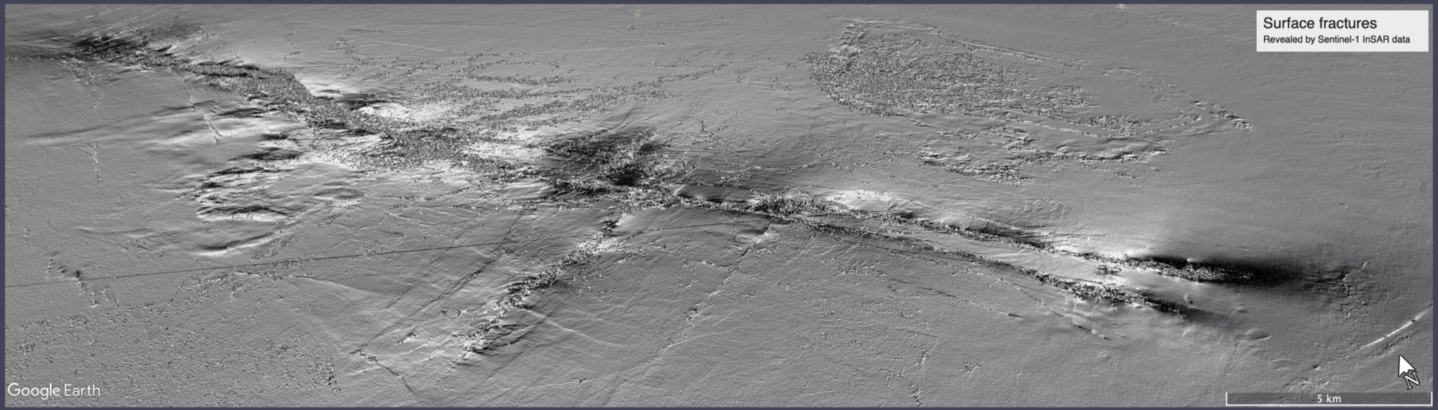
Mapping faults from space with InSAR: Ridgecrest and beyond

SCEC 2021



***Xiaohua Xu*[1], *David Sandwell*[2], *Lauren Ward*[3], *Chris Milliner*[4], *Bridget Smith-Konter*[3], *Peng Fang*[2], *Yehuda Bock*[2]

[1]*University of Texas at Austin*
[2]*University of California San Diego*
[3]*University of Hawaii at Moana*
[4]*California Institute of Technology*

TEXAS Geosciences
The University of Texas at Austin
Jackson School of Geosciences
Institute for Geophysics

SCRIPPS INSTITUTION OF OCEANOGRAPHY

UC San Diego

UNIVERSITY of HAWAI'I MĀNOA

CALIFORNIA INSTITUTE OF TECHNOLOGY GEOLOGICAL AND PLANETARY SCIENCES

Near fault observations with InSAR

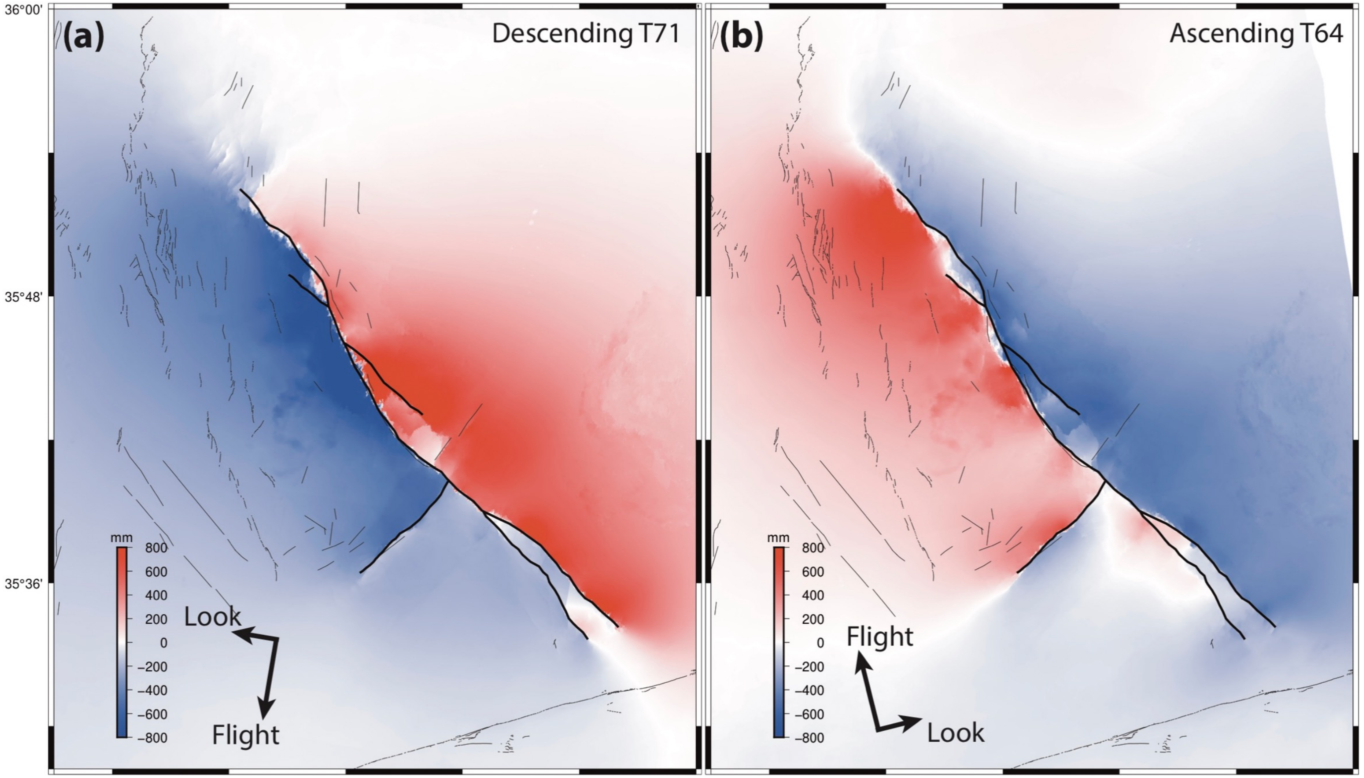
- Deformation that are off major faults/strain partitioning
- Identifying pre-existing faults and their properties
- Mechanisms of fault deformation
- Contemporary stress status?
- This work: Ridgecrest etc.

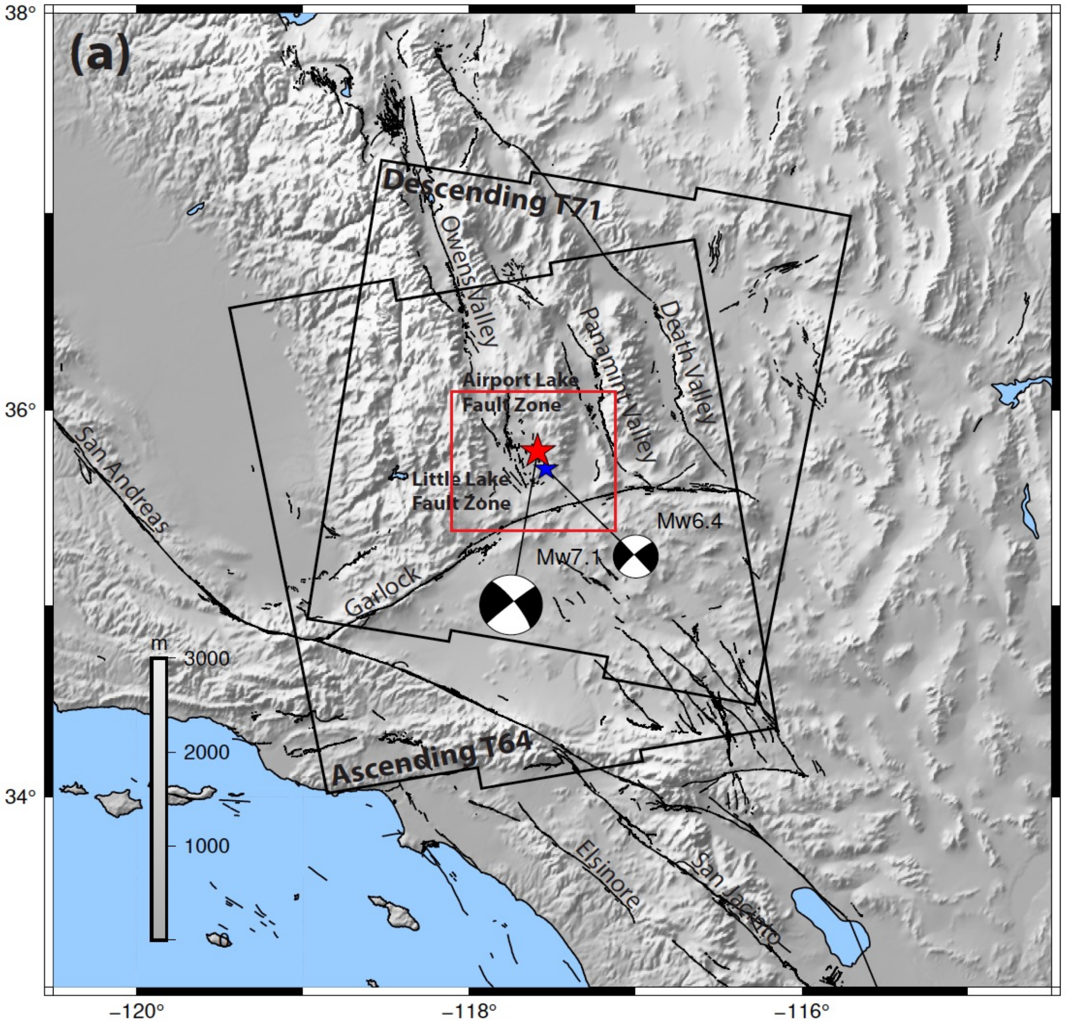
Surface fractures near Ridgecrest
Left lateral v.s. right lateral

What do we get after an event from InSAR?

