

# Earthquake Ruptures and Stress Changes in the Mexican Earthquake Sequence of 2017–2018

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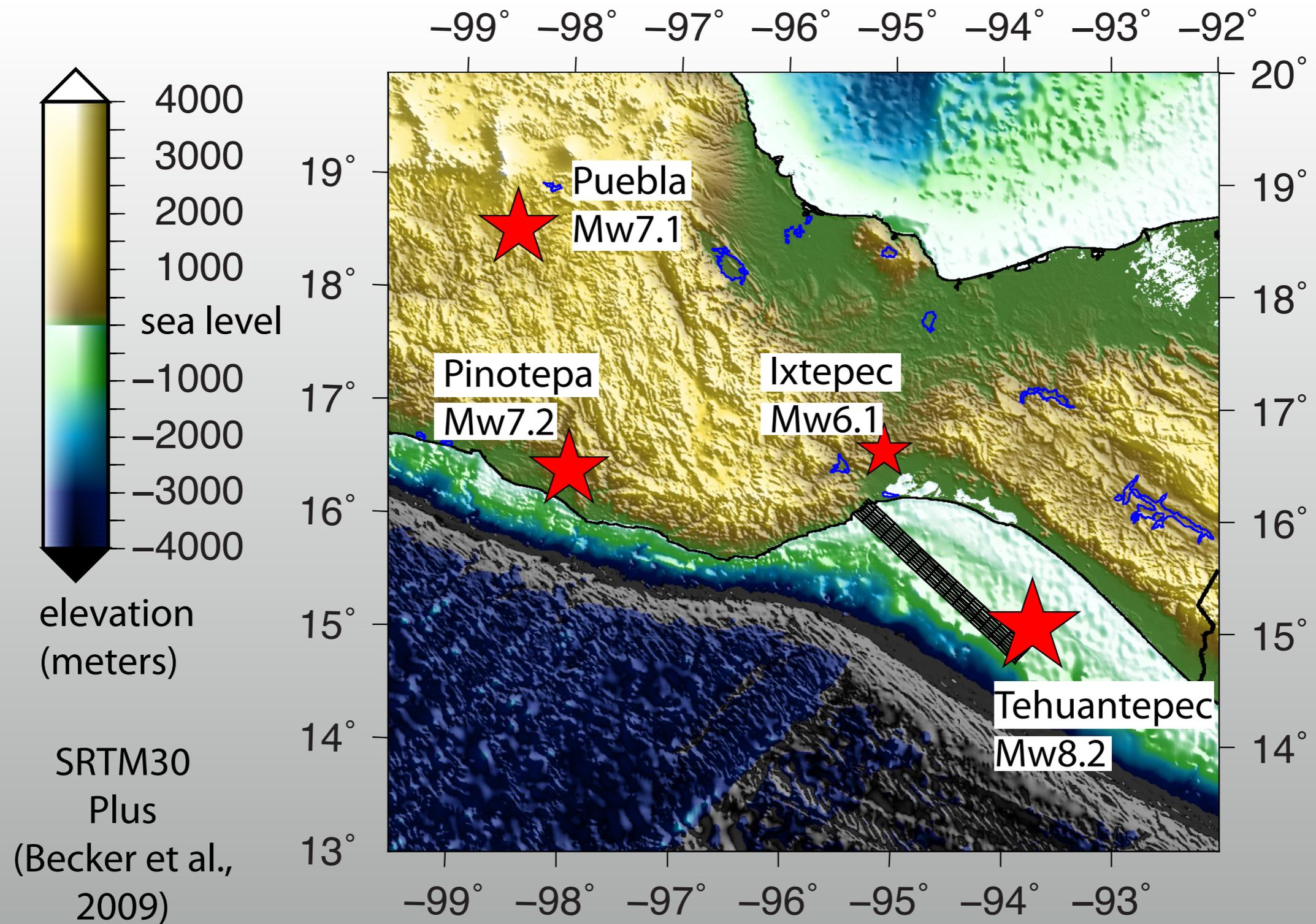
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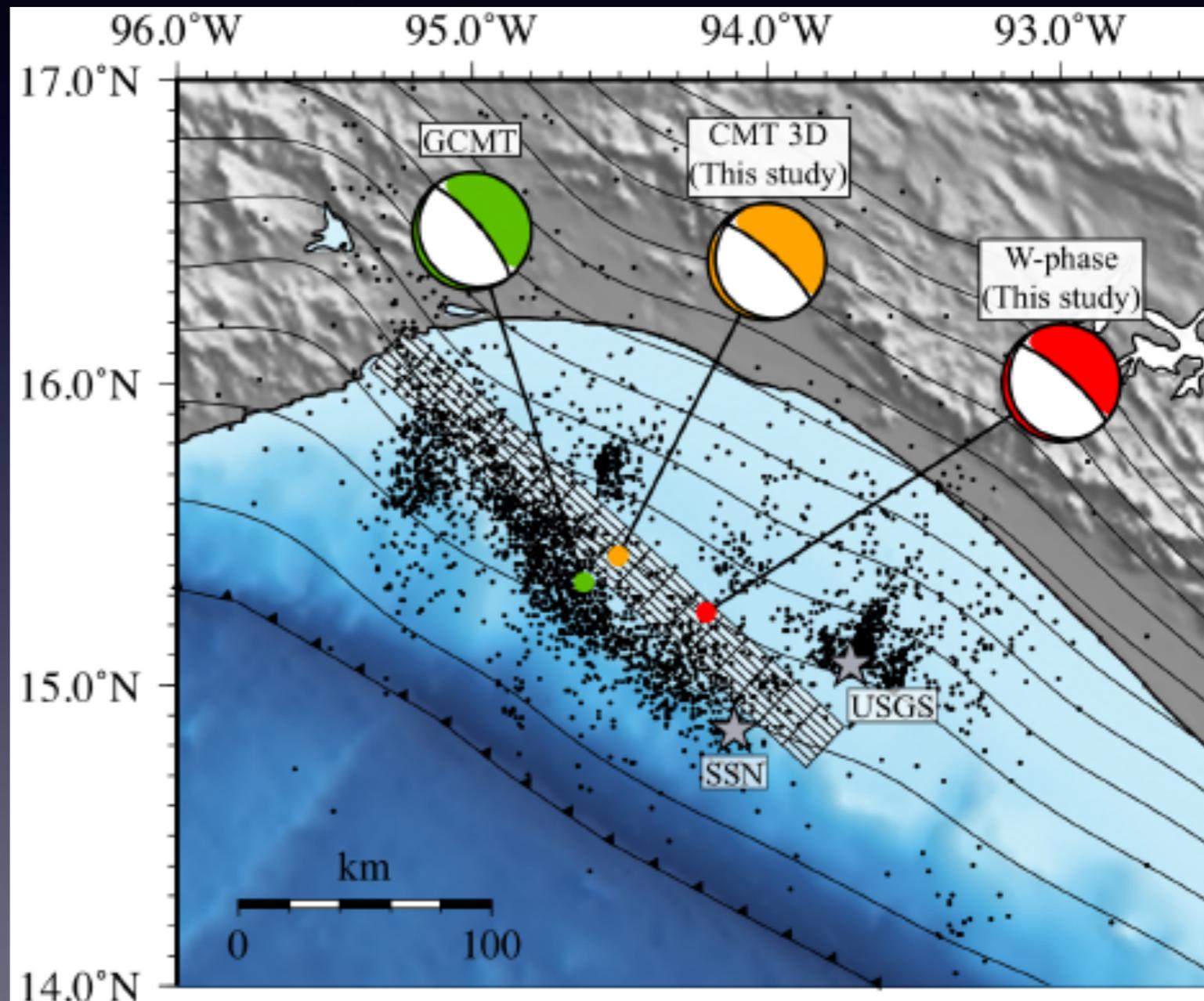
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# Southern Mexico 2017–2018



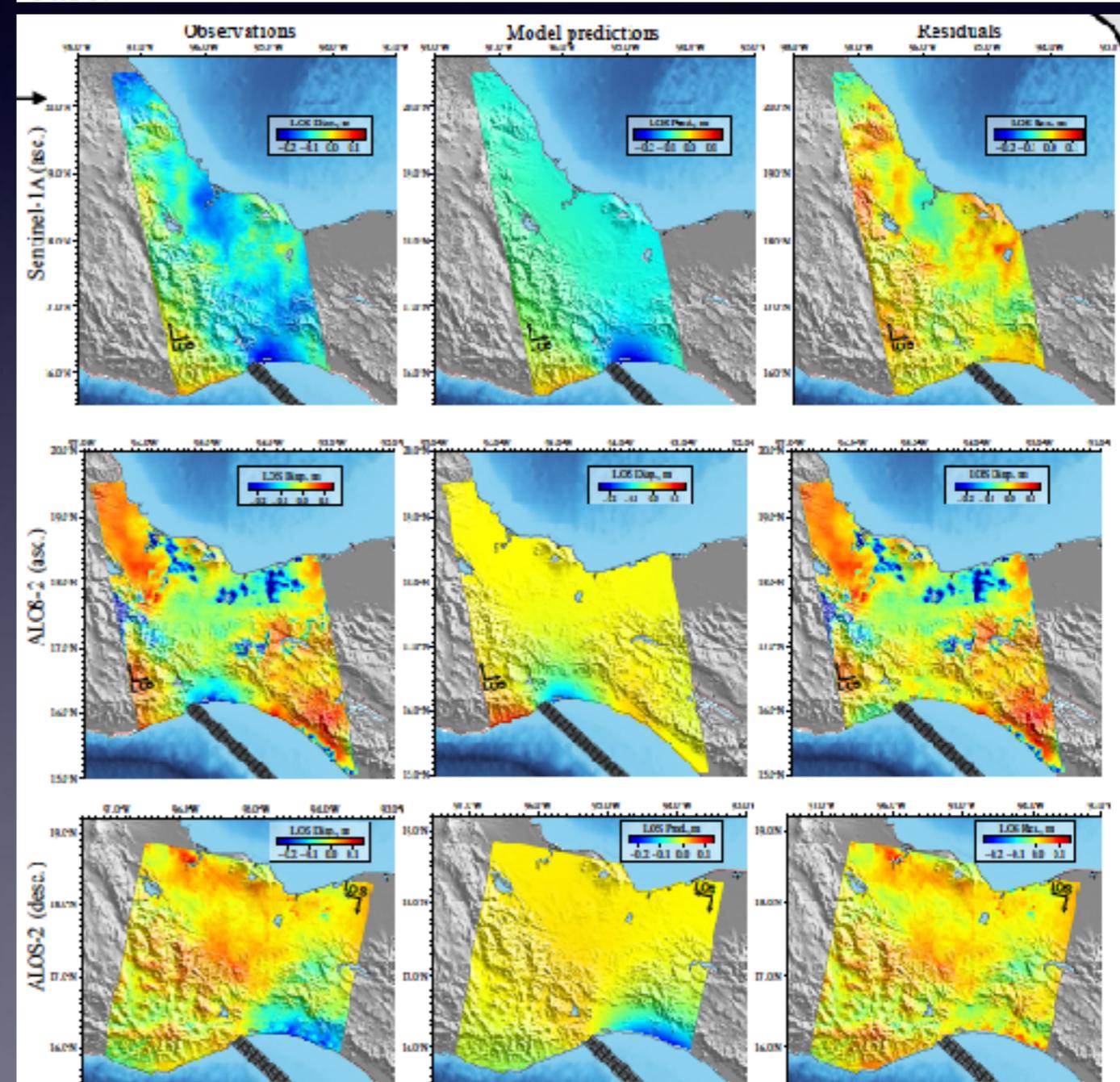
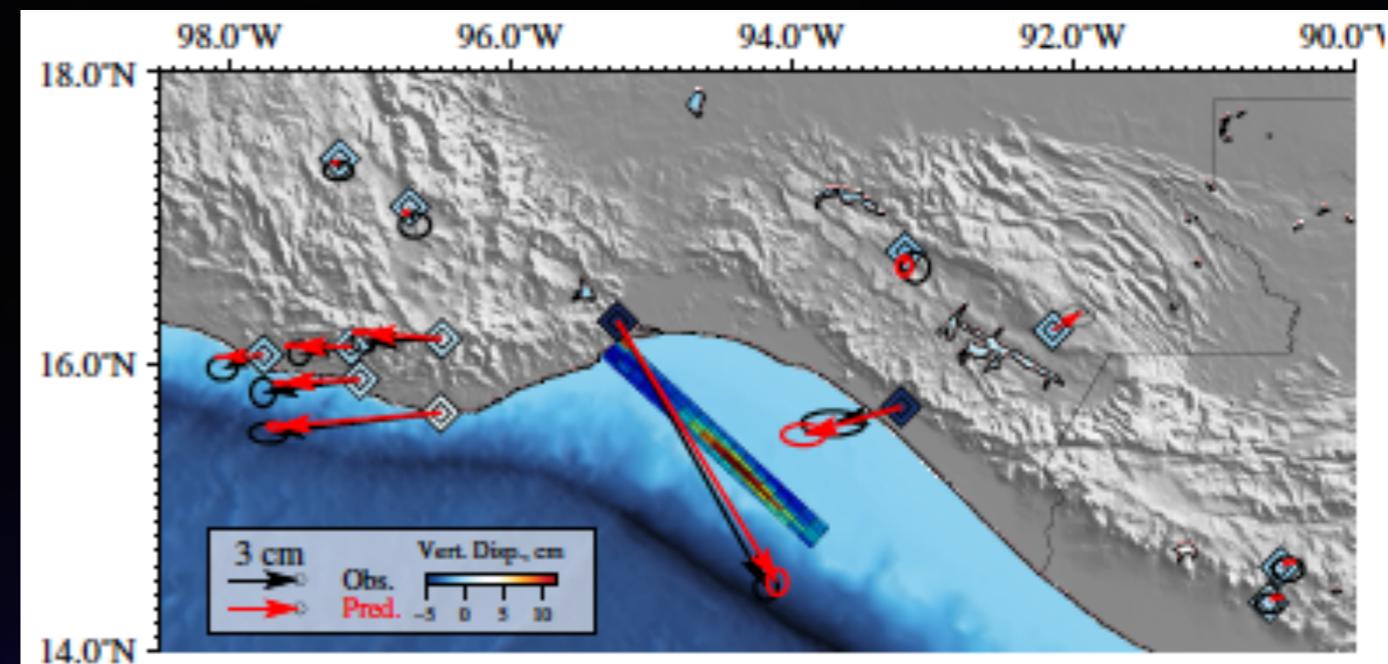
# 2017 Mw8.2 Tehuantepec

