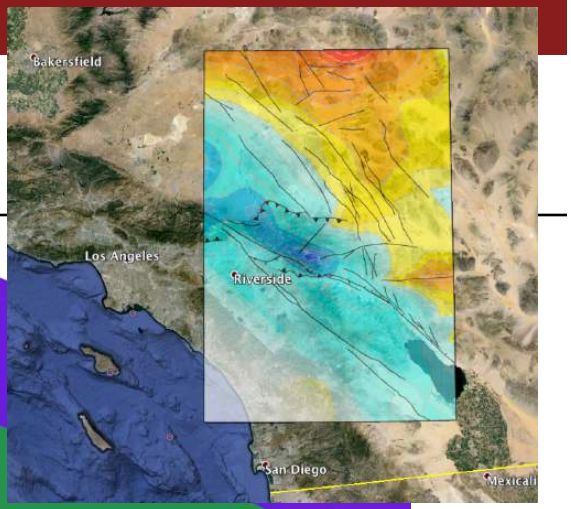
UMassAmherst

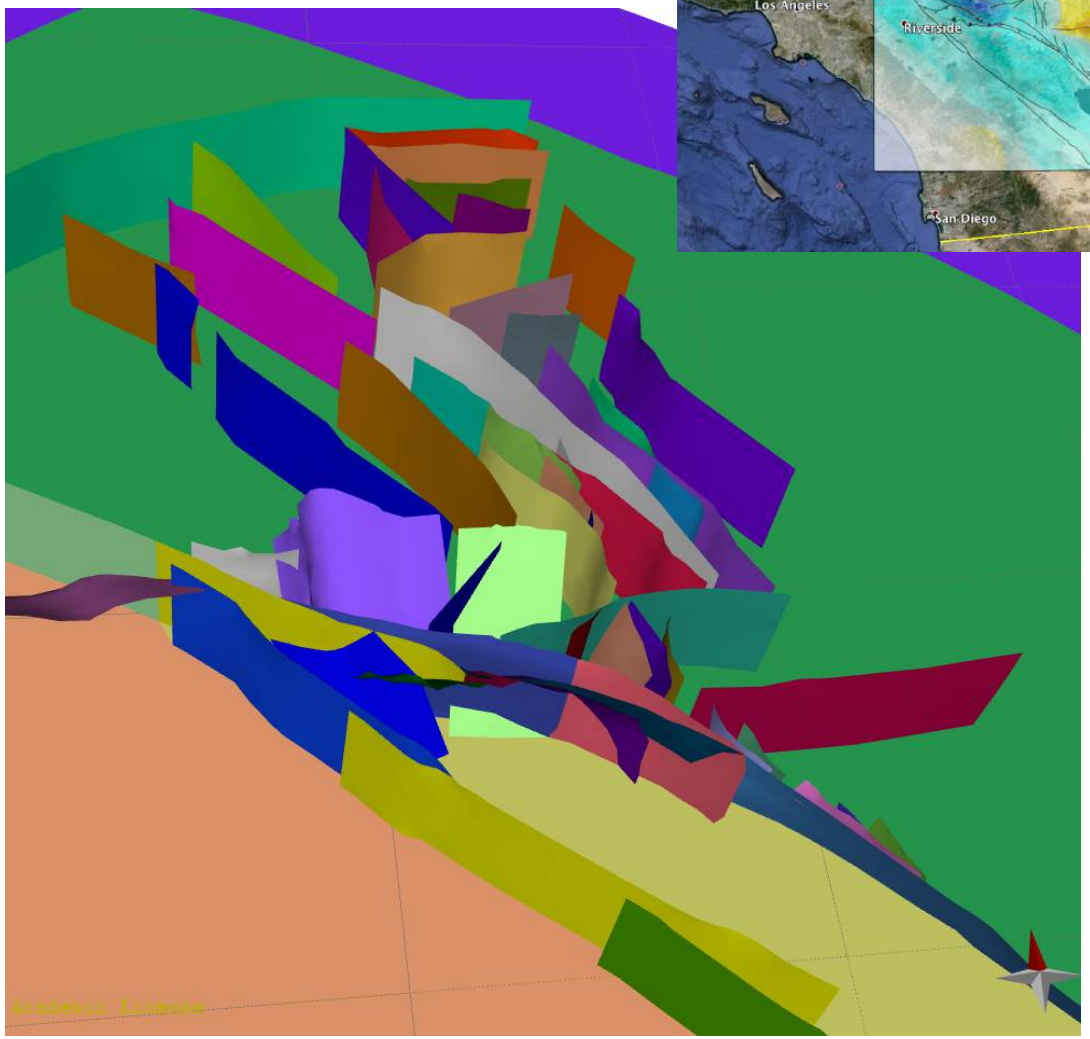
Influence of fault geometry on deformation partitioning within southern California

Michele Cooke

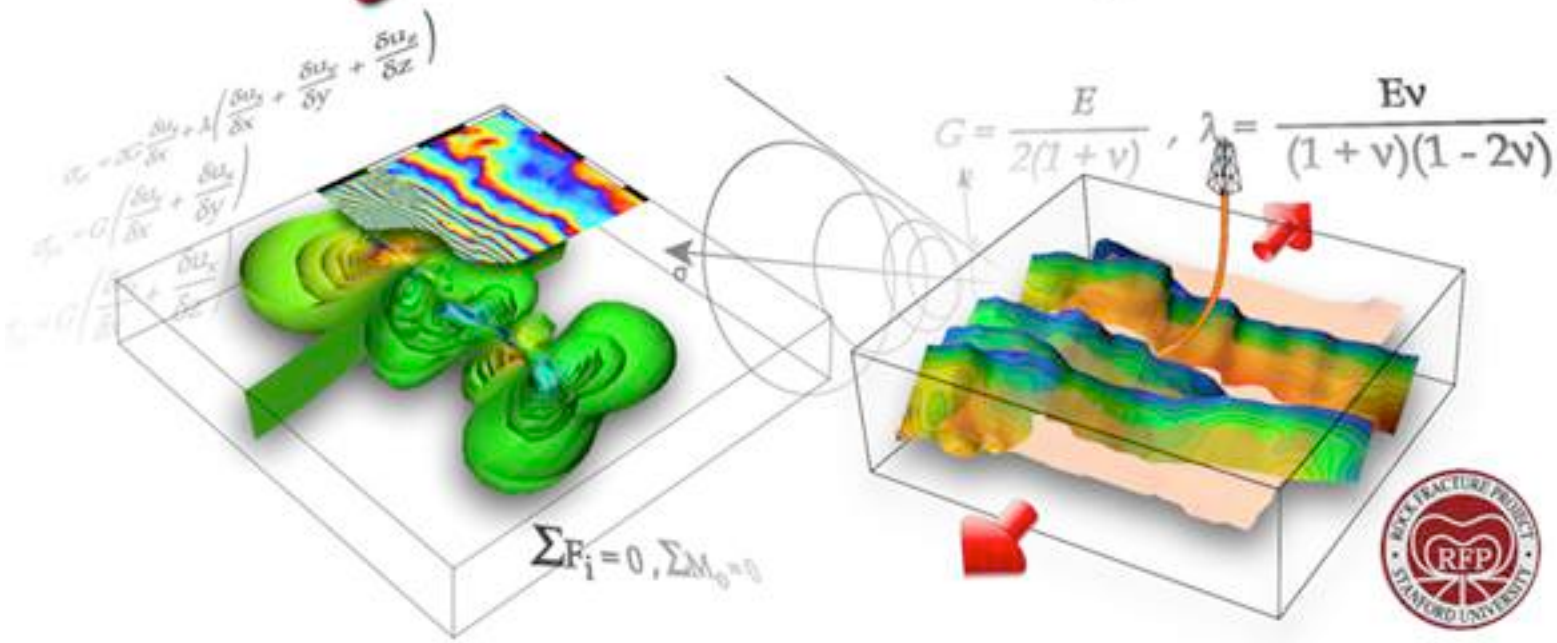
Often assumed

1. SAF vertical in Coachella valley
2. ECSZ faults essentially connected
3. SAF takes the simplest path through the San Gorgonio Pass
4. *(SAF and SJF connected at Cajon Pass)*





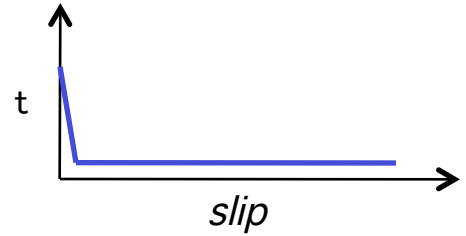
Poly3D and Poly3DGUI



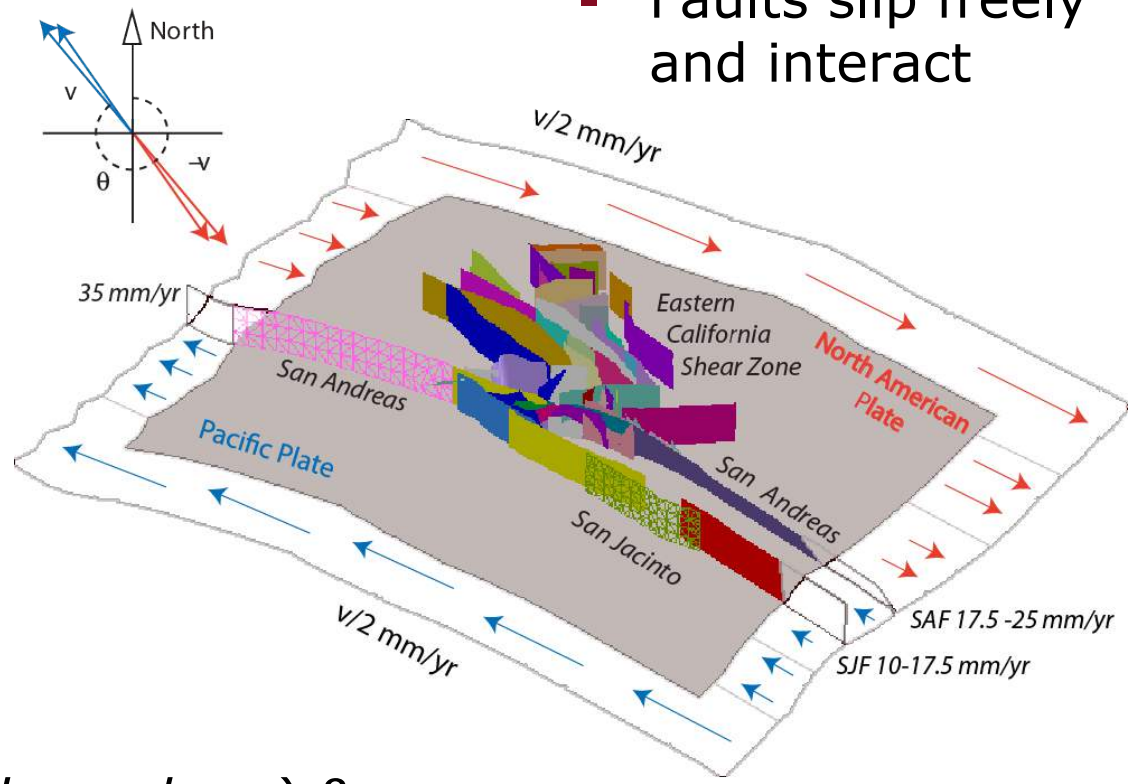
- Three-dimensional Boundary Element Method code
  - Discretize boundaries and faults into triangular displacement discontinuity elements
  - Solve for stresses/strains throughout the model

Model Set Up

- Plate velocities applied to the boundaries
- Frictionless faults simulate the low dynamic strength during slip accumulation

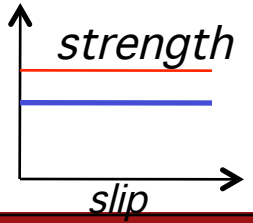


- Faults slip freely and interact

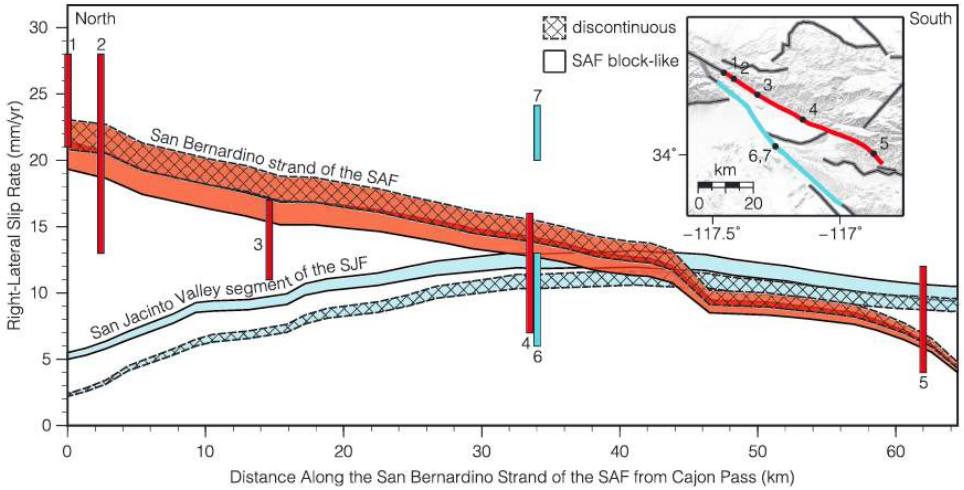


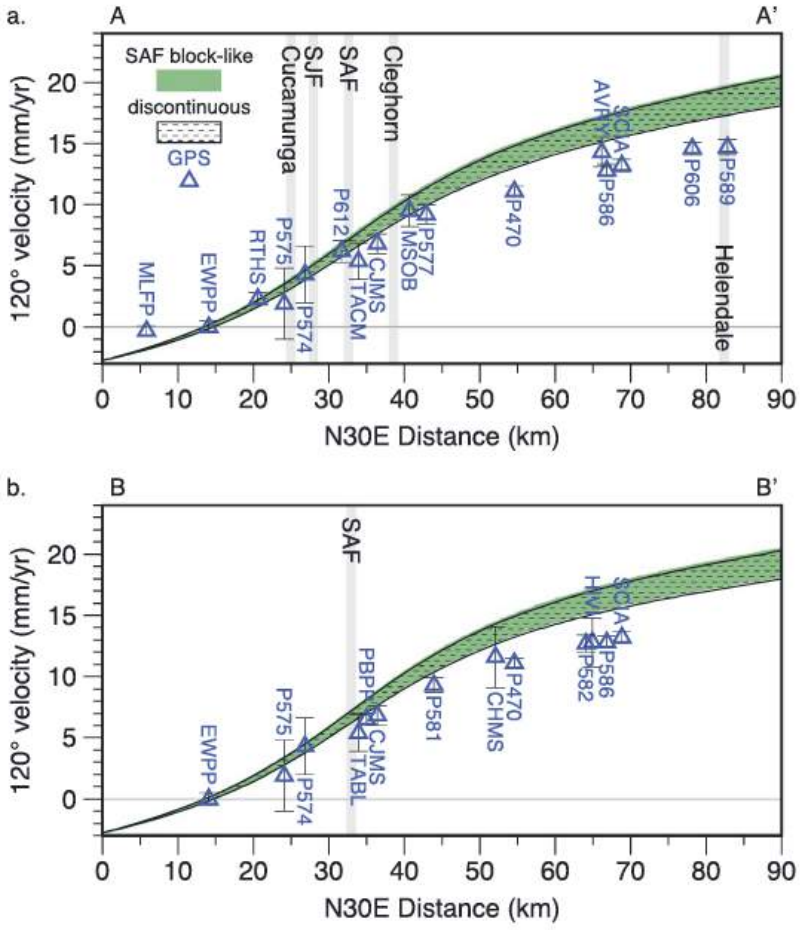
- Simulate geologic (*shown here*) & interseismic deformation (*back slip approach e.g. Marshall et al., 2009*)

