Data Analysis in Geophysics
ESCI 7205

Class 20

Bob Smalley

SAC.

Spectral Analysis Module

There is a set of Infinite Impulse Response (IIR) filters.

`lowpass (lp)` passes signal below a high corner cutoff.

`highpass (hp)` passes signal above a low corner cutoff).

`bandpass (bp)` pass signal within the low and high corner cutoffs.

`bandrej (br)` band reject filter does the opposite of a bandpass.

These recursive digital filters are all based upon classical analog designs

`Butterworth`: a good choice for most applications, since it has a fairly sharp transition from pass band to stop band, and its group delay (phase) response is moderate. This is the default.

`Bessel`: best for those applications which require linear phase without two-pass filtering. It's amplitude response is not very good however.

Chebyshev type I & Chebyshev type II:

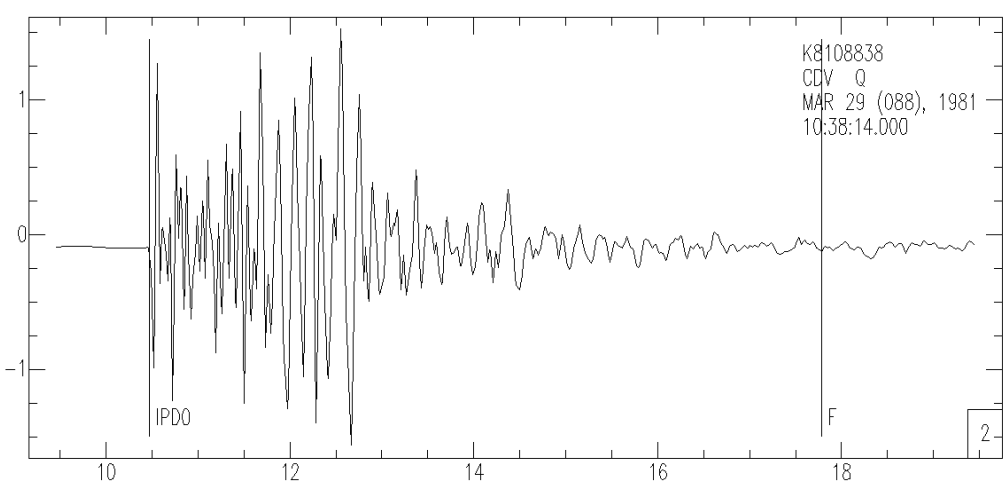
for situations which require very rapid transitions from pass band to stop band.

Does horrible things to the phase.

The Butterworth and Bessel are the easiest to set up

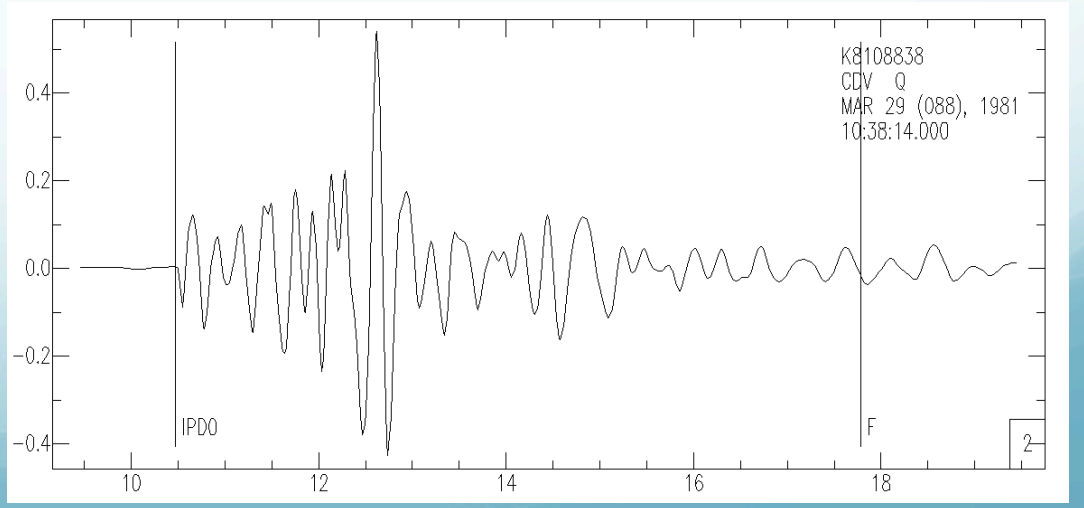
```
BANDPASS {BUTTER|BESSEL|C1|C2},{CORNERS v1 v2},{NPOLES n},{PASSES n},{TRANBW v},{ATTEN v}
```

```
sac> funcgen seismogram
```

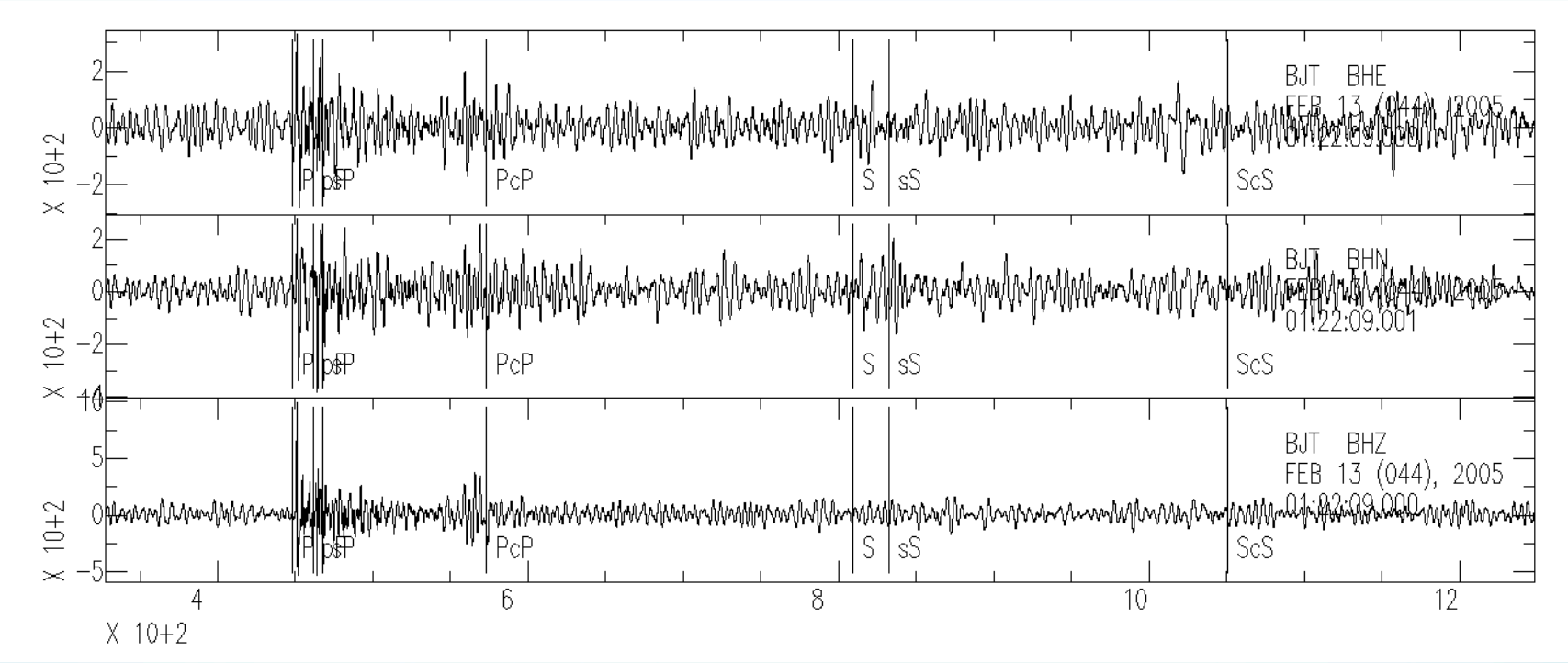



```
sac> rmean
sac> taper
sac> bp butter co 1 3
```

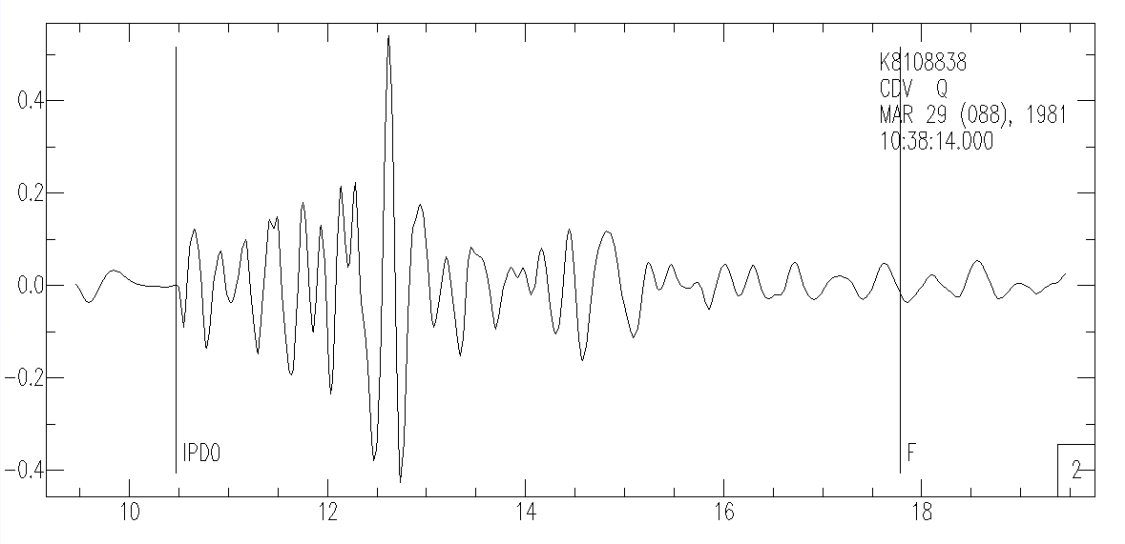
using default values
passes (p) 1
num poles (n) 2



