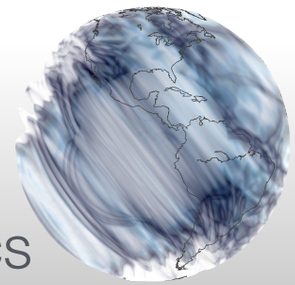
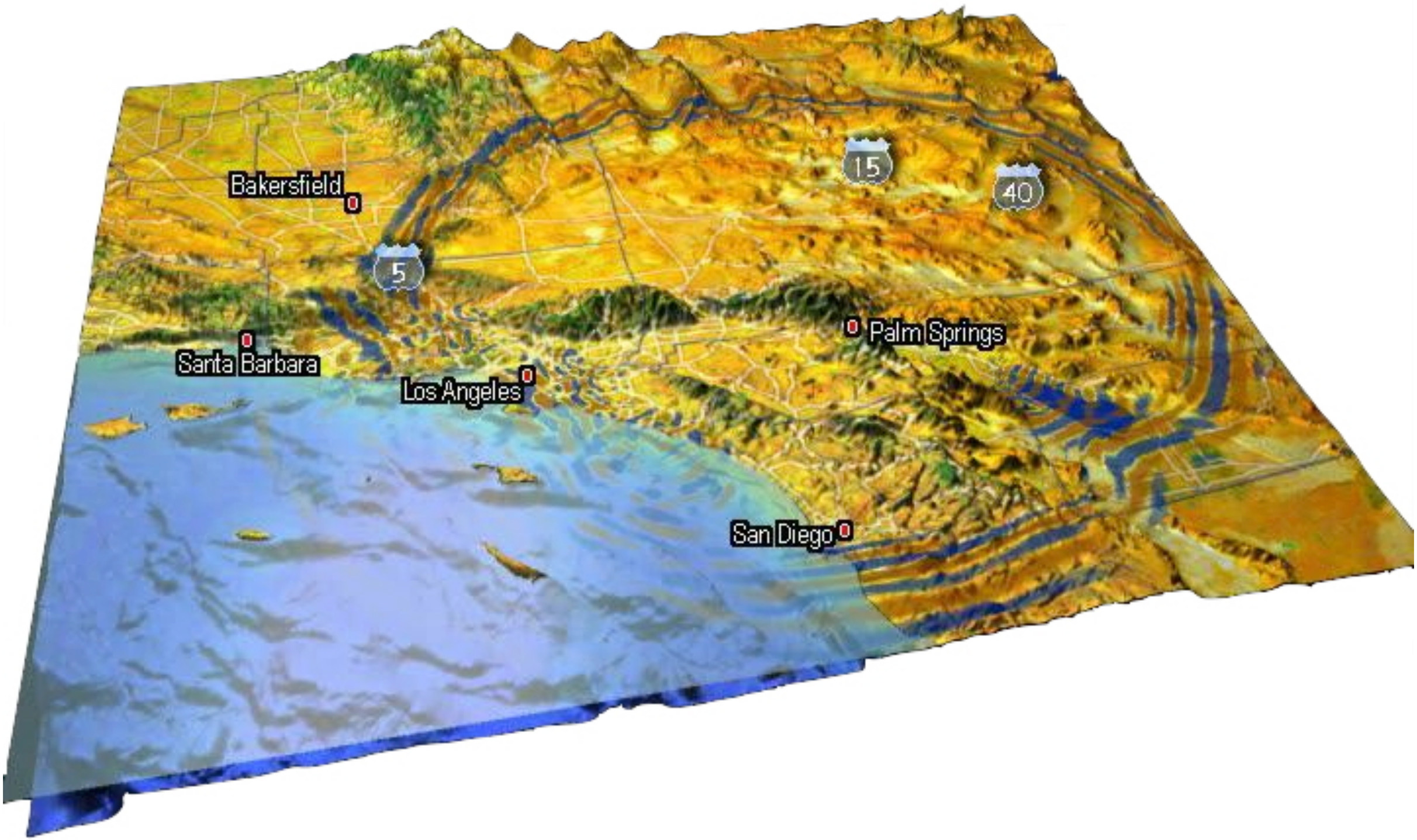
3D wave propagation

Computational Geophysics



SPECFEM3D_Cartesian

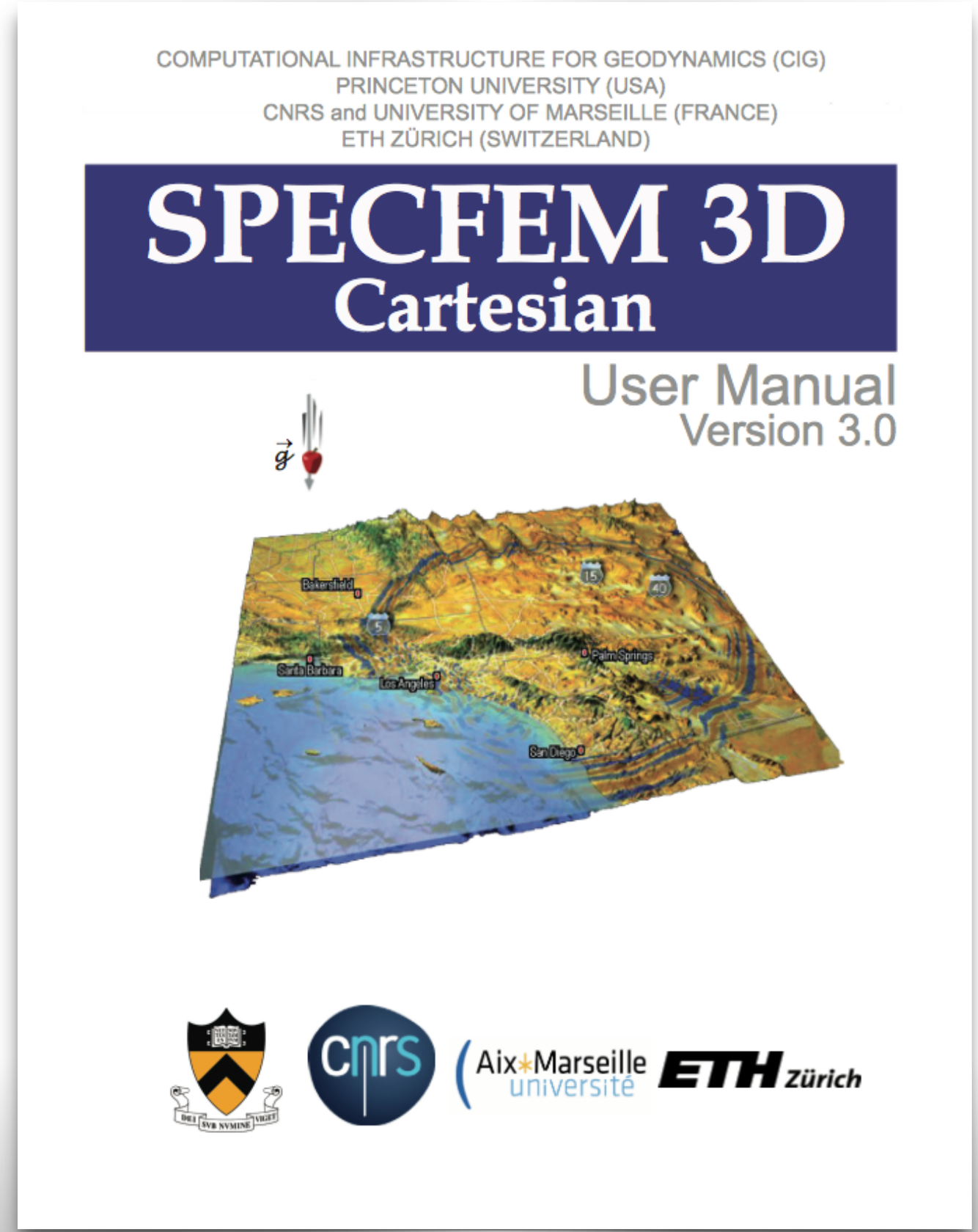


Open Source Community Software

SPECFEM3D_Cartesian

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

www.geodynamics.org



Mesh generation

meshing:

- CUBIT/Trelis
- in-house mesher xmeshfem3D

Mesh generation - CUBIT/Trelis

cubit.sandia.gov

news | divers | code | platform | journals | seismology

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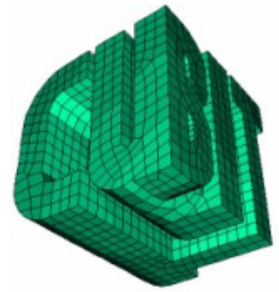
CUBIT Toolkit

- 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

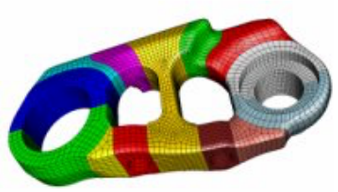
CUBIT is a full-featured software toolkit for robust generation of two- and three-dimensional finite element meshes (grids) and geometry preparation. Its main goal is to reduce the time to generate meshes, particularly large hex meshes of complicated, interlocking assemblies. It is a solid-modeler-based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

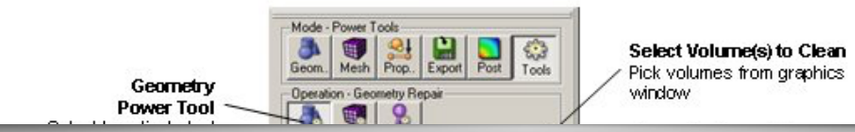
And, of course, CUBIT also includes state-of-the-art smoothing algorithms.



