Moment Tensor Inversion Toolkit (MTINV) Documentation, Manual and Tutorial

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1. License Agreement, Liability Wavier

2. Introduction

2.1 What is the MTINV toolkit?

The moment tensor inversion methodology originated from Gilbert (1970). Since then, there have been numerous studies extending the method into the time-domain, for solving higher order source terms and more recently the use of three-dimensional Earth models. For a general review please see Jost and Herrman (1989). The trick in this methodology is to use long-period regional distance seismic waves. The source process can be reduced to a simple delta function in space and time. The wave propagation is also simplified because filtering regional seismograms to long-periods (or low frequencies), result in waves that have only propagated in a few wave length cycles that can be easily predicted using relatively simple one-dimensional layered Earth models. Canceling out all of these complex effects leaves the robust extraction of the radiation pattern. We actually solve for a more generalized moment tensor with a simple constraints added that the source has no isotropic component although this constraint can be lifted for estimating the moment tensor of mining collapses, volcanic or explosion sources. Versions 2.0 3.0 and later contain the corrections (based on Herrmann and Hutchensen (1993), Herrmann and Ammon (2002)-*Computer Programs in Seismology manual on Source Inversion*, and Minson and Dreger (2008)) needed to compute full moment tensors (6-degree of freedom) that include isotropic components.

The MTINV toolkit is a collection of computer code applications written to invert for the moment tensor of an earthquake given the three components of ground motion recorded at regional seismic stations (e.g., Ichinose et al., 2003). The computer codes are organized to generate moment tensor solutions for a range of source depths and origin times because of the trade-off between these two quantities. Selection criteria can be developed or a built-in default fitness functions can be used for near-real time notification purposes but typically requires human review below some magnitude threshold. Version 3.0.3 also includes signal to noise ratios are computed and stored to be used as guide to define stations for use in the inversion. The codes are also modularized for allowing flexibility for customization and upgrades. An online man pages are available and they are in HTML format.

Gilbrt, F. (1970). Excitation of the normal modes of the earth by earthquake sources, Geophys. J. R. Astr. Soc. 77, 883-914.

Jost, M. L. and R. B. Herrmann (1989). A student's guide to and review of moment tensors, Seismological Research Letters, 86(2), 37-57.

Ichinose, Gene A., John G. Anderson, Ken D. Smith, and Yuehua Zeng (2003). Source Parameters of Eastern California and Western Nevada Earthquakes from Regional Moment Tensor Inversion, Bull. . Seismol. Soc. of America, 93, 61 - 84.

Herrmann, R. B. and C. J. Ammon (2002). Computer Programs in Seismology Mannual: Source Inversion. Version 3.30

Herrmann, R. B. & Hutchensen, K., 12 March, 1993. Quantification of m_{Lg} for small explosions, *Report PL-TR-93-2070*, 90 pp., Phillips Laboratory, Hanscom Air Force Base, Mass.

Minon, S. and D. S. Dreger (2008). Stable inversion for complete moment tensors, Geophysical Journal International, 174(2) 585-592. doi: 10.1111/j.1365-246X.2008.03797.x

2.2 Overview

The directory structure for MTINV toolkit is based on Unix and is free form. Place the source code anywhere and compile (e.g., /Users/MyHomeDirectory/. The C-shell or extended C-shell environmental `PATH` for the executable directory "~/mtinv/bin" should be set. Also set the `MANPATH` environmental path variable. In the input files the "~/mtinv/data" directory path (station and velocity model database) should be included. This allows the download of data and analysis with use of this toolkit in any directory location. Typically, directories are made with the name of the seismic event or project and a unique identifier (e.g., origin date and time). This way many events for some local area can be grouped in one directory. Within this directory, subdirectories "child directories" are made for the seismogram data (in SAC format) and instrument response in the form of simple text files in SAC pole zero format (see tutorial examples). Shell scripts can be made to run the toolkit and should be run in the parent directory and all paths should be relative to this directory or in absolute path form. The output will be in both the current parent directory (text files and postscript/PDF) and a new child directory named "./MyEventName_OriginTime/plotmech" is created with text output and an automatically generated GMT shell script that plots the variation of moment tensor as a function of origin time and source depth with the size of the mechanism scaled by the variance reduction modulated by the % double couple. In the case you are using mtinv for full moment tensor, the mechanism is scaled only by the variance reduction.

The following program's functions or subroutines are modularized and split to provide optimal flexibility. For the best scheme, there are two major shell scripts, which can run these programs. The first runs mkgrnlib that generates the Green's function libraries. The second shell-script combines the functions of glib2inv, sacdata2inv, and finally mtinv in a loop (See Figure 1).

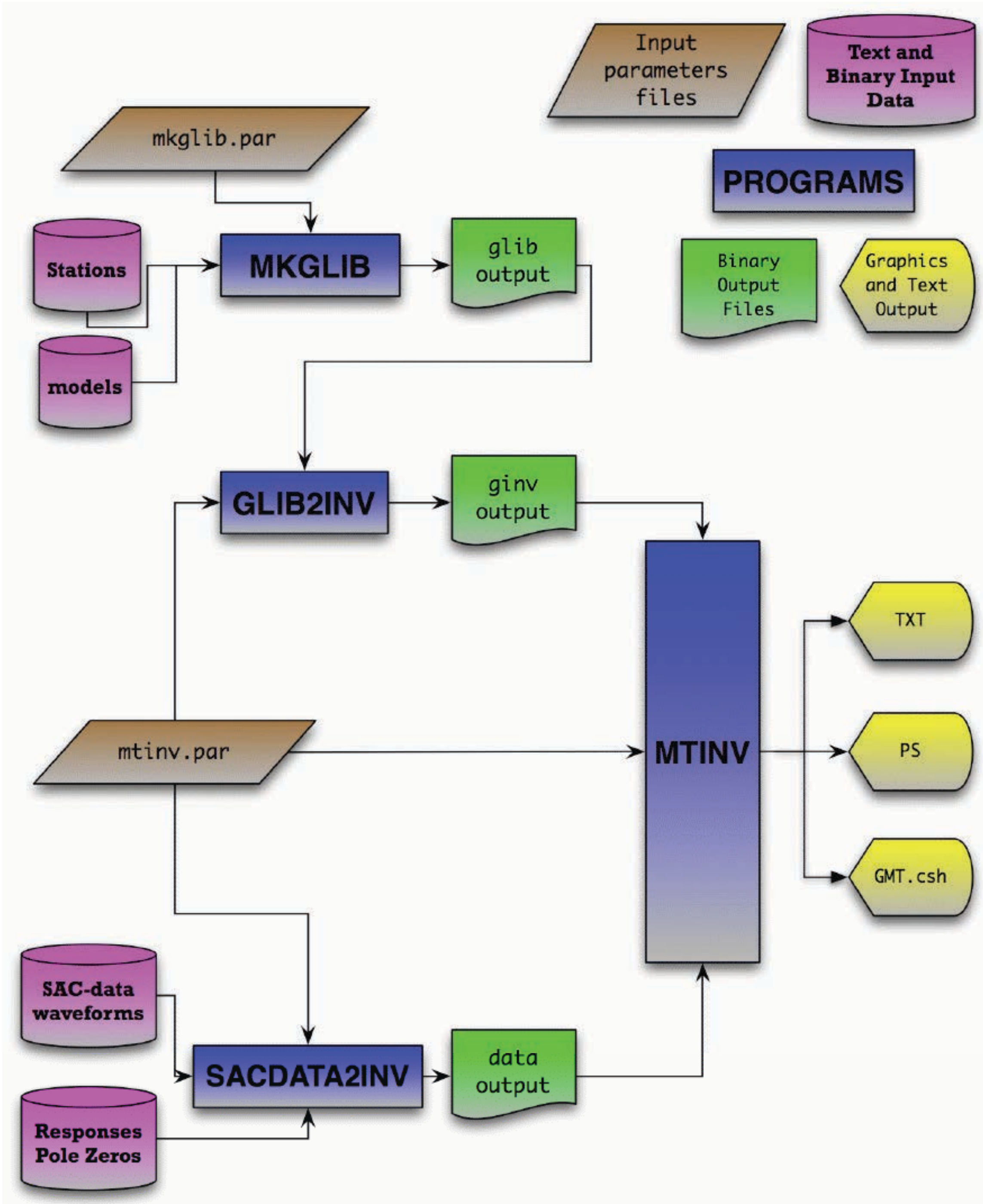


Figure 1. Flowchart of the MTINV Toolkit apps, input data files, input parameter files and output binary data files, text files, runnable C-shell scripts and postscript output. User starts with creating a parameter file for mkgrnlib. This program computes Green functions (glib output). This par file can point to text-formatted files with station locations and velocity models. The user then creates a mtinv.par file that is read by three apps (glib2inv, sacdata2inv

and mtinv). This par file contains simple event information followed by stations used in the moment tensor inversion. glib2inv reads the binary output from mkgrnlib, filters the Greens functions and makes binary output. sacdata2inv reads the SAC files (typically extracted from SEED files) and SAC pole-zero response files and outputs a binary data file. mtinv then reads the par file and binary output from sacdata2inv and glib2inv to performs a moment tensor inversion. The output are text files, runnable C-shell scripts with GMT plotting commands and results in PostScript plots.

Mkgrnlib generates the Greens function libraries as a function of depth. They are stored in station specific binary files in the form of the ten fundamental faulting orientations (RSS is radial component strike-slip, RDS is radial dip-and-strike-slip, RDD is radial component dip slip, REP is the radial component explosive component, ZSS is vertical strike-slip, ZDS, ZDD, ZEP, TSS-transverse component strike-slip, TDS). The program inputs include the station and source locations, directory path pointer to the modeldb files and station database files. The number of points and sampling rate need to be set to so that the Green's function length in time is as long or longer than the expected slowest traveling waves. Typically for full waveform, the slowest waves travel around 1 km/s therefore a station 300 km away would need at least 300 seconds. For a NPTS of 1024 time points, a sampling rate of at least 0.3 samples/sec is needed. One could also over sample at 0.15 samples/sec and 2048 points and later use decimate to higher sampling rates. This is accomplished later in the program glib2inv that will filter and interpolate/decimate the synthetics to match that of the data. Version 2 of the code also includes a reduction velocity so that the first time sample of the Green's function can be delayed from the origin time to before the first P-wave arrival that avoids wasted computation time particularly for the larger distance range. The reduction velocity is also handy for the separate inversion of Pnl and surface waves. Glib2inv reads an input file for the moment tensor inversion (stations used including band-pass corner frequencies, number of samples and sampling rate) and the output Green's function library created by mkgrnlib and generates a processed and filter library for the moment tensor inversion. All input files are in text form and keyed to the 1-8 character station code and the 1- 4 character network ID (fully qualified by the FDSN or any dummy code).

Sacdata2inv reads an input file for the moment tensor inversion (same as that used for glib2inv) and generates a processed and filtered version of the data in the form of a binary input file from SAC files extracted from SEED volume via RDSEED or elsewhere. The program requires the directory path locations for the SAC formatted data files and SAC pole-zero response files. Given a station and network character pair, the program will automatically figure out the appropriate files and load the data and do the instrument correction. Please follow the RDSEED SAC file and PZ file naming convention. A simple tool to rename the sac files is provided in version 2. SAC file also require some basic header information including kstnm, kcmpnm, knetwk, cmpaz, cmpinc, and khole.

Mtinv reads output from sacdata2inv and glib2inv, performs the inversion for each source depth and generates output. The input file (glib2inv.par), the same parameter input read by sacdata2inv and glib2inv, can be modified to remove certain stations completely or just turn stations off in the inversion yet still have a prediction made using the current solution. The forward calculation is still an option in mtinv. Just add any pure double couple solution in the EV line of the parameters file. Changing any parameters, for example, changing the filter bands requires re-running both glib2inv and sacdata2inv. The Green's functions do not need to be recalculated in makeglib, only the two programs (sacdata2inv and glib2inv) are rerun to apply any changes. The origin time shift can be introduced in mtinv version 2 without having to rerun glin2inv and sacdata2inv. Version 2 also has the correct calculation for the deviatoric and full moment tensor including the isotropic component. Additionally a distance normalization option has been added to mtinv and also a 1-degree of freedom (isotropic only) inversion has been added in version 2.

For estimating origin time and source depth a loop in the shell script provides (at best) one second increments in origin time without recalculation or reprocessing of the Green's functions. Only the data are shifted in time within mtinv without reprocessing the data windows therefore time shifts should be kept to within a few seconds because over-shifting may cause edge effects from windowing and Fourier-domain filtering.

2.3 Input file formats

Station database: The station database is a simple text file in free form column format. The first column is the 3-4 letter stations code, followed by the 1-2 letter network code, station latitude, longitude, elevations. The following are included in the file but not needed, a string including the available components (e.g., "BHZ, BHN, BHE"), description of the station location in quotes, and the start and end dates. This file is automatically generated by RDSEED (see man rdseed and unpack.csh). A file with most global stations is included in this toolkit package.

Model database: The format of the velocity mode database is also in simple free-form column format. The first column is the layer thickness, followed by the P-wave velocity in km/sec, the P-wave Q, S-wave velocity, S-wave Q, and density in grams/(cubic centimeters). Comments begin with the '#' character in the first column.

SAC binary files. The SAC file format has stayed the same over the last 25 years. The first 632 bytes are the header values, a collection of floating, integer numbers and strings. This is followed by a series of data values in 4 byte floating type words. See the file sac.h in the include directory for the format. Programs that convert SAC binary files to text files are included in the misc directory.

2.4 Output file formats

1. Binary i/o files have a suffix which end in *.data, *.glib, *.ginv (see include/mt.h and source codes for specifications).
2. SAC binary format (SEE ABOVE).
3. Postscript/PDF graphics. Files are named plot_T***XXX.X***_sec_Z***YYY.Y***km_.p01.ps where ***XXX.X*** is the origin time in seconds relative to the nearest minute, and ***YYY.Y*** is the source depth in km. These files show the predicted and observed waveform ground displacement fits in units of microns ($1x10^{-6}$ meters), the full, major and minor double couple solution and some information about the solution.
4. Text files:
   4.1. Email_T***XXX.X***_sec_Z***YYY.Y***km_.txt files list the comments, input values and resulting moment tensors in ASCII text format. The values ***XXX.X*** is the origin time in seconds relative to the nearest minute, and ***YYY.Y*** is the source depth in km. The files are ready for email or linking/posting in a html web page. The plain text files include the input parameters, the moment tensor solution including the tensor, principle axes and strike,

dip and rake, a graphical text form of the major double couple focal mechanism and information about the station and frequency bands.

