Uninhabited Aerial Vehicle Synthetic Aperture Radar Observation of Recent Earthquakes in California

Andrea Donnellan

Jet Propulsion Laboratory, California Institute of Technology

Collaborators:

Jay Parker, Robert Granat, Margaret Glasscoe, Gregory Lyzenga (JPL/Caltech), Marlon Pierce, Jun Wang, Yu Ma (Indiana University), Lisa Grant Ludwig (UC Irvine), John Rundle (UC Davis)

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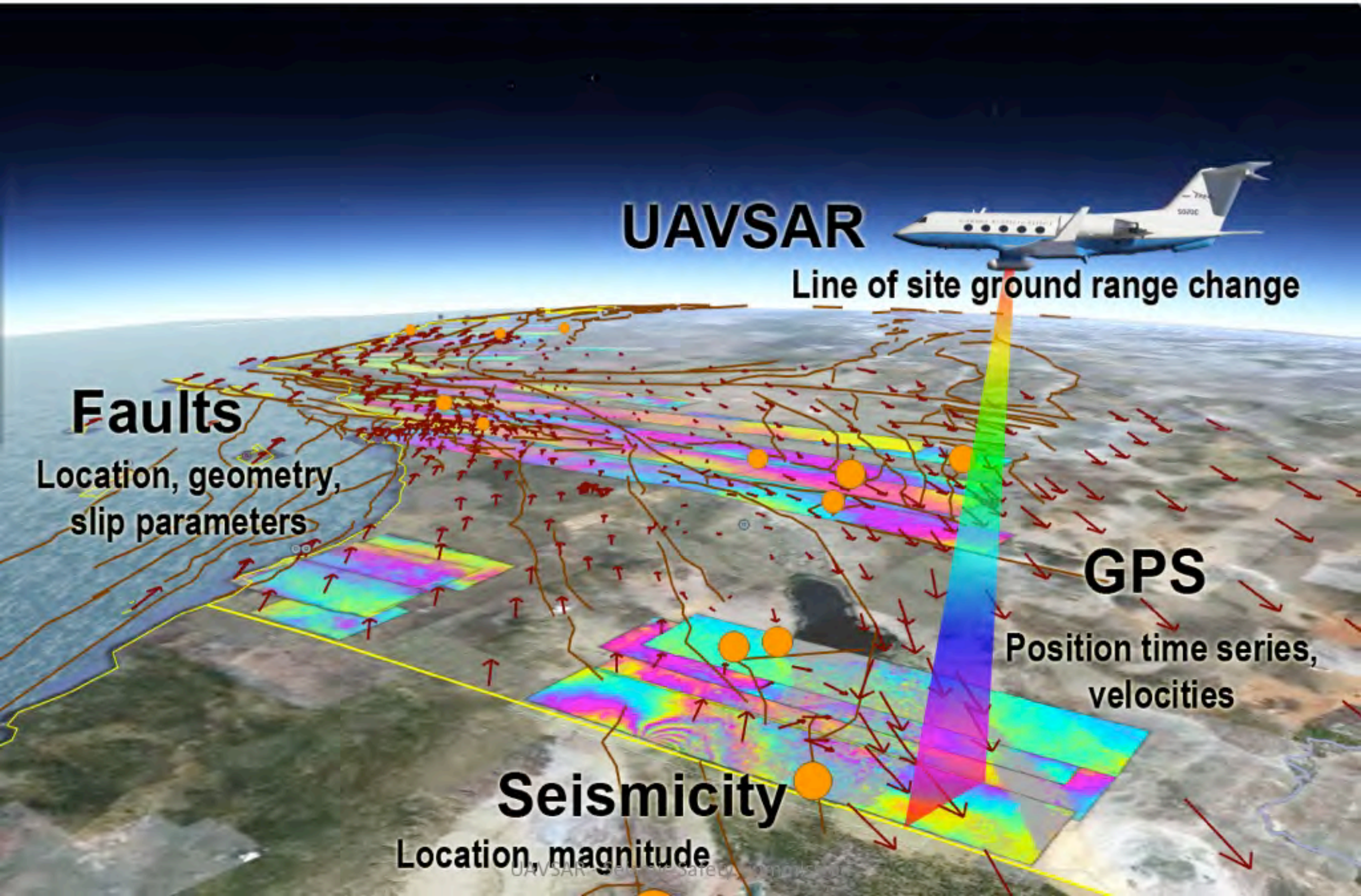
UAVSAR Studies

- UAVSAR imaging for three regions of California with earthquakes in each region
  1. San Francisco Bay (2014 South Napa M6.2)
  2. Los Angeles (2014 La Habra M5.1)
  3. Salton Trough (2010 El Mayor - Cucapah M7.2)
- Focused on areas where heightened earthquake risk was indicated by pattern analysis methods
- Each shows
  - Broad pattern of deformation
  - Triggered slip on additional structures
  - Substantial postseismic motion for the larger South Napa and El Mayor - Cucapah events
- Entire San Andreas fault system is imaged with UAVSAR

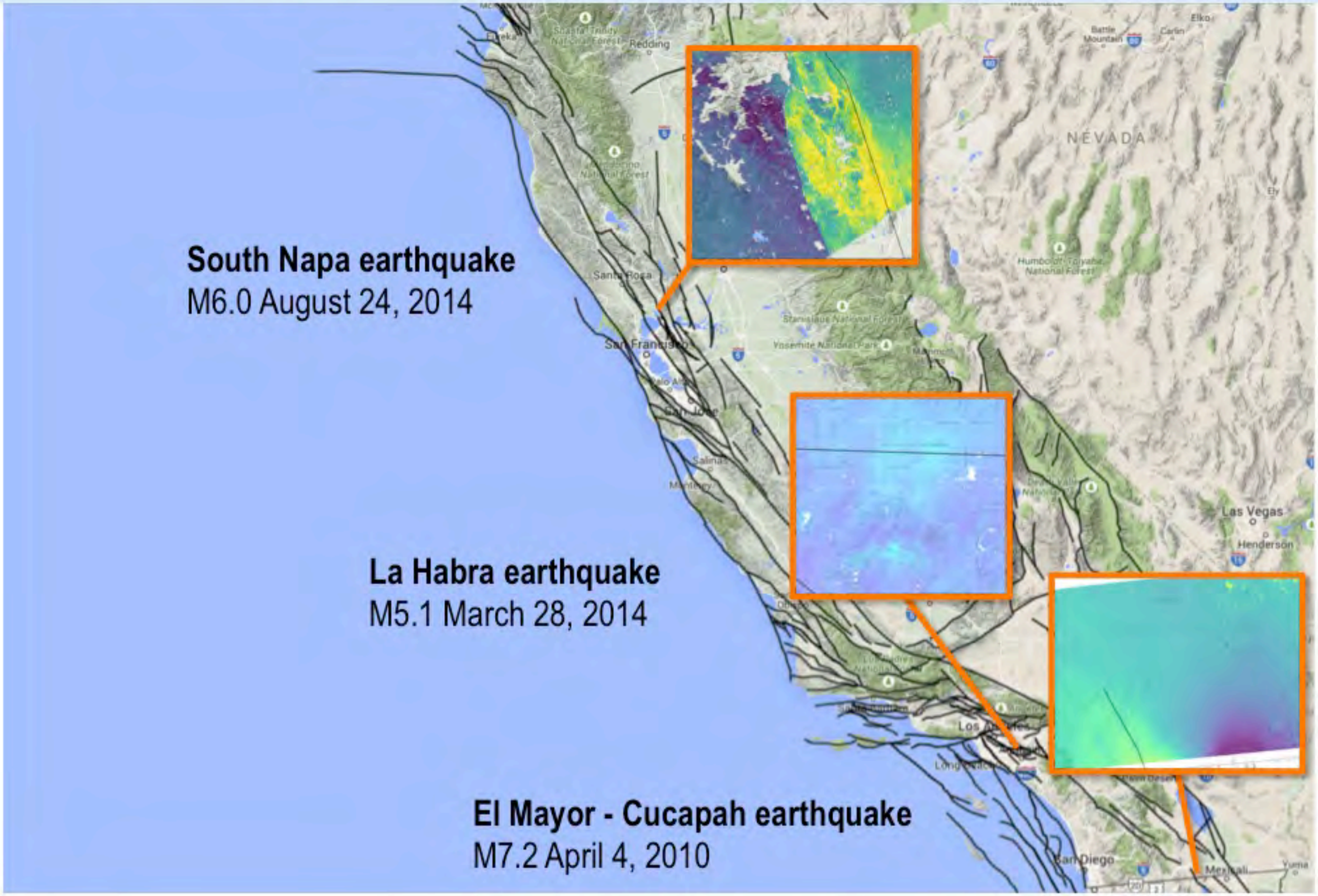
UAVSAR

- Applications
  - Identifying fault slip
    - Main Rupture and triggered slip
  - Observing damage to buildings and infrastructure
- Types of damage
  - Minor structural damage to buildings and streets, gas and water lines in the La Habra earthquake
  - Detection and location of heavily damaged houses and buildings in the South Napa earthquake
  - Damaged roads and tilled farm lands during the El Mayor - Cucapah earthquake in 2010

