Monitoring Subsidence in California with Orbiting Radar

Tom G Farr

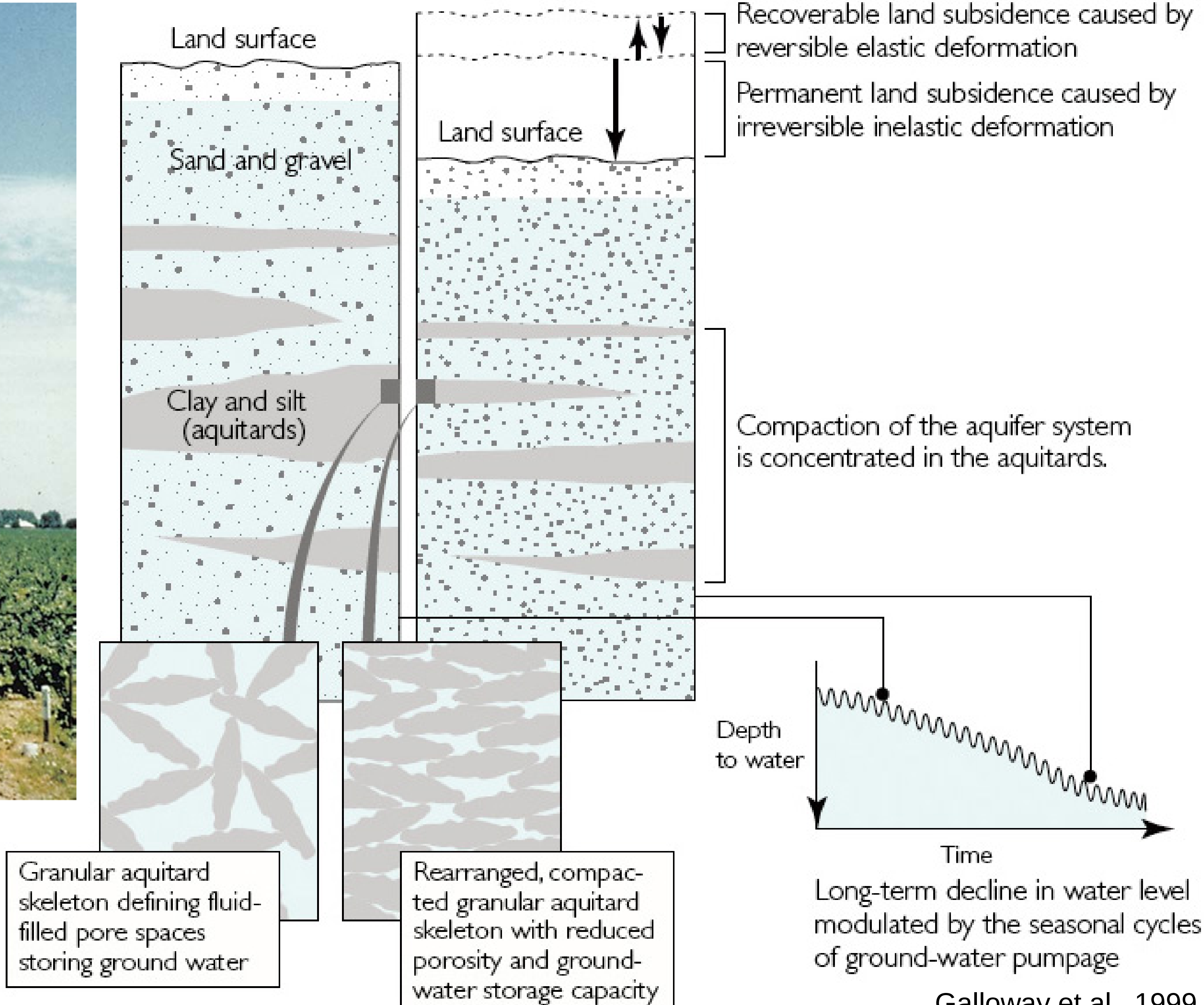
Jet Propulsion Laboratory

tom.farr@jpl.nasa.gov

Subsidence from Space

- Groundwater is becoming a more important part of water resources
- But knowledge of the groundwater level is not uniformly available
- Wells provide some monitoring capability, but there are political and practical difficulties
- Interferometric Synthetic Aperture Radar (InSAR) can provide information on groundwater levels by measuring surface deformation caused by withdrawal and recharge of aquifers
- Subsidence also causes problems for infrastructure such as roads, aqueducts, and trains
- We are developing information products for water managers, the public, and hydrologists including animations, maps of ‘hot spots’, pixel histories, and regional maps of subsidence and groundwater change
- Most of the work has been done for the Central Valley and LA basin, but we are beginning to process data for other basins of California

