Instruction

- Analysis of CCA Method -

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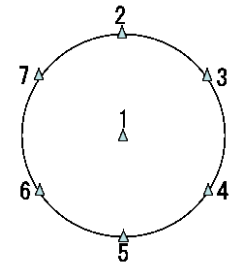
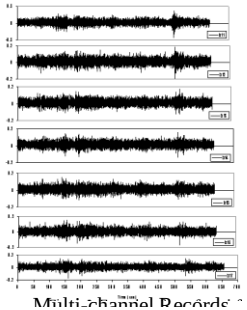
Procedures of analysis

Field Work

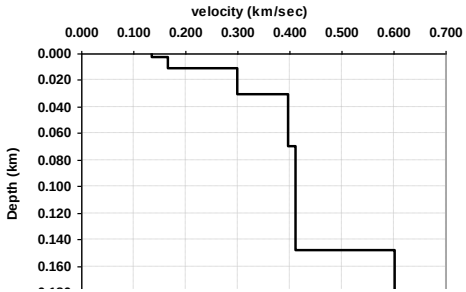


Microtremor Array Measurement
(Vertical Component)



1. Multi-plexing & Resampling

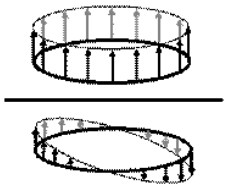
Estimation of Shear Wave Velocity Structure

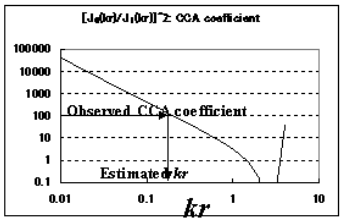


4. Heuristic Search of V_s Structure

Inversion or
Heuristic Search

Calculation of SPAC Coefficient

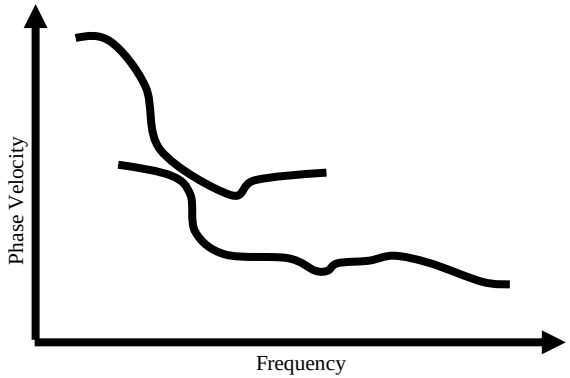




2. Calculation of CCA coefficient

Least Square Fitting to $J_0(kr)$

Calculation of the phase velocity



3. Determination of Dispersion Curve

Note: This version was developed on Linux: Ubuntu 18.04 LTS on VMWare Workstation Player 12.1.1 (build-3770994) on Windows10 Home 64bit (Build 14393) for 64bit PC, using gfortran compiler.

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

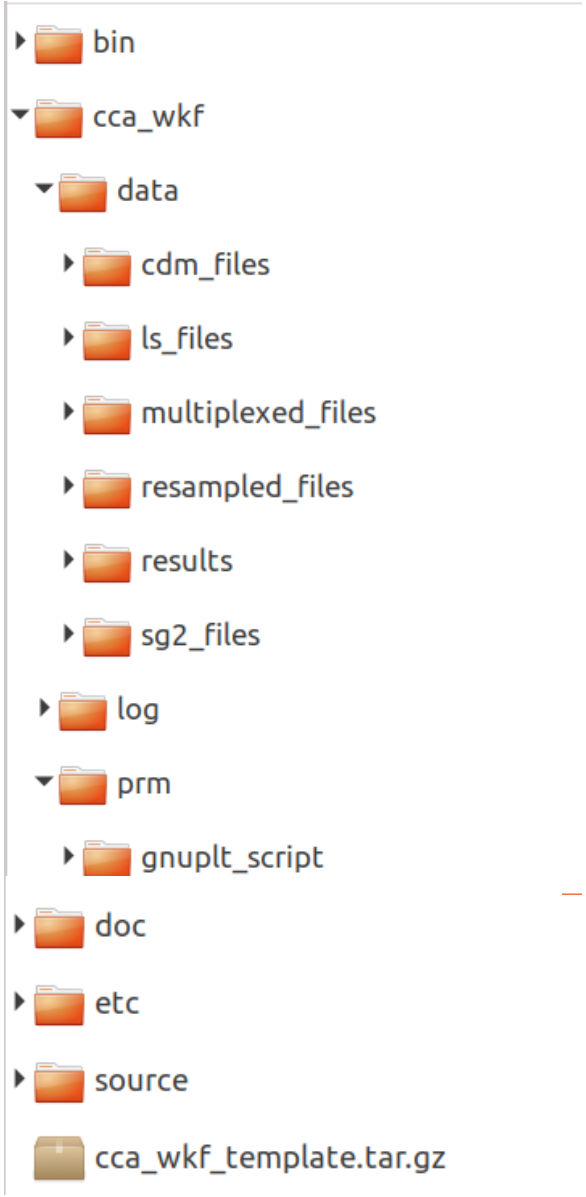
Execution of commands is conducted as

./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

Folder Structure



Every necessary programs and files are stored under the folder “CCA2019”. The command operation must be conducted in the same folder, where shell script files are stored.

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 “cca_wkf” 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 “ccawkf.tar.gz” keeps subfolder structure of “cca_wkf” and all parameter files in “cca_wkf/prm”.

Note: GNUPLOT scripts files

Some files of GNUPLOT scripts are stored under the subfolder

"./cca_wkf/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 “CCA2019” 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 CCA2019, 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 “CCA2019/bin”.

Note: Shell script files

The folder “CCA2019” 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
or
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: Cleaning up the subfolders

- Use
  sh clean_all.sh
  in the folder "CCA2019" to delete all files of input data, interim outputs and results for a new processing task.
- Use
  sh clean_sg2.sh
  in the folder "CCA2019" to delete all input files of sg2 format.
- Use
  sh clean_ls.sh
  in the folder "CCA2019" to delete all input files of win format.

Note: Format of Data Files

- Basically, users themselves are responsible to convert the format of the input data files to one of those acceptable formats by this program package.
- The acceptable format is “*.cdm” described in the section “1. Resampling”.
- The following two format converters are provided:

- sg2 (seg2 standard of IEEE)
  ➔./cca_wkf/multiplexed_files/*.dat

- ls (Win format of Hakusan-Kogyo)
  ➔./cca_wkf/cdm_files/*.cdm

Data Processing

1. Multiplexing & Resampling
    - 1.1 Format Conversion & Multiplexing
        - 1.1.1 *seg2* standard format
        - 1.1.2 *win* format for LS8800
    - 1.2 Resampling & Screening
        - “sh ./resamplec.sh”
    - 1.3 Plot Waveform:
        - “sh ./seewavc.sh”
    - 1.4 Checking the selected time blocks
        - “sh ./seeblkc.sh”
2. Estimating Dispersion Curve
    - 2.1 Calculation of CCA coefficient
        - “sh ./pwrcrs3.sh”
    - 2.2 Plot Power, Fourier Spectra & Coherence
        - “sh ./spectra_all.sh”
    - 2.3 Quality Control & Dispersion Curve
        - “sh ./results.sh”
3. Heuristic Search of Vs Structure
4. Re-arrange graphs *(in preparation)*

Note: Example1

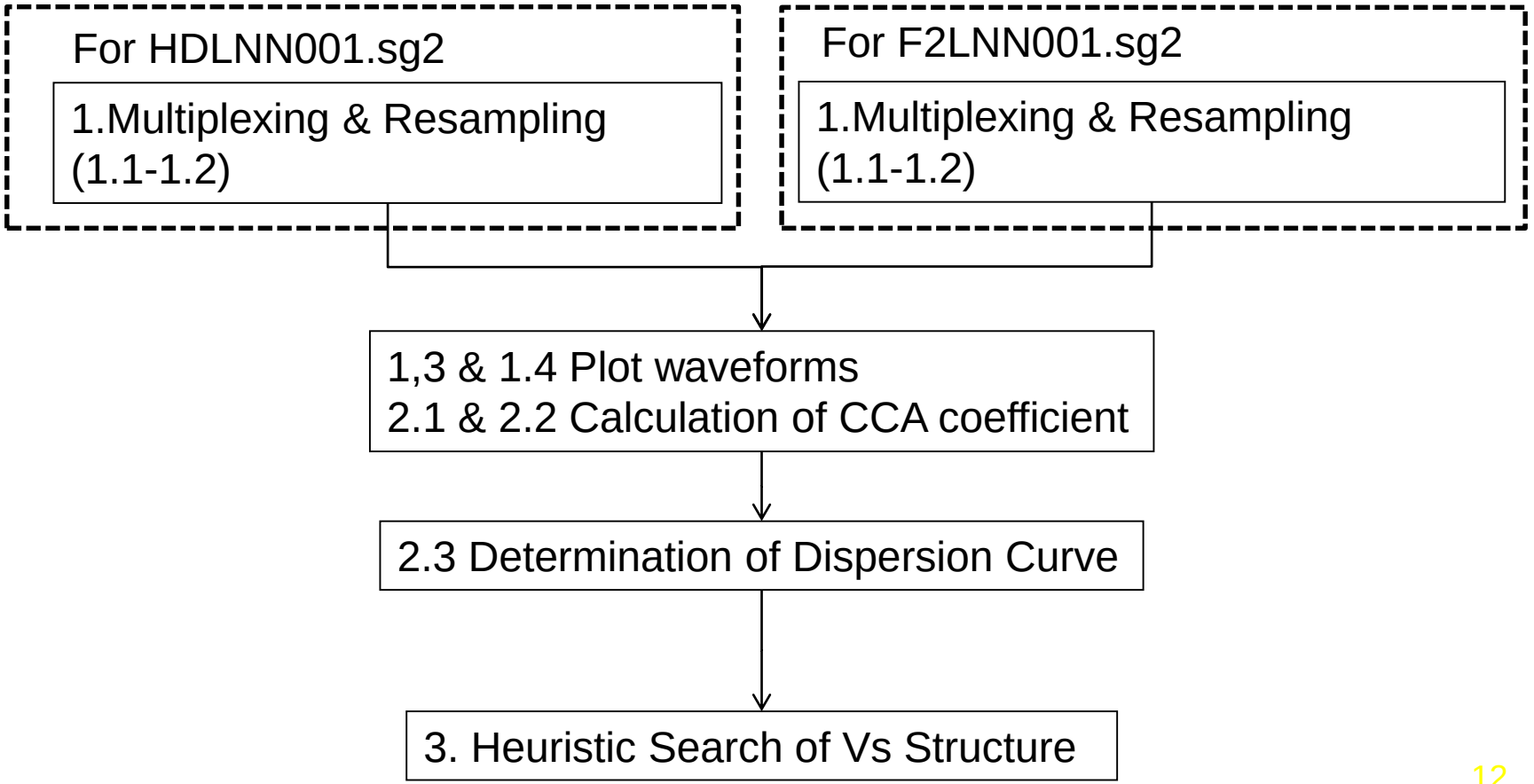
(Instrumental Correction without sensor at the center)

Example with two data sets:

HDLNN001.sg2: Huddle test data file

F2LNN001.sg2: 6 points circular array without one at the center

Both are the seg2 standard format file.



1. Multiplexing & Resampling

1.1 Format conversion & Multiplexing

1.1.1 *seg2* standard format)

Shell Script used:

sh ./seg2read.sh

Program and parameter file used:

./bin/seg2read.exe +./cca_wkf/prm/seg2read.prm

seg2read.exe is prepared for the field data files of seg2 standard format.

Terminology

Multiplexing:

To sort the data individually stored in single channel files into a multi-channel file of the time-sequential format.

Here, *seg2* standard (multiplexed binary) format (IEEE) is explained.

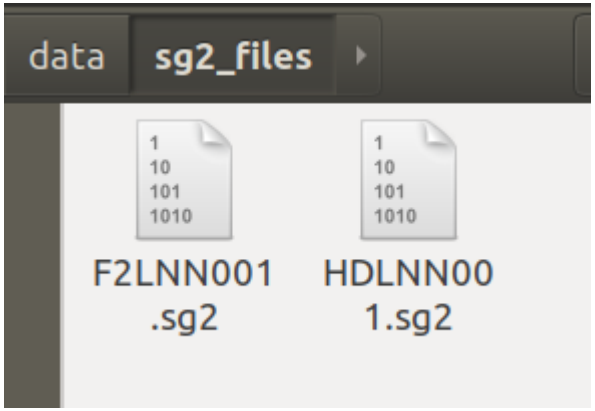
The expected input files of seg2 format are, for example, those obtained in the field using multi-channel data logger designed for the exploration geophysics.

seg2read.exe

+ Convert data format from seg2 standard format (binary & multi-channel) in the sub-folder “cca_wkf/data/sg2_files" to cdm format (ascii text, multi-channel),
+ Channel pivoting and extraction
+ Store the output files into “cca_wkf/data/multiplexed_files”

First: Copy all the seg2 format files to be converted into the sub-folder "cca_wkf/data/sg2_files".

Example:



```
seg2read.sh:

#! /bin/sh -x
cd cca_wkf/data/sg2_files
ls *.sg2 > sg2file.lst
cd ../../..
./bin/seg2read.exe | tee
cca_wkf/log/seg2read.log
cd cca_wkf/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 extention specified in the 3rd line of the parameter file “seg2read.prm”.

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

```
LCCM,Field,r=2m,L22D,No_Rs,No_A_amp,D_amp=X1,F2LNN0,Mar.15,2012      :comm(a70)
5.E-3    : 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
pvlist 1 2 3 4 5 6  : Channel Pivoting
```

The array used in the field has 6 sensors, but none of them at the center. They were installed counter-clockwise order. Then, pvlist 1 2 3 4 5 6 :

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.

If a sensor is located at the center of the circler array and used for incoherent noise correction, the corresponding data must be assigned to ch-1. Then, other channels must be listed following the order counter clock wise. The value of the azimuth of the first peripheral sensor must be given to the parameter ph00 and the in-coming azimuth of the pre-dominant wave is calculated.
“pvlist” can be used to change the channel order.

Format of output files

in ./cca_wkf/data/multiplexed _files:

Users who use single channel recorders or data loggers must multiplex the record files in the following format by themselves.

```
 6  0.0080      0.5500E-01  225000  mkine
LCCM,Field,r=2m,L22D,No_Rs,No_A_amp,D_amp=X1,F2LNN0,Mar.15,2012      :
    0.000000  0.5280000E+01  0.3795000E+01  0.6710000E+01 …
    0.008000  0.9900000E+00  0.2310000E+01 -0.7975000E+01 …
    0.016000  0.6050000E+01  0.1138500E+02 -0.1061500E+02 …
    0.024000  0.3025000E+01  0.7535000E+01 -0.1017500E+02 …
    …
```

1st line: Number of channels, Δt(sec), scale, number of samples,unit
2nd line: Comment (less than 50 characters)
3rd line: Time, 1st-ch sample, 2nd-ch sample, 3rd-ch sample, ….

In the next step (resamplec.for reads this file as follows)

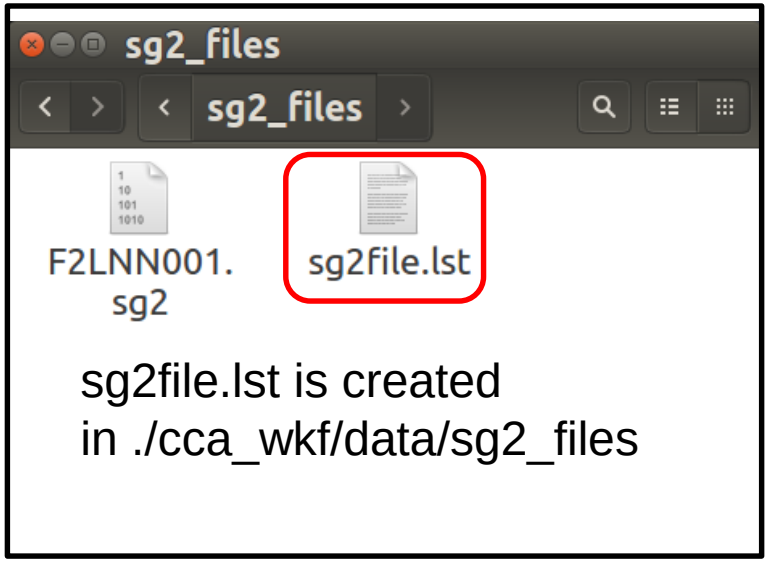
```
read(1,*)nch00,dt00,scale00,ndata00,cunit
…
read(1,'(a50)')comment
…
read(1,*,end=10) xdum,(x(i,j),j=1,nch)
```

Warning!

seg2read.exe can handle less than or equal to 25 channels and less than or equal to 500,000 samples in every channel.
Exceedance may result in a significant error.
It is recommendable to split the input data file if too long, for example, into several files of 1 hour or 30 minutes data.

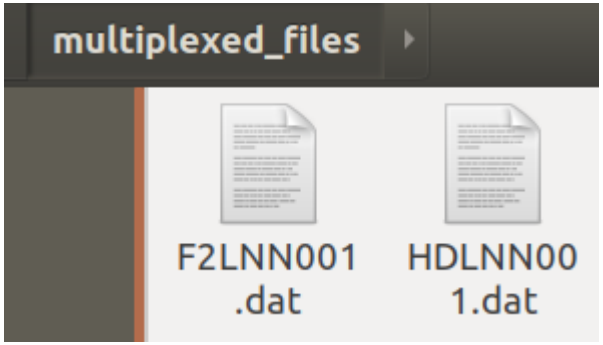
Ref:
500,000 samples correspond to 1.38 hours for 100 Hz sampling,
1.11 hours for 125 Hz sampling,
41.6 minutes for 200 Hz sampling,
33.3 minutes for 250 Hz sampling
16.6 minutes for 500 Hz sampling.

```
yokoi@ubuntu:~/CCA2017/CCA2019$ sh seg2read.sh
./cca_wkf/prm/seg2read.prm
   5.49999997E-02 mkine
./cca_wkf/data/sg2_files/sg2file.lst
F2LNN001.sg2

./cca_wkf/data/sg2_files/F2LNN001.sg2
./cca_wkf/data/multiplexed_files/F2LNN001.dat
                    :32bit fixed point.
nch= 12 dt= 0.008 nn=  225000
       6  0.0080      0.5500E-01  225000  mkine
LCCM,Field,r=2m,L22D,No_Rs,No_A_amp,D_amp=X1,F2LNN0,Mar.15,2012      :
HDLNN001.sg2

./cca_wkf/data/sg2_files/HDLNN001.sg2
./cca_wkf/data/multiplexed_files/HDLNN001.dat
                    :32bit fixed point.
nch= 12 dt= 0.008 nn=   37500
       6  0.0080      0.5500E-01   37500  mkine
LCCM,Field,r=2m,L22D,No_Rs,No_A_amp,D_amp=X1,F2LNN0,Mar.15,2012      :
     2 files have been converted.
Normal End.
```



Input file is ./cca_wkf/data/sg2_files/F2LNN001.sg2
Multiplexed output is ./cca_wkf/data/multiplexed_files/F2LNN001.dat & another.
Log file is stored in 'cca_wkf/log/seg2read.log'

Note: The converted files are already multiplexed and stored in the subfolder "./cca_wkf/data/multiplexed_files" with the extension ".dat". For these files, the next step is resampling.



1. Multiplexing & Resampling

1.1 Format conversion & Multiplexing

1.1.2 *win* format for LS8800

This is the example of individually recorded data using a tri-axial sensor at each observation point.

Format conversion & Multiplexing must be done by the users prior to the analysis for the case of individual recording at each site.

Here *win* format is explained as an example. The *win* format data files are created, e.g., LS8800 of Hakusan Kogyo.

The multiplexed files must be written in a format that is readable in the next step: resampling.

As it is impossible to cover all existing formats in the world, it is strongly recommended to make their own program for format conversion.

Format conversion is conducted using
sh lstocdm2.sh
in the folder "CCA2019".

Note: Usage of 4 seismographs in a site is assumed.

Preparation:
1) Edit the parameter file "prm_maker.prm"

```
Sitename_    : site name (a9)
 4  3        : numbers of obs_ponts and channels
 30          : duration of each connected file in min.(integer)
17120516.45 : first file name (yymmddhh.mm)
  4          : number of output connected files
```

2) Copy the data files (binary) of LS8800 into the subfolders of
"cca_wkf/data/ls_files" as follows:
"no1"🡐 files from seismograph No.1
"no2"🡐 files from seismograph No.2
"no3"🡐 files from seismograph No.3
"no4"🡐 files from seismograph No.4

lstocdm2.sh

```
#!/bin/sh
./bin/prm_maker.exe | tee cca_wkf/log/prm_maker.log
./bin/lstocdm2.exe | tee cca_wkf/log/lstocdm2.log
cd ./cca_wkf/data/cdm_files
rm *.cdm
cd ../../..
mv ./cca_wkf/data/ls_files/Combined_Data/*.cdm ./cca_wkf/data/cdm_files
```

Execution:

./bin/prm_maker.exe

➔ "lstocdm2.prm" is created in "cca_wkf/prm".

./bin/lstocdm2.exe

➔ All converted and separated files are stored in "./cca_wkf/data/ls_files/Combined_Data".

All converted and separated files are automatically stored in "cca_wkf/data/ls_files/Combined_Data".

Then, the subfolder "./cca_wkf/data/cdm_files" is cleaned.

Finally, by the command "mv" at the last line all of the cdm files are moved from "./cca_wkf/data/ls_files/Combined_Data" to "./cca_wkf/data/cdm_files".

Example:
prm_maker.prm

prm_maker.prm
~/CCA2017/CCA2019/cca_wkf/prm

```
1 Testcase_    : site name (a9)
2  4   3       : numbers of obs_ponts and channels
3  30          : duration of each connected file in min.(integer)
4 17120516.45 : first file name (yymmddhh.mm)
5   4          : number of output connected files
```

lstocdm2.prm: automatically created by lstocdm2.sh

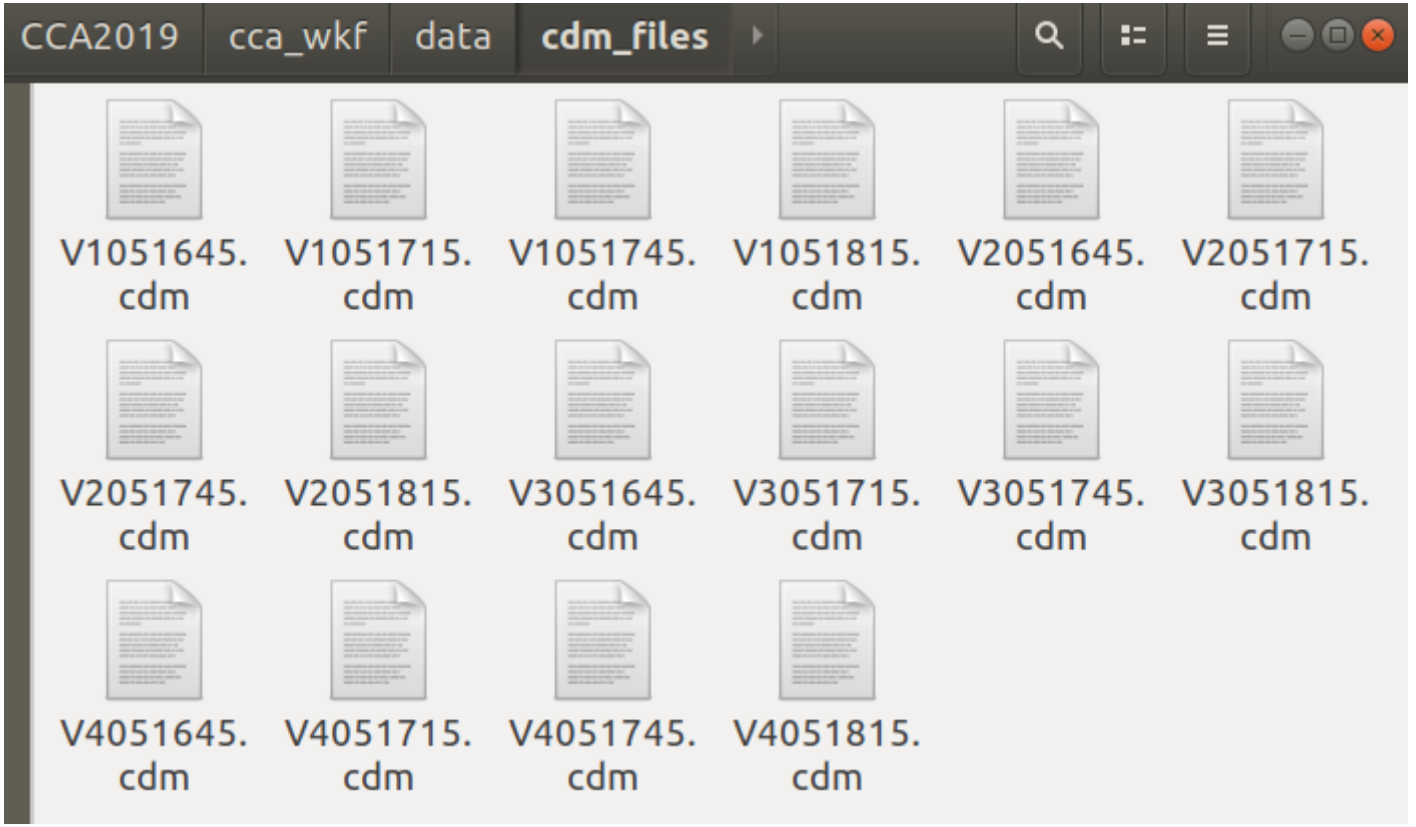
lstocdm2.prm
~/CCA2017/CCA2019/cca_wkf/prm

```
 1  4                     : case numbers
 2                        : This blank line is necessary
 3 Testcase_no1           : Data Folder Name(a12)
 4   794.   792.   798.   : #1 T44002 Sensitivity (V/M/s)
 5 NS EW V                : channel labels
 6 0.15646E-06            : voltage per Least Significant Bit (V/LSB)
 7 V1    30               : (a2) channel identifier of name; duration(min); of output file
 8  3 1 2 1               : channel pivoting, channel selection (0=all, 1=1st channel only)
 9 17120516.45   4        : 1st File name(a11),number of output files
10                        : This blank line is necessary
11 Testcase_no2           : Data Folder Name(a12)
12   798.   798.   796.   : #2 T44003 Sensitivity (V/M/s)
13 NS EW V                : channel labels
14 0.15646E-06            : voltage per Least Significant Bit (V/LSB)
15 V2    30               : (a2) channel identifier of name; duration(min); of output file
16  3 1 2 1               : channel pivoting, channel selection (0=all, 1=1st channel only)
17 17120516.45   4        : 1st File name(a11),number of output files
18                        : This blank line is necessary
19 Testcase_no3           : Data Folder Name(a12)
20   796.   794.   798.   : #3 T44004 Sensitivity (V/M/s)
21 NS EW V                : channel labels
22 0.15646E-06            : voltage per Least Significant Bit (V/LSB)
23 V3    30               : (a2) channel identifier of name; duration(min); of output file
24  3 1 2 1               : channel pivoting, channel selection (0=all, 1=1st channel only)
25 17120516.45   4        : 1st File name(a11),number of output files
26                        : This blank line is necessary
27 Testcase_no4           : Data Folder Name(a12)
28   796.   796.   796.   : #4 T44005 Sensitivity (V/M/s)
29 NS EW V                : channel labels
30 0.15646E-06            : voltage per Least Significant Bit (V/LSB)
31 V4    30               : (a2) channel identifier of name; duration(min); of output file
32  3 1 2 1               : channel pivoting, channel selection (0=all, 1=1st channel only)
33 17120516.45   4        : 1st File name(a11),number of output files
```

```
yokoi@ubuntu: ~/CCA2017/CCA2019
File Edit View Search Terminal Help

yokoi@ubuntu:~/CCA2017/CCA2019$ sh lstocdm2.sh
tee: cca_cwkf/log/prm_maker.log: No such file or directory
tee: cca_cwkf/log/lstocdm2.log: No such file or directory
 Parameter file: ./cca_wkf/prm/lstocdm2.prm

Name of the site: Testcase
No. of station: no1
 Sensitivity(M/s):    794.000000       792.000000       798.000000
 Components: NSEWV
 voltage per Least Significant Bit   1.56460004E-07 (V/LSB)
   1.97052905E-05   1.97550507E-05   1.96065157E-05
Output 1 channel  V
Start from: 17120516.45 ,    30 file
 Output file: ./cca_wkf/data/ls_files/Combined_Data/V1051645.cdm

