Presentation for November 17, 2008
Pomona, CA

The SCEC Rupture Dynamics Code Validation Workshop

Ruth A. Harris
(U.S. Geological Survey)

SCEC Rupture Dynamics Code Validation Workshop

Monday November 17, 2008
Kellogg West Conference Center, Pomona, CA

09:00-09:40	**Introduction and Overview of the Benchmarks and Results**	Ruth Harris
09:45-10:25	**What Counts for Ground Motions?**	Ralph Archuleta
10:25-10:40	Break	
10:45-11:25	**How can (or can't) 'real' friction appear from a slip-weakening view?**	Jim Rice
11:30-12:10	**Is slip-weakening and off-fault elasticity o.k.?**	Ben Duan
12:15-13:00	Lunch	
13:05-13:45	**Is slip-weakening and off-fault elasticity o.k.?**	Jean-Paul Ampuero
13:50-14:30	**Is slip-weakening and off-fault elasticity o.k.?**	Shuo Ma
14:30-14:50	Break	
14:55-15:35	**Is slip-weakening and off-fault elasticity o.k.?**	Joe Andrews
15:40-16:20	**The transition from spontaneous rupture to kinematic modeling**	Jan Schmedes
16:20-17:00	**Overall Comments and Conclusions**	All

Introduction and Overview of the Benchmarks and Results -

Part I. What we've done so far

Project Coordinator

Ruth Harris, *USGS*

Software Engineer

Michael Barall, *Invisible Software*

Modelers

Brad Aagaard, *USGS*
Jean Paul Ampuero, *Caltech*
Joe Andrews, *USGS*
Ralph Archuleta, *UCSB*
Victor Cruz-Atienza, *UNAM, Mexico*
Luis Dalguer, *ETH, Switzerland*
Steve Day, *SDSU*
Ben Duan, *TAM*
Eric Dunham, *Harvard*
Geoff Ely, *USC*
Yoshi Kaneko, *Caltech*
Yuko Kase, *GSJ, Japan*
Nadia Lapusta, *Caltech*
Yi Liu, *Caltech*
Shuo Ma, *SDSU*
Hiro Noda, *Caltech*
David Oglesby, *UCR*
Kim Olsen, *SDSU*
Arben Pitarka, *URS*
Matt Purvance, *UNR*
Seok Goo Song, *URS*
Elizabeth Templeton, *Harvard*

http://scecdata.usc.edu/cvws/participants.html

Overall Goal of our Code Verification Group

Compare the 3D methods
currently being used by SCEC and USGS scientists to
simulate (spontaneous) earthquake rupture dynamics

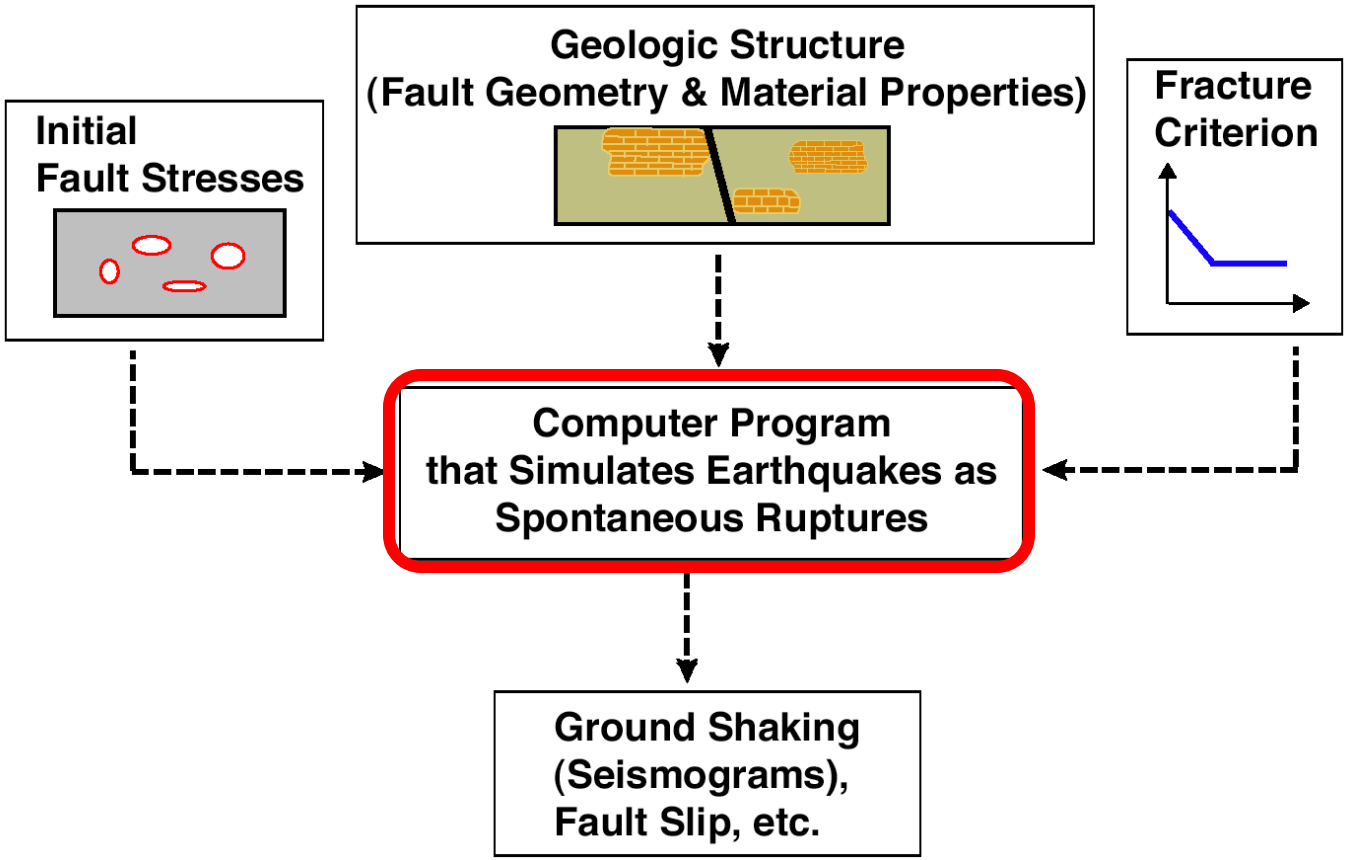
Some Specific Objectives

Understand if our methods are producing the same results when using
the same assumptions about friction, crustal structure, fault geometry, etc.

Learn which methods are best suited for which type of problem, for example,
heterogeneous stress, heterogeneous materials, dipping faults, complex friction.

Funding

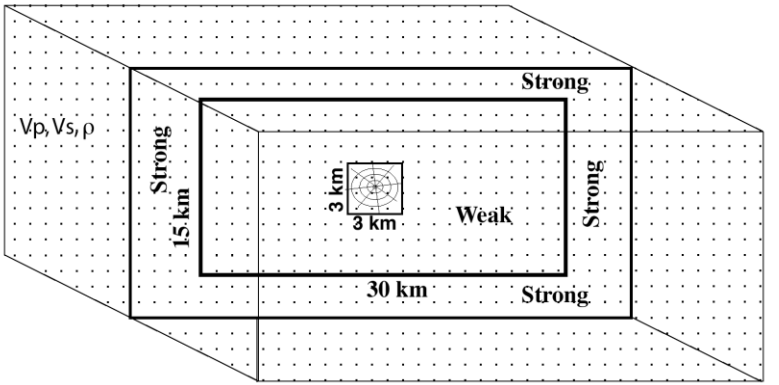
This project has been funded by the Southern California Earthquake Center,
the U.S. Geological Survey, and the U.S. Dept. of Energy/PG&E-USGS Extreme Ground Motion Project


Geologic Structure
(Fault Geometry & Material Properties)
Initial
Fault Stresses
Fracture
Criterion
Computer Program
that Simulates Earthquakes as
Spontaneous Ruptures
Ground Shaking
(Seismograms),
Fault Slip, etc.

Code Comparison Strategy

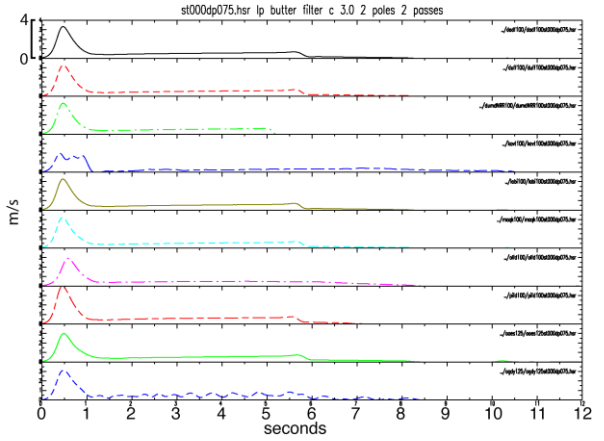
Start simply

Spontaneous rupture on a **vertical strike-slip fault set in a homogeneous (materials) Fullspace**

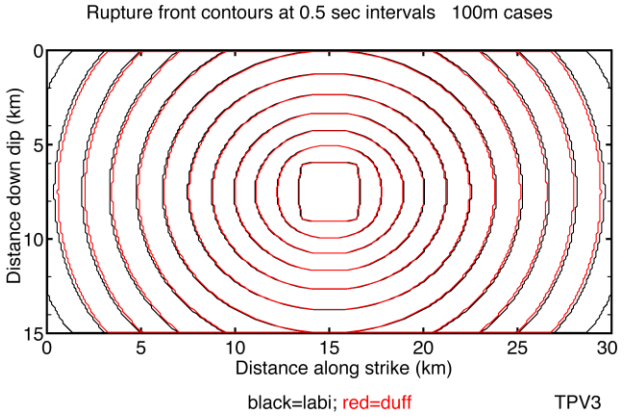


homogeneous initial stresses

slip-weakening friction



Some Results



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Code Comparison Strategy

Incrementally add complexity

Rupture on a Vertical Strike-Slip fault set in a Homogeneous (materials) **Halfspace**, Homogeneous initial stresses, Slip-weakening friction

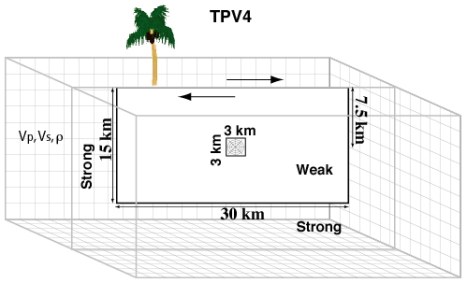
→

Rupture on a Vertical Strike-Slip fault set in a Homogeneous (materials) halfspace, **Heterogeneous Initial stresses**, Slip-weakening friction

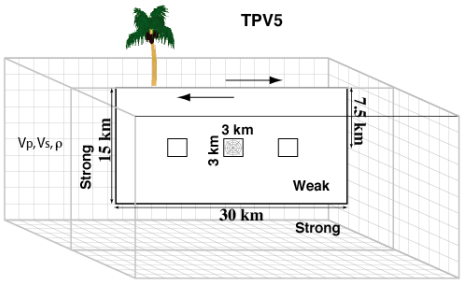
→

Rupture on a Vertical Strike-Slip fault set in a **Heterogeneous (Materials)** halfspace, homogeneous initial stresses, Slip-weakening friction

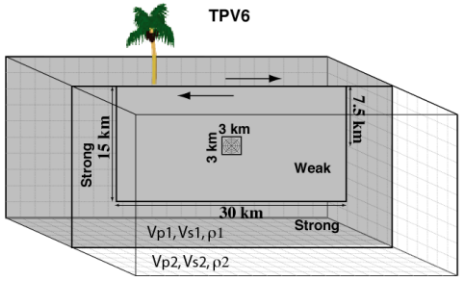
→



TPV4



TPV5



TPV6-7

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Code Comparison Strategy

Incrementally add complexity

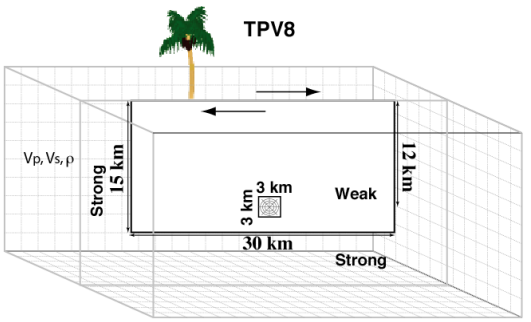
Rupture on a Vertical Strike-Slip fault set in a Homogeneous (materials) halfspace, **Depth-dependent Initial Stresses**, Slip-weakening friction

→

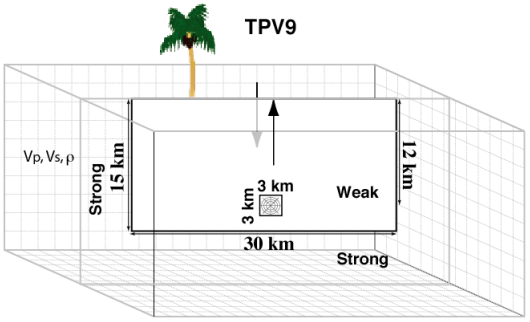
Rupture on a Vertical **Dip-Slip** fault set in a Homogeneous (materials) halfspace, Depth-dependent initial stresses, Slip-weakening friction

→

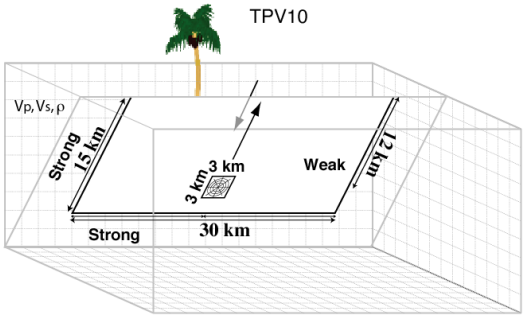
Rupture on a **Dipping** Dip-slip fault set in a Homogeneous (materials) halfspace, Depth-dependent initial stresses, Slip-weakening friction



TPV8



TPV9



TPV10-11

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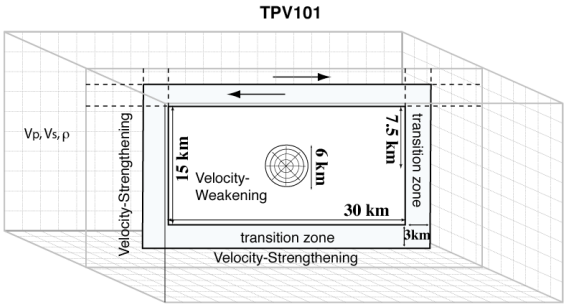
Code Comparison Strategy

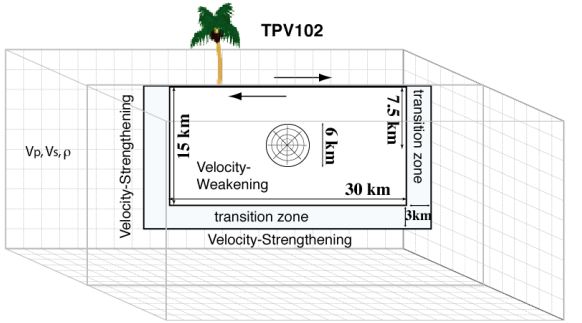
Incrementally add complexity

Rupture on a vertical strike-slip fault set in a homogeneous (materials)
Fullspace,
Homogeneous initial stresses,
Rate-state friction,
Ageing law



TPV101

Rupture on a vertical strike-slip fault set in a homogeneous (materials)
Halfspace
Homogeneous initial stresses,
Rate-state friction,
Ageing law

