GEM

GLOBAL EARTHQUAKE MODEL

working together to assess risk

Subduction modelling for PSHA: GEM experiences in Latin America

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Latin American and Caribbean Seismological Commission (LACSC)
Seismological Society of America (SSA)
Miami, Florida, 14–17 May 2018

OPENQUAKE

Outline

- Modelling subduction earthquakes in PSHA
  - Current approaches
  - GEM experiences in Latin America
  - Pending issues and challenges for the future

Subduction modelling for PSHA: GEM experiences in Latin America

Modelling subduction earthquakes

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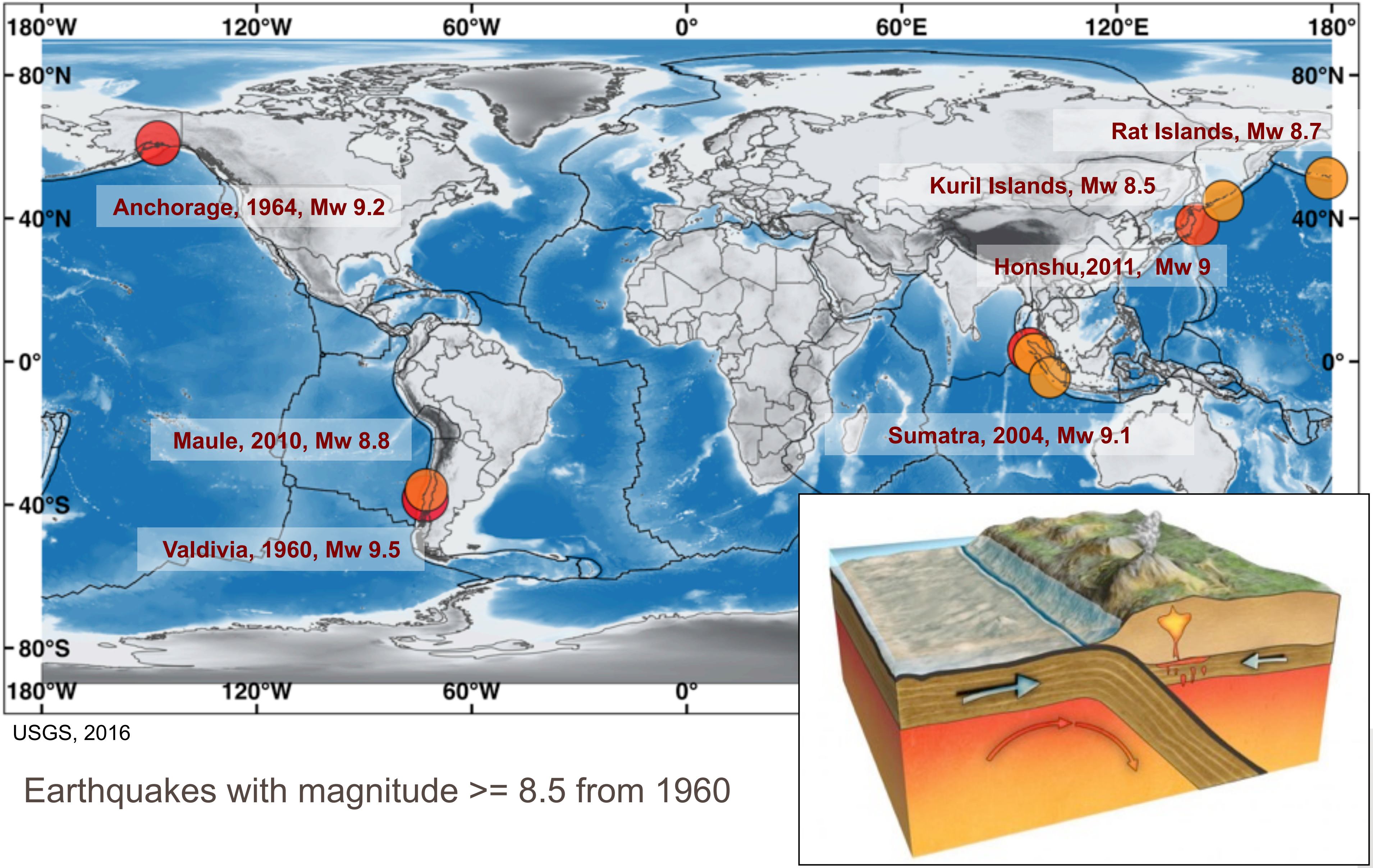
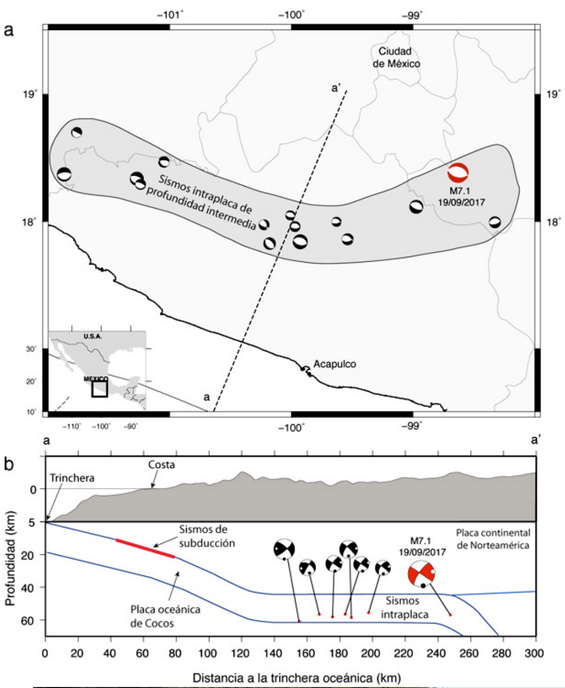
The largest earthquakes on the planet occur along subduction zones



USGS, 2016

Earthquakes with magnitude >= 8.5 from 1960

Mexico in-slab earthquake [damages]



From: Ciencia UNAM

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Challenges in modelling subduction zones for PSHA

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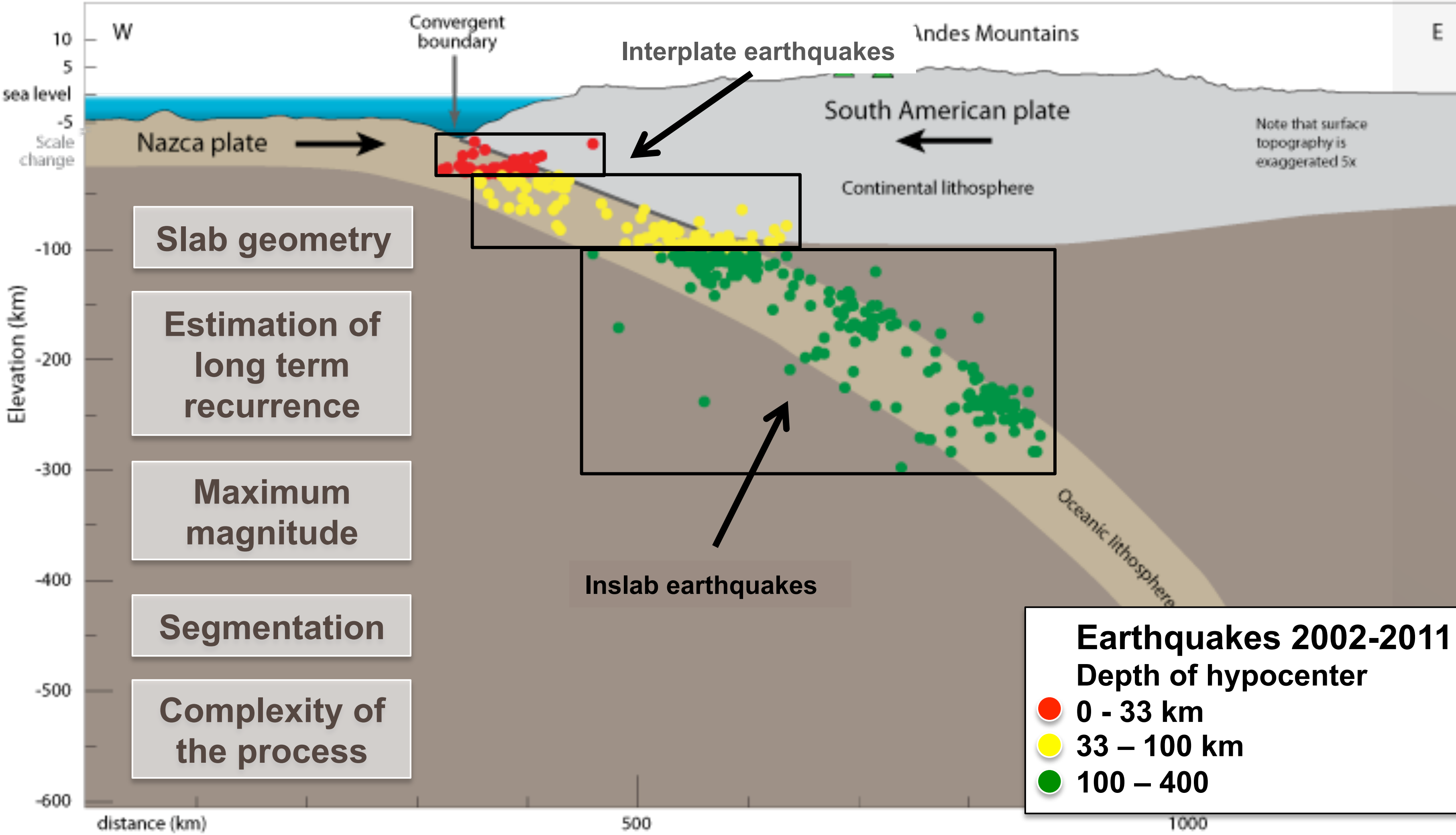
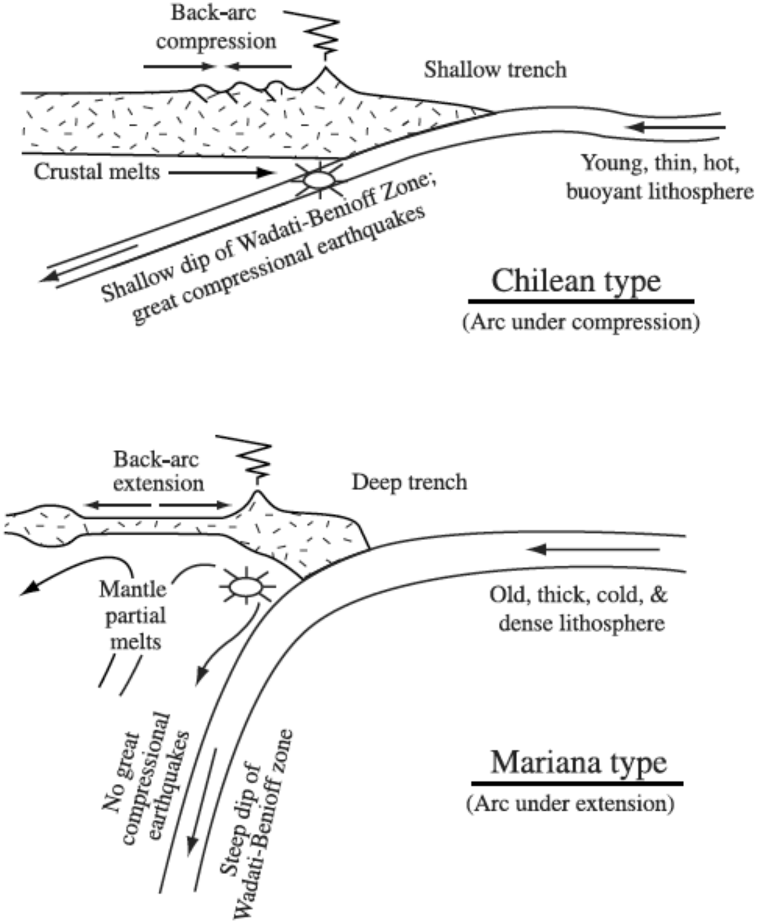


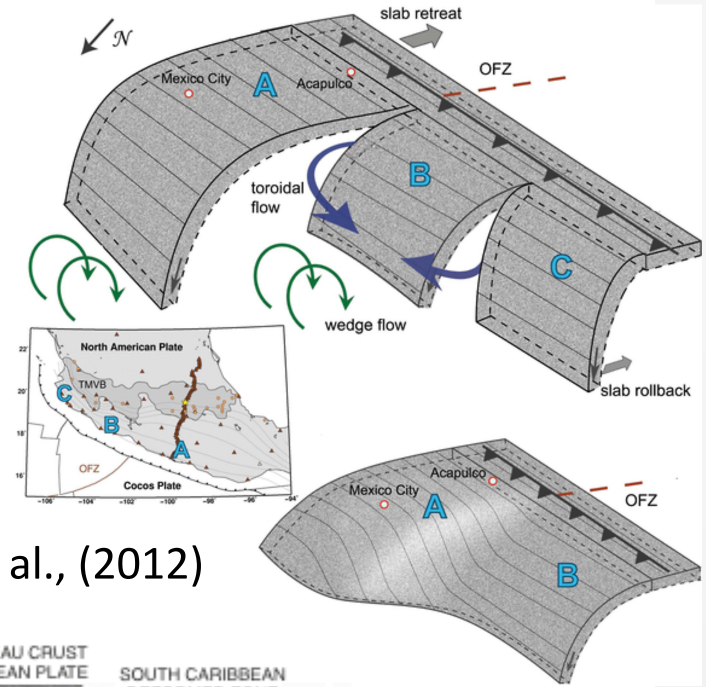
- Slab geometry
- Estimation of long term recurrence
- Maximum magnitude
- Segmentation
- Complexity of the process

Egger, 2003

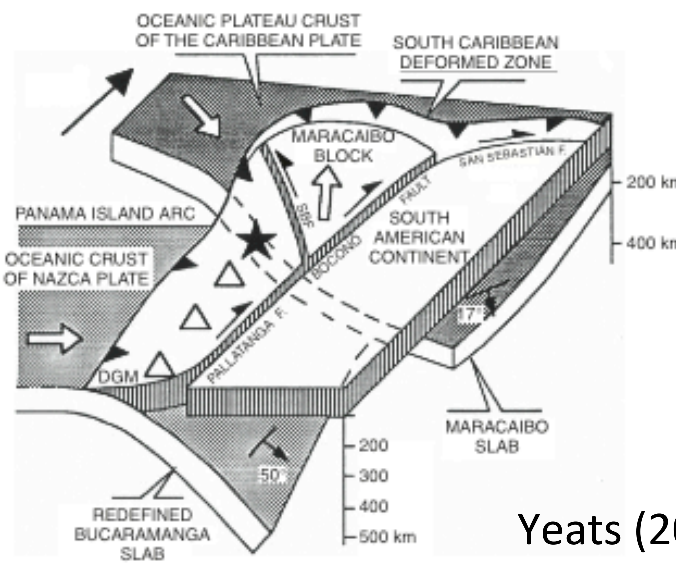
Subduction



Stern (2002)



Stubailo et al., (2012)

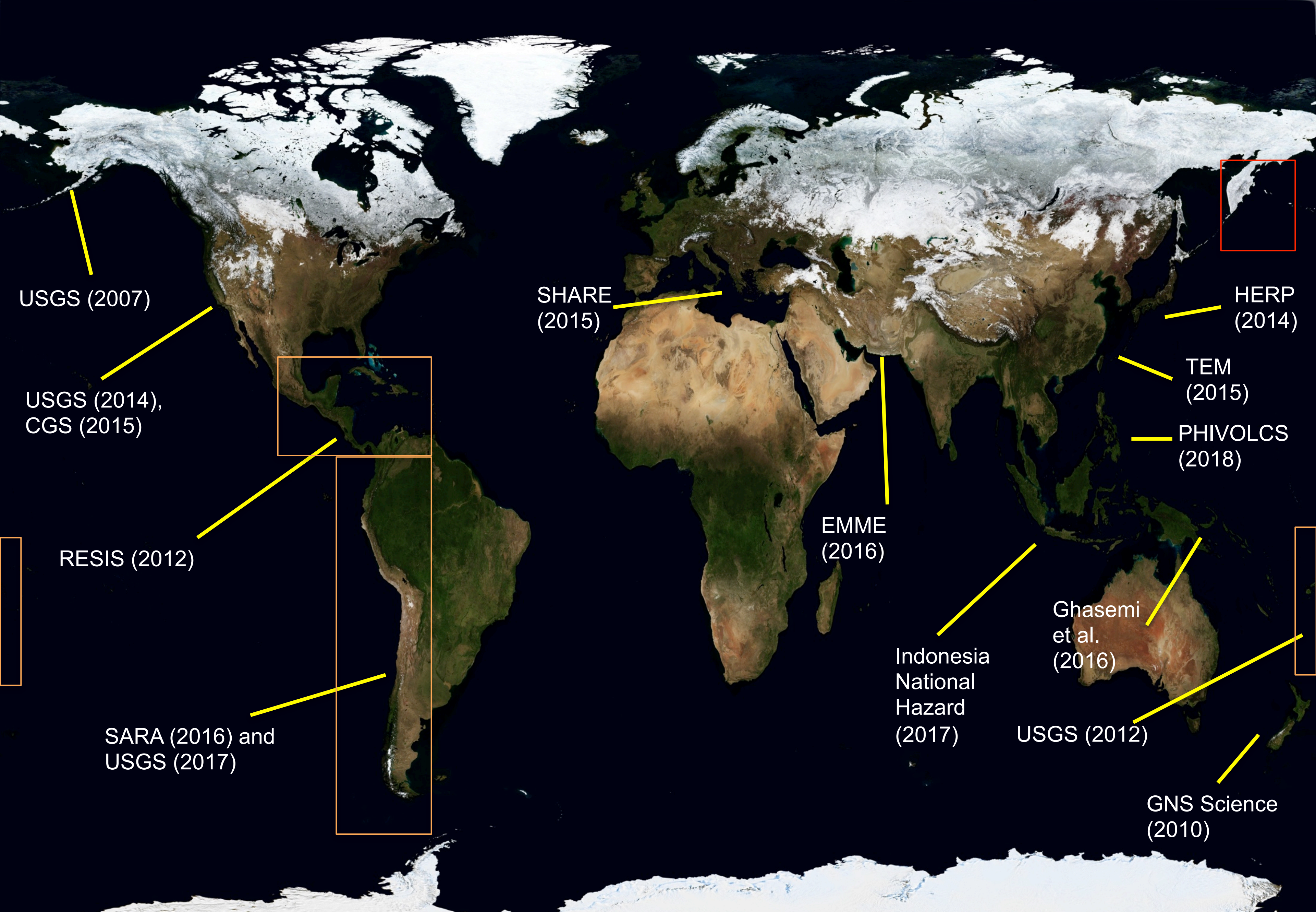


Yeats (2012)

