IISEE Lecture Note
2007-2008

Practice of Seismic Analysis Code

・Waveforam stacking(sss)

・Determination of Mwp(macro)

by

Kenji Kanjo

Kuninori Okamoto

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International Institute of

Seismology and Earthquake Engineering,

Building Research Institute

Practice of Data processing using SAC(Goldstein,2005)

1. How to start SAC program

First, type on the UNIX workstation, "**sac2000**"

Then the SAC program will start, and you will see the SAC prompt (**SAC＞**) in the window.

If you type a SAC command on this command line, you can execute a SAC program.

When you want to finish the SAC program, type "**exit**".

2. Data Handling

2.1 How to signal stack.

-Exercise.1 How to signal stack.

Sample (the earthquake occurred in Northern Sumatra on March 28,2005.)

First, change directory for training:

```
$ cd
$ cd  jica/training
```

Start SAC program:

```
$ sac2000
```

If the command shown below is typed, a figure as shown in Fig.1 will be displayed.

```
SAC> bd  x
SAC> qdp off
SAC> r  *_V.BHZ
   CTAO_V.BHZ  DGAR_V.BHZ  GNI_V.BHZ  INCN_V.BHZ  MAJO_V.BHZ
   MSEY_V.BHZ NWAO_V.BHZ PALK_V.BHZ TATO_V.BHZ YAK_V.BHZ
SAC> p1
```

If the command shown below is typed, a figure as shown in Fig.2 will be displayed

```
SAC> sss
 Signal Stacking Subprocess.
SAC/SSS> traveltime  phase  P  S
SAC/SSS> prs r off ttime on
SAC/SSS> prs red v 14
SAC/SSS> tw 0 800
SAC/SSS> prs
SAC/SSS> exit
```

