Kellogg West Conference Center
November 30, 2018

SCEC Dynamic Rupture TAG

The 2018 Ingredients Workshop:

Fault Geometry

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Michael Barall (Invisible Software)

Our group uses dynamic rupture simulation codes to examine how earthquakes work.

So far we have successfully tested these codes for a variety of
** fault geometries **
** friction formulations **
** initial stress conditions **
rock properties
(See our group paper Harris et al., SRL, 2018)

We have demonstrated that we can simulate dynamic earthquake rupture in a wide range of settings.

But, are we using the appropriate assumptions (ingredients) for our simulations?

That is the purpose of this workshop:
Investigate Ingredient #1: Fault Geometry

How Dynamic Earthquake Rupture Simulations Work

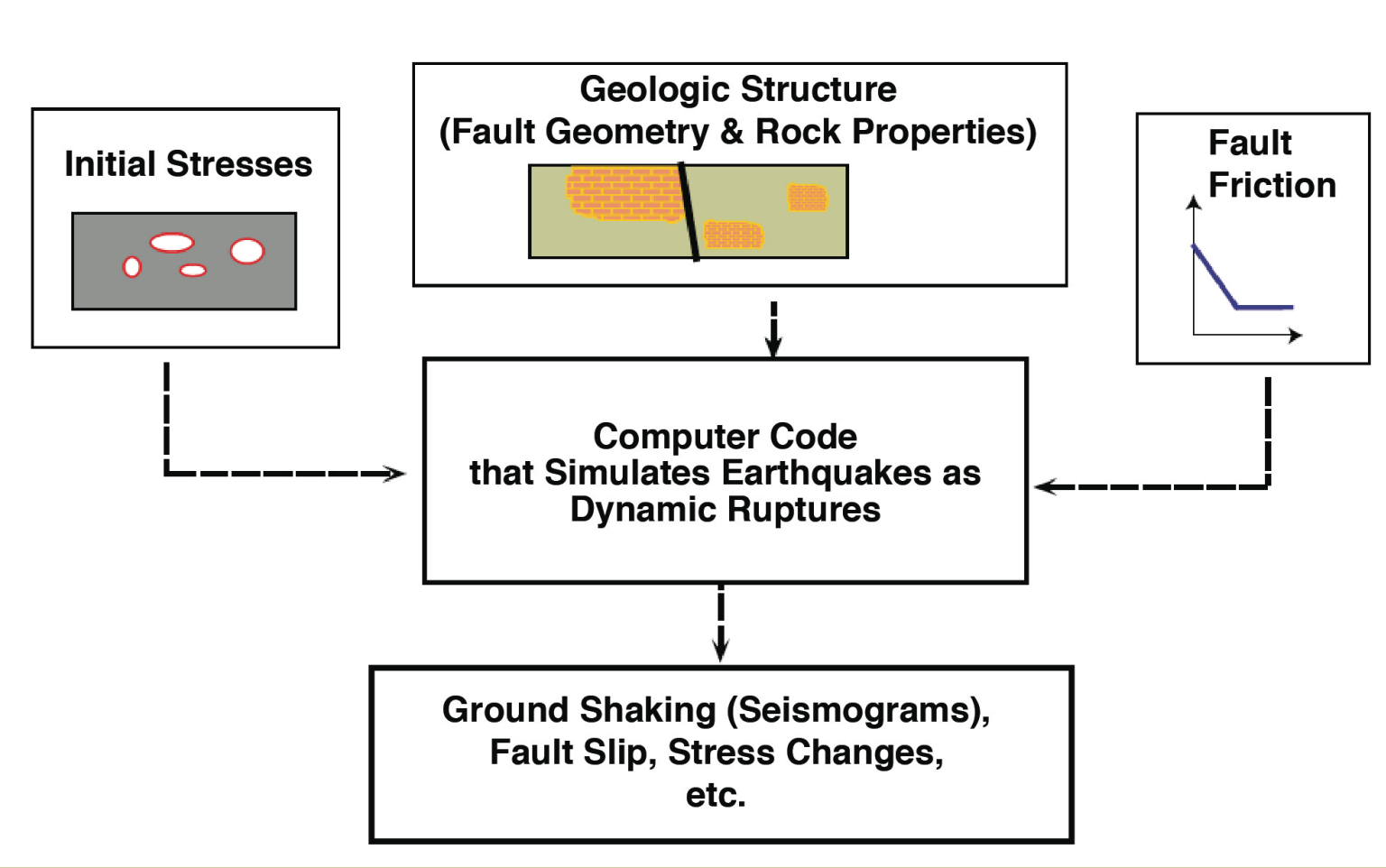
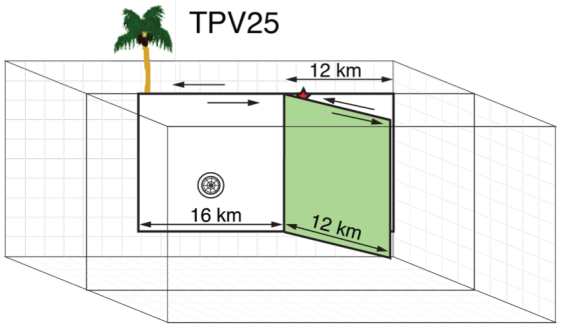
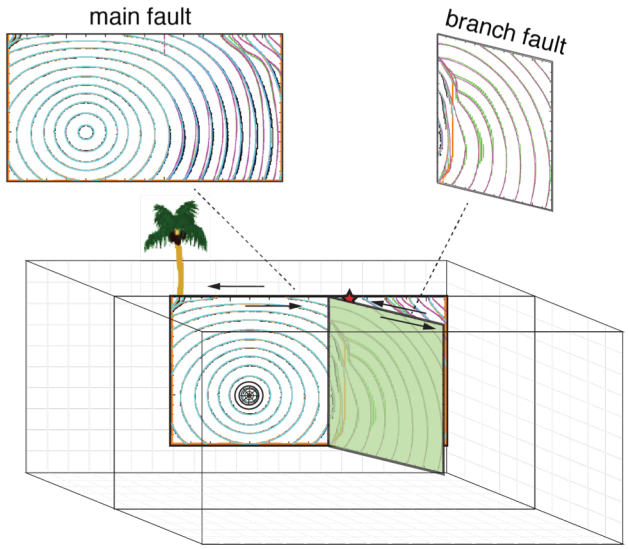
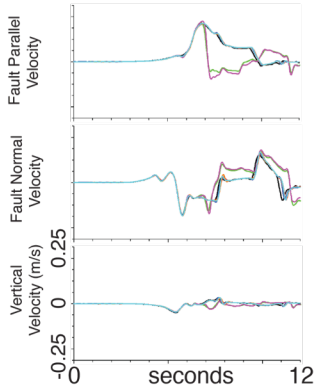


