Illuminating fault structure and properties using seismology

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Community Near-Fault Observatory
Fault Subsurface Structure Breakout

What do we really want to know about faults?

Stressing Rate

Geometry

Stress Distribution

Time Evolution of Properties

Earthquake Size Distribution

Pore fluid distribution

Roughness

Permeability

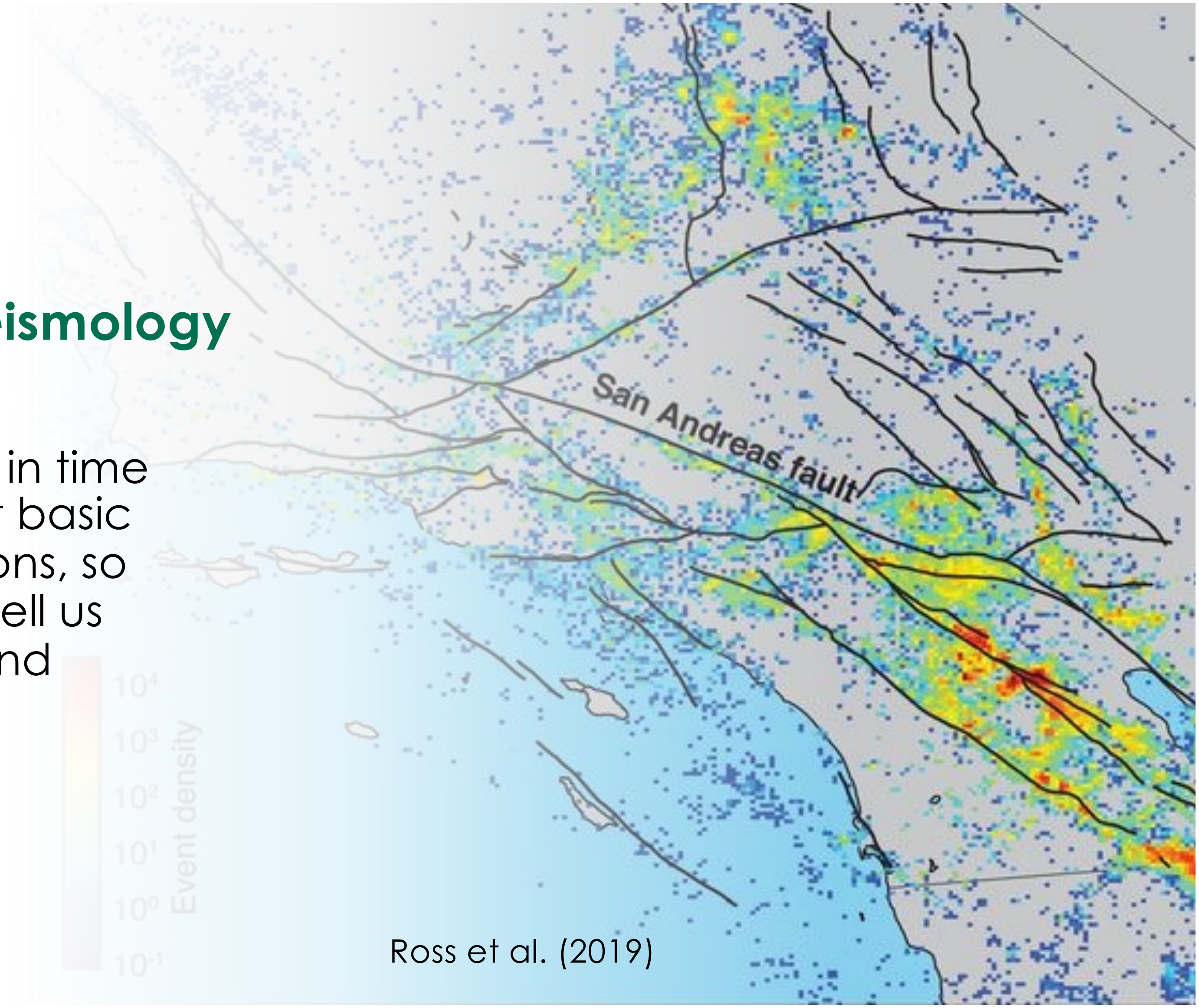
Friction & Strength

Seismic vs. Aseismic Slip

And many more…

Probing faults with seismology

Earthquake distributions in time and space are the most basic seismological observations, so let's explore what they tell us about fault properties and behavior!



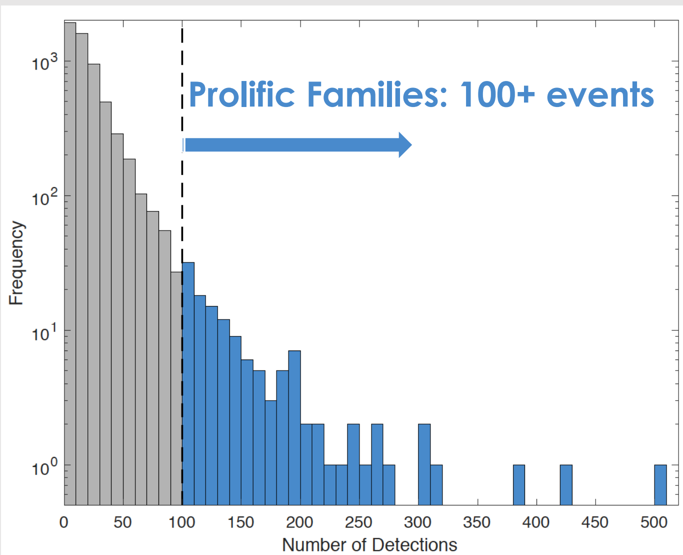
Ross et al. (2019)

