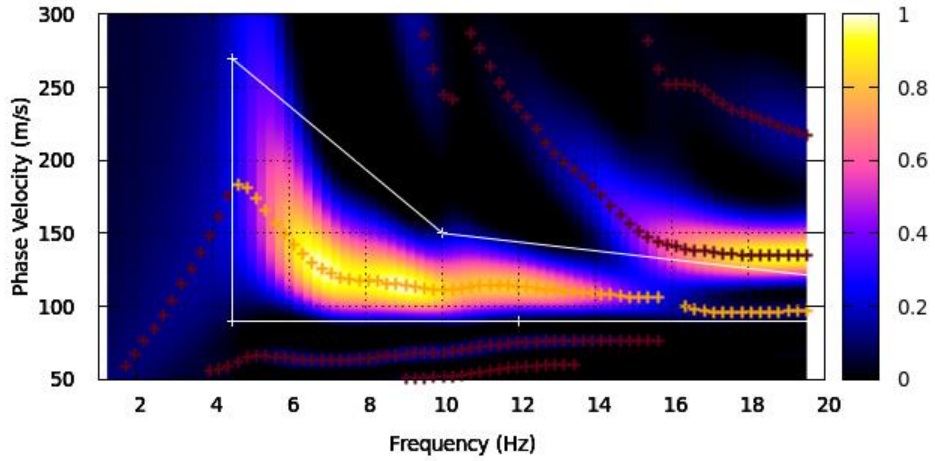

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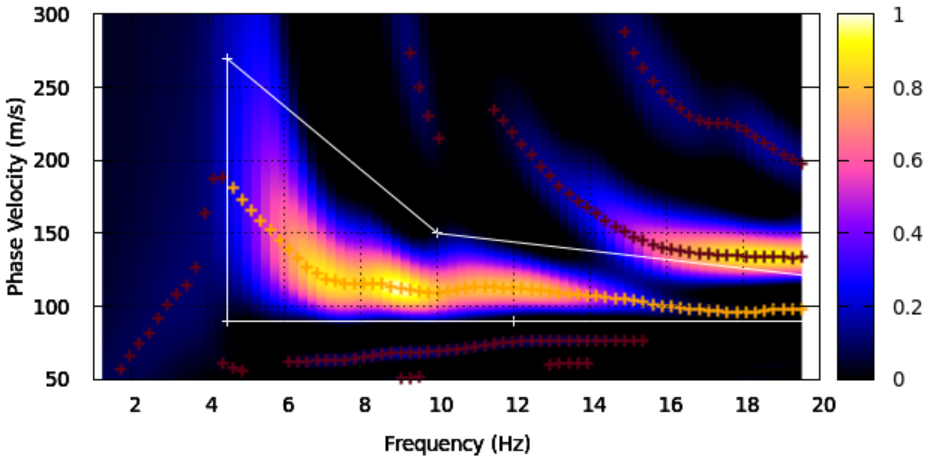

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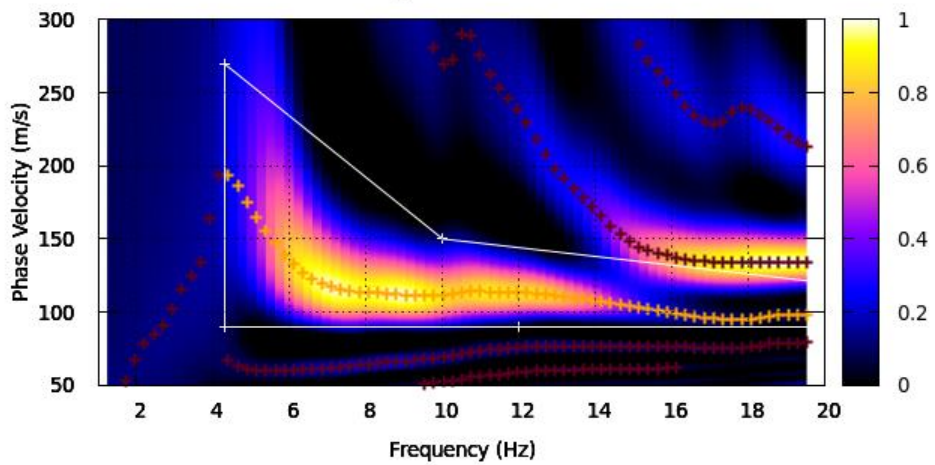

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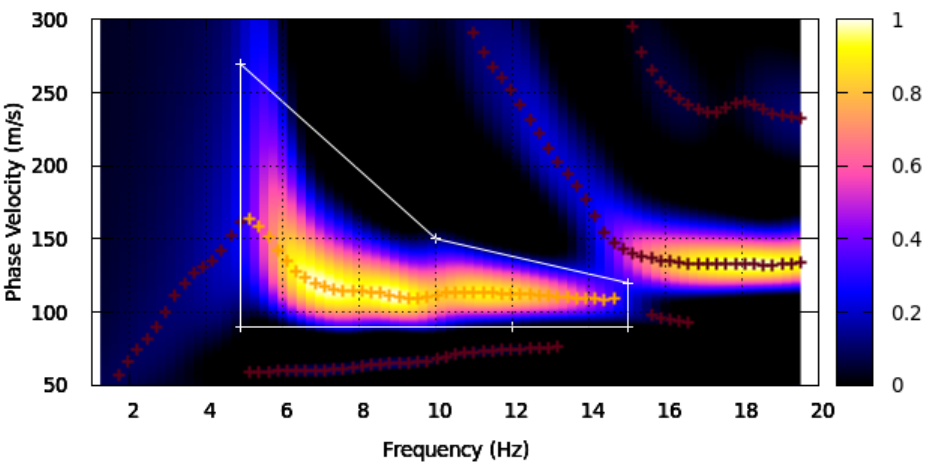

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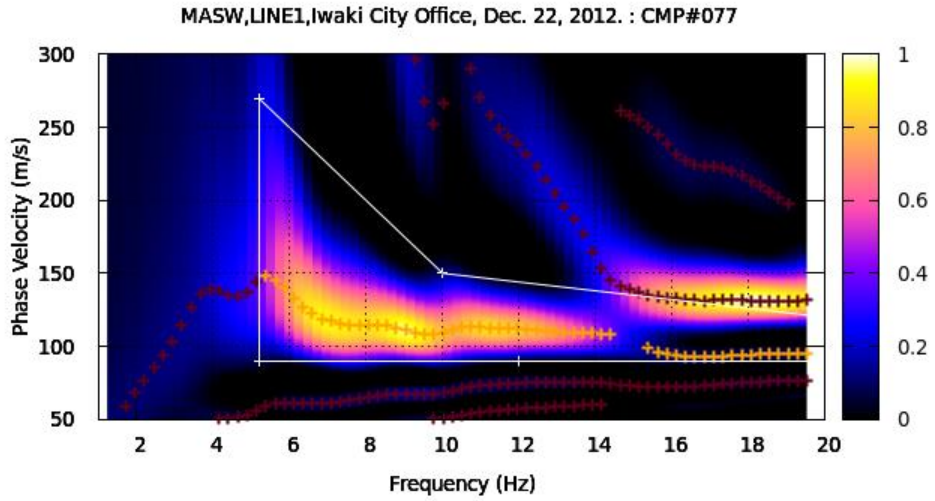

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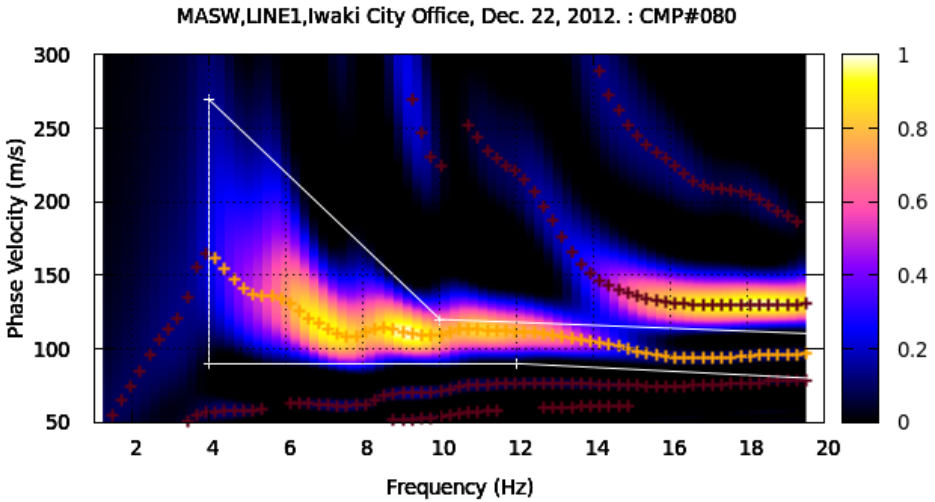

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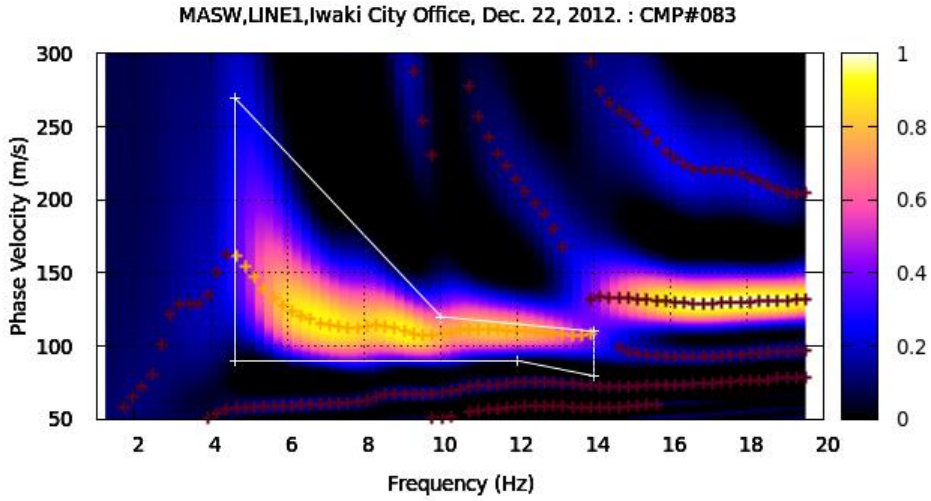

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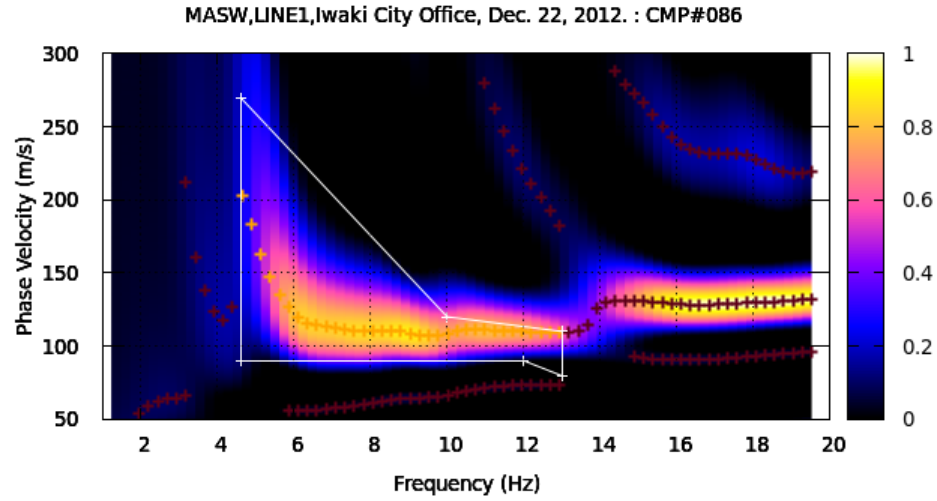

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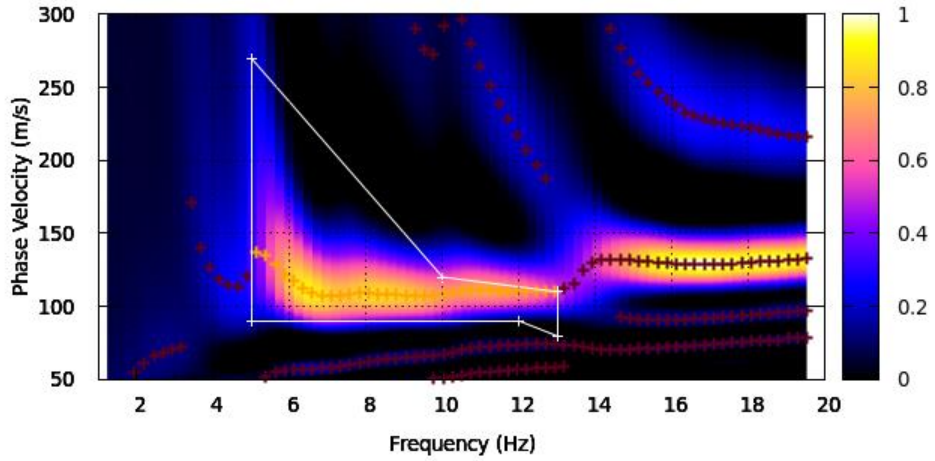

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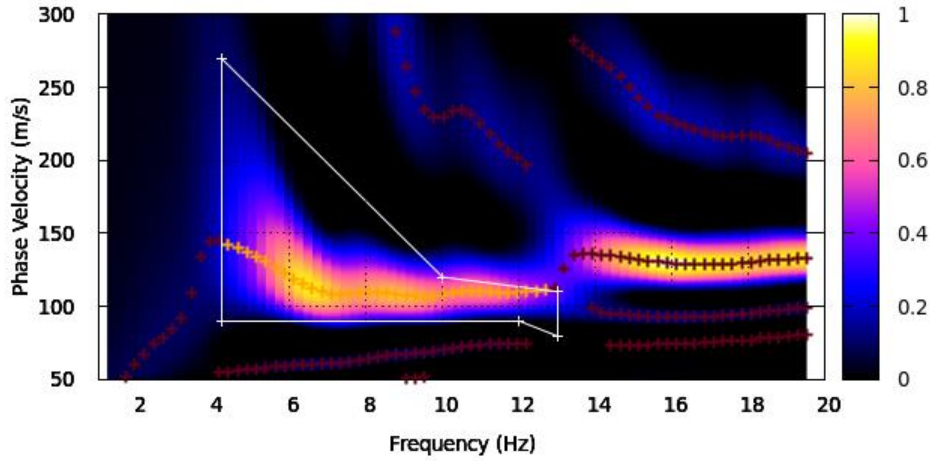

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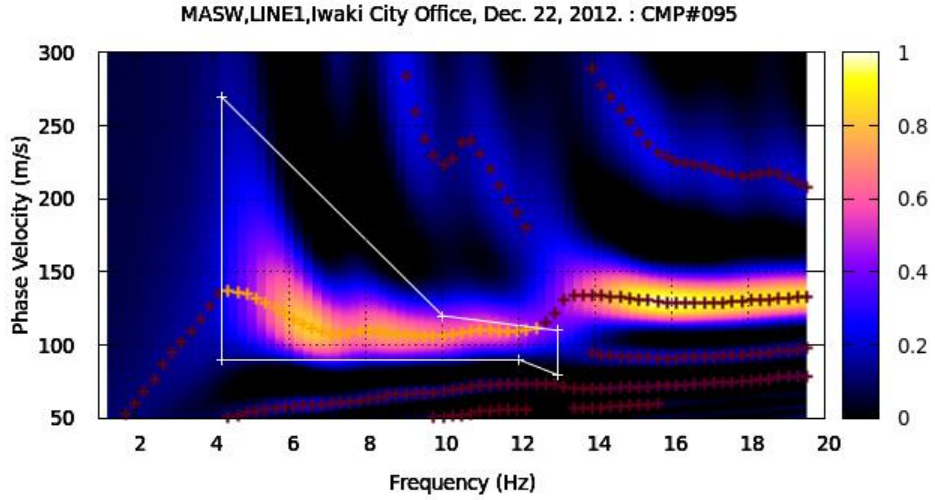

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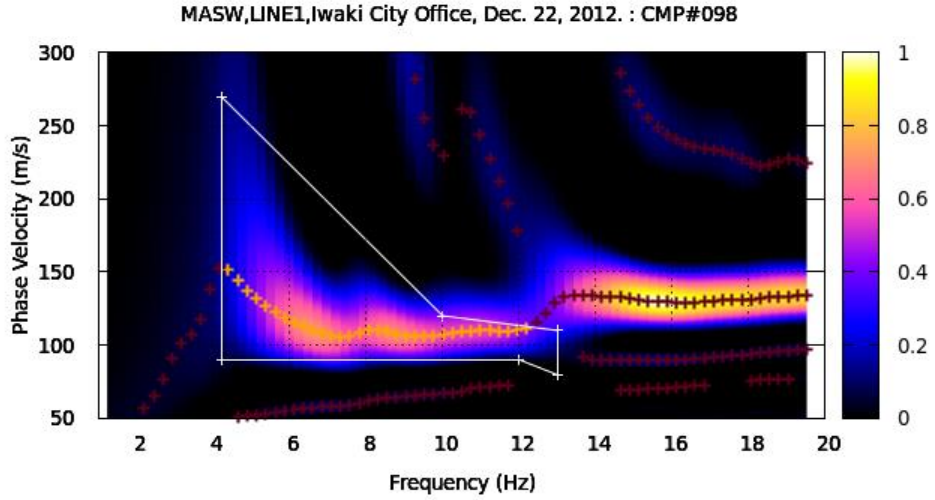

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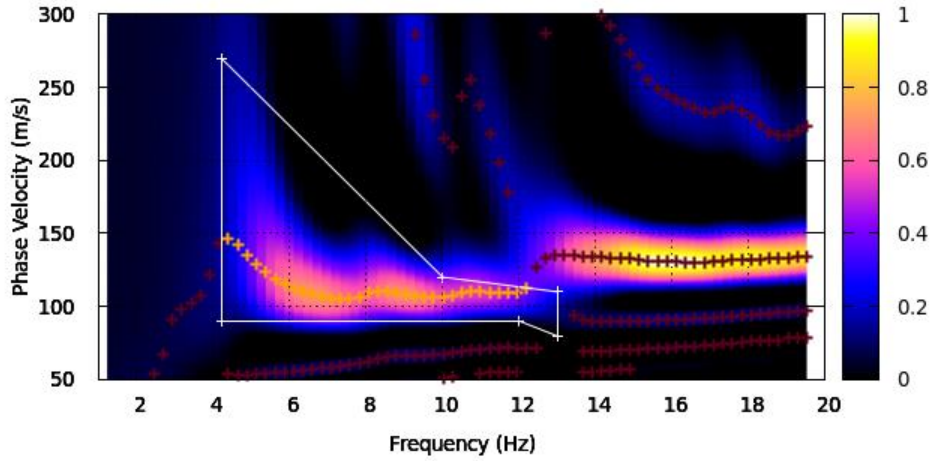

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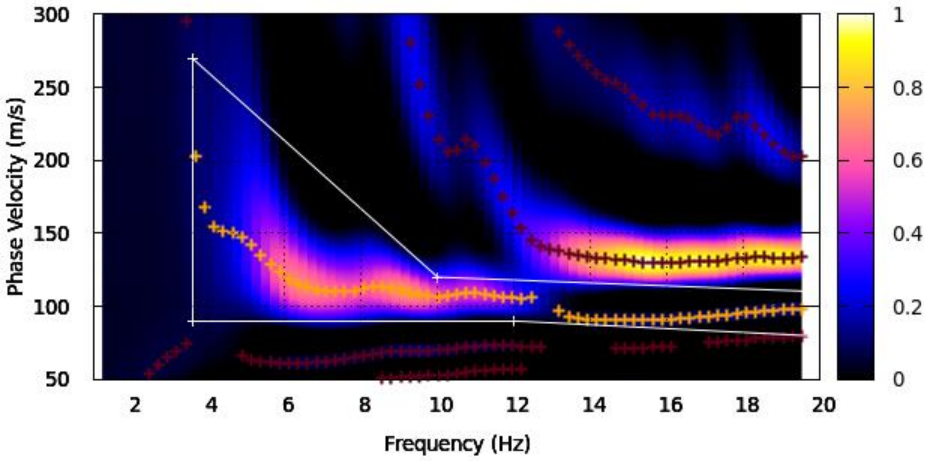

