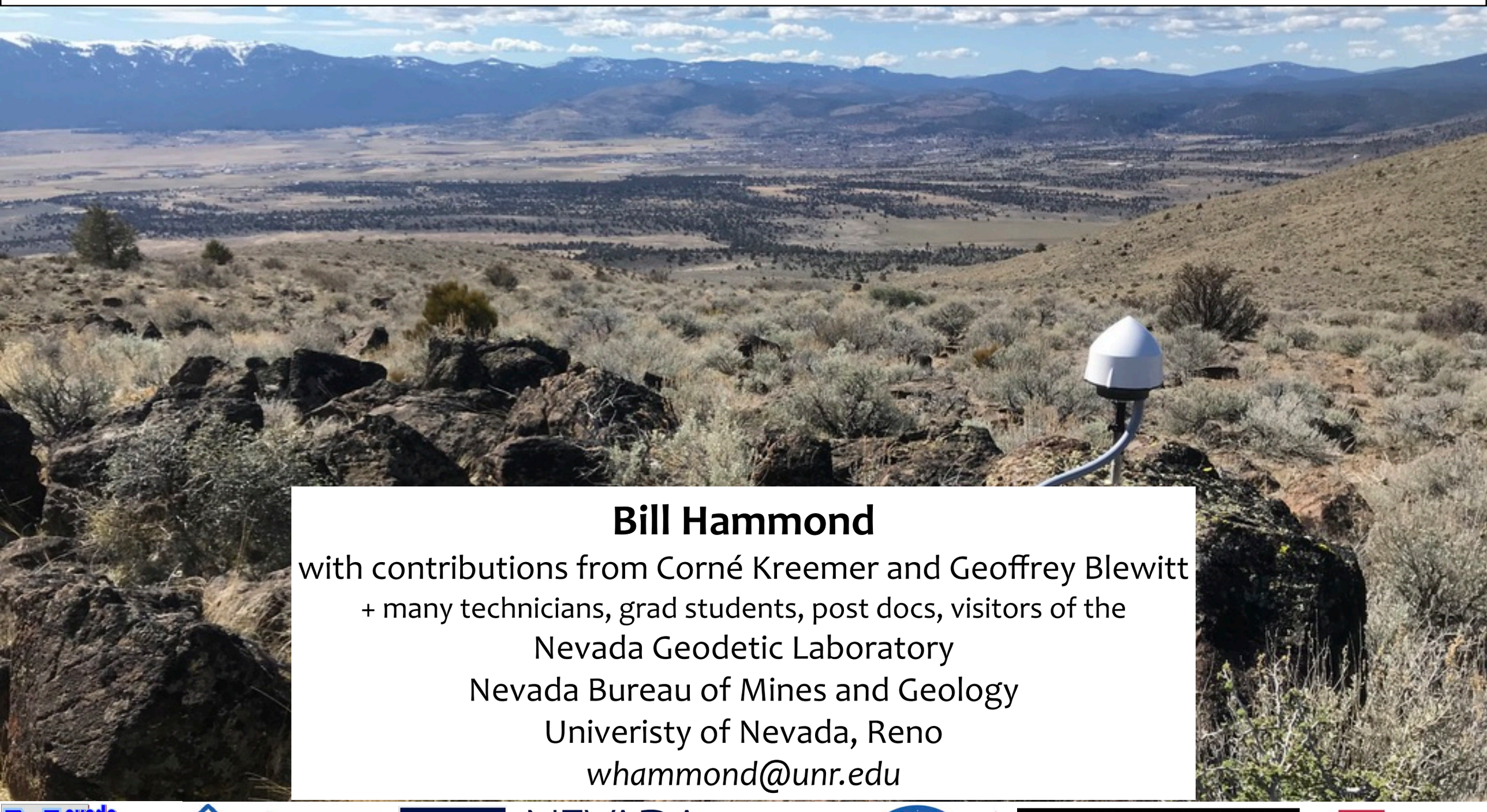
Northern Walker Lane Fault Slip Rates and Earthquakes as Seen by GNSS Networks



Bill Hammond

with contributions from Corné Kreemer and Geoffrey Blewitt

+ many technicians, grad students, post docs, visitors of the

Nevada Geodetic Laboratory

Nevada Bureau of Mines and Geology

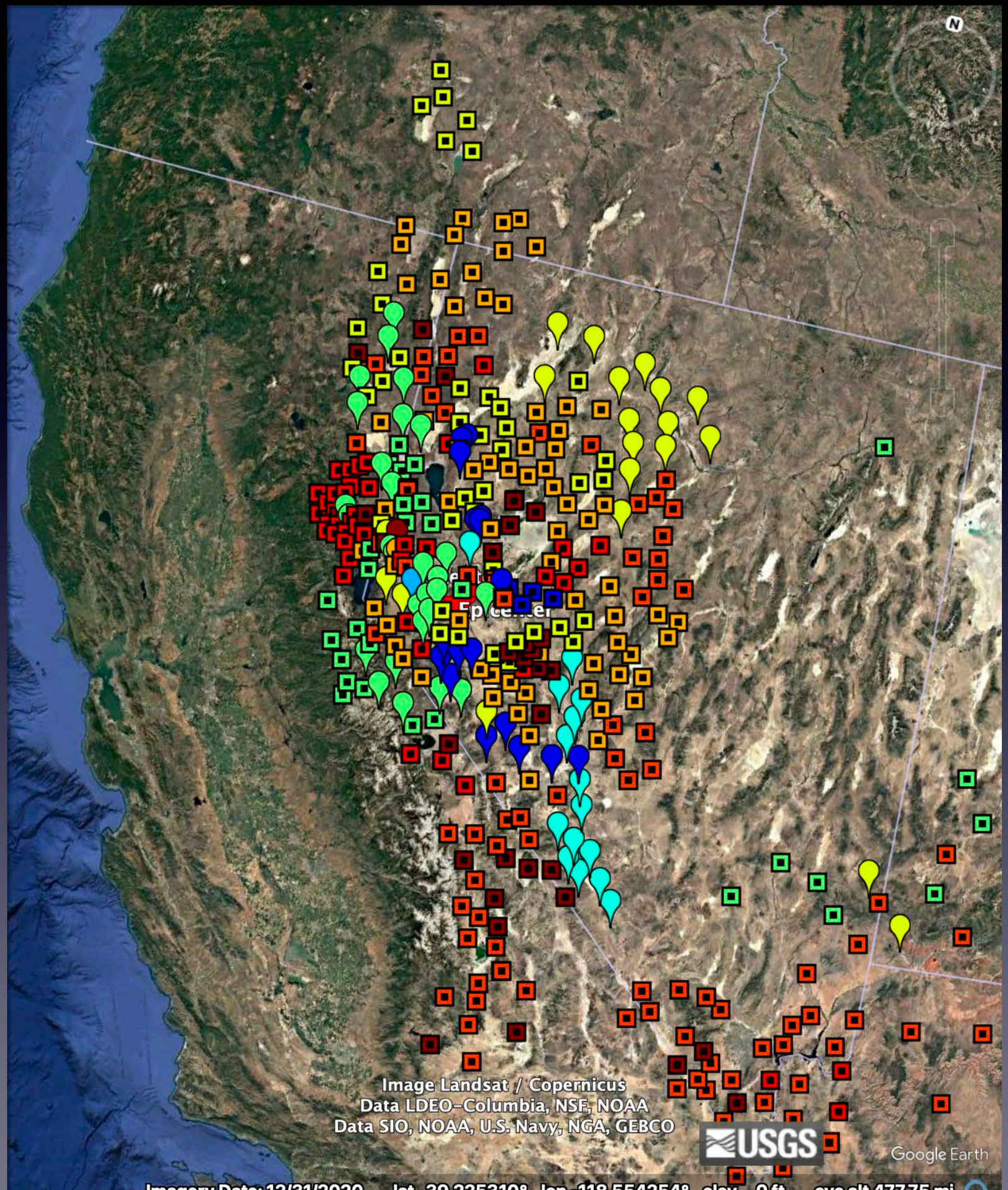
Univeristy of Nevada, Reno

whammond@unr.edu

MAGNET

"The **M**obile **A**rray of **G**PS for **Ne**vada **T**ranstension"

- 421 Stations
- 93 Instruments
- Mixed semi-continuous/ continuous observation strategy
- Maximizes coverage of large part of Basin and Range Province
- 1100 km aperture
- Spans Western Great Basin, Walker Lane + west Colorado Plateau
- NV, CA, AZ, UT, OR
- First observed in 2004
- Covers much of the Northern Walker Lane



MAGNET

"The **M**obile **A**rray of **G**PS for **Ne**vada **T**ranstension"

- Complements other Western US networks.

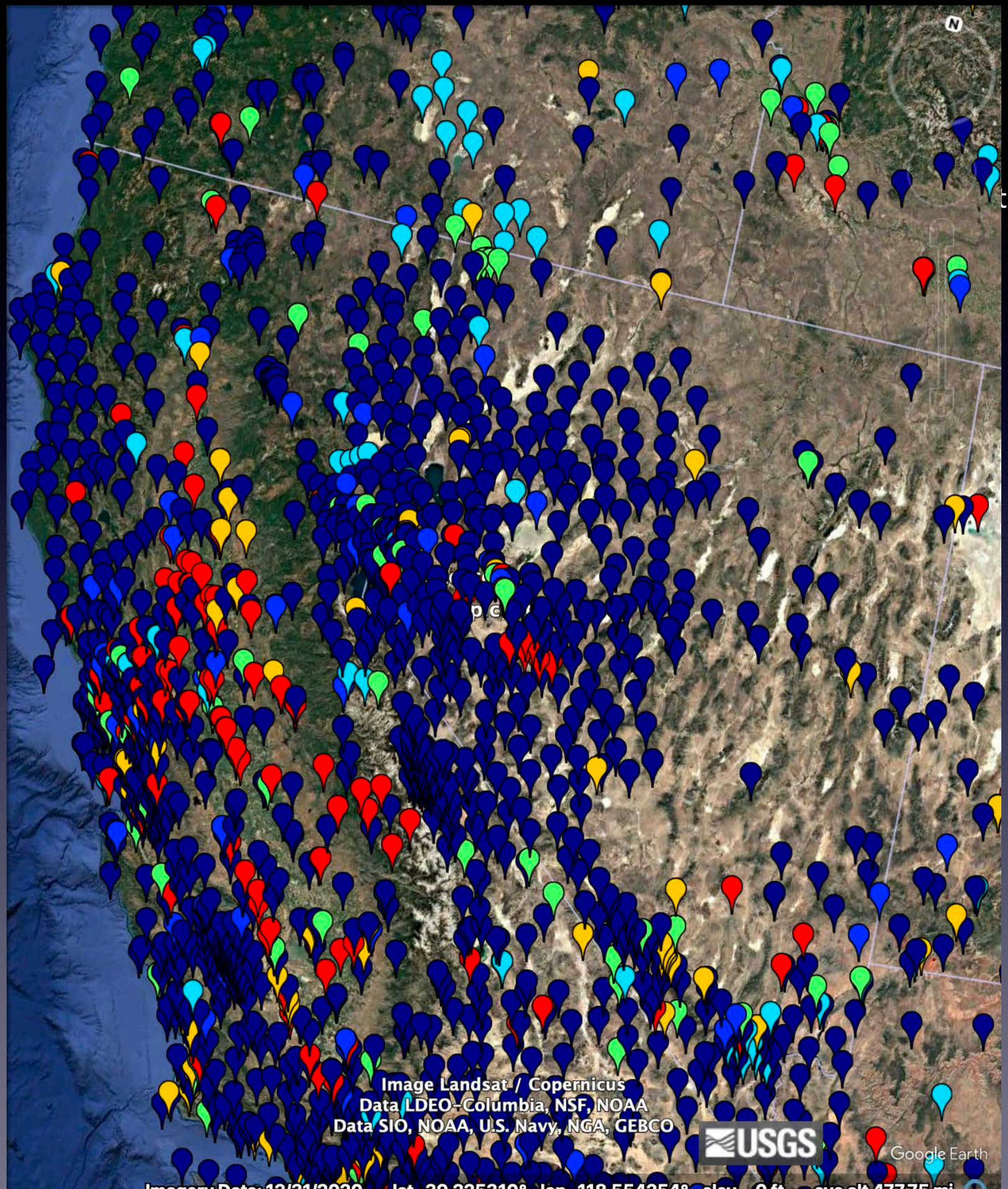
- A geodetic infrastructure that includes:

- NSF EarthScope Network of the Americas (NOTA)

- Municipal (Washoe County) and commercial networks (e.g. SmartNet North America)

- Member of a community of hundreds of other geodetic networks around the world

- NGL processes data from as many networks as possible



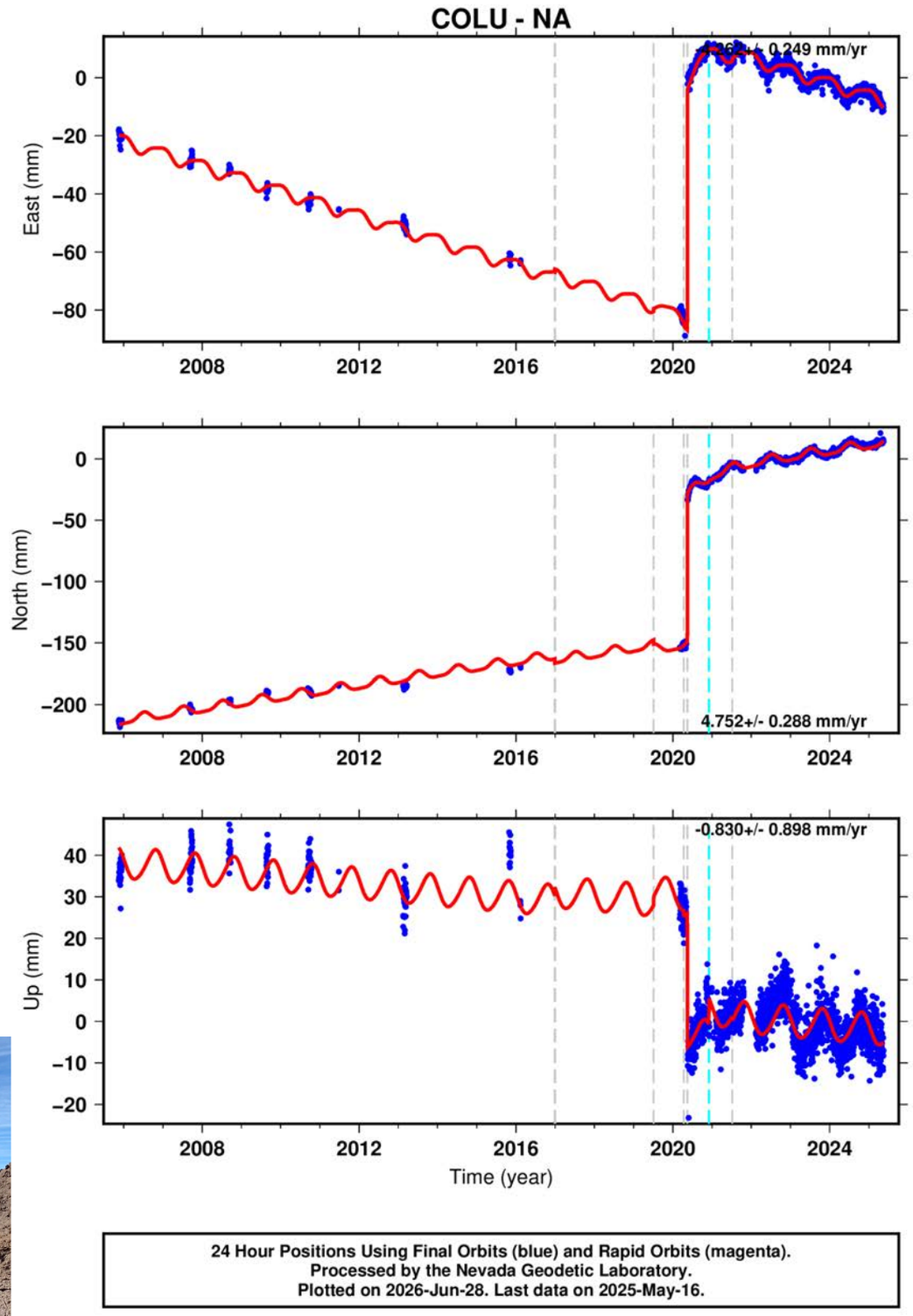
Example GNSS Time Series

MAGNET Station COLU

Station closest to the May 15, 2020 M6.5 Monte Cristo Range earthquake in Central Walker Lane

- Each blue dot: a station position in a global reference frame (over a 24 hour period)
- Uncertainties usually <1 mm
- Trends in position indicate crustal motion
- North American plate reference frame
- Big step is coseismic displacement from the earthquake
- Non-linear motion shows postseismic relaxation following event