Modelling subduction earthquakes

Current approaches

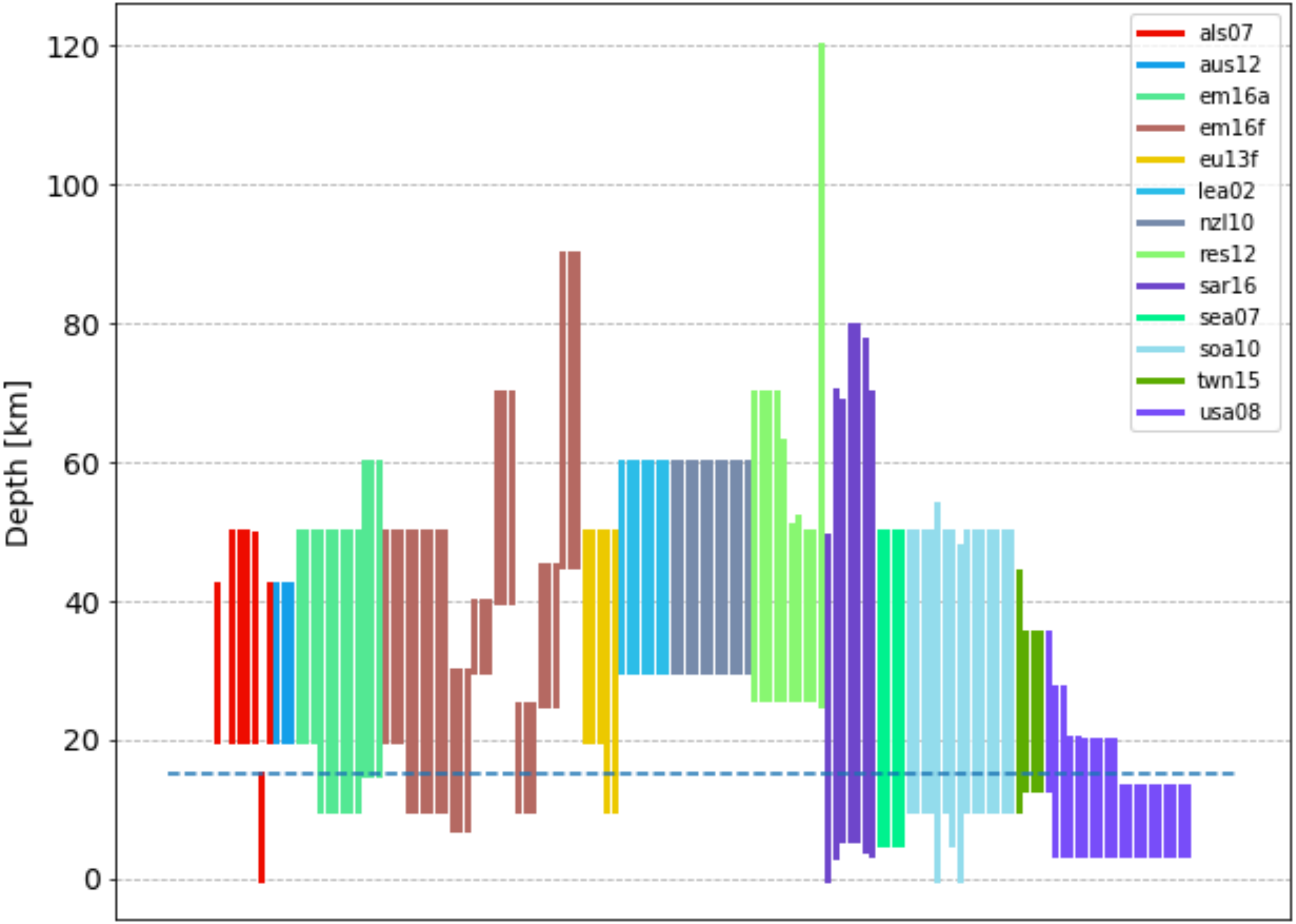
GEM's hazard model database



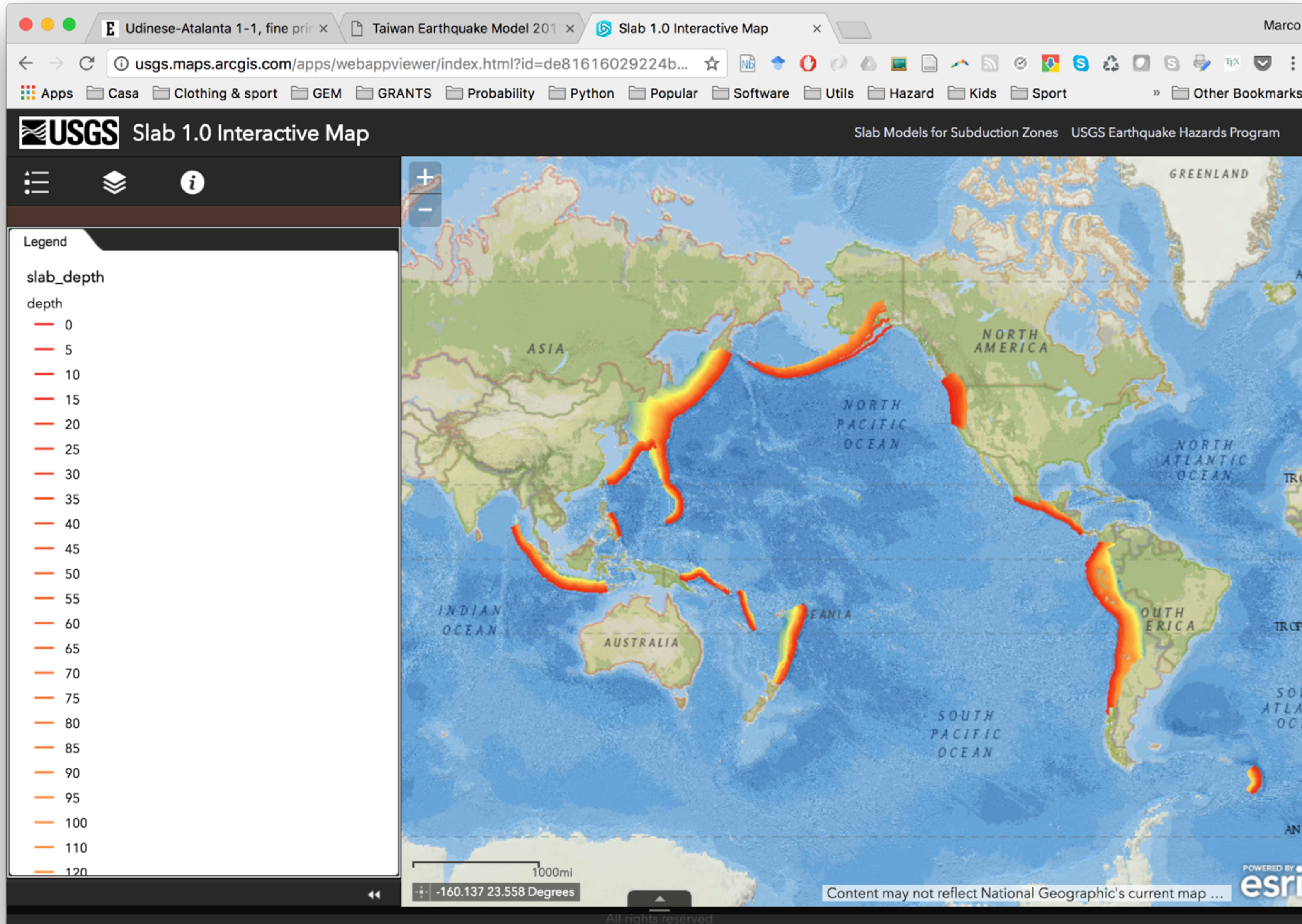
Current approaches

- Interface: the ruptures are modelled as 3D surfaces placed on a 3D surface describing the geometry of the fault plane (e.g. USGS, GEM, SHARE)
- In-slab: the ruptures are modelled:
  - Using a smoothing process of past seismicity for various depth intervals (e.g. USGS)
  - Using volumes of seismicity (e.g. GEM, Ecuador, SHARE, RESIS)
- Characterisation of earthquake occurrence considers various information including: past seismicity, tectonics, paleoseismicity
  - GR model [floating ruptures]
  - Characteristic model

Interface: along-dip constraints



Defining the top of the slab



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Modelling subduction earthquakes

GEM experiences in Latin America SARA project

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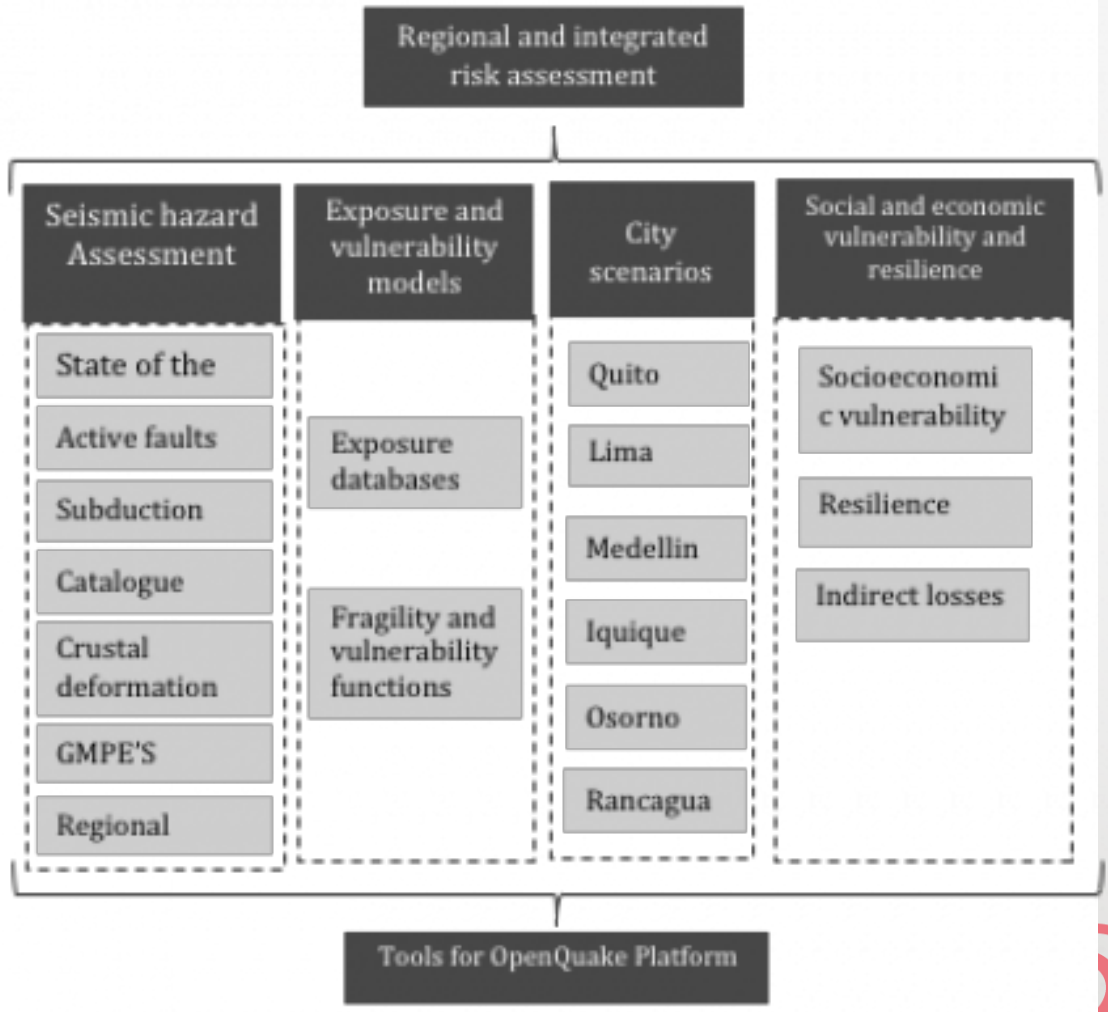
The SARA project

“South America integrated Risk Assessment ”

- Funded by SwissRE Foundation
- Duration: 2013-2015
- More than 20 local institutions involved
- Local experts led components/tasks



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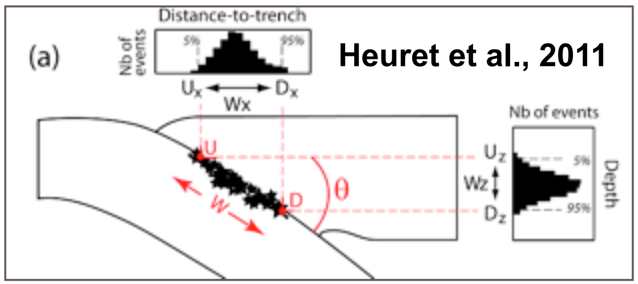
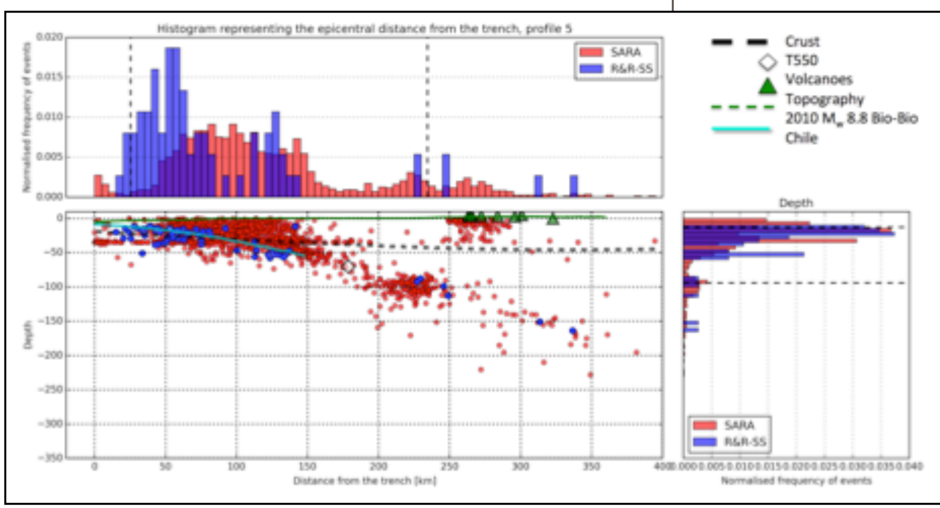
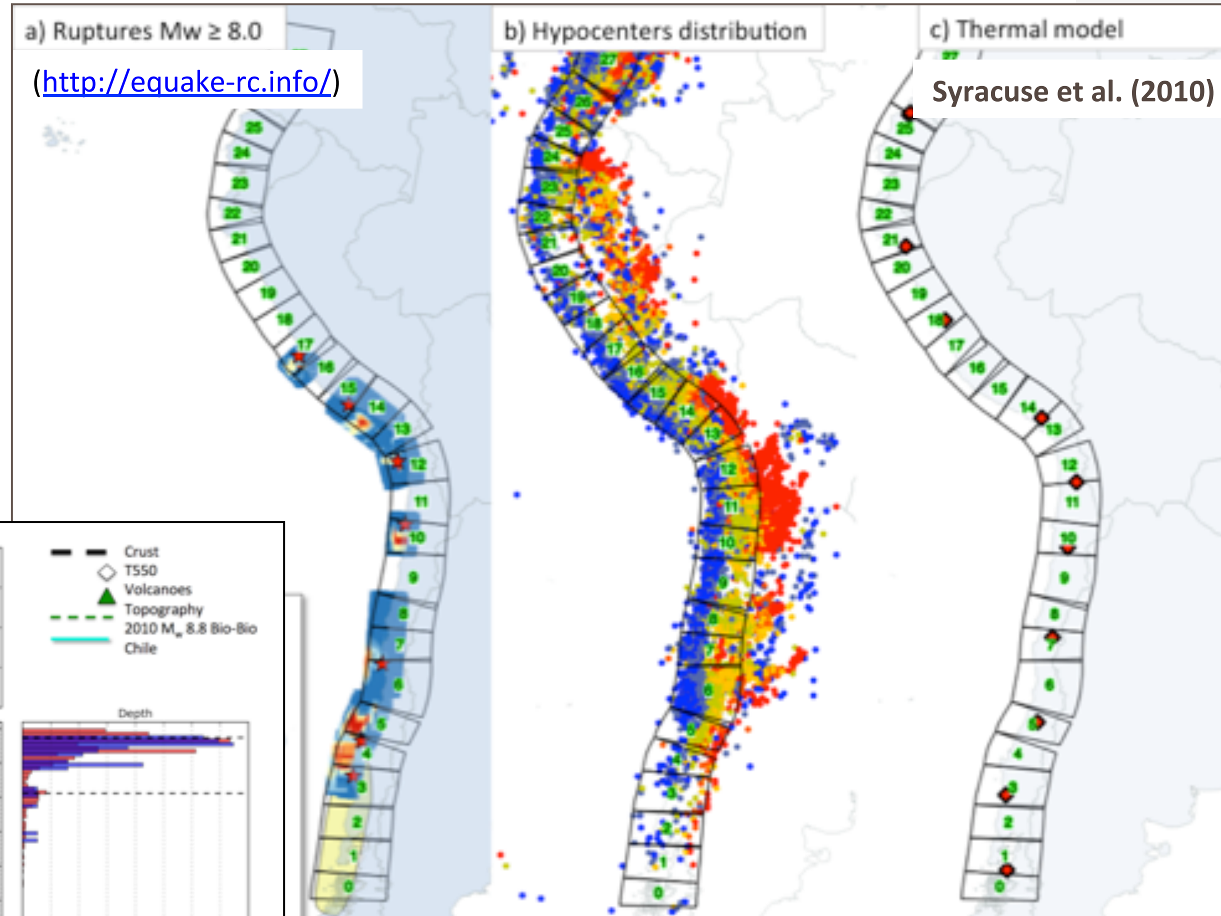
Modelling subduction [slab-geometry]

Zonation proposed by:

- GEM Hazard team
- IUSS Phd student







Interface

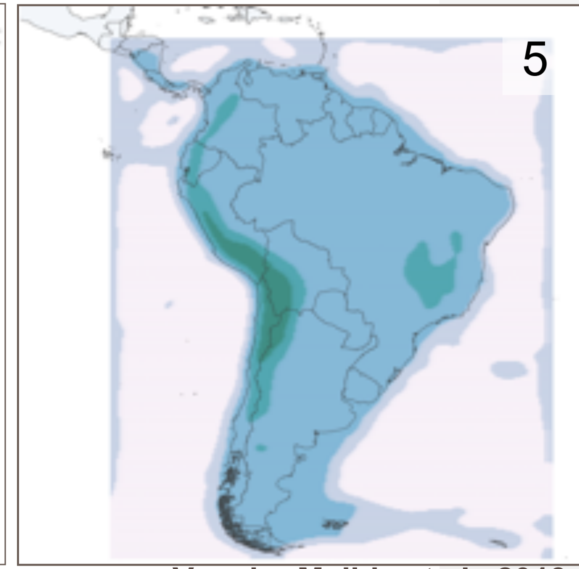
Rodriguez-Abreu L.E. (2016). Characterization of subduction source models for probabilistic seismic hazard analysis (PSHA). Thesis submited in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Engineering Seismology. IUSS, Pavia, Italy, April 2016.

