Using Seismic and Geodetic Observations in a Simultaneous Kinematic Model of the 2019 Ridgecrest, California Earthquakes

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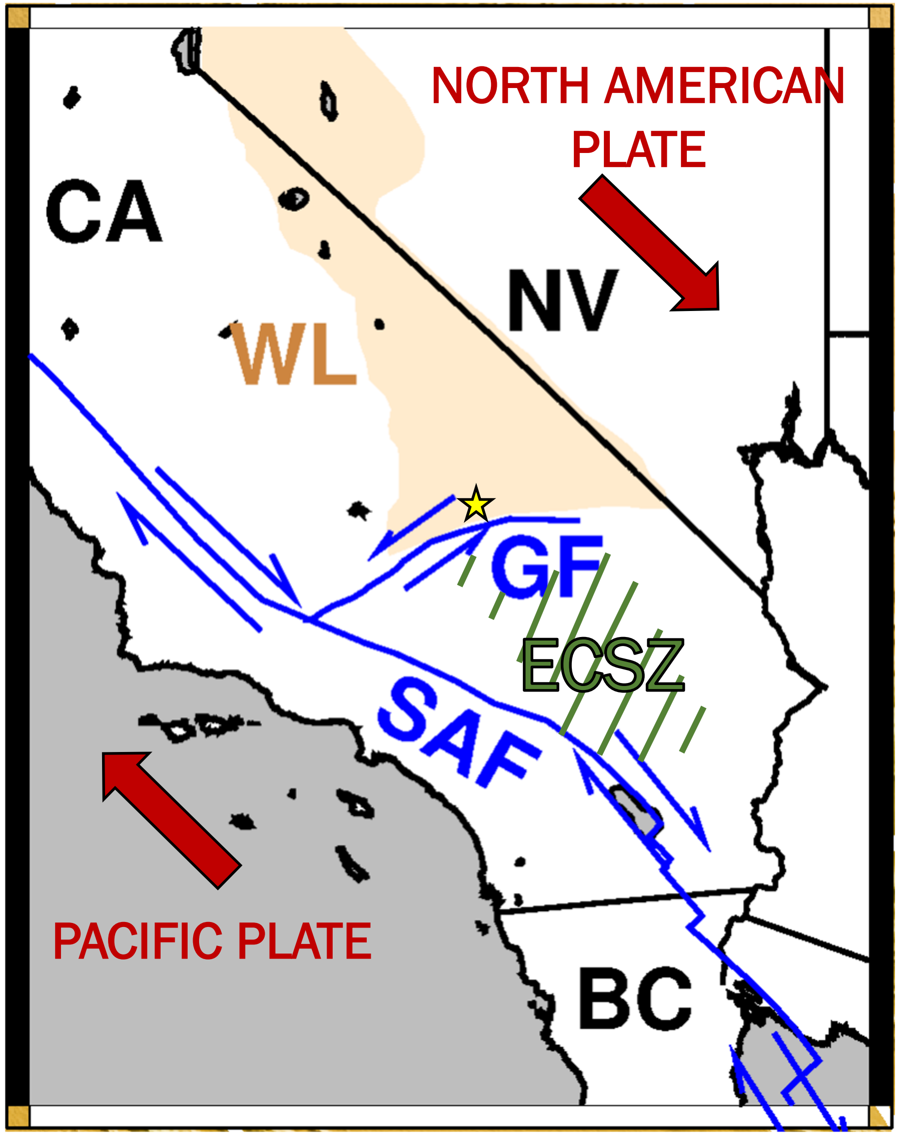
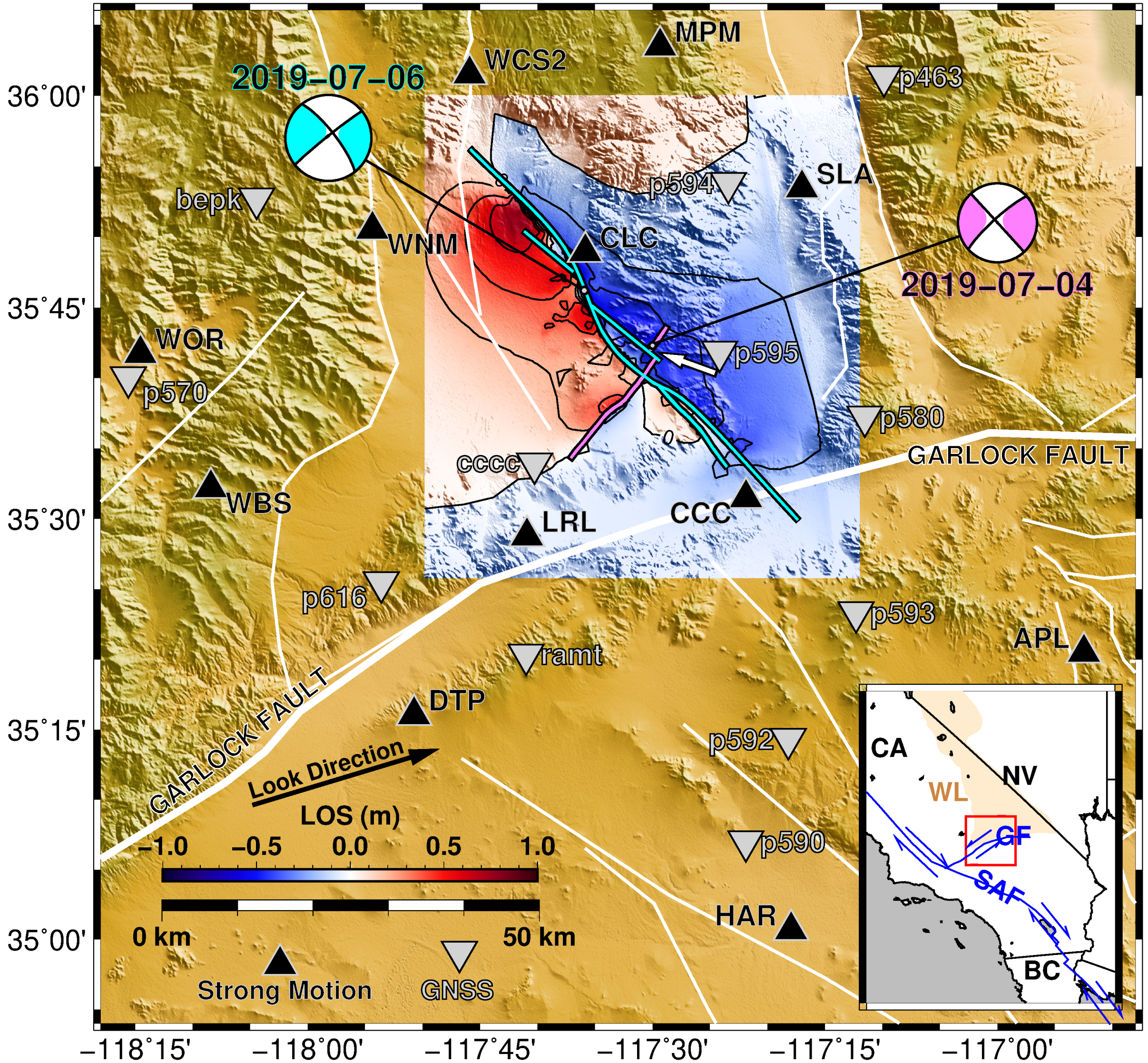
Tectonic Setting of the 2019 Ridgecrest, CA Sequence



