Source Inversion Validation
Stage 1: Forward Problems

Part 2: Forward modeling of extended-source rupture models

In this test we examine the different codes/methods for forward-modeling the ground-motions for extended-fault earthquake rupture models. Two cases are being considered:

A) Rupture on a vertical strike-slip fault with purely right-lateral motion
B) Rupture on a dipping fault with purely thrust-faulting motion

The material parameters for the two cases are identical (and as used in the Green's function test).

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, simplified from the "generic" Californian rock-site velocity model of Boore & Joyner (1997). Q_S and Q_P are assumed to be infinite everywhere (Figure 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

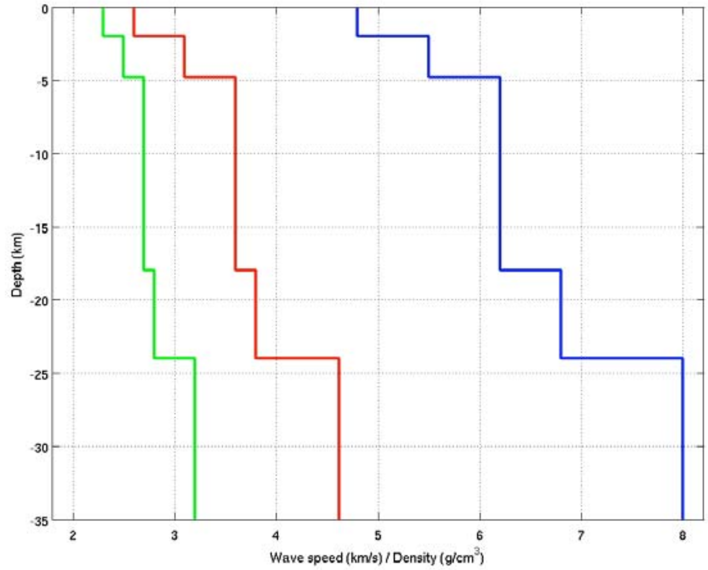

Figure 1: Velocity-density model for extended-fault forward-modeling exercise.

Part A: Strike-slip extended-fault rupture model (label: ssef0)

Source: (see data-file **`RuptureModel_SSEF0.dat`** for details)

- fault dip = 90°; fault strike = 90°
- Fault dimensions: **12 km along-strike, 11 km down-dip**
- Seismic moment: M_0 = 1.658 x 10^{18} Nm (M_W = 6.11)
- Hypocenter depth = 14 km; epicenter at the origin, i.e. the rupture nucleates at [0, 0, -14] km
- Distributed slip-rate over the fault plane (see data file for details)
- Rise time t_r variable over the fault variable (see data file for details)
- Rupture times imply non-constant rupture speed (see data file for details)
- Identical source-time function on each node: elementary boxcar of width t_r
- Discretization of rupture: node spacing is 1km in each fault-plane direction
- Note that all dip-slip values are identically zero for this strike-slip rupture model
- Note also that for all nodes at which strike-slip slip-velocity is zero, rise time and rupture time are fixed to arbitrary values of 3 sec and 5 sec, respectively. Those points do not contribute to seismic radiation anymore, and are mainly specified to achieve a regular 2D input mesh of kinematic rupture parameters.

The rupture-model data file thus specifies the kinematic rupture parameters: strike-slip slip-velocity amplitude, dip-slip slip-velocity amplitude, rise time, and rupture onset time. These parameters are given at 13 node-points in x-direction, and 12 node-points in z-direction. **The shallowest node points at -6.00 km defined the top of the fault plane.**

<u>Receivers (surface receivers only, Z = 0):</u>

The receiver configuration consists of three linear arrays: one fault-parallel array at 1 km fault-normal distance from the surface projection of a vertical fault (at X = 0 km in the chosen coordinate system), and two inclined arrays at $\alpha = 30°$ and $\alpha = 60°$ from the fault-parallel array (same as for the Green's function test).

	X [km]	Y [km]
1	0.00	1.00
2	5.00	1.00
3	10.00	1.00
4	15.00	1.00
5	4.33	3.50
6	8.66	6.00
7	12.99	8.50
8	2.50	5.33
9	5.00	9.66
10	7.50	13.99