 Input file: ./cca_wkf/data/ls_files/no1/17120516.45

 Output file: ./cca_wkf/data/ls_files/Combined_Data/V1051715.cdm

 Input file: ./cca_wkf/data/ls_files/no1/17120517.15

 Output file: ./cca_wkf/data/ls_files/Combined_Data/V1051745.cdm

 Input file: ./cca_wkf/data/ls_files/no1/17120517.45

 Output file: ./cca_wkf/data/ls_files/Combined_Data/V1051815.cdm

 Input file: ./cca_wkf/data/ls_files/no1/17120518.15

Name of the site: Testcase
```

```
yokoi@ubuntu: ~/CCA2017/CCA2017/lstocdm2
All zero for 0.5byte data 15 12 29 32 ch- 0       0.0
All zero for 0.5byte data 15 12 29 33 ch- 0       0.0
All zero for 0.5byte data 15 12 29 34 ch- 0       0.0
All zero for 0.5byte data 15 12 29 35 ch- 0       0.0
All zero for 0.5byte data 15 12 29 36 ch- 0       0.0
All zero for 0.5byte data 15 12 29 37 ch- 0       0.0
All zero for 0.5byte data 15 12 29 38 ch- 0       0.0
All zero for 0.5byte data 15 12 29 39 ch- 0       0.0
All zero for 0.5byte data 15 12 29 40 ch- 0       0.0
All zero for 0.5byte data 15 12 29 41 ch- 0       0.0
All zero for 0.5byte data 15 12 29 42 ch- 0       0.0
All zero for 0.5byte data 15 12 29 43 ch- 0       0.0
All zero for 0.5byte data 15 12 29 44 ch- 0       0.0
All zero for 0.5byte data 15 12 29 45 ch- 0       0.0
All zero for 0.5byte data 15 12 29 46 ch- 0       0.0
All zero for 0.5byte data 15 12 29 47 ch- 0       0.0
All zero for 0.5byte data 15 12 29 48 ch- 0       0.0
All zero for 0.5byte data 15 12 29 49 ch- 0       0.0
All zero for 0.5byte data 15 12 29 50 ch- 0       0.0
```

This error message means the clipping of data. Check the time and eliminate the corresponding part.



File name (E1151145.cdm) includes the following information:

1st letter: component

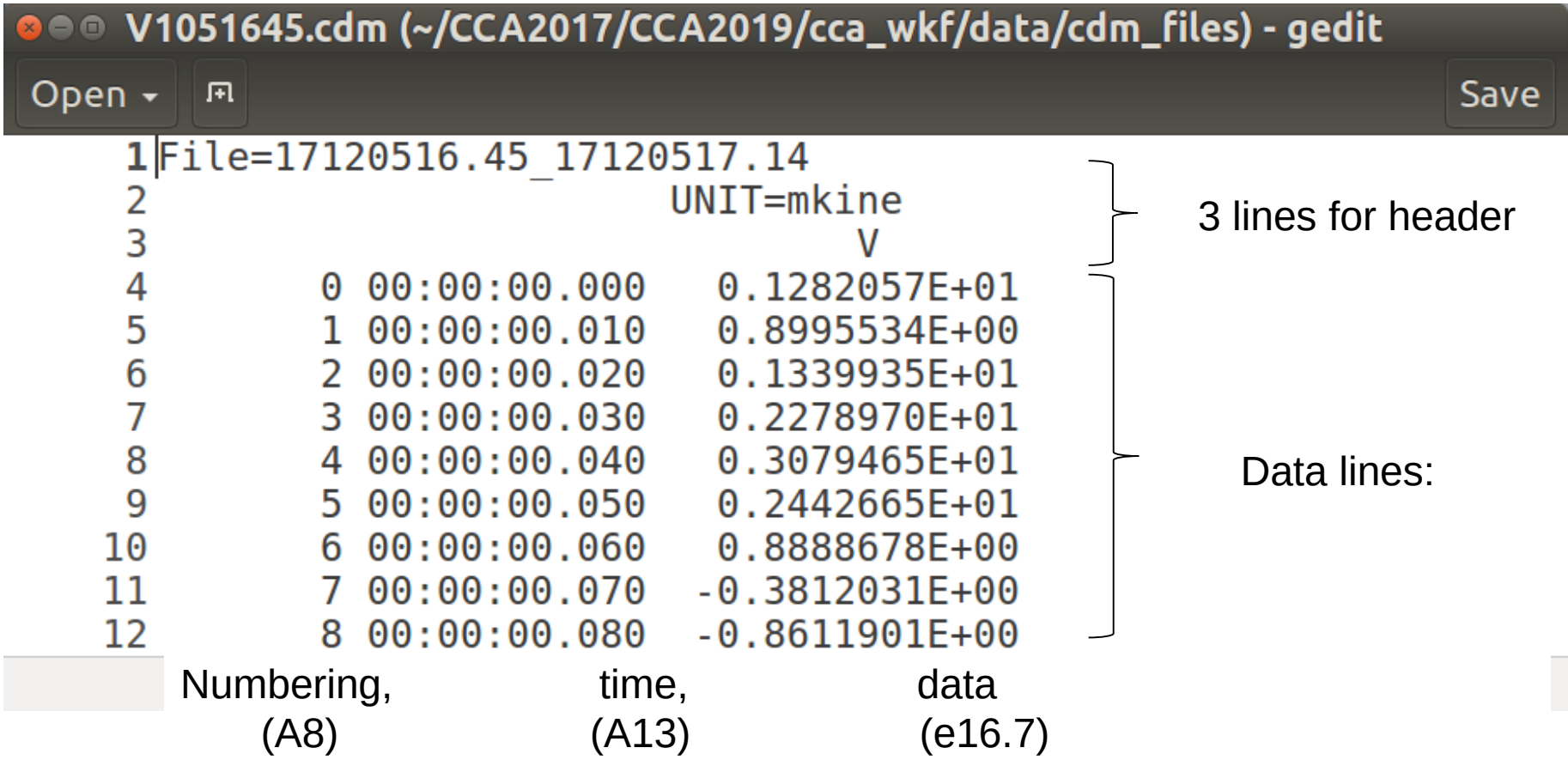
2nd letter: numbering of seismograph (=numbering of station)

3rd & 4th: Date in (i2)

5th & 6th: hour in (i2)

7th & 8th; minutes in (i2)

Example of a converted file



The created single channel file by this format conversion program will be read in the next step using “multipx6.exe” as follows.

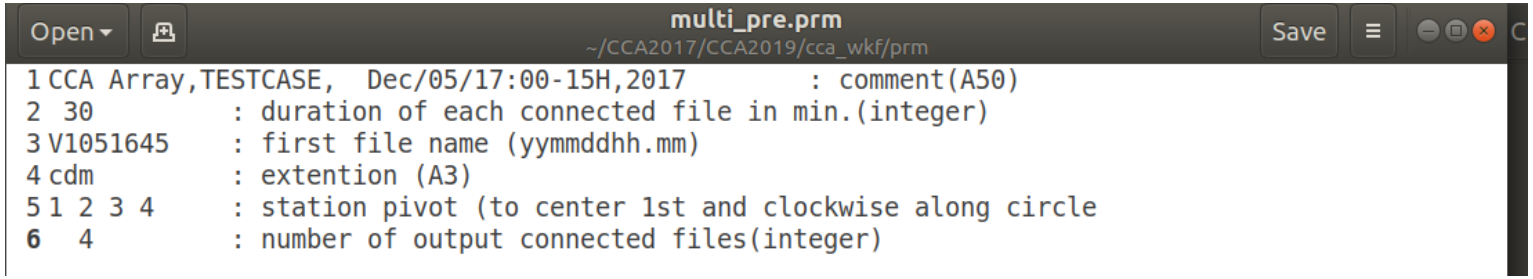
“multipx6.for”

```
     character cline(3)*80,cdum*13,cdummy*8  ! Declare three
                                              ! character strings
……..
      do i=1,3
        read(1,'(a80)')cline(i)   ! Read 3 lines header
      enddo
      do i=1,nst0-1
       read(1,*)cdummy            ! Skip first nst0 sec data
      enddo
      do i=1,ndur0
c read input data
        read(1,*,end=10)cdummy,cdum,xdum
        x(i,j)=xdum/scale
       enddo
   10  ndur0=i-1                   ! Adjust number of samples
……..
```


Character strings cline(3) are not used further. Neither cdummy nor cdum.

Preparation for Multiplexing

- In the next step, *multipx6.exe* is used with its parameter file "*multipx6.prm*".
- For automatic editing of multipx6.prm, the program *multi_pre.exe* is prepared.
- Edit the following "*multi_pre.prm*" in "cca_wkf/prm" and run *"sh multi_pre.sh*".



- 1st line: Comment but later used as the title of all graphs showing the results of analysis.
- 2nd line: Duration of connected files same as the 3rd line of "prm_maker.prm".
- 3rd line: The eariest file name for the 1st position (A8)
- 4th line: Extension of the name of files in the folder "cdm_files", i.e., cdm.
- 5th line: Station pivoting list.
- 6th line: Number of connected files same as the 5th line of "prm_maker.prm".

Execution

```
yokoi@ubuntu:~/CCA2017/CCA2019$ sh multi_pre.sh
  Working Folder=./cca_wkf/prm/
  Default Settings:
    dt      = 0.0
    np      =   4
    tst     = 0.0
    file_out=CC**.dat

V1051645 V2051645 V3051645 V4051645
V1051715 V2051715 V3051715 V4051715
V1051745 V2051745 V3051745 V4051745
```

Automatically created multipx6.prm which will be used in the next step.

```
 1    1                        : Number of cases
 2                             : This blank is necessary
 3   4 0.010                   : Number of obs points,dt
 4          0.0      1800.0    : tst,tdur(sec)
 5 1.e0  mkine                 : scale(input data is divided by this scale)
 6  0 3 0.1 1.0 1.5            : nfilter(=1:apply), ncharacter(=2:lowpass,=3:bandpass),fl,fh,fs
 7   4           .cdm          : nattach, cattach
 8  2   CC                     : n_out(A12),cout ("**.dat" is attached)
 9 CCA Array,TESTCASE,  Dec/05/17:00-15H,2017        : comment(A50)
10    32            8          : number of measurement in the same array
   configuration,n_character
11 V1051645 V2051645 V3051645 V4051645
12 V1051715 V2051715 V3051715 V4051715
```

Edit it in an appropriate way if necessary.

multipx6.prm

```
    1                          : Number of cases
                               : This blank is necessary
  4 0.010                      : Number of obs points,dt
         0.0      1800.0       : tst,tdur(sec)
1.e0  mkine                    : scale(input data is divided by this scale)
 0 3 0.1 1.0 1.5               : nfilter(=1:apply), ncharacter(=2:lowpass,=3:bandpass),fl,fh,f
  4           .cdm             : nattach, cattach
 2   CC                        : n_out(A12),cout ("**.dat" is attached)
CCA Array,TESTCASE,  Dec/05/17:00-15H,2017        : comment(A50)
    4            8             : number of measurement in the same array configuration,n_chara
V1051645 V2051645 V3051645 V4051645
…
```

← 1st Input filelist

1ch 2ch 3ch 4ch

Input file names : V1051645.cdm

consist of the character string ‘V1051645’ of 8 characters plus another character string ‘.cdm’ of 4 characters. These character strings and their number of characters are indicated in the 7th line for the latter and the 11th line and below for the former. Program ‘multipx6.exe’ automatically combines them and read the data from the files.

Don’t leave a blank line at the end of input filelist

multipx6.prm

Output file name: CC01.dat for the 1st measurement. ’01’ shows the numbering of measurement.

…

CH04.dat for the 4th measurement. ’04’ shows the numbering of measurement.

These output file names consist of the character string ‘CH’ of 2 characters as indicated in the 8th line. The following two integers show the numbering of measurement. ‘.dat’ is attached to all automatically.

The data from tst to tst+tdur are processed in every files.

Values read from the input files are divided by the scale factor given in the 5th line. This value must be selected to make the unit of data in the output file is ‘mkine’, i.e., 1.0E-5 M/sec for ground velocity. For ground acceleration ‘gal’, i.e., 1.0E-2 M/sec^2 should be used. Otherwise the amplitudes of the data will be erroneously shown in the output figures.

Execution:

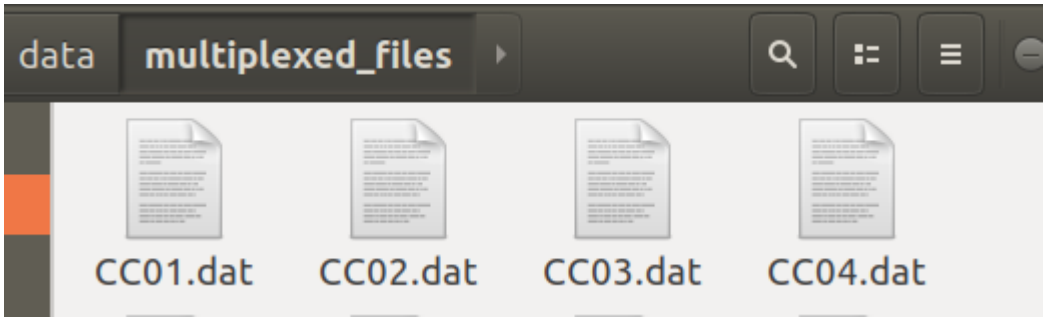
sh multipx6.sh

```
yokoi@ubuntu:~/CCA2017/CCA2019$ sh multipx6.sh
  Working Folder=./cca_wkf/prm/
  Nch=           4  dt=   9.99999978E-03
  Scale Factor=   1.00000000
  Does this scale convert the unit of data mkine ?
  Please change the value if not.
           0           3  0.100000001       1.00000000       1.50000000
 CCA Array,TESTCASE,  Dec/05/17:00-15H,2017
           1 -th measurement:           4
V1051645 V2051645 V3051645 V4051645
 ./cca_wkf/data/multiplexed_files/CC01.dat
           2 -th measurement:           4
V1051715 V2051715 V3051715 V4051715
 ./cca_wkf/data/multiplexed_files/CC02.dat
           3 -th measurement:           4
V1051745 V2051745 V3051745 V4051745
 ./cca_wkf/data/multiplexed_files/CC03.dat
           4 -th measurement:           4
V1051815 V2051815 V3051815 V4051815
 ./cca_wkf/data/multiplexed_files/CC04.dat
yokoi@ubuntu:~/CCA2017/CCA2019$
```

multipx6.sh

```
#! /bin/sh -x
./bin/multipx6.exe | tee
cca_wkf/log/multipx6.log
cd cca_wkf/data/multiplexed_files
ls *.dat > mltfile.lst
cd ../../..
./bin/mk_title_pre.exe
```

10 multiplexed data files are created in “./cca_wkf/data/multiplexed_files”



Format of multiplexed file:

Open ▾ CC01.dat ~/CCA2017/CCA2019/cca_wkf/data/multiplexed_files Save

```
1        4  0.0100      0.1000E+01  180000  mkine
2 CCA Array,TESTCASE,  Dec/05/17:00-15H,2017
3     0.000000  0.0000000E+00  0.0000000E+00 -0.0000000E+00  0.0000000E+00
4     0.010000  0.8910510E-02  0.6514205E-02 -0.1340472E-01  0.7184593E-01
5     0.020000  0.2662862E-01  0.1362474E-01 -0.6547699E-02  0.1320289E+00
6     0.030000  0.6811393E-01  0.2614746E-01  0.4290193E-01  0.1220999E+00
7     0.040000  0.1228383E+00  0.4015458E-01  0.1152715E+00  0.5129088E-01
8     0.050000  0.1217078E+00  0.1120007E+00  0.1573336E+00 -0.6455636E-02
```

ch_pivot.exe

This program is provided for changing the order of channels in a group of already multiplexed files, for example, those copied from the data processing of SPAC method.

Edit the parameter file “ch_pivot.prm” in “./cca_wkf/prm”

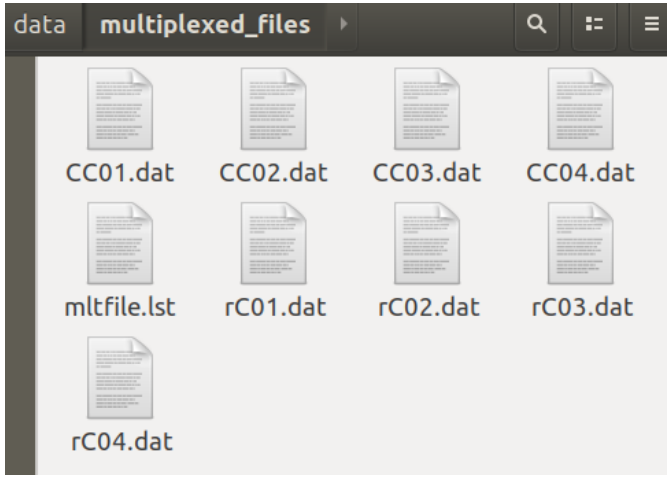
ch_pivot.prm

```
4           : channel number➔ How many channels the file has
4 1 2 3     : pivot list
```

Execute
sh ch_pivot.sh

Then, all files listed in “./cca_wkf/multiplexed_files/mltfile.lst” are processed.

The pivoted files’s name has “r” at the top.



ch_pivot.sh

```
#!/bin/sh
cd ./cca_wkf/data/multiplexed_files
ls *.dat > mltfile.lst
cd ../../..
./bin/ch_pivot.exe
```

1.2 Resampling & Screening

Shell Script used

sh resamplec.sh

Program and parameter file used:

./bin/resamplec.exe +./cca_wkf/prm/resamplec.prm

Terminology

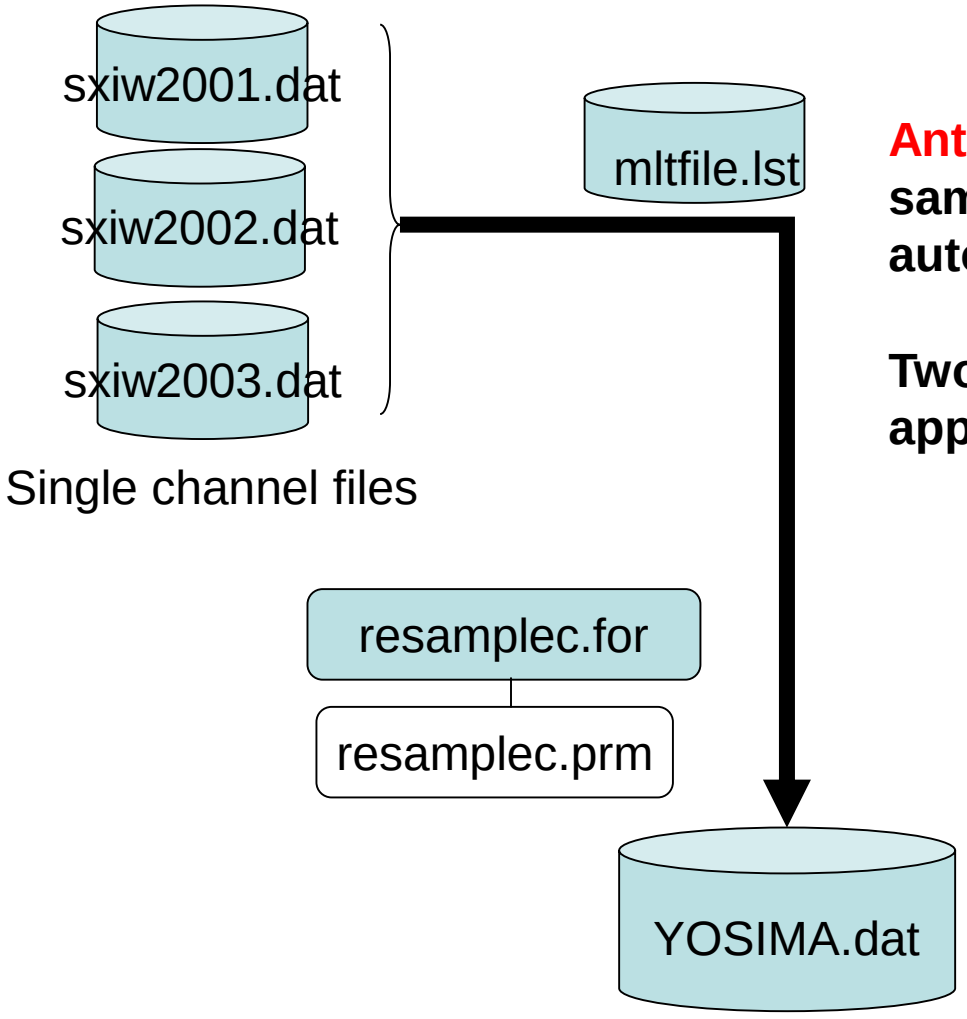
Re-sampling:

It can be done to thin the data out in order to reduce the size of data files and the load to PC for processing. This can cause the aliazing effect. Then, it Is necessary to apply the digital anti-alias filter that has high cut characteristics before thinning out.

Note: Modify the file “./cca_wkf/prm/graph_title.txt”, if you have not started the processing from “*sh seg2read.sh*”. This means that your original data files are not seg2 format.

The contents of the file “./cca_wkf/prm/graph_title.txt” is used for the title of various graphs produced in further processing. It is recommendable to give an appropriate title to the figures to prevent potential confusion.

Multi-channel data files from the same array configuration



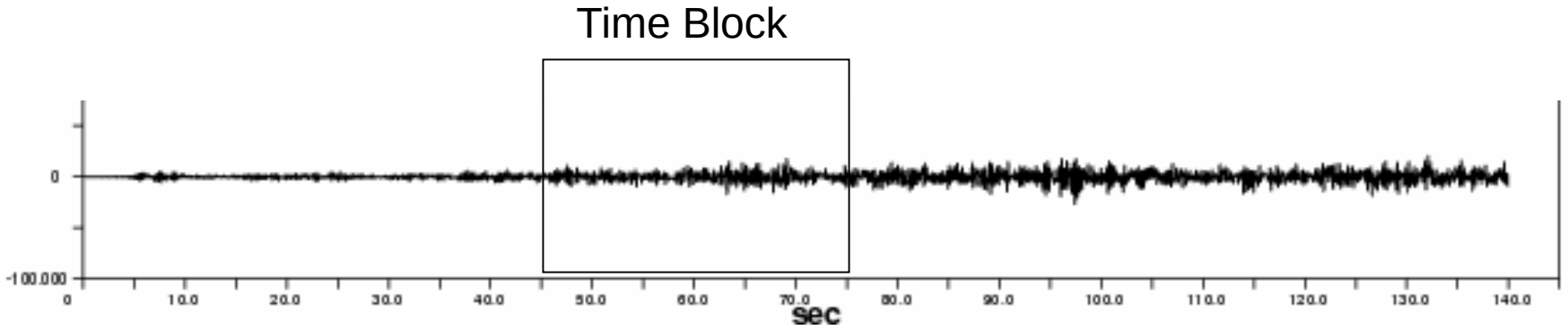
Anti-alias filter for re-sampling is applied automatically.

Two steps for screening are applied.

Resampled & screened multi-channel & multi-measurement data file

Screening: Step-1

Parameter: ajudge



If the maximum amplitude in a time block exceeds the product of "ajudge" to RMS amplitude of the same time block, this time block is not used in analysis.

This is a countermeasure against impulsive noise due to traffic, i. e., vehicles passing near by seismometers.

The bigger value of "ajudge" means looser screening. The smaller value means fewer available time blocks.

Screening: Step-2

Parameter: a_sgm

If the RMS amplitude in a time block deviates more than a_sgm X the standard deviation from the average, this time block is not used in analysis, where the average and the standard deviation are calculated over the all time blocks that survived in the screening step-1.

This is a countermeasure against outliers.
The bigger value of “a_sgm” means looser screening. The smaller value means fewer available time blocks.

resamplc.sh:

```
#! /bin/sh –x
cd ./cca_wkf/data/multiplexed_files
ls *.dat > mltfile.lst
cd ../../..
./bin/resamplec.exe | tee cca_wkf/log/resamplec.log
```

Example of resamplec.prm:

```
 6 0.008  2   0.0  0  2.0   :nch,dt,nchannel,dt,nskip,ph0,ncenter,radius
5.0 3.0                     :ajudge,a_sgm
0.0 1800.0                  :tst,tdur
F2LNN1.dat                  :output file name
1024                        :number of data in one time block after resampling
```

where

nskip: skip number for resampling (1: no resampling, 2: resample at every two samples)

ph0: azimuth from the center(1ch) to 2ch

ncenter: 0 (no sensor at the center) or 1 (1ch at the center) , cannot be bigger than 2

radius: radius of circular array (m)

tst: start time of analysis (sec)

tdur: duration of time window for analysis (sec)

Execution:

```
yokoi@ubuntu:~/CCA2017/CCA2019$ sh resamplec.sh
./cca_wkf/prm/resamplec.prm
Working Folder=./cca_wkf/prm/
Band-Pass:fl=   0.100fh=  25.312
fs=  28.125
Nch=   6
Nskip   2 f(Nyquist)=  31.250 fs=  28.125
ajudge=   5.0 a_sgm=   3.0
 tst =     0.0 tdur=  1800.0
 F2LNN001.dat
 HDLNN001.dat
  2 measurement
 First screening (peak/rms<  5.0):
 i_mea=           1
 F2LNN001.dat
          1 -th measurement:./cca_wkf/data/multiplexed_files/F2LNN001.dat
        122  blocks remained among          218  blocks
 i_mea=           2
 HDLNN001.dat
          2 -th measurement:./cca_wkf/data/multiplexed_files/HDLNN001.dat
  ndata00     =       37500
  nmax        =      500000
  ndur0+nst0-1=      224999
yokoi@ubuntu:~/CCA2017/CCA2019$
```

Example of Output (resampled) file format

F2LNN1.dat

1st line:file parameters

1st block

2nd block

```
 6  120 1024 0    0.00    2.00 (i8,f16.4, 6e15.7) mkine
       1          8.1920 -0.2134265E+01 -0.1570028E+01 -0.1464243E+01 -0.1183819E+01 -0.1944440E+01 -0.2460508E+01
       2          8.2080 -0.8561512E+00 -0.1420853E+00  0.5698163E+00 -0.7201288E+00 -0.8229986E+00 -0.1031229E+01
       3          8.2240 -0.1268116E+01 -0.1240067E+01 -0.2134730E+00 -0.2036263E+00 -0.3363592E+00 -0.7179448E+00
       4          8.2400 -0.1921562E+01 -0.1946060E+01 -0.1426458E+01  0.5525613E+00  0.5879311E-01 -0.1037454E+01
       ....
    1024         24.5600  0.2423161E+01  0.9976824E+00  0.2375970E+01  0.6267622E+01  0.5800716E+01  0.4042787E+01
       1         16.3840  0.5473618E+01  0.3885463E+01  0.6374265E+01  0.4033590E+01 -0.3046133E+01  0.5571502E+00
       ….
```

The file include mmblk=120 time blocks of nch=6 channel data. Each time block is composed of nblk=1024 data.
Each line corresponds to a time step. The format used to store each line is cform3='(i8,f16.4, 7e15.7)'.
Unit of data is 'mkine' (=1.0e-3 cm/sec)
These parameters are stored in the 1st line.

As all of the data are delimited by space, this file can be read using free format.

Note: For the data of huddle test, it is necessary to change the value of the 6th parameter of the first line of the resamples files to "0.0" .

1. Multiplexing & Resampling
1.3 Plot Waveform

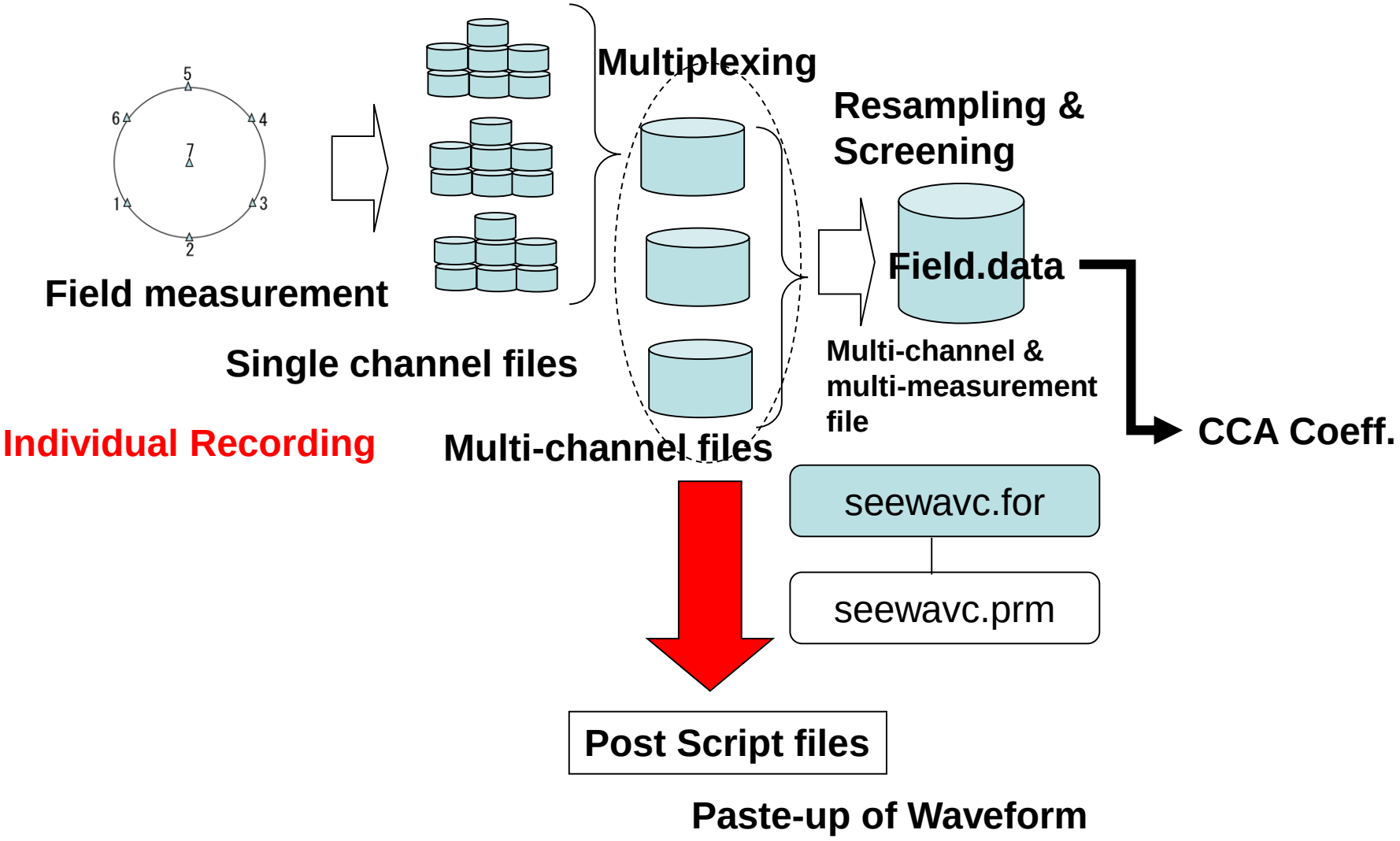
Shell Script used:

sh seewavc.sh

Program and parameter file used:

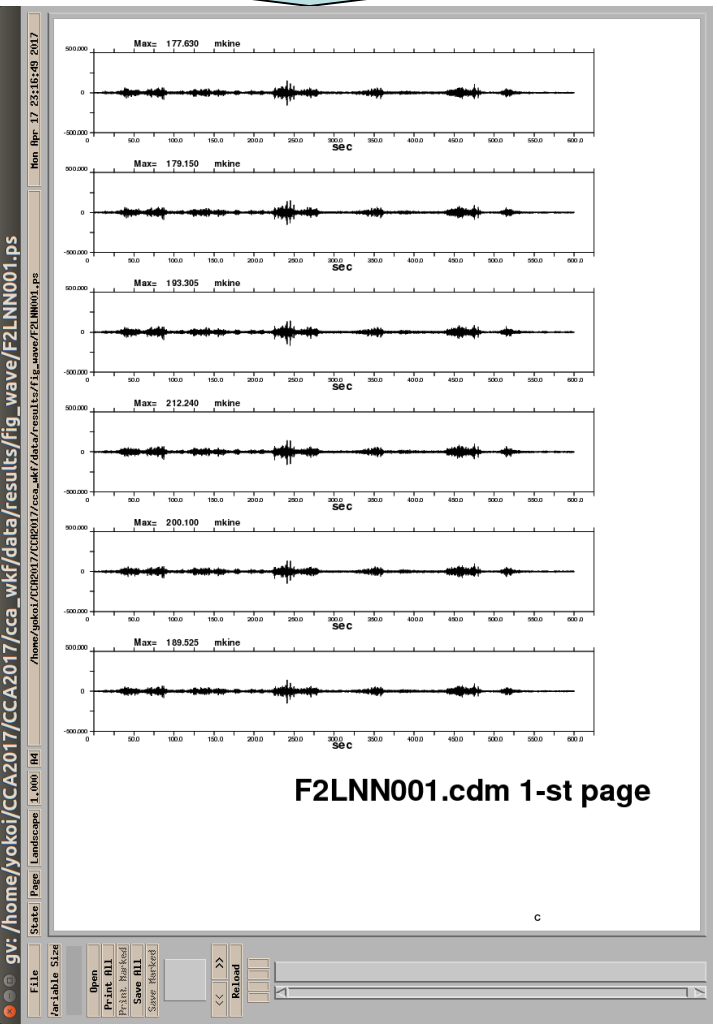
./bin/seewavc.exe +./cca_wkf/prm/seewavc.prm

Flow of the data processing for the conventional CCA



Multi-channel file: F2LNN001.dat

```
 6   0.0080        0.5000E-02   225000   mkine
LCCM,Field,r=2m,L22D,No_Rs,No_A_amp,D_amp=X1,F2LNN
     0.000000   0.4800000E+00   0.3450000E+00   0.6100000E+00   0.5650000E+00   0.3250000E+00   0.3650000E+00
     0.008000   0.9000000E-01   0.2100000E+00  -0.7250000E+00  -0.2000000E-01   0.8600000E+00  -0.1900000E+00
     0.016000   0.5500000E+00   0.1035000E+01  -0.9650000E+00   0.1250000E+00   0.1485000E+01   0.4300000E+00
     ...
```



F2LNN001.cdm 1-st page

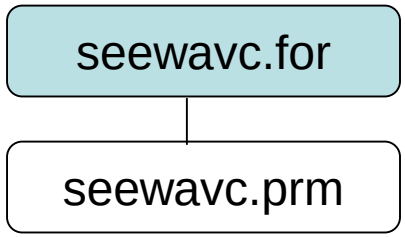


Figure in Multi-page Post Script file.
Post Script file can be opened, for example, by "gv &".

seewavc.sh:

```
#! /bin/sh -x
cd cca_wkf/data/multiplexed_files
ls *.dat > mltfile.lst
cd ../../..
./bin/seewavc.exe | tee cca_wkf/log/seewavc.log
```

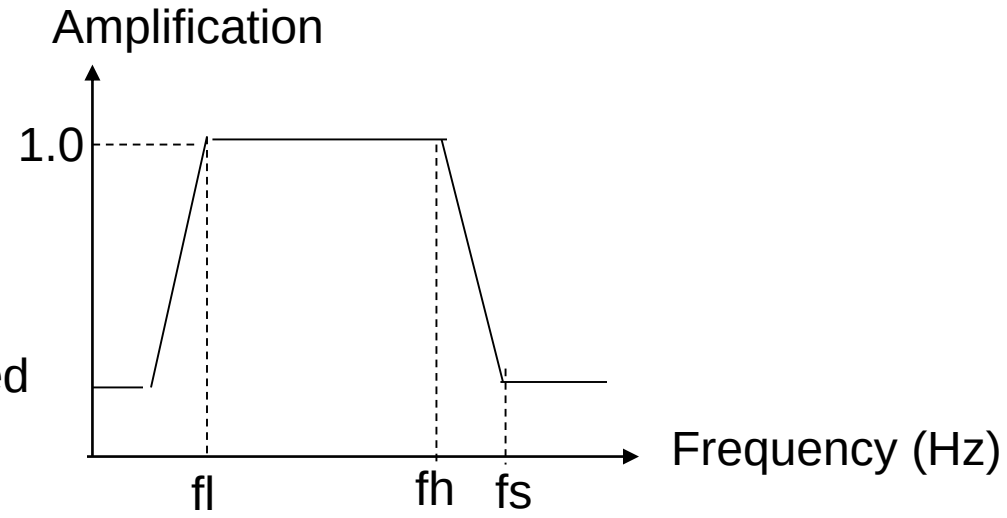
seewavc.prm

dtl denotes the time duration that corresponds to 1cm along the time axis.
In one page, 28*dtl/dt time step can be plotted. If the file has more, new pages are automatically added as much as necessary and multi-page PS file is created.