- Radar phase

  → Deformation in Satellite line of sight

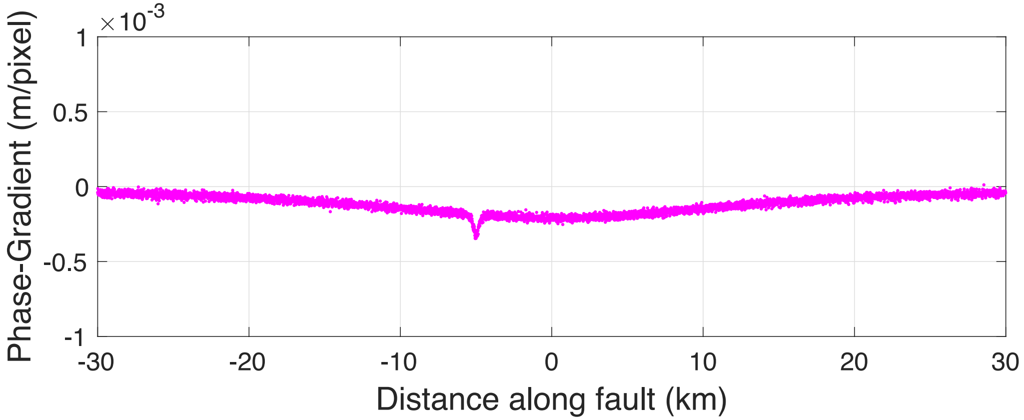




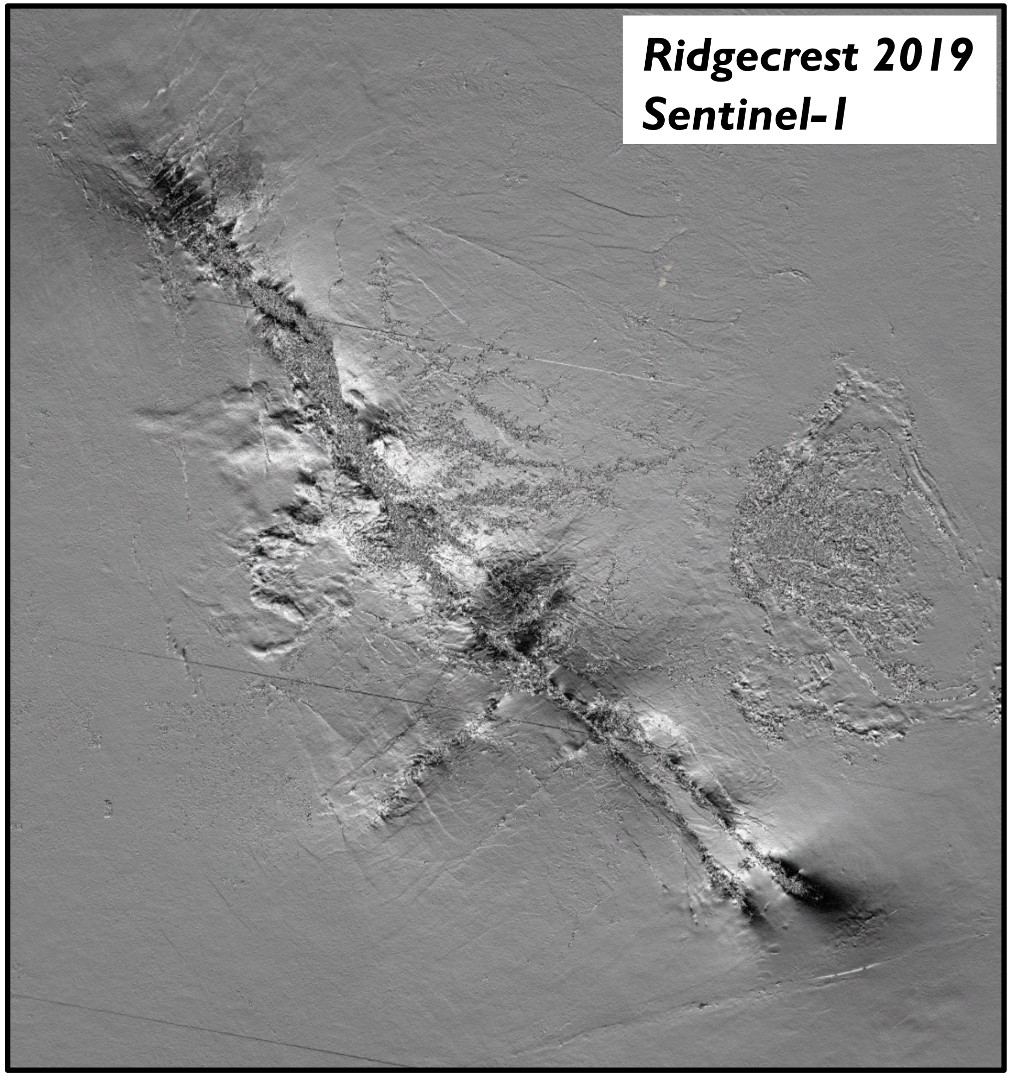
Xu et al., 2020

What do we get after an event from InSAR?

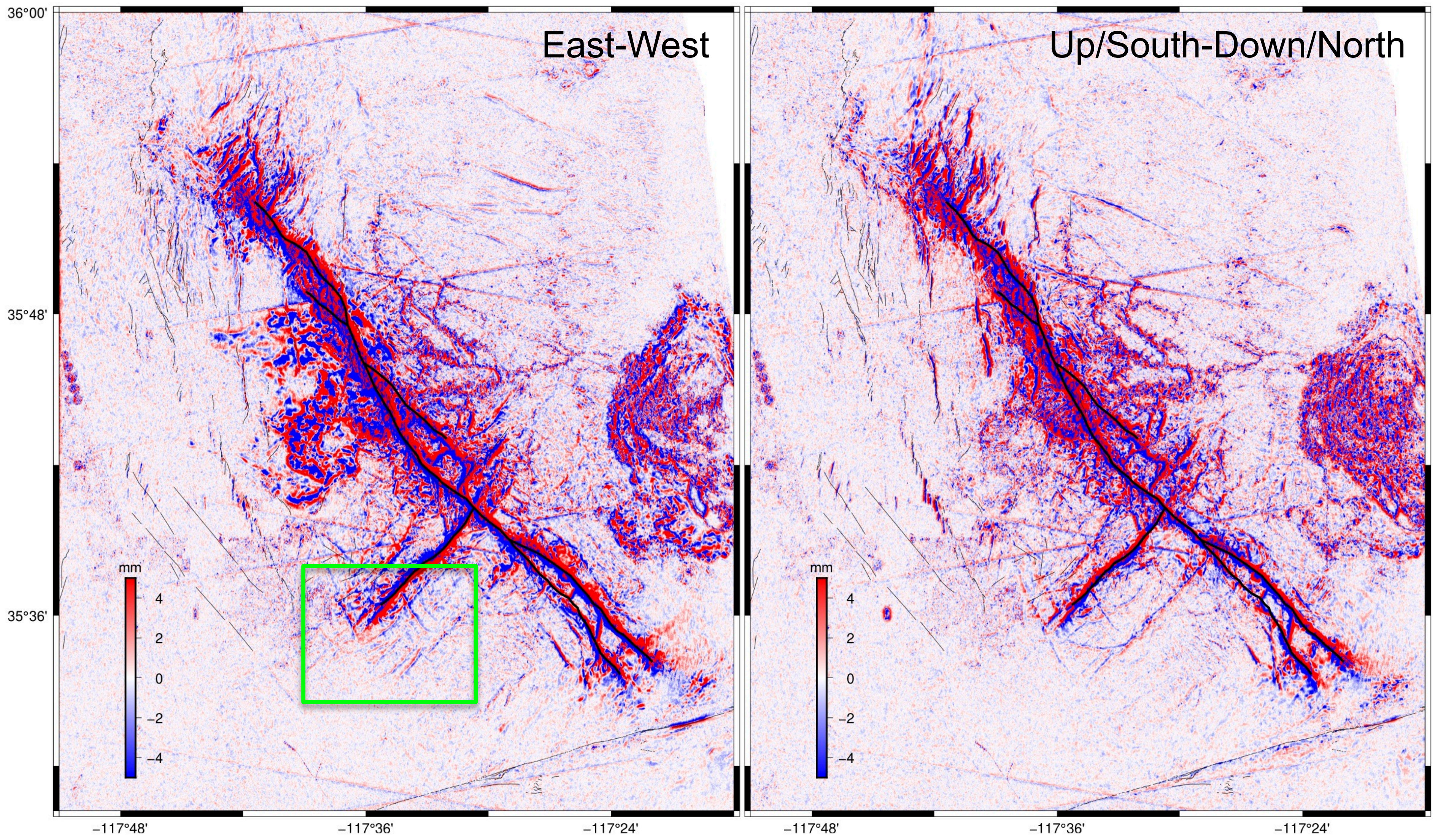
- Phase gradient maps:
  - Pros
    - No need to unwrap phase
    - Able to bring up details in map
    - Can be directly stacked to reduce noise
  - Cons
    - Derivatives magnifies noise
    - Affected by decorrelation



