Instruction

- Analysis of SPAC Method -

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Revision from SPAC2020 to SPAC2021 is minor.

Acknowledgments:
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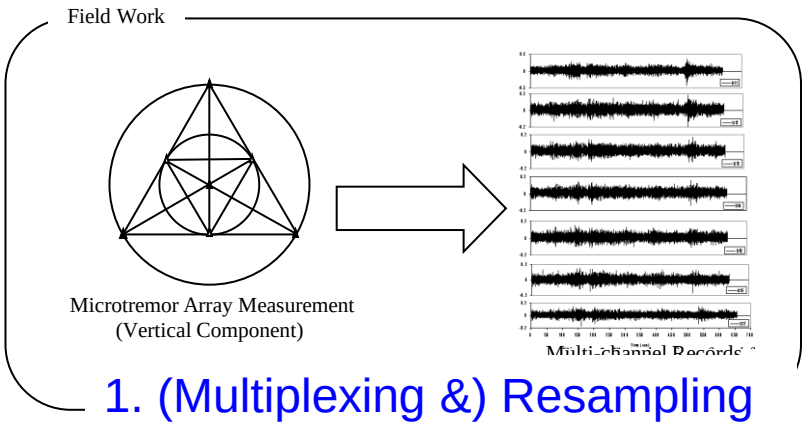
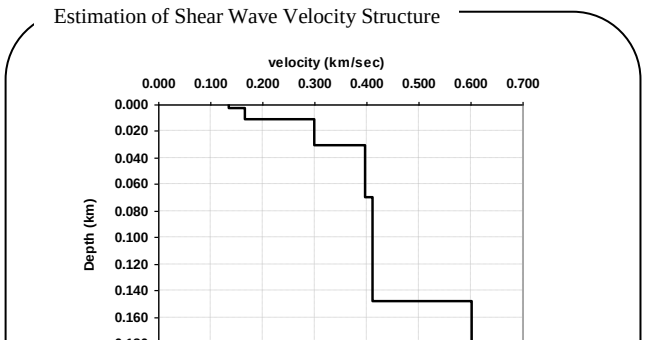
Procedures of analysis

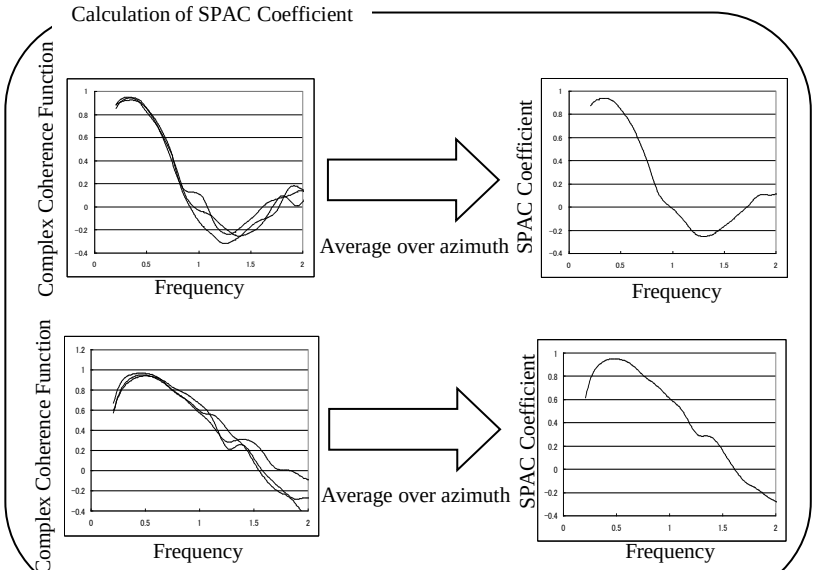


1. (Multiplexing &) Resampling



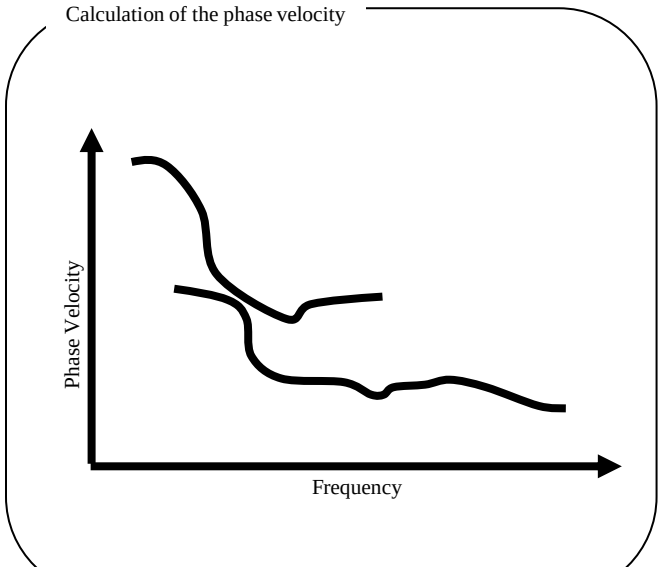
4. Heuristic Search of V_s Structure

Inversion or
Heuristic Search



2. Calculation of SPAC coefficient

Least Square Fitting to $J_0(kr)$



3. Determination of Dispersion Curve

Note: This version was developed on Linux: Ubuntu 19.10 (Eoan Ermine) on VirtualBox version 6.1.0 r135406on 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

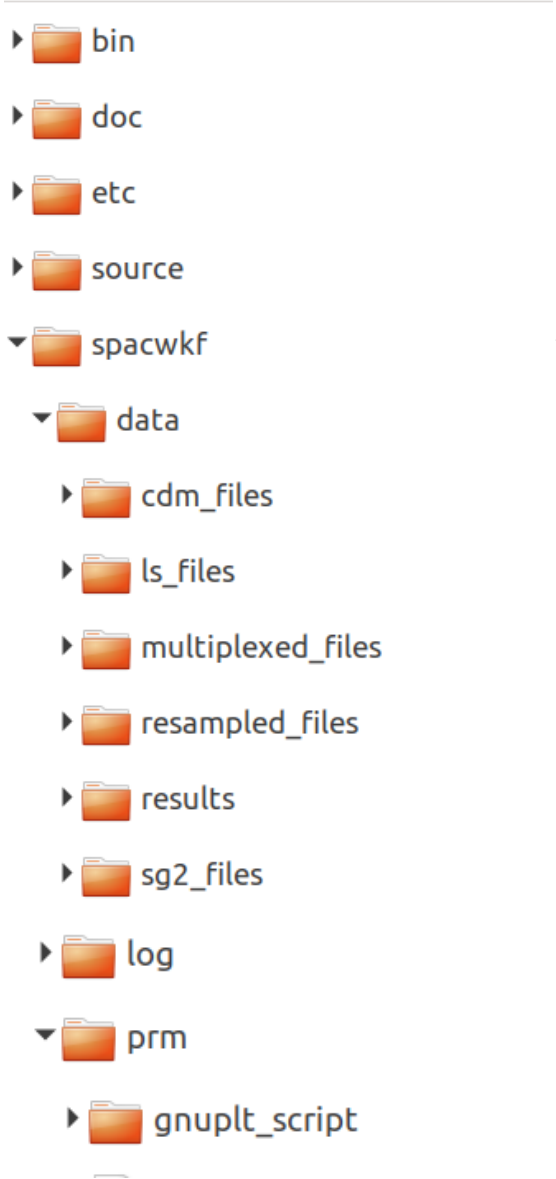
sh *shell_script_file_name*.sh

If it is necessary to leave log file of execution, for example,

./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 “SPAC2021”. 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 “spacwkf” 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 “spacwkf.tar.gz” keeps subfolder structure of “spacwkf” and all parameter files in “spacwkf/prm”.

Note: GNUPLOT scripts files

Some files of GNUPLOT scripts are stored under the subfolder

"./spacwkf/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 “SPAC2021” includes a sub-folder “bin” where several executable files are stored. 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 SPAC2021, type in the following command.

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

Or,

make all

to compile all necessary source codes at once as shown below.

Note: Shell script files

The folder “SPAC2021” includes several shell script files.
They are composed of few executing commands to reduce the typing tasks in data processing.
The following command can execute the shell script files.

sh *shell_script_file_name*.sh

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

chmod u+x *shell_script_file_name*.sh

For execution as a batch file,
shell_script_file_name.sh

Note: Cleaning up the subfolders

- Use
  sh clean_all.sh
  in the folder "SPAC2021" to delete all files of input data, interim outputs and results for a new processing task.
- Use
  sh clean_sg2.sh
  in the folder "SPAC2021" to delete all input files of sg2 format under "./spacwkf/data/sg2_files".
- Use
  sh clean_ls.sh
  in the folder "SPAC2021" to delete all input files of win format under "./spacwkf/data/ls_files", but subfolder structure is kept.

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)
  ➔./spacwkf/multiplexed_files/*.dat

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

Build SPAC2021

makefile:

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

all:          clean_log
              ${FC} ./source/cf_panel1.for      -o ./bin/cf_panel1.exe  ${store}
              ${FC} ./source/comparison_plt.for -o ./bin/comparison_plt.exe   ${store}
              ${FC} ./source/disp_err1.for      -o ./bin/disp_err1.exe ${store}
              ${FC} ./source/disp_sma1_2.for    -o ./bin/disp_sma1_2.exe ${store}
              ${FC} ./source/distazi.for        -o ./bin/distazi.exe ${store}
              ${FC} ./source/fourier_plt.for    -o ./bin/fourier_plt.exe ${store}
              ${FC} ./source/geometry.for       -o ./bin/geometry.exe ${store}
              ${FC} ./source/interim_plt.for    -o ./bin/interim_plt.exe ${store}
              ${FC} ./source/lstocdm2.for       -o ./bin/lstocdm2.exe  ${store}
              ${FC} ./source/mk_title.for       -o ./bin/mk_title.exe  ${store}
              ${FC} ./source/multi_pre.for      -o ./bin/multi_pre.exe ${store}
              ${FC} ./source/multipx6.for       -o ./bin/multipx6.exe  ${store}
              ${FC} ./source/prm_maker.for      -o ./bin/prm_maker.exe ${store}
              ${FC} ./source/resample5.for      -o ./bin/resample5.exe ${store}
              ${FC} ./source/resample6.for      -o ./bin/resample6.exe ${store}
              ${FC} ./source/resample_pre.for   -o ./bin/resample_pre.exe ${store}
              ${FC} ./source/results_plt.for    -o ./bin/results_plt.exe ${store}
              ${FC} ./source/seeblk1.for        -o ./bin/seeblk1.exe ${store}
              ${FC} ./source/seewav7.for        -o ./bin/seewav7.exe ${store}
              ${FC} ./source/seg2read.for       -o ./bin/seg2read.exe ${store}
              ${FC} ./source/vel_model_plt.for  -o ./bin/vel_model_plt.exe ${store}
              ${FC} ./source/zcorrel5_3.for     -o ./bin/zcorrel5_3.exe   ${store}

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

clean_log:
              rm –f ./spacwkf/log/make_all.log 2>/dev/null
```

0. Format conversion

0.1. *seg2* standard format

Shell Script used:

sh seg2read.sh

Program and parameter file used:

seg2read.exe +./spacwkf/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.

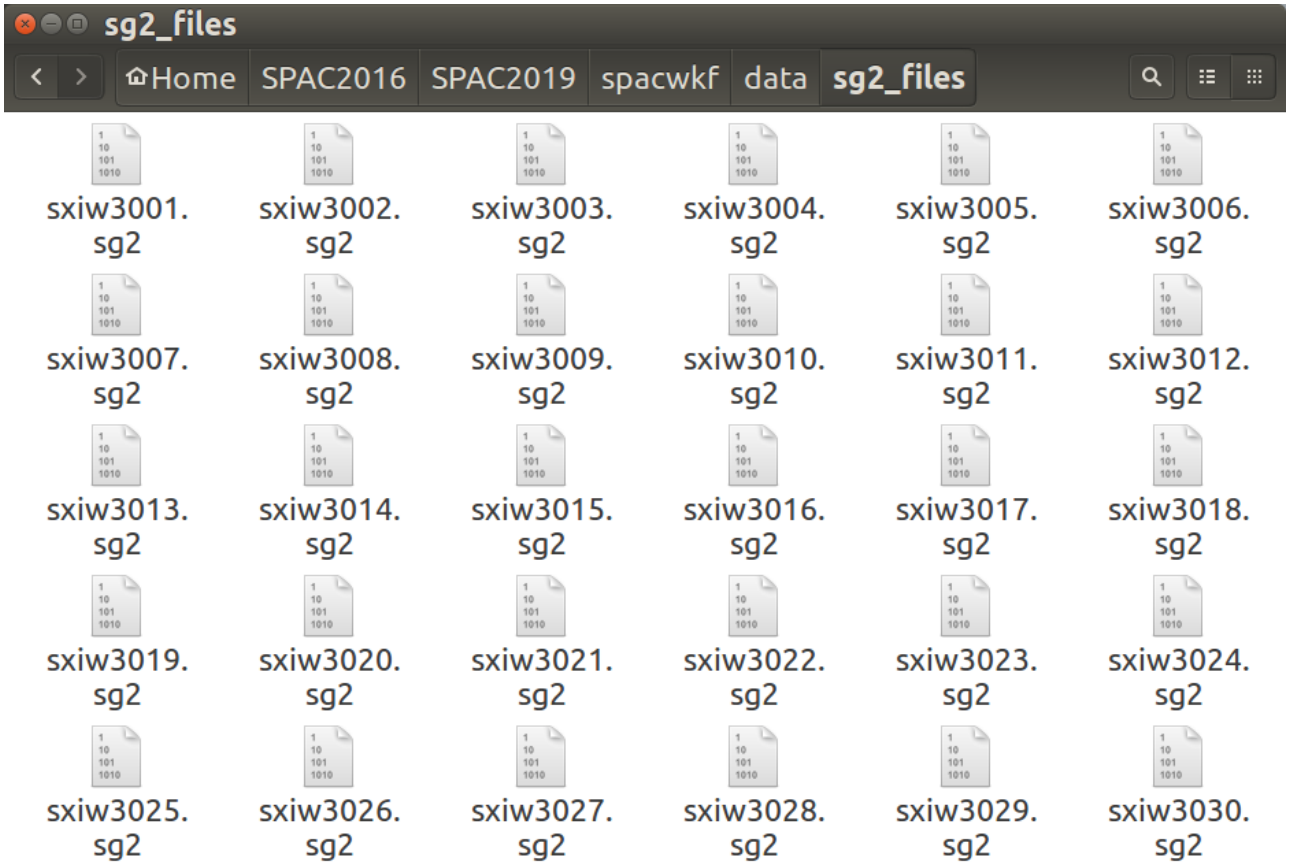
The expected input files of seg2 format are, for example, those obtained in the field using multi-channel data logger designed for the exploration geophysics.

seg2read.exe

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

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

Example:



seg2read.sh:

```
#!/bin/sh -x
cd spacwkf/data/sg2_files
ls *.sg2 > sg2file.lst
cd ../../..
./bin/seg2read.exe | tee spacwkf/log/seg2read.log
cd spacwkf/data/multiplexed_files
rename 's/^....../ss/' *.dat
ls *.dat > mltfile.lst
cd ../../..
./bin/mk_title.exe
```

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

Finally, the first line of “seg2read.prm” is copied to “graph_title.txt” in the subfolder “./spacwkf/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 editor if necessary.

seg2read.prm

```
Iwaki City Hall, radius=25m, McSeis/SW, L22 X 7 points    Dec.23 2012 :comment(a70)
 0.055       :(A12) scaling factor (for output files in mkine(1.e-3cm/s)/gal(1.e cm/s^2))
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 7 6 5 4 3 2 1
```

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 editor 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

If a channel number in pvlist is negative, the polarity of that
channel is reversed.
```

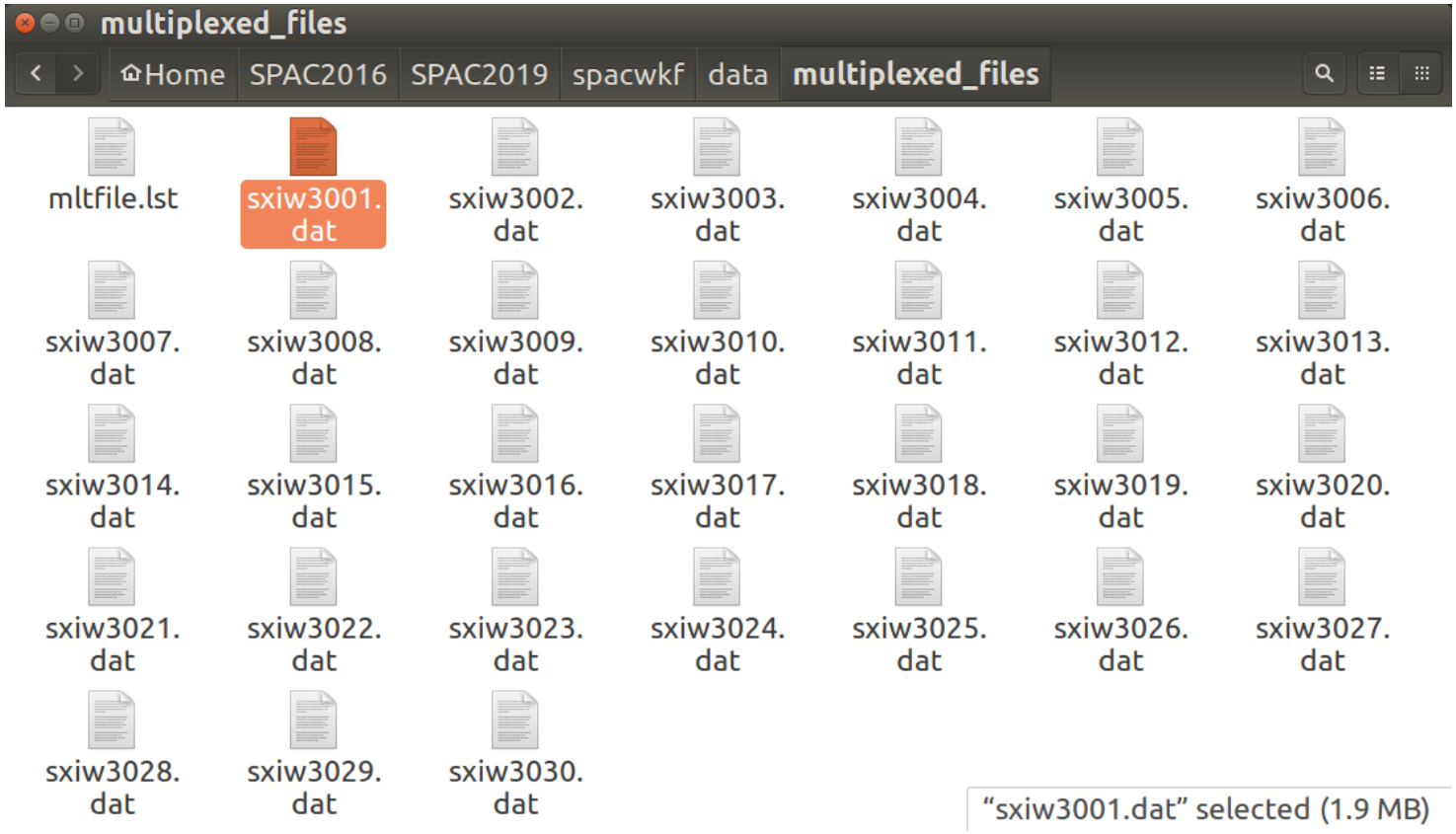
Note: Be sure to put ‘ ‘(blank) before ‘:’(colon), otherwise the program can have an error in detecting the end of line.

Execution

```
yokoi@eoan-ermine:~/Desktop/SPAC2020$ sh seg2read.sh
./spacwkf/prm/seg2read.prm
   5.49999997E-02 mkine
./spacwkf/data/sg2_files/sg2file.lst
sxiw3001.sg2

./spacwkf/data/sg2_files/sxiw3001.sg2
./spacwkf/data/multiplexed_files/sxiw3001.dat
                  :32bit floating point.
nch=  7 dt= 0.002 nn=   16384
       7  0.0020      0.5500E-01   16384  mkine
Iwaki City Hall, radius=25m, McSeis/SW, L22 X 7 points    Dec.23 2012
sxiw3002.sg2

./spacwkf/data/sg2_files/sxiw3002.sg2
./spacwkf/data/multiplexed_files/sxiw3002.dat
                  :32bit floating point.
nch=  7 dt= 0.002 nn=   16384
       7  0.0020      0.5500E-01   16384  mkine
```

Input files are copied in ‘./spacwkf/data/sg2_files’.
Multiplexed outputs are stored &./spacwkf/data/multiplexed_files”.
Log file is stored in ‘spacwkf/log/seg2read.log’

The converted files are stored in “./spacwkf/data/multiplexed_files”



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

Format of output files in ./spacwkf/data/multiplexed _files:

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

```
 7  0.0020      0.5500E-01   16384  mkine
Iwaki City Hall, radius=25m, McSeis/SW, L22 X 7 points    Dec.23 2012
    0.000000 -0.3943280E-05  0.9517429E-05 -0.2661598E-06 -0.7497172E-05  0.34044
    0.002000 -0.4349669E-05  0.9327264E-05  0.5046593E-06 -0.8176097E-05  0.35241
    0.004000 -0.4659054E-05  0.9203497E-05  0.5160243E-06 -0.8879738E-05  0.35992
    0.006000 -0.4855397E-05  0.9563433E-05 -0.1432124E-06 -0.9843301E-05  0.37105
    0.008000 -0.6745830E-05  0.1001426E-04 -0.5579629E-06 -0.1409490E-04  0.37764
```

1st line: Number of channels, Δt(sec), scale, number of samples,unit (mkine or gal)
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.

Output files is stored in “./spacwkf/data/multiplexed _files”

Jump to “1.2. Plot Waveform”.

0. Format conversion

0.2. *win* format for LS8800

This is the example of individually recorded data using a tri-axial sensor and three channel data logger 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. The *win* format data files are created, *e.g.*, LS8800 of Hakusan Kogyo.
The converted files must be written in a format that is readable in the next step: multiplexing.
As it is impossible to cover all existing formats in the world, it is strongly recommended for users to make their own program for format conversion.

Format conversion is conducted using
sh lstocdm2.sh
in the folder “SPAC2019”.

