Geodetic Imaging, Seismic Hazard and Mountain Building across the Sierra Nevada/ Great Basin Transition Using InSAR and GPS

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Nevada Geodetic Laboratory

NASA

NEVADA

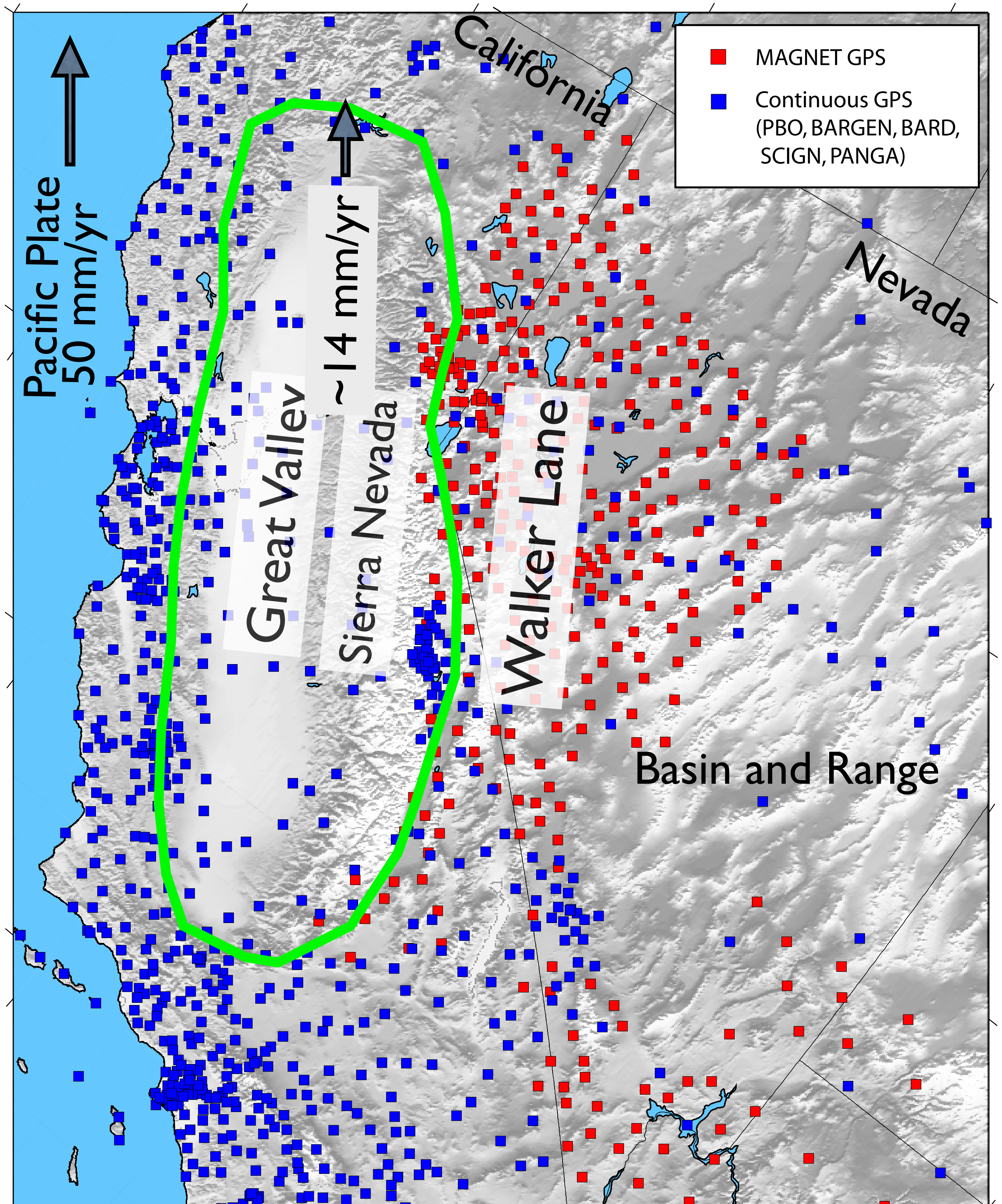
National Science Foundation
WHERE DISCOVERIES BEGIN

earth scope

Objectives:

- Improve resolution of three-component surface motion in area of complex crustal deformation.
- Many faults with varied styles of slip in an area with ~1 cm/yr of dextral transtension.
- Using ERS+Envisat data from WinSAR and GeoEarthScope archives to estimate "long-term" secular motion.
- Has potentially important impact on our estimates of seismic hazard and geodynamics.

Sierra Nevada Part of a Microplate



Dense GPS Coverage in California and Nevada

- EarthScope PBO across CA/NV quantify rate, pattern and style of deformation in 3 components.
- SNGV rigid to the level of ~1 mm/yr, Walker Lane deforms in dextral transtension ~10 mm/yr.
- <1 mm/yr deformations attributable to postseismic from historic earthquakes (e.g. 1857, 1872, 1906, 1952, 1993, 1999).
- In vertical dimension: Longer term measures of deformation e.g. topography, structure, normal fault slip rates on eastern edge of SNGV...
- Describe down to the west tilting along entire length of range 0.3 to 1.3 mm/yr.
- Do these imply vertical rigidity? coherence of vertical motion?

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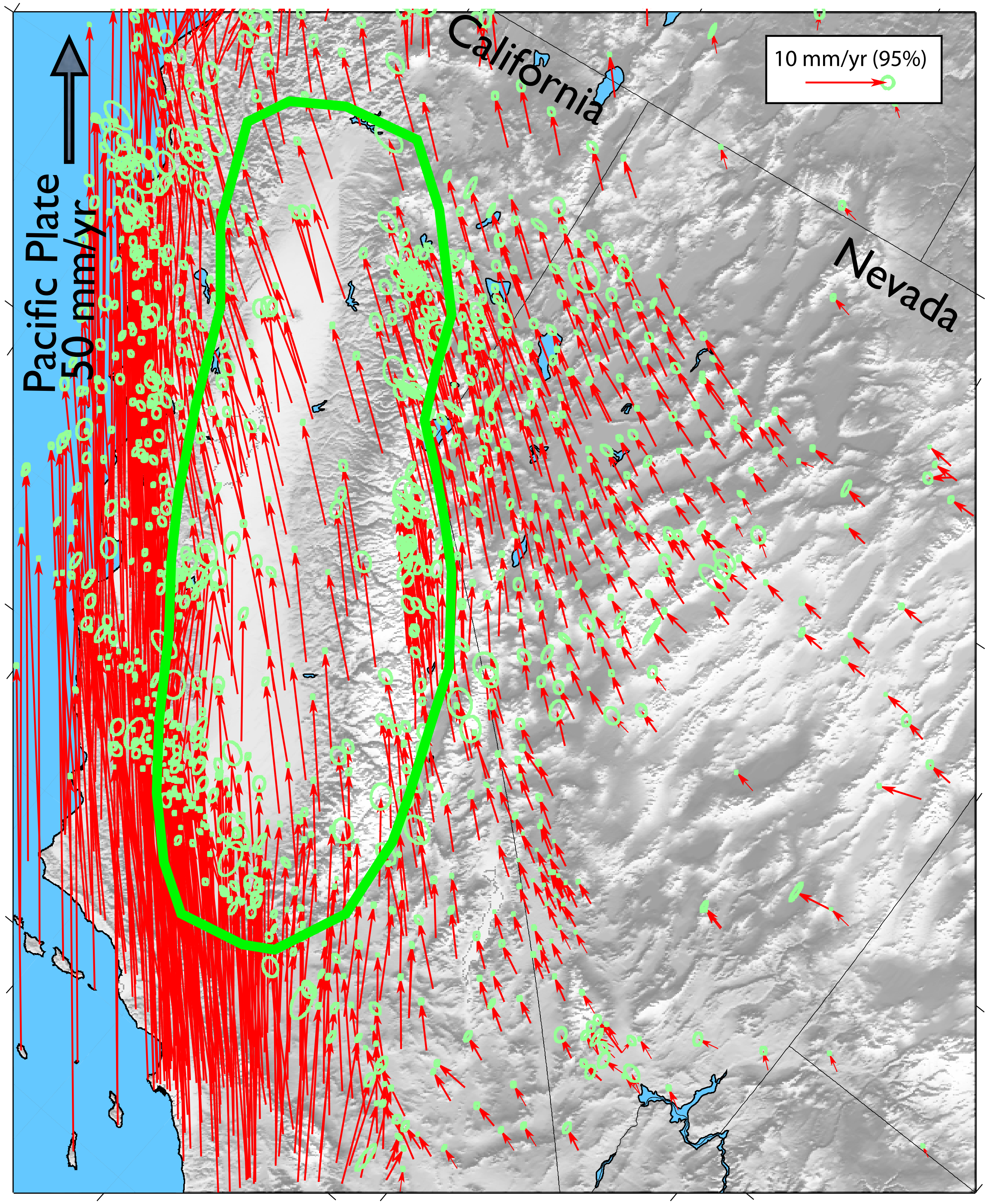

