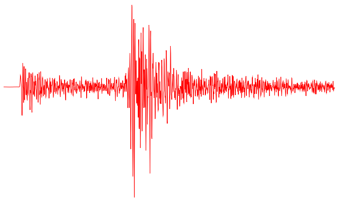
COMPUTER PROGRAMS IN SEISMOLOGY



Source Inversion - Teleseismic

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Contents

CHAPTER 1
OVERVIEW

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1. Introduction

This chapter provide an overview of the programs used for the inversion of waveforms for source inversion. The codes used are described in *Computer Programs in Seismology - 3.30: Source Inversion* by R. B. Herrmann and C. J. Ammon. This tutorial differs from that document in that the focus is on the use of teleseismic waveforms.

The organization of this tutorial is on the generation of the Green's functions, data organization and processing.

2. Programs

All of the programs required are part of the current distribution of *Computer Programs in Seismology* (CPS). I assume that these are installed and that the *PATH* variable has been properly set to access these executables. The processing scripts are part of this distribution and will be described in later chapters.

Some of the graphics will require GMT which is not distributed here.

If you have received a CDROM you will find the following files: *green.tar*, *mech.tar* and *NP330.tgz*. When unpacked, *green.tar* will expand into GREEN.TEL/GREEN/ *with all Green's functions precomputed for an Intel acrhitecture, mech.tar* will expand into *MECHANISM.TEL*, which contains previous processing results with waveforms in the Intel byte order, and *MECH.TEL* which contains the prototypes for downloading from the IRIS*WILBUR II* interface and for all processing.

CHAPTER 2
GREEN FUNCTION COMPUTATION AND ORGANIZATION

1. Introduction

This chapter discusses the computation of the Green's functions and their organization. The organization of the Green's functions is implicit in the scripts used for the inversion, which loops through different source depths, finds the Green's function which has the closest epicentral distance as the observation, and then proceeds with the inversion.

The chapter beings with the organization and then discusses the computations. If you have the *green.tar* file already, just unpack it.

2. Data Organization

The hierarchical organization is essential to the correct operation of the data processing scripts. The following picture indicates the overall layout:

```
GREEN.TEL/
            |
            |
            |----/GREEN/             (Green's functions for teleseismic P)
            |          |
            |          |-AK135sph.mod (velocity model in file96 format)
            |          |
            |          |-DOIT         (computational script)
            |          |
            |          |-DOCONVERT    (byte order conversion)
            |          |
            |          |-MKW          (final generation of W.CTL)
            |          |
            |          |-0000/        (Green's for 0.0 km depth)
            |          |
            |         ...
            |          |-0100/        (Green's for 10.0 km depth)
            |         ...
            |          |-2200/        (Green's for 220.0 km depth)
            |          |     |-W.CTL  (control file for this depth)
            |          |     |-0611602200.ZDD -
            |          |     |-0611602200.ZSS -
            |          |     |-0611602200.ZEX -
            |          |     |-0611602200.ZDS - (Green for 6116,9 km
            |          |     |        epicentral distance and 220.0 depth)
```

```
|         ...
|          |-7900/       (Green's for 790.0 km depth)
|
|
|---/GREEN.SW/         (Green's functions for S and surface wave)
|           |
```

The subdirectories such as *0010* are such that the 4 digits represent the source depth in kilometers multiplied by 10. This notation means that source depths can be considered from 0.0 to 999.9 km in 0.1 km increments.

In these depth subdirectories, you will find the Green's functions for the basic sources (ZDD, ZDS, ZSS, ZEX, RDD, RDS, RSS, REX, TDS and TSS - see *DOC/OVERVIEW.pdf/cps330o.pdf* for their definitions) in a SAC binary format. The naming convention is of the form *DDDDDdHHHh.grn*, which can permit epicentral distances (DDDDDd) from 0.0 to 99999.9 km in 0.1 km increments and depths from 0.0 to 999.9 km in 0.1 km increments; the *grn* are one of the ten basic solutions, e.g., ZSS.