- Main tectonic boundary between the North American and Pacific plates is the right-lateral San Andreas Fault (SAF)
- The Eastern California Shear Zone (ECSZ) and Walker Lane (WL) are diffuse regions of shear to the east of the SAF and accommodate up to 25% of total tectonic motion
- The Ridgecrest, CA events occurred in the WL region, just north of the Garlock Fault (GF), a left-lateral fault that intersects the SAF
- History of the SAF moving eastward over time, suggesting that as more tectonic motion transfers eastward, the diffuse WL/ECSZ will coalesce into an organized fault and become the dominant tectonic boundary in the region
- The Ridgecrest sequence gives us the opportunity to see a tectonic boundary in the making

Study Goals



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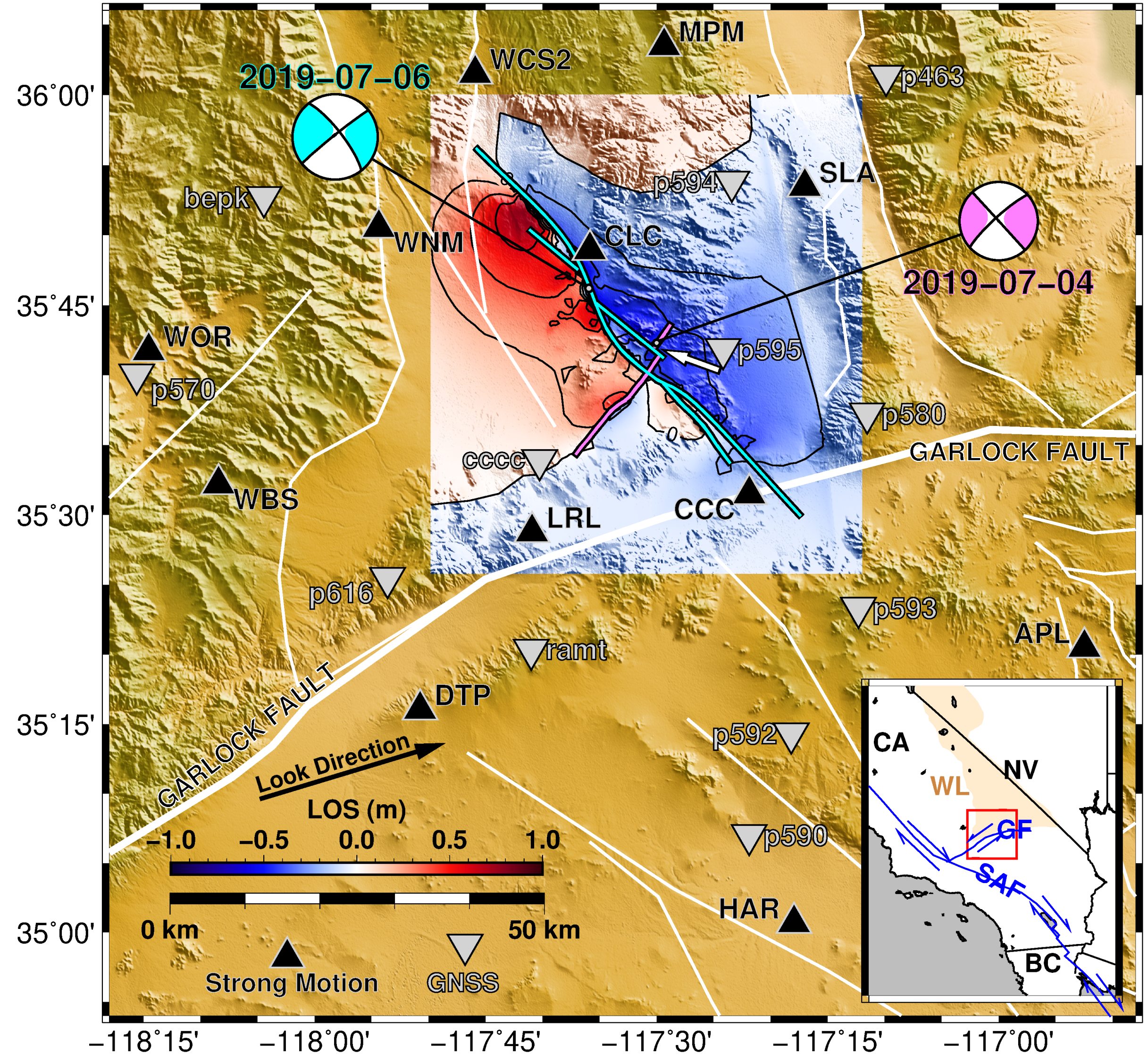
- Evaluate kinematic coseismic slip for the two largest events in the Ridgecrest Sequence
  - July 4, 2019: **M_w6.4** on NE-trending faults (pink)
  - July 6, 2019: **M_w7.1** on NW-trending faults (cyan)
- Include multiple instrument types with varying observation windows
  - *Static GNSS*
  - *High-rate GNSS*
  - *Strong-motion Accelerometer*
  - *Sentinel-1 InSAR*
- Explore fault interactions and potential seismic triggering
- Consider tectonic context:

  Immature fault zone progressing toward becoming a major tectonic plate boundary

Inversion Organization: 2 Earthquakes, 3 Observation Types



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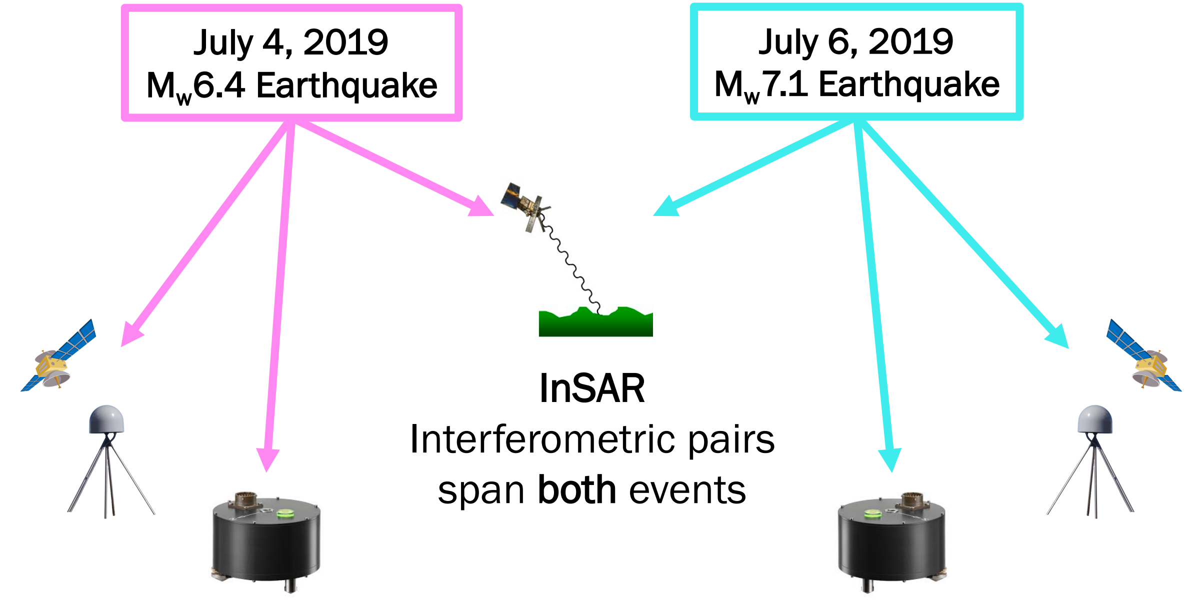
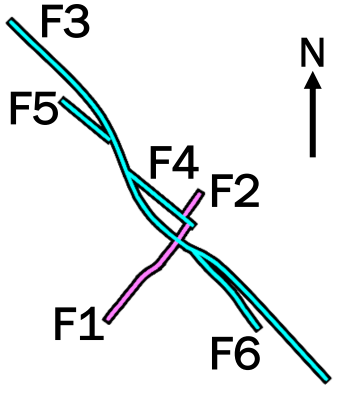


