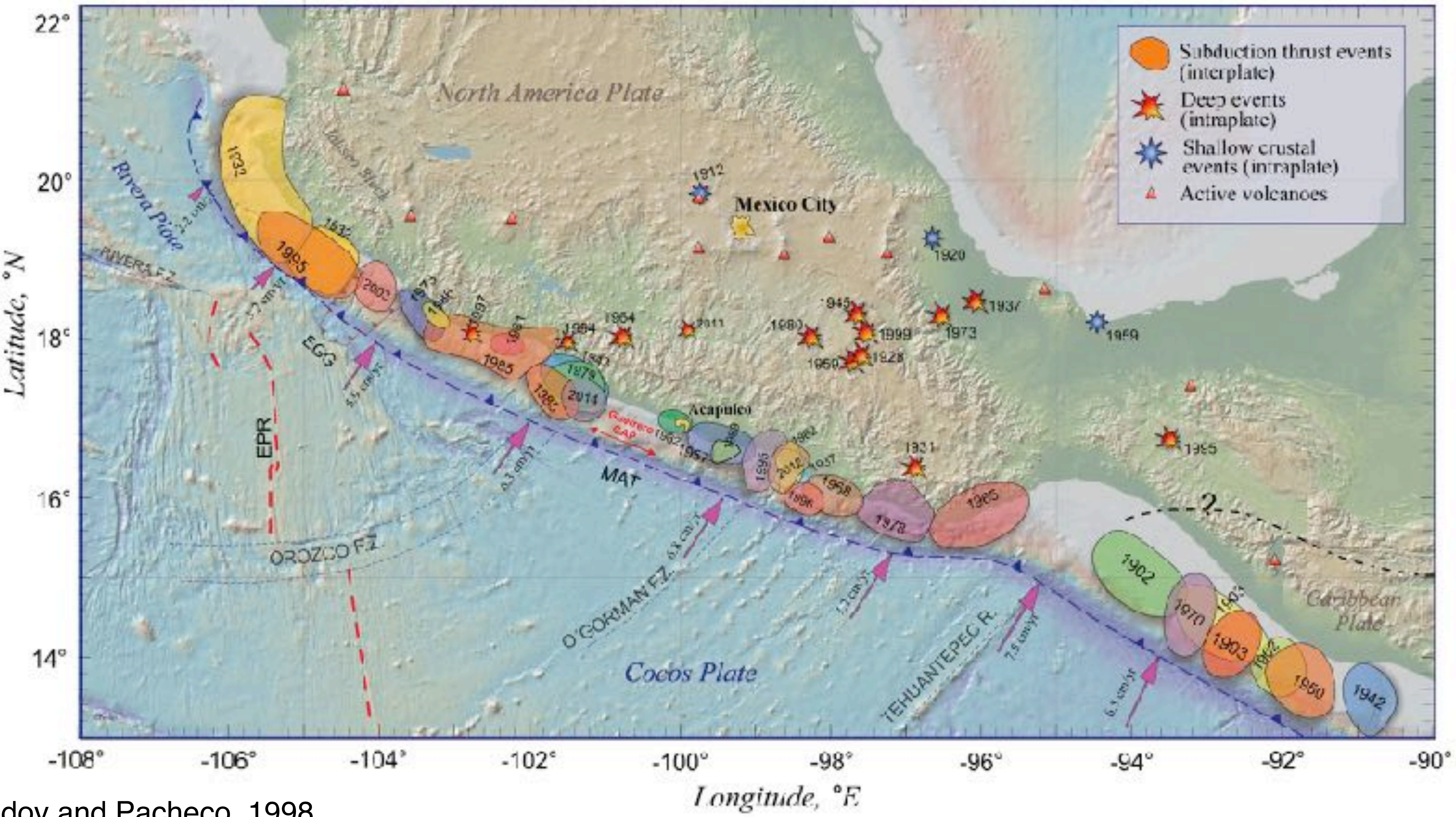
Broadband Strong Ground Motions associated with Large Subduction Earthquakes in the Guerrero Seismic Gap, Mexico

Carlos Villafuerte[1], Víctor Cruz-Atienza[1], Josué Tago[1], Nelson Pulido[2], Tomotaka Iwata[3], John Díaz-Mojica[1] and Shinichi Matsushima[3]

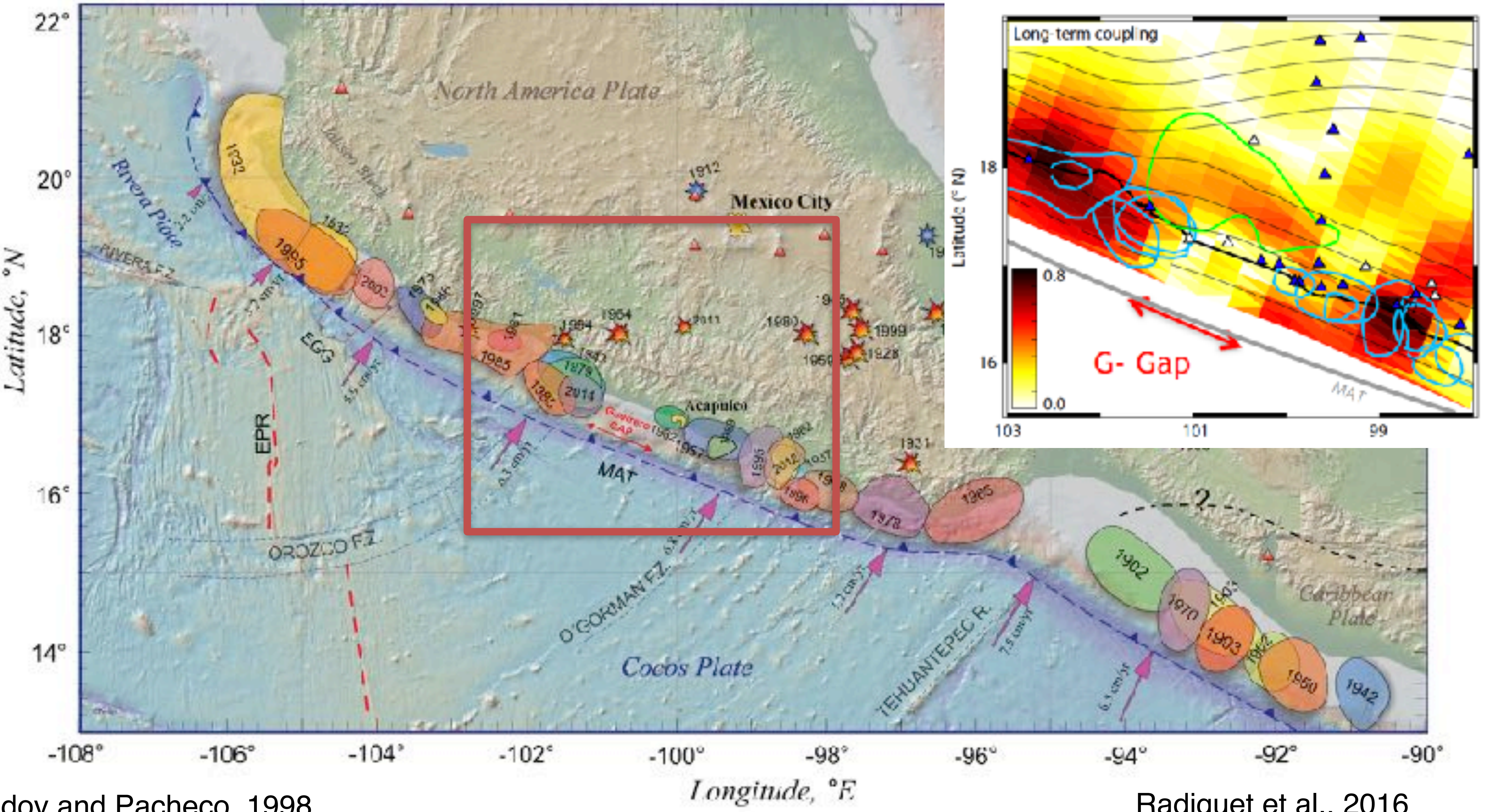
1. *UNAM (Mexico)*
2. *NIED, Tsukuba*
3. *DPRI, Kyoto University*

Rupture Areas in the last 100 years



Kostoglodov and Pacheco, 1998

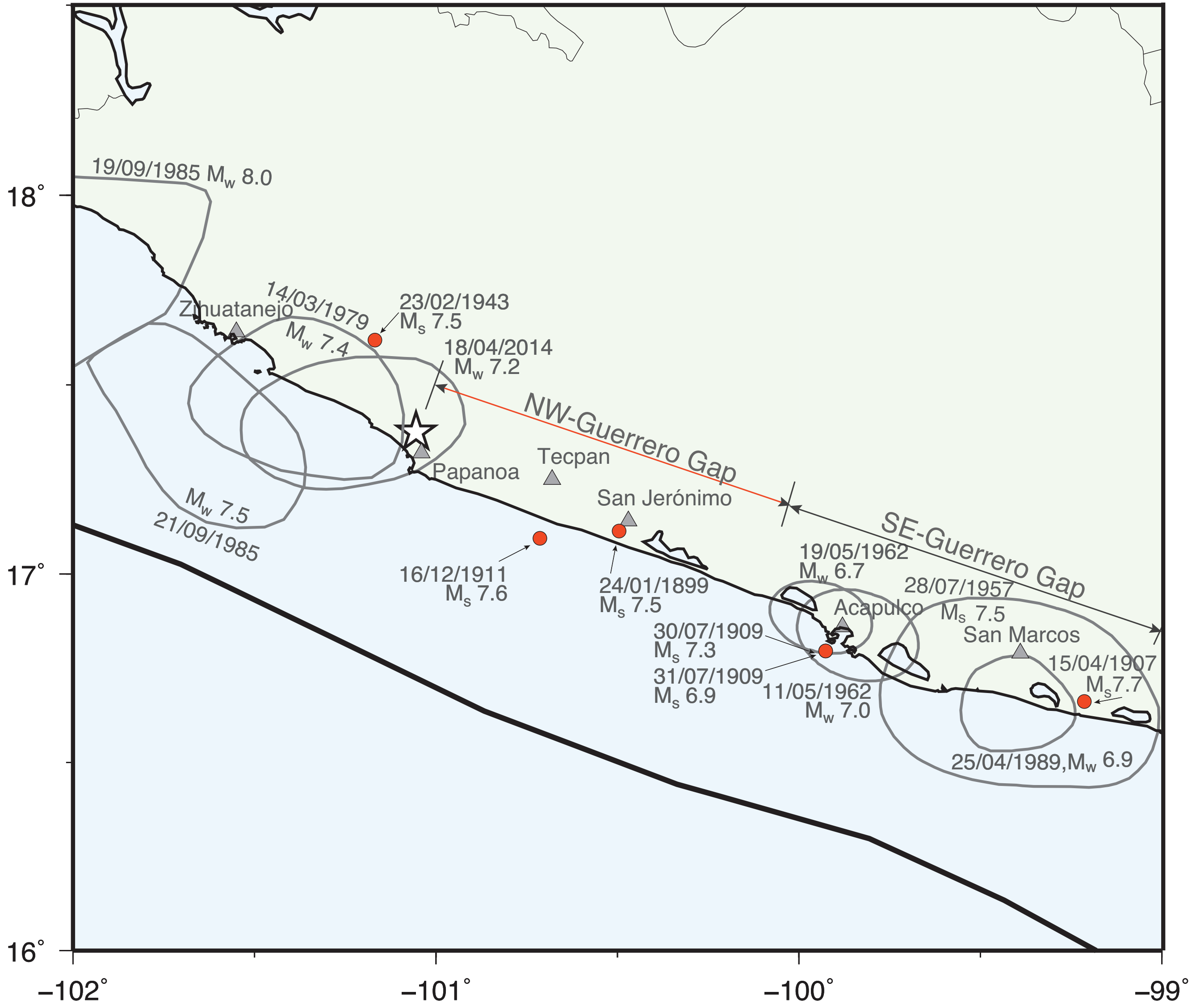
Rupture Areas in the last 100 years



Kostoglodov and Pacheco, 1998

Radiguet et al., 2016

Seismic sequence in Guerrero 1899- 1911



UNAM seismology group, 2015

●

1899 7.5 (*MS*)

1907 7.9 (*Mw*)

1908 7.5 (*Mw*)

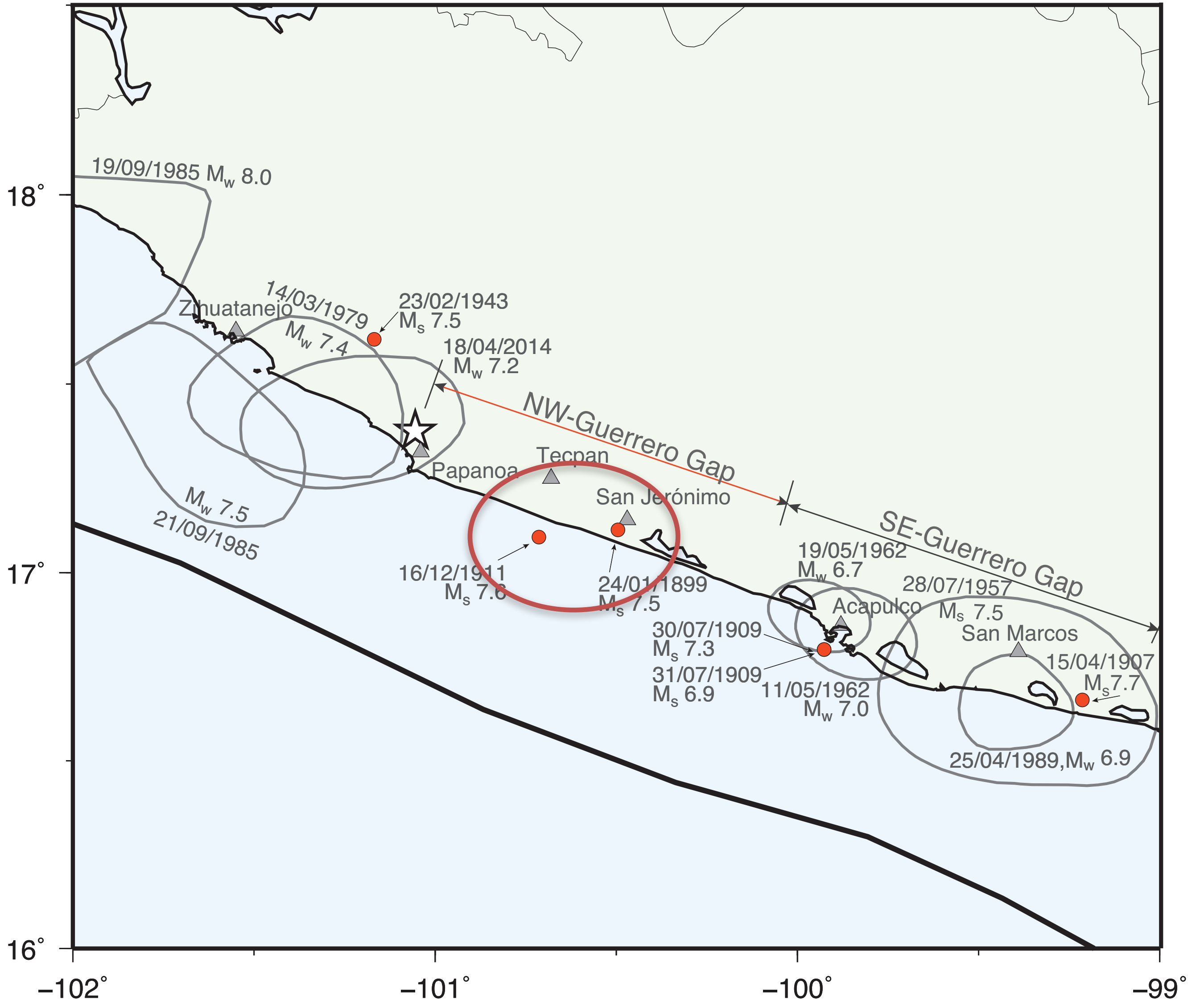
1908 7.2 (*Mw*)

1909 7.5 (*Mw*)

1909 7.0 (*Mw*)
(Posible réplica)

1911 7.6 (*Mw*)

Seismic sequence in Guerrero 1899- 1911



UNAM seismology group, 2015

●

1899 7.5 (*MS*)

1907 7.9 (*Mw*)

1908 7.5 (*Mw*)