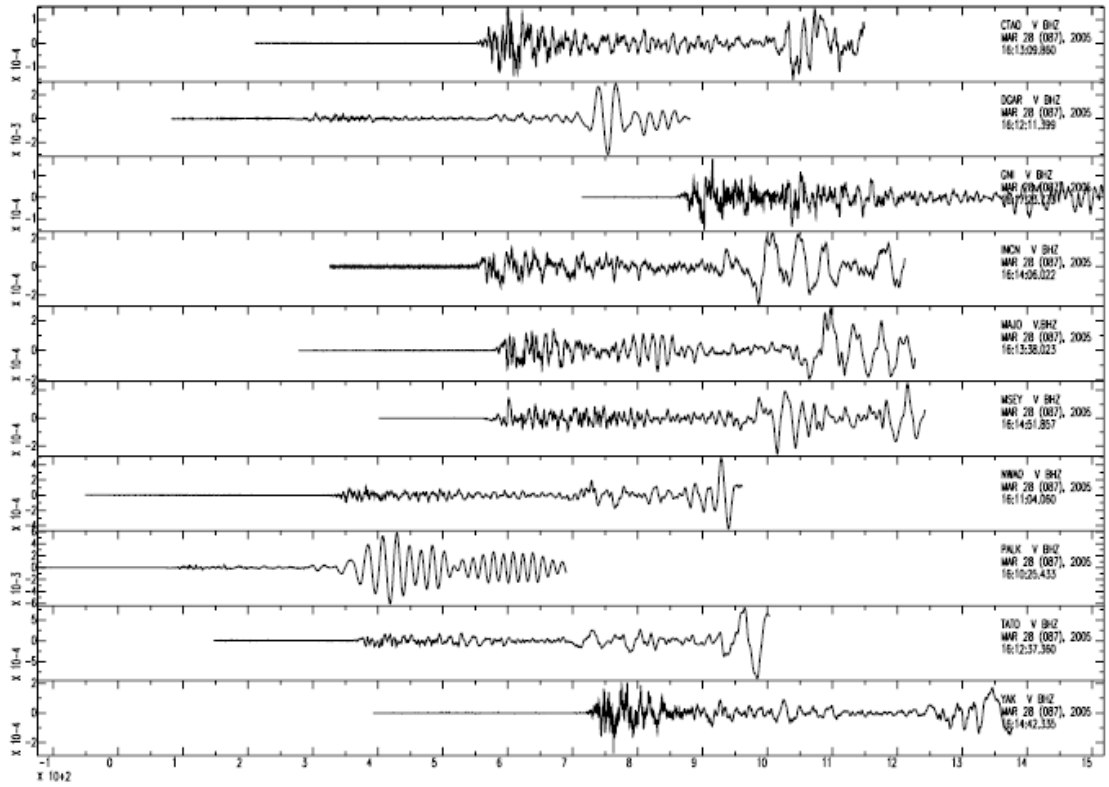

CTAO V.BHZ
DGAR V.BHZ
GNI V.BHZ
INCN V.BHZ
MAJO V.BHZ
MSEY V.BHZ
NWAO V.BHZ
PALK V.BHZ
TATO V.BHZ
YAK V.BHZ
X 10+2

Fig.1

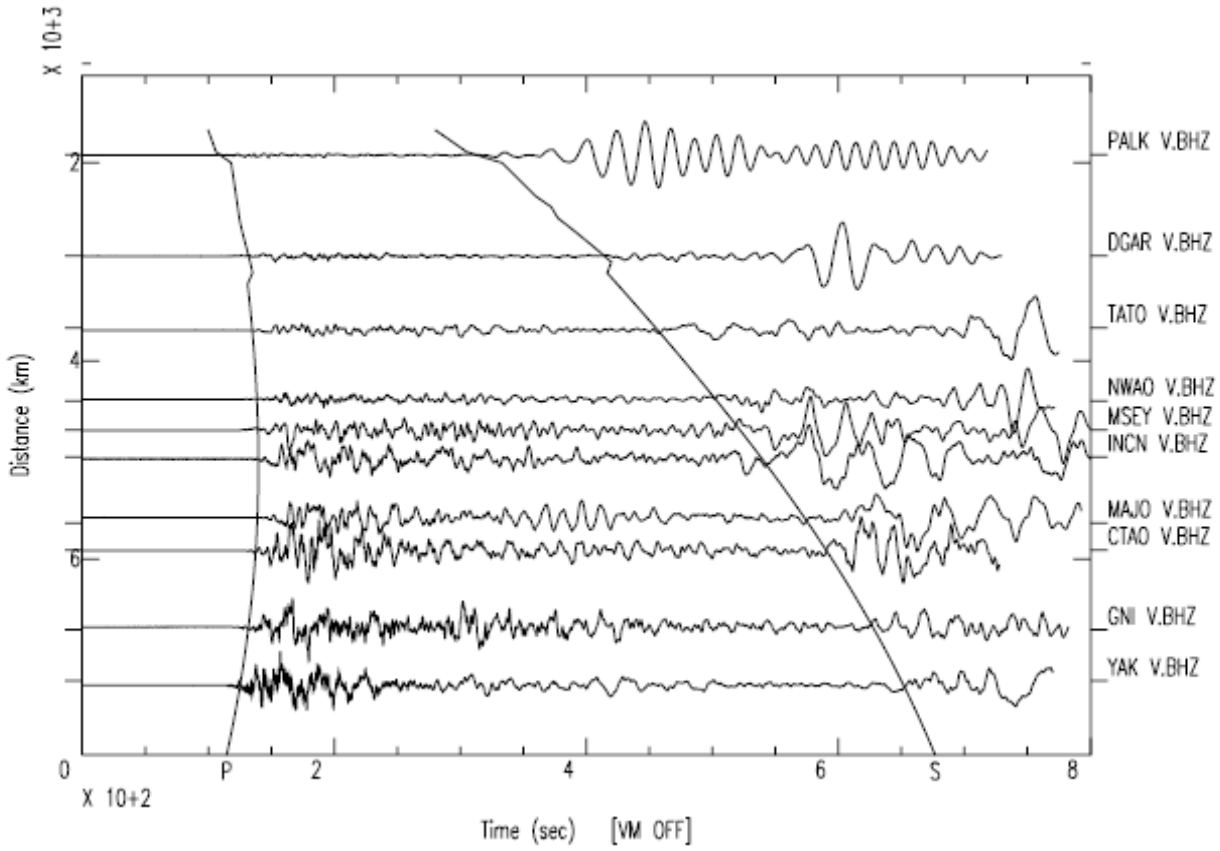

X 10+3
Distance (km)
PALK V.BHZ
DGAR V.BHZ
TATO V.BHZ
NWAO V.BHZ
MSEY V.BHZ
INCN V.BHZ
MAJO V.BHZ
CTAO V.BHZ
GNI V.BHZ
YAK V.BHZ
P
S
X 10+2
Time (sec) [VM OFF]

Fig.2

2.2 How to determine Mwp.

Rapid and precise evaluation of a potentially tsunami-genic earthquake's hypocenter and magnitude is important for saving lives from tsunami and for reducing tsunami related damage. The displacement of the P-wave portion observed on a vertical broadband seismograph record is theoretically considered as an approximate seismic source time function. The integrated displacement can then be viewed as representing the seismic moment as a function of time. We obtain the scalar seismic moment at each station from the vertical broadband record of the integrated displacement of the P-wave portion of the seismogram. The seismic moment Mo is obtained from the largest of the first peak (P1) of the P-wave portion of the seismogram, or the difference between P1 and the amplitude (P2) of pP or sP (P1-P2), on the integrated displacement record of the vertical broadband seismograph record (Tsuboi et al.,1995,1999):

$$Mo = Max(|P1|,|P1-P2|)\frac{4\pi\rho\alpha^3 r}{F^p} \qquad (1)$$

where Mo is the seismic moment, ρ and α are the mean density and P-wave velocity along the propagation path, r is the epicentral distance, and F^p is the P-wave radiation pattern. The moment magnitude is then obtained from

$$Mw = \frac{\log Mo - 9.1}{1.5} \qquad (2)$$

(Kanamori, 1977), for each vertical broadband seismic channel without a correction for radiation pattern. To get Mwp, we add 0.2 for compensation to Mw obtained using the above procedure.

