Computer Programs in Seismology
Training Course
Moment Tensor Inversion

Robert B. Herrmann
Reinert Professor of Natural Sciences
Department of Earth and Atmospheric Sciences
Saint Louis University
St. Louis, Missouri, USA
Email: rbh@eas.slu.edu

December 18, 2011

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Training Course

This course is focused primarily on the estimation of earthquake moment tensors using digital seismic data. This will be accomplished by using a special distribution of Computer Programs in Seismology (http://www.eas.slu.edu/eqc/eqccps.html) that provides a complete system for use with Windows and LINUX computers. The course focuses on the installation of the software package, and the application of the package to real data sets from regional earthquakes in the United States and Turkey and teleseisms to determine moment tensors. In addition, the use of the LINUX/CYGWIN commands is introduced to benefit the participants who have not used these systems before.

The organization of the course first emphasizes the use of the programs to perform moment tensor inversion. The participants will work with regional and teleseismic data sets, and in the process acquire a sense of the procedure. Following this initial experience, a detailed discussion of the process will be provided for further understanding.

Software Distribution

Dr. Herrmann will provide all software, Green's functions and data sets by bringing the following to the course:

Software Installation

LINUX

This will provide a fast processing environment. You will require the C and FORTRAN compilers, e.g., gcc/gfortran. You will also require the X11 development package (this provides the include files), and the termcap library.

Select a location to install Computer Programs in Seismology, the Green's functions and the data sets. I would create a sub-directory in your home directory called CPS, e.g.,

```
cd
mkdir CPS
cp NP330.Jan-14.2012.tgz CPS
cd CPS
gunzip -c NP330.Jan-14-2012.tgz | tar xvf -
```

and then install everything in CPS.

Note that you may have to change the Makefile to make gsac in PROGRAMS.330/VOLVIII/gsac.src to change the -ltermcap to -lncurses

If you are using Ubuntu LINUX, you will need to do the following from with in a terminal (you will require and internet connection)

```
sudo apt-get install libncurses5-dev
sudo apt-get install gfortran
sudo apt-get install xorg-dev
sudo apt-get install gv
sudo apt-get install graphicsmagick
sudo apt-get install imagemagick
```

MacOS-X

The requirements are the same as for LINUX.

You must have the X11 support installed (this is the of MacOS-X distribution CD-ROM
You must also have the gcc/gfortran compilers installed

Windows

You must nstall Cygwin (get the executable setup.exe from www.cygwin.com) to provide a full, free UNIX-like environment for Windows. The package includes all compilers and will provide an X11 environment.

I assume that you have at least 10 GB of free space for everything.

To avoid interfering with your Windows system, we will place everything in a new folder on the C drive, e.g., we will create a C:\usr

1. **Install CYGWIN. Read the CPSInstall.pdf tutorial (Windows Only)**

   In the following I assume have CYGWIN running and that your are using a terminal and that the CDROM/Flash Drive is on the Windows D: drive

2. **Install Computer Programs in Seismology:**

```
cd /cygdrive/c/usr
gunzip -c /cygdrive/d/usr/NP330.Jan-14-2012.tgz | tar xf -
cd PROGRAMS.330
./Setup
./Setup CYGWIN
./C
cd ..
```

3. **Set up the proper paths**

   Edit the .bash_profile and the .bashrc in the home directory as follows:

   First edit the .bash_profile so that the 'export PATH' line looks like

```
export
PATH=:.:/cygdrive/c/usr/PROGRAMS.330/bin:/bin:/usr/bin:/usr/local/bin:/usr/X11R6
/bin:/cygdrive/c/usr/GMT/bin:
```

   Note this also indicates that the Computer Programs in Seismology in on the C drive

   Next edit the .bashrc file to add the following lines at the bottom:

```
GMTHOME=/cygdrive/c/usr/GMT
export GMTHOME
GMT_SHAREDIR=$GMTHOME/share
export GMT_SHAREDIR
MANPATH=$MANPATH:$GMTHOME/man:
export MANPATH
```

   Then execute

```
source ~/.bash_profile
source ~/.bashrc
```

All Systems

Edit the .bash_profile to change the PATH so that absolute path to PROGRAMS.330/bin is listed. Edit the .bashrc to define the GREENDIR environment parameter for the inversion programs to work.

then do the following

> **cd** [return to the login directory]
> edit the .bashrc using the vi or nedit editors

.

NON-INTEL Computers

The Green's functions were computed on a machine with Intel (AMD also) architecture. The Green's functions are provided in the form of Sac files. If you wish to run the inversion code on a different architecture, e.g., PowerPC or SPARC, then the byte order of each Sac file must be changed. This is done using the program **saccvt** which is part of the Computer Programs in Seismology package.

.

MOMENT_TENSOR.tgz

This will unpack, using commands such as

```
gunzip -c MOMENT_TENSOR.tgz | tar xf -
```

into a directory called MOMENT_TENSOR

```
MOMENT_TENSOR/
        |--MECH.NA
        |--MECH.TR
        |--MECH.TEL
```

MECH.NA provides the processing area and all scripts for inversion of regional earthquakes in North America
MECH.TR provides the processing area and all scripts for inversion of regional earthquakes in Turkey
MECH.TEL provides the processing area and all scripts for inversion of telseisms 30-95 degrees away
MECH.TEL.QC provides the processing area and all scripts for using telseismic data to test instrument responses

Read the 00README files in each of these directorys for more detail

Tutorials

CPS.tgz unpacks using the command

gunzip -c CPS.tgz | tar xf -

to create a directory CPS that contains all tutorials available on Computer Programs in Seismology Web Page

GREEN's Functions

The distribution of the precomputed Green's functions is contained in the tar-archive files.: GREEN.AK135.TEL.tar, GREEN.CUS.REG.tar , GREEN.Models.tar and GREEN.WUS.REG.tar.

These will unpack, using commands such as

```
cat GREEN.Models.tar | tar xf -
```

into a directory called GREEN

```
GREEN/
   |--Models/
   |--AK135.TEL/
   |--CUS.REG/
   |--WUS.REG/
```

The Models directory contains the models used for Green's functions
In addition the Models/tak135sph.mod is used to predict arrival times

AK135.TEL - Greens functions for source depths of 1 to 790 km and great circle arc distances of 30 to 95 degrees. These are used for teleseismic source inversion
CUS.REG - Greens functions for the CUS (high velocity craton model) for source depths of 1 - 50 km and epicentral distances of 1 to 2190 km
WUS.REG - Greens functions for the WUS (tectonic model) for source depths of 1 - 69 km and epicentral distances of 1 to 2190 km

Exercise 1 – Regional Earthquakes North America

The first exercise determines the source parameters an Mw=5.2 earthquake in the central United States that occurred on April 18, 2008. This earthquake occurred within a seismic network that Saint Louis UnicRUSTversity operates for the U. S. Geological Survey, and provided significant information on high frequency ground motion scaling [Herrmann, R. B, M. Withers and H. Benz (2008). The April 18, 2008 Illinois earthquake – an ANSS monitoring success, *Seism. Res. Letters* **79,** 830-843].

For the purposes of this documentation, it is assumed that you are on the CYGWIN system, and that everything was installed in the */cygdrive/c/usr* directory.

Step 1 – Go to work area

Go to the work area for North American earthquakes

```
cd /cygdrive/c/usr/MOMENT_TENSOR/MECH.NA
```

Examine the contents of the directory:

```
rbh> ls
0XXXREG/   DOIRIS*    DOQUERY*  DOSOLUTION*  PROTO.I/
DOCWBREG*  DOISETUP*  DOSETUP*    mech.sh*   PROTO.CWB/  RAW/
```

The '*' indicates that the file is executable and the '/' indicates that the file is a directory. The purpose of each entry is as follows:

0XXXREG - a directory containing prototypes for the complete processing.

DOCWBREG - the initial script for use inside the USGS

DOIRIS - the initial script for SEED datasets from IRIS/Orfeus

DOISETUP - script called by DOIRIS to setup the instrument deconvolution

DOQUERY - script called by DOCWBREG to get the NEIC data stream (for internal use)

DOSETUP - script called by DOIRIS and DOCWBREG to create an event directory and to modify all scripts for that event

DOSOLUTION - script that performs the inversion and documentation after everything has been properly set up and the raw data has been quality controlled.

mech.sh - a script that using the program **dialog** to create a simple menu that creates the starting script

PROTO.I - a directory containing scripts for working with the SEED data sets

PROTO.CWB - a directory containing scripts for working with the NEIC data stream

RAW - a directory containing the sample data sets

Step 2 – Get the data

Normally one must get the waveform data. An easy way to accomplish this for significant earthquakes is to use the Wilbur II interface at IRIS

http://www.iris.edu/cgi-bin/wilberII_page1.pl

or at Orfeus

http://www.orfeus-eu.org/cgi-bin/wilberII/wilberII_page1.pl

The IRIS Wilbur II interface starts by selecting the earthquake, then selecting the networks, and finally the individual stations. A SEED volume is created which provides the station coordinates, the instrument orientations and responses as well as the digital data. The result is downloaded using ftp, (or wget).

Step 3 – Sample data sets

We will select a data set for inversion from the RAW directory.

```
rbh> ls RAW
00README  20080221235752.seed  20080418093700.seed
```

and look at the contents of the 00README file

```
rbh> cat RAW/00README
Year Mo Dy HR Mn Sc  Lat       Lon      H    Mag State    Seed Volume
2008/04/18 09:37:00 38.45   -87.89   11.6  5.2 Illinois 20080418093700.seed
2008/02/21 23:57:52 41.053 -114.923  10.0  4.6 Nevada   20080221235752.seed
```

This provides the information that you need about the earthquake and also indicates the name of the SEED volume for each data set. We will first look at the **20080418093700** data set.

Step 4 – Create the DO script

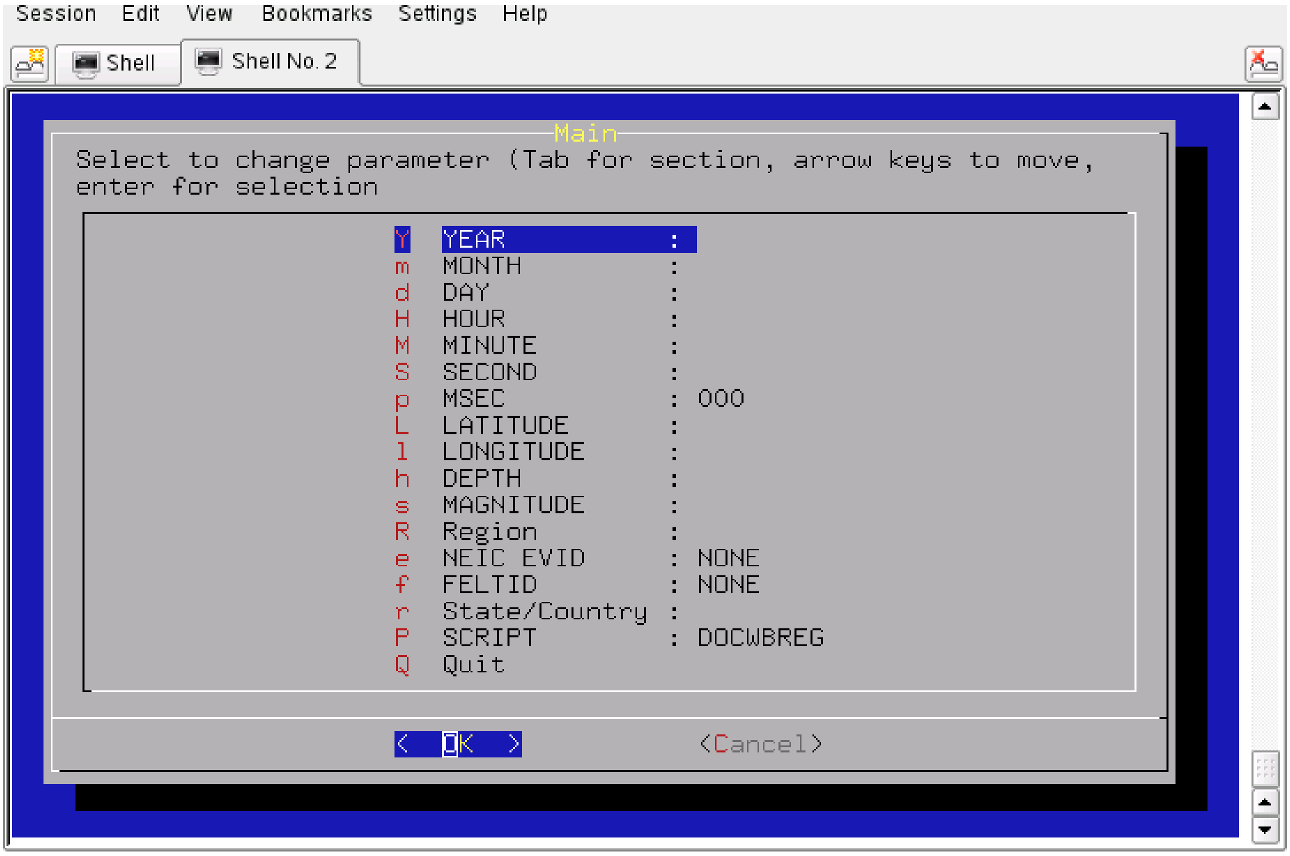
The actual processing will begin by invoking the program DOIRIS, e.g.,

```
rbh> DOIRIS
DOIRIS YEAR MO DY HR MN SC MSC LAT LON DEP MAG REG NEIC FELTID STATE
DOIRIS 2006 02 05 08 17 04 000 66.25 -143.02 18.60 5.1 CUS iuae Xiuae_06 Alaska
```