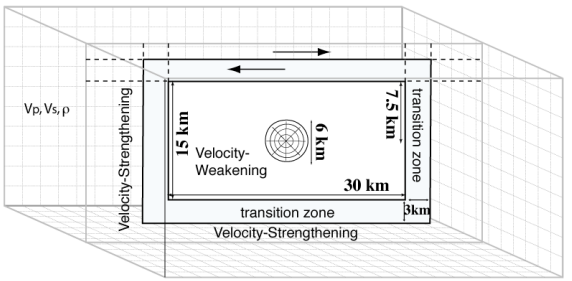


TPV102

Code Comparison Strategy

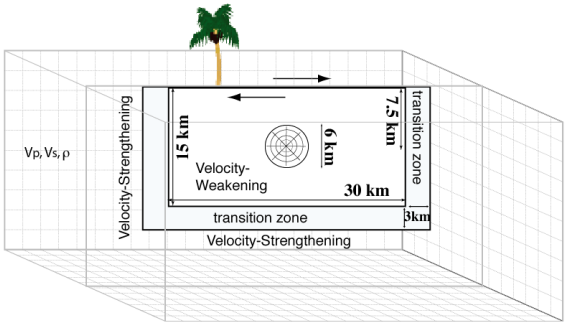
Incrementally add complexity

Rupture on a vertical strike-slip fault set in a homogeneous (materials)
Fullspace,
Homogeneous initial stresses,
Rate-state friction,
slip law, strong rate-weakening



TPV103

Rupture on a vertical strike-slip fault set in a homogeneous (materials)
Halfspace
Homogeneous initial stresses,
Rate-state friction,
slip law, strong rate-weakening



TPV104

Today's Benchmarks

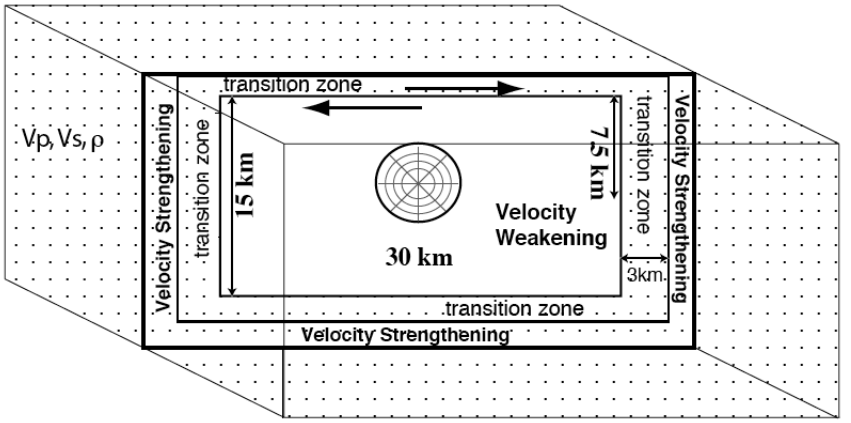
The Problem, Versions 103 and 104

The Problem, Versions 10 and 11

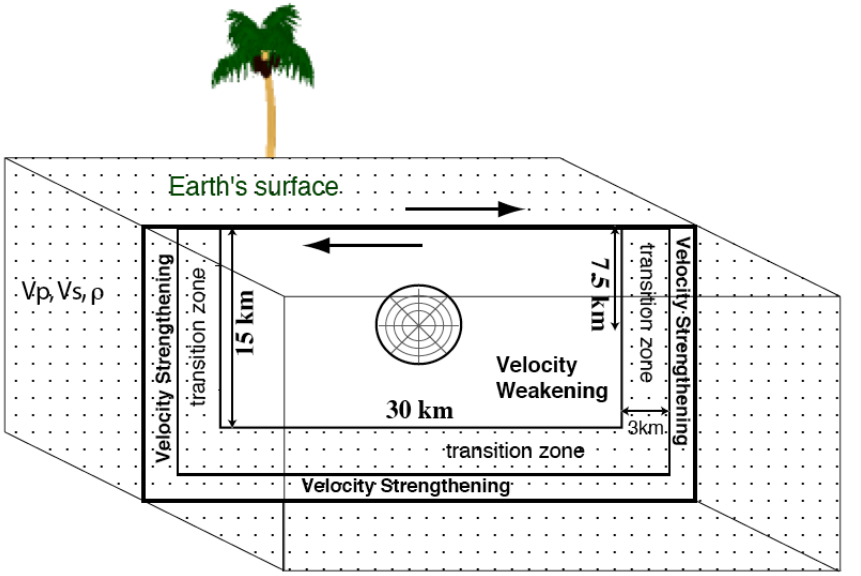
Courtesy of Eric Dunham

The Problem, Versions **103 and 104** (October-November 2008)

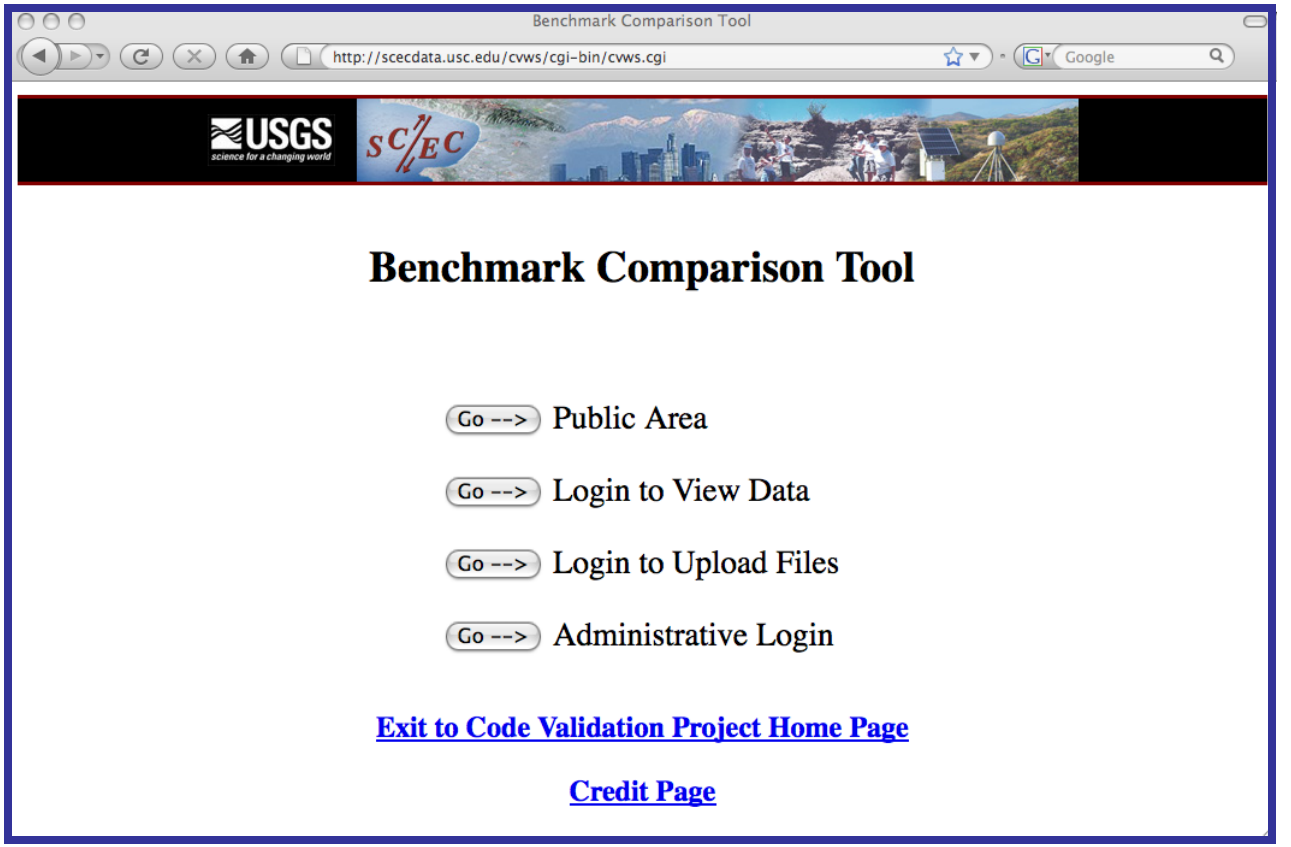
Rate-State Friction using a slip law with strong rate-weakening

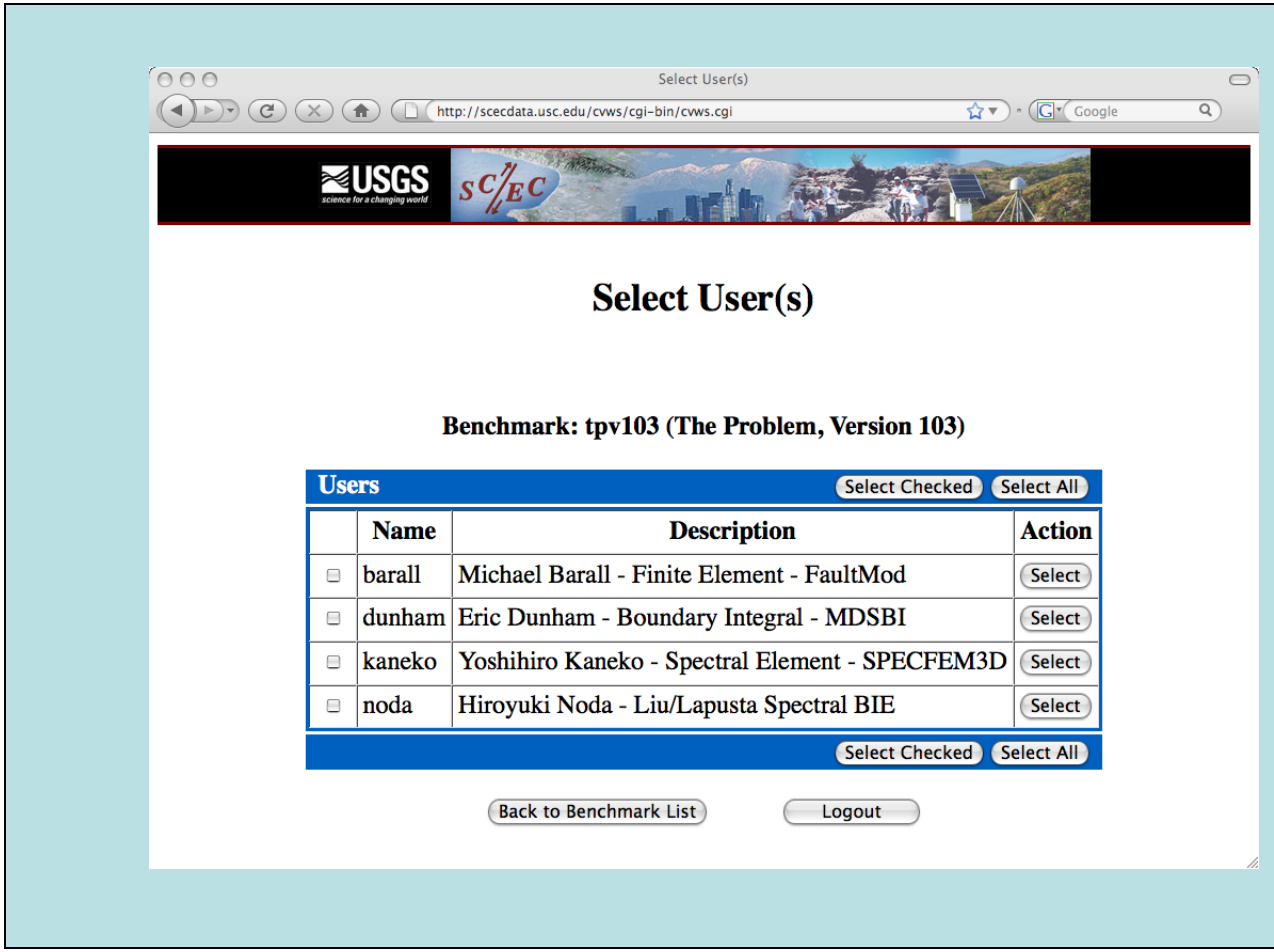


whole-space



half-space


Benchmark Comparison Tool
http://scecdata.usc.edu/cvws/cgi-bin/cvws.cgi
Google
USGS
science for a changing world
SCEC
Benchmark Comparison Tool
Go --> Public Area
Go --> Login to View Data
Go --> Login to Upload Files
Go --> Administrative Login
Exit to Code Validation Project Home Page
Credit Page


Select User(s)
http://scecdata.usc.edu/cvws/cgi-bin/cvws.cgi
Google
USGS
science for a changing world
SCEC
Select User(s)
Benchmark: tpv103 (The Problem, Version 103)
Users
Select Checked
Select All
Name
Description
Action
barall
Michael Barall - Finite Element - FaultMod
Select
dunham
Eric Dunham - Boundary Integral - MDSBI
Select
kaneko
Yoshihiro Kaneko - Spectral Element - SPECFEM3D
Select
noda
Hiroyuki Noda - Liu/Lapusta Spectral BIE
Select
Select Checked
Select All
Back to Benchmark List
Logout

Contour Plot

http://scecdata.usc.edu/cvws/cgi-bin/cvws.cgi

Google

Benchmark: tpv103 (The Problem, Version 103)

File: cplot (rupture contour plot)

Back to File List Logout

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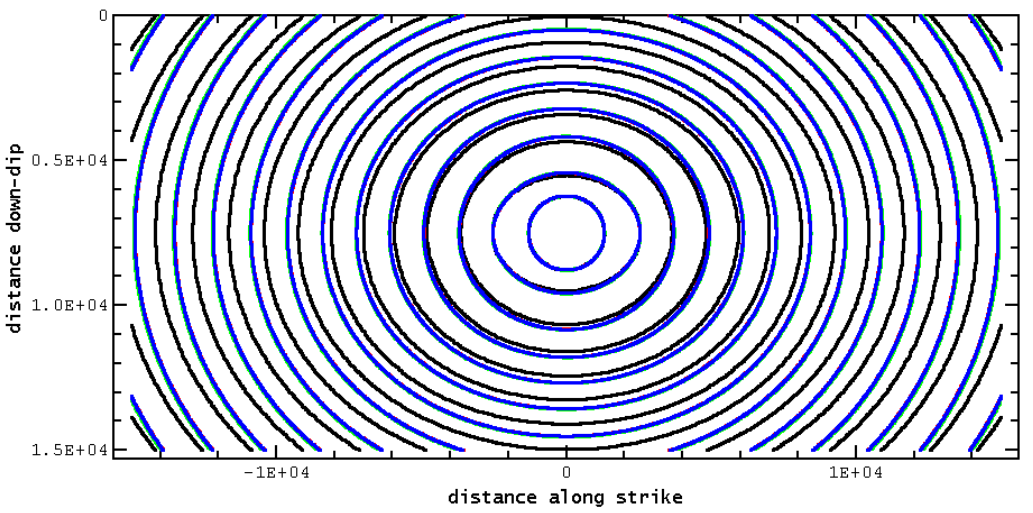

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Time-Series File

http://scecdata.usc.edu/cvws/cgi-bin/cvws.cgi

Google

Time-Series File

Benchmark: tpv103 (The Problem, Version 103)

File: faultst120dp030 (strike 12.0 km, dip 3.0 km)

Field: h-slip-rate (horizontal slip rate)