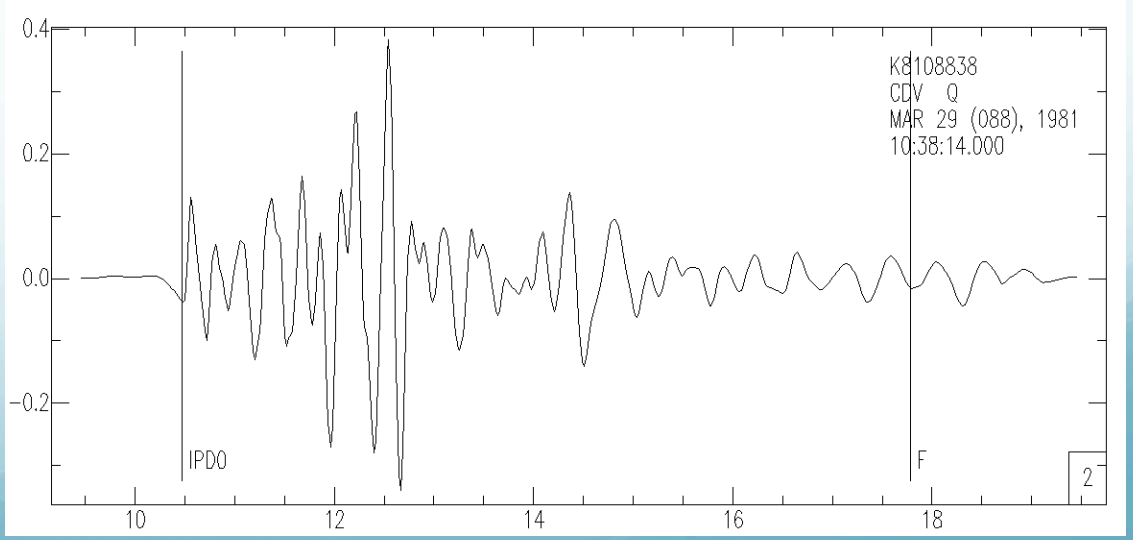
```
sac> hp butter co .2
sac> xlim t1 -120 800
```



```
sac> funcgen seismogram
sac> bp butter co 1 3
```




```
sac> rmean
sac> taper
sac> bp bessel co 1 3 n 1 p 2
```



Other filters

Finite Impulse Response filter (FIR).

Adaptive Wiener filter.

(It tailors itself to be the "best possible filter" for a given dataset.).

Two specialized filters (BENIOFF & KHRONHITE).

(lowpass filter is a digital approximation of an analog filter which was a cascade of two fourth-order Butterworth lowpass filters. This lowpass filter has been used with a corner frequency of 0.1 Hz to enhance measurements of the amplitudes of the fundamental mode Rayleigh wave (Rg) at regional distances.)

Instrument Correction Module.

This module currently contains only one command,

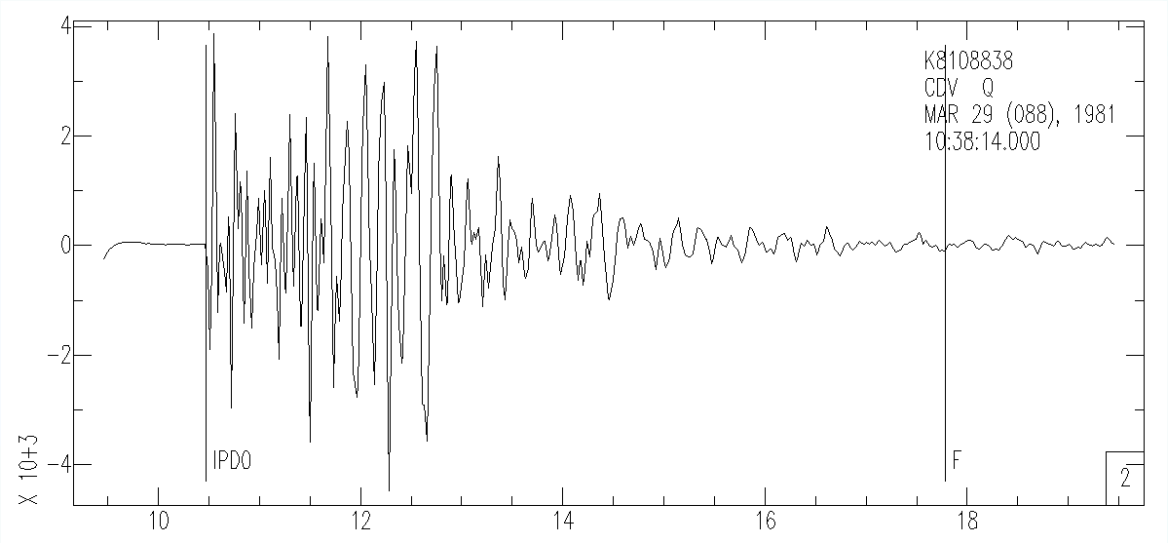
`transfer`.

`transfer`: performs a deconvolution to remove one instrument response followed a convolution to apply another instrument response.

>40 predefined instrument responses available.

A general instrument response can also be specified in terms of its poles and zeros.

```
sac> funcgen seismogram
sac> transfer to wa
```



Usually you would remove the known instrument response using '`transfer from XXX`'.

Why would you want to remove the instrument response and apply the response for a Wood-Anderson torsion seismometer?

Let's say you've downloaded some data from IRIS, unpacked the seed volume using **rdseed**, and extracted the response files.

(RESP.NET.STA.LOC.CHAN)

transfer can read seed response files (**evalresp**) and transforms velocity to displacement (**none**).

```
sac> r BJT*
sac> rtrend
sac> rmean
sac> transfer from evalresp to none
```

Spectral Analysis Module (`SAM`): Spectral/Fourier Transform analysis.

You can do a discrete Fourier transform

`fft`

and an inverse Fourier transform

`ifft`

You can also compute the amplitude and unwrapped phase of a signal ("`unwrap`"). This is an implementation of the algorithm due to Tribolet.

The `fft` and

`unwrap`

commands produce spectral data in memory.

You can plot this spectral data

`plotsp`

You can write it to disk as

`writesp`

and

read in back in again

`readsp`

You have to know the data/file is spectral data.
SAC will not figure it out.

You can also perform

- integration with

`divomega`

and

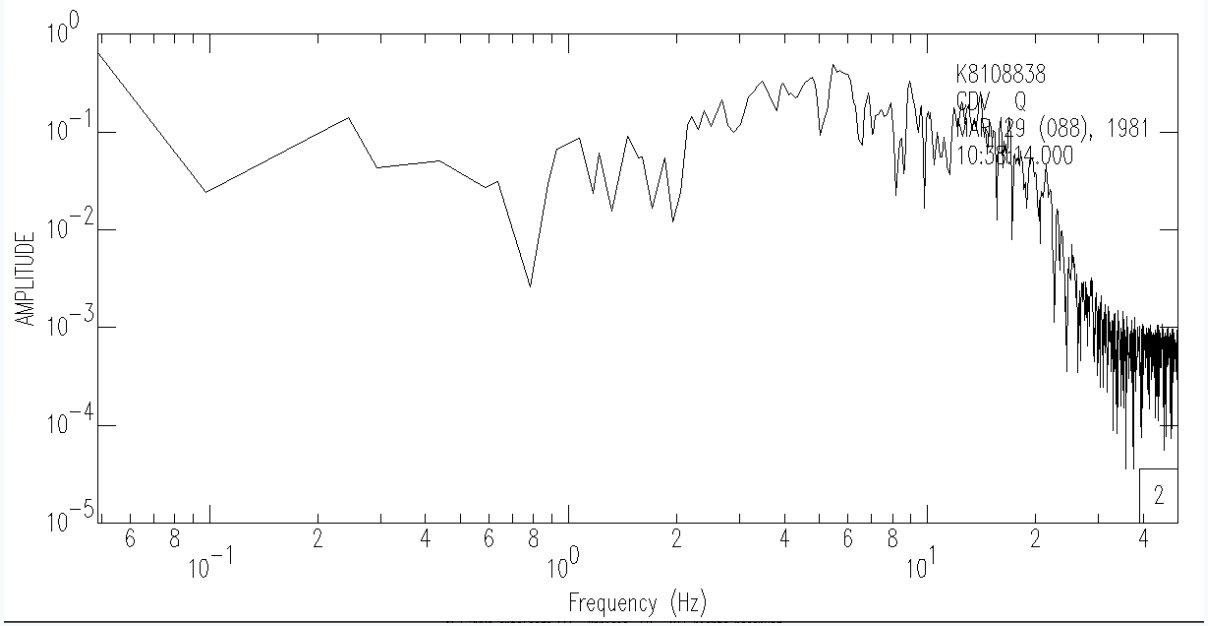
- differentiation with

`mulomega`

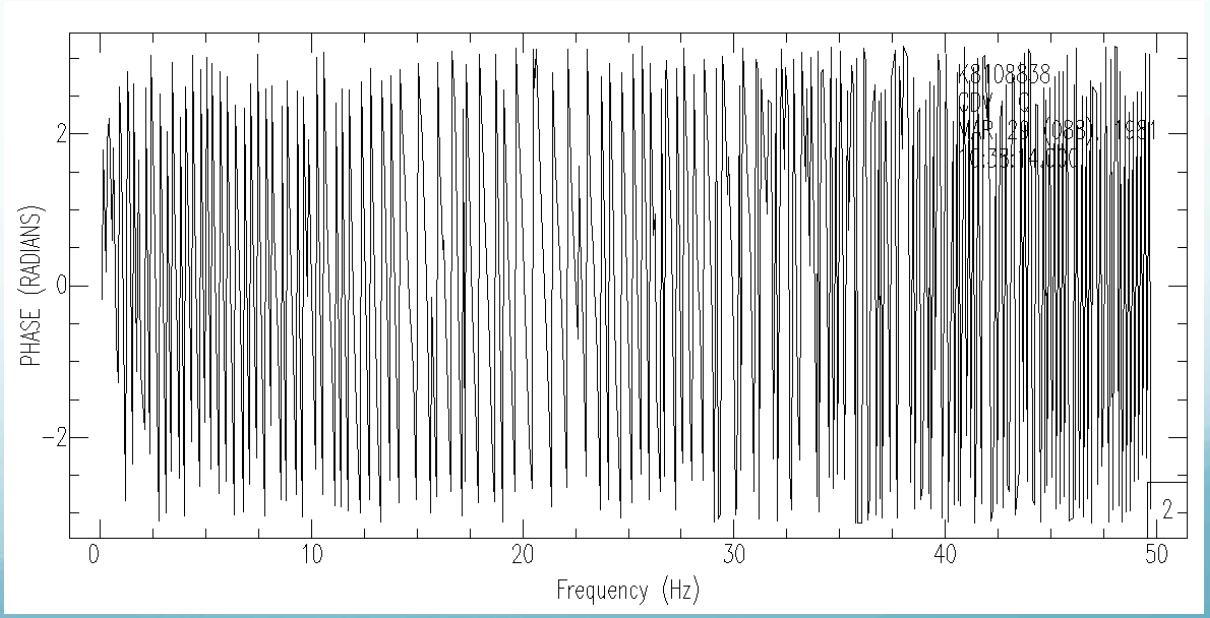
directly in the frequency domain.

```
sac> funcgen seismogram
sac> fft
sac> plotsp
```