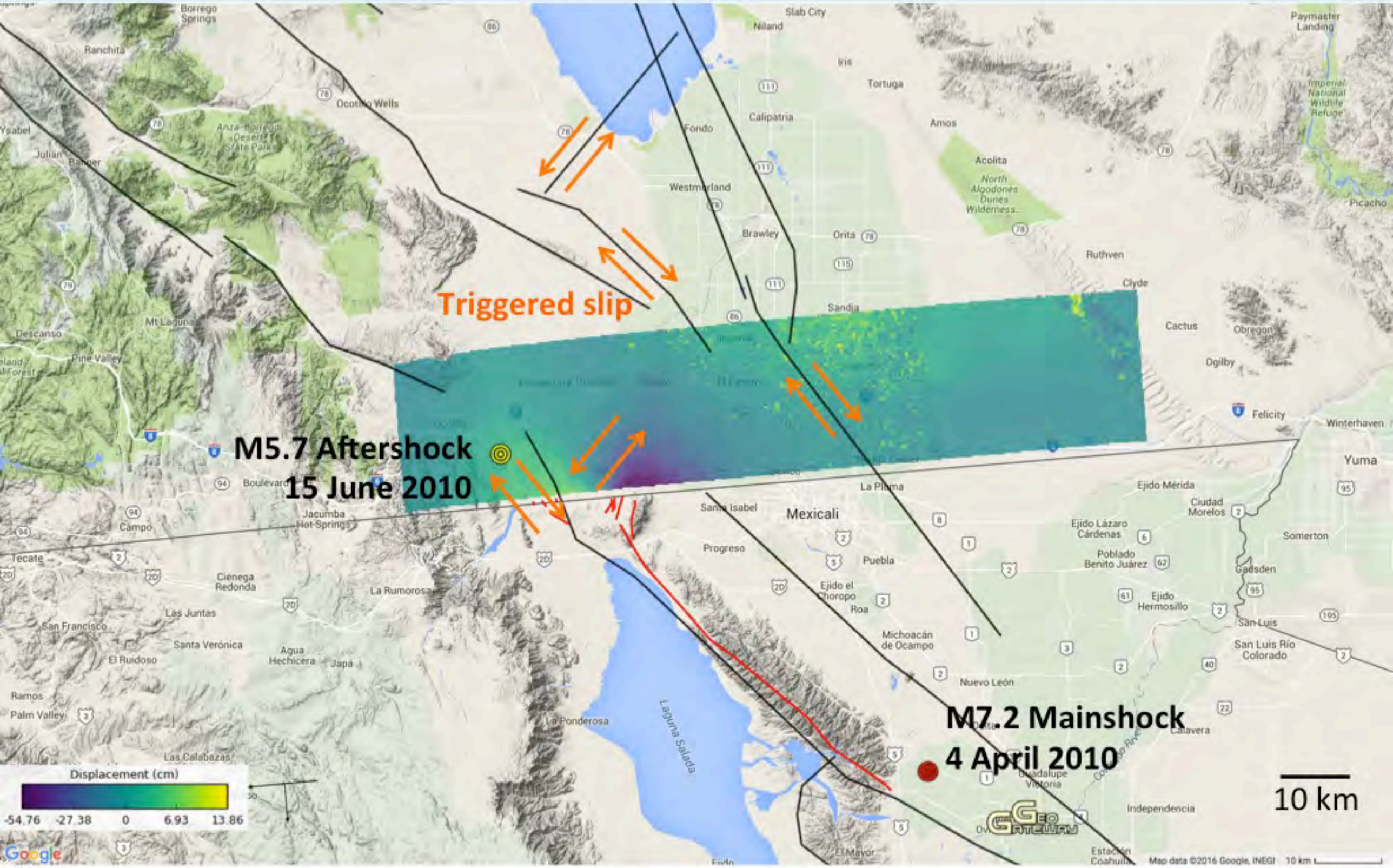
Complementary Observations



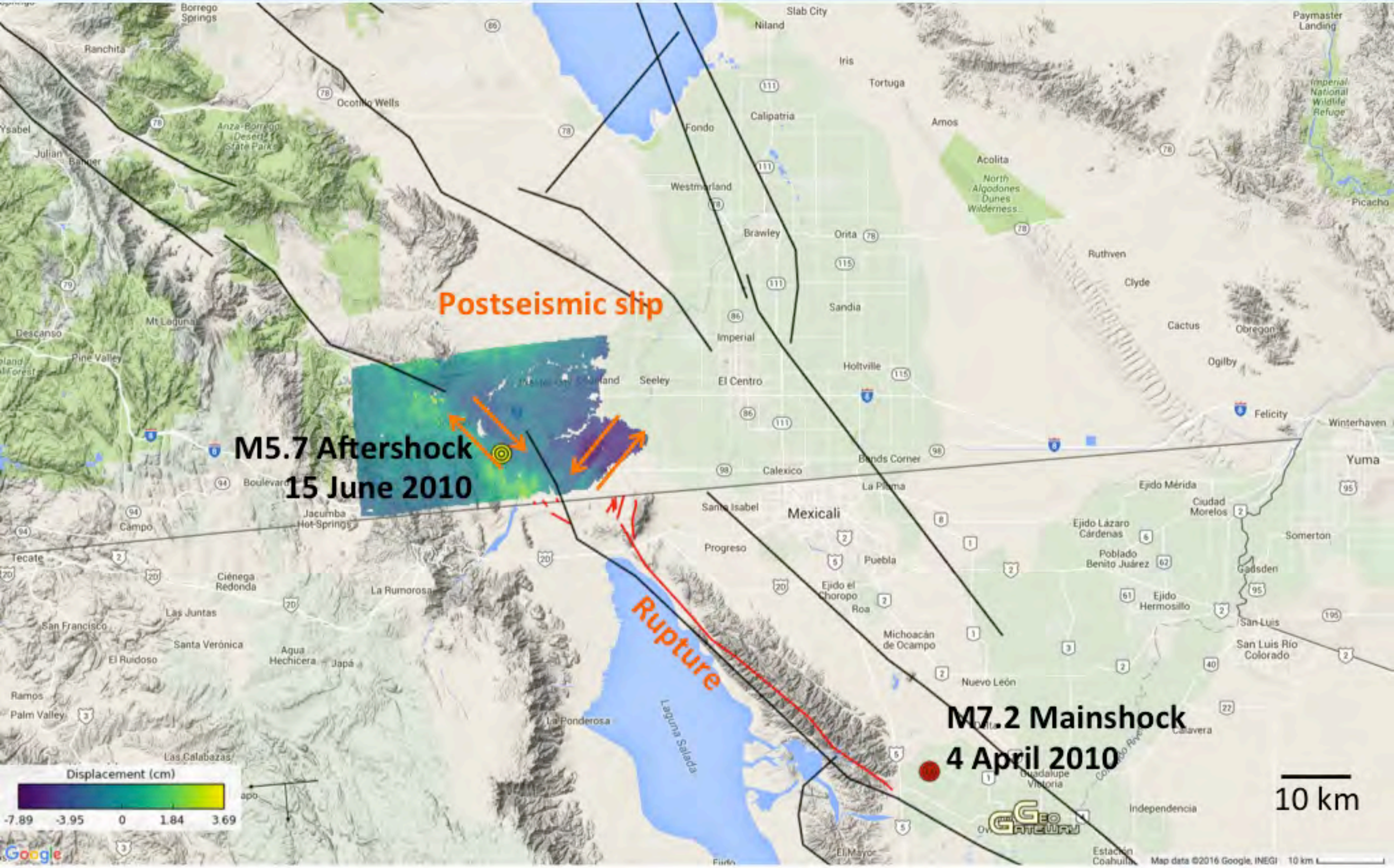
Earthquakes Observed with UAVSAR



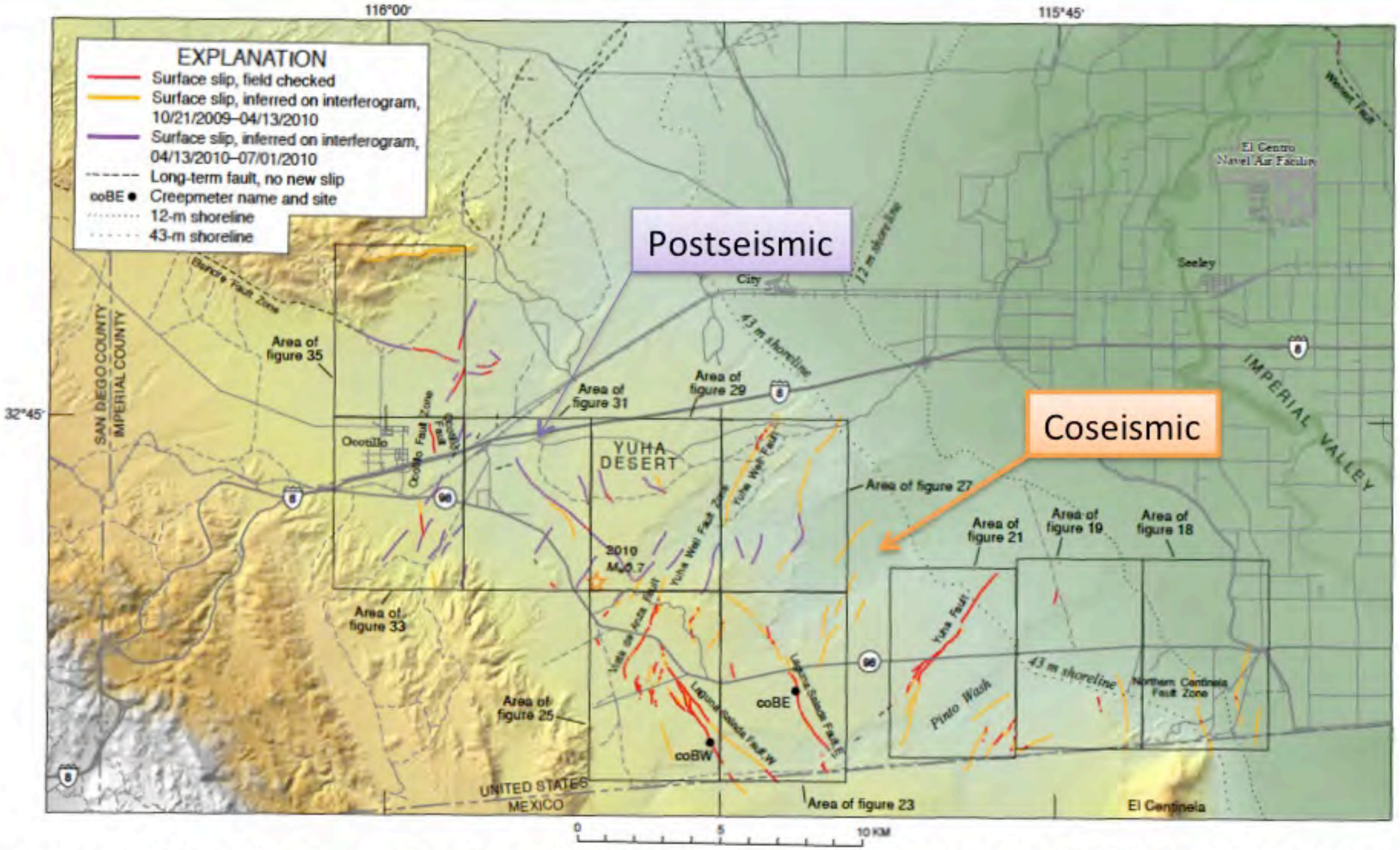
2010 M7.2 El Mayor – Cucapah Earthquake



Postseismic

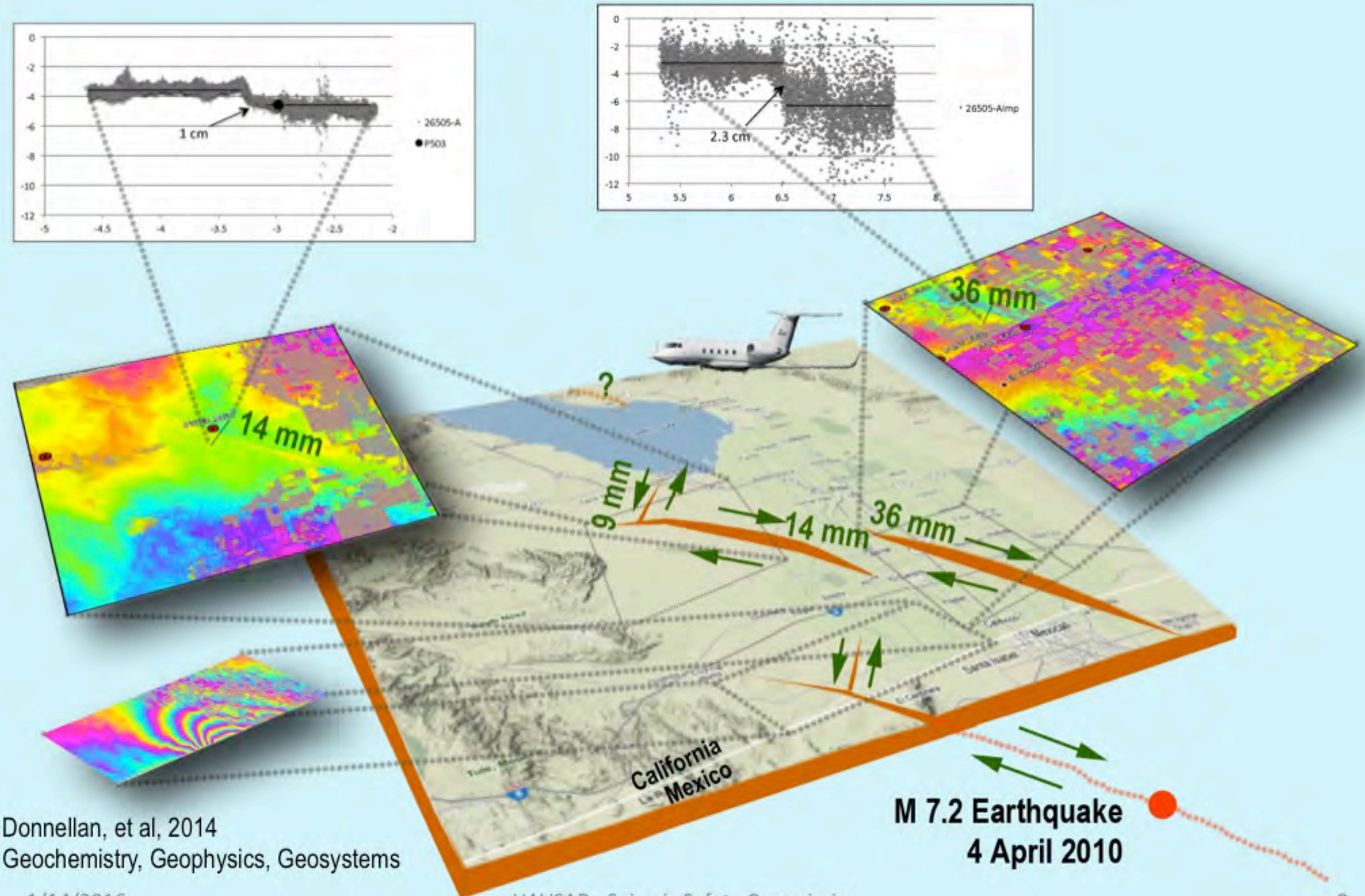


UAVSAR Guided Field Mapping



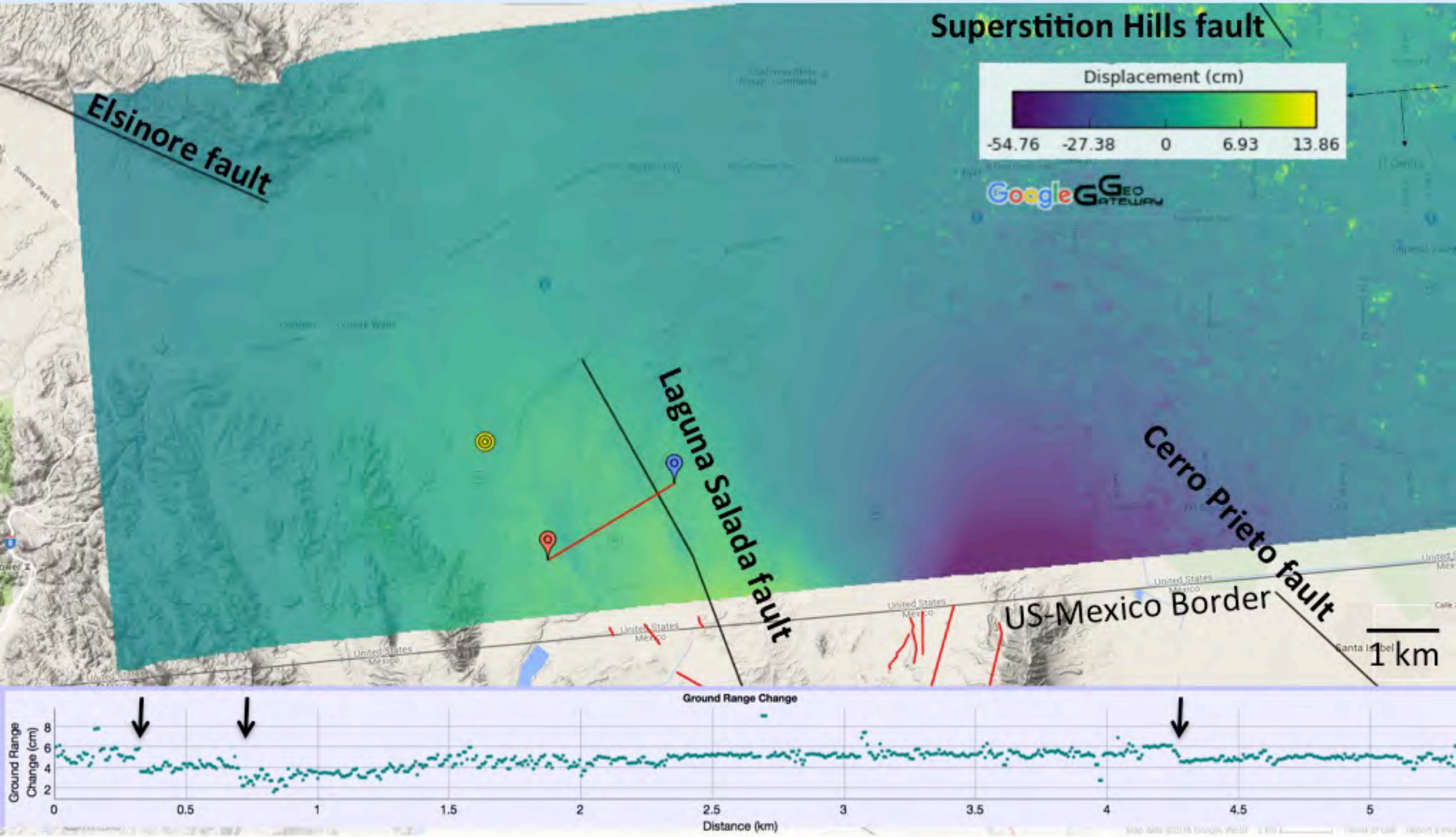
Rymer et al (2011), Triggered Surface Slips in Southern California Associated with the 2010 El Mayor – Cucapah, Baja California, Mexico Earthquake, U.S. Geological Survey Open-File Report 2010-1333 and California Geological Survey Special Report 221

