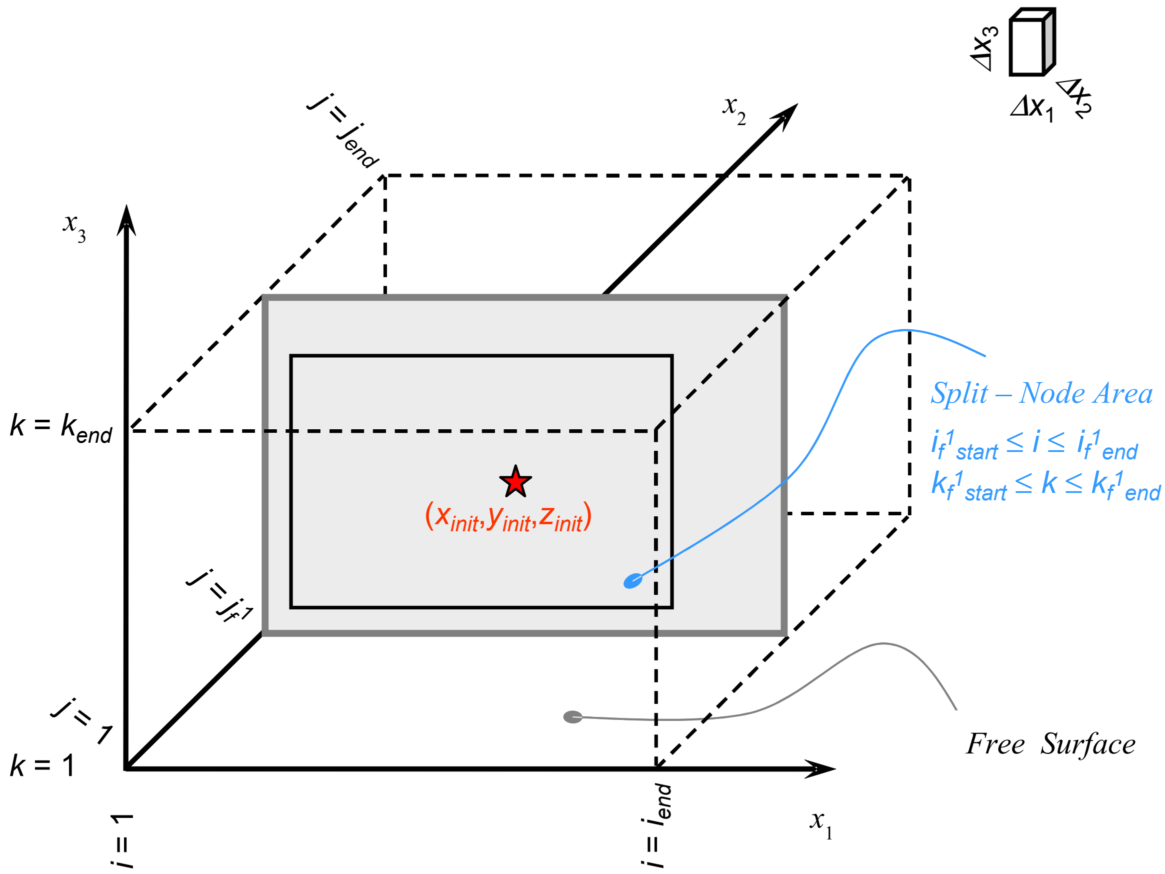
Rupture propagation in a *truly* 3 – D fault model

Numerical Method: FD 3 - D



$$\boldsymbol{u} = (\, u_1(x_1, x_3, t),\, 0,\, u_3(x_1, x_3, t)\,)$$

In the assumed fault geometry, on a generic fault point (defined by the absolute coordinate (x_1, x_2^f, x_3)), at time t, the stress tensor matrix is:

$$\sigma_{ij}^{f}\left(x_1, x_2^{f}, x_3, t\right) = \begin{bmatrix} 0 & 0 & 0 \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ 0 & 0 & 0 \end{bmatrix}$$

where:

$\sigma_{22} = -\sigma_n^{eff}$ (effective normal stress; normal stresses are negative in compression)

σ_{21}, σ_{23} (shear stresses, associated to the adopted fault constitutive law)

In the assumed fault geometry, on a generic medium point (defined by the absolute coordinate (x_1,x_2,x_3)), at time *t,* the stress tensor matrix is:

$$\sigma_{ij}(x_1,x_2,x_3,t)=\lambda\, e_{kk}(x_1,x_2,x_3,t)\delta_{ij}+2\mu\, e_{ij}(x_1,x_2,x_3,t)$$

(i. e. the Hooke’ s law for a linealry homogeneous, isotropic medium, within the small displacement approximation)

where:

$$e_{ij} = \tfrac{1}{2}\ (U_{i,j} + U_{j,i})$$

is calculated from the displacement field **U**, generated by the rupture propagation on the fault surface S.

We solve the fundamental elastodynamic equation, neglecting body forces **f**

$$\rho \ddot{U}_i = \sigma_{ij,j} + f_i$$

We discretize the volume in $x_1 x_2 x_3$ space by using cubic building blocks. The space is linearly elastic except that in **6 planes**, representing 4 dipping and 2 vertical faults

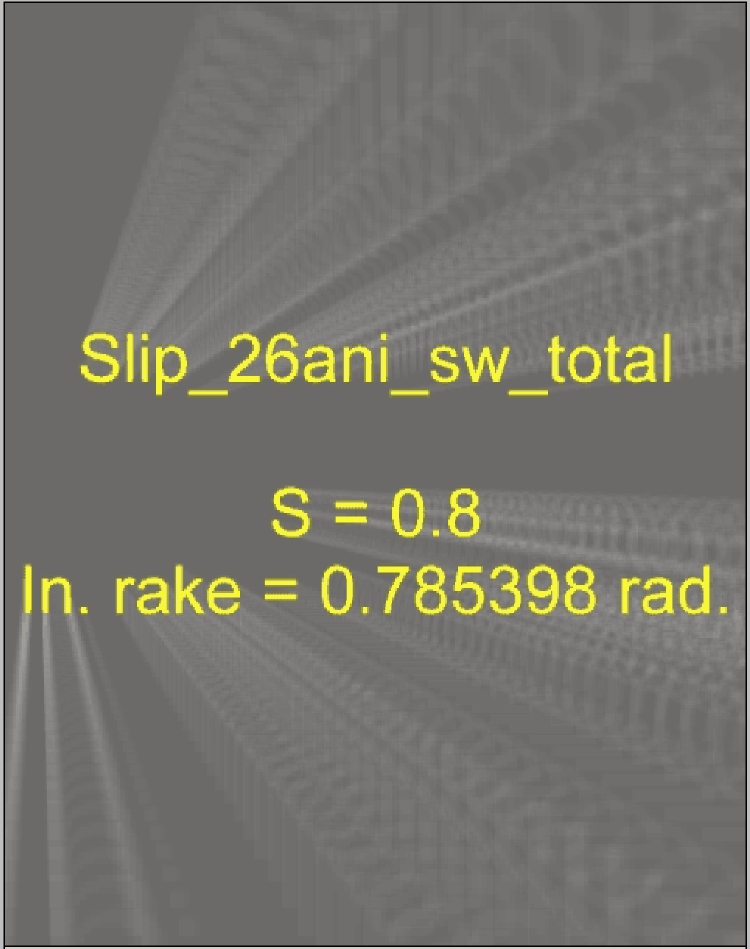
Displacements, forces and tractions are staggered in time with respect to the slip velocity components

An explicit displacement discontinuity is assumed between the two sides of faults: **Traction – at – Split – Node** scheme

We take into account the **rake rotation** during propagation: the rake direction is calculated from fault strength.

