Data Analysis in Geophysics
ESCI 7205

Bob Smalley
Room 103 in 3892 (long building), x-4929

Tu/Th - 13:00-14:30
CERI MAC (or STUDENT) LAB

Lab – 9, 09/24/13

Unary Operations Module

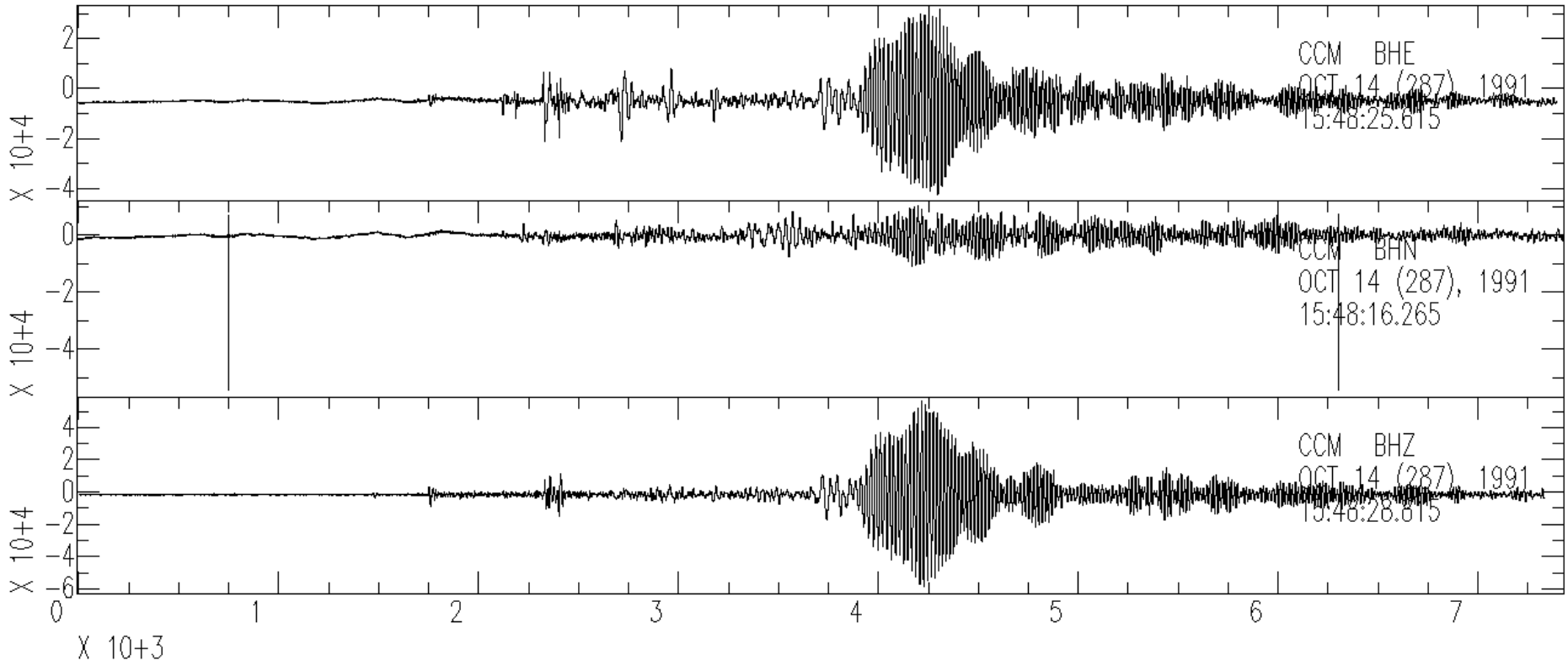
The commands in this module perform some arithmetic operation on each data point of the signals in memory.

```
add
sub
mul
div
sqr
sqrt
```

```
abs
log,log10
exp,exp10
int
dif
```

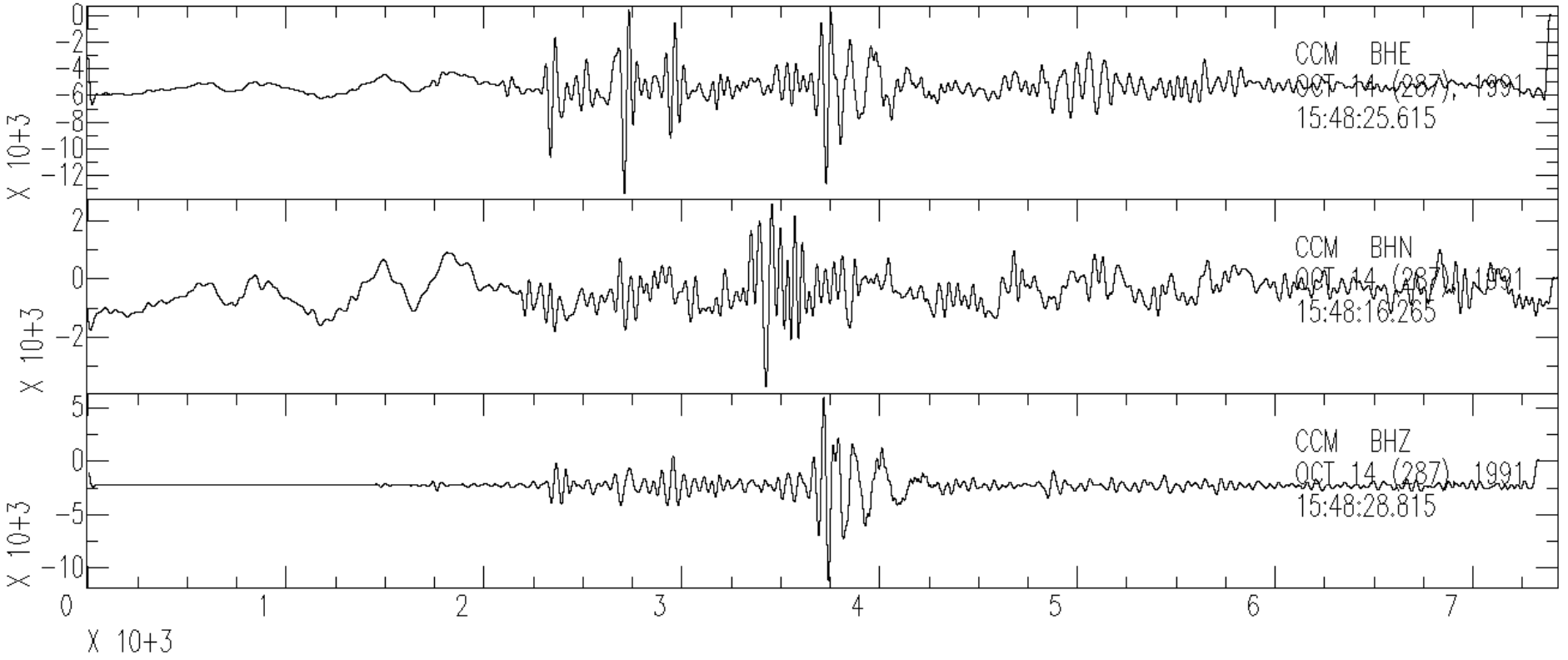
Read in some data – do some processing

```
SAC> read ./ccm_solomon*bh?
...
SAC> p1
```



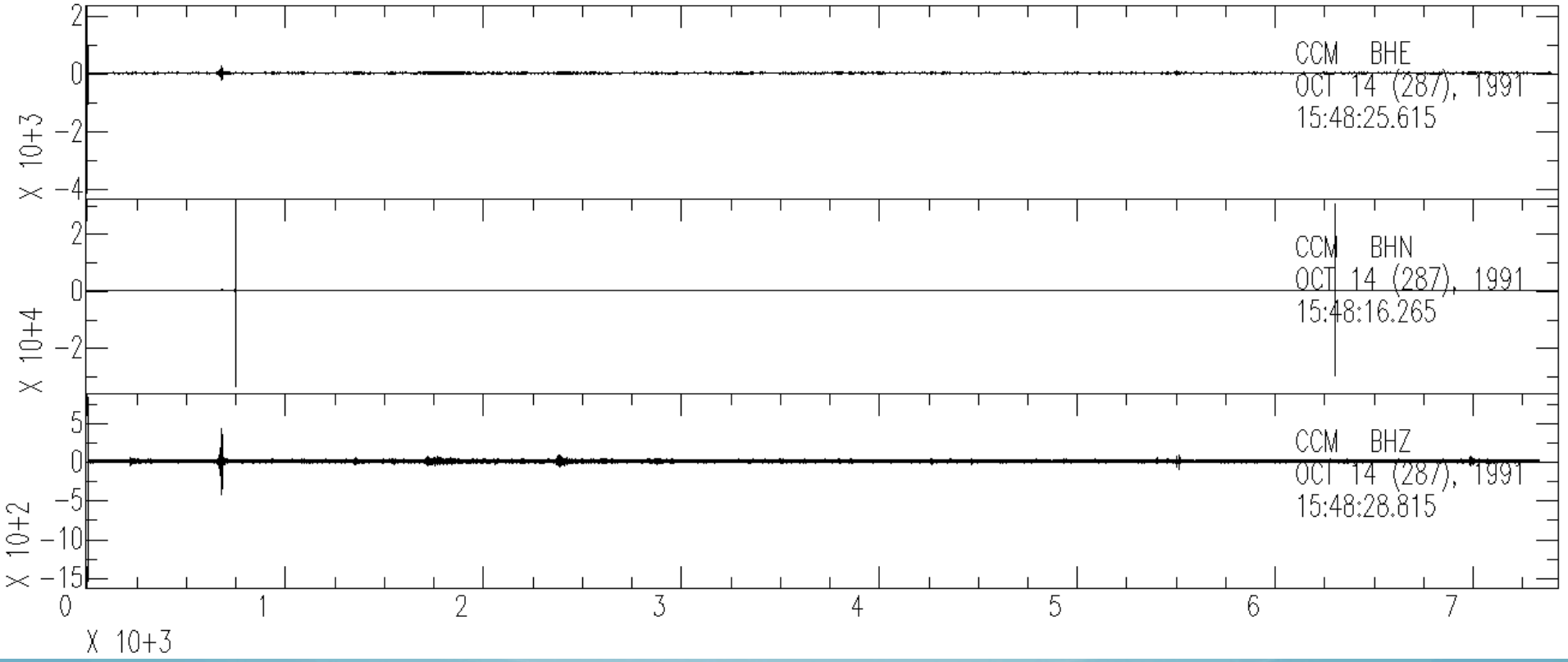
Low pass filter it

```
SAC> lp co .025 npoles 4 passes 2
SAC> p1
```



