Understanding Earthquakes using Remote Observations

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San Andreas fault

Collaborators:

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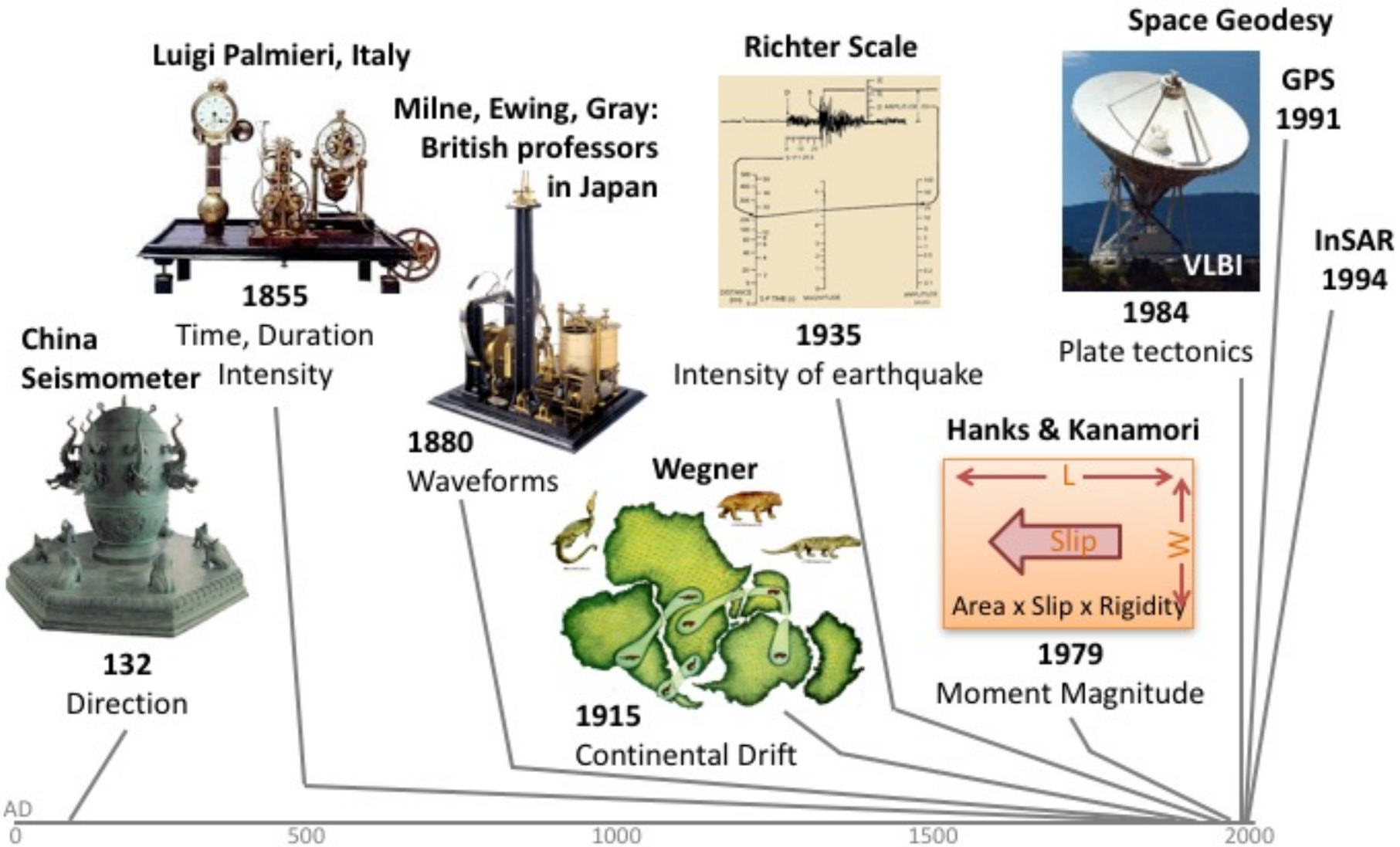
Government sponsorship acknowledged.

Earthquake Processes

- Earthquakes can cause tremendous loss of life and property
- Predicting the behavior of earthquake fault systems is exceptionally difficult
- The Earth's crust is complex
  - Seismic and aseismic motions
- Earthquakes generate at depth
  - Problematic for understanding earthquake fault behavior

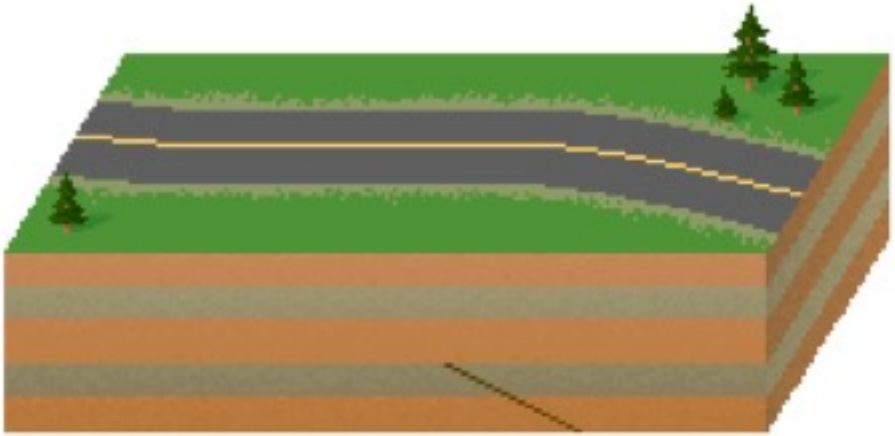
Annualized earthquake losses in California $3.5B (66% of the national losses)

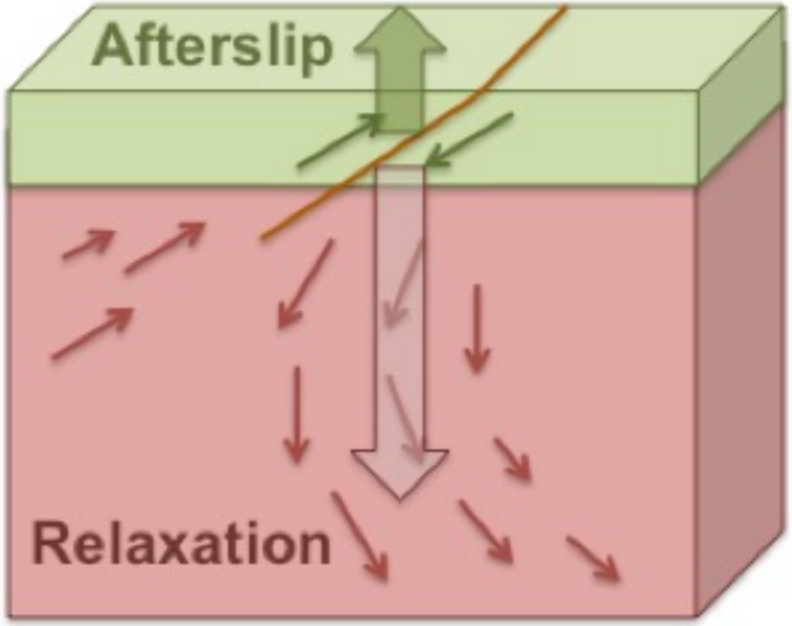
Earthquake Studies: A Brief History



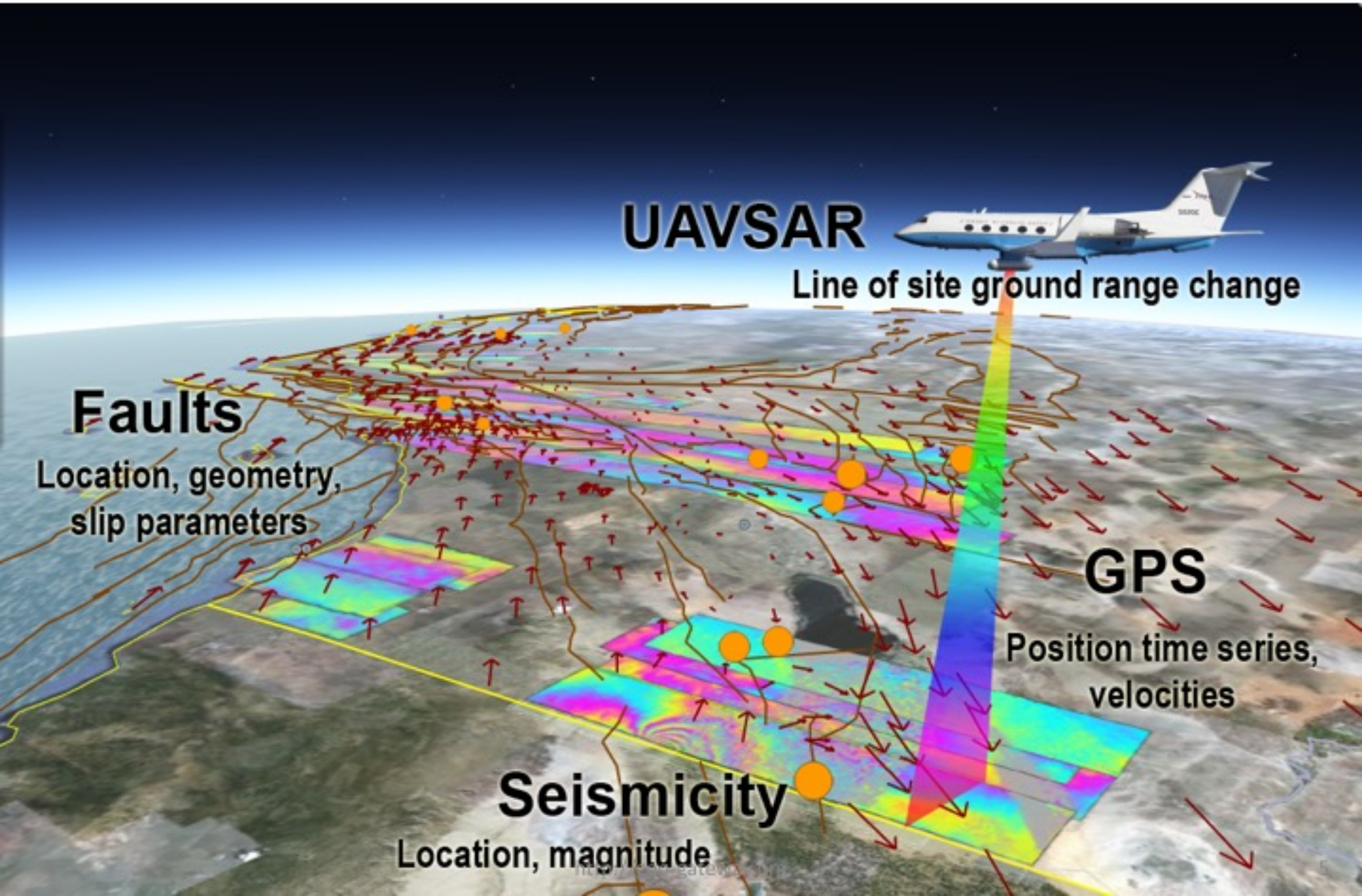
Geodetic Imaging

- Measurement of deformation of the surface of the Earth's crust
- Tectonic and fault motions deform the surface



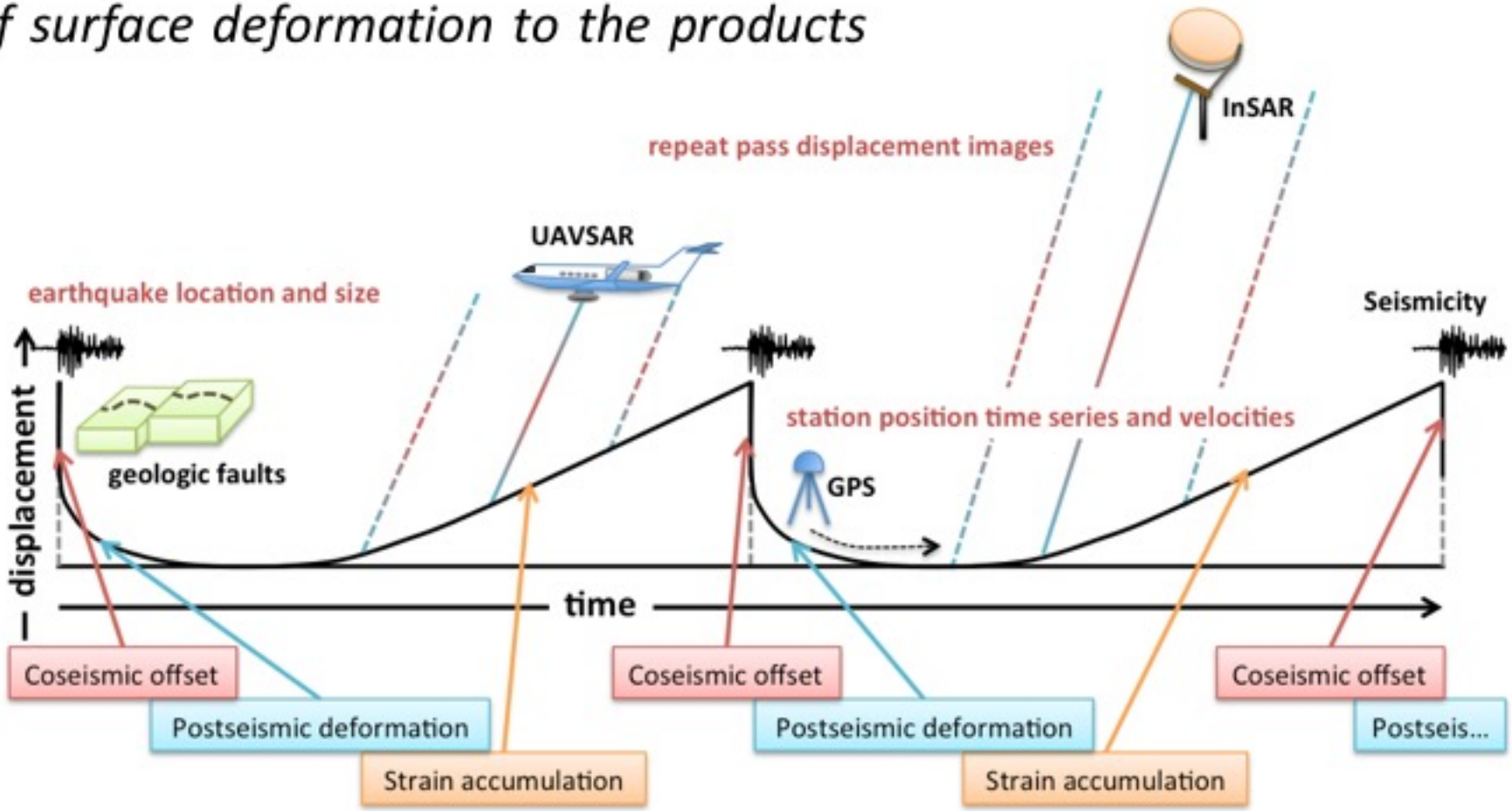


Observations



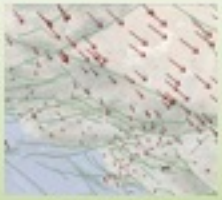
Complex Earthquake Cycle

Earthquakes and postseismic response complicate the already heterogeneous data by adding episodic jumps and changing rates of surface deformation to the products



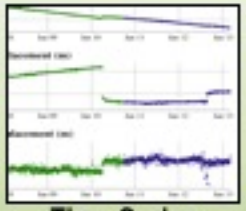
Data Sources

GPS



Velocities

Anomalies



Time Series

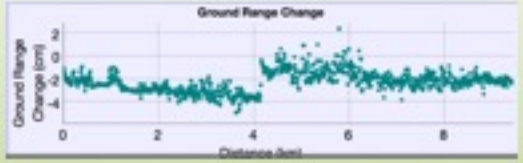
Faults

Fault Map

Metadata

InSAR/UAVSAR

Interferogram



Line of Sight Profile

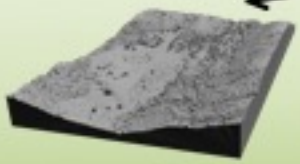
Seismicity

Earthquakes

Forecast

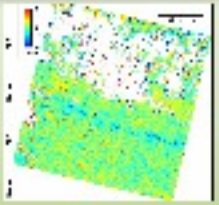
Optical

Small UAV

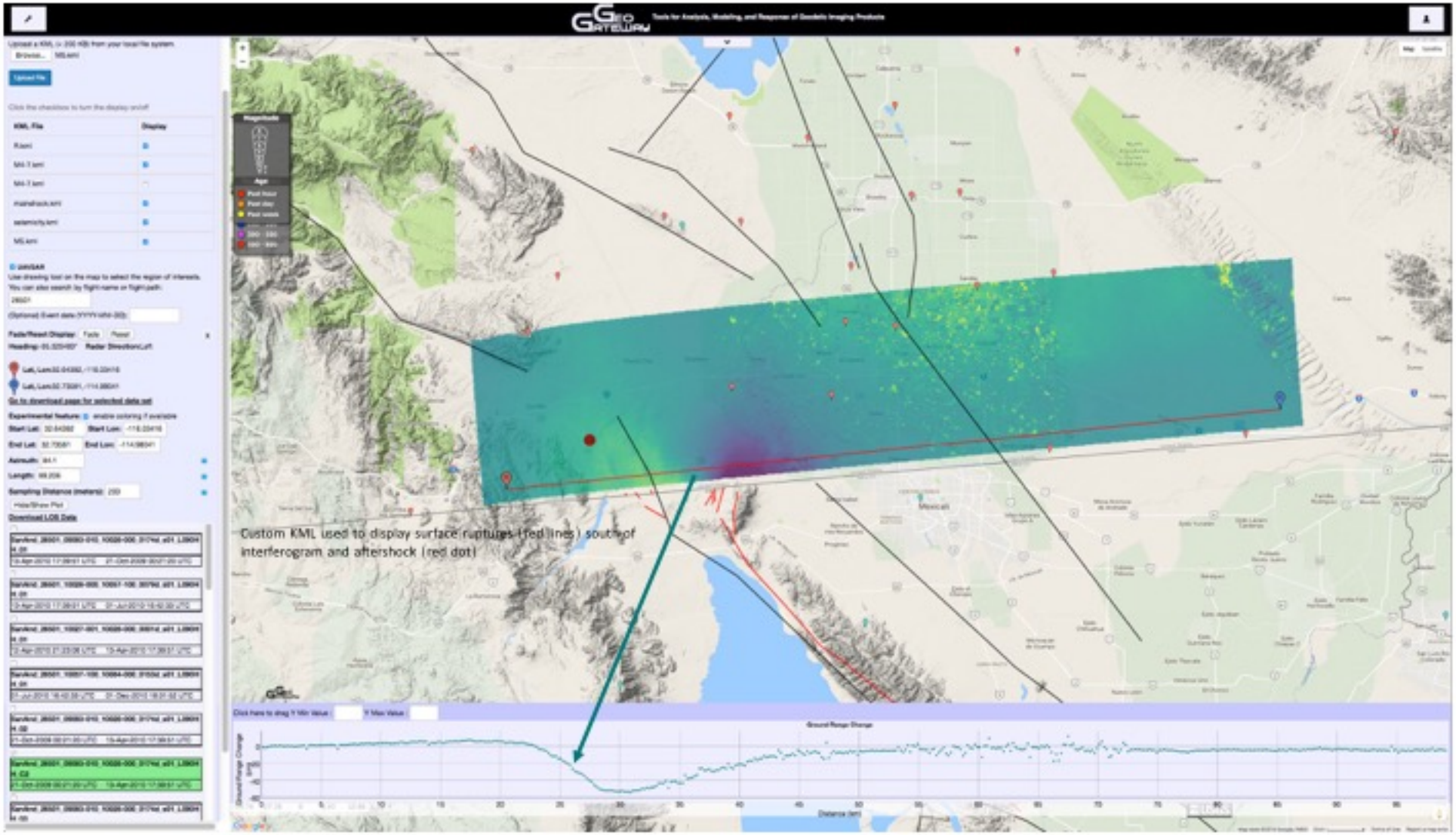


Digital Elevation Model

Displacement (Landsat)