To permit rapid determination of the appropriate Green's function for a given epicentral distance in kilometers, the control file *W.CTL* is used. This has entries such as

```
3669.000000 1.000000 1024 276.700012 0 2200 0366902200
3781.000000 1.000000 1024 285.399994 0 2200 0378102200
3892.000000 1.000000 1024 293.899994 0 2200 0389202200
4003.000000 1.000000 1024 302.500000 0 2200 0400302200
```

From left to right, the columns are distance in km, sample interval in seconds, number of points in the time series, the time of the first sample, the reduction velocity (as in a reduced travel time of refraction seismology), the depth index and the file index. This ASCII file can be searched by an awk program so that the Green's function at a distance closest to 3900 km would be 0389202200.ZSS, etc.

3. Use of Precomputed Green's Functions

If you receive the file *green.tar*, just do the following:

```
cat green.tar | tar xf -
```

This will create the directory structure given above.

If you are using a SPARC or a PowerPC based Mac computer, your MUST ensure the proper byte order. Assuming that you have already installed CPS, and that your path can find the program *saccvt*, then, following the directory structure above,

```
GREEN.TEL/GREEN
DOCONVERT
```

This script enters each source depth directory, and then changes the byte order of each of the binary SAC files in that directory.

This will take some time since there are 661 binary SAC files in each of the 84 depth directories.

4. Green's Function Computation

This is accomplished through the script *DOIT* which invokes the script *MKW*.

The velocity model in in *model96* format. For this example, we use a coarse version of AK135:

```
http://wwwrses.anu.edu.au/seismology/ak135/intro.html
```

This model has infinite Q, which is of no concern here since we will low pass filter the observed waveforms such that the Q effect is not apparent.

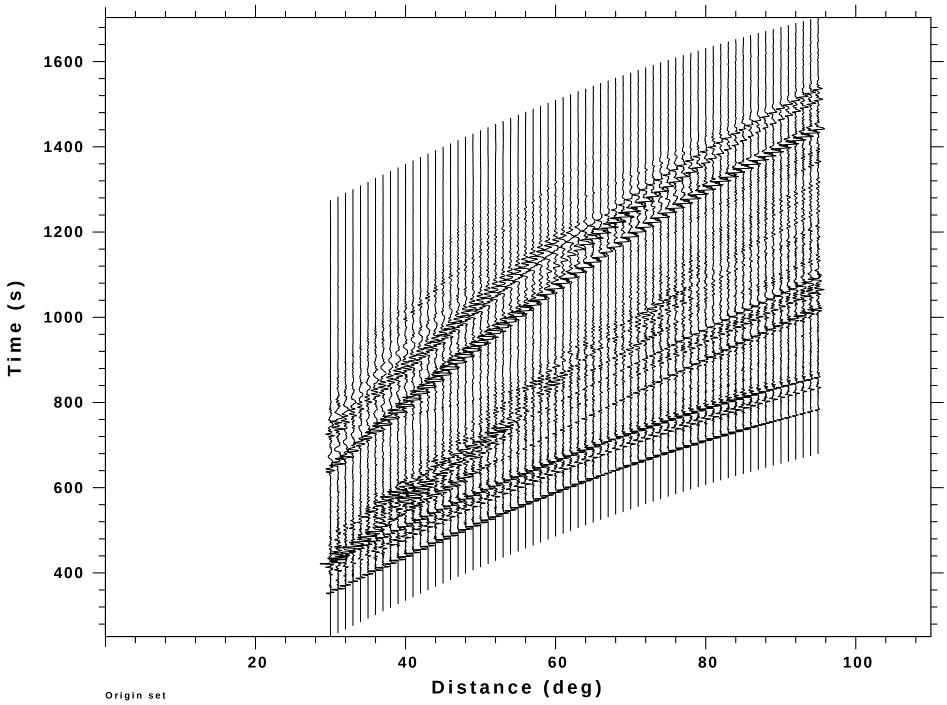
We use wavenumber integration code to make the synthetics. This requires the use of an earth flattening approximation, and also some phase velocity filtering so that we can focus on the arrivals near the direct P-wave and not have to compute the complete seismogram.

The *DOIT* is invoked using the command:

```
sh DOIT
```

since it does not have the executable flag set. This script is well notated, and does the following. It loops over source depth, creates the depth directory if necessary, and then loops over epicentral distance. Once these are set, it determines the approximate ray parameter, *p*, of the direct P-wave from the J-B tables (*this can be modified is I write modify the program time96 to provide the ray parameter for the given model*), defines a phase velocity filter with taper defined by the values [*0.46/p, 0.49/p. 3.2p, 4.0p*],, get the P-arrival time from the model, and them computes the synthetic. When the synthetic for a given distance is computed, the trace is converted to a SAC binary format. When all distances are computed, the script MKW is used to make the control file *W.CTL*.