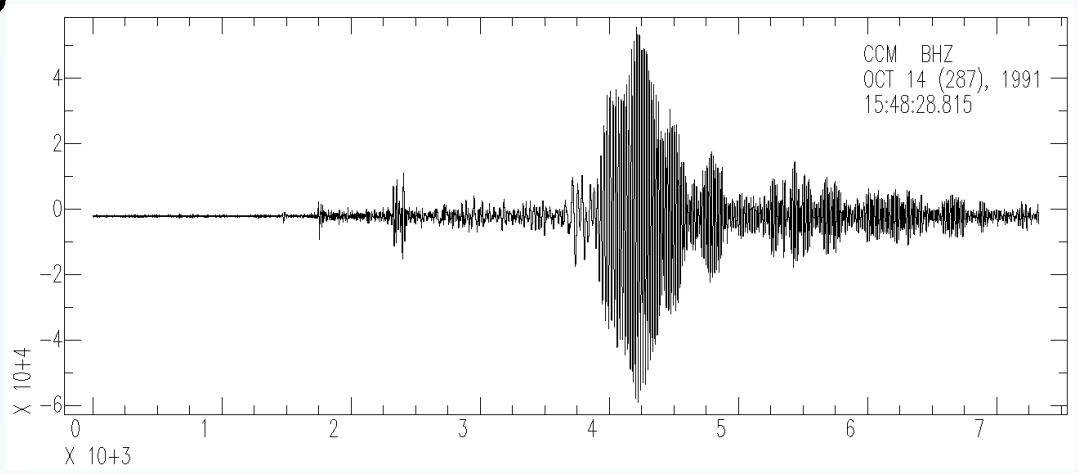
High pass filter it

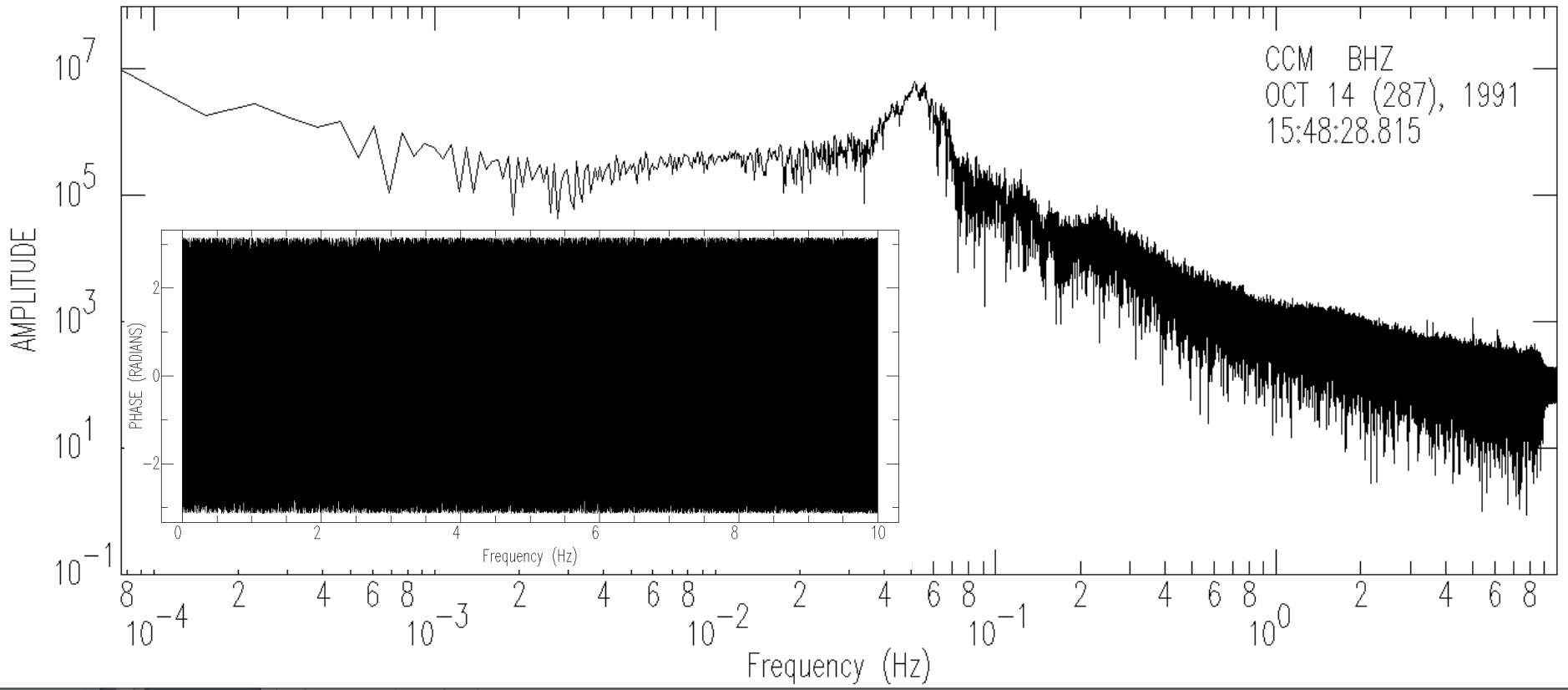
```
SAC> r
SAC> hp co 1 npoles 4
SAC> p1
```



Spectral analysis – Fourier transform

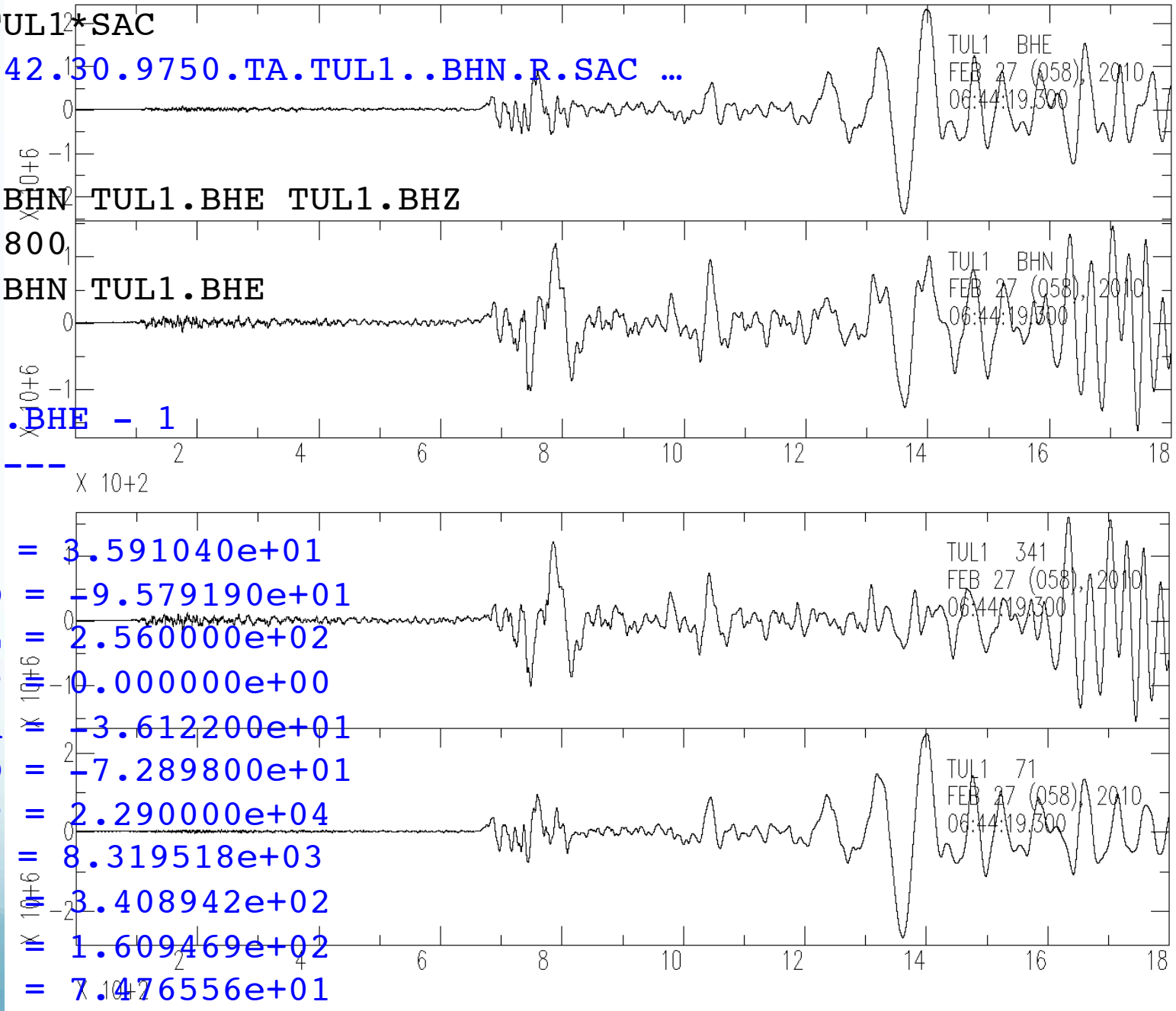
```
SAC> read ccm_solomon_*z
SAC> fft
SAC> psp
Waiting
SAC>
```



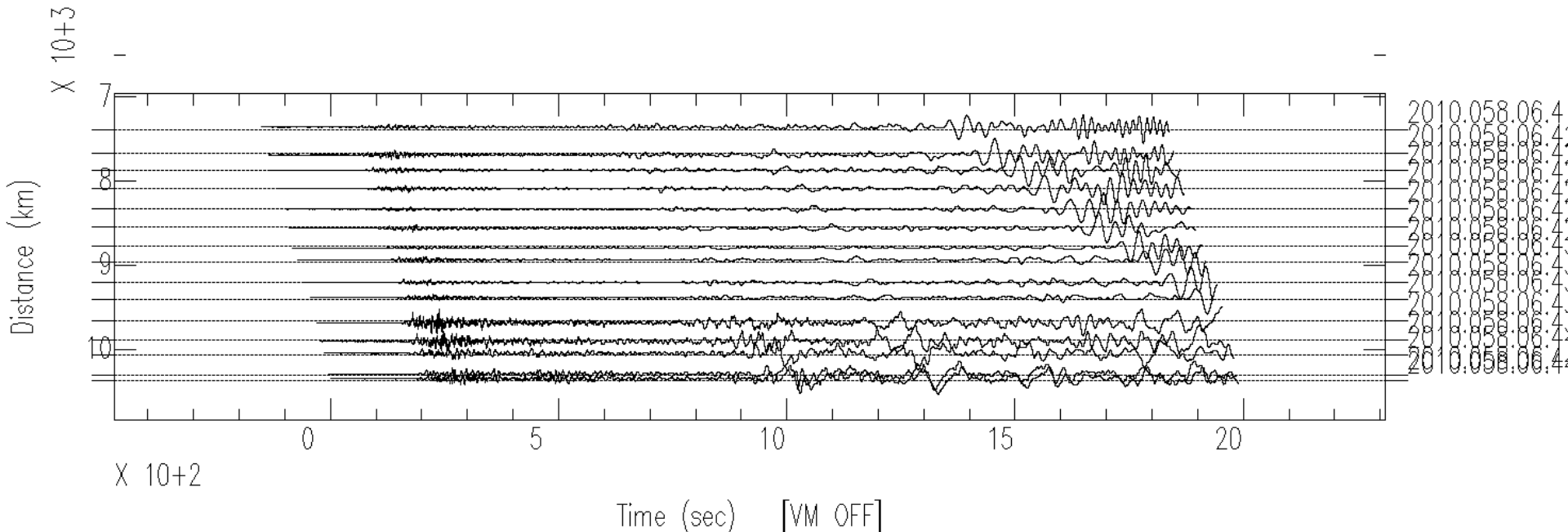


Rotate seismograms

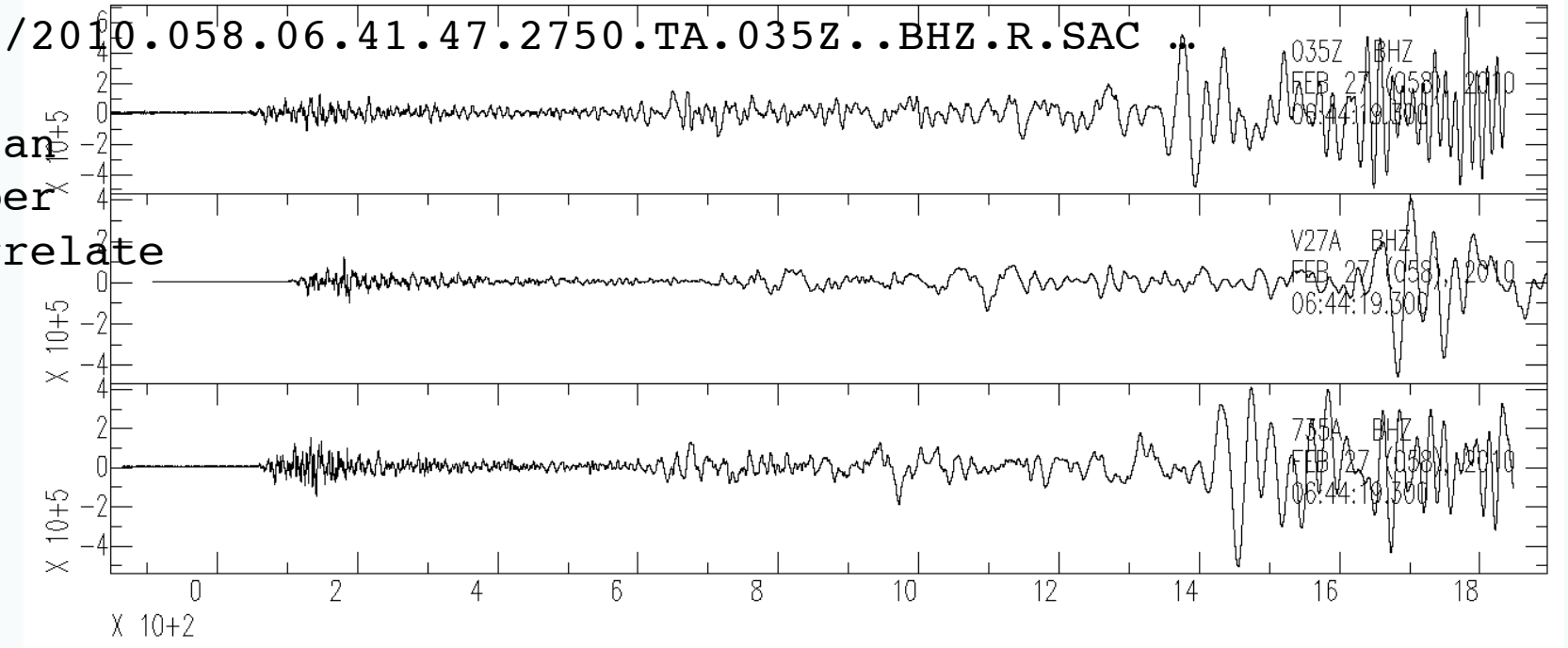
```
SAC> read *TUL1*SAC
2010.058.06.42.30.9750.TA.TUL1..BHN.R.SAC …
SAC> p1
SAC> synch
SAC> w TUL1.BHN TUL1.BHE TUL1.BHZ
SAC> cut 0 1800
SAC> r TUL1.BHN TUL1.BHE
SAC> rotate
SAC> lh
  FILE: TUL1.BHE - 1
 -------------
...
        STLA = 3.591040e+01
        STLO = -9.579190e+01
        STEL = 2.560000e+02
        STDP = 0.000000e+00
        EVLA = -3.612200e+01
        EVLO = -7.289800e+01
        EVDP = 2.290000e+04
        DIST = 8.319518e+03
          AZ = 3.408942e+02
         BAZ = 1.609469e+02
       GCARC = 7.476556e+01
```