4.2. Free form text files in column form. Lists the earthquake longitude, latitude, best depth for that origin time, origin date, origin time, moment magnitude, scalar seismic moment in Dyne-cm, percent double couple, percent variance reduction, fitness 1, fitness function 2, raw amplitude misfit, the six moment tensor elements and the exponent of the seismic moment, strike, dip, rake for nodal plane 1, strike, dip, rake for nodal plane 2, T, P, and N-axis plunge and azimuth, number of stations used, and stations codes.

4.3. Free form text files for input into GMT script plotmech.csh. The GMT script is automatically generated by mtinv, just run and view the postscript or PDF output plot showing the variation of moment tensor as a function of source depth and origin time.

2.6 Future Enhancements

Future versions will include a full centriod location as well as centriod depth. Currently we assume that the given earthquake location is correct.

3. REQUIREMENTS

3.1 Software Requirements

- C and Fortran77 compilers or compatible compilers. The code is compiled as 32bit executables. We are working on a 64bit version.
    - GCC version > 3.4.6
    - G77 version > 3.4.6
    - GNU make version > 3.8
- C-shell or Extended C-shell
- Generic Mapping Tools (GMT) version > 3.4
    - psmeca
- RDSEED version >= 4.6
- Any Postscript to PDF converted and PS/PDF viewer
    - Ghostscript and ghostview (any)
    - Evince (Linux FC > 4)
    - Acrobat reader (any)
    - XV (unix)
    - Xpdf (Linux)
    - Gvv (Linux FC)
    - Preview (mac os x)

3.2 Hardware and Operating System Requirements

- Mac OS X (Tiger, Leopard and later)
    - Intel dual and quad core processors
    - IBM PowerPC
- Linux (e.g., Fedora Core, Open solaries, SUSE)
    - Intel Pentium i686
    - AMD Opteron (x86_64)
- Sun4/Solaris/Oracle

3.3 Optional Software

- Seismic Analysis Code (SAC) – any version (SAC2000 preferred) but not necessary
- Oracle sqlplus or mysql database

4. INSTALLATION

- Step one: Download mtinv.version.tar.gz from http://crack.seismo.unr.edu/htdocs/students/Ichinose/
    - for example, download to your home directory
        - cd /Users/MyHomeDirectory/
    - http (crack.seismo.unr.edu/htdocs/students/Ichinose)
    - get mtinv.version.tar.gz (where version is the current number)
- Step two: Uncompress using gzip or uncompress and untar
    - gzip –d mtinv.version.tar.gz
    - tar xvf mtinv.version.tar
- Step three: compile
    - cd /Users/MyHomeDirectory/mtinv.version
    - make
- Step four: Add environmental variables to your ~/.tcshrc or ~/.cshrc shell resource files
    - set PATH = ($PATH /Users/MyHomeDirectory/mtinv.version/bin)
    - set MANPATH = ($MANPATH /Users/MyHomeDirectory/mtinv.version/man)
- Step 4 run examples
    - cd /Users/MyHomeDirectory/
    - gzip –d mtinv_examples.tar.gz
    - tar xvf mtinv_examples.tar
    - cd /Users/MyHomeDirectory/mtinv_examples

5. TUTORIAL EXAMPLE 1-2007/03/09 Bridgeport, California earthquake

1. > cd /Users/MyHomeDirectory/mtinv_examples
2. > cd 20070309_Bridgeport

3. > unpack.csh 20070309_bridgeport.seed
    a. unpack.csh will extract the SAC data files, SAC_PZs pole-zero files, and rdseed.station from the SEED volume
    b. unpack.csh will also make a directory ./Resp ./Data

```
Terminal
(ichinose@Genes-iMac /Users/ichinose/mtinv_examples/20070309_Bridgeport)-> ls -lR
.:
total 660
-rw-r--r--    1 ichinose staff      675840 Mar  8 22:10 20070309_Bridgeport.seed
drwxr-xr-x    2 ichinose staff         510 Mar  8 22:15 Data/
drwxr-xr-x    2 ichinose staff         476 Mar  8 22:15 Resp/
drwxr-xr-x    2 ichinose staff         204 Mar  8 22:00 dev/

./Data:
total 2004
-rw-r--r--    1 ichinose staff      212156 Mar  8 22:15 2007.068.03.16.33.0000.US.WVOR..BHE.M.SAC
-rw-r--r--    1 ichinose staff      212156 Mar  8 22:15 2007.068.03.16.33.0000.US.WVOR..BHN.M.SAC
-rw-r--r--    1 ichinose staff      212156 Mar  8 22:15 2007.068.03.16.33.0000.US.WVOR..BHZ.M.SAC
-rw-r--r--    1 ichinose staff       47124 Mar  8 22:15 2007.068.03.16.33.0069.US.ELK..BHN.M.SAC
-rw-r--r--    1 ichinose staff       46316 Mar  8 22:15 2007.068.03.16.33.0069.US.ELK..BHZ.M.SAC
-rw-r--r--    1 ichinose staff       43412 Mar  8 22:15 2007.068.03.16.33.0070.US.ELK..BHE.M.SAC
-rw-r--r--    1 ichinose staff      207672 Mar  8 22:15 2007.068.03.16.33.0106.BK.ORV..BHE.M.SAC
-rw-r--r--    1 ichinose staff      207672 Mar  8 22:15 2007.068.03.16.33.0106.BK.ORV..BHN.M.SAC
-rw-r--r--    1 ichinose staff      207672 Mar  8 22:15 2007.068.03.16.33.0106.BK.ORV..BHZ.M.SAC
-rw-r--r--    1 ichinose staff      209432 Mar  8 22:15 2007.068.03.16.33.0110.US.TPNV..BHE.M.SAC
-rw-r--r--    1 ichinose staff      209432 Mar  8 22:15 2007.068.03.16.33.0110.US.TPNV..BHN.M.SAC
-rw-r--r--    1 ichinose staff      209432 Mar  8 22:15 2007.068.03.16.33.0110.US.TPNV..BHZ.M.SAC
-rw-r--r--    1 ichinose staff         452 Mar  8 22:15 rdseed.stations

./Resp:
total 48
-rw-r--r--    1 ichinose staff        1065 Mar  8 22:15 SAC_PZs_BK_ORV_BHE__2004.167.00.00.00.0000_2010.070.20.60.60.99999
-rw-r--r--    1 ichinose staff        1065 Mar  8 22:15 SAC_PZs_BK_ORV_BHN__2004.167.00.00.00.0000_2010.070.20.60.60.99999
-rw-r--r--    1 ichinose staff        1065 Mar  8 22:15 SAC_PZs_BK_ORV_BHZ__2004.167.00.00.00.0000_2010.070.20.60.60.99999
-rw-r--r--    1 ichinose staff        1175 Mar  8 22:15 SAC_PZs_US_ELK_BHE__1996.146.00.00.00.0000_2008.352.24.60.60.99999
-rw-r--r--    1 ichinose staff        1175 Mar  8 22:15 SAC_PZs_US_ELK_BHN__1996.146.00.00.00.0000_2008.352.24.60.60.99999
-rw-r--r--    1 ichinose staff        1175 Mar  8 22:15 SAC_PZs_US_ELK_BHZ__1996.146.00.00.00.0000_2008.352.24.60.60.99999
-rw-r--r--    1 ichinose staff        1104 Mar  8 22:15 SAC_PZs_US_TPNV_BHE__2006.297.15.20.00.0000_2009.302.24.60.60.99999
-rw-r--r--    1 ichinose staff        1104 Mar  8 22:15 SAC_PZs_US_TPNV_BHN__2006.297.15.20.00.0000_2009.302.24.60.60.99999
-rw-r--r--    1 ichinose staff        1104 Mar  8 22:15 SAC_PZs_US_TPNV_BHZ__2006.297.15.20.00.0000_2009.302.24.60.60.99999
-rw-r--r--    1 ichinose staff        1105 Mar  8 22:15 SAC_PZs_US_WVOR_BHE__2006.031.17.59.58.0000_2011.122.23.26.60.99999
-rw-r--r--    1 ichinose staff        1105 Mar  8 22:15 SAC_PZs_US_WVOR_BHN__2006.031.17.59.58.0000_2011.122.23.26.60.99999
-rw-r--r--    1 ichinose staff        1105 Mar  8 22:15 SAC_PZs_US_WVOR_BHZ__2006.031.17.59.58.0000_2011.122.23.26.60.99999

./dev:
total 8
-rwxr-xr-x    1 ichinose staff         265 Mar  8 21:57 clean.csh*
-rwxr-xr-x    1 ichinose staff        1290 Mar  8 21:49 makeglib.csh*
(ichinose@Genes-iMac /Users/ichinose/mtinv_examples/20070309_Bridgeport)->
```

- > cd dev

- In this case makeglib.csh does not need to be edited. In the case where the user needs to clone and modify the file for another event,

    - Edit the file makeglib.csh with your favorite text editor (e.g., "> vi makeglib.csh").
    - The script generates a parameter file. In this case the name is wus.par. Make sure stadb= and modeldb= paths are set correctly.
    - Enter the model name, starting depth, depth increment, and ending depth, event latitude, longitude, sampling rate of the Green's functions (later can be decimated), number of time samples, max frequencies, reduction velocity.
    - The script then executes mkgrnlib and uses the parameter file to generate the Green's function libraries for a specific station code and network.
    - In version 3.0 the application multithread_mkgrnlib is provided to speed up the computation on multicore machines.

 - Create a mkgrnlib.par file that contains station code, net code, Green's function parameter file and dt (the sampling rate in seconds/sample).
 - In the command line set the parameter executable_pathname to your location of executable mkgrnlib (full pathname is necessary).
 - Version 2 includes the tool makepar. This tool will scan the directory for Green's function libraries and geneates a generic run.csh script for the inversion. This application will not over write run.csh if one exists already.

```
#!/bin/csh

##  2007/03/09 03:17:32 38.428 -119.366 10km, Mw 4.7, ML 5.0
##   22 km (14 miles) NNW (328 degrees) of Bridgeport, CA

cat >! wus.par << EOF
velmod=wus
zrange=2,2,22
evla=38.428
evlo=-119.366
dt=0.1
nt=2048
fmax=0.5
t0=0.
redv=18.
damp=1.
kmax=20000
eps=0.0005
smin=0.0005
modeldb=/Users/ichinose/Work/mtinv.v3.0.3/data/modeldb
stadb=../Data/rdseed.stations
noverbose
nodump
EOF

### run one at a time
###
# mkgrnlib par=wus.par stnm=WVOR  net=US
# mkgrnlib par=wus.par stnm=TPNV  net=US
# mkgrnlib par=wus.par stnm=ELK   net=US
# mkgrnlib par=wus.par stnm=ORV   net=BK

### multithread run
###
cat >! mkgrnlib.par << EOF
# sta net par dt
WVOR US wus.par 0.2
TPNV US wus.par 0.2
ELK  US wus.par 0.2
ORV  BK wus.par 0.1
EOF

multithread_mkgrnlib \
   parfile=mkgrnlib.par \
   executable_pathname=/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib >! multithread_mkgrnlib.out

makepar com="Bridgeport, CA" \
        date="2007/03/09,03:17:33" \
        DataDir=../Data \
        RespDir=../Resp \
        lf=0.012 hf=0.05 *.glib
~
~
"makeglib.csh" 51L, 1043C written                                         51,3          All
```

- > makeglib.csh
  - execute makeglib.csh script
  - mkgrnlib or multithread_mkgrnlib output goes to the screen or redirected to a file

