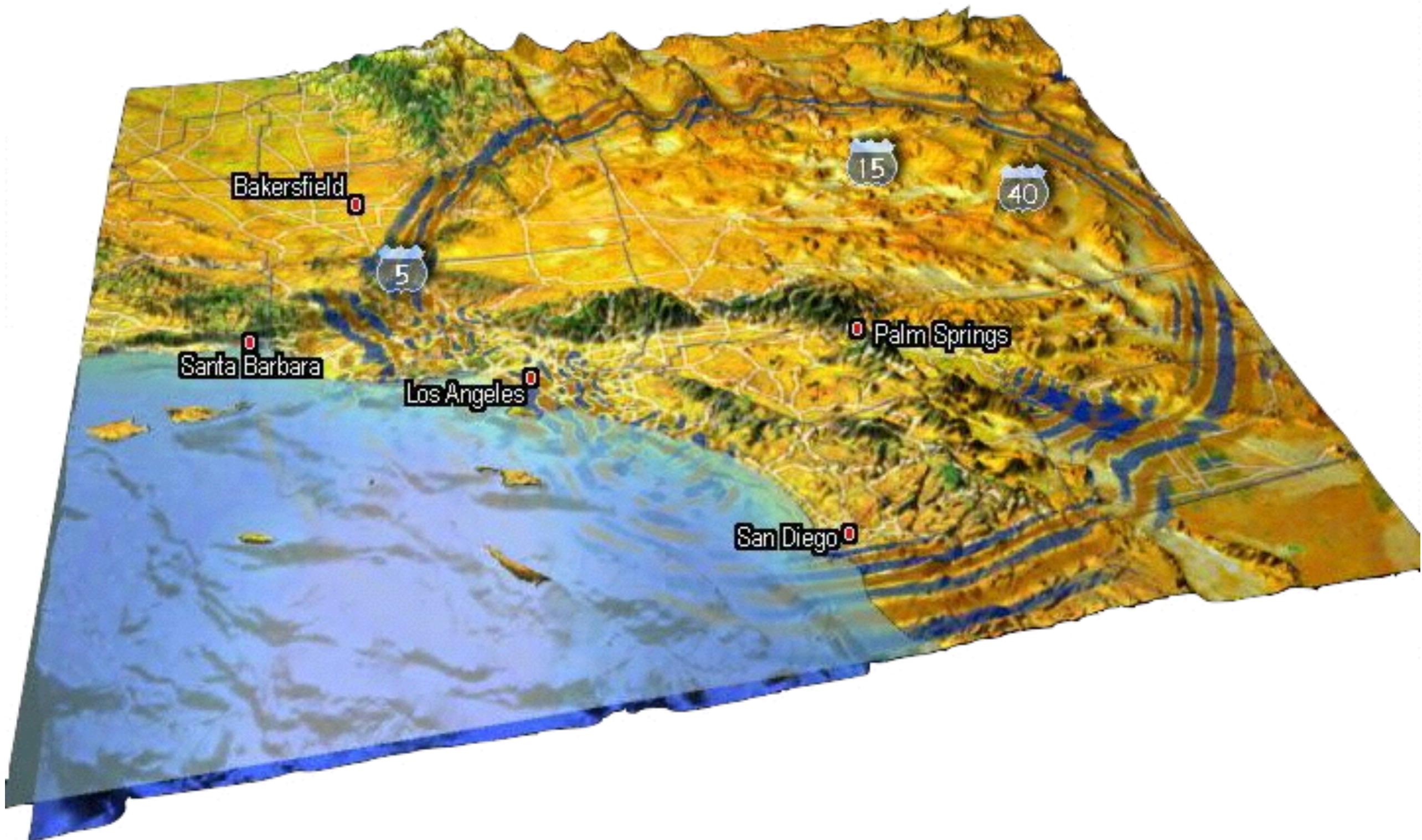


Spectral-element method  
**SPECFEM**  
Community Codes for Forward and Inverse Modeling



Computational Geophysics

# SPECFEM3D\_Cartesian



# Open Source Community Software

## SPECFEM3D\_Cartesian

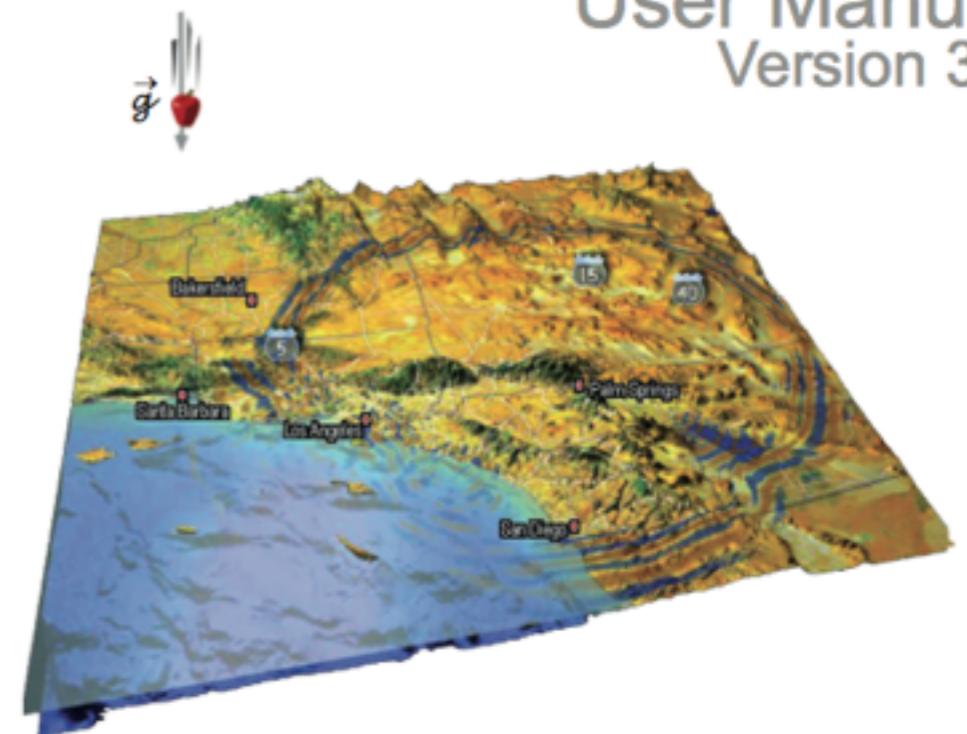
- Unstructured meshes (CUBIT)
- Load-balanced mesh partitioning
- Acoustic & elastic coupling
- Poroelasticity
- Anisotropy
- Attenuation
- Adjoint kernels

[www.geodynamics.org](http://www.geodynamics.org)

COMPUTATIONAL INFRASTRUCTURE FOR GEODYNAMICS (CIG)  
PRINCETON UNIVERSITY (USA)  
CNRS and UNIVERSITY OF MARSEILLE (FRANCE)  
ETH ZÜRICH (SWITZERLAND)

## SPECFEM 3D Cartesian

User Manual  
Version 3.0



Aix-Marseille  
université

ETH Zürich

# Installation

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Home > Software

Software Package List

SPECFEM3D CARTESIAN

Current Release

User Resources

Developer Resources

User Map

## SPECFEM3D Cartesian

SPECFEM3D Cartesian simulates acoustic (fluid), elastic (solid), coupled acoustic/elastic, poroelastic or seismic wave propagation in any type of conforming mesh of hexahedra (structured or not.) It can, for instance, model seismic waves propagating in sedimentary basins or any other regional geological model following earthquakes. It can also be used for non-destructive testing or for ocean acoustics.

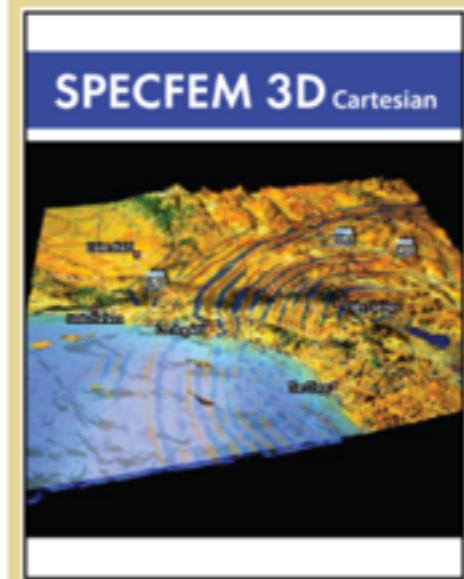
SPECFEM3D\_Cartesian version 2.0 uses the continuous Galerkin spectral-element method, which can be seen as a particular case of the discontinuous Galerkin technique with optimized efficiency owing to its tensorized basis functions, to simulate forward and adjoint coupled acoustic-(an)elastic seismic wave propagation on arbitrary unstructured hexahedral meshes.

This major new release benefits from advances in hexahedral meshing, load balancing and code optimizations. Meshing may be accomplished using a mesh generation tool kit such as **CUBIT**, **GID** or **Gmsh**, and load balancing is facilitated by graph partitioning based on the **SCOTCH** library, which is included in the package. The previous internal layer cake mesher has been extended to allow greater flexibility and also continues to be available. Topography, bathymetry and Moho undulations are readily included in a mesh, and physical dispersion and attenuation associated with anelasticity are accounted for using a series of standard linear solids. Coupling between fluid and solid regions is accommodated using domain decomposition, thereby facilitating off-shore simulations. Finite-frequency Fréchet derivatives for earthquake and seismic interferometric data are calculated based on adjoint methods in both fluid and solid domains, thereby facilitating "adjoint tomography" with earthquakes and seismic noise.