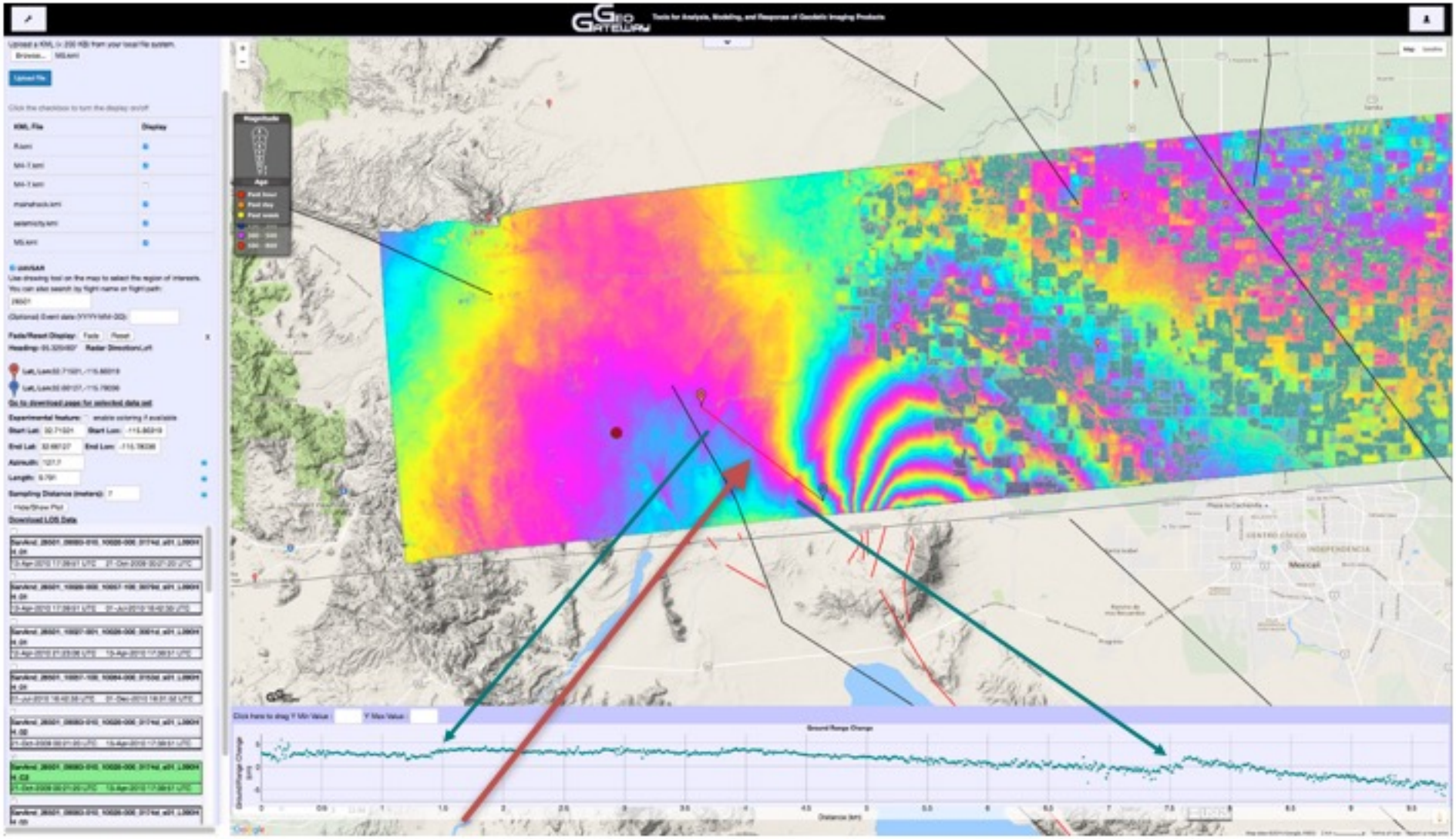


UAVSAR Line of Sight Measurement



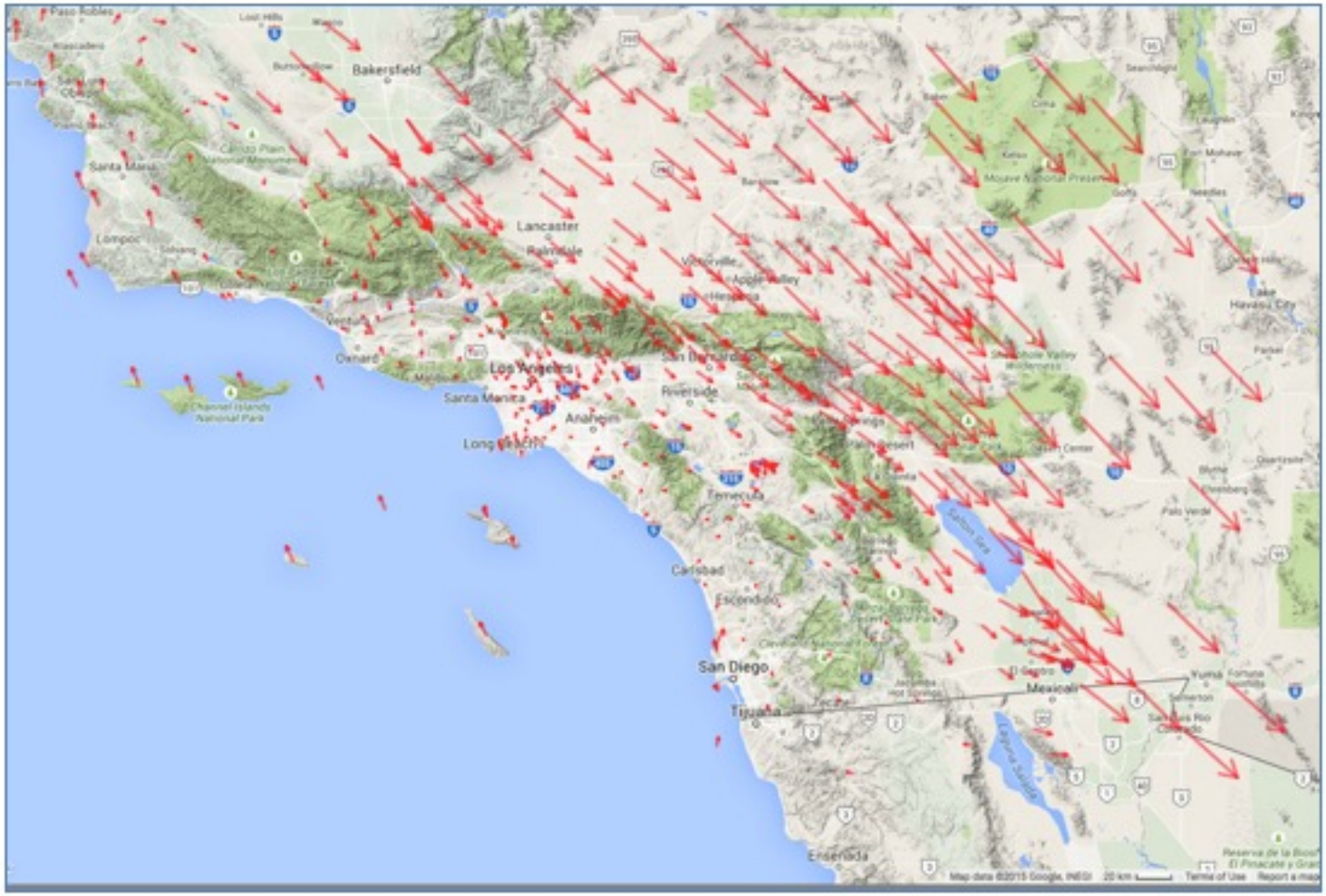
Single color range makes it easier to interpret large scale deformation

Can Find Details of Surface Motions



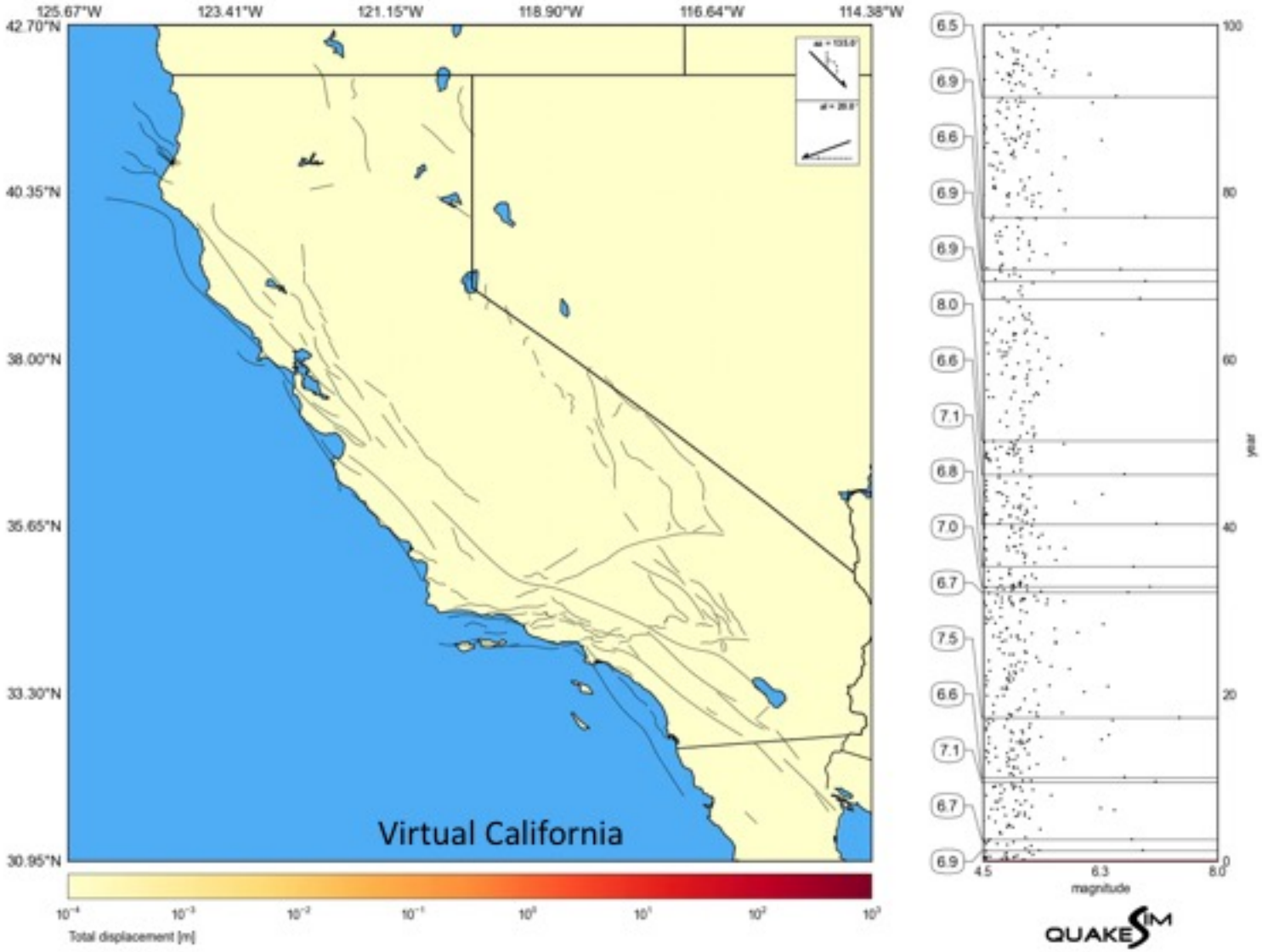
Fringes can highlight subtle features

GPS Velocities



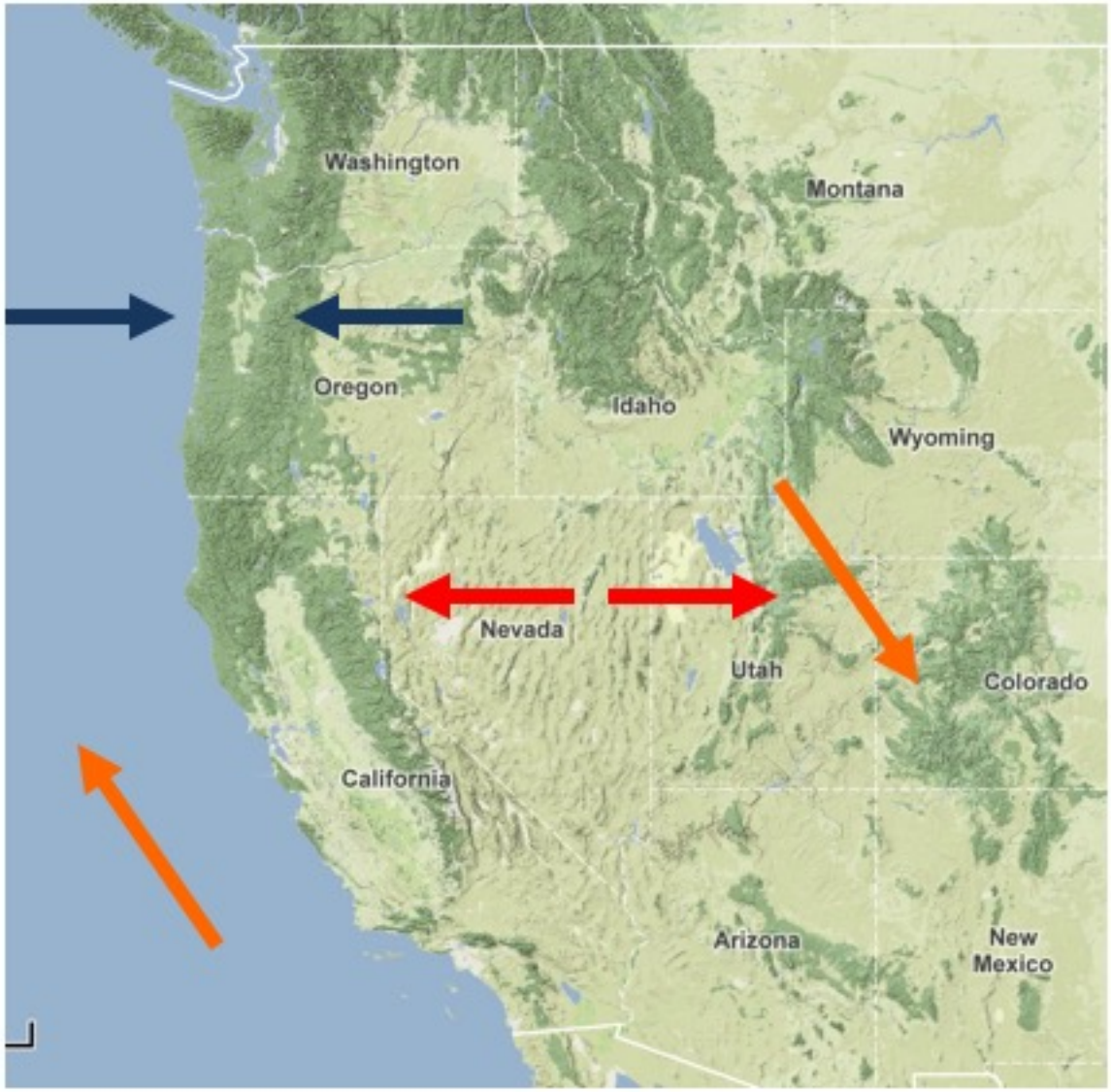
Changing the reference station highlights different aspects of crustal deformation

