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GLOBAL EARTHQUAKE MODEL

working together to assess risk

OpenQuake-engine: general introduction

GEM Hazard Team

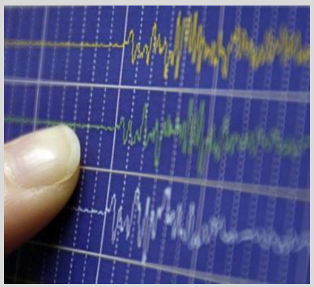
hazard@globalquakemodel.org

OPENQUAKE

October 1st-5th, 2018 – GEM OpenQuake/Hazard Tools workshop

Main characteristics of OpenQuake

A modular software for computing earthquake hazard and risk



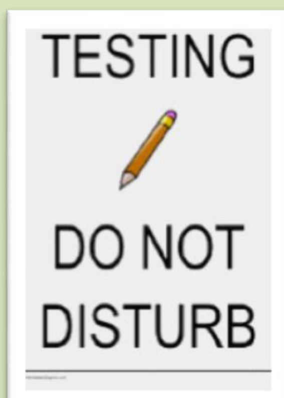
Open and Transparent software

open source

Developed in Python

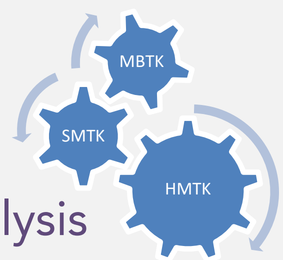
python

Extensively Tested



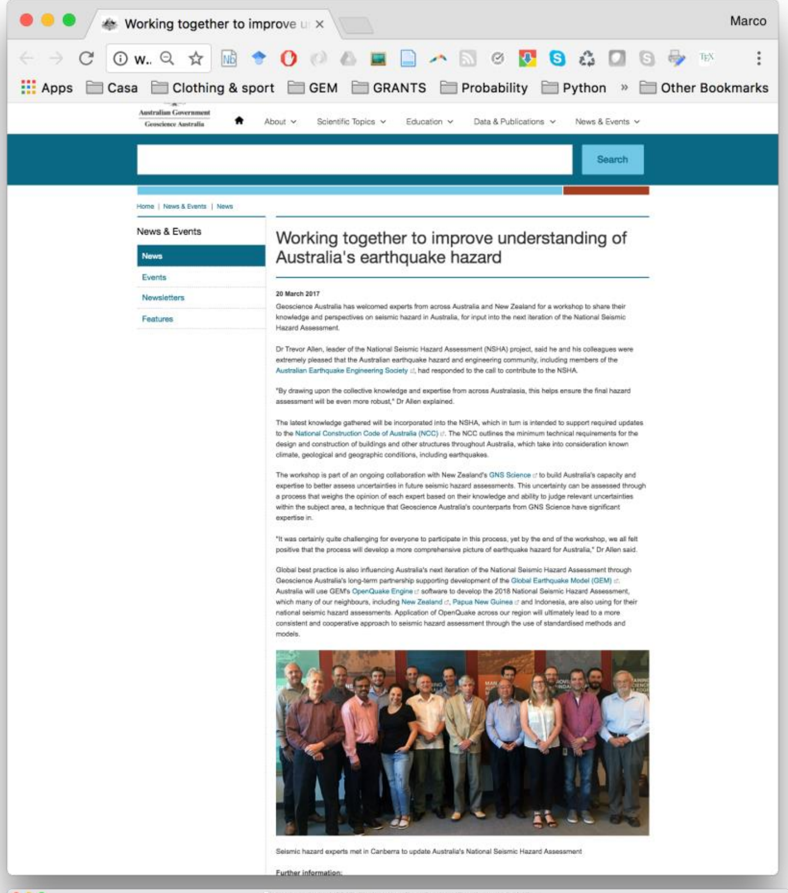
Toolkits

- Seismicity analysis
- Fault modelling
- Ground motion analysis



Use of the hazard component the OQ engine

- Regional seismic hazard analysis: SHARE, EMME, EMCA, CCARA, SARA, and SSAHARA, Southeast Asia
- National seismic hazard analysis:
  - Australia
  - Canada
  - Colombia
  - Ecuador
  - Italy
  - New Zealand
  - South Africa
  - Switzerland
  - Taiwan
  - Turkey
- Real time ground-shaking assessment: Components of OQ used in the 2.0 version of the USGS Shakemap system. EU Aristotle project.
- Site-specific studies: Nuclear earthquake hazard projects in Europe and Africa



Working together to improve understanding of Australia's earthquake hazard

20 March 2017

Geoscience Australia has welcomed experts from across Australia and New Zealand for a workshop to share their knowledge and perspectives on seismic hazard in Australia, for input into the next iteration of the National Seismic Hazard Assessment.

Dr Trevor Allen, leader of the National Seismic Hazard Assessment (NSHA) project, said he and his colleagues were extremely pleased that the Australian earthquake hazard and engineering community, including members of the Australian Earthquake Engineering Society, had responded to the call to contribute to the NSHA.

"By drawing upon the collective knowledge and expertise from across Australasia, this helps ensure the final hazard assessment will be even more robust," Dr Allen explained.

The latest knowledge gathered will be incorporated into the NSHA, which in turn is intended to support required updates to the National Construction Code of Australia (NCC). The NCC outlines the minimum technical requirements for the design and construction of buildings and other structures throughout Australia, which take into consideration known climate, geological and geographic conditions, including earthquakes.

The workshop is part of an ongoing collaboration with New Zealand's GNS Science to build Australia's capacity and expertise to better assess uncertainties in future seismic hazard assessments. This uncertainty can be assessed through a process that weighs the opinion of each expert based on their knowledge and ability to judge relevant uncertainties within the subject area, a technique that Geoscience Australia's counterparts from GNS Science have significant expertise in.

"It was certainly quite challenging for everyone to participate in this process, yet by the end of the workshop, we all felt positive that the process will develop a more comprehensive picture of earthquake hazard for Australia," Dr Allen said.

Global best practice is also influencing Australia's next iteration of the National Seismic Hazard Assessment through Geoscience Australia's long-term partnership supporting development of the Global Earthquake Model (GEM). Australia will use GEM's OpenQuake Engine software to develop the 2018 National Seismic Hazard Assessment, which many of our neighbours, including New Zealand, Papua New Guinea and Indonesia, are also using for their national seismic hazard assessments. Application of OpenQuake across our region will ultimately lead to a more consistent and cooperative approach to seismic hazard assessment through the use of standardised methods and models.

Seismic hazard experts met in Canberra to update Australia's National Seismic Hazard Assessment

Further information:

Horspool_et_al-2017-Challenges_OpenQuake_NZ.pdf (page 1 of 12)

16th World Conference on Earthquake, 16WCEE 2017
Santiago Chile, January 9th to 13th 2017
Paper N° 2987
Registration Code: S-L1463098482

CHALLENGES AND OPPORTUNITIES IN DEVELOPING A NATIONAL SEISMIC HAZARD AND RISK MODEL WITH OPENQUAKE FOR NEW ZEALAND

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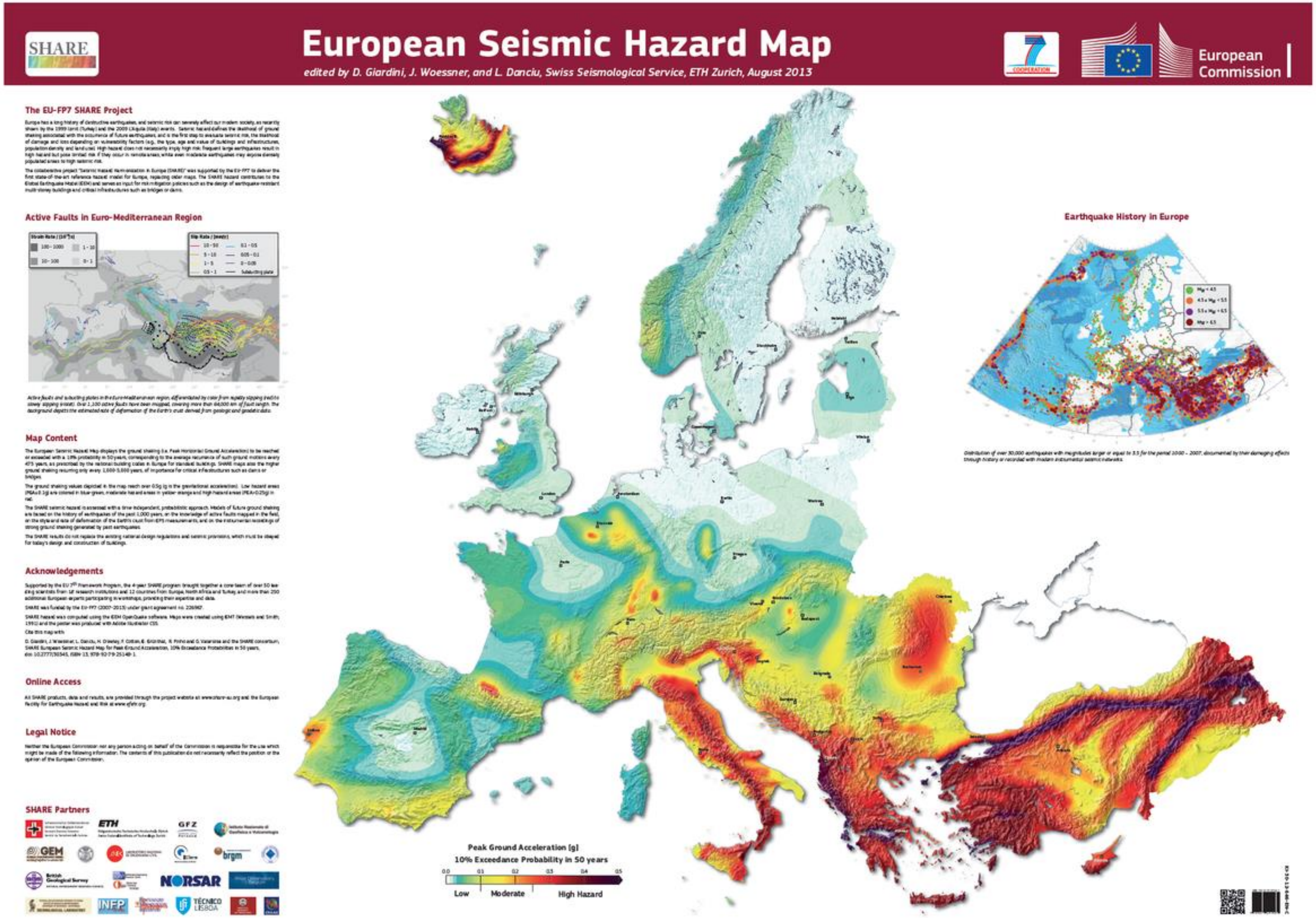
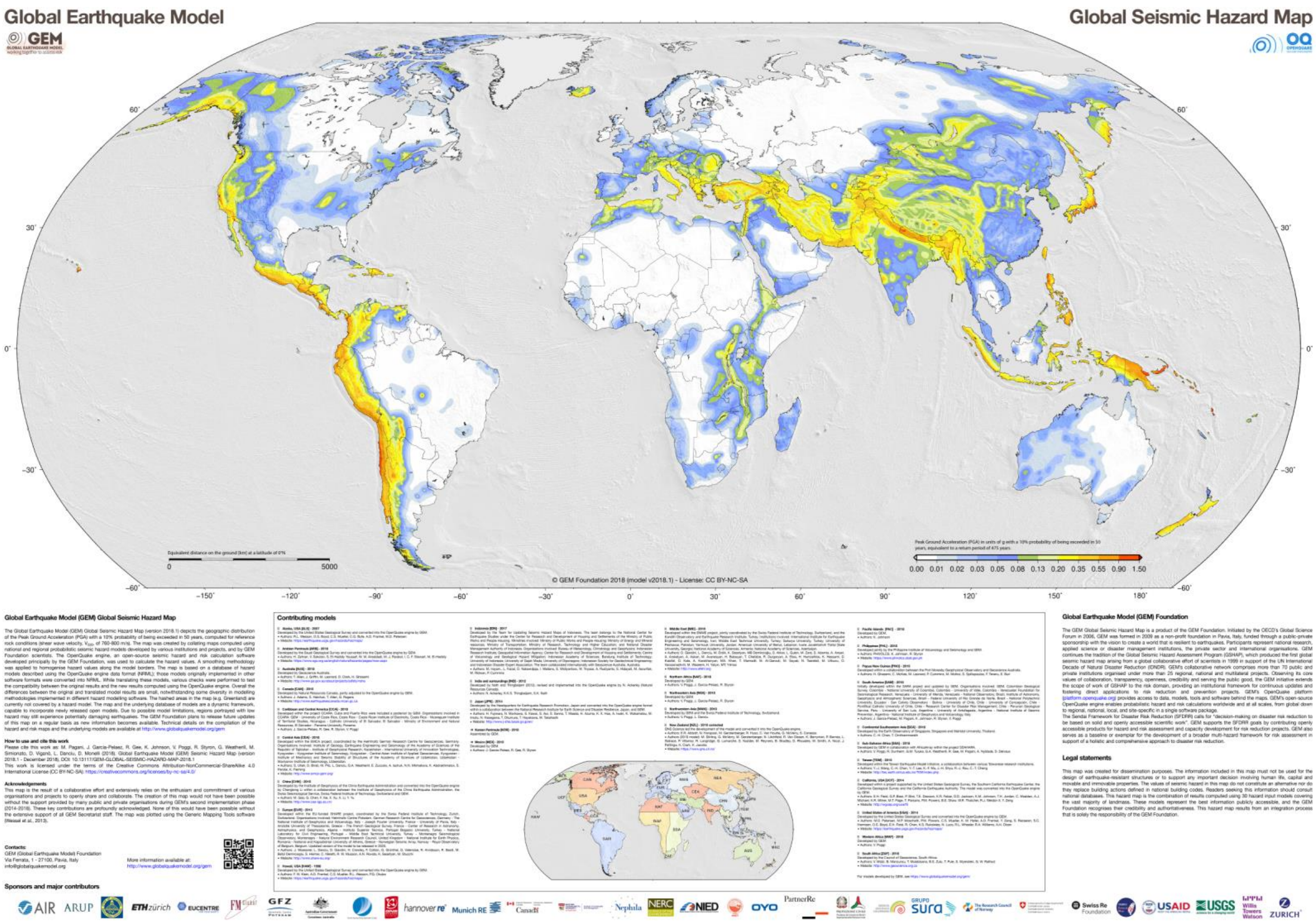
2013 SHARE Hazard Map