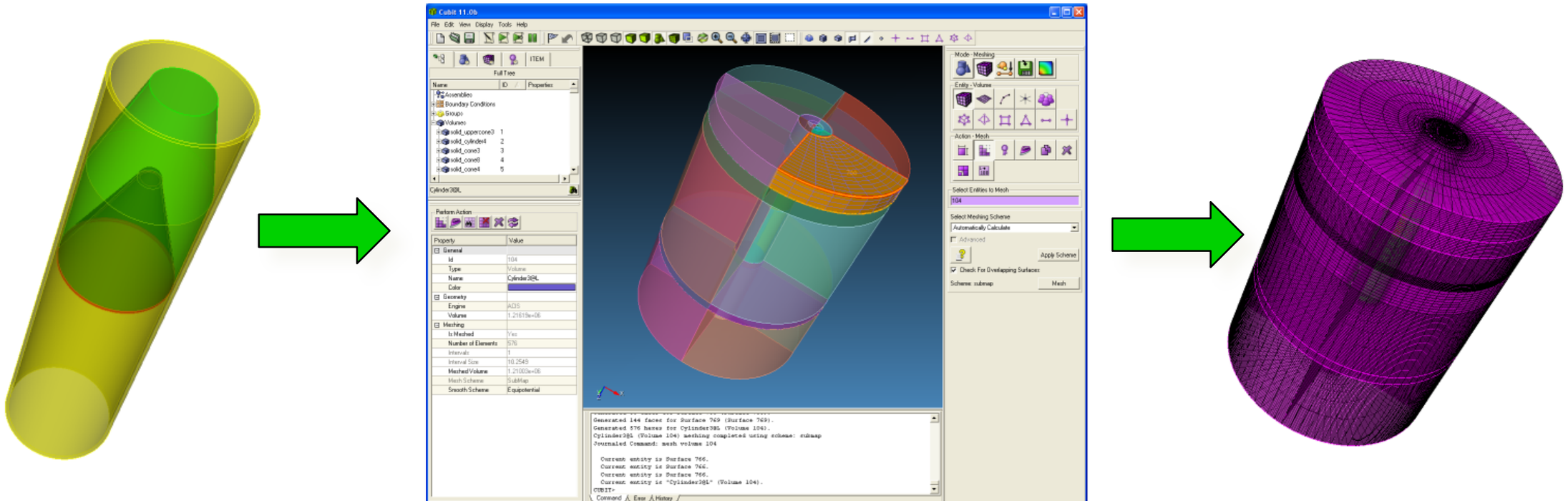
CUBIT provides an extensive suite of tools for geometry decomposition and mesh generation.

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.



Mesh generation



CAD Model

- ACIS
- STEP
- IGES
- Pro/E
- Facets
- STL
- Exodus II

CUBIT/TRELIS

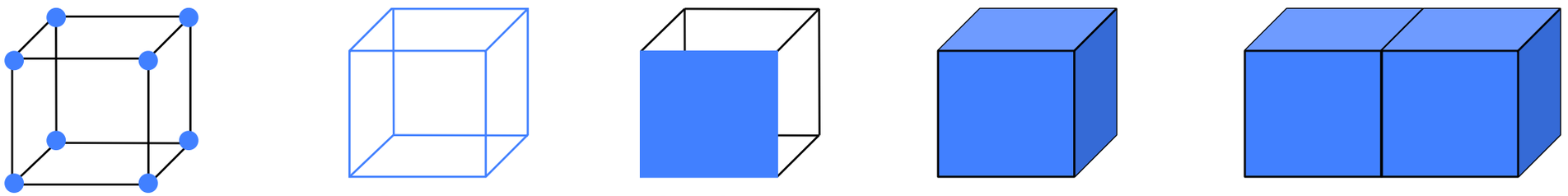
- Meshing Tools
- Geometry Creation
- Geometry Preparation
- Mesh Optimization
- Boundary Conditions
- Scripting
- Automation

Mesh

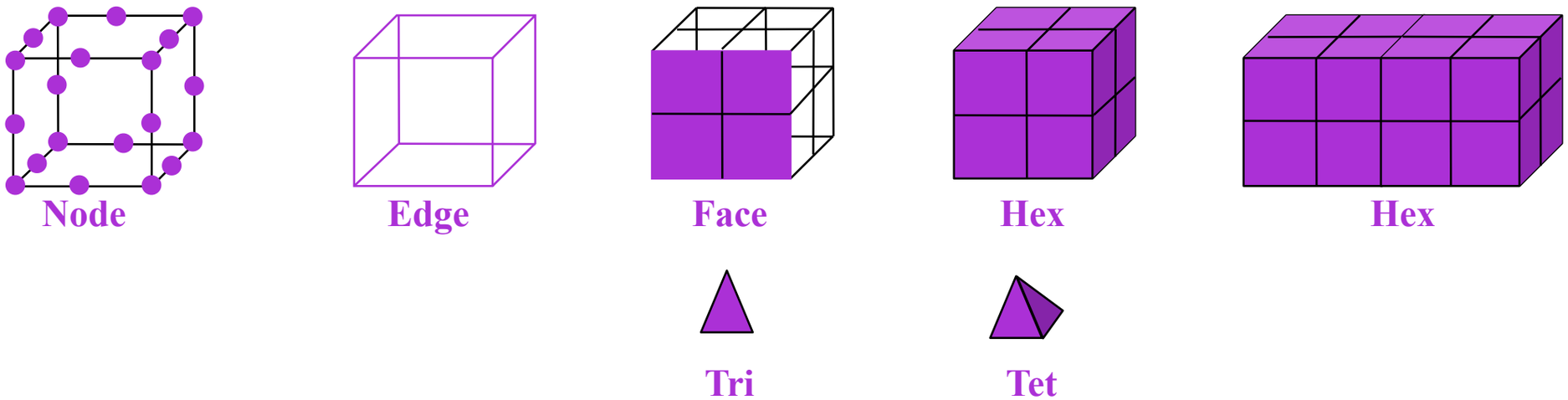
- Exodus II
- Abaqus
- IDEAS-Universal
- NASTRAN-BDF
- Patran
- LS-Dyna

Entity types

Geometry Entities in CUBIT



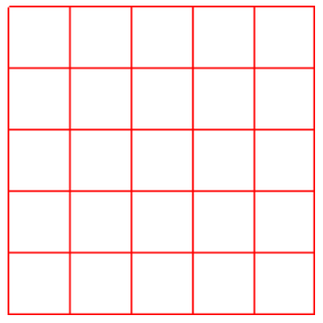
Mesh Entities, which approximate geometry entities of same dimension

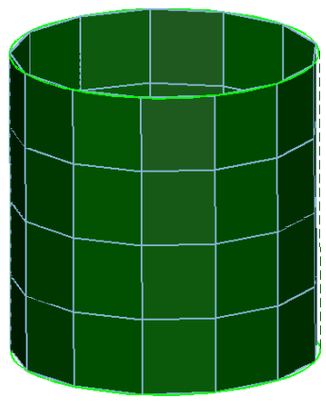


CUBIT Meshes Vertices First, Then Curves, Then Surfaces, Then Volumes (Advancing Front Paradigm)