Hydrology 101: Aquifer compaction

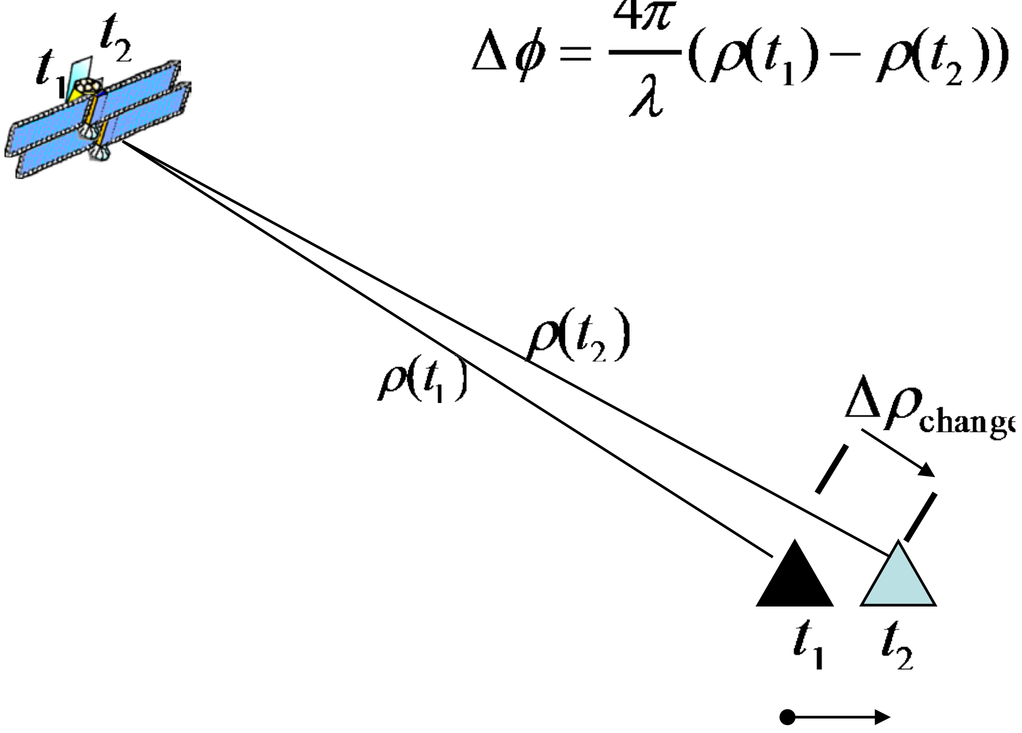


Galloway et al., 1999

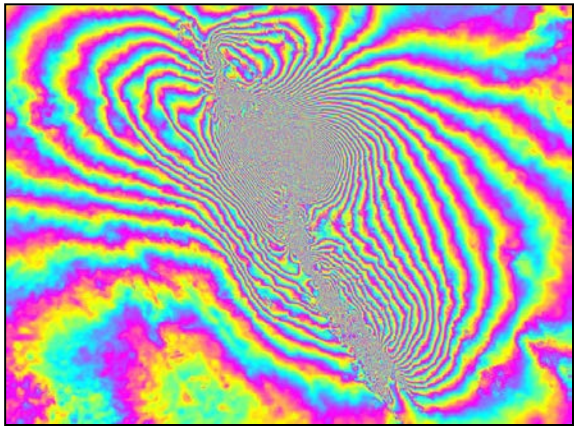
Interferometry 101: Deformation maps

When two observations are made from the same location in space but at different times, the interferometric phase is proportional to any change in the range of a surface feature.

$$\Delta\phi = \frac{4\pi}{\lambda}(\rho(t_1) - \rho(t_2)) = \frac{4\pi}{\lambda}\Delta\rho_{\text{change}}$$