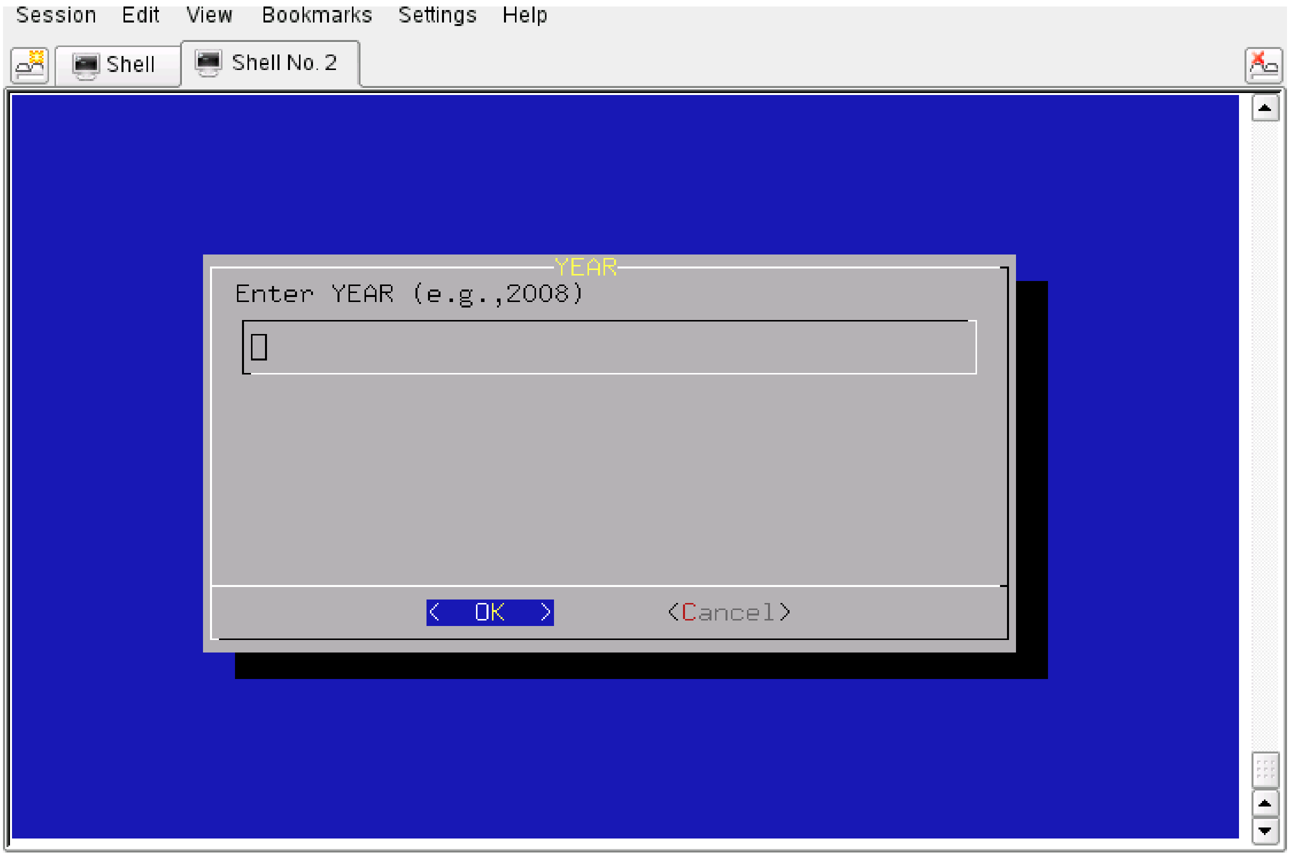
By starting DOIRIS with no arguments, this on-line help message is written to the terminal so that you know what input is required. One must enter 15 parameters after the 'DOIRIS'. Since there is a chance for error at this stage, we will use the **mech.sh** command.

```
rbh> mech.sh
```

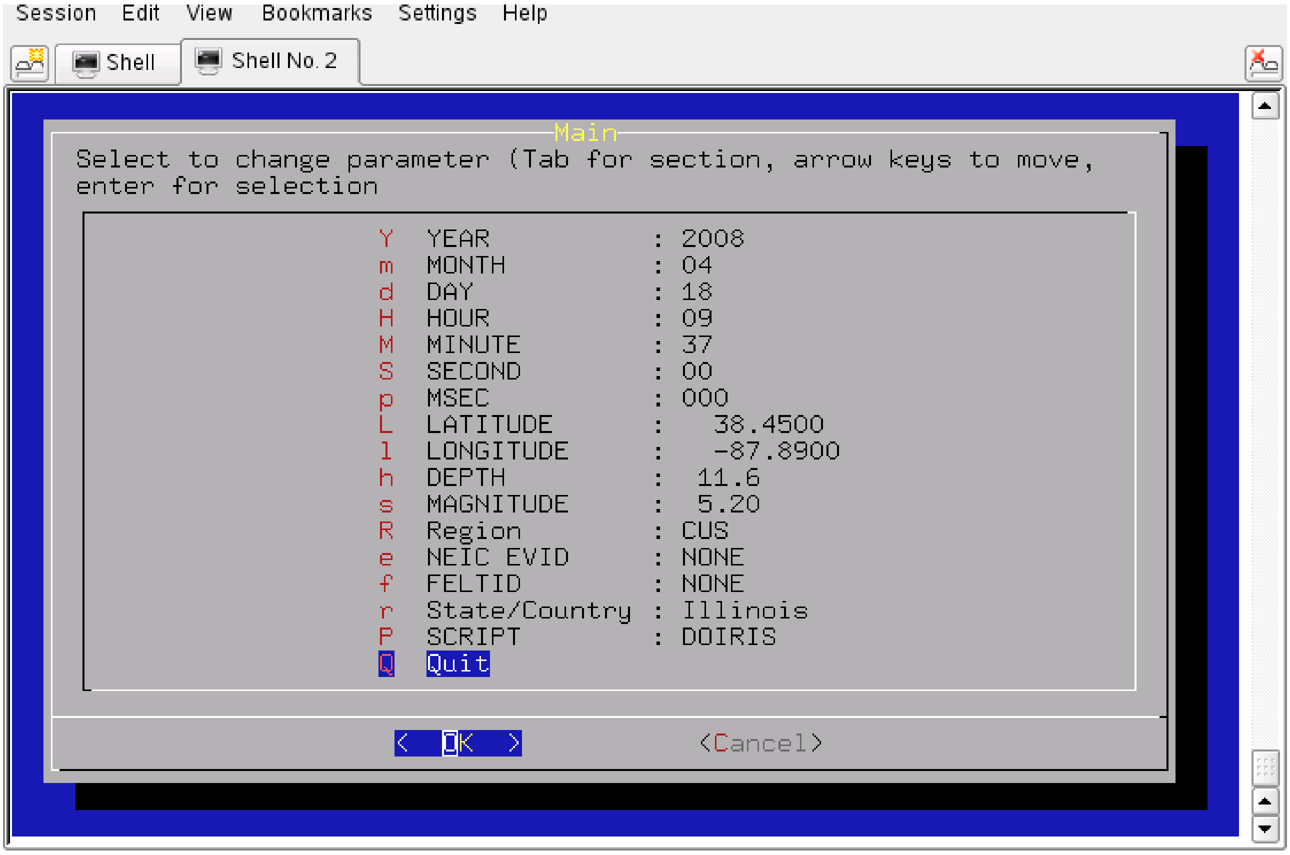
This command starts the menu based input:



You can navigate by using the up/down arrow keys or by entering the letter on the keyboard. If you hit the 'Enter' key on the keyboard, then the highlighted item will take you to another menu, e.g.,



Enter the year, e.g., 2008, and continue to make entries until the main menu looks like



After pressing the 'Enter' key for 'Quit', you will see this on the terminal:

```
#!/bin/sh
#####
# valid regions
# REG    Region              FELTID  VELOCITY_MODEL
# HI    Hawaii               hi        [Not implemented June 23, 2007]
# SAK    Alaska              ak        WUS  (to 69 km deep)
# NAK    Alaska              ak        CUS  (in continent from Rockies -no dee         p)
# CA    California           ca        WUS
# PNW   Pacific Northwestrn pnw        WUS
# IMW   Intermountain west   imw       WUS
# CUS   Central US           cus       CUS
# NE    Northeastern US      ne        CUS
# ECAN  Eastern Canada       ous       CUS (in continent from Rockies)
# WCAN  Western Canada       ous       [Not implemented June 23, 2007]
#####
# Command syntax:
#DOCWBREG YEAR MO DY HR MN SC MSC  LAT     LON    DEP  MAG REG  NEIC FELTID STATE/COUNTRY
#####
DOIRIS "2008" "04" "18" "09" "37" "00" "000" " 38.4500" " -87.8900" " 11.6" "5.20" "CUS" "NONE"
"NONE" "Illinois"
************************************************************
To enter the command DO to begin the moment tensor procedure
************************************************************
```

This shows the contents of the new command file 'DO' which was created by the menu. If you look carefully you will see that each of the required fields in the menu was provided in the 'DOIRIS' command line.

This may also be your first experience with a SHELL script. The first line tells the system that this is shell script. All other lines starting with the '#' symbol are comments. Only the last 'DOIRIS' line will be executed. Note that I have taken the time to document this script.

Step 5 – Create the event directories

Start the processing with the command:

```
rbh> DO
```

This will return the following message:

```
1. PLACE THE SEED_VOLUME FROM IRIS in /cygdrive/c/usr/MOMENT_TENSOR/MECH.NA/20080418093700/2008041809370
2. UNPACK the SEED_VOLUME FROM IRIS as follows
   cd Sac
   rdseed -f ../SEED_VOLUME -R -d -o 1
   [Note use the name of the downloaded file for SEED_VOLUME, e.g., 20090116.seed]
3. Return to the top level directory where you started:
   cd /cygdrive/c/usr/MOMENT_TENSOR/MECH.NA
4. enter the command:
   DOFINISH
```

Before we continue, examine what has changed:

```
rbh> ls
0XXXREG/         DO*        DOFINISH*  DOISETUP*  DOSETUP*     mech.sh*  PROTO.CWB/  RAW/
20080418093700/  DOCWBREG*  DOIRIS*    DOQUERY*   DOSOLUTION*  out       PROTO.I/
```

You will now see the 'DO' script, an 'out' file that contains a detailed listing of what the script 'DO' actually did, and the event directory 20080418093700. We can look at what is in this event directory by using the 'ls -R' command to get a recursive listing:

```
rbh> ls -R 20080418093700
20080418093700:
20080418093700/  GRD.REG/   MAP.REG/   NEW2.REG/
DAT.REG/         HTML.REG/  MT.OTHER/  SYN.REG/

20080418093700/20080418093700:
evt.proto  IDODIST*  IDOGCARC*  IDOQCTEL*  MFT/
IDODEC*    IDOEVT*   IDOQC*     IDOROT*    Sac/

20080418093700/20080418093700/MFT:

20080418093700/20080418093700/Sac:

20080418093700/DAT.REG:
NOUSE/

20080418093700/DAT.REG/NOUSE:

20080418093700/GRD.REG:
DOCLEANUP*  DOGRD*  DOPLTSAC*  DOSTA*

20080418093700/HTML.REG:
DOHTML*  html.tmp  QUALITY  SHWP*

20080418093700/MAP.REG:
DOCOORD*  DOMAP*  na.gmt*

20080418093700/MT.OTHER:
00README

20080418093700/NEW2.REG:
DOGRID*  DOPLTRAD*
```

```
20080418093700/SYN.REG:
DOCLEANUP*  DOMCH*  DOPLTSAC*  DOSTA*  DOSYN*
```

The directory is indicated by a line such as **20080418093799/HTML.REG**:

Each directory accomplishes a different task:

20080418093700 - this is the location of the raw and deconvolved, rotated waveforms

DAT.REG - this is where the waveforms for the source inversion are stored

GRD.REG - this is the work area for the source inversion

HTML.REG - this is where the final documentation is stored

MAP.REG - this is used for the surface-wave spectral amplitude studies

MT.OTHER - this is used to document solutions by other groups

NEW2.REG - this is where the surface-wave spectral amplitude inversion is performed

SYN.REG - this is where a forward synthetic is made to verify the surface-wave solution

For sample data sets, the first four directories will be used.

Step 6 – Place data into the event processing directory and process

We now copy the data set to the work area, unpack the SEED volume into Sac files, and then start the final process.

First remember where we are:

```
rbh> pwd
/cygdrive/c/MOMENT_TENSOR/MECH.NA
```

We now follow the instructions to copy the SEED volume, which we have in the RAW directory, to the work area. Normally this would be obtained from IRIS

```
rbh> cp RAW/20080418093700.seed \
     /cygdrive/c/MOMENT_TENSOR/MECH.NA/20080418093700/20080418093700
rbh> cd /cygdrive/c/MOMENT_TENSOR/MECH.NA/20080418093700/20080418093700
rbh> cd Sac
rbh> rdseed -f ../*.seed -R -d -o 1
```

(The '\' indicates that the command continues to the next line).

