Recovering all Geodetic Strain Along the Nicoya Subduction Interface

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Theoretical & Experimental Institute for the Subduction Cycles & Deformation Initiative
October 12-14, 2015 • Hotel Portofino, Redondo Beach, CA

INTRODUCTION

- Nicoya, Costa Rica is a unique locality that puts land directly above the seismogenic component of a very active subduction megathrust.
  - The Middle America Trench generates M 7.5+ earthquakes here approximately every 50 - 60 years.
  - Allows near-trench seismic and geodetic onland observations
- Using nearly 20 years of campaign and continuous GPS groups have imaged:
  - Late interseismic period [e.g. *Norabuena et al.*, JGR, 2005, *Feng et al.* JGR 2012],
  - Numerous slow slip events [e.g. Dixon et al., PNAS, 2015]
  - a large Mw 7.6 earthquake in 2012 [e.g. *Protti et al.*, Nat. Geosc, 2014]
  - Ongoing postseismic recovery [*Malservisi et al.*, G3, 2015].
- We present these results and discuss our efforts to create a unified model that cohesively integrates the subduction interface behavior, considering individual data sensitivities.
- Our effort should yield a truly unified look at the relationship between locking, episodic slip, coseismic rupture, and aftershocks.

SEISMOGENIC COUPLING AND STRUCTURE

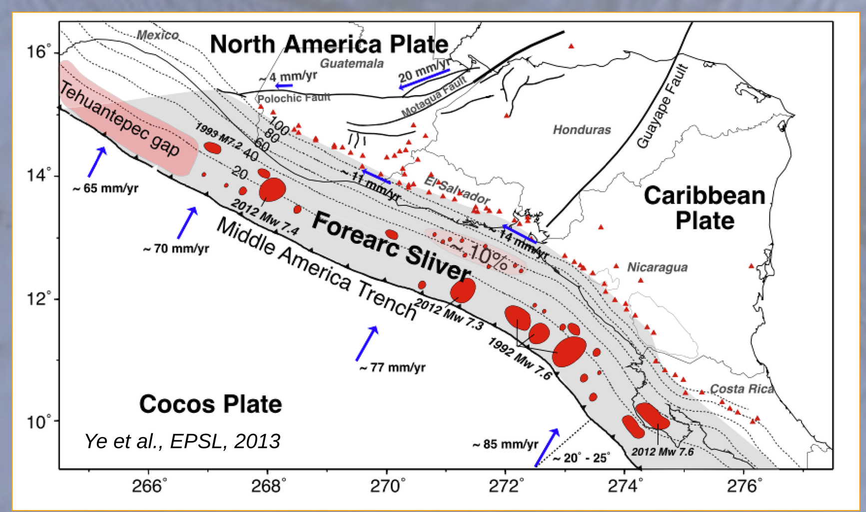


Figure 1: Though large megathrust earthquakes are common throughout the southern Middle America Trench, they only represent a small fraction of the geodetically available slip, considering the rapid plate convergence between 70 and 85 mm/yr. Regionally, it appears that the seismically derived slip accounts for less than 5 to 25% of the geodetic convergence, suggesting that most of the interface is either freely creeping, or otherwise releasing slip in episodic slow slip, or in substantial afterslip.

