Constraints on the shallow geometry of the southern San Andreas fault from dense seismic and geodetic observations

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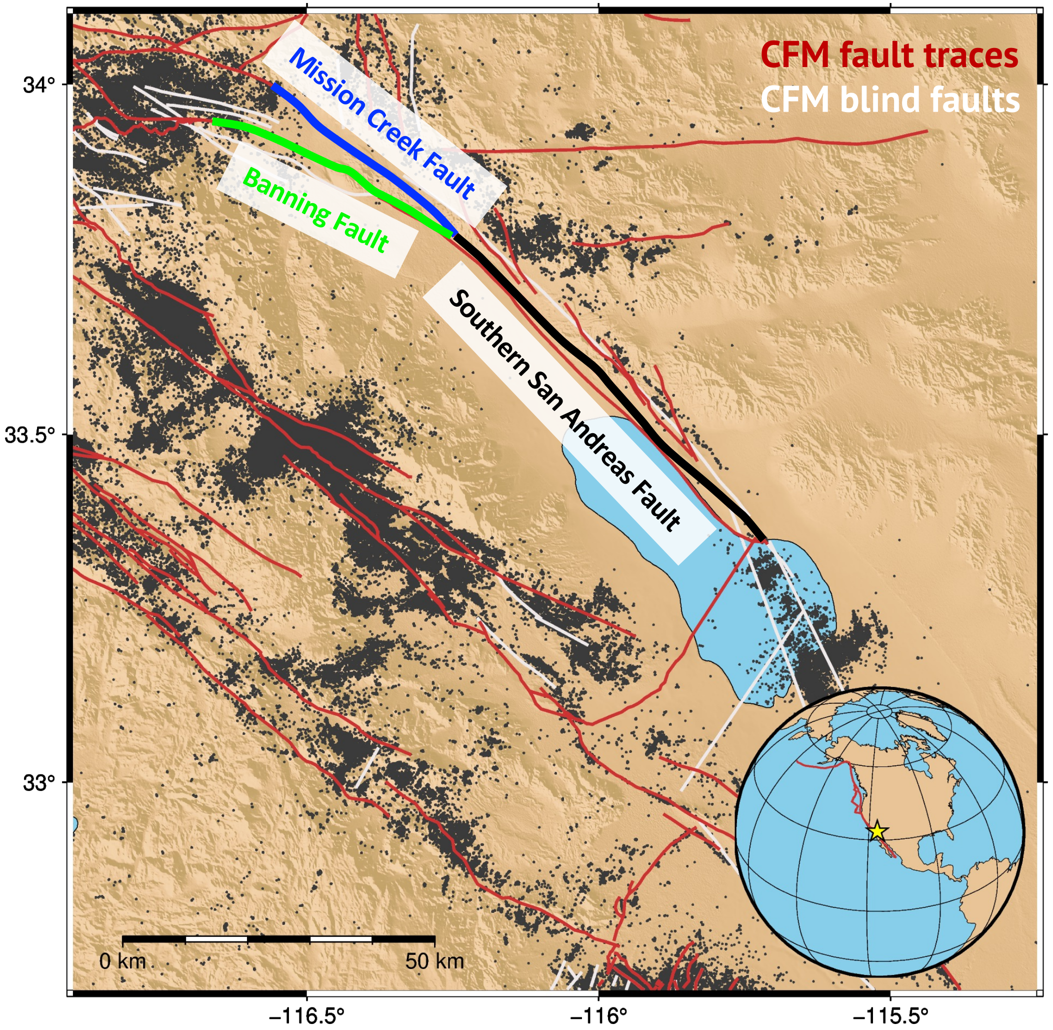
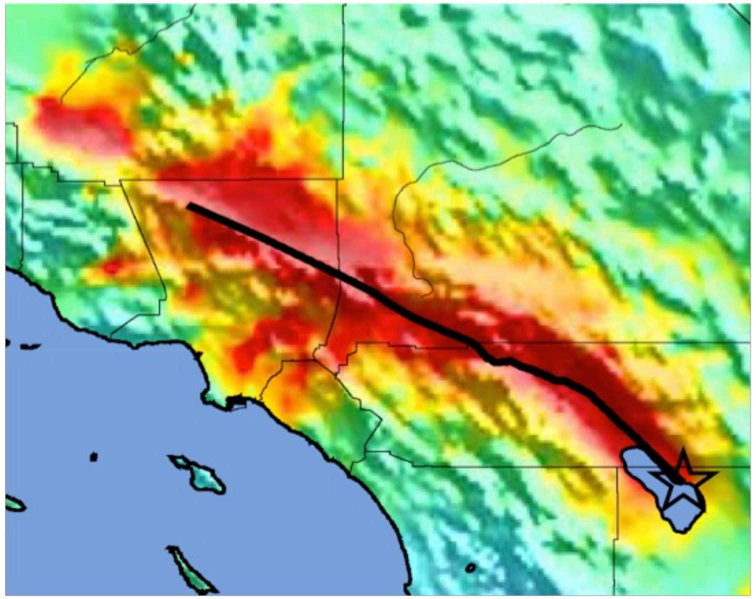
Community Near-Fault Observatory Breakout Session: Subsurface Fault Zone Structure

Southern San Andreas Fault (SSAF)



INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
Shaking	Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Damage	None	None	None	Very slight	Light	Moderate	Moderate/ heavy	Heavy	Very heavy