```
6                                   :nch
0 0.1    1.0 1.5 3                  :nfilter,fl,fh,fs,nchara(=2:lowpass, =3:bandpass)
  25.                               :dtl(sec/cm),25,50==>10,20 min/page
```

nbandp=0: no effect
nbandp=1: bandpass filter is applied

Band Pass Filter



This BPF does not affect to the data files.

Execution

Open ▾ seewavc.prm ~/CCA2017/CCA2019/cca_wkf/prm

```
1  6                          :nch
2  0 0.1    1.0 1.5 3         :nfilter,fl,fh,fs,nchara(=
3   25                        :dtl(sec/cm),25,50==>10,20
4
```

multiplexed_files

F2LNN001.dat

HDLNN001.dat

mltfile.lst

mltfile.lst is newly created.

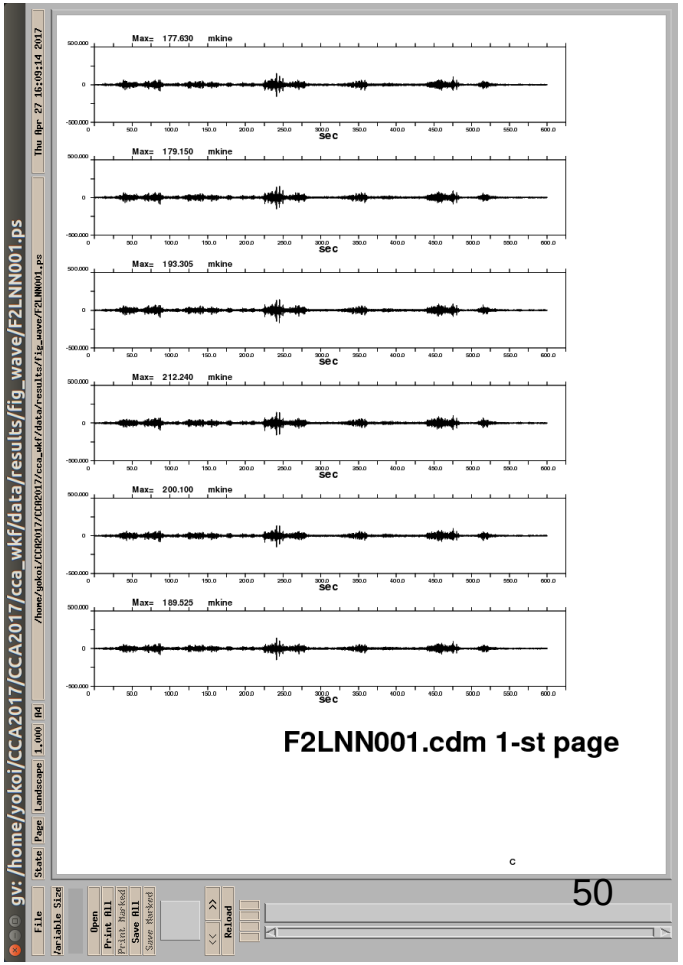
```
yokoi@ubuntu:~/CCA2017/CCA2019$ sh seewavc.sh
F2LNN001.dat
HDLNN001.dat
  2 measurement
./cca_wkf/data/results/fig_wave/F2LNN001.ps
F2LNN001.dat 1-st page
F2LNN001.dat 2-nd page
F2LNN001.dat 3-rd page
./cca_wkf/data/results/fig_wave/HDLNN001.ps
HDLNN001.dat 1-st page
```

fig_wave

results fig_wave

F2LNN001.ps

HDLNN001.ps



Waveforms are plotted in PostScript files.
Log file is stored in “./cca_wkf/log/seewavc.log

1. Multiplexing & Resampling
1.4 Check the selected time blocks

Shell Script used

sh seeblkc.sh

Program and parameter file used:

./bin/seeblkc.for +./cca_wkf/prm/seeblkc.prm

seeblkc.sh

```
#! /bin/sh -x
cd ./cca_wkf/data/resampled_files
ls *.dat > rsmfile.lst
cd ../../..
./bin/seeblkc.exe | tee cca_wkf/log/seeblkc.log
```

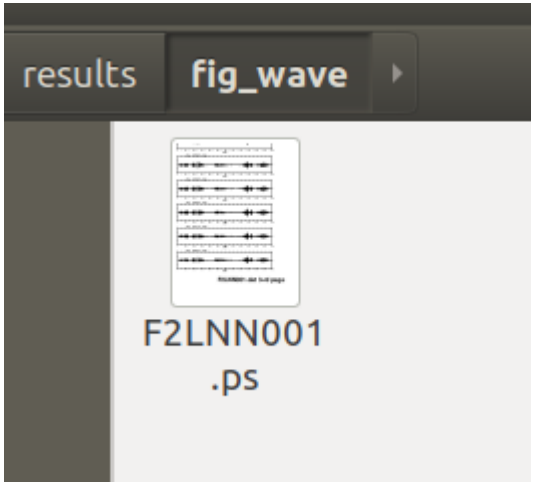
Parameter file:
./cca_wkf/prm/seeblkc.prm

0 0.1 1.0 1.5 3 :nfilter,fl,fh,fs,nchara(=2:lowpass, =3:bandpass)

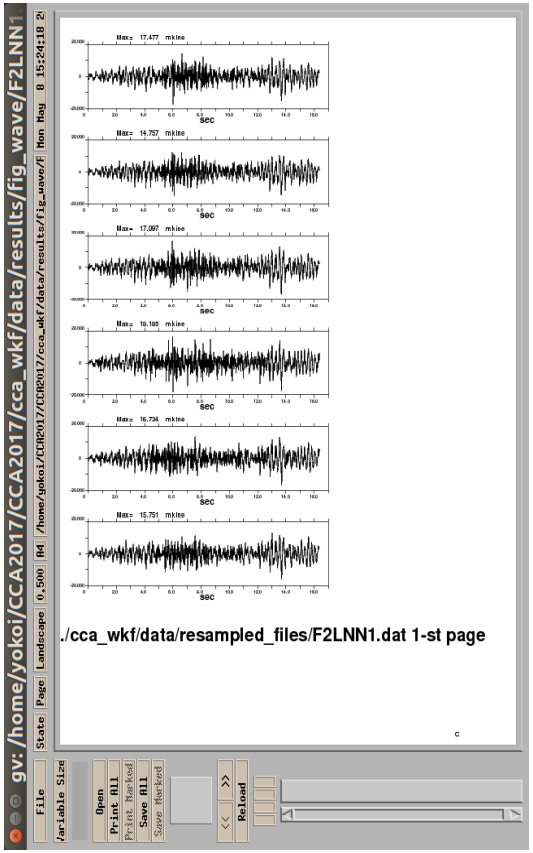
Execution

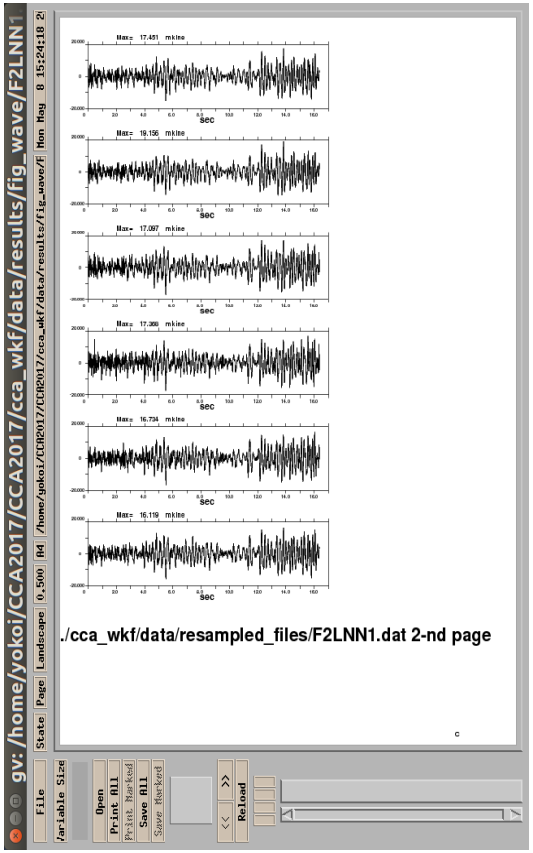
```
yokoi@ubuntu:~/CCA2017/CCA2019$ sh seeblkc.sh
 ./cca_wkf/data/resampled_files/rsmfile.lst
 ./cca_wkf/prm/seeblkc.prm
 ./cca_wkf/data/resampled_files/F2LNN1.dat
 6  120 1024 0    0.00    2.00 (i8,f16.4, 6e15.7) mkine
./cca_wkf/data/results/fig_wave/F2LNN1.ps
```

Multi-page postscript files are created in
./cca_wkf/data/results/fig_wave
Log file is stored in ./cca_wkf/log/seeblkc.log



PostScript File





Multi-page postscript files are created in ./cca_wkf/data/results/fig_wave

2. Estimating Dispersion Curve
2.1 Calculation of CCA coefficient

Shell Script used

sh pwrcrs3.sh

Program and parameter file used:

./bin/pwrcrs3.exe +./ccawkf/prm/pwrcrs3.prm

Terminology

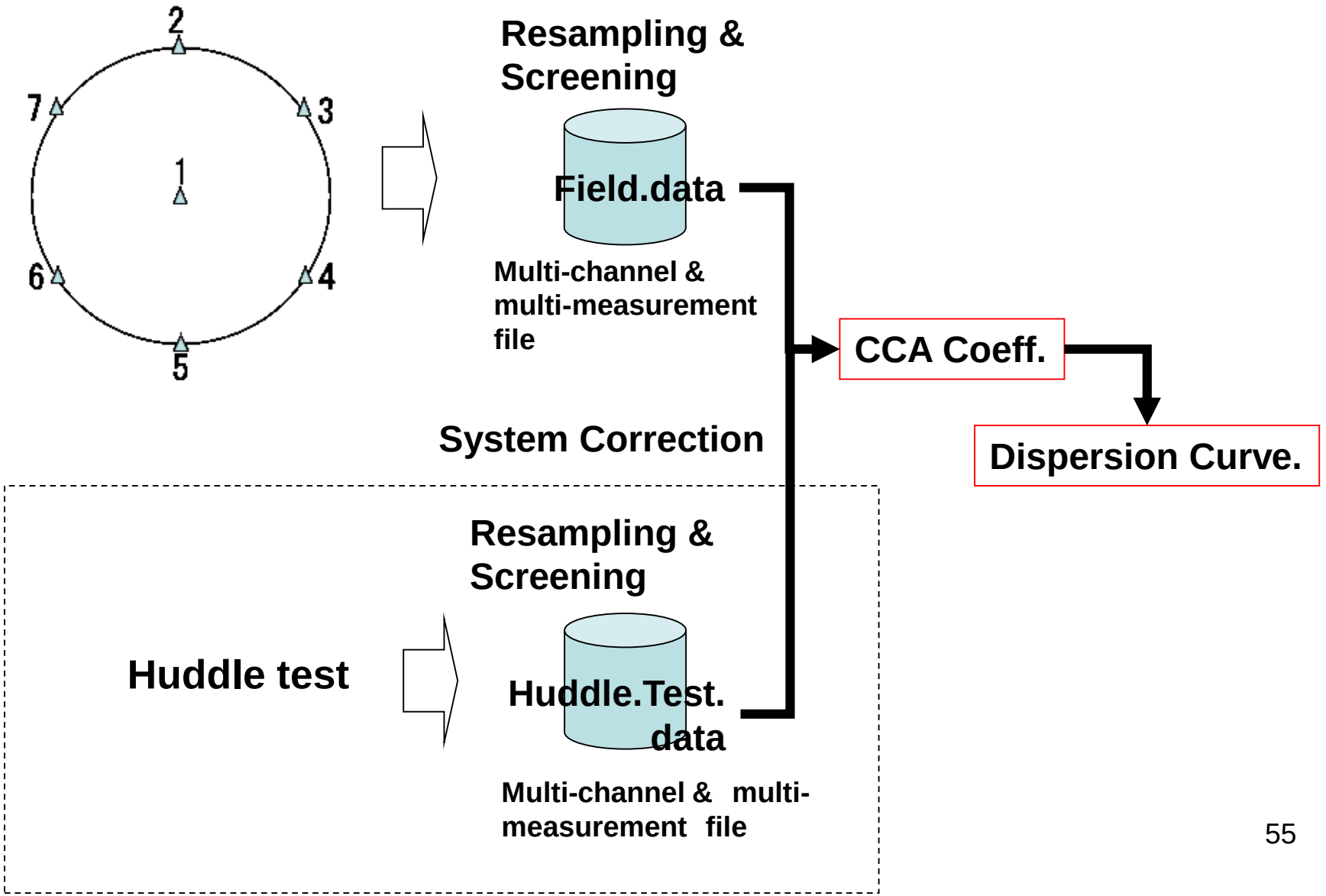
Huddle test:

Common input motion recording to determine the difference of the system characteristics among the recording system and/or channels.
The seismometers used in field measurement are put close each other like a huddle and simultaneous recording is conducted.

System correction:

The difference of the characteristics among the recording system can be corrected using the data obtained by huddle tests.

Flow of the data processing for CCA



pwrcrs3.sh

```
#! /bin/sh
./bin/pwrcrs3.exe 2>&1 | tee cca_wkf/log/pwrcrs3.log
./bin/mk_title_post.exe
```

Example of pwrcrs3.prm:

```
1.0 25.0 0.016 0.25  1 .5 :fmin,fmax,dt,bw,n_huddle,smthf
HDLNN1.dat     1 1        :Huddle Test data File name(A12), n_coh,n_pow
F2LNN1.dat     1 1        :Field data File name(A12), n_coh,n_pow
0   1                     :n_cor_center, n_mod
```

```
where
fmin, fmax     : minimum and maximum frequencies for analysis
bw             : band width of Parzen window
n_huddle       : flag for system correction using huddle test data
                 (0:no, 1:yes)
smthf          : smoothing parameter
n_coh,n_pow    : coherence & power spectra output flag : (0:no output , 1:yes)
n_cor_center   : flag for correction using sensor at the center.
                 (0:no output , 1:yes)
n_mod          : =0 no , =1 yes for plotting wavelength/3 vs Vs
```

Example of Execution

```
yokoi@ubuntu:~/CCA2017/CCA2019$ sh pwrcrs3.sh
 Program pwrcrs3.for
 ./cca_wkf/prm/pwrcrs3.prm
 HDLNN1.dat  ./cca_wkf/data/resampled_files/HDLNN1.dat
                        1           1
 6   35 1024 0    0.00    0.00 (i8,f16.4, 6e15.7) mkine
          35          10
          35          20
          35          30
  power and cross spectra for huddle test data calculated.
 Block Averaging has been done.
 ./cca_wkf/data/results/HDLNN1_psp.dat
Power Spectra Output for Huddle Test:./cca_wkf/data/results/HDLNN1_psp.dat

 ./cca_wkf/data/results/HDLNN1_coh.dat
 Coherence Output for Huddle Test.
  Correction using Huddle Test Data is conducted.
 6  120 1024 0    0.00    2.00 (i8,f16.4, 6e15.7) mkine
         120          10
         120          20
         120          30
         120          40
```

```
 ./cca_wkf/data/results/F2LNN1_coh.dat
 Coherence Output
  Correction by huddle test done.
 ./cca_wkf/data/results/F2LNN1_cor_psp.dat
Corrected Power Spectra Output
 ./cca_wkf/data/results/F2LNN1_cor_coh.dat
 Corrected Coherence Output
  No obs. point at the center.
  Power spectra: G{Z0,Z0(r,r,omg)}
  Power spectra: G{Z1,Z1(r,r,omg)}
  cross spectra: G{Z0,Z1(r,r,omg)}
  cross spectra: G{Z0,Z0(0,r,omg)}
            0
 ./cca_wkf/data/results/cca_coef.dat
./cca_wkf/data/results/dispersion.dat
Note: The following floating-point exceptions are signalling: IEEE_UNDERFLOW_FLAG
 IEEE_DENORMAL
yokoi@ubuntu:~/CCA2017/CCA2019$
```

CCA coefficient

calculated in the frequency domain

n_huddle=0

$$s_{CCA'}(r,\omega) \approx \frac{\sum_{m=1}^{M}\sum_{m'=1}^{M} E\left[C_{m,m'}(r,\omega)\right]}{\sum_{m=1}^{M}\sum_{m'=1}^{M} E\left[C_{m,m'}(r,\omega)\right]\exp\left\{-i\left(\theta_m-\theta_{m'}\right)\right\}} \approx \frac{J_0^2\left(r\omega/c\right)}{J_1^2\left(r\omega/c\right)}$$

n_huddle=1

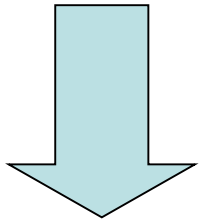
$$s_{CCA}(\omega) = \frac{\sum_{i=1}^{M}\sum_{k=1}^{M} R_{ik}(\omega)}{\sum_{i=1}^{M}\sum_{k=1}^{M} R_{ik}(\omega)\exp\left\{-j\left(\theta_i-\theta_k\right)\right\}}$$

$$R_{ik}(\omega) = \frac{C_{00}^{obs}(\omega)E\left[C_{ik}^{obs}(\omega)\right]\overline{Cor_{ik}^{huddle}(\omega)}}{\sqrt{E\left[C_{ii}^{obs}(\omega)\right]E\left[C_{kk}^{obs}(\omega)\right]}}$$

$$\overline{Cor_{ik}^{huddle}(f)} = \exp\left\{ jE\left[Arg\left(\frac{\sqrt{C_{ii}^{huddle}(f)\cdot C_{kk}^{huddle}(f)}}{C_{ik}^{huddle}(f)} \right)\right]\right\}$$

KR derived from CCA coefficient

$$s(r,\omega)=\frac{J_0^2(r\omega/c)}{J_1^2(r\omega/c)}$$



Long wavelength apploximation
(Small value of *kr*) (Cho et al,2006)

$$c(\omega)=\frac{r\omega}{2}\sqrt{s(r,\omega)+2}$$

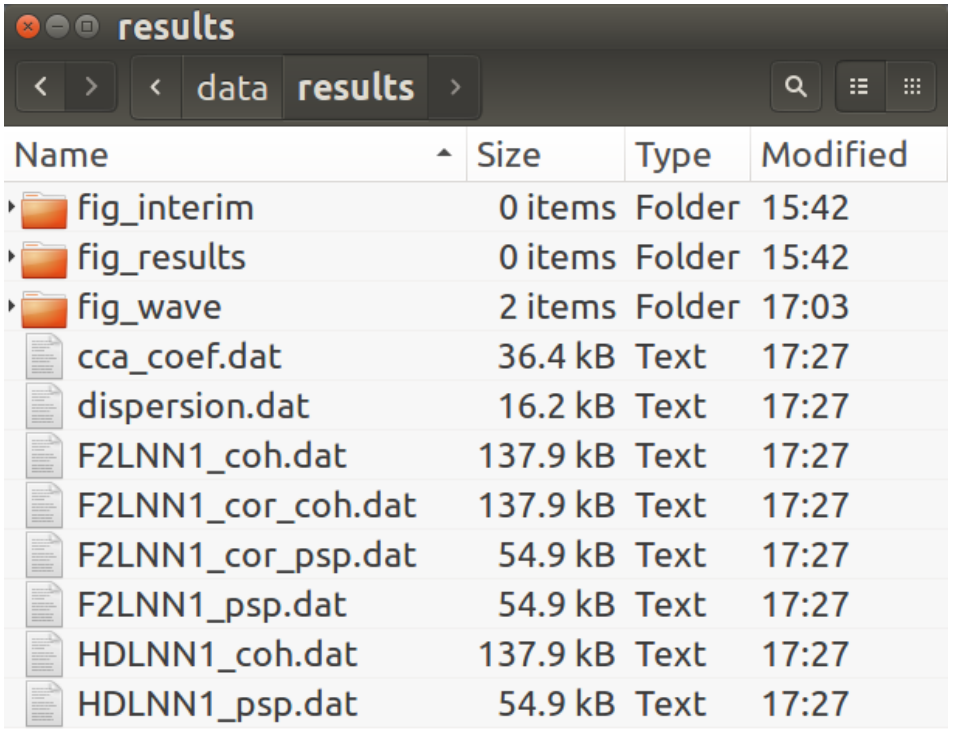
Improved approximation:Yokoi(2012)

$$\mathrm{c}(\omega)/\mathrm{r}\omega=1.0003\left(\frac{\sqrt{\mathrm{s}(\mathrm{r},\omega)+0.97221}}{2.0003}+0.0015245\right)-0.0138$$

Estimate c(ω) using the relation KR=2πR/c(ω)

Output Files

in ./ccawkf/data/results




```
cca_coef.dat        : calculated CCA coefficient
dispersion.dat      : estimated dispersion curve
F2LNN1_coh.dat      : coherence among the channels
F2LNN1_cor_coh.dat  : coherence corrected by huddle test
                      (not created if n_huddle=0 in pwrcrs3.prm)
F2LNN1_psp.dat      : power spectra of all channels
F2LNN1_cor_psp.dat  : power spectra corrected by huddle test
                      (not created if n_huddle=0 in pwrcrs3.prm)
HDLNN1_coh.dat      : coherence among the channel for huddle test
HDLNN1_psp.dat      : power spectra of huddle test
```

2. Estimating Dispersion Curve

2.2 Plot Power, Fourier Spectra & Coherence

Shell Script used

sh spectra_all.sh

Program used

./bin/power_plt.exe

./bin/fourier_plt.exe

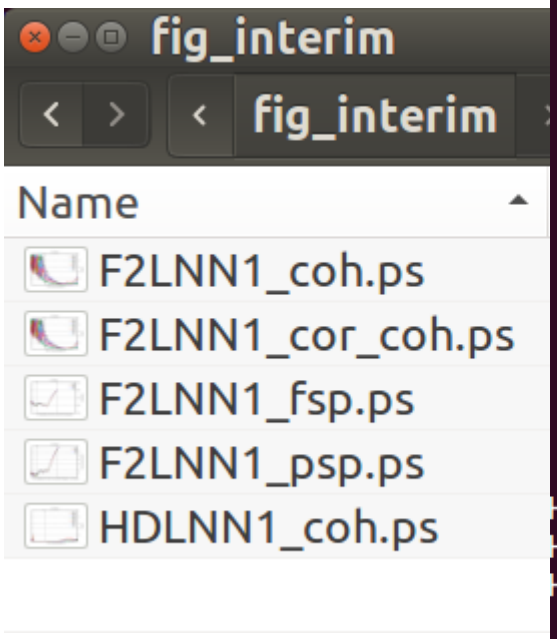
./bin/coh_plt.exe

spectra_all.sh

```
#! /bin/sh -x
./bin/power_plt.exe | tee cca_wkf/log/spectra_all.log
gnuplot -e " load './cca_wkf/prm/gnuplt_script/power.plt' ; pause -1 "
./bin/fourier_plt.exe | tee -a cca_wkf/log/spectra_all.log
gnuplot -e " load './cca_wkf/prm/gnuplt_script/fourier.plt' ; pause -1 "
./bin/coh_plt.exe | tee -a cca_wkf/log/spectra_all.log
gnuplot -e " load './cca_wkf/prm/gnuplt_script/coherence.plt' ; pause -1 "
rm ./cca_wkf/data/results/temp*.dat
```

Execution

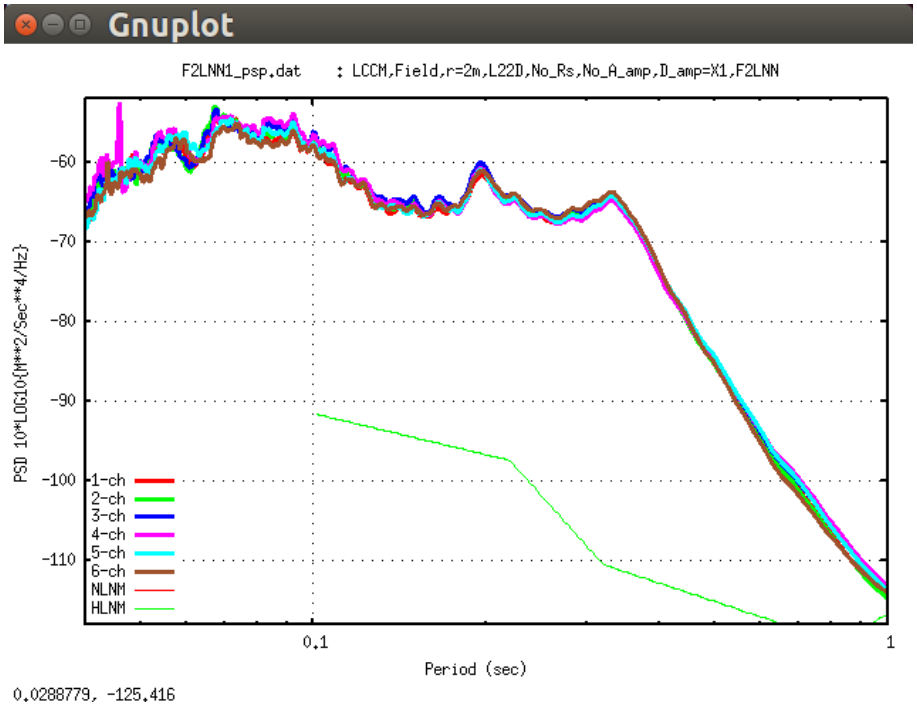
All output figures displayed in X-windows are stored in PostScript format in the subfolder ./cca_wkf/data/results/fig_interim



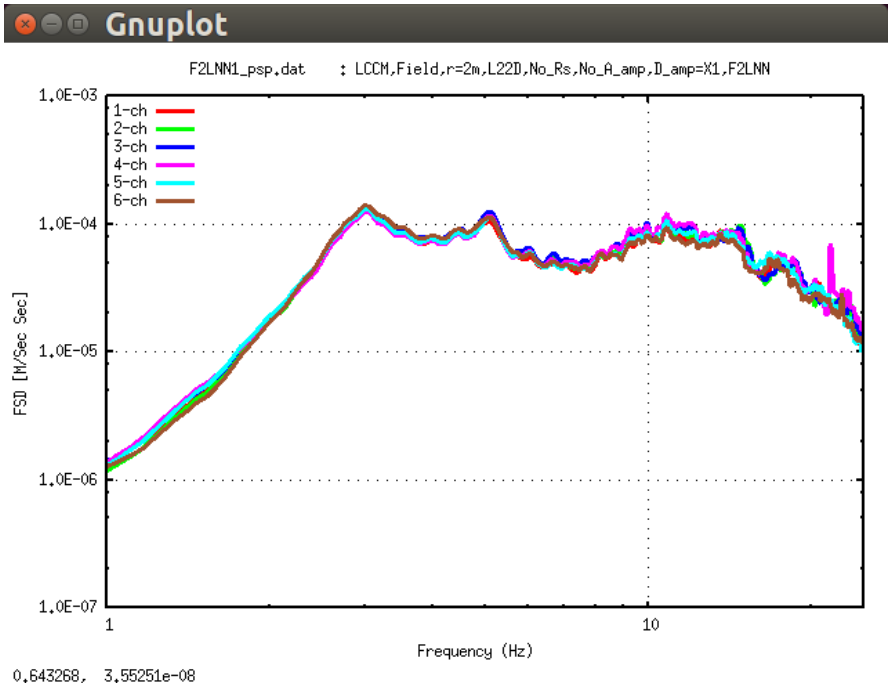

```
yokoi@ubuntu:~/CCA2017/CCA2019$ sh spectra_all.sh
 ./cca_wkf/prm/gnuplt_script/power.plt
 ./cca_wkf/prm/gnuplt_script/F2LNN1_psp.plt
 F2LNN1_psp.ps

