Systematic detection and characterization of slow slip events along the Mexican subduction zone from 2000 to 2019

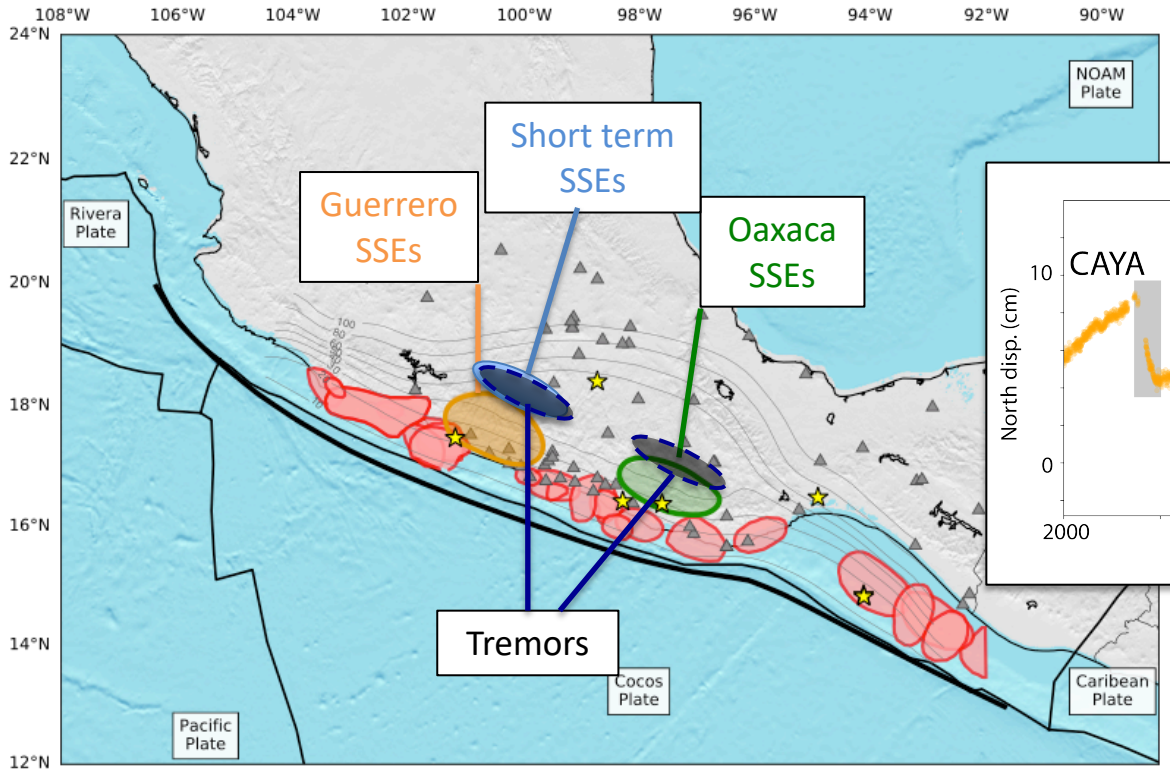
Mathilde Radiguet[1],
Ekaterina Kazachkina[2], Louise Maubant[1], Nathalie Cotte[1],
Vladimir Kostoglodov[2], Adriano Gualandi[3], Kristel Chanard [4]

1. ISTerre, University Grenoble Alpes, France
2. Instituto de Geofísica, UNAM, Mexico
3. JPL , Caltech USA
4. IGN, France

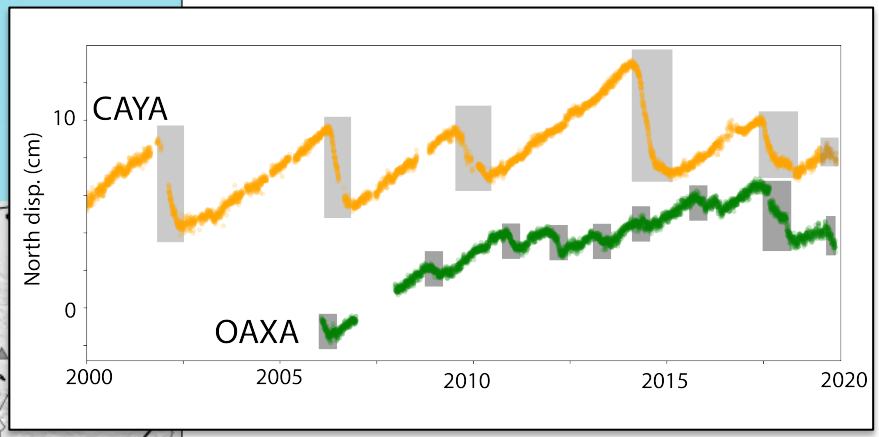
ISTerre
Institut des Sciences de la Terre

UNIVERSITÉ Grenoble Alpes

Tectonic context and Slow Slip Events



North comp. GPS times series for two stations in Guerrero and Oaxaca



- Recurrent long-term SSEs in Guerrero (4 years) and Oaxaca (1-2 years) Graham et al. 2015, Radiguet et al. 2012, 2016
- Short term SSEs (LFEs + GPS; geodetic match filter) Frank et al. 2015; Rousset et al. 2017
- Tectonic tremors Husker et al. 2012; 2019

Questions and methodology

PROBLEM

- No consistent analysis of the various slow slip processes detected geodetically at the scale of the subduction

METHOD

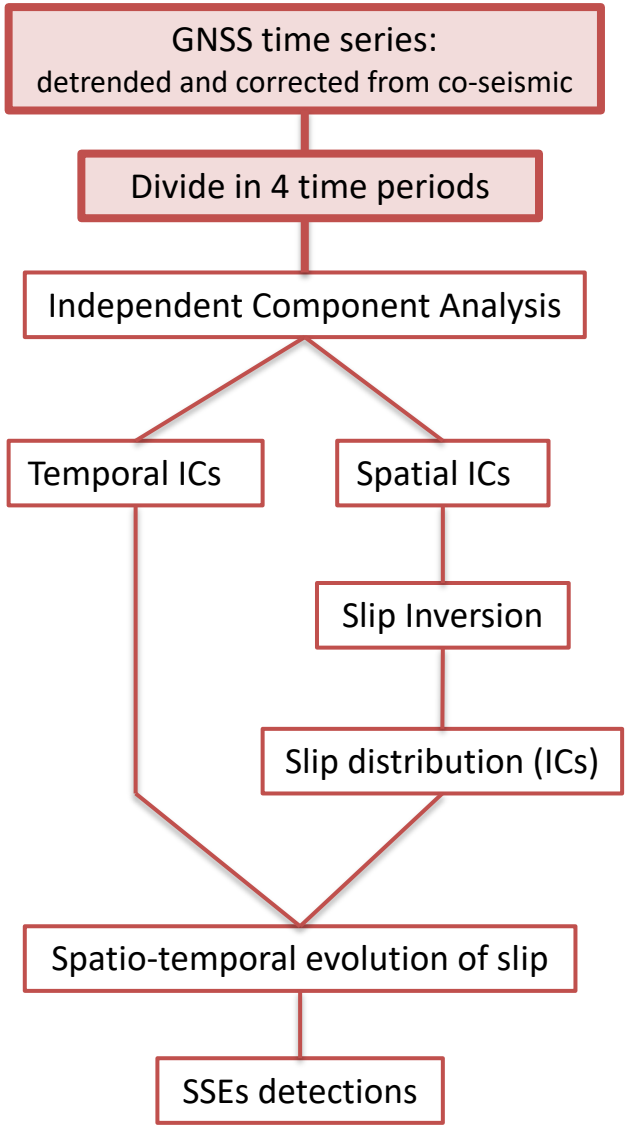
Independent Component Analysis and slip inversion: ICAIM (Michel et al. 2018 JGR)

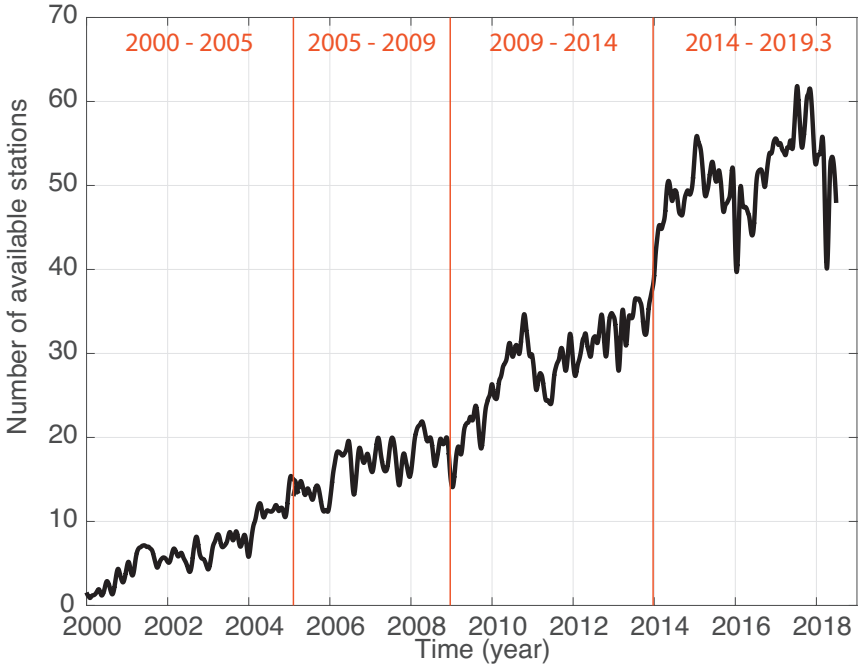
- Systematic analysis of GPS times series in the subduction over 18 years
- No a priori on slow slip characteristics (temporal evolution, duration, location…)

→
- Validate the approach and its detection efficiency

→
- Characterize slow slip processes in the region at different scales
- Discuss their main features