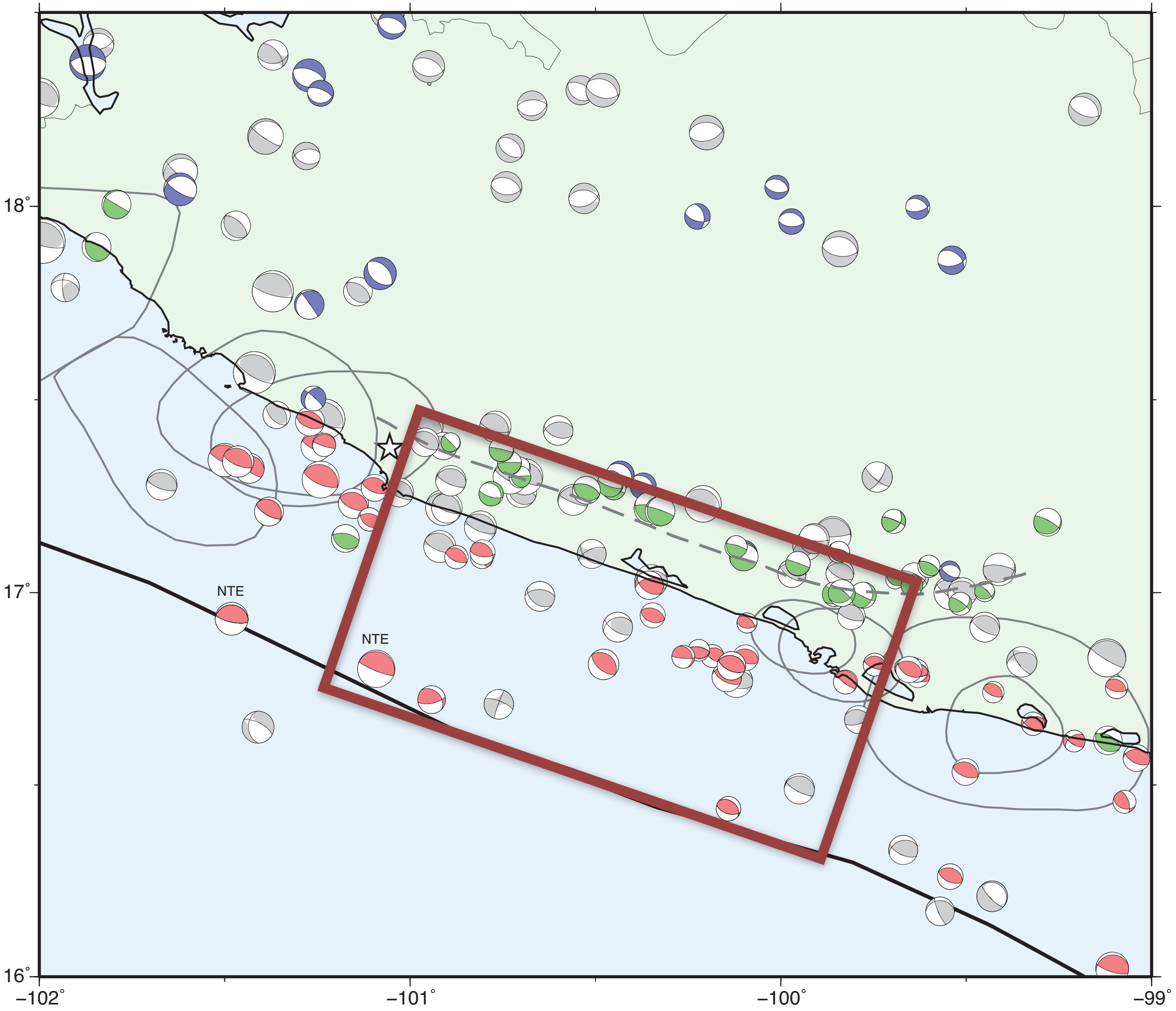
1908 7.2 (*Mw*)

1909 7.5 (*Mw*)

1909 7.0 (*Mw*)
(Posible réplica)

1911 7.6 (*Mw*)

Seismic activity in Guerrero

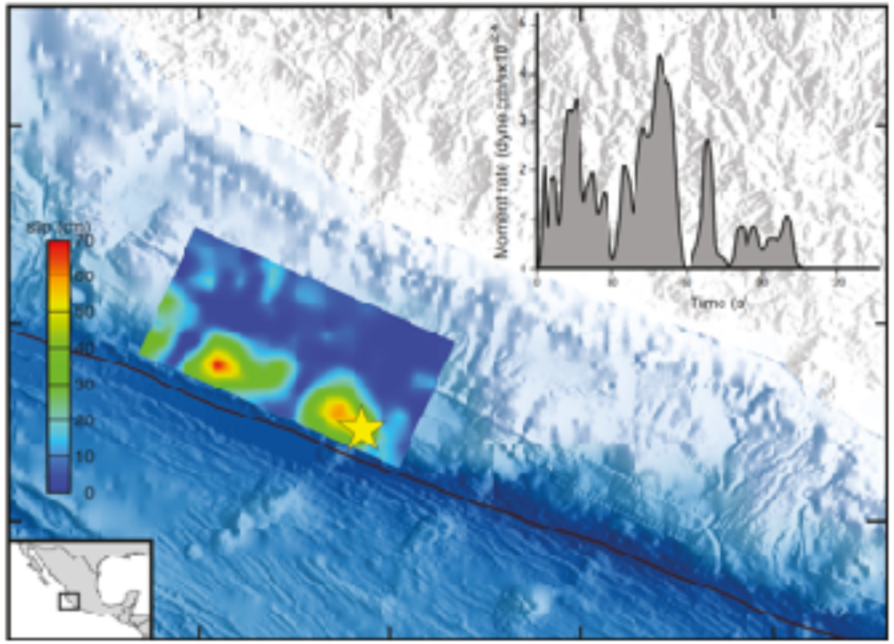


UNAM seismology group, 2015

Small scale heterogeneity observed within the Guerrero Gap

◐ Shallow thrust events

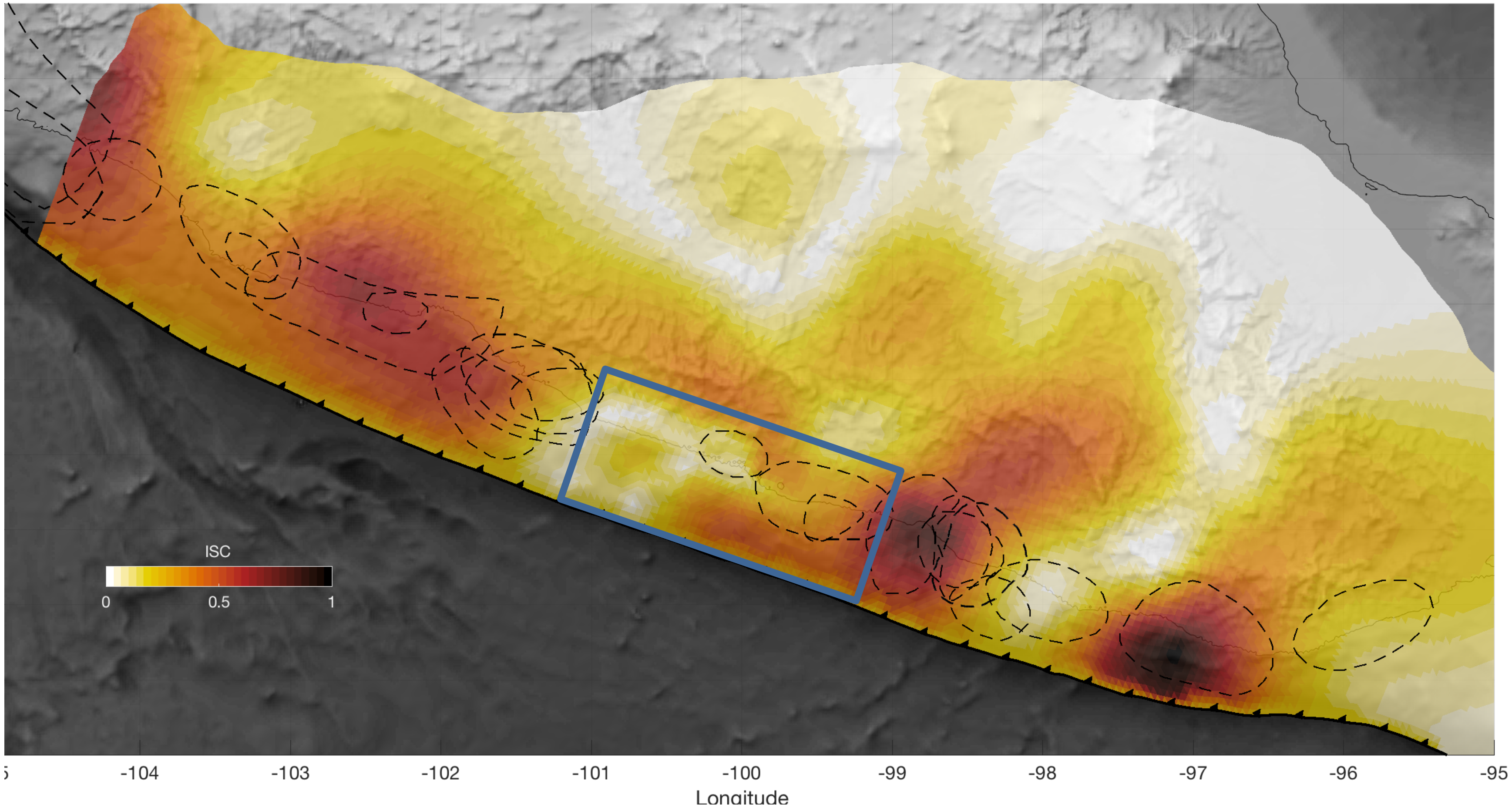
◐ GCMT events with inaccurate centroid locations



Flores, 2018

Interseismic coupling of the region

We estimate the slip distribution of plausible future megathrust earthquakes based on a model of inter-seismic coupling distribution

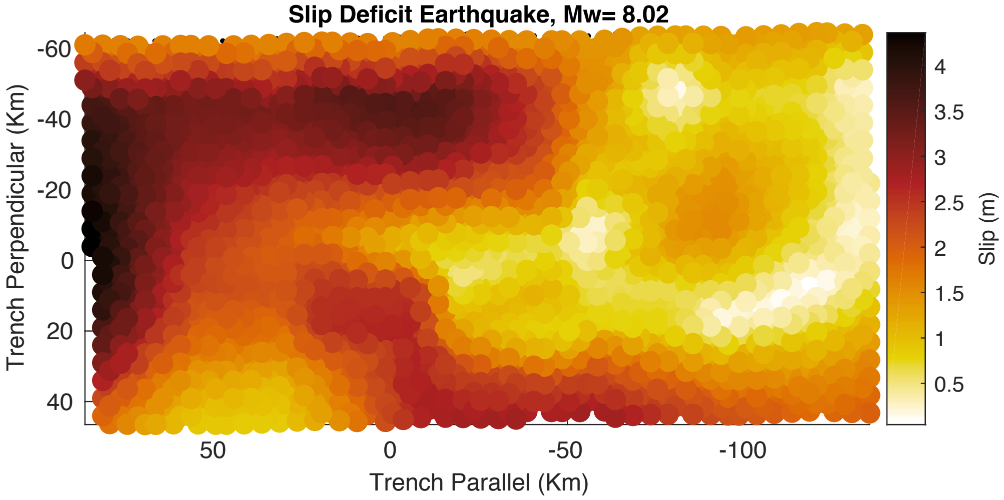


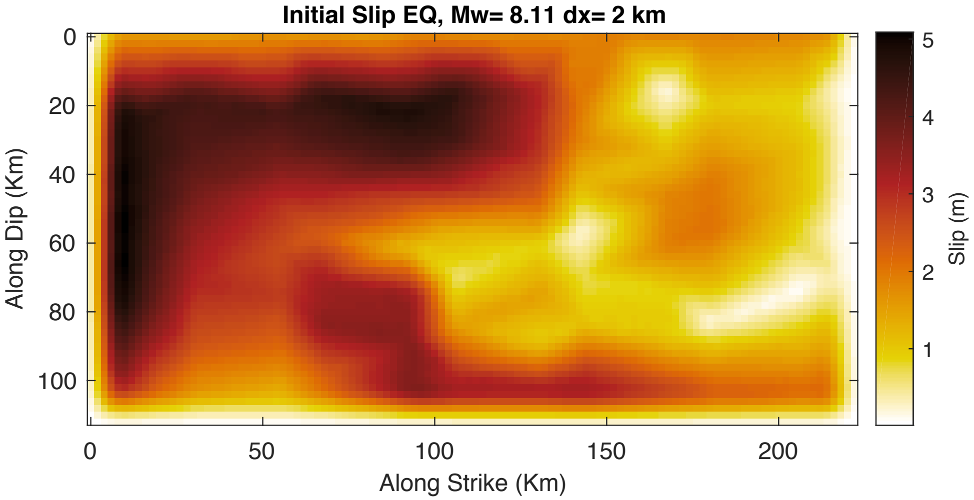
Slip deficit =
ISC * T * 6 mm/year.

Mw = 8.0 (1911- 2018)

Including areas of rupture of the doublet in 1962 and the 1957 EQ.

Adjusting slip scenario with a Mw-Area relationship





Mw = 8.0 (1911- 2018)
This magnitude assumes that the moment deficit has been completely released during the sequence 1899-1911.

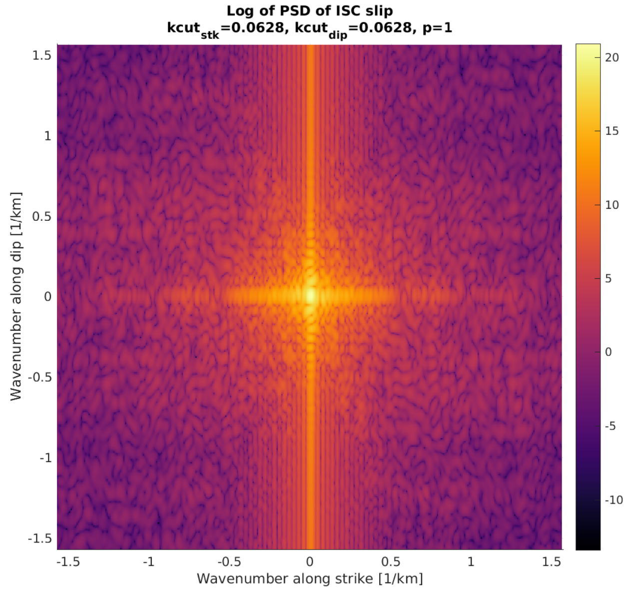
We scale the slip scenario according with a **Mw - Area** scaling law for subduction thrust earthquakes (Thingbaijam and Mai,2016)

$\log_{10}(A) = -3.292 + 0.949\ Mw$

Mw = 8.1

The slip model obtained from geodetic data represents the large scale features of asperities within the megathrust.

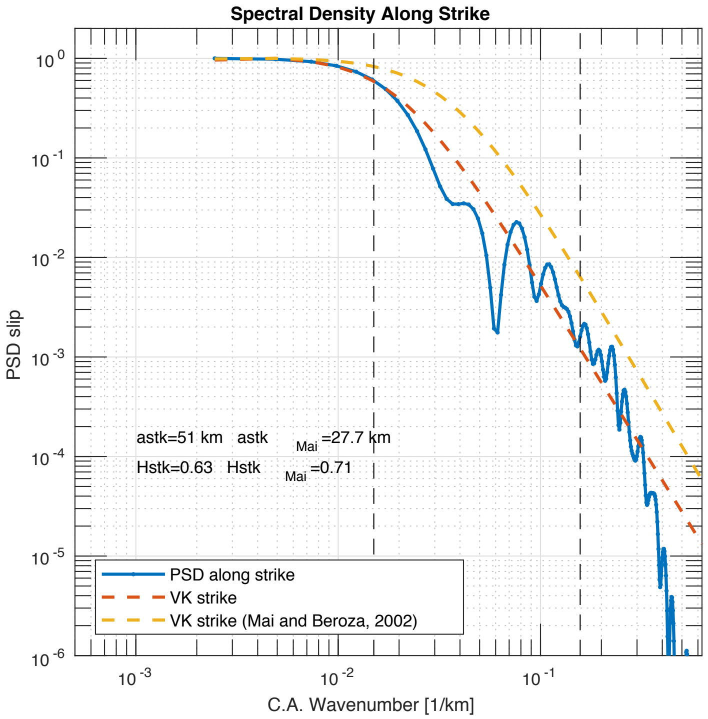
To enhance high frequency content in the simulation of strong ground motion its necessary to introduce small scale heterogeneities to the geodetic source slip.