The results show that Mwp correlates well with Harvard's Mw's obtained from their Centroid Moment Tensor(CMT) solution（Dziewonski et al al.,1981). Both U.S. Tsunami warning centers, at WC/ATWC and at the PTWC, use Mwp for their first estimate of Mw.

(From Kanjo.K et al.,2006)

The procedure of calculating Mwp using SAC.

Sample (the earthquake occurred in Northern Sumatra on March 28,2005.)

【Preparation】Change directory for training.

$ cd

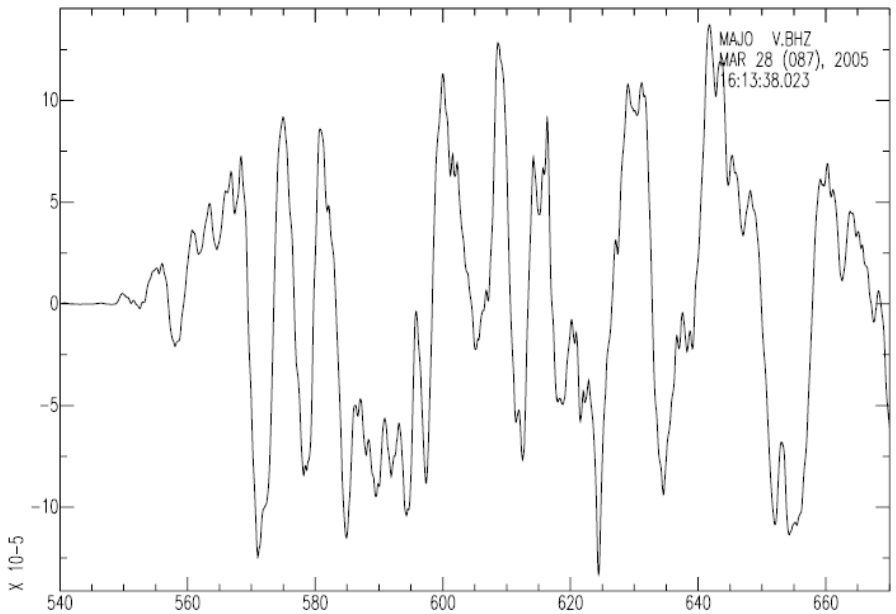
$ cd jica/training

【For example】 ---> MAJO case

- First step

If the command shown below is typed, a figure as shown in Fig. 3 will be displayed. In this case, we analyze 130 seconds of signal from the vertical component at each station beginning 10 seconds before the initial P-wave onset time.

```
$ sac2000
SAC> bd x
SAC> qdp off
SAC> r    MAJO_V.BHZ
SAC> p1
SAC> cut    540    670
SAC> r
SAC> xlim off
SAC> p1
```



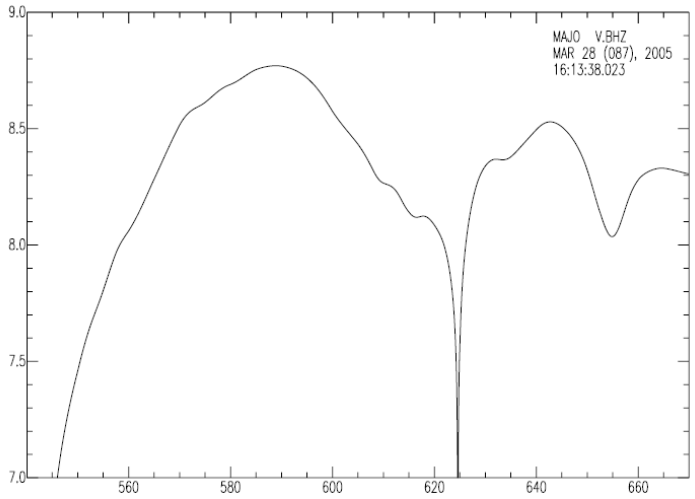
-Next step

Mwp is calculated using the already described formula (1),(2). It is as follows, when the procedure of calculating this Mw is followed by SAC command.

```
SAC> rmean
SAC> rtr
SAC> taper
SAC> p1
SAC> int
SAC> int
SAC> abs
SAC> p1
SAC> mul    4
SAC> mul    3.1415926
SAC> mul    3.5E+03
SAC> mul    4.155257E+12
SAC> mul    5.686314E+6
SAC> log10
SAC> p1
SAC> sub    9.1
SAC> div    1.5
SAC> p1
```

Lastly, in order to get Mwp, add 0.2 to Mw.

```
SAC> add    0.2
SAC> ylim    7    9
SAC> p1
```



Exercise.2　Let's try to determine Mwp using SAC command.