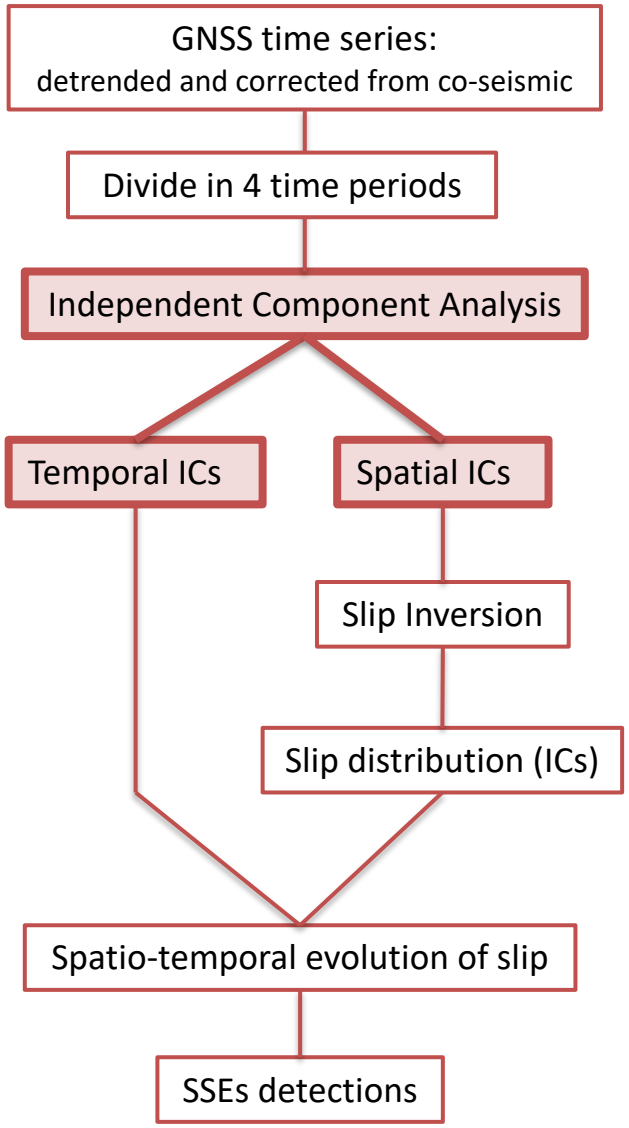
Method: GNSS times series preparation





Increase in the number of station with time
=> Separate in 4 time period for the analysis

Method: ICA decomposition



- vbICA algorithm with ICAIM software [Gualandi et al. 2016]

$$X_{M\times T} = U_{M\times R}\ S_{R\times R}\ V^{t}_{R\times T} + N_{M\times T}$$

Spatial distribution — Temporal functions — Noise

T number of time steps
M number of time series
R number of components selected

- Number of components selected as a compromise between fit to the data and model complexity (free energy parameter): **5 to 7 ICs** in our case.

Method: ICA decomposition

GNSS time series:
detrended and corrected from co-seismic

Divide in 4 time periods

Independent Component Analysis

Temporal ICs

Spatial ICs

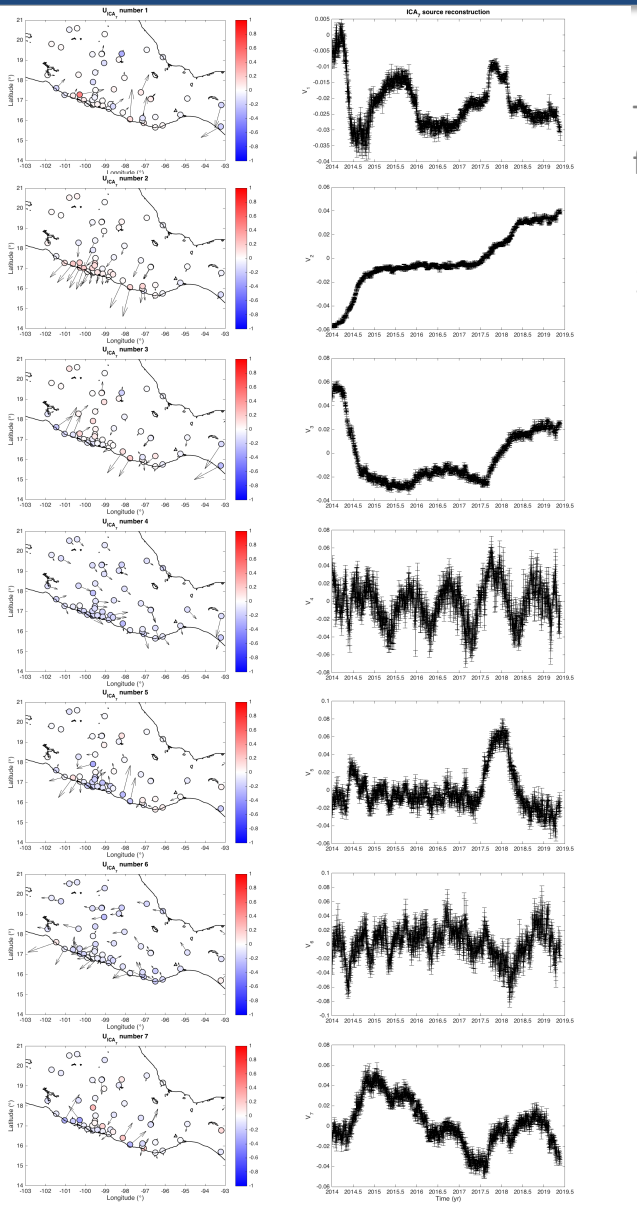
Slip Inversion

Slip distribution (ICs)

Spatio-temporal evolution of slip

SSEs detections

Spatial distribution U_i



Temporal functions V_i

2014 – 2019.5

Method: ICA decomposition

GNSS time series:
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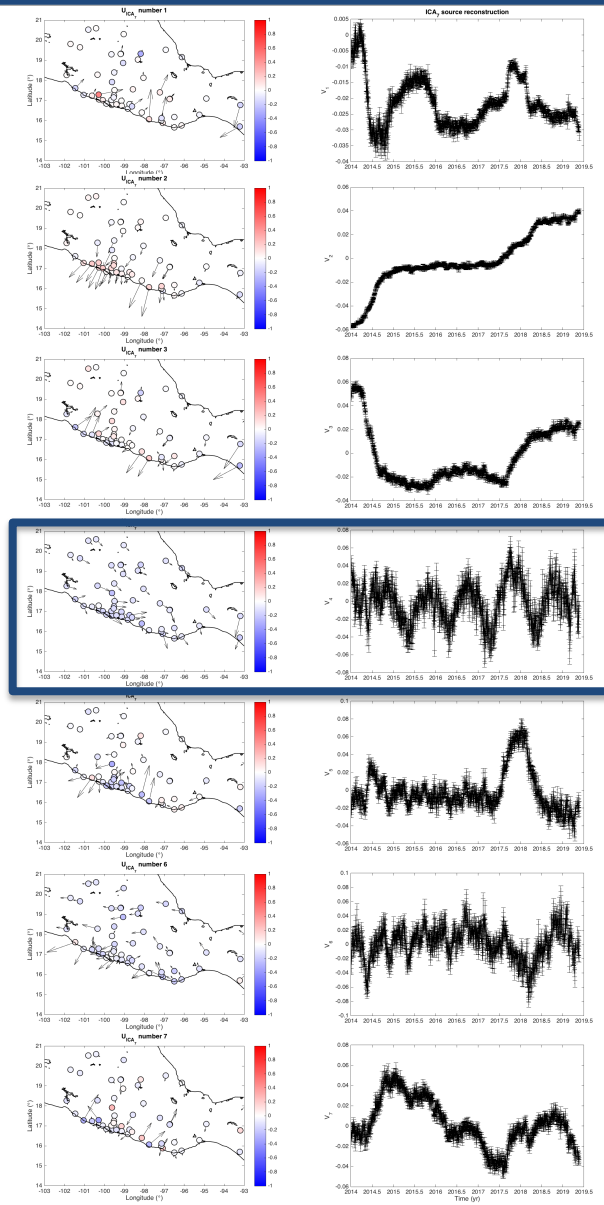

Temporal functions V_i

2014 – 2019.5

Seasonal signal

Method: ICA decomposition

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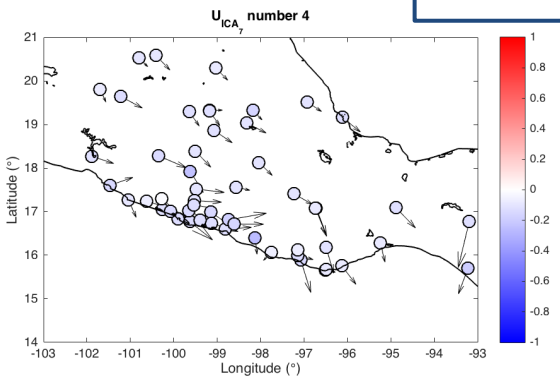

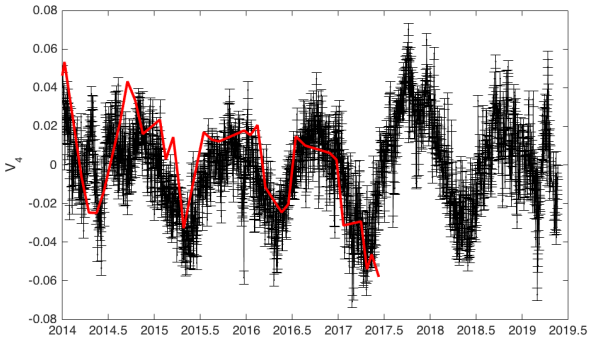

Model of temporal evolution
derived from GRACE data (vertical)

⇒ One seasonal IC for each time period is found

⇒ Seasonal IC removed for the rest of the analysis

Method: ICA decomposition

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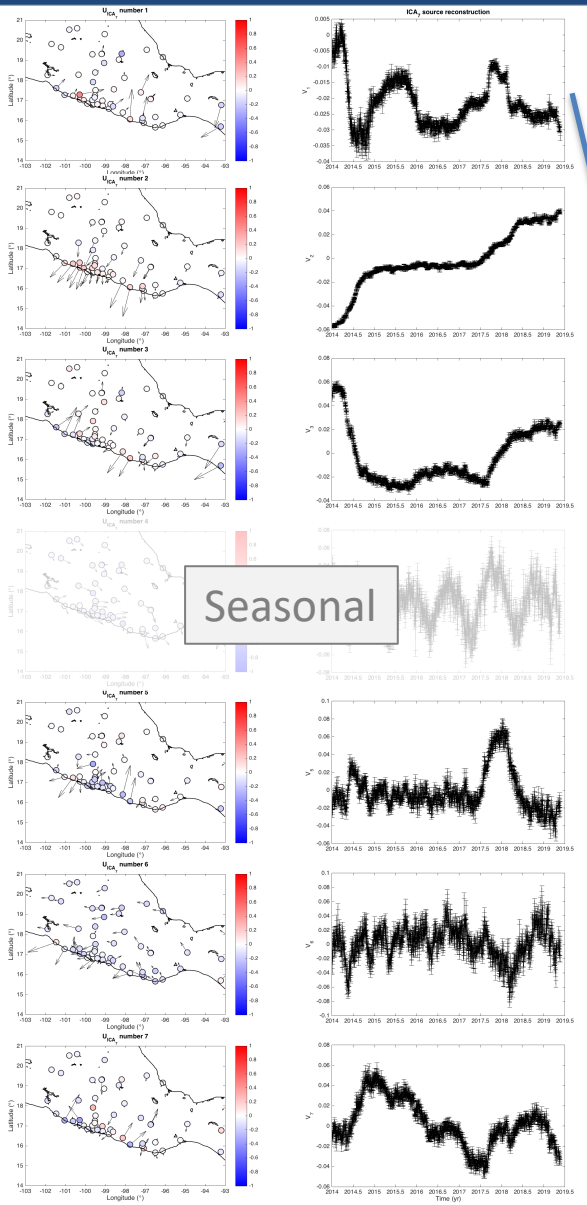