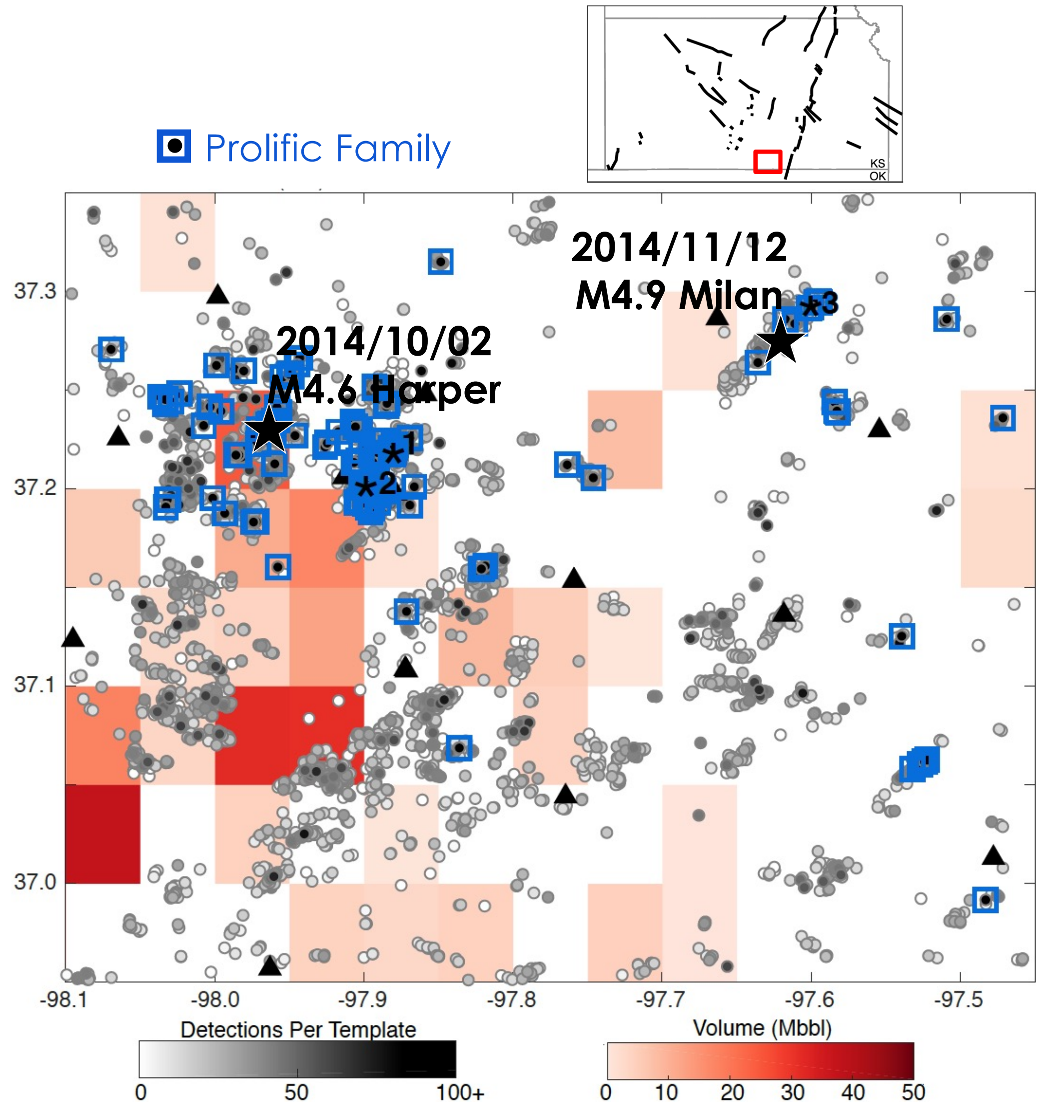
Stressing Rate & Fluid Pressures:
Southern Kansas Case Study

Identify families of near-repeating earthquakes to look at how sequence behavior varies

More prolific families near areas of higher injected volumes.

