Retrieving Focal Mechanism of Earthquakes Using the CAP Method

Hongfeng Yang

April 11, 2013

1 Introduction

Waveforms recorded at a seismic station, $W(t)$, compose of three components:

$$W(t) = S(t) * G(t) * I(t), \tag{1}$$

where $S(t)$ represents the source, $G(t)$ stands for the Green's functions, and $I(t)$ is the instrument response. Therefore, retrieving source parameters of one earthquake $S(t)$ requires deconvolving instrument response $I(t)$ and Green's functions $G(t)$ from the actual data $W(t)$.

We generally remove instrument responses after obtaining the waveform data. Therefore, we have the data in displacement or in velocity, $u(t) = S(t) * G(t)$. The corresponding synthetic displacement $s(t)$ for a double-couple source can be expressed as

$$s(t) = M_0 \sum A_i(\phi - \theta, \delta, \lambda) G_i(t), \tag{2}$$

where G_i are the Green's functions, A_i are the radiation coefficients, and ϕ is the station azimuth, M_0 is scalar moment, θ, δ, and λ are strike, dip, and rake, respectively. Then we perform a grid search in all possible solutions of strike, dip, and rake to obtain the best fit by finding the minimal residual between the data and synthetics. This procedure consists of the following three steps, (1) computing Green's functions, (2) preparing data seismograms, and (3) deriving focal mechanism solutions. This tutorial will mostly cover step (3).

Here we compute focal mechanism solutions using the "Cut and Paste" method (CAP) [*Zhu and Helmberger*, 1996]. This method decomposes seismograms and uses amplitude information in different time windows (e.g., *Pnl*/surface wave) to increase the stability and resolution of focal mechanism solution. Please refer to [*Zhu and Helmberger*, 1996] for details of the CAP method.

The earthquake example used in this tutorial is the 2008 Illinois M_w 5.2 earthquake. It is a left-lateral strike-slip event based on focal mechanism solutions and aftershock locations [*Yang et al.*, 2009].

2 Procedure

2.1 Computing Green's functions

The Green's functions are computed using a Haskell propagator matrix (fk) method [*Zhu and Rivera*, 2002]. An appropriate 1-D velocity model is needed to compute Green's functions. In this tutorial, we use a 1-D velocity model for central US.

The Green's functions are named as xxx.grn.[0-8] where xxx is the distance. All Green's functions from one source depth are placed in a single directory named as model_depth. They are in SAC format with two time marks set: t1 for the first P arrival and t2 for the first S arrival.

All Green's functions have been computed using a velocity model of cus and are put in the directory:
/home/hyang/teaching/CAPtut/Glib/cus.

2.2 Preparing seismogram

In this tutorial I use the 2008/04/18 earthquake as an example and have already processed waveform data as required by the CAP. All the processed data are located at
/home/hyang/teaching/CAPtut/20080418093700.

The waveform data can be requested from IRIS and processed by your own. One needs to process the data as the following.

1. General processing

   Waveforms must be in SAC format with header information including event latitude and longitude, station latitude and longitude. Reference time shall be set at origin time. Epicentral distance and azimuth should also be set.

   I filtered the waveforms from 0.5 to 2 Hz. Generally you need to apply a filter from 5-10 seconds to a few Hz, depending on the magnitude of the event. The smaller the event is, the higher the frequency band can be applied.

2. Remove instrument responses

   Three-component seismograms need to be in velocity with units of cm/s or displacement in cm in order to obtain meaningful magnitudes.

3. Cut and rotate

   Waveforms at each station need to be cut into same length, and named as r, t, z convention. The two horizontal components shall be rotated.

4. Arrival header information

   You need to pick first P arrival time at each station and save it to A in the sac header.

2.3 CAP

The source codes of the CAP package are from Dr. Lupei Zhu at Saint Louis University. The main code is written in C and the compilation requires a number of dependencies and environmental settings. Pre-compiled executable, cap, is located in /home/hyang/bin on the computers in the geophysics lab.

The input file for the original executable, cap, is rather complicated. Dr. Zhu generously provides a user-friendly script, cap.pl, to use the CAP with ease. In this tutorial, we will only use cap.pl. To use the above command and scripts, add /home/hyang/bin and /home/hyang/Src/cap into your directory.

1. weight.dat

   Before we run cap.pl, we need to prepare the weight.dat file under the event directory. This file is in the following format:
   station_name dist w1 w2 w3 w4 w5 tp ts.

It contains station information and weights for different time windows during the moment tensor inversion. The dist specifies the names of Green's functions (in format of dist.grn.?) to be used. w1 to w5 are the weights for 5 segments of waveforms: PnlZ, PnlR, Z, R, T. tp is first P arrival time if it's set to a positive value. ts is the initial time shift for the surface waves, positive meaning that the data is delayed. If w2 is set to -1, it indicates that the station is at teleseimic distances and only the P (PnlZ) and SH (T) are used. In this case, ts is the S arrival time when it is positive.

To turn off certain components, e.g. surface waves, then set the corresponding weighting parameters (w1-w5) to be 0.

2. Options in cap.pl

   There are many options for running cap.pl. Please refer to cap.pl for details.