Salton Trough



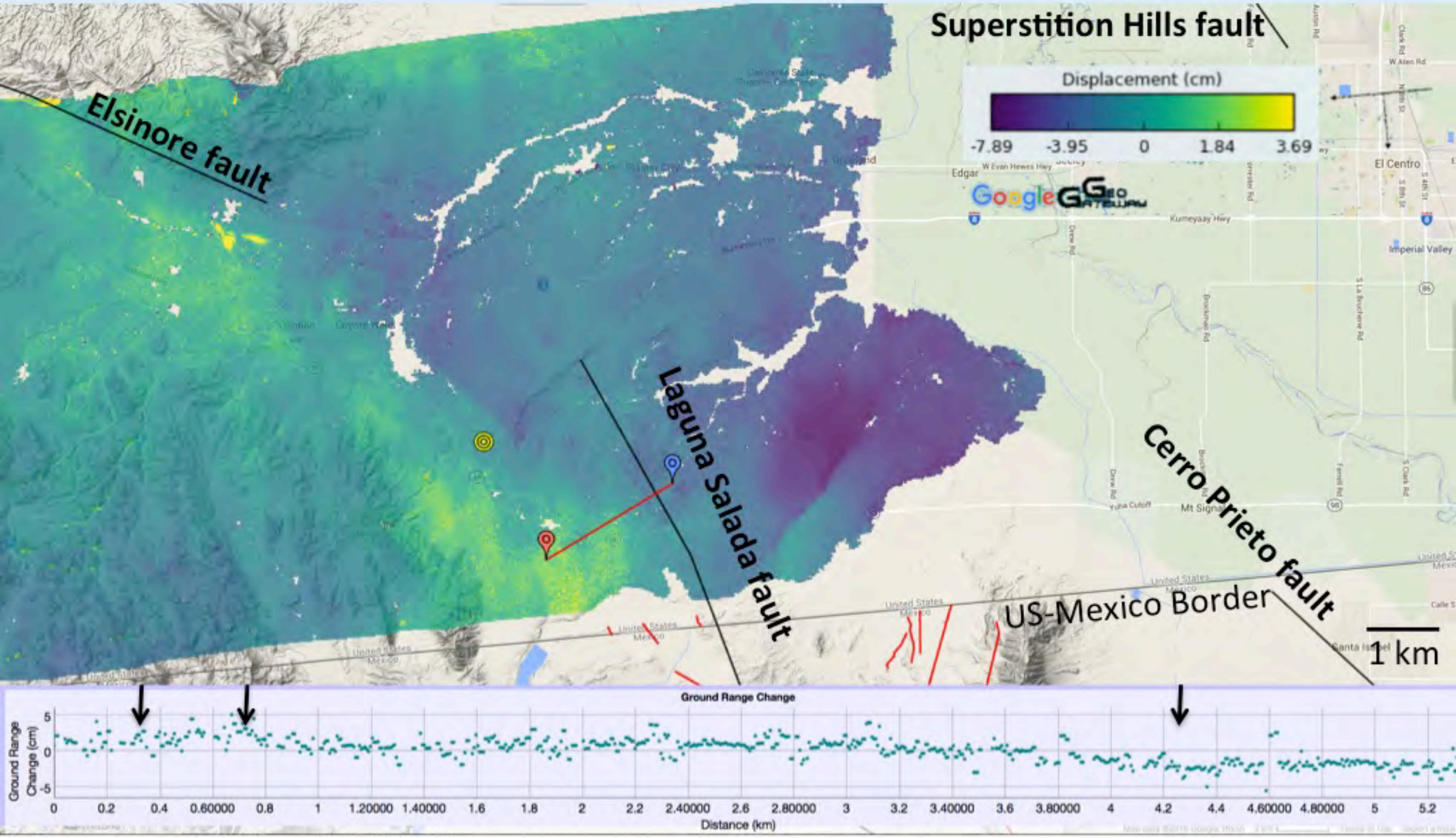
Donnellan, et al, 2014
Geochemistry, Geophysics, Geosystems

Triggered Slip NW of Main Rupture



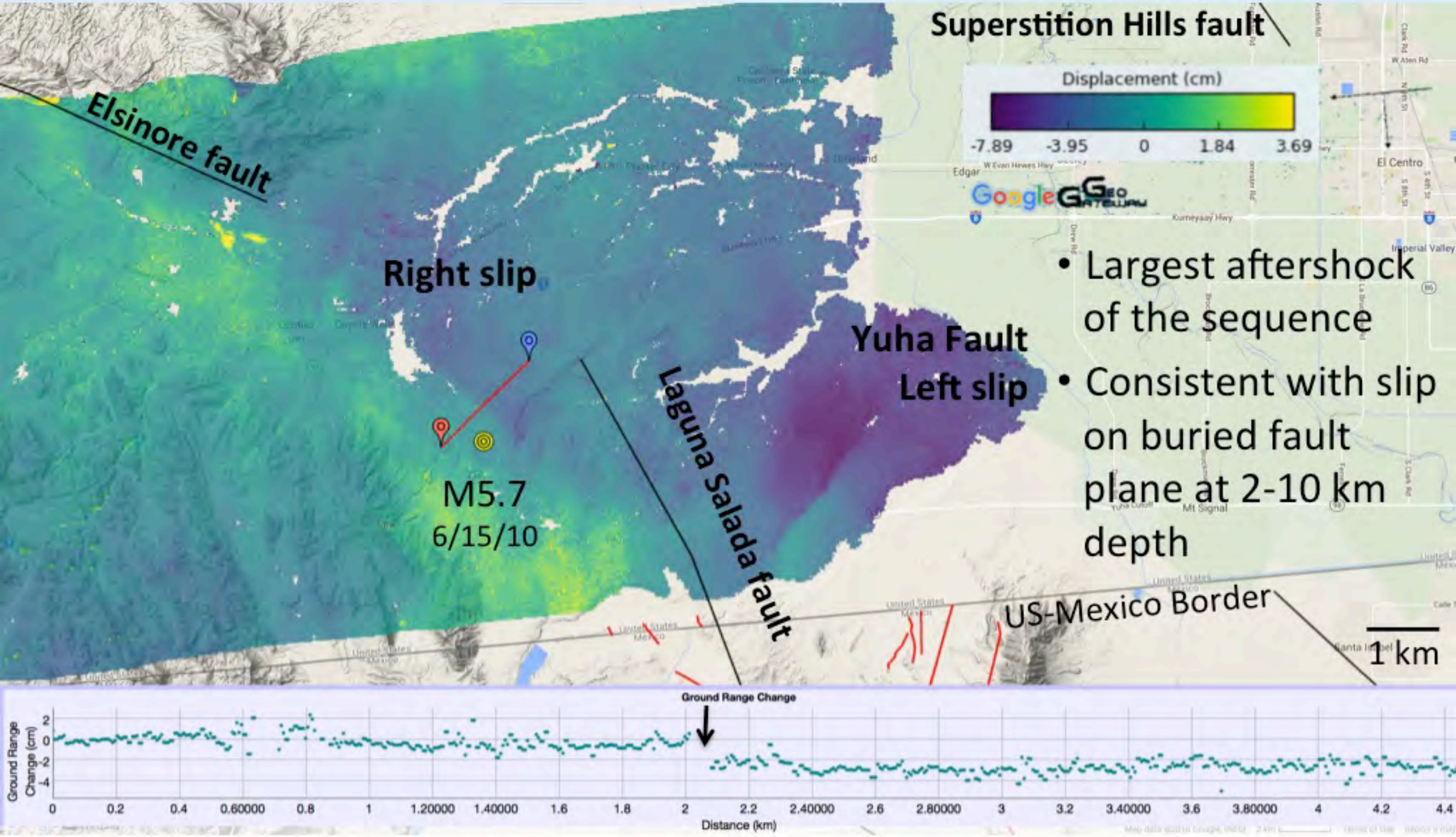
21 October 2010 – 13 April 2010

Continued Postseismic Slip



13 April 2010 – 11 February 2014

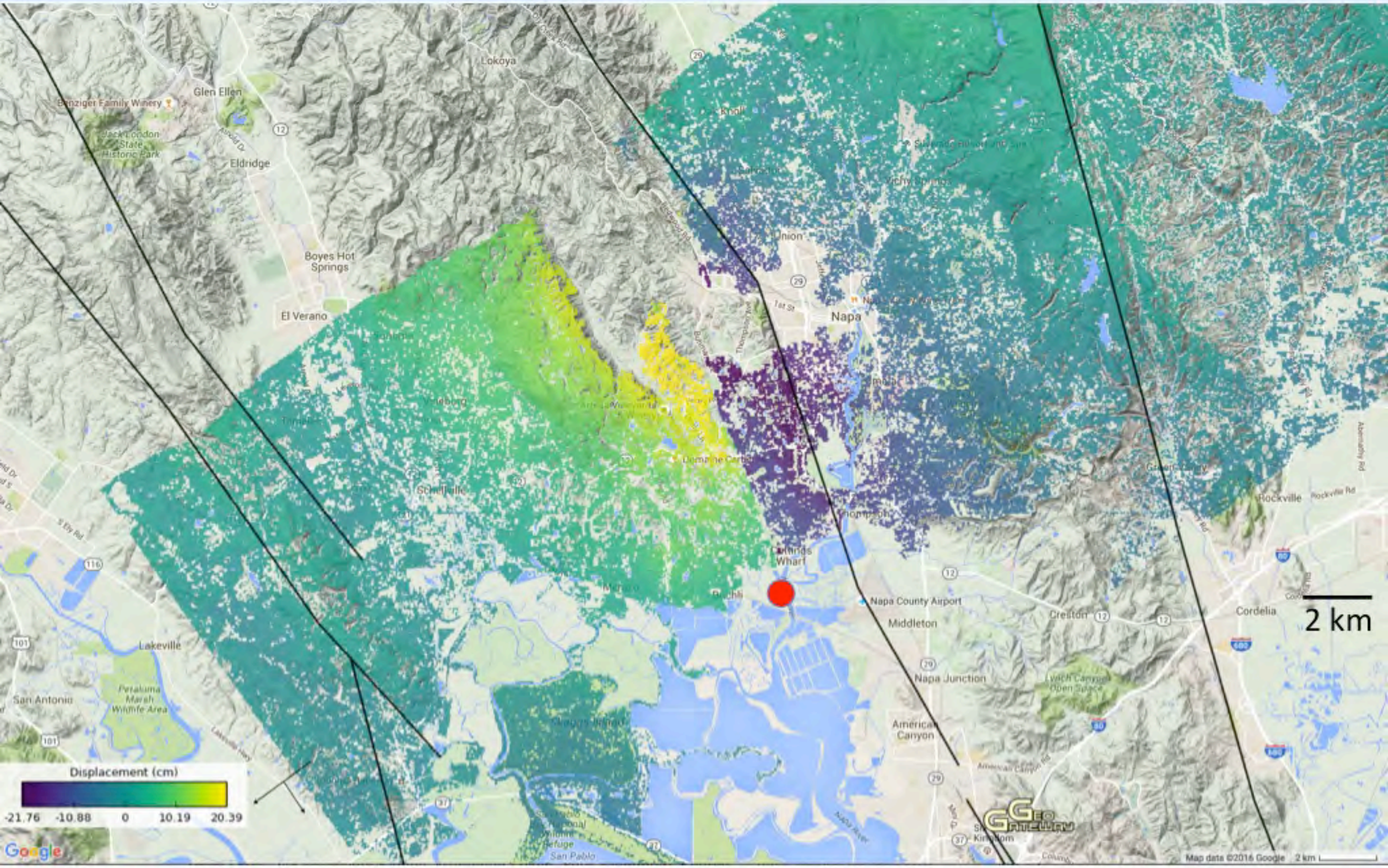
Additional Slip from M5.7 Aftershock



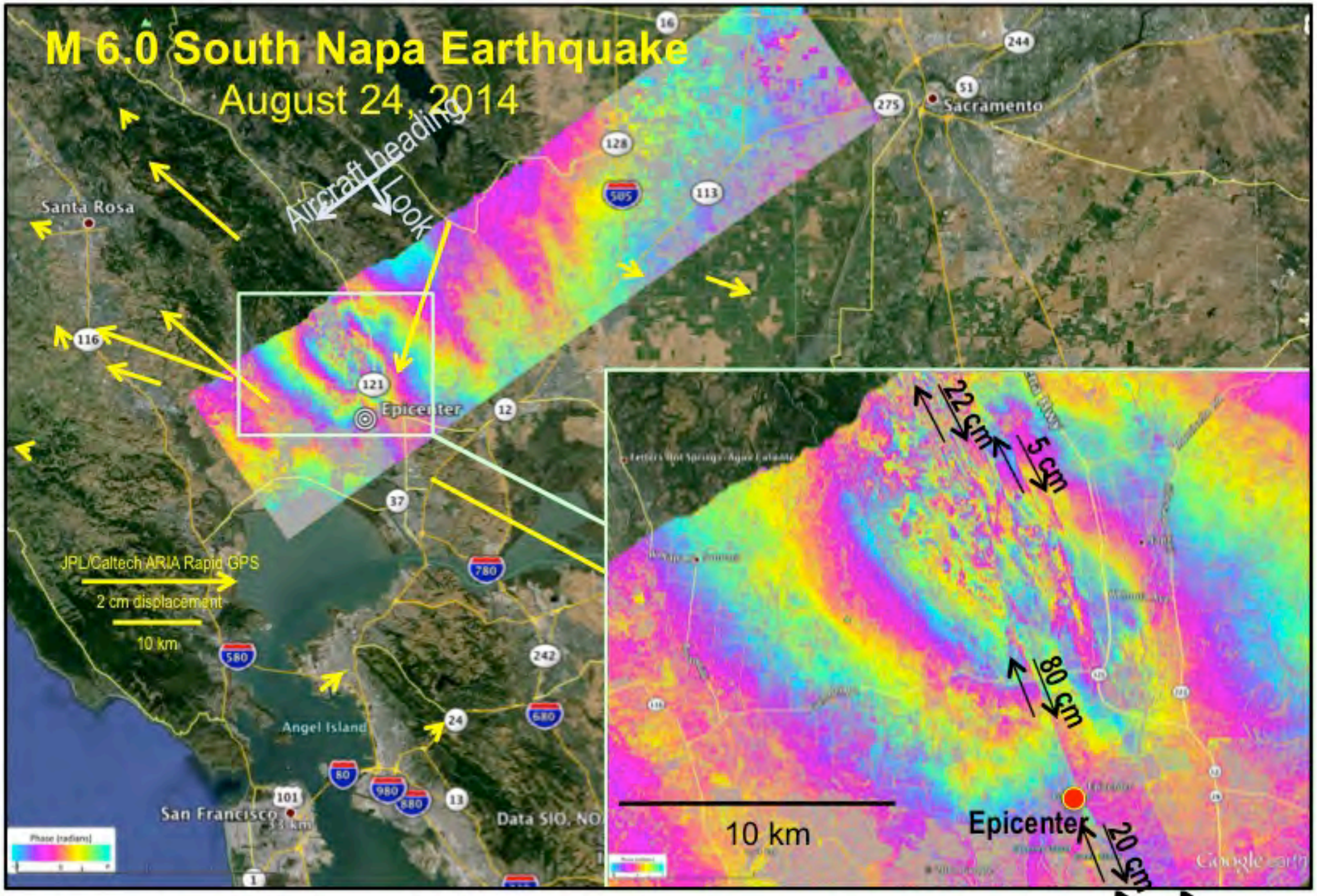
- Largest aftershock of the sequence
- Consistent with slip on buried fault plane at 2-10 km depth

