

Creepy dynamics in the Salton Trough: initiation, propagation, and sequences of aseismic rupture

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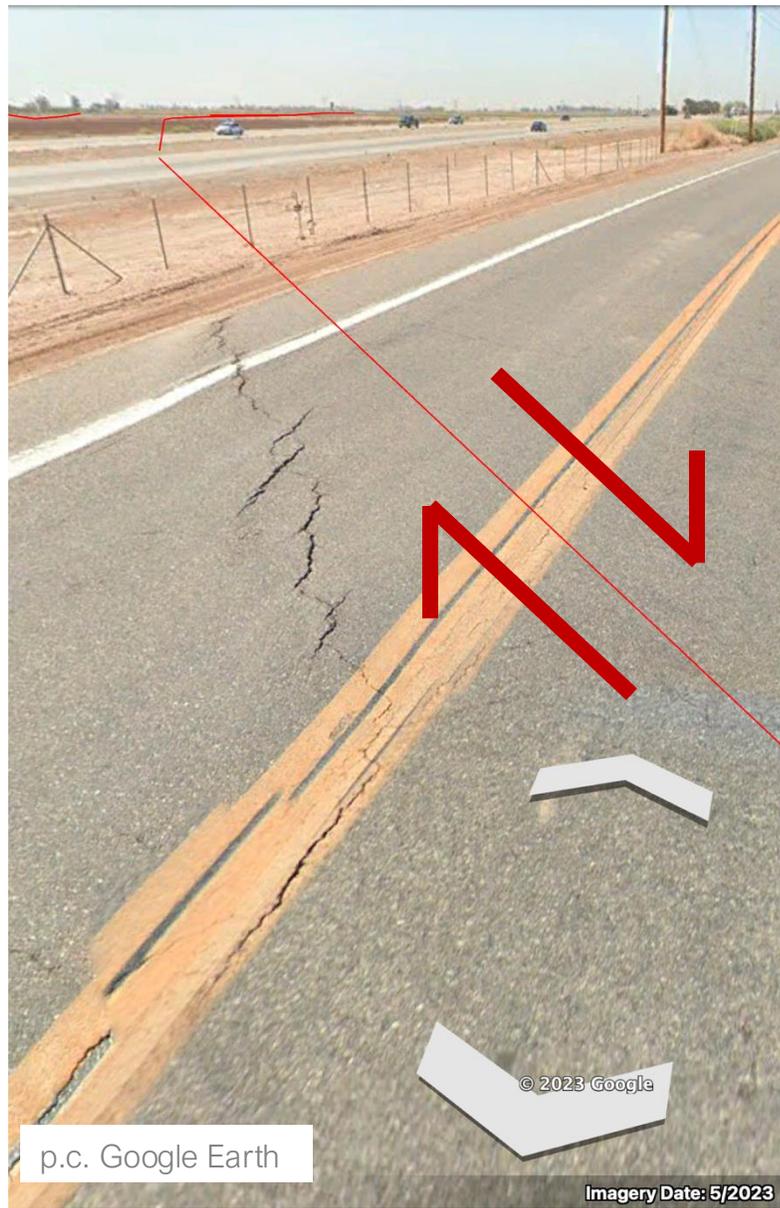
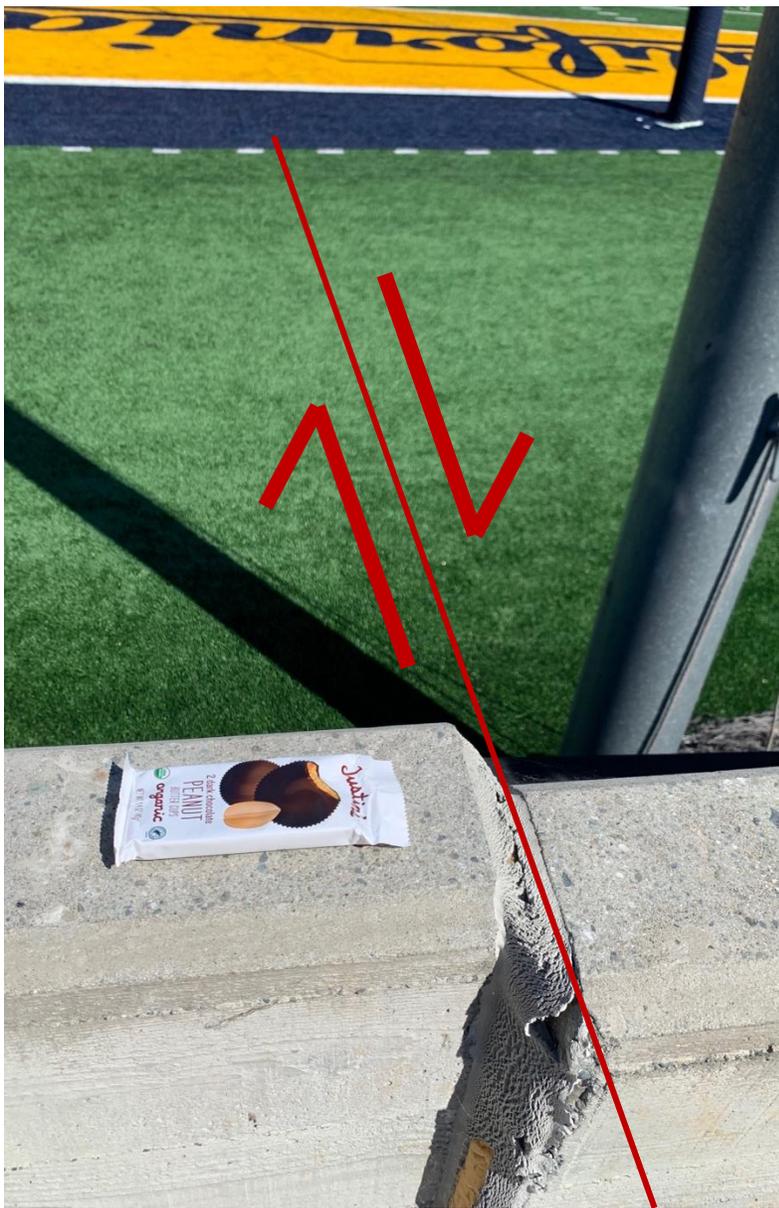
University of Colorado Boulder, Boulder, CO 80309

SCEC Shallow Earth Workshop

November 11, 2025

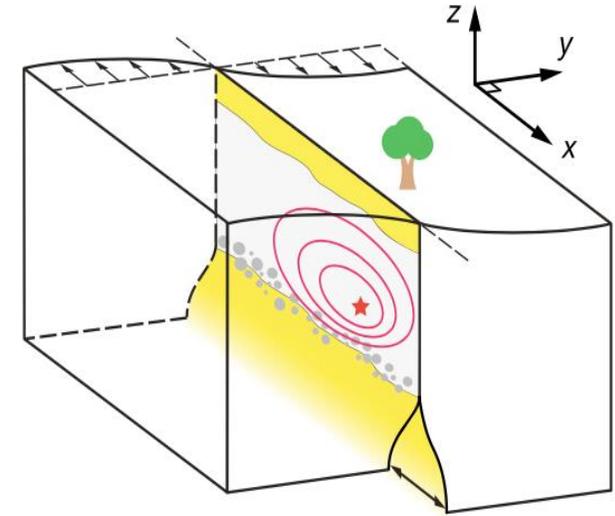


What is the importance of shallow fault creep?

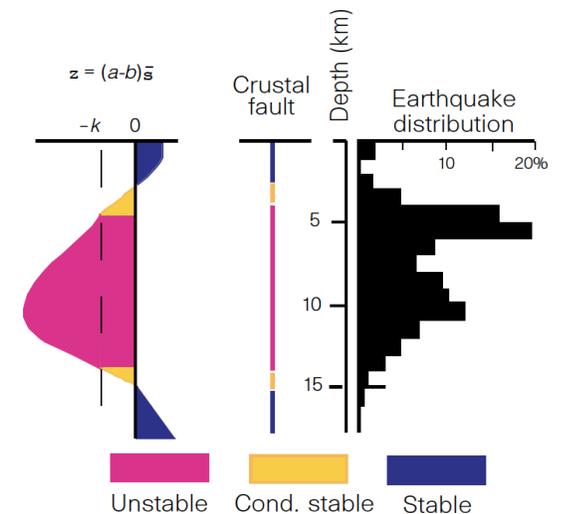


What is the importance of shallow fault creep?

- Affects earthquake rupture propagation through friction and stress conditions (Harris et al., 2017)
- Transfers stress to neighboring fault patches, potentially triggering slip (Wei et al., 2015)
- Controls process of afterslip (Bilham & Behr, 1992)
- Creates impacts to infrastructure (Berkeley stadium)
- Plays a role in induced seismicity, geothermal processes, and swarms (Eyre et al., 2022)
- Provides sensitive indicator of fault strength (Roeloffs, 2000; Lienkaemper et al., 1997)
- Reveals fundamental questions about physics of Earth materials (Barbot, 2019)
- Occurs statewide throughout California (Johnson et al., 2022)



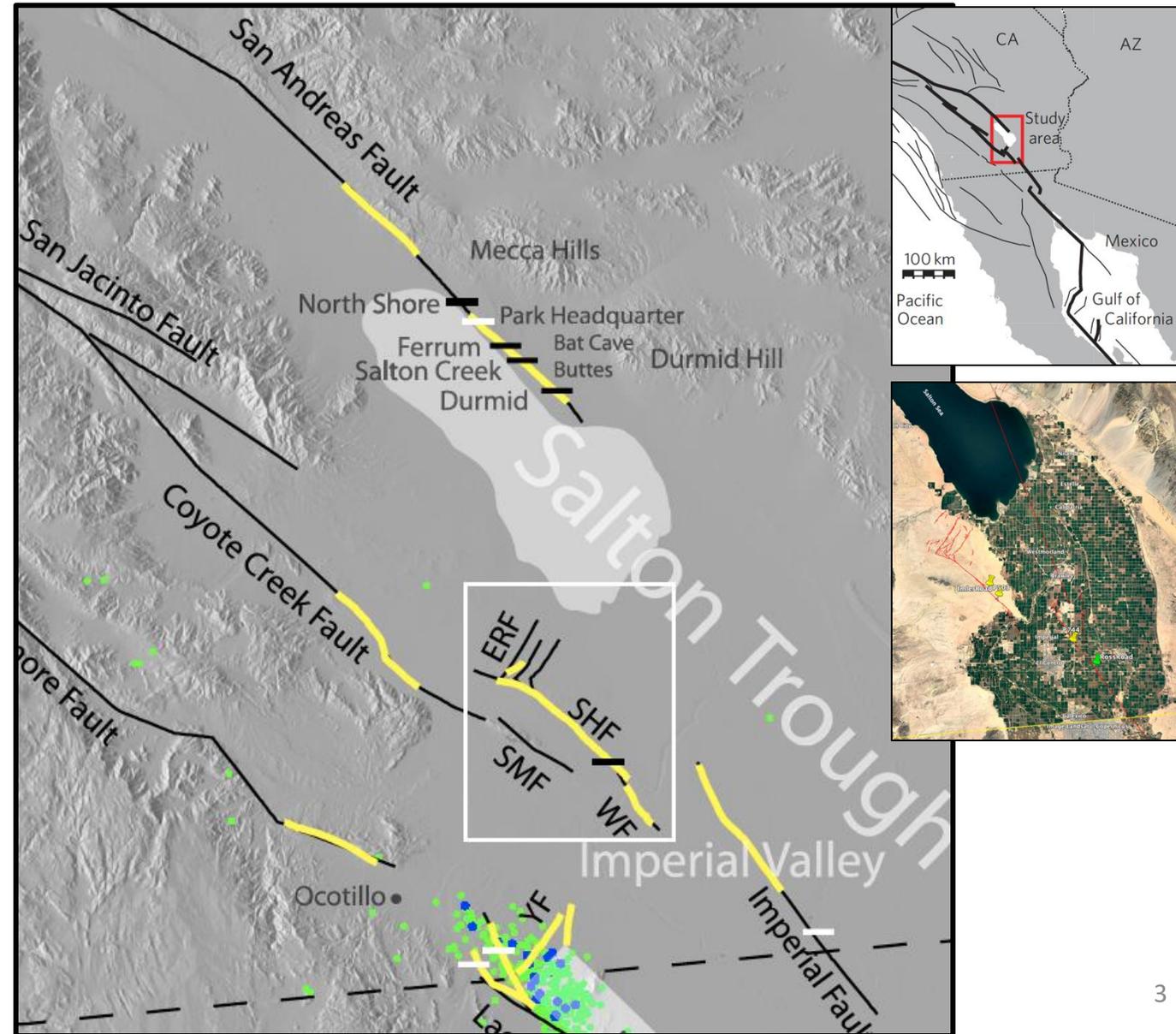
Jiang & Lapusta, 2017



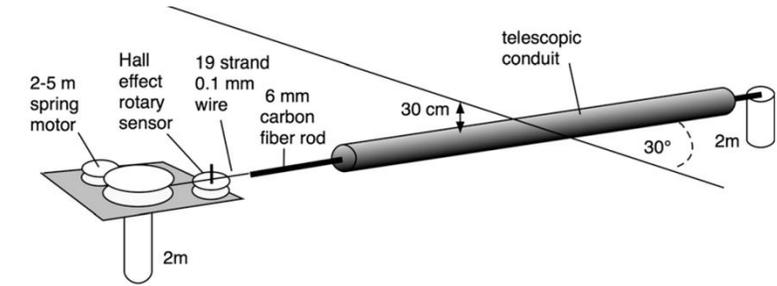
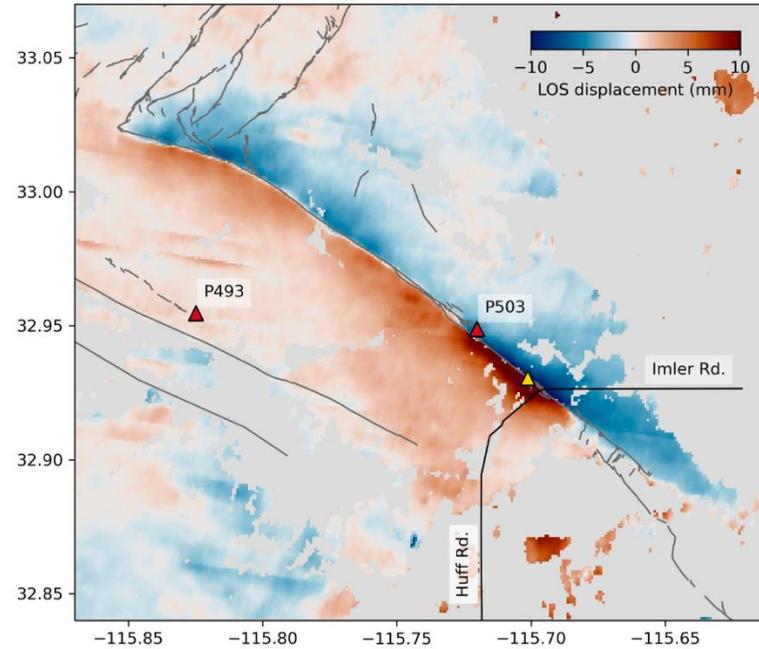
Scholz, 1998

