Using GNSS and InSAR to Maintain a Dynamic Vertical Datum

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Contributions by:

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West Coast Natural Hazards

Earthquakes

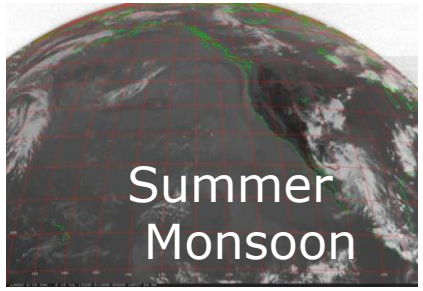
Wildfires

Volcanoes

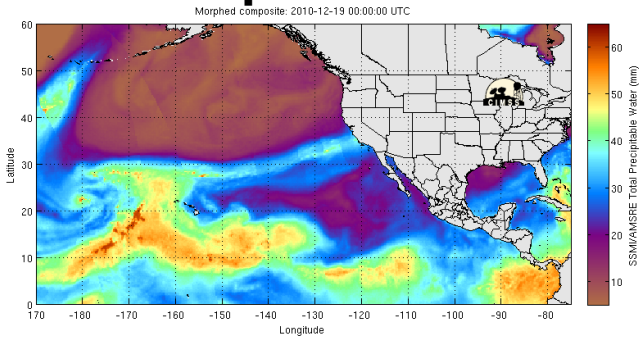
Landslides

Sea Level Rise

Flash Flooding

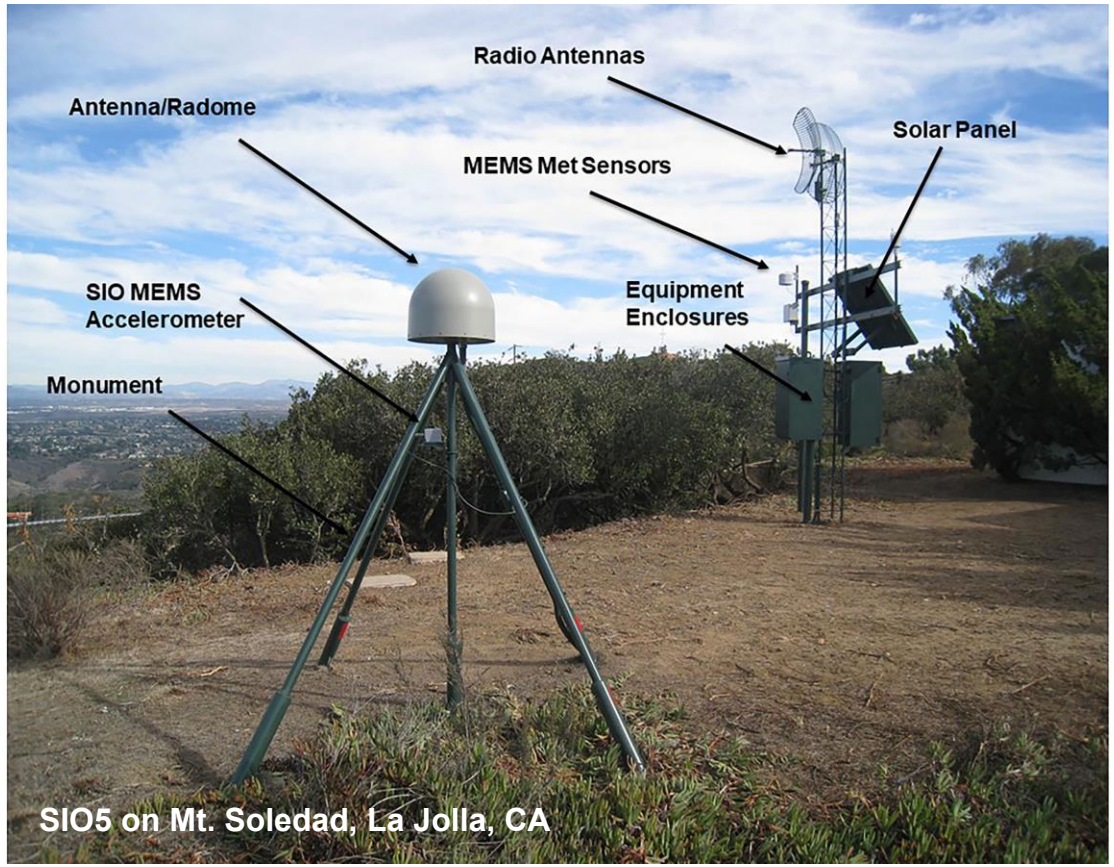


Atmospheric Rivers

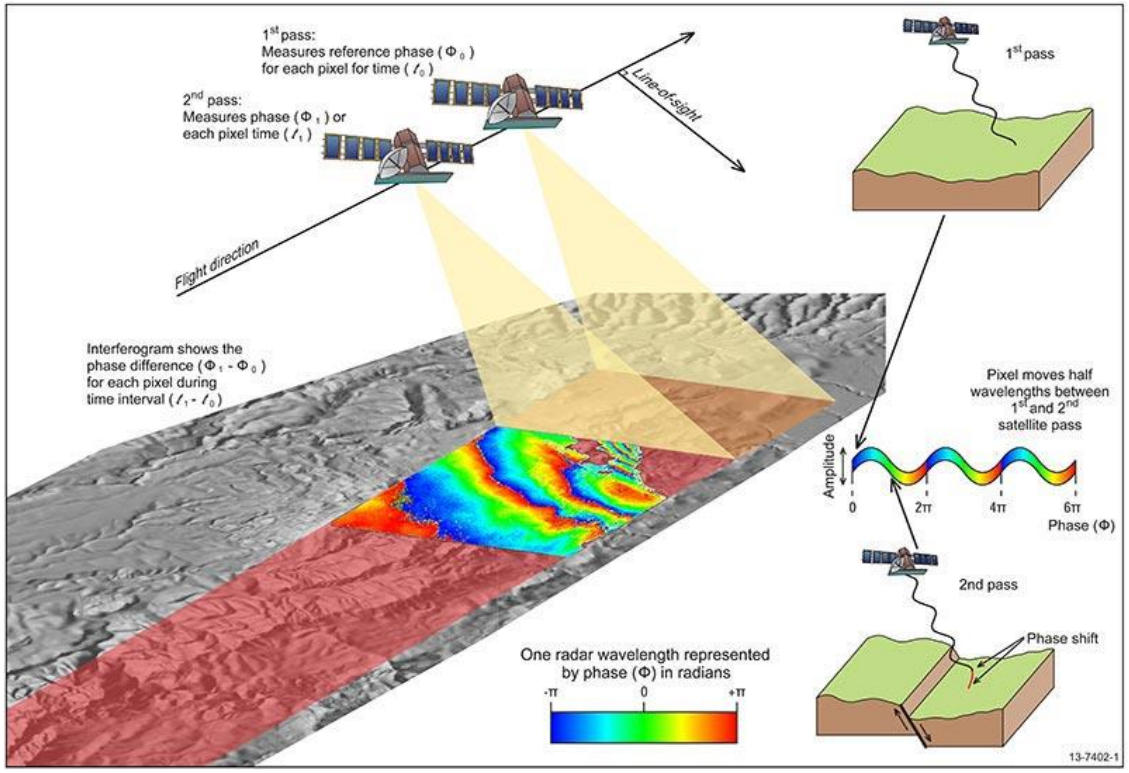


Beckwourth-complex-wildfire (summer 2021, 105,000 acres) now contained – photo courtesy NBC News

Typical Continuous GNSS Station



InSAR Method



California Spatial Reference System (Datum): @ CSRS Epoch 2017.50

- Under contract to Caltrans, estimated geodetic coordinates, velocities and 2-sigma uncertainties in NAD83(2011 – Epoch 2010.00) – tied to NSRS; orthometric heights (NGS GEOID12B)
- 957 continuous GPS stations in California and border areas from1995-2018 (849 active stations/700 real-time stations; 108 inactive stations);
- CSRS Epoch 2017.5 geodetic coordinates transmitted in RTCM3.0 by the California Real Time Network (CRTN).

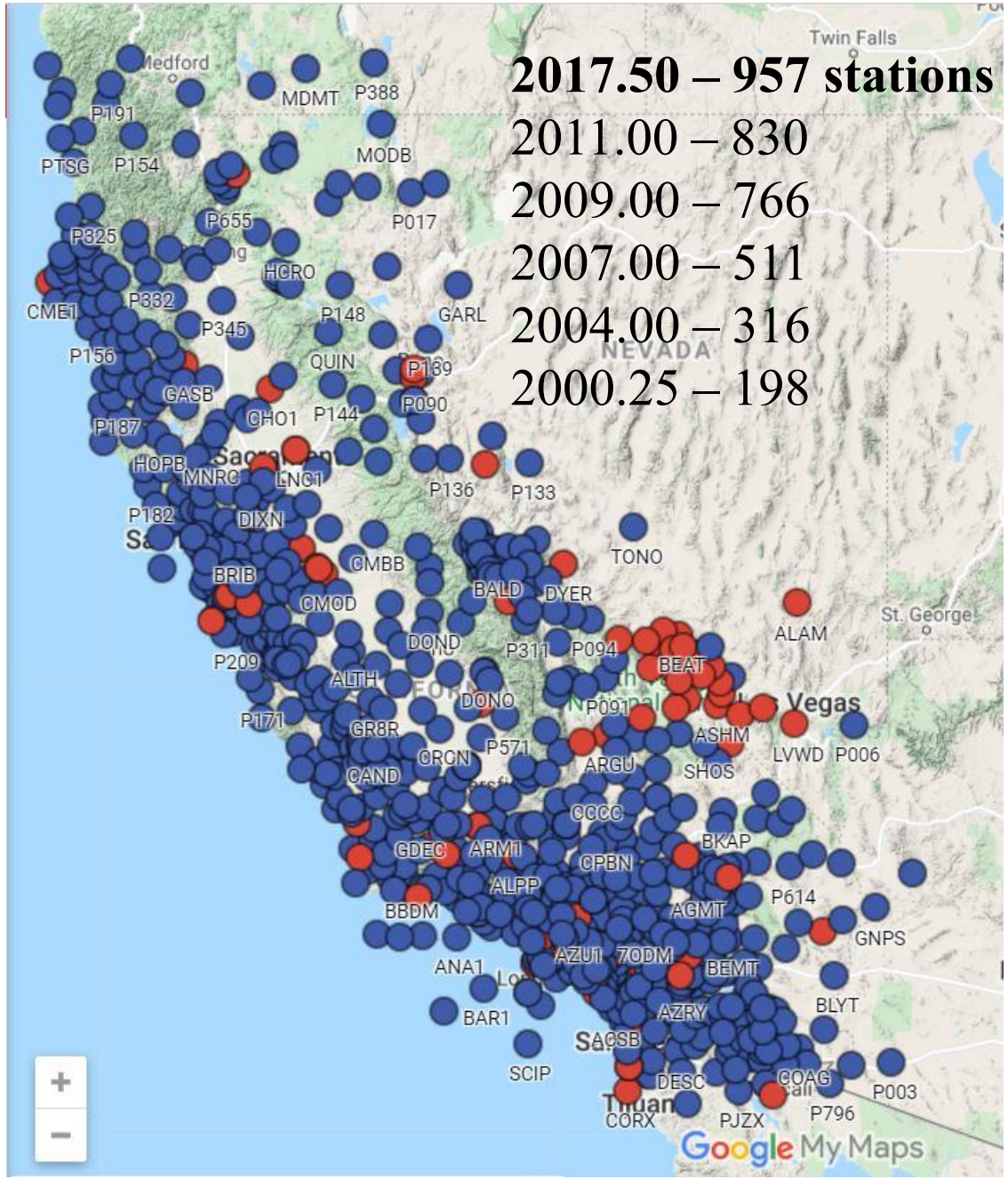
California Spatial Reference System, CSRS Epoch 2017.50 (NAD83)

The foregoing report was prepared in accordance with the California Public Resources Code, §§8850-8861 Geodetic Datums, §§8870-8880 Geodetic Coordinates, §§8890-8902 Heights, and the California Professional Land Surveyors' Act (Business and Professions Code §§ 8700 – 8805) under the responsible charge of:

John Canas, PLS
CSRC Executive Manager

1/25/18
Date

PROFESSIONAL LAND SURVEYOR JOHN CANAS No. 4408 STATE OF CALIFORNIA



http://sopac-csrc.ucsd.edu/index.php/epoch2017/

CSRS Epoch 2017.50: Methodology

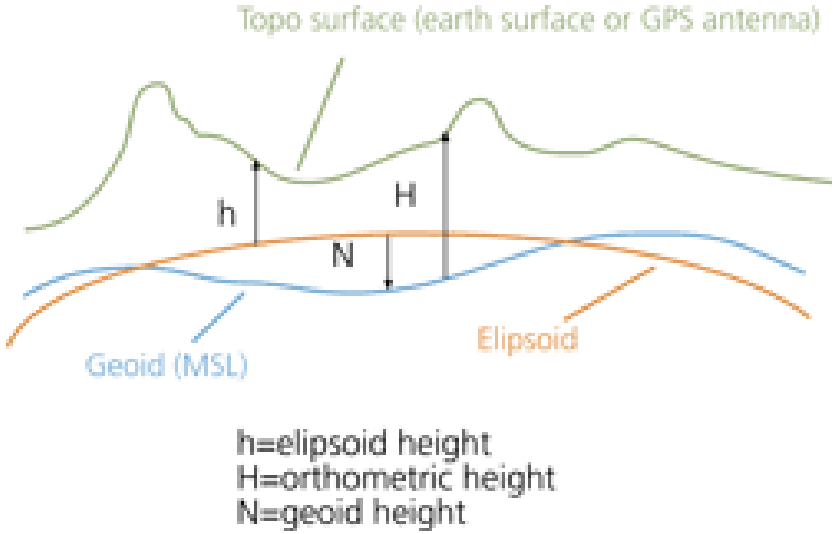
- Analyze GNSS data daily by SOPAC in IGB14 reference frame (the IGS realization of ITRF2014). The position time series began in 1995 for the earliest stations.
- Perform time series analysis solving for station velocities, coseismic offsets, postseismic decay, artificial jumps and annual and semi-annual terms.
- Estimate ITRF-XYZ positions at epoch 2017.50 with 2-sigma uncertainties.
- Transform XYZ positions to geodetic coordinates (latitude, longitude and ellipsoidal height “h”) in **NAD83(2011) epoch 2010.00** as defined by the NGS to conform with **National Spatial Reference System (NSRS)**
- Compute orthometric heights “H” using **GEOID12B** model (geoid height “N”) published by NGS, nominally in vertical datum **NAVD88**

$$H = h - N$$

h: ellipsoid height NAD83(2011) Epoch 2010.00

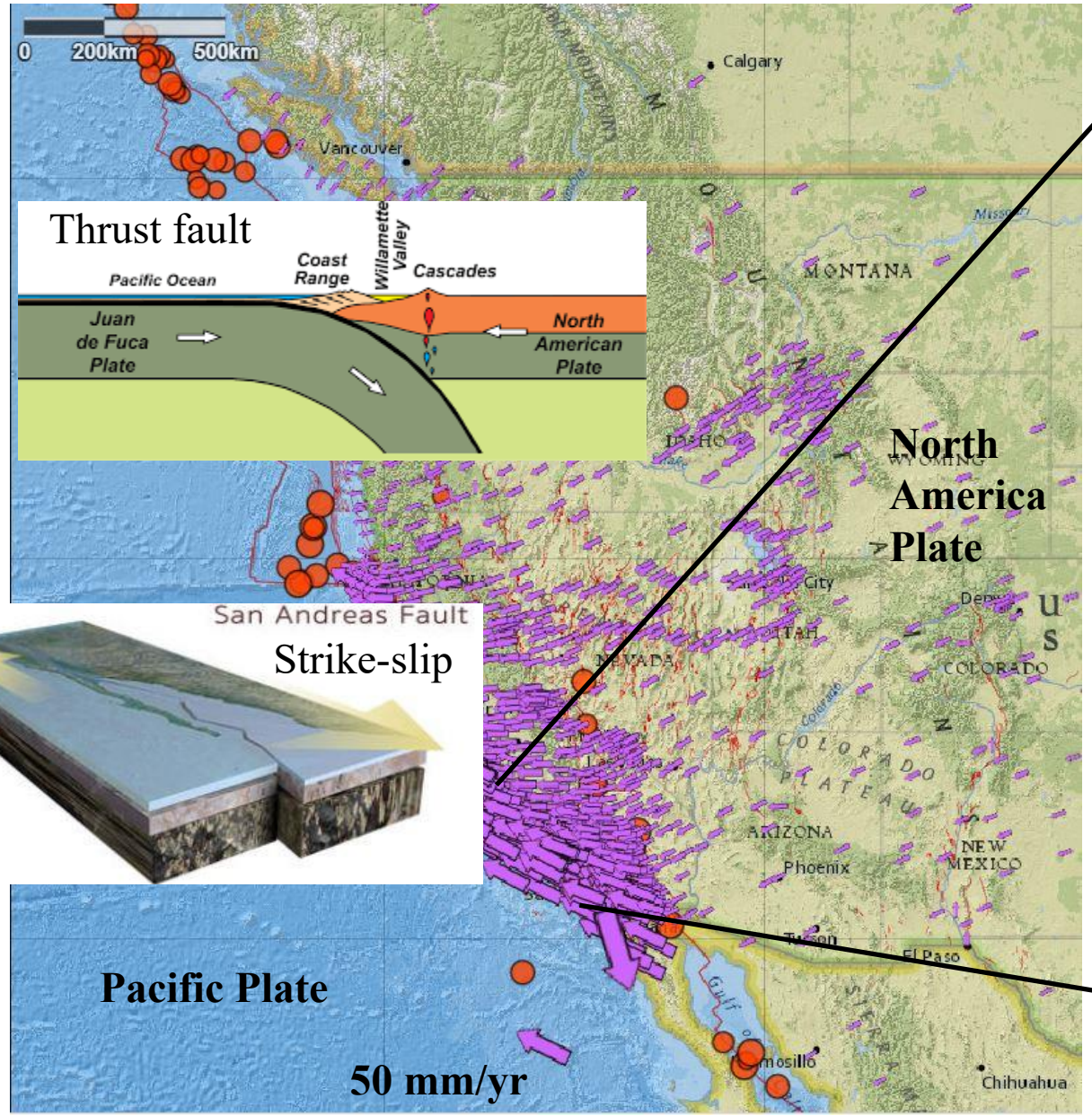
N: geoid height GEOID12B

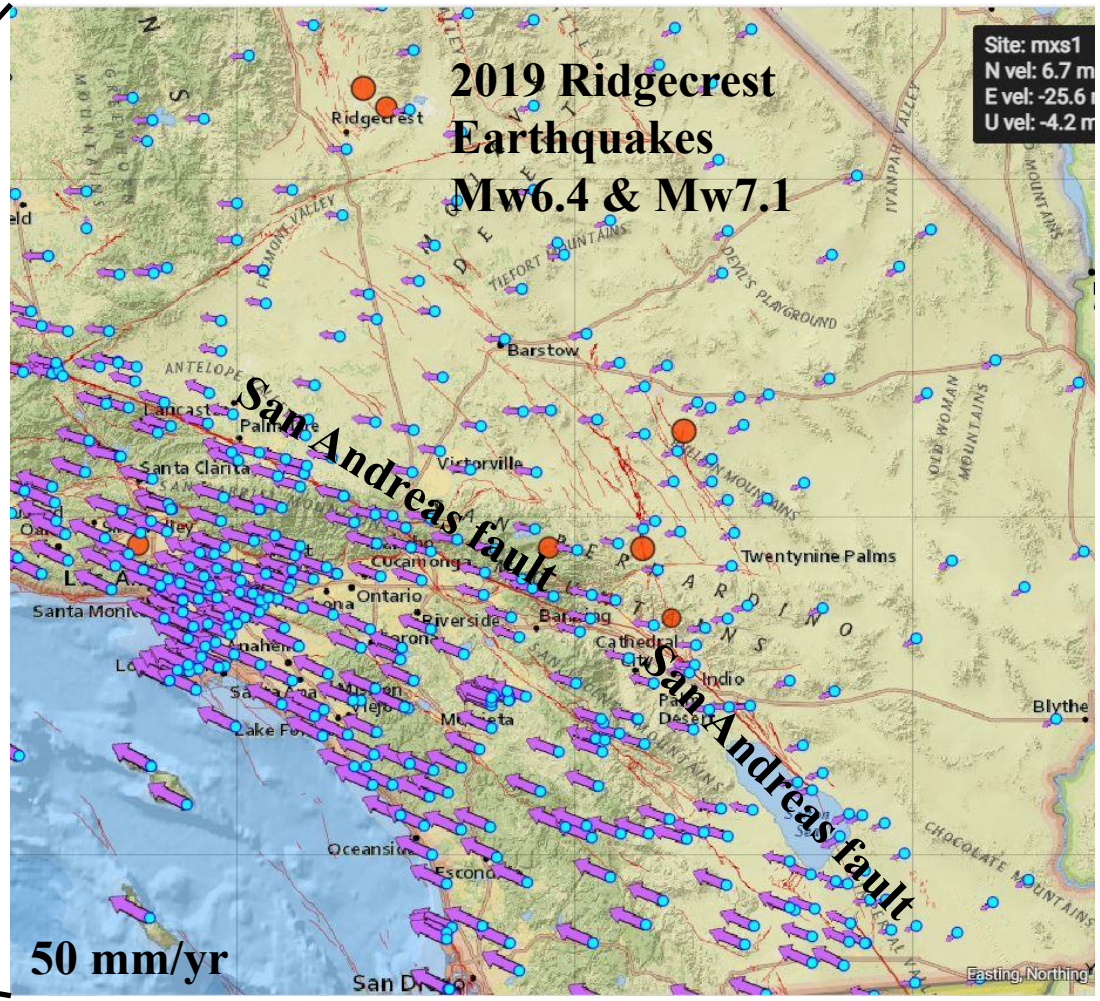
GEOID18 released by NGS in June 2020



“The relative accuracy of GEOID12B to NAVD88 is characterized by a misfit of +/-1.7 centimeters nationwide” (NGS)
We compared our results to leveling to ~75 stations in SoCal and found an rms difference of 2.7 centimeters (0.09 feet)

Complications: Plate boundary deformation in the Western U.S.