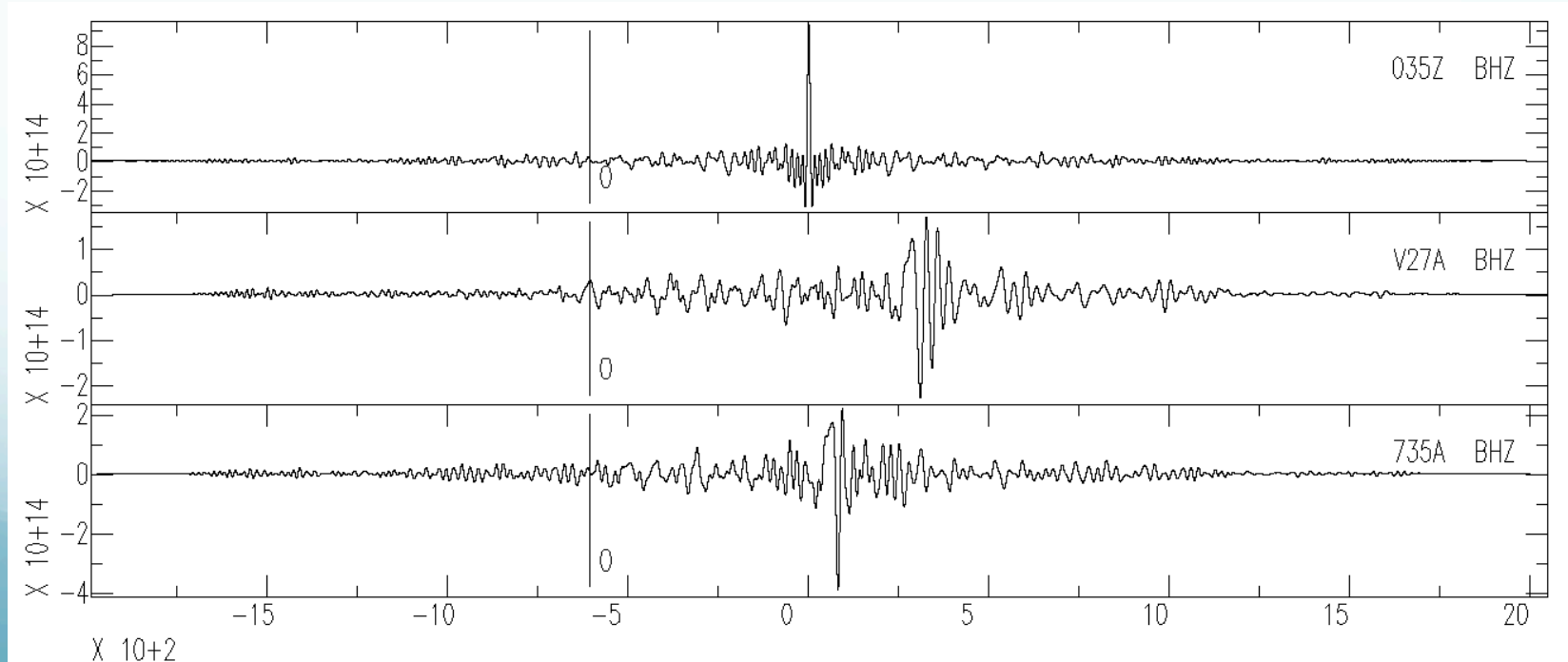


```
SAC> read *BHZ*SAC
2010.058.06.41.47.2750.TA.035Z..BHZ.R.SAC
...
SAC> qdp off
SAC> p1
SAC> sss
Signal Stacking Subprocess.
SAC/SSS> prs
```



```
SAC> r ./2010.058.06.41.47.2750.TA.035Z..BHZ.R.SAC ..
SAC> p1
SAC> rmean
SAC> taper
SAC> correlate
SAC> p1
```





Signal Correction Module

These commands let you perform certain signal correction operations.

- `rmean`: removes the mean from data.

- `rtrend`: removes linear trend (and mean) from data.

- `rglitches`: removes glitches and timing marks.

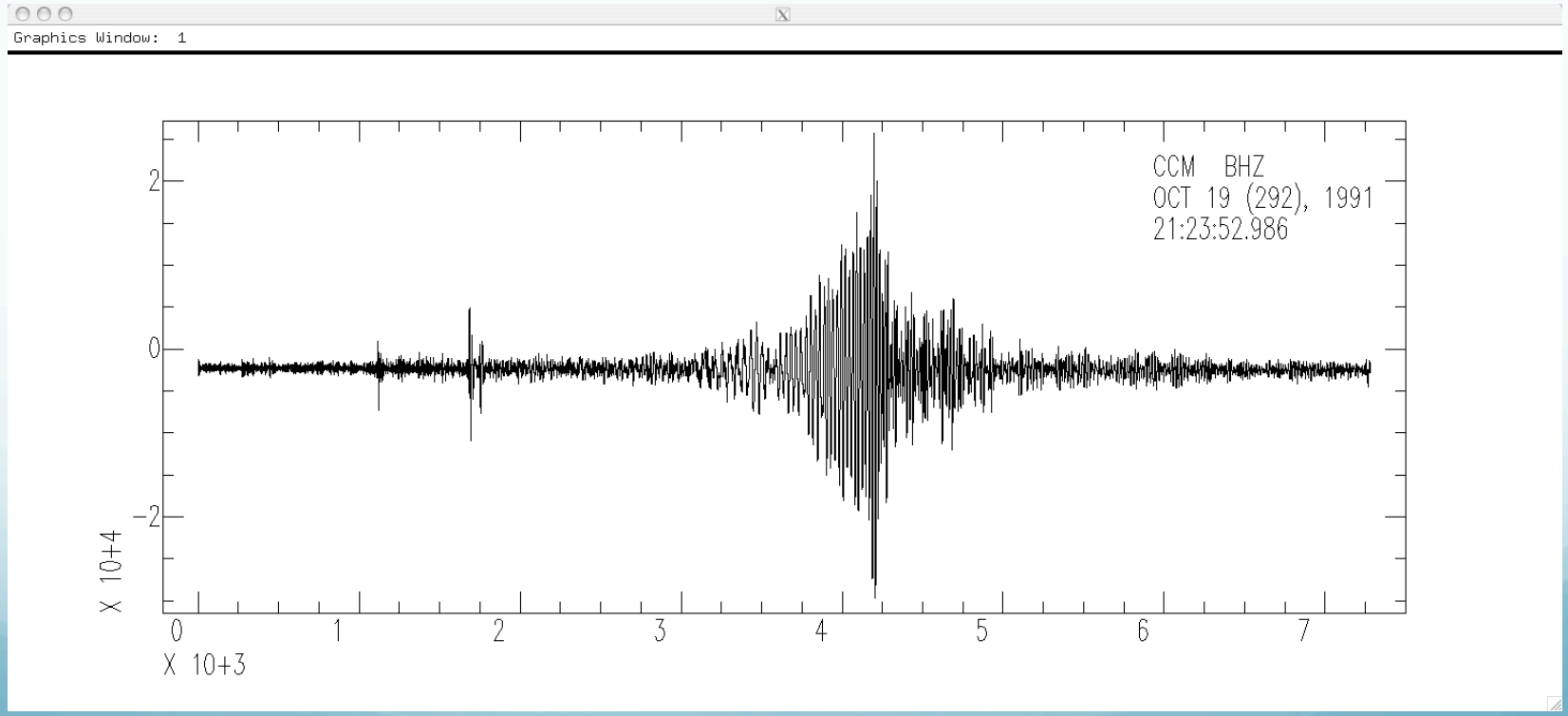
- `taper`: applies a symmetric taper to each end of the data and `SMOOTH` applies an arithmetic smoothing algorithm.

- `linefit`: computes the best straight line fit to the data in memory and writes the results to header blackboard variables.

- `reverse`: reverses the order of data points.

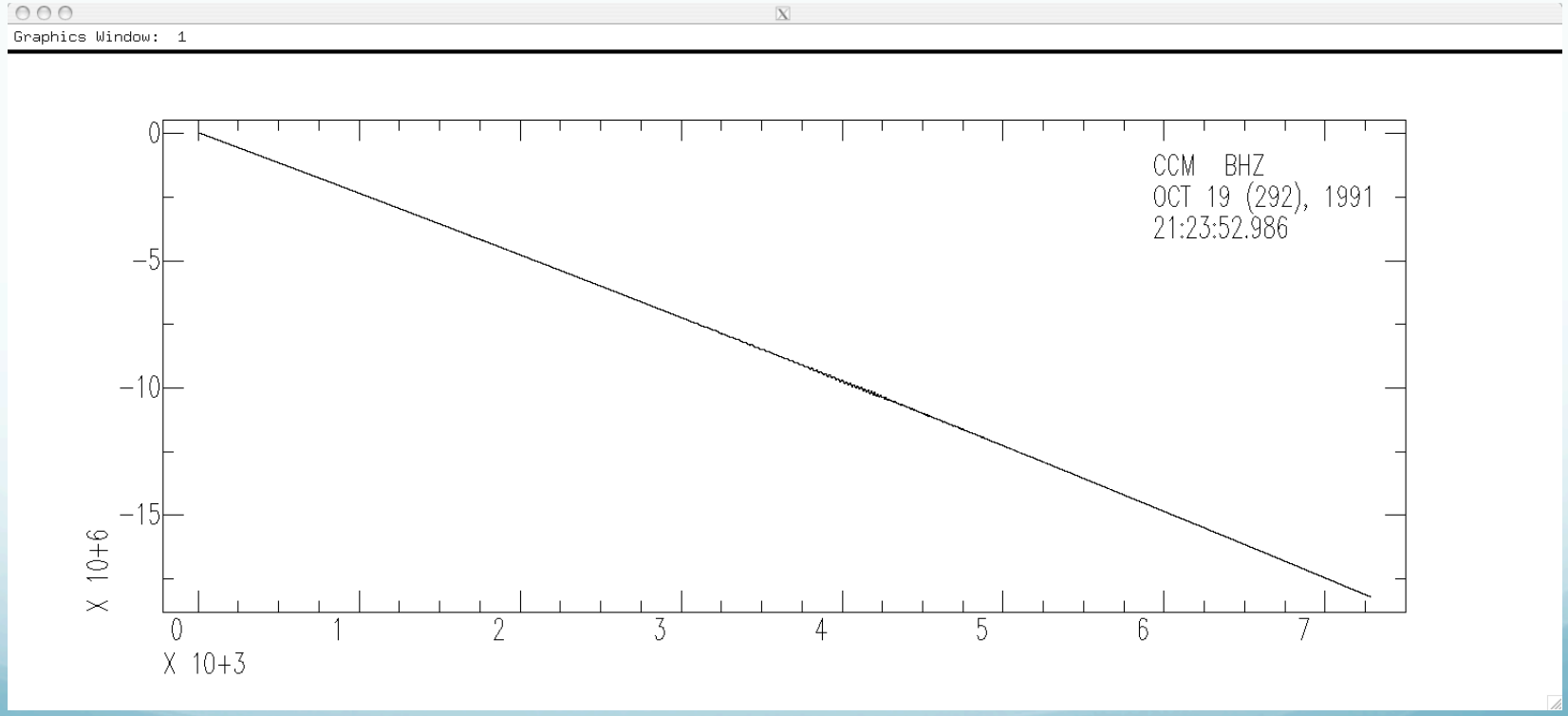
Integration – to change from acceleration to velocity, and velocity to displacement.

```
SAC> r ccm_india_.bhz
SAC> qdp off
SAC> plot
```



Integrate it (original data was vel, integrate to disp).

```
SAC> int
SAC> p
```



OOPS!

What is the problem?

(do you agree that there is a problem?!)

