FDHI Monthly Meeting

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Constrain Near-Surface Fault Displacement Using Dynamic Rupture Simulation

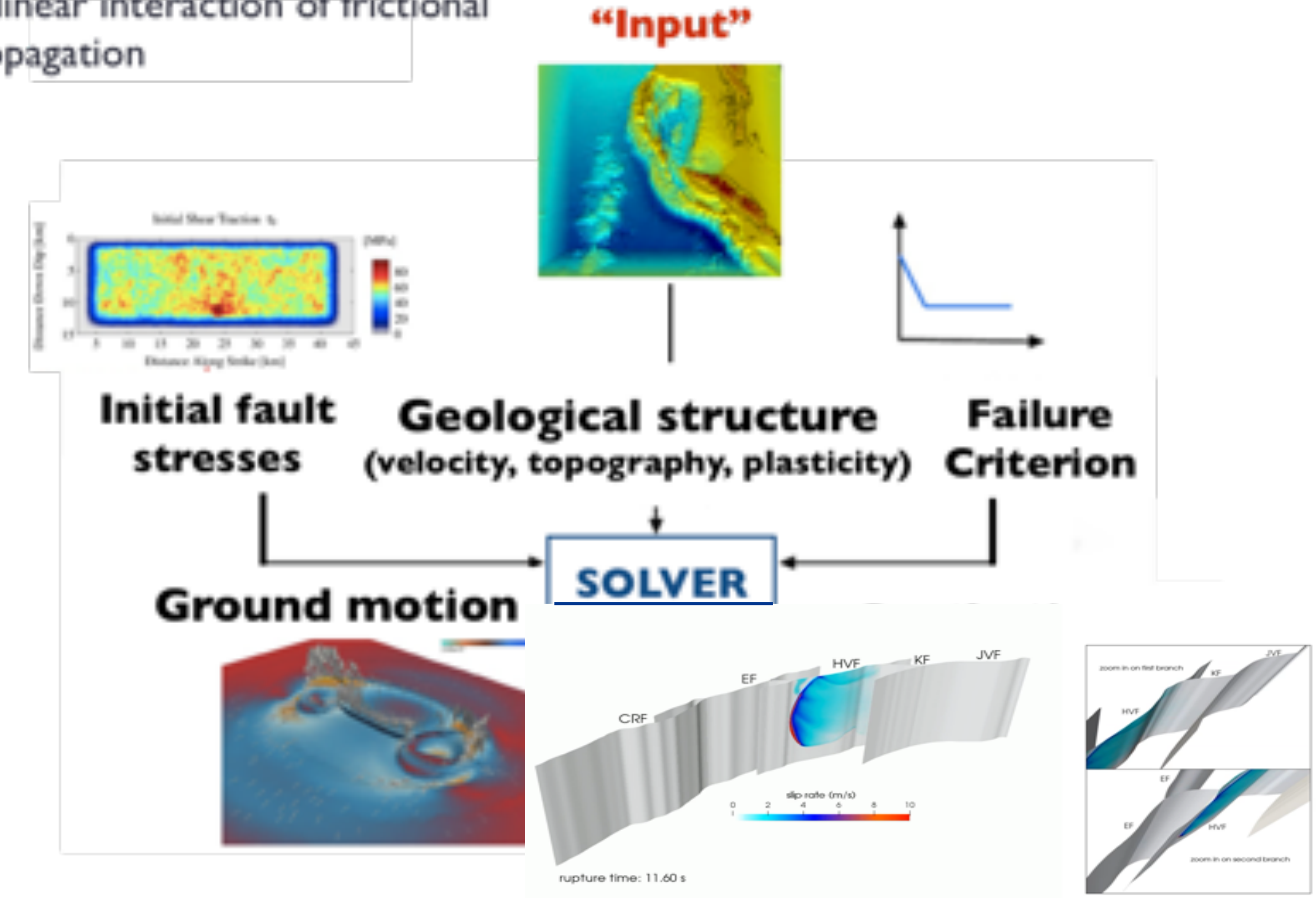
Yongfei Wang, Post-doctoral Researcher
Christine Goulet, Executive Director for Applied Science

Southern California Earthquake Center
University of Southern California

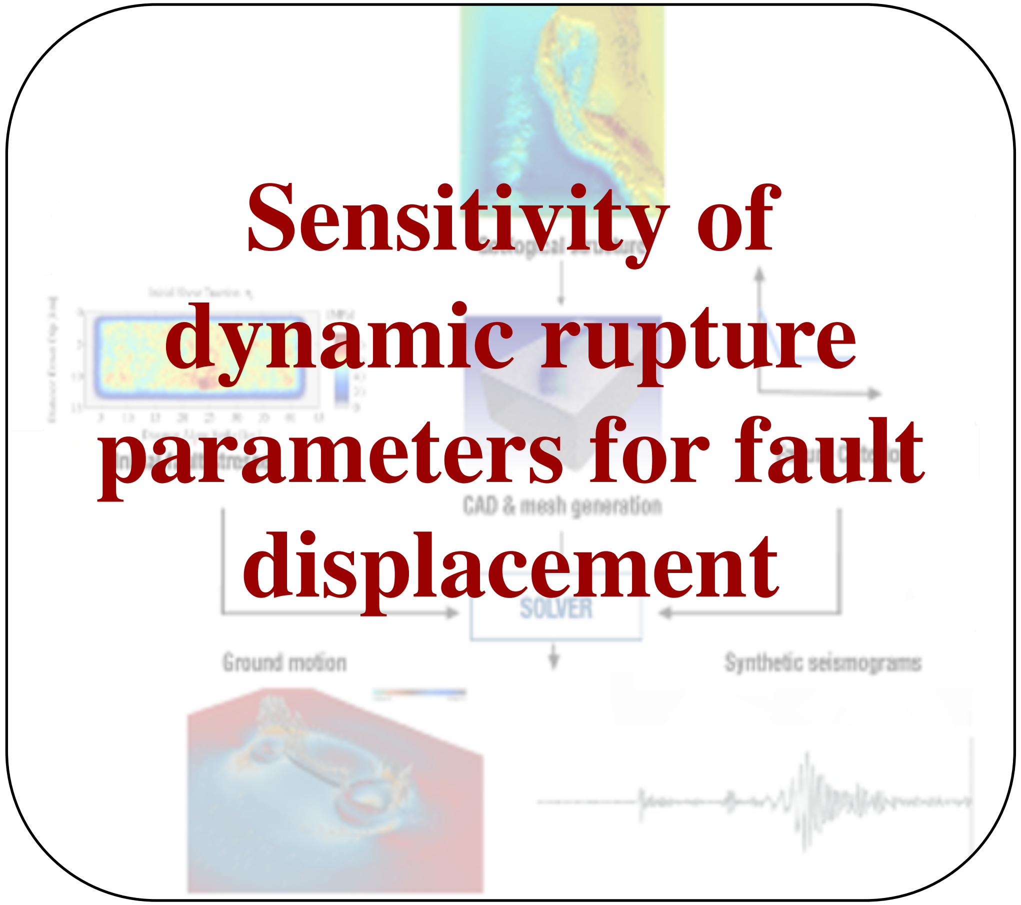
June 12th, 2020

Framework of dynamic rupture simulation

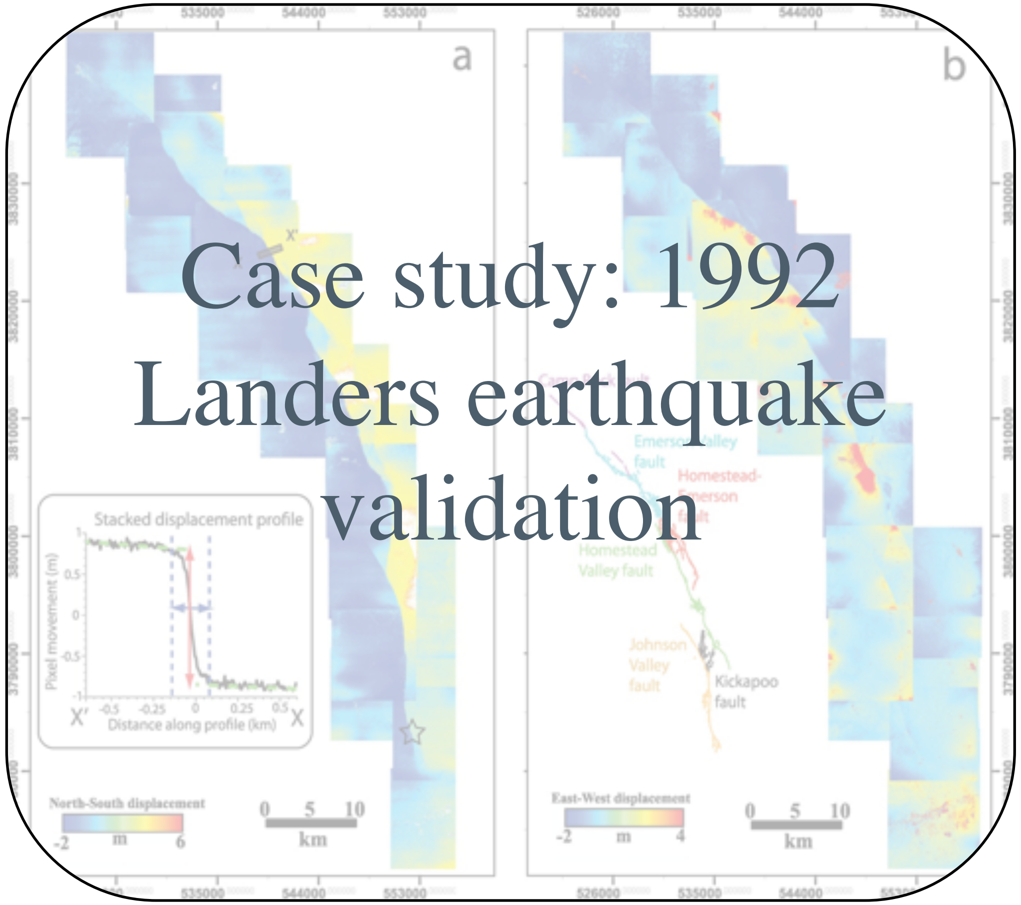
- **Physics-based approach:** Solving for spontaneous dynamic earthquake rupture as non-linear interaction of frictional failure and seismic wave propagation



Wollherr et al, 2019



Sensitivity of dynamic rupture parameters for fault displacement



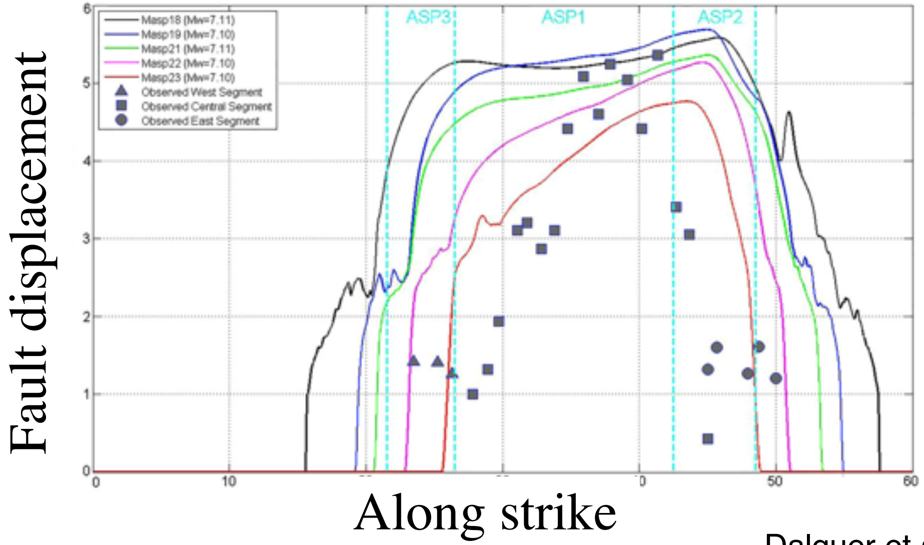
Case study: 1992 Landers earthquake validation

Where are we now?

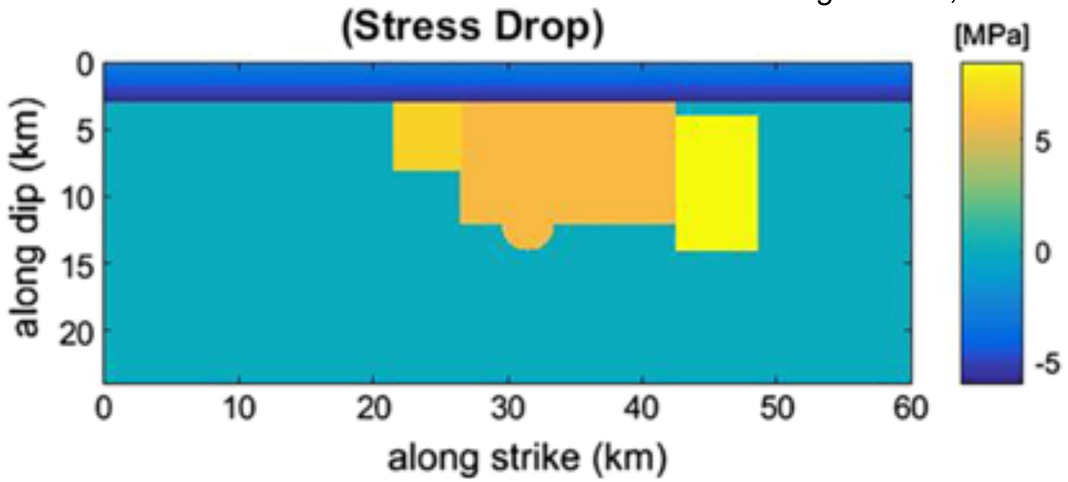
A woman stands near the 1906 ground rupture northwest of Olema in Marin County.
J. B. Macelwane Archives, Saint Louis University

Unlike ground motions, we have very limited knowledge of how and how much the fault displacements are physically influenced by faults and surrounding media.