Temporal functions V_i

2014 – 2019.5

Tectonic signal

Method: ICA decomposition

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Divide in 4 time periods

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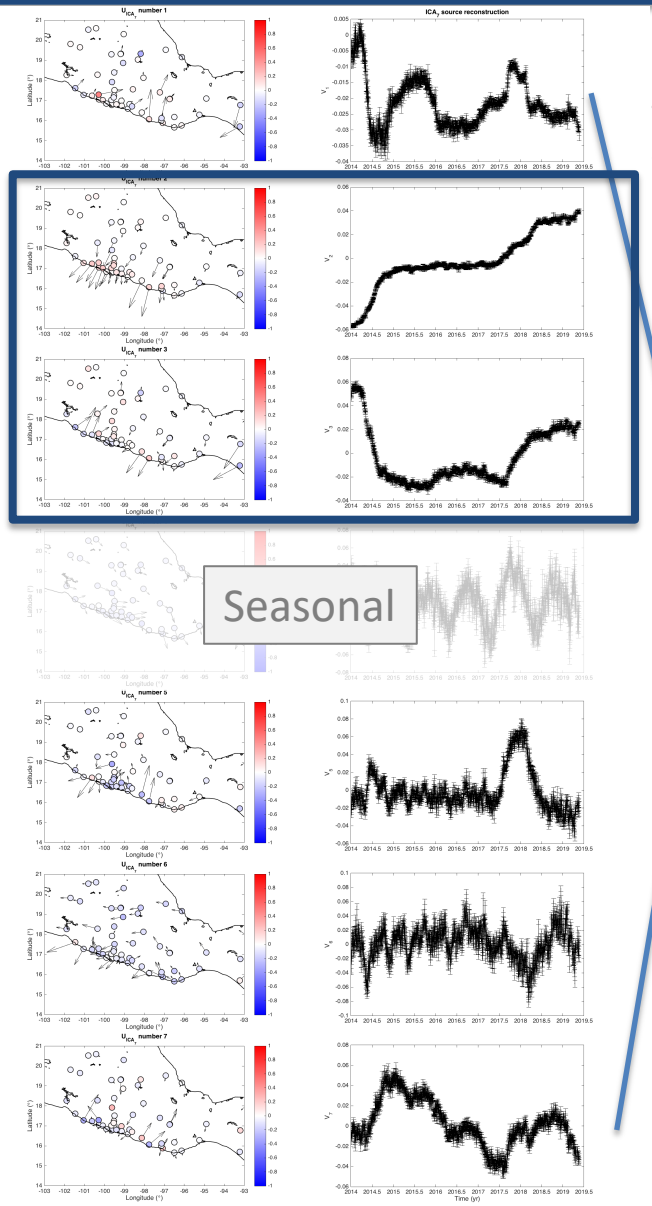

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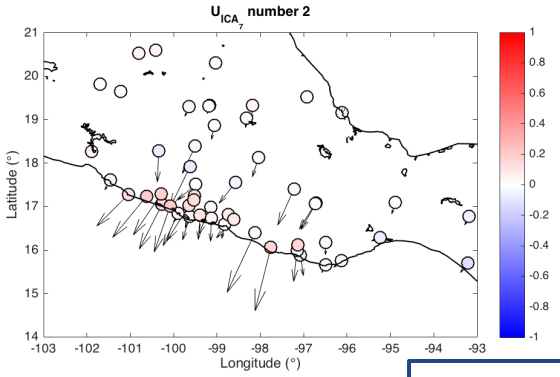
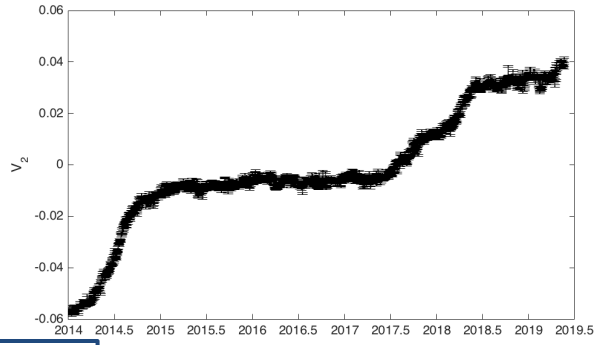
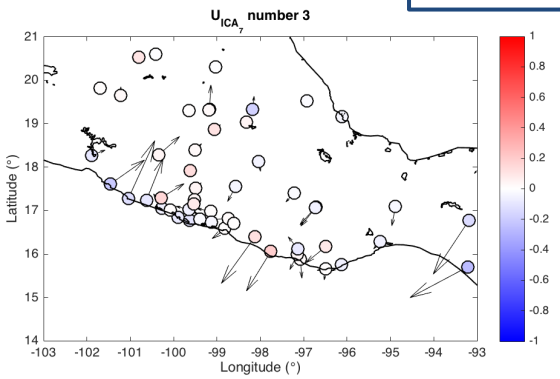
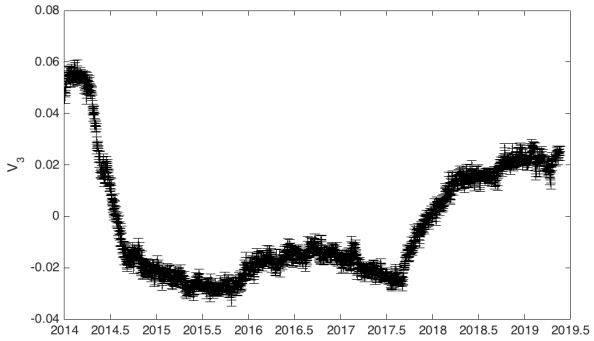
Temporal functions V_i





Tectonic signal





Method: slip inversion

GNSS time series:
detrended and corrected from co-seismic

Divide in 4 time periods

Independent Component Analysis

Temporal ICs

Spatial ICs

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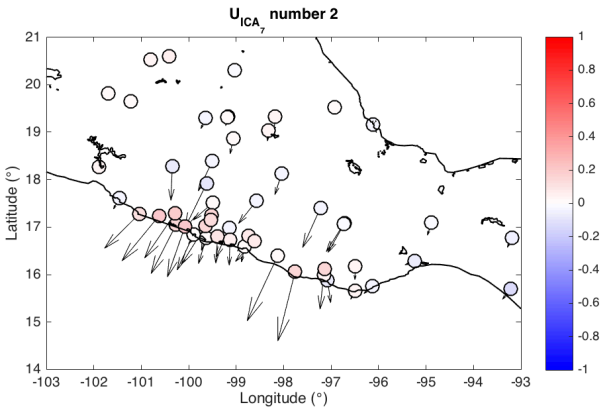
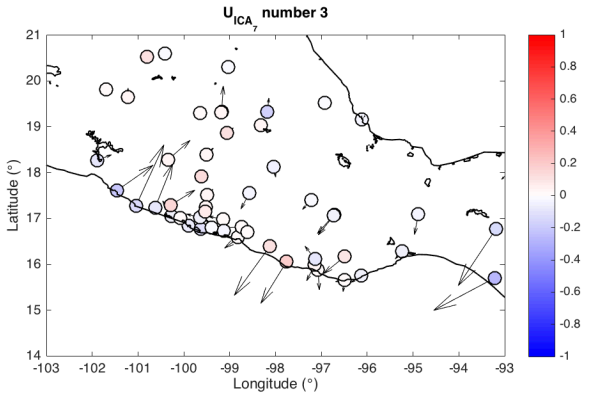
Slip distribution (ICs)

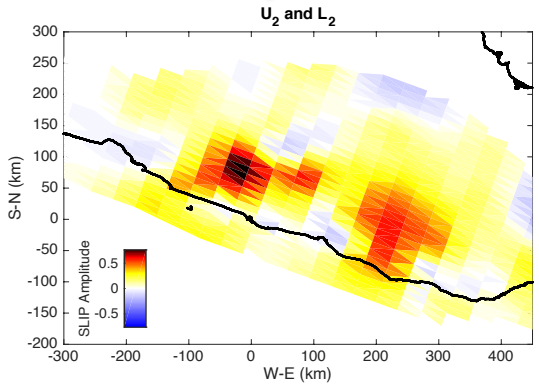
Spatio-temporal evolution of slip

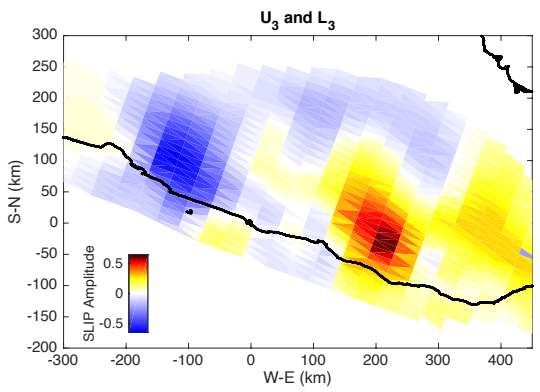
SSEs detections

- Static inversion : regularized linear least square
  [Radiguet et al. 2011; 2016]