Faults not in model



Example: Connectivity of San Jacinto and San Andreas





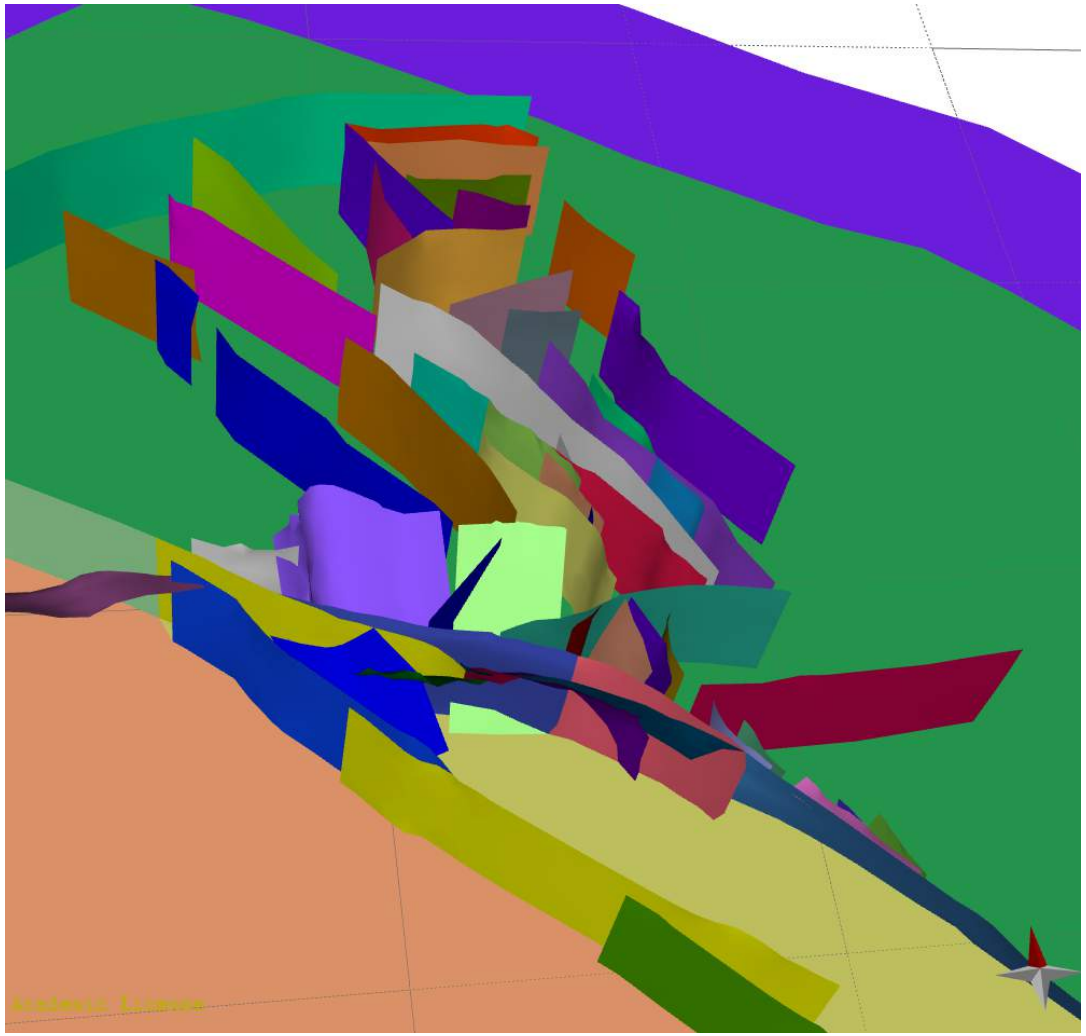
- Connection changes slip rates on both faults but these slip rates do not impact interseismic surface velocities
- Incorrect fault geometry and incorrect slip rate can still match GPS data.

(Herbert, Cooke and Marshall, JGR 2014)

Effects of fault geometry

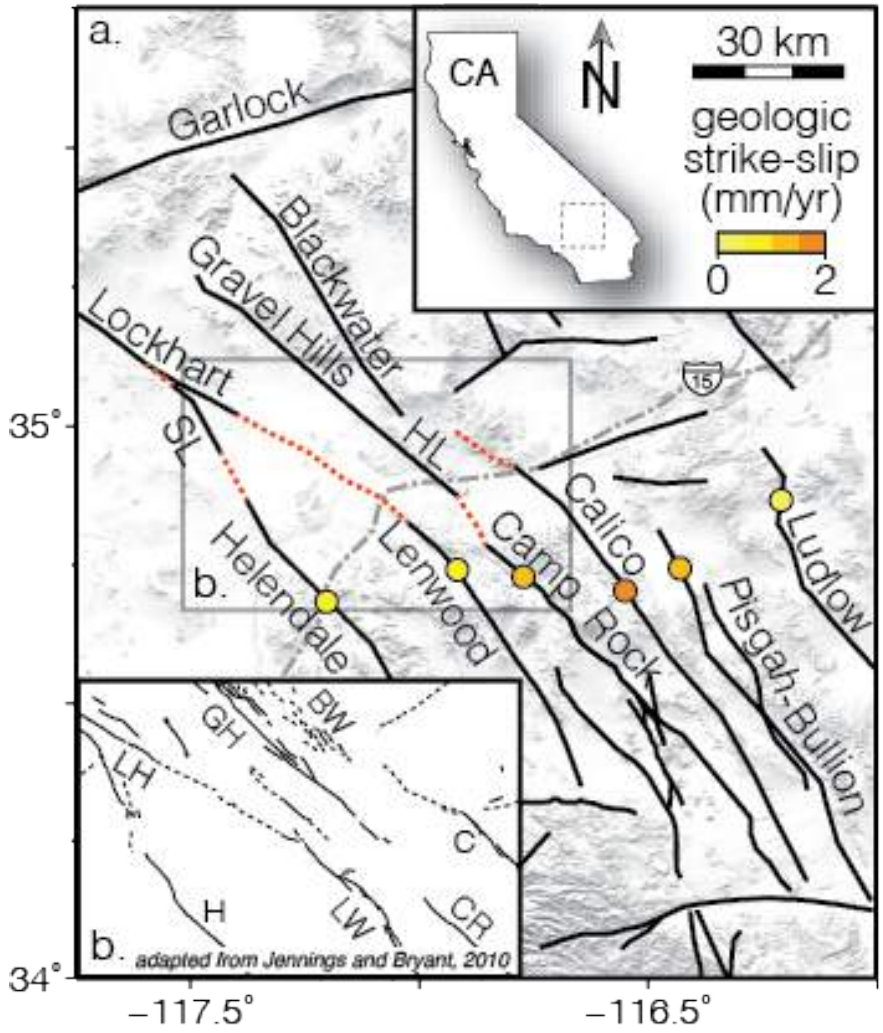
1. Disconnected ECSZ
2. Dipping Coachella segment
3. SAF through the San Gorgonio Pass

- Absolute stress conundrum

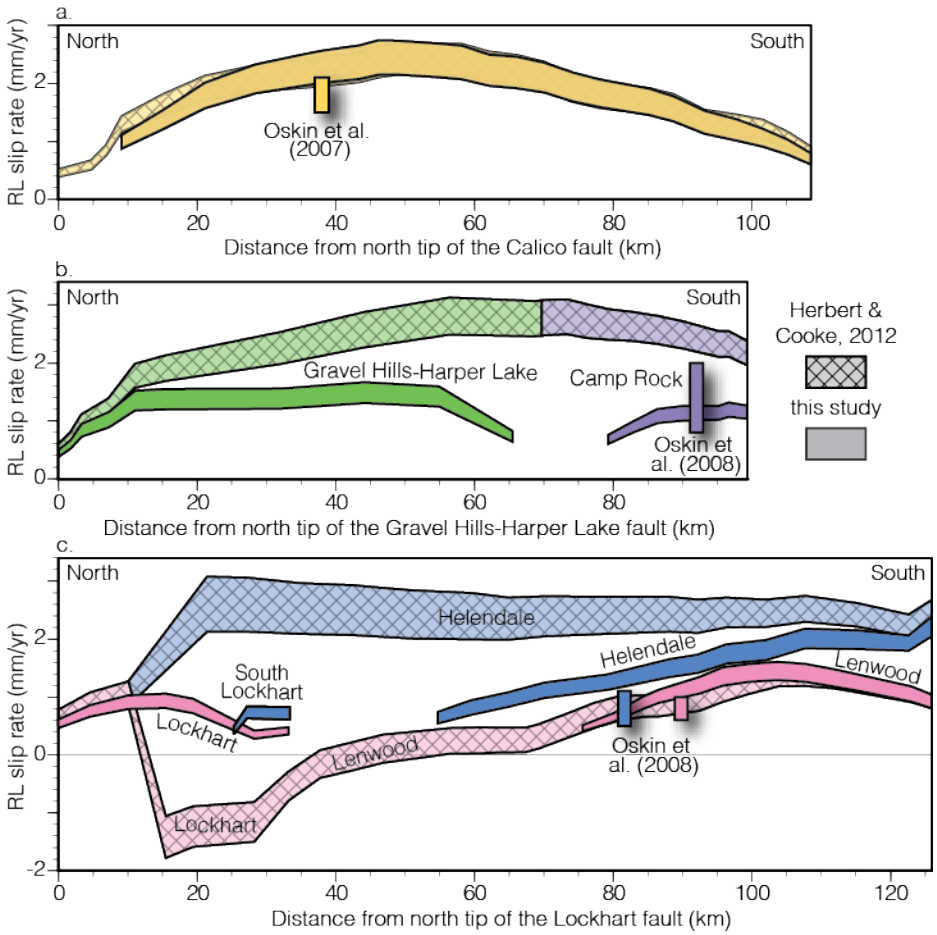


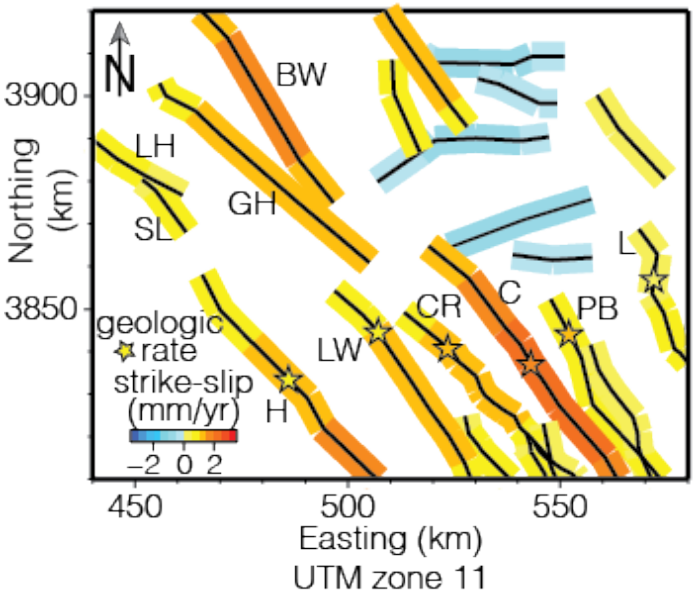
Eastern California Shear Zone strike-slip rates

- Connection of the faults across the Eastern California Shear Zone doesn't match active fault maps