Earthquake Faults Interact

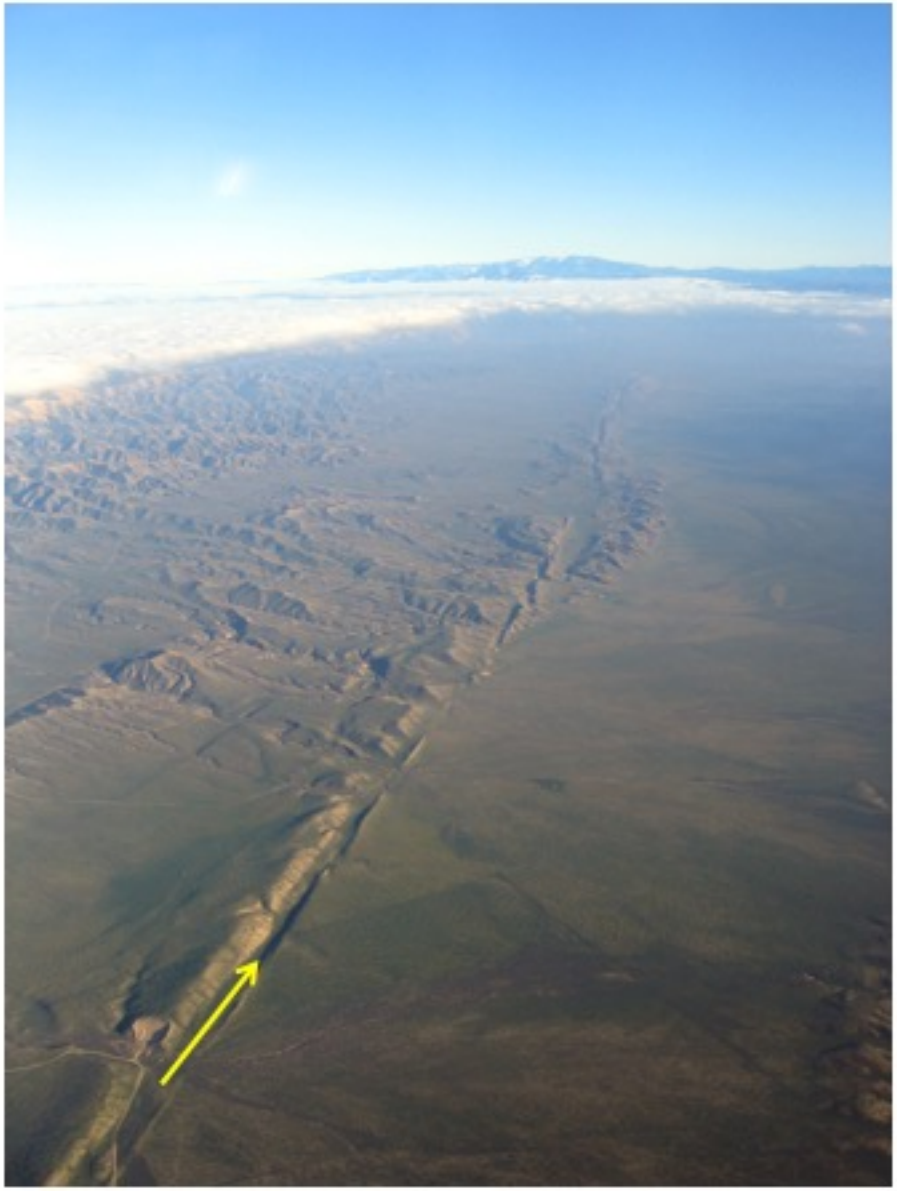


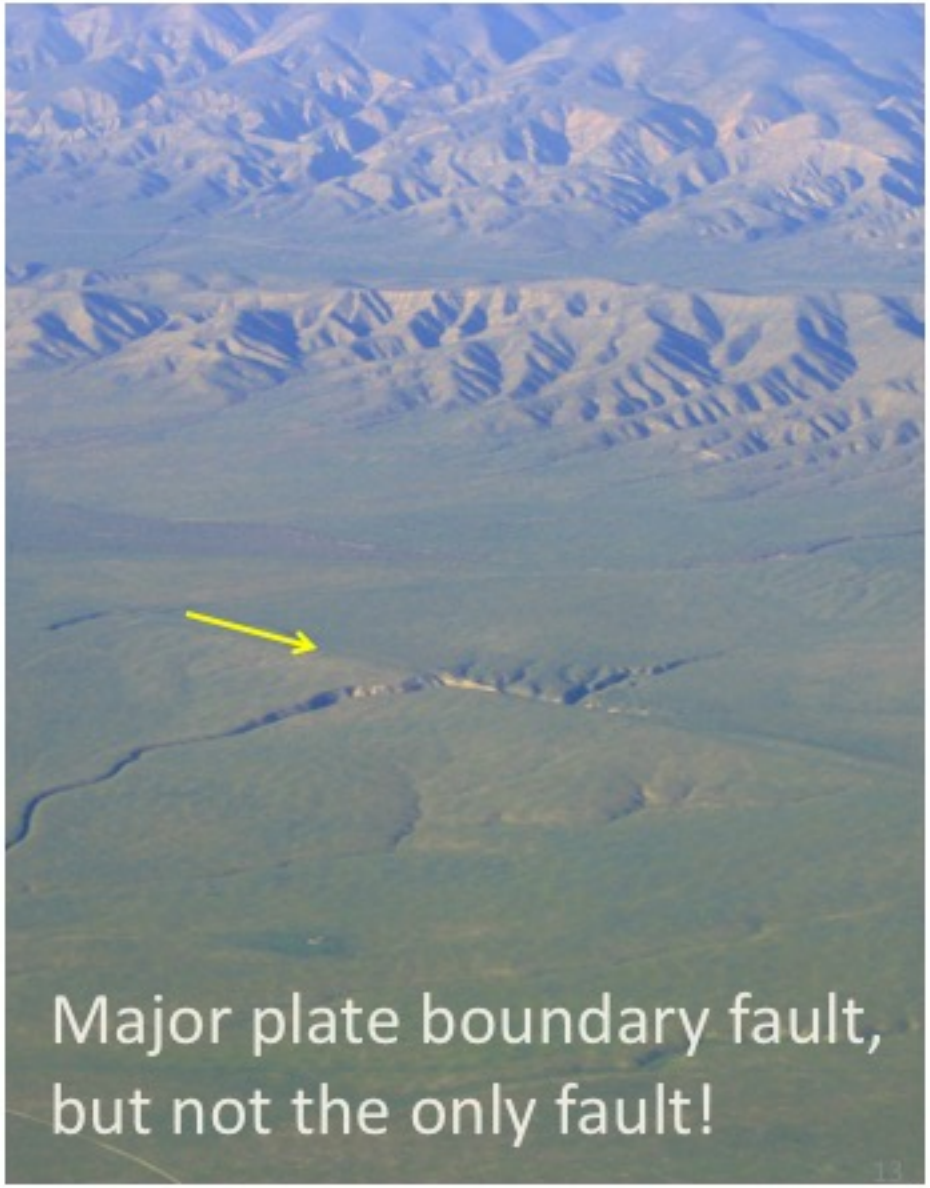
Courtesy Michael Karl Sachs, UC Davis

Western United States



San Andreas Fault

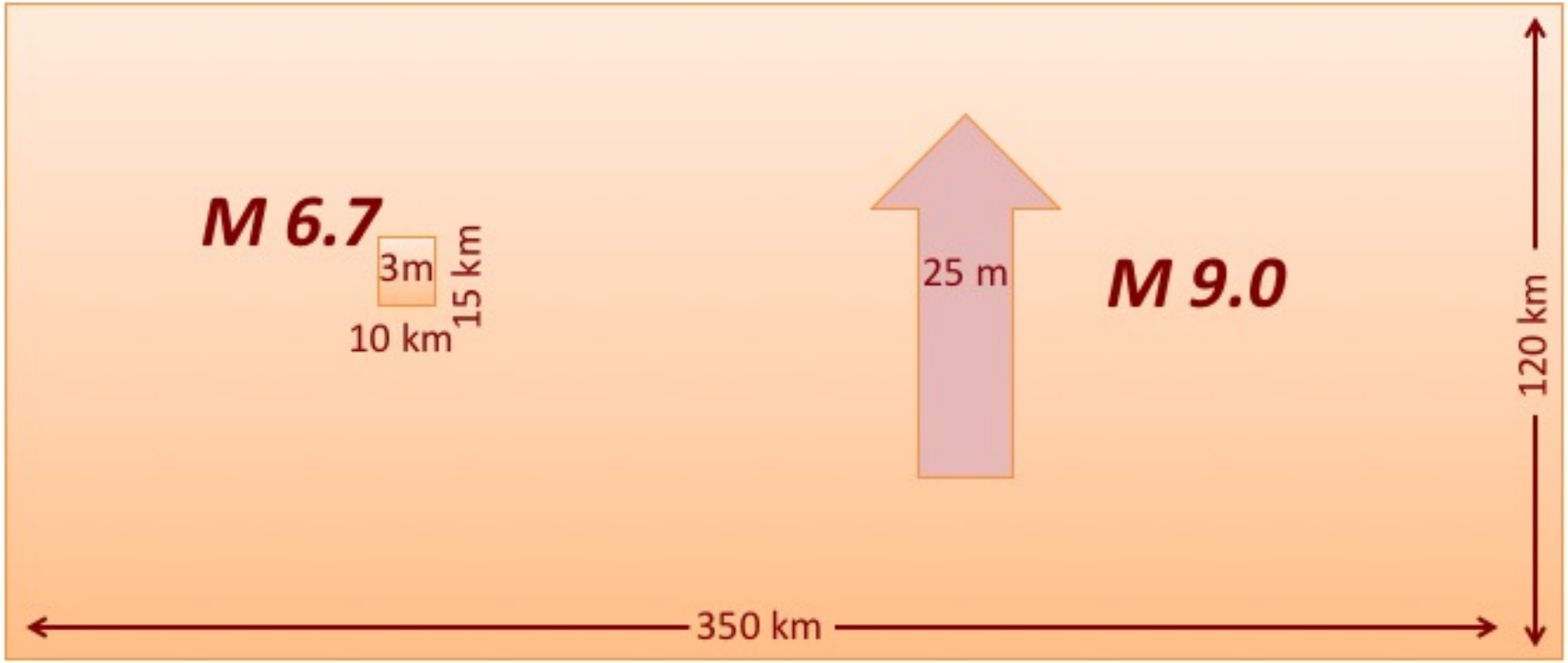




Conceptual View of Fault Motions

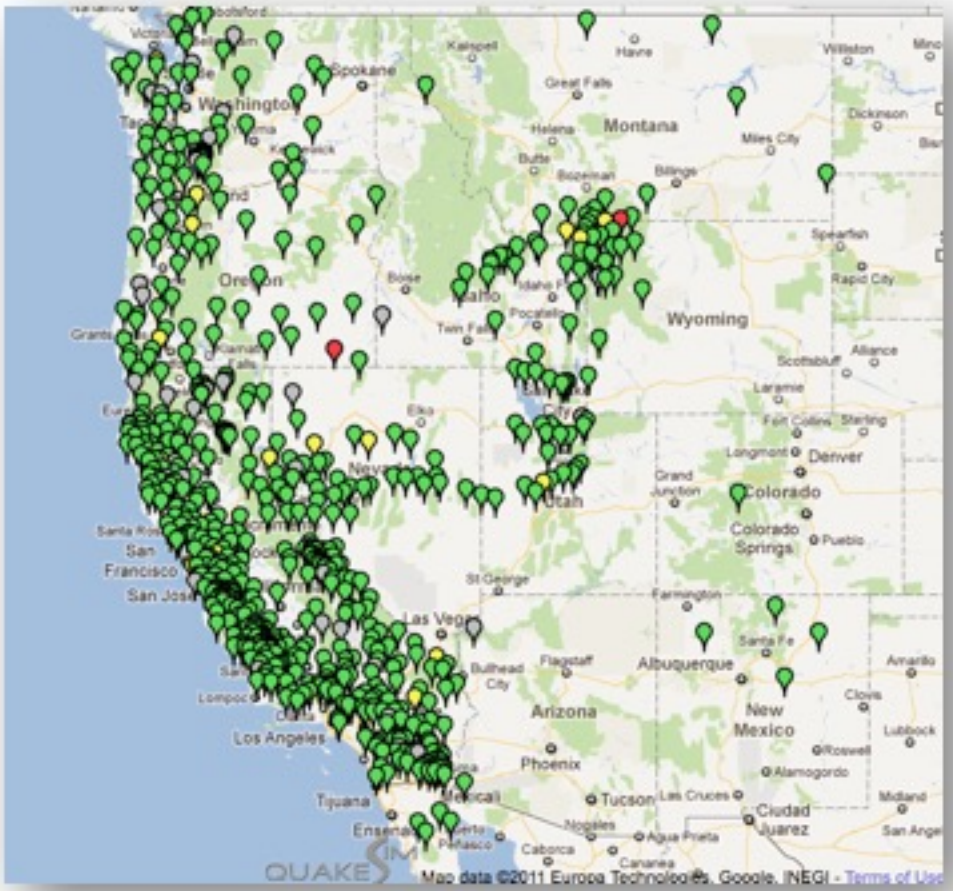
Earthquake Magnitude

Magnitude is related to size and slip on a fault plane



2011 M 9.0 Japan Earthquake versus 1994 M 6.7 Northridge Earthquake

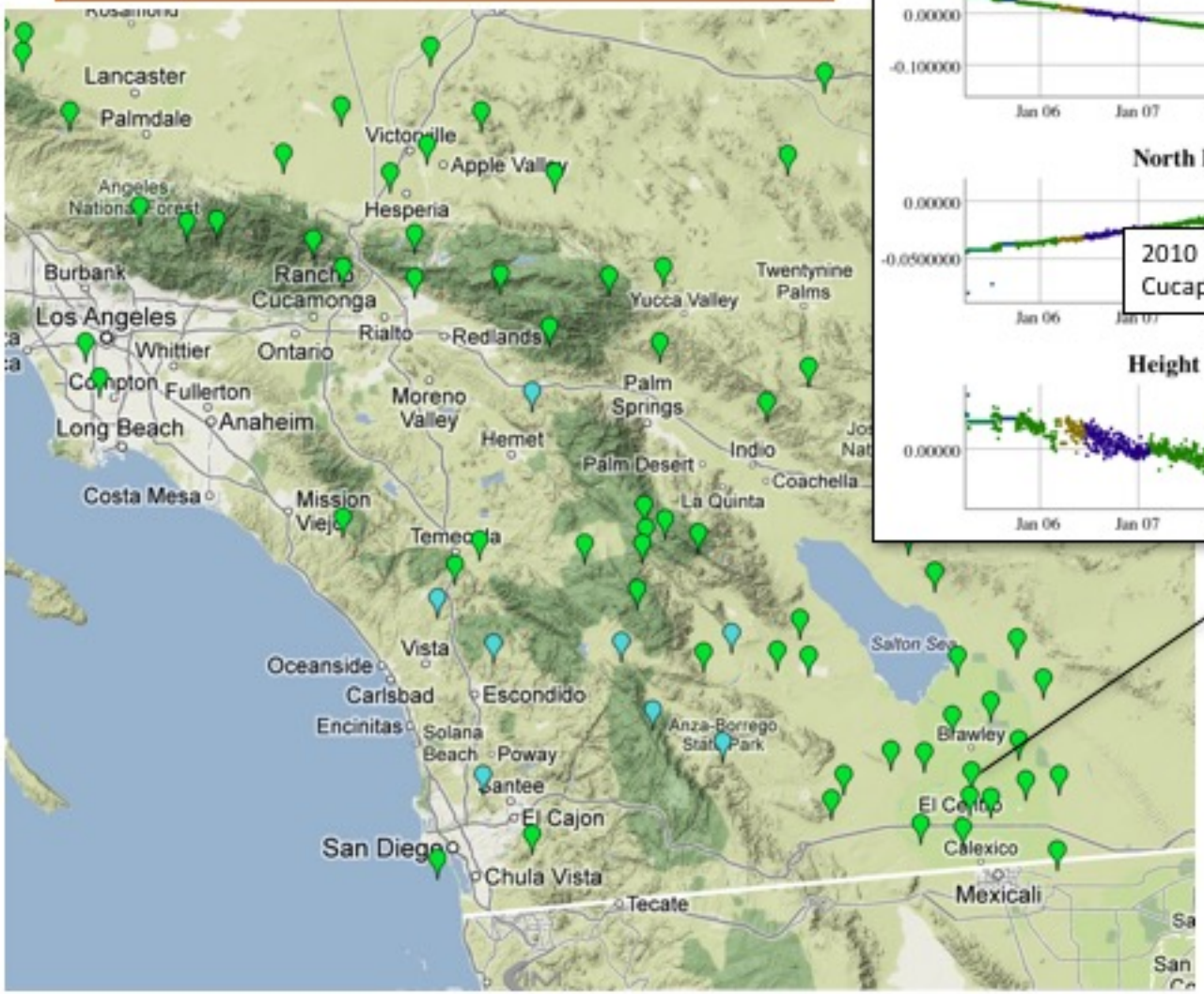
GPS Positions and Velocities

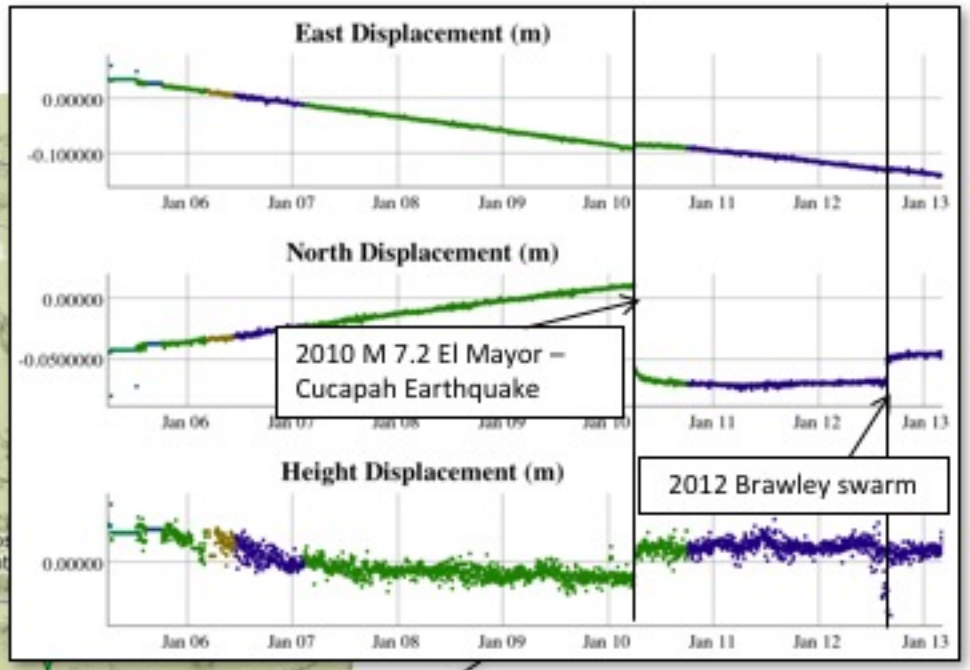


Horizontal position accuracy 1 mm
Vertical position accuracy 2 mm
1 mm/yr horizontal velocities

GPS Time Series

Incorporating high data rate GPS



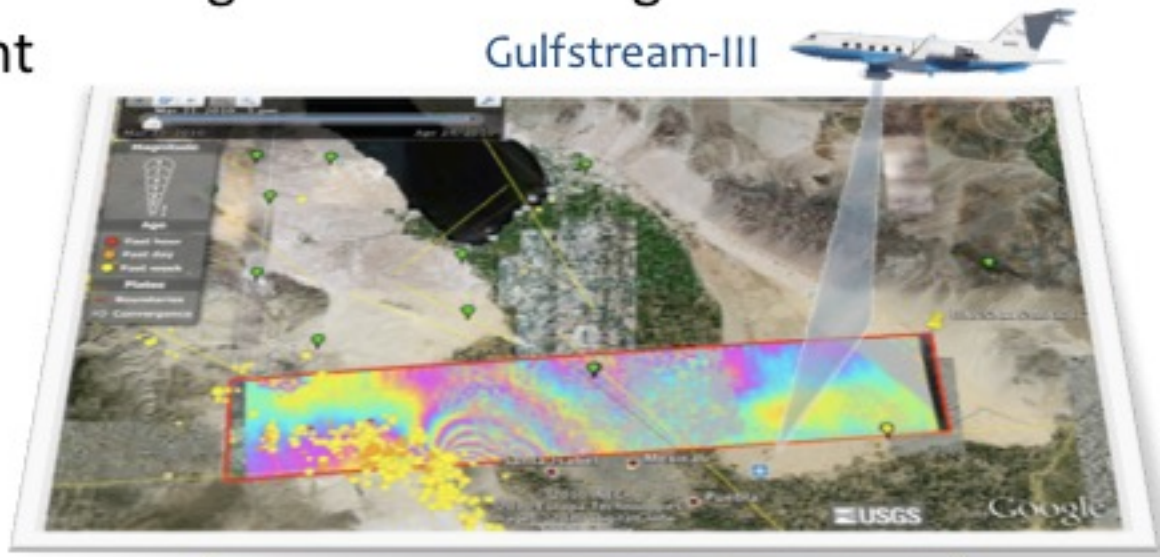


UAVSAR/InSAR

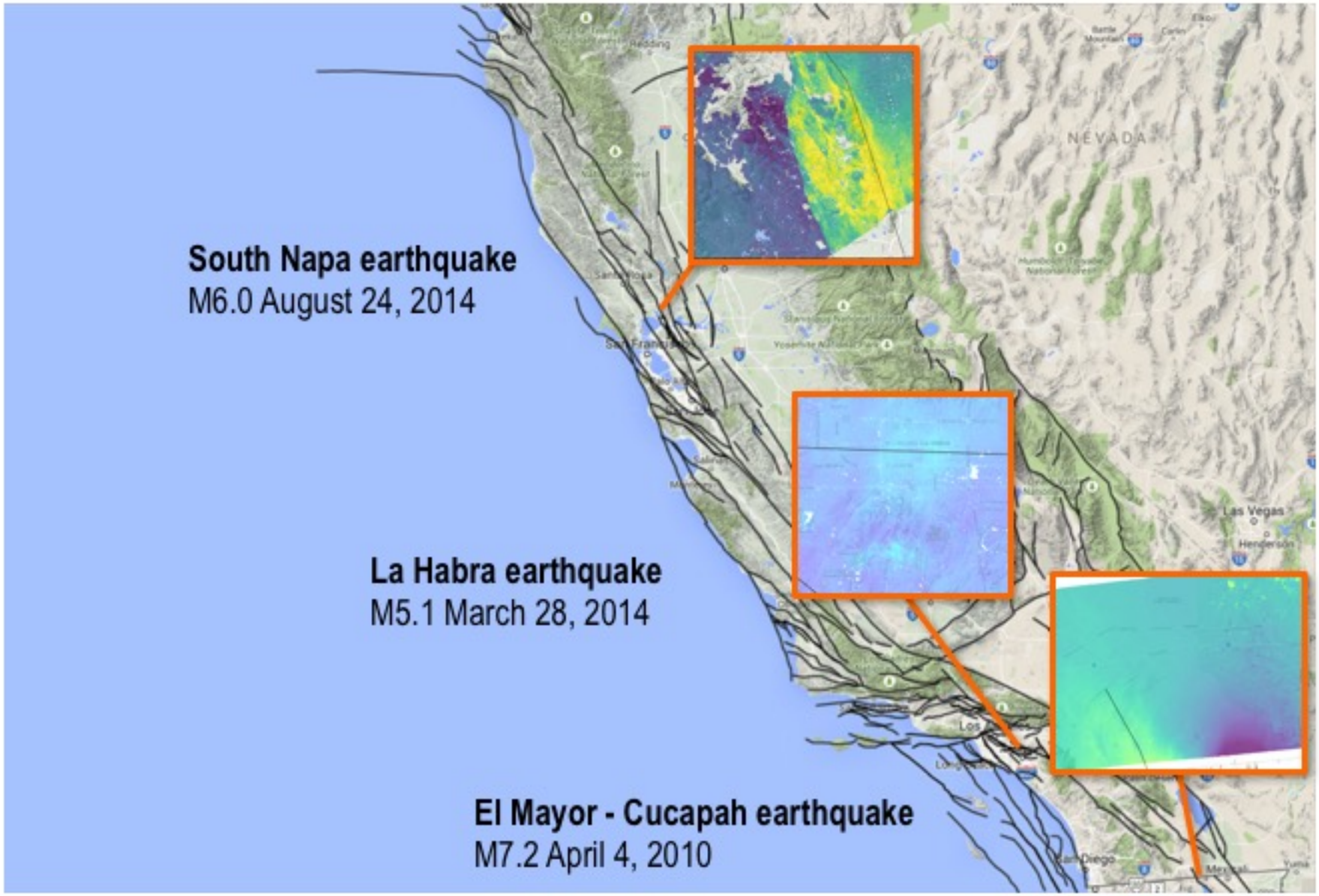
- Airborne Interferometric synthetic aperture radar (InSAR)
- Products provide ground changes in a line of sight direction to/from the instrument