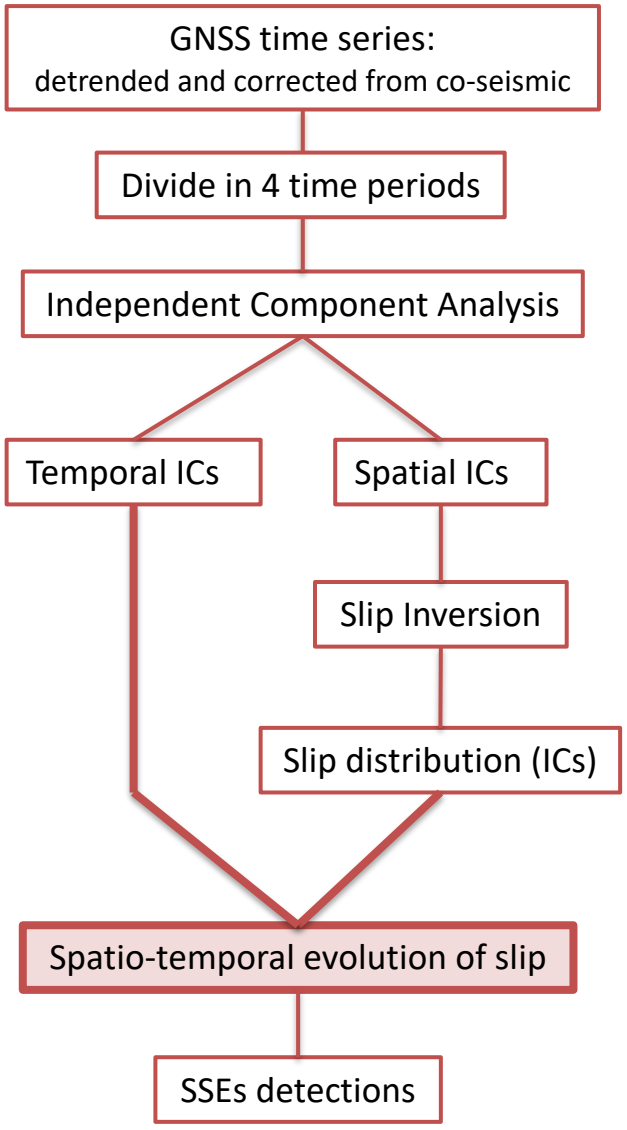






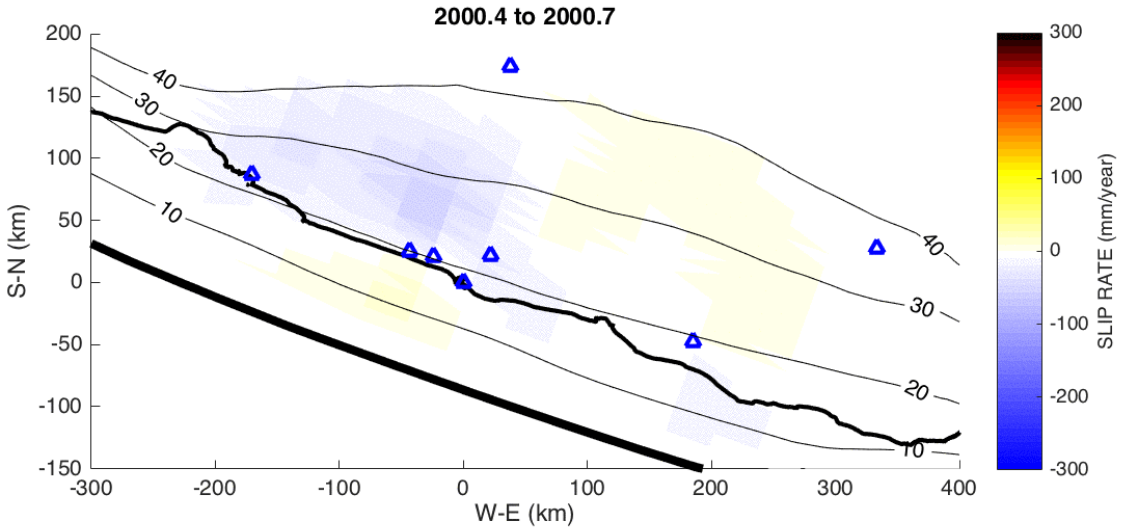


Method: recombination of ICs

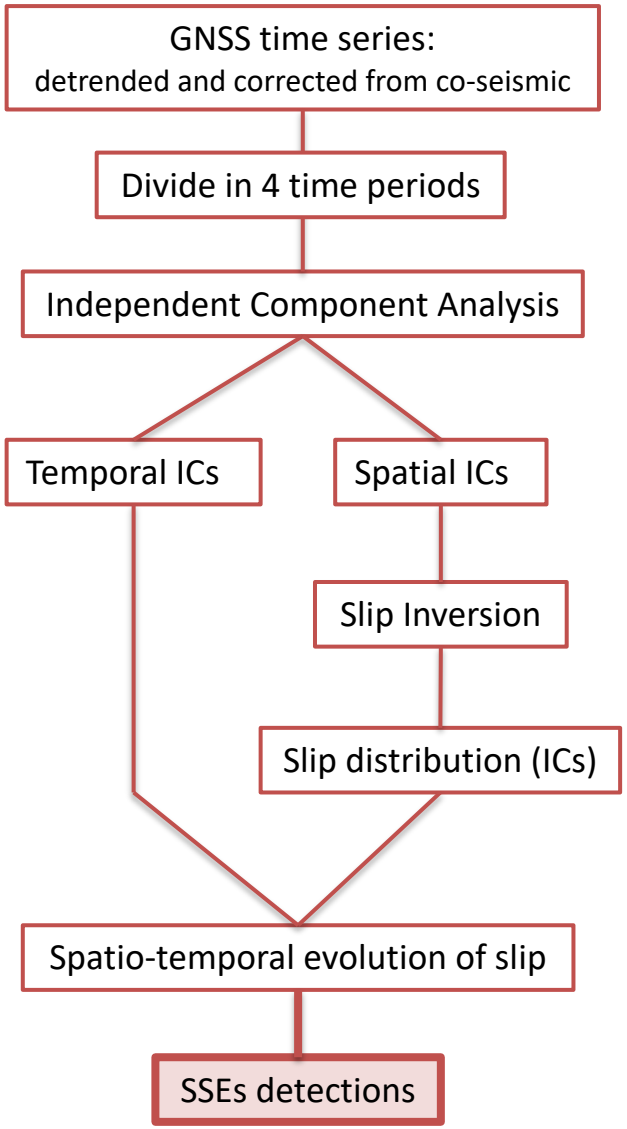


- Smooth temporal vectors (50 days moving average)

Snapshot of slip evolution on the interface
2001 -> 2019



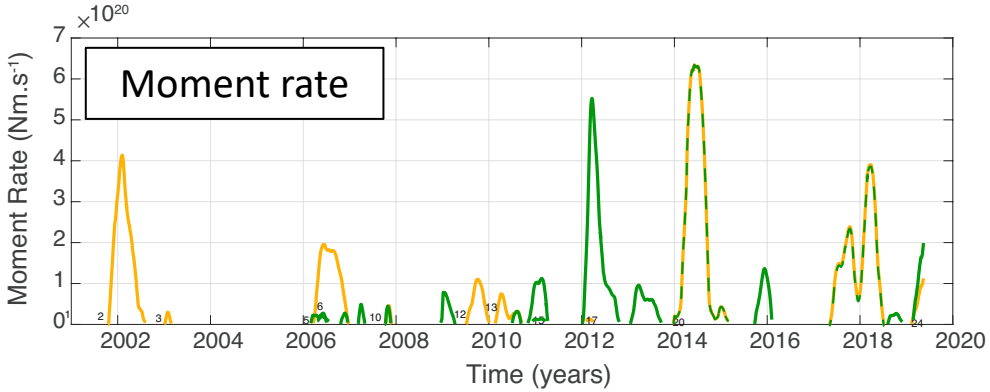
Method: SSEs detections



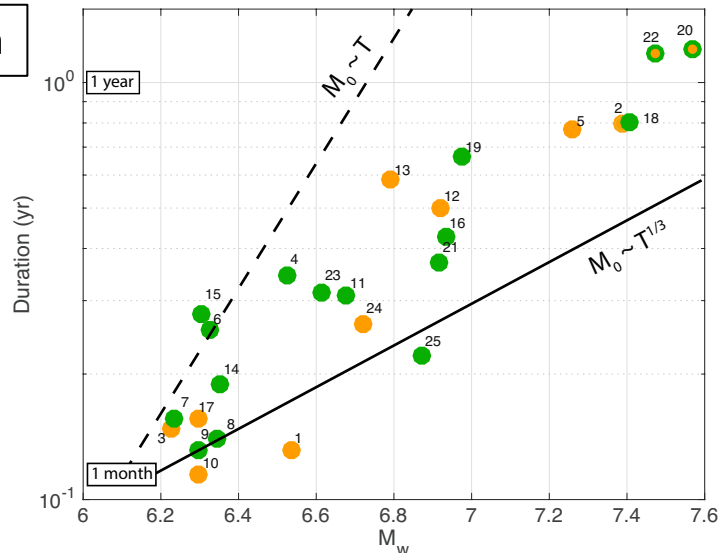
To isolate individuals events:

- At each time step ***t***: contour slip rate > ***50* mm/year**
- Connect contours between time ***t*** and ***t+1***