Slip rates in the Eastern California Shear Zone



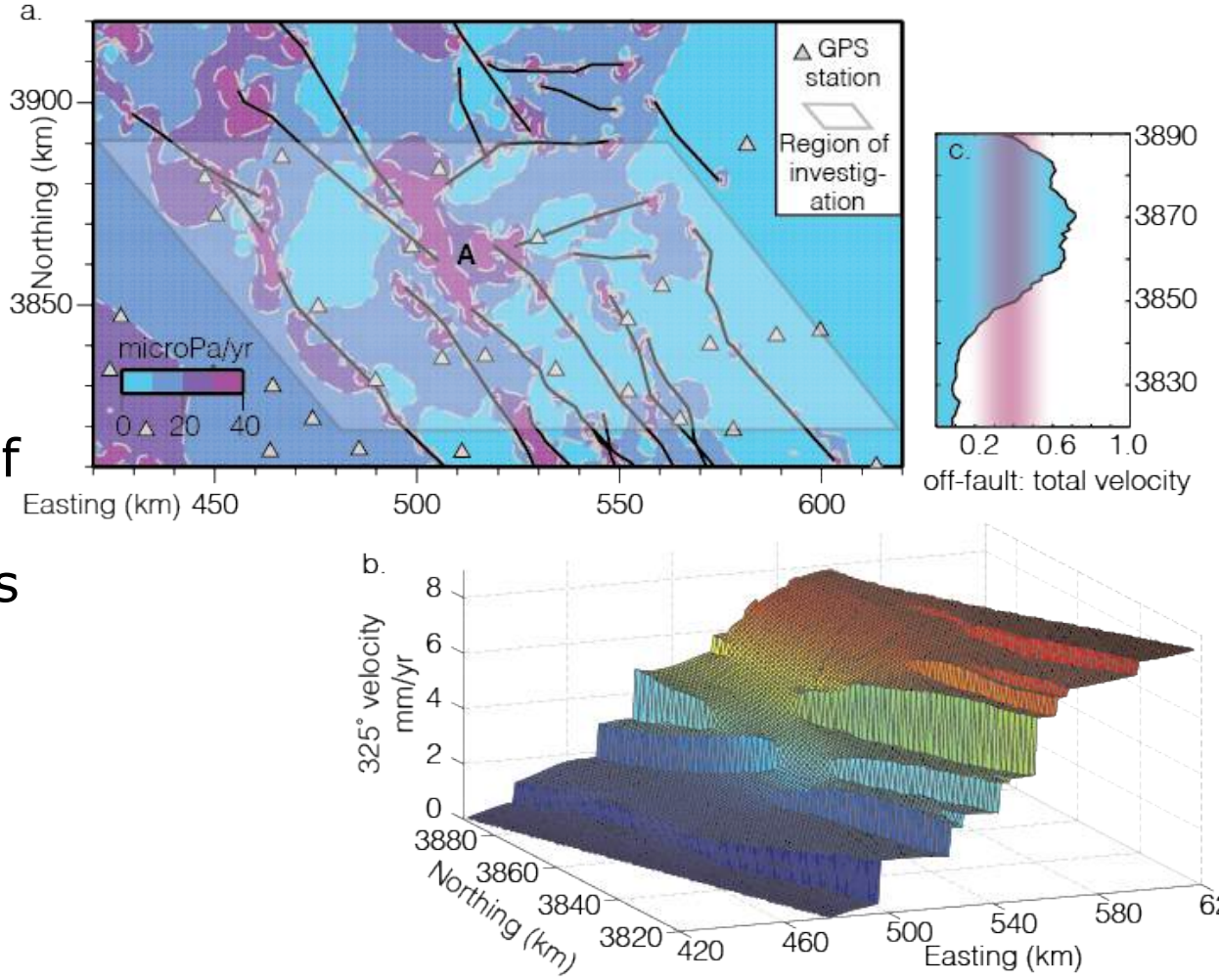


Disconnected faults produce better match to fault slip rates

Herbert, Cooke, Oskin and Difo, 2013

Off-fault deformation

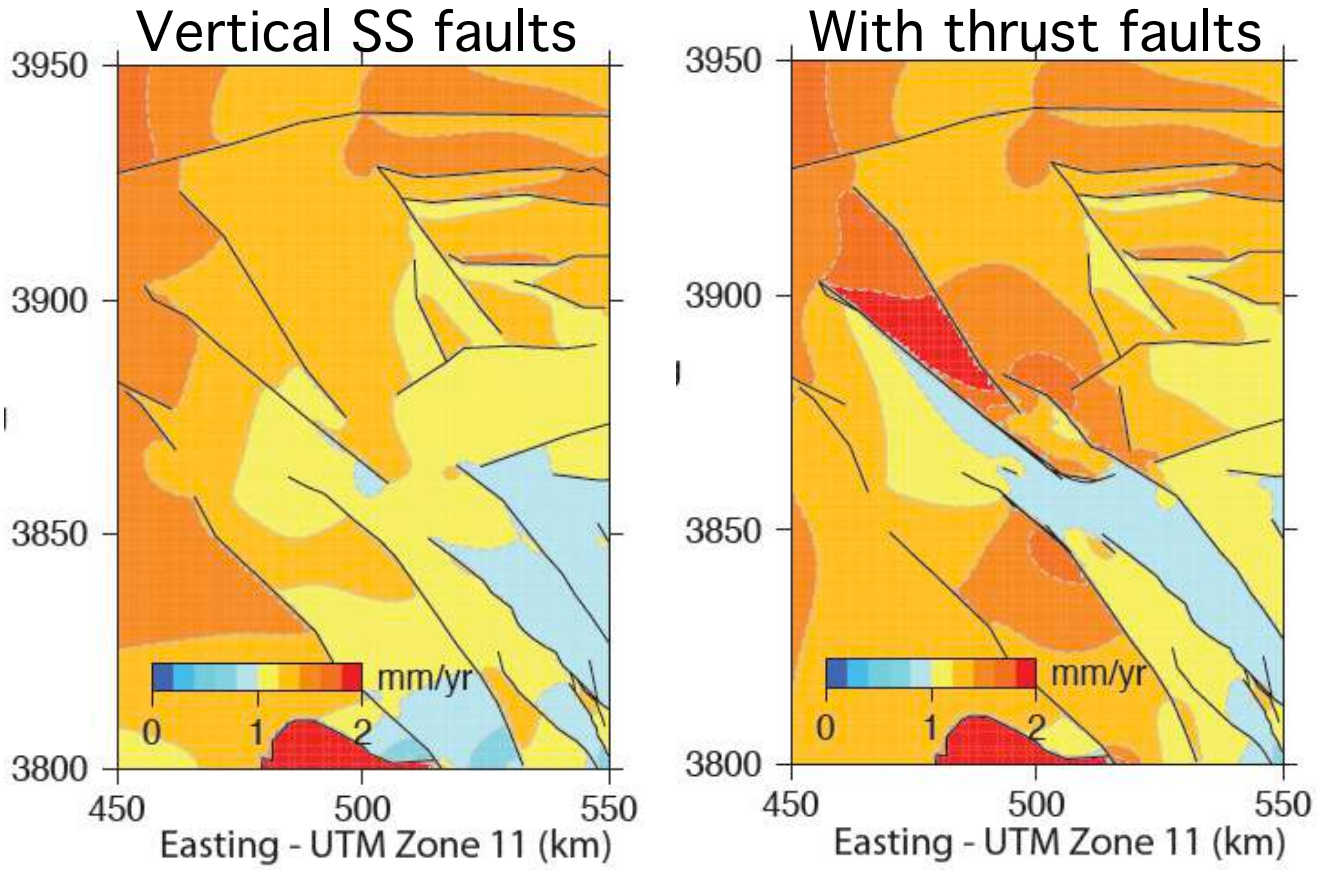
- Significant strain energy density within the central Mojave
- Off fault deformation accounts for 40% of the total displacement across the ECSZ.
- *Bird (2009) & Johnson* (2013): 28-33% off-fault deformation in southern California



Herbert, Cooke, Oskin and Difo, 2013

Uplift Patterns in the central Mojave

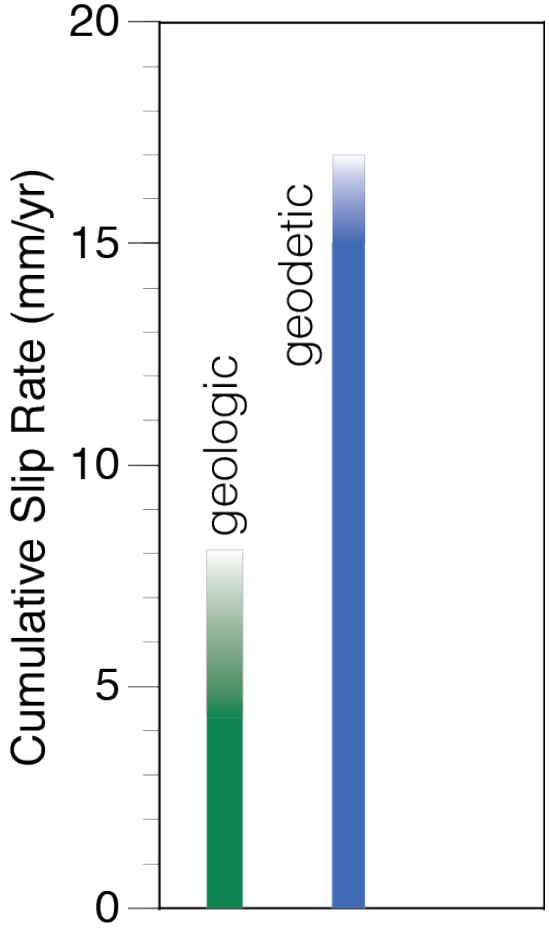
- Influence of adding thrust faults on the uplift pattern



Off-fault deformation only drops from 40% to 37%

Contribution to slip rate discrepancies

- Geologic strike-slip rates across the ECSZ are 4 to 8 mm/yr (*Oskin et al., 2007; 2008*)
- Geodetic rates of deformation: 15-17 mm/yr (*Meade & Hager, 2005; Spinler et al., 2010; Loveless & Meade,2011*)



Contribution to slip rate discrepancies

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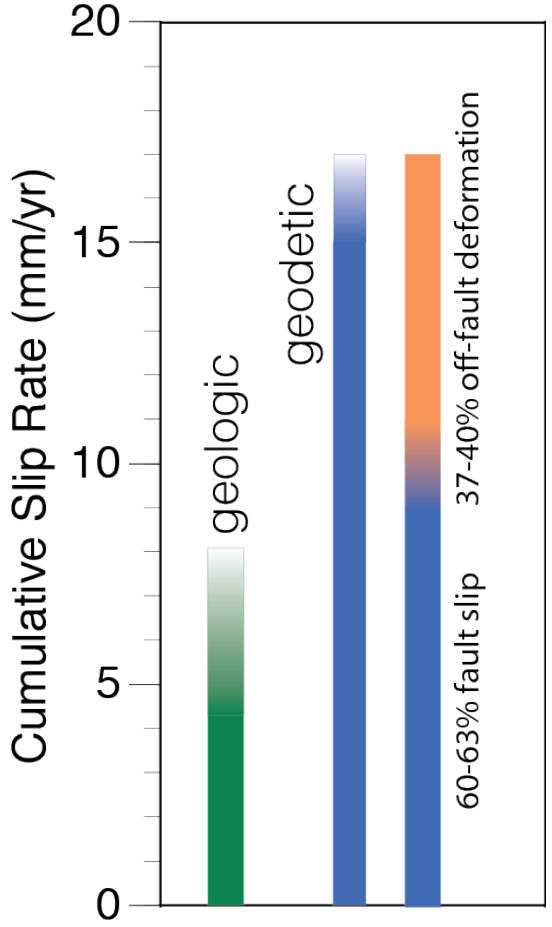
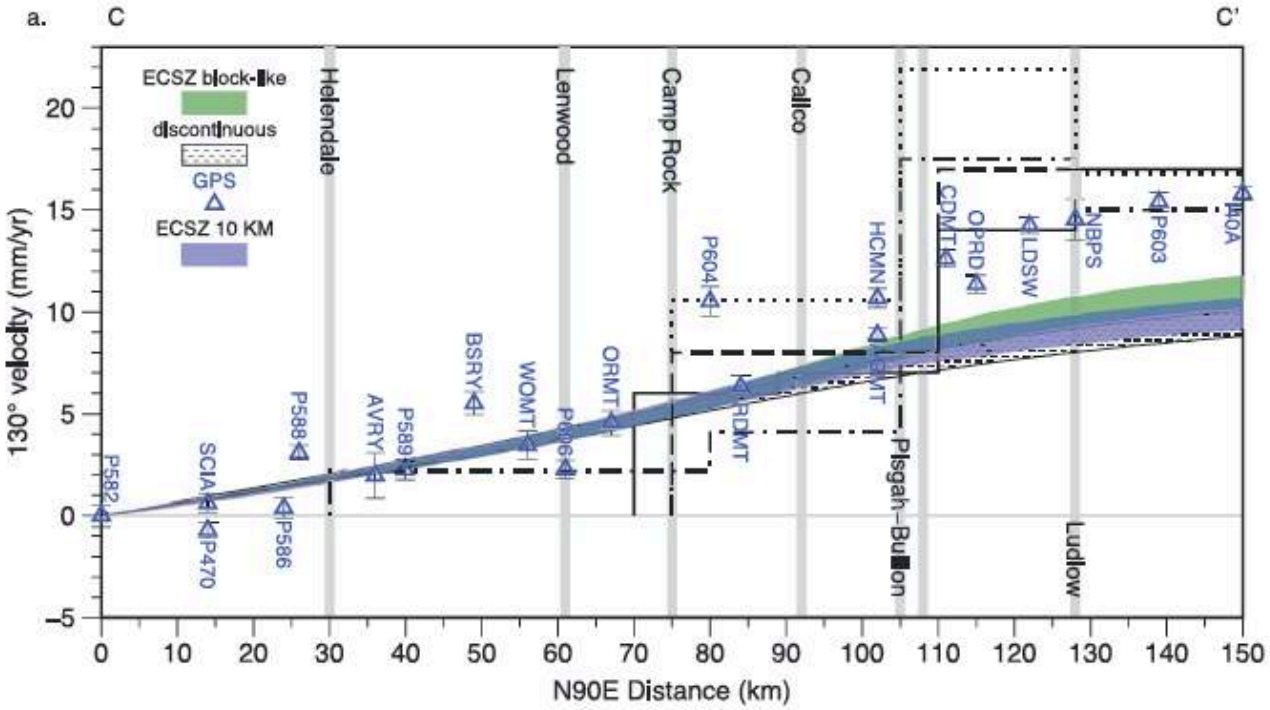
- Geodetic rates of deformation: 15-17 mm/yr (*Meade & Hager, 2005; Spinler et al., 2010; Loveless & Meade,2011*)
- Forward model slip rates 6-8 mm/yr *(Herbert et al*, 2013)
- Off-fault deformation could account for part of the discrepancy.