Artifact →

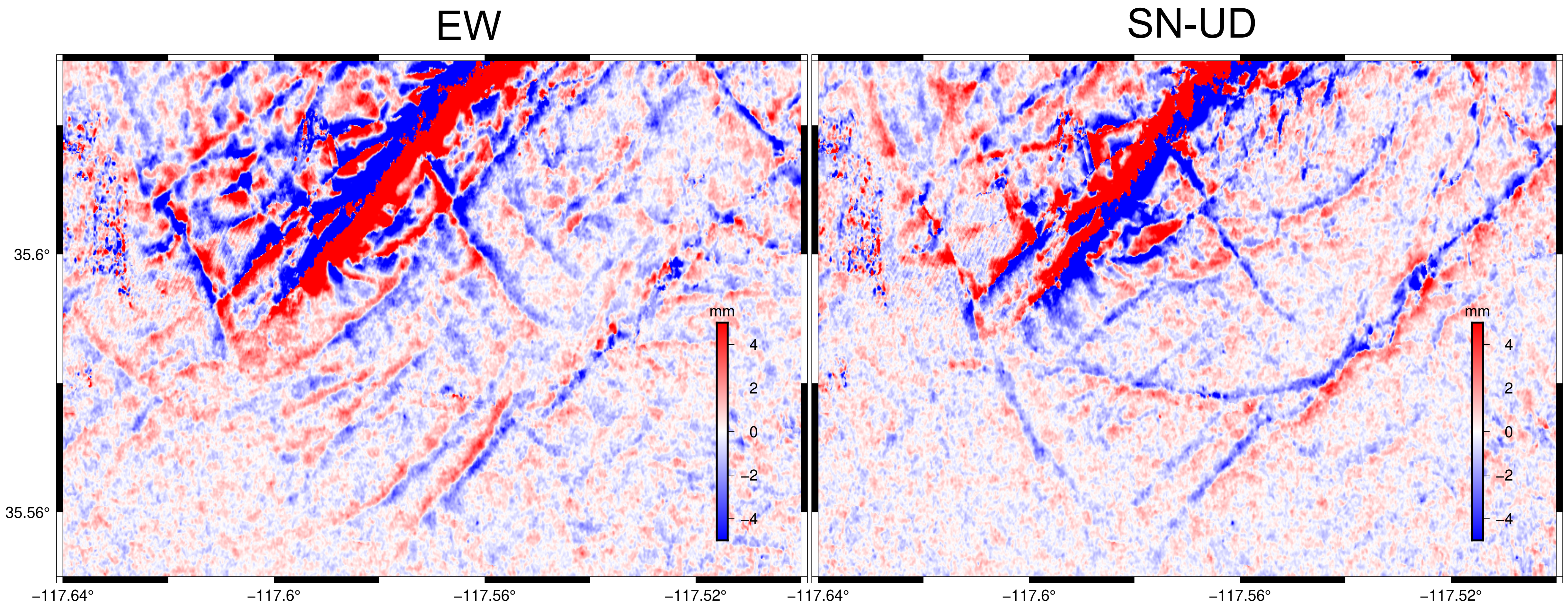


Further analysis on near fault radar phase



Xu et al., 2020

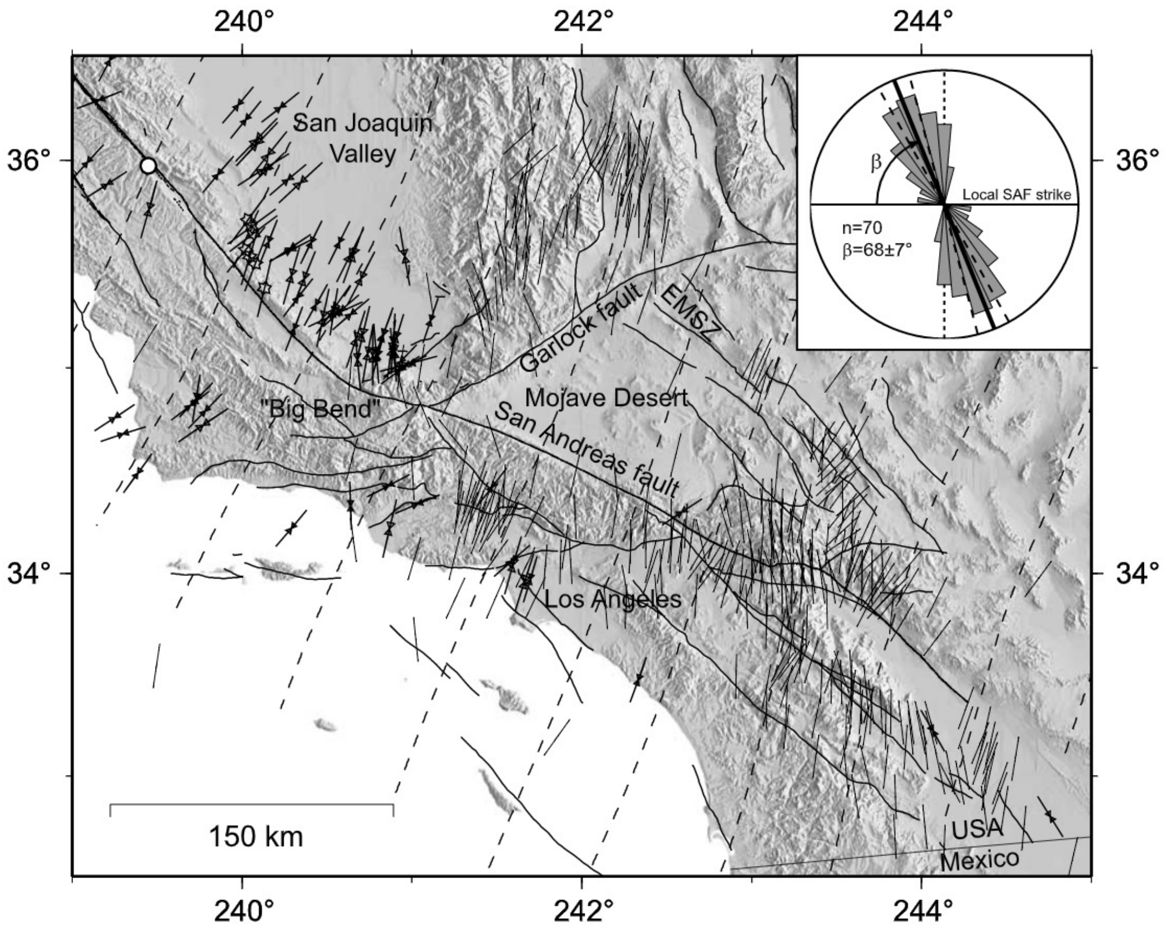
Further analysis on near fault radar phase