The figure below shows the ZSS Green's functions computed for a source depth of 220 km for epicentral distances from about 30 - 95°.



5. PATH

When you have installed or computed the Green's functions, please note the absolute path to the *GREEN* directory, since this must be manually entered into the processing scripts. For example, on my computer the absolute path is

```
/t.home/rbh/PROGRAMS.310t/HARLEY/GREEN.TEL/GREEN
```

CHAPTER 3
DATA PREPARATION

---

1. Introduction

Data processing also has its own organization to facilitate uniform processing standards. All processing is performed in the *MECH.TEL* directory and uses files in the *MECH.TEL/0XXXTEL* and *MECH.TEL/PROTO* directories.

To illustrate the processing scheme I will get a data fril from the IRIS WILBUR II interface and then download it.

NOTE THAT the GREEN's functions are in units of ground velocity in cm/sec and that the waveforms will be deconvolved to ground velocity in meters/sec. The processing script DOSTA will integrate to make displacement time histories of both the observations and Green's functions. The inversion program, *wvfmtd96* will worry about the centimeter units.

2. Getting data from WILBUR II

Open a browser and go irectly to the IRIS Wilbur II page:

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

Then select a time period and event. I will consider the event

2006/06/27 13:03:12.6 SPYDERÂ® 5.8 15.04 -94.05 29.80 NEAR COAST OF OAXACA MEXICO

The next page gives of the event coordinates and ogitin time, which I will use later in my *DO* script.

I next check the *ALL* networks and then click on the *PROCEED* buttin.

The next page list the stations by epicentral distance in degrees. To avoid complications of the upper mantle on the waveforms, I restrict myself to the 30-95° epicentral distance range. I select the *BHZ* channel, set the distance range, check the Distribute box for every 2°, and then hit the *Apply Filter* button. This gives me 32 waveforms.

Scroll to the bottom, accept the SEED default data format, change the time window to 2 minutes before P to 10 minutes after P, set the user name as *RBHerrmann* (remember this), set the request label to *20060627*, and then click the *Process Request* button. **Remember the request label**.

The Wilbur II interface will now collect the data and deposit it at the address

ftp://ftp.iris.washington.edu/pub/userdata/RBHerrmann/20060627/20060627.seed

You can download it, but there is much more to do, so

DO and DOWILBUR

Go to the directory *MECH.TEL*. Edit the shell script *DO* so that it looks like

```
#!/bin/sh

#./DOWILBUR YEAR MO DY HR MN SC MSC  LAT    LON   H   MAG FILE_NAME
```

you will note the event information and the filename that we defined.

This script invokes *DOWILBUR*. *You must edit DOWILBUR so that it DOES NOT look for RBHerrmann, but your name that you filled in the Wilbur II form*.

This script uses the program *wget*, which is usually available on LINUX and CYGWIN, to get the see file from the IRIS DMC. This script also does a number of other things.

First it creates the directory *20060627130312* from the origin time information that you enterend in the *DO* script. It also creates and populates the following file structure and reuns the deconvolution. After this you will see the following (with a lot of edits)

```
20060627130312
|-- 00README
|-- 20060627130312
|   |-- 20060627.seed
|   |-- GOOD
|   |   |-- ATKABHZ.S
|   |   |-- ATKABHZ.sac
|   |   |-- BMRBHZ.S
|   |   |-- BMRBHZ.sac
|   |-- IDODAT
|   |-- IDODEC
|   |-- IDOEVT
|   |-- IDOROT
|   |-- Sac
|   |   |-- 2006.178.13.11.02.6000.AK.BMR..BHZ.R.SAC
|   |   |-- 2006.178.13.12.29.4400.AK.ATKA..BHZ.R.SAC
|   |   |-- AMP.AK.ATKA..BHZ
|   |   |-- AMP.AK.BMR..BHZ
```

```
|   |   |-- PHASE.AK.ATKA..BHZ
|   |   |-- PHASE.AK.BMR..BHZ
|   |   |-- RESP.AK.ATKA..BHZ
|   |   |-- RESP.AK.BMR..BHZ
|   |   |-- rdseed.err_log.06.27.06
|   |   `-- resp
|   `-- evt.proto
|-- DAT
|-- DOIT
|-- HTML
|   `-- DOHTML
|-- MAP
|   `-- DOMAP
|-- MT
|   |-- DOPLTTEL
|   `-- NDOSTA
|-- MTD
|   |-- DOMTD
|   |-- DOPLTTEL
|   `-- DOSTA
|-- NDOSTA
|-- SYN
|   |-- DOMCH
|   |-- DOPLTTEL
|   `-- DOSTA
|-- USGSMT
`-- tGRD
    |-- DOGRD
    |-- DOPLTTEL
    `-- DOSTA
```