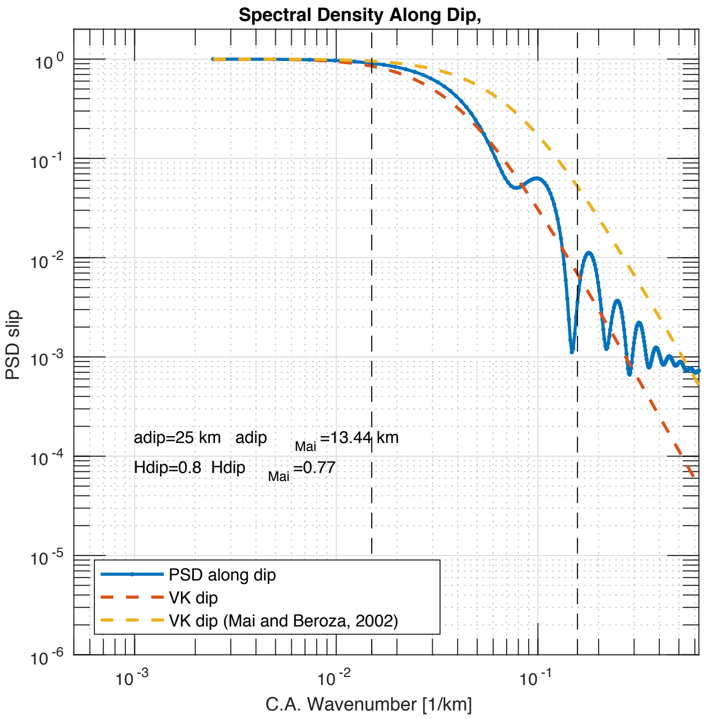


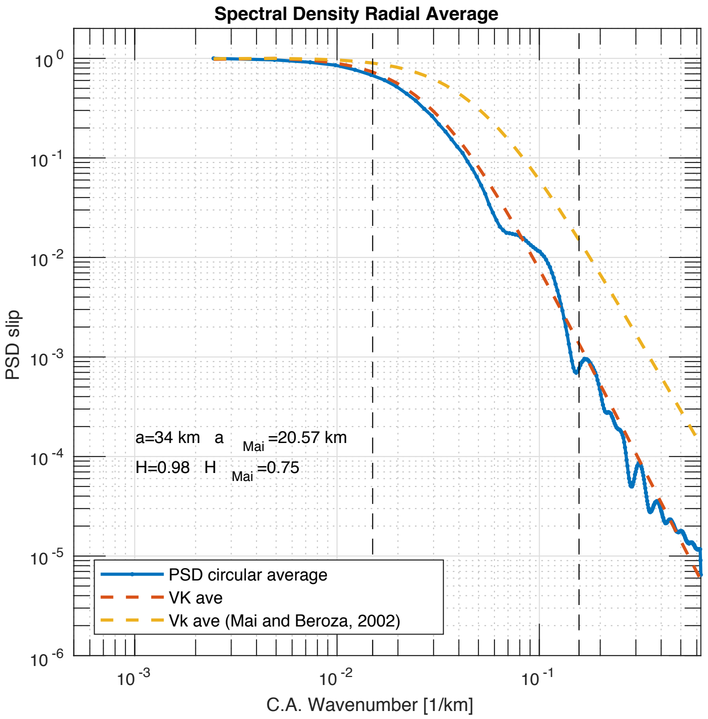
1. Compute the 2D Power Spectrum Density from the scaled slip.

2. Fitting the PSD in every direction with a Von Karman autocorrelation function.

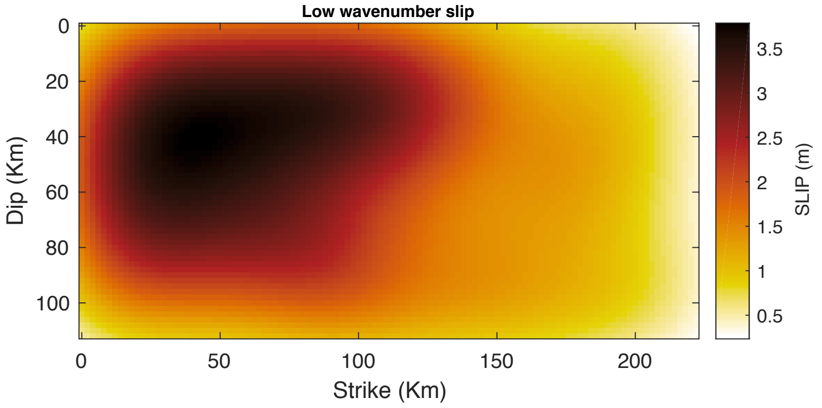
$$P(k_s, k_d) = \frac{a_s a_d}{[1 + {a_s}^2 {k_s}^2 + {a_d}^2 {k_d}^2]^{H+1}}$$

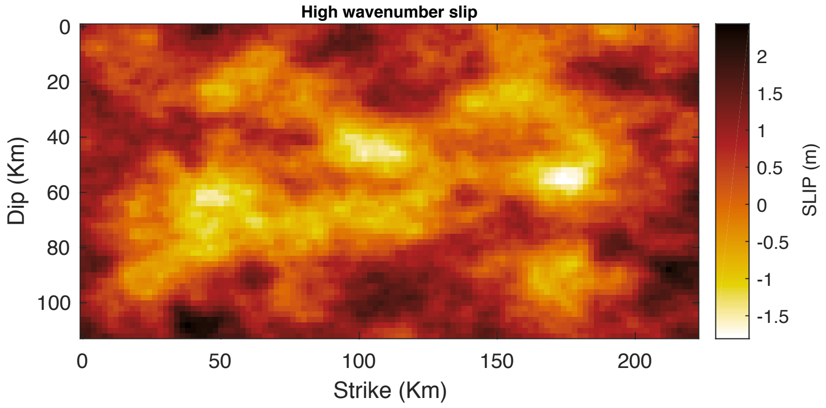


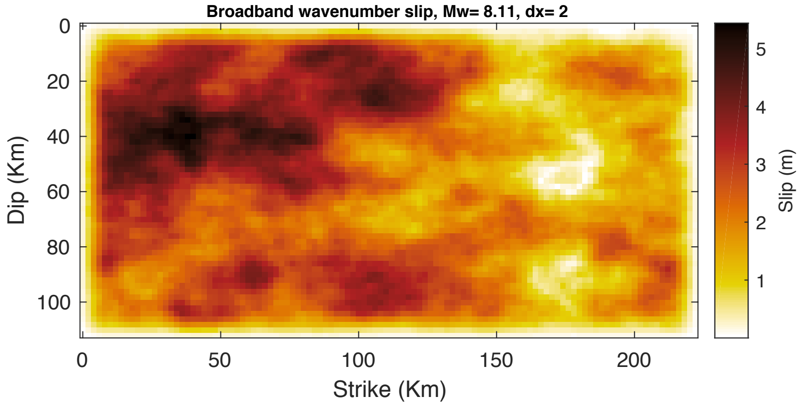




Construction of the broadband wave number source


Low wavenumber slip


High wavenumber slip

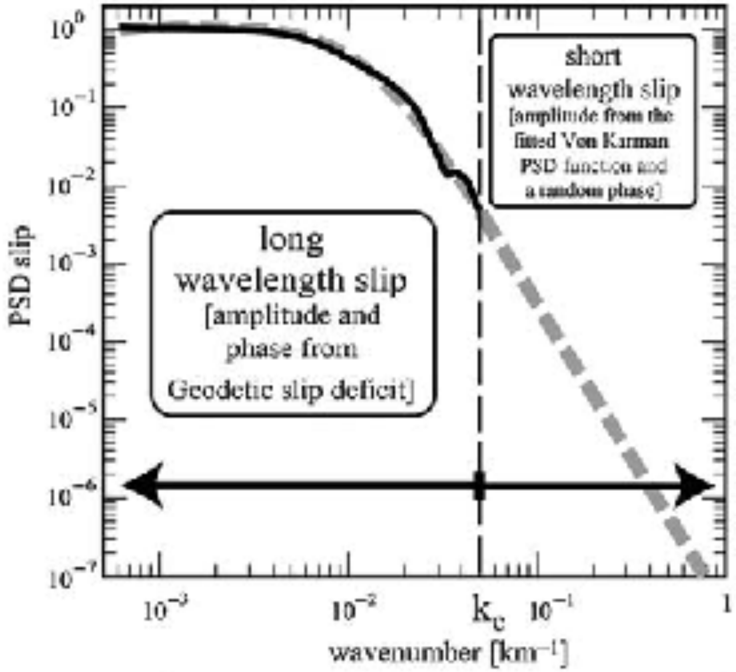

Broadband wavenumber slip, Mw= 8.11, dx= 2

1. Create a correlated random phase slip model using the Von Karman parameters obtained from the geodetic model.

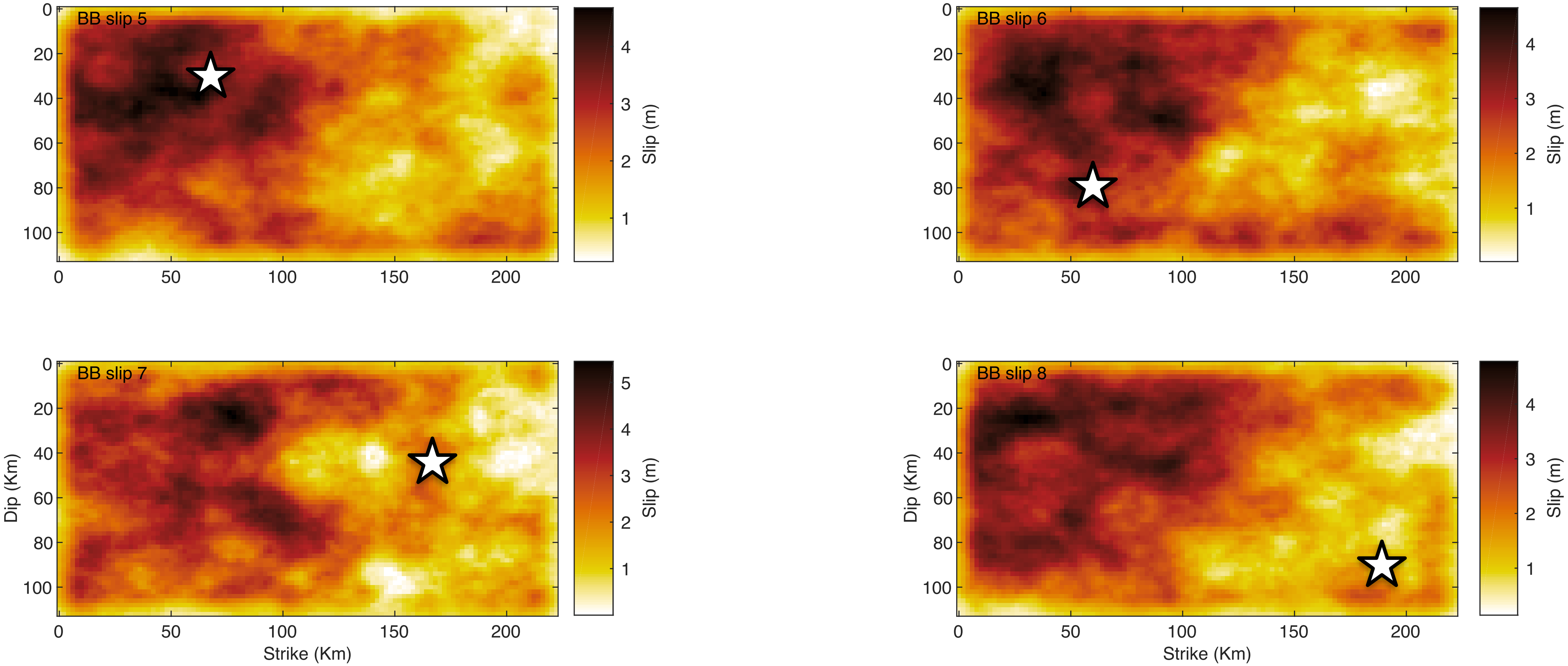
2.Apply a low pass filter to the original scenario and a high pass filter to the random phase scenario

3. We add the long-wavenumber and high-wavenumber slip scenarios to build the broadband rupture scenario.

$$P(k_s, k_d) = \frac{a_s a_d}{[1 + {a_s}^2 {k_s}^2 + {a_d}^2 {k_d}^2]^{H+1}}$$

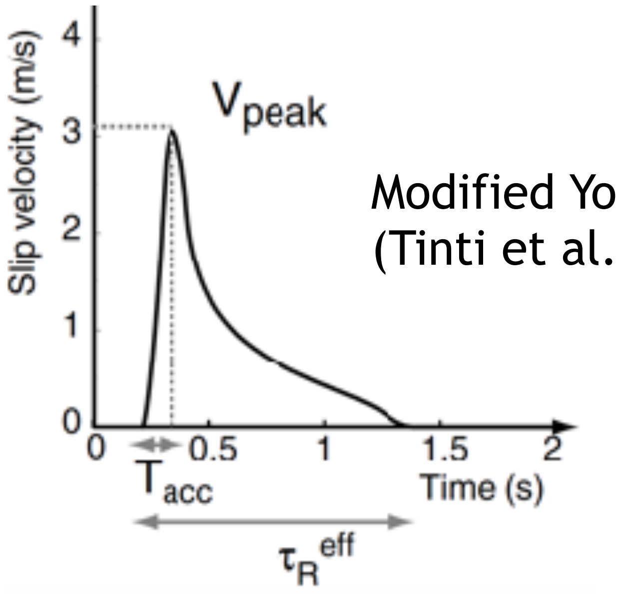


Final Broadband wavenumber slip scenarios



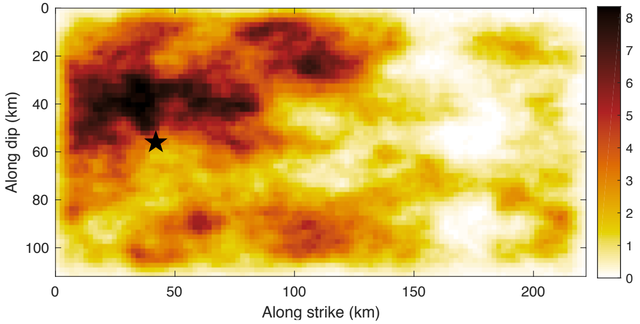
Spatio-temporal source description

We describe the kinematic rupture evolution by the spatial distribution of the slip, the rise time, Vr and the peak time and that their PSDs follow a Von Karman function

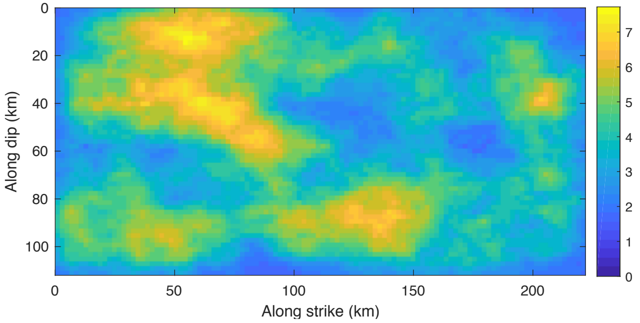


Modified Yoffe function (Tinti et al., 2005)

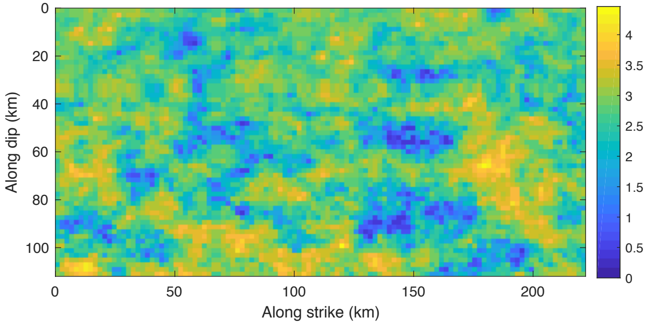
1. Slip



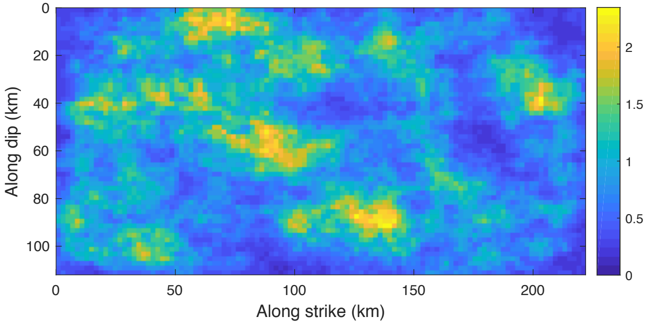
2. Rise time



3. Vr



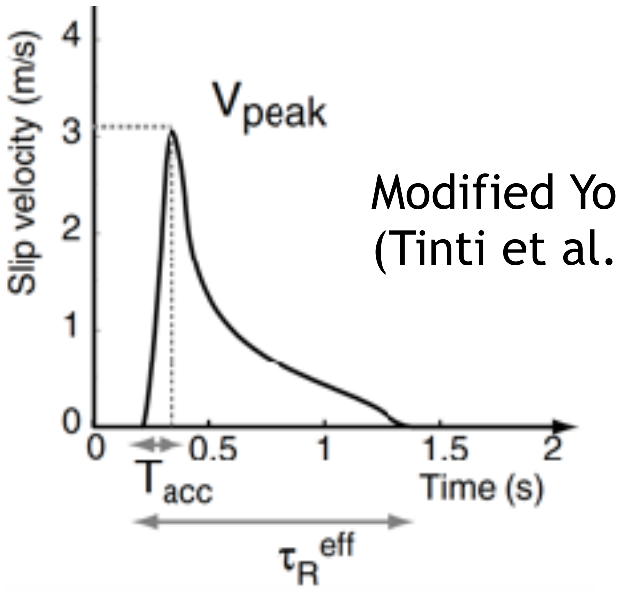
4. Peak time



Spatio-temporal source description

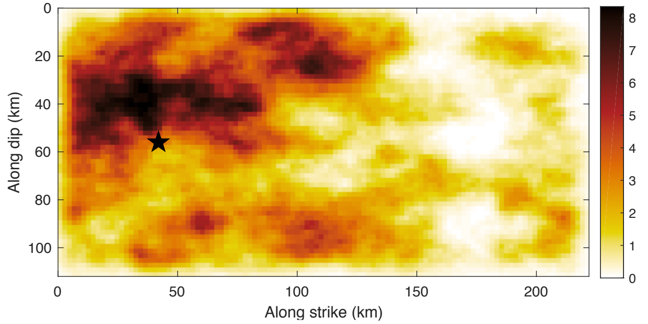
We describe the kinematic rupture evolution by the spatial distribution of the slip, the rise time, Vr and the peak time and that their PSDs follow a Von Karman function

Considers the spatial interdependency from every source parameter extracted from dynamic rupture simulations (Schemedes et al., 2010).