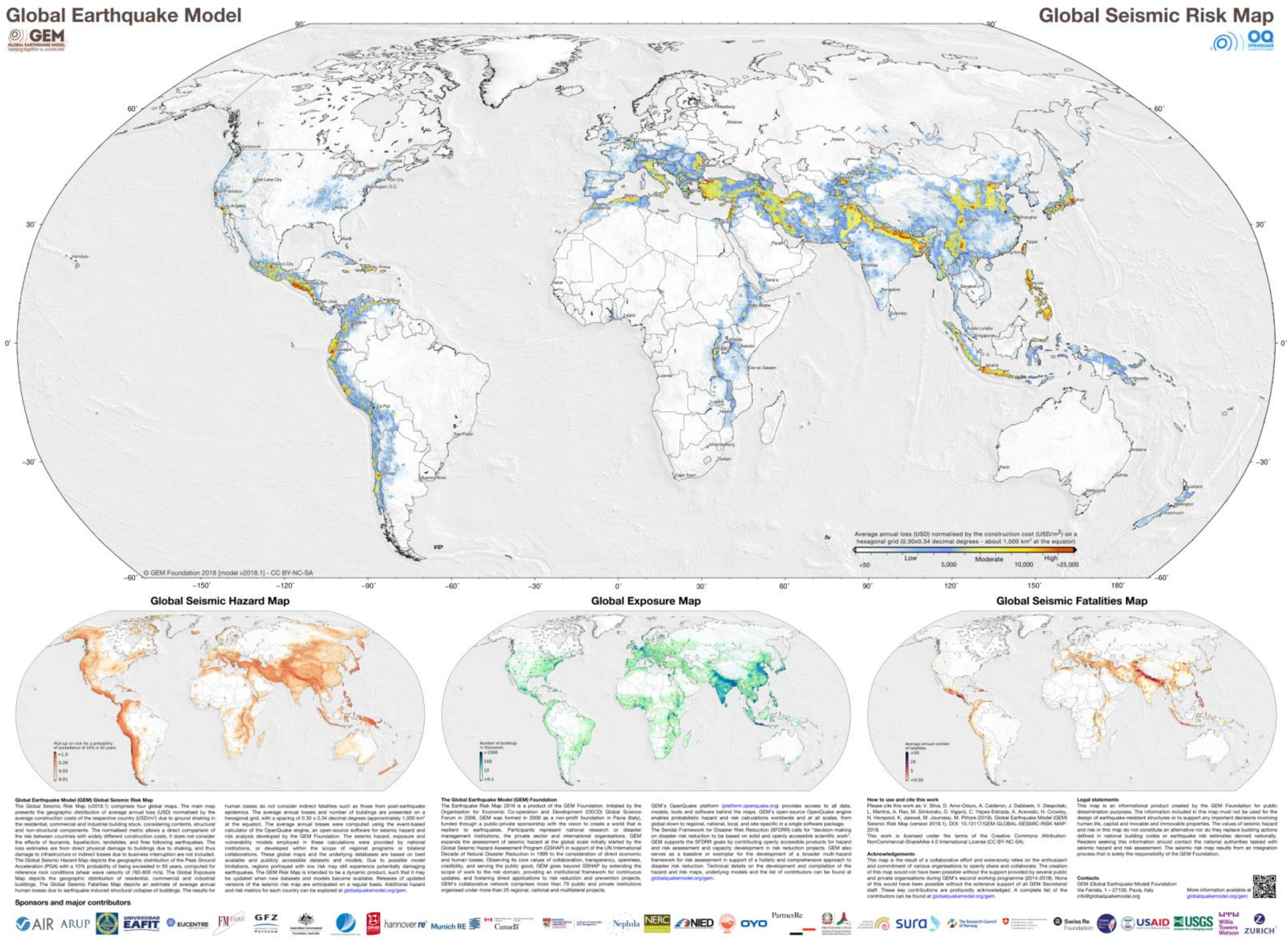


2018 GEM Global Hazard and Risk Maps



GLOBAL QUAKE MODEL .ORG

2018 GEM Global Hazard and Risk Maps



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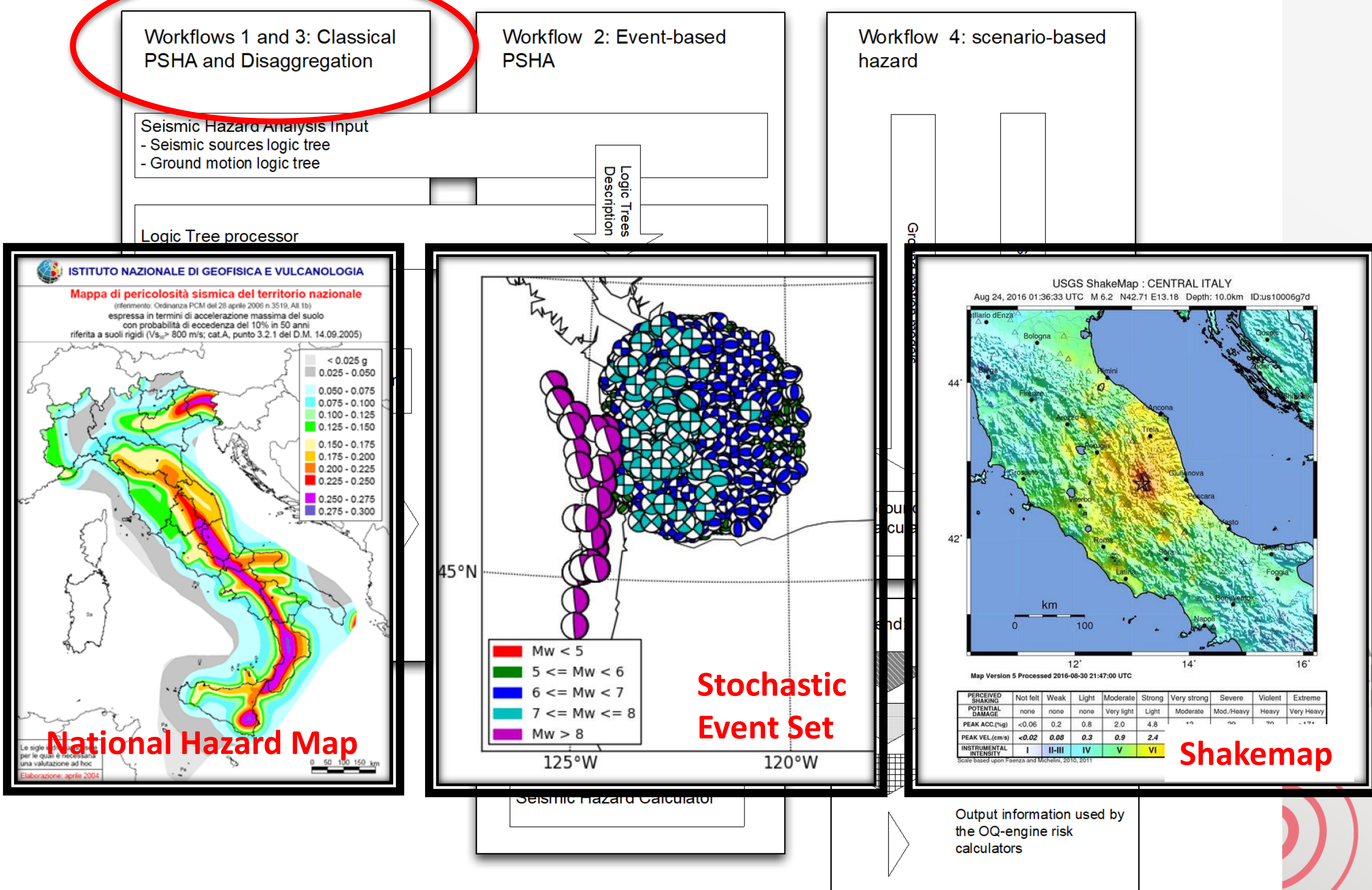
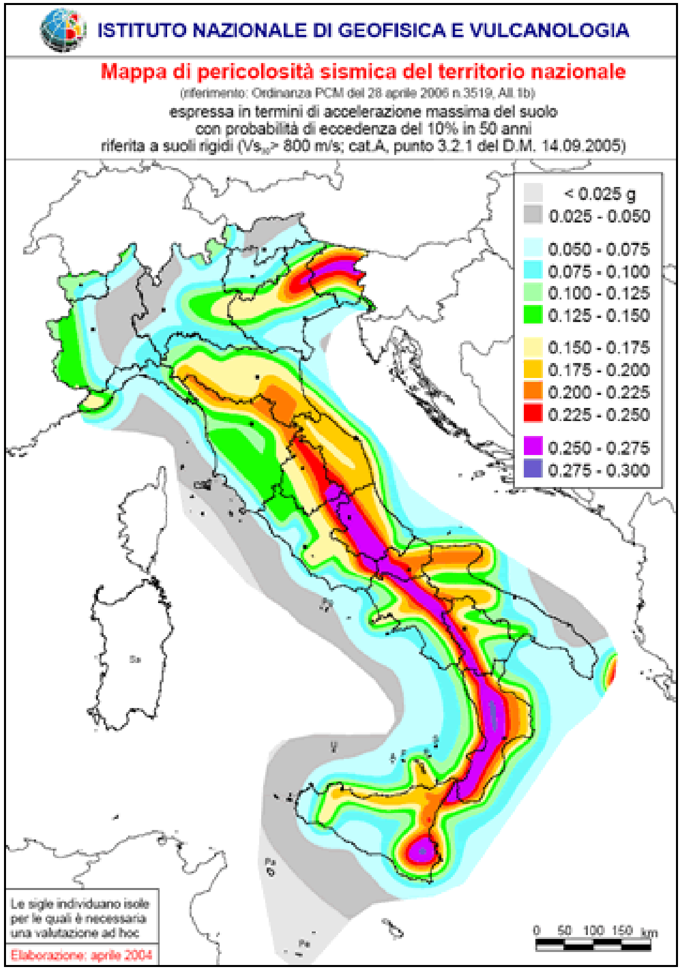
OpenQuake Calculation Workflows



Classical PSHA

- Probabilistic: All possible earthquake scenarios of engineering relevance for the investigated site are considered in the analysis

- Approach used for regional/national-scale hazard assessment, as well as in site-specific studies.



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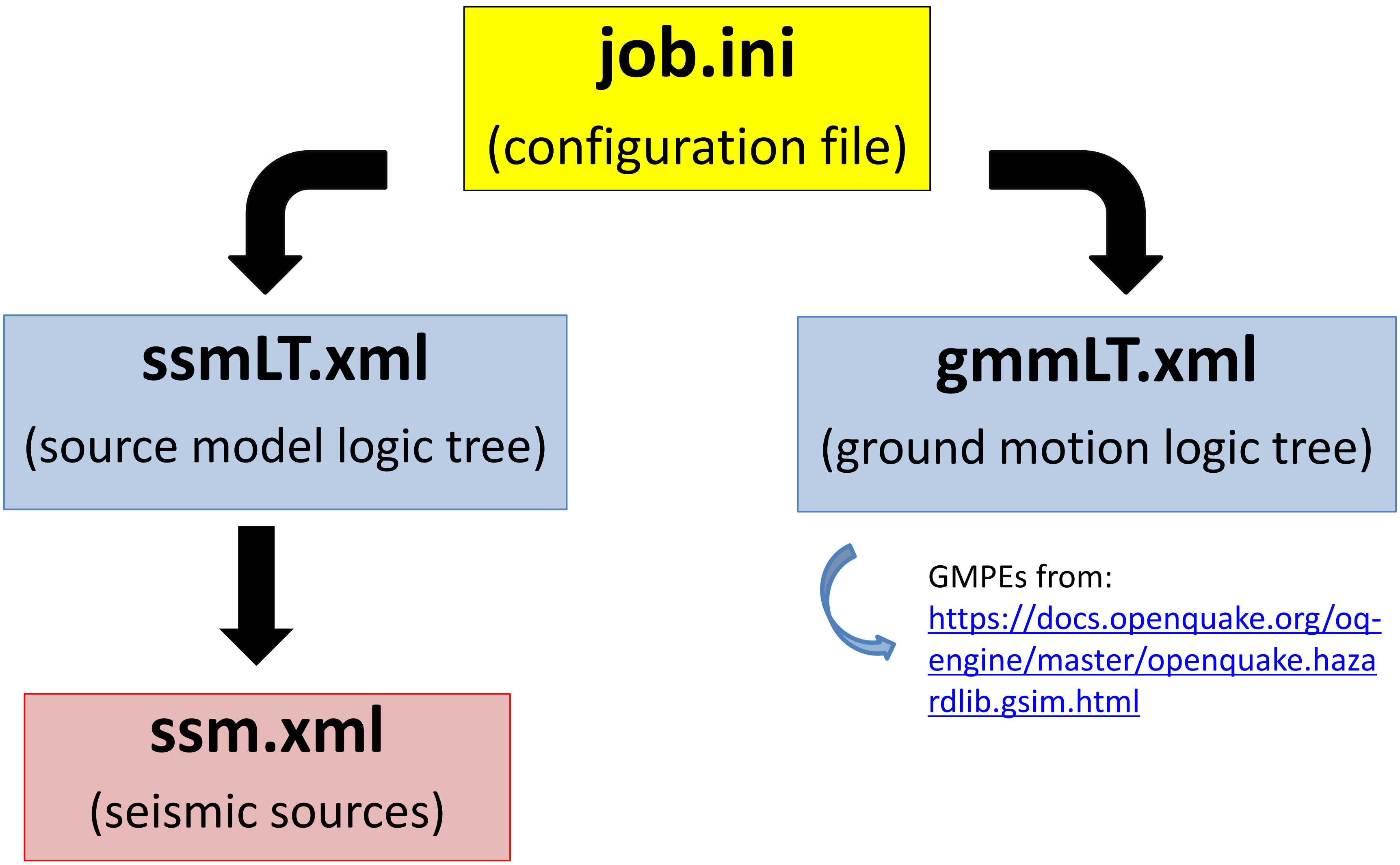
OpenQuake input file format

- Natural hazard's Risk Markup Language (NRML) format
- **Files end in ".xml"**
- A markup language is a set of markup tags
- The tags **(shown in green)** describe document content

```
<simpleFaultSource tectonicRegion="Active Shallow Crust" id="1234" name="ITCS044">
        <simpleFaultGeometry>
        …
        <magScaleRel>WC1994</magScaleRel>
        <ruptAspectRatio>1.0</ruptAspectRatio>
        <truncGutenbergRichterMFD minMag="5.0“ maxMag="6.5" bValue="1.31”aValue="4.28" />
        <rake>90.0</rake>
</simpleFaultSource>
```

Hazard Calculation Input files



Note: files can use any name; these are the standard names (keeping extensions)

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OpenQuake-engine: seismic source definition and rupture calculation

GEM Hazard Team

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OQ OPENQUAKE

October 1st-5th, 2018 – GEM OpenQuake/Hazard Tools workshop

Hazard Calculation Input files

job.ini

(configuration file)

ssmLT.xml

(source model logic tree)

gmmLT.xml

(ground motion logic tree)

GMPEs from:
https://github.com/gem/oq-engine/tree/master/openquake/hazardlib/gsim

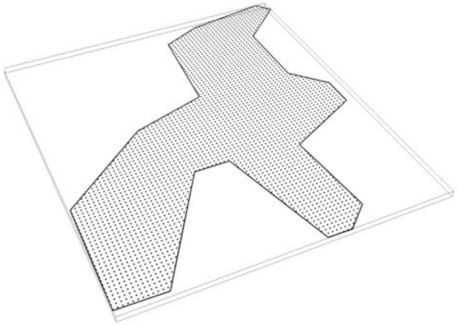
ssm.xml

(seismic sources)

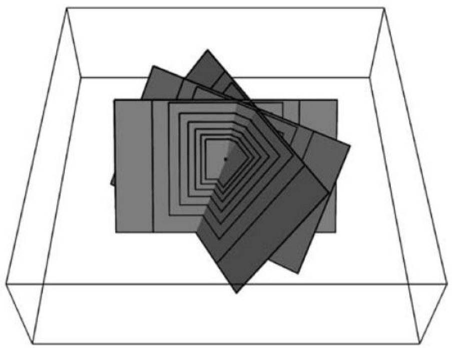
Note: files can use any name; these are the standard names (keeping extensions)

Seismic sources: essential parameters

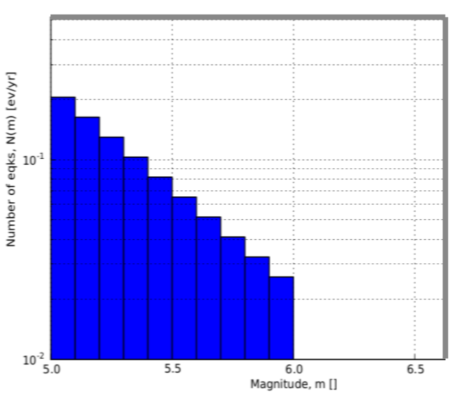
1. Source geometry
   – Typology, location



2. Magnitude-scaling relationship:
   – Required for finite (3D) rupture modelling



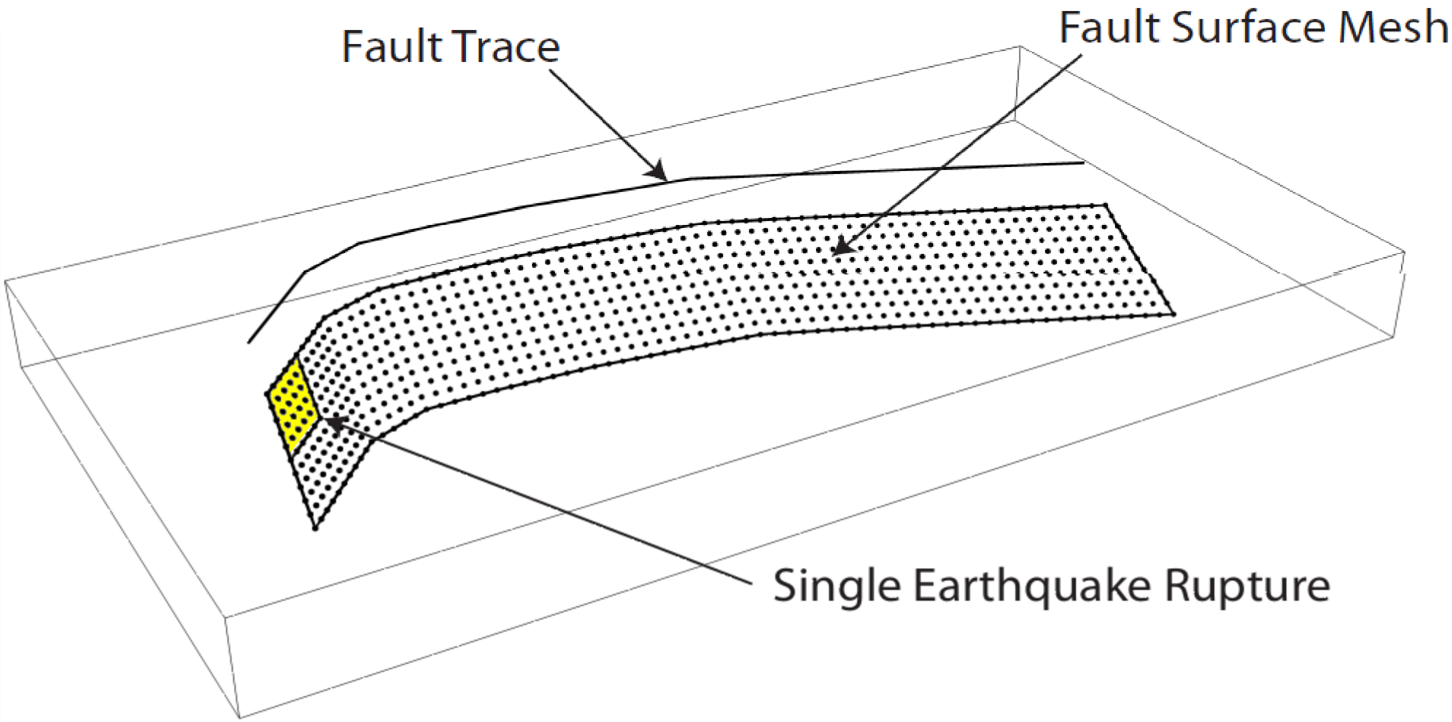
3. Magnitude-frequency distribution:
   – Frequency of occurrence of the earthquakes generated by a specific source



