EPS207 Computer Laboratory 0.1 – Some More Interesting Aspects of SAC

Introduction

The objective of this exercise is to introduce several new and very useful SAC processing commands. We will investigate time domain and frequency domain integration and differentiation, making amplitude spectra, and particle motion plots. These tools are very useful in seismic phase identification and characterization, and are essential in the modeling of seismic data with synthesized ground motions. In the following exercises that call for the use of the acceleration data for the January 17, 2000 San Jose event (Lab 0) be sure to apply the 'cut 50 68' command to window the time series.

Time Domain verses Spectral Domain Integration

In SAC time domain integration and differentiation are accomplished using the int and diff functions, respectively. These are first order time domain approximations as defined below:

Differentiation: $\quad \dot{u}_i = \dfrac{u_{i+1} - u_i}{dt}$

Integration: $\quad u_i + = \dot{u}_i$

Differentiation and integration is accomplished in the frequency domain by multiplying or dividing by $i\omega$, respectively, making use of the differential properties of the Fourier Transform (below). To perform frequency domain processing, the data is read in, the Fast Fourier Transform (fft) function is used, and the "mulomega" and "divomega" commands are used for differentiation and integration, respectively. The ifft command is then used for the inverse Fourier Transform back to the time domain.

$$\dot{u}(t) = \frac{\partial}{\partial t} \int_{-\infty}^{\infty} U(\omega)e^{i\omega t} d\omega = \int_{-\infty}^{\infty} \left[i\omega U(\omega) \right] e^{i\omega t} d\omega$$

Using the instrument deconvolved, transverse component data, apply both time domain and frequency domain integrations to generate velocity seismograms. Compare the results in both the time domain and frequency domain. In the time domain you will find the p2 command useful in preparing overlay plots of two or more time series. The 'line' and 'color' commands may be used to apply different line styles and/or colors to the different time series on a given plot.

To plot spectra read the time series into memory, remove the mean, fft and use the 'writesp amph'. New files with the .am and .ph extensions, indicating amplitude and phase spectra, will be written. Note that when a real valued time series is Fourier transformed the resulting spectra have real and imaginary components, e.g.

$$u(t) \xrightarrow{\quad FFT \quad} u(\omega) = u\_real(\omega) + i \cdot u\_imag(\omega).$$

The real and imaginary components may be saved by using 'writesp reim'. When the 'writesp amph' command is used the spectra are represented as $A(\omega)e^{i\Phi(\omega)}$, where

$$A(\omega) = \sqrt{u\_real^2(\omega) + u\_imag^2(\omega)} \quad \& \quad \Phi(\omega) = \tan^{-1}\left(\frac{u\_imag(\omega)}{u\_real(\omega)}\right).$$

Generate amplitude spectra files for the velocity seismograms using both the time domain and spectral domain methods. Read the *.am files back into memory. The amplitude spectra can be viewed in a linear-linear presentation (default) using the p1 or p2 commands. It is sometimes useful to prepare spectral plots in a log-log presentation, which is accomplished by using the loglog command before typing p1 or p2. Note that ranges of the x and y axes of spectral plots may be adjusted using the "xlim" and "ylim" commands.

Another very useful tool is spectral division (ratios), where the amplitude spectra of one time series is divided by the amplitude spectra of another time series. The division of two spectral amplitude functions emphasizes the differences between the spectra. Spectral ratios are computed by first reading the numerator (firstfile.am) spectra file and then using the "divf secondfile.am" command to divide the spectra point-by-point resulting in the ratio as a function of frequency.

The time domain integration method is less accurate than the frequency domain approach at higher frequencies, but is more convenient to use. Quantify the differences of the two estimated velocity seismograms for the San Jose event using the spectral ratio.

SAC Filters

SAC has a variety of filters that may be used. We will focus our attention on the Butterworth Filter (BWF) to keep things manageable. With the BWF the options are for high pass (hp), low pass (hp) and band pass (bp). The command line of the filter expects arguments for the corner frequency, the number of poles and the number of passes. Examples of the low pass and band pass filter options are below

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lp co     1.0 n 4 p 2
bp co 0.1 1.0 n 4 p 2
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Both of these filters have 4 poles (higher the number the more severe the filter), and 2 passes (acausal response). The lp filter suppresses Fourier components at frequencies above 1 Hz. And the bp filter suppresses Fourier components at frequencies above 1 Hz and below 0.1 Hz. The causality of the filter is very important to take into account when analyzing seismic data. We will usually use a 2-pass filter, which has an acausal response with zero phase distortion. The acausal, zero phase distortion filter makes the comparison of several spectral pass bands of the same data easier. A causal filter (1-pass) is necessary when precise first arrivals are

being measured. To illustrate the different phase response of the filters we begin by generating an impulse function using SAC.