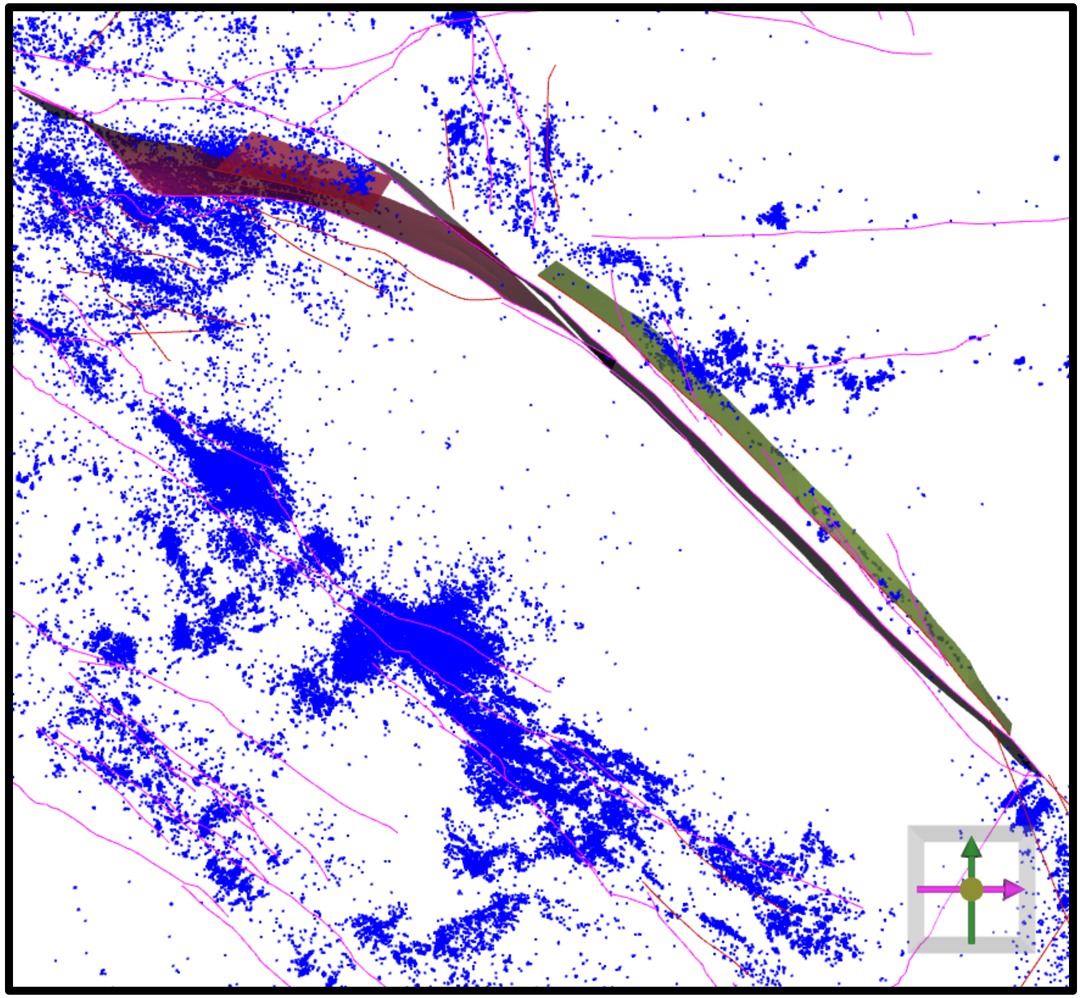


The Shakeout Scenario – Jones et al., 2008

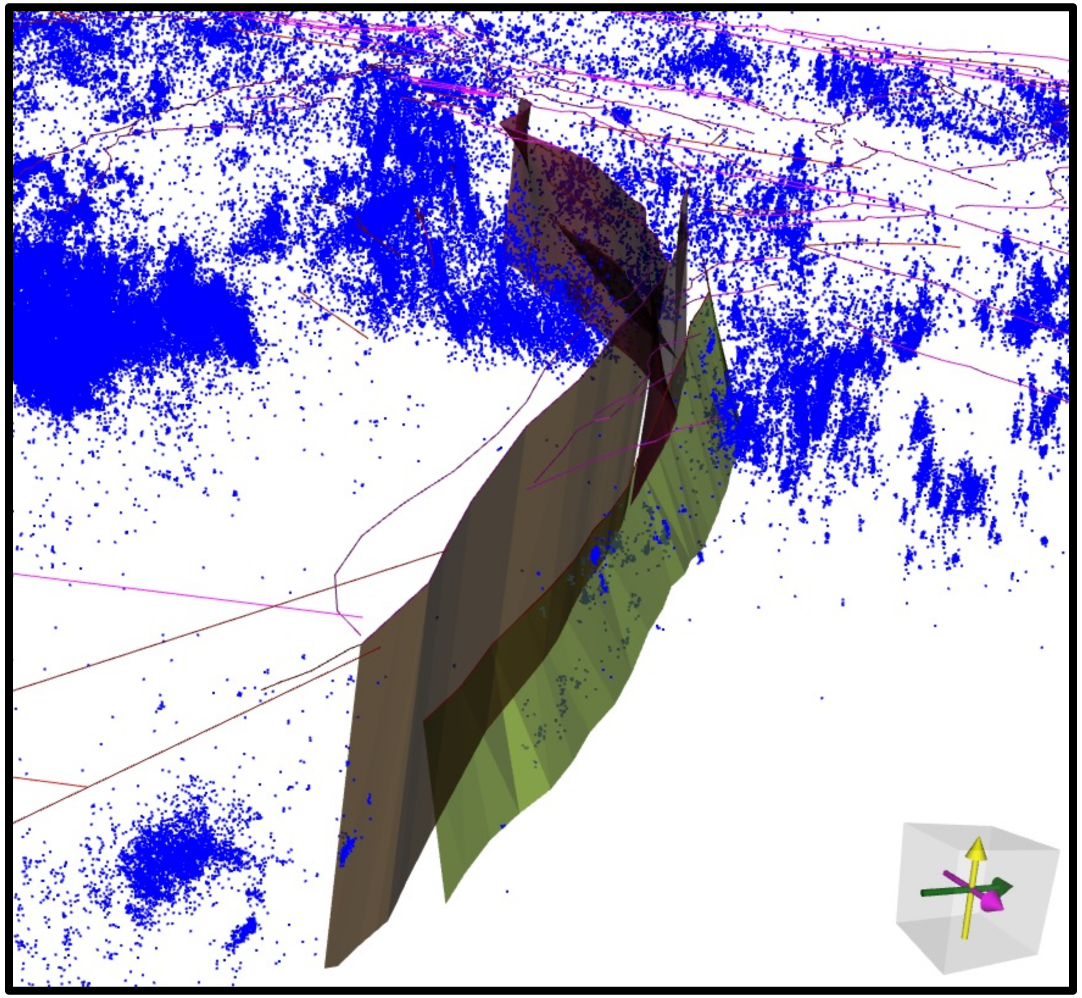
- Capable of destructive M 8+ earthquakes
- Has not produced a major event in ~300 years