The SEED volume is now unpacked and we return to the top level:

```
rbh> cd /cygdrive/c/MOMENT_TENSOR/MECH.NA
```

and enter the last command

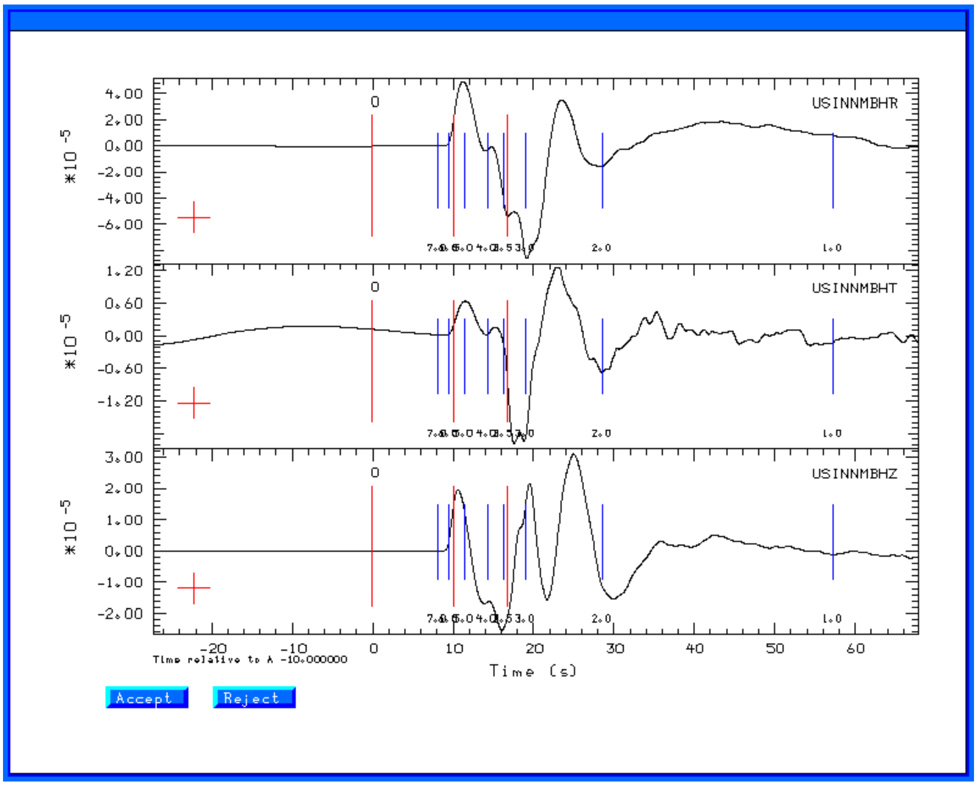
```
rbh> DOFINISH
```

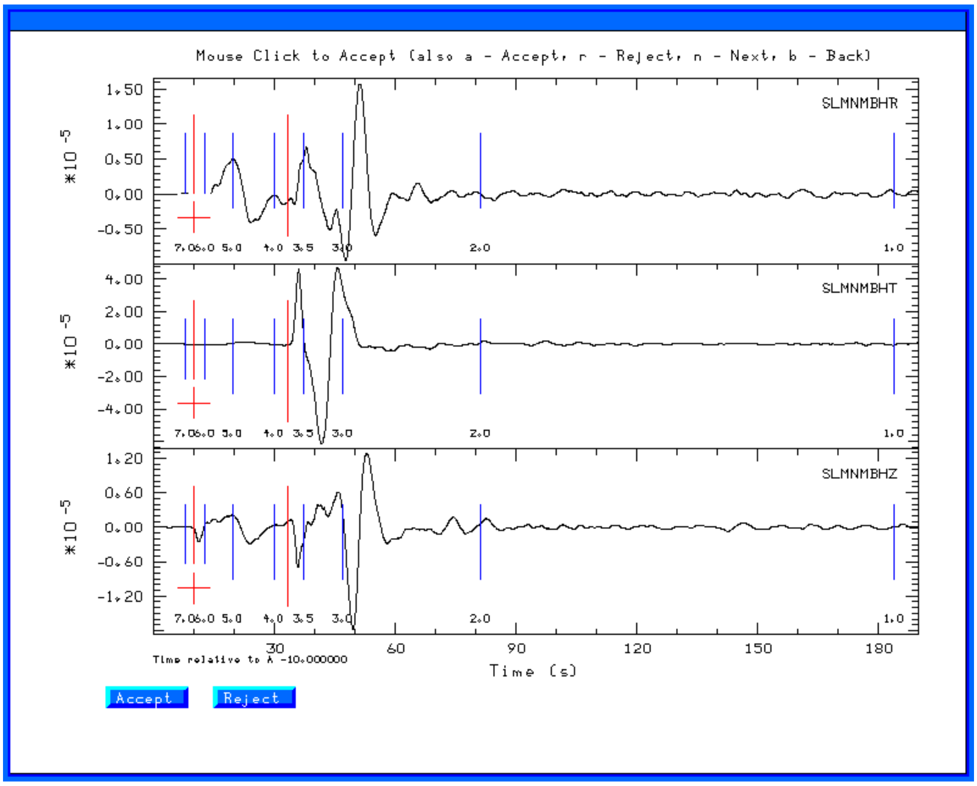
You will see a lot of output as the instrument response is removed to convert the digital counts to ground velocity in *m/s*. The predicted P arrival times using the AK135 continental model are placed in the trace headers, the three-component traces are rotated to vertical (up positive), radial and transverse components, all traces at distances less than 700 km are selected, and an interactive quality control begins.

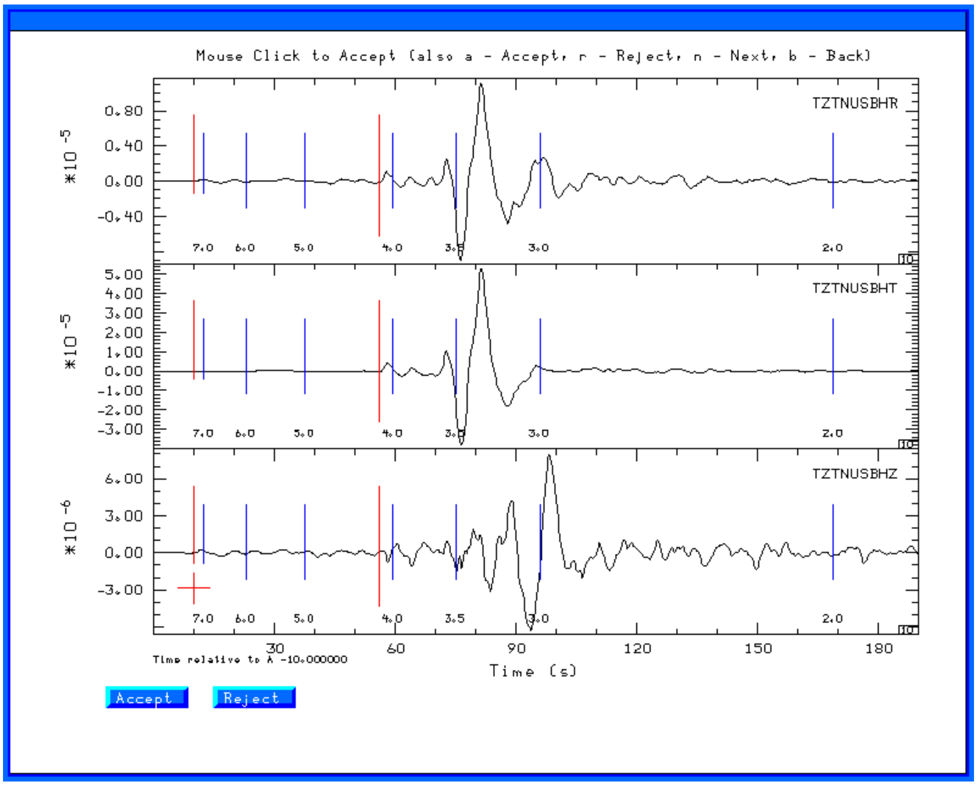
The quality control presents the waveforms in the same manner that they will be used for the inversion, e.g., the time window and filtering are the same. Placing the cursors on a trace, and clicking any mouse button will cause a red '+' symbol to be plotted to indicate that this trace should be used for inversion. A trace will not be used if you do not click or if you enter 'r', for reject, from the keyboard. You can use the Sac commands 'x' and 'x' to reposition the trace (or the gsac '+' '-' 'spacebar'). The traces are presented in increasing distance order. Use the 'n' key to go to the next set of traces.

I look for the same P-wave polarity on the vertical and radial, little or no P-wave on the transverse, and Rayleigh wave particle motion on the vertical and radial at large distance. Recall that the fundamental Rayleigh-wave motion is retrograde elliptical. The display indicates the group velocity of the arrival by the vertical blue bars with the numbers indicating the velocity. The vertical red lines indicate the origin time and the AK-135 P- and S-arrival time predictions for this distance.

The station USIN is closest. SLM is far enough away that the Love and Rayleigh waves separate out and the Rayleigh wave particle motion on the Z and R traces is seen. The TZTN horizontals are not used since the T and R traces are identical in shape, an indication of problems with the original N and E traces.







When done with the data set, either when you run out of traces to review or when you enter the 'q', the traces selected will be moved from the **`20080418093700/20080418093700/FINAL.QC`** directory up one level to **`20080418093799/DAT.REG`** and the processing will begin in the **`20080418093700/GRD.REG`** directory.

As the grid-search inversion proceeds, you will see output such as

```
 What is the input file name?
 What is the output file name?
WVFGRD96    0.5   125    80     5   4.85 0.2144
 What is the input file name?
 What is the output file name?
WVFGRD96    1.0   305    85    10   4.89 0.2319
 What is the input file name?
 What is the output file name?
WVFGRD96    2.0   300    85    -5   4.96 0.2599
 What is the input file name?
 What is the output file name?
WVFGRD96    3.0   300    75     5   5.01 0.2681
 What is the input file name?
 What is the output file name?
WVFGRD96    4.0   300    70     0   5.03 0.2797
 What is the input file name?
 What is the output file name?
WVFGRD96    5.0   300    70    -5   5.05 0.2977
```

This shows the best solution for each source depth. The output gives the program name, e.g., WVFGRD96, the depth, strike, dip and rake angles, the goodness of fit. The largest value indicates the correct depth. For the stations selected, and the filter settings, the best depth is 15 km. The scripts will then select the best depth, compare synthetics for the best solution and put all graphics files in the HTML.REG directory, and finally run the DOHTML script to create the web page index.html file.

The best depth is given in the **fmdfit.dat** file in the GRD.REG directory. The best fits for all depths are given in the **FMDSUM** file, which is listed next. I indicate the final solution by the bold font.

```
WVFGRD96    0.5   125    80     5   4.85 0.2144
WVFGRD96    1.0   305    85    10   4.89 0.2319
WVFGRD96    2.0   300    85    -5   4.96 0.2599
WVFGRD96    3.0   300    75     5   5.01 0.2681
WVFGRD96    4.0   300    70     0   5.03 0.2797
WVFGRD96    5.0   300    70    -5   5.05 0.2977
WVFGRD96    6.0   300    75    -5   5.07 0.3165
WVFGRD96    7.0   295    75    -5   5.10 0.3342
WVFGRD96    8.0   295    75   -10   5.11 0.3520
WVFGRD96    9.0   120    90   -10   5.12 0.3686
WVFGRD96   10.0   295    75    -5   5.16 0.3887
WVFGRD96   11.0   295    85     5   5.18 0.4048
WVFGRD96   12.0   295    85     5   5.19 0.4171
WVFGRD96   13.0   295    85     5   5.20 0.4244
WVFGRD96   14.0   295    85     5   5.21 0.4289
WVFGRD96   15.0   295    85     5   5.22 0.4301
WVFGRD96   16.0   295    85     5   5.23 0.4281
WVFGRD96   17.0   295    85     0   5.23 0.4245
WVFGRD96   18.0   295    85     0   5.24 0.4196
WVFGRD96   19.0   115    90    -5   5.25 0.4116
WVFGRD96   20.0   295    85     0   5.26 0.4042
WVFGRD96   21.0   115    90    -5   5.26 0.3940
WVFGRD96   22.0   295    85     0   5.27 0.3849
WVFGRD96   23.0   115    90    -5   5.27 0.3736
WVFGRD96   24.0   295    85    -5   5.27 0.3611
WVFGRD96   25.0   115    90    -5   5.27 0.3490
WVFGRD96   26.0   295    85    -5   5.27 0.3380
WVFGRD96   27.0   295    85    -5   5.28 0.3251
WVFGRD96   28.0   120    85     0   5.26 0.3147
```

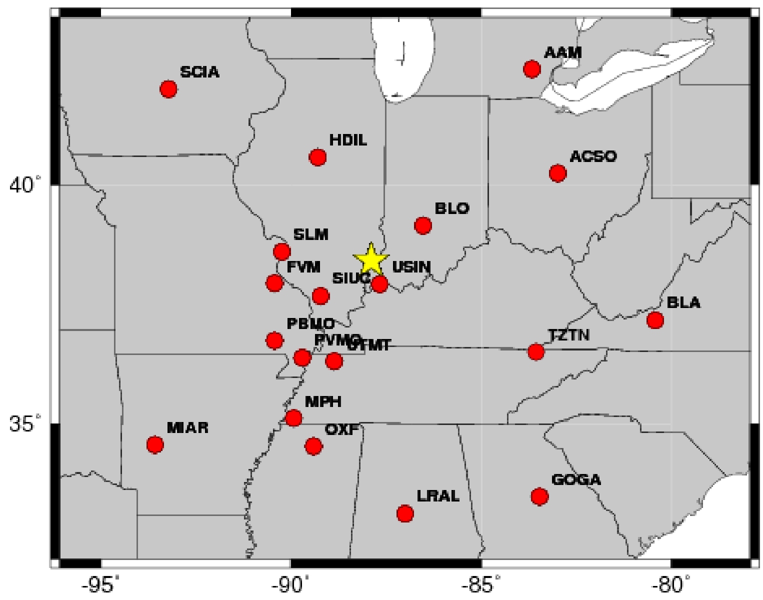
```
WVFGRD96    29.0    120     85      5    5.26 0.3061
```