11 directories, 249 files

Looking at the data first, the script creates 20060627130312 and 20060627130312/20060627130312. It copies the IDOEVT, IDODEC, IDOROT and IDODAT scripts from MECH.TEL/PROTO into 20060627130312/20060627130312. The event information is added to the *IDOEVT* script.

```
20060627130312/20060627130312
wget ftp://ftp.iris.washington.edu/pub/userdata/RBHerrmann/20060627/20060627.seed
```

To get the SEED volume from the IRIS DMC. Then the subriectory *Sac* is created, and the SEED volume is opened:

```
mkdir Sac
cd Sac
rdseed -f ../20060627.seed -R -d -o 1
```

and the original traces, with modified headers and the deconvolved traces (meters/sec) are places in the parallel *GOOD* directory.

Now we begin interactive work.

```
cd 20060627130312/20060627130312/GOOD
gsac
GSAC - Computer Programs in Seismology [V1.1 10 JAN 2005]
       Copyright 2004, 2005, 2006 R. B. Herrmann
```

```
GSAC> r *sac
ATKABHZ.sac BMRBHZ.sac BPAWBHZ.sac C03ABHZ.sac CPUPBHZ.sac
CRAGBHZ.sac DSBBHZ.sac FALSBHZ.sac FFCBHZ.sac FUORNBHZ.sac
HOPEBHZ.sac ISABHZ.sac K01ABHZ.sac KBSBHZ.sac LVCBHZ.sac
MAHOBHZ.sac MELIBHZ.sac O01CBHZ.sac PABBHZ.sac PINBHZ.sac
PSZBHZ.sac Q03CBHZ.sac RARBHZ.sac RPNBHZ.sac SAWBHZ.sac
SDPTBHZ.sac SITBHZ.sac TNABHZ.sac TRISBHZ.sac
UNVBHZ.sac V03CBHZ.sac VSLBHZ.sac
GSAC> sort depmax
Sorting on DEPMAX in ascending order
GSAC> lh depmax
GSAC> sort down
Sorting on DEPMAX in descending order
GSAC> lh
```

The objective here is to identify traces not to use because they are bad or because the instrument responses are wrong. This is usually seen by very large and very small values of the SAC header value *DEPAMX*.

Note the BMRBHZ.sac is the ground velocity in meters/sec and the BMRBHZ.S is the trace in digital counts.

Now from within the GOOD subdirectory run the command

```
            ../IDOROT
```

This will complain since if you do not have any horizontal traces, but will create parallel directory called *FINAL*. In this directory we will find

```
ATKABHZ  CPUPBHZ  FFCBHZ    K01ABHZ  MELIBHZ  PSZBHZ   SAWBHZ   TRISBHZ
BMRBHZ   CRAGBHZ  FUORNBHZ  KBSBHZ   O01CBHZ  Q03CBHZ  SDPTBHZ  UNVBHZ
BPAWBHZ  DSBBHZ   HOPEBHZ   LVCBHZ   PABBHZ   RARBHZ   SITBHZ   V03CBHZ
C03ABHZ  FALSBHZ  ISABHZ    MAHOBHZ  PINBHZ   RPNBHZ   TNABHZ   VSLBHZ
```

Note the renaming of the traces. The terminal *Z* if important. If we had had horizontals we would also have seen files such as CPUPBHZ CPUPBHR and CPUPBHT.We will now pick the P-arrivals. If these are available from a picker, they can be entered into the corresponding SAC header at this point.

To see the P-arrival I will bandpass filter the traces, and be very careful after I make the picks to write the header and not the trace (since I do not want a short period filtered trace).

```
GSAC> r *
GSAC> rtr
GSAC> sort up dist
GSAC> ppk perplot 3  (you could do a ppk teleseism but that takes too long)
            Use the ’p’ key to make a P arrival pick
GSAC> wh
GSAC> quit
```

The picks do not have to be perfect, since we only need to identify the beginning of the P-arrival and we are not locating the earthquake.