Plots amplitude



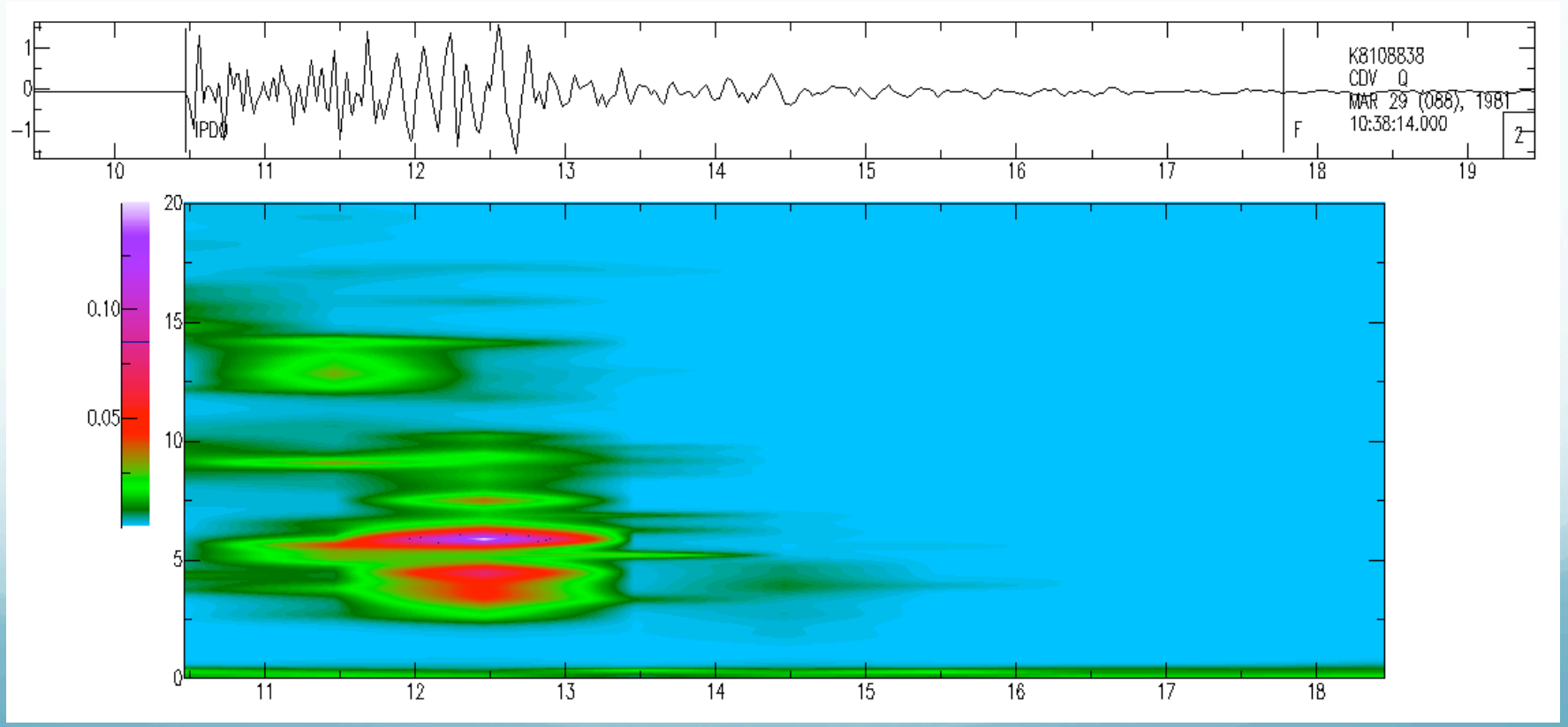
Then the phase after a <CR>



SPECTROGRAM

(DEFAULT VALUES: SPECTROGRAM WINDOW 2, SLICE 1, METHOD MEM, ORDER 100, NOSCALING, YMIN 0, YMAX FNYQUIST, COLOR)

```
sac> funcgen seismogram
sac> spectrogram ymin 0 ymax 20
Window size: 200  Overlap: 100  FFT size: 512
Spectrogram dimensions are 512  by 9 .
```



```
SAC> help spectrogram

SAC Command Reference Manual                                SPECTROGRAM

SUMMARY:
Calculate a spectrogram using all of the data in memory.

SYNTAX:
SPECTROGRAM options
where options are one or more of the following:

WINDOW v
SLICE v
ORDER n
CBAR    {ON|OFF}
{SQRT|NLOG|LOG10|NOSCALING}
YMIN v
YMAX v
METHOD {PDS|MEM|MLM}
{COLOR|GRAY}
PRINT {pname}

INPUT:
      WINDOW v  :  Set the sliding data window length in seconds to v.  This
          window length determines the size of the fft.

      SLICE v  :  Set the data slice interval in seconds to v.  A single
          spectrogram line is produced for each slice interval.

      ORDER n  :  Specifies the number of points in the autocorrelation
          function used to compute the spectral estimate.

      CBAR {ON|OFF}  :  Turn reference color bar on or off.

      {SQRT|NLOG|LOG10|NOSCALING}  :  Specify natural log, log base 10, or
          square root scaling of amplitudes.

      YMIN v  :  Specifies the minimum frequency to plot.

      YMAX v  :  Specifies the maximum frequency to plot.

      METHOD {PDS|MEM|MLM}  :  Specifies the type of spectral estimator used.
          MLM stands for maximum likelihood and MEM stands for maximum
          entropy spectral estimators, respectively.  See description and
          references below.

      {COLOR|GRAY}  :  Specifies a color or grayscale image.

      PRINT {pname}  :  Prints the resulting plot to the printer named in
           pname, or to the default printer if pname is not used.  (This
           makes use of the SGF capability.)

DEFAULT VALUES:
SPECTROGRAM WINDOW 2 SLICE 1 METHOD MEM ORDER 100 NOSCALING YMIN 0 YMAX
FNYQUIST COLOR

DESCRIPTION: …
```

SAM: other commands

`correlate`: computes the auto- and cross-correlation functions.

`convolve`: computes the auto- and cross-convolution functions.

`hanning`: applies a "hanning" window (recursive smoothing algorithm) to each data file.

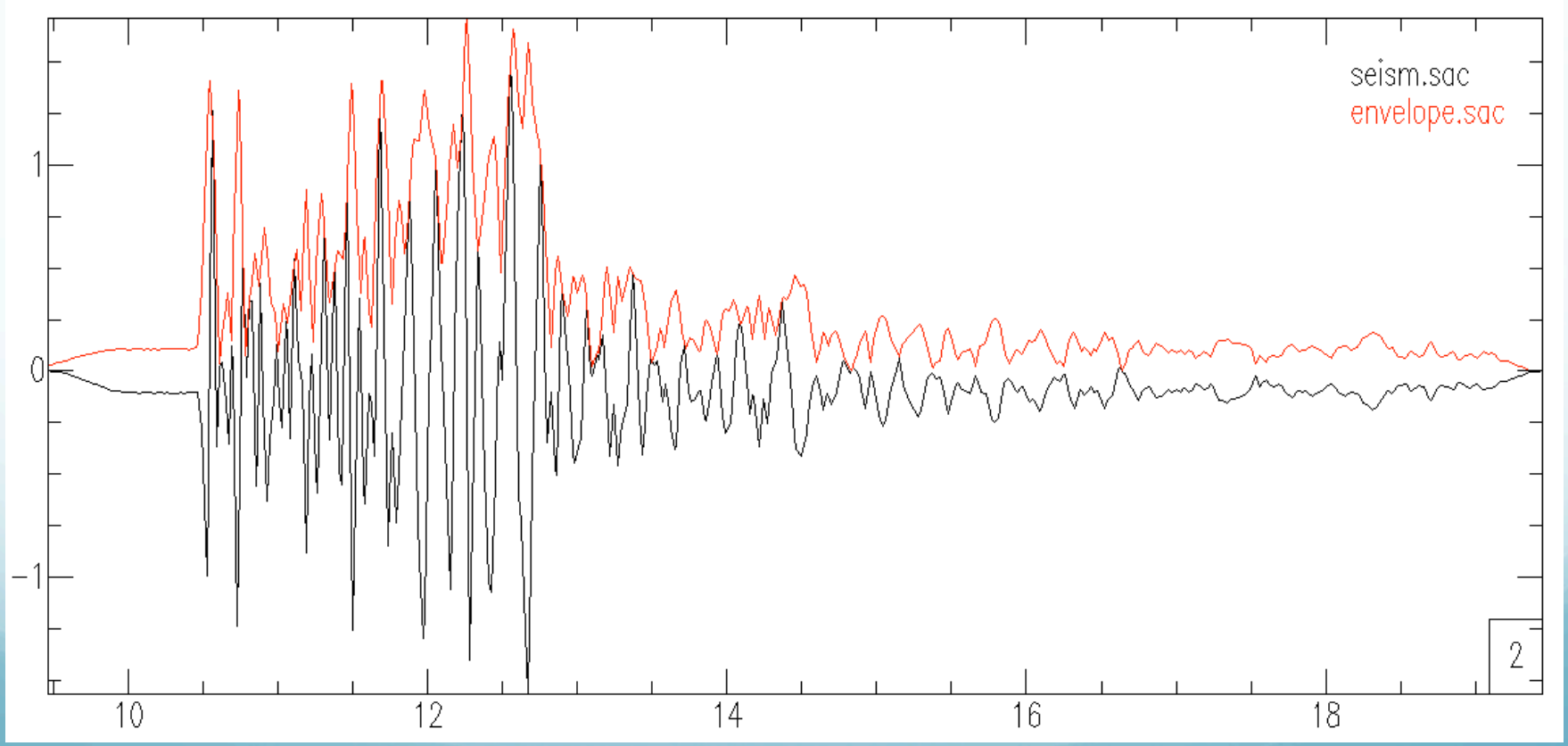
SAM: other commands

`hilbert`: applies a Hilbert transform (90° phase shift at all frequencies in the signal in the frequency domain).