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

Preparation:
1) Edit the parameter file “prm_maker.prm”

```
Sitename_    : site name (a9)
 3  3        : numbers of obs_ponts and channels
 10          : duration of each connected file in min.(integer)
17091511.45  : first file name (yymmddhh.mm)
 20          : number of output connected files (integer)
```

2) Copy the data files (binary) of LS8800 into the subfolders of
“spacwkf/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 -x
./bin/prm_maker.exe | tee spacwkf/log/prm_maker.log
./bin/lstocdm2.exe | tee spacwkf/log/lstocdm2.log
cd ./spacwkf/data/cdm_files
rm *.cdm 2>/dev/null
cd ../../..
mv ./spacwkf/data/ls_files/Combined_Data/*.cdm ./spacwkf/data/cdm_files
```

Execution:

./bin/prm_maker.exe

➔ “lstocdm2.prm” is created in “spacwkf/prm”.

./bin/lstocdm2.exe

➔ All converted and separated files are stored in “./spacwkf/data/ls_files/Combined_Data”.

All converted and separated files are automatically stored in “spacwkf/data/ls_files/Combined_Data”.

Then, the subfolder “./spacwkf/data/cdm_files” is cleaned.

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

Example:

lstocdm2.prm: automatically created by lstocdm2.sh

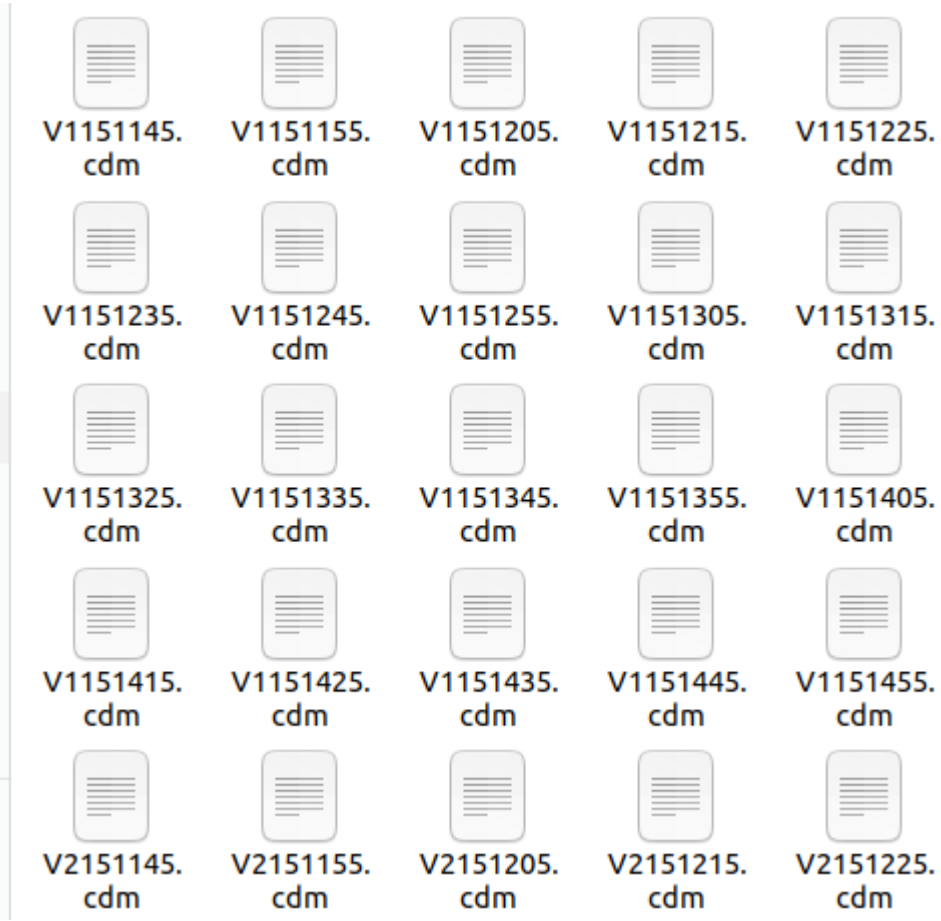
```
 3                      : case numbers
                        : This blank line is necessary
City_Hallno1            : Data Folder Name(a12)
  794.  792.  798.      : #1 T44002 Sensitivity (V/M/s)
NS EW V                 : channel labels
0.15646E-06             : voltage per Least Significant Bit (V/LSB)
V1    10                : (a2) channel identifier of name; duration(min); of output file
 3 1 2 1                : channel pivoting, channel selection (0=all, 1=1st channel only)
17091511.45  20         : 1st File name(a11),number of output files
                        : This blank line is necessary
City_Hallno2            : Data Folder Name(a12)
  798.  798.  796.      : #2 T44003 Sensitivity (V/M/s)
NS EW V                 : channel labels
0.15646E-06             : voltage per Least Significant Bit (V/LSB)
V2    10                : (a2) channel identifier of name; duration(min); of output file
 3 1 2 1                : channel pivoting, channel selection (0=all, 1=1st channel only)
17091511.45  20         : 1st File name(a11),number of output files
                        : This blank line is necessary
City_Hallno3            : Data Folder Name(a12)
  796.  794.  798.      : #3 T44004 Sensitivity (V/M/s)
NS EW V                 : channel labels
0.15646E-06             : voltage per Least Significant Bit (V/LSB)
V3    10                : (a2) channel identifier of name; duration(min); of output file
 3 1 2 1                : channel pivoting, channel selection (0=all, 1=1st channel only)
17091511.45  20         : 1st File name(a11),number of output files

Constants
  794.  792.  798.      : #1 T44002 Sensitivity (V/M/s)
  798.  798.  796.      : #2 T44003 Sensitivity (V/M/s)
  796.  794.  798.      : #3 T44004 Sensitivity (V/M/s)

pivoting
 1 2 3 1                : NS output
 2 3 1 1                : EW output
 3 1 2 1                :  V output
```

```
yokoi@eoan-ermine:~/Desktop/SPAC2020$
yokoi@eoan-ermine:~/Desktop/SPAC2020$ sh lstocdm2.sh > output
yokoi@eoan-ermine:~/Desktop/SPAC2020$ sh lstocdm2.sh
 Parameter file: ./spacwkf/prm/lstocdm2.prm

Name of the site: City_Hal
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: 17091511.45 ,    10 file
 Output file: ./spacwkf/data/ls_files/Combined_Data/V1151145.cdm

 Input file: ./spacwkf/data/ls_files/no1/17091511.45

 Output file: ./spacwkf/data/ls_files/Combined_Data/V1151155.cdm

 Input file: ./spacwkf/data/ls_files/no1/17091511.55

 Output file: ./spacwkf/data/ls_files/Combined_Data/V1151205.cdm

 Input file: ./spacwkf/data/ls_files/no1/17091512.05

 Output file: ./spacwkf/data/ls_files/Combined_Data/V1151215.cdm

 Input file: ./spacwkf/data/ls_files/no1/17091512.15
```

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

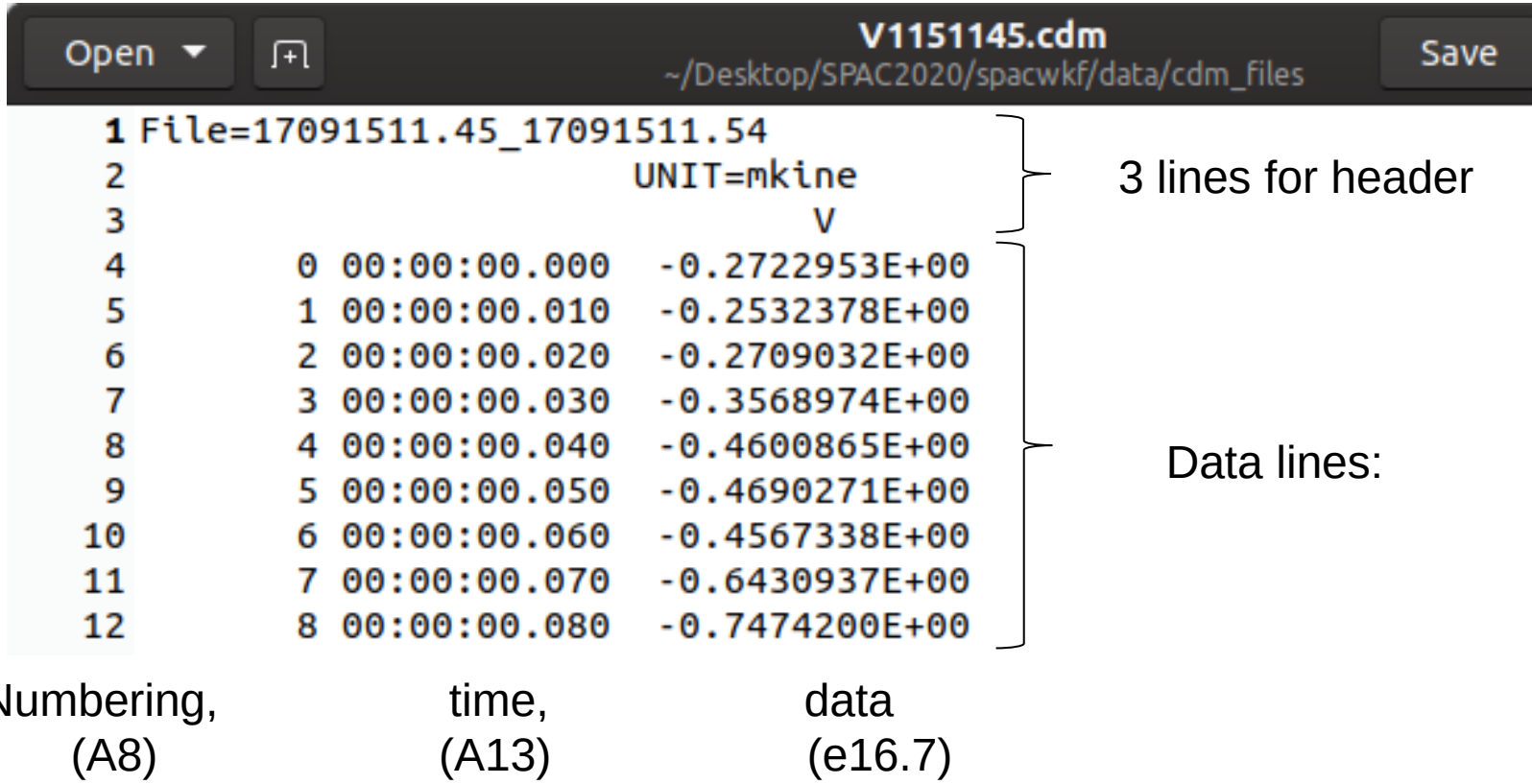
2nd letter: numbering of seismograph (=numbering of station)

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.sh* is used with the parameter file "*multipx6.prm*".
- For automatic editing of multipx6.prm, *multi_pre.sh* is prepared.
- Edit the following "*multi_pre.prm*" in "spacwkf/prm" and run *"sh multi_pre.sh*".

```
CityHall 3P-Array l=35m 2017/09/11:45-2H20M       :comment(A50)
 10          : duration of each connected file in min.(integer)
V1151145     : first file name (yymmddhh.mm)
cdm          : extention (A3)
1 2 3 0      : station pivot  (0=4th_ch_not_used)
 20          : number of output connected files(integer)
```

- 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@eoan-ermine:~/Desktop/SPAC2020$ sh multi_pre.sh
  Working Folder=./spacwkf/prm/
  Default Settings:
    dt      = 0.0
    np      =   3
    tst     = 0.0
    file_out=CC**.dat

V1151145 V2151145 V3151145
V1151155 V2151155 V3151155
V1151205 V2151205 V3151205
V1151215 V2151215 V3151215
V1151225 V2151225 V3151225
V1151235 V2151235 V3151235
V1151245 V2151245 V3151245
V1151255 V2151255 V3151255
```

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

```
 1    1                        : Number of cases
 2                             : This blank is necessary
 3   3 0.010                   : Number of obs points,dt
 4          0.0       600.0    : 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 CityHall 3P-Array l=35m 2017/09/11:45-2H20M       : comment(A50)
10    20            8          : number of measurement in the same array configuration,n_character
11 V1151145 V2151145 V3151145
12 V1151155 V2151155 V3151155
13 V1151205 V2151205 V3151205
14 V1151215 V2151215 V3151215
15 V1151225 V2151225 V3151225
16 V1151235 V2151235 V3151235
17 V1151245 V2151245 V3151245
```

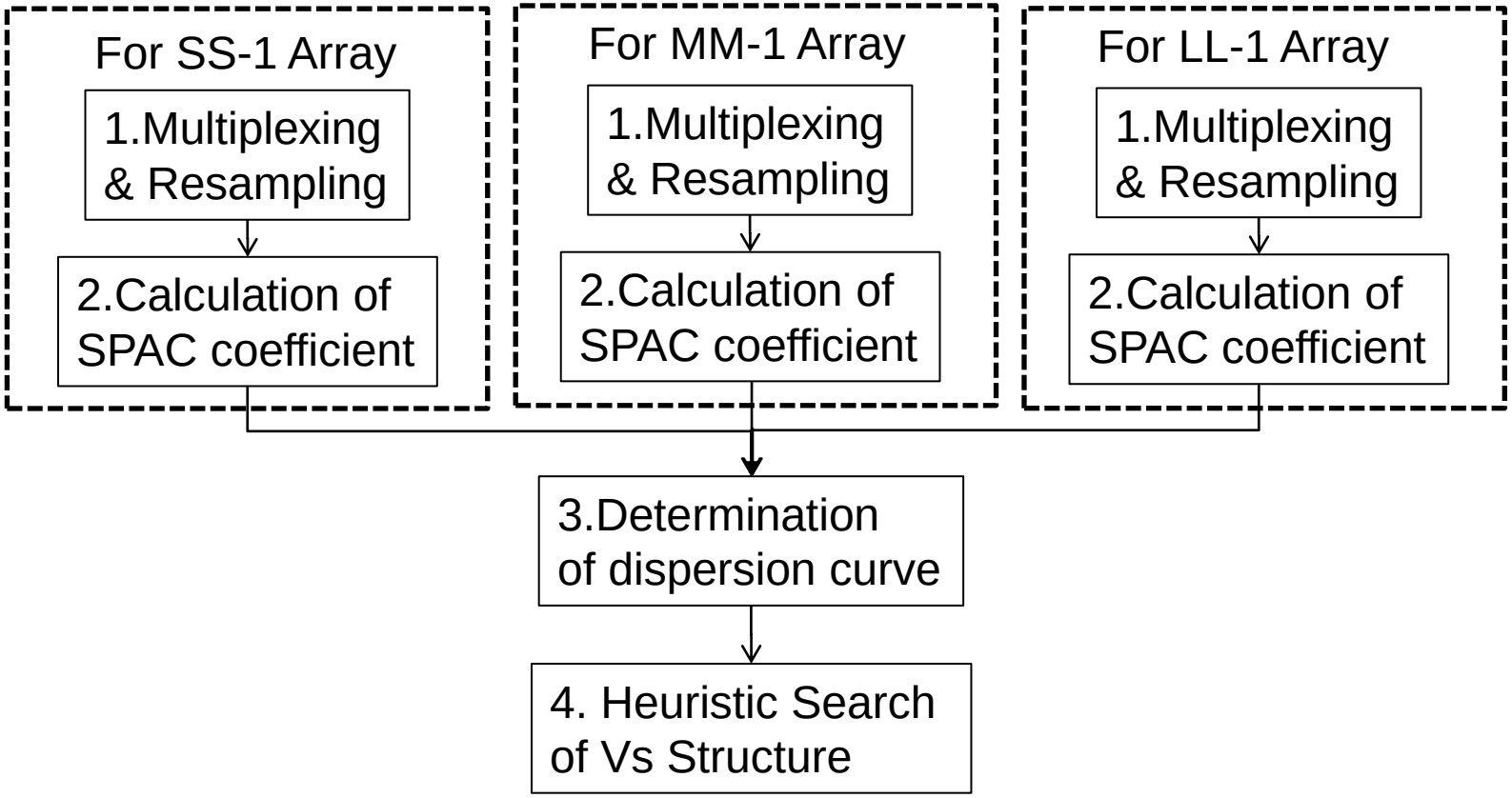
Edit it in an appropriate way if necessary.

Note: Example for the instruction below

An example that consists of three arrays of different sizes is shown below.

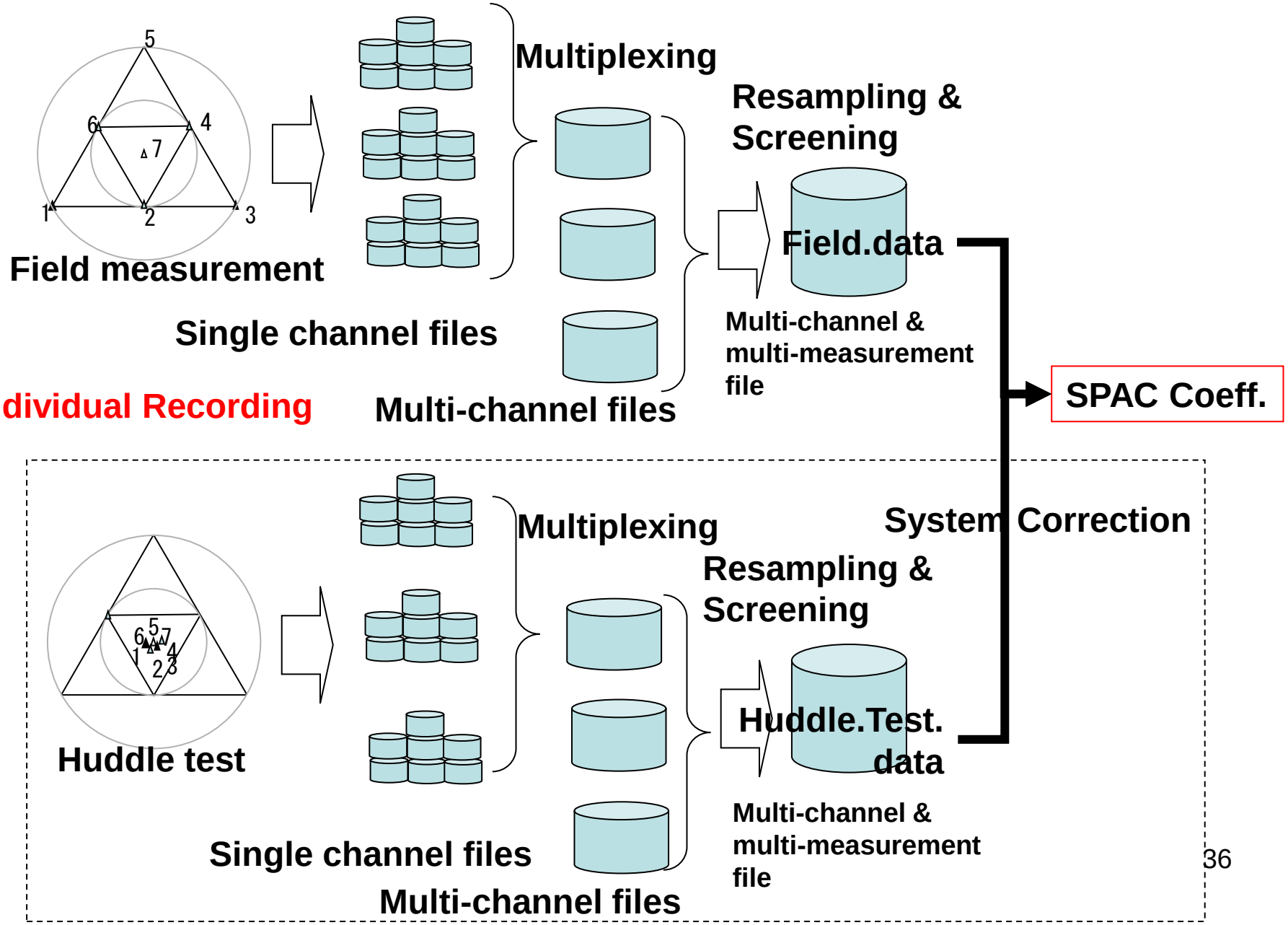
+ SS-1 Array: 7 points equilateral triangle array with the center
+ MM-1 Array: 4 points equilateral triangle array with the center
+ LL-1 Array: 4 points equilateral triangle array with the center

Note: these are different from the examples of the data format conversion shown in the previous slides.



1. (Multiplexing &) Resampling

Flow of the data processing for the conventional SPAC



1. Multiplexing & Resampling

1.1. Multiplexing (Optional)

Single channel files are combined into a multi-channel file
(This step is not necessary for the multi-channel recording cases)

multipx6.sh + ./spacwkf/prm/multipx6.prm

First step is to edit the parameter file multipx6.prm.

However, it is recommendable for users to make own conversion program from her/his original format files directly to multiplexed files of the format explained below.

Terminology

Multiplexing:

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

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.

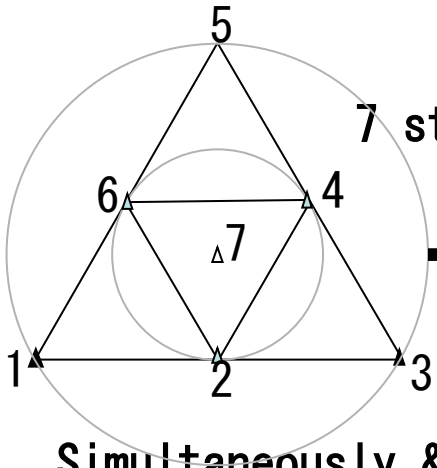
Re-sampling:

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.

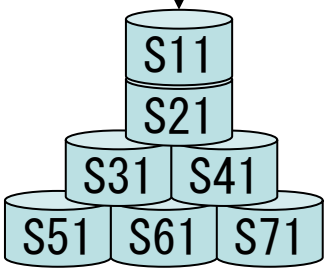
System correction:

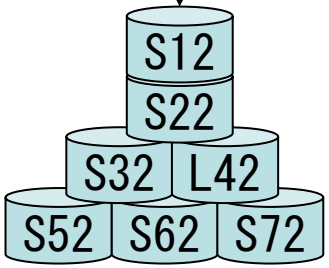
The difference of the characteristics among the recording system can be corrected using the data obtained by huddle tests.

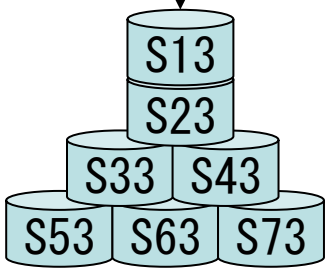
Multiplexing the single channel files



Simultaneously & individually recorded data







Multipx6.for

multipx6.prm

Multiplexing

Multiplexing

Multiplexing

SS01.dat

SS02.dat

SS03.dat

Multi-channel files

Warning:

The program multipx6.sh does not have the functionality to adjust the time difference among the single channel files. The input files must have the same timing.

Confirm the following:
+ All input files have the same sampling interval.
+ All input files have their first datum that are sampled at the same time.

multipx6.prm

```
 3                          :Number of cases
                            :This blank is necessary
 4 0.01                     :Number of Channels,dt
0.0   163.83                :tst,tdur
1.e11  mkine                :scale(input data is divided by this scale),unit(a5)
0 3 0.005 1.0 1.5           :nfilter(=1:apply), ncharacter(=2:lowpass,=3:bandpass),fl,fh,fs
 4   .cdm                   :nattach, cattach
2 MM                        :n_out(A12),cout    ("**.dat" is attached)
MM-1, Iwaki City Hall, Dec.22, 2012              :comment(A50)
21 8                        :number of measurement in the same array configuration,n_character
sxm21001 sxm21002 sxm21003 sxm21004
...
sxm23601 sxm23602 sxm23603 sxm23604
                            :This blank is necessary
 7 0.002                    :Number of Channels,dt
0.0    32.766               :tst,tdur
3.16e2  mkine                 :scale(input data is divided by this scale)
0 3 0.005 1.0 1.5           :nfilter(=1:apply), ncharacter(=2:lowpass,=3:bandpass),fl,fh,fs
 4   .cdm                   :nattach, cattach
2 SS                        :n_out(A12),cout    ("**.dat" is attached)
SS-1, Iwaki City Hall, Dec.22, 2012              :comment(A50)
30 8                        :number of measurement in the same array configuration,n_character
sxs10101 sxs10102 sxs10103 sxs10104 sxs10105 sxs10106 sxs10107
…
sxs13001 sxs13002 sxs13003 sxs13004 sxs13005 sxs13006 sxs13007
                            :This blank is necessary
 4 0.01                     :Number of Channels,dt
0.0   163.83                :tst,tdur
3.16e10  mkine                :scale(input data is divided by this scale)
0 3 0.005 1.0 1.5           :nfilter(=1:apply), ncharacter(=2:lowpass,=3:bandpass),fl,fh,fs
 4   .cdm                   :nattach, cattach
2 LL                        :n_out(A12),cout    ("**.dat" is attached)
LL-1, Iwaki City Hall, Dec.22, 2012              :comment(A50)
28 8                        :number of measurement in the same array configuration,n_character
sxl21001 sxl21003 sxl21005 sxl21007
…
sxl24601 sxl24603 sxl24605 sxl24607
```

1st case

2nd case

3rd case

multipx6.prm

```
 3                  :Number of cases
                    :This blank is necessary
 4 0.01             :Number of Channels,dt
0.0   163.83        :tst,tdur
1.e11  mkine        :scale(input data is divided by this scale),unit(a5)
0 3 0.1 1.0 1.5 :nfilter(=1:apply),ncharacter(=2:lowpass,=3:bandpass),fl,fh,fs
 4   .cdm           :nattach, cattach ➔ Input single channel file name
2 MM                :n_out(A12),cout ("**.dat" is attached)
MM-1, Iwaki City Hall, Dec.22, 2012                :comment(A50)
21 8          :number of measurement in the same array configuration,n_character
sxm21001 sxm21002 sxm21003 sxm21004 ←— 1st
...
sxm23601 sxm23602 sxm23603 sxm23604 ←— 21th measurement
```

1ch 2ch 3ch 4ch

Input file names : sxm2??0?.cdm

consist of the character string ‘sxm2??0?’ 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.

multipx6.prm

Output file name: SS01.dat for the 1st measurement. ’01’ shows the numbering of measurement.