$\Rightarrow$ **25 events** of $M_w > 6.2$

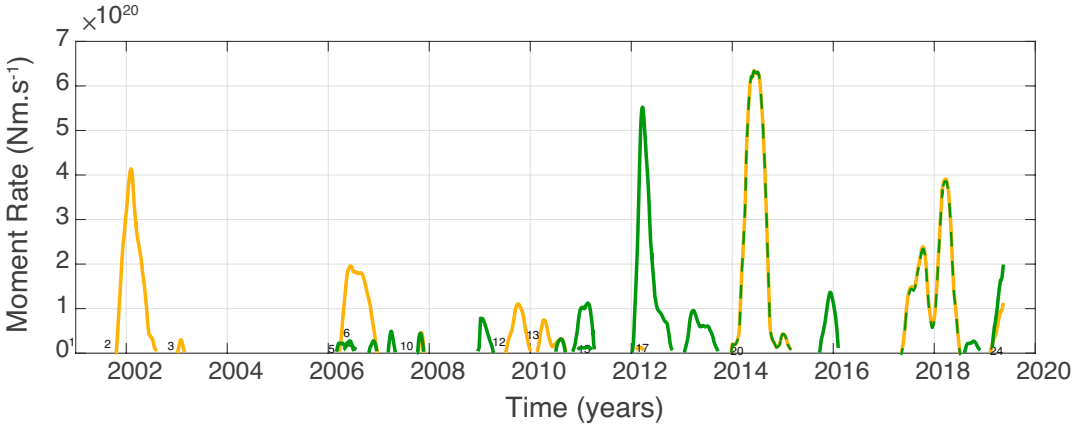


M_w - Duration

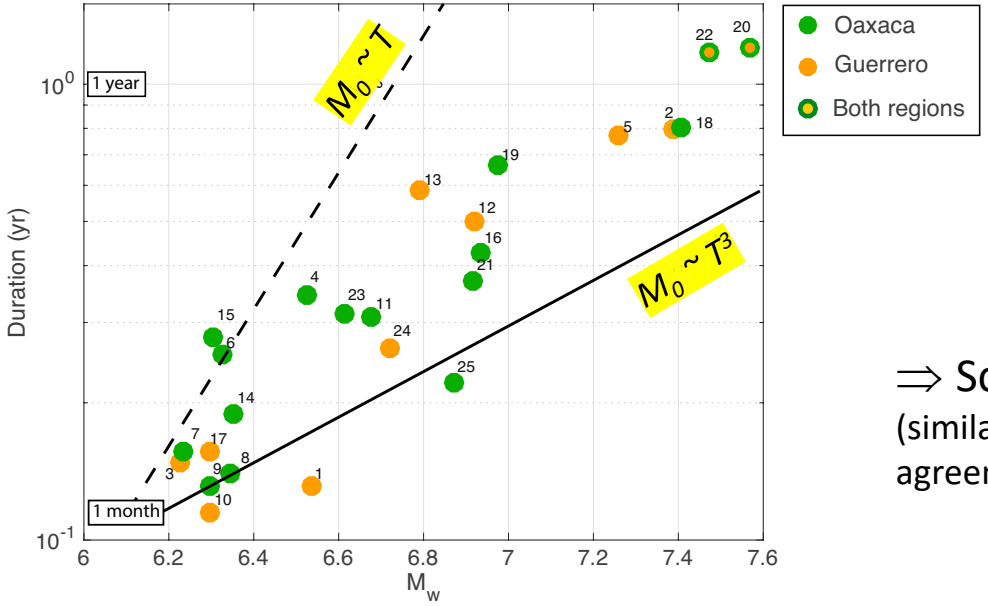


Results of the SSE detection

Moment rate

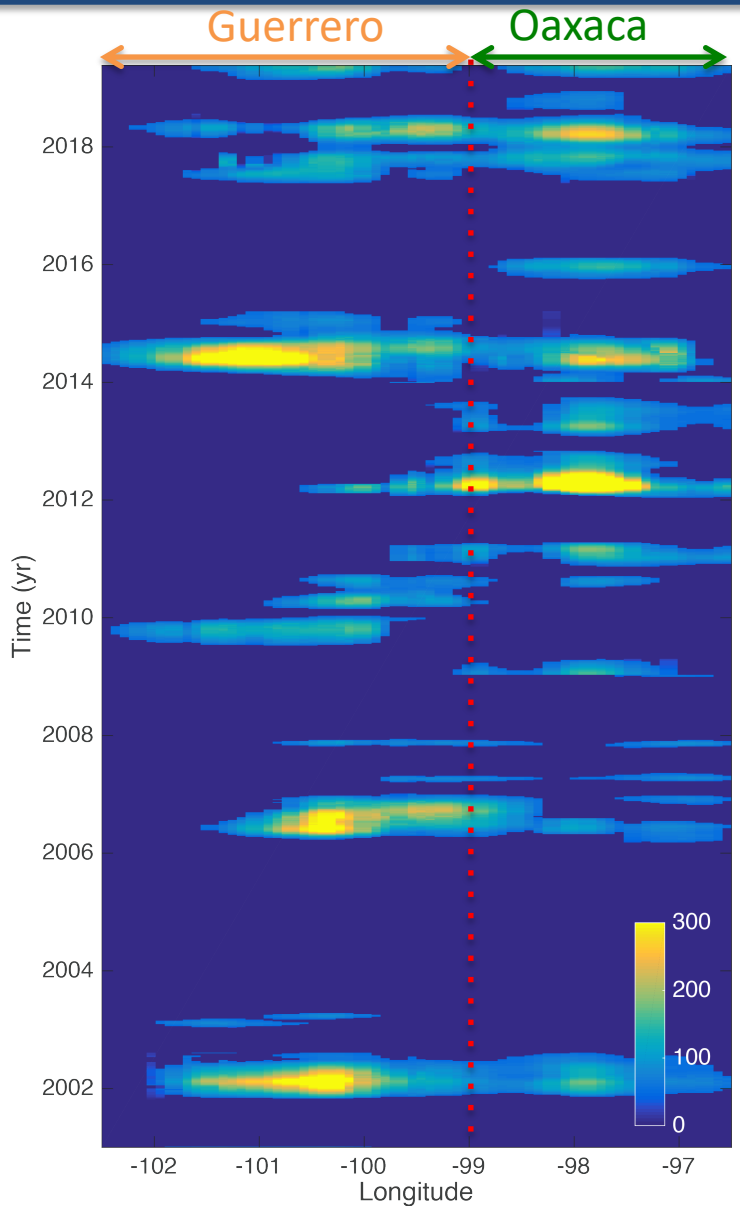


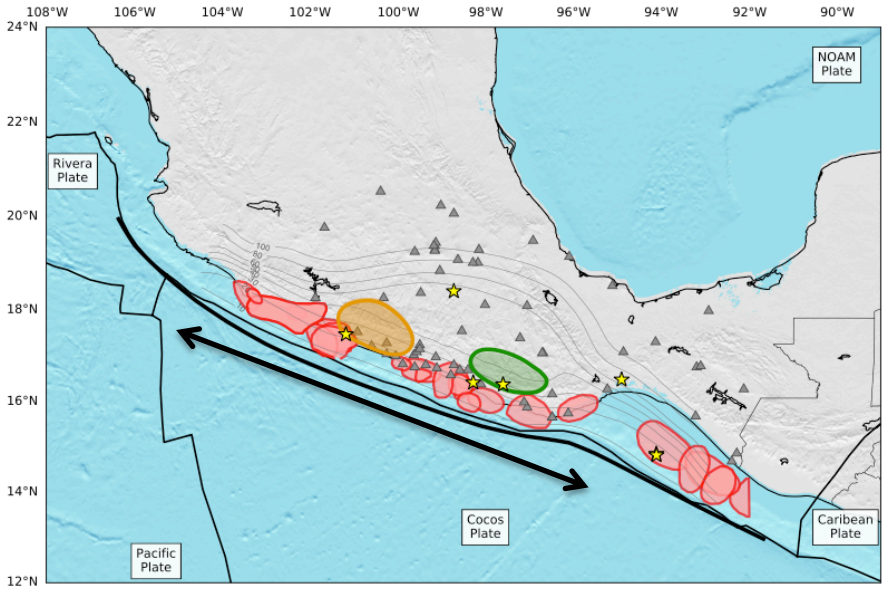
M_w - Duration



⇒ Scaling close to $M_0 \sim T^3$
(similar to regular earthquakes), in agreement with *Michel et al. 2019 (Nature)*

Slow slip occurrence along the subduction

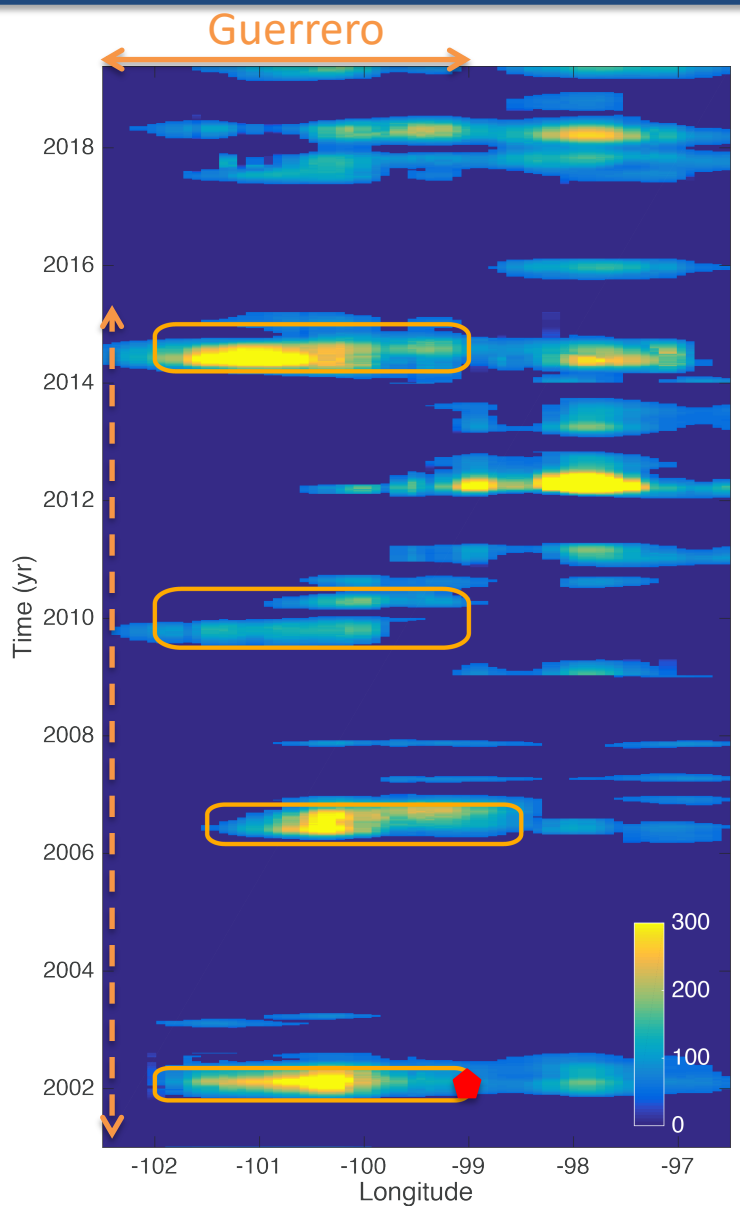




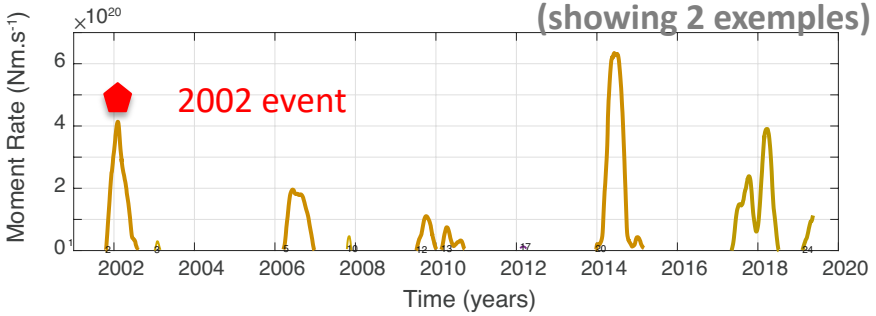
Colors represent the average slip rate along depth, projected along a line parallel to the Trench (see black arrow on the map).
Color scale is in mm/yr

Guerrero long-term SSEs

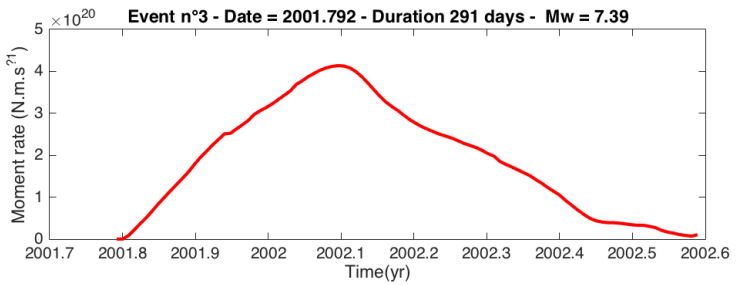
Validation by comparing with previous studies