Sample (the earthquake occurred Northern Sumatra on March 28,2005.)

Use the parameters shown in Table.1, calculate Mwp for every observation point, and, finally calculate the average value of Mwp.

Refer to the value of "DEPMAX" for the Mwp value for every observation point with a "lh" command. The "DEPMAX", the highest value of Mwp, is then shown.

SAC> bd　x
SAC> qdp off
SAC> r　***File_NAME***
SAC> p1
SAC> cut　***CR1　CR2***
SAC> r
SAC> xlim off
SAC> p1
SAC> rmean
SAC> rtr
SAC> taper
SAC> p1
SAC> int
SAC> int
SAC> abs
SAC> p1
SAC> mul　4
SAC> mul　3.1415926
SAC> mul　3.5E+03
SAC> mul　***APV3***
SAC> mul　***DISTANCE***
SAC> log10
SAC> p1
SAC> sub　9.1
SAC> div　1.5
SAC> p1
SAC> add　0.2
SAC> ylim　7　9
SAC> p1
SAC> lh

Table.1 Variables for Mwp equation.

Station	File name	Cut range		Δ ang.dis (degree)	apprent velocity	$(0.16\Delta+7.9)^3$	distance (m)
input Val. →	FILE_NAME	CR1	CR2			APV3	DISTANCE
PALK	PALK_V.BHZ	220	350	17.139	10642.243	1.205312E+12	1.907867E+06
DGAR	DGAR_V.BHZ	310	440	26.348	12115.614	1.778428E+12	2.932967E+06
TATO	TATO_V.BHZ	380	510	32.725	13136.024	2.266688E+12	3.642136E+06
NWAO	NWAO_V.BHZ	430	560	39.681	14248.987	2.893024E+12	4.415861E+06
MSEY	MSEY_V.BHZ	450	580	42.132	14641.136	3.138516E+12	4.690114E+06
INCN	INCN_V.BHZ	480	610	44.468	15014.902	3.385069E+12	4.947829E+06
MAJO	MAJO_V.BHZ	540	670	51.105	16076.789	4.155257E+12	5.686314E+06
CTAO	CTAO_V.BHZ	545	675	52.981	16376.995	4.392408E+12	5.897083E+06
GNI	GNI_V.BHZ	595	725	60.598	17595.659	5.447743E+12	6.741837E+06
YAK	YAK_V.BHZ	620	750	64.602	18236.259	6.064671E+12	7.183543E+06

2.3 How to use macro command.

If you create a file of the procedure followed by ***Exercise.2***, you can call macro file in SAC command line. Then, by being able to simplify the procedure, it is possible to save working hours.

The method of calling a macro file and calculating Mwp from the SAC command line is as follows.

【For example】 ---> MAJO case

-Execution of macro command.

```
$ sac2000
SAC> macro MAJO.m
```

-Content of MAJO.m file

```
bd    x
qdp    off
r    MAJO_V.BHZ
cut    540    670
r
xlim off
rmean
rtr
taper
int
int
abs
mul    4
mul    3.1415926
mul    3.5E+03
mul    4.155257E+12
mul    5.686314E+6
log10
sub    9.1
div    1.5
add    0.2
ylim    7    9
p1
```

Exercise.3　Let's try to use macro command.

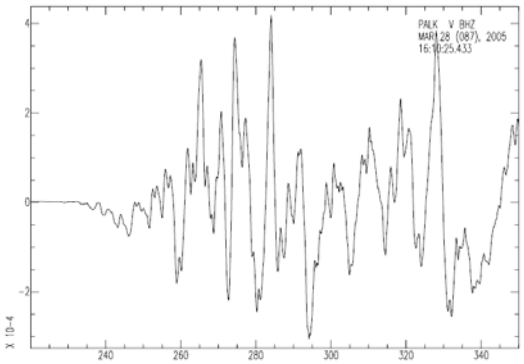
Create macro file. (First, copy from MAJO.m to STATION.m. Next, for every observation point, transpose the italic variable name to the variables shown in Table 1. Finally, execute a command and get the value of Mwp.