SSAF in the SCEC Community Fault Model

Map View

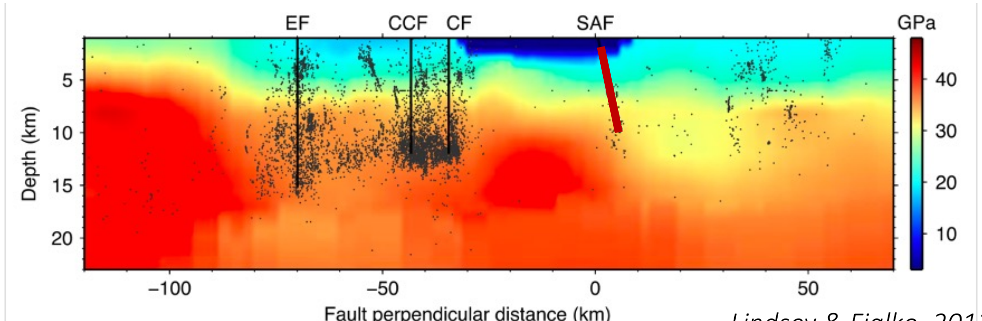


Looking North



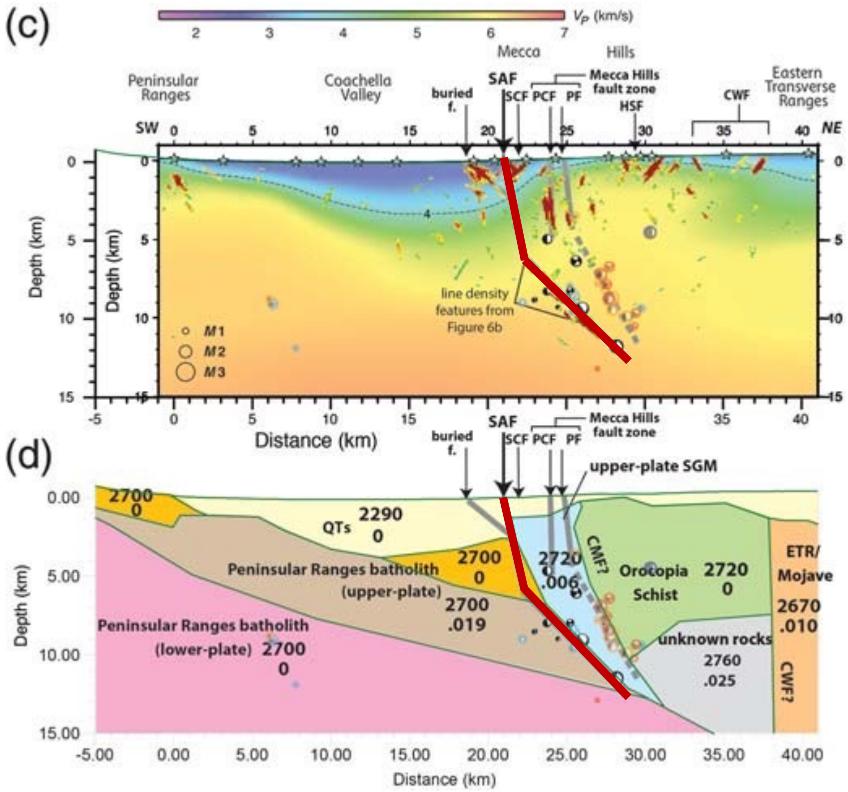
Evidence for Non-Vertical Fault Structure

Inversions of secular tectonic deformation:



Lindsey & Fialko, 2013, JGR

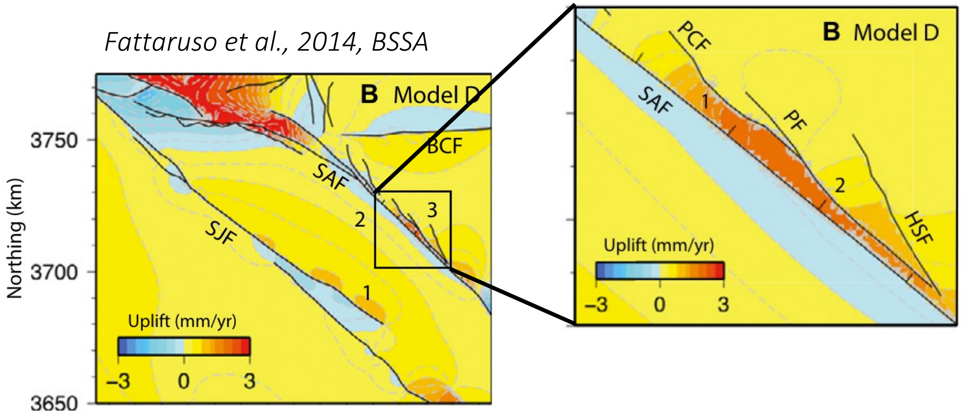
Reflection seismology and potential field data:



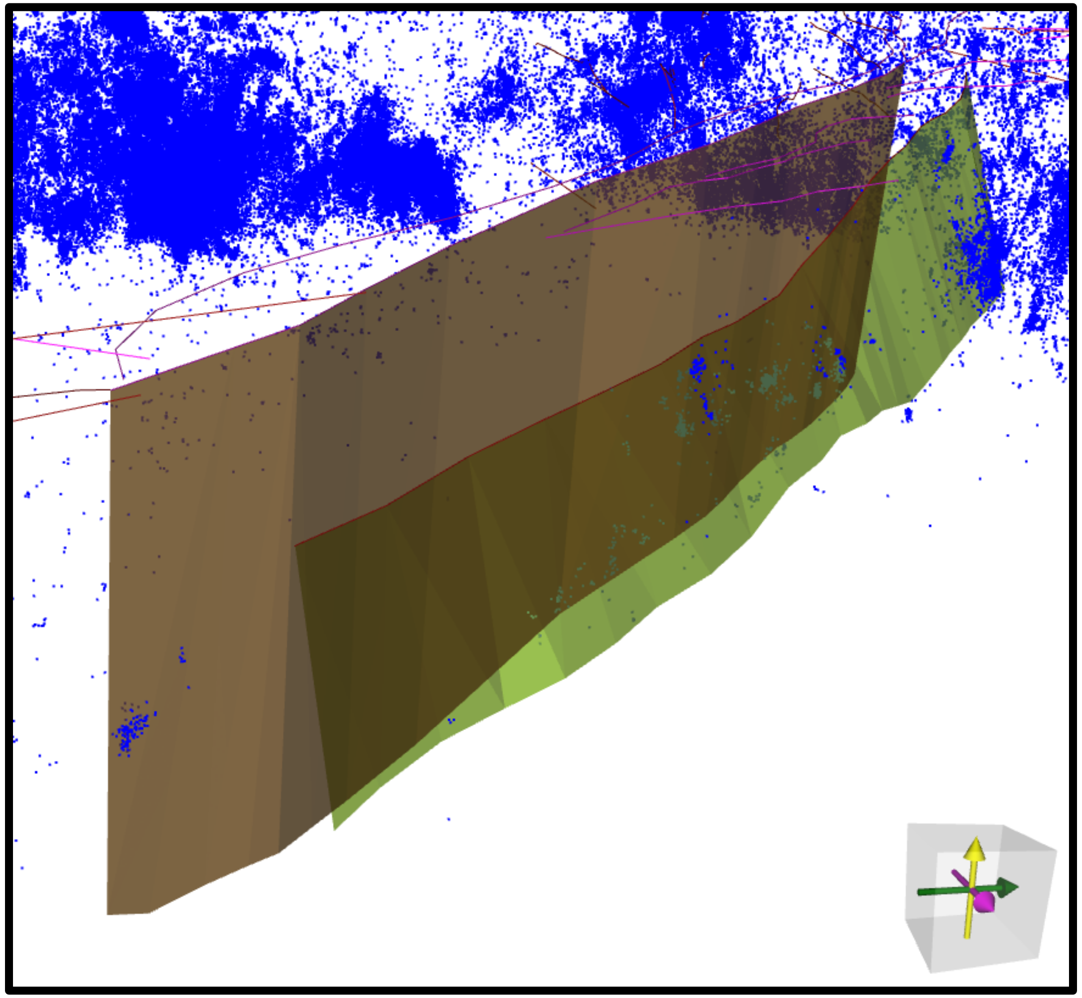
Fuis et al., 2017, BSSA

Observed and modeled uplift patterns:

Fattaruso et al., 2014, BSSA

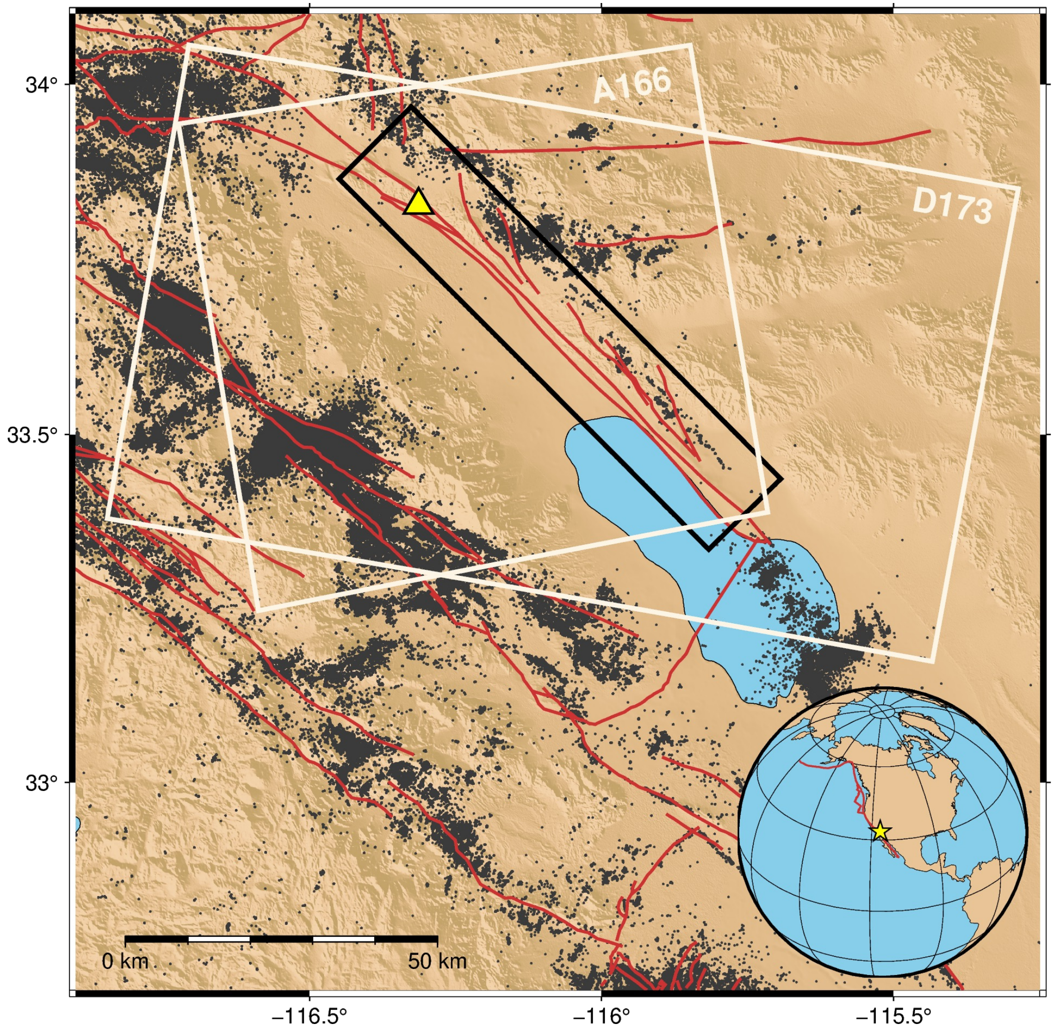


SSAF in the SCEC Community Fault Model



- Secular tectonic deformation, uplift patterns, potential-field data, and reflection seismology support a SSAF with a dip of 60-70 degrees.
- Compatible with offset microseismicity
- *Challenging to reconcile due to limited constraints on shallow fault structure.*

Joint seismo-geodetic SSAF experiment



Goal: Use multiple observational modes to obtain independent constraints on the shallow SSAF geometry and resolve its relationship to inferred deeper structures.

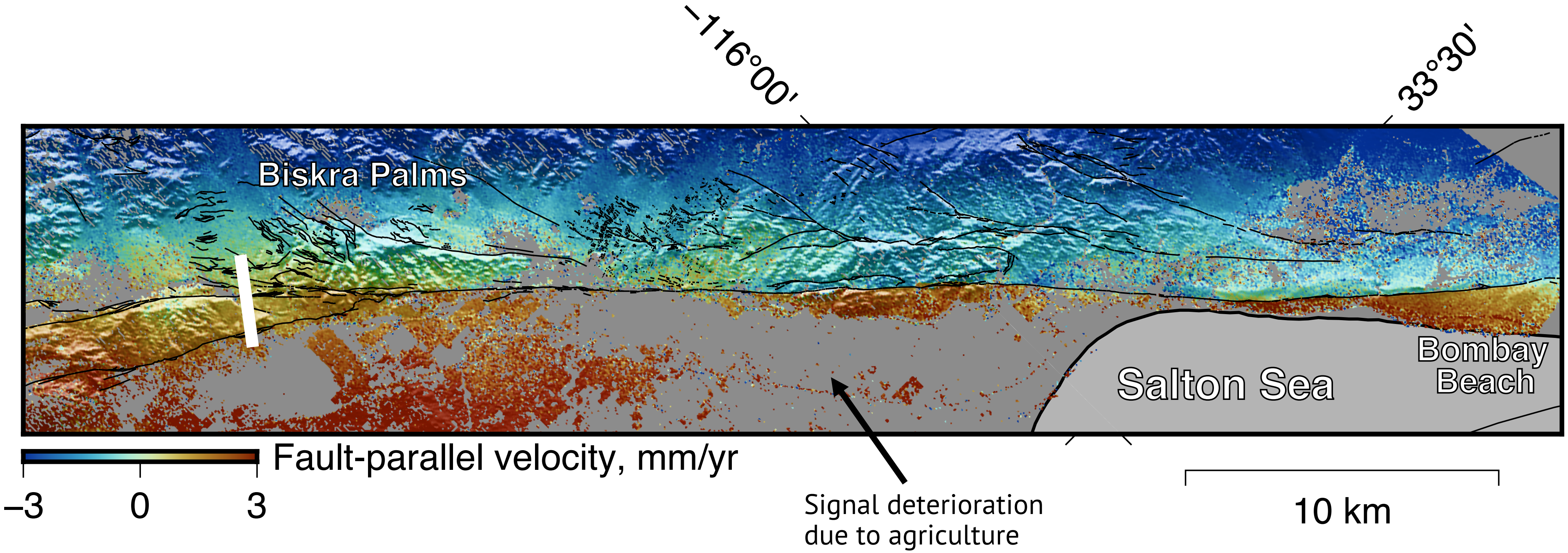
Geodetic: 5 years of Sentinel-1 InSAR measurements from two satellite tracks.