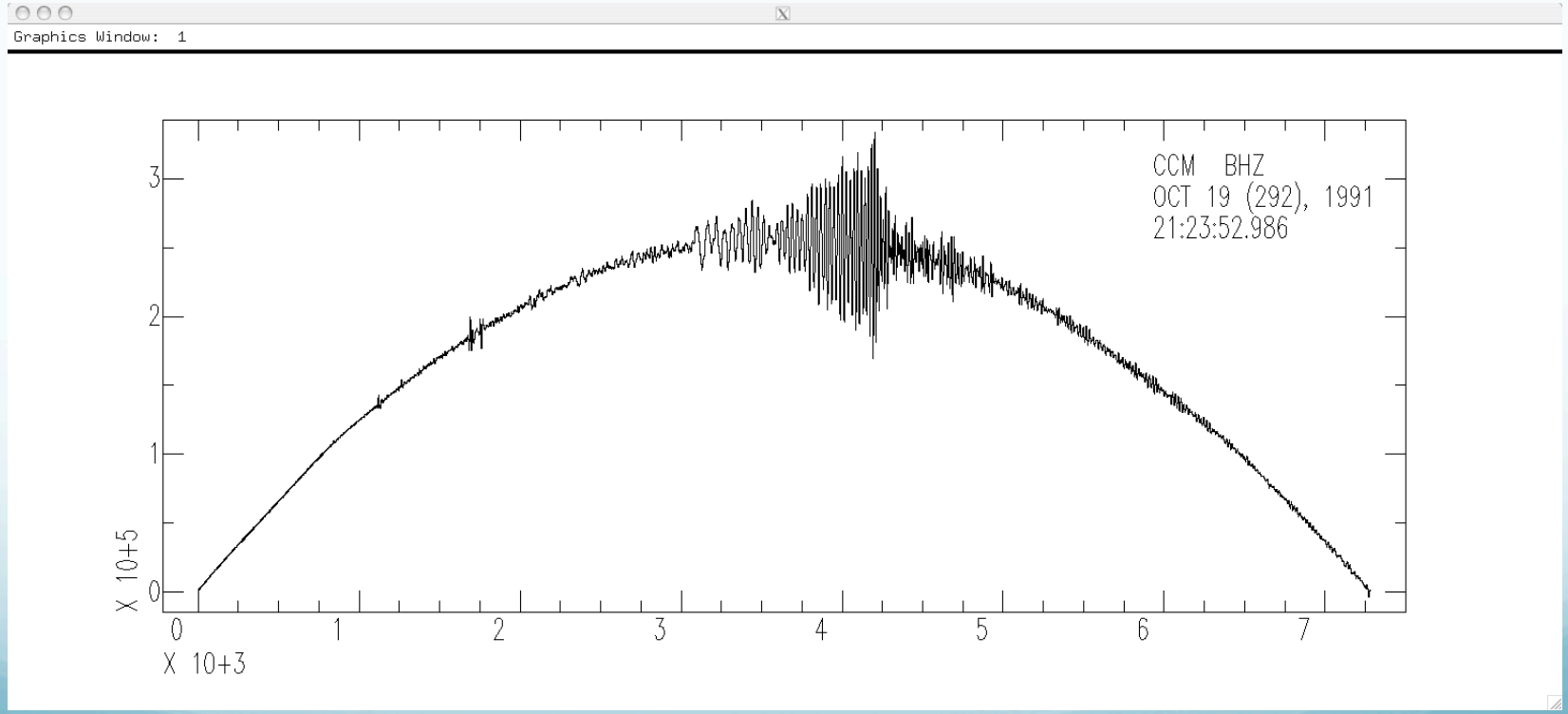
Integral of constant is a straight sloping line.

The seismic data has a (small) DC offset (a constant).

So remove the mean.

Try again.

```
SAC> r
SAC> rmean
SAC> int
SAC> p
```



OOPS again!

Is this an improvement?
Are we getting any better?

What's the problem now?

Integral of linear fn (line) is a quadratic fn (parabola).

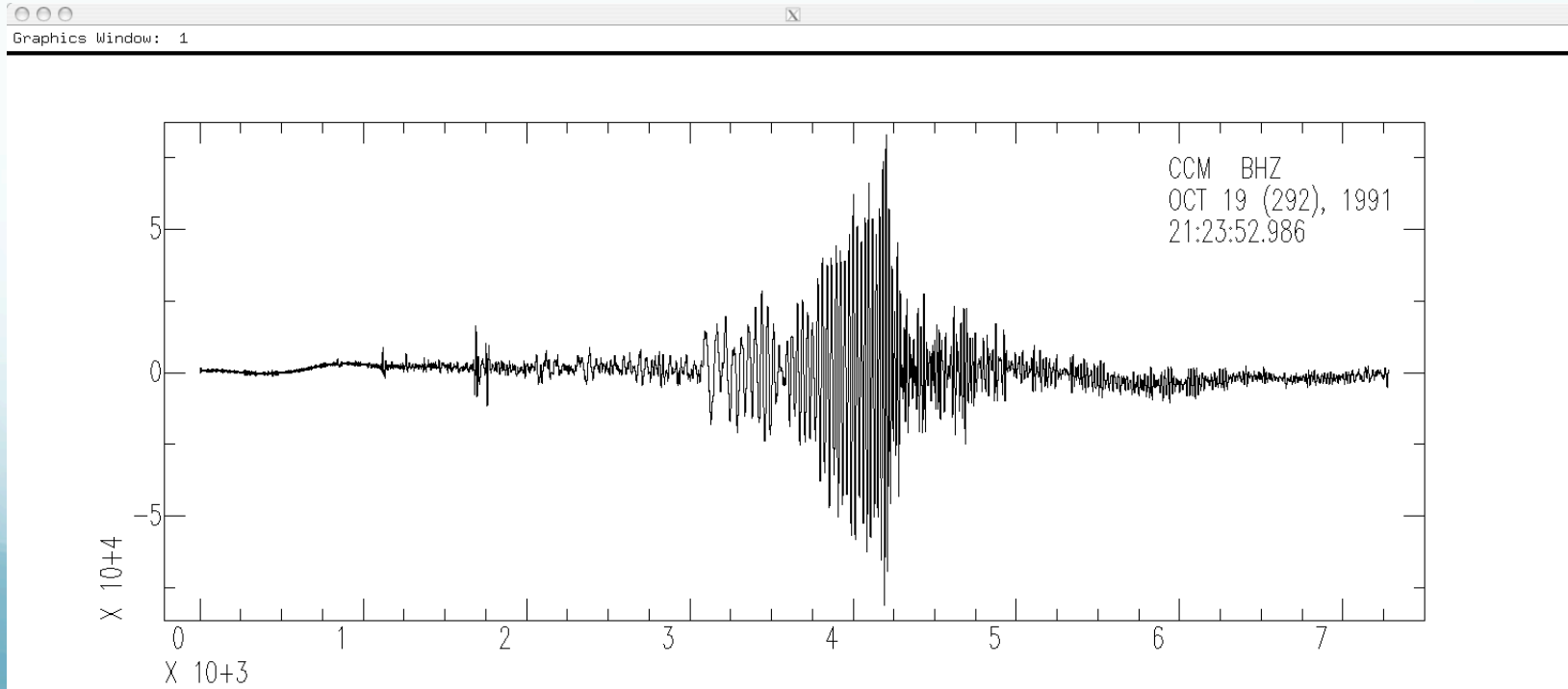
So data has a linear trend - remove trend (line) from data

(y=mx+b)

(this will also remove the mean through the intercept **b**).

Remove trend (line) with `rtrend`.

```
SAC> r
SAC> rtrend
 Slope and standard deviation are: -0.038705 0.0037565
 Intercept and standard deviation are: -2365.1 15.788
 Data standard deviation is: 3010.9
 Data correlation coefficient is: 0.026988
SAC> int
SAC> p
```

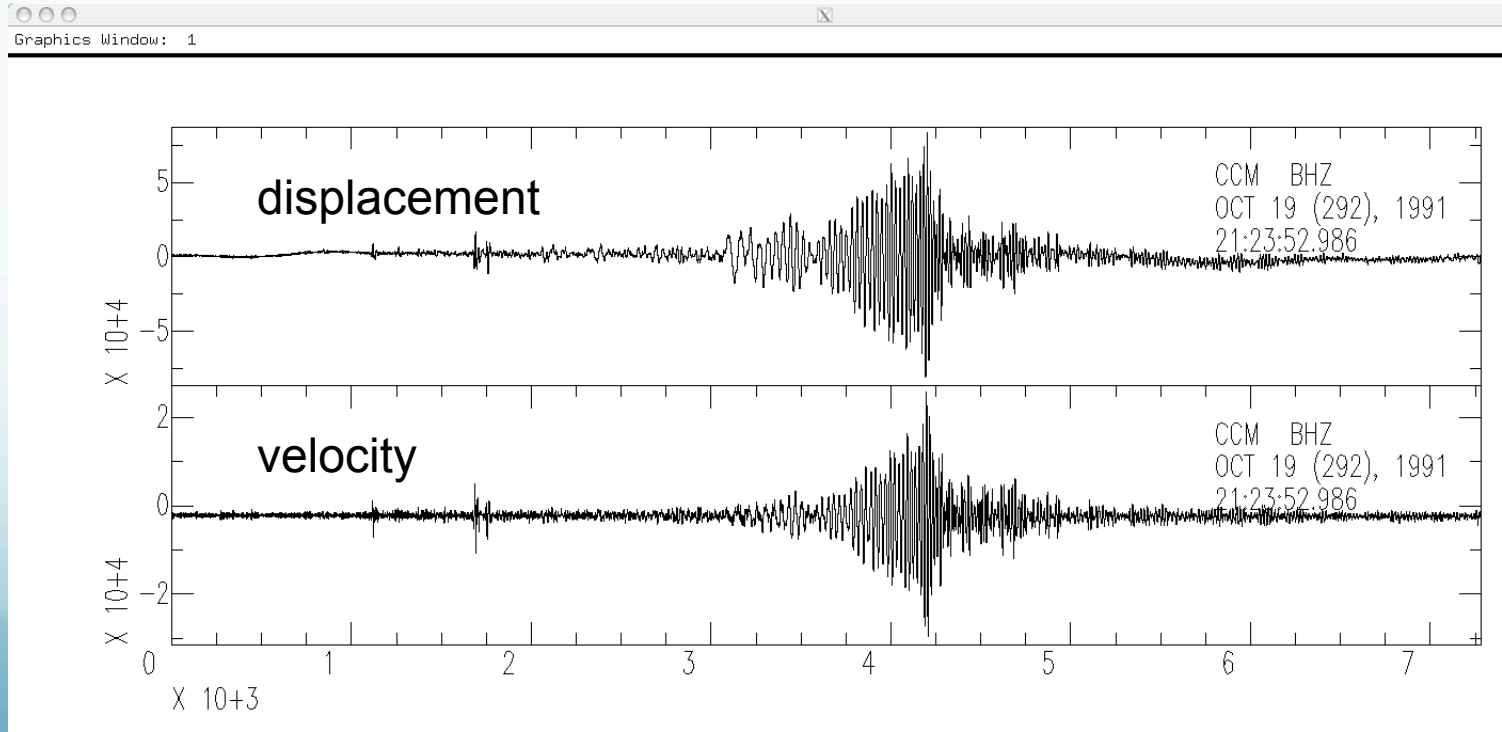


Removing the line will also remove the mean if it is not zero.

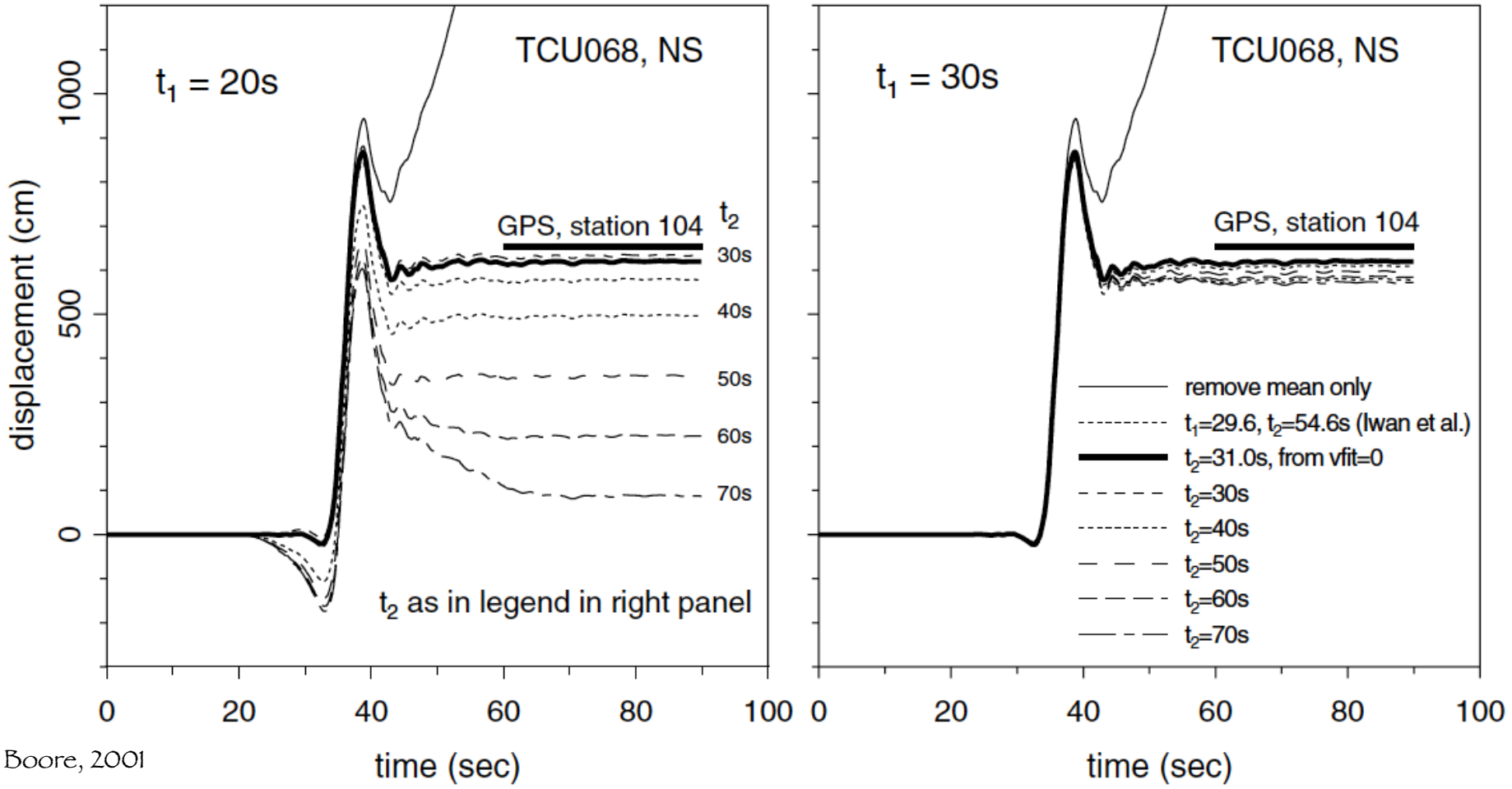
So don't really need to do the `rmean` first.