…

SS30.dat for the 30th measurement. ’30’ shows the numbering of measurement.

These output file names consist of the character string ‘MM’ 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.

sxm21001.cdm:

Example: format of input file (dt=0.01 sec) of single channel data
in ./spacwkf/data/cdm_files

```
File=01001.cdm       ch. 1
                unit
                 V
    0 00:00:00.000  -0.1396391E+11
    1 00:00:00.010  -0.1513392E+11
    2 00:00:00.020  -0.1472600E+11
    3 00:00:00.030  -0.1314799E+11
    4 00:00:00.040  -0.7706377E+10
    5 00:00:00.050  -0.3947473E+10


16383 00:02:43.830  -0.7844215E+10
```

3 lines for header

Data lines:

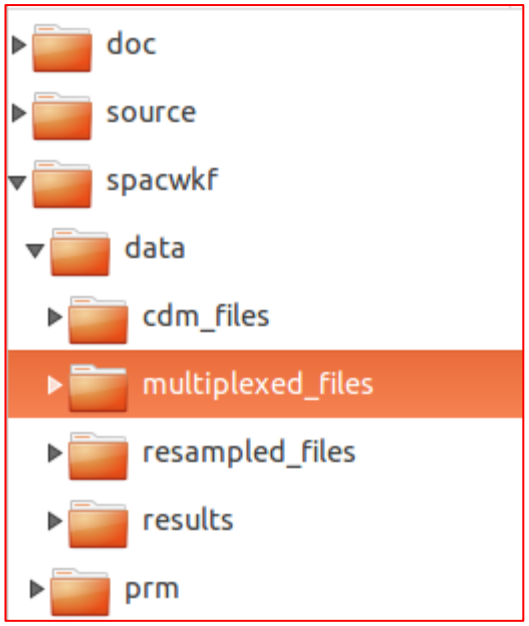
Numbering,	time,	data
(A8)	(A13)	(e16.7)

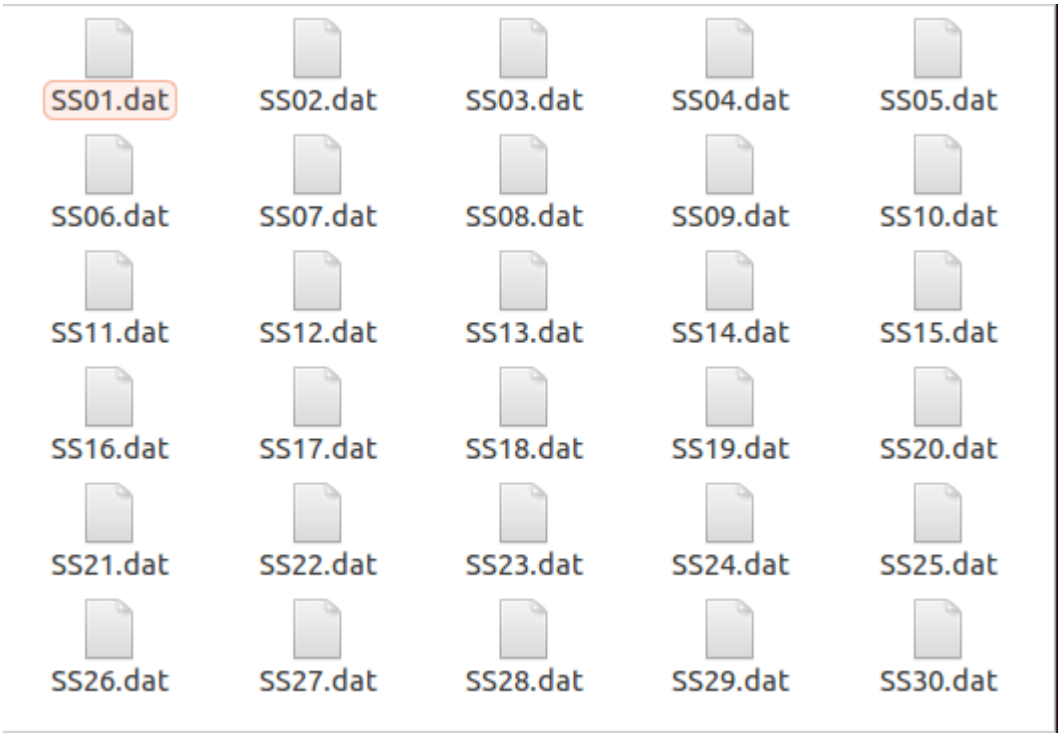
Example of execution (from the folder SPAC2021):

```
~$sh multipx6.sh
```

```
 Working Folder=./spacwkf/prm/
  Nch=           4  dt=   9.99999978E-03
  Scale Factor=   9.99999980E+10
  Does this scale convert the unit of data mkine ?
  Please change the value if not.
           0           3   4.99999989E-03   1.00000000       1.50000000
 MM-1, Iwaki City Hall, Dec.22, 2012              :
           1 -th measurement:           4
sxm21001 sxm21002 sxm21003 sxm21004
       16383



 ./spacwkf/data/multiplexed_files/MM01.dat
           2 -th measurement:           4
…
 Normal End
```

Example of output file (stored in the subfolder ./spacwkf/data/multiplexed_files






```
  7  0.0020      0.3160E+03   16382  mkine
SS-1, Iwaki City Hall, Dec.22, 2012              :
    0.000000 -0.0000000E+00 -0.0000000E+00 -0.0000000E+00  0.0000000E+00 -0.0000000E+00  0.0000000E+00 -0.0000000E+00
    0.002000 -0.8961562E-04  0.5361709E-05 -0.2044998E-04  0.1081865E-03 -0.1978091E-05  0.2530022E-04 -0.4171700E-04
    0.004000 -0.1640327E-03  0.8138977E-04 -0.1974745E-04  0.1997052E-03  0.2068763E-04  0.4874512E-04 -0.9626019E-04
…
```

1st line: channel number, dt, scale factor, number of samples, unit
2nd line & below: time, 1ch,2ch,3ch,…, 7ch.

Warning!

- The declared array size for input data in multipx6.for is 1,200,000. This gives the constraint: tdur/dt < or =1,200,000
- Similarly nch< or =15

For much longer data file:

“multipx6.for” can handle 1200,000 samples of 15 channels at once. If you have data of longer recording time, it is recommendable to separate them beforehand.
An alternative may be the following way of using “tst” and “tdur” in ”multipx5.prm” can let you utilize the data fully.

For the 1st operation:

```
   0.0    3600.0                  :tst(start time)),tdur(duration) in sec.
```

For the 2nd operation:

```
3600.01   3600.0                  :tst(start time)),tdur(duration) in sec.
```

For the 3rd operation:

```
7200.01   3600.0                  :tst(start time)),tdur(duration) in sec.
```

…

Namely, “multipx6.for”skips int(tst/dt) data and then starts reading the next data.

Example Data files: These are already multiplexed.

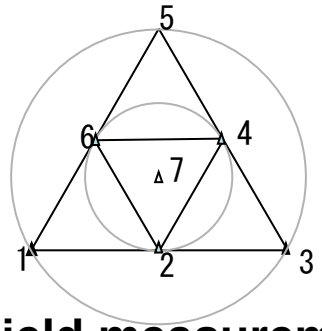
multi_SS.tar.gz
multi_MM.tar.gz
multi_LL.tar.gz

Copy these three compressed files into the subfolder "./spacwkf/data/multiplexed_files" for exercise with these example Data files.

1.2. Plot Waveform

seewav7.sh+ ./spacwkf/prm/seewav7.prm

Flow of the data processing for the conventional SPAC



Field measurement

Individual Recording

Single channel files

Multiplexing

Multi-channel files

Resampling & Screening

Field.data

Multi-channel & multi-measurement file

SPAC Coeff.

seewav7.for

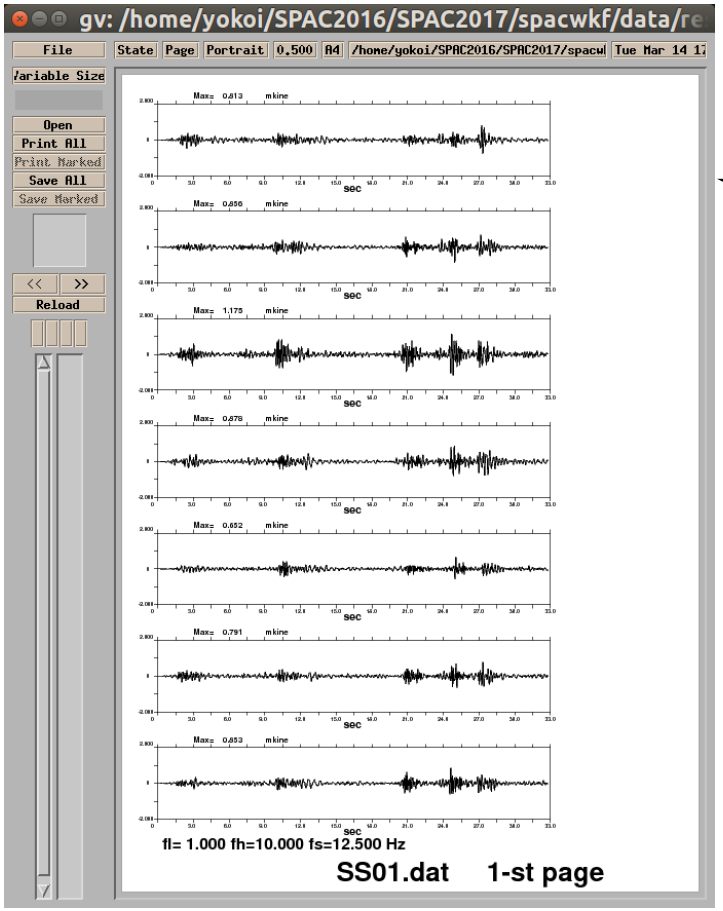
seewav7.prm

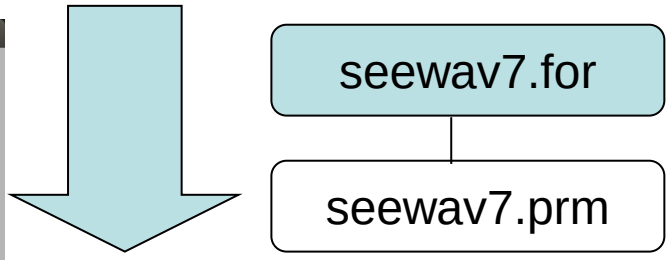
Post Script files

Paste-up of Waveform

Multi-channel file: SS01.dat

```
 7  0.0020       0.3160E+03    16382  mkine
SS-1, Iwaki City Hall, Dec.22, 2012                    :
     0.000000 -0.0000000E+00 -0.0000000E+00 -0.0000000E+00  0.0000000E+00 -0.0000000E+00  0.0000000E+00 -0.0000000E+00
     0.002000 -0.8961562E-04  0.5361709E-05 -0.2044998E-04  0.1081865E-03 -0.1978091E-05  0.2530022E-04 -0.4171700E-04
     0.004000 -0.1640327E-03  0.8138977E-04 -0.1974745E-04  0.1997052E-03  0.2068763E-04  0.4874512E-04 -0.9626019E-04
...
```





SS01.ps

Figures in Multi-page Post Script file. Post Script file can be opened, for example, by “gv &”, where “gv and “&” stand for “ghost view” and background operation.

If “ghost view” is not installed yet:
sudo apt-get install gv

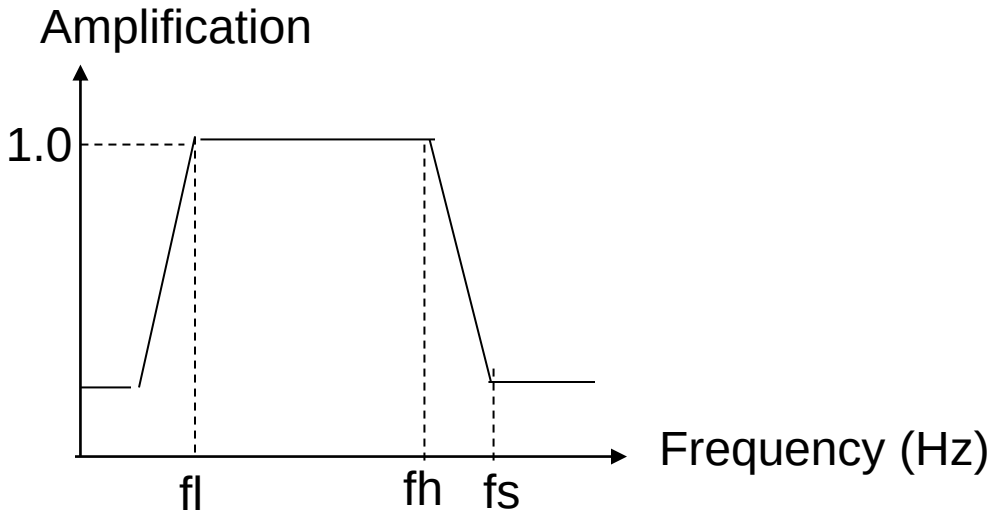
seewav7.prm

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.

```
1  1.0 10.0 12.5 3      :nfilter,fl,fh,fs,nchara(=2:lowpass, =3:bandpass)
  1.5                   :dtl(sec/cm),25,50==>10,20 min/page
```

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

Band Pass Filter



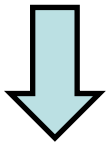
This BPF does not affect to the data files.

If the records have significant DC-offset
(base line shift due to DC component)

seewav7.prm

```
 1  0.1 50.  60.0        :nfilter,,fl,fh,fs
   1.0                   :dtl(sec/cm)
```

Set nbandpass = 1 and
fs>Nyquist frequency



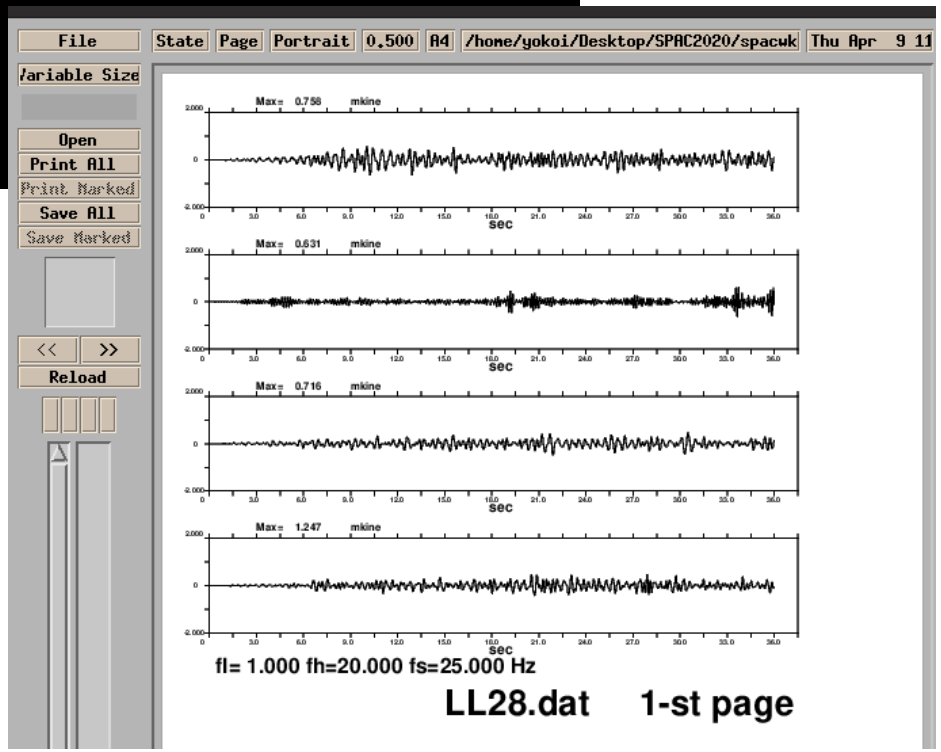
Waveform plots with DC-offset correction, but without applying bandpass filter, are given.

This program plots at once all data files listed in ./spacwkf/data/multiplexed_files/mltfile.lst .

Number of channels is read from the first line of the data files.

Example of execution:

```
yokoi@eoan-ermine:~/Desktop/SPAC2020$ sh seewav7.sh
 ./spacwkf/data/multiplexed_files/mltfile.lst

 ./spacwkf/prm/seewav7.prm

          1   1.00000000       20.0000000       25.0000000              3
 79 measurement
 ./spacwkf/data/multiplexed_files/LL01.dat

  DC-offset removed & tapered;
  0.870511591       1.00000000
./spacwkf/data/results/fig_wave/LL01.ps
LL01.dat     1-st page
LL01.dat     2-nd page
LL01.dat     3-rd page
```



Output files:

PostScript files are stored in the folder:

./spacwkf/data/results/fig_wave

with extension “ps”. Use “gv &” to draw it.

1.3. Re-sampling & Screening

Re-sampling & Screening

resample_pre.sh

resample5.sh + ./spacwkf/prm/resample5.prm

or

resample6.sh + ./spacwkf/prm/resample6.prm

Then, check the selected time blocks using

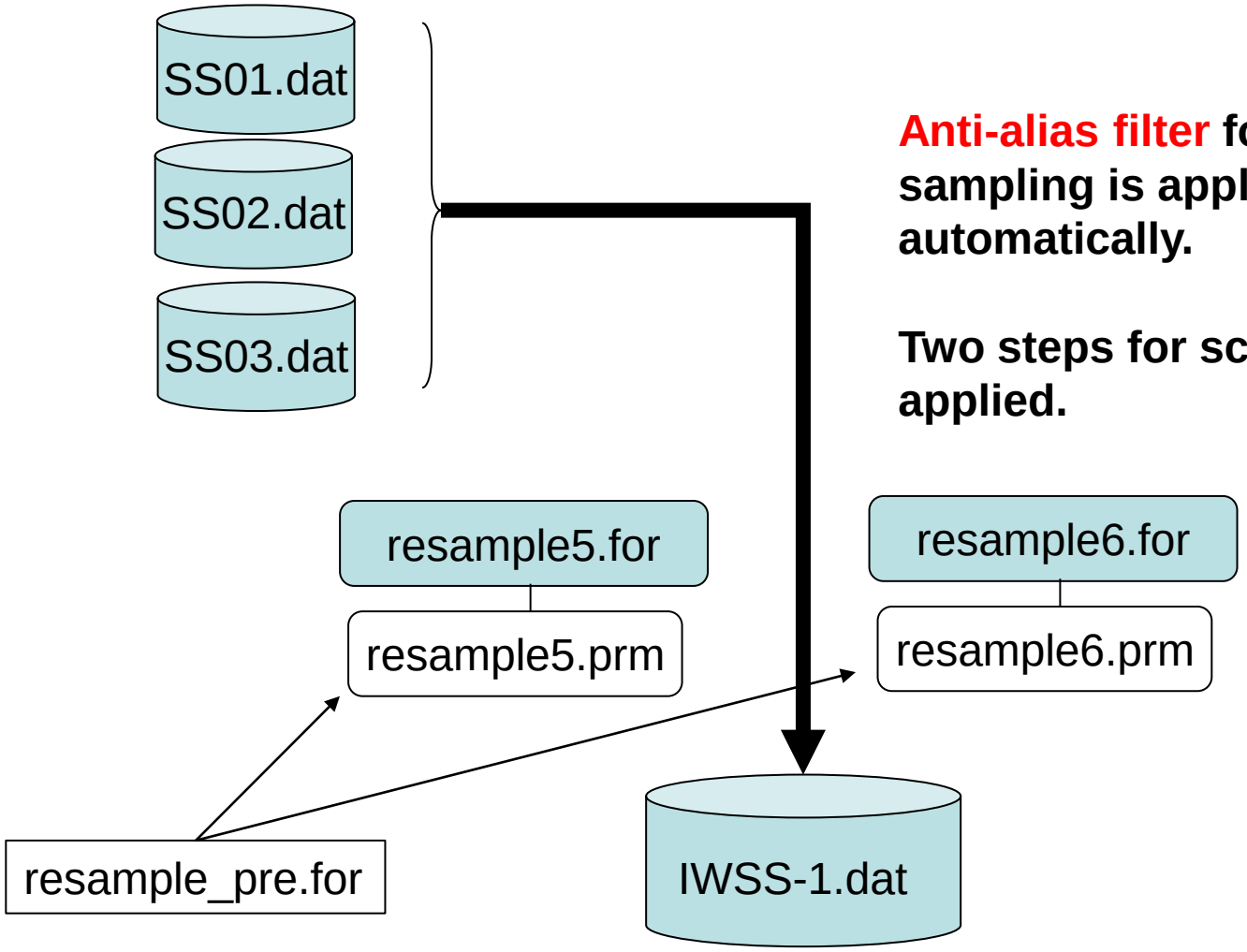
seeblk1.sh + seeblk1.prm

Note: Modify the file “./spacwkf/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 “./spacwkf/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.

Re-sampling & Screening

Multi-channel data files from the same array configuration



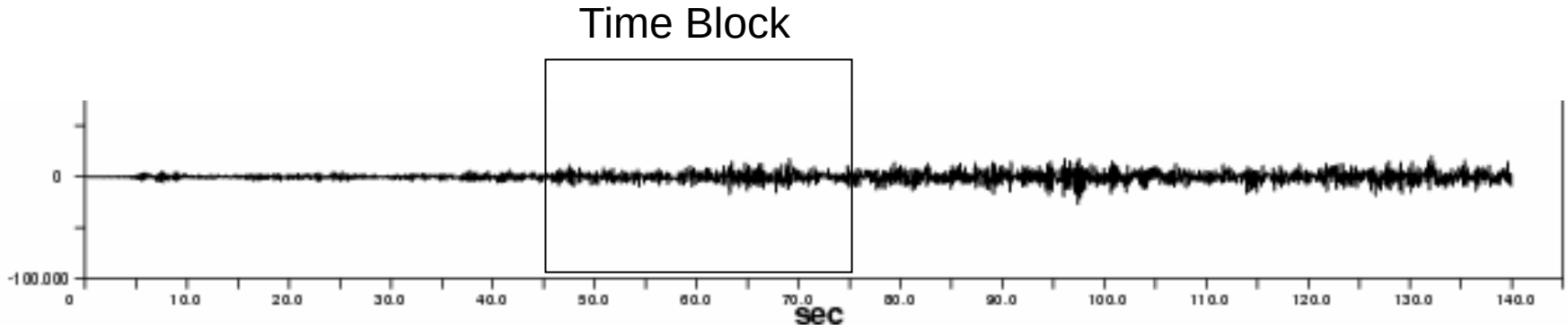
Anti-alias filter for re-sampling is applied automatically.

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 the "ajudge" parameter 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 the “a_sgm” parameter multiplied to 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.

Warning:

Be sure to use the same resampling interval and the same block size, in case of the combination of arrays of various sizes. Otherwise, a heavy problem will take place in the further step of analysis, namely, the determination of dispersion curves.