An important distinction

- Seismic "**source**" vs "**rupture**"
- A seismic source can host **many possible ruptures**

Seismic Source



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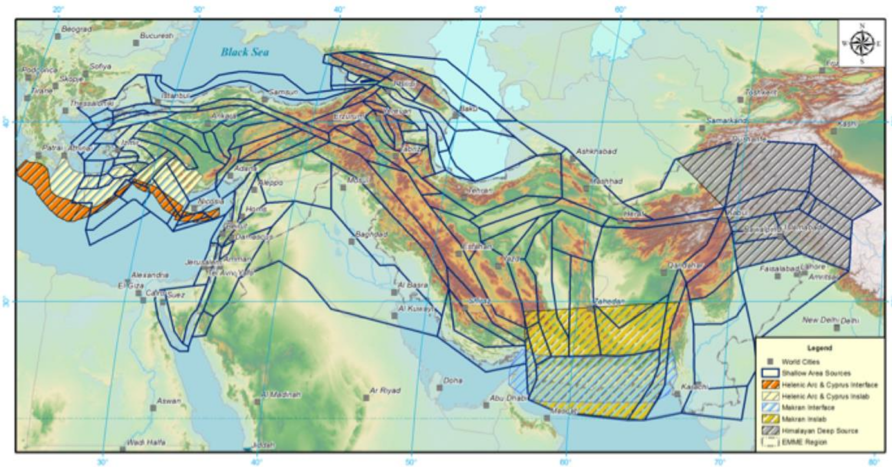
Seismic sources: Source Typologies in OpenQuake

Modelling **off-fault** seismicity

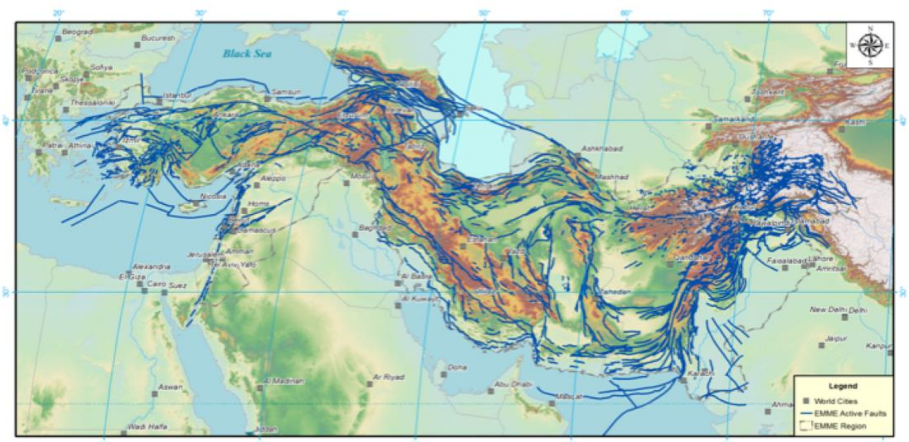
- Point Source
- Area Source



EMME Area Source Model

Modelling **on-fault** seismicity

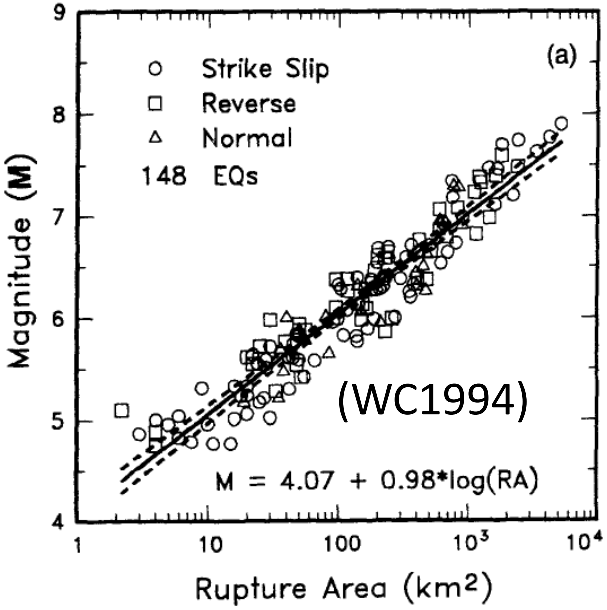
- Simple fault
- Complex fault

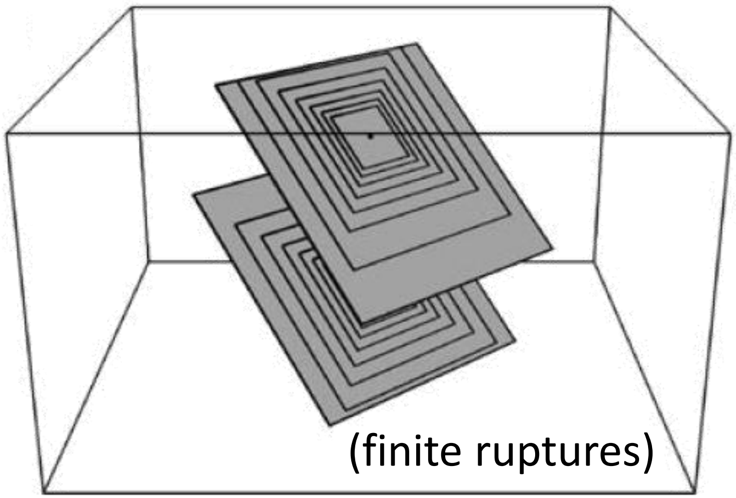


EMME Active Faults

Magnitude scaling relationships (MSR)

- All sources typologies in OQ generate "finite ruptures" (i.e. 3D rectangular planes)
- Rupture area is computed using a MSR, e.g. Wells and Coppersmith, 1994 (WC1994)



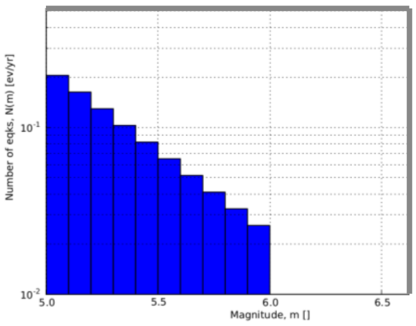


MSRs in OQ: http://docs.openquake.org/oq-hazardlib/master/openquake.hazardlib.scalerel.html

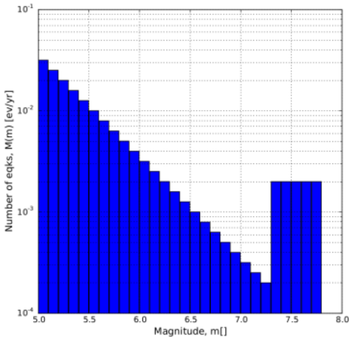
Magnitude-frequency distribution (MFD)

MFDs supported in OQ are:

- Double truncated Gutenberg-Richter
- Evenly Discretised MFD
- Youngs and Coppersmith (1985)



> All represented in discrete form

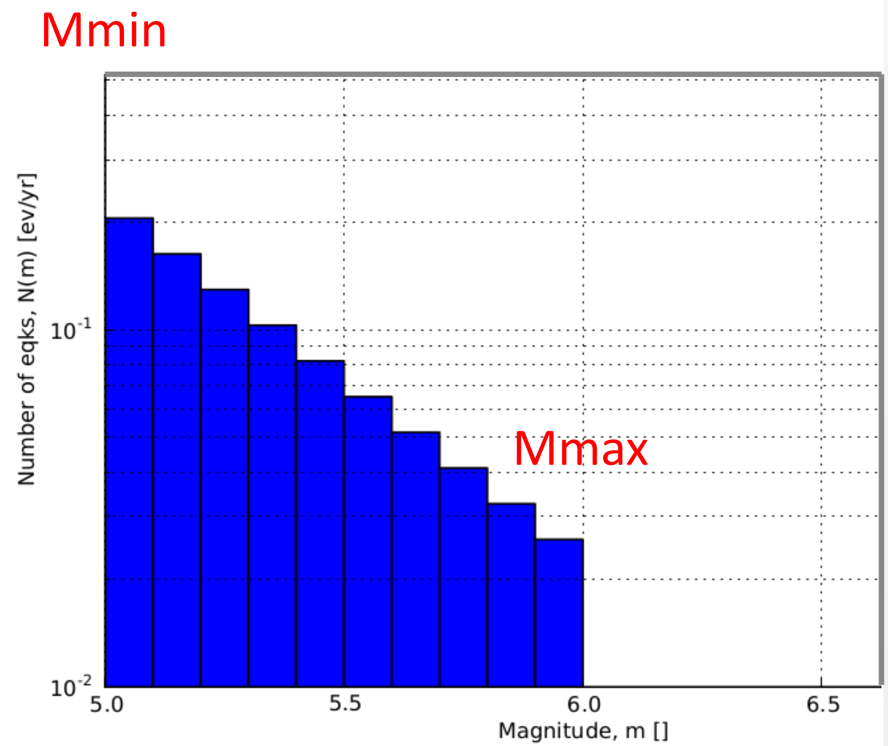


MFDs in OQ: http://docs.openquake.org/oq-hazardlib/master/openquake.hazardlib.mfd.html

Double truncated Gutenberg-Richter MFD

Parameters:

- **a-value**: log of the number of earthquakes with M > 0
- **b-value**
- Minimum magnitude (**Mmin**)
- Maximum magnitude (**Mmax**)
- *Note: bin width is specified in the job.ini*



The xml syntax (the order of xml parameters doesn’t matter):

```
<truncGutenbergRichterMFD avalue=“5.0" bValue="1.0" minMag="5.0" maxMag=“0.5" />
<truncGutenbergRichterMFD minMag="5.0" maxMag=“0.5"  avalue=“5.0" bValue="1.0" />
```

OpenQuake-engine: seismic source definition and rupture calculation

Source Typologies

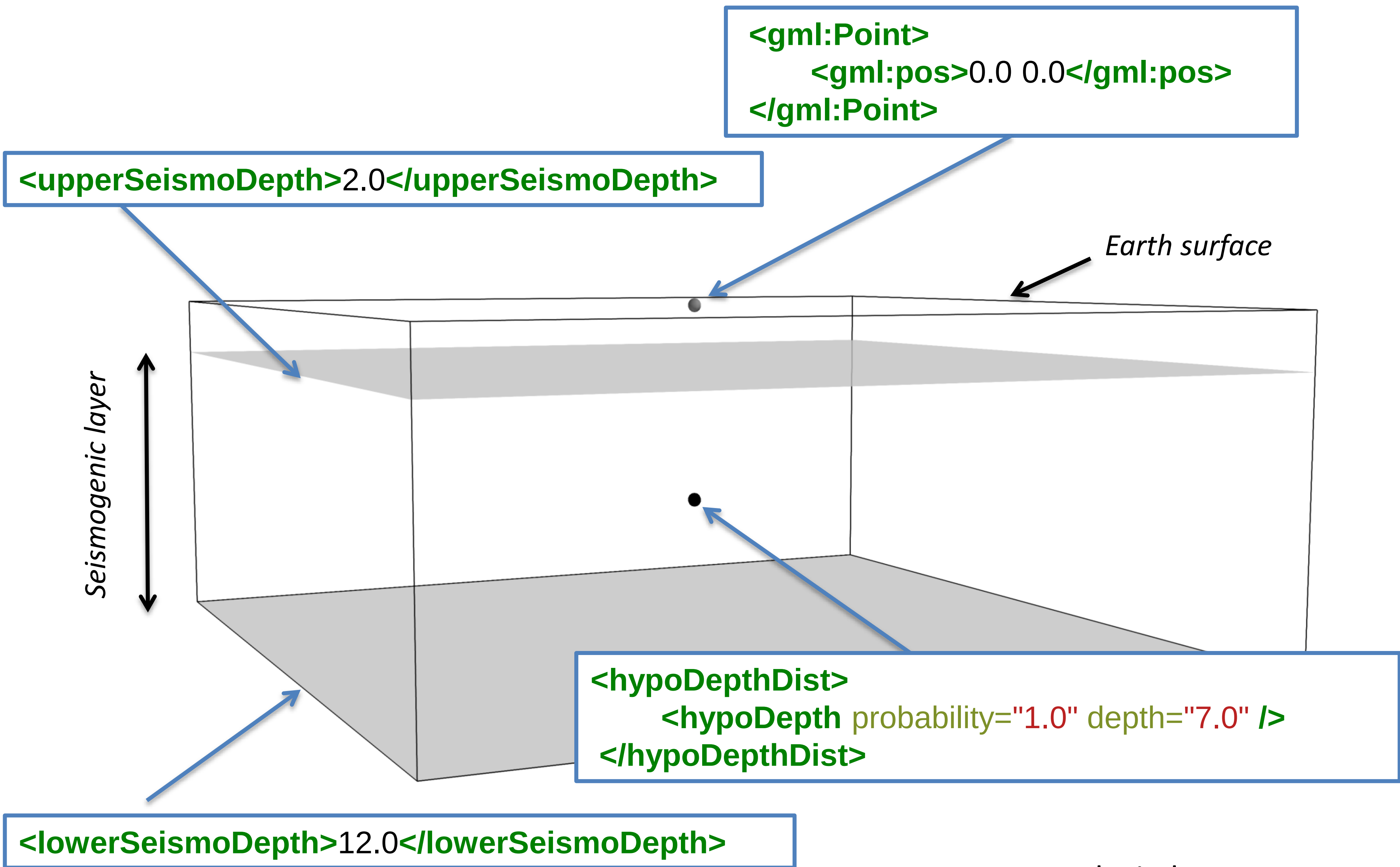
Point Source

Point source

- The simplest source typology in OQ

- Used to model distributed seismicity, e.g. through an **area source**

- As with all sources in OQ, ruptures are extended (despite being called “point” source)



Depths in km
Coordinates in lon,lat

Source geometry definition

Point Source – Example of input file


```
<pointSource id=”1234" name="Point Source”
        tectonicRegion="Active Shallow Crust">
    <pointGeometry>
        <gml:Point>
            <gml:pos>0.0 0.0</gml:pos>
        </gml:Point>
        <upperSeismoDepth>2.0</upperSeismoDepth>
        <lowerSeismoDepth>12.0</lowerSeismoDepth>
    </pointGeometry>
    <magScaleRel>WC1994</magScaleRel>
    <ruptAspectRatio>1.</ruptAspectRatio>
    <truncGutenbergRichterMFD
            aValue=“0.1" bValue="1.0" minMag="5.0" maxMag="6.5" />
    <nodalPlaneDist>
        <nodalPlane probability="1." strike="0.0" dip="90.0" rake="0.0”/>
    </nodalPlaneDist>
  <hypoDepthDist>
        <hypoDepth probability="1." depth="7." />
    </hypoDepthDist>
</pointSource>
```


Source geometry

Point Source – Example of input file

```
<pointSource id=”1234" name="Point Source”
        tectonicRegion="Active Shallow Crust">
    <pointGeometry>
        <gml:Point>
            <gml:pos>0.0 0.0</gml:pos>
        </gml:Point>
        <upperSeismoDepth>2.0</upperSeismoDepth>
        <lowerSeismoDepth>12.0</lowerSeismoDepth>
    </pointGeometry>
    <magScaleRel>WC1994</magScaleRel>
    <ruptAspectRatio>1.</ruptAspectRatio>
    <truncGutenbergRichterMFD
            aValue=“0.1" bValue="1.0" minMag="5.0" maxMag="6.5" />
    <nodalPlaneDist>
        <nodalPlane probability="1." strike="0.0" dip="90.0" rake="0.0”/>
    </nodalPlaneDist>
  <hypoDepthDist>
        <hypoDepth probability="1." depth="7." />
    </hypoDepthDist>
</pointSource>
```

Seismicity occurrence (rupture generation)