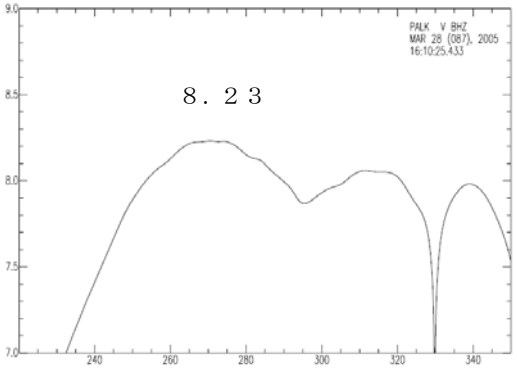
$ cp MAJO.m　*STATION*.m
$ vi　STATION.m
bd x
qdp off
r　***FILE_NAME***
cut　***CR1　CR2***
r
xlim off
rmean
rtr
taper
int
int
abs
mul　4
mul　3.1415926
mul　3.5E+03
mul　***APV3***
mul　***DISTANCE***
log10
sub　9.1
div　1.5
add　0.2
ylim　7　9
p1

Execute macro command.

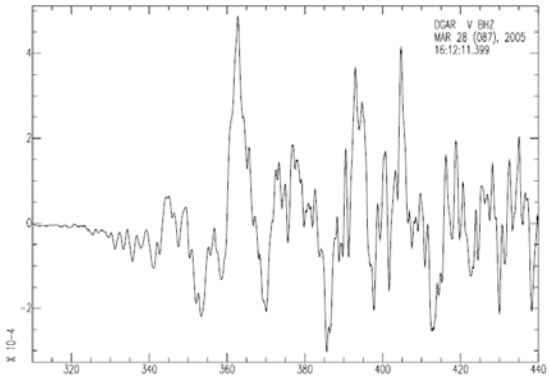
$ sac2000
　SAC> macro ***STATION***.m

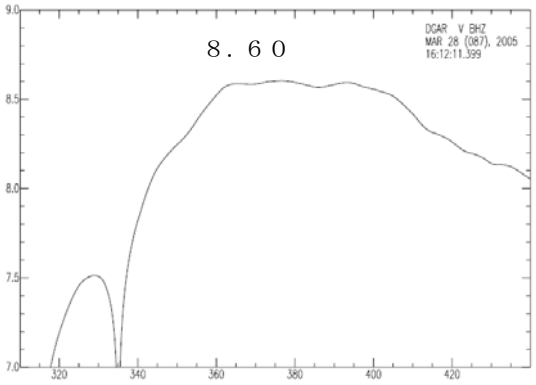
【PALK】 Velocity Mwp



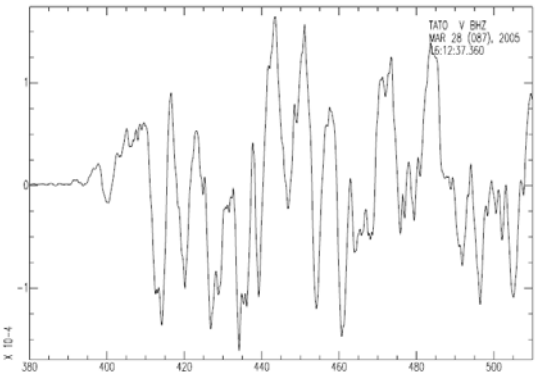


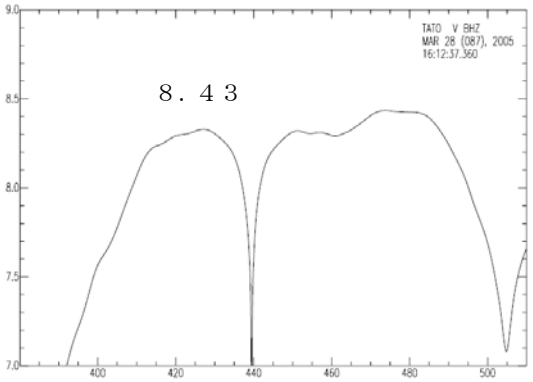
【DGAR】 Velocity Mwp



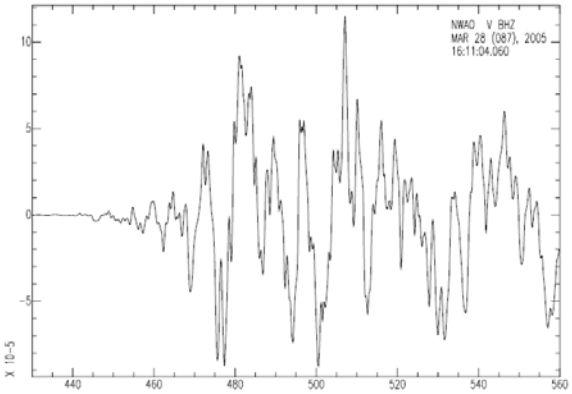


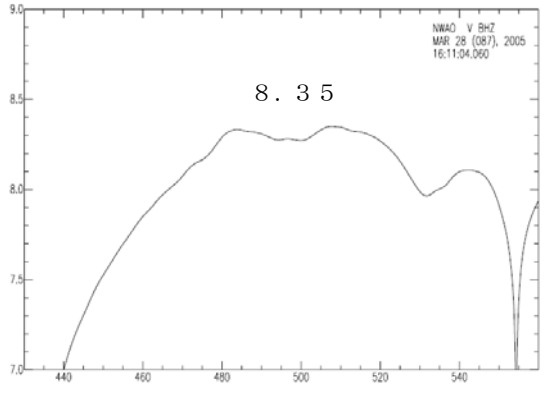
【TATO】 Velocity Mwp



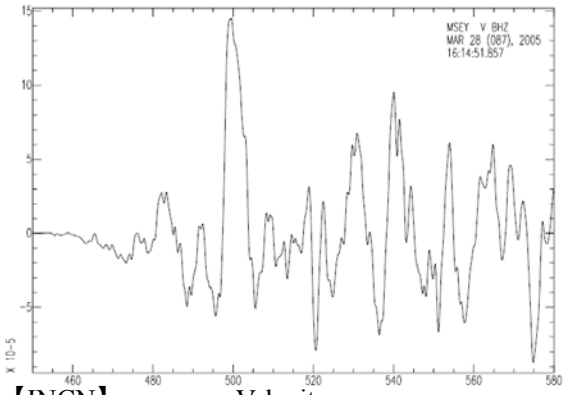