Modelling subduction [slab-geometry]

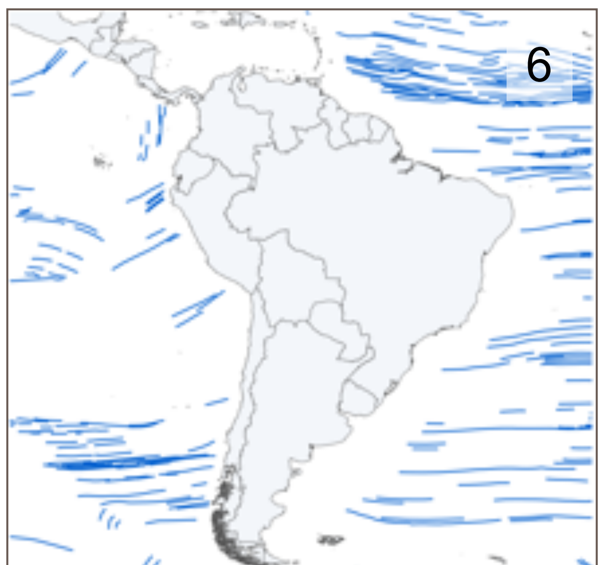
Second order information

4. Volcanoes database
5. Crustal thickness
6 and 7. Bathymetry and topography features (Fracture zones and sea mounts)

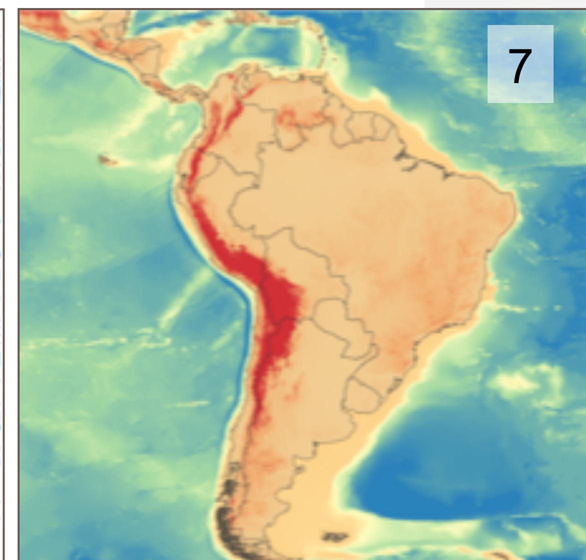
http://volcano.si.edu/



Van der Meijde et al., 2013



Matthews et al. 2011



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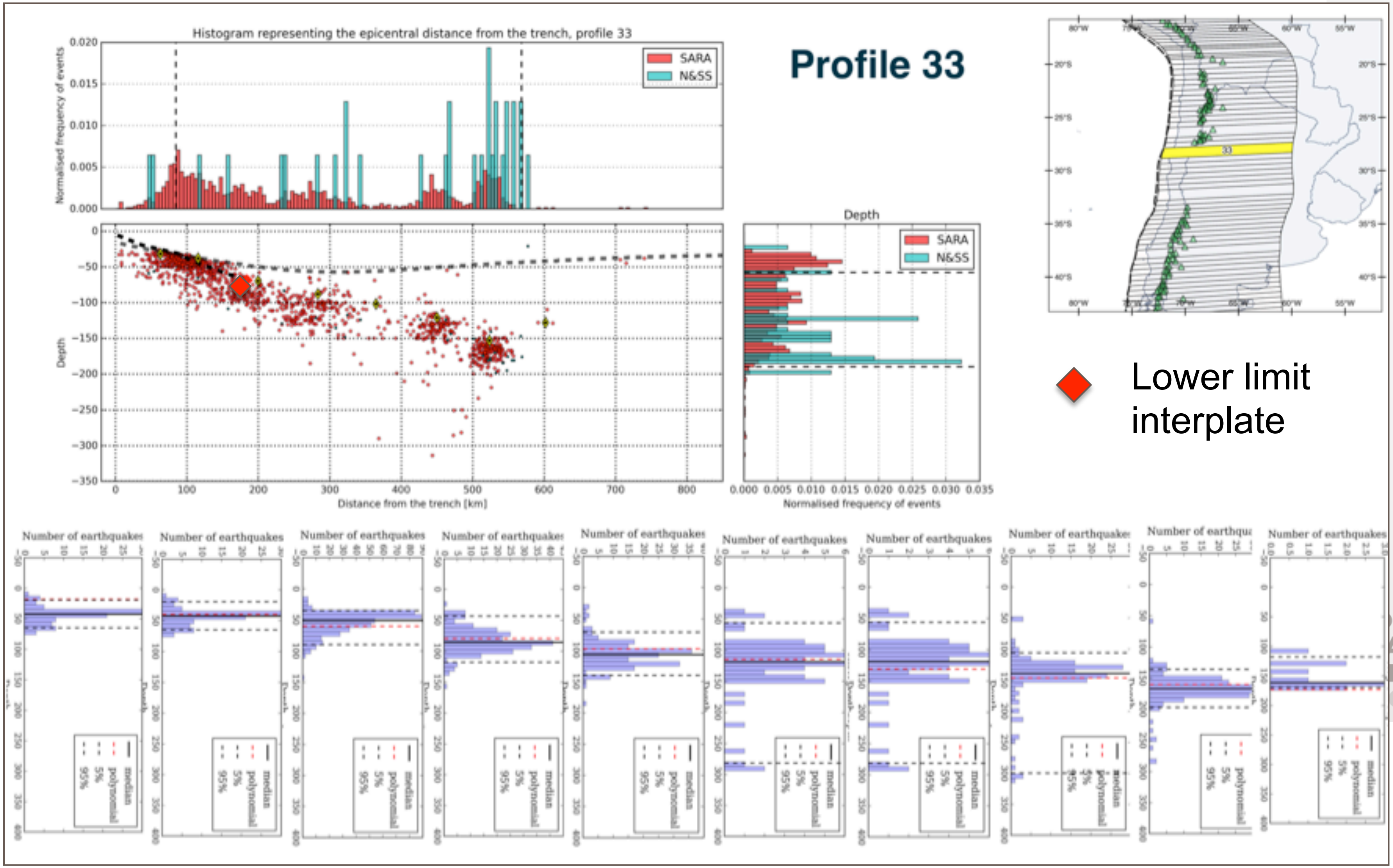
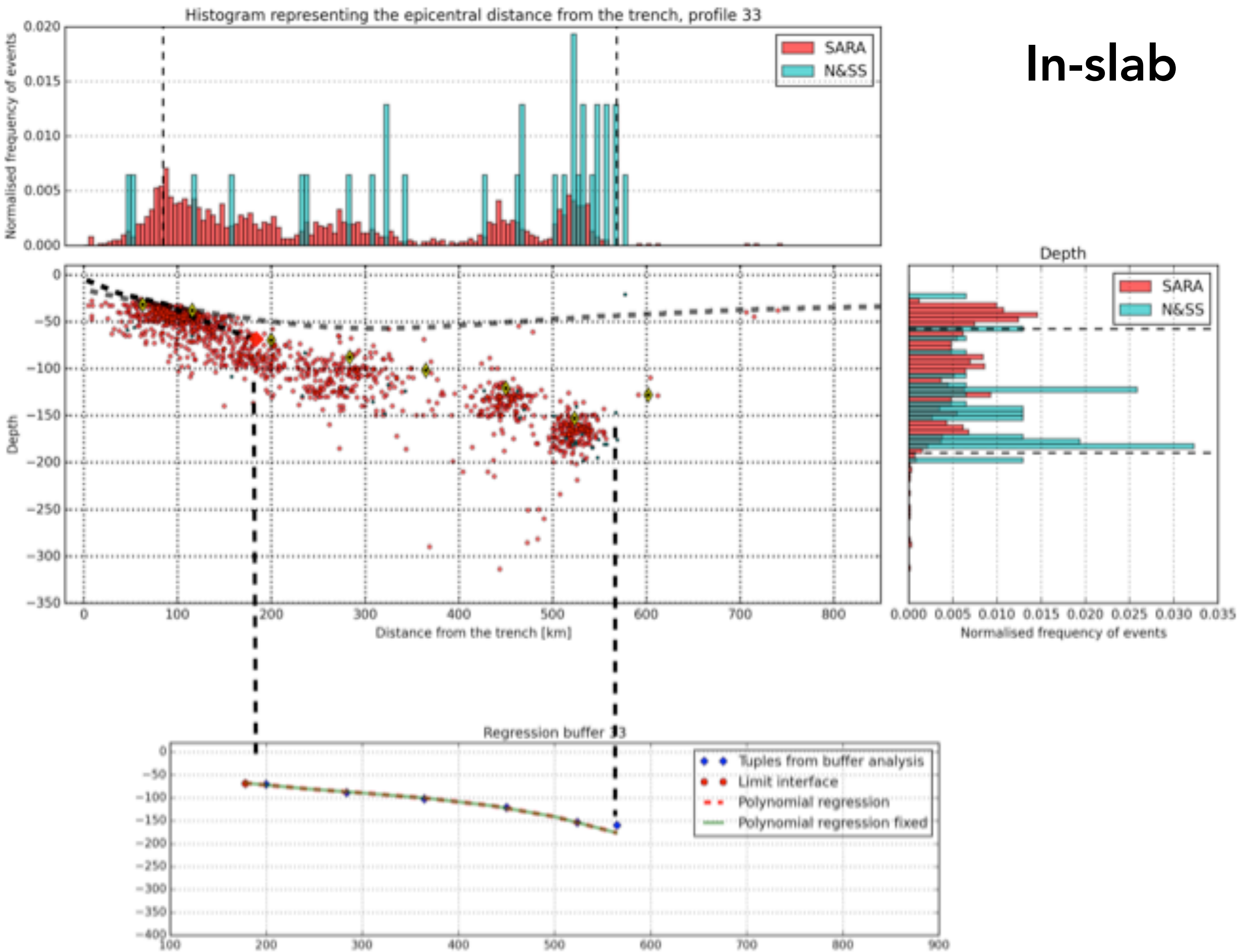
Modelling subduction [slab-geometry]

In-slab



Modelling subduction [slab-geometry]



In-slab

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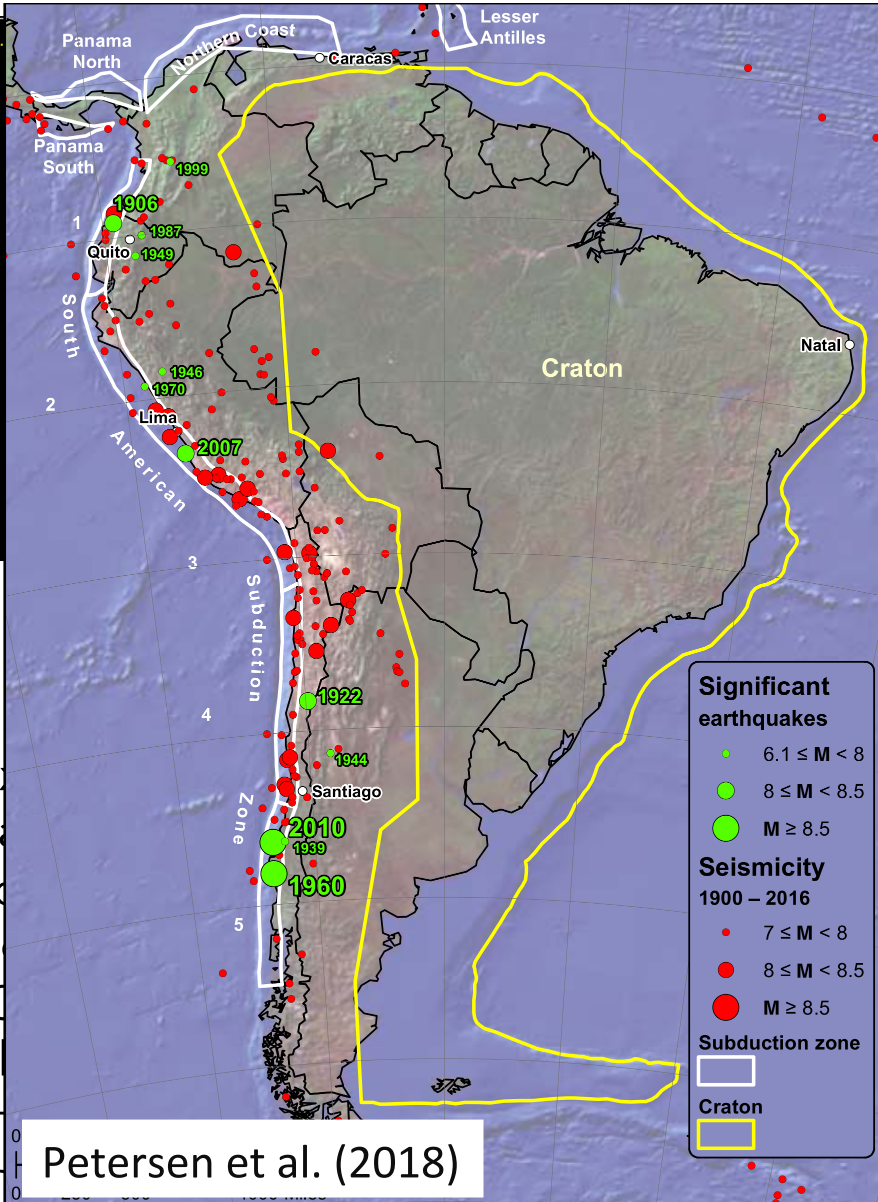
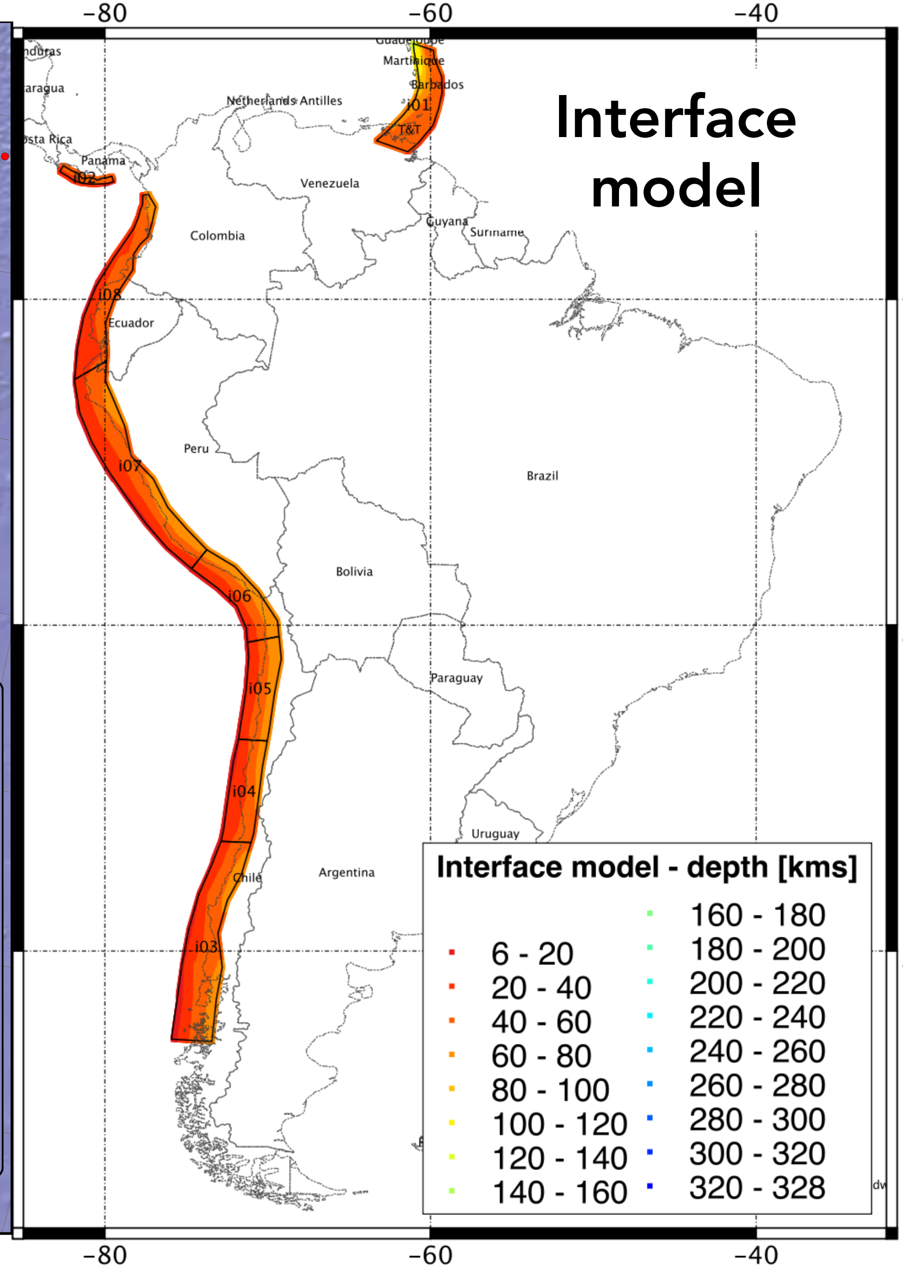
Modelling subduction [interface segmentation]