Salton Trough is world-class natural laboratory for fault creep

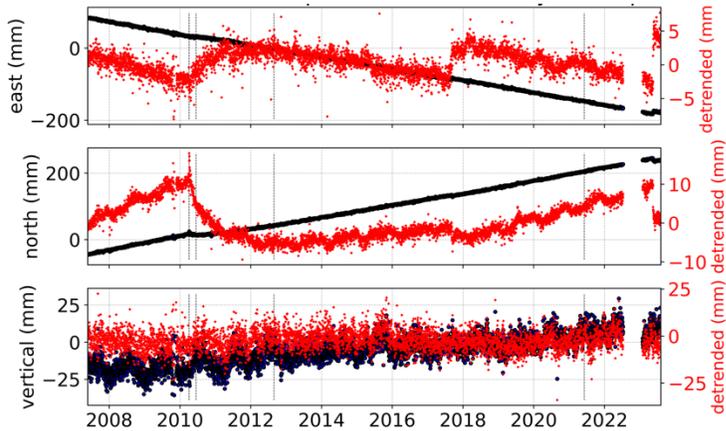
- Major creeping faults include the San Andreas, Imperial, Superstition Hills faults
- Minor faults observed to creep: Yuha desert, ERF, Brawley fault, many smaller faults associated with pull-aparts and geothermal fields in Imperial Valley
- Observations date from the 1960s onward



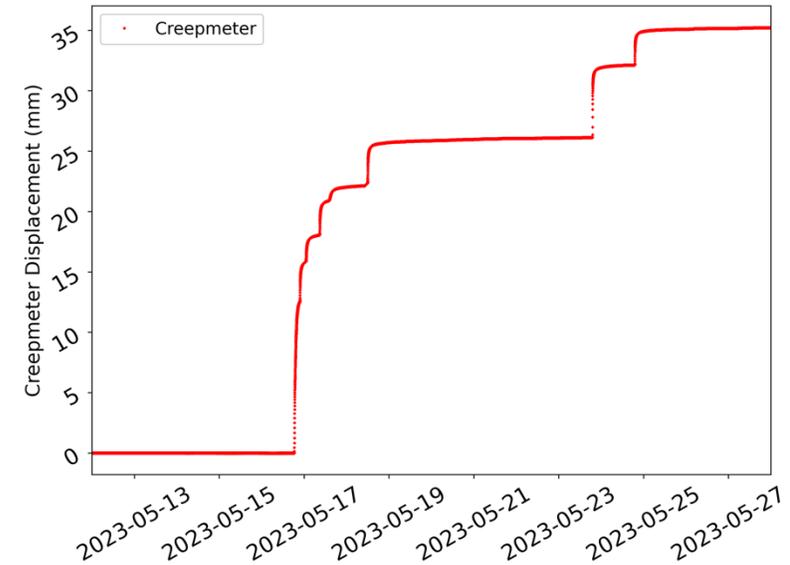
Observations of creep: GNSS, InSAR, Creepmeters



Bilham et al., 2004; Tymofyeyeva et al., 2019



Vavra et al., 2024



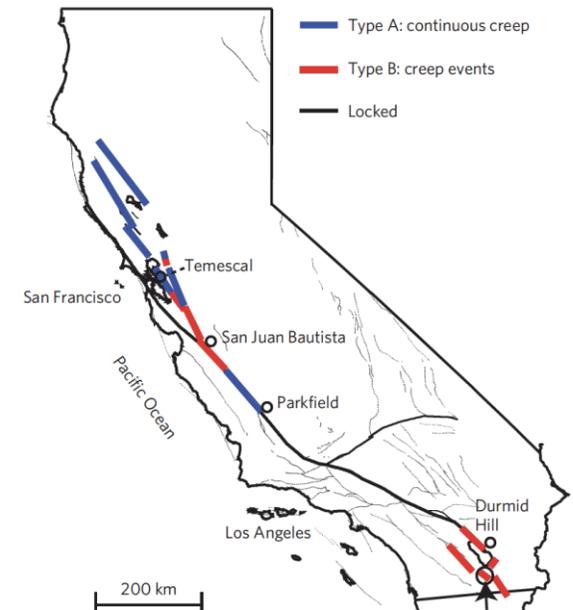
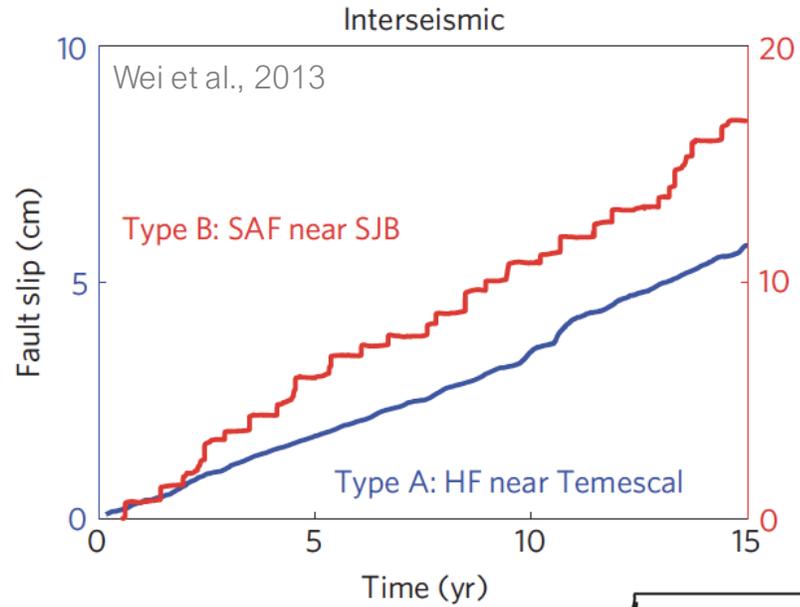
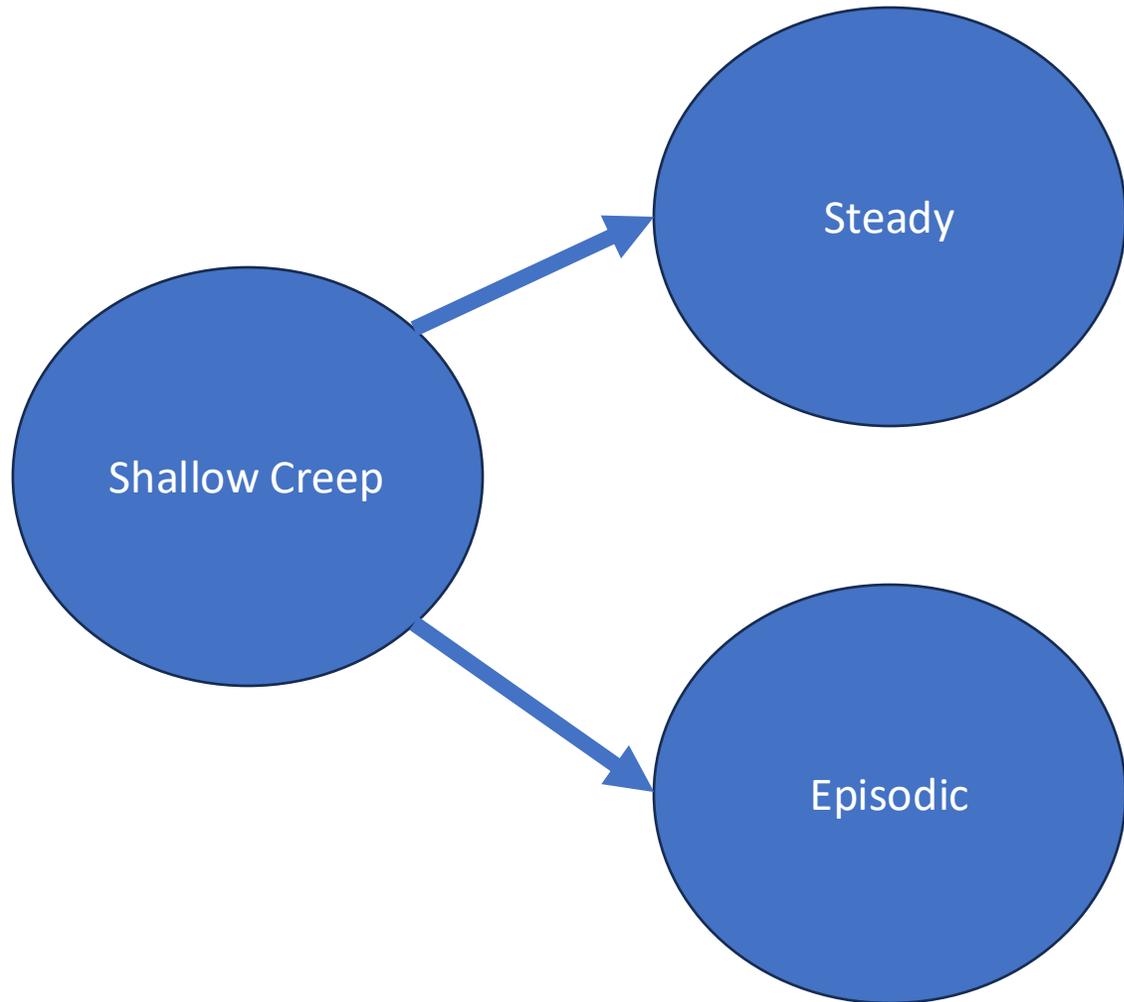
P503; p.c. EarthScope

What controls creep throughout the earthquake cycle?

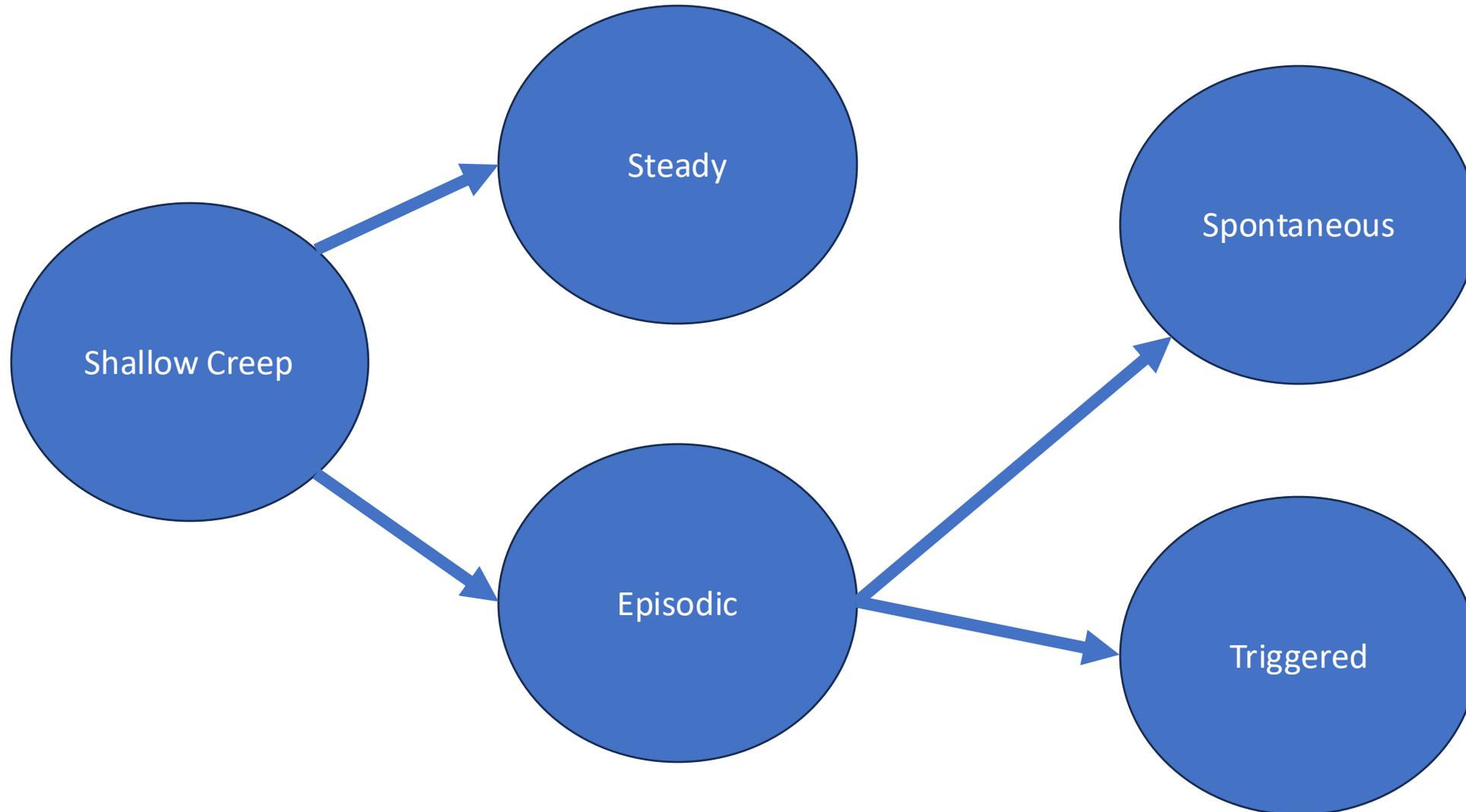
- We seek to understand causative mechanisms, dynamics, and controls on the process of shallow creep:
 - Step 1: Organize our observations to establish common terminology
 - Step 2: Understand creep behaviors of each fault
 - Step 3: Perform modeling to determine best-fitting slip and structural parameters and their implications