figure from Harris et al., SRL, 2018
(and earlier related Harris publications)

How it works – dynamic earthquake rupture and a fault branch



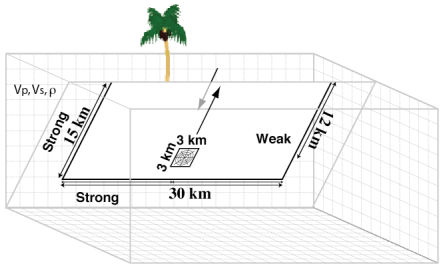




aagaard.2 (Brad Aagaard - PyLith v1.9.0a - Tet4 100m)	disconnected
barall.2 (Michael Barall - Finite Element - FaultMod - 50 m)	disconnected
daub (Eric Daub - Finite Difference - fdfault)	connected
duan.2 (Benchun Duan - Finite Element - EQdyna - 50 m)	disconnected
ma (Shuo Ma - Finite Element - MAFE (100 m))	disconnected
ulrich (Thomas Ulrich - DG - SeisSol -fault 150m - o5 -0.15c - no gap)	connected
ulrich.2 (Thomas Ulrich - DG - SeisSol -fault 150m - o5 -0.15c - 25m gap)	disconnected

Lightly rearranged figure 14
from Harris et al., SRL, 2018

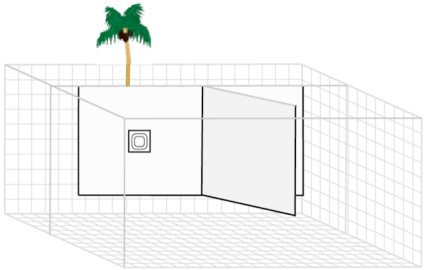
Code Comparison Benchmarks - Testing Fault Geometry Implementations