There is still some "drift", but this seismogram might be useful for displacement analysis.

```
SAC> r
SAC> rtrend
 Slope and standard deviation are: -0.038705 0.0037565
 Intercept and standard deviation are: -2365.1 15.788
 Data standard deviation is: 3010.9
 Data correlation coefficient is: 0.026988
SAC> int
SAC> r more
SAC> p1
```



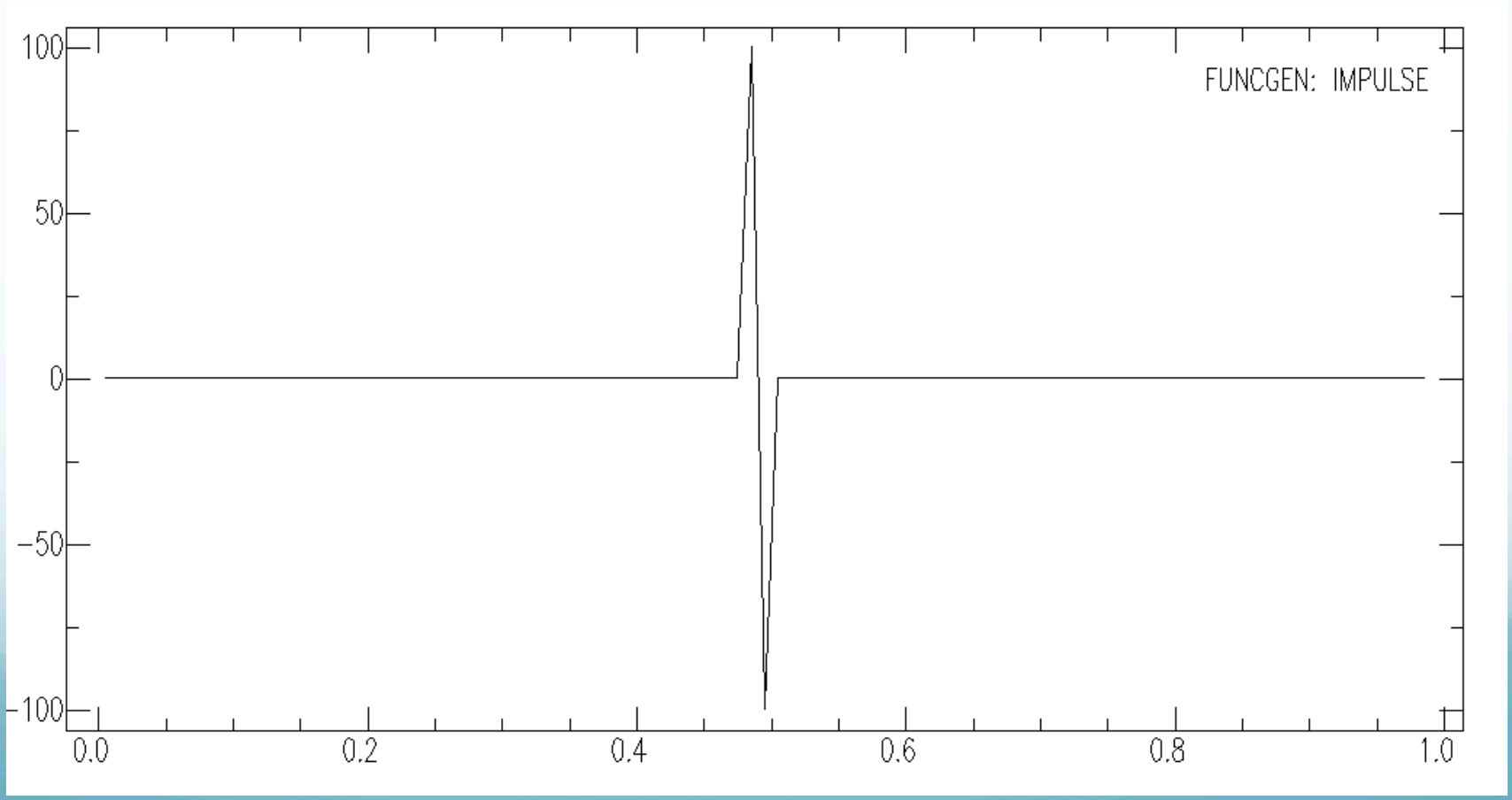
Big problems with "baseline" drift when trying to integrate acceleration up to displacement to when trying to obtain/estimate co-seismic static displacement.



Boore, 2001

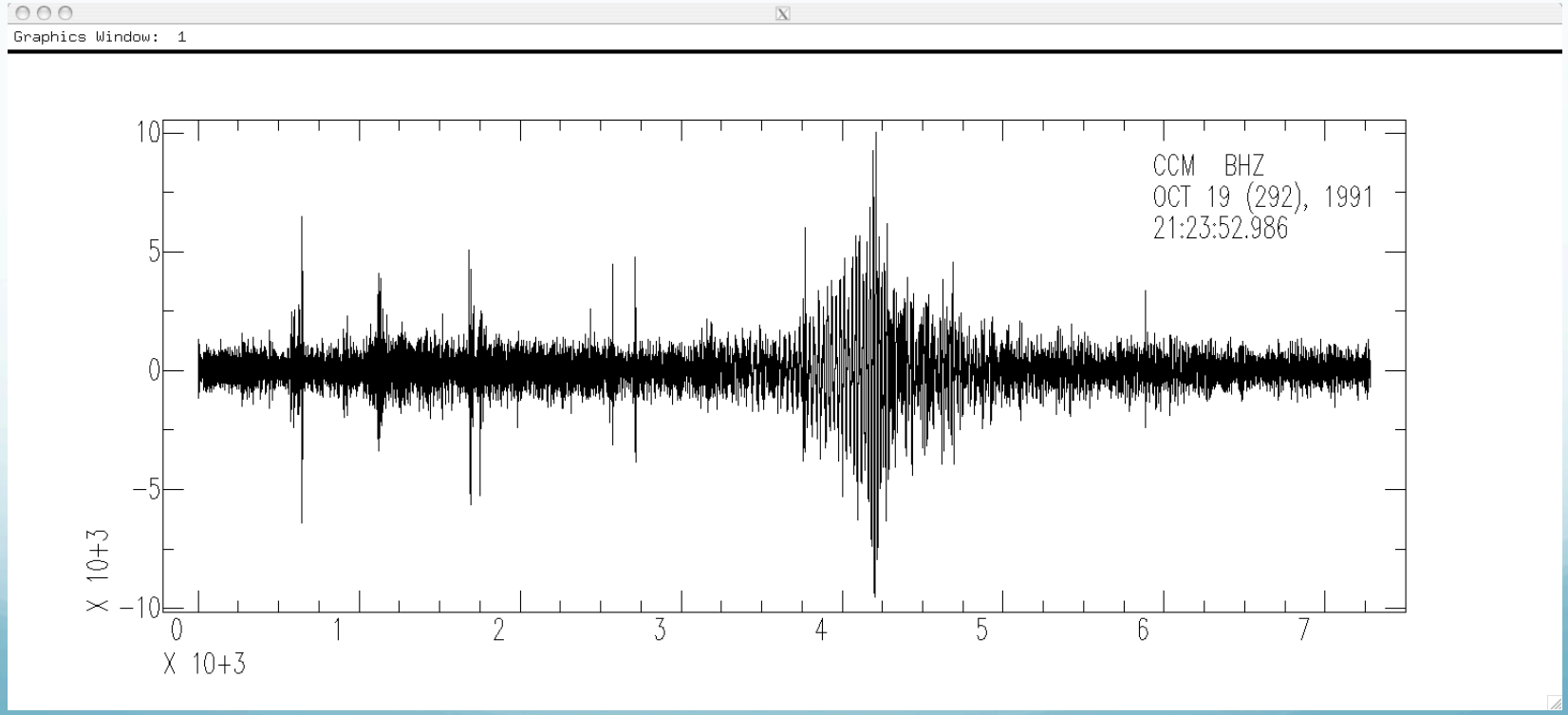
Differentiation - default is 2 point difference y=(x1-x0)/delta.

```
sac> funcgen impulse delta 0.01 npts 100
sac> dif
sac> p
```



Differentiate velocity to acceleration.

```
SAC> r
SAC> dif
SAC> p
```



Binary Operations Module

These commands perform operations on pairs of data files.

- `merge`: merges (concatenates) a set of files to the data in memory.

Binary Operations Module

- `addf`: Adds a set of data files to data in memory.

```
READ FILE1 FILE2
ADDF FILE3 FILE4

READ FILE1 FILE2 FILE3
ADDF FILE4
```

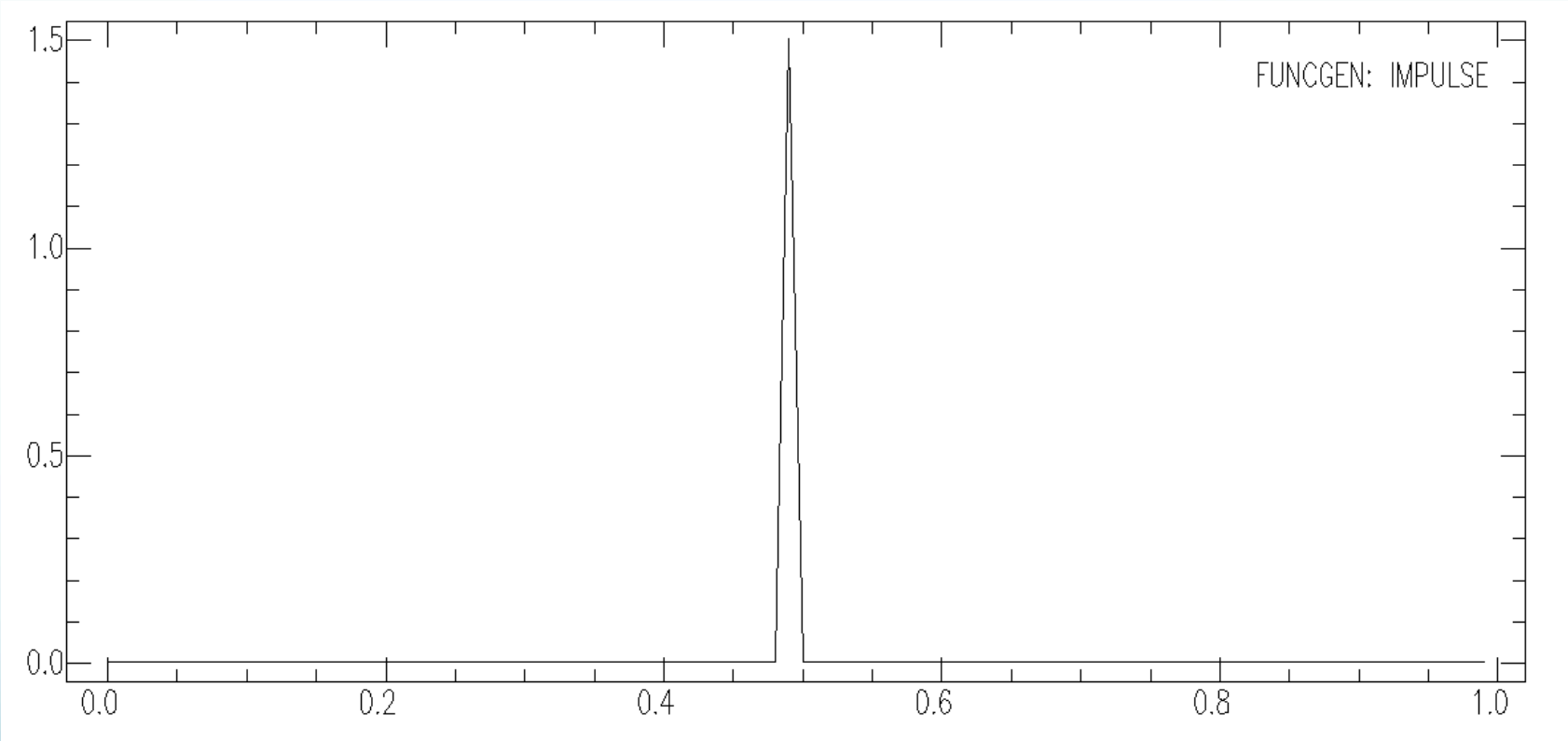
- `subf`: subtracts a set of data files from the ones in memory.

- `mulf`: multiplies the data in memory by a set of data files.

- `divf`: divides the data in memory by a set of files.