- ➢ **Measure and model shallow fault creep**

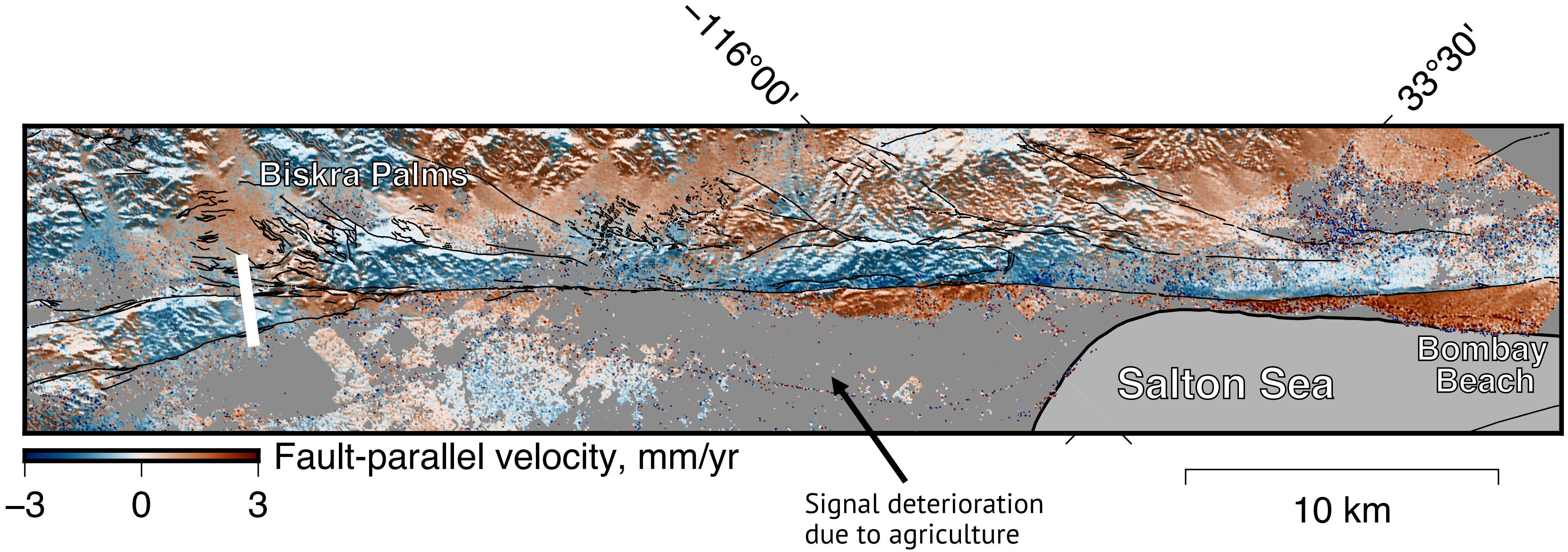
Seismic: Temporary deployment of dense nodal array (300+ recievers)

- ➢ **Analyze fault zone reflected (and transmitted) waves**

Near-fault geodetic measurements

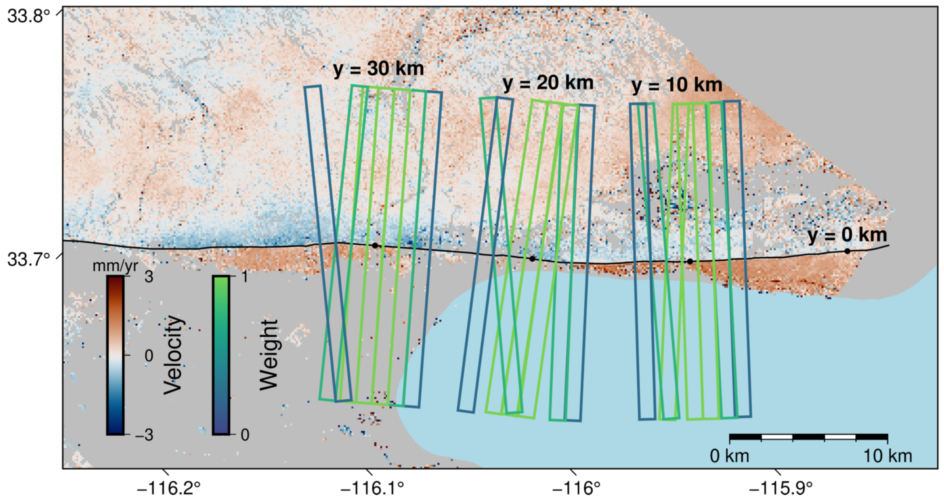


Near-fault geodetic measurements



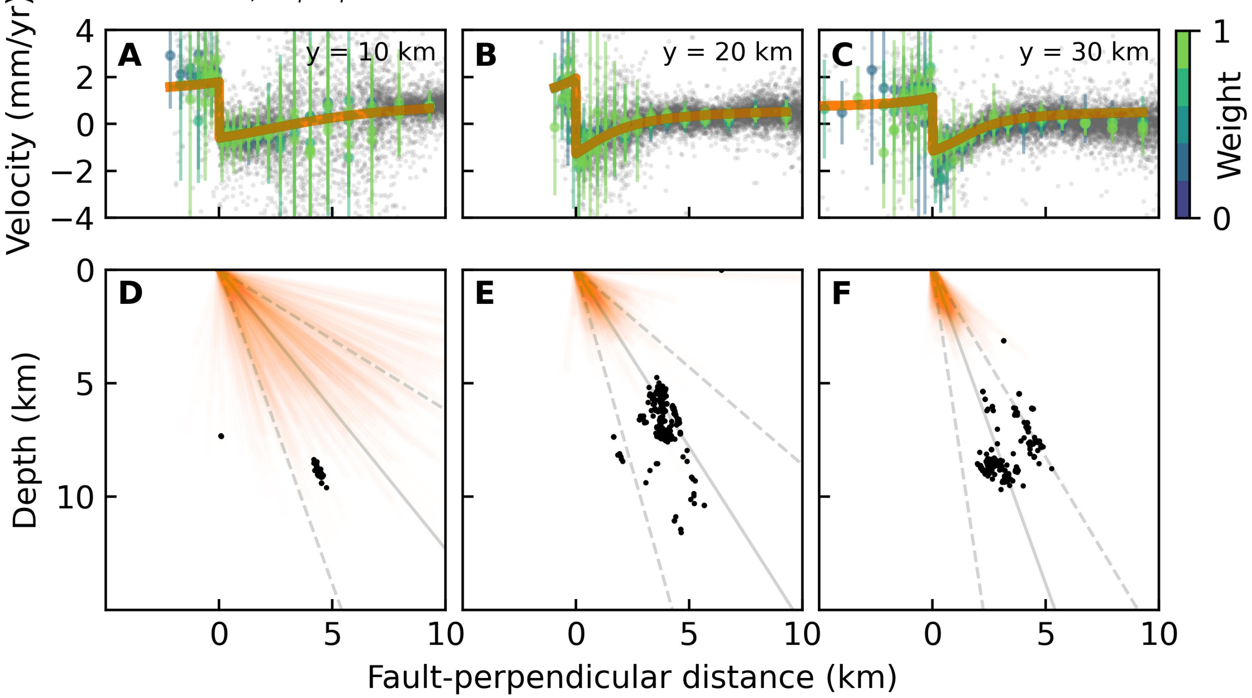
- Isolate creep using model of secular tectonic deformation
- Fault creep produces deformation which reflects the shallow geometry

Inversions for shallow fault structure



- Develop 2D models of creeping portion of fault
- Obtain Bayesian estimates of model uncertainties
- **Northeast dip is preferred along entire creeping section.**