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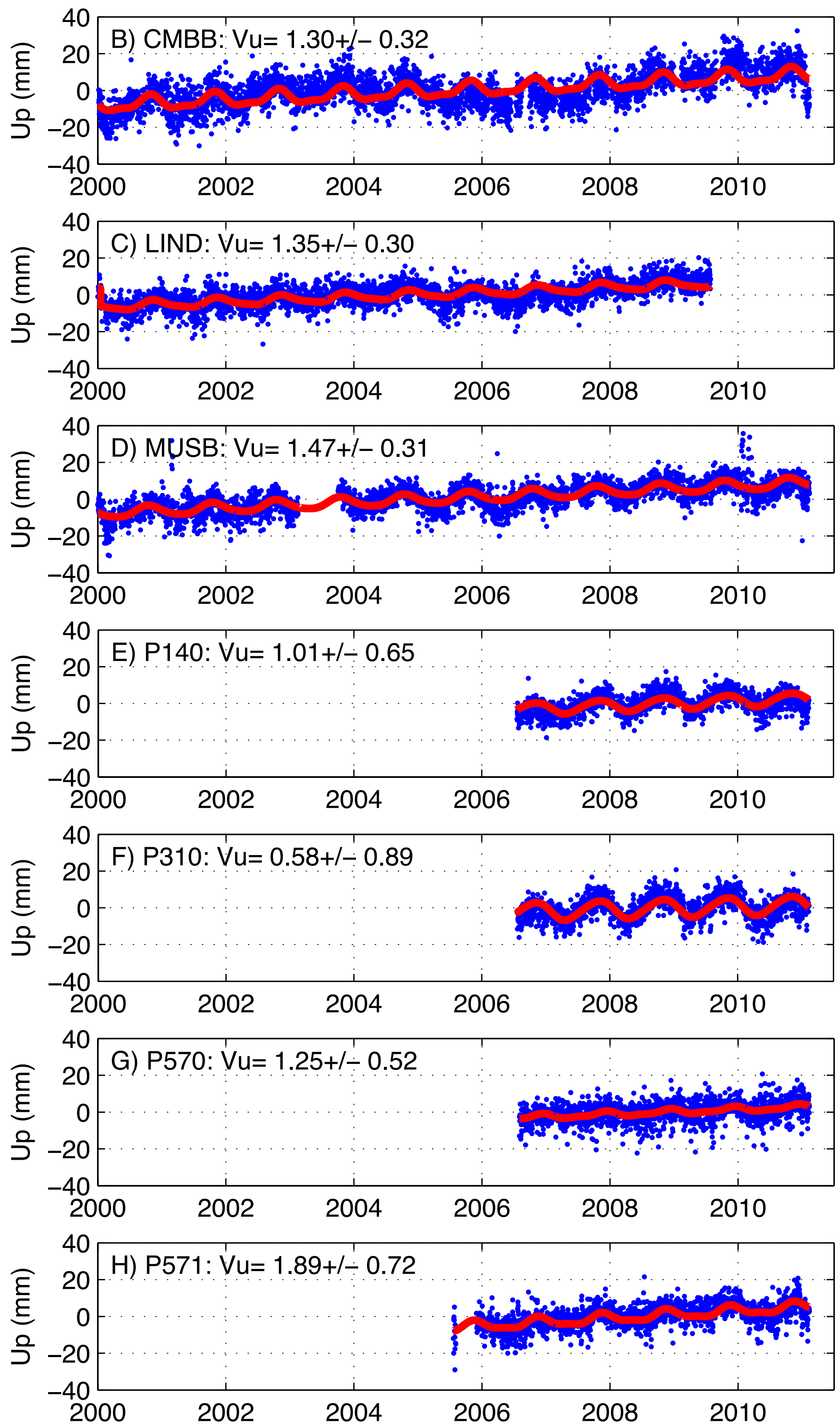
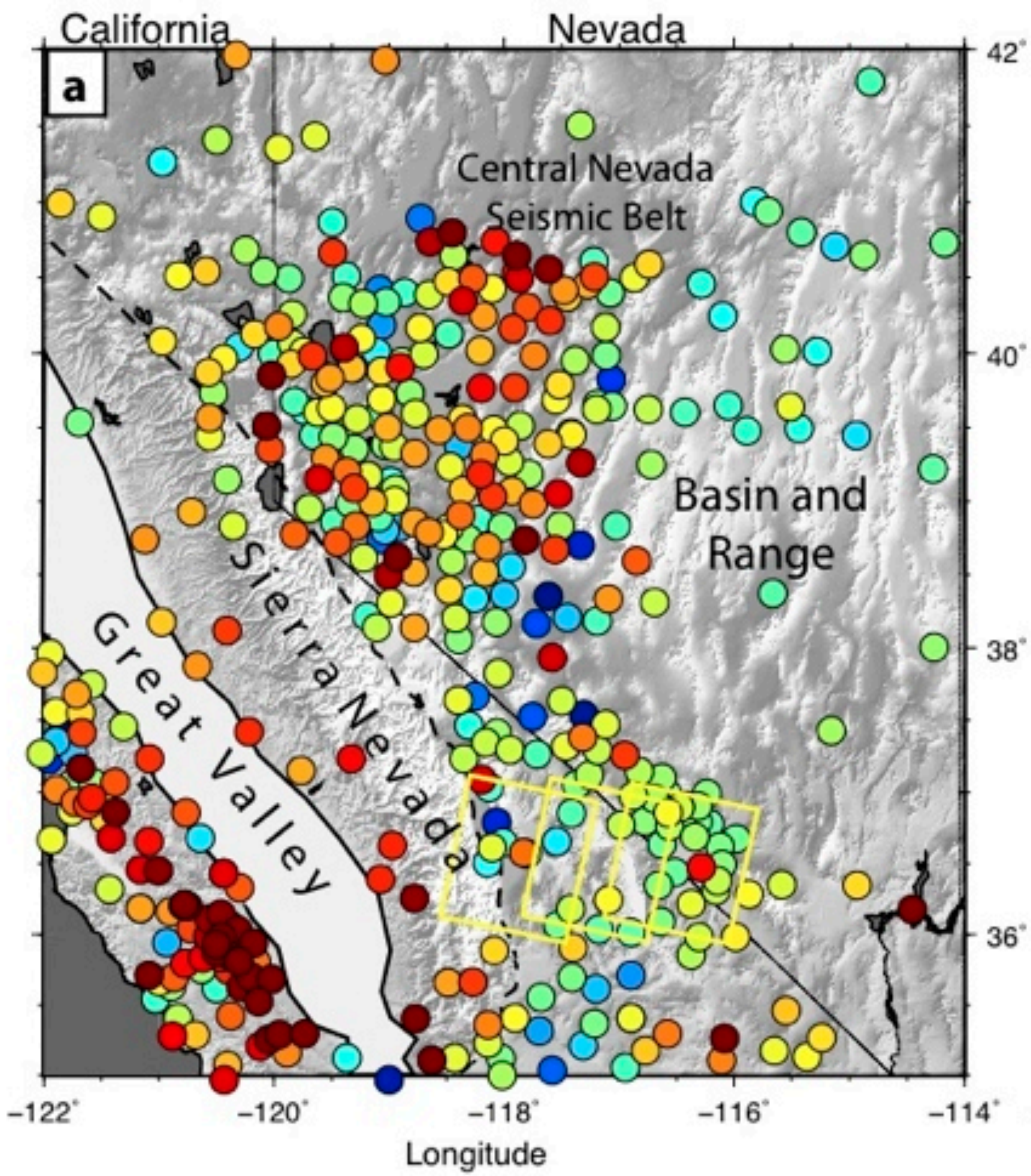
Vertical GPS Time Series
on west slope of Sierra Nevada Range



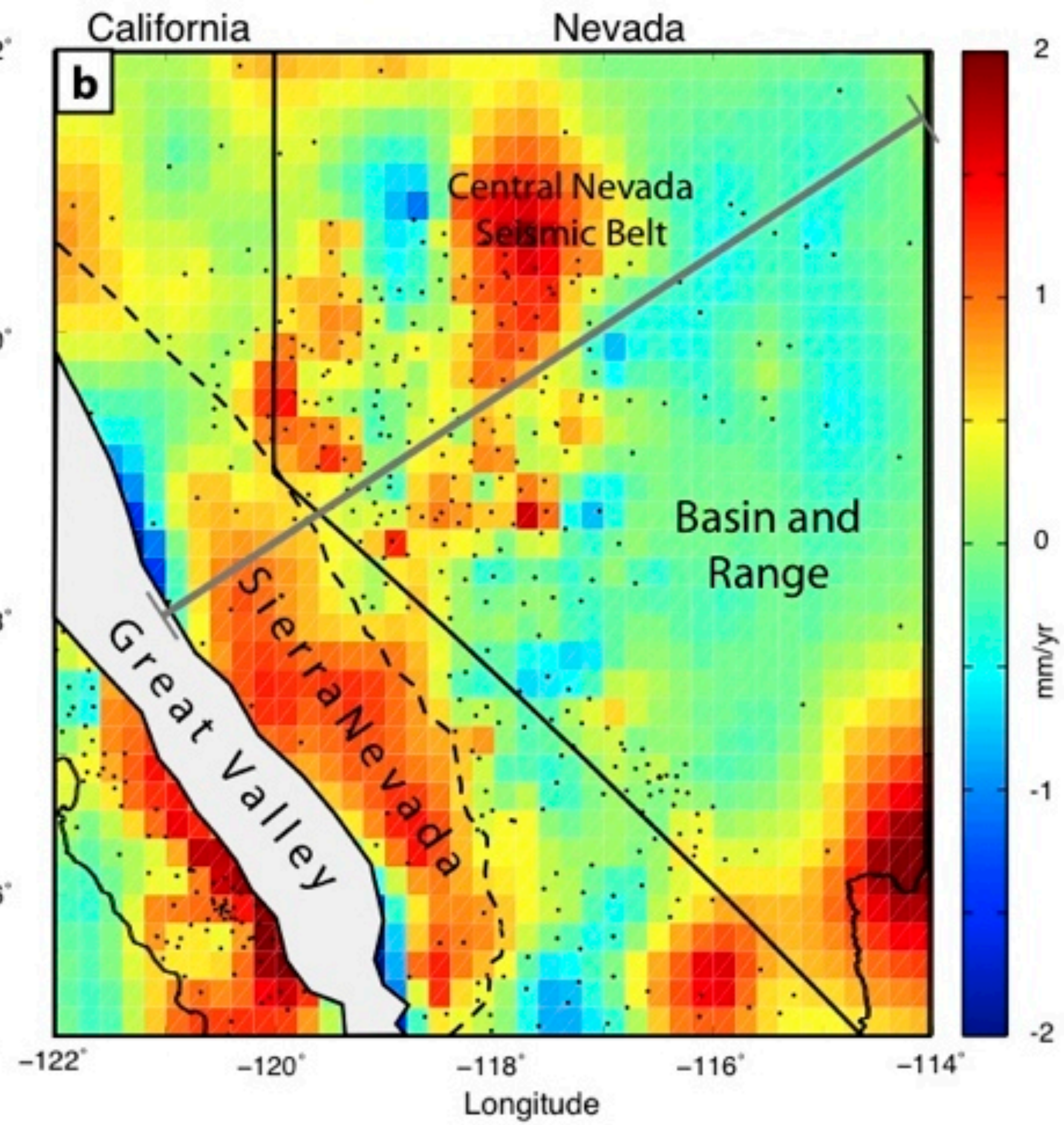
- >1 dozen stations (7 shown here)
- Trends nearly all upward ~1-2 mm/yr
- These in a NA filtered frame
- Station pairs (Sierra Nevada vs. eastern Nevada) show relief generation.
- Longest running stations indicate Sierra Nevada moving upward in ITRF2005 (center of mass of whole Earth System)
- Analysis performed on mega-network of ~10000 stations globally distributed
- Developed criteria to focus on long term motion: 3 years minimum, <5 mm annual terms, linear time series.
- This criteria accepts most stations.