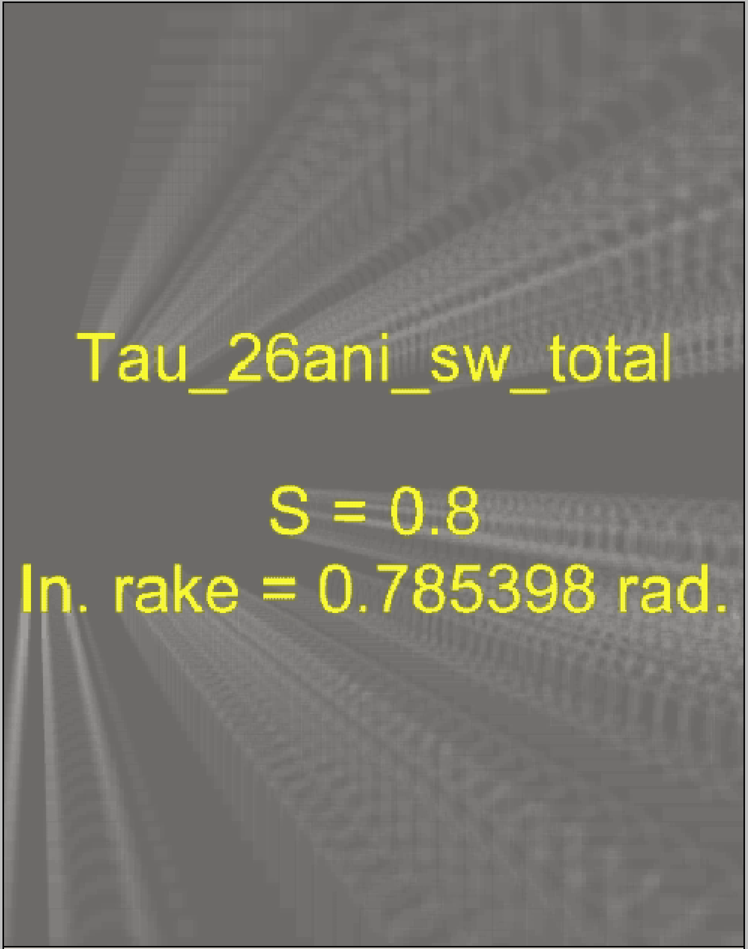
Reference Case

Slip



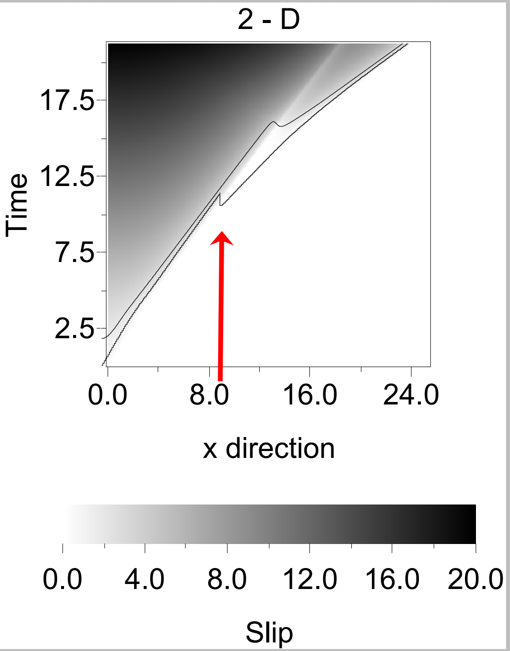
Anim_Slip_26ani_sw_total.avi

Traction

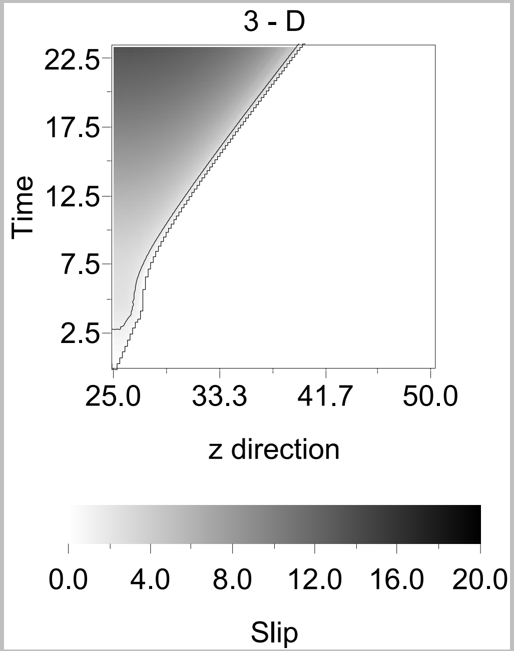


Anim_Tau_26ani_sw_total.avi

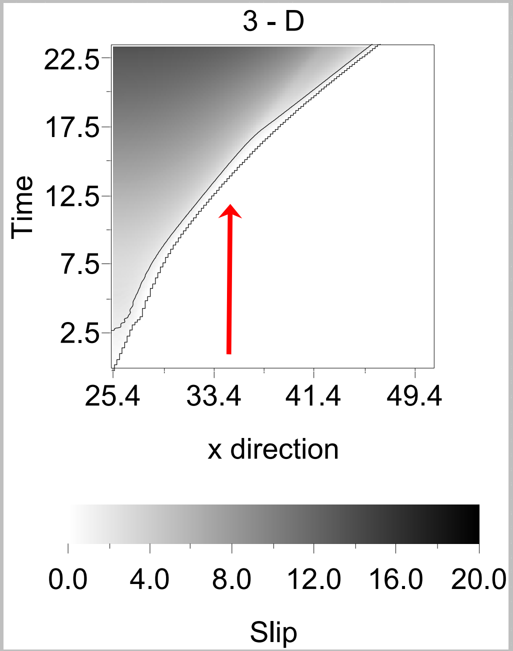
Comparision between 2 – D and 3 – D models #1