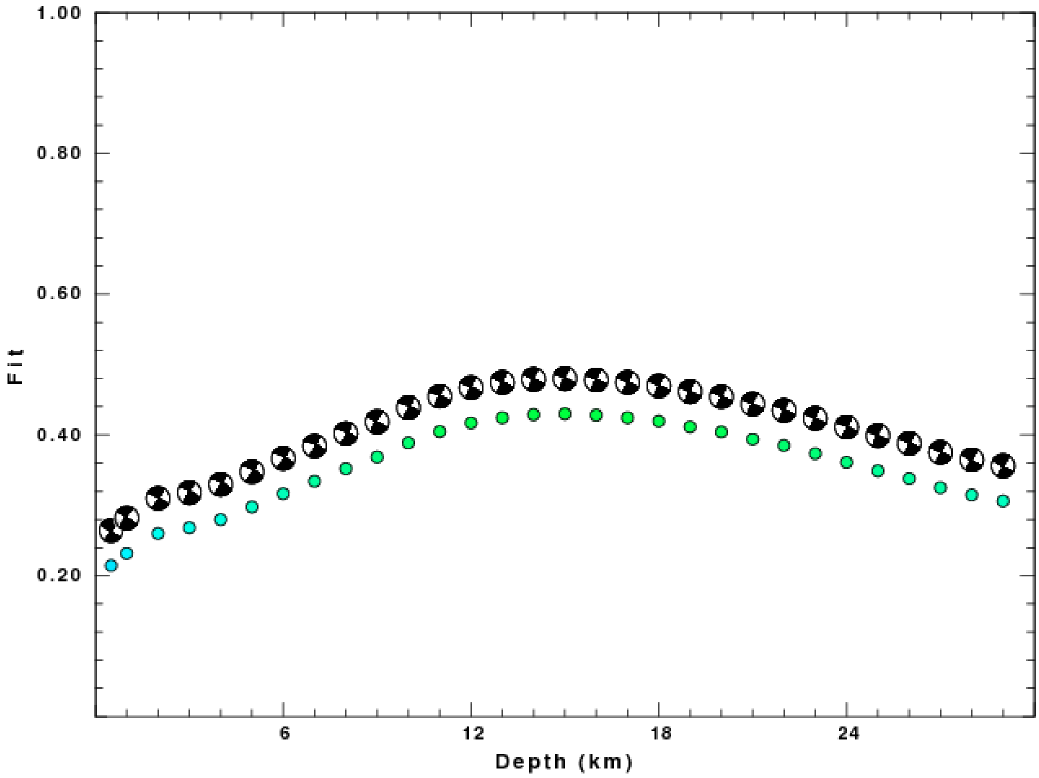
You can review the inversion results my opening the browser (Firefox or Internet Explorer) to

`C:\usr\MOMENT_TENSOR\MECH.NA\20080418093700\HTML.REG`

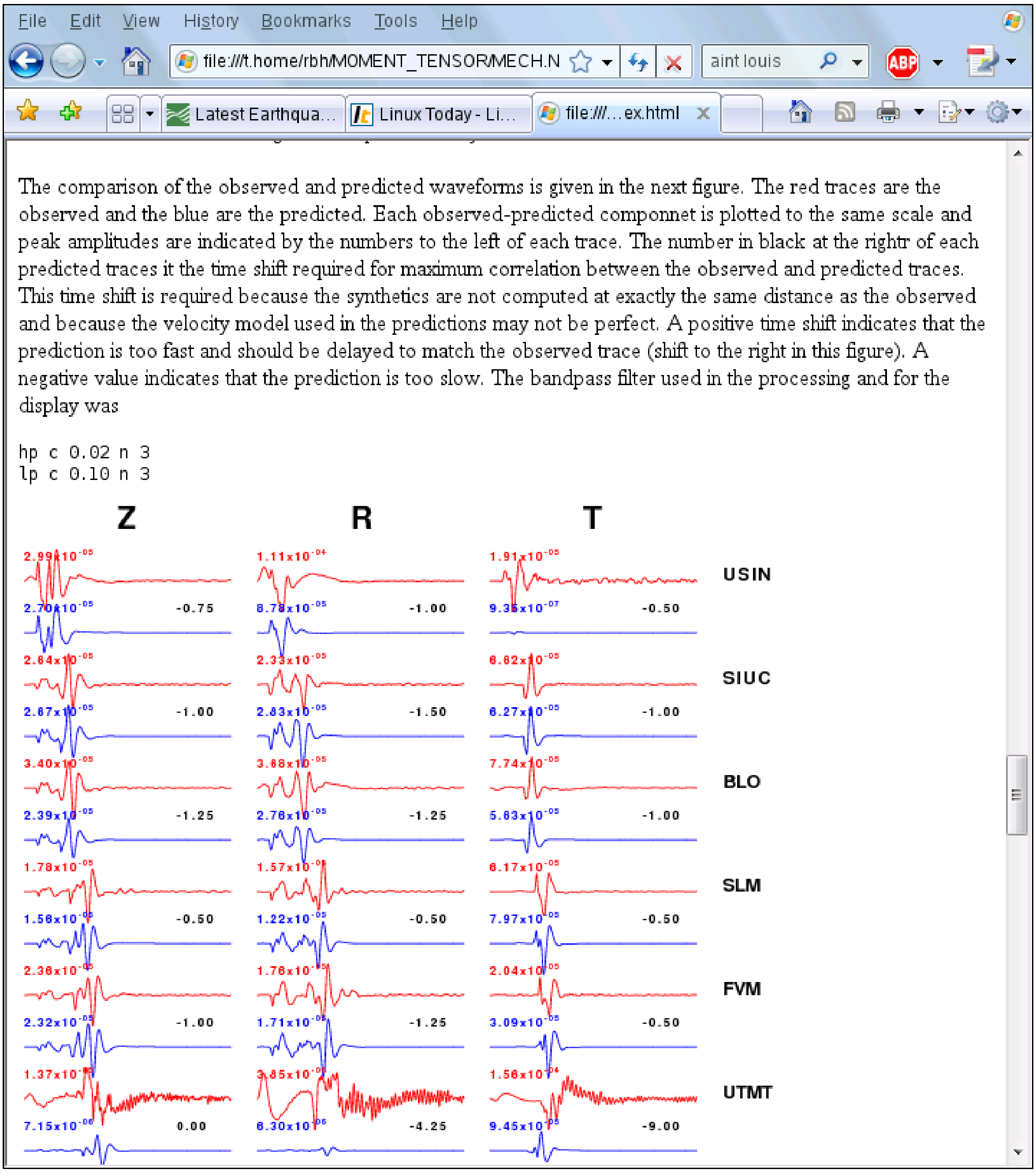
and then selecting the 'index.html' file. Note on Windows, Internet Explorer or Firefox uses the Windows view of the file system and not that of CYGWIN. You will see five figures, two of which are shown here. The seismogram comparison is useful. On can justify removing traces if it seems that the instrument is not working correctly, e.g., the USIN horizontals, or the UTMT instruments. Such decisions require some experience and an understanding of seismic wave propagation.

The figures below show the stations used in the inversion (a map created using GMT), the goodness of fit with source depth, and a portion of the trace display.





1.00
0.80
0.60
0.40
0.20
Fit
6
12
18
24
Depth (km)



The comparison of the observed and predicted waveforms is given in the next figure. The red traces are the observed and the blue are the predicted. Each observed-predicted componnet is plotted to the same scale and peak amplitudes are indicated by the numbers to the left of each trace. The number in black at the rightr of each predicted traces it the time shift required for maximum correlation between the observed and predicted traces. This time shift is required because the synthetics are not computed at exactly the same distance as the observed and because the velocity model used in the predictions may not be perfect. A positive time shift indicates that the prediction is too fast and should be delayed to match the observed trace (shift to the right in this figure). A negative value indicates that the prediction is too slow. The bandpass filter used in the processing and for the display was

```
hp c 0.02 n 3
lp c 0.10 n 3
```


The solution for this earthquake is given at

http://www.eas.slu.edu/eqc/eqc_mt/MECH.NA/20080418093700/index.html

More things to do

Remove bad traces

To remove some traces and then to rerun, there are two steps:

First, go to the DAT.REG directory and move the unwanted traces. I place them in the NOUSE subdirectory

```
rbh> mv UTMT* NOUSE
rbh> mv USINBHT NOUSE
```

Second go to the processing directory, and cleanup

```
rbh> cd ../GRD.REG
rbh> DOCLEANUP
```

The DOCLEANUP script removes all files ending with .obs .pre Z R and T. If you wish to change the filtering bands, e.g., to change the time window, bandpass corner frequencies or apply the microseism filter, carefully modify the DOSTA script. Now restart everything and generate the revised documentation.

```
rbh> DOGRD; DOPLTSAC; cd ../HTML.REG; DOHTML
```

The ';' indicates the end of a command. This is one way to issue all of the commands at once, and then have everything run to completion.

Try a different model.

The **`mech.sh`** permits the use of the WUS model, which is not proper for the April 18, 2008 eastern U.S. earthquake. Rerun the inversion and compare the results. You will see that the fit is not as good.

Determine the source parameters of the Nevada earthquake

This is the 20080221235752 earthquake in the western U.S. Use the WUS model for this data set. The preferred solution for this earthquake is found at

http://www.eas.slu.edu/eqc/eqc_mt/MECH.NA/20080221235752/index.html

You may wish to change the corner frequencies from 0.02 – 0.10 Hz to 0.02 – 0.06 Hz.

Exercise 2 - Regional Earthquakes – Turkey

For the purposes of this documentation, it is assumed that you are on the CYGWIN system, and that everything was installed in the */cygdrive/c/usr* directory.

Step 1 -Go to work area

Go to the work area for Turkey earthquakes

cd /cygdrive/c/usr/MOMENT_TENSOR/MECH.TR

Examine the contents of the directory:

```
rbh> ls
00README  DOFINISH*  DOSETUP*     out       RAW/
0XXXREG/  DOIRIS*    DOSOLUTION*  PROTO.I/  Response/
DO*       DOISETUP*  mech.sh*     PROTO.TR/ Stations/
```

This is very similar to the files seen in the North American directory MECH.NA, except that the **PROTO.TR** and **Response** are new directories.

Step 2 – Get the data

The waveform data are available in two formats: continuous data and SEED volumes for events . We will work with the event data.

The broadband data are from stations in Turkey which are operated by

Boğaziçi Üniversitesi and Kandilli Rasathanesi ve Deprem Araştırma Enstitüsü (Kandiill Observatory). To obtain access to these data one must have an account. You can request an access account from the login page. To login, go to

http://barbar.koeri.boun.edu.tr/sismo/zKDRS/login.asp

and then get access to data at

http://www.koeri.boun.edu.tr/sismo/veri_bank/mainw.htm

A map of broadband station locations is given at the link

http://www.koeri.boun.edu.tr/sismo/istasyonlar/bb_istasyonlar.htm

[Note: This would be a better map if latitudes and longitudes were given on the map.]

Event Data:

The event data are presented as Sac files and seem to have the event origin time and location as well as the station coordinates places in the Sac headers of each trace. The selected events will include the larger earthquakes, e.g., with M > 3.5 or so.

Continuous Data:

With the continuous data, it may be necessary to place the station coordinates into the Sac header. A list of the station coordinates is given at

http://www.koeri.boun.edu.tr/sismo/istasyonlar/bbstn.htm

This software distribution has the station coordinate information in the directory **`Stations`** which contains a shell script **`DOLISTCOORD`** that creates the file **`ko.coord`**, which can be used with a shell script that you can write to set the parameters in the Sac files. The **`DOLISTCOORD`** reads the web based format, which is in DDMM, e.g., 3643.74 means and 36 degrees and 43.74 minutes and converts to 36.729 degrees, which is the format required for the Sac header.

[Note: this web page would be better if there were a link to a separate text file and if the coordinates were given in degrees.]

Response:

The broadband responses can be downloaded from the link:

http://www.koeri.boun.edu.tr/sismo/veri_bank/util/Polezero.zip

[e.g., **`wget http://www.koeri.boun.edu.tr/sismo/veri_bank/util/Polezero.zip`** wil get the file].

The responses provide the velocity sensitivity of the instruments in a Sac pole-zero file, with meters/s input and digital counts output, e.g., counts/m/s are the units of the transfer function. These response are placed in the directory **`Response`**. Note these should be checked periodically since the responses may change at the observatory. Note also that there is no FROM/TO associated with the response to indicate the times for which the response apply (this is one reason to use the SEED RESP format which can contain the entire history or instrumentation). The processing scripts require access to the **`Response`** directory.

Test data sets:

The folder RAW contains digital data from 9 events which were downloaded from the data archive. When downloading, I changed the name of the file names to avoid problems with the SHELL, e.g., I renamed the file

```
20080315_101538-KARAALI-BALA-(ANKARA).M=4.9.ZIP
```

to the following form

```
20080315_101538-AFSAR-BALA-ANKARA.M.4.9.ZIP
```

since the () and = would require extra effort for the use of the file in a shell script.