Petersen et al. (2018)



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3. T
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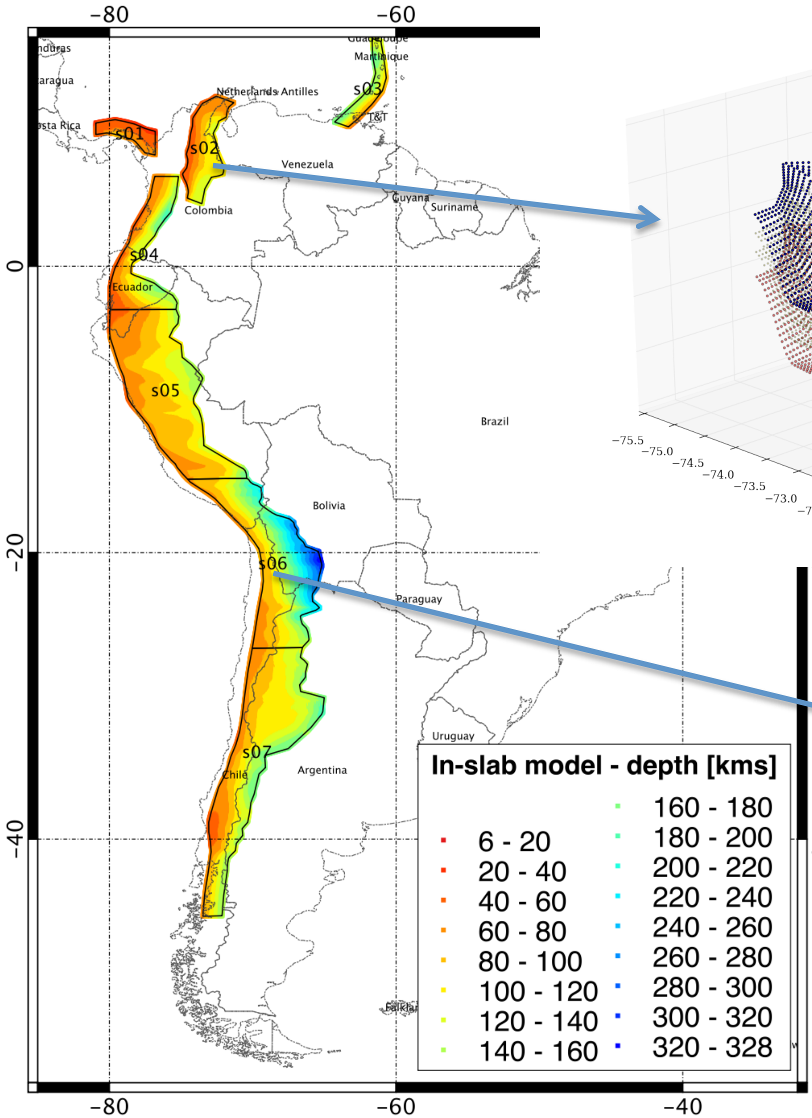
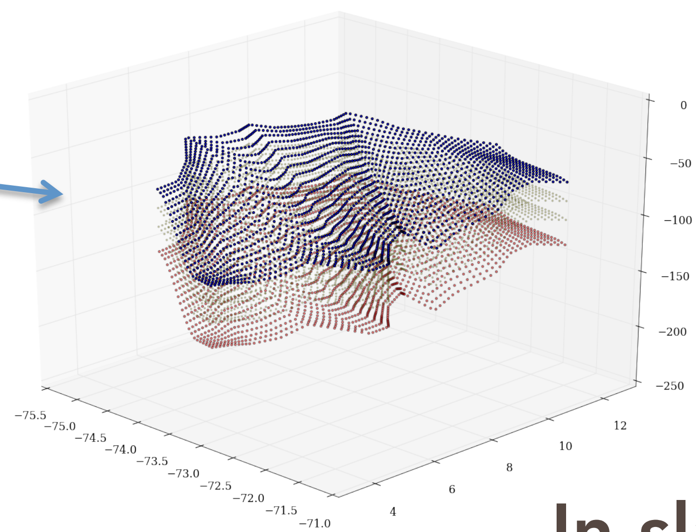
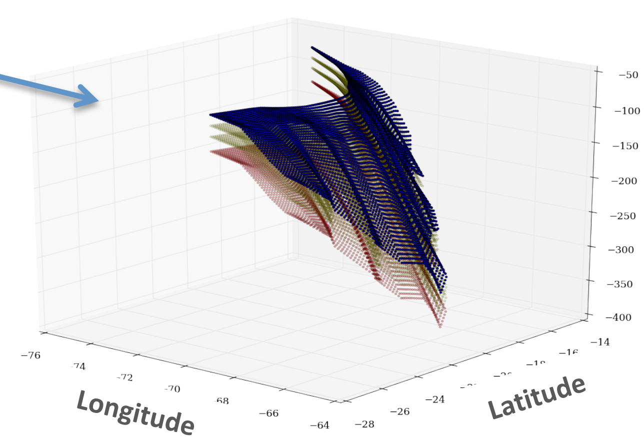
Modelling subduction [in-slab segmentation]

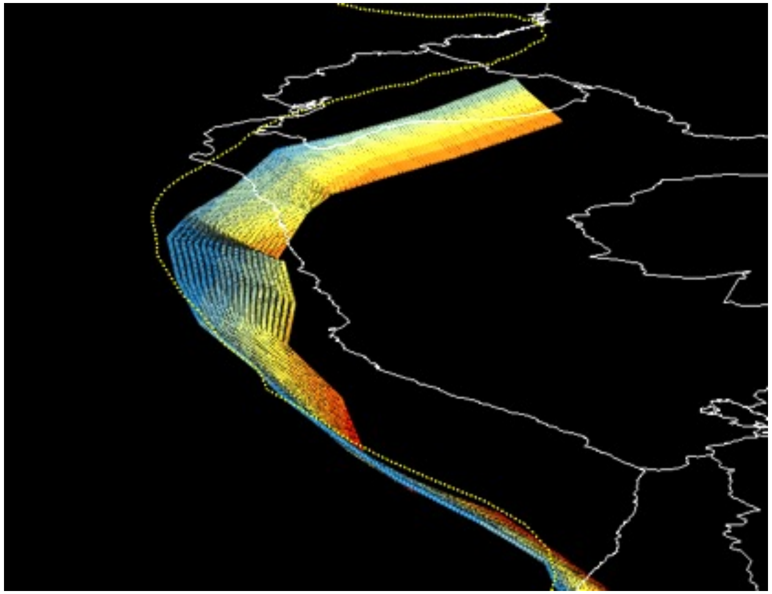




In-slab model



Modelling subduction [interface sources]

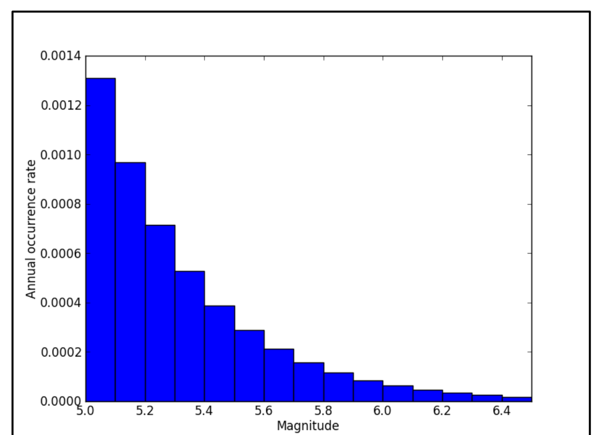


"Complex" Fault Source

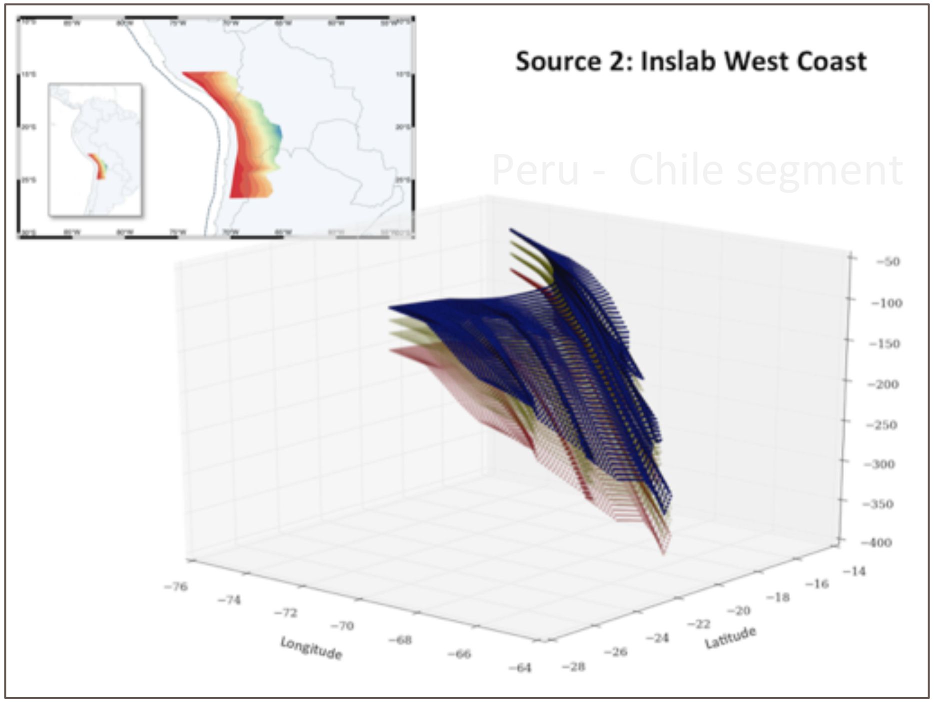
"Complex" refers to faults that can be more irregular in shape, e.g.:

- Changes in dip angle
- Non-parallel upper, intermediate and lower edges
- Widening/narrowing of the fault with depth

Ruptures are still able to "float" , but small perturbations in aspect ratio and area can occur depending on the location of the rupture on the fault



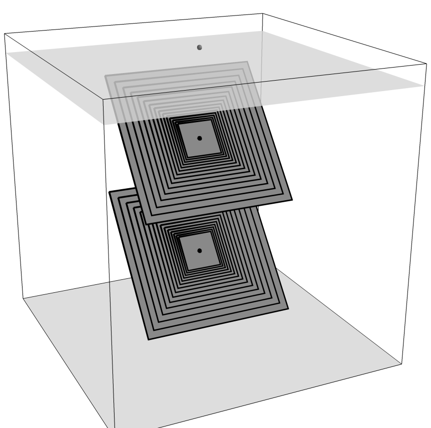
Modelling subduction [in-slab sources]

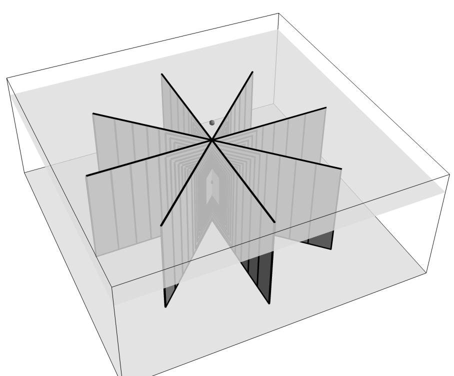


In-slab Sources

Point sources distributed in 3D volume, following the slab geometry

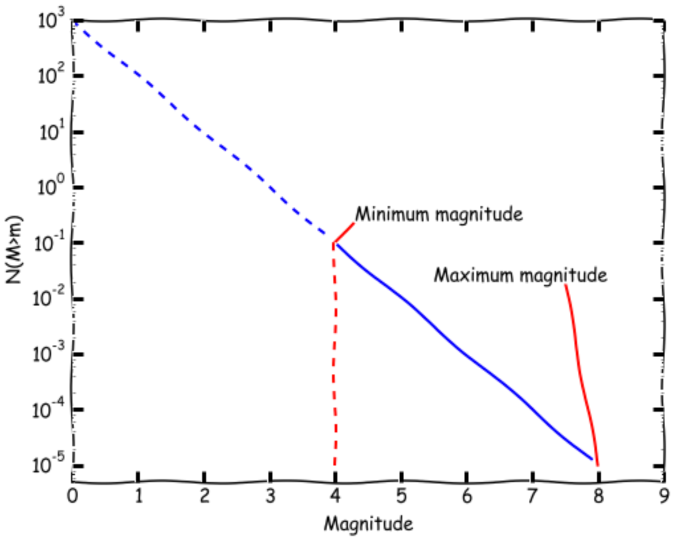
- Changes in dip angle
- The finite ruptures are generated with the centroids anchored to the nucleation points
- The finite ruptures are constrained on both their spatial extent and their orientation

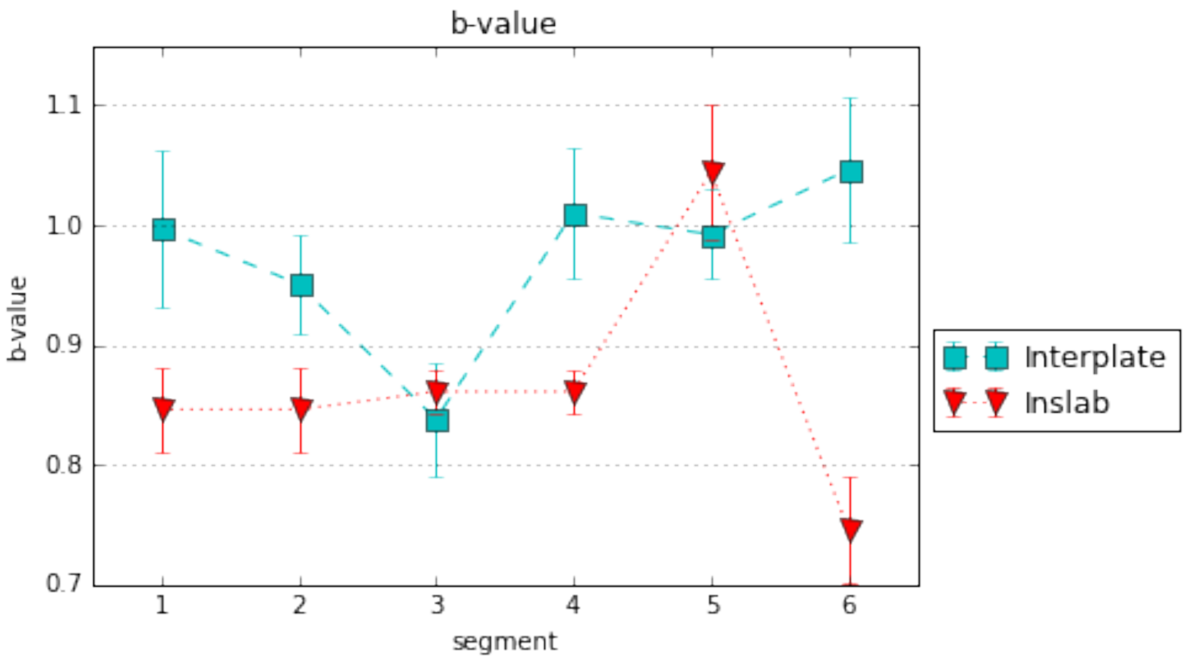




Earthquake occurrence and Mmax

- MFD: Double Truncated GR
- Characterization of occurrence
  - Using past seismicity (instrumental, historical and paleo-seismicity)
  - (future versions) Using information from tectonics and geodesy
- Mmax: based on global datasets and constrained by Strasser et al. (2010)