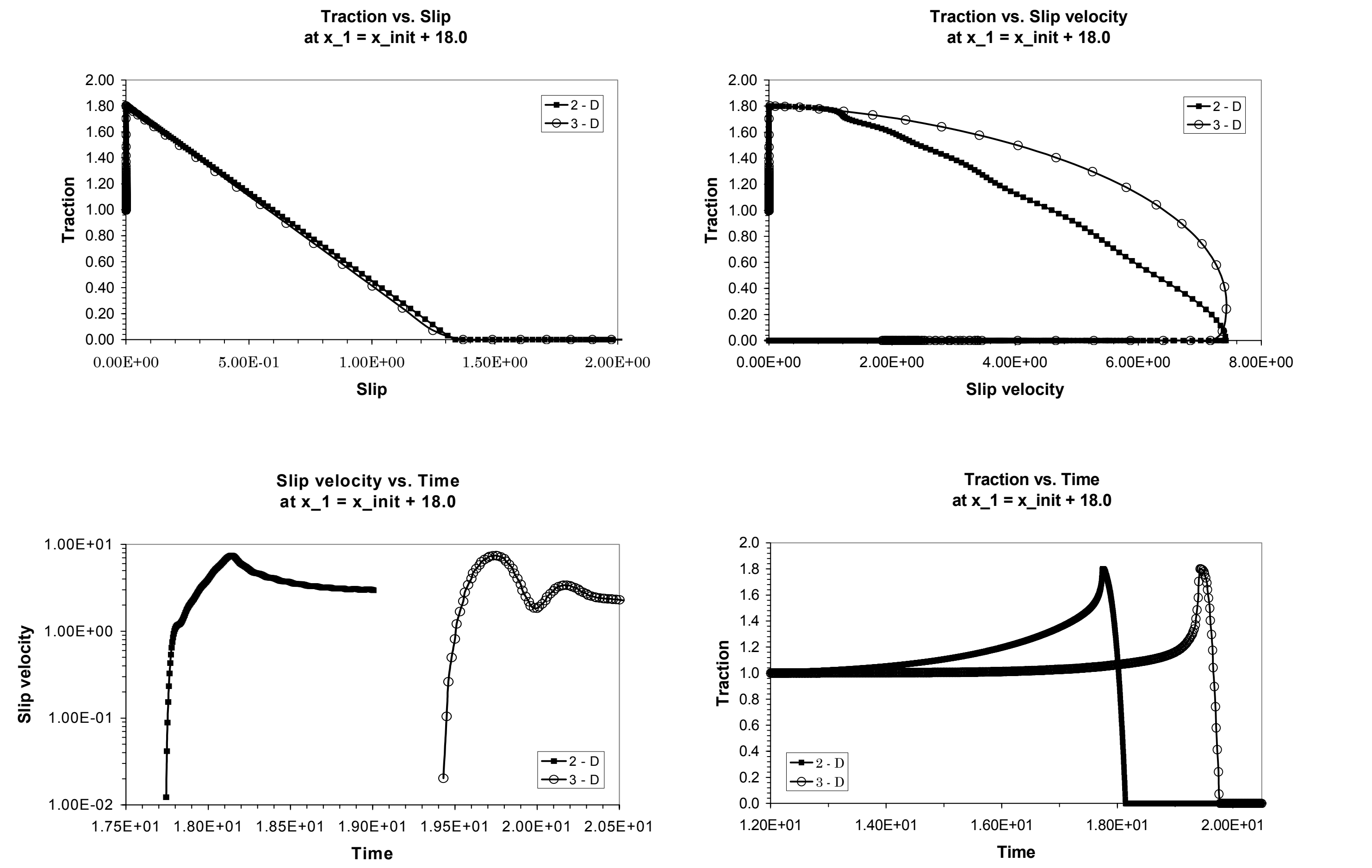
Fixed x_1 coordinate



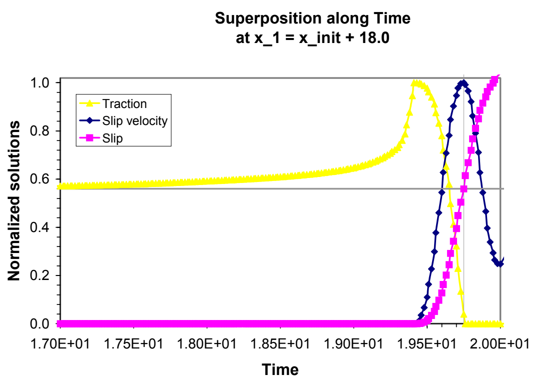
Fixed x_3 coordinate

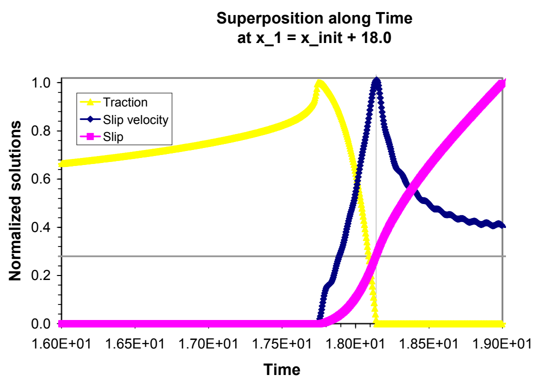


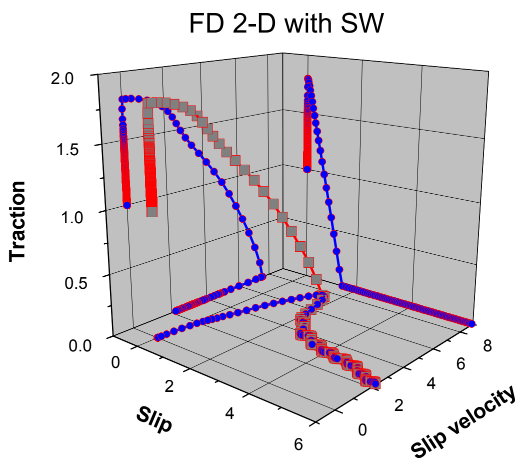
Comparision between 2 – D and 3 – D models #2