Surface Deformation Phase

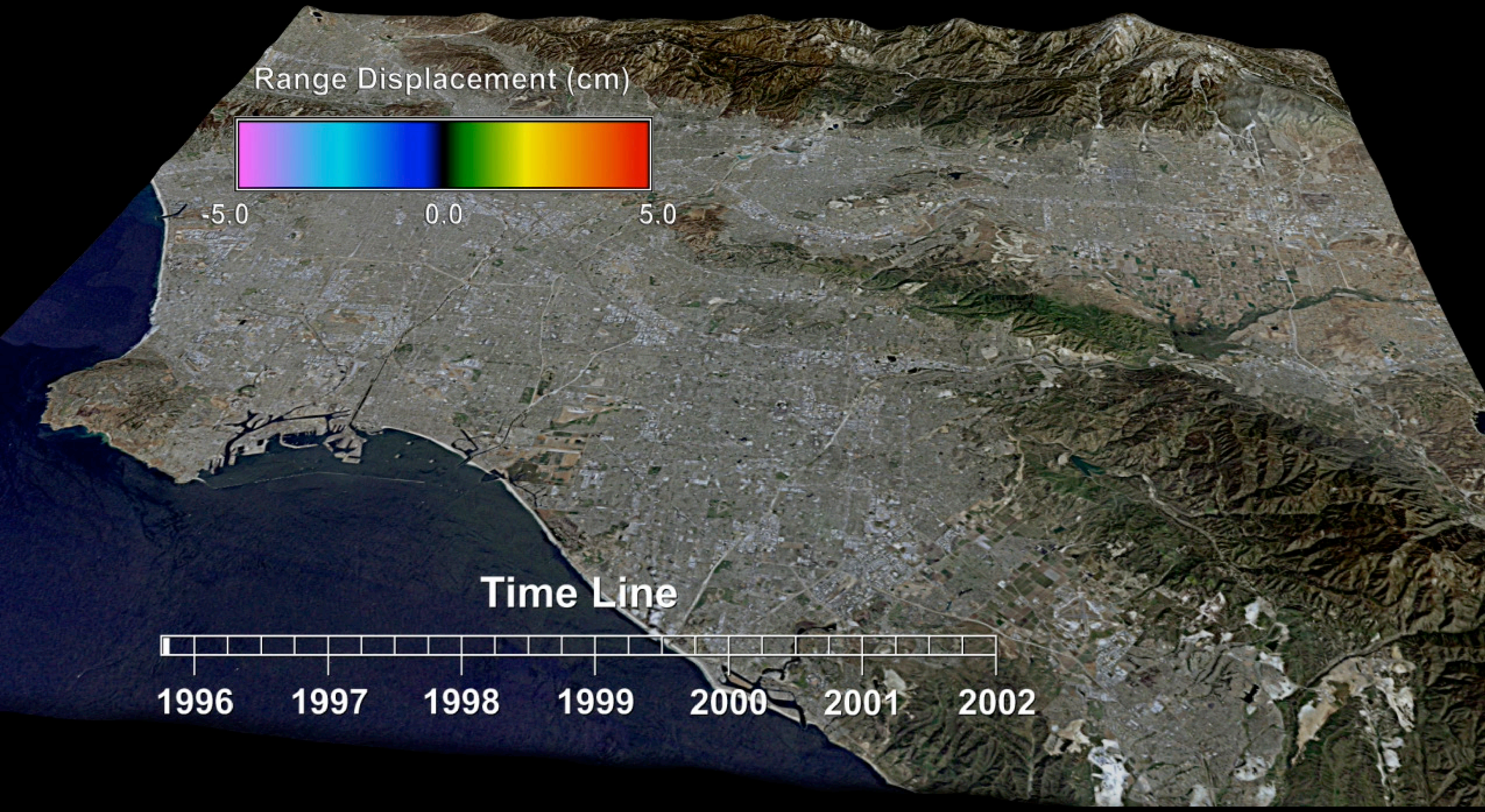


Orbital Radars for Interferometry

Satellite	dates	resolution (m)	swath (km)	incidence angles	minimum revisit (days)	band*/pol
ERS 1,2	1991-2010	25	100	25°	35	CVV
Envisat	2002-2010	25	100	15-45°	35	CVV, CHH
PALSAR	2006-2011	10-100	40-350	10-60°	46	L-quad
Radarsat 1	1995-2013	10-100	45-500	20-49°	24	CHH
Radarsat 2	2008-	3-100	25-500	10-60°	24	C-quad
TerraSAR-X	2007-	1-16	5-100	15-60°	11	X-quad
Cosmo-Skymed	2007-	1-100	10-200	20-60°	<1	X-quad
PALSAR-2	2014-	3-60	50-350	8-70°	14	L-quad
Sentinel-1	2014-	20	250	30-45°	12	C-dual
NISAR	2020	35	350	15-60°	12	L-quad

* wavelengths: X ~ 1”, C ~ 2”, L ~10”