Applied twice, this flips the sign of the amplitude.

`envelope`: computes the envelope function using a Hilbert transform.

```
sac> funcgen seismogram
sac> w seism.sac
sac> taper
sac> envelope
sac> w envelope.sac
sac> r seism.sac envelope.sac
sac> color on increment on
sac> p2
```



Phase picking, Blackboard Variables & Macros

Seismic analysis code (sac)

Event Analysis Module:

This module is used to pick seismic phases.

An automatic phase picking algorithm can be applied using

APK.

Event Analysis Module:

You can also use

PPK

to pick phases using the graphics cursor.

(PPK is described in the section on Graphics Capabilities).

Event Analysis Module:

Picks can be saved in **HYPO** format using the **OHPF** (open HYPO pick file) and **CHPF** (close HYPO pick file) commands; **WHPF** writes auxiliary cards into the **HYPO** pick file.

These picks can also be saved in a more general Alphanumeric format using the **OAPF** (open alphanumeric pick file) and **CAPF** (close alphanumeric pick file) commands.

The picks are also saved in the headers (so all might not be lost if you forget to write them to the pick file – as long as you write out the header or the sac file).

```
sac> ppk
```

Opens X window with all data loaded in memory.

```
sac> ppk perplot 6
```

open 6 files at a time.

Cursors on TEK401X.

```
# cheat sheet:

click on window to make it active

Mouse controls cursor position

zoom in: type "x" to define left side time window, followed by a
left click of mouse to define the right side time window

zoom out: type "o"

p arrival: type "a", or "p" at the time of the p wave arrival.

s arrival: type "t0", or "s" at the time of the s wave arrival.

other phases: type "tX" to place that time in header

quit: type "q"
```

SAC macros

A SAC macro is a file that contains a set of SAC commands to be executed together.

As well as regular commands and inline functions, a SAC macro file can contain references to SAC header variables and blackboard variables that are evaluated and substituted into the command before it is executed.

SAC macros can also have arguments that are evaluated as the macro is executed.

Control flow features such as “if tests” and “do loops” are also available.

These features let you control and alter the order of execution of commands within a macro.

example: macro for creating a plot

```
%vim plot1.macro
r BJT.BHZ* BJT.BHN* BJT.BHE*
xvport 0.1 0.6
qdp off
xlim t1 -5 50
title on "Sumatra Event 2/13/2005 1:22:09 at BJT"
xlabel on "Time, sec"
ylabel on "Digital Counts"
bd sgf
p1
ed sgf
sgftops f001.sgf plot1.ps 1 y
```

example: macro for creating a plot

There are two ways to run the sac macro, from within `sac`

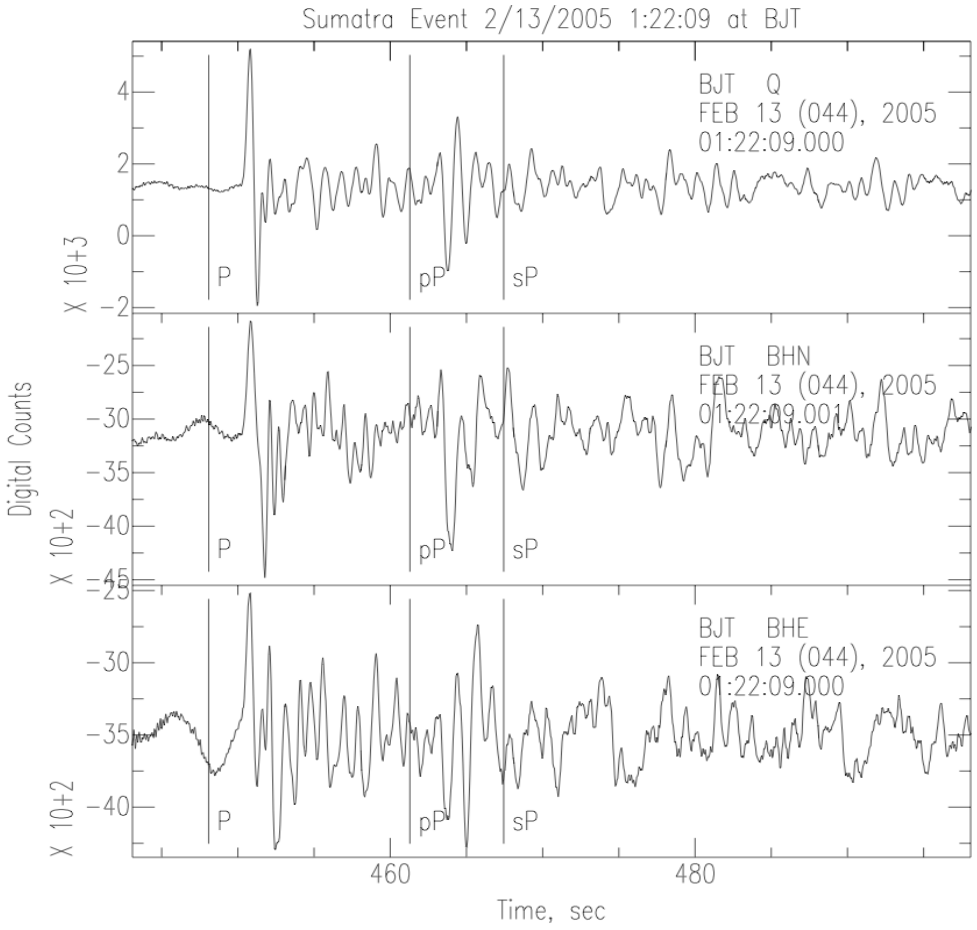
```
%sac
sac> macro plot1.macro
```

or from the command line (two ways)

```
%sac plot1.macro        (may not work on UNIX, did on Prime)

%sac < plot1.macro      (standard UNIX method)
```

Postscript file made by macro.



Order dependent arguments

```
alpaca.ceri.memphis.edu656:> vi prt.macro
r $1 $2 $3
xvport 0.1 0.6
qdp off
xlim t1 -5 50
title on "demo"
xlabel on "Time"
ylabel on "Digital Counts"
bd sgf
p1
ed sgf
sgftops f001.sgf plot1.ps 1 y
```

```
alpaca.ceri.memphis.edu649:> sac

 SEISMIC ANALYSIS CODE [09/04/2008 (Version 101.2)]

 Copyright 1995 Regents of the University of California


SAC> macro prt.macro AREN.BHZ AREN.167 AREN.257

SAC> quit

alpaca.ceri.memphis.edu650:> ls *.ps

plot1.ps

alpaca.ceri.memphis.edu651:>
```

Note: we are within SAC, not at the SHELL command line.

keyword driven arguments

```
%vim plot3.macro
$keys files plot
r $files
xvport 0.1 0.6
qdp off
xlim t1 -5 50
title on "Sumatra Event 2/13/2005 1:22:09 at BJT”
xlabel on "Time, sec”
ylabel on "Digital Counts”
bd sgf
P1
ed sgf
sgftops $plot plot3.ps 1 y

sac>macro plot3.macro files BJT.BHZ.SAC BJT.BHN.SAC BJT.BHE.SAC
plot f001.sgf
```

Default keyword arguments

```
% vim plot3.macro
$keys files plot
$default plot f001.sgf
r $files
xvport 0.1 0.6
qdp off
xlim t1 -5 50
title on "Sumatra Event 2/13/2005 1:22:09 at BJT"
xlabel on "Time, sec"
ylabel on "Digital Counts"
bd sgf
P1
ed sgf
sgftops $plot plot3.ps 1 y

sac> macro plot3.macro files BJT.BHZ.SAC    BJT.BHN_SAC
BJT.BHE.SAC
```

Missing Keyword arguments

Argument query

If you fail to enter a value for an argument on the SAC macro execute line and it has no default value, SAC will ask you to enter a value from the terminal.

```
SAC> macro plot3.macro
files? BJT.BHZ.SAC BJT.BHN.SAC BJT.BHE.SAC
```

SGFTOPS

SUMMARY Converts an **SGF** file to a **POSTSCRIPT** formatted file.

SYNTAX

```
SGFTOPS sgf-file ps-file {width} {YES|NO} {scale} INPUT sgf-file
```

`SGFTOPS sgf-file ps-file {width} {YES|NO} {scale} INPUT sgf-file`

`sgs-file`: name of a SAC Graphics File (**SGF**).

`ps-file` : The desired name for the POSTSCRIPT file.

`width` : A number specifying the width or thickness of lines in the output file.

This is an integer in the range 1 to 8.

Default is 1.

`SGFTOPS sgf-file ps-file {width} {YES|NO} {scale} INPUT sgf-file`

YES|NO : Flag to apply additional scaling.

A value of **YES** turns scaling on, **NO** ignores the additional scale parameter.

scale : An additional scale factor. Can be used for making large or full-size maps.

Blackboard variables.

The blackboard feature can be used to temporarily store and retrieve information.

A blackboard entry consists of a name and a value.

They are used extensively in macros

Blackboard entries are created using the **SETBB** and **EVALUATE** commands.

You can also substitute the value of a blackboard variable directly in other commands by preceding its name with a percent sign ("%").

Default is to print to terminal.

```
sac> setbb c1 2.45
sac> evaluate to c2 %c1 * 2
sac> bp butter co %c1 %c2
sac> evaluate %c1 * 2
 4.9000001e+00
```

The value of a blackboard variable can be obtained using the **GETBB** command.

```
sac> getbb c1 c2
c1 = 2.45
c2 = 4.9000001e+00
```

Blackboard variables can also be saved in a disk file using

`WRITEBBF`

and later restored (`SAC2000`) using

`READBBF`.