Near-surface stress asperities



Dalguer et al, 2019



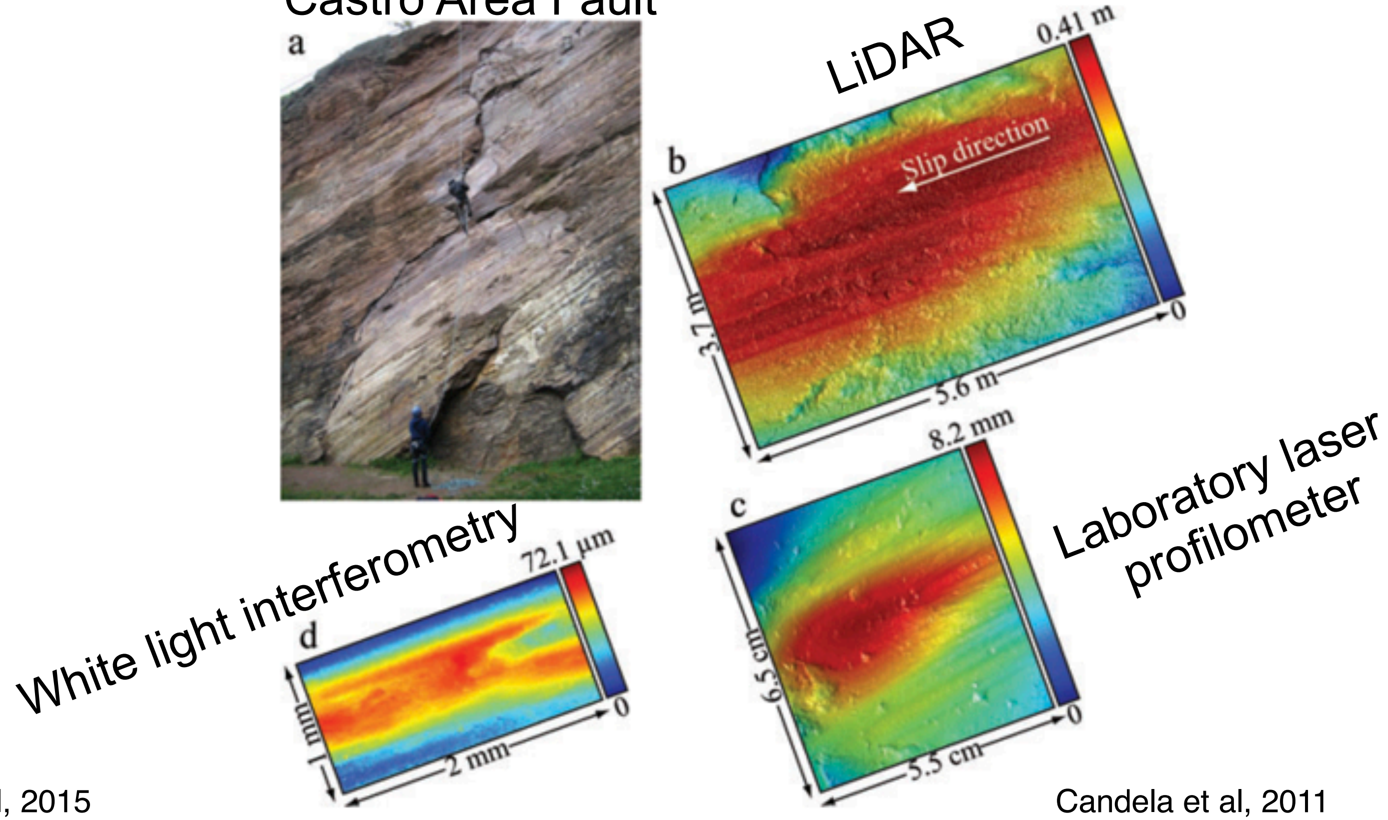
Stress asperities physically lead to first-order fault displacements (smooth curve)

Near-surface fault geometry

1992 Landers

Milliner et al, 2015

Castro Area Fault

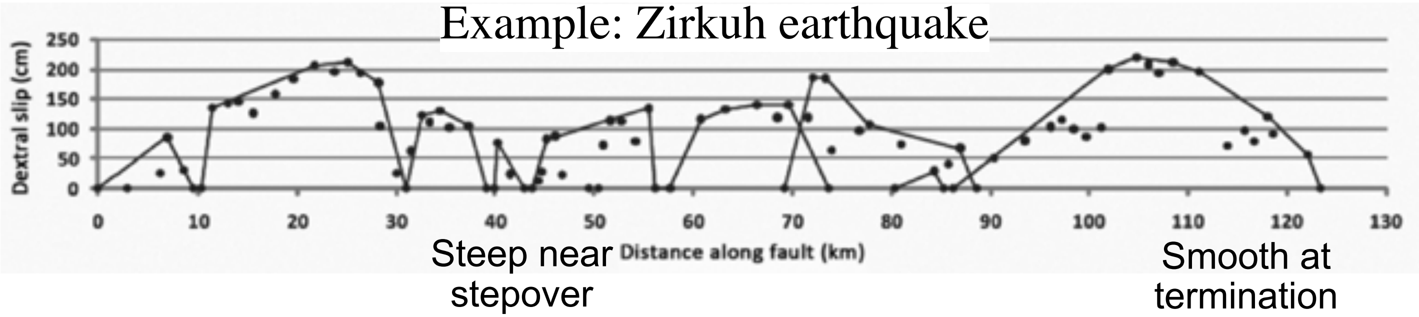


Candela et al, 2011

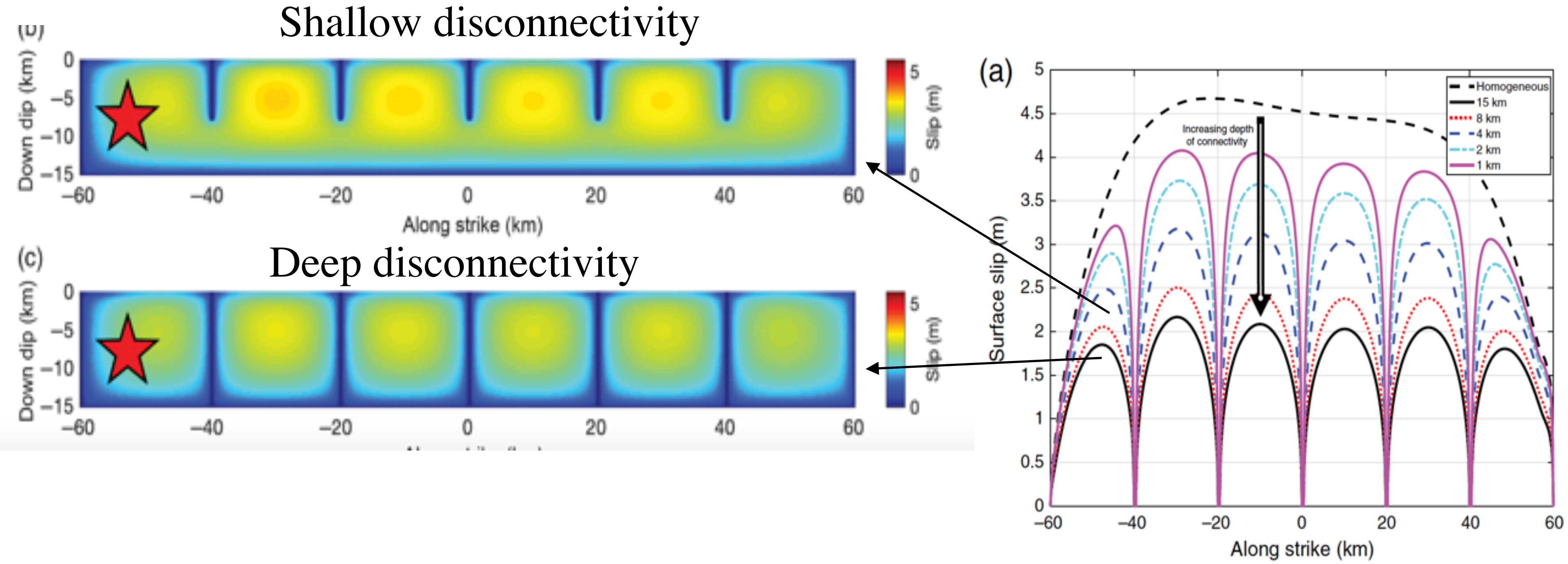
Multi-scale fault roughness

Geometrical complexities (segmentation, branch, roughness etc.) may introduce fault-displacement complexities

Fault connectivity at depth



Higher **slip gradients** at the edges of stepovers **that are jumped** than at the edges of stepovers that **do not show evidence of being jumped** *(Elliott et al., 2009)*

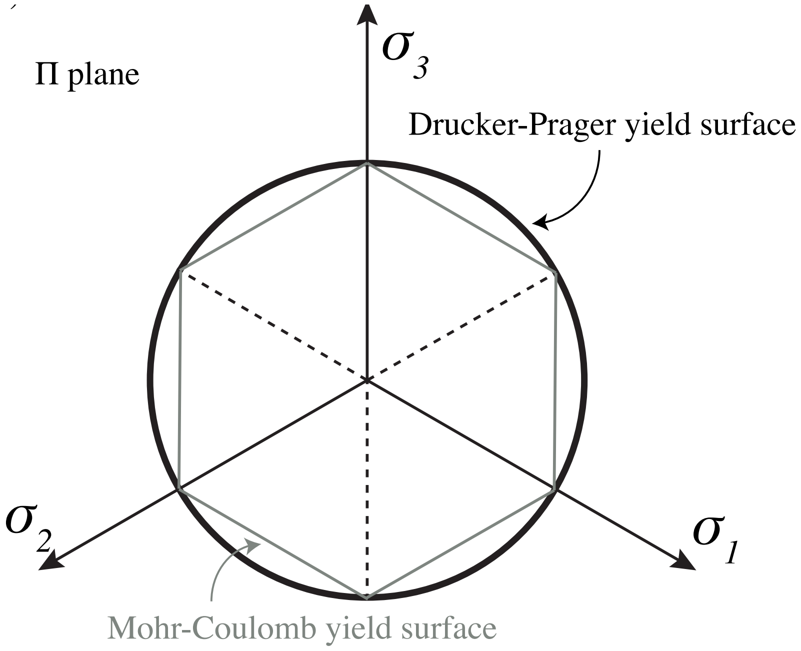


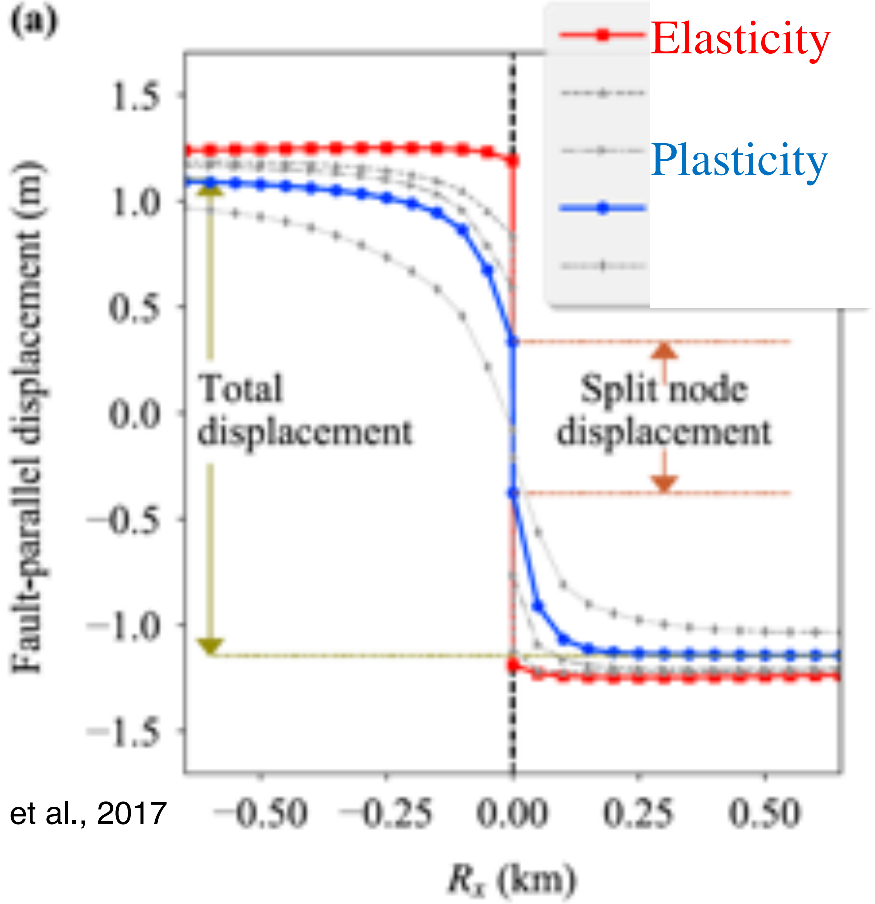
Oglesby, 2020

Fault connectivity at depth affects gradient of fault displacement on ground surface. Steep ground slip gradient may indicate shallow disconnectivity