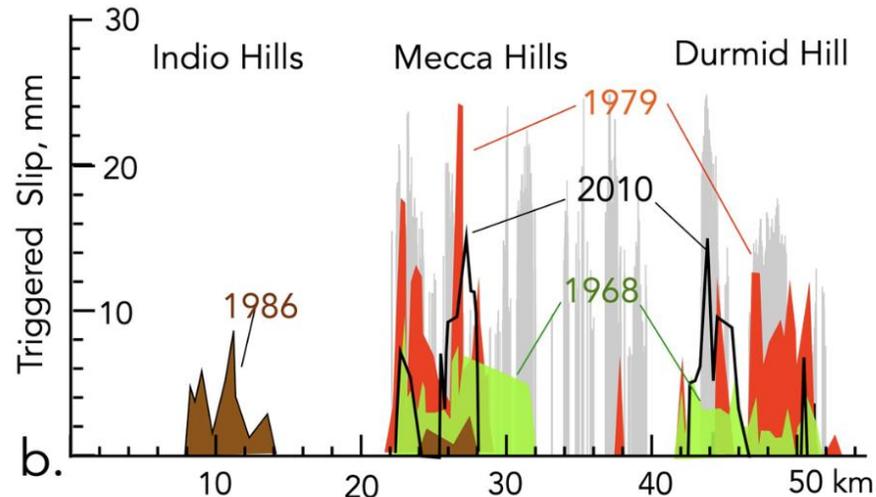
Step 1: Classification of creep as Steady vs. Episodic



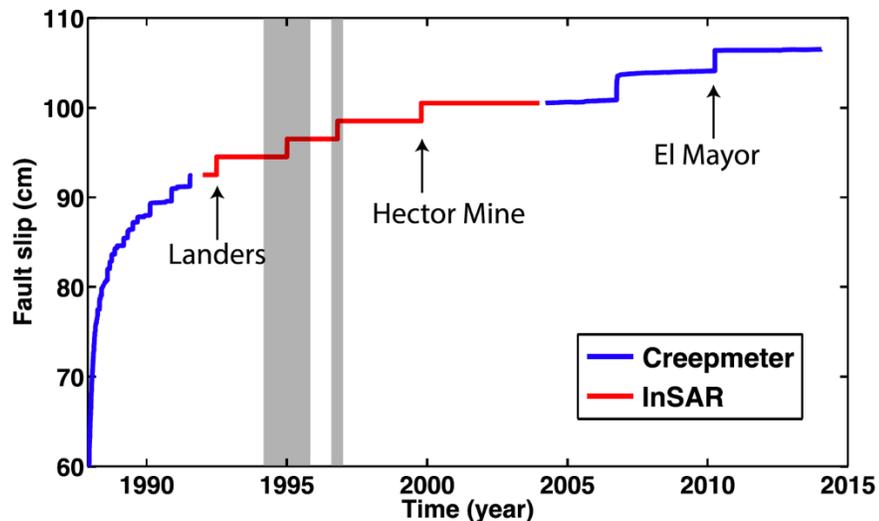
Step 1: Classification of creep as Steady vs. Episodic



Triggered vs. Spontaneous Creep Episodes



SSAF fault creep record; Parker et al., 2021

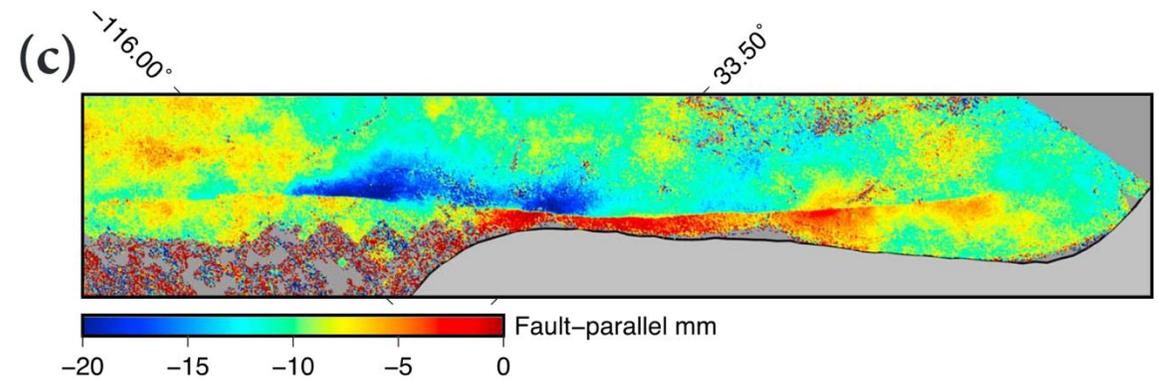
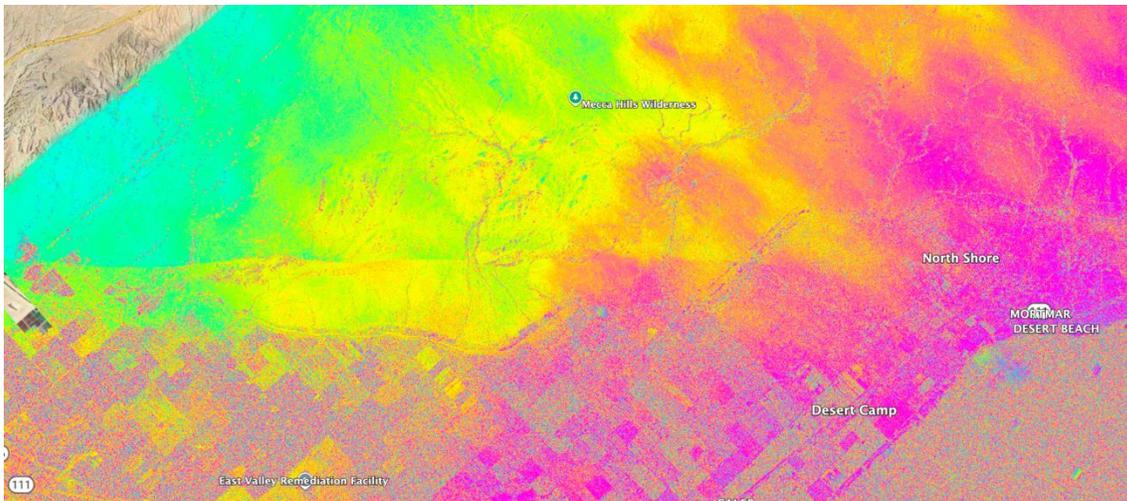
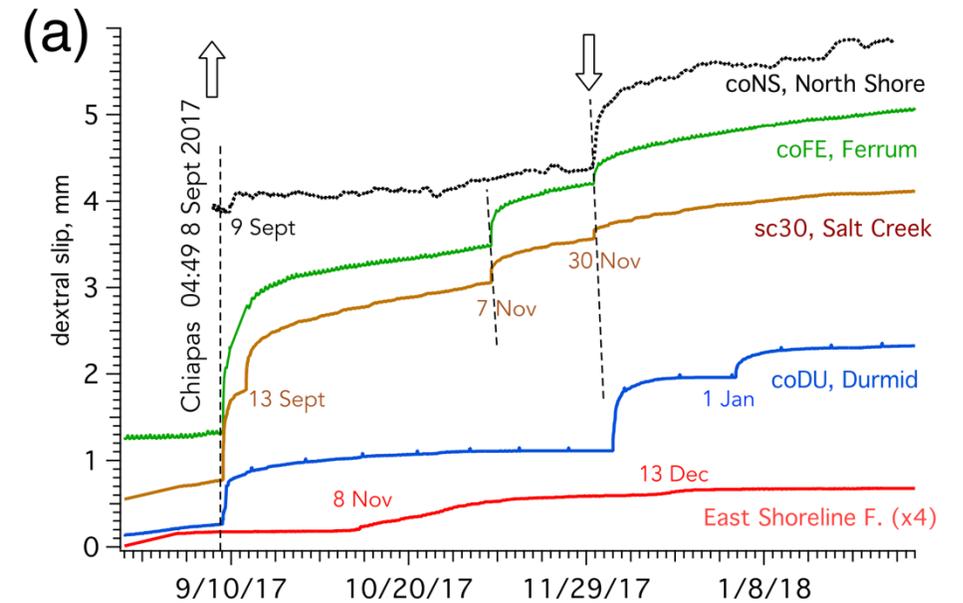
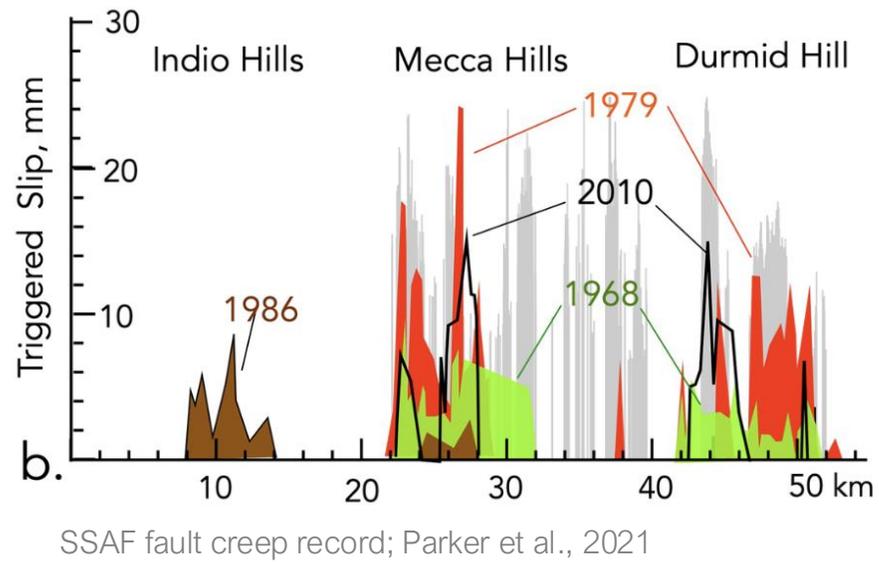


Superstition Hills fault creep record; Wei et al., 2015

Known triggering events in Salton Trough:

- 1968 M6.6 Borrego Mountain
- 1979 M6.5 Imperial
- 1987 M6 Superstition Hills
- 1992 M7 Landers
- 1999 M7 Hector Mine
- 2010 M7.2 El Mayor Cucapah
- 2017 M8.2 Chiapas
- 2019 M7.1 Ridgecrest