Detections per template





Cochran et al. (2018)

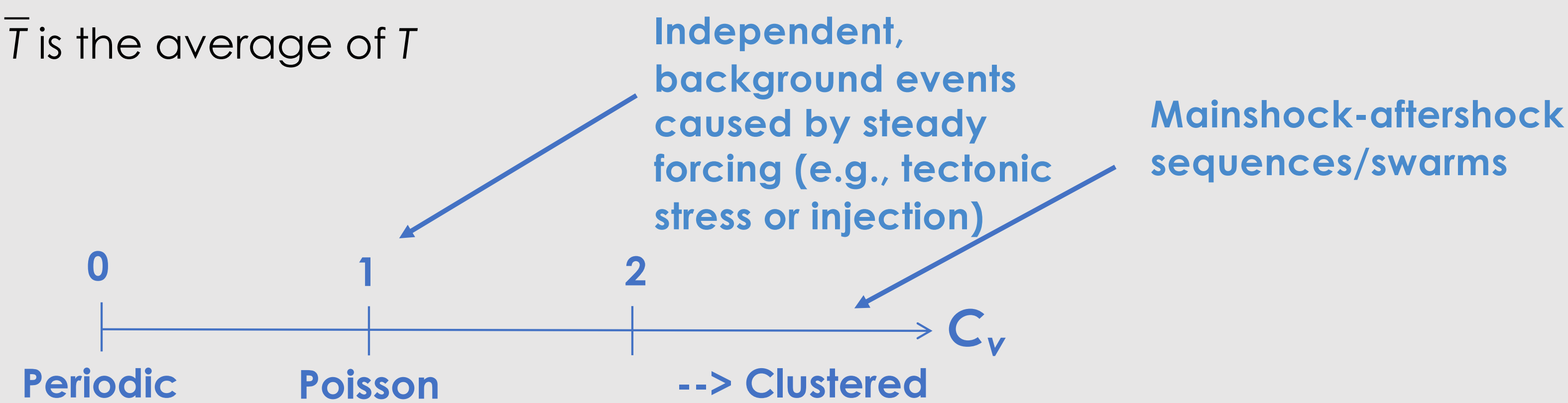
Quantifying Earthquake Clustering Behavior

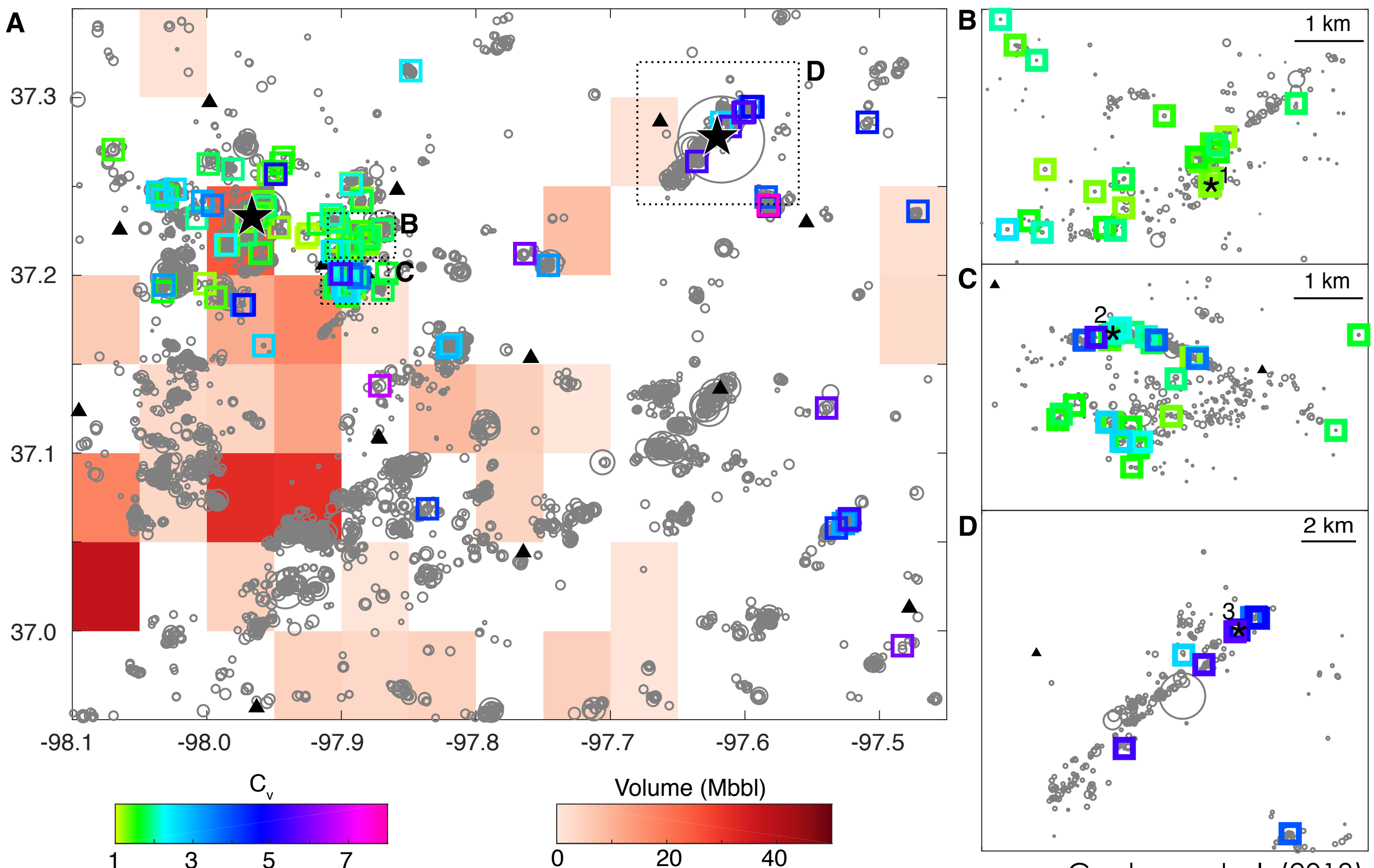
Kagan and Jackson (1991) define a coefficient of variation (C_v) of inter-event times (T) to characterize the temporal evolution of earthquake sequences.