 ./cca_wkf/prm/gnuplt_script/F2LNN1_fsp.plt
   16.3840008
 F2LNN1_fsp.ps

 ./cca_wkf/prm/gnuplt_script/F2LNN1_coh.plt
 1 ./cca_wkf/data/results/F2LNN1_coh.dat
 ./cca_wkf/data/results/fig_interim/F2LNN1_coh.ps
 2./cca_wkf/data/results/HDLNN1_coh.dat
 ./cca_wkf/data/results/fig_interim/HDLNN1_coh.ps
 3./cca_wkf/data/results/F2LNN1_cor_coh.dat
 ./cca_wkf/data/results/fig_interim/F2LNN1_cor_coh.ps
Hit return to continue
Hit return to continue
Hit return to continue

yokoi@ubuntu:~/CCA2017/CCA2019$
```

Power & Fourier Spectra

(Velocity) Power Spectra



(Velocity) Fourier Spectra



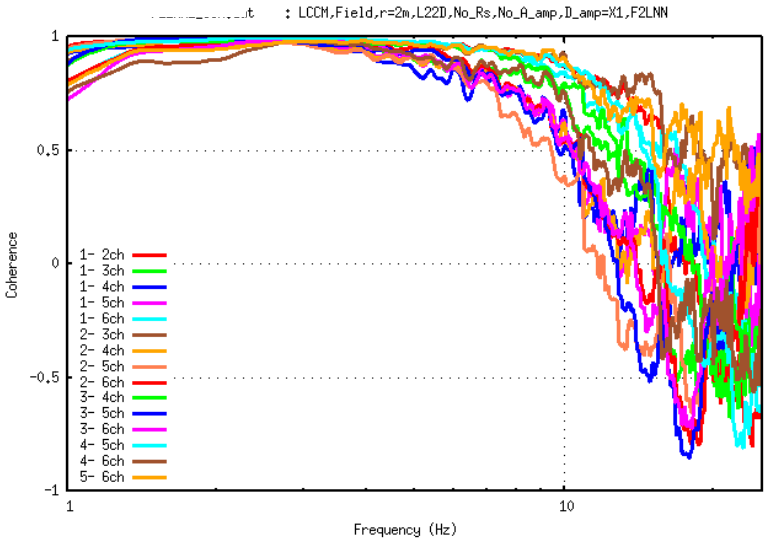
Power spectra corrected using huddle test records are in “cca_coef.dat” and its example is shown few slide later.

In the shown example, seismometers of which natural frequency is 2Hz are used, then the power & Fourier spectra decays in the frequency range lower than that frequency.

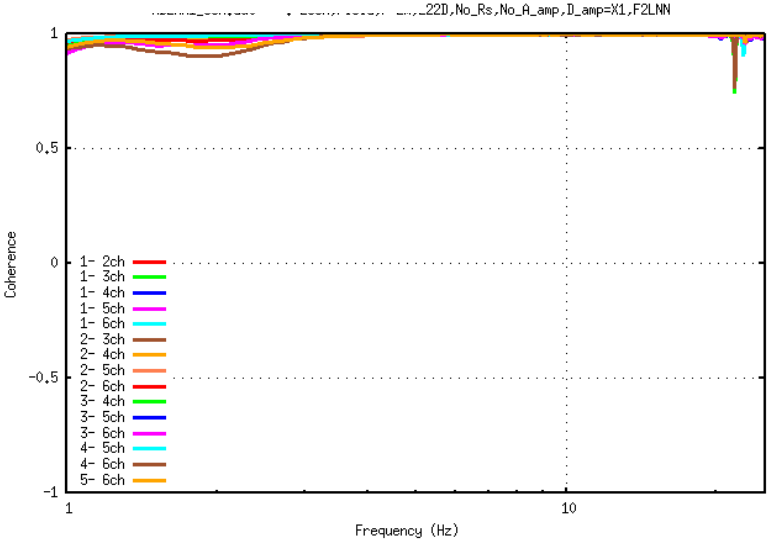
These figures are stored in ./cca_wkf/data/results/fig_results in PostScript format.

Coherence

Field Data

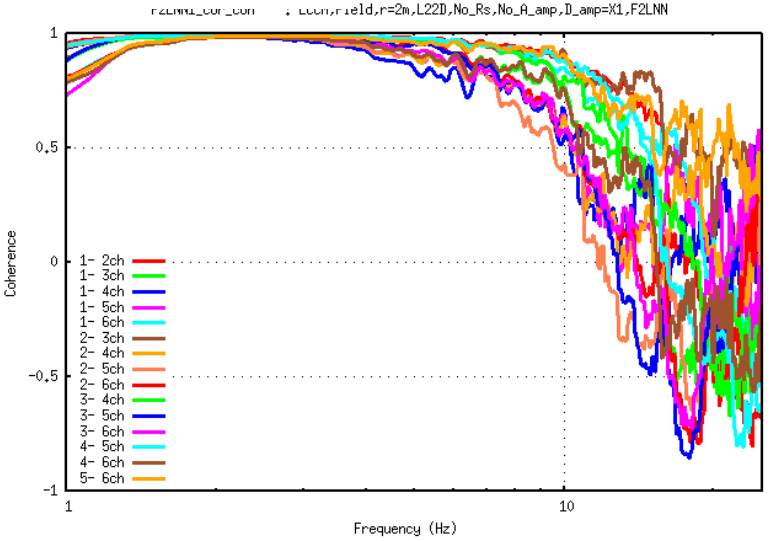


Huddle Test Data



14.5963, 1.13661

Corrected Data



5.35681, 1.19574

These figures are stored in ./cca_wkf/data/results/fig_results in PostScript format.

2. Estimating Dispersion Curve

2.3 Quality Control & Dispersion Curve

Shell Script used

sh results.sh

Program used

./bin/resultc._plt.exe

./bin/q_control.exe

./bin/vel_model_plt.exe

results.sh

```
#! /bin/sh -x
./bin/resultc_plt.exe | tee cca_wkf/log/results.log
gnuplot -e " load './cca_wkf/prm/gnuplt_script/results.plt' ; pause -1 "
./bin/q_control.exe | tee -a cca_wkf/log/results.log
gnuplot -e " load './cca_wkf/prm/gnuplt_script/q_control.plt' ; pause -1 "
./bin/vel_model_plt.exe | tee -a cca_wkf/log/results.log
gnuplot -e " load './cca_wkf/prm/gnuplt_script/vel_model.plt' ; pause -1 "
rm ./cca_wkf/data/results/temp*.dat
```

cca_coef.dat

```
Freq.        ALL          Z0/ALL       Z1/ALL        Z0/Z1        Azi          err/N          2.000     1.000    25.000 :Radius, fmin, fmax
0.916          0.182E-11    0.869E+00    0.284E-01    0.306E+02   -0.209E+03    0.000E+00
0.977          0.279E-11    0.895E+00    0.223E-01    0.401E+02   -0.210E+03    0.000E+00
1.038          0.429E-11    0.909E+00    0.196E-01    0.465E+02   -0.210E+03    0.000E+00
1.099          0.652E-11    0.927E+00    0.163E-01    0.570E+02   -0.210E+03    0.000E+00
1.160          0.102E-10    0.942E+00    0.133E-01    0.707E+02   -0.210E+03    0.000E+00
1.221          0.164E-10    0.954E+00    0.106E-01    0.899E+02   -0.210E+03    0.000E+00
1.282          0.269E-10    0.964E+00    0.821E-02    0.117E+03   -0.210E+03    0.000E+00
1.343          0.435E-10    0.972E+00    0.633E-02    0.154E+03   -0.210E+03    0.000E+00
1.404          0.674E-10    0.978E+00    0.501E-02    0.195E+03   -0.209E+03    0.000E+00……..
```

1st line : titles of columns (Freq.,All, Zo/ALL, Z1/ALL, Z0/Z1,Azi,err/N), radius,fmin,fmax

Freq. : frequency

ALL : Total power spectra

Z0/ALL :

Z1/ALL :

Z0/Z1 : CCA coefficient

azi : azimuth estimated from array analysis

err/N : actually not used

Z0: numerator of CCA coefficient

power of zero order component of Fourier expansion over azimuth

Z1: denominator of CCA coefficient

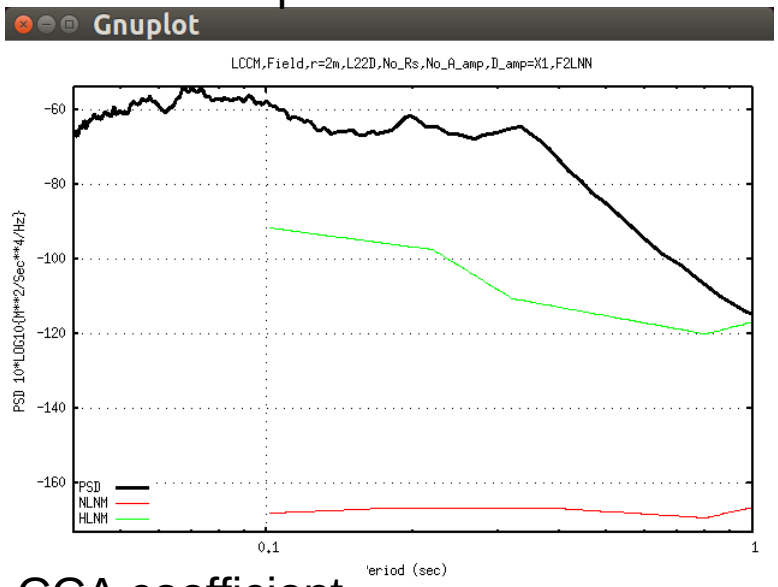
power of first order component of Fourier expansion over azimuth

Execution

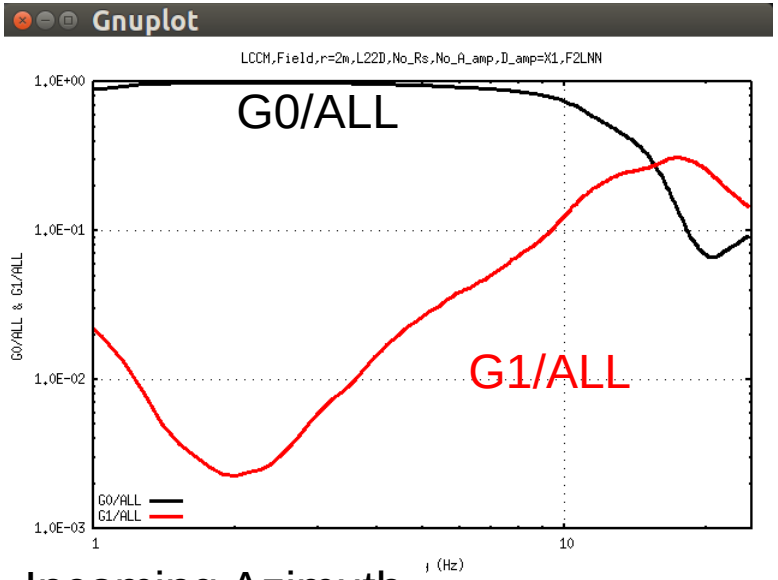
```
yokoi@ubuntu:~/CCA2017/CCA2019$ sh results.sh
 ./cca_wkf/data/results/cca_coef.dat
 ./cca_wkf/prm/gnuplt_script/resultS.plt
 ./cca_wkf/data/results/fig_results/
 results_psp.ps
 ./cca_wkf/data/results/temp1.dat
 results_G0_G1.ps
 results_cca.ps
 results_azi.ps
Hit return to continue
Hit return to continue
Hit return to continue

 ./cca_wkf/prm/gnuplt_script/q_control.plt
 ./cca_wkf/prm/gnuplt_script/q_controL.plt
 ./cca_wkf/data/results/fig_results/g0_all.ps
 ./cca_wkf/data/results/fig_results/g1_all.ps
 ./cca_wkf/data/results/fig_results/q_control.ps
Hit return to continue
Hit return to continue
Hit return to continue

 ./cca_wkf/prm/gnuplt_script/vel_model.plt

yokoi@ubuntu:~/CCA2017/CCA2019$
```

cca_coef.dat

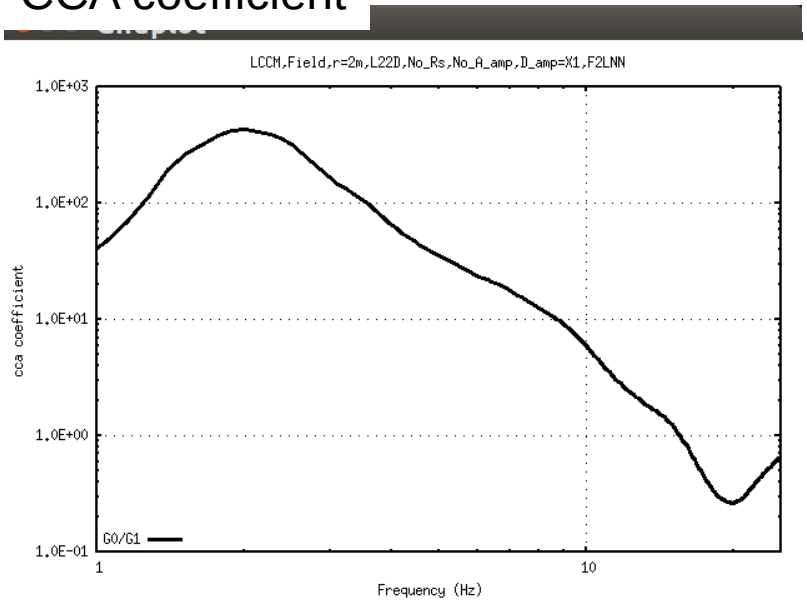
Power Spectra of ch1



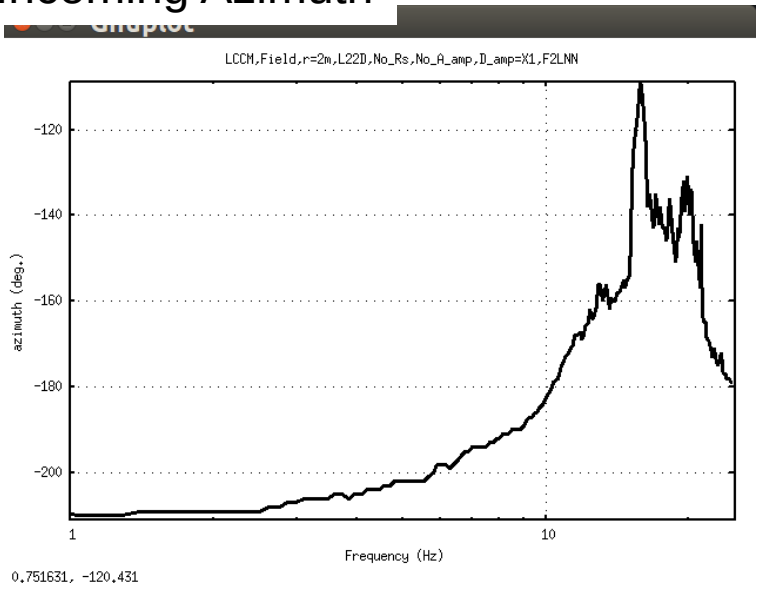
G0/ALL & G1/ALL



CCA coefficient



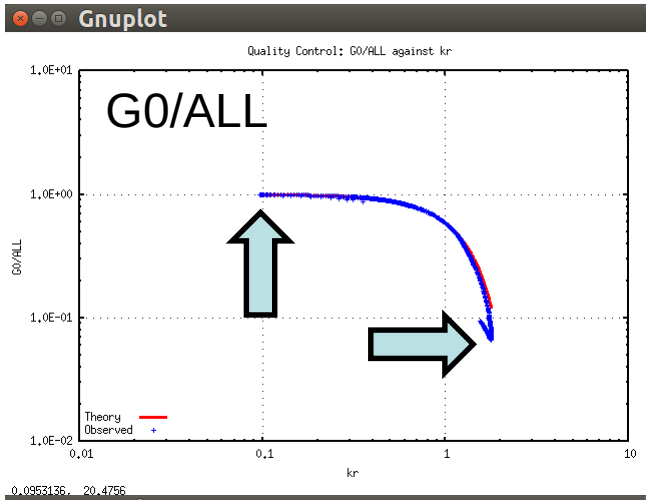
Incoming Azimuth

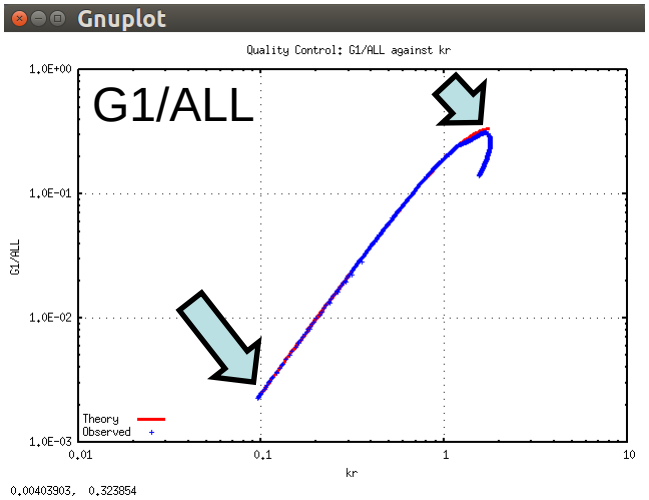


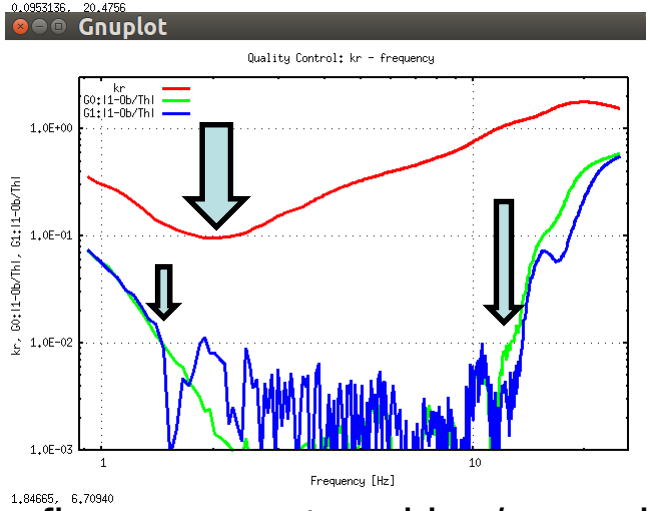
These figures are stored in ./cca_wkf/data/results/fig_results in PostScript format.

Quality Control

Using the values of “kr” in the file “dispersion.dat”, Z0/ALL and Z1/ALL in the file “cca_coef.dat” are compared with the theoretical $J_0(kr)^2$ and $J_1(kr)^2$, respectively. Arrows indicate the limit of the range of “kr” for analysis, where the observed curves run off from the theoretical ones.







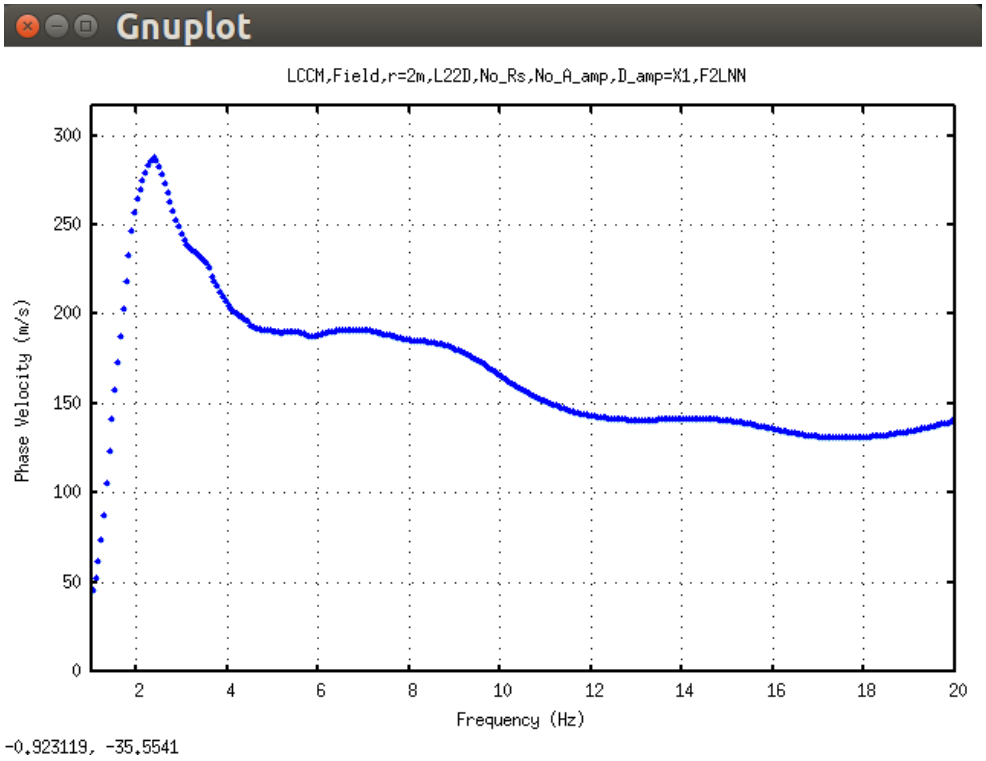
(Example 1-5)

These figures are stored in ./cca_wkf/data/results/fig_results in PostScript format.

dispersion.dat

Frequency	Velocity	Azimuth	KR
0.916	32.348	-208.786	0.356
0.977	39.342	-210.076	0.312
1.038	44.918	-210.351	0.290
1.099	52.573	-210.471	0.263
1.160	61.721	-210.378	0.236

…



This figure is stored in ./cca_wkf/data/results/fig_results in PostScript format.

4. Heuristic Search of Vs Structure

Shell Script used:

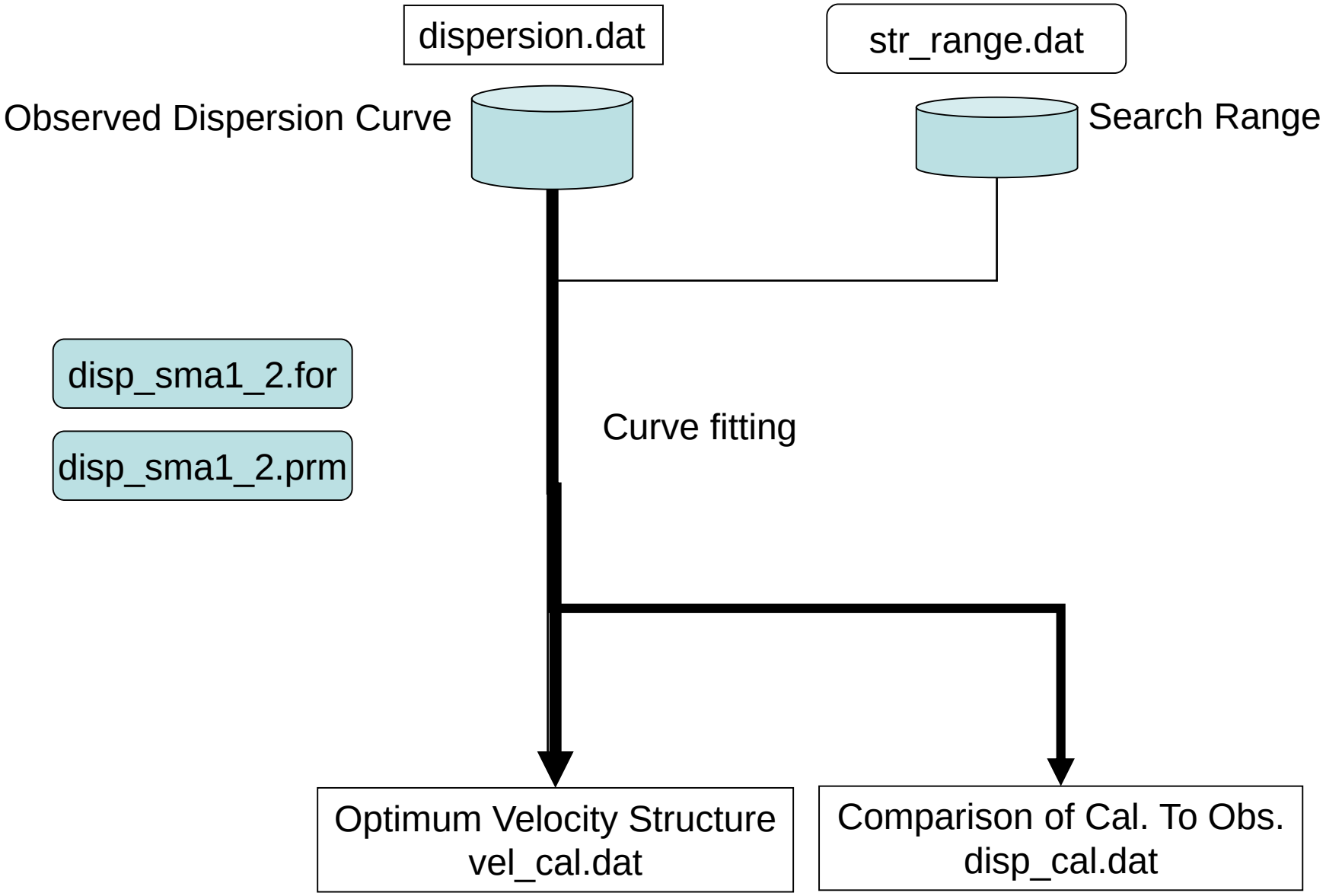
sh inversion.sh

Programs and parameter file used:

./bin/disp_sma1_2.exe + disp_sma1_2.prm

inversion.sh:

```
#!/bin/sh
./bin/disp_sma1_2.exe | tee ./cca_wkf/log/inversion.log
./bin/inv_plt.exe | tee -a ./cca_wkf/log/inversion.log
gnuplot -e "load ‘./cca_wkf/prm/gnuplt_script/inv.plt' ; pause -1 "
rm ./cca_wkf/data/results/temp*.dat
```


dispersion.dat
str_range.dat
Observed Dispersion Curve
Search Range
disp_sma1_2.for
disp_sma1_2.prm
Curve fitting
Optimum Velocity Structure
vel_cal.dat
Comparison of Cal. To Obs.
disp_cal.dat

disp_sma1_1.for Yokoi(2006)

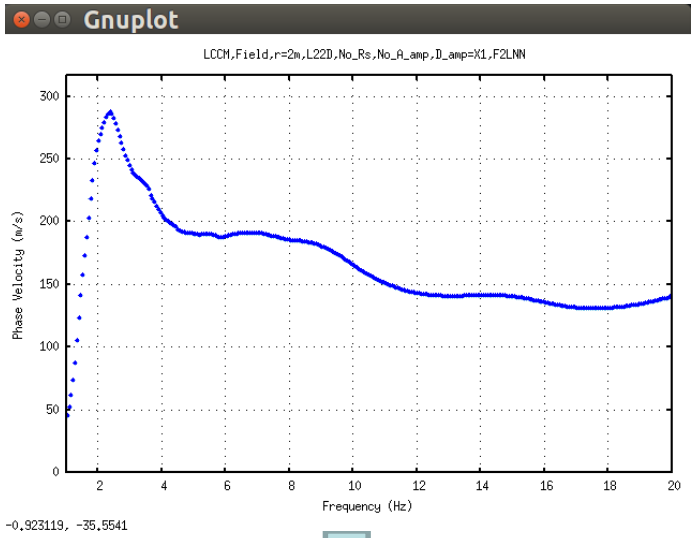
Combination of the Down Hill Simplex Method (Nelder & Mead (1965)) and the Very Fast Simulated Annealing method (Ingber, 1989).

DHSM: Down Hill Simplex Method (Nelder & Mead (1965))
An efficient algorithm to find "local minimum".
Faster than Geiger's method. Partial derivatives are not necessary.
Result is controlled by given initial values and easily captured by local minimum.
Example of application to the microtremor array: Ohori et al(2002)

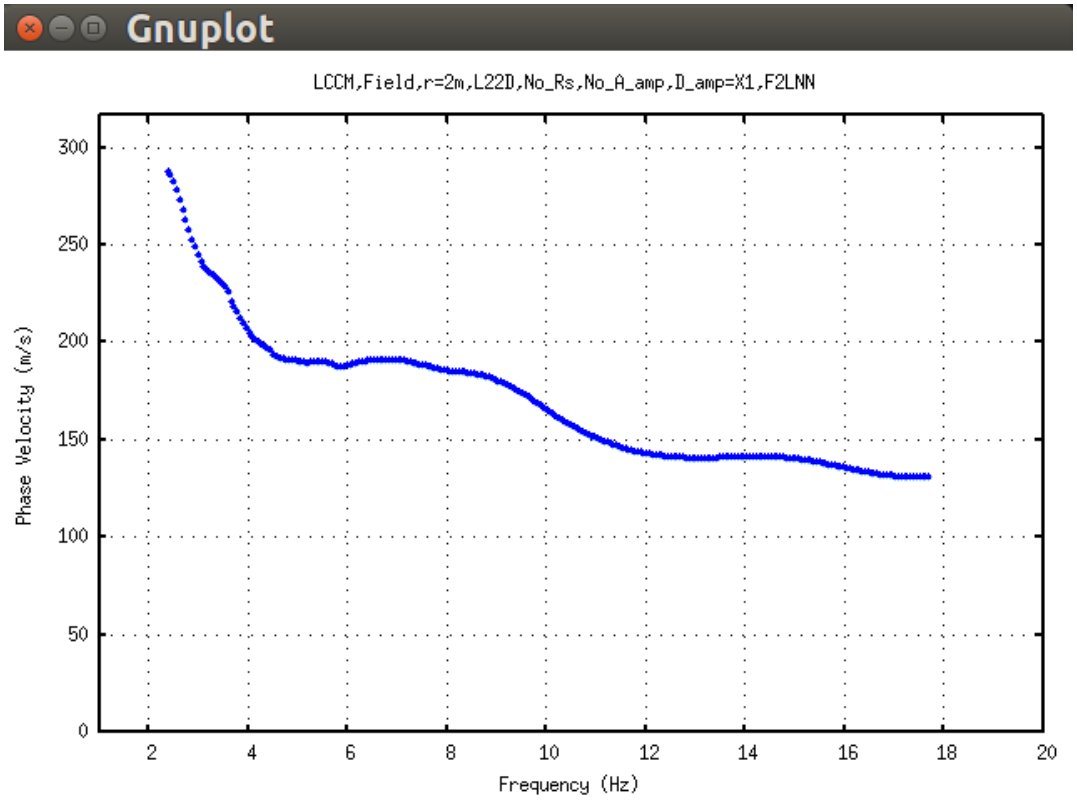
VFSA: Very Fast Simulated Annealing method (Ingber, 1989)
One of the heuristic search methods.
Analogy of cooling and crystallization process of metals.
Results can escape from local minimum and can get global minimum with some probability.
Time consuming due to the probabilistic search for each parameter.
Example of application to the microtremor array & appropriate values of parameters for this purpose: Yamanaka (2004)

Edit “dispersion.dat” using “gedit” or other text editor

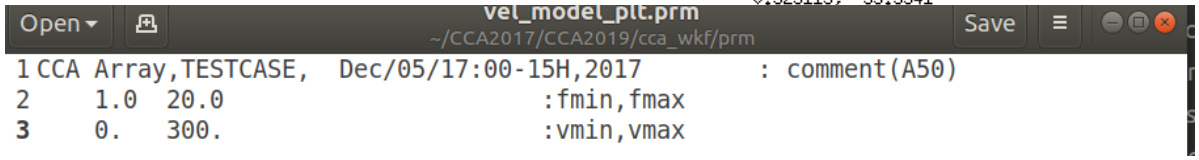
(Example 1-6)



Then, redraw it using:
sh ./vel_model_plt.sh



Vel_model_plt.prm



Parameter file: disp_sma1_2.prm

(Example 1-6)

```
 1 1. 0.6 1.3 10000  5   :idum,t0,a,c,ntemp,j0
 0.0002                 :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).
dispersion.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)
```

Explanation

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 to grasp 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 : acceptable misfit.

Search Range file: str_range.dat

(Example 1-6)

```
LCCM,r=2m,L22D,F2LNN0,12/03/15:Model(a30)
         6                          :IL(I5),Layer Number
1.9     1.5    0.001  0.020  0.10 0.15 :density,Vp,hmin,hmax,vmin,vmax
1.9     1.5    0.001  0.020  0.12 0.20 :density,Vp,hmin,hmax,vmin,vmax
1.9     1.5    0.001  0.020  0.18 0.25 :density,Vp,hmin,hmax,vmin,vmax
1.9     1.5    0.001  0.020  0.15 0.30 :density,Vp,hmin,hmax,vmin,vmax
1.9     1.5    0.001  0.020  0.15 0.35 :density,Vp,hmin,hmax,vmin,vmax
2.0     1.70   998.0  999.0  0.20 0.50 :density,Vp,hmin,hmax,vmin,vmax
```

If n_vp=1 in parameter file, the given values of Vp are not used

If n_roh=1 in parameter file, the given values of density are not used

Execution (Example 1-6).

```
yokoi@ubuntu: ~/CCA2017/CCA2019
yokoi@ubuntu:~/SPAC2016/SPAC2019$ sh inversion.sh
rm: cannot remove './spacwkf/data/results/temp*.dat': No such file or directory
 +--------------------------------------------------+
 +                                                  +
 +                    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.+
 +--------------------------------------------------+
 ./spacwkf/data/results/progress.dat
```

Initial values randomly selected within the search range.

