



Multi-decadal GPS data set developed by the USGS Earthquake Science Center for measuring and modeling interseismic creep on faults in central and northern California

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U.S. Geological Survey

Earthquake Science Center

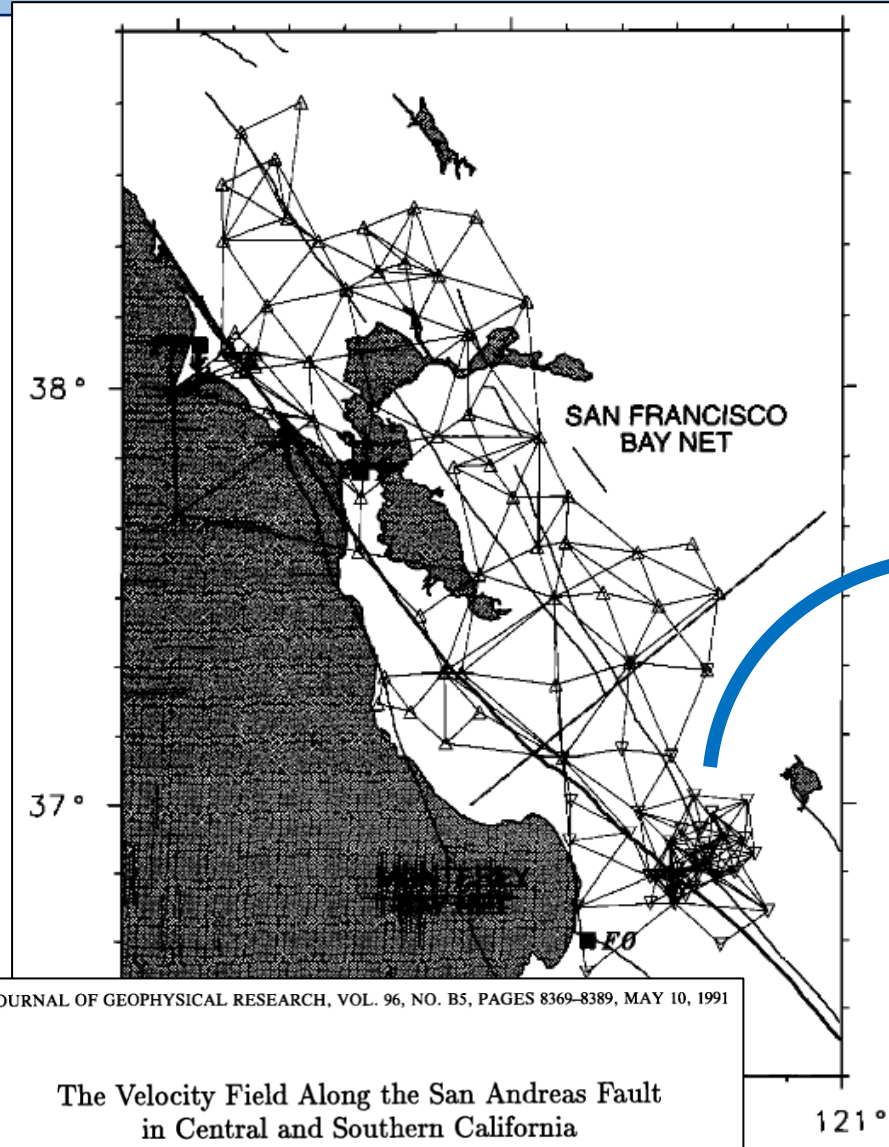
Mar. 5, 2026

Bottom Line Up Front

- Understanding the depth extent of creep is important for hazard assessment and follow-on models.
- Depth extent is hard to estimate for vertical strike-slip faults.
- Alignment arrays or other near-fault measurements provide good constraint on the shallowest creep rates.
- InSAR can reveal high creep rates, but low creep rates are still hard to measure in highly vegetated areas like much of northern California.
- GNSS coverage is spatially sparse, but it provides 3D velocities and is needed as a constraint when developing a 3D velocity field that includes InSAR data.
- USGS Earthquake Science Center has compiled a multi-decade dataset of campaign GPS observations for northern California (and elsewhere) that complements alignment array and InSAR data.

Early Geodetic Measurements

- USGS monitored trilateration networks for crustal deformation measurement from 1959 – 1993
- Used to study broad-scale plate boundary deformation and fault creep (also coseismic and postseismic).

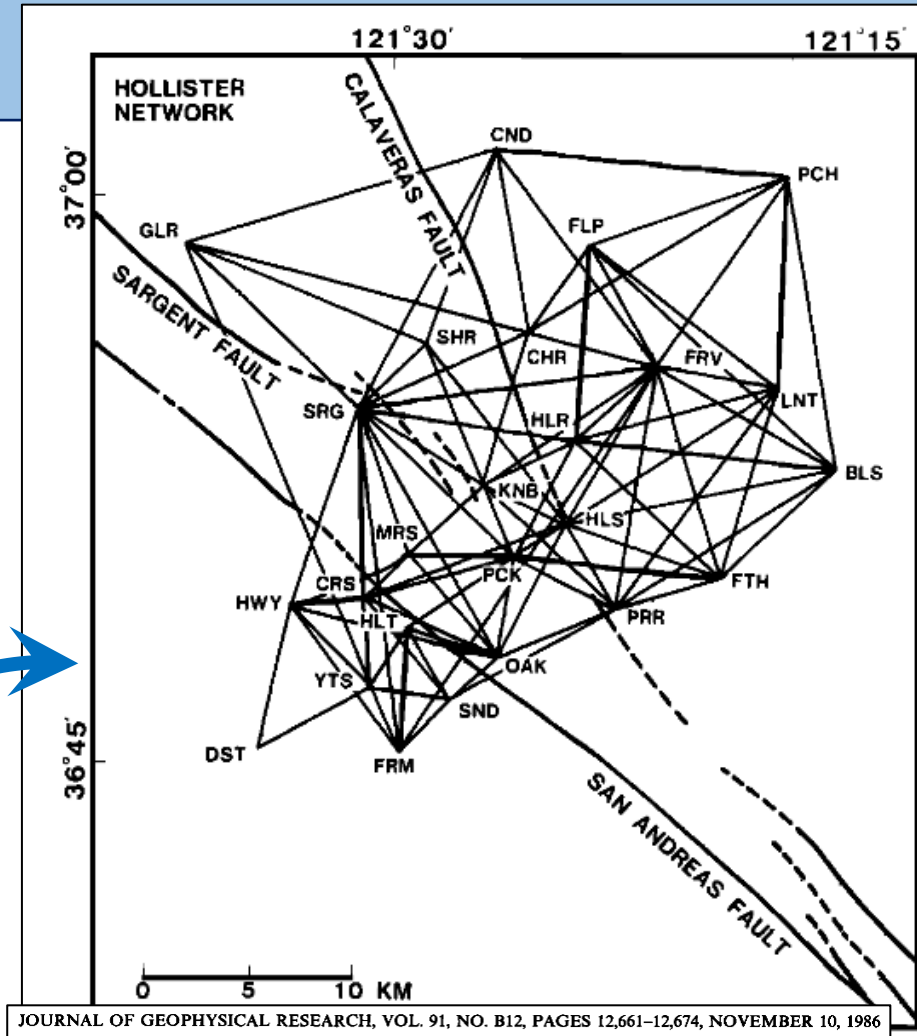


JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 96, NO. B5, PAGES 8369–8389, MAY 10, 1991

The Velocity Field Along the San Andreas Fault in Central and Southern California

M. LISOWSKI, J. C. SAVAGE, AND W. H. PRESCOTT

U.S. Geological Survey, Menlo Park, California



JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 91, NO. B12, PAGES 12,661–12,674, NOVEMBER 10, 1986

Dislocation Model for Aseismic Crustal Deformation at Hollister, California

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Early Geodetic Measurements

- USGS monitored trilateration networks for crustal deformation measurement from 1959 – 1993
- Used to study broad-scale plate boundary deformation and fault creep (also coseismic and postseismic).
- Data are still available

USGS
science for a changing world

Earthquake Hazards Program

← Monitoring

National Earthquake Information Center-NEIC

ANSS-Advanced National Seismic System

GSN-Global Seismographic Network

Volunteer Monitoring

Seismogram Displays

NSMP-National Strong Motion Project

Crustal Deformation Monitoring

Geodolite Trilateration Data Set

For a description of the data collection procedures and precision, see: Savage, J.C., and W.H. Prescott, Precision of Geodolite distance measurements for determining fault movements, *Journal of Geophysical Research*, 78, 6001-6008, 1973.

Geodolite Positions

Download (189 kB)

Sample	Station	Code	Year	Lat	Long	Dist	Code	Year	Agency
anza	arling	a	33	52	16.842	-117	28	14.350	d 564.00 aa 'arling 1974' NCER
anza	arling80	n	33	52	17.000	-117	28	14.000	n 564.00 aa 'arling 1980' USGS
anza	asbesrm1	n	33	37	39.000	-116	27	29.000	n 1600.20 hh 'asbestos no 1 1939' USCGS
anza	asbestos	a	33	37	39.304	-116	27	29.872	a 1604.80 bb 'asbestos 1939' USCGS
anza	bachelor	a	33	36	19.504	-117	03	41.192	a 780.00 bb 'bachelor 1939' USCGS

Geodolite Line Lengths

Download (5.7 MB)

Sample	Station	Code	Year	Lat	Long	Dist	Code	Year	Agency
anza	asbestos	laquinta	871211	1434	58.1	16061.7423	+ 16012.7427	0.0002	red 16053.466 0.471 251
anza	asbestos	laquinta	881116	1417	58.1	16061.7374	+ 16012.7378	0.0011	red 16055.094 2.006 257

<https://earthquake.usgs.gov/monitoring/deformation/geodolite/>

HOLLISTER NETWORK

CALA

121°30'

121°15'