- 8 September 2017
- First large earthquake of sequence
- Rupture off-shore Chiapas and Oaxaca
- Hypocenter depth 58 km (SSN)  
47.5 km (USGS)
- CMTs show normal slip on steeply dipping fault
- 3D CMT (Duputel) optimal centroid depth 40 km, time shift 24 sec
- W-phase (Duputel) optimal centroid depth 50 km



# Bayesian static slip inversion

- Modeling Baptiste Gombert
- Grid search for optimum fault geometry strike  $313^\circ$ , dip  $76^\circ$
- 72 by 216 km model fault, 12x12 km patches, Okada for Green's functions
- 2 Sentinel-1 interferograms (ascending and descending)
- ALOS-2 interferogram (desc.)
- 12 GPS displacements
- 3 DART buoy tsunami waveforms (Jiang)
- ATar estimation of posterior PDFs for each fault patch (Minson et al., 2013)

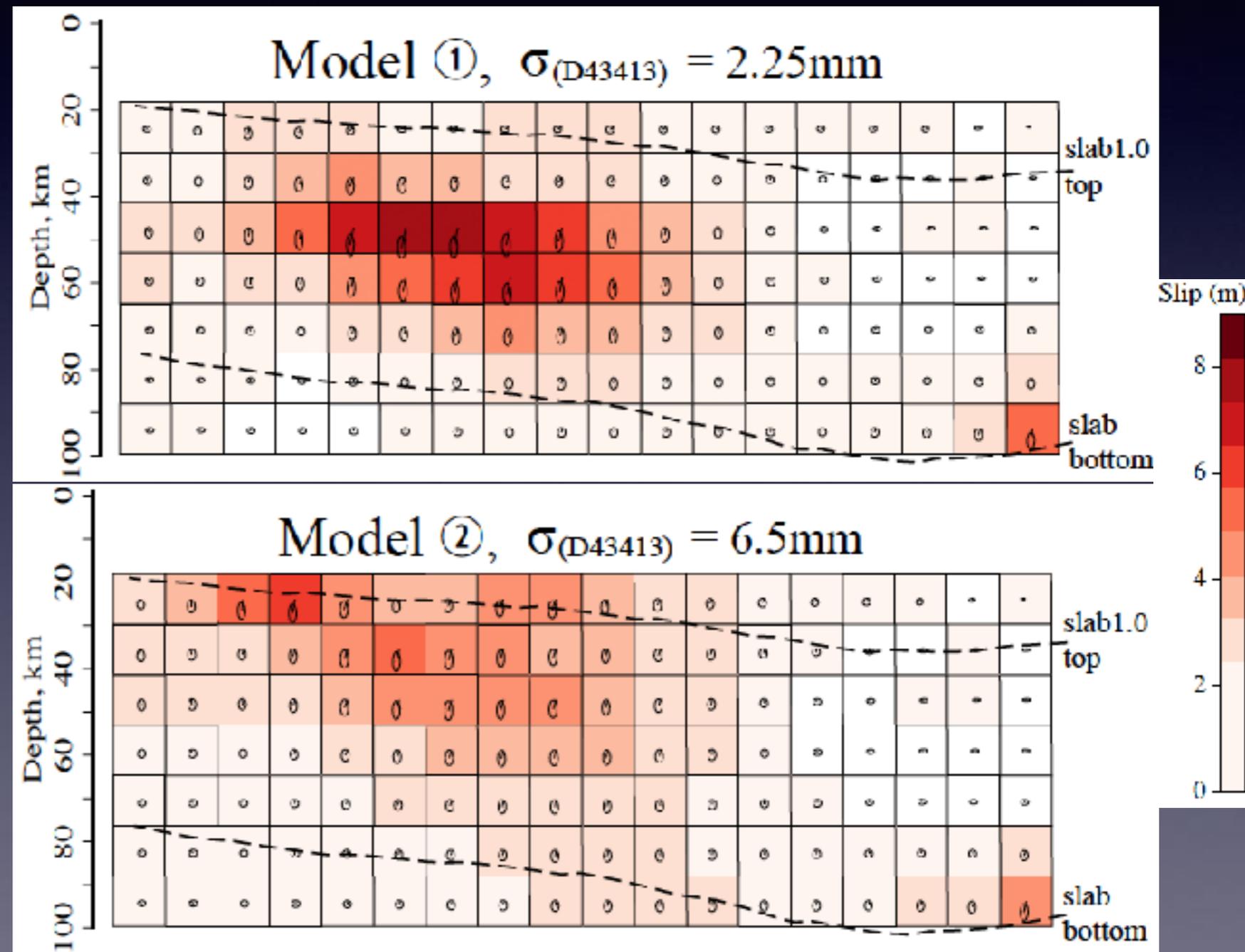


# Tehuantepec static slip model

- ALTar Posterior mean slip
- No smoothing function
- Ellipses show 1- $\sigma$  confidence from posterior PDF
- Slab top from Slab 1.0 (Hayes et al., 2012)
- Bottom assuming 50 km lithospheric thickness (Manea & Manea, 2008)
- Model 1 uses smaller *a priori*  $\sigma$  for DART station 43413
- Slip at NW end required to fit GPS and InSAR, could be very early postseismic