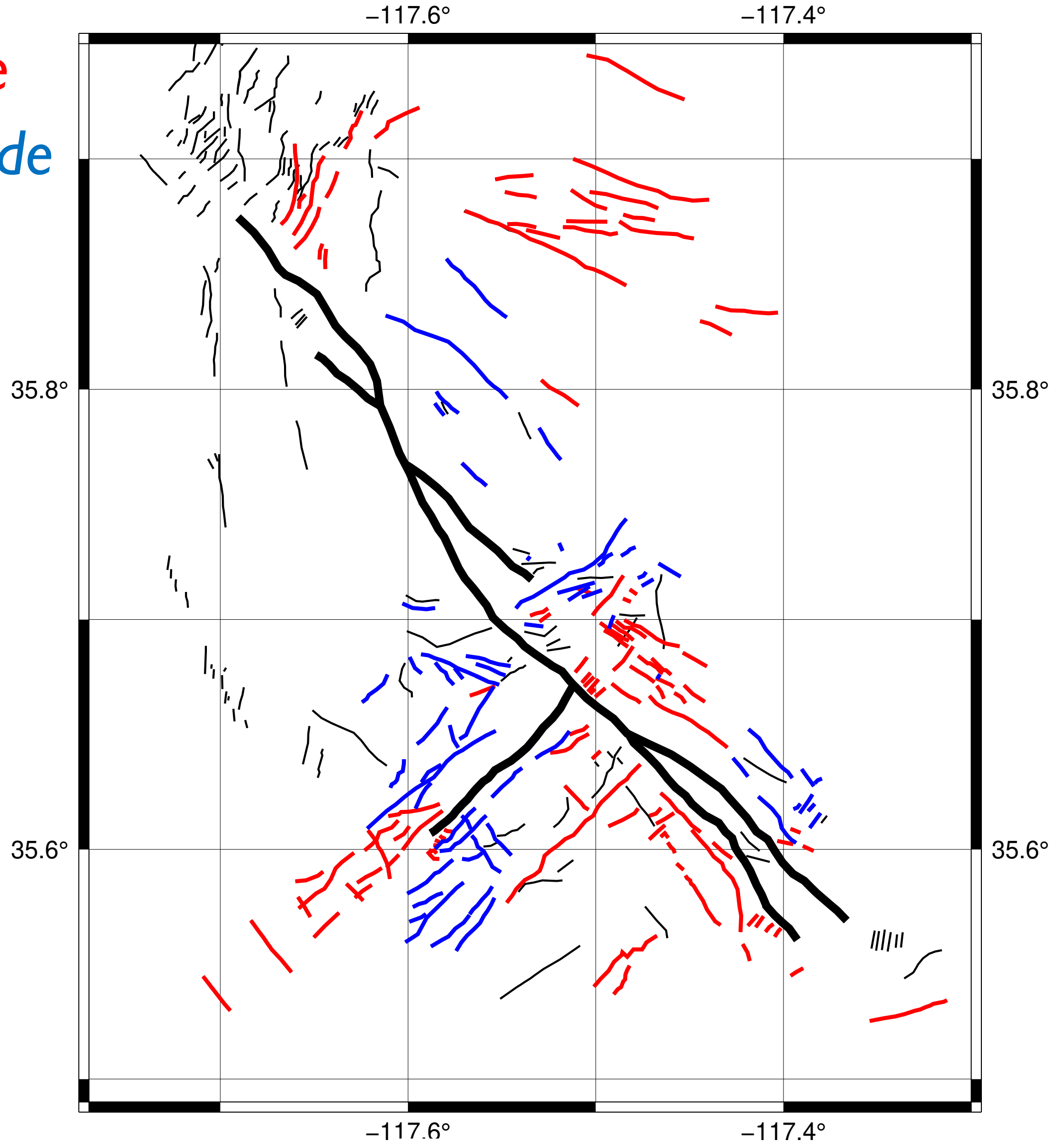
Xu et al., 2020

Defining the fractures

- *Red: prograde*
- *Blue: retrograde*



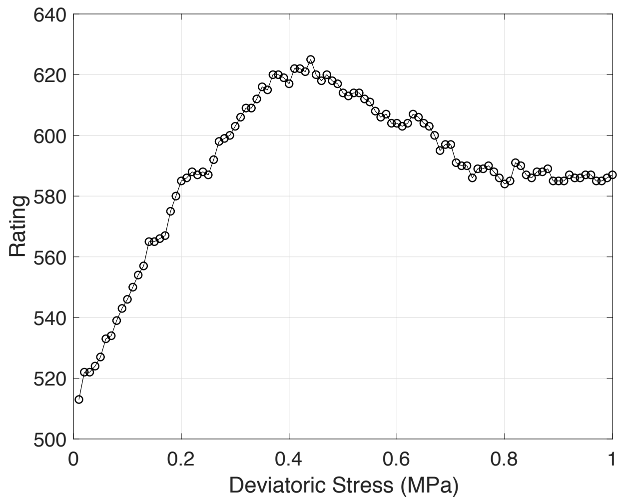
Townend & Zoback, 2004

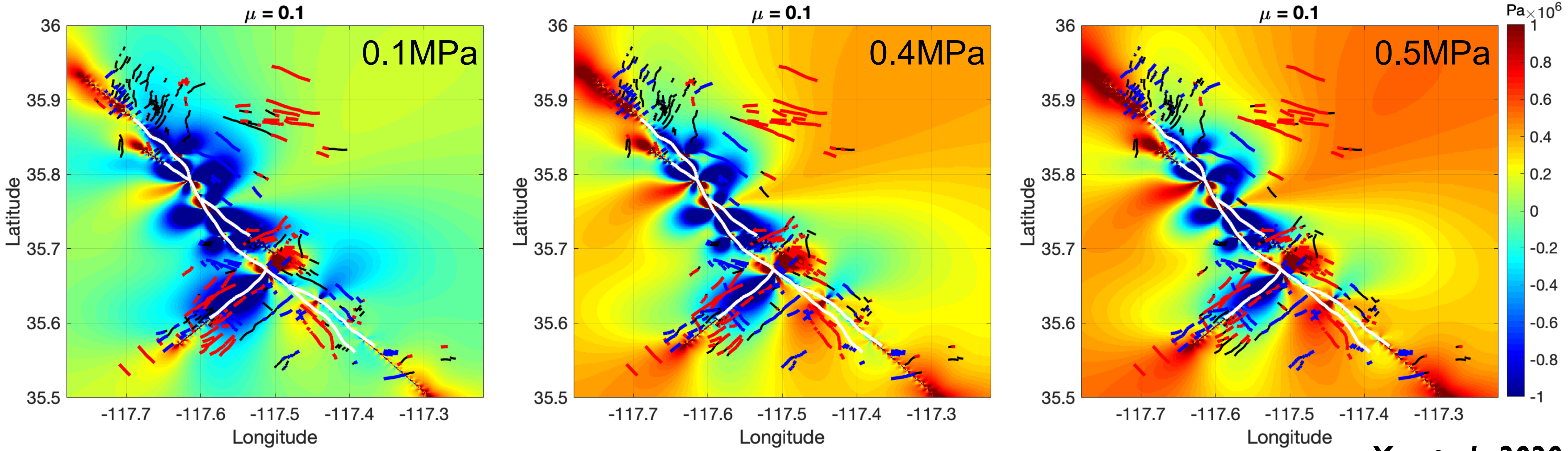


Xu et al., 2020

Analysis and interpretation

- Stress analysis
  - Adding deviatoric stress with N-S compression + equal E-W extension
  - This is an average number for surface, deeper depth has much larger stress



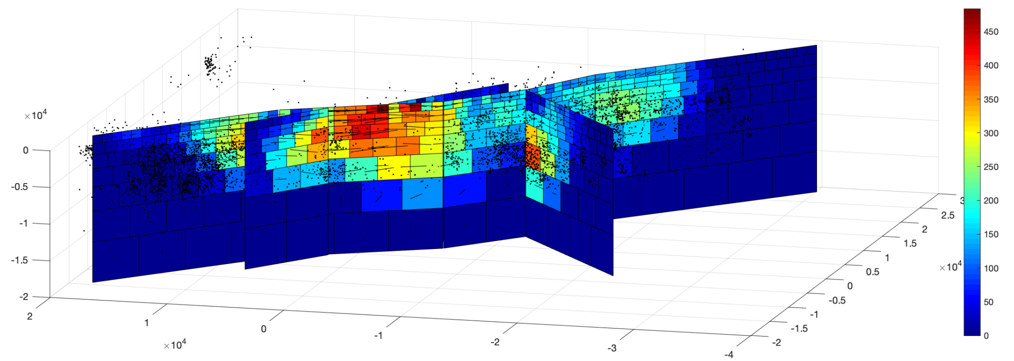


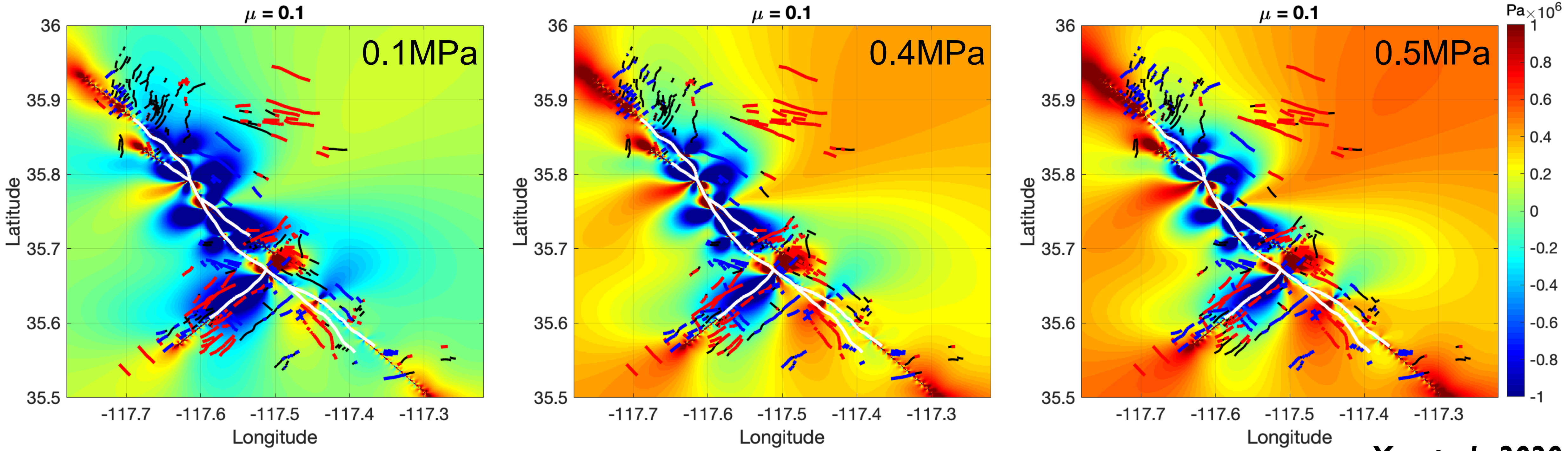
Colors in the back denote stress along the main rupture direction

Xu et al., 2020

Analysis and interpretation

- Stress analysis
  - Adding deviatoric stress with N-S compression + equal E-W extension
  - This is an average number for surface, deeper depth has much larger stress



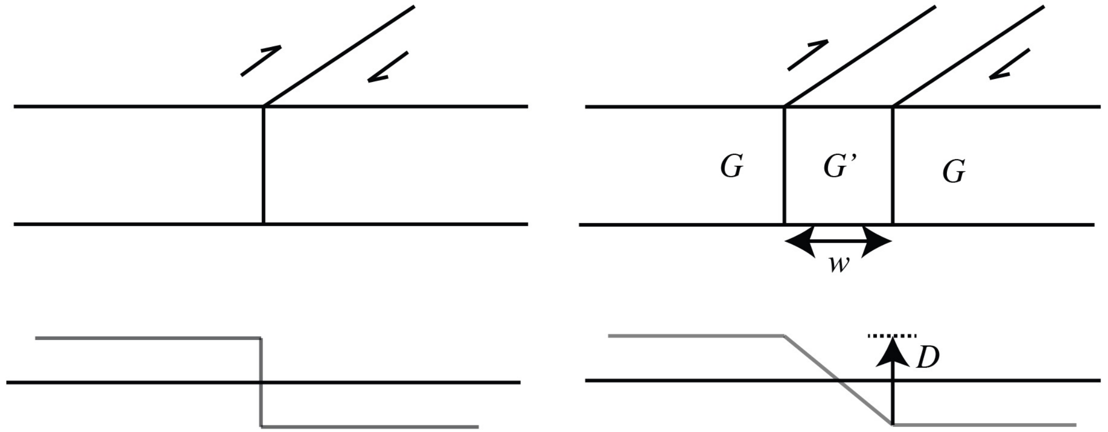


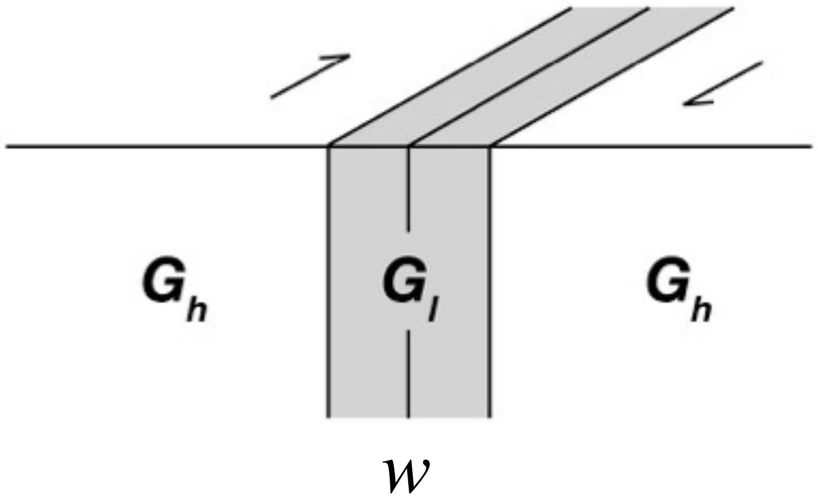
Colors in the back denote stress along the main rupture direction

Xu et al., 2020

What are the mechanisms?