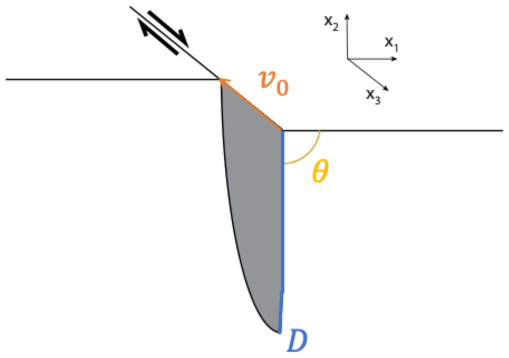
Vavra et al., in prep



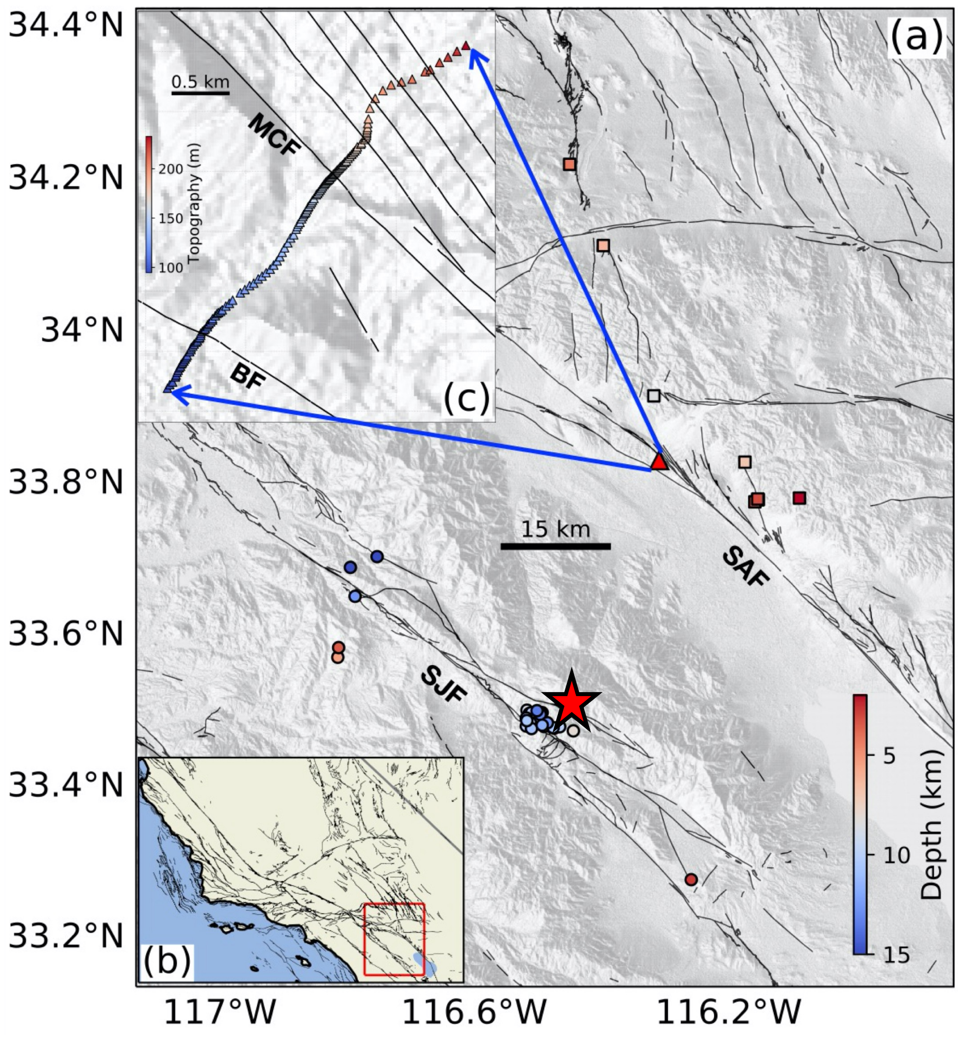
Fault parameters:

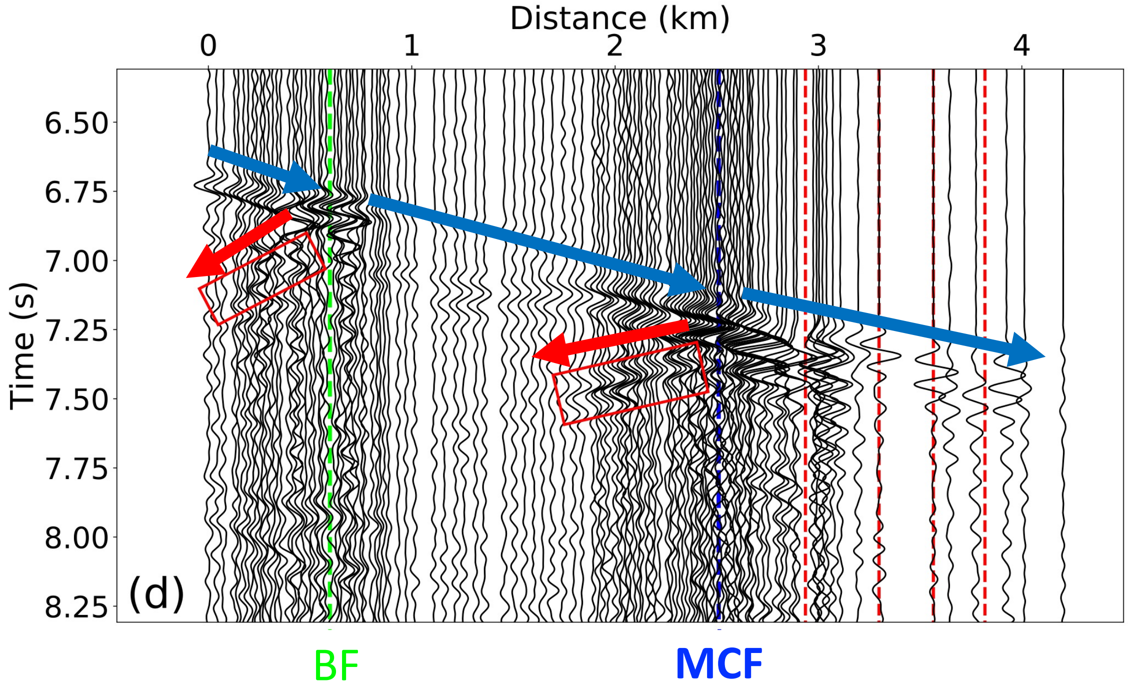
v_0 – max. fault slip
D – locking depth
θ – dip angle

(v_c – velocity shift)



