

Instruction

- Analysis of SPAC Method -

April. 15, 2020

IISEE, BRI, Japan

By T. Yokoi

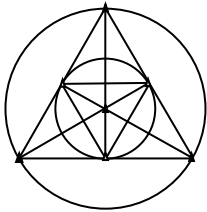
Revision from SPAC2019 to SPAC2020 is minor.

Acknowledgments:

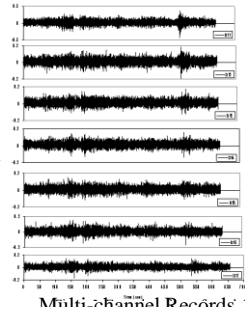
The revision for the 2020 version was partly supported by Japan Science and Technology Agency (JST) and Japan International Cooperation Agency (JICA) under the “Science and Technology Research Partnership for Sustainable Development (SATREPS): Integrated Research on Great Earthquakes and Disaster Mitigation in Nepal Himalaya (FY2016-2020)”.

Procedures of analysis

Field Work

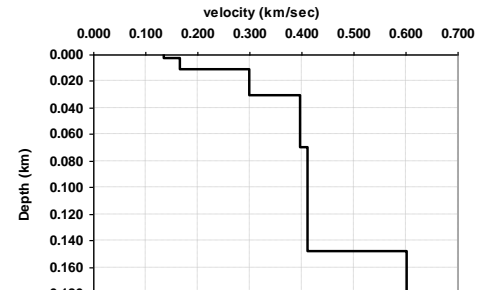


Microtremor Array Measurement
(Vertical Component)



1. (Multiplexing &) Resampling

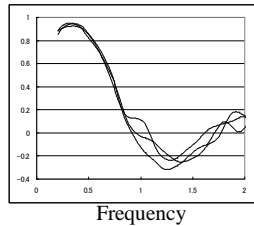
Estimation of Shear Wave Velocity Structure



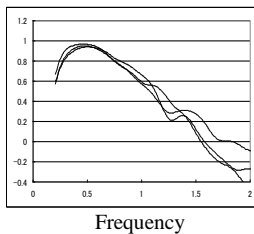
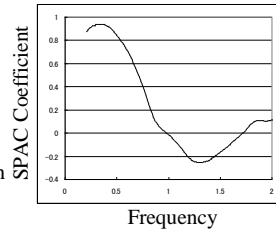
4. Heuristic Search of V_s Structure

Calculation of SPAC Coefficient

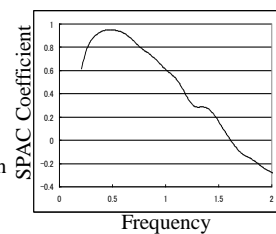
Complex Coherence Function



Average over azimuth



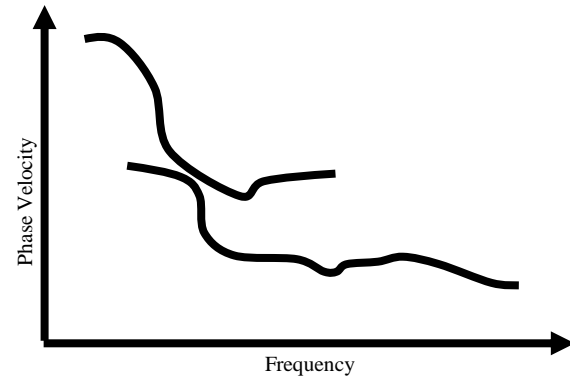
Average over azimuth



2. Calculation of SPAC coefficient

Least Square Fitting to $J_0(kr)$

Calculation of the phase velocity



Inversion or
Heuristic Search

3. Determination of Dispersion Curve

Note: This version was developed on Linux: Ubuntu 19.10 (Eoan Ermine) on VirtualBox version 6.1.0 r135406 on Windows 10 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

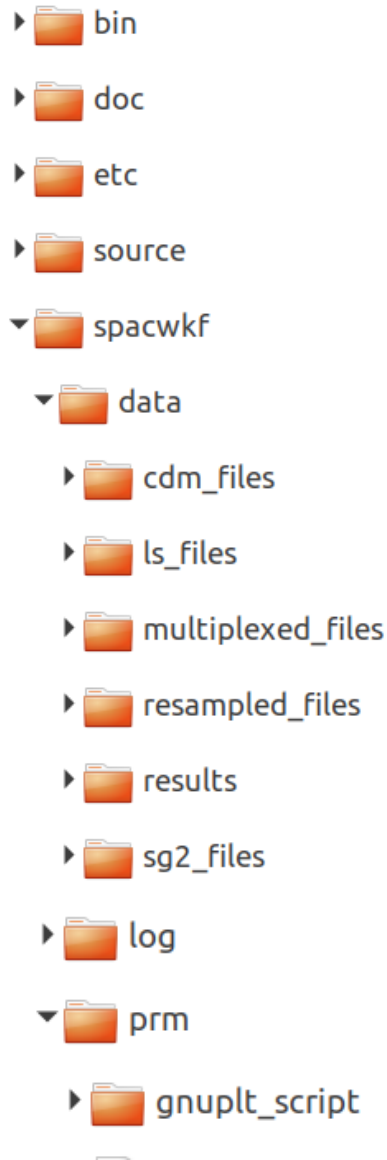
If it is necessary to leave log file of execution, for example,

./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 “**SPAC2020**”. 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 GNU PLOT 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 “SPAC2020” 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 SPAC2019, type in the following command.

```
gfortran ./source/???.for -o ./bin/???.exe
```

Note: Shell script files

The folder “SPAC2020” 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 “**SPAC2020**” to delete all files of input data, interim outputs and results for a new processing task.
- Use *sh clean_sg2.sh* in the folder “**SPAC2020**” to delete all input files of sg2 format under “./spacwkf/data/sg2_files”.
- Use *sh clean_ls.sh* in the folder “**SPAC2020**” 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

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.

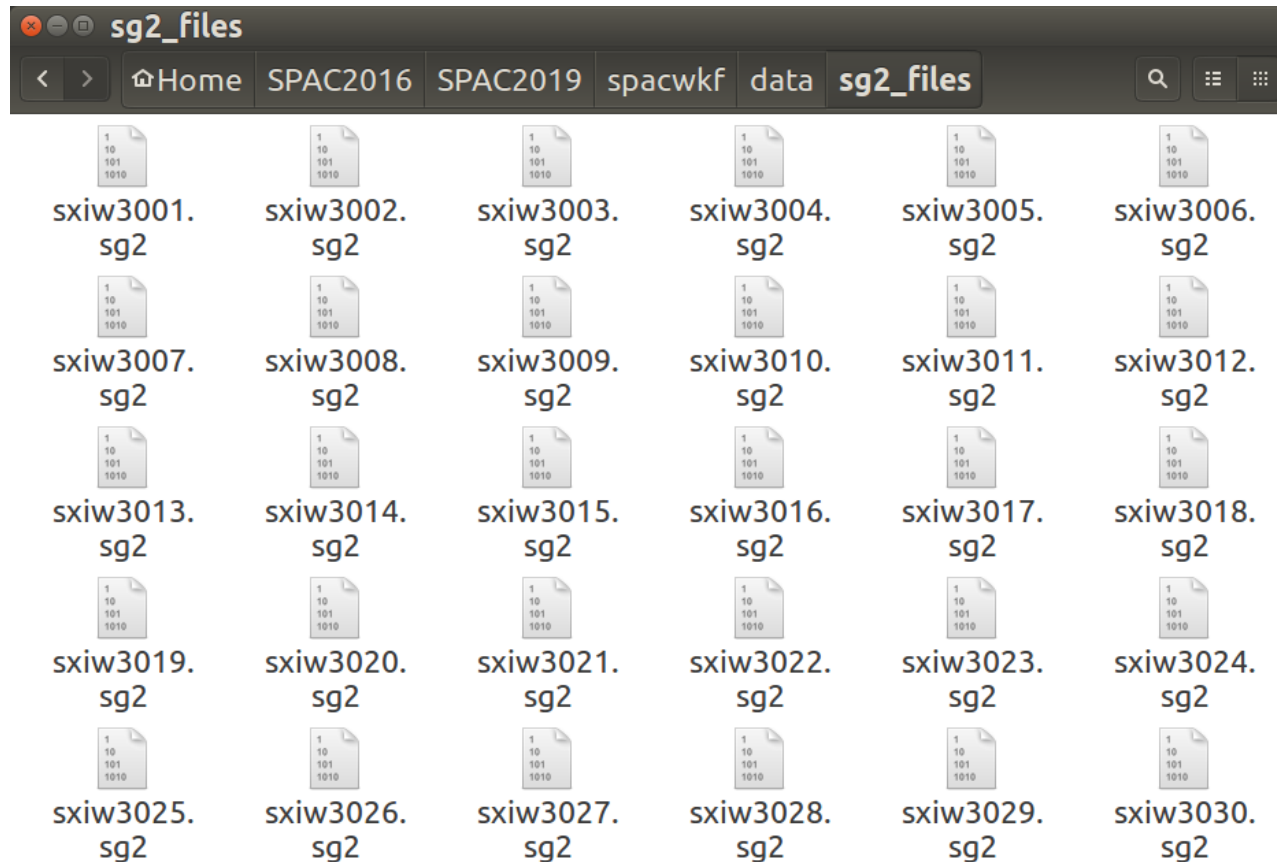
The expected input files of *seg2* format are, for example, those obtained in the field using multi-channel data logger designed for the exploration geophysics.

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 subfolder "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".

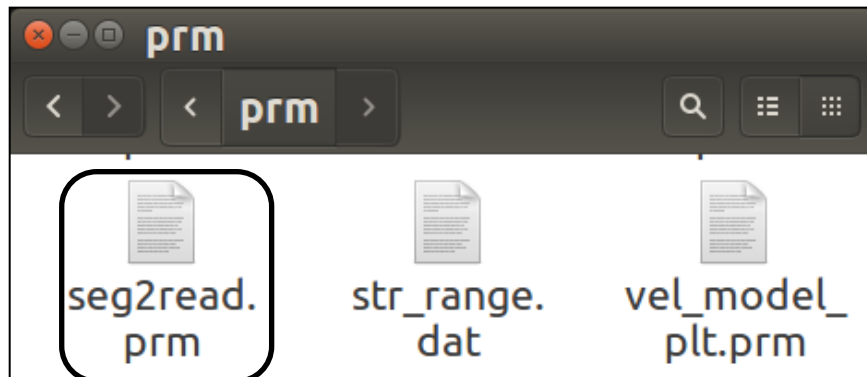
Finally, the first line of "seg2read.prm" is copied to "graph_title.txt" in the subfolder "./spacwkf/prm".

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),f1,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),f1,fh,fs
6th line : Channel Pivoting
 'normal' : no pivoting, all channel used
 'rev_al' : all channel used but in reversed order
 'rev_fh' : all channel used but former half in reversed order
 'rev_lh' : all channel used but latter half in reversed order
 'pvlist 2 1 3 4 6 23 24' : Pivoting list.

Examples of the 6th line of seg2read.prm

Use all channels without pivoting:

`normal : Channel Pivoting`

Use all channels but reversed order:

`reverse : Channel Pivoting`

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

`pvlist 1 2 3 4 5 6 7 : Channel Pivoting`

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

`pvlist 7 1 2 3 4 5 6 : Channel Pivoting`

Use only odd numbered channels among 24 without changing order:

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

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

Execution

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

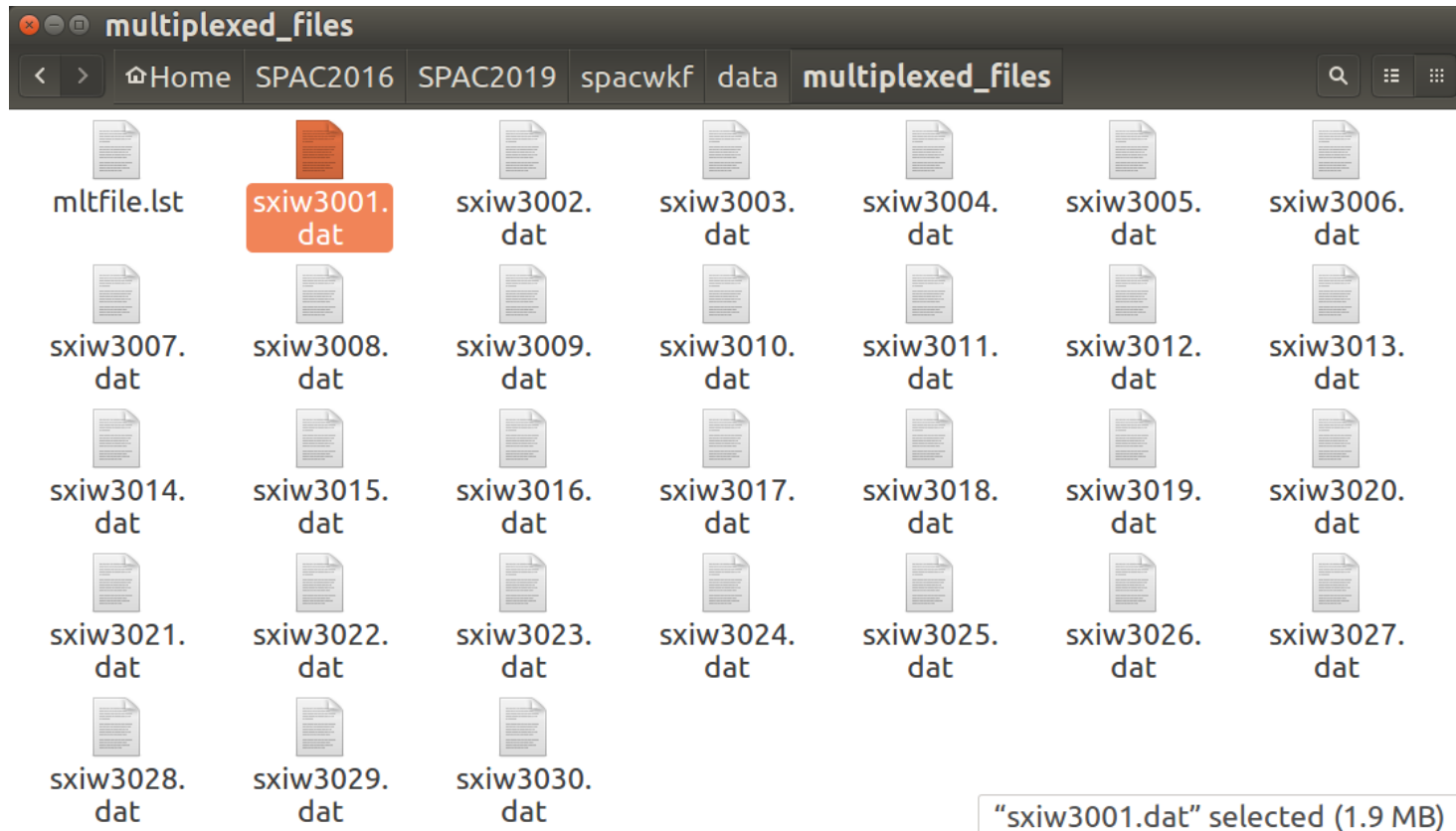
./spacwkf/data/sg2_files/sxiw3002.sg2
./spacwkf/data/multiplexed_files/sxiw3002.dat
:32bit floating point.
nch= 7 dt= 0.002 nn= 16384
7 0.0020 0.5500E-01 16384 mkine
```

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, $\Delta t(\text{sec})$, 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*”

<i>Sitename_</i>	:	site name (a9)
3 3	:	numbers of obs_ponts and channels
10	:	duration of each connected file in min.(integer)
<i>17091511.45</i>	:	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:

Istocdm2.prm: automatically created by Istocdm2.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

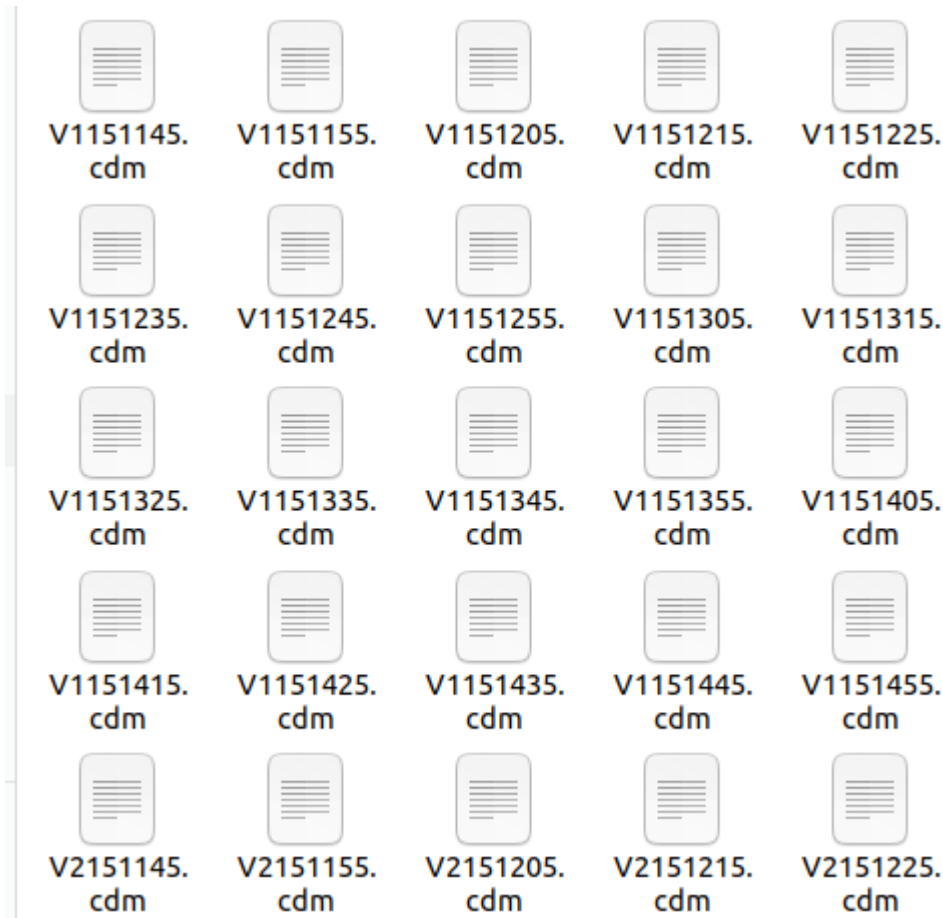
```

```

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

Open ▾

+

V1151145.cdm

~/Desktop/SPAC2020/spacwkf/data/cdm_files

Save

1

File=17091511.45_17091511.54

2

UNIT=mkine

3

V

4

0 00:00:00.000 -0.2722953E+00

5

1 00:00:00.010 -0.2532378E+00

6

2 00:00:00.020 -0.2709032E+00

7

3 00:00:00.030 -0.3568974E+00

8

4 00:00:00.040 -0.4600865E+00

9

5 00:00:00.050 -0.4690271E+00

10

6 00:00:00.060 -0.4567338E+00

11

7 00:00:00.070 -0.6430937E+00

12

8 00:00:00.080 -0.7474200E+00

3 lines for header

Data lines:

Numbering,
(A8)

time,
(A13)

data
(e16.7)

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,x dum
  x(i,j)=x dum/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 earliest 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
V1151265 V2151265 V3151265
```