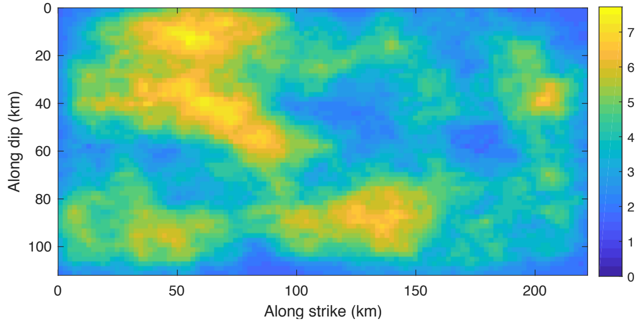


Modified Yoffe function (Tinti et al., 2005)

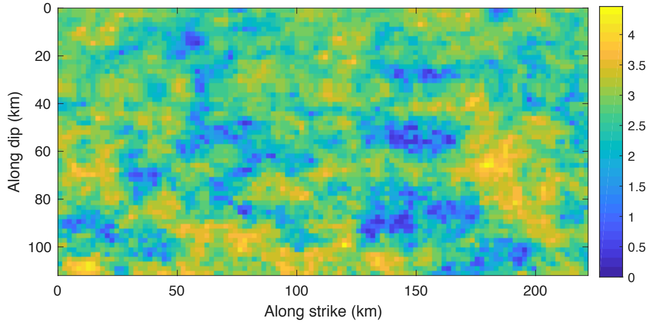
1. Slip



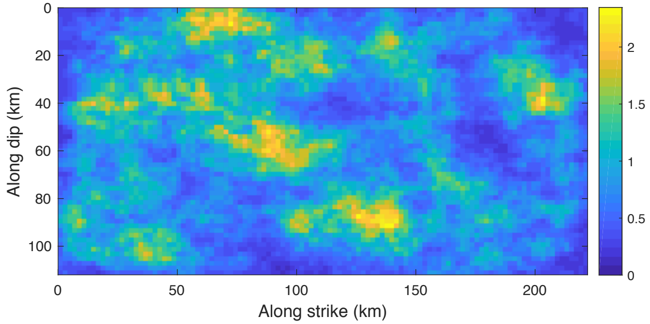
2. Rise time



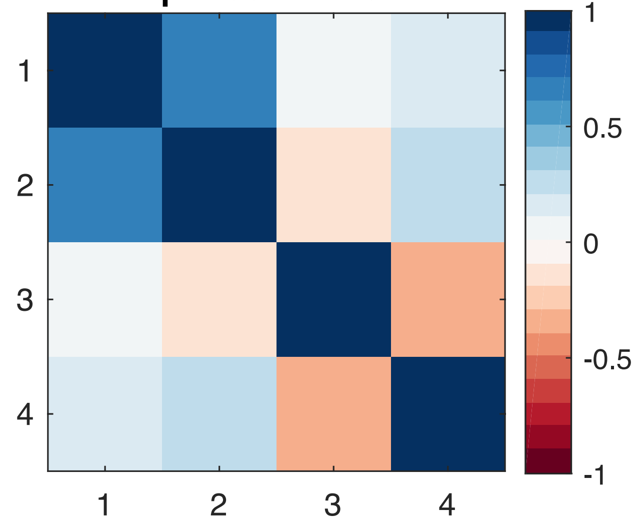
3. Vr



4. Peak time



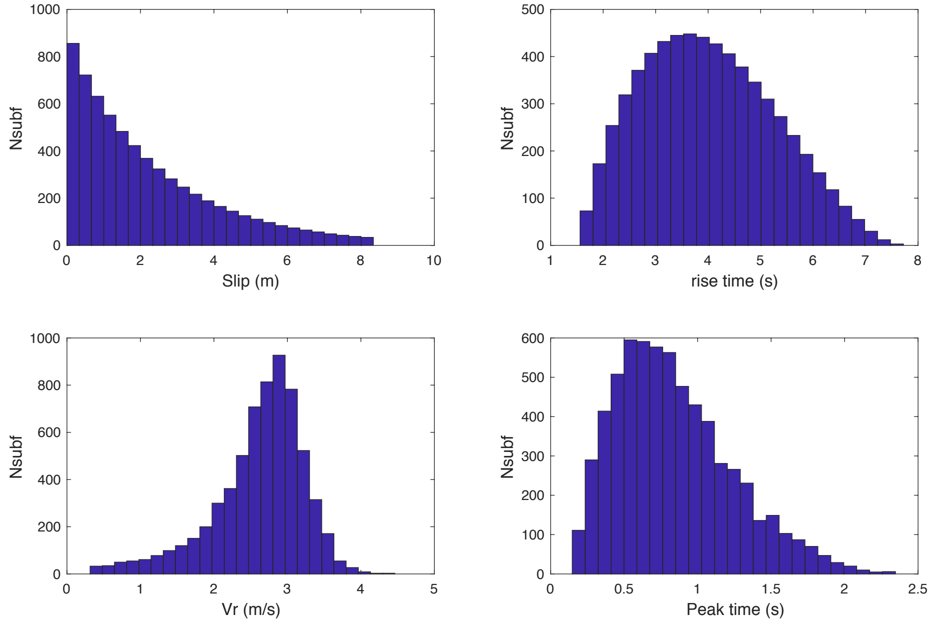
Input correlations



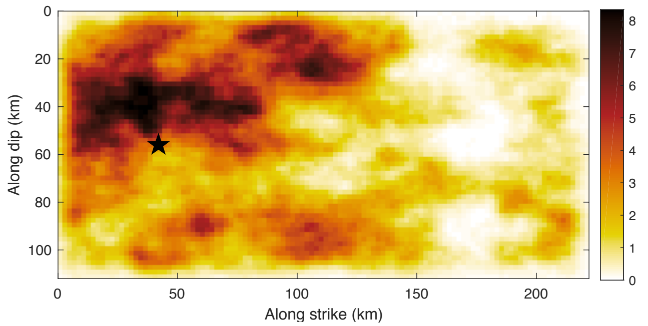
Spatio-temporal source description

We sample every source parameter with an specific probability density function.

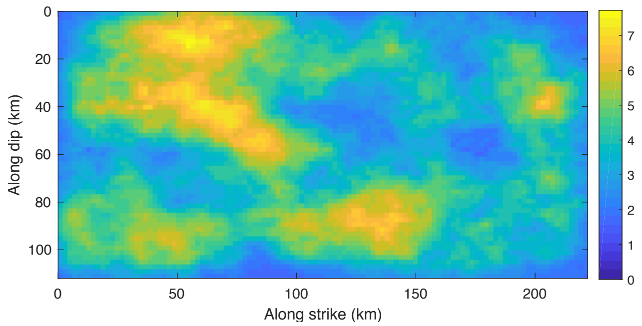
- **Truncated exponential PDF** (Thingbaijam and Mai, 2016)
- **Gamma PDF** for the rise time and the peak time (Schemedes, et al, 2010)
- **Levy PDF** for the Vr (Schemedes et al., 2010, Crempien et al. 2015)



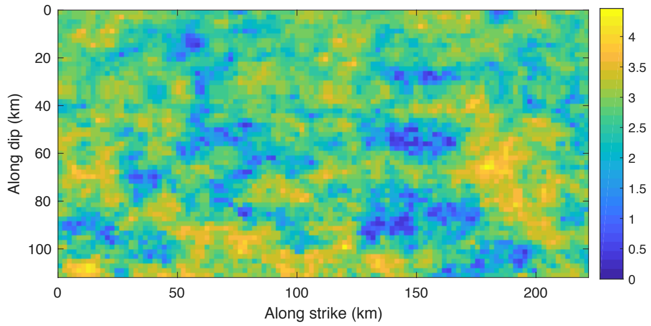
1. Slip



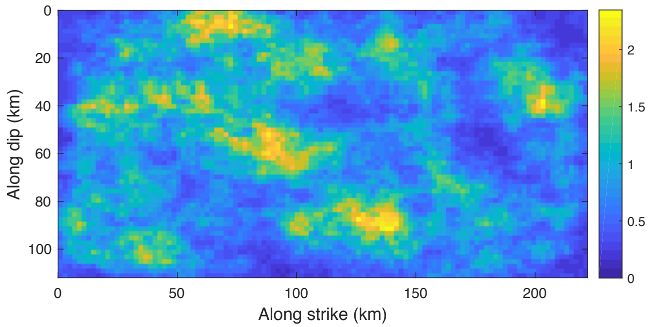
2. Rise time



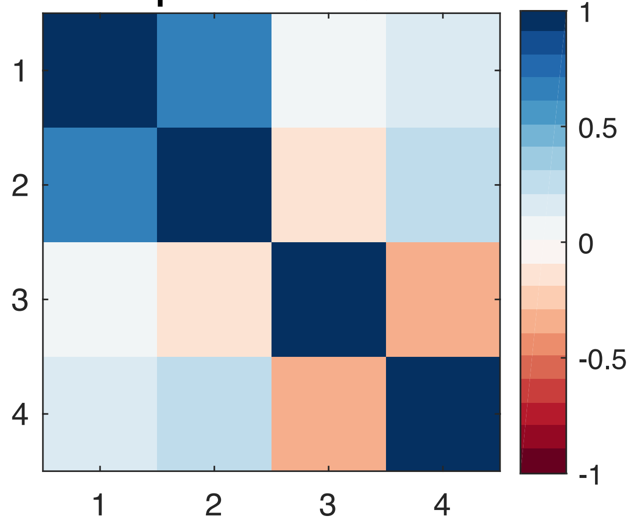
3. Vr



4. Peak time



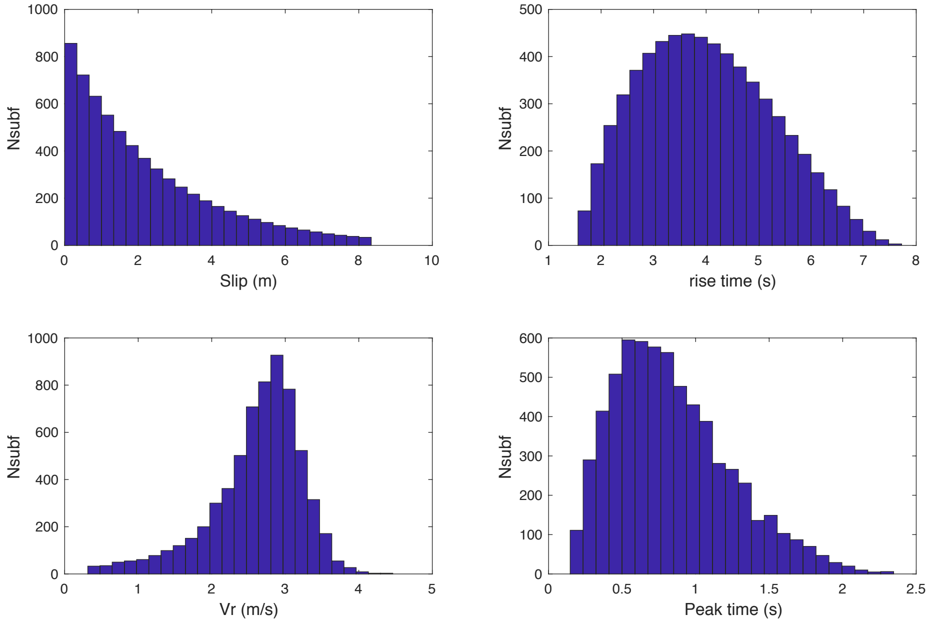
Input correlations



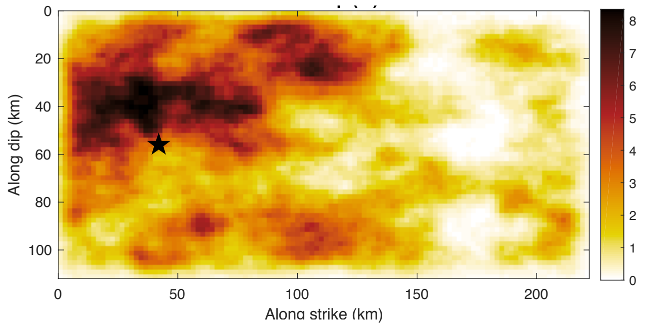
Spatio-temporal source description

We sample every source parameter with an specific probability density function.

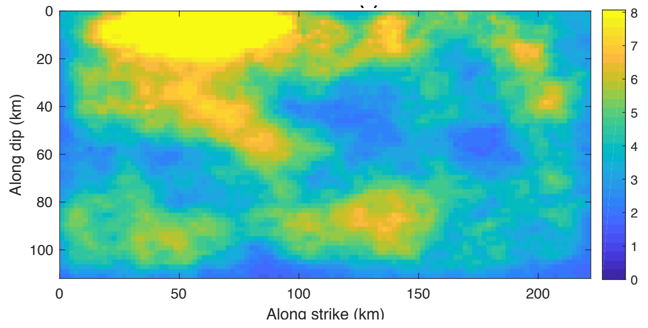
- **Truncated exponential PDF** (Thingbaijam and Mai, 2016)
- **Gamma PDF** for the rise time and the peak time (Schemedes, et al, 2010)
- **Levy PDF** for the Vr (Schemedes et al., 2010, Crempien et al. 2015)