Now go to the parent directory of FINAL, and enter

```
IDODAT
```

This script examines all of the files in the FINAL sub-directory, and if the P-wave arrival was paick, the SAC header value A, then the trace is moved to MECH.TEL/20060627130312/DAT. These are the traces to be used for the inversion.

We see that there are only 12 traces

```
BMRBHZ   CPUPBHZ  FFCBHZ  KBSBHZ  PSZBHZ   SAWBHZ
BPAWBHZ  DSBBHZ   ISABHZ  PABBHZ  Q03CBHZ  V03CBHZ
```

Use GSAC to examine these traces with a low pass filter. The trace CPUPBHZ has a lot of high frequency noise, so I create a subdirectory NOUSE and place it there. Note that *NOUSE* does not end with a Z, R or T. Patterns are important.

Now

```
cd MECH.TEL/20060627130312/MTD
```

EDIT THE SCRIPT DOSTA TO GIVE THE CORRECT PATH TO THE GREEN's FUNCTIONS, e.g., make sure that line 32 is correct:

```
####
#       define the path to the Green's Function Directory
#####
GREEN=/t.home/rbh/PROGRAMS.310t/HARLEY/GREEN.TEL/GREEN
```

Now start the inversion

```
DOMTD
DOPLTSAC
```

While this is occurring, we will do a few more things for our final product.

```
cd ../MAP
DOMAP                (this requires GMT on your machine)
cd ../USGSMT
                     (copy the USGS rapid moment tensor int the file
            usgsmt, copy the Harvard moment tensor into the
            file cmt)
```

Returning to the MTD directory, where the inversion is happening, look at the FMD-SUM file:

```
WVFMTD96    0.0  146.   45.  -90.   6.24    -0.105 0.333E-06    -0.126     0.375 0.292E-06  19.0
WVFMTD96    5.0  307.   80. -111.   6.17     0.257 0.272E-06     0.277     0.511 0.233E-06   2.1
WVFMTD96   10.0  312.   82. -127.   6.07     0.319 0.261E-06     0.343     0.573 0.224E-06  10.1
WVFMTD96   15.0  318.   85. -140.   6.02     0.337 0.258E-06     0.361     0.587 0.220E-06   3.2
WVFMTD96   20.0  135.   59.  127.   5.83     0.378 0.248E-06     0.408     0.615 0.209E-06  31.0
WVFMTD96   25.0  322.   54.   50.   5.94     0.352 0.253E-06     0.375     0.594 0.215E-06  27.1
WVFMTD96   30.0  219.   68.  153.   6.00     0.350 0.254E-06     0.373     0.592 0.215E-06  60.4
```

This listing is a summary fo the processing, The entries are depth, strike, dip, rake, moment magnitude and goodness of fit parameters. We use the 9'th colum,n. - here the best solution corresponds to a depth of 20 km and has a goodness of fit parameter of 0.408.

When the *DOMTD* script is done the best solution is in the file fmdfit,.dat and indicates a 20 km depth.

For final documentation,

```
cd ../HTML
DOHTML
```

Now if you point your browser to his directory and the file index.html, e.g., on my machine

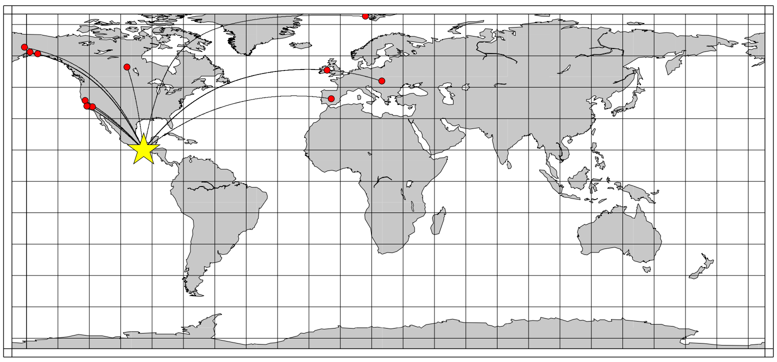
file:///backup/home/rbh/PROGRAMS.310t/MECH.TEL/20060627130312/HTML/index.html