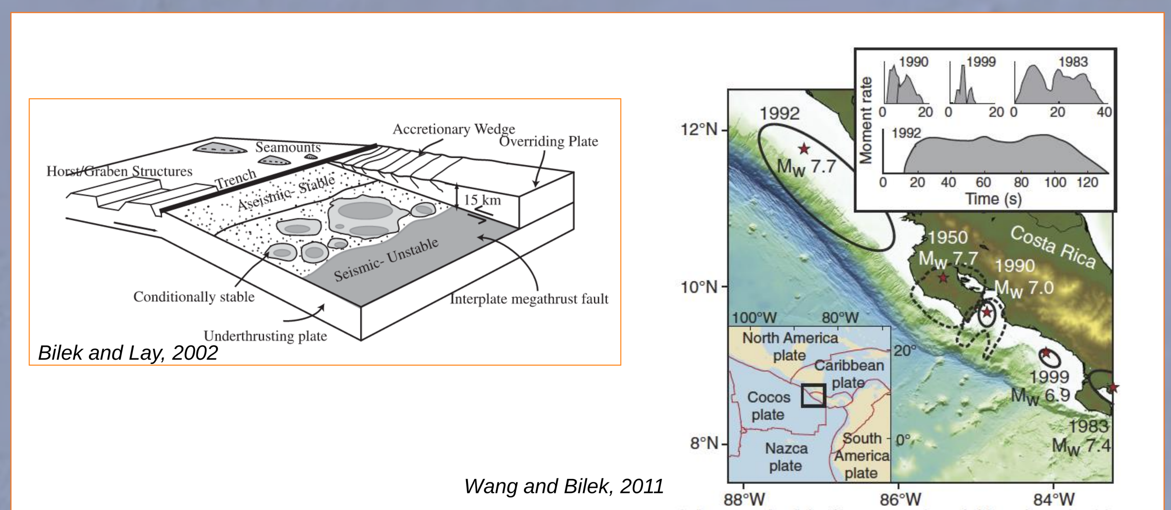


Figure 2: Along the Middle America Trench (MAT) numerous seamounts may act to create numerous smaller to moderate asperities, which may help dictate where earthquakes occur, and how large they may get. Such seamounts particularly dominate central Costa Rica, where the Quepos Plateau subducts just south of Nicoya. However, the oceanic crust west of Nicoya remains relatively free of such structures, promoting larger and more uniform coupling and release.