### Current Release

#### SOURCE PACKAGES

#### Current Stable Release



**SPECFEM 3D Cartesian**

**Status:**  
Actively adding features to support improved science or performance by CIG.

**Code changes:**  
18 commits this past month,  
282 commits this past year.

**Contact:**  
[cig-seismo@geodynamics.org](mailto:cig-seismo@geodynamics.org)

**Bug reports:**  
[Github Issue Tracker](#)

**License:**  
GNU Public License

# Installation

download:

- git checkout / web download

# Installation

configuration & compilation:

- ./configure F90=ifort
- make

# Quick start

## EXAMPLES/

- homogeneous\_halfspace
- layered\_halfspace
- tomographic\_model
- waterlayered\_halfspace
- .... contribute your own models!

# Quick start



# Mesh generation

meshing:

- CUBIT/Trelis
- in-house mesher xmshfem3D

# Mesh generation

Sandia National Laboratories

cubit.sandia.gov

news divers code platform journals seismology

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**CUBIT Toolkit**

- Licensing
- Documentation
- Tutorials
- Other Tools
- Support
- Passwords needed:
- Downloads
- Developers' Pages

## CUBIT

### News of Note:

- [CUBIT 15.2 Released July 19, 2016](#)
- [Next Cubit Tutorials November 15-16, 2016](#)
- [CUBIT 15.1 Released February 29, 2016](#)
- [CUBIT 15.0 Released April 16, 2015](#)
- [25th International Meshing Roundtable](#)  
will be held September 2016, Washington DC
- [CUBIT 14.1 Released January 13, 2014](#)

### The CUBIT Geometry and Mesh Generation Toolkit

CUBIT is a full-featured software toolkit for robust generation of two- and three-dimensional finite element meshes (grids) and geometry preparation. Its main goal is to reduce the time to generate meshes, particularly large hex meshes of complicated, interlocking assemblies. It is a solid-modeler-based preprocessor that meshes volumes and surfaces for finite element analysis. Mesh generation algorithms include:

- Quadrilateral and triangular paving
- 2D and 3D mapping
- Hex sweeping and multi-sweeping
- Tet meshing
- Many special purpose primitives.

CUBIT also contains many algorithms for controlling and automating much of the meshing process, such as

- Automatic scheme selection
- Interval matching
- Sweep grouping
- Sweep verification

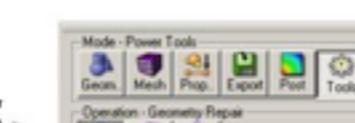
And, of course, CUBIT also includes state-of-the-art smoothing algorithms.



CUBIT provides an extensive suite of tools for geometry decomposition and mesh generation.

[More-extensive list of CUBIT Features...](#)

See [Cubit Licensing](#) for information on obtaining the Cubit Geometry and Mesh Generation Toolkit. Licensed users may [download](#) the current release from this website.



Select Volume(s) to Clean  
Pick volumes from graphics window

# Mesh generation

partitioning:

- SCOTCH

# Mesh generation

The screenshot shows the Inria Forge project page for the Scotch software package. The top navigation bar includes links for news, divers, code, platform, journals, and seismology. The main header features the Inria logo and a search bar. The top menu bar has tabs for HOME, MY PAGE, PROJECTS, and SCOTCH, with SCOTCH currently selected. Below the menu, there are sub-tabs for SUMMARY, ACTIVITY, FORUMS, TRACKER, LISTS, TASKS, DOCS, NEWS, SCM, and FILES.

**Project description:**  
Scotch is a software package for graph and mesh/hypergraph partitioning, graph clustering, and sparse matrix ordering.

**Project Information:**

- Development Status: 6 - Mature
- Environment: Console (Text Based)
- Intended Audience: Developers
- License: CeCILL-C
- Operating System: POSIX
- Programming Language: C
- Programming Language: Fortran
- Topic: Scientific/Engineering: Mathematics

Registered: 2006-01-31 13:41  
Activity Ranking: 272  
[View project Statistics or Activity](#)  
[View list of RSS feeds available for this project.](#)

**Latest File Releases:**

Package	Version	Date	Notes	Download
scotch	6.0.4	2015-03-14		

[View All Project Files](#)

**Public Tools:**

- [Project Home Page](#)
- [Tracker](#)

[Bugs \(6 open / 29 total\)](#)

**Project Members:**

Project Admins  
Francois PELLEGRINI

[View the 1 Member\(s\)](#)  
[Request to join](#)

**Latest News** [rss](#)

**Scotch 6.0.4 is out!**  
Francois PELLEGRINI - 2015-03-19 16:40 -  
1 Comment [Read More/Comment](#)

**Scotch 6.0.3 is out!**  
Francois PELLEGRINI - 2014-10-01 12:04 -  
1 Comment [Read More/Comment](#)

**Scotch 6.0.2 is out!**  
Francois PELLEGRINI - 2014-09-23 17:40 -  
1 Comment [Read More/Comment](#)

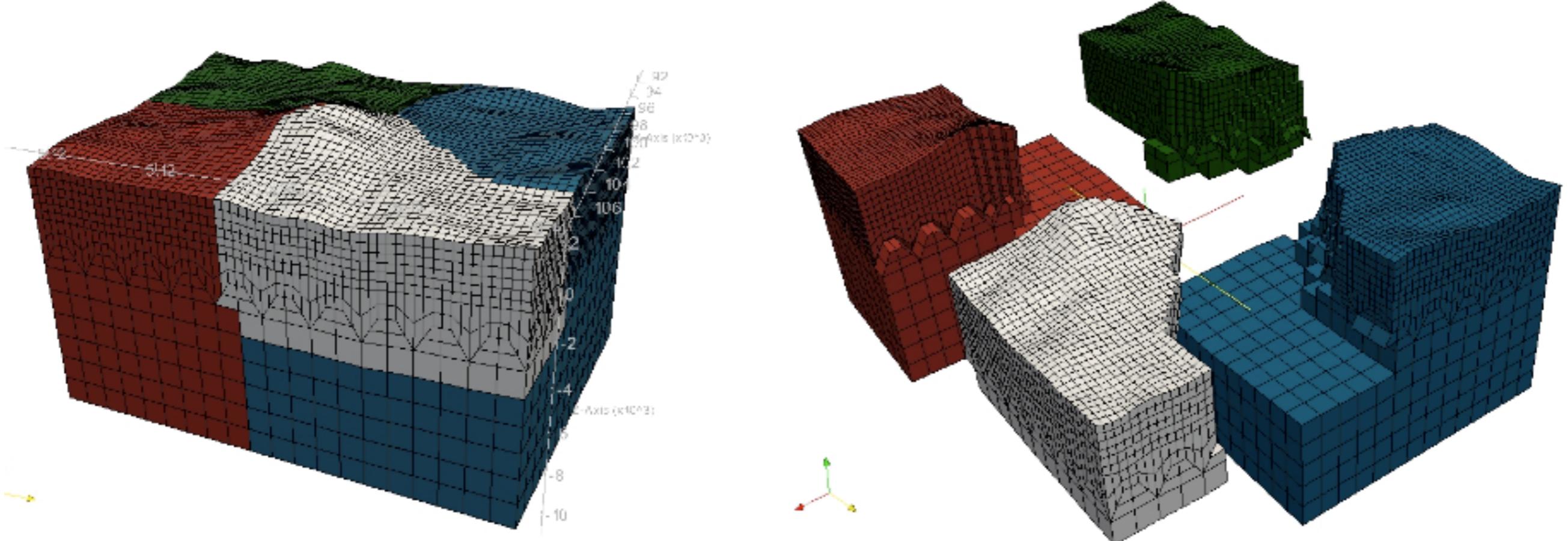
**Release 6.0.1 of Scotch is out !**  
Francois PELLEGRINI - 2014-09-20 20:36 -  
1 Comment [Read More/Comment](#)

**The "20 y.o. Scotch" edition, aka version 6.0, is out !**  
Francois PELLEGRINI - 2012-12-01 23:49 -  
0 Comment [Read More/Comment](#)

# Mesh generation

partitioning:

- decompose\_mesh\_SCOTCH/



# Input

# CMT solutions:

# ● DATA/CMTSOLUTION

PDE 1999 01 01 00 00 00.00 67000 67000 -25000 4.2 4.2 hom\_explosion  
event name: hom\_explosion  
time shift: 0.0000  
half duration: 5.0  
latitude: 67000.0  
longitude: 67000.0  
depth: -25.0  
Mrr: 1.000000e+23  
Mtt: 1.000000e+23  
Mpp: 1.000000e+23  
Mrt: 0.000000  
Mrp: 0.000000  
Mtp: 0.000000

# Input

stations:

- DATA/STATIONS

STATIONS						
X1	DB	67000.00	0.000000	0.0	0.0	
X2	DB	67000.00	1196.429	0.0	0.0	
X3	DB	67000.00	2392.857	0.0	0.0	
X4	DB	67000.00	3589.286	0.0	0.0	
X5	DB	67000.00	4785.714	0.0	0.0	
X6	DB	67000.00	5982.143	0.0	0.0	
X7	DB	67000.00	7178.571	0.0	0.0	
X8	DB	67000.00	8375.000	0.0	0.0	
X9	DB	67000.00	9571.429	0.0	0.0	
X10	DB	67000.00	10767.86	0.0	0.0	
X11	DB	67000.00	11964.29	0.0	0.0	
X12	DB	67000.00	13160.71	0.0	0.0	
X13	DB	67000.00	14357.14	0.0	0.0	
X14	DB	67000.00	15553.57	0.0	0.0	
X15	DB	67000.00	16750.00	0.0	0.0	
X16	DB	67000.00	17946.43	0.0	0.0	
X17	DB	67000.00	19142.86	0.0	0.0	
X18	DB	67000.00	20339.29	0.0	0.0	
X19	DB	67000.00	21535.71	0.0	0.0	
X20	DB	67000.00	22732.14	0.0	0.0	

# Input

forward simulation

# Input

```
Par_file.default

# forward or adjoint simulation
SIMULATION_TYPE          = 1    # 1 = forward, 2 = adjoint, 3 = both simultaneously
SAVE_FORWARD              = .false.

# UTM projection parameters
UTM_PROJECTION_ZONE      = ii
SUPPRESS_UTM_PROJECTION   = .true.

# number of MPI processors
NPROC                      = 4

# time step parameters
NSTEP                      = 1000
DT                          = 0.05d0

# parameters describing the model
OCEANS                     = .false.
TOPOGRAPHY                 = .false.
ATTENUATION                = .false.
USE_OLSEN_ATTENUATION      = .false.
ANISOTROPY                 = .false.

# absorbing boundary conditions for a regional simulation
ABSORBING_CONDITIONS     = .false.

# save AVS or OpenDX movies
MOVIE_SURFACE              = .false.
MOVIE_VOLUME                = .false.
NTSTEP_BETWEEN_FRAMES      = 200
CREATE_SHAKEMAP             = .false.
SAVE_DISPLACEMENT           = .false.
USE_HIGHRES_FOR_MOVIES     = .false.
HDUR_MOVIE                  = 0.0

# save AVS or OpenDX mesh files to check the mesh
SAVE_MESH_FILES             = .true.

# path to store the local database file on each node
LOCAL_PATH                  = DATABASES_MPI

# interval at which we output time step info and max of norm of displacement
NTSTEP_BETWEEN_OUTPUT_INFO = 500

# interval in time steps for writing of seismograms
NTSTEP_BETWEEN_OUTPUT_SEISMOS = 10000

# print source time function
PRINT_SOURCE_TIME_FUNCTION = .false.
```

- 1: forward
- 2: pure adjoint
- 3: kernels

# Input

cluster run: (template scripts in utils/Cluster)

- qsub go\_generate\_databases\_pbs.bash
- qsub go\_solver\_pbs.bash

# Input

adjoint simulation

# Input

```
# forward or adjoint simulation
SIMULATION_TYPE          = 1    # 1 = forward, 2 = adjoint, 3 = both simultaneously
SAVE_FORWARD              = .true.

# UTM projection parameters
UTM_PROJECTION_ZONE      = 11
SUPPRESS_UTM_PROJECTION   = .true.

# number of MPI processors
NPROC                      = 4

# time step parameters
NSTEP                      = 1000
DT                          = 0.05d0

# parameters describing the model
OCEANS                     = .false.
TOPOGRAPHY                 = .false.
ATTENUATION                = .false.
USE_OLESEN_ATTENUATION     = .false.
ANISOTROPY                 = .false.

# absorbing boundary conditions for a regional simulation
ABSORBING_CONDITIONS      = .false.

# save AVS or OpenDX movies
MOVIE_SURFACE               = .false.
MOVIE_VOLUME                = .false.
NTSTEP_BETWEEN_FRAMES       = 200
CREATE_SHAKEMAP             = .false.
SAVE_DISPLACEMENT           = .false.
USE_HIGHRES_FOR_MOVIES      = .false.
HDUR_MOVIE                  = 0.0

# save AVS or OpenDX mesh files to check the mesh
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# interval at which we output time step info and max of norm of displacement
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# interval in time steps for writing of seismograms
NTSTEP_BETWEEN_OUTPUT_SEISMOS = 10000

# print source time function
PRINT_SOURCE_TIME_FUNCTION   = .false.
```

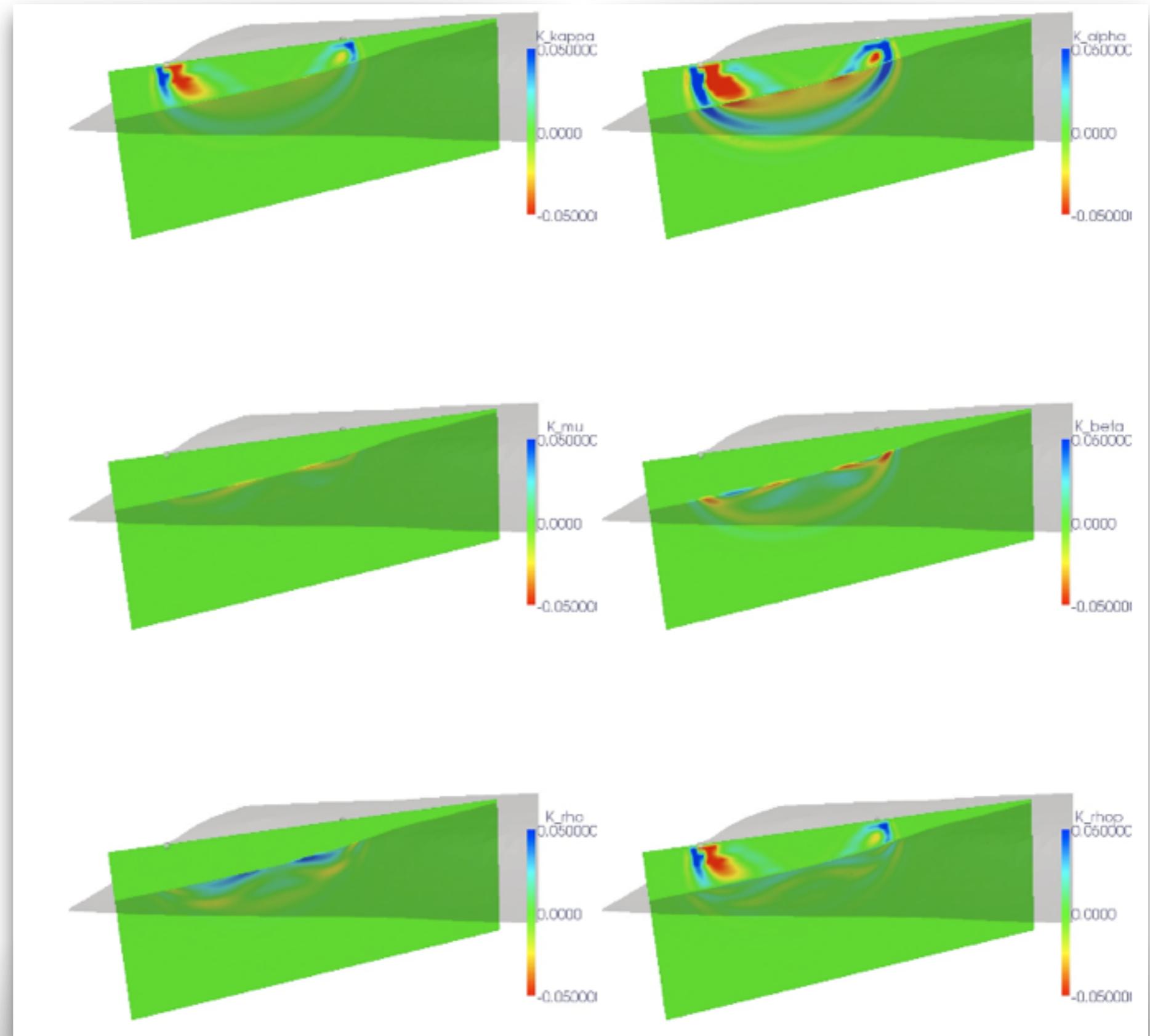
1. run: forward type=1,  
SAVE\_FORWARD

2.run: both type=3

./change\_simulation\_type.pl -F/-b

# Output

fluid-solid  
sensitivity kernels



# Output

## visualizations

- Paraview
- GMT
- openDX

# Outreach

Southern California  
shakemovie

shakemovie.caltech.edu

news divers code platform journals seismology

# southern california ShakeMovie

CALTECH'S NEAR REAL TIME SIMULATION OF SOUTHERN CALIFORNIA SEISMIC EVENTS PORTAL :: STATUS [ALIVE] :: Monday, November 28, 2016 ::