Vertical GPS Velocities Show Sierra Nevada Uplift and Central Nevada Postseismic Relaxation

GPS Observations

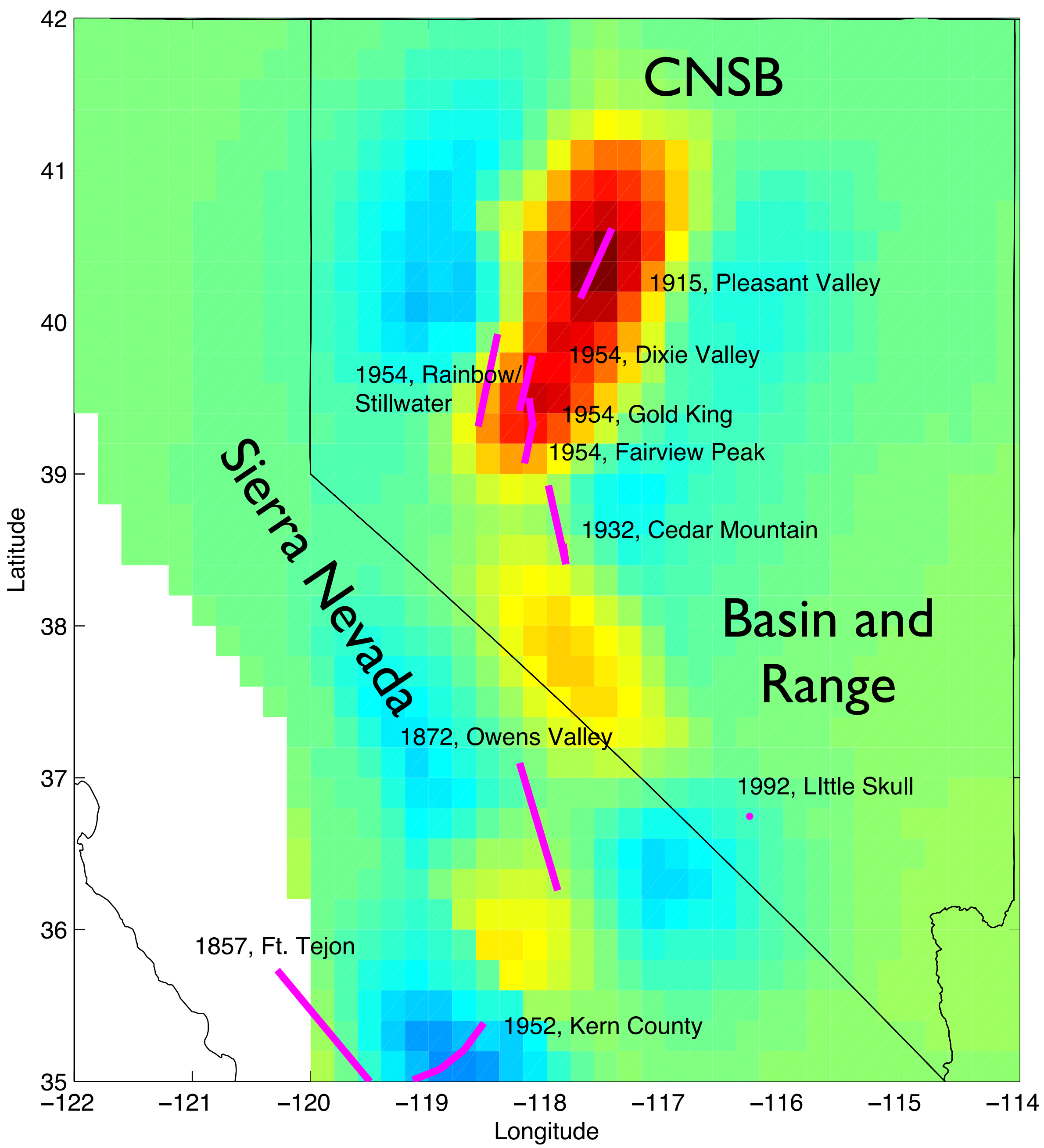


Interpolated Using Kriging



We Need Earthquake Cycle Models: Central Nevada Postseismic Viscoelastic Relaxation

Postseismic Relaxation Model



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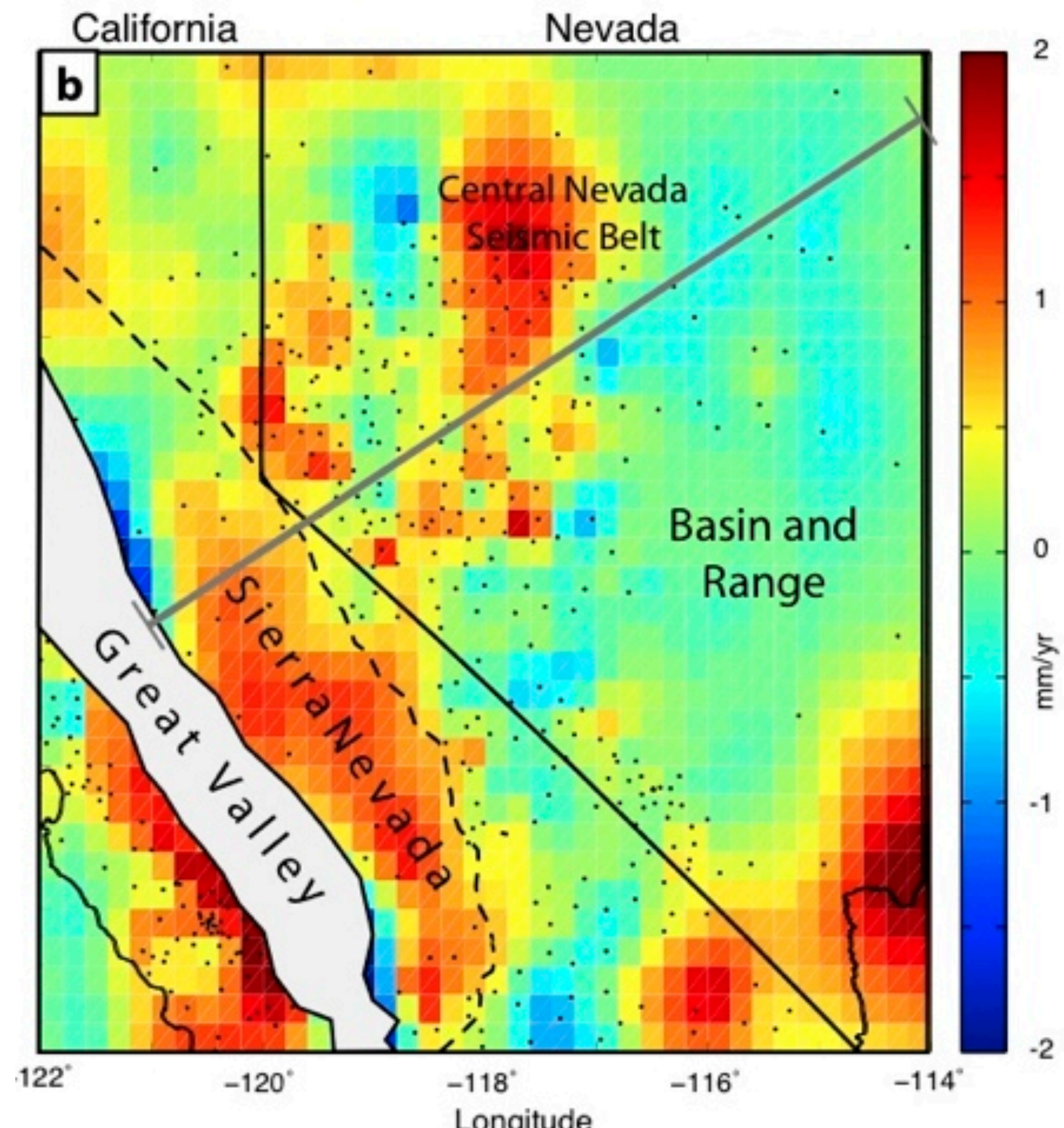
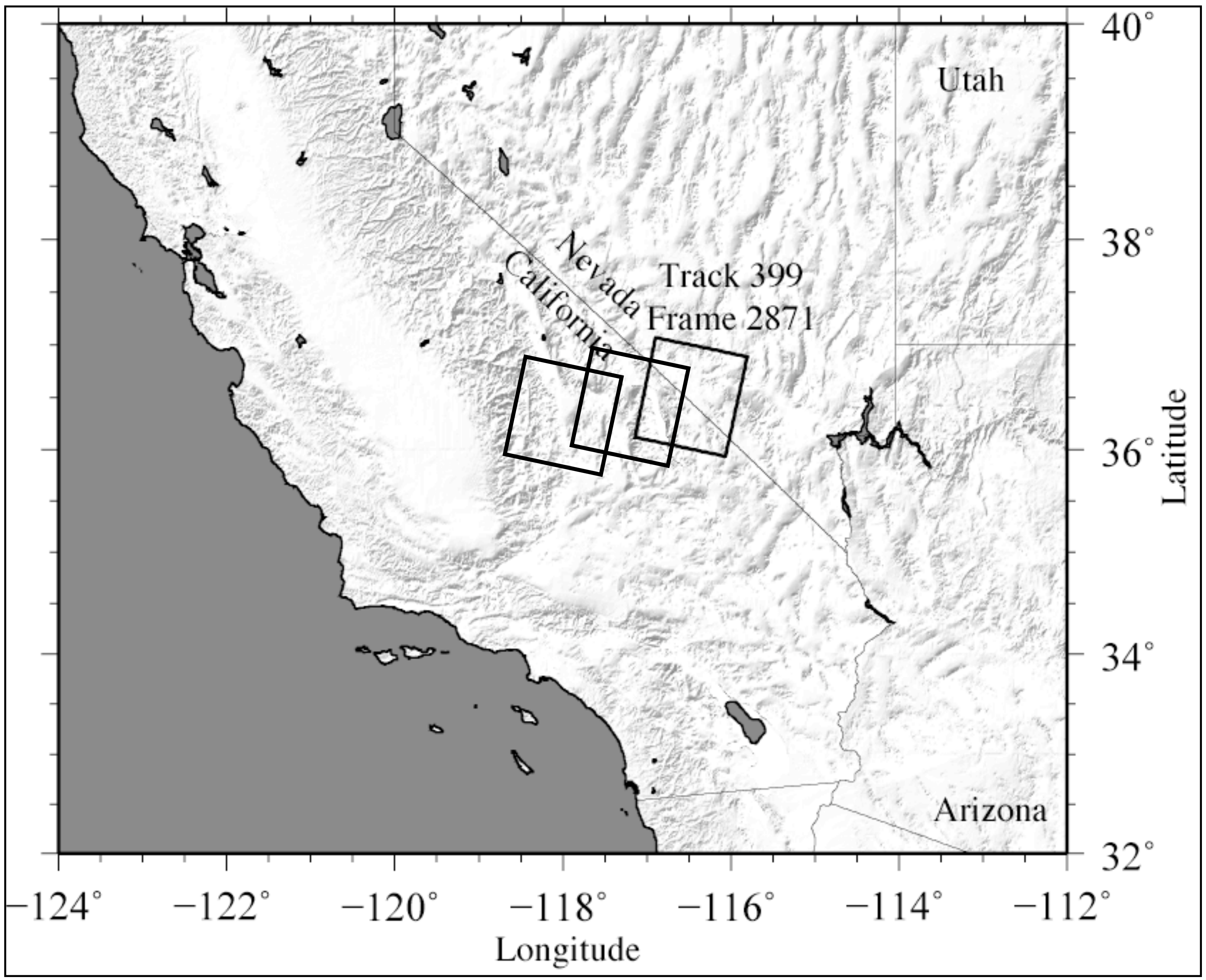


Note: GPS results on right not used to make this model

InSAR Results Corroborate Upward Motion of Sierra Nevada

Getting True Vertical from InSAR+GPS



- 19 years of ERS1/ERS2/ENVISAT data from 1992 - 2010.
- 3 overlapping tracks (442, 170, 399) spanning Sierra Nevada to Yucca Mountain
- Interferometry w/ROI_PAC and unwrapping with SNAFU
- Estimate los rates from unwrapped results using Time Series and Atmospheric Estimation Model: InSAR TS+AEM (Li et al., 2009)
- Dense GPS coverage
- Conform InSAR los rate to GPS los rates, and convert to vertical rates.

