Source Inversion Validation

Stage 2: Initial Inversion Exercises

Inverting noise-free synthetic seismograms, computed on a dense receiver grid, for a simple crack-like spontaneous dynamic rupture model

In this test we consider a crack-like spontaneous dynamic rupture, embedded in a layered isotropic velocity-density structure, to test how well source-inversion techniques can retrieve the macroscopic source properties as well as the spatio-temporal evolution of the rupture process. The material parameters are identical to the ones used in the Green's function tests.

Coordinate system:
Right-handed Cartesian coordinate system, with positive X pointing East, positive Y pointing North, and positive Z upward. All coordinates are in km.

Material properties:
Layered isotropic velocity-density structure; Q_S and Q_P are assumed to be infinite everywhere (Fig. 1).

Depth [km]	V_P [km/s]	V_S [km/s]	Density [g/cm^3]
0.0	4.8	2.6	2.3
-2.0	4.8	2.6	2.3
-2.0	5.5	3.1	2.5
-4.8	5.5	3.1	2.5
-4.8	6.2	3.6	2.7
-18.0	6.2	3.6	2.7
-18.0	6.8	3.8	2.8
-24.0	6.8	3.8	2.8
-24.0	8.0	4.62	3.2
-45.0	8.0	4.62	3.2

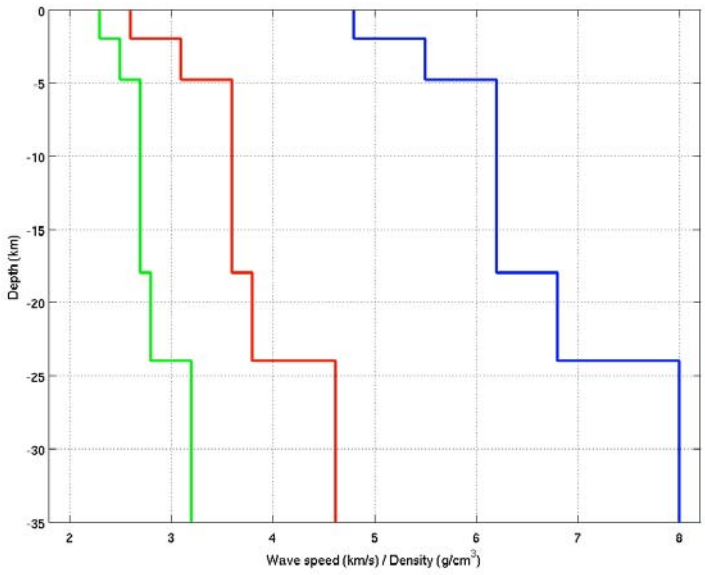

Figure 1: Velocity-density model for inversion exercise.

General source information (**label: ss_inv1**)

- Vertical strike-slip fault: fault dip = 90°; fault strike = 90°
- The rupture remains buried and does not reach the surface
- Fault dimensions: **approximately 30 km in length, 15 km in down-dip extent**
- Seismic moment: $M_0 \approx 1.0 \times 10^{19}$ Nm (M_W 6.6)
- Hypocenter depth = 14.1 km;
- Slip and slip-rate are heterogeneous over the fault plane, as a result of the dynamic rupture simulation with heterogeneous initial stress on the fault.
- Rupture times imply some variations in rupture speed over the fault
- The source-time function may vary over the rupture plane

Receivers (surface receivers only, Z = 0):

The receiver configuration consists of 168 receivers arranged in a "race-track" pattern around the surface-projection of the top-edge of the fault (Fig.2). The locations of the receivers at which synthetic ground-motions are computed are given in the file **`StationLocations.dat`**. It is intended to keep this station configuration (or a somewhat modified one) for all upcoming inversion exercises.
Synthetic seismograms are contained in the zip-file **`inv1_synthetics.zip`**, in the format given below.