Step 3 – Sample data sets

We will select a data set from inversion from the RAW directory.

```
rbh> ls RAW
00README
20080312_185331-CINARCIK-YALOVA.M.4.8.ZIP
20080315_101538-AFSAR-BALA-ANKARA.M.4.9.ZIP
20080315_101538-KARAALI-BALA-ANKARA.M.4.9.ZIP
20080725_112901-AKDENIZ.M.4.1.ZIP
20080726_221650-VAN.M.4.6.ZIP
20080903_022249-SAMSAT-ADIYAMAN.M.5.1.ZIP
20080917_120812-OTLUKBELI-ERZINCAN.M.4.7.ZIP
20080930_073000-DUMLUPINAR-KUTAHYA.M.4.7.ZIP
20081105_073649-BULGARISTAN.M.4.0.ZIP
20090117_074526-OSMANIYE.M.4.5.ZIP
```

and look at the contents of the 00README file:

```
rbh> cat RAW/00README
```

```
These are Turkey Time
        subtract 2 or 3 for UT
     LOCAL TIME                                                        UT
DD MM YEAR HR MN SC  LAT     LON     H   MAG  LOCATION             YEAR MN DY HR MI SC
12.03.2008 20:53:31 40.621N 29.011E 11.2 4.8 CINARCIK (YALOVA)    2008 03 12 18 53 31
15.03.2008 12:15:38 39.501N 32.951E 14.9 4.9 AFSAR-BALA (ANKARA)  2008 03 15 10 15 38
25.07.2008 14:29:01 35.689N 27.767E 41.6 4.1 AKDENIZ             2008 07 25 11 29 01
27.07.2008 01:16:50 38.437N 43.392E 10.9 4.6 VAN                 2008 07 26 22 16 50
03.09.2008 05:22:47 37.507N 38.503E  5.7 5.1 SAMSAT (ADIYAMAN)    2008 09 03 02 22 47
17.09.2008 15:08:12 40.010N 39.978E  5.4 4.7 OTLUKBELI (ERZINCAN) 2008 09 17 12 08 12
30.09.2008 10:30:00 38.990N 29.866E  5.0 4.7 DUMLUPINAR (KUTAHYA) 2008 09 30 07 30 00
05.11.2008 09:36:49 43.445N 27.379E 13.1 4.0 BULGARISTAN         2008 11 05 07 36 49
17.01.2009 09:45:26 37.096N 36.313E  5.6 4.5 OSMANIYE            2009 01 17 07 45 26

The Zip files containing the Data are:

20080312_185331-CINARCIK-YALOVA.M.4.8.ZIP
20080315_101538-AFSAR-BALA-ANKARA.M.4.9.ZIP
20080725_112901-AKDENIZ.M.4.1.ZIP
20080726_221650-VAN.M.4.6.ZIP
20080903_022249-SAMSAT-ADIYAMAN.M.5.1.ZIP
20080917_120812-OTLUKBELI-ERZINCAN.M.4.7.ZIP
20080930_073000-DUMLUPINAR-KUTAHYA.M.4.7.ZIP
20081105_073649-BULGARISTAN.M.4.0.ZIP
20090117_074526-OSMANIYE.M.4.5.ZIP
```

This provides the information that you need and also indicates the name of the SEED volume for each data set. We will first look at the **20080917_120812-OTLUKBELI-ERZINCAN.M.4.7.ZIP** data set.

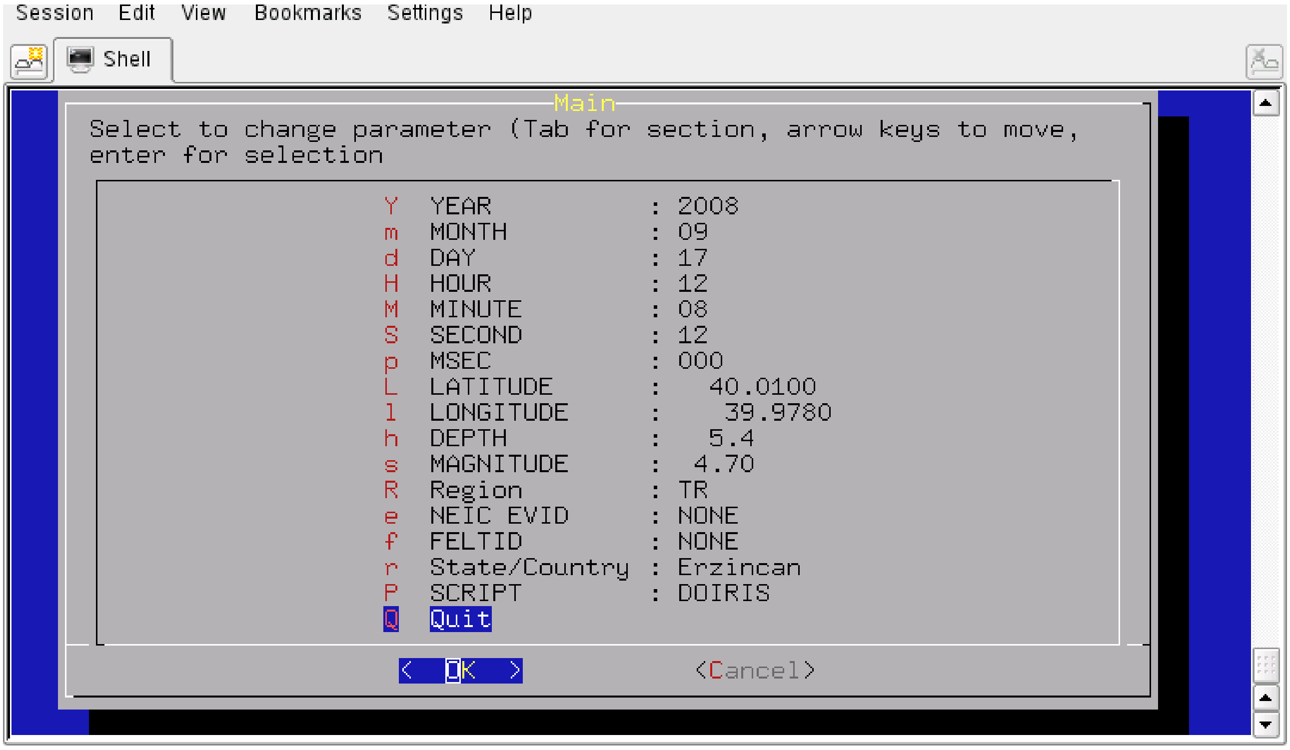
Note the difference between local time and UT. We must use UT for the inversion.

Step 4 – Create the DO script

We will use the 17.09.2008 earthquake for our initial example. We start by interactively creating the **DO** script by using the program **mech.sh**.

```
Rbh> mech.sh
```

After setting all parameters the screen looks like:



and the **DO** script is

```
DOIRIS "2008" "09" "17" "12" "08" "12" "000" "40.0100" " 39.9780" "5.4" "4.70"
"TR" "NONE" "NONE" "Erzincan"
```

(which is just one line).

Step 5 – Create the event directories

Start the processing with the command:

```
rbh> DO
```

This will return the following message:

1. PLACE THE ZIP_FILE FROM KO into

```
        /cygdrive/c/usr/MOMENT_TENSOR/MECH.TR/20080917120812/20080917120812
  2. UNPACK the ZIP_FILE FROM KO as follows
     cd Sac
     unzip  ../ZIP_FILE
     [Note use the name of the downloaded file for ZIP_FILE, e.g.,
         20080312_185331-CINARCIK-YALOVA.M.4.8.ZIP]
         You may have to enclose the name in quotes for this to work in the shell
  3. Return to the top level directory where you started:
     cd /cygdrive/c/usr/MOMENT_TENSOR/MECH.TR
  4. enter the command:
     DOFINISH
```

Step 6 – Place data into the event processing directory and process

We now copy the data set to the work area, using the following steps:

```
rbh> pushd .
rbh> cp RAW/20080917_120812-OTLUKBELI-ERZINCAN.M.4.7.ZIP  20080917120812/20080917120812
rbh> cd 20080917120812/20080917120812/Sac
rbh> unzip ../*.ZIP
Archive:  ../20080917_120812-OTLUKBELI-ERZINCAN.M.4.7.ZIP
    inflating: AFSR.BHE.KO
    inflating: AFSR.BHN.KO
      . . . . . . . . .
    inflating: YOZ.SHZ.KO
rbh> popd
```

I start in the **MECH.TR** directory. I use the "**pushd .**" command so that the shell remembers this directory (the "." means current working directory). I then copy the correct ZIP file to the proper work area. I do not have to use the exact absolute path, since I am also permitted to define the destination relative the the **MECH.TR** directory. I then go to the Sac work directory, and unpack the ZIP file. The command **popd** returns me to **MECH.TR**.

Finally we start the processing with the single command:

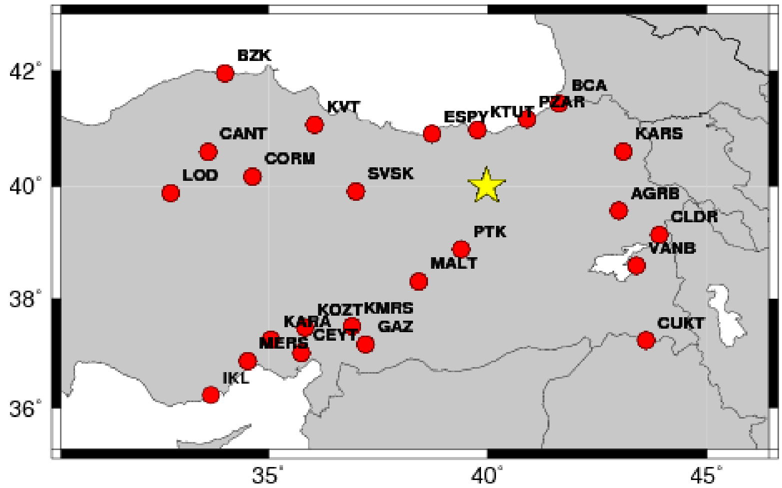
```
rbh> DOFINISH
```

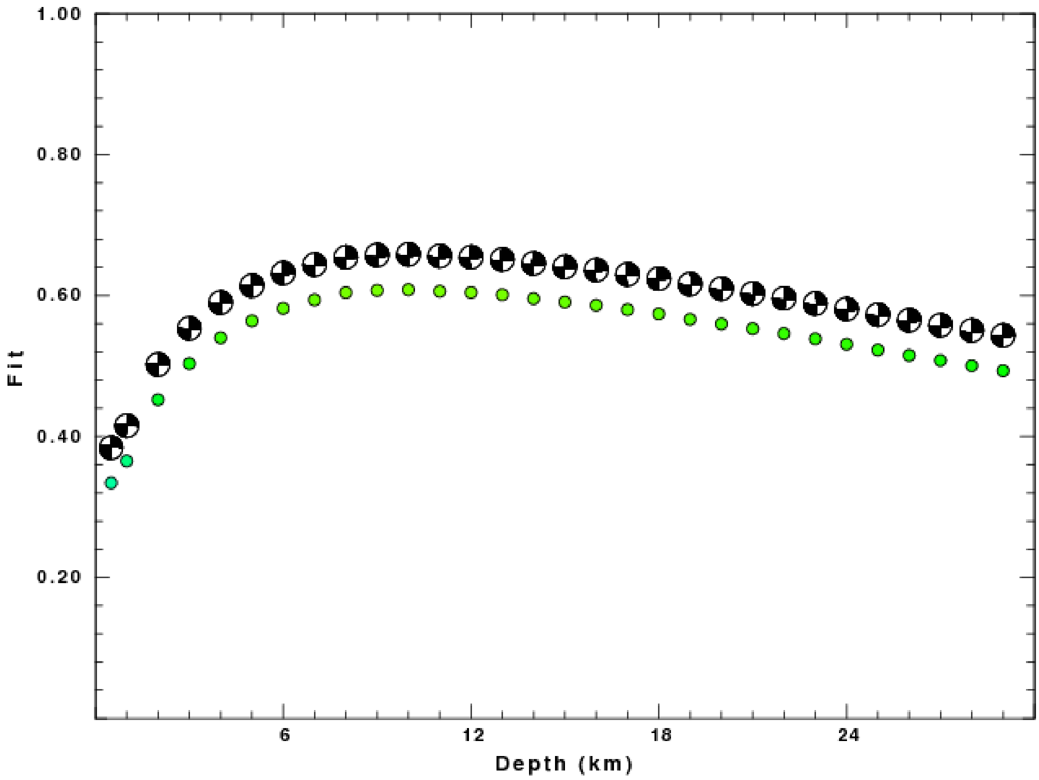
At the quality control display, I do not use URFA since the trace is truncated or the KRTS traces since the signal is too late. Since the signal-to-noise ratio is high and since my WUS model is not designed for use in Turkey, I edited the **DOSTA** script in **GRD.REG** to set **FLOWPASS=0.05** instead of the default **FLOWPASS=0.10**.