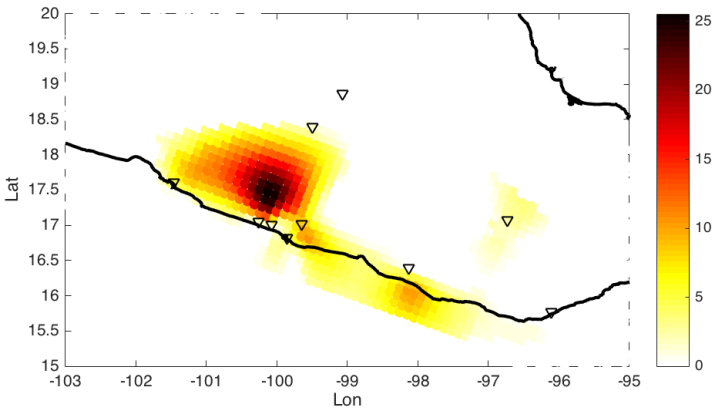


From Radiguet et al. 2012; 2016 ⇒ **We retrieve well the events previously identified (showing 2 exemples)**



Slip distribution and moment rate for 2002 event





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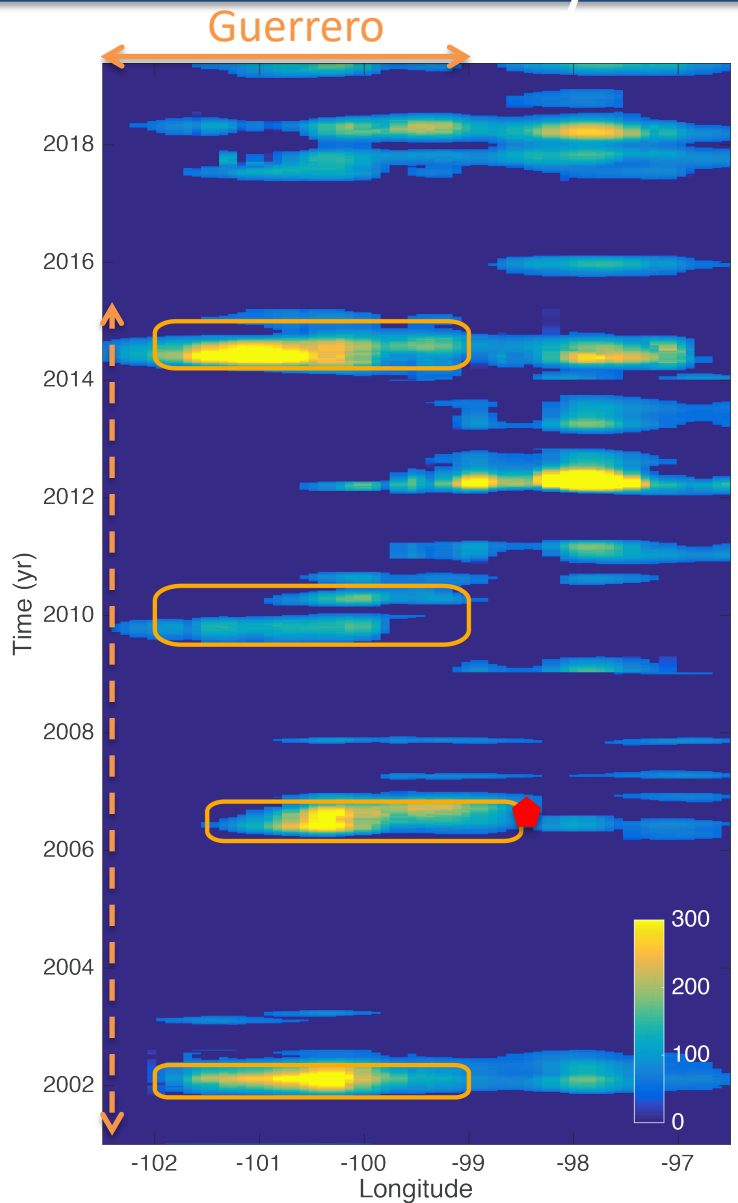

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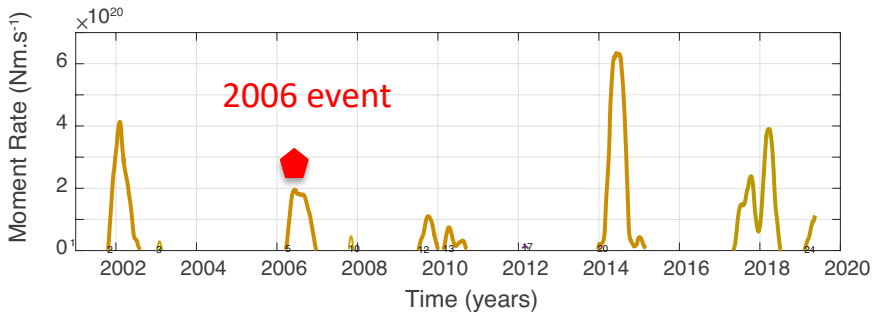
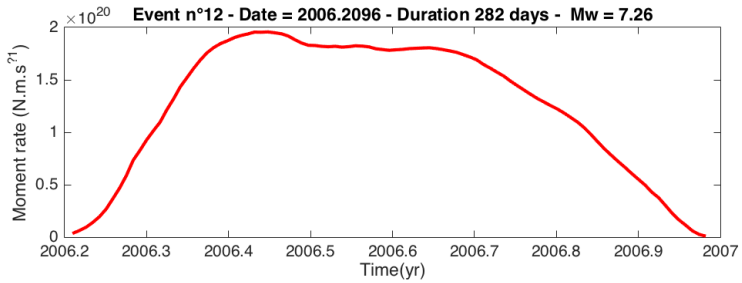
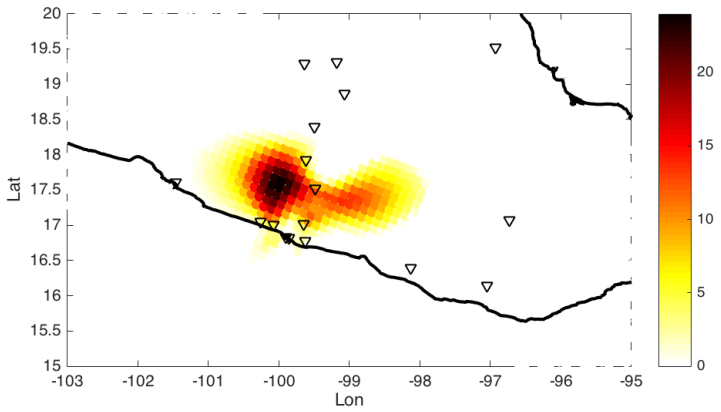


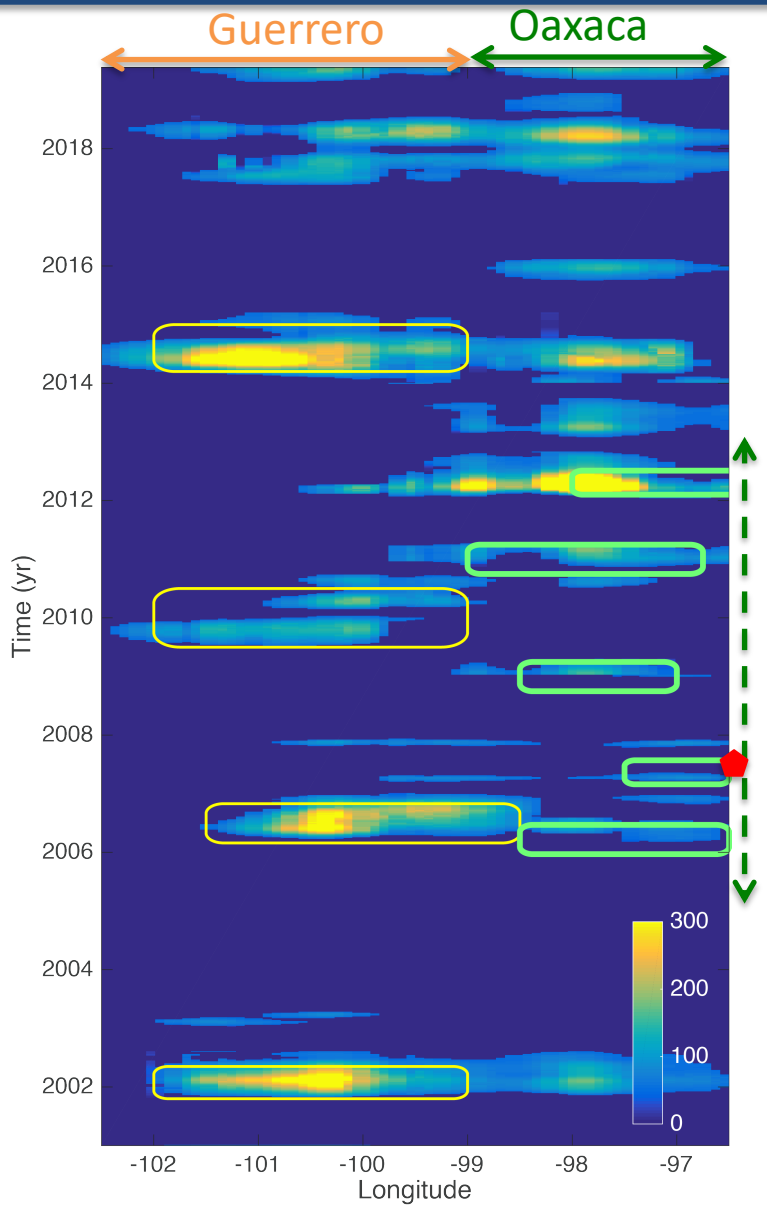
Slip distribution and moment rate for 2006 event