MOST RECENT EARTHQUAKE

**3.5** 37449175  
13 miles NE of Olancha, CA  
Thu Aug 18 03:39:54 2016 utc  
(36.40, -117.87)

OTHER RECENT EVENTS

**4.0** 37644544  
11 miles WSW of Westmorland, CA  
Sun Jul 31 16:21:05 2016 utc  
(32.96, -115.76)

**5.2** 37374587  
14 miles NNW of Borrego Springs, CA  
Fri Jun 10 08:04:38 2016 utc  
(33.44, -116.45)

**4.1** 37534708  
13 miles ENE of Ojai, CA  
Sat Mar 12 08:42:40 2016 utc  
(34.53, -119.07)

**4.8** 37528064  
27 miles WNW of Bakersfield, CA  
Wed Feb 24 00:02:23 2016 utc  
(35.53, -119.38)

**4.1** 37527664  
39 miles N of Joshua Tree, CA  
Tue Feb 23 03:19:52 2016 utc  
(34.70, -116.24)

**4.3** 37526424  
24 miles ENE of Lucerne Valley, CA  
Sat Feb 20 06:13:20 2016 utc  
(34.61, -116.63)

**3.9** 37524378  
3 miles NNW of Big Bear City, CA  
Tue Feb 16 09:24:20 2016 utc  
(34.30, -116.86)

[archive]

= Moment Magnitude  
= closest city  
= date/time of origin  
= (latitude,longitude)  
= event ID

RECENT DATABASE SCIENCE SIGN UP

MOST RECENT :: event: 13 miles NE of Olancha, CA :: Thu Aug 18 03:39:54 2016

Event Id: 37449175 UTC: Thu Aug 18 03:39:54 2016 Mag: 3.5

13 miles NE of Olancha, CA Latitude: Longitude: 36.3993 -117.8653

[download movies]  
Southern California 320x240 | mpeg  
[DOWNLOAD]

[view maps]  
Peak Ground Acceleration  
500x488 | jpg

Welcome to ShakeMovie: Caltech's Near Real Time Simulation of Southern California Seismic Events Portal. This portal has been designed to present the public with near real time visualizations of recent significant seismic events in the Southern California Region. These movies are the results of simulations carried out on a large computer cluster. Movies are simulated based upon the software package SPECFEM3D. Earthquake movies will be available for download approximately 45 mins after the occurrence of a quake of magnitude 3.5 or greater.

FACTS

When an earthquake occurs, seismic waves are generated which propagate away from the fault rupture.

Here we see the up-and-down velocity of the Earth's surface. Strong blue waves indicate the surface is moving rapidly downward. Strong red waves indicate rapid upward motion.

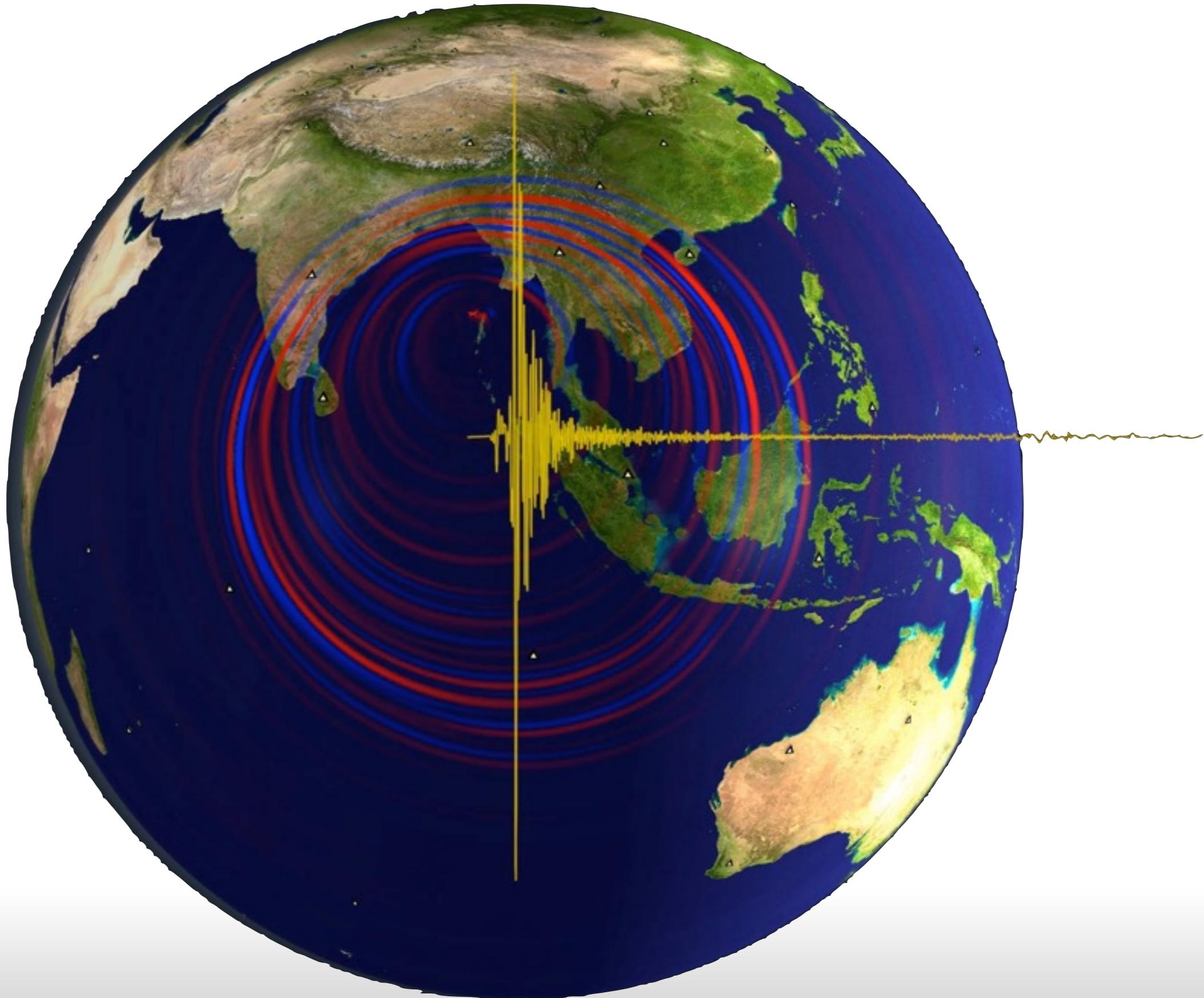
When the waves pass through soft soils (sediments) they slow down and amplify. Waves speed up when they pass through hard rock.

The color of the waves oscillates between red and blue indicating alternating up and down motion.

shakemovie.caltech.edu

[ Sign up for Event Email Notifications | Search the Event DataBase | Learn more about earthquakes | Latest Events Processed | Scientific Synthetics DataBase | About ShakeMovie ]

# SPECFEM3D\_GLOBE

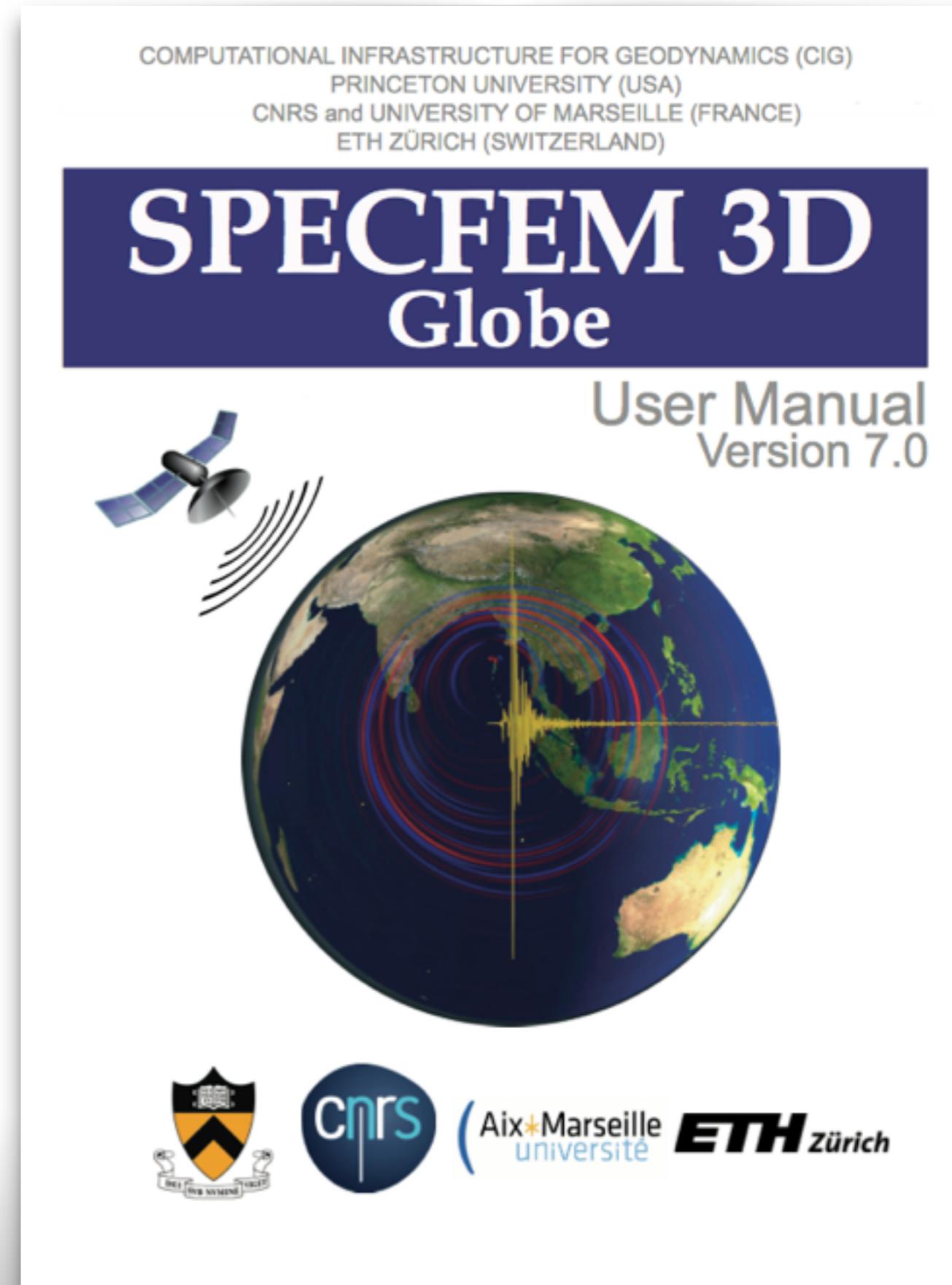


# Open Source Community Software

## SPECFEM3D\_GLOBE

- 3D crust and mantle models
- Topography & Bathymetry
- Rotation
- Ellipticity
- Gravitation
- Anisotropy
- Attenuation