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
```

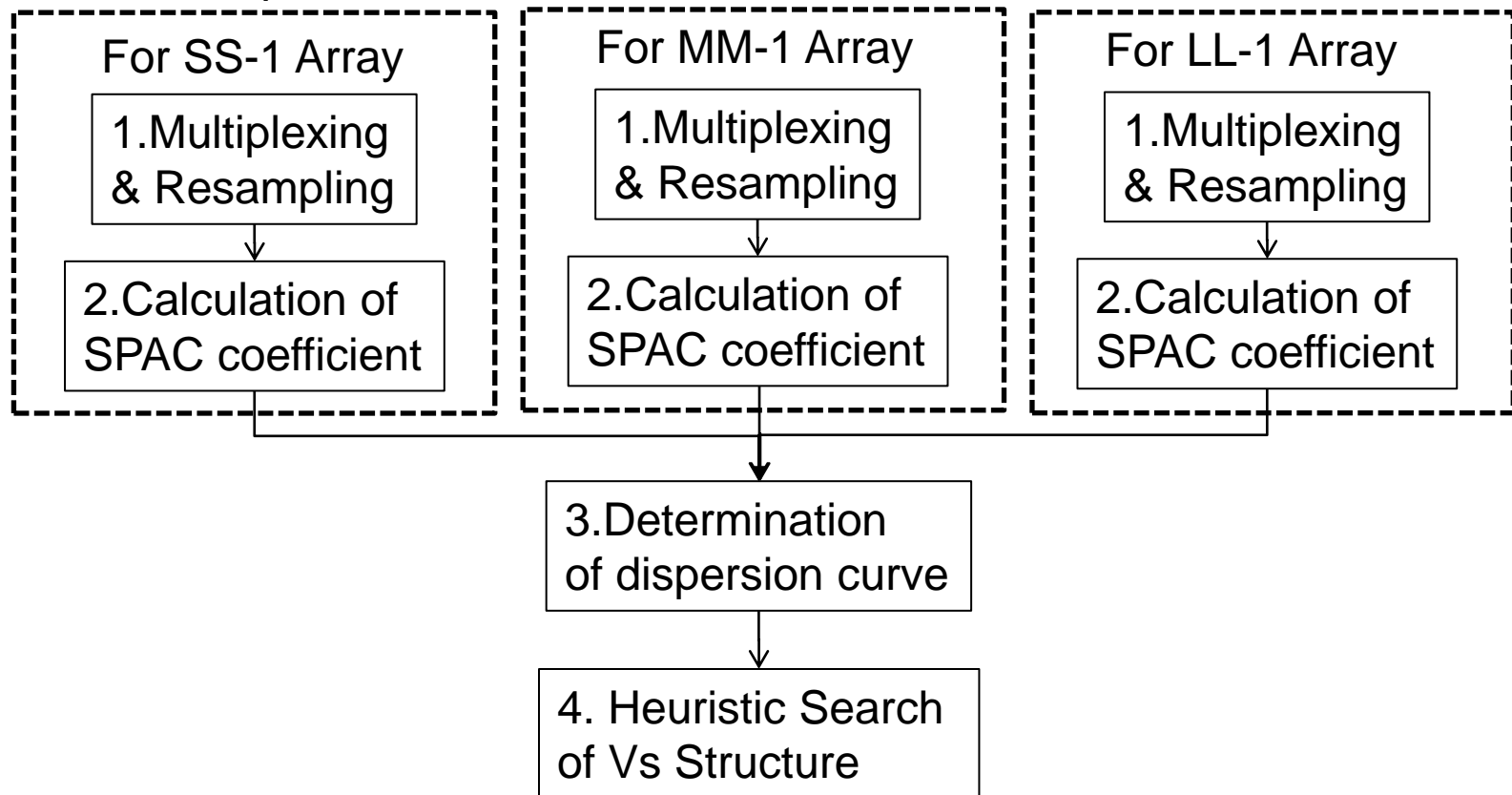
Edit it in an appropriate way if necessary.

Note: Example for the instruction below

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

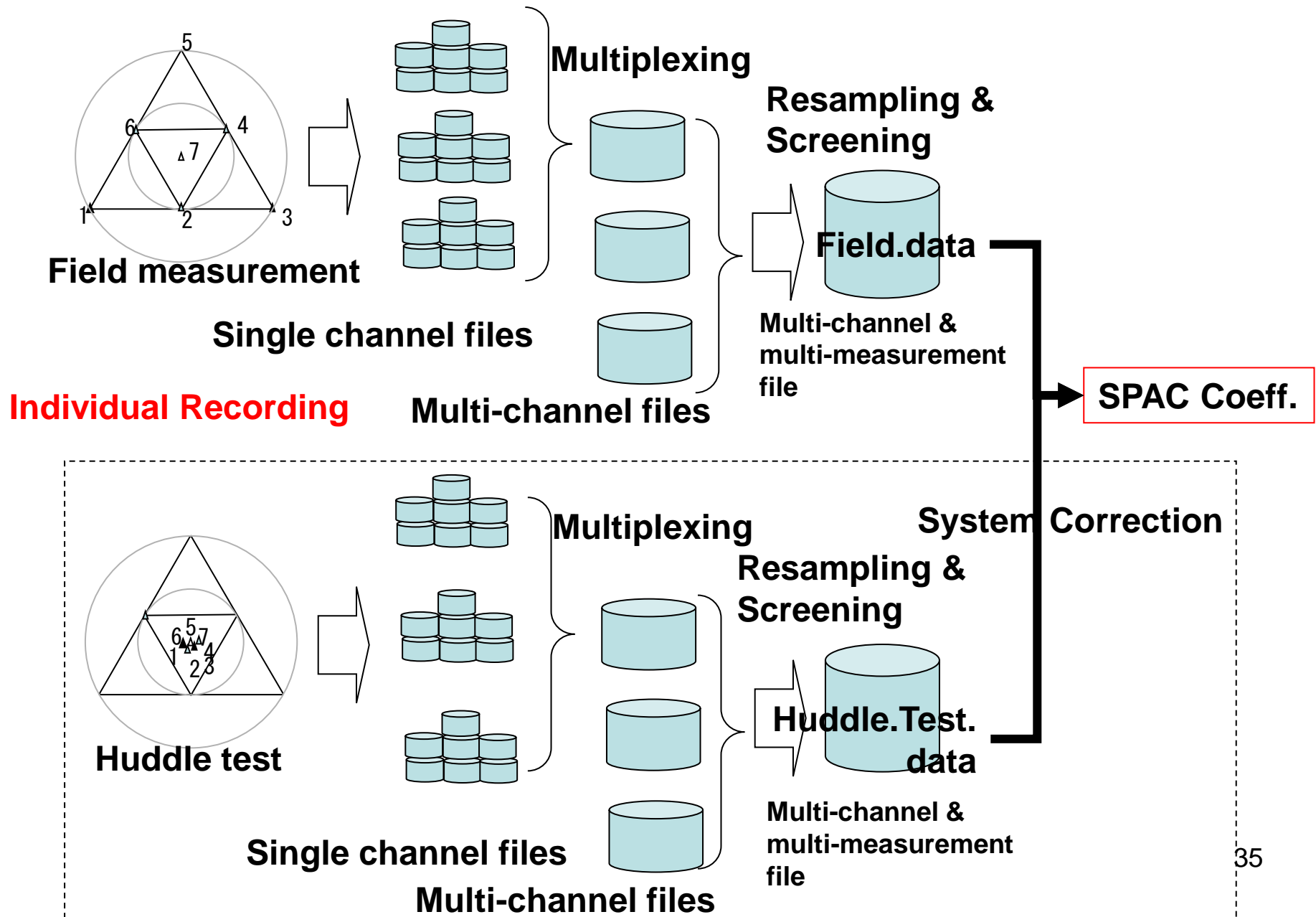
- + SS-1 Array: 7 points equilateral triangle array with the center
- + MM-1 Array: 4 points equilateral triangle array with the center
- + LL-1 Array: 4 points equilateral triangle array with the center

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.

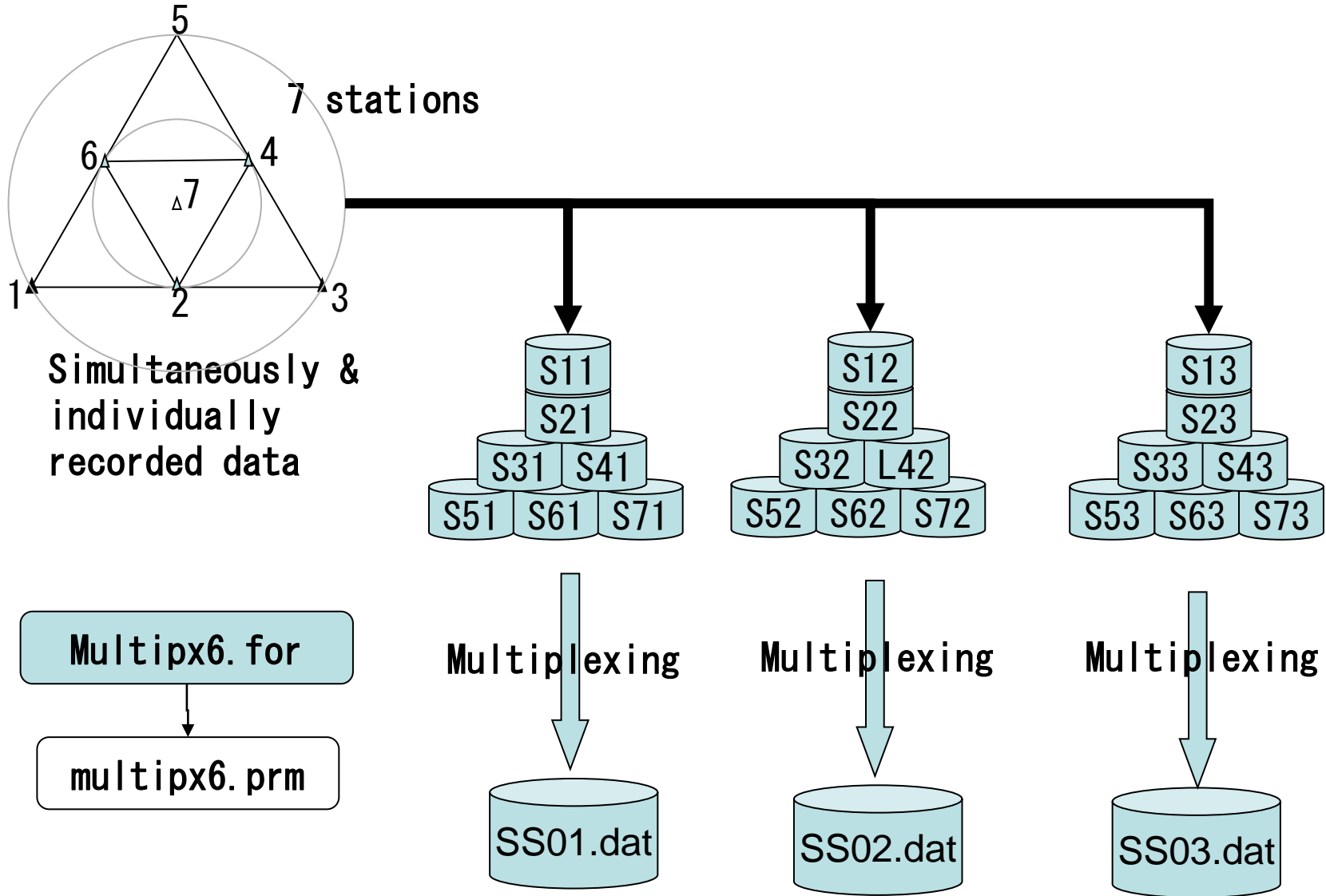
Re-sampling:

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 aliasing 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



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.

3

: Number of cases

: This blank is necessary

: Number of Channels, dt

: tst, tdur

: scale(input data is divided by this scale), unit(a5)

: nfilter(=1:apply), ncharacter(=2:lowpass,=3:bandpass), fl, fh, fs

: nattach, cattach

: n_out(A12), cout ("**.dat" is attached)

: comment(A50)

: number of measurement in the same array configuration, n_character

```

4 0.01
0.0 163.83
1.e11 mkine
0 3 0.005 1.0 1.5
4 .cdm
2 MM
MM-1, Iwaki City Hall, Dec.22, 2012
21 8
sxm21001 sxm21002 sxm21003 sxm21004
...
sxm23601 sxm23602 sxm23603 sxm23604

```

: This blank is necessary

: Number of Channels, dt

: tst, tdur

: scale(input data is divided by this scale)

: nfilter(=1:apply), ncharacter(=2:lowpass,=3:bandpass), fl, fh, fs

: nattach, cattach

: n_out(A12), cout ("**.dat" is attached)

: comment(A50)

: number of measurement in the same array configuration, n_character

```

7 0.002
0.0 32.766
3.16e2 mkine
0 3 0.005 1.0 1.5
4 .cdm
2 SS
SS-1, Iwaki City Hall, Dec.22, 2012
30 8
sxs10101 sxs10102 sxs10103 sxs10104 sxs10105 sxs10106 sxs10107
...
sxs13001 sxs13002 sxs13003 sxs13004 sxs13005 sxs13006 sxs13007

```

: This blank is necessary

: Number of Channels, dt

: tst, tdur

: scale(input data is divided by this scale)

: nfilter(=1:apply), ncharacter(=2:lowpass,=3:bandpass), fl, fh, fs

: nattach, cattach

: n_out(A12), cout ("**.dat" is attached)

: comment(A50)

: number of measurement in the same array configuration, n_character

```

4 0.01
0.0 163.83
3.16e10 mkine
0 3 0.005 1.0 1.5
4 .cdm
2 LL
LL-1, Iwaki City Hall, Dec.22, 2012
28 8
sxl21001 sxl21003 sxl21005 sxl21007
...
sxl24601 sxl24603 sxl24605 sxl24607

```



```

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.

