Source Inversion Validation

Problem inv2b: Inversion of complex kinematic rupture

In this test we consider two kinematic rupture models with the same fault geometry, embedded in a layered isotropic velocity-density structure. In one case, 3D random variations in the velocity structure are added that lead to high-frequency scattering, and therefore some arrival-time variations. These can be interpreted as being due to incomplete knowledge of Earth structure that lead to uncertainties Green's function calculations. Note that the dip angle of the fault is only approximately given, likewise the slip-direction (oblique slip), but both are constant.

Two sets of synthetic waveforms are distributed, using different selections of sites. Case **inv2a** uses the same station distribution as the previous **inv1** ("crack-like" dynamic rupture), for case **inv2b** a smaller number of sites is available for the inversion. In both cases, a specific set of stations are used as "blind prediction sites" for which the synthetic data are not distributed, but modeling teams need to forward-predict the ground-motion based on their preferred source-model solution.
For case inv2a, synthetics GPS data are available. The given values are obtained by subjecting the computed permanent displacements to small random (variations), as specified in the corresponding data file (inv2a_gps.dat).

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. *Note: this corrected RHS-definition deviates from the one used in inv1 where Z was given as positive downward*).

Material properties:
Average 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

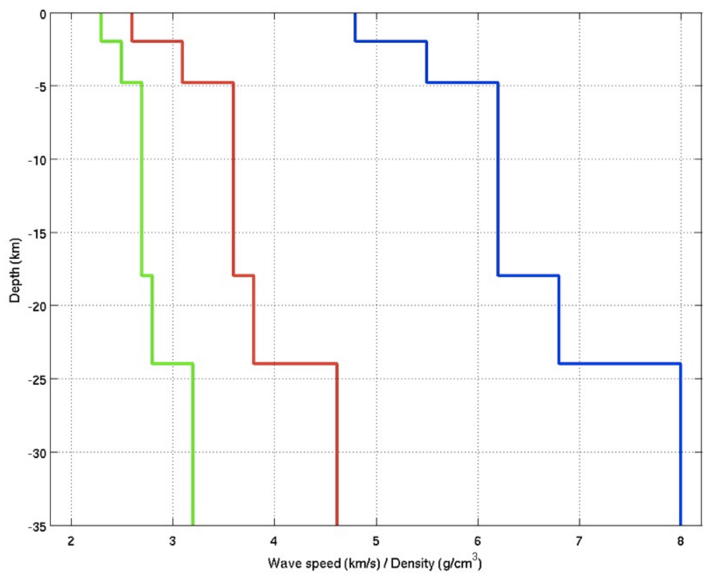

Figure 1: Average velocity-density model for inversion exercise; 3D random perturbations are superimposed to this structural model.

General source information (label: inv2b)

- Dipping normal-fault: **fault dip = (45 ± 5)°; fault strike = 90°; oblique slip λ = (240 ± 10)°**
- The rupture remains buried and does not reach the surface
- Fault dimensions: **approximately 40 km in length, 20 km in down-dip extent**
- Seismic moment: **M_0 ~ 3.5 x 10^{19} Nm (M_W 7.0)**
- Epicentral location: **X = - 4.57 km; Y = -9.54 km**
- Hypocenter depth: **Z = -(10.0 ± 1.0) km;**
- Slip and slip-rate are heterogeneous over the fault plane.
- Rupture times imply some variations in rupture speed over the fault

Receivers (surface receivers only, Z = 0):

The receiver configuration consists of 20 receivers for the inversion itself and 10 receivers for the forward prediction (Fig.2). The locations of the receivers at which synthetic ground-motions are computed are given in the file **`inv2b_stations.dat`**; locations named as 'Ixx' are to be used in the inversion, sites named 'Pxx' have to be used for forward-predicting the waveforms for validation purposes utilizing the inferred rupture model. Synthetic seismograms are contained in the zip-file inv2b_SIVdata.zip, in the format given below.