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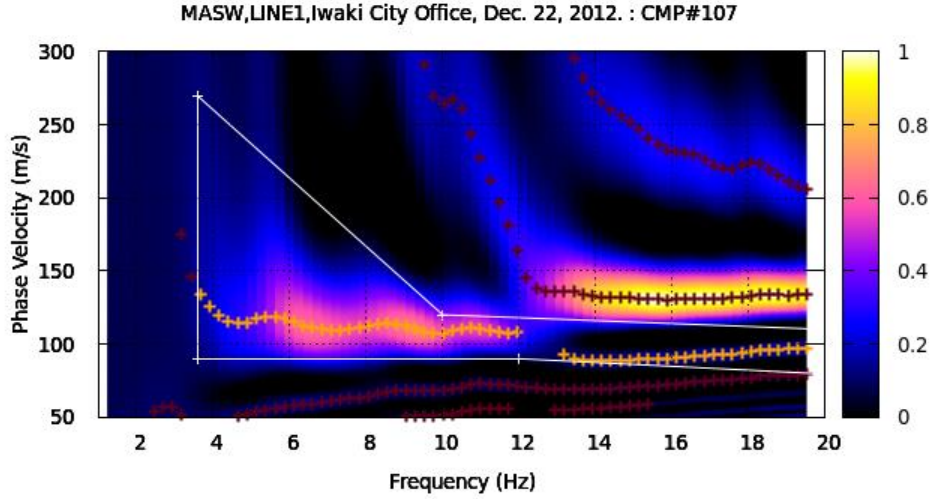

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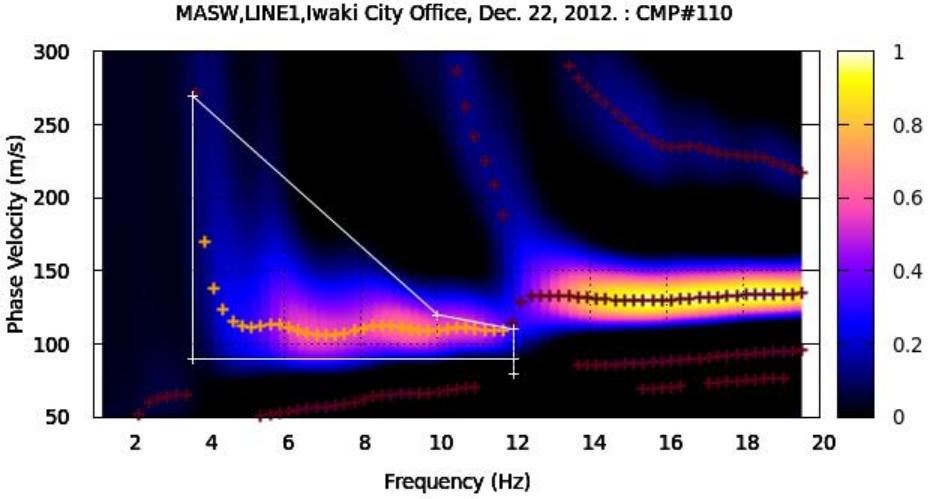

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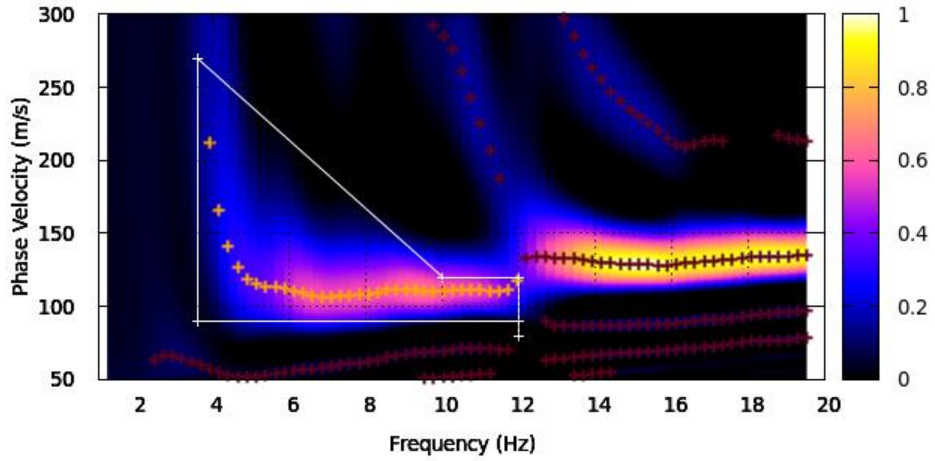

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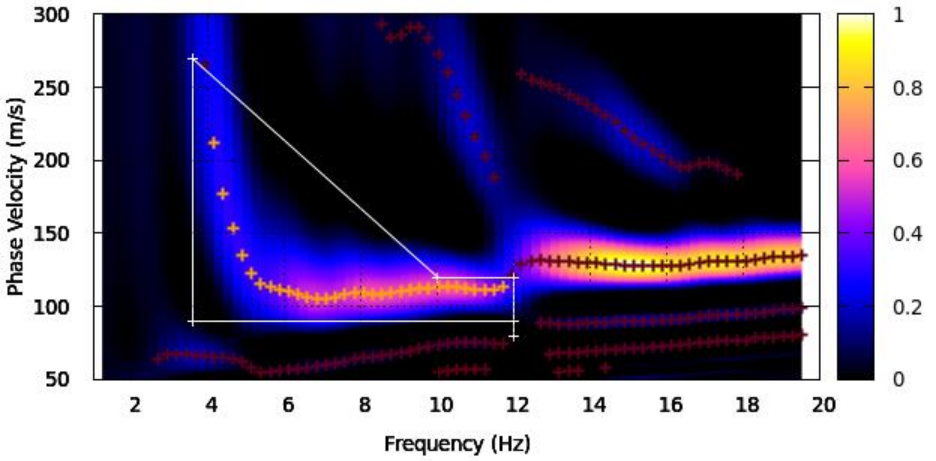

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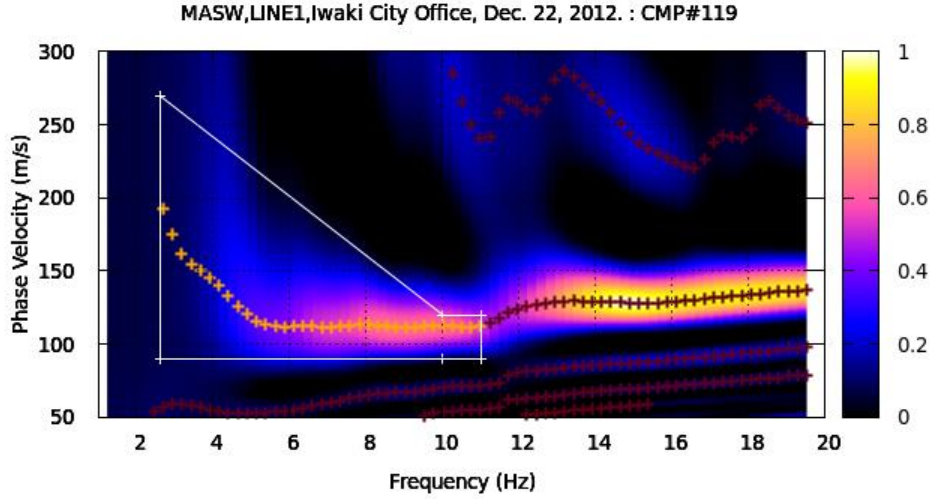

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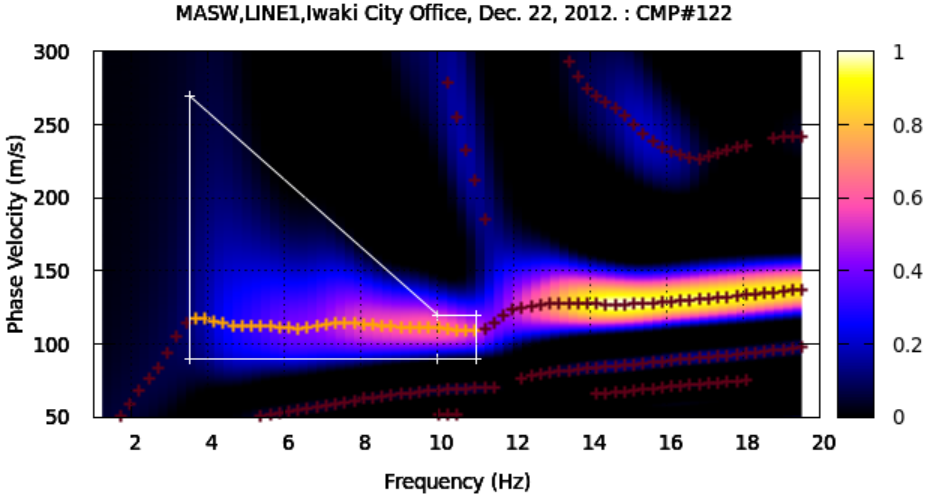

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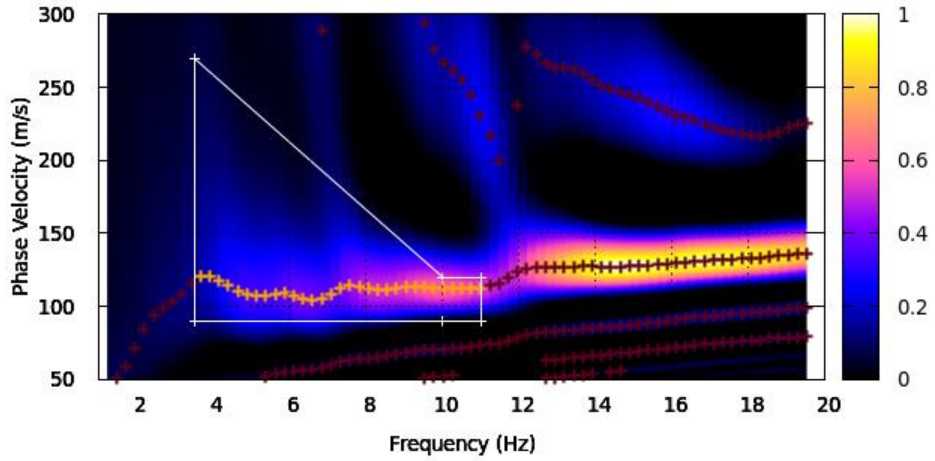

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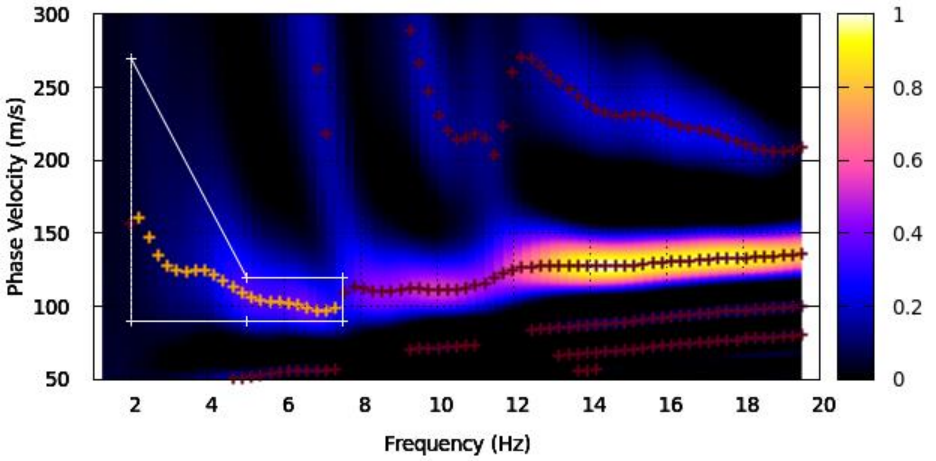

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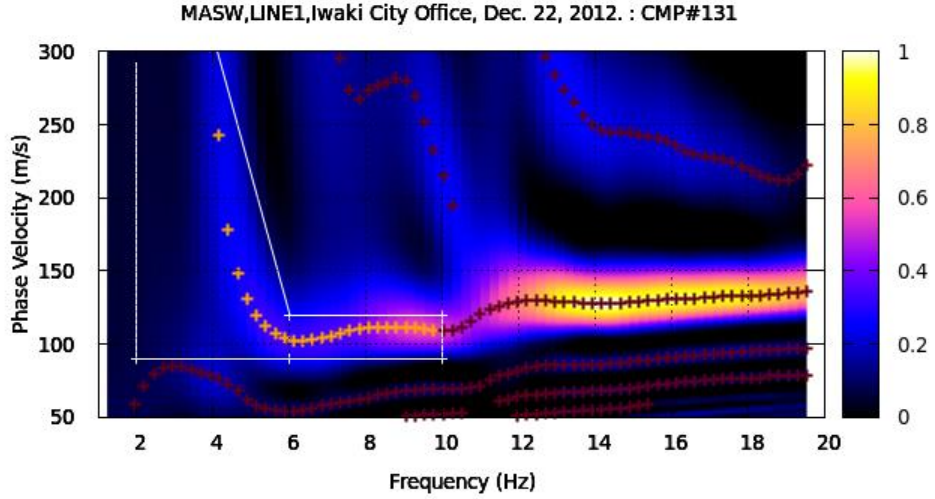

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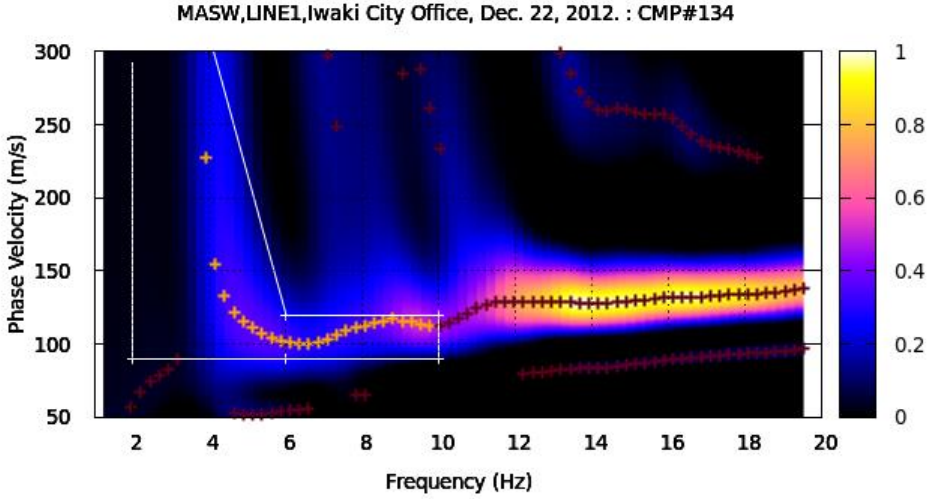

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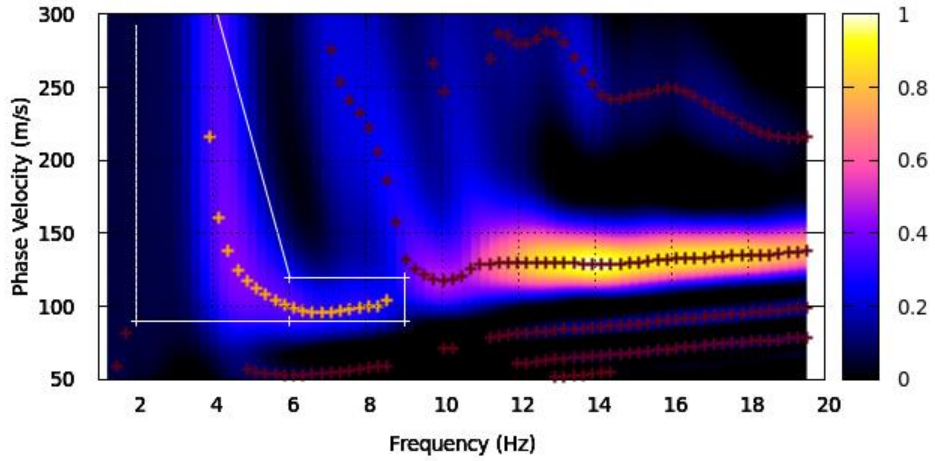

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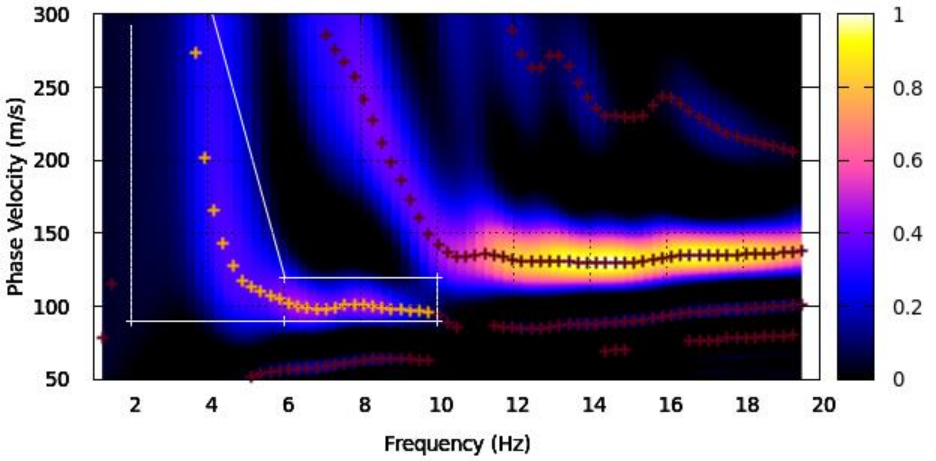

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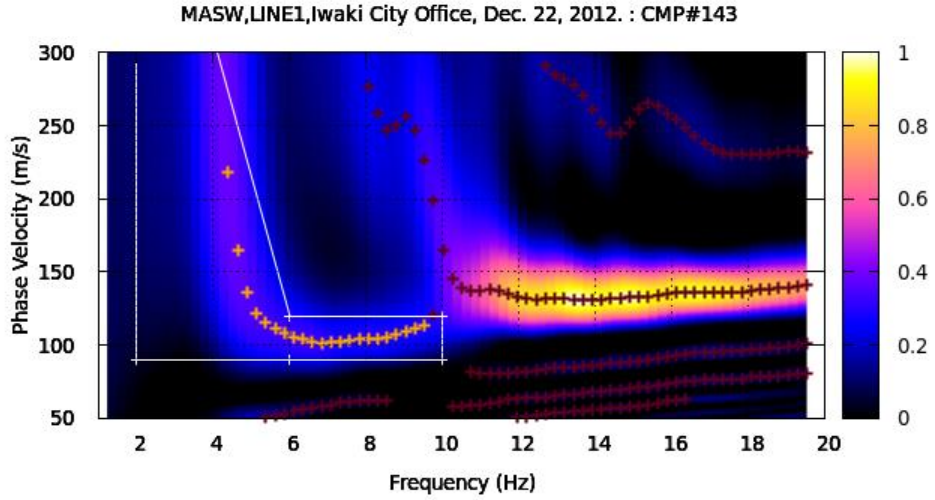

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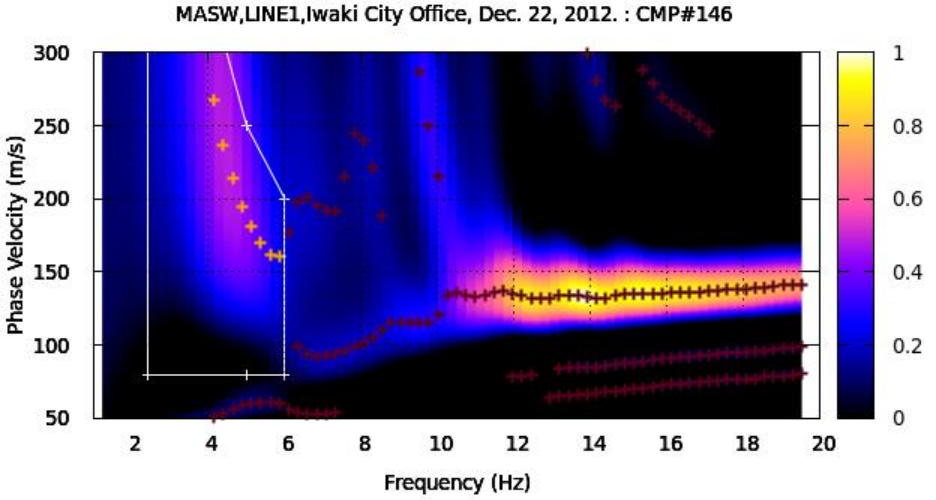