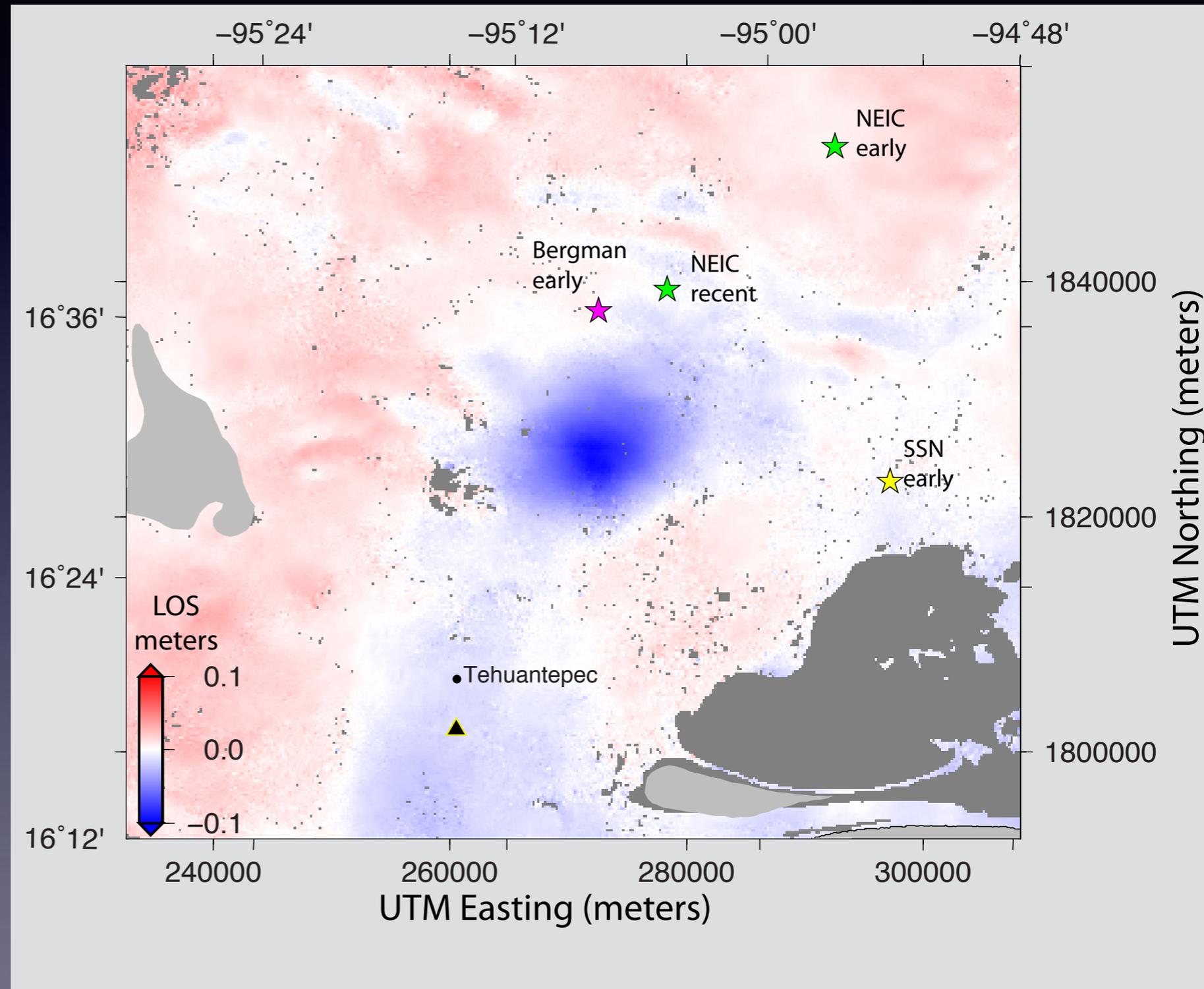
SE

NW



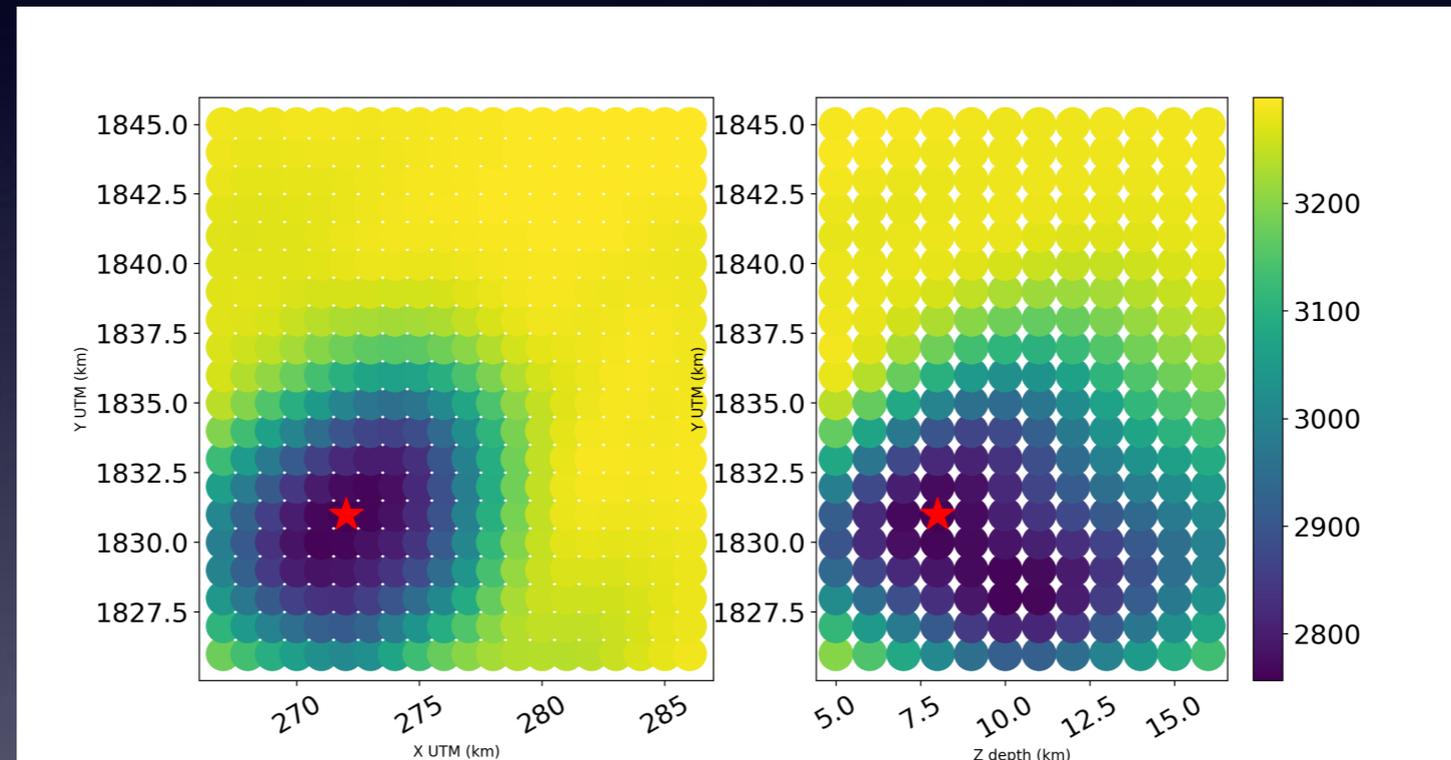
# Mw 6.1 Ixtepec Earthquake

- 23 September 2017 near Ixtepec, Oaxaca
- Shallow normal-faulting event in upper plate crust
- Sentinel-1 InSAR descending track
- USGS NEIC early epicenter 30 km NE of InSAR signal, updated to about 10 km away
- SSN early epicenter 20 km east

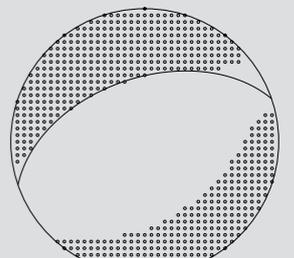


# Ixtepec fault geometry

- InSAR not sensitive to strike and dip of fault
- Fixed strike  $59^\circ$  and dip  $52^\circ$  from GCMT
- Grid search for fault depth and location using Sentinel-1 Asc. & Desc., ALOS-2 Desc.
- Optimum depth of fault center 8 km, but could be as deep as 12 km

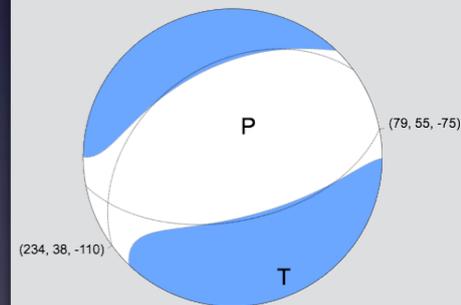


Oaxaca\_20170923

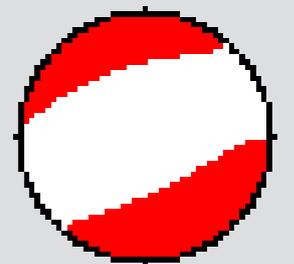


WCMT,  $M_w = 5.99$

WCMT (this study)



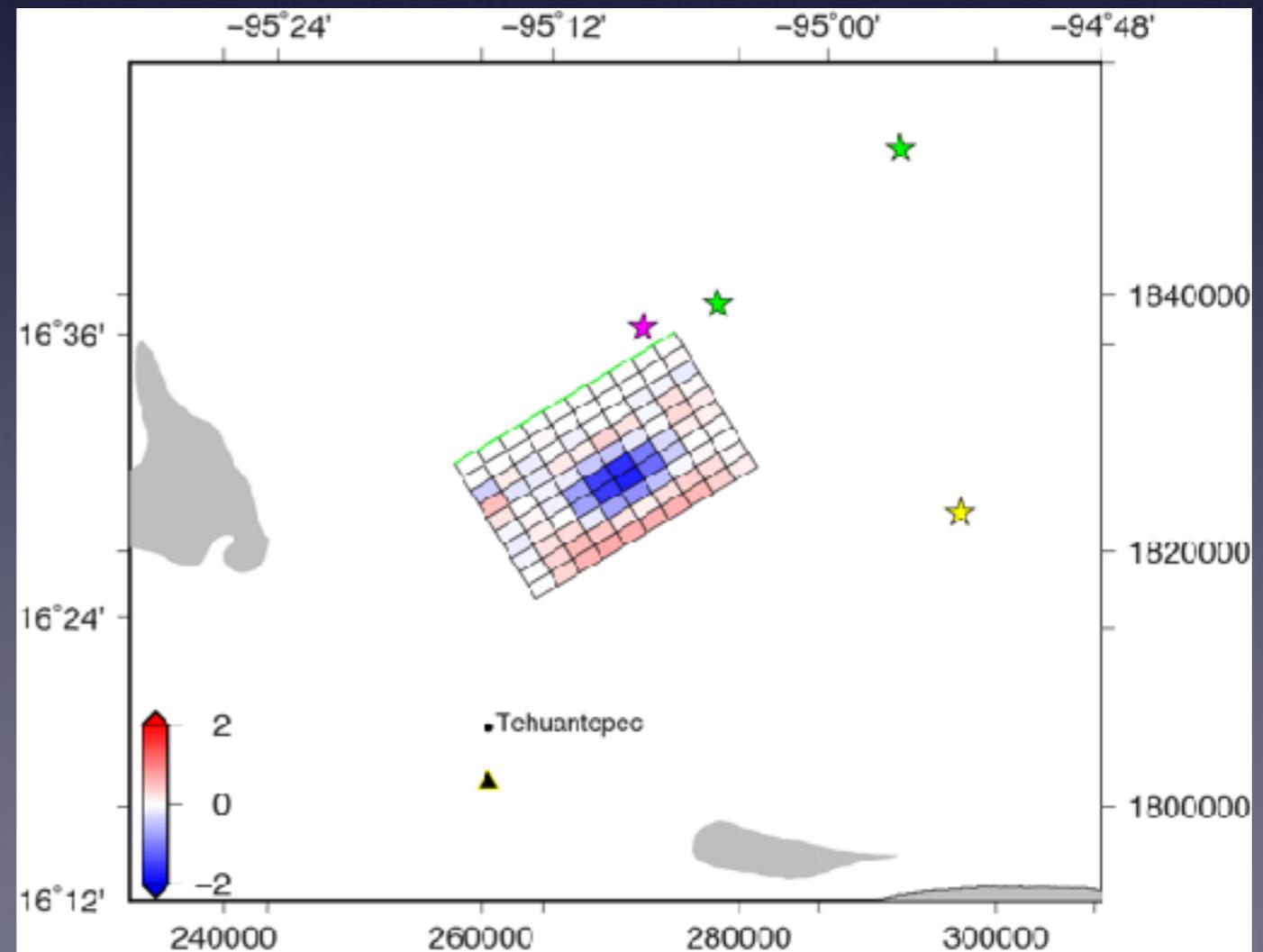
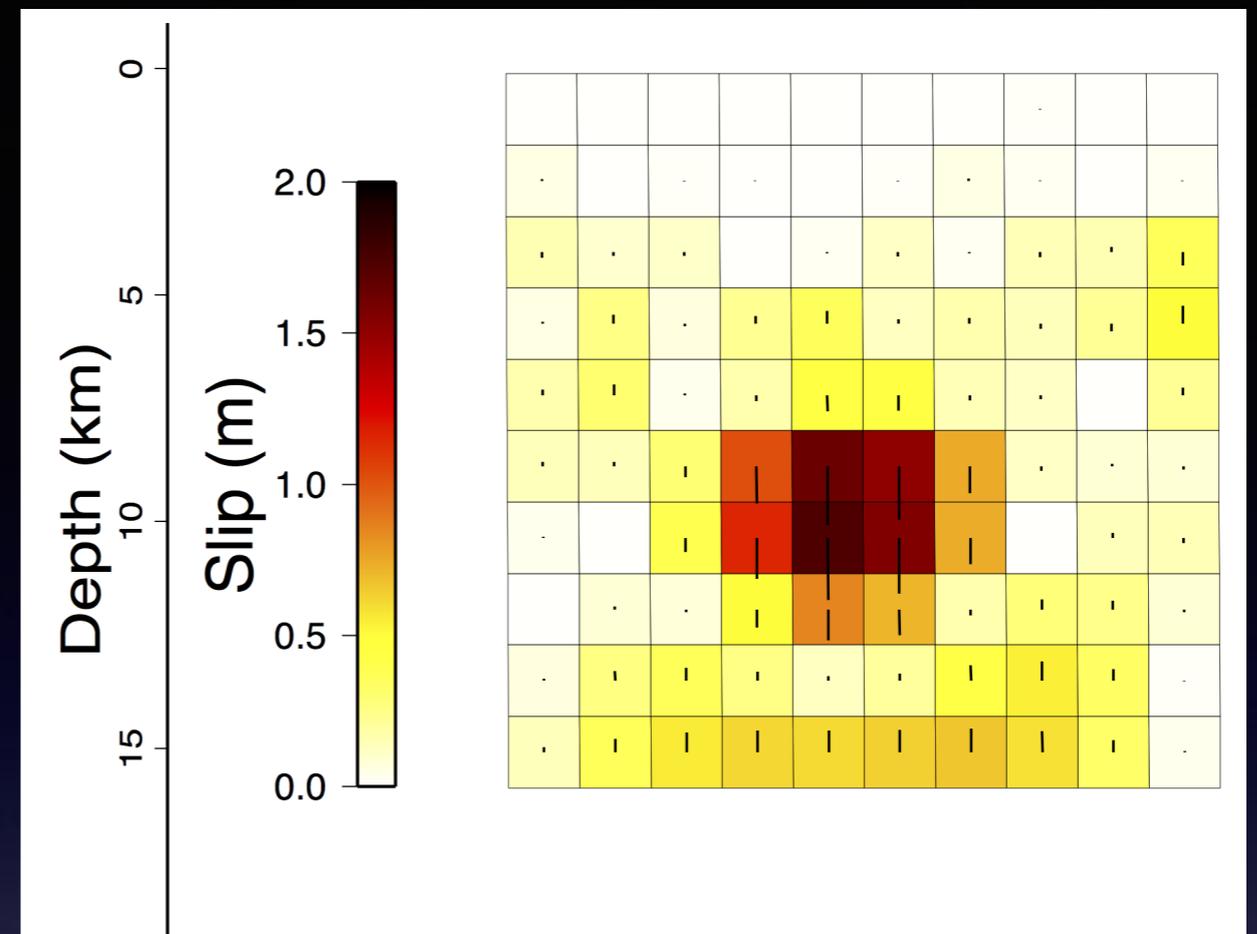
NEIC Mww