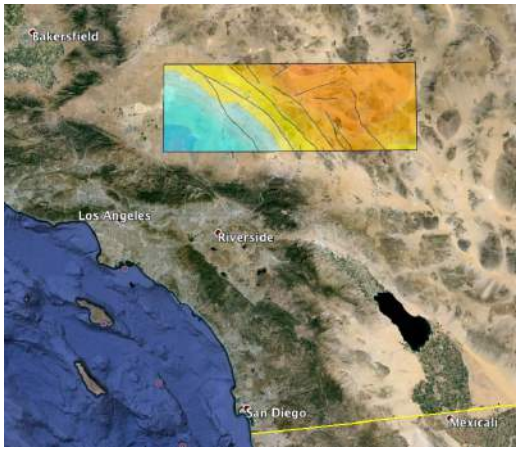


GPS evidence

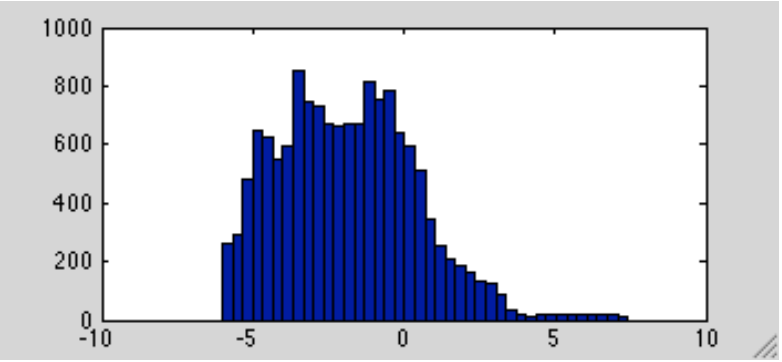


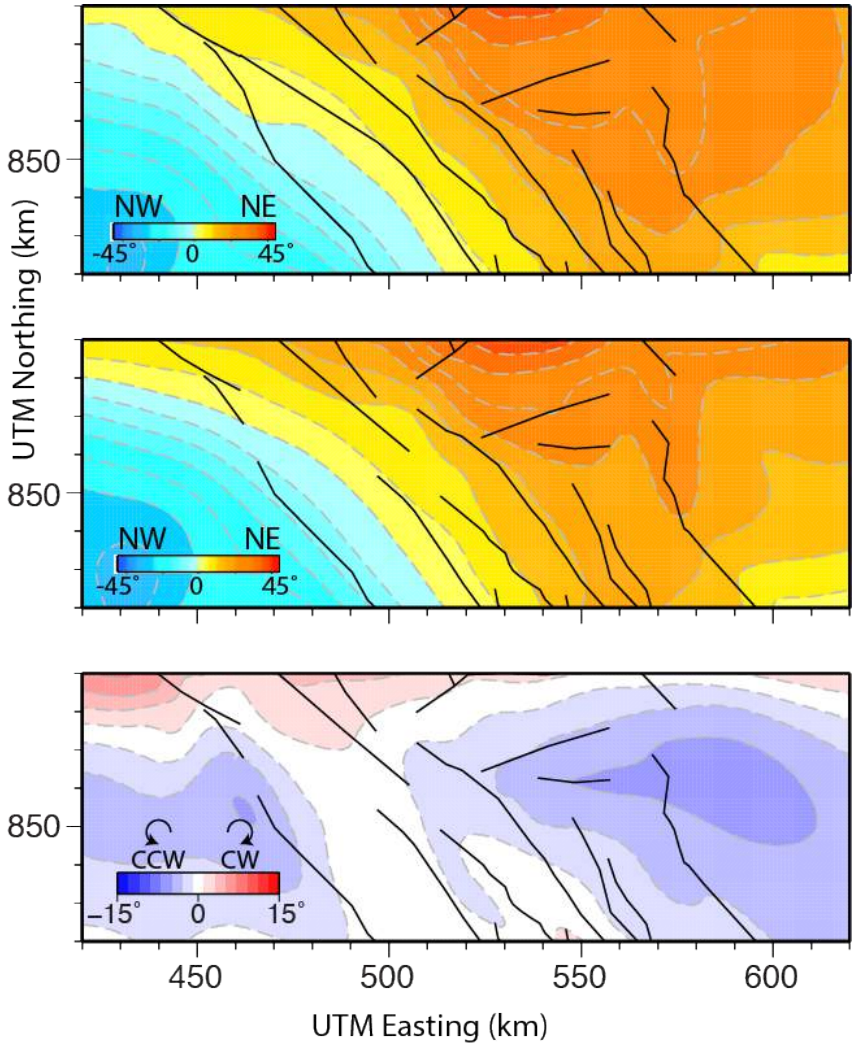
- More complex than that...

Effect on SHmax

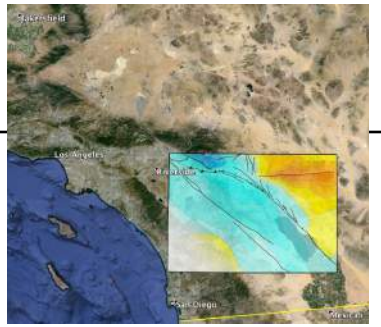


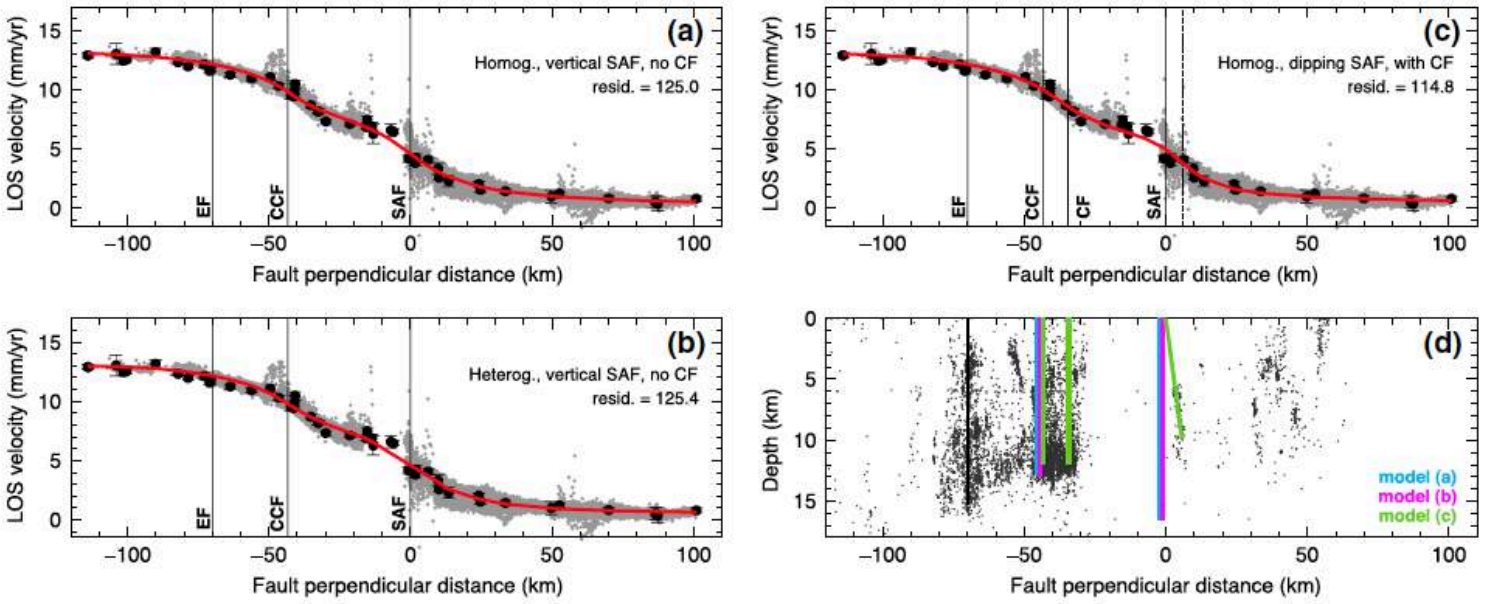
- Up to 5° CCW shift in orientation of SHmax





Dip of the SAF in Coachella Valley





Lindsey and Fialko, 2013

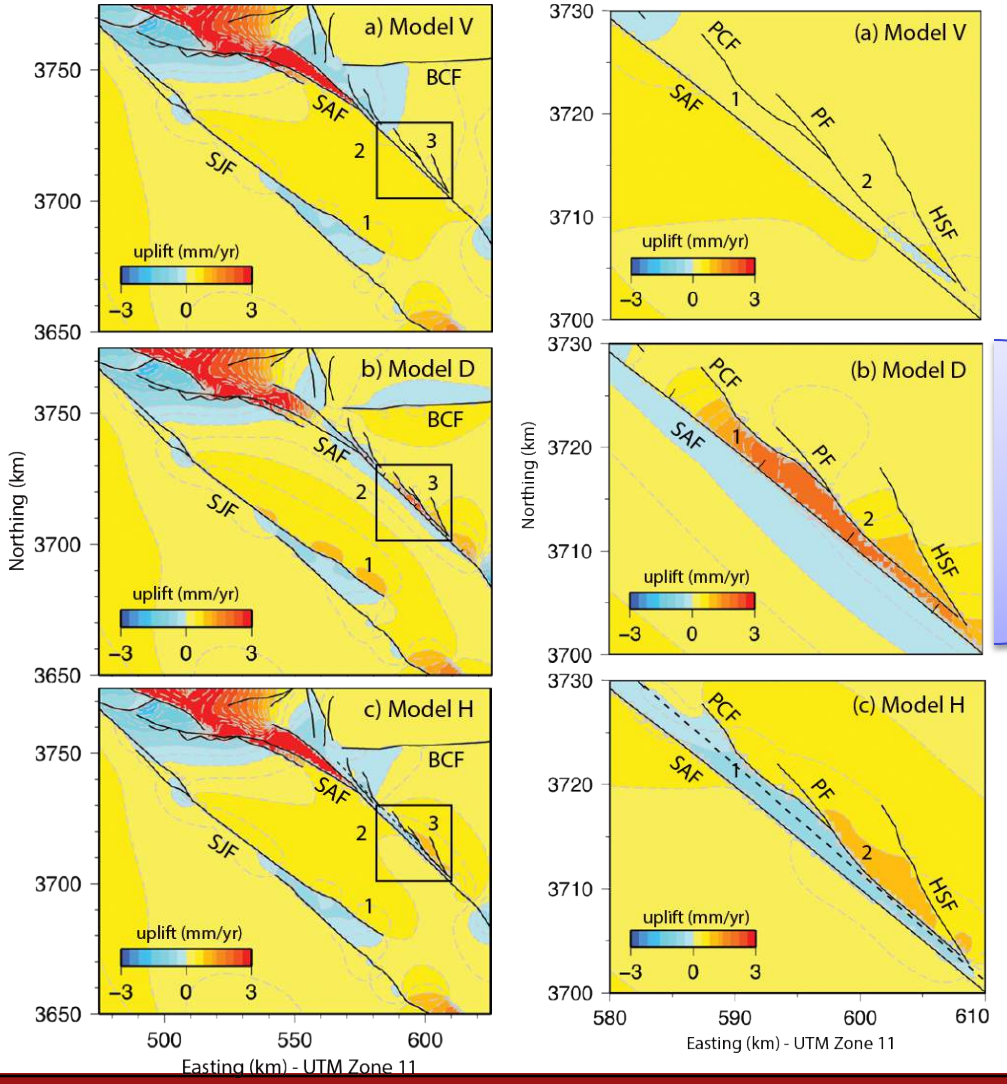
- Seismicity and geodetic inversion suggest active SAF dips to NE *(Lin, Shearer & Hauksson,* 2007*; Lindsey & Fialko*, 2013; *Lin*, 2013)
- Magnetic and gravity suggest NE dip (*Fuis et al.*, 2012)

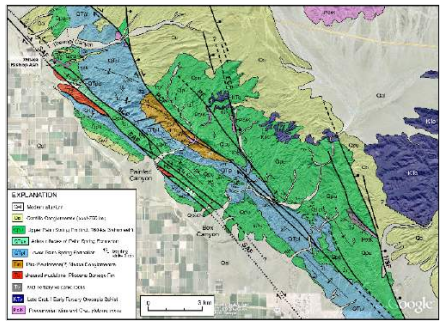
Dip of the SAF in Coachella Valley

Vertical SAF

Dipping SAF

Vertical and Dipping SAFs



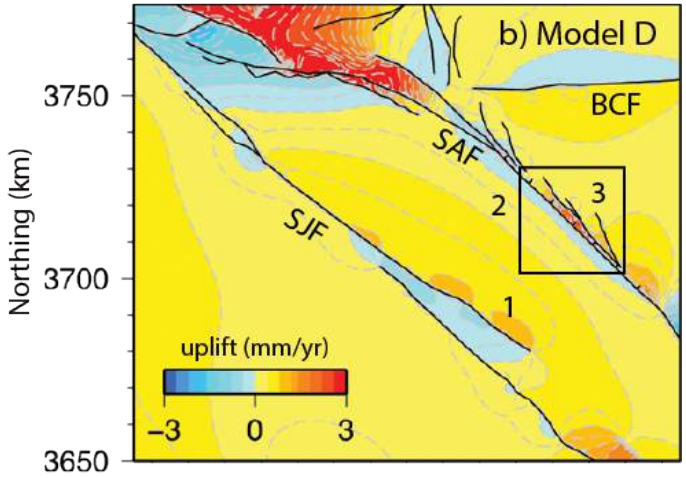


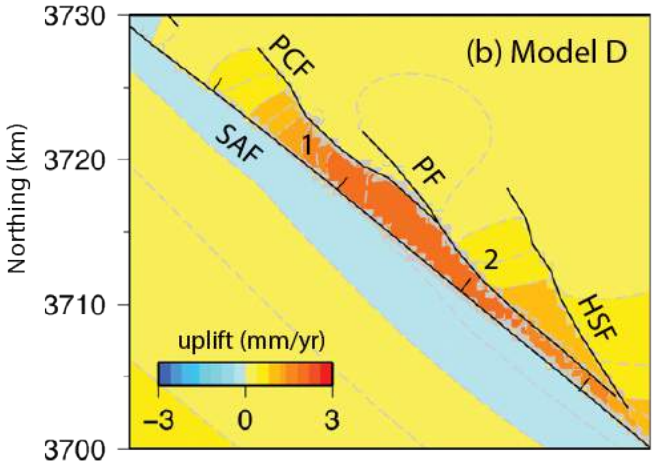
Dipping Coachella segment matches east tilt of the Coachella Valley *(Dorsey & Langenheim*, in prep)