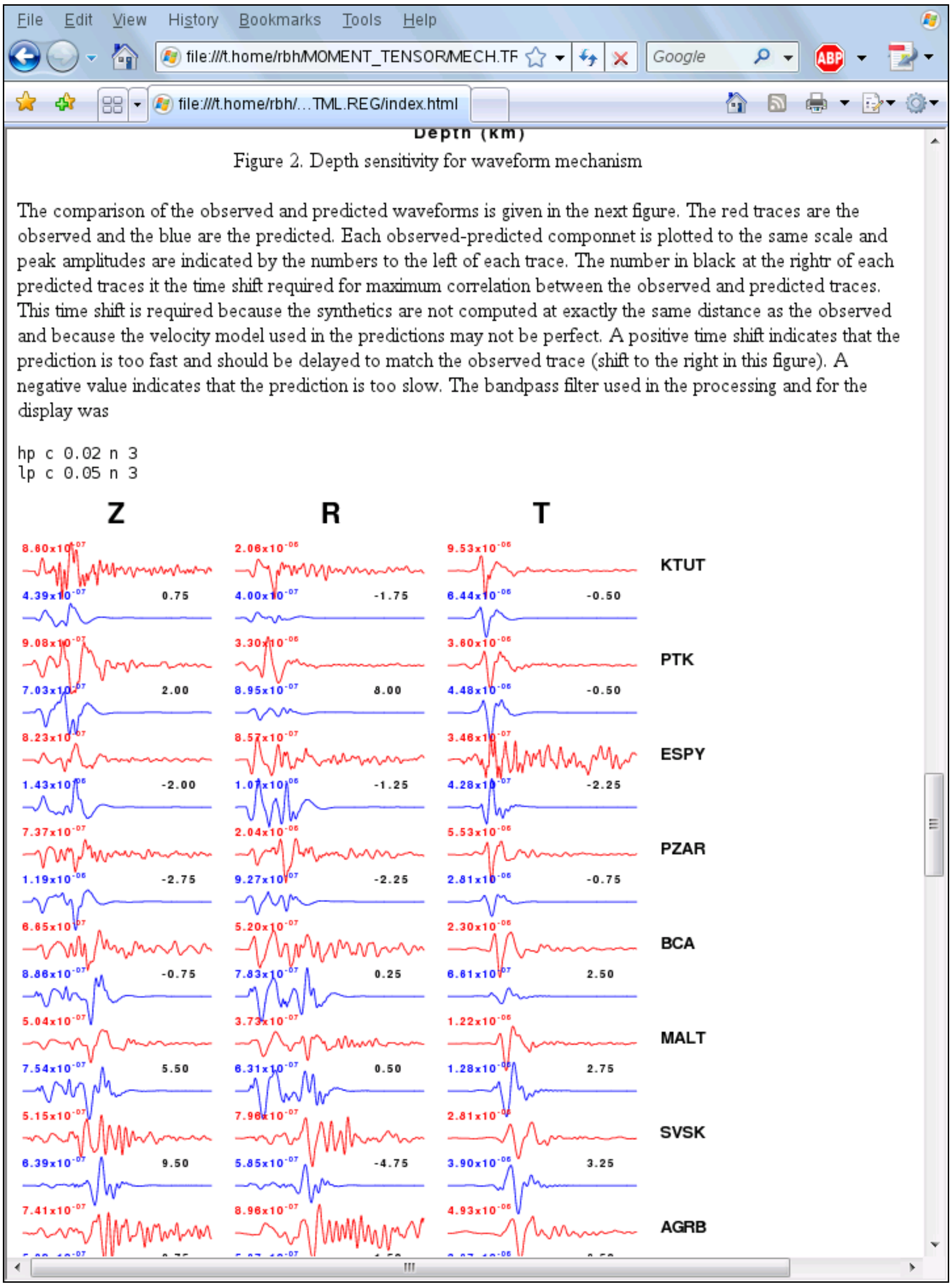
The contents of the **FMDSUM** listing in the **DAT.REG** directory are as follow:

```
WVFGRD96    0.5   185    90   -15    4.27 0.3341
WVFGRD96    1.0   185    90   -10    4.29 0.3653
WVFGRD96    2.0     5    85     0    4.38 0.4521
WVFGRD96    3.0     0    85    -5    4.43 0.5034
WVFGRD96    4.0     0    85    -5    4.47 0.5400
WVFGRD96    5.0   180    90    -5    4.50 0.5640
WVFGRD96    6.0     0    90   -10    4.52 0.5818
WVFGRD96    7.0     0    90   -10    4.55 0.5938
WVFGRD96    8.0   180    90    10    4.57 0.6042
WVFGRD96    9.0   180    90    15    4.59 0.6073
WVFGRD96   10.0     0    90   -15    4.60 0.6083
WVFGRD96   11.0   185    80    15    4.60 0.6060
WVFGRD96   12.0   180    80    10    4.62 0.6043
WVFGRD96   13.0   180    80    10    4.63 0.6011
WVFGRD96   14.0   185    80    15    4.63 0.5956
WVFGRD96   15.0   185    80    15    4.64 0.5907
WVFGRD96   16.0   180    80    10    4.65 0.5862
WVFGRD96   17.0   180    80    10    4.66 0.5800
WVFGRD96   18.0   180    80     5    4.66 0.5739
WVFGRD96   19.0     0    80   -10    4.67 0.5662
WVFGRD96   20.0     0    80   -10    4.67 0.5597
WVFGRD96   21.0     0    80   -10    4.68 0.5529
WVFGRD96   22.0     0    80   -10    4.69 0.5460
WVFGRD96   23.0     0    80   -10    4.69 0.5386
WVFGRD96   24.0     0    80   -10    4.70 0.5308
WVFGRD96   25.0     0    80   -10    4.70 0.5228
WVFGRD96   26.0     0    90   -15    4.71 0.5150
WVFGRD96   27.0     0    90   -15    4.71 0.5079
WVFGRD96   28.0     0    90   -15    4.72 0.5004
WVFGRD96   29.0   180    85    10    4.72 0.4933
```

From this we see that the event was at a depth of 10.0 km, and a moment magnitude of 4.6 and is mostly strike-slip. Some of the figures from the **MECH.REG** directory are shown here.







Although some traces are noisy, I consider these good fits because the large value of the goodness of fit parameter indicates that the shapes are fit well. I also look at the time shifts to evaluate the model, and keep in mind that low amplitude signals do not contribute must to the solution. One can remove some of the stations to the southwest since they are at the same distance and azimuth, and thus do not contribute any additional information for the solution. On the other hand, a comparison provides a check on the instruments. For example the horizontal components at CEYT have long-period noise.   The good fits and the relatively small time shifts indicate that the WUS velocity model used is almost adequate for use in this part of Turkey.

More things to do

Process the other 8 data set sets.

Exercise 3 – Quality Control Using Teleseisms

Using a known moment tensor solution for a teleseism (great circle arc distance 30° – 95°), forward synthetics will be generated to compare to observed three component observations. To ensure a comparison of a large amplitude signal, we model the vertical component P, the transverse component SH and the radial component SV. The scripts to accomplish this are essentially those use for the determination of the moment tensor using long-period body waves.

For the purposes of this documentation, it is assumed that you are on the CYGWIN system, and that everything was installed in the */cygdrive/c/usr* directory.

NOTE THESE SCRIPTS ARE AVAILABLE BY REQUEST

Step 1

Go to the work area for quality control using teleseisms.

cd /cygdrive/c/usr/MOMENT_TENSOR/MECHQC.TEL

Examine the contents of the directory:

```
rbh> ls
0XXXTELQC/       DOIRISTELQC*  DO.save*           mechqctel.sh*  RAW/
DOCWBTELQC*      DOISETUPTEL*  DOSETUPTELQC*      PROTO.CWB/
DOFINISHTELQC*   DOQUERYTEL*   DOSOLUTIONTELQC*   PROTO.I/
```

As you can see, the naming is very similar to that used for the regional inversion, except that the scripts have been renamed to indicate that they are designed to be used for waveform comparison using teleseisms. The **0XXXTELQC** directory has the prototypes for the processing and documentations.

Step 2 – Get the data

Normally one must get the waveform data. An easy way to accomplish this for significant earthquakes is to use the Wilbur II interface at IRIS

http://www.iris.edu/cgi-bin/wilberII_page1.pl

or at Orfeus

http://www.orfeus-eu.org/cgi-bin/wilberII/wilberII_page1.pl

The IRIS Wilbur II interface starts by selecting the earthquake, followed by selecting the station networks, and finally by selecting the individual stations. A SEED volume is created which provides the station coordinates, the instrument orientations and responses as well as the digital data. The result is downloaded using ftp or wget.

Step 3 – Sample data sets

We will select a data set from inversion from the RAW directory,

```
rbh> ls RAW
00README  20081129055917.seed  20090115174939.seed
```

and look at the contents of the **00README** file:

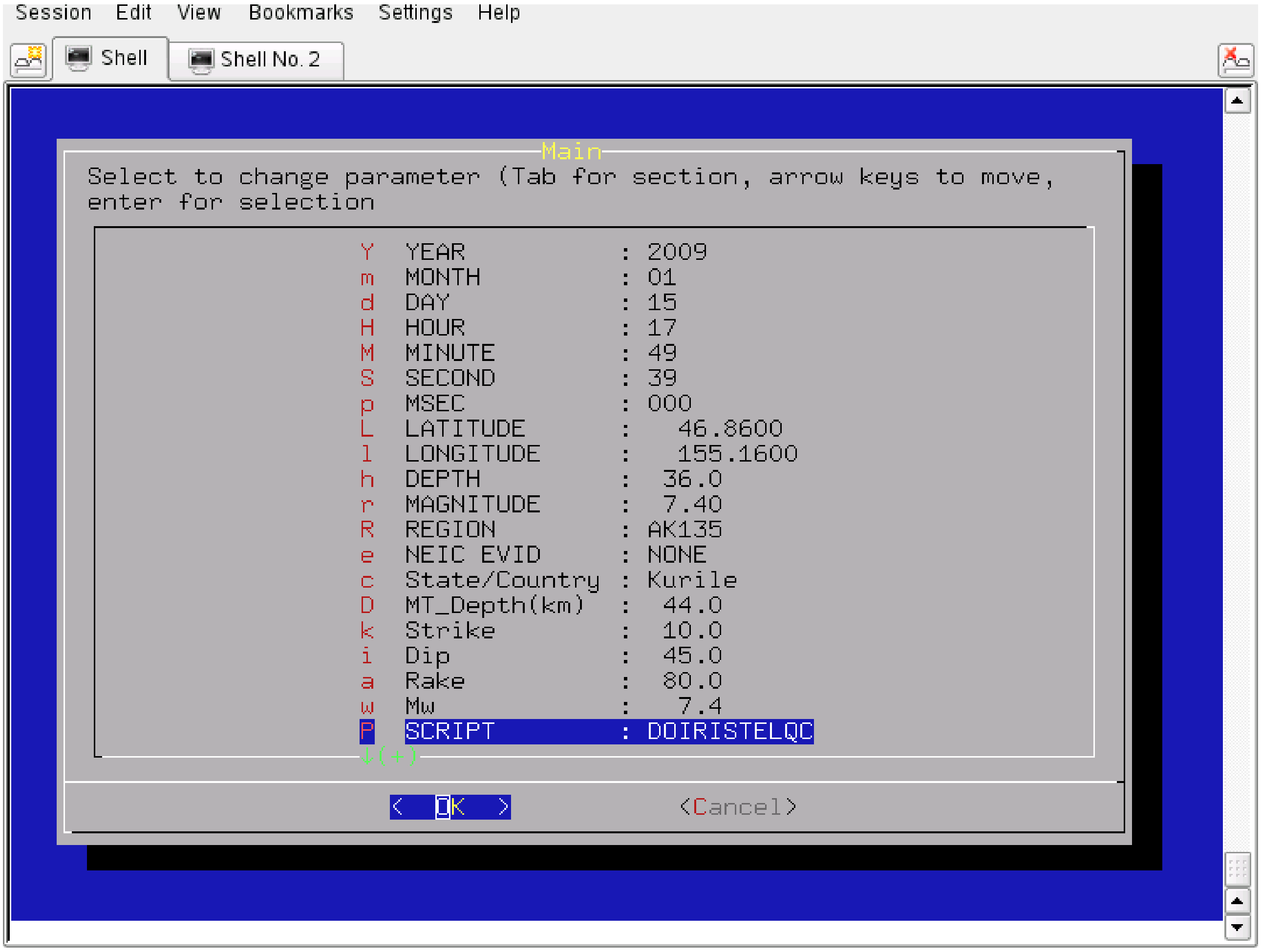
```
rbh> cat RAW/00README
```

```
YEAR MO DY HR MN SC    LAT     LON    DEP MAG   SEED_VOLUME       MT_DEPTH STRIKE DIP RAKE MW
2008/11/29 05:59:17 -18.69 -177.72 386 6.0 20081129055917.seed  396       30    42  17  6.0
2009/01/15 17:49:39  46.86  155.16  36 7.4 20090115174939.seed  44        10    45  80  7.4
```

This file provides the origin time and location of the earthquake as well as the body-wave moment tensor solution obtained by the GCMT.

Step 4 – Create the DO script

We will use the magnitude 7.4 Kurile event of 2009/01/15 as an example. We run the script **`mechqctel.sh`** to create the **`DO`** script. The last interactive screen is shown next.



And the script is

`DOIRISTELQC "2009" "01" "15" "17" "49" "39" "000" "46.8600" "155.1600" "36.0" "7.40" "AK135" "NONE" "NONE" "Kurile" "44.0" "10.0" "45.0" "80.0" "7.4"`

Step 5 – Create the event directories

Start the processing with the command:

```
rbh> DO
```

This will return the following message:

```
rbh> DO
1.    PLACE THE SEED_VOLUME FROM IRIS in
       /cygdrive/c/usr/MOMENT_TENSOR/MECHQC.TEL/20090115174939/20090115174939
2. UNPACK the SEED_VOLUME FROM IRIS as follows
   cd Sac
   rdseed -f ../SEED_VOLUME -R -d -o 1
   [Note use the name of the downloaded file for SEED_VOLUME, e.g., 20090116.seed]
3. Return to the top level directory where you started:
   cd /cygdrive/c/usr/MOMENT_TENSOR/MECHQC.TEL
4. enter the command:
   DOFINISHTELQC
rbh> DO
1. PLACE THE SEED_VOLUME FROM IRIS in
/cygdrive/c/usr/MOMENT_TENSOR/MECHQC.TEL/20090115174939/20090115174939
2. UNPACK the SEED_VOLUME FROM IRIS as follows
   cd Sac
   rdseed -f ../SEED_VOLUME -R -d -o 1
   [Note use the name of the downloaded file for SEED_VOLUME, e.g., 20090116.seed]
3. Return to the top level directory where you started:
   cd /cygdrive/c/usr/MOMENT_TENSOR/MECHQC.TEL
4. enter the command:
   DOFINISHTELQC
```

Step 6 – Place data into the event processing directory and process

We now copy the data set to the work area and unpack the SEED volume in the Sac subdirectory using the following steps:

```
rbh> pushd .
rbh> cp RAW/20090115174939.seed 20090115174939/20090115174939
rbh> cd 20090115174939/20090115174939/Sac
rbh> rdseed -f ../*.seed -R -d -o 1
<< IRIS SEED Reader, Release 4.7.5  >>
        R = print response data (with addressing for evresp)
        d = read data from tape
        Taking input from ../20090115174939.seed
Output data format will be sac.binary.
Warning... Azimuth and Dip out of Range on ANMO,BH1
Defaulting to subchannel identifier (for multiplexed data only)
Warning... Azimuth and Dip out of Range on ANMO,BH1
Defaulting to subchannel identifier (for multiplexed data only)
Writing IU.ANMO.00.BH1, 50528 samples (binary), starting 2009,015 17:58:39.0195 UT
 . . . . . . . . . . . . . . . . . . . .
 IU  XMAS 10 BHZ 2007,164,17:00:00 2999,000,00:00:00.0000   2.044849 -157.445320     1.0 -90.0   0.0
40 RESP.IU.XMAS.10.BHZ
rdseed completed.
rbh> popd
```