GCMT

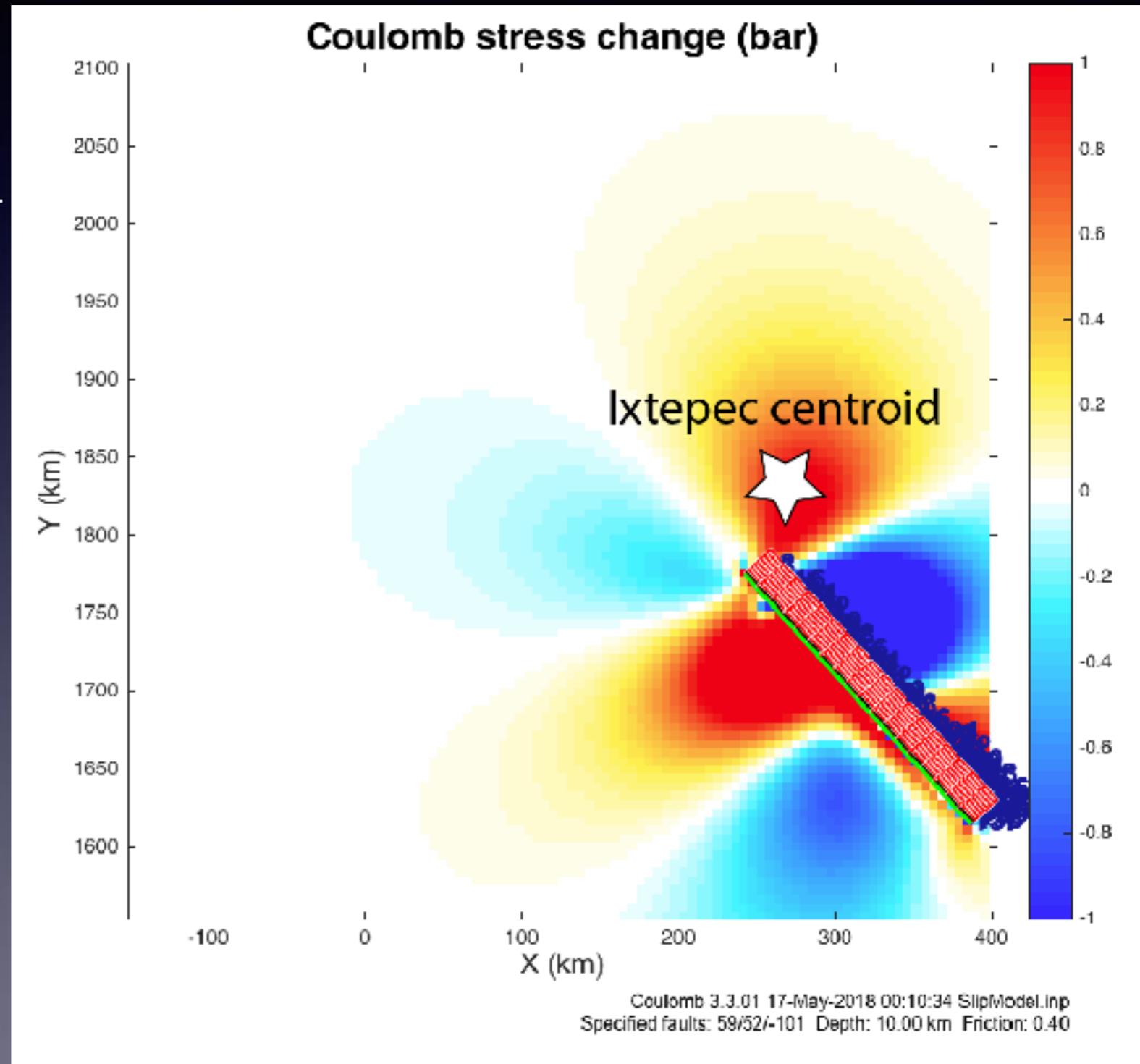
# Ixtepec static slip

- Finite fault slip model with fixed fault geometry
- Classic Slip Inversion (CSI) package (Jolivet et al.)
- 2 Sentinel-1 interferograms 1 ALOS-2 interferogram
- 2x2 km slip patches on 20 by 20 km model fault
- Only dip-slip allowed, no positivity constraint
- Very compact rupture between 8 and 12 km depth, 4–6 km length



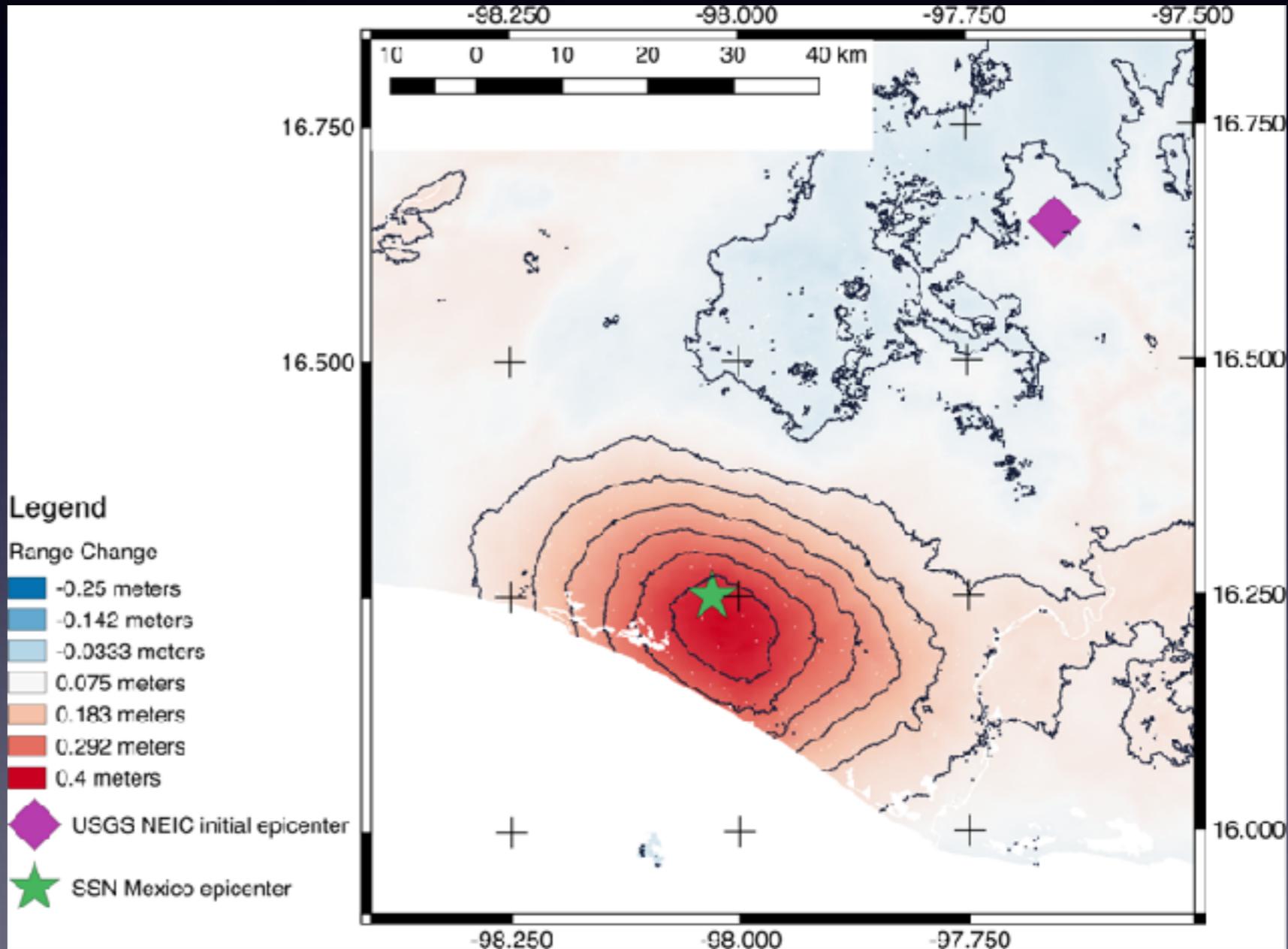
# Coulomb stress change

- Coulomb stress change from Tehuantepec quake Altar slip model for faults strike/dip/rake  $59^\circ/52^\circ/-101^\circ$  like Ixtepec CMT
- Map at depth 10 km
- Increased Coulomb stress on normal faults over large area northwest of Tehuantepec earthquake
- $\sim 1$  bar Coulomb stress change on Ixtepec fault, so very likely triggered event



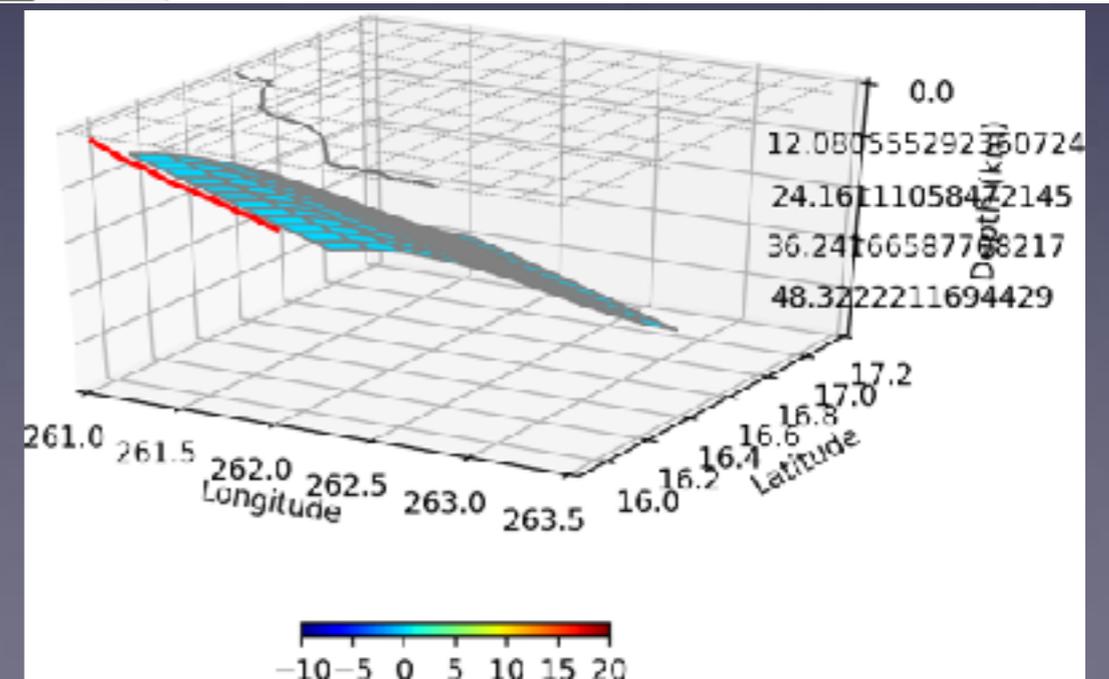
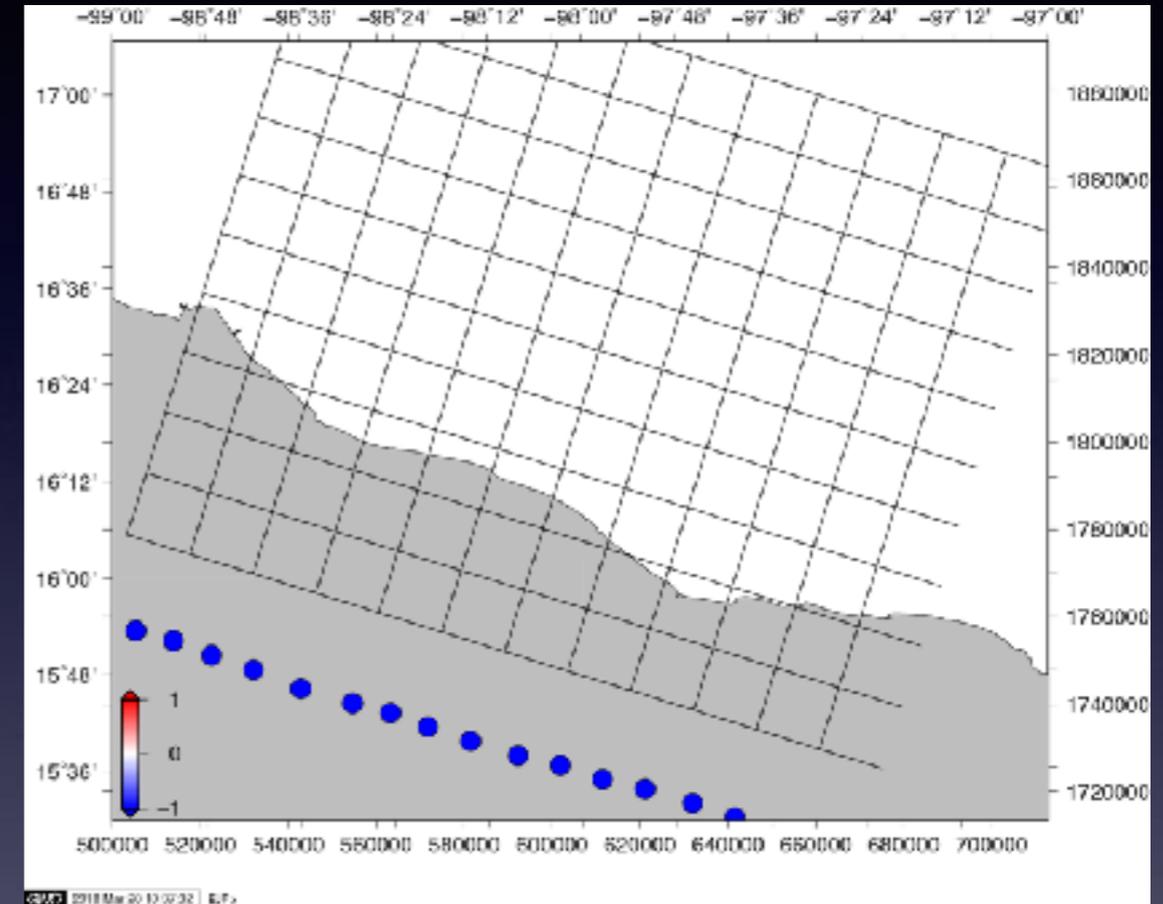
# 2018 Mw 7.2 Pinotepa Earthquake