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/sec² 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 SPAC2020):

```
~$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
```

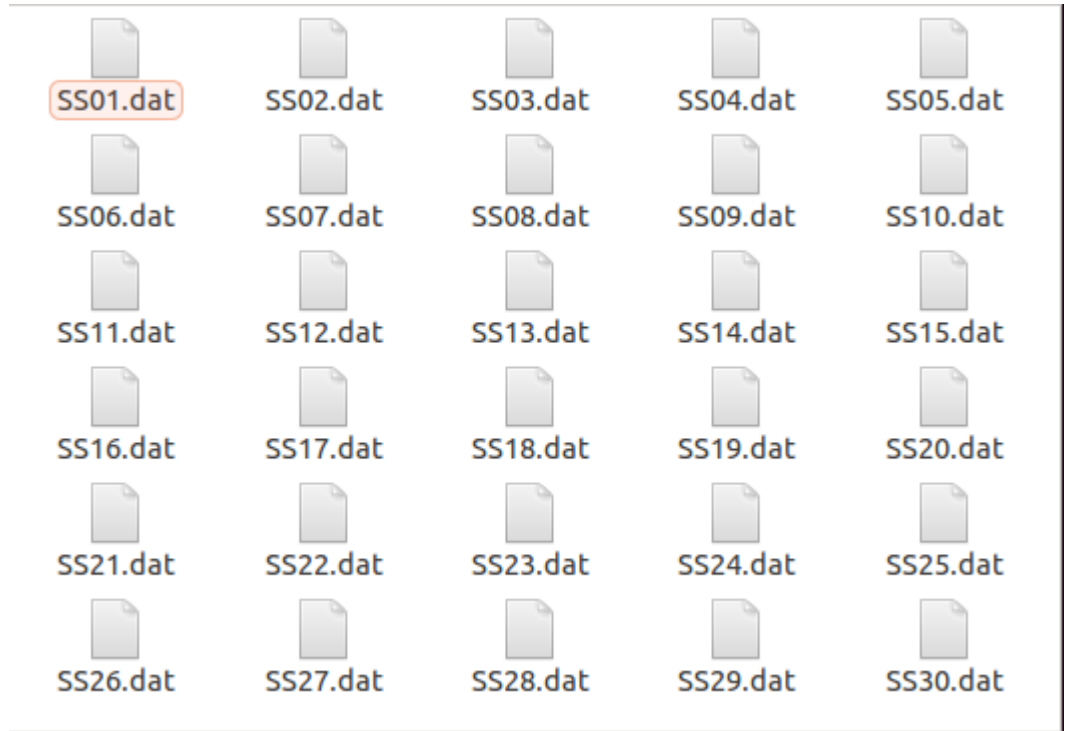
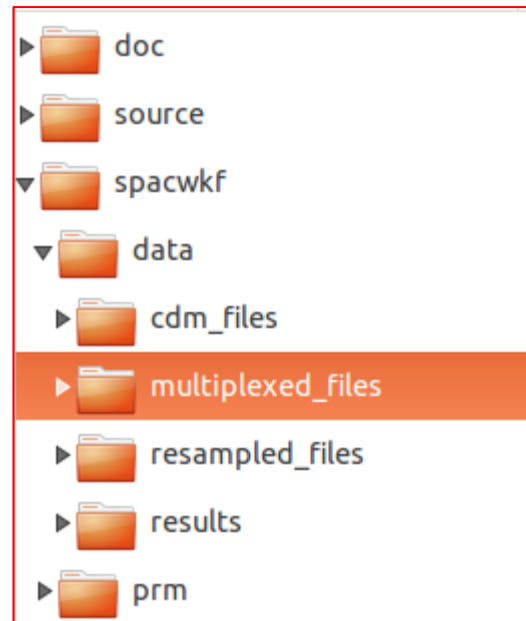
```
./spacwkf/data/multiplexed_files/MM01.dat
```

```
      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: $t_{dur}/dt \leq 1,200,000$
- Similarly $n_{ch} \leq 15$

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 $\text{int}(\text{tst}/\text{dt})$ data and then starts reading the next data.

Example Data files: These are already multiplexed.

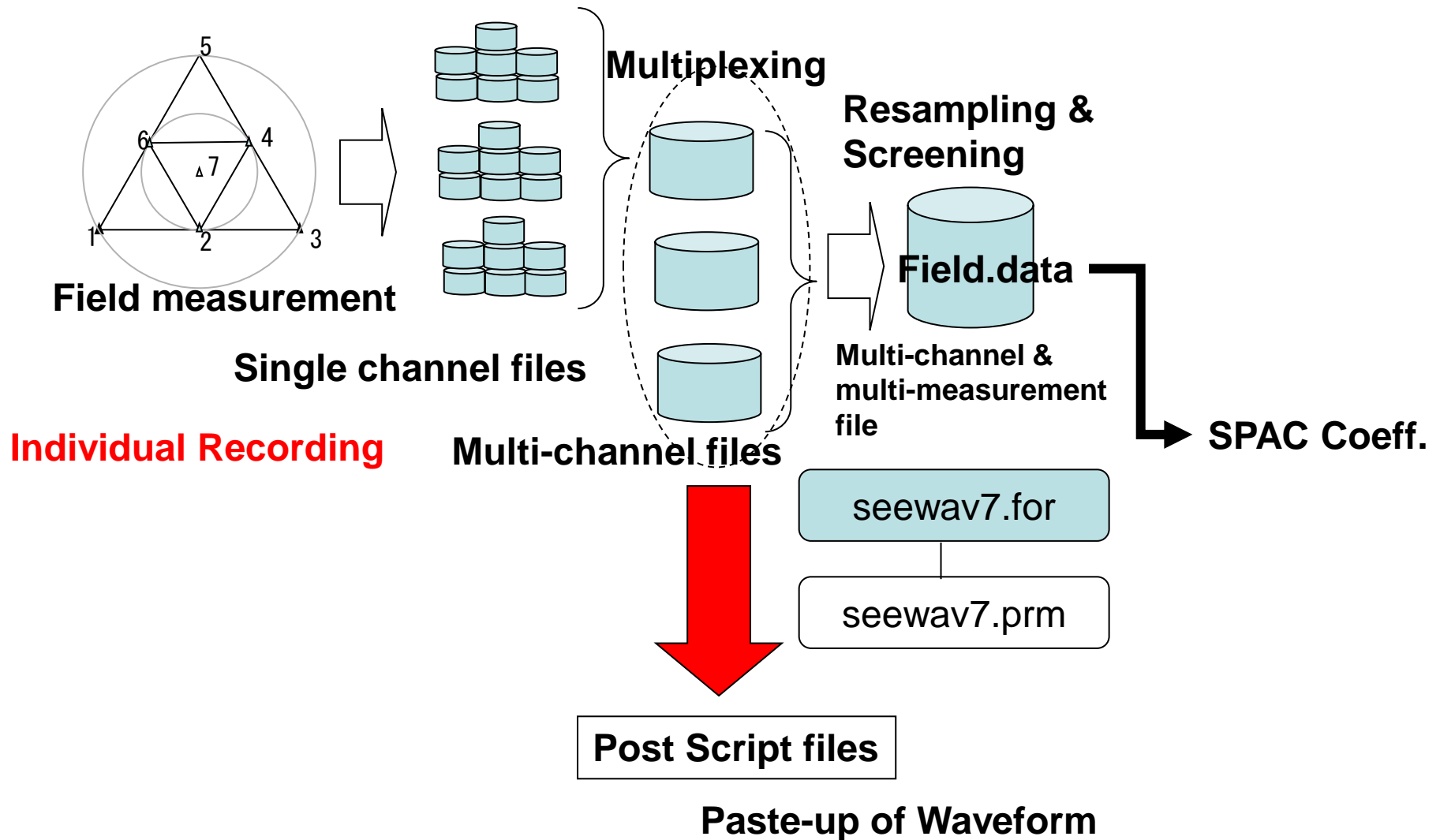
multi_SS.tar.gz
multi_MM.tar.gz
multi_LL.tar.gz

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

1.2. Plot Waveform

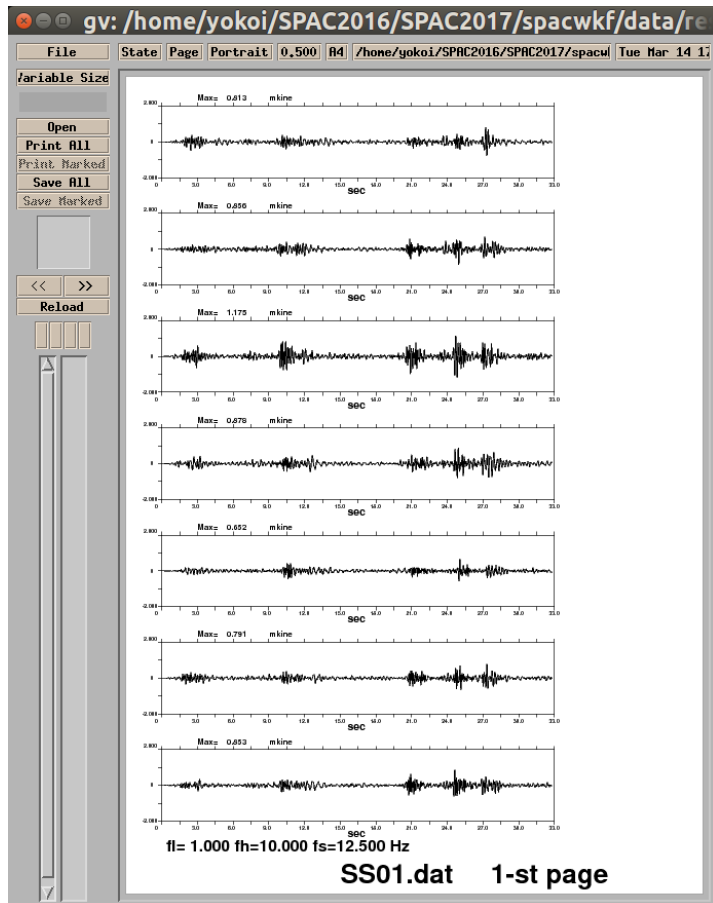
seewav7.sh+ ./spacwkf/prm/seewav7.prm

Flow of the data processing for the conventional SPAC



Multi-channel file: SS01.dat

```
7 0.0020      0.3160E+03  16382  mkine
SS-1, Iwaki City Hall, Dec.22, 2012      :
0.000000 -0.000000E+00 -0.000000E+00 -0.000000E+00  0.000000E+00 -0.000000E+00  0.000000E+00 -0.000000E+00
0.002000 -0.896156E-04  0.536170E-05 -0.204499E-04  0.108186E-03 -0.197809E-05  0.253002E-04 -0.417170E-04
0.004000 -0.164032E-03  0.813897E-04 -0.197474E-04  0.199705E-03  0.206876E-04  0.487451E-04 -0.962601E-04
...
```



SS01.ps

seewav7.for

seewav7.prm

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

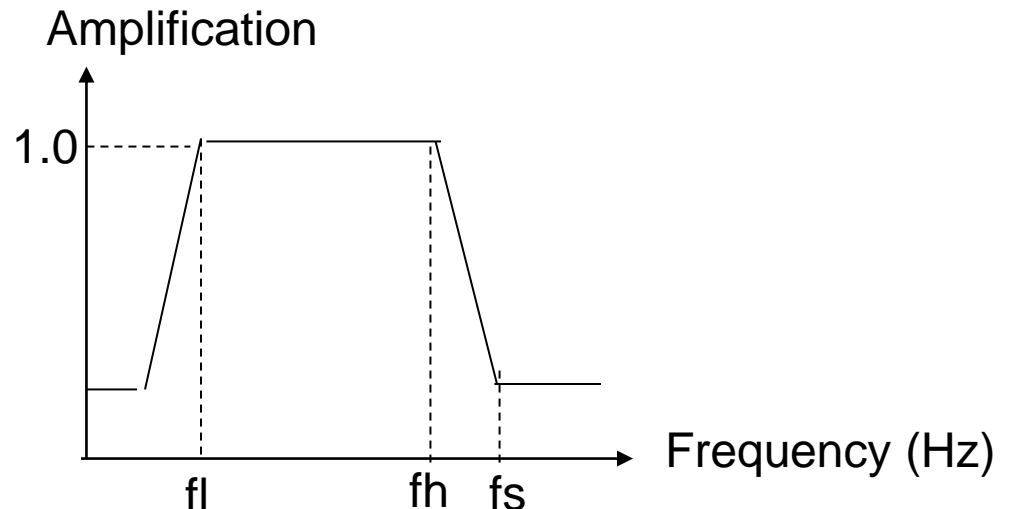
1	1.0	10.0	12.5	3
1.5				

dtl denotes the time duration that corresponds to 1cm along the time axis.
In one page, $28 \cdot \text{dtl} / \text{dt}$ 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.

:nfilter, fl, fh, fs, nchara (=2: lowpass, =3: bandpass)
: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. ⁵²

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

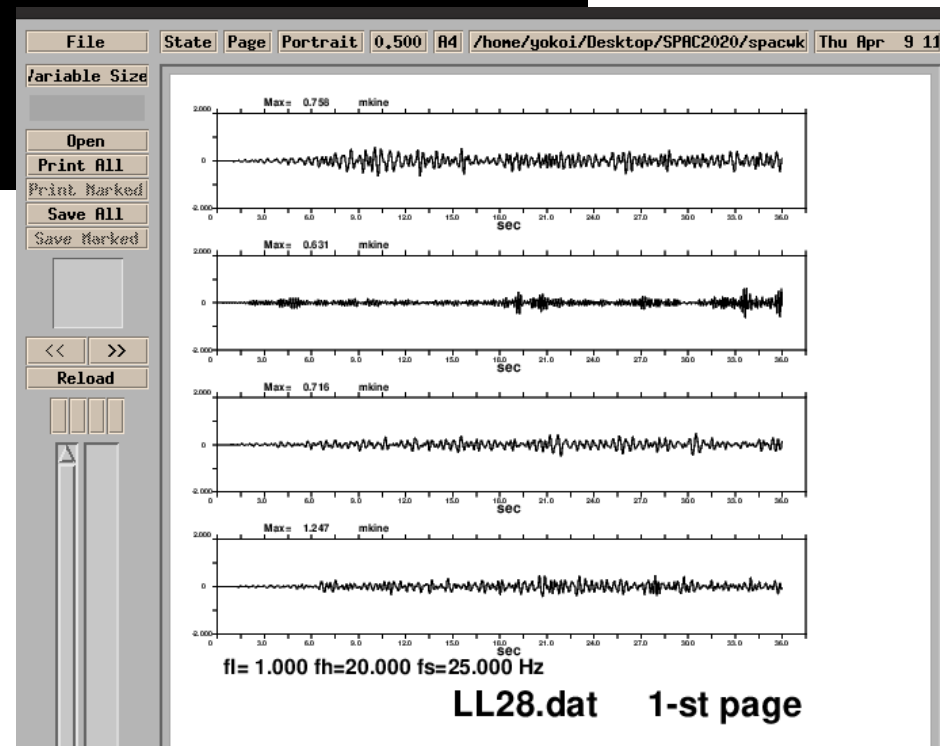
DC-offset removed & tapered;
0.870511591      1.00000000
./spacwkf/data/results/fig_wave/LL01.ps
LL01.dat      1-st page
LL01.dat      2-nd page
LL01.dat      3-rd page
```