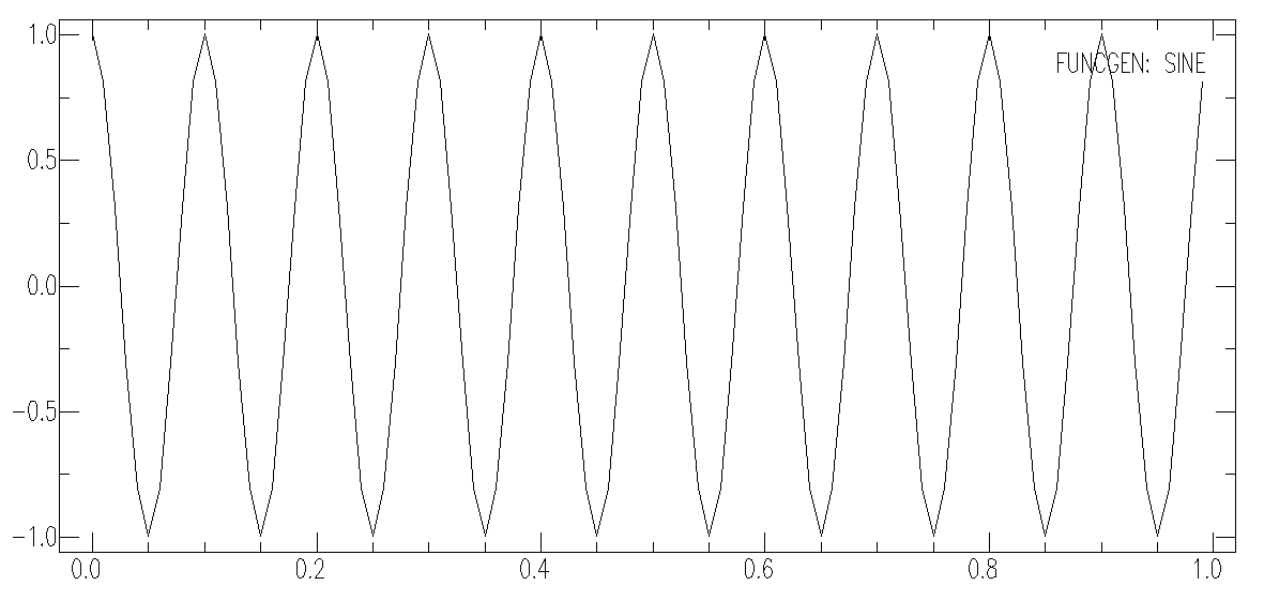
- `binoperr`: controls errors that can occur during these binary operations. Can use to override the requirement for the same number of points and/or the same sampling interval.

```
sac> funcgen impulse delta 0.01 npts 100
sac> w impulse1.sac
sac> div 2
sac> w impulse2.sac
sac> r impulse1.sac
sac> addf impulse2.sac
```

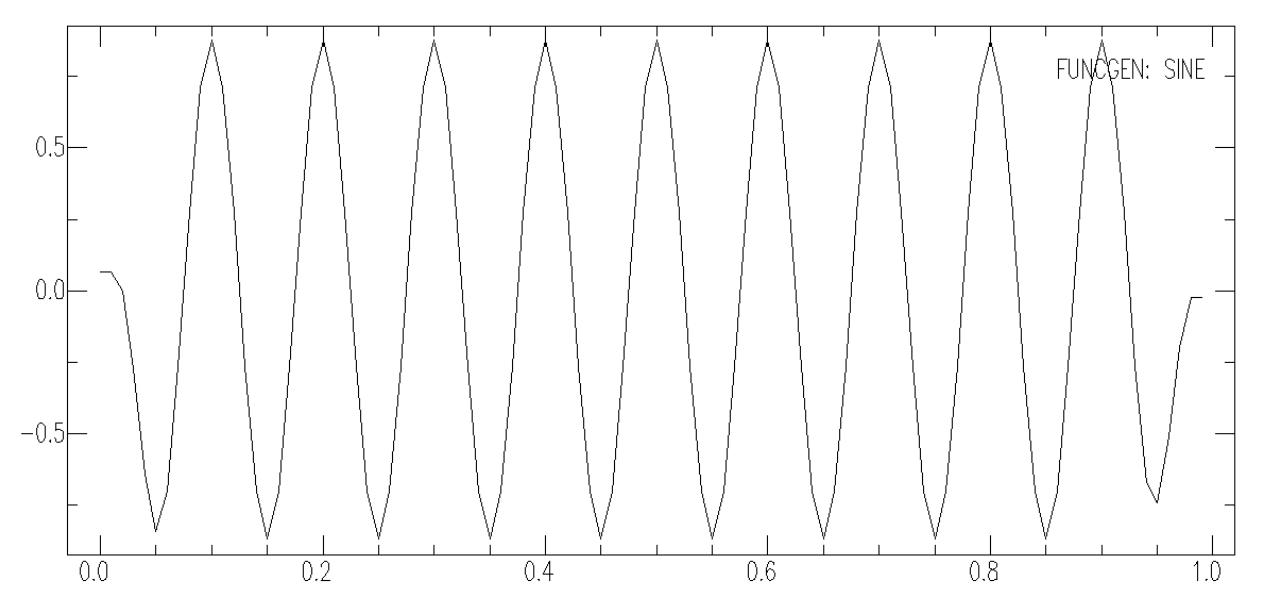


Notice you have to write intermediate stuff out to disk.

```
sac> funcgen sine 10 90 delta 0.01 npts
100
sac> p
```




```
sac> taper
```



More

- `stretch`: upsamples data, including an optional interpolating FIR filter.

- `decimate`: downsamples data, including an optional anti-aliasing FIR filter.

- `interpolate`: interpolate evenly or unevenly spaced data to a new sampling interval using the interpolate command.

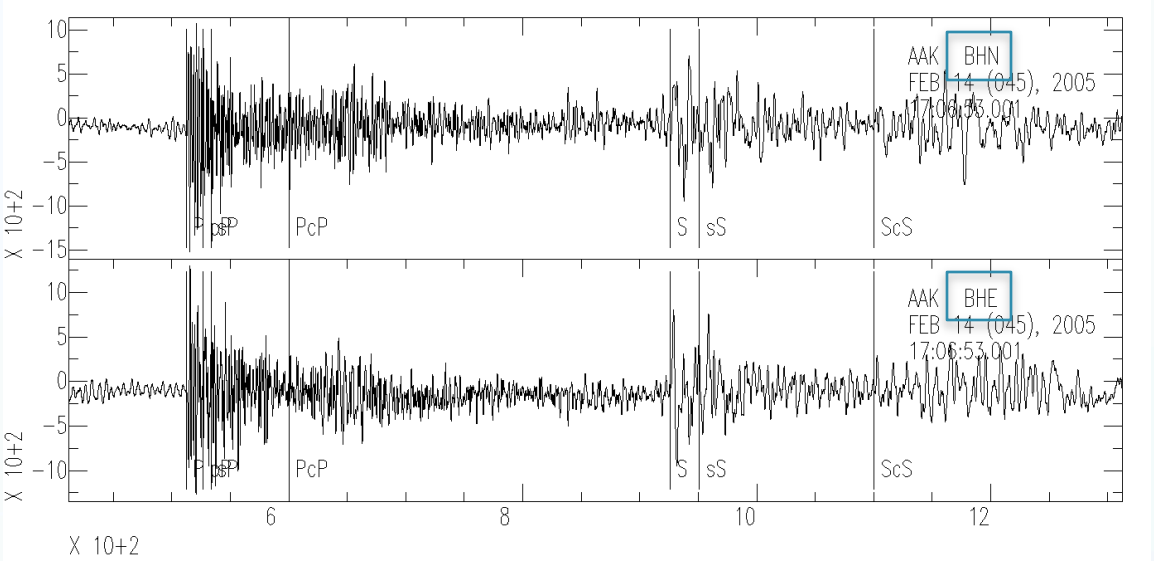
More

- `quantize`: converts continuous data into its quantized equivalent.

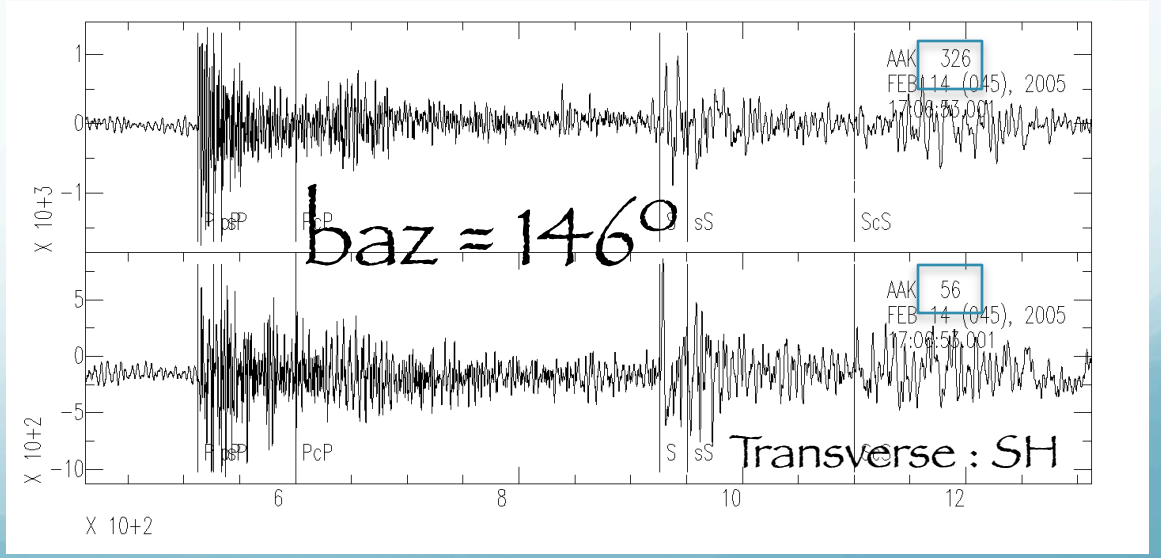
- `rotate`: pairs of data components through a specified angle.

- `rq`: removes the seismic Q factor from spectral data.

```
sac> r II.AAK.00.BHN.Q.SAC II.AAK.
00.BHE.Q.SAC
sac> p1
```




```
sac> rotate to gcp normal
```



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.

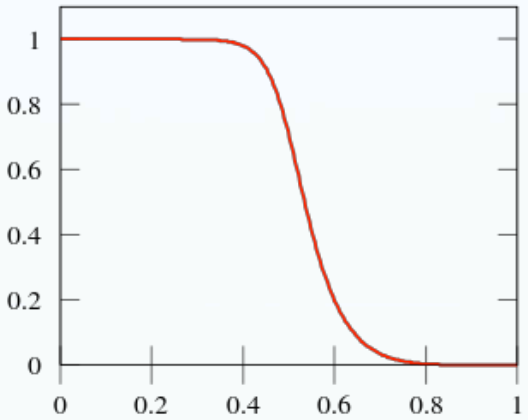
Chebyshev type I & Chebyshev type II:

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

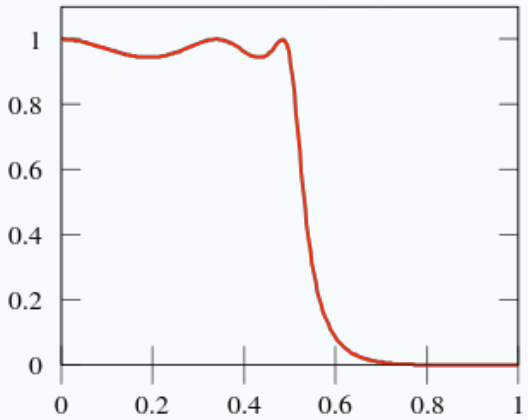
Does horrible things to the phase.

The Butterworth filter rolls off more slowly around the cutoff frequency than the Chebyshev filter or the Elliptic filter, but without ripple.