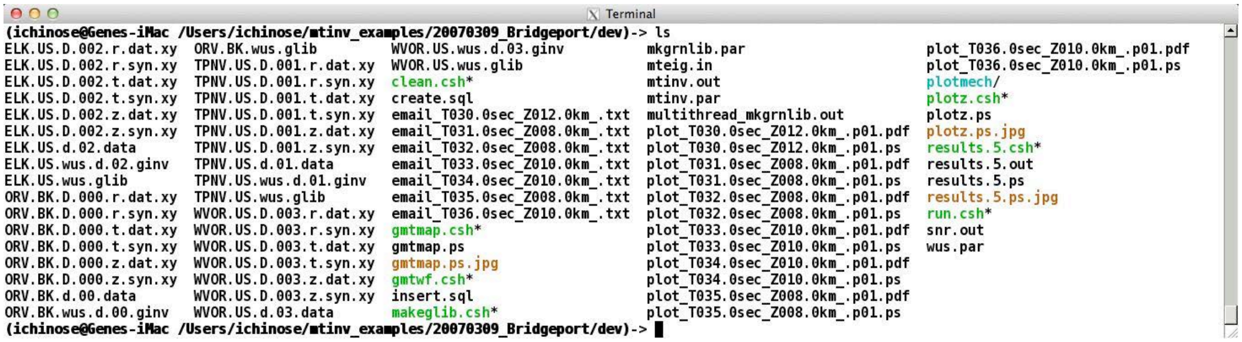
```
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: ELK.US.wus.glib evdp=  4.00 rdist=  437.13 az= 53 nt=2048 dt=0.200 fmax= 0.50 t0=24.2853 twin=409.6  p=0.1286 rb=  36.0 tt=  62.55 toa= 35.6
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: ELK.US.wus.glib evdp=  6.00 rdist=  437.13 az= 53 nt=2048 dt=0.200 fmax= 0.50 t0=24.2853 twin=409.6  p=0.1286 rb=  36.0 tt=  62.31 toa= 53.1
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: ELK.US.wus.glib evdp=  8.00 rdist=  437.13 az= 53 nt=2048 dt=0.200 fmax= 0.50 t0=24.2853 twin=409.6  p=0.1286 rb=  36.0 tt=  62.12 toa= 53.1
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: ELK.US.wus.glib evdp= 10.00 rdist=  437.13 az= 53 nt=2048 dt=0.200 fmax= 0.50 t0=24.2853 twin=409.6  p=0.1286 rb=  36.0 tt=  61.93 toa= 53.1
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: ELK.US.wus.glib evdp= 12.00 rdist=  437.13 az= 53 nt=2048 dt=0.200 fmax= 0.50 t0=24.2853 twin=409.6  p=0.1286 rb=  36.0 tt=  61.74 toa= 53.2
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: ELK.US.wus.glib evdp= 14.00 rdist=  437.13 az= 53 nt=2048 dt=0.200 fmax= 0.50 t0=24.2853 twin=409.6  p=0.1286 rb=  36.0 tt=  61.54 toa= 53.2
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: ELK.US.wus.glib evdp= 16.00 rdist=  437.13 az= 53 nt=2048 dt=0.200 fmax= 0.50 t0=24.2853 twin=409.6  p=0.1286 rb=  36.0 tt=  61.35 toa= 53.2
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: ELK.US.wus.glib evdp= 18.00 rdist=  437.13 az= 53 nt=2048 dt=0.200 fmax= 0.50 t0=24.2853 twin=409.6  p=0.1286 rb=  36.0 tt=  61.16 toa= 53.2
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: ELK.US.wus.glib evdp= 20.00 rdist=  437.13 az= 53 nt=2048 dt=0.200 fmax= 0.50 t0=24.2853 twin=409.6  p=0.1286 rb=  36.0 tt=  60.97 toa= 53.3
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: ELK.US.wus.glib evdp= 22.00 rdist=  437.13 az= 53 nt=2048 dt=0.200 fmax= 0.50 t0=24.2853 twin=409.6  p=0.1286 rb=  36.0 tt=  60.77 toa= 53.3
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: program finished. Bye-Bye!


/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: Version=3.0.3 Release Date=Thu Mar 6 19:29:27 EST 2014
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: stnm=WVOR net=US stla=42.4339 stlo=-118.637 stel=1344 evla=38.428 evlo=-119.366
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: distaz: r=449.343 az=7.65475 baz=188.128
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: dist=449.343 reduction velocity=18(km/sec) t0=24.9635 tstart=24.9635 tend=434.564 twin=409.6
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib:
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: number of layers=4 file=/Users/ichinose/Work/mtinv.v3.0.3/data/modeldb/wus.mod
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib:          Layer Thick  Ztop    Vp      Qa      Vs      Qb       Rho     Sigma
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib:                (km)   (km)  (km/s)          (km/s)             (g/cc)
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib:          000    4.00   0.00   4.52   500.00   2.61   250.00   2.39    0.25
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib:          001   28.00   4.00   6.21   500.00   3.59   250.00   2.76    0.25
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib:          002   20.00  32.00   7.73  1000.00   4.34   500.00   3.22    0.27
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib:          003  700.00  52.00   7.64  1000.00   4.29   500.00   3.19    0.27
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib:
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: WVOR.US.wus.glib evdp=  2.00 rdist=  449.34 az=  8 nt=2048 dt=0.200 fmax= 0.50 t0=24.9635 twin=409.6  p=0.1286 rb=  36.0 tt=  64.48 toa= 35.6
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: WVOR.US.wus.glib evdp=  4.00 rdist=  449.34 az=  8 nt=2048 dt=0.200 fmax= 0.50 t0=24.9635 twin=409.6  p=0.1286 rb=  36.0 tt=  64.12 toa= 35.6
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: WVOR.US.wus.glib evdp=  6.00 rdist=  449.34 az=  8 nt=2048 dt=0.200 fmax= 0.50 t0=24.9635 twin=409.6  p=0.1286 rb=  36.0 tt=  63.88 toa= 53.1
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: WVOR.US.wus.glib evdp=  8.00 rdist=  449.34 az=  8 nt=2048 dt=0.200 fmax= 0.50 t0=24.9635 twin=409.6  p=0.1286 rb=  36.0 tt=  63.69 toa= 53.1
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: WVOR.US.wus.glib evdp= 10.00 rdist=  449.34 az=  8 nt=2048 dt=0.200 fmax= 0.50 t0=24.9635 twin=409.6  p=0.1286 rb=  36.0 tt=  63.50 toa= 53.1
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: WVOR.US.wus.glib evdp= 12.00 rdist=  449.34 az=  8 nt=2048 dt=0.200 fmax= 0.50 t0=24.9635 twin=409.6  p=0.1286 rb=  36.0 tt=  63.31 toa= 53.2
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: WVOR.US.wus.glib evdp= 14.00 rdist=  449.34 az=  8 nt=2048 dt=0.200 fmax= 0.50 t0=24.9635 twin=409.6  p=0.1286 rb=  36.0 tt=  63.11 toa= 53.2
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: WVOR.US.wus.glib evdp= 16.00 rdist=  449.34 az=  8 nt=2048 dt=0.200 fmax= 0.50 t0=24.9635 twin=409.6  p=0.1286 rb=  36.0 tt=  62.92 toa= 53.2
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: WVOR.US.wus.glib evdp= 18.00 rdist=  449.34 az=  8 nt=2048 dt=0.200 fmax= 0.50 t0=24.9635 twin=409.6  p=0.1286 rb=  36.0 tt=  62.73 toa= 53.2
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: WVOR.US.wus.glib evdp= 20.00 rdist=  449.34 az=  8 nt=2048 dt=0.200 fmax= 0.50 t0=24.9635 twin=409.6  p=0.1286 rb=  36.0 tt=  62.54 toa= 53.3
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: WVOR.US.wus.glib evdp= 22.00 rdist=  449.34 az=  8 nt=2048 dt=0.200 fmax= 0.50 t0=24.9635 twin=409.6  p=0.1286 rb=  36.0 tt=  62.34 toa= 53.3
/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib: program finished. Bye-Bye!


multithread_mkgrnlib: STDERR: finished.
(ichinose@Genes-iMac /Users/ichinose/mtinv_examples/20070309_Bridgeport/dev)-> ls -l
total 8532
-rw-r--r--    1 ichinose staff     2172768 Mar  8 22:38 ELK.US.wus.glib
-rw-r--r--    1 ichinose staff     2172768 Mar  8 22:38 ORV.BK.wus.glib
-rw-r--r--    1 ichinose staff     2172768 Mar  8 22:38 TPNV.US.wus.glib
-rw-r--r--    1 ichinose staff     2172768 Mar  8 22:38 WVOR.US.wus.glib
-rwxr-xr-x    1 ichinose staff         265 Mar  8 21:57 clean.csh*
-rwxr-xr-x    1 ichinose staff        1042 Mar  8 22:42 makeglib.csh*
-rw-r--r--    1 ichinose staff         100 Mar  8 22:38 mkgrnlib.par
-rw-r--r--    1 ichinose staff       14191 Mar  8 22:37 multithread_mkgrnlib.out
-rwxr-xr-x    1 ichinose staff        2452 Mar  8 22:36 run.csh*
-rw-r--r--    1 ichinose staff         235 Mar  8 22:38 wus.par
(ichinose@Genes-iMac /Users/ichinose/mtinv_examples/20070309_Bridgeport/dev)->
```

- > makeglib.csh finishes
    - cat multithread_mkgrnlib.out, the redirected output from mkgrnlib and use ls –l to examine *.glib output files

- open, examine and modify the auto-generated run.csh script if needed.
    - Make or edit the shell script "run.csh" if necessary (e.g., "> vi run.csh").
    - The script is automatically set DEGFREE=5 for solving for a deviatoric moment tensor (major and minor double couple + CLVD) which is the recommended setting for all tectonic sources. The advance user can use the setting DEGFREE=1 that will only invert for pure isotropic sources or DEGFREE=6 for full moment tensor (isotropic + deviatoric).
    - The script will generate a parameter file for 3 toolkit applications: glib2inv, sacdata2inv, and mtinv. The par file can have any name. See the man pages for the format.
    - The first line tagged CM is a comment for the event that get printed as a title for output files. The second line tagged OT is the origin time. Be careful with the format, the date and time are one string separated by commas.
    - The EV tagged line is only needed if the user would like to do a forward calculation assuming a pure double couple source.
    - The following lines are the station parameters.
    - Check and modify the run.csh file so that the system dependent plotting and graphics routines are available.

```
#!/bin/csh

### uncomment the one needed
#set DEGFREE=1
set DEGFREE=5
#set DEGFREE=6

cat >! mtinv.par << EOF
#### REGION COMMENT ############################
CM Bridgeport, CA
#### Date and Origin Time #####################
OT 2007/03/09,03:17:33
#### Forward Calculations ######################
## stk  dip rak   Mw  evlo  evla  Z   ##########
EV   0    0   0   0.0 -119.366    38.428    15
#####################################################################################################
# sta net model  np pas lf  hf  nt  dt   tr  tt v/d  mulfac used(Y/N)  ts0  weight ###             #
ORV     BK      wus 3 2 0.012 0.050   512  0.20 0.0 0.0 d 1.0 y 0.0 +1.0 Surf/Pnl ### R=222.8 Az=305
TPNV    US      wus 3 2 0.012 0.050   512  0.28 0.0 0.0 d 1.0 y 0.0 +1.0 Surf/Pnl ### R=319.5 Az=120
ELK     US      wus 3 2 0.012 0.050   512  0.39 0.0 0.0 d 1.0 y 0.0 +1.0 Surf/Pnl ### R=437.1 Az=53
WVOR    US      wus 3 2 0.012 0.050   512  0.40 0.0 0.0 d 1.0 y 0.0 +1.0 Surf/Pnl ### R=449.3 Az=8
EOF


### CLEAN UP ###
rm -rf plotmech plot_T???.?sec_Z???.?km_.p??.ps email_T???.?sec_Z???.?km_.txt *.?.dat.xy *.?.syn.xy  plot_T
???.?sec_Z???.?km_.p??.ps.jpg mtinv.out results.?.* plot_T???.?sec_Z???.?km_.p??.pdf

### PROCESS GREENS FUNCTIONS ###
glib2inv par=mtinv.par noverbose

### PROCESS DATA ###
sacdata2inv par=mtinv.par path=../Data respdir=../Resp noverbose

### FORWARD CALCULATION (Set Parameters in EV line of mtinv.par) ###
# mtinv ts0=0 par=mtinv.par mtdegfree=${DEGFREE} fwd  ### FixISOZ=1.0

### SINGLE INVERSION ###
# mtinv ts0=0 par=mtinv.par mtdegfree=${DEGFREE}

### MULTIPLE INVERSIONS ###
#foreach ts0 ( -3 -2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5 3 )
foreach ts0 ( -3 -2 -1 0 1 2 3 )
  mtinv ts0=${ts0} par=mtinv.par mtdegfree=${DEGFREE} >> mtinv.out
end

### CHECK ORIGIN TIME SHIFT ###
csh results.${DEGFREE}.csh
xv results.${DEGFREE}.ps.jpg

### Use Ghostview to view PS files ###
#gs -dEPSCrop plot_T???.?sec_Z???.?km_.p??.ps
foreach ps ( plot_T???.?sec_Z???.?km_.p??.ps )
  ps2pdf $ps
#ps2jpg.csh $ps 90
end
                                                                                          18,28-37      Top
```

- > run.csh
- examine the output files



```
(ichinose@Genes-iMac /Users/ichinose/mtinv_examples/20070309_Bridgeport/dev)-> ls
ELK.US.D.002.r.dat.xy  ORV.BK.wus.glib        WVOR.US.wus.d.03.ginv            mkgrnlib.par                       plot_T036.0sec_Z010.0km_.p01.pdf
ELK.US.D.002.r.syn.xy  TPNV.US.D.001.r.dat.xy WVOR.US.wus.glib                 mteig.in                           plot_T036.0sec_Z010.0km_.p01.ps
ELK.US.D.002.t.dat.xy  TPNV.US.D.001.r.syn.xy clean.csh*                       mtinv.out                          plotmech/
ELK.US.D.002.t.syn.xy  TPNV.US.D.001.t.dat.xy create.sql                       mtinv.par                          plotz.csh*
ELK.US.D.002.z.dat.xy  TPNV.US.D.001.t.syn.xy email_T030.0sec_Z012.0km_.txt    multithread_mkgrnlib.out           plotz.ps
ELK.US.D.002.z.syn.xy  TPNV.US.D.001.z.dat.xy email_T031.0sec_Z008.0km_.txt    plot_T030.0sec_Z012.0km_.p01.pdf   plotz.ps.jpg
ELK.US.d.02.data       TPNV.US.D.001.z.syn.xy email_T032.0sec_Z008.0km_.txt    plot_T030.0sec_Z012.0km_.p01.ps    results.5.csh*
ELK.US.wus.d.02.ginv   TPNV.US.d.01.data      email_T033.0sec_Z010.0km_.txt    plot_T031.0sec_Z008.0km_.p01.pdf   results.5.out
ELK.US.wus.glib        TPNV.US.wus.d.01.ginv  email_T034.0sec_Z010.0km_.txt    plot_T031.0sec_Z008.0km_.p01.ps    results.5.ps
ORV.BK.D.000.r.dat.xy  TPNV.US.wus.glib       email_T035.0sec_Z008.0km_.txt    plot_T032.0sec_Z008.0km_.p01.pdf   results.5.ps.jpg
ORV.BK.D.000.r.syn.xy  WVOR.US.D.003.r.dat.xy email_T036.0sec_Z010.0km_.txt    plot_T032.0sec_Z008.0km_.p01.ps    run.csh*
ORV.BK.D.000.t.dat.xy  WVOR.US.D.003.r.syn.xy gmtmap.csh*                      plot_T033.0sec_Z010.0km_.p01.pdf   snr.out
ORV.BK.D.000.t.syn.xy  WVOR.US.D.003.t.dat.xy gmtmap.ps                        plot_T033.0sec_Z010.0km_.p01.ps    wus.par
ORV.BK.D.000.z.dat.xy  WVOR.US.D.003.t.syn.xy gmtmap.ps.jpg                    plot_T034.0sec_Z010.0km_.p01.pdf
ORV.BK.D.000.z.syn.xy  WVOR.US.D.003.z.dat.xy gmtwf.csh*                       plot_T034.0sec_Z010.0km_.p01.ps
ORV.BK.d.00.data       WVOR.US.D.003.z.syn.xy insert.sql                       plot_T035.0sec_Z008.0km_.p01.pdf
ORV.BK.wus.d.00.ginv   WVOR.US.d.03.data      makeglib.csh*                    plot_T035.0sec_Z008.0km_.p01.ps
(ichinose@Genes-iMac /Users/ichinose/mtinv_examples/20070309_Bridgeport/dev)->
```

- Use your favorite postscript or pdf viewer to view plotmech.ps or plotmech.pdf
    - You may need to edit the bottom of plotmech.csh if the defaults are not available.