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

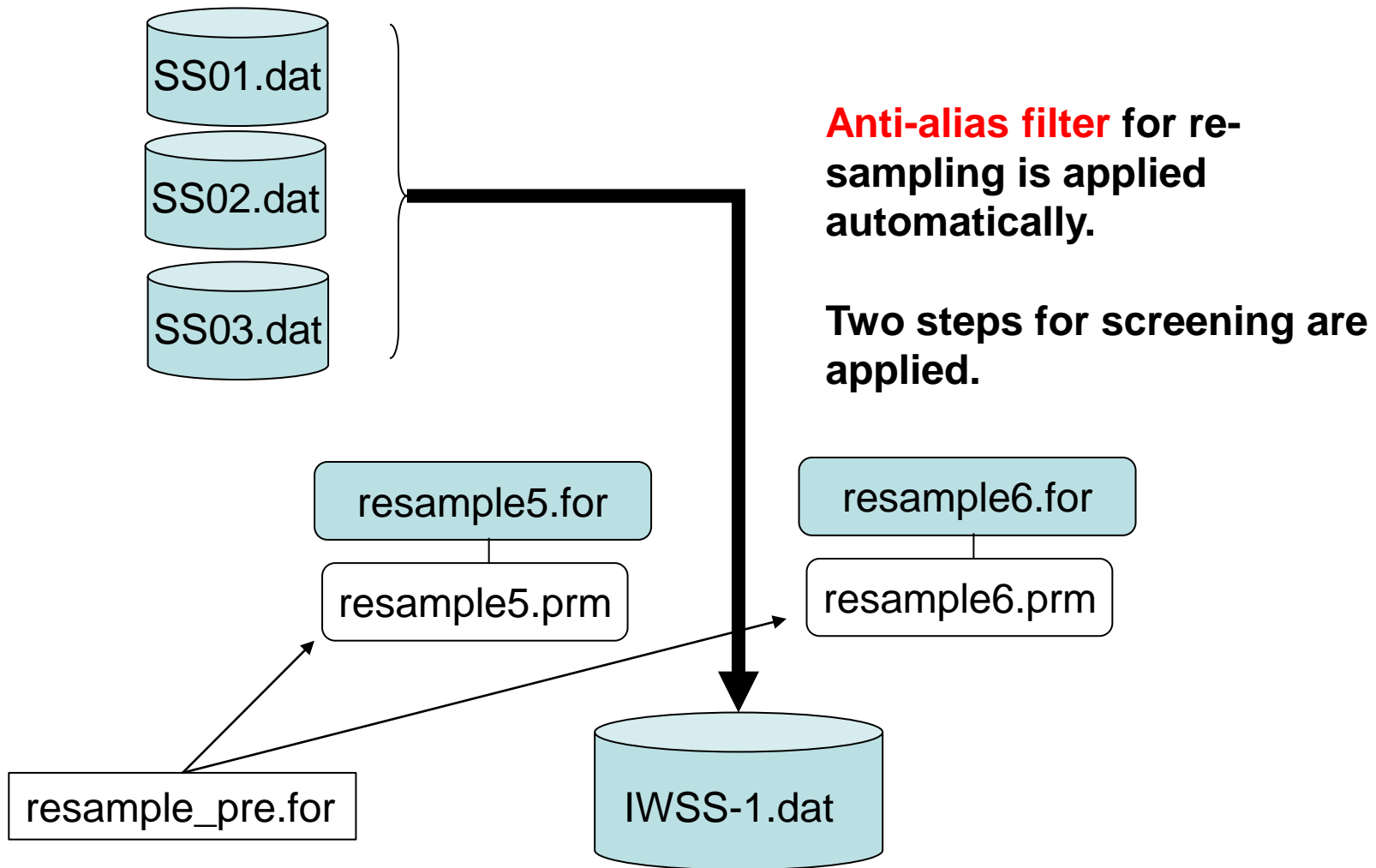
seeblk1.sh + seeblk1.prm

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

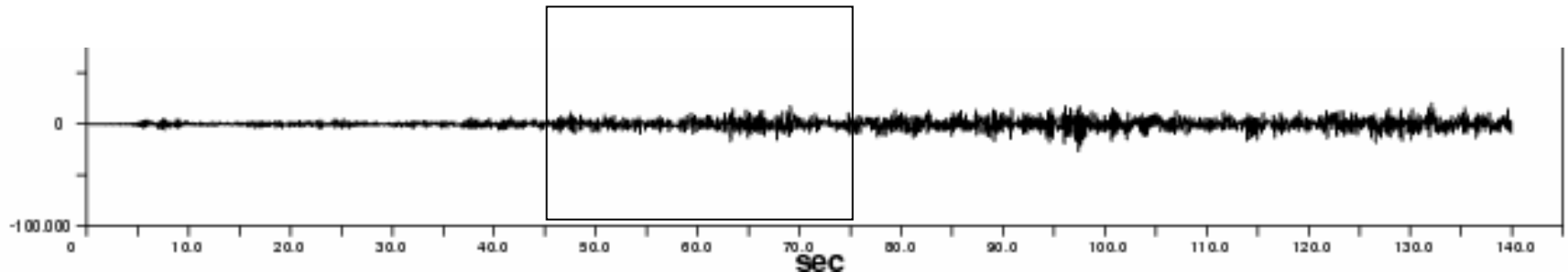


**Resampled & screened multi-channel
& multi-measurement data file**

Screening: Step-1

Parameter: **ajudge**

Time Block



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: $tdur/dt \leq 750,000$

Similarly $nch \leq 11$

and number of data in one time block ≤ 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
30 :number of measurement in the same array configuration
SS01.dat
SS02.dat
SS03.dat
...
SS30.dat

```
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.

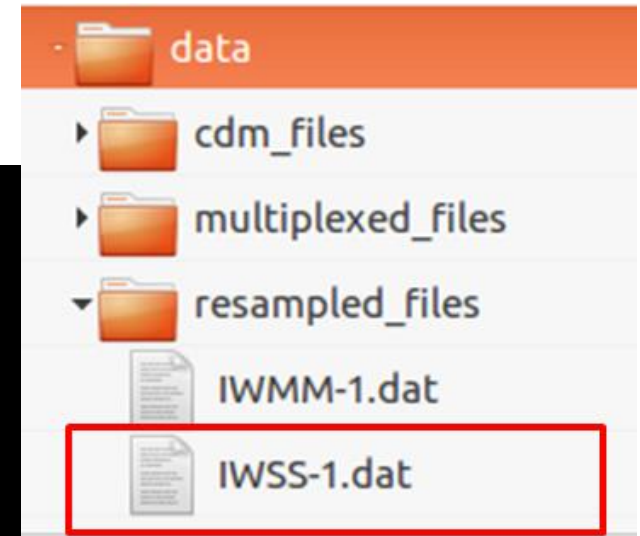
7th line: Input file name

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
 4 -th measurement:./spacwkf/data/multiplexed_files/SS04.dat
 0 blocks remained among 2 blocks
 5 -th measurement:./spacwkf/data/multiplexed_files/SS05.dat
 0 blocks remained among 2 blocks
 6 -th measurement:./spacwkf/data/multiplexed_files/SS06.dat
 0 blocks remained among 2 blocks
 7 -th measurement:./spacwkf/data/multiplexed_files/SS07.dat
 0 blocks remained among 2 blocks
 8 -th measurement:./spacwkf/data/multiplexed_files/SS08.dat
 0 blocks remained among 2 blocks
 9 -th measurement:./spacwkf/data/multiplexed_files/SS09.dat
 0 blocks remained among 2 blocks
10 -th measurement:./spacwkf/data/multiplexed_files/SS10.dat
 0 blocks remained among 2 blocks
11 -th measurement:./spacwkf/data/multiplexed_files/SS11.dat
 0 blocks remained among 2 blocks
12 -th measurement:./spacwkf/data/multiplexed_files/SS12.dat
 0 blocks remained among 2 blocks
13 -th measurement:./spacwkf/data/multiplexed_files/SS13.dat
 0 blocks remained among 2 blocks
14 -th measurement:./spacwkf/data/multiplexed_files/SS14.dat
 0 blocks remained among 2 blocks
15 -th measurement:./spacwkf/data/multiplexed_files/SS15.dat
 0 blocks remained among 2 blocks
16 -th measurement:./spacwkf/data/multiplexed_files/SS16.dat
 0 blocks remained among 2 blocks
17 -th measurement:./spacwkf/data/multiplexed_files/SS17.dat
 0 blocks remained among 2 blocks
18 -th measurement:./spacwkf/data/multiplexed_files/SS18.dat
 0 blocks remained among 2 blocks
19 -th measurement:./spacwkf/data/multiplexed_files/SS19.dat
 0 blocks remained among 2 blocks
20 -th measurement:./spacwkf/data/multiplexed_files/SS20.dat
 0 blocks remained among 2 blocks
21 -th measurement:./spacwkf/data/multiplexed_files/SS21.dat
 0 blocks remained among 2 blocks
22 -th measurement:./spacwkf/data/multiplexed_files/SS22.dat
 0 blocks remained among 2 blocks
23 -th measurement:./spacwkf/data/multiplexed_files/SS23.dat
 0 blocks remained among 2 blocks
24 -th measurement:./spacwkf/data/multiplexed_files/SS24.dat
 0 blocks remained among 2 blocks
25 -th measurement:./spacwkf/data/multiplexed_files/SS25.dat
 0 blocks remained among 2 blocks
26 -th measurement:./spacwkf/data/multiplexed_files/SS26.dat
 0 blocks remained among 2 blocks
27 -th measurement:./spacwkf/data/multiplexed_files/SS27.dat
 0 blocks remained among 2 blocks
28 -th measurement:./spacwkf/data/multiplexed_files/SS28.dat
 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

1st line:file parameters
↗

	7	27	1024	(i8,f16.4, 7e15.7)	mkine						
1 st block	1			0.0000	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
	2			0.0200	-0.6542959E-10	0.6730985E-10	0.8688813E-11	-0.9121746E-10	0.3278066E-10	0.3681669E-10	-0.2157925E-10
	...										
2 nd block	1024			20.4600	0.6798404E-01	0.8341893E-01	0.7360612E-01	-0.3876965E-01	0.1080229E+00	-0.9545929E-01	-0.1346539E+00
	1			10.2400	-0.1701506E+00	0.9676924E-01	0.3960467E-01	-0.3436972E+00	0.1931517E+00	0.1742720E-01	0.8249036E-01
	...										
	1024			30.7000	-0.4059438E-01	0.2059561E-02	0.2788787E-01	-0.1173913E+00	0.2213649E-01	-0.1785946E-01	-0.9963673E-01
	1			0.0000	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
	...										

The file includes mmblok=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

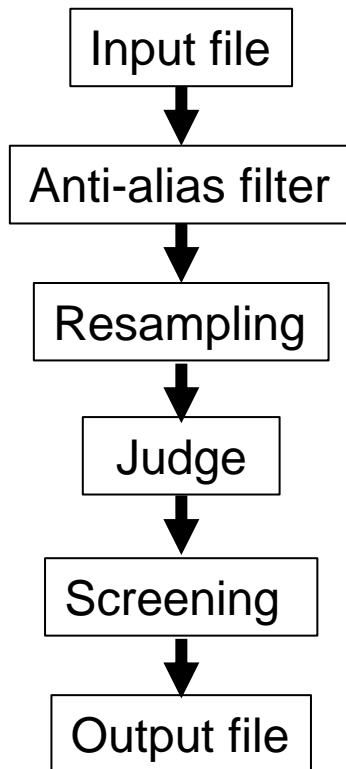
4 0.01 2 :nch,dt,number of Channels,dt,nskip
4.0 2.0 :ajudge,a_sgm
0.0 163.83 :tst,tdur
IWMM-1.dat :output file name
1024 :number of data in one time block after resampling
21 :number of measurement in the same array configuration
MM01.dat
...
MM21.dat

Execution:

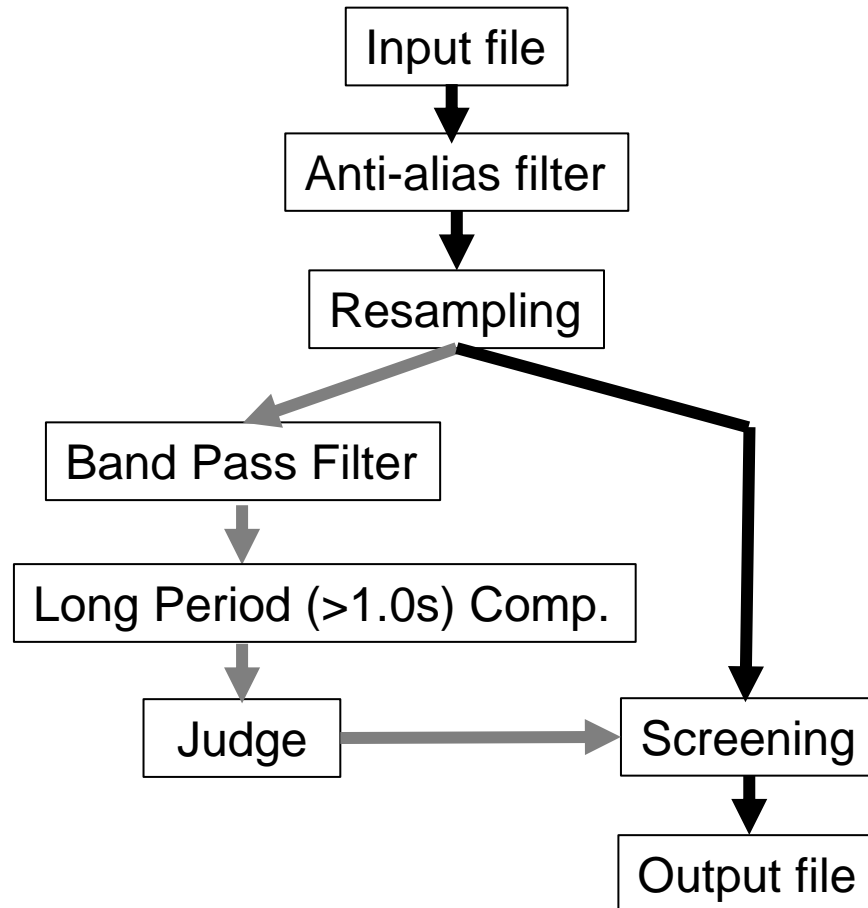
```
~SPAC2020$ sh resample6.sh
./spacwkf/prm/resample6.prm
Working Folder=./spacwkf/prm//
Band-Pass:fl= 0.100000001 fh= 20.2500000 fs= 22.5000000
Nch= 4
Nskip= 2 f(Nyquist)= 25.0000000 fh= 20.2500000
ajudge= 4.00000000 a_sgm= 2.00000000
0.00000000 163.830002
First screening (peak/rms< 4.00000000 ):
  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
~SPAC2020$
```


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

./bin/resample5.exe



./bin/resample6.exe



For short period observation

For long period observation

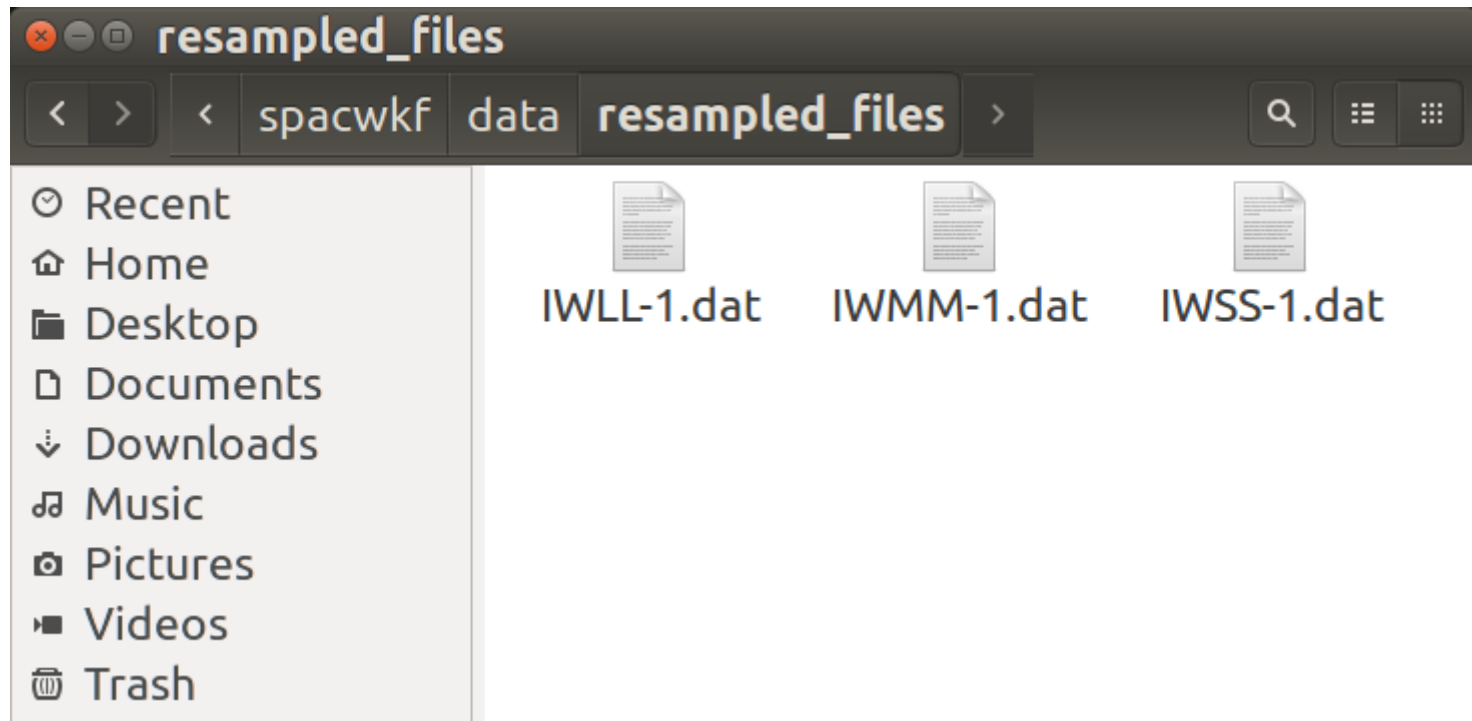
Output files:

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'

```
~SPAC2020$ .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
```

```
~SPAC2020$
```

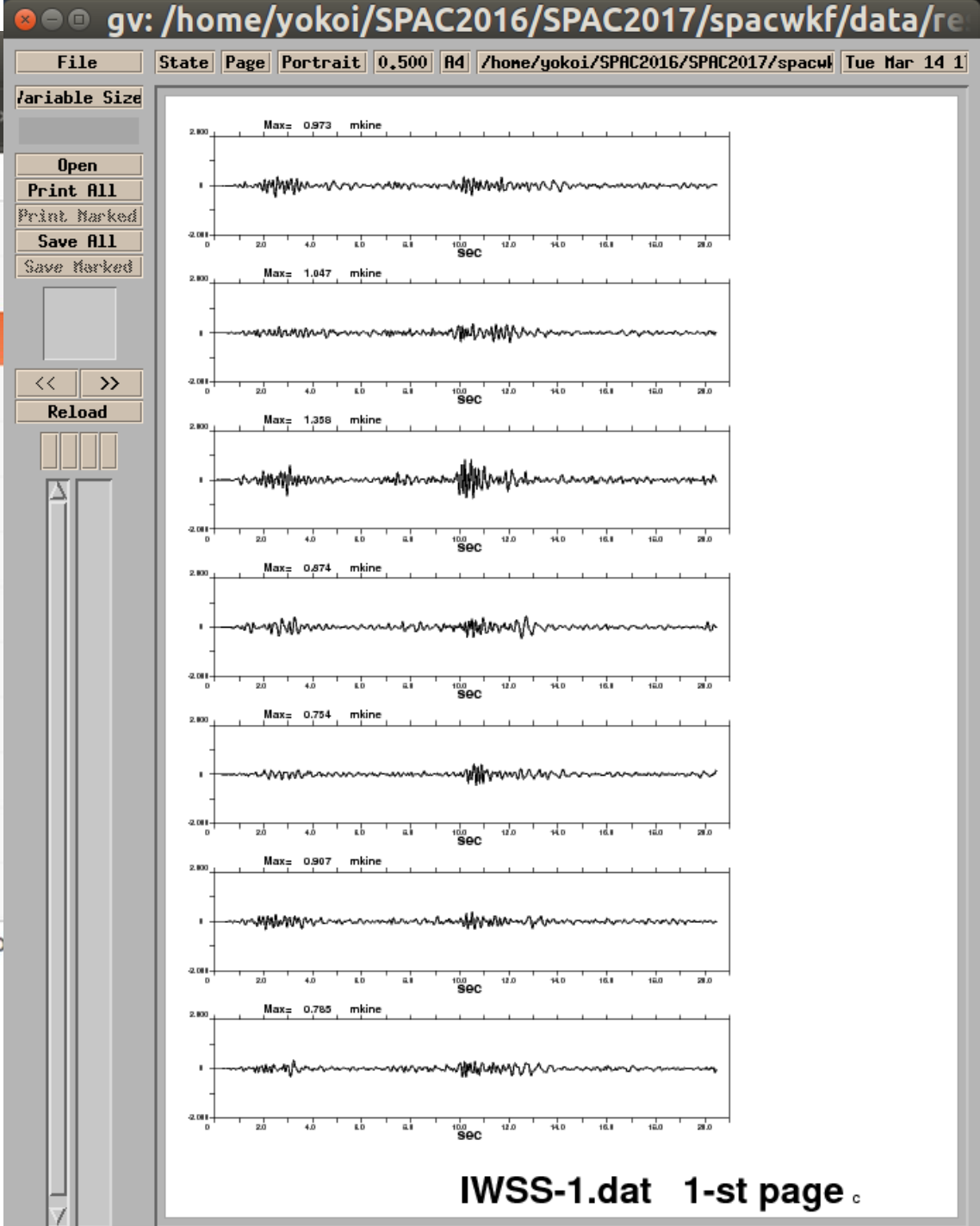
Multi-page postscript files are created in ./spacwkf/data/results/fig_wave

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



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

Programs used:

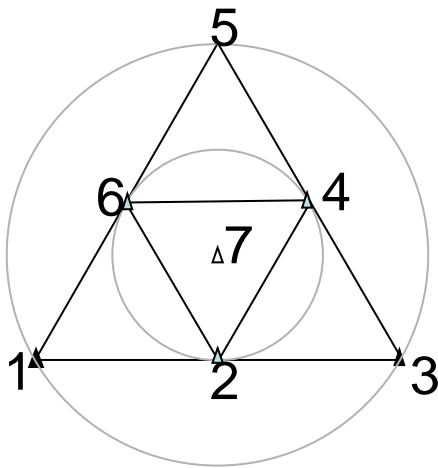
distazi.sh

that controls:

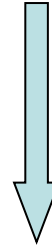
distazi.exe + ./spacwkf/prm/distazi.prm

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
"
```

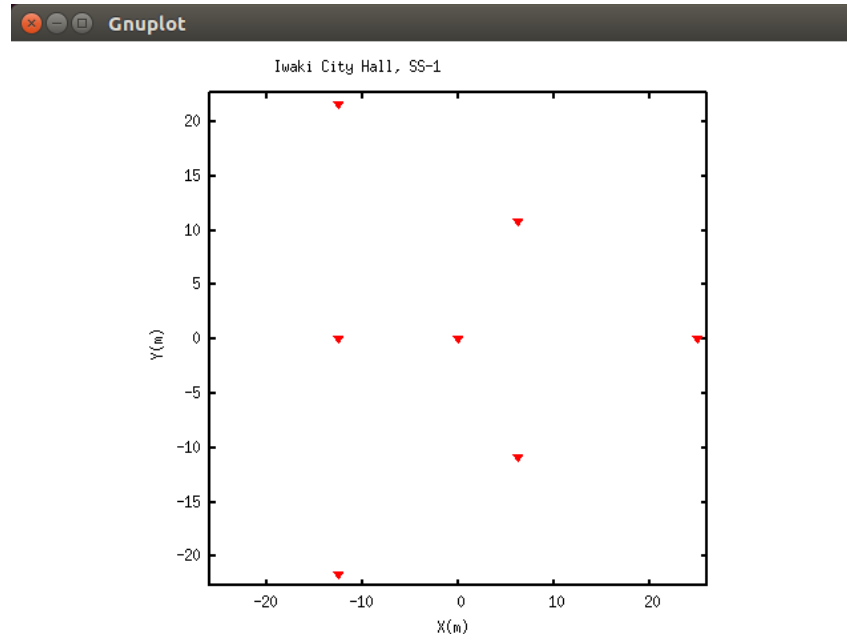
gnuplot is used for plotting.
If not yet installed,
sudo apt-get install gnuplot -x11

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



-46.8870, -27.7410

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

```
-----: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:

```
~SPAC2020$ 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
---	---	---	--------	----------

...