Back to Field List Logout

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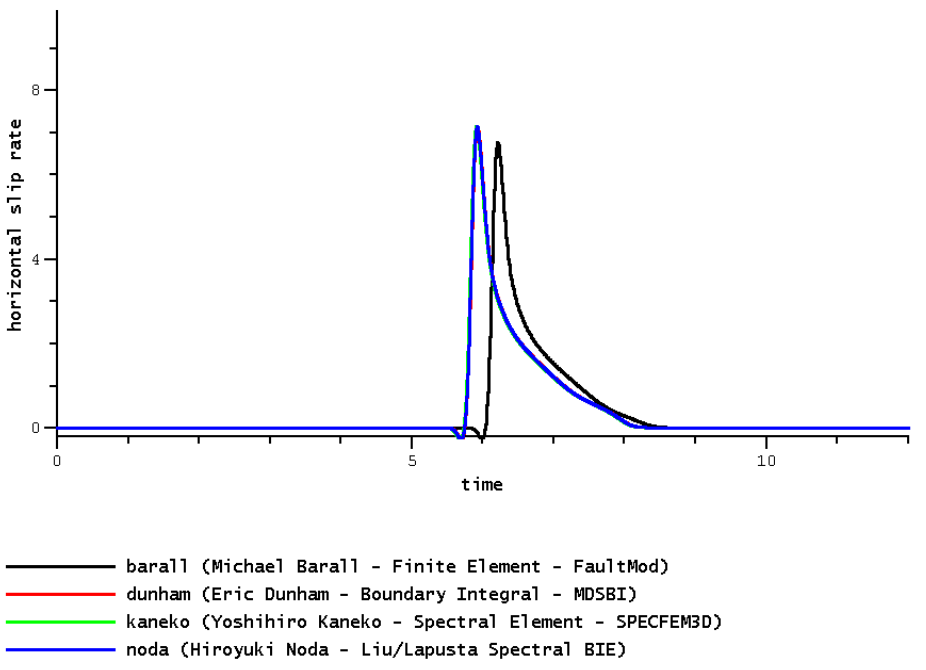


The Problem, Versions 10 and 11

Andrews et al., BSSA, 2007 Figure 7

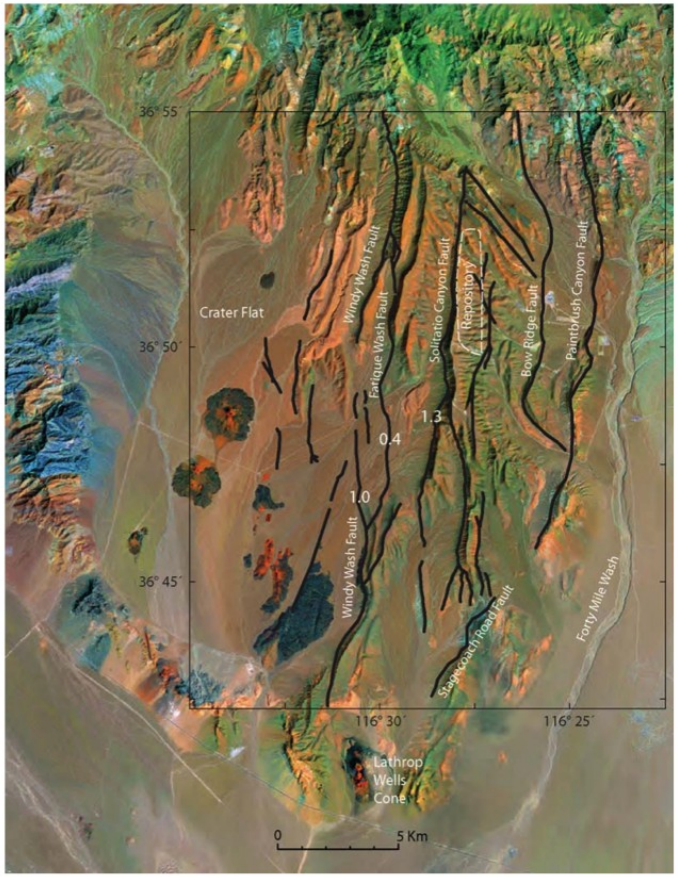
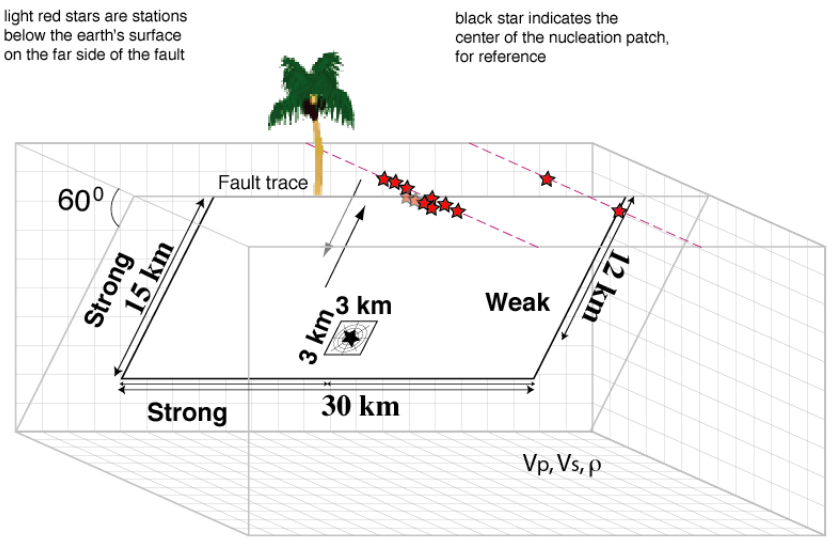


Figure 7. Color orthophoto map of the Yucca Mountain area with surface fault traces from figure 2 of Whitney, Taylor, and Menges, 2004 shown in the smaller boxed area. Numbers show locations of observed maximum-slip values of 1.3 m on the Solitario Canyon fault, 0.4 m on the Fatigue Wash fault, and 1.0 m on the Windy Wash fault at the time of the Lathrop Wells eruption. The footprint of the proposed repository is approximate.

TPV10 and TPV11 Off-fault Stations



12 Off-fault Station Locations

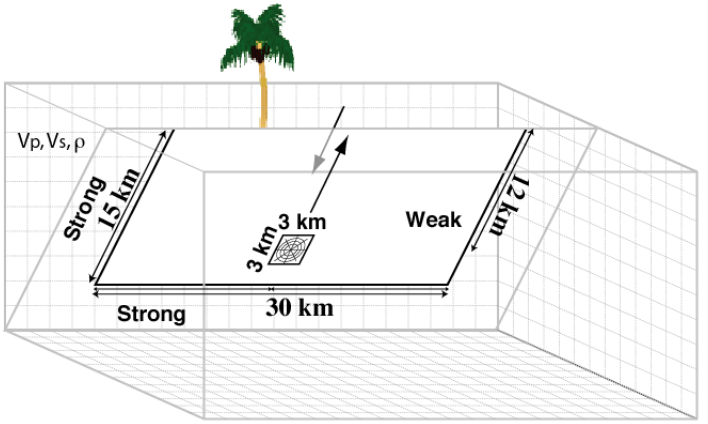
8 stations at the earth's surface:
0 km along strike, 0 km depth, and +/-1.0, +/-2.0, +/-3.0 km perpendicular-distance from the fault **trace**
+12 km along strike, 0 km depth, and +/- 3.0 perpendicular-distance from the fault **trace**

4 deeper stations:
0 km along strike, 0.3 km depth, and +/-0.5 and +/-1.0 horizontal-distance from the **location of the fault at 0.3 km depth**

Courtesy of Joe Andrews

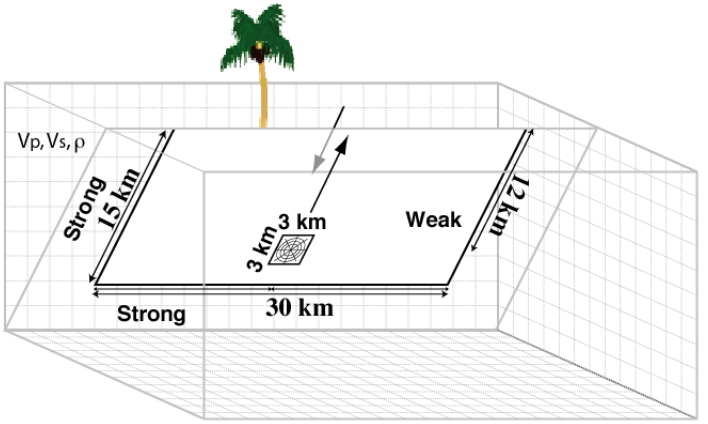
The Problem, Versions **10 and 11** (October-November 2008)

Slip-weakening Elastic Dynamic Rupture with Depth-Dependent Stresses



subshear

TPV10

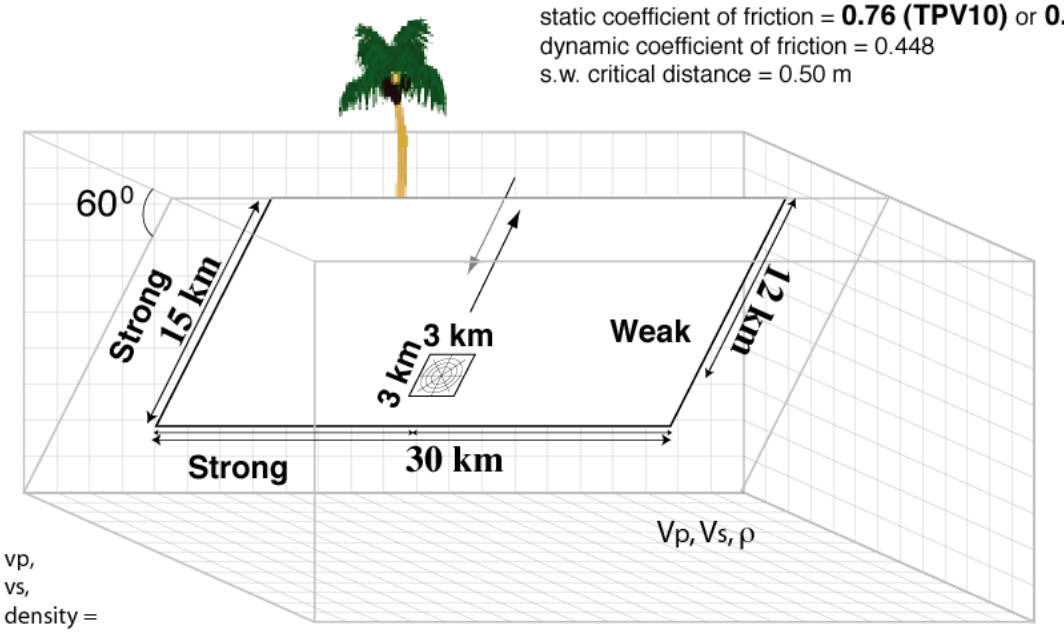


supershear

TPV11

Source Physics for The Problem, Versions 10 and 11

slip-weakening friction everywhere
cohesion = 0.2 MPa
static coefficient of friction = **0.76 (TPV10)** or **0.57 (TPV11)**
dynamic coefficient of friction = 0.448
s.w. critical distance = 0.50 m



vp,
vs,
density =
5716 m/s,
3300. m/s,
2700. kg/m

initial normal stress = 7378 Pa/m x downdip distance (m)

outside nucleation patch:
initial shear stress = 0.55 x initial normal stress

nucleation patch:
initial shear stress = cohesion + ((mu_s + 0.0057) x initial normal stress)

outside nucleation patch:
initial stress drop = - cohesion + ((0.55-mu_d) x initial normal stress)