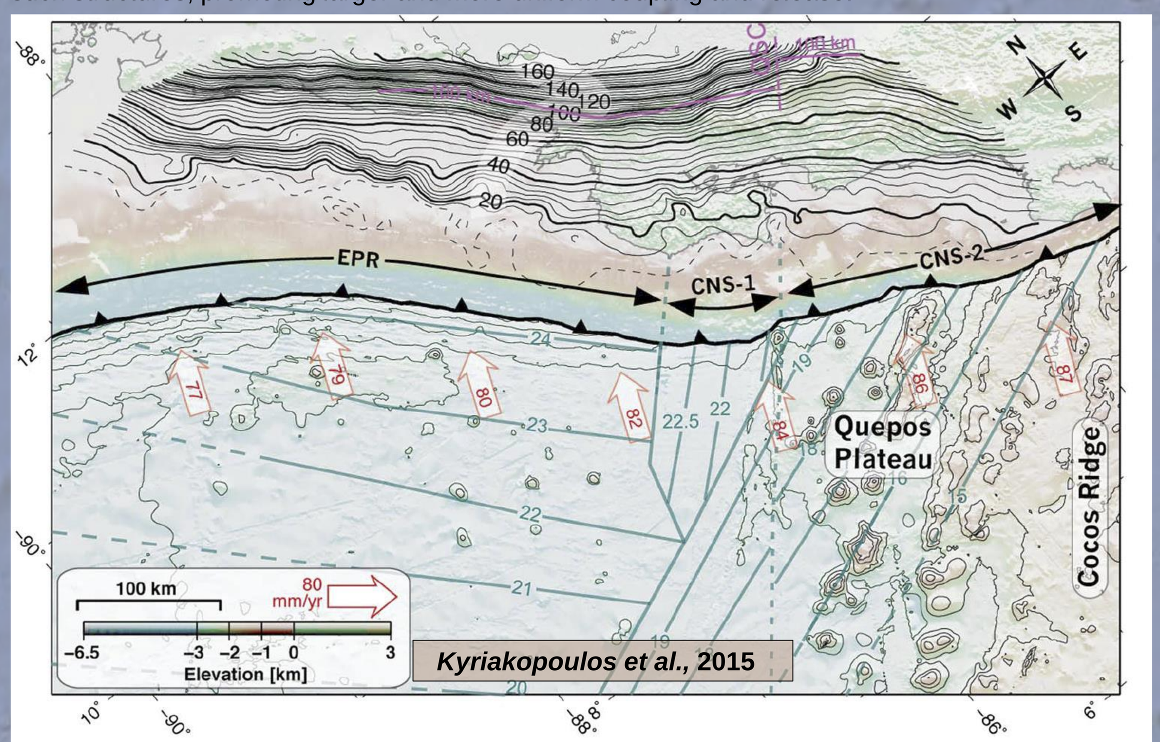


Figure 3: A new detailed Subduction plate interface model derived from numerous regional high-resolution local seismic catalogs, identifies a substantial and robust topographic high stand along the central Nicoya Peninsula [*Kyriakopoulos et al.*, 2015]. This structure corresponds to the suture between the East Pacific Rise (EPR) and a segment of Cocos-Nazca Spreading Center (CNS-1) crust, as well as depth of interface seismicity [*Newman et al.*, 2002] (not shown), and seismic velocity changes near the interface [*Deshon et al.*, 2006] (not shown)

COUPLING AND SLIP MODELS

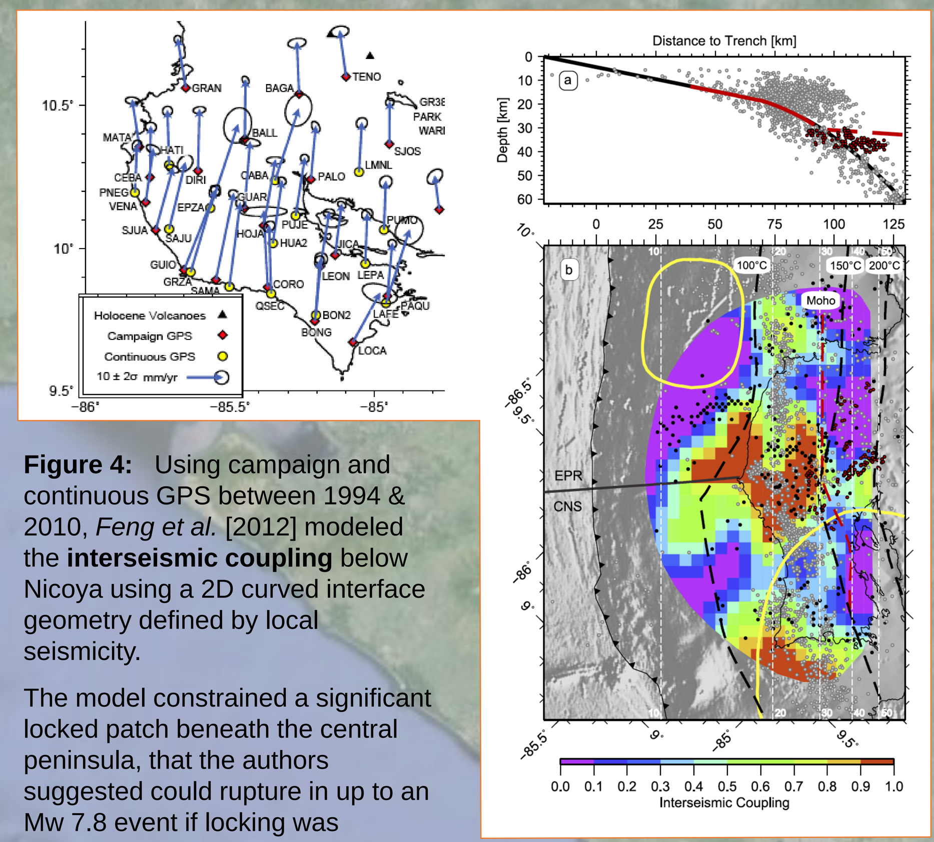


Figure 4: Using campaign and continuous GPS between 1994 & 2010, *Feng et al.* [2012] modeled the **interseismic coupling** below Nicoya using a 2D curved interface geometry defined by local seismicity.

The model constrained a significant locked patch beneath the central peninsula, that the authors suggested could rupture in up to an Mw 7.8 event if locking was constant following the 1950 earthquake.

Figure 5: Along with crustal shortening (shown above) GPS results found that that the coastal region near the central part of the peninsula was subsiding by about 1.2 cm/yr, illuminating the cause of substantial local beach erosion (left).