$$\boldsymbol{d} = \boldsymbol{Gm}$$

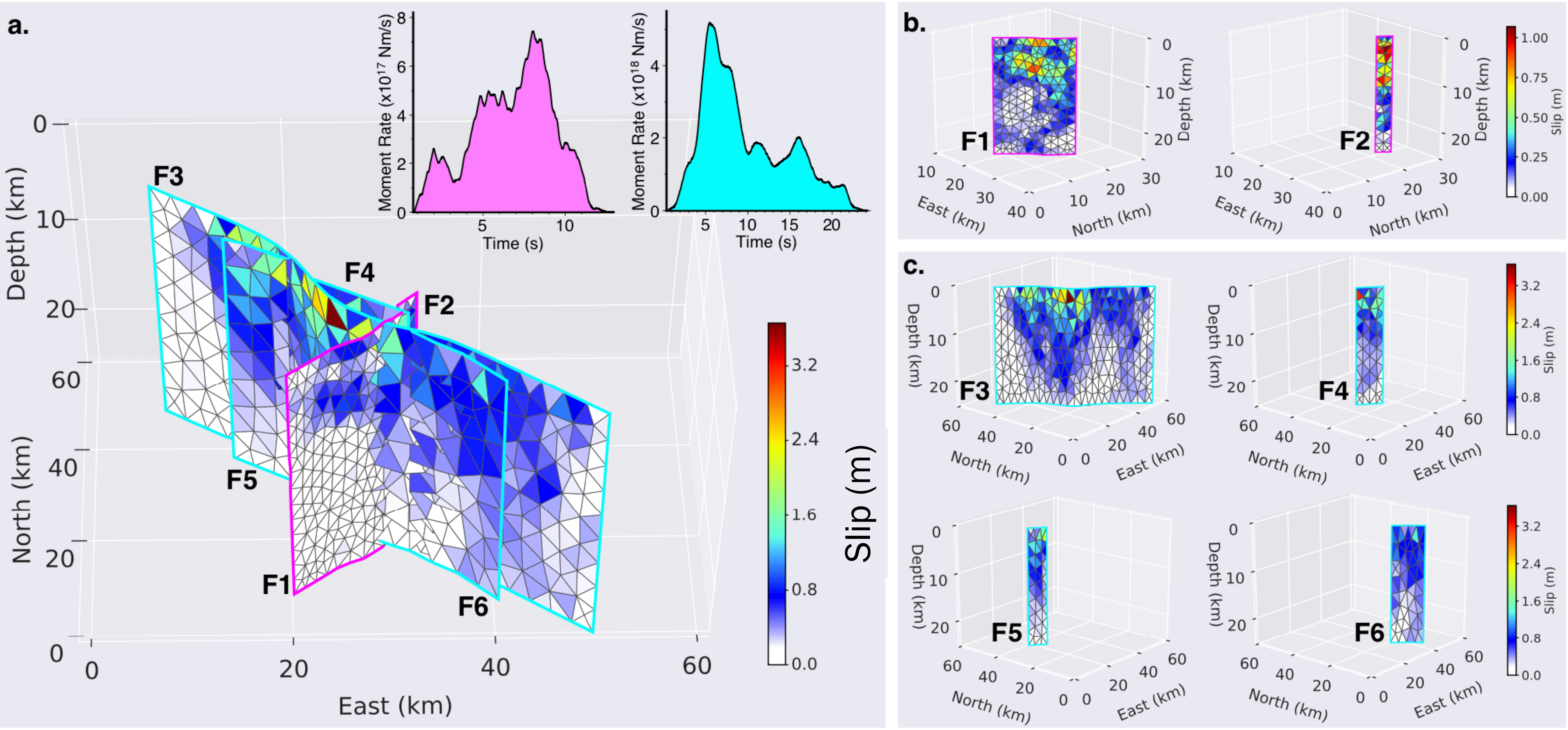
$$d = \begin{bmatrix} d^{2019-07-04}_{static} \\ d^{2019-07-04}_{displacement} \\ d^{2019-07-04}_{velocity} \\ d^{2019-07-06}_{static} \\ d^{2019-07-06}_{displacement} \\ d^{2019-07-06}_{velocity} \\ d_{InSAR-T71D} \\ d_{InSAR-T64A} \end{bmatrix} \quad G = \begin{bmatrix} G^{2019-07-04}_{static} & 0 \\ G^{2019-07-04}_{displacement} & 0 \\ G^{2019-07-04}_{velocity} & 0 \\ 0 & G^{2019-07-06}_{static} \\ 0 & G^{2019-07-06}_{displacement} \\ 0 & G^{2019-07-06}_{velocity} \\ G_{InSAR-T71D} & G_{InSAR-T71D} \\ G_{InSAR-T64A} & G_{InSAR-T64A} \end{bmatrix} \quad m = \begin{bmatrix} m^{2019-07-04} \\ m^{2019-07-06} \end{bmatrix}$$

Inversion Results



MAP VIEW

	July 4 M_w6.36	July 6 M_w7.03
Rupture Duration	12.2 s	23.8 s
Maximum Slip	1.1 m	4 m



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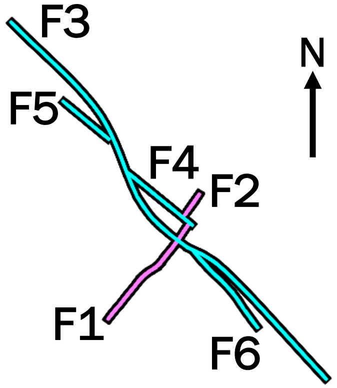
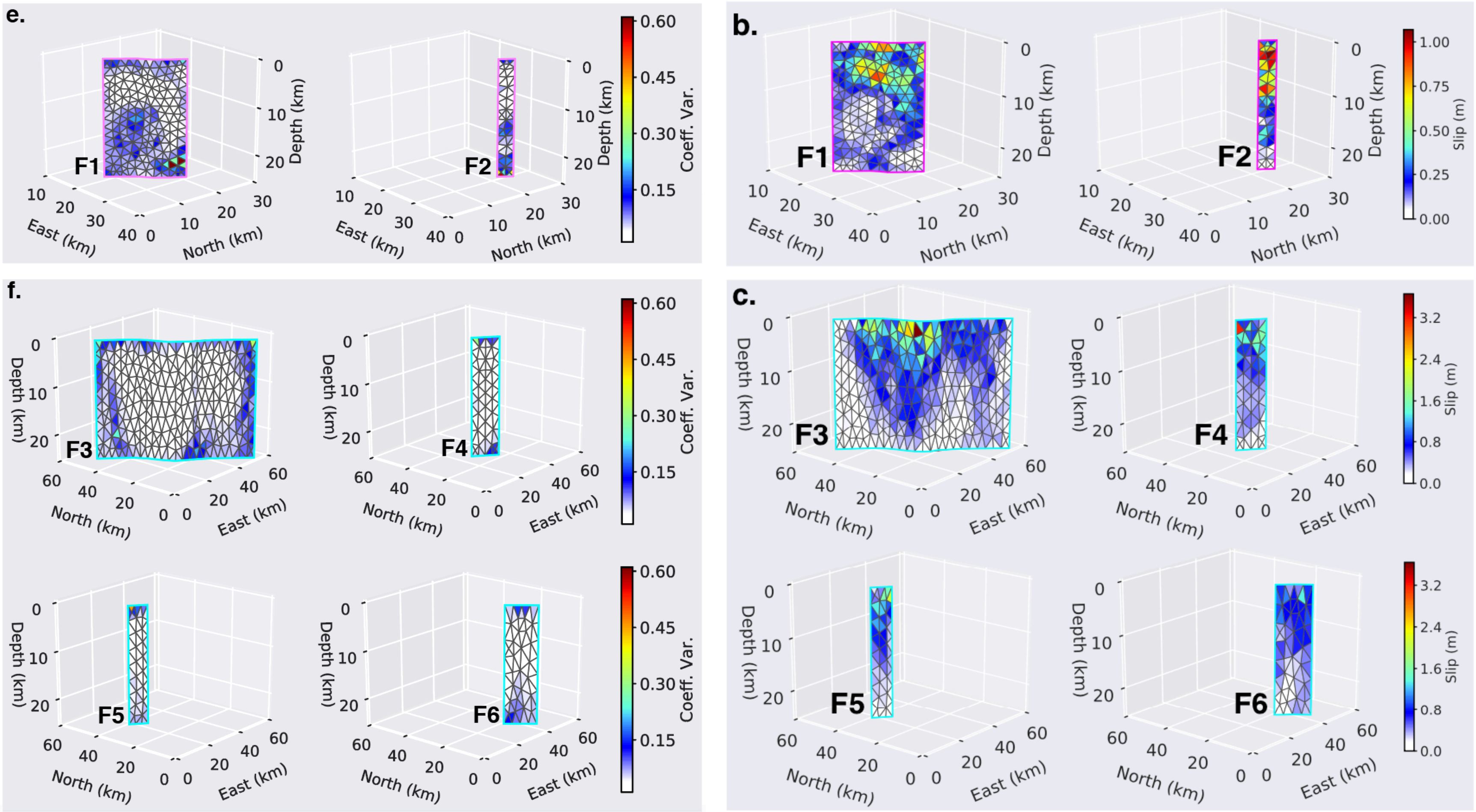
Inversion Results: Jackknife Testing