El Mayor Cucapah and Chiapas triggered slip on SSAF

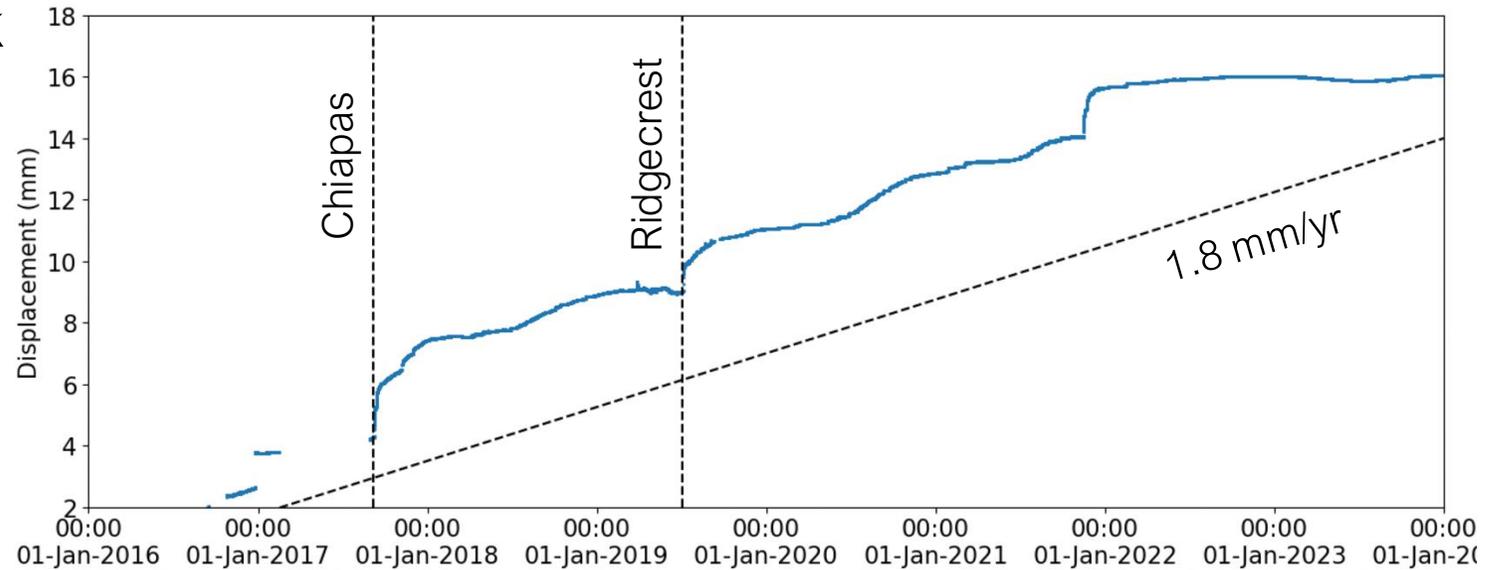


Tymofeyeva et al., 2019

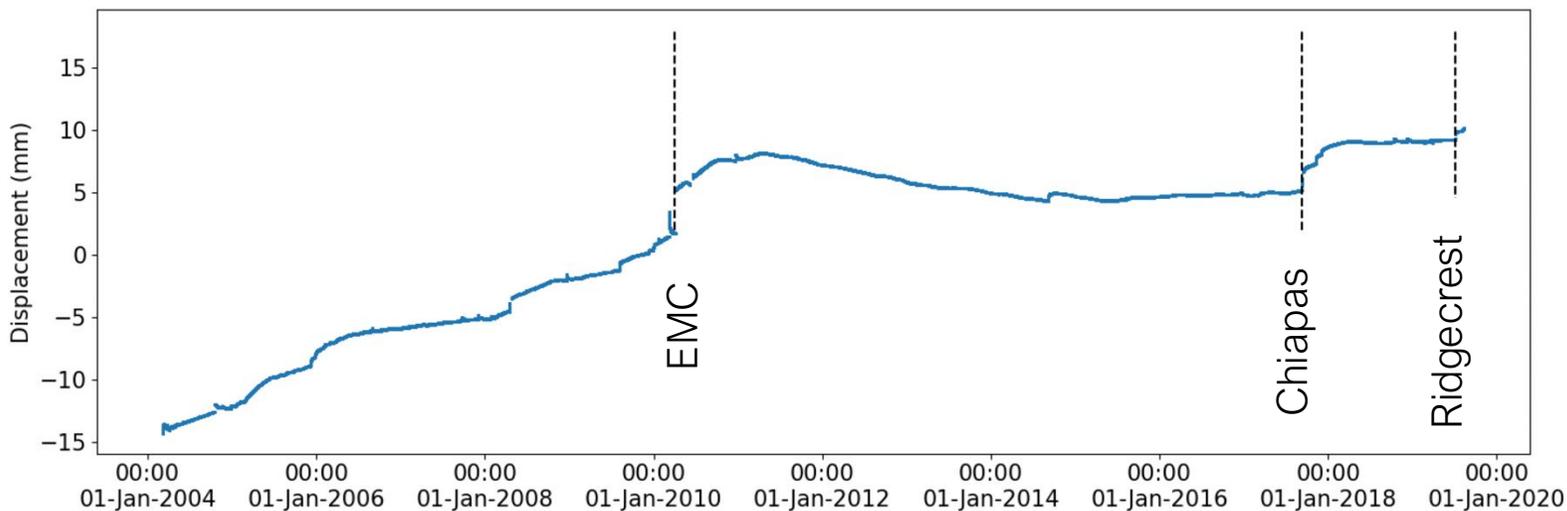
UAVSAR data, Sept 2009 - April 2010

Creepmeter time series at SC30 and FE30

Salt Creek



Ferrum



- Events typically 2-5 mm
- Some background creep rate
- Mix of triggered and spontaneous creep events

Full taxonomy: largest catalog of creep events

- In total, we have classified creep into six phenomena

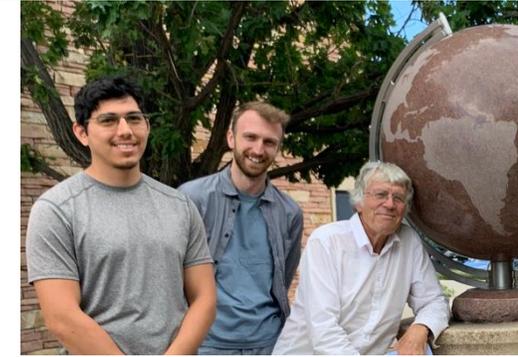
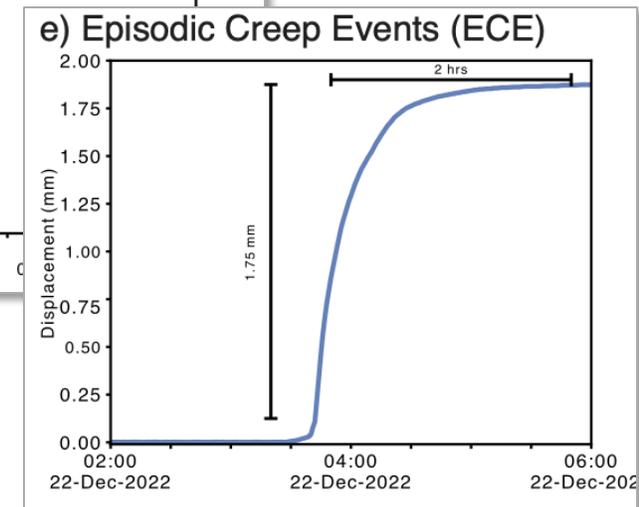
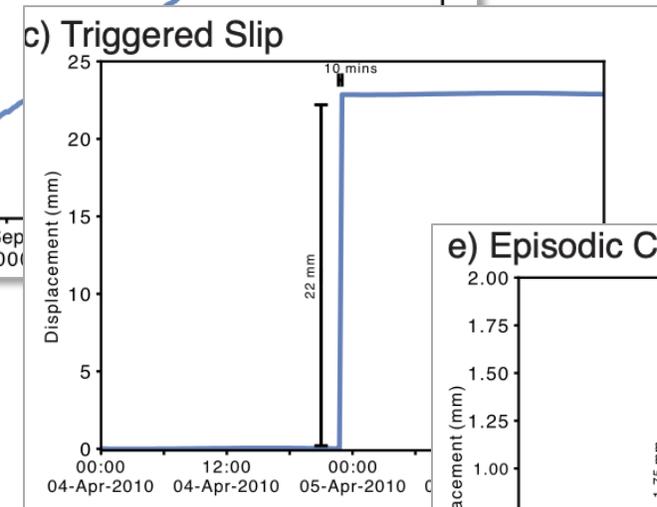
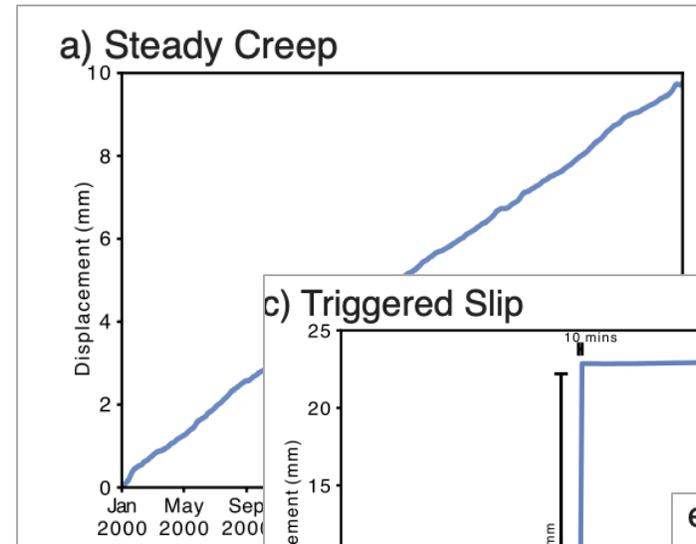
- Steady, Triggered, and Spontaneous ECE

*Not shown: Afterslip, Acceleration, and “Creeplet”

- Developed a new catalog of 5,700 creep event picks and associated creepmeter time series (1980-2023), now available on Zenodo

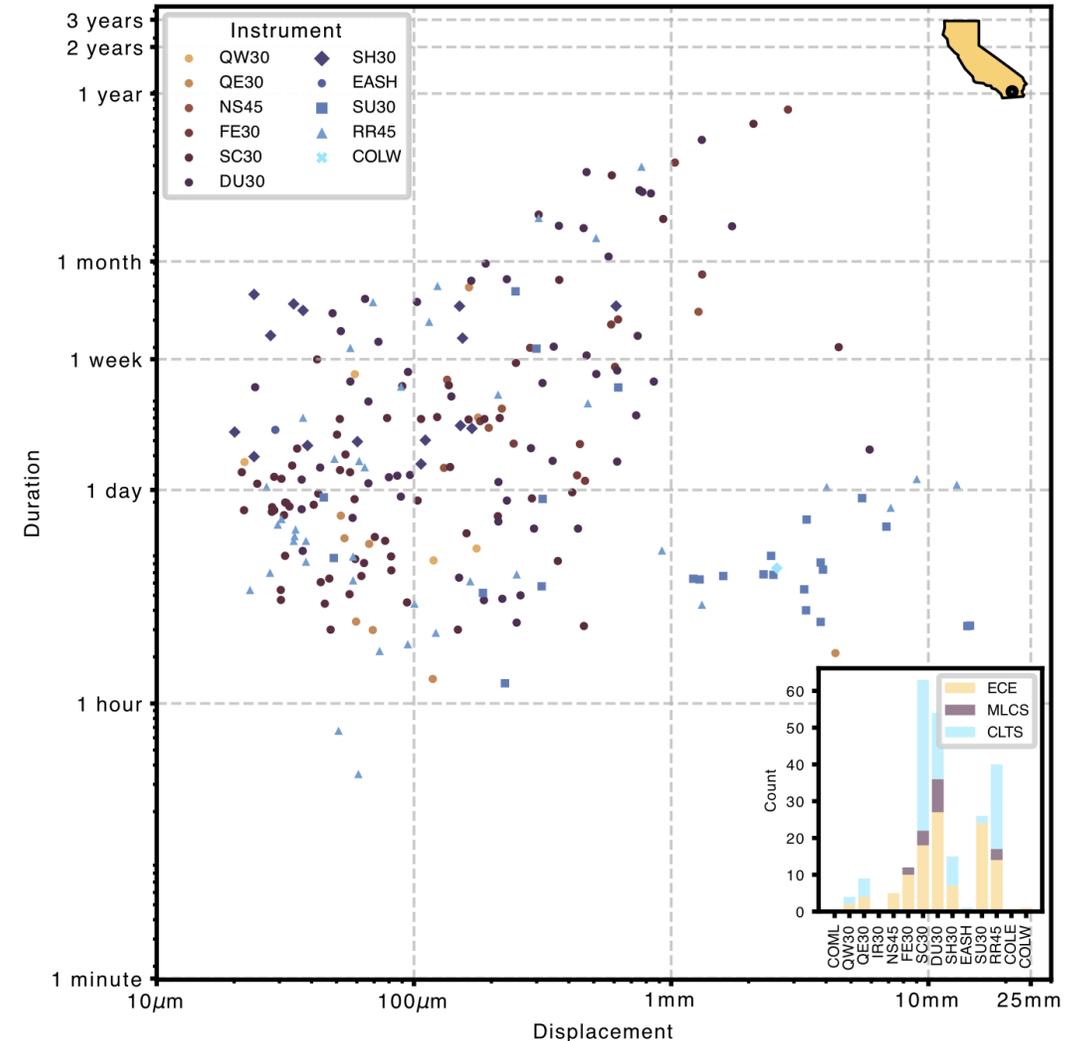
<https://doi.org/10.5281/zenodo.17087957>

- Postdoc Dan Gittins developed catalog in prep for publication. Earthscope intern Juan Cruz determined how many were triggered by rainfall or EQs.



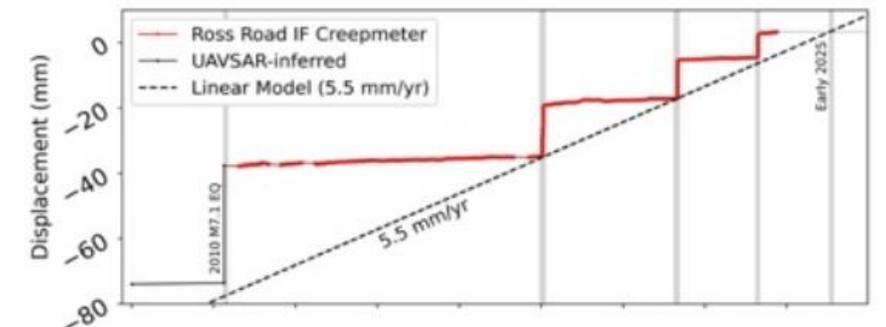
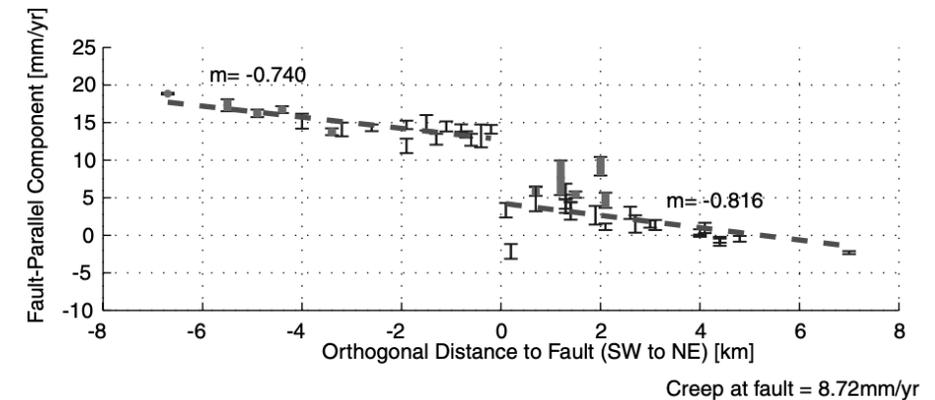
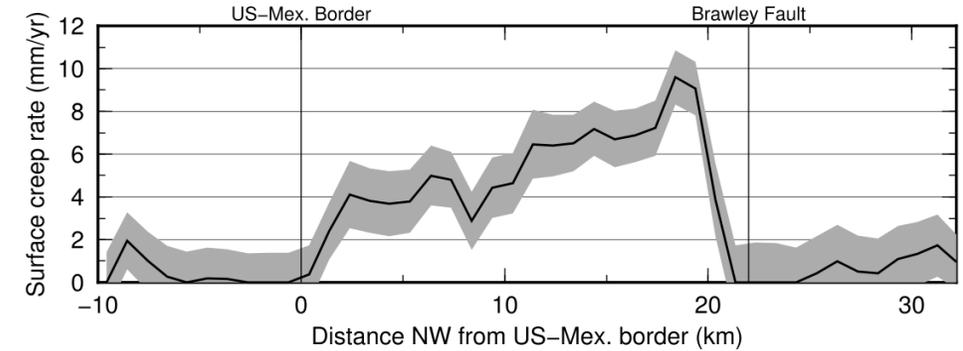
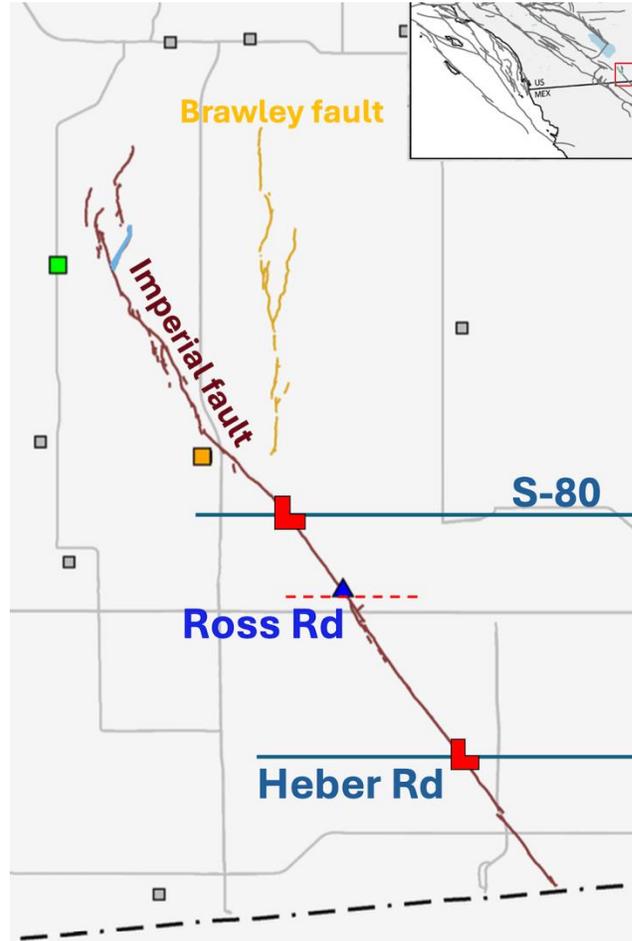
Full taxonomy: largest catalog of creep events

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Step 2: Specific faults in the Salton Trough

- Imperial fault is a major fault of the Pa-NA plate boundary. Large earthquakes in 1906, 1915, 1940, and 1979.
- Known to be creeping at 5-10 mm/yr, but not known how that evolves in space and time.