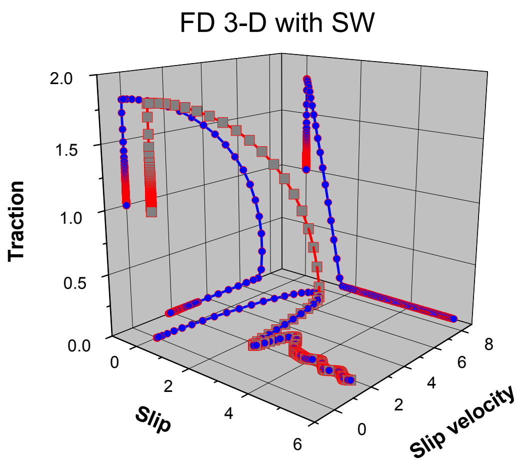


Comparision between 2 – D and 3 – D models #3

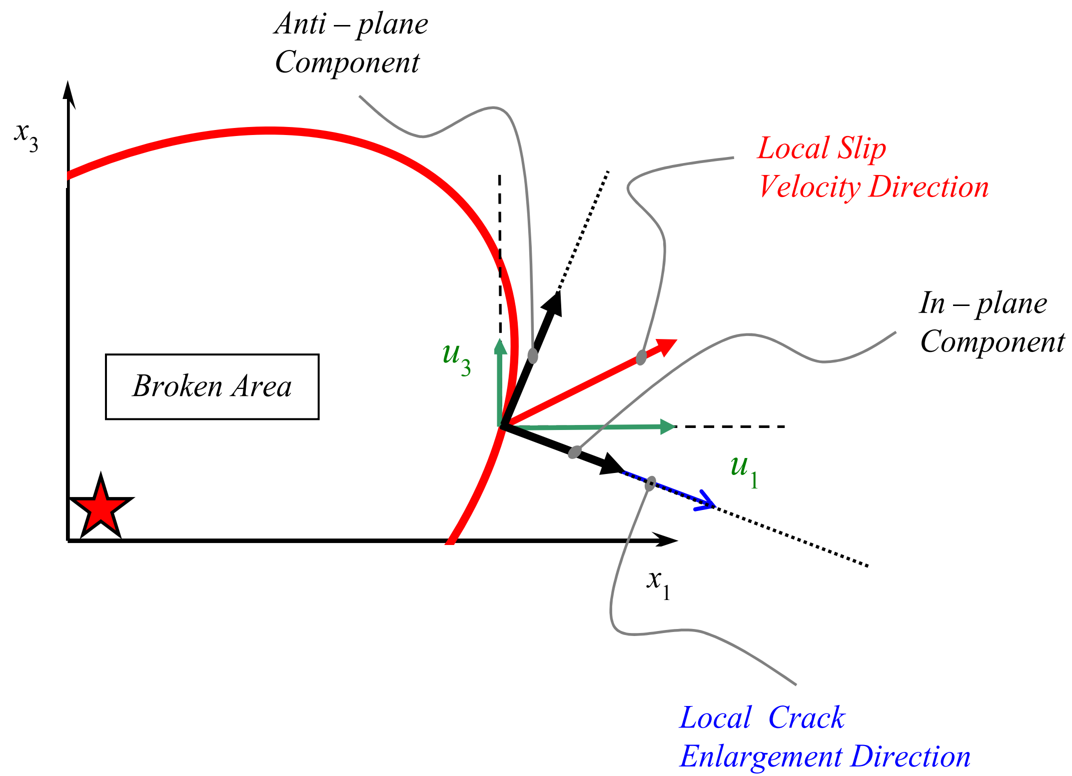


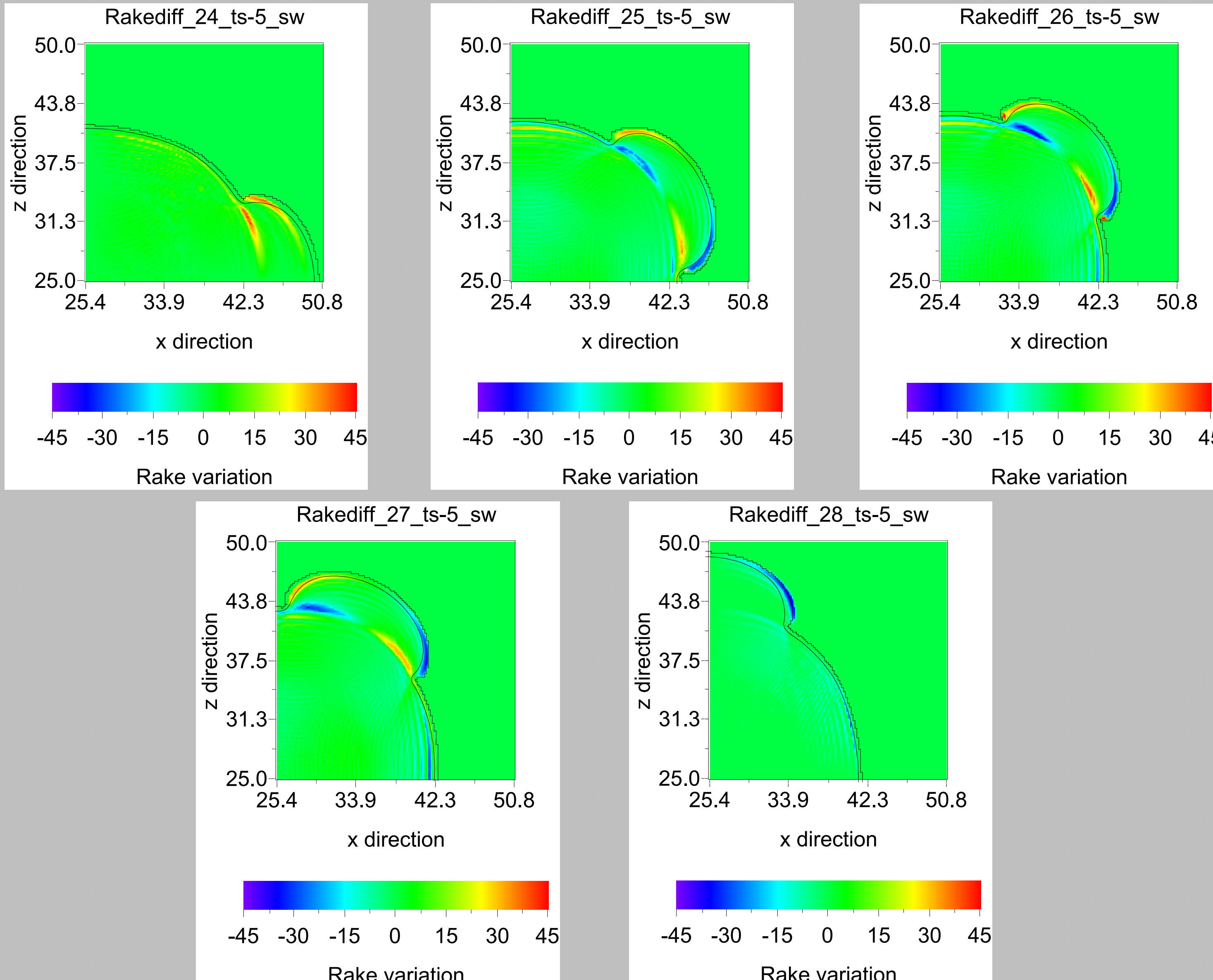




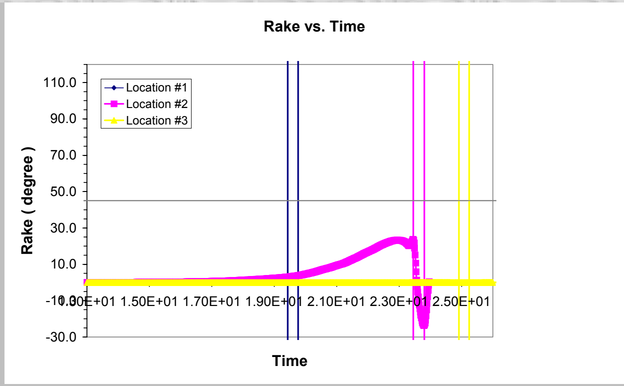


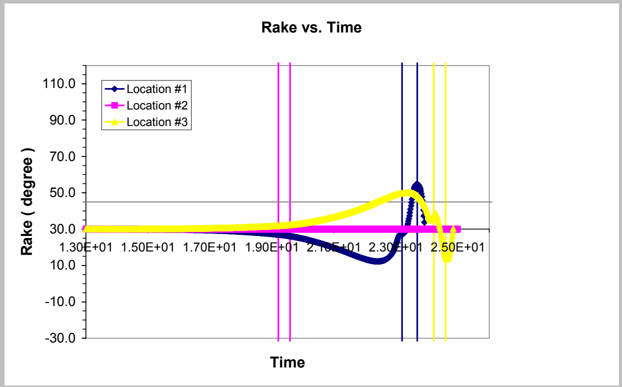
Coupling of two modes of propagation. The rake variation

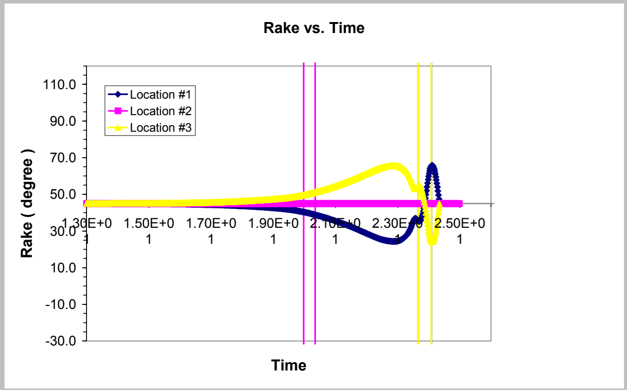


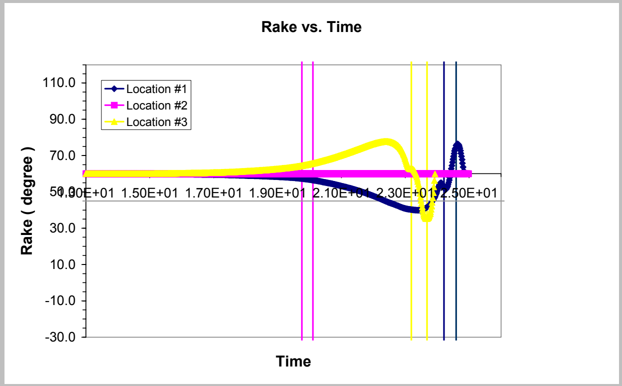


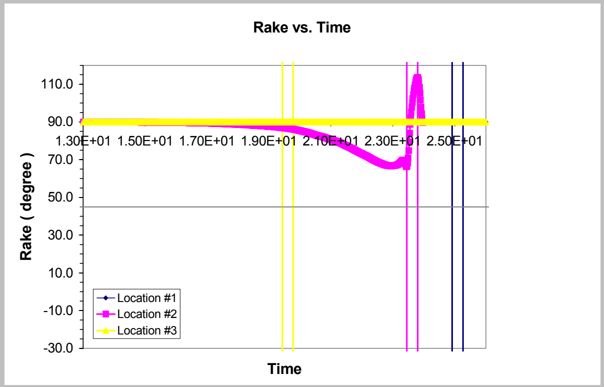
Rakediff_24_ts-5_sw
Rakediff_25_ts-5_sw
Rakediff_26_ts-5_sw
Rakediff_27_ts-5_sw