UAVSAR

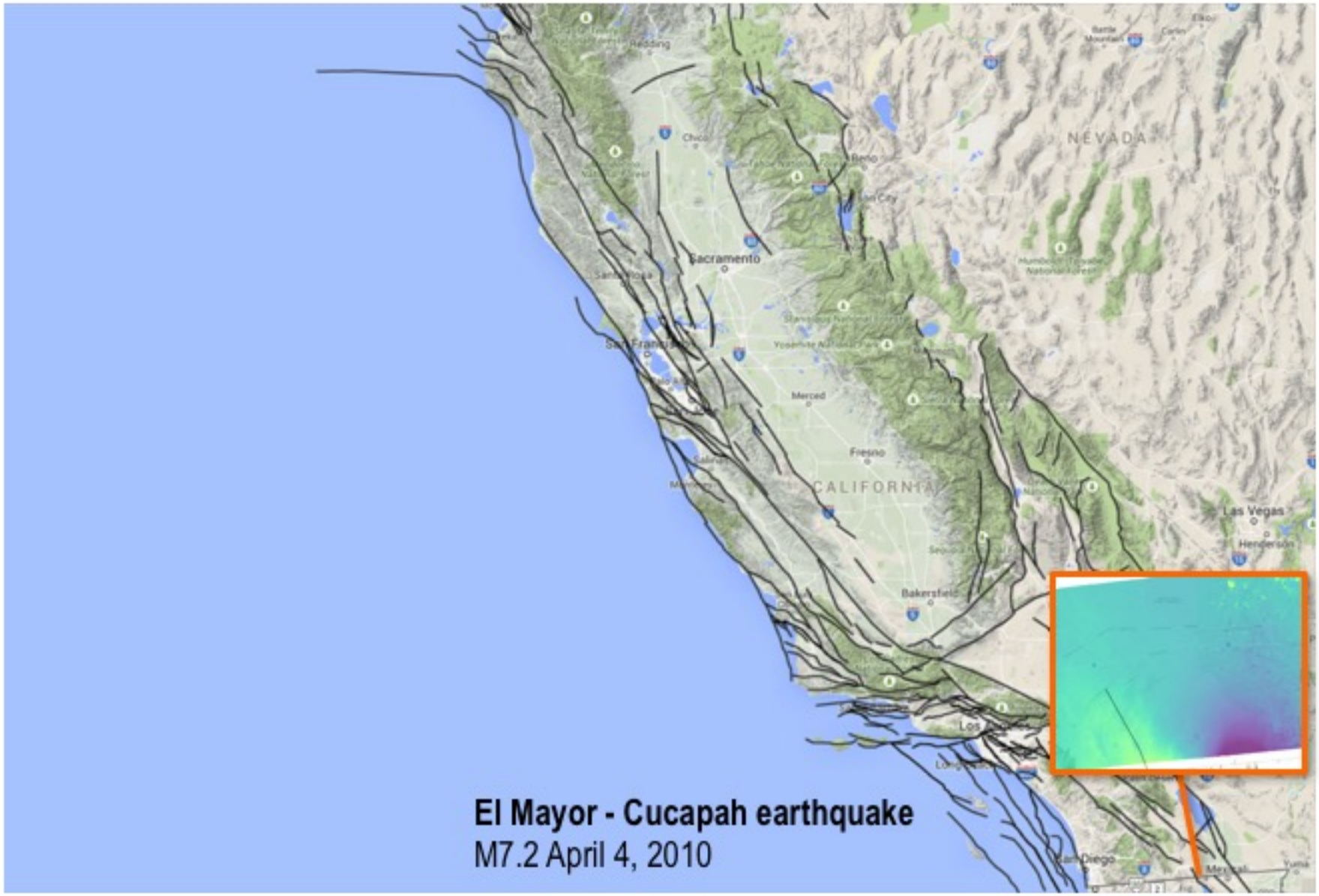
- Airborne InSAR
- L-band (24 cm wavelength)
- Repeat pass interferometry
- Flown on a Gulfstream III
- Color cycle is 12 cm