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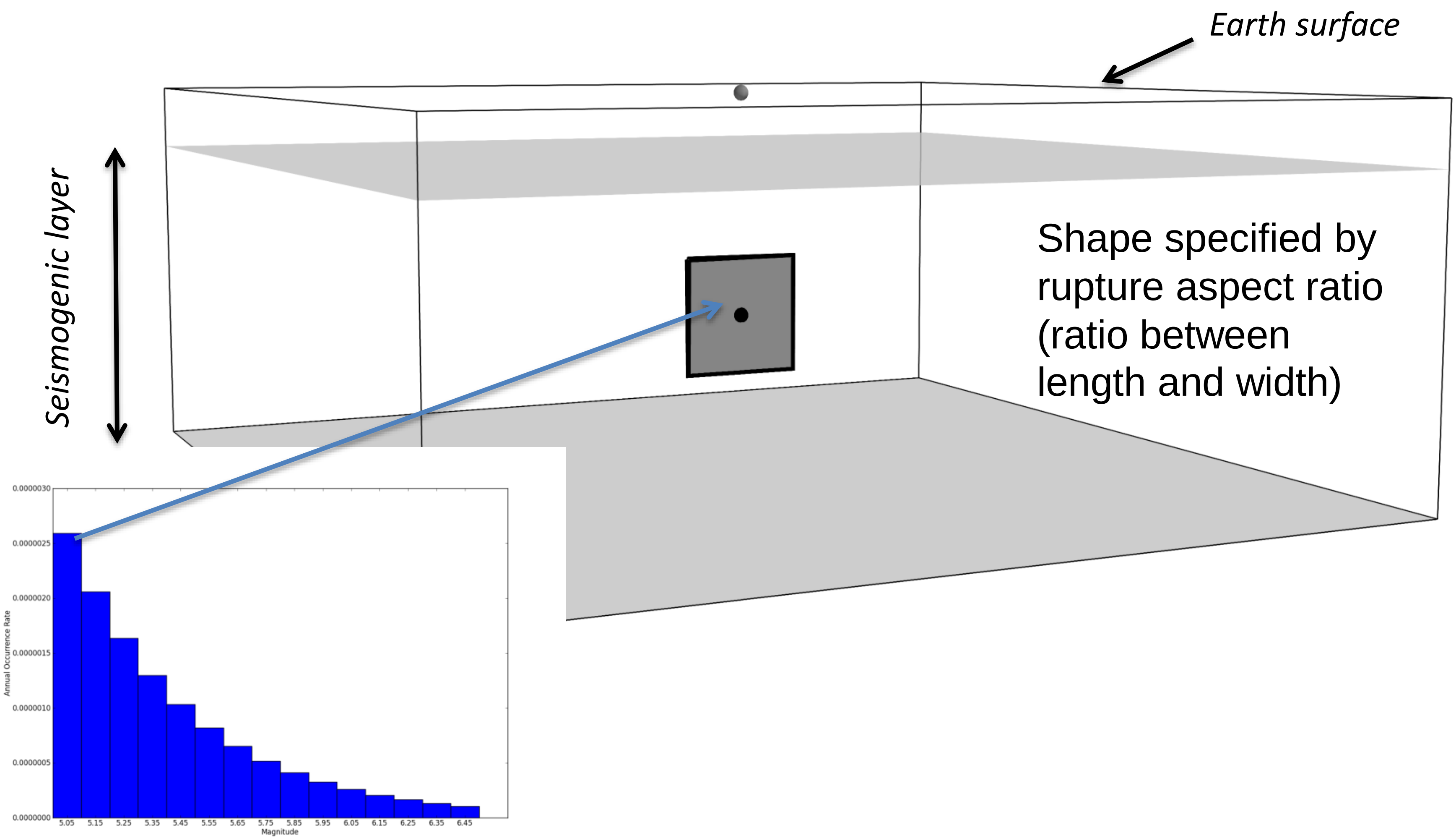
```xml
<truncGutenbergRichterMFD
    aValue="0.1" bValue="1.0"
    minMag="5.0" maxMag="6.5"
/>
```

\+

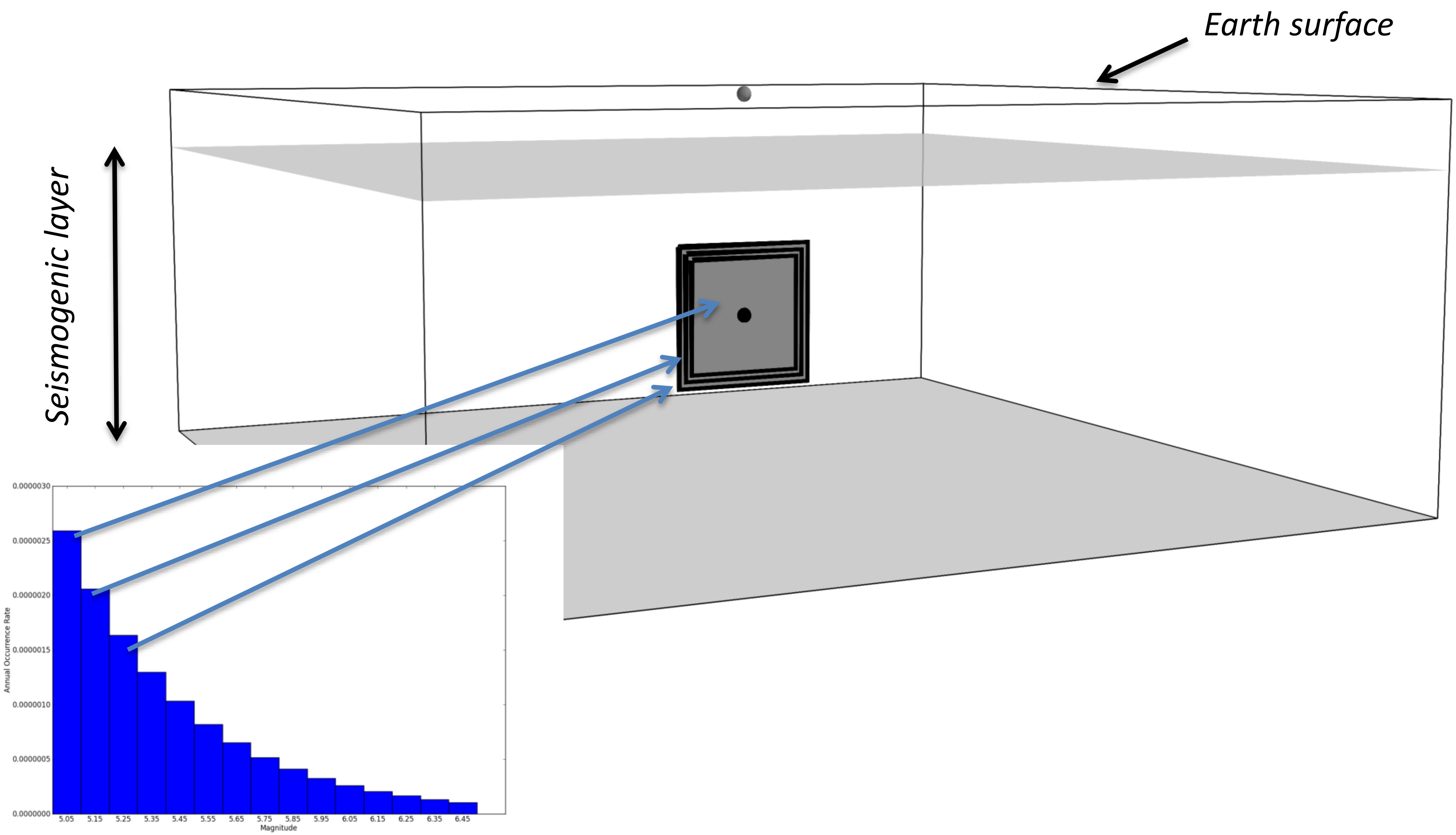
```xml
<magScaleRel>WC1994</magScaleRel>
<ruptAspectRatio>1.0</ruptAspectRatio>
<nodalPlaneDist>
    <nodalPlane probability="1.0"
    strike="0.0" dip="90.0" rake="0.0" />
</nodalPlaneDist>
```



<truncGutenbergRichterMFD
aValue=“0.1" bValue="1.0”
minMag="5.0" maxMag="6.5"
/>

➕

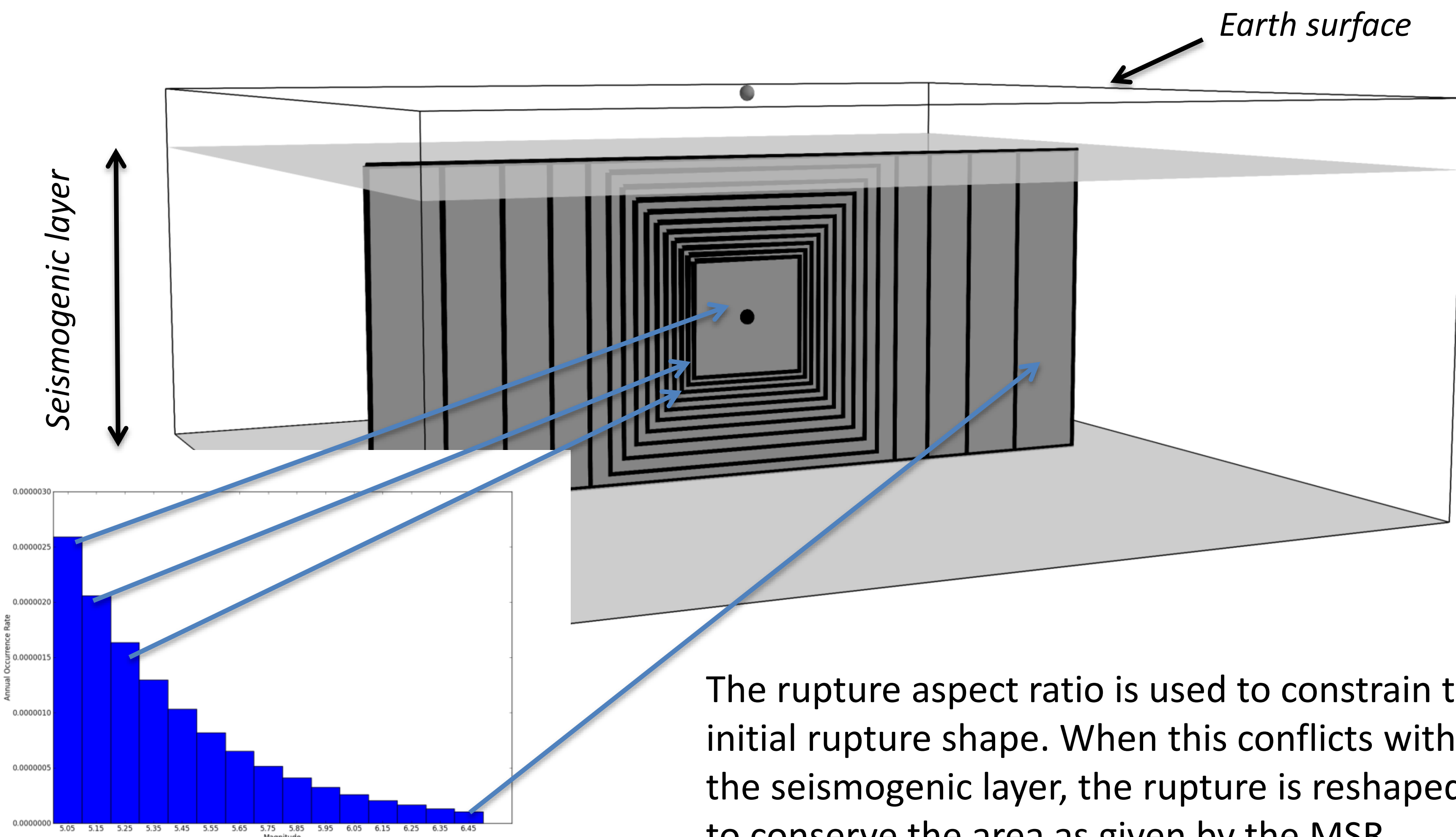
<magScaleRel>WC1994**</magScaleRel>**
<ruptAspectRatio>1.0**</ruptAspectRatio>**
<nodalPlaneDist>
<nodalPlane probability="1.0”
strike="0.0" dip="90.0" rake="0.0" **/>**
</nodalPlaneDist>



```xml
<truncGutenbergRichterMFD
        aValue="0.1" bValue="1.0"
        minMag="5.0" maxMag="6.5"
/>
```

+

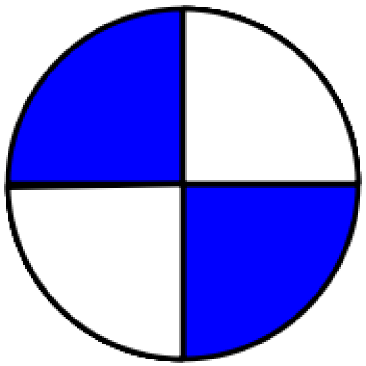
```xml
<magScaleRel>WC1994</magScaleRel>
<ruptAspectRatio>1.0</ruptAspectRatio>
<nodalPlaneDist>
        <nodalPlane probability="1.0"
        strike="0.0" dip="90.0" rake="0.0" />
</nodalPlaneDist>
```



The rupture aspect ratio is used to constrain the initial rupture shape. When this conflicts with the seismogenic layer, the rupture is reshaped to to conserve the area as given by the MSR

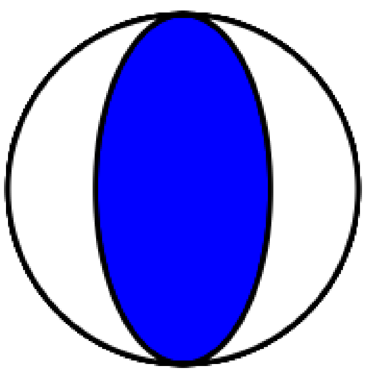
Defining rupture planes

Strike slip



```
<nodalPlaneDist>
    <nodalPlane probability="1.0"  strike="0.0"
        dip="90.0" rake="180" />
</nodalPlaneDist>
```

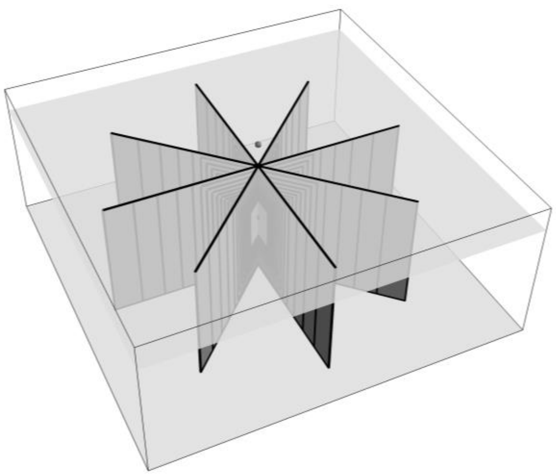
Reverse



```
<nodalPlaneDist>
    <nodalPlane probability="1.0"  strike="0.0"
        dip="45.0" rake="90" />
</nodalPlaneDist>
```

Defining multiple rupture planes

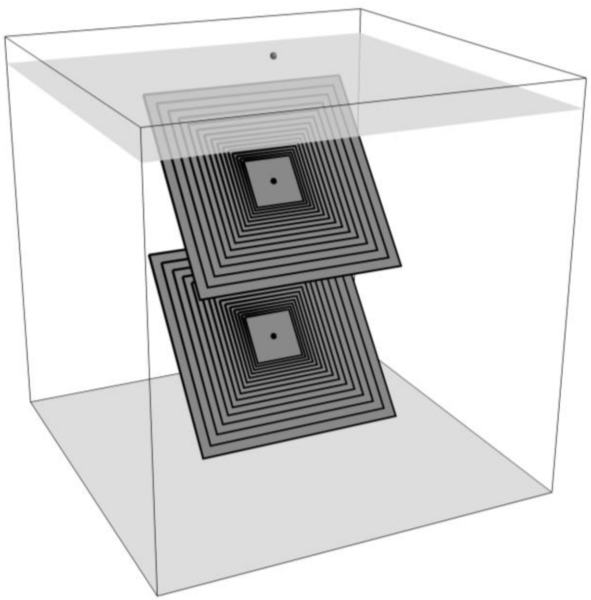
- Multiple nodal planes are sometimes called “spinning ruptures”
- Used to consider (aleatory) uncertainty of ruptures planes, if there isn’t a predominant rupture orientation



```
<nodalPlaneDist>
    <nodalPlane probability=“0.25”  strike="0.0”
        dip="90.0" rake="0.0" />
    <nodalPlane probability=“0.25”  strike=”45.0”
        dip="90.0"rake="0.0" />
    <nodalPlane probability=“0.25”  strike=”90.0”
        dip="90.0"rake="0.0" />
    <nodalPlane probability=“0.25”  strike=”135.0”
        dip="90.0"rake="0.0" />
</nodalPlaneDist>
```

Defining multiple hypocentral depths

- Used to consider (aleatory) uncertainty of hypocentral depth



```
<hypoDepthDist>
    <hypoDepth probability="0.5" depth="10.0" />
    <hypoDepth probability="0.5" depth="15.0" />
</hypoDepthDist>
```

Point source – summary of parameters

- The **coordinates of the point** (longitude and latitude) [degrees]
- The **upper and lower seismogenic depths** [km]
- A **magnitude-frequency distribution** (e.g. Gutenberg-Richter)
- A **magnitude-scaling relationship** (e.g. Wells and Coppersmith, 1994)
- A **rupture aspect ratio** (e.g. 1)
- A *distribution* of **nodal planes** i.e. one (or several) instances of the following set of parameters. All probabilities must sum to 1
  - strike [degrees]
  - dip [degrees]
  - rake [degrees]
- A *distribution* of **hypocentral depths** [km] i.e. one (or several) instances. All probabilities must sum to 1

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Area Source

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Area source

- Area sources rely almost entirely on **point source** implementation.