Modelling subduction earthquakes

GEM experiences in Latin America CCARA project

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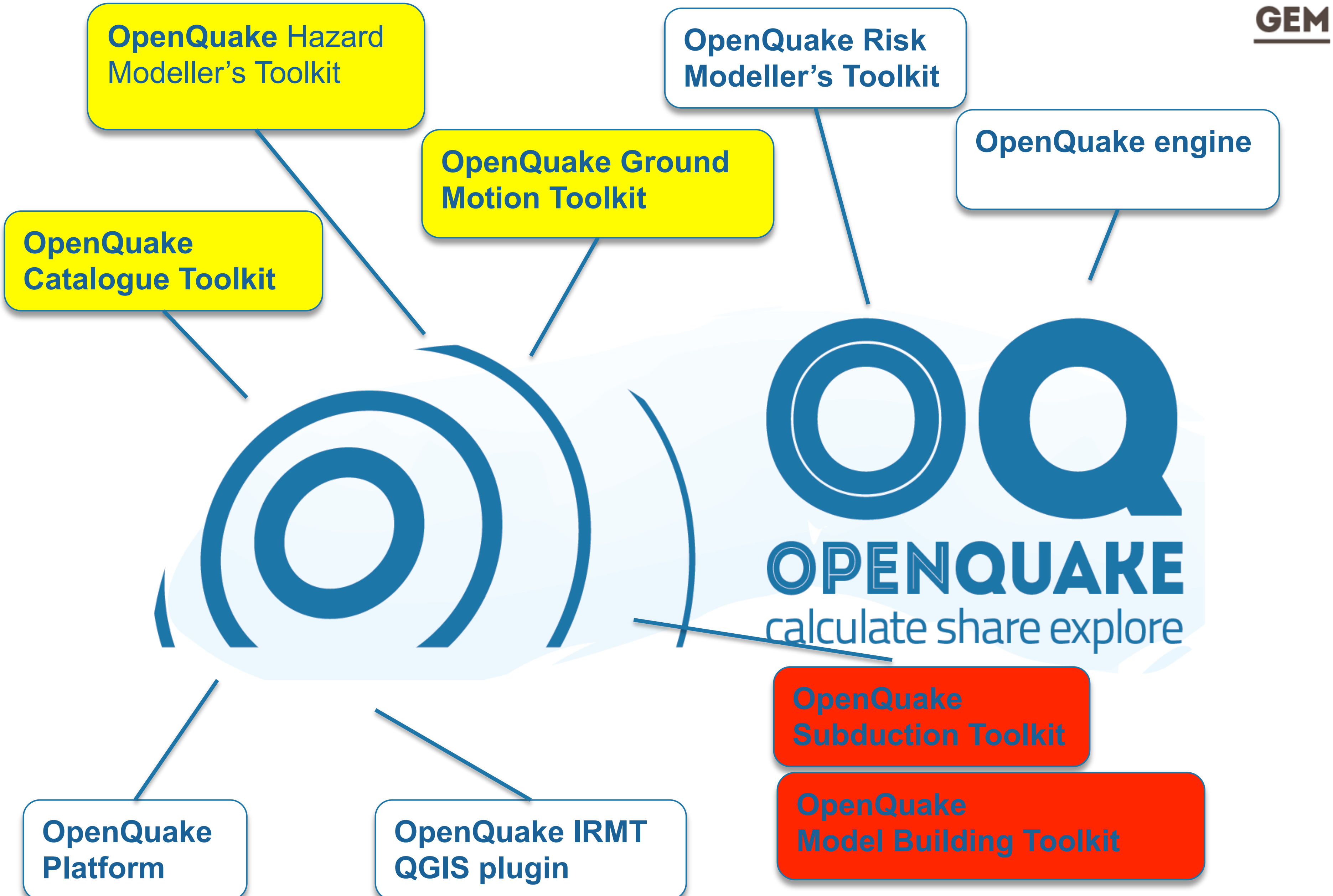
The CCARA project

Assessing and Mitigating Earthquake Risk in the Caribbean and Central America (CCARA)

– Funded by USAID
– Duration: 2016 – 2018

Main goals:
To develop capacity in the region of Central America and the Caribbean for earthquake risk assessment by leveraging GEM tools and resources, to enhance the understanding of earthquake risk, and to bridge the gap between risk assessment and disaster risk reduction.



https://github.com/gem
https://github.com/GEMScienceTools

Subduction Modelling

Workflow to define and characterize the sources:

- Definition of [2.5D] geometry of the whole slab
  - Creation of interface and in-slab source geometry
- Tectonic regionalization of the catalogue
- Characterization of sources

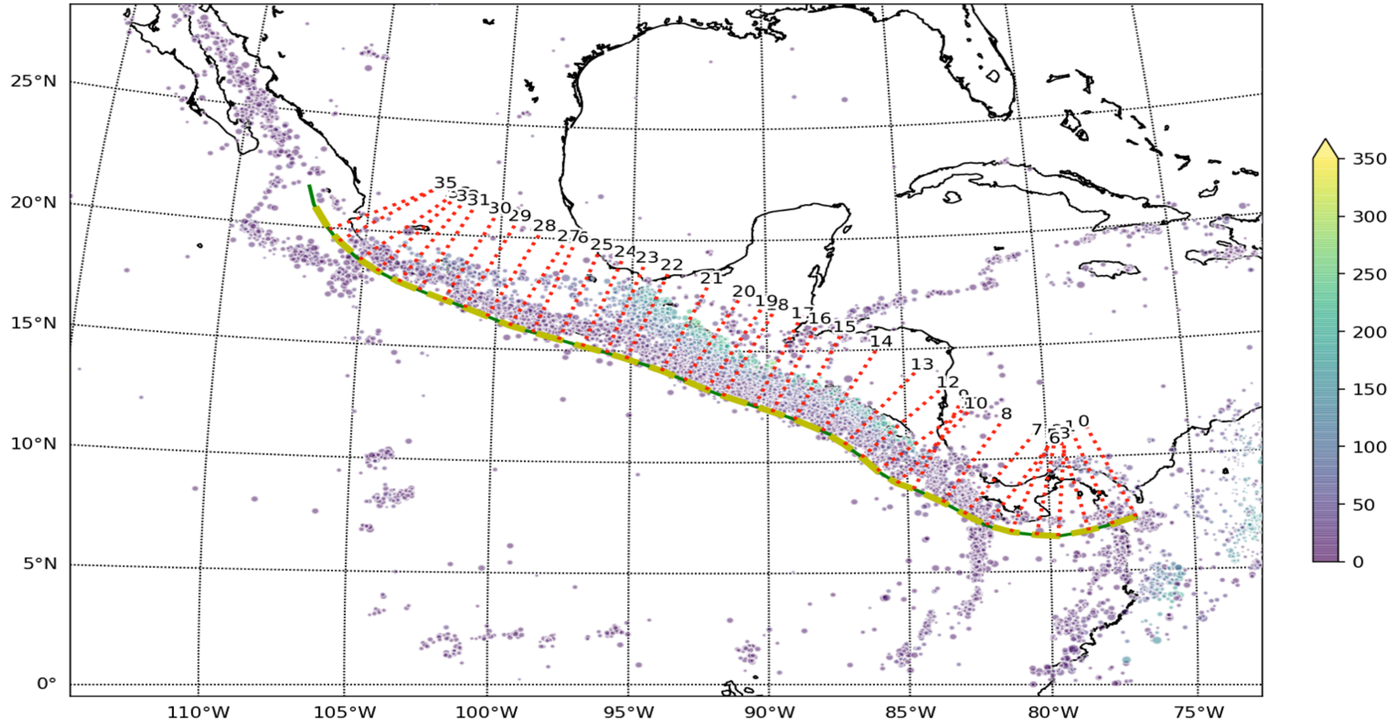
Modelling subduction earthquakes

Building the geometry

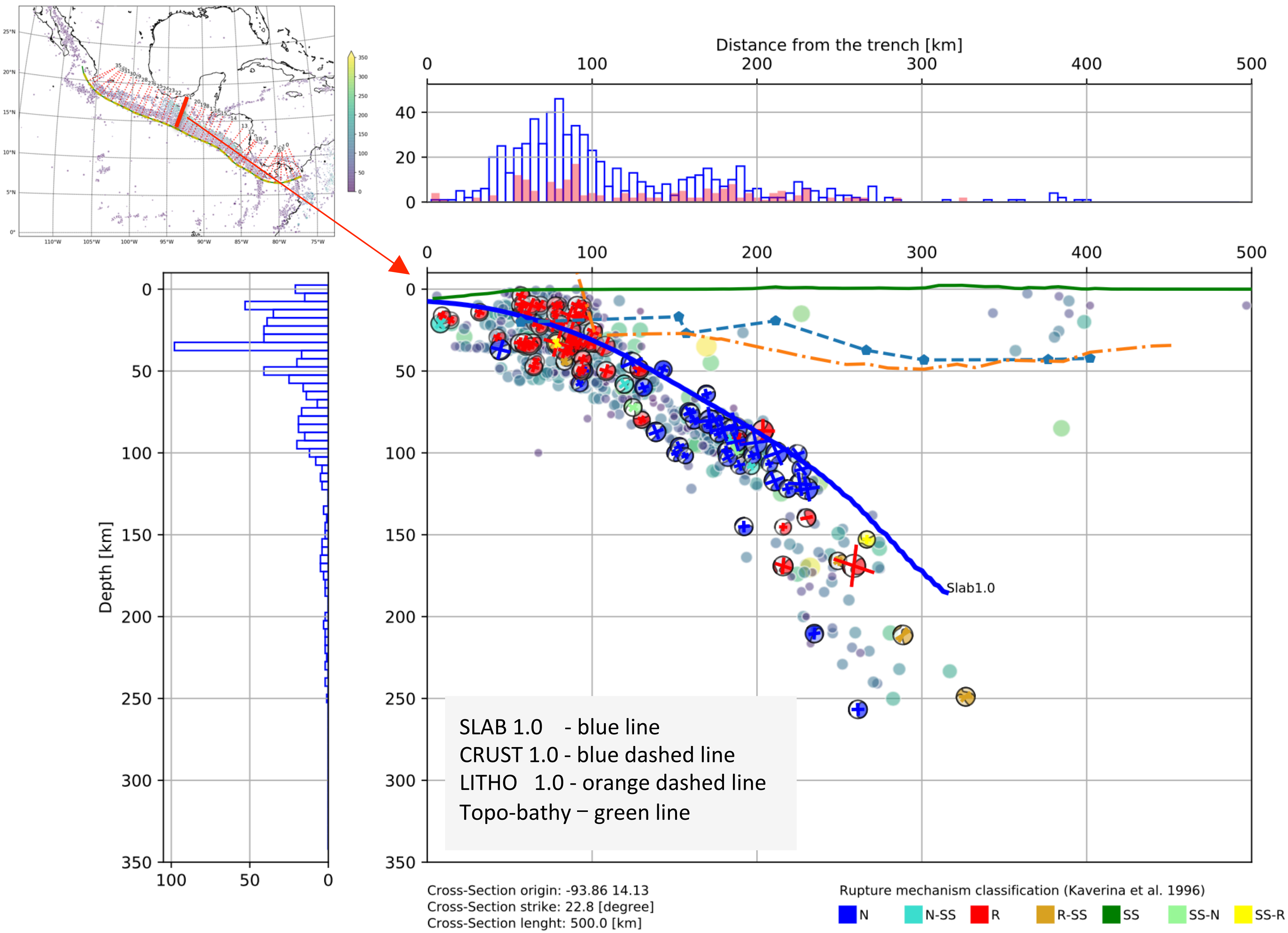
Defining the geometry of the slab

The definition of the slab geometry mostly consists on the delineation of the surface representing the top of the slab.

The procedure starts with the definition of a number of cross-sections [along the subduction trench]…

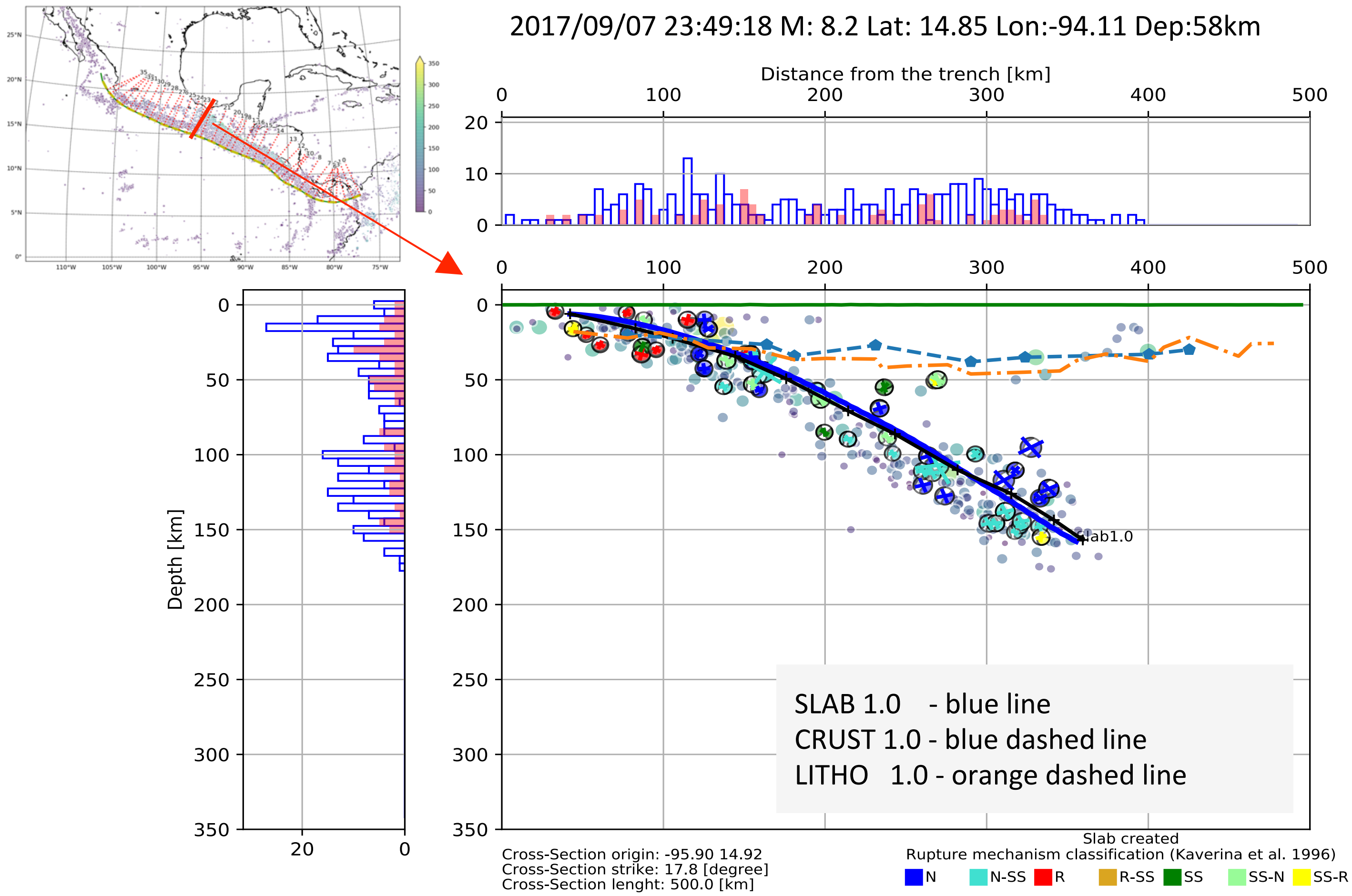


Subduction geometry: top of the slab

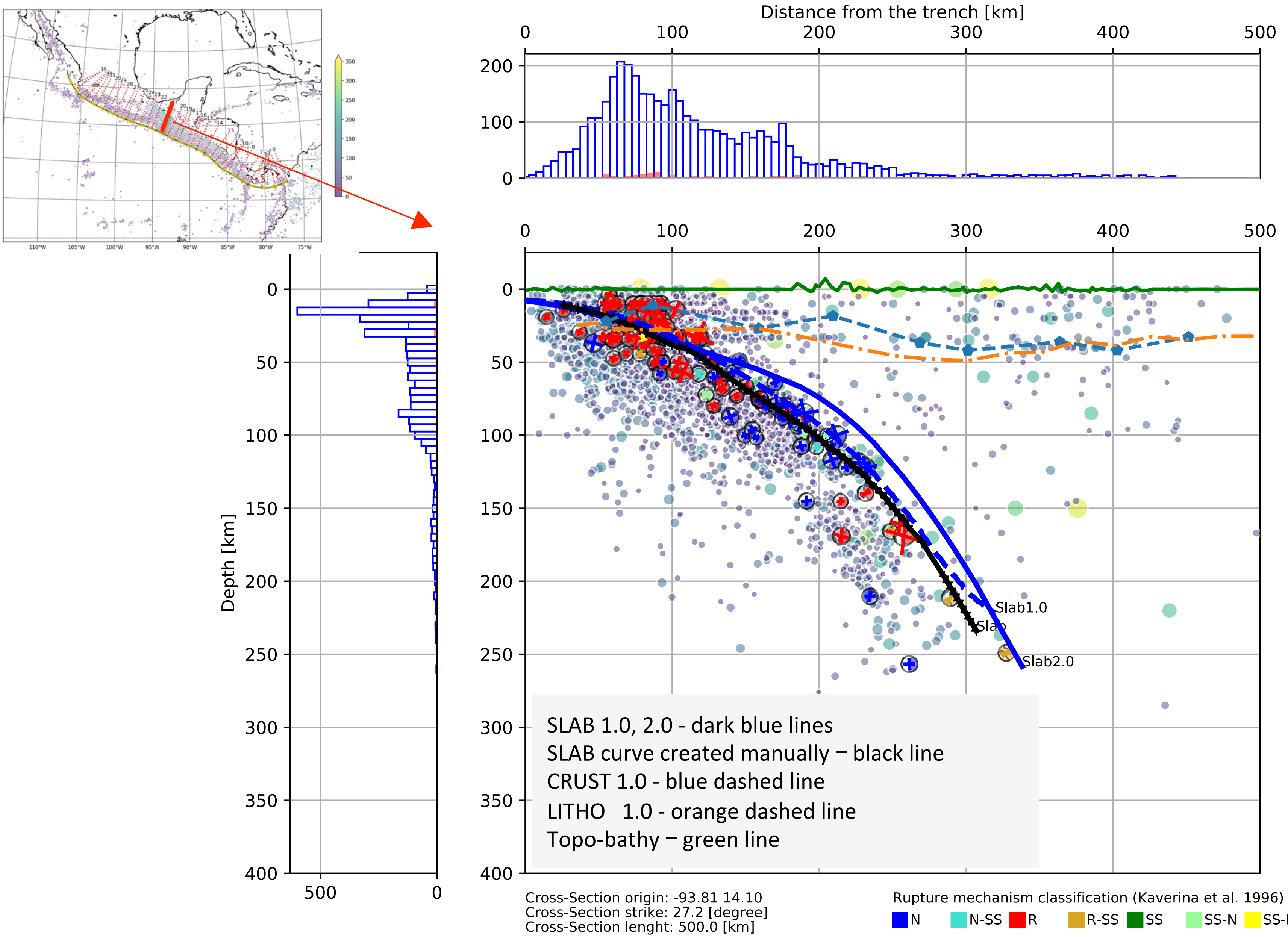


Defining the geometry of the slab [cont.]