- Megathrust rupture 16 February 2018 near Pinotepa Nacional, Oaxaca
- Sentinel-1 SAR image acquired 1 hour after earthquake
- Interferogram automatically processed by ARIA data system ~12 hours after earthquake
- Initial USGS NEIC epicenter ~40 km to NW of InSAR
- Sent initial interferogram to USGS to inform hypocenter used in finite fault model and revised ShakeMap



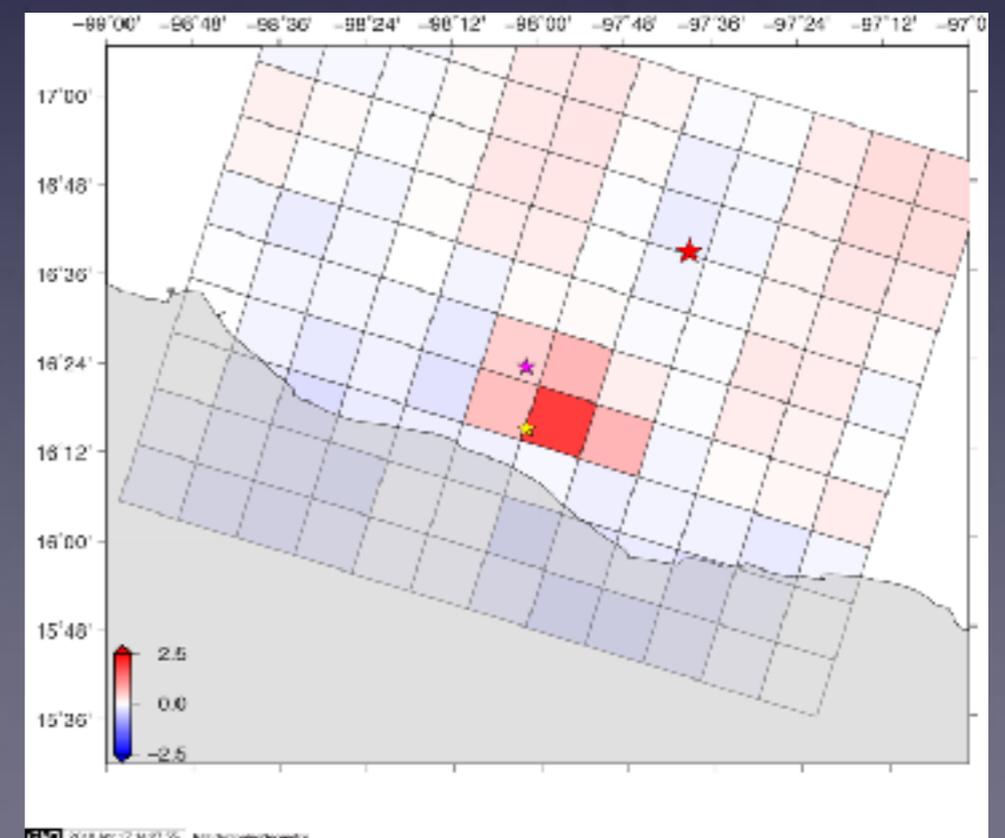
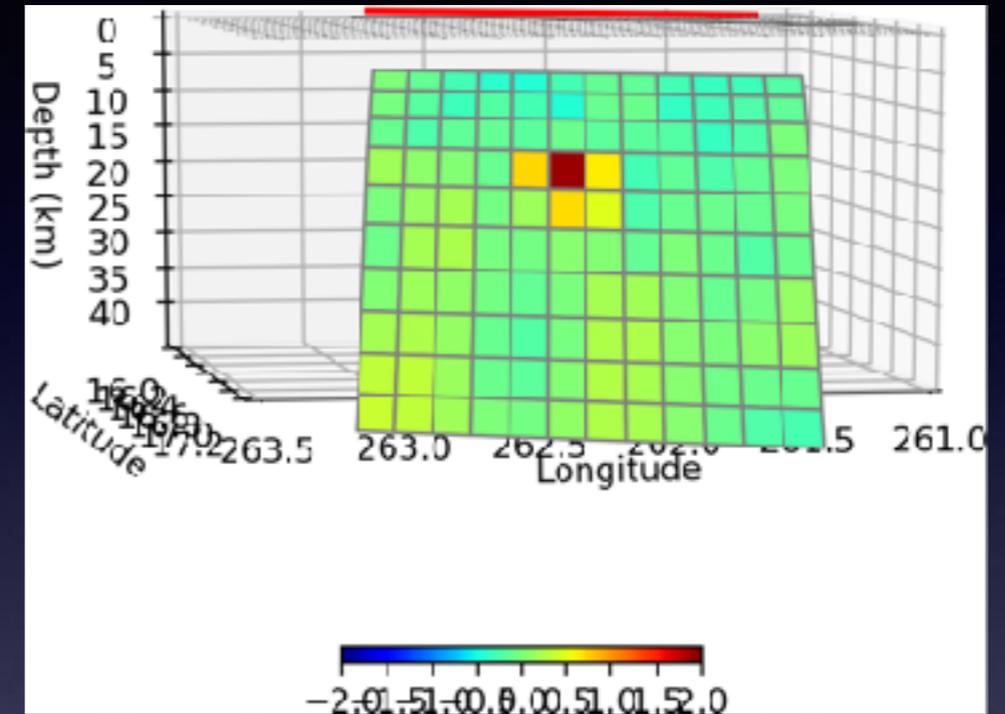
# Pinotepa slip modeling

- Generated model fault from Slab1.0 database
- Includes down-dip curvature but not along-strike curvature
- Model fault v1: 20 km offset from trench, 160 km along-strike and 200 km down-dip
- 15x15 km patches
- CSI modeling



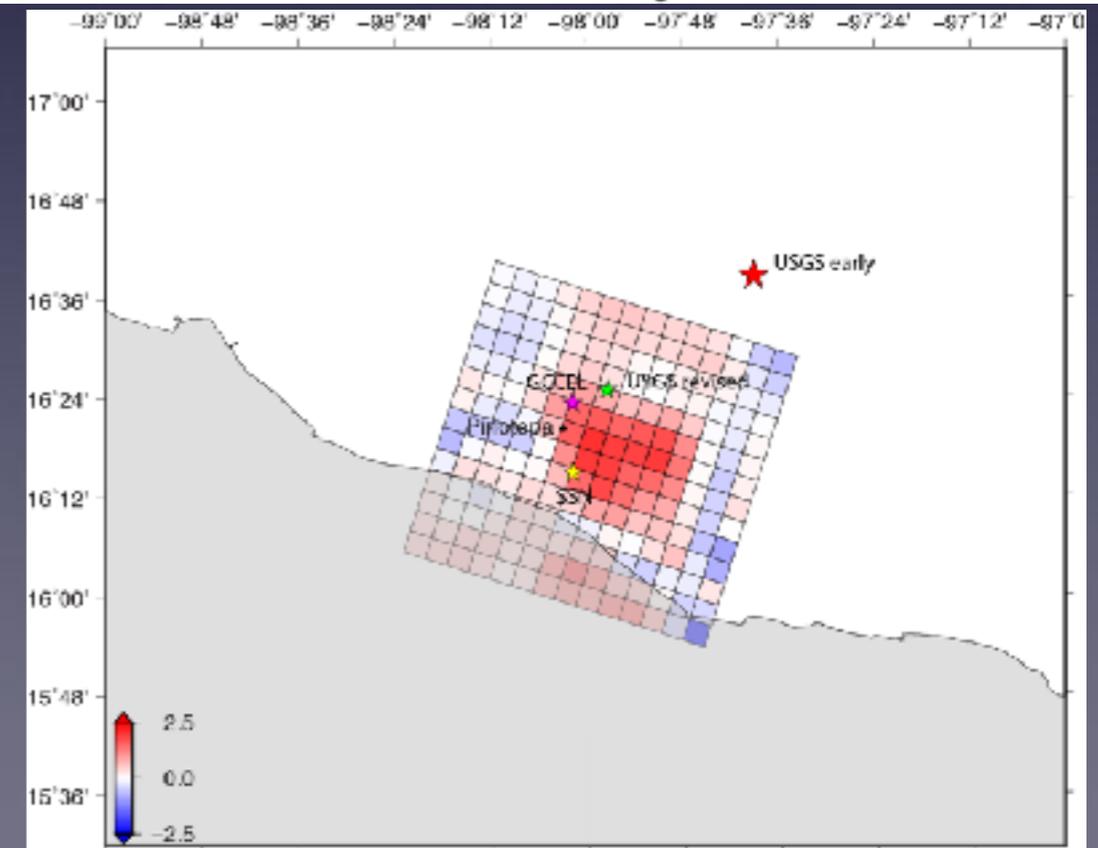
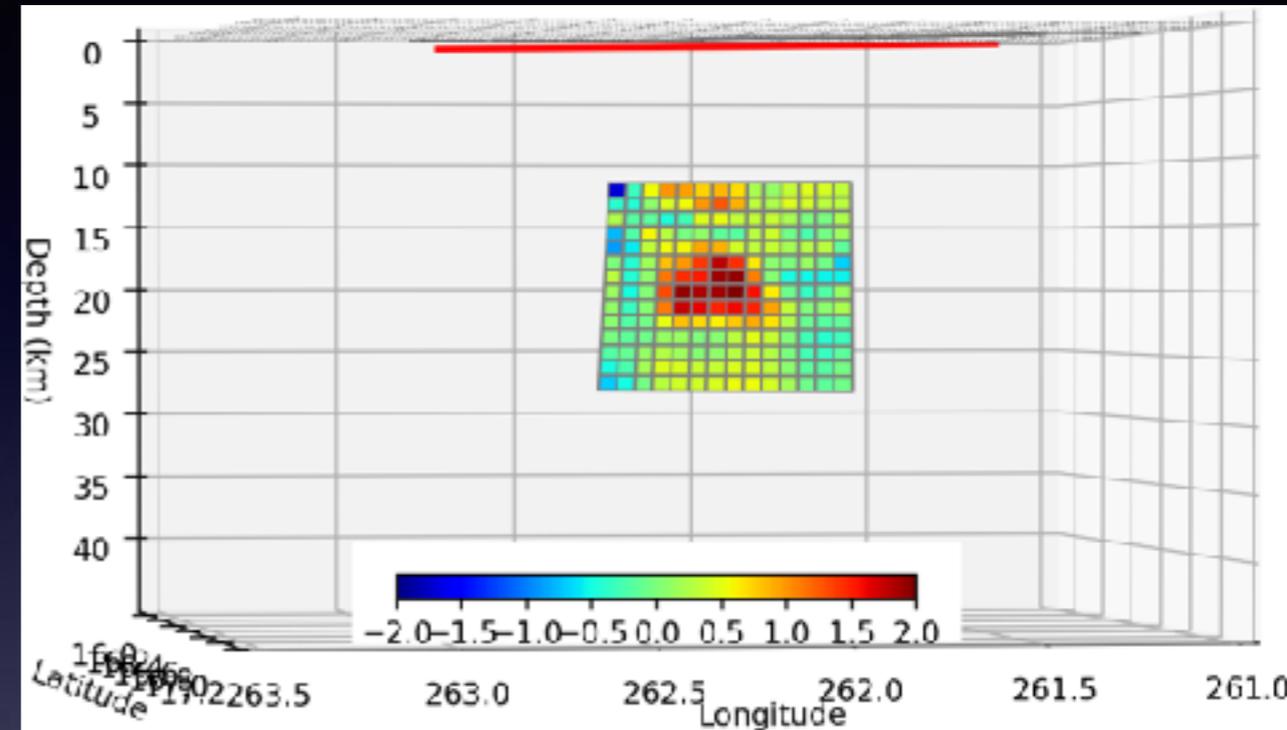
# Pinotepa slip modeling