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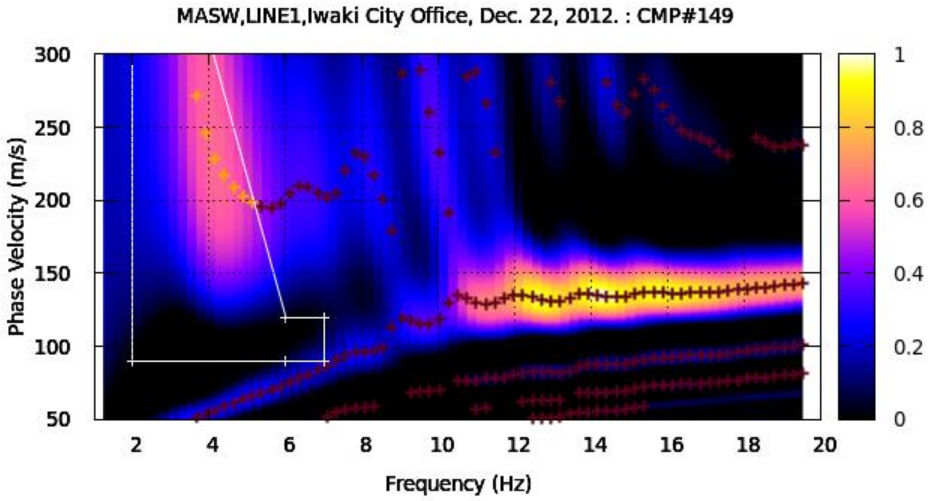

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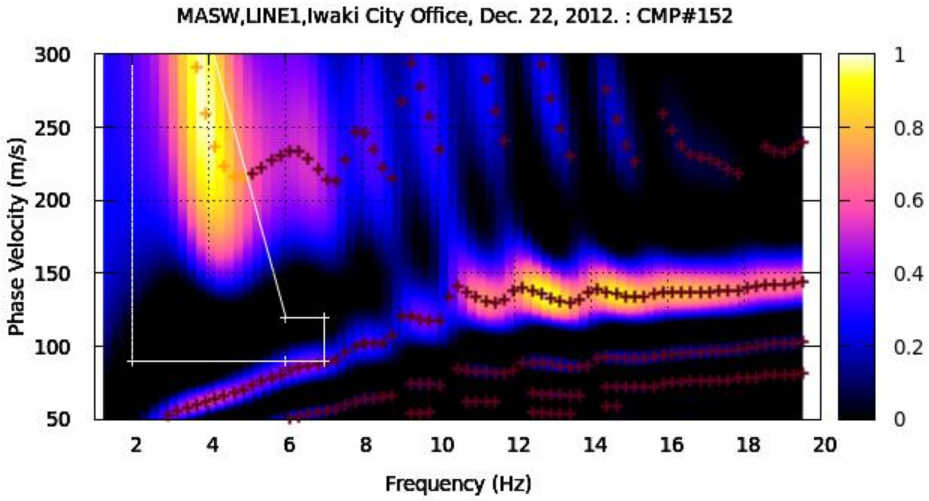

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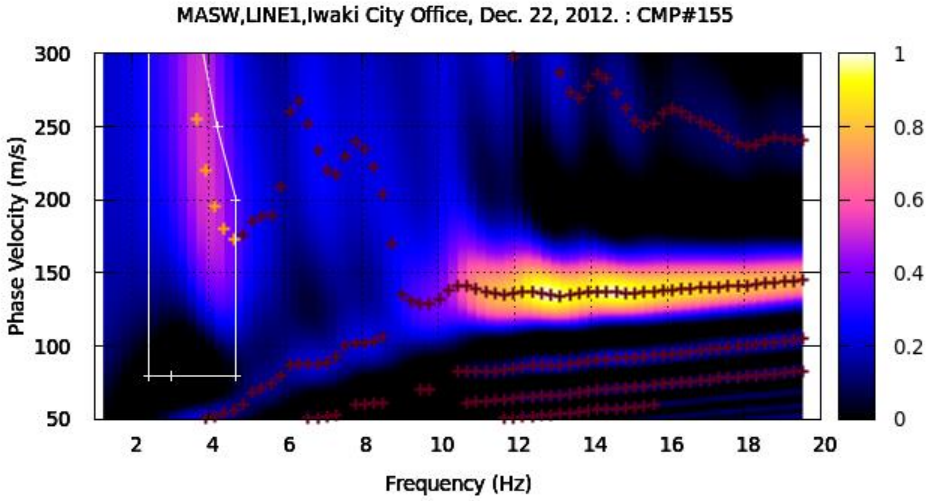

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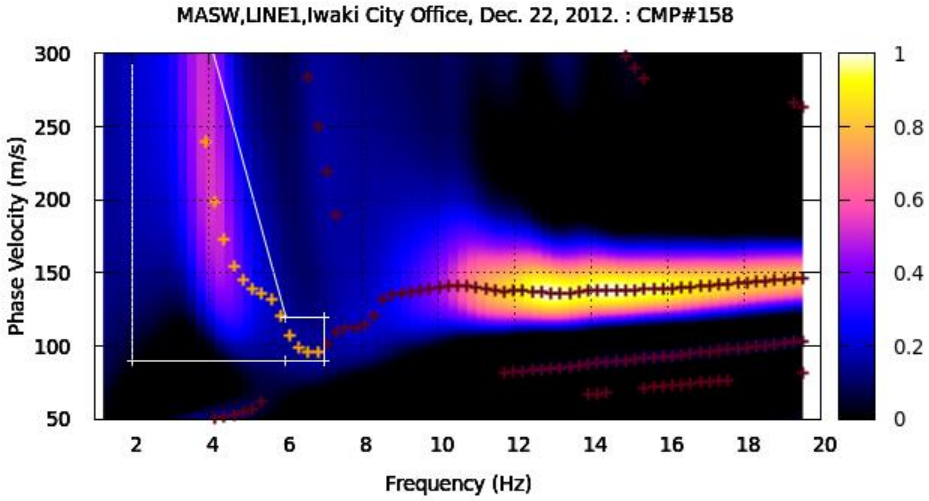

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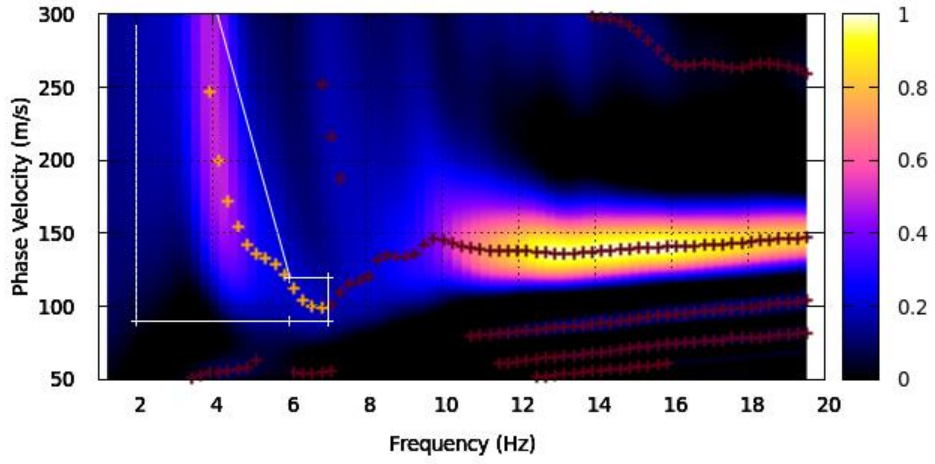

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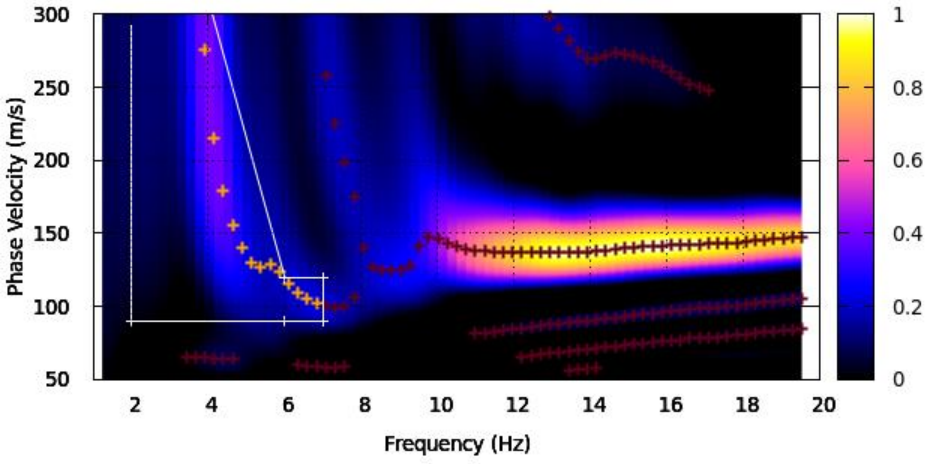

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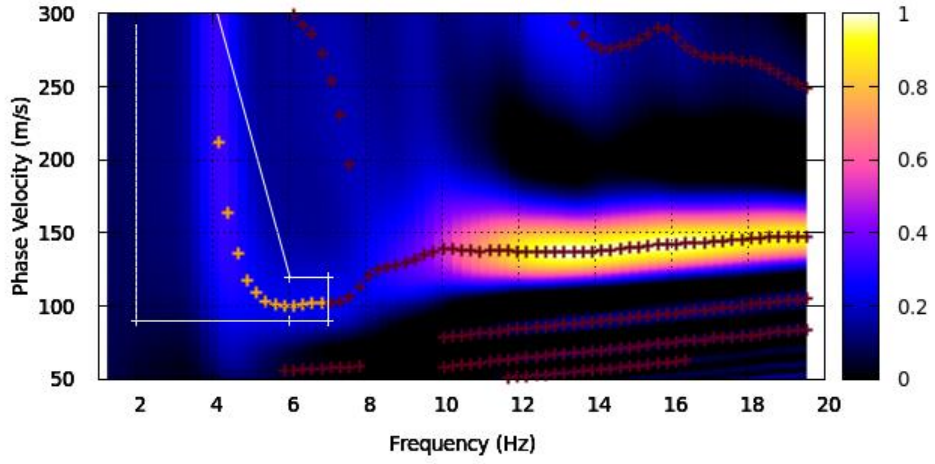

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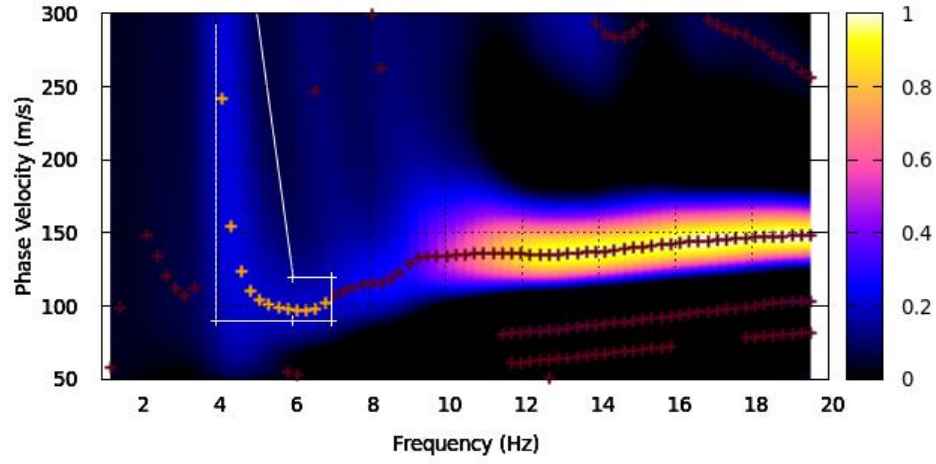

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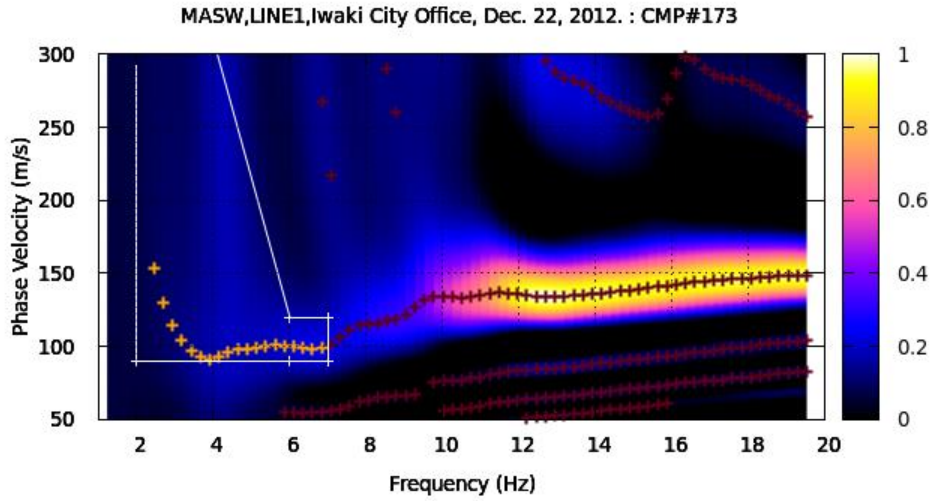

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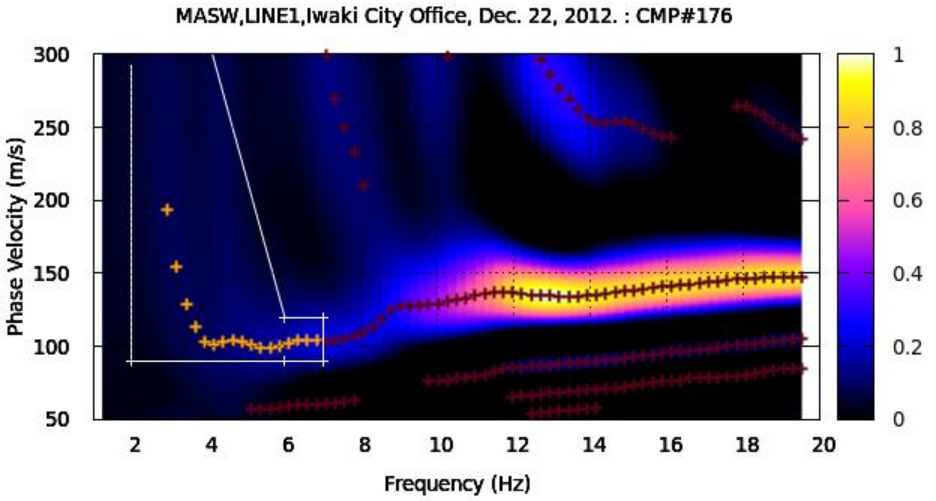

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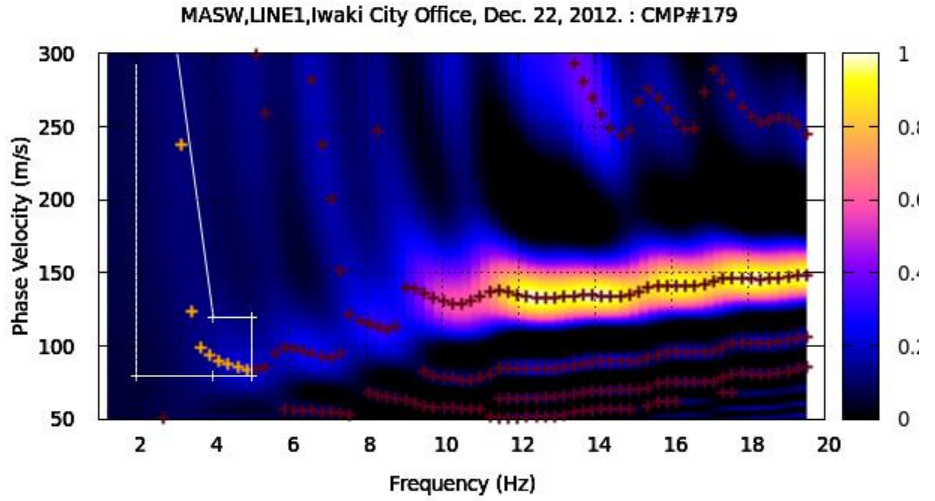

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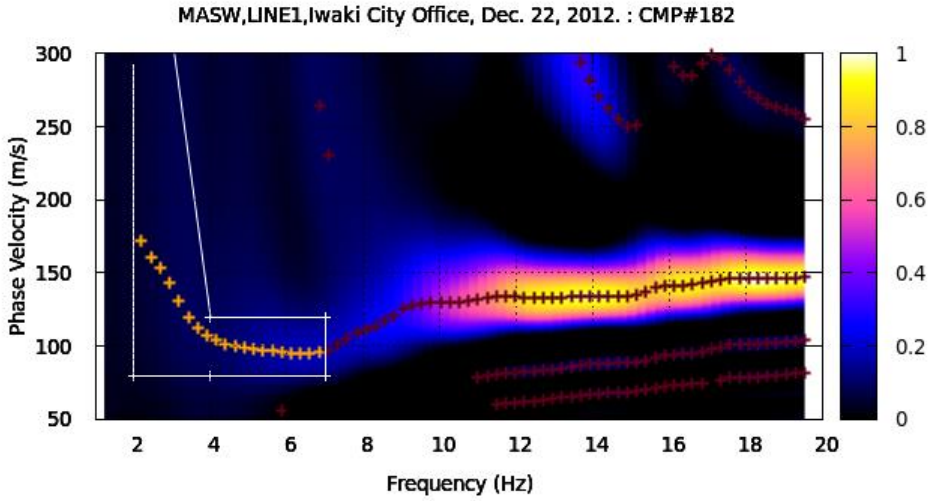

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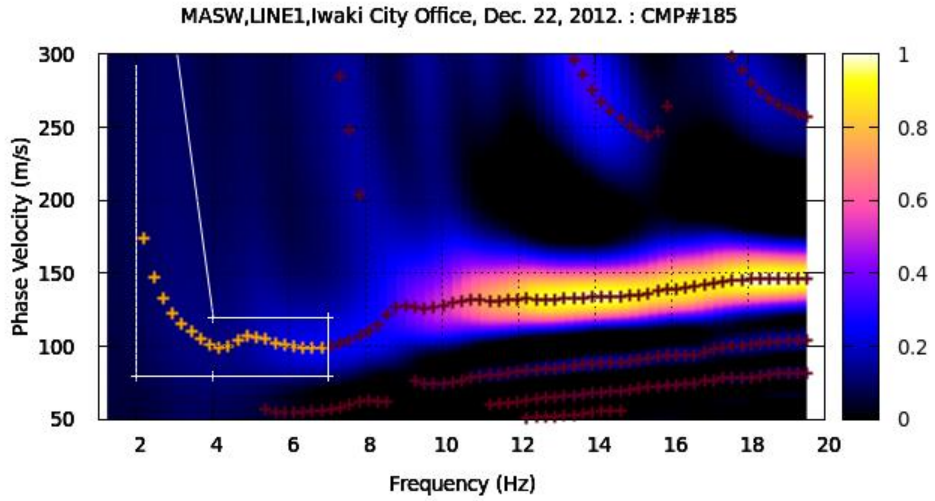