3. Output

   The inversion results are saved in a file named model_depth.out, where model represents the velocity model and depth stands for the focal depth at which a grid search of strike, dip, and rake is performed. The first line of model_depth.out is in the following format:
   Event 20080418093700 Model cus_15 FM 115 90 -2 Mw 5.19 rms 1.341e-02 110 ERR 1 3 4.
   This means that the best-fit fault plane solution is strike 115, dip 90, and rake -2 degrees, with the axial lengths of the 1-σ error ellipsoid of 1, 3, and 4 degrees. The rest of the output file shows rms, cross-correlation coef., and time shift of individual waveforms starting with "station epicentral_distance/constant_shift".

   cap.pl will also generate a plot of waveforms at each stations (Figure 1).

4. Find best-fit focal depth

   Usually the grid search needs to be performed for a number of focal depths, such as 5, 10, 15, 20, and 25 km. At each depth, cap will generate an output file. There is a script to extract the best fit focal depth by taking all output files together. See /home/hyang/teaching/CAPtut/getdepth.sh

   The results are shown in Figure 2.

References

Yang, H., L. Zhu, and R. Chu, Fault-plane determination of the 18 April 2008 Mt. Carmel, Illinois, earthquake by detecting and relocating aftershocks, *Bull. Seismol. Soc. Am.*, *99(6)*, 3413–3420, doi:10.1785/0120090038, 2009.

Zhu, L., and D. V. Helmberger, Advancement in source estimation techniques using broadband regional seismograms, *Bull. Seismol. Soc. Am.*, *86*, 1634–1641, 1996.

Zhu, L., and L. A. Rivera, A note on the dynamic and static displacements from a point source in multi-layered media, *Geophys. J. Int.*, *148*, 619–627, 2002.
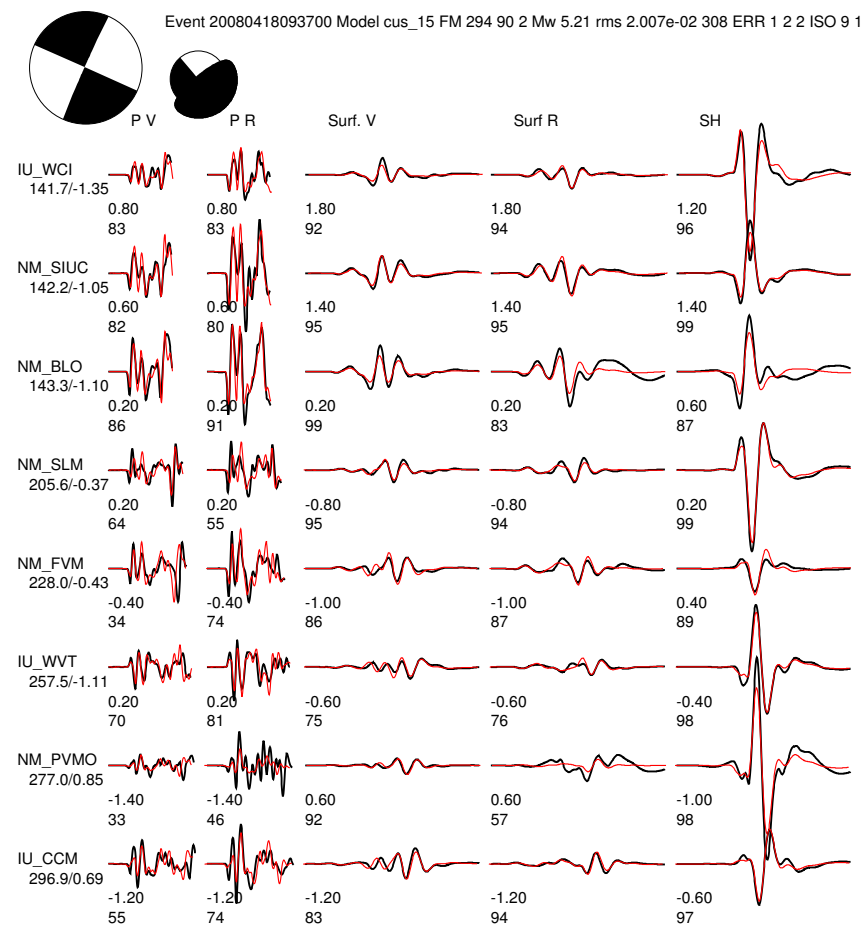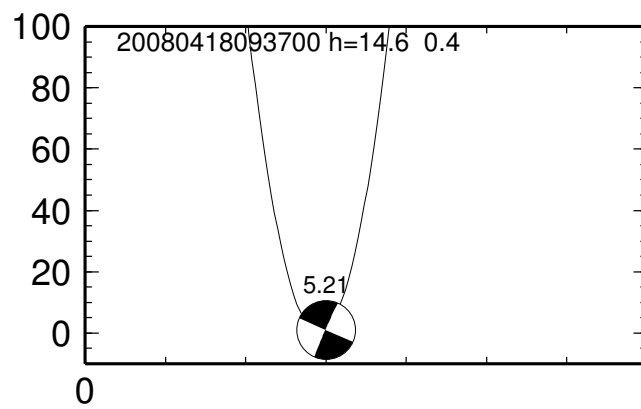
Figure 1: An example plot of CAP solutions.

Figure 2: An example plot of best fit depth.