```
                                  Range of random fluctuation
Thicknes Density      Vp      Vs   Thickness          Vs
   0.011   1.755   1.399   0.099   0.001   0.020   0.090   0.200
   0.017   1.759   1.411   0.109   0.001   0.020   0.050   0.200
   0.015   1.800   1.539   0.224   0.001   0.020   0.100   0.250
   0.008   1.806   1.557   0.241   0.001   0.020   0.150   0.250
 999.000   1.814   1.584   0.265 998.000 999.000   0.150   0.500
 ./cca_wkf/data/results/dispersion.dat
    5    0.0016076231
   10    0.0015863872
   15    0.0015863872
   20    0.0013621505
   25    0.0013621505
```

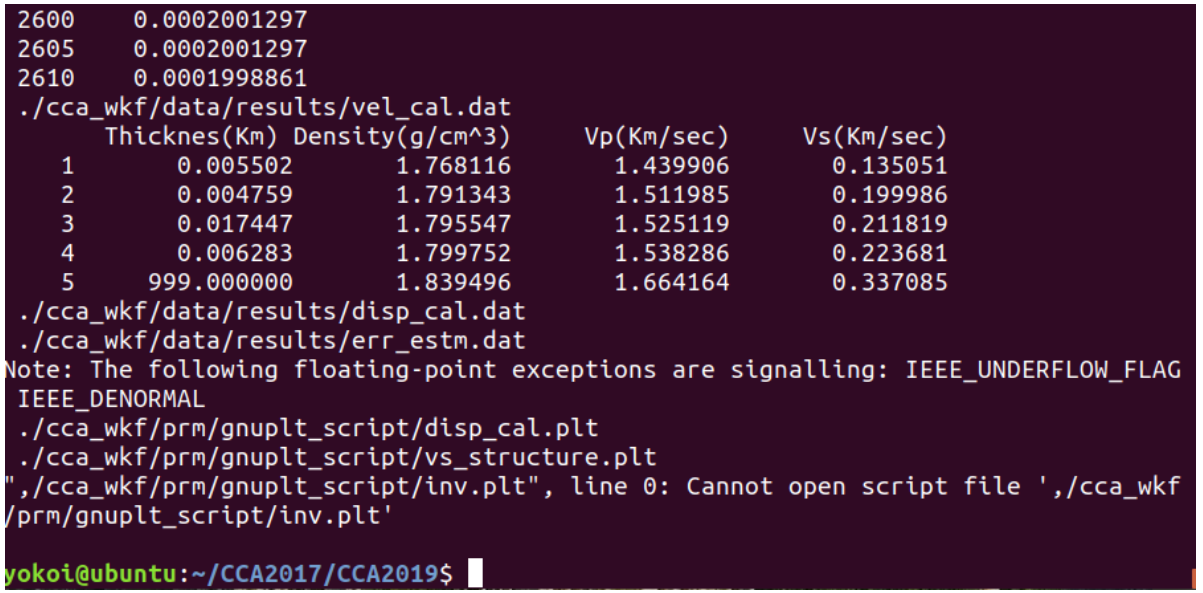
Iteration Starts

Execution (Example 1-6 cont).

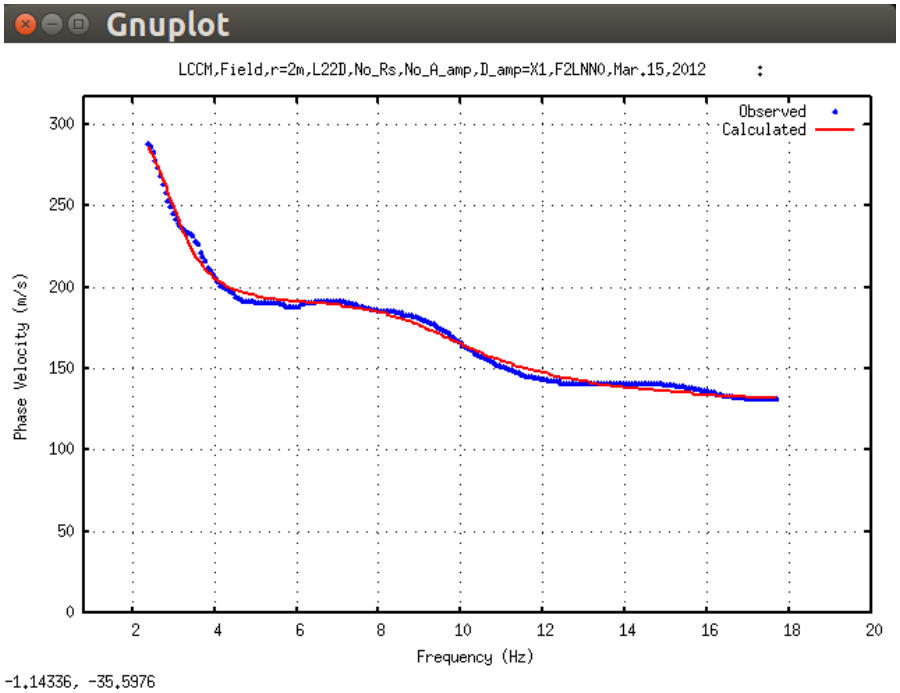
Conversion of misfit to the threshold eps0

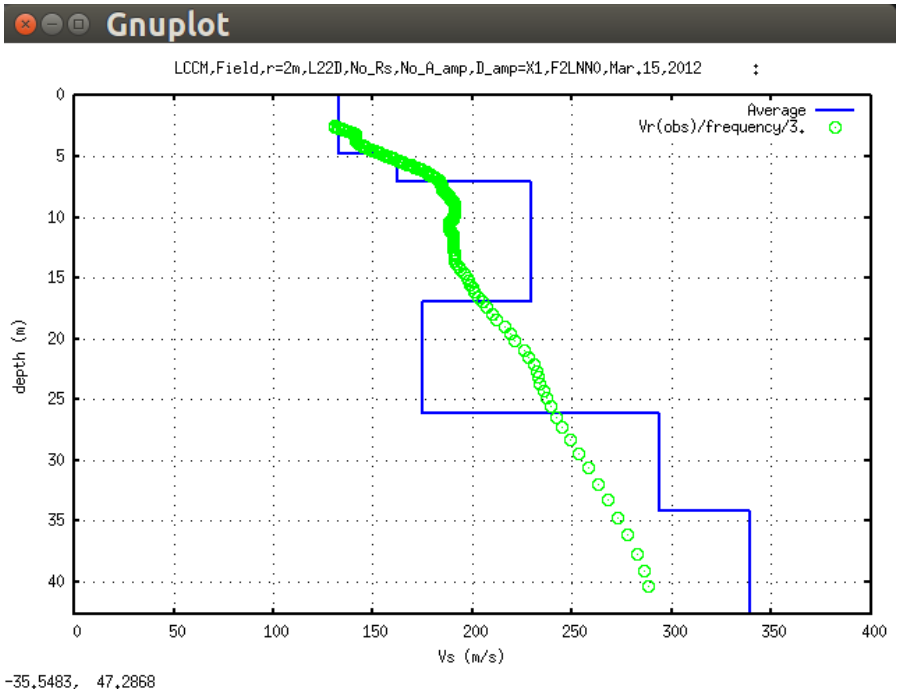
Optimum Underground velocity structure

Plotting



Plotting (Example 1-6 cont).





The same figures are stored in Post Script files:

./cca_wkf/data/results/fig_results/disp_cal.ps

./cca_wkf/data/results/fig_results/vs_structure.ps

Green points can be eliminated by setting n_mod=0 in pwrcrs3.prm.

Example1

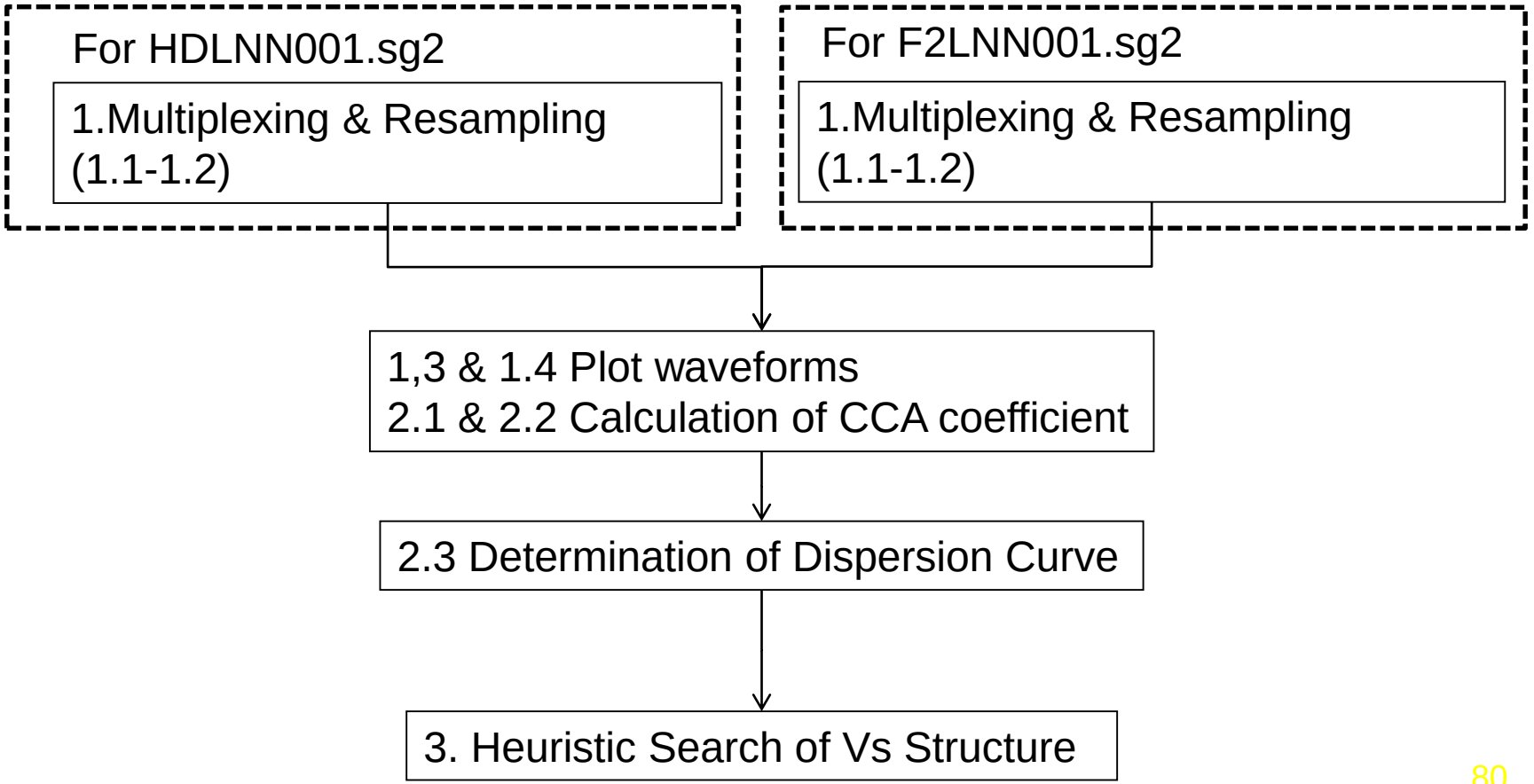
(Instrumental Correction without sensor at the center)

Example with two data sets:

HDLNN001.sg2: Huddle test data file

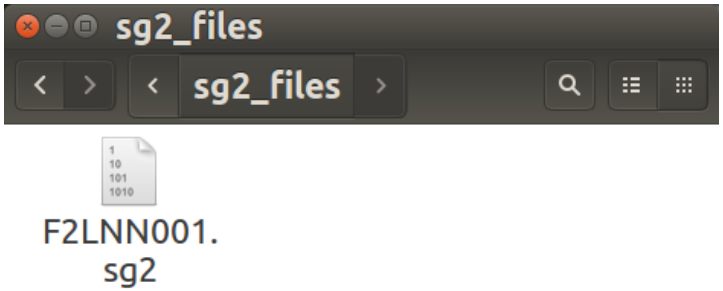
F2LNN001.sg2: 6 points circular array without one at the center

Both are the seg2 standard format file.



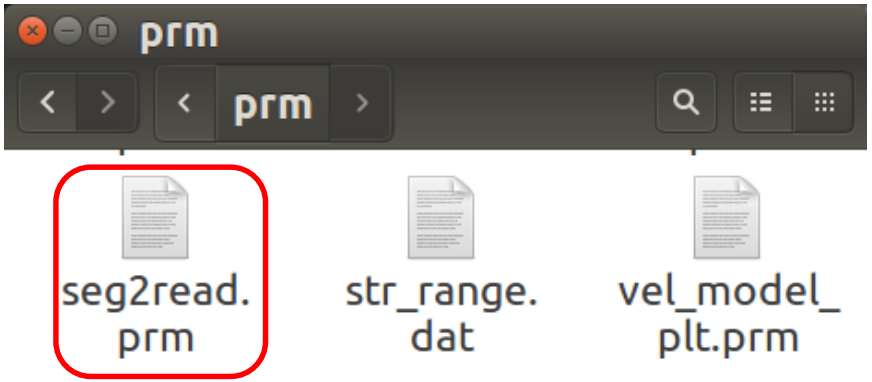
Example 1-1: For Field Data:

Copy the field data file “F2LNN001.sg2” into “./cca_wkf/data/sg2_files”.



Edit the parameter file “seg2read.prm” in “./cca_wkf/prm”.

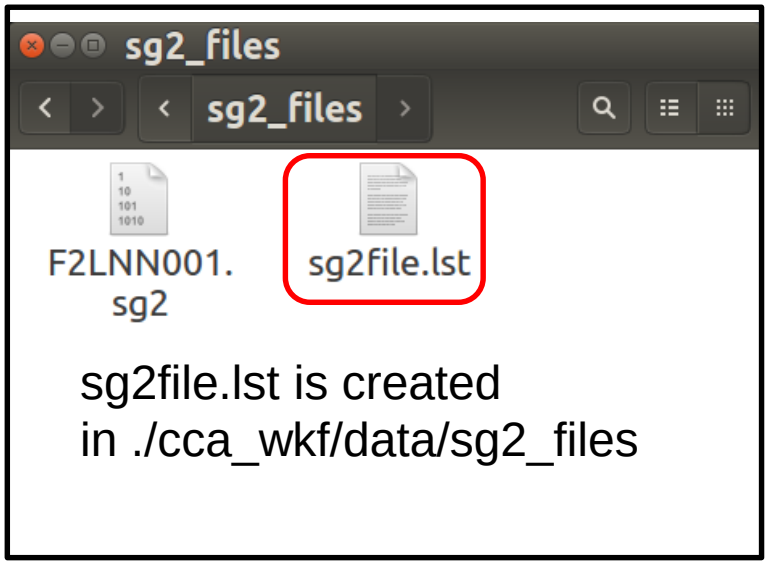
```
(seg2read.prm)
LCCM,Field,r=2m,L22D,No_Rs,No_A_amp,D_amp=X1,F2LNN0,Mar.15,2012      :comm(a70)
5.E-3    : scaling factor (for output files in mkine(1.e-3cm/s))
sg2      : extension of input seg2 format files(a3)
dat      : extension of output ascii text files(a3)
0 3 0.1 1.0 1.5  :nfilter(=1:apply),nchara=3:bandpass),fl,fh,fs
pvlist 1 2 3 4 5 6  : Channel Pivoting
```



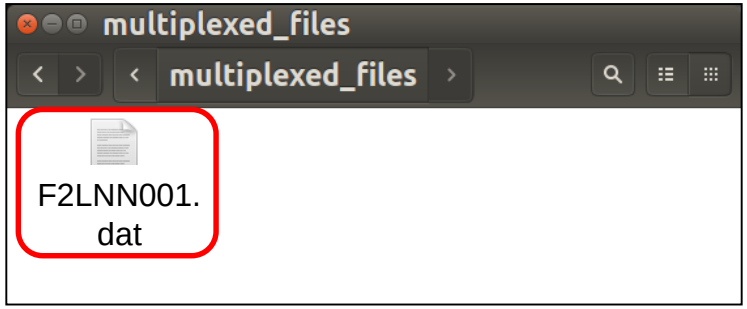
The array used in the field has 6 sensors, but none of them at the center. They were installed counter-clockwise order. Then, pvlist 1 2 3 4 5 6 :

Example 1-1 (cont): Execution

```
yokoi@ubuntu: ~/CCA2017/CCA2019
yokoi@ubuntu:~/CCA2017/CCA2019$ sh ./seg2read.sh
./cca_wkf/prm/seg2read.prm
./cca_wkf/data/sg2_files/sg2file.lst
 F2LNN001.sg2


./cca_wkf/data/sg2_files/F2LNN001.sg2
./cca_wkf/data/multiplexed_files/F2LNN001.cdm
nch= 12 dt= 0.008 nn=  225000
     1 files have been converted.
Normal End.
yokoi@ubuntu:~/CCA2017/CCA2019$
```



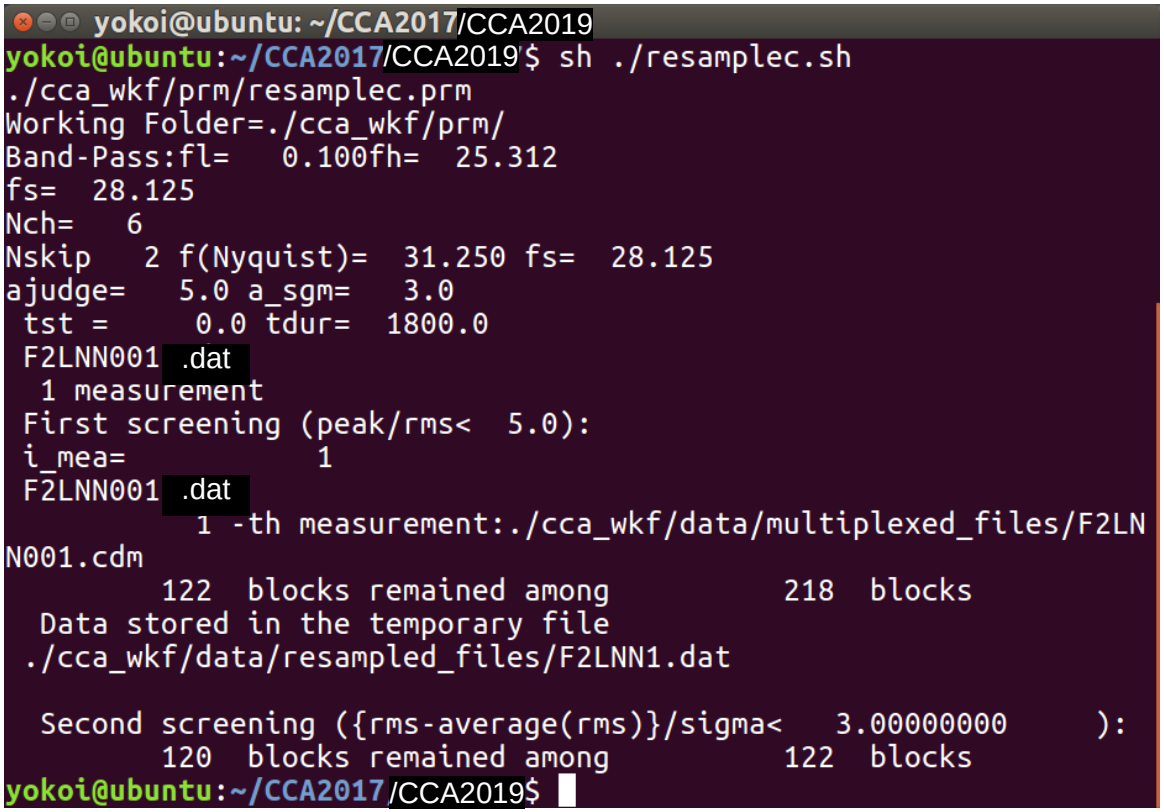
Input file is ./cca_wkf/data/sg2_files/F2LNN001.sg2
Multiplexed output is ./cca_wkf/data/multiplexed_files/F2LNN001.cdm
Log file is stored in ‘cca_wkf/log/seg2read.log’



Example 1-1(Cont): For Field Data

(mltfile.lst for “multiplexed_files)
F2LNN001.dat

(resamplec.prm)
```
 6 0.008  2   0.0  0  2.0  :nch,dt,nchannel,dt,nskip,ph0,ncenter,radius
5.0 3.0                    :ajudge,a_sgm
0.0 1800.0                 :tst,tdur
F2LNN1.dat                 :output file name
1024                       :number of data in one time block after resampling
```



Output file: ./cca_wkf/data/resampled_files/F2LNN1.dat
Log file: ./ cca_wkf/log/resamplec.log

Output file: cca_wkf/data/resampled_files/F2LNN1.dat

F2LNN1.dat (~/CCA2017/CCA2019/cca_wkf/data/resampled_files) - gedit

Open Save

resamplec.prm F2LNN1.dat

```
1 6  120 1024 0     0.00    2.00 (i8,f16.4, 6e15.7) mkine
2        1          8.1920 -0.2134265E+01 -0.1570028E+01 -0.1464243E+01 -0.1183819E+01 -0.1944440E+01 -0.2460508E+01
3        2          8.2080 -0.8561512E+00 -0.1420853E+00  0.5698163E+00 -0.7201288E+00 -0.8229986E+00 -0.1031229E+01
4        3          8.2240 -0.1268116E+01 -0.1240067E+01 -0.2134730E+00 -0.2036263E+00 -0.3363592E+00 -0.7179448E+00
5        4          8.2400 -0.1921562E+01 -0.1946060E+01 -0.1426458E+01  0.5525613E+00  0.5879311E-01 -0.1037454E+01
6        5          8.2560 -0.1496630E+00 -0.1971388E+00 -0.5178442E+00  0.3342248E-01  0.2441409E+00 -0.2223579E+00
7        6          8.2720  0.1691884E+01  0.1940500E+01  0.1464395E+01  0.4097762E-01  0.5695816E+00  0.9296002E+00
8        7          8.2880  0.1703986E+01  0.2342472E+01  0.2387742E+01  0.1132192E+01  0.1037764E+01  0.1928447E+01
9        8          8.3040  0.1691325E+01  0.1653560E+01  0.1467912E+01  0.1262632E+01  0.8586157E+00  0.1551036E+01
10       9          8.3200  0.1749979E+01  0.9793880E+00  0.2770654E+00 -0.3539335E-01  0.1746513E+00  0.7429792E+00
11      10          8.3360 -0.1422137E-01 -0.2752598E+00 -0.2738954E+00 -0.1380785E+00 -0.3472582E+00 -0.9527585E-01
12      11          8.3520 -0.2684537E+00  0.1853040E+00  0.6619582E+00  0.1160535E+01  0.7660274E+00 -0.1265951E-01
13      12          8.3680  0.1374736E+01  0.1114815E+01  0.1076111E+01  0.7220107E+00  0.1642688E+01  0.1402611E+01
14      13          8.3840  0.6888835E+00  0.2348001E+00  0.3182783E+00  0.2095545E+00  0.2143849E+00  0.7790853E+00
```

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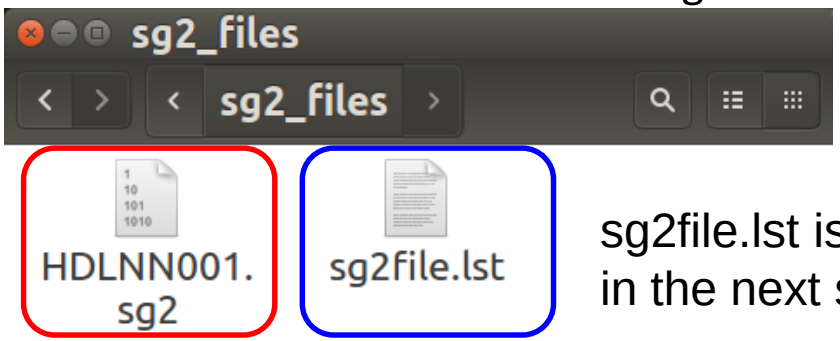
Example 1-2: For Huddle Test Data:

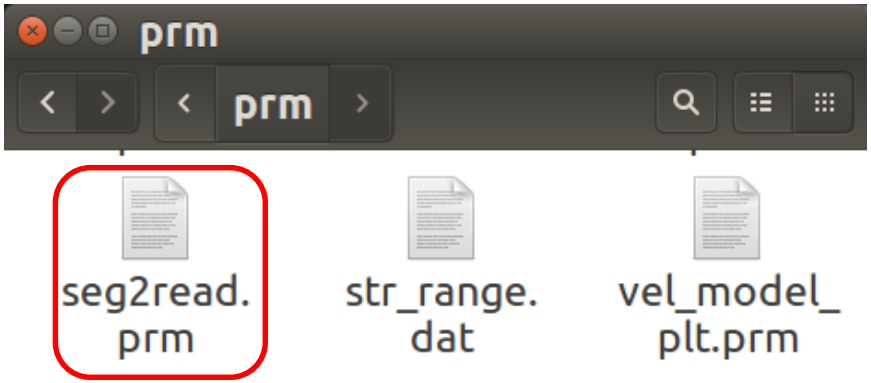
Copy the Huddle Test data file “HDLNN001.sg2” into “./cca_wkf/data/sg2_files”.



sg2file.lst is overwritten in the next slide

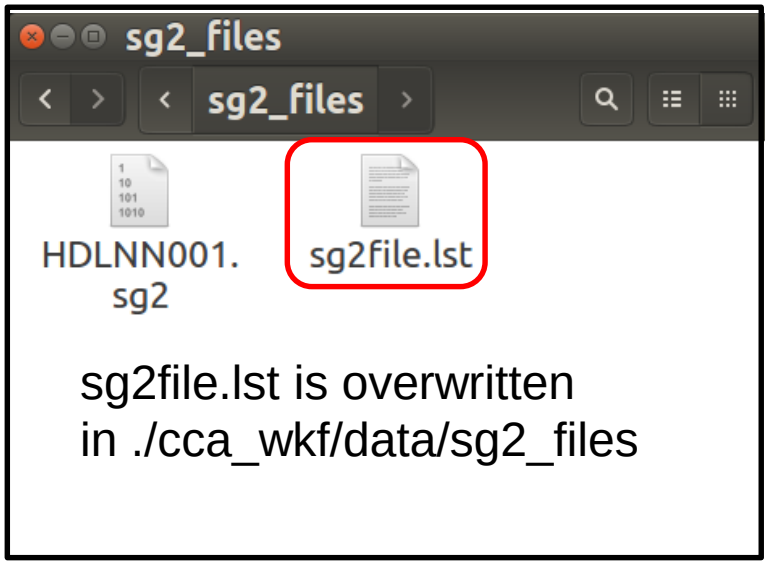
Edit the parameter file “seg2read.prm” in “./cca_wkf/prm”.

```
(seg2read.prm)
LCCM,Huddle,r=0m,L22D,No_Rs,No_A_amp,D_amp=X1,HDLNN0,Mar.15,2012      :comm(a70)
5.E-3     : scaling factor (for output files in mkine(1.e-3cm/s))
sg2       : extension of input seg2 format files(a3)
cdm       : extension of output ascii text files(a3)
0 3 0.1 1.0 1.5  :nfilter(=1:apply),nchara=3:bandpass),fl,fh,fs
pvlist 1 2 3 4 5 6   : Channel Pivoting
```

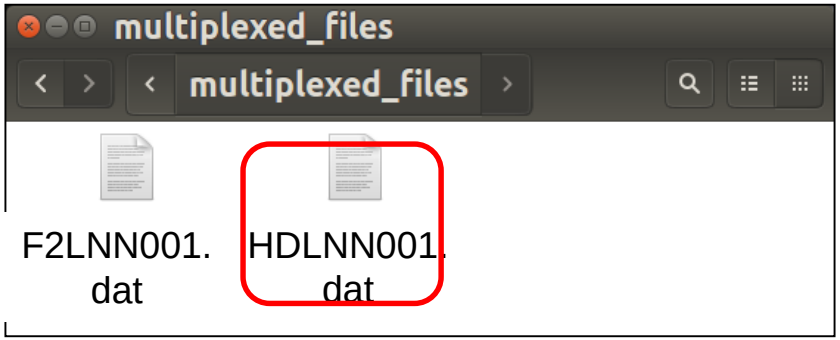


Example 1-2(cont): Execution

```
yokoi@ubuntu: ~/CCA2017/CCA2019
yokoi@ubuntu:~/CCA2017/CCA2019$ sh seg2read.sh
./cca_wkf/prm/seg2read.prm
./cca_wkf/data/sg2_files/sg2file.lst
 HDLNN001.sg2


./cca_wkf/data/sg2_files/HDLNN001.sg2
./cca_wkf/data/multiplexed_files/HDLNN001.cdm
nch= 12 dt= 0.008 nn=   37500
     1 files have been converted.
Normal End.
yokoi@ubuntu:~/CCA2017/CCA2019$
```



Input file is ./cca_wkf/data/sg2_files/HDLNN001.sg2
Multiplexed output is ./cca_wkf/data/multiplexed_files/HDLNN001.cdm
Log file is stored in 'cca_wkf/log/seg2read.log'

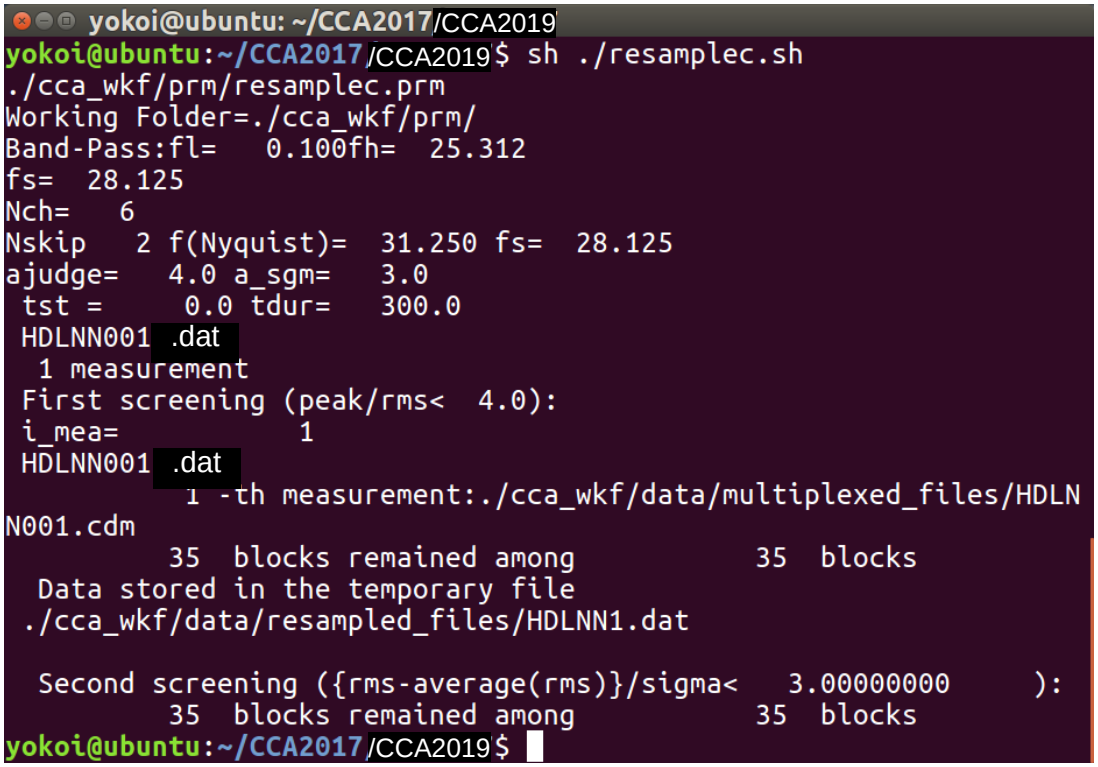


Example 1-2 (cont) For Huddle Test Data

(mltfile.lst for “multiplexed_files)
HDLNN001.dat

It is necessary to edit resamplec.prm

(resamplec.prm)
```
 6 0.008  2   0.0  0  0.0  :nch,dt,nskip,ph0,n_center,rr
4.0 3.0                    :ajudge,a_sgm
0.0  300.0                 :tst,tdur
HDLNN1.dat                 :output file name
1024                       :number of data in one time block after resampling
```



Output file: cca_wkf/data/resampled_files/HDLNN1.dat

This parameter must be 0.0 for Huddle Test Data !

HDLNN1.dat (~/CCA2017/CCA2019/cca_wkf/data/resampled_files) - gedit

Open Save