The declared array size for input data in resample5.for and resample6.for is 750,000.
This gives the constraint: tdur/dt < or =750,000
Similarly nch< or =11
and number of data in one time block < or = 8192

It is recommendable to make a multiplexed data file for every 30 minutes or shorter duration, in order to avoid the problem due to the exceedance of input data quantity.

resample5.prm or resample6.prm

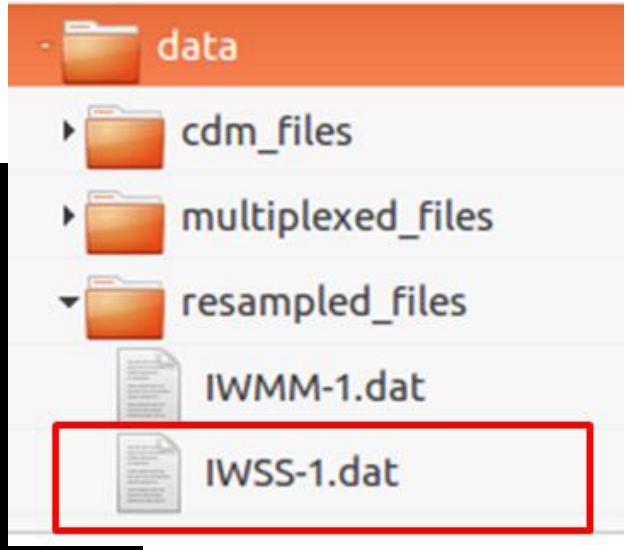
```
7 0.002 10          :nch,dt,number of Channels,dt,nskip
7.0 1.5             :ajudge,a_sgm
0.0  32.766         :tst,tdur
IWSS-1.dat          :output file name
1024                :number of data in one time block after resampling
```

sh resample_pre.sh

activates pre-processor to modify resample5.prm and/or resample6.prm easier.

1st line: Channel number, sampling interval, skip data number
2nd line: ajudge, a_sgm: parameters for two step screening
3rd line: start time and duration for processing
4th line: Output file name
5th line: number of data in one time block after resampling.
resample5.for divides all the data into the time blocks that have this number of data allowing overlapping of 50 % between neighboring blocks.
6th line: number of measurement in the same array configuration.
Example1 is the single measurement case.

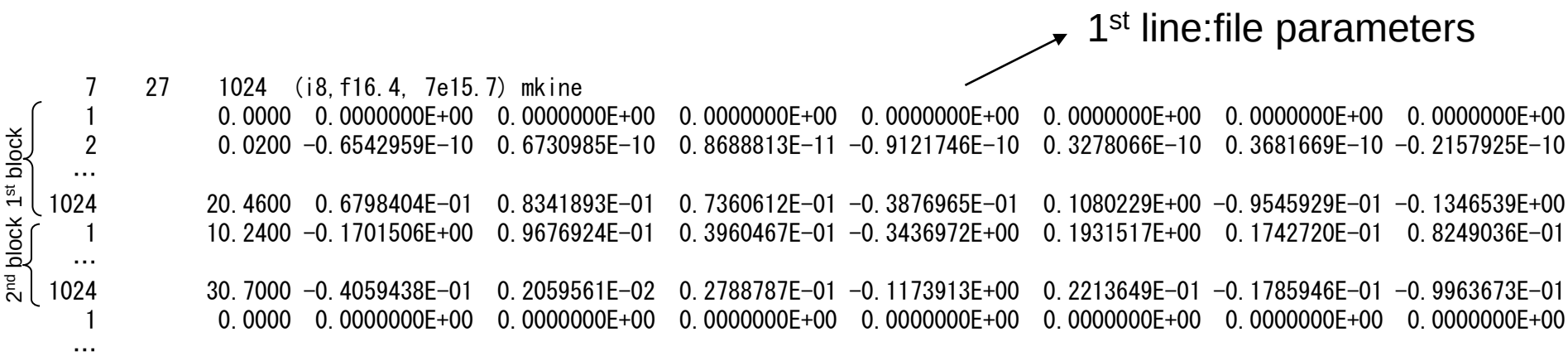
Example of execution: Output file is stored in ‘./spacwkf/data/resampled_files’




```
yokoi@eoan-ermine:~/Desktop/SPAC2020$ sh resample5.sh
 ./spacwkf/prm/resample5.prm

  Working Folder=./spacwkf/prm/
 Band-Pass:fl=  0.100000001     fh=   20.2499981     fs=   22.4999981
  Nch=           7
  Nskip=          10  f(Nyquist)=   24.9999981      fs=   22.4999981
  ajudge=   7.00000000      a_sgm=   1.50000000
   0.00000000       32.7659988
  First screening (peak/rms<   7.00000000     ):
          1 -th measurement:./spacwkf/data/multiplexed_files/SS01.dat
          2  blocks remained among            2  blocks
          2 -th measurement:./spacwkf/data/multiplexed_files/SS02.dat
          0  blocks remained among            2  blocks
          3 -th measurement:./spacwkf/data/multiplexed_files/SS03.dat
          0  blocks remained among            2  blocks
```

```
          0  blocks remained among            2  blocks
         29 -th measurement:./spacwkf/data/multiplexed_files/SS29.dat
          2  blocks remained among            2  blocks
         30 -th measurement:./spacwkf/data/multiplexed_files/SS30.dat
          2  blocks remained among            2  blocks
  Data stored in the temporary file
 ./spacwkf/data/resampled_files/IWSS-1.dat

  Second screening ({rms-average(rms)}/sigma<   1.50000000     ):
         28  blocks remained among           40  blocks
yokoi@eoan-ermine:~/Desktop/SPAC2020$
```

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



The file includes mmblk=27 time blocks of nch=7 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)'.
The unit for these data is "mkine".
These file parameters are stored in the 1st line.
As all of the data are delimited by space, this file can be read using free format.

For MM-1 array: resample6.prm

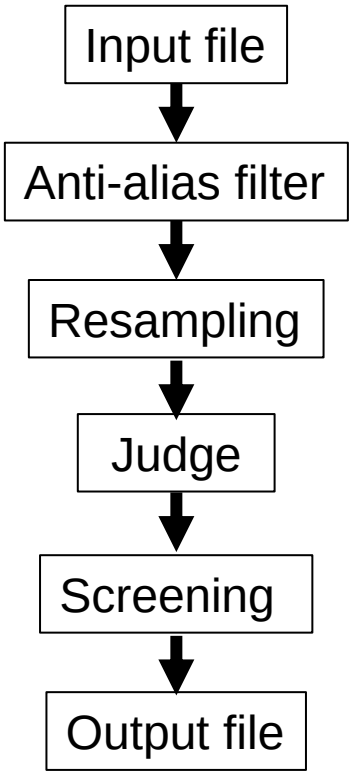
```
4 0.01  2              :nch,dt,number of Channels,dt,nskip
4.0 2.0                :ajudge,a_sgm
0.0 163.83               :tst,tdur
IWMM-1.dat                 :output file name
1024                   :number of data in one time block after resampling
```

Execution:

```
~SPAC2021$ sh resample6.sh
 ./spacwkf/prm/resample6.prm
  Working Folder=./spacwkf/prm//
 Band-Pass:fl=  0.100000001     fh=   20.2500000     fs=   22.5000000
  Nch=           4
  Nskip=           2  f(Nyquist)=   25.0000000      fh=   20.2500000
  ajudge=   4.00000000      a_sgm=   2.00000000
   0.00000000       163.830002
  First screening (peak/rms<   4.00000000     ):
           1 -th measurement:./spacwkf/data/multiplexed_files/MM01.dat
 Band-Pass:fl1=   5.00000007E-02 fh1=   1.00000000     fs1=   1.50000000
          14  blocks remained among           14  blocks
…
 21 -th measurement:./spacwkf/data/multiplexed_files/MM21.dat
 Band-Pass:fl1=   5.00000007E-02 fh1=   1.00000000     fs1=   1.50000000
 14  blocks remained among           14  blocks
  Data stored in the temporary file
 ./spacwkf/data/resampled_files/IWMM-1.dat
  Second screening ({rms-average(rms)}/sigma<   2.00000000     ):
         280  blocks remained among          294  blocks
~SPAC2021$
```

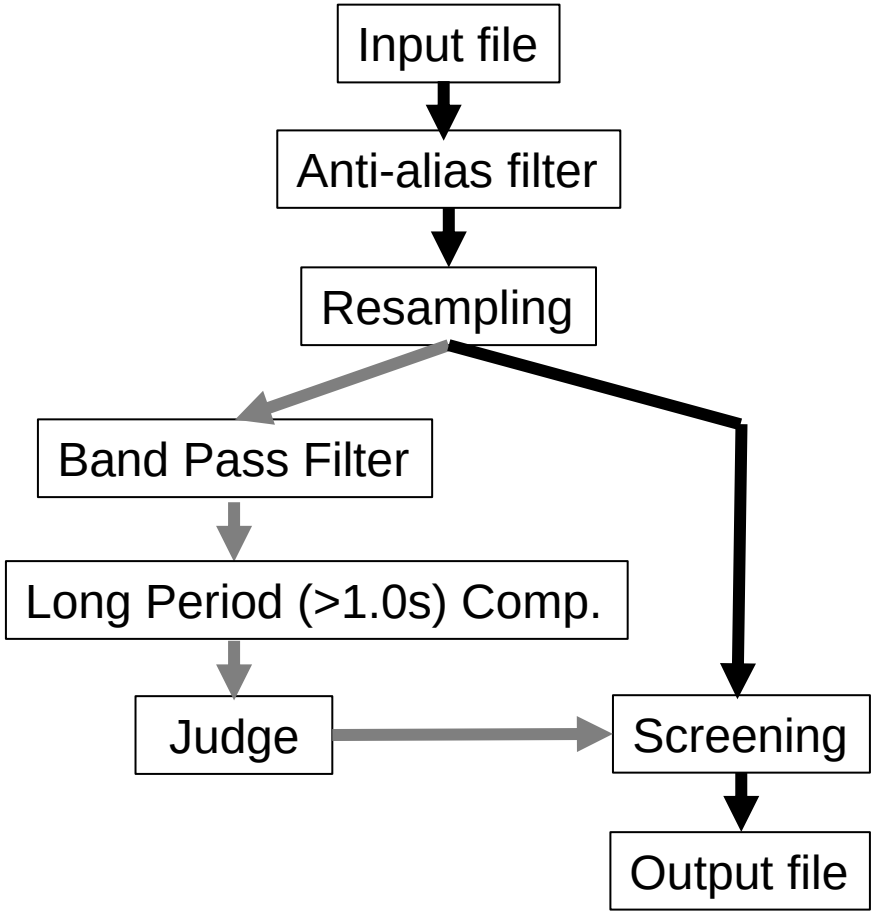
What's special of resample6.exe in comparison with resample5.exe

./bin/resample5.exe



For short period observation

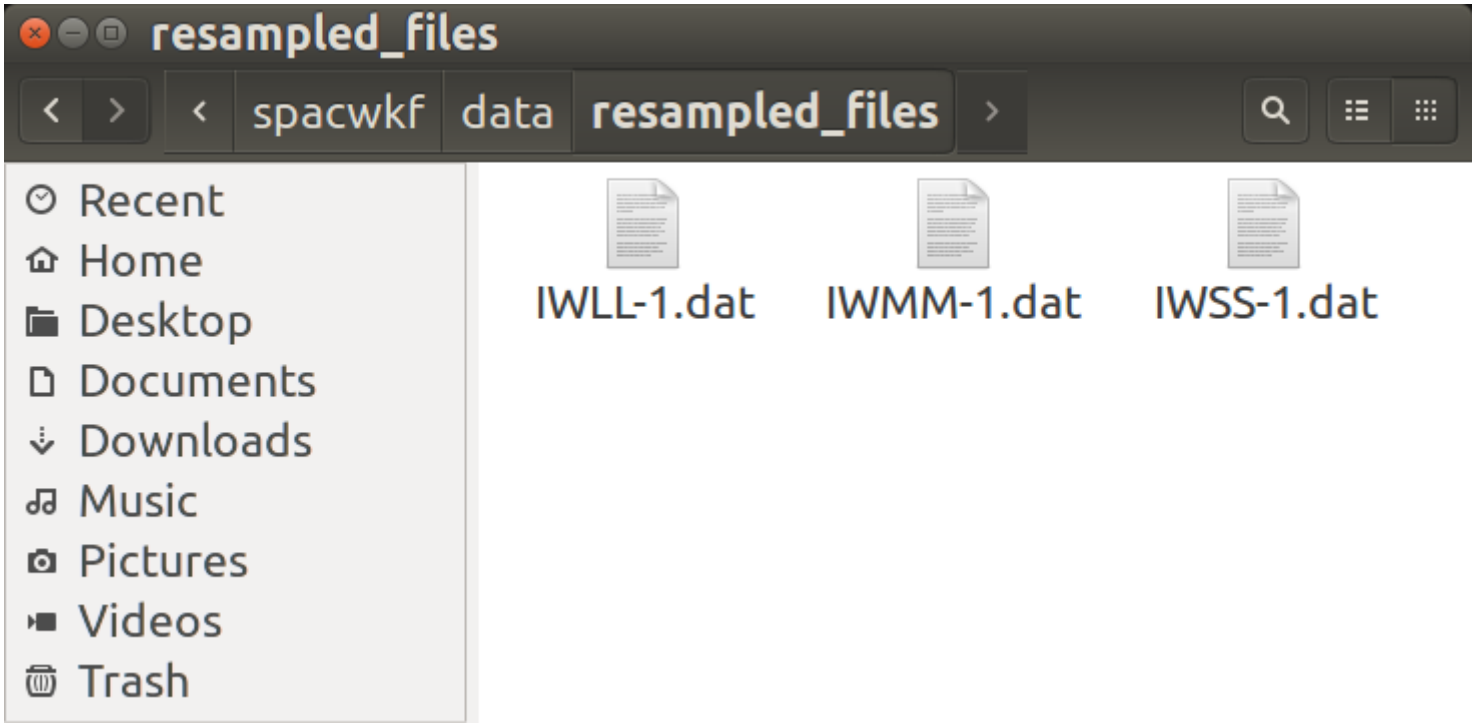
./bin/resample6.exe



For long period observation

Output files:
IWSS-1.dat ← resample5.exe
IWMM-1.dat ← resample6.exe
IWLL-1.dat ← resample6.exe

Resample6.prm is edited after obtaining IWMM-1.dat



Check the selected time blocks

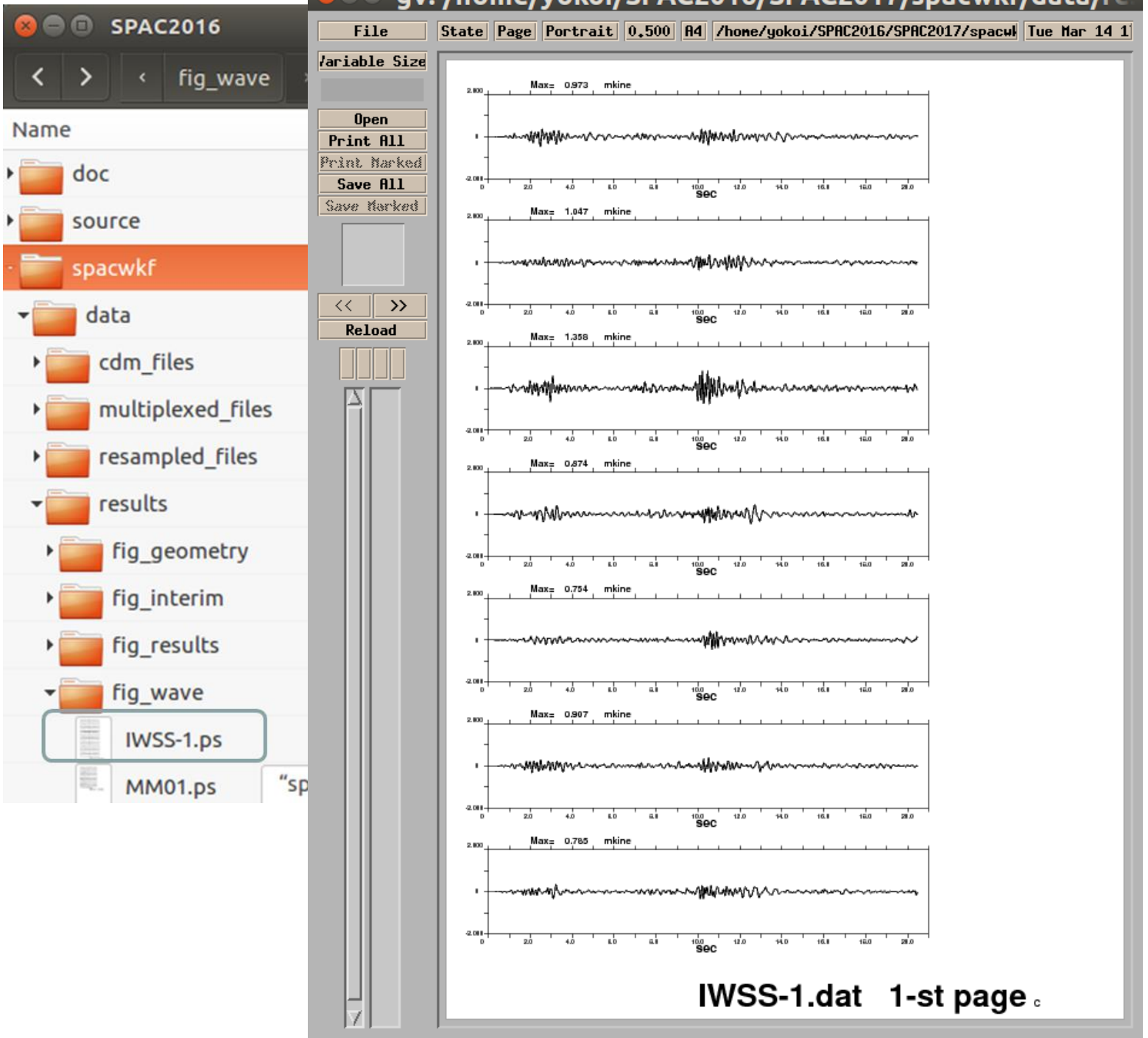
Parameter file:
./spacwkf/prm/seeblk1.prm

```
0  0.005 1.0 1.5 3     :nfilter,fl,fh,fs,nchara(=2:lowpass, =3:bandpass)
 1 10                  :n_mea,n_character
IWSS-1.dat
```

Example of execution: Output file is stored in ./spacwkf/data/results/fig_wave'

```
~SPAC2021$ .sh seeblk1.sh
 ./spacwkf/prm/seeblk1.prm
 ./spacwkf/data/resampled_files/IWSS-1.dat
         28         10
         28         20
   4.42062318E-03   4.99999989E-03
./spacwkf/data/results/fig_wave/IWSS-1.ps
~SPAC2021$
```

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


SPAC2016
fig_wave
Name
doc
source
spacwkf
data
cdm_files
multiplexed_files
resampled_files
results
fig_geometry
fig_interim
fig_results
fig_wave
IWSS-1.ps
MM01.ps
gv: /home/yokoi/SPAC2016/SPAC2017/spacwkf/data/re
File
State
Page
Portrait
0.500
A4
/home/yokoi/SPAC2016/SPAC2017/spacwk
Tue Mar 14 1
Variable Size
Open
Print All
Print Marked
Save All
Save Marked
<<
>>
Reload
Max= 0.973 mkine
Max= 1.047 mkine
Max= 1.358 mkine
Max= 0.874 mkine
Max= 0.754 mkine
Max= 0.907 mkine
Max= 0.785 mkine
sec
IWSS-1.dat 1-st page

1.2 Calculation of Inter station Distance and Azimuth & Plot Geometry of array

Programs used:

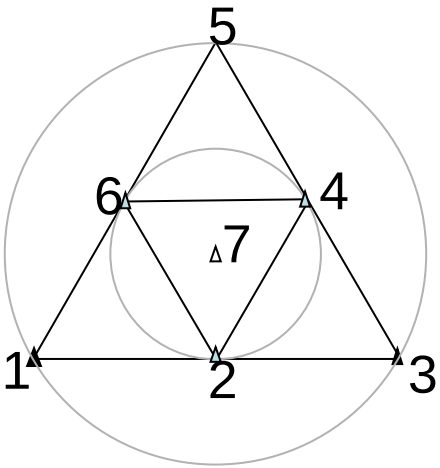
distazi.sh

that controls:

distazi.exe + ./spacwkf/prm/distazi.prm

geometry.exe + ./spacwkf/prm/distazi.prm

A temporary file is used: temp0.dat



Coordinates

distazi.for

distazi.prm

dist_azi.dat

(Inter-station distances & azimuths)

distazi.sh

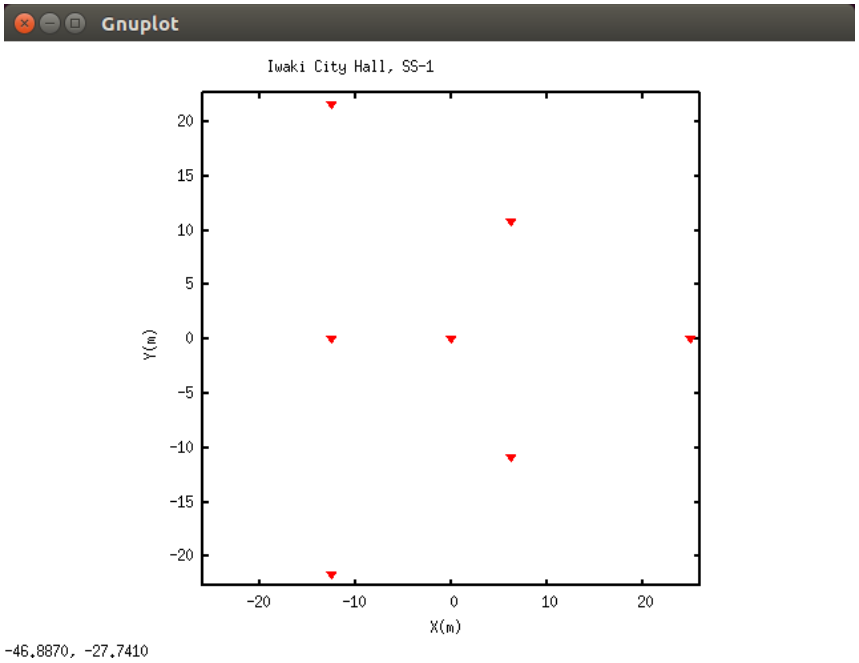
```
#!/bin/sh
rm ./spacwkf/data/results/temp0.dat
# rm ./spacwkf/data/results/distazi.dat
# rm ./spacwkf/prm/
./bin/distazi.exe
./bin/geometry.exe
gnuplot -e "
load 'geometry.plt' ;
pause -1
"
```

gnuplot is used for plotting.
If not yet installed,
sudo apt-get install gnuplot –x11

Example：SS-1 Array

distazi.prm

```
Iwaki City Hall, SS-1                    :Explanation (a45)
2                                        :Type X-Y(=0), Lat-Long(=1),Dist-Angle(=2)
7   SS-1                                 :Number of stations, Title of figure
 25.0     90.0    1
 12.50    30.0    2
 25.0    -30.0    3
 12.50   -90.0    4
 25.00  -150.0    5
 12.50   150.0    6
  0.0      0.0    7
```



dist_azi.dat

Iwaki City Hall, SS-1
7 :number of station

id	st1	st2	distance	azimuth
1	2	7	12.500	-150.000
2	4	7	12.500	90.000
3	6	7	12.500	-30.000
4	1	2	21.651	-60.000
5	1	6	21.651	-120.000
6	2	3	21.651	-60.000
7	2	4	21.651	-120.000
8	2	6	21.651	180.000
9	3	4	21.651	180.000
10	4	5	21.651	-180.000
11	4	6	21.651	120.000
12	5	6	21.651	60.000
13	1	7	25.000	-90.000
14	3	7	25.000	150.000
15	5	7	25.000	30.000
16	1	4	37.500	-90.000
17	2	5	37.500	-150.000
18	3	6	37.500	150.000
19	1	3	43.301	-60.000
20	1	5	43.301	-120.000
21	3	5	43.301	-180.000

The same image is saved simultaneously in a PostScript file in the subfolder “./spacwkf/data/results/fig_geometry/”.

distazi.prm

```
Iwaki City Hall, SS-1                    :Explanation (a45)
2                                        :Type X-Y(=0), Lat-Long(=1),Dist-Angle(=2)
7   SS-1                                 :Number of stations, Title of figure
  25.0     90.0    1
  12.50    30.0    2
  25.0    -30.0    3
  12.50   -90.0    4
  25.00  -150.0    5
  12.50   150.0    6
   0.0      0.0    7
```

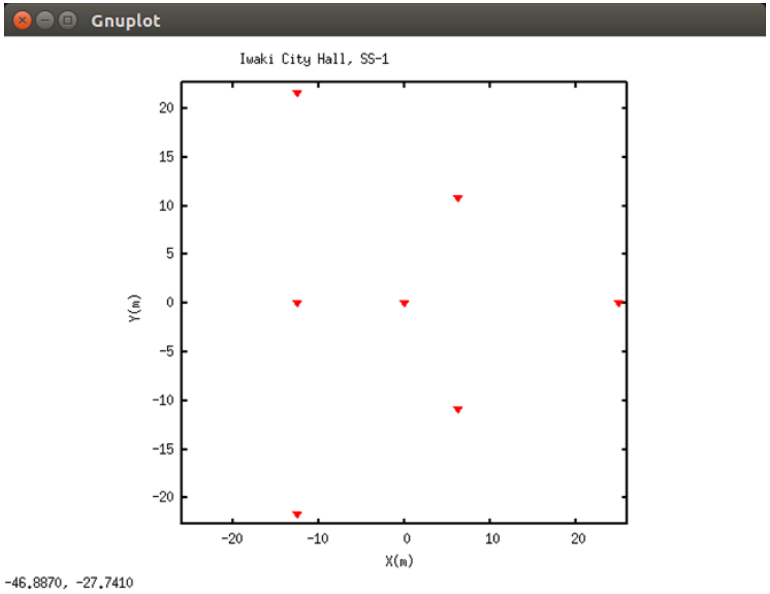
The 1st line & the 2nd parameter of the 3rd line are read and used later.