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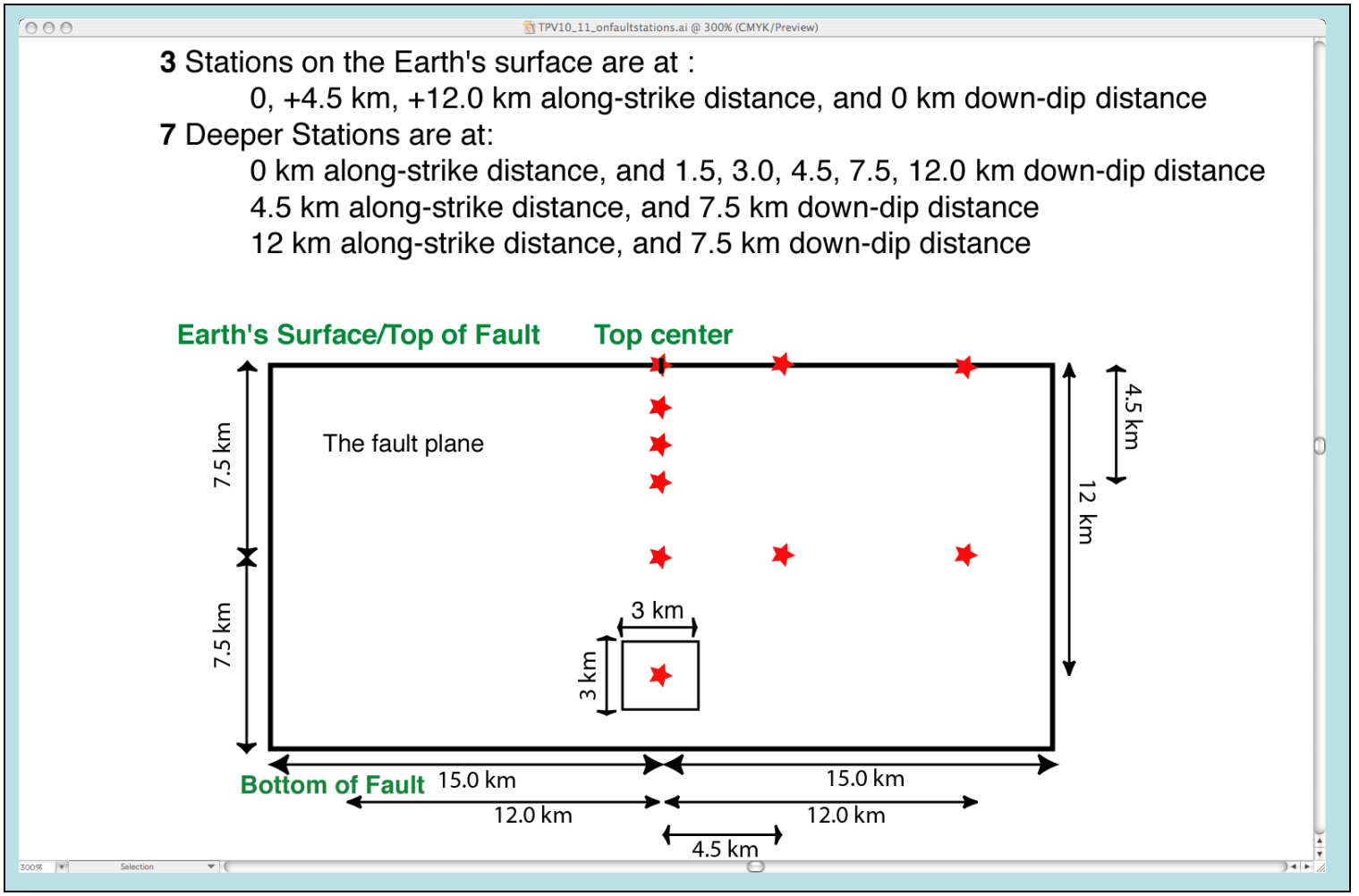
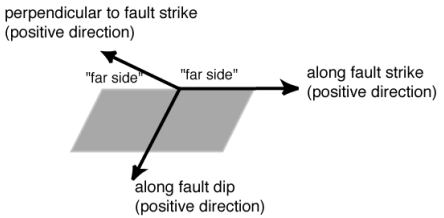
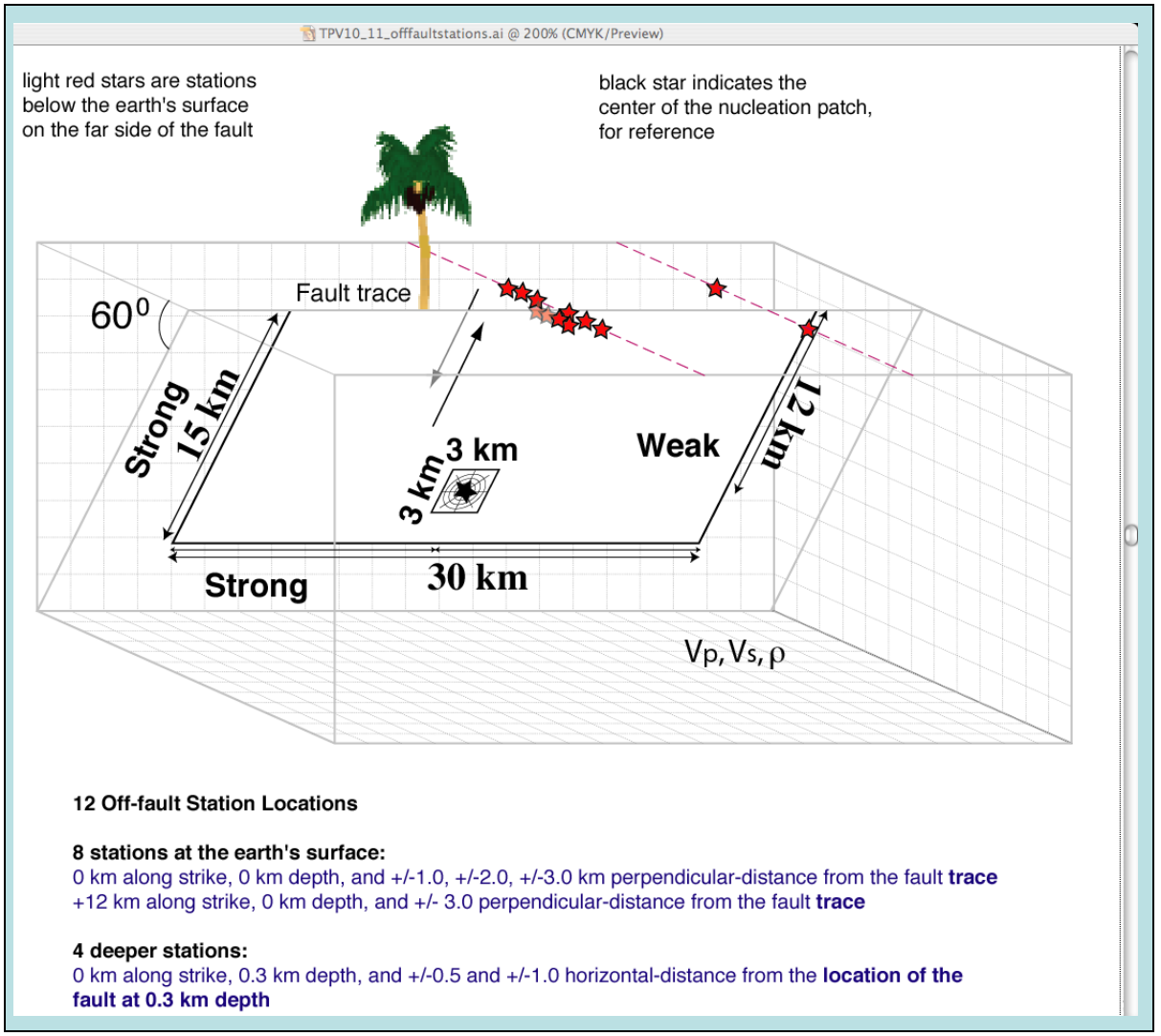
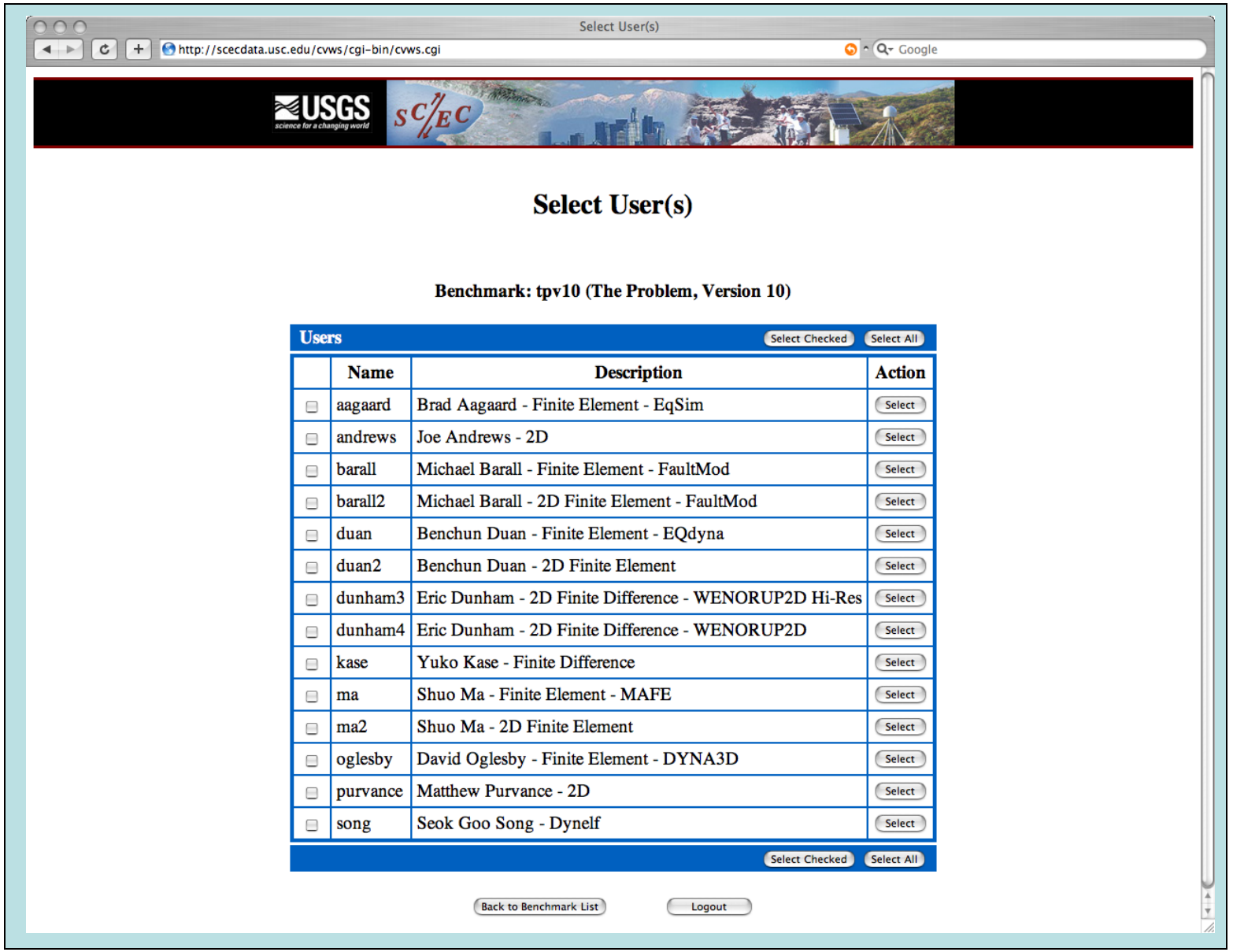
On-Fault Station Locations for The Problem, Versions 10 and 11



Off-Fault Station Locations for The Problem, Versions 10 and 11







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3D

Contour Plot

http://scecdata.usc.edu/cvws/cgi-bin/cvws.cgi

Google

Contour Plot

Benchmark: tpv10 (The Problem, Version 10)

File: cplot (rupture contour plot)

Back to File List | Logout

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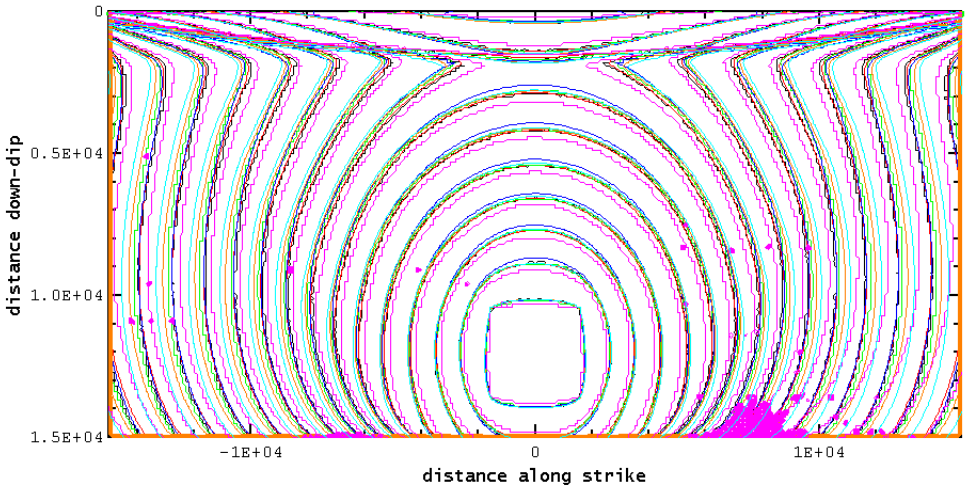
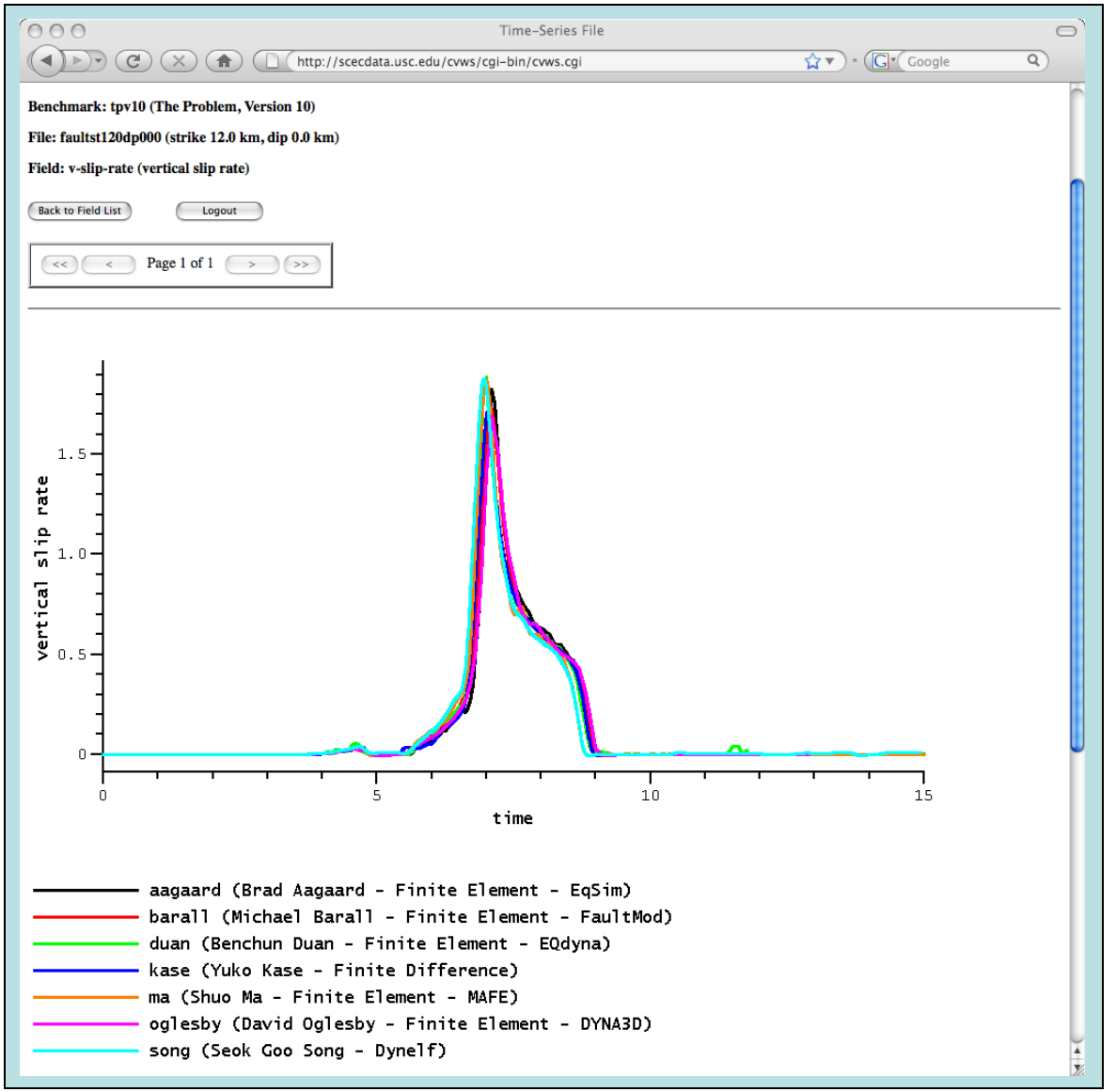
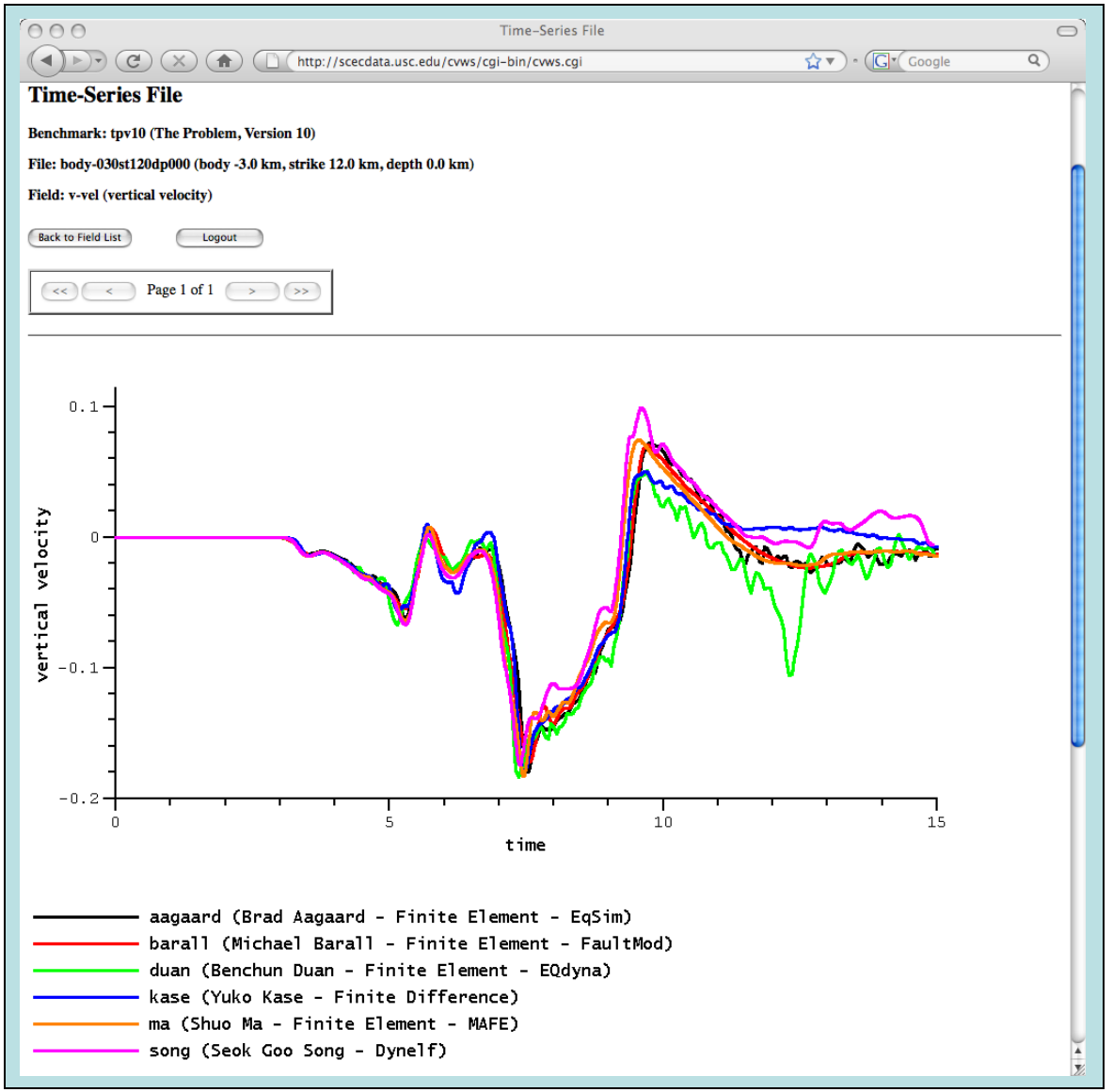


aagaard (Brad Aagaard - Finite Element - EqSim)
barall (Michael Barall - Finite Element - FaultMod)
duan (Benchun Duan - Finite Element - EQdyna)
kase (Yuko Kase - Finite Difference)
ma (Shuo Ma - Finite Element - MAFE)
oglesby (David Oglesby - Finite Element - DYNA3D)
song (Seok Goo Song - Dynelf)