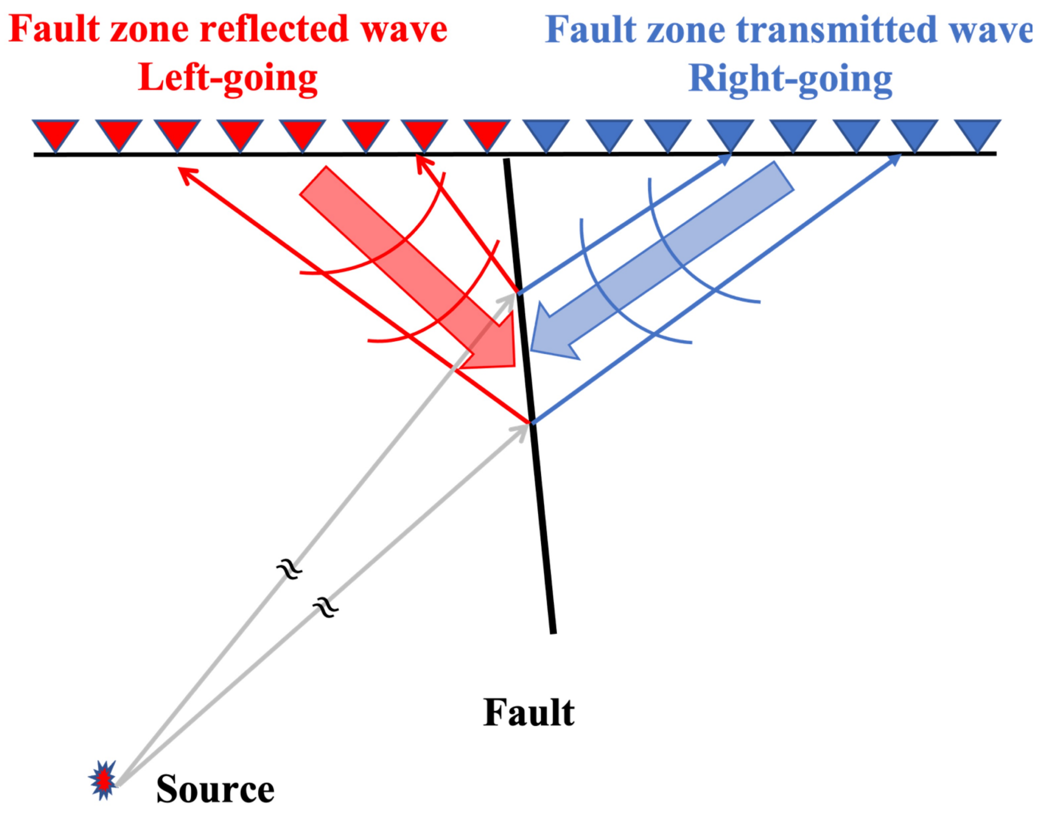
Insight from fault zone reflected waves

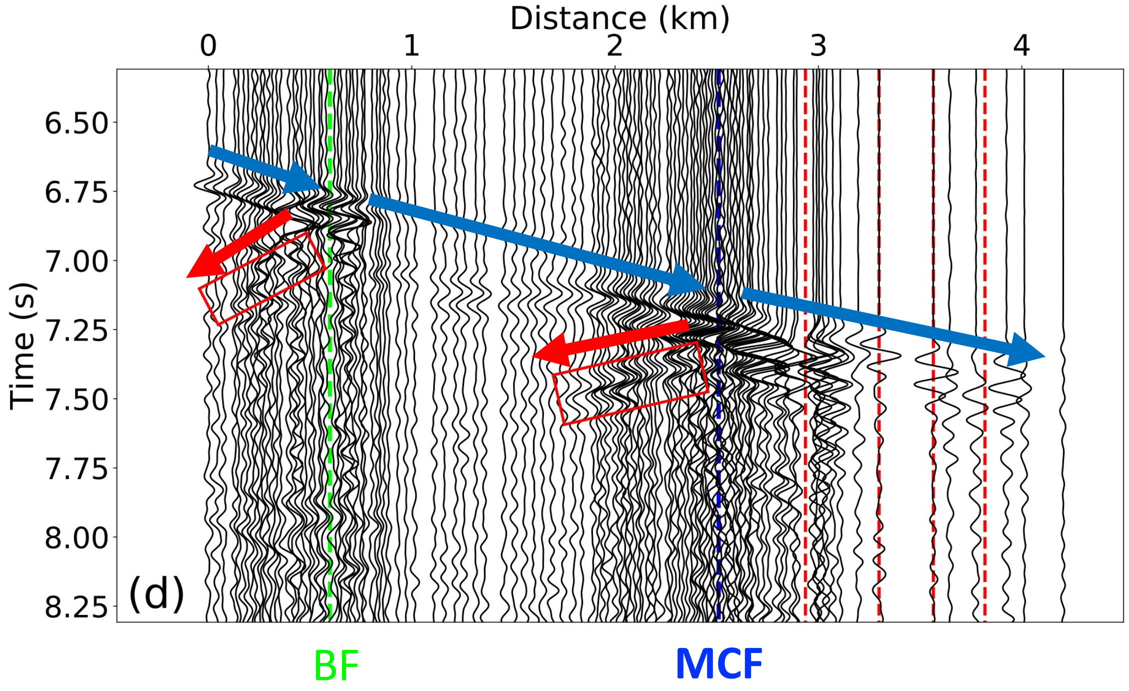




- Array records fault zone reflected and transmitted waves from ~30 regional and teleseismic earthquakes.
- Analysis by Hongrui Qiu, Benxin Chi, Pieter Share, & Yehuda Ben-Zion