you can review all processing. In this case our solution is similar to the USGS rapid moment tensor solution but differs from the Harvard Solution

```
Location

2006/06/27 13:03:12 15.04 -94.05 30
Moment Tensor Comparison

The following compares this source inversion to the
USGS Rapid Moment Tensor Solution and to the Harvard CMT solutions,
if they are available.



SLU
Mw=5.8

2006/06/27 13:03:12    EVID:
LAT: 15.04N, LON:  94.05W, DEPTH:  20
Mw: 5.8, mb: 0.0, Ms: 0.0
Mo=  0.624E+25 (dyne-cm)

No. of Stations:  11, GAP: 264
Error (clvd/dc)*100=  30.97
Bandpass:  12 -  60 sec
Nodal plane parameters
      strike     dip    rake
NP1:     135      59     127
NP2:     260      47      46

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


Stat Dist Az Misfit   Stat Dist Az Misfit
BMR   58 333  0.36    BPAW  62 335  0.42
DSB   76  38  0.75    FFC   40 352  0.38
ISA   29 317  0.57    KBS   78  10  0.58
PAB   80  51  0.47    PSZ   94  38  0.48
Q03C  34 318  0.86    SAW   60 333  0.84
V03C  32 315  0.74
 Misfit > 1 heavily downweighted
```

```
USGS
 OFFSHORE CHIAPAS, MEXICO
 Epicenter:  15.039  -94.053
 MW 5.8

 USGS MOMENT TENSOR SOLUTION
 Depth  11         No. of sta: 40
 Moment Tensor;   Scale 10**17 Nm
   Mrr= 2.53       Mtt=-3.12
   Mpp= 0.58       Mrt= 4.72
   Mrp=-1.74       Mtp=-0.56
  Principal axes:
   T  Val=  5.81  Plg=56  Azm= 35
   N        0.00      15      283
   P       -5.81      30      184

 Best Double Couple:Mo=5.8*10**17
  NP1:Strike=237 Dip=20 Slip=  43
  NP2:       106     77       105

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

```
HARVARD CMT
Subject: quick CMT: 06/27/06, 13:03:12.0, OFFSHORE CHIAPAS, MEXICO, MW=5.8


Here is the solution for the recent event.

June 27, 2006, OFFSHORE CHIAPAS, MEXICO, MW=5.8

Natasha Maternovskaya

CENTROID, MOMENT TENSOR SOLUTION
HARVARD EVENT-FILE NAME C062706E
DATA USED: GSN
L.P. BODY WAVES: 64S,140C, T= 40
SURFACE WAVES:   66S,165C, T= 50
CENTROID LOCATION:
ORIGIN TIME       13:03:13.3 0.1
LAT 14.95N 0.01;LON  94.53W 0.01
DEP  12.0 FIX;HALF-DURATION  2.0
MOMENT TENSOR; SCALE 10**24 D-CM
  MRR= 4.00 0.05; MTT=-2.46 0.05
  MPP=-1.53 0.06; MRT= 3.95 0.14
  MRP=-3.42 0.15; MTP= 1.90 0.04
 PRINCIPAL AXES:
 1.(T) VAL=  6.59;PLG=64;AZM= 43
 2.(N)      -0.04;     1;    310
 3.(P)      -6.54;    26;    219
BEST DOUBLE COUPLE:M0=6.6*10**24
 NP1:STRIKE=306;DIP=19;SLIP=  86
 NP2:STRIKE=130;DIP=71;SLIP=  91

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


Deviatoric Moment Tensor Solution

The following broadband stations were used for the source inversion:
BMR BPAW DSB FFC ISA KBS PAB PSZ Q03C SAW V03C
```



Location of the earthquake (yellow star) and great circle path from the epicenter to each station (red) [created using GMT (Wessel, P., and W. H. F. Smith, New version of Generic Mapping Tools released, EOS Trans. AGU, 76 329, 1995.)]

All observed and Greens function waveforms are corrected to instrument
response to ground velocity in meters/sec for the passband of 0.01 - 5 Hz.
Next the traces were bandpass filtered by the application of the
following high- and low-pass stages:

```
hp c 0.0167 2
lp c 0.0833 2
int
```

The traces were next integrated to ground displacment in meters.
Finally waveforms were cut from 30 seconds before to 140 seconds
after the P arrival so that the direct P wave, pP and perhaps the
sP are included.

The source inversion is a multipass operation since a lower frequency filter
band is used for larger earthquakes and since a search is made over depth.
Up to three passed of the outer loop are made, after which the moment magnitude
is determined and filter settings readjusted. The inner loop over depth samples
all depths from 0 to 800 km with 5 km increments in depth to 50 km, followed by
10 km depth sampling for the remaining range.

The following filter ranges are used according to the moment magnitude Mw:

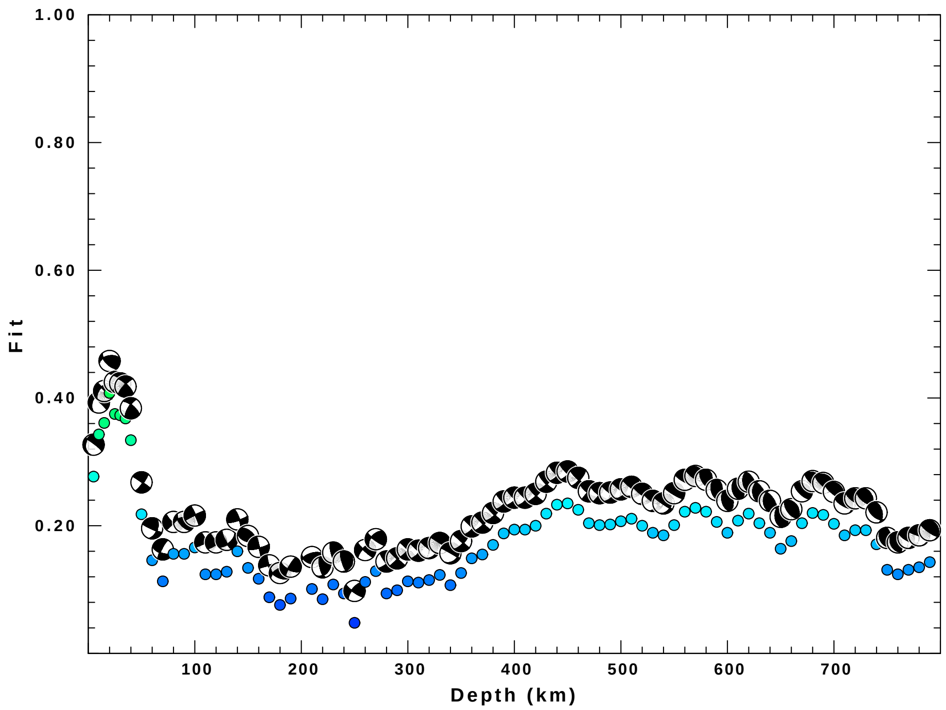
FILTER_BAND	FH(s)	FL(s)	
1	60	12	Mw < 6.4
2	100	20	6.4 < Mw <= 6.9
3	120	40	Mw > 6.9

For this data set the favored solution is