$$C_v = \sigma_T / \overline{T}$$

σ_T is the standard deviation of T

$\overline{T}$ is the average of T





Cochran et al. (2018)

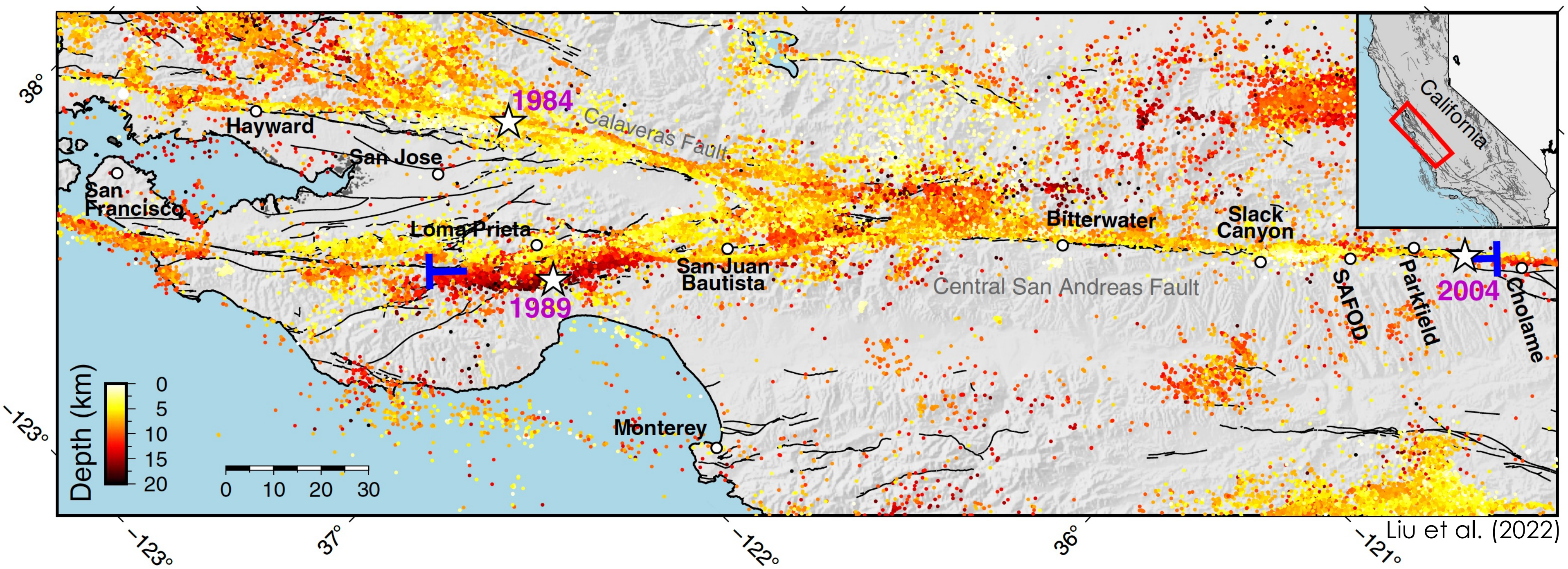
Clustering behavior tells us about stressing rate and fault conditions (pore pressure, strength, pre-existing stress); more work and data needed to untangle!

Families close to high volume injection are generally Poissonian distributed (C_v<2). Some families have events every ~10 days.

→ Earthquakes are continually driven by high stressing rate & pore pressure from nearby injection