Rakediff_28_ts-5_sw
z direction
50.0
43.8
37.5
31.3
25.0
x direction
25.4
33.9
42.3
50.8
-45
-30
-15
0
15
30
45
Rake variation


Rake vs. Time
Location #1
Location #2
Location #3
110.0
90.0
70.0
50.0
30.0
10.0
-10.0
-30.0
1.30E+01 1.50E+01 1.70E+01 1.90E+01 2.10E+01 2.30E+01 2.50E+01
Rake (degree)
Time

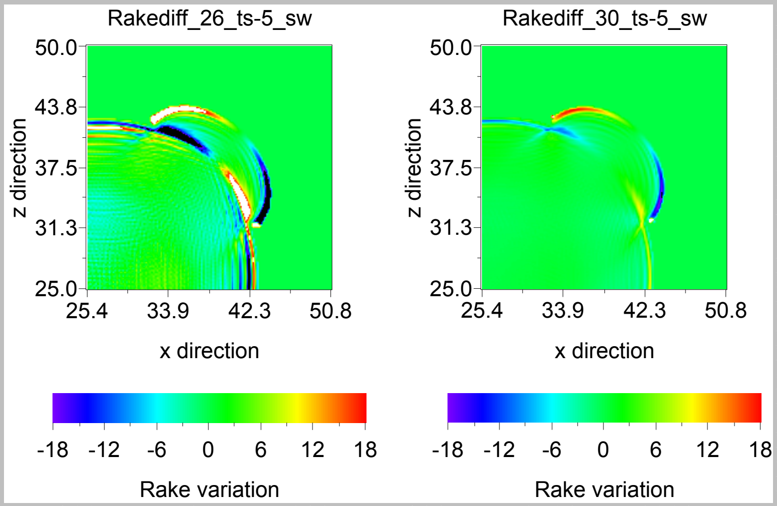

Rake vs. Time
Location #1
Location #2
Location #3
110.0
90.0
70.0
50.0
30.0
10.0
-10.0
-30.0
1.30E+01 1.50E+01 1.70E+01 1.90E+01 2.10E+01 2.30E+01 2.50E+01
Rake (degree)
Time