For Lat-Long (=1):
The statement for reading in distazi.for is:

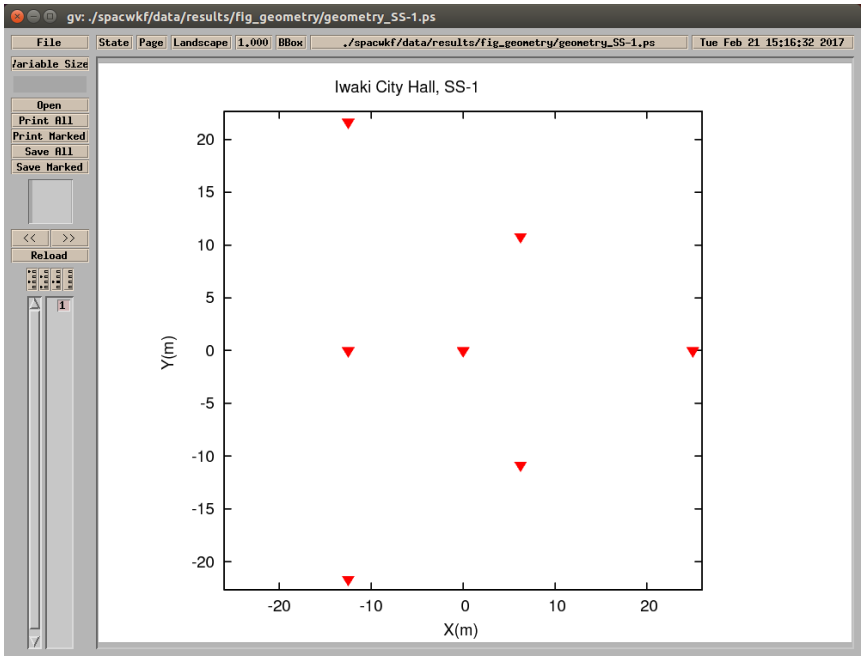
read(1,*)xla(ista),ylo(ista),id(ista)

Example of execution:

```
~SPAC2021$ sh distazi.sh
  Dist-Azimuth coordinates are selected
 X-axis toward East, Y-axis toward North.
      1    25.0    -0.0
      2     6.2    10.8
      3   -12.5    21.7
      4   -12.5    -0.0
      5   -12.5   -21.7
      6     6.3   -10.8
      7     0.0     0.0
         1         2   21.6506348      -59.9999962
...
         6         7   12.5000010      -30.0000038
 ./spacwkf/data/
 ./spacwkf/data/results/distazi.dat
    1    2    7   12.500 -150.000
...
   21    3    5   43.301 -180.000
Iwaki City Hall, SS-1
          7 SS-1
   25.0000000      -9.99999997E-07
   6.25000000       10.8253174
  -12.5000000       21.6506348
  -12.5000000      -9.99999997E-07
  -12.5000019      -21.6506348
   6.25000095      -10.8253174
   0.00000000       0.00000000
```



Plot appears in a pop-up window



~SPAC2021$ gv &

Automatically stored in a PS file, too.

Output files

./spacwkf/data/results/distazi.dat

./spacwkf/data/results/geometry.dat

./spacwkf/prm/gnuplt_script/geometry_SS-1.plt

geometry.plt

Contents of ‘geometry.plt’

load './spacwkf/prm/gnuplt_script/geometry_SS-1.plt'

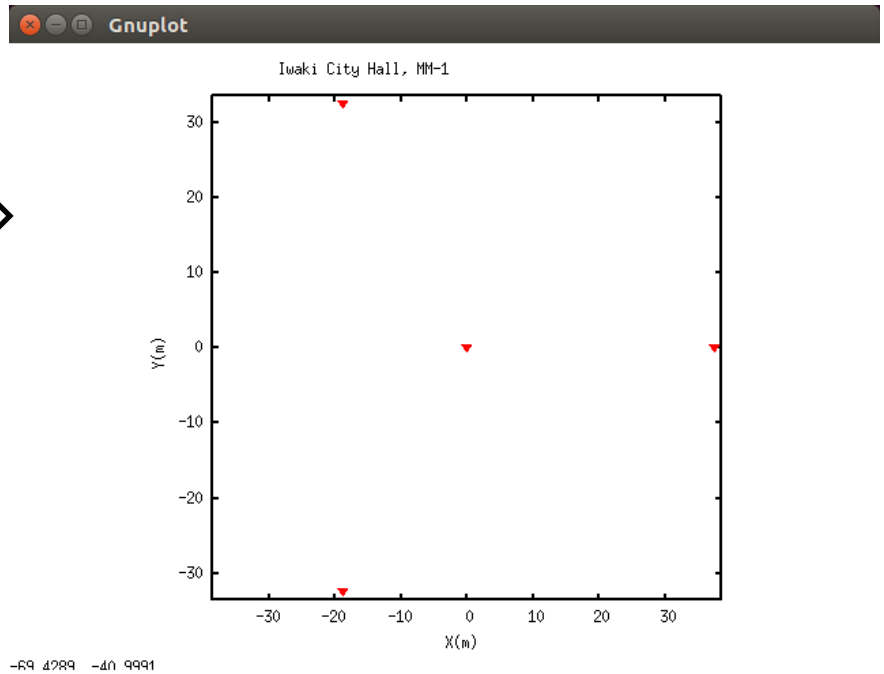
./spacwkf/data/results/fig_geometry/geometry_SS-1.ps

Example: MM-array

distazi.prm

```
Iwaki City Hall, MM-1                    :Explanation (a45)
2                :Type X-Y(=0), Lat-Long(=1),Dist-Angle(=2)
4   MM-1          :Number of stations, Title of figure
  37.5    90.0   1
  37.5   -30.0   2
  37.5  -150.0   3
   0.0     0.0   4
```

Then run distazi.sh



distazi.dat

```
Iwaki City Hall, MM-1
   4      :number of station
        ID          X          Y
         1   37.500000   -0.000002
         2  -18.750000   32.475952
         3  -18.750002  -32.475952
         4    0.000000    0.000000
   id  st1  st2 distance  azimuth
   1    1    4   37.500  -90.000
   2    2    4   37.500  150.000
   3    3    4   37.500   30.000
   4    1    2   64.952  -60.000
   5    1    3   64.952 -120.000
   6    2    3   64.952 -180.000
```

2. Calculation of SPAC coefficient

Program used:

zcorrel.sh

that controls

./bin/zcorrel5_3.exe + ./spacwkf/prm/zcorrel5_3.prm

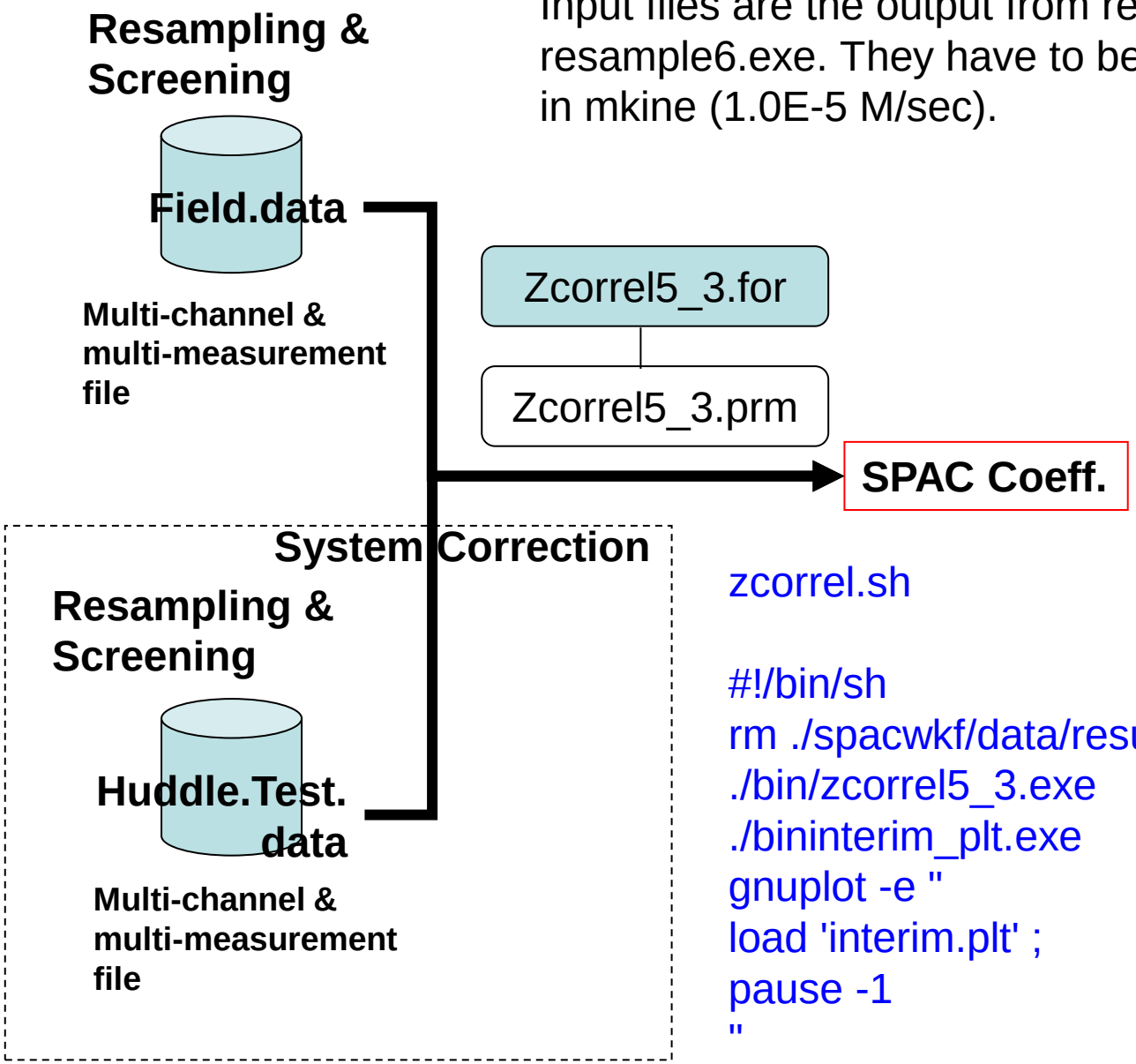
and

./bin/interim_plt.exe + ./spacwkf/prm/zcorrel5_3.prm

for plotting the results

Calculation of SPAC coefficients

Input files are the output from resample5.exe or resample6.exe. They have to be velocity records in mkine (1.0E-5 M/sec).



zcorrel.sh

```
#!/bin/sh
rm ./spacwkf/data/results/temp*.dat
./bin/zcorrel5_3.exe
./bininterim_plt.exe
gnuplot -e "
load 'interim.plt' ;
pause -1
"
```

zcorrel5_3.prm

```
Iwaki City Hall, SS-1
0.1 10.0 0.02 0.25  0 2 :fmin,fmax,dt,bw(>3.71/Td),n_huddle,nhide
HDSS-1.dat   1 1        :Huddle test file name (A12),n_coh_hud,n_pow_hud
IWSS-1.dat   1 1        :input file name (A12),n_coh,n_pow
 5
 3 27 47 67                          12.5
 9 12 16 23 24 26 34 45 46 56        21.65
 3 17 37 57                          25.0
 3 14 25 36                          37.5
 3 13 15 35                          43.3
 SPCSS1.dat                 :output file name(a10)
```

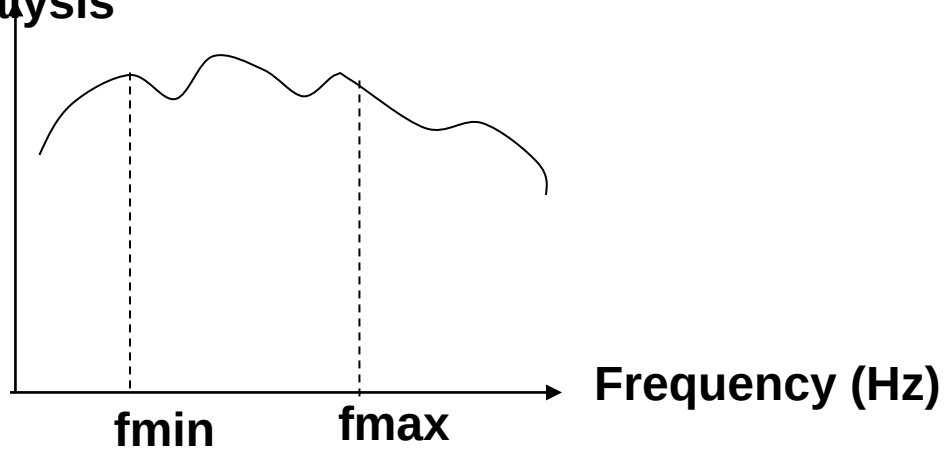
1st line is used as the title of figures created

For the inter-station distance, 12.5m, 3 pairs namely stations (#2,#7),(#4,#7),(#6,#7) are averaged.

In the program nn=nn_org*nhide is conducted, where nn_org denotes length of a time block in the input data file. This means the zero padding in order to shorten the interval of frequency for the calculation of FFT.
Time window length including padded zeros is given by Td=nn_org*nhide*dt

1st line
Parameters: fmin, fmax, bw, n_huddle

Selection of frequency range for analysis



bw: bandwidth of Parzen Window that is used for smoothing the averaged cross- and auto- correlations. The bigger value of "bw" corresponds to smoother SPAC coefficient. bw=0.0 means exection without applying Parzen Window.

n_huddle: Flag for executing the system correction using the huddle test data (0= no effect, =1 conducting system correction). Correction using the huddle test data is usually not necessary when the array is composed of the seismographs of the same type.

2nd line
Parameters: Huddle test file name (A12),n_coh_hud,n_pow_hud

Resampled & screened Multi-channel & multi-measurement file of the huddle test data

***huddle*.dat**

Flag for outputing the coherence file of the huddle test data
0= no effect
1= output

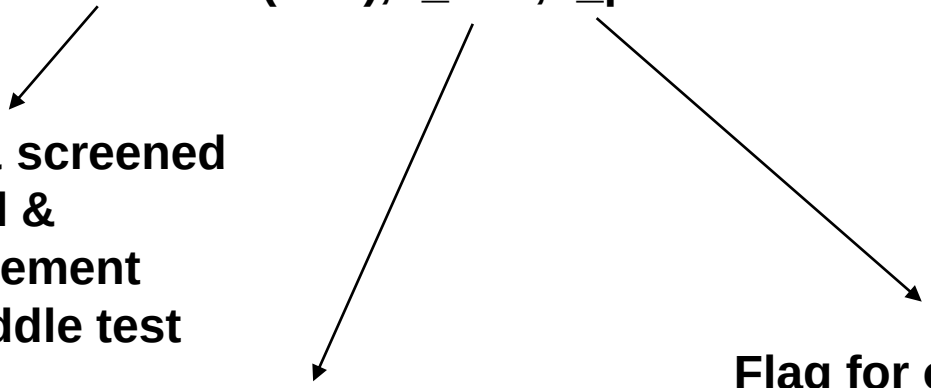
***huddle*_coh.dat**

Flag for outputing the power spectra file of the huddle test data
0= no effect
1= output

***huddle*_psp.dat**

This line is read but not used in the analysis if n_huddle in the 1st line is “0”.

3rd line
Parameters: input file name (A12),n_coh,n_pow



Resampled & screened Multi-channel & multi-measurement file of the huddle test data

***Input*.dat**

Flag for outputing the coherence file of the huddle test data
0= no effect
1= output

***Input*_cor_coh.dat**

Flag for outputing the power spectra file of the huddle test data
0= no effect
1= output

***Input*_cor_psp.dat**

The coherence and the power spectra of the field data without the system correction are output as default.

***Input*_coh.dat**
***Input*_psp.dat**

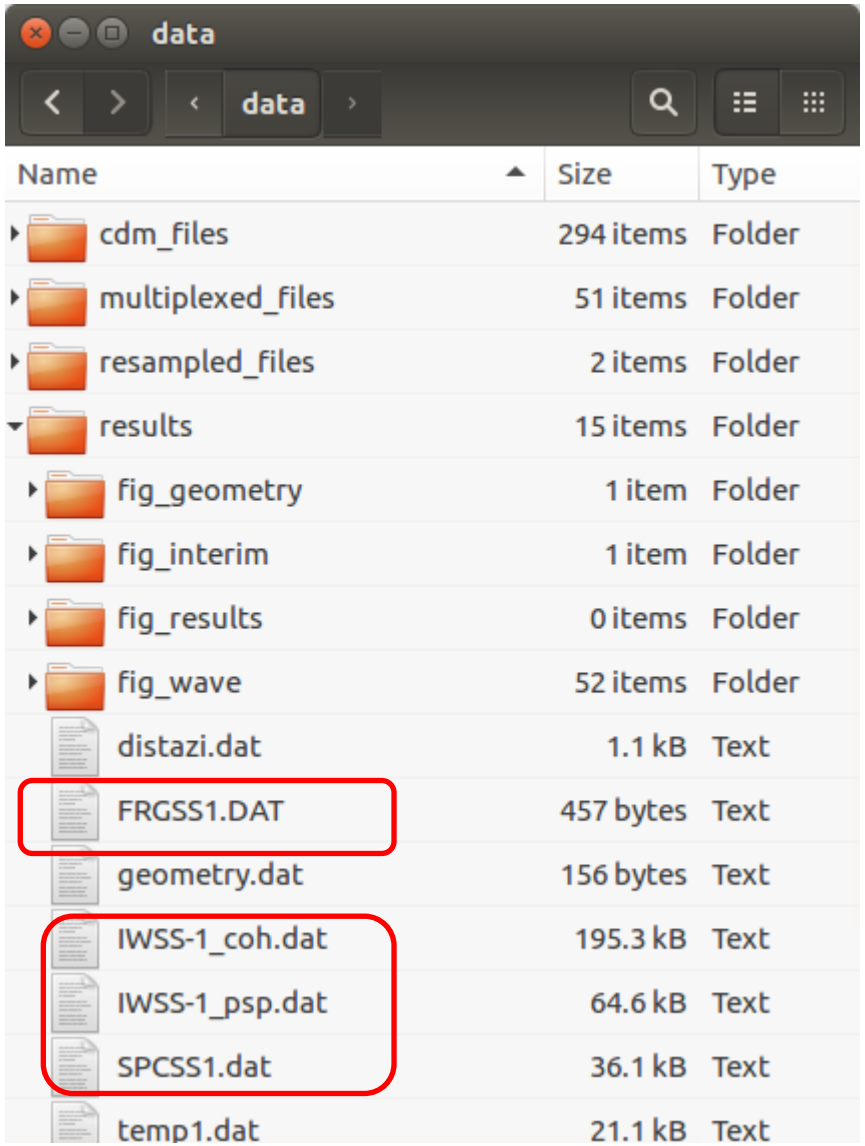
Example of execution:

zcorrel5_3.exe

```
~SPAC2021$ sh zcorrel.sh
 Program zcorrel5_3.for
 ./spacwkf/prm/zcorrel5_3.prm
  Huddle Test Skipped.
 nn=  2048
          28          10
          28          20
  power and cross spectra for field data calculated.
 Block Averaging has been done.
 ./spacwkf/data/results/IWSS-1_psp.dat
Output:./spacwkf/data/results/IWSS-1_psp.dat
 ./spacwkf/data/results/IWSS-1_coh.dat
 ./spacwkf/data/results/SPCSS1.dat
```

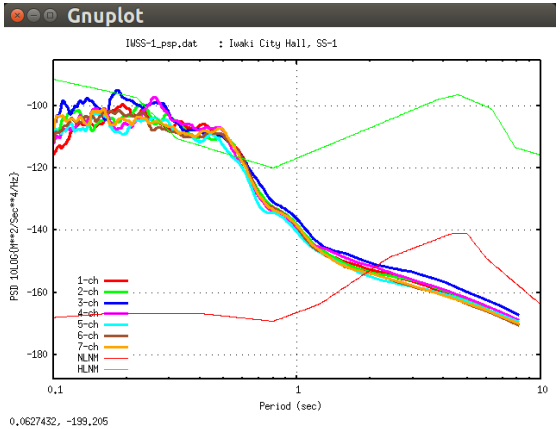
interim_plt.exe

Look the next page

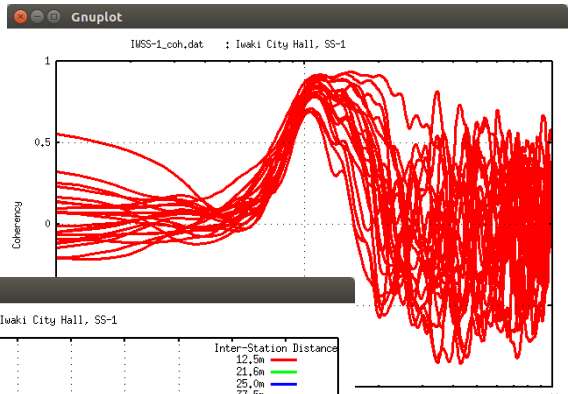


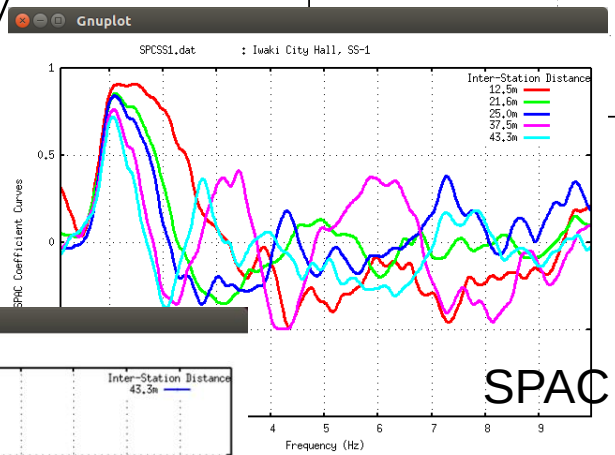
interim_plt.exe

```
Iwaki City Hall, SS-1
Iwaki City Hall, SS-1
Hit return to continue
Hit return to continue
Hit return to continue
Hit return to continue
Hit return to continue
Hit return to continue
Hit return to continue

~SPAC2021$
```



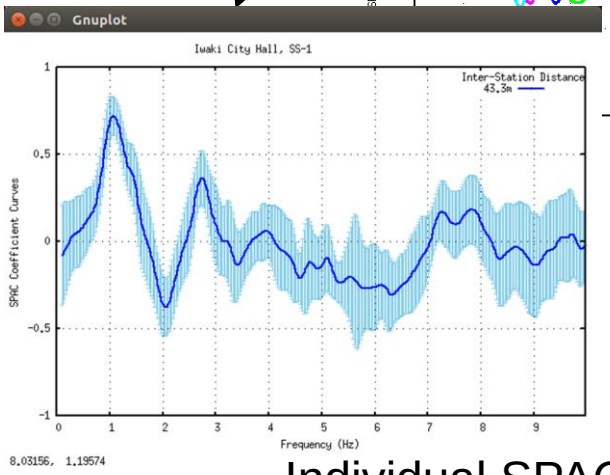
Power spectra





All Coherence functions

SPAC coefficients

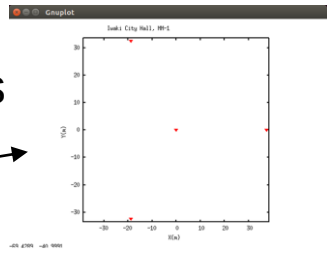


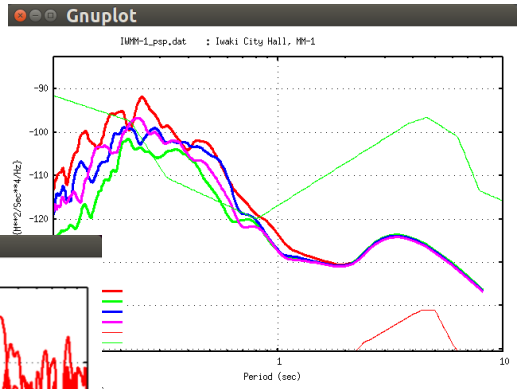
Individual SPAC function with error bar

These figures are automatically stored as PS files in ./spacwkf/data/results/fig_interim

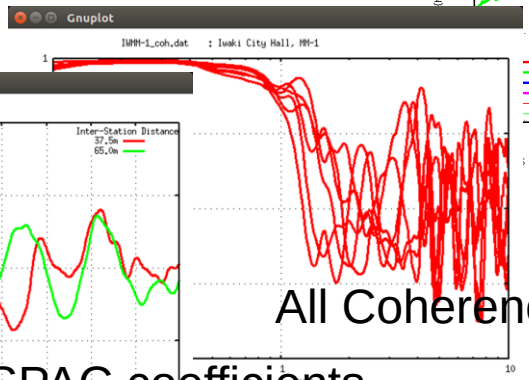
Procedure for MM-1 Array

+ Edit ./spacwkf/prm/resample6.prm for MM-1 Array
+ $ sh resample5.sh ➔ resampled & screened file IWMM-1.dat
+ Edit ./spacwkf/prm/seewav6.prm for MM-1 Array
+ $ sh seewav6.sh ➔ Waveform plot files MM??.ps
+ Edit ./spacwkf/prm/distazi.prm for MM-1 Array
+ $ sh distazi.sh ➔geometry plot file geometry_MM-1.ps
+ Edit ./spacwkf/prm/zcorrel5_3.prm for MM-1 Array
+ $ sh zcorrel.sh ➔ SPAC coefficient file SPCMM1.dat etc.