SAC>fg impulse dt 0.01 npts 4096
SAC>write impulse

The convolution of any function with an impulse function returns the function. Therefore the impulse function may be used to examine the characteristics of the causal and acausal BWF. Read the impulse function you created into memory and apply the band pass filter above and write to a new file. Reread the impulse and apply the same band pass filter, but with 'p 1' instead of p 2'. Read the impulse function and the two filter responses into memory and compare the results in both the time domain and in the amplitude spectra domain. The filters are clearly quite different, and there are modeling situations where each filter is more appropriate than the other.

Compare the differences in vertical component acceleration seismograms using both the causal and acausal filters. Note that since the 2-pass filter involves two passes of the data through the filter it is possible to obtain a result that is similar to a single pass filter with a lower pole order. In your comparision try 'bp co 0.1 1.0 n 1 p 2' for the acausal response, and 'bp co 0.1 1.0 n 4 p 1' for the causal response. Examine the seismograms for the effects of causality and phase-delay.

Using several different filter passbands to compare the waveforms is a useful technique for identifying phases, and is essential in developing earth structure models that reproduce the broadband character of seismograms.

Macros of SAC commands can be a very useful way to construct scripts for processing that may be repeated many times. Appendix A shows a SAC macro file. An electronic copy of this file will be emailed to you so you don't have to type it in. This macro contains commands that apply filters for several passbands and prepares a plot that compares all of the 3-component waveforms. Save the macro to a file (filename.macro), and execute the macro using the following command,

SAC>macro filename.macro

Note that the macro expects to read acceleration data with the mhcacc.[t,r,z] file naming convention. Take time to study the macro commands as you will need to write SAC macros in future exercises.

Particle Motion Analysis

Particle motion analysis is another useful tool. It can be used to verify that the rotation from the geographical reference frame to an earthquake source reference frame (the radial direction points away from the source, and the transverse direction is perpendicular in the clockwise sense to the radial direction) is done correctly. It can also help to illustrate complications in

the wavefield due to 3D earth structure, and can be useful in identifing P, SV, SH and Rayleigh waves. To plot the particle motion use the "ppm" command. Note that when using "ppm" you should have two time series in memory that must be orthogonal. The two horizontal components may be used to determine the polarization azimuth of the waves, and the vertical component and radial component may be used to determine the incidence angle of P and SV waves. You will find it useful to isolate phase arrivals of interest, which can be done using the "xlim" command to limit the time range of the plot. I.e. if there is an interesting phase between 50 and 55 seconds then "xlim 50 55" will cause ppm to plot the particle motions for only that range of time.

Using the three-component data, with the instrument response removed and integrated to ground velocity identify the SV, SH and Rayleigh waves using their respective particle motions (note that you will need to use different band pass filters to emphasize the body waves and the Rayleigh waves). I recommend comparing the data in the 0.1-5.0, 0.1-2.0 and 0.1-0.8 Hz passbands.

*Bring plots of the filtered three-component data, the particle motion plots, and the identified phases for next week's discussion, and think about how the observed phases agree with what is expected based on the first motion focal mechanism provided below. You may want to review focal mechanisms and radiation patterns in section 8.6 of Lay and Wallace.
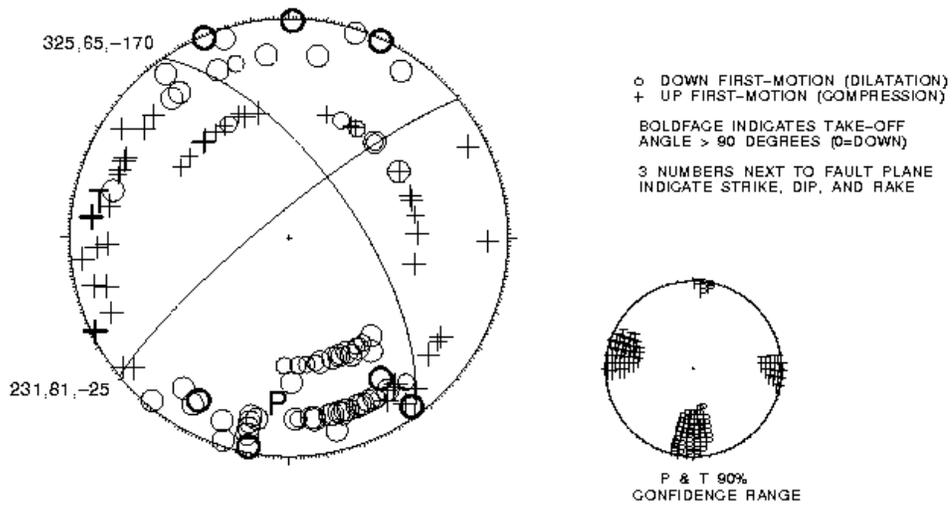
Figure 1. First motion focal mechanism for the January 17, 2000 San Jose earthquake. Plusses denote compressional first motions, and open circles denote dilatational first motions. The strike, dip and rake for each nodal plane is shown.