Off-fault inelasticity: plasticity and microfracture

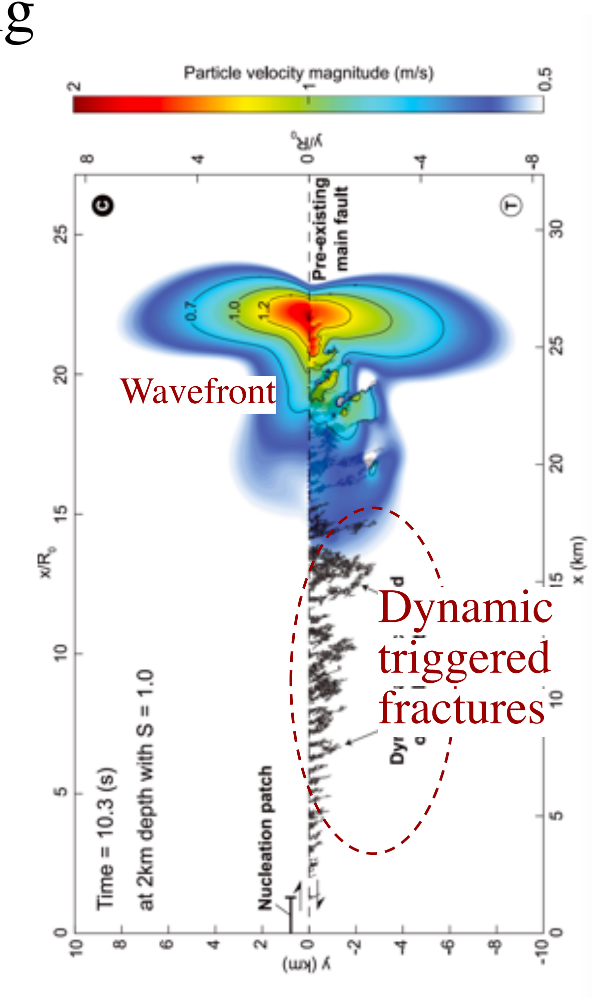
Plasticity can mimic observed off-fault displacement and microfracture can also mimic off-fault deformation and distributed faulting



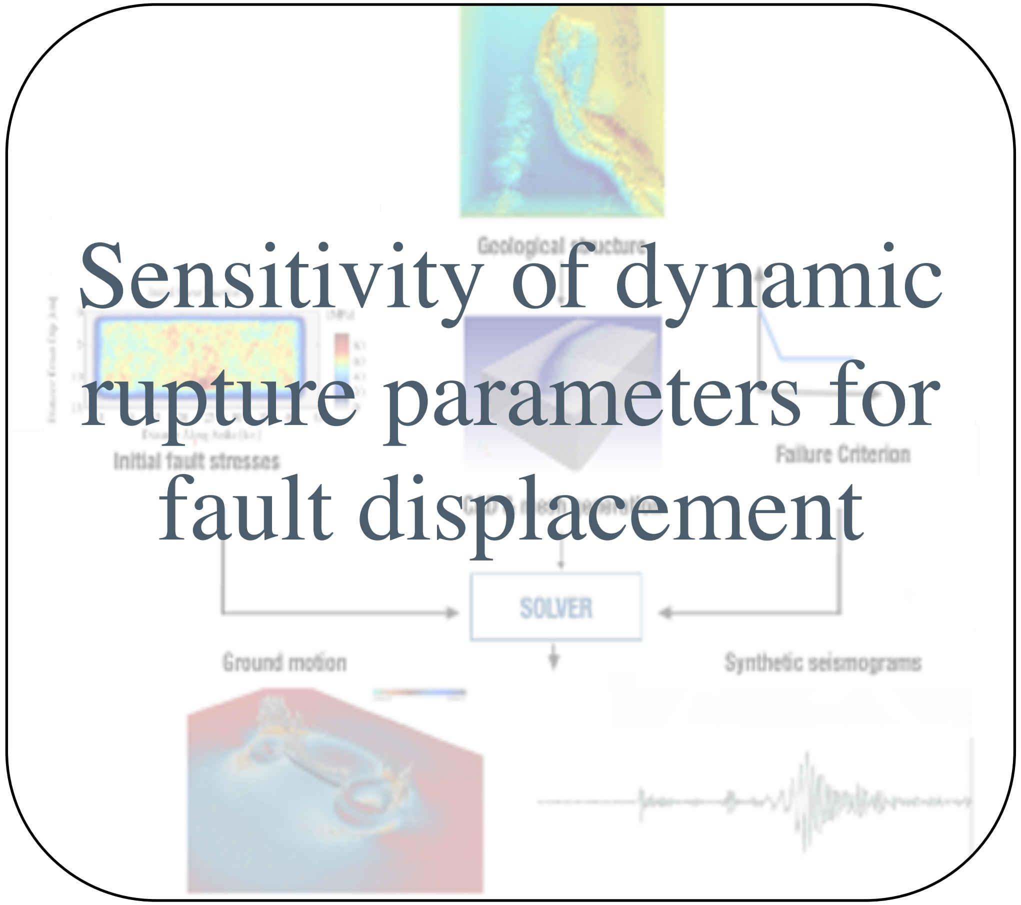


Roten et al., 2017

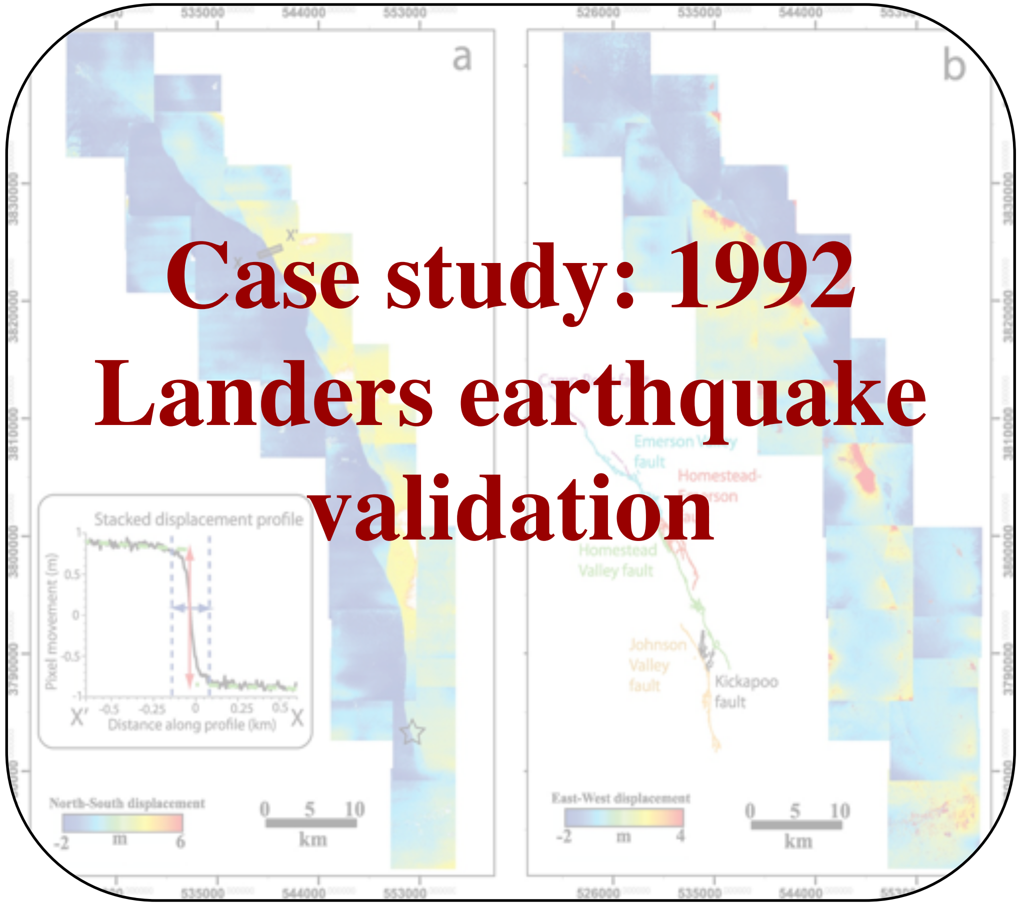
Simulated off-fault displacement



Okubo et al, 2019

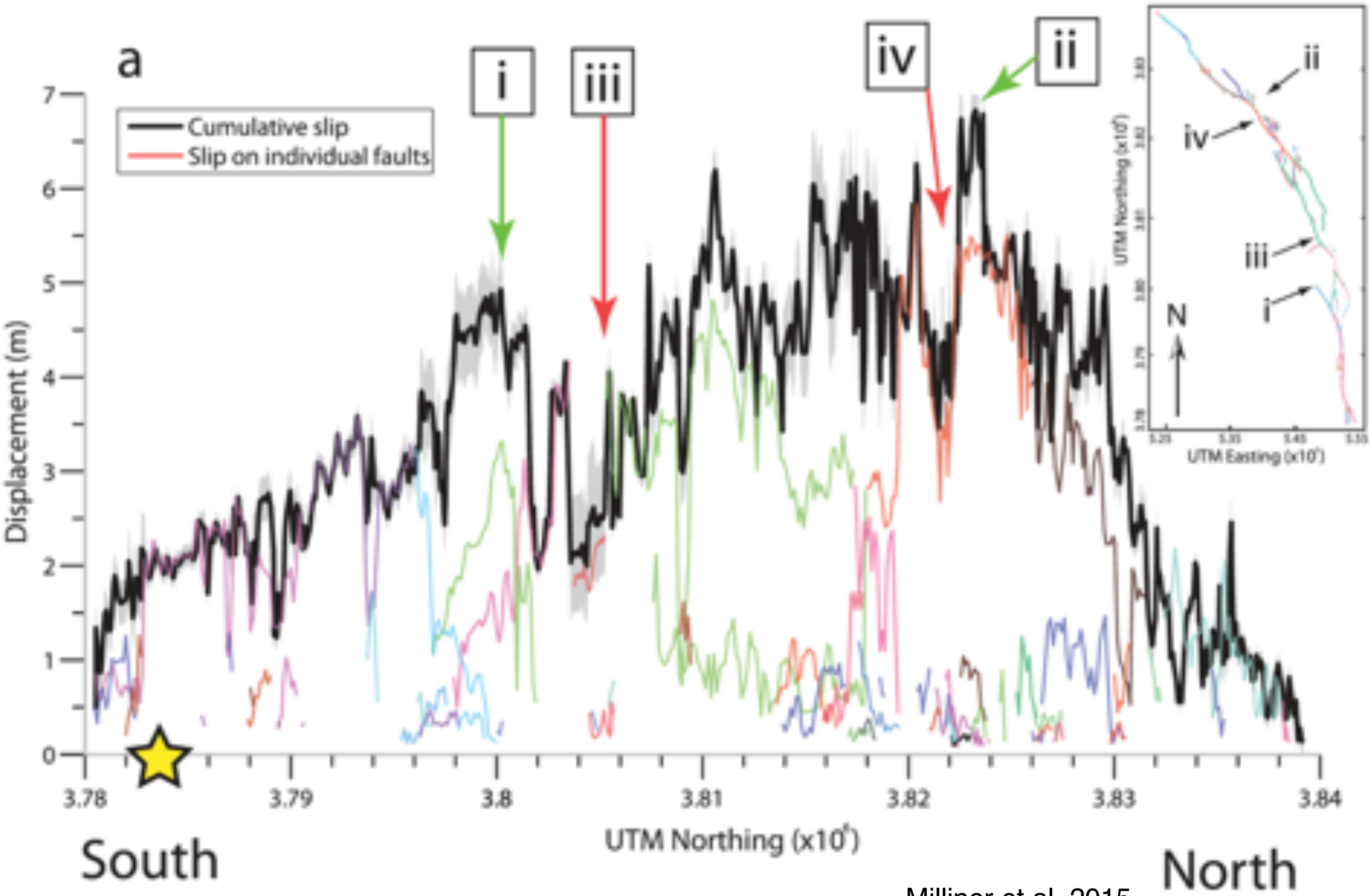


Sensitivity of dynamic rupture parameters for fault displacement



Case study: 1992 Landers earthquake validation

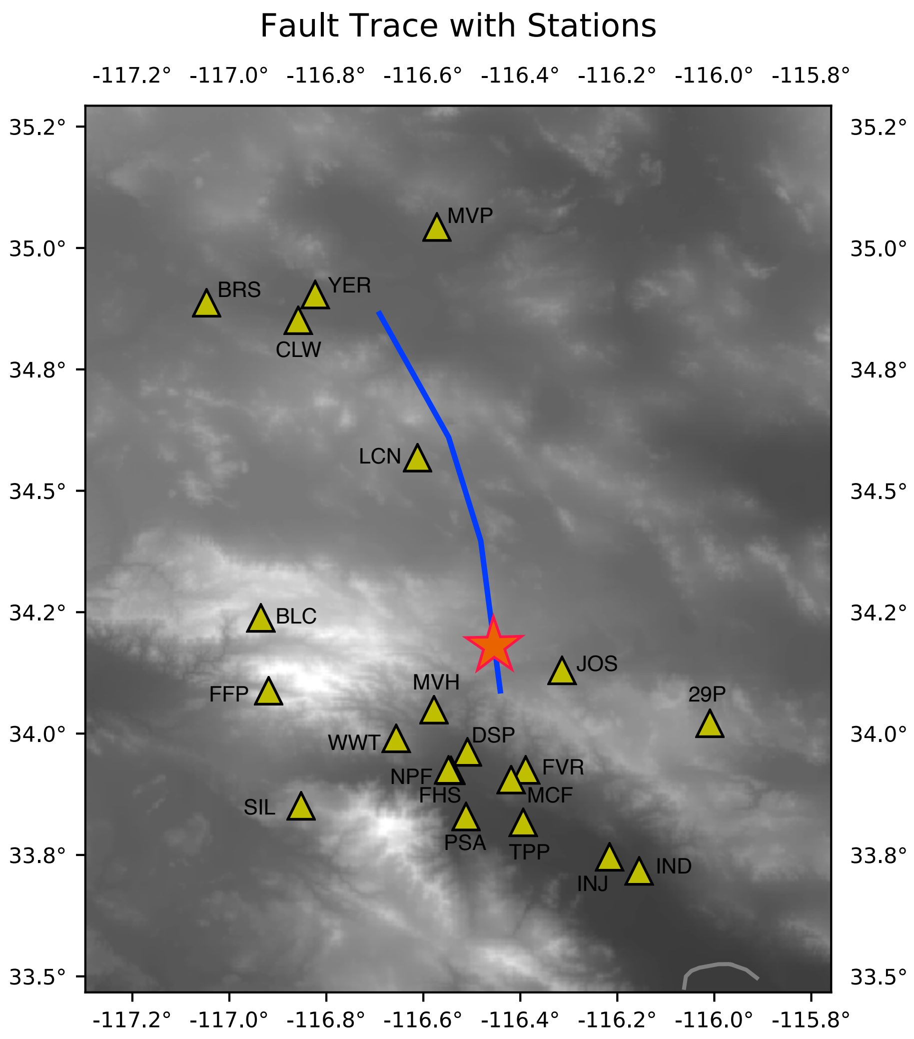
Why Landers?