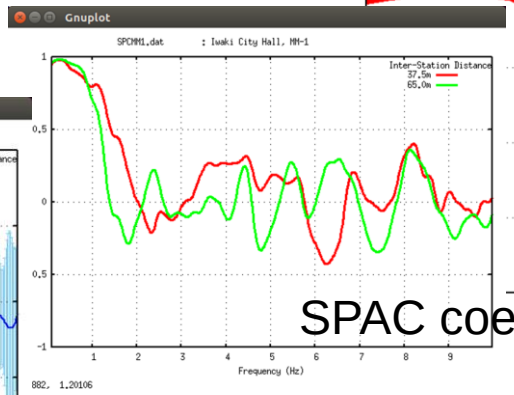




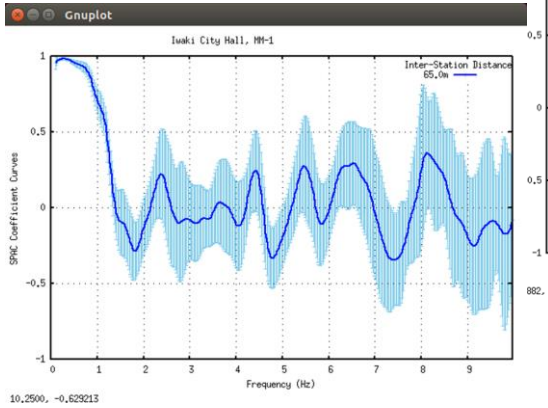
Power spectra



All Coherence functions



SPAC coefficients

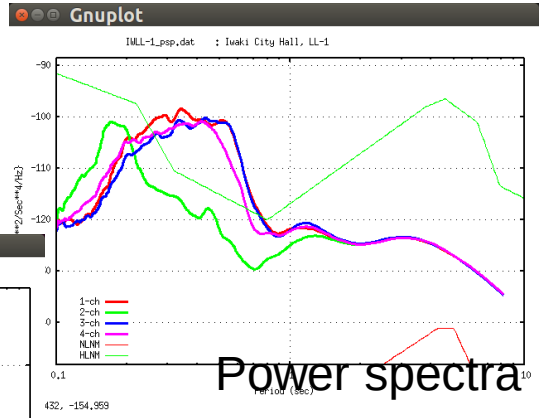


Individual SPAC function with error bar

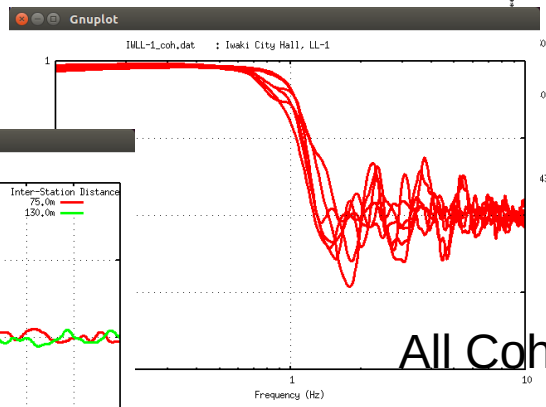
These figures are automatically stored as PS files in ./spacwkf/data/results/fig_interim

Procedure for LL-1 Array

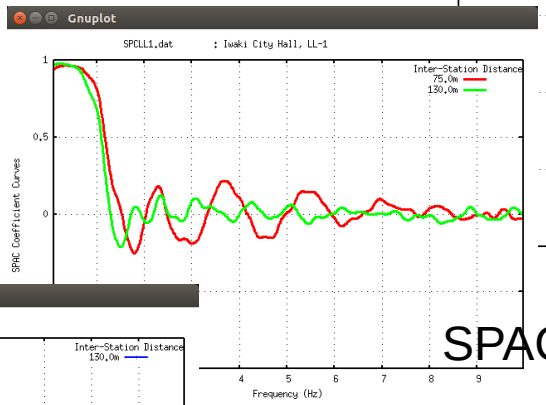
+ Edit ./spacwkf/prm/resample6.prm for LL-1 Array
+ $ sh resample6.sh ➔ resampled & screened file IWLL-1.dat
+ Edit ./spacwkf/prm/seewav6.prm for LL-1 Array
+ $ sh seewav6.sh ➔ Waveform plot files LL??.ps
+ Edit ./spacwkf/prm/distazi.prm for LL-1 Array
+ $ sh distazi.sh ➔geometry plot file geometry_LL-1.ps
+ Edit ./spacwkf/prm/zcorrel5_3.prm for LL-1 Array
+ $ sh zcorrel.sh ➔ SPAC coefficient file SPCLL1.dat etc.



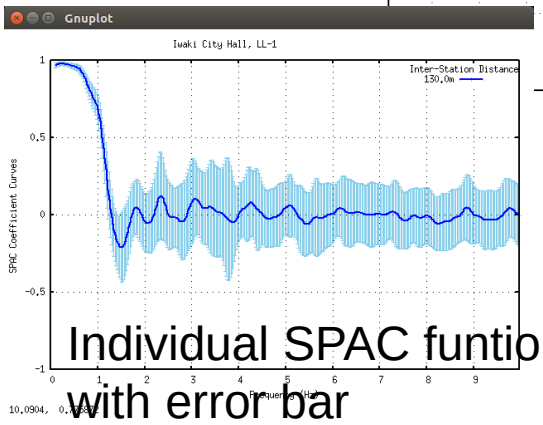
Power spectra



All Coherence functions



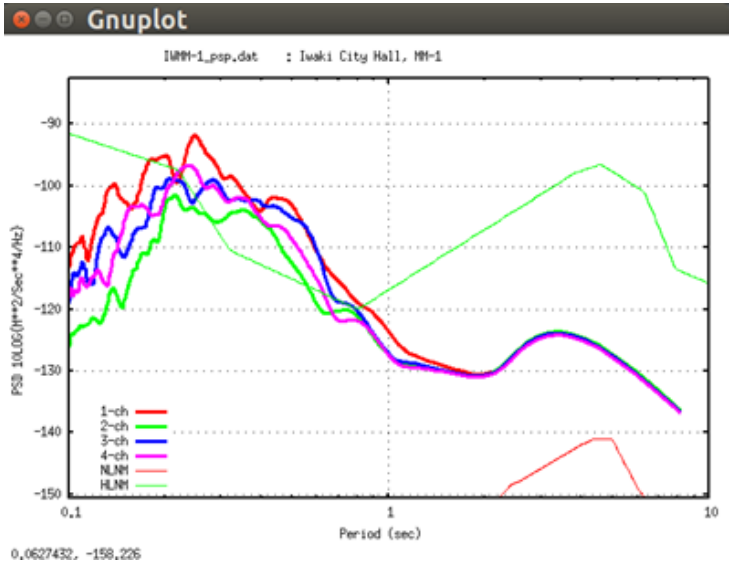
SPAC coefficients



Individual SPAC funtion with error bar

These figures are automatically stored as PS files in ./spacwkf/data/results/fig_interim

Power Spectra



10*Log$_{10}$ (Fourier Coefficient *Td* omg**2) of each frequency is plotted in PostScript file spacwkf/data/results/fig_interim/IWMM-1_psp.ps in the unit 10*Log10(M**2/Sec**4/Hz)
Also output into spacwkf/data/results/IWMM-1_psp.dat that is CSV format file.

IWMM-1_psp.dat

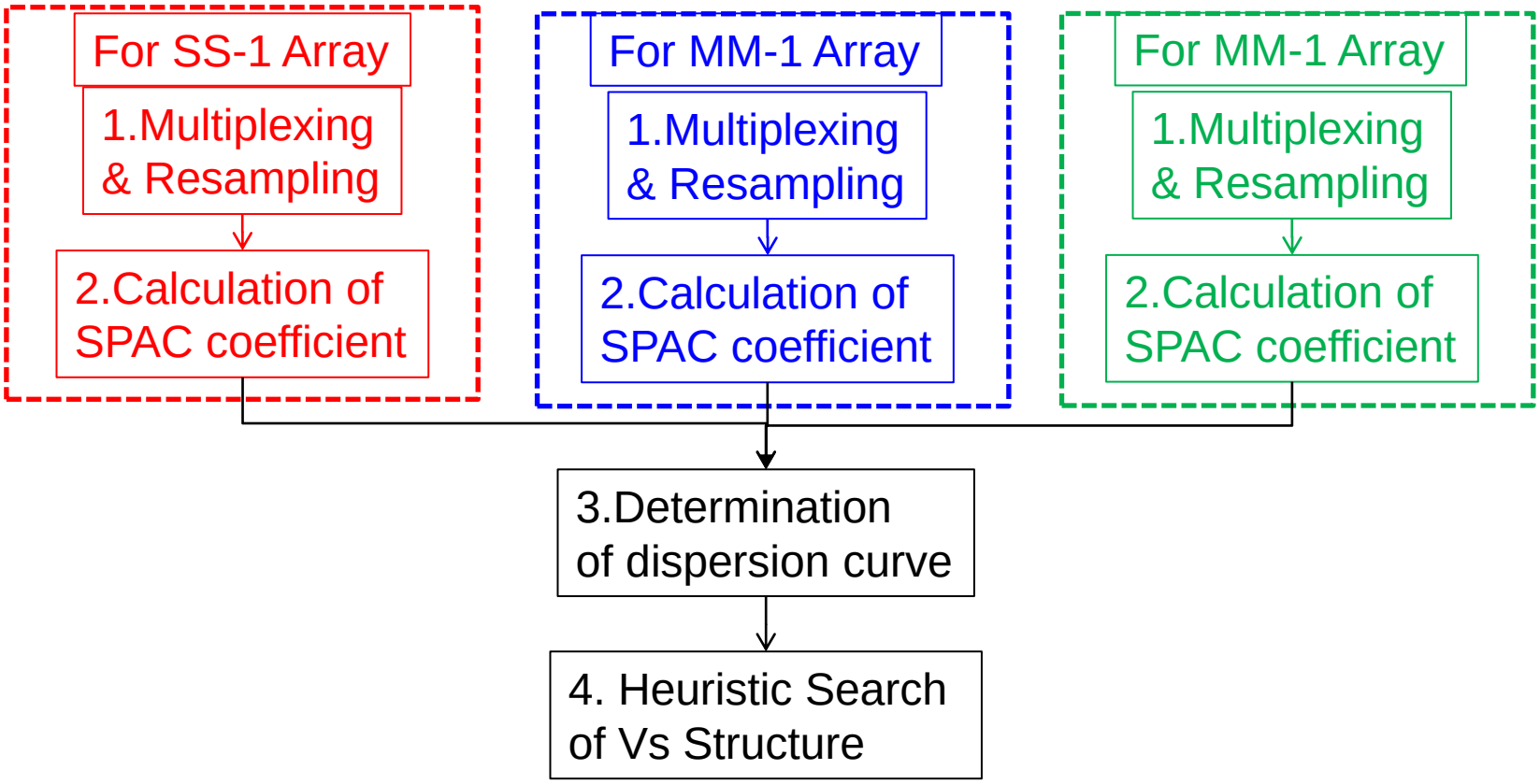
# Period	1-ch	2-ch	3-ch	4-ch	Power Spc 1-ch	2-ch	3-ch	4-ch	S.D.
0.100	-122.523	-121.038	-123.098	-122.525	-123.525	-121.061	-123.484	-122.815	
0.100	-121.617	-120.174	-122.290	-121.659	-122.703	-120.218	-122.836	-122.091	
0.101	-120.964	-119.546	-121.741	-121.039	-122.073	-119.536	-122.445	-121.599	
...									

10*Log10 (Fourier Coefficient * Td * omg**2)

10*LOG10(sqrt(variance of Fourier Coefficient)*Td*omg**2)

where omg=2π/period
When Velocity Fourier Amplitude Spectral Density is required, type
sh fourier.sh
in the folder SPAC2017. fourier_plt.exe convert the above mentioned psp to Fourier Amplitude Spectra.

Example: Up to this slide the red part of the below shown diagram has been performed for SS-1 Array (7 points). The next step is to do the same procedure for MM-1 Array (4 points), i.e., the blue part of the diagram below. Then, the green part.



SPCSS1.dat, SPCMM1.dat, SPCLL1.dat are used in the next step of analysis.

3. Determination of Dispersion Curve

Programs used:

cf_panel1.sh

that controls

./bin/cf_panel1.exe + cf_panel1.prm

for fitting to Bessel function, plotting SPAC coefficient and determination of dispersion curve using the imaging technique.

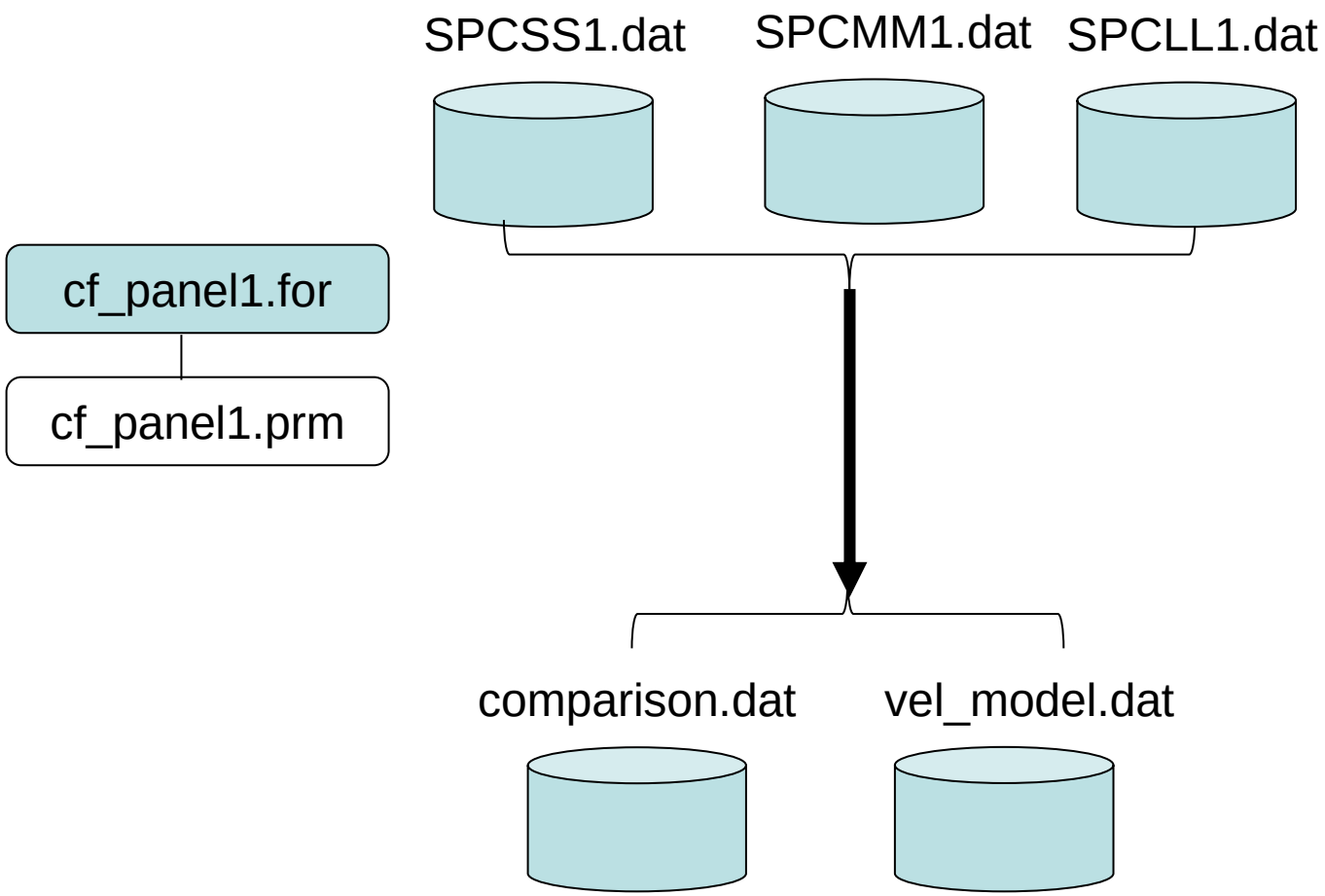
For plotting

vel_model.sh

that controls

./bin/vel_model_plt.exe + vel_model_plt.prm

All input files must have the same df=1/Td



The same file name is used for every case

Determination of dispersion curve

1st step:

+ The fif-th order polynomial that approximates the inverse function of $J_o(x)$

$$y=-6.0803x^5+9.2477x^4-3.9322x^3+0.1815x^2-1.7079x+2.4121$$

is used to calculate the tentative values of the phase velocity $c(r,\omega)$, where $y=kr=r\omega/c(r,\omega)$, $x=\rho(r,\omega)$.

+ The wave lengths are estimated from the observed SPAC coefficients through this tentative phase velocity.

+ The frequency range for analysis is narrowed below the frequency that corresponds to the spacial Nyquist wave length, i.e., 2 times the minimum interstation distance.

+ The frequency range for analysis is again narrowed above the frequency of the maximum value of SAC coefficient curves.

2nd step:

+ Imaging technique is applied to determine the phase velocity of each frequency. The misfit function is set for the SPAC coefficient curves.

Example:

cf_panel1.prm

```
Iwaki city Hall (test data)    2017 version       :graph title(a50)
 0  1  0 40.96  0.1    :n_message,n_comparison(0=no, 1=yes),nfskip(0=no, 1=yes),Td, aps
 0.10  5.0  80.0  1000.0 :fmin,fmax,vmin,vmax that specify the range of analysis
3                    :file number
SPCSS1.dat              :file name (a12)
   5                 :Number of Radius
 12.5  1.0            :Radius(m),Min and Max of the frequency(Hz) for fitting
 21.6  1.0
 25.0  1.0
 37.5  1.0
 43.3  1.0
SPCMM1.dat              :file name (a12)
   2                 :Number of Radius
 37.5                  :Radius(m),Min and Max of the frequency(Hz) for fitting
 65.0
SPCLL1.dat              :file name (a12)
   2                 :Number of Radius
 75.0                  :Radius(m),Min and Max of the frequency(Hz) for fitting
130.0
```

SS-1-array

MM-1-array

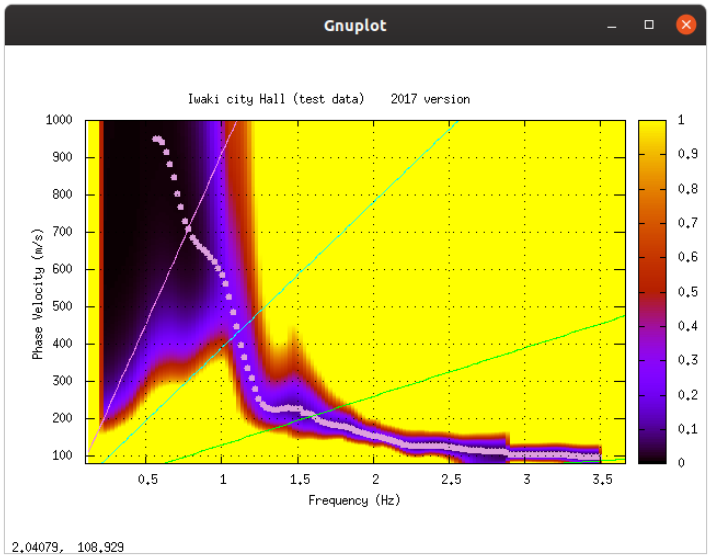
LL-1-array

The list of inter-station distances must be coincident to the contents of the SPAC coefficient's file.

The minimum and maximum frequency for fitting can be specified, if not f_{min} and f_{max} in the 3rd line will be used in place of them.