Other families are highly clustered (C_v>2) and mostly occur far from wells

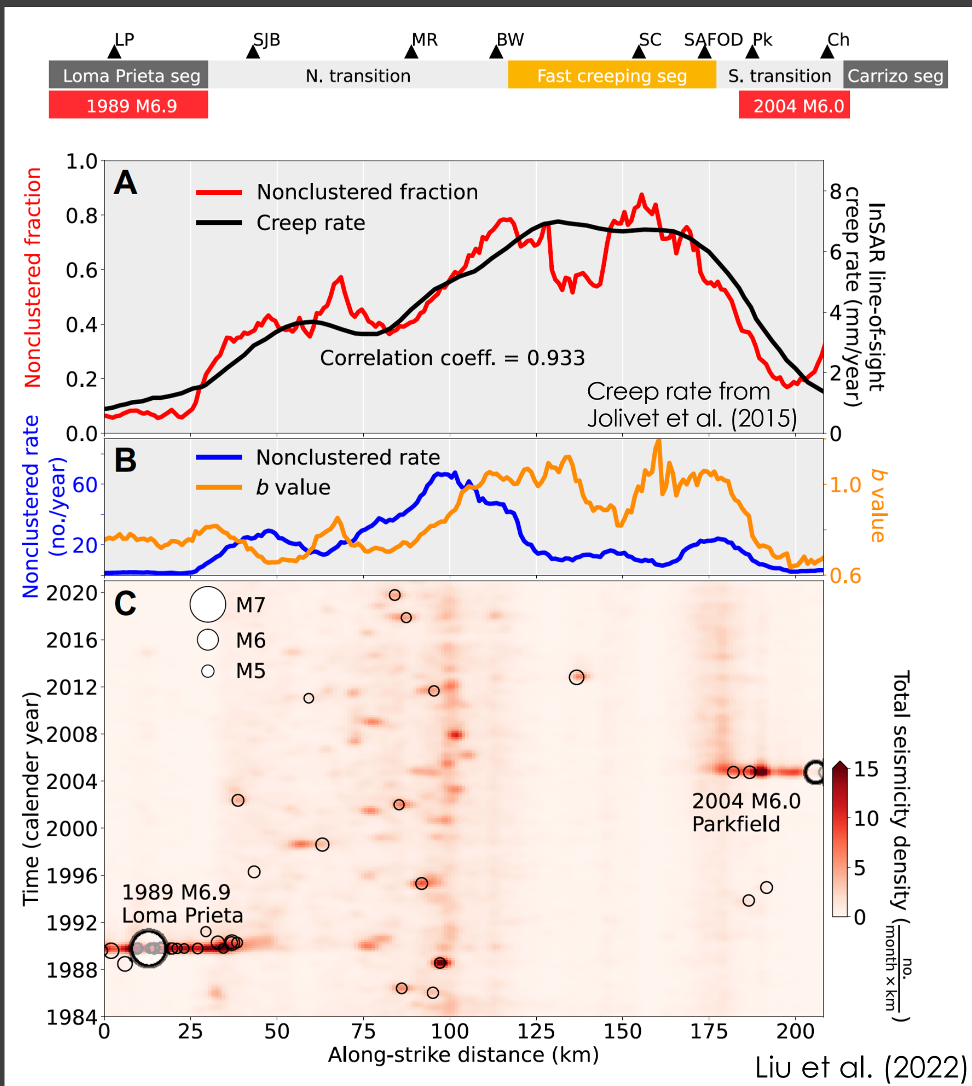
→ Events occur on highly stressed faults where small stress changes from pore pressure trigger the first event that is followed by an aftershock sequence.



Liu et al. (2022)

Fault Slip Behavior:
SAF Case Study

Can we tell - with seismology - if a fault will slip seismically or aseismically?