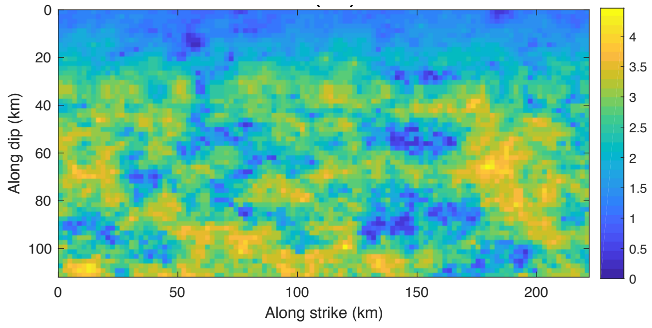
1. Slip



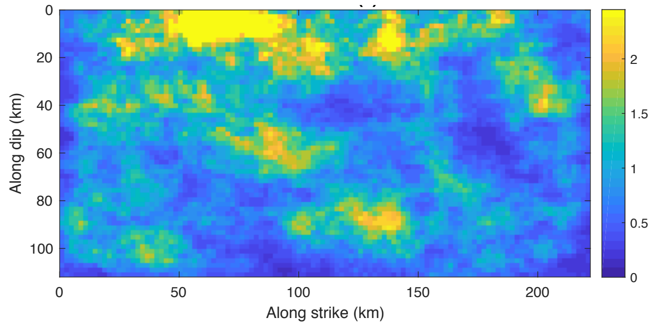
2. Rise time



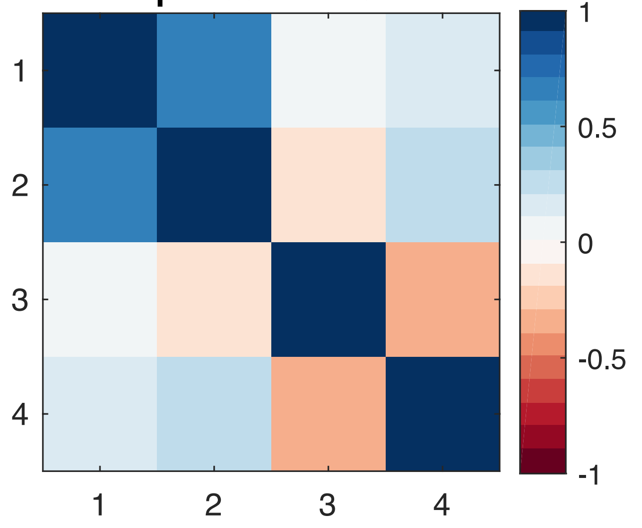
3. Vr



4. Peak time

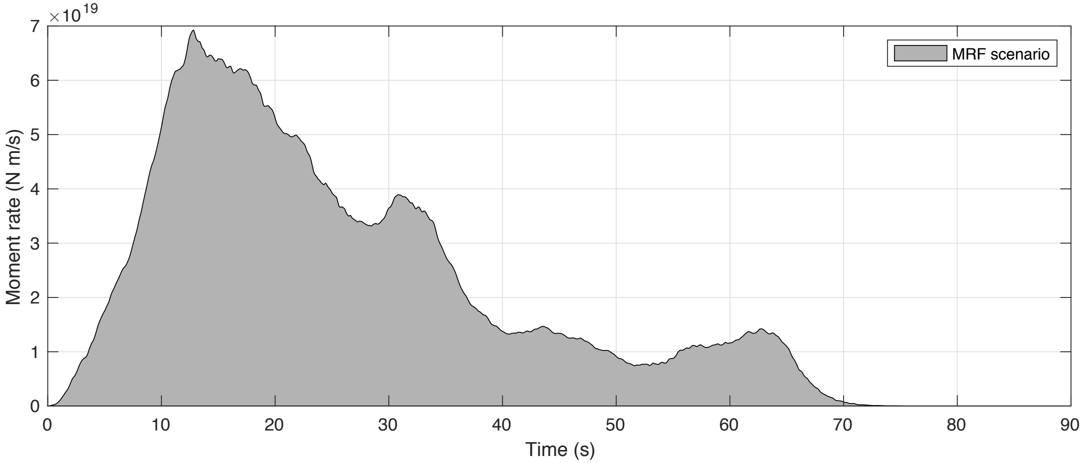


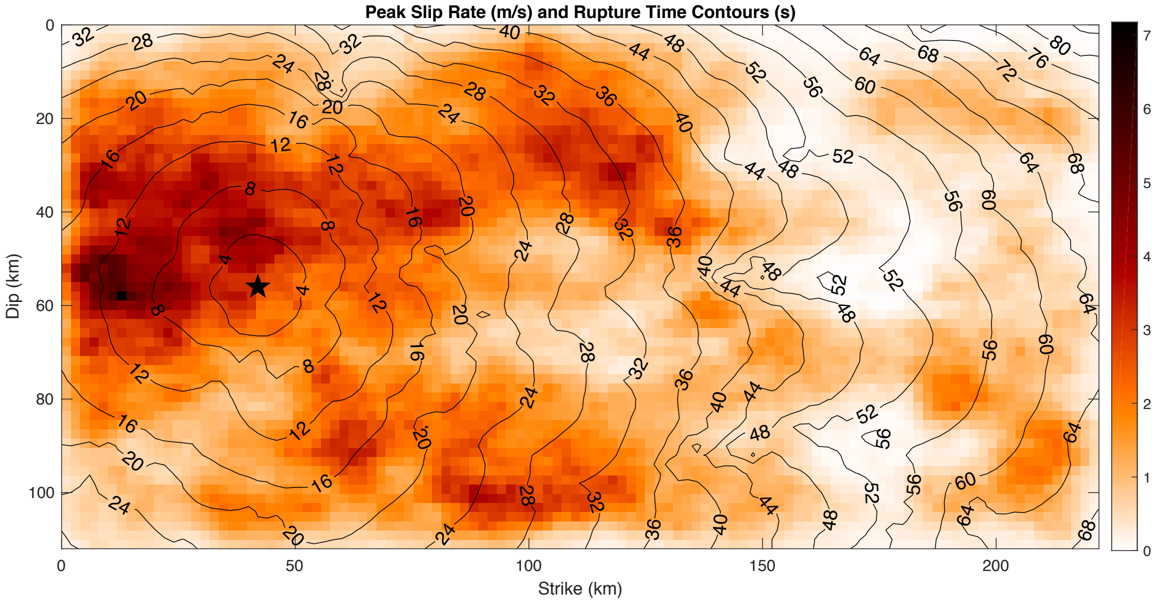
Input correlations

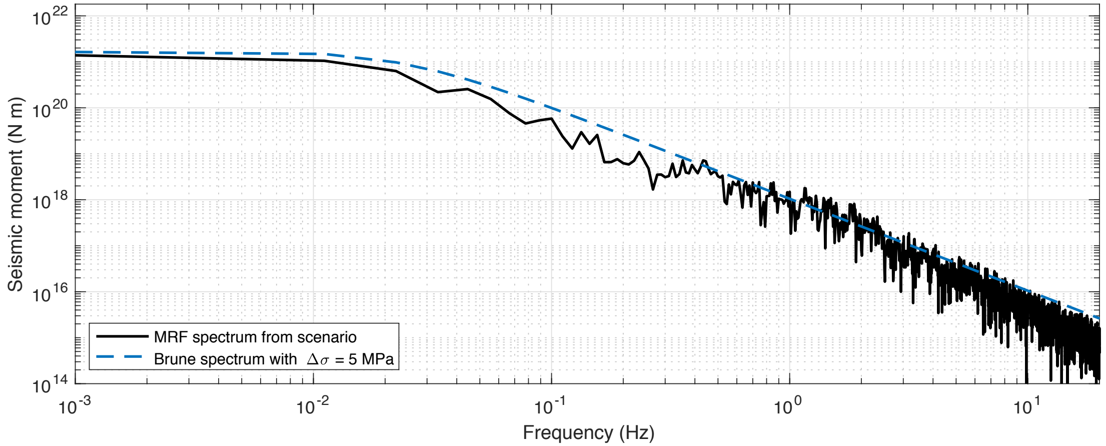


Spatio-temporal source description

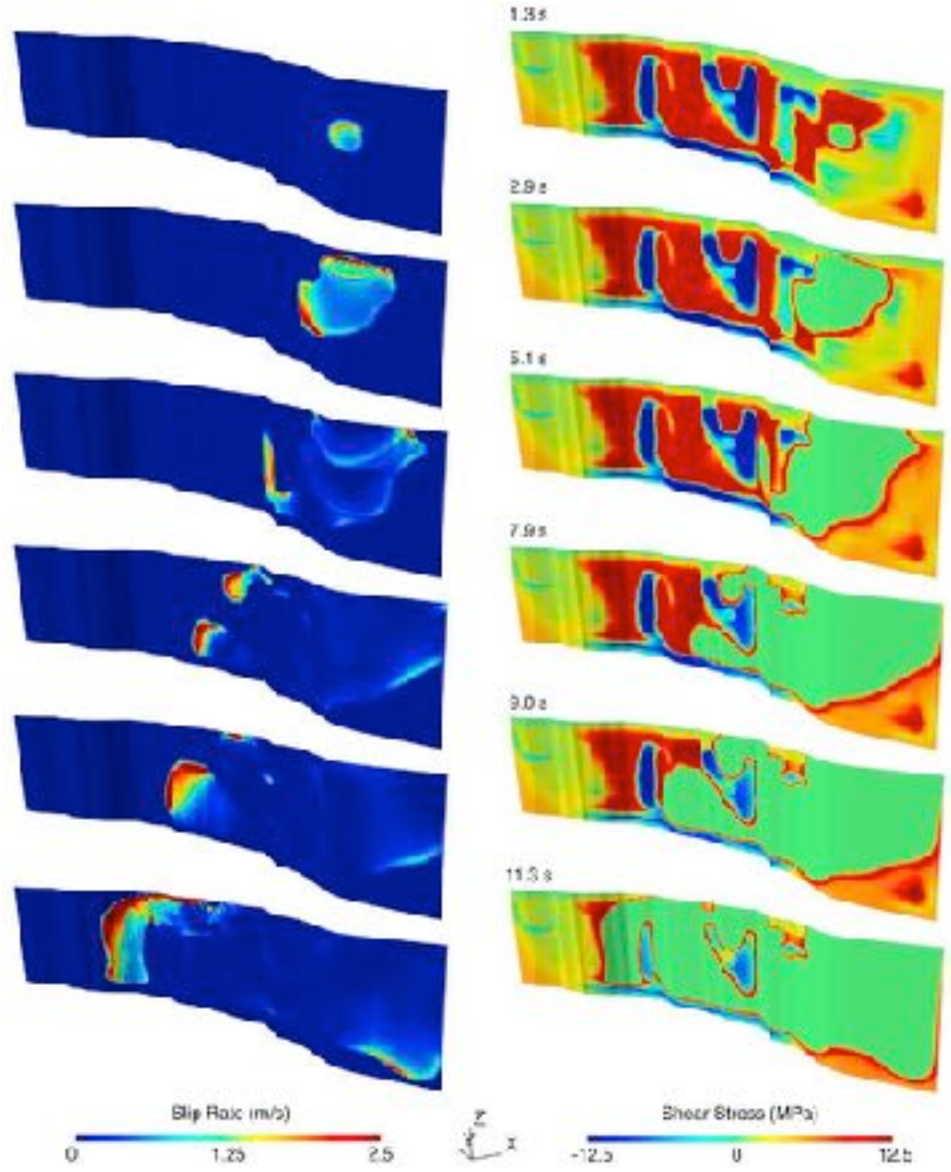
We scale the rise time and peak time to match an objective source time spectrum in a similar fashion as proposed by the UCSB method (Schmedes et al, 2013, Crempien et al., 2015).







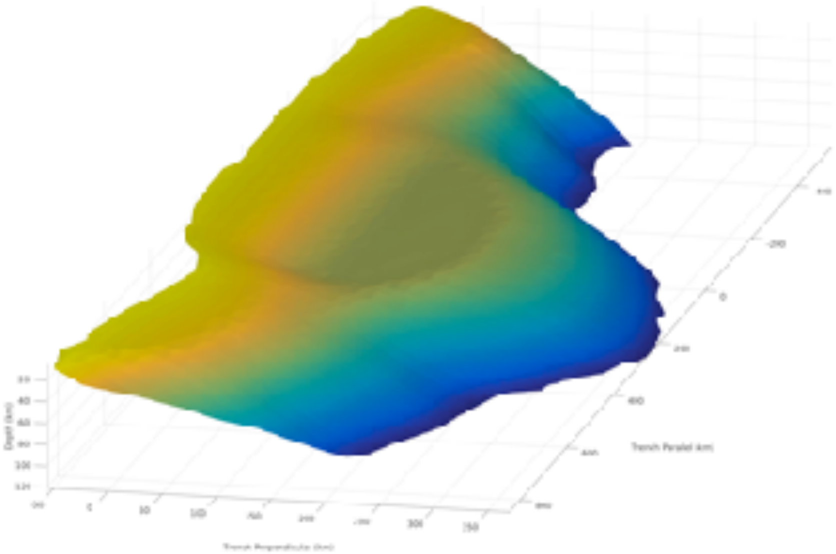
Discontinuos Galerkin Finite Element Method (DG-Crack)



Tago et al., 2012

- Based on the code introduced by Etienne et al. (2010)
- Solve the velocity-stress system for a unstructrured tetrahedral mesh allowing arbitrary refinements (**h-adaptivity**) and local interpolation orders. (**p-adaptivity**).
- Efficient to model the kinematic and the dynamic of the rupture as well as the wave propagation in complex geometries embed in complex 3D viscoelastic media.
- The implemented friction law is slip-weakening and we will soon verified the rate-and-state friction law.

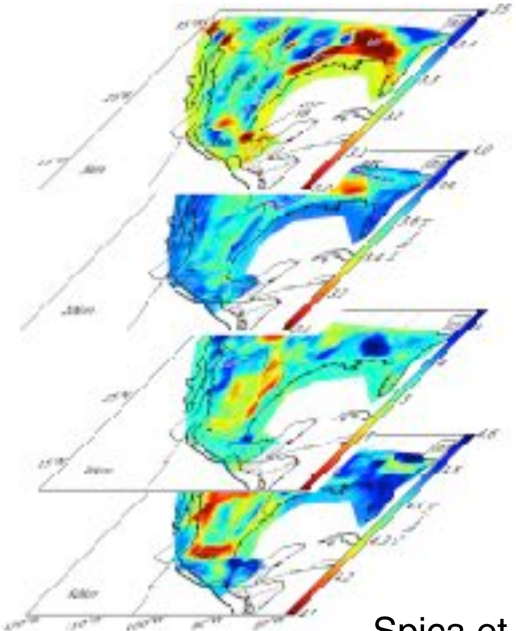
Construction of the tetrahedral mesh



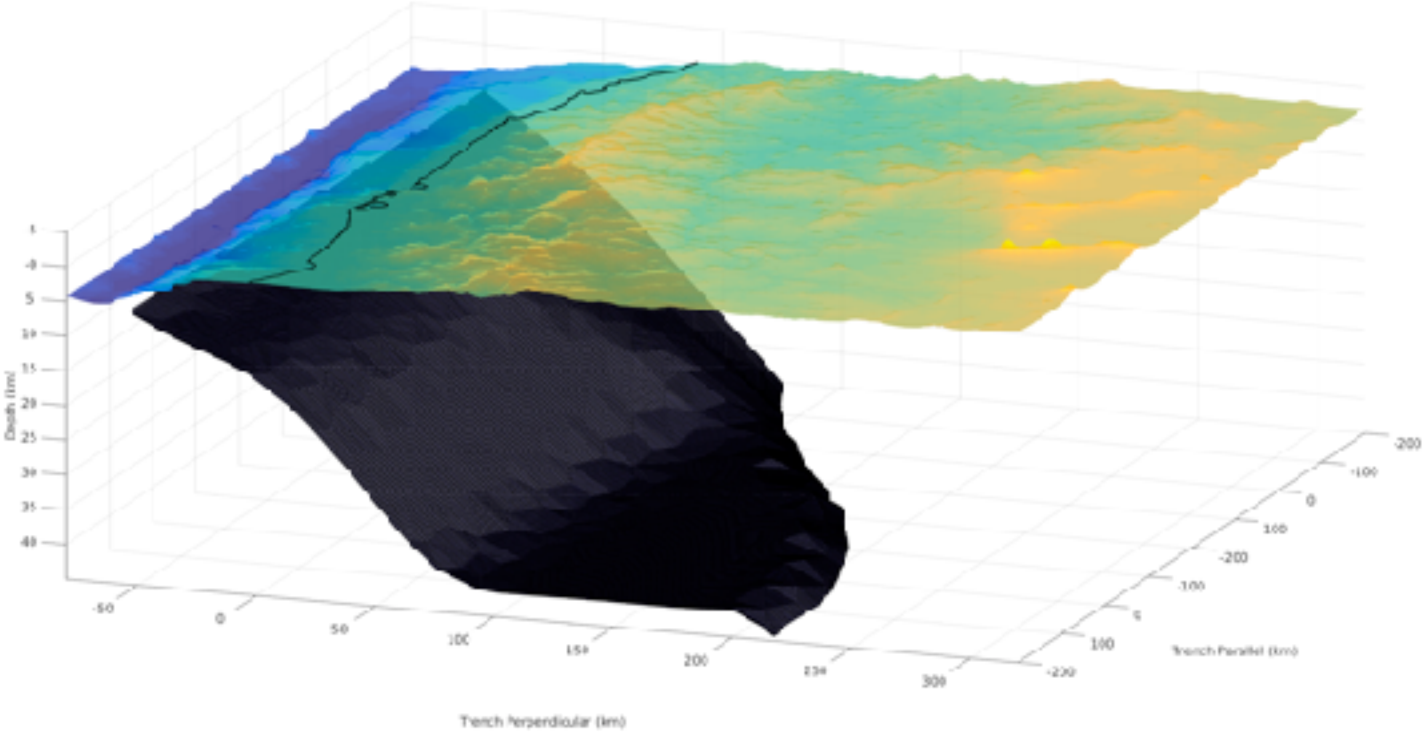
Inputs to create the tetrahedral mesh

a) Topography and bathymetry of the region (srt15 model, UCSD).
b) New 3D Geometry of the plate interface .
c) 3D tomographic model of Mexico (Spica et al., 2016).

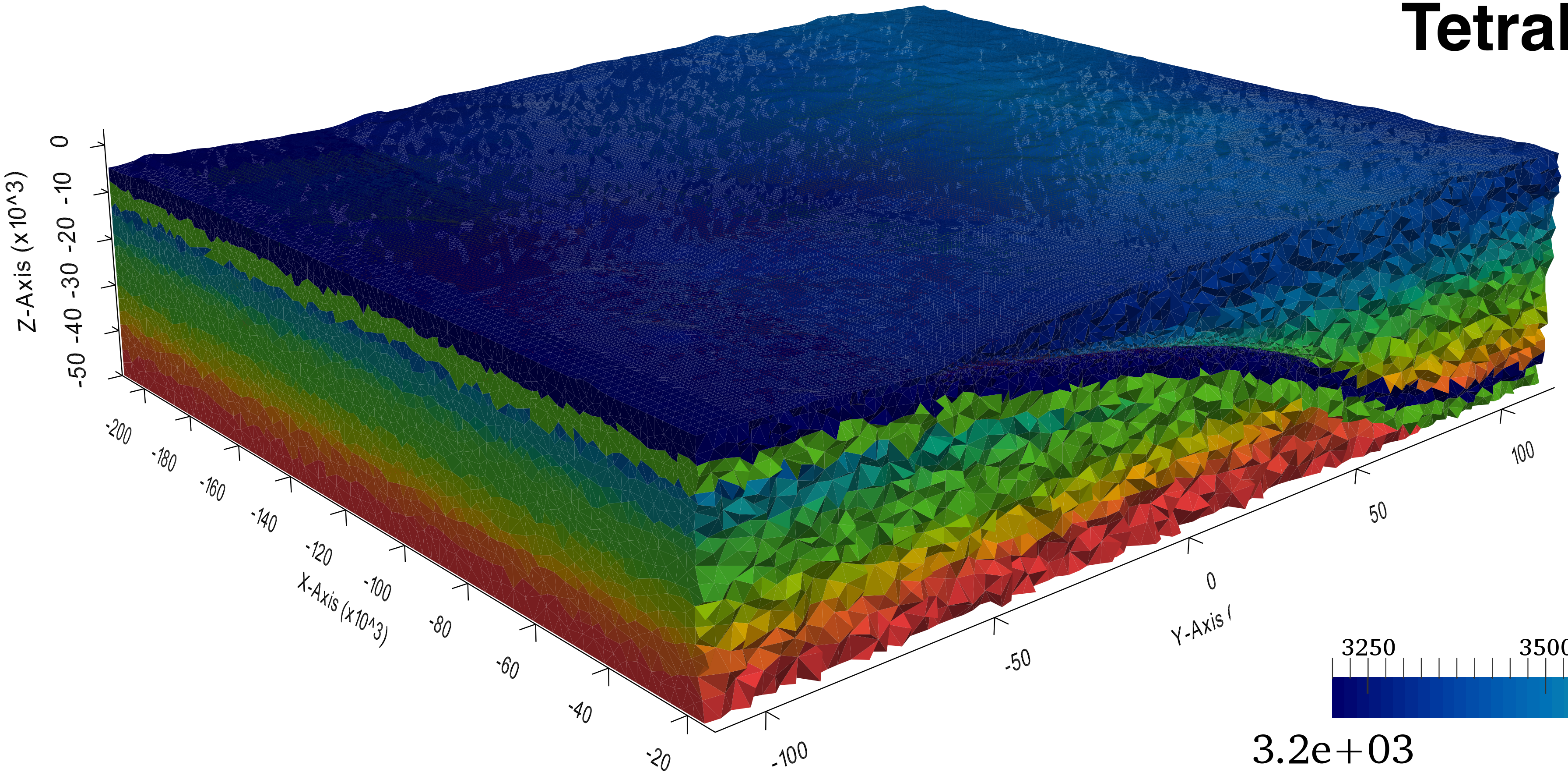
The unstructured mesh assigns the properties of the medium to every element by means of the TETGEN mesher and an iterative process to guarantee the h-adaptivity.