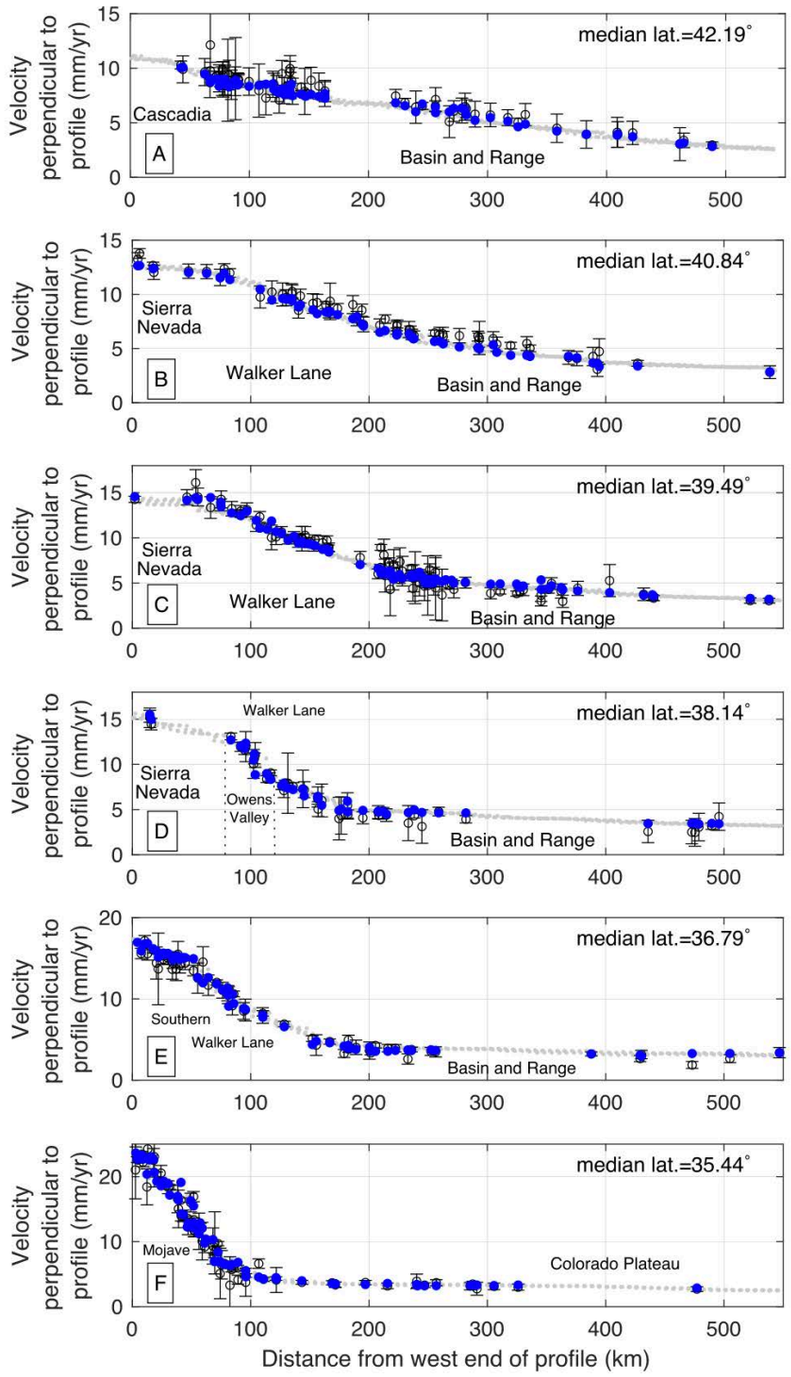




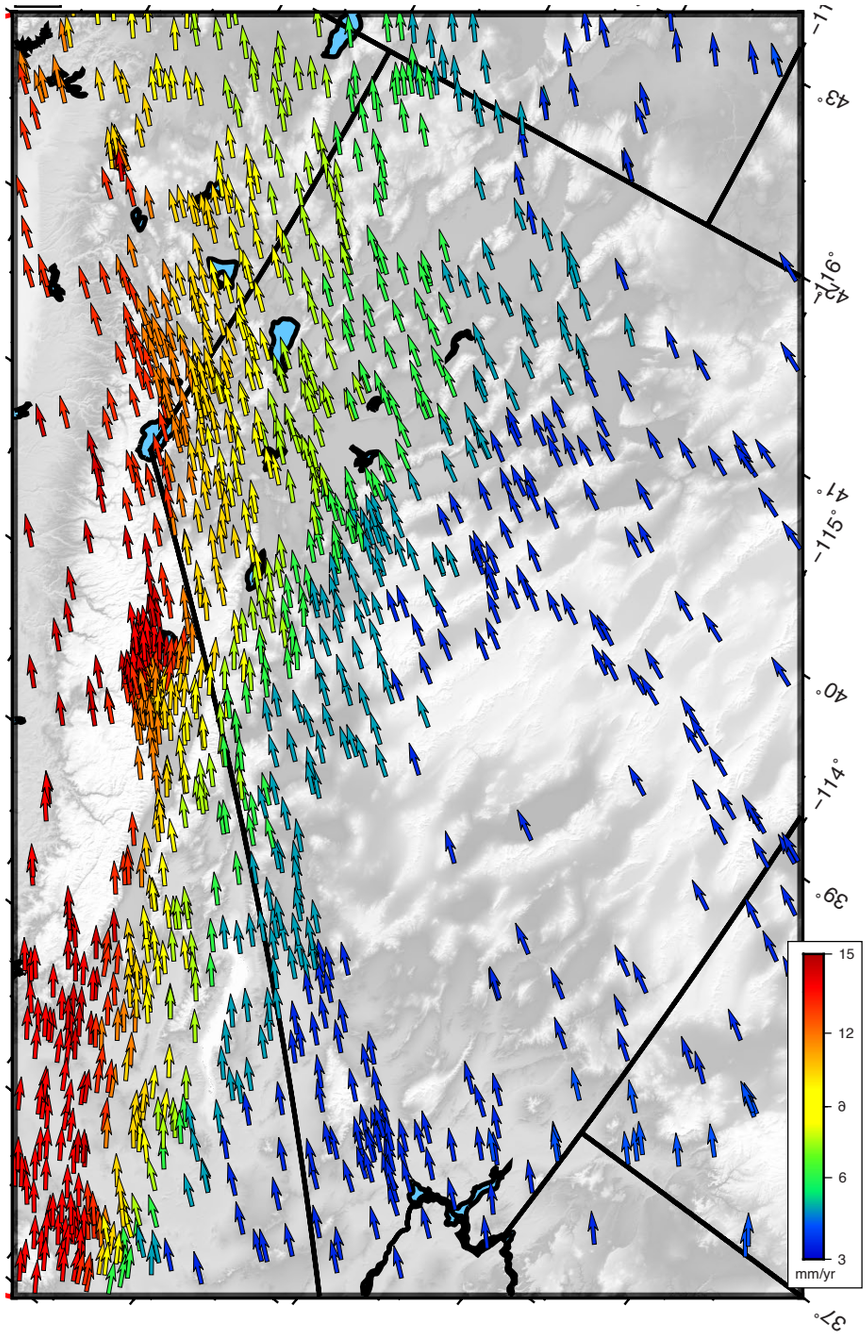
from: https://geodesy.unr.edu

Northern Walker Lane Velocities and Strain Rates

GNSS Velocity Profiles Across Great Basin

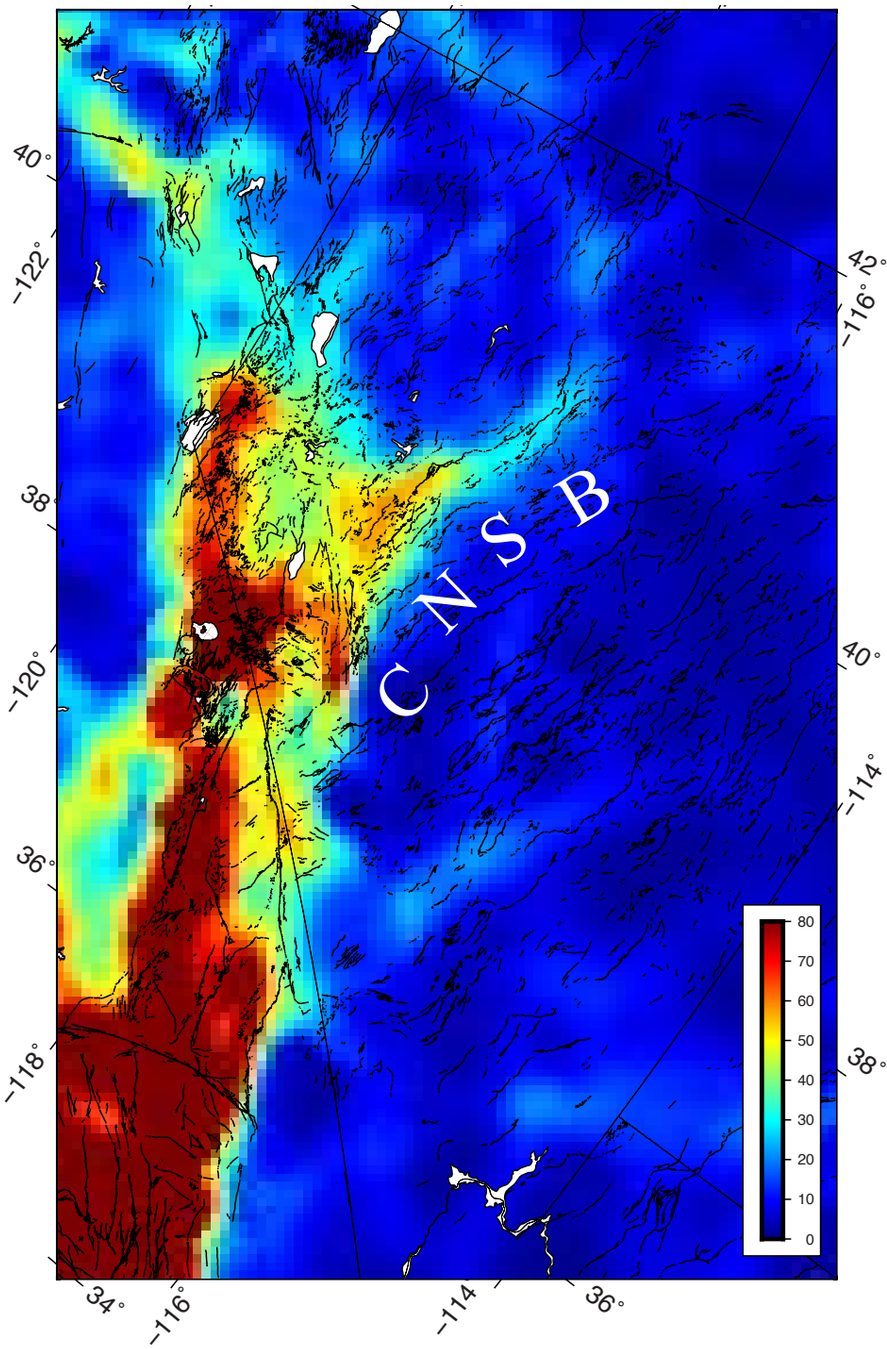


Horizontal Velocity wrt North America



Color indicates velocity magnitude

Strain Rate Magnitude from GNSS Velocity Gradients

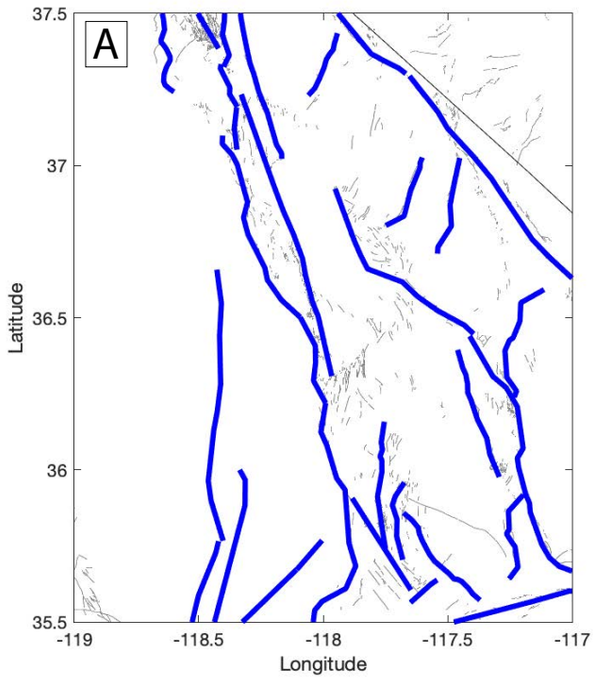


Color indicates strain rate in 10^{-9}/yr

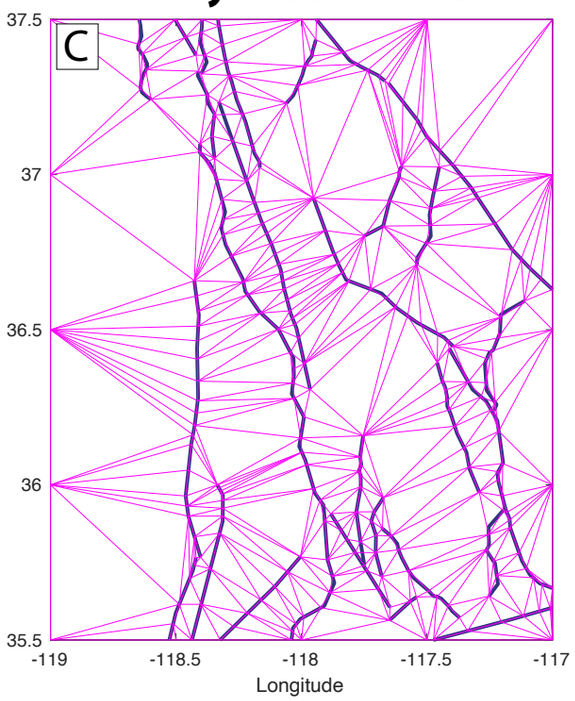
Hammond et al., 2024 JGR

Ensemble Block Modeling

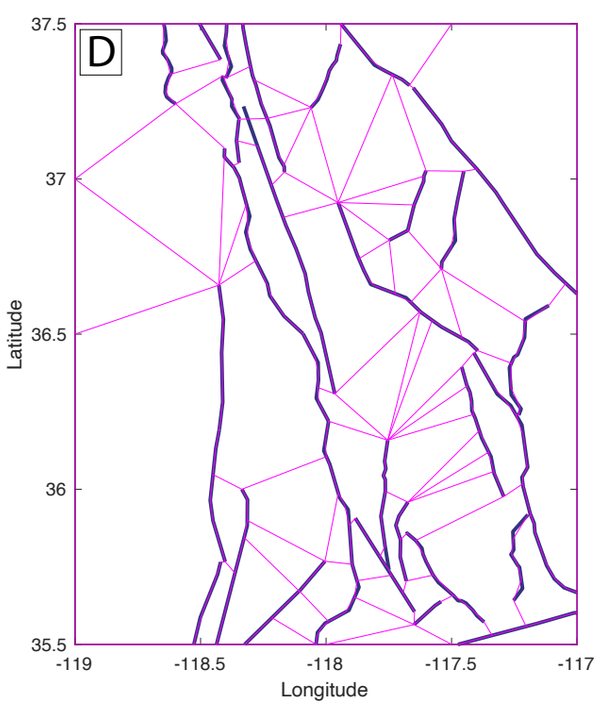
USGS NSHM Fault Geometries:
Hatem et al., 2021



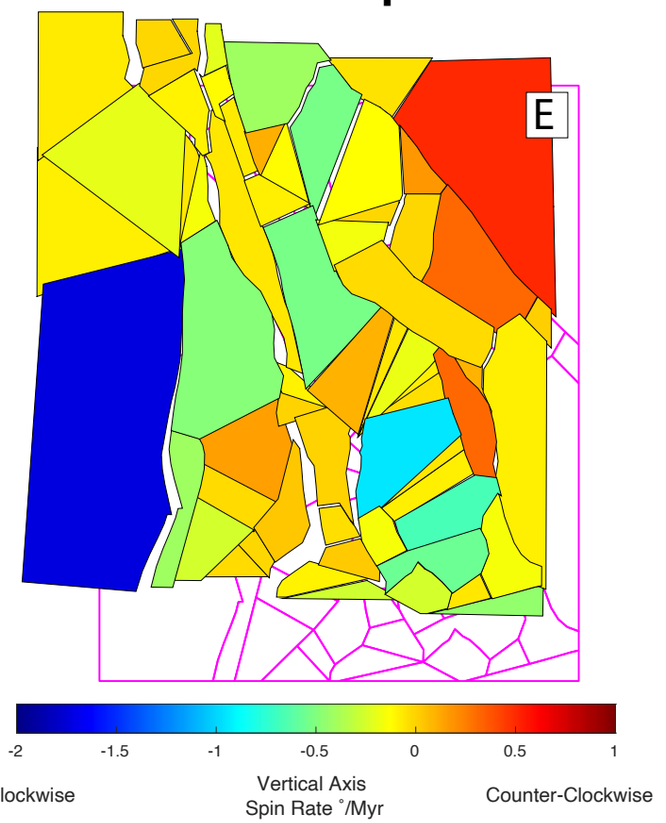
Generate:
Many Block Model



Refine:
Good Block Model



Solve:
Block Motion+Slip Rates



Method:

- Fault slip rates from velocities
- Assume NSHM fault geometries
- Thousands of models solving for slip rates and block rotations
- Slip **style assumed** constrained by rake in NSHM database
- But **rate is free** (not constrained by geologic rates)

Hammond et al., 2024 JGR

A model for a single 2° x 2° subdomain
Blocks algorithmically generated from fault database
Faults —> Many blocks
Simplify —> Fewer but enough blocks
Solve using GNSS data —> Block rotation and slip rates

REPEAT many times to cover Western Great Basin
1238 models
creates distribution of slip rate estimates, take median