PCH

LNT

BLS

FTH

NOVEMBER 10, 1986

FORMATION

JOURNAL OF GEOPHYSICAL RESEARCH

The Velocity of Crustal Deformation in Central and Southern California

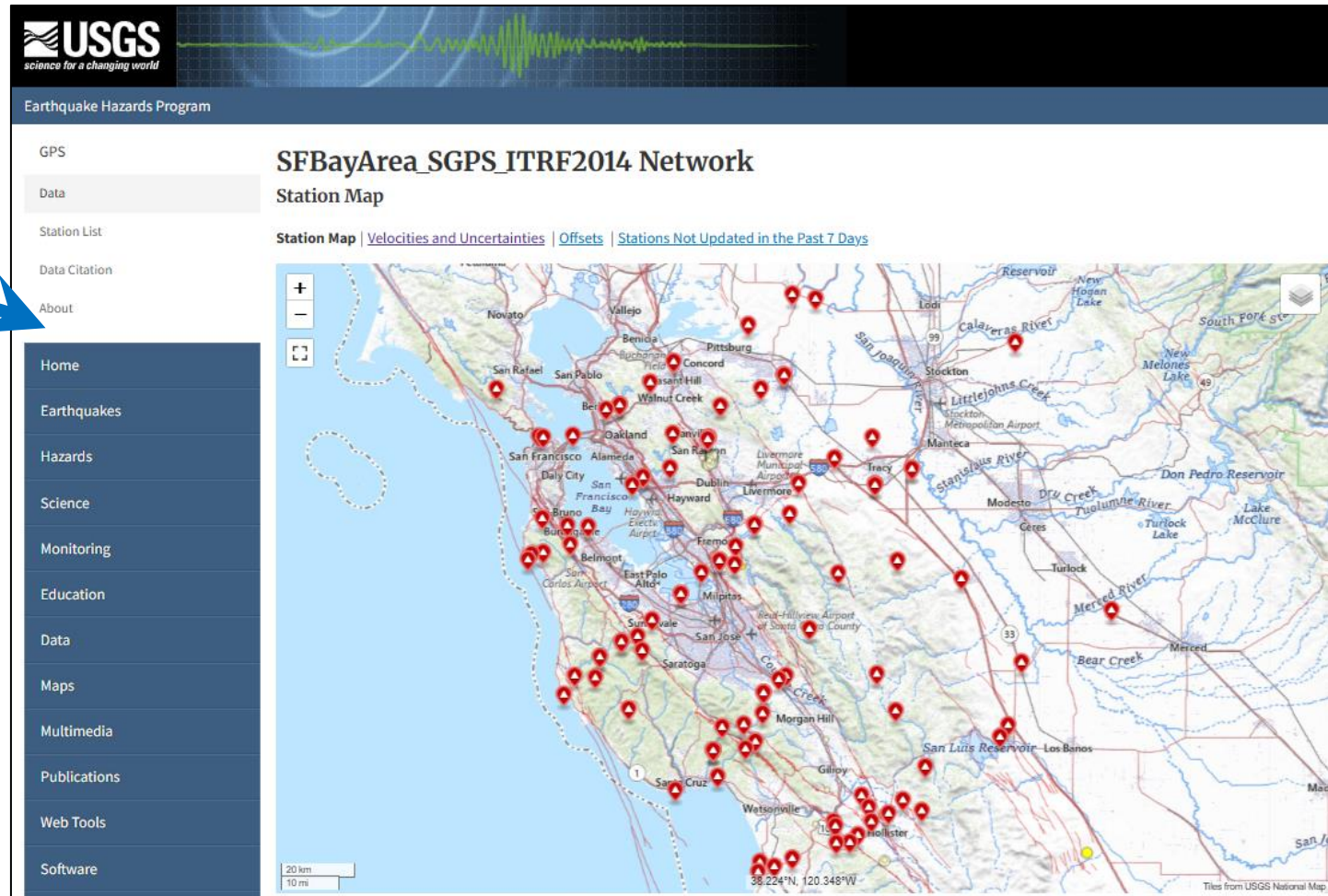
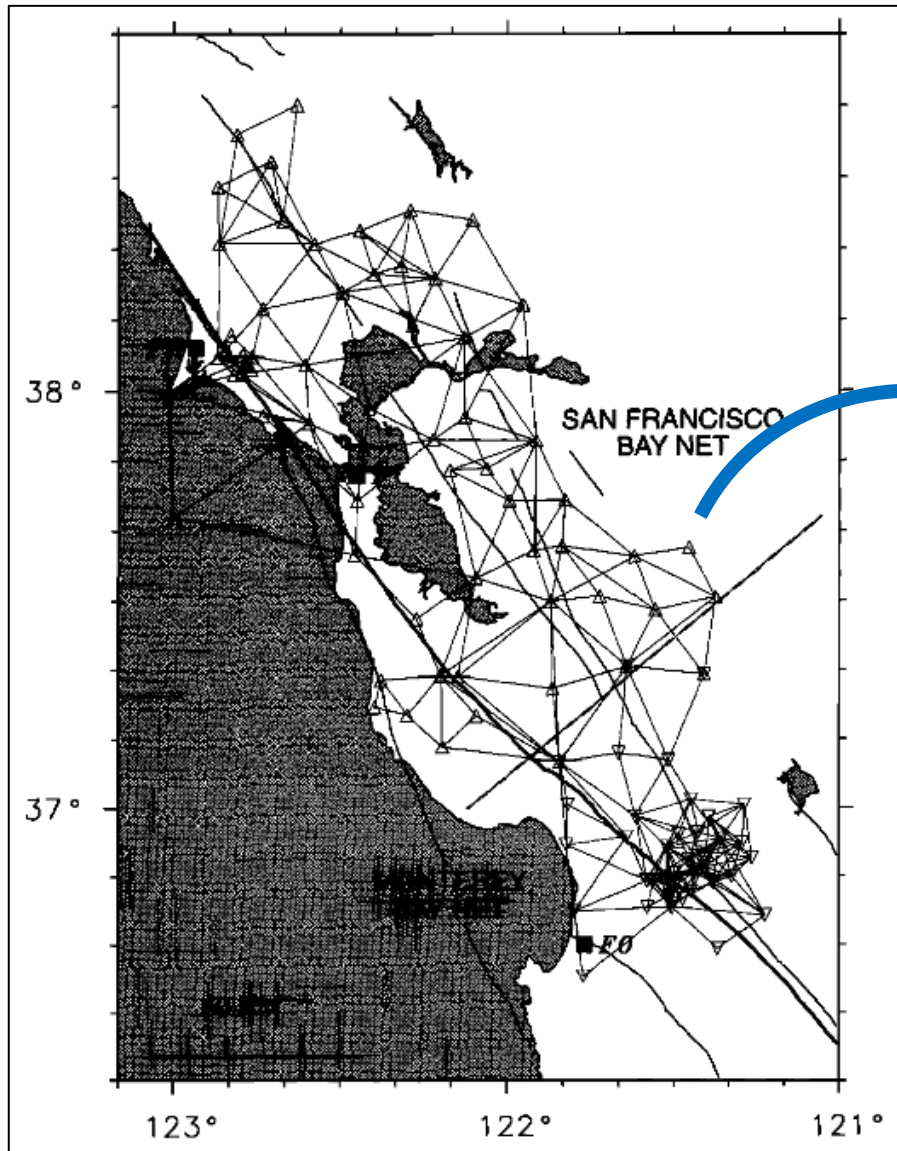
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Mid-1990s: Transition to Campaign GPS