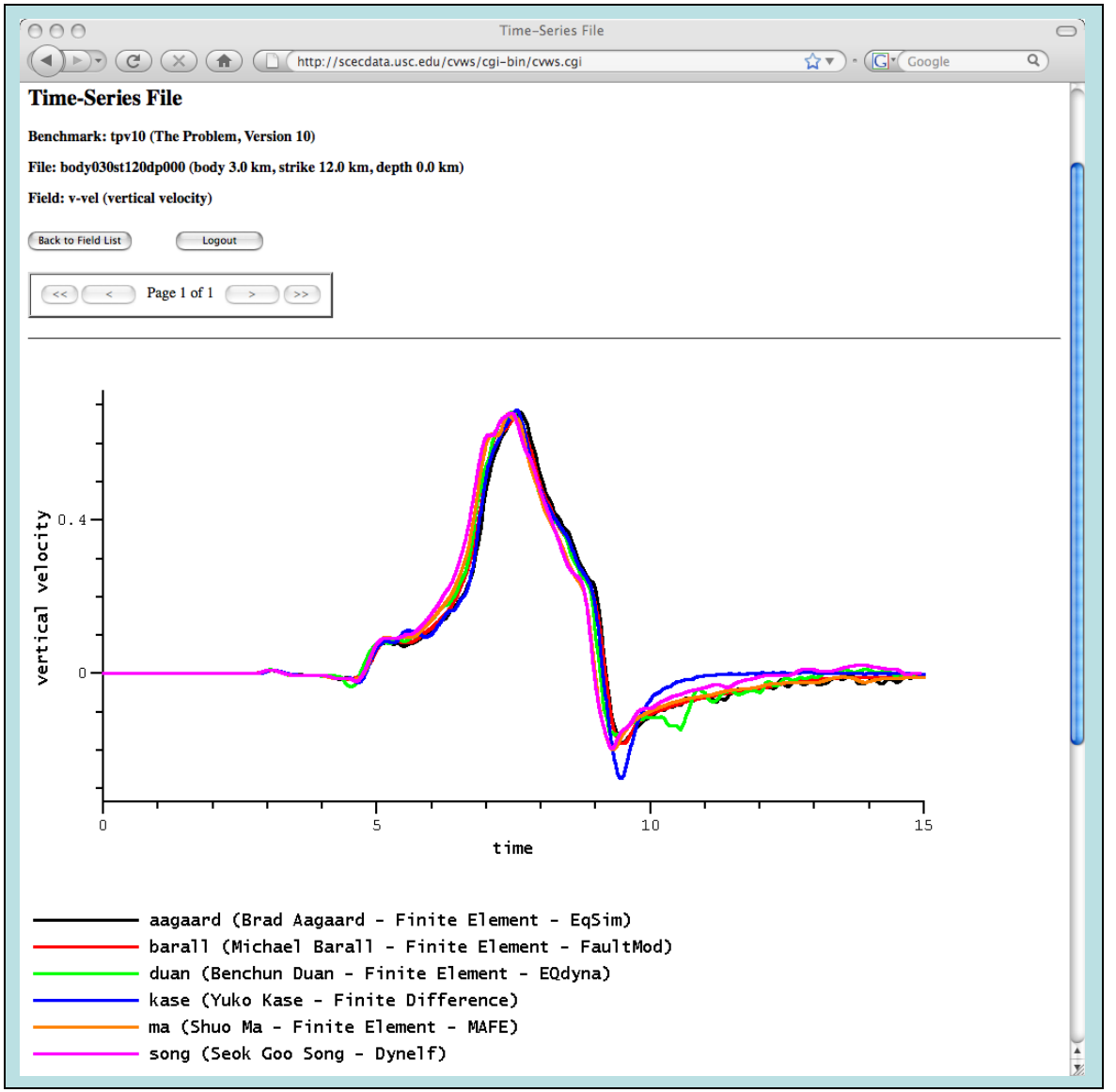
3D
on-fault
station
earth's
surface
12 km
along strike



3D
off-fault
station
earth's
surface
-3 km from
fault trace
12 km
along strike

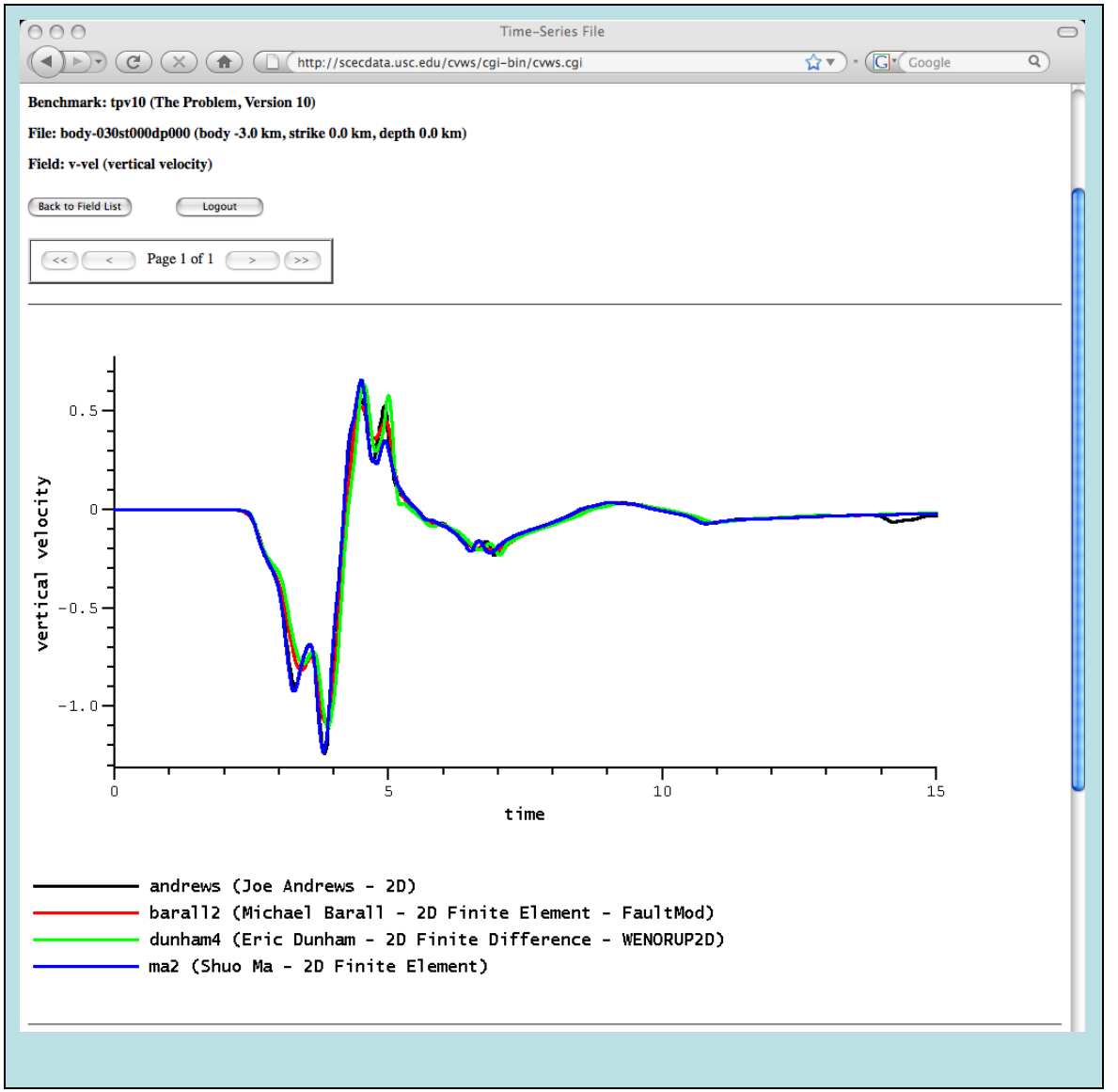


3D
off-fault
station
earth's
surface
+3 km from
fault trace
12 km
along strike

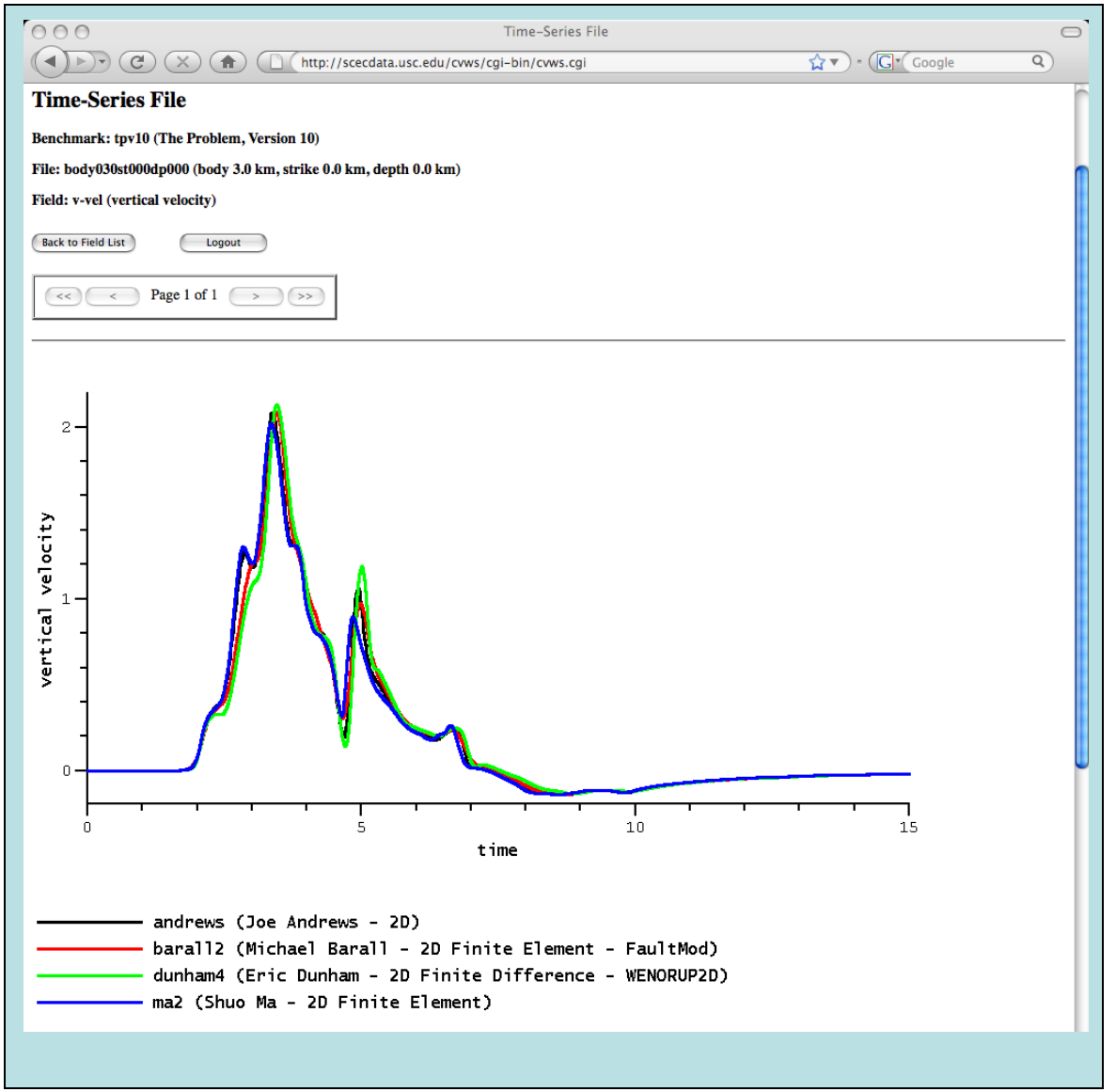


2D

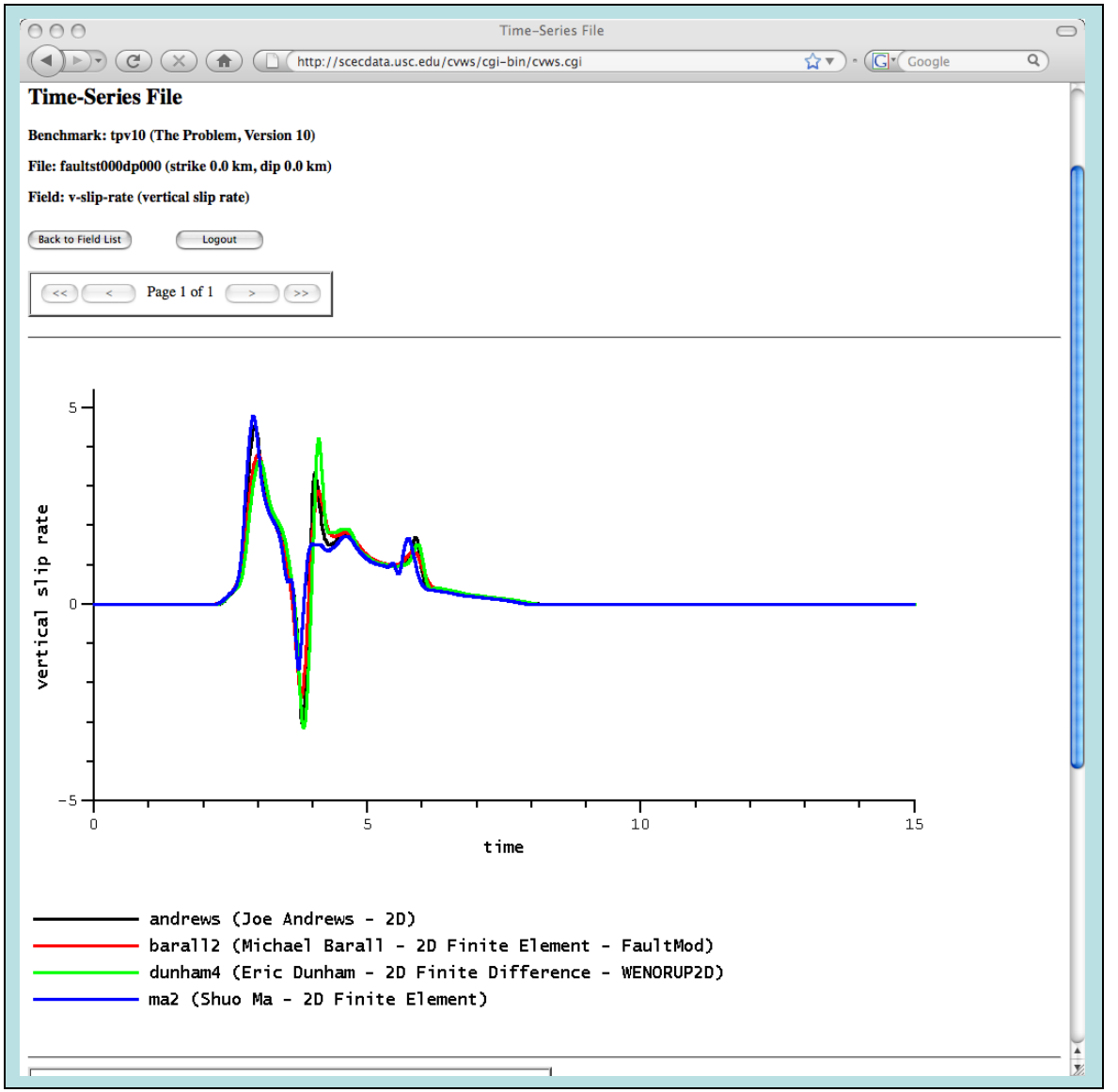
2D
off-fault
station
earth's
surface
-3 km
from fault
trace