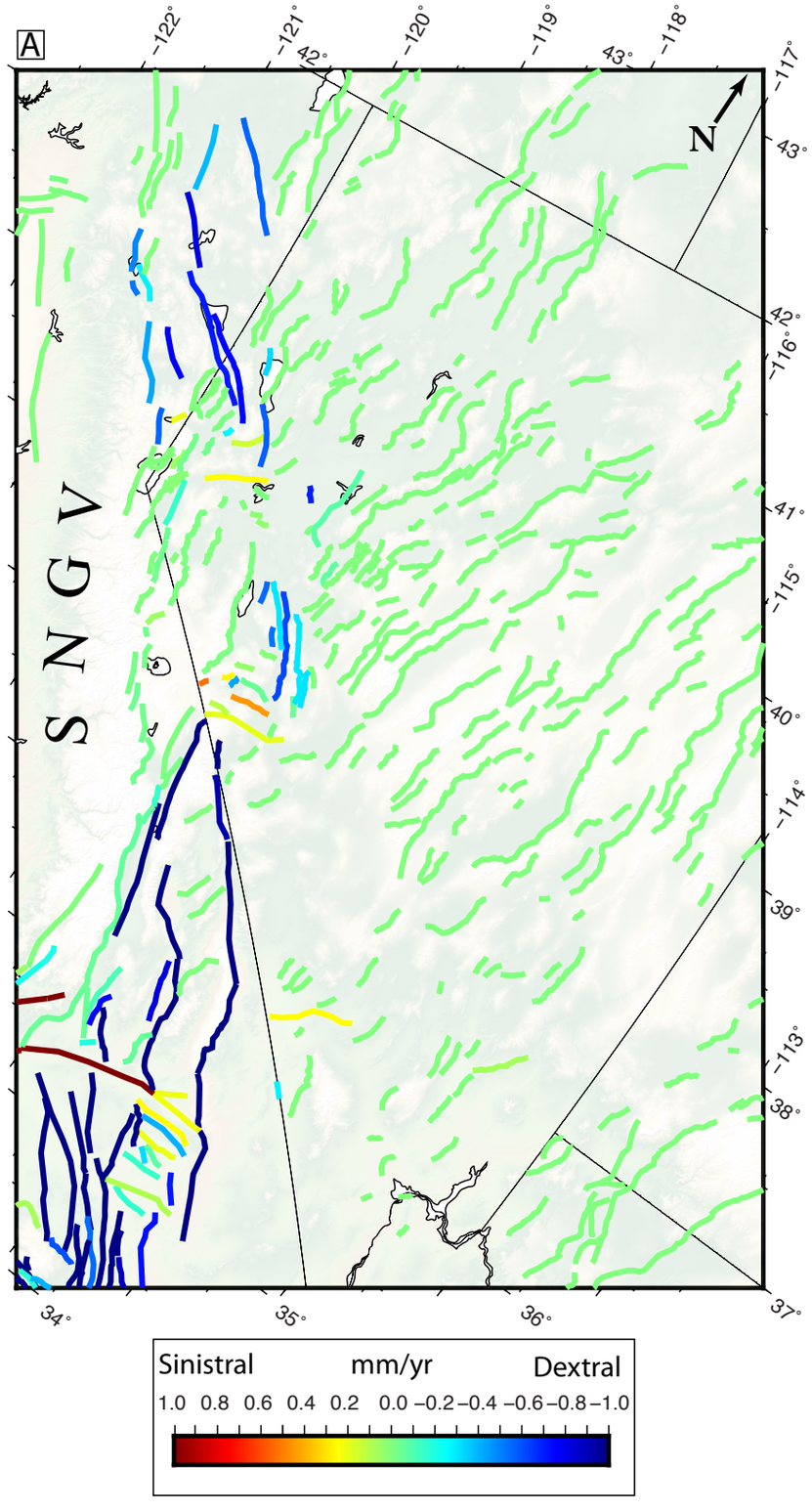
Fault Slip Rates

Notable Results:

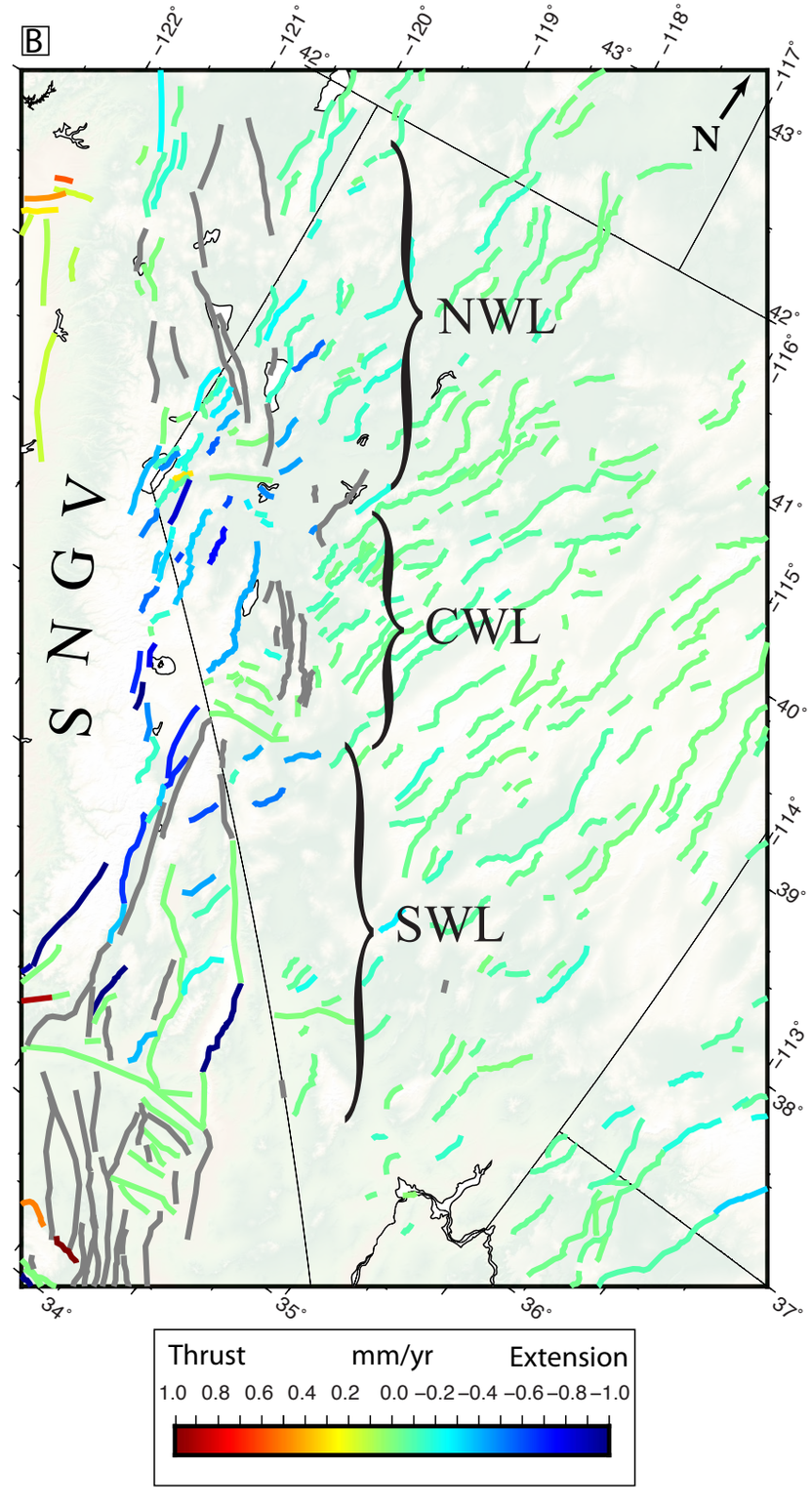
- Partitioning of strike slip/ normal slip
- Central Walker Lane strike slip steps right at Mina Deflection
- Normal slip distributed from Wasatch to Tahoe Basin
- Faster in Northern Walker Lane that in the Basin and Range
- North of Tahoe dextral slip is dominant until its not…
- Dextral slip Eagle Lake, Likely, Big Valley to
- Normal slip on Hat Creek/ McArthur/Pondosa faults