```
WVFMTD96   20.0  135.   59.  127.   5.83     0.378 0.248E-06     0.408     0.615 0.209E-06  31.0
```

The following figures show the sensitivity of the goodness of fit parameter to
source depth, the waveform comparison as a function of epicentral distance
in degrees and the source to station azimuth

Depth Sensitivity

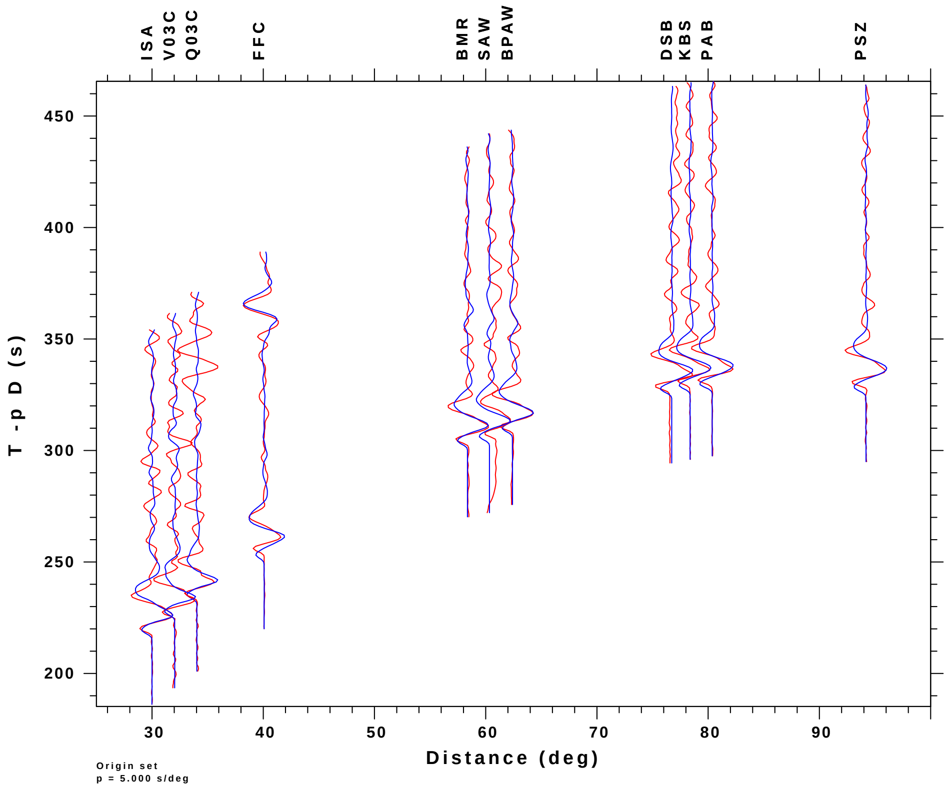


Goodness of fit as a function of source depth. The measure is
1 - SUM (o -p)2 / SUM o2. A value of 1.0 is the best fit.
The best double couple mechanism for the solution depth is
plotted above goodness of fit value to indicate how the
mechanism may change with depth.

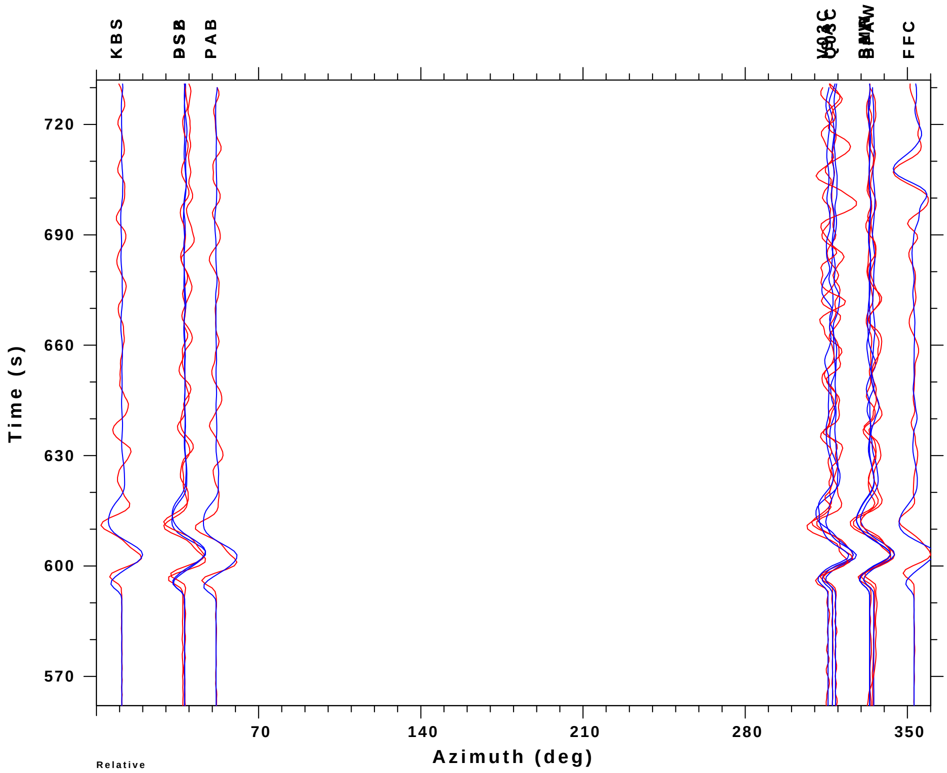
Fit with Distance

Comparison of the observed traces (red) and solution predicted traces

```
(blue) as a function of epicentral distance in degrees (D).
For ease of comparison, the time axis is T - p D, where p is
5.0 seconds/degree and T is the actual travel time. The traces are
annotated with the station name at the top.
```




```
Fit with Azimuth
```



Comparison of the observed traces (red) and solution predicted traces (blue) as a function of source to station azimuth in degrees (D). The purpose of this display is to highlight the azimuthal dependence on the first motion. The traces are annotated with the station name at the top.