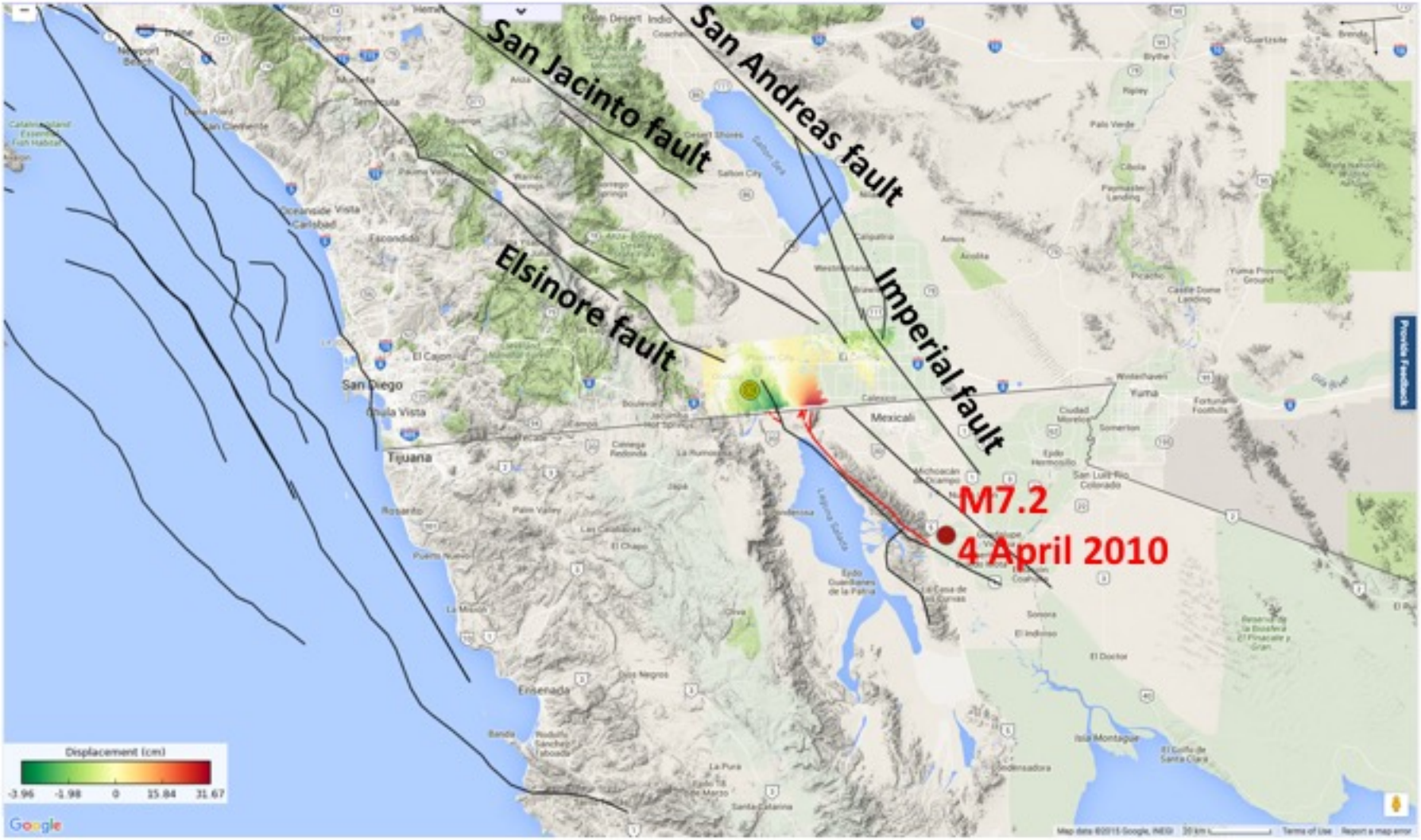
Earthquakes Observed with UAVSAR



2010 M7.2 El Mayor – Cucupah Earthquake

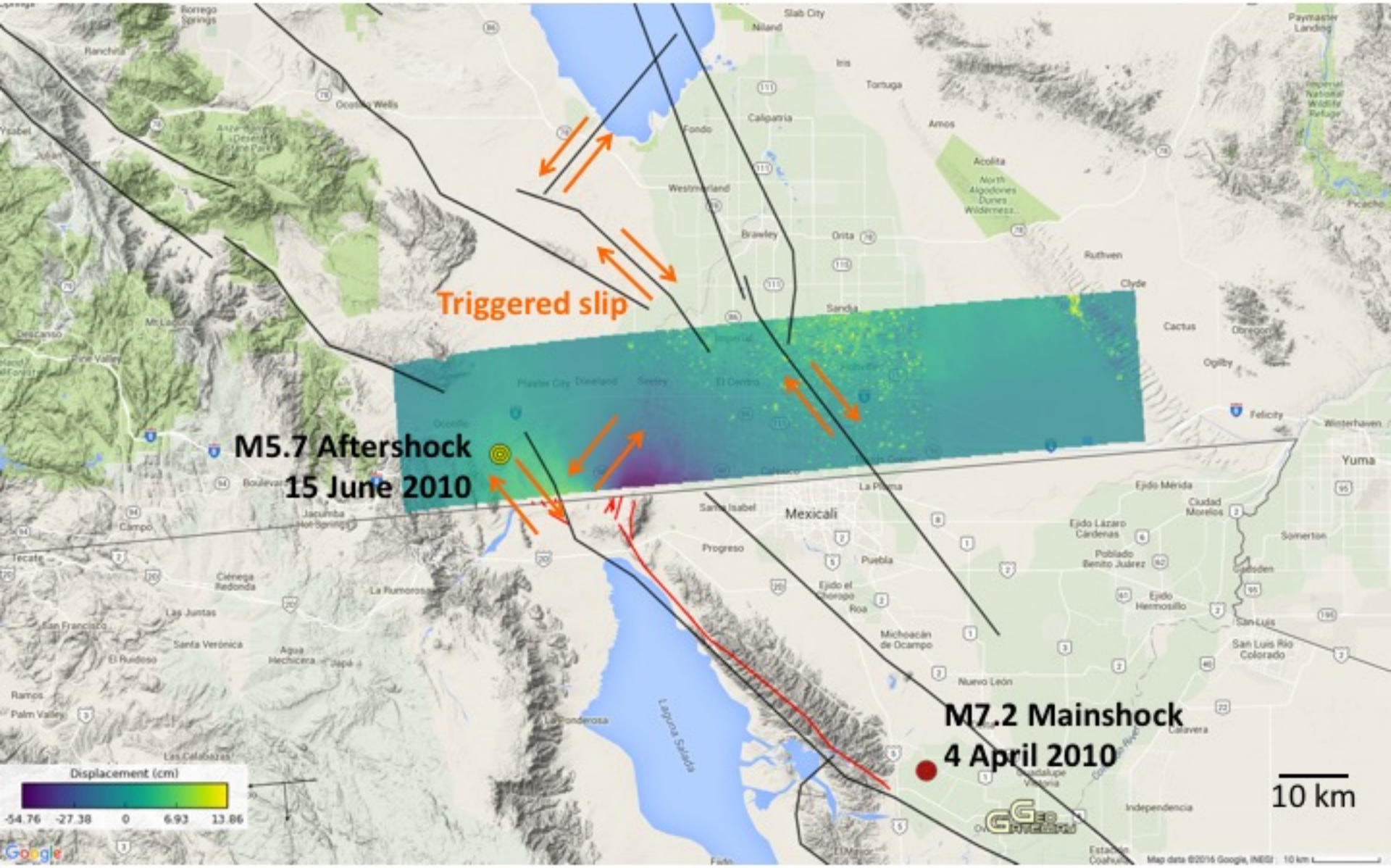


Setting

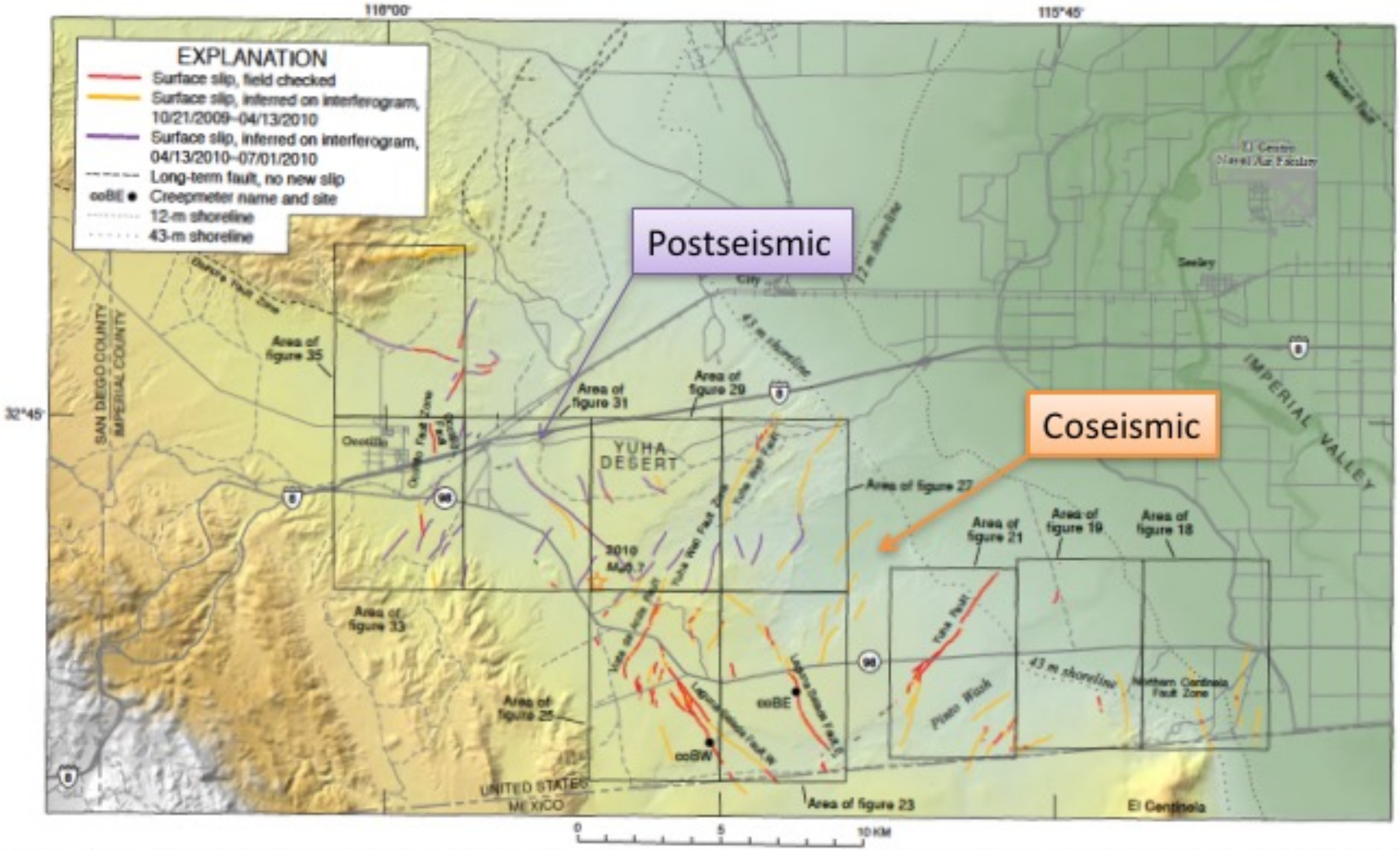


UAVSAR Interferogram 21 October 2009 – 13 April 2010

2010 M7.2 El Mayor – Cucapah Earthquake

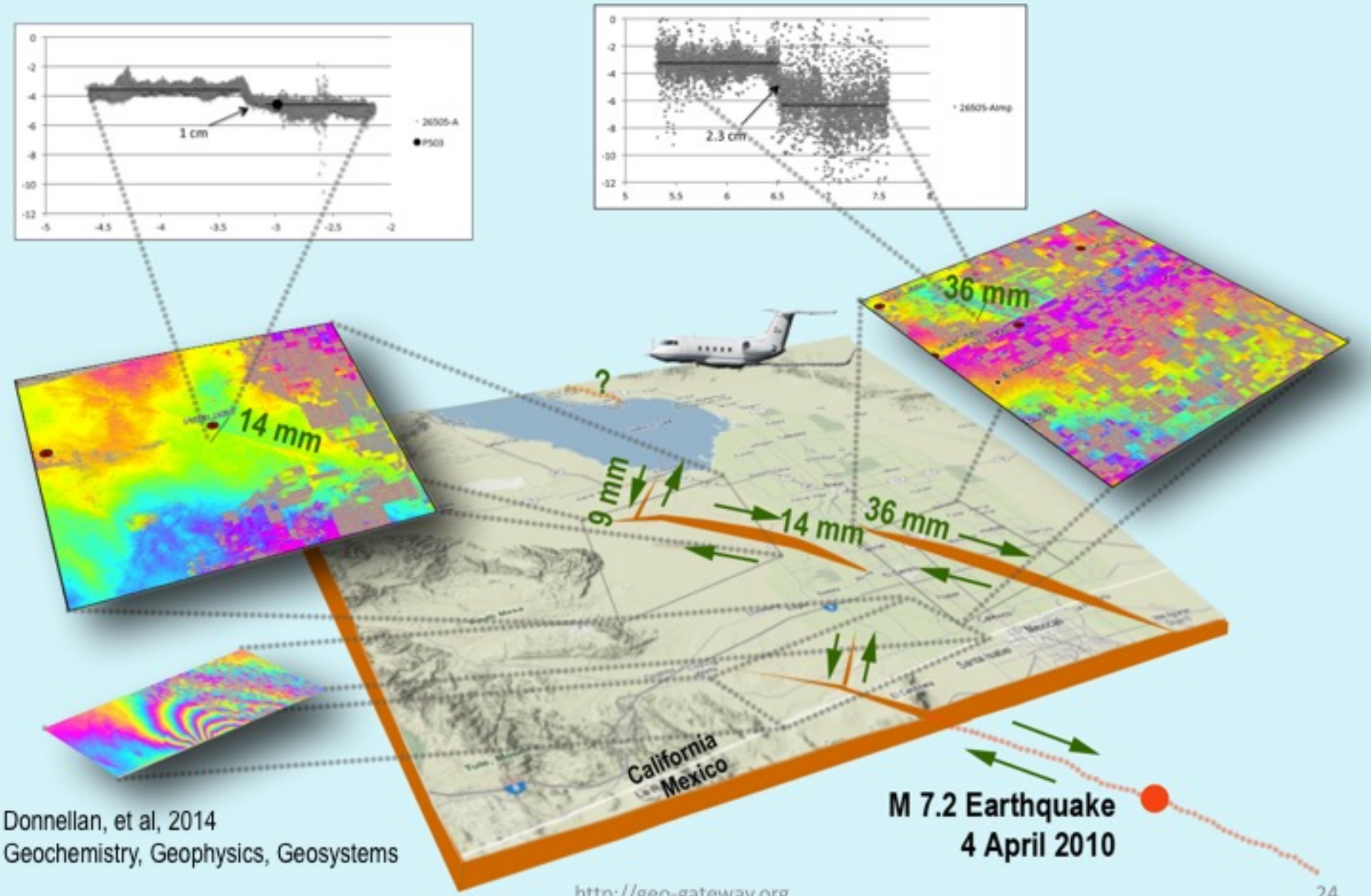


UAVSAR Guided Field Mapping



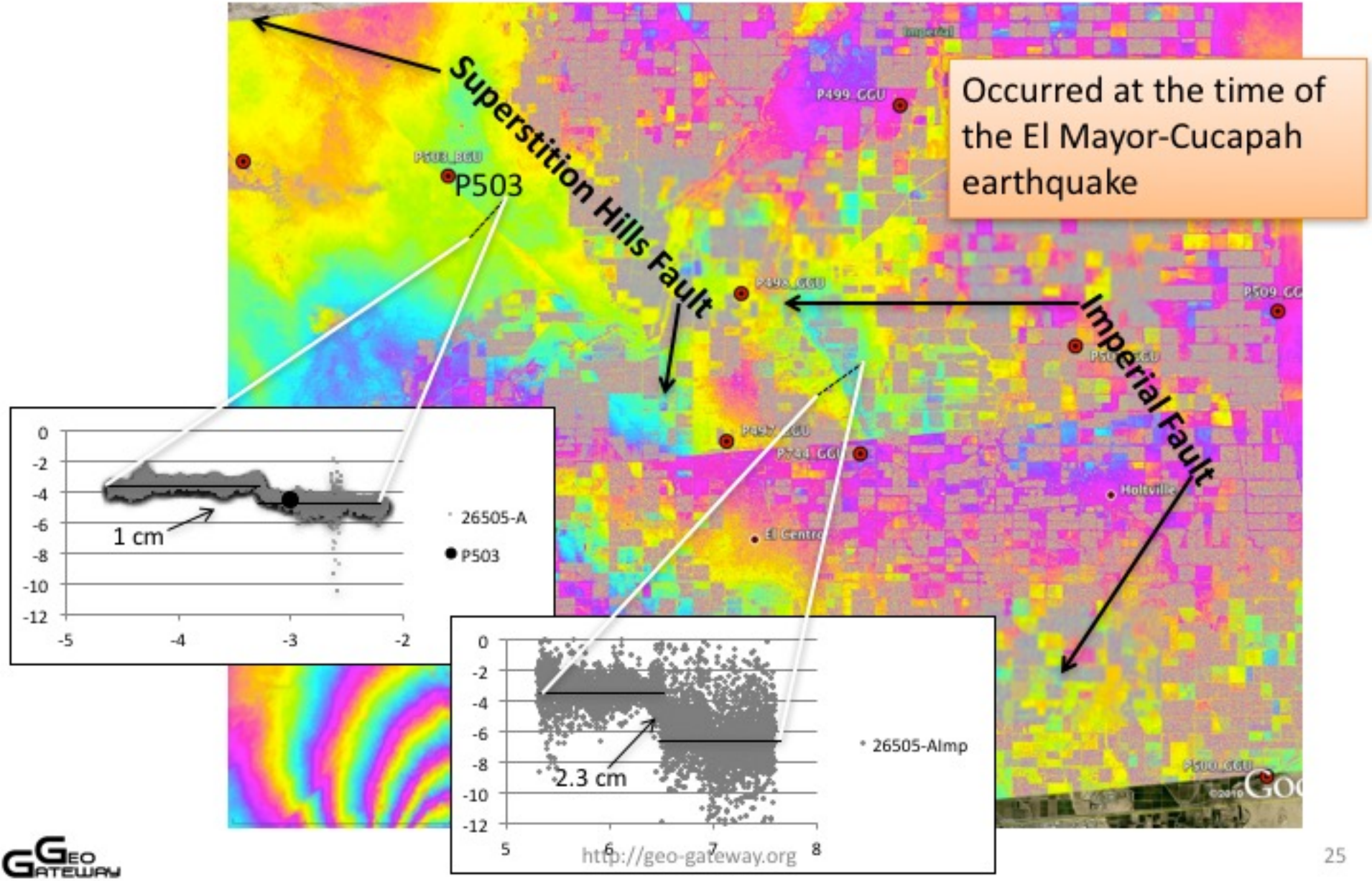
Rymer et al (2011), Triggered Surface Slips in Southern California Associated with the 2010 El Mayor – Cucapah, Baja California, Mexico Earthquake, U.S. Geological Survey Open-File Report 2010-1333 and California Geological Survey Special Report 221

Salton Trough Coseismic Triggered Slip

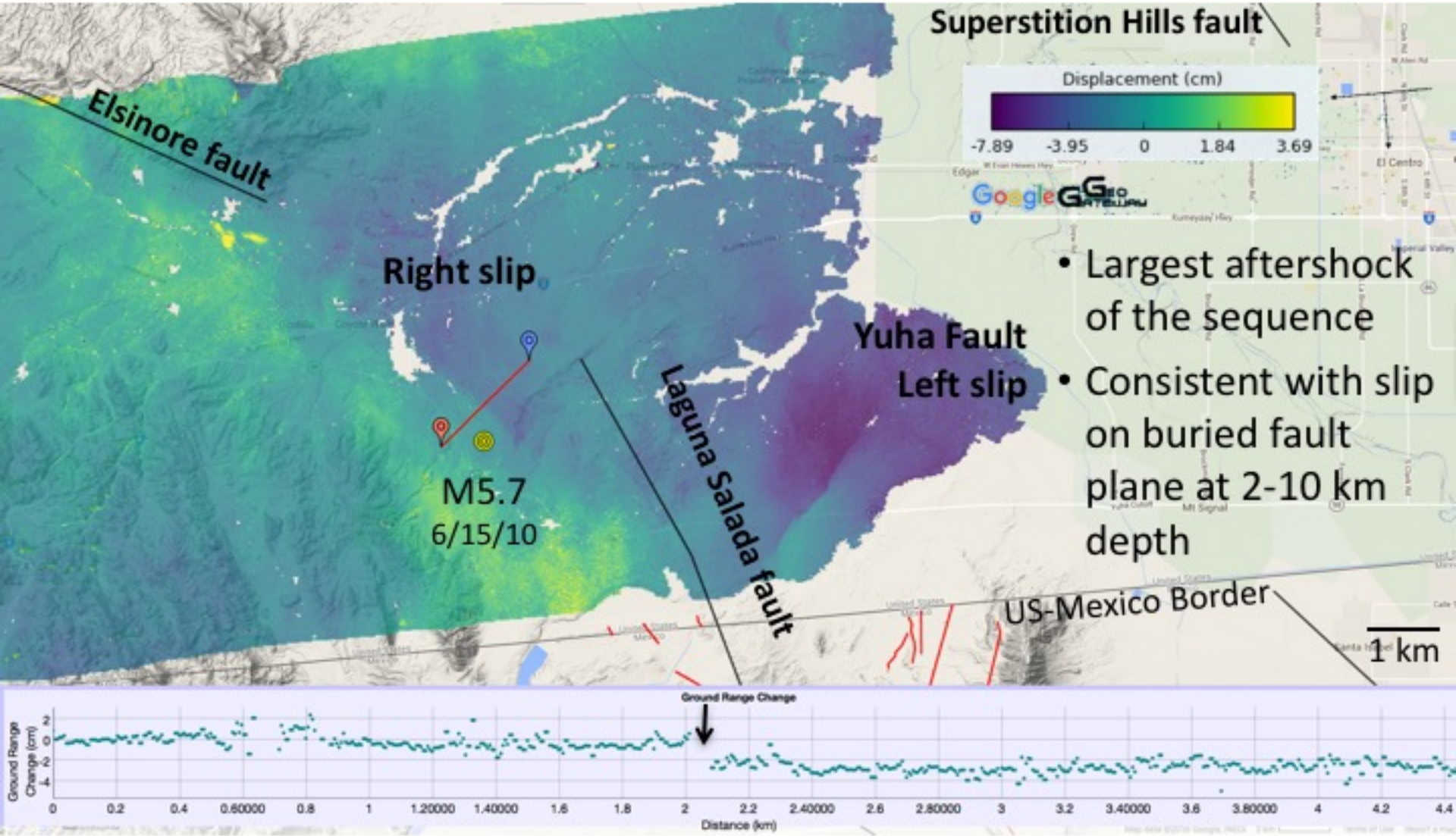


Donnellan, et al, 2014
Geochemistry, Geophysics, Geosystems

Creep Occurred on Faults to the North



Additional Slip from M5.7 Aftershock

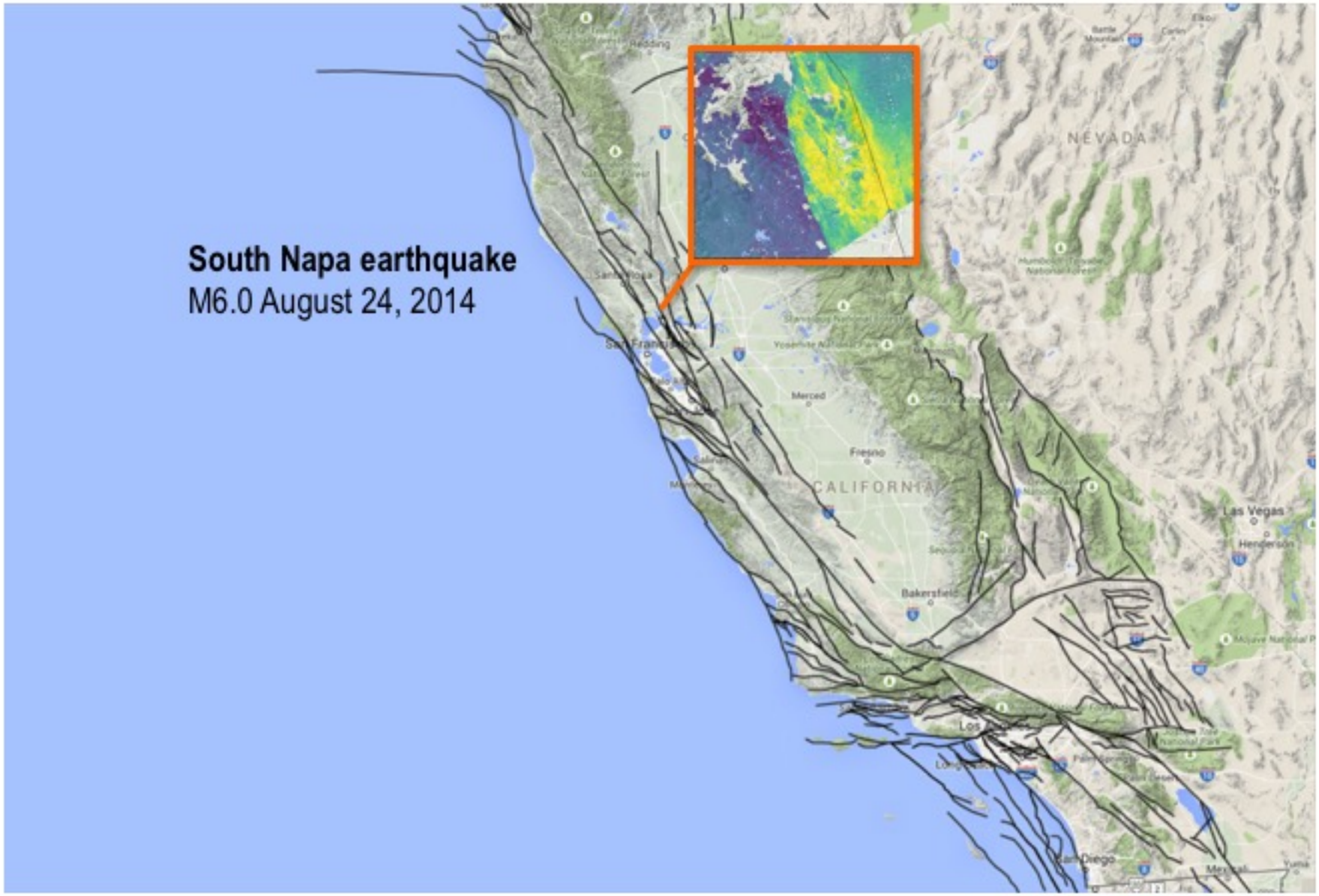


- Largest aftershock of the sequence
- Consistent with slip on buried fault plane at 2-10 km depth