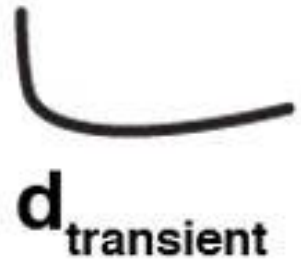




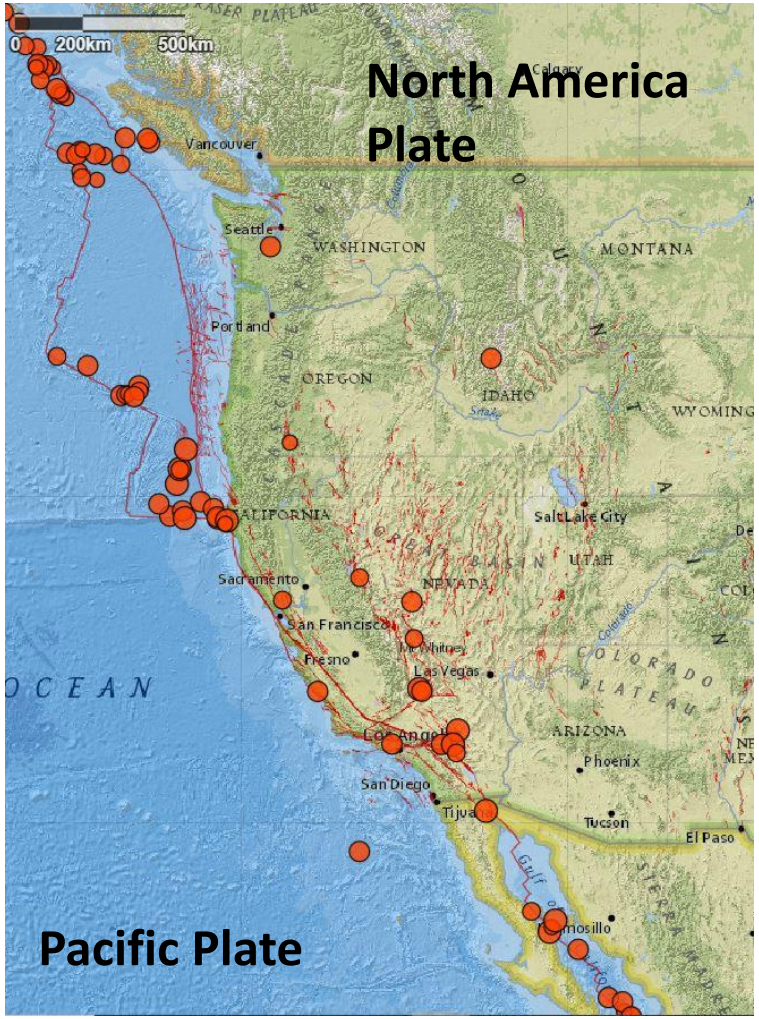
$d_{interseismic}$

MGViz: http://geoapp20.ucsd.edu/?mission=ESESES

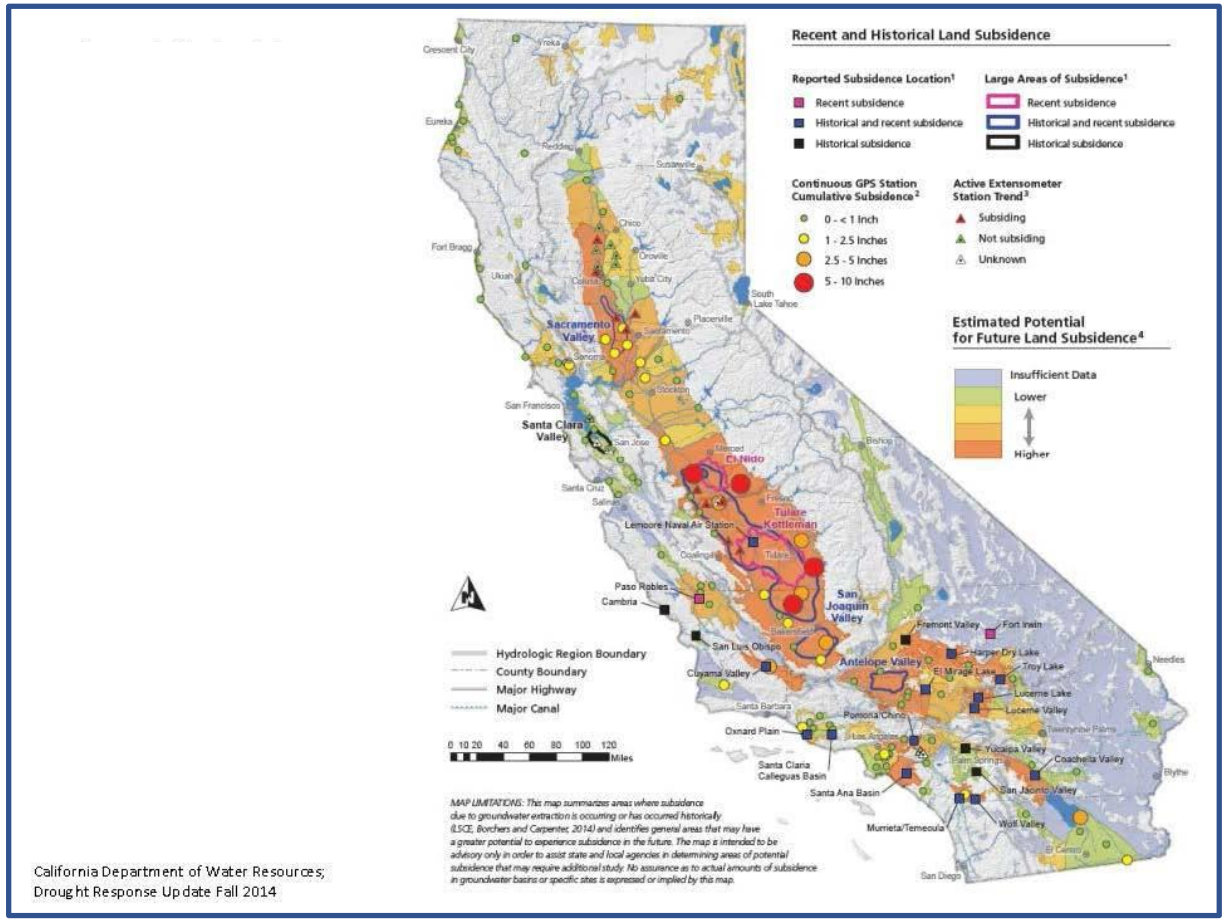
Complications: Earthquakes and Land Subsidence



Significant Earthquakes Western U.S (1992-2019)

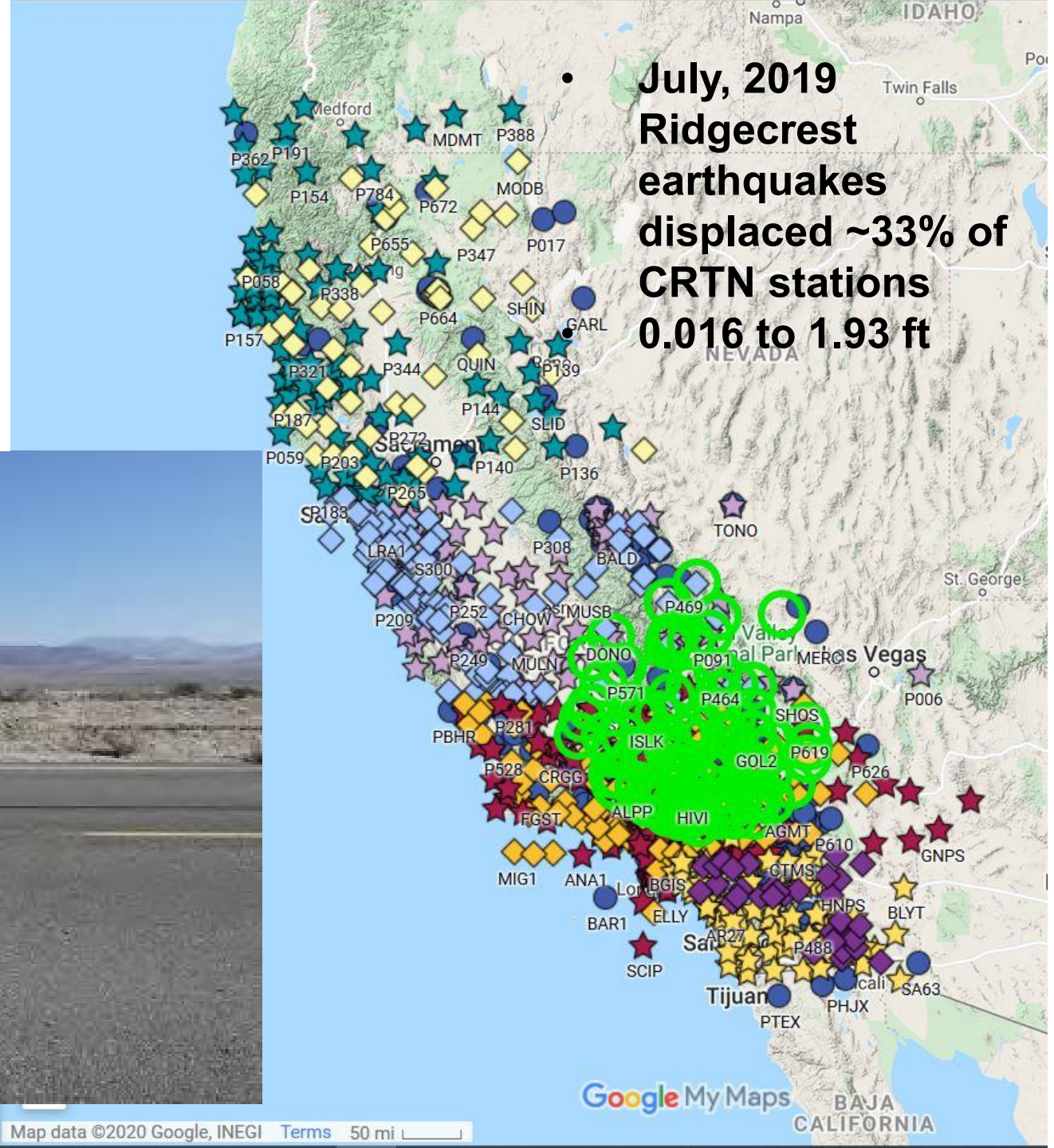


Land Subsidence

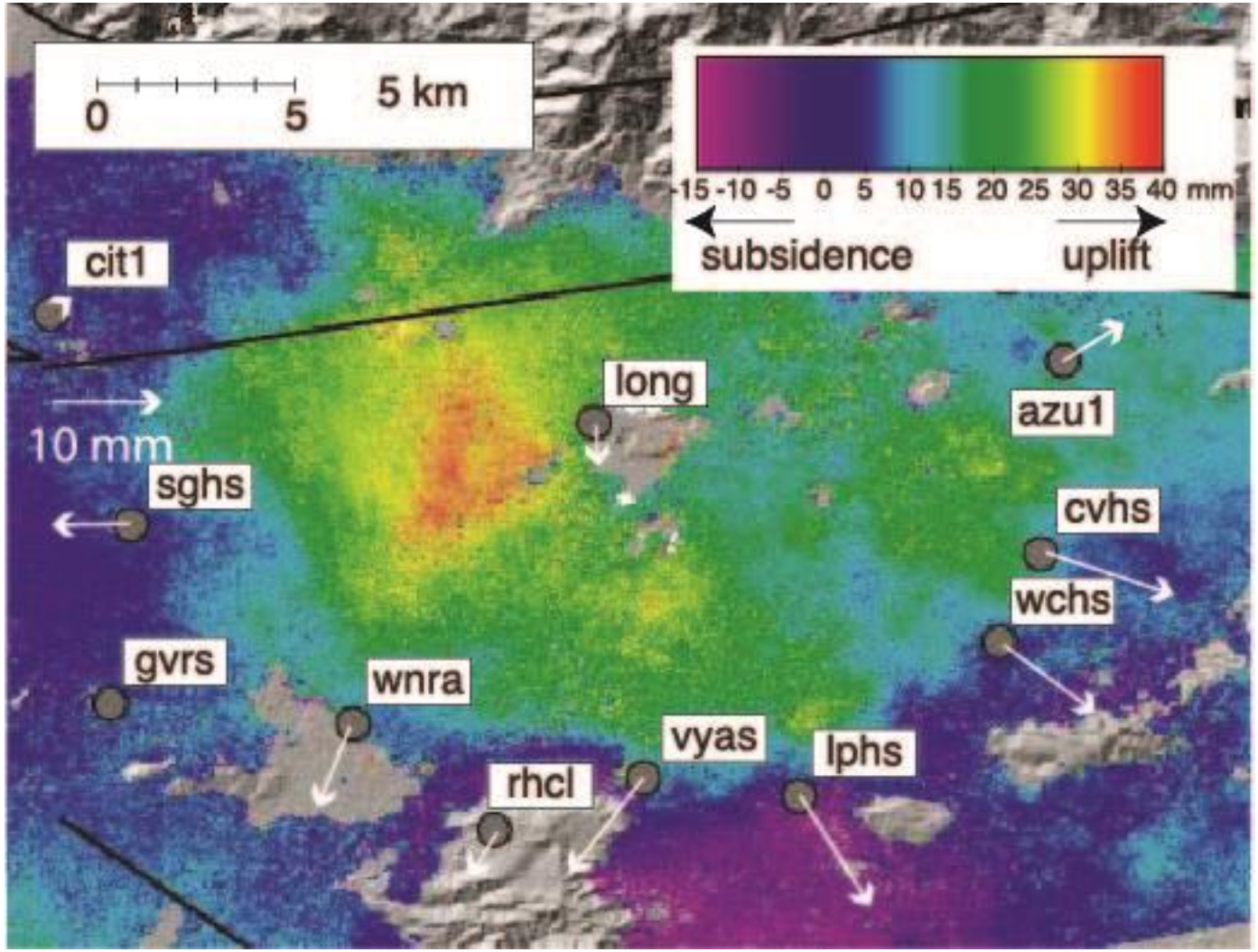


California Department of Water Resources; Drought Response Update Fall 2014

Special Epoch-Date 2019.55



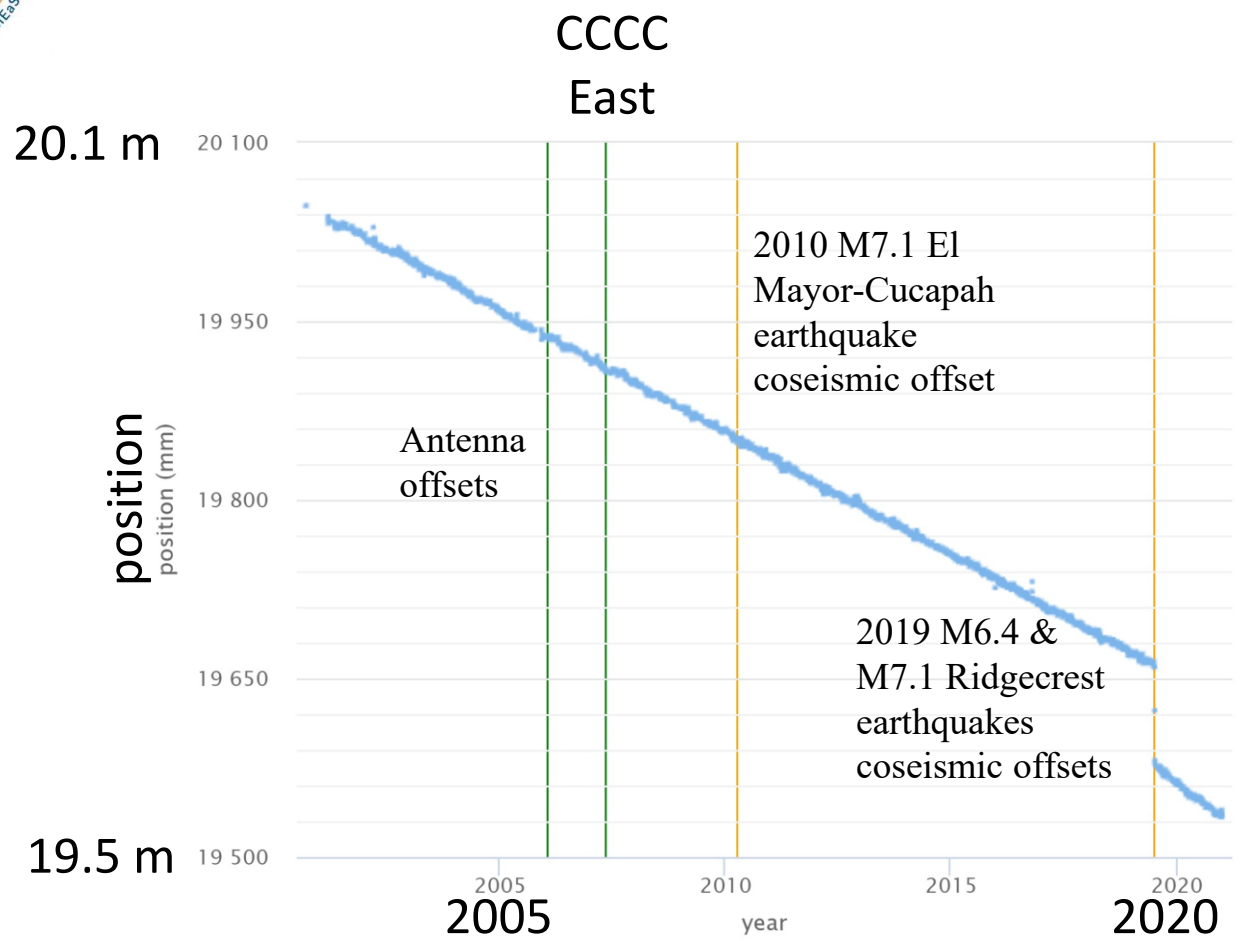
Transient Non-Tectonic Motions from Aquifer Recharge