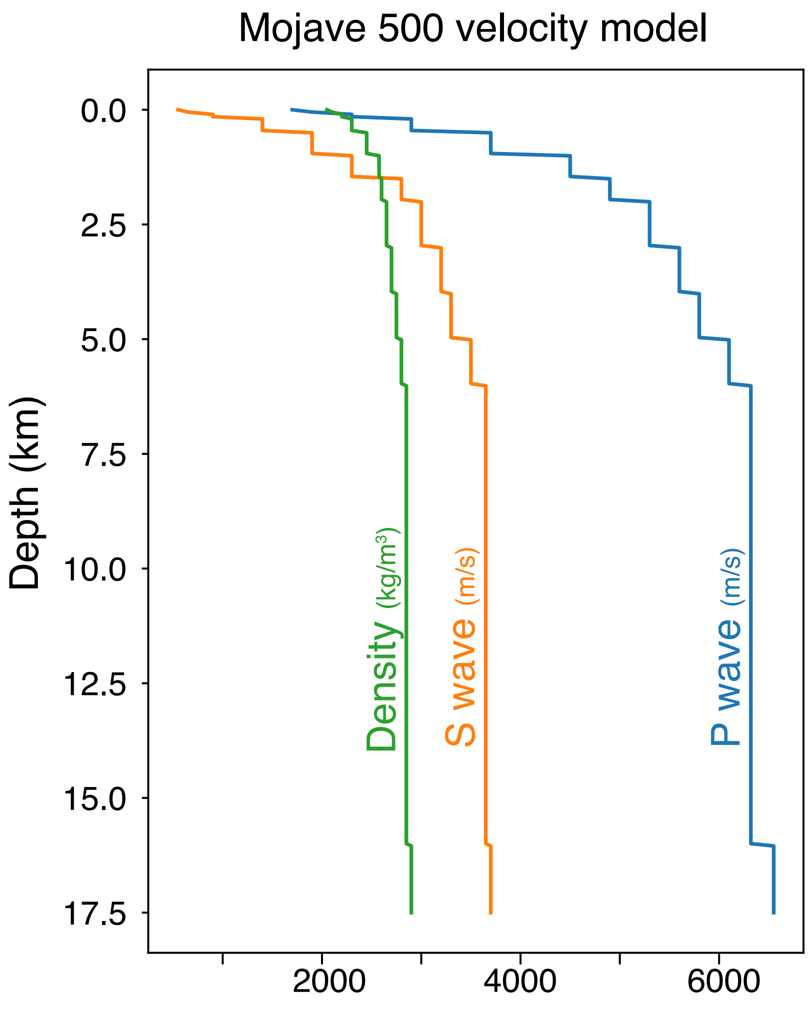


Milliner et al, 2015

- Best documented case (maybe before Ridgecrest EQ?): abundant near-field observations (e.g., fault displacement, ground motion, aerial imaging).
- Input parameters of our dynamic rupture have been widely explored (e.g., fault zone width, fault geometry and velocity structure)

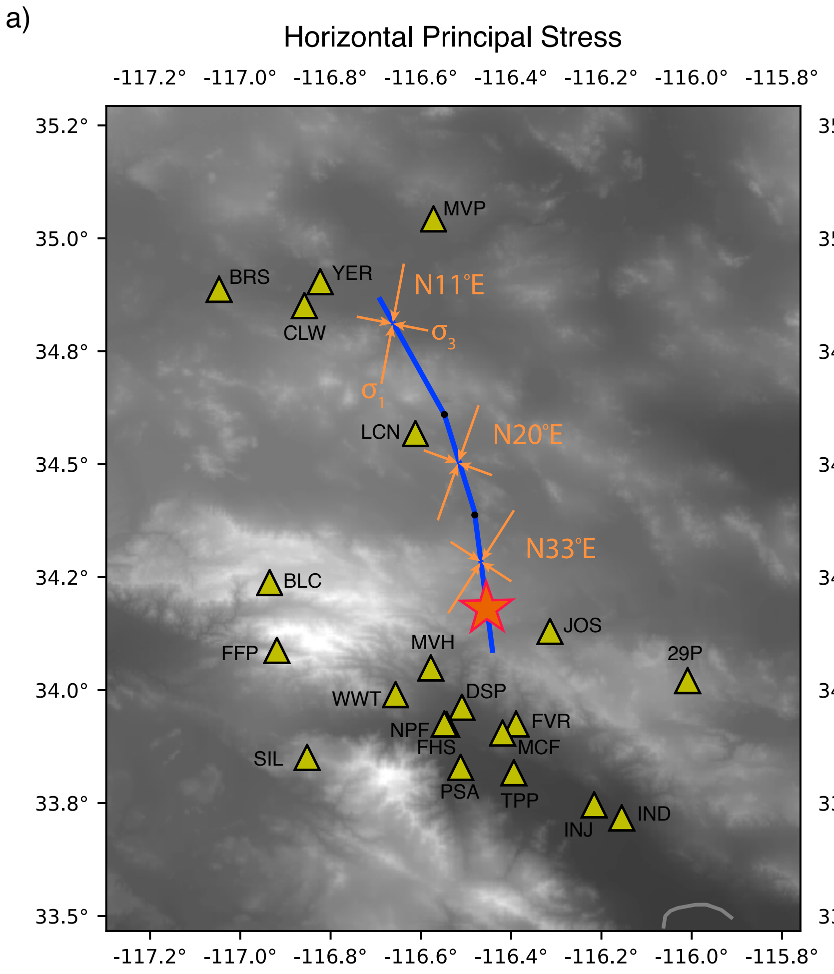
Fault geometry and velocity model

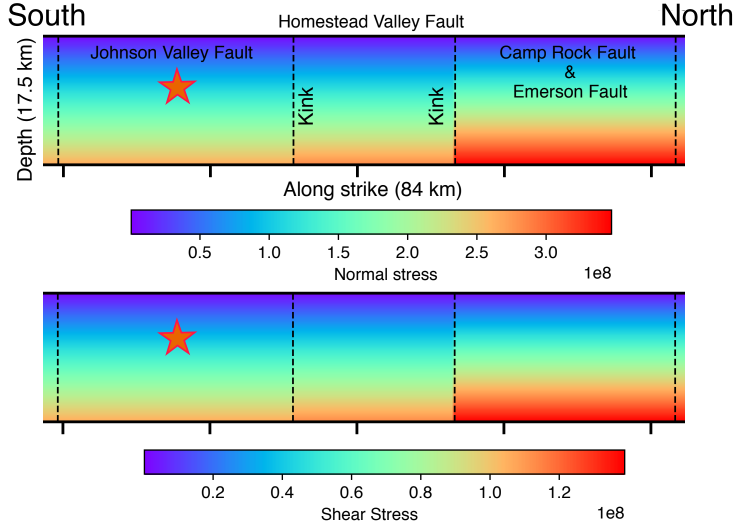




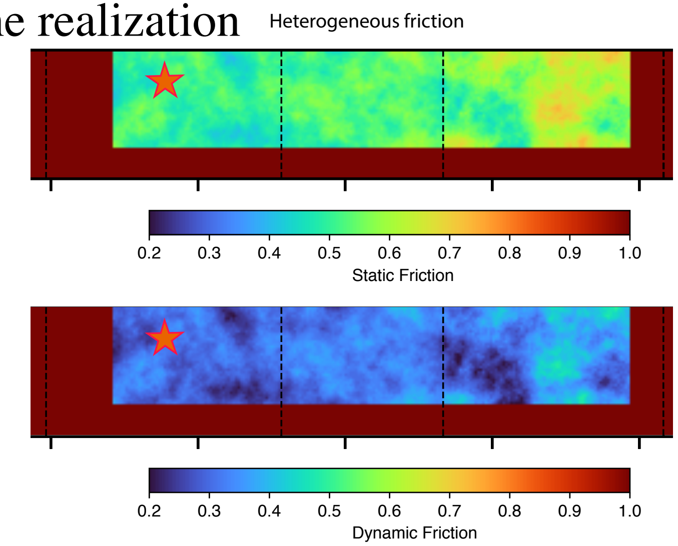
- 3-segmented planar fault geometry
- 21 ground-motion stations for sanity check
- 1D velocity structure
- No scatter/attenuation involved
- Grid size = 50 m (a very fine grid in dynamic rupture models)
- Simulate up to 1Hz waveforms

Prestress and friction

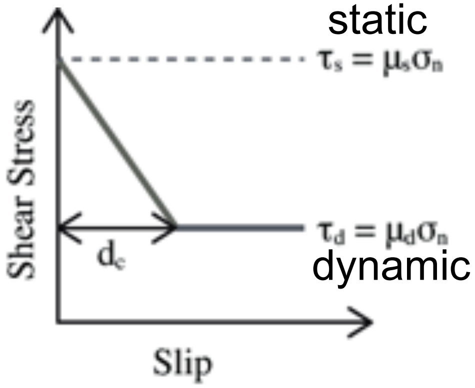




One realization

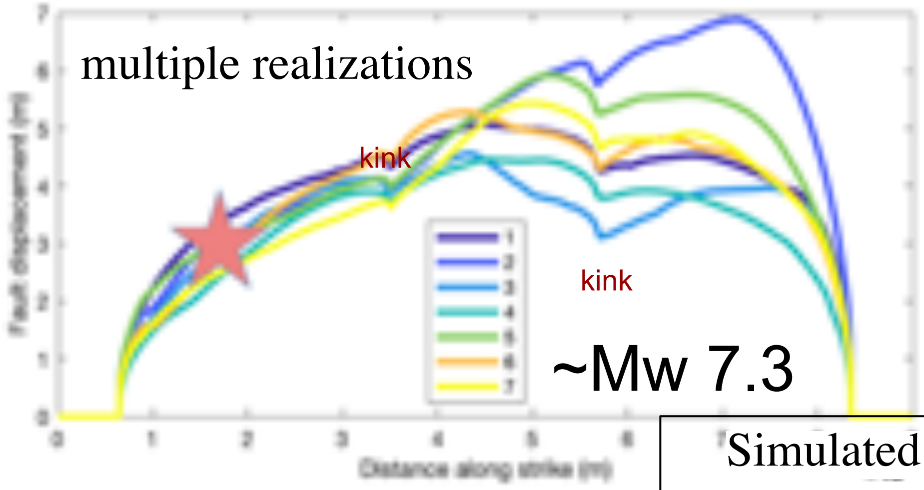


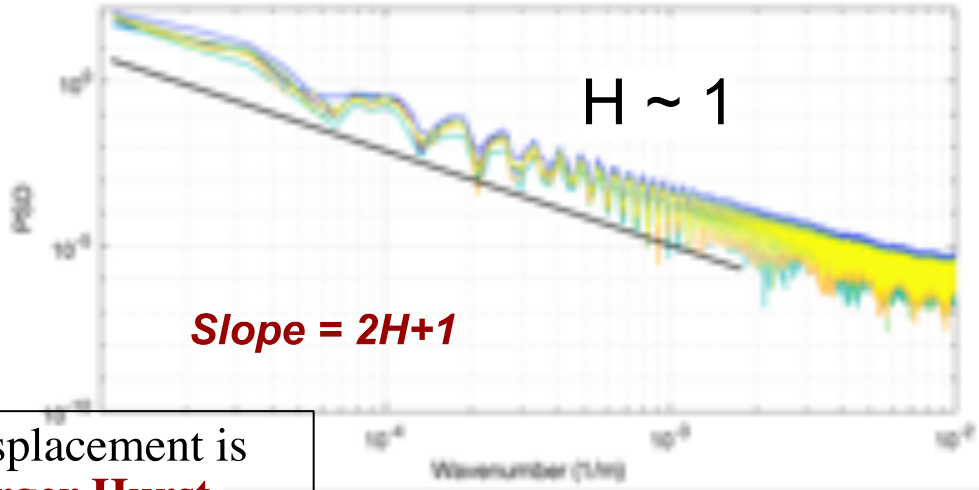
Slip weakening Friction



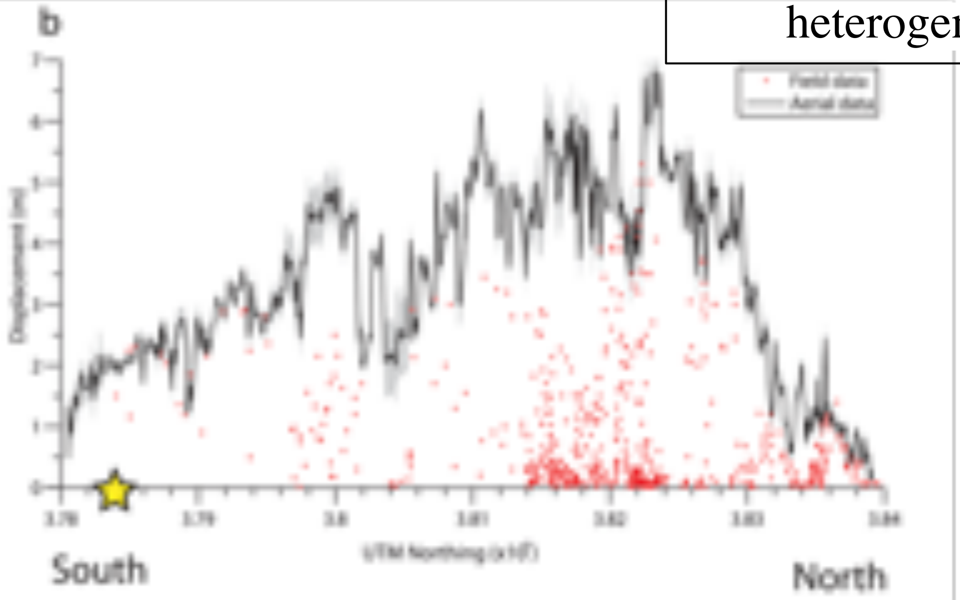
- Depth-dependent prestress is created from fault orientation and **stress model (e.g., SCEC CSM)**
- Ratio between shear and normal stress is constant over the whole fault
- **Heterogeneous prescribed stress drop**