How does Imperial fault creep evolve in space and time?

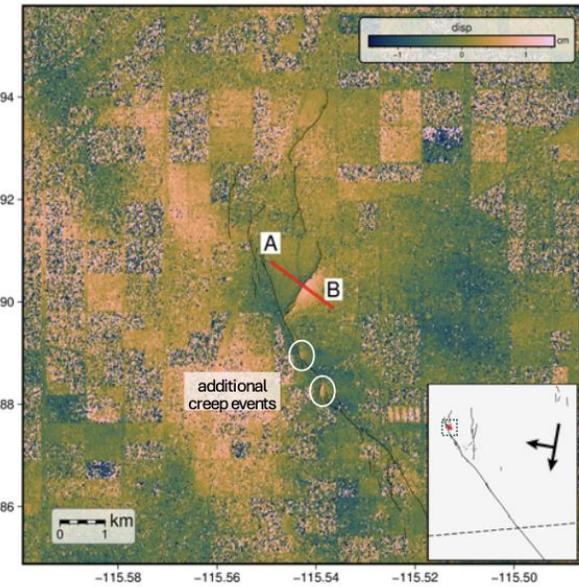
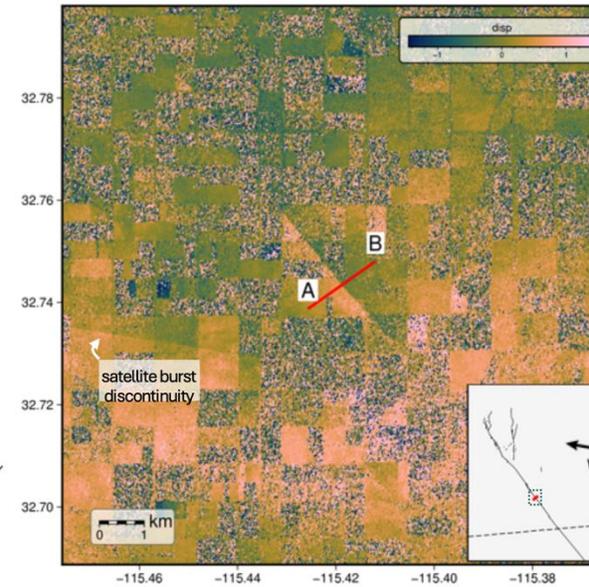
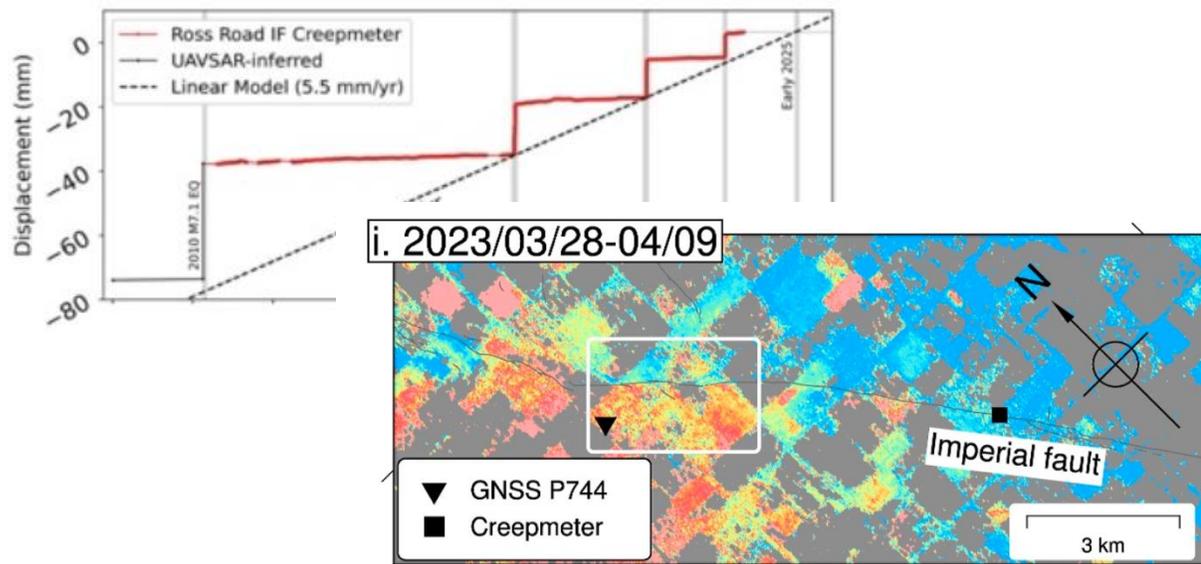
- Can individual creep events be detected with InSAR, corroborated by ground measurements?
- What can we learn from them?



Morow Tan

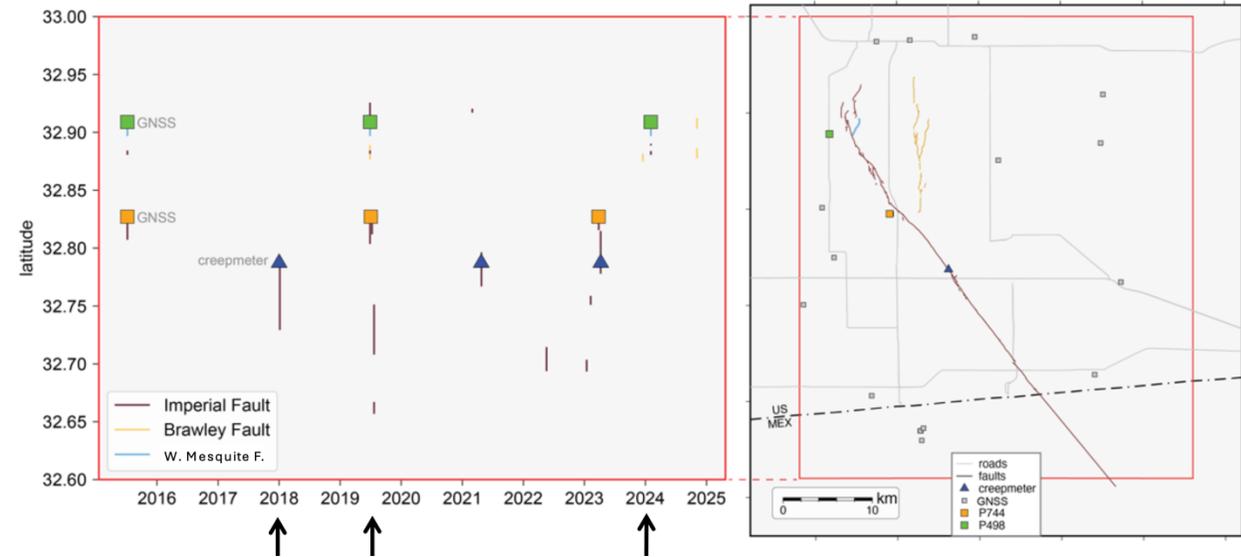


James Genero

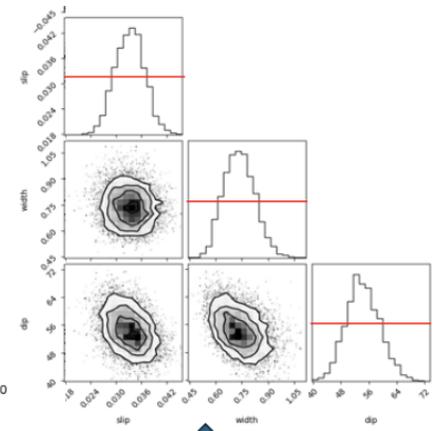
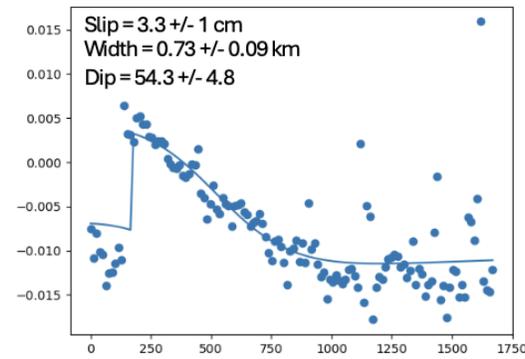


Results of Imperial Fault study

- InSAR can find IF creep events
- 17 creep events identified
- Ridgecrest triggering extent
- Creep events are not mechanically segmented
- Migrate/propagate slowly, ~ 1 km/day
- Normal faults creep too, on both sides of basin
- Initial modeling shows creep confined to top 2 km