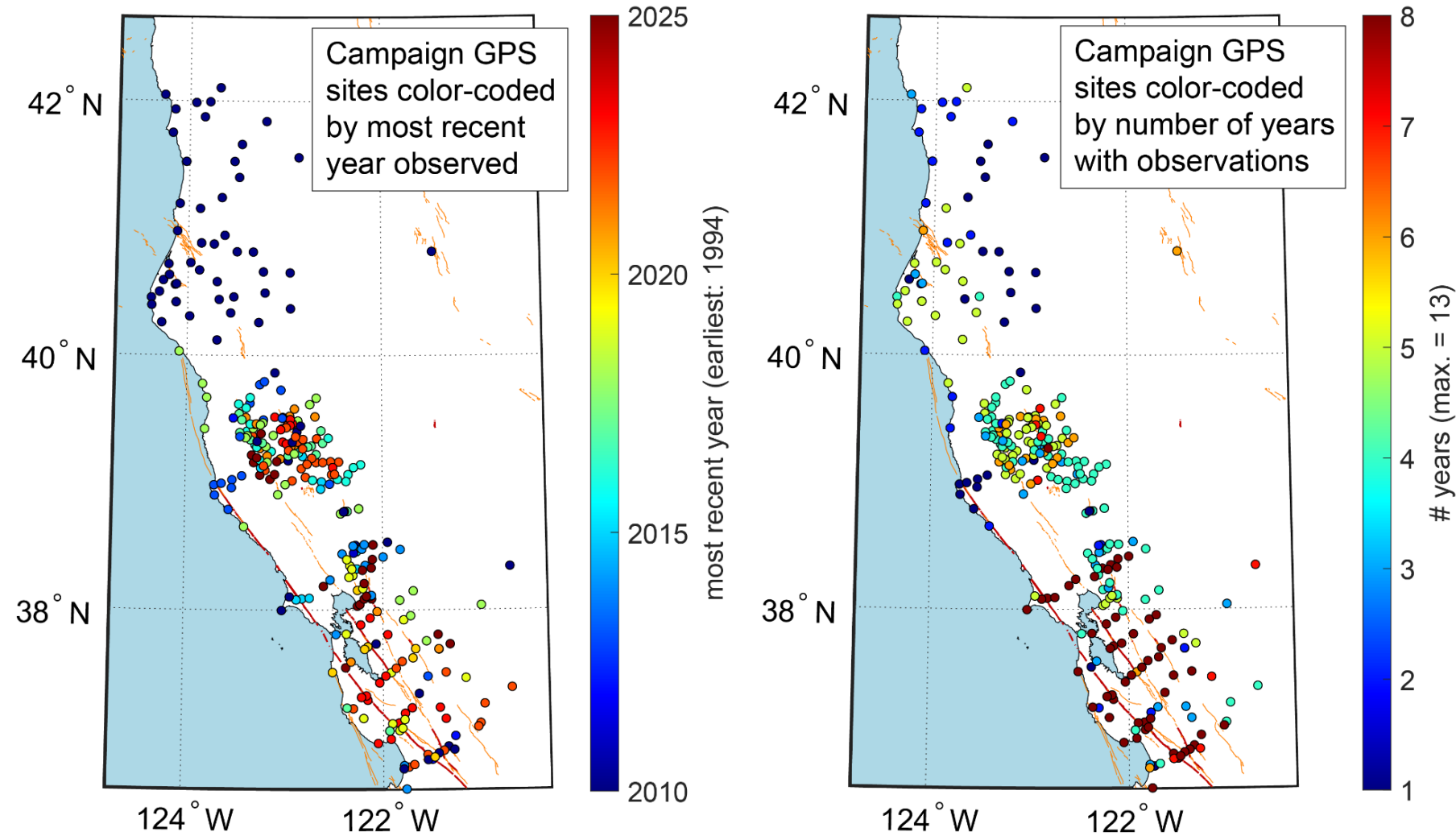


<https://earthquake.usgs.gov/monitoring/gps>

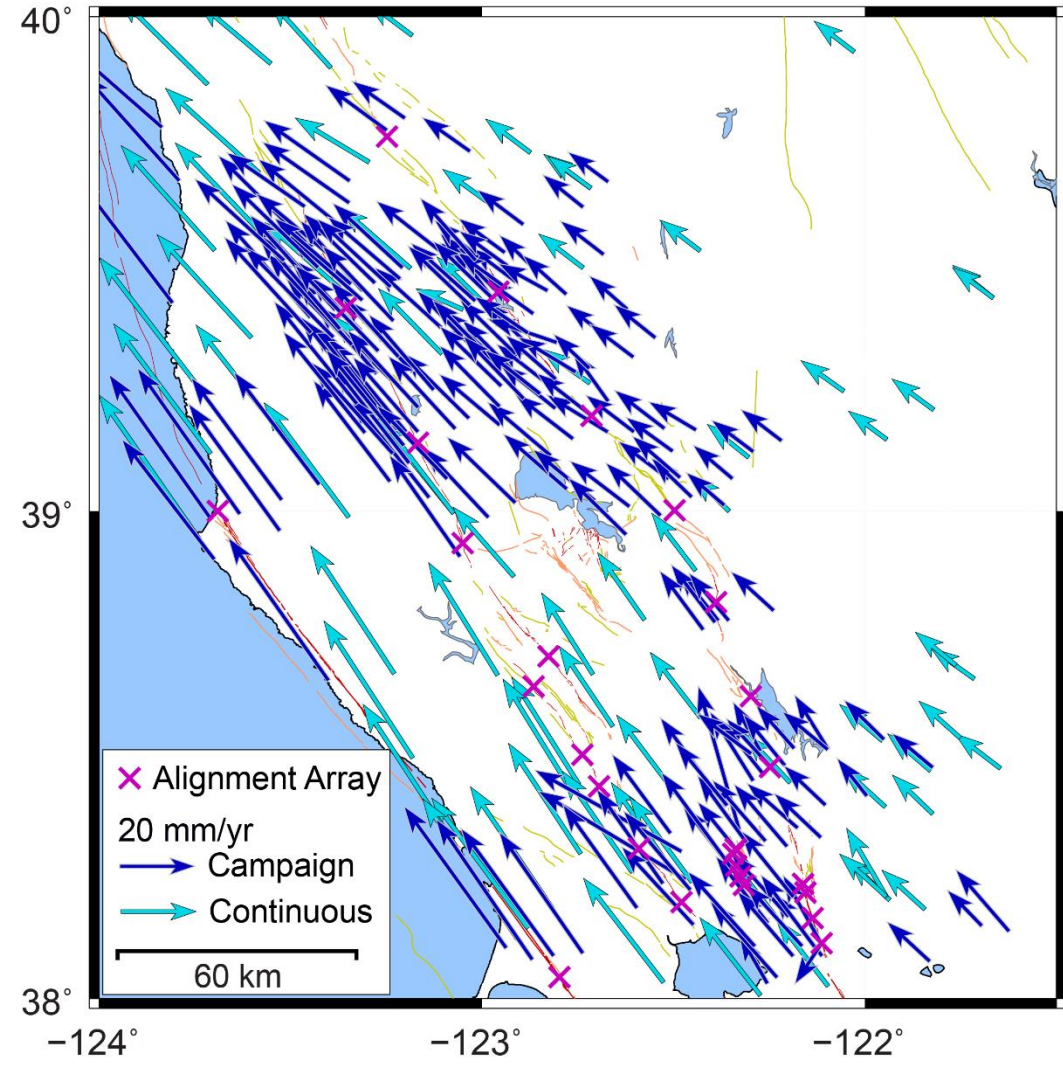
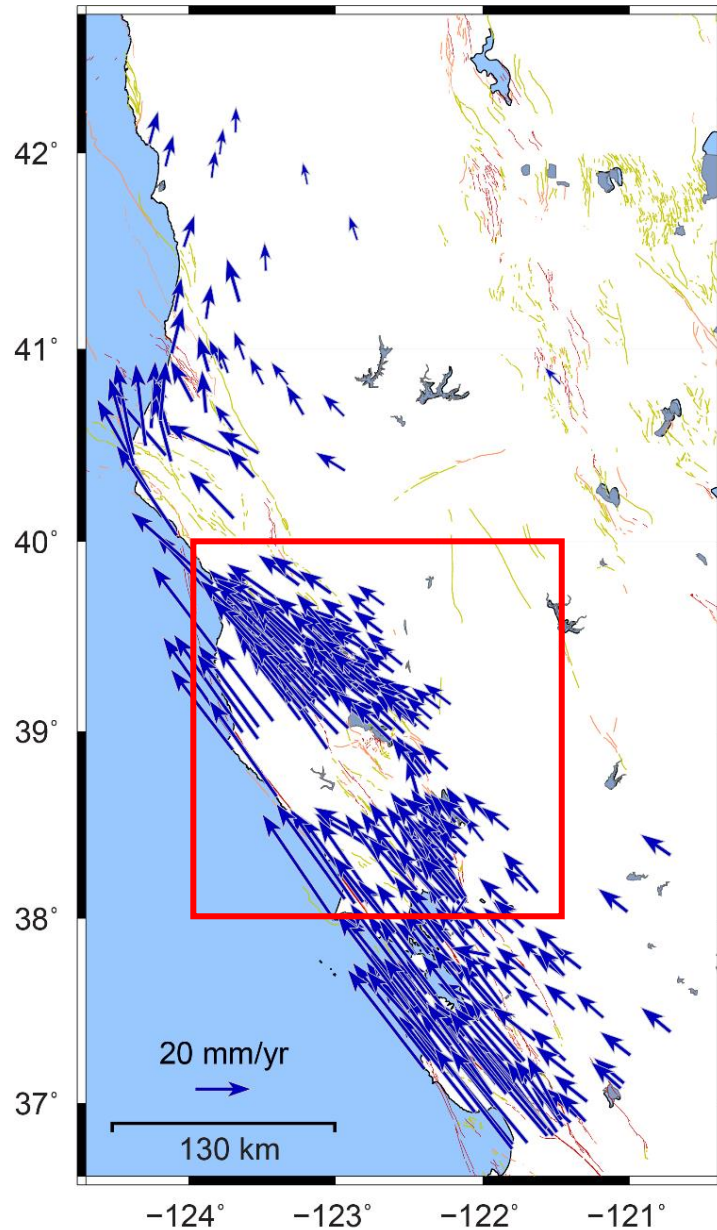
History of Campaign GPS Measurements

Geographic focus

- Has evolved due to
 - Programmatic research priorities
 - Growth of continuous GNSS networks
 - Reduction in personnel
- Complements partner efforts
- Maintains core coverage in Bay Area, Maacama, and Bartlett Springs faults