2D
off-fault
station
earth's
surface
+3 km
from fault
trace

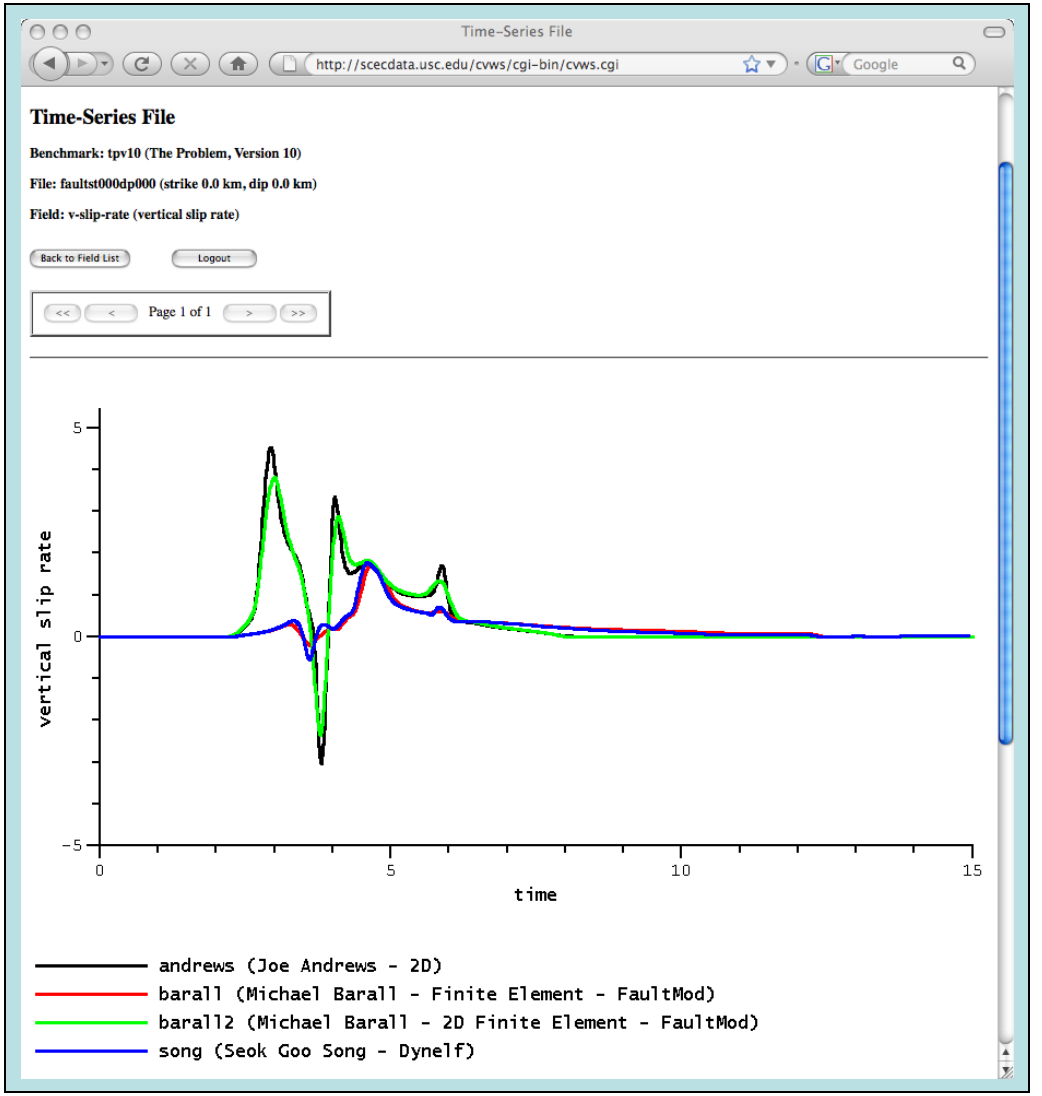


2D
on-fault
station
earth's
surface
top center
of fault

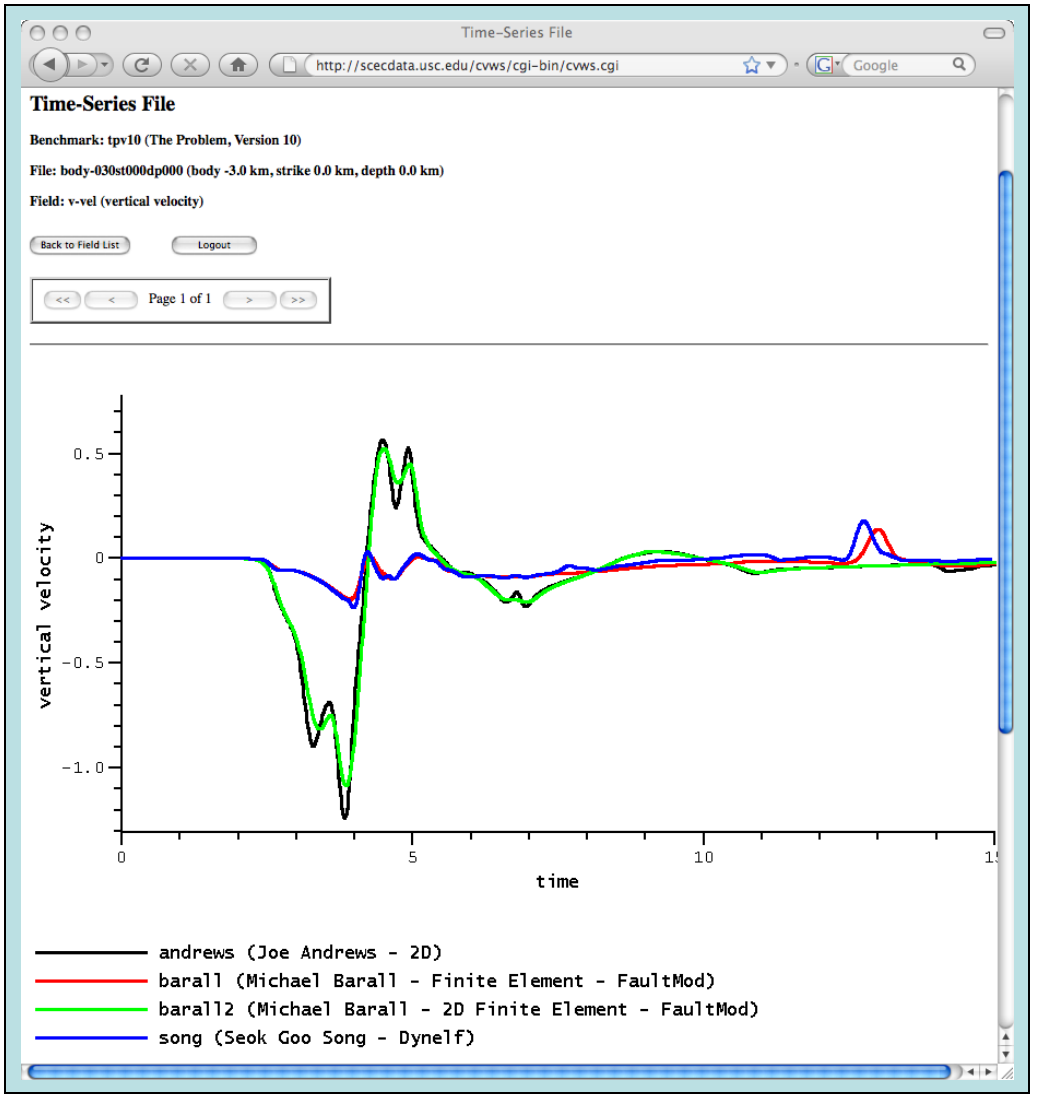


3D vs. 2D

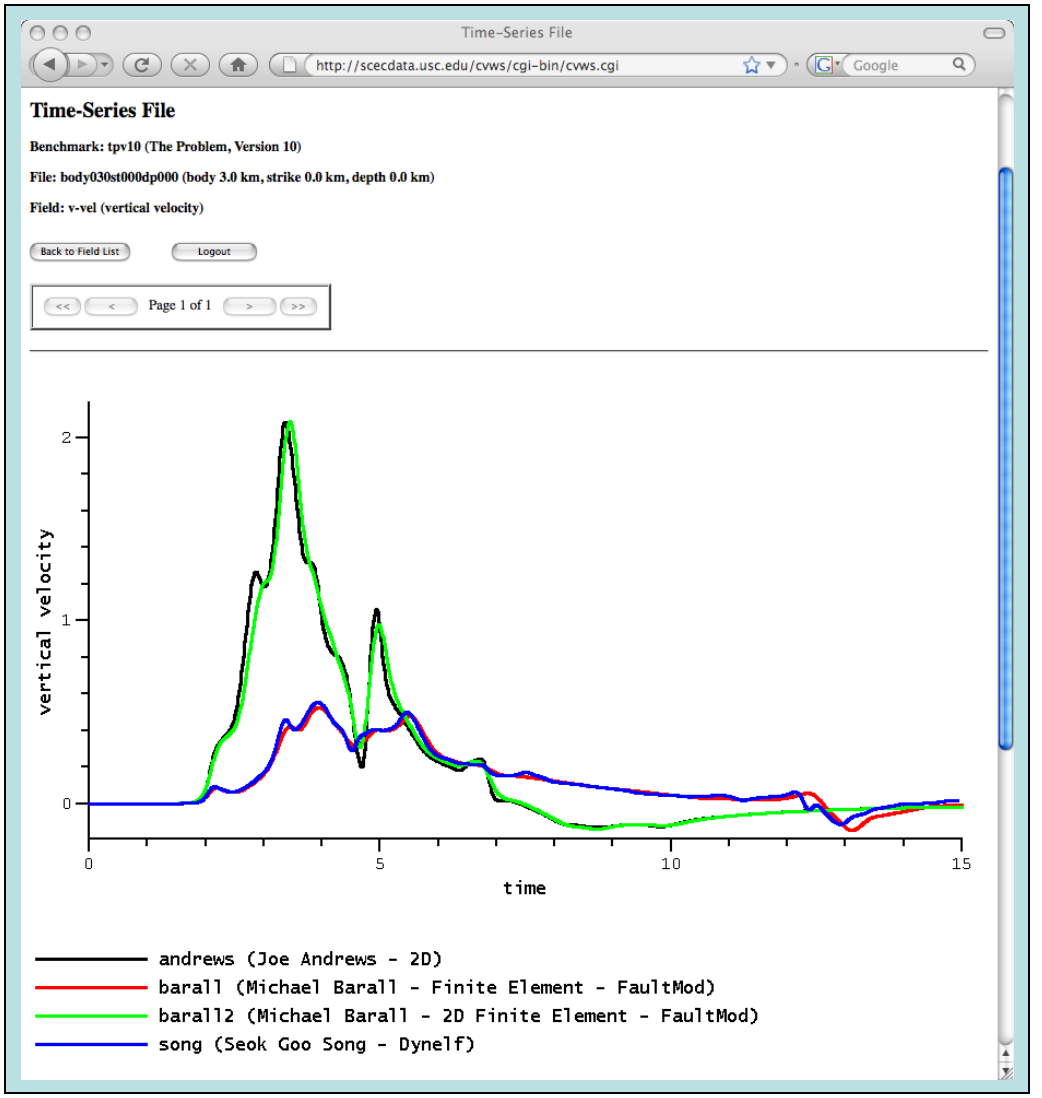
3D and 2D on-fault station earth's surface top center of fault

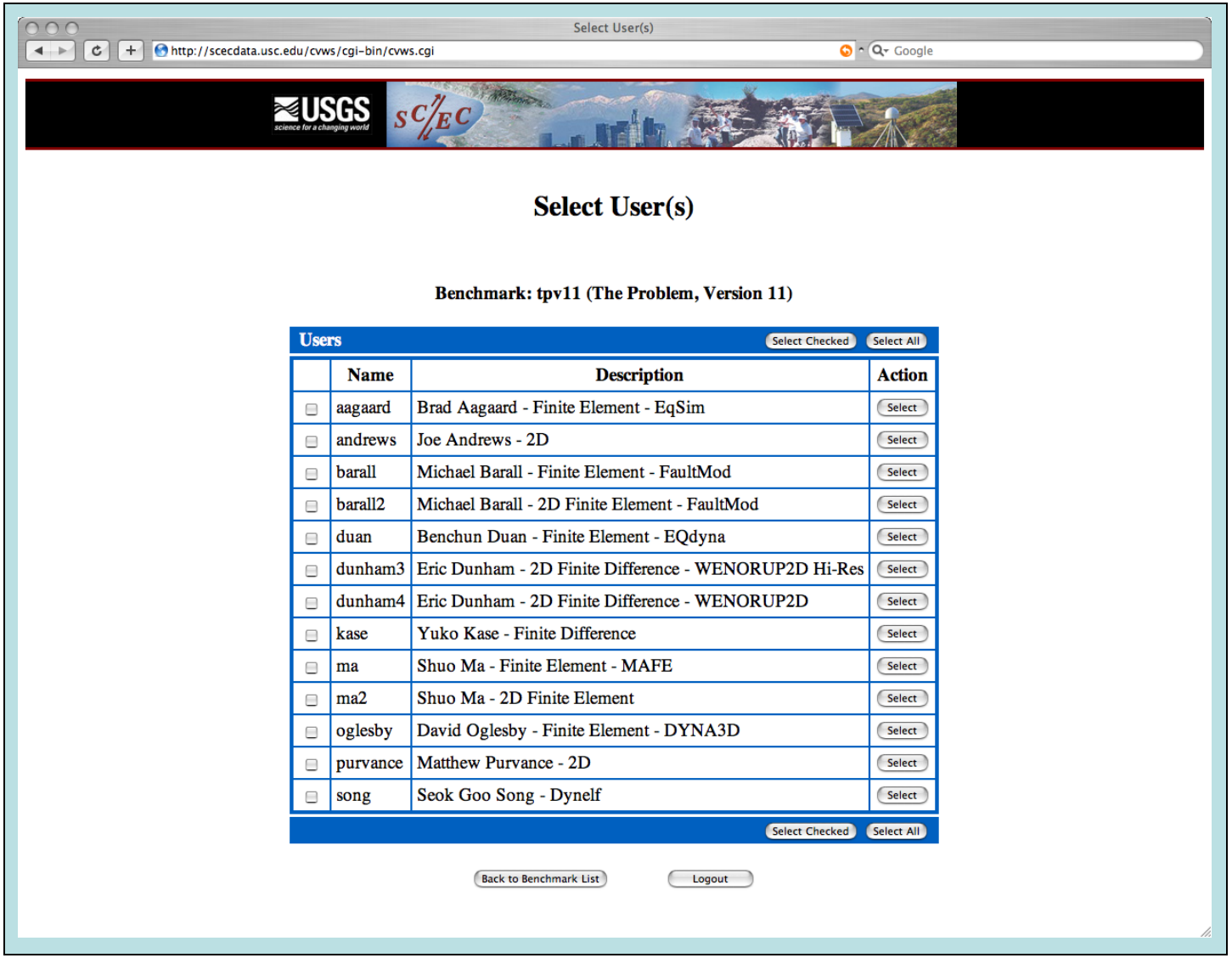


3D and 2D off-fault station earth's surface -3 km from fault trace



3d and 2D off-fault station earth's surface +3 km from fault trace




Select User(s)
http://scecdata.usc.edu/cvws/cgi-bin/cvws.cgi
Google
USGS science for a changing world
SCEC
Select User(s)
Benchmark: tpv11 (The Problem, Version 11)
Users
Select Checked
Select All
Name
Description
Action
aagaard
Brad Aagaard - Finite Element - EqSim
andrews
Joe Andrews - 2D
barall
Michael Barall - Finite Element - FaultMod
barall2
Michael Barall - 2D Finite Element - FaultMod
duan
Benchun Duan - Finite Element - EQdyna
dunham3
Eric Dunham - 2D Finite Difference - WENORUP2D Hi-Res
dunham4
Eric Dunham - 2D Finite Difference - WENORUP2D
kase
Yuko Kase - Finite Difference
ma
Shuo Ma - Finite Element - MAFE
ma2
Shuo Ma - 2D Finite Element
oglesby
David Oglesby - Finite Element - DYNA3D
purvance
Matthew Purvance - 2D
song
Seok Goo Song - Dynelf
Select
Select Checked
Select All
Back to Benchmark List
Logout