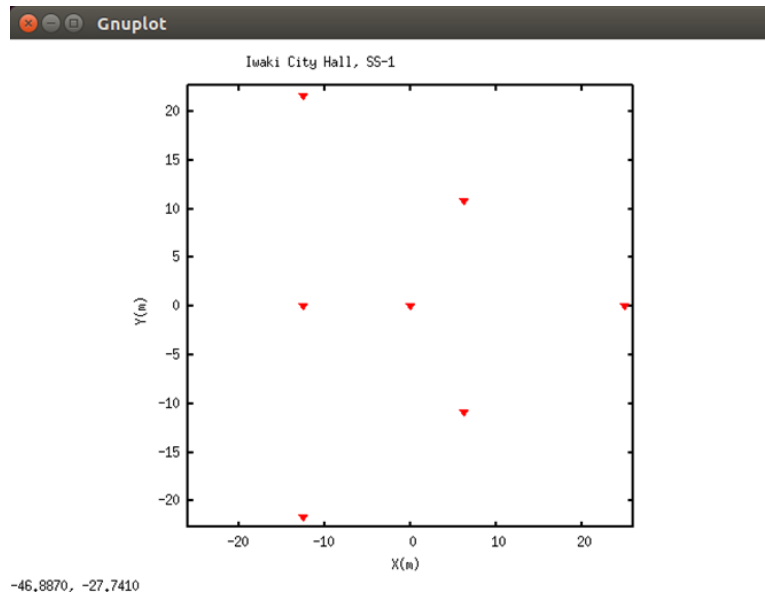
21	3	5	43.301	-180.000
----	---	---	--------	----------