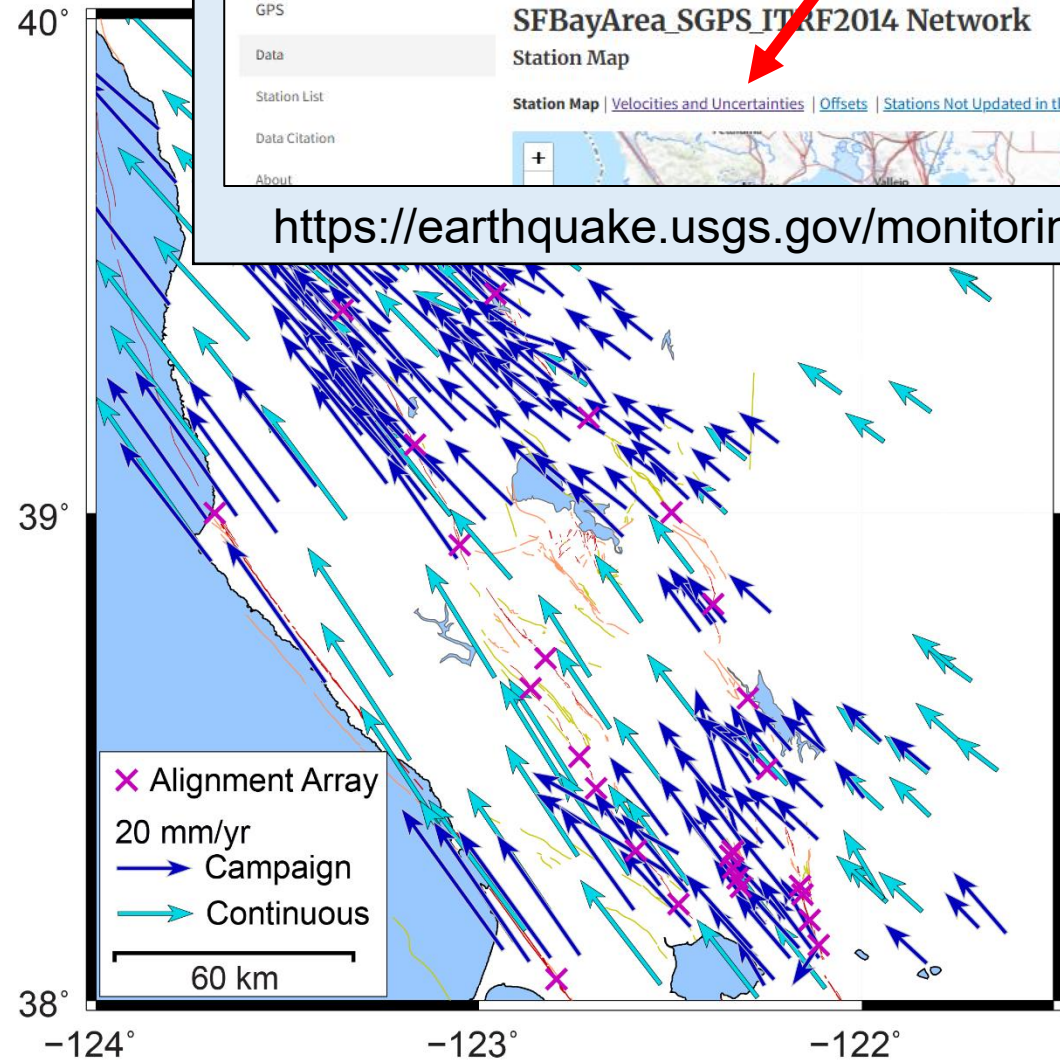
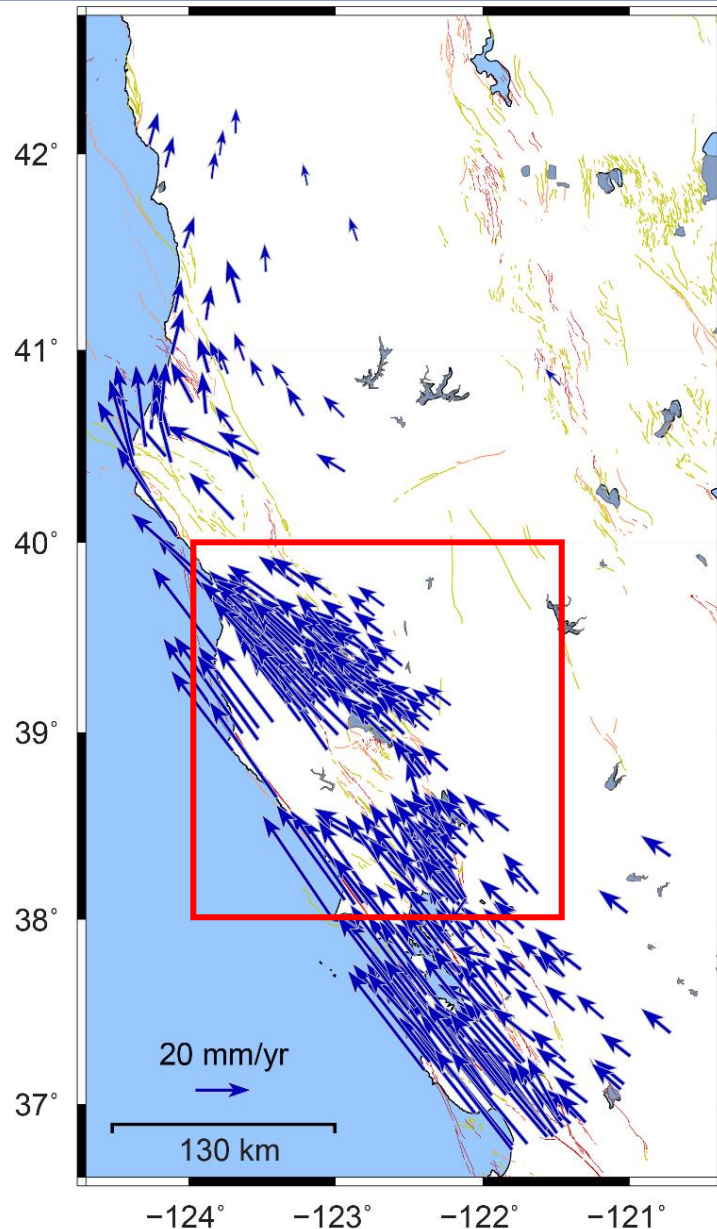
Northern California Campaign GPS Velocity Field



[Velocities relative to stable North America]



Northern California Campaign GPS Velocity Field

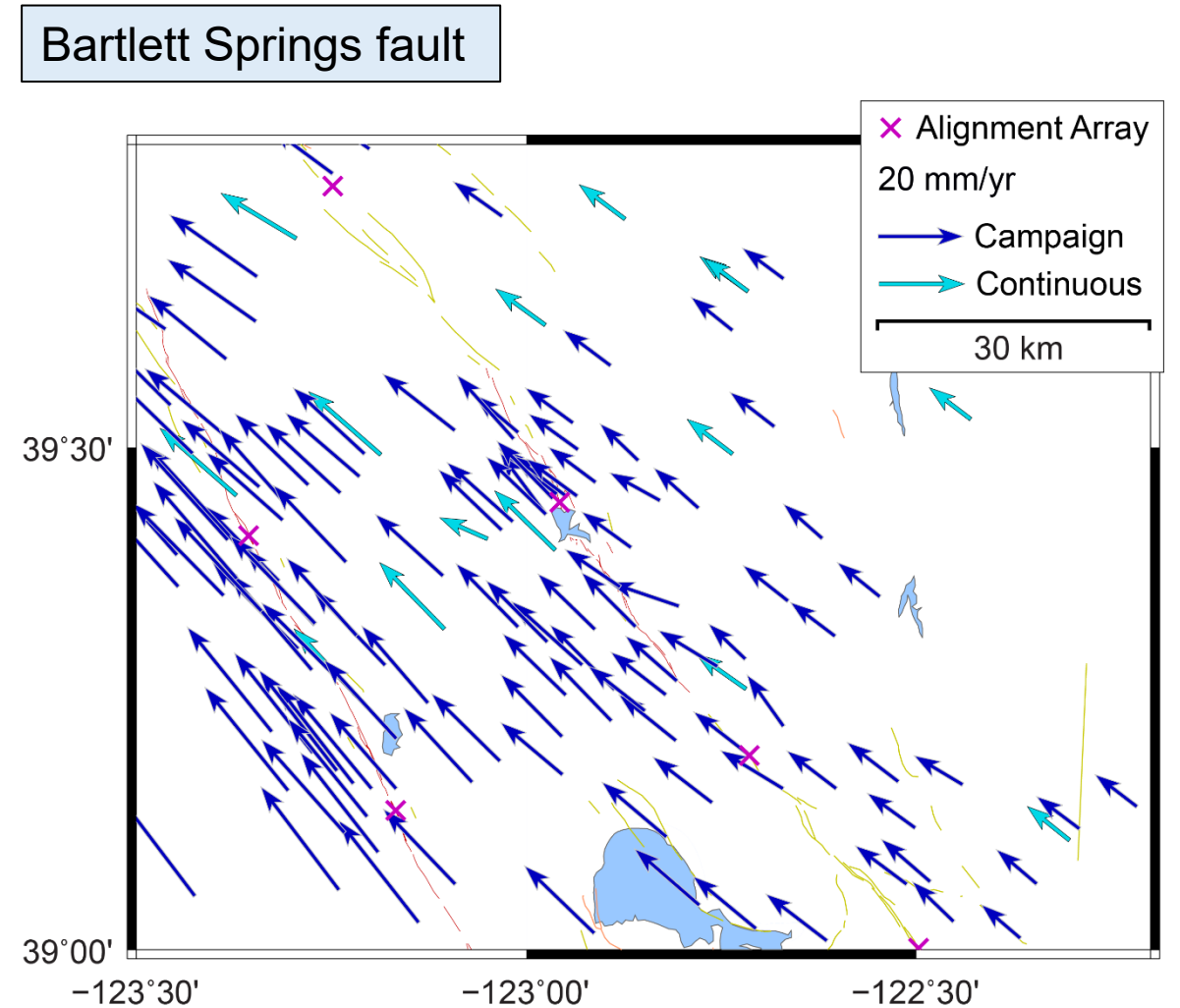
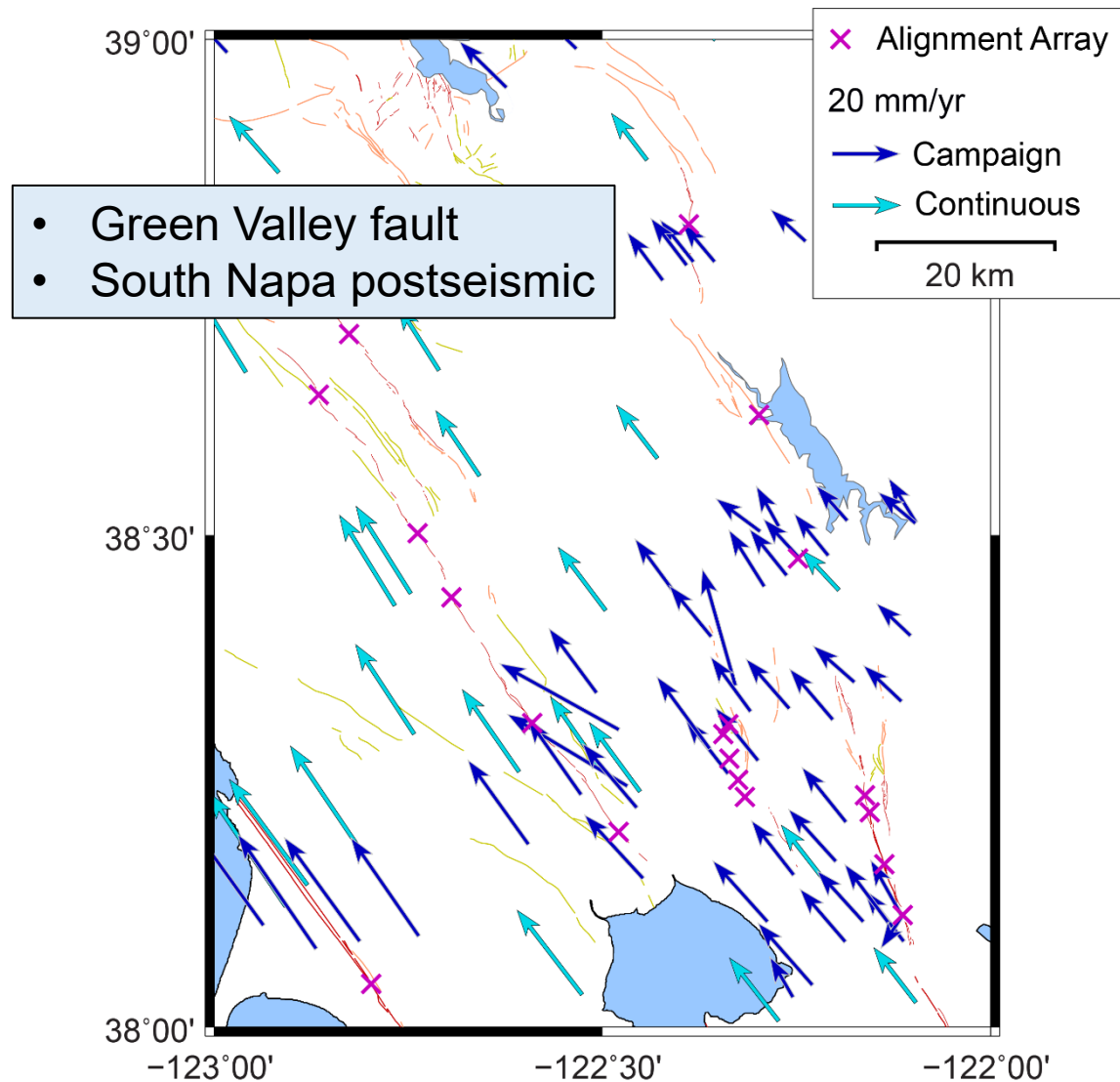


The screenshot shows the USGS Earthquake Hazards Program website for the SFBayArea_SGPS_ITRF2014 Network. The page includes a navigation menu with options for GPS, Data, Station List, Data Citation, and About. The 'Station Map' link is highlighted with a red arrow. Below the navigation menu, there are links for 'Station Map', 'Velocities and Uncertainties', 'Offsets', and 'Stations Not Updated in the Past 7 Days'. A small map of the region is visible at the bottom right of the screenshot. The URL <https://earthquake.usgs.gov/monitoring/gps> is displayed below the screenshot.