[www.geodynamics.org](http://www.geodynamics.org)



# Installation

geodynamics.org

news divers code platform journals seismology

Google™ Cite

## CIG COMPUTATIONAL INFRASTRUCTURE for GEODYNAMICS

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Software Package List

**SPECFEM3D GLOBE**

**Current Release**

User Resources

Developer Resources

User Map

### SPECFEM3D GLOBE

**SPECFEM3D\_GLOBE simulates global and regional (continental-scale) seismic wave propagation.**

Effects due to lateral variations in compressional-wave speed, shear-wave speed, density, a 3D crustal model, ellipticity, topography and bathymetry, the oceans, rotation, and self-gravitation are all included.

The version 7.0 release offers GPU graphics card support for both OpenCL and CUDA hardware accelerators, based on an automatic source-to-source transformation library (Videau et al. 2013). It offers additional support for ADIOS file I/O formats and contains important bug fixes related to 3D topography and geographic/geocentric transformations. Seismogram file names adapt a new naming convention, with better compatibility to the seismogram specifications by the Incorporated Research Institutions for Seismology (IRIS).

The version embeds non-blocking MPI communications and includes several performance improvements in mesher and solver. It provides a perfectly load-balanced mesh for 3D mantle models honoring shallow oceanic Moho (depths less than 15 km) and deep continental Moho (depths greater than 35 km). It also accommodates European crustal models EPcrust (Molinari & Morelli, 2011) and EuCrust07 (Tesauro et al., 2008), which may be combined with global crustal model Crust2.0. Sedimentary wavespeeds are superimposed on the mesh if sediment thickness exceeds 2 km.

Additional new model routines are provided for the Comprehensive Earth Model (CEM) project, generic point-profile models (PPM) and Gauss-Lobatto-Legendre based models (GLL), with complementary tools for postprocessing adjoint sensitivity kernels and gradient-based model updates. The structure of the software has been simplified to facilitate easier implementation of new 3D models. The code accommodates general moment tensor files, and provides complete information in the SAC headers, as explained in detail in the updated user manual. New matrix-matrix multiplication routines, adapted from the book of Deville et al. (2002), and loop-vectorization help reduce the total number of memory accesses performed in each spectral element and improve

**Status:**  
Actively adding features to support improved science or performance by CIG.

**Code changes:**  
12 commits this past month,  
184 commits this past year.

**Contact:**  
[cig-seismo@geodynamics.org](mailto:cig-seismo@geodynamics.org)

**Bug reports:**  
[Github Issue Tracker](#)

**License:**  
GNU Public License

# Input

CMT solutions:

- [globalcmt.org](http://globalcmt.org)
- kinematic rupture simulation

# Input

Global CMT Search Results  
http://www.globalcmt.org/cgi-bin/globalcmt-cgi-bin/CMT4/form?itype=ymd&yr=20 Google

news divers code platform journals seismology

## Global CMT Catalog

### Search criteria:

```
Start date: 2010/9/23    End date: 2010/10/22
-90 <=lat<= 90          -180 <=lon<= 180
0 <=depth<= 1000         -9999 <=time shift<= 9999
0 <=mb<= 10              0<=Ms<= 10            0<=Mw<= 10
0 <=tension plunge<= 90      0 <=null plunge<= 90
```

### Results

Output in CMTSOLUTION format

---

#### From Quick CMT catalog

```
PDE 2010 9 23 5 28 35.00 52.2300 179.8000 161.8 5.6 5.6 RAT ISLANDS, ALEUTIAN IS
event name: 201009230528A
time shift: 2.1400
half duration: 1.4000
latitude: 52.2500
longitude: 179.8200
depth: 170.9600
Mrr: 7.000000e+22
Mtt: -6.210000e+23
Mpp: 5.510000e+23
Mrt: 2.080000e+24
Mrp: -1.270000e+24
Mtp: -4.660000e+23
```

---

End of events found with given criteria.

---

See the [CMT project](#) web page for more information on CMTs.

---

Please [email comments](#).

# Input

CMTSOLUTION\_POLET\_YORBA\_LINDA

```
PDE 2002 9 3 7 8 51.00 33.9190 -117.7640 7.0 4.3 4.3 Yorba Linda (JASCHA)
event name: 9818433
time shift: 0.0000
half duration: 1.0000
latitude: 33.9190
longitude: -117.7640
depth: 7.0000
Mrr: -0.124000e+23
Mtt: -0.219000e+23
Mpp: 0.343000e+23
Mrt: -0.094000e+23
Mrp: -0.105000e+23
Mtp: -0.170000e+23
```

CMTSOLUTION\_Northridge

```
PDE 2003 7 7 23 59 17.78 34.0745 -118.3792 6.4 4.2 4.2 FICTITIOUS
event name: 9903873
time shift: 0.5447953452769341E+01
half duration: 0
latitude: 34.2438031511517800
longitude: -118.7368191131799000
depth: 20.4269026324769500
Mrr: 0.3741044075662543E+24
Mtt: -0.3117105402966140E+24
Mpp: -0.6239386726964047E+23
Mrt: -0.8591611017176262E+23
Mrp: -0.1381384998281119E+23
Mtp: 0.1473147100031584E+24
PDE 2003 7 7 23 59 17.78 34.0745 -118.3792 6.4 4.2 4.2 FICTITIOUS
event name: 9903873
time shift: 0.5020661887758161E+01
half duration: 0
latitude: 34.2373686758751600
longitude: -118.7239386070113000
depth: 20.4269026324769500
Mrr: 0.4980058767550058E+24
Mtt: -0.4156140537288186E+24
Mpp: -0.8319182302618730E+23
Mrt: -0.1145548135623502E+24
Mrp: -0.1735179987041493E+23
Mtp: 0.1964196133375445E+24
PDE 2003 7 7 23 59 17.78 34.0745 -118.3792 6.4 4.2 4.2 FICTITIOUS
event name: 9903873
time shift: 0.4599210132417263E+01
half duration: 0
latitude: 34.2309327808731100
longitude: -118.7110600237053000
depth: 20.4269026324769500
Mrr: 0.6431970516051390E+24
Mtt: -0.5359233850713713E+24
Mpp: -0.1072736665337679E+24
Mrt: -0.1477154174882937E+24
Mrp: -0.2237468930658767E+23
Mtp: 0.2532779224615705E+24
PDE 2003 7 7 23 59 17.78 34.0745 -118.3792 6.4 4.2 4.2 FICTITIOUS
event name: 9903873
time shift: 0.4185136269172839E+01
half duration: 0
latitude: 34.2244954671005500
longitude: -118.6981833632119000
depth: 20.4269026324769500
Mrr: 0.3886676427867150E+24
Mtt: -0.3171791462667300E+24
Mpp: -0.6348849651998050E+23
Mrt: -0.8742341035021457E+23
Mrp: -0.1324216305900087E+23
Mtp: 0.1498991785997050E+24
```

# Input

stations:

- FDSN network stations

# Input

FDSN: Station Information <http://www.fdsn.org/stations/FDSNstations.htm> [Google](#)

news divers code platform journals seismology

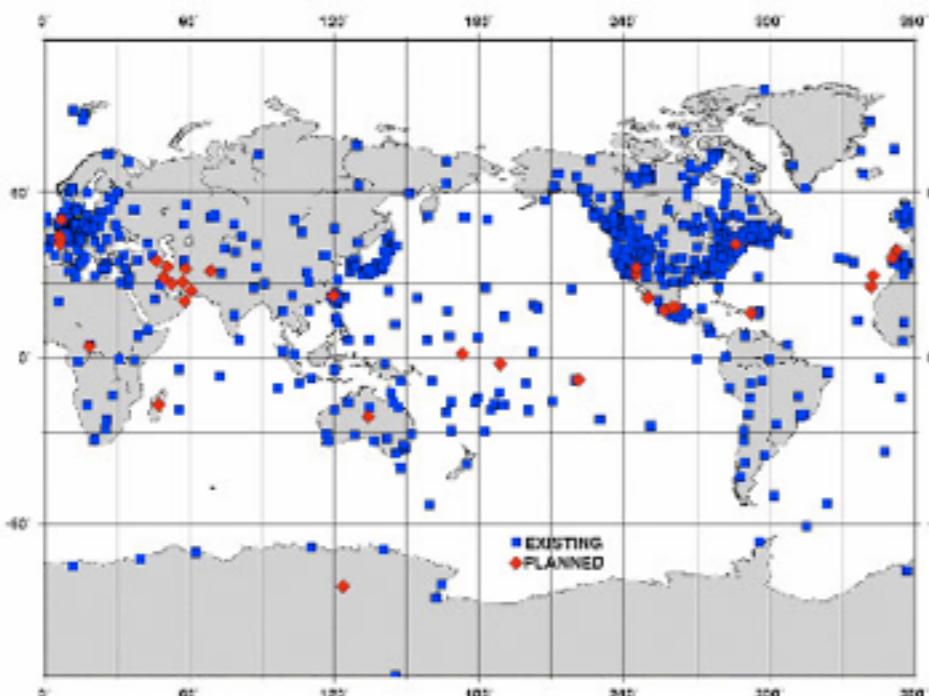
## DIGITAL BROADBAND SEISMOGRAPH STATIONS by Region