Iwaki City Hall, SS-1

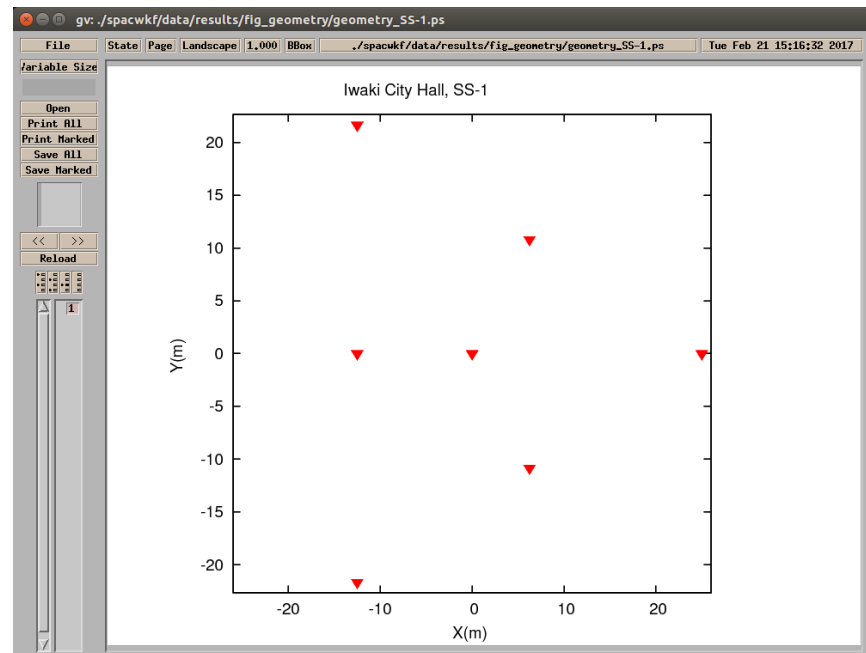
7 SS-1

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

```
~SPAC2020$ gv &
```



Plot appears in a pop-up window



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

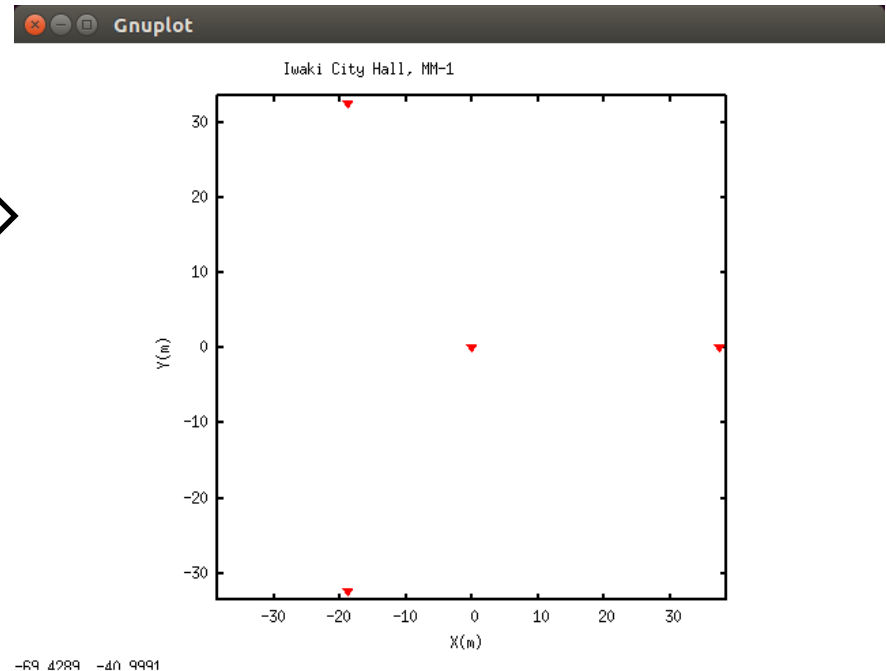
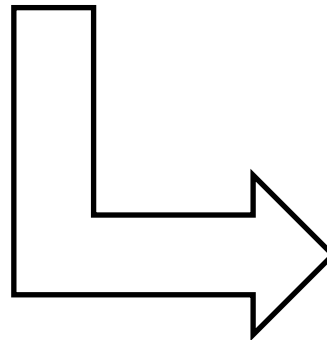
distazi.prm

```
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

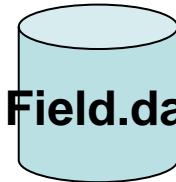
and

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

for plotting the results

Calculation of SPAC coefficients

Resampling & Screening



Field.data

Multi-channel &
multi-measurement
file

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

Zcorrel5_3.for

Zcorrel5_3.prm

SPAC Coeff.

System Correction

Resampling & Screening



**Huddle.Test.
data**

Multi-channel &
multi-measurement
file

zcorrel.sh

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

zcorrel5_3.prm

Iwaki City Hall, SS-1 ← 1st line is used as the title of figures created
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)

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

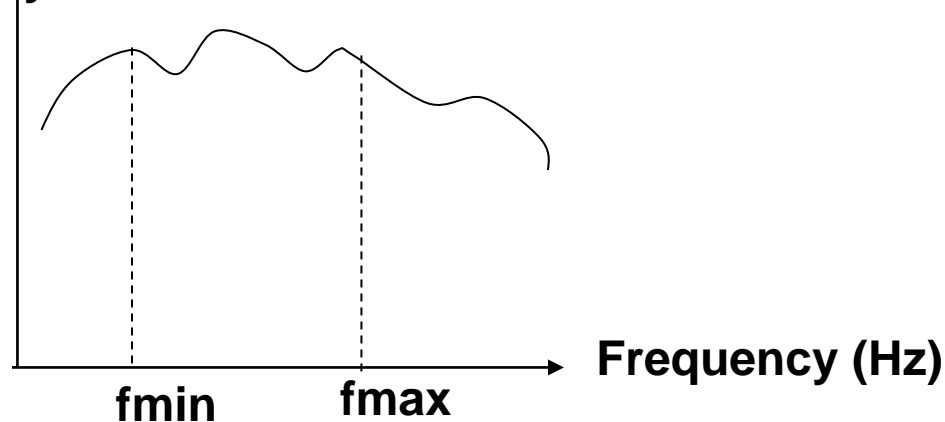
In the program $nn = nn_org * nhide$ is conducted, where nn_org denotes length of a time block in the input data file. This means the zero padding in order to shorten the interval of frequency for the calculation of FFT.

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 execution 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 outputting the
coherence file of the
huddle test data**

0= no effect

1= output

huddle_coh.dat

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

Input_cor_coh.dat

Flag for outputting 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:

~SPAC2020\$ 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.

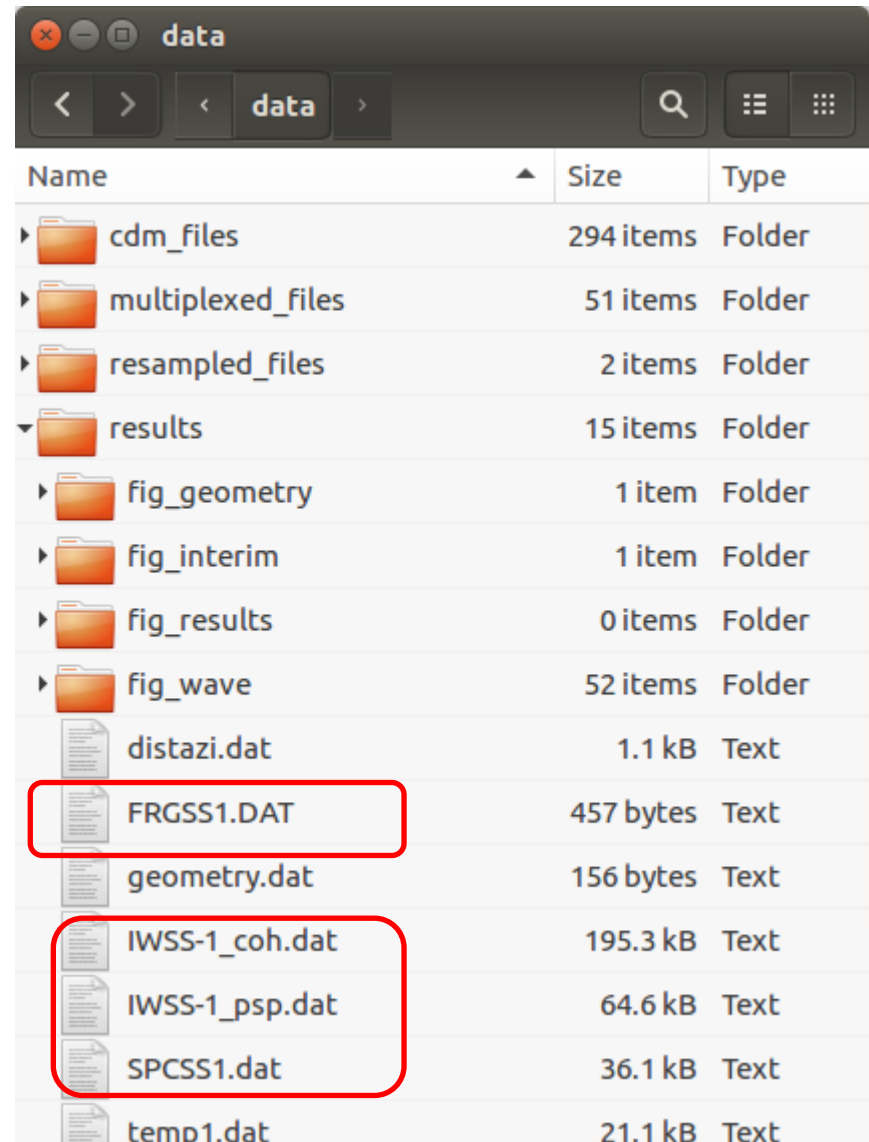
./spacwkf/data/results/IWSS-1_psp.dat

Output:./spacwkf/data/results/IWSS-1_psp.dat

./spacwkf/data/results/IWSS-1_coh.dat

./spacwkf/data/results/SPCSS1.dat

Look the next page

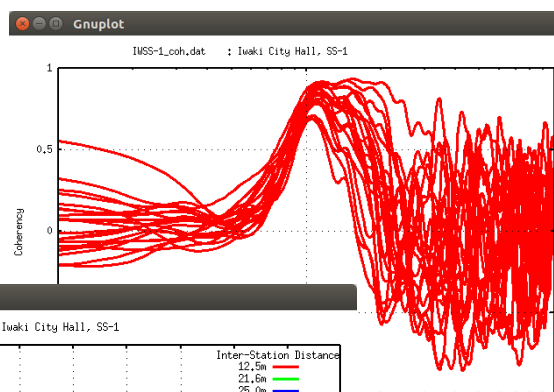


Name	Size	Type
cdm_files	294 items	Folder
multiplexed_files	51 items	Folder
resampled_files	2 items	Folder
results	15 items	Folder
fig_geometry	1 item	Folder
fig_interim	1 item	Folder
fig_results	0 items	Folder
fig_wave	52 items	Folder
distazi.dat	1.1 kB	Text
FRGSS1.DAT	457 bytes	Text
geometry.dat	156 bytes	Text
IWSS-1_coh.dat	195.3 kB	Text
IWSS-1_psp.dat	64.6 kB	Text
SPCSS1.dat	36.1 kB	Text
temp1.dat	21.1 kB	Text

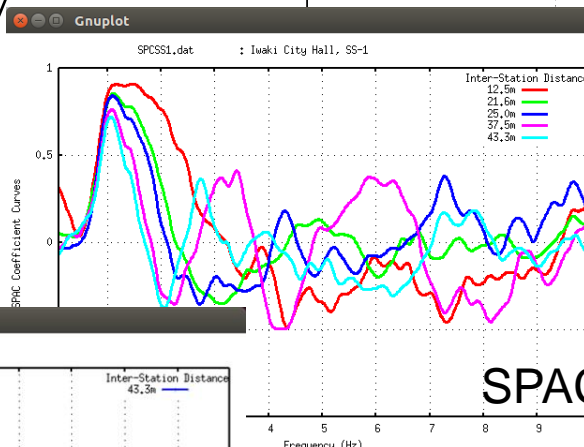
interim_plt.exe

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

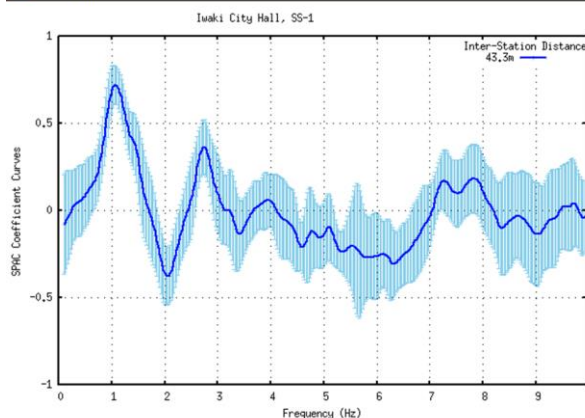
~SPAC2020\$



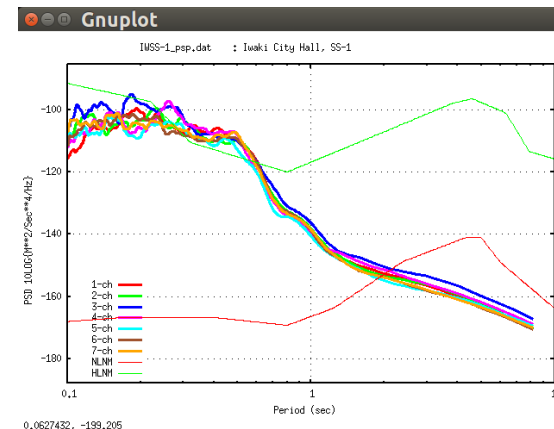
All Coherence functions



SPAC coefficients



Individual SPAC function
with error bar

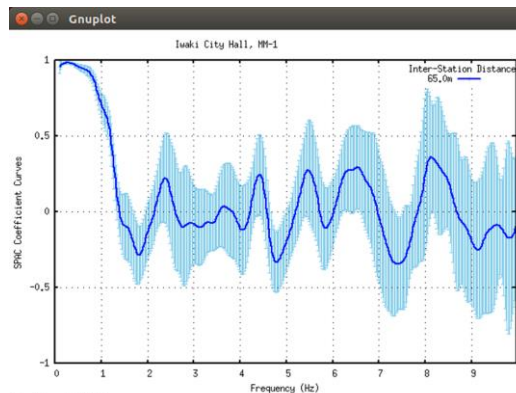


Power spectra

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

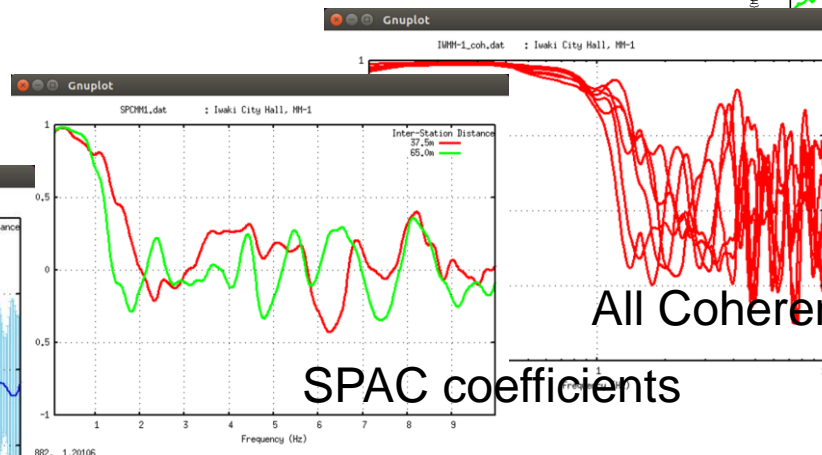
Procedure for MM-1 Array

- + Edit `./spacwkf/prm/resample6.prm` for MM-1 Array
➔ resampled & screened file `IWMM-1.dat`
- + `$ sh resample5.sh`
- + Edit `./spacwkf/prm/seewav6.prm` for MM-1 Array
➔ 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.

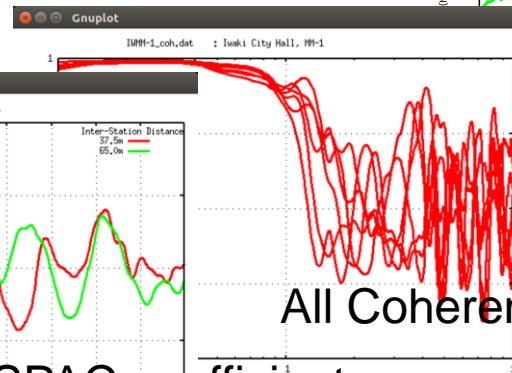


10,2500, -0,629213

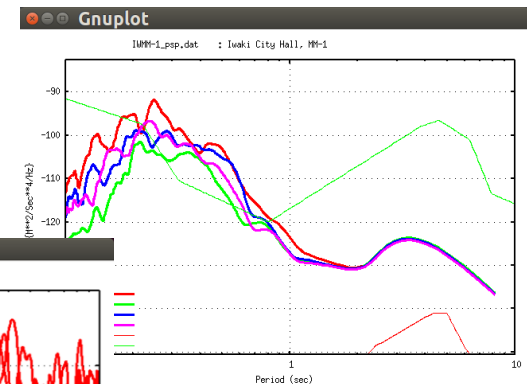
Individual SPAC function
with error bar



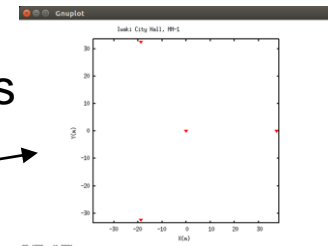
SPAC coefficients



All Coherence functions



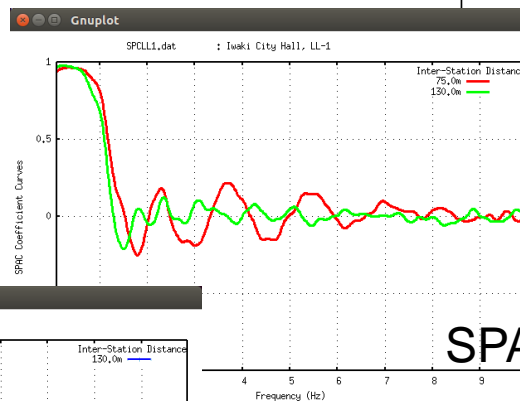
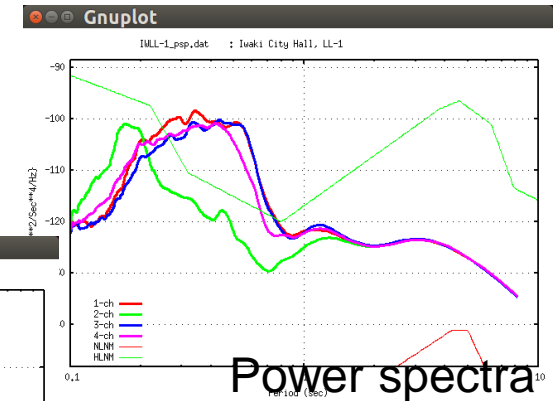
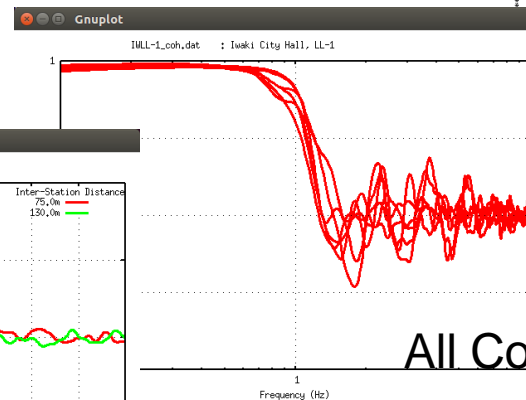
Power spectra



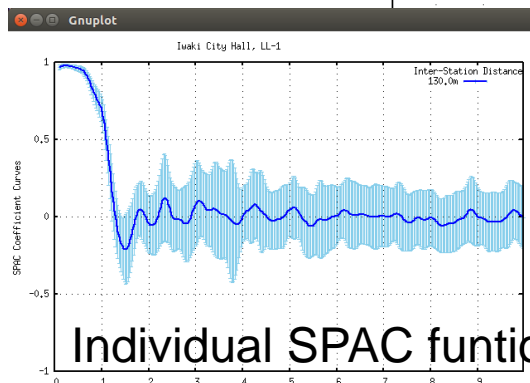
These figures are automatically stored as PS files in
`./spacwkf/data/results/fig_interim`

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.



SPAC coefficients



Individual SPAC function with error bar

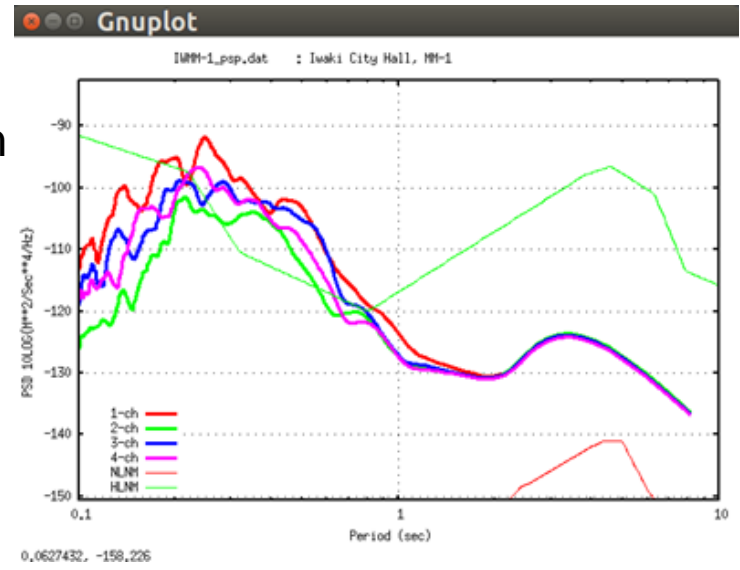
These figures are automatically stored as PS files in `./spacwkf/data/results/fig_interim`

Power Spectra

$10 \cdot \text{Log}_{10}$ (Fourier Coefficient * T_d * ω^2) of each frequency is plotted in PostScript file `spacwkf/data/results/fig_interim/IWMM-1_psp.ps` in the unit $10 \cdot \text{Log}_{10}(\text{M}^2/\text{Sec}^4/\text{Hz})$
 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	
...											



$$10 \cdot \text{Log}_{10} (\text{Fourier Coefficient} * T_d * \omega^2)$$

$$10 \cdot \text{LOG}_{10}(\text{sqrt}(\text{variance of Fourier Coefficient}) * T_d * \omega^2)$$

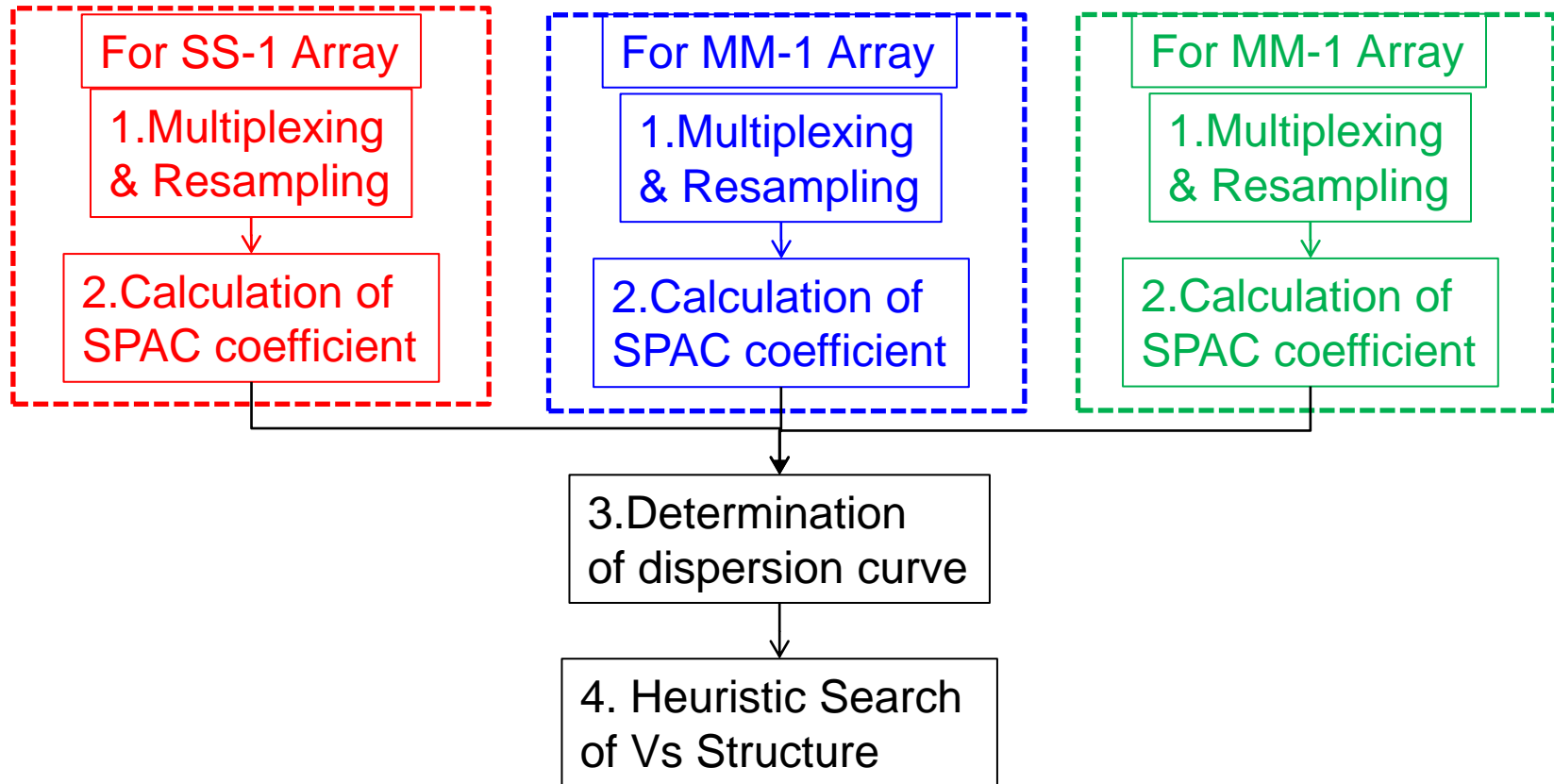
where $\omega = 2\pi/\text{period}$

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.

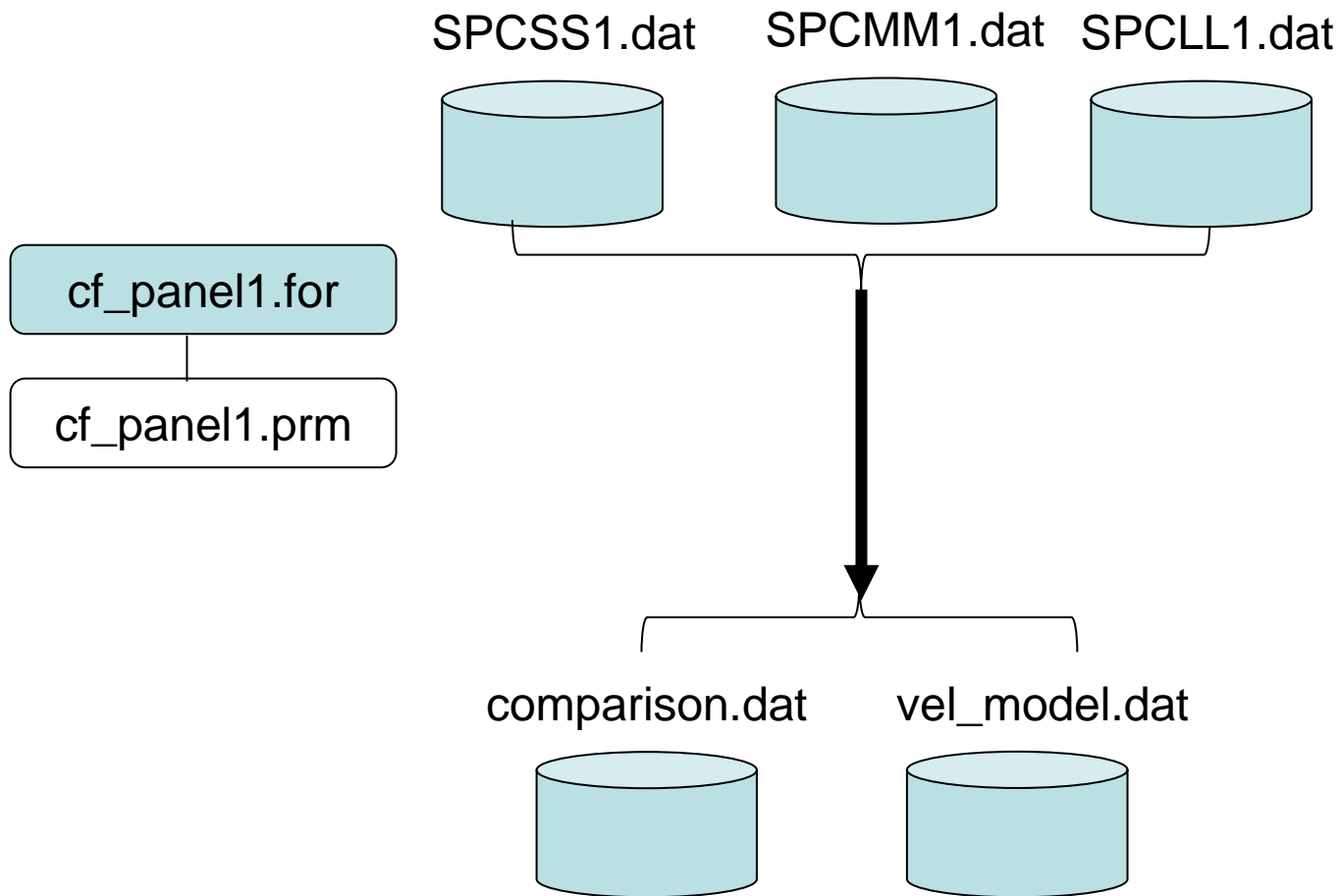
For plotting

`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 fifth order polynomial that approximates the inverse function of $J_0(x)$

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

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 spatial 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

SS-1-array

SPCMM1.dat :file name (a12)

2 :Number of Radius

37.5 :Radius(m),Min and Max of the frequency(Hz) for fitting
65.0

MM-1-array

SPCLL1.dat :file name (a12)

2 :Number of Radius

75.0 :Radius(m),Min and Max of the frequency(Hz) for fitting
130.0

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
```