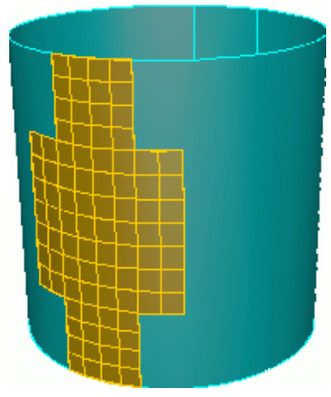
Meshing schemes

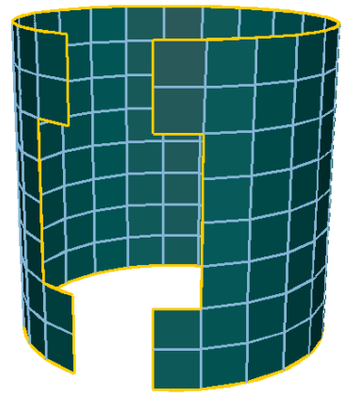
Surface Meshing



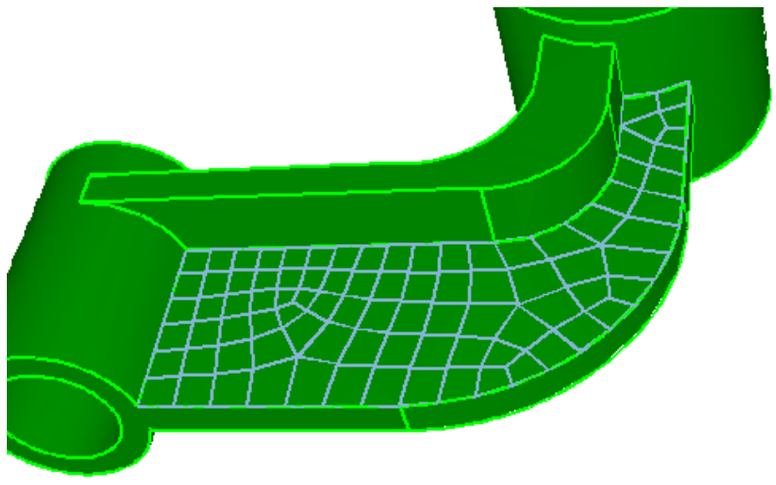


Mapped

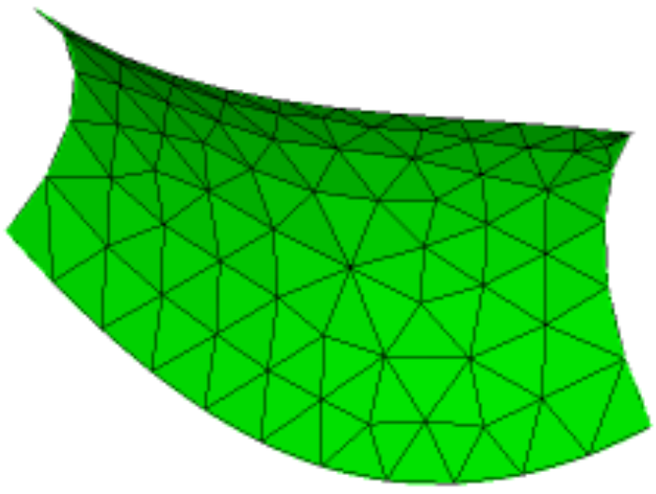




Sub-map



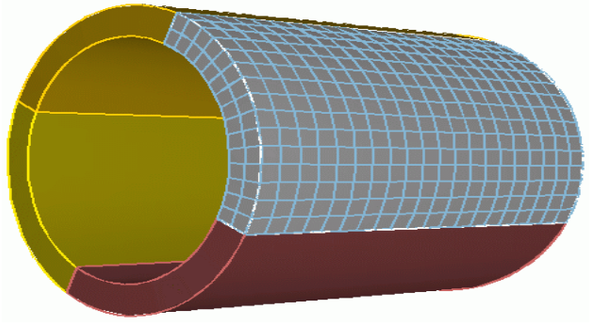
Pave



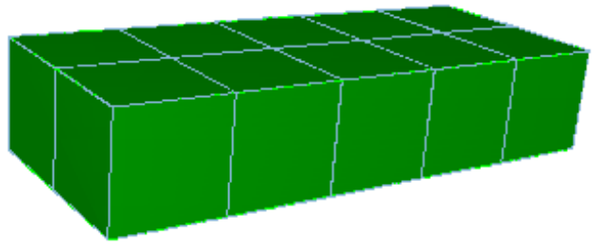
Trimesh

Meshing schemes

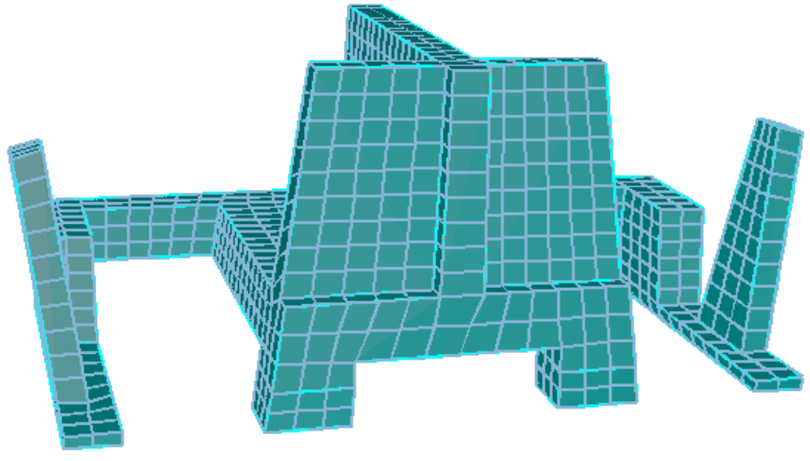
Volume Meshing



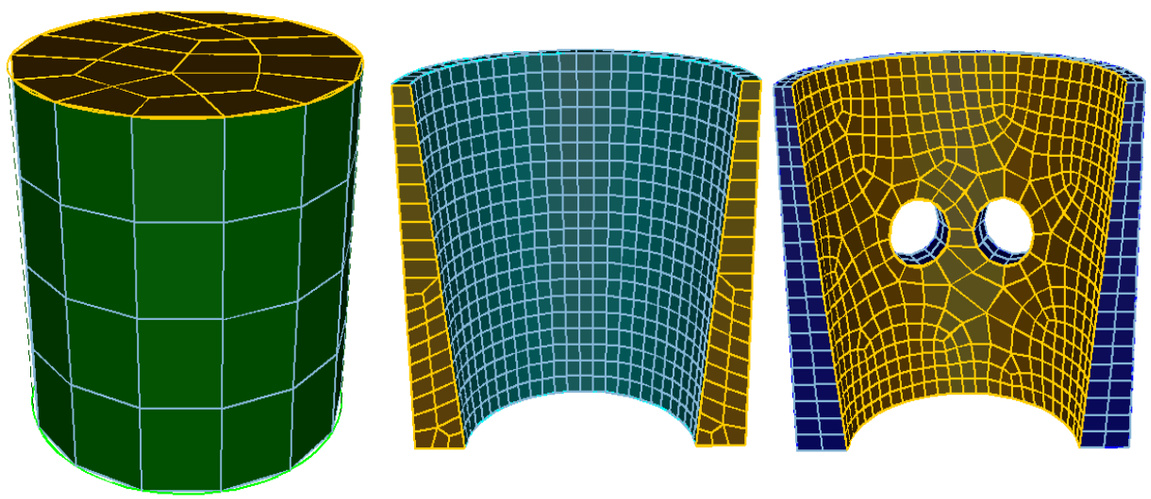
Mapped



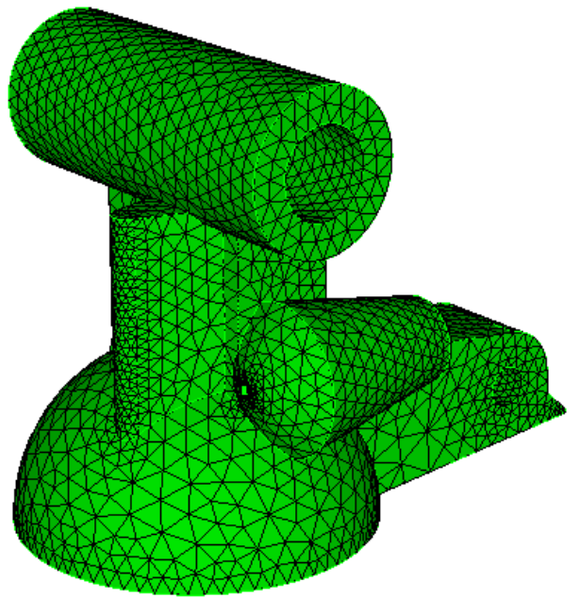
Sub-map



Sweep



Tetmesh



Cubit 13.1

File Edit View Display Tools Help

Power Tools

Current View: Full Tree

Name	ID	Proper
Assemblies		
Boundary Conditi...		
Materials		
Groups		
Volumes		
Volume 1	1	