You are now back at the top level. Complete the processing:

```
rbh> DOFINISHTELQC
```

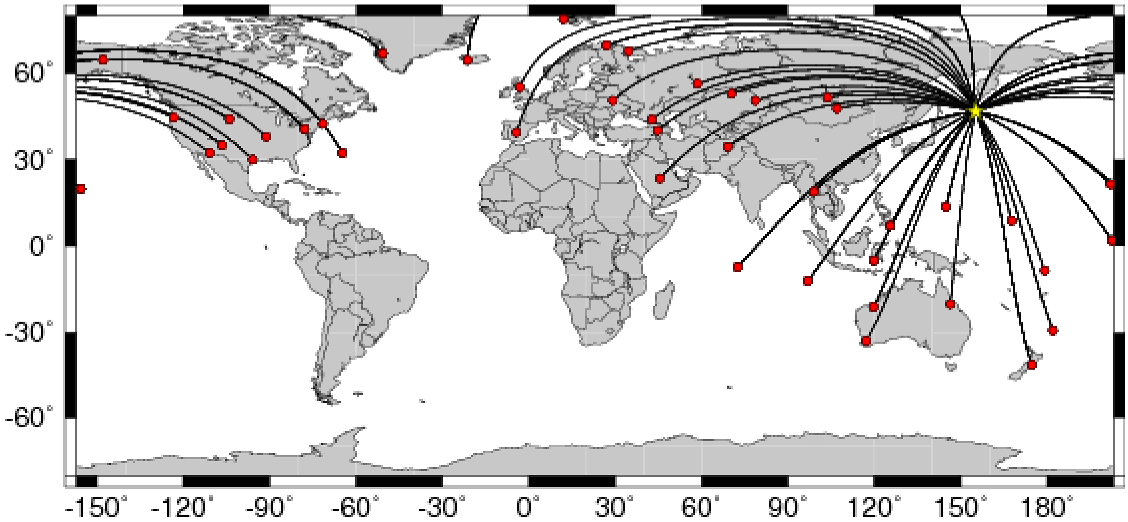
The script will remove the instrument response, rotate the components, and select traces at distances of 30°-95°.

There is no trace quality step since the purpose is to compare observed and predicted traces.

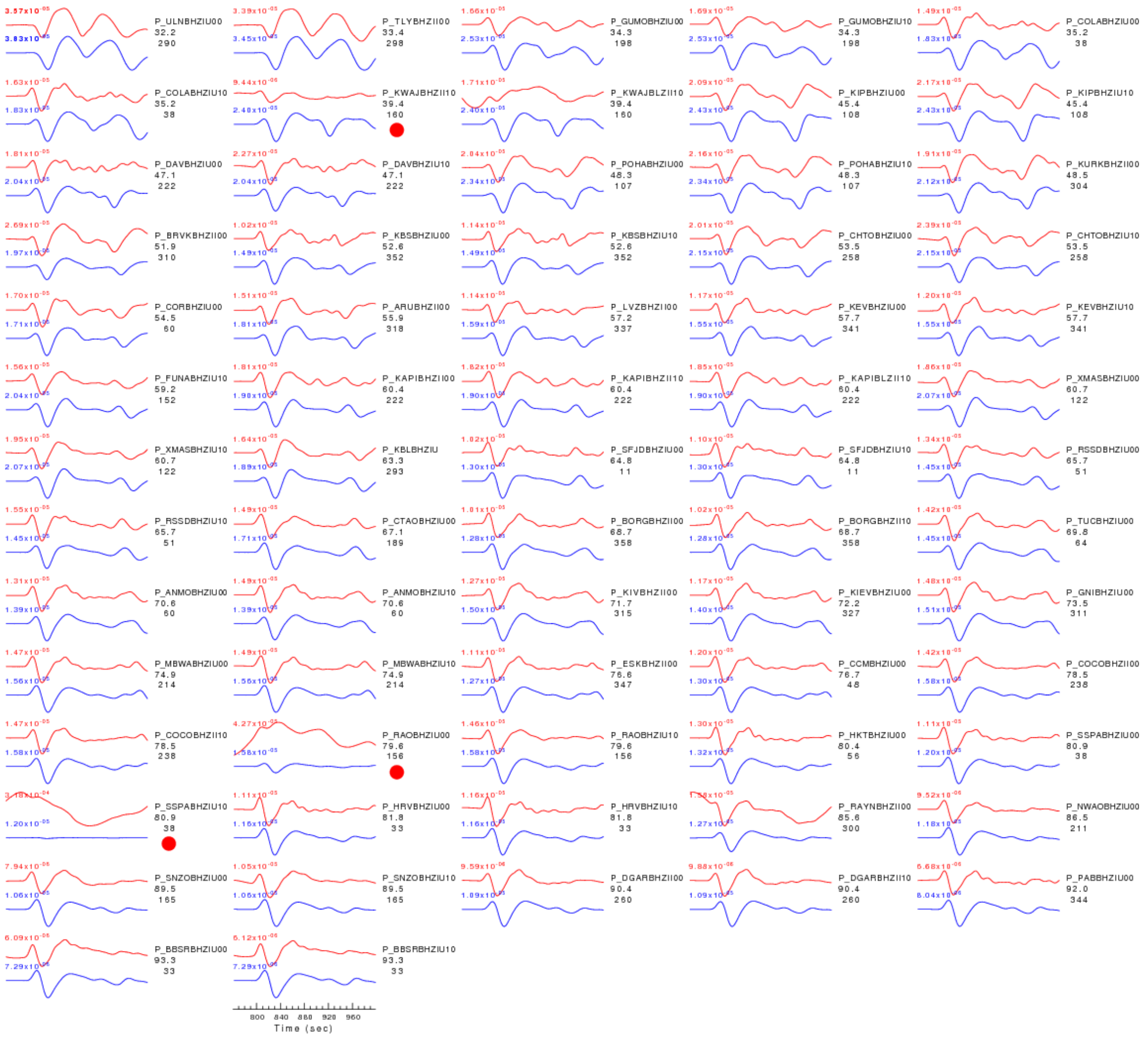
When the **DOFINISHTELQC** is completed, the results can be viewed by pointing the browser at the

C:\usr\MOMENT_TENSOR\MECHQC.TEL\20090115174939\HTML.TEL\index.html file. The initial part of the display documents the processing done to make the synthetics, by defining the band-pass filters as well as the source parameters. Four figures are generated that show the station distribution and the comparison of the P-wave signal on the vertical component, the SH-wave signal on the transverse and the SV-wave signal on the radial component.

The station distribution is shown on the next figure:



The next figure shows the P-wave comparison:



For this figure, observed (red) and predicted seismograms (blue) are ordered by increasing epicentral distance. Each pair of traces is annotated with the wave type and a station identifier (station, network, and channel id's), epicentral distance in degrees, source-to-station azimuth in degrees. Each seismogram pair is plotted with the same scale and the peak amplitudes in meters are shown above to the left of each trace. Red circles flag seismograms with amplitude misfits of a factor of 2 or more.

The processing serves two purposes. First it can be used to check the performance of instruments. The SSPA station has a high long-period noise level, where the noise is 25 times larger than the prediction. One would then verify that the station was operating correctly. The other purpose is the ability to remove a trace from source inversion if the anomalous amplitude can be attributed to malfunction or, in some cases, improperly recorded instrument responses.

One can change the time windows in the DOPZSTA, DOSHSTA and DOSVSTA scripts in the SYN.TEL directory to compare more signal, including the mantle surface waves.

Exercise 4 – Moment Tensors of Teleseisms

For the purposes of this documentation, it is assumed that you are on the CYGWIN system, and that everything was installed in the **/cygdrive/c/usr** directory.

Step 1

Go to the work area for North American earthquakes

cd /cygdrive/c/usr/MOMENT_TENSOR/MECH.TEL

Examine the contents of the directory:

```
rbh> ls
0XXXTEL/      DOIRISTEL*    DO.save*        mechtel.sh*  RAW/
DOCWBTEL*     DOISETUPTEL*  DOSETUPTEL*     PROTO.CWB/
DOFINISHTEL*  DOQUERYTEL*   DOSOLUTIONTEL*  PROTO.I/
```

As you can see, the naming is very similar to that used for the regional inversion, except that the scripts have been renamed to indicate that they are designed to be used for inversion of long period teleseismic body waves. The **0XXXTEL** directory has the prototypes for the processing and documentations.

Step 2 – Get the data

Normally one must get the waveform data. An easy way to accomplish this for significant earthquakes is to use the Wilbur II interface at IRIS

http://www.iris.edu/cgi-bin/wilberII_page1.pl

or at Orfeus

http://www.orfeus-eu.org/cgi-bin/wilberII/wilberII_page1.pl

The IRIS Wilbur II interface starts by selecting the earthquake, followed by selecting the station networks, and finally by selecting the individual stations. A SEED volume is created which provides the station coordinates, the instrument orientations and responses as well as the digital data. The result is downloaded using ftp, (or wget).

Step 3 – Sample data sets

We will select a data set from inversion from the RAW directory,

```
rbh> ls RAW
00README  20081129055917.seed  20090115174939.seed
```

and look at the contents of the **00README** file:

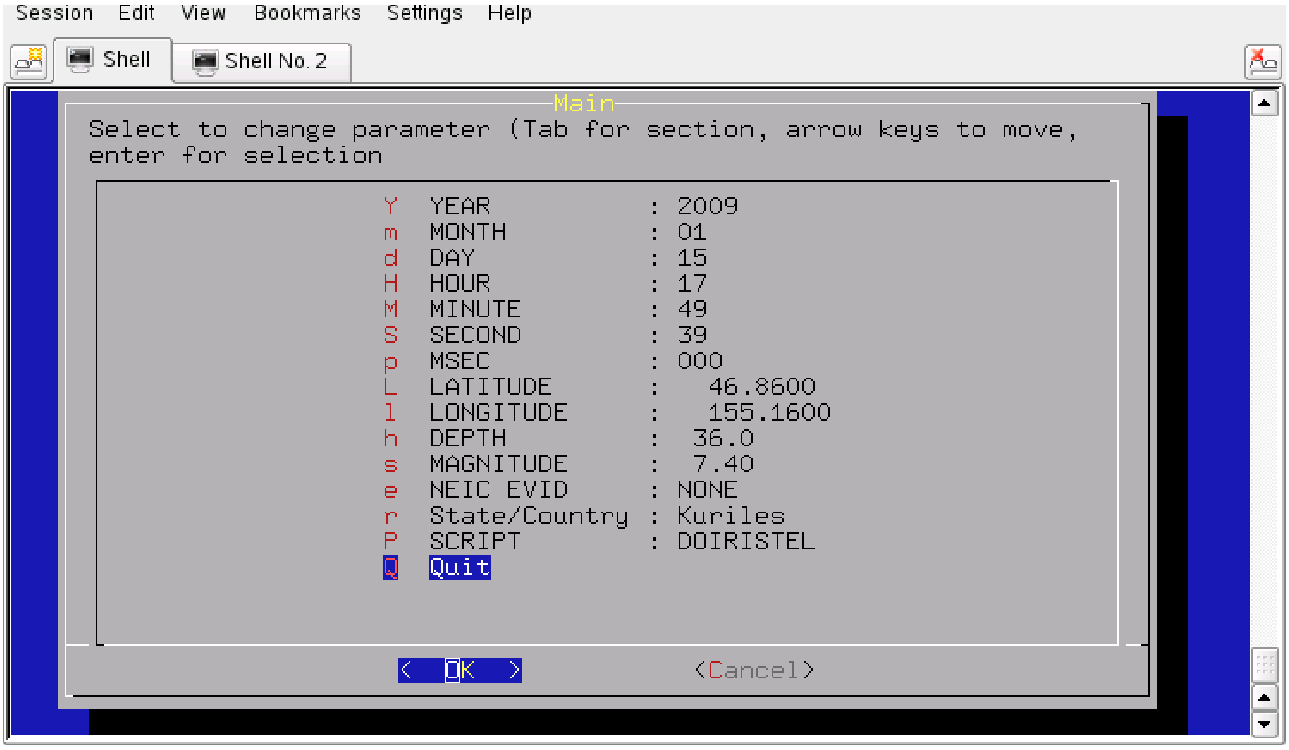
```
rbh> cat RAW/00README
YEAR MO DY HR MN SC   LAT    LON   DEP MAG   SEED_VOLUME
2008/11/29 05:59:17 -18.69 -177.72 386 6.0 20081129055917.seed
2009/01/15 17:49:39  46.86  155.16  36 7.4 20090115174939.seed
```

This file provides the origin time and location of the earthquake as well as the body-wave moment tensor solution obtained by the USGS.

Step 4 – Create the DO script

We will use the magnitude 7.4 Kurile event of 2009/01/15 as an example. We run the script

mechtel.sh to create the **DO** script. The last interactive screen is shown next.