2019 Jun 29- Jul 11



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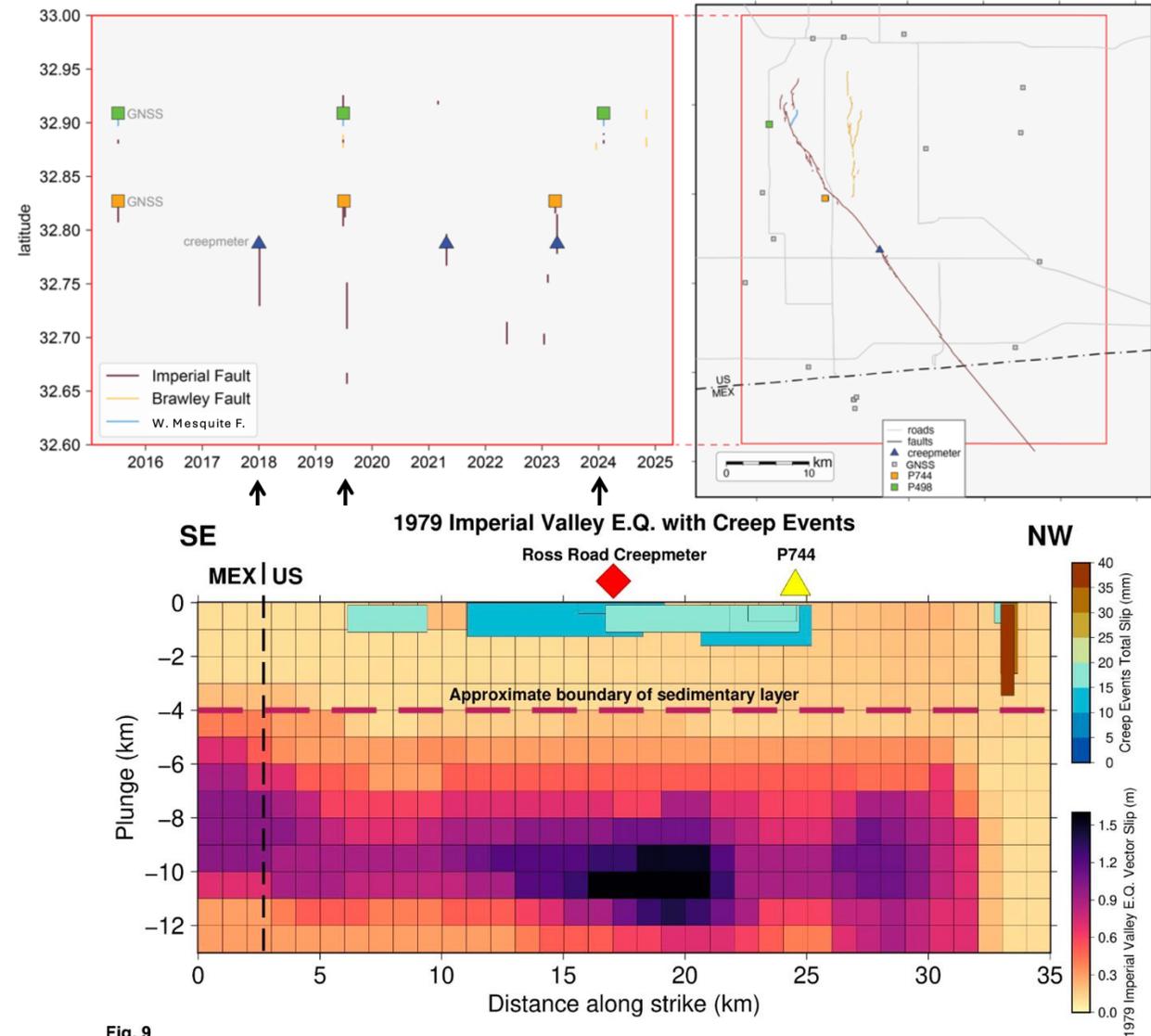
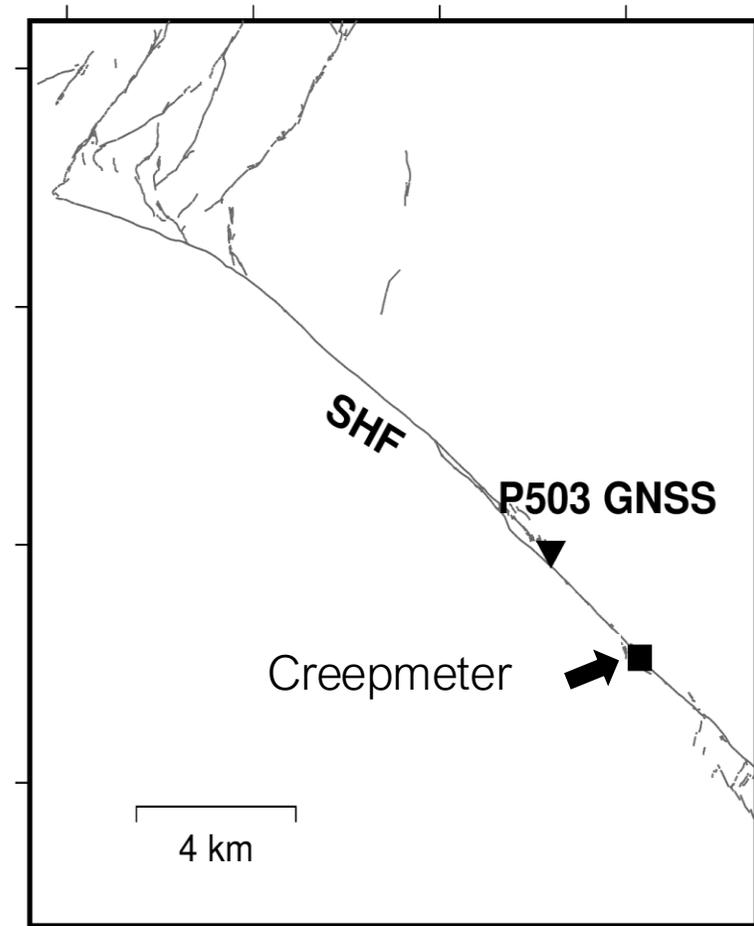
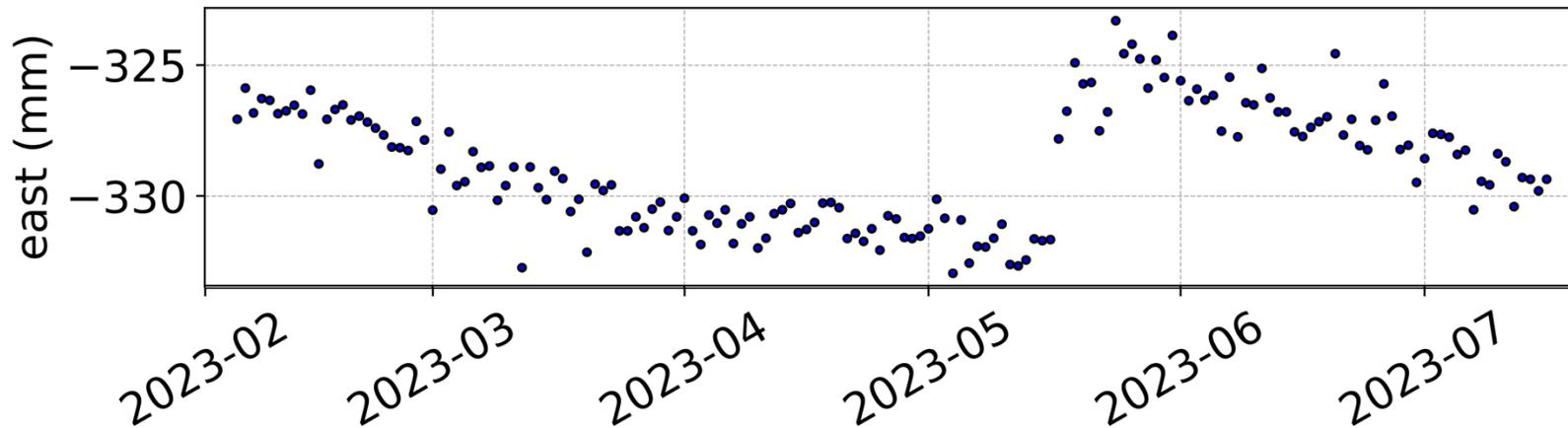
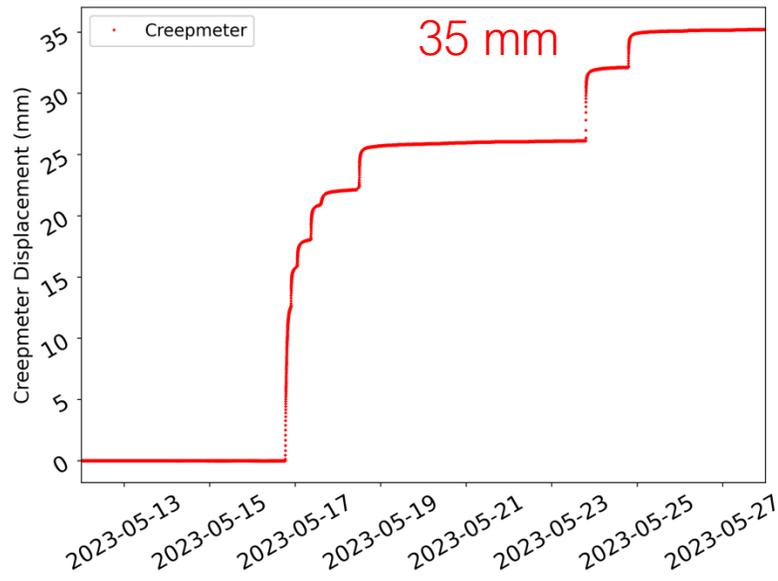


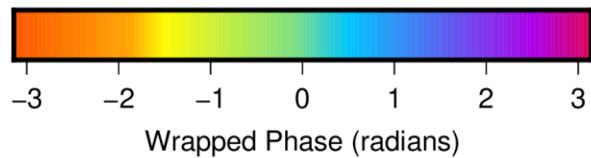
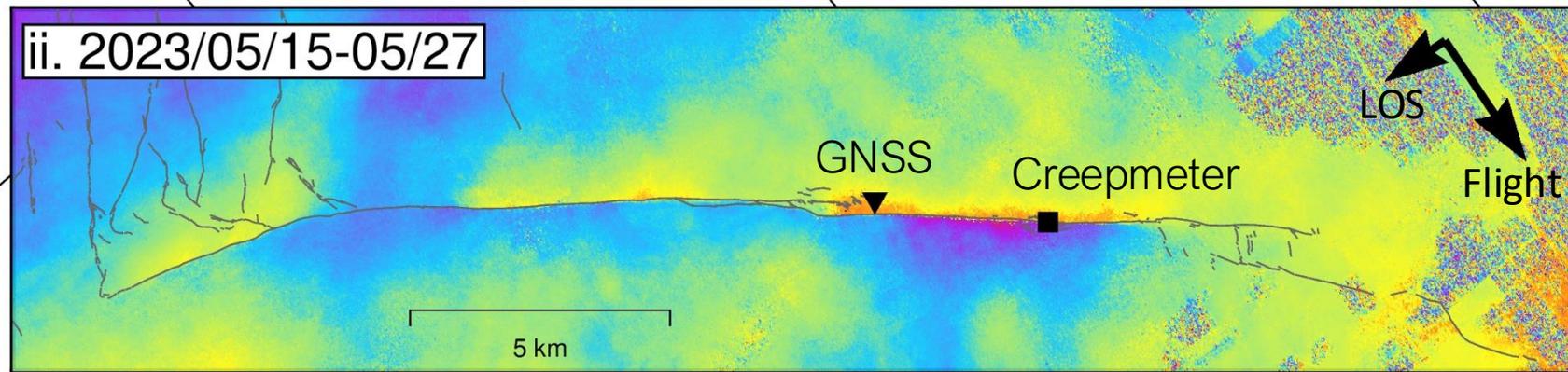
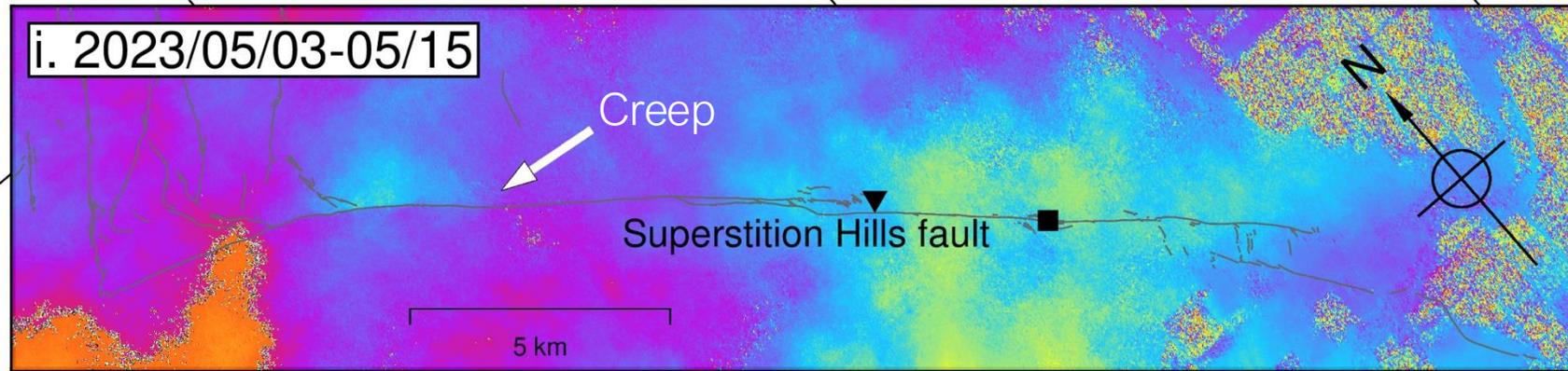
Fig. 9