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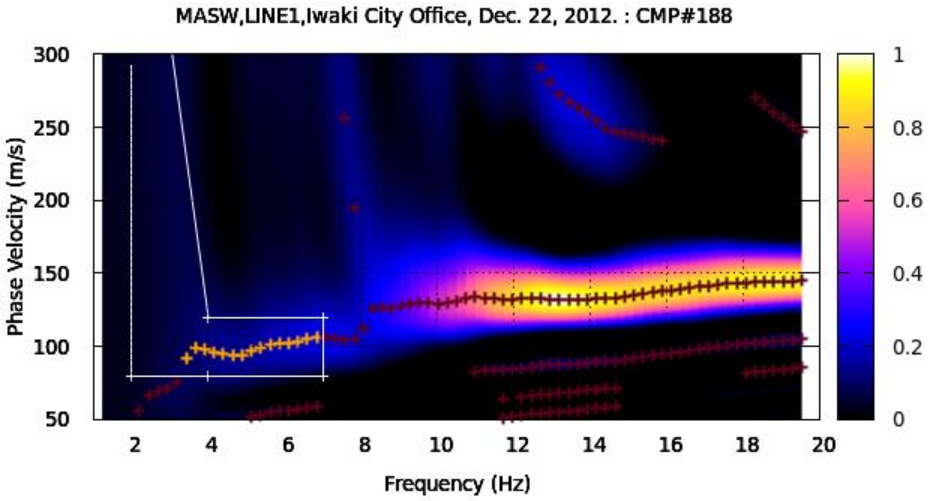

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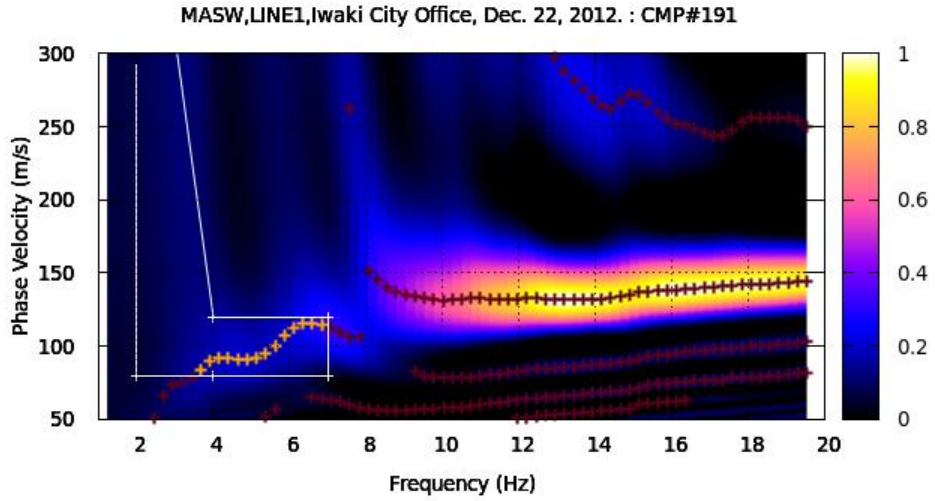

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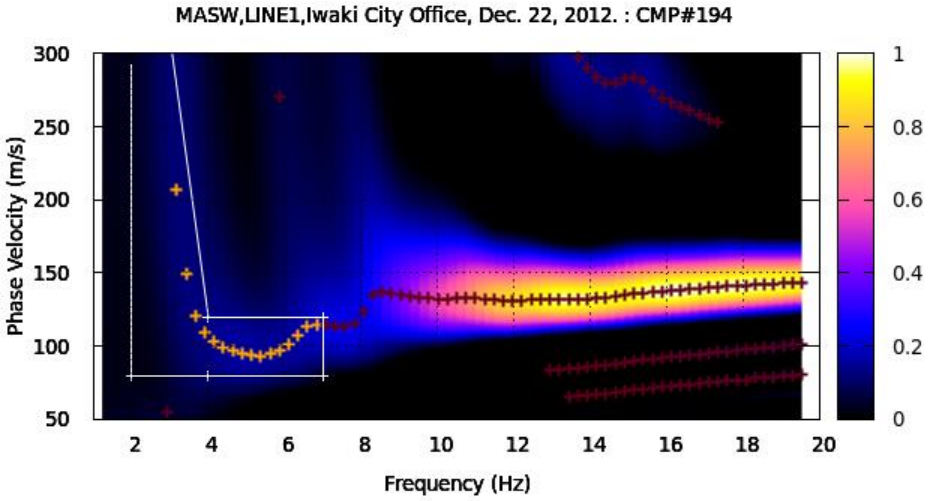

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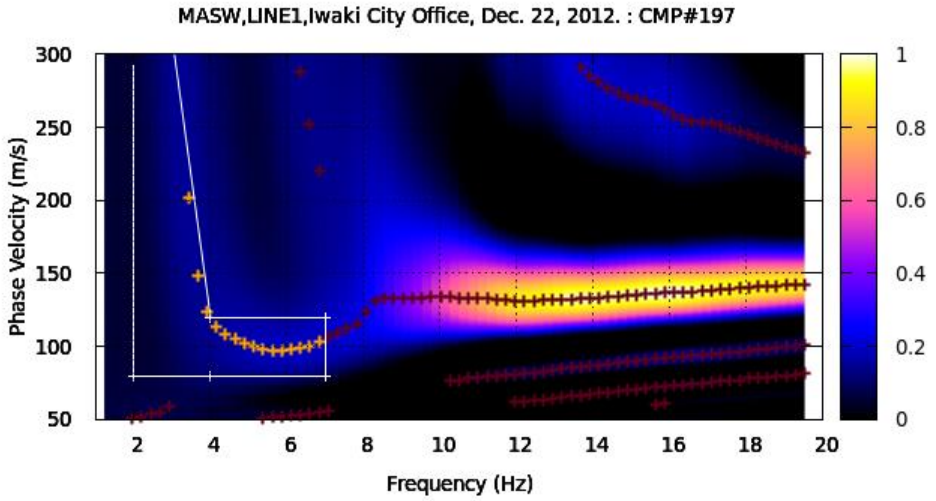

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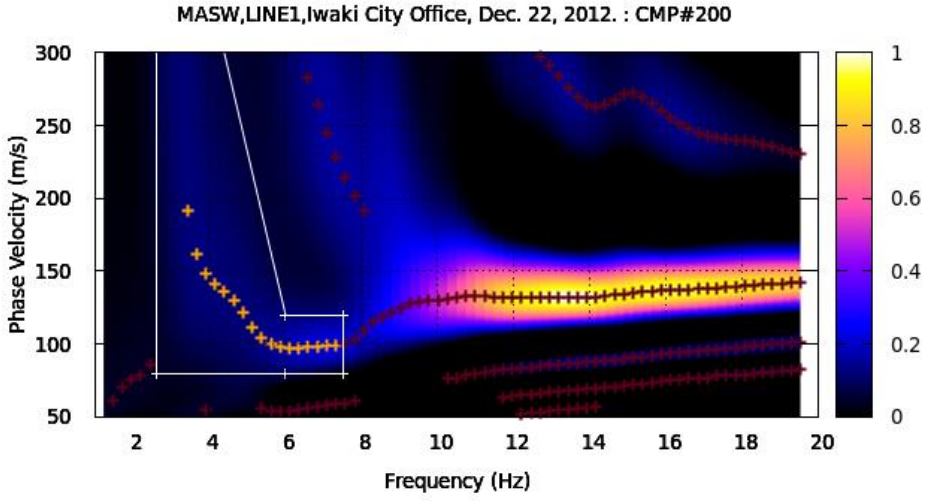

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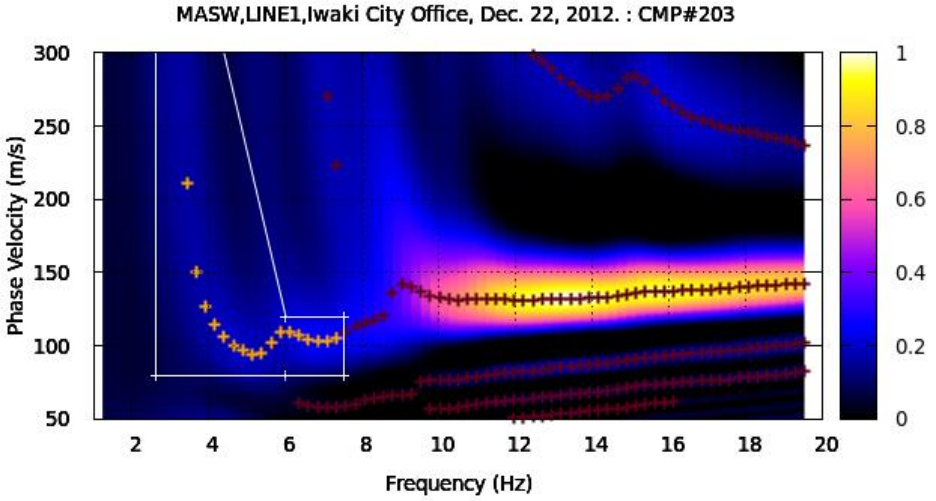

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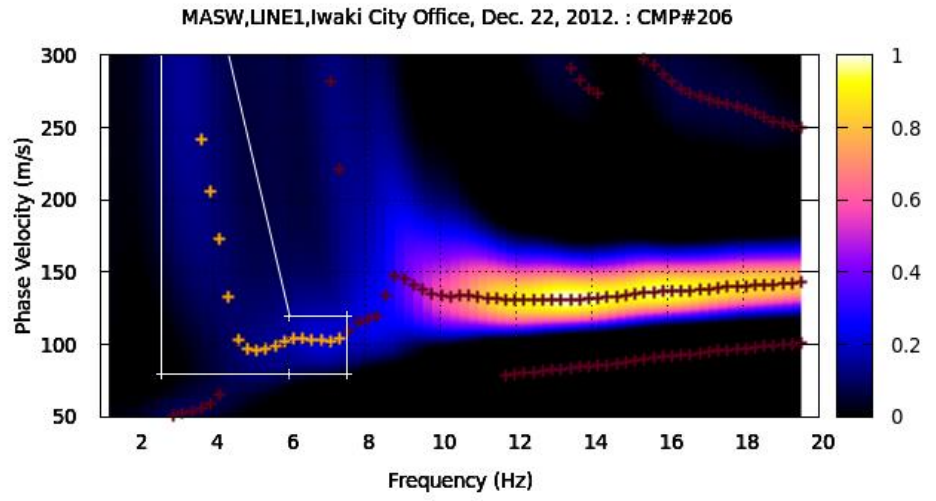

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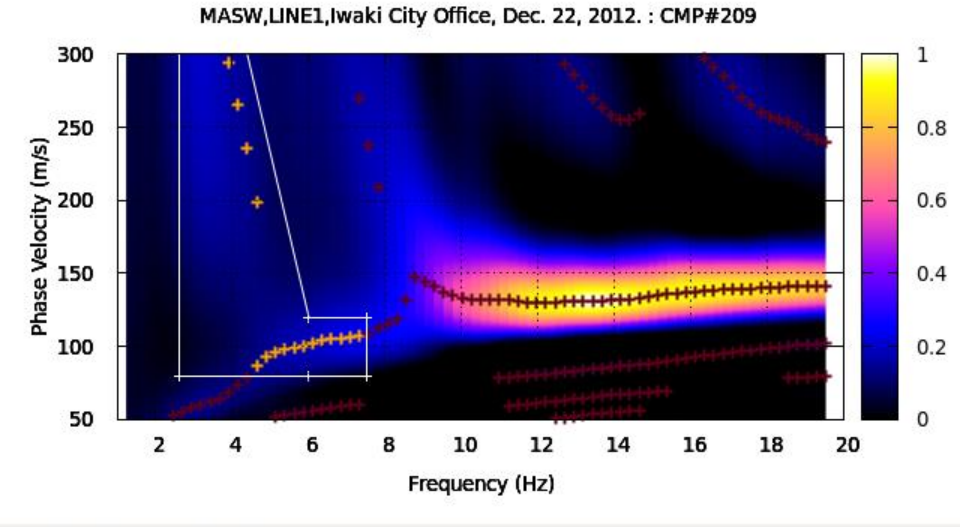

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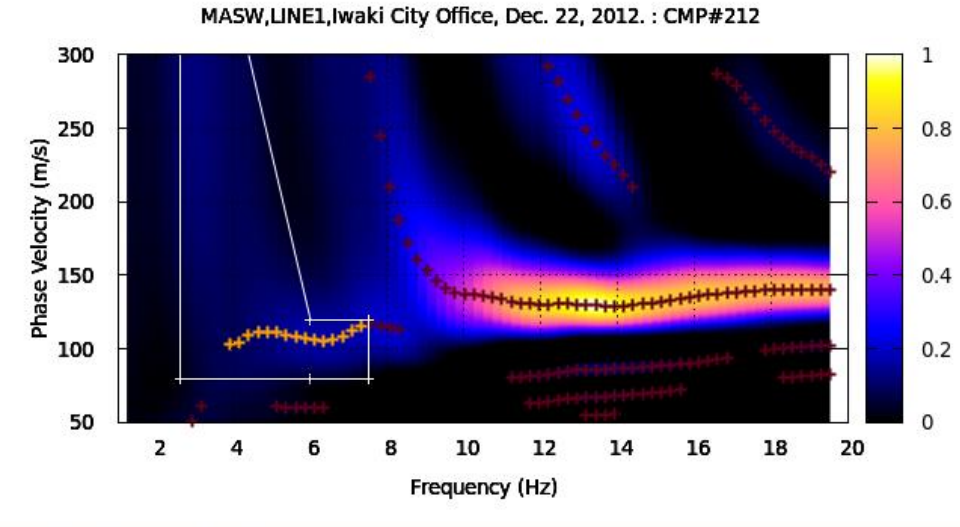
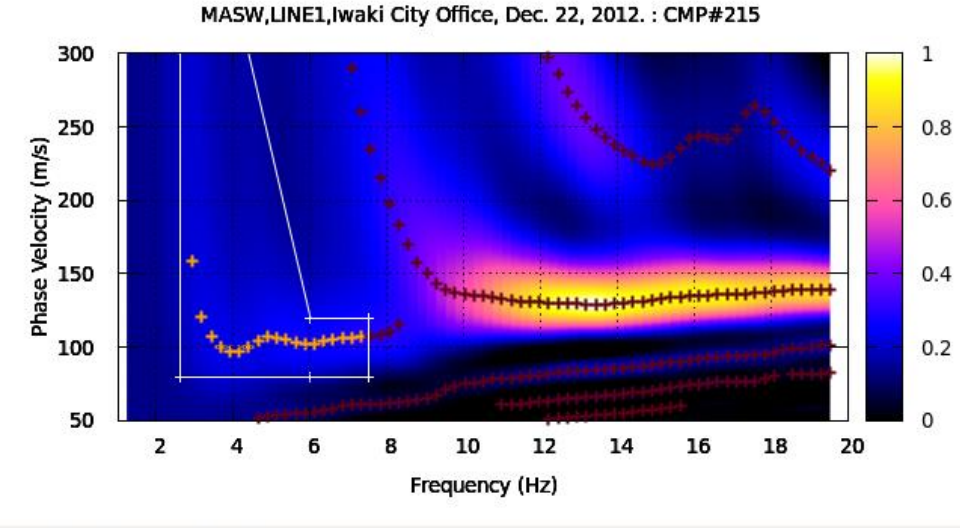


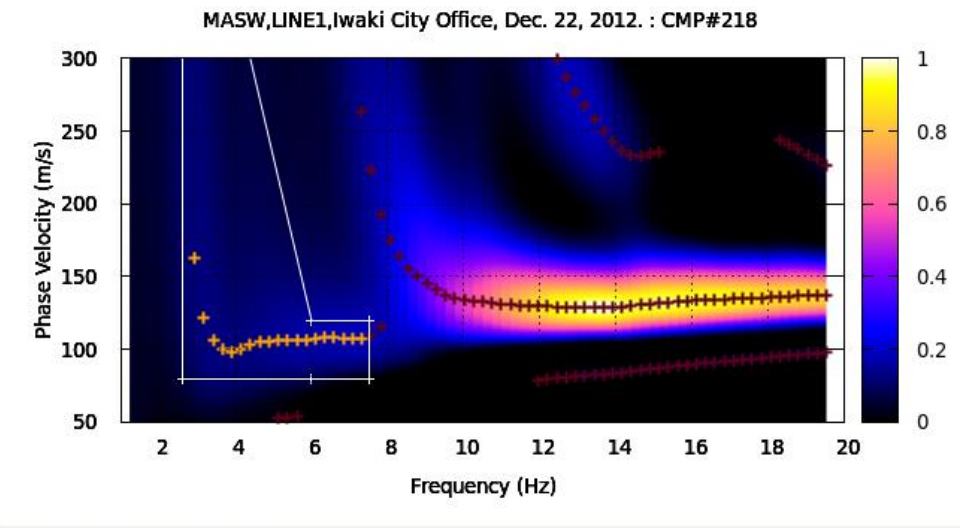
-2.06395, -22.1253

Gnuplot (window id : 0)



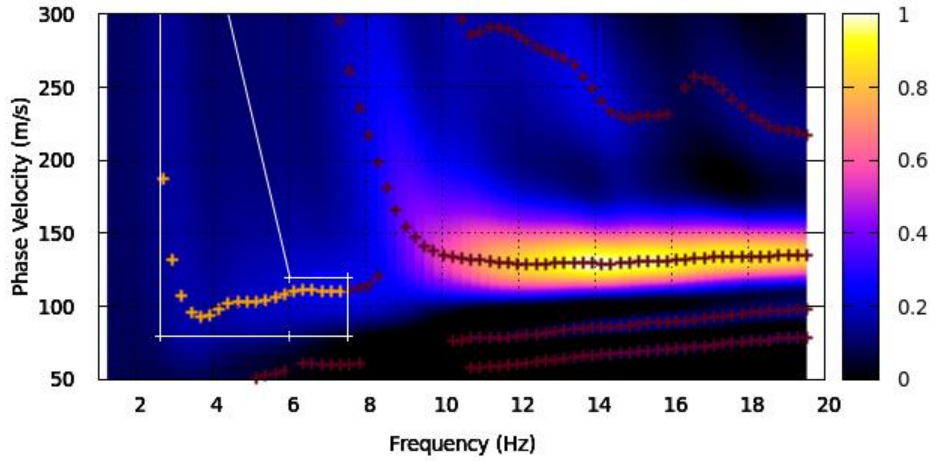
-2.06395, -22.1253

Gnuplot (window id : 0)



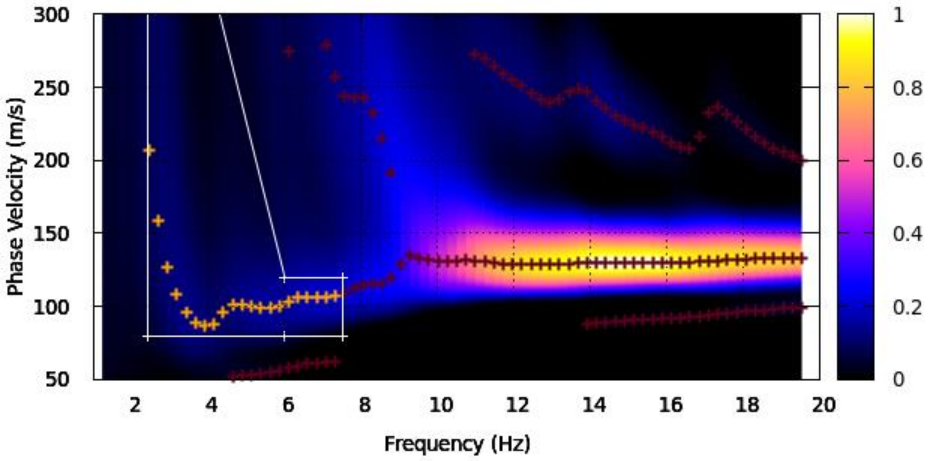
-2.06395, -22.1253

Gnuplot (window id : 0)