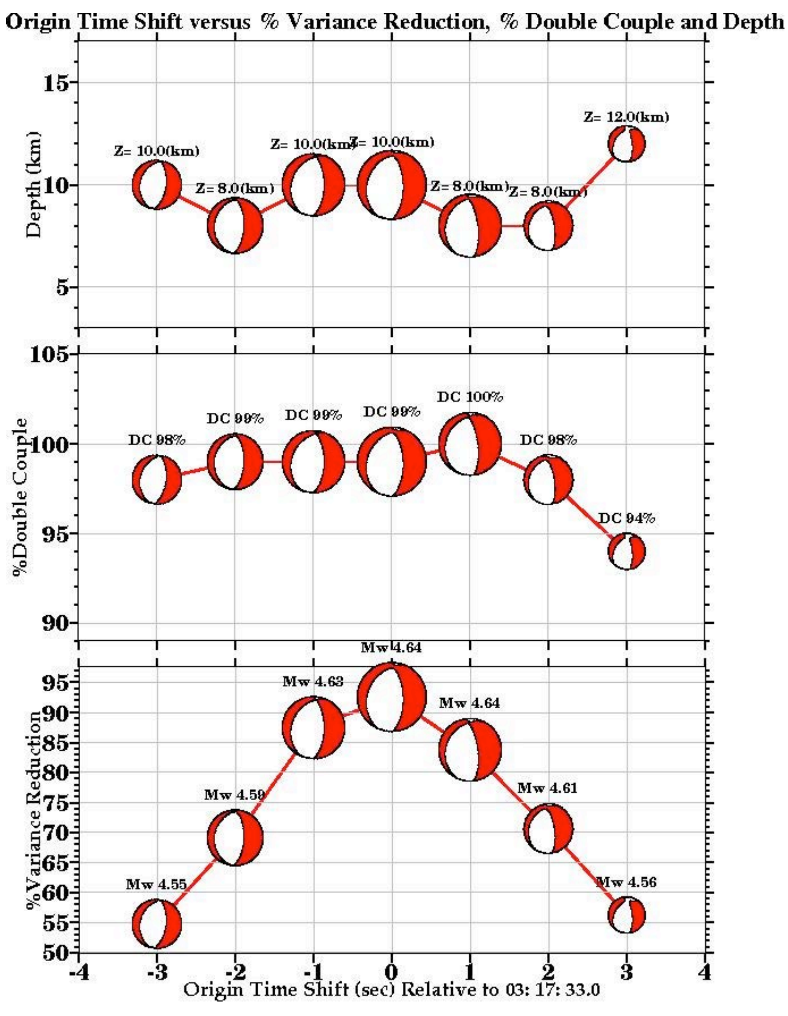


Figure 2. Results script is auto-generated, using output from multiple runs save in results.out file. The script uses GMT to generate a postscript plot that shows the best solution at each origin time shift.

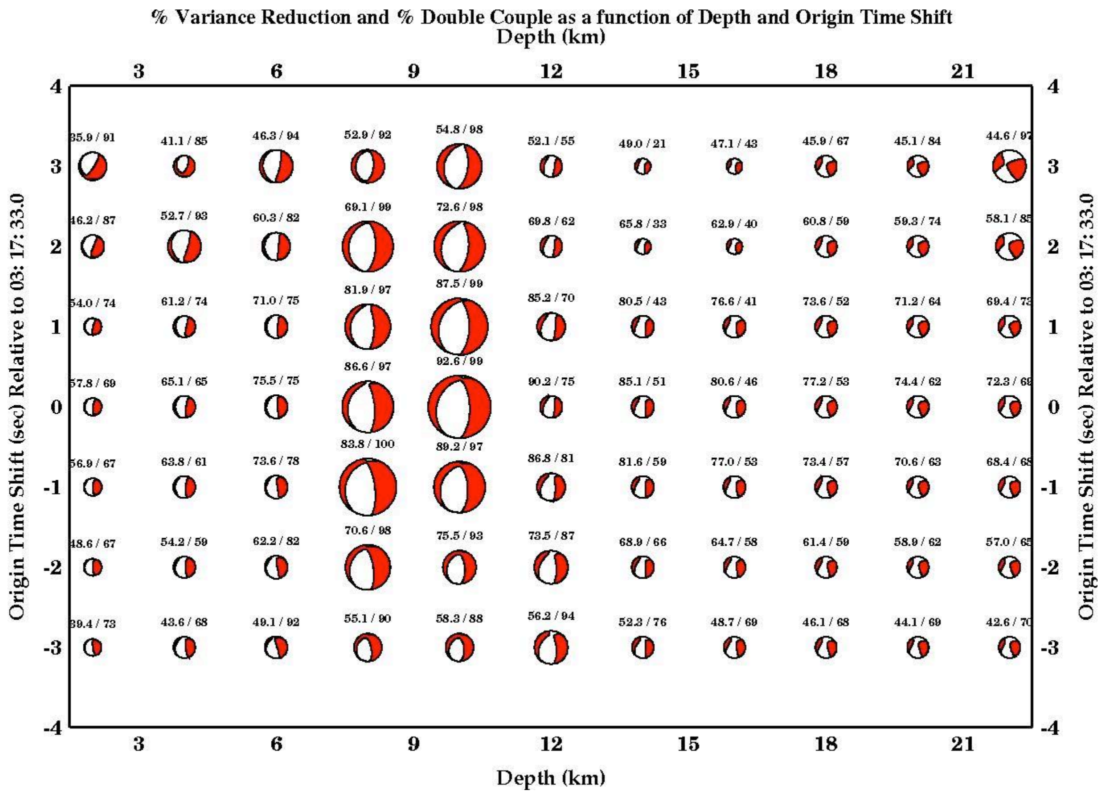


Figure 3. Find the largest mechanism that has the highest percent double couple and highest percent variance reduction, and read off the source depth (Z) on the x-axis and origin time (OT) on the y-axis. In this case the highest variance reduction (VRED) is 84.43% and highest double couple (DC) is 99% at (OT=03:17:31 Z=10 km). The OT shift in second is relative to the best guess time of the earthquake origin (03hr 17min and 32 sec) while negative shifts are subtracted and positive shifts are subtracted.

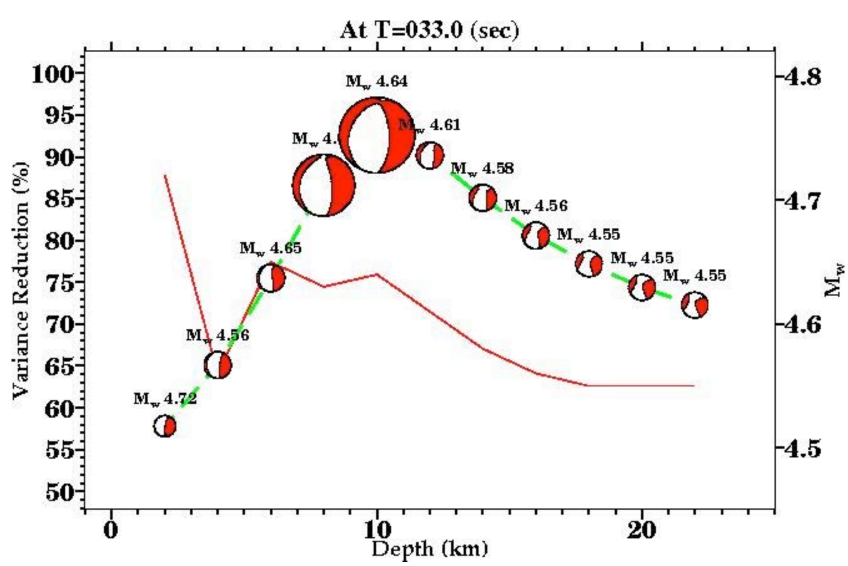


Figure 4. This plot shows the variance reduction as a function of depth with origin time shift of zero relative to origin time of 2007/03/09 03:17:33 GMT.

```
Terminal
Seismic Moment Tensor Solution

2007/03/09 (068) 03:17:33.00 38.4280 -119.3660 Bridgeport, CA
        Depth =  10.0 (km)
        Mw    =  4.64
        Mo    =  1.13x10^23 (dyne x cm)

        Percent Double Couple =  99 %
        Percent CLVD          =   1 %
        no ISO calculated
        Epsilon=-0.00
         Percent Variance Reduction =  92.57 %
         Total Fit                  =  50.14
        Major Double Couple
                            strike dip   rake
                Nodal Plane 1: 206  30  -65
                Nodal Plane 2: 358  63 -104

        DEVIATORIC MOMENT TENSOR

        Moment Tensor Elements: Spherical Coordinates
                Mrr= -0.89 Mtt= -0.01 Mff=  0.90
                Mrt=  0.15 Mrf= -0.64 Mtf=  0.20 EXP=23


        Moment Tensor Elements: Cartesian Coordinates
                -0.01 -0.20  0.15
                -0.20  0.90  0.64
                 0.15  0.64 -0.89

        Eigenvalues:
                T-axis eigenvalue=  1.13
                N-axis eigenvalue=  0.00
                P-axis eigenvalue= -1.13

        Eigenvalues and eigenvectors of the Major Double Couple:
                T-axis ev= 1.13 trend=98 plunge=17
                N-axis ev= 0.00 trend=4 plunge=12
                P-axis ev=-1.13 trend=240 plunge=69

        Maximum Azmuithal Gap=185 Distance to Nearest Station=222.8 (km)

        Number of Stations (D=Displacement/V=Velocity) Used=4 (defining only)

         ORV.BK.D TPNV.US.D ELK.US.D WVOR.US.D


              ##########-------
          #########################
        #############----############
      ############--------#############
     ##########-----------###############
    #########--------------###############
  -#########----------------###############
"email_T033.0sec_Z010.0km_.txt" 90L, 3280C                  1,1          Top
```

```
   #########--------------###############
  -#########----------------###############
  ########------------------###############
 #########-------------------###############
 ########--------------------###############
 #######---------------------################
 ######----------------------################
 ######----------------------###########   ##
 ######------   -------------########### T ##
 ######------ P -------------###########   #
 ######------   -------------###############
  ######---------------------##############
   #####--------------------###############
   ######-------------------##############
     ####------------------##############
      #####----------------############
        ####--------------###########
          ####-----------##########
              ---------#########



All Stations defining and nondefining:
Station.Net     Def     Distance        Azi     Bazi    lo-f    hi-f vmodel
                         (km)           (deg)   (deg)   (Hz)    (Hz)
ORV.BK (D)      Y          222.8        305     124     0.012   0.050 ORV.BK.wus.glib
TPNV.US (D)     Y          319.5        120     302     0.012   0.050 TPNV.US.wus.glib
ELK.US (D)      Y          437.1         53     235     0.012   0.050 ELK.US.wus.glib
WVOR.US (D)     Y          449.3          8     188     0.012   0.050 WVOR.US.wus.glib

 (V)-velocity (D)-Displacement

Author: ichinose
Date: 2014/03/09 03:50:28 UTC

Date: 2014/03/08 22:50:28 EST

mtinv Version 3.0.3 Thu Mar 6 19:29:27 EST 2014
~
~
~
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~
~
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~
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~
~
~
                                                                  53,5          Bot
```

Figure 4. Alternatively view the output files email.xxx.yyy.txt with a text editor to find the best fit mechanisms for each origin time interval and select the mechanism with the highest percent double couple and variance reduction.