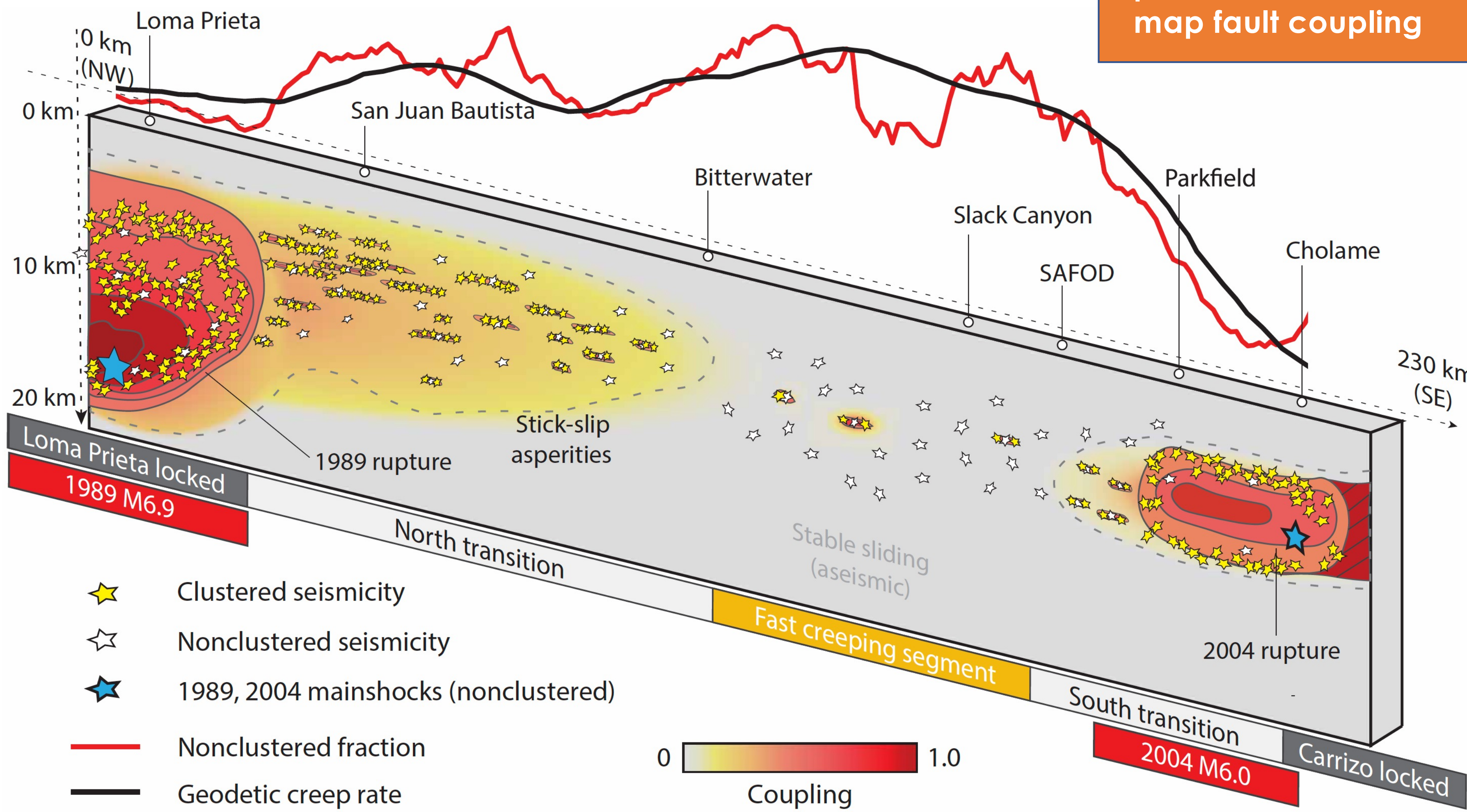


Examine earthquake behavior (clustering, seismicity rate, b-value) along a 150-km-long section of the SAF

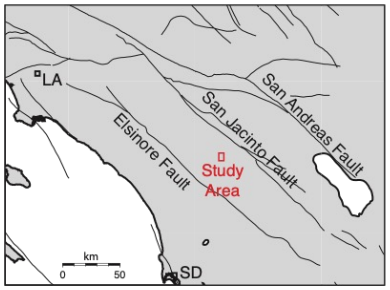
The fraction of clustered events, and to a lesser extent b-value, correlate with the creep rate.

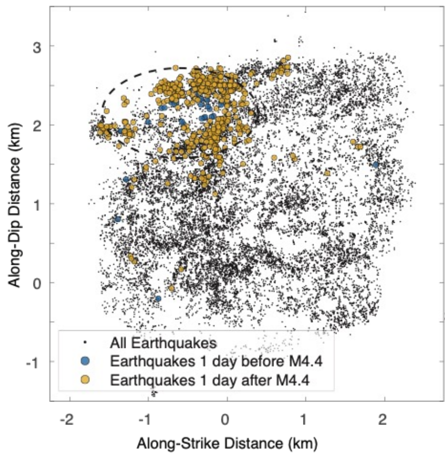
Strong clustering is associated with regions of the fault capable of hosting larger magnitude events.

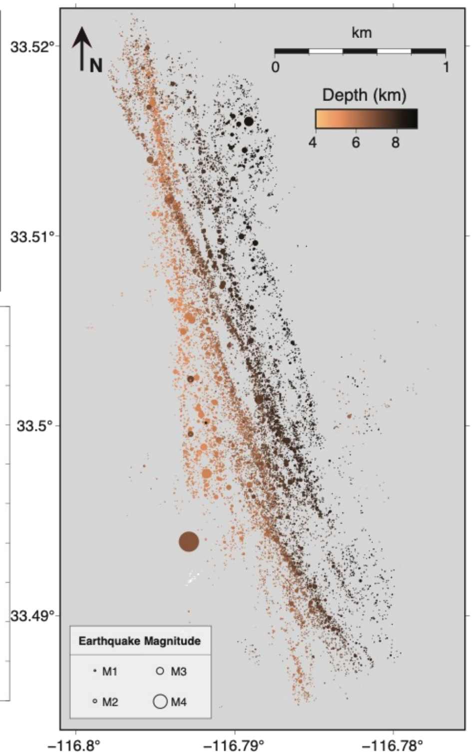
Long records of seismicity patterns can be used to map fault coupling

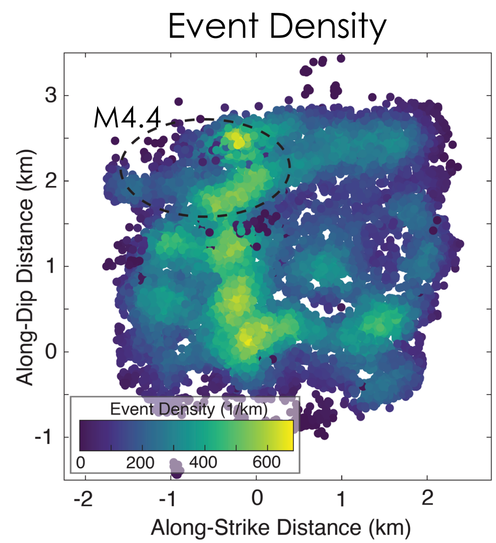


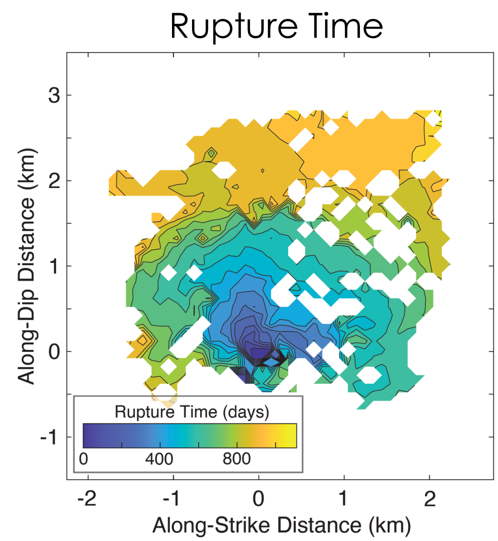
Liu et al. (2022)











Also see: Hauksson et al (2019) & Ross et al. (2021)

Fault Roughness:
Cahuilla Swarm Case Study

Can we estimate fault roughness at seismogenic depths?