The script is

DOIRISTEL "2009" "01" "15" "17" "49" "39" "000" "46.8600" "155.1600" "36.0" "7.40" "" "NONE" "NONE" "Kuriles"

Step 5 – Create the event directories

Start the processing with the command:

```
 rbh> DO
1. PLACE THE SEED_VOLUME FROM IRIS in
       /cygdrive/c/usr/MOMENT_TENSOR/MECH.TEL/20090115174939/20090115174939
2. UNPACK the SEED_VOLUME FROM IRIS as follows
   cd Sac
   rdseed -f ../SEED_VOLUME -R -d -o 1
   [Note use the name of the downloaded file for SEED_VOLUME, e.g., 20090116.seed]
3. Return to the top level directory where you started:
   cd /cygdrive/c/usr/MOMENT_TENSOR/MECH.TEL
4. enter the command:
   DOFINISHTELQC
rbh> DO
1. PLACE THE SEED_VOLUME FROM IRIS in
/cygdrive/c/usr/MOMENT_TENSOR/MECH.TEL/20090115174939/20090115174939
2. UNPACK the SEED_VOLUME FROM IRIS as follows
   cd Sac
   rdseed -f ../SEED_VOLUME -R -d -o 1
   [Note use the name of the downloaded file for SEED_VOLUME, e.g., 20090116.seed]
3. Return to the top level directory where you started:
   cd /cygdrive/c/usr/MOMENT_TENSOR/MECH.TEL
4. enter the command:
  DOFINISHTEL
```

Step 6 – Place data into the event processing directory and process

We now copy the data set to the work area, using the following steps:

```
rbh> pushd .
rbh> cp RAW/20090115174939.seed 20090115174939/20090115174939
rbh> cd 20090115174939/20090115174939/Sac
rbh> rdseed -f ../*.seed -R -d -o 1
<< IRIS SEED Reader, Release 4.7.5  >>
        R = print response data (with addressing for evresp)
        d = read data from tape
        Taking input from ../20090115174939.seed
Output data format will be sac.binary.
Warning... Azimuth and Dip out of Range on ANMO,BH1
Defaulting to subchannel identifier (for multiplexed data only)
Warning... Azimuth and Dip out of Range on ANMO,BH1
Defaulting to subchannel identifier (for multiplexed data only)
Writing IU.ANMO.00.BH1, 50528 samples (binary), starting 2009,015 17:58:39.0195 UT
 . . . . . . . . . . . . . . . . . . . .
 IU  XMAS 10 BHZ 2007,164,17:00:00 2999,000,00:00:00.0000   2.044849 -157.445320     1.0 -90.0   0.0
40 RESP.IU.XMAS.10.BHZ
rdseed completed.
rbh> popd
```

You are now at the top level. Complete the processing:

```
rbh> DOFINISHTEL
```

The script will remove the instrument response, rotate the components, and select traces at distances of 30º-95º. The Quality Control will present the traces filtered and windowed as for an M=6 earthquake.

The source inversion will take a long time because of the many traces and the exhaustive source at all depths between the surface and 700 km.

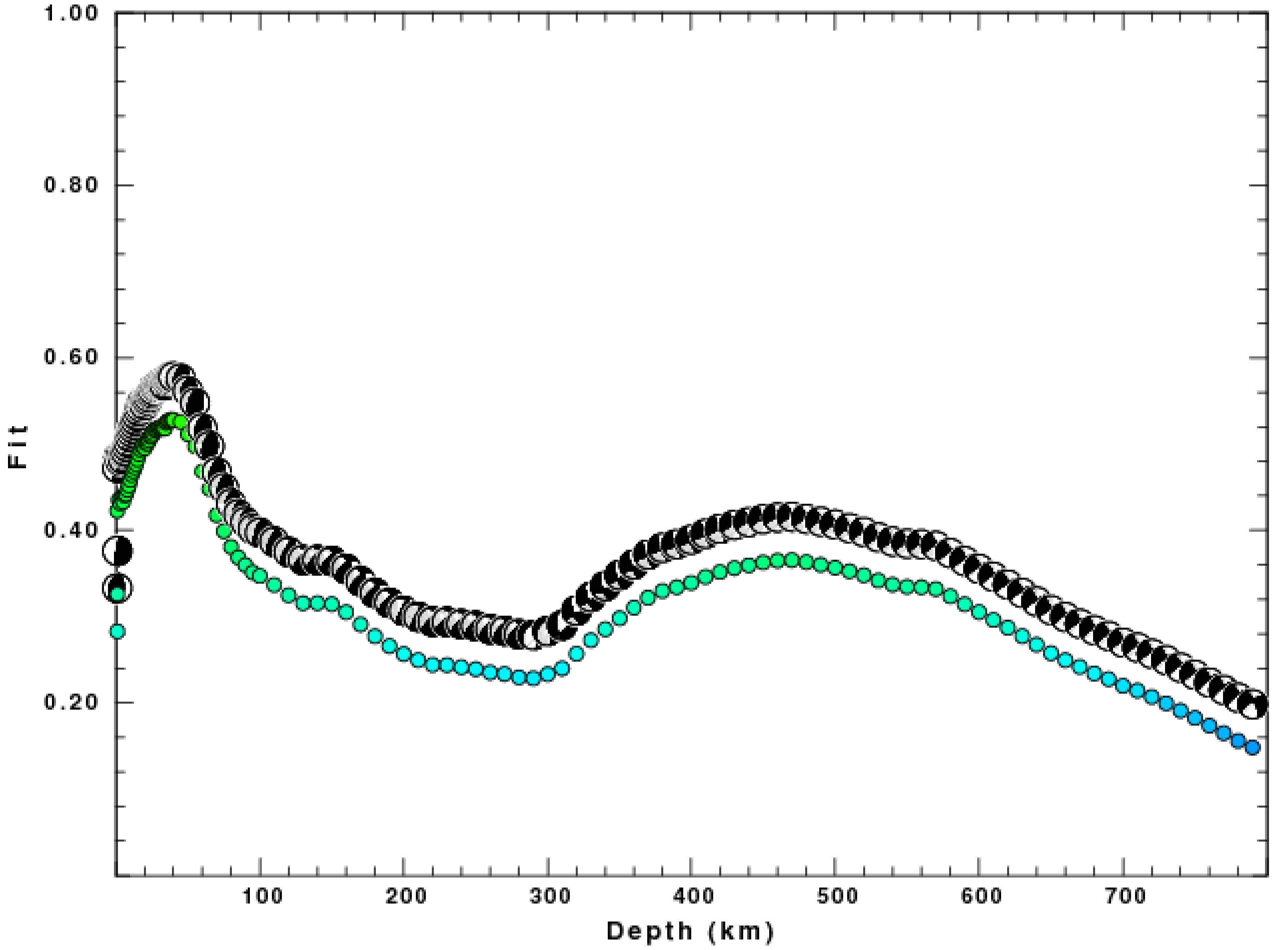
The best fitting solution is associated with the maximum value in the **FMDSUM** file in the **GRD.TEL** directory, and is

```
WVFGRD96   39.0    10    40    85   7.23 0.5288
```

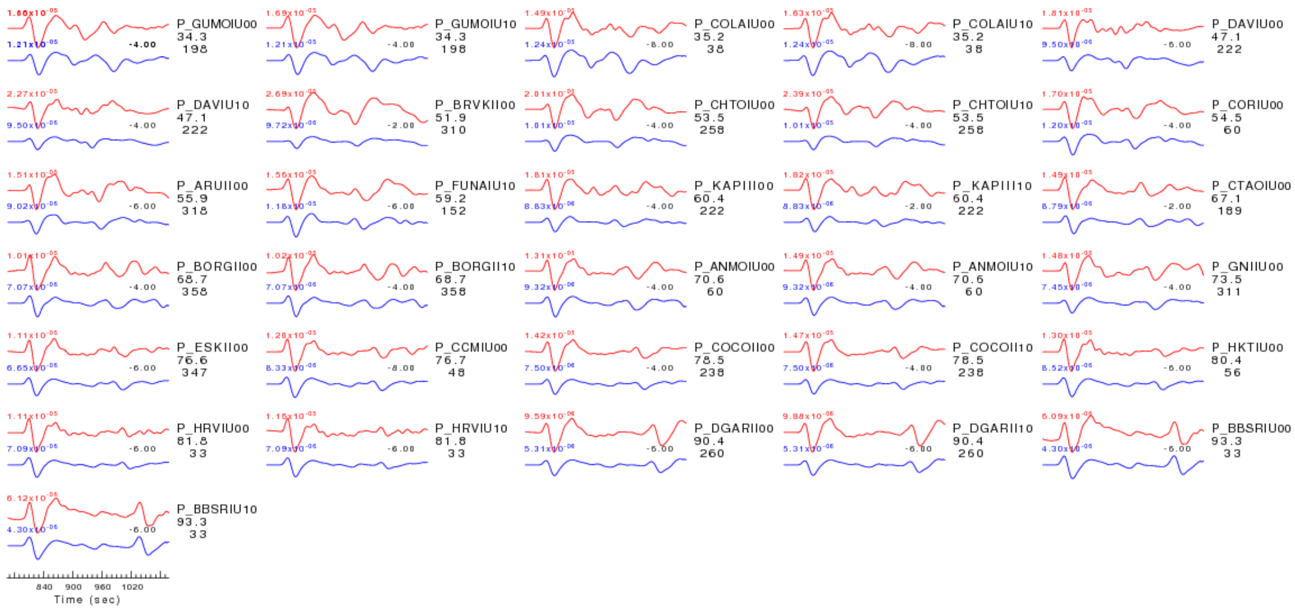
The solution given on the USGS Body-Wave Moment tensor page had a depth of 35 km, strike dip and rake angles of 24, 45 and 106 degrees, respectively and a moment magnitude of 7.3. The Global CMT Project solution gave 44.6 km, strike of 10, dip of 45 and a rake of 80 degrees with a moment magnitude of 7.4 which is very similar tot he USGS Centroid Moment Tensor solution.

The web page created in the `HTML.TEL` directory provides detail on the choice of filters used for the inversion. The inversion starts by assuming a moment magnitude 6 earthquake, and if the computed moment is much larger, the inversion will be repeated at the same depth, but now assuming the larger moment magnitude. The inversion uses frequencies much less that the corner frequency of the earthquake to avoid the extra effort to define the source time function. The time window and source time function are modified as a function of the moment magnitude to ensure that the effect of the direct and depth phases are included.

The goodness of fit as a function of depth clearly selects the source depth as seed in the figure generated:



The fit to the vertical component P-wave is good.



Modifications for other regional networks

The are two areas of modification: the regional velocity model and the raw network responses and data sets.

To generate a new set of Green's functions, you can follow the tutorial:

http://www.eas.slu.edu/Earthquake_Center/CPS/TUTORIAL/GREEN/index.html

which is also included in this distribution in the C:\usr\CPS directory.

To simplify the other changes that you will make, use a simple name for the model, e.g., ETUR for eastern Turkey. Follow the procedures in the tutorial but edit the script to compute only the distacnes that you actually need. Finally put a copy of the model, e.g., ETUR.mod into the upper level Models directory. If you do a

```
rbh> ls ${GREENDIR}
```

you will then see

```
AK135.TEL/  CUS.REG/  ETUR.REG/ Models/ WUS.REG/
```

Since this change applies to just Turkey, go to the MOMENT_TENSOR/MECH.TR directory and carefully change the **`DOSETUP`** and **`mech.sh`** files to add the option of using a new model. The result would be that one could select the ETUR model in the interactiive **`mech.sh`** and that this would be used for the processing and the documentation in the **`HTML.REG/index.html`** would indicate this fact. [You will observe that I believe in complete documentation so that another researcher can repeat the processing and obtain the same results.]

The other modification required for use with other networks is to convert the distributed data to Sac and to properly characterize the instrument response. Some networks use SEISAN, and a SEISAN → Sac conversion program is required. We must also be careful about the instrument response.

It may be simpler to create a pole-zero file of the instrument response. Since the pole-zero file just defines a filter, it knows nothing of physical units. You are permitted to use comments in a Sac pole-zero file by placing a '*' is the first column. The **`rdseed`** program distributed with Computer Programs in Seismology can create pole-zero response files from the SEED volume by using the command

```
rdseed -f seed_volume -p
```

which will provide a documented file

```
* ****
* NETWORK   (KNETWK): CN
* STATION   (KSTNM ): WHY
* COMPONENT (KCMPNM): BHZ
* LOCATION  (KHOLE ):
* START             :      1997,308,22:04:00
* END               :         No Ending Time
* INPUT UNIT        : METER
* OUTPUT UNIT       : COUNT
* LATITUDE  (DEG)   :   60.65970
* LONGITUDE (DEG)   : -134.88060
* ELEVATION (M)     : 1292.00000
* DEPTH     (M)     :    0.00000
```

```
* DIP        (DEG)   :  -90.00000
* AZIMUTH    (DEG)   :    0.00000
* INSTRUMENT COMMENT:
* CHANNEL_FLAG       : G
* ****
ZEROS 3
POLES 4
-0.0314  0.0000
-0.2090  0.0000
-222.1110  -222.1780
-222.1110  222.1780
CONSTANT 4.937605e+14
```

Only the last 7 lines are used by Sac or gsac to remove the instrument response. The most important information concerns the units. This is a filter that converts ground displacement in meters to counts.

If this file is called SAC_PZs_CN_WHY_BHZ, then the Sac/gsac command to convert the recorded digital counts to gound velocity in m/s is

```
transfer from polezero subtype  SAC_PZs_CN_WHY_BHZ to vel freqlimits 0.002 0.004  ${FHL} ${FHH}
```

Here the FHL and FHH are defined at 0.25/dt and 0.50/dt, respectively, where dt is the sample interval. The purpose of the freqlimits 0.004 0.005 ${FHL} ${FHH} is to provide stability to the deconvolution.

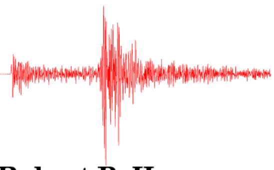
In the case of the responses for the Turkish network, the response converts ground velocity to digital counts and the command used is

```
transfer from polezero subtype  pzfile TO NONE FREQLIMITS 0.002 0.004 ${FHL} ${FHH}
```

Here the NONE is used to indicate that we wish to use the response as given without further modification. Also recall that I wish to work with ground velocity in m/s units.

If there are any questions, please sent me Email.

SAINT LOUIS UNIVERSITY
Department of Earth and Atmospheric Sciences



Robert B. Herrmann
Reinert Chair Natural Sciences
Email: rbh@eas.slu.edu
Tel: 314 977 3120
http://www.eas.slu.edu/
O'Neil Hall, 3642 Lindell Blvd.
St. Louis, MO 63108 USA
Fax: 314 977 3117