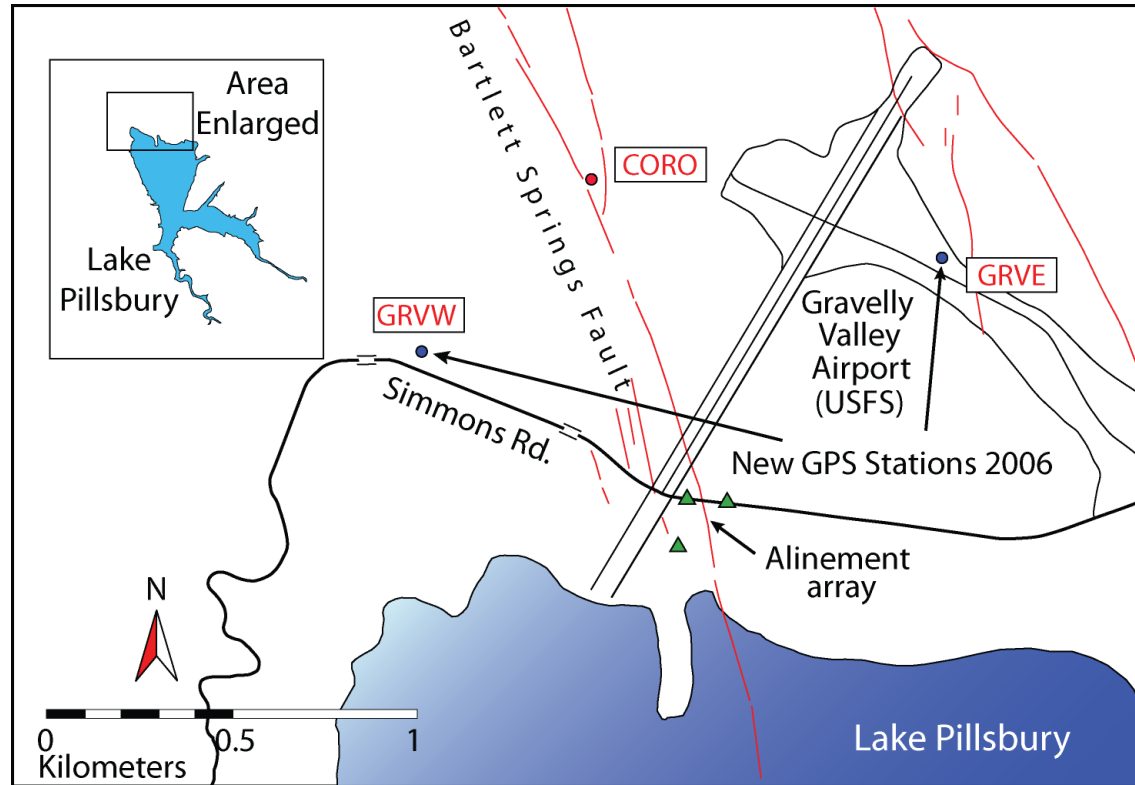
[Velocities relative to stable North America]

Coordinated Observation with Campaign GPS and Alignment Arrays

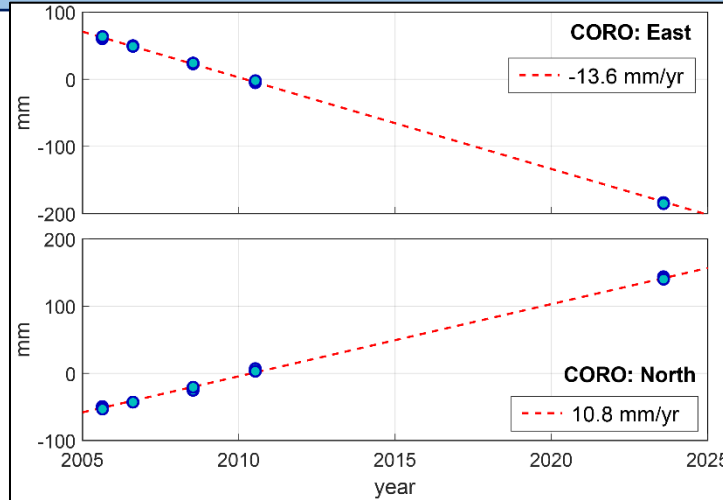
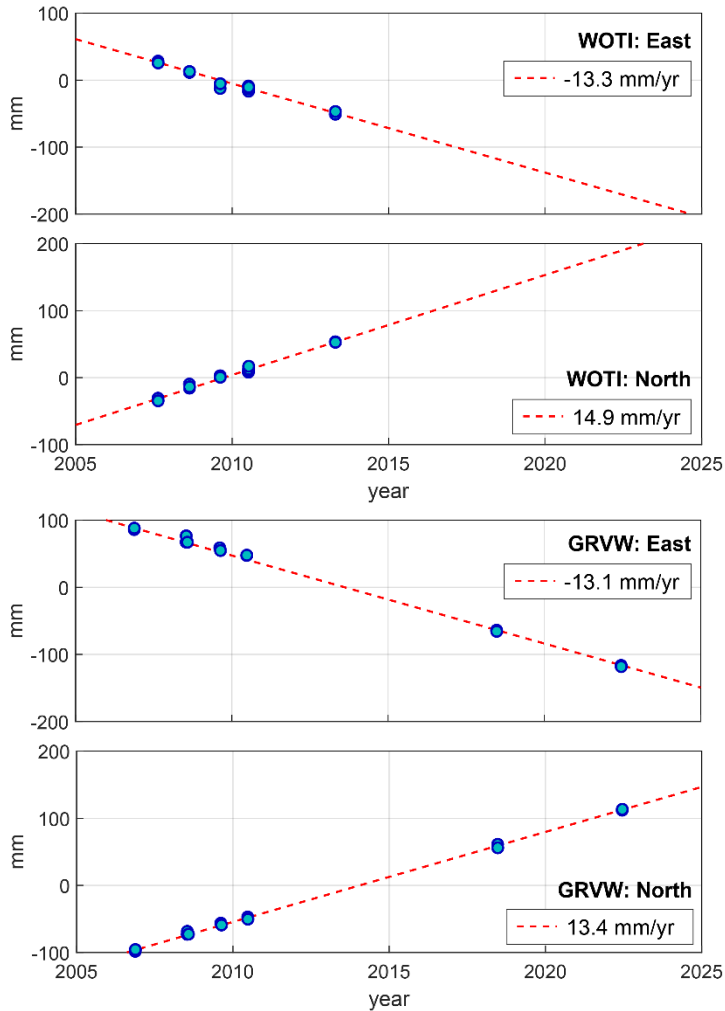


Bartlett Springs Fault Creep Measurement

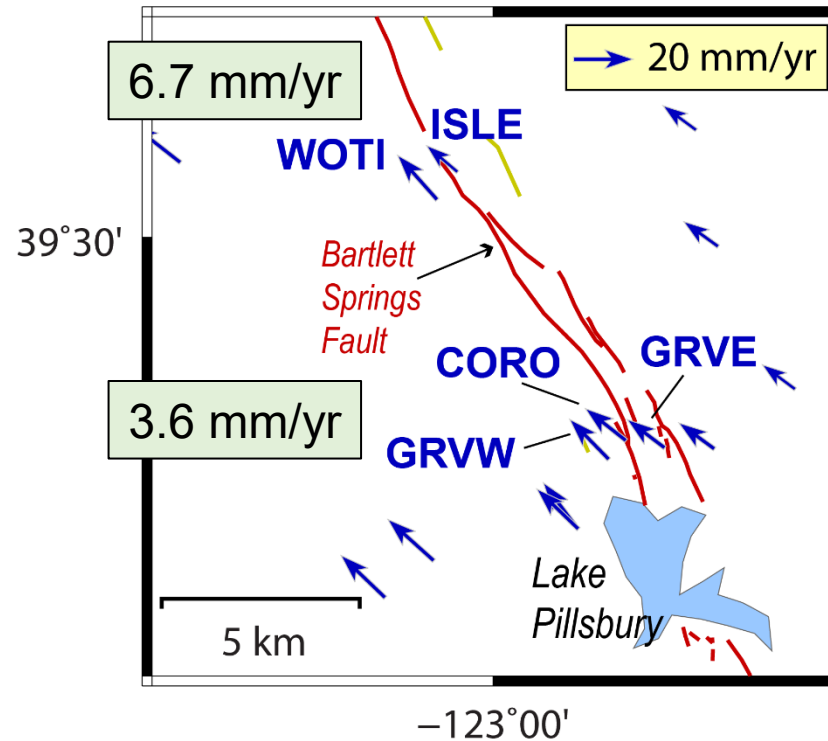
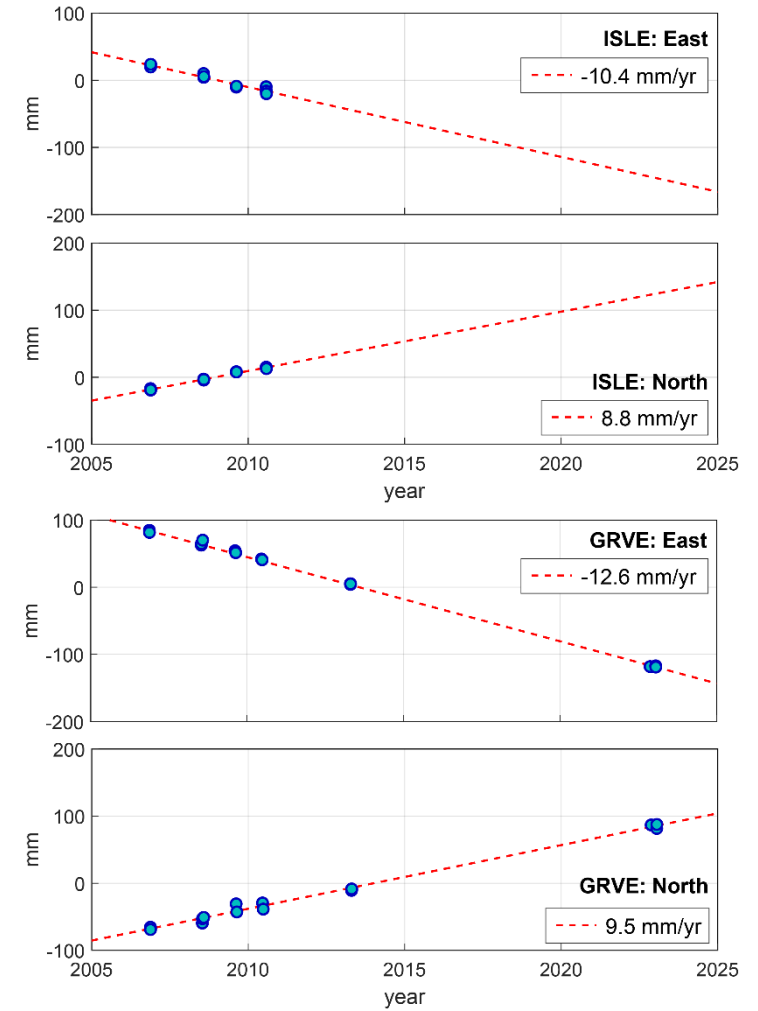
- The USGS Earthquake Science Center established a campaign GPS network in 2005 to measure deformation near Scott Dam (Lake Pillsbury)
- Included an alignment array at north end of lake and three GPS sites spanning fault zone
- Episodic creep evident in cracked pavement