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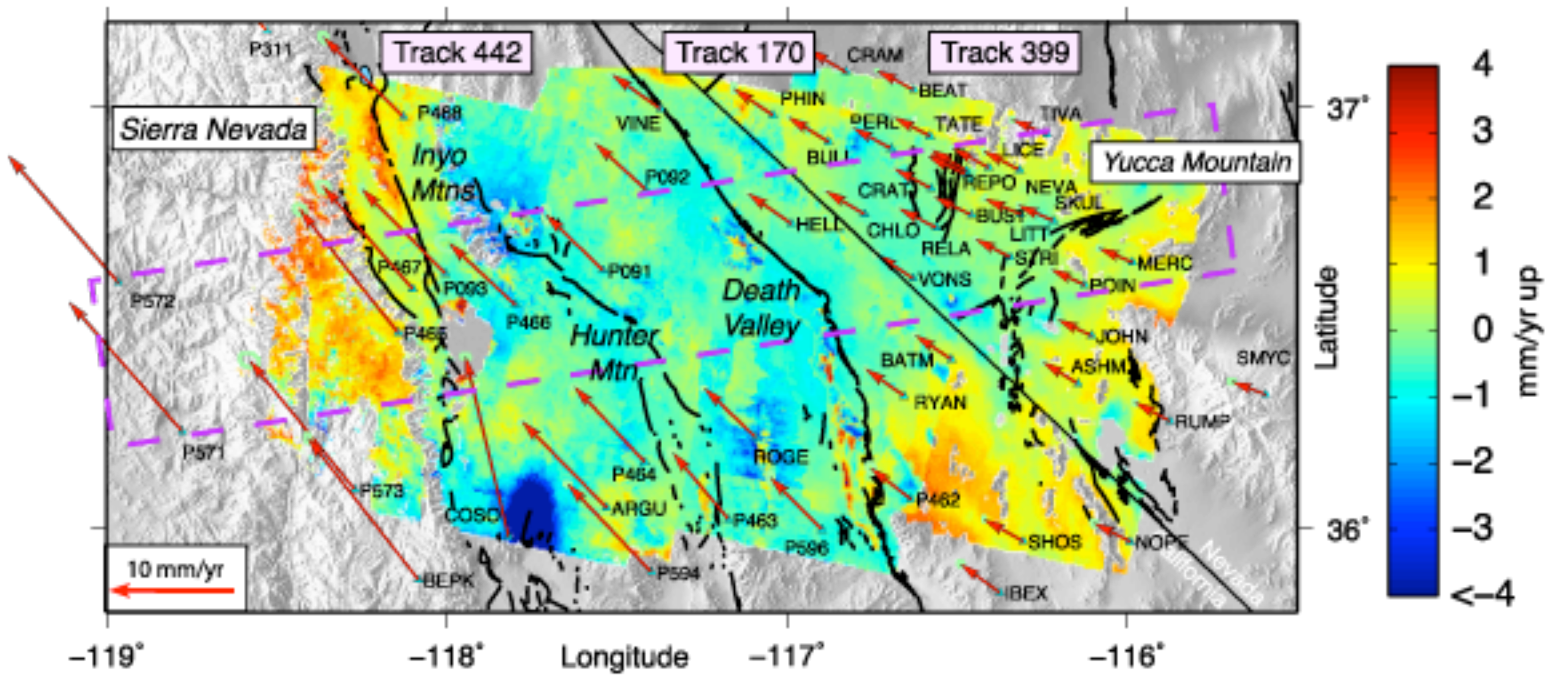
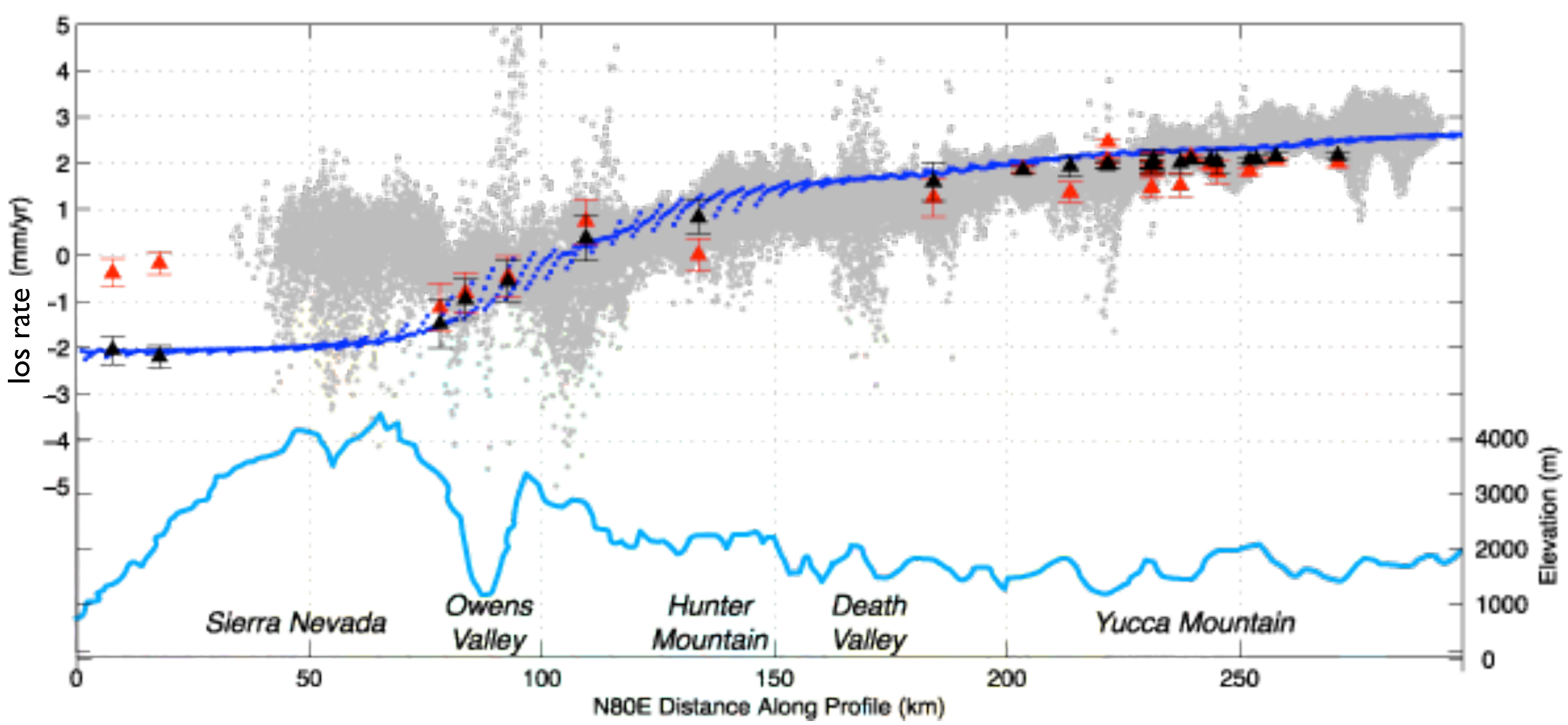


GPS wrt NA

Location of profile shown below



InSAR los velocity

GPS (Horizontal-only) projected in los direction • v_{los}

GPS (3D) projected in los direction • v_{los}

Kreemer et al., (2009) strain map (horizontal only) • v_{los}

- See signals of vertical motion and step near Hunter Mountain

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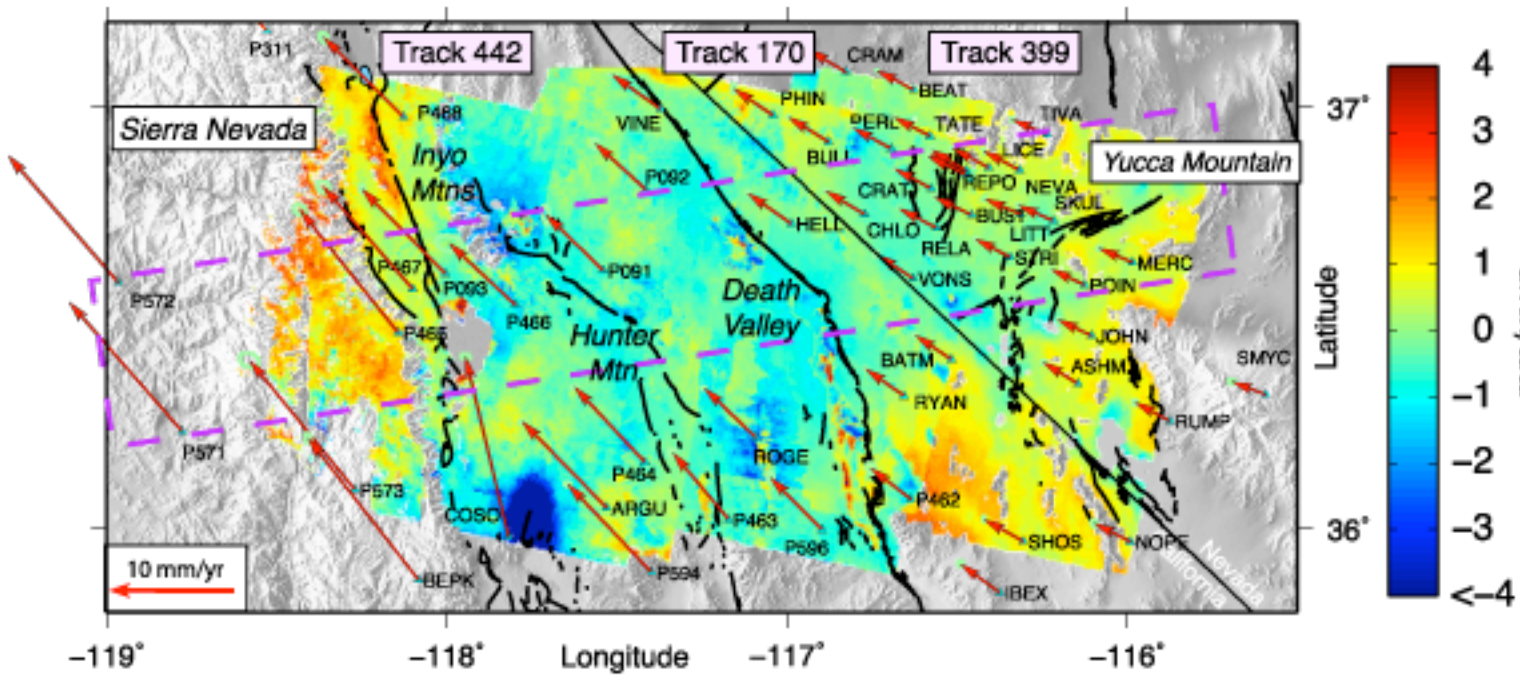
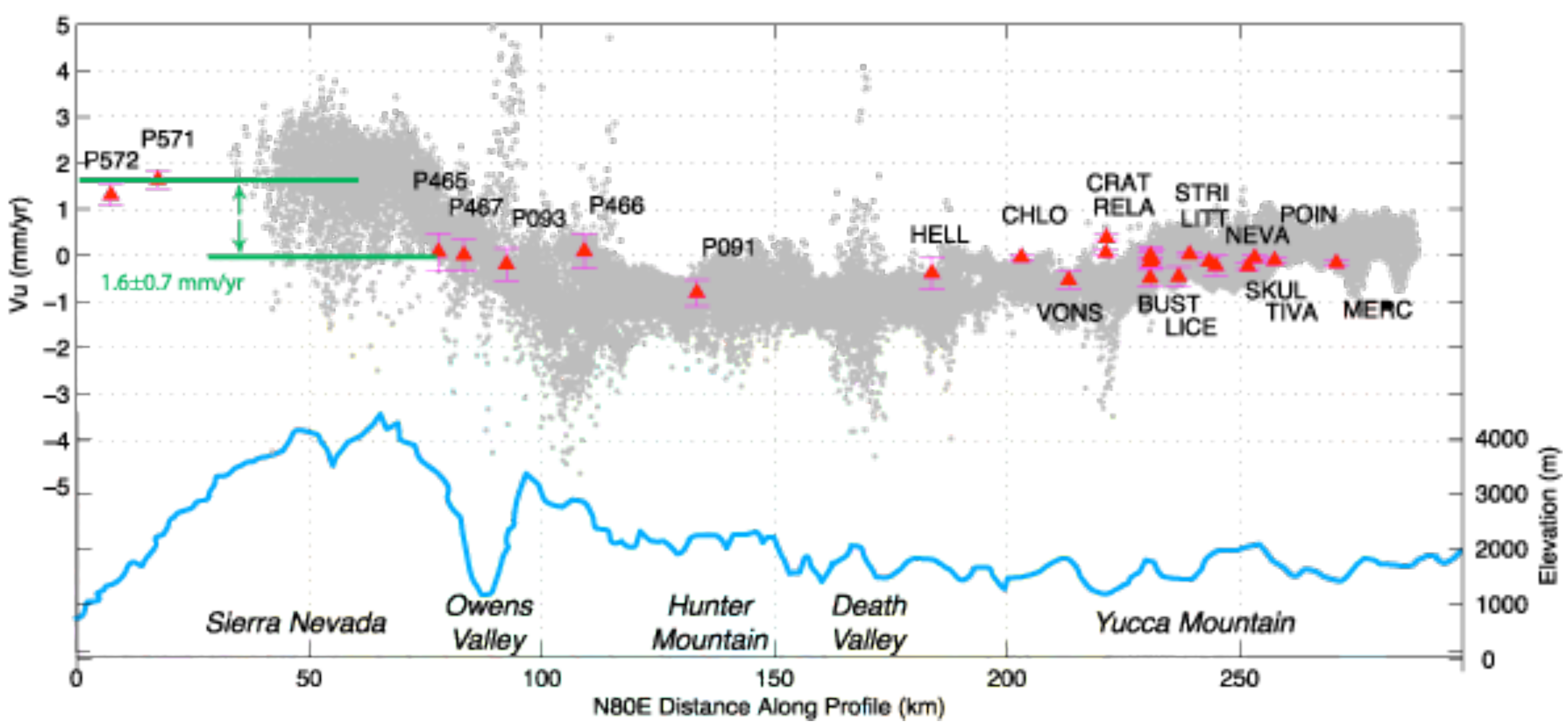