Continuous GPS horizontal (arrows) and vertical (color scale) displacements from InSAR in the period 2005.0-2005.4 in the San Gabriel Valley, southern California caused by aquifer recharge due to heavy rains. The station LONG had an uplift of 47 mm.

King et al., 2007

Daily Displacement Time Series

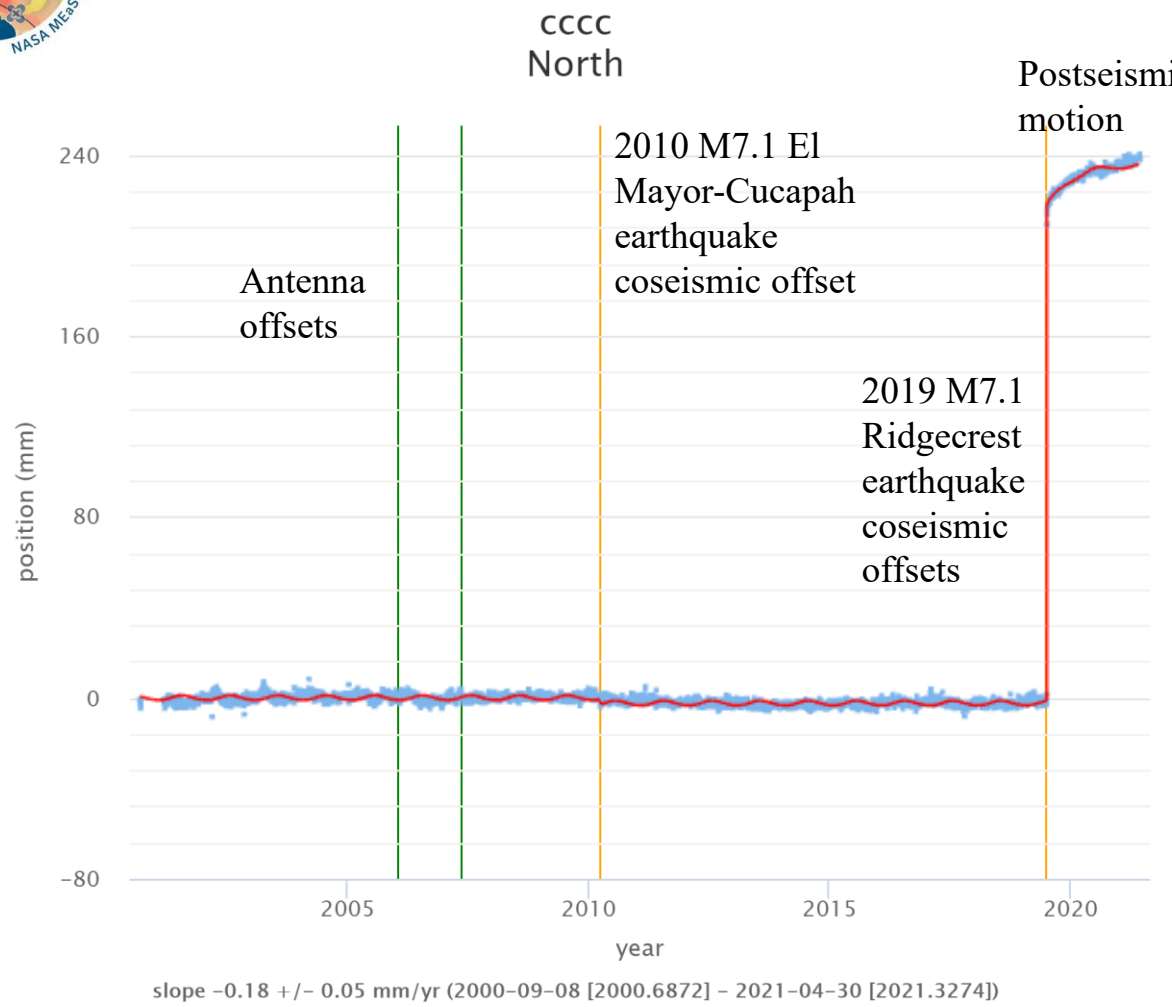


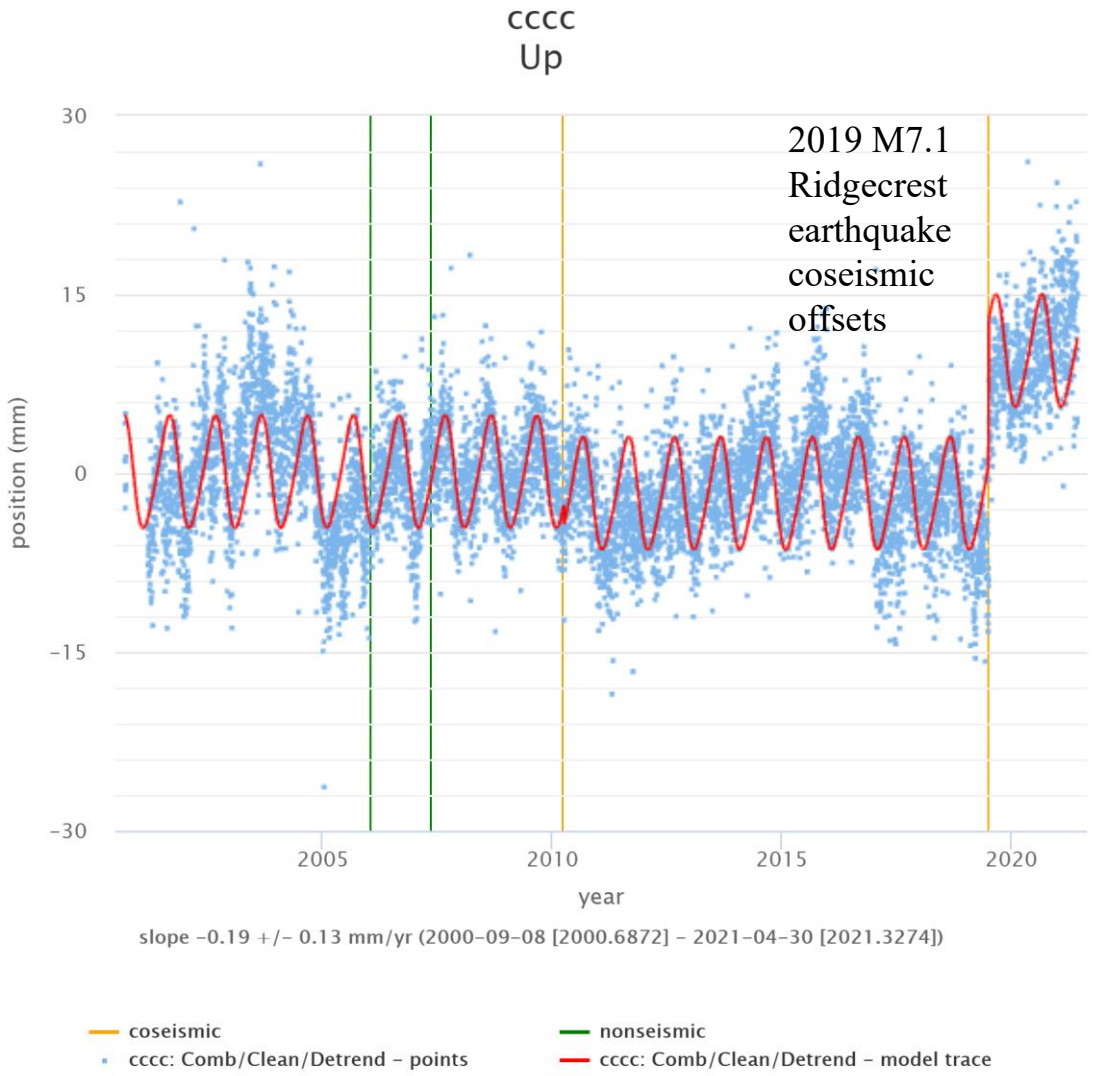
- Remove outliers
- Flag problematic stations
- Correct for metadata errors such as incorrect antenna models and antenna heights
- Identify & correct for non-tectonic offsets primarily due to exchanging different model GNSS antennas.
- Flag coseismic offsets
- Provide uncertainties/rms values

The modified time series are then assumed to represent purely physical processes of interest due to the crustal deformation cycle, earthquakes, magmatism, hydrology, etc.

Source: MGViz project portal

Detrended daily displacement time series

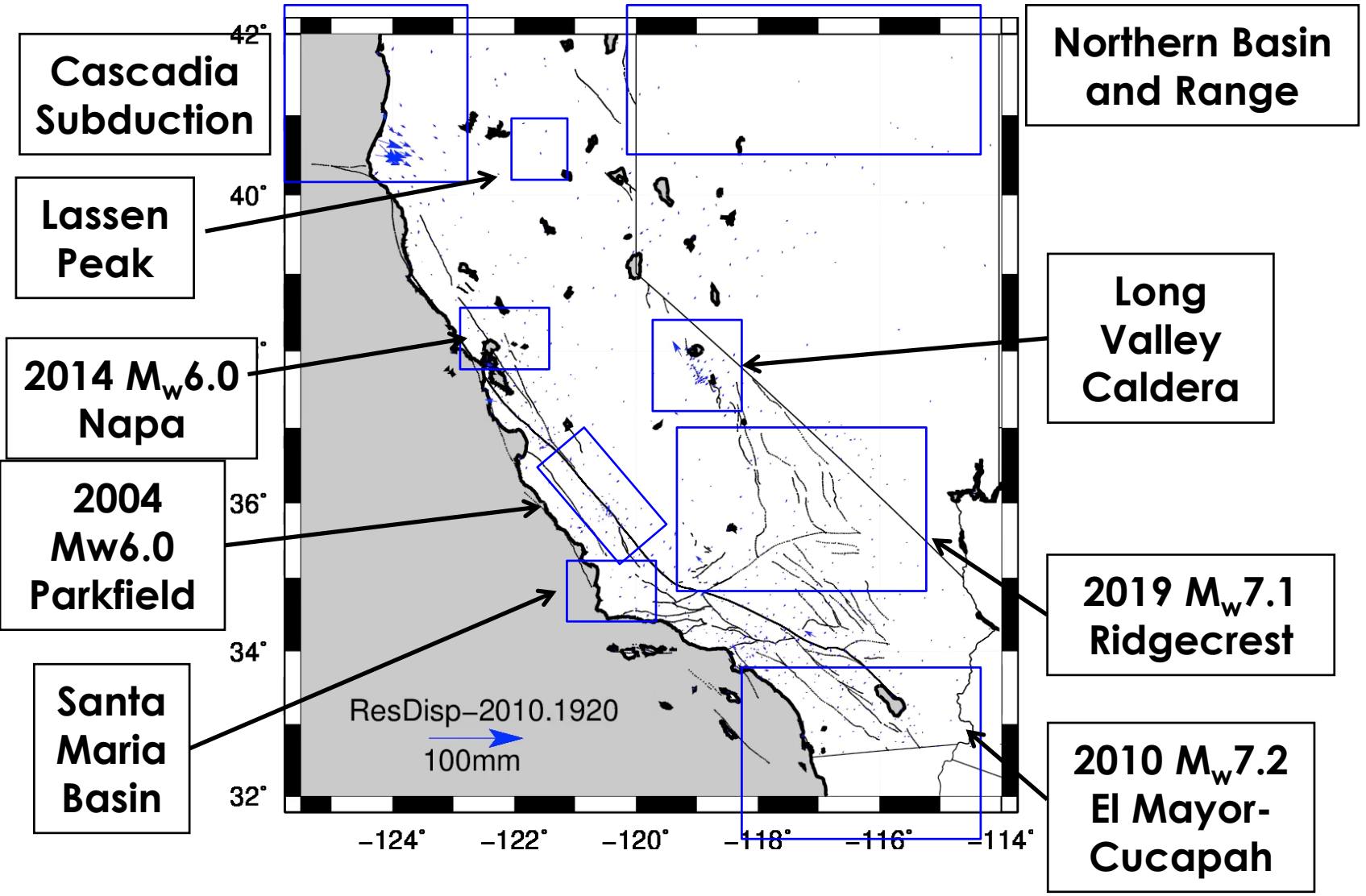


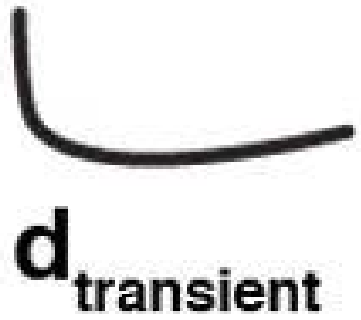


Horizontal rms: 1.0-1.5 mm
Vertical rms: 3.0-4.0 mm

Source: MGViz portal

Complications in Maintaining a Datum in Deforming Regions



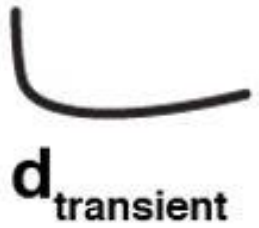


Weekly displacement record of 2010-2019 highlight ongoing transient crustal motion