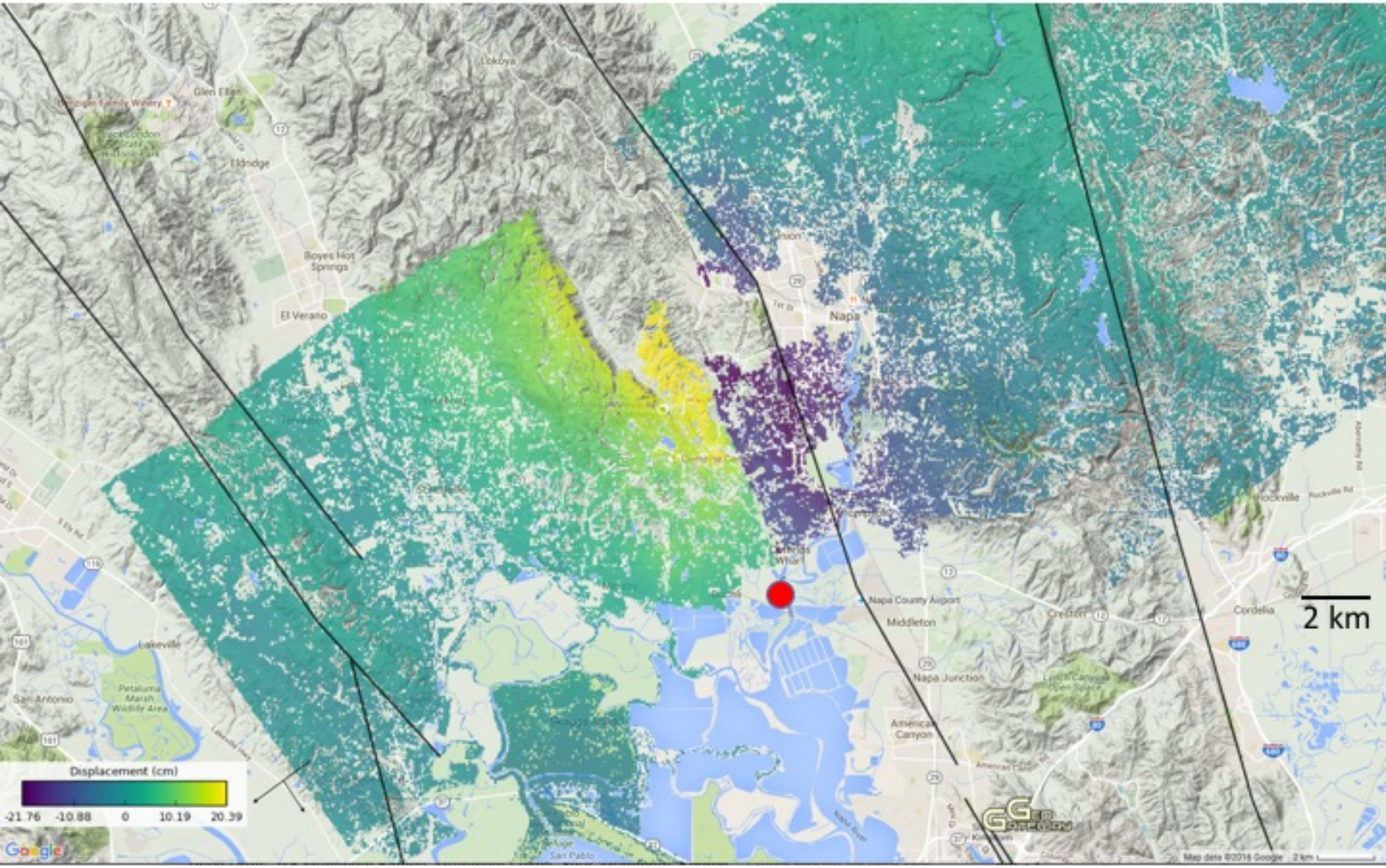
13 April 2010 – 11 February 2014

Structure connects El Mayor – Cucapah rupture and Elsinore Fault

2014 M6.1 South Napa Earthquake



2014 M6.2 South Napa Earthquake



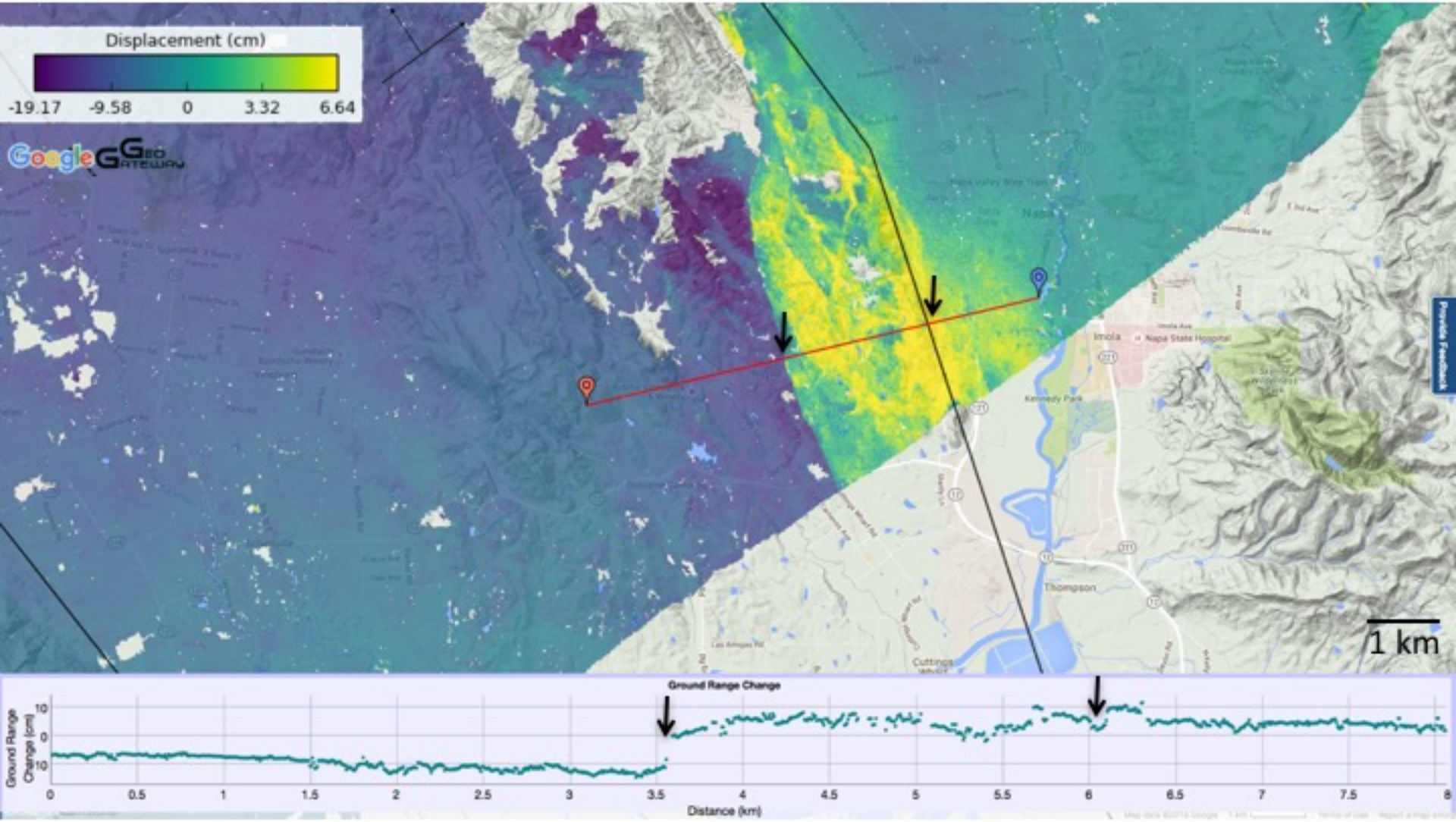
UAVSAR Guides South Napa Assessment

"The UAVSAR image… shows that afterslip extends northward, but with a steadily decreasing amount, up to the intersection of the main fault strand with Partrick Road... From that point to the north, there is no evidence for afterslip, so that section of the fault is rated low afterslip hazard."

Hudnut, K.W., et al.,, 2014, Key recovery factors for the August 24, 2014, South Napa earthquake: U.S. Geological Survey Open-File Report 2014–1249.

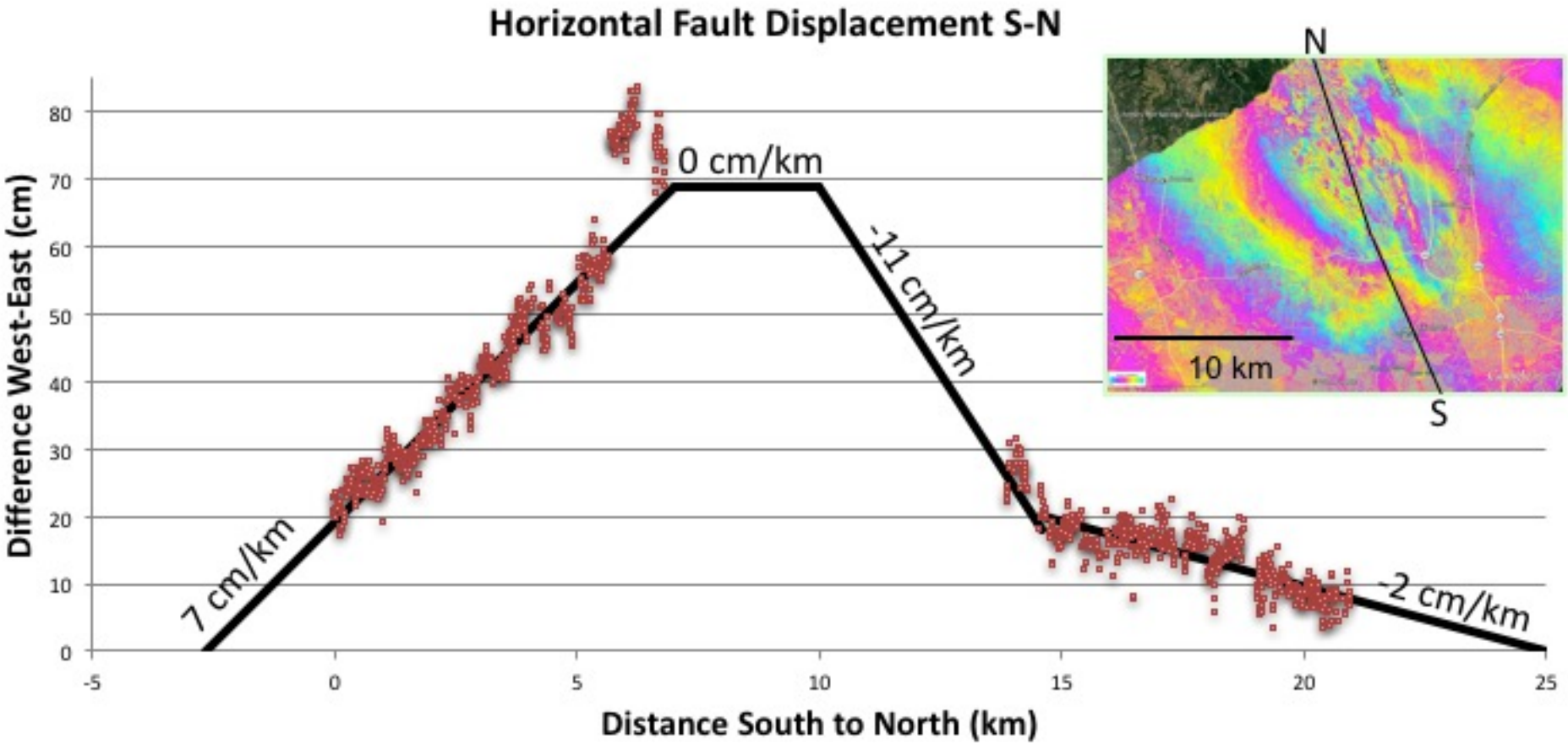
SSA 2015
Collaboration between USGS, GCS, and JPL

South Napa Earthquake Coseismic



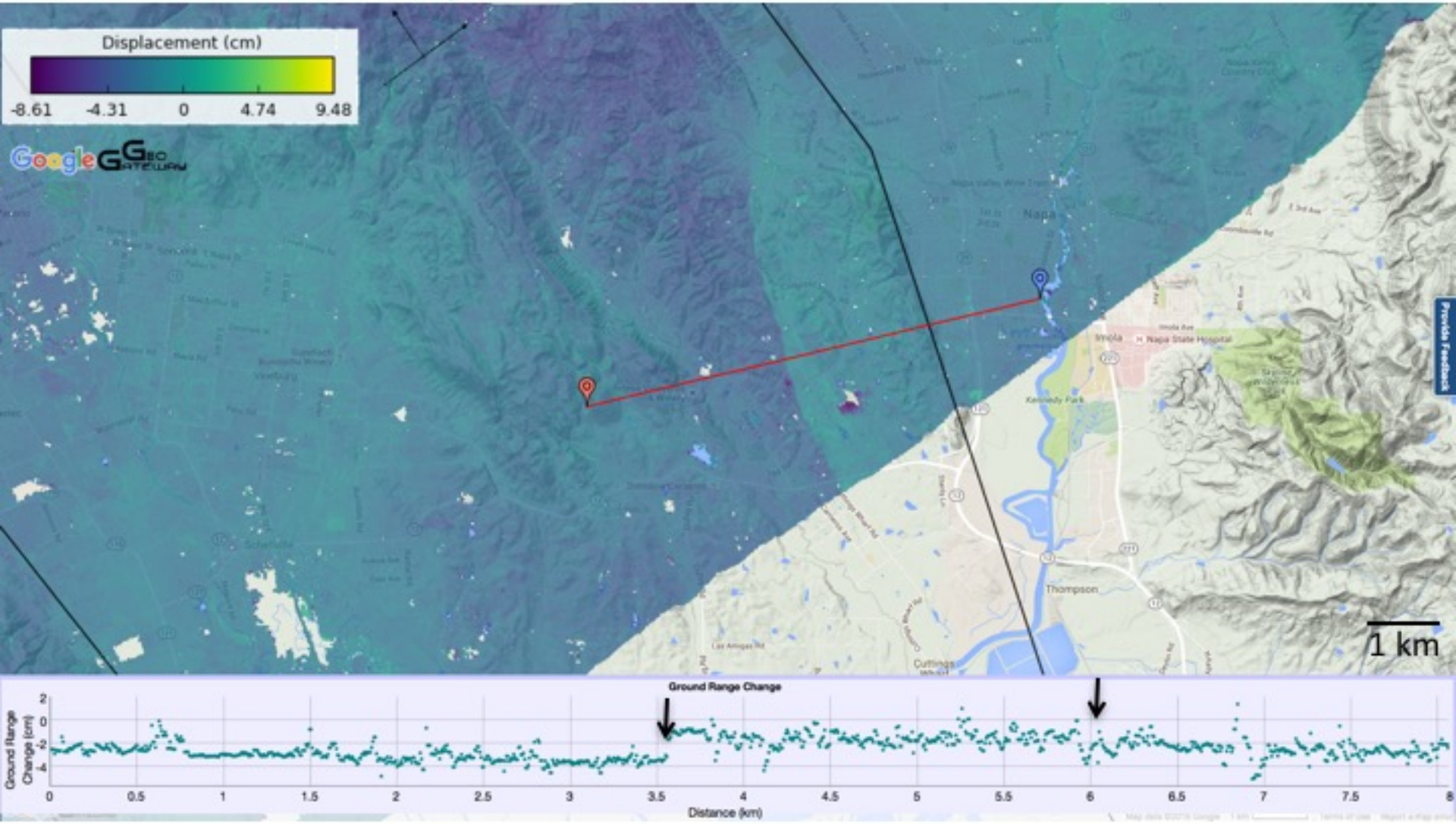
Slip on multiple structures

South Napa Earthquake



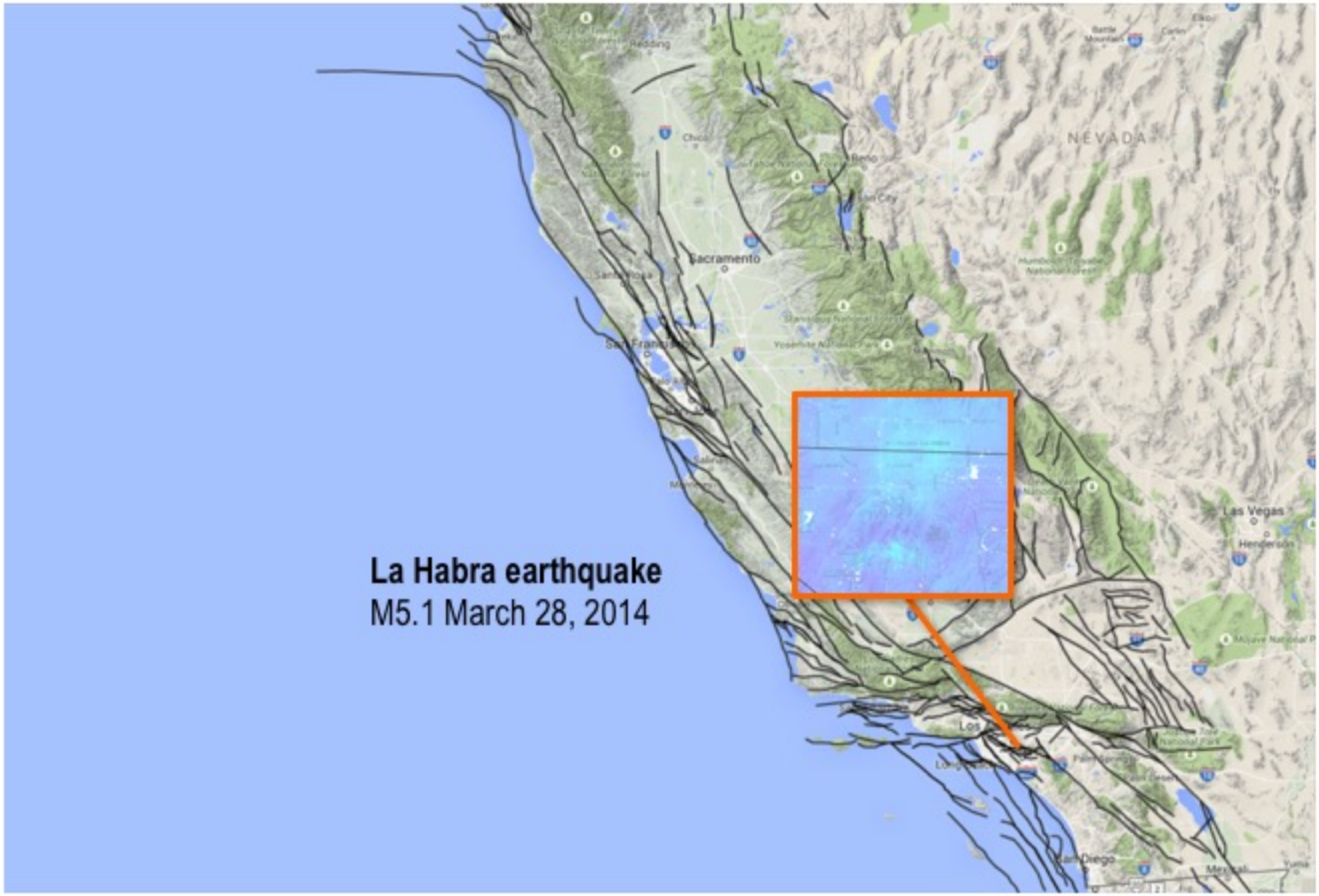
Adjusted for elevation angle across image
Assumes all horizontal motion – vertical motion observed to north