Monitoring LA Basin



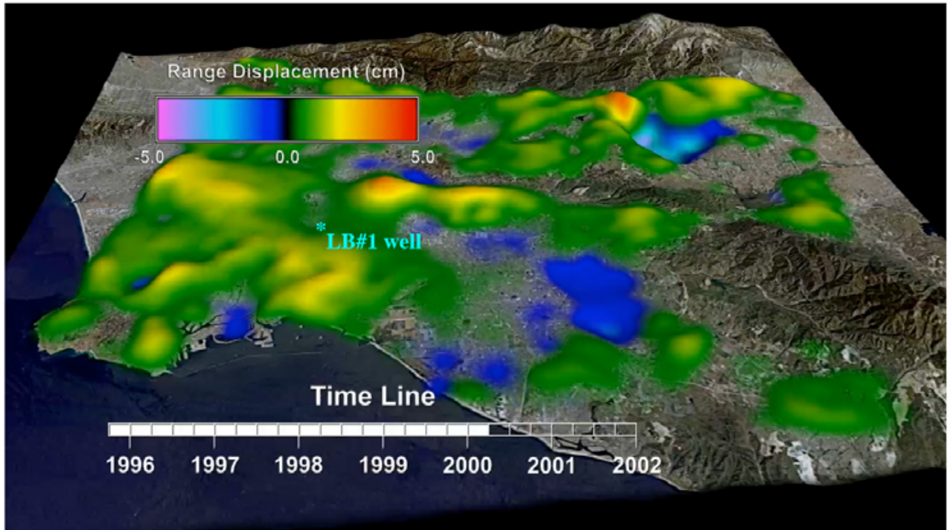
Paul Lundgren, Vince Realmuto, JPL

Monitoring LA Basin

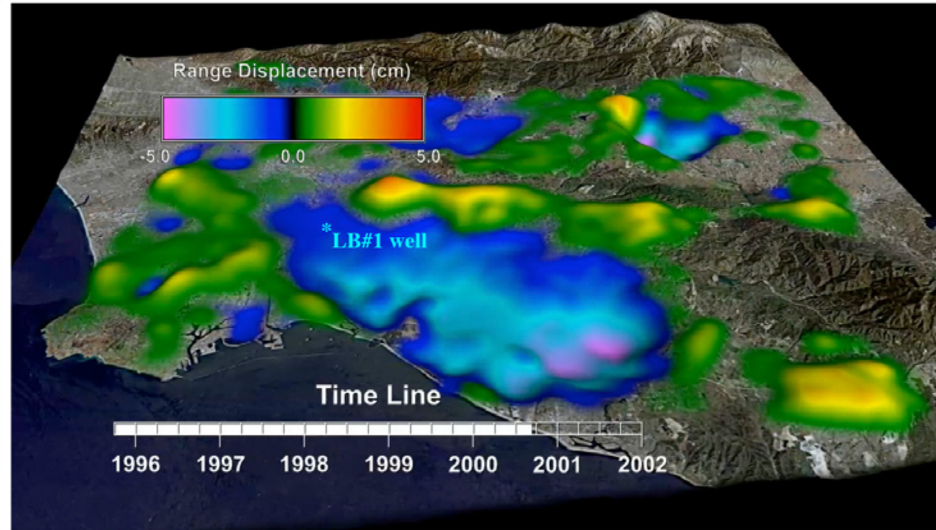
Paul Lundgren, Vince Realmuto, JPL

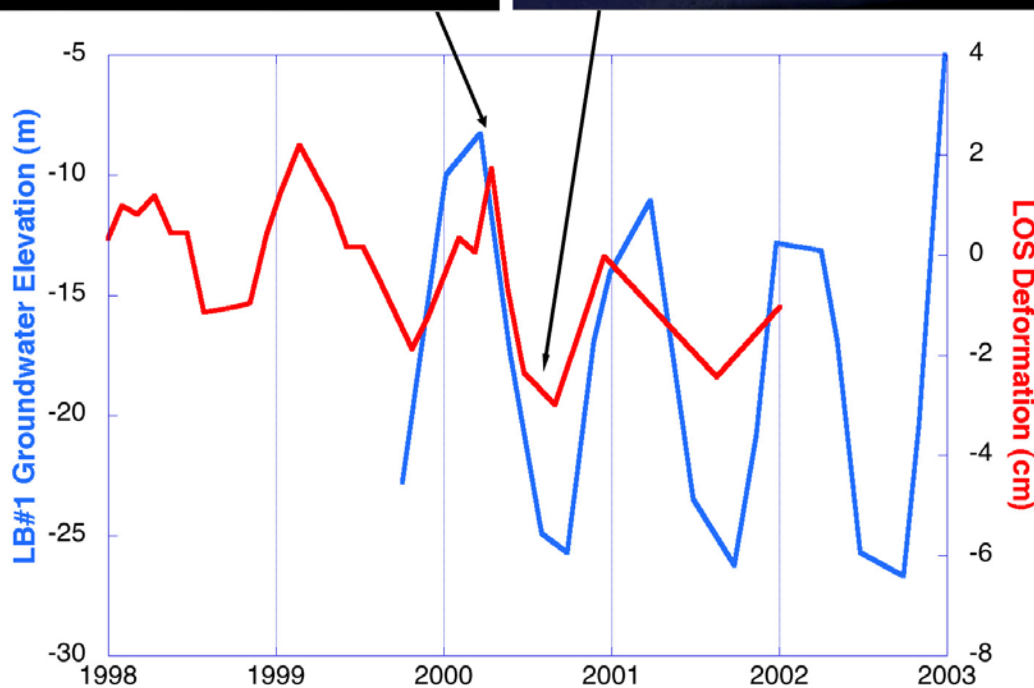
Two frames of the LA movie compared with Long Beach #1 well data

Spring recharge (inflation)



Summer withdrawal (subsidence)