3D

Contour Plot

http://scecdata.usc.edu/cvws/cgi-bin/cvws.cgi

Google

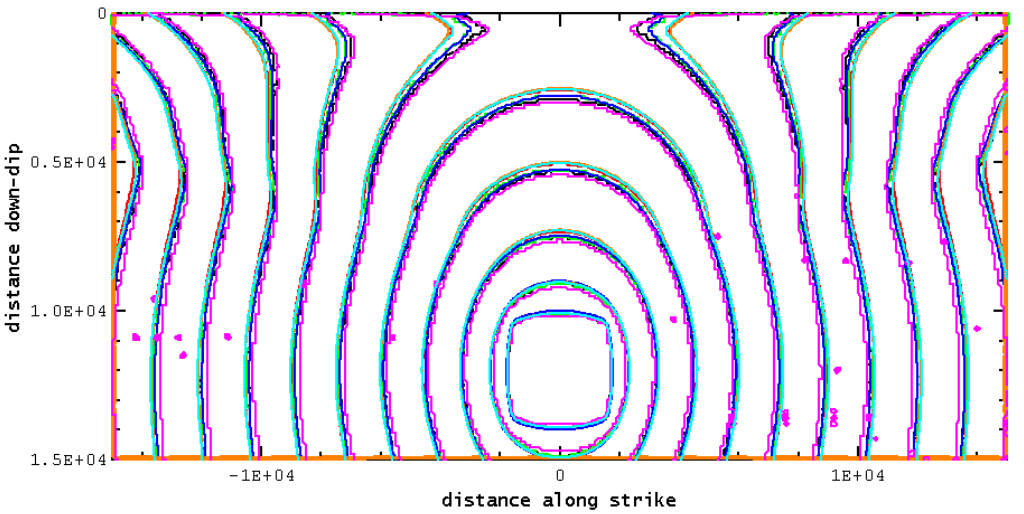
Contour Plot

Benchmark: tpv11 (The Problem, Version 11)

File: cplot (rupture contour plot)

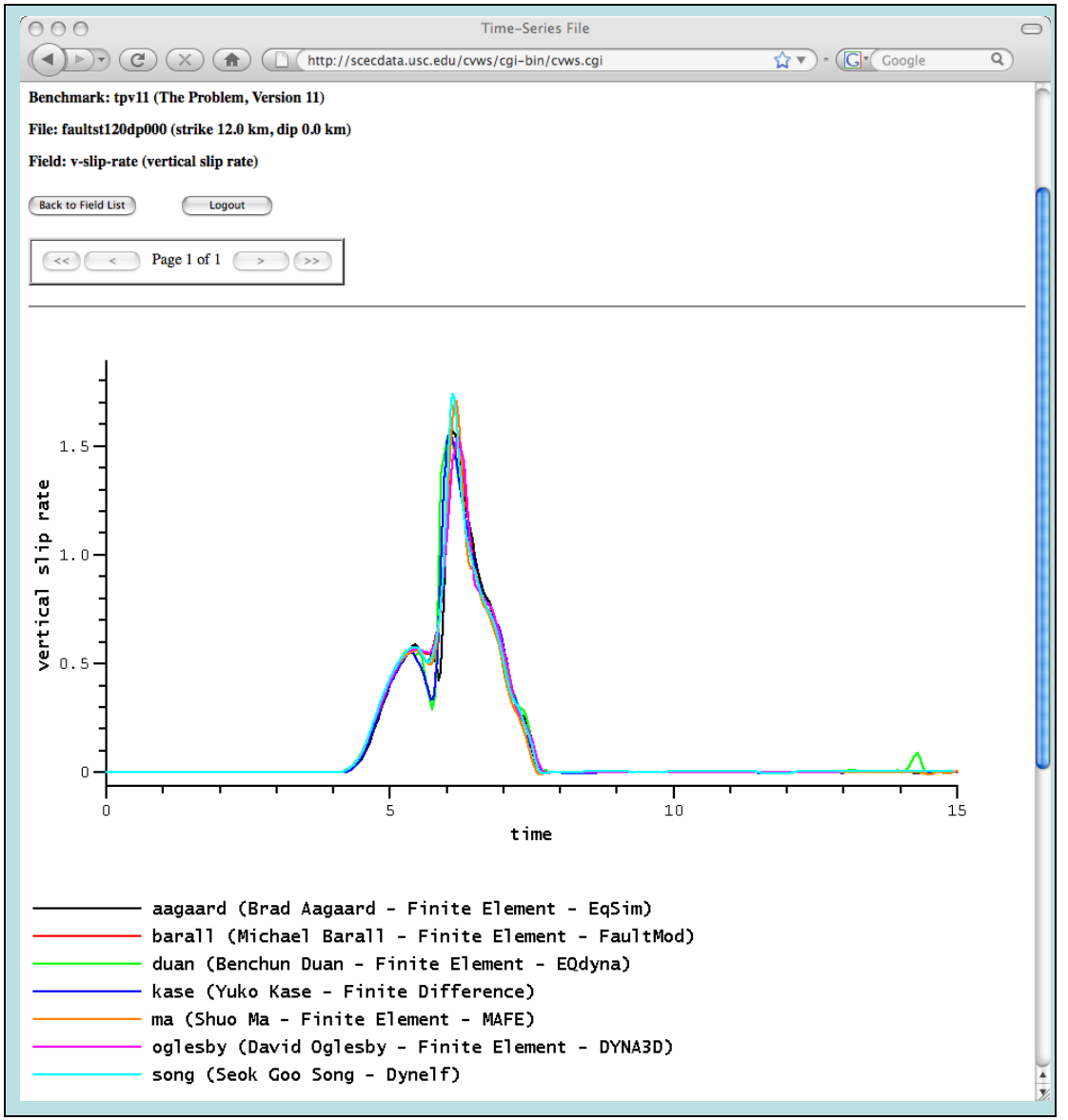
Back to File List | Logout

<< < Page 1 of 1 > >>

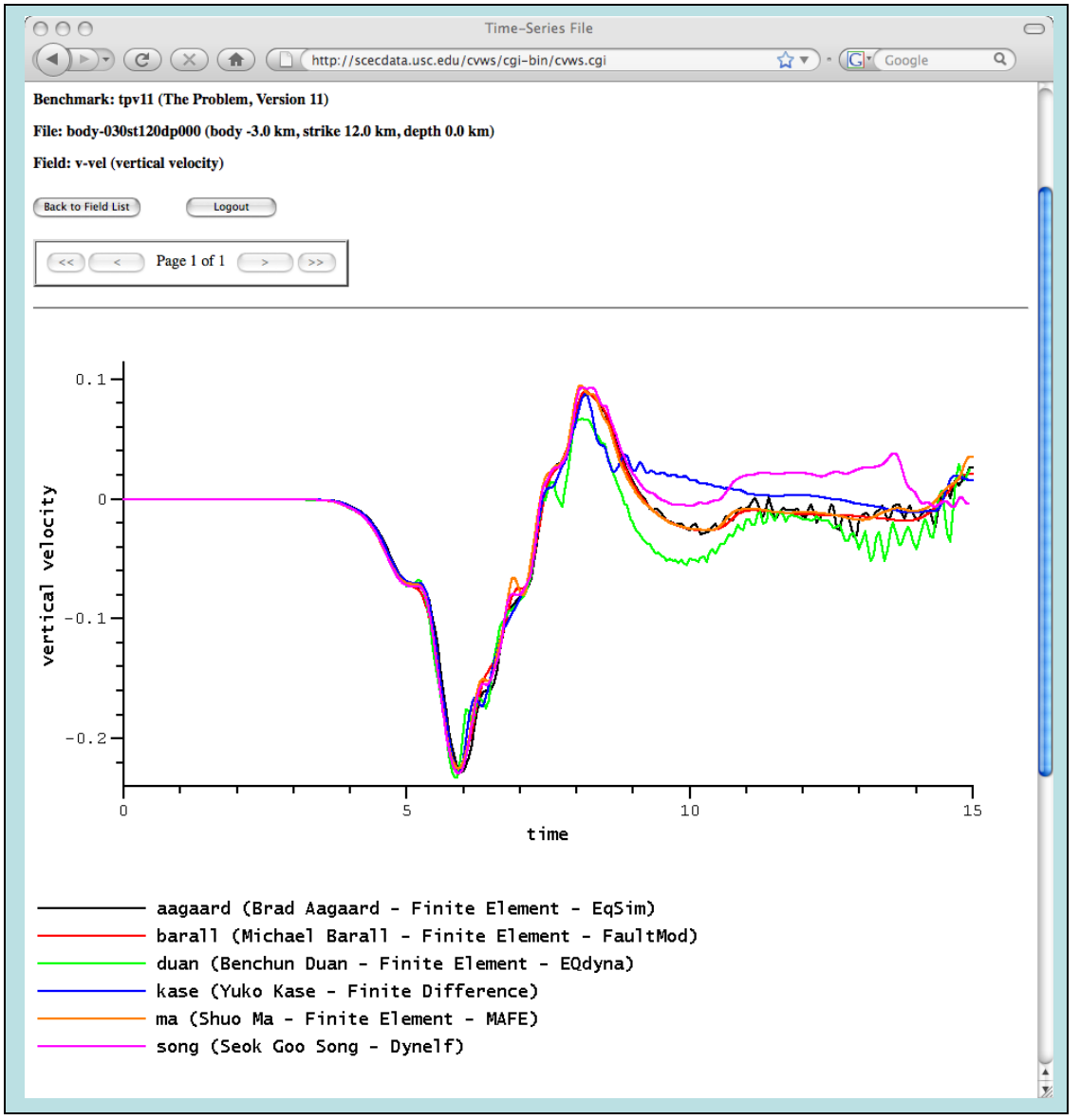


aagaard (Brad Aagaard - Finite Element - EqSim)
barall (Michael Barall - Finite Element - FaultMod)
duan (Benchun Duan - Finite Element - EQdyna)
kase (Yuko Kase - Finite Difference)
ma (Shuo Ma - Finite Element - MAFE)
oglesby (David Oglesby - Finite Element - DYNA3D)
song (Seok Goo Song - Dynelf)