GPS wrt NA

Location of profile shown below

Vertical from GPS

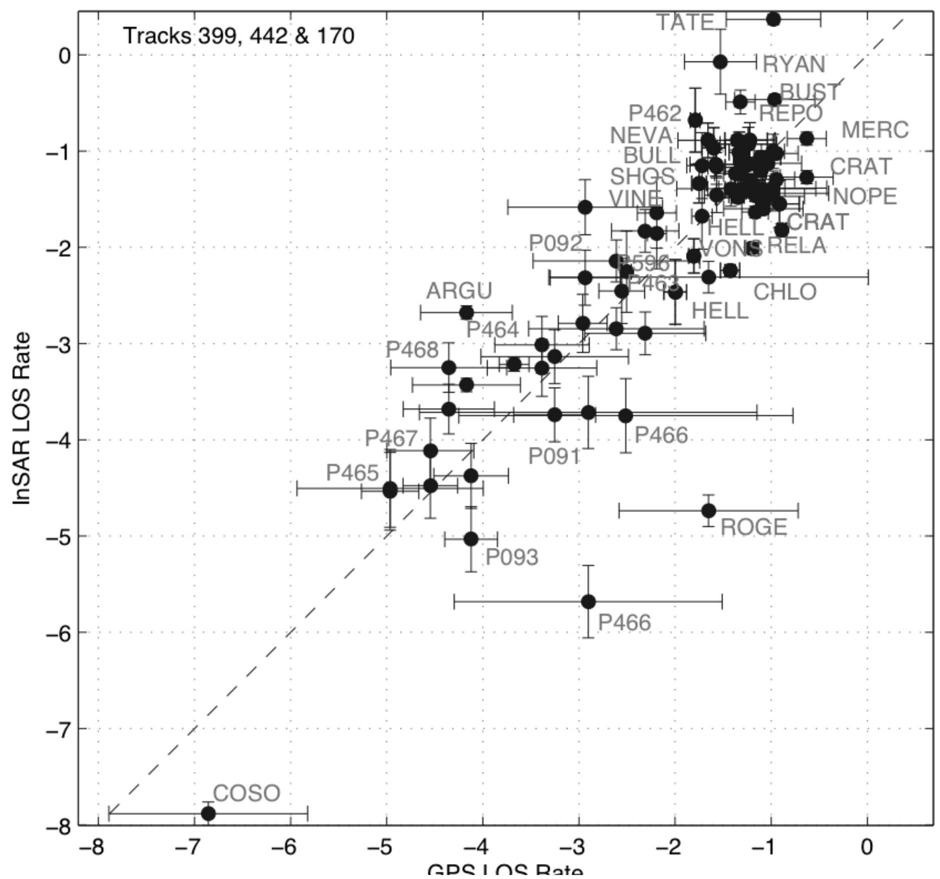
Vertical inferred from InSAR los minus strain map • v_{los} velocity

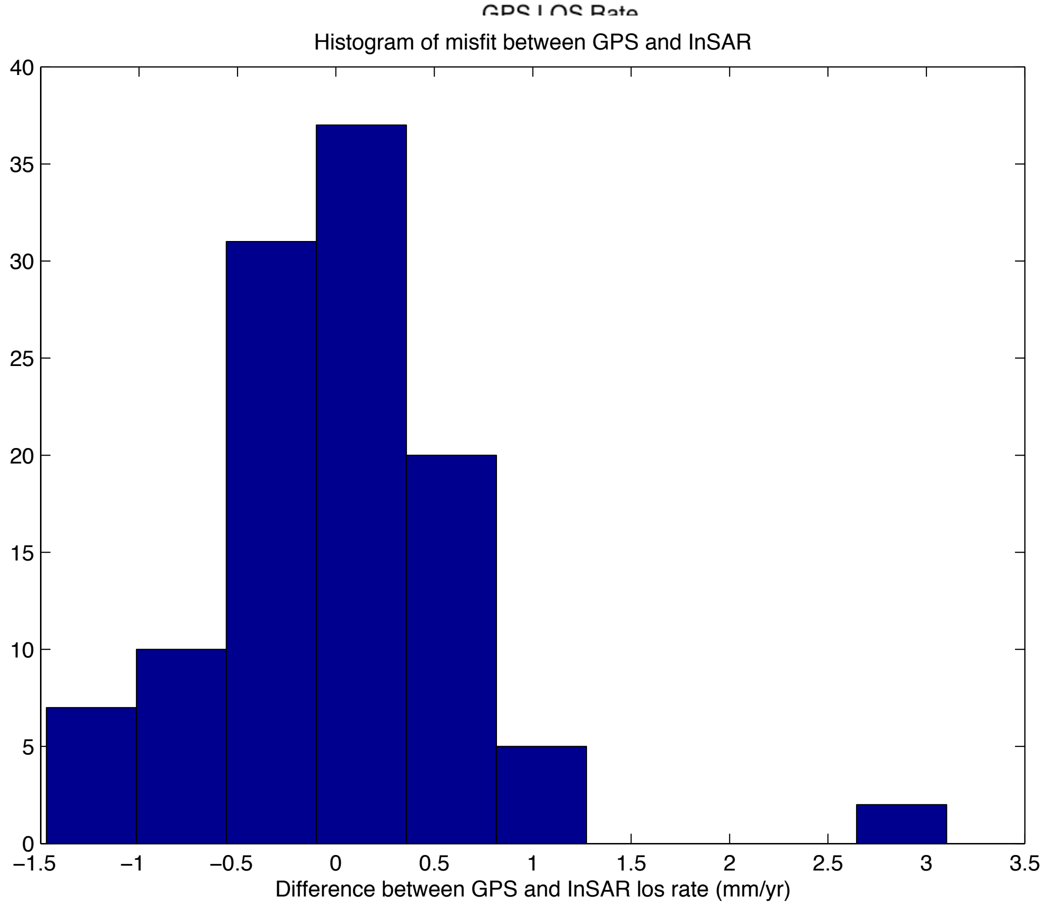
Sierra Nevada Uplift Rate

Topography

- Rate near target for global strain rate mapping... Sentinel/DESDynI will help.
- GPS Station distribution important

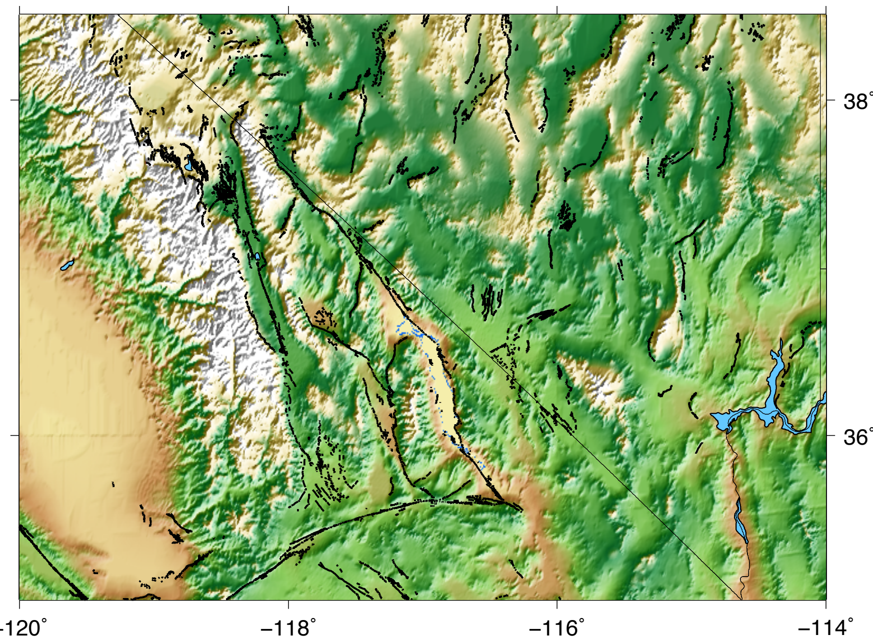
How good are these alignments?