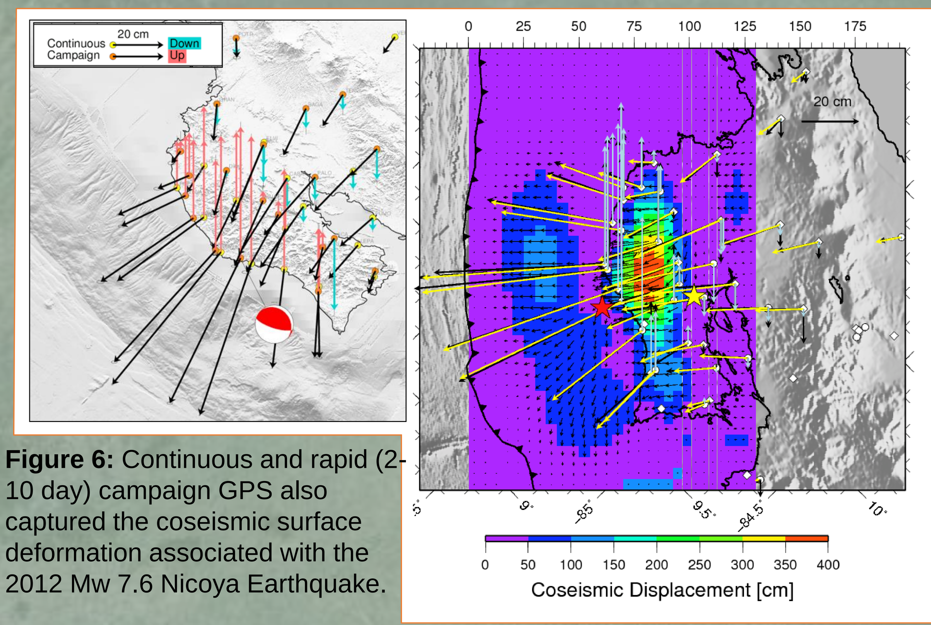
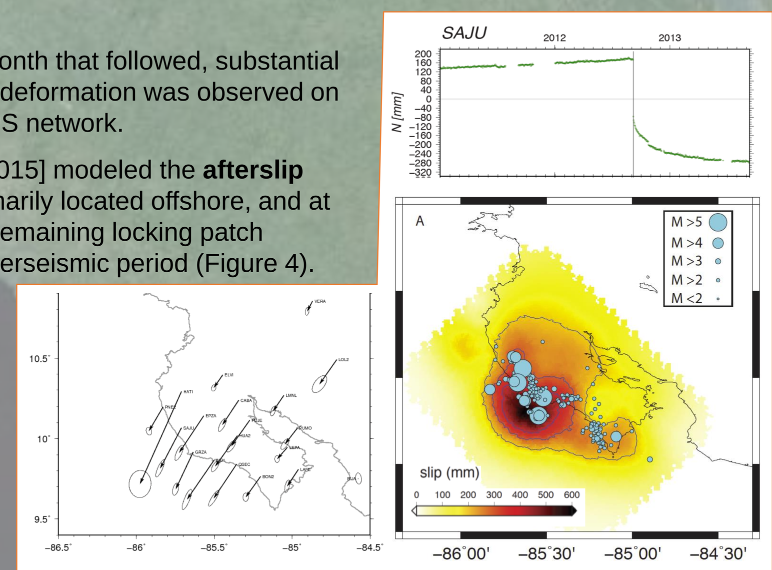


Figure 6: Continuous and rapid (2-10 day) campaign GPS also captured the coseismic surface deformation associated with the 2012 Mw 7.6 Nicoya Earthquake.

Using the same geometry as *Feng et al.* (Figure 4), *Protti et al.*, [2014] created derived **coseismic slip** model from the surface deformation. They found that the slip largely could be described by the deep-seated locking path beneath the peninsula. However, a shallow patch did no rupture, at least coseismically.

Figure 7: In the month that followed, substantial surface deformation was observed on the continuous GPS network.

Malservisi et al.,[2015] modeled the **afterslip** finding that its primarily located offshore, and at least partly in the remaining locking patch observed in the interseismic period (Figure 4).