- In the OQ-engine an area source is a set of equally spaced **point sources**

- Typically used to model seismicity occurring over wide areas where identification/characterization of single fault structures is difficult.

Area Source – Example of input file

```
<areaSource id=”1234" name="Zone20” tectonicRegion="Cratonic">
    <areaGeometry>
        <gml:Polygon>
            <gml:exterior>
                <gml:LinearRing>
                    <gml:posList>
                        133.5 -22.5 133.5 -23.0 130.75 -23.75 130.75 -24.5 133.5 -26.0
                        133.5 -27.0 130.75 -27.0 128.977 -25.065 128.425 -23.436
                        126.082 -23.233 125.669 -22.351 125.4 -20.5 125.75 -20.25 126.7
                         -21.25 128.5 -21.25 129.25 -20.6 130.0 -20.6 130.9 -22.25 133.0
                         -22.0 133.5 -22.5
                    </gml:posList>
                </gml:LinearRing>
            </gml:exterior>
        </gml:Polygon>
        <upperSeismoDepth>0.0</upperSeismoDepth>
        <lowerSeismoDepth>15.0</lowerSeismoDepth>
    </areaGeometry>
    <magScaleRel>WC1994</magScaleRel>
    <ruptAspectRatio>1.0</ruptAspectRatio>
    <truncGutenbergRichterMFD aValue="2.6218375188" bValue="0.763" maxMag="6.5" minMag=“5.0"/>
    <nodalPlaneDist>
        <nodalPlane dip=”90.0" probability=“0.25" rake=“0.0" strike="0.0"/>
        <nodalPlane dip=”90.0" probability=“0.25" rake=“0.0" strike=“45.0"/>
        <nodalPlane dip=”90.0" probability=“0.25" rake=“0.0" strike=”90.0"/>
        <nodalPlane dip=”90.0" probability=“0.25" rake=“0.0" strike=“135.0"/>
    </nodalPlaneDist>
    <hypoDepthDist>
        <hypoDepth depth="7.5" probability="1.0"/>
    </hypoDepthDist>
</areaSource>
```

Source geometry

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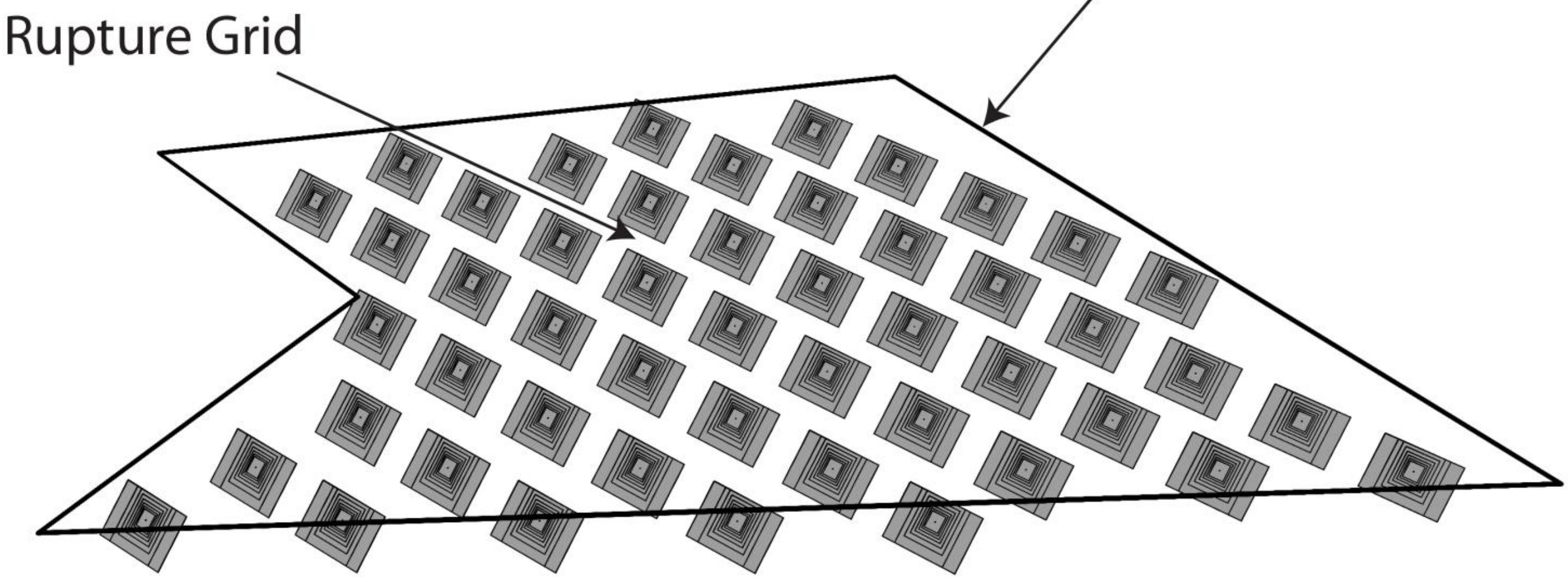
Area source boundary

```
<gml:Polygon>
    <gml:exterior>
        <gml:LinearRing>
            <gml:posList>
                ...
            </gml:posList>
        </gml:LinearRing>
    </gml:exterior>
</gml:Polygon>
```



Area Source – Example of NRML definition

```xml
<areaSource id="1234" name="Zone20" tectonicRegion="Cratonic">
        <areaGeometry>
                <gml:Polygon>
                        <gml:exterior>
                                <gml:LinearRing>
                                        <gml:posList>
                                                133.5 -22.5 133.5 -23.0 130.75 -23.75 130.75 -24.5 133.5 -26.0
                                                133.5 -27.0 130.75 -27.0 128.977 -25.065 128.425 -23.436
                                                126.082 -23.233 125.669 -22.351 125.4 -20.5 125.75 -20.25 126.7
                                                 -21.25 128.5 -21.25 129.25 -20.6 130.0 -20.6 130.9 -22.25 133.0
                                                 -22.0 133.5 -22.5
                                        </gml:posList>
                                </gml:LinearRing>
                        </gml:exterior>
                </gml:Polygon>
                <upperSeismoDepth>0.0</upperSeismoDepth>
                <lowerSeismoDepth>15.0</lowerSeismoDepth>
        </areaGeometry>
        <magScaleRel>WC1994</magScaleRel>
        <ruptAspectRatio>1.0</ruptAspectRatio>
        <truncGutenbergRichterMFD aValue="2.6218375188" bValue="0.763" maxMag="6.5" minMag="5.0"/>
        <nodalPlaneDist>
                <nodalPlane dip="90.0" probability="0.25" rake="0.0" strike="0.0"/>
                <nodalPlane dip="90.0" probability="0.25" rake="0.0" strike="45.0"/>
                <nodalPlane dip="90.0" probability="0.25" rake="0.0" strike="90.0"/>
                <nodalPlane dip="90.0" probability="0.25" rake="0.0" strike="135.0"/>
        </nodalPlaneDist>
        <hypoDepthDist>
                <hypoDepth depth="7.5" probability="1.0"/>
        </hypoDepthDist>
</areaSource>
```

Seismicity occurrence (rupture generation)

Same as for point source

Area source – summary of parameters

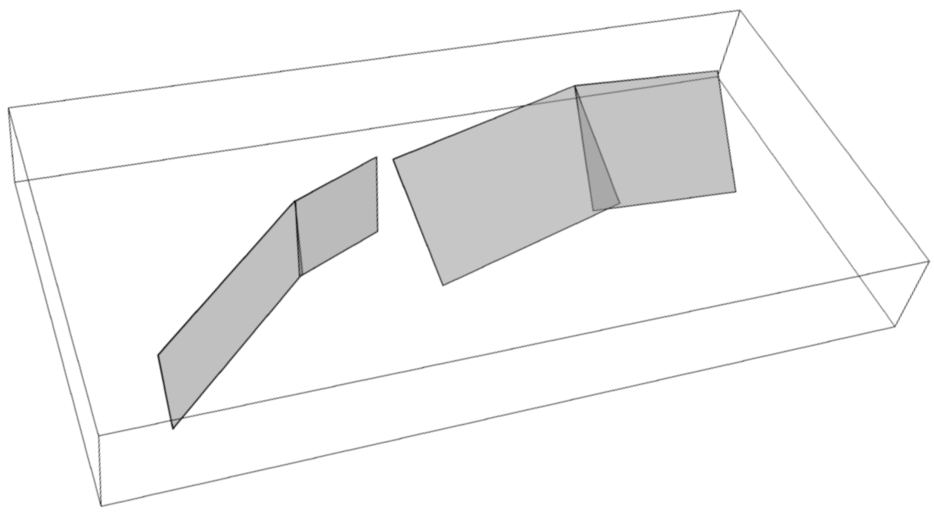
- A **polygon** defining the external border of the area (i.e. a list of Longitude-Latitude [degrees] coordinates)
- The **upper and lower seismogenic depths** [km]
- One **magnitude-frequency distribution** (e.g. Gutenberg-Richter)
- One **magnitude-scaling relationship** (e.g. Wells and Coppersmith, 1994)
- One **rupture aspect ratio** (e.g. 1)
- A *distribution* of **nodal planes** i.e. one (or several) instances of the following set of parameters. All probabilities must sum to 1
  - strike [degrees]
  - dip [degrees]
  - rake [degrees]
- A *distribution* of **hypocentral depths** [km] i.e. one (or several) instances. All probabilities must sum to 1

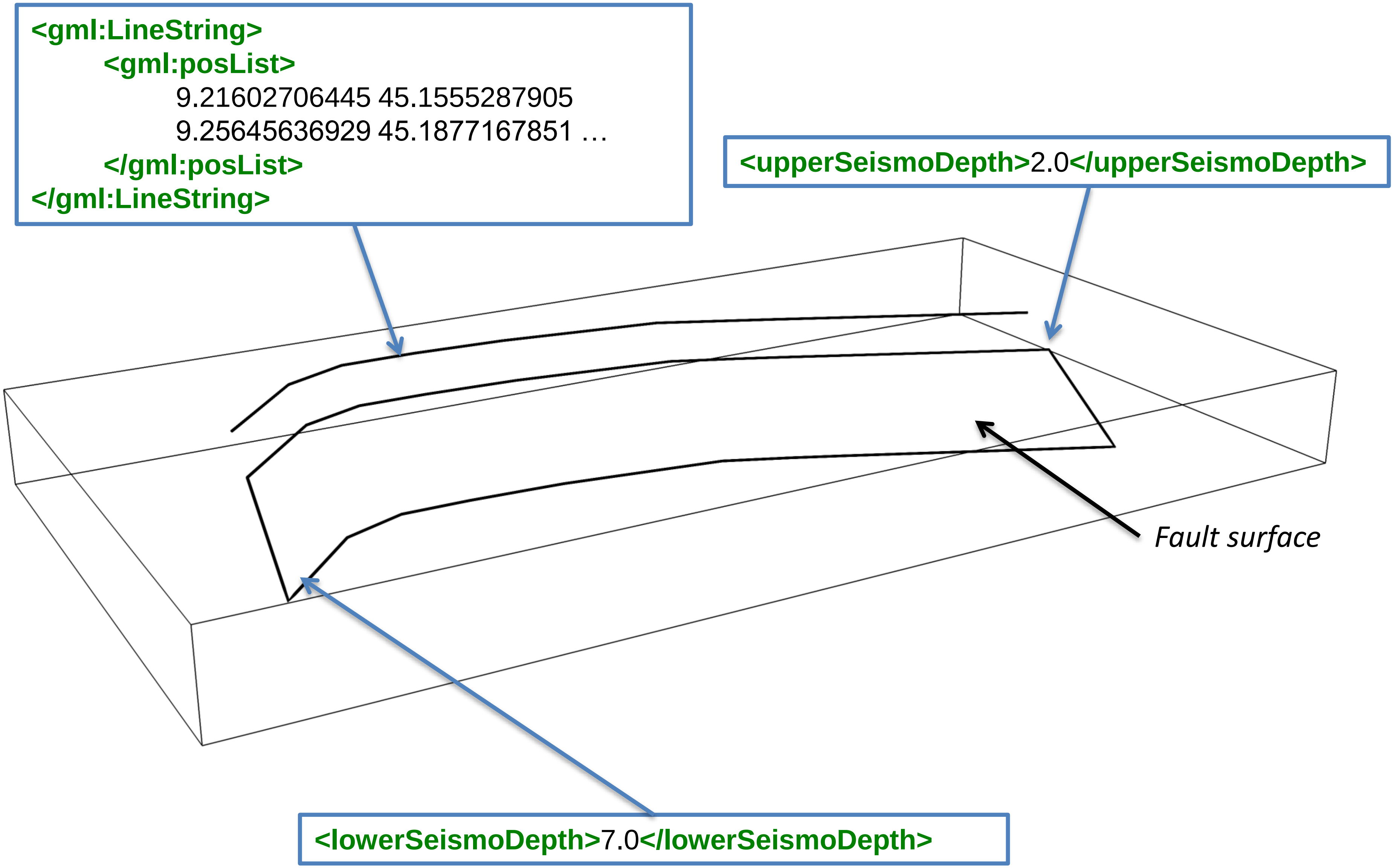
Simple fault source

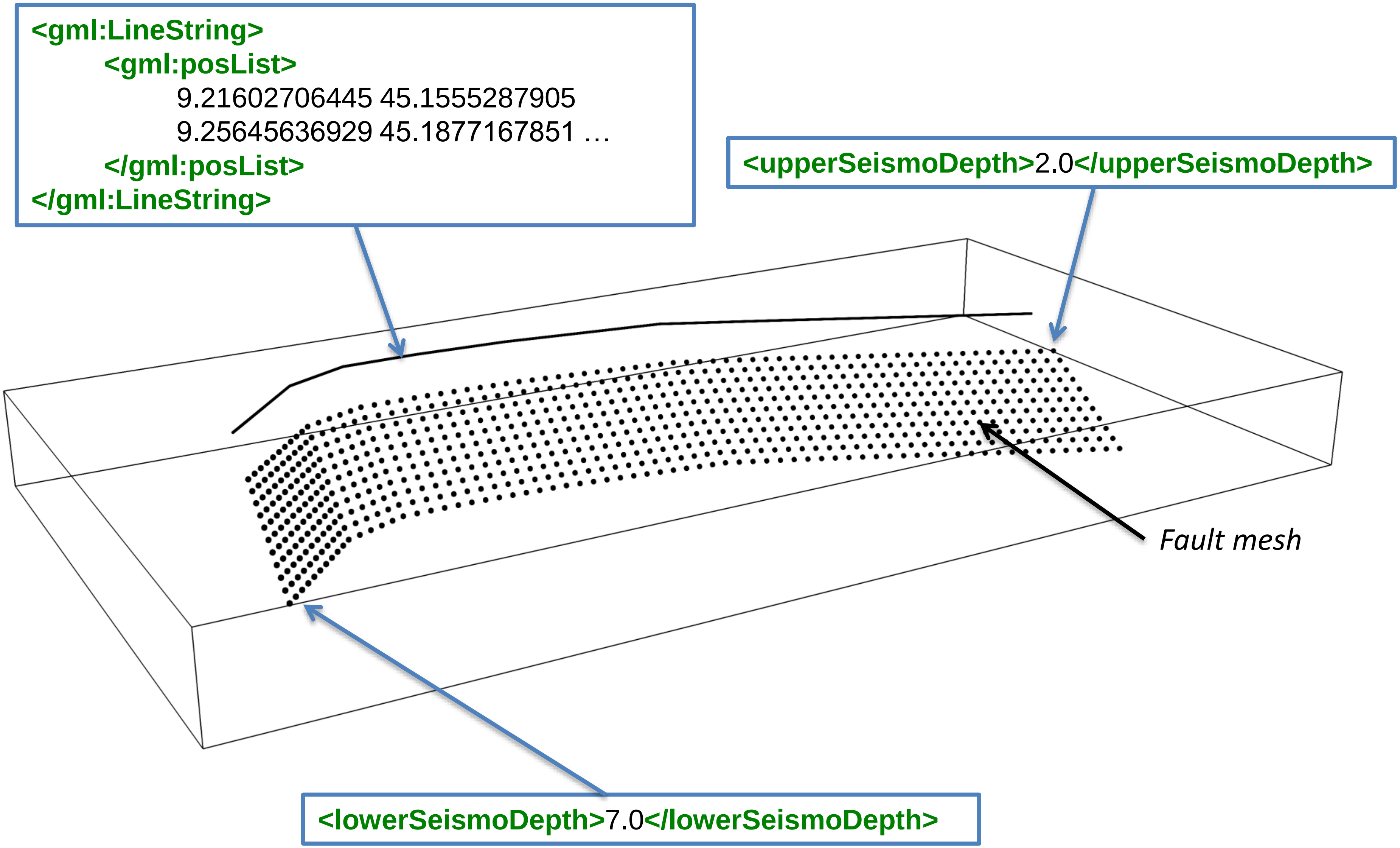
Simple Fault Source

- The most common source type used to model **shallow faults**

- "simple" is related to the geometry of the source which is obtained by projecting the fault trace (i.e. a line) along a dip direction, forming **planar** surfaces