Example of execution:

```
$ sh cf_panel1.sh
 n_message=  0 n_comparison=  1 nfskip=  0   0.200E+00
 Range of Analysis: from     0.10(Hz) to     5.00(Hz)
                and from    50.00(m/s) to  1000.00(m/s)
 Number of files=   3 for SPAC Coef. curves.
 1  SPCSS1.dat
 2  SPCMM1.dat
 3  SPCLL1.dat
 No. Distance min_fr  max_fr
                m     Hz     Hz
      1   12.50    1.47    3.56
      2   21.60    1.42    2.86
      3   25.00    1.10    2.32
      4   37.50    1.07    2.03
      5   43.30    1.05    1.93
      6   37.50    1.10    2.34
      7   65.00    0.24    1.81
      8   75.00    0.34    1.81
      9  130.00    0.17    1.51
 Range of analysis: fmin=  0.561999977      fmax=  3.56399989
 ./spacwkf/prm/gnuplt_script/SPAC_coef.plt
 ./spacwkf/prm/gnuplt_script/cf_panel1.plt
Hit return to continue
```



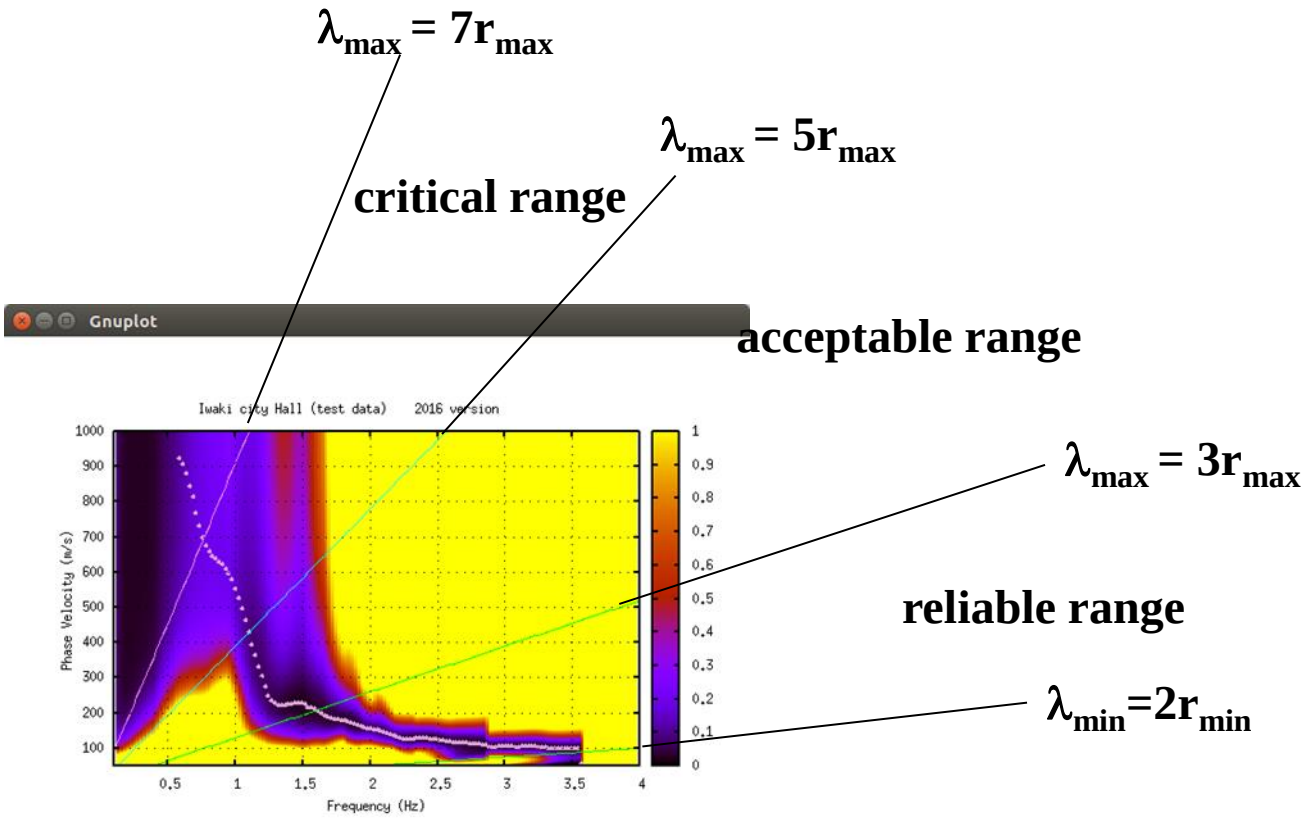
These figures are automatically stored as PS files in
./spacwkf/data/results/fig_results

Wave_Length λ = Phase_Velocity c / Frequency f

Nyquist_Wave $\longrightarrow$ $\lambda_{min}=2r_{min}$

λ_{max} < $7r_{max}$: longer side limit of the critical range
< $3r_{max}$: limit between the critical and the acceptable ranges
< r_{max} : limit between the acceptable and the reliable ranges

(After Cornou et al., 2006)



Example of Output

vel_model.dat for the determined dispersion curve

```
#  freq.(Hz) Vel.(km/s)
      0.561      0.951      0.165
      0.586      0.950      0.158
      0.610      0.941      0.153
      0.635      0.914      0.140
      0.659      0.883      0.130
…
```

Standard Deviation

Comparison.dat

for checking the glade of fitting

```
…
 6   37.500      0.071     -0.180      0.199
f=    1.953       Hz   160.00          =c
      r    SPAC_Coef.    Cal_Bessel    S.D.
      0.000                1.000
 1   12.500      0.777      0.783      0.076
 2   21.600      0.388      0.423      0.091
 3   25.000      0.176      0.272      0.205
 4   37.500     -0.241     -0.215      0.186
 6   37.500      0.048     -0.215      0.198
f=    1.977       Hz   157.00          =c
      r    SPAC_Coef.    Cal_Bessel    S.D.
…
```

- Standard deviation of the observed SPAC coefficient
- SPAC coefficient calculated using determined phse velocity
- Observed SPAC coefficient
- Inter-station distance

Plot the determined dispersion curve:
Execution: After editing ./spacwkf/prm/vel_model_plt.prm
for the graph title, [fmin,fmax] and [vmin, vmax]

./spacwkf/prm/vel_model_plt.prm

```
Iwaki City Hall SS,MM,LL Arrays  2012/09/15      :title(a50)
  0.5  4.0                      :fmin,fmax
  80. 1000.                     :vmin,vmax
 1                              : n_mod

+++
1st line: title of phase velocity plot
2nd line: fmin and fmax for plotting
3rd line: vmin and vmax for plotting
4th line: n_mod
        =1: wavelength/3 – Vs will be plotted in Vs structure plot
        otherwise not plotted.
```

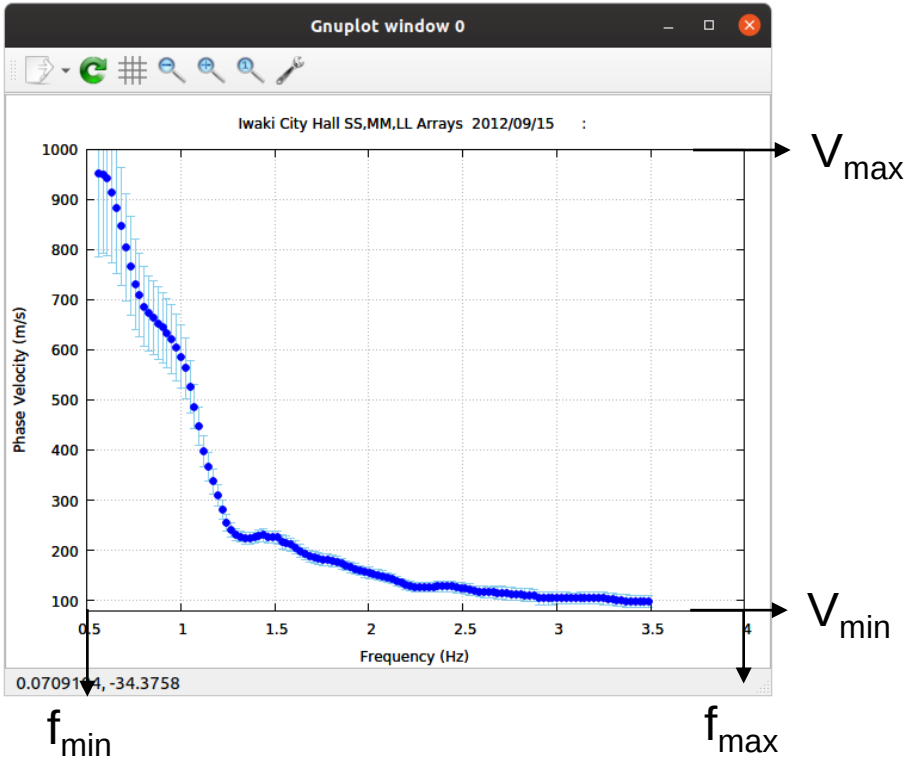
File: vel_model.dat

- [fmin, fmax] described in vel_model_plt.prm and used by vel_model_plt.exe and cf_panel.exe are not reflected to the contents of the file vel_model.dat.
- It is recommendable to edit vel_model.dat manually to select the frequency range used in the next step.
- Don't leave a blank line at the end of the file vel_model.dat after editing.
- Run vel_model_plt.exe after editing it.➔ *sh .vel_model.sh*

~SPAC2021$ sh vel_model.sh
./spacwkf/prm/gnuplt_script/vel_model.plt

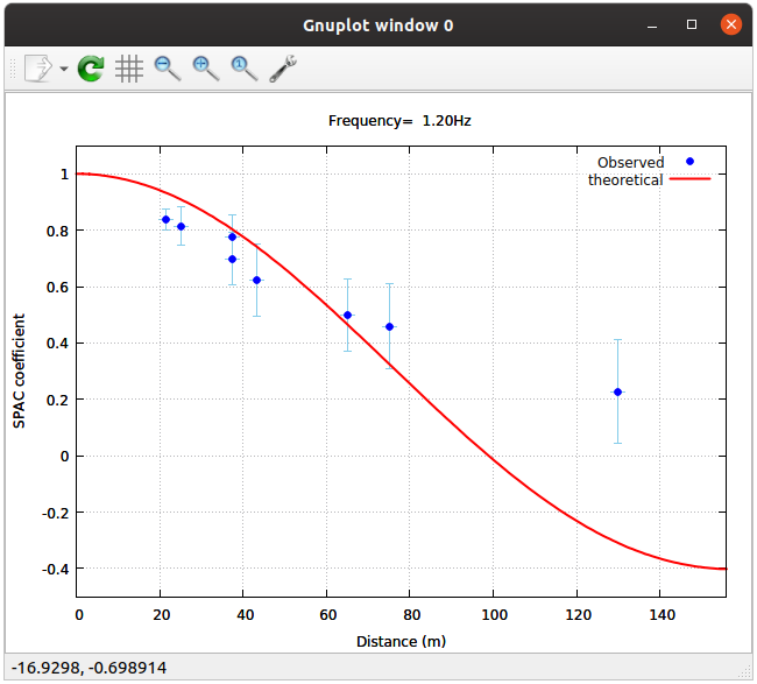
This figure is automatically stored as PS files in

./spacwkf/data/results/fig_results



Plot the SPAC coefficient curve fitting:

Execution:
$ sh comparison.sh
…
Type in the frequency that you want to select.
…
./spacwkf/prm/gnuplt_script/comparison.plt



Simultaneously the same imge is saved in a PostScript file:
./spacwkf/data/results/fig_results/comparison.ps

4. Heuristic Search of Vs Structure

Programs used:

inversion.sh

that controls

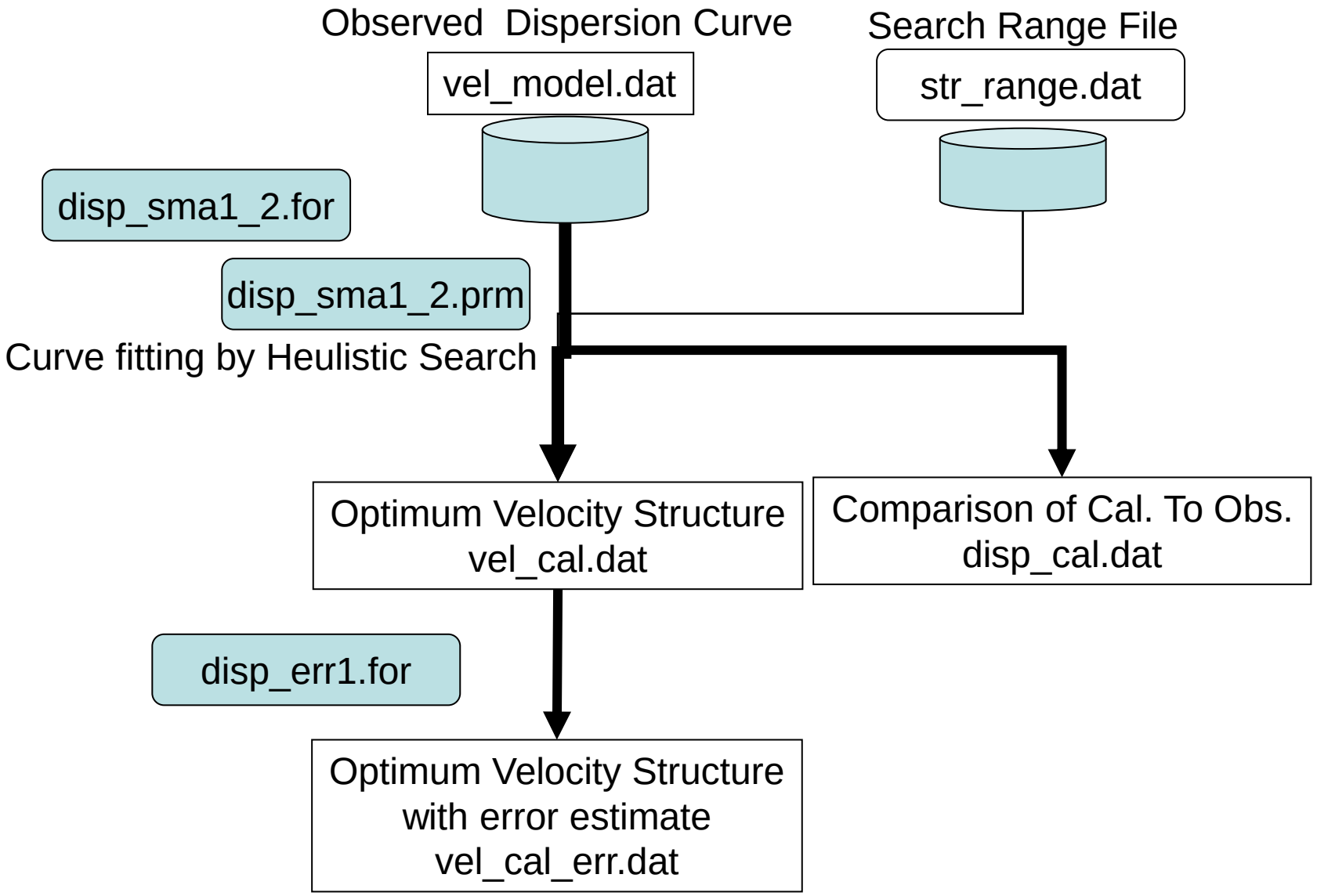
./bin/disp_sma1_2.exe + ./spacwkf/prm/disp_sma1_2.prm

./bin/disp_err1.exe

results.sh

that controls

./bin/results_plt.exe


Observed Dispersion Curve
vel_model.dat
Search Range File
str_range.dat
disp_sma1_2.for
disp_sma1_2.prm
Curve fitting by Heulistic Search
Optimum Velocity Structure
vel_cal.dat
Comparison of Cal. To Obs.
disp_cal.dat
disp_err1.for
Optimum Velocity Structure
with error estimate
vel_cal_err.dat

inversion.sh

```
#!/bin/sh -x
rm ./spacwkf/data/results/temp*.dat 2>/dev/null
./bin/disp_sma1_2.exe | tee spacwkf/log/disp_sma1_2.log
./bin/disp_err1.exe | tee spacwkf/log/disp_err1.log
rm ./spacwkf/data/results/temp*.dat
```

results.sh

```
#!/bin/sh -x
./bin/results_plt.exe
gnuplot -e "load 'results.plt’ ; pause -1"
```

disp_sma1_2.for

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)

Example: disp_sma1_2.prm

```
 1 1. 0.6 1.3 10000  5  :idum,t0,a,c,ntemp,j0
 0.0025                 :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).
vel_model.dat          :File name for the obseved dispersion relation (a25).
vel_cal.dat            :File name for the estimated velocity structure (a25)
disp_cal.dat           :File name for the calculated dispersion relation (a25)
```

Control parameter for the simulated annealing method

idum :Random seed (integer): As the result may depend on the initial velocity model given by random number, it is strongly recommended for users to apply this program several times with various values of random seed and to grasp the scatter of result.

t0, a,c :Initial Temperature, Coefficients for T=T0*exp(-c*k**a), where k is iteration number. T0=1.0, a=0.6 & c=1.3 are of the fastest schedule

ntemp :Maximum number of temparature change

j0 :Number of iteration for each temperature

threshold for conversion

eps0 : threshold of misfit function

flags for roh and vp

n_vp : 1=by Ludwig et al(1970): vp=1.11*vs+1.29; 0=fixed to the initial values

n_roh : 1=by Kitzunezaki et al(1990): roh=1.2475+0.399*vp-0.026*vp**2; 0=fixed to the initial values

flags for output to Display

ini_flg : Initial Velocity Structure Model. 1=yes

ndsp_flg : Observed Dispersion Relation . 1=yes

n_err : Error at each iteration, 1=yes

kflg : Missfit at each temp. change, 1=yes

jflg : Missfit at each itration with the same temp. 1=yes

n_vs : Vs value (n_vs=layer number, 0=no output)

n_th : Thickness value (n_th=layer number, 0=no output)

n_err :

Example: str_range.dat ← Initial Search Range

```
Iwaki City, S-M-L 22/12/2012  :Model(a30)
        6                     :IL(I5),Layer Number
1.9   1.5    0.005  0.030  0.10 0.12 :density,Vp,hmin,hmax,vmin,vmax
1.9   1.5    0.005  0.030  0.10 0.20 :density,Vp,hmin,hmax,vmin,vmax
1.9   1.5    0.005  0.030  0.20 0.40 :density,Vp,hmin,hmax,vmin,vmax
1.9   1.5    0.005  0.300  0.40 0.70 :density,Vp,hmin,hmax,vmin,vmax
1.9   1.5    0.005  0.300  0.70 1.00 :density,Vp,hmin,hmax,vmin,vmax
2.0   1.70   998.0 999.0   1.00 3.20
```

(hmin, hmax) : Search range for layer thickness.
(vmin, vmax) : Search range for Vs (Shear Wave Velocity)

Example of execution(1): inversion.sh

```
$ 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.+
+-------------------------------------------------+
./spacwkf/data/results/progress.dat
./spacwkf/prm/disp_sma1_2.prm
./spacwkf/prm/str_range.dat
 Initial values randomly produced
```

Opening

Interim output

Input files

Example of execution(2):

```
 Range of random fluctuation
Thicknes Density      Vp      Vs   Thickness          Vs
   0.018   1.756   1.403   0.102   0.005   0.030   0.100   0.120
   0.026   1.770   1.445   0.139   0.005   0.030   0.100   0.200
   0.023   1.849   1.696   0.365   0.005   0.030   0.200   0.400
   0.120   1.952   2.036   0.672   0.005   0.300   0.400   0.700
   0.275   1.993   2.176   0.798   0.005   0.300   0.700   1.000
 999.000   2.356   3.645   2.121 998.000 999.000   1.000   3.200
 ./spacwkf/data/results/vel_model.dat
    5    0.0092043458
   10    0.0059573189
   15    0.0059573189
...
 810    0.0024932232
 ./spacwkf/data/results/vel_cal.dat
       Thicknes(Km) Density(g/cm^3)     Vp(Km/sec)     Vs(Km/sec)
    1       0.021996       1.755735       1.401826       0.100744
    2       0.006866       1.784393       1.490328       0.180476
    3       0.006150       1.850516       1.699537       0.368953
    4       0.146807       1.861471       1.734910       0.400820
    5       0.027075       2.031596       2.314106       0.922618
    6     999.000000       2.101820       2.572326       1.155249
 ./spacwkf/data/results/disp_cal.dat
 ./spacwkf/data/results/err_estm.dat
```

Initial model selected using random number with in the given initial search range

Input file (Dispersion Curve)

Iterations (Number , Misfit func.)

Output file

Optimum Solution

Output files

Output-1

progress.dat: Structure Models of every j0 iterations are stored.

err_estm.dat: Data for error estimation (Next Step) are stored.

Example of execution(3): inversion.sh

Error estimate by disp_err1.exe

```
 ./spacwkf/prm/disp_sma1_2.prm
 ./spacwkf/prm/str_range.dat
 ./spacwkf/data/results/vel_model.dat
 ./spacwkf/data/results/err_estm.dat
 IL= 6 MP=13 NP=12
minimum =  1th vertex
 Sensitivity calculated by finite diference
 & stored in the output file sensitivity.dat
 ./spacwkf/data/results/Vel_cal_err.dat
```

Input files

Output files

	Thicknes(Km)	SD	Roh(g/cm^3)	SD	Vp(Km/sec)	SD	Vs(Km/sec)	SD
1	0.022	0.000	1.756	0.000	1.402	0.000	0.101	0.000
2	0.007	0.000	1.784	0.002	1.490	0.005	0.180	0.004
3	0.006	0.006	1.851	0.013	1.700	0.043	0.369	0.039
4	0.147	0.011	1.861	0.003	1.735	0.010	0.401	0.009
5	0.027	0.131	2.032	0.222	2.314	0.795	0.923	0.717
6	999.000	0.000	2.102	0.041	2.572	0.154	1.155	0.139

Output-1

vel_cal.dat: Optimum Solution

Thicknes(Km)	Density(g/cm^3)	Vp(Km/sec)	Vs(Km/sec)
1	0.021996	1.755735	1.401826	0.100744
2	0.006866	1.784393	1.490328	0.180476
3	0.006150	1.850516	1.699537	0.368953
4	0.146807	1.861471	1.734910	0.400820
5	0.027075	2.031596	2.314106	0.922618
6	999.000000	2.101820	2.572326	1.155249

disp_cal.dat: Observed & Calculated Dispersion Curves

#	Frequency(Hz)	Observed Velocity	Calculated Velocity	
	0.561	0.951	0.957	0.165
	0.586	0.950	0.942	0.158
	0.610	0.941	0.925	0.153
	0.635	0.914	0.903	0.140
	0.659	0.883	0.880	0.130
	0.684	0.846	0.853	0.117
	0.708	0.804	0.827	0.107
	0.732	0.767	0.801	0.098
	0.757	0.731	0.775	0.090
	0.781	0.709	0.750	0.084
	0.806	0.686	0.726	0.079

…

Output-2

vel_cal_err.dat: Optimum Solution with estimated error (SD).

Thicknes(Km)	SD	Roh(g/cm^3)	SD	Vp(Km/sec)	SD	Vs(Km/sec)	SD
1	0.022	0.000	1.756	0.000	1.402	0.000	0.101	0.000
2	0.007	0.000	1.784	0.002	1.490	0.005	0.180	0.004
3	0.006	0.006	1.851	0.013	1.700	0.043	0.369	0.039
4	0.147	0.011	1.861	0.003	1.735	0.010	0.401	0.009
5	0.027	0.131	2.032	0.222	2.314	0.795	0.923	0.717
6	999.000	0.000	2.102	0.041	2.572	0.154	1.155	0.139

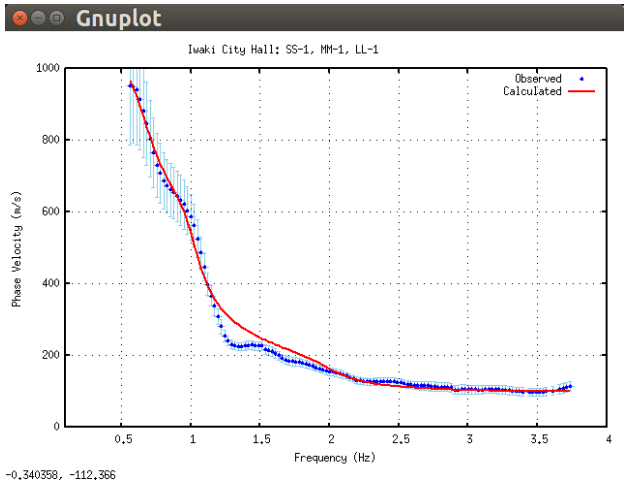
sensitivity.dat: results of sensitivity analysis of structural parameters (h & vs) to Vs.