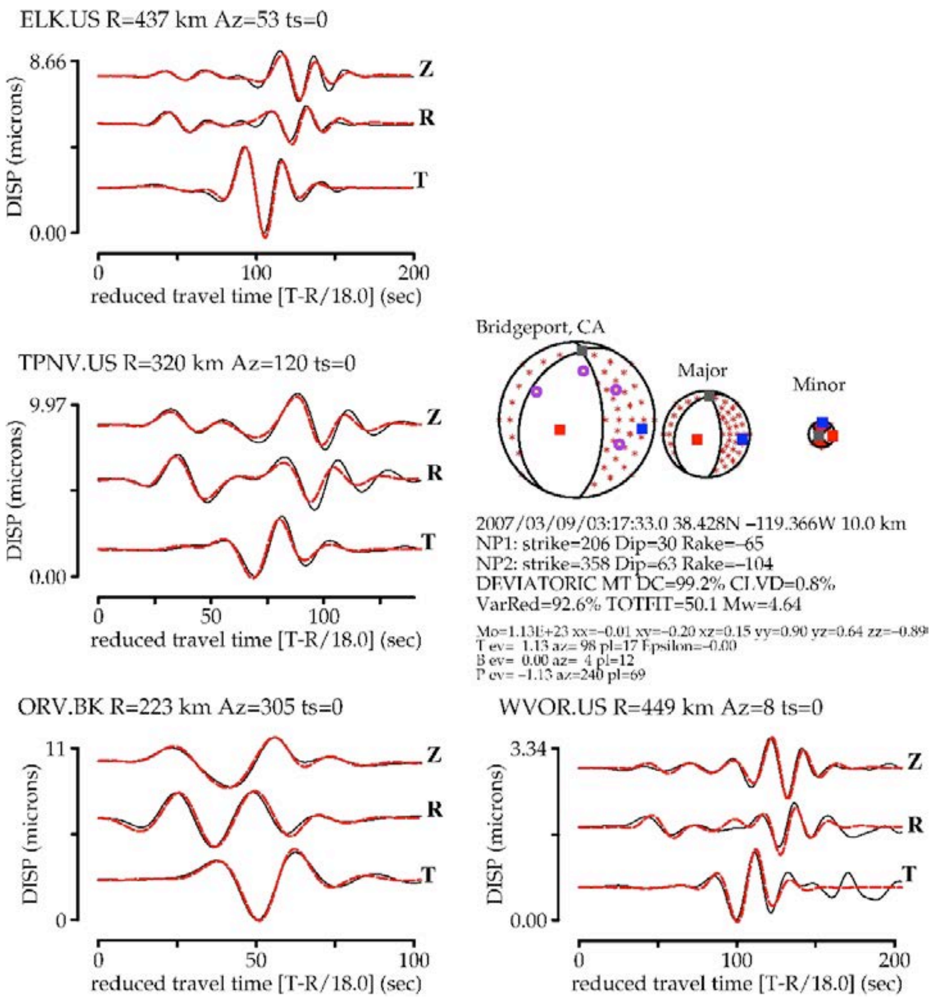

Figure 5. Predicted and observed waveform fits. Use your favorite postscript or pdf viewer to view the waveform fits for the best fit. The user can also use gs and cjpeg to convert to jpeg file or use the GMT application `ps2raster -P -A -Tj -E600 plot.ps`

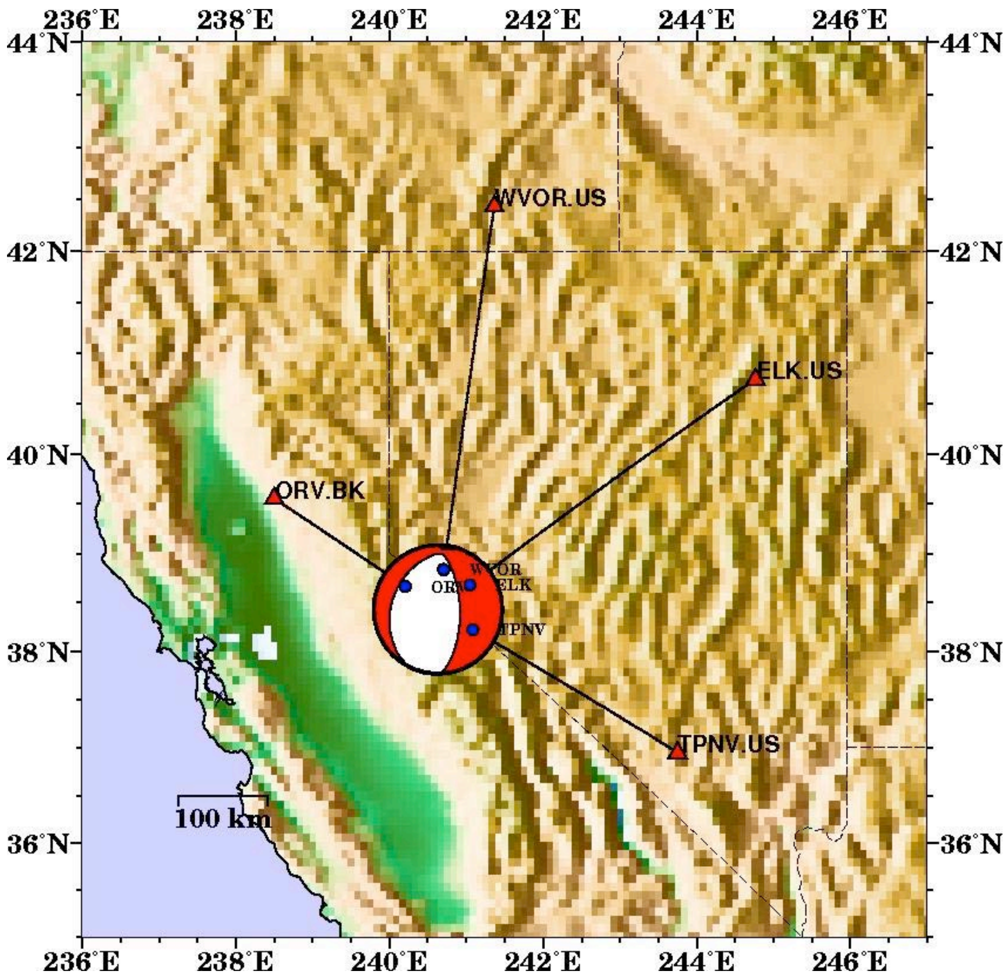

Figure 6. Postscript map produced by the automatically generated C-shell script gmtmap.csh by mtinv gmtmap flag option. To get topography add setenv to the top of the run.csh script.

```
#!/bin/csh

setenv MTINV_GMT_GRID_FILE  /usr/local/gmt/share/dbase/etopo5.grd
setenv MTINV_GMT_INT_FILE /usr/local/gmt/share/dbase/etopo5.int
setenv MTINV_GMT_CPT_FILE /usr/local/gmt/share/cpt/GMT_globe.cpt

### uncomment the one needed
#set DEGFREE=1
set DEGFREE=5
#set DEGFREE=6

cat >! mtinv.par << EOF
#### REGION COMMENT ############################
CM Bridgeport, CA
#### Date and Origin Time ######################
OT 2007/03/09,03:17:33
#### Forward Calculations ######################
## stk  dip rak   Mw  evlo  evla  Z   ##########
EV   0    0   0   0.0 -119.366   38.428    15
###################################################################################################
# sta net model  np pas lf  hf  nt  dt   tr  tt v/d  mulfac used(Y/N)  ts0  weight ###             #
ORV     BK      wus 3 2 0.012 0.050   512  0.20 0.0 0.0 d 1.0 y 0.0 +1.0 Surf/Pnl ### R=222.8 Az=305
TPNV    US      wus 3 2 0.012 0.050   512  0.28 0.0 0.0 d 1.0 y 0.0 +1.0 Surf/Pnl ### R=319.5 Az=120
"run.csh" 77L, 2649C                                                                7,1          Top
```

5. TUTORIAL EXAMPLE 2 – 1992/03/26 16:30 Junction NTS/NNSS Nuclear Explosion

Figure 7. Moment tensor solution for the 1992/03/26 16:30GMT NTS/NNSS explosion. The map was generated using the GMT C-shell script called gmtmap.csh that was automatically created by the program mtinv. The parameter file glib2inv.par used by mtinv only has 6 stations turned on shown in red triangles. The blue triangles are stations that are in the parameter file but turned off so that they are only predicted but not used in the inversion.

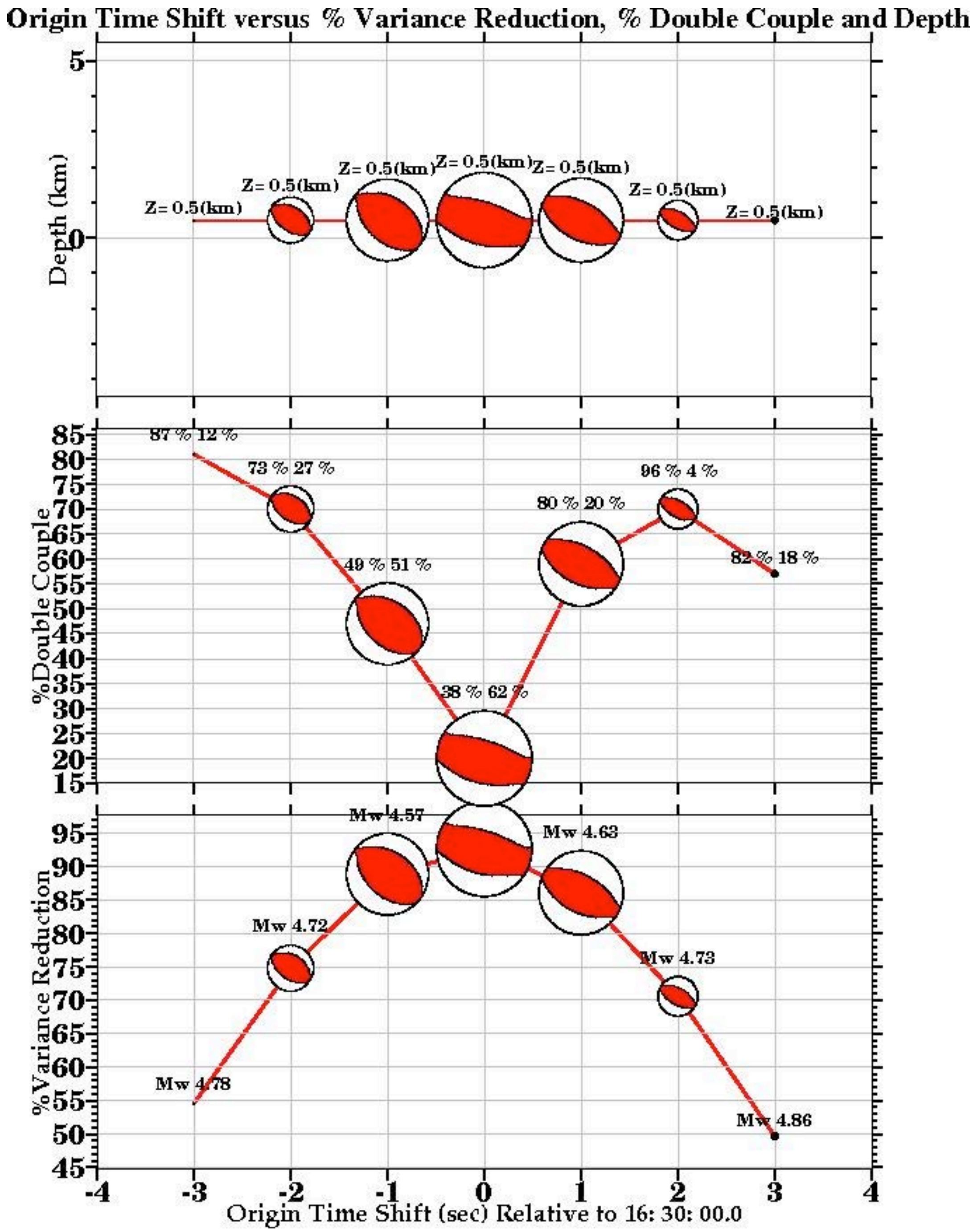

Figure 8. The sensitivity plot for origin time shift made by the script results.csh. The best solution is at 0 seconds origin time shift (16hr 30min 00.0sec). The depth is fixed at 0.5 km and the Percent Double Couple is 38% at this time shift. We know the explosion was set to a depth of burial of 500m. Instead of fixing the depth in the mtinv.par file, we instead only calculate one Greens function in the mkgrnlib par files.