Hammond et al., 2024 JGR

Strike Slip



Normal



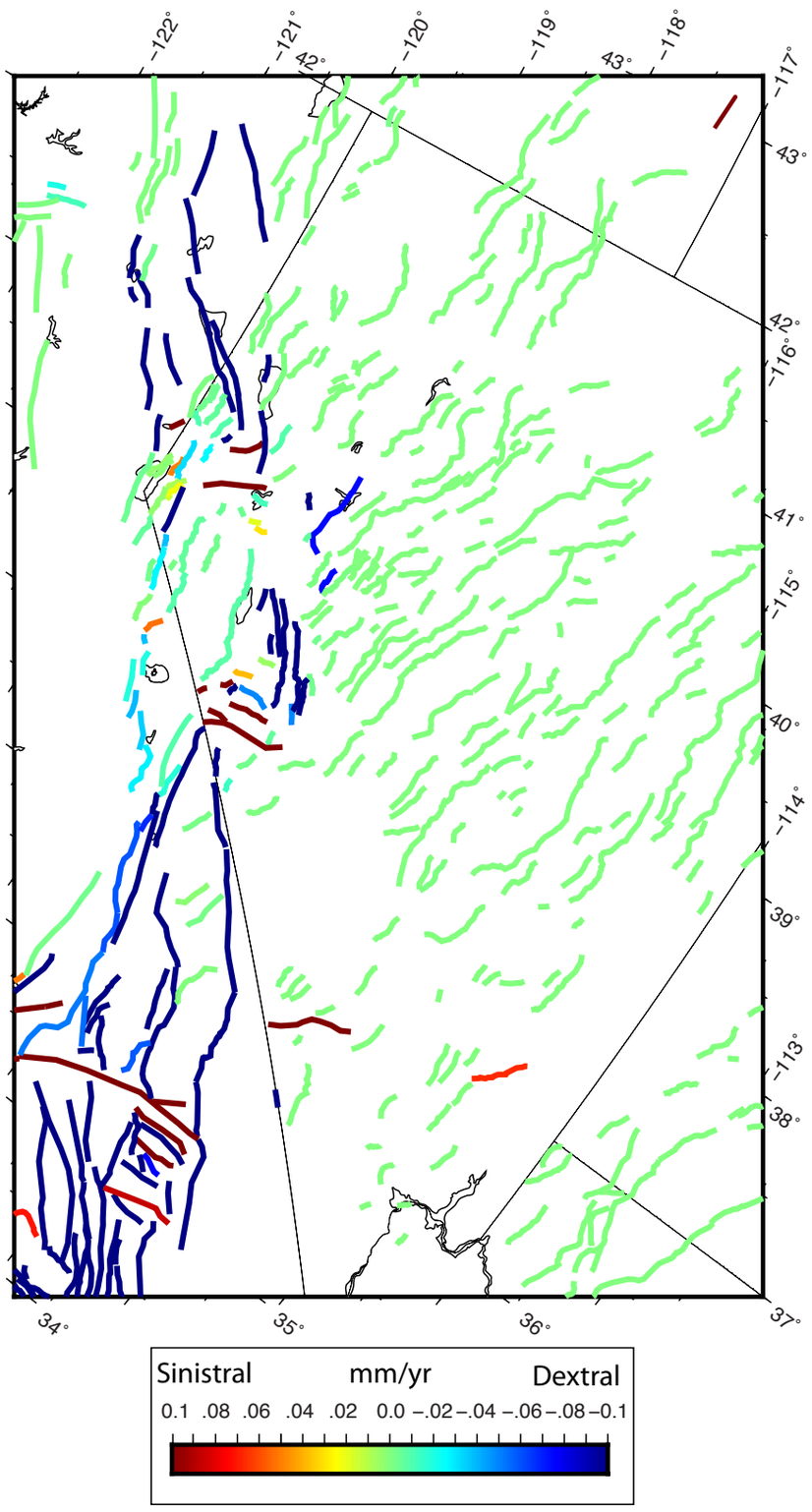
Fault Slip Rates

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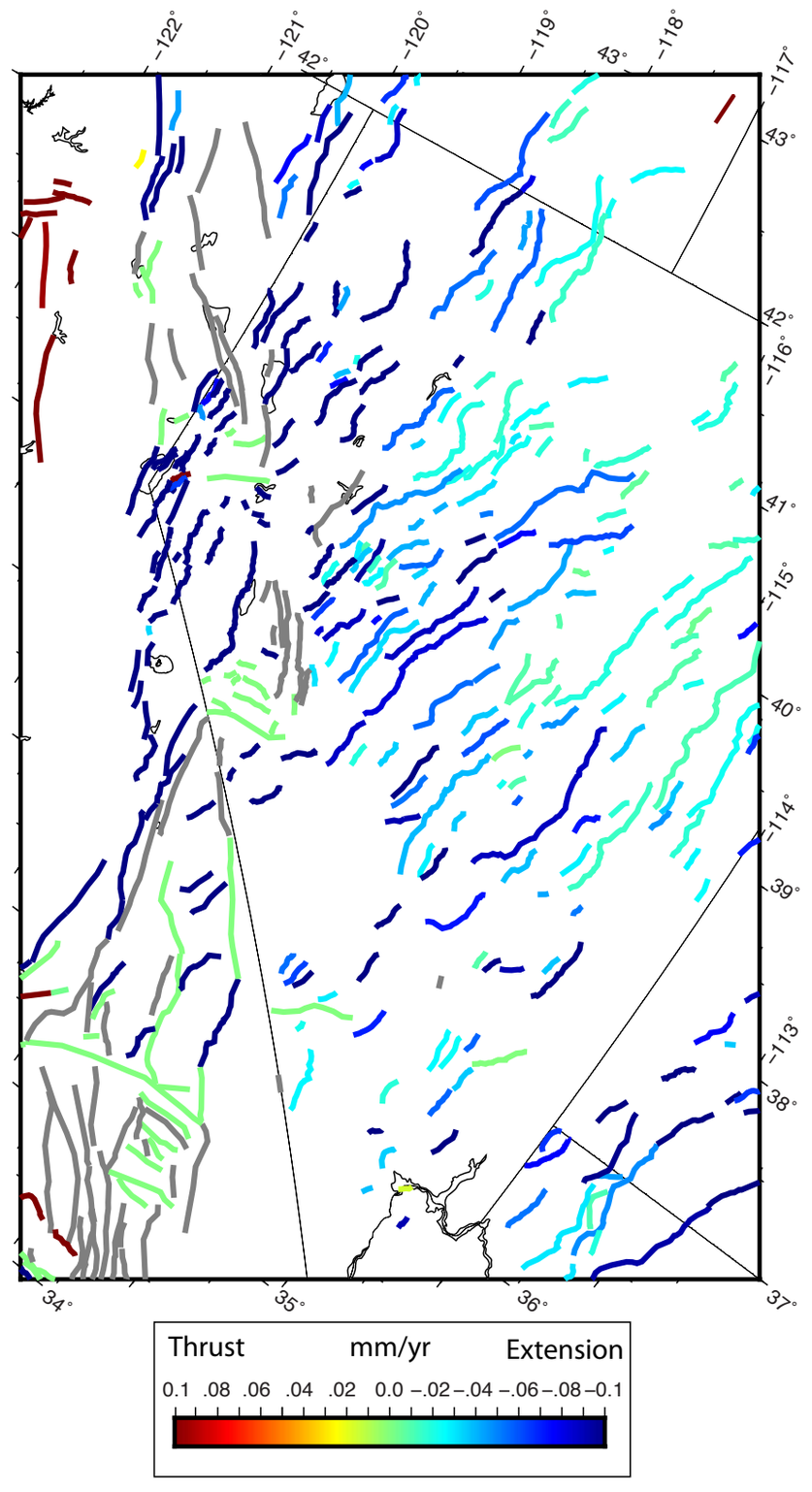
- Change color scale **±0.1 mm/yr** and remove topography for clarity
- Variation in slow normal slip rates across Nevada
- Slip rates responding to small changes in velocity gradients
- Can see thrusts in northern Central Valley
- Left lateral across Southern Nevada

Hammond et al., 2024 JGR

Strike Slip



Normal



Fault Slip Rates

Comparison:

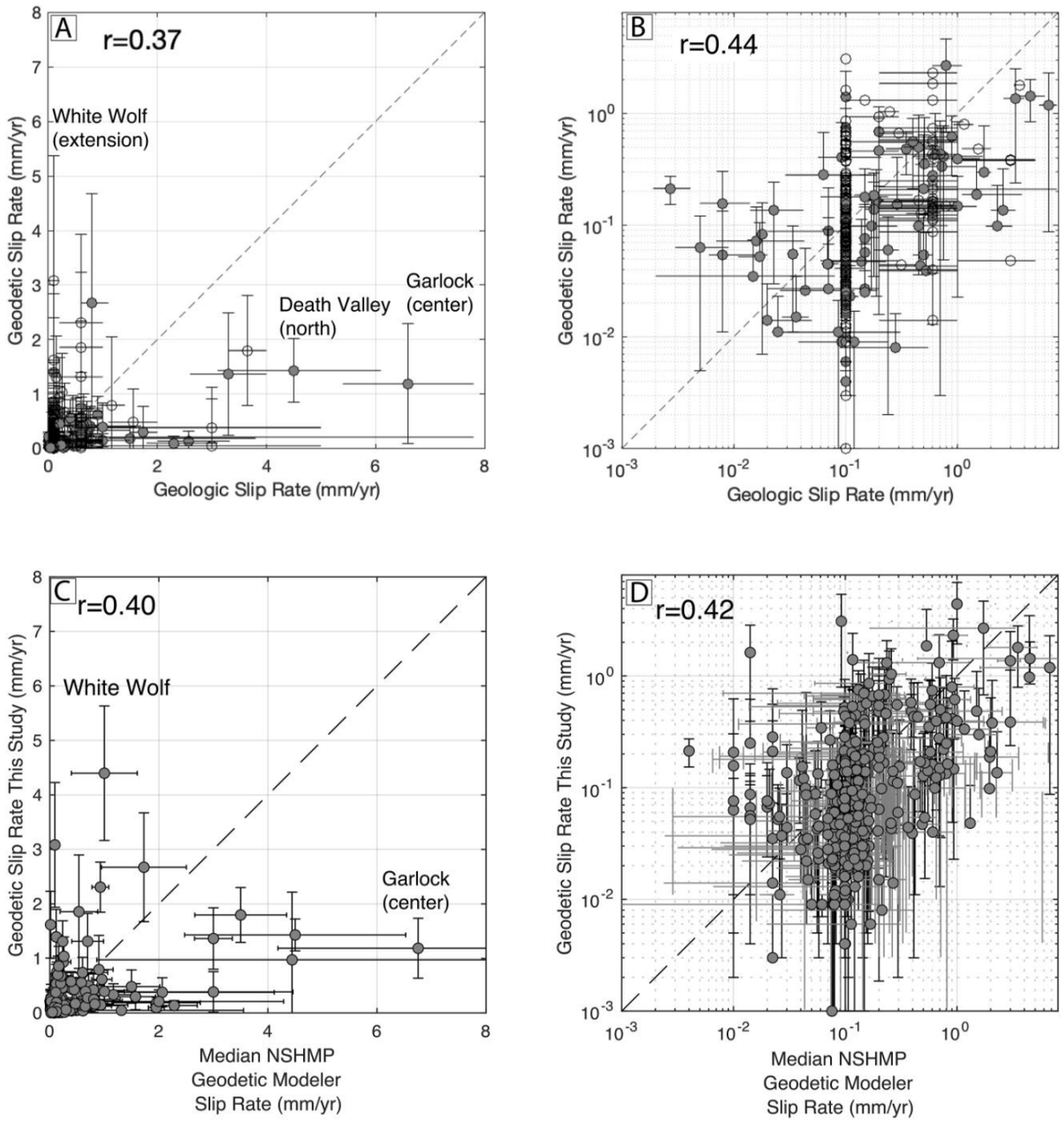
- Agreement to within uncertainty for ~80% of faults
- Positive correlation

Notice:

- linear scale - outliers dominate visual impression
- log/log scale cloud is well-bisected by the 1:1 line
- Unbiased
- Geologic rates cluster of 0.1 mm/yr
- Sorting each set reveals:
  - Similar for NSHM modelers
  - Slower slip rates for geodetic

Hammond et al., 2024 JGR

Geologic vs. Geodetic Slip Rates



Fault Slip Rates

Comparison:

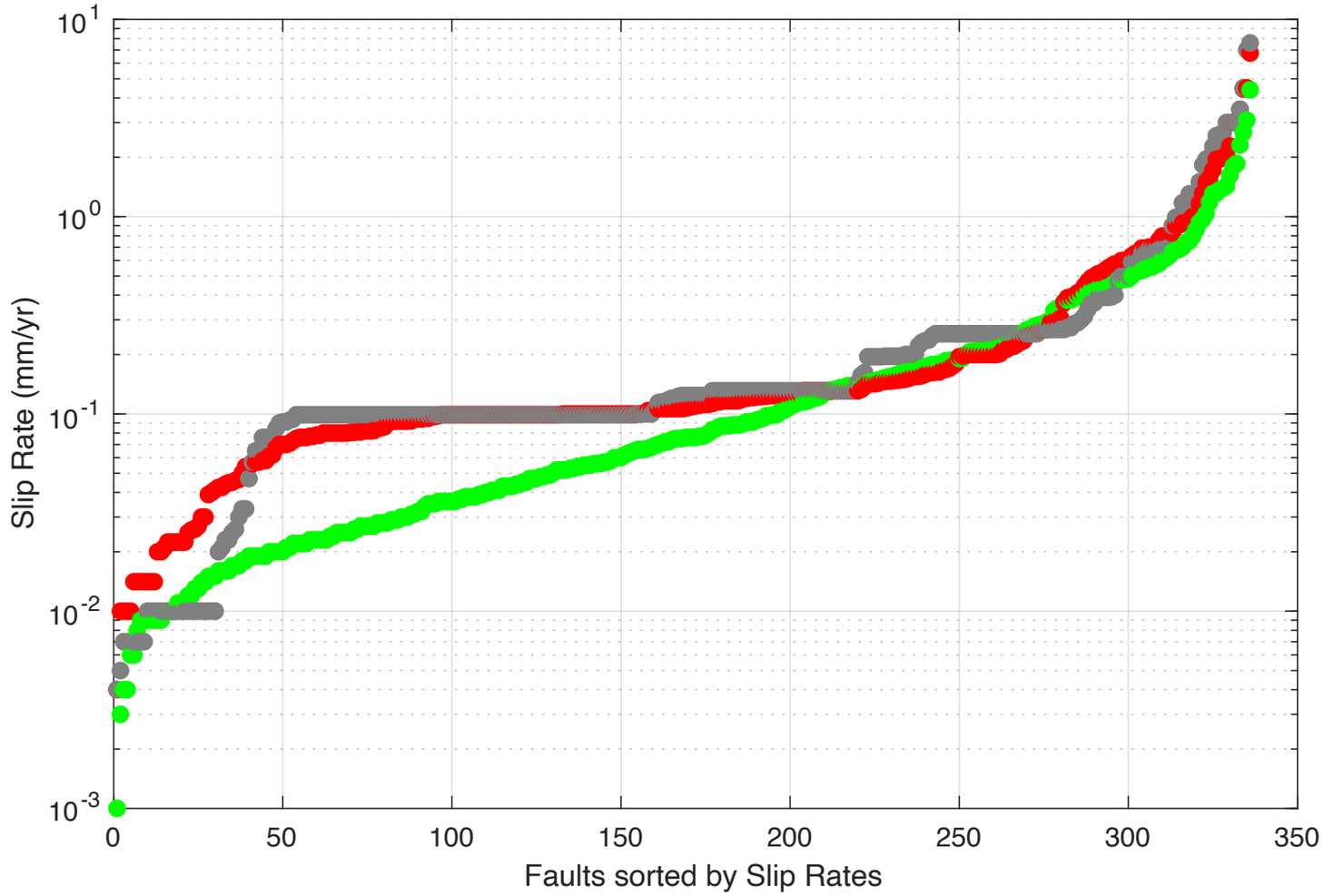
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Hammond et al., 2024 JGR

Geologic vs. Geodetic Slip Rates



Off Fault Deformation and Rotation

What is Off-Fault deformation?