Continued GPS Measurements of Bartlett Springs Creep Rate

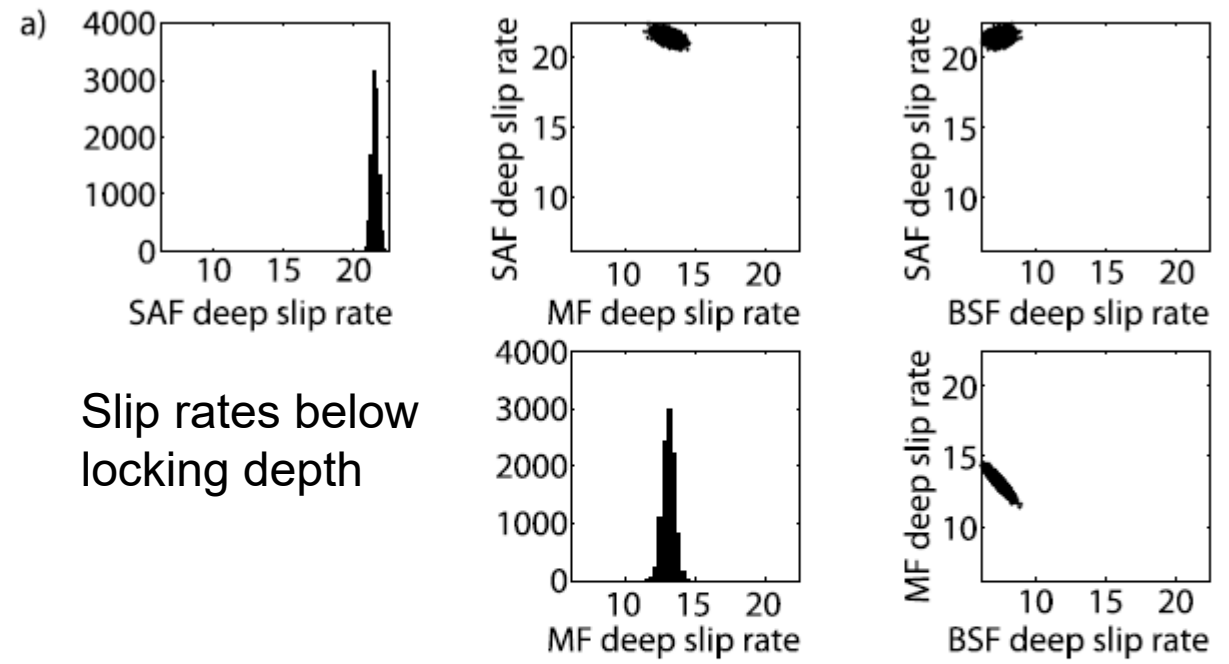
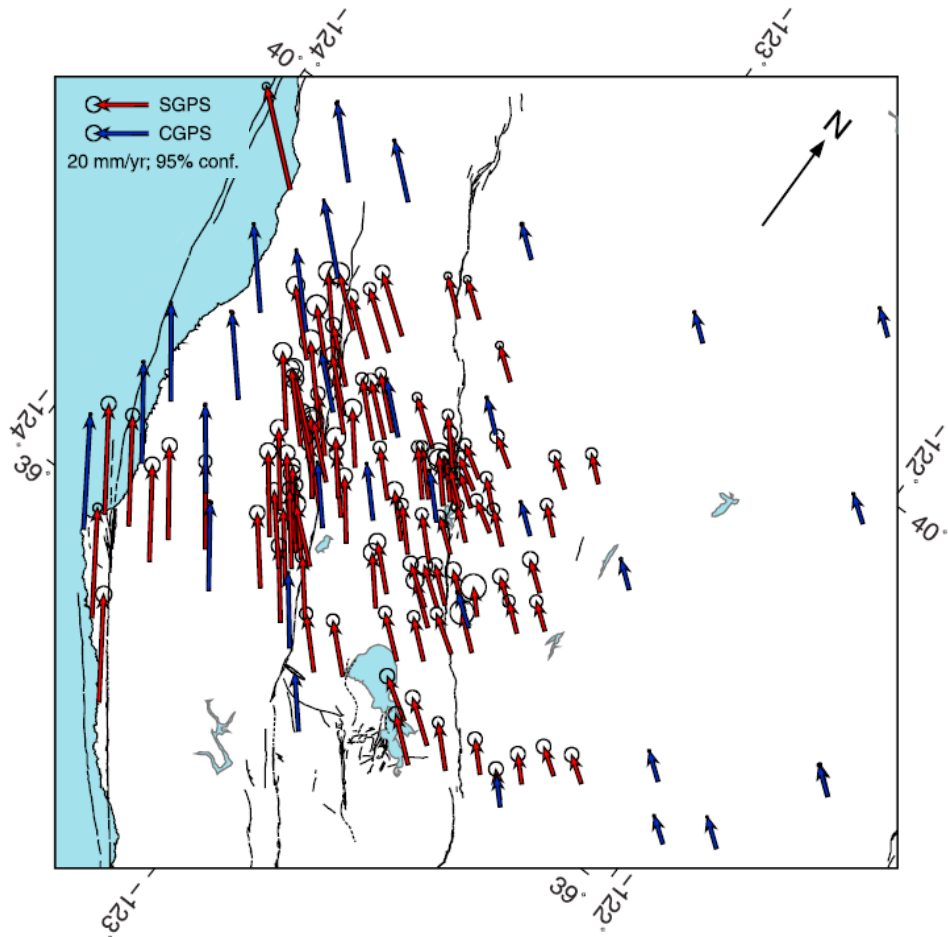


[Positions and velocities relative to stable North America]

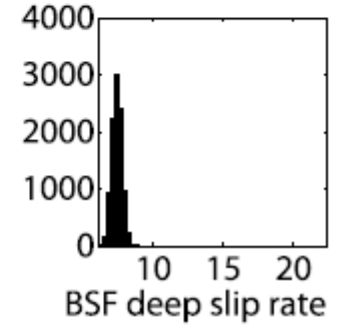
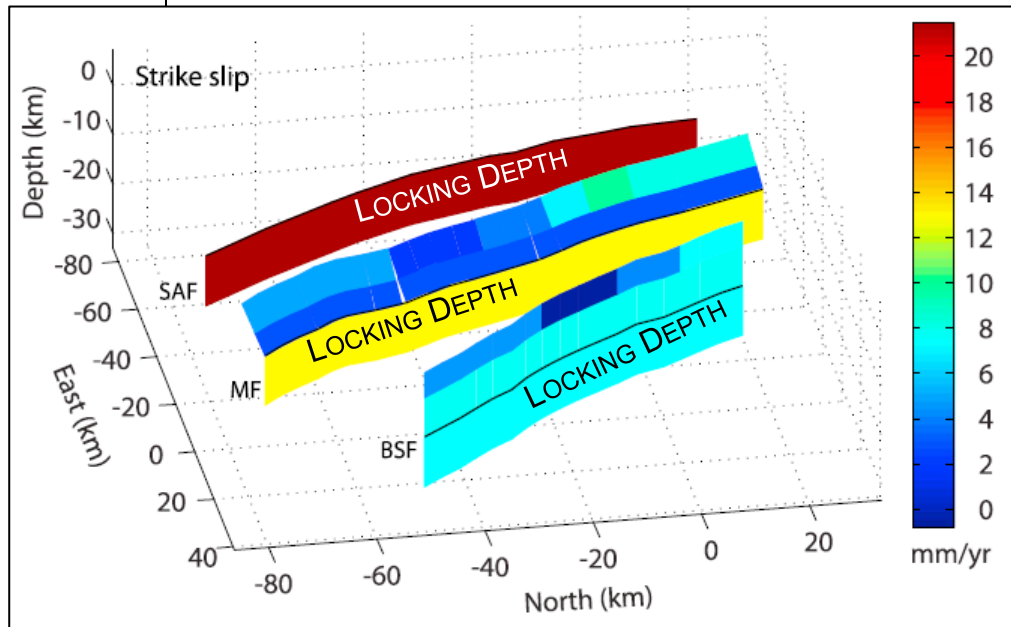


Northern CA Slip and Creep Rate Model

Bayesian inversion for long-term (deep) slip rates and along-strike creep rate variation in upper 5 km.