•Uplift between SAF and Painted Canyon Fault

(Fattaruso, Cooke & Dorsey, in press Geosphere)

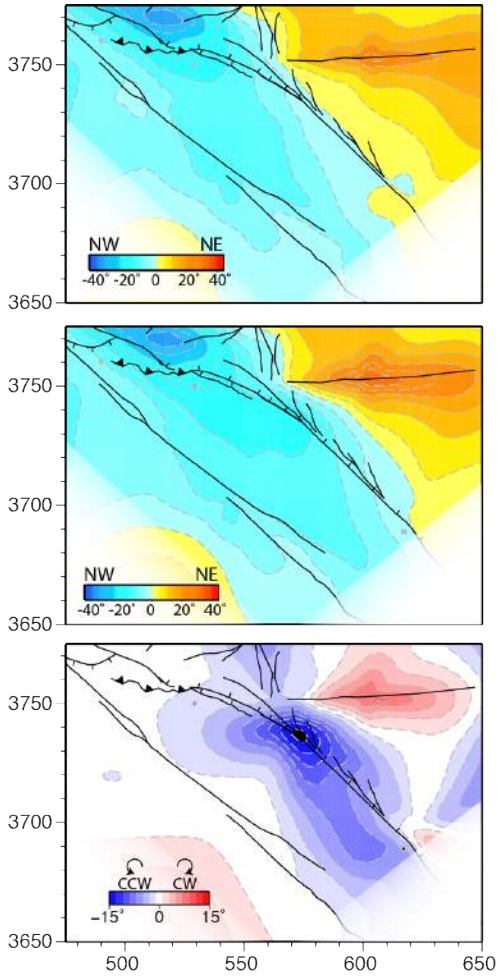
So what?





- Accommodates similar rate of strike-slip
- Different fault surface area.
- Alters SHmax…

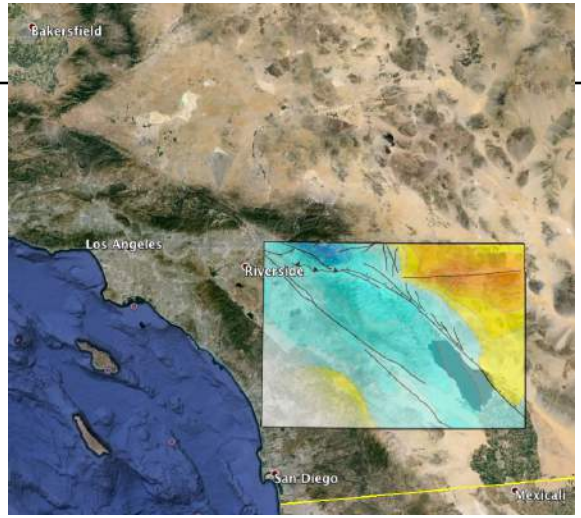
Effect on SHmax

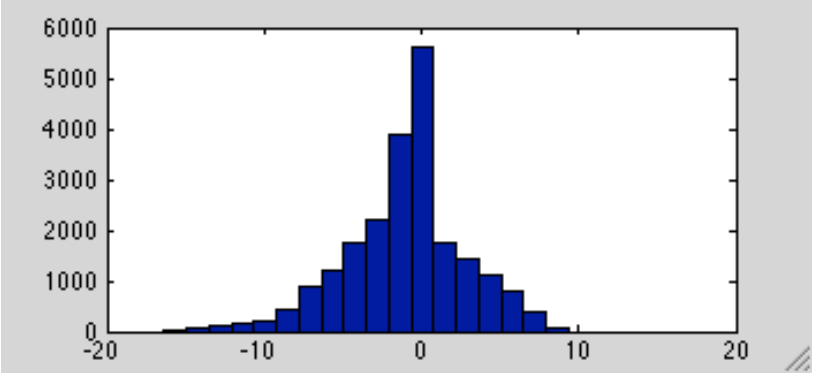


Vertical SAF

NE Dipping SAF

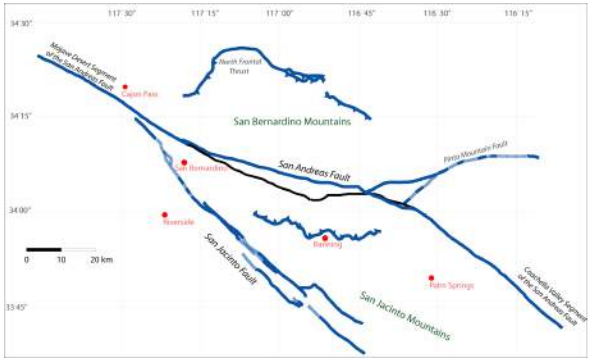
Difference
dipping-vertical

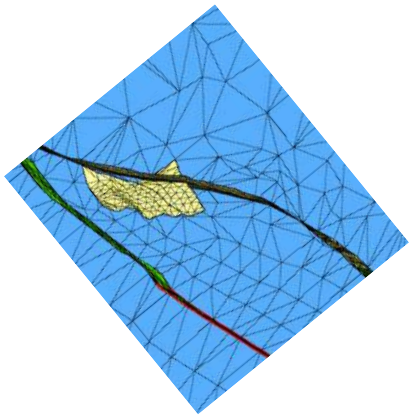


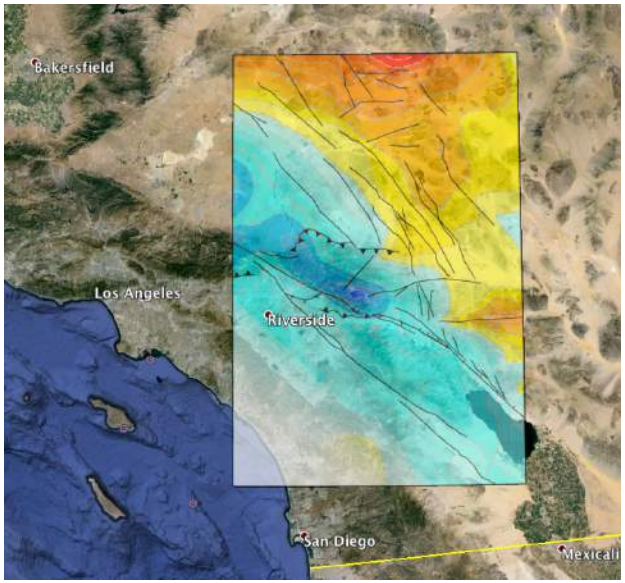


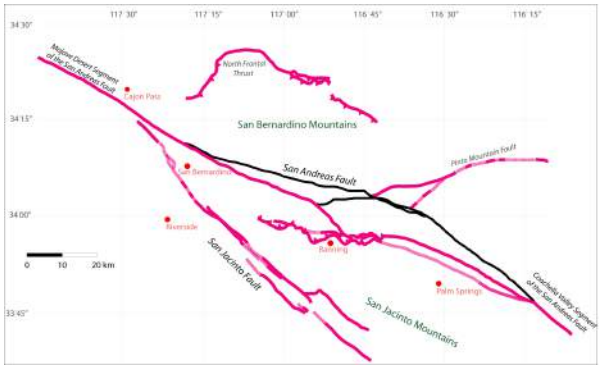
- Local CCW rotation of as much as 10°-15°

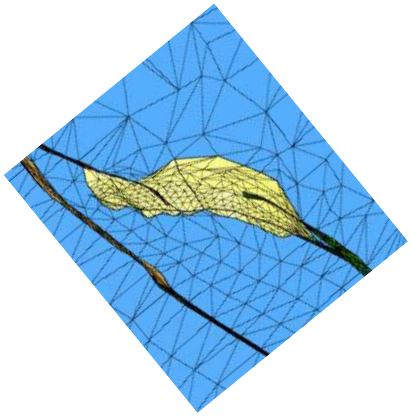
Active SAF through San Gorgonio Pass





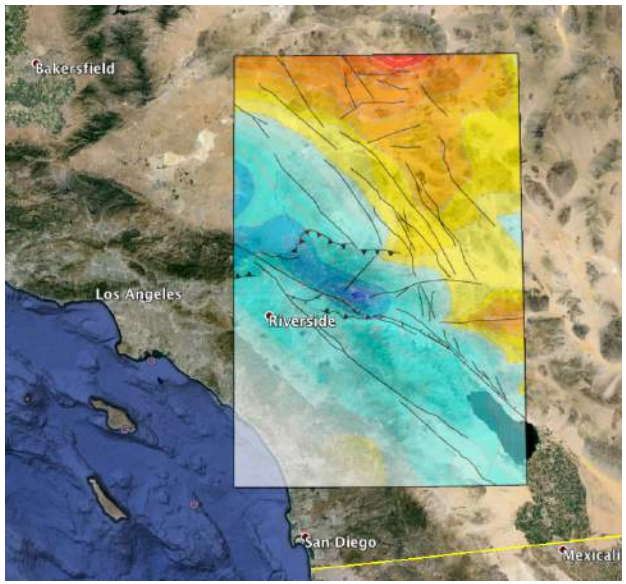


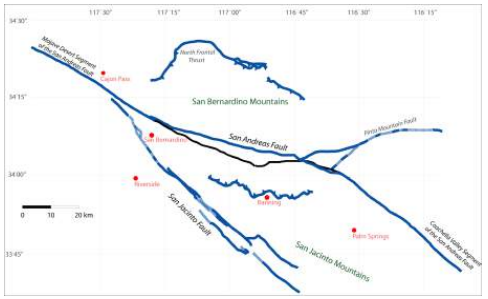


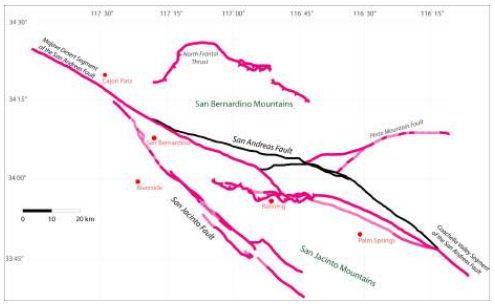


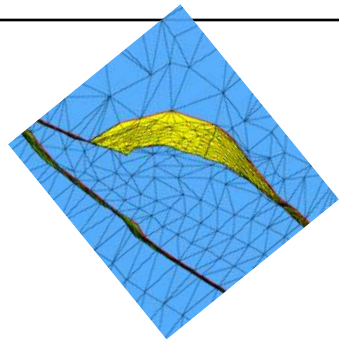
Modified from Mati et al, 1992

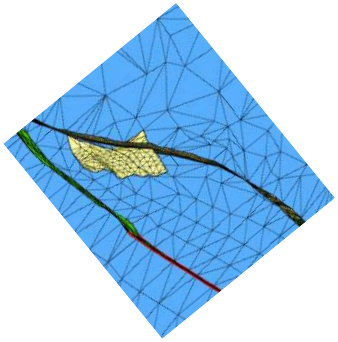
Active SAF through San Gorgonio Pass

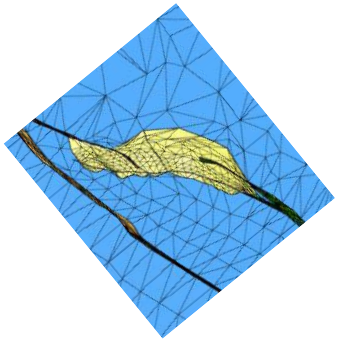








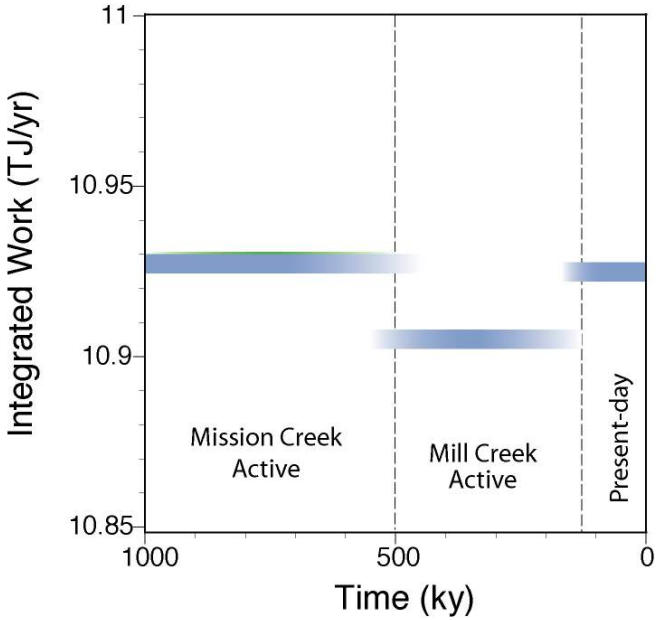




Modified from Mati et al, 1992

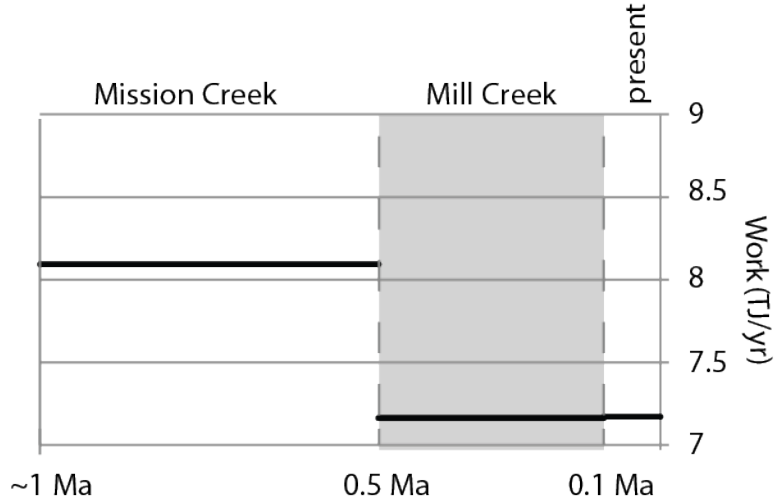
Refined geometry shows lesser 'work' conundrum