Volume 1

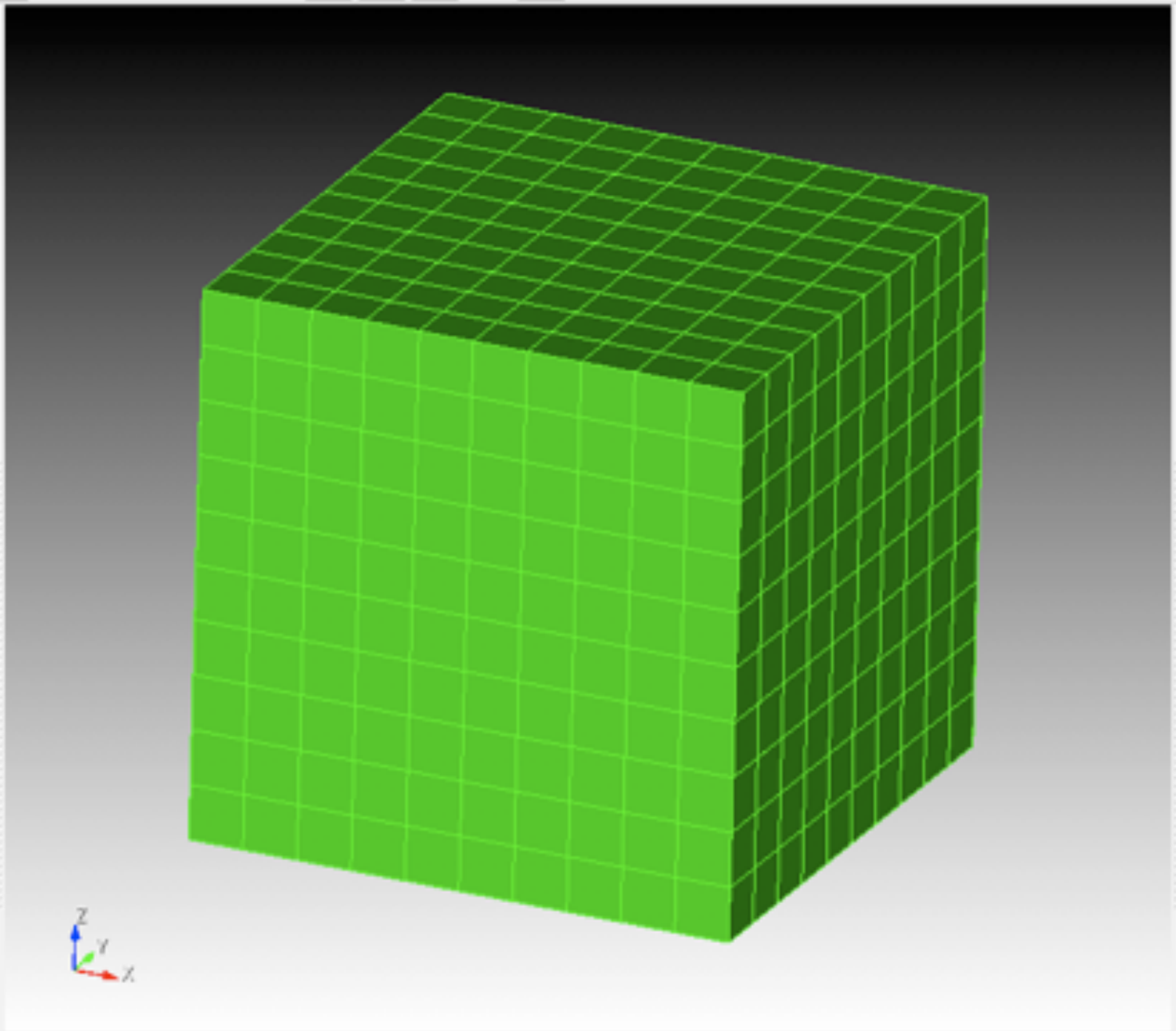
Properties Page

Perform Action

Aprepro Editor

	Variable Name	Current Value
1		

Delete



Command Panel

Mesh - Meshing

Entity - Volum

Action - Mesh

Select Entities to Mesh

1

Select Meshing Scheme

Map

Apply Scheme

Check For Overlapping Surfaces

Scheme: Default

Mesh

Command Line

```
Generated 100 faces for Surface 4 (Surface 4).
Generated 100 faces for Surface 5 (Surface 5).
Generated 100 faces for Surface 6 (Surface 6).
Generated 1000 hexes for Volume 1 (Volume 1).
Volume 1 (Volume 1) meshing completed using scheme: map

Meshing time: 0.040000
Journaled Command: mesh volume 1

CUBIT>
```

Command Error History

Working Directory: /u/dpeter/Data/programs/fortran/models/SPECFEM3D/daniel/examples/cubit_tests

Downloads

STL surfaces

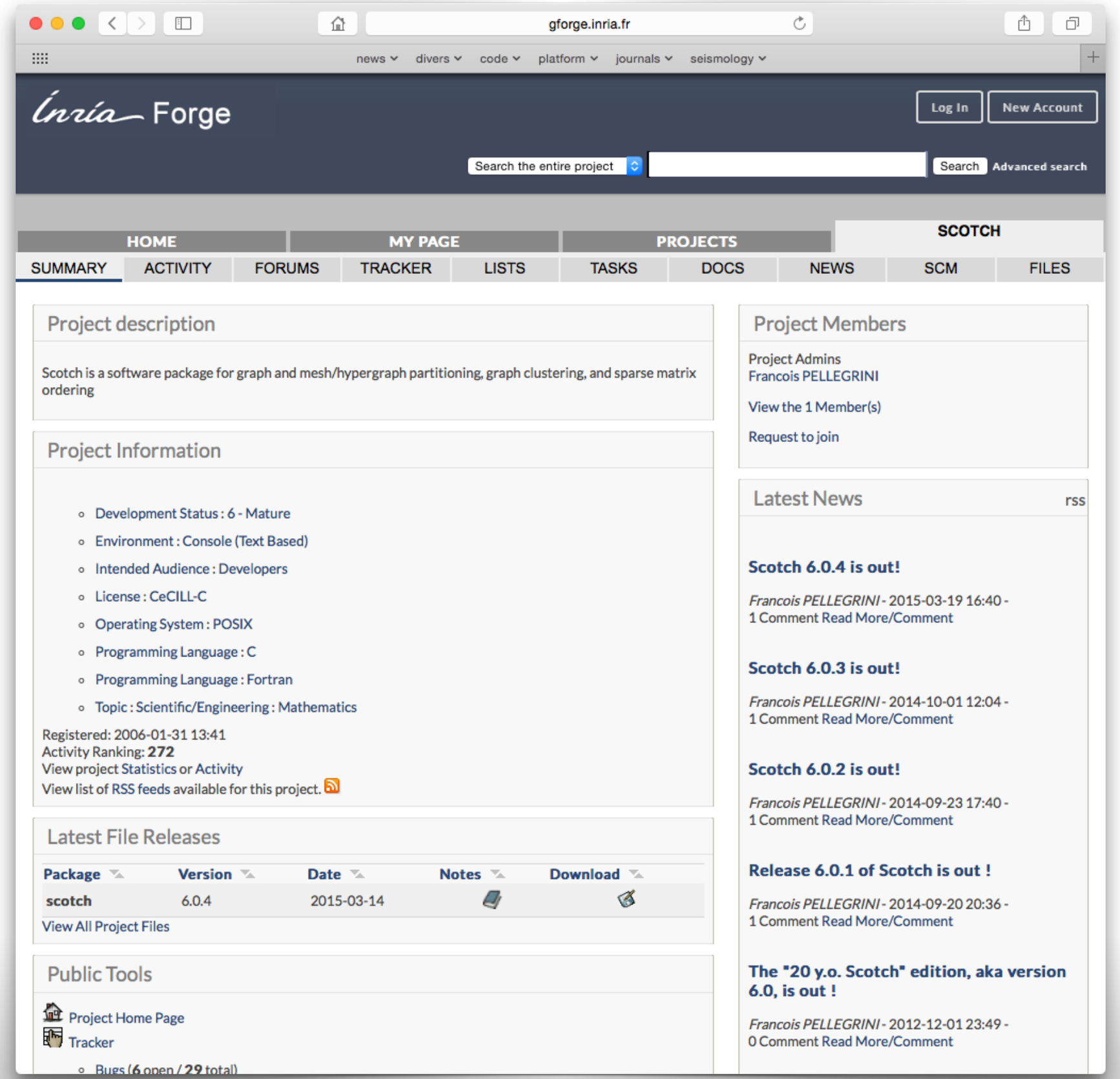
- google: STL download
- https://www.thingiverse.com
- https://grabcad.com/library
- https://nasa3d.arc.nasa.gov