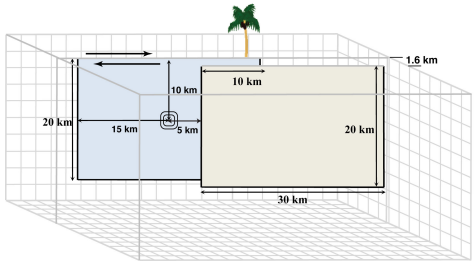
TPV10-13, 210

Dipping fault: elastic, plastic

TPV14-15,
18-21,
24, 25



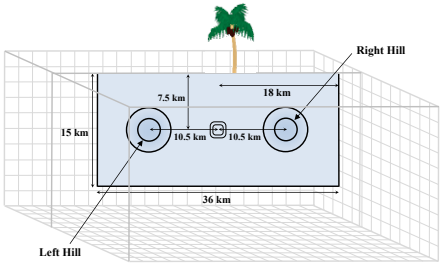
Fault Branches: elastic, viscoplastic



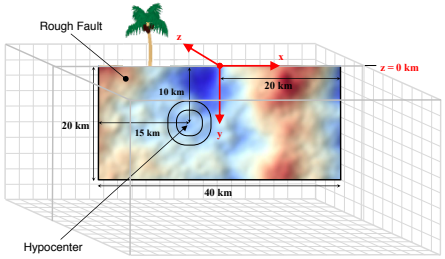
TPV22-23

Fault Stepovers

TPV28



Slightly rough fault



TPV29-30

Rough Fault: elastic, viscoplastic

Today's Workshop – How to Choose the Fault Geometry Ingredient

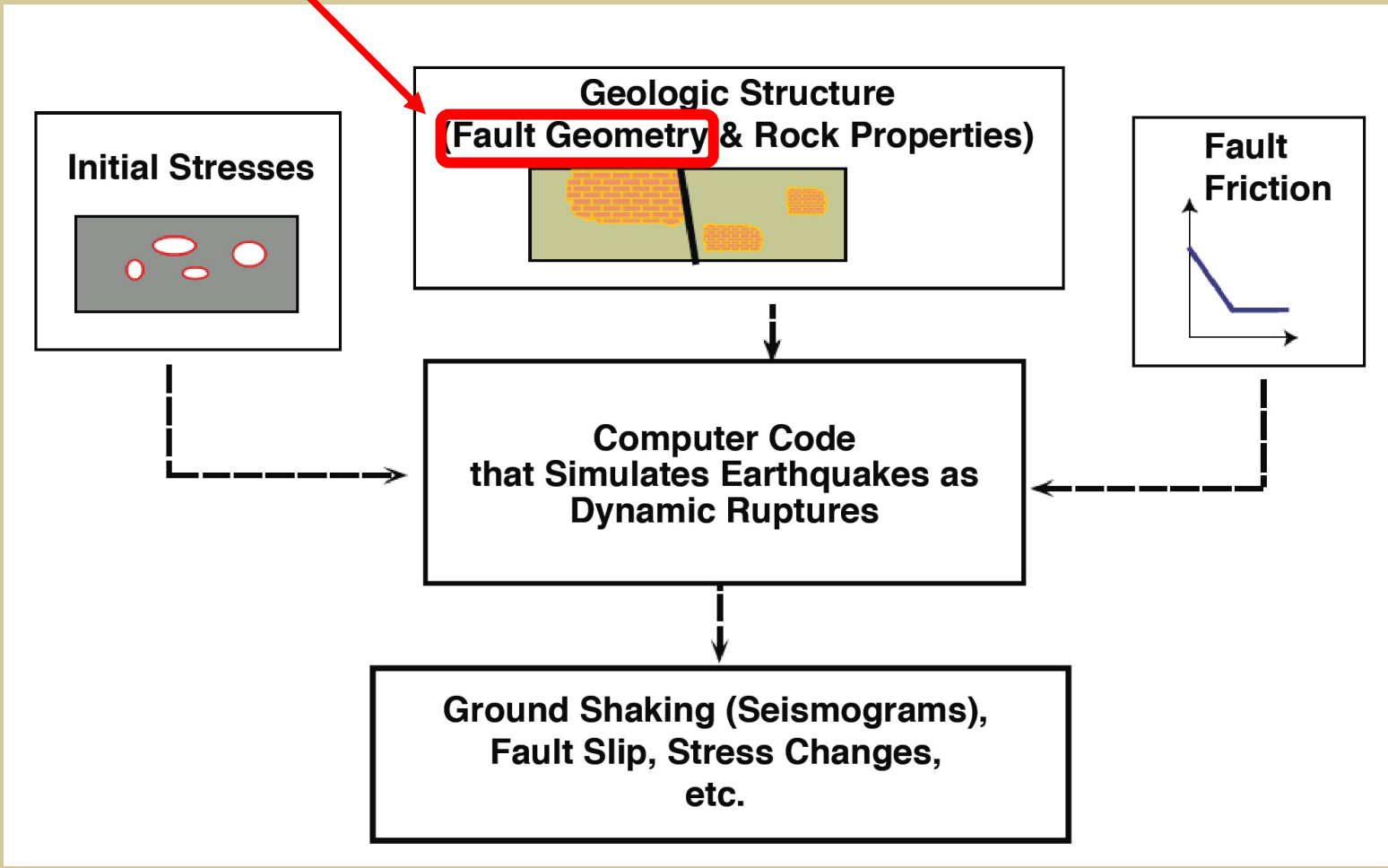


figure from Harris et al., SRL, 2018
(and earlier related Harris publications)

	SCEC Dynamic Rupture Fault Geometry Workshop November 30, 2018	
	Session 1: Overview, Motivation, and Desired Outcomes	
09:30	Welcome and Overview of Workshop Objectives, Introductions	Ruth Harris
	Session 2: What Does Fault Geometry Look Like?	
09:45	Observations from the Field - Big Scale - Community Fault Model (CFM)	Craig Nicholson
10:10	Inferences from the Field - Big Scale - Effects of Geometry on Earthquake Ruptures	Glenn Biasi
10:35	Observations from the Field - Big and Small Scale	Jamie Kirkpatrick
11:00	Discussion - Observations	All