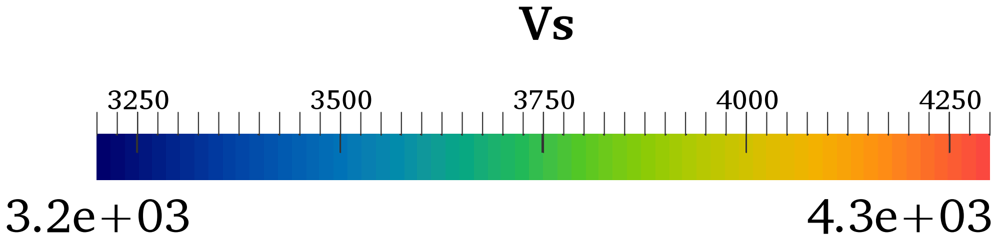
Spica et al., 2016

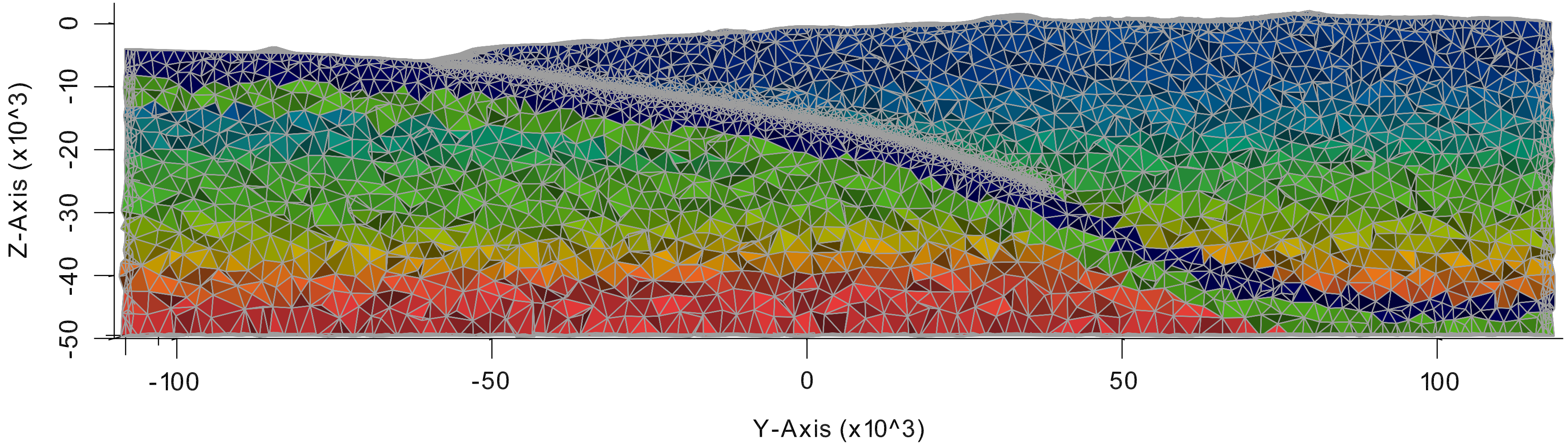


Tetrahedral mesh for the study region



Model for 500 km x 300 km





Broadband seismograms generation

High Frequency generation

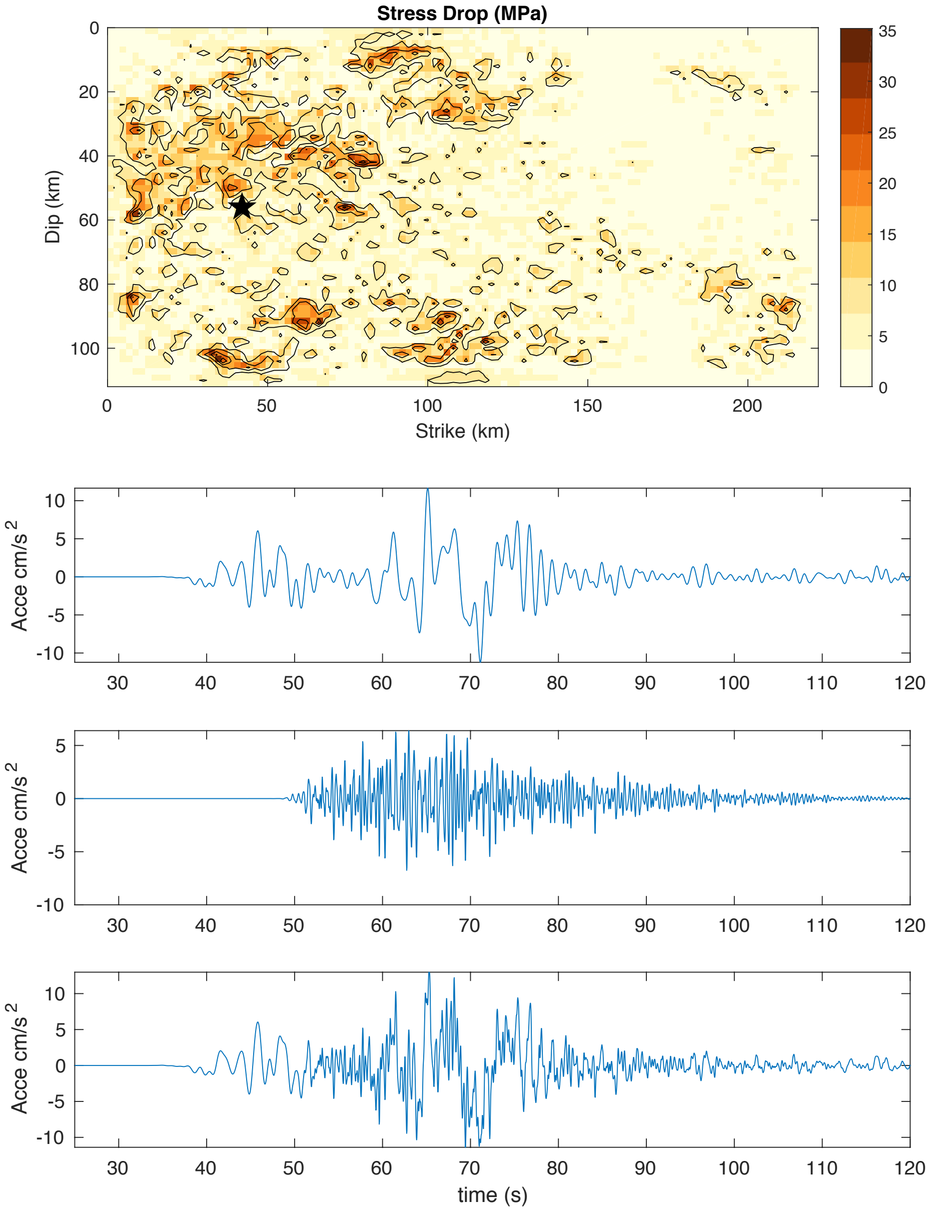
- For the high frequency generation we modified the methodology of Pulido et al. (2015) that considers:

1. The spatial distribution of the source parameters (Mo, stress drop) for the calculations of high frequency point sources.

2. Characterization of scattering using and empirical envelope (Pulido and Dalguer, 2009).

3. Frequency-dependent radiation pattern correction.

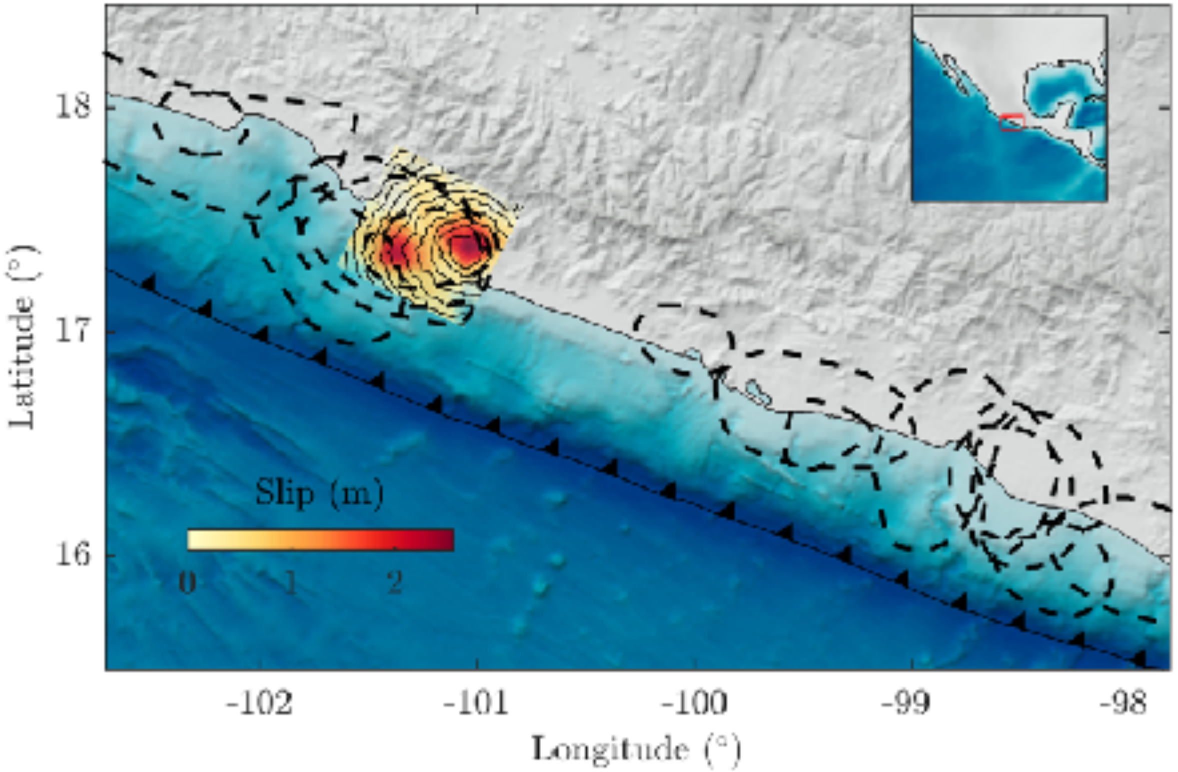
- We use these point sources functions together with the rise time and rupture velocity from our source generator to compute the total high frequency ground motion by applying the empirical Green's function method (Irikura 1978)



Validation of the kinematic source generator

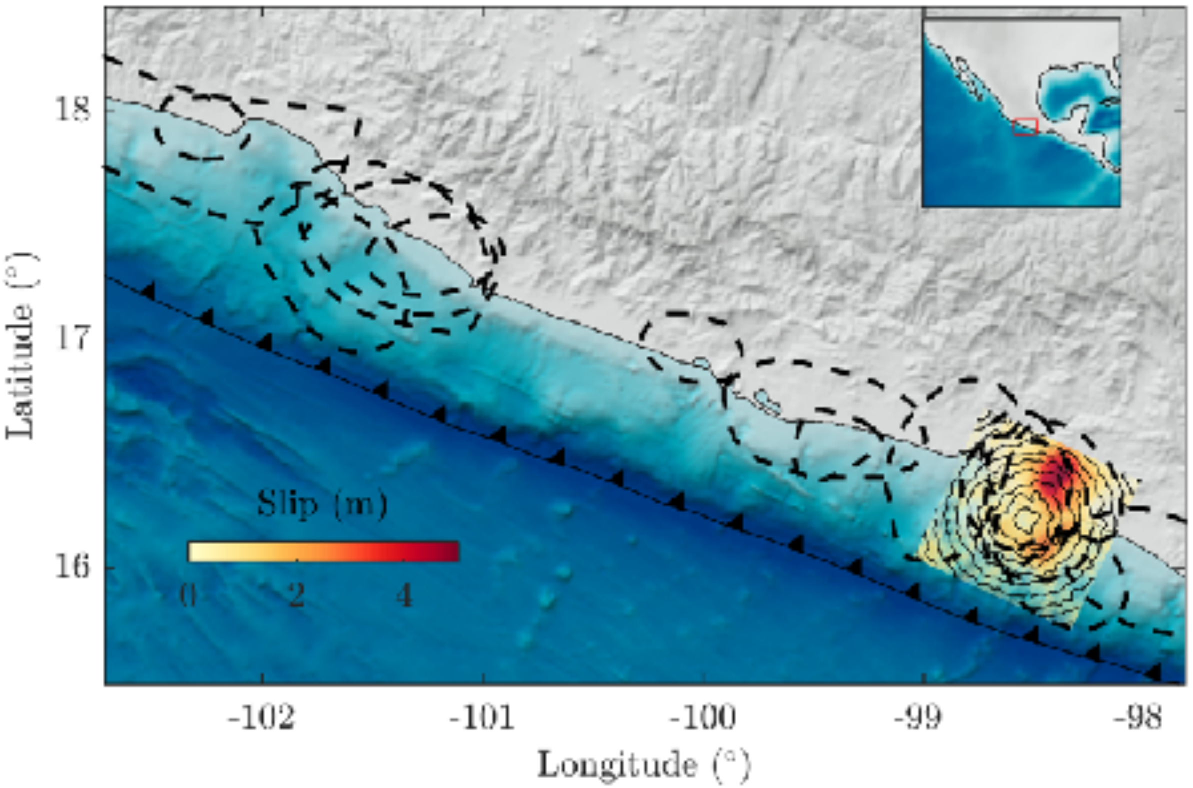
Papanoa Earthquake

Mw 7.3
18-April-2014 (Guerrero)



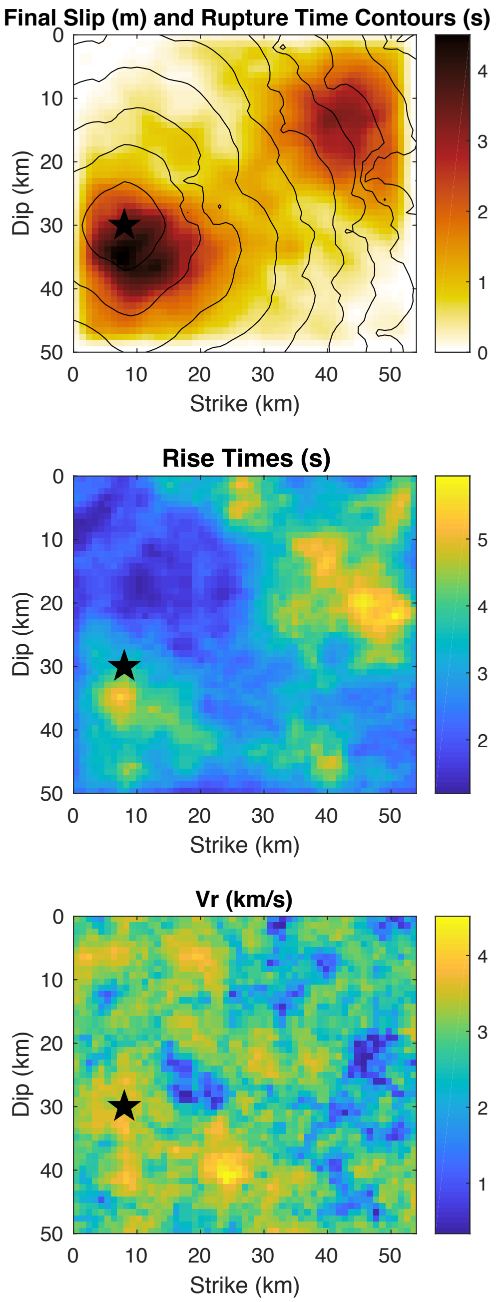
Pinotepa Earthquake

Mw 7.5
20-March-2012 (Oaxaca)