```
  1  6    35 1024 0     0.00     0.00 (i8,f16.4, 6e15.7) mkine
  2         1           0.0000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
  3         2           0.0160 -0.1799401E-04 -0.1802137E-04 -0.1899779E-04 -0.1662859E-04 -0.1702372E-04 -0.1857386E-04
  4         3           0.0320 -0.7969931E-03 -0.7861268E-03 -0.8226026E-03 -0.7348599E-03 -0.7667689E-03 -0.8235789E-03
  5         4           0.0480 -0.8717992E-02 -0.8514004E-02 -0.8888785E-02 -0.8073429E-02 -0.8518445E-02 -0.8909193E-02
  6         5           0.0640 -0.3686757E-01 -0.3588269E-01 -0.3764278E-01 -0.3471331E-01 -0.3662400E-01 -0.3666741E-01
  7         6           0.0800 -0.7309145E-01 -0.7125510E-01 -0.7582537E-01 -0.7128865E-01 -0.7417893E-01 -0.6874647E-01
  8         7           0.0960 -0.7732718E-01 -0.7530410E-01 -0.8230261E-01 -0.8054324E-01 -0.8182846E-01 -0.6387848E-01
  9         8           0.1120 -0.5401370E-01 -0.5133029E-01 -0.5919810E-01 -0.6365591E-01 -0.6399111E-01 -0.3049762E-01
 10         9           0.1280 -0.3739453E-01 -0.3451442E-01 -0.4545669E-01 -0.5466346E-01 -0.5457631E-01 -0.4959976E-02
 11        10           0.1440 -0.3376586E-01 -0.3379093E-01 -0.4955791E-01 -0.6377745E-01 -0.6028046E-01  0.4544184E-02
 12        11           0.1600 -0.2756345E-01 -0.2850467E-01 -0.4630365E-01 -0.7146899E-01 -0.6520363E-01  0.1350301E-01
 13        12           0.1760  0.3891129E-01  0.4415184E-01  0.2591697E-01 -0.1340199E-01 -0.5242409E-02  0.8341260E-01
 14        13           0.1920  0.2147468E+00  0.2197260E+00  0.2062652E+00  0.1506829E+00  0.1653118E+00  0.2597901E+00
 15        14           0.2080  0.4681795E+00  0.4648618E+00  0.4612210E+00  0.3906569E+00  0.4158294E+00  0.5116217E+00
 16        15           0.2240  0.7006696E+00  0.6903515E+00  0.7000675E+00  0.6297039E+00  0.6625425E+00  0.7402074E+00
 17        16           0.2400  0.8677690E+00  0.8466564E+00  0.8776230E+00  0.8165579E+00  0.8551915E+00  0.8929079E+00
 18        17           0.2560  0.9461321E+00  0.9166424E+00  0.9621816E+00  0.9201996E+00  0.9672987E+00  0.9525769E+00
 19        18           0.2720  0.7992548E+00  0.7551323E+00  0.8049649E+00  0.8111597E+00  0.8561526E+00  0.7765470E+00
 20        19           0.2880  0.5417326E+00  0.4852985E+00  0.5423326E+00  0.5998430E+00  0.6403743E+00  0.4843208E+00
 21        20           0.3040  0.4659206E+00  0.4213558E+00  0.4925604E+00  0.5820567E+00  0.6198716E+00  0.3836835E+00
 22        21           0.3200  0.4229394E+00  0.3819969E+00  0.4677614E+00  0.5888388E+00  0.6057218E+00  0.3058384E+00
 23        22           0.3360  0.7009304E-02 -0.3643999E-01  0.4173096E-01  0.2025956E+00  0.1996857E+00 -0.1503141E+00
 24        23           0.3520 -0.6074927E+00 -0.6383445E+00 -0.5899900E+00 -0.3878586E+00 -0.4092204E+00 -0.7946633E+00
 25        24           0.3680 -0.1100389E+01 -0.1132873E+01 -0.1109132E+01 -0.8804224E+00 -0.9233926E+00 -0.1309035E+01
 26        25           0.3840 -0.1599649E+01 -0.1619796E+01 -0.1622063E+01 -0.1401182E+01 -0.1468702E+01 -0.1821403E+01
 27        26           0.4000 -0.1783578E+01 -0.1757640E+01 -0.1800498E+01 -0.1625903E+01 -0.1722452E+01 -0.2001098E+01
 28        27           0.4160 -0.1781523E+01 -0.1734324E+01 -0.1798014E+01 -0.1682066E+01 -0.1779111E+01 -0.1962144E+01
 29        28           0.4320 -0.2147067E+01 -0.2089513E+01 -0.2173675E+01 -0.2092460E+01 -0.2183438E+01 -0.2260478E+01
 30        29           0.4480 -0.2049970E+01 -0.1964119E+01 -0.2073261E+01 -0.2038199E+01 -0.2139653E+01 -0.2075512E+01
```

Plain Text Tab Width: 8 Ln 1, Col 28 INS

Example 1-3: execution

Open ▾ seewavc.prm ~/CCA2017/CCA2019/cca_wkf/prm

```
1  6                          :nch
2  0 0.1    1.0 1.5 3         :nfilter,fl,fh,fs,nchara(=
3   25                        :dtl(sec/cm),25,50==>10,20
4
```

multiplexed_files

multiplexed_files

F2LNN001.dat　HDLNN001.dat　mltfile.lst

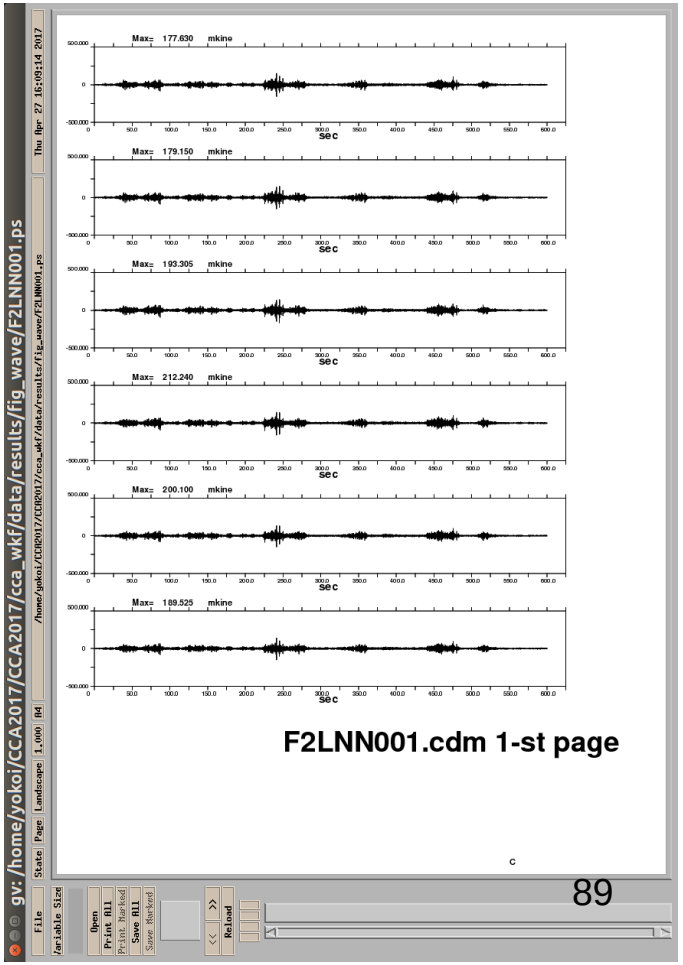
```
yokoi@ubuntu:~/CCA2017/CCA2019$ sh seewavc.sh
F2LNN001.dat
HDLNN001.dat
  2 measurement
./cca_wkf/data/results/fig_wave/F2LNN001.ps
F2LNN001.dat 1-st page
F2LNN001.dat 2-nd page
F2LNN001.dat 3-rd page
./cca_wkf/data/results/fig_wave/HDLNN001.ps
HDLNN001.dat 1-st page
```

mltfile.lst is newly created.

fig_wave

results fig_wave

F2LNN001.ps　HDLNN001.ps



Waveforms are plotted in PostScript files.
Log file is stored in "./cca_wkf/log/seewavc.log

seeblkc.sh

```
#! /bin/sh -x
cd ./cca_wkf/data/resampled_files
ls *.dat > rsmfile.lst
cd ../../..
./bin/seeblkc.exe | tee cca_wkf/log/seeblkc.log
```

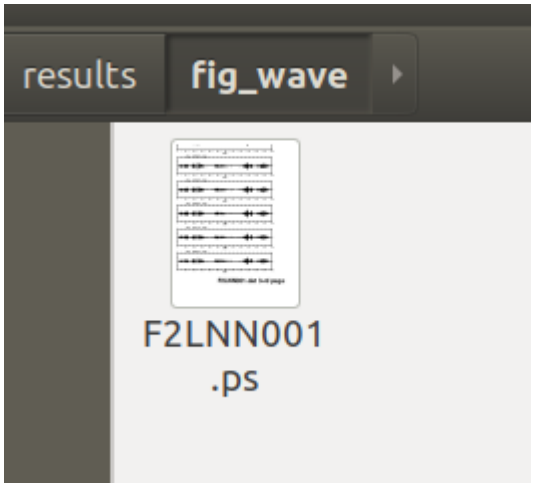
Parameter file:
./cca_wkf/prm/seeblkc.prm

```
 0 0.1 1.0 1.5 3    :nfilter,fl,fh,fs,nchara(=2:lowpass, =3:bandpass)
```

Example 1-4: Execution

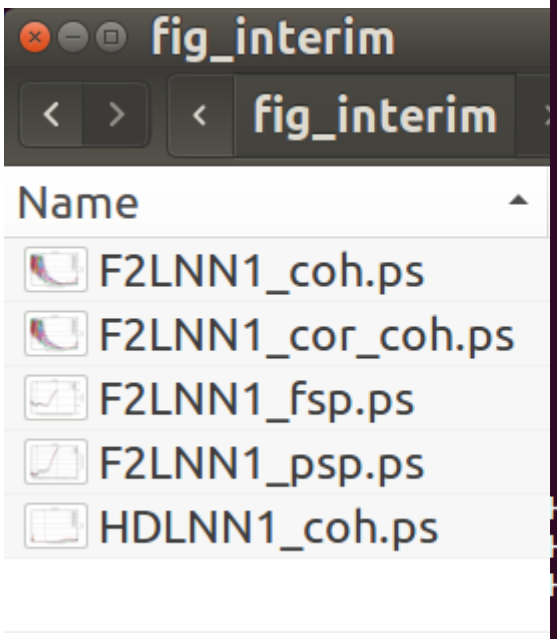
```
yokoi@ubuntu:~/CCA2017/CCA2019$ sh seeblkc.sh
 ./cca_wkf/data/resampled_files/rsmfile.lst
 ./cca_wkf/prm/seeblkc.prm
 ./cca_wkf/data/resampled_files/F2LNN1.dat
 6  120 1024 0    0.00    2.00 (i8,f16.4, 6e15.7) mkine
./cca_wkf/data/results/fig_wave/F2LNN1.ps
```

Multi-page postscript files are created in ./cca_wkf/data/results/fig_wave
Log file is stored in ./cca_wkf/log/seeblkc.log



Example of execution
(Example 1-5)

All output figures displayed in X-windows are stored in PostScript format in the subfolder ./cca_wkf/data/results/fig_interim

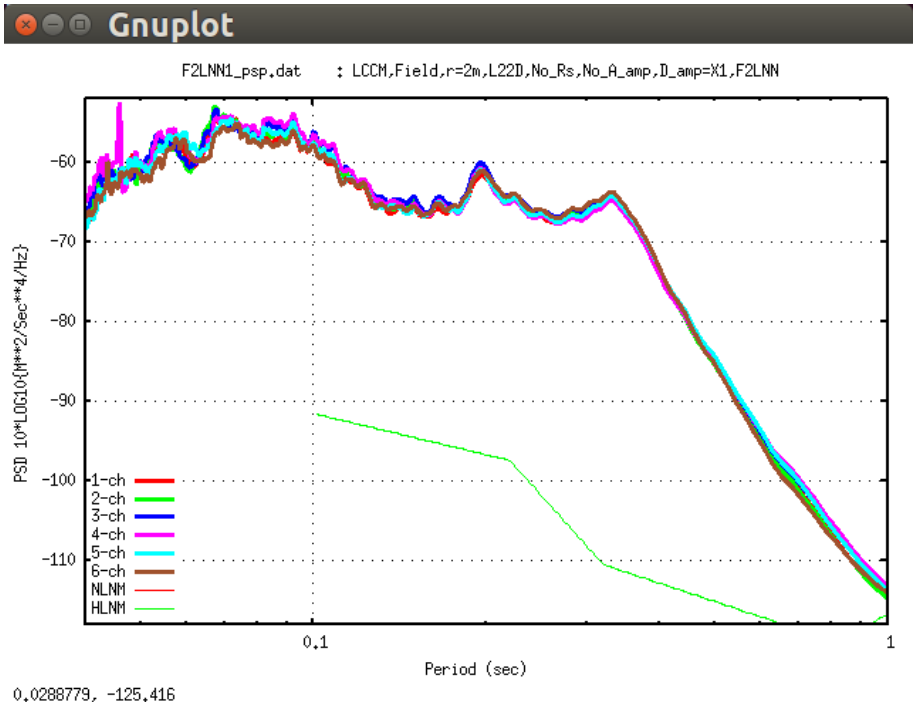



```
yokoi@ubuntu:~/CCA2017/CCA2019$ sh spectra_all.sh
 ./cca_wkf/prm/gnuplt_script/power.plt
 ./cca_wkf/prm/gnuplt_script/F2LNN1_psp.plt
 F2LNN1_psp.ps

 ./cca_wkf/prm/gnuplt_script/F2LNN1_fsp.plt
   16.3840008
 F2LNN1_fsp.ps

 ./cca_wkf/prm/gnuplt_script/F2LNN1_coh.plt
 1 ./cca_wkf/data/results/F2LNN1_coh.dat
 ./cca_wkf/data/results/fig_interim/F2LNN1_coh.ps
 2./cca_wkf/data/results/HDLNN1_coh.dat
 ./cca_wkf/data/results/fig_interim/HDLNN1_coh.ps
 3./cca_wkf/data/results/F2LNN1_cor_coh.dat
 ./cca_wkf/data/results/fig_interim/F2LNN1_cor_coh.ps
Hit return to continue
Hit return to continue
Hit return to continue

yokoi@ubuntu:~/CCA2017/CCA2019$
```

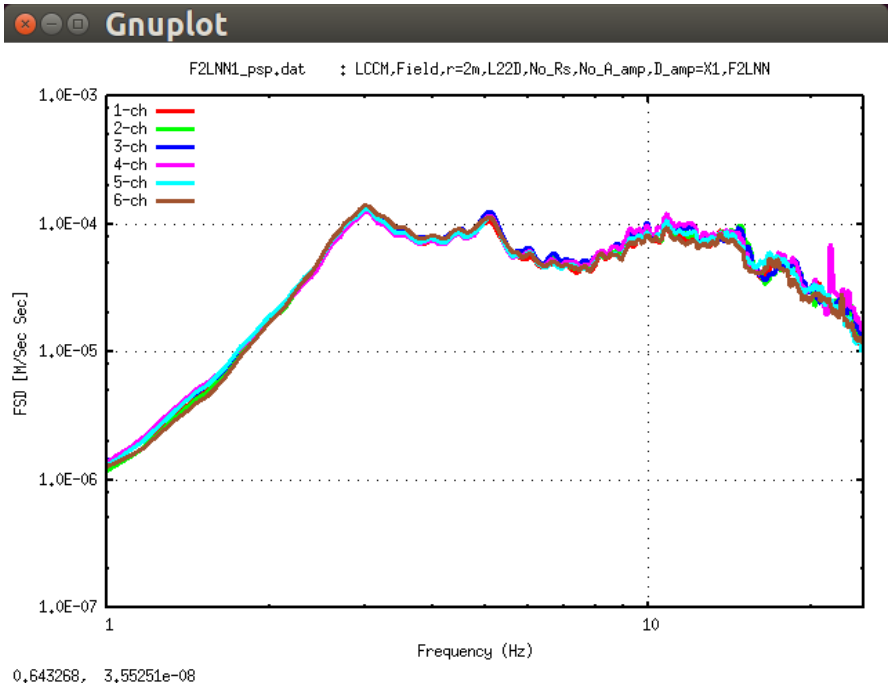
Power & Fourier Spectra

(Example 1-6)

(Velocity) Power Spectra



(Velocity) Fourier Spectra



Power spectra corrected using huddle test records are in “cca_coef.dat” and its example is shown few slide later.

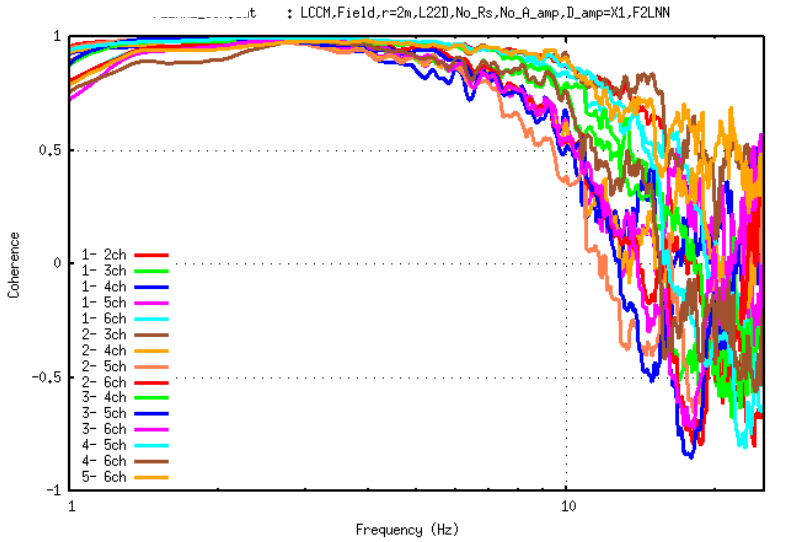
In the shown example, seismometers of which natural frequency is 2Hz are used, then the power & Fourier spectra decays in the frequency range lower than that frequency.

These figures are stored in ./cca_wkf/data/results/fig_results in PostScript format.

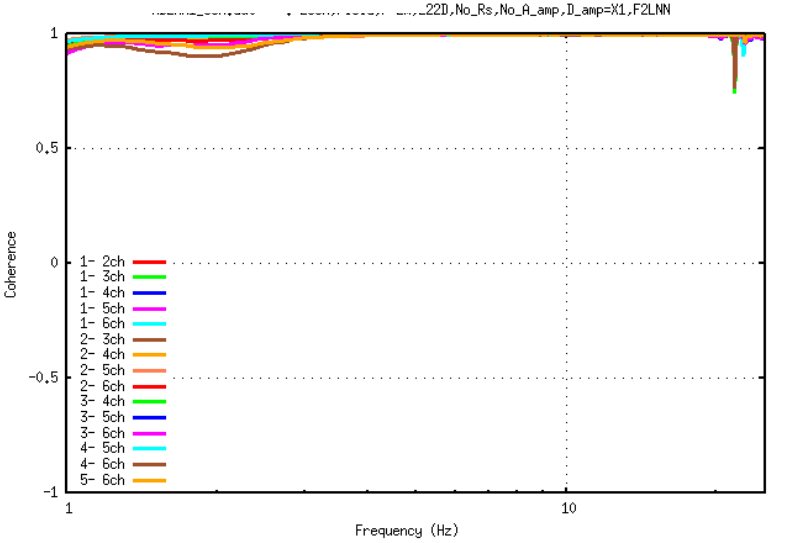
Coherence

(Example 1-7)

Field Data

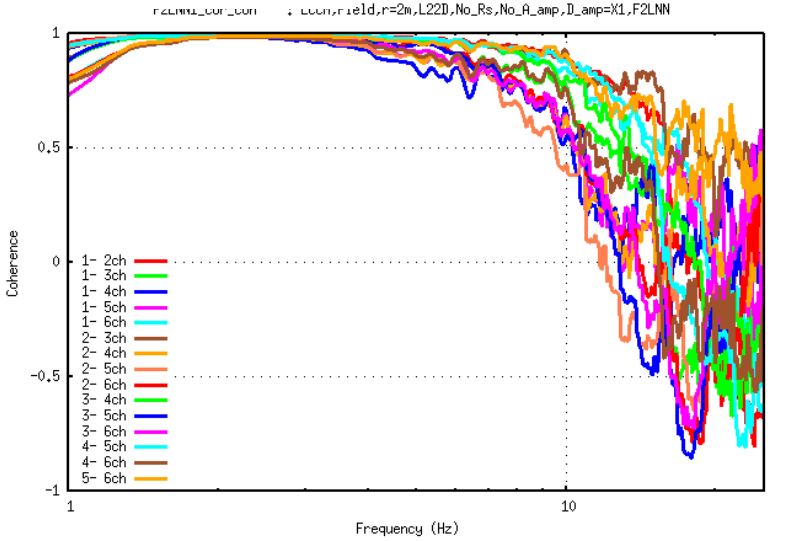


Huddle Test Data



14.5963, 1.13661

Corrected Data



5.35681, 1.19574

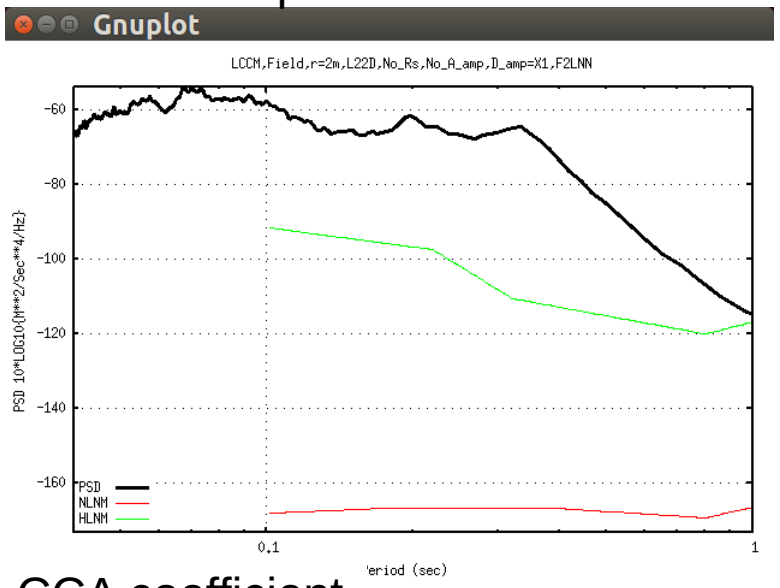
These figures are stored in ./cca_wkf/data/results/fig_results in PostScript format.

(Example 1-5)

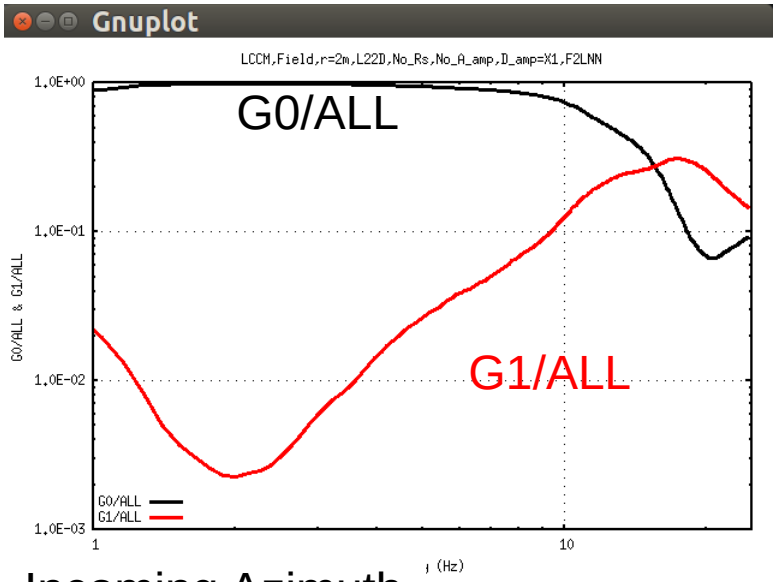
```
yokoi@ubuntu:~/CCA2017/CCA2019$ sh results.sh
 ./cca_wkf/data/results/cca_coef.dat
 ./cca_wkf/prm/gnuplt_script/resultS.plt
 ./cca_wkf/data/results/fig_results/
 results_psp.ps
 ./cca_wkf/data/results/temp1.dat
 results_G0_G1.ps
 results_cca.ps
 results_azi.ps
Hit return to continue
Hit return to continue
Hit return to continue

 ./cca_wkf/prm/gnuplt_script/q_control.plt
 ./cca_wkf/prm/gnuplt_script/q_controL.plt
 ./cca_wkf/data/results/fig_results/g0_all.ps
 ./cca_wkf/data/results/fig_results/g1_all.ps
 ./cca_wkf/data/results/fig_results/q_control.ps
Hit return to continue
Hit return to continue
Hit return to continue

 ./cca_wkf/prm/gnuplt_script/vel_model.plt

yokoi@ubuntu:~/CCA2017/CCA2019$
```

cca_coef.dat

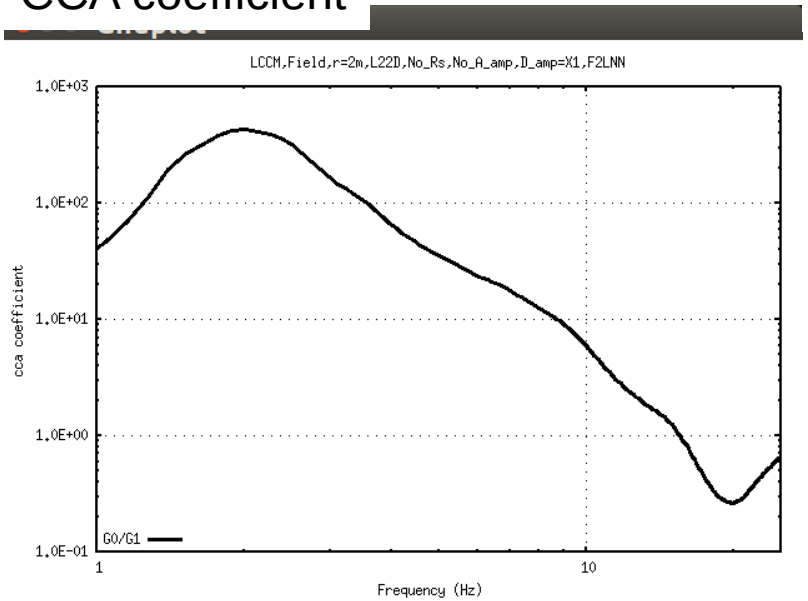
Power Spectra of ch1



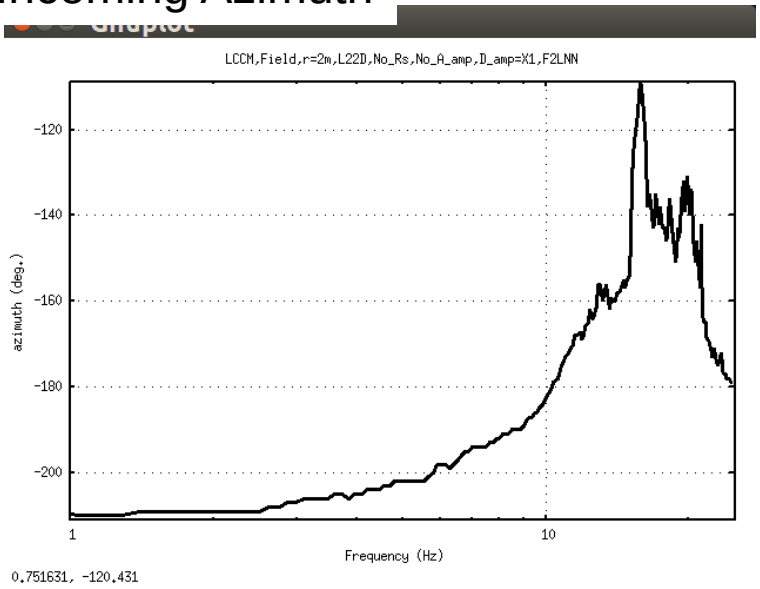
G0/ALL & G1/ALL



CCA coefficient



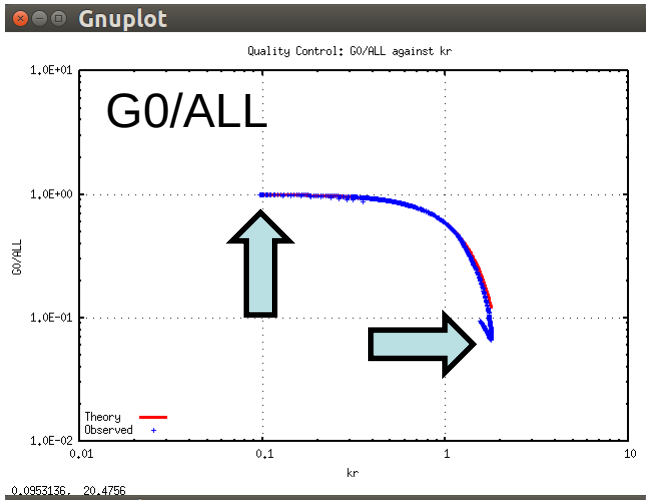
Incoming Azimuth

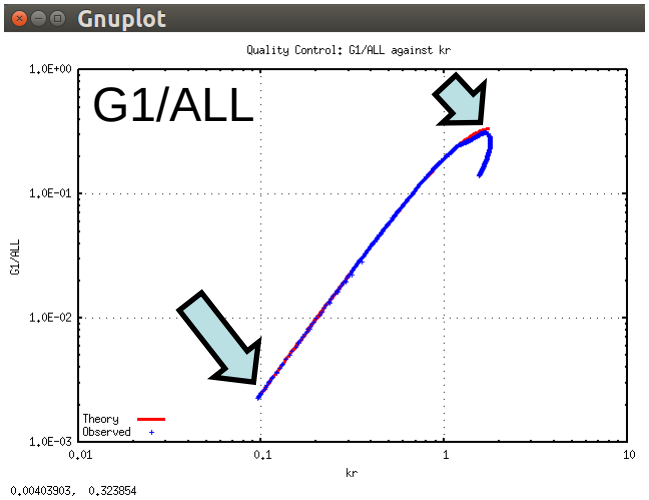


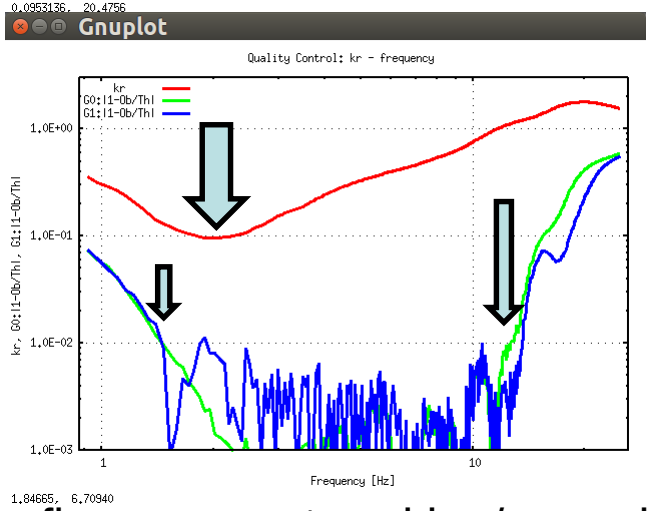
These figures are stored in ./cca_wkf/data/results/fig_results in PostScript format.

Quality Control

Using the values of “kr” in the file “dispersion.dat”, Z0/ALL and Z1/ALL in the file “cca_coef.dat” are compared with the theoretical $J_0(kr)^2$ and $J_1(kr)^2$, respectively. Arrows indicate the limit of the range of “kr” for analysis, where the observed curves run off from the theoretical ones.







(Example 1-5)

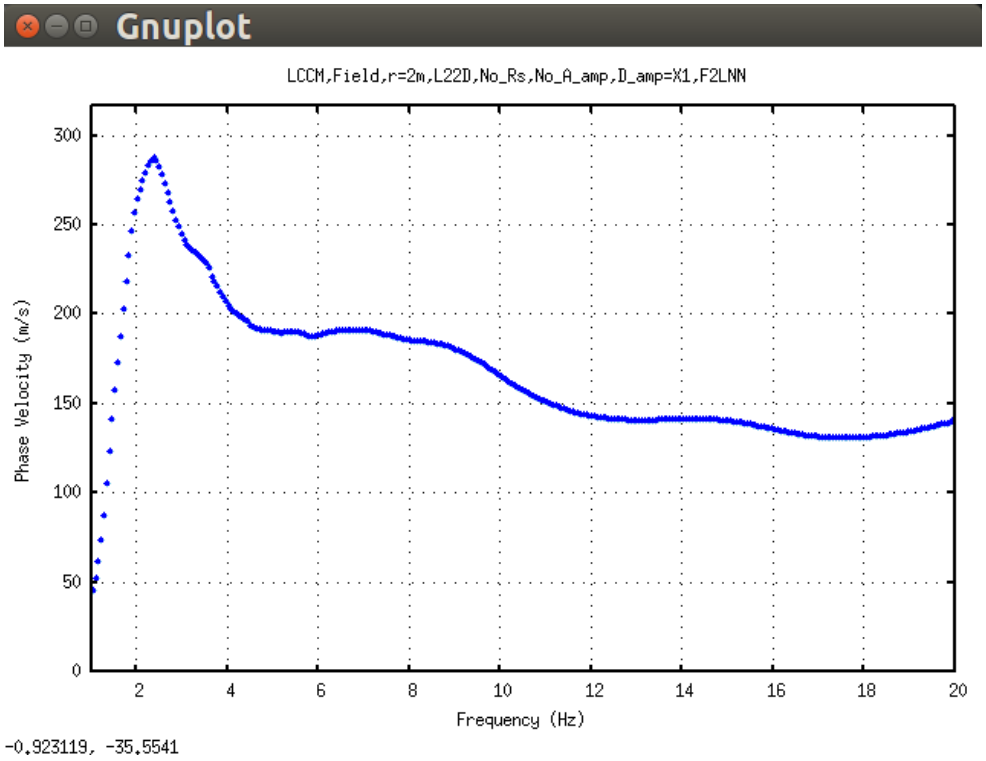
These figures are stored in ./cca_wkf/data/results/fig_results in PostScript format.

dispersion.dat

(Example 1-5)

Frequency	Velocity	Azimuth	KR
0.916	32.348	-208.786	0.356
0.977	39.342	-210.076	0.312
1.038	44.918	-210.351	0.290
1.099	52.573	-210.471	0.263
1.160	61.721	-210.378	0.236

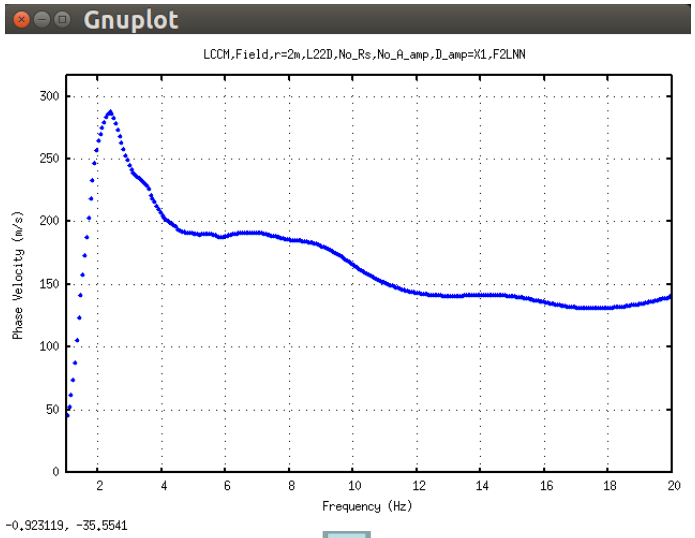
…



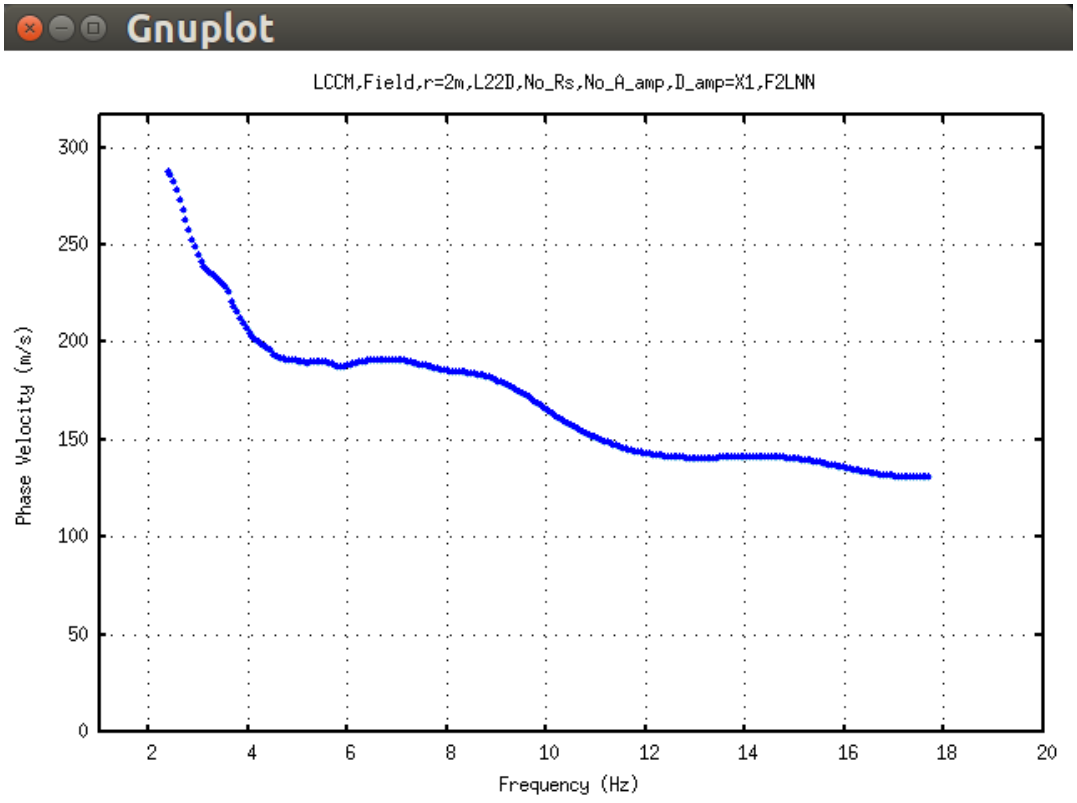
This figure is stored in ./cca_wkf/data/results/fig_results in PostScript format.

Edit “dispersion.dat” using “gedit” or other text editor

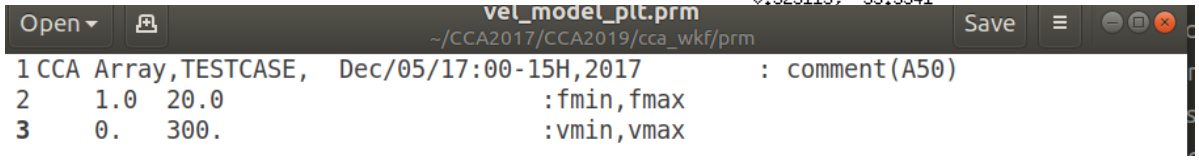
(Example 1-6)



Then, redraw it using:
sh ./vel_model_plt.sh



Vel_model_plt.prm



Execution (Example 1-6).