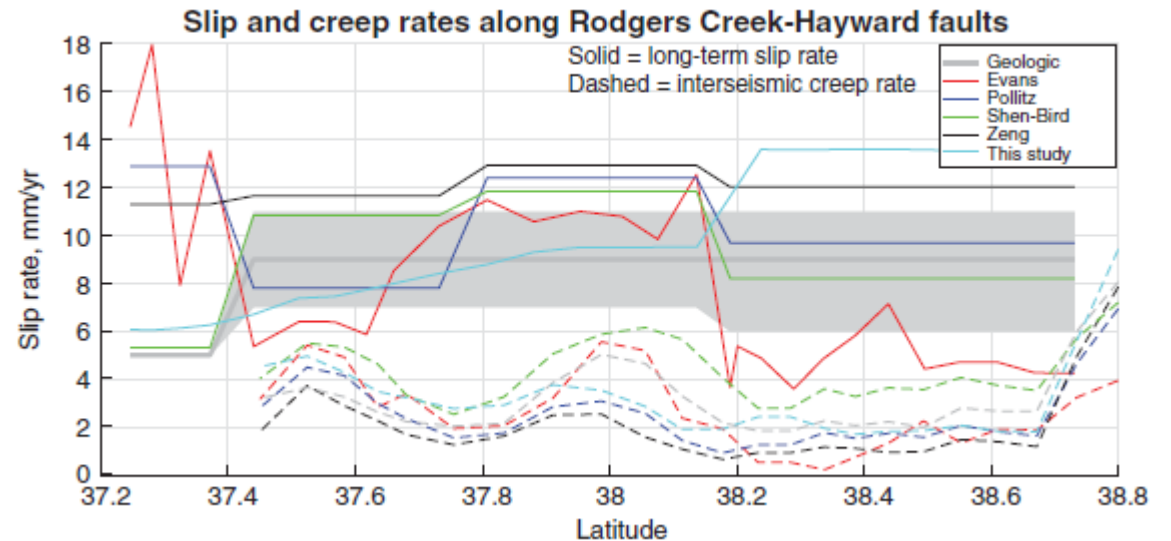
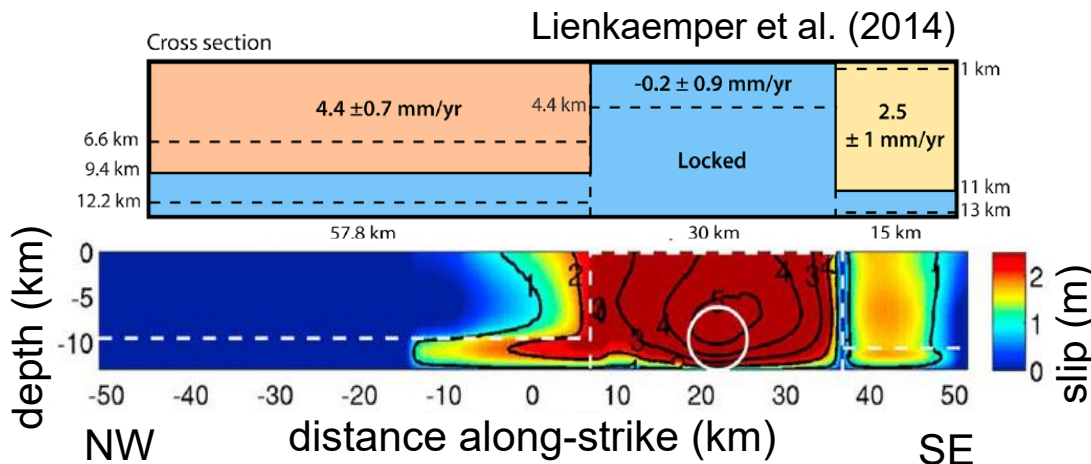
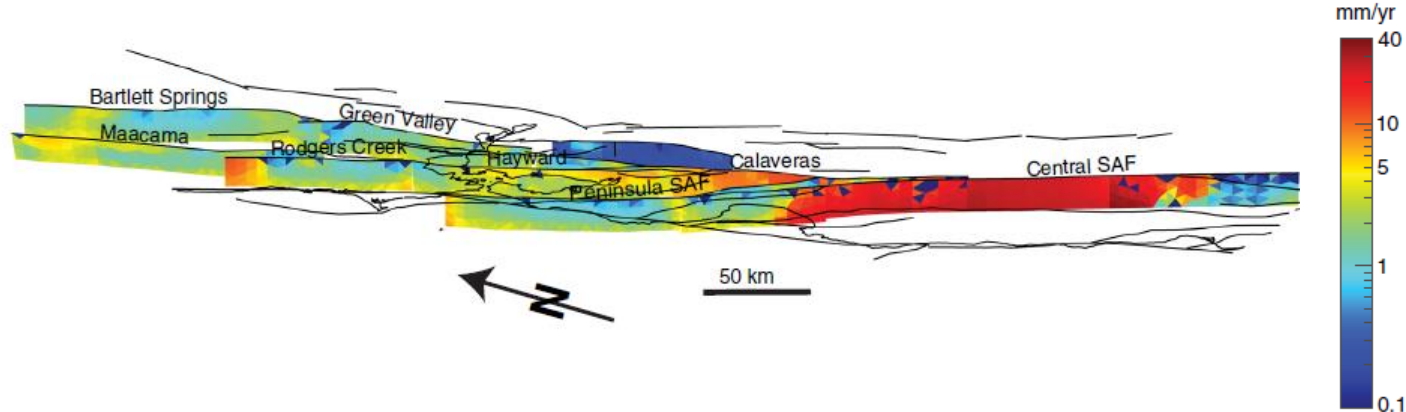
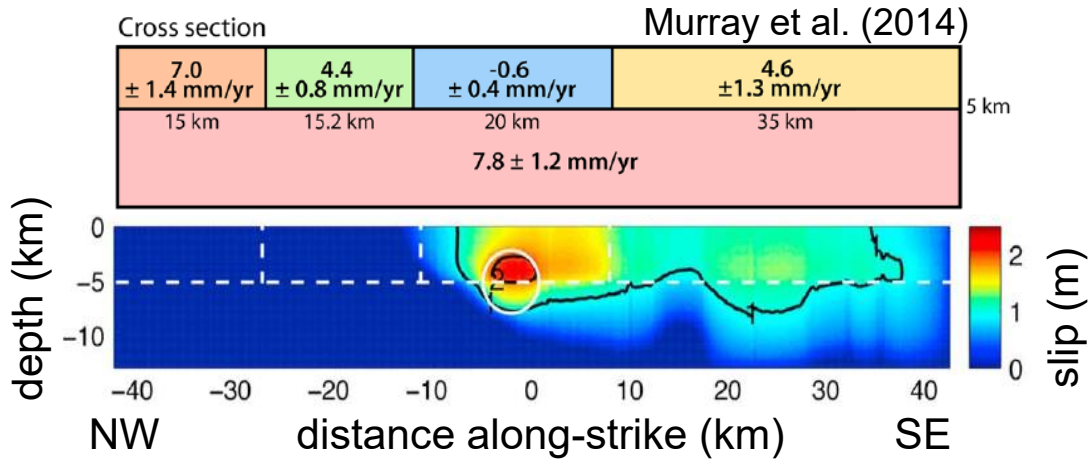
Slip rates below locking depth



The Importance of Constraining the Depth Extent of Fault Creep

Differences in assumed creep rate distribution strongly impact the results of follow-on models

Creep rate distribution influenced geodetic slip rates and moment rate reduction used in NSHM 2023 update