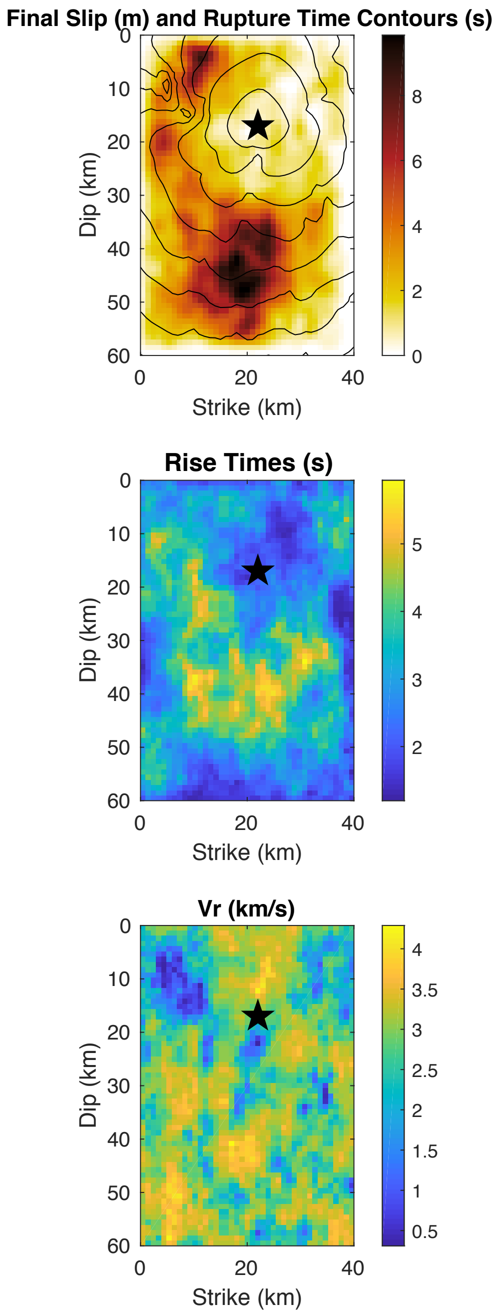


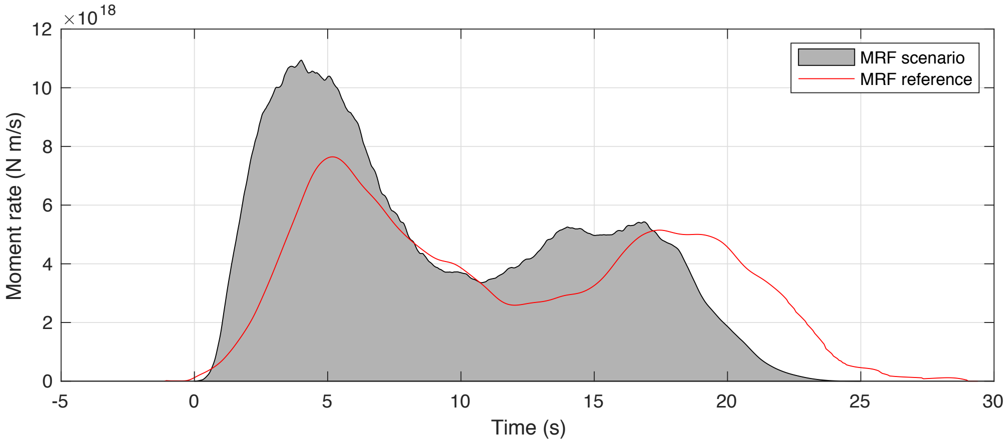
Validation of the source generator

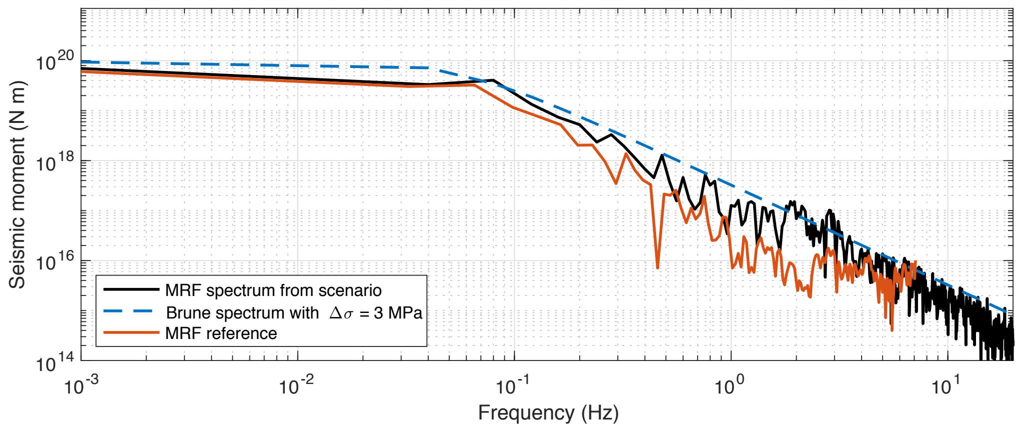
Papanoa Earthquake

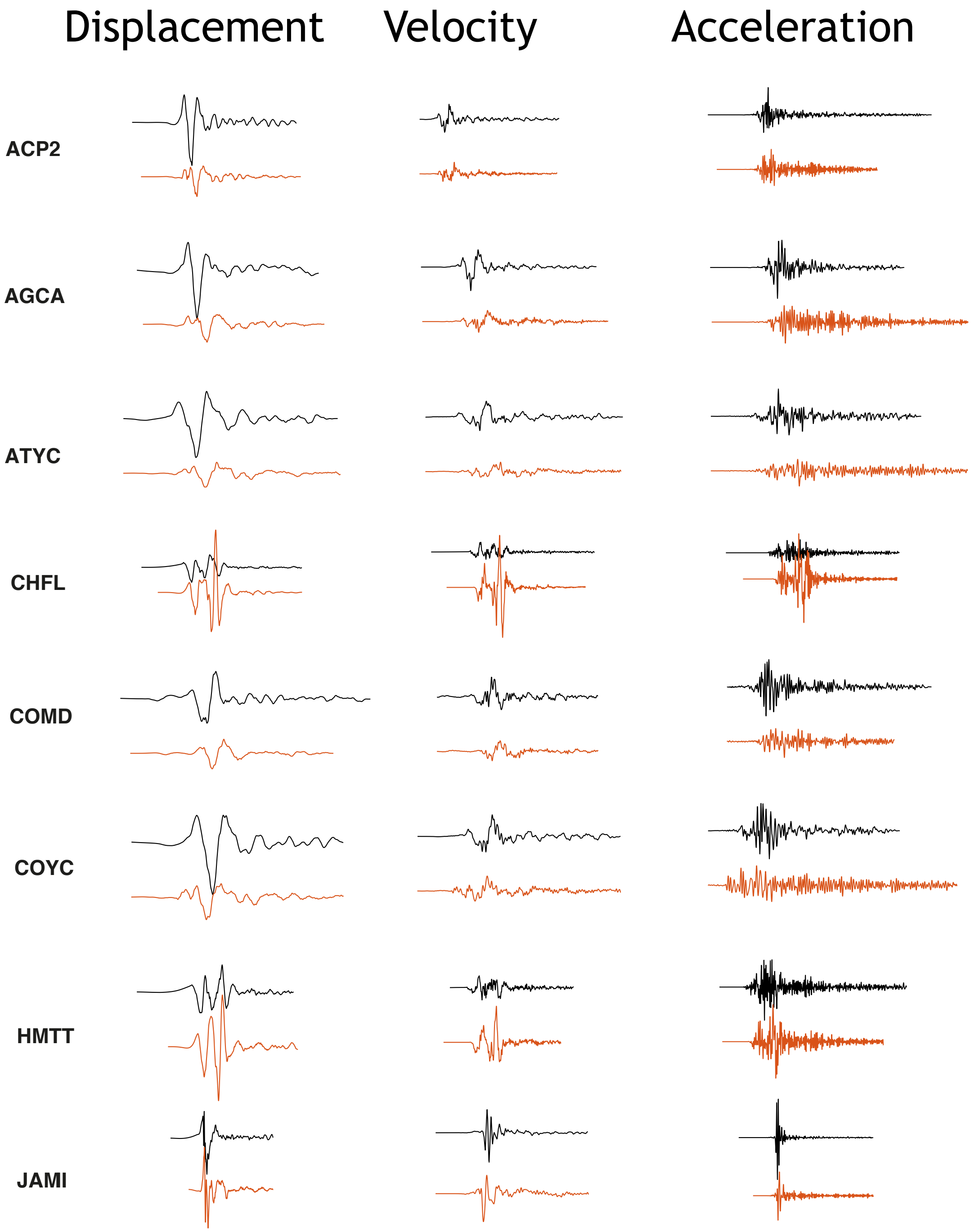


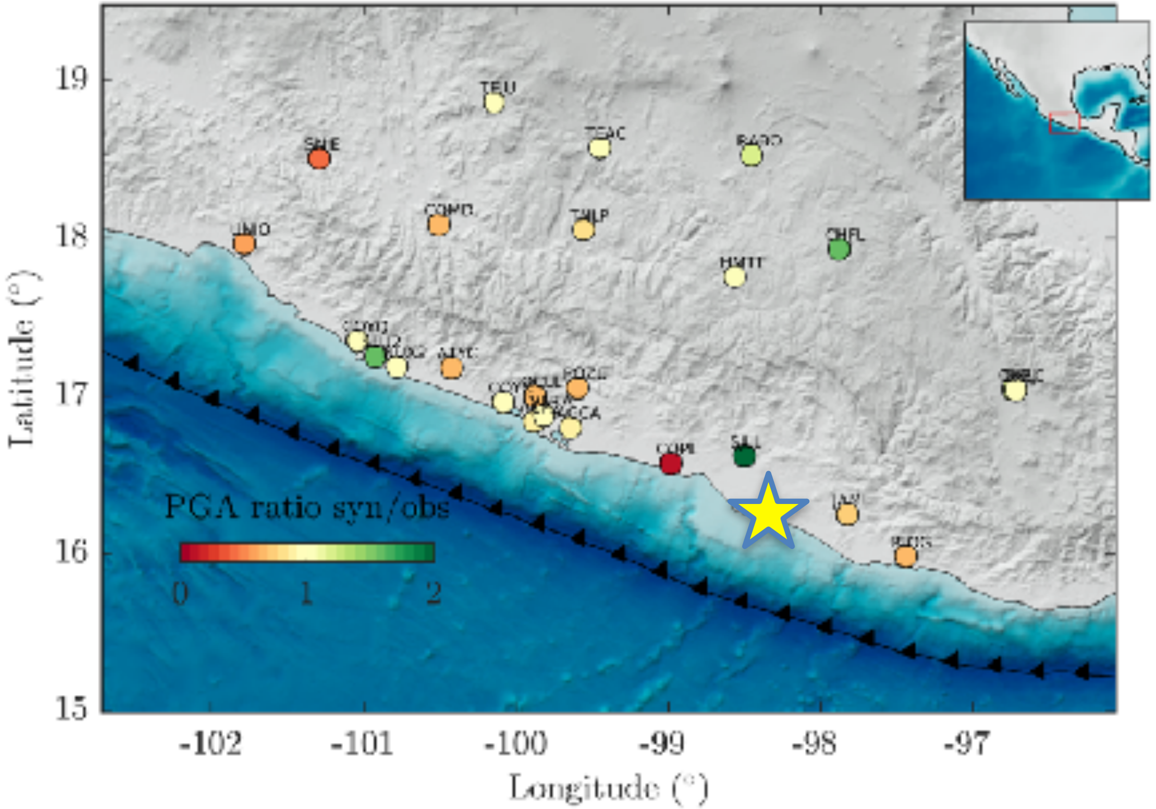
Pinotepa Earthquake

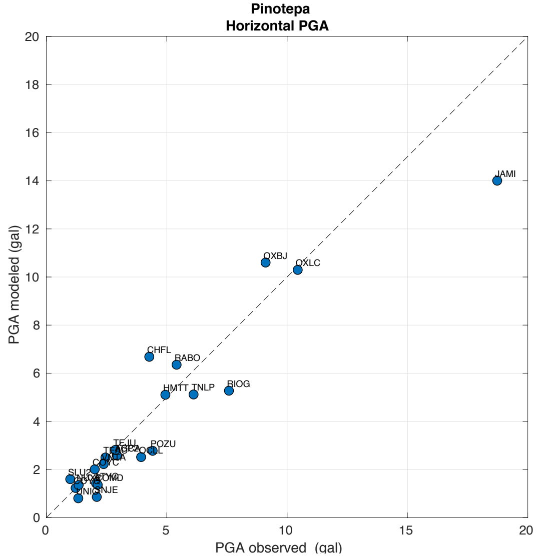


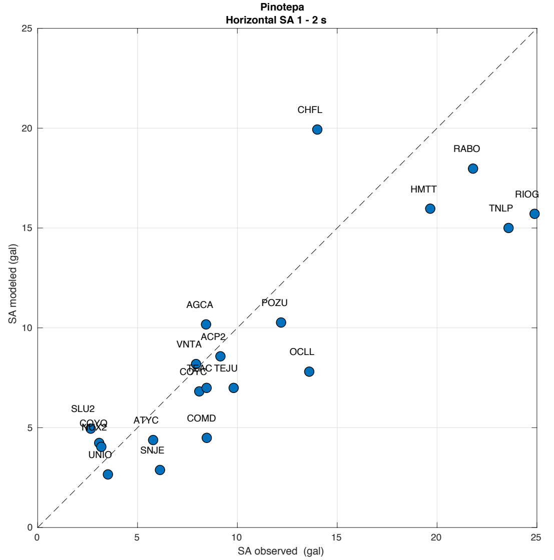




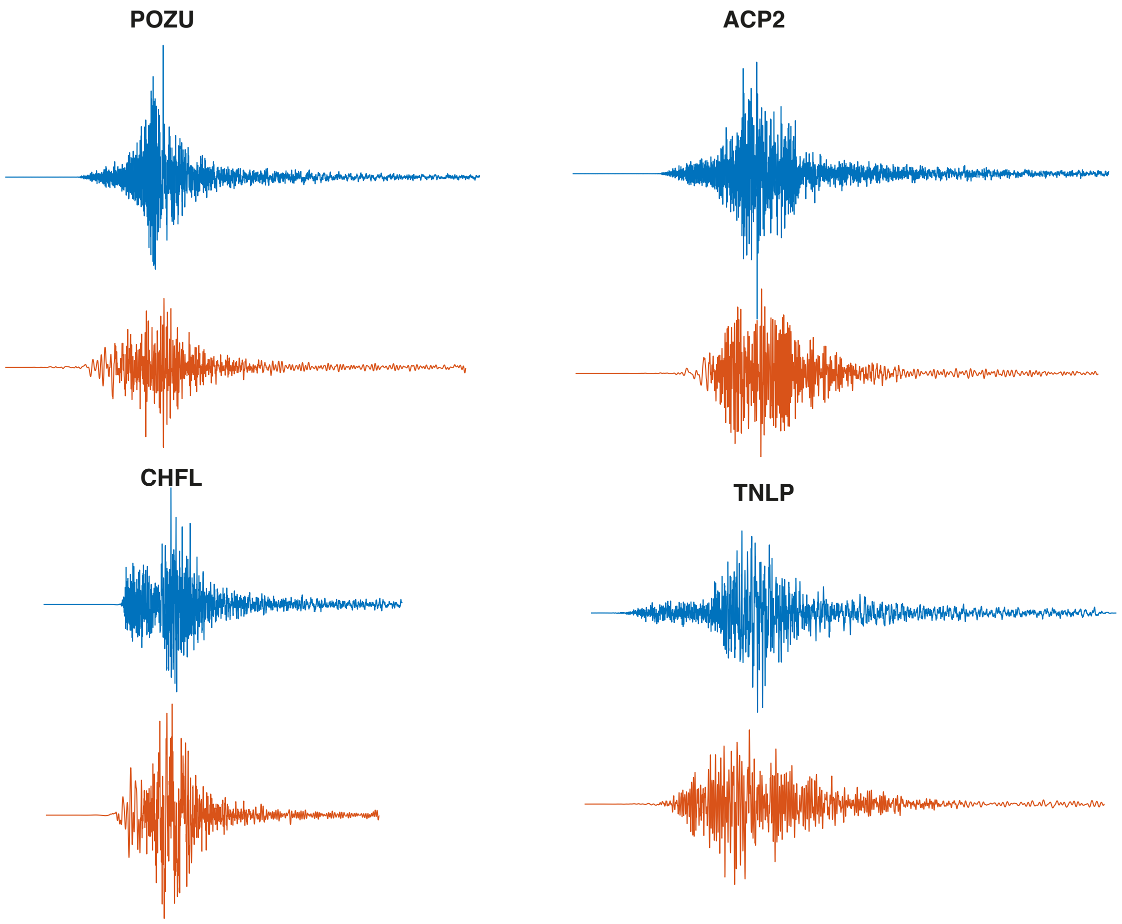

Displacement
Velocity
Acceleration
ACP2
AGCA
ATYC
CHFL
COMD
COYC
HMTT
JAMI


TEJU
SNJE
TEAC
RABO
COMD
TNLP
UNIO
CHFL
HMTT
ATYC
POZU
AGCA
COPI
SLLI
OCLL
RIOG
PGA ratio syn/obs
0
1
2
19
18
17
16
15
Latitude (°)
-102
-101
-100
-99
-98
-97
Longitude (°)