South Napa Earthquake Postseismic



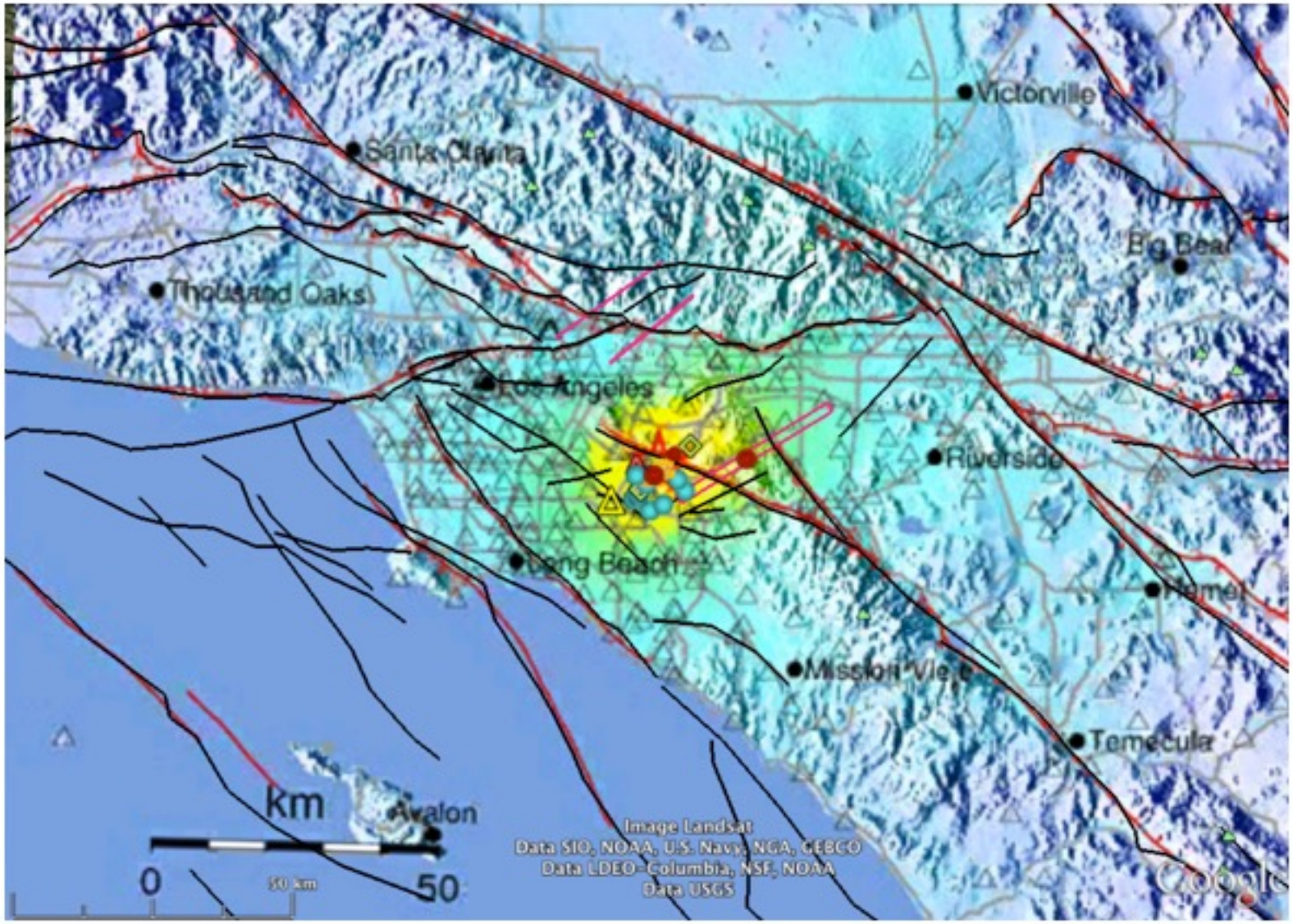
Slip confined to main rupture plane

2014 M5.1 La Habra Earthquake

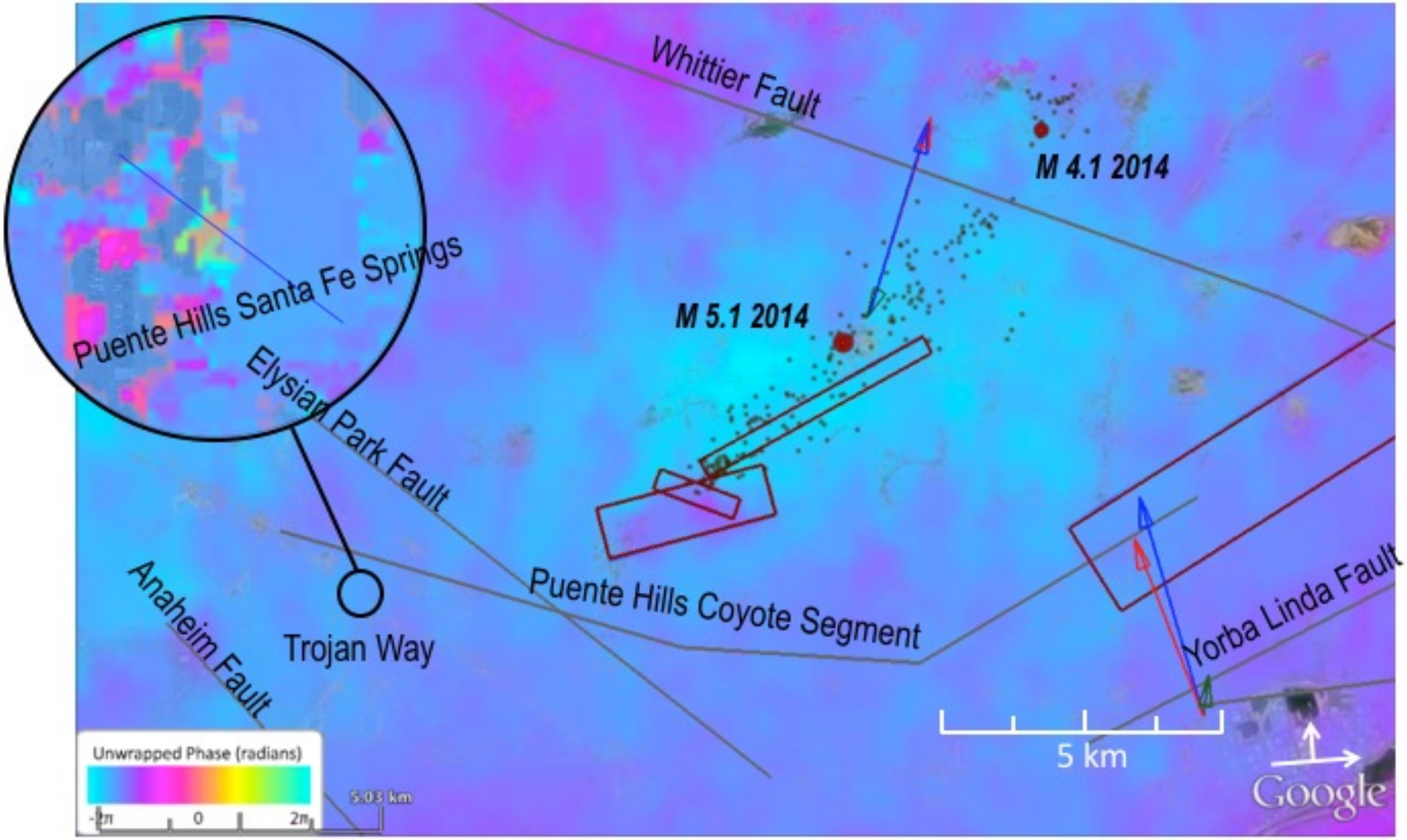


M 5.1 2010 La Habra Earthquake

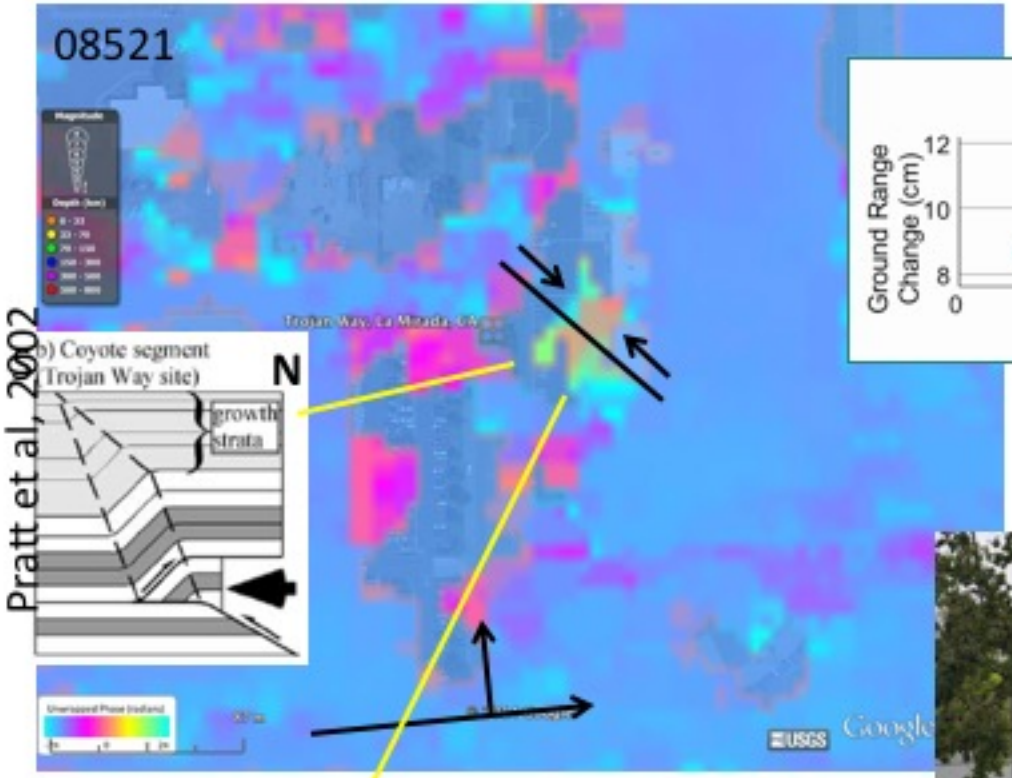
USGS/SCSN ShakeMap



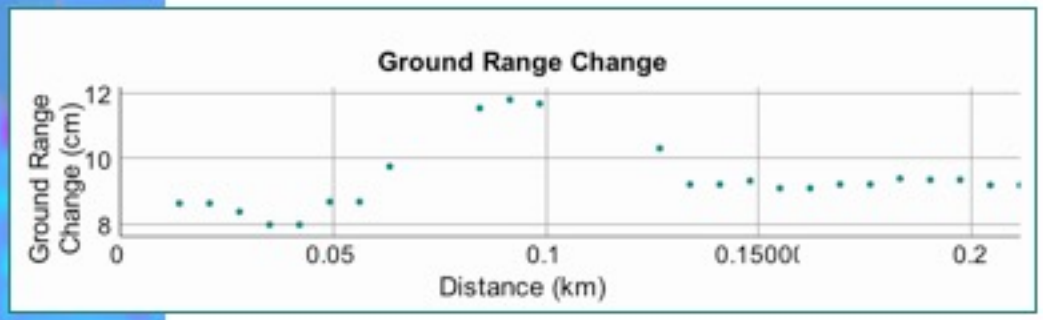
UAVSAR 08521

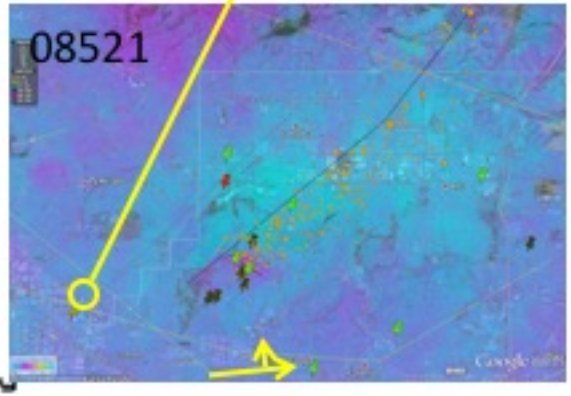


Fault Hinge Line



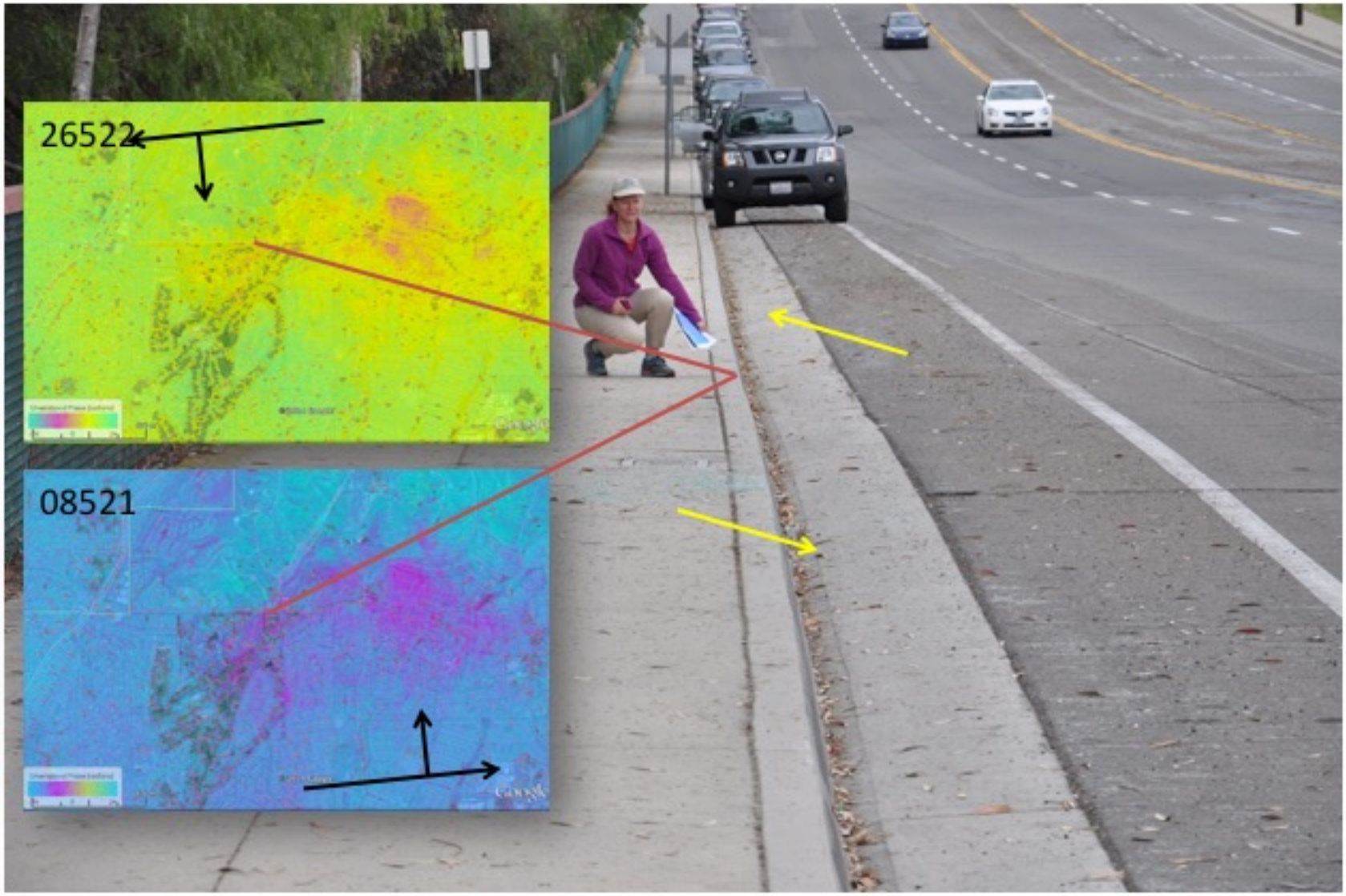
Pratt et al., 2002



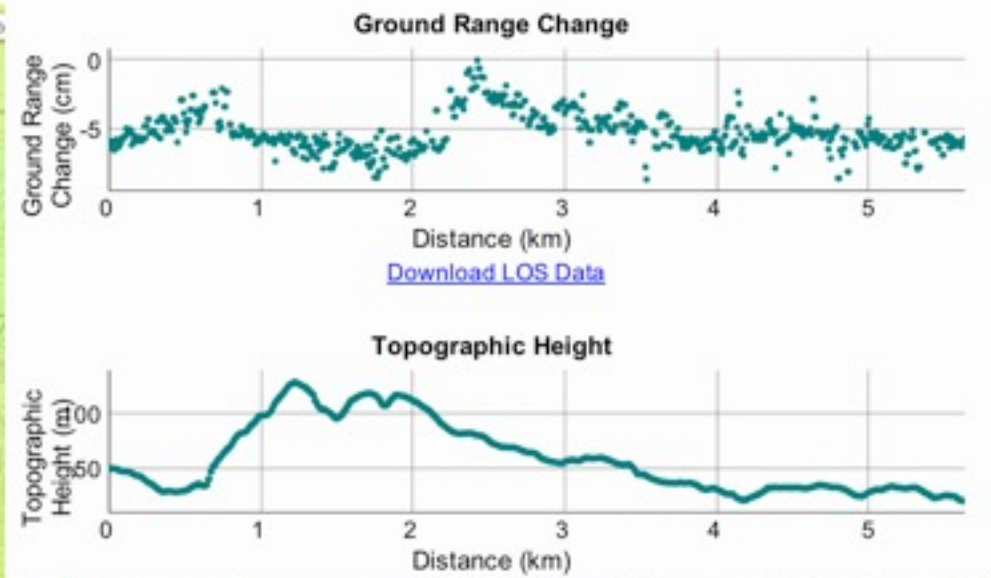


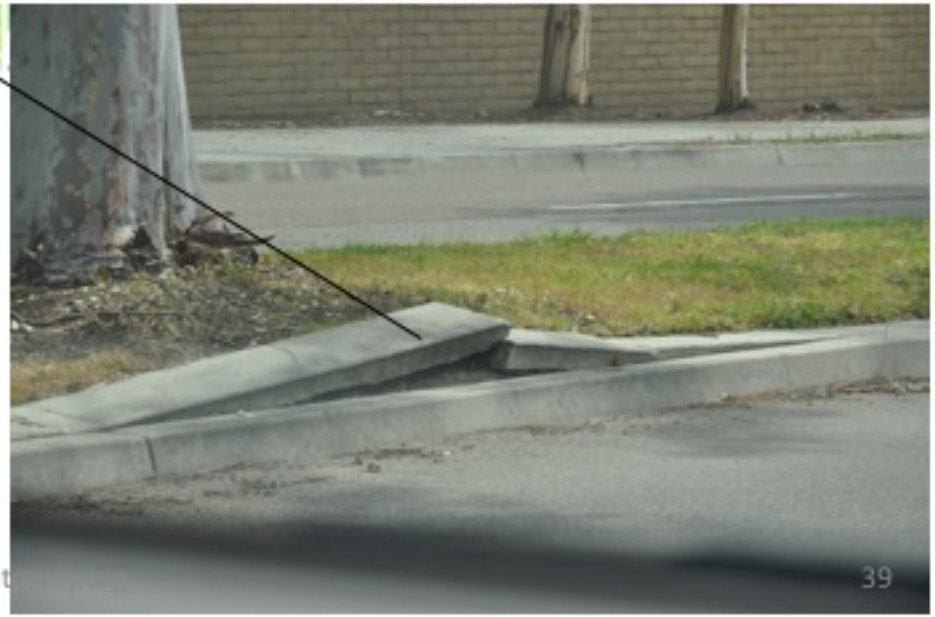
Field Validation

Left Offset Identified by UAVSAR

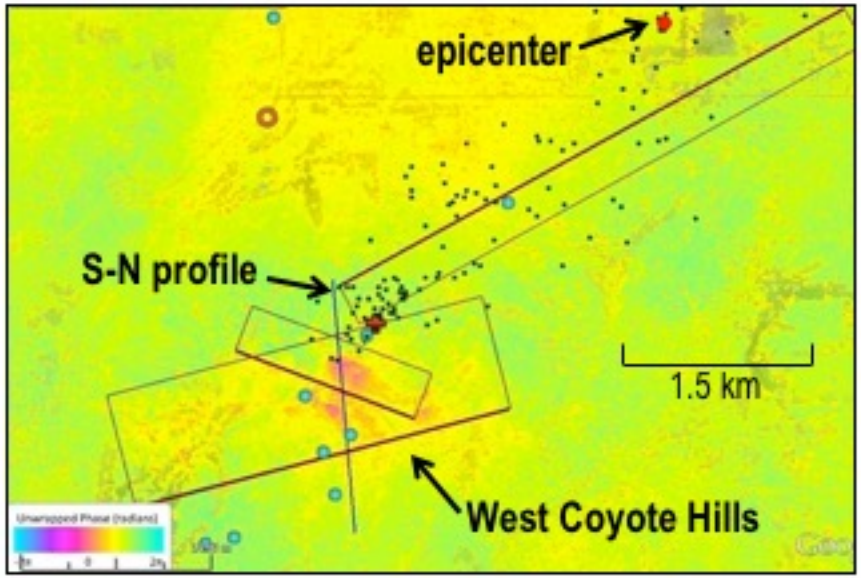


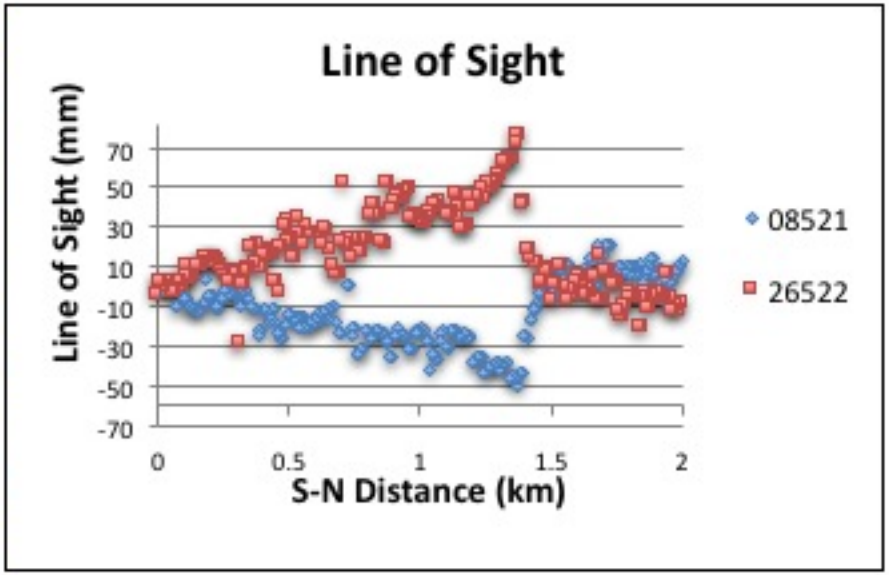
UAVSAR: 7 m Resolution

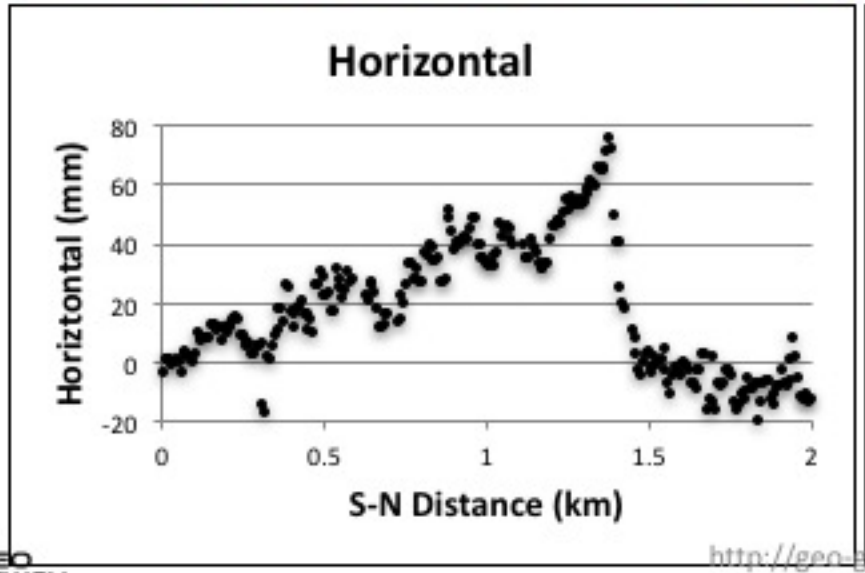


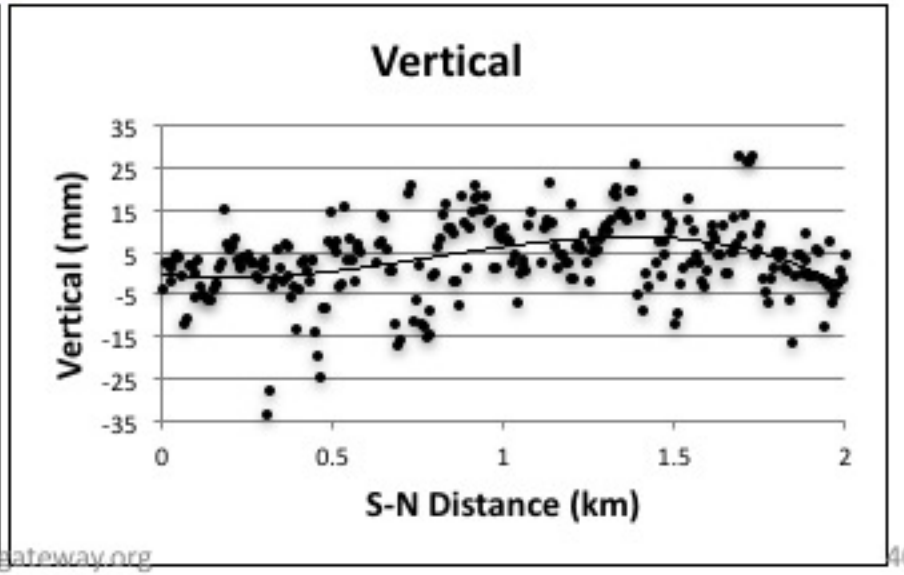


West Coyote Hills



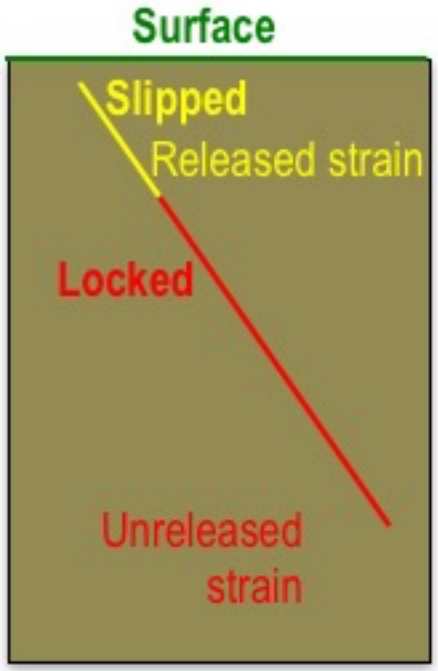






Seismic Implications

- Seismic moment
  - 82% of the total geodetic moment released
- Slip within the unconsolidated upper sedimentary layer
  - May reflect shallow release of accumulated strain on still-locked deeper structures
- Future M6.1–6.3 earthquake would account for the accumulated strain
- Could occur on any one or several of these faults
  - May not have been identified by geologic surface mapping

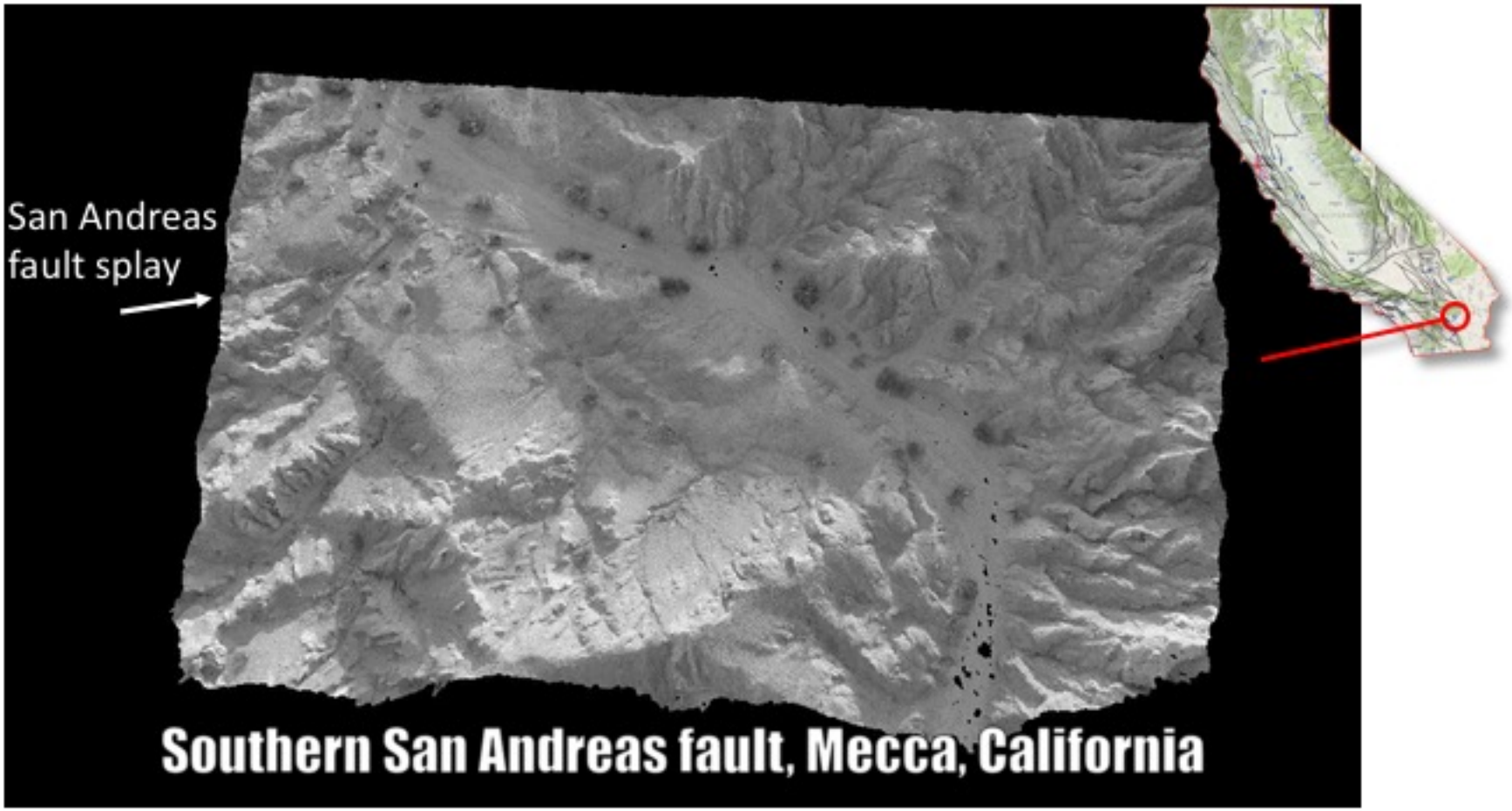