Insight from fault zone reflected waves

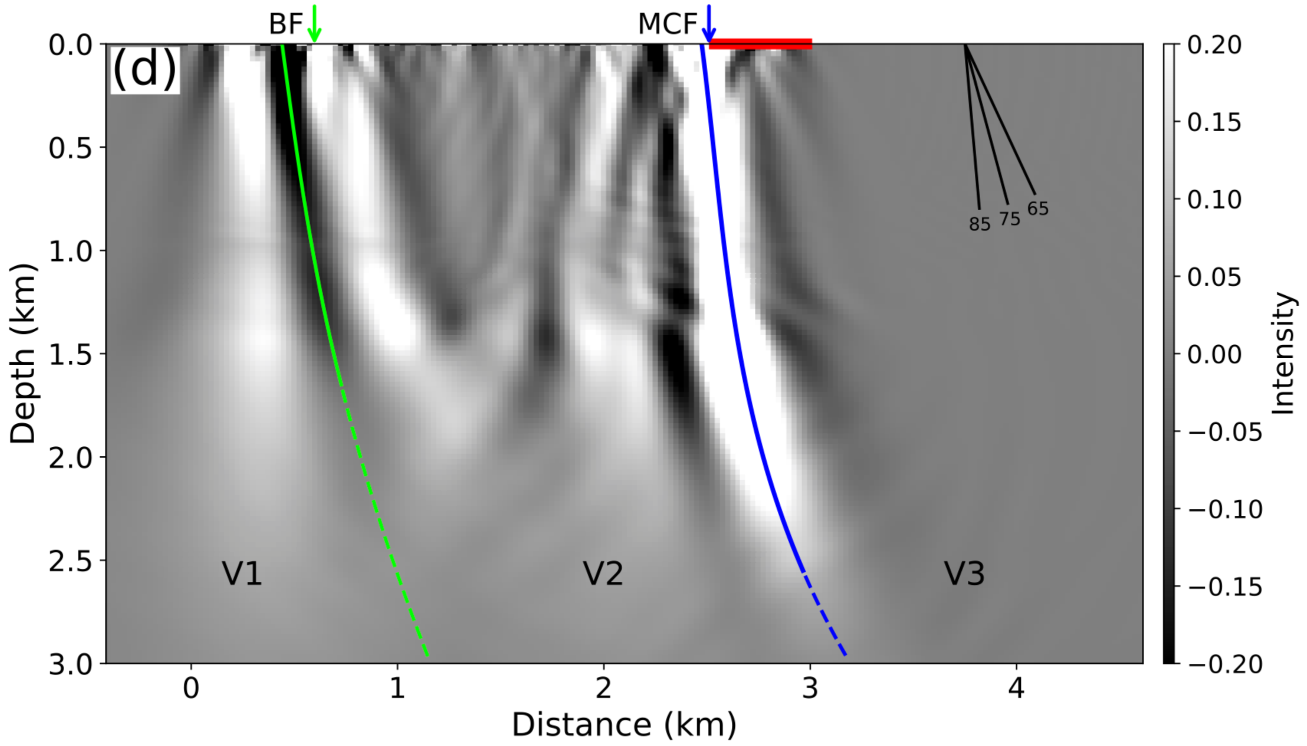




Develop a new reverse time migration approach using reflected and transmitted fault zone wavefields.

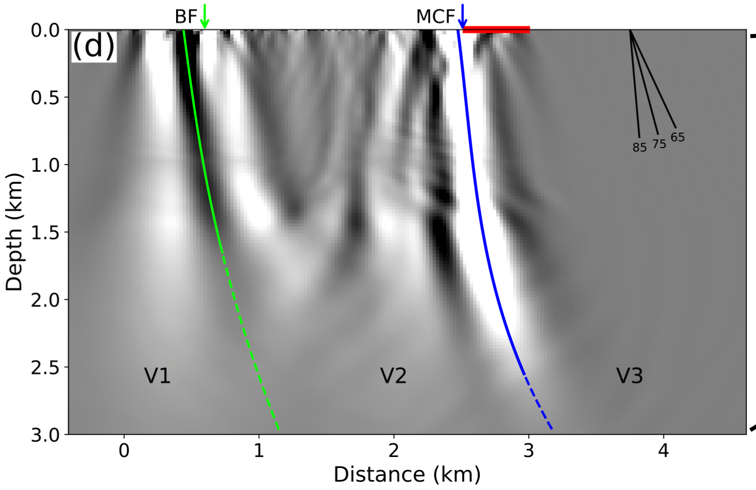
No source required!

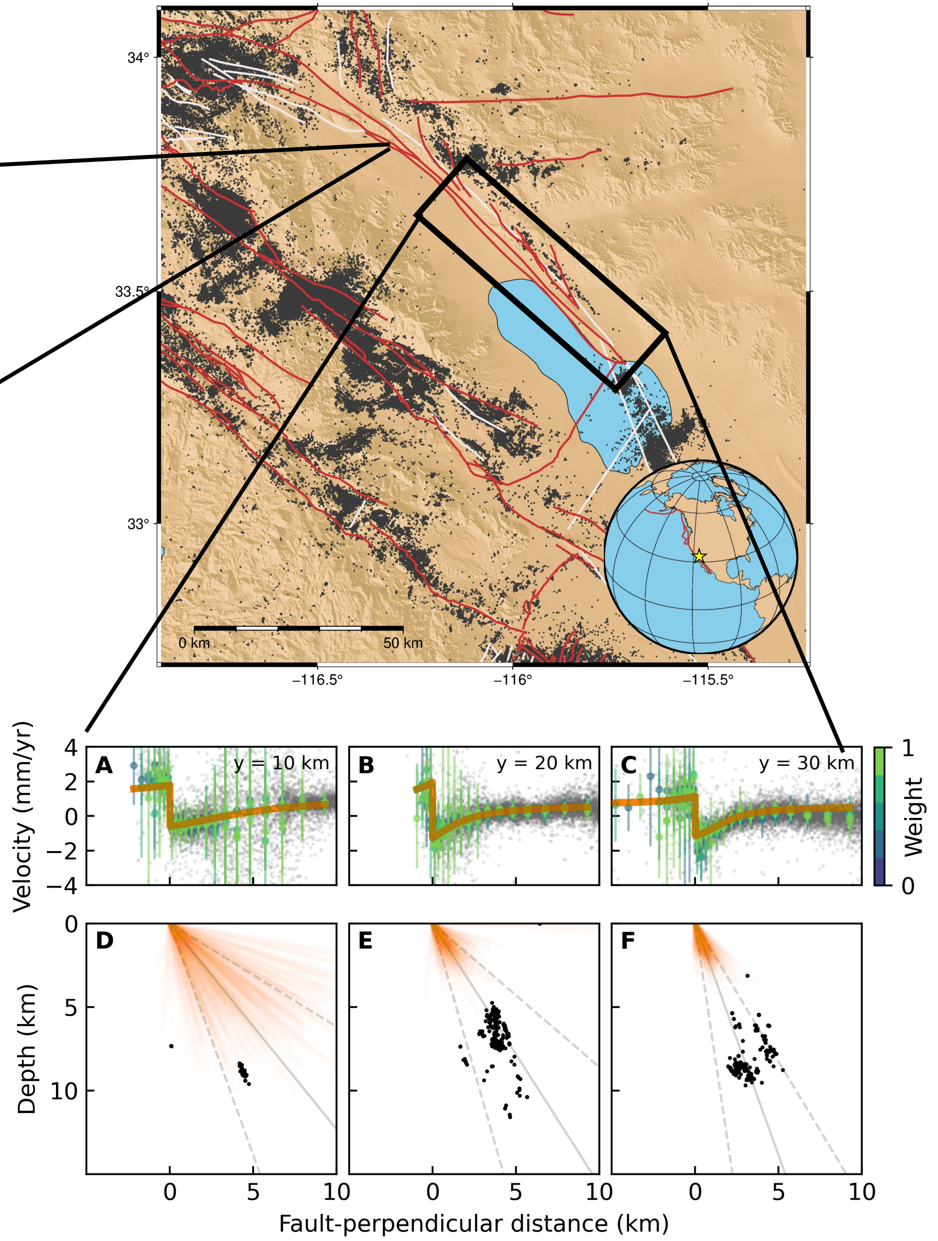
Insight from fault zone reflected waves



- Reflective subsurface structures imaged with reverse time migration.
- Both Banning and Mission Creek segments dip steeply northeast.
- Continued dip is indicated at greater depth, but with decreased resolution.

Takeaways





1. Modern InSAR processing techniques allow for shallow fault geometries to be resolved for fault creep of <3 mm/yr.
2. Dense fault-crossing arrays enable imaging of near-surface fault structures without source information.
3. We observe strong evidence for northeast dip of the SSAF in the top 2-4 km of the crust.

Outlook and Implications for RuFZO

Geodetic data coverage:

- If there is fault creep, InSAR can be used to resolve shallow fault geometry.
- InSAR coherence/data quality can be used to identify sites which would benefit most from increased geodetic instrumentation.
  - Permanent & campaign GNSS sites, corner reflectors, creepmeters, etc.
- Increased instrumentation on faults known to experience shallow creep.

Temporary nodal surveys:

- Allocation for temporary nodal array to refine shallow fault structure and monitor damage zone evolution.