… and the definition [manually] of a curve describing the contact between the slab and the overriding plate.



Subduction geometry: top of the slab



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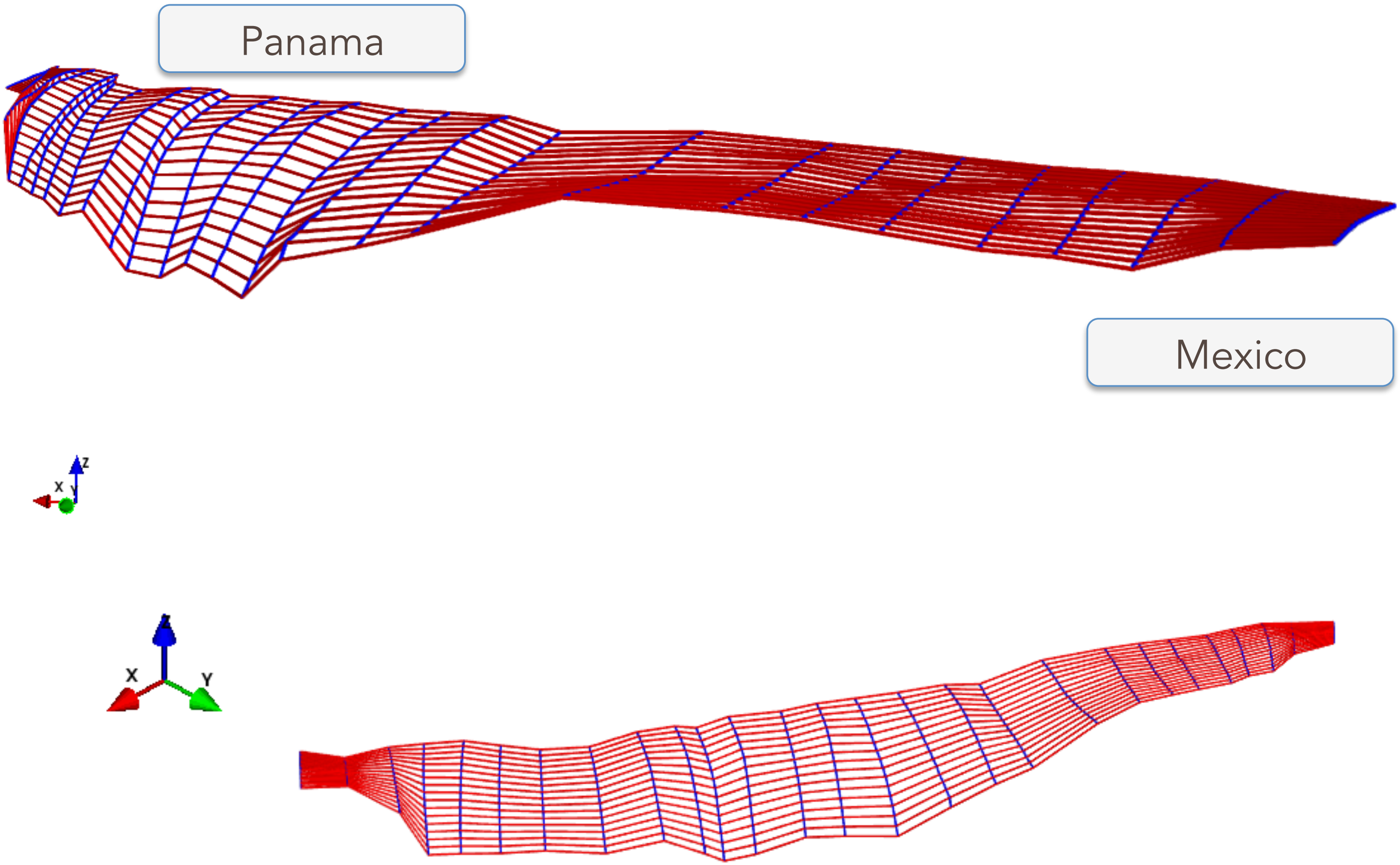
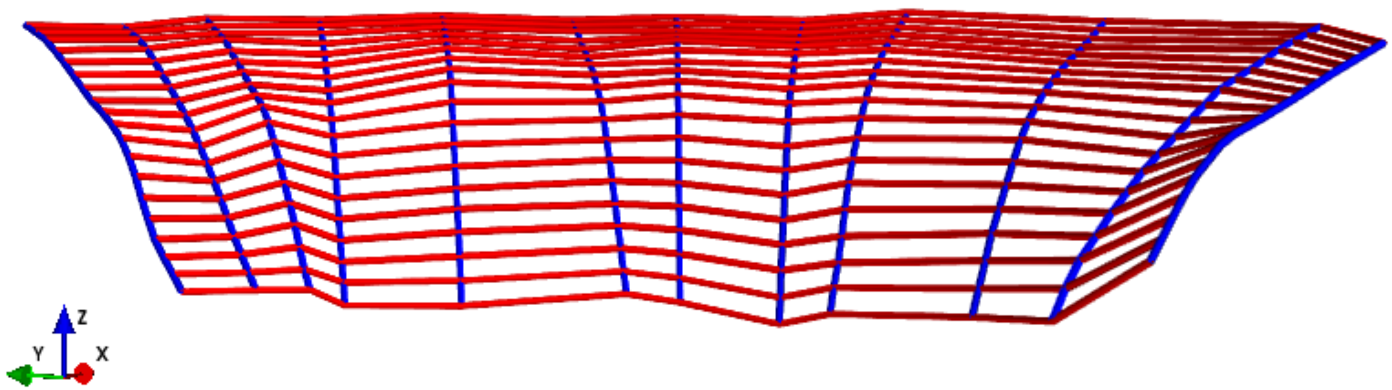
Results: Central America + Mexico

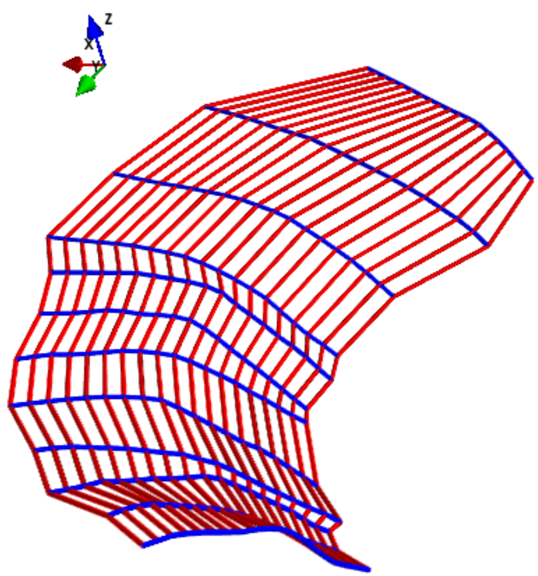


Results: Lesser Antilles

North

South

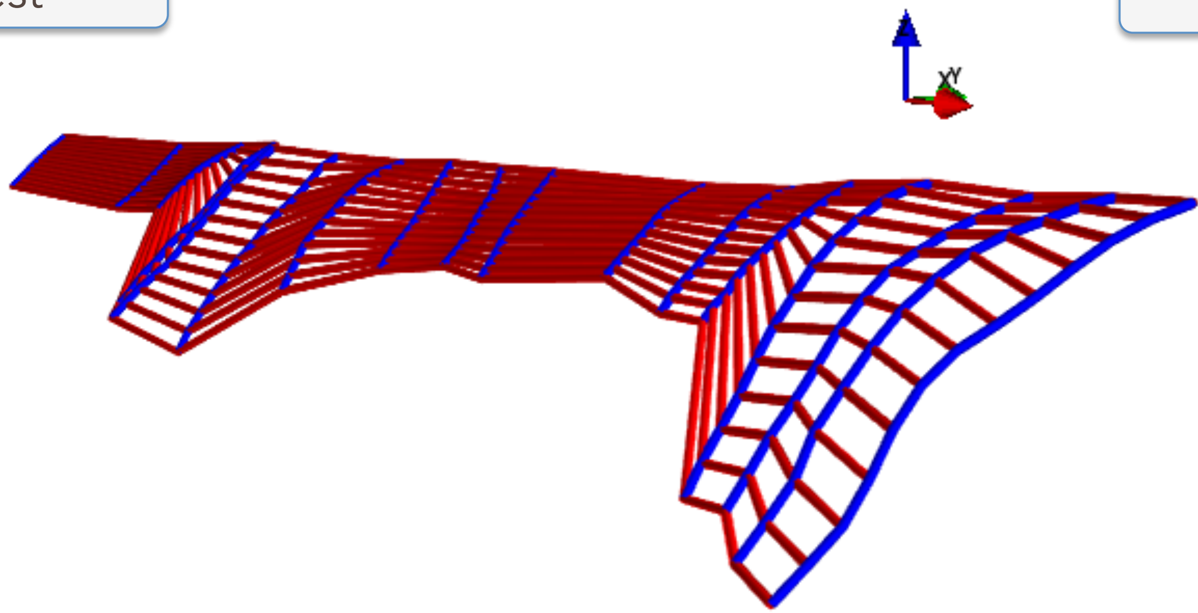


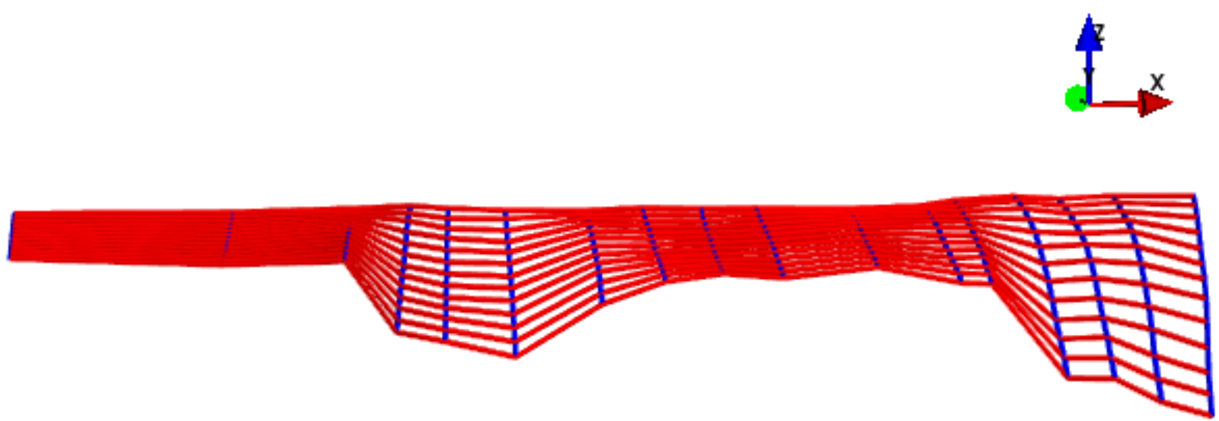


Results: Puerto Rico - Hispaniola

West

East





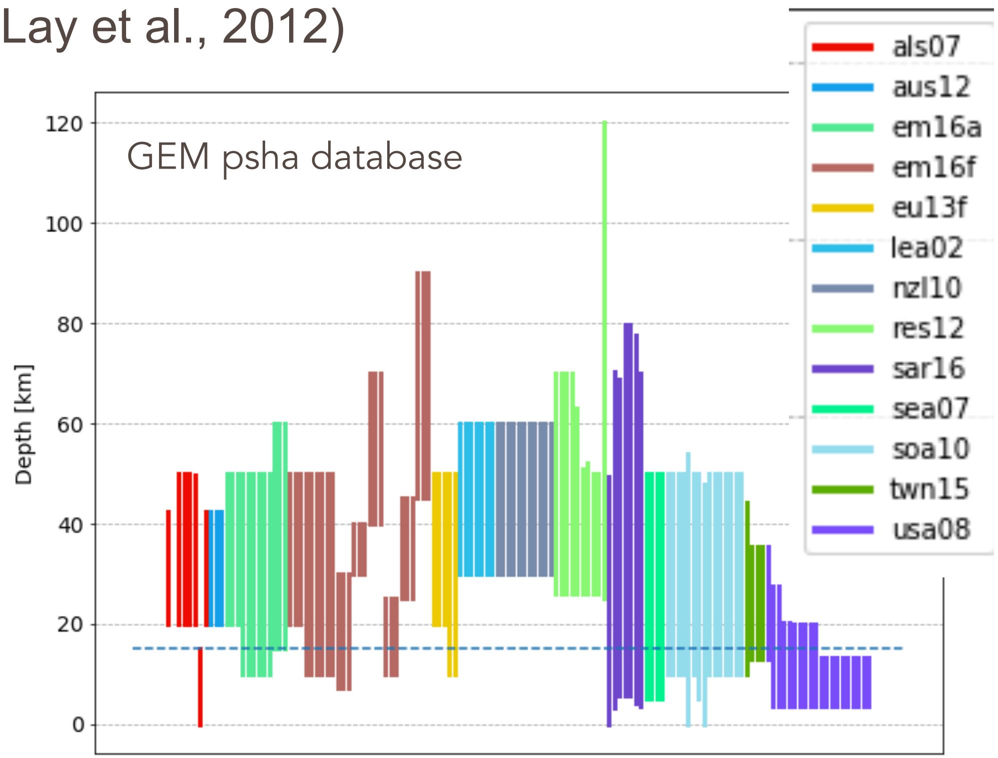
Modelling subduction earthquakes

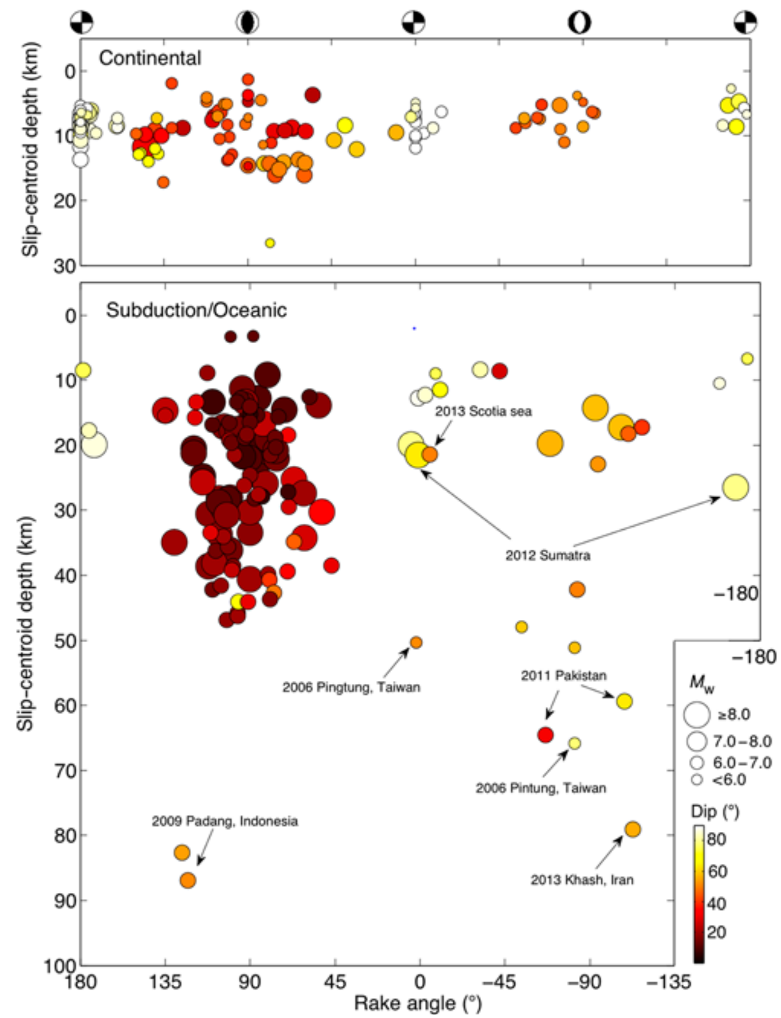
Creating interface and in-slab geometry

Segmentation

Interface: along-dip constraints

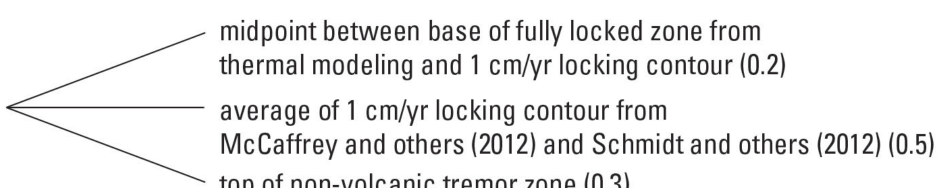
In the literature [and psha models] interface is generally constrained between 15 and 50 km (e.g. Lay et al., 2012)