Mesh generation - CUBIT/Trelis

partitioning:

- SCOTCH

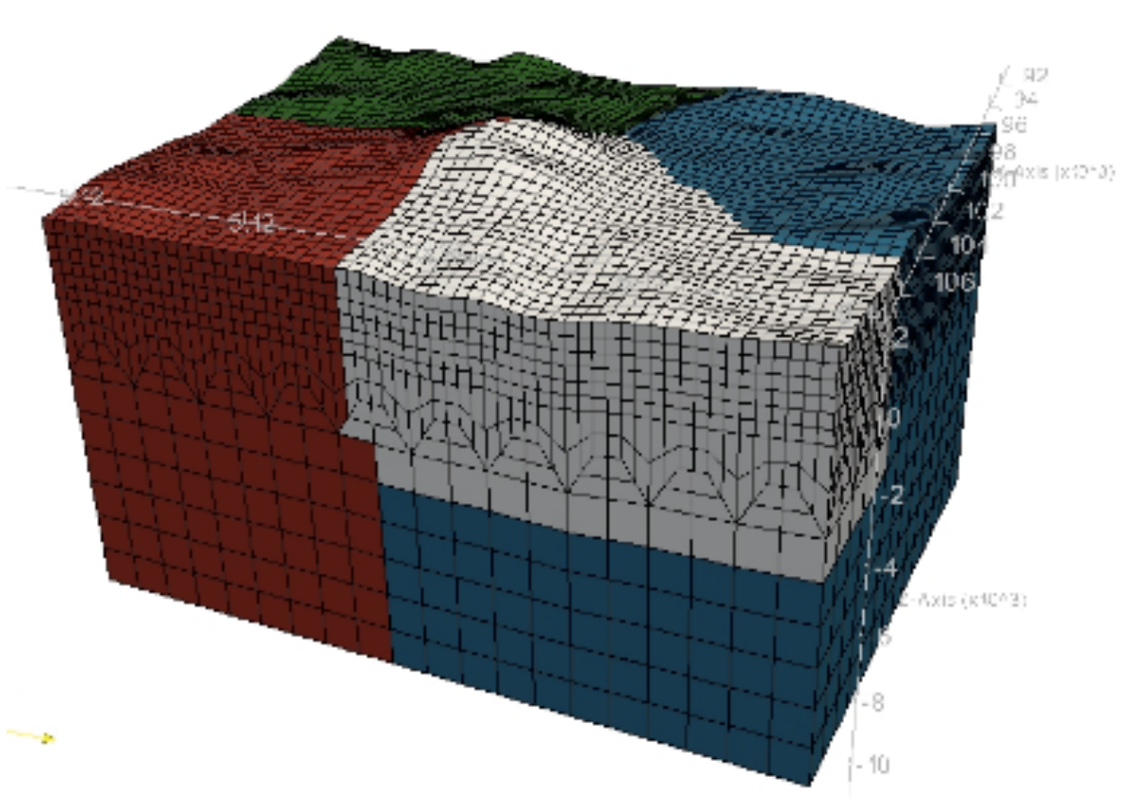
Mesh generation - CUBIT/Trelis

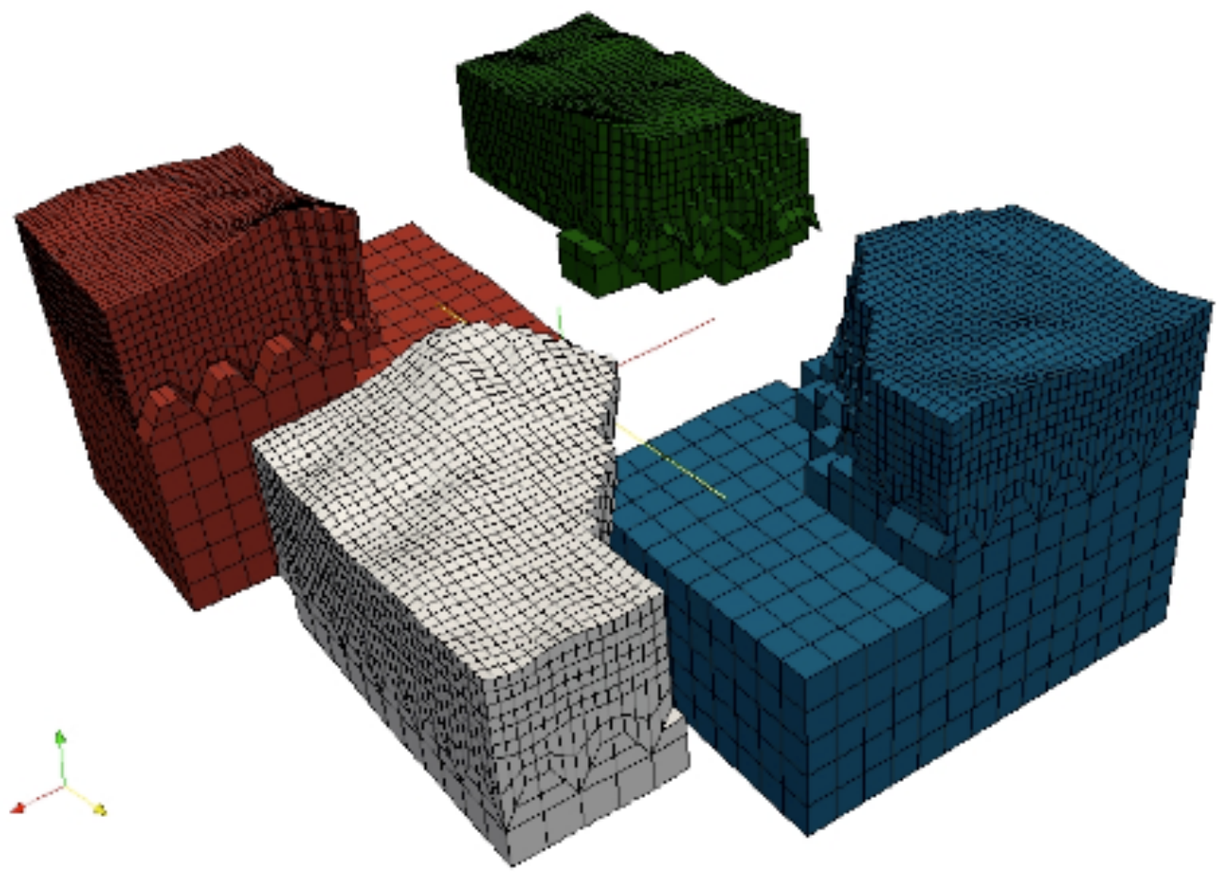


Mesh generation - CUBIT/Trelis

partitioning:

- decompose_mesh_SCOTCH/





Simulations

simulation input files:

- simulation parameters: Par_file
- source: CMTSOLUTION
- stations: STATIONS

Input

CMT solutions:

- DATA/CMTSOLUTION

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 - forward simulation

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             = 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_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

adjoint simulation

Input - adjoint/kernel simulation

Par_file

```
# 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_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.
```