<gml:LineString>
<gml:posList>
9.21602706445 45.1555287905
9.25645636929 45.1877167851 …
</gml:posList>
</gml:LineString>
<upperSeismoDepth>2.0</upperSeismoDepth>
Fault surface
<lowerSeismoDepth>7.0</lowerSeismoDepth>


<gml:LineString>
<gml:posList>
9.21602706445 45.1555287905
9.25645636929 45.1877167851 …
</gml:posList>
</gml:LineString>
<upperSeismoDepth>2.0</upperSeismoDepth>
Fault mesh
<lowerSeismoDepth>7.0</lowerSeismoDepth>

Simple Fault Source – Example of input file

```xml
<simpleFaultSource tectonicRegion="Active Shallow Crust"
        id=”1234” name="ITCS044">
    <simpleFaultGeometry>
        <gml:LineString>
            <gml:posList>
                9.21602706445 45.1555287905
                9.25645636929 45.1877167851 …
            </gml:posList>
        </gml:LineString>
        <dip>30.0</dip>
        <upperSeismoDepth>2.0</upperSeismoDepth>
        <lowerSeismoDepth>7.0</lowerSeismoDepth>
    </simpleFaultGeometry>
    <magScaleRel>WC1994</magScaleRel>
    <ruptAspectRatio>1.0</ruptAspectRatio>
    <truncGutenbergRichterMFD maxMag="6.5" bValue="1.317”
                              aValue="4.28448" minMag="5.0"/>
    <rake>90.0</rake>
</simpleFaultSource>
```

Source geometry

Simple Fault Source – Example of input file

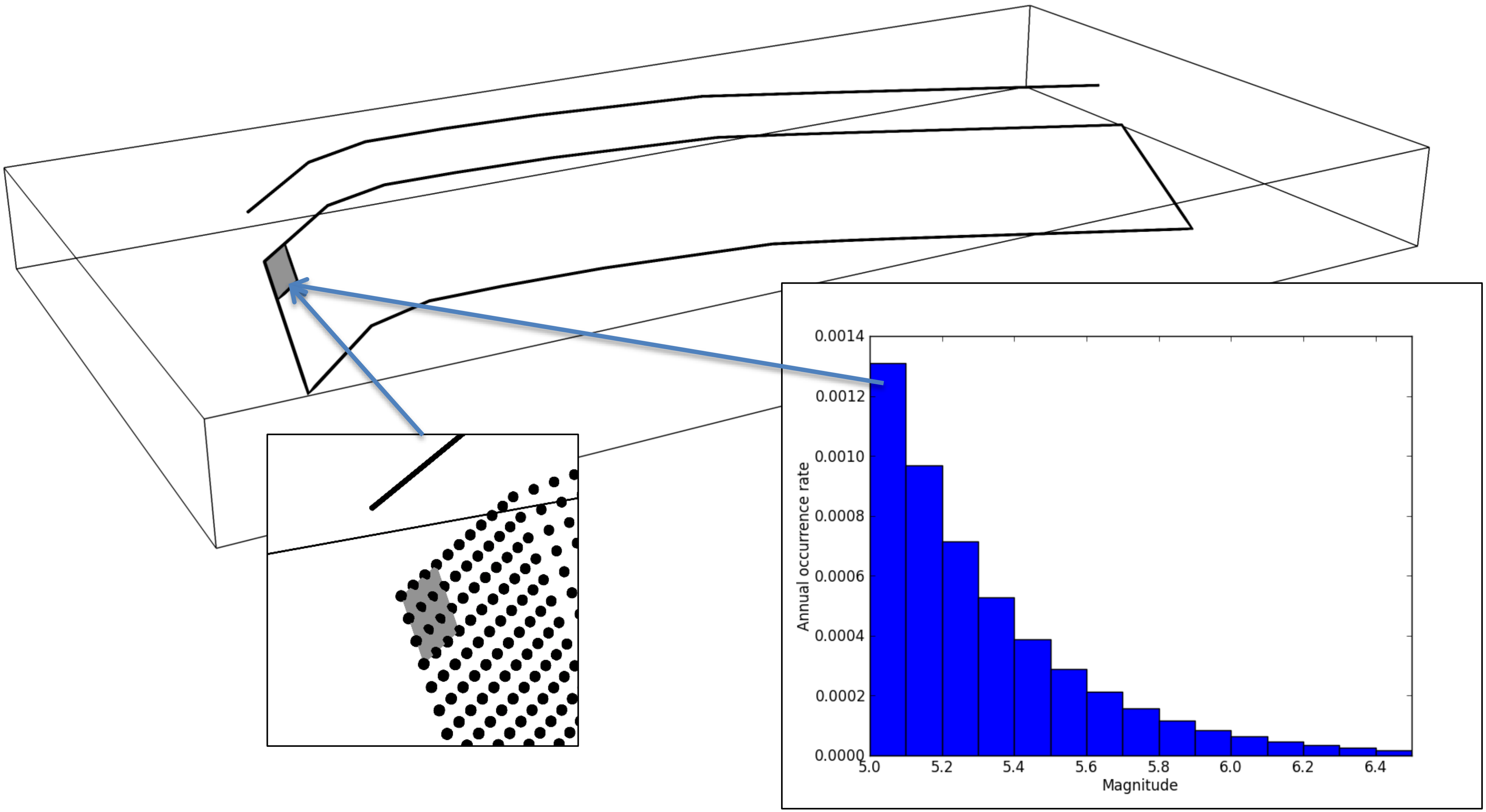
```
<simpleFaultSource tectonicRegion="Active Shallow Crust"
        id="1234" name="ITCS044">
    <simpleFaultGeometry>
        <gml:LineString>
            <gml:posList>
                9.21602706445 45.1555287905
                9.25645636929 45.1877167851 …
            </gml:posList>
        </gml:LineString>
        <dip>30.0</dip>
        <upperSeismoDepth>2.0</upperSeismoDepth>
        <lowerSeismoDepth>7.0</lowerSeismoDepth>
    </simpleFaultGeometry>
    <magScaleRel>WC1994</magScaleRel>
    <ruptAspectRatio>1.0</ruptAspectRatio>
    <truncGutenbergRichterMFD maxMag="6.5" bValue="1.317"
                              aValue="4.28448" minMag="5.0"/>
    <rake>90.0</rake>
</simpleFaultSource>
```

Seismicity occurrence

(rupture generation)

```
<truncGutenbergRichterMFD
      maxMag="6.5" bValue="1.317"
      aValue="4.28448" minMag="5.0"/>
```

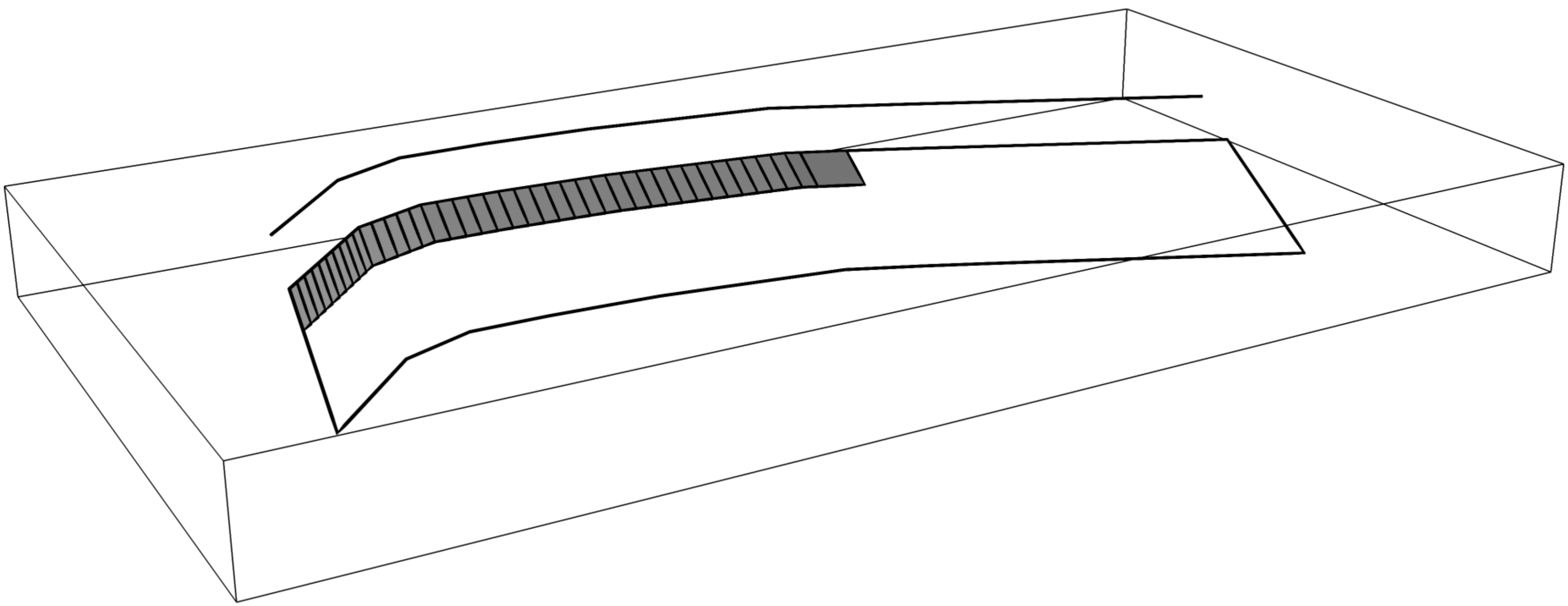
```
<magScaleRel>WC1994</magScaleRel>
<ruptAspectRatio>1.</ruptAspectRatio>
```



```
<truncGutenbergRichterMFD
        maxMag="6.5" bValue="1.317”
        aValue="4.28448" minMag="5.0"/>
```

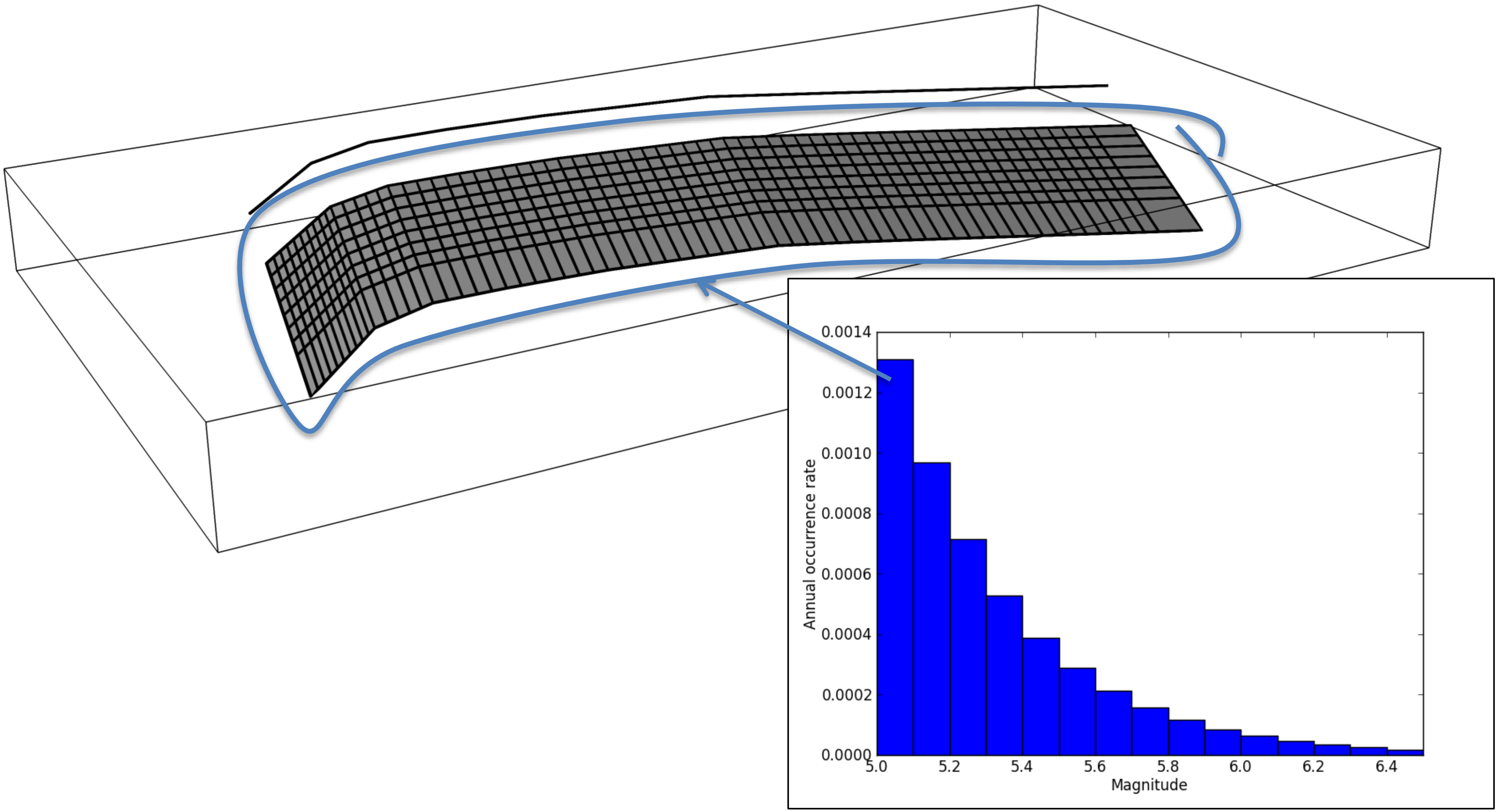
\+

```
<magScaleRel>WC1994</magScaleRel>
<ruptAspectRatio>1.</ruptAspectRatio>
```