13 April 2010 – 11 February 2014

2014 M6.2 South Napa Earthquake



Multiple Coseismic Fault offsets



Each color band fringe is 12 cm displacement toward the instrument

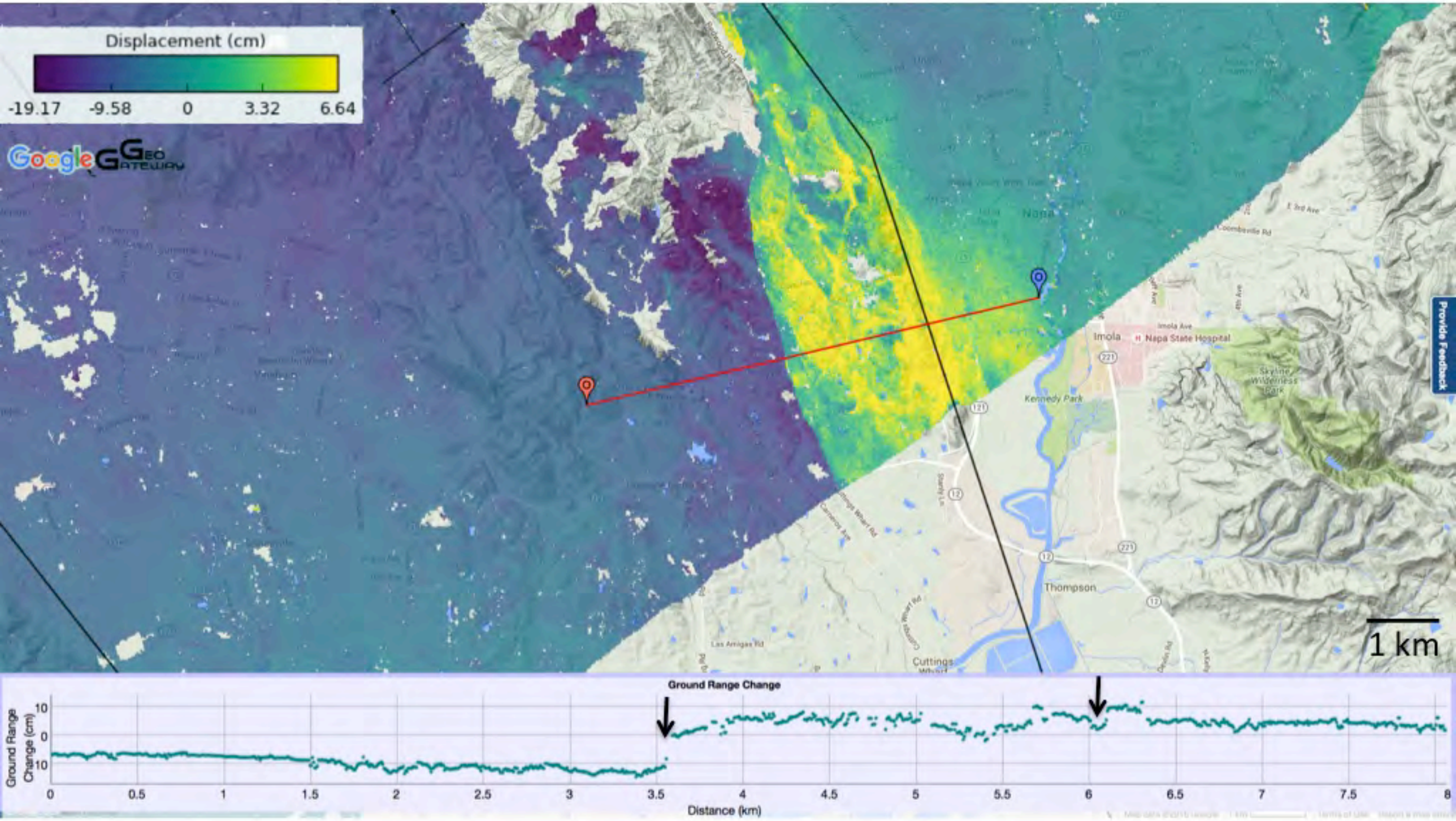
UAVSAR Guides South Napa Assessment

"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.

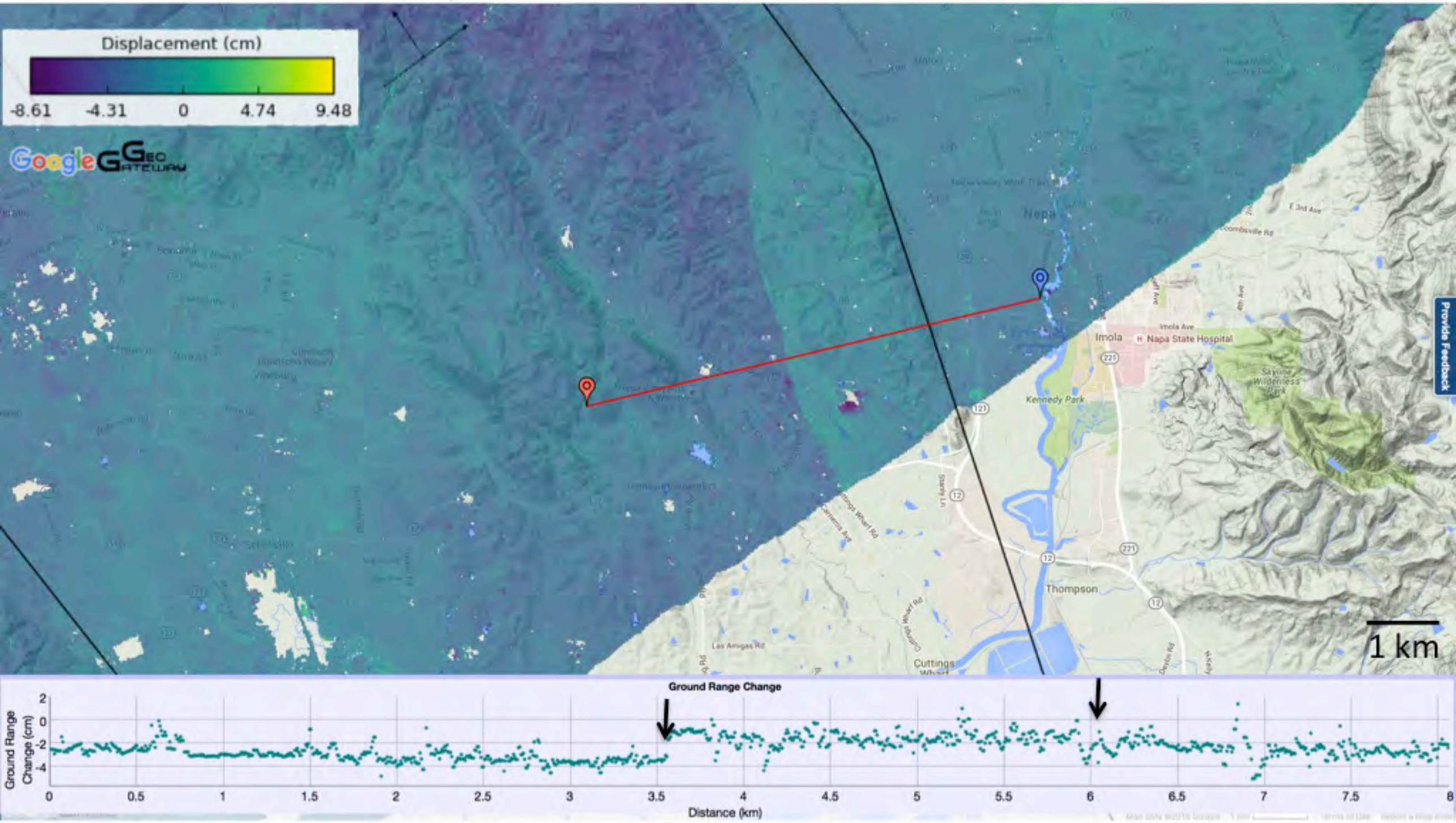
SSA 2015
Collaboration between USGS, GCS, and JPL

South Napa Earthquake Coseismic



Slip on multiple structures

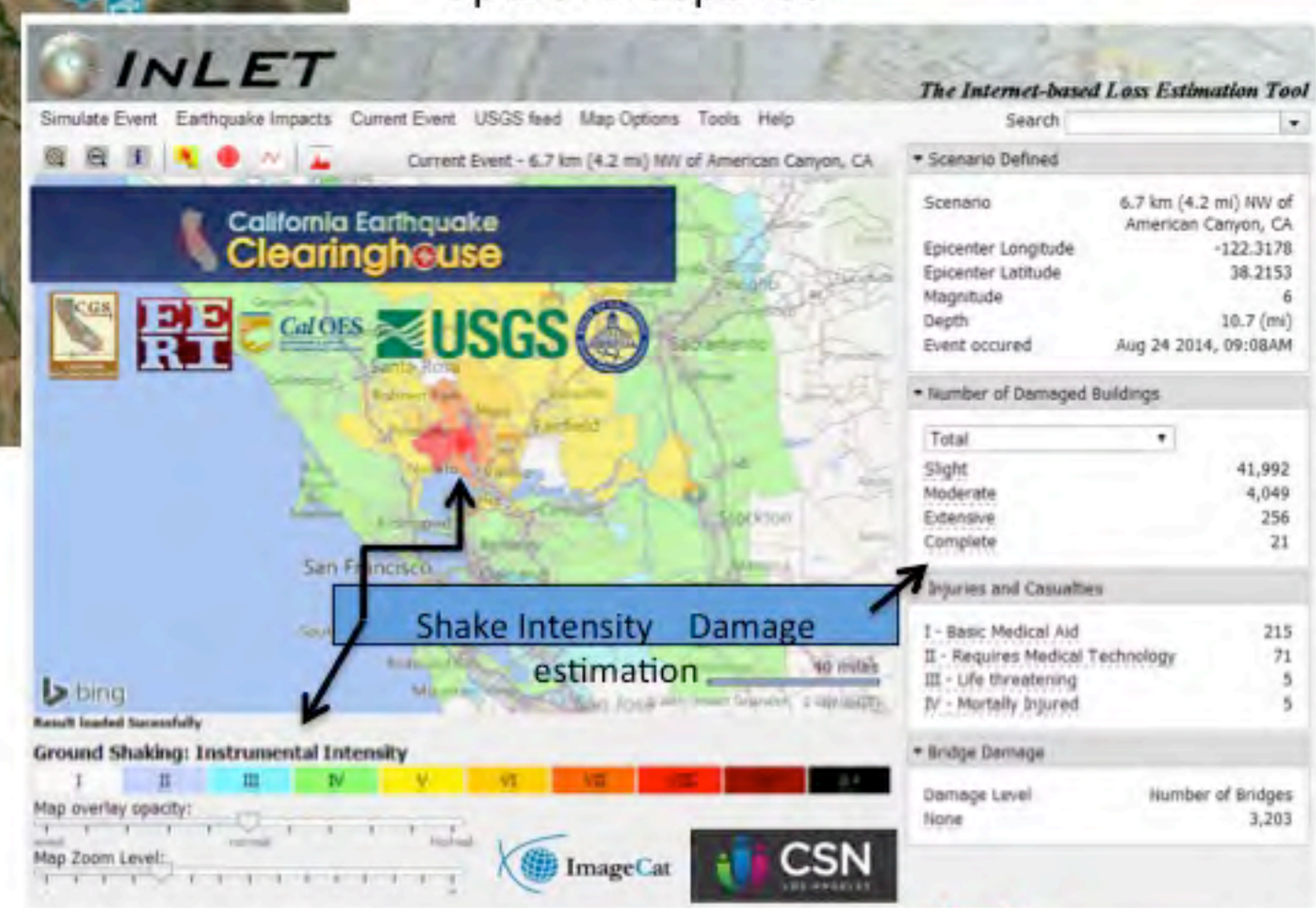
South Napa Earthquake Postseismic



Slip confined to main rupture plane

South Napa Earthquake Response

- **Products**
  - Deformation models
  - Damage and loss estimation models
  - Aftershock forecasts
  - InSAR/UAVSAR imagery
- **Collected and posted for distribution to Clearinghouse participants**
  - Field validation efforts
  - Integration into combined map data products via XchangeCore and SpotOnResponse



Damage/loss estimation for critical infrastructure in KML layers for 17 HAZUS types

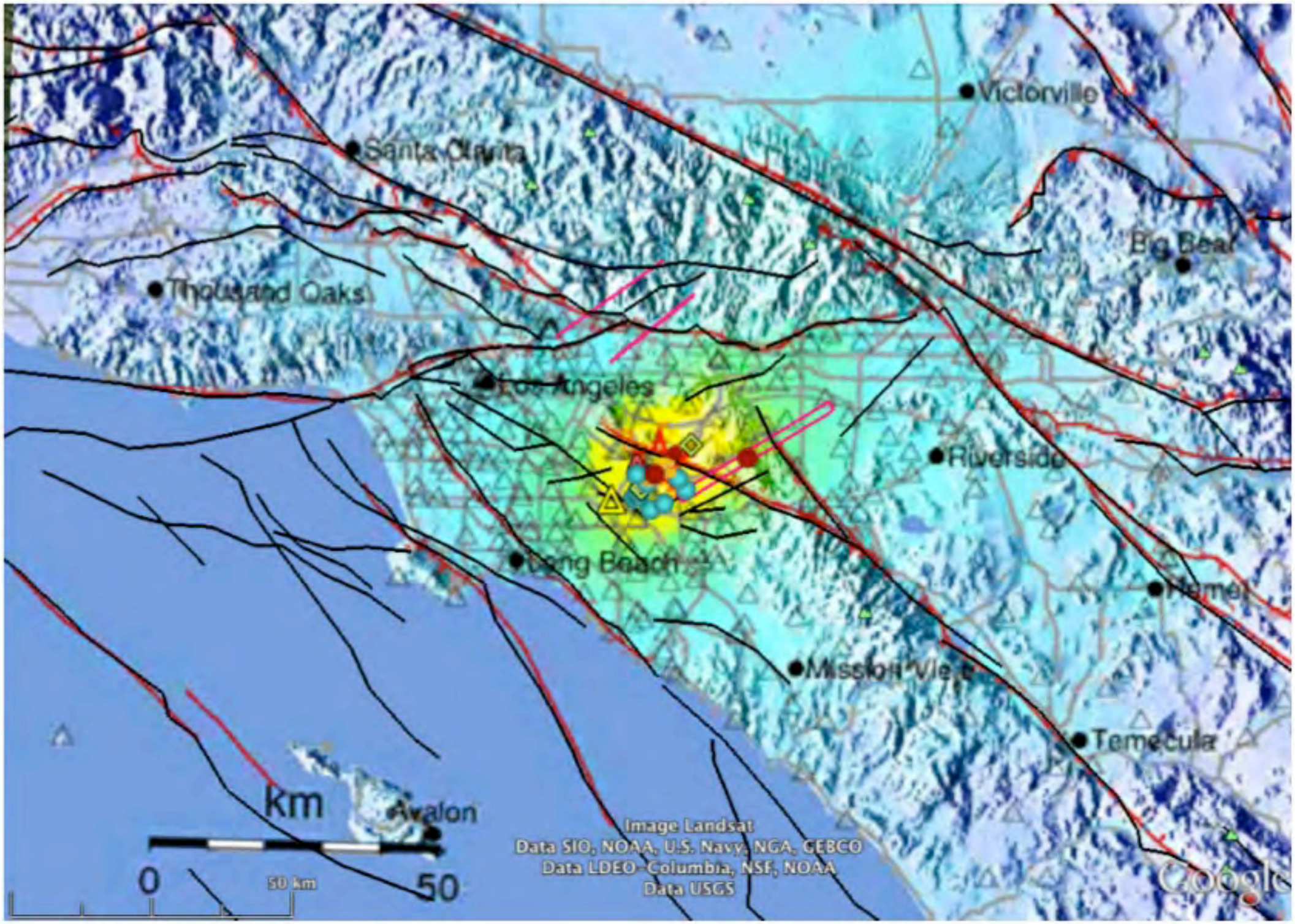
InLET loss estimation results within a few hours of the earthquake in partnership with ImageCat and the Community Stakeholders Network (CSN)