11:15	Break	
	Session 3: Fault Geometry Applications - Hazards	
11:30	Fault Geometry Decisions and Alquist Priolo	Tim Dawson
11:55	Fault Geometry Decisions and UCERF3 (Rupture Extent)	Morgan Page
12:20	Discussion - Hazards	All
12:30	Lunch	
	Session 4: Fault Geometry Applications - EQ's and Scenarios	
13:30	Fault Geometry Effects and the 1992 Landers earthquake	Stephanie Wollherr
13:55	The role of 3D fault geometry in the rupture propagation and arrest during the 2016 Kaikoura (New Zealand) earthquake	Yoshi Kaneko
14:20	Large EQ Scenarios for the Eastern San Gorgonio Pass	Roby Douilly
14:45	Large Earthquakes Near Cajon Pass	Julian Lozos
15:10	Break	
15:25	Earthquake Rupture on 3D Rough Faults	Steve Day
15:50	Fault Geometry and Multi-Cycle Models: From Single-Event Dynamics to Multicycle Dynamics of Geometrically Complex Faults	Ben Duan
16:15	Fault Geometry and Ground Motions	Ralph Archuleta
16:40	**Session 5: Discussion and Future Plans**	All

EXTRA SLIDES

List of many of our group's dynamic earthquake rupture codes (Table 1 of Harris et al., SRL, 2018)