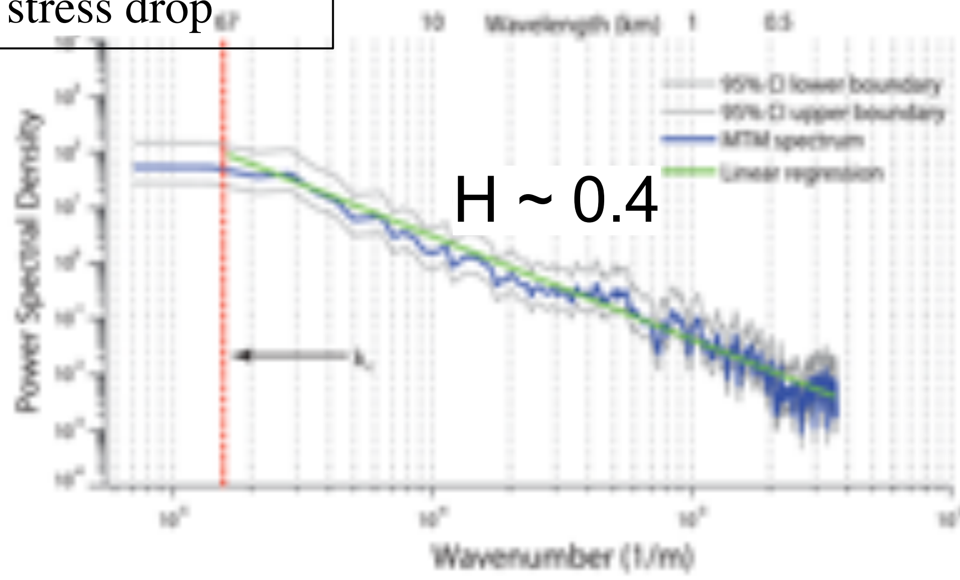
Validation by PSD slope (Hurst exponent)



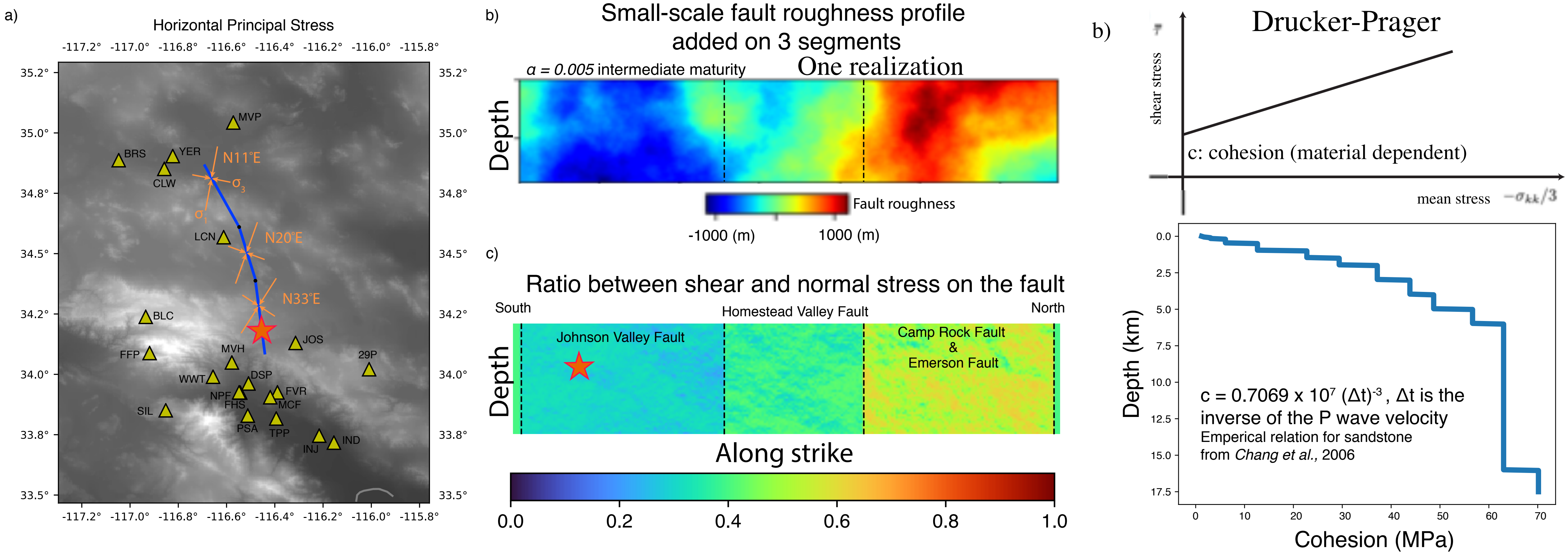


Simulated fault displacement is very **smooth (larger Hurst exponent than of data)** even with heterogeneous stress drop



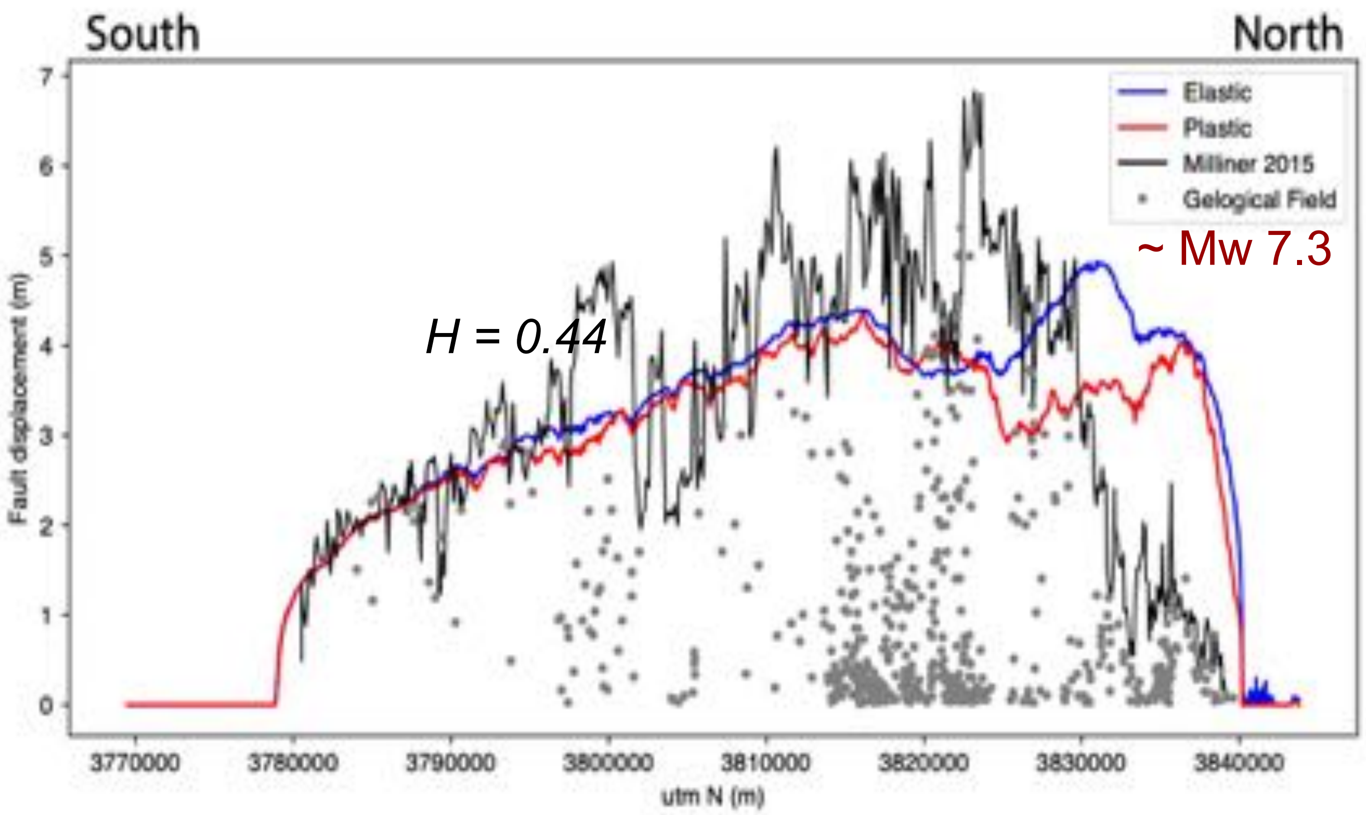


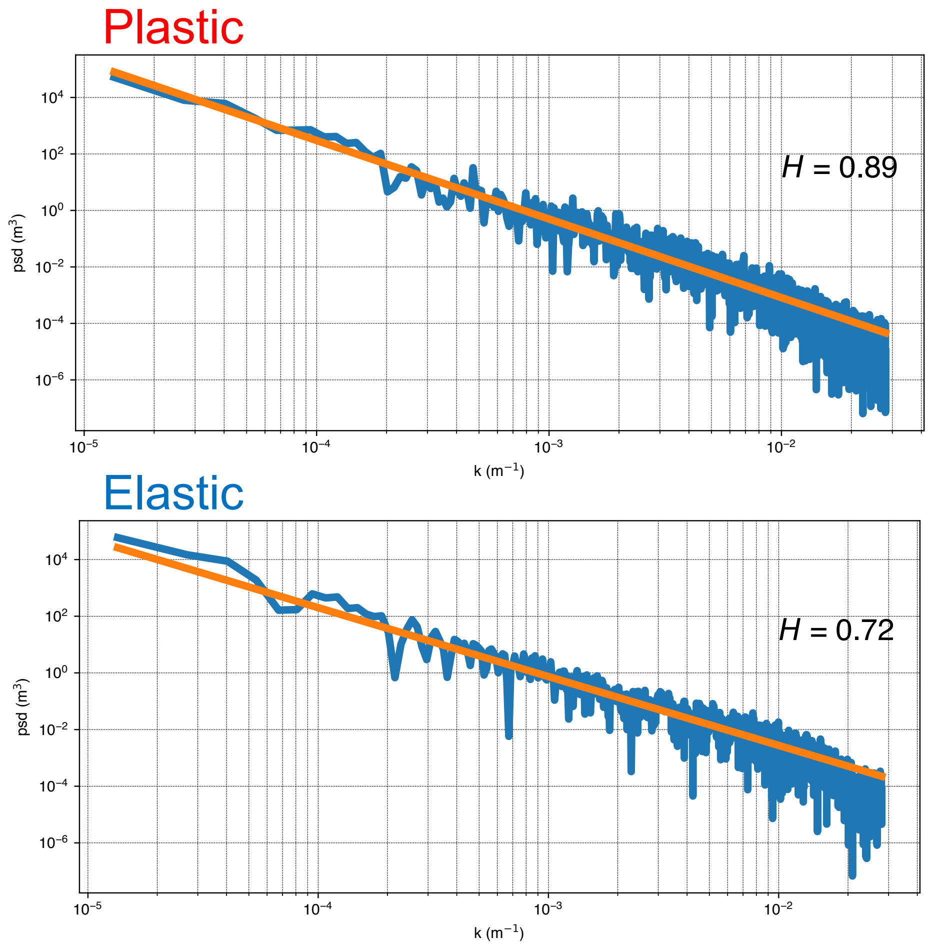
Add roughness + plasticity



We start with a simple self-similar rough fault and Drucker-Prager plasticity model. While they are simple, we can understand the **first-order on-fault geometrically rough and off-fault inelastic impacts**.