Vertical Banning and Coachella, no Crafton Hills



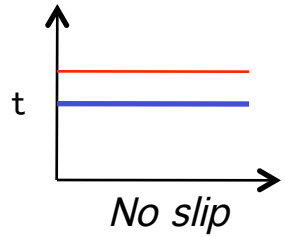
(Cooke & Dair, JGR 2011)

Dipping Banning and Coachella, crafton Hills

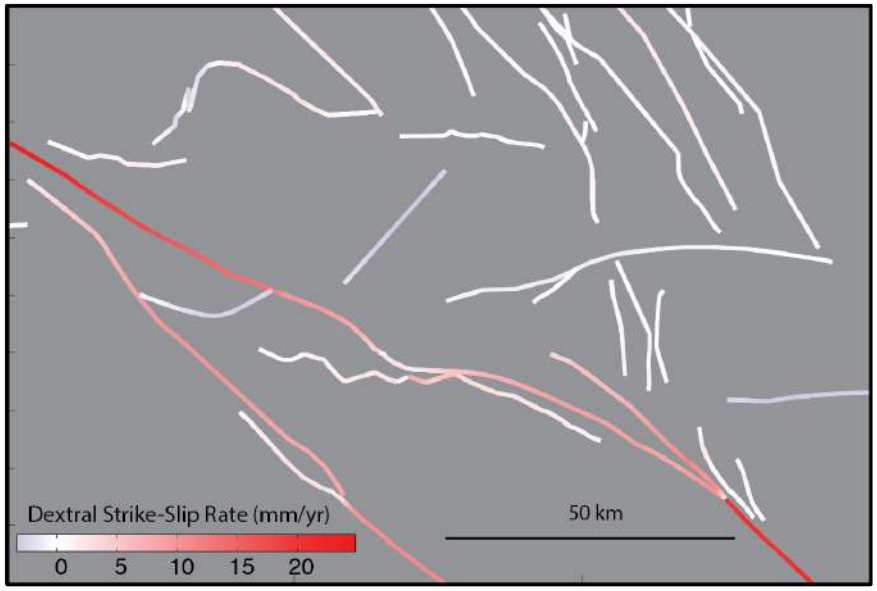


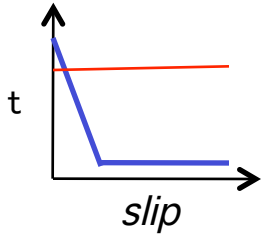
- The relative inefficiency of the present-day model is greatly reduced. (*Fattaruso and Cooke*, in prep)

Mill Creek and Garnet Hill/Banning both active?

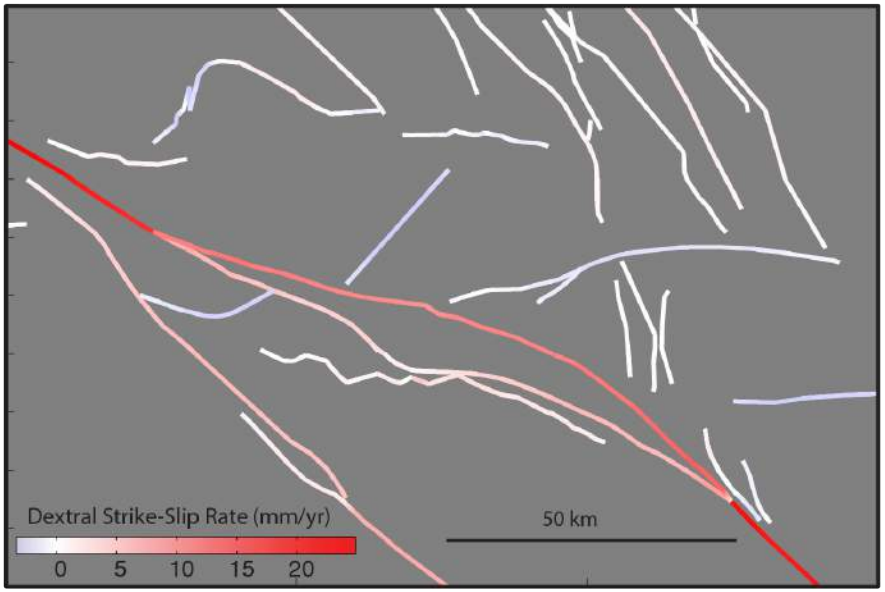


Mill Creek not active





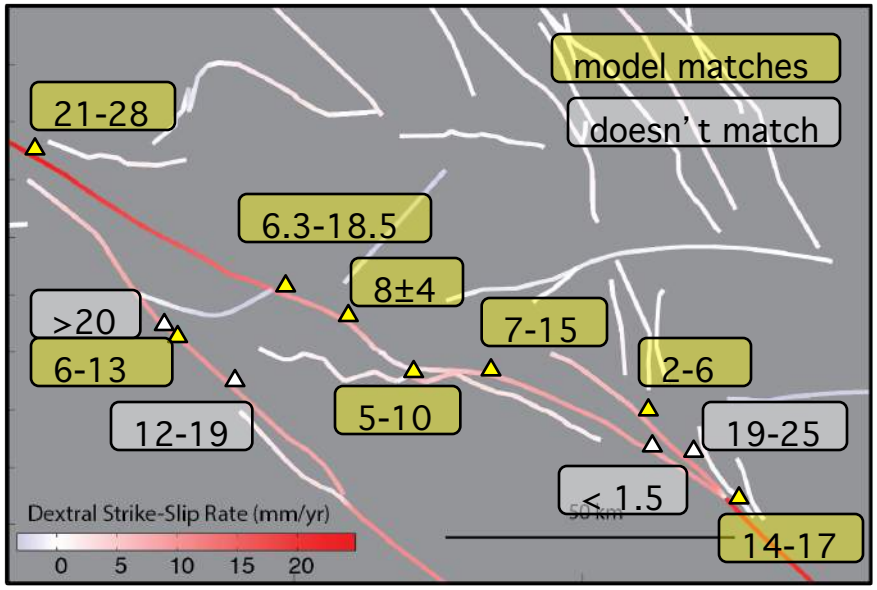
Mill Creek slips

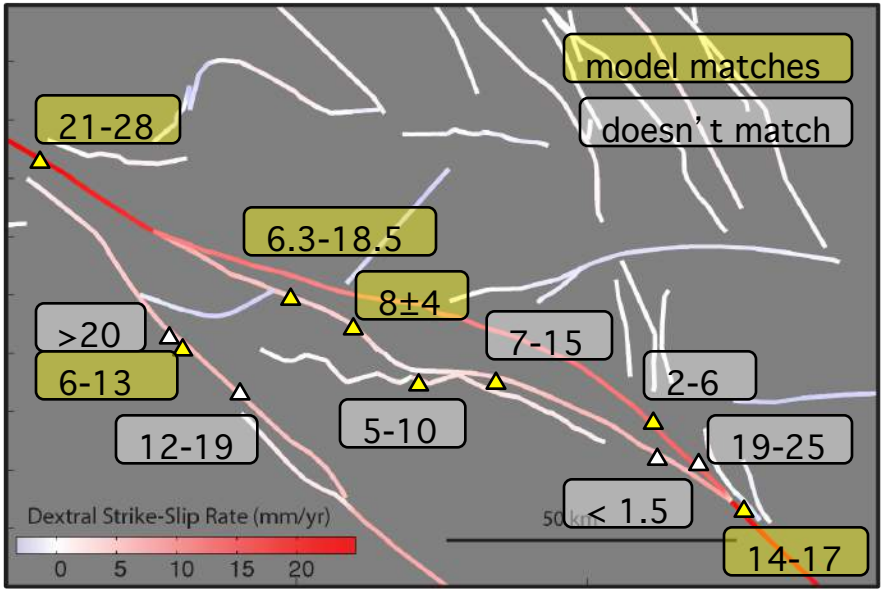


- Strike slip is transferred to the Mill Creek strand.
  - San Jacinto and Banning have slower strike-slip rates

Mill Creek and Garnet Hill/Banning both active?

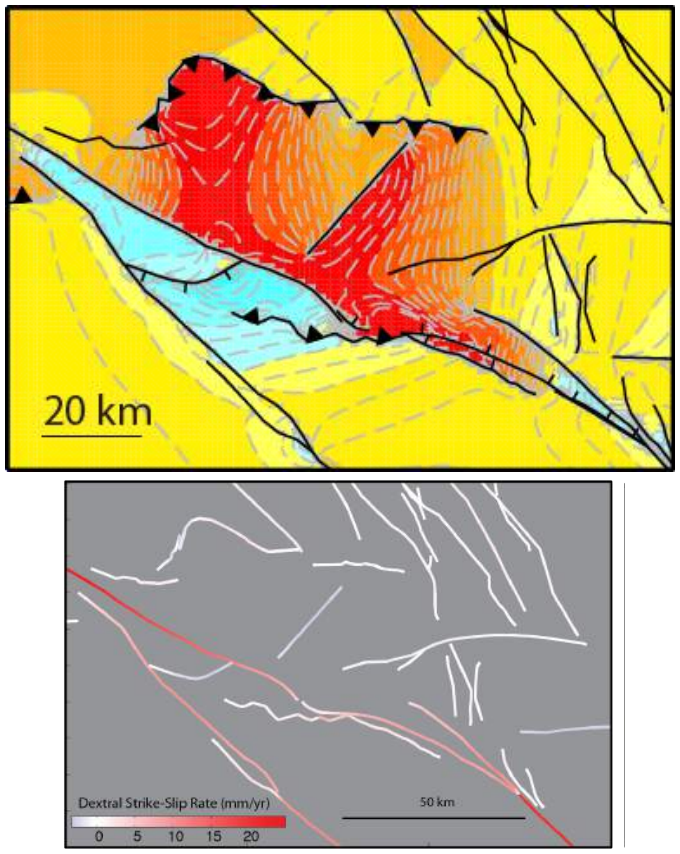
- Neither model matches all slip rates.
- With Mill Creek
  - San Jacinto is further from Kendrick and Onderdonk rates
  - Mission Creek and Banning are closer to Blisniuk and Scharer rates
  - San Gorgonio Thrust and Banning are farther from Yule and Behr rates

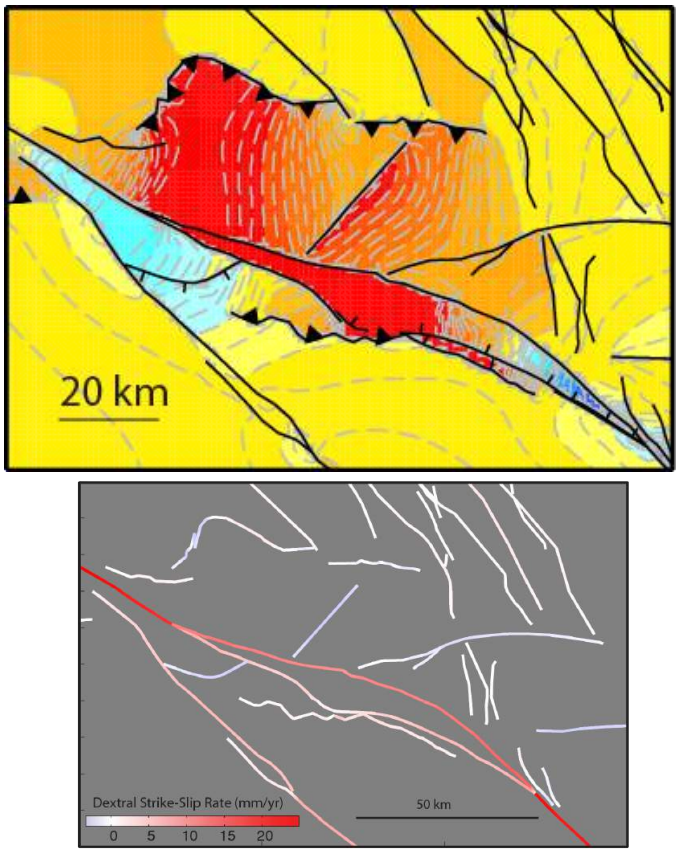




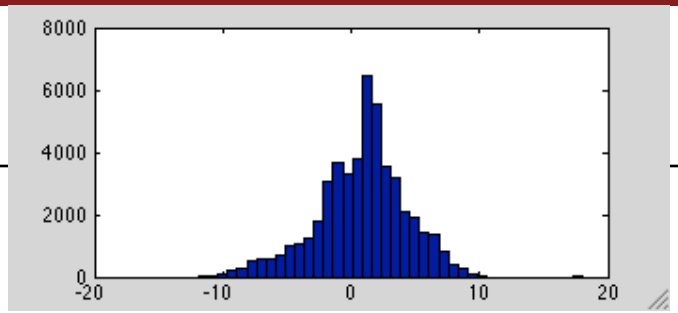
Mill Creek and Garnet Hill/Banning both active?

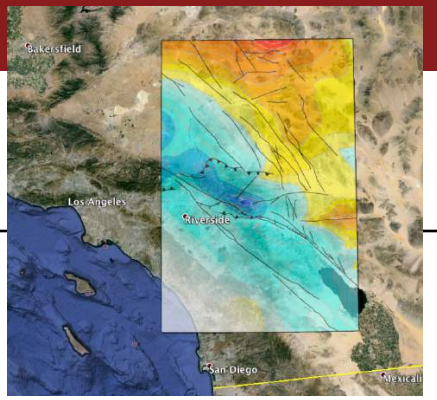
- Uplift differs most in the Banning Bench and Between the Banning and Mission Creek strands.