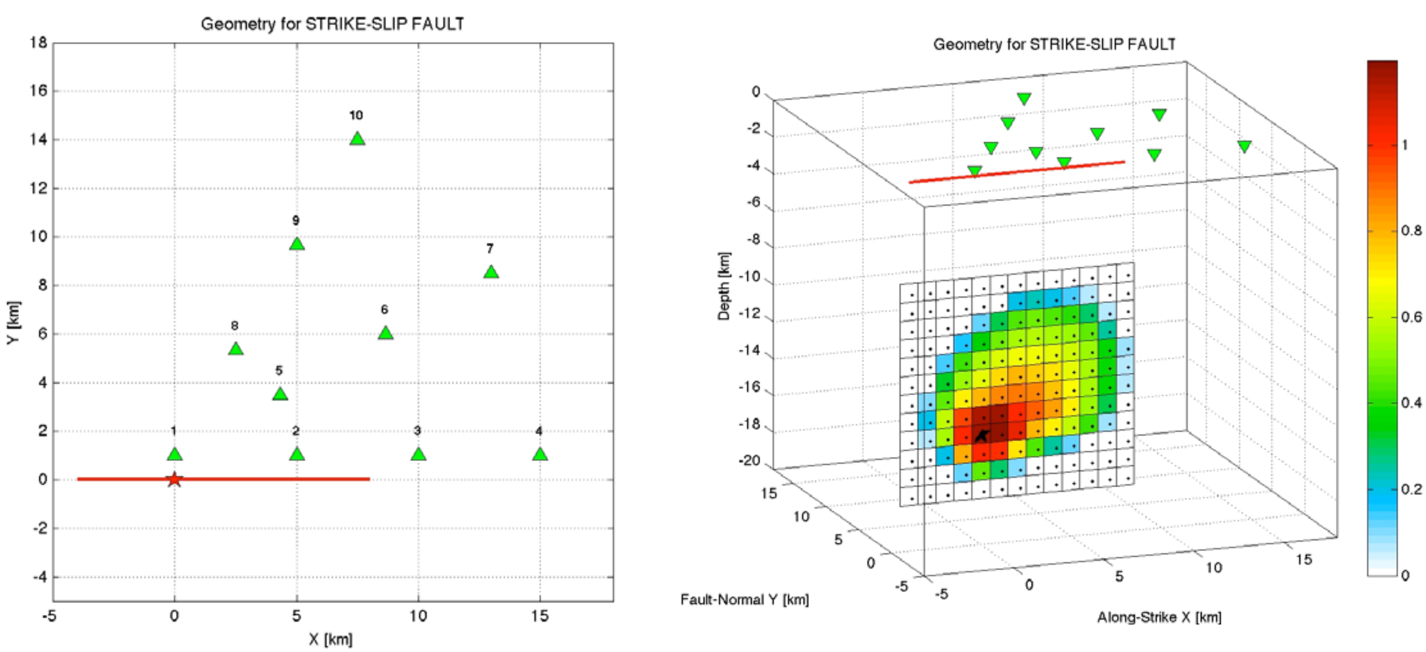

Figure 2: (Left) Source-receiver geometry for the strike-slip extended-source in map view. The red star shows the epicenter at X = 0, Y = 0 in a right-handed coordinate system with positive X pointing East, positive Y pointing North, and positive Z pointing up. The red line indicates the vertical projection of the updip-edge of an extend fault plane at depth. (Right) 3D-view of the rupture plane with an inhomogeneous slip distribution, colored-coded according to the amount of slip (in m). Small black dots indicate the centers of "subfaults", but kinematic rupture quantities for the simulations, given in the data file **`RuptureModel_SSEFO.dat`**, are defined on node points. The black star denotes the hypocenter.

Part B: Dip-slip extended-fault rupture model (label: dsef0)

Source: (see data-file ***RuptureModel_DSEFO.dat*** for details)

- fault dip = 40°; fault strike = 270°
- Fault dimensions: **12 km along-strike, 12 km down-dip**
- Seismic moment: $M_0 = 1.824 \times 10^{18}$ Nm ($M_W = 6.14$)
- Hypocenter depth = 9.785 km;
- Hypocenter position: X = 0.00; Y = 6.511 km, Z = -9.463 km
- Distributed slip-rate over the fault plane (see data file for details)
- Rise time t_r variable over the fault variable (see data file for details)
- Rupture times imply non-constant rupture speed (see data file for details)
- Identical source-time function on each node: elementary boxcar of width t_r
- Discretization of rupture: node spacing is 1km in each fault-plane direction; given the dip of the fault (40°), the node-spacing is 0.766 km in y-direction, and 0.643 km in z-direction
- Note that all strike-slip values are identically zero for this dip-slip rupture model
- Note also that for all nodes at which strike-slip slip-velocity is zero, rise time and rupture time are fixed to arbitrary values of 3 sec and 4 sec, respectively. Those points do not contribute to seismic radiation anymore, and are mainly specified to achieve a regular 2D input mesh of kinematic rupture parameters.

The rupture-model data file thus specifies the kinematic rupture parameters: strike-slip slip-velocity amplitude, dip-slip slip-velocity amplitude, rise time, and rupture onset time. These parameters are given at 13 node-points in both x-direction and z-direction. **The shallowest node points at -4.00 km defined the top of the fault plane, whose surface projection intersects the Earth-surface at y = 0 km along the x-axis of the chosen coordinate system.**

Receivers (surface receivers only, Z = 0):

The receiver configuration consists of three linear arrays: one fault-parallel array at 1 km fault-normal distance from the surface projection of a vertical fault (at X = 0 km in the chosen coordinate system), and two inclined arrays at α = 30° and α = 60° from the fault-parallel array. These three arrays are then mirrored across the X = 0 surface-projection of the fault to capture both hanging-wall and foot-wall sites (same as in the Green's function test).