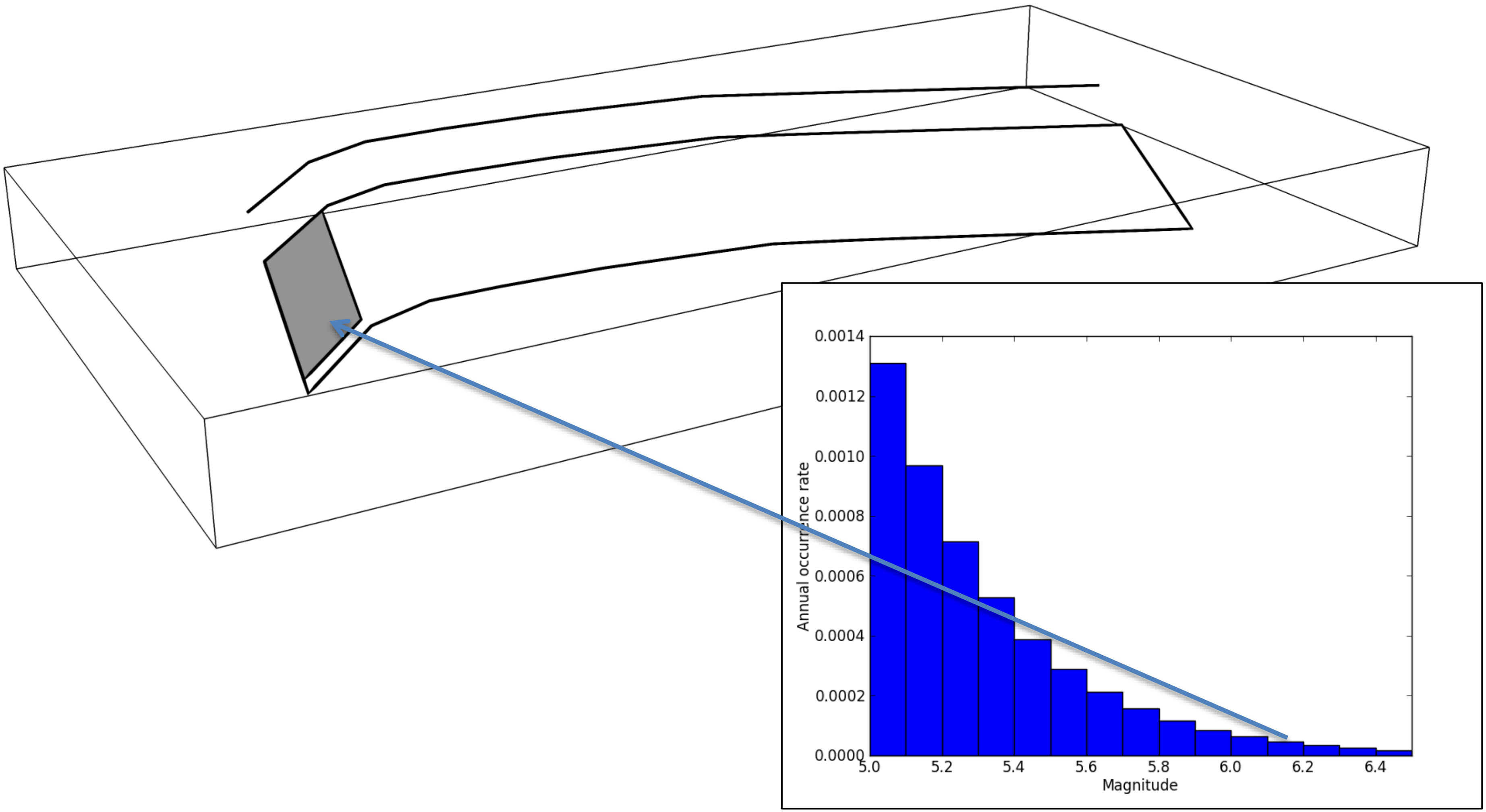
```
<truncGutenbergRichterMFD
        maxMag="6.5" bValue="1.317"
        aValue="4.28448" minMag="5.0"/>
```

```
<magScaleRel>WC1994</magScaleRel>
<ruptAspectRatio>1.</ruptAspectRatio>
```



```
<truncGutenbergRichterMFD
      maxMag="6.5" bValue="1.317”
      aValue="4.28448" minMag="5.0"/>
```

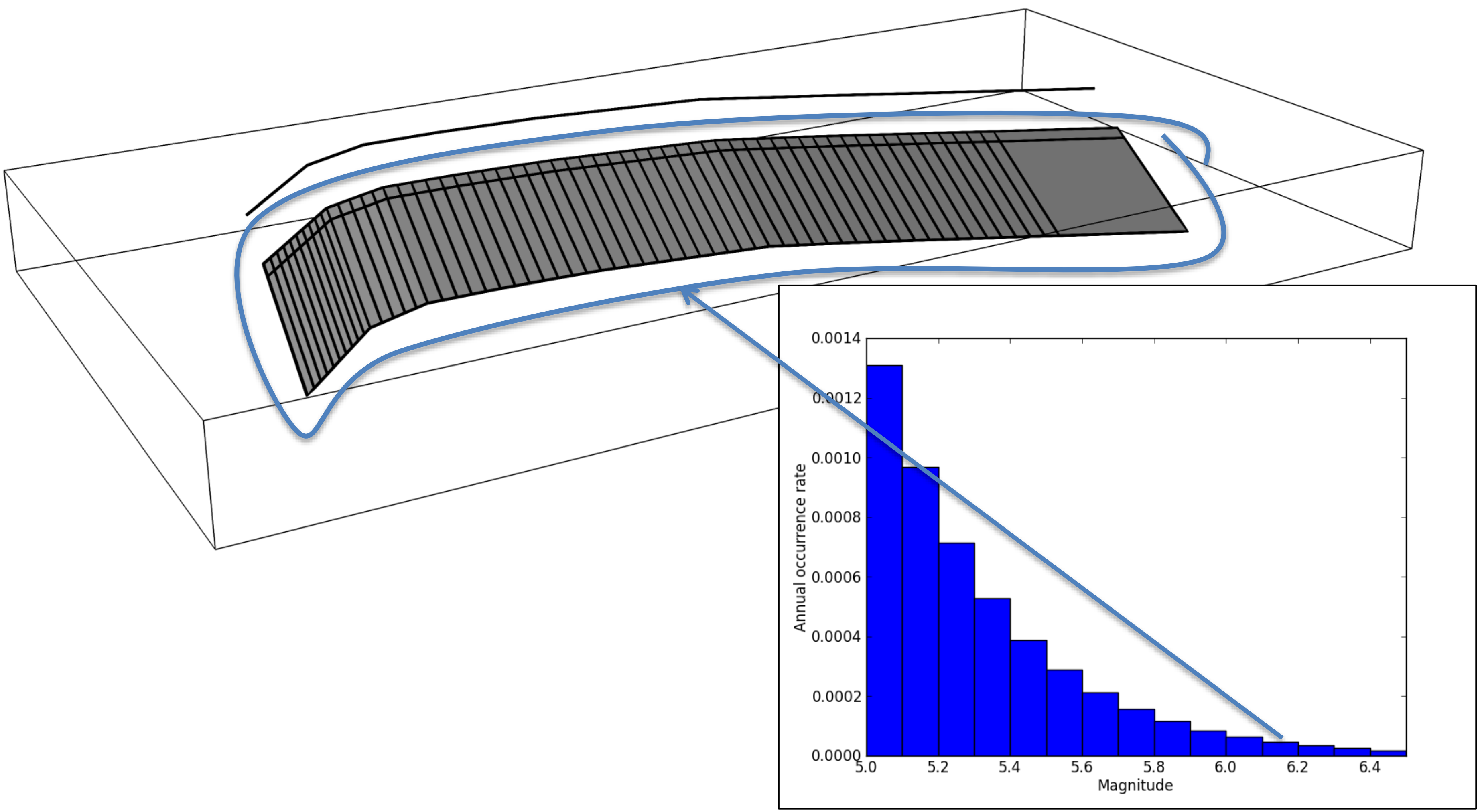
```
<magScaleRel>WC1994</magScaleRel>
<ruptAspectRatio>1.</ruptAspectRatio>
```



<truncGutenbergRichterMFD
maxMag="6.5" bValue="1.317”
aValue="4.28448" minMag="5.0"/>

+

<magScaleRel>WC1994</magScaleRel>
<ruptAspectRatio>1.</ruptAspectRatio>



Simple Fault Source– summary of parameters

- A horizontal **fault trace** (polyline). It is a list of longitude-latitude tuples [degrees]
- Dip angle (specified following the *Aki-Richards convention; see Aki and Richards, (2002)) [degrees]
- The **upper and lower seismogenic depths** [km]
- One **magnitude-frequency distribution** (e.g. Gutenberg-Richter)
- One **magnitude-scaling relationship** (e.g. Wells and Coppersmith, 1994)
- One **rupture aspect ratio** (e.g. 1)
- **Rake** angle [degrees]

* The *Aki & Richards convention* requires that the order of the coordinates of the fault trace should be such that if we were to walk a path along the coordinates the fault should be dipping to the right.

Source Model Logic Tree

Hazard Calculation Input files

job.ini

(configuration file)

ssmLT.xml

(source model logic tree)

gmmLT.xml

(ground motion logic tree)

GMPEs from: https://docs.openquake.org/oq-engine/master/openquake.hazardlib.gsim.html

ssm.xml

(seismic sources)

Note: files can use any name; these are the standard names (keeping extensions)

Source model logic tree

- The source model logic tree file points to the seismic source model(s)
- Used to formally specify the **epistemic uncertainties** in the source model
- Every logic tree branch represents one complete source model
- Every branch is assigned **weights** expressing the degree of belief in that model.

Source model logic tree

Example 1: One source model

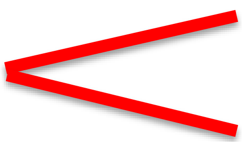
Branch 1: ssm.xml
(weight =1.0)

Only 1 source model file means epistemic uncertainty **is not** considered

```
<logicTree logicTreeID="lt1">
    <logicTreeBranchingLevel branchingLevelID="bl1">
        <logicTreeBranchSet uncertaintyType="sourceModel" branchSetID="bs1">
            <logicTreeBranch branchID="b1">
                <uncertaintyModel>ssm.xml</uncertaintyModel>
                <uncertaintyWeight>1.0</uncertaintyWeight>
            </logicTreeBranch>
        </logicTreeBranchSet>
    </logicTreeBranchingLevel>
</logicTree>
```

Source model logic tree

Example 2: Two alternative source models



Branch 1: ssm1.xml
weight (0.5)

Branch 2: ssm2.xml
weight (0.5)

> 1 source model file means epistemic uncertainty **is** considered

```
<logicTree logicTreeID="lt1">
    <logicTreeBranchingLevel branchingLevelID="bl1">
        <logicTreeBranchSet uncertaintyType="sourceModel" branchSetID="bs1">
            <logicTreeBranch branchID="b1">
                <uncertaintyModel>ssm1.xml</uncertaintyModel>
                <uncertaintyWeight>0.5</uncertaintyWeight>
            </logicTreeBranch>
            <logicTreeBranch branchID="b2">
                <uncertaintyModel>ssm2.xml</uncertaintyModel>
                <uncertaintyWeight>0.5</uncertaintyWeight>
            </logicTreeBranch>
        </logicTreeBranchSet>
    </logicTreeBranchingLevel>
</logicTree>
```

Ground Motion Logic Tree

Hazard Calculation Input files

job.ini

(configuration file)

ssmLT.xml

(source model logic tree)

ssm.xml

(seismic sources)

gmmLT.xml

(ground motion logic tree)

GMPEs from: https://docs.openquake.org/oq-engine/master/openquake.hazardlib.gsim.html

Note: files can use any name; these are the standard names (keeping extensions)

Ground motion logic tree

- The ground motion logic tree file points to the GMPE(s)
- Used to formally specify the **epistemic uncertainties** in the ground motion
- Every logic tree branch represents one GMPE
- Every branch is assigned **weights** expressing the degree of belief in that GMPE

Ground motion logic tree

GEM

Example 1: One source GMPE

Branch 1: BooreAtkinson2008
(weight =1.0)

Only 1 GMPE means epistemic uncertainty **is not** considered

```
<logicTree logicTreeID='lt1'>
    <logicTreeBranchingLevel branchingLevelID="bl1">
        <logicTreeBranchSet uncertaintyType="gmpeModel" branchSetID="bs1"
                applyToTectonicRegionType="Active Shallow Crust">
            <logicTreeBranch branchID="b1">
                <uncertaintyModel>BooreAtkinson2008</uncertaintyModel>
                <uncertaintyWeight>1.0</uncertaintyWeight>
            </logicTreeBranch>
        </logicTreeBranchSet>
    </logicTreeBranchingLevel>
</logicTree>
```

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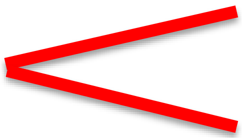
Ground motion logic tree

GEM

Example 2: Two alternative GMPEs



Branch 1: BooreAtkinson2008
weight (0.5)

Branch 2: ChiouYoungs2008
weight (0.5)

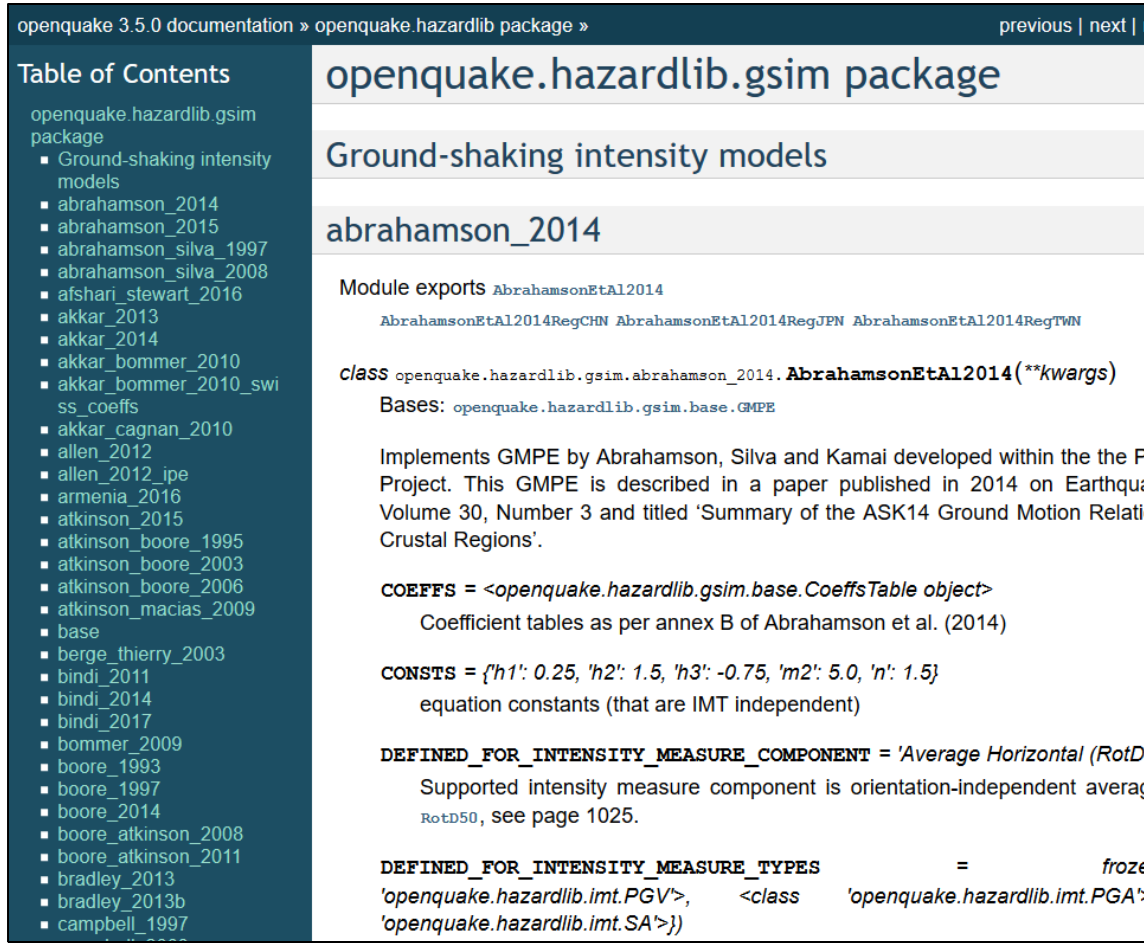
> 1 GMPE means epistemic uncertainty **is** considered

```xml
<logicTree logicTreeID='lt1'>
    <logicTreeBranchingLevel branchingLevelID="bl1">
        <logicTreeBranchSet uncertaintyType="gmpeModel" branchSetID="bs1"
                applyToTectonicRegionType="Active Shallow Crust">
            <logicTreeBranch branchID="b11">
                <uncertaintyModel>BooreAtkinson2008</uncertaintyModel>
                <uncertaintyWeight>0.5</uncertaintyWeight>
            </logicTreeBranch>
            <logicTreeBranch branchID="b12">
                <uncertaintyModel>ChiouYoungs2008</uncertaintyModel>
                <uncertaintyWeight>0.5</uncertaintyWeight>
            </logicTreeBranch>
        </logicTreeBranchSet>
    </logicTreeBranchingLevel>
</logicTree>
```

GLOBAL QUAKE MODEL .ORG

GMPEs in OpenQuake

OpenQuake includes one of the most comprehensive libraries of GMPEs (“GSIMs”) for the most common tectonic regions considered in SHA e.g. active shallow crust, stable continental region, subduction interface, subduction inslab, with 100+ GMPEs



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- akkar_2013
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- boore_1993
- boore_1997
- boore_2014
- boore_atkinson_2008
- boore_atkinson_2011
- bradley_2013
- bradley_2013b
- campbell_1997

openquake.hazardlib.gsim package

Ground-shaking intensity models

abrahamson_2014

Module exports `AbrahamsonEtAl2014` `AbrahamsonEtAl2014RegCHN` `AbrahamsonEtAl2014RegJPN` `AbrahamsonEtAl2014RegTWN`

class `openquake.hazardlib.gsim.abrahamson_2014.`**`AbrahamsonEtAl2014`**(***kwargs*)

Bases: `openquake.hazardlib.gsim.base.GMPE`

Implements GMPE by Abrahamson, Silva and Kamai developed within the the PE Project. This GMPE is described in a paper published in 2014 on Earthquak Volume 30, Number 3 and titled ‘Summary of the ASK14 Ground Motion Relatio Crustal Regions’.

COEFFS = *<openquake.hazardlib.gsim.base.CoeffsTable object>*

Coefficient tables as per annex B of Abrahamson et al. (2014)

CONSTS = *{'h1': 0.25, 'h2': 1.5, 'h3': -0.75, 'm2': 5.0, 'n': 1.5}*

equation constants (that are IMT independent)

DEFINED_FOR_INTENSITY_MEASURE_COMPONENT = *'Average Horizontal (RotD5*

Supported intensity measure component is orientation-independent average `RotD50`, see page 1025.