triggered slip vs. compliant fault zone

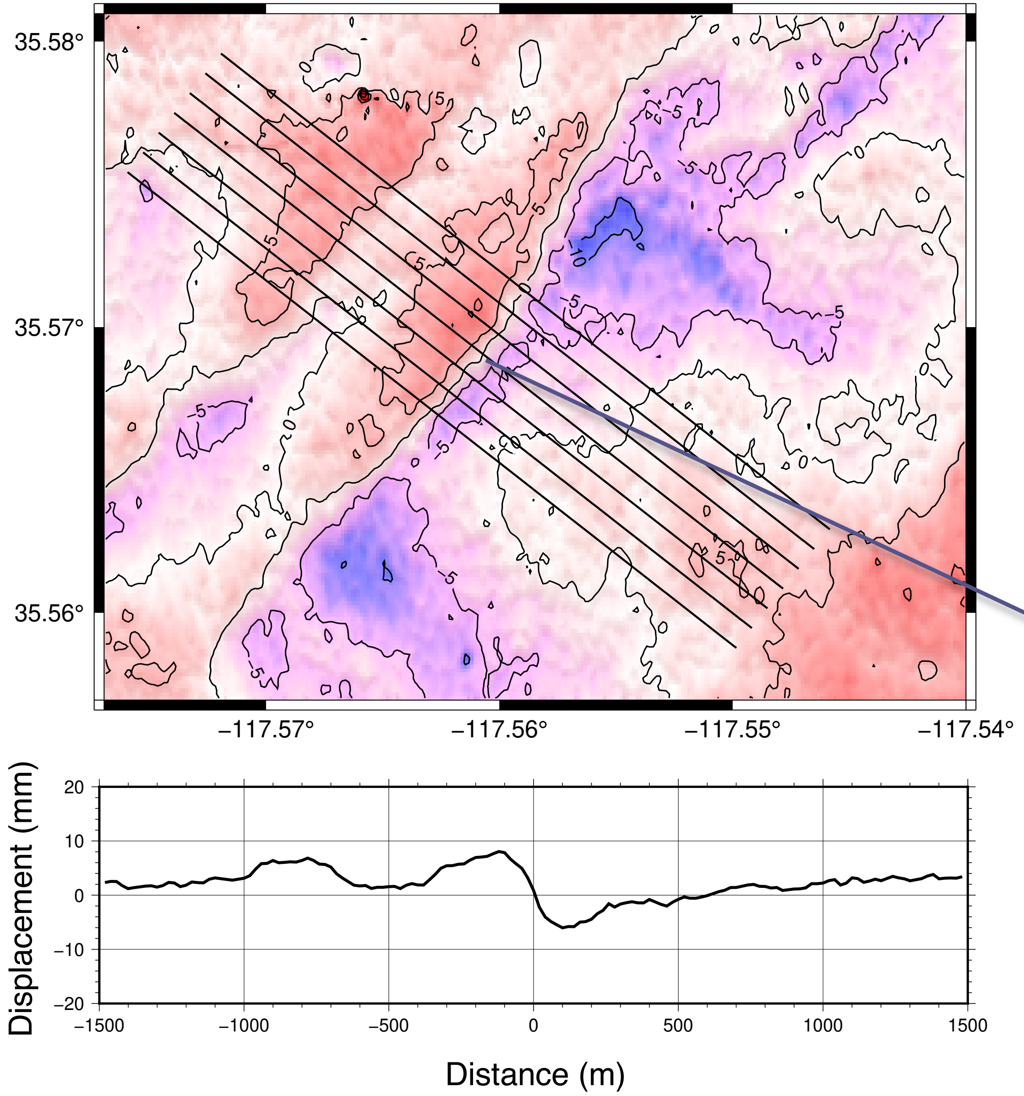


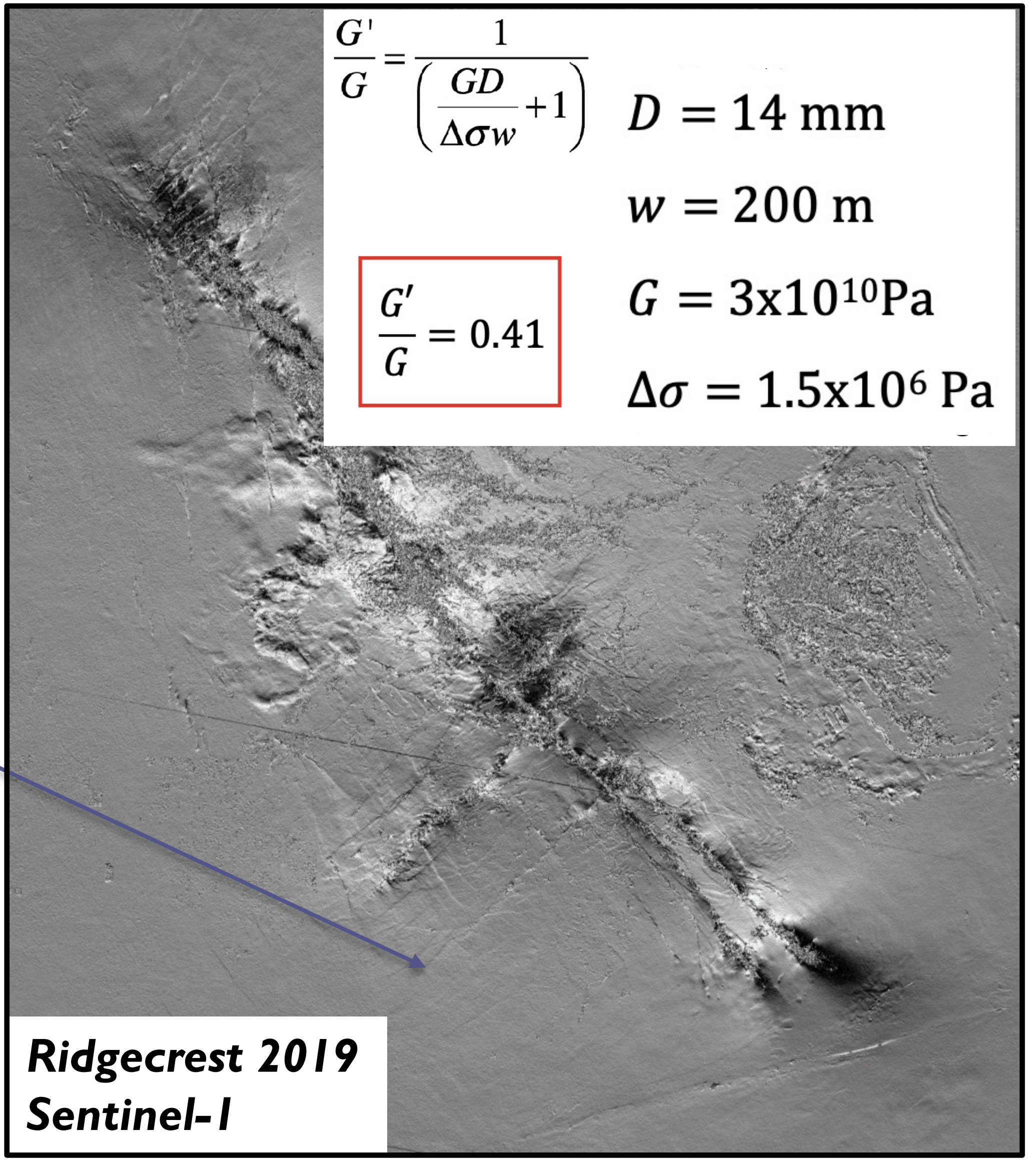


$$\frac{G_l}{G_h} = \frac{1}{\frac{DG_h}{w\Delta\sigma_t} + 1}$$

Fialko et al., 2002

Delineating the deformation





Xu et al., 2020

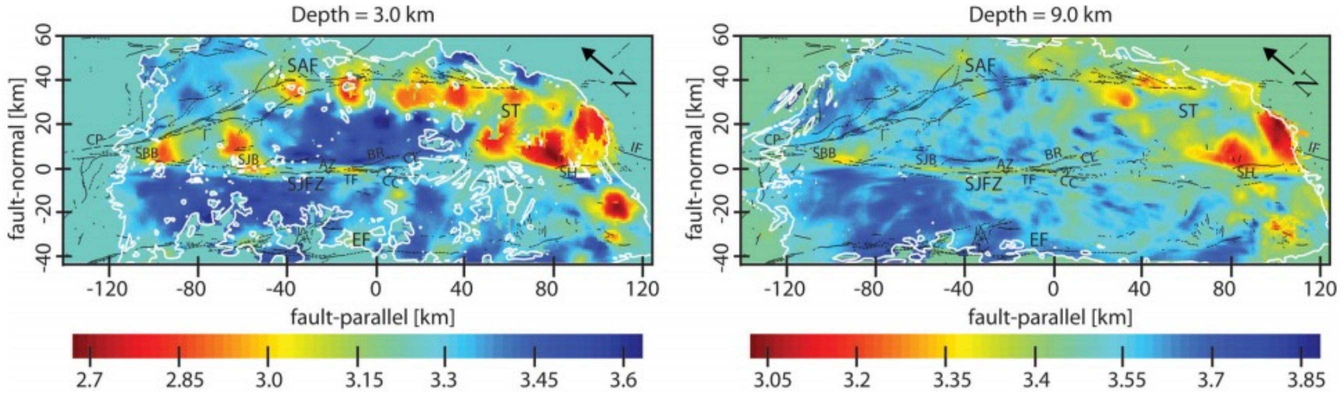
Compliant fault deformation?