- Model fault v1 slip inversion with two Sentinel-1 interferograms (Desc. 143, Asc. 005)
- Dip-slip only, no positivity constraint
- Slip almost entirely in one 15x15 km patch near coast at 20–25 km depth
- USGS initial epicenter ~45 km NE (red star), SSN epicenter very close (yellow), GCCEL (Bergman et al.) relocation close (magenta star)



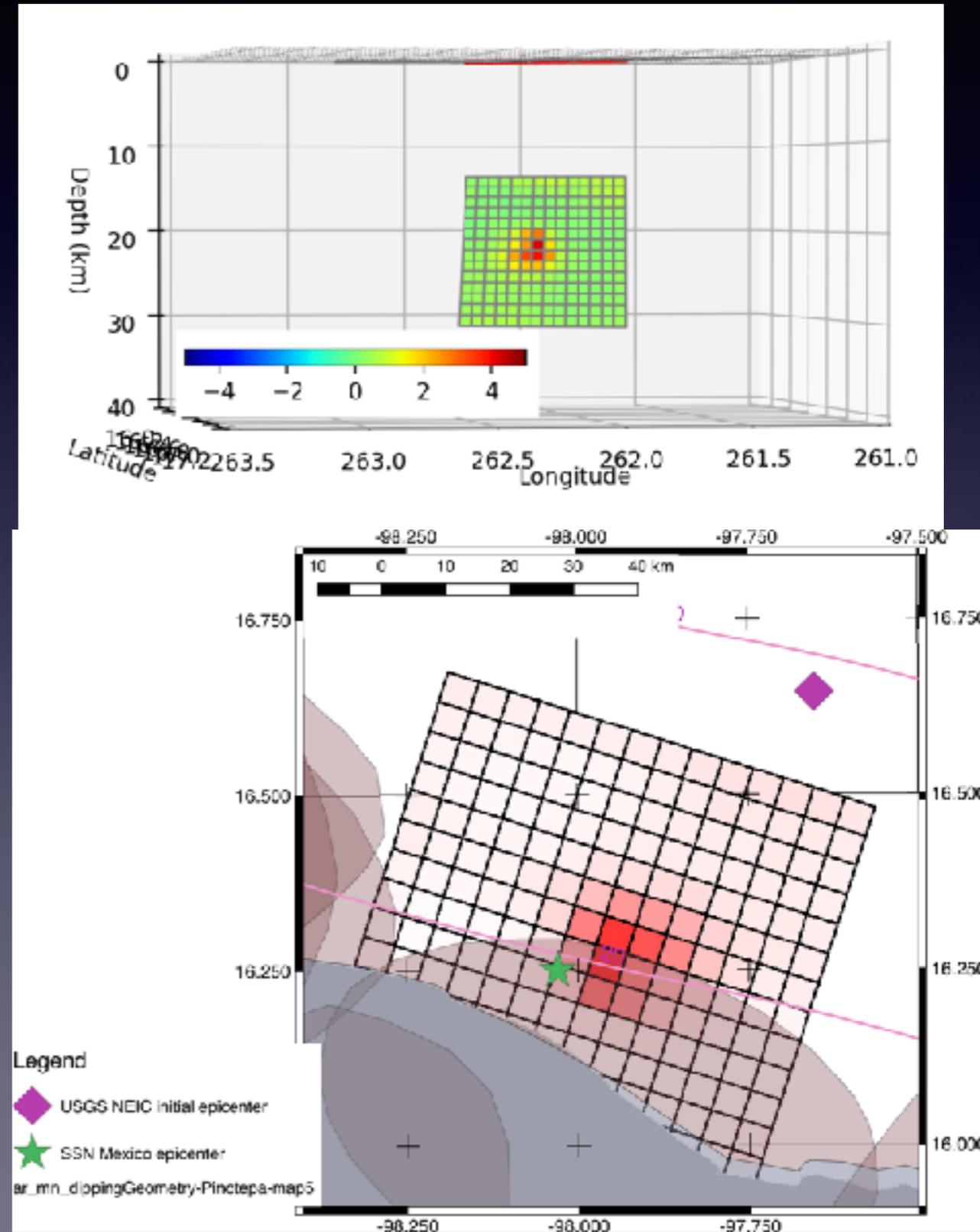
# Pinotepa slip modeling

- Model fault v3 slip inversion with three Sentinel-1 ifgs (Desc. 143, Desc. 070, Asc. 005), ALOS-2 ifg (Desc. 150), GPS
- smaller model fault 70 x 70 km with 5x5 km patches from Slab1.0 database
- Dip-slip only, no positivity constraint, smoothing function of Radiguet et al. (2012)
- Depth 17–22 km with Slab1.0 geometry
- Slip about 10 by 20 km in this result, to be confirmed with full Bayesian inversion



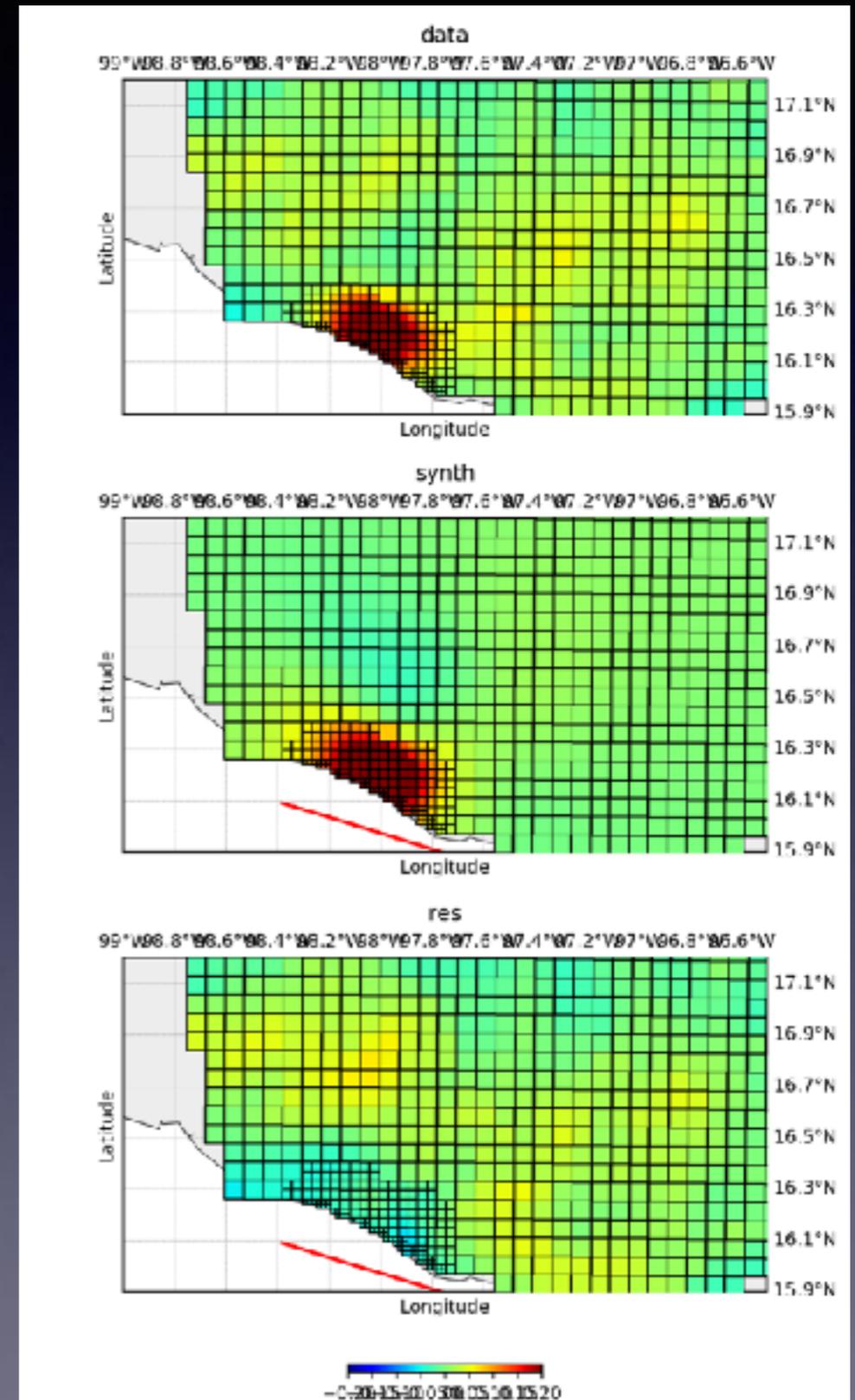
# Pinotepa slip modeling

- Model fault v4 slip inversion with three Sentinel-1 ifgs (Desc. 143, Desc. 070, Asc. 005), ALOS-2 ifg (Desc. 150), GPS
- Smaller model fault 70 x 70 km with 5x5 km patches from Slab2.0 database (Hayes et al., 2018)
- Depth of slip 20–25 km with Slab2 geometry
- Slip parallel to W-phase CMT slip ( $-158^\circ$  azimuth)
- Full Bayesian inversion with AlTar 1.1, uniform prior for along-rake slip  $[-0.1, 20 \text{ m}]$  and Gaussian prior for rake-perpendicular  $\sigma=0.8 \text{ m}$



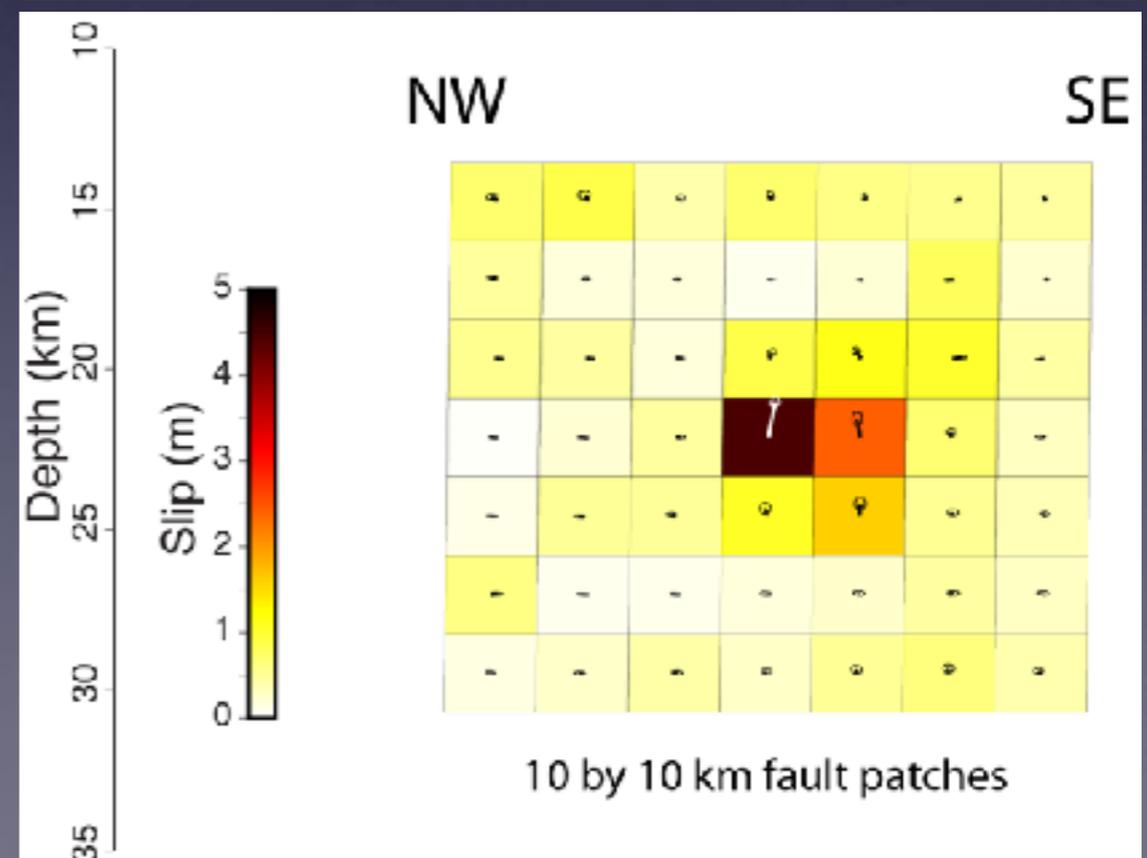
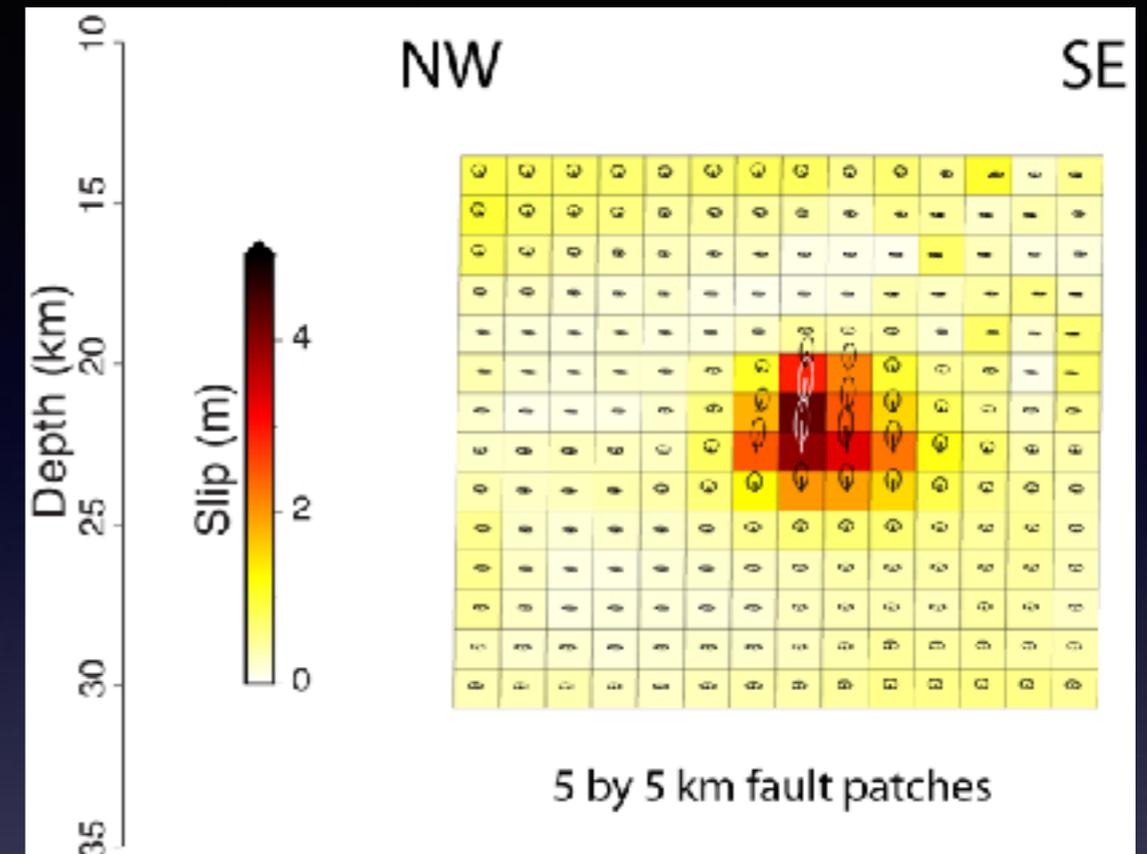
# Pinotepa slip modeling