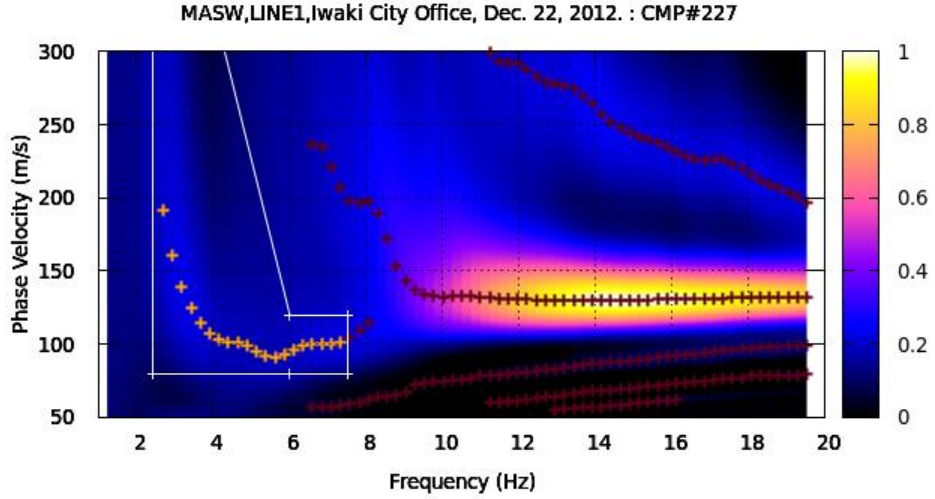
-2.06395, -22.1253

Gnuplot (window id : 0)



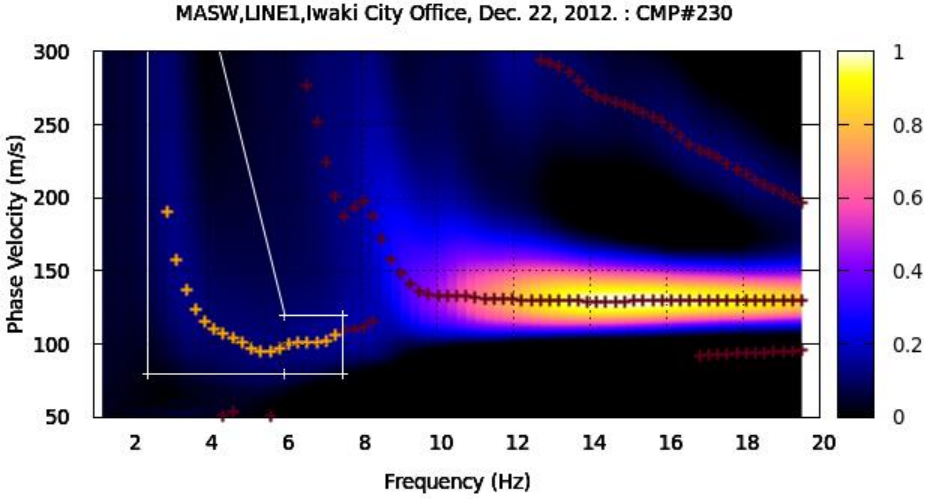
-2.06395, -22.1253

Gnuplot (window id : 0)



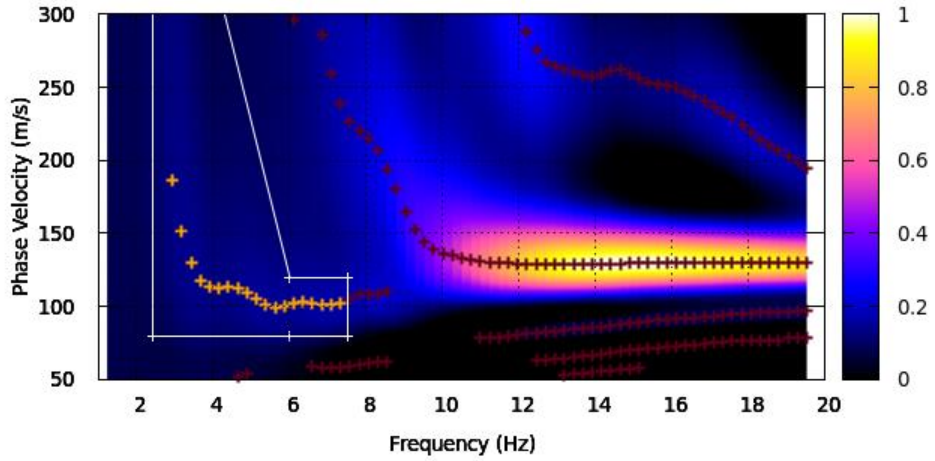
-2.06395, -22.1253

Gnuplot (window id : 0)



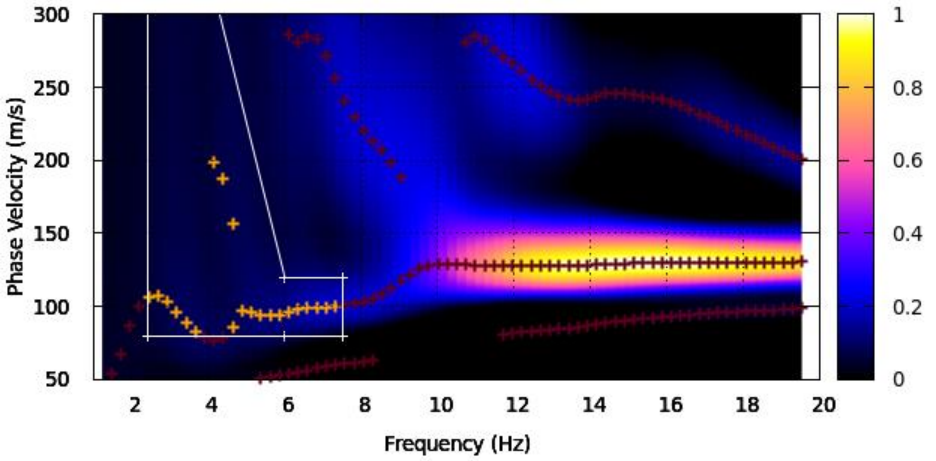
-2.06395, -22.1253

Gnuplot (window id : 0)



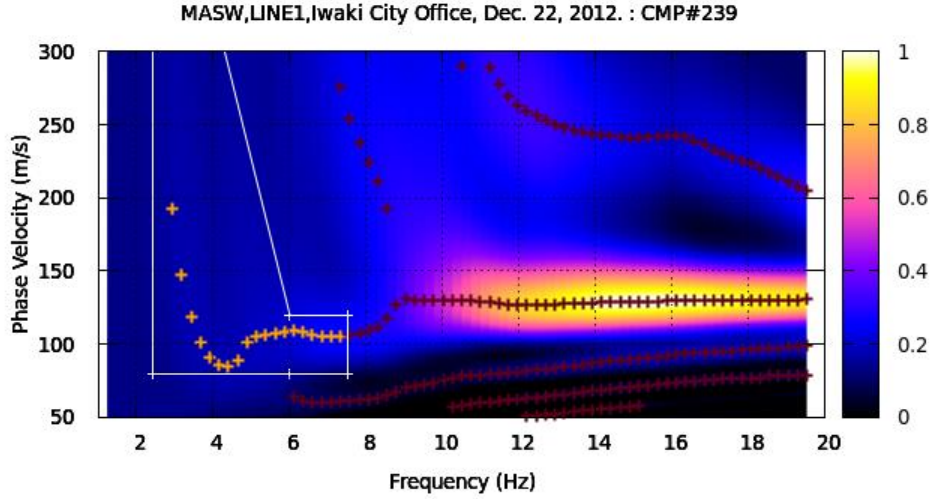
-2.06395, -22.1253

Gnuplot (window id : 0)



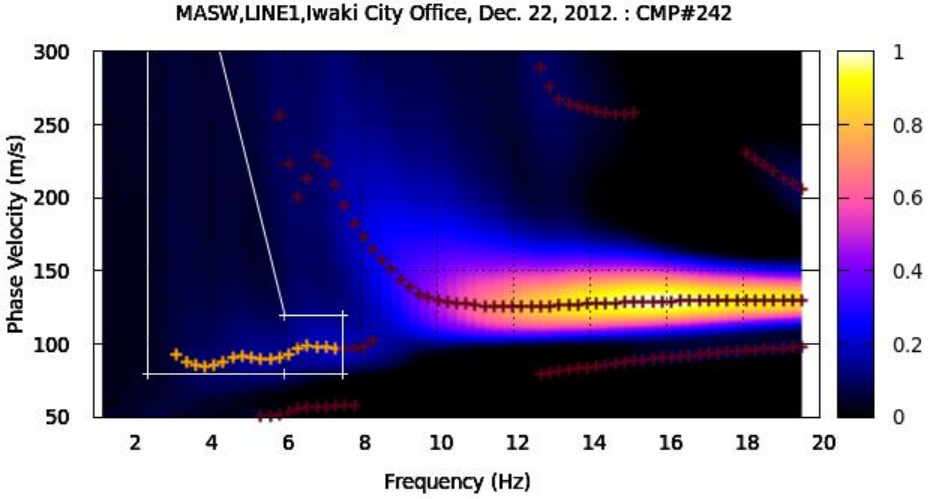
-2.06395, -22.1253

Gnuplot (window id : 0)



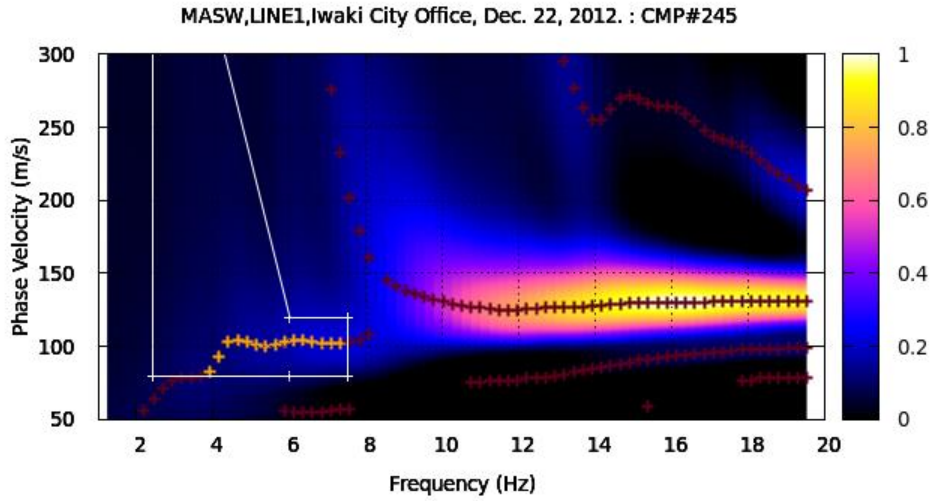
-2.06395, -22.1253

Gnuplot (window id : 0)



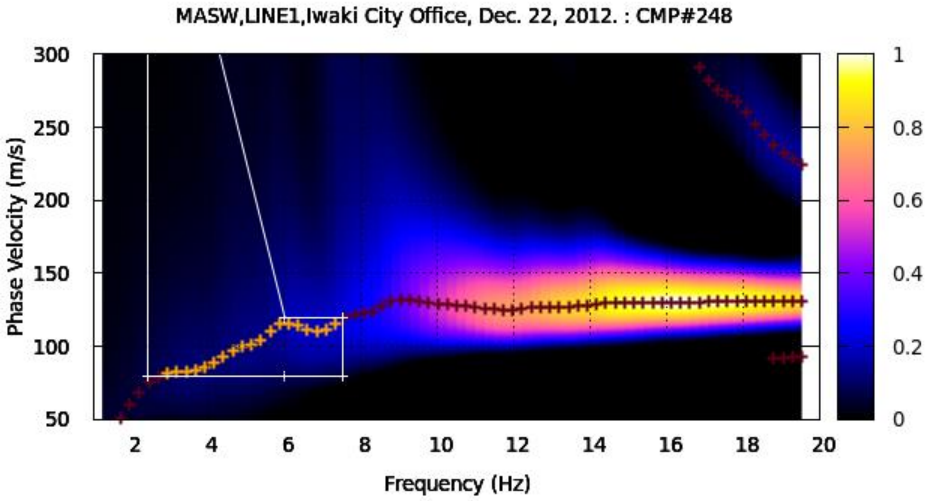
-2.06395, -22.1253

Gnuplot (window id : 0)



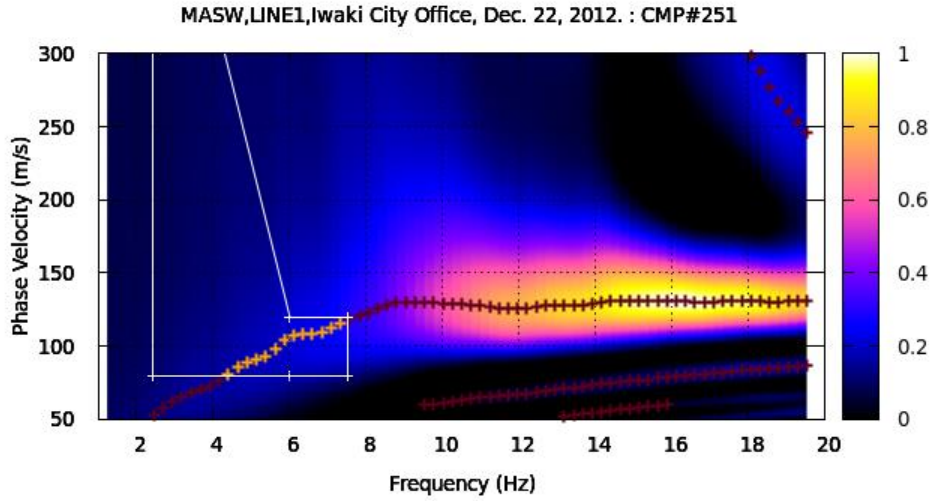
-2.06395, -22.1253

Gnuplot (window id : 0)



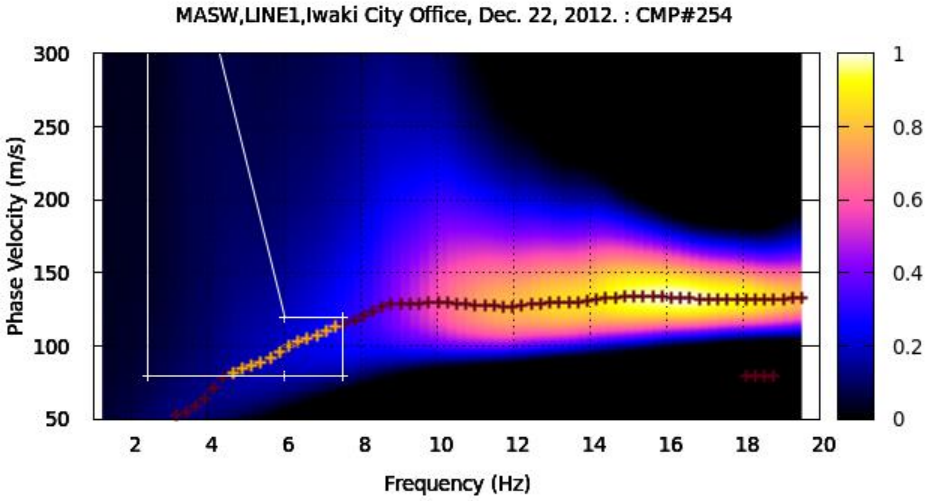
-2.06395, -22.1253

Gnuplot (window id : 0)



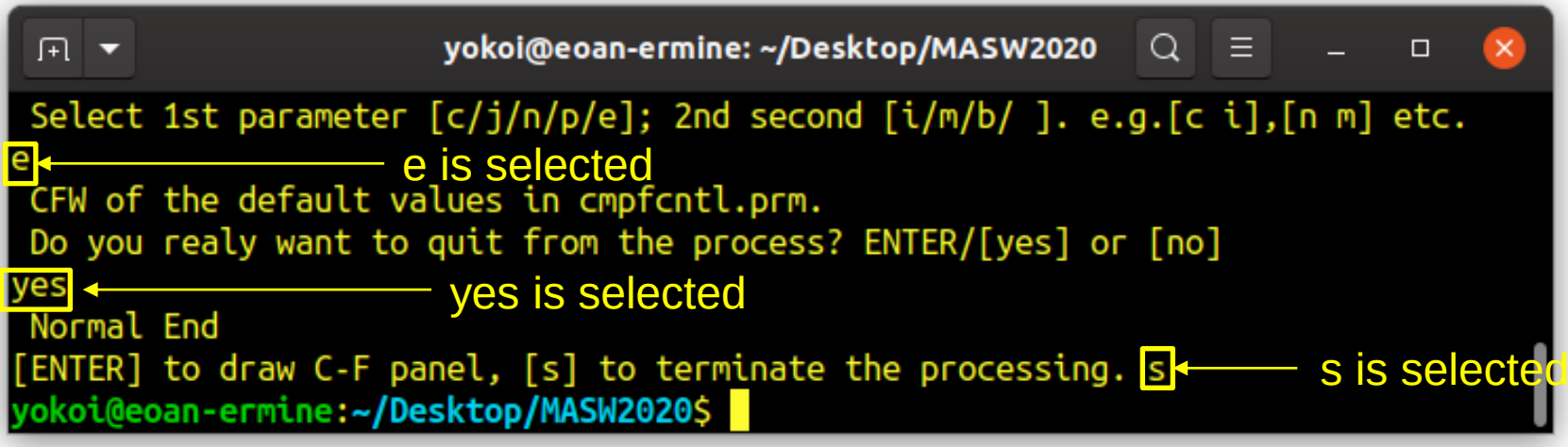
-2.06395, -22.1253

Gnuplot (window id : 0)



-2.06395, -22.1253

How to end the processing:



Example (cont.)

3. After loading ‘multi_cf’ and running it, the images of c-f panel with “+” marks are stored in the postscript file

./maswkf/data/c_f_panels/fig/cmp???.ps

; the GNUPLOT script file is

./maswkf/prm/gnuplt_script/c_f_panels/masw???.plt

; the data to plot this image are stored in

./maswkf/data/c_f_panels/crs_cd???.dat

; the data of c(f) are stored in

./maswkf/data/c_f_panels/crs_cd???.dat

, where ??? denotes the numbering of CMPs.

Beside the data for the determined dispersion curves are stored in

./maswkf/data/dispersion/cmp???ds.dat .

Their format is

```
#  Freq.  V.m/s
  5.371  221.000
  5.615  193.000
  5.859  172.000
  6.104  156.000
  6.836  129.000
  7.080  125.000
….
```

masw030.plt: a script file of GNUPLOT

```
reset
unset key
# Graph title
set title "MASW,LINE1,Iwaki City Office, Dec. 22, 2012. : CMP#030 "
# Horizontal axis: label & range
set xlabel "Frequency (Hz)"
set xrange [0:20]
# Verical axis: label & range
set ylabel "Phase Velocity (m/s)"
set yrange [0:400]
# C-F spectra
set zrange [0:1]
#
set pm3d map
set multiplot
splot "./maswkf/data/c_f_panels/crs_cf030.dat"
splot "./maswkf/data/c_f_panels/coh_pk030.dat" with points pt 1 lt 8
unset multiplot
set terminal postscript color enhanced
set output "./maswkf/data/c_f_panels/fig/cmp030.ps"
# Graph title
set title "MASW,LINE1,Iwaki City Office, Dec. 22, 2012. : CMP#030 "
# Horizontal axis: label & range
set xlabel "Frequency (Hz)"
set xrange [0:20]
# Verical axis: label & range
set ylabel "Phase Velocity (m/s)"
set yrange [0:400]
# C-F spectra
set zrange [0:1]
#
set pm3d map
set multiplot
splot "./maswkf/data/c_f_panels/crs_cf030.dat"
splot "./maswkf/data/c_f_panels/coh_pk030.dat" with points pt 1 lt 8
unset multiplot
set output
set terminal wxt
```

multi_cf.plt: a script file of GNUPLOT

```
...
 load './maswkf/prm/gnuplt_script/c_f_panels/masw032.plt'
 pause -1 "Hit return to continue for cmp033.
 load './maswkf/prm/gnuplt_script/c_f_panels/masw033.plt'
 pause -1 "Hit return to continue for cmp034.
 load './maswkf/prm/gnuplt_script/c_f_panels/masw034.plt'
 pause -1 "Hit return to continue for cmp035.
 load './maswkf/prm/gnuplt_script/c_f_panels/masw035.plt'
 pause -1 "Hit return to continue for cmp036.
…
```

Example (cont.)