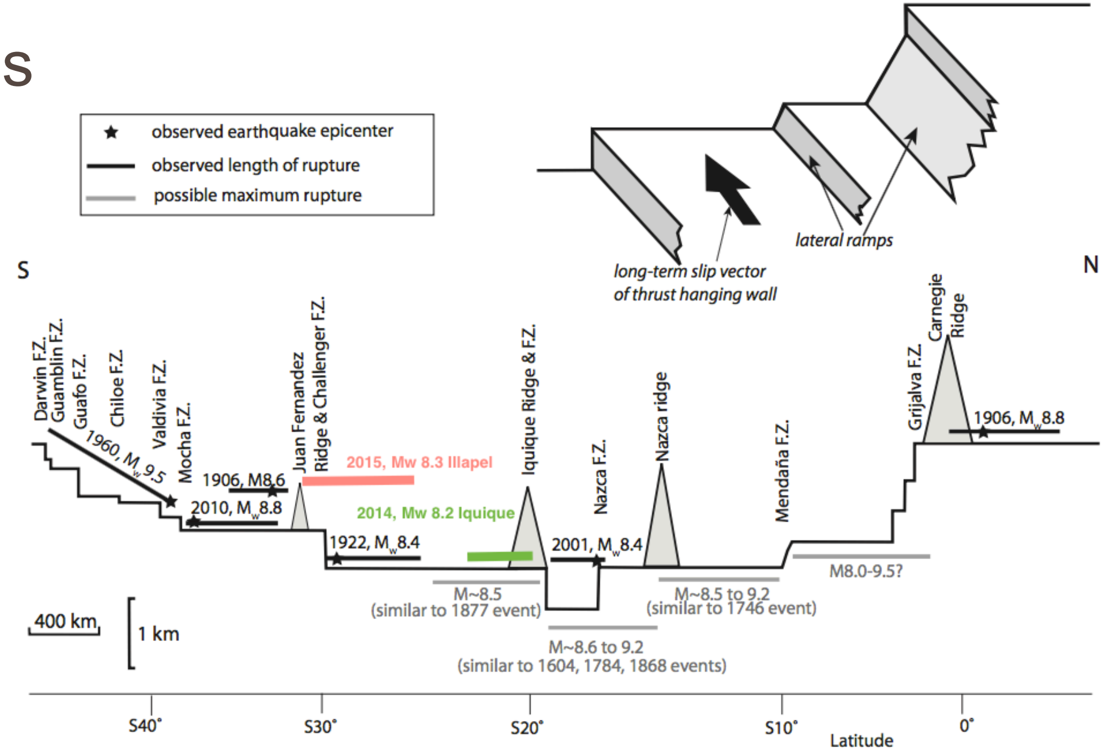
Thingbaijam and Mai (2017, BSSA)

Affected by uncertainty (e.g. Petersen et al. 2014)



Subduction interface: along strike constraints

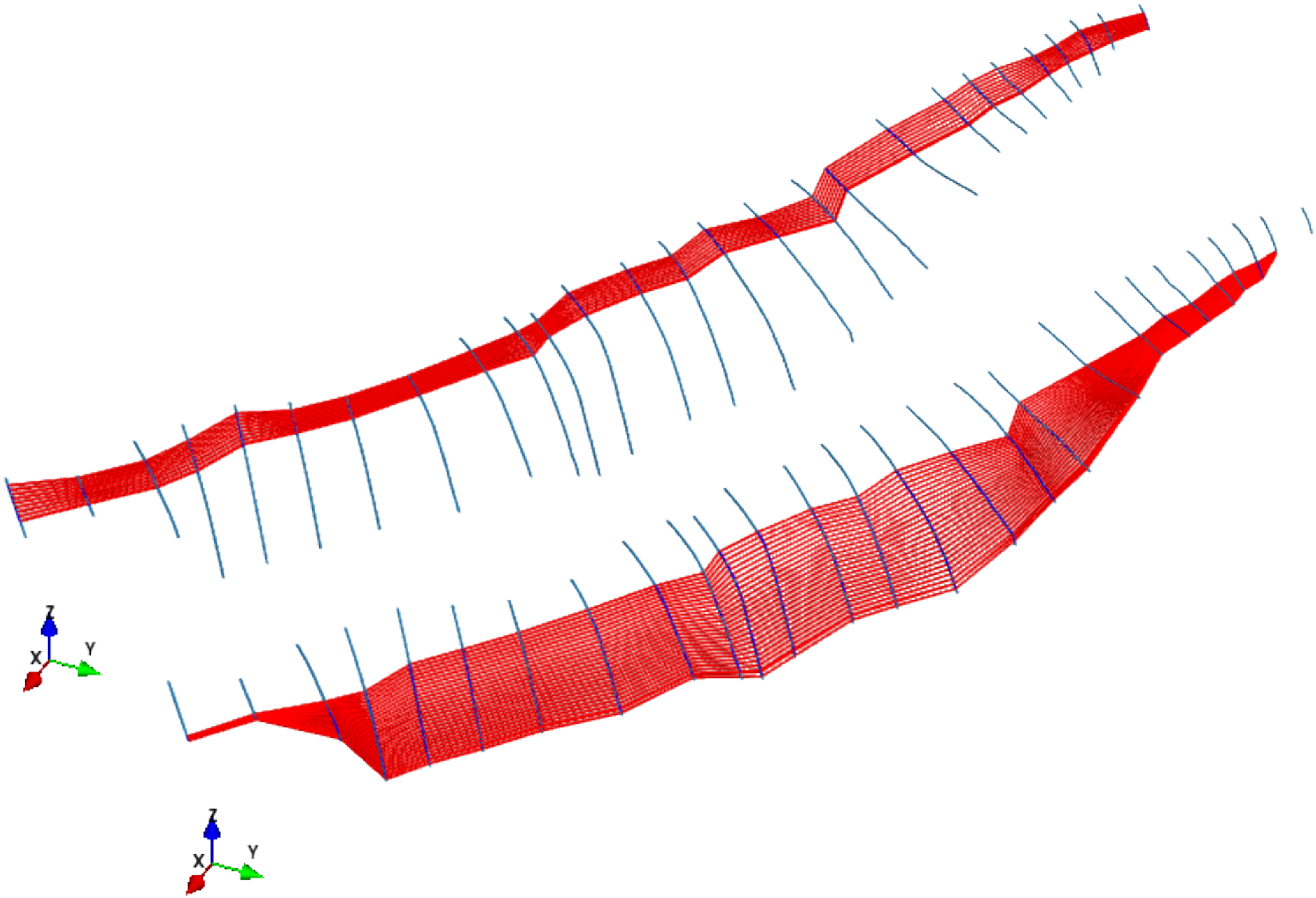
- Topography of subducted plate (e.g. Geersen et al., 2015 for the Iquique earthquake; Carena, 2011)
- Low coupling regions (Scholz and Campos, 2012)
- Paleotsunami + turbidites information (Petersen et al., 2014)
- Past ruptures



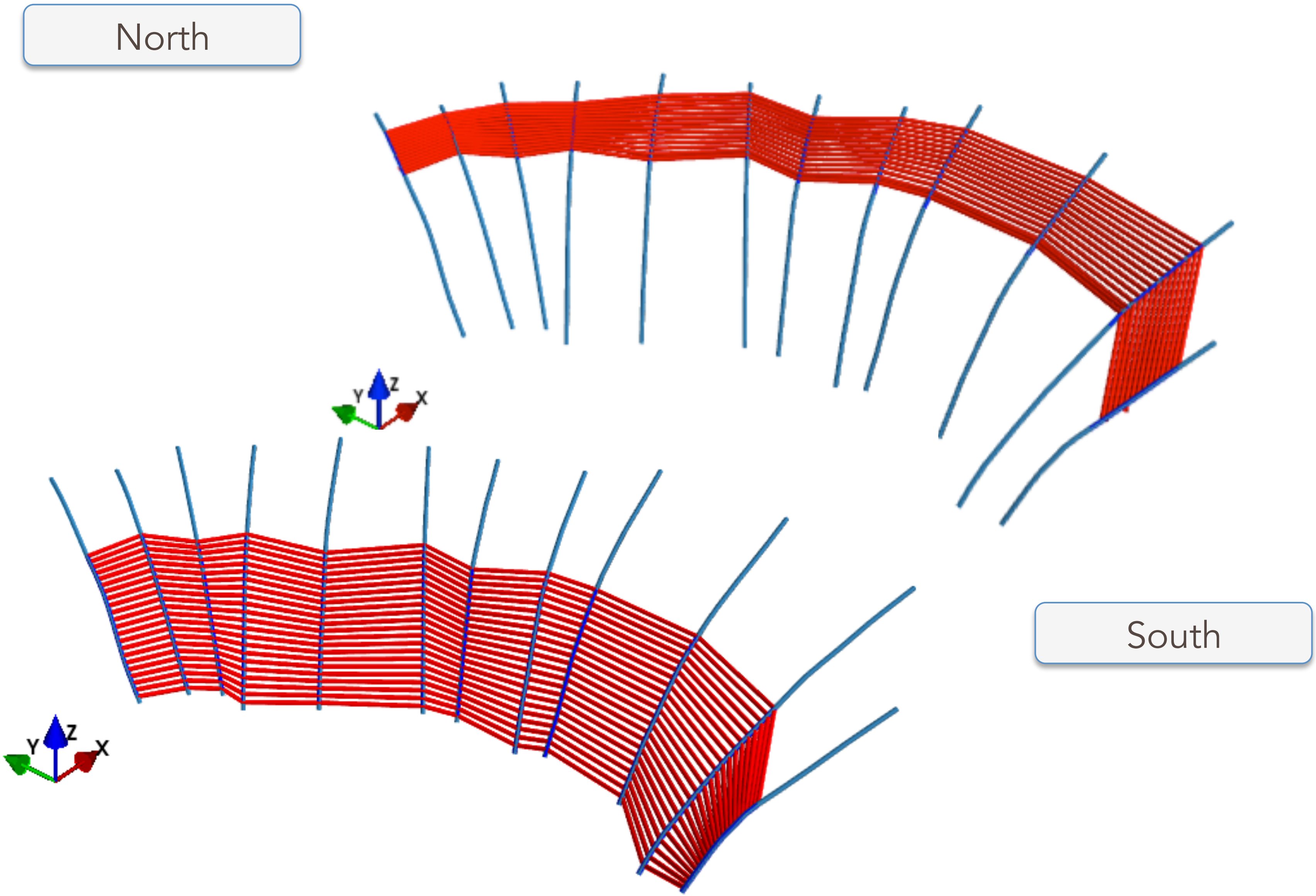
Results: Central America + Mexico

North

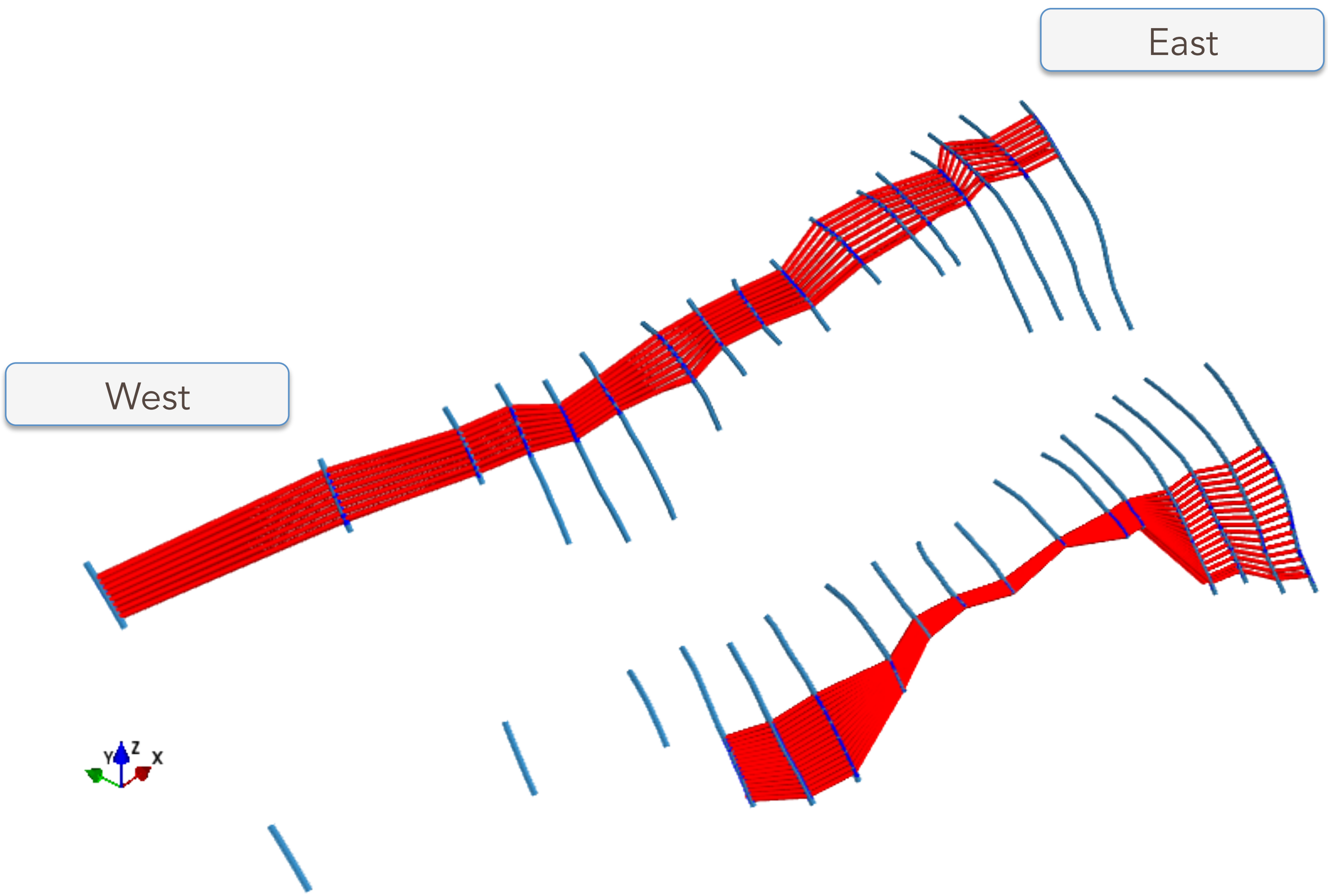
South



Results: Lesser Antilles



Results: Puerto Rico - Hispaniola



Modelling subduction earthquakes

Tectonic regionalization of seismicity

Regionalization of seismicity

The concept of regionalization already appeared in the scientific literature and used in PSHA.

For example:

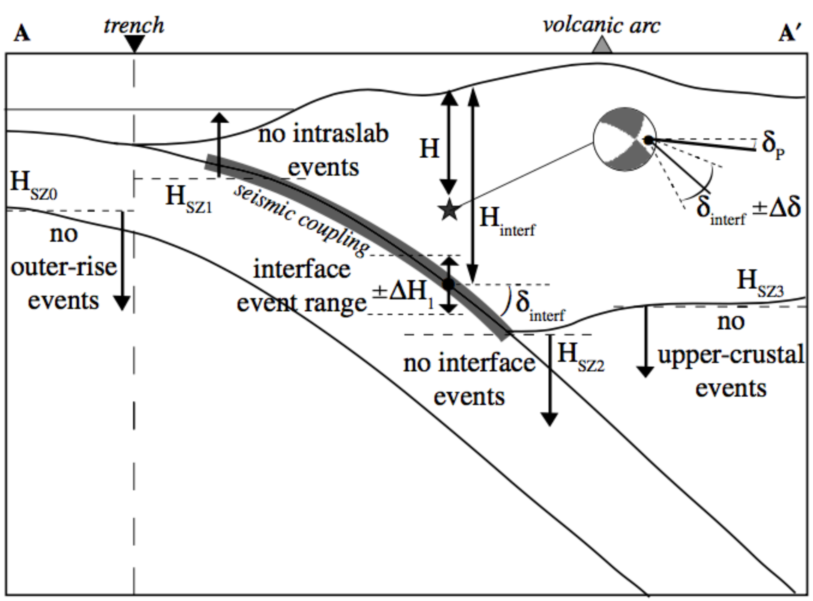
- In PSHA, the use of specific GMPEs for groups of sources in a hazard input model often presuppose the existence of an underlying regionalisation.