Code Name	Code Type	References	Notes	Code Availability
AWP-ODC	finite difference	Roten et al., 2016; Dalguer & Day, 2007		contact author Roten
beard	DG finite element	Kozdon et al., 2015		contact author Kozdon
CG-FDM	finite difference	Zhang et al., 2014		contact author Zhang
EqSim	finite element	Aagaard et al., 2001	superseded by PyLith	
DFM	finite difference	Day & Ely, 2002		contact author Dalguer
DGCrack	DG finite element	Tago et al., 2012		contact authors Tago or Cruz-Atienza
EQdyna	finite element	Duan & Oglesby, 2006		contact author Duan
FaultMod	finite element	Barall, 2009		contact author Barall
Fdfault	finite difference	Daub, 2016		https://github.com/egdaub/fdfault
Kase code	finite difference	Kase & Kuge, 2001		contact author Kase
MAFE	finite element	Ma et al., 2008; Ma & Andrews, 2010		contact author Ma
PyLith	finite element	Aagaard et al., 2013		https://geodynamics.org/cig/software/pylith
SeisSol	DG finite element	Pelties et al., 2012; Pelties et al., 2014		https://github.com/SeisSol/SeisSol/wiki
SESAME	spectral element	Galvez et al., 2014	same as SPECFEM3D	
SORD	finite difference	Ely et al., 2009; Shi & Day, 2013		contact author Shi
SPECFEM3D	spectral element	Galvez et al., 2014		https://geodynamics.org/cig/software/specfem3d
SPECFEM3D-old	spectral element	Kaneko et al., 2008	superseded by SPECFEM3D	
WaveQLab3D	finite difference	Duru & Dunham, 2016		https://bitbucket.org/ericmdunham/waveqlab3d

Harris Nov. 2018

Simulated Seismic Waves at Earth's surface produced by a 2004 M6 Parkfield earthquake rupture simulation

TPV35

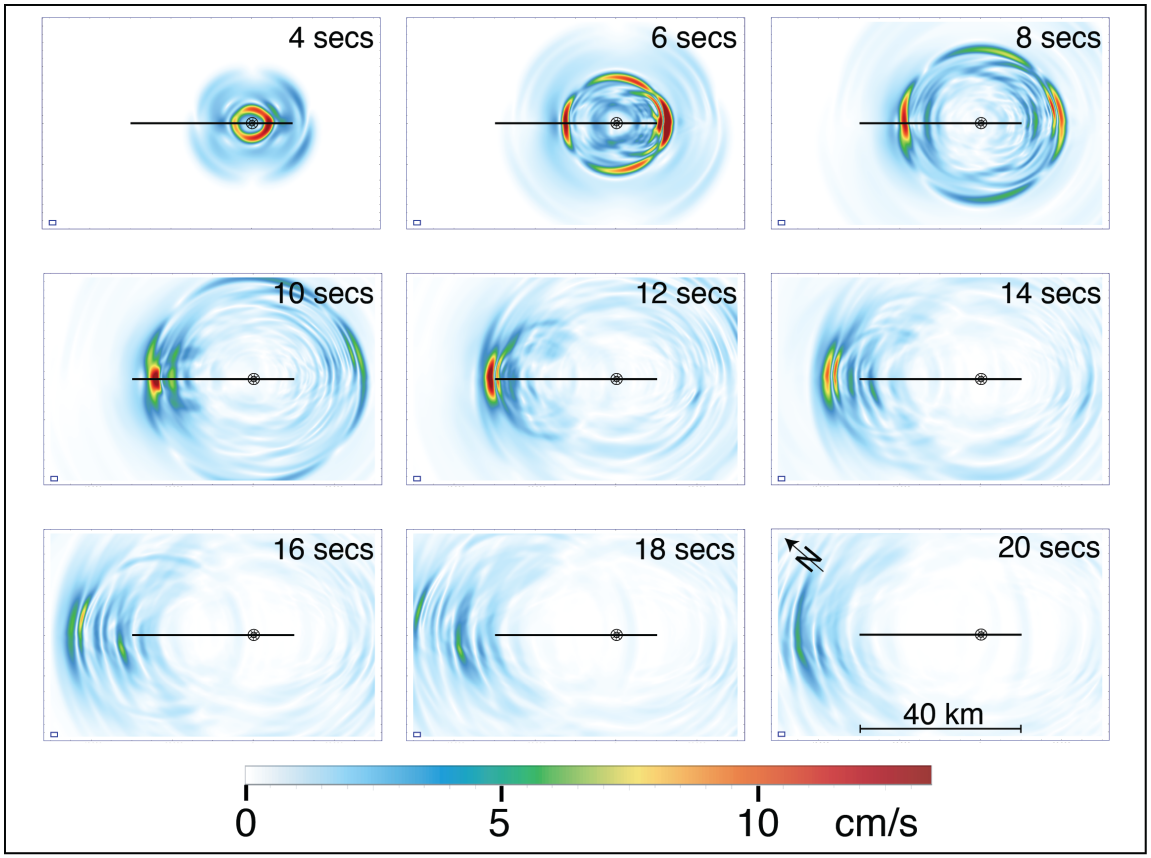
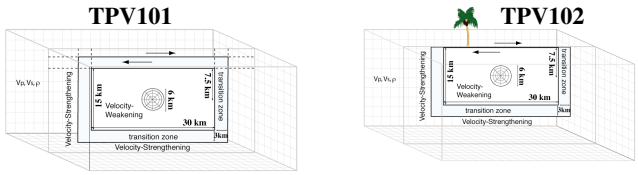
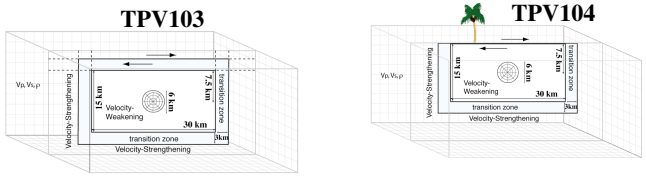