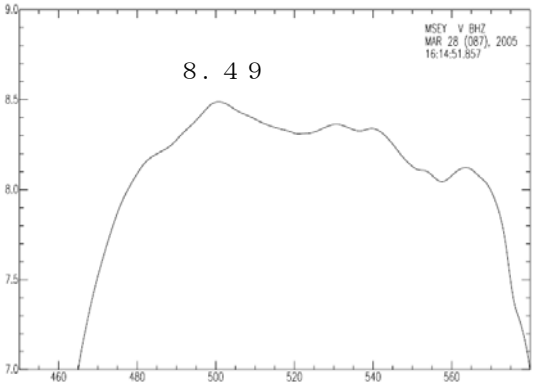
【NWAO】 Velocity Mwp



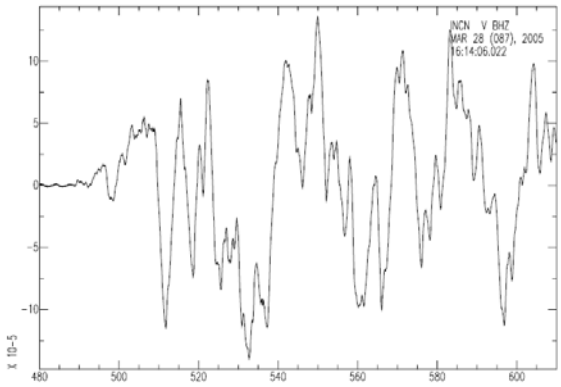


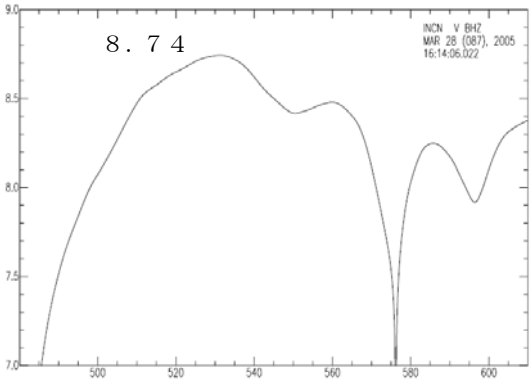
【MSEY】 Velocity Mwp



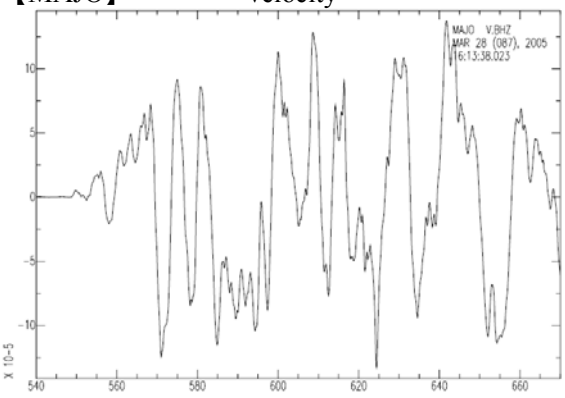


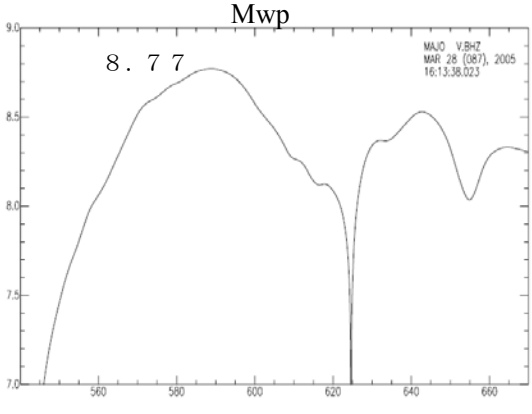
【INCN】 Velocity Mwp



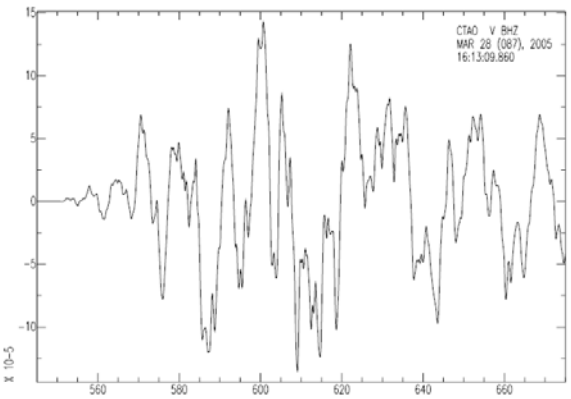


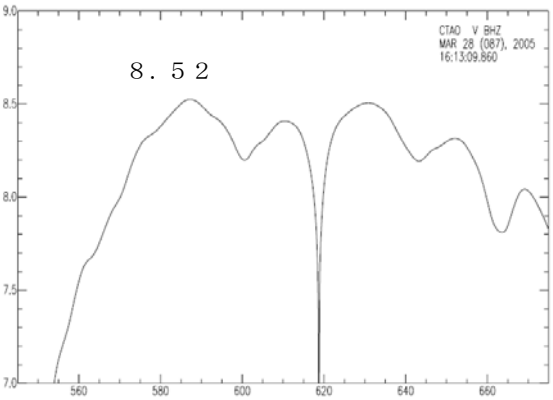
【MAJO】 Velocity Mwp



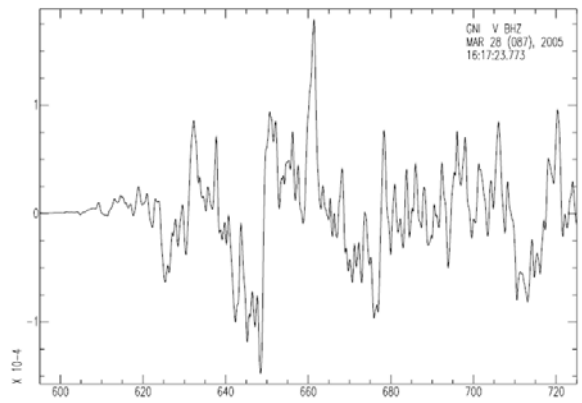


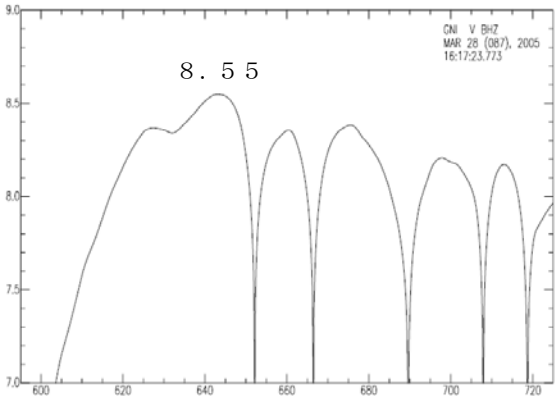
【CTAO】 Velocity Mwp



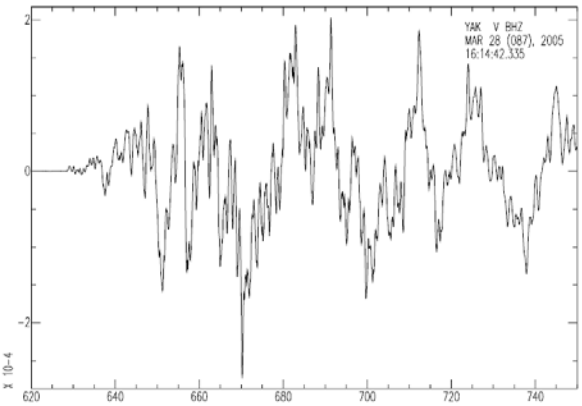


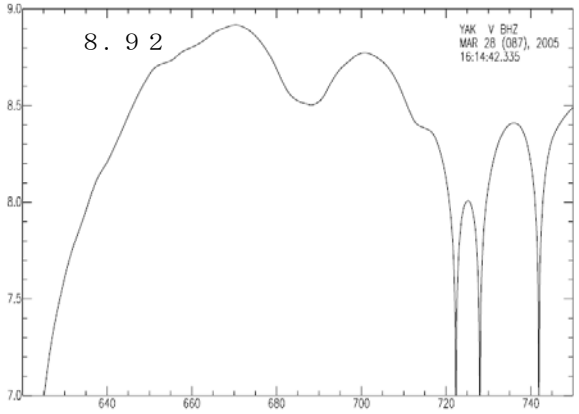
【GNI】 Velocity Mwp





【YAK】 Velocity Mwp





Mwp(Ave_10) ：8.56