DEFINED_FOR_INTENSITY_MEASURE_TYPES = *frozen 'openquake.hazardlib.imt.PGV'>, <class 'openquake.hazardlib.imt.PGA'>, 'openquake.hazardlib.imt.SA'>})*

To access the GMPE Library go to: https://docs.openquake.org/oq-engine/master/openquake.hazardlib.gsim.html

Example: Bindi et al., 2011

Name

Description

Tectonic region

bindi_2011

Module exports `BindiEtAl2011`.

class `openquake.hazardlib.gsim.bindi_2011.`**`BindiEtAl2011`**(***kwargs*) [source]

Bases: `openquake.hazardlib.gsim.base.GMPE`

Implements GMPE developed by D.Bindi, F.Pacor, L.Luzi, R.Puglia, M.Massa, G. Ameri, R. Paolucci and published as “Ground motion prediction equations derived from the Italian strong motion data”, Bull Earthquake Eng, DOI 10.1007/s10518-011-9313-z. SA are given up to 2 s. The regressions are developed considering the geometrical mean of the as-recorded horizontal components

COEFFS = *<openquake.hazardlib.gsim.base.CoeffsTable object>*

DEFINED_FOR_INTENSITY_MEASURE_COMPONENT = *'Average horizontal'*

Supported intensity measure component is the geometric mean of two horizontal components

DEFINED_FOR_INTENSITY_MEASURE_TYPES = *frozenset({<class 'openquake.hazardlib.imt.PGA'>, <class 'openquake.hazardlib.imt.SA'>, <class 'openquake.hazardlib.imt.PGV'>})*

Set of `intensity measure types` this GSIM can calculate. A set should contain classes from module `openquake.hazardlib.imt`.

DEFINED_FOR_STANDARD_DEVIATION_TYPES = *frozenset({'Inter event', 'Intra event', 'Total'})*

Supported standard deviation types are inter-event, intra-event and total, page 1904

DEFINED_FOR_TECTONIC_REGION_TYPE = *'Active Shallow Crust'*

Supported tectonic region type is ‘active shallow crust’ because the equations have been derived from data from Italian database ITACA, as explained in the ‘Introduction’.

REQUIRES_DISTANCES = *frozenset({'rjb'})*

Required distance measure is RRup (eq. 1).

REQUIRES_RUPTURE_PARAMETERS = *frozenset({'mag', 'rake'})*

Required rupture parameters are magnitude and rake (eq. 1).

REQUIRES_SITES_PARAMETERS = *frozenset({'vs30'})*

Required site parameter is only Vs30

GMPEs in OpenQuake

- The name(s) after "module exports" is the name that should be specified in the ground motion logic tree
- Examples:

GMPE	name to be used
bindi_2011	BindiEtAl2011
boore_atkinson_2008	BooreAtkinson2008
chiou_youngs_2014	ChiouYoungs2014
akkar_2014	AkkarEtAlRjb2014 AkkarEtAlRepi2014 AkkarEtAlRhypo2014

Hazard Calculation Input files

job.ini

(configuration file)

ssmLT.xml

(source model logic tree)

gmmLT.xml

(ground motion logic tree)

ssm.xml

(seismic sources)

GMPEs from: https://docs.openquake.org/oq-engine/master/openquake.hazardlib.gsim.html

Note: files can use any name; these are the standard names (keeping extensions)

Job.ini

GEM

```
[general]
description = Seismic hazard analysis for Italy - simplified model
calculation_mode = classical

[geometry]
region = 5.7 47, 5.7 35, 18 35, 18 47
region_grid_spacing = 20

[calculation]
source_model_logic_tree_file = ssmLT.xml
gsim_logic_tree_file = gmmLT.xml
investigation_time = 50.0
intensity_measure_types_and_levels = {
  "PGA": [0.005, 0.0098, 0.0192, 0.0376, 0.0738, 0.145, 0.284, 0.556, 1.09, 2.13],
  "SA(0.1)": [0.005, 0.0098, 0.0192, 0.0376, 0.0738, 0.145, 0.284, 0.556, 1.09, 2.13]}
truncation_level = 3
maximum_distance = 200

[erf]
rupture_mesh_spacing = 2
width_of_mfd_bin = 0.2
area_source_discretization = 10.0

[site_params]
reference_vs30_value = 800.0
reference_vs30_type = measured
reference_depth_to_2pt5km_per_sec = 5.0
reference_depth_to_1pt0km_per_sec = 100.0

[output]
poes = 0.1
mean_hazard_curves = true
quantile_hazard_curves = 0.15 0.5 0.85
hazard_maps = true
uniform_hazard_spectra = true
export_dir = .
```

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Job.ini

```
[general]
description = Seismic hazard analysis for Italy - simplified model
calculation_mode = classical
```

- Calculation description
- Calculation type (in this course we perform classical PSHA)

```
[geometry]
region = 5.7 47, 5.7 35, 18 35, 18 47
region_grid_spacing = 20
```

- Geometry of calculation sites defined by a polygon (longitude-latitude) and a distance (in km) to be used to discretize the polygon area into individual sites

Job.ini

GEM

```
[calculation]
source_model_logic_tree_file = ssmLT.xml
gsim_logic_tree_file = gmmLT.xml
```

- Points to the seismic source and ground motion logic tree files

```
investigation_time = 50.0
```

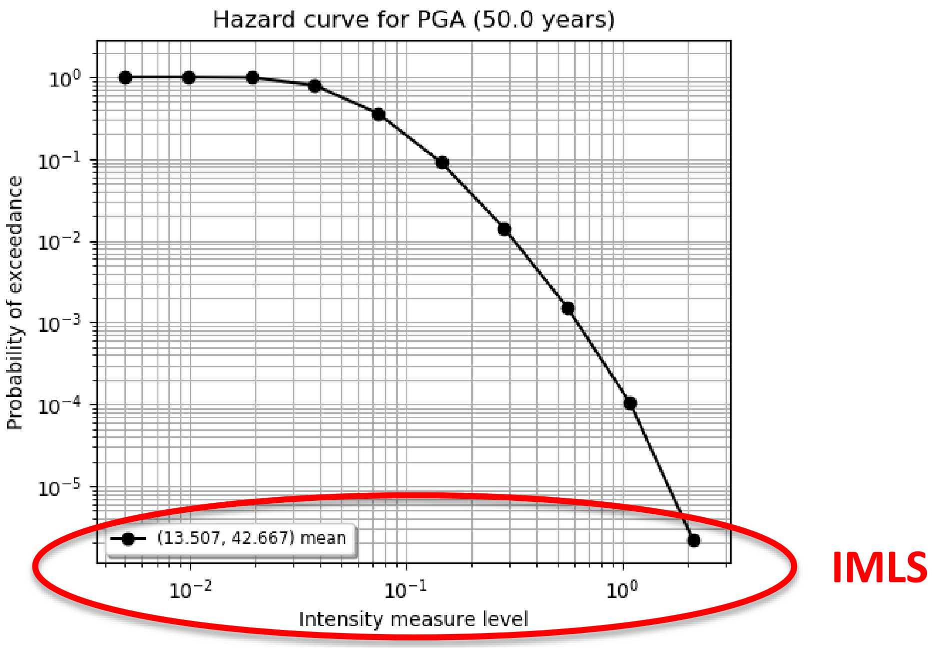
- Investigation time of the calculation (in years)

Job.ini

GEM

```
intensity_measure_types_and_levels = {
  "PGA": [0.005, 0.0098, 0.0192, 0.0376, 0.0738, 0.145, 0.284, 0.556, 1.09, 2.13],
  "SA(0.1)": [0.005, 0.0098, 0.0192, 0.0376, 0.0738, 0.145, 0.284, 0.556, 1.09, 2.13]}
```

- Ground motion intensity measure types and levels (usually in g) for which the probability of exceedence will be computed
- The independent variable (x-axis)
- Values must be consistent with GMPE(s) being used



GLOBAL QUAKE MODEL .ORG

Job.ini

GEM

```
truncation_level = 3
```

- Level of truncation of the Gaussian distribution of the logarithm of ground motion used in the calculation of hazard (typically 3)

```
maximum_distance = 200
```

- The largest distance (in km) between a rupture and the target calculation sites in order for the rupture to be considered in the PSHA calculation.
- (i.e. the distance within which sources will contribute to the computation of the hazard).

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Job.ini

```
[erf]
rupture_mesh_spacing = 2
width_of_mfd_bin = 0.2
area_source_discretization = 10.0
```

- Parameters related to the ruptures (ERF = earthquake rupture forecast)
- Here we specify the level of discretization of the:
  - mesh representing faults (km)
  - magnitude-frequency distribution bins
  - grid used to delineate the area sources (km)

Job.ini

```
[site_params]
reference_vs30_value = 800.0
reference_vs30_type = measured
reference_depth_to_2pt5km_per_sec = 5.0
reference_depth_to_1pt0km_per_sec = 100.0
```

- Specification of local soil conditions for computation sites

- Parameter required by the majority of GMPEs:
  - Vs30 (m/s)
- Parameters only used by a few GMPEs (ignored if not needed)
  - If Vs30 was "measured" or "inferred"
  - Depth (km) to Vs=2500m/s
  - Depth (m) to Vs=1000m/s

Job.ini

GEM

```
[output]
poes = 0.1
mean_hazard_curves = true
quantile_hazard_curves = 0.15 0.5 0.85
hazard_maps = true
uniform_hazard_spectra = true
export_dir = .
```

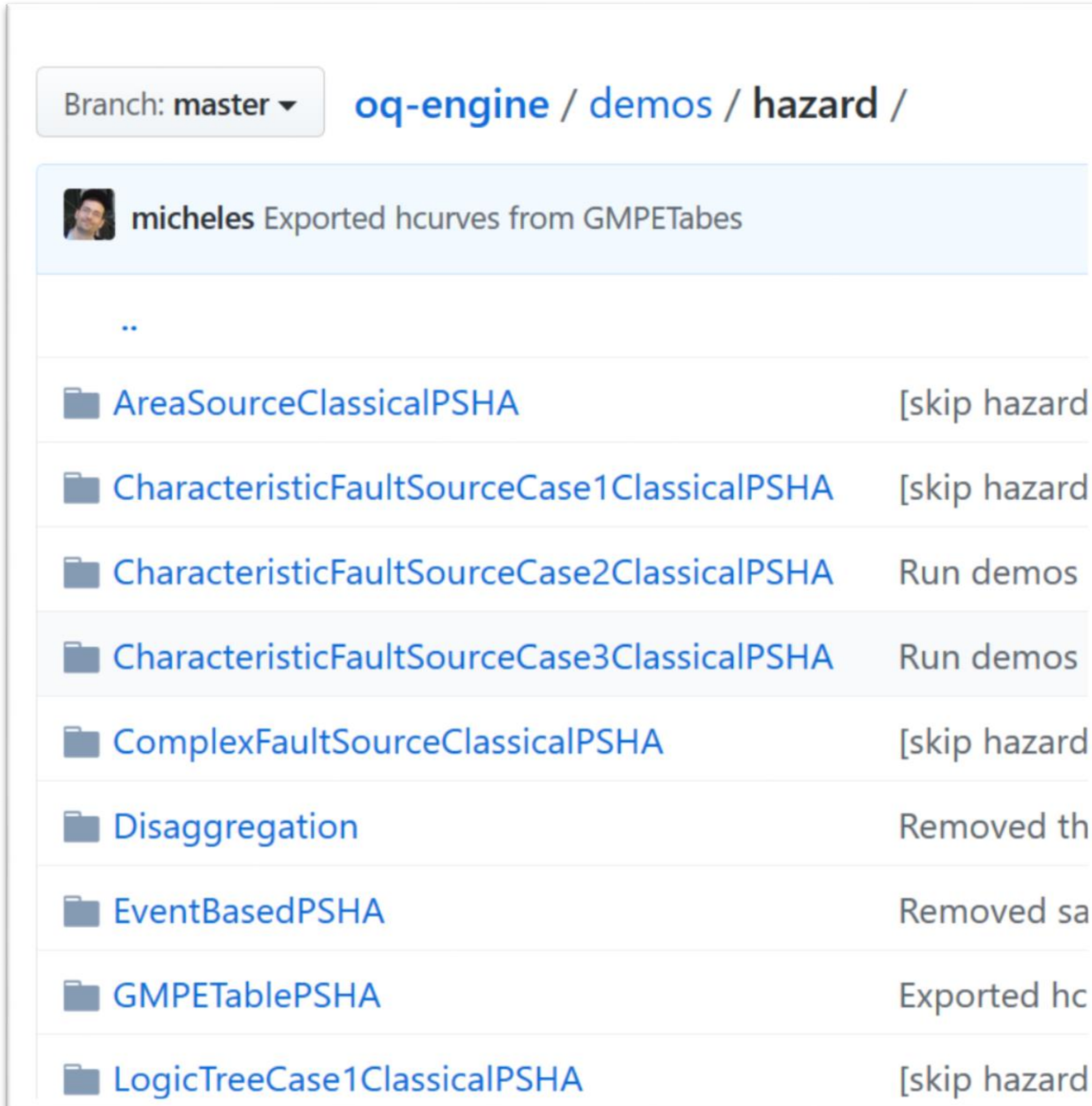
- Specifying poes (probability of exceedance) will output hazard maps
- Setting mean_hazard_curves to true will result in a specific output containing the mean curves of the logic tree
- quantile_hazard_curves will produce separate files containing the quantile hazard curves at the quantiles listed
- Setting uniform_hazard_spectra to true will output the uniform hazard spectra at the poes specified
- Providing an export directory will tell OpenQuake where to place the output files if the --exports flag is used in the command line (e.g. oq engine –run job.ini –exports=csv

Want to see more calculation examples?

GEM

- OpenQuake Demos: https://github.com/gem/oq-engine/tree/master/demos/hazard

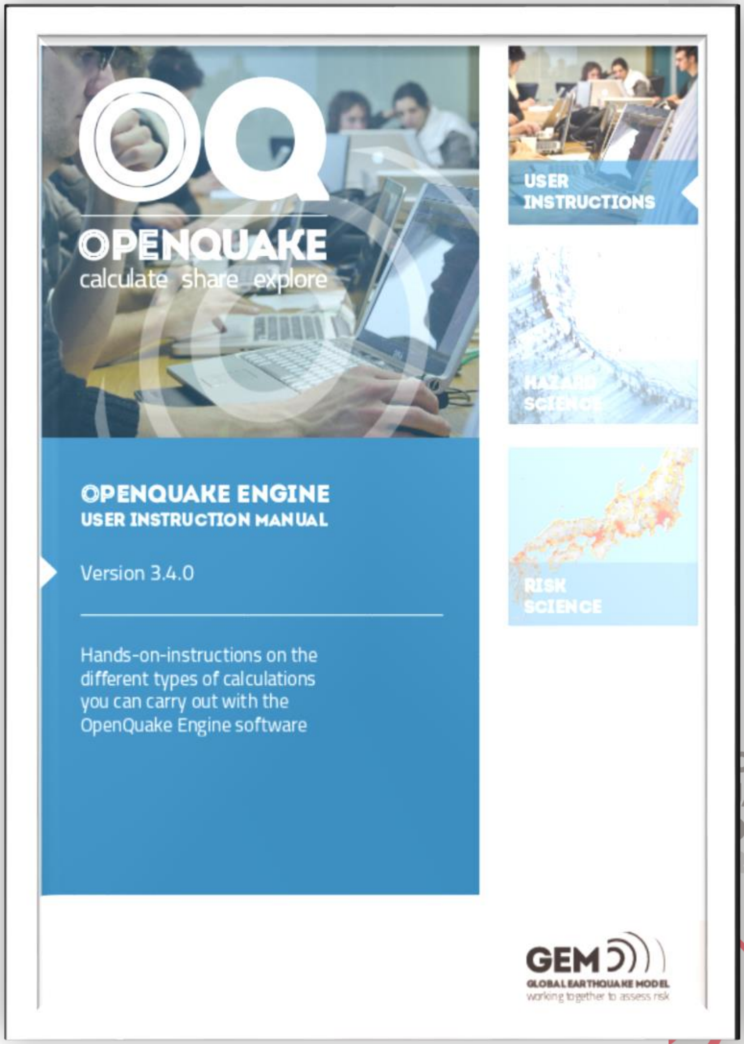
- Examples of hazar calculations using different source typologies, logic trees, etc..



Your OQ reference for this course

- The OQ manual explains all the input parameters required to run hazard (and risk) calculations, including examples.

- The manual can be found here: https://docs.openquake.org/manuals/OpenQuake%20Manual%20%28latest%29.pdf



Your OQ reference for this course

- Mistakes? Anything unclear?
- Add you comments to this Google Document, and we'll include your suggestion in future versions of the manual.