Oaxaca SSEs

Validation by comparing with previous studies



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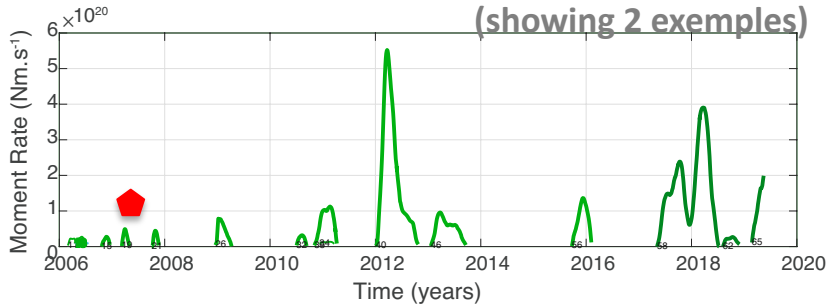
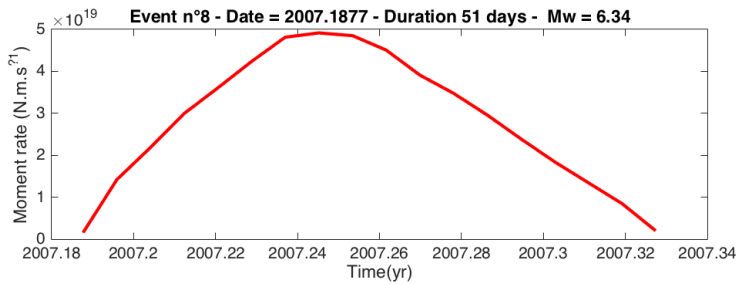
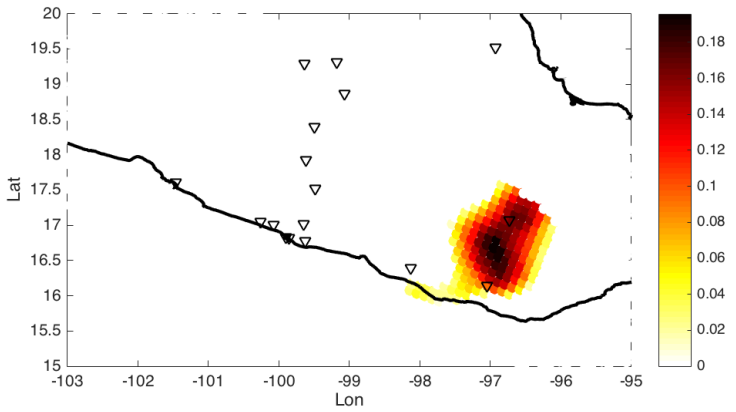


Slip distribution and moment rate for one event





Oaxaca SSEs

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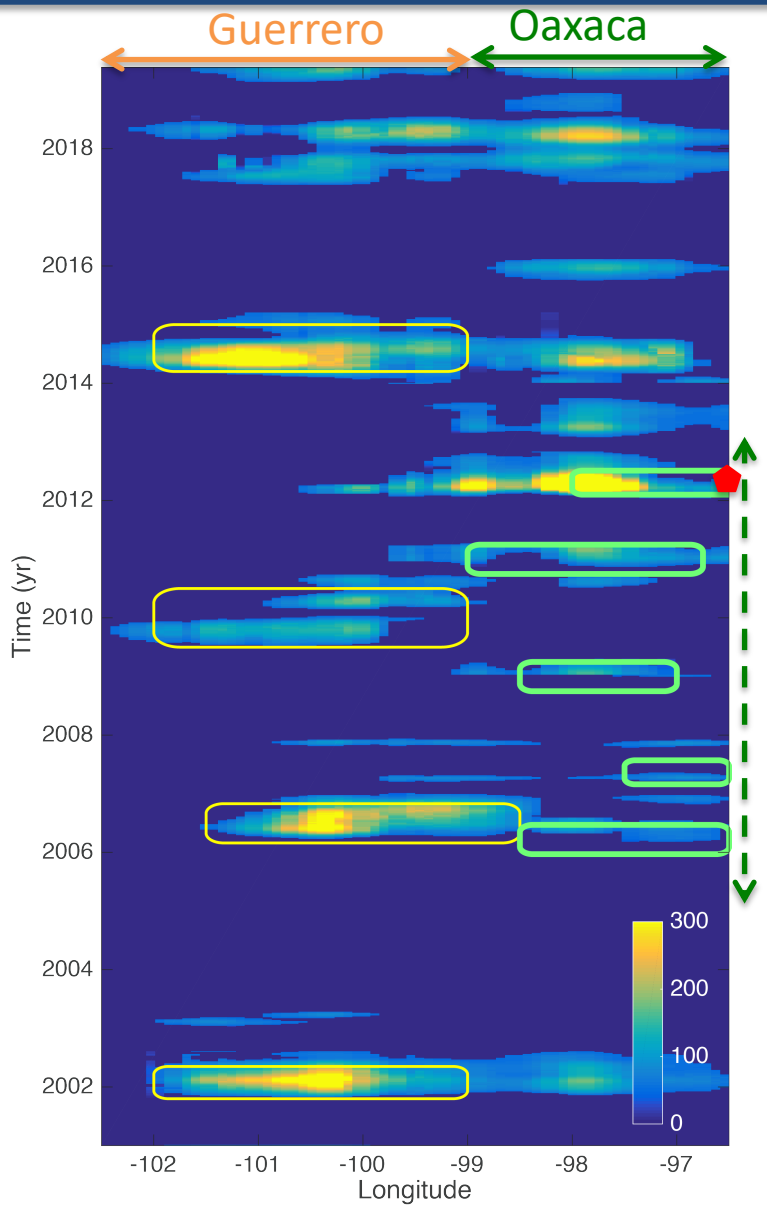

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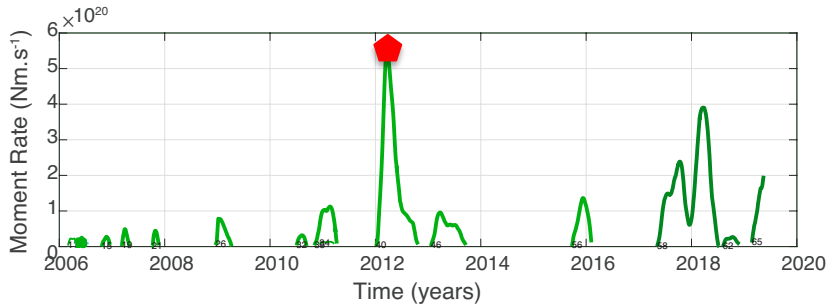
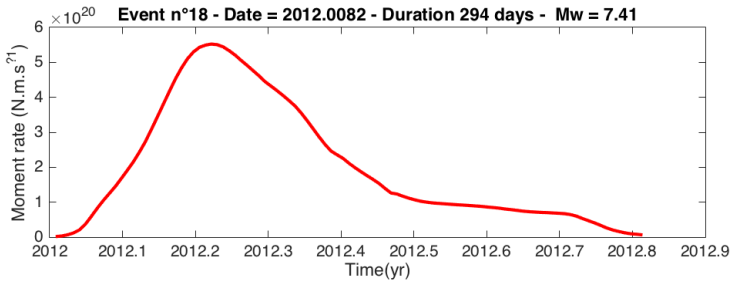
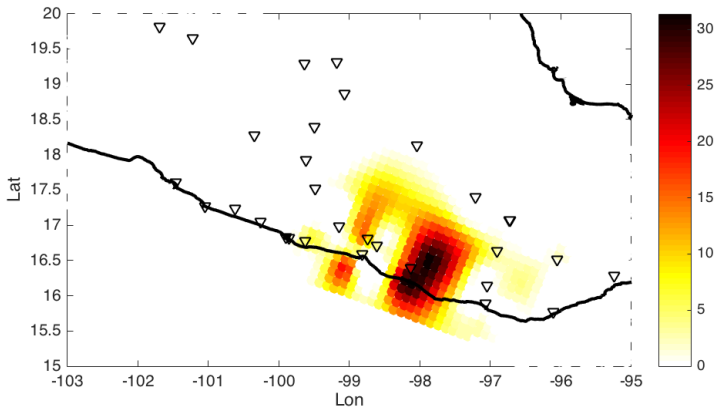


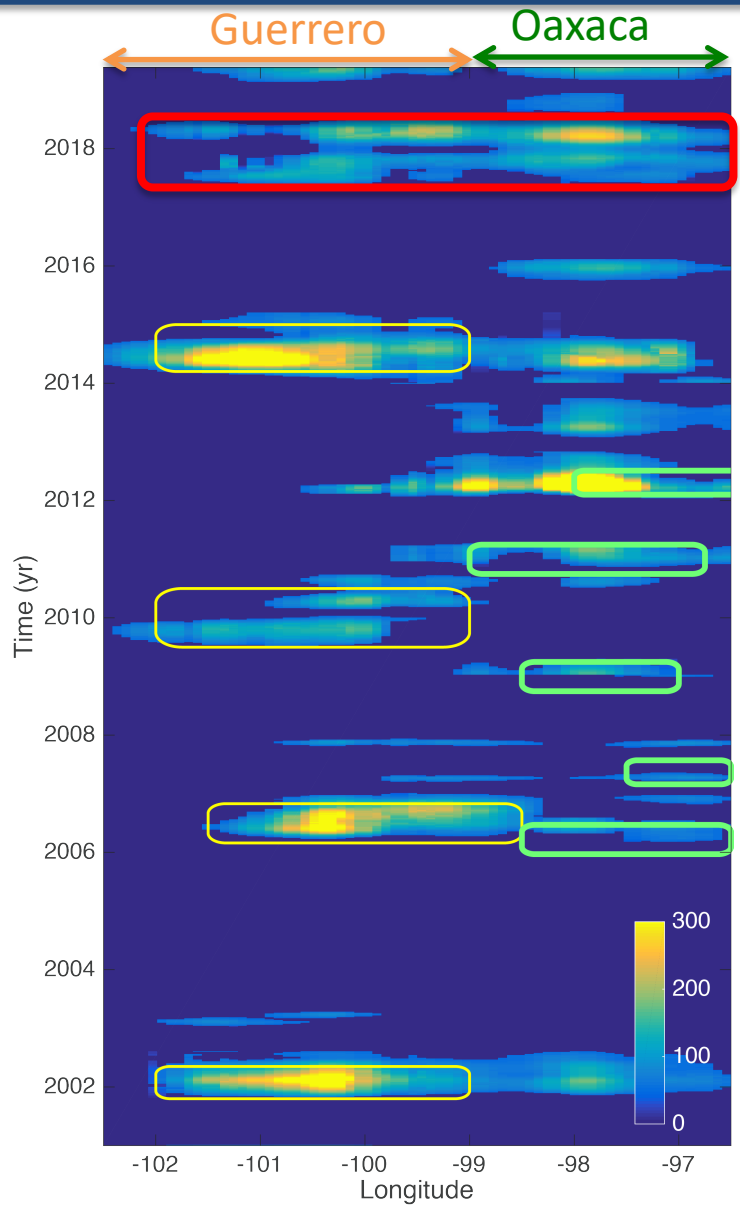
Slip distribution and moment rate for one event