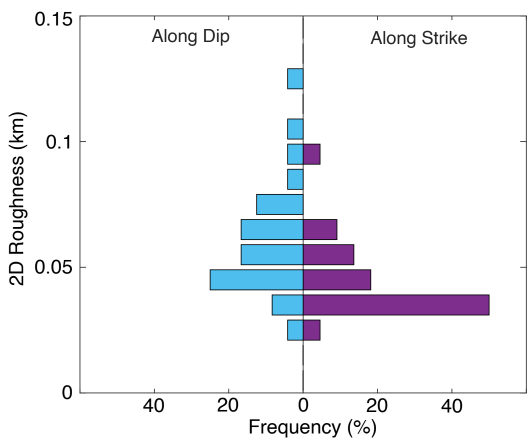
How does roughness influence earthquake behavior?

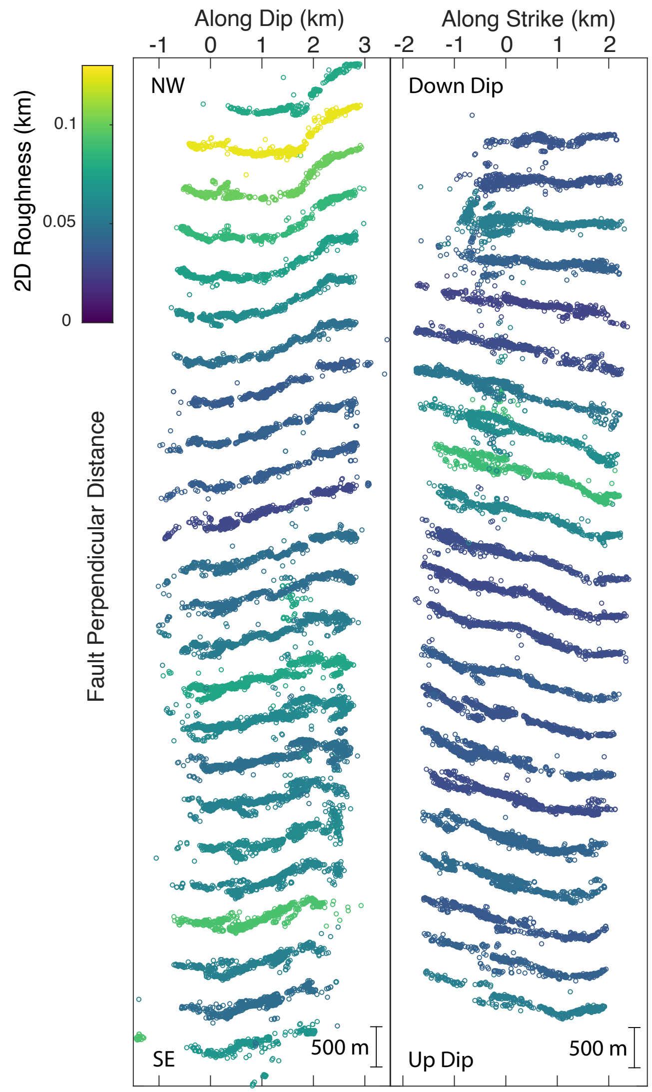
Roughness defined as the mean out of profile (or plane) distance.

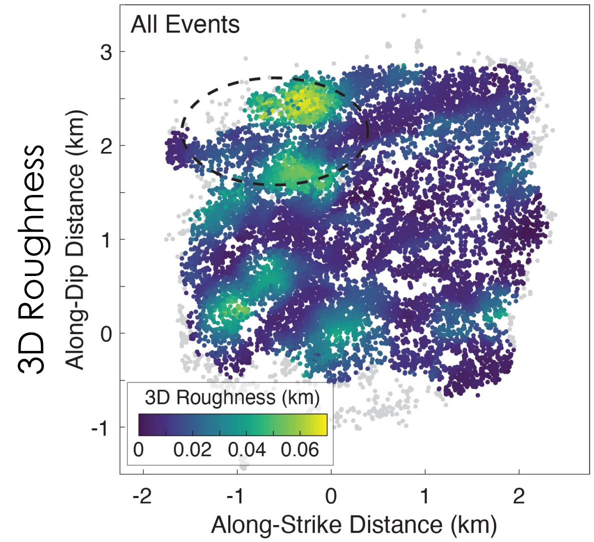
Fault is 50% rougher in the along dip direction compared to along strike

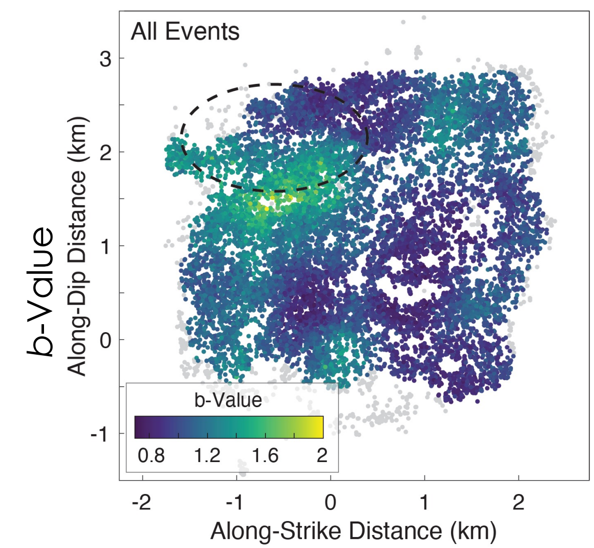
Fault corrugation sub-parallel to strike apparent in 3D roughness maps