Potential for a Large Earthquake Near Los Angeles Inferred from the 2014 La Habra Earthquake
Andrea Donnellan, Lisa Grant Ludwig , John Rundle , Jay Parker , Jun Wang , Marlon Pierce , Geoffrey Blewitt , Scott Hensley
Earth and Space Science (2015).

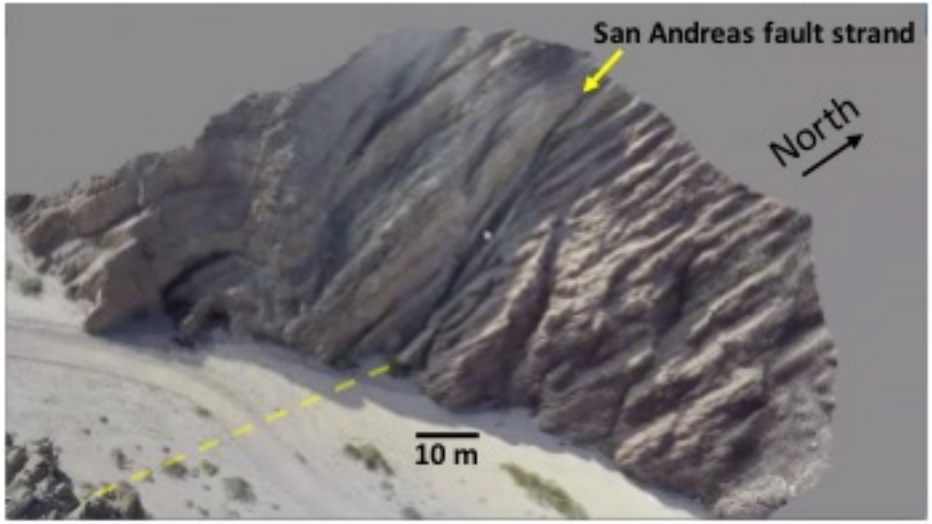
Topographic Mapping of Fault Zones

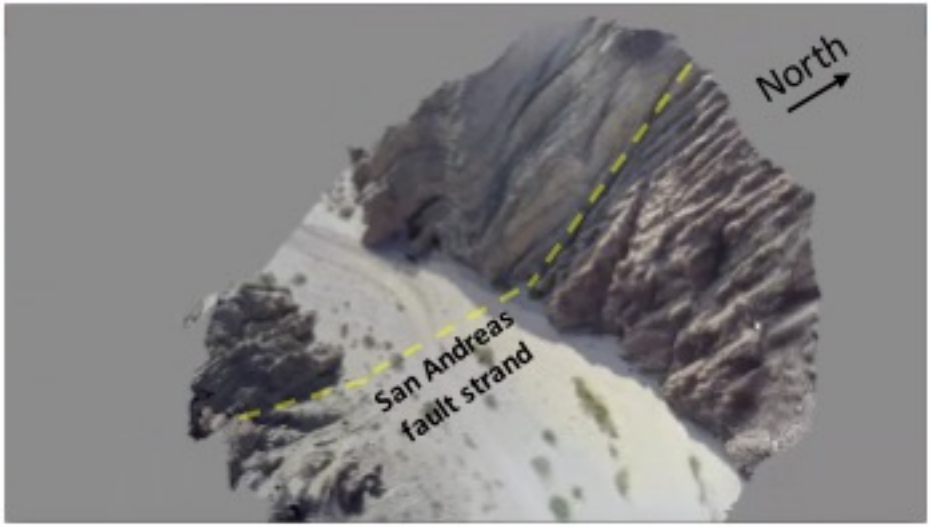
The Southern San Andreas fault has multiple strands

Southern San Andreas fault

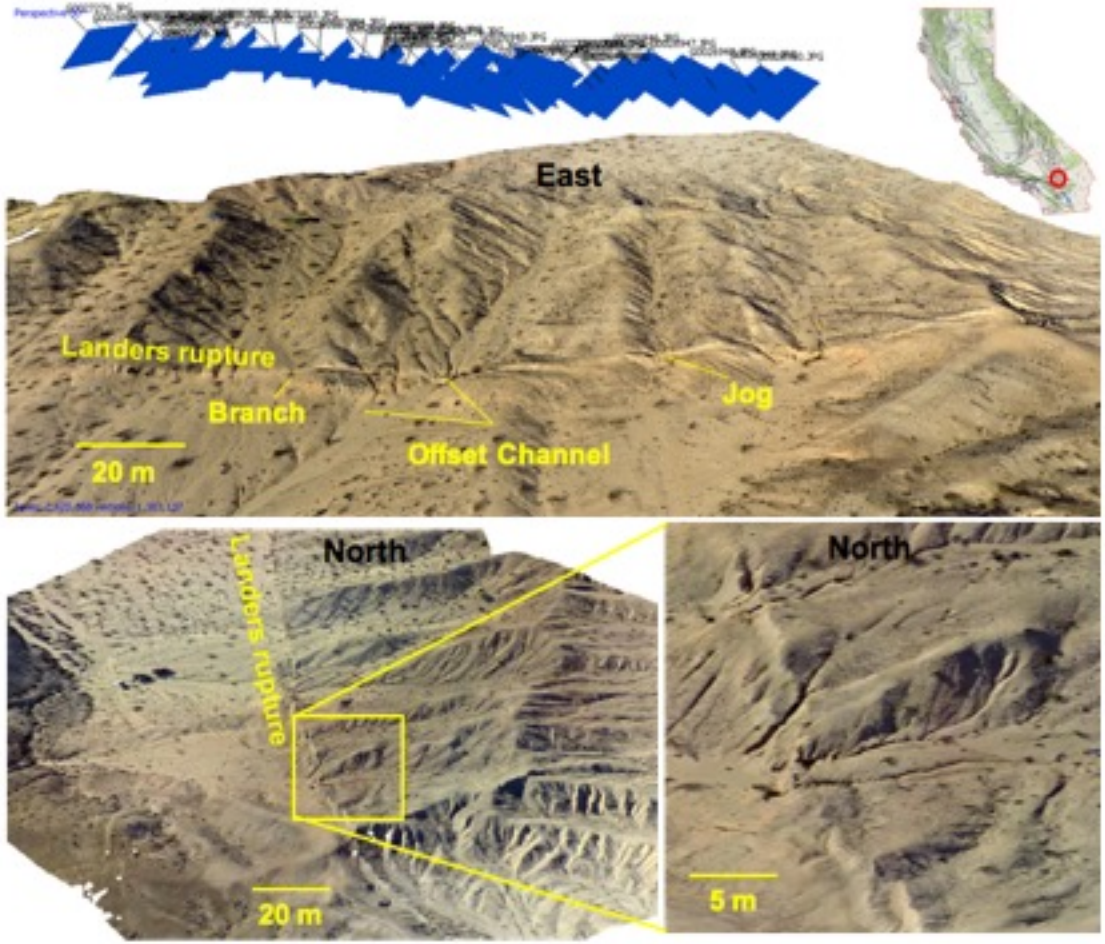


Southern San Andreas Fault





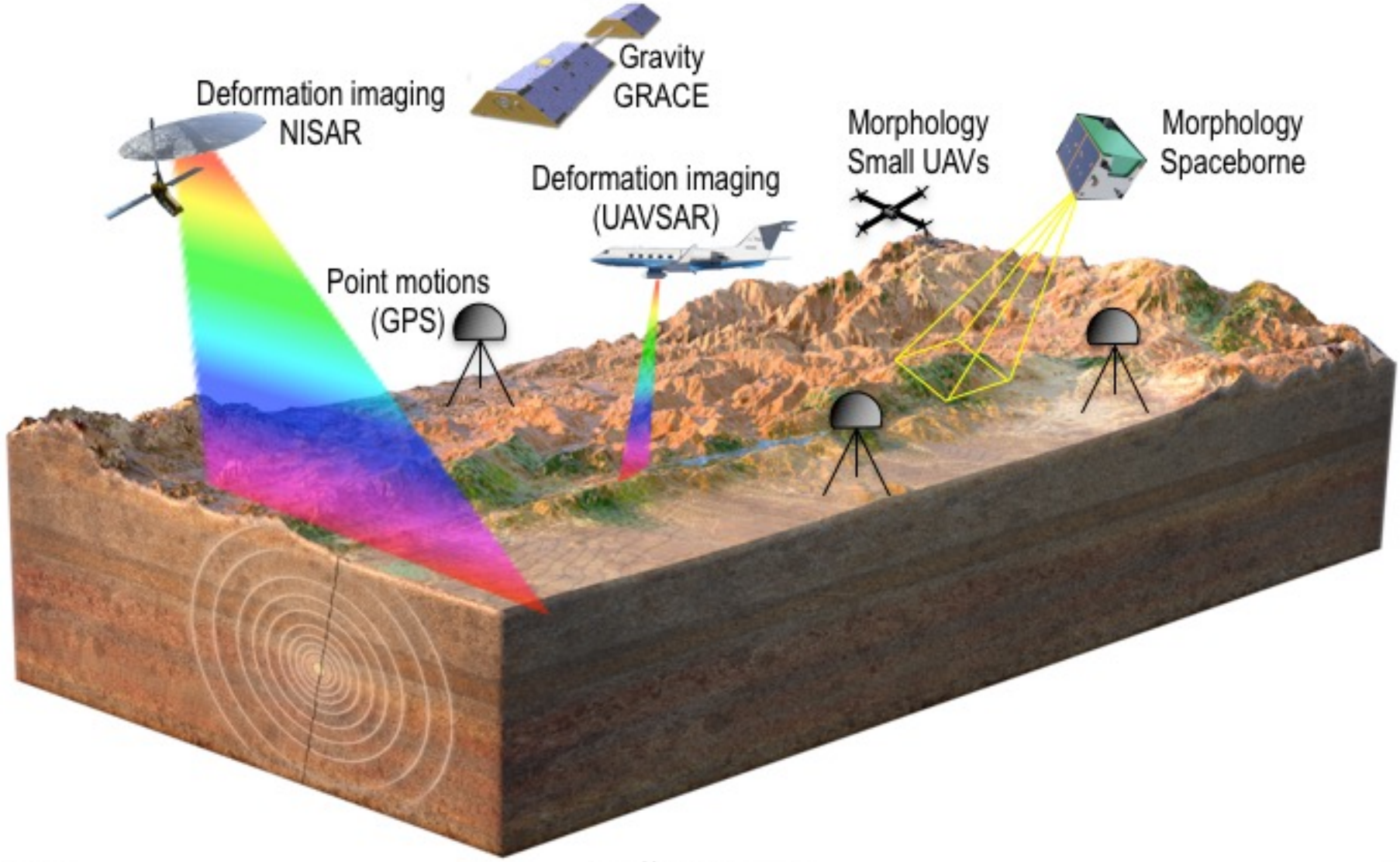
M7.3 1992 Landers Earthquake Rupture



Mustang Ridge, Central California

Offset fence from 32 mm/yr creep along the fault

Integrated Methods



Summary

- Remote sensing measurements allow observation of earthquake ground motion
  - Including the quiet part
  - Provide unprecedented details of earthquake fault behavior
- Providing insight into earthquake fault processes and interactions
- Useful for addressing our exposure and responding to these disastrous events
- Need GeoGateway for maximizing science from geodetic imaging data

  - 1980s: Handful of infrequently measured GPS stations
  - 1990s: Advent of InSAR and continuous GPS
  - 2000s: Dense continuous GPS networks
  - 2010s: UAVSAR
  - 2020s: NISAR, topographic imaging