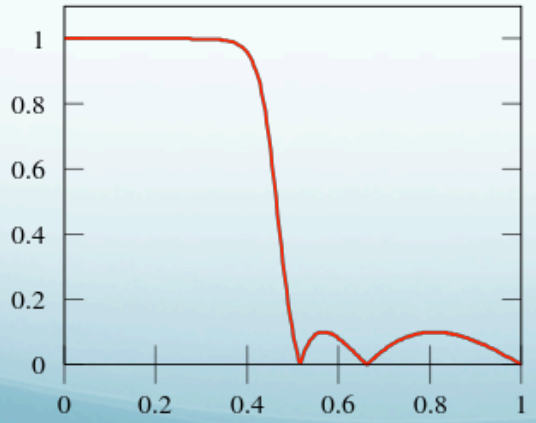
Butterworth



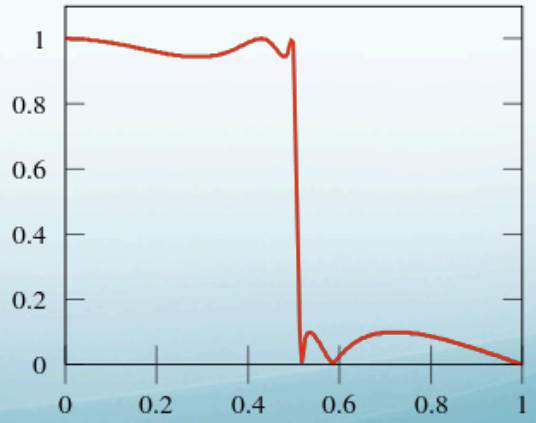
Chebyshev type 1



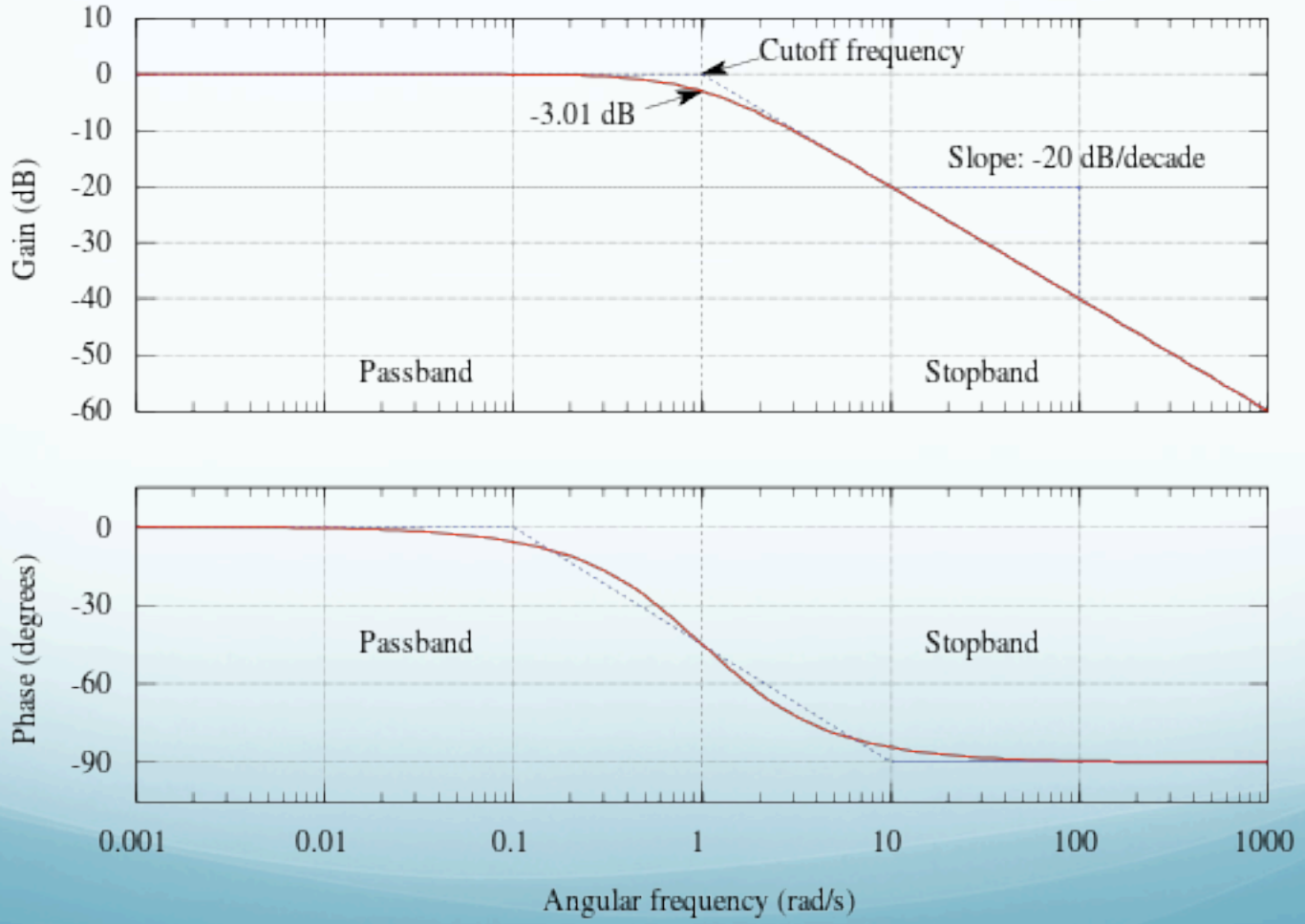
Chebyshev type 2



Elliptic



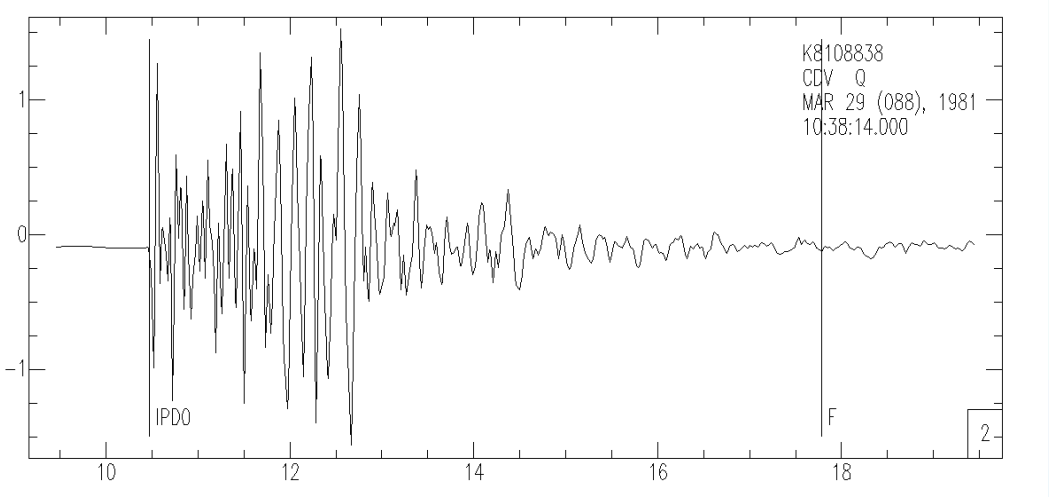
The Butterworth filter is relatively nice with the phase.



The Butterworth and Bessel are the easiest to set up

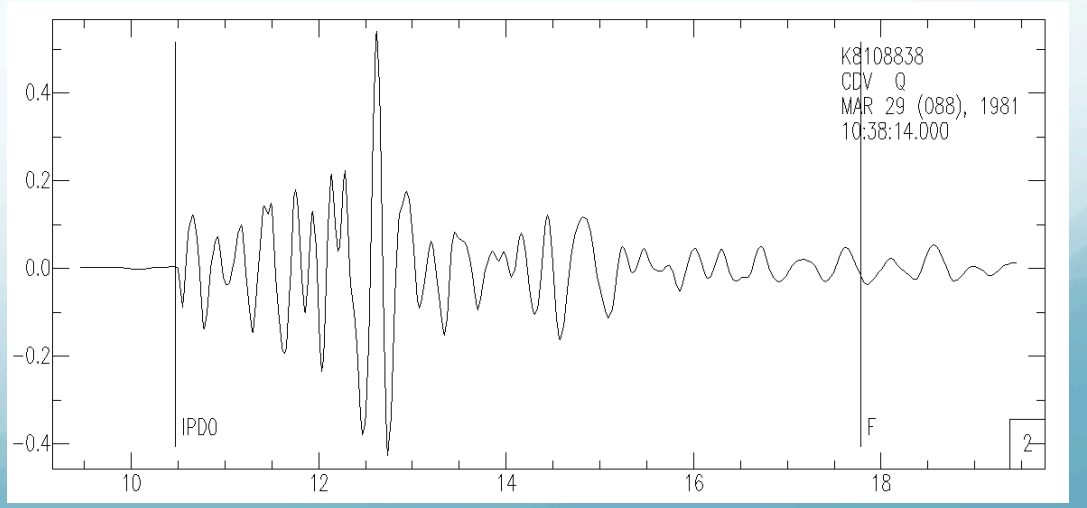
```
BANDPASS {BUTTER|BESSEL|C1|C2},{CORNERS v1 v2},{NPOLES n},{PASSES n},{TRANBW v},{ATTEN v}
```

```
sac> funcgen seismogram
```

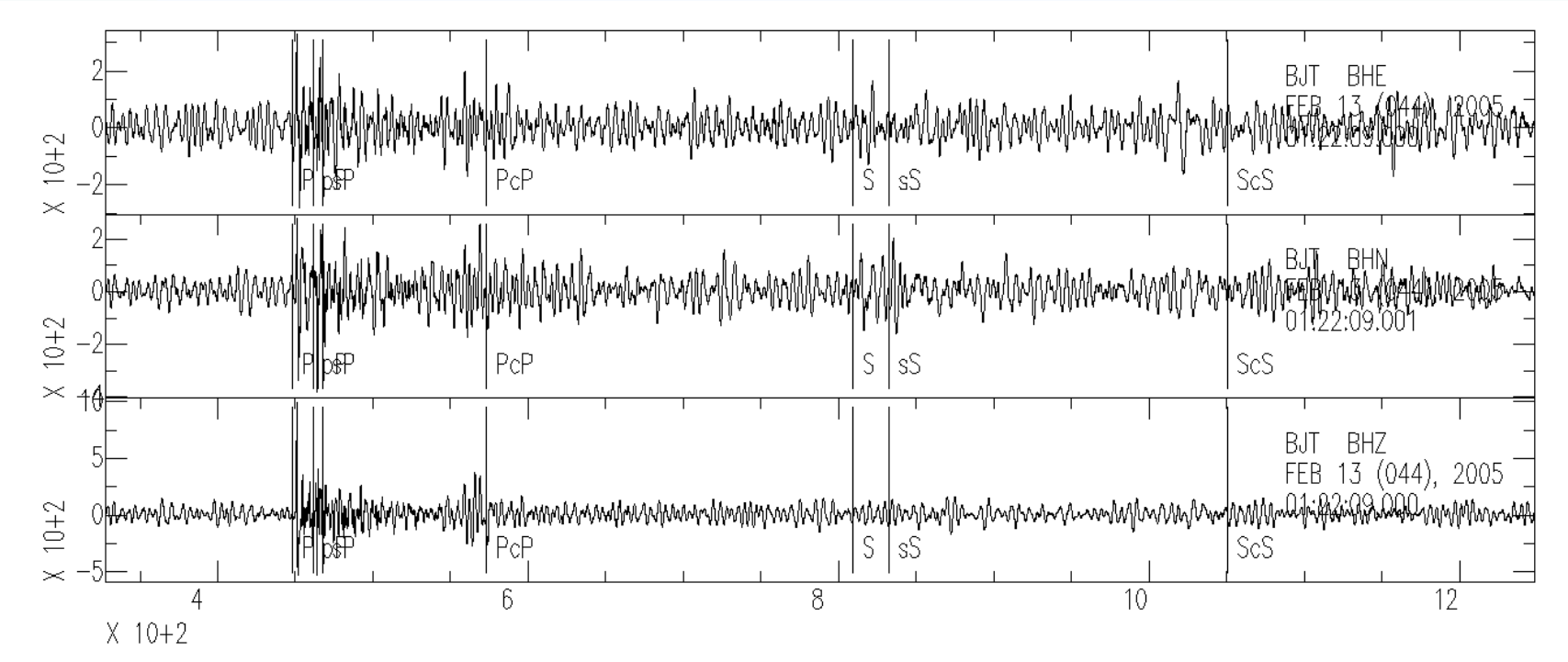



```
sac> rmean
sac> taper
sac> bp butter co 1 3
```

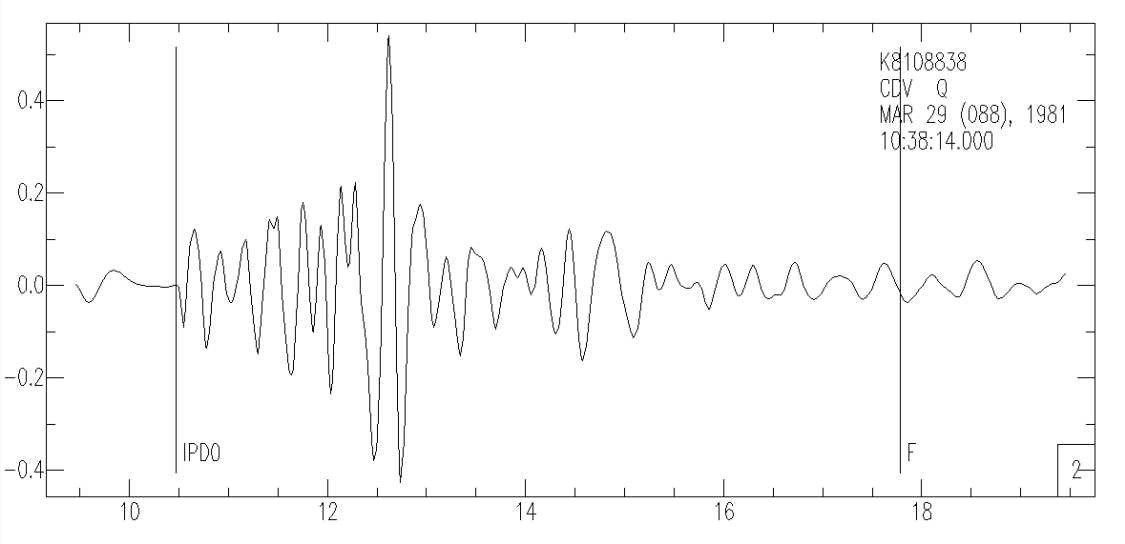
using default values
passes (p) 1
num poles (n) 2