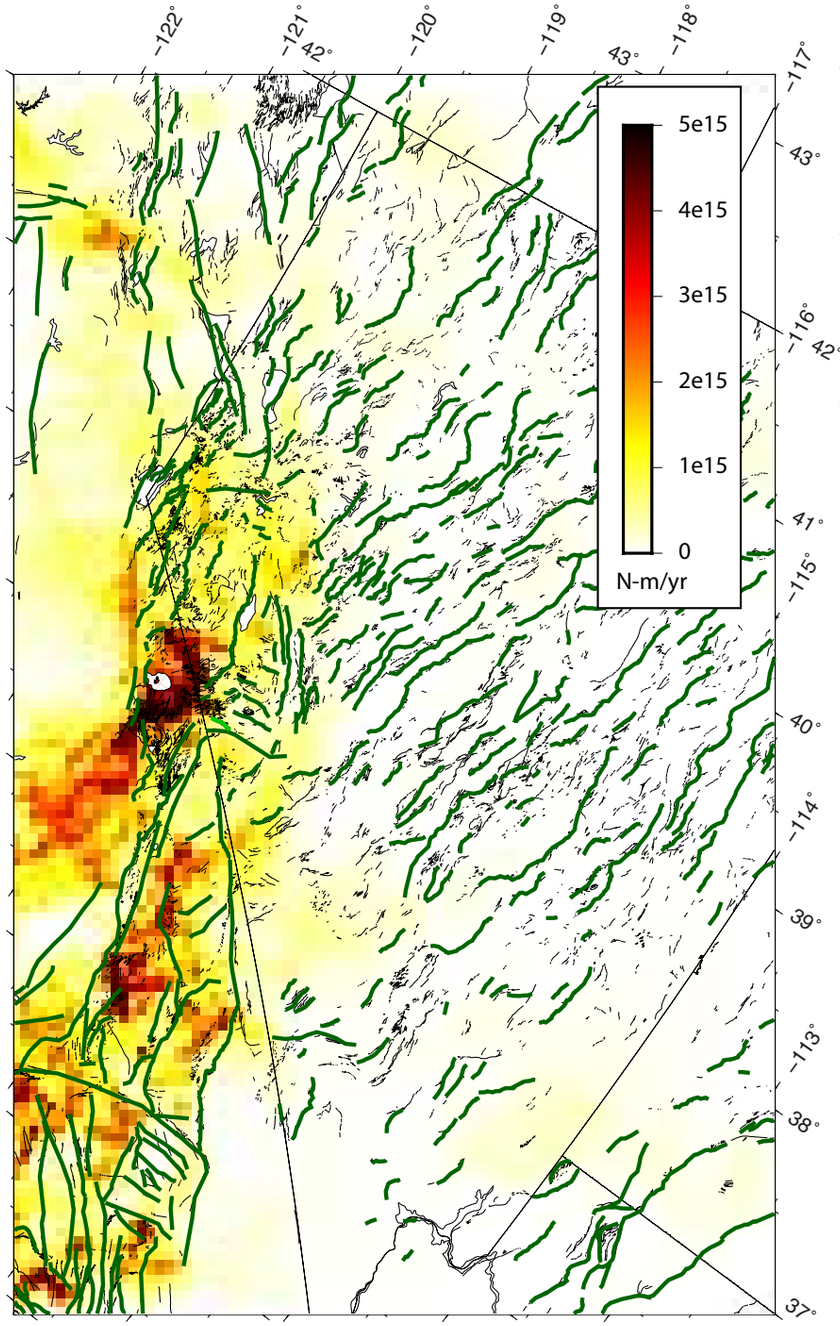
- Strain rates in GNSS data not attributable to an NSHM fault
- Higher where strain rates are higher
- And at model fault end

Reasons for it:

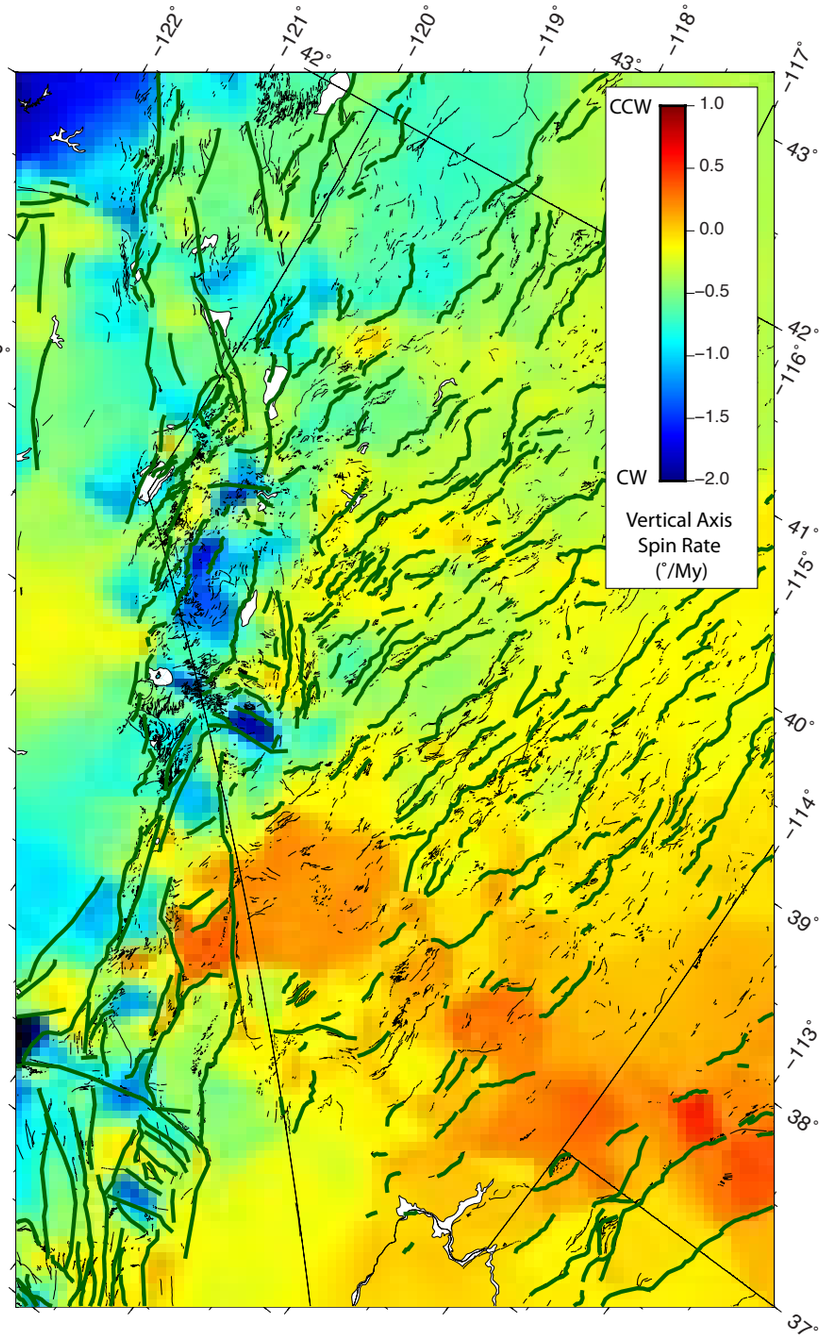
- Fault database incompleteness
- NSHM faults terminate without connecting to another fault
- Aseismic deformation (e.g., magmatic, postseismic, transient loading, etc.)
- Magmatic inflation at Long Valley Caldera:

Hammond et al., 2024 JGR

Off-Fault Deformation



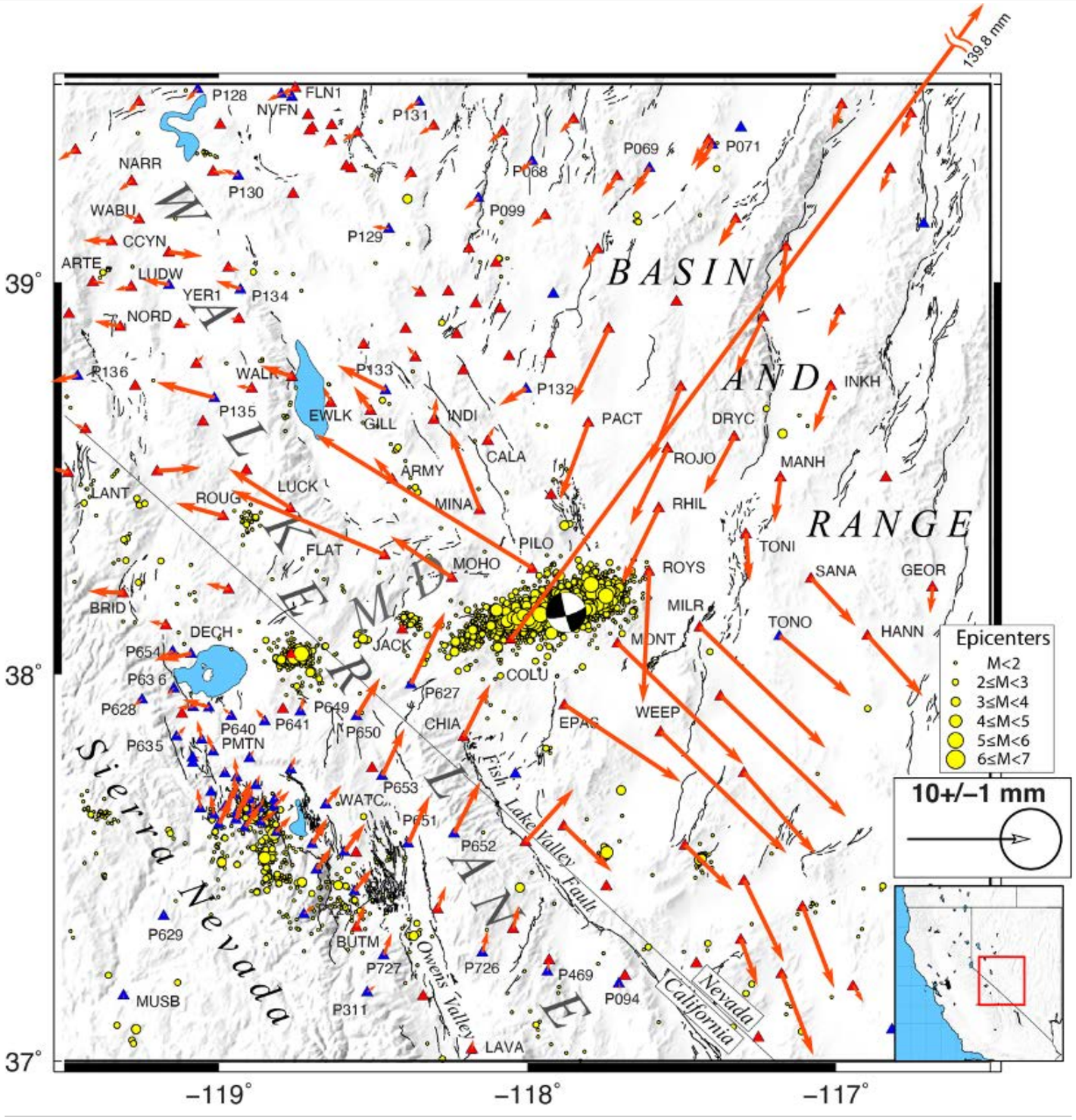
Vertical Axis Rotation



M6.5 Monte Cristo Range, May 15, 2020

Earthquake response

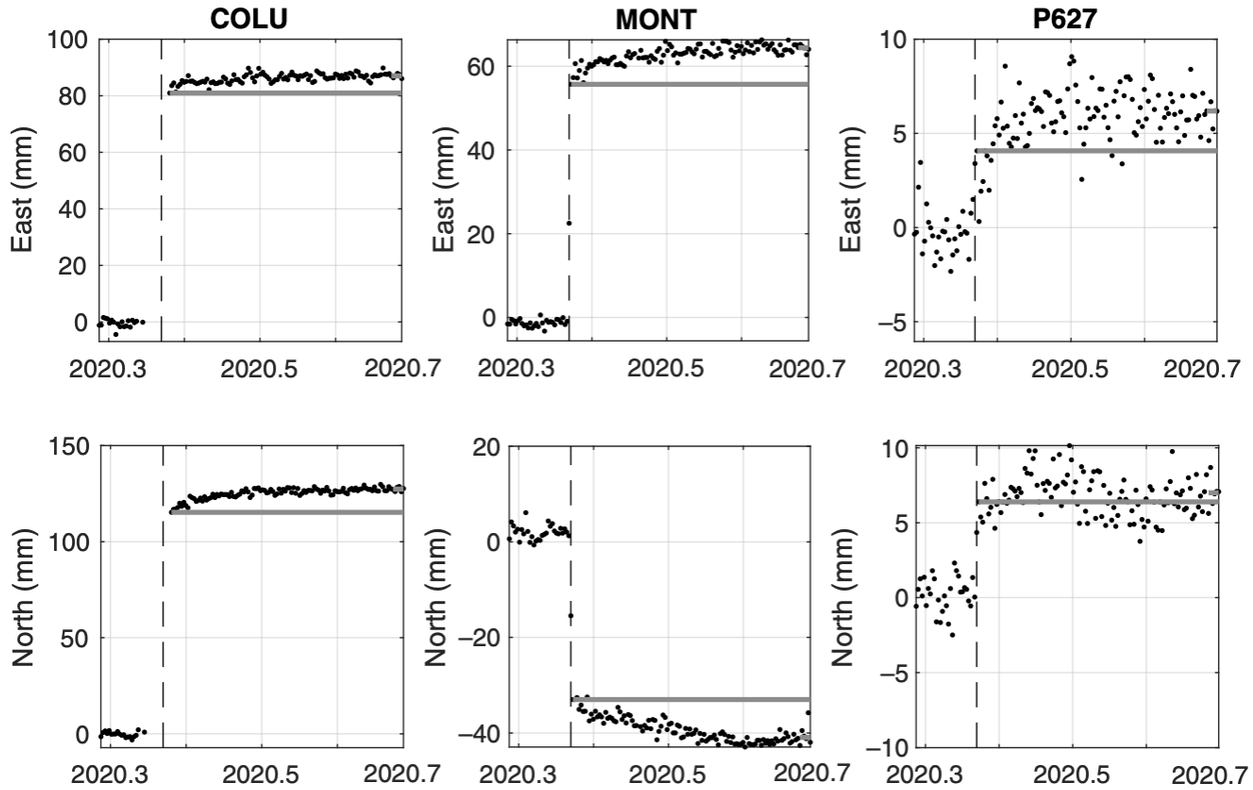
- GNSS images full reach of the earthquake
- Not just where seismic waves travelled but where the ground moved permanently
- Needed for research on the physics and effects of earthquakes
- 197 had offsets significantly larger than zero
- Significant up to >200 km from epicenter
- Constrain extent, depth, rake of slip, event magnitude
- Offsets that are zero are important too because they constrain the depth and extent of slip
- So we tend to survey as many stations as we can following earthquakes



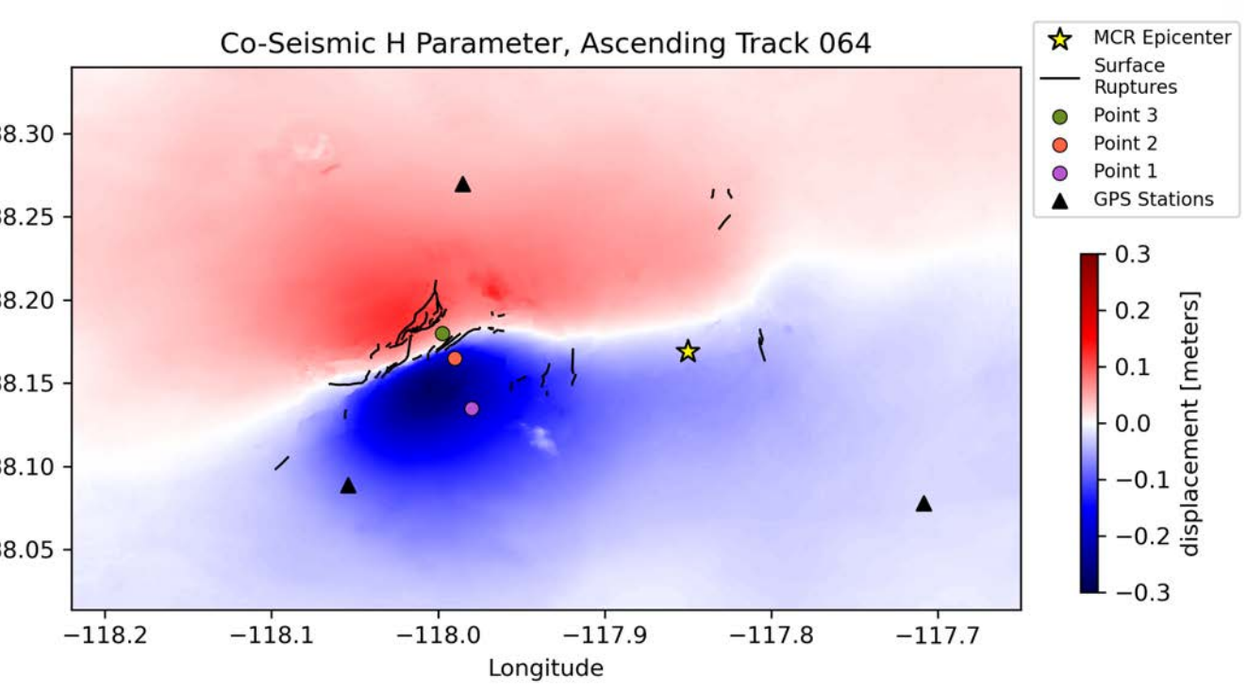
Updated from Hammond et al. (2021). *Seismol. Res. Lett.* 92(2A), 647-662, doi: 10.1785/0220200338.

Monte Cristo Range Postseismic

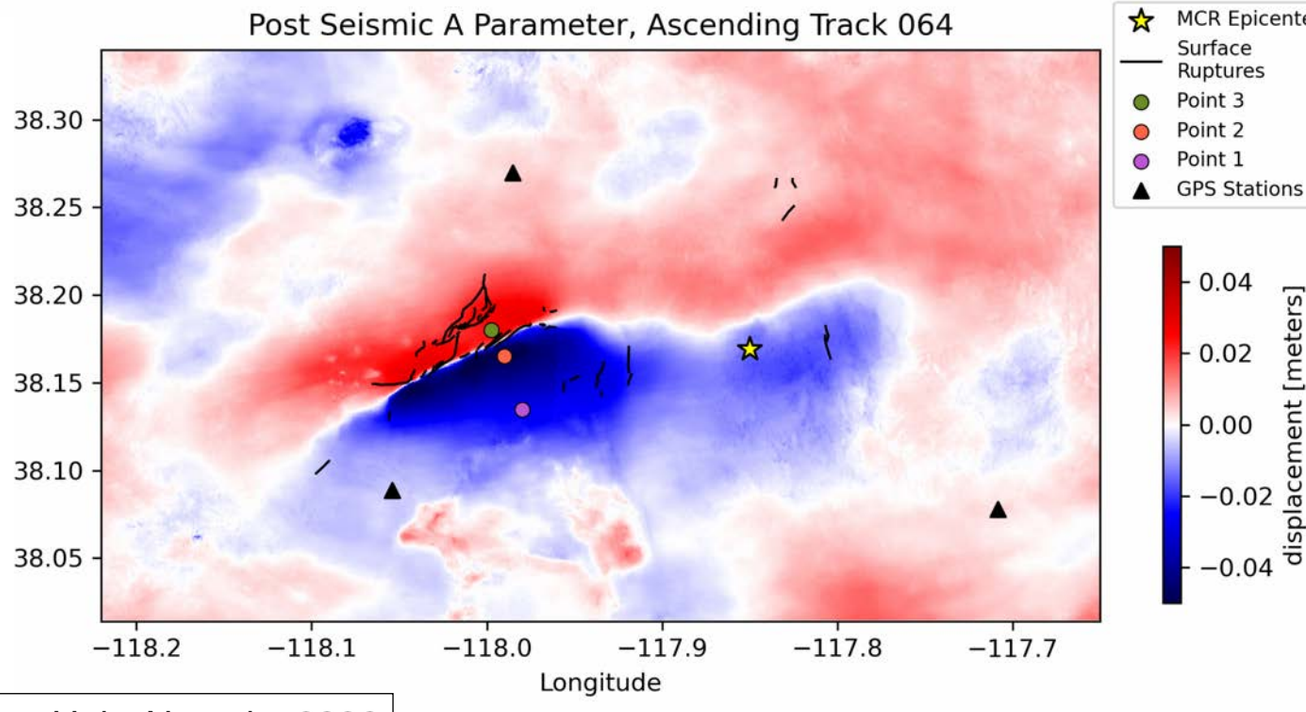
- GNSS and InSAR work very well together to show clear signal of post event motion
- Lasted several months
- Co- and post-seismic deformation similar in form and direction
- Strongly suggests after slip



Coseismic



Post-seismic



Crandall-Bear Ph.D Dissertation, Univ. Nevada, 2026



Take Aways

In the northern Walker Lane geodesy constrains fault slip rates, distribution and changes in slip style along the system

Off-fault deformation is identified as GNSS strain not occurring on the NSHM faults

Geologic constraints on seismic sources are still very much needed to improve the model, since changes in the database will influence slip rate estimates.

GNSS and InSAR are key contributors to earthquake cycle geodesy, important for co- and post-seismic phase

MAGNET

"The **M**obile **A**rray of **G**PS for **Ne**vada **T**ranstension"

Examples of MAGNET instruments in the field:

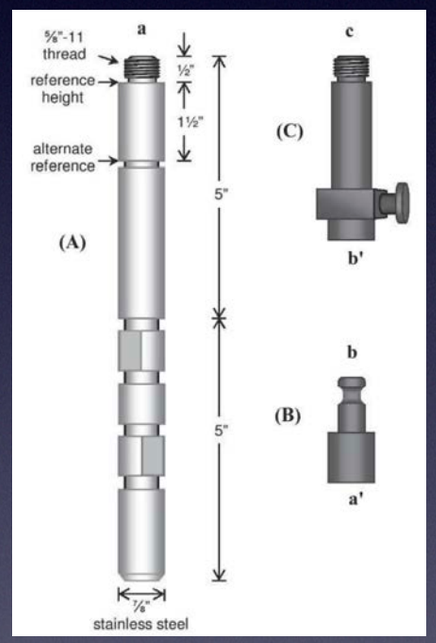
- A station is essentially:
  - Steel monument pin set in rock
  - Antenna
  - Receiver

Properties:

- Precise positioning
- Repeatable
- Low profile
- Mobile
- Efficient
- Achieves precision in tectonic rates similar to continuous stations