South Napa Earthquake Summary

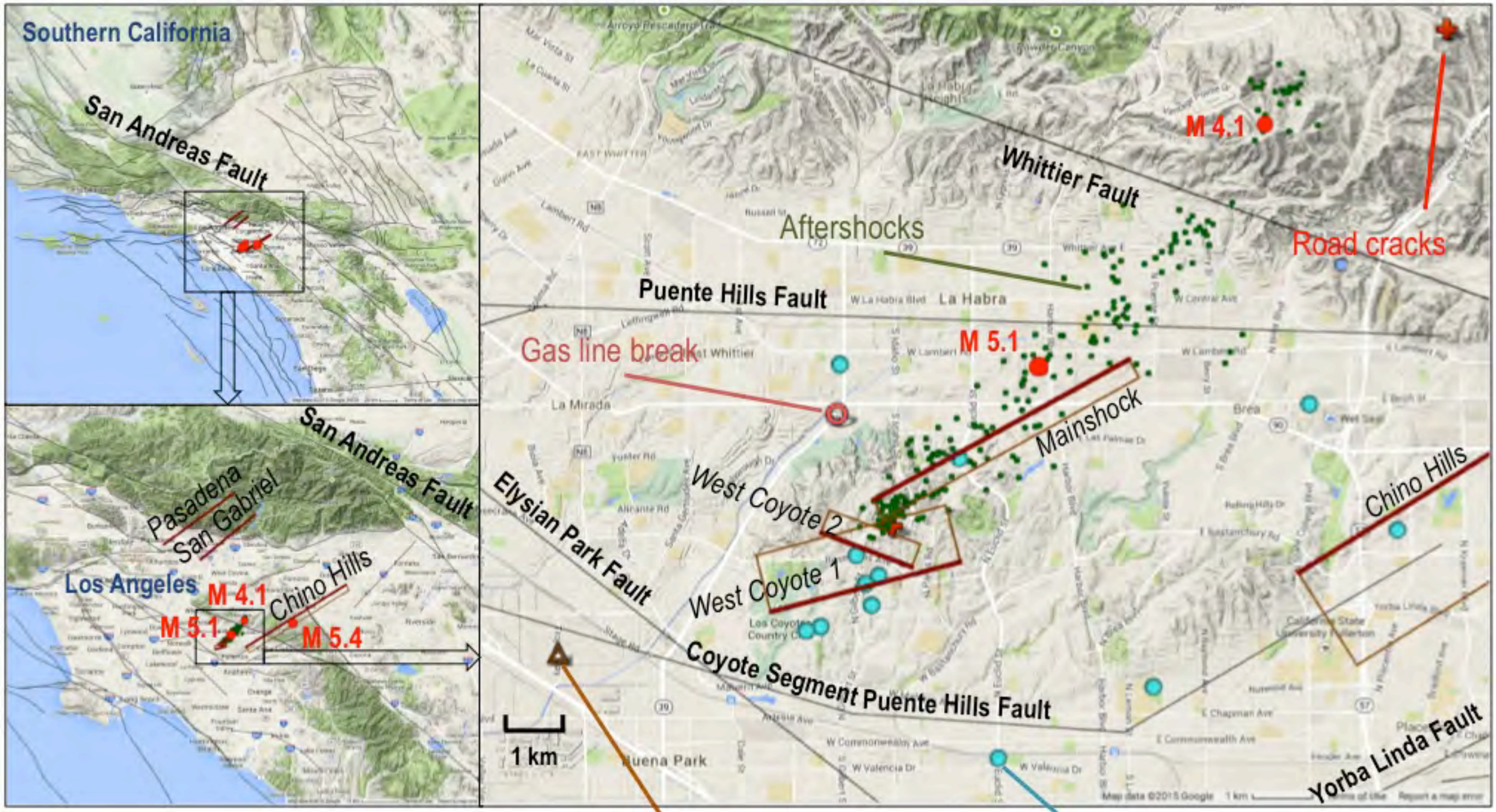
- Extensive shattering observed in UAVSAR for mainshock along multiple strands
  - Rupture is about 27 km long
  - Slip reaches 60–70 cm for about 5 km in middle of rupture
- Postseismic motion confined to a single fault
  - Propagation up fault from main rupture at depth?
  - 80 mm of slip to south
  - Postseismic rupture is about 15 km long
- Provided response products during immediately post event
- Continued collaborations using UAVSAR to assess fault activity and damage

M 5.1 2010 La Habra Earthquake

USGS/SCSN ShakeMap

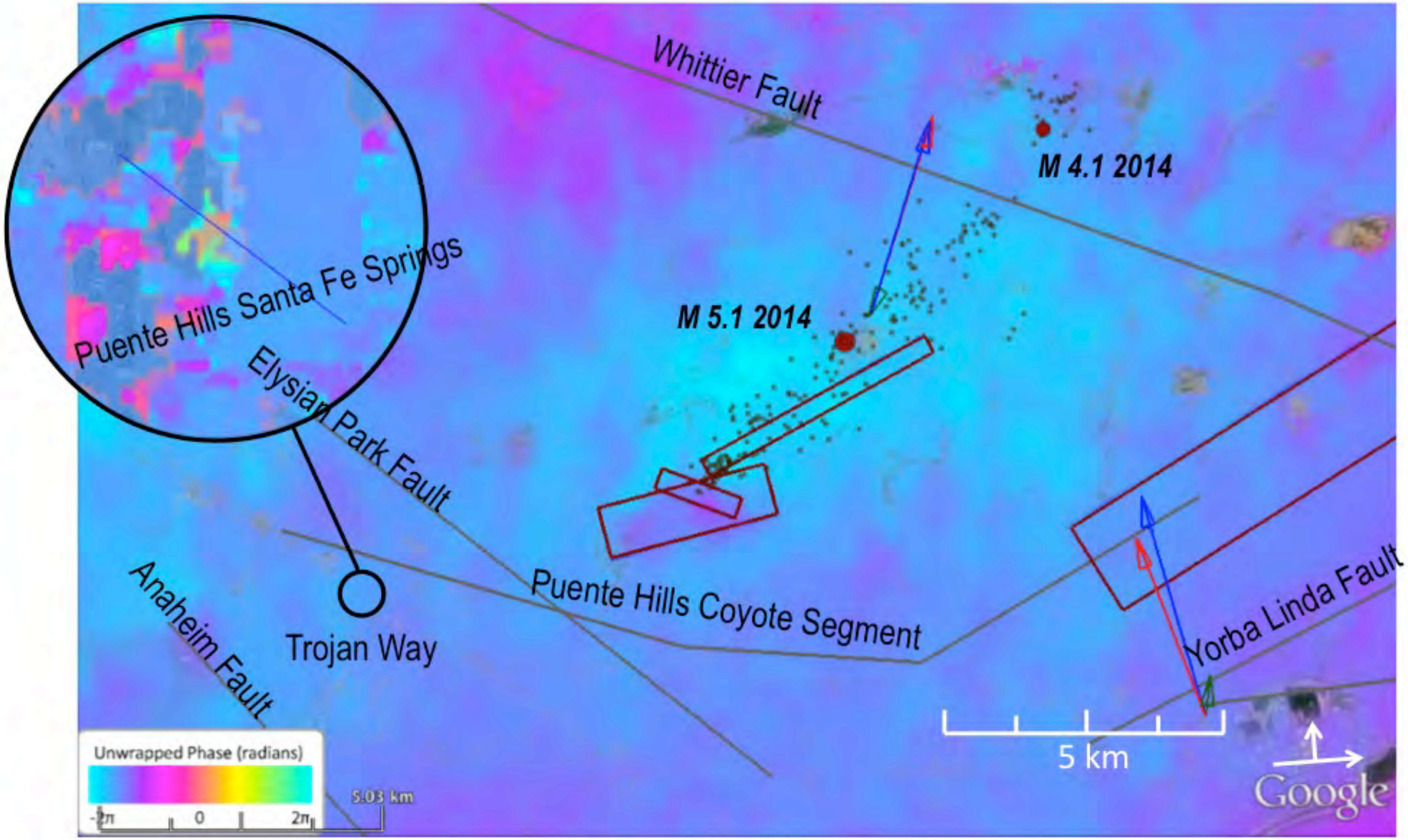


2014 M 5.1 La Habra Earthquake

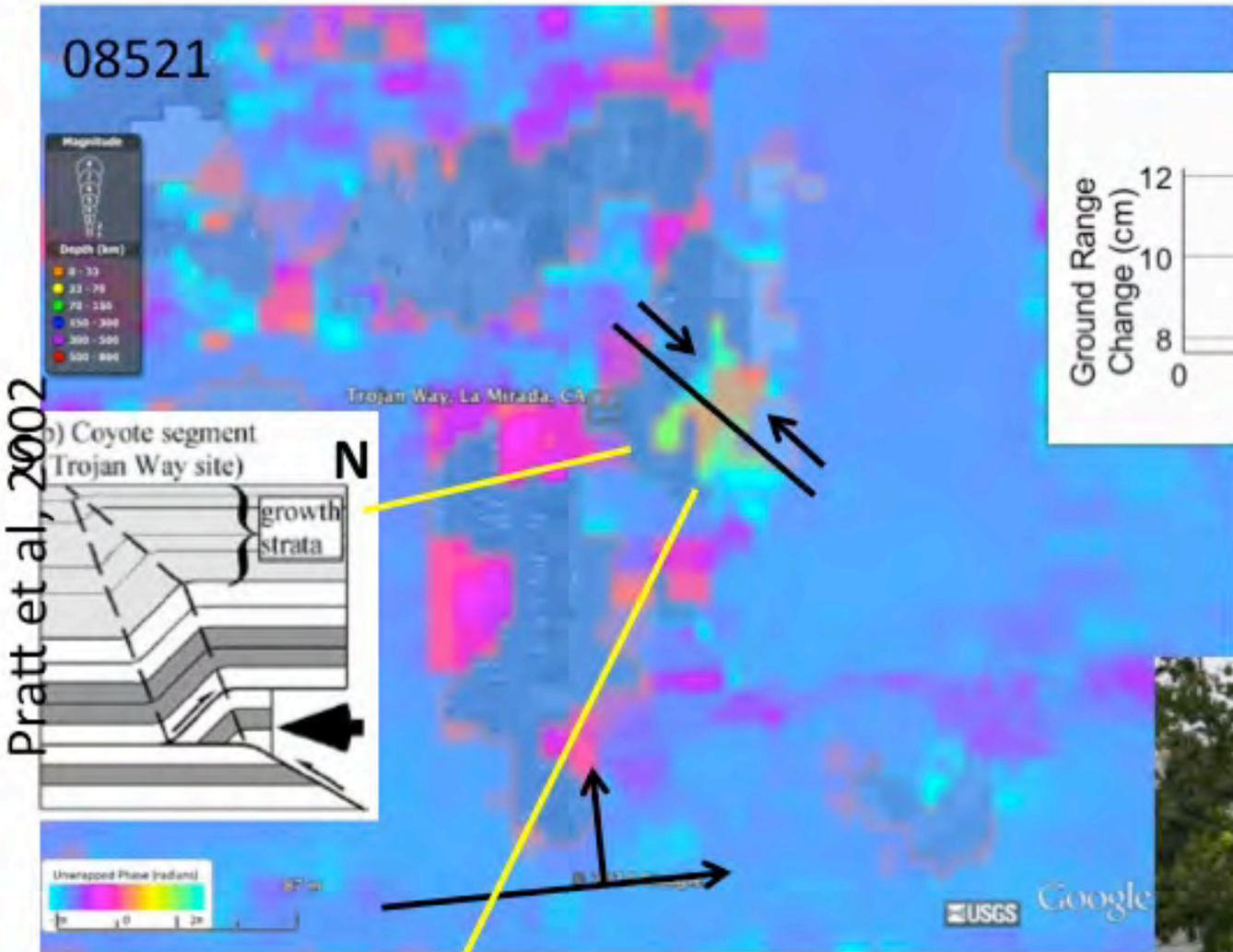


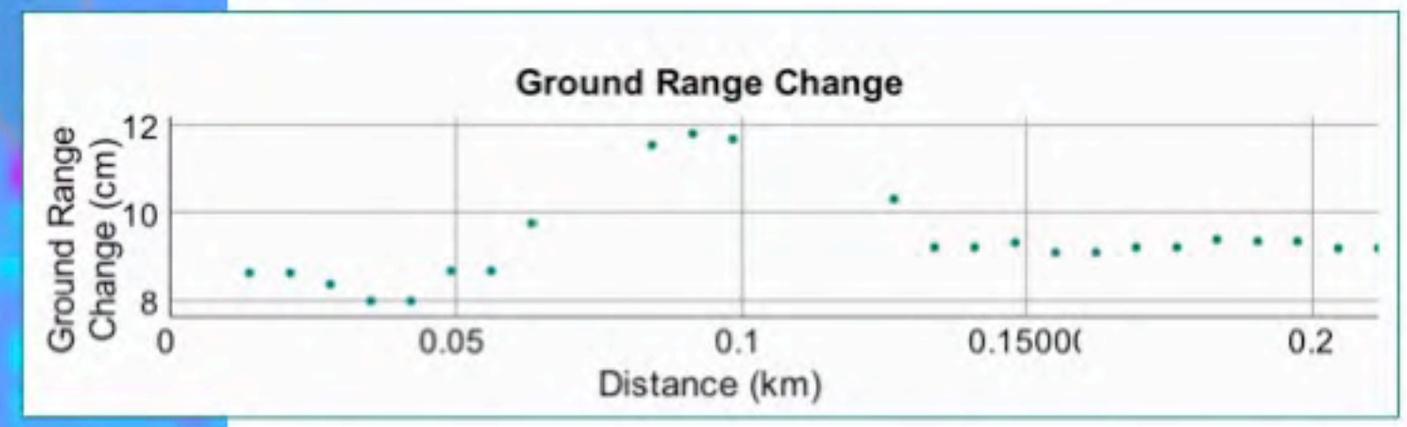
Donnellan et al (2015), *Earth and Space Science*