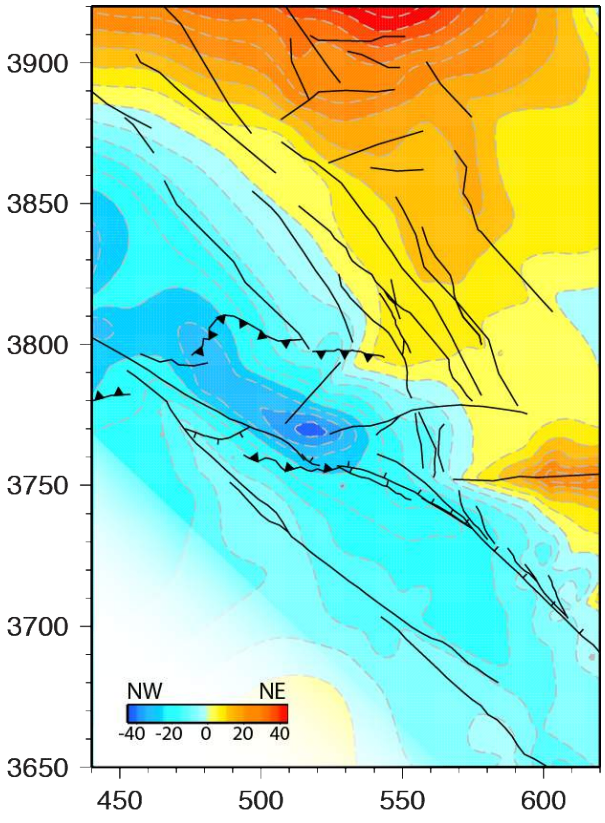


Effect on SHmax

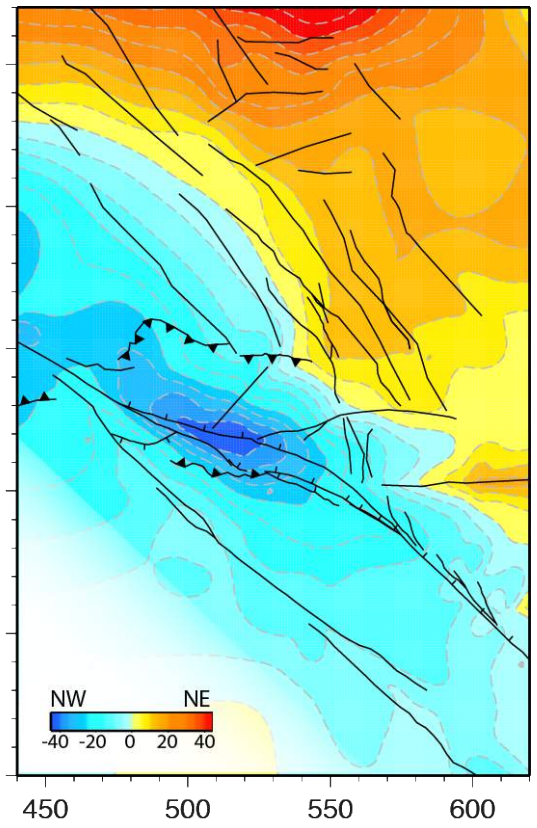




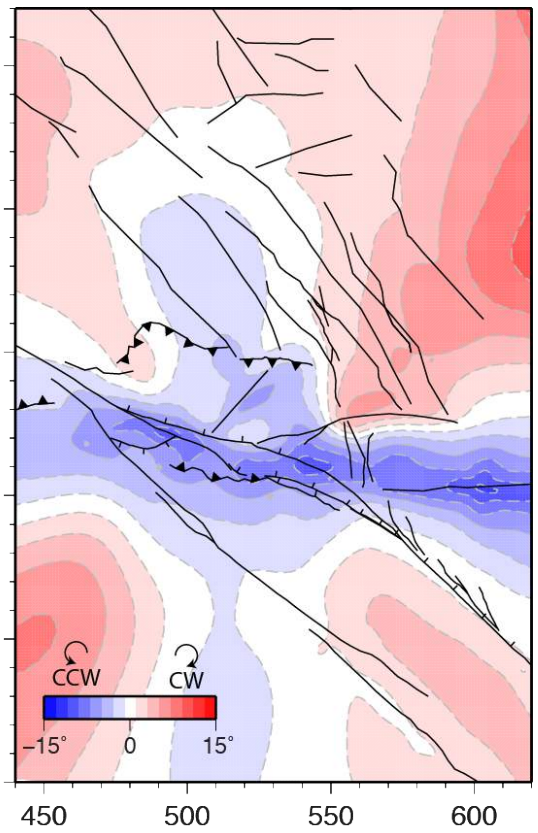
No Mill Creek



Adding Mill Creek



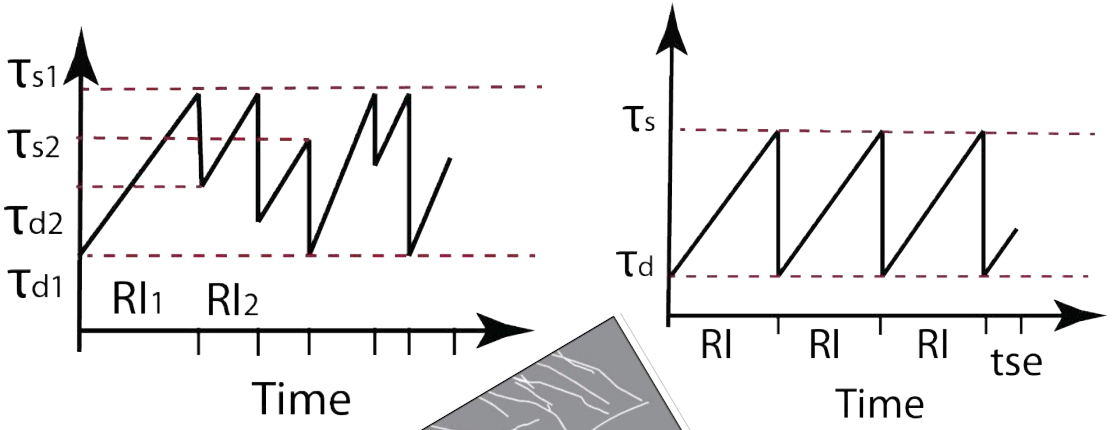
difference

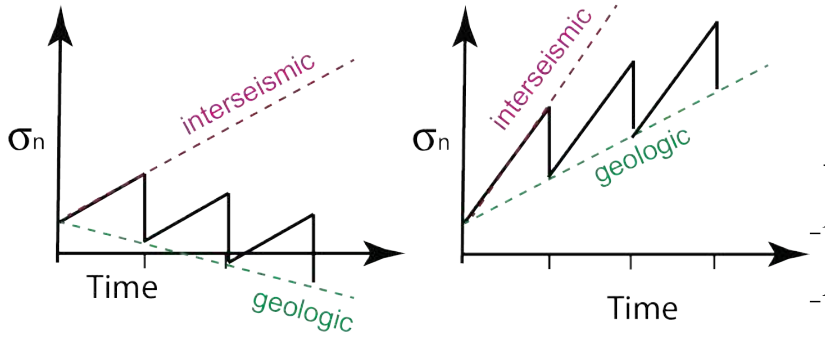


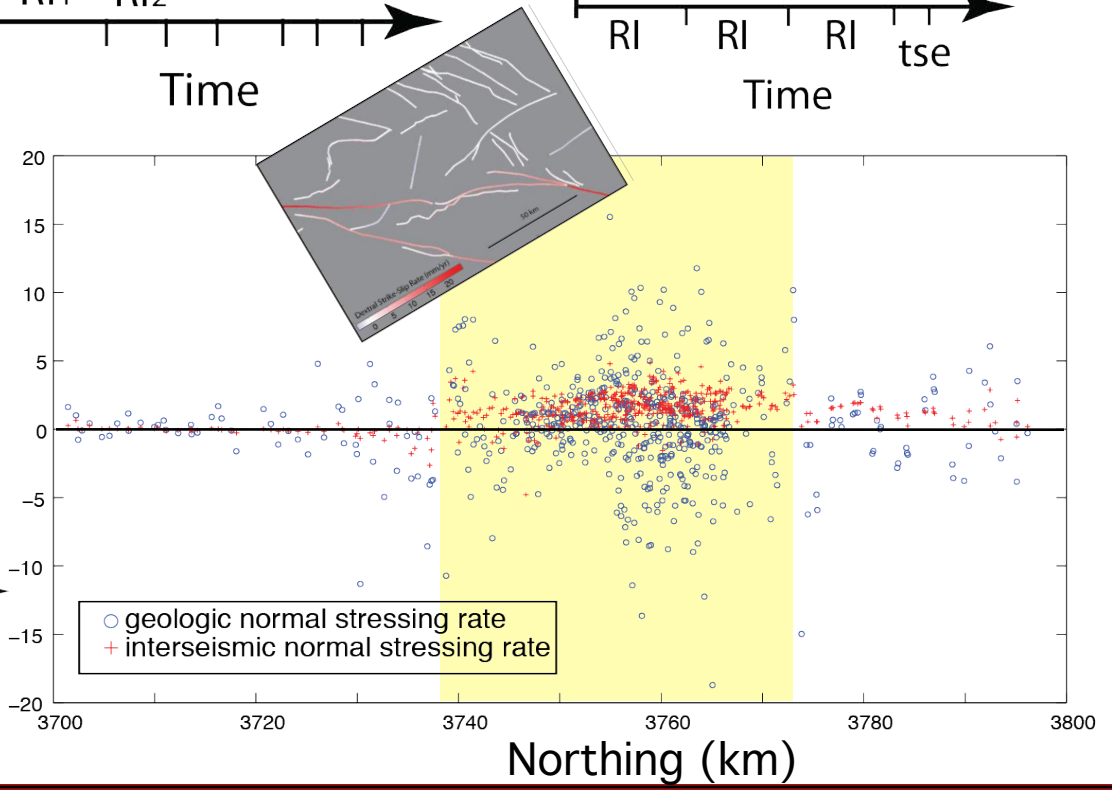
Conundrum

- Shear stress cycle

- Normal compression within restraining bends accumulates







Geometry matters

- Partitioning of deformation controlled by fault geometry *(e.g. Cooke and Dair, 2011; Herbert et al. 2014a, Herbert et al., 2014b; Fattaruso et al., in press)*
  - Connectivity of ECSZ faults
  - NE Dipping Coachella
  - *Active strand of the SAF through the San Gorgonio Pass*
- While the effects are local, fault geometry corrections alter SHmax orientations by 10°.