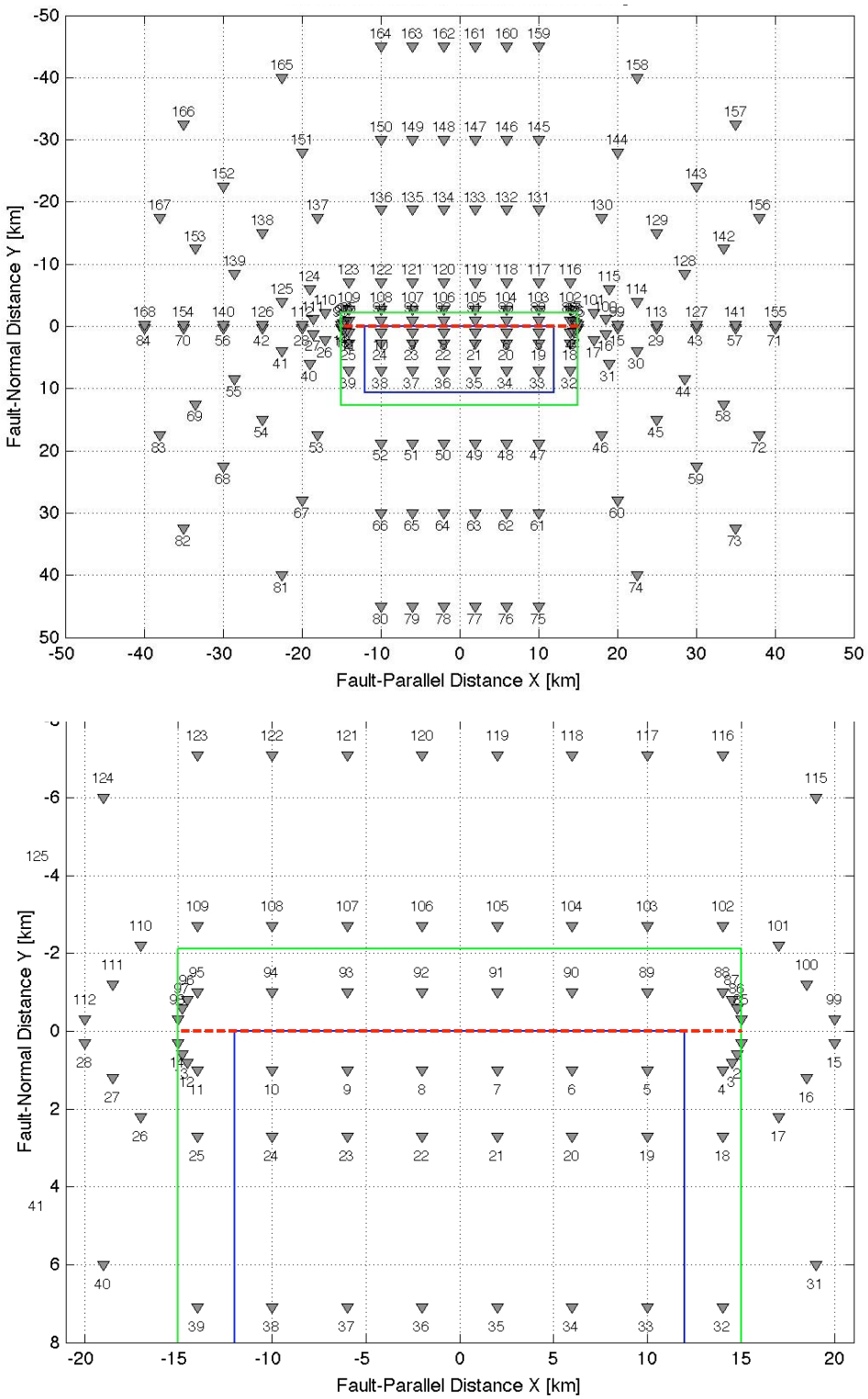

Figure 2: Receiver geometry for inversion exercises. (Top): Entire domain; (Bottom): Close-up of near-source region. We use a right-handed coordinate system with positive X pointing East, positive Y pointing North, and positive Z pointing up. The red line indicates the surface projection of the up-dip edge of the vertical strike-slip fault plane at depth. The green and blue lines mark surface projections for a dipping fault (part of a later exercise).