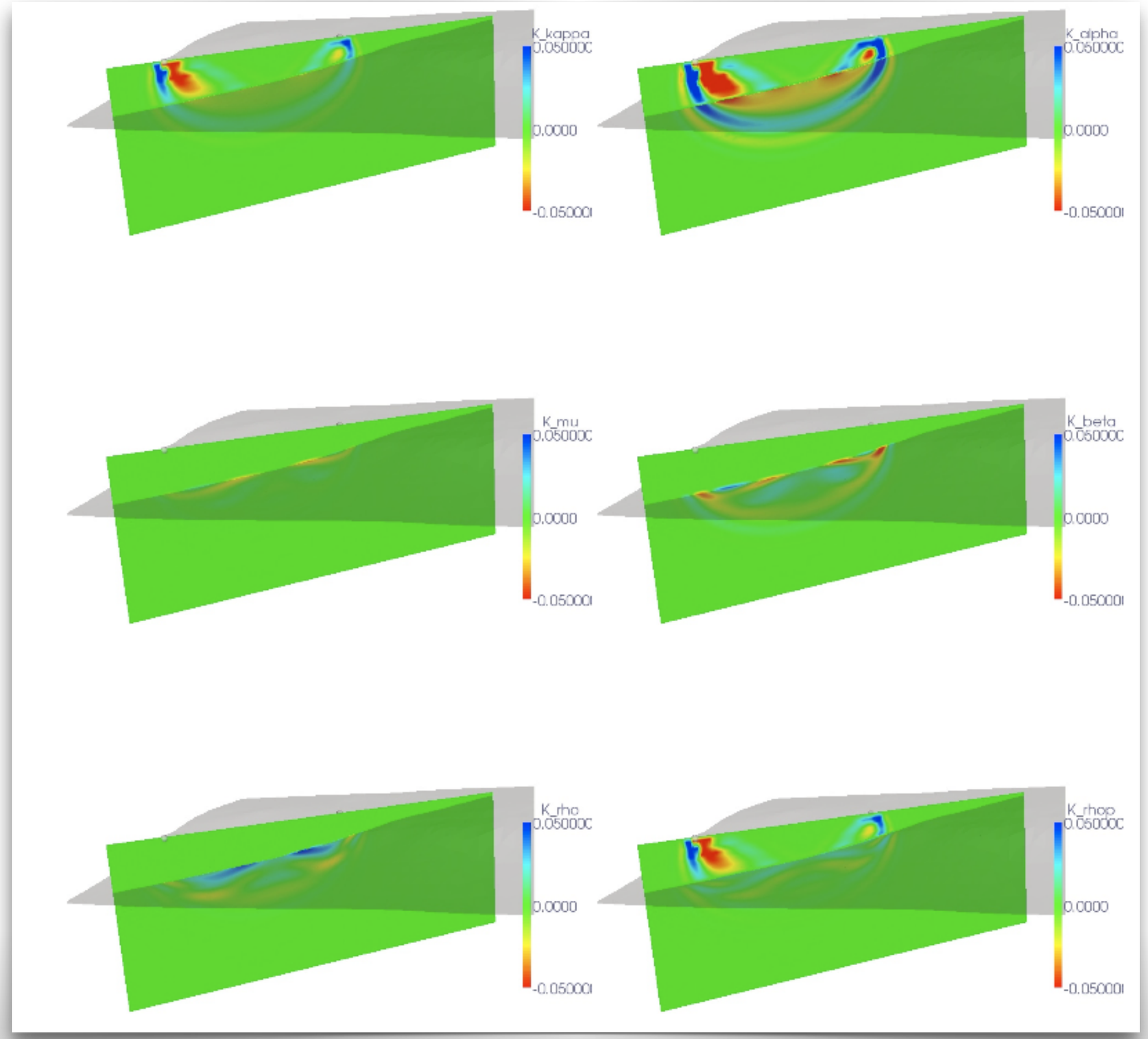
1. run: forward type=1, SAVE_FORWARD

2.run: both type=3

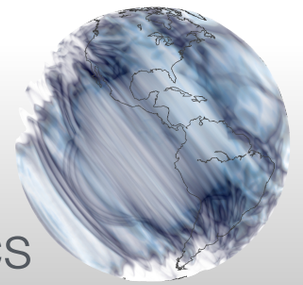
./change_simulation_type.pl -F/-b

Output

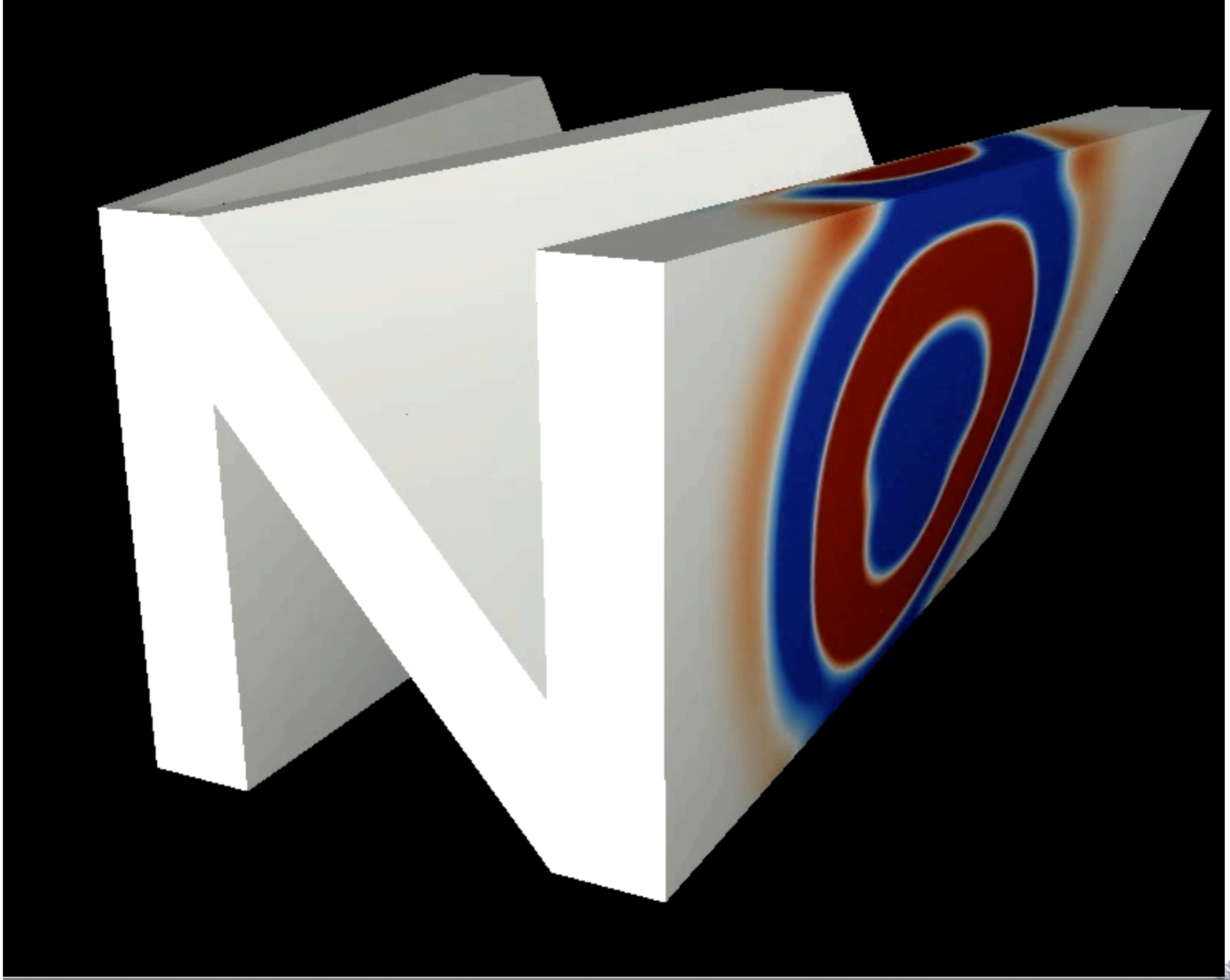
fluid-solid
sensitivity kernels



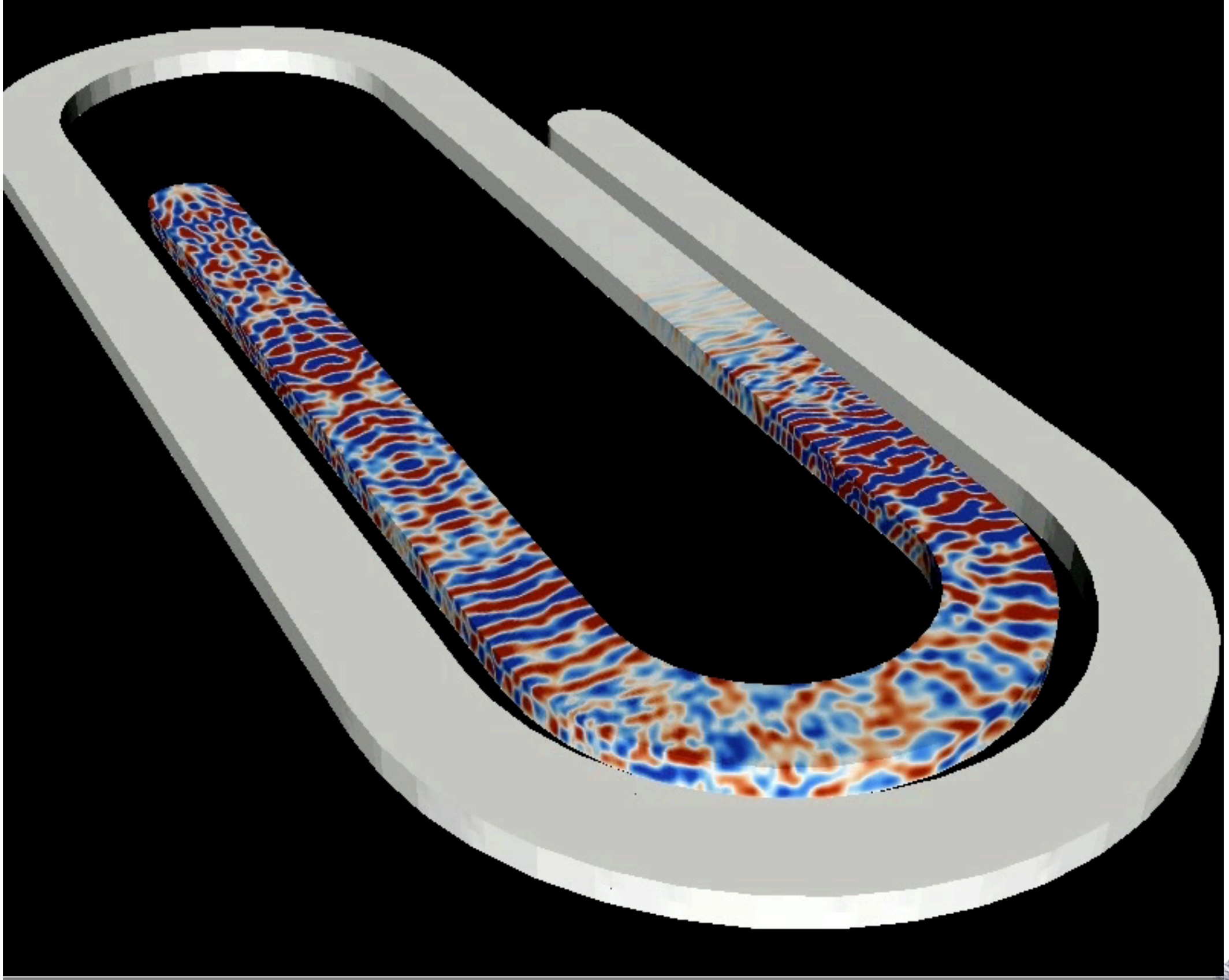
3D wave propagation student projects