4. After determined all necessary dispersion curves:
   Execute “sh disp_comb.sh” after completing “sh masw2cmp2D.sh”,
   to create the parameter file ./maswkf/prm/disp_comb.prm
   and then run ./disp_comb.exe.
   This program creates the following files.
   ./maswkf/data/dispersion/disp_all.dat
   ./maswkf/prm/gnuplt_script/disp_all.plt
   ./maswkf/prm/gnuplt_script/dispersion/disp???.plt
   , where ??? denotes the numbering of CMPs.

disp_comb.sh

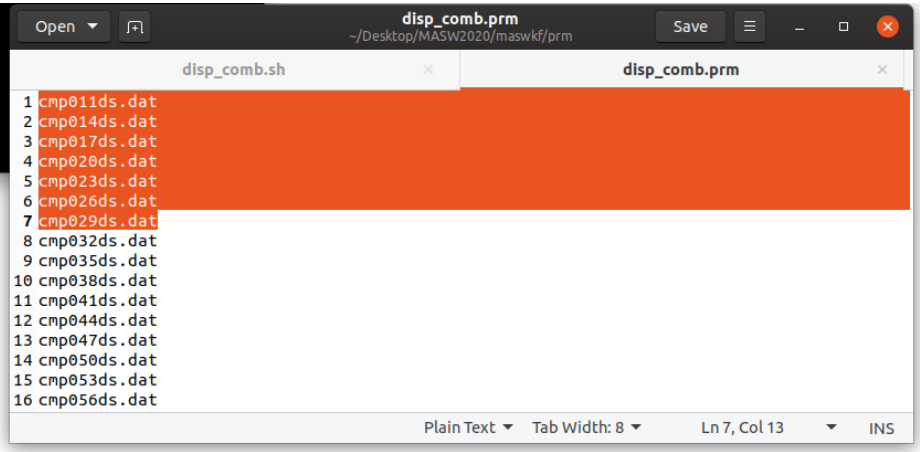
```
cd ./maswkf/data/dispersion
ls -1 cmp*ds.dat > ../../prm/disp_comb.prm
cd ../../..
echo "Edit ./maswkf/prm/disp_comb.prm, then Press [Enter] key to proceed."
gedit ./maswkf/prm/disp_comb.prm
read Wait
./bin/disp_comb.exe | tee maswkf/log/disp_comb.log
gnuplot -e "load './maswkf/prm/gnuplt_script/dispersion/disp_all.plt' ; pause
-1 "
```

Example (cont.)

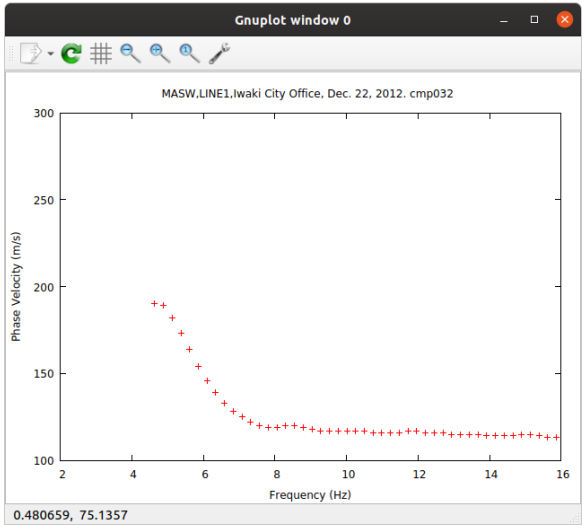
```
yokoi@eoan-ermine: ~/Desktop/MASW2020
yokoi@eoan-ermine:~/Desktop/MASW2020$ sh disp_comb.sh
Edit ./maswkf/prm/disp_comb.prm, then Press [Enter] key to proceed.

 Program disp_comb.for
 ./maswkf/data/dispersion/disp_all.dat
 ./maswkf/prm/gnuplt_script/dispersion/disp_all.plt
MASW,LINE1,Iwaki City Office, Dec. 22, 2012.
 ./maswkf/prm/gnuplt_script/dispersion/disp032.plt
 ./maswkf/prm/gnuplt_script/dispersion/disp035.plt
 ./maswkf/prm/gnuplt_script/dispersion/disp038.plt
 ./maswkf/prm/gnuplt_script/dispersion/disp041.plt
 ./maswkf/prm/gnuplt_script/dispersion/disp044.plt
 ./maswkf/prm/gnuplt_script/dispersion/disp047.plt
```

sh disp_comb.sh

Automatically window of gedit open with ./maswkf/prm/disp_comb.prm
Delete un-necessary lines and press [Enter]



Then, disp???.plt files are created. These contain the individual dispersion curves of selected CMP (???).

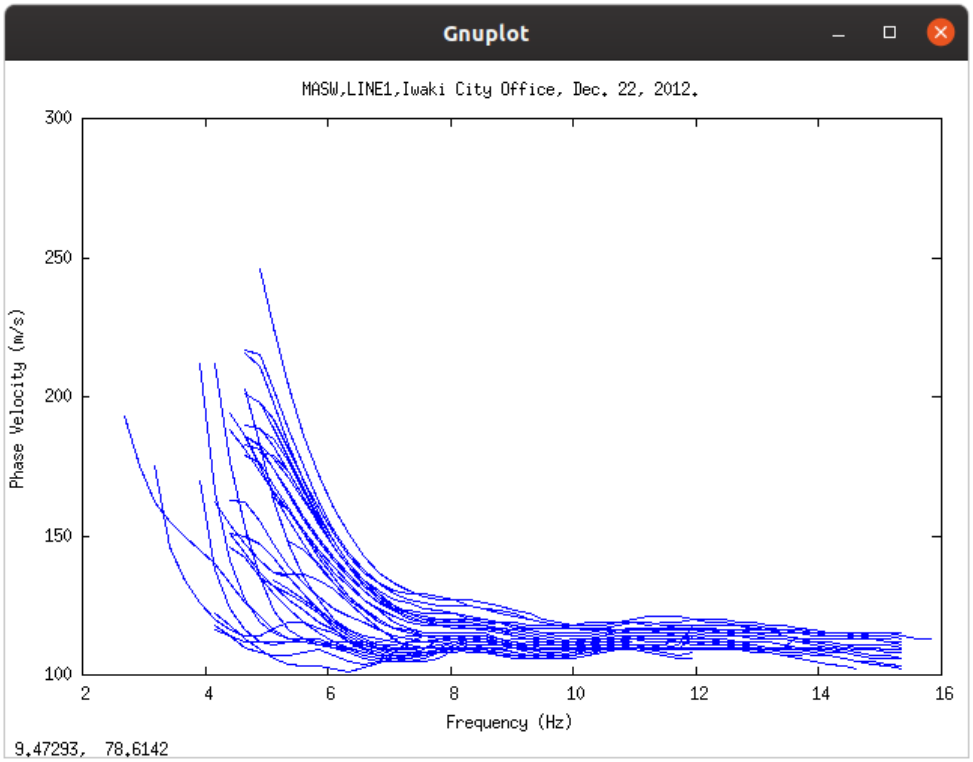


After the creation of all cmp???.plt files, X-window opens with the plot of dispersion curve, one by one. The same figure in PostScript files are simultaneously created and stored in "./maswkf/data/dispersion/fig/"
Press [Enter] to proceed to the next CMP.

Example cont.

5. At the final of “sh disp_comb.sh”

The dispersion curves of all CMPs on a X-window are plotted all together.
Simultaneously a postscript file is created:
./maswkf/data/dispersion/fig/disp_all.ps



disp032.plt: a script file of GNUPLOT

```
 reset
unset key
# Graph title
set title "MASW,LINE1,Iwaki City Office, Dec. 22, 2012. cmp032 "
# Horizontal axis: label & range
set xlabel "Frequency (Hz)"
set xrange [   2.00000000     :   16.0000000     ]
# Verical axis: label & range
set ylabel "Phase Velocity (m/s)"
set yrange [   100.000000     :   300.000000     ]
plot "./maswkf/data/dispersion/cmp032ds.dat" with points lc rgb "red"
unset multiplot
set terminal postscript color enhanced
set output "./maswkf/data/dispersion/fig/disp032.ps"
reset
unset key
# Graph title
set title "MASW,LINE1,Iwaki City Office, Dec. 22, 2012. cmp032 "
# Horizontal axis: label & range
set xlabel "Frequency (Hz)"
set xrange [   2.00000000     :   16.0000000     ]
# Verical axis: label & range
set ylabel "Phase Velocity (m/s)"
set yrange [   100.000000     :   300.000000     ]
plot "./maswkf/data/dispersion/cmp032ds.dat" with points lc rgb "red"
unset multiplot
set output
set terminal x11
pause -1
```

disp_all.plt: a script file of GNUPLOT

```
load './maswkf/prm/gnuplt_script/dispersion/disp032.plt’
...
load './maswkf/prm/gnuplt_script/dispersion/disp128.plt'
reset
unset key
# Graph title
set title "MASW,LINE1,Iwaki City Office, Dec. 22, 2012.  "
# Horizontal axis: label & range
set xlabel "Frequency (Hz)"
set xrange [   2.00000000     :   16.0000000     ]
# Verical axis: label & range
set ylabel "Phase Velocity (m/s)"
set yrange [   100.000000     :   300.000000     ]
set multiplot
plot "./maswkf/data/dispersion/disp_all.dat" with lines lc rgb "blue"
unset multiplot
set terminal postscript color enhanced
set output "./maswkf/data/dispersion/fig/disp_all.ps"
reset
unset key
# Graph title
set title "MASW,LINE1,Iwaki City Office, Dec. 22, 2012.  "
# Horizontal axis: label & range
set xlabel "Frequency (Hz)"
set xrange [   2.00000000     :   16.0000000     ]
# Verical axis: label & range
set ylabel "Phase Velocity (m/s)"
set yrange [   100.000000     :   300.000000     ]
set multiplot
plot "./maswkf/data/dispersion/disp_all.dat" with lines lc rgb "blue"
unset multiplot
set output
set terminal x11
```

Note: A way to combine many c-f panels

"sh connect_all.sh" combines many postscript files of c-f panels in one. This refers to a parameter file ./maswkf/prm/connect.prm.

A postscript file 'cmp_all.ps' is created in ./maswkf/data/c_f_panels/fig

Example of 'connect.prm'

```
'maswkf/data/c_f_panels/fig'   26  :folder name ('./' is added), number of letters
'cmp'   3                          :top part of file name, number of letters
'.ps'   3                          :tail part of file name, number of letters
18 250 1                           :ncmps, ncmpe, ncmpd
```

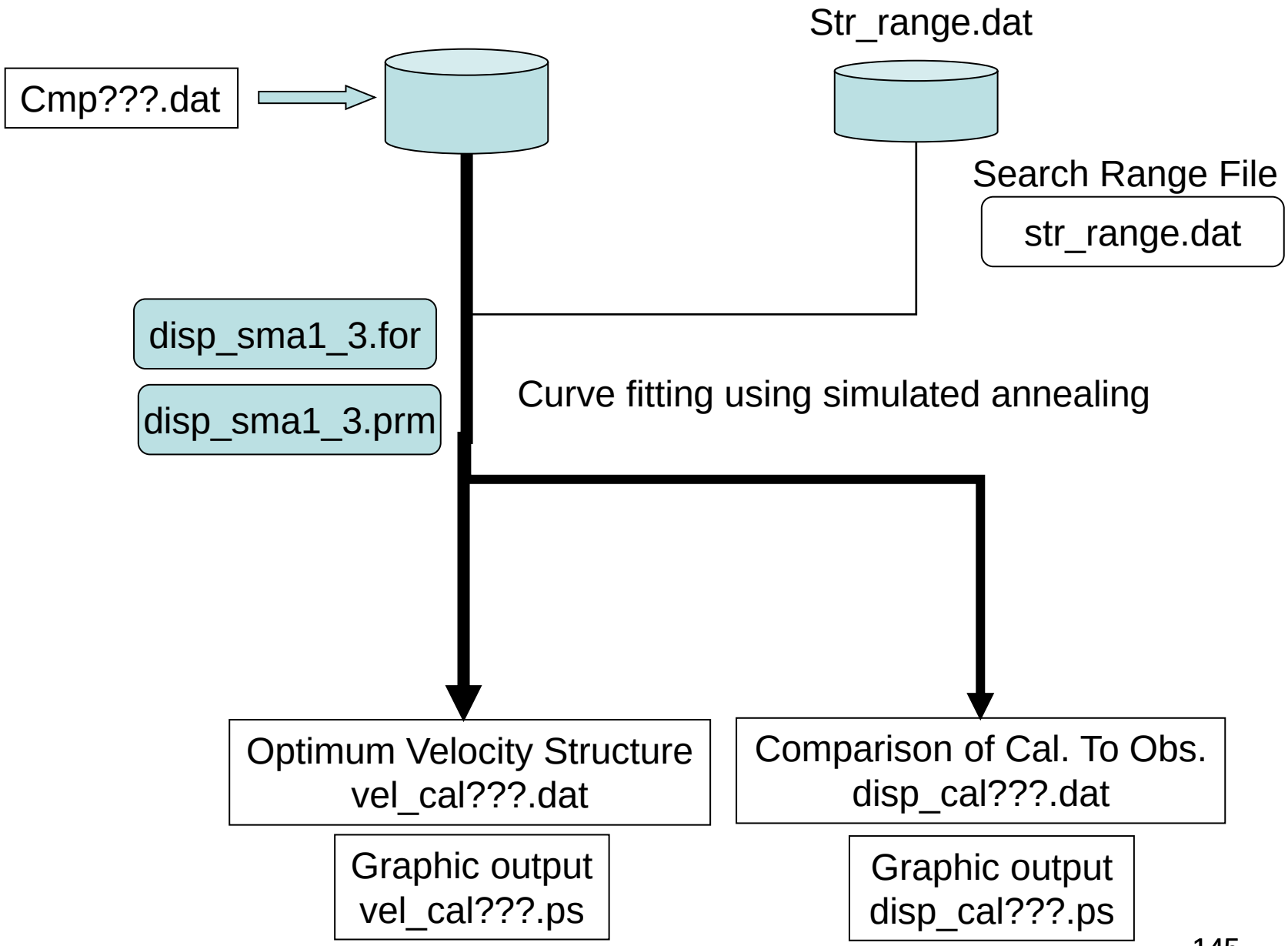
This means that the postscript files from cmp018.ps (ncmps=18) to cmp250.ps (ncmpe=250) with increment 1 (ncmpd=1) are searched in ./maswkf/data/c_f_panels/fig and combined into a multi page postscript file cmp_all.ps in the same folder.
It is sometimes useful to check the gradual change of c-f panels using this combined postscript file as a flip book.
It is possible to combine other series of postscript files by re-writing 'connect.prm', e.g., disp???.ps in ./maswkf/data/dispersion/fig .

4. Instruction Manual of Programs for Analysis

4.1 Inversion of dispersion curves

sh inversion_2D.sh

disp_sma1_3.for + disp_sma1_3.prm


Str_range.dat
Cmp???.dat
Search Range File
str_range.dat
disp_sma1_3.for
disp_sma1_3.prm
Curve fitting using simulated annealing
Optimum Velocity Structure
vel_cal???.dat
Comparison of Cal. To Obs.
disp_cal???.dat
Graphic output
vel_cal???.ps
Graphic output
disp_cal???.ps

Conduct inversion and plot the results.

sh inversion_2D.sh

inversion_2D.sh

```
#!/bin/sh -x
./bin/disp_sma1_3.exe | tee ./maswkf/log/inversion_2D.log
sh inversion_2D_plt.sh
```

inversion_2D_plt.sh

```
#!/bin/sh -x
./bin/inv_plt.exe | tee -a ./maswkf/log/inversion_2D.log
gnuplot -e "load './maswkf/prm/gnuplt_script/dispersion/disp_cal.plt' ; pause -1 "
gnuplot -e "load './maswkf/prm/gnuplt_script/structure/vs_structure.plt' ; pause -1 "
rm ./maswkf/temp/temp*.dat 2>/dev/null
```

inversion_2D_plt.sh can be executed solely to plot the results.
sh inversion_2D_plt.sh

Parameter File: disp_sma1_3.prm

```
  1 1. 0.6 1.3 5000  5 :idum,t0,a,c,ntemp,j0
  0.005                :eps0
     1    1    1       :n_roh,n_vp,n_initial
     1    0    1       :ini_flg,ndsp_flg,n_err
     0    1            :kflg,jflg
     0    0            :n_vs,n_th
 str_range.dat         :File name for the initial velocity model (a25).
  30 15 1 0            :ncmps,ncmpe,ncmpd, mnflg(theo_cal=1, inversion=others)
```

```
Control parameter for the simulated annealing method
idum      :Random seed (integer). As the result may
          depend on the initial velocity model given by
          random number, it is strongly recommended for
          users to apply this program several times with
          various values of random seed and tograsp the
          scatter of result.
t0        :Initial Temperature
a,c       :Coefficients for T=T0*exp(-c*k**a), where k is
          iteration number
ntemp     :Maximum number of temparature change
j0        :Number of iteration for each temperature

Threshold for conversion
 eps0     : averaged deviation

CMP numbers
ncmps,ncmpe,ncmpd: start, end, interval
          ncmpd>0 if ncmps<ncmpe,ascending  cmp number
          ncmpd<0 if ncmps>ncmpe,descending cmp number
```

```
flags of empirical relations for roh and vp
 n_vp     : 1=by Ludwig et al(1970),
            vp=1.11*vs+1.29
            0=fixed to the initial values
 n_roh    : 1=by Kitzunezaki et al(1990),
            roh=1.2475+0.399*vp-0.026*vp**2
            0=fixed to the initial values
 n_initial: 1=Initial model is set to the given value
            0=Initial model is set using random seed
flags for output to Display
 ini_flg  : Initial Velocity Structure Model 1=yes
 ndsp_flg : Observed Dispersion Relation     1=yes
 n_err    : Error at each iteration          1=yes
 kflg     : Missfit at each temp. change     1=yes
 jflg     : Missfit at each itration with the same temp.
                                             1=yes
 n_vs     : Vs value  (n_vs=layer number, 0=no output)
 n_th     : Thickness (n_th=layer number, 0=no output)
 n_err    : errors
```

Input File

- “str_range.dat” is the name of the file that includes the initial structure model and the search range.
- “cmp??ds.dat” that includes the observed dispersion curve.

Format of “str_range.dat”

```
Iwaki City, SS-1,22/12/2012                                          :Comment(a30)
    5                                                                :IL(I5),Layer Number
1.9   1.5    0.001  0.010  0.06 0.12  0.0032  0.10 :density,Vp,hmin,hmax,vmin,vmax,hini,vini
1.9   1.5    0.001  0.010  0.10 0.15  0.0035  0.15
1.9   1.5    0.001  0.020  0.06 0.12  0.0014  0.08
1.9   1.5    0.001  0.020  0.10 0.18  0.0045  0.16
2.0   1.70   998.0  999.0  0.18 0.35  998.0   0.34
```

(hmin, hmax): the minimum and maximum of the serach range of layers thickness. For the deepest layer they must be (998.0, 999.0).

(vmin, vmax): the minimum and maximum of the search range of shear wave velocity Vs.

(hini,vini):given initial values of the thickness and Vs of each layer.

Format of the file for Dispersion curve

```
# Freq.  V.m/s
  5.371  206.000
  5.615  186.000
  5.859  169.000
  6.104  156.000
  6.348  146.000
  6.592  138.000
  6.836  132.000
  7.080  128.000
  7.324  125.000
  7.568  123.000
  7.812  121.000
  8.057  121.000
....
```

It's the same as the output file "cmp??ds.dat" of "masw2cmp.exe"

Output file

- “vel_cal???.dat” of the example of the parameter file shown above. File for the estimated velocity structure by the heuristic search.
- “disp_cal???.dat” of the example of the parameter file shown above. File that includes the observed and calculated dispersion curve together.
- Both can be read by Excel.