There is also
a function called

`UNSETBBV`

which deletes a variable from the blackboard.

Header variables.

SAC header variables can also be evaluated and substituted directly in commands much like blackboard variables.

You must specify which file (by name or number) and which variable to be evaluated.

You must precede this specification with an ampersand ("&")
and you must separate the file and variable names with a comma.

Header variables.

The first example is referenced by file name, the second by file number.

```
sac> read ABC
sac> evaluate to temp1 &ABC,a + 10
sac> evaluate to temp2 &1,depmax * 2
sac> chnhdr t5 %temp1
sac> chnhdr user0 %temp2
```

Concatenation

To prepend simply concatenate the text string with the argument or variable.

```
sac> setbb temp BJT.BHZ.SAC
sac> w XYZ.%temp
XYZ.BJT.BHZ.SAC
```

Concatenation

To append you must repeat the delimiter ($, %, or &) after the argument or variable (surround the string you are appending with the delimiter) and before the text string.

```
sac> setbb temp BJT.BHZ.SAC
sac> w %temp%.XYZ
BJT.BHZ.SAC.XYZ
```

Using various programs to write SAC macros.

SAC macros are essentially just a set of SAC commands and therefore

you can create SAC macros using other programs

(shell scripts, Fortran, c, Matlab, etc.).

This shell script is in a file called **sta.csh**. The shell script runs sac independently for each file matching the name (*${sta}*z) and appends the output of the sac **listhdr** command to the **sta.log** file (loop in shell, not sac).

```
alpaca.ceri.memphis.edu668:> vi sta.csh
#!/usr/bin/csh
# Script to report b, e and t1 sac header values for a given
station
#  usage: sta.csh [NAME]
\rm sta.log
set sta=$1
foreach file ( *${sta}*BH* )
sac <<EOF >> sta.log
r $file
lh b e t1
q
EOF
end
```

```
alpaca.ceri.memphis.edu666:> sta.csh AREN
sta.log: No such file or directory
alpaca.ceri.memphis.edu667:> more sta.log
 SEISMIC ANALYSIS CODE [09/04/2008 (Version 101.2)]
 Copyright 1995 Regents of the University of California
  FILE: AREN.BHE - 1
 --------------
     b = 7.400000e+04
     e = 7.600000e+04
 SEISMIC ANALYSIS CODE [09/04/2008 (Version 101.2)]
 Copyright 1995 Regents of the University of California
  FILE: AREN.BHN - 1
 --------------
     b = 7.400000e+04
     e = 7.600000e+04
 SEISMIC ANALYSIS CODE [09/04/2008 (Version 101.2)]
 Copyright 1995 Regents of the University of California
  FILE: AREN.BHZ - 1
 --------------
     b = 7.400000e+04
     e = 7.600000e+04
alpaca.ceri.memphis.edu668:> vi stainfo.csh
```

What is this awk line testing if if I apply it to the output of `sta.csh`?

```
awk '{if (/FILE/) f=$2; if ($1=="b") b=$3; if ($1=="e") e=$3; if
(/t1/ && $3>b && $3<e) \ print "r more",f}' sta.log
```

Using shell scripts to run SAC

```
#!/usr/bin/csh
foreach file ( *.SAC )
echo $file

sac << EOF >>! log
setbb eqname Sum_2002_EGF
setbb evlat 2.84
setbb evlon 95.38
setbb chg 6.002

r $file
setbb old &1,o
evaluate to new %old + %chg
ch o %new
ch evlo %evlon
ch evla %evlat
ch kevnm %eqname
wh
cut o 0 8000
r $file
setbb chg2 &1,o
ch allt -%chg2
w over
q
EOF

end
```

Prepare set of sac data (rename, cut)

```
carpincho:sacex smalley$ cp /Volumes/carpincho_TB/charge/data/2001.174*SAC .
carpincho:sacex smalley$ ls
2001.174.00.00.00.0010.YC.PENA.01.BHE.D.SAC  2001.174.00.00.00.0070.YC.CONS.01.BH2.D.SAC  2001.174.00.00.00.0140.YC.AMER.01.BH2.D.SAC
2001.174.00.00.00.0010.YC.PENA.01.BHN.D.SAC  2001.174.00.00.00.0070.YC.CONS.01.BH3.D.SAC  2001.174.00.00.00.0140.YC.AMER.01.BH3.D.SAC
2001.174.00.00.00.0010.YC.PENA.01.BHZ.D.SAC  2001.174.00.00.00.0070.YC.CONS.01.BHZ.D.SAC  2001.174.00.00.00.0140.YC.AMER.01.BHZ.D.SAC
2001.174.00.00.00.0030.YC.HURT.01.BHE.D.SAC  2001.174.00.00.00.0070.YC.RAFA.01.BHE.D.SAC  2001.174.00.00.00.0190.YC.ELBO.01.BHE.D.SAC
2001.174.00.00.00.0030.YC.HURT.01.BHN.D.SAC  2001.174.00.00.00.0070.YC.RAFA.01.BHN.D.SAC  2001.174.00.00.00.0190.YC.ELBO.01.BHN.D.SAC
2001.174.00.00.00.0030.YC.HURT.01.BHZ.D.SAC  2001.174.00.00.00.0070.YC.RAFA.01.BHZ.D.SAC  2001.174.00.00.00.0190.YC.ELBO.01.BHZ.D.SAC
2001.174.00.00.00.0030.YC.MAUL.01.BHE.D.SAC  2001.174.00.00.00.0100.YC.HEDI.01.BHE.D.SAC  2001.174.00.00.00.0240.YC.HUER.01.BHE.D.SAC
2001.174.00.00.00.0030.YC.MAUL.01.BHN.D.SAC  2001.174.00.00.00.0100.YC.HEDI.01.BHN.D.SAC  2001.174.00.00.00.0240.YC.HUER.01.BHN.D.SAC
2001.174.00.00.00.0030.YC.MAUL.01.BHZ.D.SAC  2001.174.00.00.00.0100.YC.HEDI.01.BHZ.D.SAC  2001.174.00.00.00.0240.YC.HUER.01.BHZ.D.SAC
2001.174.00.00.00.0040.YC.RINC.01.BHE.D.SAC  2001.174.00.00.00.0100.YC.JUAN.01.BHE.D.SAC  2001.174.00.00.00.0240.YC.LLAN.01.BHE.D.SAC
2001.174.00.00.00.0040.YC.RINC.01.BHN.D.SAC  2001.174.00.00.00.0100.YC.JUAN.01.BHN.D.SAC  2001.174.00.00.00.0240.YC.LLAN.01.BHN.D.SAC
2001.174.00.00.00.0040.YC.RINC.01.BHZ.D.SAC  2001.174.00.00.00.0100.YC.JUAN.01.BHZ.D.SAC  2001.174.00.00.00.0240.YC.LLAN.01.BHZ.D.SAC
2001.174.00.00.00.0050.YC.LITI.01.BHE.D.SAC  2001.174.00.00.00.0110.YC.PACH.01.BHE.D.SAC  2001.174.00.00.00.0240.YC.SJAV.01.BH2.D.SAC
2001.174.00.00.00.0050.YC.LITI.01.BHN.D.SAC  2001.174.00.00.00.0110.YC.PACH.01.BHN.D.SAC  2001.174.00.00.00.0240.YC.SJAV.01.BH3.D.SAC
2001.174.00.00.00.0050.YC.LITI.01.BHZ.D.SAC  2001.174.00.00.00.0110.YC.PACH.01.BHZ.D.SAC  2001.174.00.00.00.0240.YC.SJAV.01.BHZ.D.SAC
2001.174.00.00.00.0060.YC.AREN.01.BHE.D.SAC  2001.174.00.00.00.0120.YC.BARD.01.BHE.D.SAC  2001.174.17.25.50.2830.YC.ELBO.01.BHE.D.SAC
2001.174.00.00.00.0060.YC.AREN.01.BHN.D.SAC  2001.174.00.00.00.0120.YC.BARD.01.BHN.D.SAC  2001.174.17.25.50.2830.YC.ELBO.01.BHN.D.SAC
2001.174.00.00.00.0060.YC.AREN.01.BHZ.D.SAC  2001.174.00.00.00.0120.YC.BARD.01.BHZ.D.SAC  2001.174.17.25.50.2830.YC.ELBO.01.BHZ.D.SAC
2001.174.00.00.00.0060.YC.NIEB.01.BHE.D.SAC  2001.174.00.00.00.0130.YC.NEGR.01.BHE.D.SAC  2001.174.17.29.16.2900.YC.ELBO.01.BHE.D.SAC
2001.174.00.00.00.0060.YC.NIEB.01.BHN.D.SAC  2001.174.00.00.00.0130.YC.NEGR.01.BHN.D.SAC  2001.174.17.29.16.2900.YC.ELBO.01.BHN.D.SAC
2001.174.00.00.00.0060.YC.NIEB.01.BHZ.D.SAC  2001.174.00.00.00.0130.YC.NEGR.01.BHZ.D.SAC  2001.174.17.29.16.2900.YC.ELBO.01.BHZ.D.SAC
carpincho:sacex smalley$ rename.sh SAC 8 10
carpincho:sacex smalley$ ls
AMER.BH2        BARD.BHZ        HEDI.BHN        JUAN.BHE        LLAN.BHZ        NIEB.BHN        RAFA.BHE        SJAV.BHZ
AMER.BH3        CONS.BH2        HEDI.BHZ        JUAN.BHN        MAUL.BHE        NIEB.BHZ        RAFA.BHN
AMER.BHZ        CONS.BH3        HUER.BHE        JUAN.BHZ        MAUL.BHN        PACH.BHE        RAFA.BHZ
AREN.BHE        CONS.BHZ        HUER.BHN        LITI.BHE        MAUL.BHZ        PACH.BHN        RINC.BHE
AREN.BHN        ELBO.BHE        HUER.BHZ        LITI.BHN        NEGR.BHE        PACH.BHZ        RINC.BHN
AREN.BHZ        ELBO.BHN        HURT.BHE        LITI.BHZ        NEGR.BHN        PENA.BHE        RINC.BHZ
BARD.BHE        ELBO.BHZ        HURT.BHN        LLAN.BHE        NEGR.BHZ        PENA.BHN        SJAV.BH2
BARD.BHN        HEDI.BHE        HURT.BHZ        LLAN.BHN        NIEB.BHE        PENA.BHZ        SJAV.BH3
carpincho:sacex smalley$ sac
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SAC> cut 74000 76000
SAC> r *BHE* *BHN* *BHZ*
AREN.BHE BARD.BHE ELBO.BHE HEDI.BHE HUER.BHE HURT.BHE JUAN.BHE LITI.BHE LLAN.BHE MAUL.BHE NEGR.BHE NIEB.BHE PACH.BHE PENA.BHE RAFA.BHE RINC.BHE
AREN.BHN BARD.BHN ELBO.BHN HEDI.BHN HUER.BHN HURT.BHN JUAN.BHN LITI.BHN LLAN.BHN MAUL.BHN NEGR.BHN NIEB.BHN PACH.BHN PENA.BHN RAFA.BHN RINC.BHN
AMER.BHZ AREN.BHZ BARD.BHZ CONS.BHZ ELBO.BHZ HEDI.BHZ HUER.BHZ HURT.BHZ JUAN.BHZ LITI.BHZ LLAN.BHZ MAUL.BHZ NEGR.BHZ NIEB.BHZ PACH.BHZ PENA.BHZ
RAFA.BHZ RINC.BHZ SJAV.BHZ
 WARNING: Start cut greater than file end for file ELBO.BHE
 WARNING: Start cut greater than file end for file ELBO.BHN
 WARNING: Start cut greater than file end for file ELBO.BHZ
 WARNING: Unable to read some files  reading the rest of the files.
SAC> w over
```

```
carpincho:sacex smalley$ sac
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SAC> read *
AMER.BH2 AMER.BH3 AMER.BHZ AREN.BHE AREN.BHN AREN.BHZ BARD.BHE BARD.BHN BARD.BHZ CONS.BH2 CONS.BH3 CONS.BHZ ELBO.BHE ELBO.BHN ELBO.BHZ HEDI.BHE
HEDI.BHN HEDI.BHZ HUER.BHE HUER.BHN HUER.BHZ HURT.BHE HURT.BHN HURT.BHZ JUAN.BHE JUAN.BHN JUAN.BHZ LITI.BHE LITI.BHN LITI.BHZ LLAN.BHE LLAN.BHN
LLAN.BHZ MAUL.BHE MAUL.BHN MAUL.BHZ NEGR.BHE NEGR.BHN NEGR.BHZ NIEB.BHE NIEB.BHN NIEB.BHZ PACH.BHE PACH.BHN PACH.BHZ PENA.BHE PENA.BHN PENA.BHZ
RAFA.BHE RAFA.BHN RAFA.BHZ RINC.BHE RINC.BHN RINC.BHZ SJAV.BH2 SJAV.BH3 SJAV.BHZ
SAC> listhdr
  FILE: AMER.BH2 - 1
 --------------

      NPTS = 3455983                          B = 0.000000e+00
         E = 8.639955e+04                IFTYPE = TIME SERIES FILE
     LEVEN = TRUE                         DELTA = 2.500000e-02
      IDEP = UNKNOWN                     DEPMIN = -2.000632e+06
    DEPMAX = 2.115793e+06                DEPMEN = -6.740461e+02
    KZDATE = JUN 23 (174), 2001          KZTIME = 00:00:00.014
     KSTNM = AMER                         CMPAZ = 6.000000e+00
    CMPINC = 9.000000e+01                  STLA = -3.570000e+01
      STLO = -7.110487e+01                 STEL = 6.360000e+02
      STDP = 0.000000e+00                 KHOLE = 01
    LOVROK = TRUE                         NVHDR = 6
     SCALE = 1.048580e+09                 NORID = 0
     NEVID = 0                           LPSPOL = FALSE
    LCALDA = TRUE                        KCMPNM = BH2
    KNETWK = YC

SAC> chnhdr EVLA -16.27
SAC> chnhdr EVLO -73.64
SAC> listhdr
  FILE: AMER.BH2 - 1
 --------------

      NPTS = 3455983                          B = 0.000000e+00
         E = 8.639955e+04                IFTYPE = TIME SERIES FILE
     LEVEN = TRUE                         DELTA = 2.500000e-02
      IDEP = UNKNOWN                     DEPMIN = -2.000632e+06
    DEPMAX = 2.115793e+06                DEPMEN = -6.740461e+02
    KZDATE = JUN 23 (174), 2001          KZTIME = 00:00:00.014
     KSTNM = AMER                         CMPAZ = 6.000000e+00
    CMPINC = 9.000000e+01                  STLA = -3.570000e+01
      STLO = -7.110487e+01                 STEL = 6.360000e+02
      STDP = 0.000000e+00                  EVLA = -1.627000e+01
      EVLO = -7.364000e+01                KHOLE = 01
      DIST = 2.167411e+03                    AZ = 1.738032e+02
       BAZ = 3.526821e+02                 GCARC = 1.948290e+01
    LOVROK = TRUE                         NVHDR = 6
     SCALE = 1.048580e+09                 NORID = 0
     NEVID = 0                           LPSPOL = FALSE
    LCALDA = TRUE                        KCMPNM = BH2
    KNETWK = YC

SAC> wh
```