search

- [North America](#)
- [South America & Atlantic Ocean](#)
- [Antarctica and Temporary Stations](#)
- [Europe](#)
- [Asia](#)
- [Africa & Indian Ocean](#)
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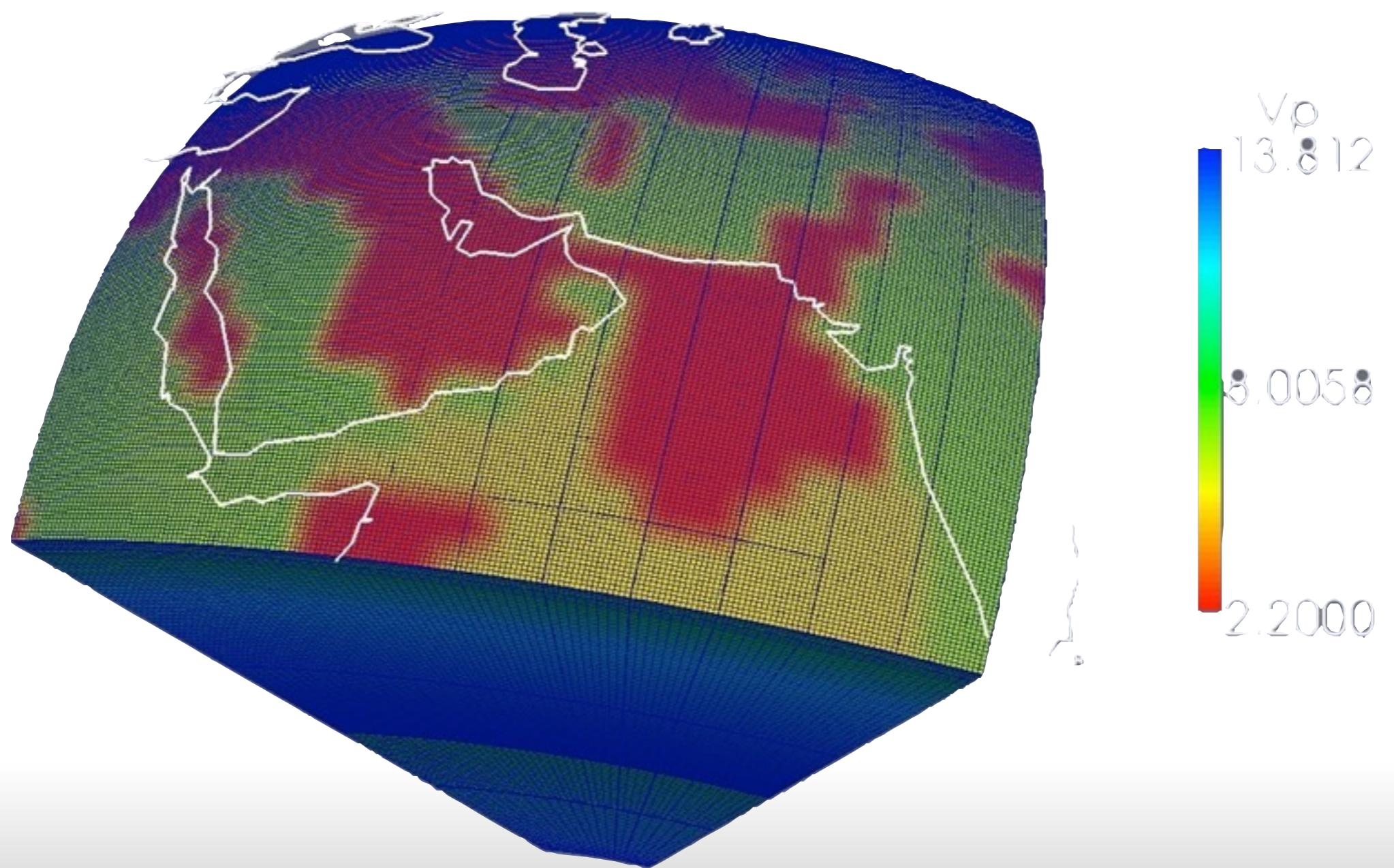
[click to zoom map]

STATIONS_ALL						
ASBS	AZ	33.6208	-116.4664	0.0	0.0	
BZN	AZ	33.4915	-116.6670	0.0	0.0	
CRY	AZ	33.5654	-116.7373	0.0	0.0	
ELKS	AZ	33.5813	-116.4496	0.0	0.0	
FRD	AZ	33.4947	-116.6022	0.0	0.0	
GLAC	AZ	33.6014	-116.4781	0.0	0.0	
KNW	AZ	33.7141	-116.7119	0.0	0.0	
LVA2	AZ	33.3516	-116.5615	0.0	0.0	
MONP	AZ	32.8927	-116.4225	0.0	0.0	
PFO	AZ	33.6117	-116.4594	0.0	0.0	
RDM	AZ	33.6300	-116.8478	0.0	0.0	
SHUM	AZ	33.6327	-116.4445	0.0	0.0	
SMTA	AZ	32.9449	-115.7999	0.0	0.0	
SND	AZ	33.5519	-116.6129	0.0	0.0	
SOL	AZ	32.8410	-117.2480	0.0	0.0	
THSB	AZ	32.8788	-117.2269	0.0	0.0	
TR0	AZ	33.5234	-116.4257	0.0	0.0	
WMC	AZ	33.5736	-116.6747	0.0	0.0	
YAQ	AZ	33.1666	-116.3539	0.0	0.0	
CMB	BK	38.0346	-120.3865	0.0	0.0	
CMB	BK	38.0346	-120.3865	0.0	0.0	
CVS	BK	38.3453	-122.4584	0.0	0.0	
HOPS	BK	38.9935	-123.0723	0.0	0.0	
JCC	BK	40.8175	-124.0296	0.0	0.0	
MHC	BK	37.3416	-121.6426	0.0	0.0	
ORV	BK	39.5545	-121.5004	0.0	0.0	
SAO	BK	36.7640	-121.4472	0.0	0.0	
WDC	BK	40.5799	-122.5411	0.0	0.0	
YBH	BK	41.7320	-122.7104	0.0	0.0	
G405	CE	33.7870	-118.3560	0.0	0.0	
J732	CE	34.1900	-117.3300	0.0	0.0	
K400	CE	34.0370	-118.1780	0.0	0.0	
K851	CE	34.0700	-118.3460	0.0	0.0	
K853	CE	34.0770	-118.2860	0.0	0.0	
ADD	CI	34.5505	-117.4339	0.0	0.0	

# Input

regional simulations:

- 1-chunk / 2-chunk run



# Input

```
Par_file

# forward or adjoint simulation
SIMULATION_TYPE          = 1
SAVE_FORWARD              = .false. # save last frame of forward simulation or not

# number of chunks (1,2,3 or 6)
NCHUNKS                  = 1

# angular width of the first chunk (not used if full sphere with six chunks)
ANGULAR_WIDTH_XI_IN_DEGREES = 45.d0      # angular size of a chunk
ANGULAR_WIDTH_ETA_IN_DEGREES = 40.d0
CENTER_LATITUDE_IN_DEGREES  = 29.d0
CENTER_LONGITUDE_IN_DEGREES = 55.d0
GAMMA_ROTATION_AZIMUTH     = 0.d0

# number of elements at the surface along the two sides of the first chunk
# (must be multiple of 16 and 8 * multiple of NPROC below)
NEX_XI                   = 480
NEX_ETA                  = 480

# number of MPI processors along the two sides of the first chunk
NPROC_XI                 = 12
NPROC_ETA                 = 12

# 1D models with real structure:
# 1D_isotropic_prem, 1D_transversely_isotropic_prem, 1D_iasp91, 1D_1066a, 1D_ak135, 1D_ref, 1D_ref_iso
#
# 1D models with only one fictitious averaged crustal layer:
# 1D_isotropic_prem_onecrust, 1D_transversely_isotropic_prem_onecrust, 1D_iasp91_onecrust, 1D_1066a_onecrust, 1D_ak135_onecrust
#
# fully 3D models:
# transversely_isotropic_prem_plus_3D_crust_2.0, 3D_anisotropic, 3D_attenuation,
# s20rts, s362ani, s362iso, s362wmani, s362ani_prem, s362ani_3DQ, s362iso_3DQ,
# s29ea, s29ea, sea99_jp3d1994, sea99_jp3d1994, heterogen
MODEL                     = s29ea

# parameters describing the Earth model
OCEANS                    = .true.
ELLIPTICITY               = .true.
TOPOGRAPHY                = .true.
GRAVITY                   = .true.
ROTATION                  = .true.
ATTENUATION               = .true.

# absorbing boundary conditions for a regional simulation
ABSORBING_CONDITIONS     = .true.

# record length in minutes
RECORD_LENGTH_IN_MINUTES  = 22.0d0
```