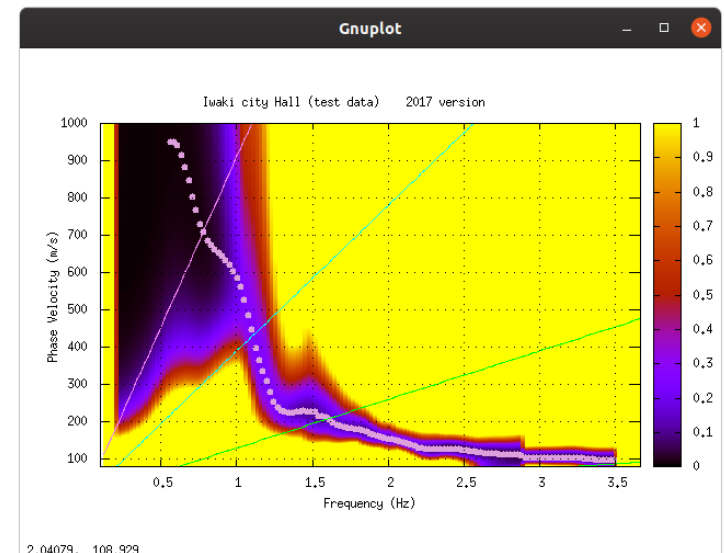
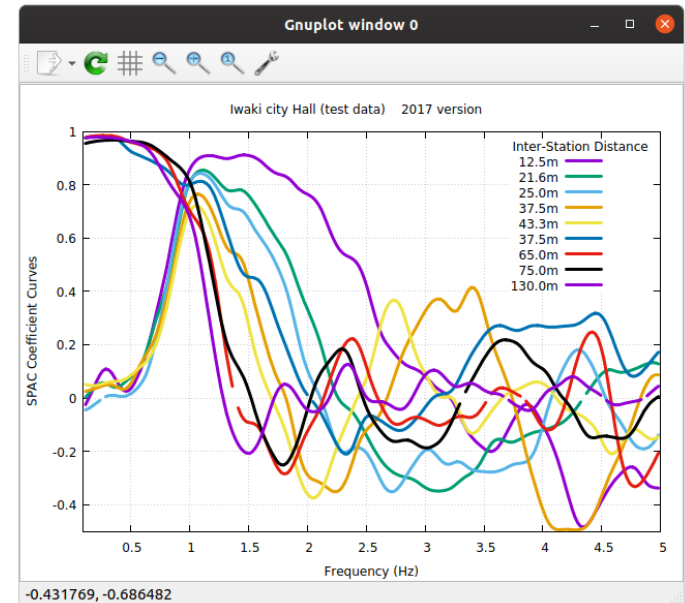
```
./spacwkf/prm/gnuplt_script/SPAC_coef.plt
```

```
./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

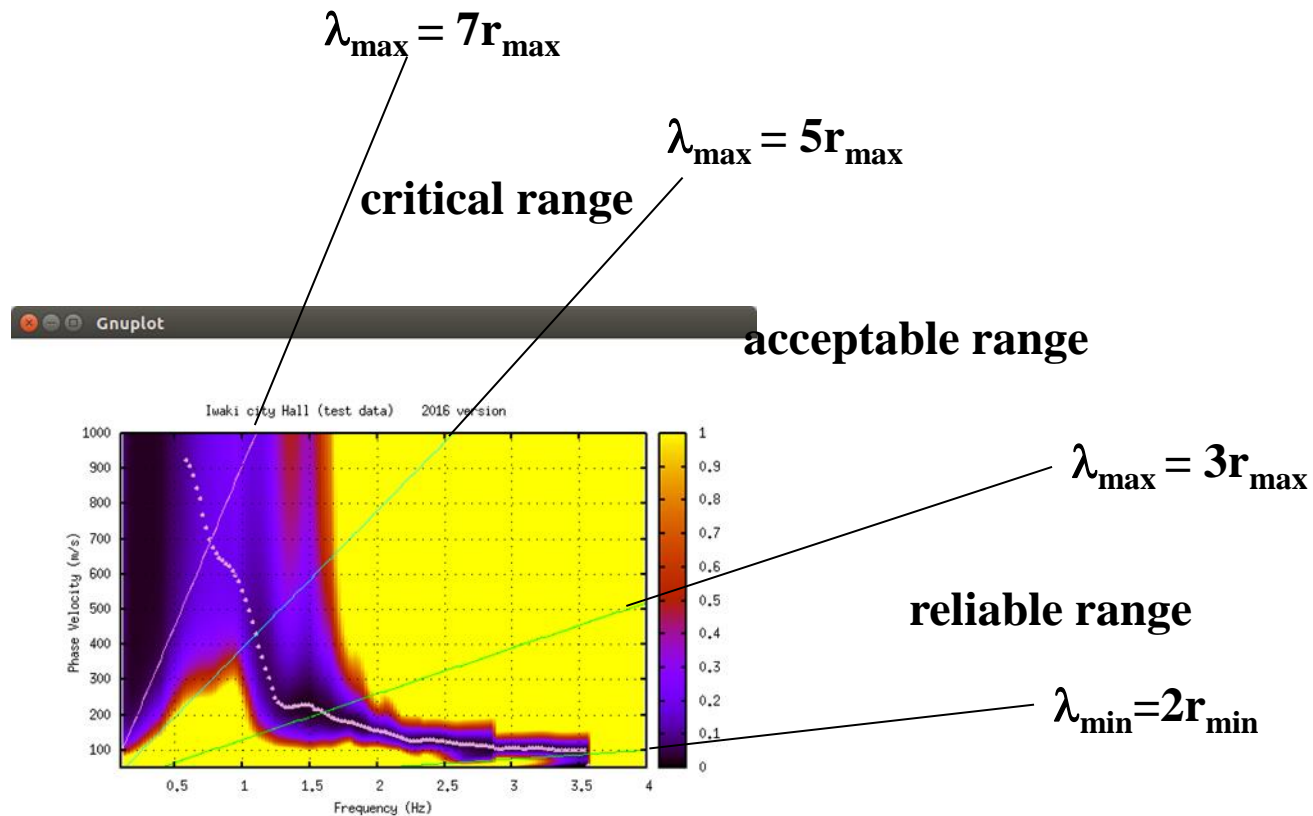
Nyquist_Wave $\longrightarrow \lambda_{\min}=2r_{\min}$

$\lambda_{\max} < 7r_{\max}$: 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.

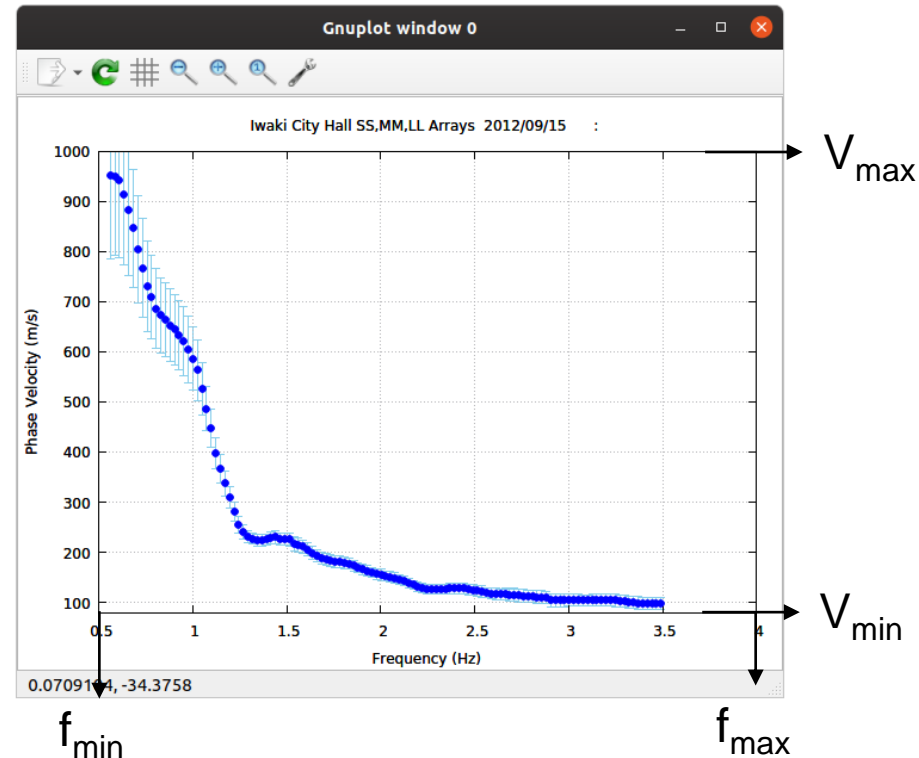
File: vel_model.dat

- [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*

~SPAC2020\$ *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:

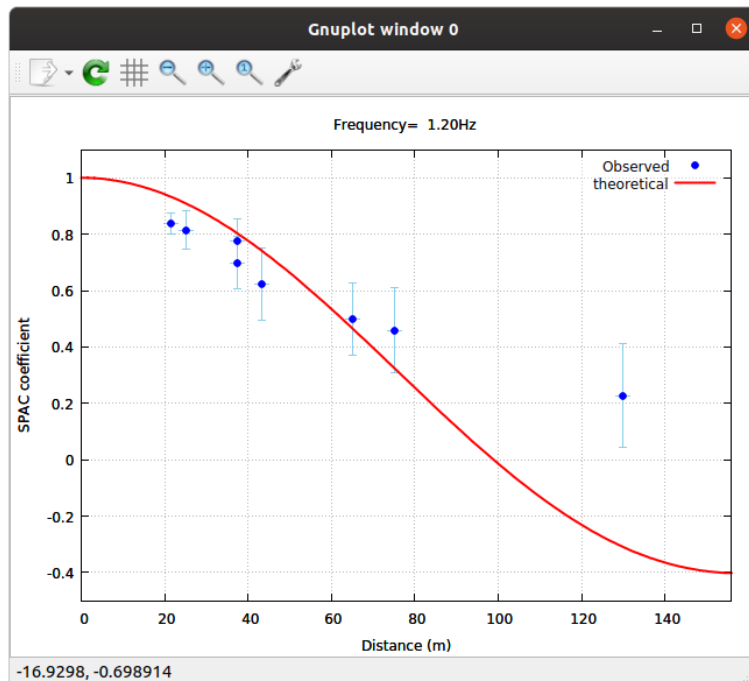
```
$ sh comparison.sh
```

...

Type in the frequency that you want to select.

...

```
./spacwkf/prm/gnuplt_script/comparison.plt
```



Simultaneously the same image 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

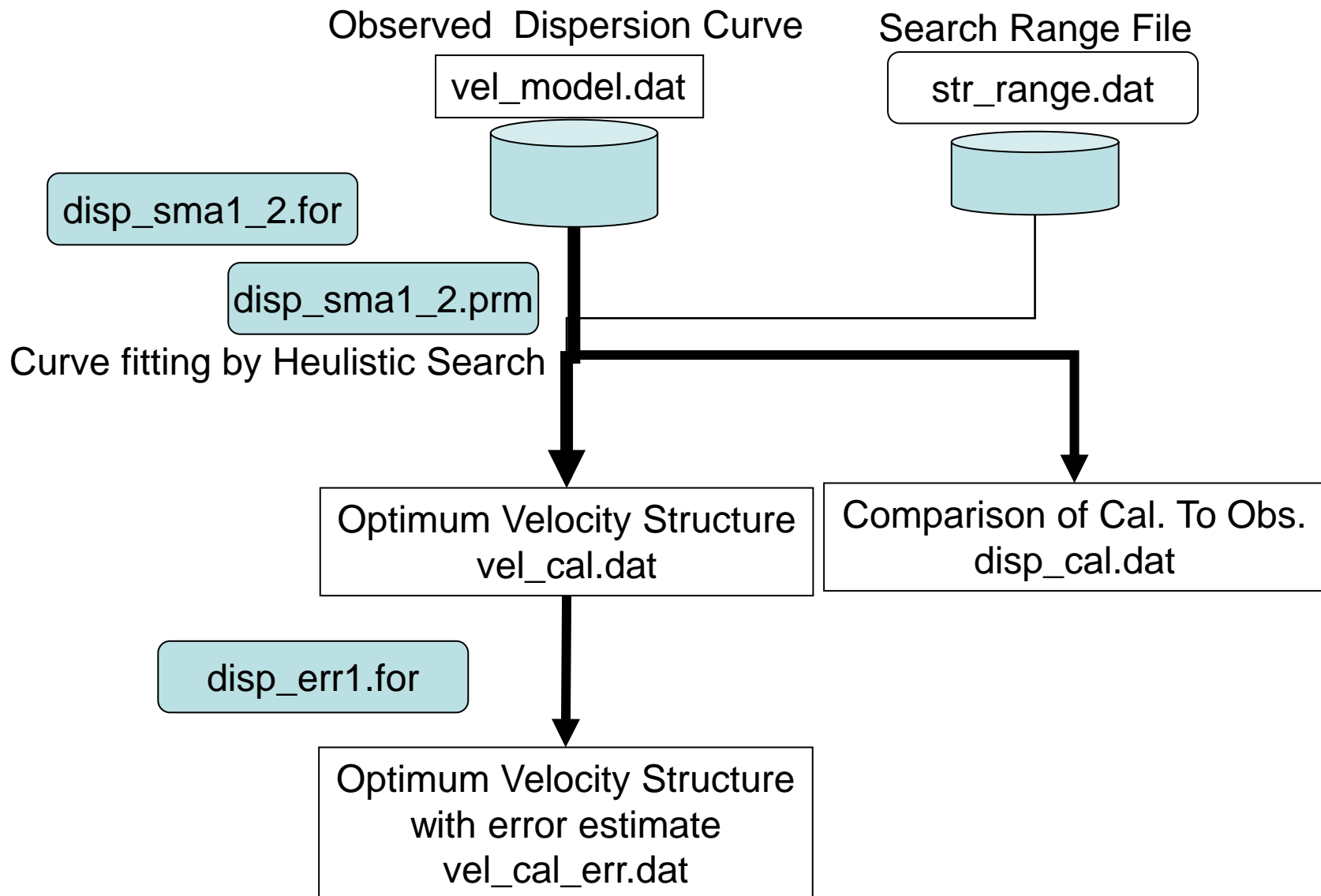
`./bin/disp_sma1_2.exe + ./spacwkf/prm/disp_sma1_2.prm`

`./bin/disp_err1.exe`

`results.sh`

that controls

`./bin/results_plt.exe`



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                  :k_flg,j_flg
0 0                  :n_vs,n_th
str_range.dat        :File name for the initial velocity model (a25).
vel_model.dat         :File name for the observed 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 $T=T_0 \cdot \exp(-c \cdot k^a)$, where k is iteration number. **$T_0=1.0$, $a=0.6$ & $c=1.3$ are of the fastest schedule**

ntemp :Maximum number of temperature 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): $vp=1.11 \cdot vs+1.29$; 0=fixed to the initial values

n_roh : 1=by Kitzunezaki et al(1990): $roh=1.2475+0.399 \cdot vp-0.026 \cdot vp^2$; 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

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

j_flg : Missfit at each iteration 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
```

Opening


```
+-----+
+
+           Disp_sma1
+
+ Program to obtain the optimum underground 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
```

 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	0.100
0.026	1.770	1.445	0.139	0.005	0.100
0.023	1.849	1.696	0.365	0.005	0.200
0.120	1.952	2.036	0.672	0.005	0.400
0.275	1.993	2.176	0.798	0.005	0.700
999.000	2.356	3.645	2.121	998.000	1.000

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

./spacwkf/data/results/vel_model.dat → Input file (Dispersion Curve)

Iterations (Number , Misfit func.)