Superstition Hills fault creep events: Case study 2023

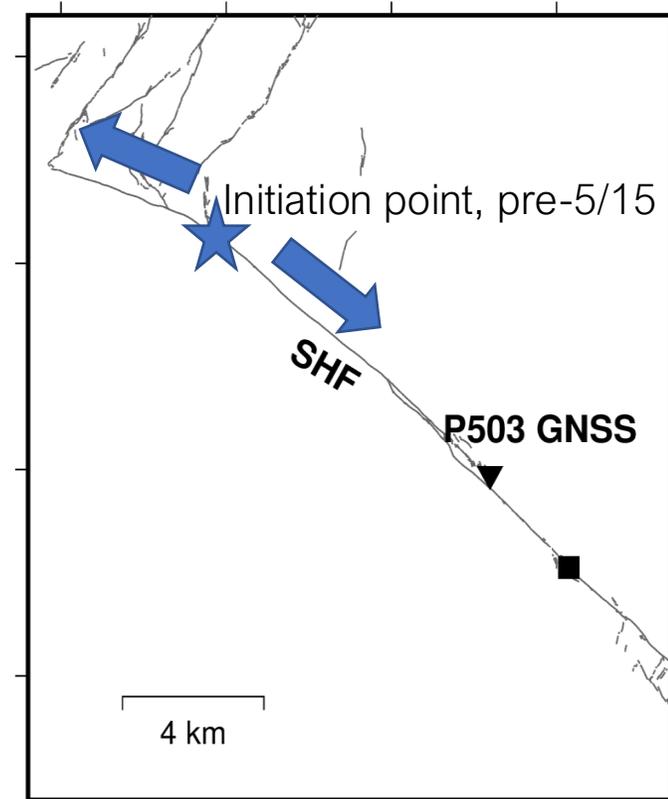


Materna et al., 2024; Vavra et al., 2024

InSAR shows time-dependent slip, propagation



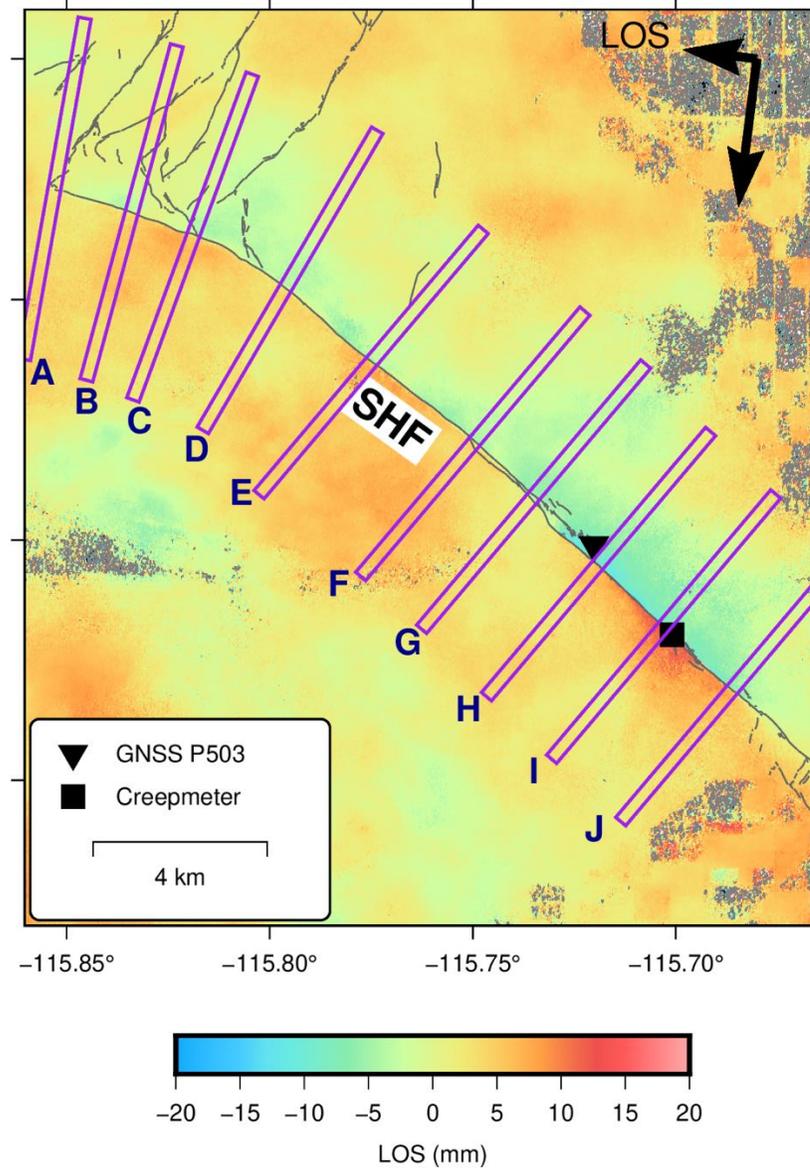
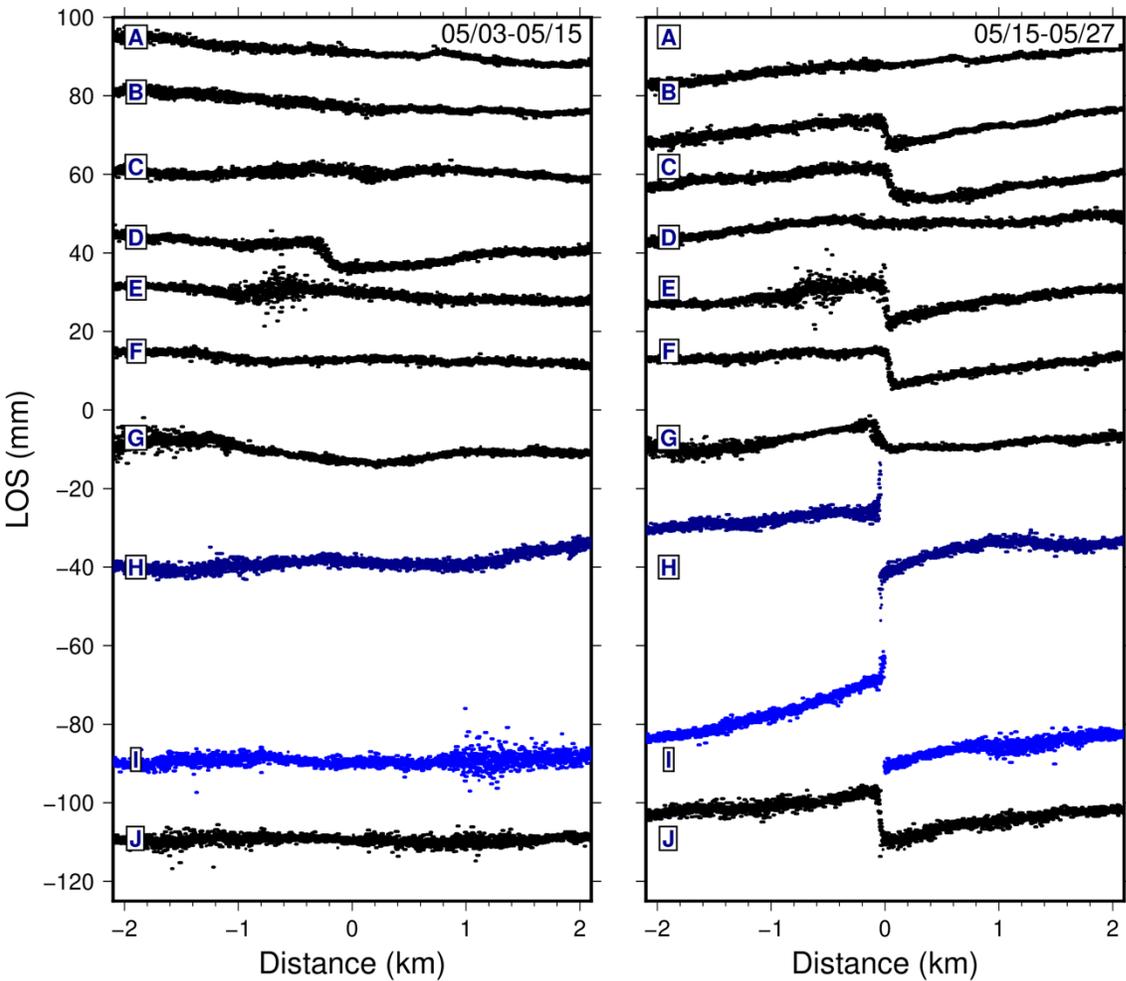
Average Propagation Velocity:
12 km/29 hours \rightarrow 10.1 km / day
Slower to GNSS, faster from GNSS to creepmeter.



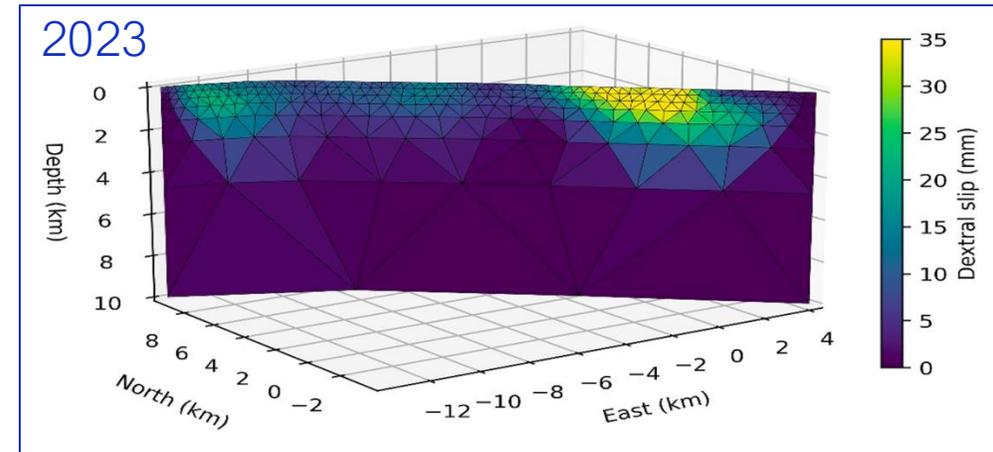
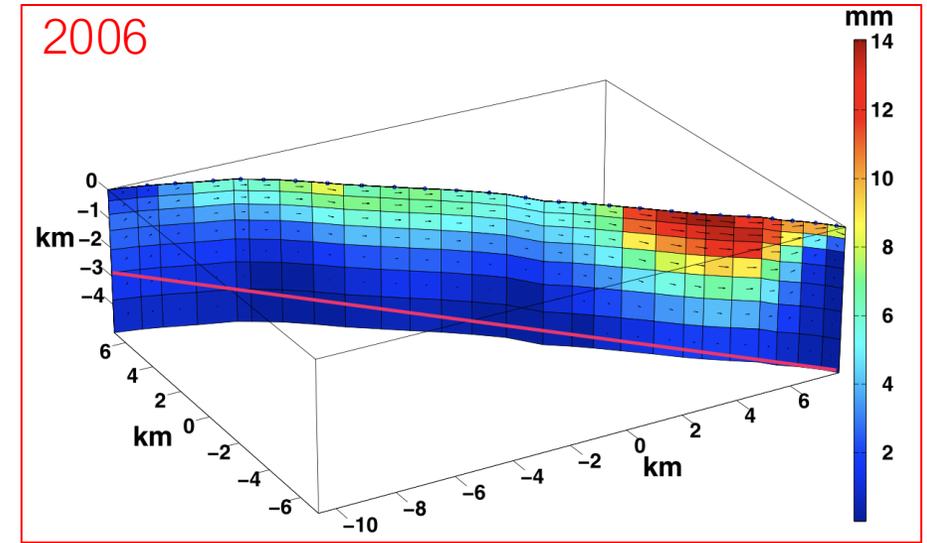
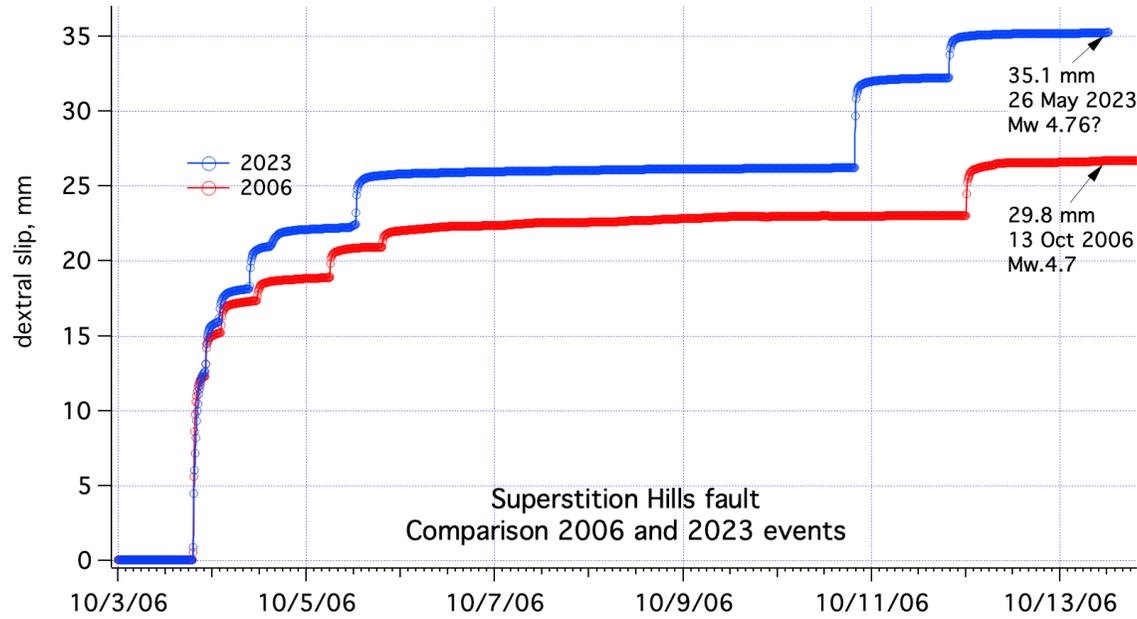
Materna et al., 2024



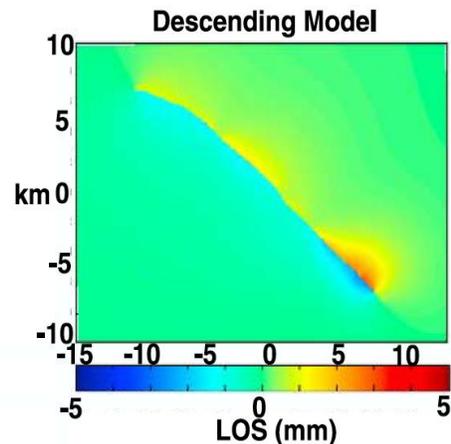
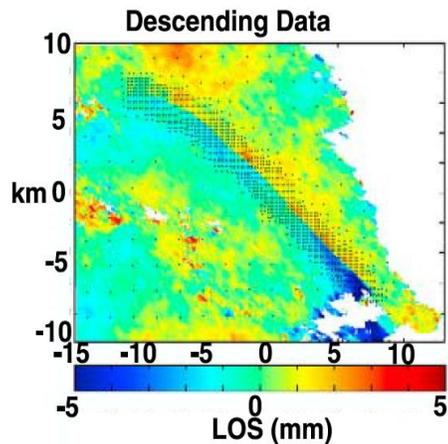
Profiles show pulse-like propagation