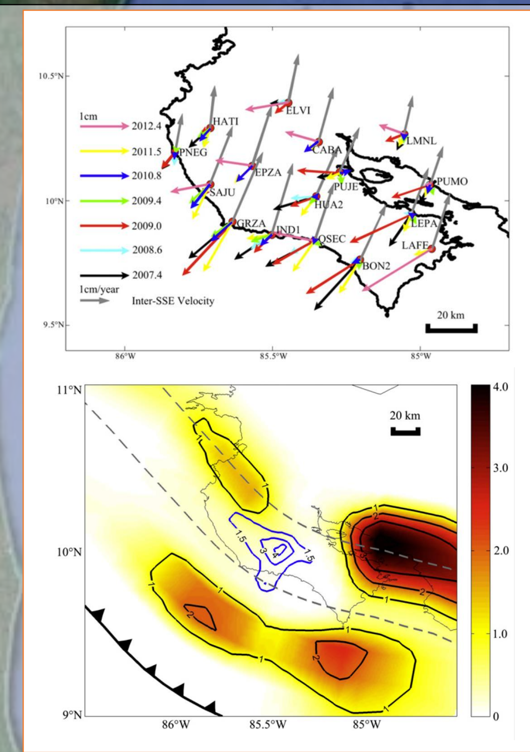
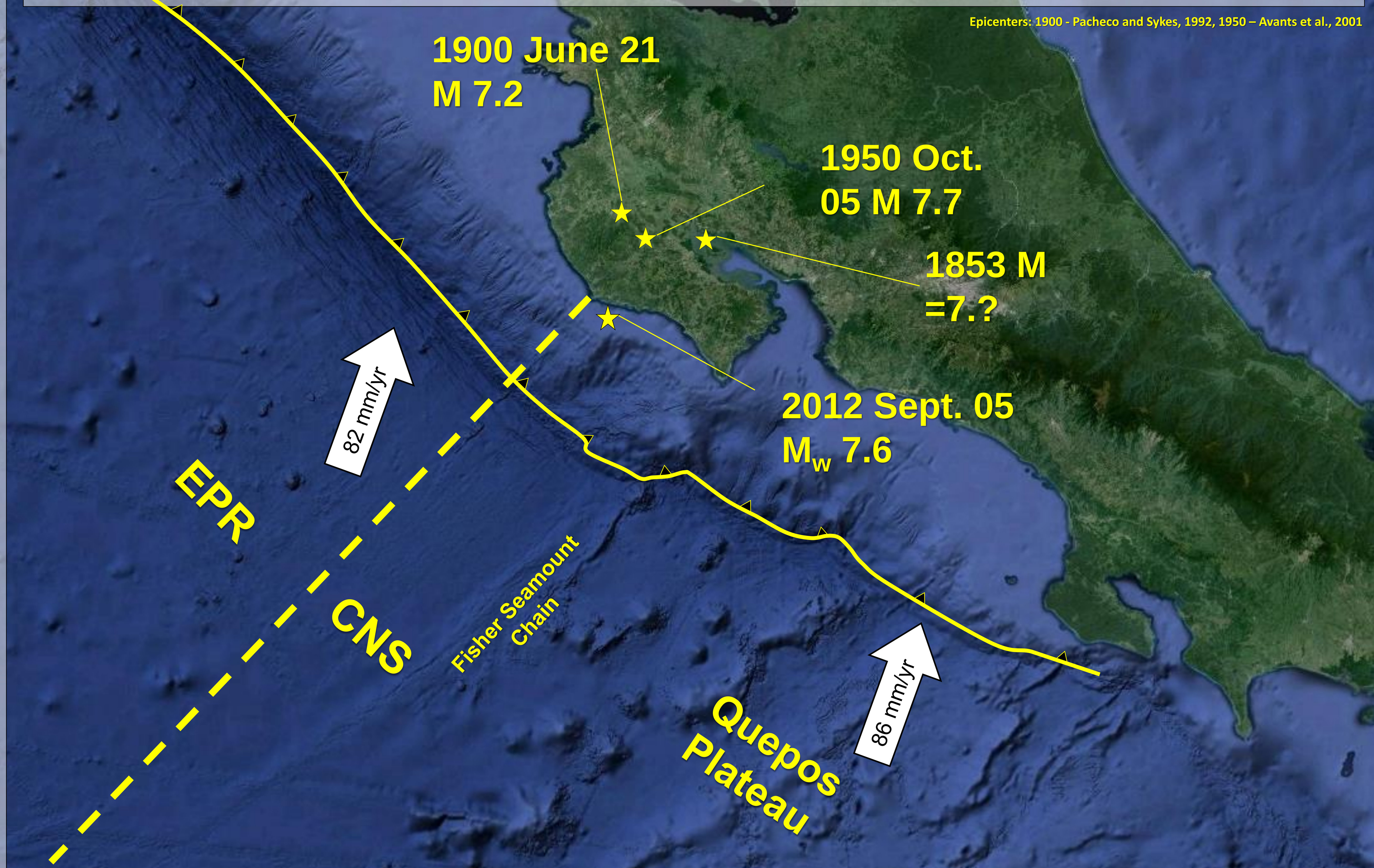