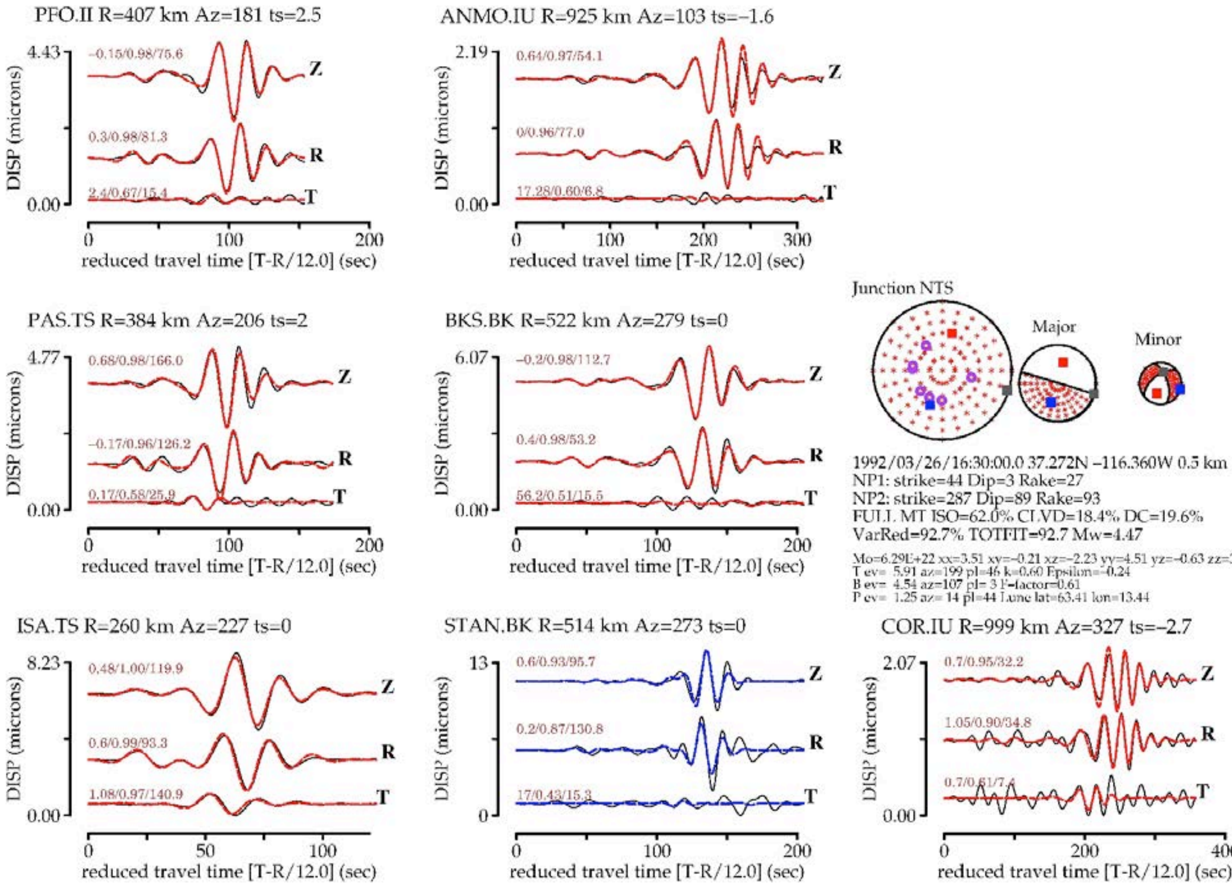

Figure 9. The 1992/03/26 Junction underground nuclear explosion test at the Nevada test site. This is an example of a moment tensor inversion using 6 degrees of freedom (Full Moment Tensor). Above are the waveform fits where red waveforms represents stations used in the solution and blue are predicted. The black waveforms are observed displacement data.

```
Seismic Moment Tensor Solution

1992/03/26 (086) 16:30:00.00 37.2720 -116.3600 Junction NTS
        Depth =   0.5 (km)
        Mw    =  4.47
        Mo    =  6.29x10^22 (dyne x cm)

        Percent Double Couple =  20 %
        Percent CLVD          =  18 %
        Percent Isotropic     =  62 %
        Lune latitude=63.409 longitude=13.444
        Epsilon=-0.24 k=0.60 F-factor=0.61
         Percent Variance Reduction =  92.67 %
         Total Fit                  =  92.67
        Major Double Couple
                            strike dip   rake
                Nodal Plane 1:  44   3   27
                Nodal Plane 2: 287  89   93

        FULL MOMENT TENSOR

        Moment Tensor Elements: Spherical Coordinates
                Mrr= -0.21 Mtt= -0.40 Mff=  0.61
                Mrt= -2.23 Mrf=  0.63 Mtf=  0.21 EXP=22


        Moment Tensor Elements: Cartesian Coordinates
                -0.40 -0.21 -2.23
                -0.21  0.61 -0.63
                -2.23 -0.63 -0.21

        Eigenvalues:
                T-axis eigenvalue=  5.91
                N-axis eigenvalue=  4.54
                P-axis eigenvalue=  1.25

        Eigenvalues and eigenvectors of the Major Double Couple:
                T-axis ev= 2.01 trend=199 plunge=46
                N-axis ev= 0.00 trend=107 plunge=3
                P-axis ev=-2.01 trend=14 plunge=44

        Maximum Azmuithal Gap=137 Distance to Nearest Station=260.1 (km)

        Number of Stations (D=Displacement/V=Velocity) Used=6 (defining only)

         ISA.TS.D PAS.TS.D PFO.II.D BKS.BK.D
         ANMO.IU.D COR.IU.D


              -----------------
          -------------------------
        ----------------   ----------
      ------------------ P ----------##
"email_T000.0sec_Z000.5km_.txt" 95L, 3565C                          1,1           Top
```

```
        ----------------   ----------
      ------------------ P ----------##
     -------------------   -----------###
    ------------------------------------##
  ---------------------------------------##
  ----------------------------------------#
 ####-------------------------------------##
 ###########-------------------------------#
 #################-------------------------##
 #######################-------------------##
 #############################-------------##
 ###################################-------##
 ########################################--#
 ###########################################
  #########################################
   #######################################
   ############   #######################-
     ########## T #######################
      #########   #####################-
        #############################-
          -########################
              #################-


All Stations defining and nondefining:
Station.Net      Def     Distance        Azi     Bazi     lo-f     hi-f vmodel
                         (km)            (deg)   (deg)    (Hz)     (Hz)
ISA.TS (D)       Y          260.1        227      46      0.020    0.060 ISA.TS.wus.glib
PAS.TS (D)       Y          383.6        206      25      0.020    0.060 PAS.TS.wus.glib
PFO.II (D)       Y          406.9        181       1      0.020    0.060 PFO.II.wus.glib
STAN.BK (D)      N          513.8        273      90      0.030    0.080 STAN.BK.wus.glib
BKS.BK (D)       Y          521.7        279      96      0.020    0.060 BKS.BK.wus.glib
ANMO.IU (D)      Y          925.2        103     289      0.020    0.050 ANMO.IU.wus.glib
COR.IU (D)       Y          999.2        327     142      0.020    0.050 COR.IU.wus.glib

 (V)-velocity (D)-Displacement

Author: ichinose
Date: 2014/03/09 04:44:57 UTC

Date: 2014/03/08 23:44:57 EST

mtinv Version 3.0.3 Thu Mar 6 19:29:27 EST 2014
~
~
~
~
~
~
~
~
~
                                                                         52,9          Bot
```

Figure 11. Email text file.

6. TUTORIAL EXAMPLE 3 – 1995/02/03 15:26:10 Solvay Trona Mine collapse, Wyoming

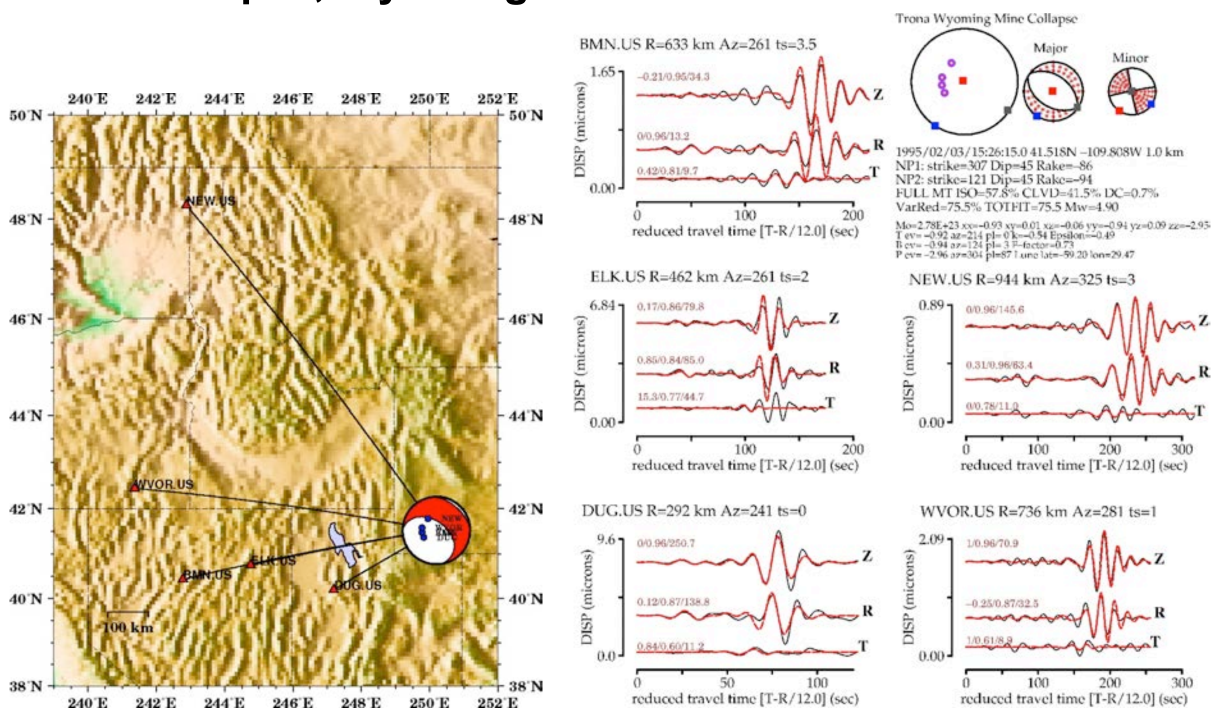

Figure 12. Moment tensor solution for the 1995/02/03 15:26:10 Solvay Trona Mine collapse, Wyoming.

```
Terminal
Seismic Moment Tensor Solution

1995/02/03 (034) 15:26:15.00 41.5183 -109.8083 Trona Wyoming Mine Collapse
        Depth =   1.0 (km)
        Mw    =  4.90
        Mo    =  2.78x10^23 (dyne x cm)

        Percent Double Couple =   1 %
        Percent CLVD          =  42 %
        Percent Isotropic     =  58 %
        Lune latitude=-59.204 longitude=29.472
        Epsilon=-0.49 k=-0.54 F-factor=0.73
         Percent Variance Reduction =  75.53 %
         Total Fit                  =  75.53
        Major Double Couple
                    strike dip   rake
                Nodal Plane 1: 307  45  -86
                Nodal Plane 2: 121  45  -94

        FULL MOMENT TENSOR

        Moment Tensor Elements: Spherical Coordinates
                Mrr= -1.35 Mtt=  0.68 Mff=  0.67
                Mrt= -0.06 Mrf= -0.09 Mtf= -0.01 EXP=23


        Moment Tensor Elements: Cartesian Coordinates
                 0.68  0.01 -0.06
                 0.01  0.67  0.09
                -0.06  0.09 -1.35

        Eigenvalues:
                T-axis eigenvalue= -0.92
                N-axis eigenvalue= -0.94
                P-axis eigenvalue= -2.96

        Eigenvalues and eigenvectors of the Major Double Couple:
                T-axis ev= 0.69 trend=214 plunge=0
                N-axis ev= 0.00 trend=124 plunge=3
                P-axis ev=-0.69 trend=304 plunge=87

        Maximum Azmuithal Gap=276 Distance to Nearest Station=292.2 (km)

        Number of Stations (D=Displacement/V=Velocity) Used=5 (defining only)

         DUG.US.D ELK.US.D BMN.US.D WVOR.US.D
         NEW.US.D


              ##################
          #########################
        #############################
      #################################
"email_T015.0sec_Z001.0km_.txt" 93L, 3437C                          1,1          Top
```

```
        #############################
      #################################
     #####---------######################
   ---------------------##################
  -#-----------------------################
  ###-------------------------#############
 ####---------------------------############
 ####-----------------------------##########
 #####------------   --------------##########
 ######----------- P ---------------#########
 #######----------   ----------------########
 ########-----------------------------#######
 ##########----------------------------#####
 ############--------------------------#####
  #############-------------------------###
   ###############----------------------###
   ###################---------------###-
     ###################################
      ##   ############################
         T ##########################
           ########################
              ##################
                      #

All Stations defining and nondefining:
Station.Net     Def     Distance        Azi     Bazi    lo-f    hi-f vmodel
                        (km)            (deg)   (deg)   (Hz)    (Hz)
DUG.US (D)      Y          292.2        241      59     0.030   0.080 DUG.US.wus.glib
ELK.US (D)      Y          462.4        261      78     0.020   0.080 ELK.US.wus.glib
BMN.US (D)      Y          633.3        261      77     0.030   0.060 BMN.US.wus.glib
WVOR.US (D)     Y          736.0        281      95     0.030   0.060 WVOR.US.wus.glib
NEW.US (D)      Y          944.0        325     140     0.020   0.050 NEW.US.wus.glib

 (V)-velocity (D)-Displacement

Author: ichinose
Date: 2014/03/09 05:20:15 UTC

Date: 2014/03/09 00:20:15 EST

mtinv Version 3.0.3 Thu Mar 6 19:29:27 EST 2014
~
~
~
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~
~
~
~
~
~
~
                                                                        52,9          Bot
```

Figure 13. Email text file.

7. INDEX OF MAN PAGES

- Glib2inv
- Grnlib2sac
- Mkgrnlib
- Mtinv
- Sacdata2inv
- Sacmerge
- Sacswapbytes
- Unpack.csh
- renamesac
- multithread_mkgrnlib
- makepar
- pea [no documentation yet]
- ellipse [no documentation yet]
- Hudson [no documentation yet]
- makehudson [no documentation yet]
- mtsim[no documentation yet]
- sac2xy [no documentation yet]

NAME

glib2inv

SYNOPSIS

glib2inv par= [no]verbose [no]dumpsac [no]dumpgrn [no]special

DESCRIPTION

Reads the Green's function library (as a function of depth) for a single source station pair and process the Green's functions (interpolate/decimate and bandpass filter) for moment tensor inversion.

REQUIRED PARAMETERS

par={string}
The file name of the parameter file. See format of this file below (PARAMETER FILE FORMAT).

OPTIONAL PARAMETERS

[no]verbose
Verbosy output for debugging is *verbose* and for no verbosy output is *noverbose* [optional, default verbose off].

[no]dumpgrn
Write out "Dump" the Green's functions as SAC formatted binary files [optional, default nodumpgrn].

[no]dumpsac
Write out "Dump" the Green's functions as SAC formatted binary files [optional, default nodumpsac]. The focal mechanism, depth, and moment is applied from the input parameter file EV line (see format below).

PARAMETER FILE FORMAT

A '#' in the first column signifies that the following is a non printing comment

CM A 'CM ' in columns 1-3 marks the beginning of a comment, typically the region, area, city and country name for reference purposes only.

OT A 'OT ' in columns 1-3 is followed by the earthquake origin time string in year/month/day,hour:minute:seconds format, (e.g., 2005/06/12,15:41:46.000). Origin time is required for setting the origin time in the synthetics and shifting the observed seismograms in time to improve the fit the synthetics and percent double couple component.

EV A 'EV ' in columns 1-3 is followed by six free formatted floating point values: strike, dip, rake, Mw, event_longitude, event_latitude, and event_depth. Only event_longitude and event_latitude need to be set for the correct calculation of the source and receiver azimuth and distance. Should be the same as the *evla=* and *evlo=* values used to calculate the Green's function library using "mkgrnlib". Other values can be set to zero and are only used to forward calculate synthetic ground displacements when the dump option is set (dumpsac).