```
yokoi@ubuntu: ~/CCA2017/CCA2019
yokoi@ubuntu:~/SPAC2016/SPAC2019$ sh inversion.sh
rm: cannot remove './spacwkf/data/results/temp*.dat': No such file or directory
 +--------------------------------------------------+
 +                                                  +
 +                    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.+
 +--------------------------------------------------+
 ./spacwkf/data/results/progress.dat
```

Initial values randomly selected within the search range.

```
                                  Range of random fluctuation
Thicknes Density      Vp      Vs   Thickness          Vs
   0.011   1.755   1.399   0.099   0.001   0.020   0.090   0.200
   0.017   1.759   1.411   0.109   0.001   0.020   0.050   0.200
   0.015   1.800   1.539   0.224   0.001   0.020   0.100   0.250
   0.008   1.806   1.557   0.241   0.001   0.020   0.150   0.250
 999.000   1.814   1.584   0.265 998.000 999.000   0.150   0.500
 ./cca_wkf/data/results/dispersion.dat
    5    0.0016076231
   10    0.0015863872
   15    0.0015863872
   20    0.0013621505
   25    0.0013621505
```

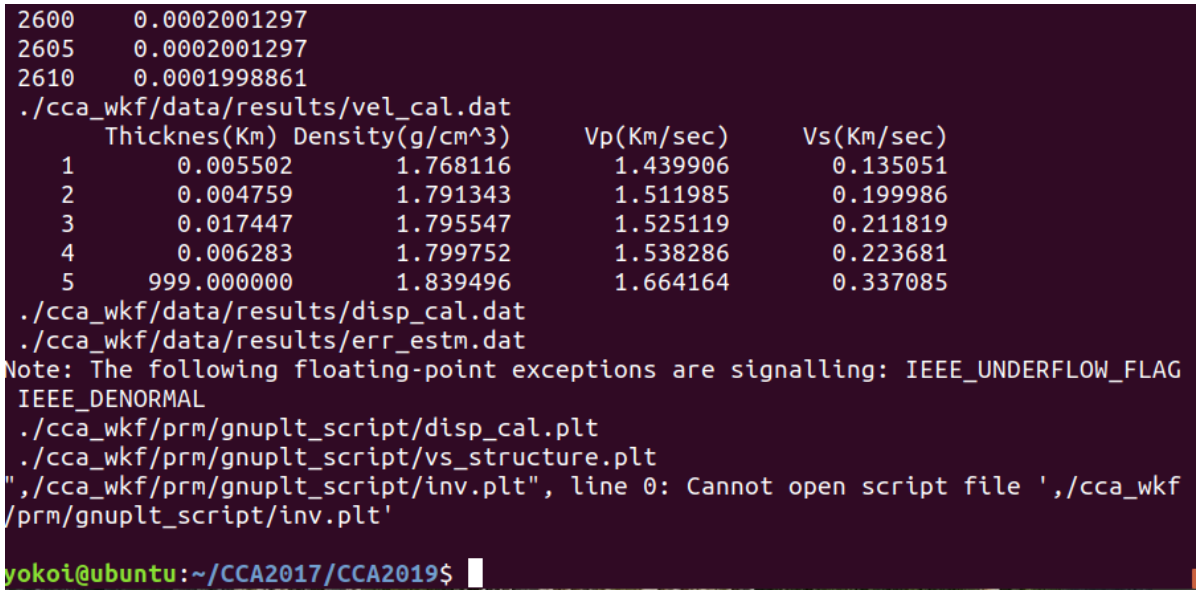
Iteration Starts

Execution (Example 1-6 cont).

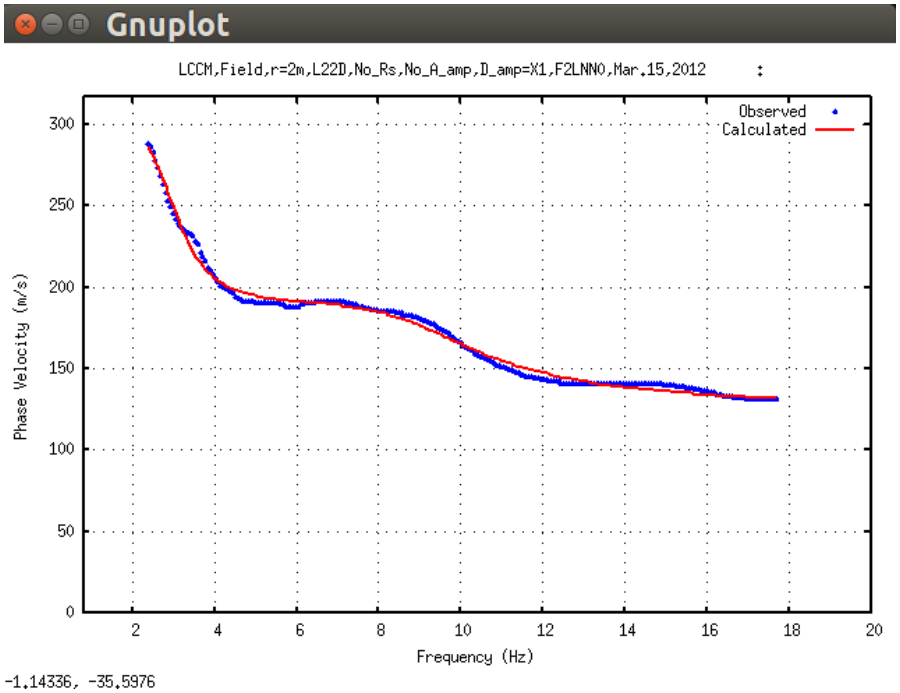
Conversion of misfit to the threshold eps0

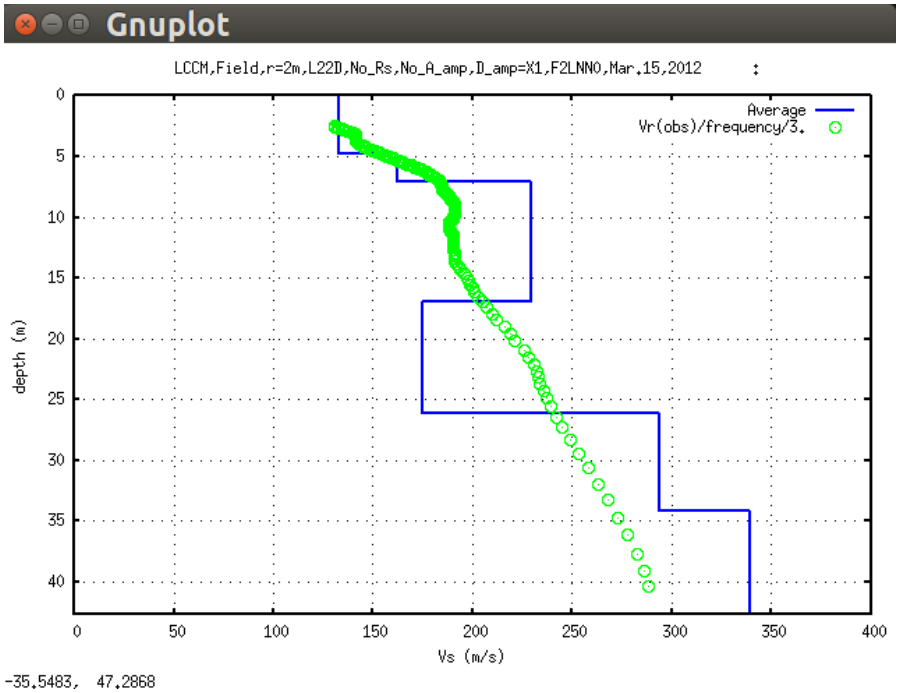
Optimum Underground velocity structure

Plotting



Plotting (Example 1-6 cont).





The same figures are stored in Post Script files:

./cca_wkf/data/results/fig_results/disp_cal.ps

./cca_wkf/data/results/fig_results/vs_structure.ps

Green points can be eliminated by setting n_mod=0 in pwrcrs3.prm.

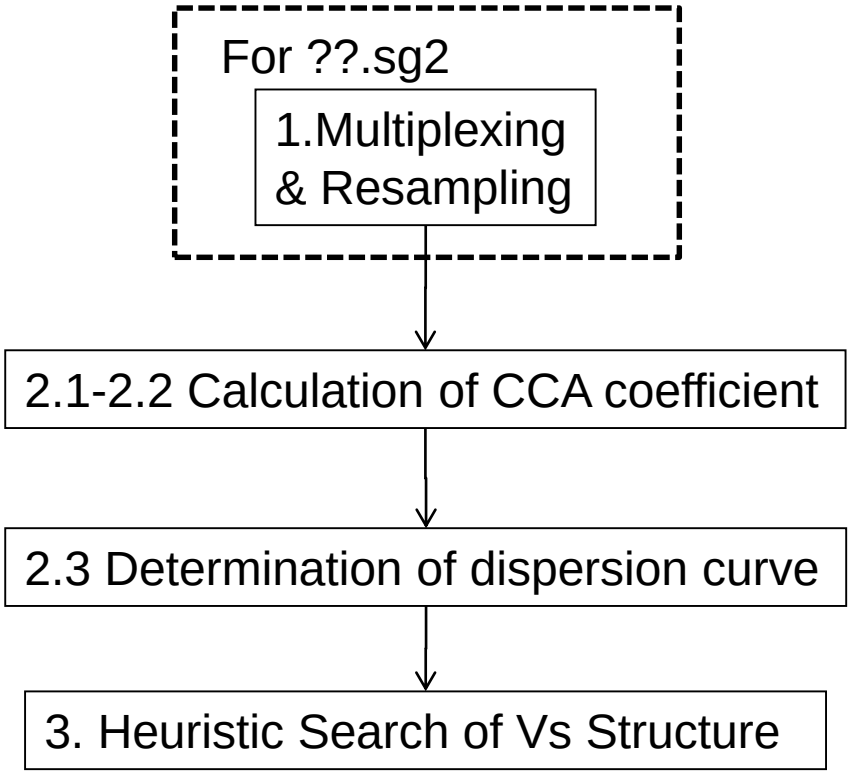
Example2

(Sensor at Center without Instrumental Correction)

Example with two data sets:

7 points circular array, one of which is at the center

Both are the seg2 standard format file.



The array used in the field has 7 sensors and 7-th sensor (CH-7) at the center. Other 6 sensors were installed clockwise order. Then,
pvlist 7 6 5 4 3 2 1 :

seg2read.sh: Execution

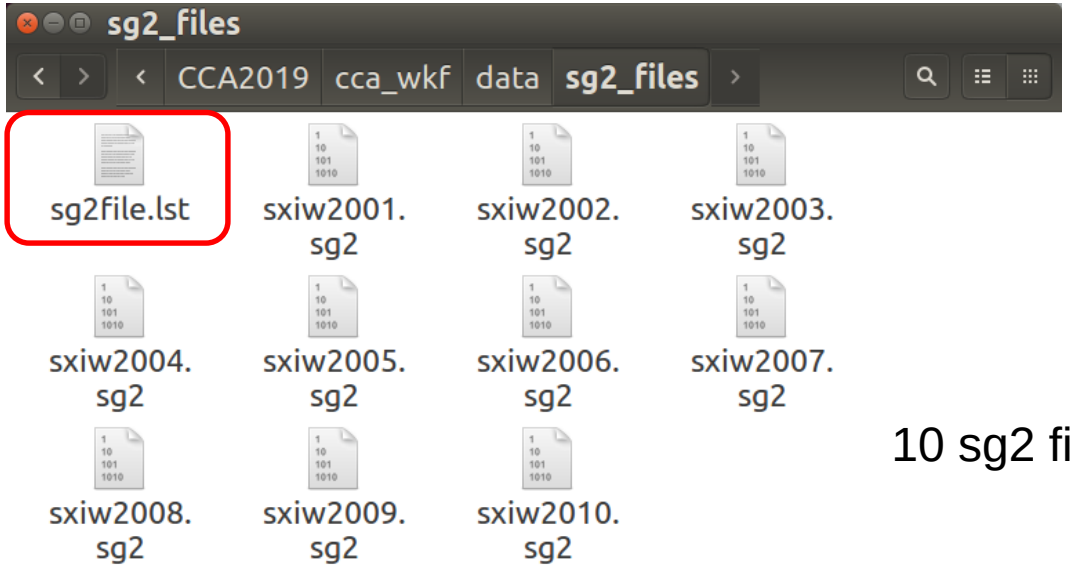
This title is used for every figures

seg2read.prm

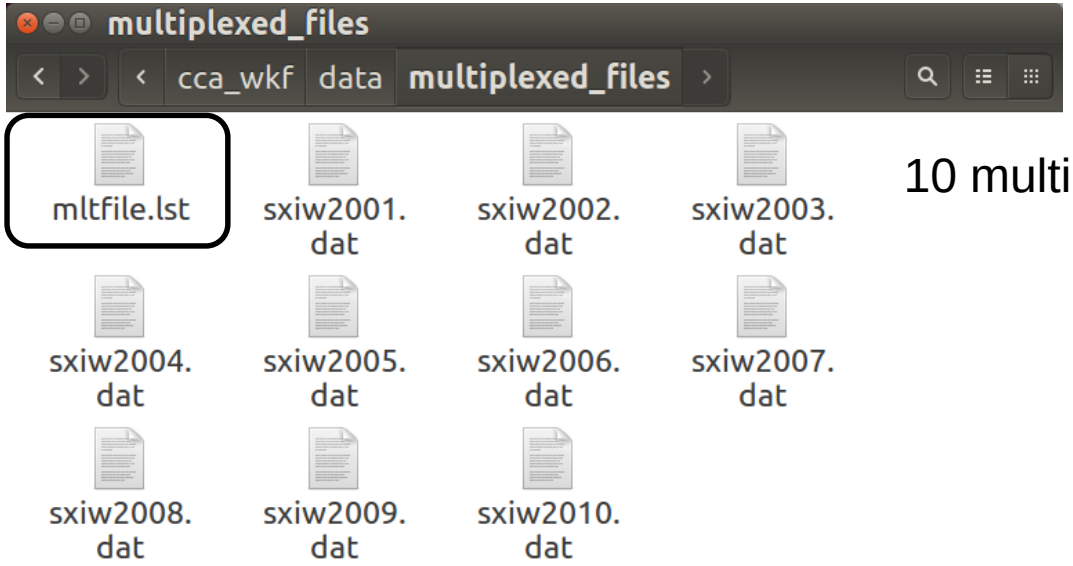
```
Yoshima Elementary School, L22, Feb. 15 2016                    :comm(a70)
5.E-3     : scaling factor (for output files in mkine(1.e-3cm/s))
sg2       : extension of input seg2 format files(a3)
cdm       : extension of output ascii text files(a3)
0 3 0.1 1.0 1.5  :nfilter(=1:apply),nchara=3:bandpass),fl,fh,fs
pvlist 7 6 5 4 3 2 1 :Channel Pivoting
```

```
yokoi@ubuntu: ~/CCA2017/CCA2019
yokoi@ubuntu:~/CCA2017/CCA2019$ sh seg2read.sh
./cca_wkf/prm/seg2read.prm
   4.99999989E-03 mkine
./cca_wkf/data/sg2_files/sg2file.lst

./cca_wkf/data/sg2_files/sxiw2001.sg2
./cca_wkf/data/multiplexed_files/sxiw2001.dat
nch=  7 dt= 0.002 nn=   16384

./cca_wkf/data/sg2_files/sxiw2002.sg2
./cca_wkf/data/multiplexed_files/sxiw2002.dat
nch=  7 dt= 0.002 nn=   16384

./cca_wkf/data/sg2_files/sxiw2003.sg2
./cca_wkf/data/multiplexed_files/sxiw2003.dat
nch=  7 dt= 0.002 nn=   16384

./cca_wkf/data/sg2_files/sxiw2004.sg2
./cca_wkf/data/multiplexed_files/sxiw2004.dat
```

```
9

.sg2
/sxiw2007.dat

.sg2
/sxiw2008.dat

.sg2
./cca_wkf/data/multiplexed_files/sxiw2009.dat
nch=  7 dt= 0.002 nn=   16384

./cca_wkf/data/sg2_files/sxiw2010.sg2
./cca_wkf/data/multiplexed_files/sxiw2010.dat
nch=  7 dt= 0.002 nn=   16384
    10 files have been converted.
Normal End.
yokoi@ubuntu:~/CCA2017/CCA2019$
```

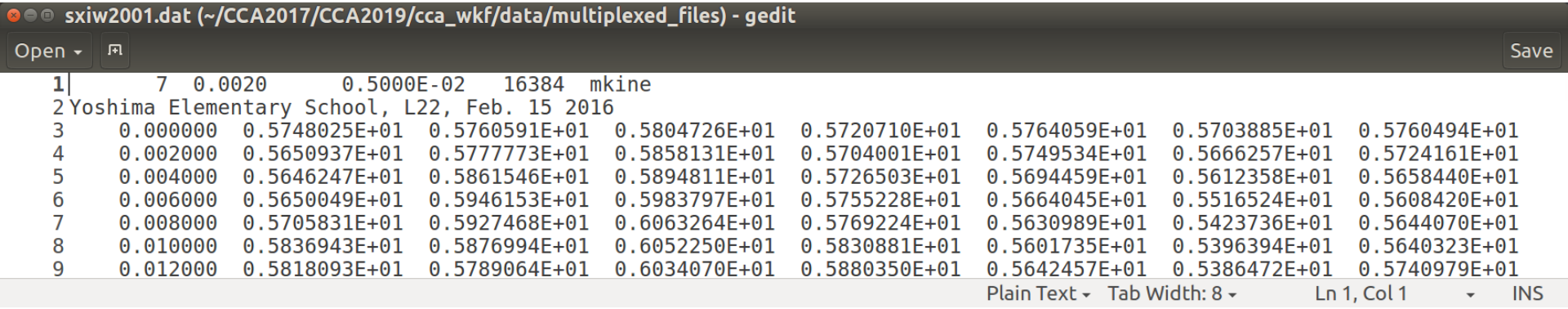


10 sg2 files



10 multiplexed files

cdm files in ./cca_wkf/data/multiplexed_files



7 channels
Sampling interval dt = 0.002 sec (0.5kHz)
Scaling factor = 0.005
16384 samples in each file

➔ 16.384 sec in each file

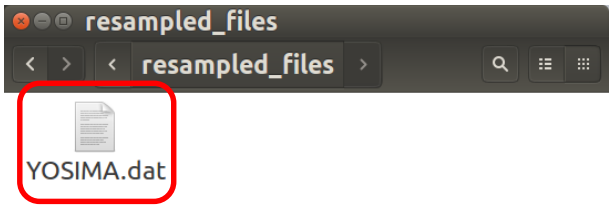
resamplec.sh: Execution

resamplec.prm:

```
 7 0.002 10   0.0  1  1.0   :nch,dt,nchannel,dt,nskip,ph0,ncenter,radius
9.0 4.0                     :ajudge,a_sgm
0.0 16.383                  :tst,tdur
YOSIMA.dat                  :output file name (A10)
 512                        :number of data in one time block after resampling
```

```
yokoi@ubuntu: ~/CCA2017/CCA2019
yokoi@ubuntu:~/CCA2017/CCA2019$ sh resamplec.sh
./cca_wkf/prm/resamplec.prm
Working Folder=./cca_wkf/prm/
Band-Pass:fl=   0.100fh=  20.250
fs=  22.500
Nch=   7
Nskip  10 f(Nyquist)=  25.000 fs=  22.500
ajudge=   9.0 a_sgm=   4.0
 tst =     0.0 tdur=    16.4
 sxiw2001.dat
 sxiw2002.dat
 sxiw2003.dat
 sxiw2004.dat
 sxiw2005.dat
 sxiw2006.dat
 sxiw2007.dat
 sxiw2008.dat
 sxiw2009.dat
 sxiw2010.dat
```

```
                                                    2  blocks

                                                ata/multiplexed_files/sxiw2008.dat
                                                    2  blocks

                                                ata/multiplexed_files/sxiw2009.dat
                                                    2  blocks
 i_mea=          10
 sxiw2010.dat
          10 -th measurement:./cca_wkf/data/multiplexed_files/sxiw2010.dat
           2  blocks remained among            2  blocks
  Data stored in the temporary file
 ./cca_wkf/data/resampled_files/YOSIMA.dat

  Second screening ({rms-average(rms)}/sigma<   4.00000000     ):
          20  blocks remained among           20  blocks
yokoi@ubuntu:~/CCA2017/CCA2019$
```



resampled file in ./cca_wkf/data/resampled_files: Yoshima.dat

```
7   20  512 1    0.00    1.00 (i8,f16.4, 7e15.7) mkine
      1          0.0000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      2          0.0200  0.1886124E-06  0.1951861E-06  0.1940966E-06  0.1863137E-06  0.1889530E-06  0.1898792E-06  0.1919477E-06
      3          0.0400  0.2108473E-03  0.2167535E-03  0.2173618E-03  0.2086327E-03  0.2086433E-03  0.2078045E-03  0.2122828E-03
      …
```

7 channels
Resampling interval dt = 0.02 sec (50Hz)
512 samples in each time block➔ 10.24 sec/block
Sensor at the center: ON
ϕ_0=0.0 rad.
Radius:=1.0 m
Unit: mkine=1.0e-3 cm/sec

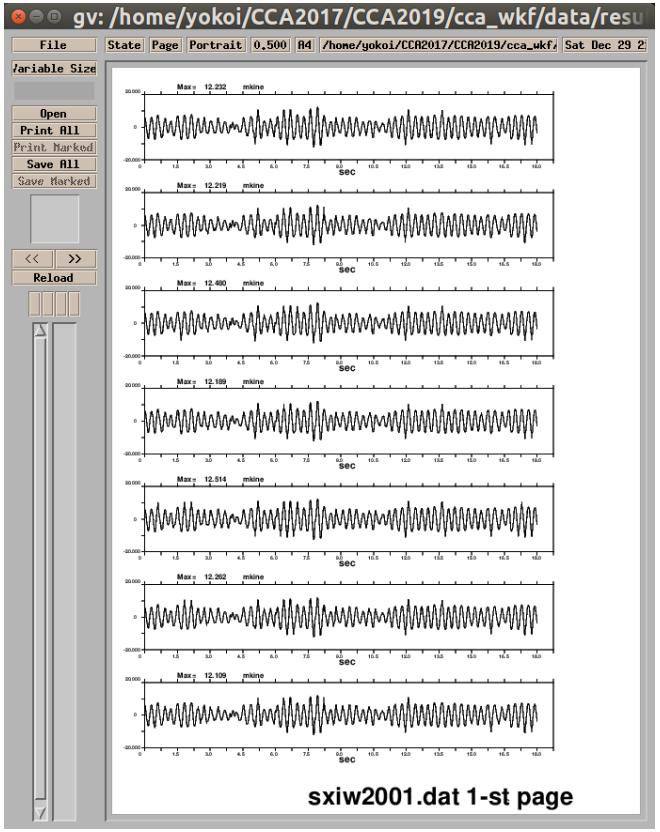
seewavc.sh: Execution

seewavc.prm:

```
7                          :nch
0 0.1    1.0 1.5 3         :nfilter,fl,fh,fs,nchara(=2:lowpass, =3:bandpass)
 0.75                      :dtl(sec/cm),25,50==>10,20 min/page
```

```
yokoi@ubuntu: ~/CCA2017/CCA2019
yokoi@ubuntu:~/CCA2017/CCA2019$ sh seewavc.sh
sxiw2001.dat
sxiw2002.dat
sxiw2003.dat
sxiw2004.dat
sxiw2005.dat
sxiw2006.dat
sxiw2007.dat
sxiw2008.dat
sxiw2009.dat
sxiw2010.dat
```