3D
on-fault
station
earth's
surface
12 km
along strike

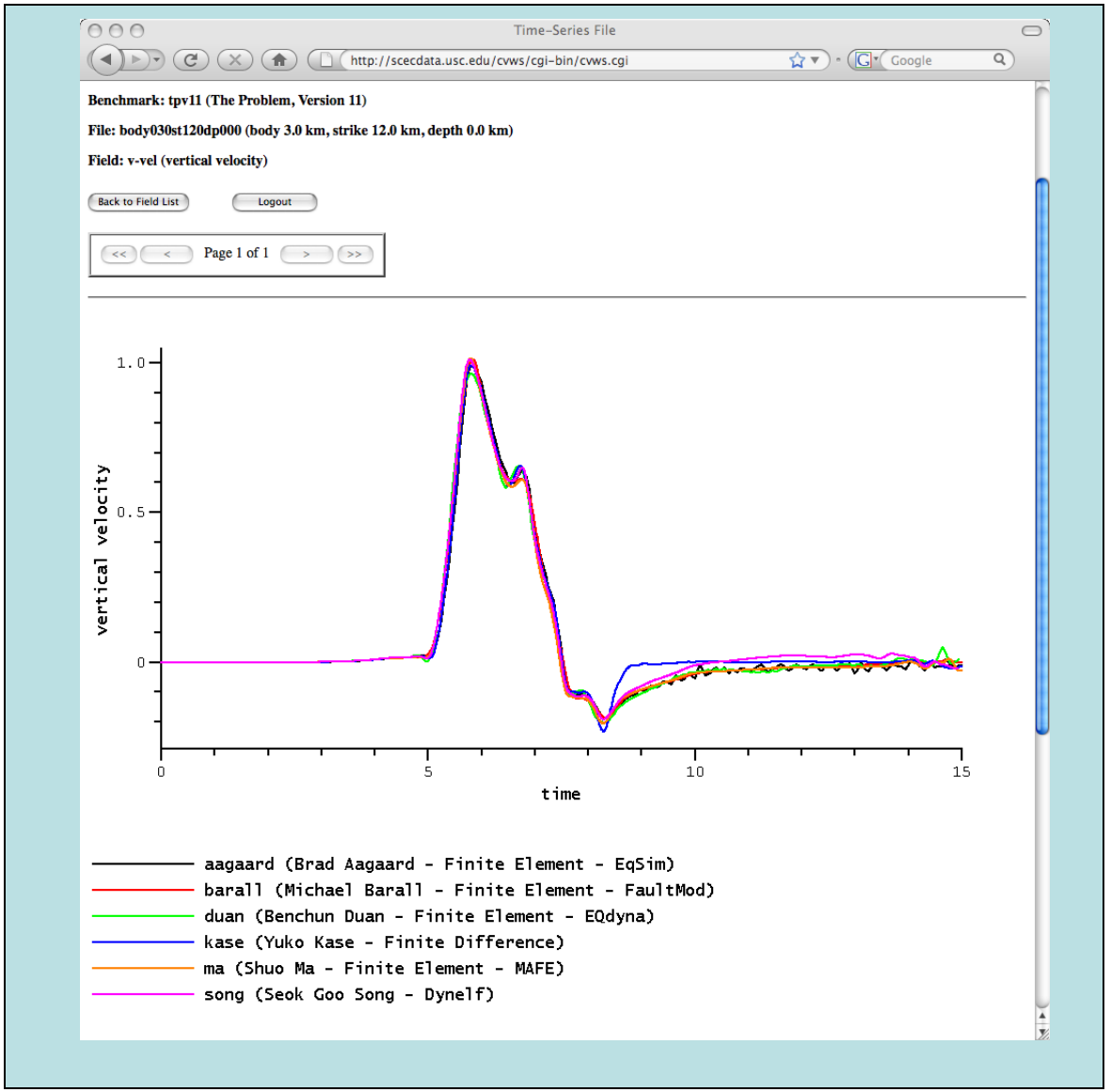


3D
off-fault
station
earth's
surface
-3 km from
fault trace
12 km
along strike



Harris Nov. 2008

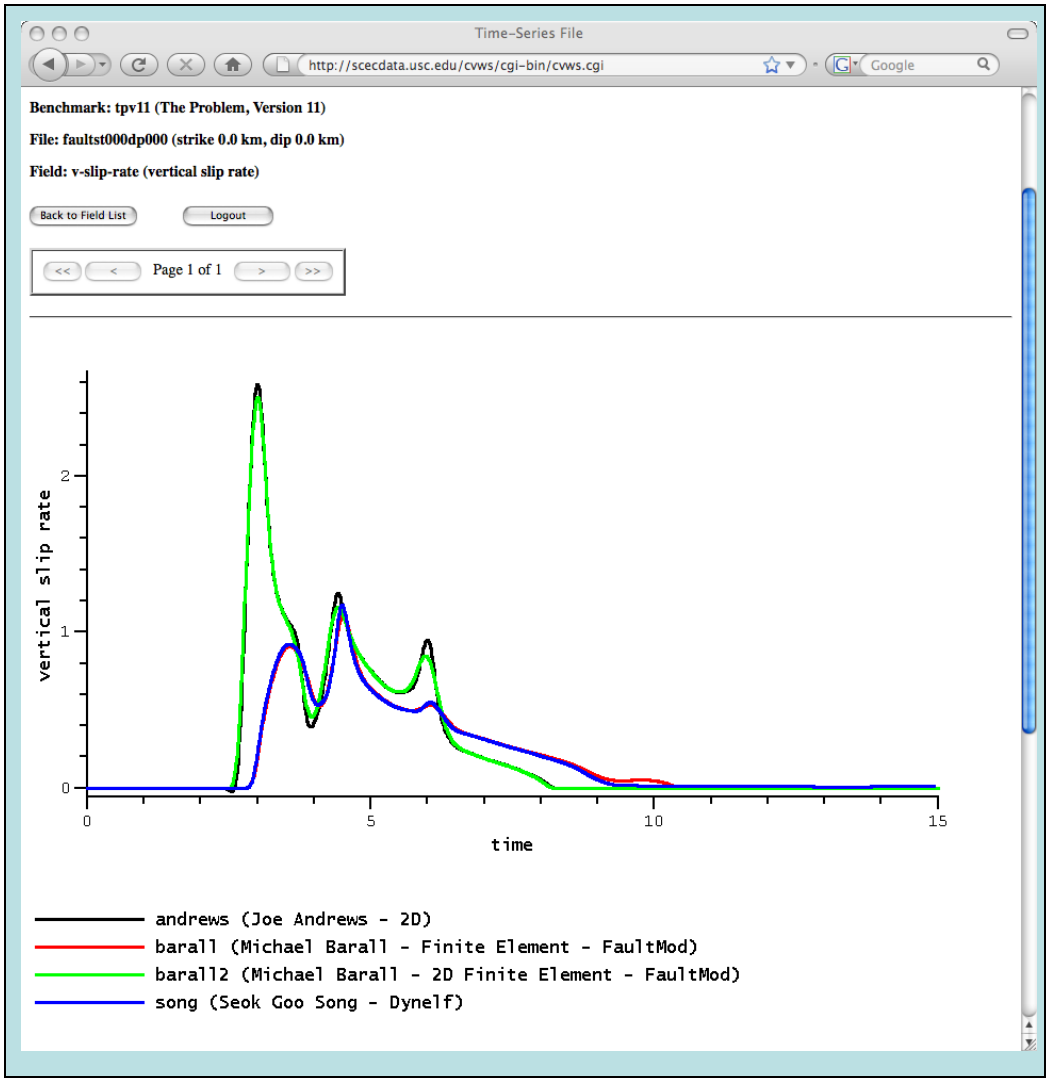
3D
off-fault
station
earth's
surface
+3 km from
fault trace
12 km
along strike



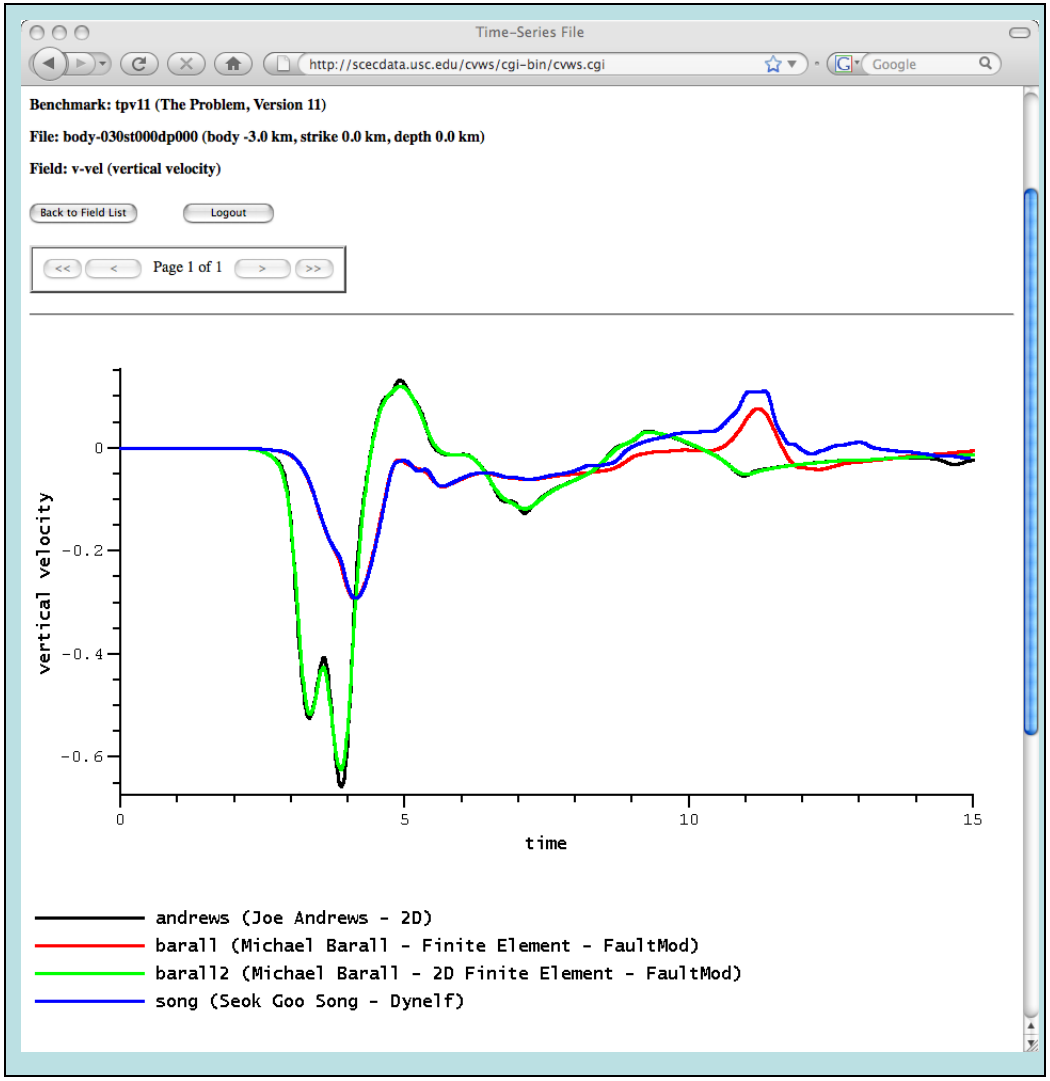
Harris Nov. 2008

3D vs. 2D

3D and 2D
on-fault
station
earth's
surface
top center
of fault

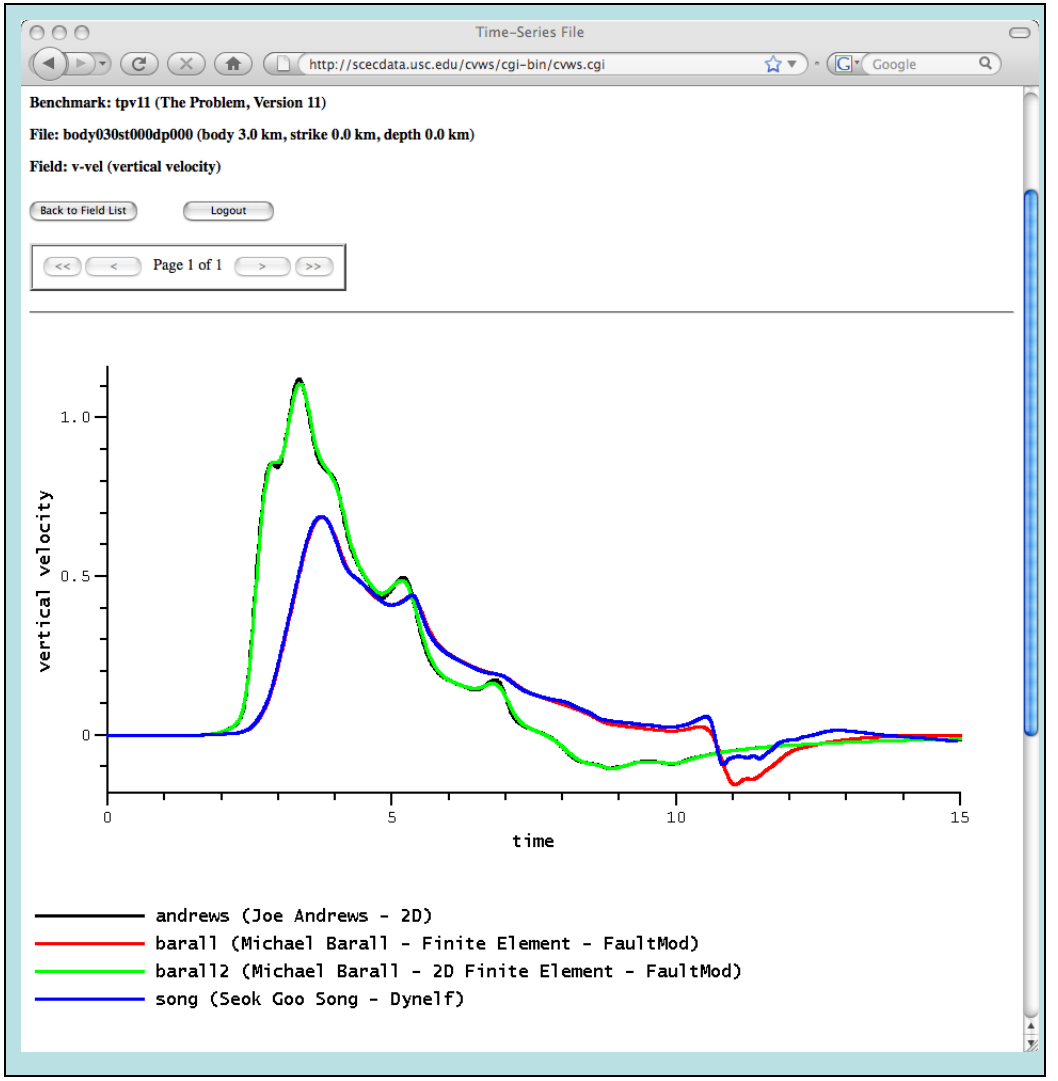


3D and 2D off-fault station earth's surface -3 km from fault trace



Harris Nov. 2008

3d and 2D off-fault station earth's surface +3 km from fault trace



Introduction and Overview of the Benchmarks and Results -

Part II. Where we're going next

The science:

Our SCEC2009 group proposal addresses 3 areas:
Off-fault yielding
Thermal pressurization
3D vs. 2D

The 2009 ExGM funding:

Two modelers run >100 YM-related 3D dip-slip simulations, followed by smooth transfer of results to kinematic effort
+
Maybe some of our 'the science' topics?

Introduction and Overview of the Benchmarks and Results -

Part III. What we hope to decide by the end of today

So far our dip-slip benchmarks have assumed slip-weakening and elastic off-fault yielding.

These are the assumptions under which the codes have been verified, and therefore the assumptions that would be approved by reviewers of our work.

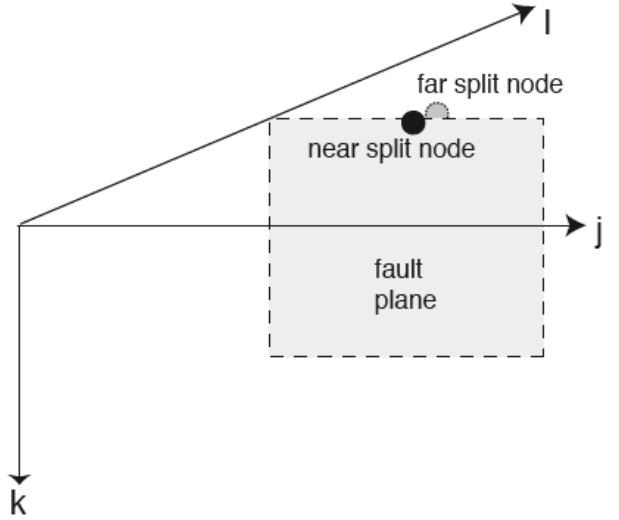
Is this sufficient, to pursue the YM 3D dynamic rupture simulations assuming slip-weakening and off-fault elasticity?

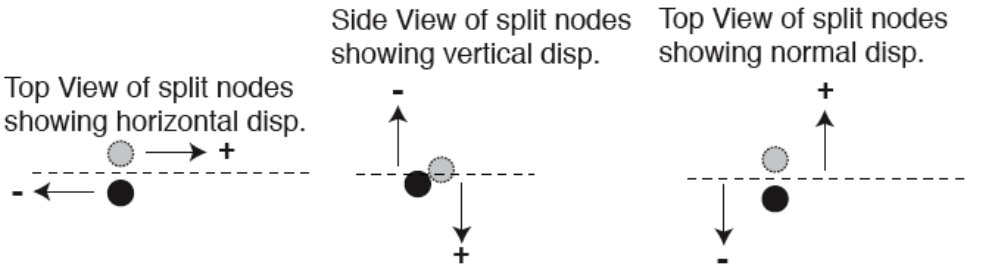
Please read our SRL article

preprint available on our website

http://scecdata.usc.edu/cvws

Harris, R.A., M. Barall, R. Archuleta, B. Aagaard, J.-P. Ampuero,
H. Bhat, V. Cruz-Atienza, L. Dalguer, P. Dawson, S. Day,
B. Duan, E. Dunham, G. Ely, Y. Kaneko, Y. Kase, N. Lapusta, Y. Liu,
S. Ma, D. Oglesby, K. Olsen, A. Pitarka, S. Song, and E. Templeton,
The SCEC/USGS Dynamic Earthquake-Rupture Code Verification Exercise,
Seismological Research Letters, vol. 80, no. 1, 2009.





horizontal displacement of split node on far side of fault = $u(j,k,l^+)$
horizontal displacement of split node on near side of fault = $u(j,k,l^-)$
horizontal slip = $u(j,k,l^+) - u(j,k,l^-)$ (>0 for right-lateral strike-slip)

vertical displacement of split node on far side of fault = $v(j,k,l^+)$
vertical displacement of split node on near side of fault = $v(j,k,l^-)$
vertical slip = $v(j,k,l^+) - v(j,k,l^-)$ (>0 for downward slip)

normal displacement of split node on far side of fault = $w(j,k,l^+)$
normal displacement of split node on near side of fault = $w(j,k,l^-)$
normal slip = $w(j,k,l^+) - w(j,k,l^-)$ (>0 for extension)