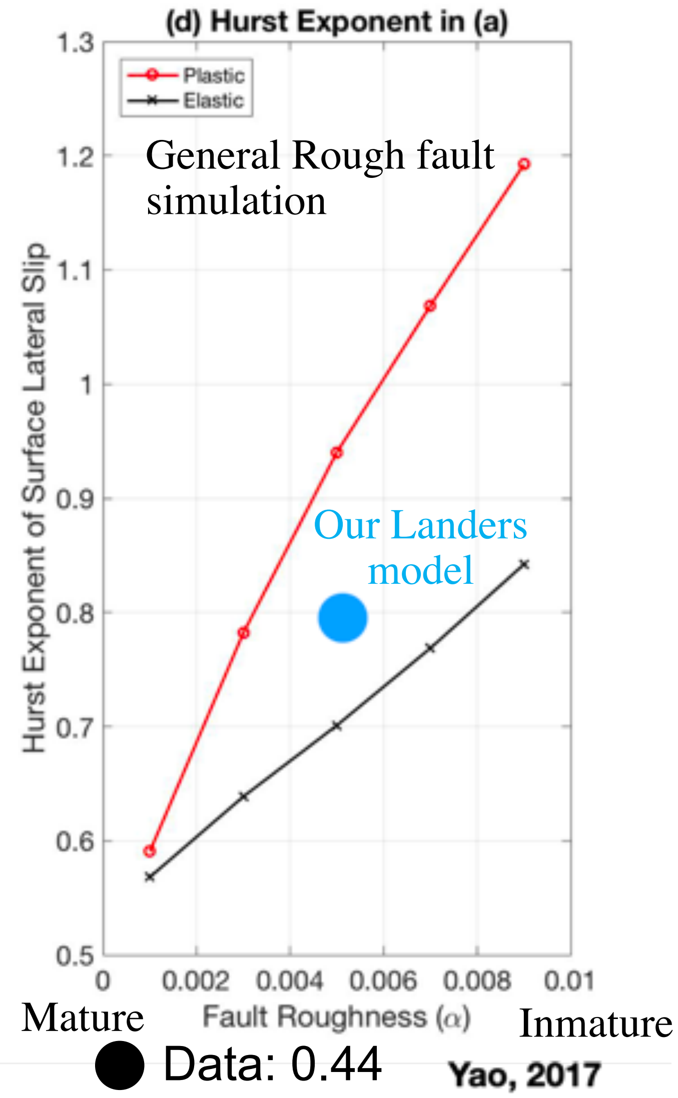
Simulated fault displacements

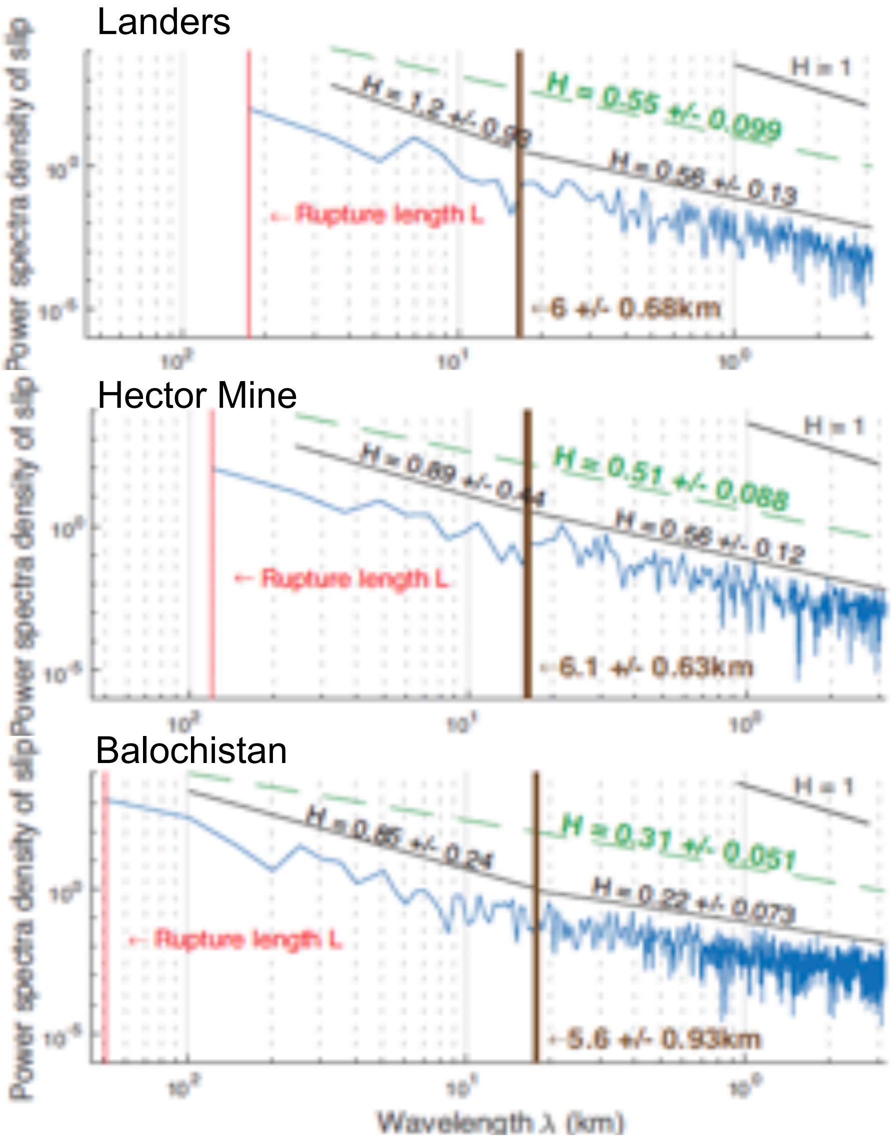




Fault roughness improves validation of PSD Hurst exponent but not sufficient.

Hurst exponent as a metric for validation?



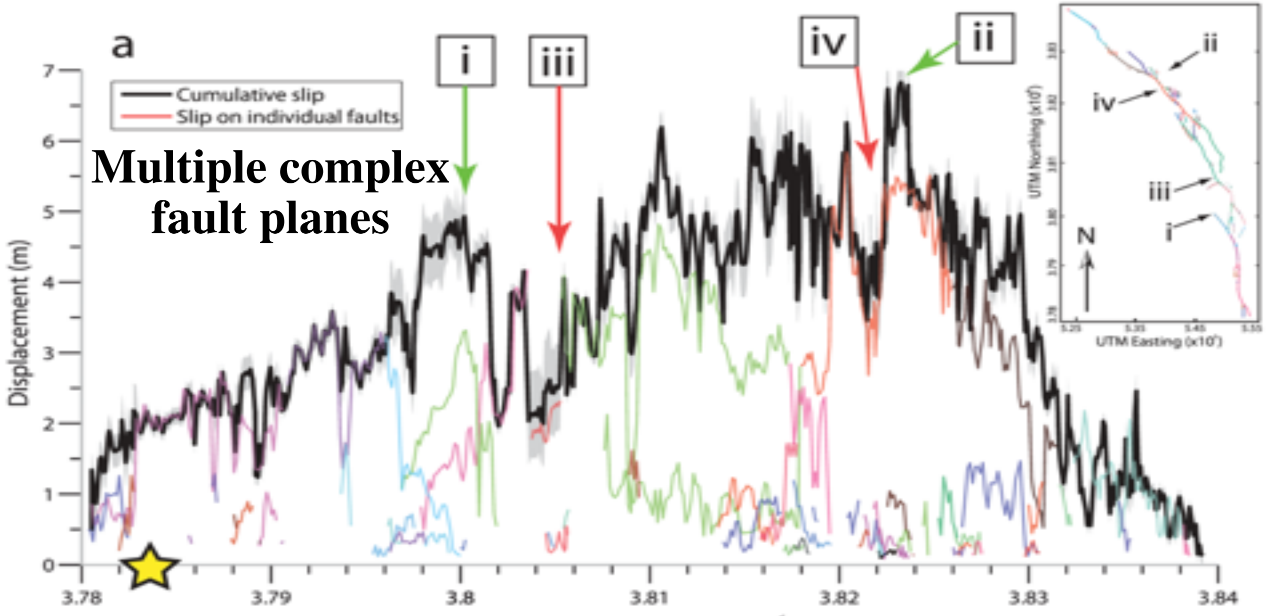


Bruhat et al 2020

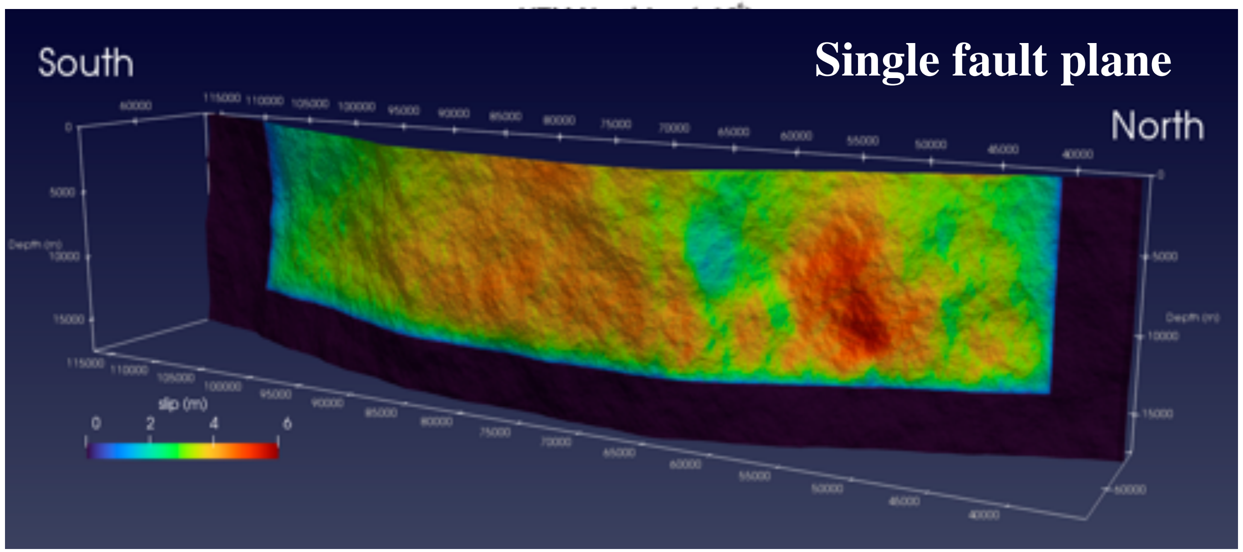
- **Two Hurst** components discovered in Landers, Hector Mine and Balochistan EQs
- Hurst exponents in our simulations are consistent with those in large wavelength
- **Minimal resolvable wavelength** by simulations? Is it related to biased geological measurements, classifications of principal and distributed faulting?

Hurst exponent as a metric?