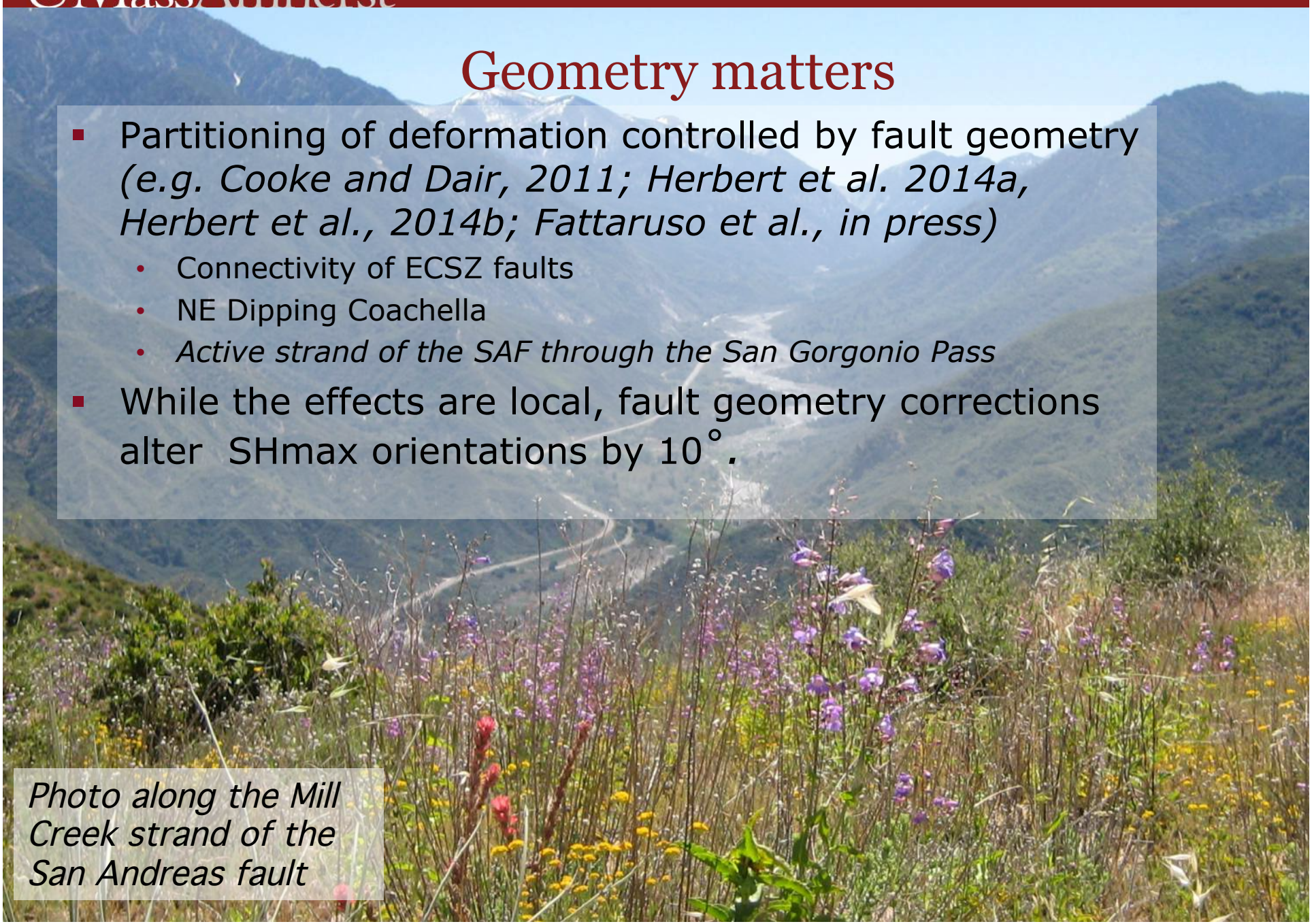
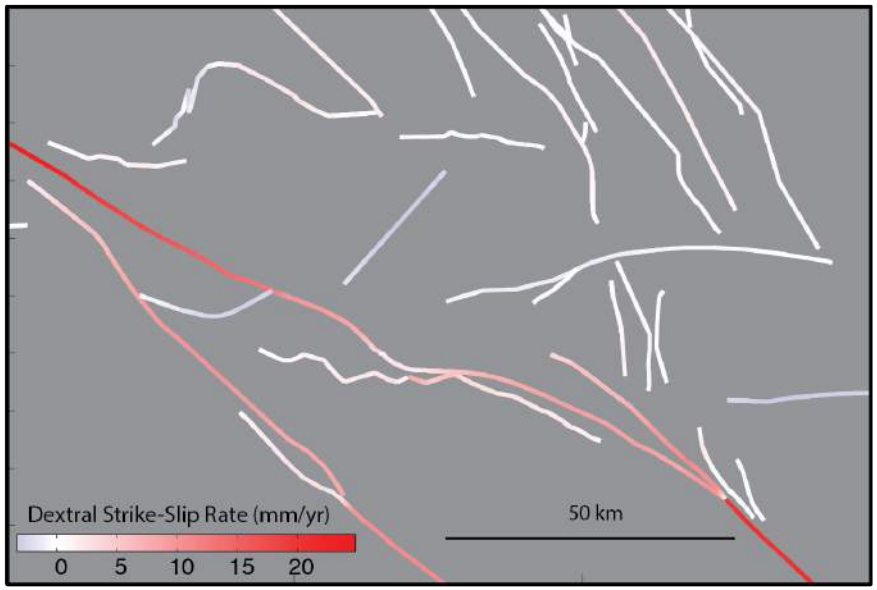
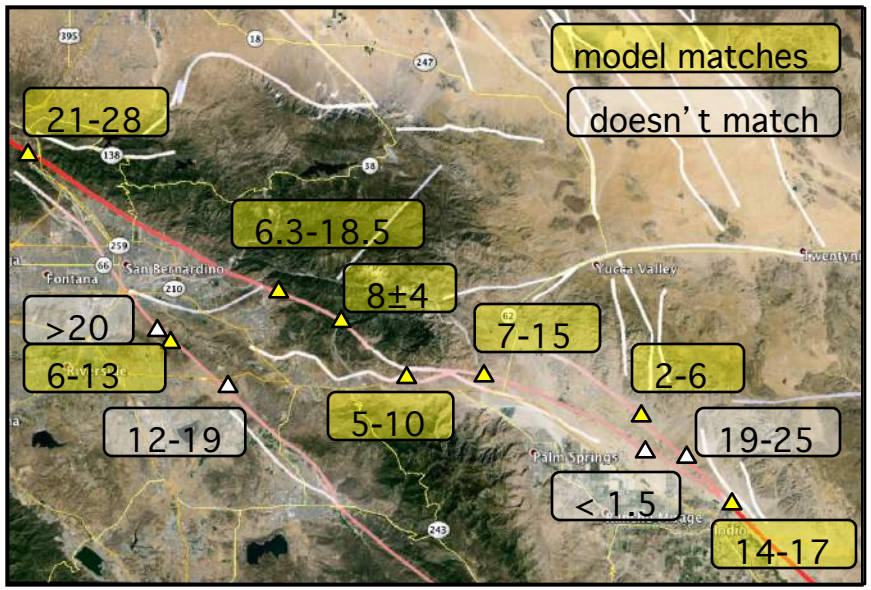


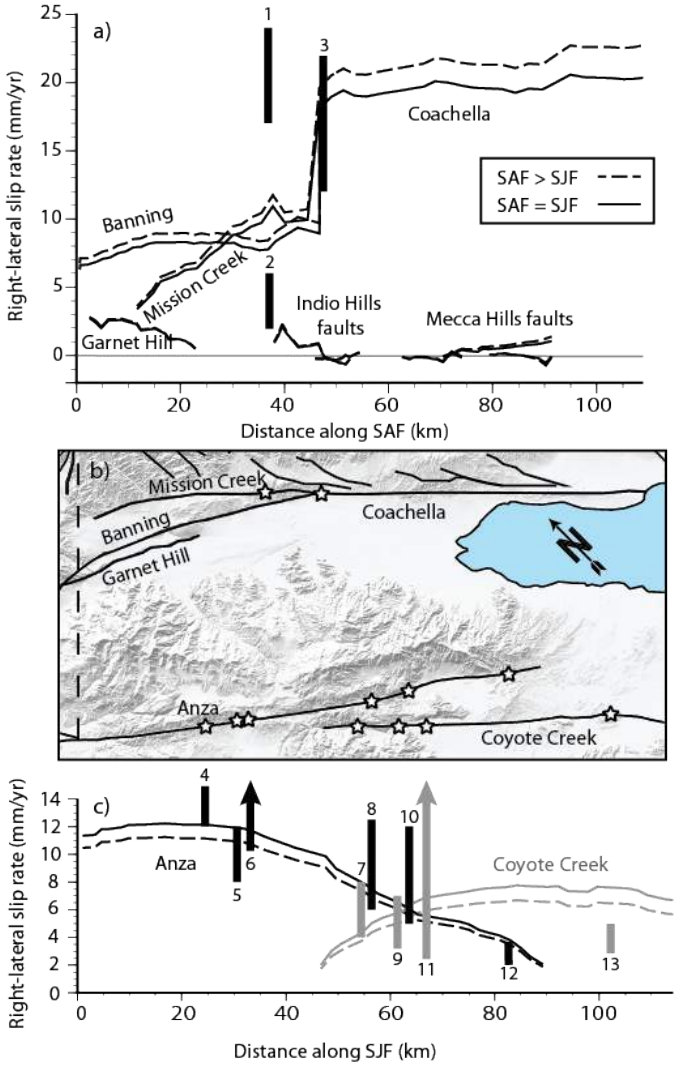
Photo along the Mill Creek strand of the San Andreas fault

Model validation: Comparison with slip rates

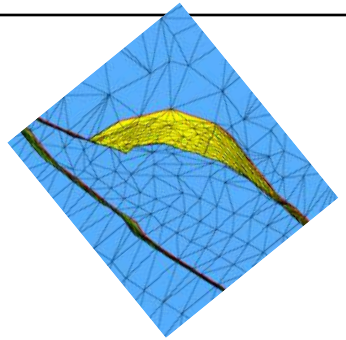




- Strike-slip rates along the SAF slow within the Pass.
- Modeled rates match many but not all sites along the San Andreas and San Jacinto

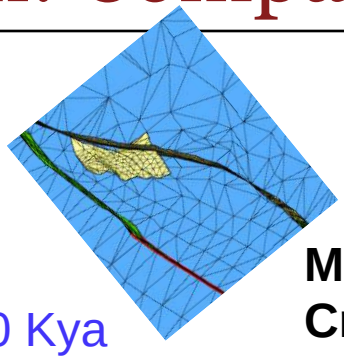

a)
Right-lateral slip rate (mm/yr)
Distance along SAF (km)
Coachella
Banning
Mission Creek
Garnet Hill
Indio Hills faults
Mecca Hills faults
SAF > SJF
SAF = SJF
b)
Mission Creek
Banning
Garnet Hill
Coachella
Anza
Coyote Creek
c)
Anza
Coyote Creek
Right-lateral slip rate (mm/yr)
Distance along SJF (km)

Model validation: Comparison of Uplift



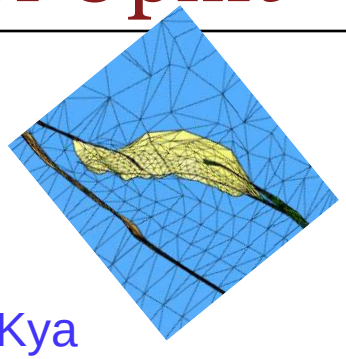
Mission Creek

500 Kya

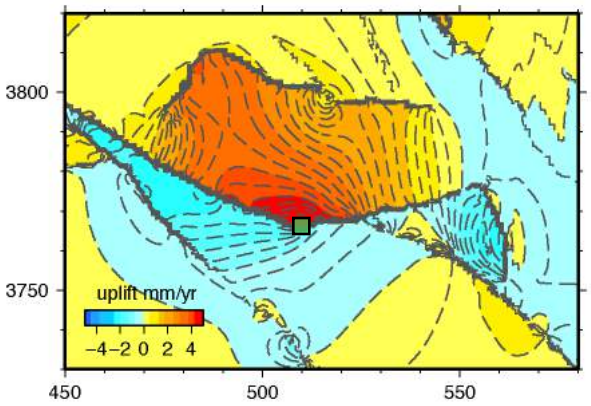


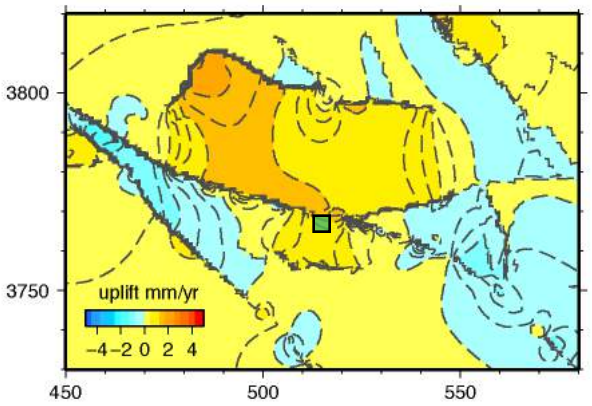
Mill Creek

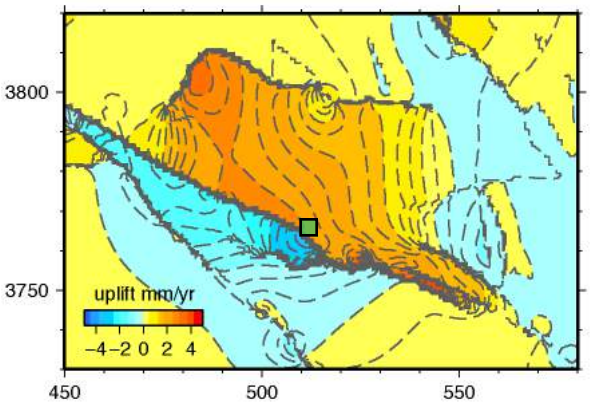
125 Kya



Present -day



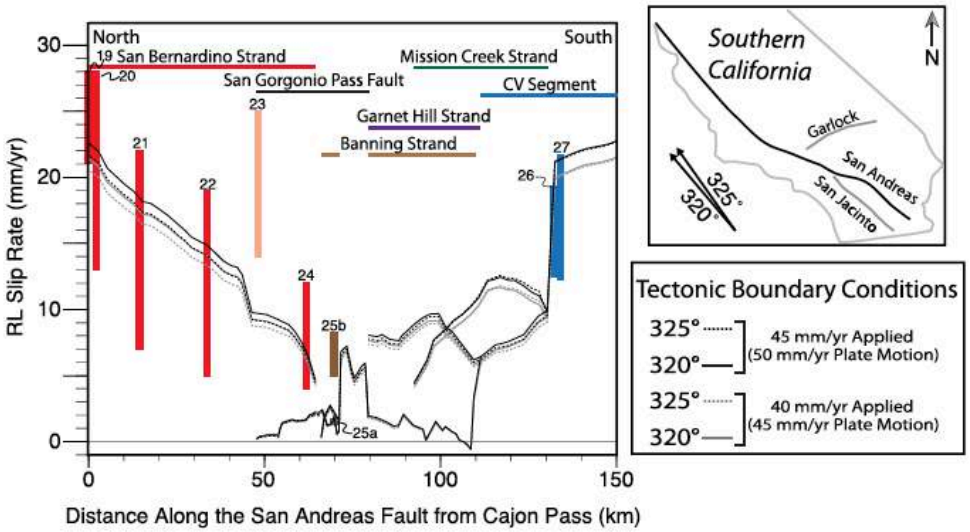


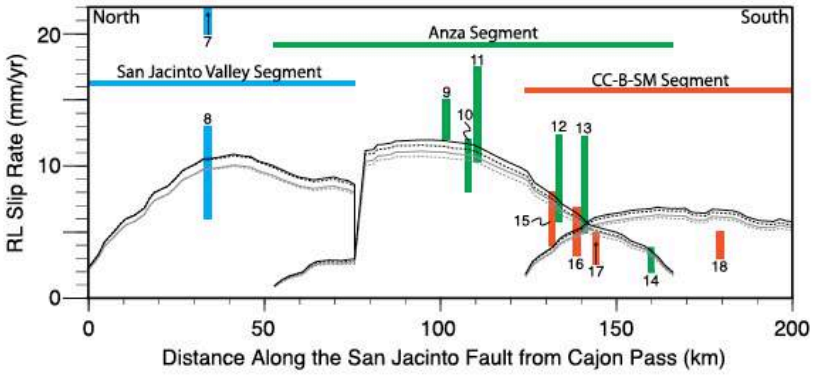


- Time averaged uplift
  - Yucaipa Ridge: 1.6-3.3 mm/yr over 1.8 million years *(Spotila et al, 2001)*
  - Model: 3.5 mm.yr over 1.8 million years (slower recently)

(Cooke & Dair, JGR 2011)

Model validation: Comparison with slip rates





(Herbert & Cooke, BSSA 2011)