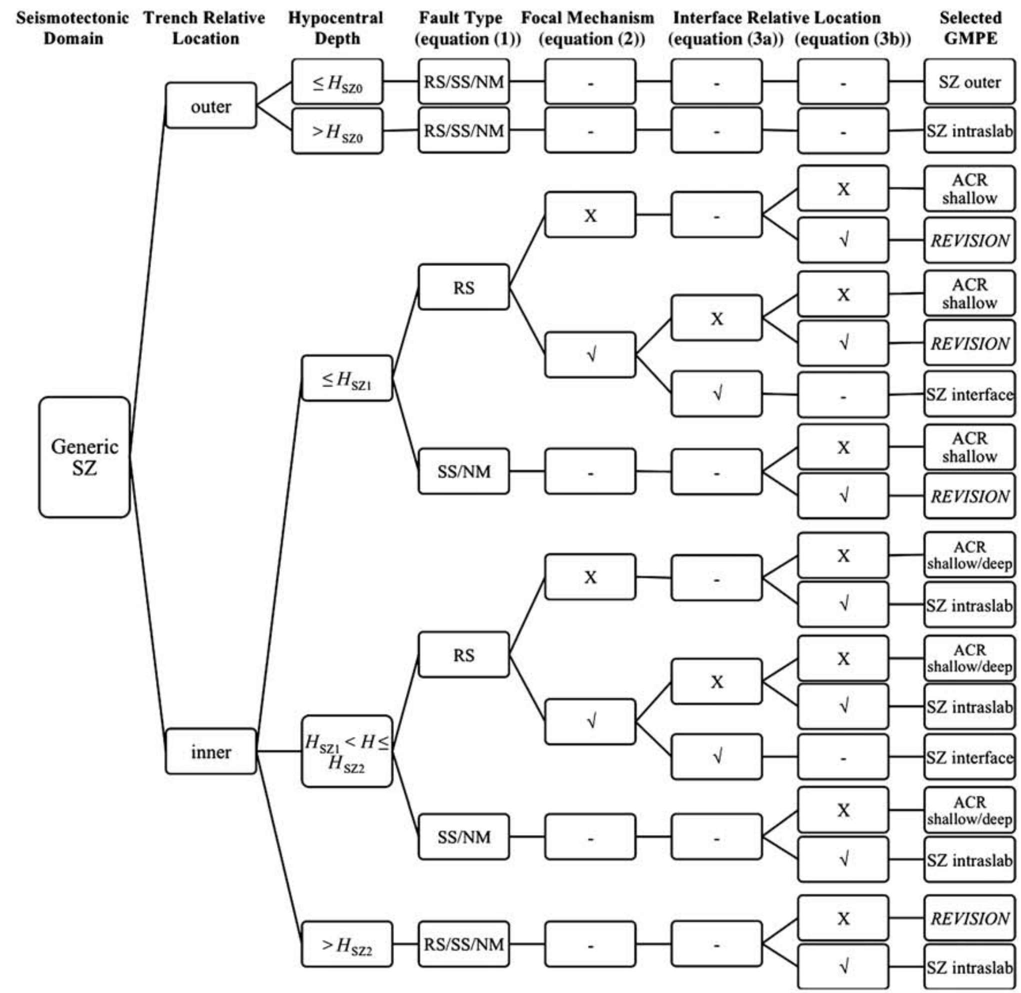
- The USGS Shakemap system uses an automated classification process (Garcia et al., 2012) for assigning to each event proper ground-motion prediction equations.

Regionalization of seismicity

Some schemes available:

- Garcia et al. (2012)





Regionalization of seismicity

Some schemes available:

- Zhao et al. (2015)

Similar to Garcia et al. (2012)

1. For events up to the end of 2004, ISC-EHB locations can be used. For events after 2004, the catalog preference is (a) JMA locations with high-precision level, (b) ISC-EHB locations, and (c) NEIC locations if the depth is not fixed at a specified value.
2. The geometry model from Slab1.0 by Hayes *et al.* (2012) can be used.
3. Events that have a reverse-faulting mechanism, a depth within ± 5 km from the subduction interface, a depth < 50 km, and the dip angle for one of the nodal planes within $\pm 15°$ from the interface dip angle can be classified as subduction interface earthquakes.
4. Events that are above the subduction interface, not classified as interface earthquakes, and have a depth of 25 km or less can be classified as shallow crustal earthquakes.
5. Events that are above the subduction interface but not shallow crustal events can be classified as upper-mantle events.
6. Events that are not in any of the groups specified above are subduction slab earthquakes.

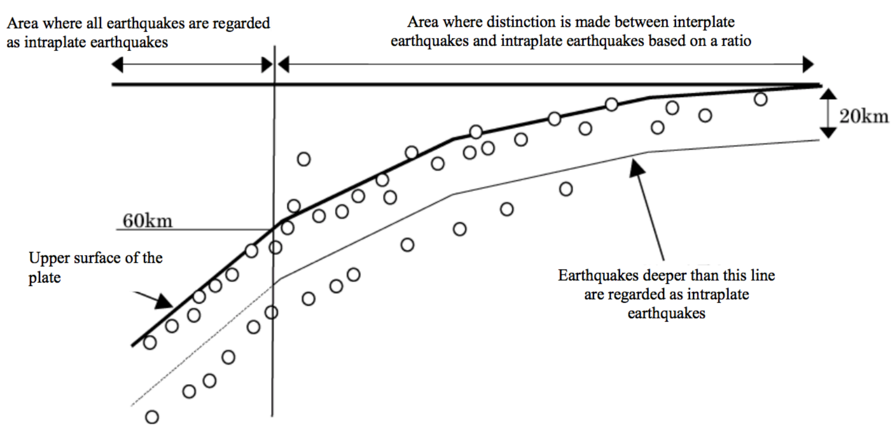
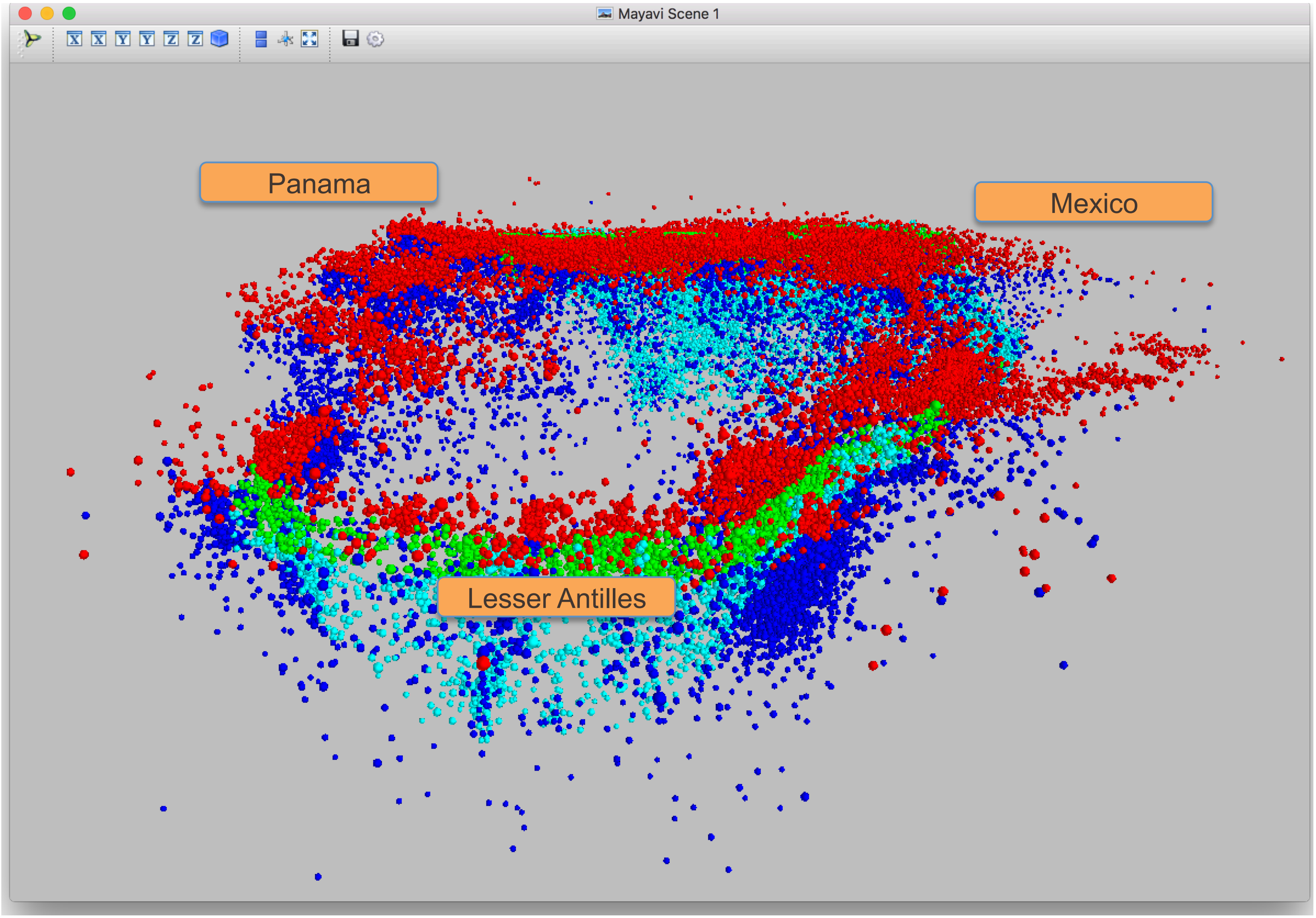


Figure 3.3.4.3-8 Idea of distinguishing between interplate earthquakes and intraplate earthquakes (SLTE/SESGM, ERC, 2003).

Regionalization of seismicity

GEM

We implemented a methodology similar (but simpler) to the one used in the Shakemap system (Garcia et al., 2012)



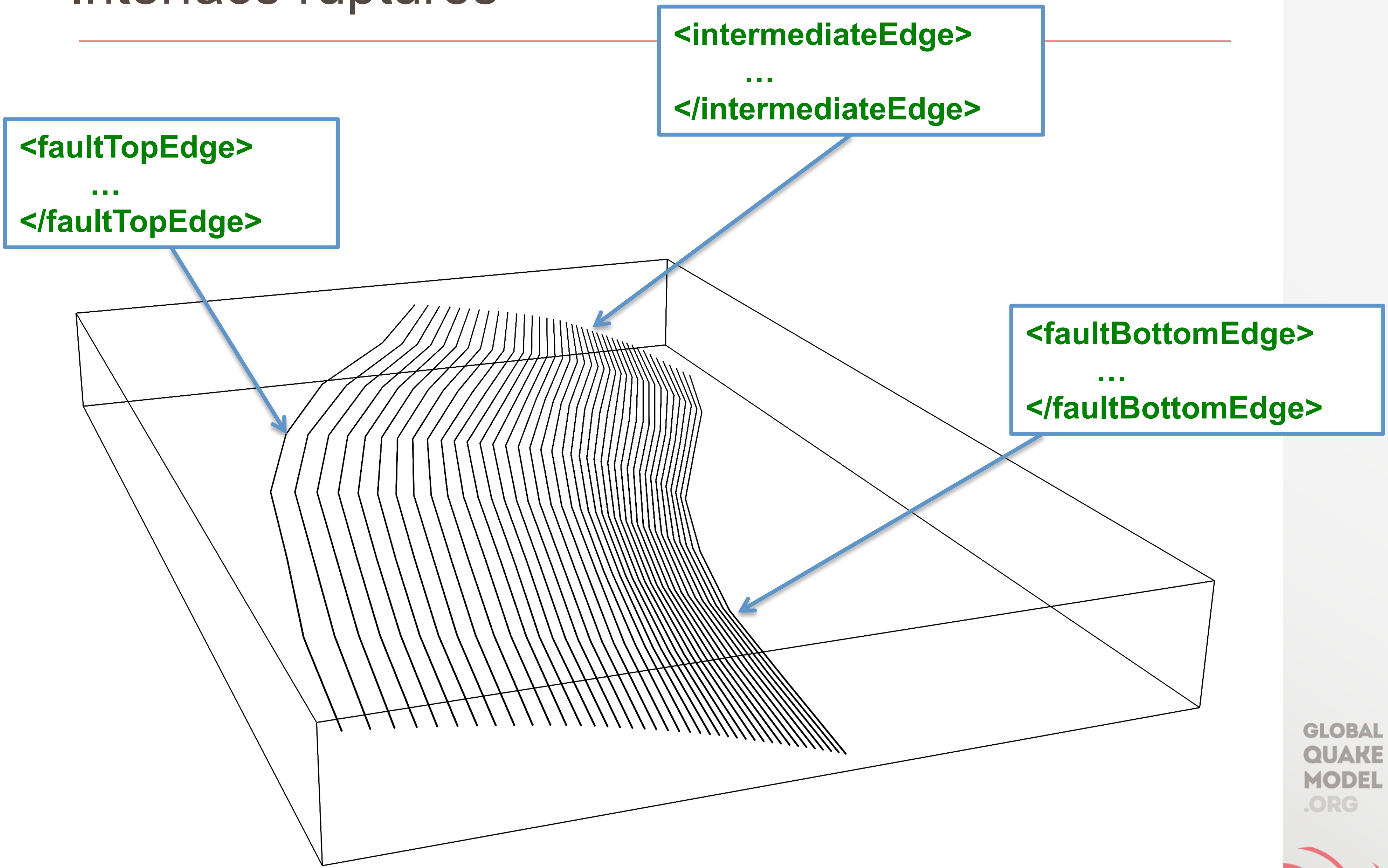
Modelling subduction earthquakes

Earthquake occurrence
Ruptures

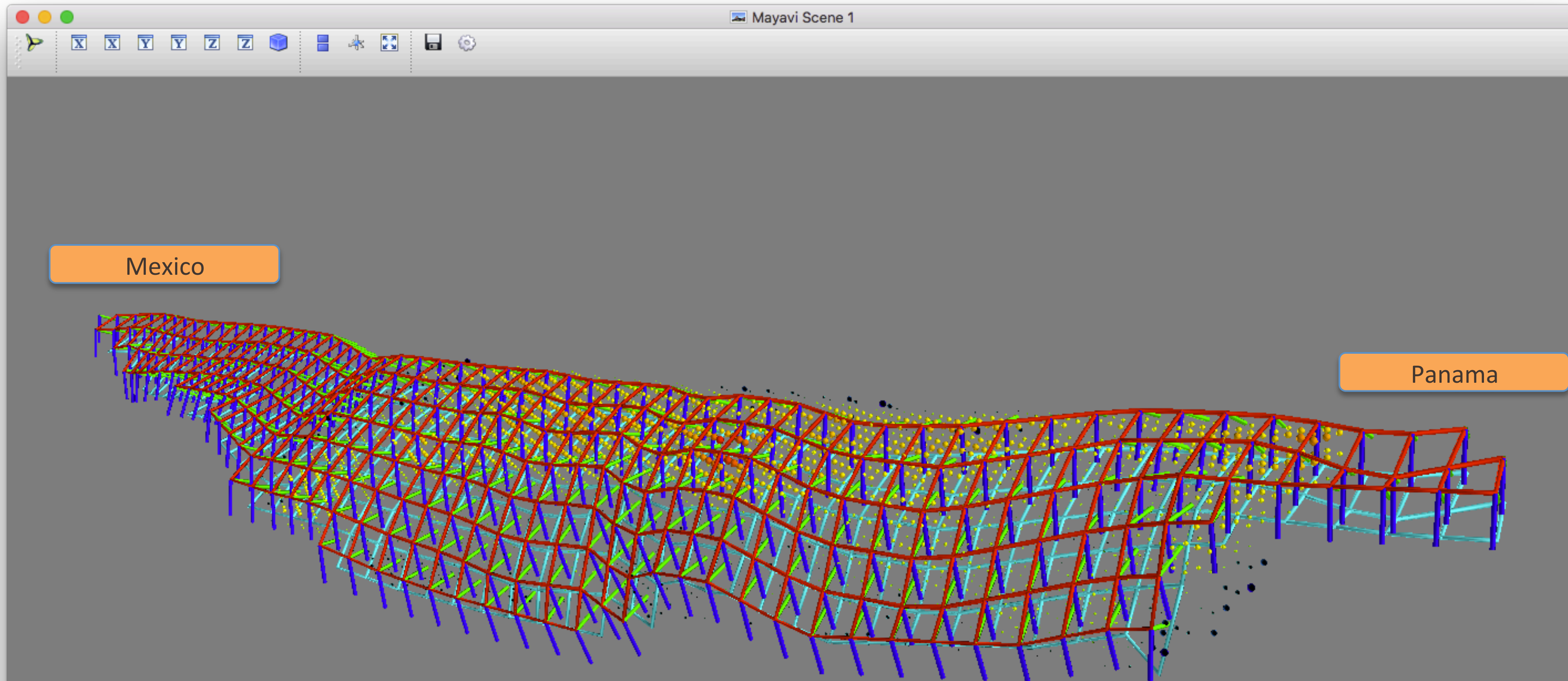
Interface and In-slab

- MFD: Double Truncated GR (in future versions we will also consider combinations of characteristic and GR distribution)
- Characterization of occurrence
  - Using past seismicity (instrumental, historical and paleo-seismicity) for interface
  - Using past seismicity (instrumental) for in-slab
  - (future versions) Using information from tectonics and geodesy
- Mmax: based on global datasets, local information and constrained by a magnitude-scaling relation (Strasser 2010)

Interface ruptures



Subduction Inslab ruptures: CAM



- The ruptures are constrained by the limits of the slab
- Two preferred dip values are used [45 and 135 degrees]
- Diverse aspect ratios are used, but unrealistic or no physical ruptures are excluded
- A magnitude-scaling relation (e.g. Strasser et al.,2010) constrains the dimension of the ruptures

Subduction modelling for PSHA: GEM experiences in Latin America

Pending issues and challenges

What we know vs. What we don’t know

- How to consider an uneven distribution of seismicity within the slab?
- How should the hypocentres be distributed within the rupture planes?
- How to treat the lateral limits of the slab – how far can ruptures propagate?
- How to incorporate more epistemic uncertainties on physical properties of the subducting slab?
- Explore physical relationship between interface and in-slab segmentation?
- How to reconcile seismicity and tectonic information in the characterization of the earthquake occurrence (e.g. plate convergence, coupling?)

Where Next?

Improve the GEM methodology in order to:

- provide more capability and flexibility to hazard modellers
- more epistemic uncertainties can be incorporated
- incorporate as much of the known physics of a given subduction zone as possible (e.g. Slab2.0)
- to be aware of the modelling implications (more testing)

Hazard modellers need to start to incorporate more subduction physics into the current approaches

Issues such as limits on rupture scaling and aspect ratio need to be explored and tested

Gracias
Thank you