All other lines are for station and synthetic data processing parameters. There are 18 columns in the following order:

sta, net, model, np, pas, lf, hf, nt, dt, tr, tt, grdmo, mulfac, used, ts, Zmulfac, Rmulfac, Tmulfac.

sta= station code (see stadb file).

net= network code (see stadb file).

model= velocity model name (without .mod extension)

np= number of poles (0,1,2,3,4,5,...) for Butterworth bandpass filter

pas= number of passes (1 or 2) for Butterworth bandpass filter

lf= low frequency corner in Hz for Butterworth bandpass filter

hf= high frequency corner in Hz for Butterworth bandpass filter

nt= number of points (in power of 2)

dt= sampling rate in sec/sample

tr= rise time or duration of ramp in trapezoid function in seconds

tt= duration of boxcar portion of trapezoid function in seconds (tt=0 then triangle function of duration 2*tr)

grdmo= Ground motion type is either 'd' for displacement or 'v' for velocity (no default)

mulfac= Multiplcation factor applied to all components for this station. Useful for applying gain corrections easily. Default is 1.

used= Use this station for inversion 'y' or just make a preduction 'n'

ts= Time shift for all components in seconds. Negative is back-

EXAMPLE PARAMETER FILE (glib2inv.par)

```
#### Region Comment ####
CM Anza, California
#### Origin Time ####
#   year/mo/da,hr:mn:sec
OT 2005/06/12,15:41:46.00
#### Forward calculations ####
#    str dip  rak  Mw    evlo      evla     Z
EV   41  87    29  5.1  -116.573  33.529    14
#
#sta  net  model  np pas  lf   hf  nt  dt   tr  tt grdmo mulfac used ts
Zmulfac Rmulfac Tmulfac
BAR  CI  wus   3  2   0.03 0.10 256 0.25 0.0 0.0  d    1.0     y    0.0
1.0   1.0     1.0
GSC   CI   wus   3  2   0.02 0.08 256 0.4  0.0 0.0  d    1.0    y   0.0
1.0   1.0     1.0
```

Example

```
glib2inv par=glib2inv.par noverbos
```

SEE ALSO

mkgrnlib(1), grnlib2sac(1), sacdata2inv(1), mtinv(1) rdseed(1)

NAME

grnlib2sac

SYNOPSIS

```
grnlib2sac glib= z= [no]dumpgn [no]verbose tr= tt= [no]noise type=
```

if noise

```
nMw= seed=
```

if type=0

```
Mxx= Myy= Mzz= Mxy Mxz= Myz= Mo=
```

if type=1

```
str= dip= rak= Mw=
```

if type=2

```
str= dip= rak= Mw= Piso=
```

DESCRPTION

Computes the ground displacements (z,r,t) given one type of source input, type=0 is the tensor input, type=1 is the focal mechanism and seismic moment, or type=2 which seperates the moment into isotropic and double couple. The synthetic seismograms can be convolved with a source time function (ramp rise time and boxcar time lengths). The program reads the Green's function library (as a function of depth) for a single source station pair. The output are SAC formatted binary files. Use sac2xy.c to get the raw ASCII data. The program is ideal for when quick forward calculations are needed to check recorded data. Version 2 include a feature that adds noise relative to a moment magnitude.

REQUIRED PARAMETERS

glib={string}
The file name of the Green's function library ".glib" file.

z={float}
The source depth. Must be a depth computed in the Green's function library ".glib" file. See par file from mkgrnlib

OPTIONAL PARAMETERS

[no]dumpgrn
write out only Green's functions for z= depth.

[no]verbose
verbosy output for diagnosis

tr={float}
The ramp rise time in seconds. If tr=0 and tt>0 then the source

time function is a boxcar.

tt={float}
The boxcar rise time in seconds. If tt=0 and tr>0 then the source time function is a triangle.

[no]noise
add white Gaussian noise

nMw={float}
If noise then enter the level of the noise in units of Mw for freq band of interest

seed={integer}
If noise then enter the random seed for noise

type={integer}
Source Input Mode Type where type=0 Input Moment Tensor, type=1 Input Pure Deviatoric Source (Strike/Dip/Rake) and type=2 Input Pure Deviatoric source plus isotropic component

If type=0 Mxx={float} Myy={float} Mzz={float} Mxy={float} Mxz={float} Myz={float}
Normalized Moment Tensor Elements

If type=0 Mo={float}
Total Seismic Moment in Dyne Cm.

If type=1 str={float} dip={float} rake={float}
Fault Strike, dip, and rake in degrees. Aki's convention.

If type=1 Mw={float}
Scalar seismic moment magnitude.

If type=2 str={float} dip={float} rake={float}
Fault Strike, dip, and rake in degrees. Aki's convention.

If type=2 Mw= Piso=
Total Moment Magnitude and The percent of the total moment allo-

SEE ALSO

mkgrnlib(1), grnlib2sac(1), sacdata2inv(1), mtinv(1) rdseed(1)

NAME

Mkgrnlib - Makes the Green's function library for a single source station pair

SYNOPSIS

mkgrnlib par= stnm= net=

or

mkgrnlib stnm= net= velmod= zrange= evla= evlo= dt= nt= fmax= t0= redv= damp= kmax= eps= smin= modeldb= stadb= [no]verbose [no]dump

DESCRIPTION

mkgrnlib reads in a parameter file and/or command line arguments which points to a station database file in rdseed format, a 1D velocity model file in simple ASCII column format, and several parameters including source and receiver latitude and longitude, number of points, sampling rate, and source depth interval. The program then computes the Green's functions using the f-k reflectivity methodology of Zeng and Anderson (1995). The output is a binary formatted file with the Green's functions as a function of depth and the ten (ZSS, ZDS, ZDD, ZEP, RSS, RDS, RDD, REP, TSS, TDS) fundamental faulting orientations.

REQUIRED PARAMETERS

stnm={string}
The station code name in the same capitalization and spelling as typed in column one of the station database file [required no default]. The path to the station database for is defined by the parameter *stadb*. The station database file is in rdseed format. Try *rdseed -S -f foobar.seed* to extract the station file. The station code has an eight character length limit.

net={string}
The network code name (see www.FDSN.org) in the same capitalization and spelling as typed in column 2 of the the station database file [required no default]. The station database file is in rdseed format. Try *rdseed -S -f foobar.seed* to extract the station file. The network code has an eight character length limit.

velmod={string}
The file name of the velocity model without the .mod extension. The path is defined by *modeldb* (see below). [required no default].

zrange={floating point number},{floating point number},{floating point number}
The minimum, interval and maximum values of the centroid source

depth in (kilometers) for the Green's function library [required no default].

evla={floating point number}
The earthquake latitude in decimal degrees format [required no default].

evlo={floating point number}
The earthquake longitude in decimal degrees format [required no default].

dt={floating point number}
The Green's function sampling rate in seconds per sample [required no default].

nt={integer number}
The number of points for the Green's functions. Must be a power of 2 (i.e., 64, 128, 256, 512, 1024, 2048(maximum)) [required no default].

eps={floating point number}
Error tolerance. Typically values of *eps*=0.001 to *eps*=0.000001 are adequate. When *kmax* or *fmax* are not set properly mkgrnlib will exit and ask to reset these values. This feature can be controlled by *eps* and *smin*. [required no default].

smin={floating point number}
Error tolerance. Typically values of *smin*=0.001 to *smin*=0.000001 are adequate. When *kmax* or *fmax* are not set properly mkgrnlib will exit and ask to reset these values. This feature can be controlled by *eps* and *smin*. [required no default].

modeldb={string}
The path to the model database directory. [required no default].

stadb={string}
The path and file name to the station database. The file is in rdseed format. [required no default].

OPTIONAL PARAMETERS

par={string}
The name of the parameter file [optional no default]. Allows all or some of the parameters to be defined in a file rather

without loss of information. This speeds calculation time significantly. Typically *fmax* can be set to 0.5 seconds when inverting 100 to 10 sec period waves [optional, default is Nyquist frequency=1/(2*dt)].

t0={floating point number}

The time of the first sample in the Green's function, (*t0*=0 is the earthquake origin time) [optional, default is *t0*=0.0]

redv={floating point number}

The reduction velocity in km/sec [optional, default is *redv*=-1.0 (no reduction velocity)]. To avoid wasting time computing Green's function for times before the first arrival particularly when the origin-time is used as the time of the first sample at large distances. The reduction velocity can move the time of the first sample to a later time based on a horizontal apparent velocity.

damp={floating point number}

The value damp is for the exp(-damp*(pi/twin)*t) exponential function for dampening the rap around effects in the time domain. When the length of the time history is too short, then the seismic surface waves may rap around to the beginning of the Green's function because of the cyclic nature of the FFT [optional, default off *damp*=1.0].

kmax={integer number}

Similar to fmax but for maximum spatial frequency (k=wave number). Warning low fmax and kmax values may led to instability and inaccuracies in the calculations. [optional, default is kmax=10000000]. Typically kmax=20000 is adequate for most moment tensor inversions.

verbose={integer=1 or 0}

Verbosy output for debugging is *verbose*=1 and for no verbosy output is *verbose*=0 [optional, default no verbose=0].

dump={integer=1 or 0}

Write out "Dump" the Green's functions as SAC formatted binary files [optional, default no dump=0].

VELOCITY MODEL FILE FORMAT

```
###
### Western US model Ritsema and Lay 1995 JGR.
###
### thick Vp     Qp      Vs    Qs      rho
###  (km) (km/s)        (km/s)         (g/cc)
```

```
   4.00  4.52   500.00  2.61   250.00  2.39
  28.00  6.21   500.00  3.59   250.00  2.76
  20.00  7.73  1000.00  4.34   500.00  3.22
 700.00  7.64  1000.00  4.29   500.00  3.19
```

Example entries in the station database file

```
GSC  CI  +35.301800 -116.805700  +954.0 "BHE BHN BHZ" "Goldstone, Cali-
fornia, USA" 1990,220,00:00:00 2599,365,23:59:59

BAR CI +32.680100 -116.672200  +496.0 "BHE BHN BHZ" "Barrett,  Califor-
nia, USA" 1992,275,00:00:00 2599,365,23:59:59
```

EXAMPLE

To calculate the Green's functions of an earthquake in Anza, California (latitude=33.529, longitude=-116.573) at the UC Berkeley digital seismograph station Columbia (CMB.BK) within the central Sierra Nevada, California, for depths of 2 to 22 km in 2 km increments (i.e., 2,4,6,8,10,12,14,16,18,20,and 22 km). The Western U.S. velocity model is used and the time histories will be computed up to 0.5 Hz, at a sampling rate of 0.2 samples per second and a total of 1024 points (204.8 seconds).

```
mkgrnlib evla=33.529 evlo=-116.573 zrange=2,2,22 velmod=wus \
  dt=0.2 nt=1024 fmax=0.5 eps=0.0005 smin=0.0005 \
  modeldb=/Users/ichinose/mtinv.v0.9/modeldb/ \
  stadb=/Users/ichinose/mtinv.v0.9/stadb/station_database.txt
```

SEE ALSO

glib2inv(1), grnlib2sac(1), sacdata2inv(1), mtinv(1) rdseed(1)

MTINV Version 3.0.3 07 Mar 2014 **MKGRNLIB(1)**

NAME

mtinv - moment tensor inversion

SYNOPSIS

mtinv par= mtdegfree=(1,5,6) [no]verbose [no]dumpsac output-path=[./plotmech] [no]fwd [no]gmtmap ts0= fixz= [no]test_mode [no]norm [no]shift ctol= FixISOZ= [no]WgtCovarResid [no]PltXcorLabel [no]dumpxy [no]use_snr minsnr= [no]mysql [no]oracle

DESCRIPTION

mtinv reads the same input file used by glib2inv and sacdata2inv to generate processed and filtered data and Green's function input files and performs an inversion for the 5 or 6 moment tensor elements in a least squares sense (by Singular Value Decomposition). The response or fitness of percent double couple and variance reduction are checked for each source depth and an ASCII formatted E-mail file is generated with the best fit. A postscript plot is also generated with the waveform fit. Typically sacdata2inv and mtinv can be run inside a C-shell script looped over origin time values to estimate the optimal origin time and centroid depth.

REQUIRED PARAMETERS

par={string}
The file name of the parameter file. See format of this file below (PARAMETER FILE FORMAT).

mtdegfree={integer=1, 5 or 6}
The number of degrees of freedom for the moment tensor. If mtdegfree=5 then Mzz is equal to -(Mxx+Myy) and the trace of (Mij) is assume zero. The isotropic component is also assume zero. When mtdegfree=1 the moment tensor solution is constrained to be only Misotropic=Mxx=Myy=Mzz while the off diagonal elements are Mxy=Mxz=Myz=0. When mtdegfree=6 the solution includes all 6 unqiue elements of the tensor.

ts0={float}
The number of seconds to shift all of the data relative to the origin time. The data are shifted within mtinv and not windowed again by sacdata2inv saving much time.

OPTIONAL PARAMETERS

[no]verbose
Verbosy output for debugging is *verbose* and for no verbosy output is *verbose* [optional, default noverbose].

[no]dumpsac
Write out "Dump" the processed data as SAC formatted binary files and synthetics [optional, default nodumpsac].

outputpath=[./plotmech]
This is the path for the plot mechanism files GMT C-shell script and individual solution files for plotting the mechanism solution version origin time shift and depth with the mechanism size scaled to the variance reduction and modulated by the percent double couple. Default is ./plotmech/

[no]fwd
Use the EV line in the parameter input file for a forward caclu-ation of the pure double couple focal mechanism and moment. All the plots and output files are made as in the inversion. Default is inversion mode. Forward calculation is off.

[no]gmtmap
Make a GMT C-shell script that plots a map with the event and station locations. The solution is also shown. mtinv needs to be run with the current best origin time shift that results with the best fitting depth. Topography can be shown in the map by setting some C-shell environment variables. Defautl off.

setenv MTINV_GMT_GRID_FILE /my/topography.grid

setenv MTINV_GMT_INT_FILE /my/topography.shade

setenv MTINV_GMT_CPT_FILE /my/togography.colorpal

fixz= Do an inversion with the depth fixed. Program checks for valid depth. Default off.

[no]test_mode
A test mode that forces deviatoric solution. Default off.

[no]norm
Distance normalization. Normalizes the data and synthetics. Defautl is off.

[no]shift
Shift the data by the maximum of the cross correlation between data and synthetics computed from the best fitting solution. Default is off.

ctol= When the shift option is on, this is the minimum correlation coefficient allowed to shift the data. If the correlation is larger than ctol=(0.0 to 1.0) then the data is shifted to the lag time for this maximum correlation. Default off.

[no]WgtCovarResid
Weight the covariance matrix by the variance of the residuals. Otherwise weight by the variance of the data. Default off, always weight variance by the data.

PltXcorLabel = Do not plot the correlation coefficient and time shift in second. this is to reduce clutter on the plot

[no]use_snr = uses SNR to make defining or nondefining staions in the inversion.

minsnr=[number] the minimum SNR threshold, all 3-components must be below this to make stations non-defining. [default 3]

[no]mysql = creates two files, one to create tables and key indexes and another to populate the table for the current event.