- Performed 100 inversions, each with 80% of the dataset
- Coefficient of Variation (CoV) (mean/standard deviation) describes model resolution: low CoV = good resolution
- Model is well resolved in regions of significant slip
- Least certain of area below July 4 peak slip and shallow/ surface slip

Coefficient of Variation

Slip Model



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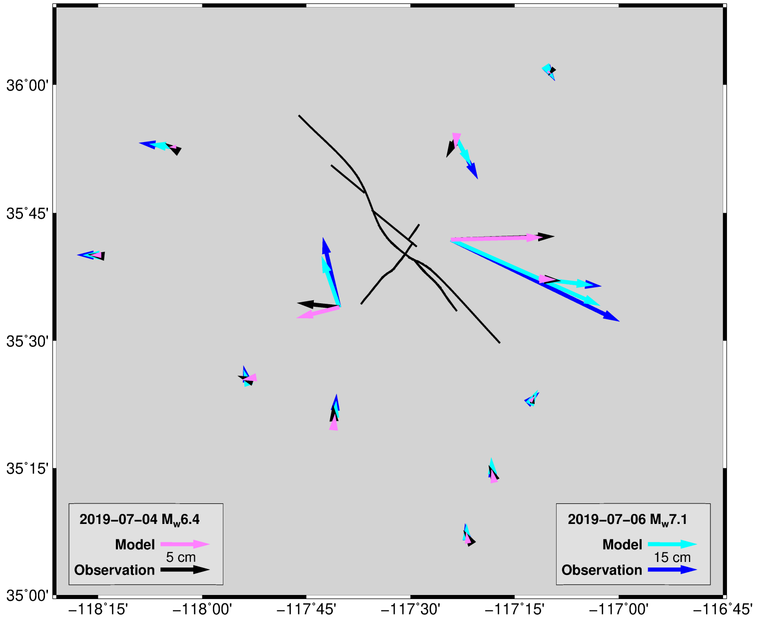
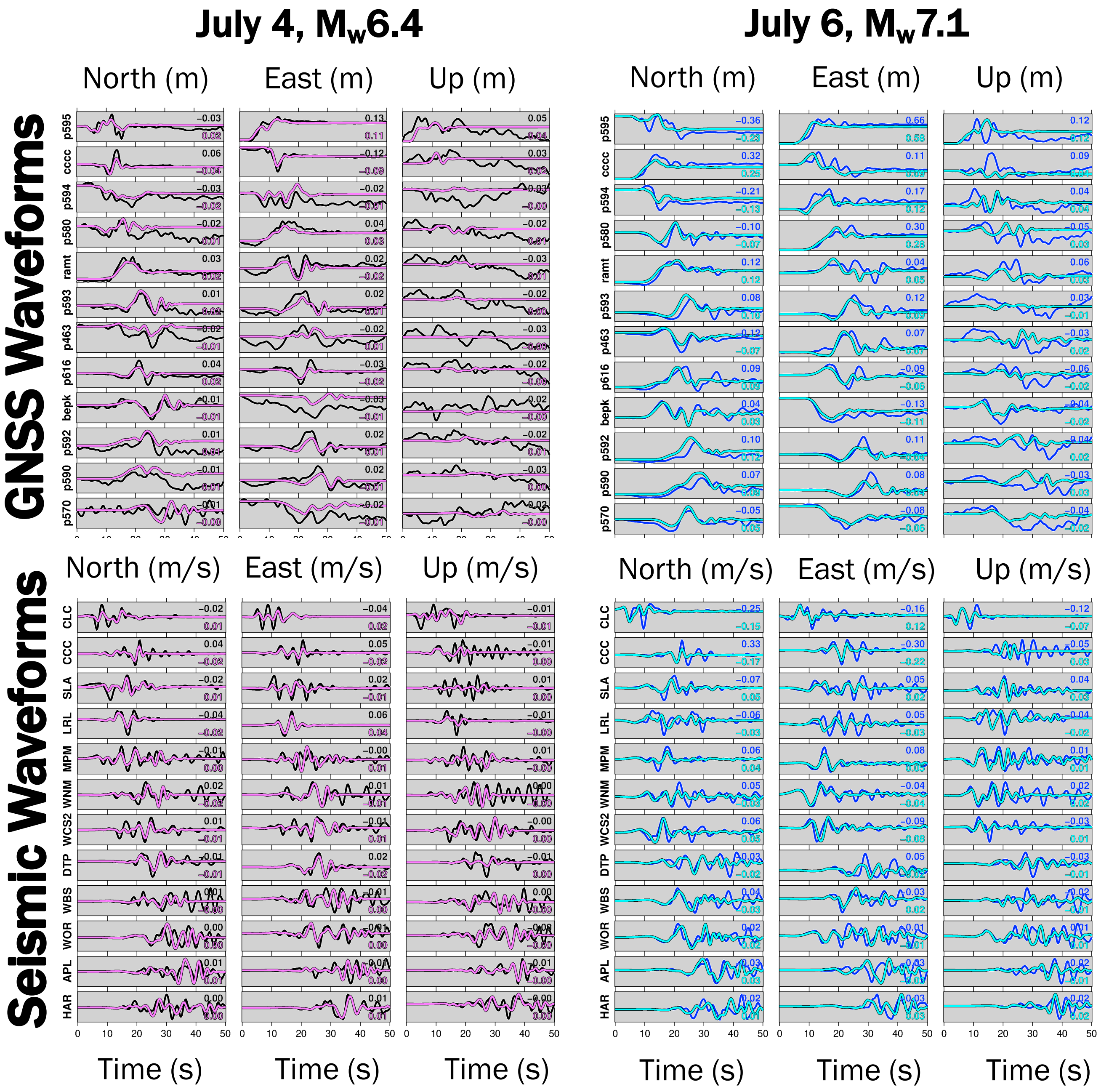
Synthetic Fits:

GNSS & Accelerometer

GNSS Static Offsets





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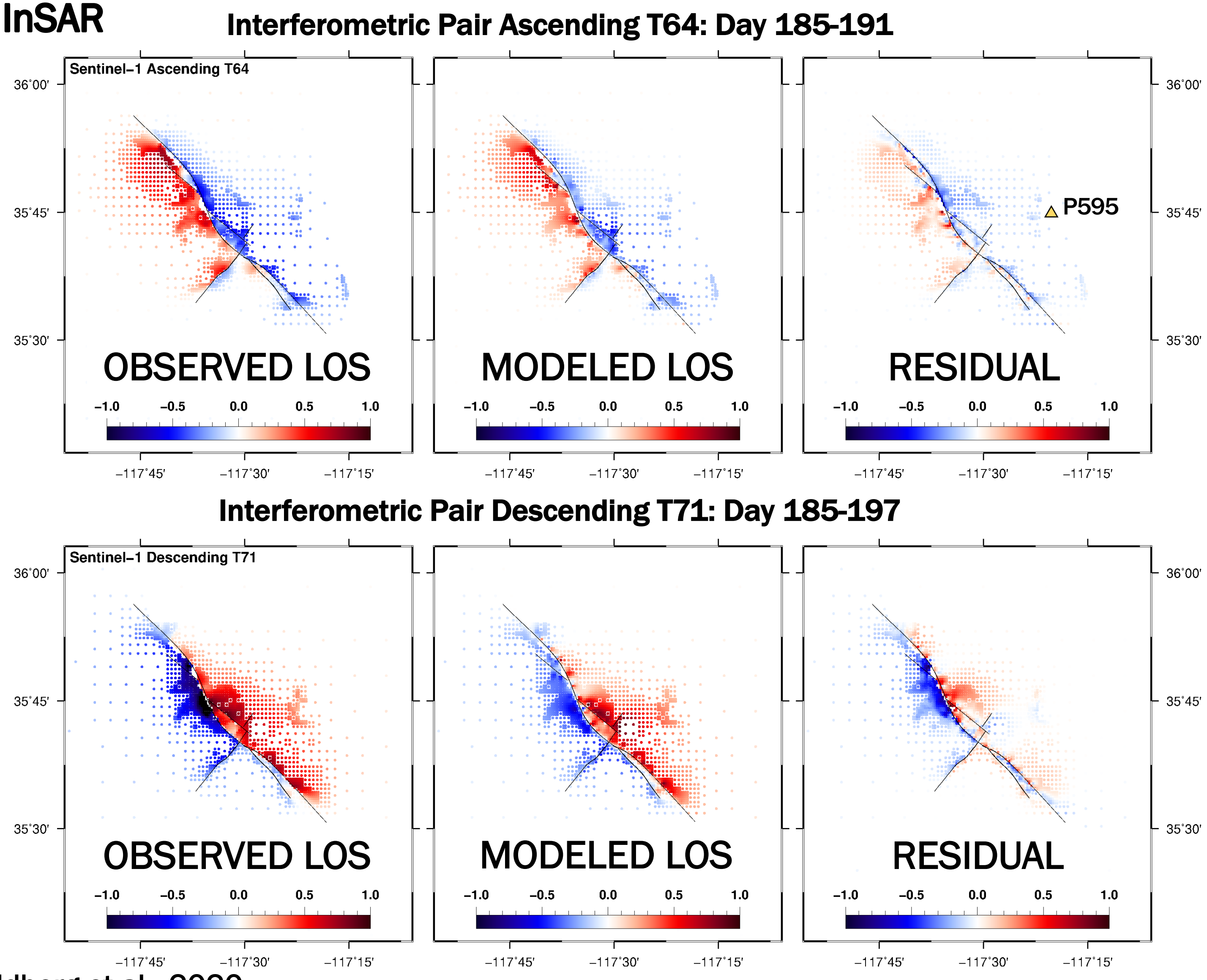
Synthetic Fits:

InSAR



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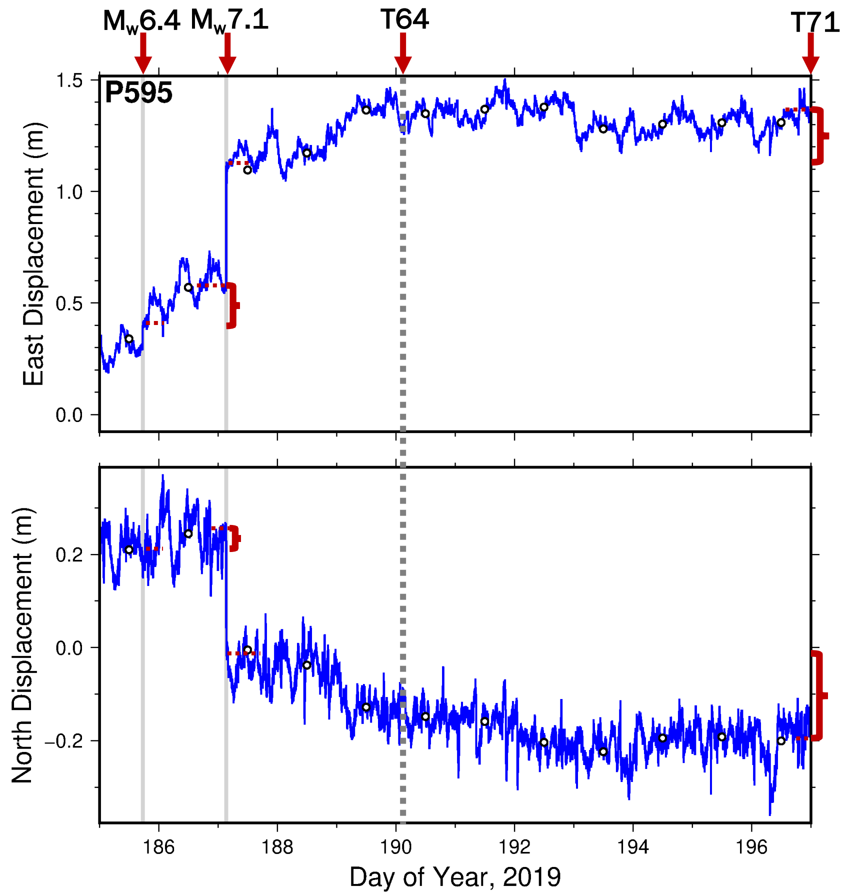
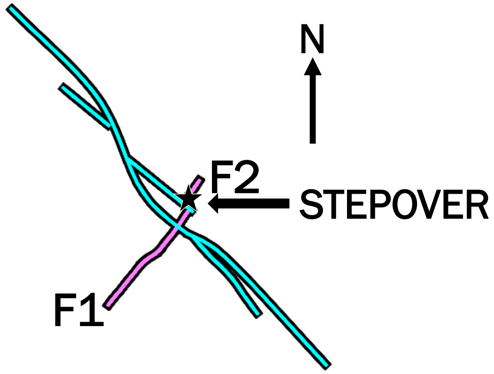
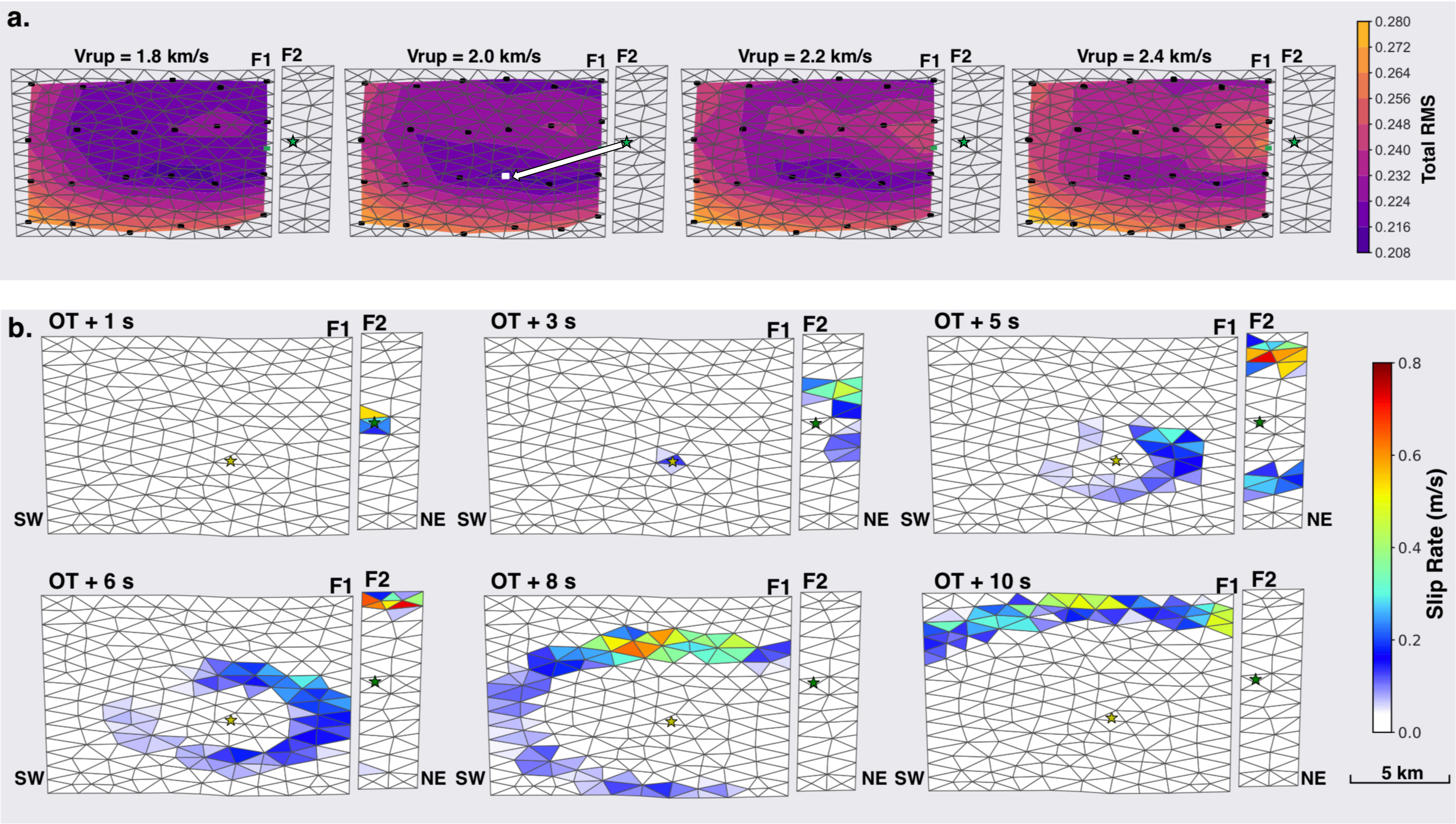