Read in sac files, list and change header, write headers.

```
carpincho:sacex smalley$ sac
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SAC> r AREN.BHE AREN.BHN
SAC> qdp off
SAC> p1
```
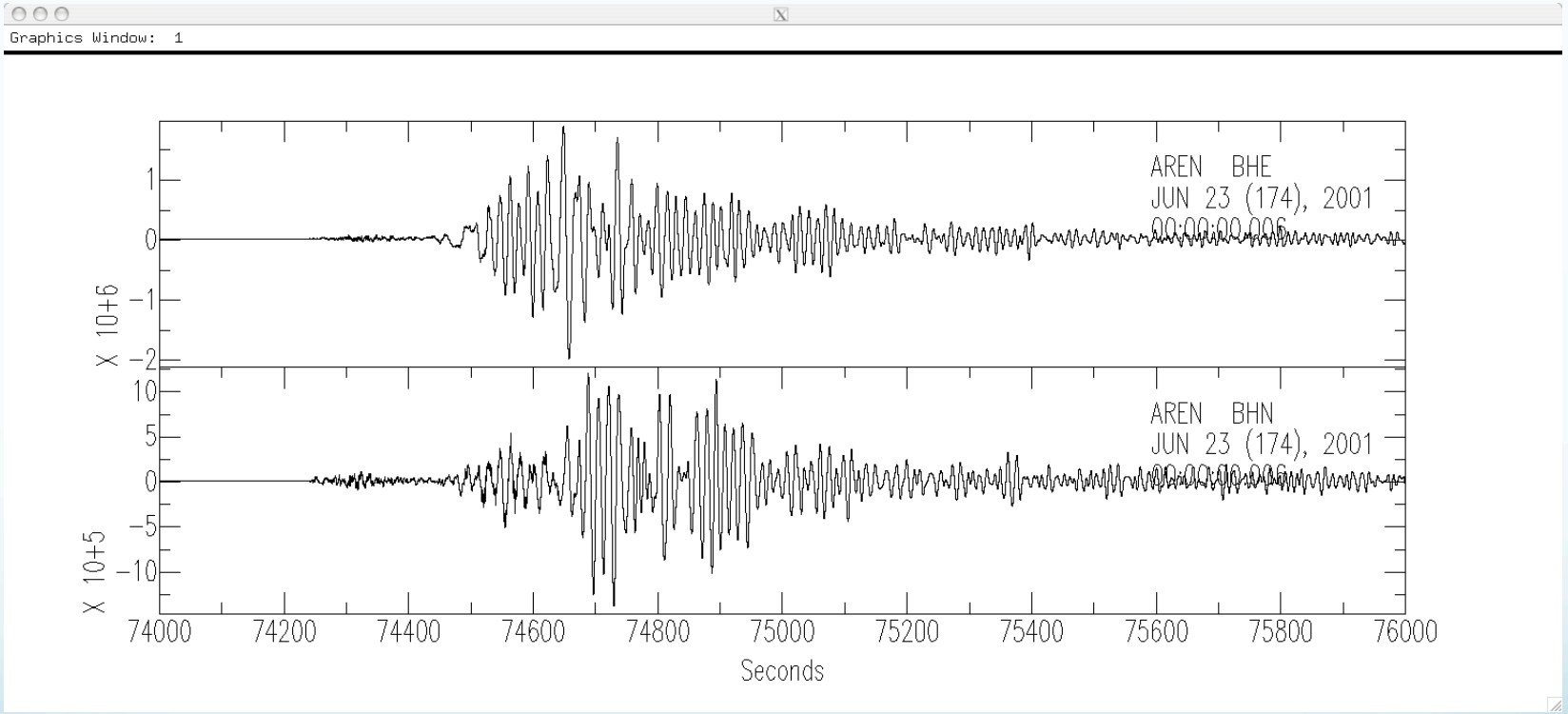
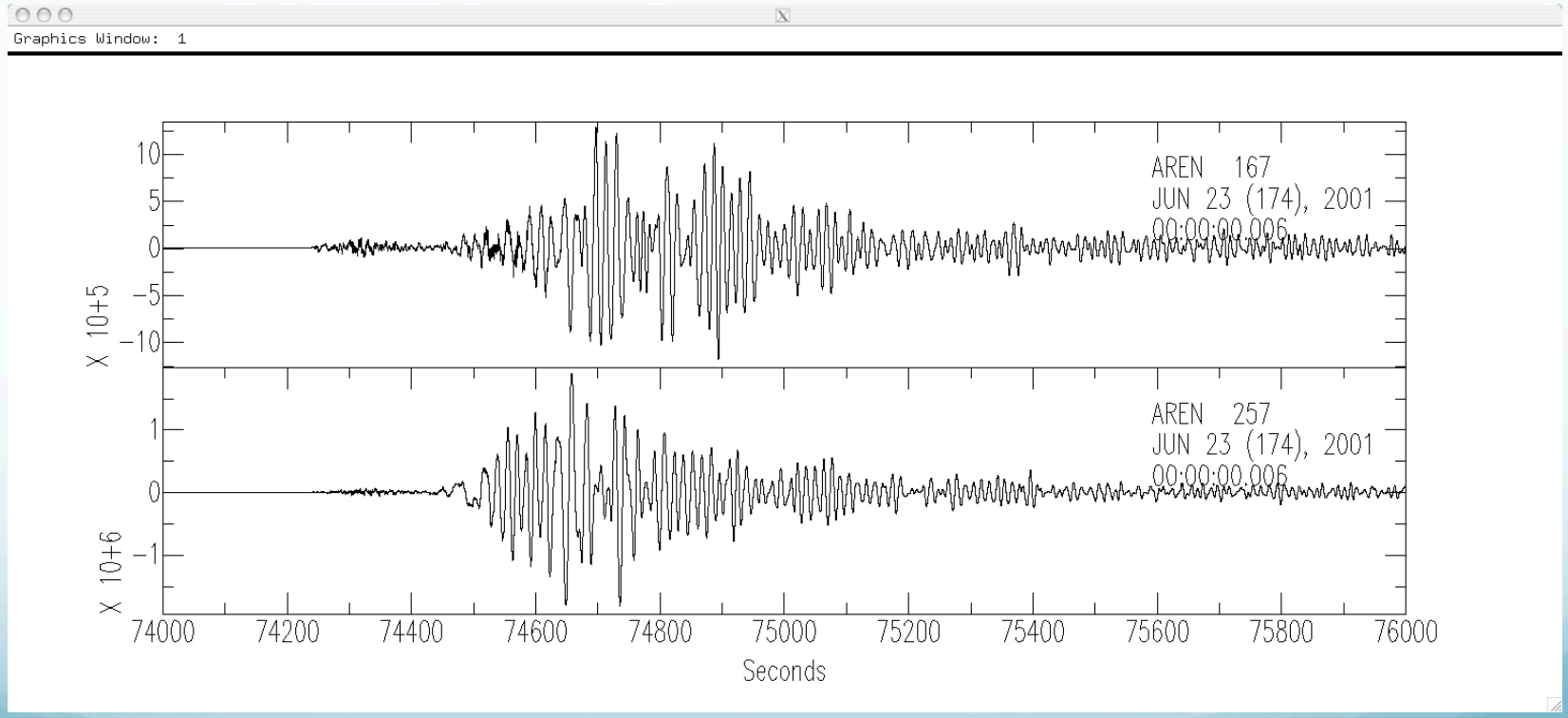