Computational Geophysics

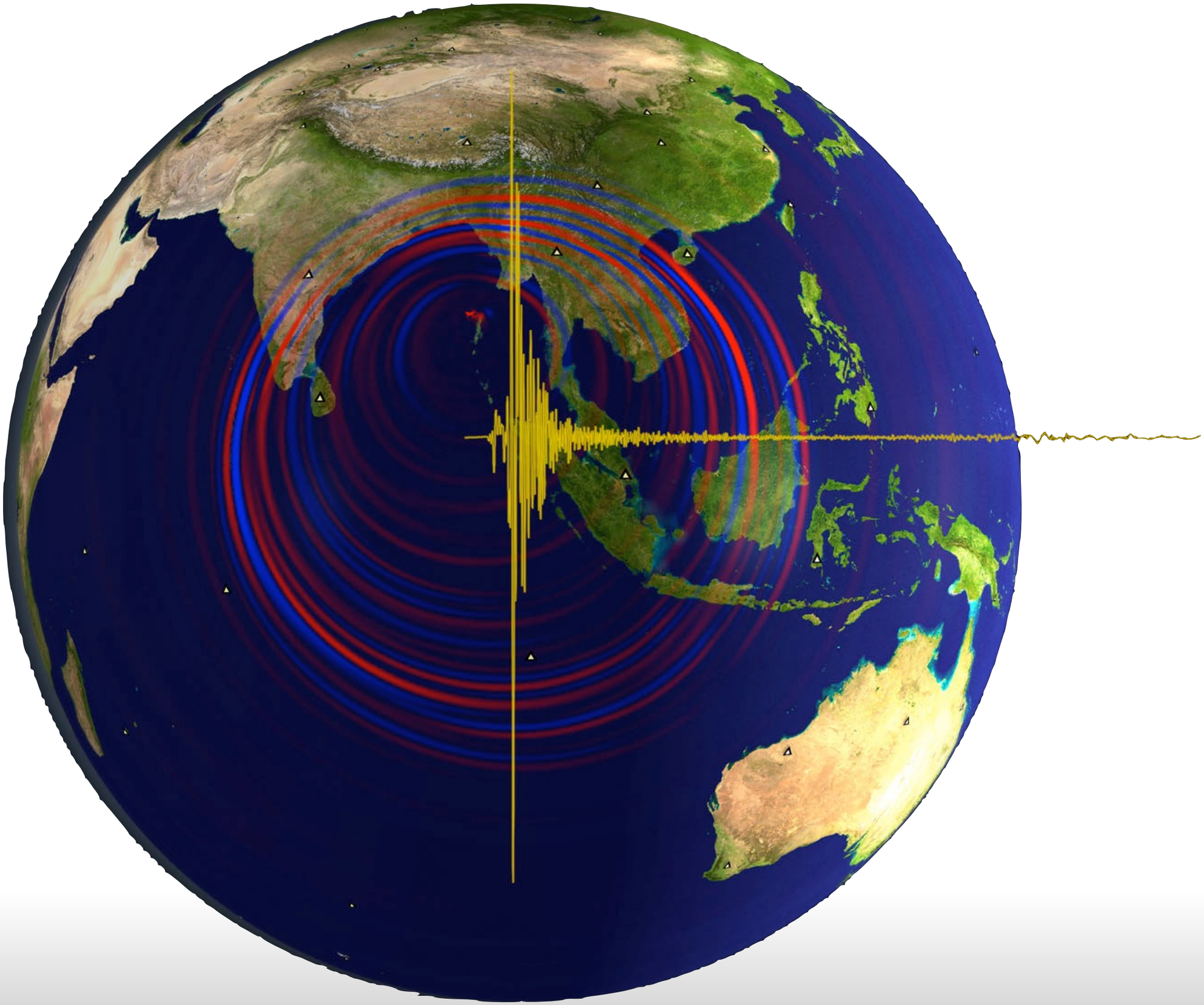


Computational Geophysics



Computational Geophysics

SPECFEM3D_GLOBE

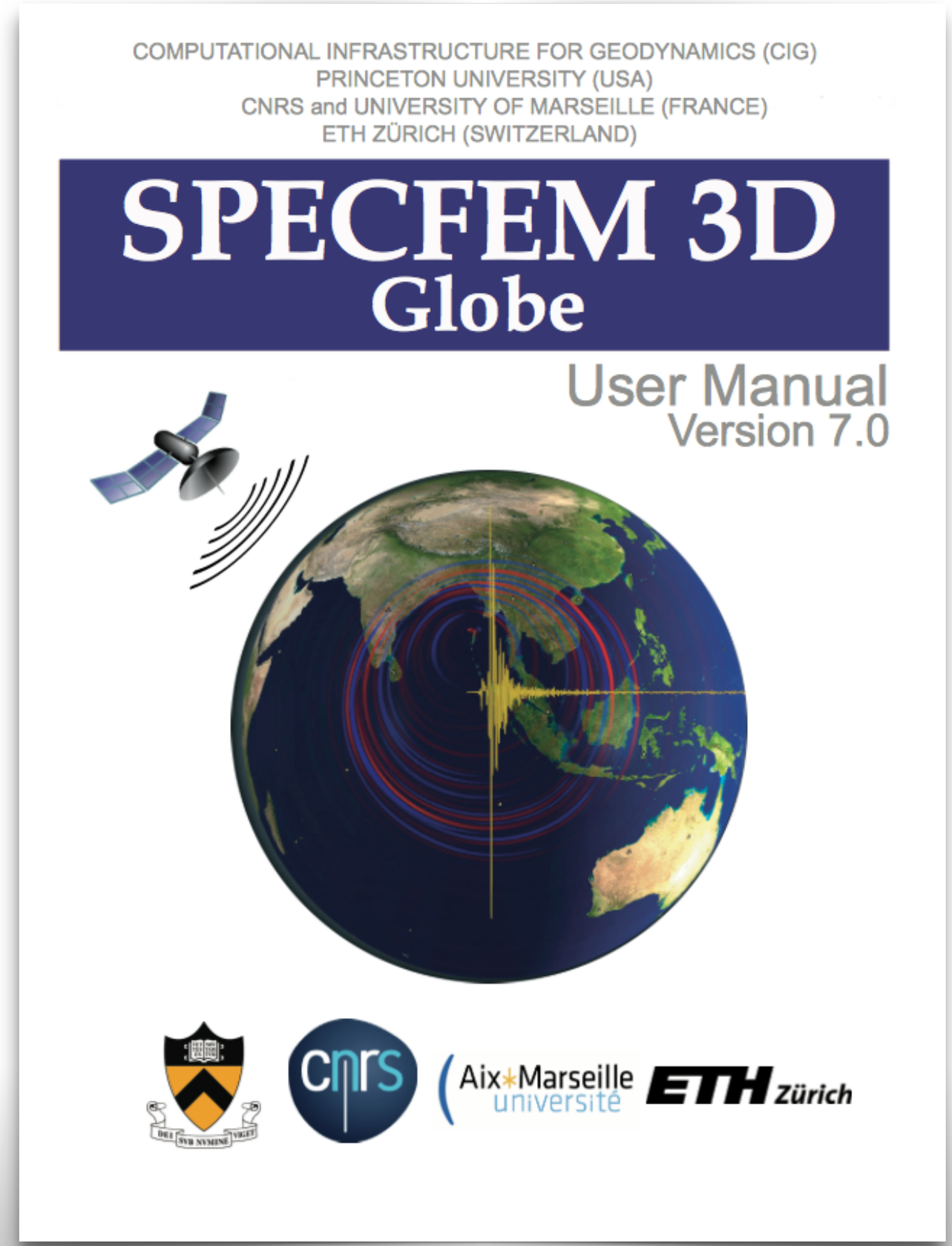


Open Source Community Software

SPECFEM3D_GLOBE

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

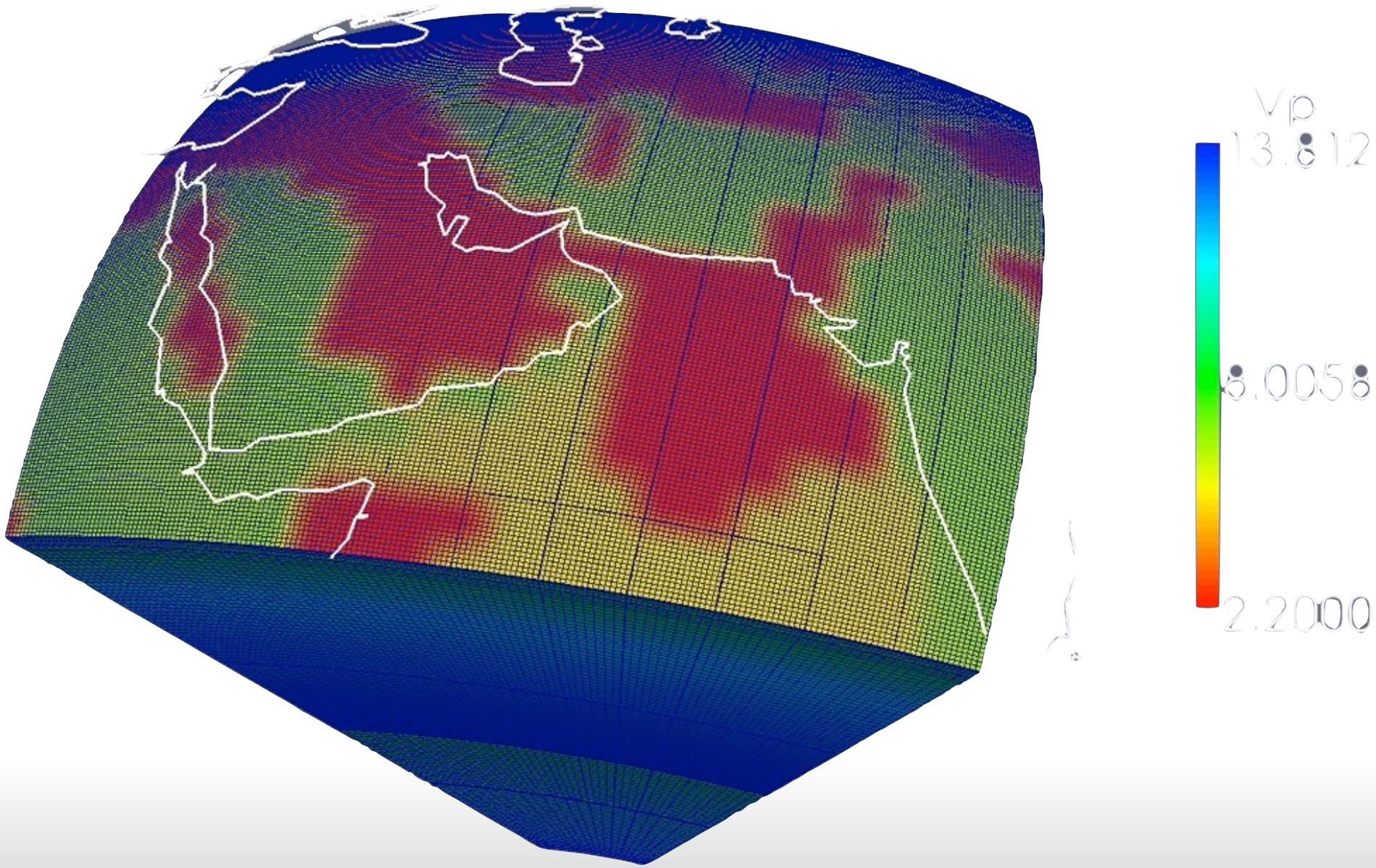
www.geodynamics.org