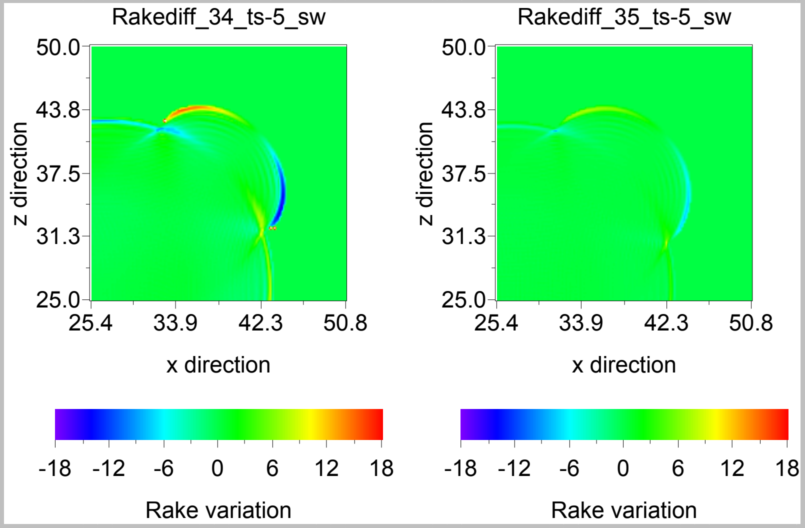

Rake vs. Time
Location #1
Location #2
Location #3
110.0
90.0
70.0
50.0
30.0
10.0
-10.0
-30.0
1.30E+01 1.50E+01 1.70E+01 1.90E+01 2.10E+01 2.30E+01 2.50E+01
Rake (degree)
Time

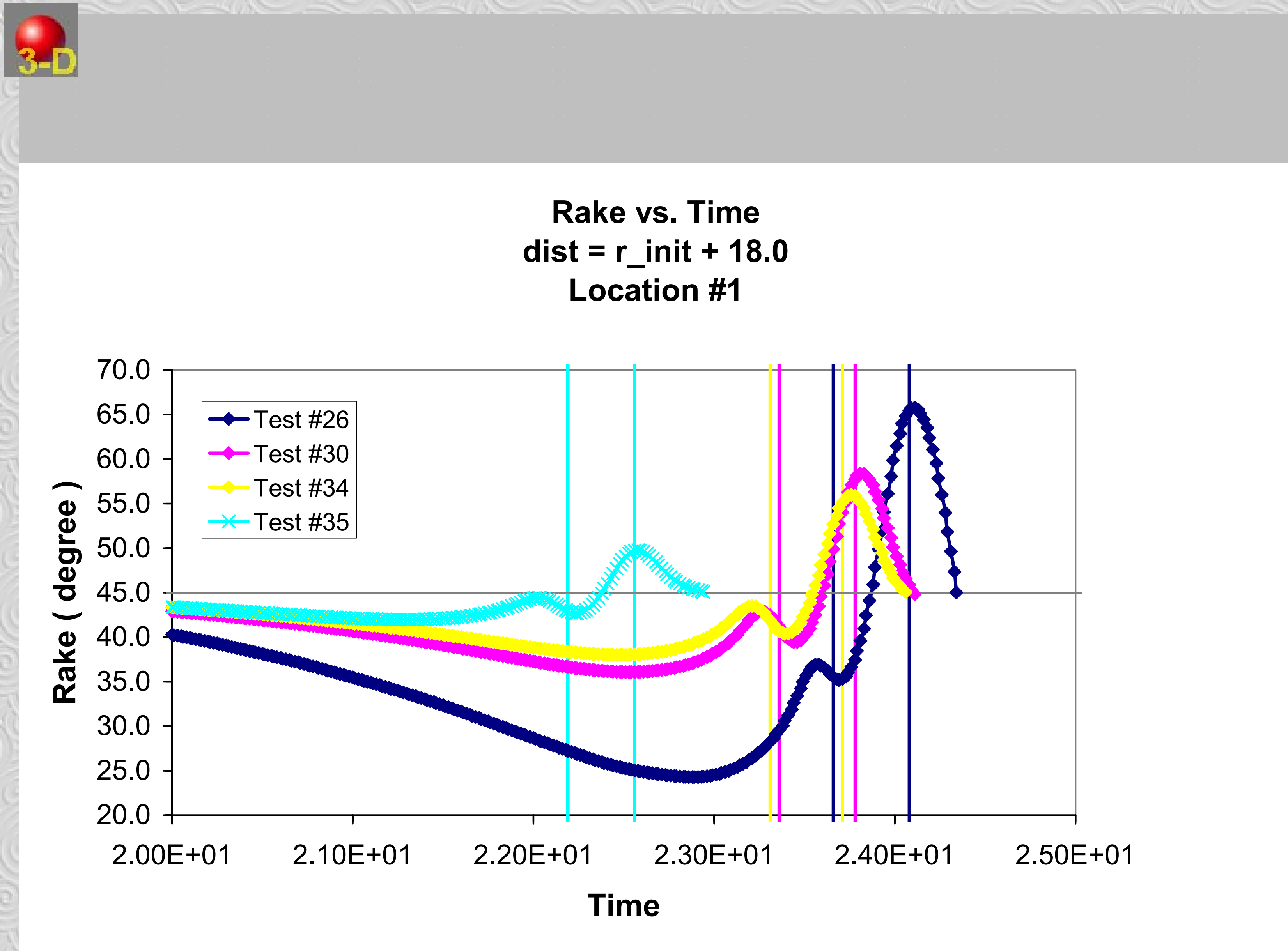

Rake vs. Time
Location #1
Location #2
Location #3
110.0
90.0
70.0
50.0
30.0
10.0
-10.0
-30.0
1.30E+01 1.50E+01 1.70E+01 1.90E+01 2.10E+01 2.30E+01 2.50E+01
Rake (degree)
Time