Figure 8: Since 2007 almost annual **slow slip events** have occurred in the region. These events vary in size and slip amount, as well as in location – occurring either updip or downdip of the main seismogenic zone. The most recent of which started in the updip region in May 2012, and continued up until the 2012 earthquake [*Dixon et al.*, 2015]. The most recent models (as well as the afterslip model in Figure 7), use Slab 1.0, which was derived from regional seismic lines and teleseismic earthquake activity.

SSE bound the major coseismic and locked region.



Epicenters: 1900 - Pacheco and Sykes, 1992, 1950 – Avants et al., 2001

FINITE ELEMENT MESH

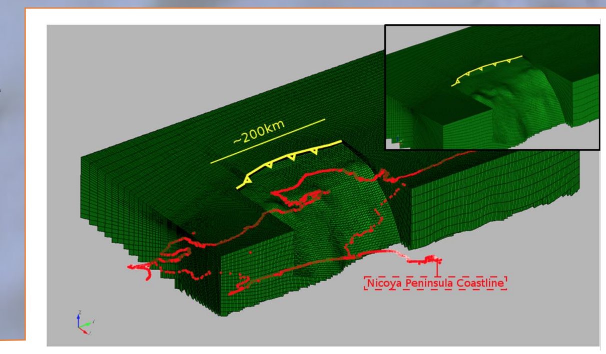
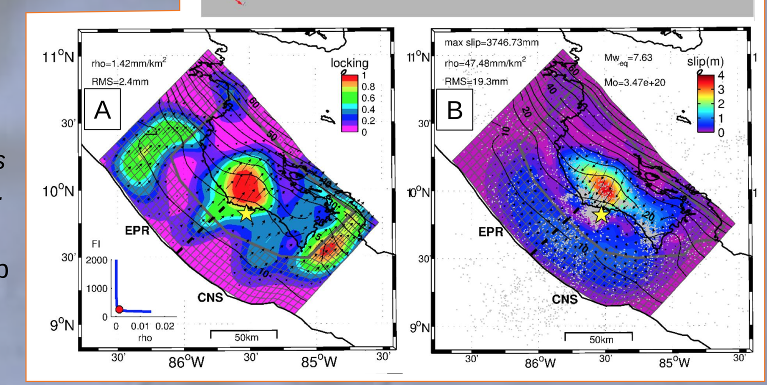


Figure 9: Using the seismically defined interface of *Kyriakopoulos et al.* [2015] (Figure 4), we've developed a Finite Element Model defining the regional environment.

With this model, we've been working to develop locking and slip models for all the behavior shown at the left.



Using the same interseismic and coseismic data we've constrained new models for interseismic and coseismic behavior [*Kyriakopoulos and Newman, (in prep/submitted)*].

We're still working on developing similar models for both the afterslip and slow-slip events.