figure from
Harris et al.,
SRL, 2018

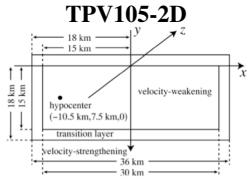
Code Comparison Benchmarks – Testing Fault Friction Implementations



Rate-state friction using an ageing law



Rate-state friction using a slip law with strong rate-weakening



Thermal pressurization, rate-state friction, slip-law, strong rate-weakening

For More Information about our group:

Please see our website: scecdata.usc.edu/cvws

and our group's papers:

Harris, R.A., M. Barall, B. Aagaard, S. Ma, D. Roten, K. Olsen, B. Duan, B. Luo, D. Liu, K. Bai, J.-P. Ampuero, Y. Kaneko, A.-A. Gabriel, K. Duru, T. Ulrich, S. Wollherr, Z. Shi, E. Dunham, S. Bydlon, Z. Zhang, X. Chen, S.N. Somala, C. Pelties, J. Tago, V.M. Cruz-Atienza, J. Kozdon, E. Daub, K. Aslam, Y. Kase, K. Withers, and L. Dalguer, A suite of exercises for verifying dynamic earthquake rupture codes, Seism. Res. Lett., 89(3), 1146-1162, **2018**.

Harris, R.A., M. Barall, D.J. Andrews, B. Duan, E.M. Dunham, S. Ma, A.-A. Gabriel, Y. Kaneko, Y. Kase, B. Aagaard, D. Oglesby, J.-P. Ampuero, T.C. Hanks, N. Abrahamson, Verifying a computational method for predicting extreme ground motion, Seism. Res. Lett., 82(5), 638-644, **2011**.

Harris, R.A., M. Barall, R. Archuleta, E. Dunham, B. Aagaard, J.P. Ampuero, H. Bhat, V. Cruz-Atienza, L. Dalguer, P. Dawson, S. Day, B. Duan, G. Ely, Y. Kaneko, Y. Kase, N. Lapusta, Y. Liu, S. Ma, D. Oglesby, K. Olsen, A. Pitarka, S. Song, E. Templeton, The SCEC/USGS dynamic earthquake rupture code verification exercise, Seism. Res. Lett., 80(1), 119-126, **2009**.