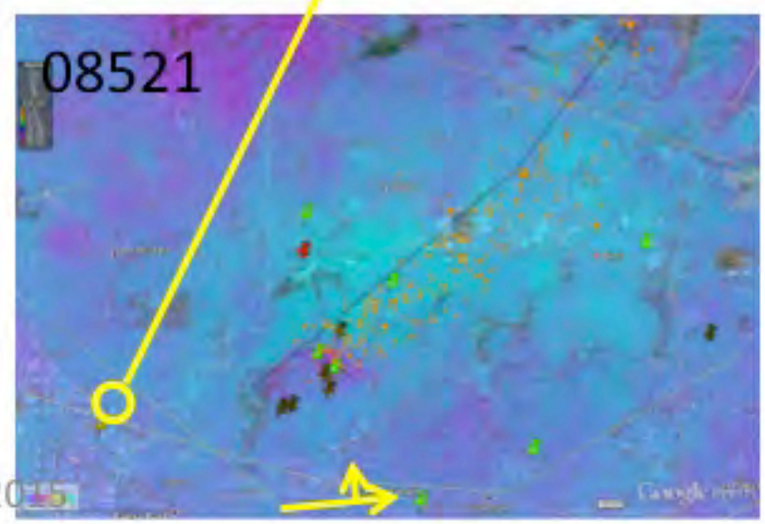
UAVSAR 08521

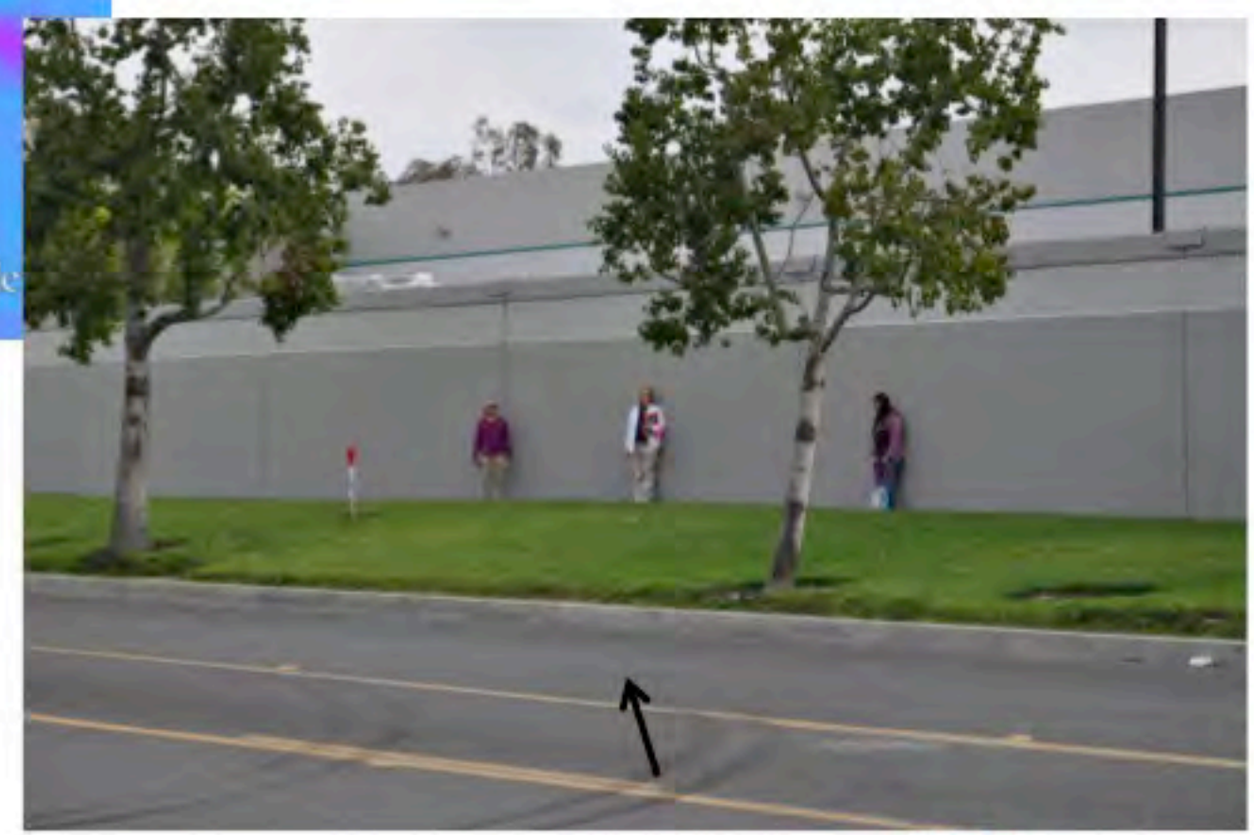


Fault Hinge Line



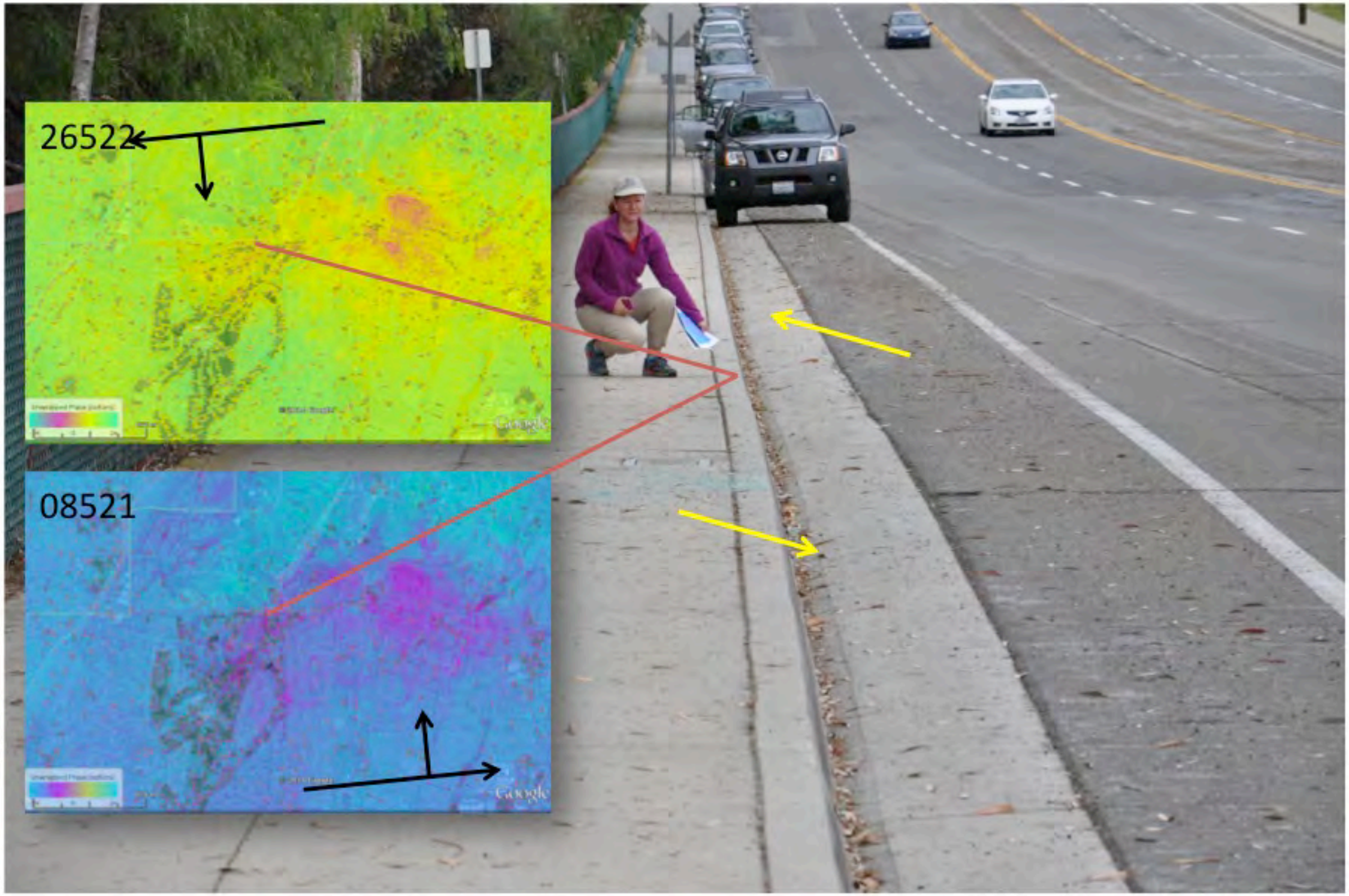




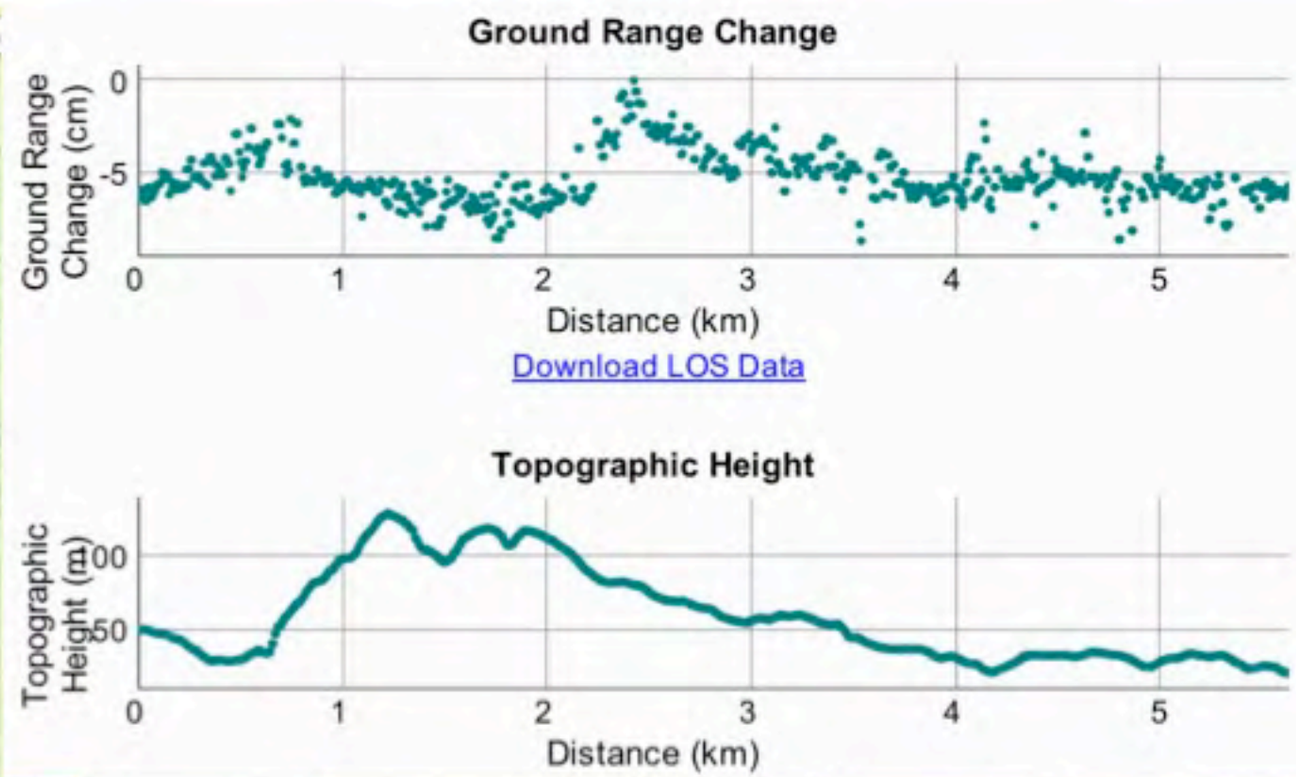


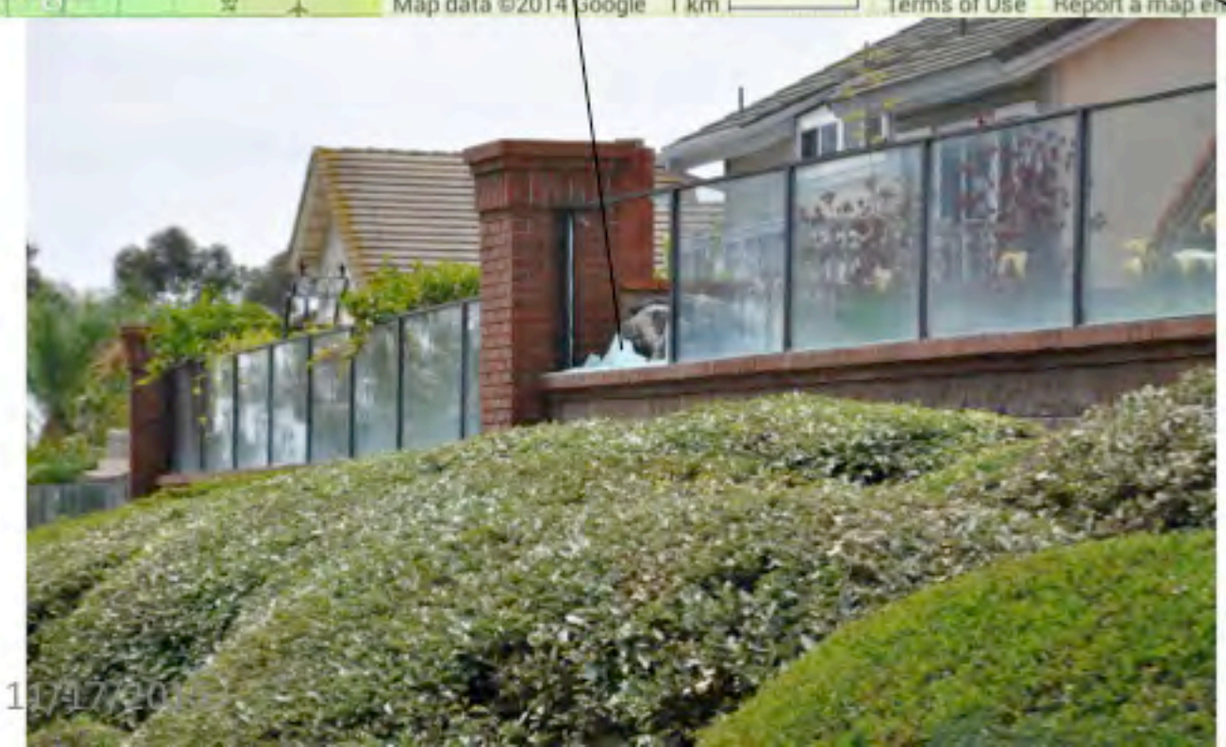
Field Validation

Left Offset Identified by UAVSAR

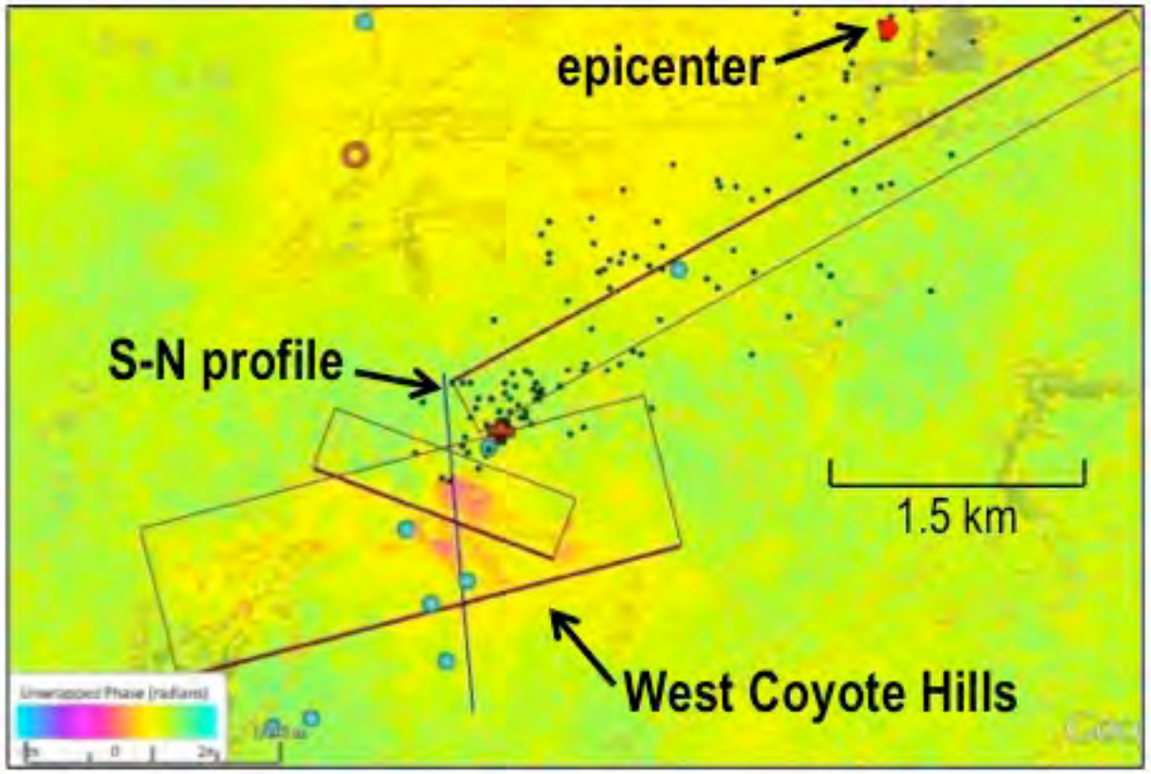


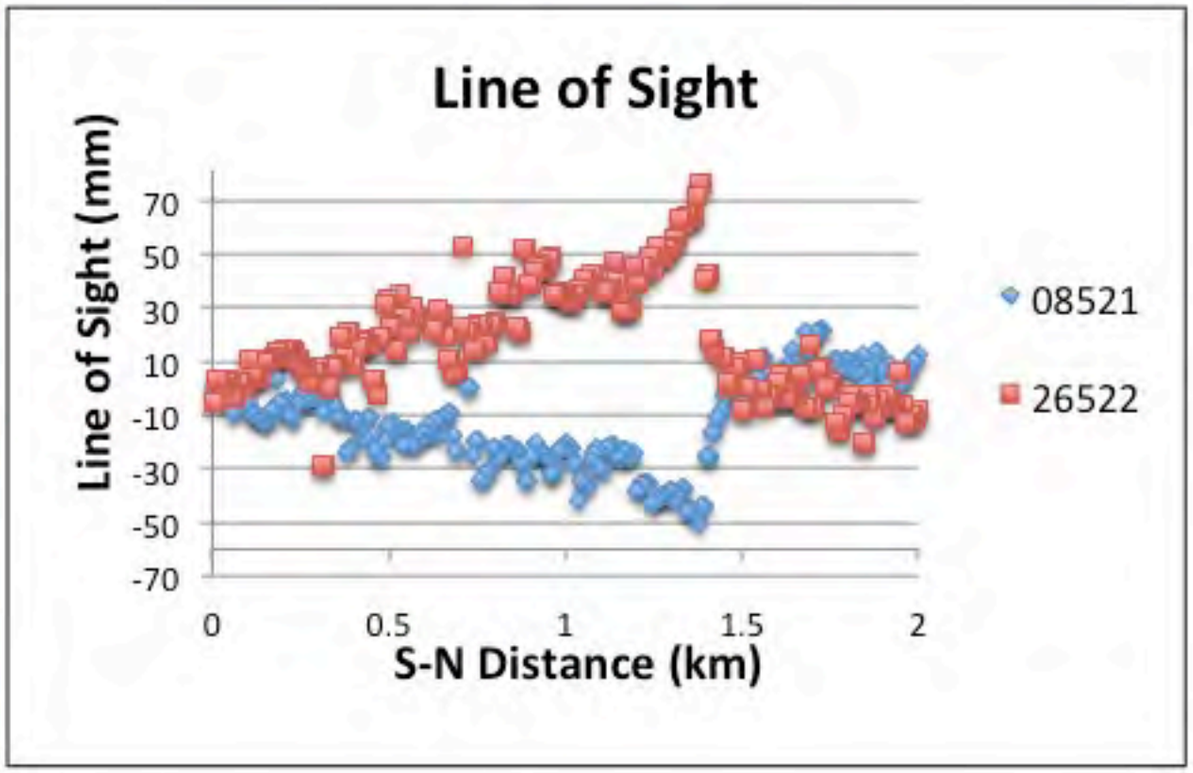
UAVSAR: 7 m Resolution

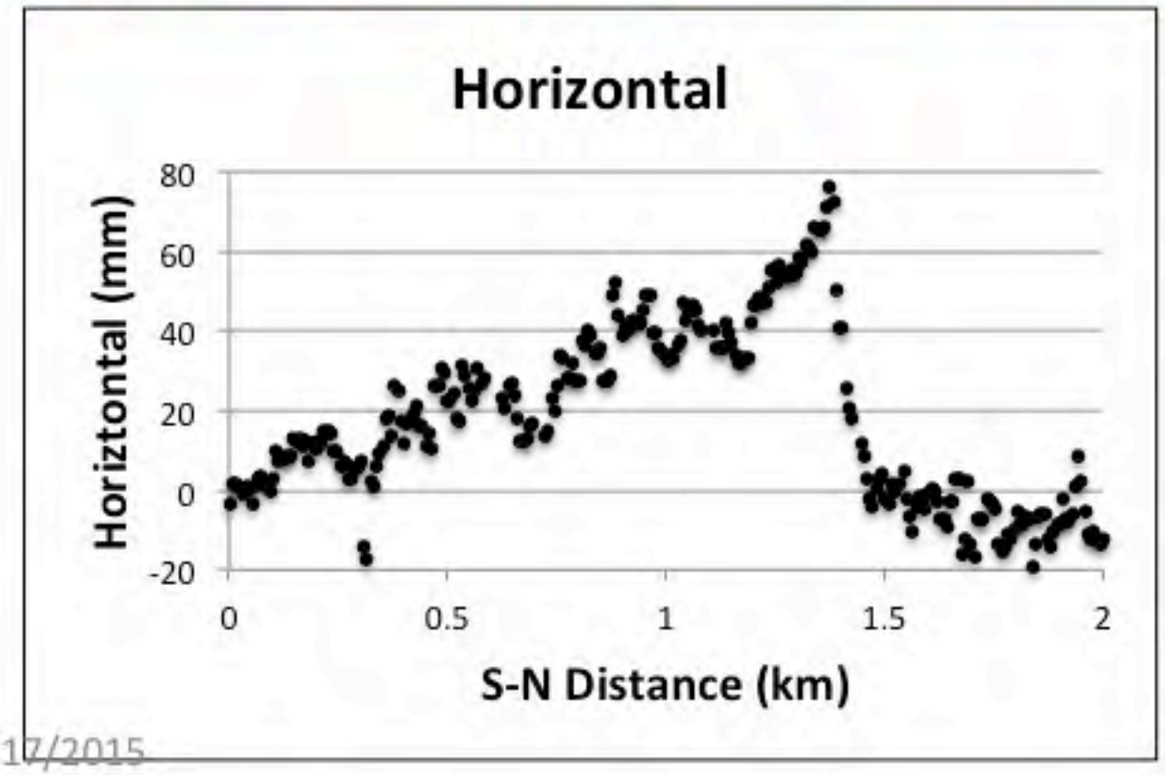


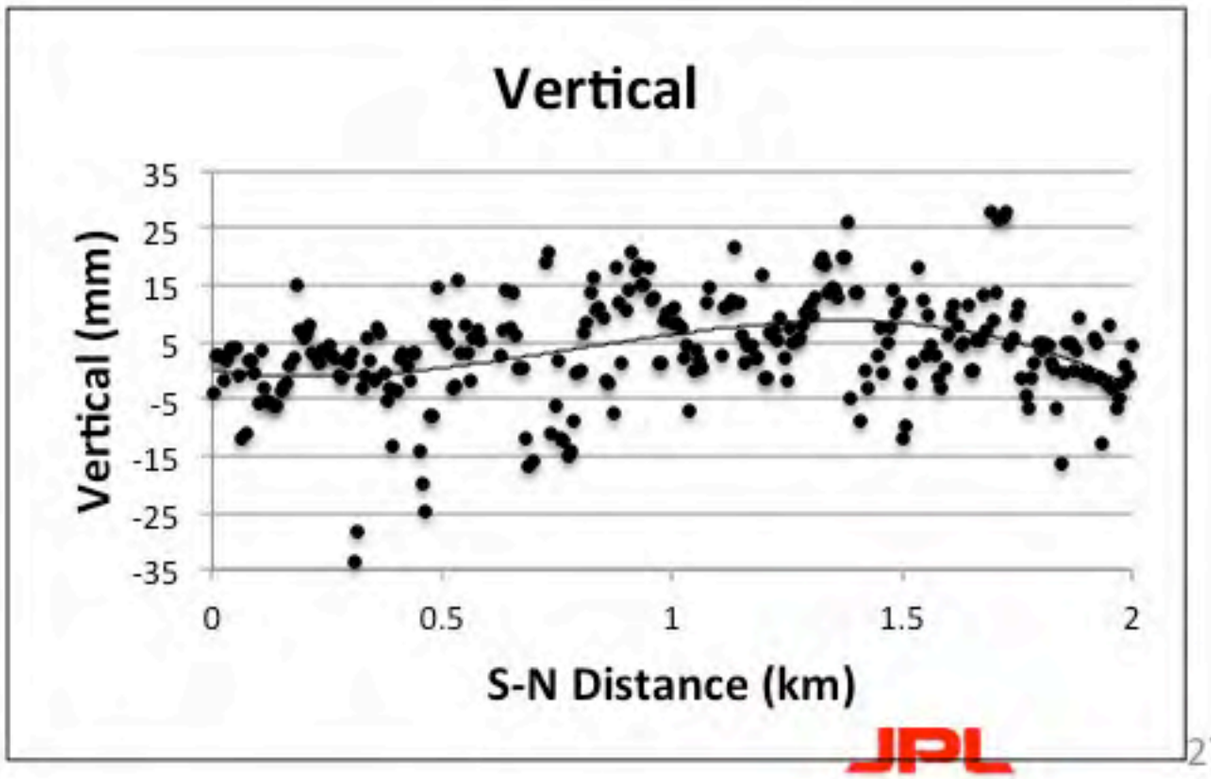


West Coyote Hills

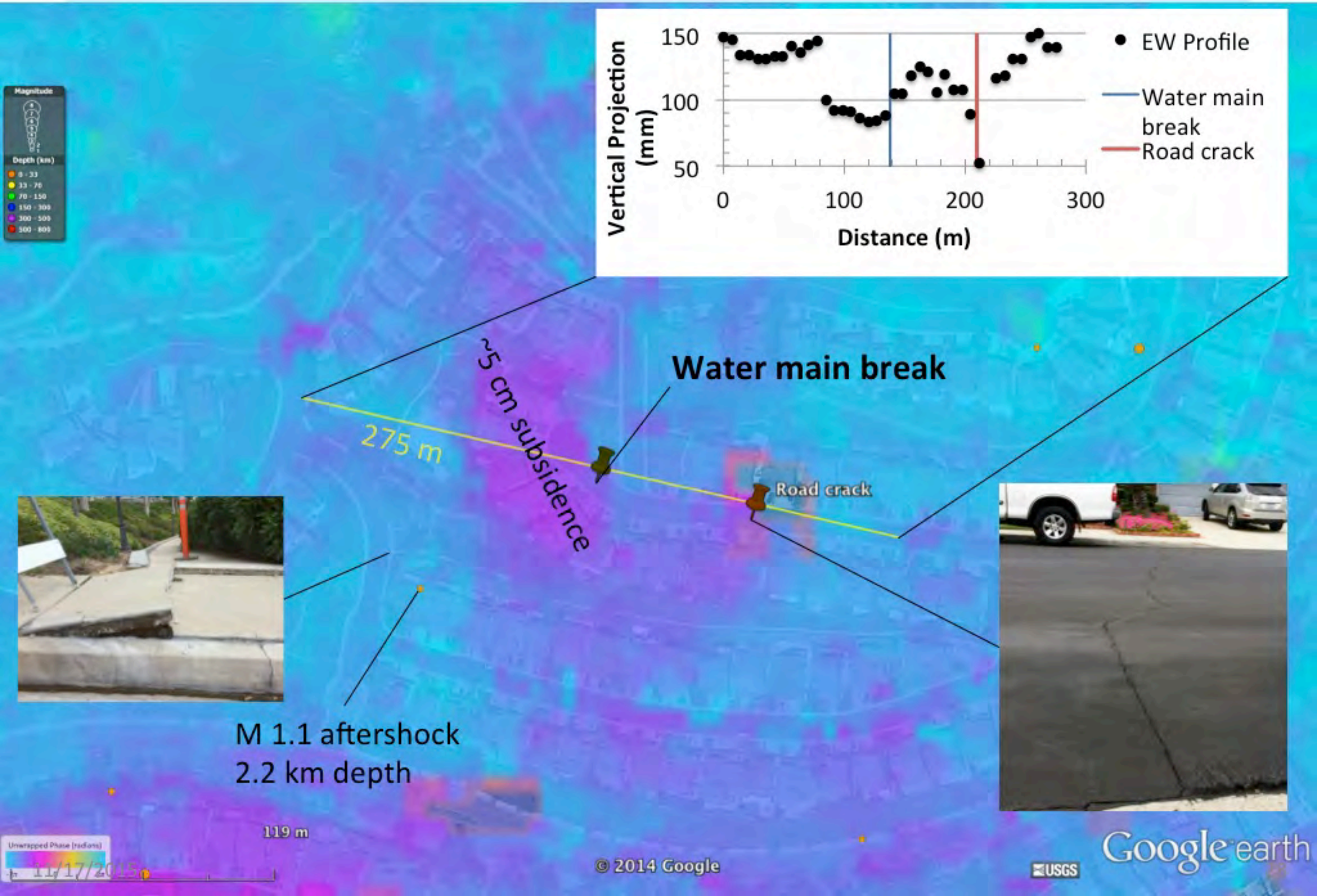




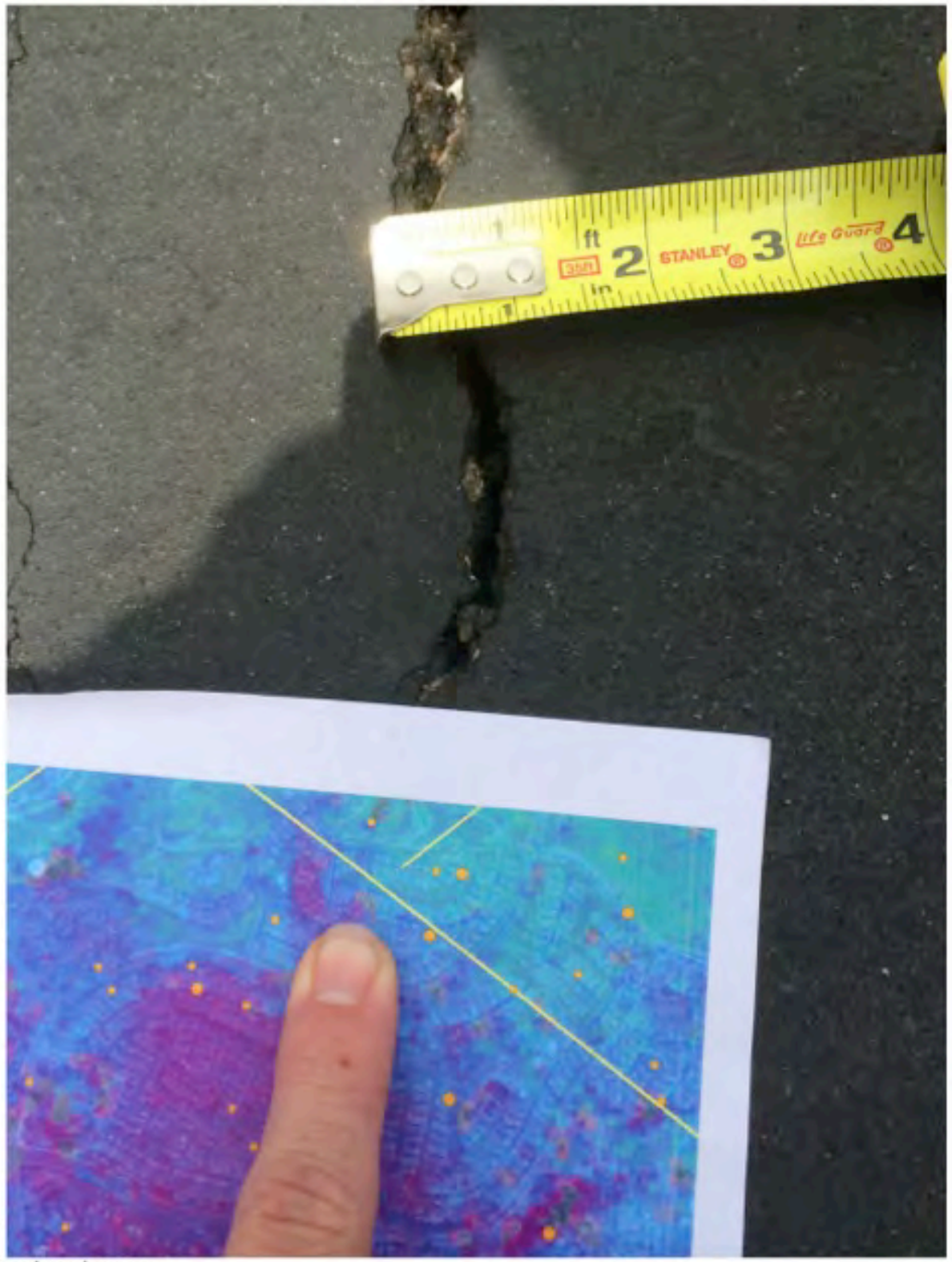