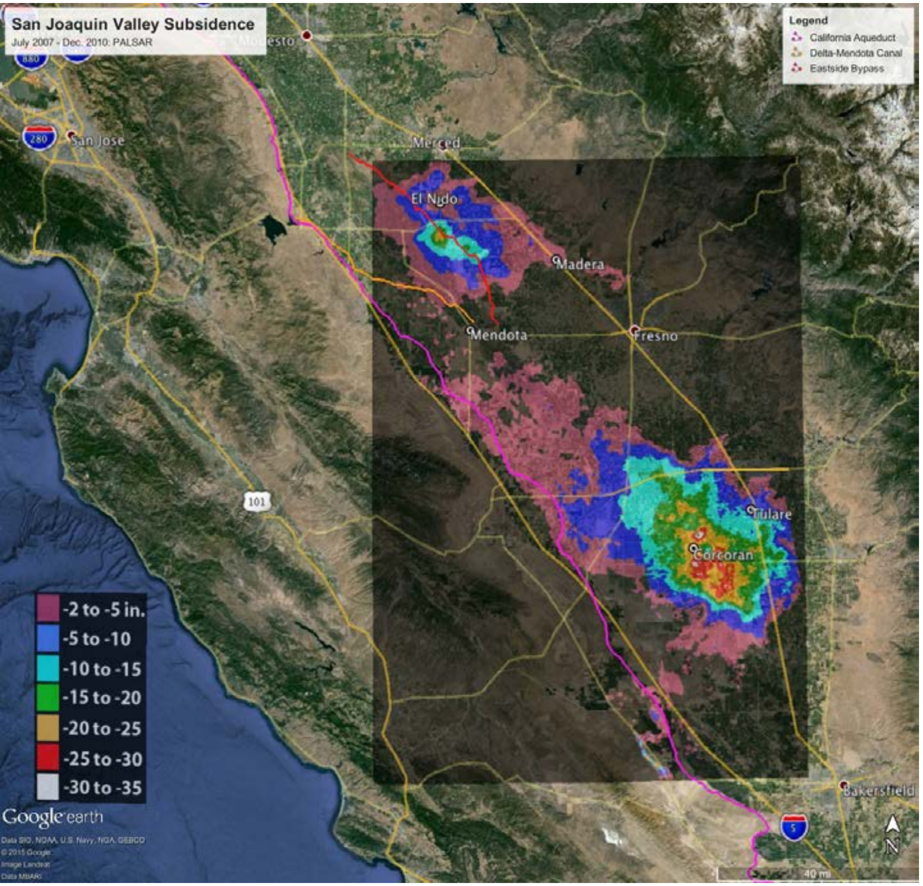


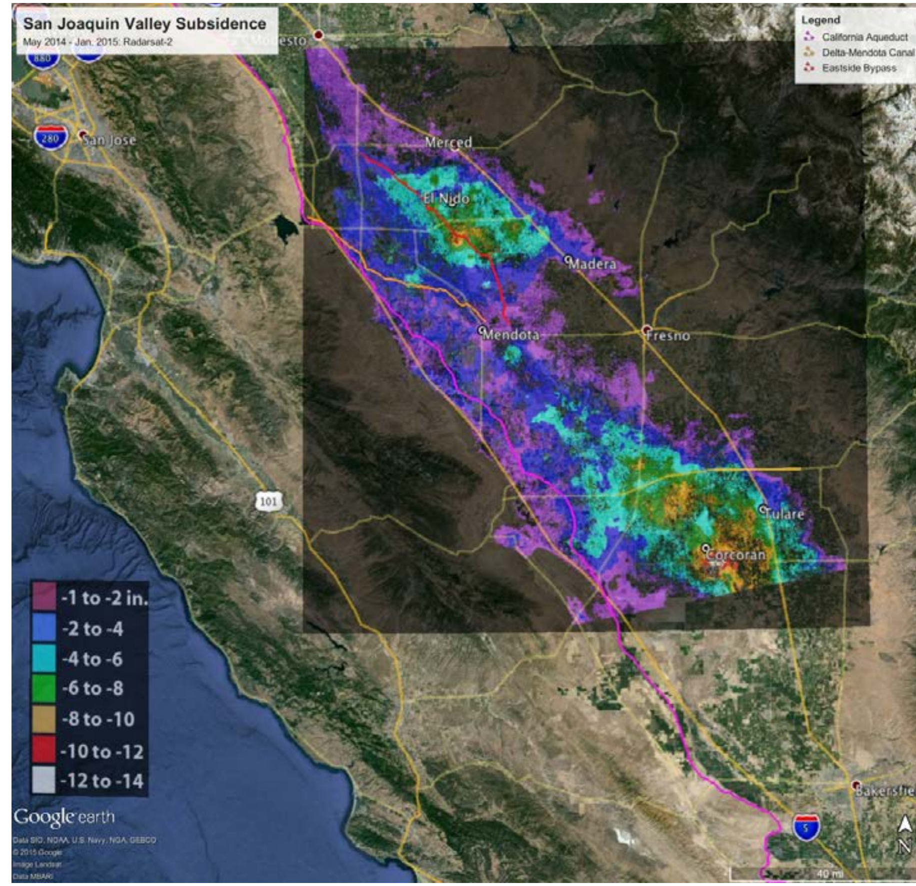
Try it yourself at: http://webgis.irea.cnr.it/