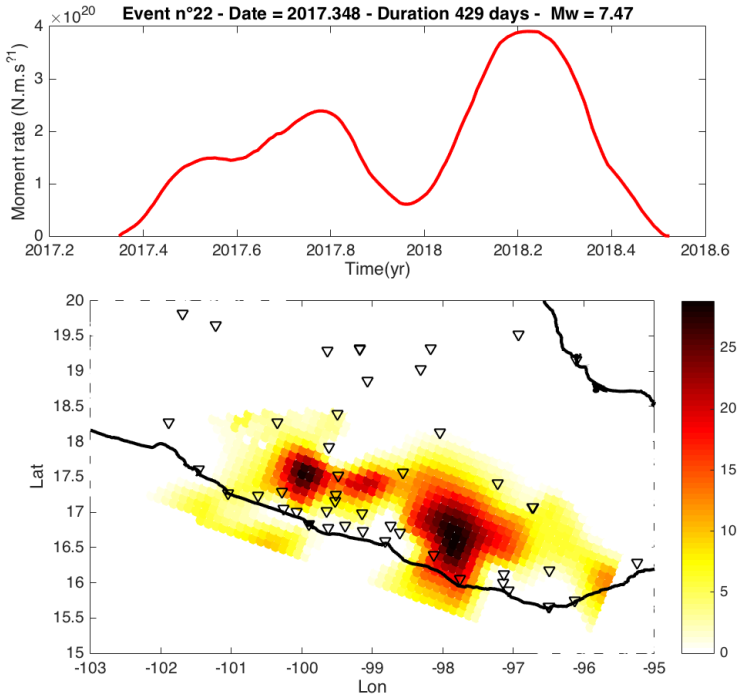
Recent SSEs

Both in Guerrero and Oaxaca



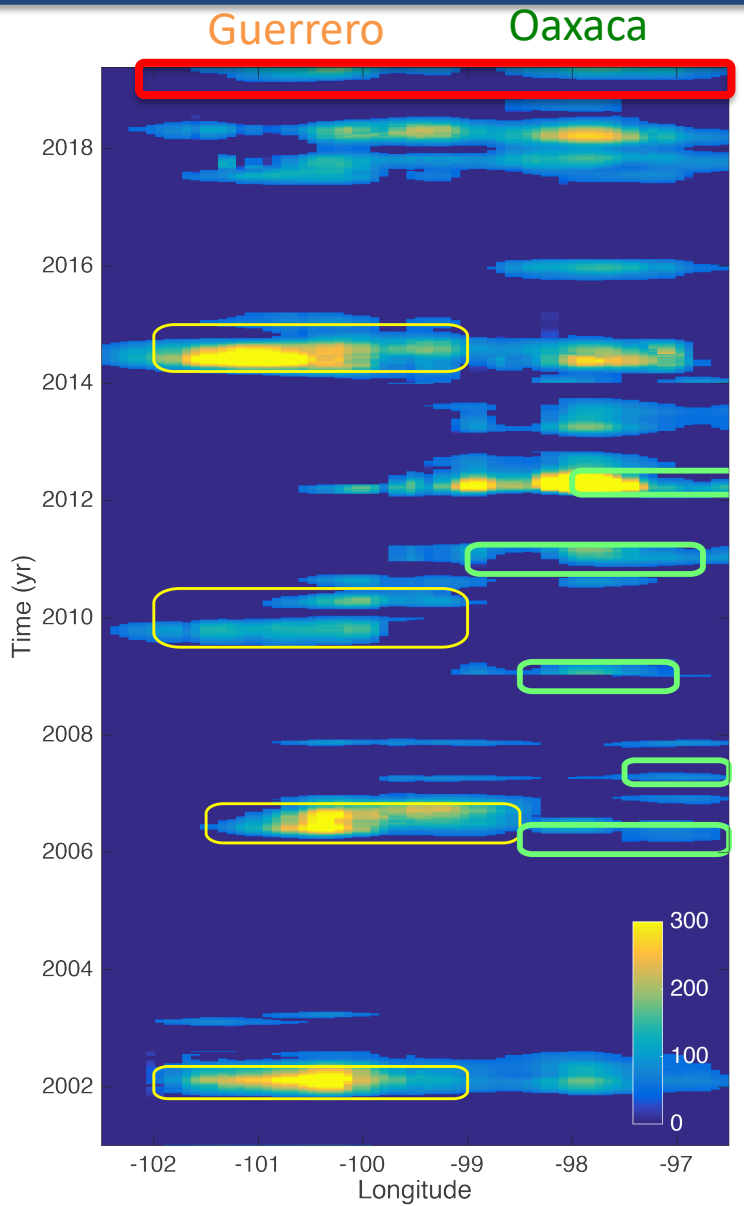
SSEs associated with the 2017 – 2018 earthquake sequence

Slip distribution and moment rate for one event

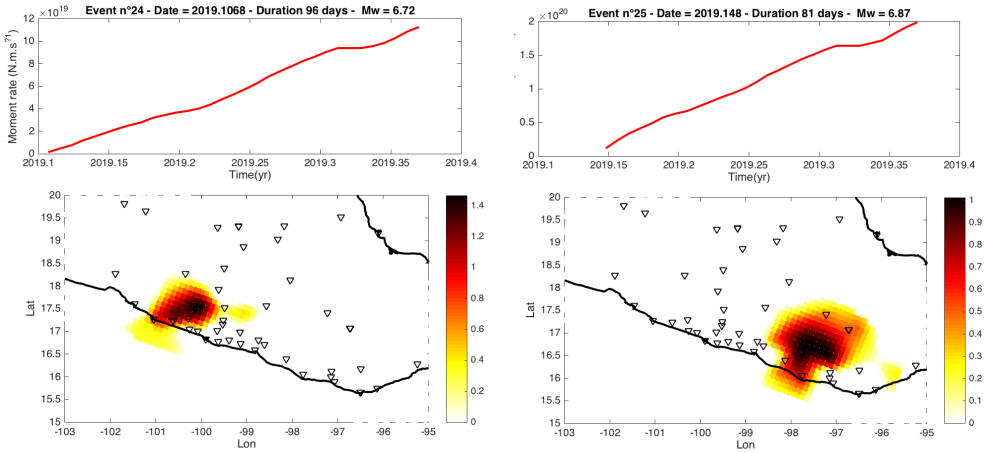


Recent SSEs

Both in Guerrero and Oaxaca

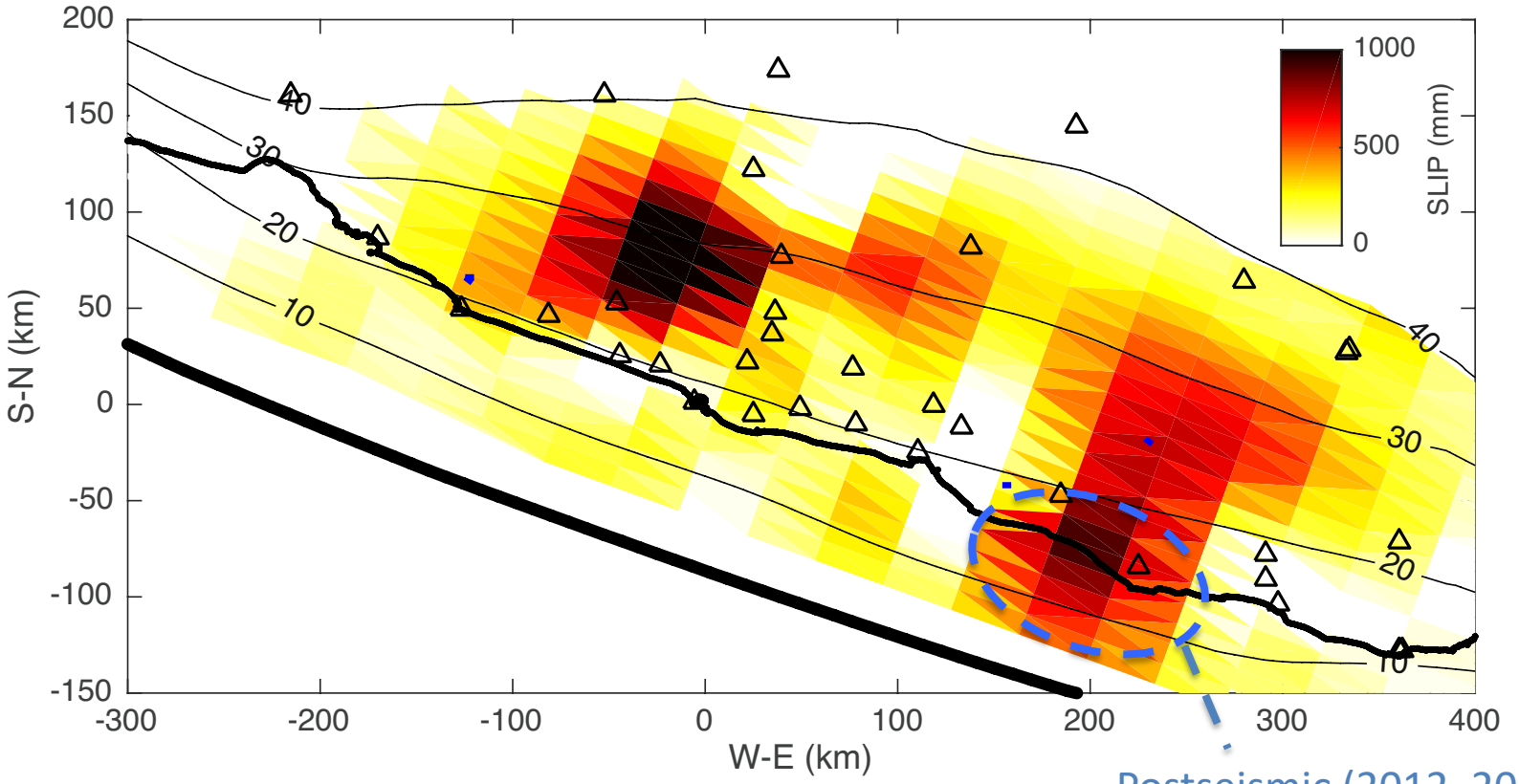


Ongoing events in 2019
(data end in April 2019)



⇒ Synchronization of Guerrero and Oaxaca slow slip after 2014.

Cumulative slow slip over 18 years



Postseismic (2012, 2018)
(not removed from the SSE analysis)

- The study confirms the existence of two major slow slip areas
- Low cumulated slow slip in the central zone

Conclusions

- ICAIM (Independent Component Analysis Inversion Method) allows to detect and characterize the long-terms SSEs in Guerrero and Oaxaca (M_w ~ 6.5 – 7.5)
- Scaling of detected events consistent with $M_0 \sim T^3$ as recently suggested by *Michel et al. Nature 2019.*
- ICA allows the isolate and correct from a seasonal signal

- The detected events confirm the segmentation in two main slow slip zones: Guerrero and Oaxaca, with larger events in Guerrero.
- Before 2014, the two regions appear to have independent cycles
- In the recent years, SSEs in the two regions are synchronized in time