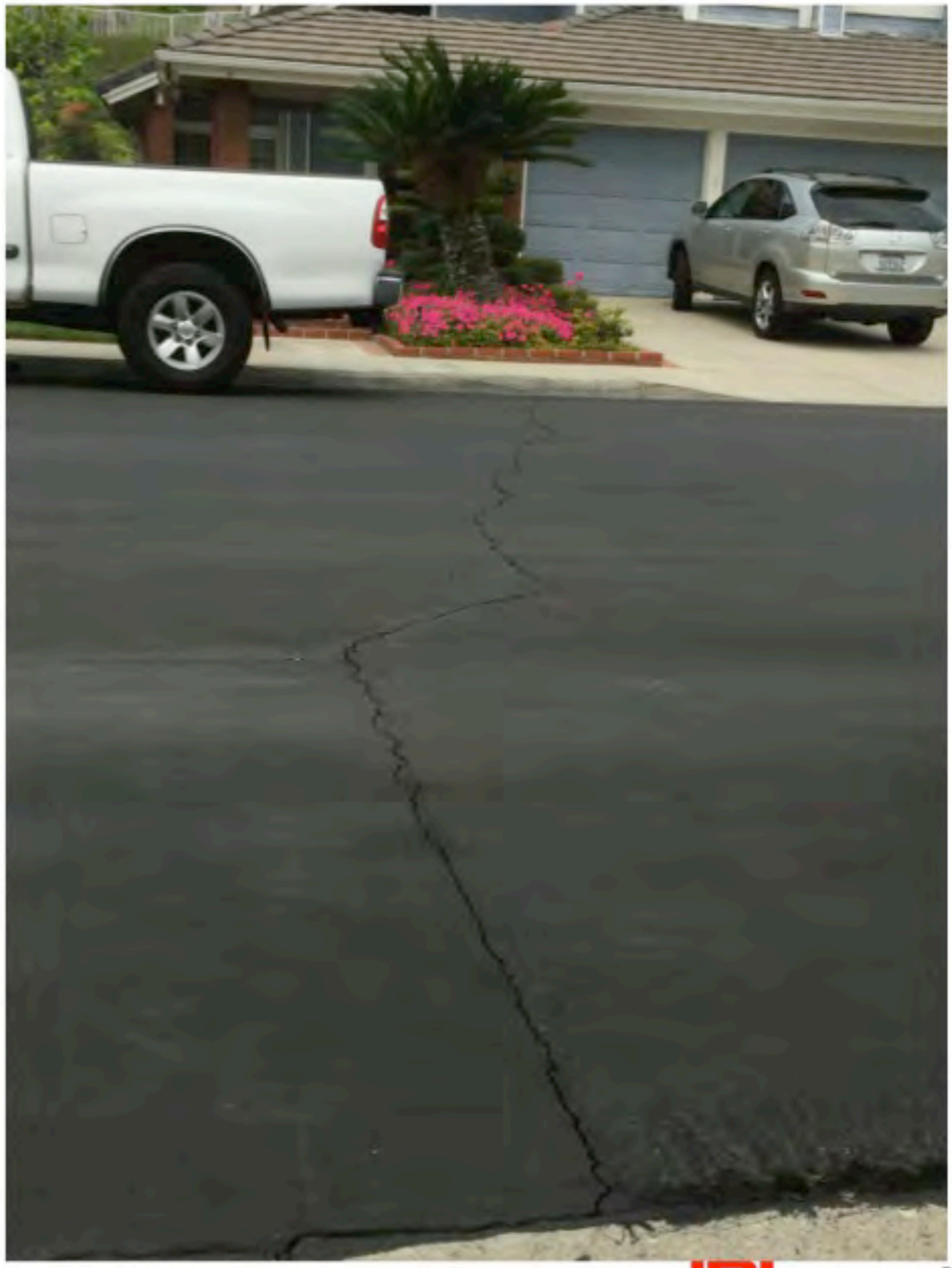


Chantilly Lane, La Habra



Finding Damage at Meter Scale



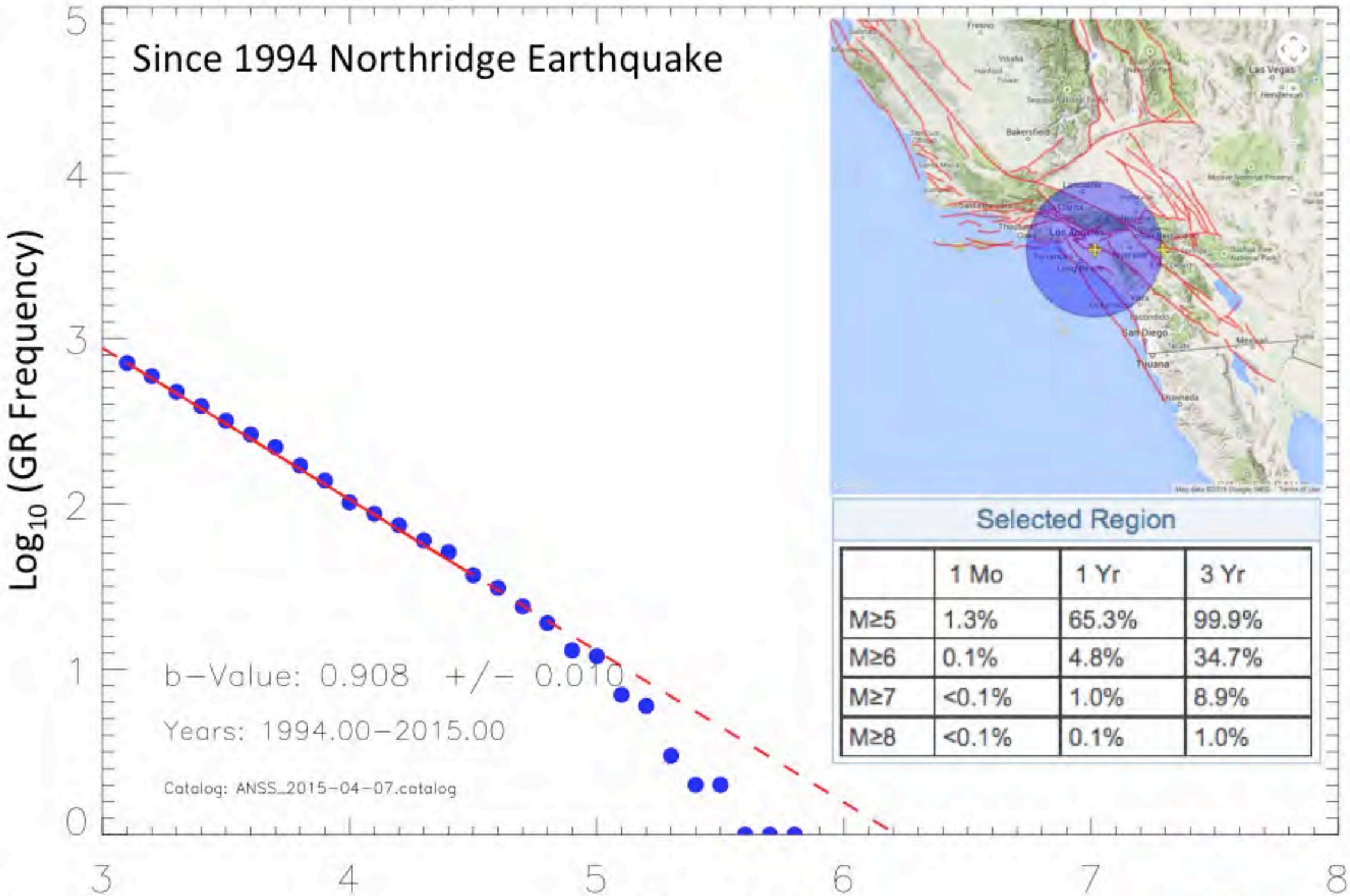


Seismic Implications

- 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).

Gutenberg-Richter Relation



Selected Region

	1 Mo	1 Yr	3 Yr
M≥5	1.3%	65.3%	99.9%
M≥6	0.1%	4.8%	34.7%
M≥7	<0.1%	1.0%	8.9%
M≥8	<0.1%	0.1%	1.0%

Conclusions

Recent California earthquakes show considerable off fault slip

- 2010 M 7.2 El Mayor – Cucapah earthquake
  - Slip on Imperial, Superstition Hills, and East Elmore Ranch faults
    - Decreases to north
    - Depth of slip increases to north
  - M 5.7 aftershock connects EMC rupture and Elsinore fault
- 2014 M 5.1 La Habra earthquake
  - Expected mainshock slip observed
  - Broader pattern of displacements apparent in GPS data
  - Substantial slip in West Coyote Hills south of rupture
  - Deformation exhibits a pattern of north-south shortening and westward escape tectonics on northwest dipping left-lateral faults
- 2014 M 6.0 South Napa earthquake
  - Extensive shattering observed in UAVSAR for the earthquake along multiple strands
  - Postseismic motion confined to a single fault
  - Likely due to propagation up fault from main rupture at depth