Subsidence in the San Joaquin Valley: PALSAR, 2007-2011

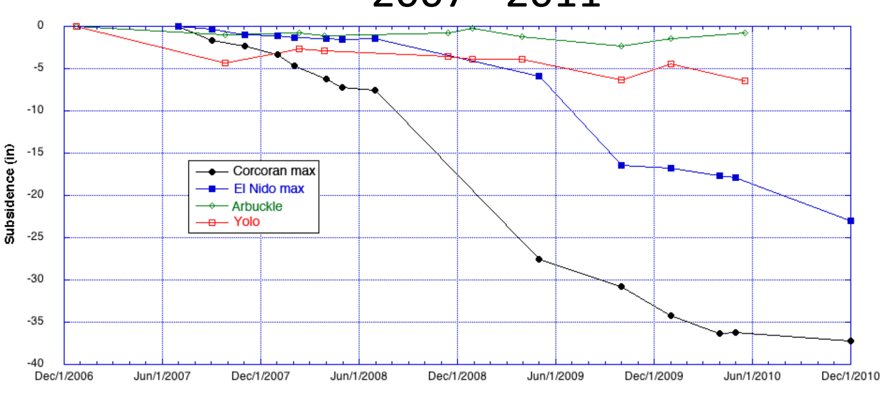
Zhen Liu, Vince Realmuto, Tom Farr, JPL