Format of output file "vel_cal???.dat"

#	depth (m)	Density(Kg/m^3)	Vp (m/sec)	Vs (m/sec)
1	0.0	1755.5	1401.0	100.0
2	3.3	1773.5	1456.5	150.0
3	6.8	1748.2	1378.8	80.0
4	8.2	1777.3	1468.3	160.6
5	12.7	1847.1	1688.6	359.1
6	14.0	1847.1	1688.6	359.1

Format of output file “disp_cal???.dat”

# Frequency(Hz)	Observed Vel(m/	Calculated Vel(m/s)
5.371	206.000	196.983
5.615	186.000	179.416
5.859	169.000	165.158
6.104	156.000	154.711
6.348	146.000	147.245
6.592	138.000	141.766
6.836	132.000	137.630
7.080	128.000	134.424
7.324	125.000	131.881
7.568	123.000	129.825
7.812	121.000	128.135
8.057	121.000	126.719
8.301	121.000	125.526

…

Example

1. 1st trial for a representative CMP:

Select a representative CMP that is not located close to the ends of measurement line where an accurate dispersion curve can not be expected due to a shortage of stacking. In this example, CMP032 is selected, however, it is case by case in reality.

ncmps=32 in disp_sma1_3.prm

Set the search range of thickness and Vs in the file “str_range.dat” together with the values of density (roh) and Vp. It is better to refer the borehole data nearby if available. Leave (hini,vini) with arbitrary values, because they are not used in the 1st trial.

```
Iwaki City, SS-1,22/12/2012   :Model(a30)
         5                      :IL(I5),Layer Number
1.9   1.5    0.001  0.010  0.06 0.12  0.0032  0.10 :density,Vp,hmin,hmax,vmin,vmax
1.9   1.5    0.001  0.010  0.10 0.15  0.0035  0.15 :density,Vp,hmin,hmax,vmin,vmax
1.9   1.5    0.001  0.020  0.06 0.12  0.0014  0.08 :density,Vp,hmin,hmax,vmin,vmax
1.9   1.5    0.001  0.020  0.10 0.18  0.0045  0.16 :density,Vp,hmin,hmax,vmin,vmax
2.0   1.70   998.0  999.0  0.18 0.35  998.0   0.34
```

Example (cont.)

Edit the parameter file “disp_sma1_3.prm”. Especially set n_initial=0, then (hini,vini) are given randomly among the search range.

```
disp_sma1_3.prm

 1 1. 0.6 1.3 5000 10    :idum,t0,a,c,ntemp,j0
 0.0005                  :eps0
    1    1    0          :n_roh,n_vp,n_initial
    1    0    1          :ini_flg,ndsp_flg,n_err
    1    1               :kflg,jflg
    0    0               :n_vs,n_th
str_range.dat            :File name for the initial velocity model (a25).
 32 32 3  0              :ncmps,ncmpe,ncmpd,mnflg(theo_cal=1, inversion=others)
```

First, set ncmps=ncmpe (=32). This means that the inversion is applied only to the selected CMP032.

sh inversion_2D.sh

The structure of the converged solution is shown in X-window.

This solution (estimated velocity structure) is simultaneously stored in ./maswkf/data/structure/vel_cal???.dat.

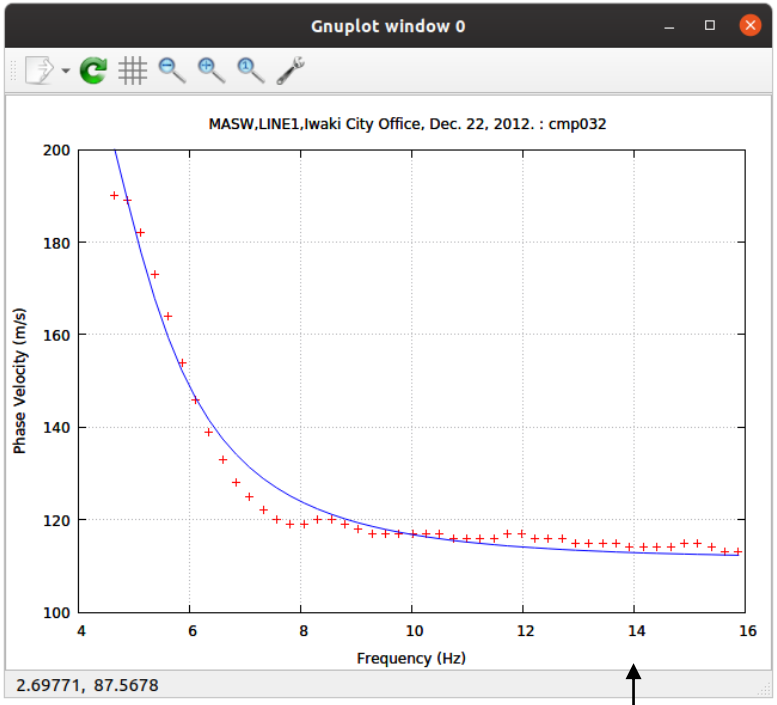
The observed and theoretical dispersion curves are simultaneously stored in ./maswkf/data/dispersion/disp/cal???.dat.

Using a representative CMP, an appropriate way to set the search range and threshold value is determined as shown above.

yokoi@eoan-ermine: ~/Desktop/MASW2020

```
yokoi@eoan-ermine:~/Desktop/MASW2020$ sh inversion_2D.sh
+------------------------------------------------+
+                                                +
+                    Disp_sma1                   +
+                                                +
+ Program to obtain the optimum undeground velocity +
+ structure for the given dispersion relation of  +
+ Rayleigh wave.                                 +
+                                                +
+ The used method is a combination of the down hill +
+ simplex method (Nelder & Mead (1965)) and the  +
+ very fast simulated annealing method (Ingber   +
+ (1989)).                                       +
+                                                +
+ The subroutine DSPRAY and DSPMRX published in   +
+ "Seismological Algorithm" are used directly.    +
+ AMOEBA and AMOTRY published in "Numerical Recipe" +
+ are also used, but with significant modification +
+ for the adaptation with the very fast simulated  +
+ annealing method.                               +
+                                                +
+ By the combination with the down hill simplex   +
+ method, the very fast simulated annealing method +
+ is gotten much faster.                          +
+                                                +
+                                  July 6, 2005+
+    CopyRight by Toshiaki Yokoi, IISEE, BRI, Japan.+
+------------------------------------------------+
./maswkf/data/dispersion/progress.dat
./maswkf/prm/disp_sma1_3.prm
fnam2=cmp032ds.dat
fnam3=vel_cal032.dat
fnam4=disp_cal032.dat
./maswkf/prm/str_range.dat
```

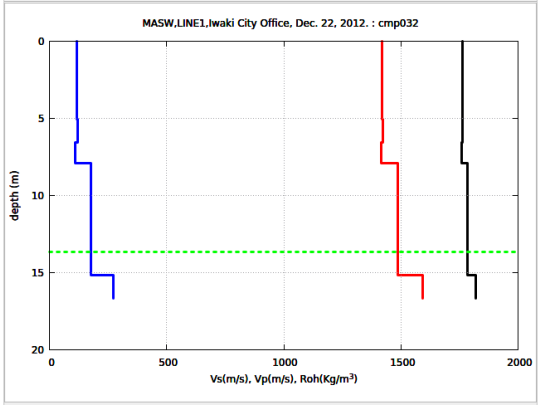
Gnuplot window 0



Thicknes	Density	Vp	Vs	Ranges of Thickness & Vs			
0.0056	1.7426	1.3618	0.0647	0.0010	0.0100	0.0600	0.1200
0.0086	1.7626	1.4229	0.1197	0.0010	0.0100	0.1000	0.1500
0.0149	1.7589	1.4117	0.1096	0.0010	0.0200	0.0600	0.1200
0.0084	1.7815	1.4815	0.1725	0.0010	0.0200	0.1000	0.1800
999.0000	1.8040	1.5517	0.2357	998.0000	999.0000	0.1800	0.3500

```
./maswkf/data/dispersion/cmp032ds.dat
<<Inversion>>
  10    0.0028343482
  20    0.0023985964
```

Gnuplot window 0



	Thickness(km)	Density(g/cm^3)	Vp(km/sec)	Vs(km/sec)
1	0.0051	1.7616	1.4197	0.1168
2	0.0016	1.7622	1.4217	0.1186
3	0.0013	1.7594	1.4131	0.1109
4	0.0073	1.7831	1.4864	0.1770
5	999.0000	1.8164	1.5906	0.2708

```
./maswkf/data/structure/vel_cal032.dat
./maswkf/data/dispersion/disp_cal032.dat
./maswkf/data/dispersion/err_estm.dat
Graphic data output for GNUPLOT
./maswkf/prm/gnuplt_script/dispersion/disp_cal032.plt
./maswkf/prm/gnuplt_script/structure/vel_cal032.plt
Note: The following floating-point exceptions are signalling: IEEE_UNDERFLOW_FLA
G IEEE_DENORMAL
Hit return to continue for cmp032

Hit return to continue

yokoi@eoan-ermine:~/Desktop/MASW2020$
```

Example (cont.)

2. Inversion for a group of CMPs:

Set n_initial=1 and (ncmps, ncmpe,ncmpd) to the CMPs that will be analyzed.
For example, (32 122 3).
Run again
sh inversion_2D.sh

The inversion is conducted from CMP032 to CMP122, with incrementing numbering with 3.
The converged solution of the previously processed CMP is used for the next CMP sequentially.
Have a coffee break, it really takes time.

```
disp_sma1_3.prm

1 1. 0.6 1.3 5000 10    :idum,t0,a,c,ntemp,j0
 0.0005                  :eps0
    1    1    0          :n_roh,n_vp,n_initial
    1    0    1          :ini_flg,ndsp_flg,n_err
    1    1               :kflg,jflg
    0    0               :n_vs,n_th
str_range.dat            :File name for the initial velocity model (a25).
 32 122 3  0             :ncmps,ncmpe,ncmpd,mnflg(theo_cal=1, inversion=others)
```

Example (cont.)

After the convergence for CMP032, the next CMP037 is processed,

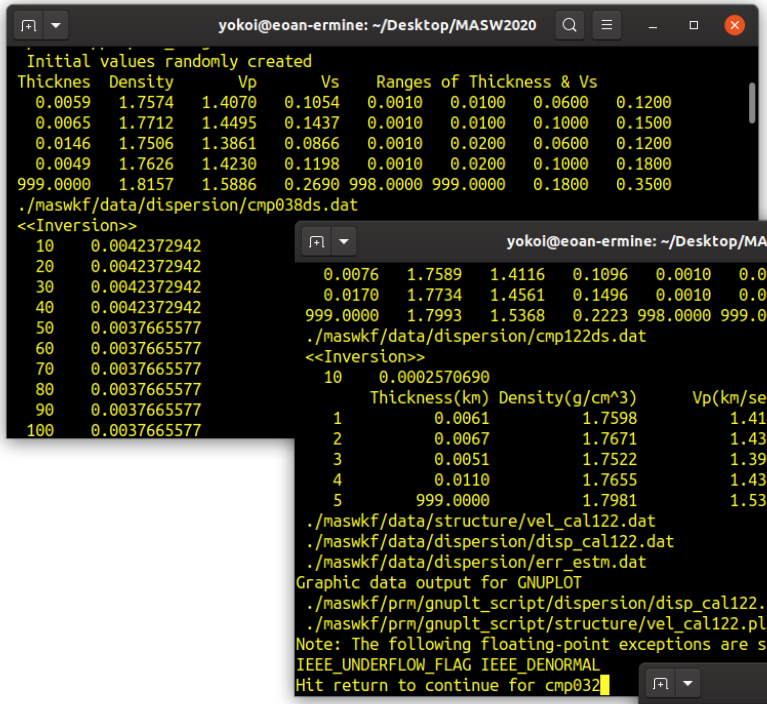
…

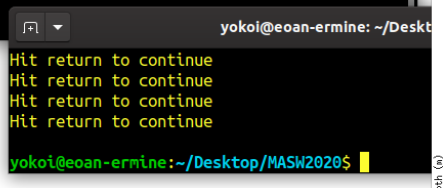
CMP110 is processed,

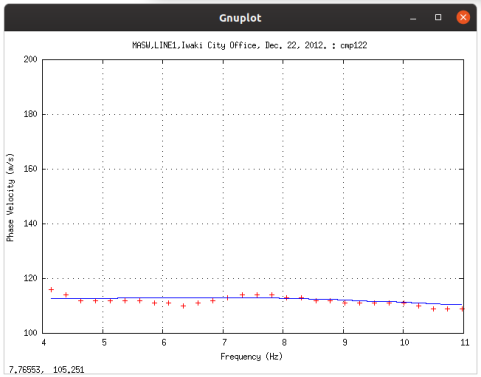
…

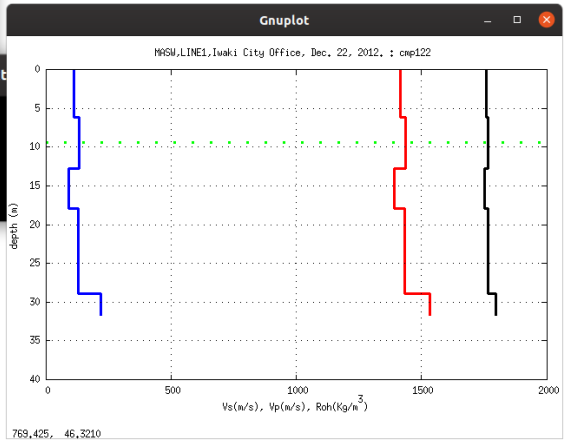
and

CMP122 is processed, in order.









These solutions (estimated velocity structures) are simultaneously stored in ./maswkf/data/structure/vel_cal???.dat.

, whereas the images are in ./maswkf/data/structure/fig/vel_cal???.ps

The observed and theoretical dispersion curves are simultaneously stored in ./maswkf/data/dispersion/disp_cal???.dat

,whereas the images are in ./maswkf/data/dispersion/fig/disp_cal???.dat

5. Instruction Manual of Programs for Analysis

5.1 Plotting 2D velocity structures

draw2d.for + draw2d.prm

Parameter File

draw2d.prm

0. 10. 60. 200. 1 :dep_min,dep_max (m), v_min, v_max (m/s), n_reverse for drawing

Input File

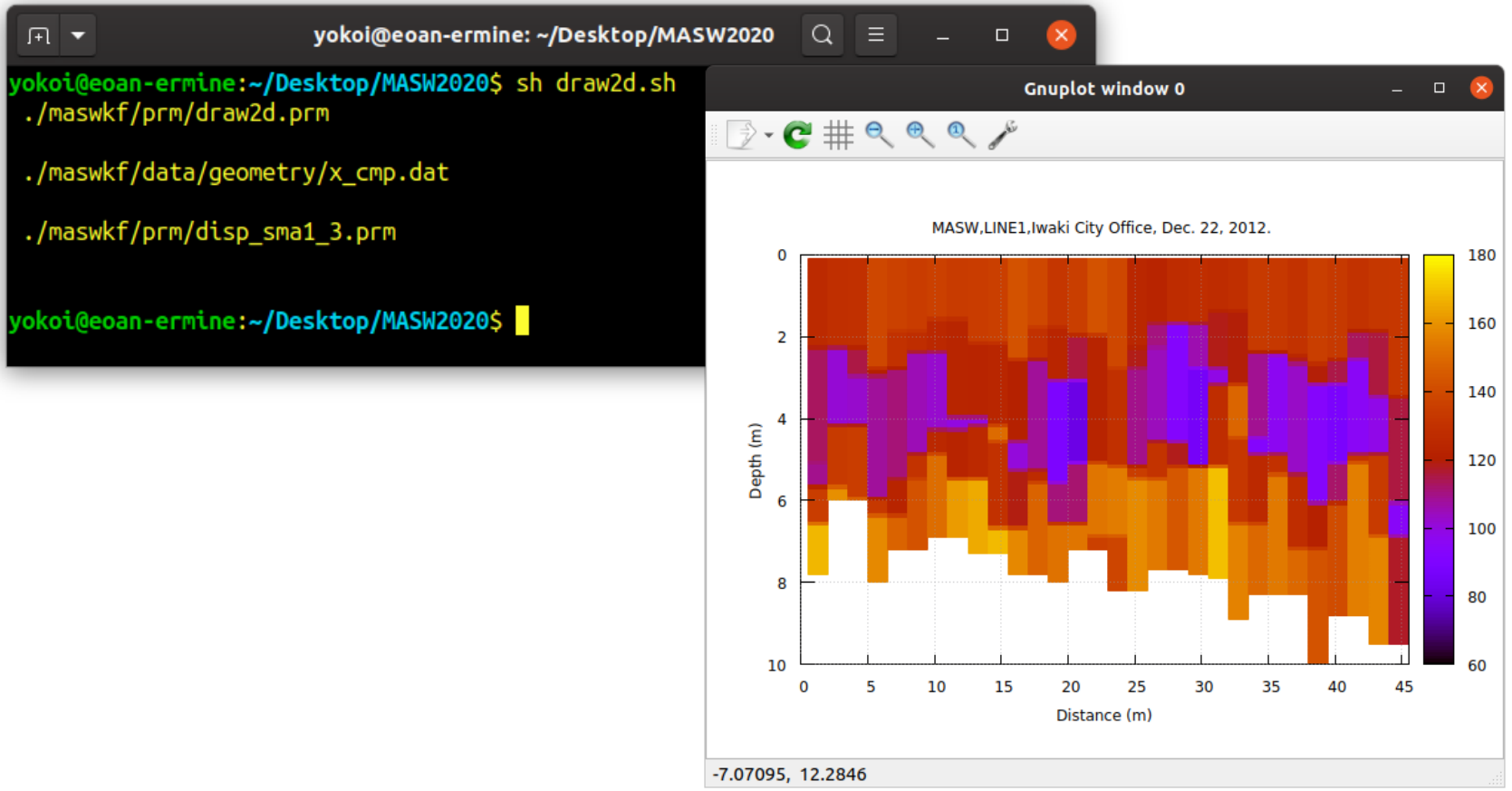
- The file of the estimated Vs structure “vel_cal???.dat” stored in ./maswkf/data/structure .

Output File

- Interim data file: ./maswkf/data/structure/draw2d.dat
- Interim script file of GNUPLOT:
  ./maswkf/prm/gnuplt_script/draw2d.plt
- Output PostScript file
  ./maswkf/structure/fig/draw2d.ps

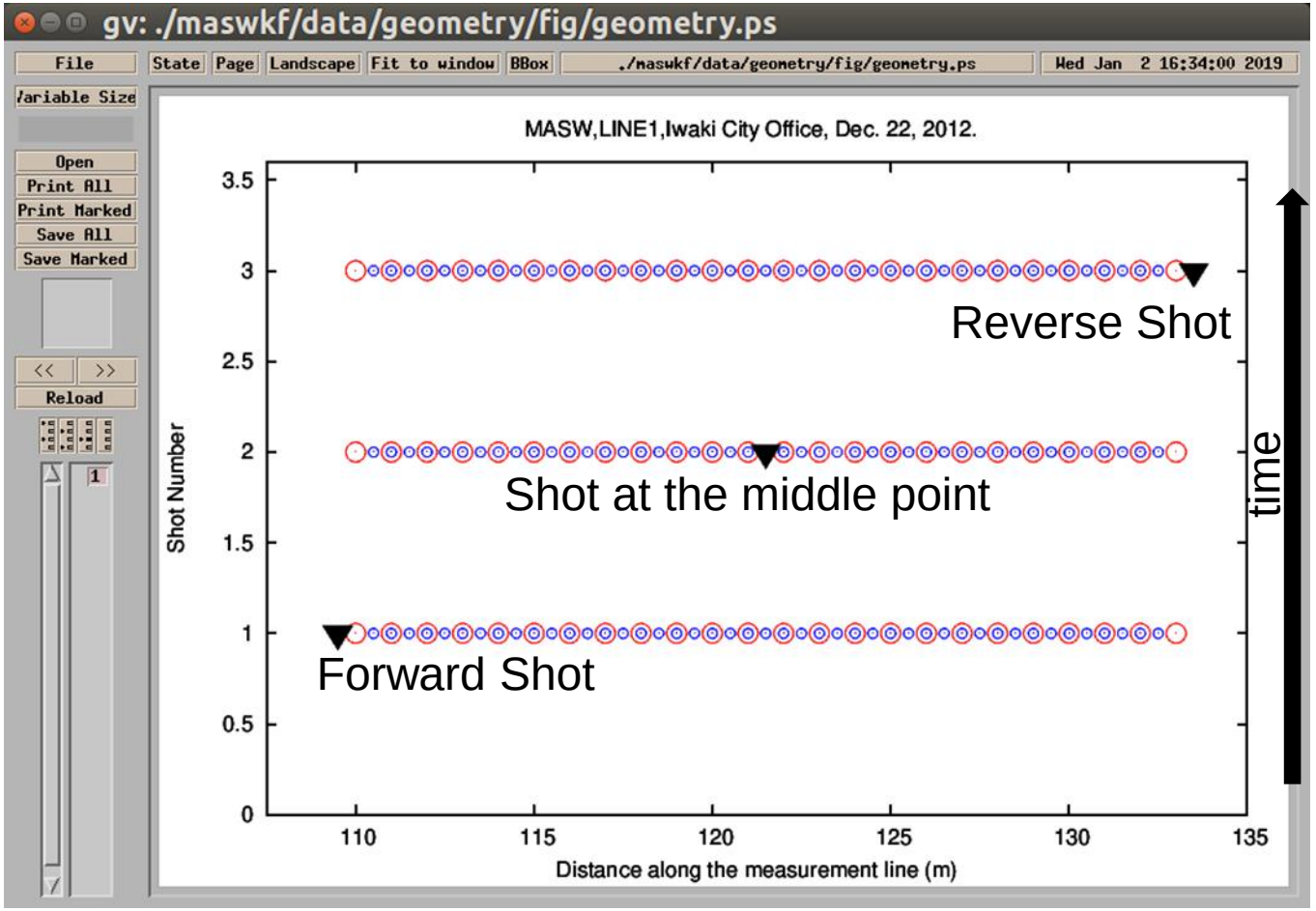
sh draw2d.sh

2D plot of velocity structure is drawn in a X-window. Simultaneously, the same image is stored in ./maswkf/data/structure/fig/draw2d.ps .