- Model fault v4 AlTar slip inversion with three Sentinel-1 ifgs (Desc. 143, Desc. 070, Asc. 005), ALOS-2 ifg (Desc. 150), GPS
- Excellent fit to InSAR data—example Sentinel-1 Ascending track 005
- Downsampled data (top), synthetic (middle), residual (bottom)
- Residuals likely all atmospheric noise



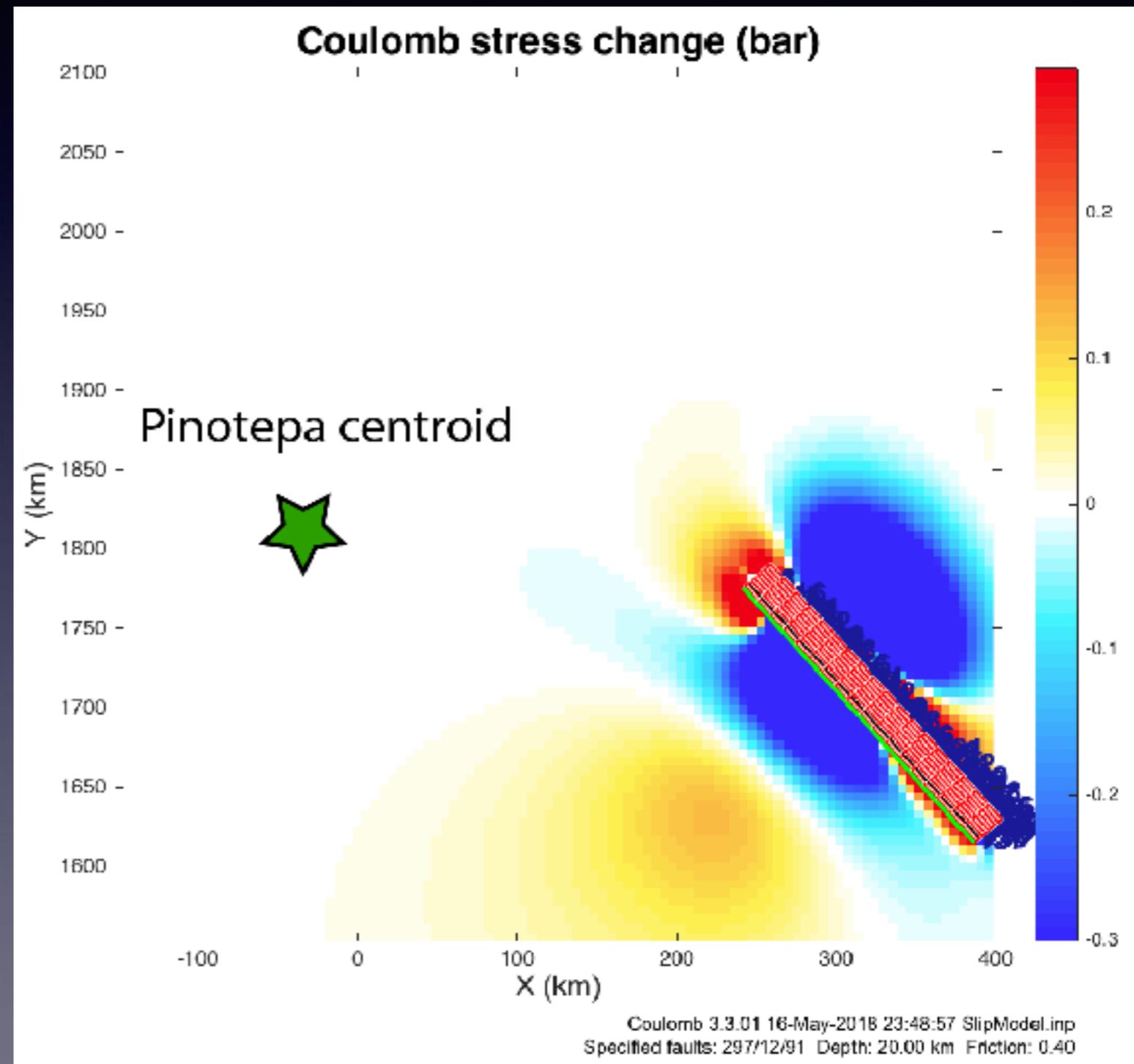
# Pinotepa slip modeling

- ATar slip inversion with 5x5 km patches (top) shows high slip uncertainty on each small patch
- ATar slip inversion with 10x10 km patches (below) shows much lower uncertainty of slip on coarser patches
- slip area likely very compact ~20 km along strike and 10-15 km down dip
- Both models show greatest slip at depth ~22 km, based on Slab2 megathrust geometry

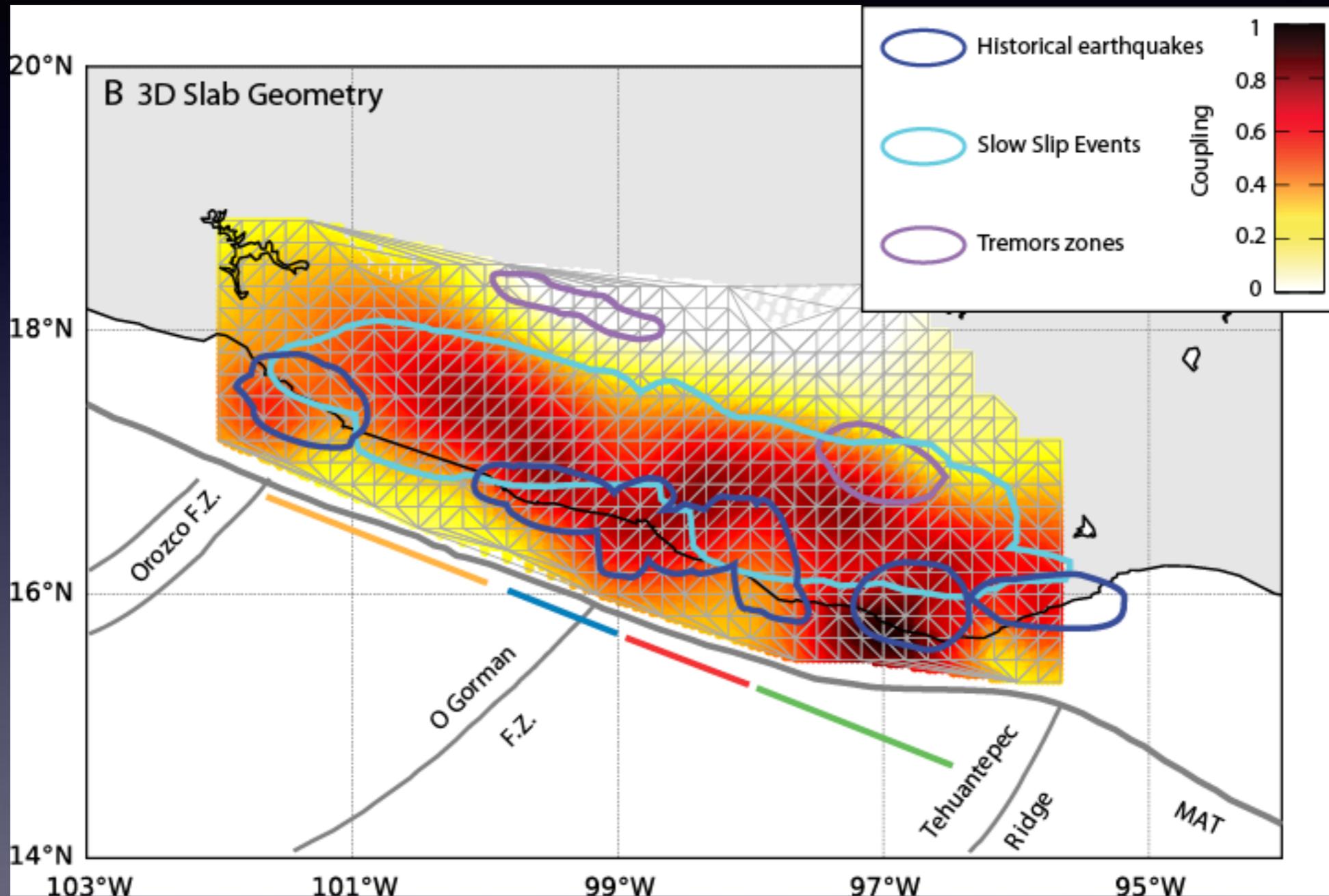


# Coulomb stress change

- Coulomb static stress change from Tehuantepec quake for thrust faults strike/dip/rake  $297^\circ/12^\circ/91^\circ$  like Pinotepa CMT
- Map at depth 20 km
- Increased Coulomb stress only very close to Tehuantepec earthquake
- No significant static stress change at Pinotepa hypocenter