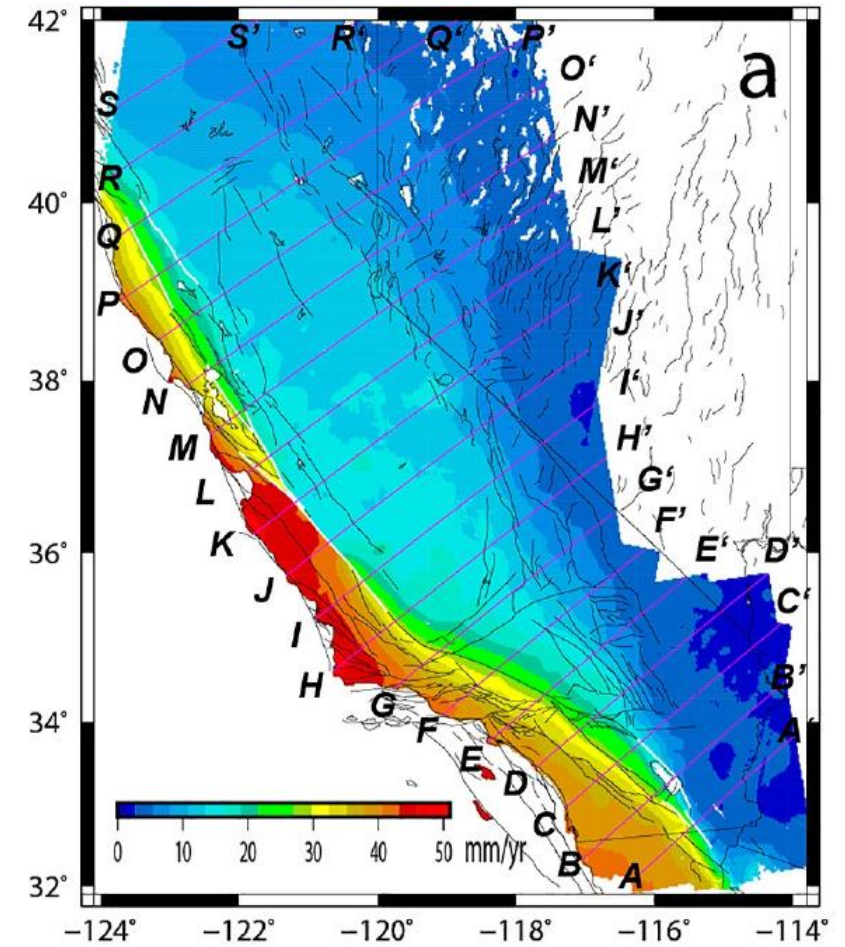
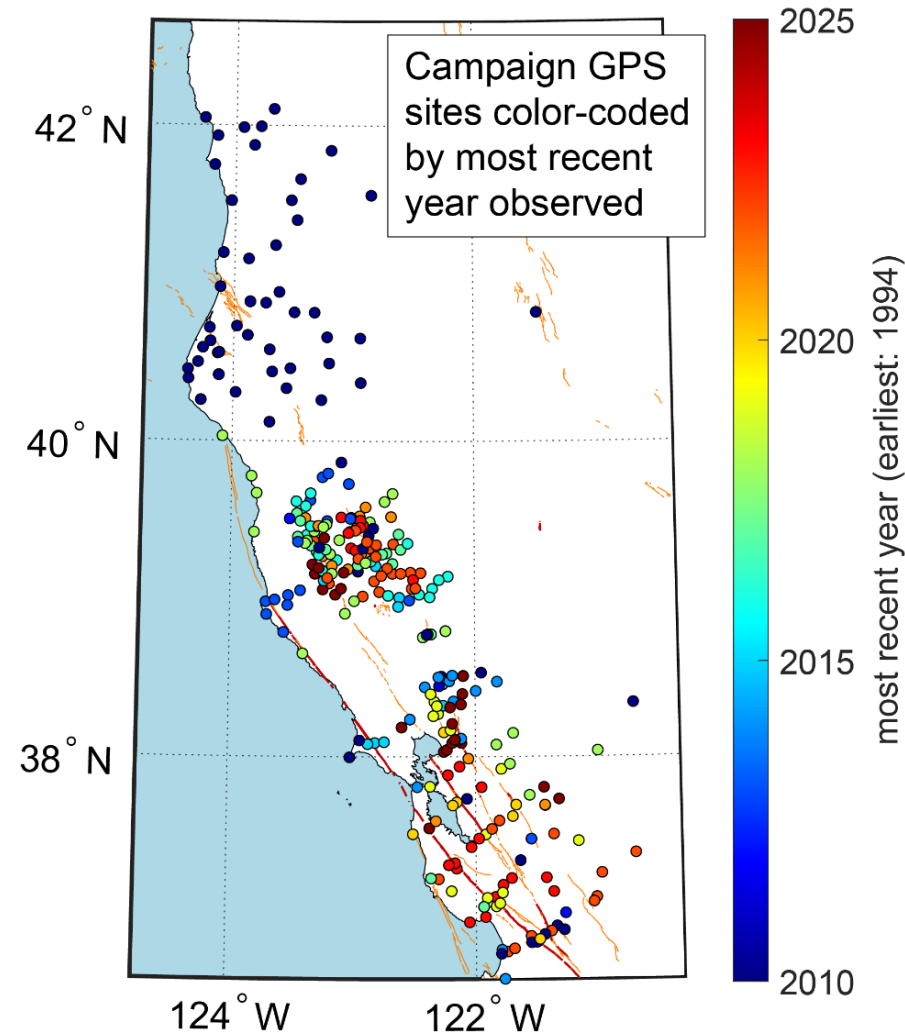
Lozos et al., GRL (2015)

Johnson et al. (2022)



GNSS Contribution to Increased Spatial Resolution

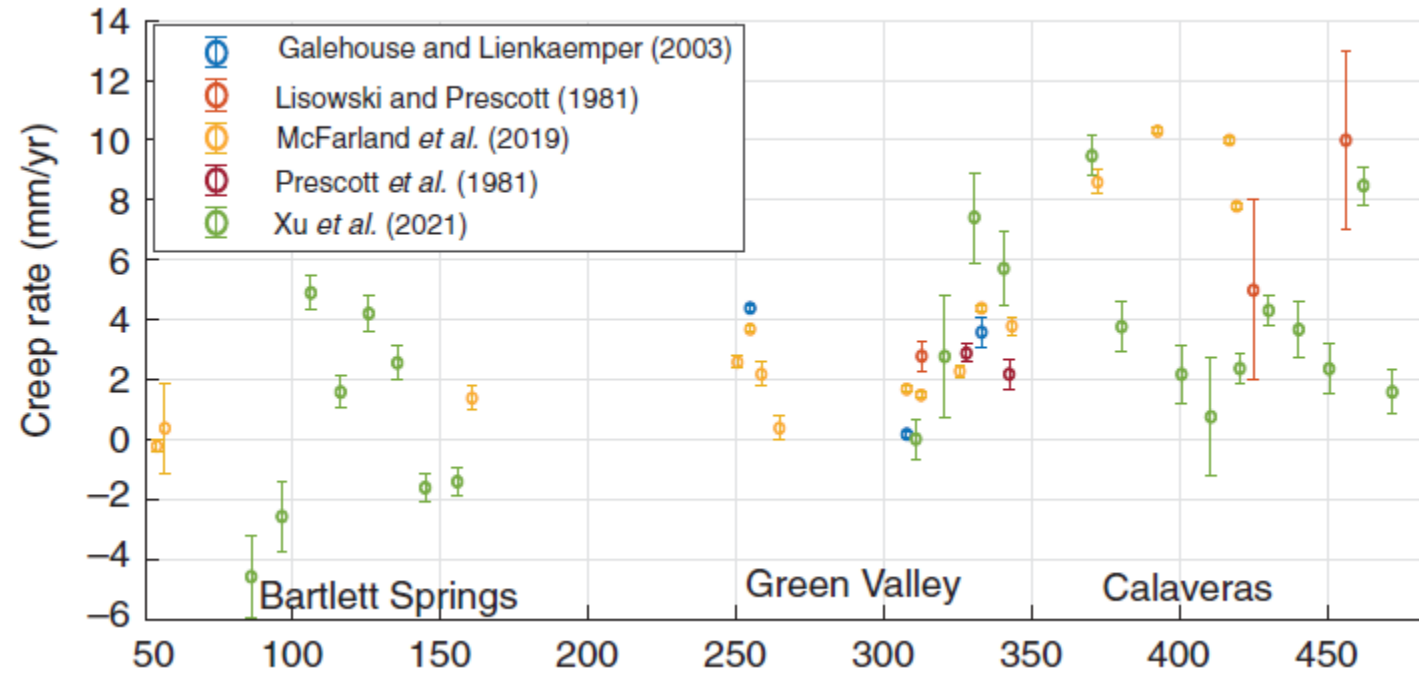
- Campaign GPS densifies coverage within a locking depth of the fault
- Three-component GNSS data provide constraints for leveraging spatially dense InSAR LOS data to obtain 3D velocity field



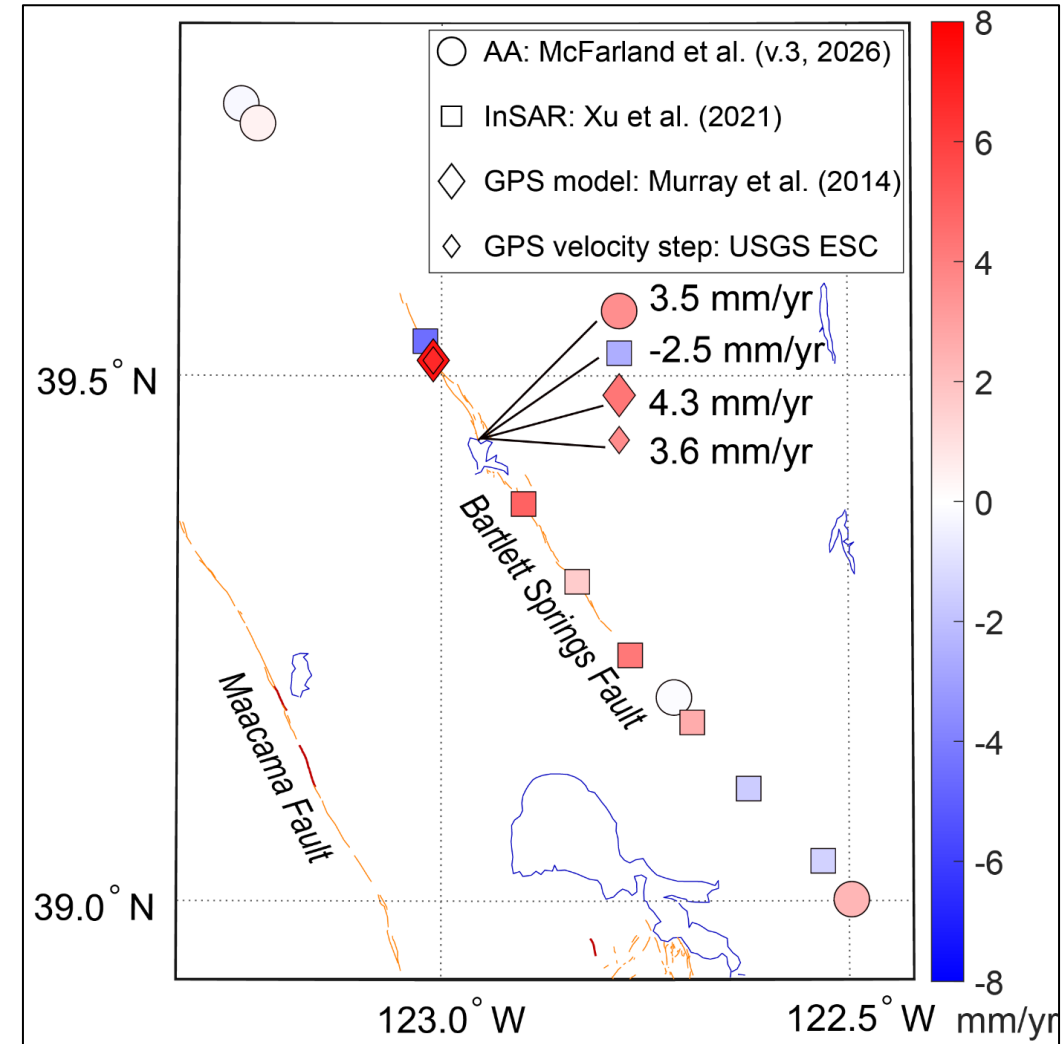
Shen and Liu (2025)

Deriving Surface Creep Rates from InSAR Data Remains Challenging

Vegetation and low creep rates are impediments in many parts of northern California



Johnson *et al.* (2022)



Take-home Points

- Understanding the depth extent of creep is important for hazard assessment and follow-on models.
- Depth extent is hard to estimate for vertical strike-slip faults.
- Alignment arrays or other near-fault measurements provide good constraint on the shallowest creep rates.
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