Similar characteristics in 2006 and 2023 slip events

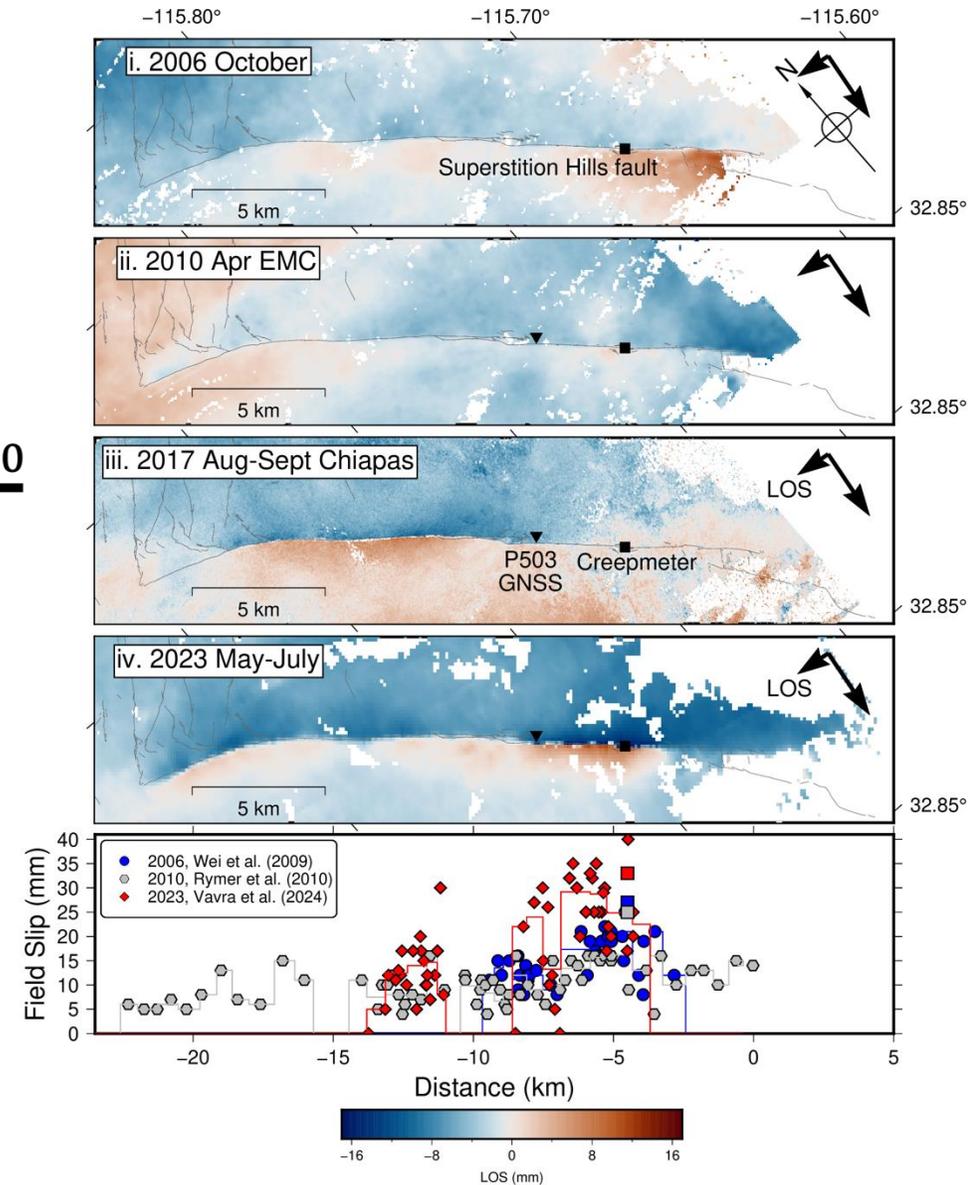
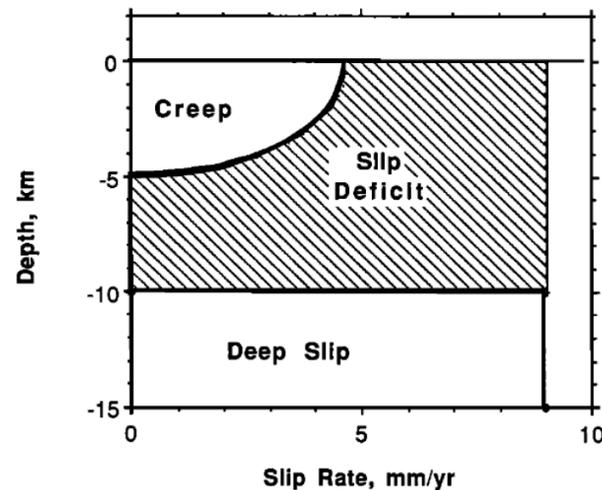
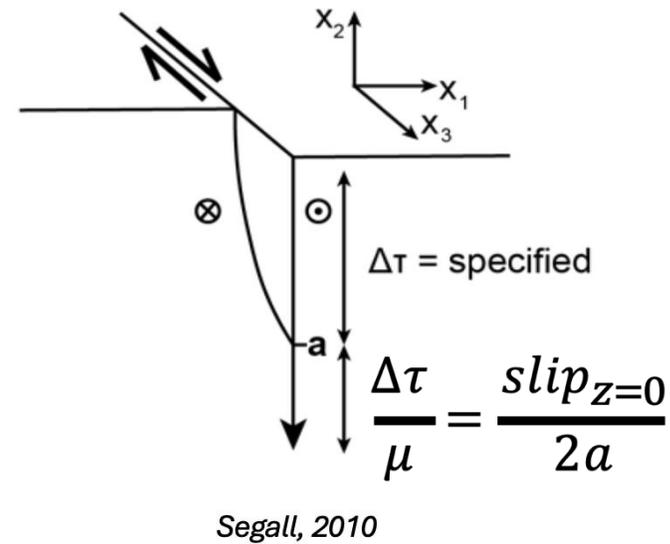


p.c. R. Bilham



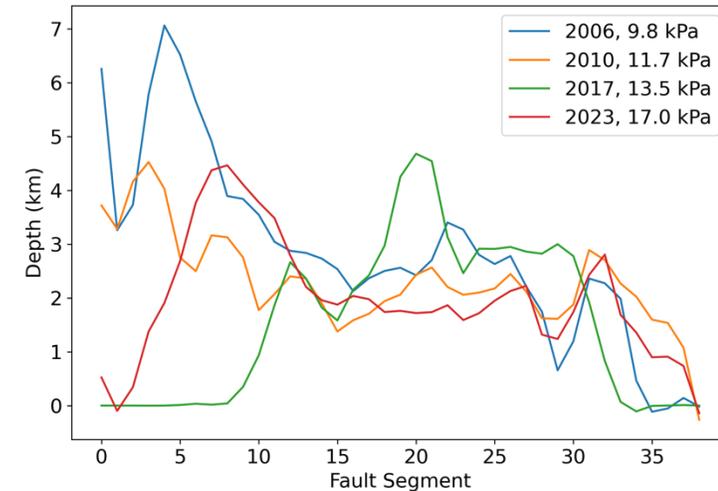
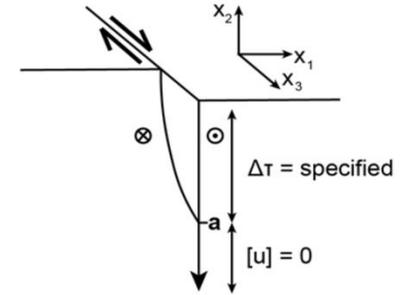
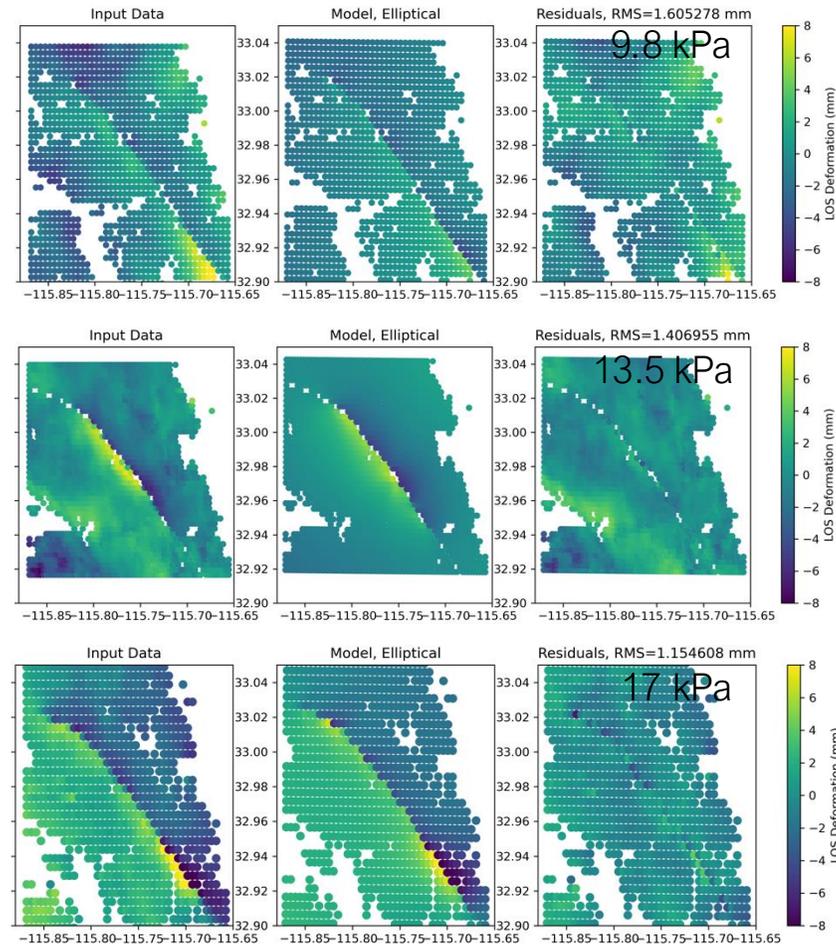
Step 3: Modeling creep kinematics/mechanics

- Hypothesis: creep events act to release all available strain (on their own timescales).
- Model using elliptical dislocation elements with constant strain drop (nonlinear).
- Apply this to each creep event with Envisat/Sentinel-1 InSAR and field data.



Results: slip distribution is not constant over time

- More complex than 2006-2023 “repeats”
- Strain drop is 2-4 μstr , stress drop 10-20 kPa
- Observed recurrence interval is 3x faster than predicted...
- Releasing more strain than we expect it has
- Suggests higher slip rate on SHF or postseismic slip

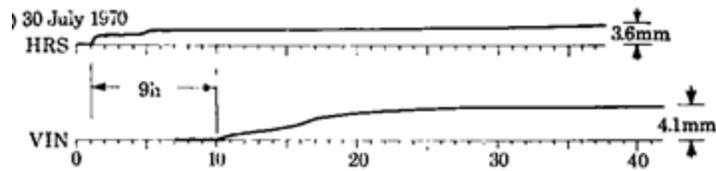


Materna et al., in prep

Many propagating creep events share similar velocities

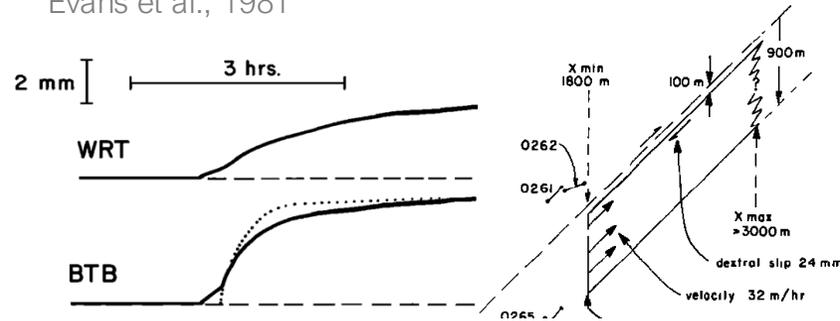
7-24 km / day
SAF and Calaveras, 1970-1971

King et al., 1973



1-3 km / day
Calaveras, 1977
Shallowest 50m w/o slip

Evans et al., 1981

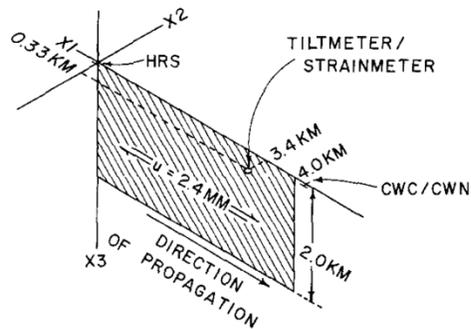


10 km / day average
Superstition Hills, 2023

17 km / day
SSAF Ferrum/SC, 2017
Tymofyeyeva et al., 2019

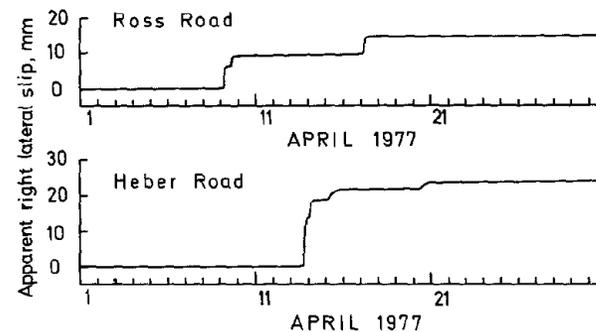
12-20 km / day
SAF (DeRose Winery), 1975

Mortensen et al., 1977



~1 km / day
Imperial, 1977

Goultly et al., 1978



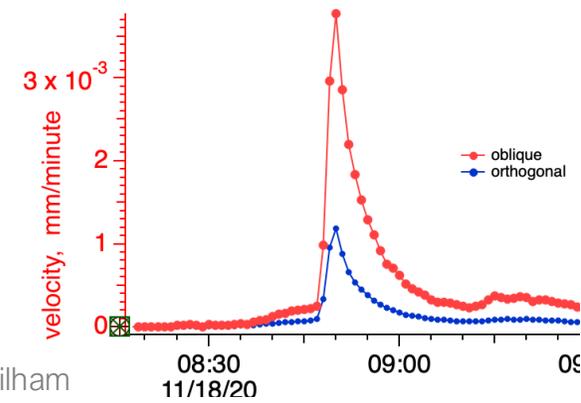
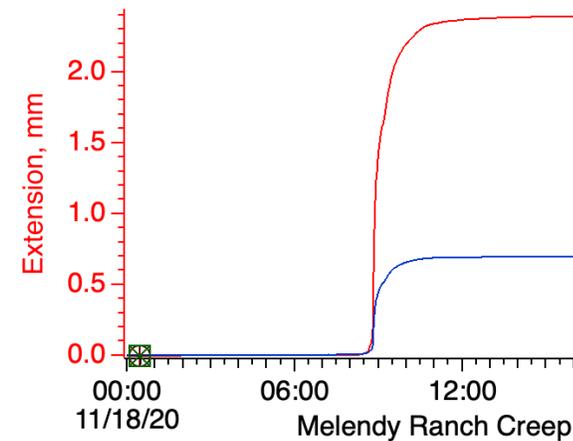
0.5 km / day
Imperial, 2023

Can numerical modeling reproduce propagation?

- Creep events have peak slip velocities of 10^{-7} to 10^{-6} m/s, durations of hours at one creepmeter (days for entire event), and propagation velocities of km/day.
- What physical processes are necessary to reproduce these observations?
- R+S friction alone is insufficient (Barbot, 2019)
- Additional mechanisms like dilatancy+pore pressure diffusion indicated (Segall et al., 2010)
- Current: parameter exploration in FEM code (Tal & Hager, 2018)



Dr. Yuval Tal,
Sabbatical @ CU



Conclusions and Ongoing Questions for Discussion

- “Creep” is a range of physical phenomena with different occurrence patterns on Earth and implications
- Creep events can and do propagate throughout fault systems, often occurring in sequences
- We observe creep at the surface, but its depth is a proxy for strain drop and recurrence interval. We are making progress on constraining it
- What controls triggering interactions?
- What does propagation velocity depend on?
- Does the strain budget for creep events close?
- What else besides R+S friction is needed to explain velocities and propagation?
- Do lessons learned in SC apply to NC (Hayward, Calaveras, Rodgers Creek) or more broadly?
- Dynamics: Moment-vs-duration scaling



An aerial photograph of a vast, flat, sandy landscape, possibly a beach or a desert. The sand is light-colored and shows signs of wind erosion, with numerous small, dark, circular depressions scattered across the surface. A white rectangular text box is overlaid on the right side of the image, containing the text "Thank you!" in a black, sans-serif font.

Thank you!