- InSAR data is systematically ***underfit***
- Repeat imagery occurs 4 or 10 days after July 6 mainshock
- Evidence for postseismic slip in GNSS time series, on the order of the InSAR residuals

The Case for Dynamic Triggering



- 1.5 km stepover
- Evidence for dynamic triggering up to ~5 km, especially prevalent in immature fault zones
- Data prefers rupture jumping to middle of second fault
- Also prefers relatively slow rupture velocity, 2.0 km/s



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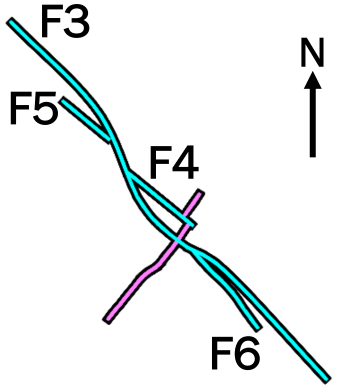
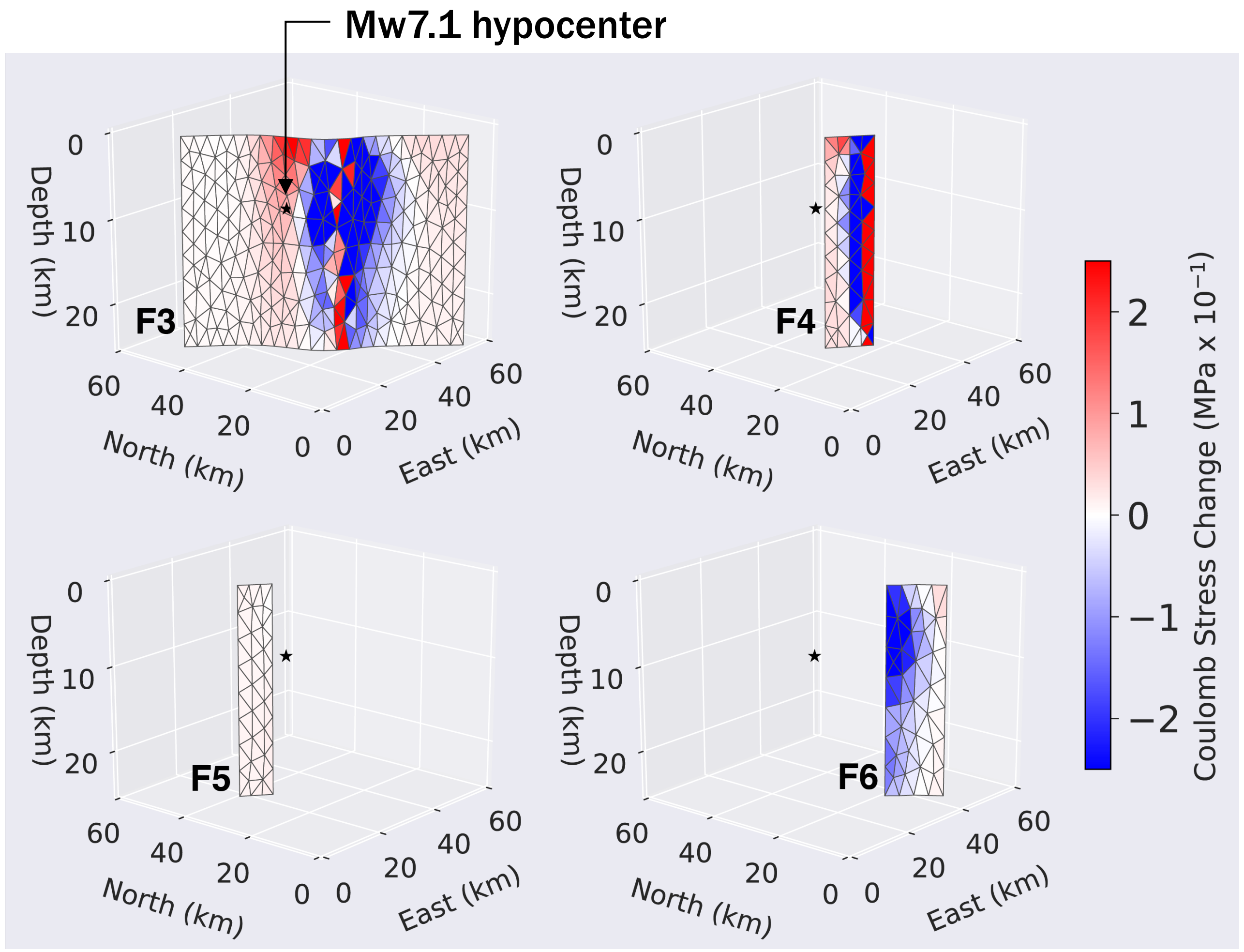
The Case for Static Triggering



Coulomb stress change on faults **F3-F6** due to slip on faults **F1-F2**



- Slip from July 4 event increases Coulomb stress at location of July 6 event initiation
- Result is robust based on additional testing of varying data weights in slip inversion (see manuscript)
- Note: we have not considered the aftershock sequence following the July 4 but preceding the July 6 event

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Take Home Messages

- With some careful arrangement of the data and Green's function matrix, we can invert for two events simultaneously, accommodating instruments with varying observation windows (importantly, the InSAR data which spans both events)

- We find evidence for seismic triggering

  - ***DYNAMIC:*** across a stepover during the July M_w6.4 event
  - ***STATIC***: increased Coulomb stress at the location of rupture initiation of the July 6 mainshock caused by slip from the July 4 foreshock

- Multi-fault rupture, relatively slow rupture velocities, and complex fault interactions is consistent with the view of the Eastern California Shear Zone/ Walker Lane as an incipient transform boundary

Manuscript Available at *Geophysical Research Letters*

Complex Rupture of an Immature Fault Zone:
A Simultaneous Kinematic Model of the 2019 Ridgecrest, CA Earthquakes

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