- Parameters
  - Deformation Width
  - Displacement
  - Shear modulus contrast

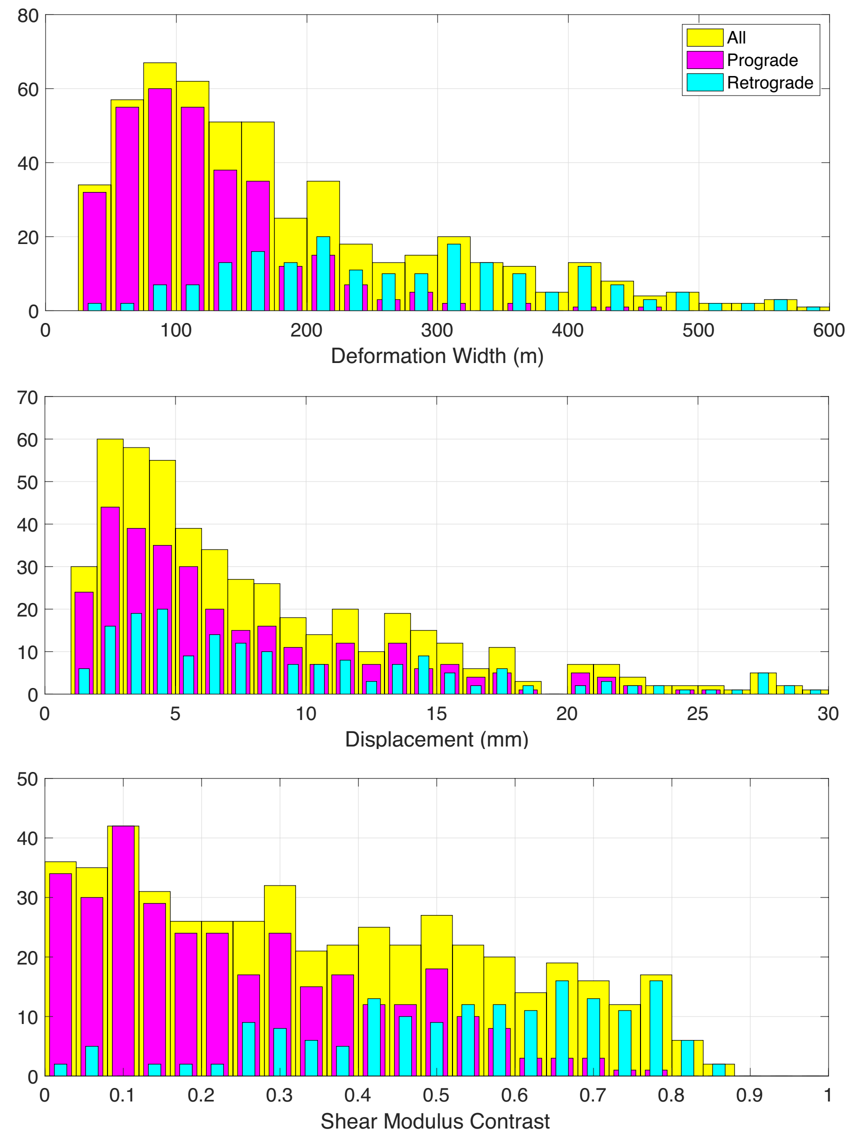
$$\frac{G_l}{G_h} = \frac{1}{\frac{DG_h}{w\Delta\sigma_t} + 1}$$