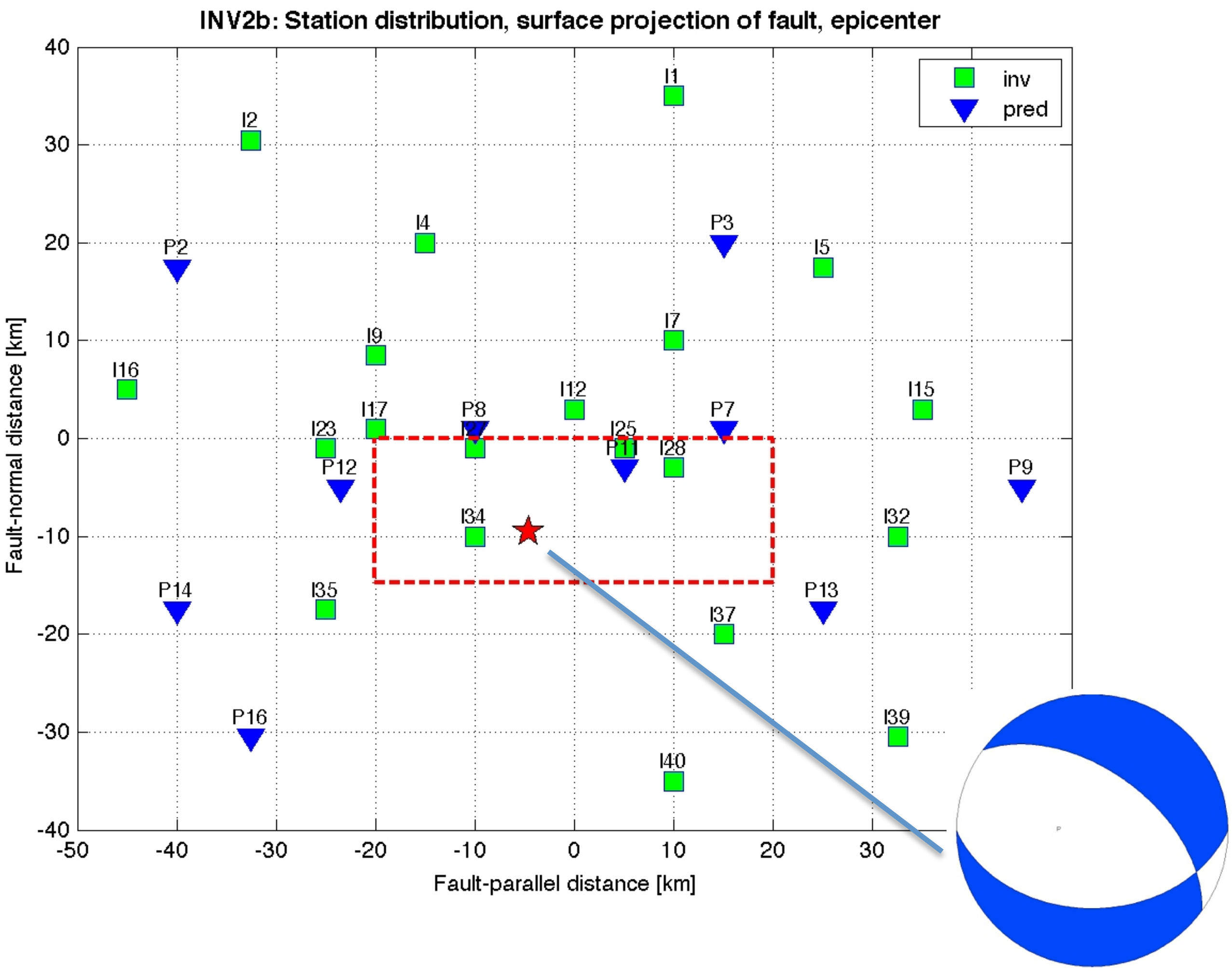

Figure 2: Receiver geometry for **inversion exercise inv2b**. We use a right-handed coordinate system with positive X pointing East, positive Y pointing North, and positive Z pointing up the dotted rectangle indicates the fault-surface projection of the fault that is allowed to rupture, the star marks the epicenter with the shown fault-plane solution. Green squares mark the stations that have to be used in the inversion, the blue inverted triangles denote the stations at which waveforms have to be forward-predicted.

Additional 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)

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)

Important note: For the SIV-online submission, all modeled waveforms need to be arranged/grouped into a single .synar-file, which is then read by the online processing software. The station ordering matters (I1-I40 first, followed by P1-P16) as well as their correct formatting. See http://equake-rc.info/sivdb/utilities/ for further information.

filename:
label_modeler_receiver#.syn
e.g. inv2a_mai_I12.syn for a site used in the inversion
inv2a_mai_P3.syn 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: inv2b_mai_I11.syn

inv_2b	mai	15.03.2013
I11	10.00	35.00
500	0.01	2.5
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 :  inv2a_mai
#  Date                   :  15.03.13
#  Modeler                :  M. Mai
#  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 :  inv2a_mai
#  Date                   :  15.03.13
#  Modeler                :  M. Mai
#  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
```