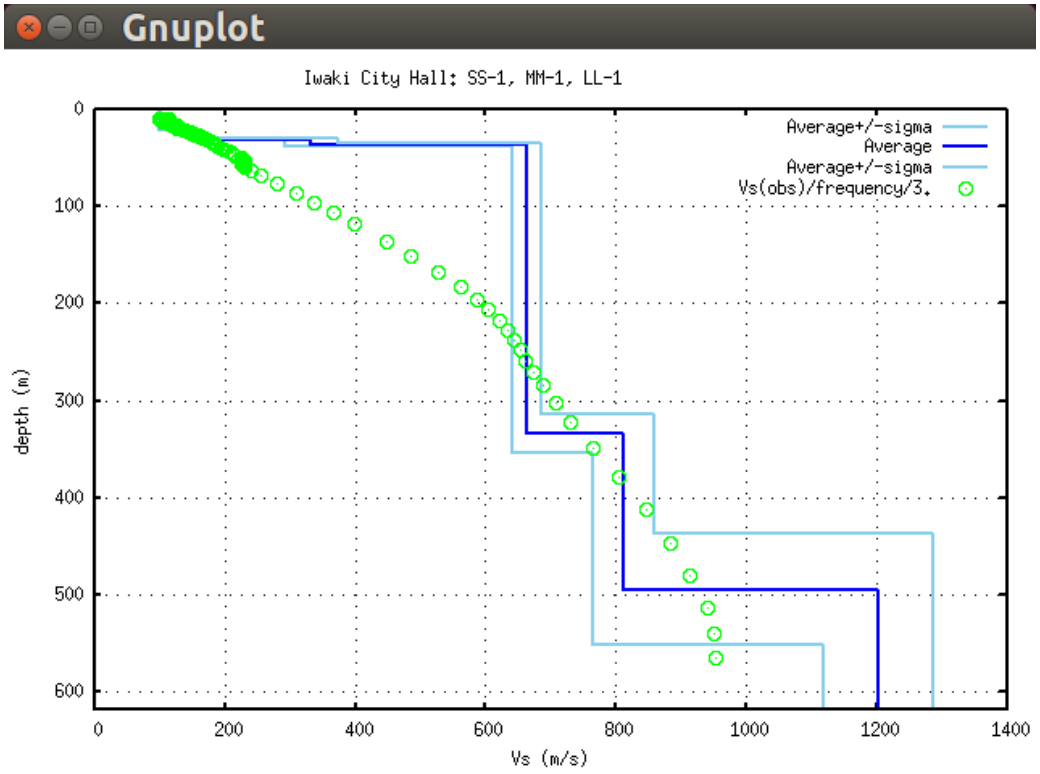
Frequency	h=1	h=2	h=3	h=4	h=5	v=1	v=2	v=3	v=4	v=5	v=6
0.561E+00	0.596E+01	0.398E+01	0.171E+01	0.124E+01	0.258E+00	0.511E+00	0.120E+00	0.679E-01	0.804E+00	0.375E-01	0.610E+00
0.586E+00	0.711E+01	0.440E+01	0.176E+01	0.134E+01	0.227E+00	0.664E+00	0.141E+00	0.746E-01	0.116E+01	0.340E-01	0.548E+00
0.610E+00	0.912E+01	0.515E+01	0.196E+01	0.156E+01	0.216E+00	0.869E+00	0.175E+00	0.877E-01	0.155E+01	0.334E-01	0.459E+00
0.635E+00	0.119E+02	0.682E+01	0.244E+01	0.182E+01	0.231E+00	0.122E+01	0.248E+00	0.117E+00	0.195E+01	0.371E-01	0.355E+00
0.659E+00	0.143E+02	0.794E+01	0.267E+01	0.195E+01	0.218E+00	0.157E+01	0.305E+00	0.137E+00	0.228E+01	0.368E-01	0.260E+00
0.684E+00	0.166E+02	0.894E+01	0.280E+01	0.200E+01	0.200E+00	0.191E+01	0.363E+00	0.156E+00	0.250E+01	0.353E-01	0.179E+00

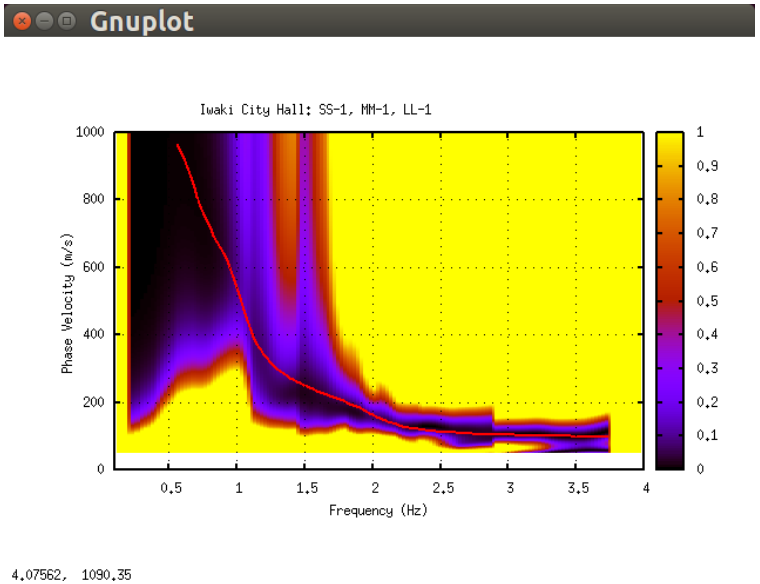
...

Graphical Output: *sh results.sh*

./spacwkf/prm/gnuplt_script/disp_cal.plt
./spacwkf/prm/gnuplt_script/cal_cf_panel.plt
./spacwkf/prm/gnuplt_script/vs_structure.plt
Hit return to continue
Hit return to continue



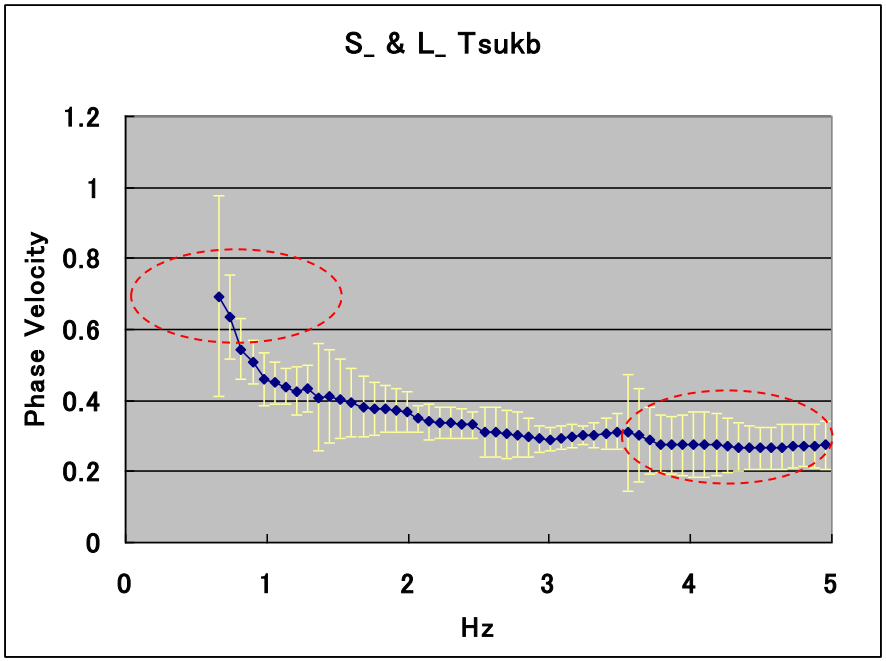




Set n_mod=0 in ‘vel_model_plt.prm’ to eliminate green circles.

These figures are automatically stored as PS files in ./spacwkf/data/results/fig_results

A way to find the optimum solution
- Explanation using another example -



In the highest frequency range, the phase velocity is about 0.3 (Km/sec).

At the lowest frequency 0.664 (Hz) the phase velocity estimated is 0.695 (Km/sec). Then, the corresponding wave length is about 1 (Km) and the expected explored depth very roughly estimated may be about 250 (m).

Examples of Search Range

str_range.dat (4 layer model for exploration from surface to the seismic bedrock)

```
Yamanaka (2001)                          :Model(a30)
    4                                    :IL(I5),Layer Number
1.8 1.956 0.001 0.05  0.4  0.9 :density,Vp,hmin,hmax,vmin,vmax
2.0 2.400 0.001 0.30  0.7  1.3
2.3 2.955 0.010 0.30  1.2  1.8
2.5 4.842 998.0 999.0 2.6  3.6
```

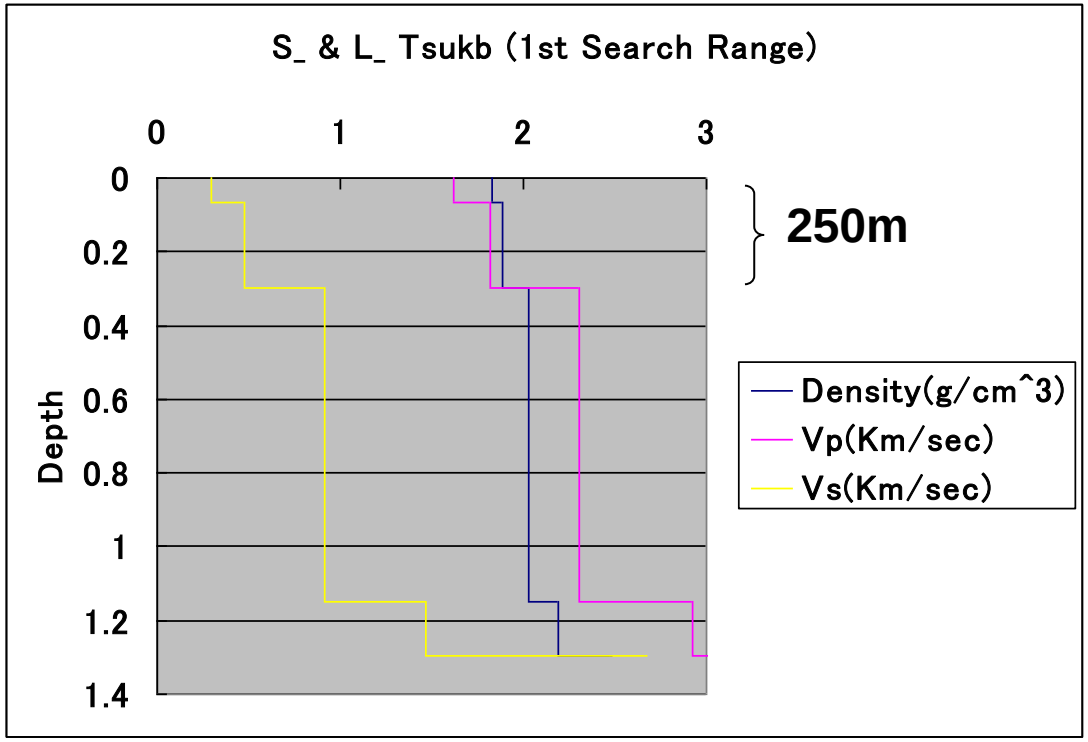
str_range.dat(4 layer model for exploration from surface to the engineering bedrock)

```
Engineering Bedrock                      :Model(a30)
    6                                    :IL(I5),Layer Number
1.5 1.5  0.0   0.03  0.08 0.15 :density,Vp,hmin,hmax,vmin,vmax
1.5 1.5  0.001 0.03  0.10 0.15
1.5 1.5  0.001 0.03  0.08 0.15
1.6 1.5  0.001 0.03  0.15 0.25
1.7 1.6  0.001 0.03  0.25 0.35
1.8 1.8  998.0 999.0 0.35 0.8
```

1st Search Range

```
S_ & L_ Tsukb                                  :Model(a30)
    5                                          :IL(I5),Layer Number
1.5   1.6    0.001 0.2   0.2  0.5 :density,Vp,hmin,hmax,vmin,vmax
1.8   1.956  0.01  1.0   0.4  0.9
2.0   2.4    0.1   1.0   0.7  1.3
2.3   2.955  0.1   1.0   1.2  1.8
2.5   3.2    998.0 999.0 2.6  3.6
```

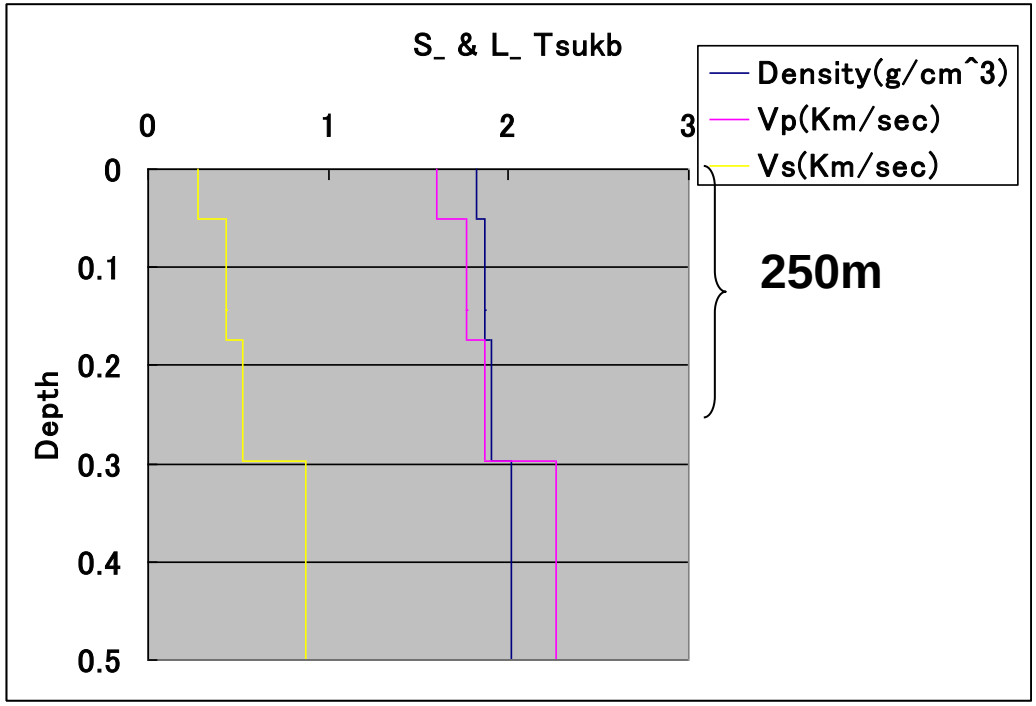
eps=0.01



2nd Search Range

```
S_ & L_ Tsukb                                  :Model(a30)
    5                                          :IL(I5),Layer Number
1.5   1.6    0.001 0.2   0.2  0.4 :density,Vp,hmin,hmax,vmin,vmax
1.5   1.6    0.001 0.2   0.3  0.5
1.5   1.6    0.001 0.2   0.3  0.5
1.5   1.6    0.001 0.2   0.4  0.6
1.8   1.956  998.0 999.0 0.5  0.9
```

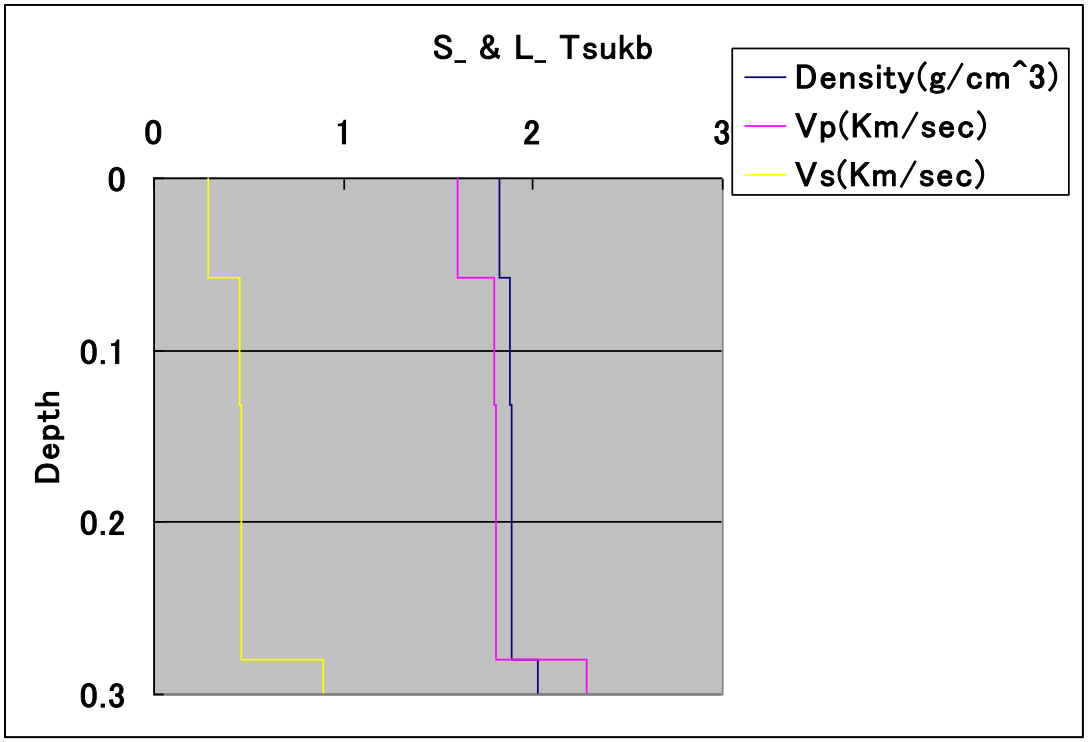
eps=0.0065



3rd Search Range

```
S_ & L_ Tsukb                              :Model(a30)
     4                                     :IL(I5),Layer Number
1.5    1.6     0.001 0.2    0.2   0.4  :density,Vp,hmin,hmax,vmin,vmax
1.5    1.6     0.001 0.2    0.3   0.5
1.5    1.6     0.001 0.2    0.4   0.6
1.8    1.956   998.0 999.0  0.5   0.9
```

eps=0.0065



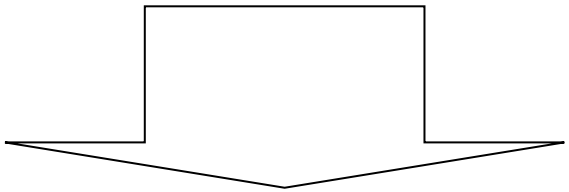
disp_sma1_2.prm

```
 1 1.  0.6 1.3 500   5   :idum,t0,a,c,ntemp,j0
 0.0065                    :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).
vel_model.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)

c idum      :Random seed (integer)
c t0          :Initial Temperature
c a,c         :Coefficients for T=T0*exp(-c*k**a), where k is iteration number

<The optimum schedule is given t0=1.0, a=0.6, c=1.3 (Yokoi(2006)).>

c ntemp     :Maximum number of temparature change
c j0            :Number of iteration for each temperature
c threshold for conversion
c  eps0      : averaged deviation
```

disp_sma1_2.prm (continuation)

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

```
S_ & L_ Tsukb                                  :Model(a30)
    4                                          :IL(I5),Layer Number
1.5   1.6    0.001 0.2   0.2  0.4 :density,Vp,hmin,hmax,vmin,vmax
1.5   1.6    0.001 0.2   0.3  0.5
1.5   1.6    0.001 0.2   0.4  0.6
1.8   1.956  998.0 999.0 0.5  0.9
```

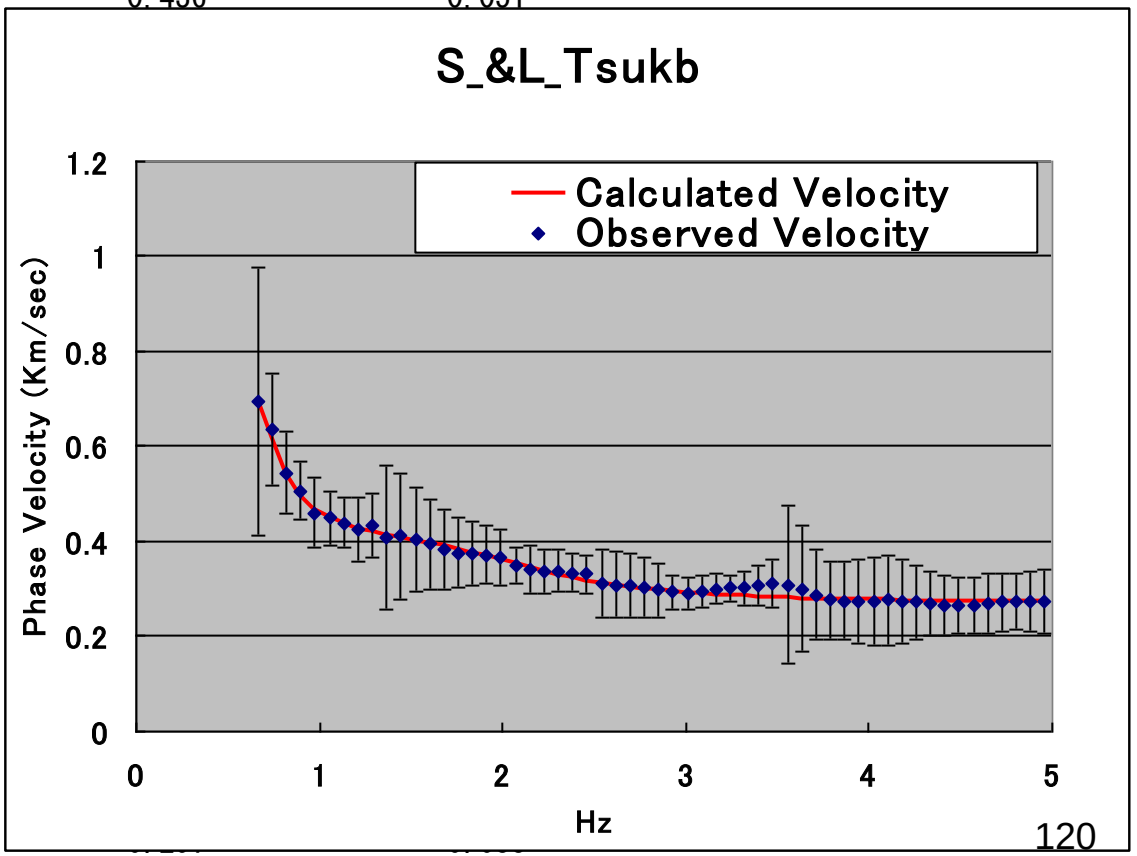


	Thicknes(Km)	Density(g/cm^3)	Vp(Km/sec)	Vs(Km/sec)
1	0.057347	1.820632	1.604092	0.282966
2	0.074116	1.878893	1.791601	0.451893
3	0.147796	1.882880	1.804653	0.463651
4	999.000000	2.021464	2.277869	0.889972

Comparison of Cal. to Obs.

disp_cal.dat

Frequency(Hz)	Observed Velocity	Calculated Velocity	
0.664	0.694	0.698	0.281
0.742	0.636	0.618	0.118
0.820	0.545	0.543	0.085
0.898	0.507	0.496	0.061
0.977	0.460	0.467	0.074
1.055	0.449	0.449	0.058
1.133	0.440	0.436	0.051
1.211	0.426		
1.289	0.434		
1.367	0.408		
1.445	0.411		
1.523	0.405		
1.602	0.394		
1.680	0.382		
1.758	0.376		
1.836	0.375		
1.914	0.372		
1.992	0.367		
2.070	0.350		
2.148	0.341		
2.227	0.337		
2.305	0.338		
2.383	0.334		
2.461	0.331		
2.539	0.312		
2.617	0.309		
2.695	0.306		
2.773	0.303		
2.852	0.297		
2.930	0.293	0.294	0.037
3.008	0.291	0.292	0.033



Determined Velocity Structure

vel_cal.dat

	Thicknes(Km)	Density(g/cm^3)	Vp(Km/sec)	Vs(Km/sec)
1	0.057347	1.820632	1.604092	0.282966
2	0.074116	1.878893	1.791601	0.451893
3	0.147796	1.882880	1.804653	0.463651
4	999.000000	2.021464	2.277869	0.889972