```
yokoi@ubuntu: ~/CCA2017/CCA2019
sxiw2006.dat 1-st page
sxiw2006.dat 2-nd page
./cca_wkf/data/results/fig_wave/sxiw2007.ps

sxiw2007.dat 1-st page
sxiw2007.dat 2-nd page
./cca_wkf/data/results/fig_wave/sxiw2008.ps

sxiw2008.dat 1-st page
sxiw2008.dat 2-nd page
./cca_wkf/data/results/fig_wave/sxiw2009.ps

sxiw2009.dat 1-st page
sxiw2009.dat 2-nd page
./cca_wkf/data/results/fig_wave/sxiw2010.ps

sxiw2010.dat 1-st page
sxiw2010.dat 2-nd page
yokoi@ubuntu:~/CCA2017/CCA2019$
```

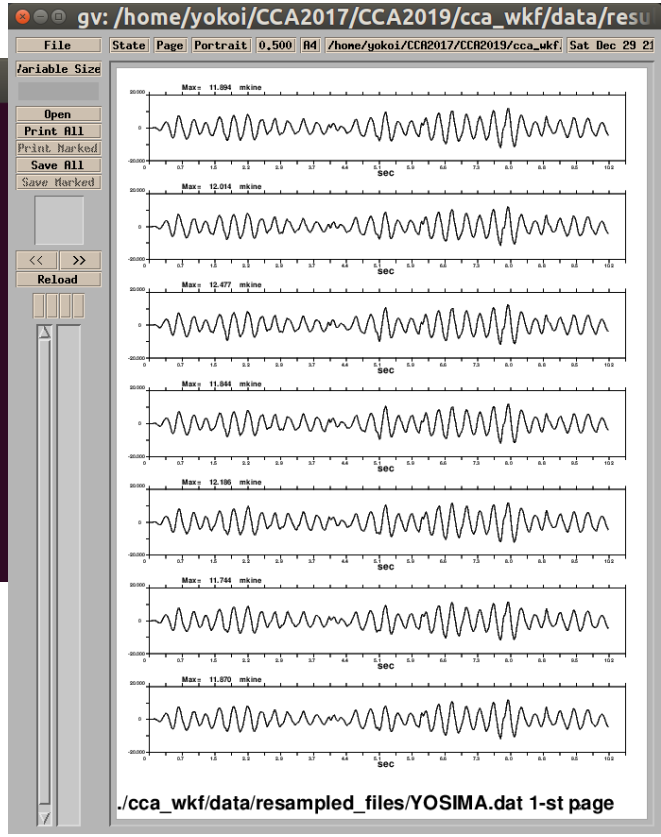


seeblkc.sh: Execution

seeblkc.prm:

```
0 0.1 1.0 1.5 3    :nfilter,fl,fh,fs,nchara(=2:lowpass, =3:bandpass)
```

```
yokoi@ubuntu: ~/CCA2017/CCA2019
yokoi@ubuntu:~/CCA2017/CCA2019$ sh seeblkc.sh
 ./cca_wkf/data/resampled_files/rsmfile.lst

 ./cca_wkf/prm/seeblkc.prm

 ./cca_wkf/data/resampled_files/YOSIMA.dat

 7   20   512 1    0.00    1.00 (i8,f16.4, 7e15.7) mkine
./cca_wkf/data/results/fig_wave/YOSIMA.ps

yokoi@ubuntu:~/CCA2017/CCA2019$
```



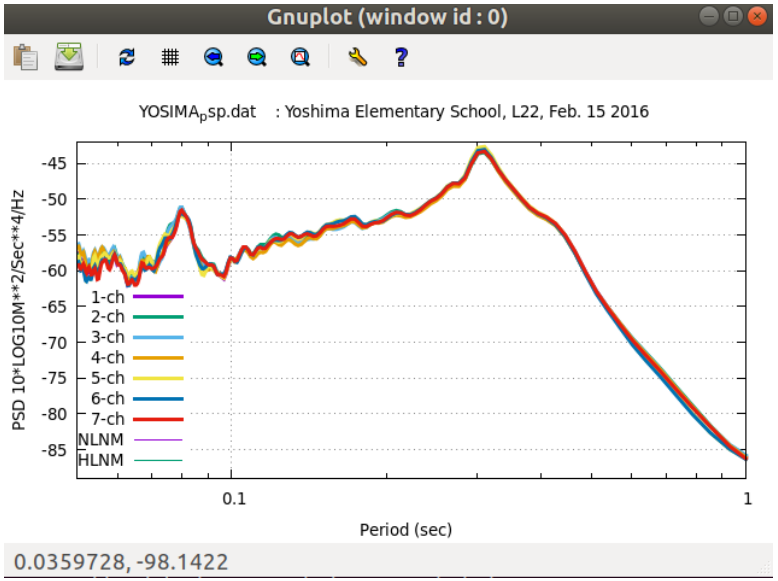
pwrcrs3.sh: Execution

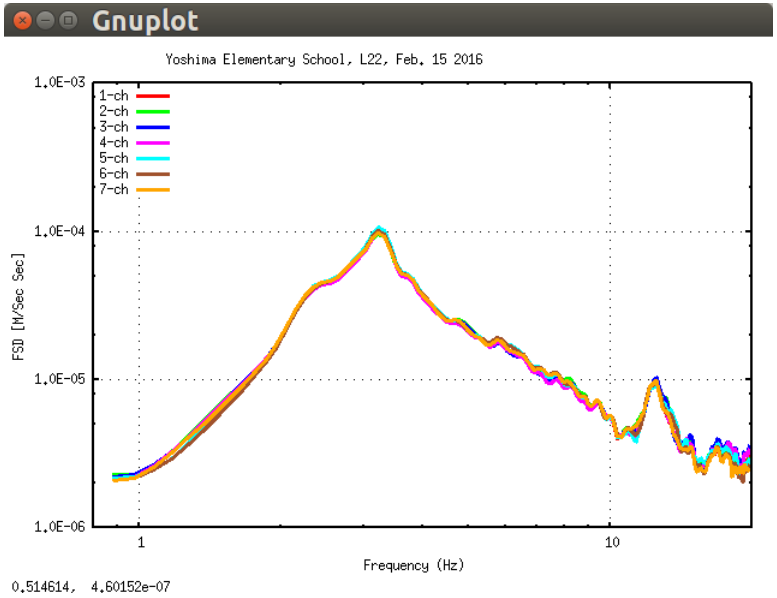
pwrcrs3.prm:

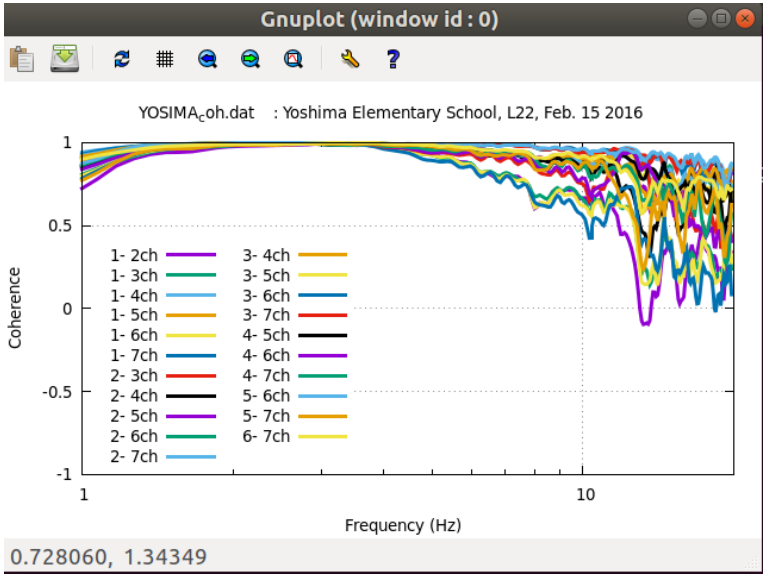
```
 1.0 20.0 0.02 0.4  0 .3 :fmin,fmax,dt,bw,n_huddle,smthf
DUMMY1.dat     1 1       :Huddle Test data File name(A12),coherence,power spectra,output flag
YOSIMA.dat     1 1       :Field data File name(A12) ,coherence, power pectra,output flag
1  0                     :n_cor_center, n_mod
```

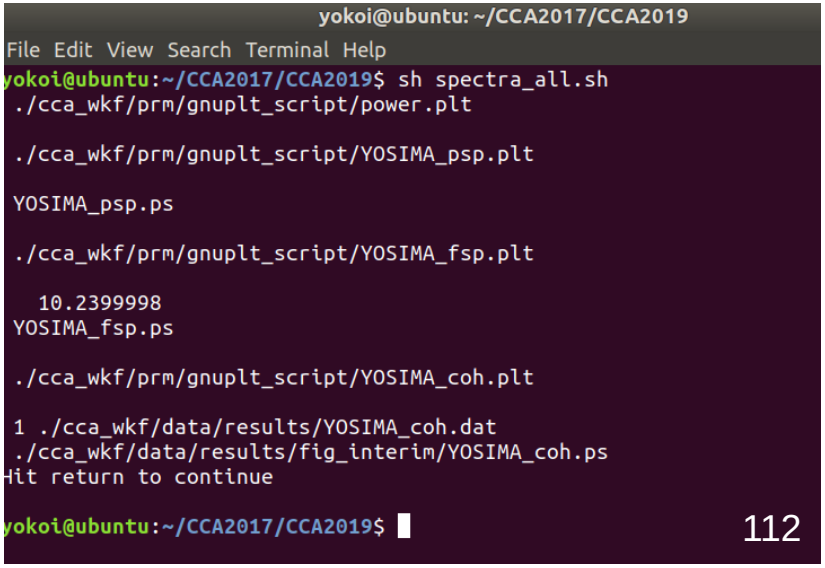
```
yokoi@ubuntu: ~/CCA2017/CCA2019
yokoi@ubuntu:~/CCA2017/CCA2019$ sh pwrcrs3.sh
 Program pwrcrs3.for
 ./cca_wkf/prm/pwrcrs3.prm

 go to 100
  Huddle Test Skipped.
 7   20  512 1    0.00    1.00 (i8,f16.4, 7e15.7) mkine
          20          10
          20          20
  power and cross spectra for field data calculated.
 Block Averaging has been done.
 ./cca_wkf/data/results/YOSIMA_psp.dat
    Power Spectra Output:./cca_wkf/data/results/YOSIMA_psp.dat

 ./cca_wkf/data/results/YOSIMA_coh.dat
     Coherence Output
  Obs. point at the center.
  Power spectra: G{Z0,Z0(r,r,omg)}
  Power spectra: G{Z1,Z1(r,r,omg)}
  cross spectra: G{Z0,Z1(r,r,omg)}
  cross spectra: G{Z0,Z0(0,r,omg)}
           1
 Correction using the seismometer at the center
 ./cca_wkf/data/results/cca_coef.dat

./cca_wkf/data/results/dispersion.dat
Note: The following floating-point exceptions are signalling: IEEE_UNDERFLOW_
FLAG IEEE_DENORMAL
yokoi@ubuntu:~/CCA2017/CCA2019$
```

spectra_all.sh: Execution



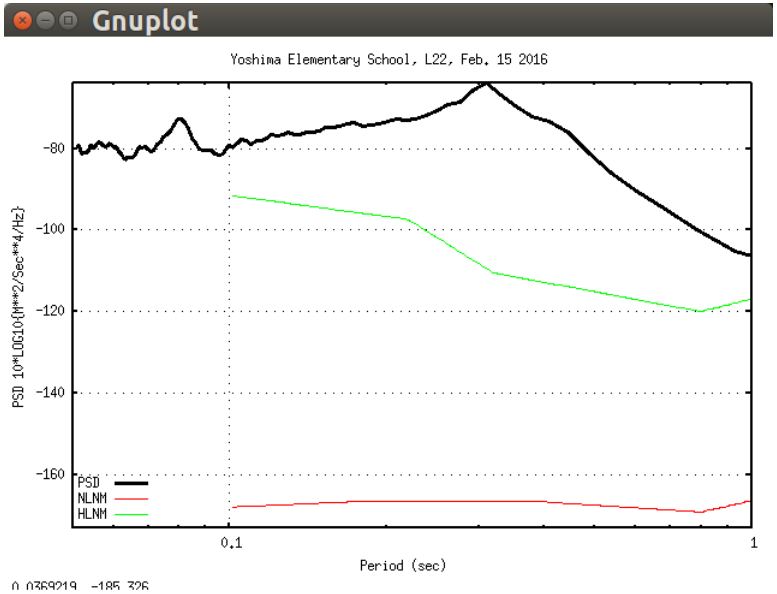


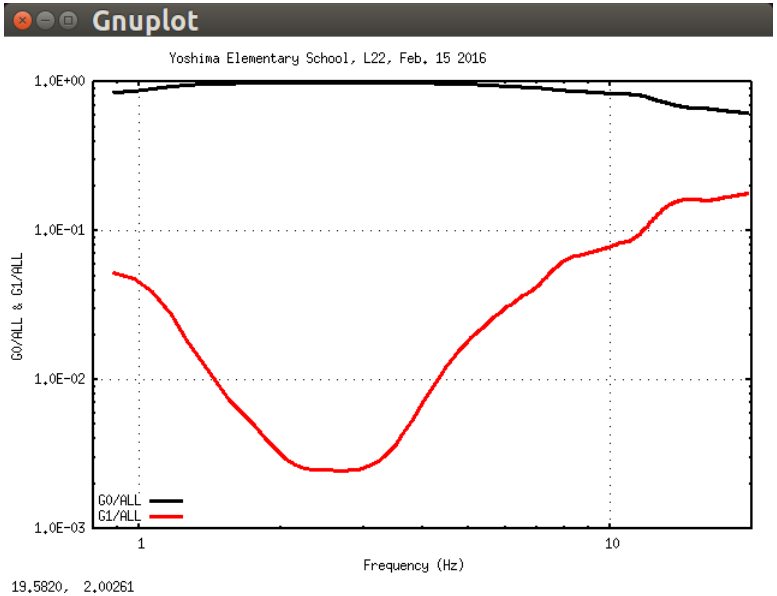


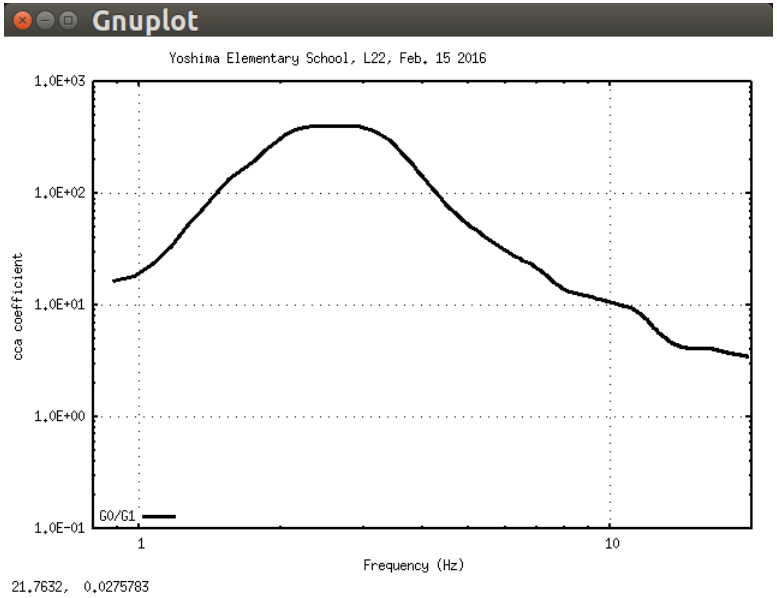


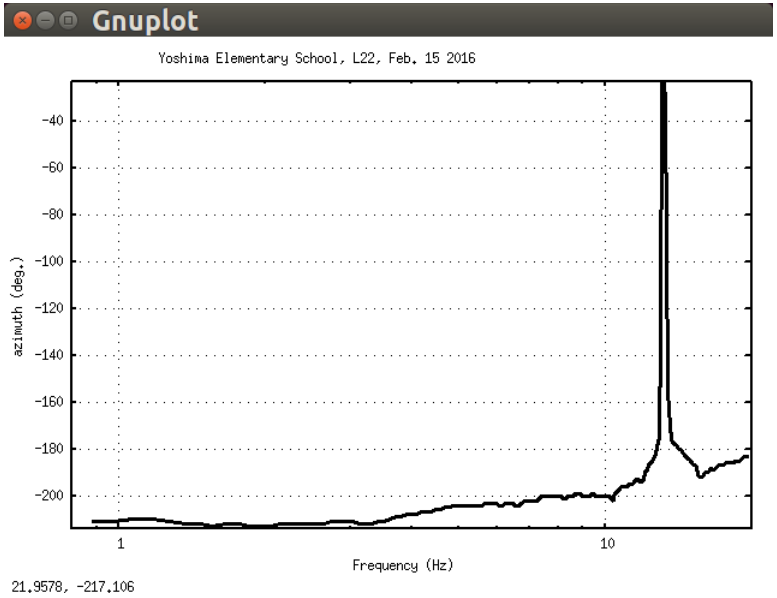
results.sh: Execution

```
yokoi@ubuntu: ~/CCA2017/CCA2019
yokoi@ubuntu:~/CCA2017/CCA2019$ sh results.sh
 ./cca_wkf/data/results/cca_coef.dat

 ./cca_wkf/prm/gnuplt_script/results.plt
 ./cca_wkf/data/results/fig_results/
 results_psp.ps
 ./cca_wkf/data/results/temp1.dat
 results_G0_G1.ps
 results_cca.ps
 results_azi.ps
Hit return to continue
Hit return to continue
Hit return to continue

 q_control.plt

 ./cca_wkf/prm/gnuplt_script/q_control.plt

 ./cca_wkf/data/results/fig_results/g0_all.ps
 ./cca_wkf/data/results/fig_results/g1_all.ps
 ./cca_wkf/data/results/fig_results/q_control.ps
Hit return to continue
Hit return to continue
Hit return to continue

 ./cca_wkf/prm/gnuplt_script/vel_model.plt


yokoi@ubuntu:~/CCA2017/CCA2019$
```

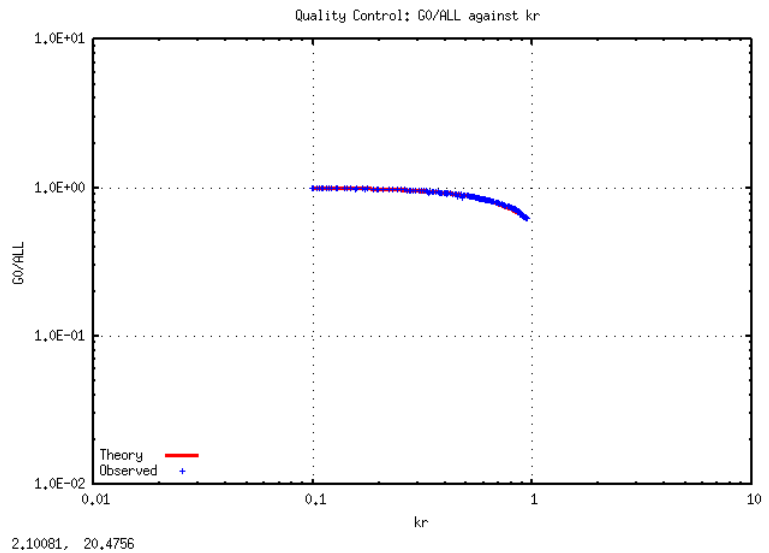

Gnuplot
Yoshima Elementary School, L22, Feb. 15 2016
PSD 10*LOG10(M**2/Sec**4/Hz)
-80
-100
-120
-140
-160
PSD
NLNM
HLNM
0.1
1
Period (sec)
0.0369219 -185.326


Gnuplot
Yoshima Elementary School, L22, Feb. 15 2016
1.0E+00
1.0E-01
1.0E-02
1.0E-03
GO/ALL & G1/ALL
GO/ALL
G1/ALL
1
10
Frequency (Hz)
19.5820, 2.00261


Gnuplot
Yoshima Elementary School, L22, Feb. 15 2016
1.0E+03
1.0E+02
1.0E+01
1.0E+00
1.0E-01
cca coefficient
GO/G1
1
10
Frequency (Hz)
21.7632, 0.0275783

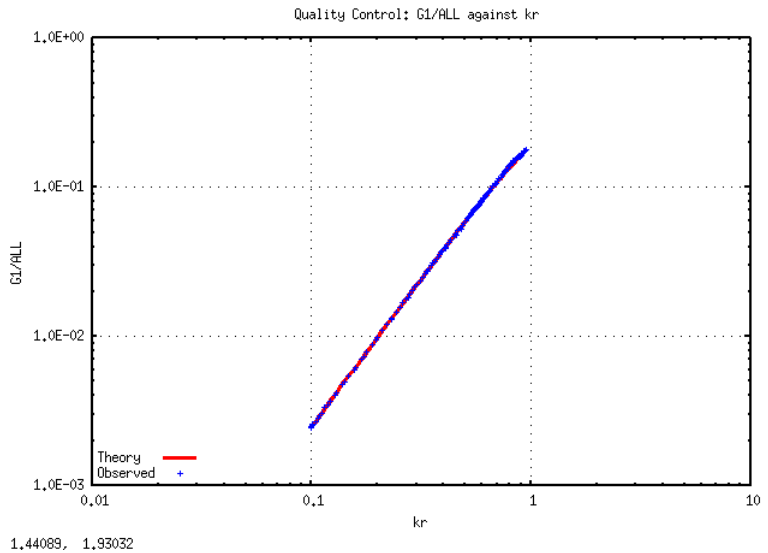

Gnuplot
Yoshima Elementary School, L22, Feb. 15 2016
-40
-60
-80
-100
-120
-140
-160
-180
-200
azimuth (deg.)
1
10
Frequency (Hz)
21.9578, -217.106

Gnuplot



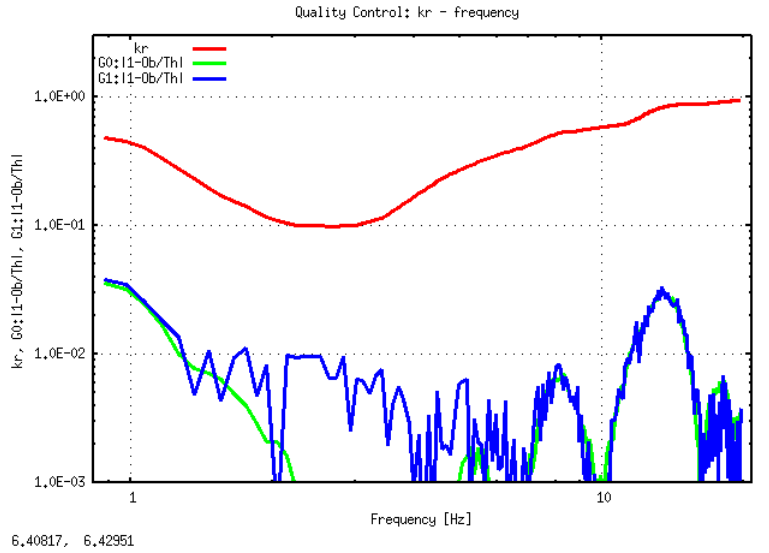
2.10081, 20.4756

Gnuplot



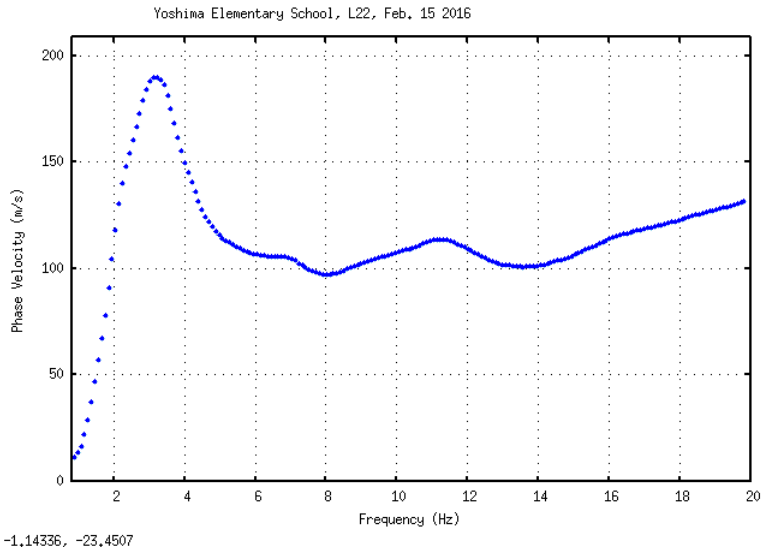
1.44089, 1.93032

Gnuplot



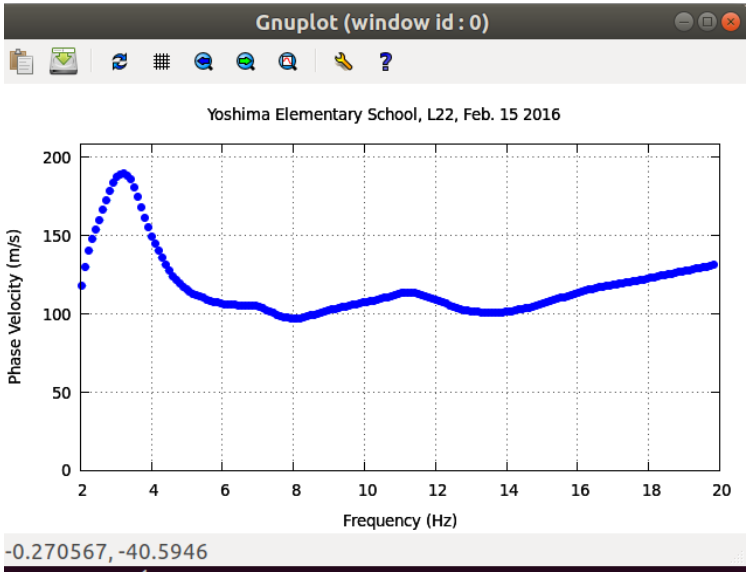
6.40817, 6.42951

Gnuplot

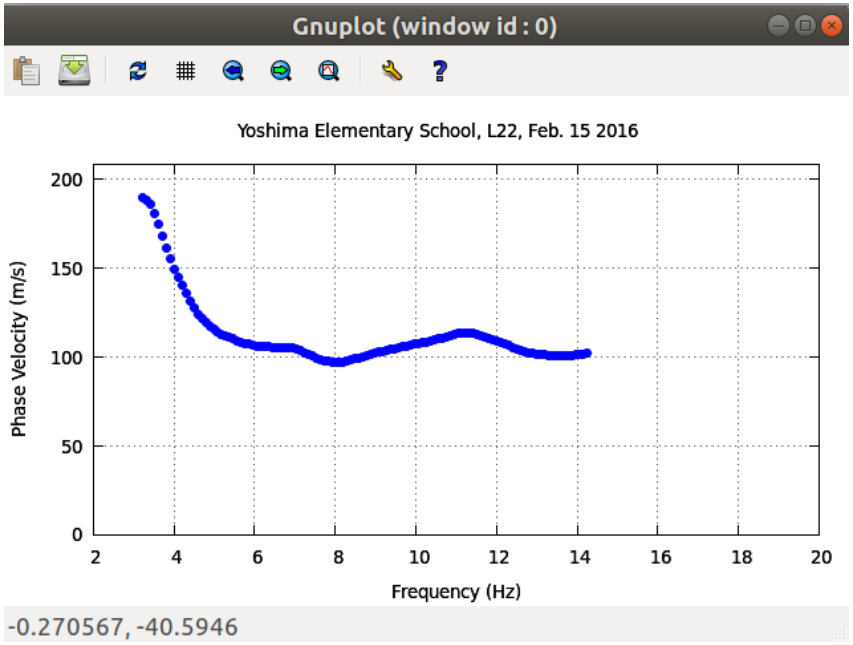


-1.14336, -23.4507

Edit “dispersion.dat” using “gedit” or othrt text editor



Then, redraw it using:
sh ./vel_model_plt.sh



inversion.sh: Execution

```
Yoshima Elementary School, L22, Feb. 15 2016
          5                          :IL(I5),Layer Number
1.9    1.5     0.001   0.005   0.08 0.12 :density,Vp,hmin,hmax,vmin,vmax
1.9    1.5     0.001   0.005   0.08 0.12 :density,Vp,hmin,hmax,vmin,vmax
1.9    1.5     0.001   0.005   0.10 0.15 :density,Vp,hmin,hmax,vmin,vmax
1.9    1.5     0.001   0.010   0.15 0.20 :density,Vp,hmin,hmax,vmin,vmax
2.0    1.70    998.0   999.0   0.20 0.30 :density,Vp,hmin,hmax,vmin,vmax
```

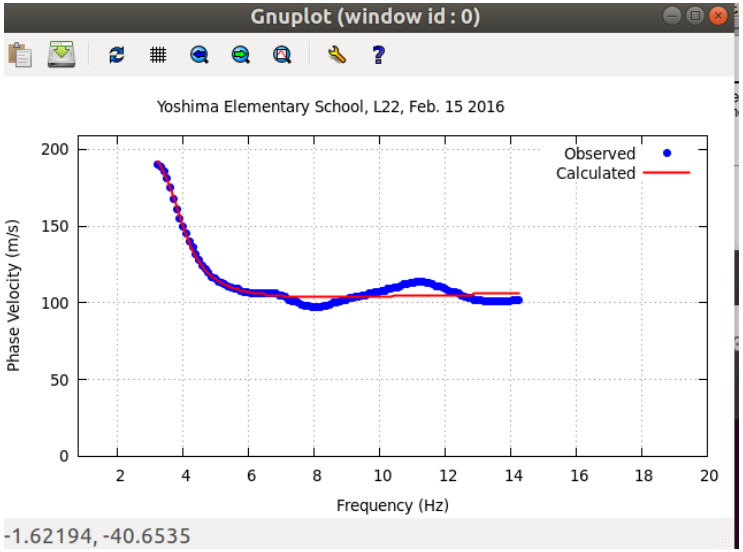
str_range.dat

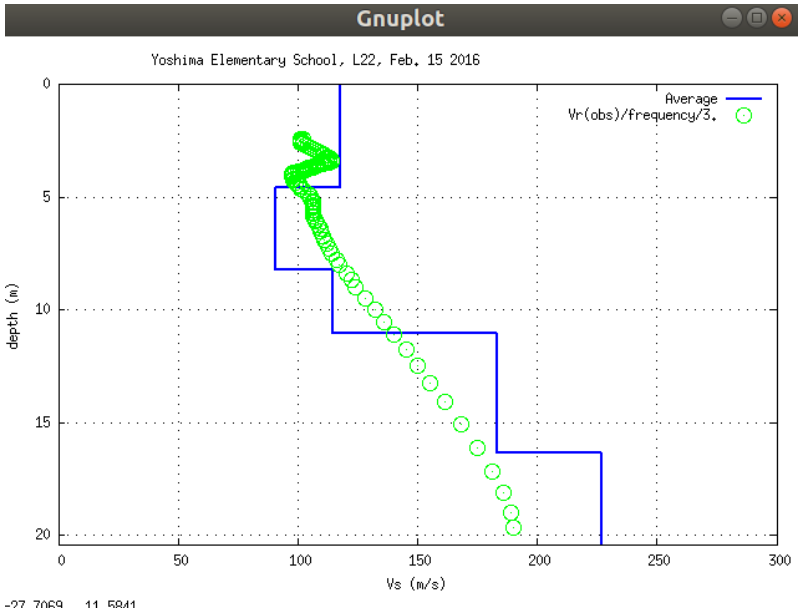
```
yokoi@ubuntu: ~/CCA2017/CCA2019
yokoi@ubuntu:~/CCA2017/CCA2019$ sh inversion.sh
 +-------------------------------------------------+
 +                                                 +
 +                   Disp_sma1                     +
 +                                                 +
 + Program 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.+
 +-------------------------------------------------+
./cca_wkf/data/results/progress.dat
```

```
 1 1. 0.6 1.3 10000  5    :idum,t0,a,c,ntemp,j0
0.00037                    :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
```

disp_sma1_2.prm

```
 1835    0.0003699786
 ./cca_wkf/data/results/vel_cal.dat
       Thicknes(Km) Density(g/cm^3)     Vp(Km/sec)     Vs(Km/sec)
    1       0.004584       1.761831       1.420547       0.117610
    2       0.003630       1.751991       1.390354       0.090409
    3       0.002826       1.760692       1.417045       0.114455
    4       0.005311       1.785299       1.493147       0.183015
    5     999.000000       1.800798       1.541566       0.226636
 ./cca_wkf/data/results/disp_cal.dat
 ./cca_wkf/data/results/err_estm.dat
Note: The following floating-point exceptions are signalling: IEEE_UNDERFLOW_FLA
G IEEE_DENORMAL
 ./cca_wkf/prm/gnuplt_script/disp_cal.plt

 ./cca_wkf/prm/gnuplt_script/vs_structure.plt

Hit return to continue

rm: cannot remove './cca_wkf/prm/temp*.dat': No such file or directory
yokoi@ubuntu:~/CCA2017/CCA2019$
```





Green circles can be eliminated by setting n_mod=0 in pwrcrs3.prm.