Other information:

- Provided synthetic seismogram have a nominal maximum resolved frequency of ~3 Hz
- If the inversion is carried out with filtered ground-motions, please specify the chosen frequency range as well as the type of filter (i.e. 'butterworth') and filter order.
- Specify the ground-motion computation tool used (i.e. CompSyn, Axitra, 3D-finite-difference code), and the inversion approach (i.e. multi time-window linearized inversion; non-linear inversion using an genetic algorithm)
- The modeler can choose the receivers he/she uses for the inversion; ideally, he/she would use a sufficiently large set of stations, and then computes the forward-predictions from his/her rupture model at 10-20 sites **NOT** used in the inversion procedure.
  - Predicted motion at sites that have been used in the inversion will receive a corresponding file name with the suffix `'.inv'` (see below)
  - Prediction motions that are computed from forward-modeling with the inferred rupture model will receive a file name with the suffix `'.fwd'` (see below)

Output instructions:

Predicted ground motions
Submit clearly and unambiguously labeled ascii-files in the following format, containing velocity time histories in m/s (Vx positive East, Vy positive North, Vz positive up)

- "label" is the above (in red) noted source-model indicator
- "modeler": name/identifier of modeler or modeling group
- date: date when calculations were performed (format dd.mm.yy)
- rec#: receiver number (see above tables)
- rec_crd_X, rec_crd_Y: receiver coordinates (see above tables, in km)
- npts: number of points in time series
- dt: sampling interval (in sec)
- fmax: maximum resolved frequency in these calculations (in Hz)

filename:

label_modeler_receiver#.inv or label_modeler_receiver#.fwd
e.g. ss_inv1_mai_12.inv for a site used in the inversion
ss_inv1_mai_12.fwd if motions are computed using the inferred rupture model

header:

label	modeler	date
rec#	rec_crd_X	rec_crd_Y
npts	dt	fmax

time-series data (formatted as 15.6e, see example below):

x-comp	y-comp	z-comp

Example time-series output file: ss_inv1_MaiMartin_3.inv

```
ss_inv_1        MaiMartin           15.10.2010
3               10.0                1.0
1666            0.006               5.0
1               12.2880             9.9960
2.708477e-01  2.854577e-01  2.933980e-01
2.953652e-01  2.918521e-01  2.831548e-01
2.694041e-01  2.505884e-01  2.266108e-01
1.973462e-01  1.627026e-01  1.226894e-01
7.748341e-02  2.749405e-02 -2.658398e-02
```

Rupture model output

Submit clearly and unambiguously labeled ascii-files in the following format, containing the estimated macroscopic source parameters in the header as well as information on the source-inversion parameters. We accept two different formats, specified below, depending on whether a single time window or several time windows are used in the inversion. The following parameters are reported in the header section:

- "label" is the above (in red) noted source-model indicator
- "modeler": name/identifier of modeler or modeling group
- date: date when calculations were performed (format dd.mm.yy)
- "inversion method": specify the inversion approach used
- "Ground-motion code": specify the numerical code for ground-motion computation
- SourcePar1: moment magnitude and seismic moment (in Nm)
- SourcePar2: estimated length and width of fault plane (in km)
- Hypocenter: estimated hypocenter coordinates in X, Y, Z (in km)
- Depth2Top: estimated depth to top of fault plane (in km)
- NumPoints: number of points in along-strike (Nx) and down-dip (Nz) direction of the rupture model
- NumTimeWn: number of time windows (Nt) and their spacing (Dt, in sec)
- ElemSTF: string to indicate elementary source-time function used

For each point on the fault, indicated by its X, Y, and Z position, several rupture quantities are then listed in subsequent columns, i.e. each row of the output table contains the source parameters at a given point on the fault plane. Thus, the rupture-model output looks as follows:

If the inversion is carried out using a single time window:

```
# ------------------------------------------------------------------------
#  SIV Inversion Exercise :  ss_inv1_frog
#  Date                   :  23.10.10
#  Modeler                :  Kermit „The Frog“
#  Inversion Method       :  non-linear single time-window
#  Ground-motion code     :  Axitra
#  SourcePar1  Mw-Mo [Nm] :  6.113, 1.658e+18
#  SourcePar2  L-W [km]   :  25.0, 14.00
#  Hypocenter  X-Y-Z [km] :  3.00, 0.00, -12.50
#  Depth2Top   Z2top [km] :  -3.000
#  NumPoints   Nx-Nz      :  13, 12
#  NumTimeWn   Nt-Dt      :  1, 0.0
#  ElemSTF                :  iso-tri
# ------------------------------------------------------------------------
#  X           Y           Z      TotalSlip    Rake      RupTime    RiseTime
# km          km          km         m         deg         s          s
# ------------------------------------------------------------------------
 -4.0000    -0.0000    -6.0000     0.0000     0.0000     3.0000     5.0000
 -3.0000    -0.0000    -6.0000     0.0000     0.0000     3.0000     5.0000
 -2.0000    -0.0000    -6.0000     0.0000     0.0000     3.0000     5.0000
 -1.0000    -0.0000    -6.0000     0.0000     0.0000     3.0000     5.0000
  0.0000    -0.0000    -6.0000     0.0000     0.0000     3.0000     5.0000
  1.0000    -0.0000    -6.0000     0.0000     0.0000     3.0000     5.0000
  2.0000    -0.0000    -6.0000     0.0000     0.0000     3.0000     5.0000
  3.0000    -0.0000    -6.0000     0.0000     0.0000     3.0000     5.0000
  4.0000    -0.0000    -6.0000     0.0000     0.0000     3.0000     5.0000
```

If the inversion is carried out using several time windows:

```
# ------------------------------------------------------------------------------------------
#  SIV Inversion Exercise :  ss_inv1_frog
#  Modeler                :  „Miss Piggy“
#  Inversion Method       :  linearized multi time-window
#  Ground-motion code     :  own 3D-FD code
#  SourcePar1  Mw-Mo [Nm] :  6.113, 1.658e+18
#  SourcePar2  L-W [km]   :  25.0, 14.00
#  Hypocenter  X-Y-Z [km] :  3.00, 0.00, -12.50
#  Depth2Top   Z2top [km] :  -3.000
#  NumPoints   Nx-Nz      :  13, 12
#  NumTimeWn   Nt-Dt      :  4, 0.5
#  ElemSTF                :  iso-tri
# ------------------------------------------------------------------------------------------
#  X           Y           Z      TotalSlip    Rake      RupTime    SlipTW1   SlipTW2 ...
# km          km          km         m         deg         s          m         m
# ------------------------------------------------------------------------------------------
 -4.0000    -0.0000    -6.0000     0.0000     0.0000     3.0000     1.0000    0.5555
 -3.0000    -0.0000    -6.0000     0.0000     0.0000     3.0000     1.0000    0.5555
 -2.0000    -0.0000    -6.0000     0.0000     0.0000     3.0000     1.0000    0.3333
 -1.0000    -0.0000    -6.0000     0.0000     0.0000     3.0000     1.0000    0.6666
  0.0000    -0.0000    -6.0000     0.0000     0.0000     3.0000     1.0000    0.1111
  1.0000    -0.0000    -6.0000     0.0000     0.0000     3.0000     1.0000    0.2345
  2.0000    -0.0000    -6.0000     0.0000     0.0000     3.0000     1.0000    0.4444
  3.0000    -0.0000    -6.0000     0.0000     0.0000     3.0000     1.0000    0.1111
  4.0000    -0.0000    -6.0000     0.0000     0.0000     3.0000     1.0000    077777
```