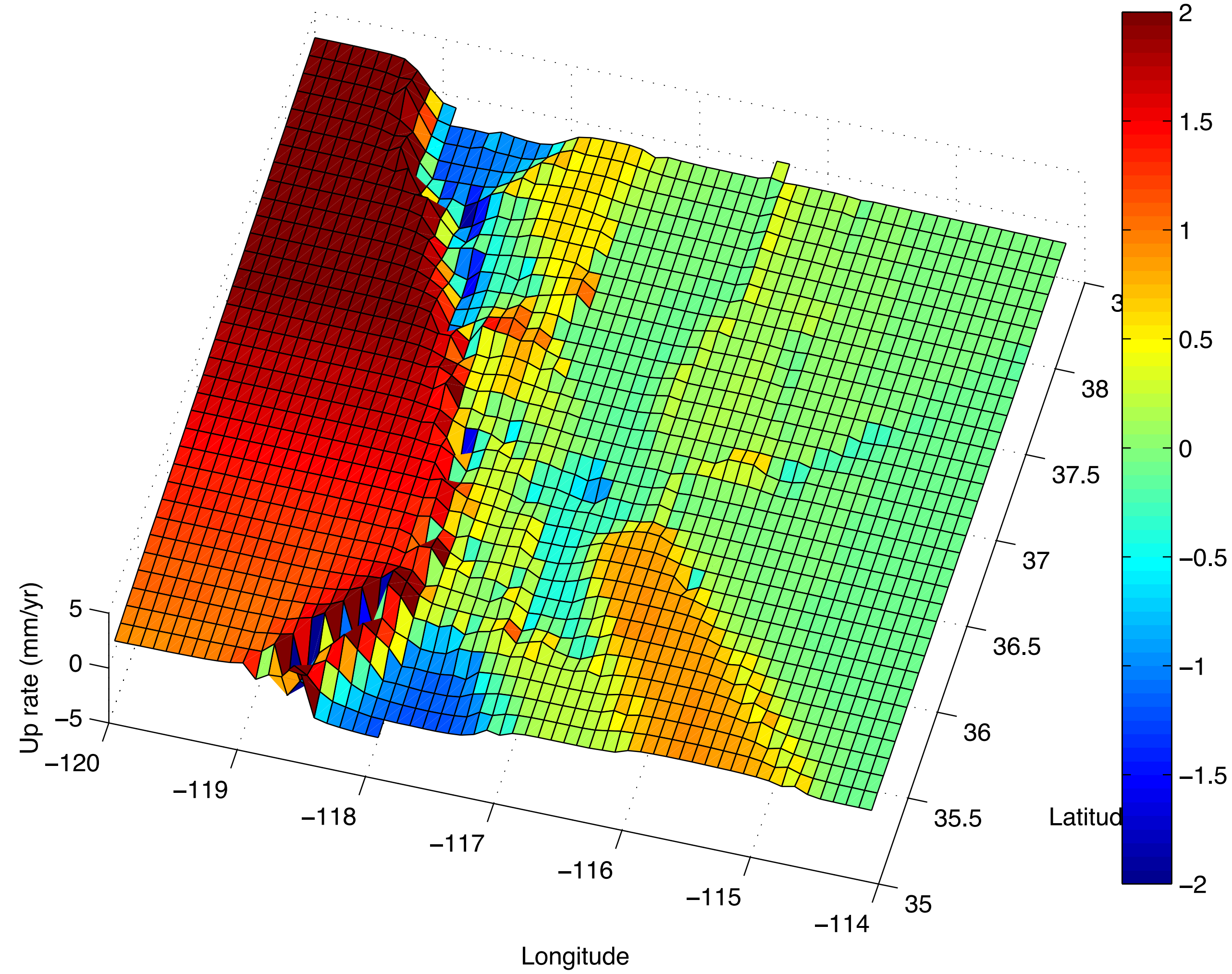


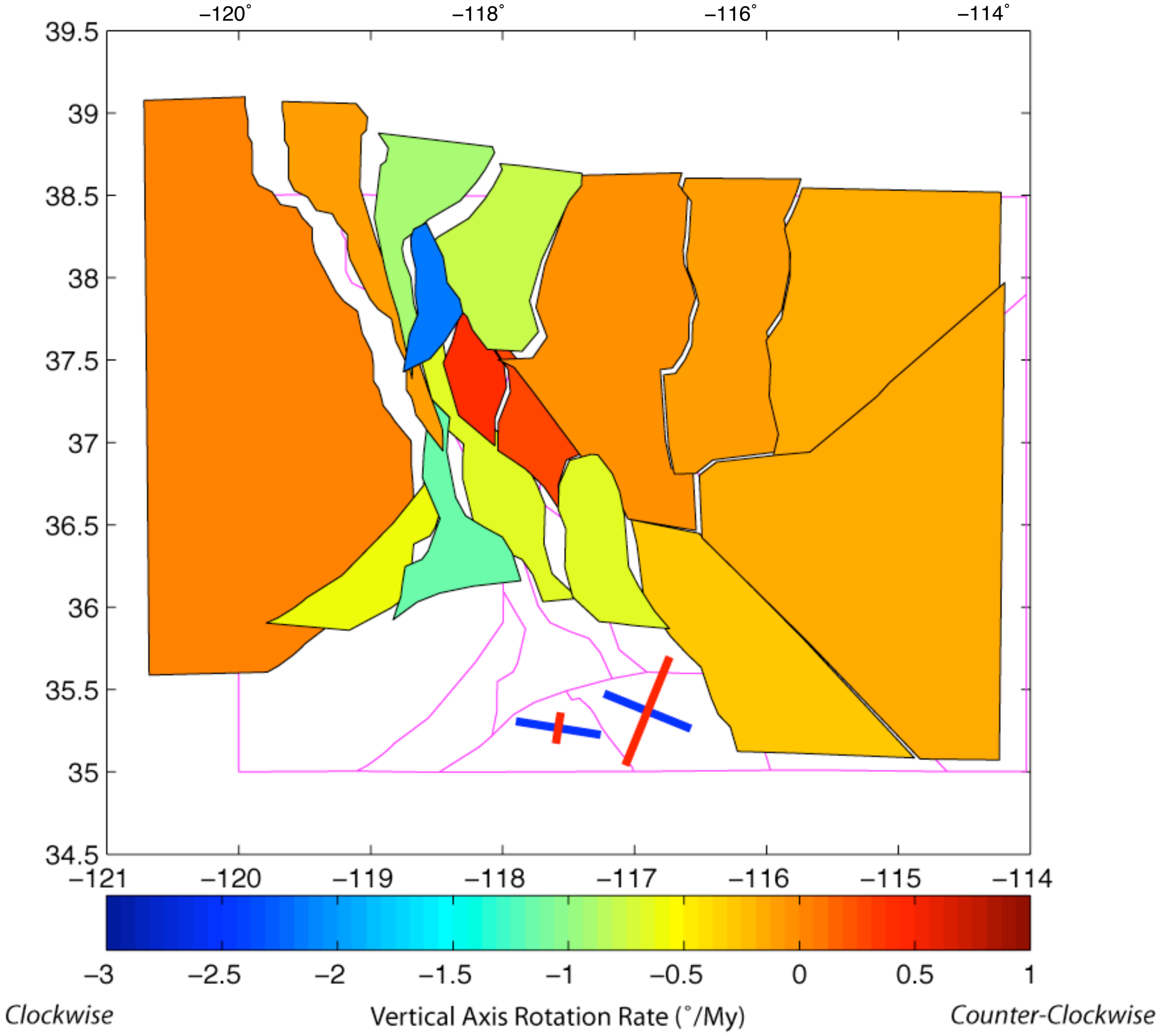


- RMS of misfit between InSAR and GPS is ~0.7 mm/yr (warts and all).
- Must be careful, though, because *correlation* is a function of crustal deformation signal.
- Best to use RMS as measure of similarity between internal structure of InSAR and GPS velocity fields, identify outliers, etc.
- RMS can be reduced using more aggressive masking (geology, flatness, coherence, etc.)
- Suggests InSAR rates are precise enough to contribute to crustal deformation studies in Great Basin.

Southern Sierra Nevada and Walker Lane



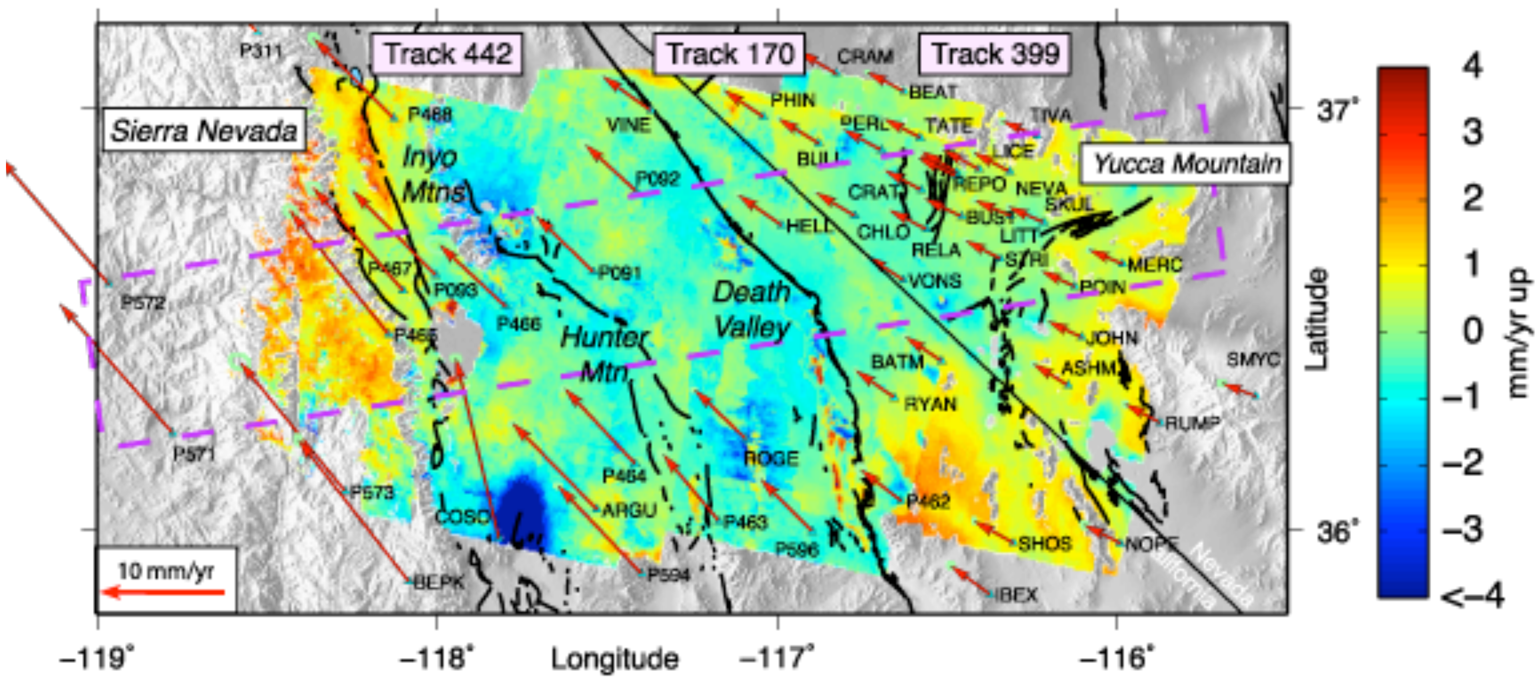




3D Block Models

- Preliminary results
- Solve for rates of rotation on horizontal and vertical axes
- Blanket coverage with InSAR makes problem better constrained.
- Faults locked at surface and slipping at depth
- 3D data and modeling suggest concentration of normal slip a Sierra Nevada range front