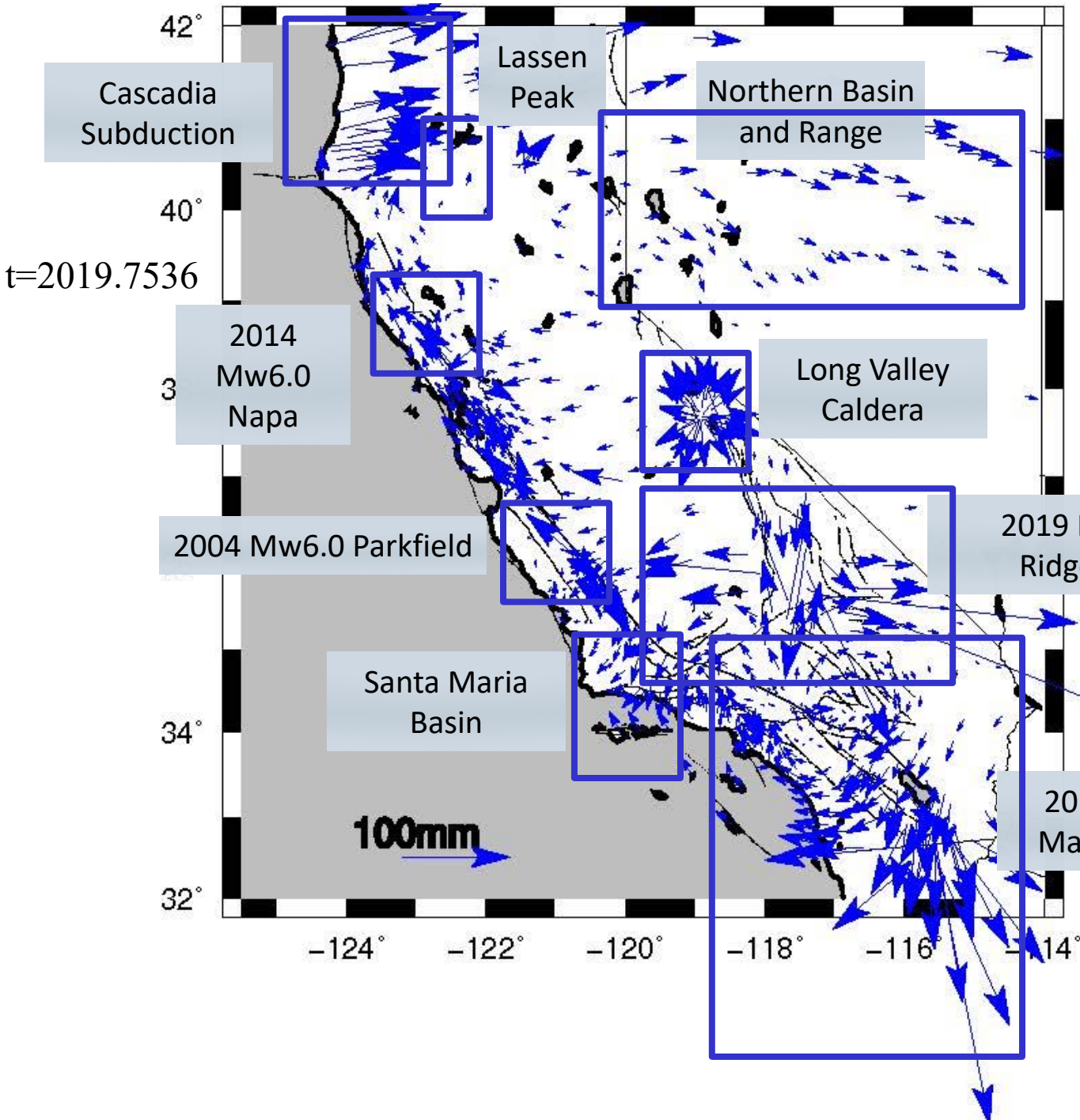
Katherine Guns

Transient motions = Observed GNSS – Model-predicted motions (from Zeng & Shen, 2017)

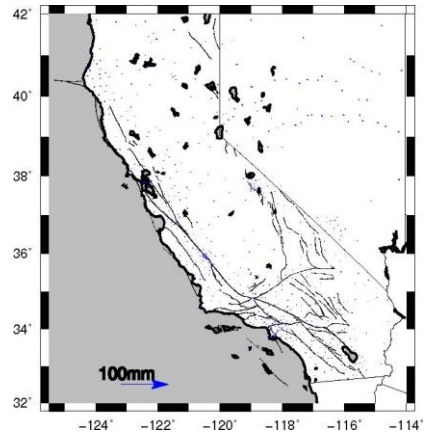
Deviations from Interseismic Model: Accumulated (2010.0192-2019.7536)



O – C = observed MEaSUREs weekly displacements minus predicted by Zeng & Shen (2017) 2-D interseismic fault slip model for the Western U.S.



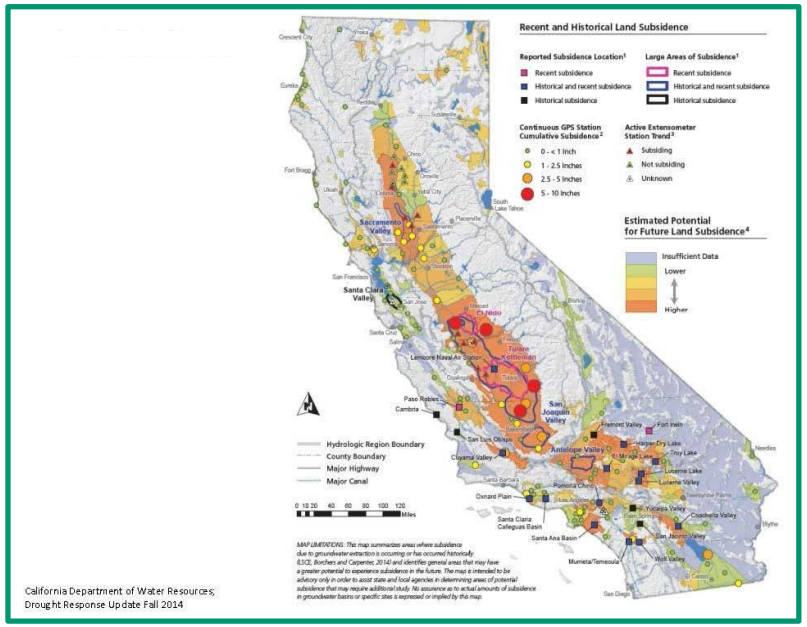
t_o=2010.0192

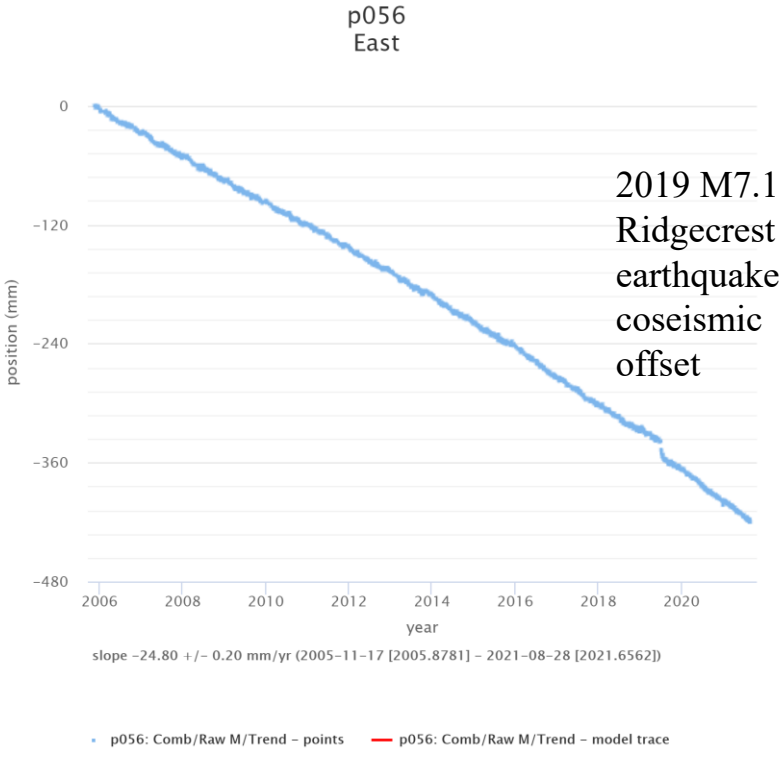


Zeng, Y., & Shen, Z.-K. (2017). A fault-based model for crustal deformation in the western United States based on a combined inversion of GPS and geologic inputs. Bulletin of the Seismological Society of America, 107(6), 2597–2612. https://doi.org/10.1785/0120150362

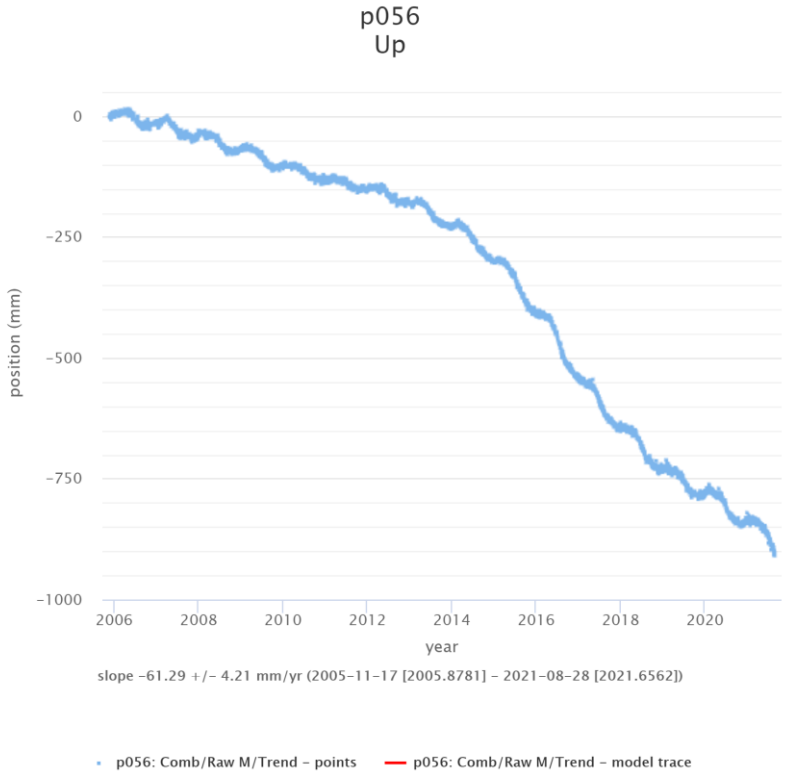
California's Central Valley Vertical Datum Considerations