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:

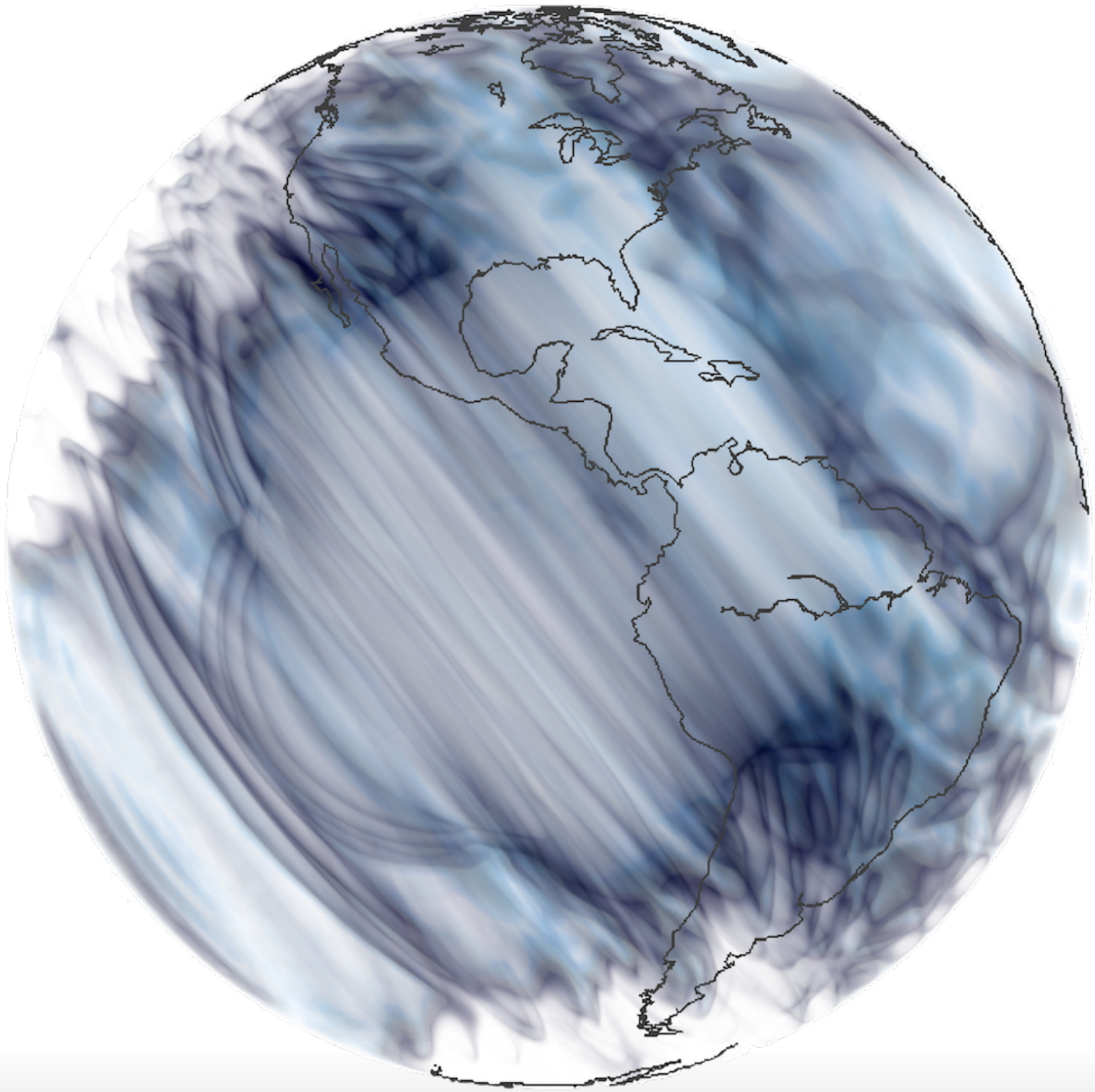
- 6-chunk run

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_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                           = 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



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