# Input

global simulations:

- 6-chunk run

# Input

```
Par_file

# forward or adjoint simulation
SIMULATION_TYPE          = 1
SAVE_FORWARD              = .false. # save last frame of forward simulation or not

# number of chunks (1,2,3 or 6)
NCHUNKS                   = 6

# angular width of the first chunk (not used if full sphere with six chunks)
ANGULAR_WIDTH_XI_IN_DEGREES = 45.d0      # angular size of a chunk
ANGULAR_WIDTH_ETA_IN_DEGREES = 40.d0
CENTER_LATITUDE_IN_DEGREES  = 29.d0
CENTER_LONGITUDE_IN_DEGREES = 55.d0
GAMMA_ROTATION_AZIMUTH     = 0.d0

# number of elements at the surface along the two sides of the first chunk
# (must be multiple of 16 and 8 * multiple of NPROC below)
NEX_XI                     = 480
NEX_ETA                    = 480

# number of MPI processors along the two sides of the first chunk
NPROC_XI                  = 12
NPROC_ETA                  = 12

# 1D models with real structure:
# 1D_isotropic_prem, 1D_transversely_isotropic_prem, 1D_iasp91, 1D_1066a, 1D_ok135, 1D_ref, 1D_ref_iso
#
# 1D models with only one fictitious averaged crustal layer:
# 1D_isotropic_prem_onecrust, 1D_transversely_isotropic_prem_onecrust, 1D_iasp91_onecrust, 1D_1066a_onecrust, 1D_ok135_onecrust
#
# fully 3D models:
# transversely_isotropic_prem_plus_3D_crust_2.0, 3D_anisotropic, 3D_attenuation,
# s20rts, s362ani, s362iso, s362wmani, s362ani_prem, s362ani_3DQ, s362iso_3DQ,
# s29ea, s29ea, sea99_jp3d1994, sea99_jp3d1994, heterogen
MODEL                      = s362ani

# parameters describing the Earth model
OCEANS                     = .true.
ELLIPTICITY                = .true.
TOPOGRAPHY                 = .true.
GRAVITY                     = .true.
ROTATION                    = .true.
ATTENUATION                 = .true.

# absorbing boundary conditions for a regional simulation
ABSORBING_CONDITIONS       = .false.

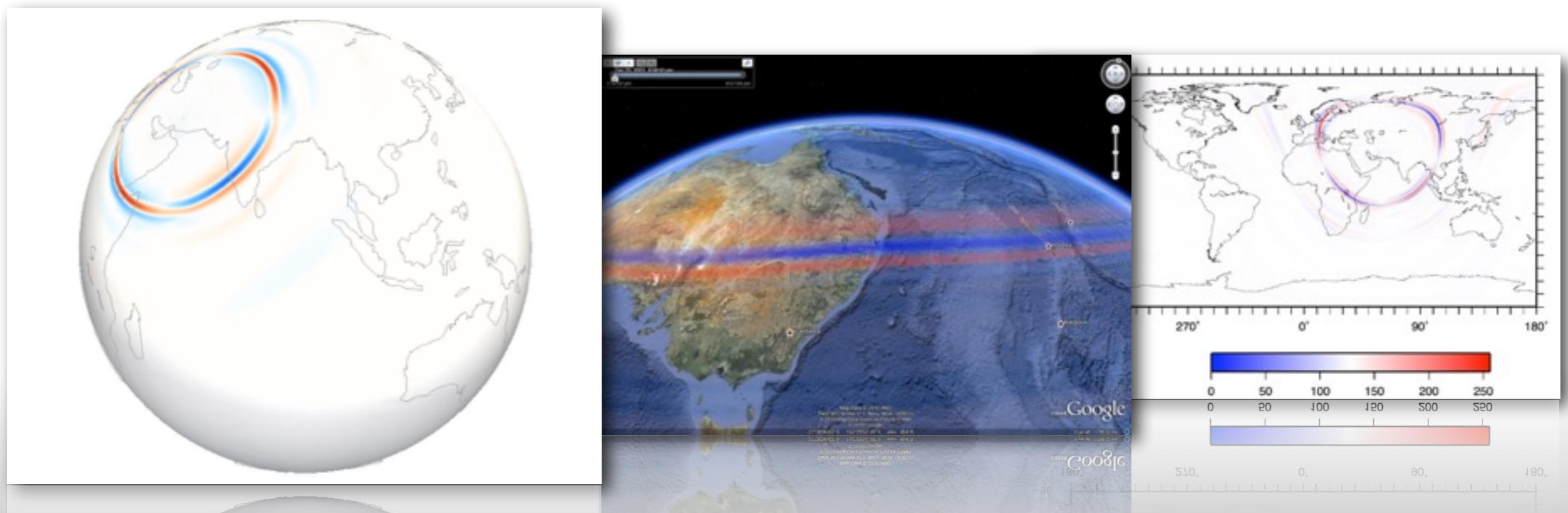
# record length in minutes
RECORD_LENGTH_IN_MINUTES    = 22.0d0
```

# Output

utils/:

- data & synthetics processing
- visualizations:

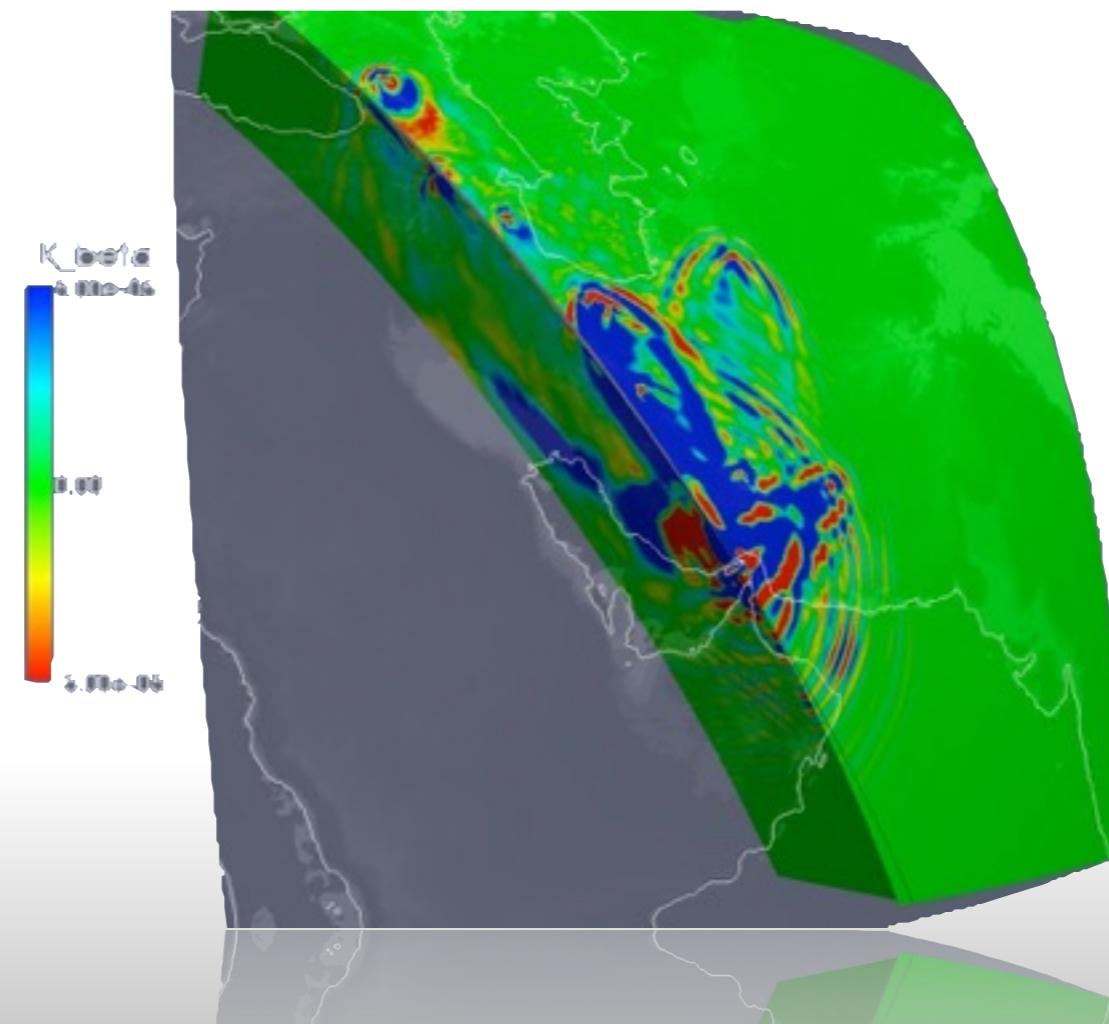
Paraview / VTK, GMT,  
Google Earth...