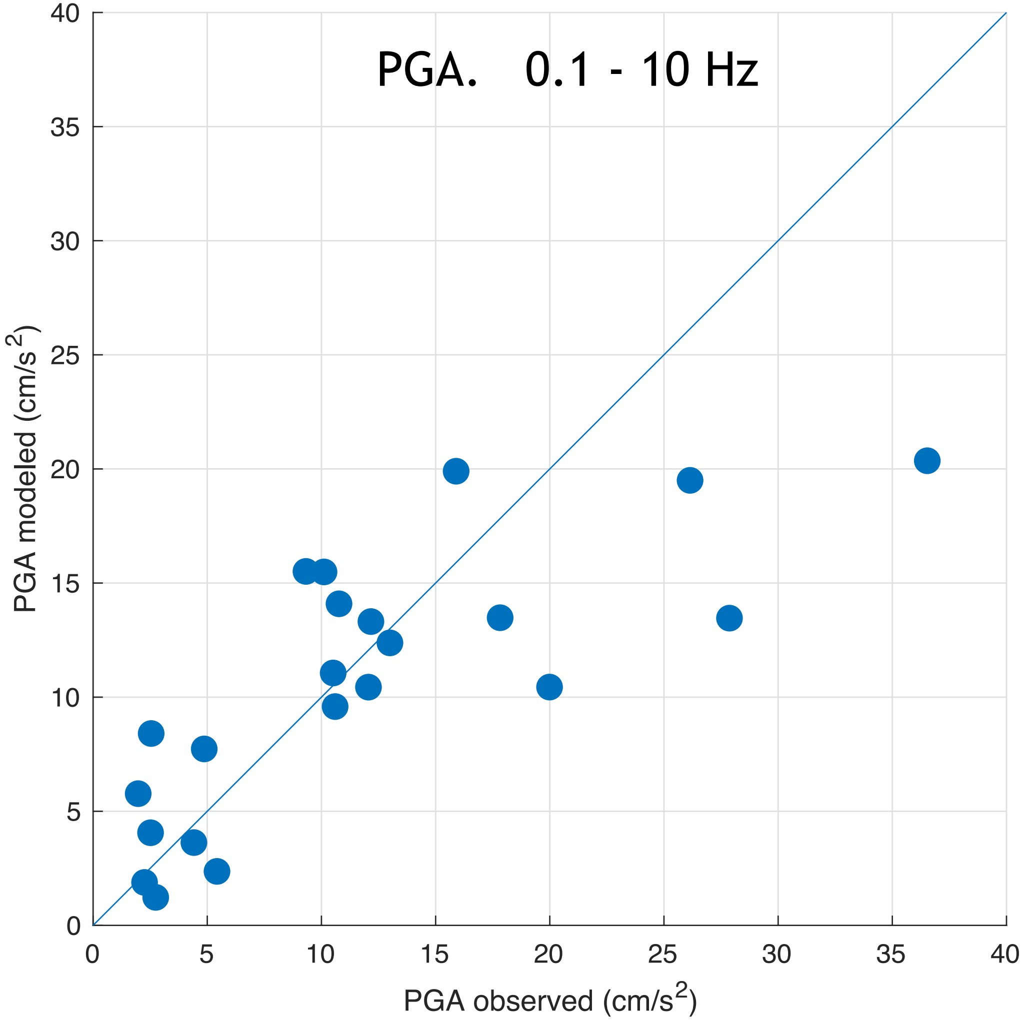

Pinotepa
Horizontal PGA
PGA modeled (gal)
PGA observed (gal)
0
2
4
6
8
10
12
14
16
18
20
0
5
10
15
20
JAMI
OXBJ
OXLC
CHFL
RABO
HMTT
TNLP
RIOG
TEJU
TEAC
ACP2
VNTA
OCLL
POZU
COYC
SLU2
ATYC
COMD
UNIO
SNJE


Pinotepa
Horizontal SA 1 - 2 s
SA modeled (gal)
SA observed (gal)
0
5
10
15
20
25
0
5
10
15
20
25
CHFL
RABO
HMTT
RIOG
TNLP
AGCA
POZU
ACP2
VNTA
OCLL
TEAC
TEJU
COYC
SLU2
COYO
NUX2
ATYC
COMD
UNIO
SNJE

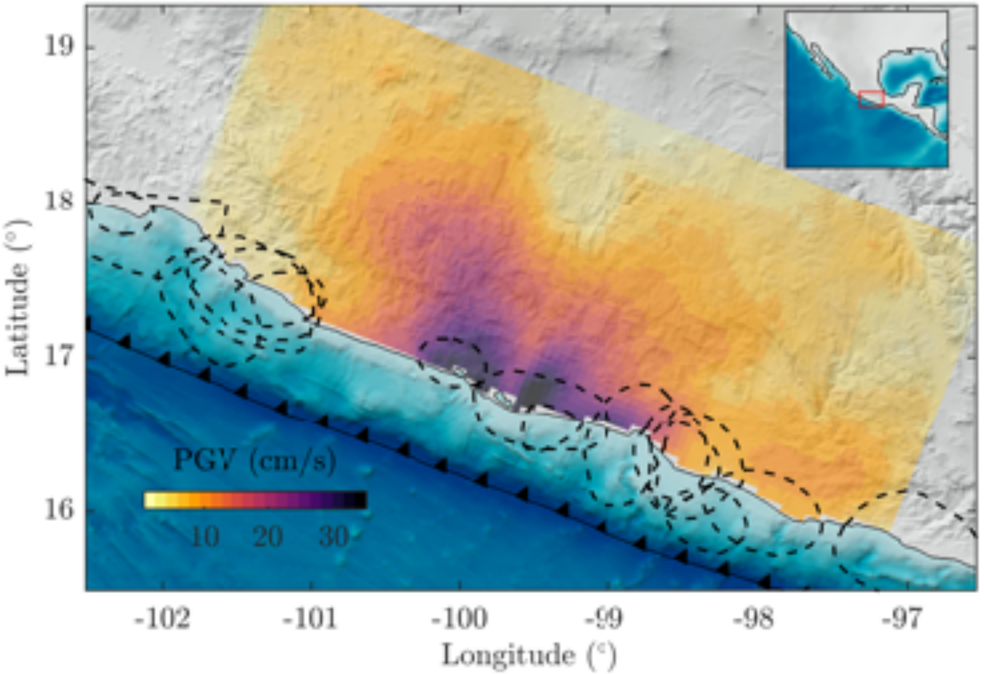
Broadband seismograms generation

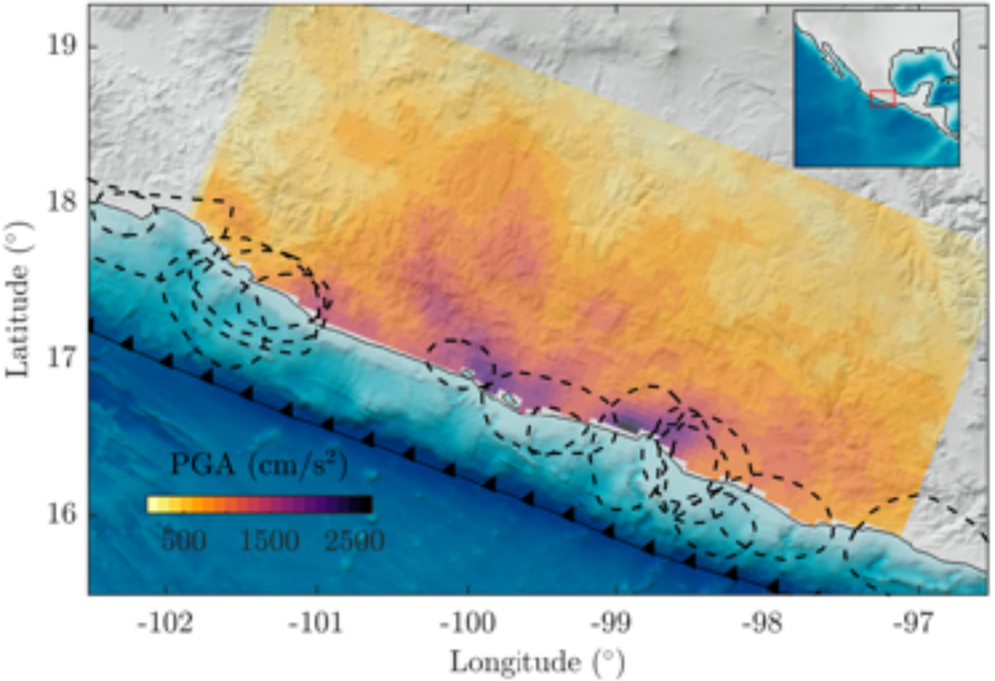


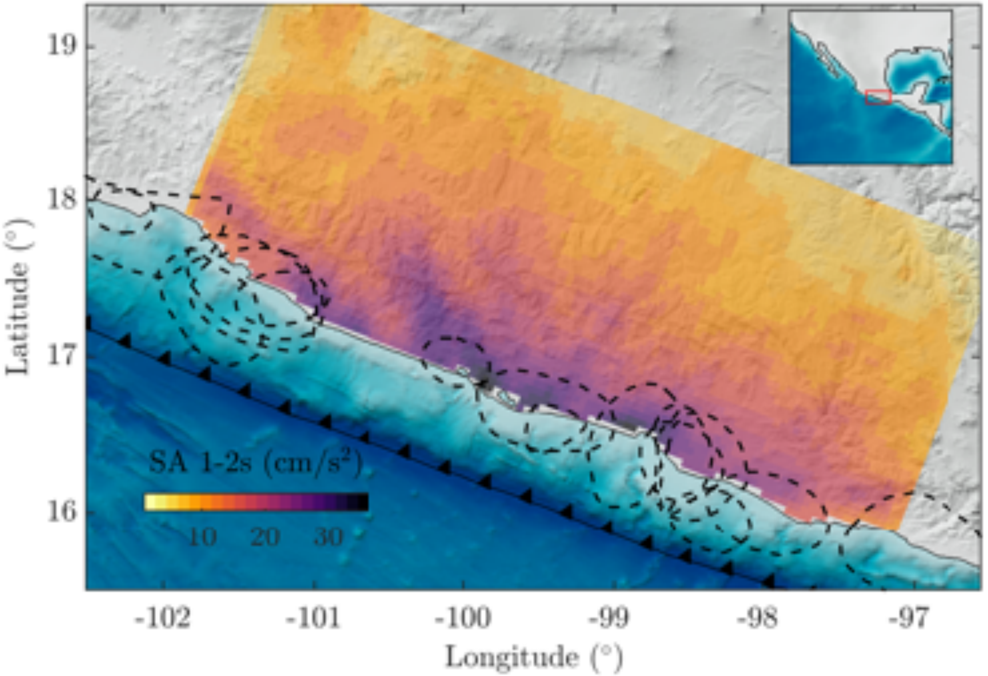
Acceleration trench - perpendicular

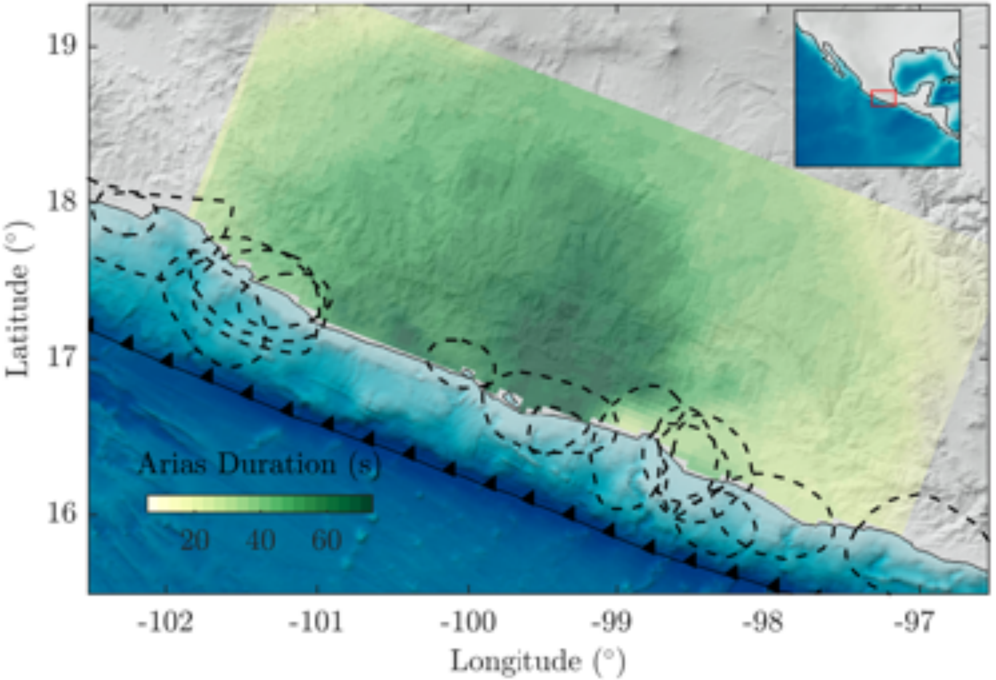


PGA. 0.1 - 10 Hz

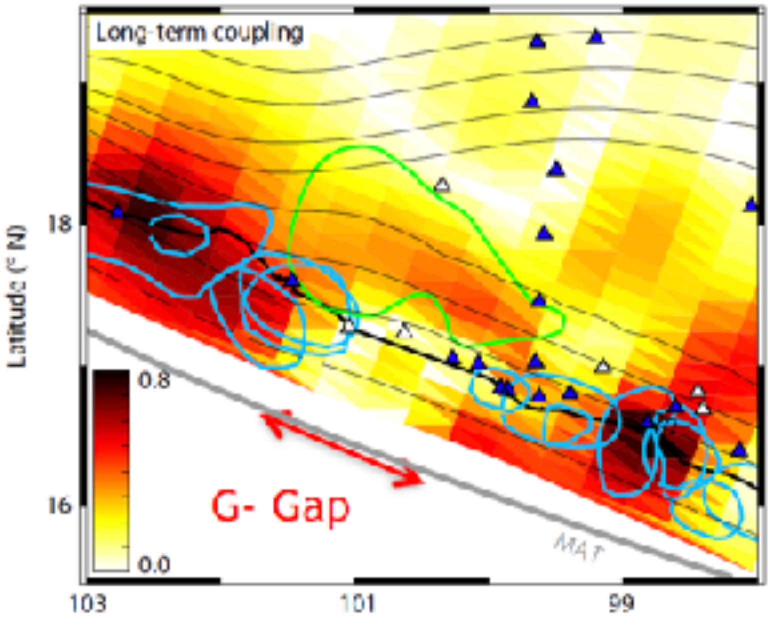

PGV (cm/s)
10
20
30
19
18
17
16
Latitude (°)
-102
-101
-100
-99
-98
-97
Longitude (°)


PGA (cm/s^2)
500
1500
2500
19
18
17
16
Latitude (°)
-102
-101
-100
-99
-98
-97
Longitude (°)

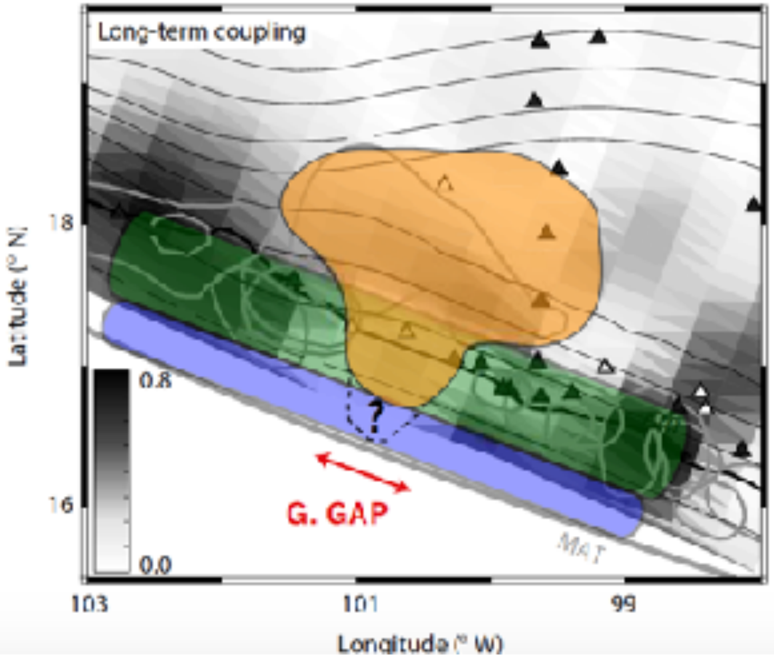

SA 1-2s (cm/s^2)
10
20
30
19
18
17
16
Latitude (°)
-102
-101
-100
-99
-98
-97
Longitude (°)


Arias Duration (s)
20
40
60
19
18
17
16
Latitude (°)
-102
-101
-100
-99
-98
-97
Longitude (°)

Lateral variation of mechanical properties



- The interseismic coupling estimated considering the occurrence of SSEs (i.e., long-term inter seismic coupling) is low.
- Possible lateral segmentation of the frictional properties on the plate interface.



Hipótesis: Posible segmentación en Guerrero

🟦	Velocity strengthening	High permeability
🟩	Velocity weakening	
🟧	Velocity strengthening - High fluid pressures	Low permeability

Remarks, Work in Progress and Future Directions

1. We applied and improved the methodology of Pulido et al., 2015 to build broadband wavenumber slip scenarios in the Guerrero subduction zone.

2. We improved the temporal characterization of our rupture models based on the pseudodynamic representation of the source .

3. We are validating our methodology with two moderate magnitude earthquakes in the region.

4. Address the seismic hazard by means of dynamic rupture simulations using rate and state friction law.