Vs'/Vs = 0.6 - 0.9

G'/G = 0.4~0.8 ***Vs*** **= sqrt(*G/ρ*)**

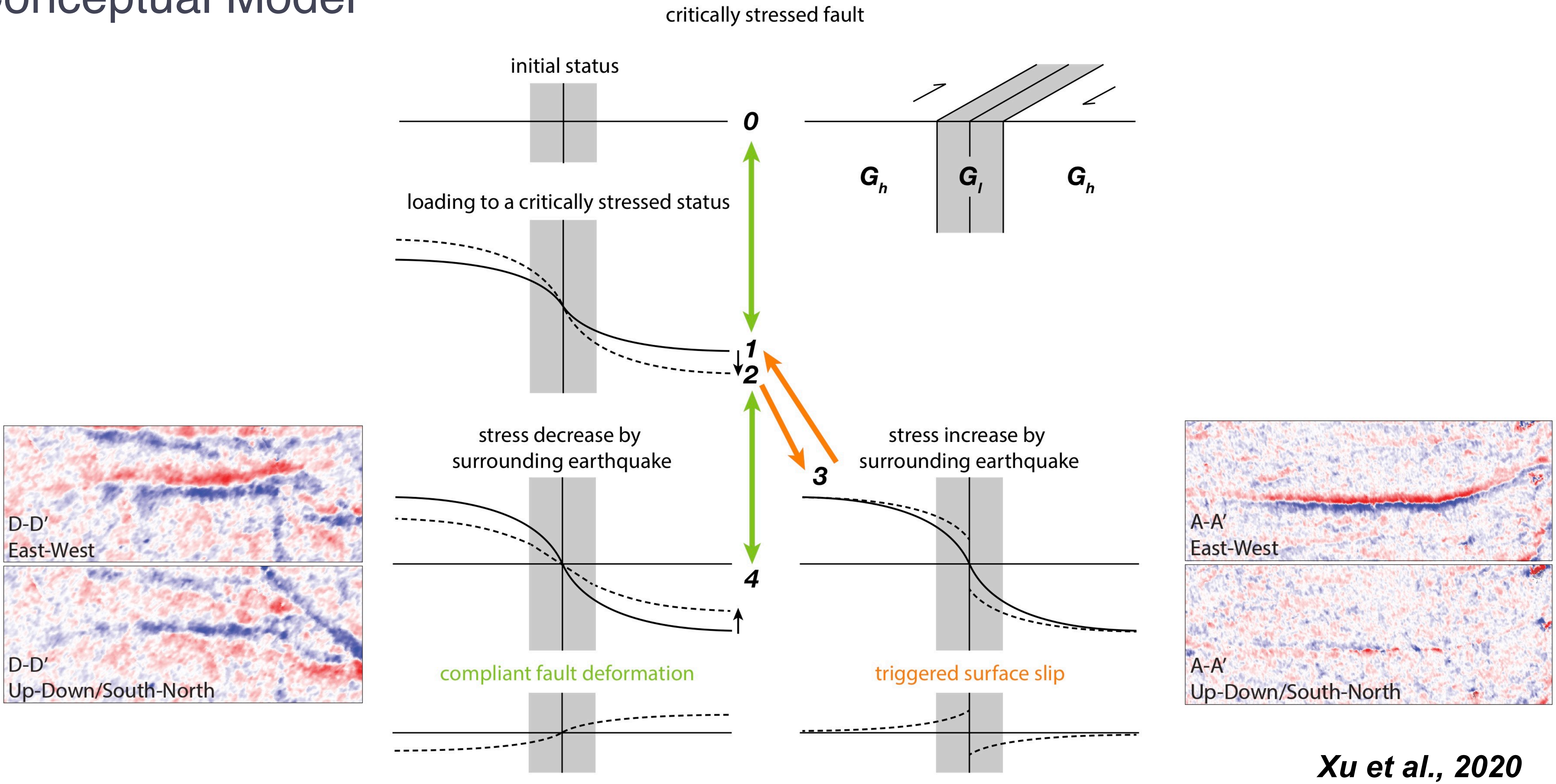


Allam & Ben-Zion 2012



Xu et al., 2020

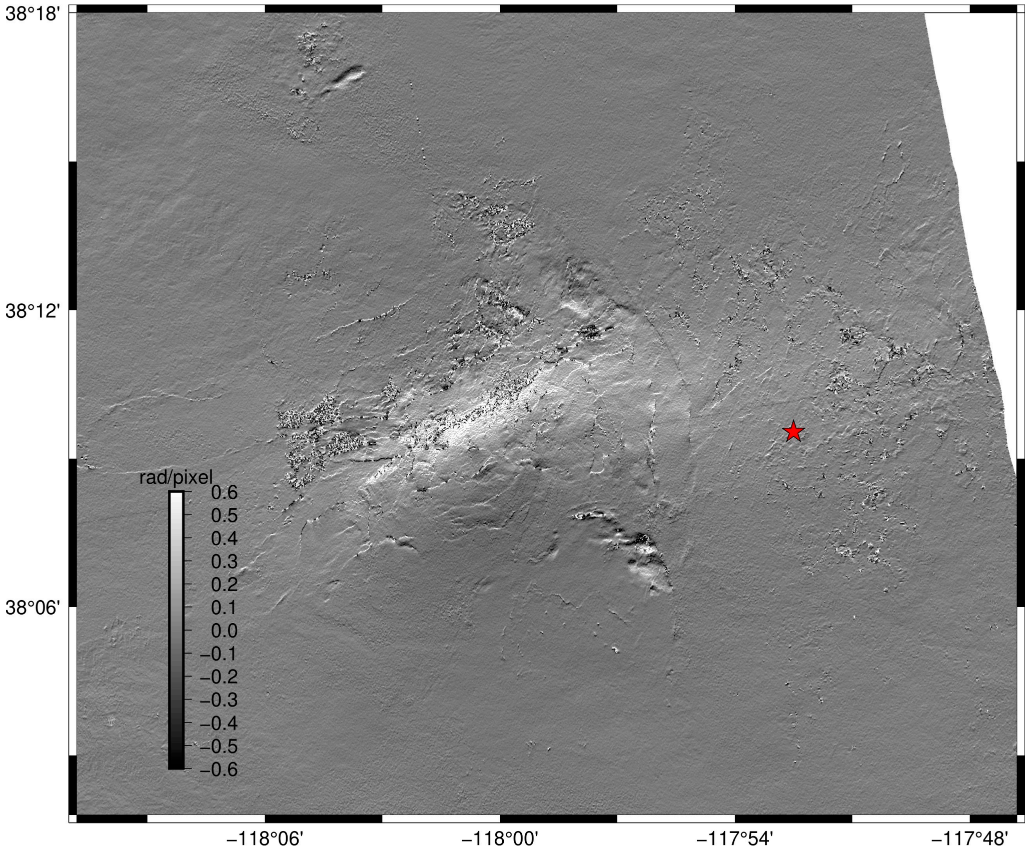
Conceptual Model



Xu et al., 2020

Implications: mapping faults from space

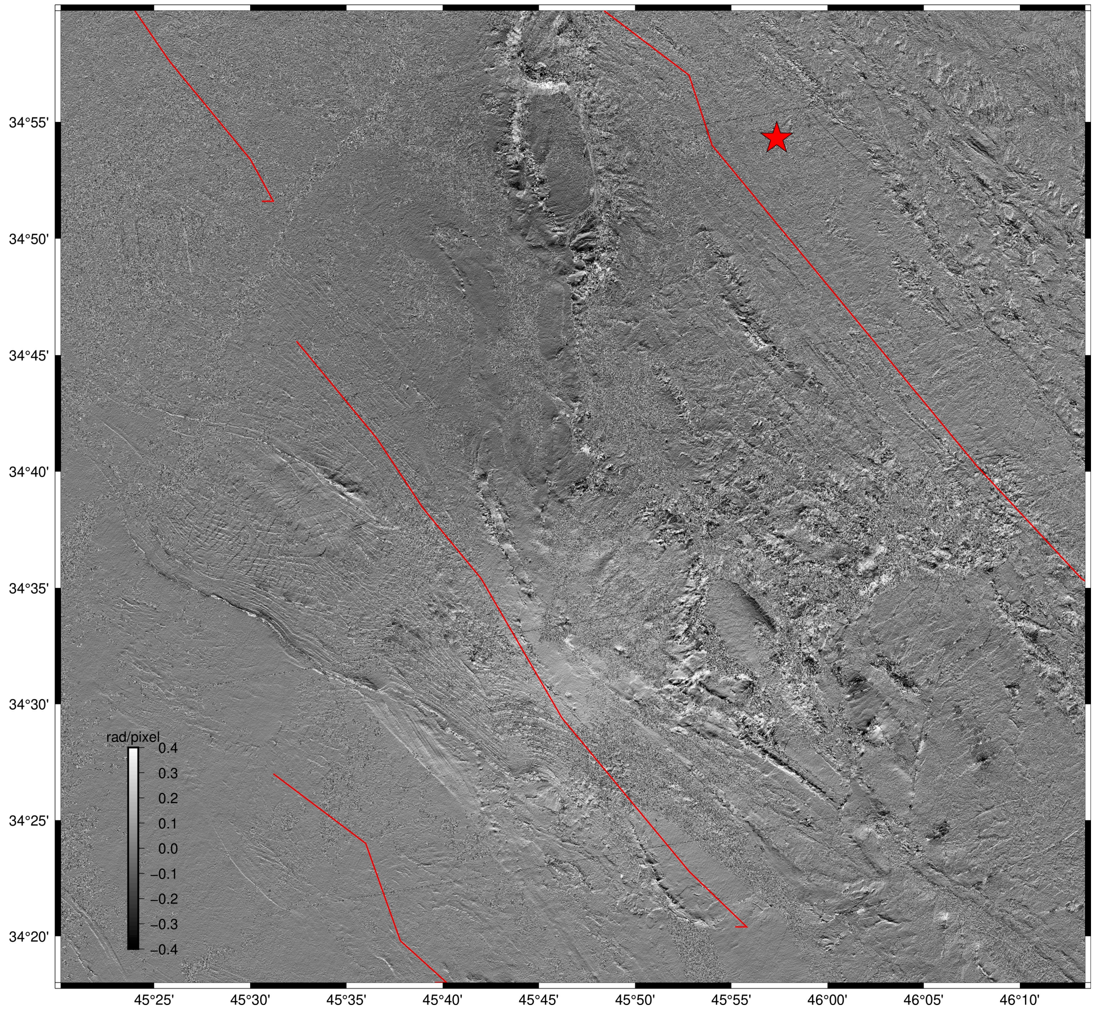
- Help map faults from space
- May commonly exists in other diffuse strike-slip system
- New cracks may indicate regional rock properties
- May hopefully help constraint the rupture



2020 M6.5 Monte Cristo Range Earthquake

Implications: mapping faults from space

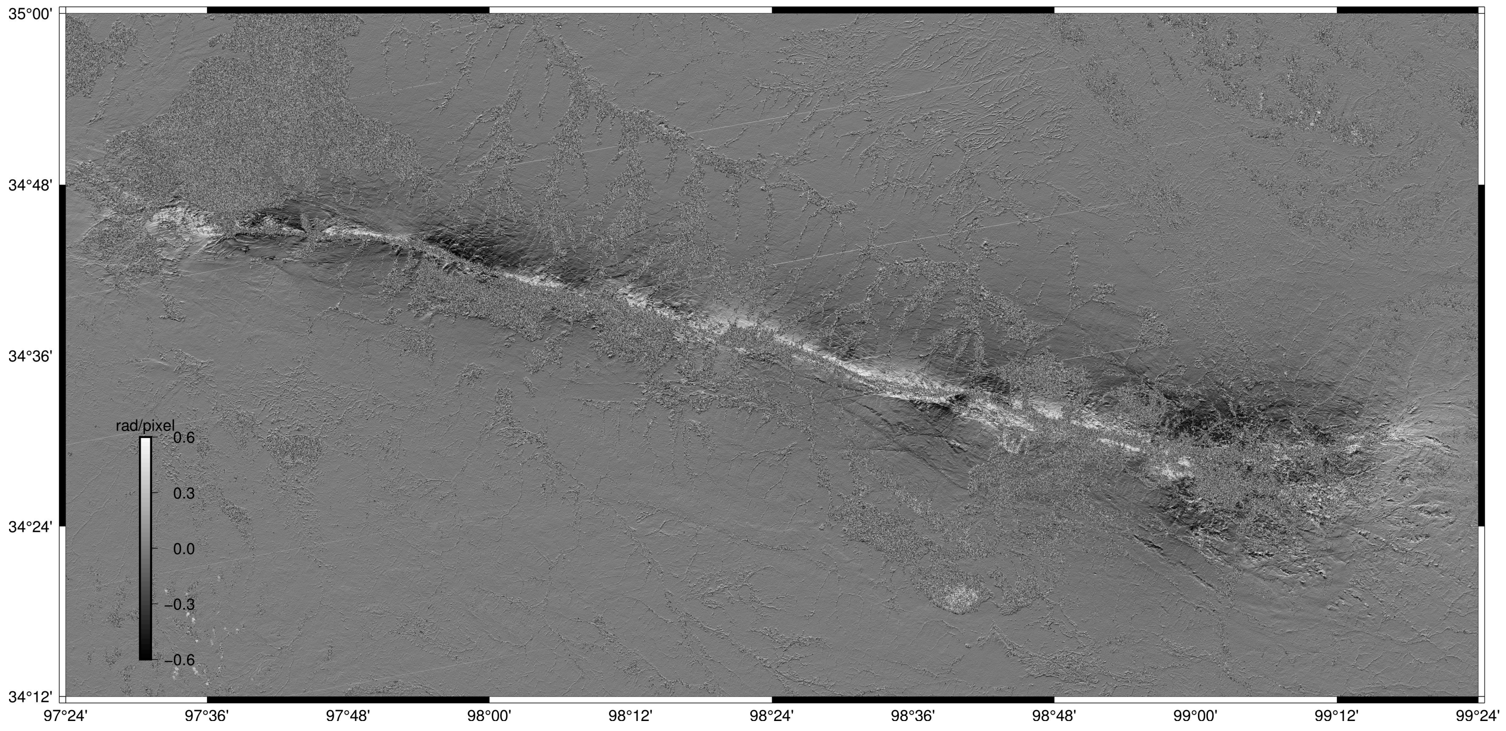
- Help map faults from space
- May commonly exists in other diffuse strike-slip system
- New cracks may indicate regional rock properties
- May hopefully help constraint the rupture



2017 Mw 7.3 Sarpol-e Zahab Iran-Iraq earthquake

Implications: mapping faults from space

- Help map faults from space
- May commonly exists in other diffuse strike-slip system
- New cracks may indicate regional rock properties
- May hopefully help constraint the rupture

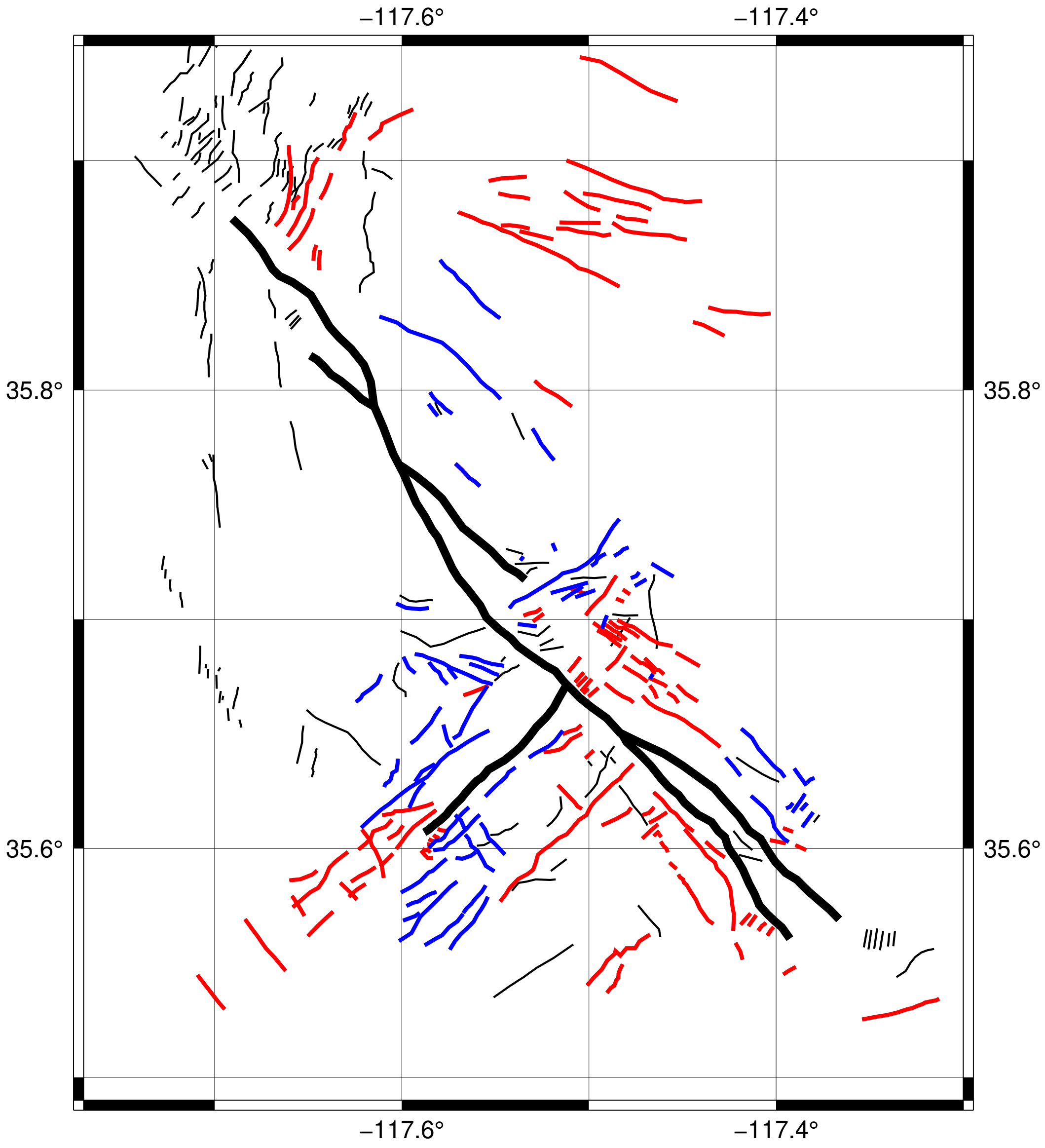


2021 Mw7.3 Maduo China earthquake

Implications: fault maturity

- [Cowie & Scholz, 1992]
  e.g. fault historic displacement
  ~ 3.6-7.6*10e-3 fault length