Data

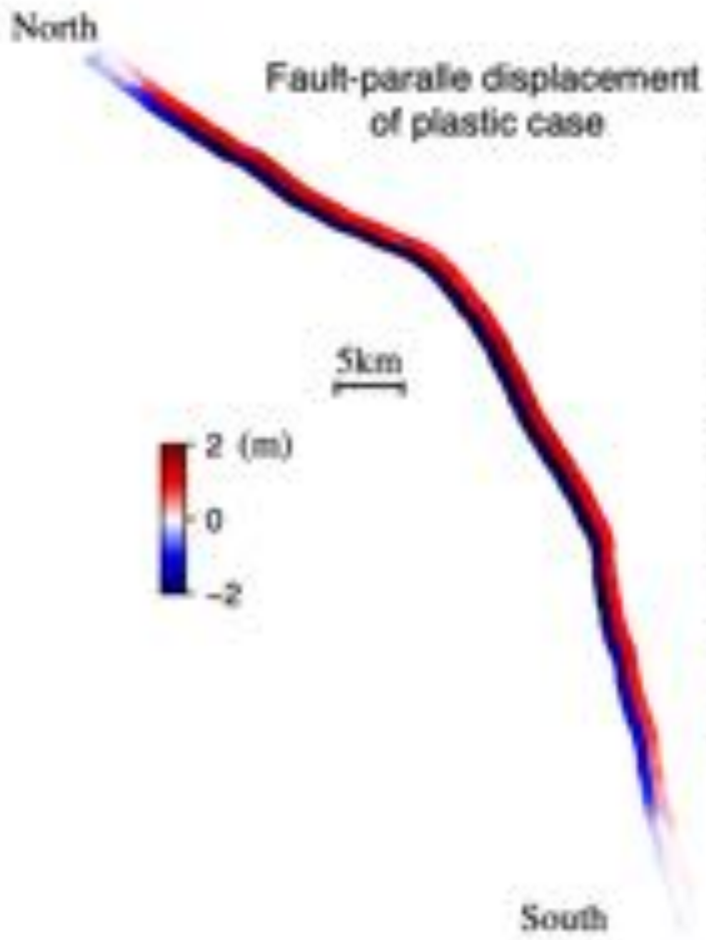


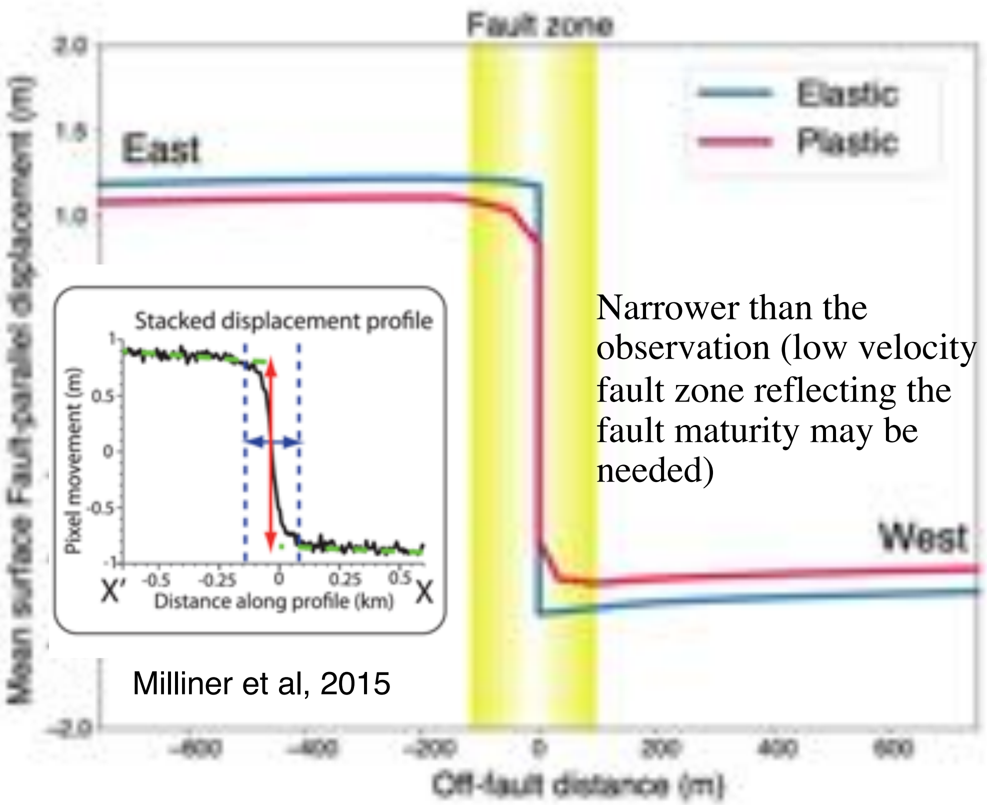
Our simulation



- **Two Hurst** components discovered in Landers, Hector Mine and Balochistan EQs
- Hurst exponents in our simulations are consistent with those in large wavelength
- **Minimal resolvable wavelength** by simulations? Is it related to biased geological measurements, classifications of principal and distributed faulting?
- How about looking at **isolated** contribution of **principal and distributed** fault in our database?
- Add more **off-fault secondary ruptures** in simulation for compensate small-scale deficiency?
- Our dataset may shed light on these !

Plastic case results in observed fault zone with off-fault coseismic deformation and reduces on-fault slip at shallow depth

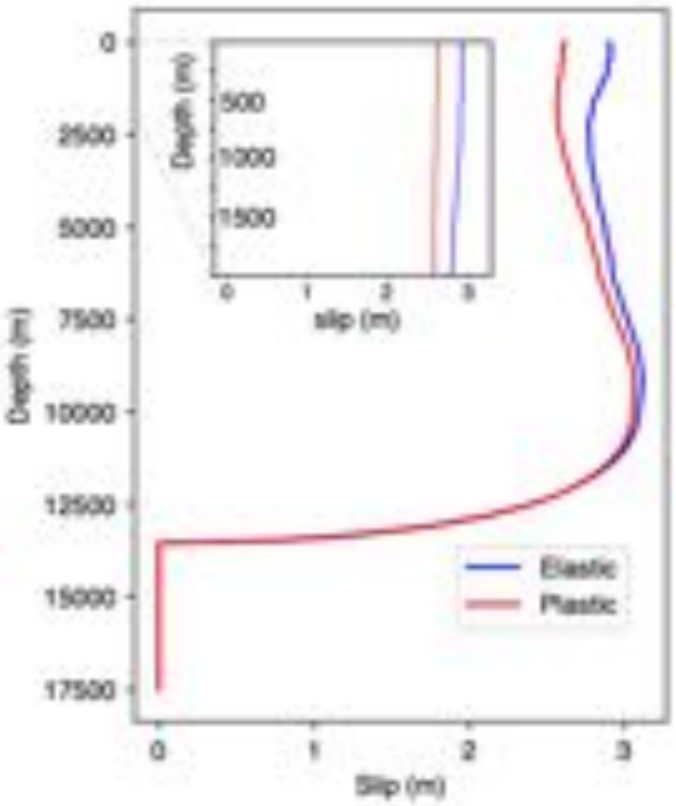




Narrower than the observation (low velocity fault zone reflecting the fault maturity may be needed)

Milliner et al, 2015

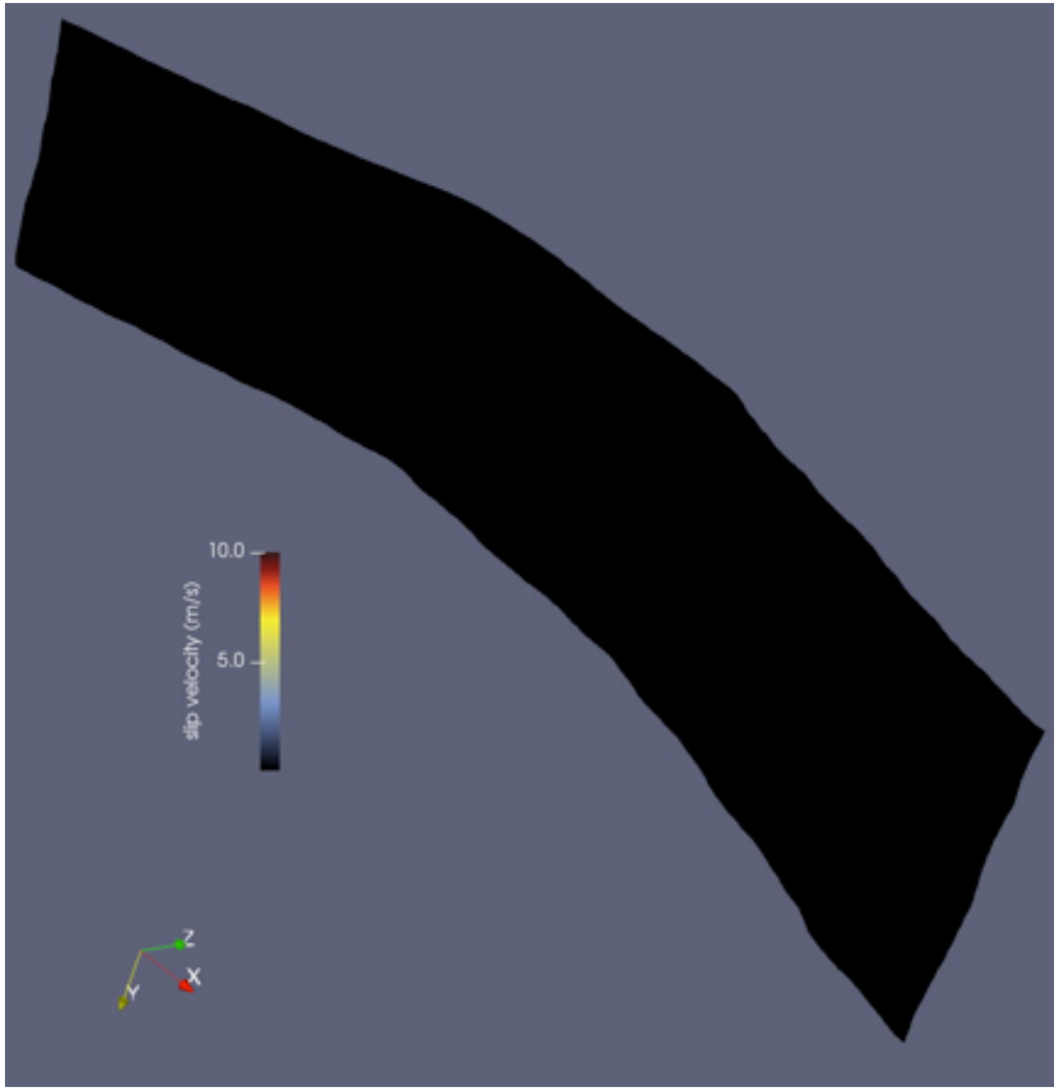
On-fault slip



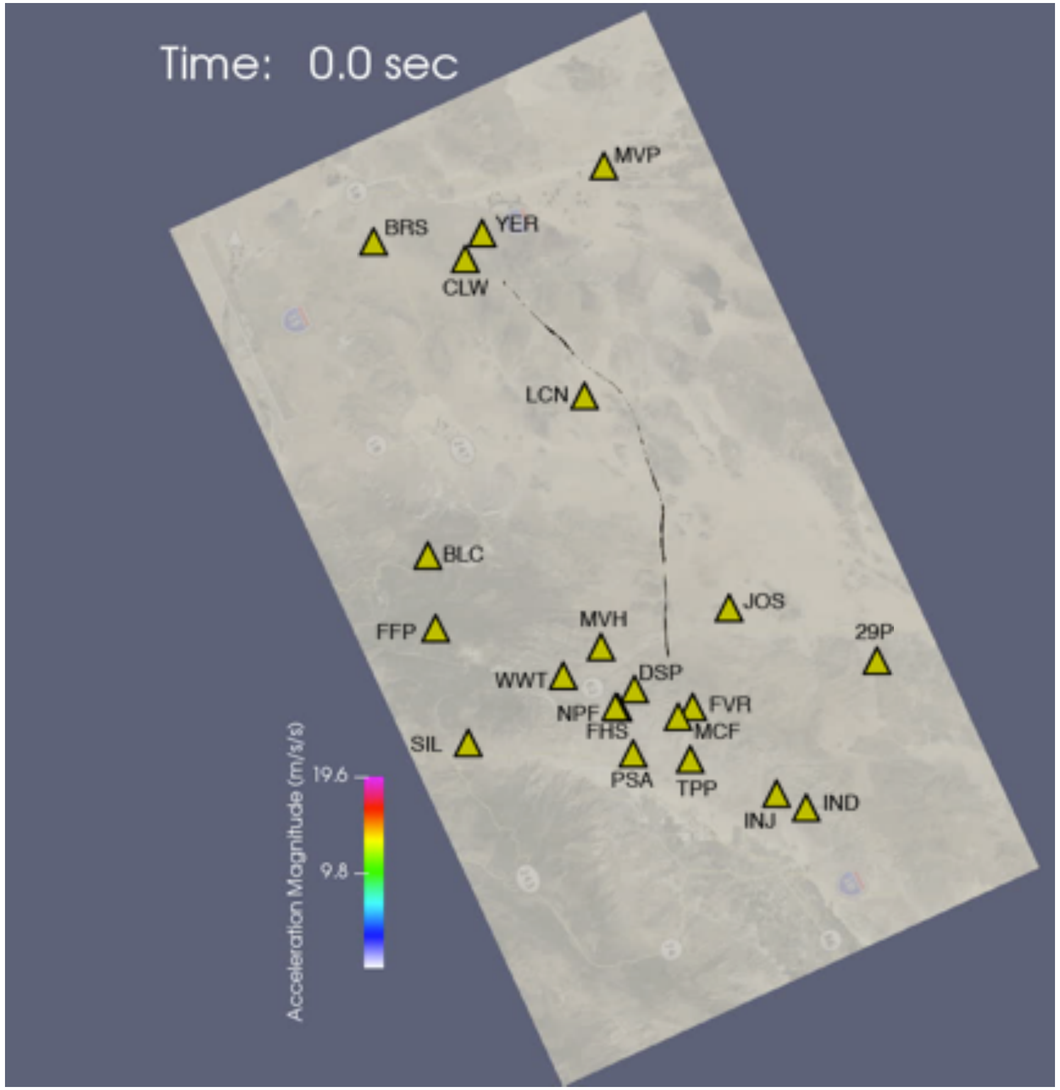
Can fault zone width distribution be constrained from the dataset?