Predictions from Block Modeling



GPS wrt NA

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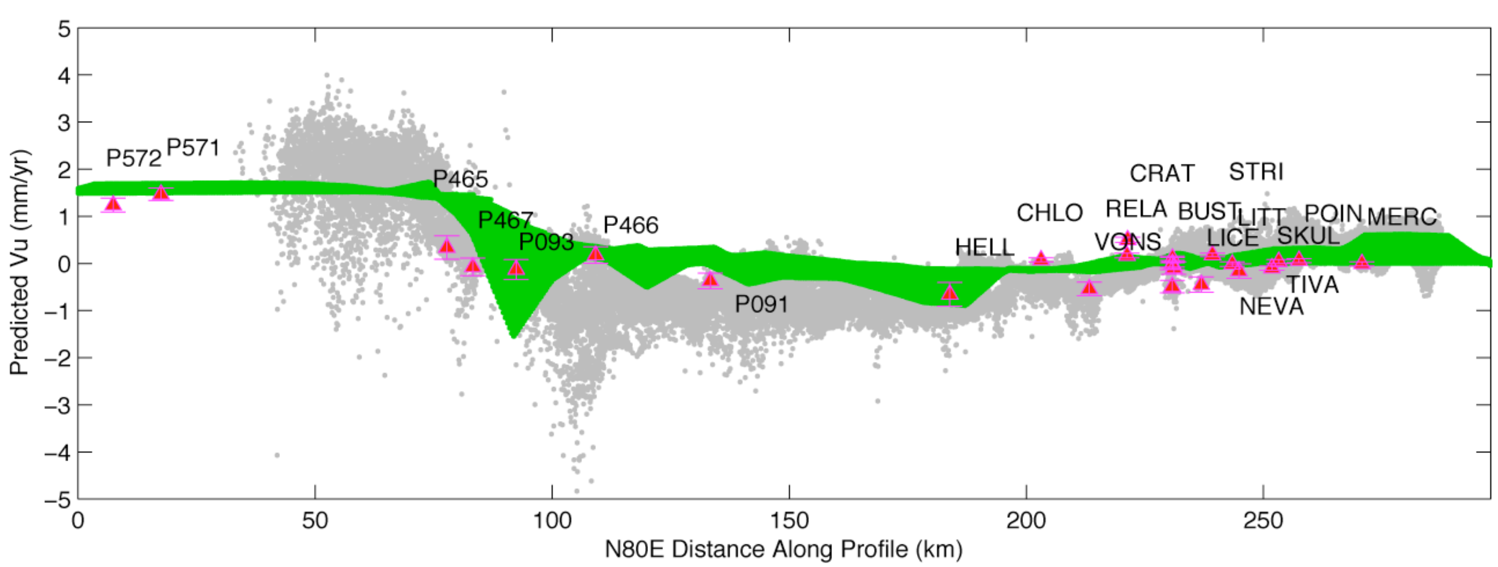


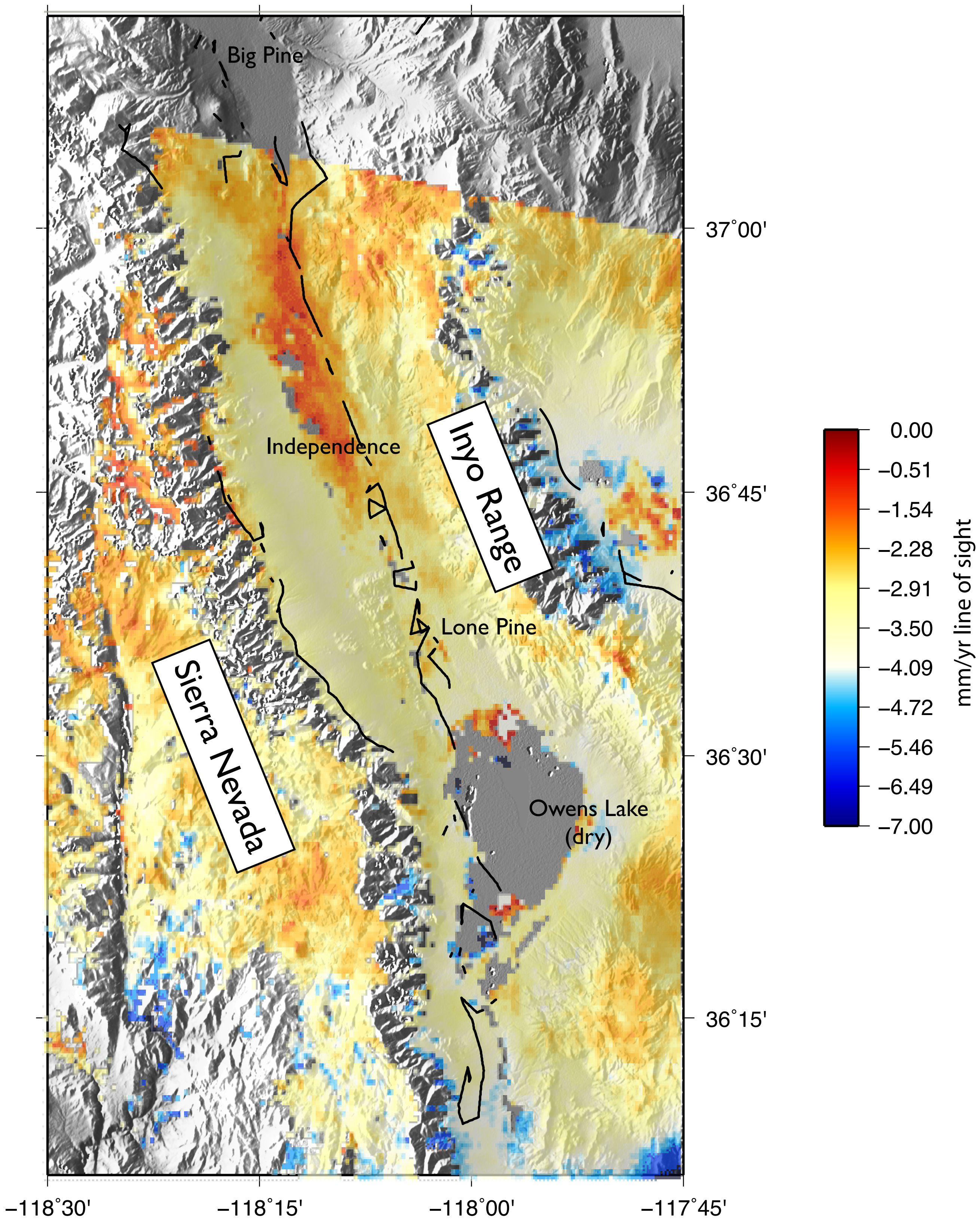
Vertical from GPS

Vertical inferred from InSAR los minus strain map • v_{los} velocity

Vertical predicted by block model

- Getting first order signals (e.g. Sierra Uplift)
- But not yet capturing every bit of signal in InSAR

Not Tectonics Everywhere

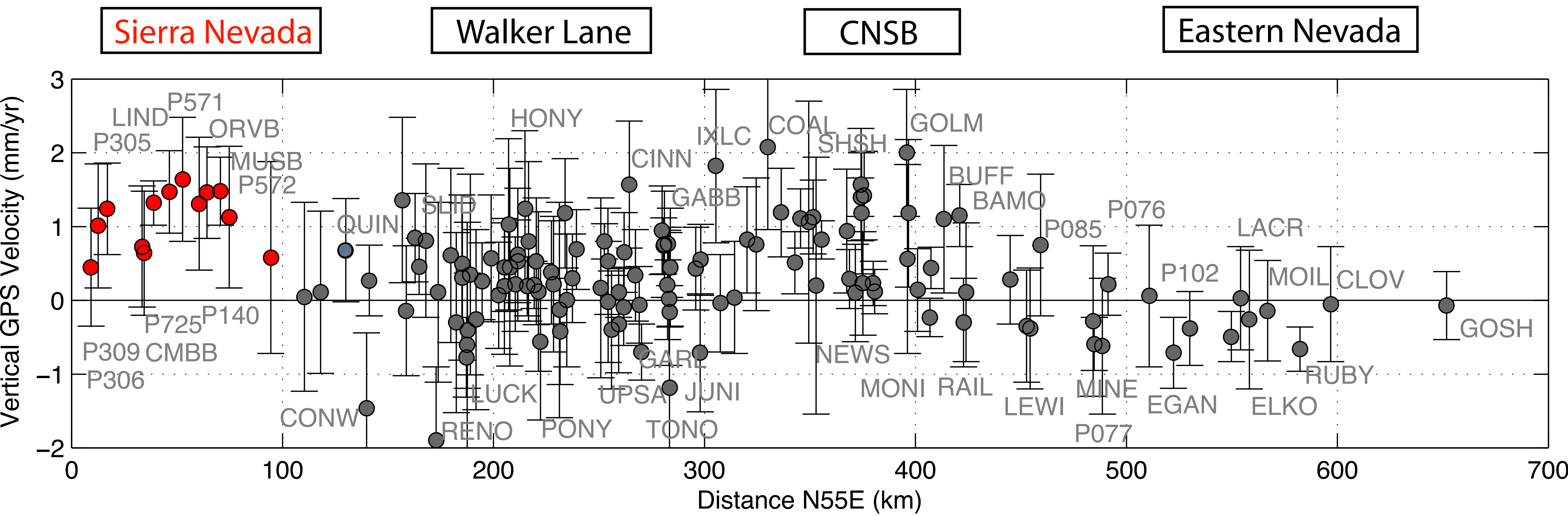


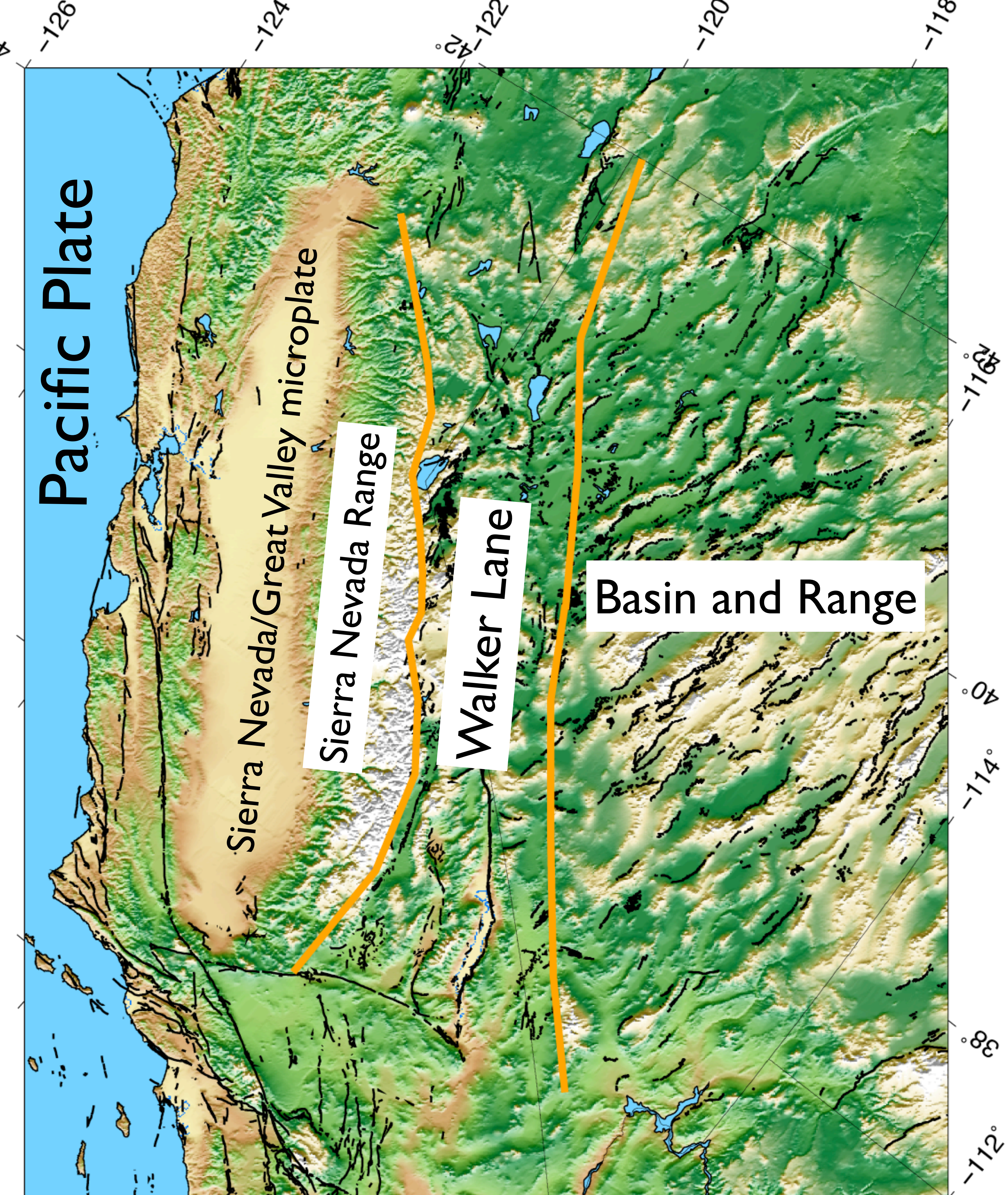
- Owens Valley
- Signals, likely hydrology, associated with Owens River, agriculture.
- Structurally bounded by Owens Valley fault, location of 1872 earthquake.
- In block models we omit these areas with mask based on flatness of topography.
- Works as well as a mask based on geology but is easier to implement.