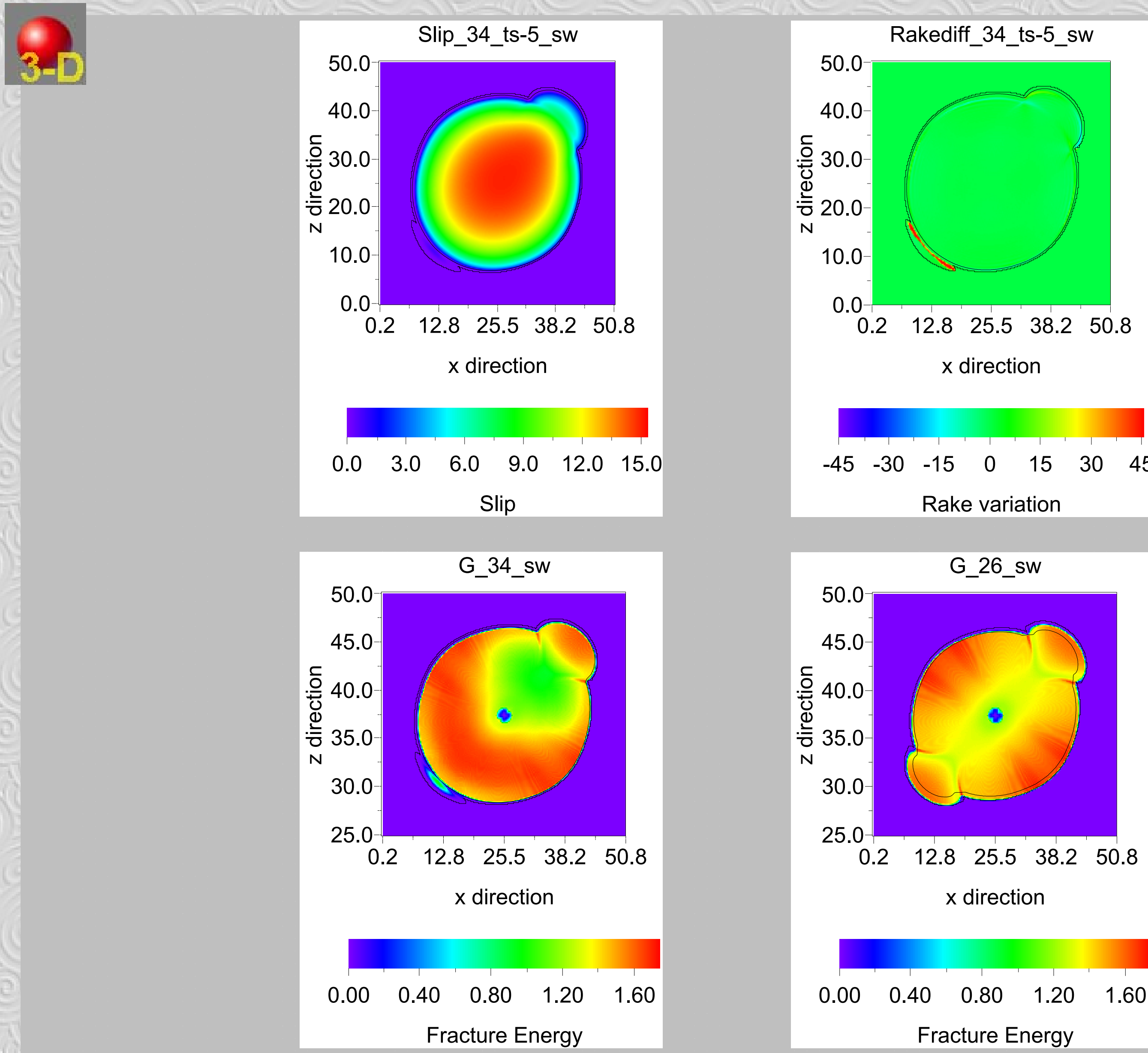

Rake vs. Time
Location #1
Location #2
Location #3
110.0
90.0
70.0
50.0
30.0
10.0
-10.0
-30.0
1.30E+01 1.50E+01 1.70E+01 1.90E+01 2.10E+01 2.30E+01 2.50E+01
Rake (degree)
Time

Dependence on the absolute stress level. Symmetry leak



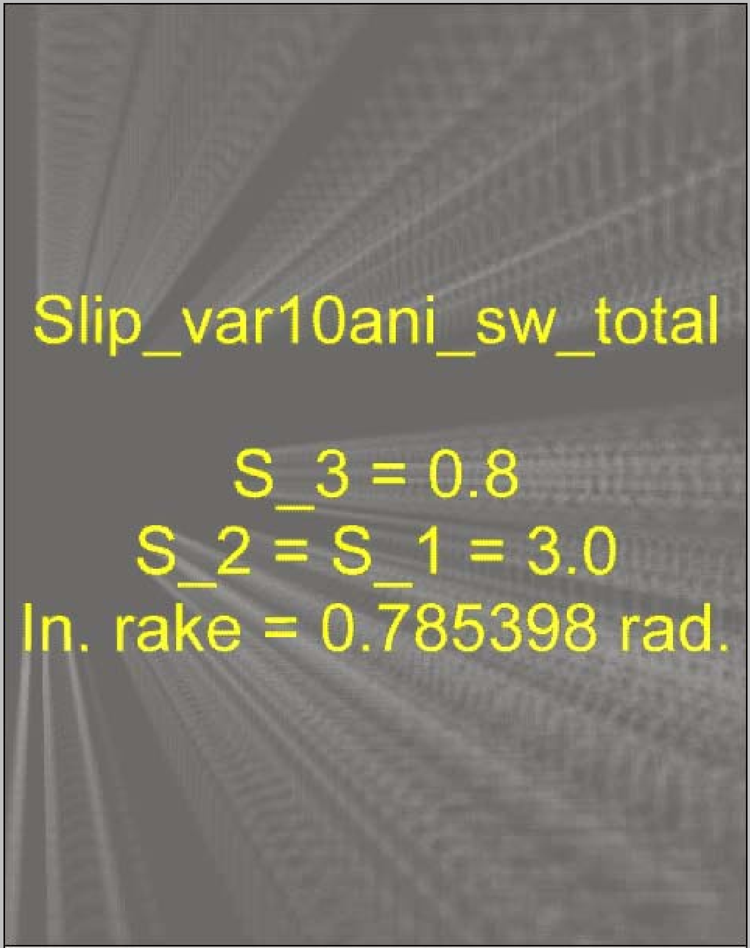



3-D
Rake vs. Time
dist = r_init + 18.0
Location #1
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
Rake (degree)
Test #26
Test #30
Test #34
Test #35
2.00E+01
2.10E+01
2.20E+01
2.30E+01
2.40E+01
2.50E+01
Time



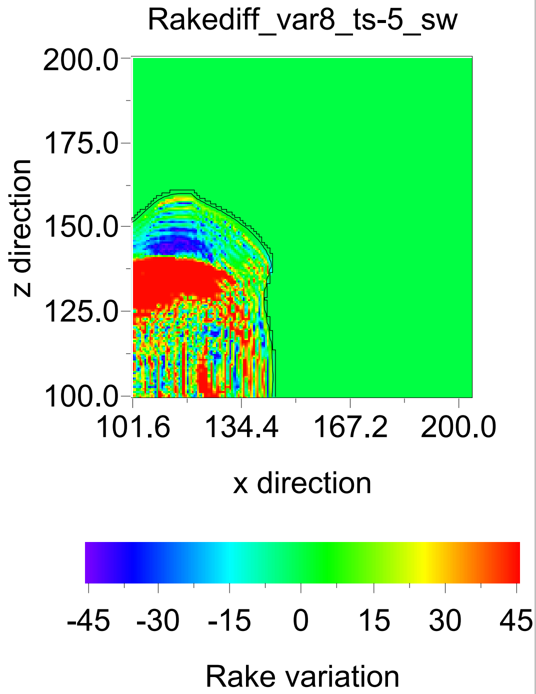
3-D
Slip_34_ts-5_sw
50.0
40.0
30.0
20.0
10.0
0.0
z direction
0.2
12.8
25.5
38.2
50.8
x direction
0.0
3.0
6.0
9.0
12.0
15.0
Slip
Rakediff_34_ts-5_sw
50.0
40.0
30.0
20.0
10.0
0.0
z direction
0.2
12.8
25.5
38.2
50.8
x direction
-45
-30
-15
0
15
30
45
Rake variation
G_34_sw
50.0
45.0
40.0
35.0
30.0
25.0
z direction
0.2
12.8
25.5
38.2
50.8
x direction
0.00
0.40
0.80
1.20
1.60
Fracture Energy
G_26_sw
50.0
45.0
40.0
35.0
30.0
25.0
z direction
0.2
12.8
25.5
38.2
50.8
x direction
0.00
0.40
0.80
1.20
1.60
Fracture Energy