read in, plot horizontals



```
SAC> rotate to gca
SAC> p1
SAC> write
```

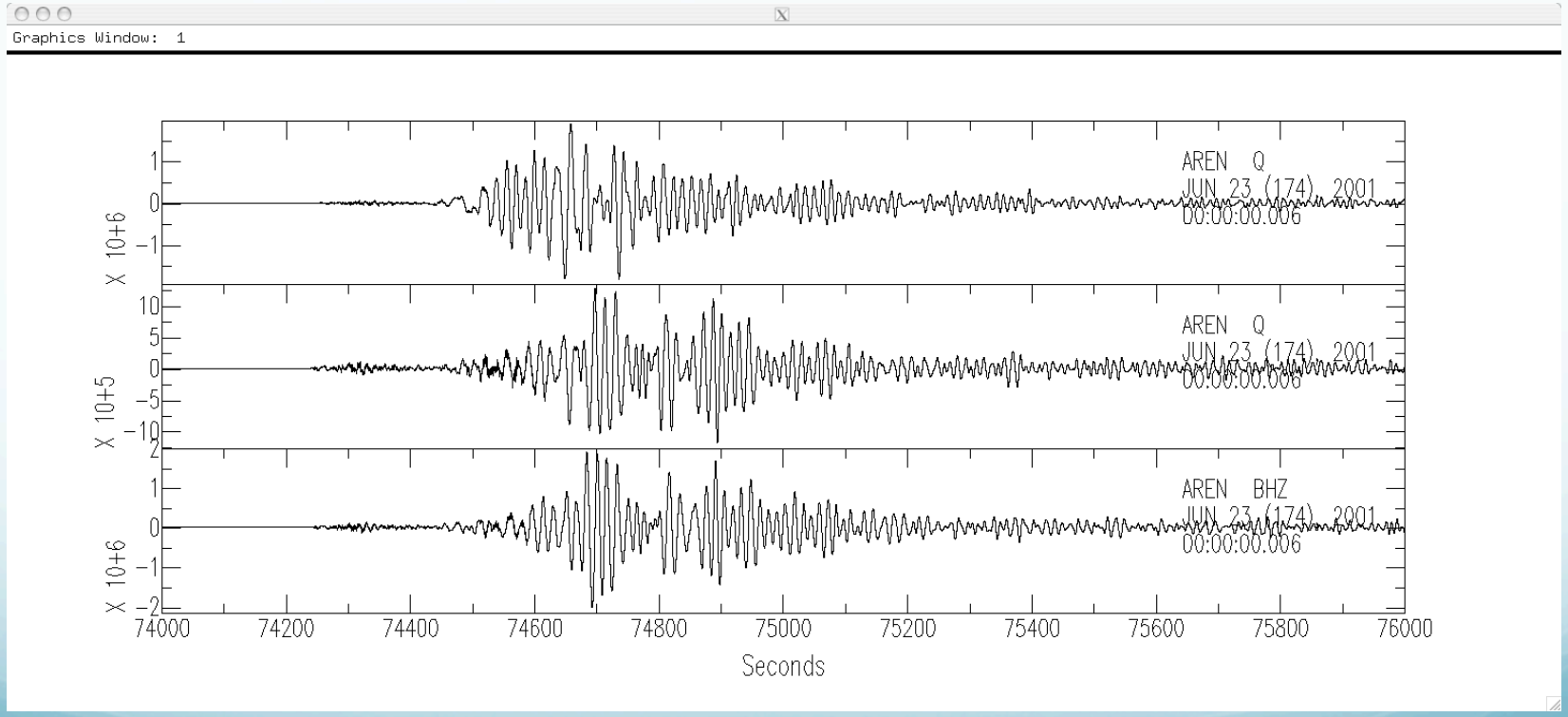
Rotate and save rotated seismograms to disk



```
SAC> read AREN.257 AREN.167 AREN.BHZ
SAC> p1
```

read in rotated seismograms (the 257 and 167) and vertical to show all 3

Notice love waves on top one and rayleigh waves (90° phase shift from vertical)



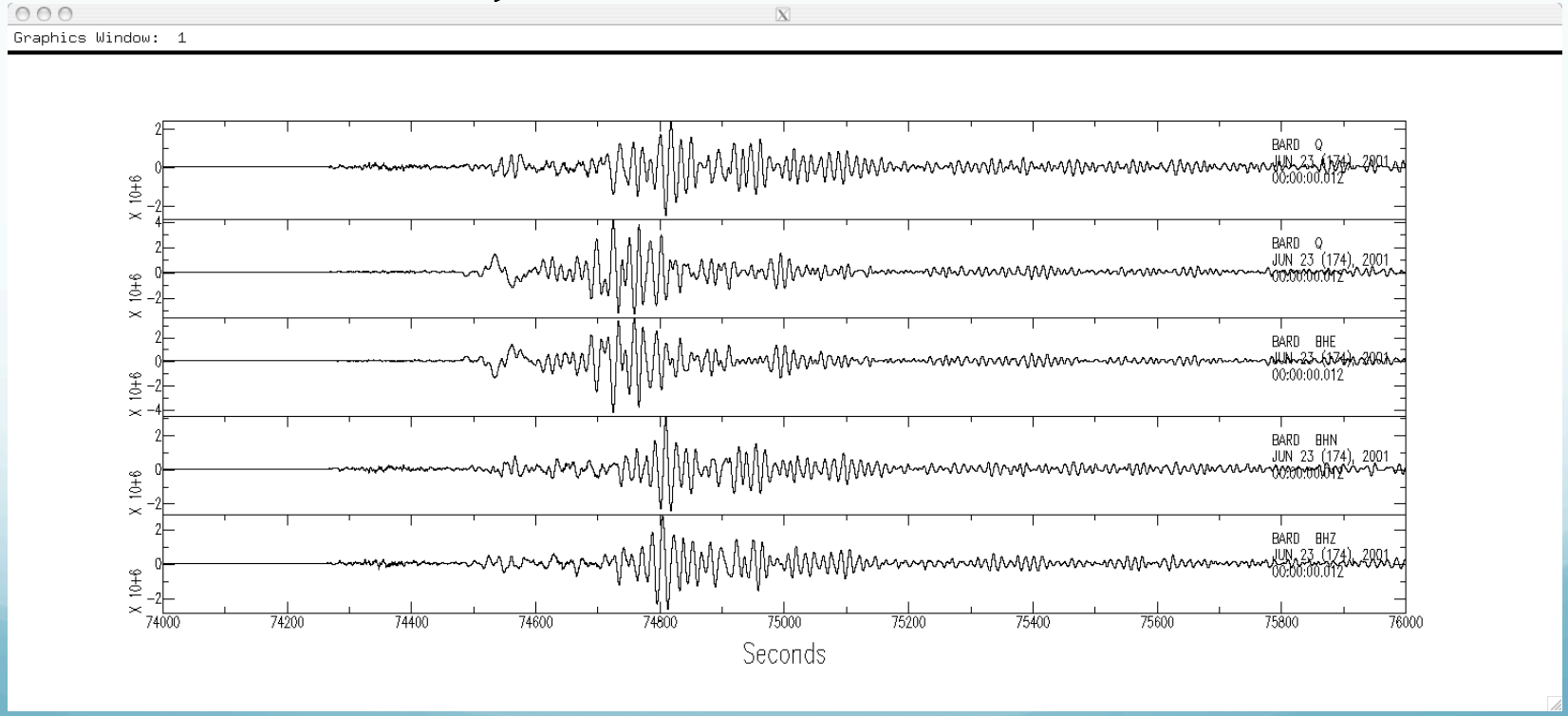
```
FILE: AREN.257 - 1
--------------

     NPTS = 80001                        B = 7.400000e+04
        E = 7.600000e+04                 IFTYPE = TIME SERIES FILE
    LEVEN = TRUE                         DELTA = 2.500000e-02
     IDEP = UNKNOWN                      DEPMIN = -1.824698e+06
   DEPMAX = 1.883052e+06                 DEPMEN = -8.282498e+03
   KZDATE = JUN 23 (174), 2001           KZTIME = 00:00:00.006
    KSTNM = AREN                         CMPAZ = 2.568291e+02
   CMPINC = 9.000000e+01                 STLA = -3.361547e+01
     STLO = -6.951091e+01                STEL = 2.786000e+03
     STDP = 0.000000e+00                 EVLA = -1.627000e+01
     EVLO = -7.364000e+01                KHOLE = 01
     DIST = 1.965666e+03                    AZ = 1.685817e+02
      BAZ = 3.468291e+02                 GCARC = 1.766853e+01
   LOVROK = TRUE                         NVHDR = 6
    SCALE = 4.194300e+08                 NORID = 0
    NEVID = 0                            NWFID = 15
   LPSPOL = TRUE                         LCALDA = TRUE
   KCMPNM = Q                            KNETWK = YC

 FILE: AREN.167 - 2
--------------

     NPTS = 80001                        B = 7.400000e+04
        E = 7.600000e+04                 IFTYPE = TIME SERIES FILE
    LEVEN = TRUE                         DELTA = 2.500000e-02
     IDEP = UNKNOWN                      DEPMIN = -1.190844e+06
   DEPMAX = 1.274883e+06                 DEPMEN = 3.710197e+02
   KZDATE = JUN 23 (174), 2001           KZTIME = 00:00:00.006
    KSTNM = AREN                         CMPAZ = 1.668291e+02
   CMPINC = 9.000000e+01                 STLA = -3.361547e+01
     STLO = -6.951091e+01                STEL = 2.786000e+03
     STDP = 0.000000e+00                 EVLA = -1.627000e+01
     EVLO = -7.364000e+01                KHOLE = 01
     DIST = 1.965666e+03                    AZ = 1.685817e+02
      BAZ = 3.468291e+02                 GCARC = 1.766853e+01
   LOVROK = TRUE                         NVHDR = 6
    SCALE = 4.194300e+08                 NORID = 0
    NEVID = 0                            NWFID = 31
   LPSPOL = TRUE                         LCALDA = TRUE
   KCMPNM = Q                            KNETWK = YC
```