Land Subsidence





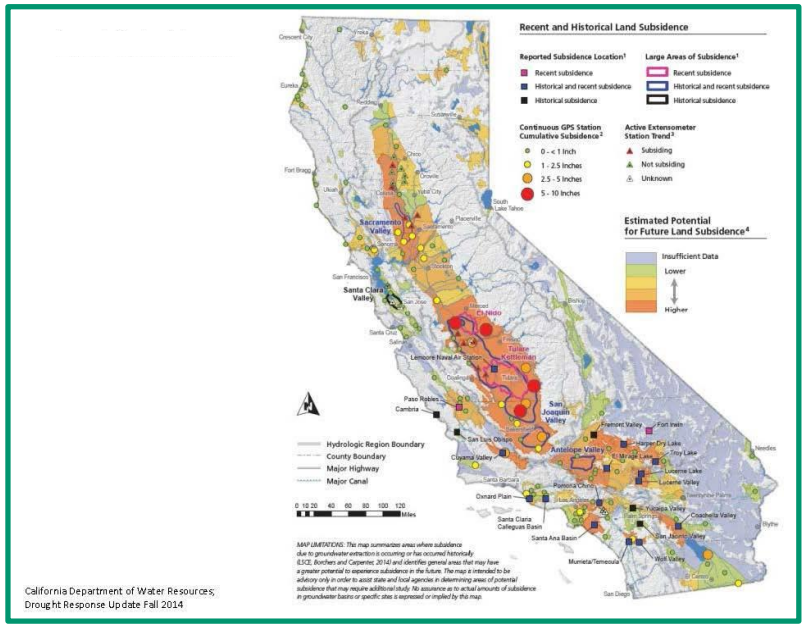
2019 M7.1 Ridgecrest earthquake coseismic offset

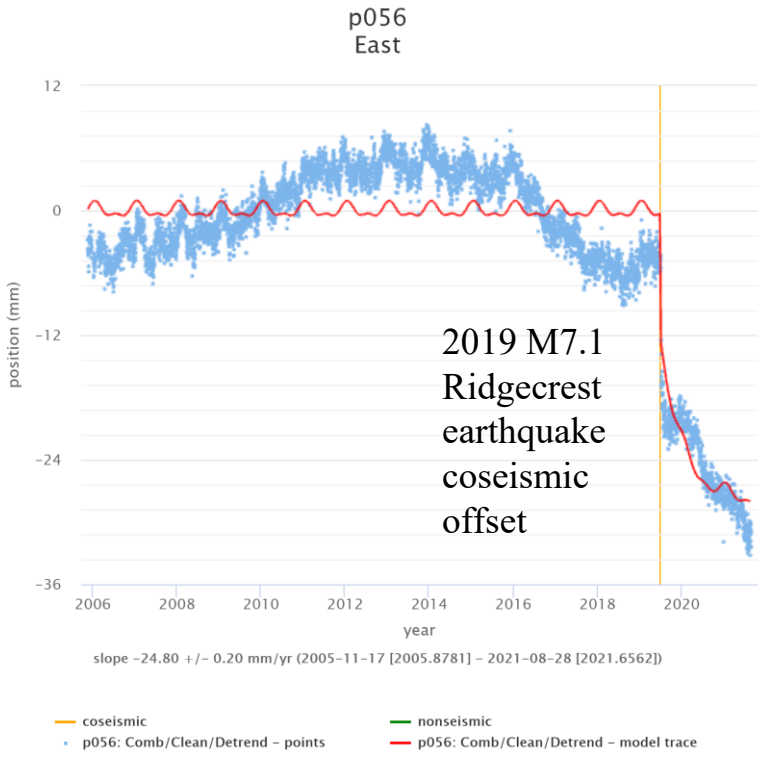


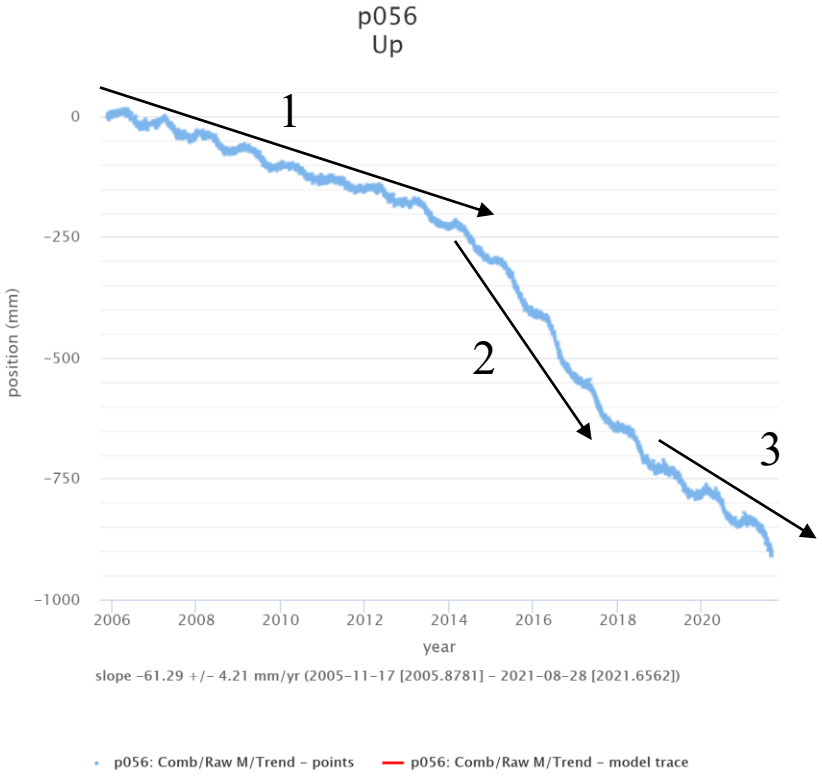
Source: MGViz portal

California's Central Valley Vertical Datum Considerations

Land Subsidence



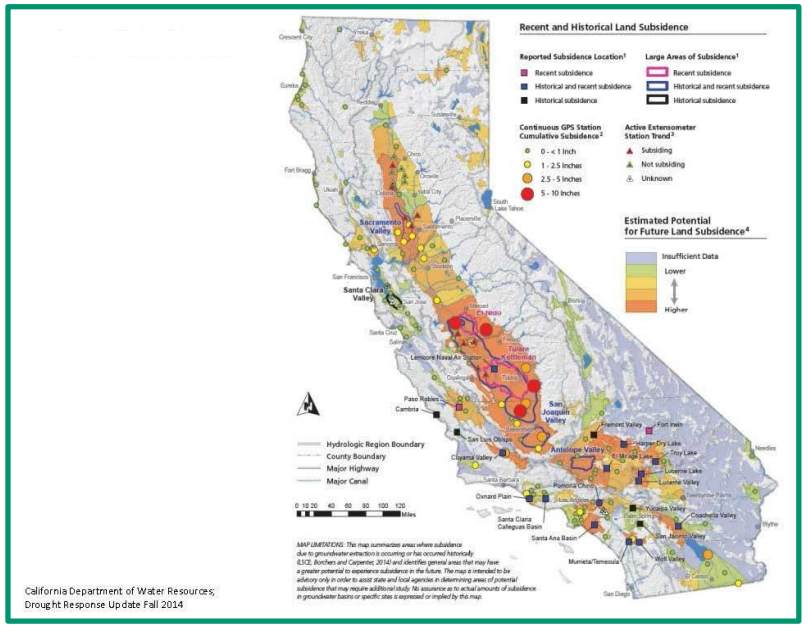


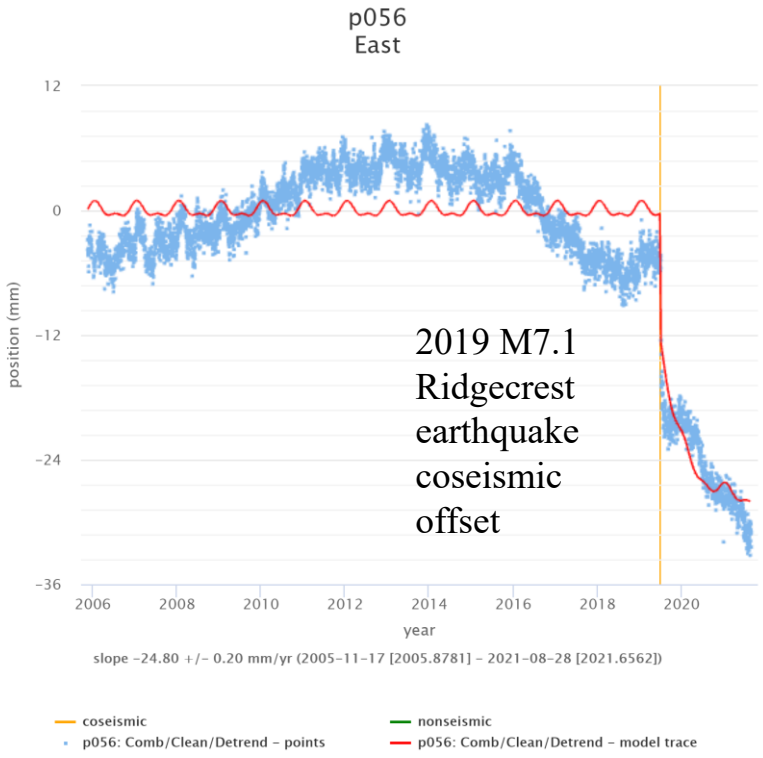


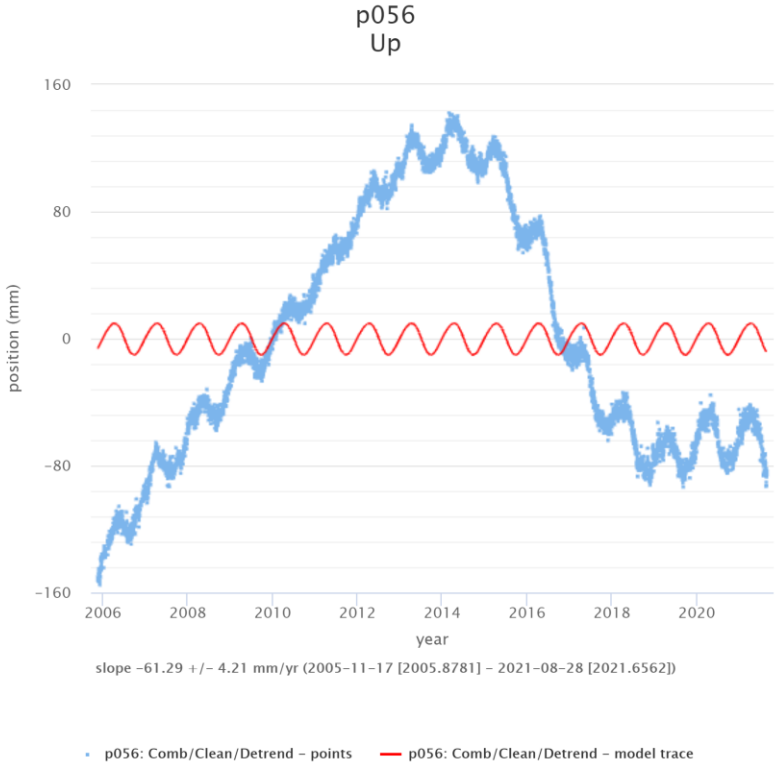
Source: MGViz portal

California's Central Valley
Vertical Datum Considerations

Land Subsidence

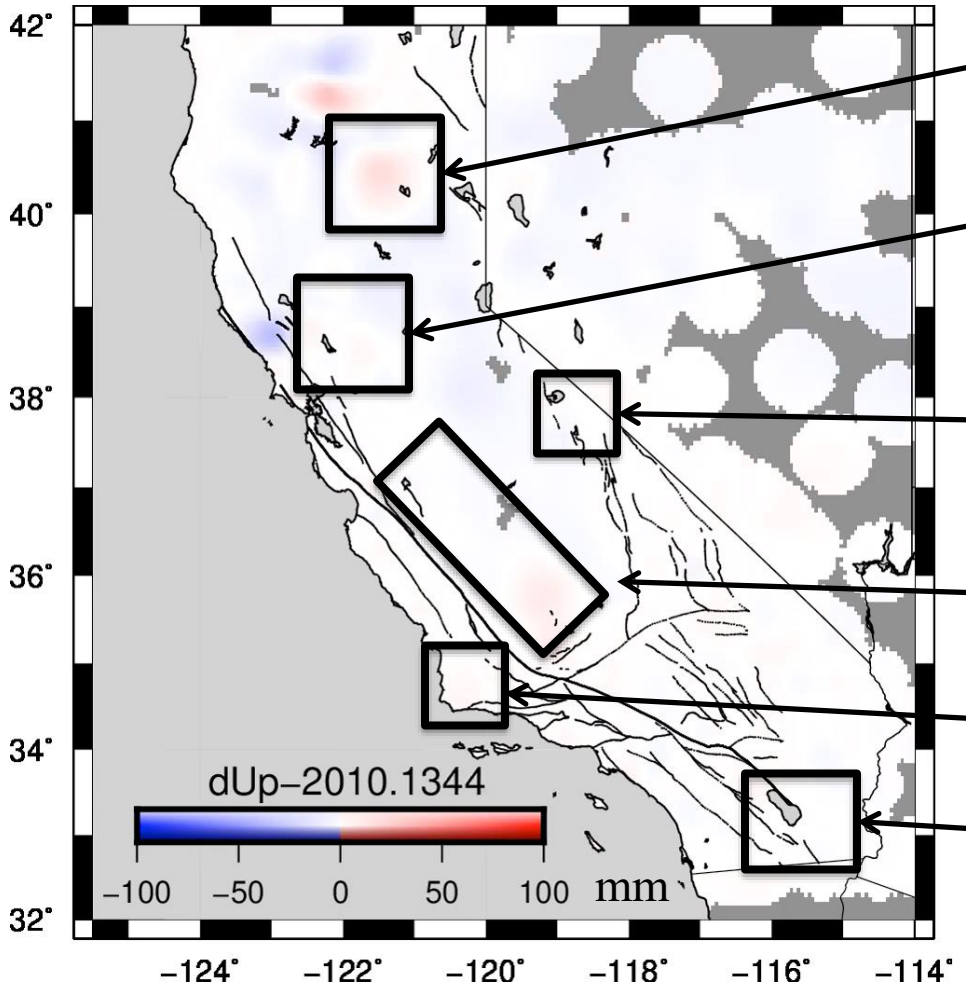






Source: MGViz portal

Vertical displacement grids highlight water storage, tectonic, and volcanic processes