Simulation animations

Rupture propagation on the fault

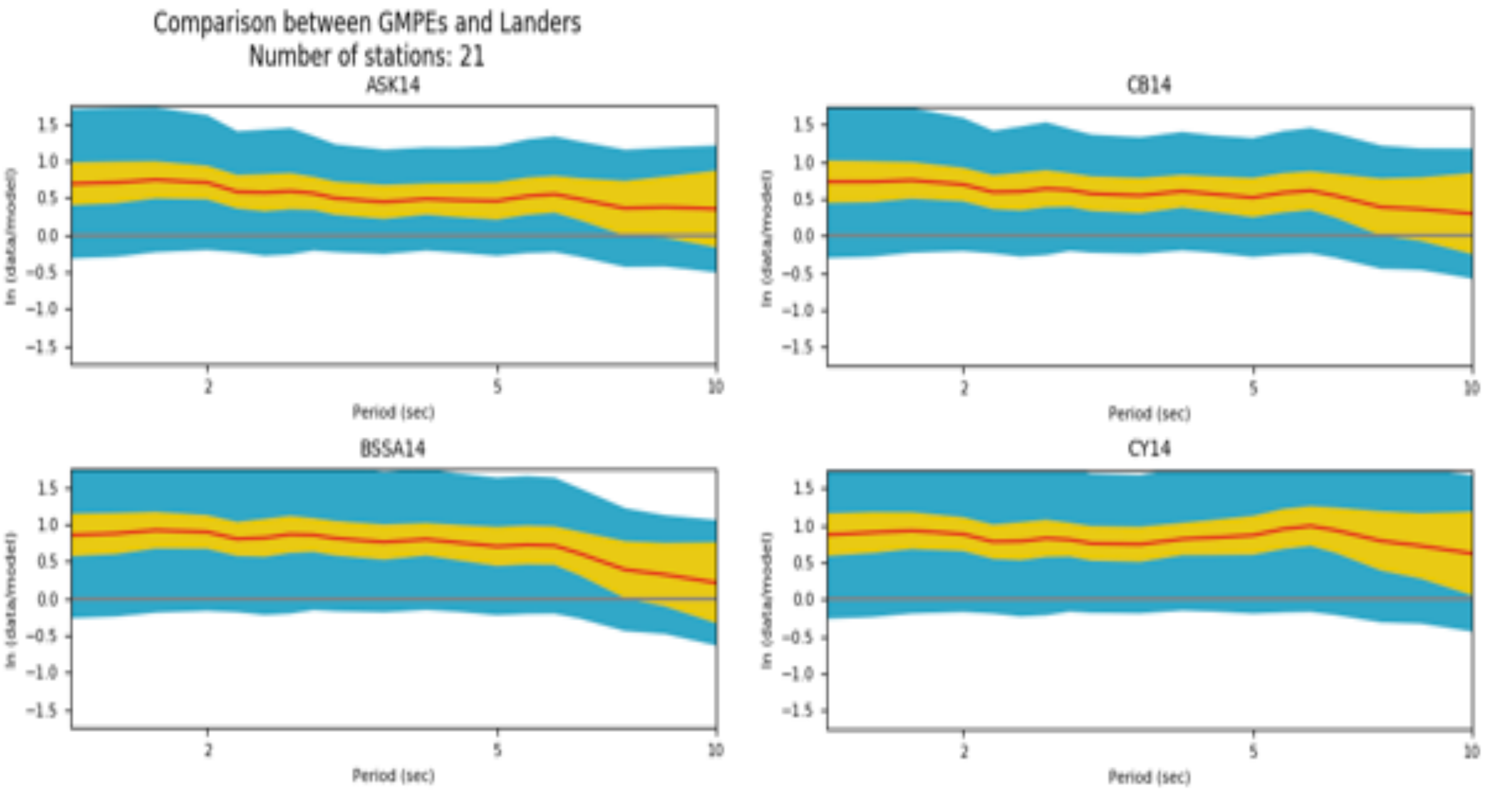


Seismic wave propagation on the ground

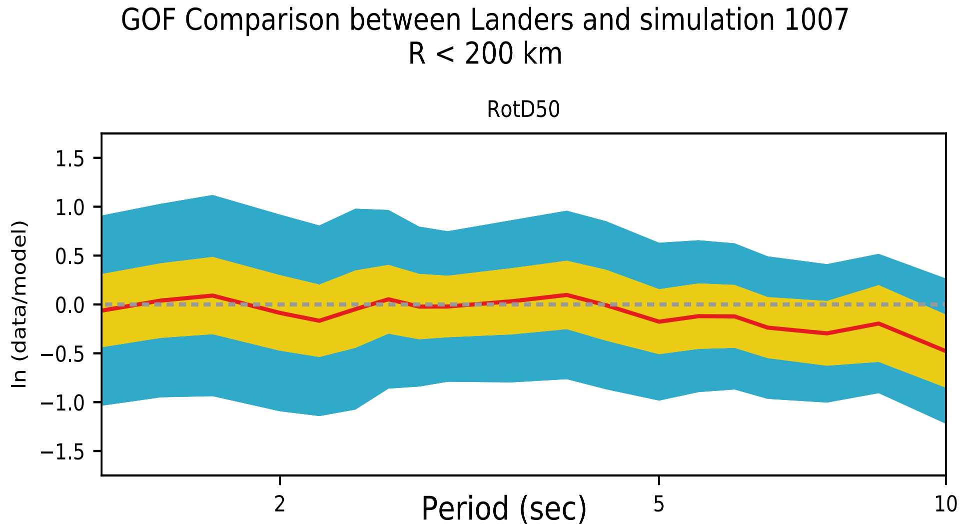


Ground-motion sanity check of Landers Scenario

Goodness of fit (GMPE vs Data)

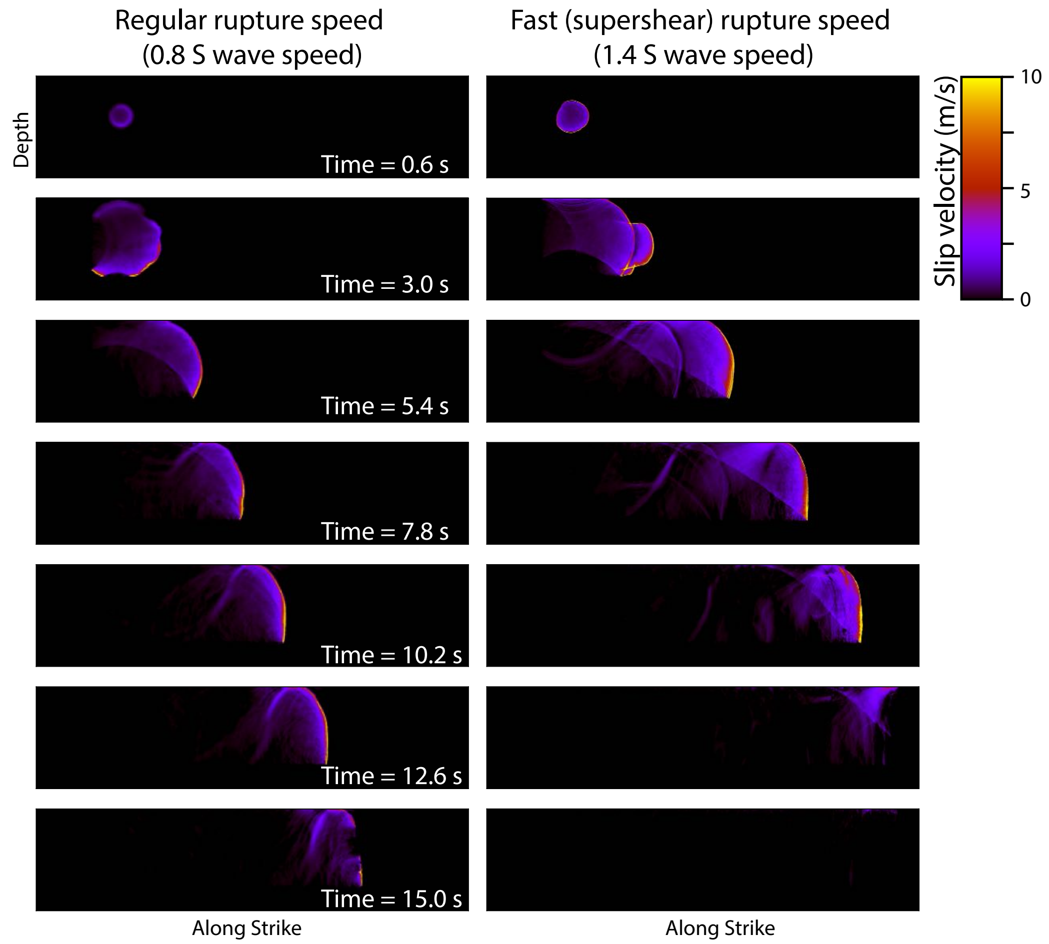


Goodness of fit (Dynamic rupture vs Data)

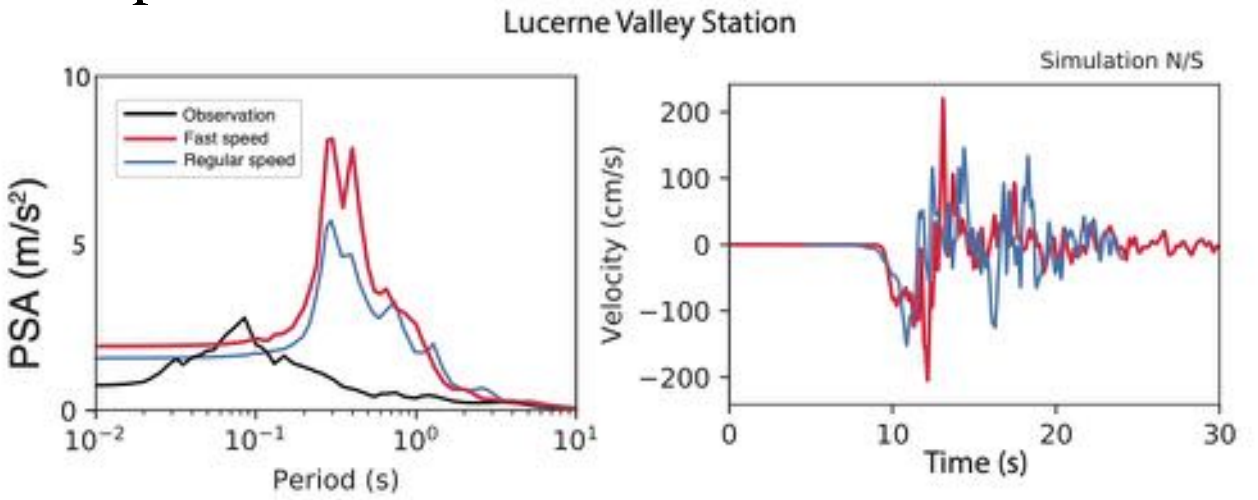


Dynamic rupture model creates reasonable ground motions (better than GMPE in long period because of the event term)

Are fault displacement and ground motion correlated? Not really …

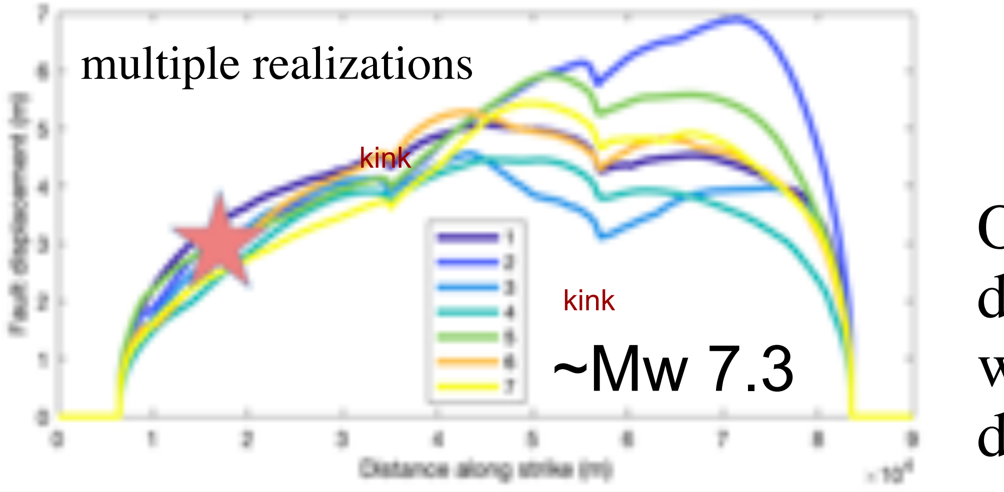


Two scenarios with very similar stress drop and slip distribution

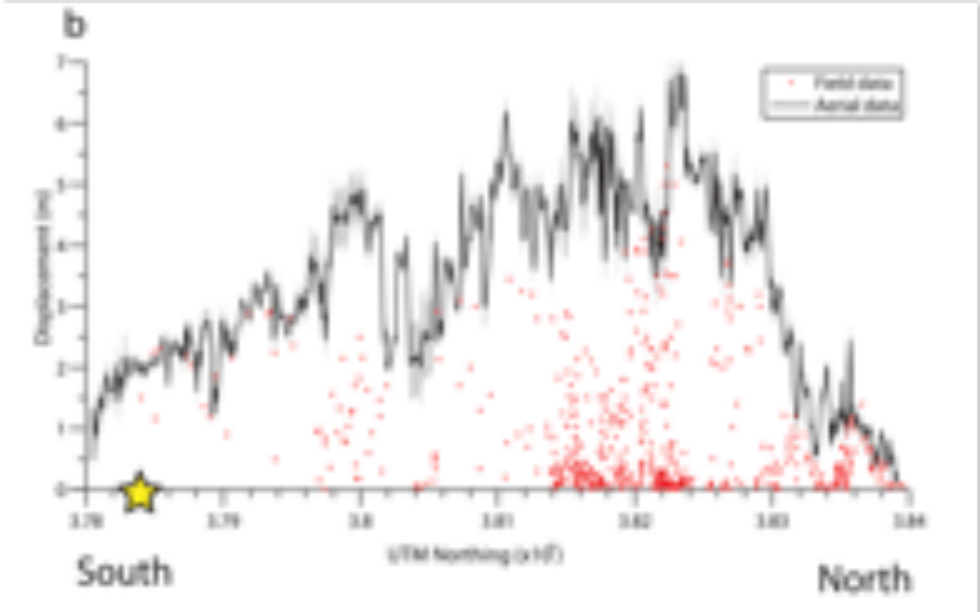


Fast rupture velocity induces a large ground motion. Ground motion can only provide loose constraints on the fault-displacement model.

Deliverables



Once validated, we will have technically defensible and plausible suites of models, from which we can deliver multiple realizations of displacement for a given scenario.



Interface Simulation Group with Dataset/Modeling Group

Simulation Group

- Continue validation of individual events
- Start validation using aggregate results from database/Modeling Group
- Separate principal and distributed displacements
- Provide displacement with meaningful metrics

Dataset/Modeling Group

- Is this validation approach OK?
- Aggregate statistical properties from database (maturity, cumulative slip, PSD Hurst exponent, fault zone width, rock type and properties)
- Define scenarios for simulations
  - Magnitude, geometry, fault zone width, rock type and properties
  - Resolution and level of complexity
  - Range of realizations

Toward a finer and shallower world

Ideally Dr. Christine Goulet's height
will be our finest grid size (~ 2 m)

July 6th, Ridgecrest M7.1 Earthquake

Fault displacement is very sensitive to shallow geological properties (fault structure, surrounding velocity, inelasticity and so on).

Our future plan: toward a finer grid (~ meters, current grid is 50 m) in shallower (< 1km) depth but need to consider computational costs

Thank you!

Comments and questions?

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