# Output

## Paraview visualizations:

- kernel run                      -> proc\*\*\*alpha\_kernel.bin
- combine\_vol\_data -> reg\_1\_alpha\_kernel.mesh
- mesh2vtu                      -> reg\_1\_alpha\_kernel.vtu



# Outreach

SHAKEMOVIE GLOBAL: Princeton University's Near Real Time Global Seismicity Portal

<http://global.shakemovie.princeton.edu/home.jsp?mode=scientific>

RSS Google

news divers code platform journals seismology

Scientific Mode Enabled :: Earthquake movies, 1D and 3D synthetic seismograms for seismologists.

Public Scientific

Friday, September 24, 2010

# ShakeMovie

GLOBAL

Princeton University's Near Real Time Global Seismicity Portal

HOME RECENT SEARCH SCIENCE

© MOST RECENT EVENT

**5.6** C201009231253A (-6.12, 151.78) 18.3 km  
Thu Sep 23 2010 12:53:10 utc NEW BRITAIN REGION, P.N.G.

© OTHER RECENT EVENTS

**5.5** C201009230528A (52.25, 179.82) 171.0 km  
Thu Sep 23 2010 05:28:37 utc RAT ISLANDS, ALEUTIAN ISLANDS

**5.7** C201009220800A (-13.43, -78.62) 63.6 km  
Wed Sep 22 2010 08:00:19 utc NEAR COAST OF PERU

**6.3** C201009171921A (36.47, 70.78) 206.3 km  
Fri Sep 17 2010 19:21:18 utc HINDU KUSH REGION, AFGHANISTAN

**5.8** C201009160154A (-15.99, -173.48) 93.7 km  
Thu Sep 16 2010 01:54:45 utc TONGA ISLANDS

MOST RECENT EVENT: NEW BRITAIN REGION, P.N.G. Thu Sep 23 2010 12:53:10 utc

Event Id: C201009231253A

**MW: 5.6**

Latitude, Longitude: (-6.1200, 151.7800)  
Depth: 18.3 km

PRINCETON UNIVERSITY 0:02:50

Koror Port Moresby Tarawa Port-Vila

Focal Mechanism Learn more...

Angled Zoomed In

orange [satellite imagery] DOWNLOAD .mpeg

640x320 (Full)

Synthetics

DOWNLOAD 3D Synthetics 729 MB | .sac.tar.gz

DOWNLOAD 1D Synthetics 59 MB | .sac.tar.gz

LHZ (PDF) LHT (PDF) LHR (PDF)

View Moment Tensor SAC Headers (PDF)

Download CMTSOLUTION Par\_file STATIONS constants.h

Scripts process\_data.pl process\_syn.pl rotate.pl

global shakemovie

# Modifications

create new crust/mantle model

# Modifications

```
meshfem3D_models.f90  
model_1dref.f90  
model_1066a.f90  
model_ak135.f90  
model_aniso_inner_core.f90  
model_aniso_mantle.f90  
model_atten3D_QRFSI12.f90  
model_attenuation.f90  
model_crust.f90  
model_crustmaps.f90  
model_eucrust.f90  
model_gll.f90  
model_heterogen_mantle.f90  
model_iasp91.f90  
model_jp1d.f90  
model_jp3d.f90  
model_ppm.f90  
model_prem.f90  
model_s20rts.f90  
model_s40rts.f90  
model_s362ani.f90  
model_sea1d.f90  
model_sea99_s.f90  
model_sb4I18.f90  
model_sb10I18.f90  
model_topo_bathy.f90
```

**fortran code:  
search & follow comments**

!---  
!  
**! ADD YOUR MODEL HERE**  
!  
!---

# Code optimizations

High-order methods for incompressible fluid flow, M.O. Deville, P.M. Fischer, E.H. Mund, 2002, Cambridge University Press

Software optimizations for high performance computing: creating faster applications, I.L. Crawford & K.R. Wadleigh, 2003, Prentice Hall Professional

Bentley's rules, J. Bentley, <http://www.hipecc.wichita.edu/bentley.htm>

# Code optimizations

## matrix-vector multiplications:

```
do j=1,m2
  do i=1,m1
    C1_m1_m2_5points(i,j) = hprime_xx(i,1)*B1_m1_m2_5points(1,j) + &
      hprime_xx(i,2)*B1_m1_m2_5points(2,j) + &
      hprime_xx(i,3)*B1_m1_m2_5points(3,j) + &
      hprime_xx(i,4)*B1_m1_m2_5points(4,j) + &
      hprime_xx(i,5)*B1_m1_m2_5points(5,j)

    C2_m1_m2_5points(i,j) = hprime_xx(i,1)*B2_m1_m2_5points(1,j) + &
      hprime_xx(i,2)*B2_m1_m2_5points(2,j) + &
      hprime_xx(i,3)*B2_m1_m2_5points(3,j) + &
      hprime_xx(i,4)*B2_m1_m2_5points(4,j) + &
      hprime_xx(i,5)*B2_m1_m2_5points(5,j)

    C3_m1_m2_5points(i,j) = hprime_xx(i,1)*B3_m1_m2_5points(1,j) + &
      hprime_xx(i,2)*B3_m1_m2_5points(2,j) + &
      hprime_xx(i,3)*B3_m1_m2_5points(3,j) + &
      hprime_xx(i,4)*B3_m1_m2_5points(4,j) + &
      hprime_xx(i,5)*B3_m1_m2_5points(5,j)

  enddo
enddo
do j=1,m1
  do i=1,m1
    ! for efficiency it is better to leave this loop on k inside, it leads to slightly faster code
    do k = 1,NGLLX
      tempx2(i,j,k) = dummyx_loc(i,1,k)*hprime_xxT(1,j) + &
        dummyx_loc(i,2,k)*hprime_xxT(2,j) + &
        dummyx_loc(i,3,k)*hprime_xxT(3,j) + &
        dummyx_loc(i,4,k)*hprime_xxT(4,j) + &
        dummyx_loc(i,5,k)*hprime_xxT(5,j)
```

# Code optimizations

## do-loops:

! way 1:

```
!      do i_sls = 1,N_SLS
!        R_xx_val = R_memory(1,i_sls,i,j,k,ispec)
!        R_yy_val = R_memory(2,i_sls,i,j,k,ispec)
!        sigma_xx = sigma_xx - R_xx_val
!        sigma_yy = sigma_yy - R_yy_val
!        sigma_zz = sigma_zz + R_xx_val + R_yy_val
!        sigma_xy = sigma_xy - R_memory(3,i_sls,i,j,k,ispec)
!        sigma_xz = sigma_xz - R_memory(4,i_sls,i,j,k,ispec)
!        sigma_yz = sigma_yz - R_memory(5,i_sls,i,j,k,ispec)
!      enddo
```

! way 2:

! note: this should help compilers to pipeline the code and make better use of the cache;  
! depending on compilers, it can further decrease the computation time by ~ 30%.  
! by default, N\_SLS = 3, therefor we take steps of 3

```
do i_sls = 1,mod(N_SLS,3)
  R_xx_val1 = R_memory(1,i_sls,i,j,k,ispec)
  R_yy_val1 = R_memory(2,i_sls,i,j,k,ispec)
  sigma_xx = sigma_xx - R_xx_val1
  sigma_yy = sigma_yy - R_yy_val1
  sigma_zz = sigma_zz + R_xx_val1 + R_yy_val1
  sigma_xy = sigma_xy - R_memory(3,i_sls,i,j,k,ispec)
  sigma_xz = sigma_xz - R_memory(4,i_sls,i,j,k,ispec)
  sigma_yz = sigma_yz - R_memory(5,i_sls,i,j,k,ispec)
enddo
```

```
do i_sls = mod(N_SLS,3)+1,N_SLS,3
  R_xx_val1 = R_memory(1,i_sls,i,j,k,ispec)
  R_yy_val1 = R_memory(2,i_sls,i,j,k,ispec)
```

# Code optimizations

## file I/O:

```
/* fastest performance on nehalem nodes:  
Linux 2.6.18-164.11.1.el5 #1 SMP Wed Jan 20 10:04:55 EST 2010 x86_64 x86_64 x86_64 GNU/Linux  
achieved with 16 KB buffers:  
  
##define MAX_B 65536 // 64 KB  
##define MAX_B 32768 // 32 KB  
#define MAX_B 16384 // 16 KB  
##define MAX_B 8192 // 8 KB  
  
// absorbing files: instead of passing file descriptor, we use the array index  
// first 0 - 3 indices for crust mantle files  
// last 4 - 8 indices for outer core files  
#define ABS_FILEID 9  
  
// file points  
static FILE * fp_abs[ABS_FILEID];  
// file work buffers  
static char * work_buffer[ABS_FILEID];  
  
//void  
//FC_FUNC_(open_file_abs_r_fbin,OPEN_FILE_ABS_R_FBIN)(int *fid, char *filename,int *length, int *filesize){  
void open_file_abs_r_fbin(int *fid, char *filename,int *length, int *filesize){  
  
// opens file for read access  
  
//This sequence assigns the MAX_B array work_buffer to the file pointer  
// to be used for its buffering. performance should benefit.  
    char * fncopy;  
    char * blank;  
    FILE *ft;  
  
// checks filesize  
if( *filesize == 0 ){  
    perror("Error file size for reading");  
    exit(EXIT_FAILURE);  
}
```

## More details

CIG - <https://geodynamics.org/cig/software/specfem3d/>

CIG wiki - <https://wiki.geodynamics.org/software:specfem3d:start>

github - <https://github.com/geodynamics/specfem3d>

github wiki - <https://github.com/geodynamics/specfem3d/wiki>