Lassen Peak Magmatic Activity

Sacramento Valley Net Subsidence

Long Valley Caldera Magmatic Uplift

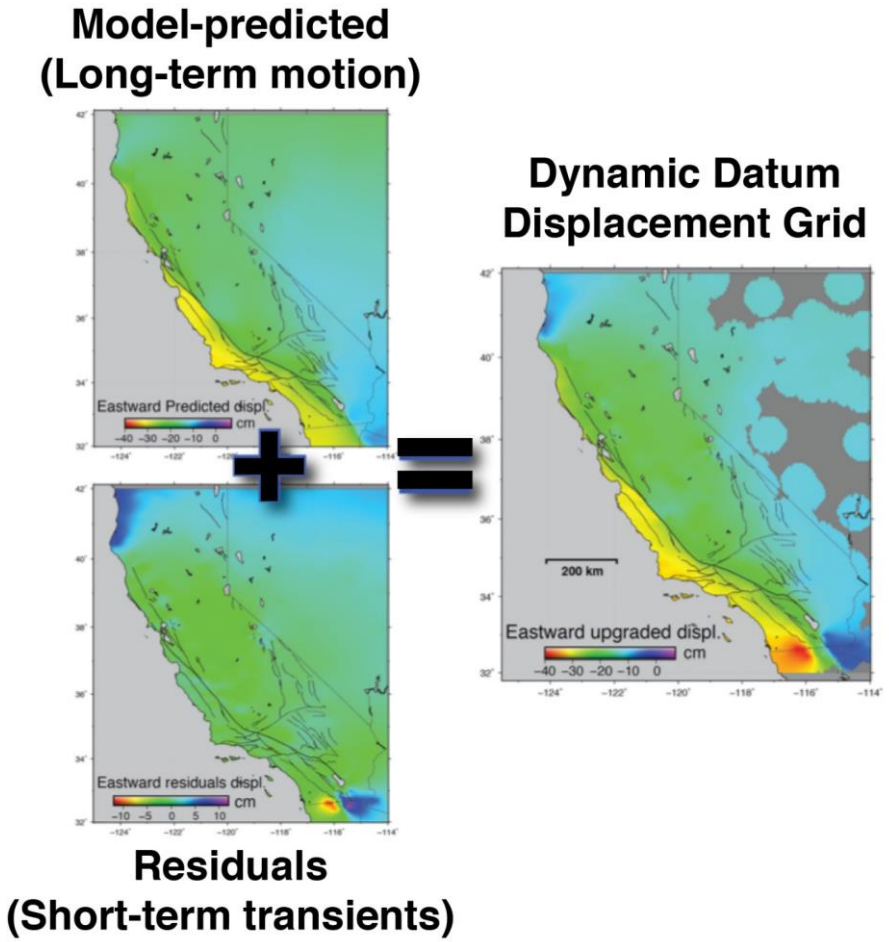
Central Valley Net Subsidence

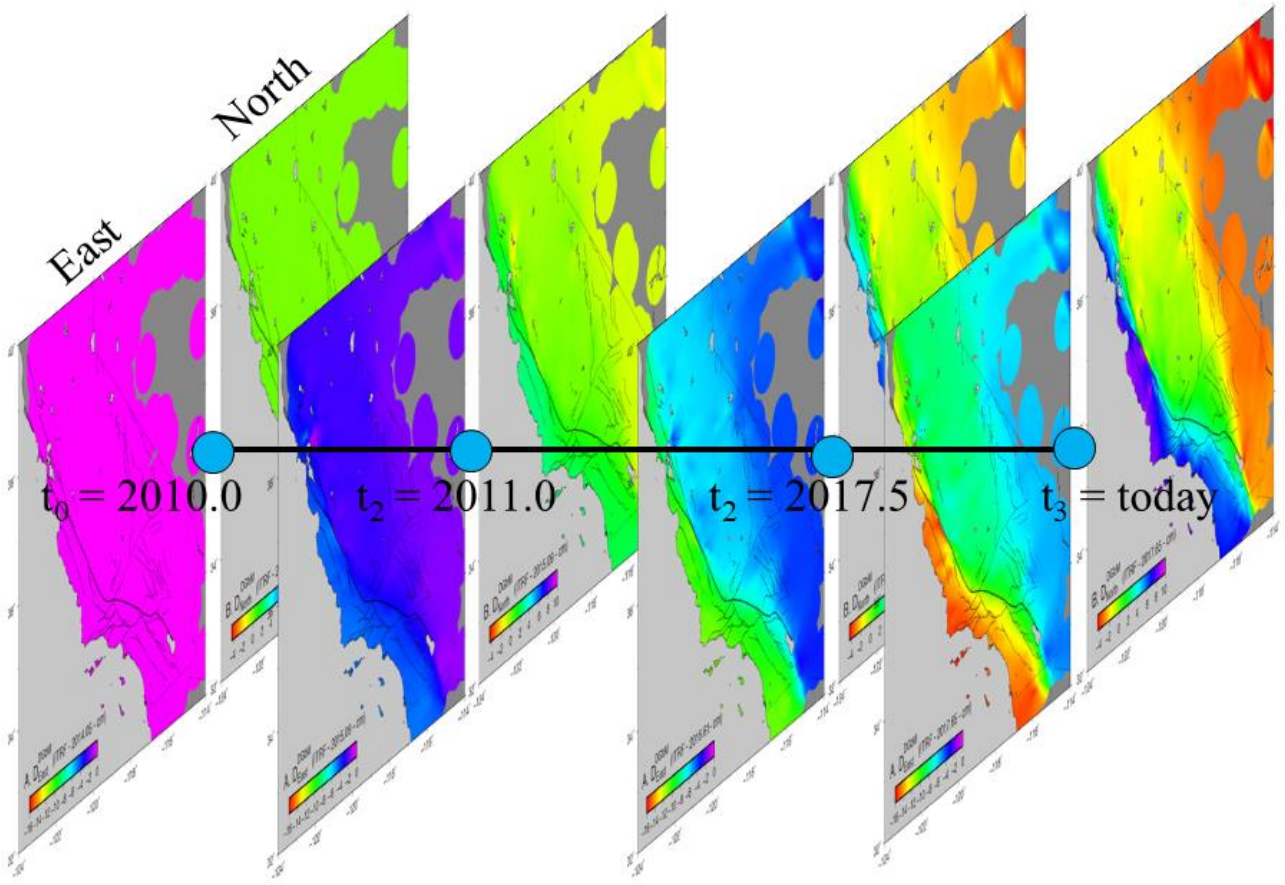
Santa Maria Basin Net Subsidence

Salton Trough Complexity (tectonic)

Katherine Guns

Dynamic Data Concept

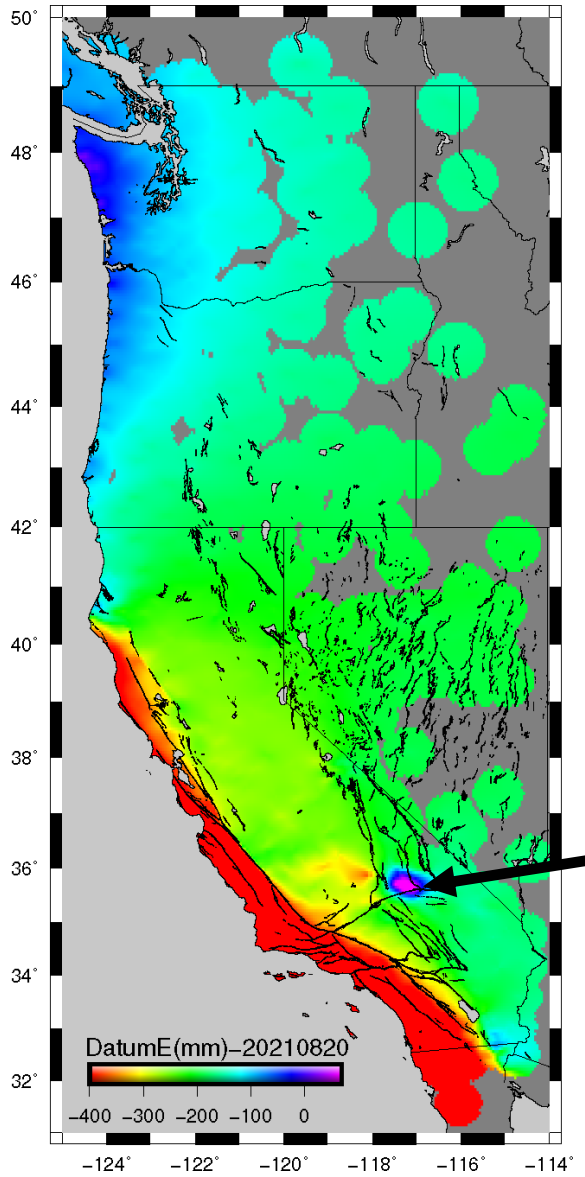




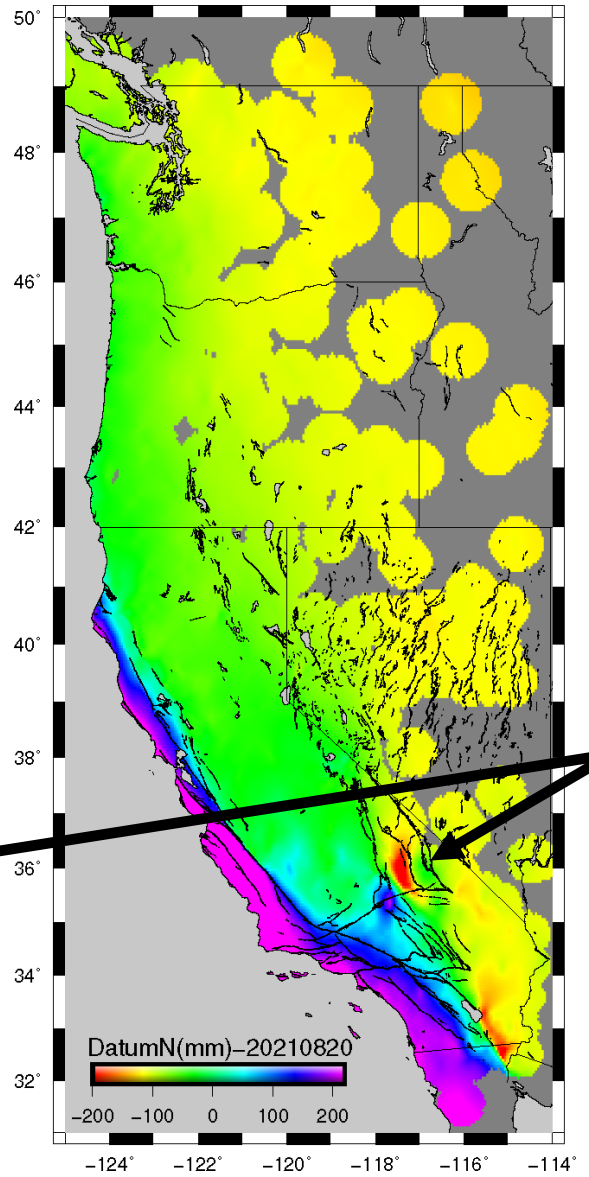
The CSRC produces weekly surface displacement grids in North and East components that allow users to calculate horizontal coordinates at any epoch of time with respect to the CSRS. The grids include the effects of tectonic motions, earthquakes and transients such as postseismic deformation and irregular subsidence and uplift. The CSRC also provides weekly vertical grids. We are working to integrate GNSS and InSAR to increase spatial resolution.
Source: Klein et al. (2019)