	X [km]	Y [km]
1	0.00	1.00
2	5.00	1.00
3	10.00	1.00
4	15.00	1.00
5	4.33	3.50

6	8.66	6.00
7	12.99	8.50
8	2.50	5.33
9	5.00	9.66
10	7.50	13.99
11	0.00	-1.00
12	5.00	-1.00
13	10.00	-1.00
14	15.00	-1.00
15	4.33	-3.50
16	8.66	-6.00
17	12.99	-8.50
18	2.50	-5.33
19	5.00	-9.66
20	7.50	-13.99

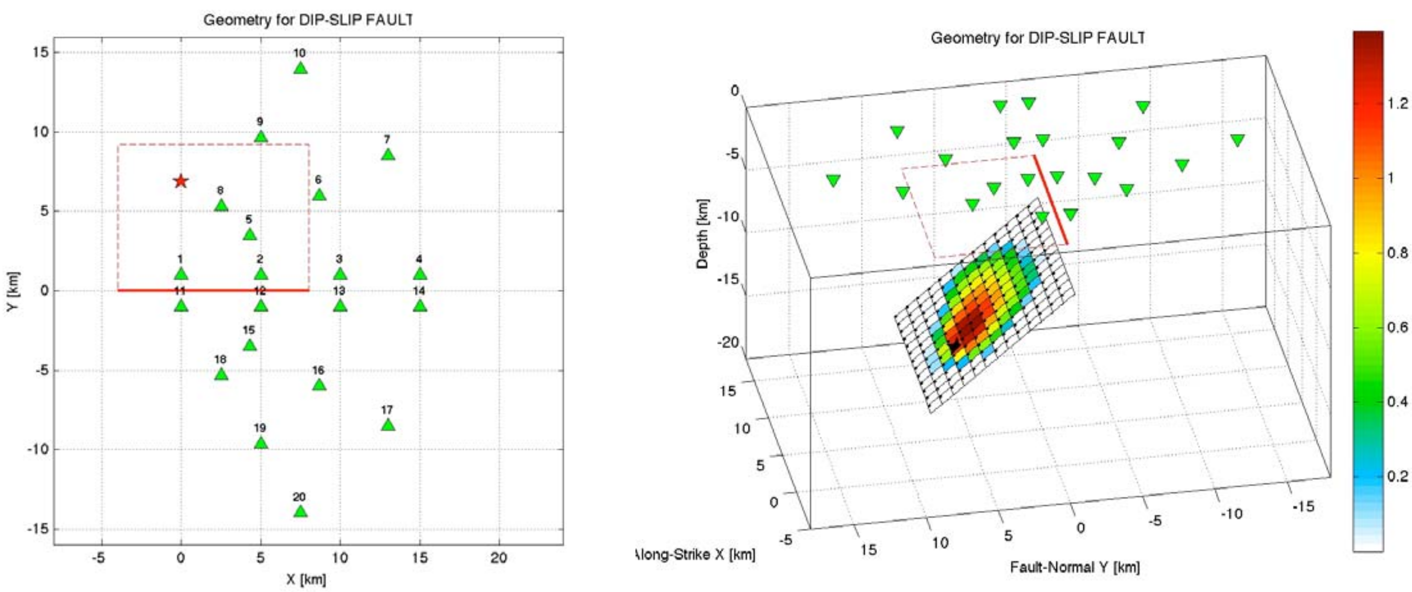

Figure 3: (Left) Source-receiver geometry for the dip-slip extended-source in map view. The red star shows the epicenter at X = 0, Y = 0 in a right-handed coordinate system with positive X pointing East, positive Y pointing North, and positive Z pointing up. The red line indicates the vertical projection of the updip-edge of an extend fault plane at depth. (Right) 3D-view of the rupture plane with a inhomogeneous slip distribution, colored-coded according to the amount of slip (in m). Small black dots indicate the centers of “subfaults”, but kinematic rupture quantities for the simulations, given in the data file **`RuptureModel_DSEFO.dat`**, are defined on node points. The fault dips by 40° to the positive Y side, resulting in a strike of 270°. The black star denotes the hypocenter.

Other information:

- Target frequency: 5 Hz
- If computed ground-motions are filtered, please specify the chosen frequency range as well as the type of filter (i.e. 'butterworth') and filter order.
- If it is known that the forward-modeling code generates velocity time series that do not exactly go back to zero after the seismic waves have passed, the time series could be truncated. This needs to be stated in the output file (see below).
- Choose mesh-size/discretization such that adequate waveforms with minimal numerical oscillations are generated.
- Place domain boundaries at large-enough distances to avoid boundary reflections, or use absorbing boundary conditions

Output instructions:

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)
- trunc: 3-record line to state whether or not a time-series truncation has been applied to avoid non-zero velocity after the waves have passed.
  - If yes, than enter [1   original length of time-series   truncated time-series length]
  - If not, than enter [0   0   0]

filename:

label_modeler_receiver#.syn   (e.g. ssef0_mai_12.syn)

header:

label	modeler	date
rec#	rec_crd_X	rec_crd_Y
npts	dt	fmax
trunc1	trunc2	trunc3

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

x-comp	y-comp	z-comp

Example time-series output file: ssp0_MaiMartin_3.syn

ssef0	MaiMartin	10.08.2009
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