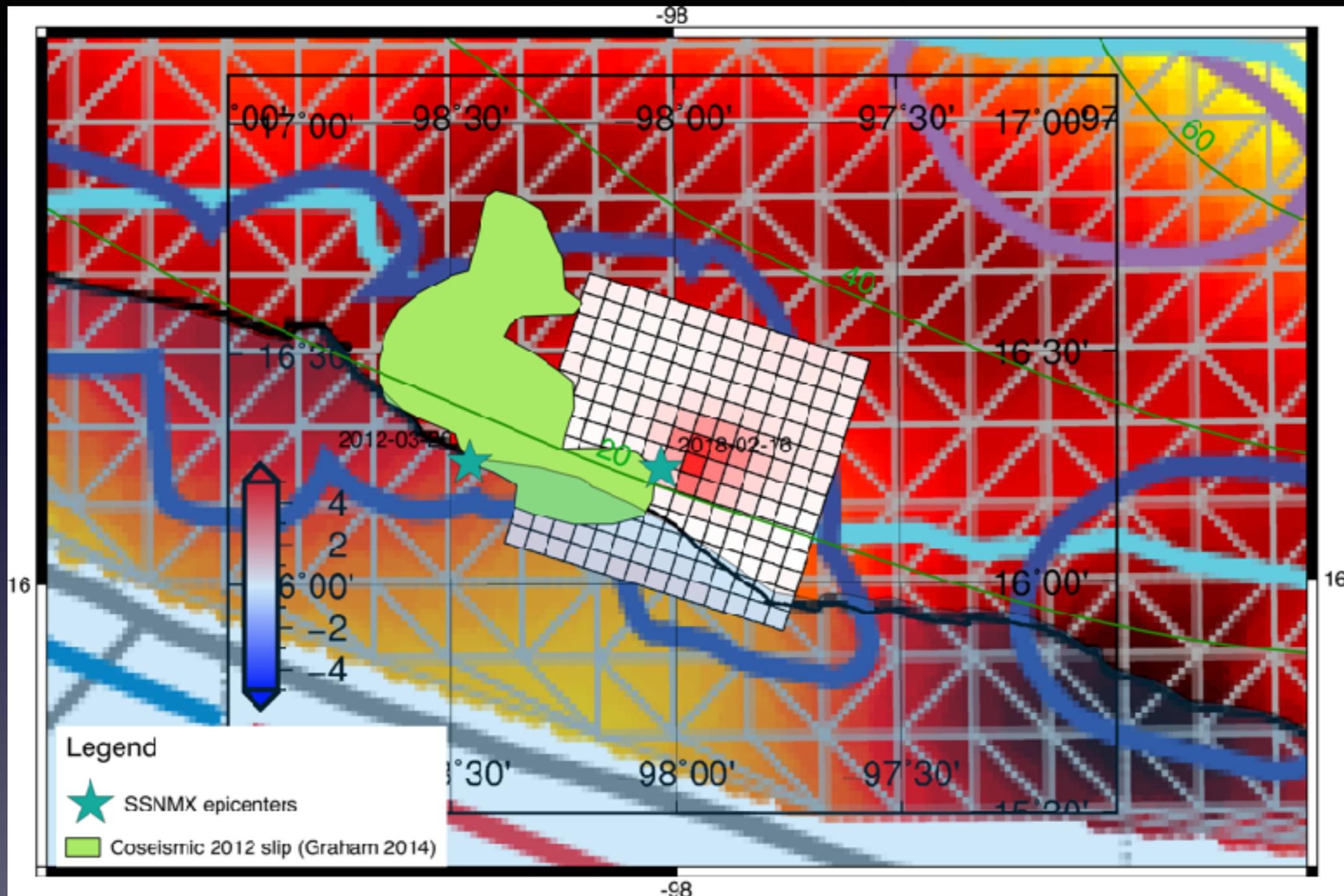


# Oaxaca megathrust coupling



- Rousset et al. (2015) Pure Appl. Geoph. estimate from GPS

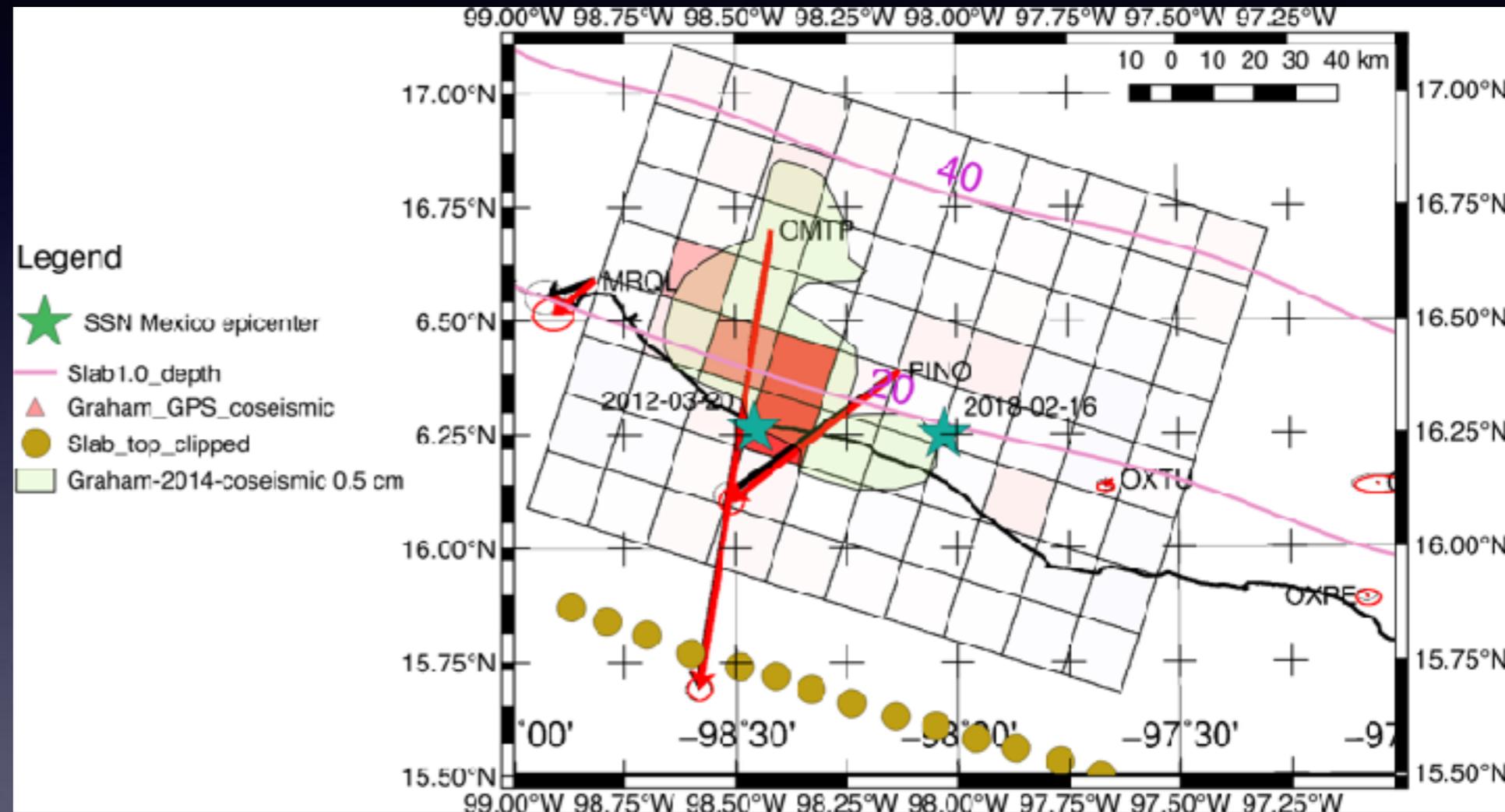
# Oaxaca megathrust coupling



- 2018 M7.2 Pinotepa quake ruptured area that overlaps with slow-slip event zone (cyan), in partial coupling zone of Rousset et al. (2015) (background color)
- 2018 slip just east of 2012 M7.1 earthquake slip from Graham et al. (2014) (green)

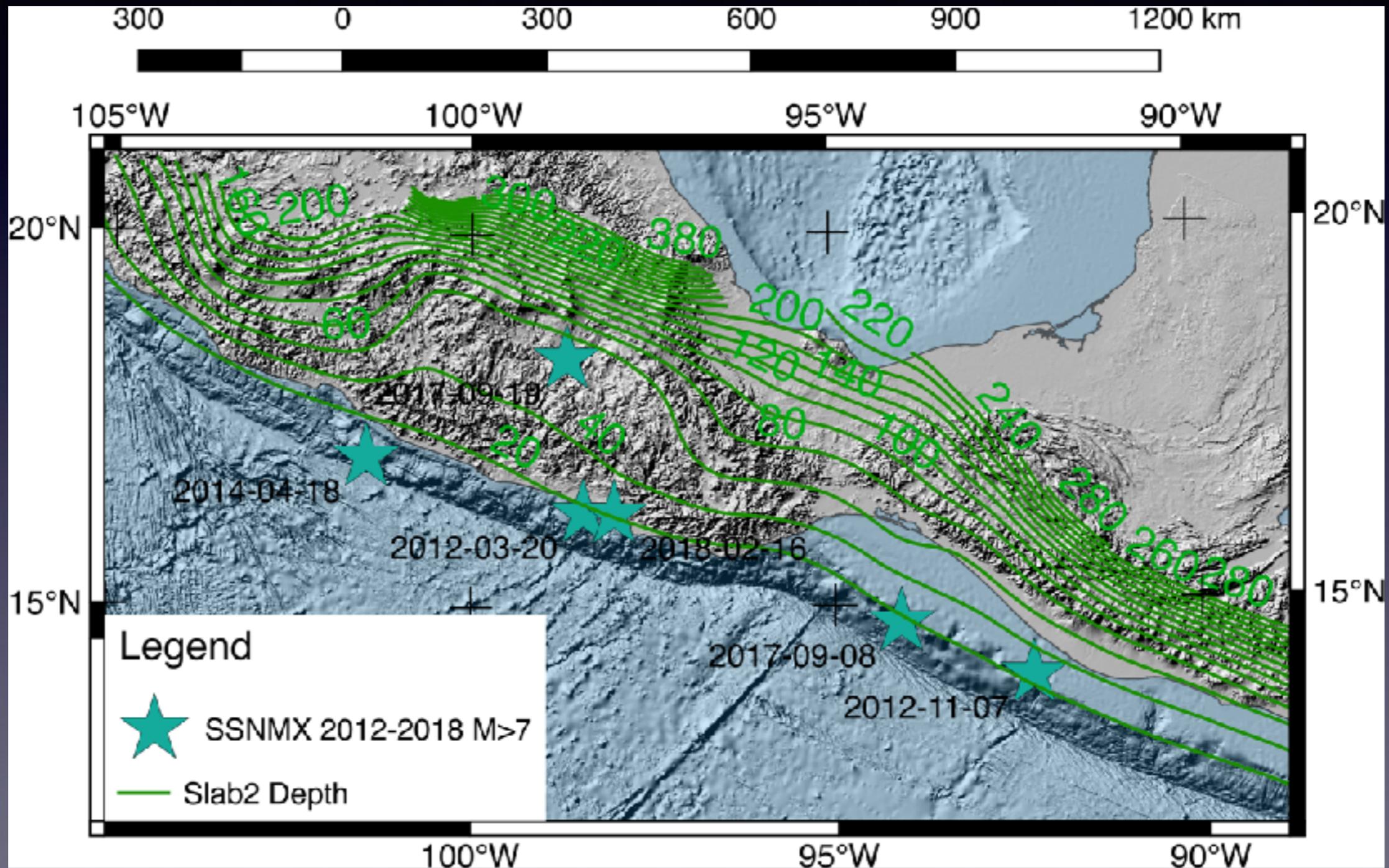
# 2012 Ometepepec EQ slip modeling

- 20 March 2012 Mw 7.4 megathrust earthquake
- ATar slip inversion with model fault from Slab2.0 database
- 15x15 km patches
- GPS offsets from Graham et al. (2014)
- High slip likely on central part of previous slip model
- No overlap with 2018 earthquake slip



Graham, S. E., C. DeMets, E. Cabral-Cano, V. Kostoglodov, A. Walpersdorf, N. Cotte, M. Brudzinski, R. McCaffrey, and L. Salazar-Tlaczani (2014), GPS constraints on the Mw = 7.5 Ometepepec earthquake sequence, southern Mexico: coseismic and post-seismic deformation, *Geophys. J. Int.*, 199(1), 200-218, doi:10.1093/gji/ggu167.

# Central America Slab



# Conclusions

- M8.2 Tehuantepec 8 Sept. 2017 quake normal-fault rupture through most of subducting Cocos plate, at least 150 and maybe 220 km long
- M6.1 Ixtepec 23 Sept. 2017 quake in Oaxaca compact 4 x 6 km rupture at ~10 km depth in upper plate crust, likely aftershock of M8.2
- M7.2 Pinotepa 16 Feb. 2018 quake in Oaxaca on megathrust very compact 10x20 km at depth ~20-25 km at edge of zone of many M7 quakes that may overlap SSEs
- Partial “coupling” likely has small locked patches like one that ruptured in 2018