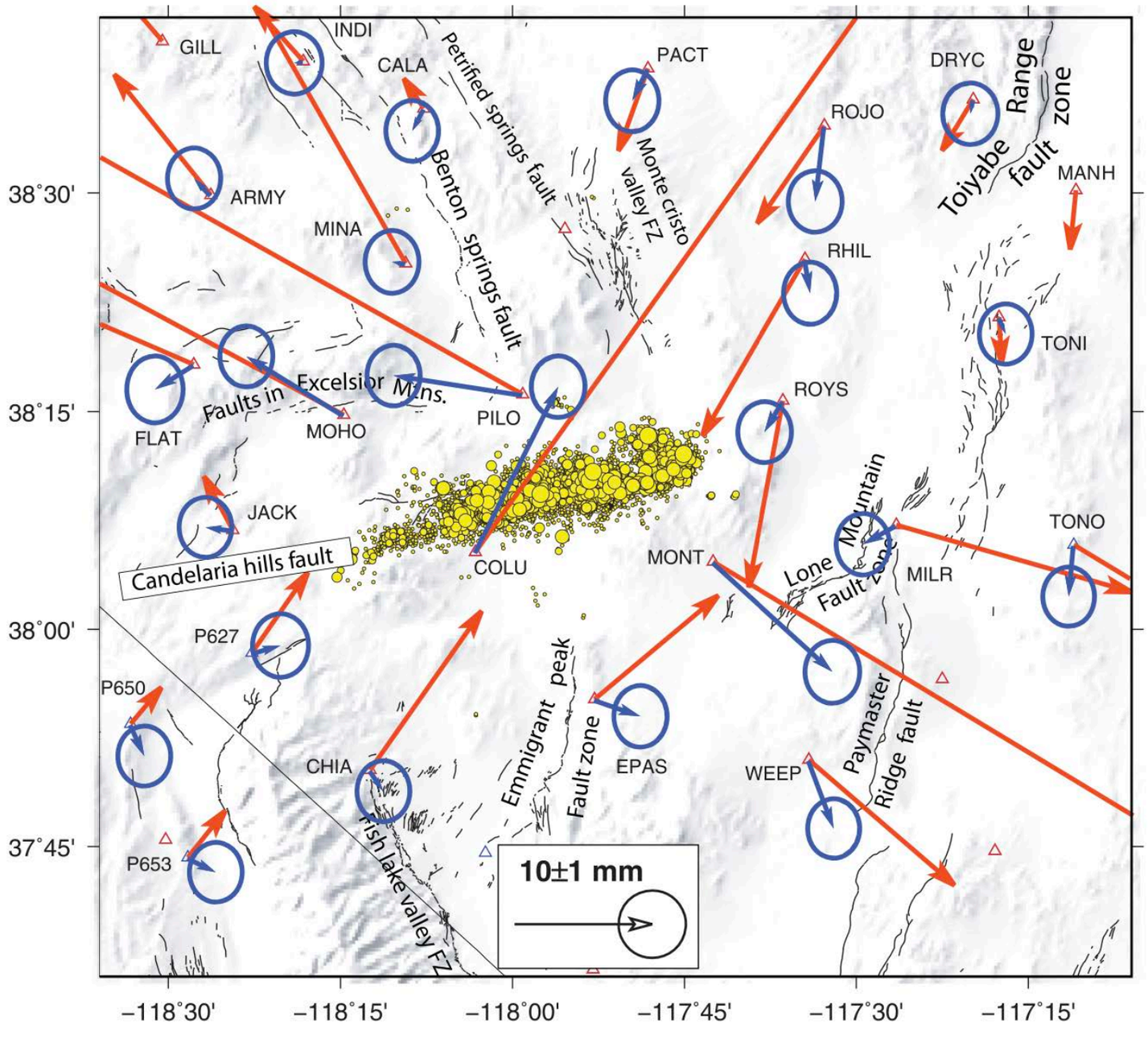
Kit open during service visit



- Mix of instrument types: Trimble and Septentrio
- Mix of vintages, some instruments are quite old, >20 years. Some brand new.
- Essential that we minimize changes in make/model of receivers antennas
- Assign instrument types to specific sites to maintain consistency
- Take tender care of the older instruments
- Sometimes ingenuity is needed to keep them running!

Monte Cristo Range Postseismic

- Moved in same direction as coseismic slip
- Suggests afterslip is dominant mechanism.
- Recent InSAR+GPS work and focus on vertical motion (Aren Crandall-Bear Ph.D. dissertation 2026) shows evidence that afterslip is not a complete explanation.

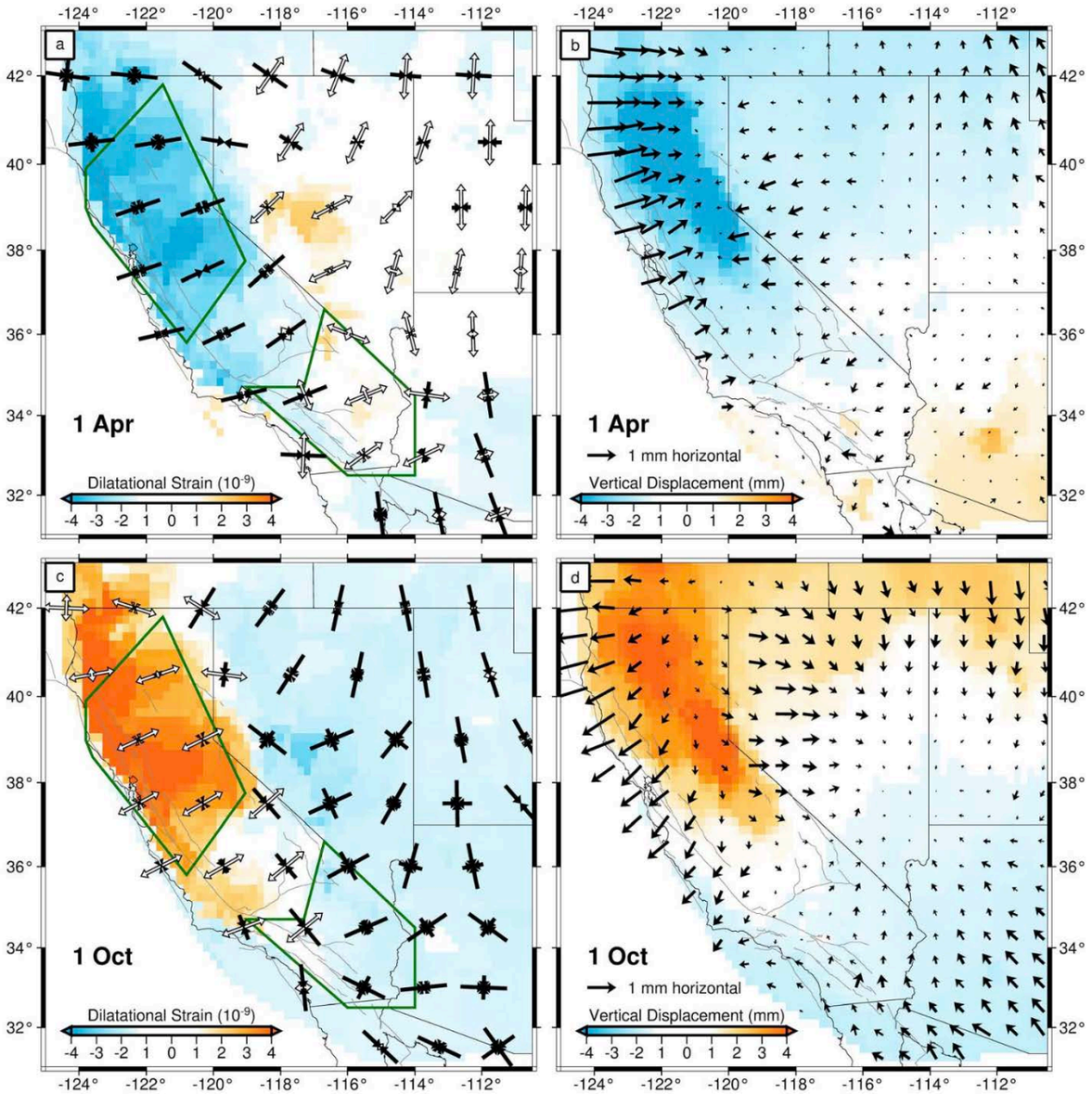


Red = Coseismic, Blue = Postseismic

Seasonal Motions in Nevada and California

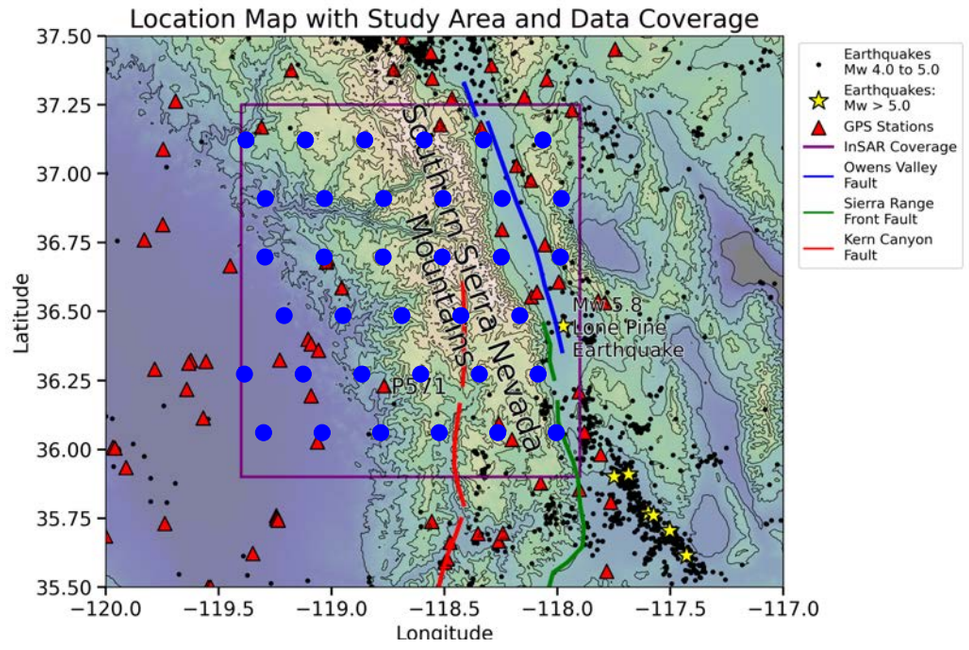
Strain

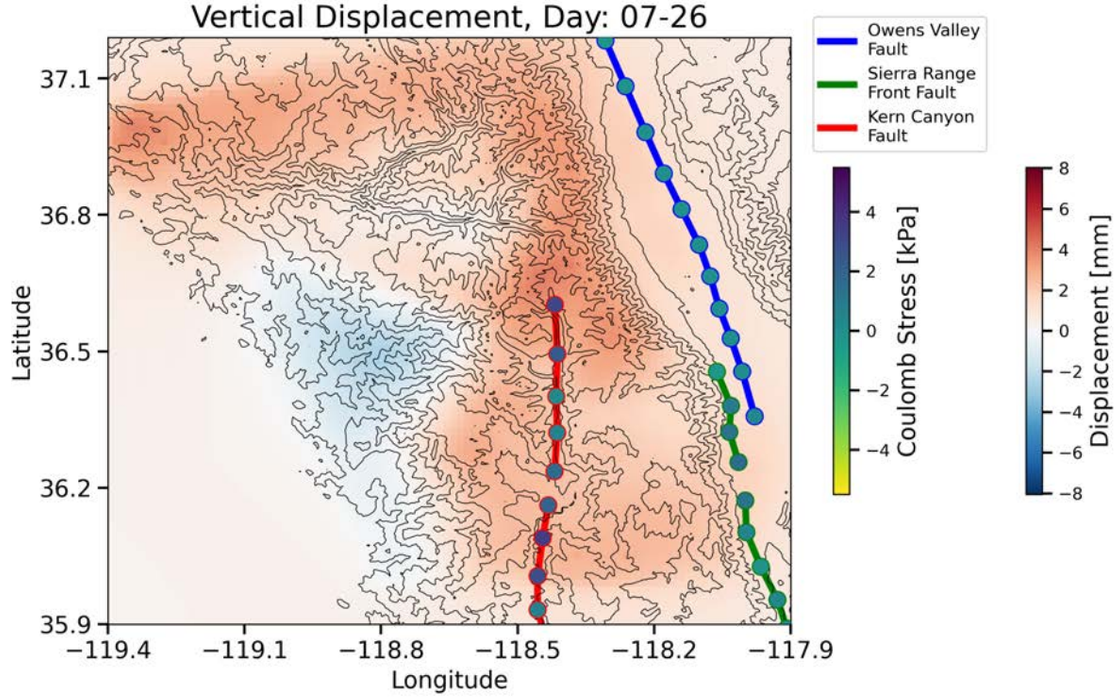
Displacement



Kreemer and Zaliapin, 2018, GRL

Southern Sierra Nevada





Aren Crandall-Bear, UNR Ph.D. dissertation 2026