AN INTEGRATED VIEW

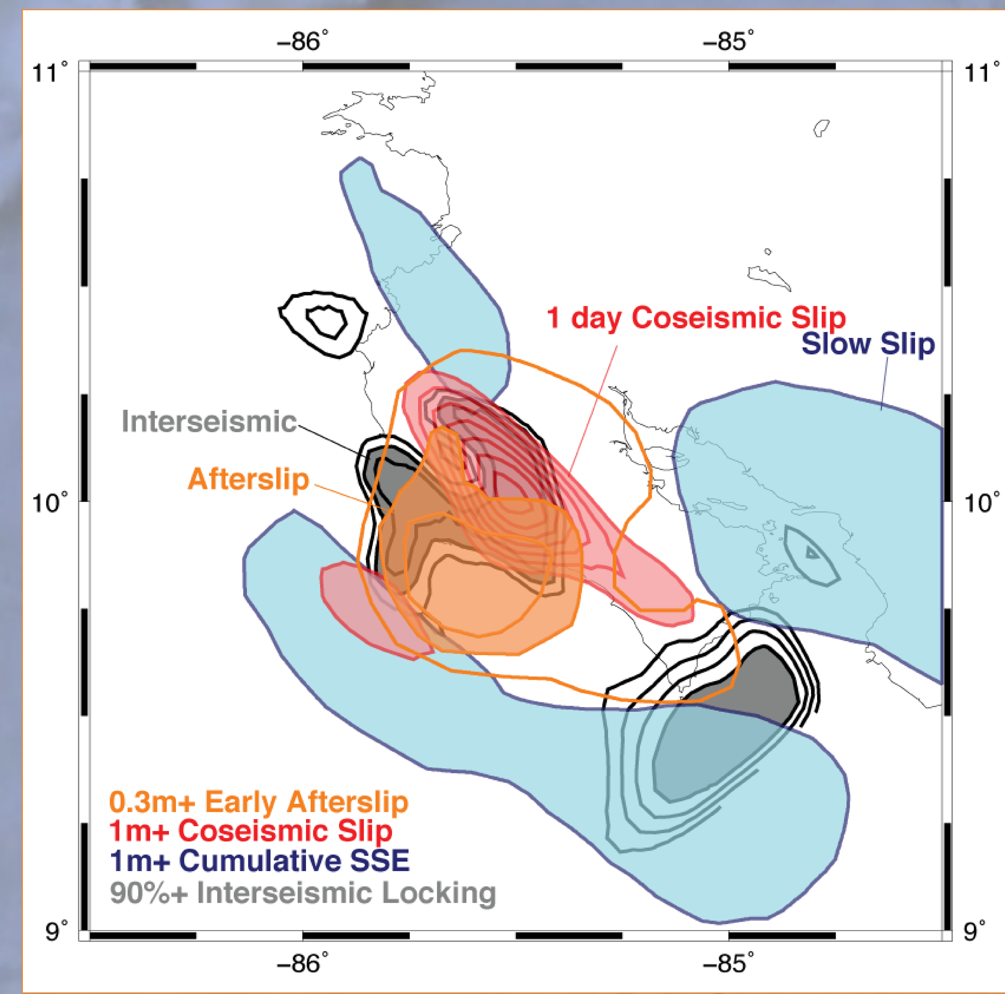


Figure 10: Combining the published models in a single plot, we highlight some of the preliminary differences between each component. Its easy to over-interpret these results at this point, but since models are based on different inversion techniques by different authors, and using different interface models, details are not well constrained. Instead, one should examine just the gross behavior.

Current findings:

- **Locking is largely exclusive of slow-slip.**
  - **This is expected, as locking is constrained over more than one decade.**
  - **Should one be successful at imaging sub-annual locking, they may constrain "inter-transient" locking that would include energy building for these events.**
- **Locking largely maps out region that earthquake related slip.**
  - **combination of coseismic and afterslip rupture along the interface.**
  - **Unslipped region south of peninsula, corresponds to Mw 6.4 EQ in 1990.**
  - **Most locking and slip agrees with seismically image high-stand (Figure 3).**

Figure 11: Conceptual model of the expected relationship between what we expect to find between geodetic moment accumulation and release. As well, continuous creep will occur in week or unlocked zones. As shown above, and as expect, coseismic rupture occurs in most-locked region, episodic slip will occur in areas that are temporally locked, occasionally observed as fractionally locked (e.g. 40%). Afterslip may occur in zones that are at the transitions.