Conclusions

- InSAR time series results indicate a 1.6±0.7 mm/yr uplift rate of Southern Sierra Nevada.
- This corroborates results from GPS stations which are rising 1-2 mm/yr and localizes the gradient in vertical rate to lie near the Sierra Nevada rangefront faults.
- These results apply to solid rock uplift rate, not rate of motion of surface (i.e. mountain). Geodesy not measuring erosion. However erosion rate is likely ~0.1 mm/yr or less.
- We interpret these observations to indicate a young (<3 Myr) and growing Sierra Nevada, part of an actively uplifting range.

Profile of Vertical GPS Velocity

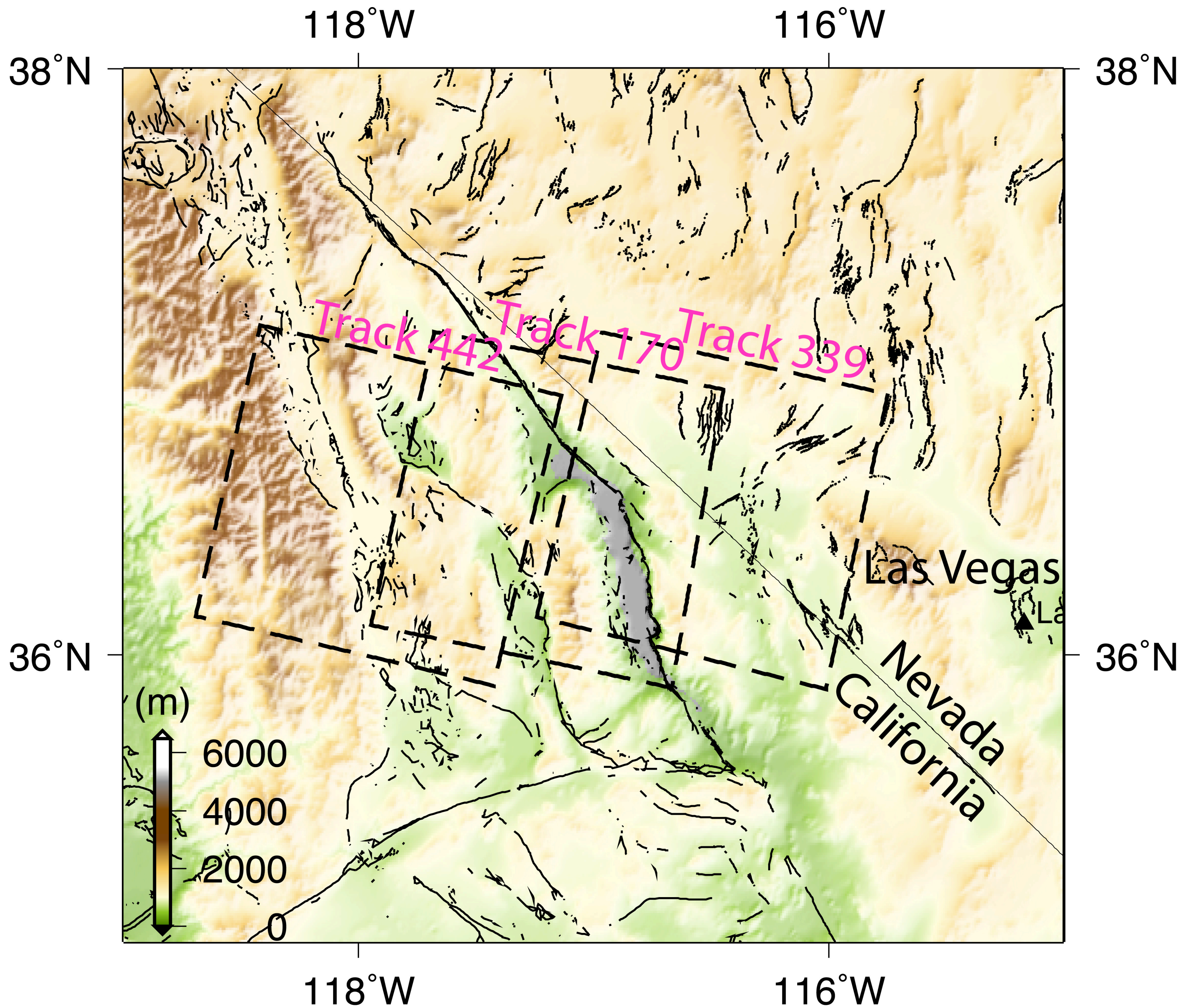




Ideas About Sierra Nevada Elevation

- Westward tilting of the SNGV owing to a combination of loads, including
- Denudation/unloading of High Sierra
- Sedimentation increases load on the Great Valley
- Lithospheric delamination, Isabella anomaly in southern Sierra, may explain higher elevations to the south
- Deglaciation, expected to have a small contribution
- Weakening of the plate at SNGV eastern edge
- Active tectonics drive normal faulting at 0.3 to 1.3 mm/yr normal slip rates on the eastern edge of the microplate (to form 2–3 km of relief)

InSAR Time Series Approach



- Looking at a portion of the SNGV/Great Basin transition: Southern Walker Lane/ECSZ

- Using InSAR TS method of Li et al., 2009 (see Monday talk G13B-07), a descendant of SBAS Berardino et al., 2002.

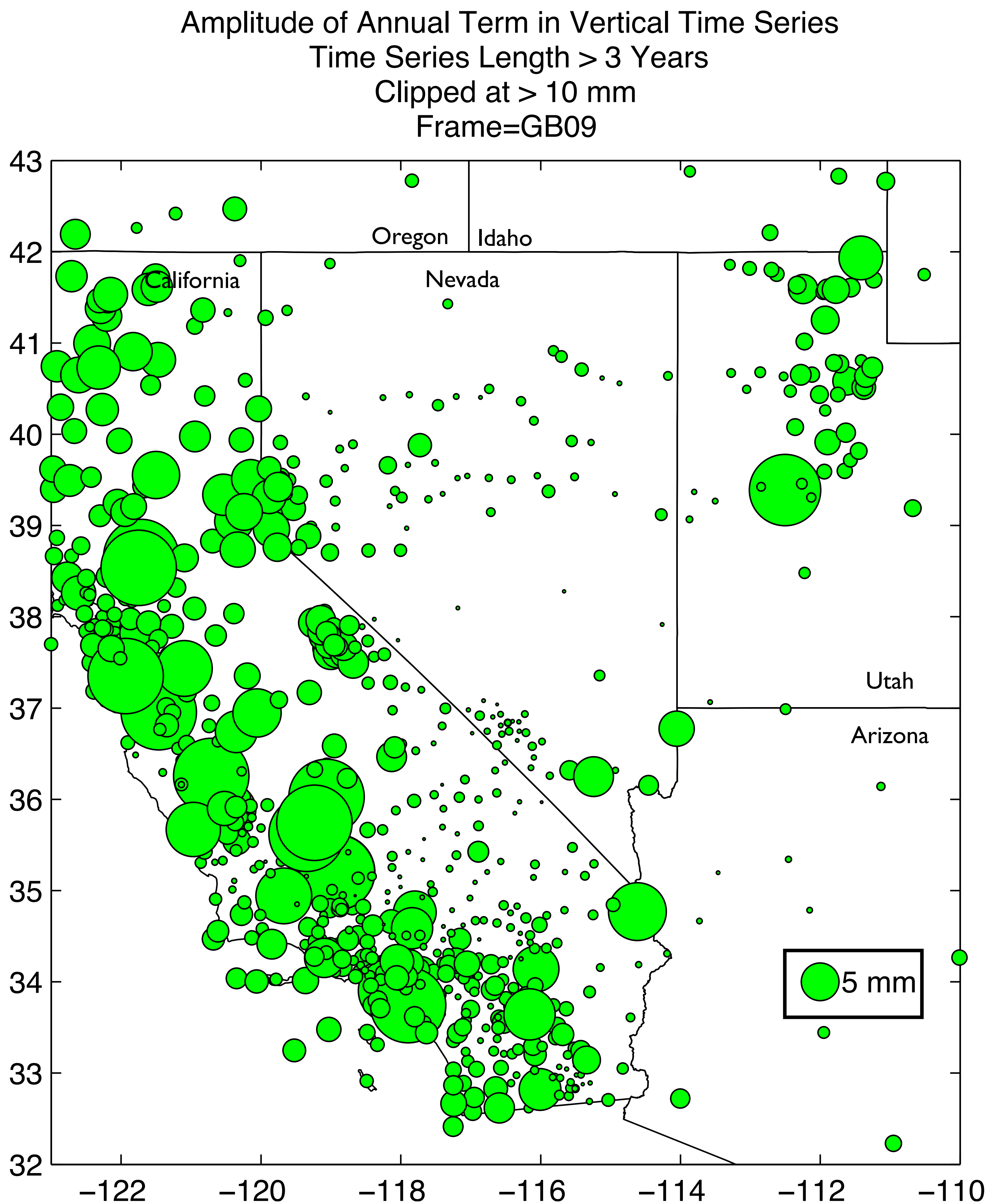
- Accounts for effects of orbit/ atmosphere error to estimate steady linear motion.

- Descending tracks, up to 109 scenes.

- ERS data between 1992 and 2009

- Envisat coming soon...

Seasonal Terms in Vertical GPS Time Series



Relative Motion Between Two Stations