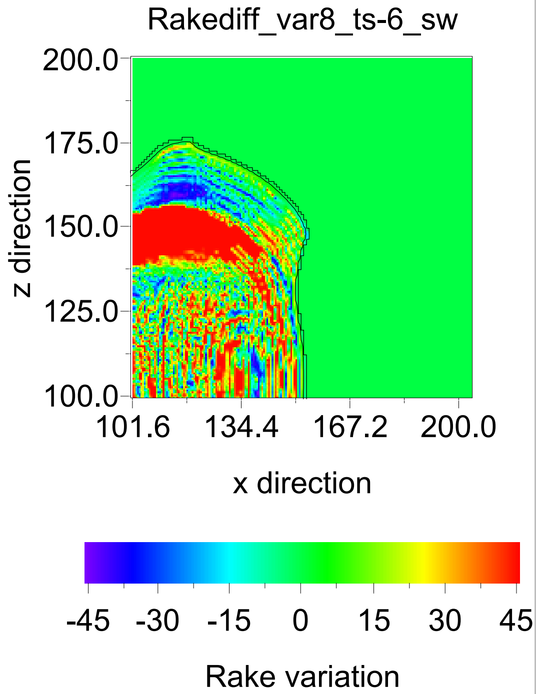
Effects of Strength Heterogeneity #1

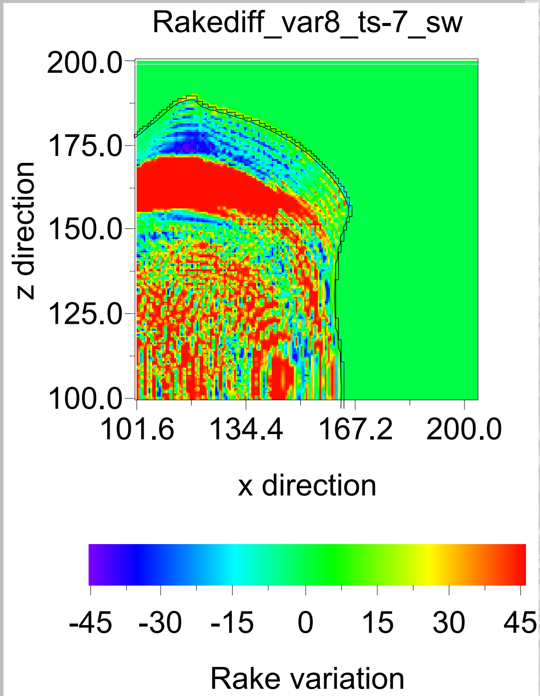


Anim_Slip_var10ani_sw_total.avi

Effects of Strength Heterogeneity #2







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Support Slides:
Parameters, Notes, etc.

To not be displayed directly. Referenced above.

Why " *truly* " 3 – D ?

Remembering the dimensionality d' of the problem:

2 – D Mode II (pure in – plane):	$\mathbf{u} = (u_1(x_1,t), 0, 0)$
2 – D Mode III (pure anti – plane):	$\mathbf{u} = (0, u_2(x_1,t), 0)$
3 – D Mixed mode:	$\mathbf{u} = (u_1(x_1,t), u_2(x_1,t), 0)$
3 – D having only one non null component:	$\mathbf{u} = (u_1(x_1,x_2,t), 0, 0)$
Truly 3 – D:	$\mathbf{u} = (u_1(x_1,x_2,t), u_2(x_1,x_2,t), 0)$

Test #	**26ani_sw**	**3 – D**	**FD**
Constitutive law	**Slip - weakening**		
Simulation Date	14-12-02		
System	*Mk*		
Categorized as	**Homogeneous**		
Input Set type	*Non - dimensional units*		
Δx , Δy , Δz	0.2	0.2	0.2
Arrays size	254	83	251
Iterations in time	350		
Mass density (ρ)	1.		
v_S , v_P	1.	1.732	
Initial stress (τ_0)	1.		
Yield stress (τ_u)	1.8		
Frictional level (τ_f)	0.		
Strength (S)	0.8		
Characteristic length (d_0)	1.3	1.3	1.3
Normal stress (σ_n)	1.		
Initial rake	0.785398 rad.		
Initial slip velocity	0.5		
Nucleation point	25.4	25.	
Fault type	*Vertical Strike - slip*		

Test #	37ani_sw	3 – D	FD
Constitutive law	**Slip - weakening**		
Simulation Date	15-10-02		
System	*Mk*		
Categorized as	**Homogeneous**		
Input Set type	*Non - dimensional units*		
Δx , Δy , Δz	0.2	0.2	0.2
Arrays size	254	83	251
Iterations in time	350		
Mass density (ρ)	1.		
v_S , v_P	1.	1.732	
Initial stress (τ_0)	1.		
Yield stress (τ_u)	1.8		
Frictional level (τ_f)	0.		
Strength (S)	0.8		
Characteristic length (d_0)	1.3	1.3	1.3
Normal stress (σ_n)	1.		
Initial rake	0.785398 rad.		
Initial slip velocity	0.5		
Nucleation point	25.4	25.	
Fault type	*Vertical Strike - slip*		

Test #	**var10ani_sw**	**3 – D**	**FD**
Constitutive law	**Slip - weakening**		
Simulation Date	19-12-02		
System	*Mk*		
Categorized as	**Heterogeneous**		
Input Set type	*Non - dimensional units*		
Δx , Δy , Δz	0.8	0.2	0.8
Arrays size	254	83	251
Iterations in time	700		
Mass density (ρ)	1.		
v_S , v_P	1.	1.732	
Initial stress (τ_0)	1.	1.	1.
Yield stress (τ_u)	1.8	4.	4.
Frictional level (τ_f)	0.	0.	0.
Strength (S)	0.8	3.	3.
Characteristic length (d_0)	1.3	1.3	1.3
Normal stress (σ_n)	1.		
Initial rake	0.785398 rad.		
Initial slip velocity	0.5		
Nucleation point	25.4	10.	
Fault type	*Vertical Strike - slip*		