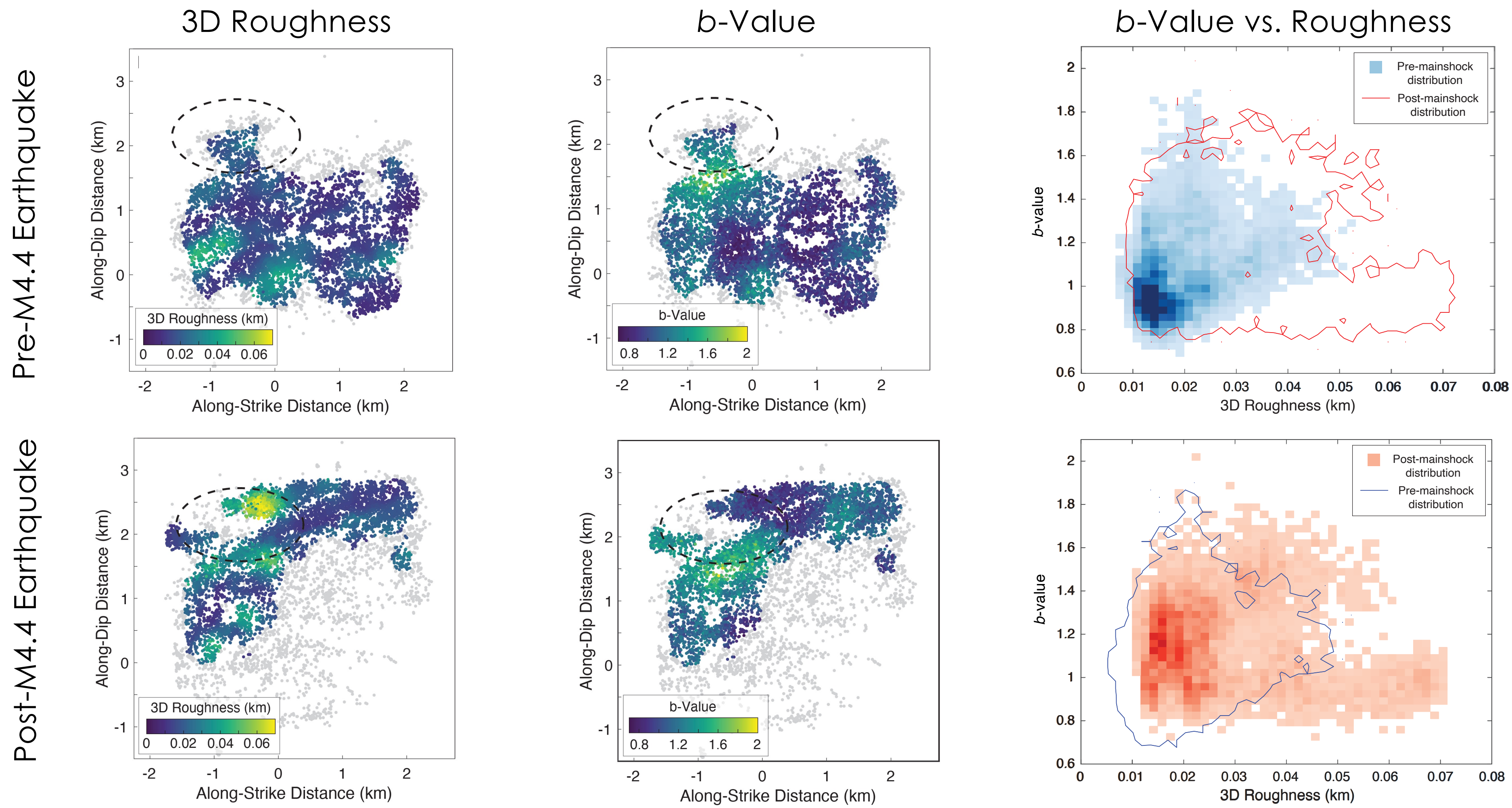
Highest roughness is within the rupture area of the largest earthquake (M4.4)











- Roughness and *b*-value are weakly correlated.
- Exception: Largest event is near the roughest fault section with corresponding low *b*-values.

Fault Zone Observatory Opportunities

Dense grids of seismic instrumentation recording seismicity over several years would provide:

- ❖ Spatio-temporal evolution of seismicity at very high resolution for understanding clustering and fault coupling
- ❖ Dense focal mechanism mapping for stress inversions
- ❖ Stress drop and finite fault inversions for rupture properties and complexity
- ❖ Fault geometry and roughness at a range of depths
- ❖ Comparison of fault properties across different faults or fault segments
- ❖ Integration with co-located geodetic data

Near-fault observatories could probe the fault properties we really want to know!

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