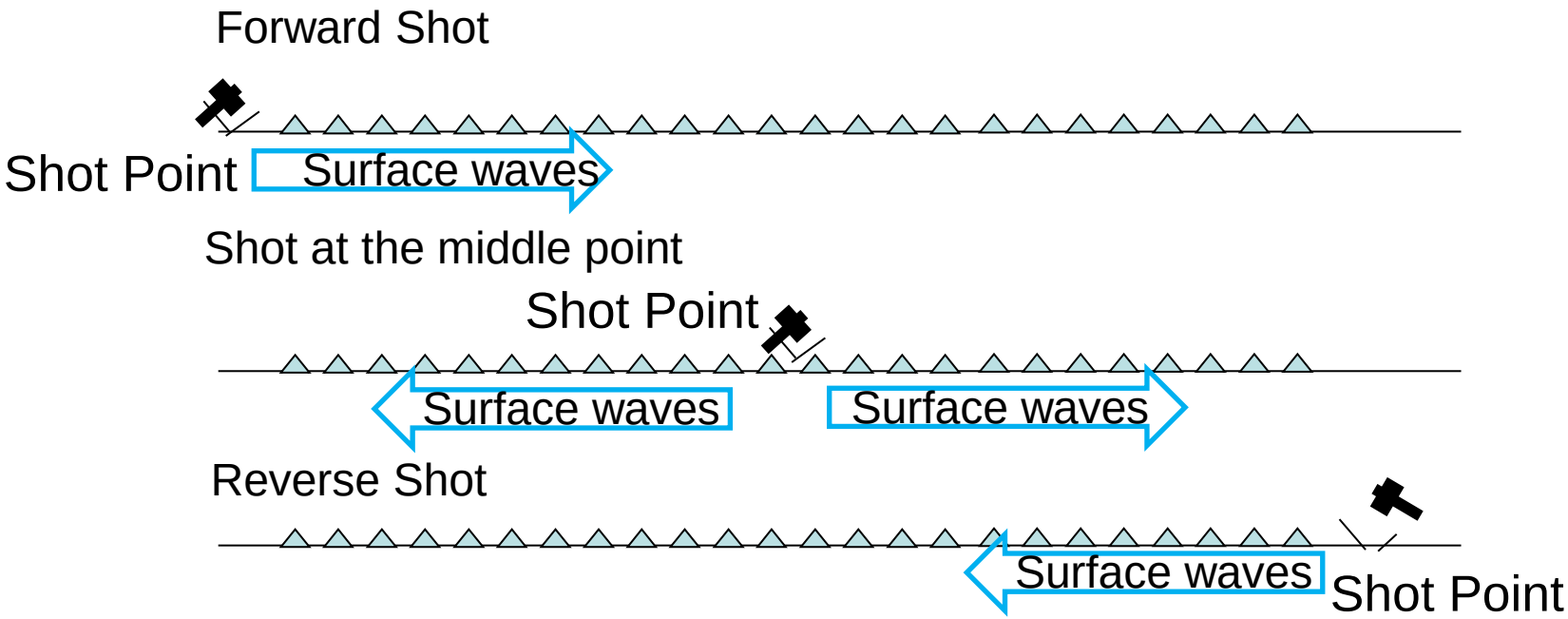
2. Note: Field Data Acquisition

1D exploration
(configuration)



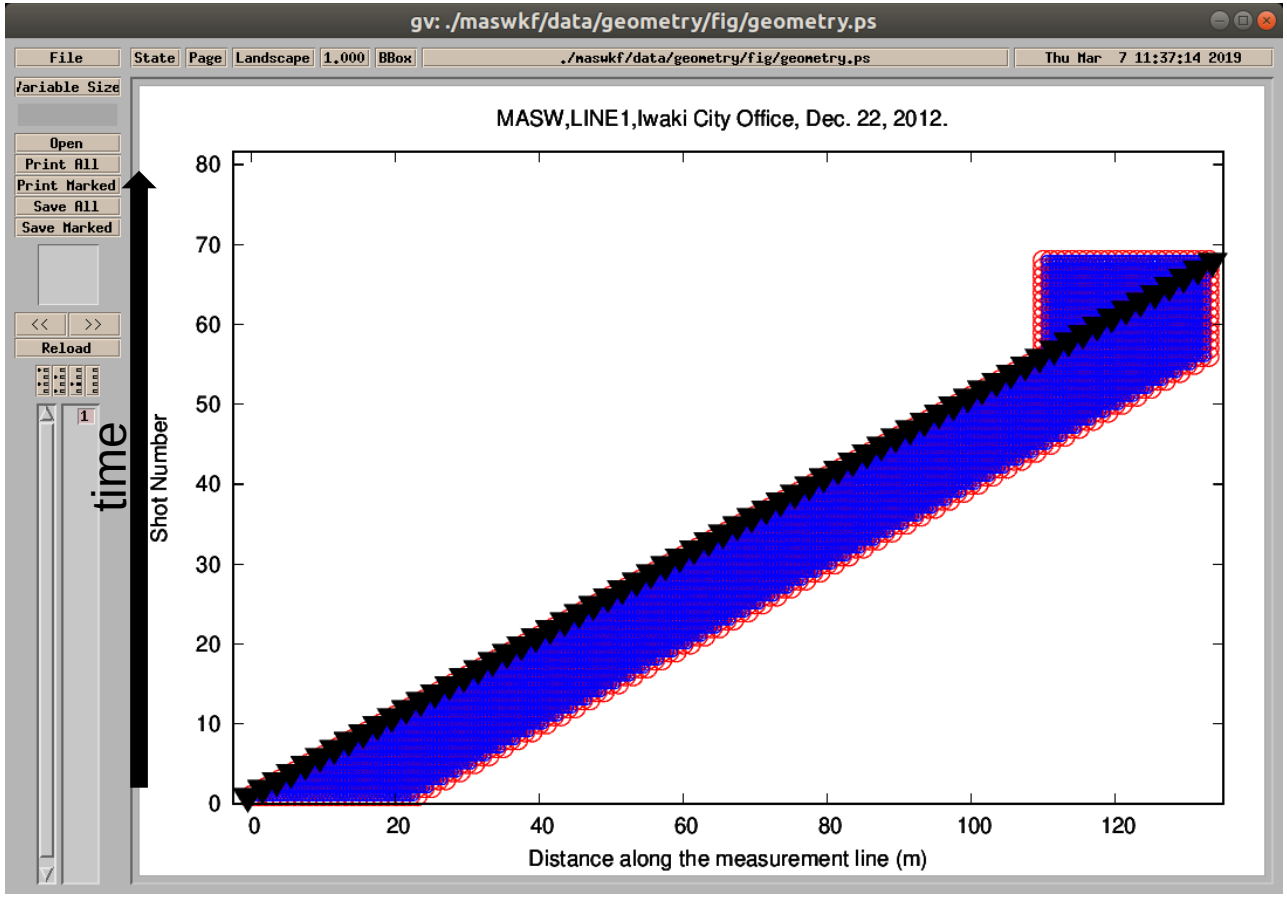
1D exploration

A pair of measurements is conducted in the field changing the shot position as shown below.



Then, the velocity analysis is conducted for all the geophone pairs on the measurement line. Shot at the middle point is not essential.

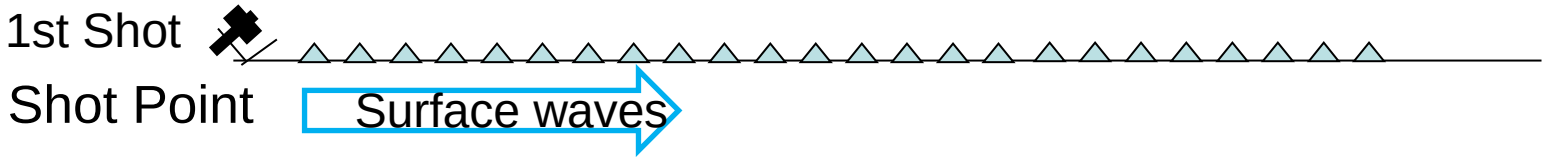
2D Exploration
(configuration)



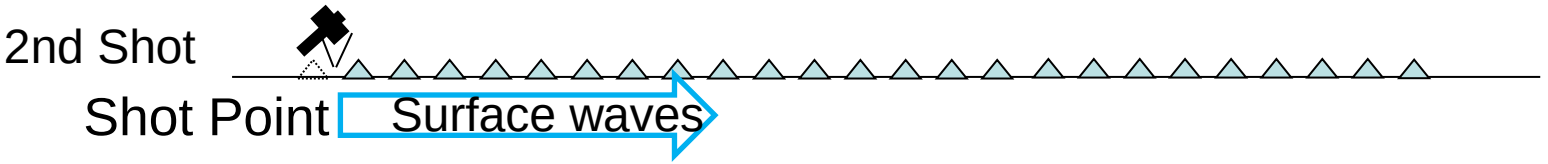
Triangles: shot points, Red dots: geophone locations,
Blue dots: CMP location.

2D Exploration (cont.)

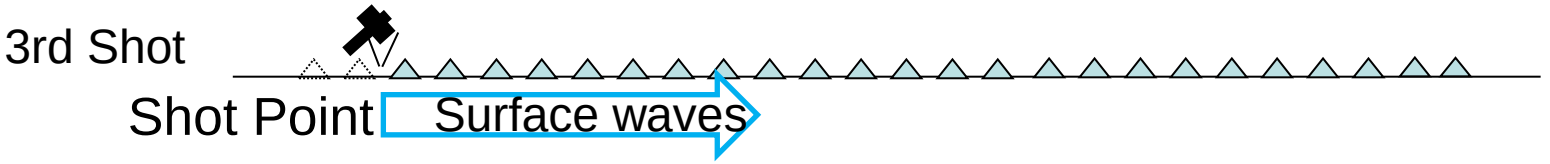
+ 1st shot is applied at an end of the measurement line.



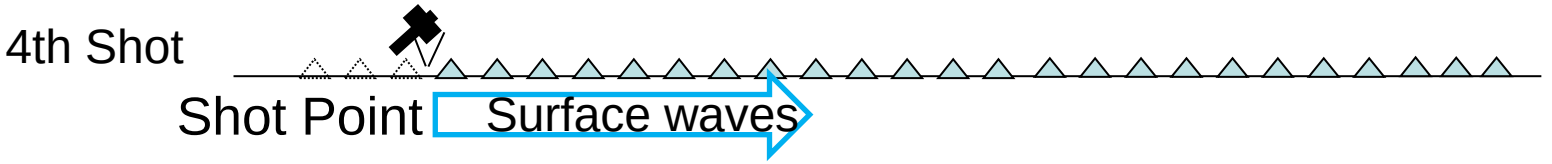
+ Geophone array is moved with dx (geophone interval). 2nd shot is applied.



+ Geophone array is moved with dx (geophone interval). 3rd shot is applied.



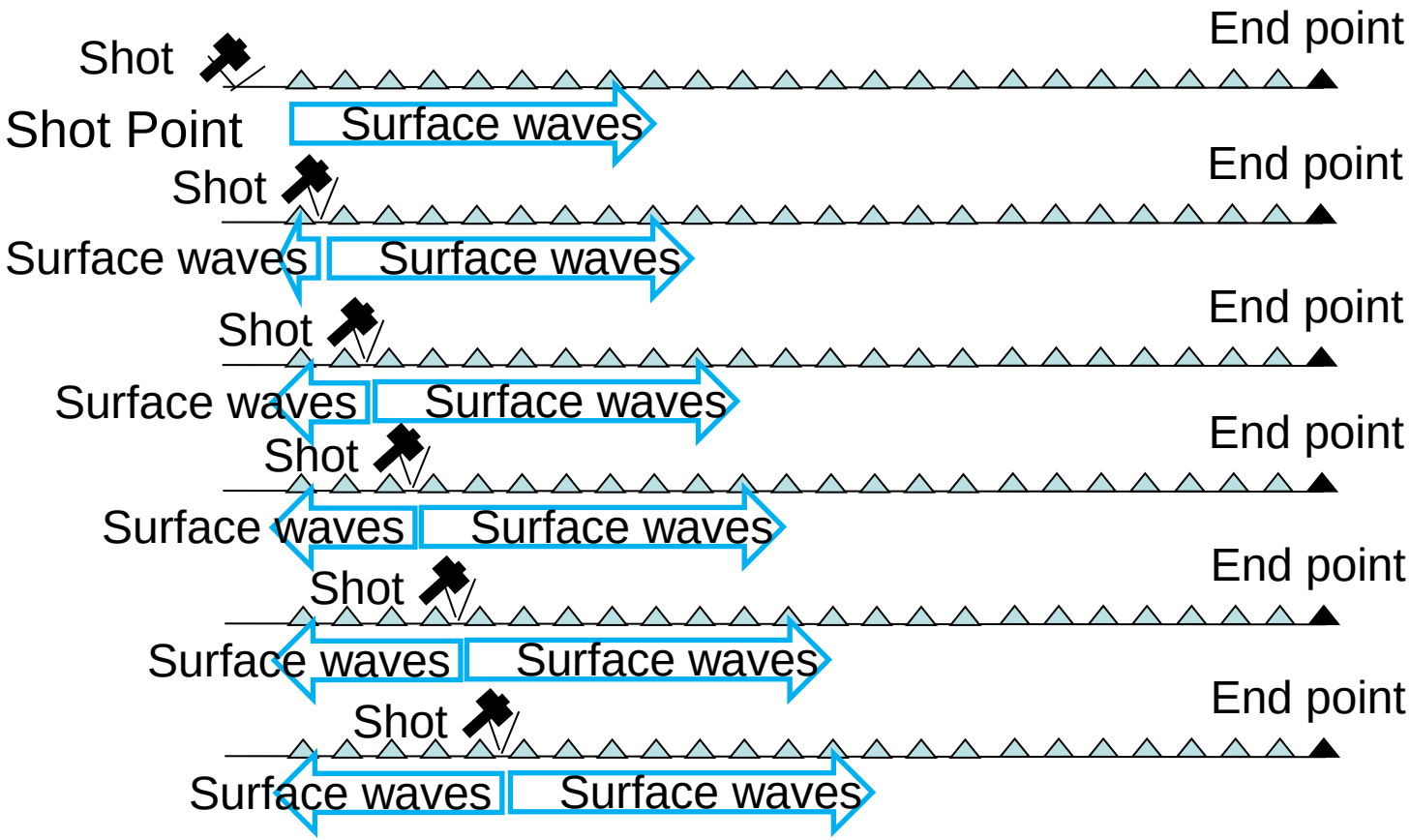
+ Geophone array is moved with dx (geophone interval). 4th shot is applied.



+ Continue the same procedure until the final channel's geophone reaches at another end of the measurement line.

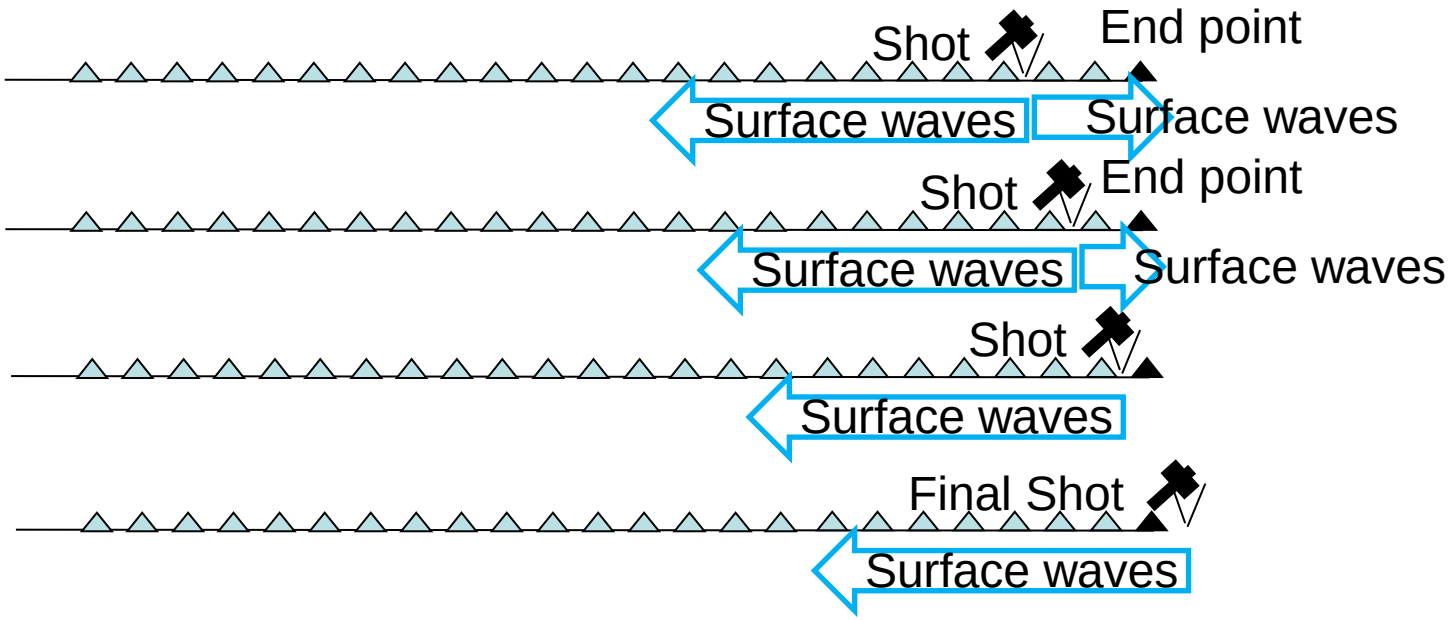
2D Exploration (cont.)

+ When the final channel's geophone reaches at another end of the measurement line, Geophone array stops and shot point goes on moving toward the end point



2D Exploration (cont.)

+ The final shot is applied at outside of the end.



3. References

Hayashi, K. and H. Suzuki, 2004, CMP cross-correlation analysis of multi-channel surface-wave data, Exploration Geophysics, **35**, Butsuri-Tansa, 57, Mulli-Tamsa, 7, 7–13 (one issue published jointly in English)..