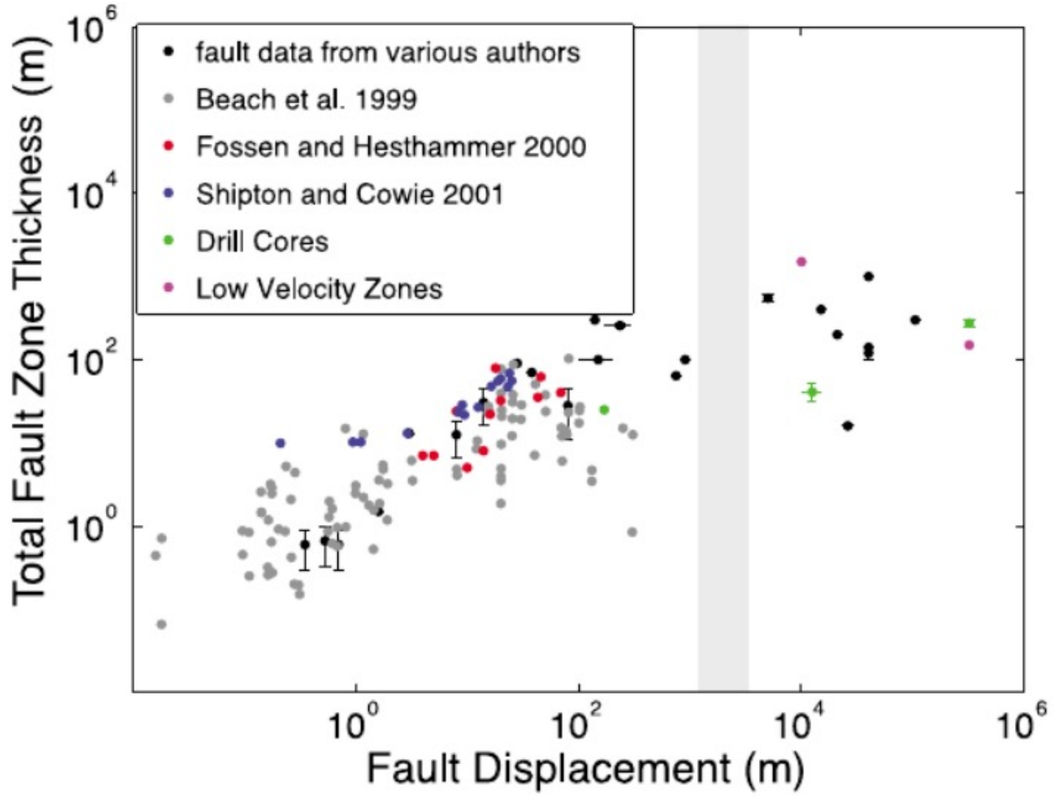
- Savage and Brodsky [2011]
  e.g. fault historic displacement
  ∝ fault damage zone width



Implications: fault maturity

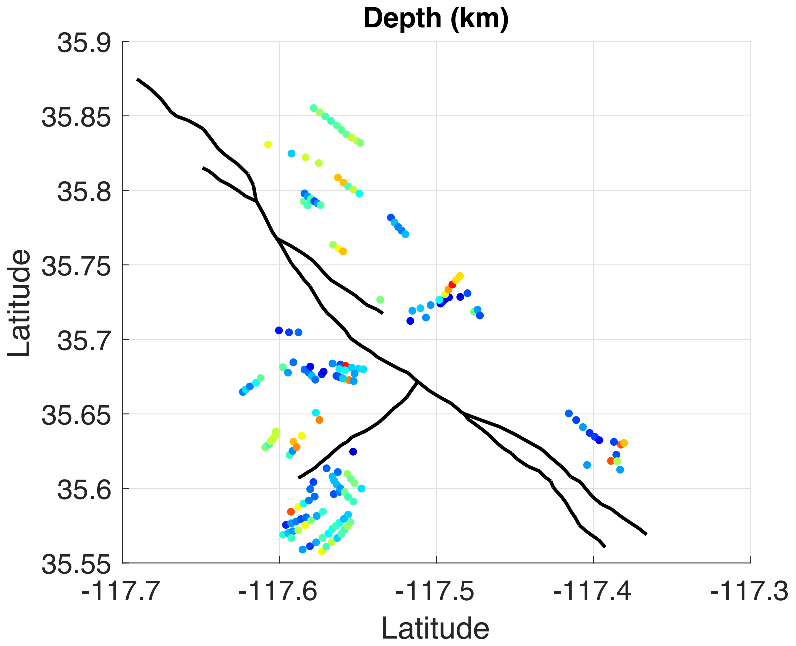
- [Cowie & Scholz, 1992]
  e.g. fault historic displacement
  ~ 3.6-7.6*10e-3 fault length

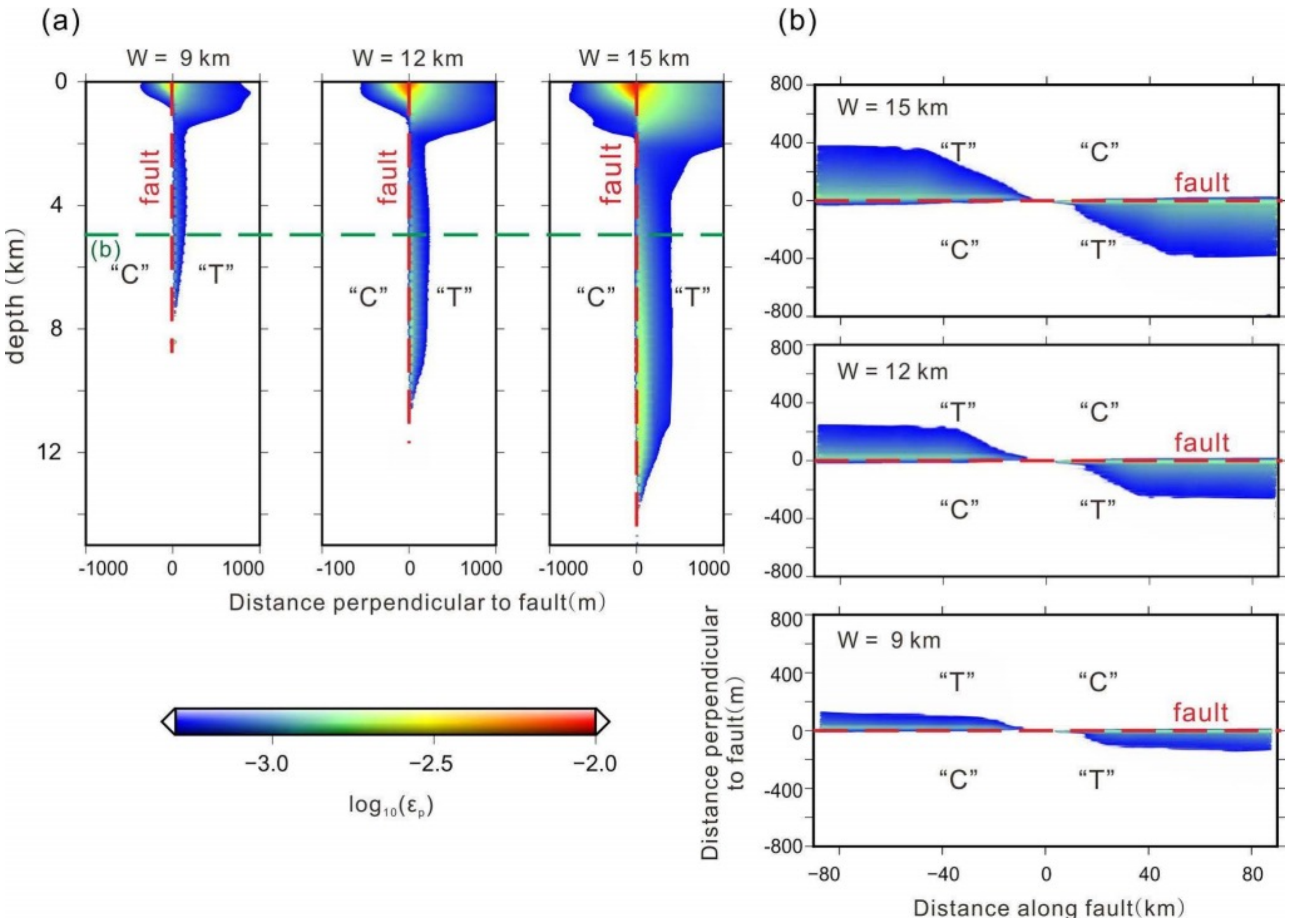
- Savage and Brodsky [2011]
  e.g. fault historic displacement
  ∝ fault damage zone width



Implications: fault depth

- Faults here are shallow
- Immature faults also have well established damage zones





Ampuero & Mao, 2017

Implications: shallow slip deficit

- We found ~29% SSD from the 2019 Ridgecrest earthquakes.

Hypotheses:
(1) Shallow slip occurs on shallow fault at other times in the earthquake cycle.
(2) Shallow slip is taken up on other distributed structures.

- Compared to the total cumulative slip on the main fault, the summed total deformation on the fractures is a very small (~4%).
- Based on the conceptual model, these faults has to be aseismically releasing strain over the interseismic period.
- Strain partitioned differently with depth?
- Strain partitioning related to the major fault maturity?

Takeaways

- Hundreds of unmapped faults are revealed by the Sentinel-1 satellites surrounding the 2019 Ridgecrest earthquake ruptures.

- A large number of these faults have displacement in the direction opposite to the prevailing tectonic stress.

- The mechanism for prograde and retrograde displacement are different, i.e. frictional slip for prograde and compliant fault deformation for retrograde.

- These are in-situ records that immature faults also have well established fault damage zones.

- These fractures, might account for the larger SSD (~29%) derived for the 2019 Ridgecrest earthquakes, and indicate a wider distribution of shallow strain over the region.