cmpaz has azimuth of rotated traces

One is azimuth (radial), other is perpendicular (transverse)

```
SAC> READ BARD.BHE BARD.BHN
SAC> qdp off
SAC> p1
SAC> rotate to gcp
SAC> p1
SAC> write KSTCMP
SAC> ls
AMER.BH2        AREN.BHZ        CONS.BH3        HEDI.BHZ        JUAN.BHE        LLAN.BHN        NEGR.BHZ        PENA.BHE        RINC.BHN
AMER.BH3        BARD.168        CONS.BHZ        HUER.BHE        JUAN.BHN        LLAN.BHZ        NIEB.BHE        PENA.BHN        RINC.BHZ
AMER.BHZ        BARD.258        ELBO.BHE        HUER.BHN        JUAN.BHZ        MAUL.BHE        NIEB.BHN        PENA.BHZ        SJAV.BH2
AREN.167        BARD.BHE        ELBO.BHN        HUER.BHZ        LITI.BHE        MAUL.BHN        NIEB.BHZ        RAFA.BHE        SJAV.BH3
AREN.257        BARD.BHN        ELBO.BHZ        HURT.BHE        LITI.BHN        MAUL.BHZ        PACH.BHE        RAFA.BHN        SJAV.BHZ
AREN.BHE        BARD.BHZ        HEDI.BHE        HURT.BHN        LITI.BHZ        NEGR.BHE        PACH.BHN        RAFA.BHZ        saveorig
AREN.BHN        CONS.BH2        HEDI.BHN        HURT.BHZ        LLAN.BHE        NEGR.BHN        PACH.BHZ        RINC.BHE
SAC> read BARD*
BARD.168 BARD.258 BARD.BHE BARD.BHN BARD.BHZ
SAC> p1
```

Read in/plot all 5 after rotation



Do rotation with macro
Note filenames of rotated data

```
carpincho:sacex smalley$ more elbo.macro
read ELBO.BHE ELBO.BHN
rotate to gca
w KSTCMP
quit

carpincho:sacex smalley$ sac < elbo.macro
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carpincho:sacex smalley$ ls
AREN.167        BARD.258        ELBO.BHE        HUER.BHE        JUAN.BHE        LLAN.BHE        NEGR.BHE        PACH.BHE        RAFA.BHE        elbo.macro
AREN.257        BARD.BHE        ELBO.BHN        HUER.BHN        JUAN.BHN        LLAN.BHN        NEGR.BHN        PACH.BHN        RAFA.BHN
AREN.BHE        BARD.BHN        ELBO.BHZ        HUER.BHZ        JUAN.BHZ        LLAN.BHZ        NEGR.BHZ        PACH.BHZ        RAFA.BHZ
AREN.BHN        BARD.BHZ        HEDI.BHE        HURT.BHE        LITI.BHE        MAUL.BHE        NIEB.BHE        PENA.BHE        RINC.BHE
AREN.BHZ        ELBO.168        HEDI.BHN        HURT.BHN        LITI.BHN        MAUL.BHN        NIEB.BHN        PENA.BHN        RINC.BHN
BARD.168        ELBO.258        HEDI.BHZ        HURT.BHZ        LITI.BHZ        MAUL.BHZ        NIEB.BHZ        PENA.BHZ        RINC.BHZ
```

Use macro to rotate all seismograms in directory

```
carpincho:sacex smalley$ vi makerotatemacro.sh
#!/bin/sh
OUT=all.macro
STNNAMES=`ls *.BHZ | nawk 'BEGIN {FS="."}{print $1}'`
for stn in $STNNAMES
do
#echo process $stn
echo r $stn.BHE $stn.BHN >> $OUT
echo rotate to gcr >> $OUT
echo w KSTCMP >> $OUT
done
echo quit >> $OUT
sac < all.macro:wq
carpincho:sacex smalley$

carpincho:sacex smalley$ ls
AREN.BHE              HEDI.BHZ              LITI.BHN              NIEB.BHE              RAFA.BHZ
AREN.BHN              HUER.BHE              LITI.BHZ              NIEB.BHN              RINC.BHE
AREN.BHZ              HUER.BHN              LLAN.BHE              NIEB.BHZ              RINC.BHN
BARD.BHE              HUER.BHZ              LLAN.BHN              PACH.BHE              RINC.BHZ
BARD.BHN              HURT.BHE              LLAN.BHZ              PACH.BHN              all.macro
BARD.BHZ              HURT.BHN              MAUL.BHE              PACH.BHZ              elbo.macro
ELBO.BHE              HURT.BHZ              MAUL.BHN              PENA.BHE              huer.log
ELBO.BHN              JUAN.BHE              MAUL.BHZ              PENA.BHN              huer.macro
ELBO.BHZ              JUAN.BHN              NEGR.BHE              PENA.BHZ              makerotatemacro.sh
HEDI.BHE              JUAN.BHZ              NEGR.BHN              RAFA.BHE
HEDI.BHN              LITI.BHE              NEGR.BHZ              RAFA.BHN

carpincho:sacex smalley$ makerotatemacro.sh
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carpincho:sacex smalley$ ls
AREN.167              HEDI.BHE              JUAN.BHZ              NEGR.255              PENA.BHN
AREN.257              HEDI.BHN              LITI.171              NEGR.BHE              PENA.BHZ
AREN.BHE              HEDI.BHZ              LITI.261              NEGR.BHN              RAFA.165
AREN.BHN              HUER.154              LITI.BHE              NEGR.BHZ              RAFA.255
AREN.BHZ              HUER.244              LITI.BHN              NIEB.167              RAFA.BHE
BARD.168              HUER.BHE              LITI.BHZ              NIEB.257              RAFA.BHN
BARD.258              HUER.BHN              LLAN.154              NIEB.BHE              RAFA.BHZ
BARD.BHE              HUER.BHZ              LLAN.244              NIEB.BHN              RINC.157
BARD.BHN              HURT.168              LLAN.BHE              NIEB.BHZ              RINC.247
BARD.BHZ              HURT.258              LLAN.BHN              PACH.161              RINC.BHE
ELBO.168              HURT.BHE              LLAN.BHZ              PACH.251              RINC.BHN
ELBO.258              HURT.BHN              MAUL.171              PACH.BHE              RINC.BHZ
ELBO.BHE              HURT.BHZ              MAUL.261              PACH.BHN              all.macro
ELBO.BHN              JUAN.161              MAUL.BHE              PACH.BHZ              elbo.macro
ELBO.BHZ              JUAN.251              MAUL.BHN              PENA.165              huer.log
HEDI.160              JUAN.BHE              MAUL.BHZ              PENA.255              huer.macro
HEDI.250              JUAN.BHN              NEGR.165              PENA.BHE              makerotatemacro.sh
carpincho:sacex smalley$
```

```
carpincho:sacex smalley$ more all.macro
r AREN.BHE AREN.BHN
rotate to gcr
w KSTCMP
r BARD.BHE BARD.BHN
rotate to gcr
w KSTCMP
r ELBO.BHE ELBO.BHN
rotate to gcr
w KSTCMP
r HEDI.BHE HEDI.BHN
rotate to gcr
w KSTCMP
r HUER.BHE HUER.BHN
rotate to gcr
w KSTCMP
r HURT.BHE HURT.BHN
rotate to gcr
w KSTCMP
r JUAN.BHE JUAN.BHN
rotate to gcr
w KSTCMP
r LITI.BHE LITI.BHN
rotate to gcr
w KSTCMP
r LLAN.BHE LLAN.BHN
rotate to gcr
w KSTCMP
r MAUL.BHE MAUL.BHN
rotate to gcr
w KSTCMP
r NEGR.BHE NEGR.BHN
rotate to gcr
w KSTCMP
r NIEB.BHE NIEB.BHN
rotate to gcr
w KSTCMP
r PACH.BHE PACH.BHN
rotate to gcr
w KSTCMP
r PENA.BHE PENA.BHN
rotate to gcr
w KSTCMP
r RAFA.BHE RAFA.BHN
rotate to gcr
w KSTCMP
r RINC.BHE RINC.BHN
rotate to gcr
w KSTCMP
quit
```

Look at the sac macro written by the shell script