San Joaquin Valley Subsidence

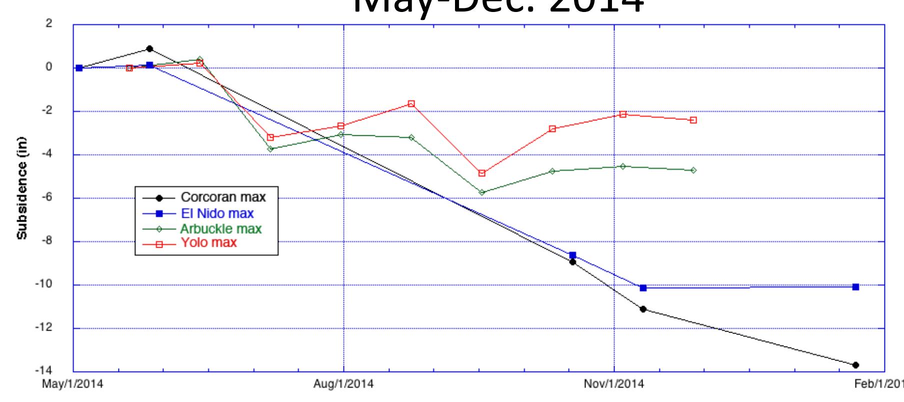




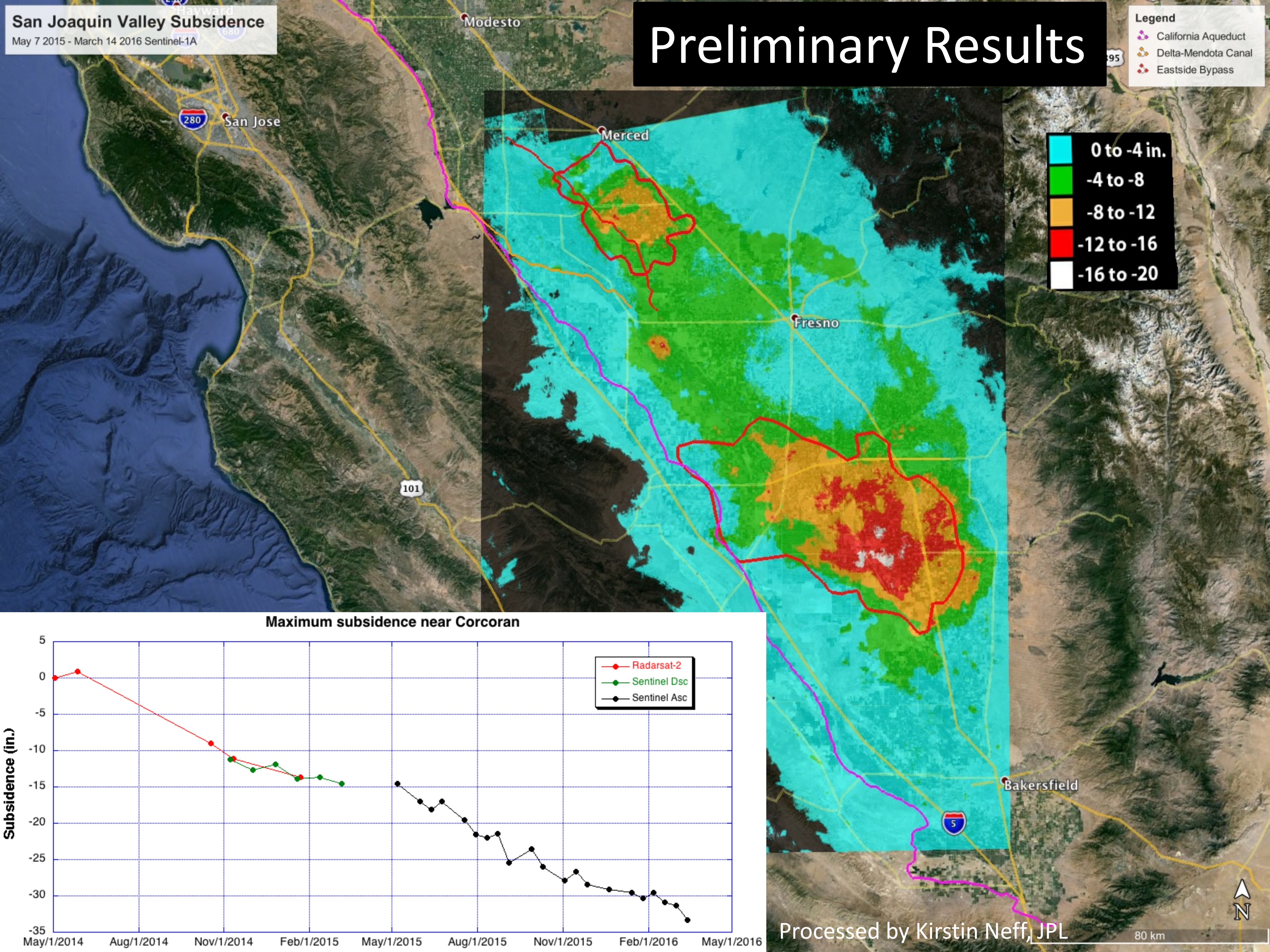