Iterations	Misfit func.
5	0.0092043458
10	0.0059573189
15	0.0059573189
...	
810	0.0024932232

./spacwkf/data/results/vel_cal.dat → Output file

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

Optimum Solution

./spacwkf/data/results/disp_cal.dat
./spacwkf/data/results/err_estm.dat → 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
```

} Input files

```
IL= 6 MP=13 NP=12
```

```
minimum = 1th vertex
```

```
Sensitivity calculated by finite difference  
& stored in the output file sensitivity.dat
```

} Output files

```
./spacwkf/data/results/Vel_cal_err.dat
```

	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.

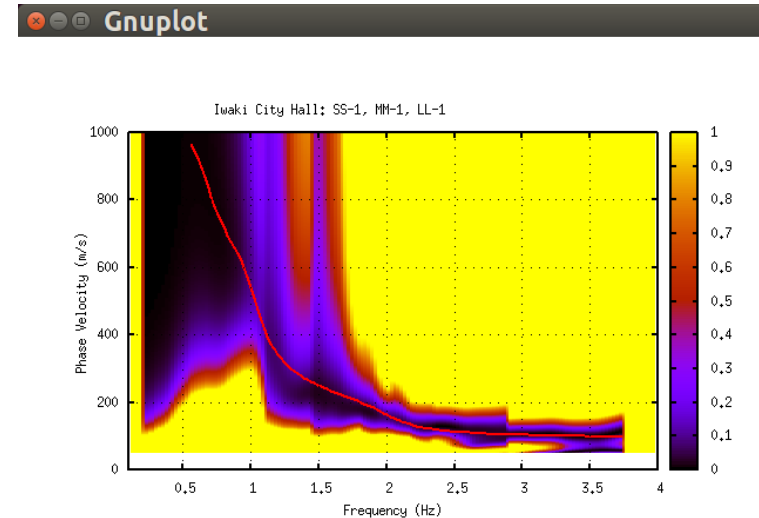
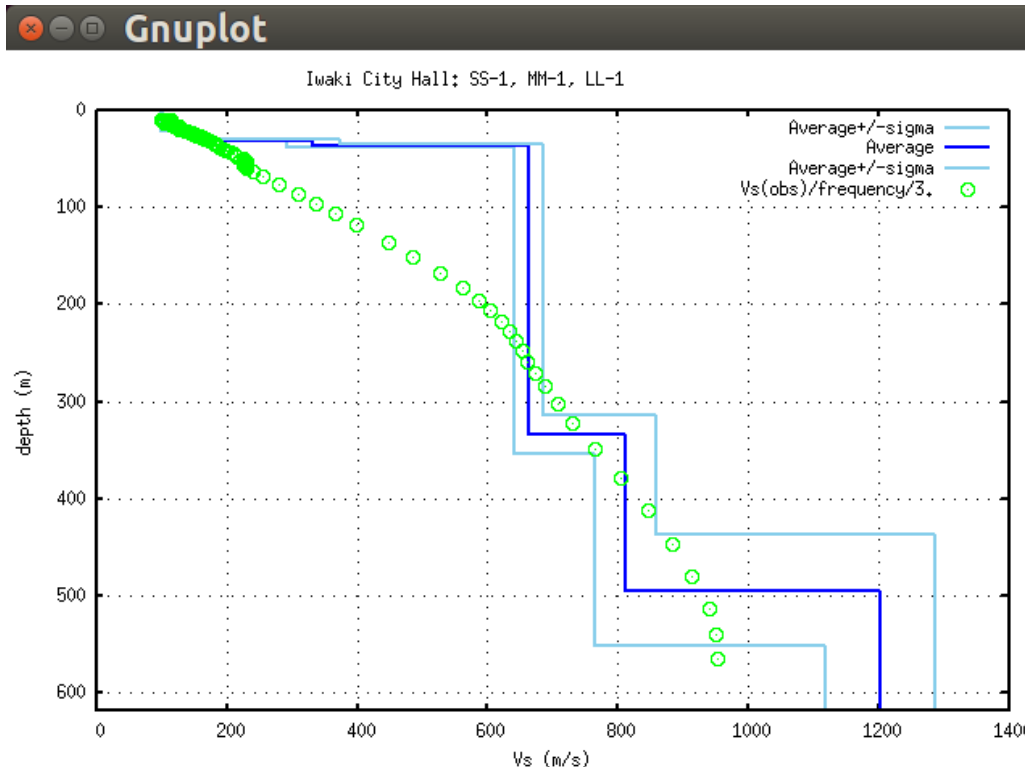
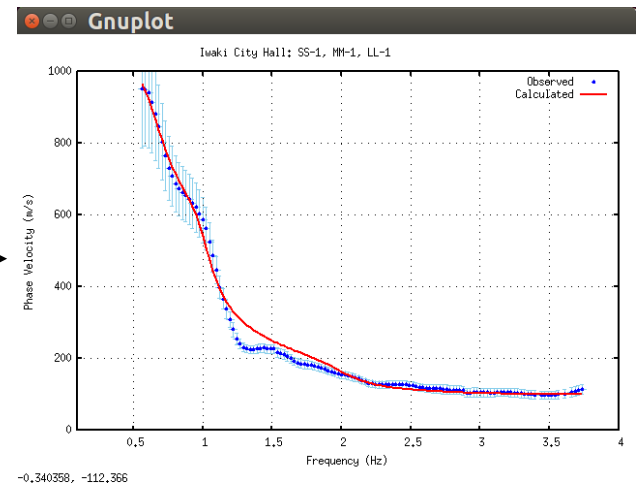
Frequency	h=1	h=2	h=3	h=4	h=5	v=1	v=2	v=3	v=4	v=5	v=6
0.561E+00	0.596E+01	0.398E+01	0.171E+01	0.124E+01	0.258E+00	0.511E+00	0.120E+00	0.679E-01	0.804E+00	0.375E-01	0.610E+00
0.586E+00	0.711E+01	0.440E+01	0.176E+01	0.134E+01	0.227E+00	0.664E+00	0.141E+00	0.746E-01	0.116E+01	0.340E-01	0.548E+00
0.610E+00	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
```

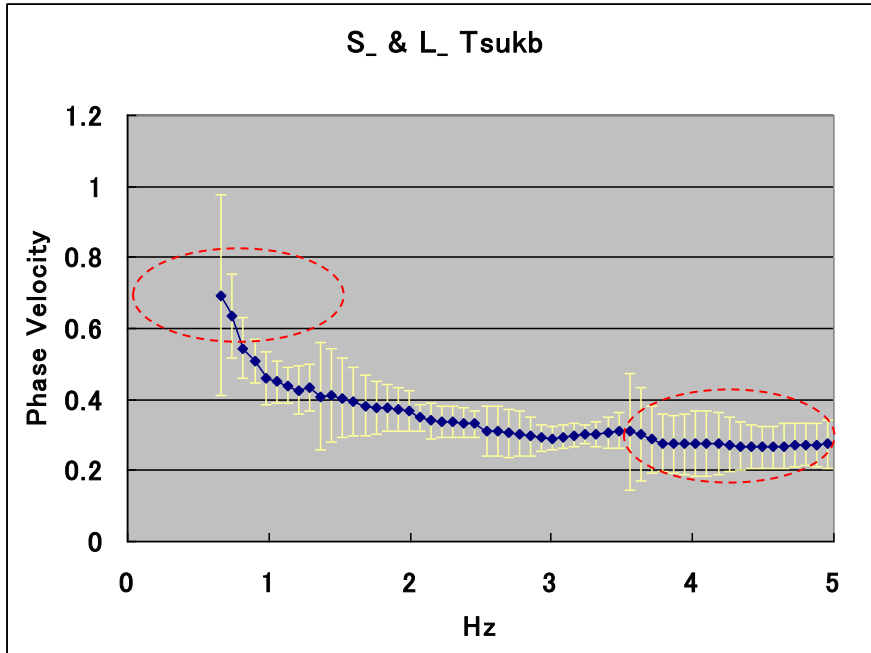
Hit return to continue
Hit return to continue



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

5

:Model (a30)

:IL(I5), Layer Number

1.5 1.6 0.001 0.2 0.2 0.5 :density, Vp, hmin, hmax, vmin, vmax

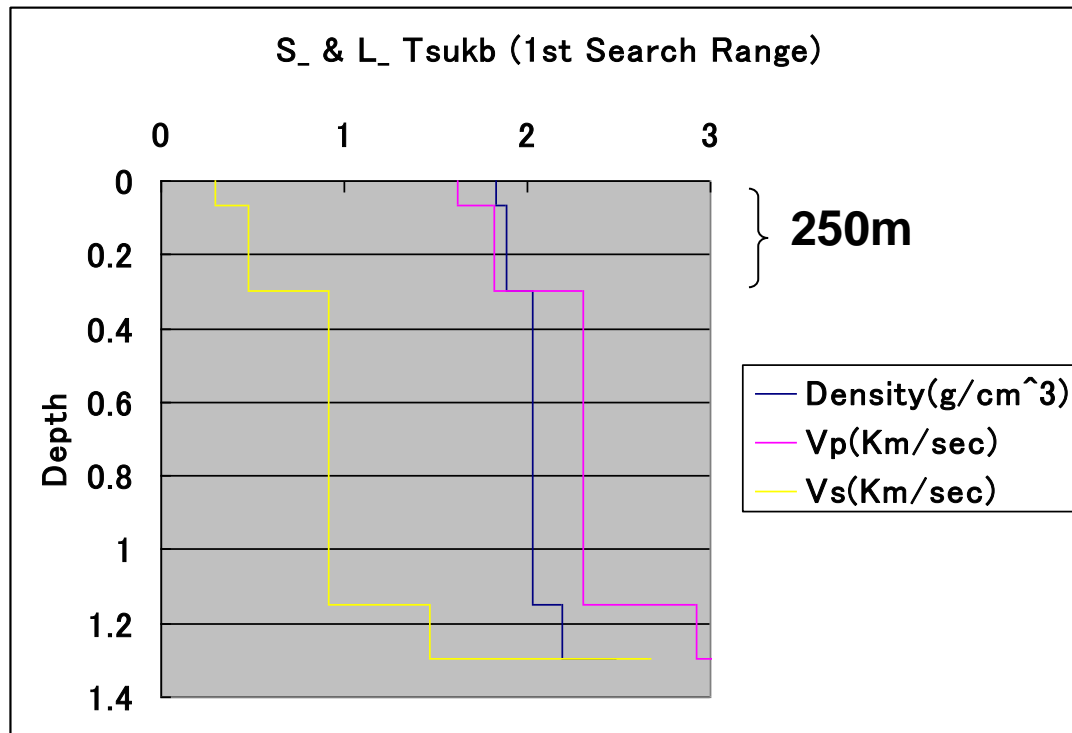
1.8 1.956 0.01 1.0 0.4 0.9

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

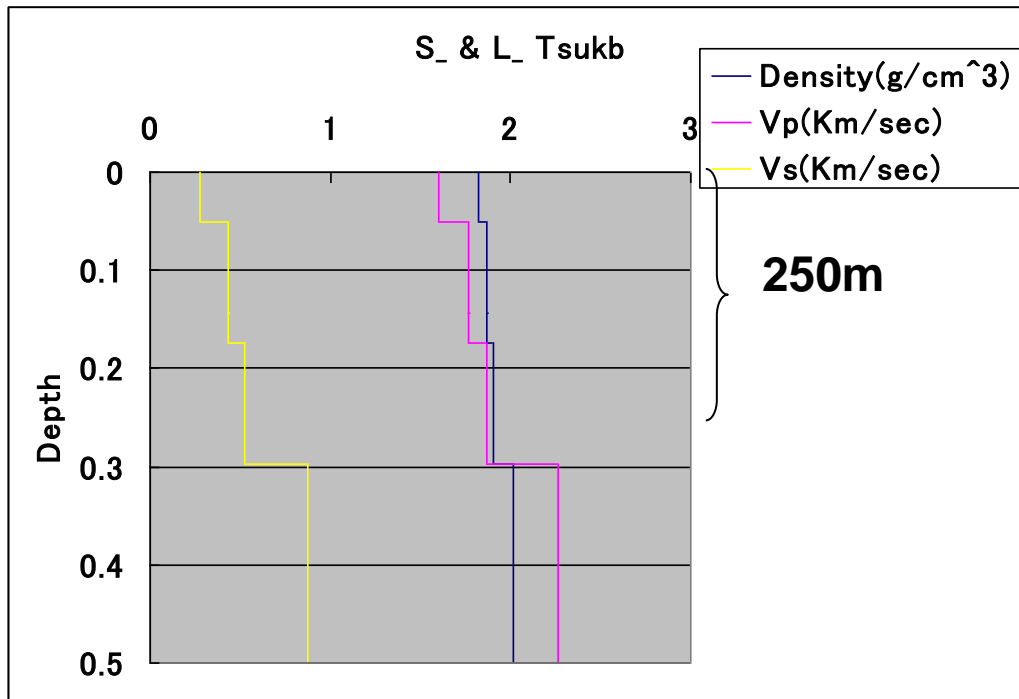
S_ & L_ Tsukb
5

: Model (a30)

: 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

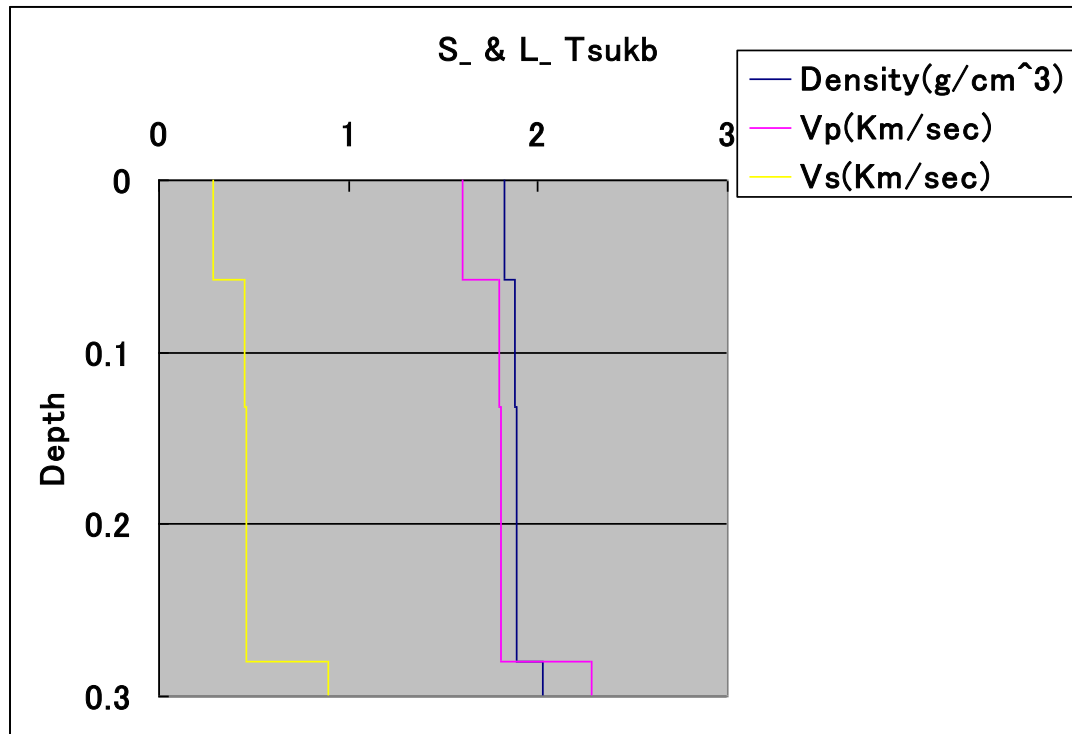
1.5 1.6 0.001 0.2 0.2 0.4 :density, Vp, hmin, hmax, vmin, vmax

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 :k_flg, j_flg
0 0 :n_vs, n_th
str_range.dat :File name for the initial velocity model (a25).
vel_model.dat :File name for the observed 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  $T=T_0 \cdot \exp(-c \cdot k \cdot a)$ , where k is iteration number

<The optimum schedule is given  $t_0=1.0$ ,  $a=0.6$ ,  $c=1.3$  (Yokoi (2006)).>

c ntemp :Maximum number of temperature 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 k_flg : Missfit at each temp. change 1=yes

c j_flg : Missfit at each iteration with the same temp. 1=yes

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

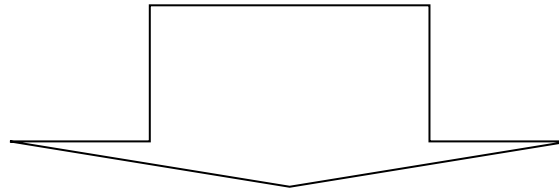
c n_th : Thickness value (n_th=layer number, 0=no output)

S_ & L_ Tsukb
4

:Model (a30)

:IL (I5), Layer Number

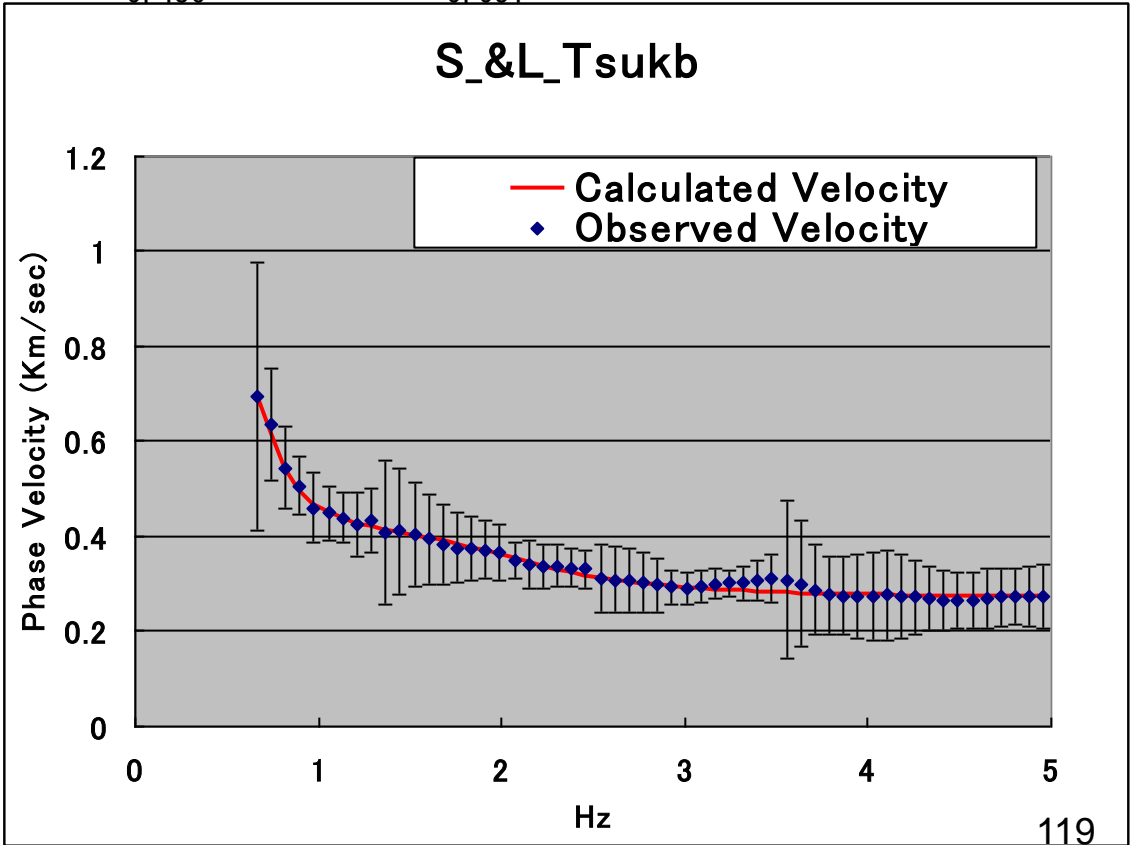
1.5	1.6	0.001	0.2	0.2	0.4	:density, Vp, hmin, hmax, vmin, vmax
1.5	1.6	0.001	0.2	0.3	0.5	
1.5	1.6	0.001	0.2	0.4	0.6	
1.8	1.956	998.0	999.0	0.5	0.9	



	Thicknes (Km)	Dens ity (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		
3.008	0.291		



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