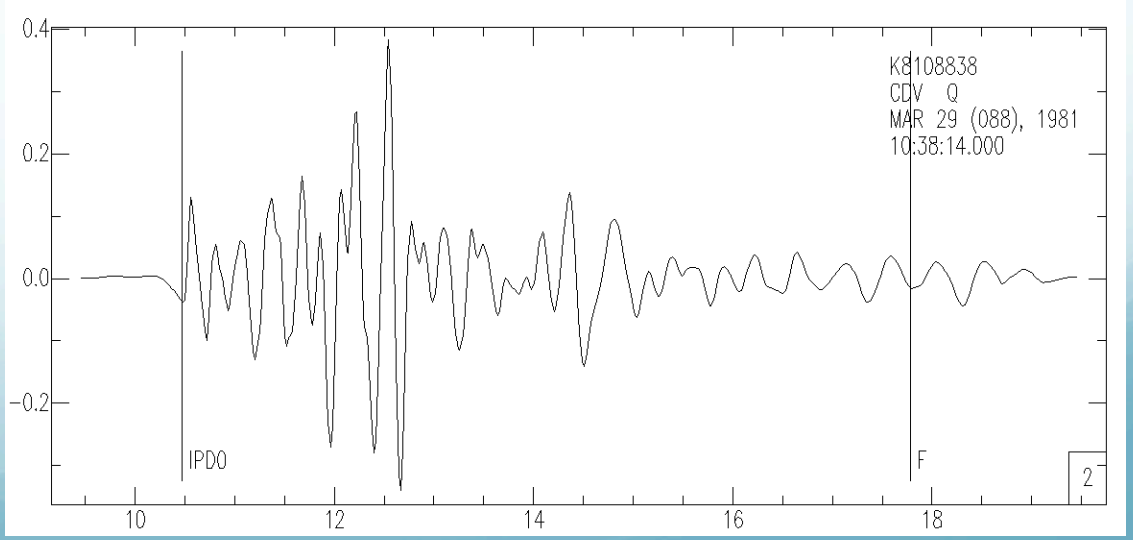
```
sac> hp butter co .2
sac> xlim t1 -120 800
```



```
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,

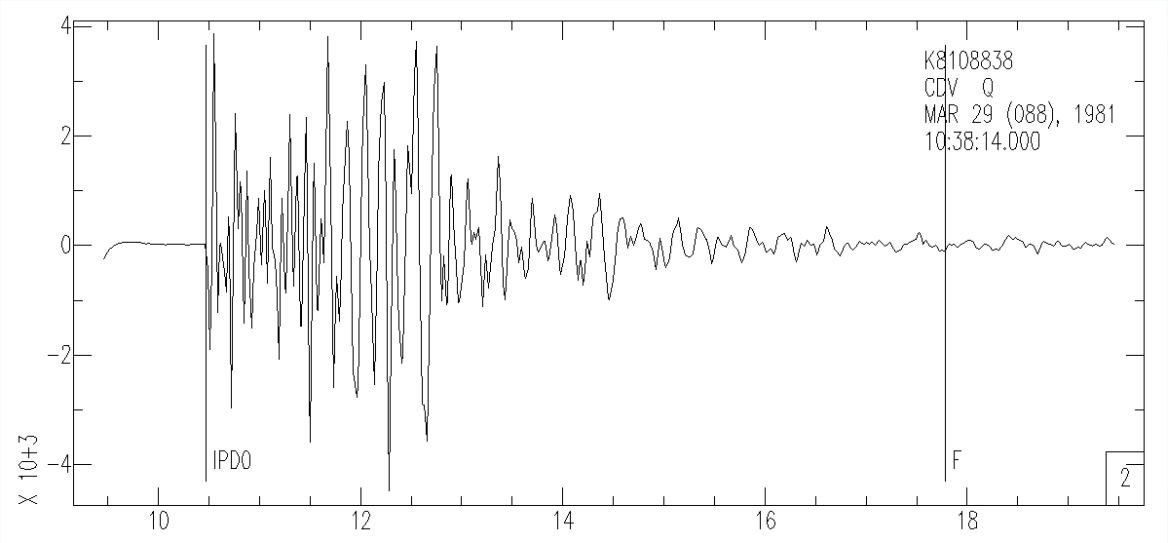
`transfer`.

`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 transform 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

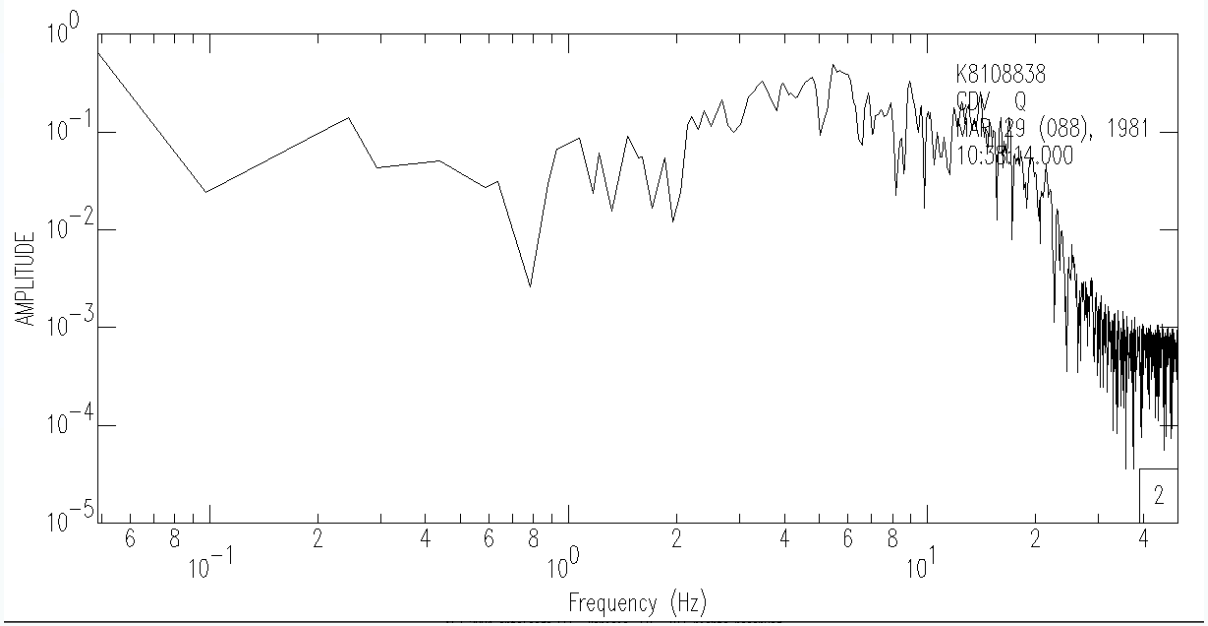
- differentiation with

`mulomega`

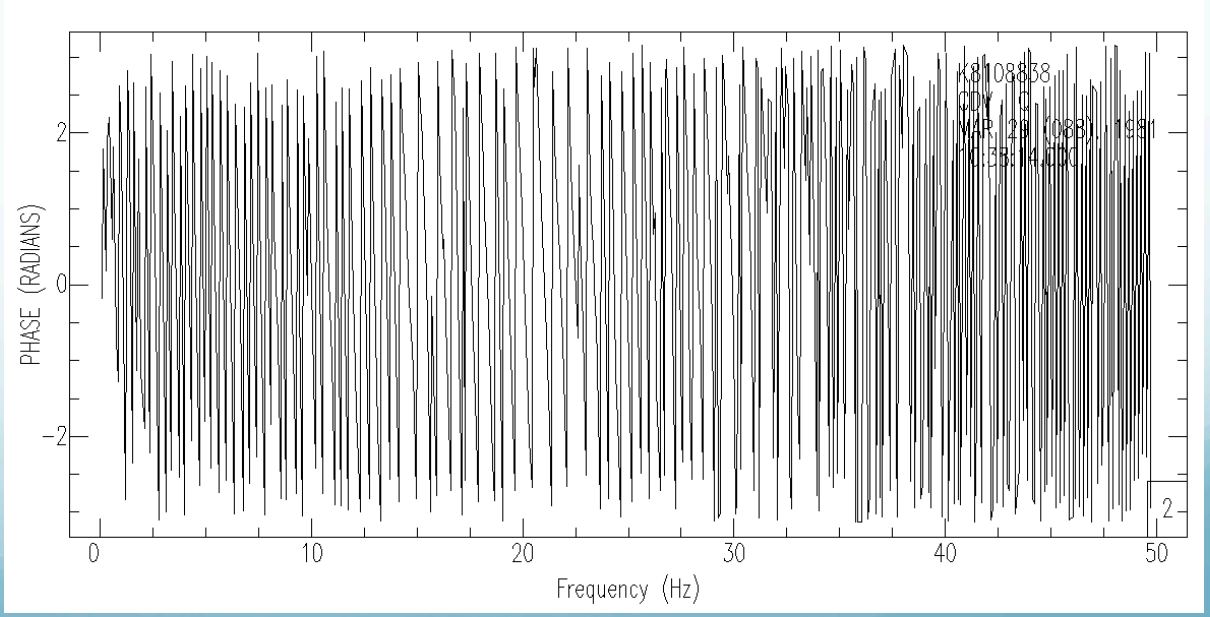
directly in the frequency domain.

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

Plots amplitude



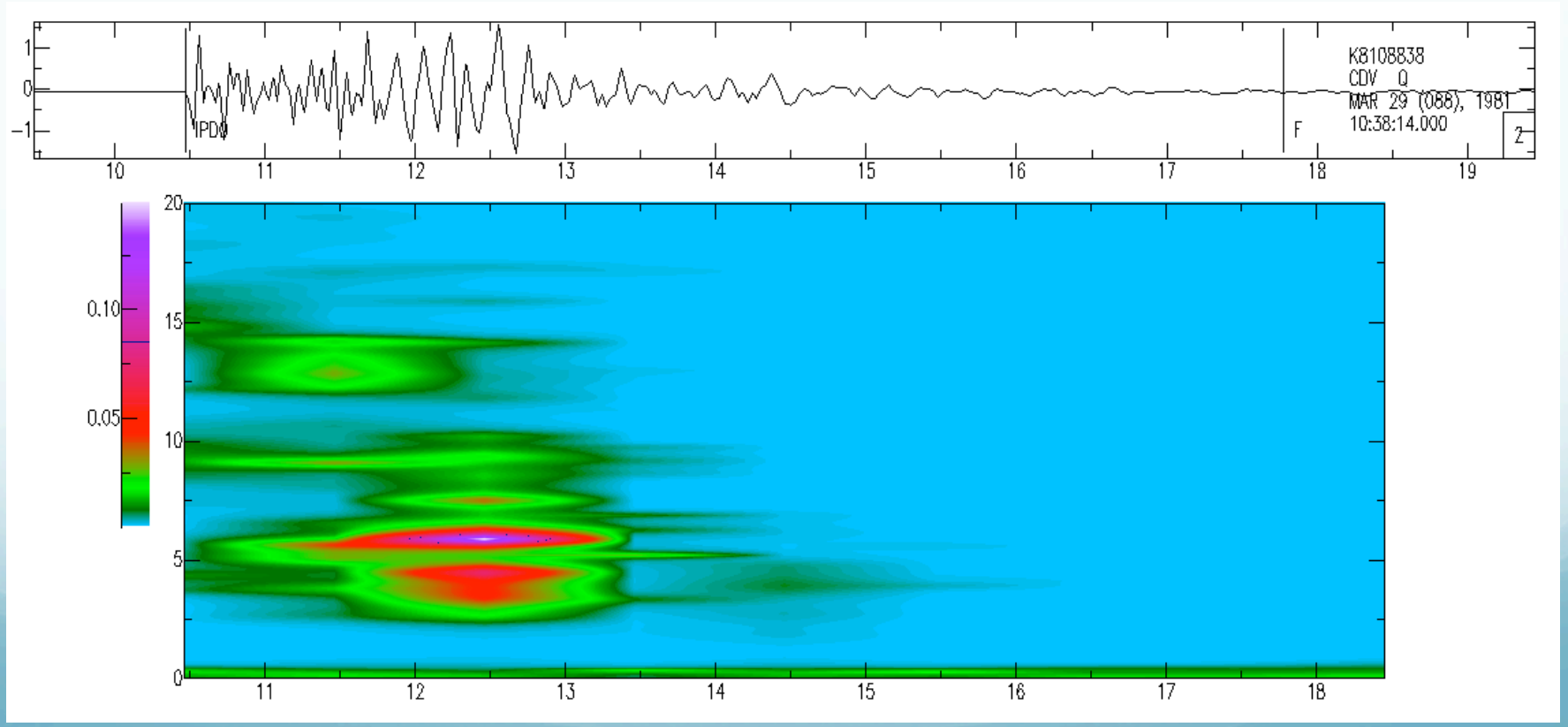
Then the phase after a <CR>



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: …
```