3. Measurement of the high frequency energy radiation time.

Exercise.4 Let's try to use macro command

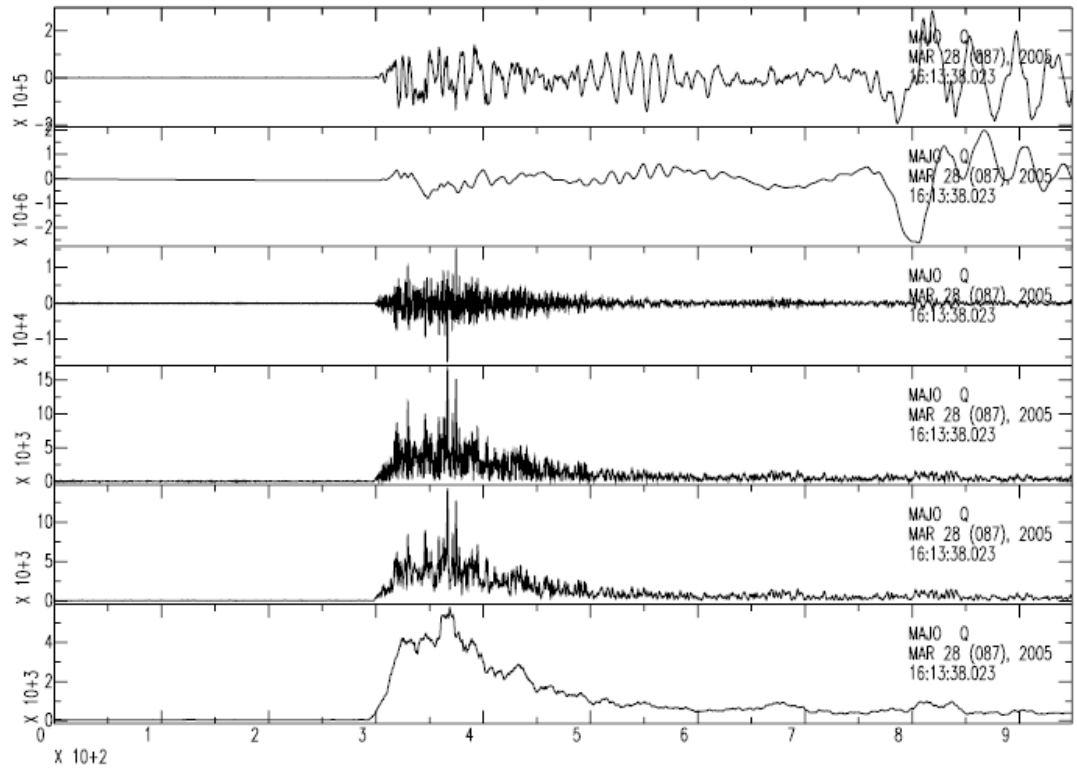
First,create macro file.

```
$ vi int.m
r   *IU.MAJO*
rmean
rtrend
int
write   MAJO_INT.SAC
r   *IU.MAJO*
rmean
rtrend
hp bu co 1
write   MAJO_1H.SAC
r   *IU.MAJO*
rmean
rtrend
hp bu co 1
envelope
write   MAJO_ENV.SAC
r   *IU.MAJO*
rmean
rtrend
hp bu co 1
envelope
smooth mean halfwidth 8
write   MAJO_E8.SAC
r   *IU.MAJO*
rmean
rtrend
hp bu co 1
envelope
smooth mean halfwidth 128
write   MAJO_E128.SAC
```

bd x
qdp off
r 2005.087.16.13.38.0231.IU.MAJO.00.BHZ.Q.SAC MAJO_INT.SAC
MAJO_1H.SAC MAJO_ENV.SAC MAJO_E8.SAC MAJO_E128.SAC
p1

Next, execute macro command.

$ sac2000
SAC> macro int.m



References

Dziewonski,A.,A.,M.,T.A.Chou, and J.H.Woodhouse, Determination of earthquake source parameters from waveform data for studies of global and regional seismicity, J,Geophys.Res.,86,2825-2852,1981.

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Kanjo.K,T.Furudate,and S.Tsuboi,Application of Mwp of the Great December 26,2004 Sumatra Earthquake,Earth Planets Space,58,121-126,2006.

Tsuboi.S,K.Abe,K.Takano,and Y.Yamanaka,Rapid determination of Mw from broadband P waveforms,Bull.Seism.Soc.Am.,83.606-613,1995.

Tsuboi.S,P.M.Whitmore, and T.J.Sokolowski,Application of Mwp to deep and teleseismic earthquake,Bull Seism.Soc.Am.89,1345-351,1999.