3-D Weekly Displacement Grids

East



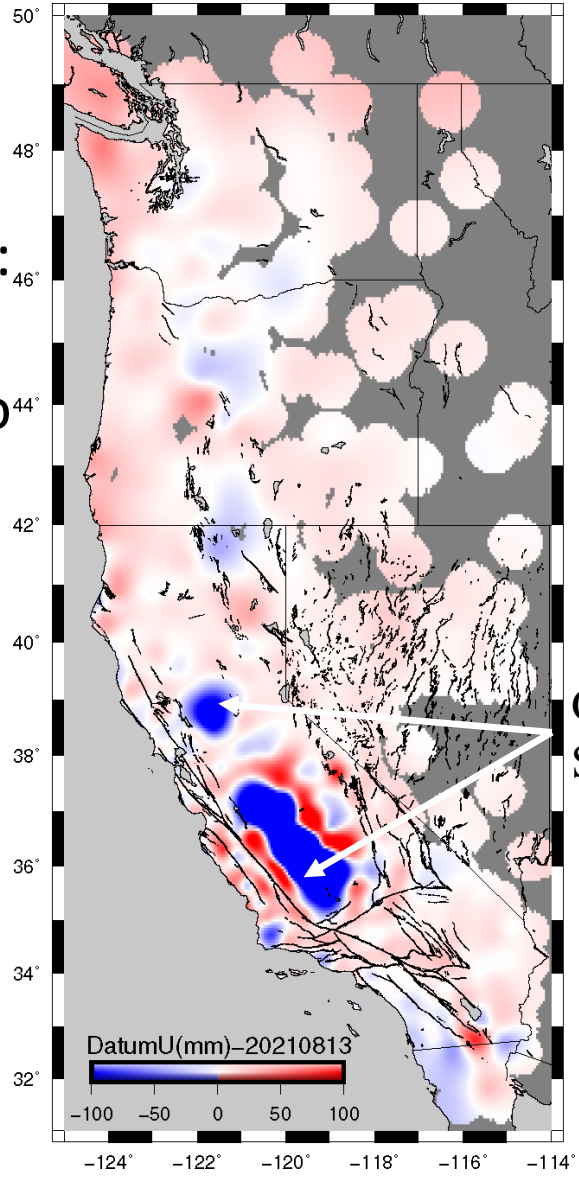
North



Steady and transient displacements: 2021-08-20 with respect to 2010-01-01

2019 Ridgecrest earthquakes

Up

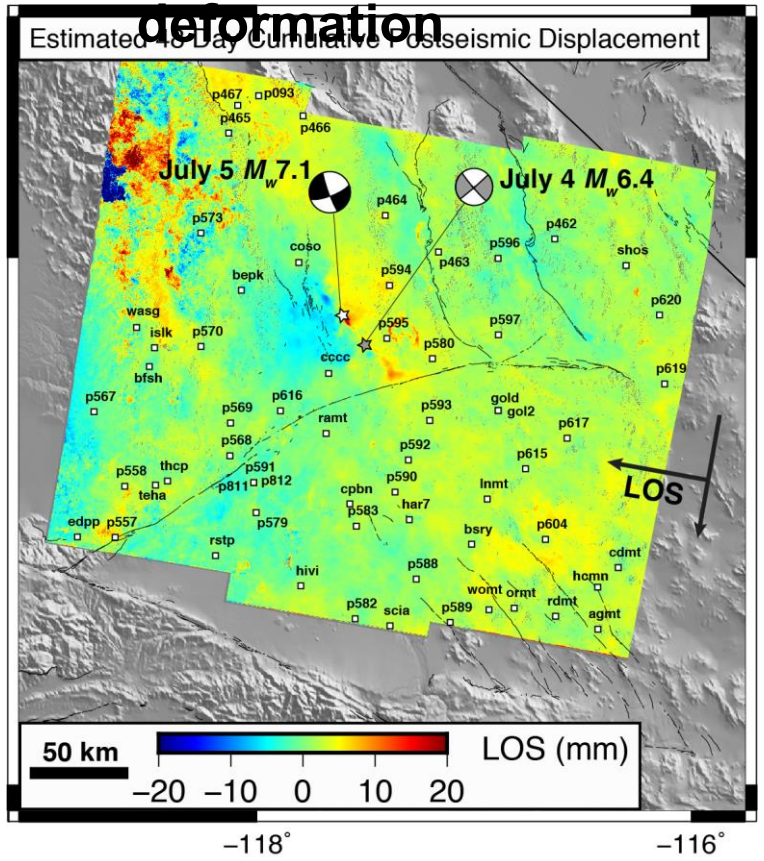


Central Valley Subsidence

Source: http://garner.ucsd.edu/pub/measuresESESES_products/DisplacementGrids/

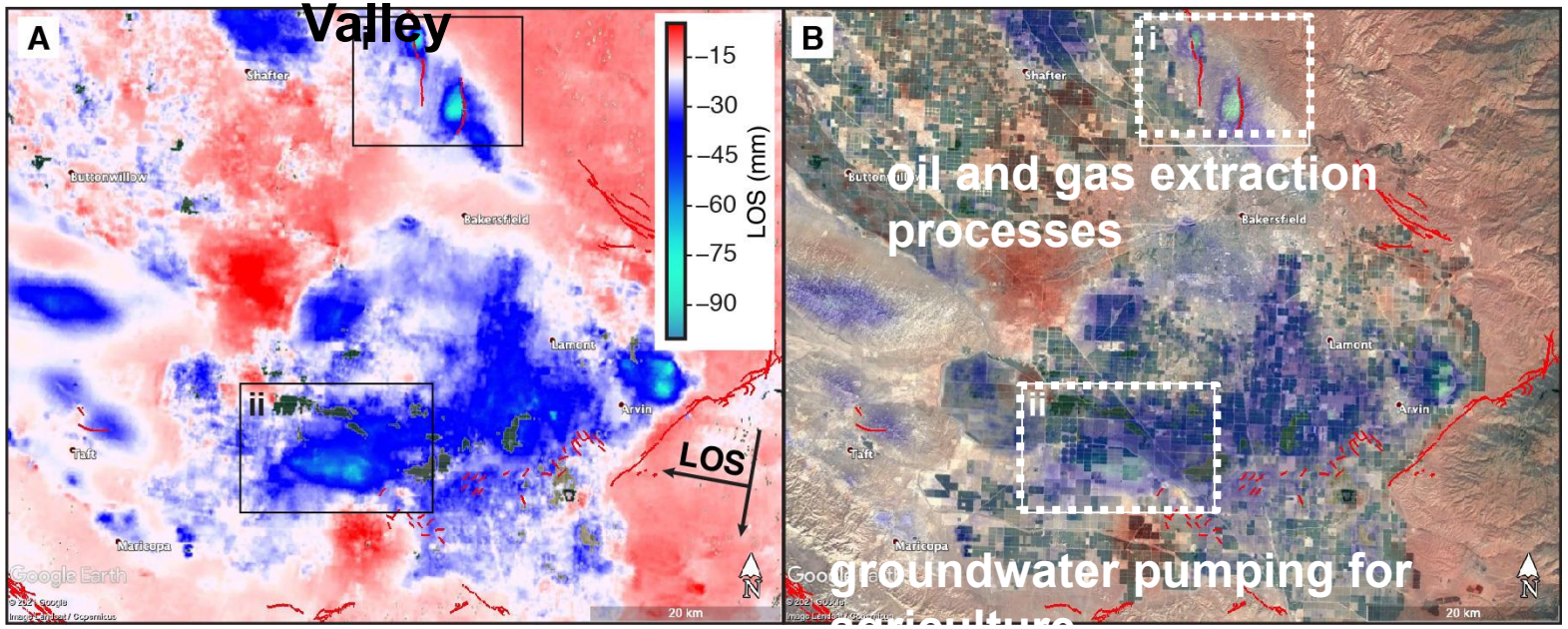
InSAR/GNSS Integration

Postseismic deformation



Cumulative 48-day line of sight **postseismic displacements** estimated pixel-by-pixel from a **GNSS-corrected InSAR time series** spanning the July, **2019 Ridgecrest earthquake sequence**. Source: Katherine Guns

Subsidence in the southern San Joaquin Valley



InSAR/GNSS-derived line of sight velocities showing **subsidence in the southern San Joaquin Valley**; (A) shows the velocity map covering the period 2014 - 2019, where the entire Valley is subsiding (note scale); (B) shows the same transparent velocity field overlying Landsat satellite imagery. Box (i) shows an area of subsidence due to oil and gas extraction processes, while box (ii) shows an area of groundwater

SOPAC Coordinate Interpolator Prompt

Translate coordinates across epochs

Info and references

Input

(•) Single Point ( ) List of Points

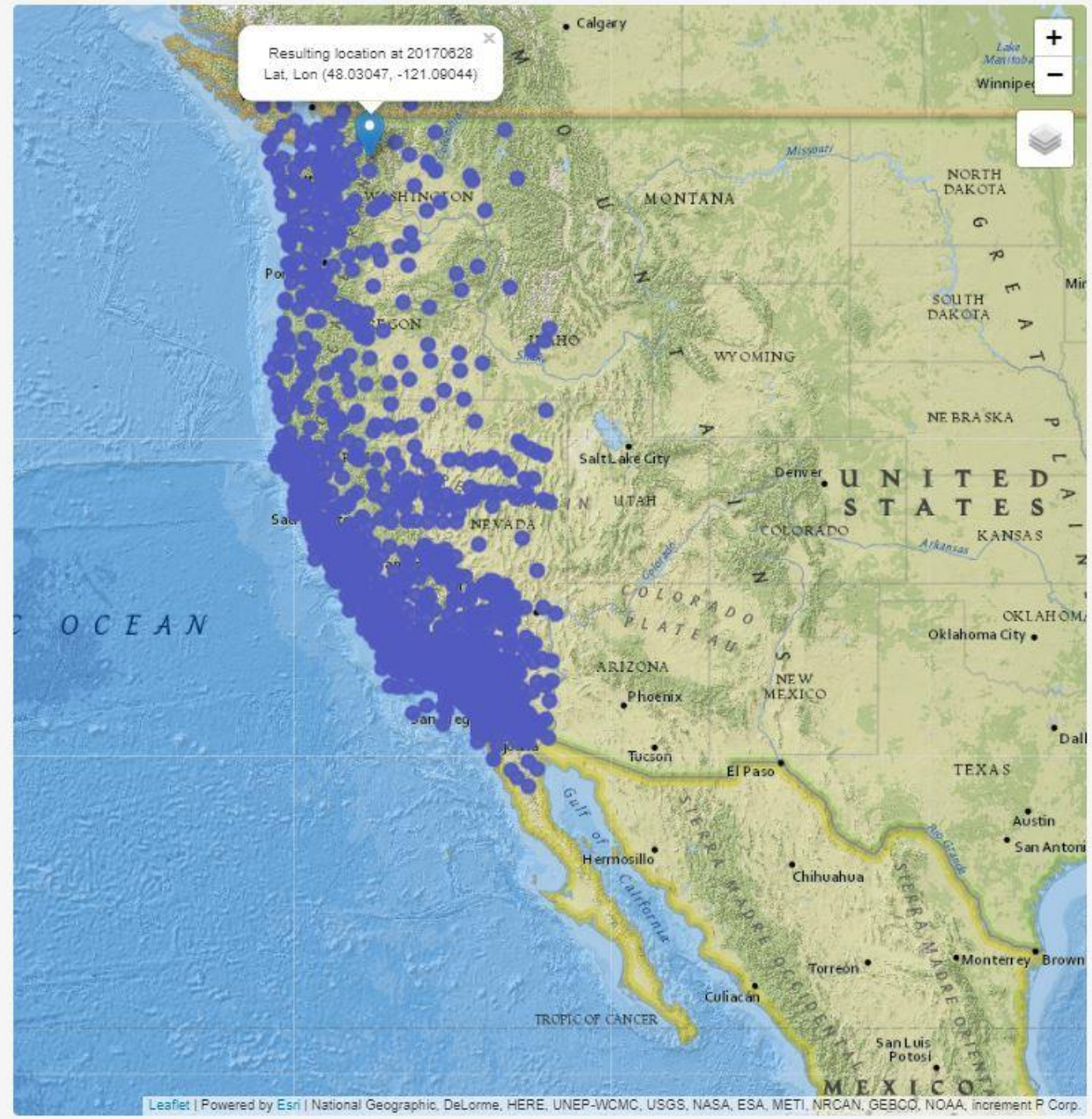
Format

Input Datum	WGS84 (Lat, Lon, Height)
Output Datum	NAD83(2011) (Lat, Lon, Height)
Date Format	Calendar Date
Lat/Lon Format	Decimal
Height Units	Feet

Location

Latitude (N)	48.03047798105397
Longitude (E)	-121.09045976833643
Ellipsoidal Height (ft) (optional)	100
T-in (range: 2010-present)	09/01/2020
T-out (range: 2010-present)	07/01/2017

Get Coordinates




Thank you!
Questions?
Photo by Catherine Johnson, November 2005