[no]oracle = creates two files, one to create tables and key indexes and another to populate the table for the current event.

PARAMETER FILE FORMAT

same format as par file for GLIB2INV(1) and SACDATA2INV(1)

A '#' in the first column signifies that the following is a non printing comment

CM A 'CM ' in columns 1-3 marks the beginning of a comment, typically the region, area, city and country name for reference purposes only.

OT A 'OT ' in columns 1-3 is followed by the earthquake origin time string in year/month/day,hour:minute:seconds format, (e.g., 2005/06/12,15:41:46.000). Origin time is required for setting the origin time in the synthetics and shifting the observed seismograms in time to improve the fit the synthetics and percent double couple component.

EV A 'EV ' in columns 1-3 is followed by six free formatted floating point values: strike, dip, rake, Mw, event_longitude, event_latitude, and event_depth. Only event_longitude and event_latitude need to be set for the correct calculation of the source and receiver azimuth and distance. Should be the same as the *evla=* and *evlo=* values used to calculate the Green's function library using "mkgrnlib". Other values can be set to zero and are only used to forward calculate synthetic ground displacements when the dump option is set (nodumpsac).

All other lines are for station and synthetic data processing parameters. There are 18 columns in the following order:

sta, net, model, np, pas, lf, hf, nt, dt, tr, tt, grdmo, mulfac, used, ts, Zmulfac, Rmulfac, Tmulfac.

sta= station code (see stadb file).

net= network code (see stadb file).

model= velocity model name (without .mod extension)

np= number of poles (0,1,2,3,4,5,...) for Butterworth bandpass filter

pas= number of passes (1 or 2) for Butterworth bandpass filter

lf= low frequency corner in Hz for Butterworth bandpass filter

hf= high frequency corner in Hz for Butterworth bandpass filter

nt= number of points (in power of 2)

dt= sampling rate in sec/sample

tr= rise time or duration of ramp in trapezoid function in seconds

tt= duration of boxcar portion of trapezoid function in seconds (tt=0 then triangle function of duration 2*tr)

grdmo= Ground motion type is either 'd' for displacement or 'v' for velocity (no default)

mulfac= Multiplcation factor applied to all components for this station. Useful for applying gain corrections easily. Default is 1.

used= Use this station for inversion 'y' or just make a preduction 'n'

ts= Time shift for all components in seconds. Negative is backward time shift in time and positive shifts are forward shift in time. Default is 0;

weight= number between 0 and 1. This is the weight the station gets in the iversion.

Phase Name = Not used, for future use. Name of the phase used to invert, Surface Wave or Pnl wave.

EXAMPLE PARAMETER FILE (glib2inv.par)

```
#### Region Comment ####
CM Anza, California
#### Origin Time ####
#   year/mo/da,hr:mn:sec
OT 2005/06/12,15:41:46.00
#### Forward calculations ####
#    str dip  rak  Mw    evlo      evla     Z
EV   41  87    29  5.1  -116.573  33.529    14
##########################################################################################
#sta net mod npole npass lf hf nt dt tr tt v/d fac use ts0 weight phase
BAR CI wus 3 2 0.03 0.10 256 0.25 0.0 0.0  d  1.0 y 0.0 1.0  Surf/Pnl #comment
GSC CI wus 3 2 0.02 0.08 256 0.4  0.0 0.0  d  1.0 y 0.0 1.0  Surf/Pnl #comment
```

Example 1. C-Shell Script With solution at origin time at 2005/06/12,15:41:46

```
#!/bin/csh
glib2inv par=glib2inv.par noverbose
sacdata2inv par=glib2inv.par path=./IRIS  respdir=./Resp  noverbose nodumpsac
foreach ts0 ( -2 -1 0 +1 +2 )
       mtinv ts0=${ts0} par=glib2inv.par mtdegfree=5
end
```

SEE ALSO

glib2inv(1), **grnlib2sac(1)**, **mkgrnlib(1)**, **sacdata2inv(1)**, **rdseed(1)**, *sac.h mt.h*

NAME

sacdata2inv - processes and filters the SAC formatted data files for moment tensor inversion by mtinv

SYNOPSIS

```
sacdata2inv par= path= respdir= [no]verbose [no]dumpsac
```

DESCRIPTION

sacdata2inv takes input from both the command line and the parameter file from glib2inv about the station information and SAC formatted binary file locations and generates input files for moment tensor inversion using "mtinv". The directories of the SAC files and Sac Pole and Zero response correction files are scanned automatically. The data files are processed, detrended, bandpass filtered, interpolated, windowed, scaled to the correct units, tapered and rotated into the Vertical, Radial and Transverse (Z,R,T) coordinate system.

REQUIRED PARAMETERS

par={string}
The file name of the parameter file. See format of this file below (PARAMETER FILE FORMAT).

path={string}
The relative or absolute path to where the SAC files are stored. Use rdseed -d -p -f myrdseed.seed to extract SAC and SAC pole zero files from a seed file.

respdir={string}
The relative or absolute path to where the SAC pole zero files are stored. Use rdseed -d -p -f myrdseed.seed to extract SAC and SAC pole zero files from a seed file.

OPTIONAL PARAMETERS

[no]verbose
Verbosy output for debugging is *verbose* and for no verbosy output is *noverbose* [optional, default no verbose].

[no]dumpsac
Write out "Dump" the processed data as SAC formatted binary files [optional, default nodump].

PARAMETER FILE FORMAT

same format as par file for GLIB2INV(1)

\# A '#' in the first column signifies that the following is a non printing comment

CM A 'CM ' in columns 1-3 marks the beginning of a comment, typically the region, area, city and country name for reference purposes only.

OT A 'OT ' in columns 1-3 is followed by the earthquake origin time string in year/month/day,hour:minute:seconds format, (e.g., 2005/06/12,15:41:46.000). Origin time is required for setting the origin time in the synthetics and shifting the observed seismograms in time to improve the fit the synthetics and percent double couple component.

EV A 'EV ' in columns 1-3 is followed by six free formatted floating point values: strike, dip, rake, Mw, event_longitude, event_latitude, and event_depth. Only event_longitude and event_latitude need to be set for the correct calculation of the source and receiver azimuth and distance. Should be the same as the *evla=* and *evlo=* values used to calculate the Green's function library using "mkgrnlib". Other values can be set to zero and are only used to forward calculate synthetic ground displacements when the dump option is set (dumpsac).

All other lines are for station and synthetic data processing parameters. There are 18 columns in the following order:

sta, net, model, np, pas, lf, hf, nt, dt, tr, tt, grdmo, mulfac, used, ts, Zmulfac, Rmulfac, Tmulfac.

sta= station code (see stadb file).

net= network code (see stadb file).

model= velocity model name (without .mod extension)

np= number of poles (0,1,2,3,4,5,...) for Butterworth bandpass filter

pas= number of passes (1 or 2) for Butterworth bandpass filter

lf= low frequency corner in Hz for Butterworth bandpass filter

hf= high frequency corner in Hz for Butterworth bandpass filter

nt= number of points (in power of 2)

dt= sampling rate in sec/sample

tr= rise time or duration of ramp in trapezoid function in seconds

used= Use this station for inversion 'y' or just make a preduction 'n'

ts= Time shift for all components in seconds. Negative is backward time shift in time and positive shifts are forward shift in time. Default is 0;

Zmulfac= Vertical component multplication factor

Rmulfac= Radial component multplication factor

Tmulfac= Transverse component multplication factor

EXAMPLE PARAMETER FILE (glib2inv.par)

```
#### Region Comment ####
CM Anza, California
#### Origin Time ####
#   year/mo/da,hr:mn:sec
OT 2005/06/12,15:41:46.00
#### Forward calculations ####
#    str dip  rak  Mw    evlo      evla     Z
EV   41  87    29  5.1  -116.573  33.529    14
#
BAR CI wus 3  2 0.03 0.10 256 0.25 0.0 0.0  d 1.0  y 0.0 1.0   1.0     1.0
GSC CI wus 3  2 0.02 0.08 256 0.4  0.0 0.0  d 1.0  y 0.0 1.0   1.0     1.0
```

Example C-Shell Script

```
#!/bin/csh
sacdata2inv  par=glib2inv.par  path=./IRIS   respdir=./Resp noverbose nodumpsac
```

SEE ALSO

glib2inv(1), grnlib2sac(1), mkgrnlib(1), mtinv(1), rdseed(1),

MTINV Version 3.0.3 07 Mar 2014 **SACDATA2INV(1)**

NAME

sacmerge

SYNOPSIS

sacmerge f1= f2=

DESCRIPTION

Merges two Seismic Analysis Code (SAC) binary formatted files into a single SAC file. Typically real-time seismic data are split into packets/segments and sent through the Internet. Packets may get lost or arrive too late for posting causing drop outs. If you run unpack.csh on data ordered from IRIS and data are segmented into 2 or more files then use this program to merge the files into a single file for processing in **SACDATA2INV(1).**

REQUIRED PARAMETERS

f1={string}
the first sac file

f2={string}
the second sac file to be merged with the first

SEE ALSO

sacdata2inv(1), unpack.csh(1)

NAME

sacswapbytes

SYNOPSIS

sacswapbytes {sac binary files}

DESCRIPTION

Motorola and IBM processors (CPU's) were designed to read and write bits from left to right like humans but Intel decided to do it from right to left (backwards). This is called computer Endianess... big-endian (Motorola/IBM) and little-endian (Intel). Therefore files written from one type of processor/computer will need to have its byte-order byte-swapped in order for it to be readable on another type of computer. This includes Seismic Analysis Code (SAC) binary formatted files. This program performs an intelligent assessment of the file type and converts if necessary. NOTE... if you created sac files using rdseed then those sac files inherit the native byte order of that computer. SACSWAPBYTES is only necessary if those files were transferred to another type of computer with different architecture. Also note that SAC2000 performs this function automatically but beware that upon writing the files over using SAC2000 it inherits the native byte-order.

REQUIRED PARAMETERS

none

SEE ALSO

sacdata2inv(1), knet2sac(1)

MTINV Version 3.0.3 07 Mar 2014 **SACSWAPBYTES(1)**

NAME

unpack.csh

SYNOPSIS

unpack.csh {seed file}

DESCRIPTION

A C-Shell script which "unpacks" or extracts SAC binary formatted files, SAC Pole Zero instrument response files, and station information among other things that rdseed can extract.

REQUIRED PARAMETERS

seed file name

SEE ALSO

sacdata2inv(1), sacmerge(1), sacswapbytes(1), *rdseed*

MTINV Version 3.0.3 07 Mar 2014 **UNPACK.CSH(1)**

NAME

renamesac

SYNOPSIS

renamesac {sac files}

DESCRIPTION

Renamesac simply renames SAC formatted binary files using a convention similar to that used by RDSEED. SACDATA2INV requires that sac data files have at least a .SAC or .sac file extension and that the station and network of the data are in the filename separated by periods. The program reads the sac file header and uses the fields to create a file name.

For example, 2005.344.00.08.41.6311.GE.CSS..BHE.R.SAC

Remember that the SAC Pole-zero files also need to have a specific name format. For example, SAC_PZs_GE_CSS_BHE__1999.202.00.00.00.0000

REQUIRED PARAMETERS

sac file name

MTINV Version 3.0.3 07 Mar 2014 **renamesac(1)**

NAME

multithread_mkgrnlib

SYNOPSIS

multithread_mkgrnlib parfile= executable_pathname=

DESCRIPTION

multithread_mkgrnlib reads parfile= which contains the station code, network code, Greens function parameter file for mkgrnlib and the sampling rate dt in seconds per sample. This application uses system calls fork and retv to execute multiple mkgrnlib simultaneously in parallel. This is ideal for multicore processors systems and greatly decreases the computation time compared to running mkgrnlib in serial. Most dual core or quad core systems can handle 10-20 stations simultaneously. The operating system handles %cpu each process takes.

REQUIRED PARAMETERS

parfile = see format below

executeable_pathname = must be full path name and executable name of mkgrnlib

Example:

```
#!/bin/csh
### 1992/03/26 16:30:00.0 37.272 -116.360 ML 5.5 Mw 4.5 Junction

cat >! wus.par << EOF
velmod=wus
zrange=0.5,0.5,0.5
evla=37.272
evlo=-116.360
dt=0.1
nt=2048
fmax=0.5
t0=-1.0
redv=12.
damp=1.
kmax=9999999
eps=0.000001
smin=0.000001
```

```
modeldb=/Users/ichinose/Work/mtinv.v3.0.3/data/modeldb/
stadb=../Data/rdseed.stations
noverbose
nodump
EOF

#### comment out the serial version
# mkgrnlib par=wus.par stnm=PFO  net=TS
# mkgrnlib par=wus.par stnm=SCZ  net=G

###
cat >! mkgrnlib.par << EOF
#sta net par  dt
PAS  TS wus.par 0.1
PFO  II wus.par 0.1
ISA  TS wus.par 0.1
SBC  TS wus.par 0.1
BKS  BK wus.par 0.1
STAN BK wus.par 0.1
ANMO IU wus.par 0.2
COR  IU wus.par 0.2
# PFO  TS wus.par 0.1
EOF
```

Parallel version

```
####
multithread_mkgrnlib \
   parfile=mkgrnlib.par \
   executable_pathname=/Users/ichinose/Work/mtinv.v3.0.3/bin/mkgrnlib > \
multithread_mkgrnlib.out
```

MTINV Version 3.0.3 07 Mar 2014 **multithread_mkgrnlib(1)**

NAME

makepar

SYNOPSIS

makepar com= date= lf= hf= [no]verbose *.glib

DESCRIPTION

Automatically creates a run.csh C-shell script that does the Greens function processing, SAC data loading and processing, mtinv and runs GMT C-shell scripts to generate PS plots.

REQUIRED PARAMETERS

date=yyyy/mm/dd,HH:MM:SS.S Origin time in year, month, day, hour, minute and seconds format

OPTIONAL PARAMETERS

[no]verbose
com= comment string
lf = low frequency corner
hf = high frequency corner

SEE ALSO

mtinv, sacdata2inv, glib2inv, mkgrnlib