2007 - 2011

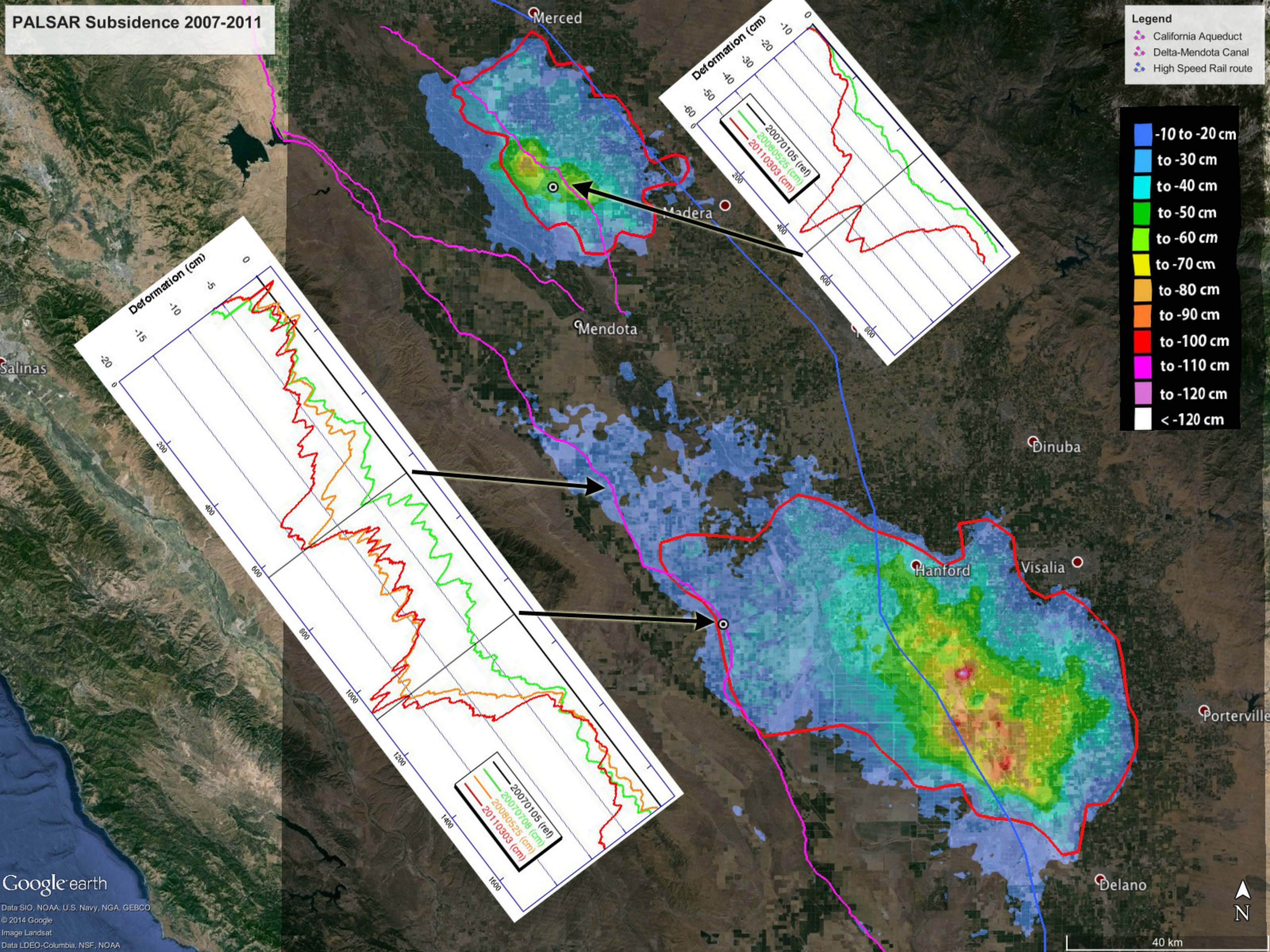


May-Dec. 2014

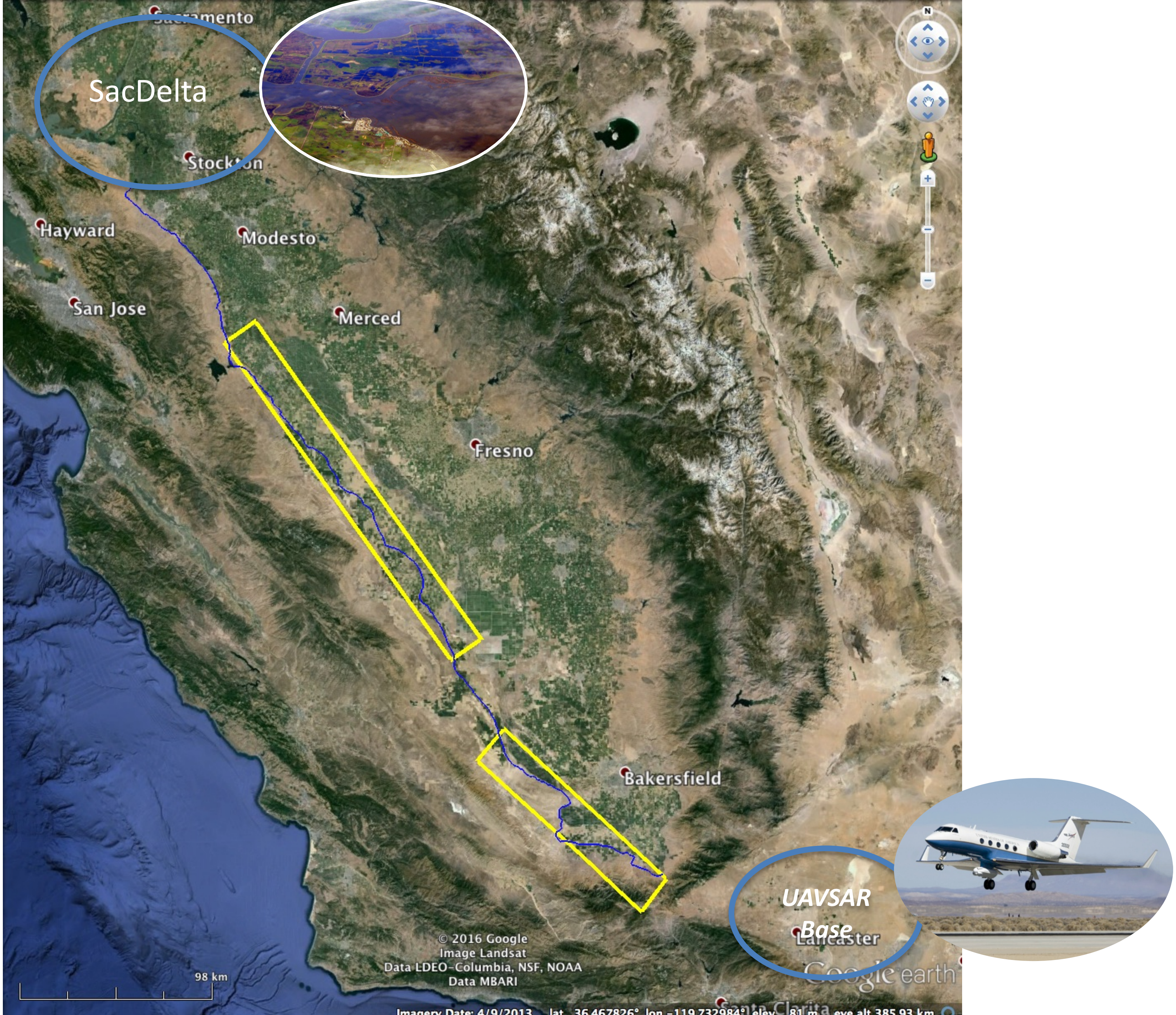


Preliminary Results



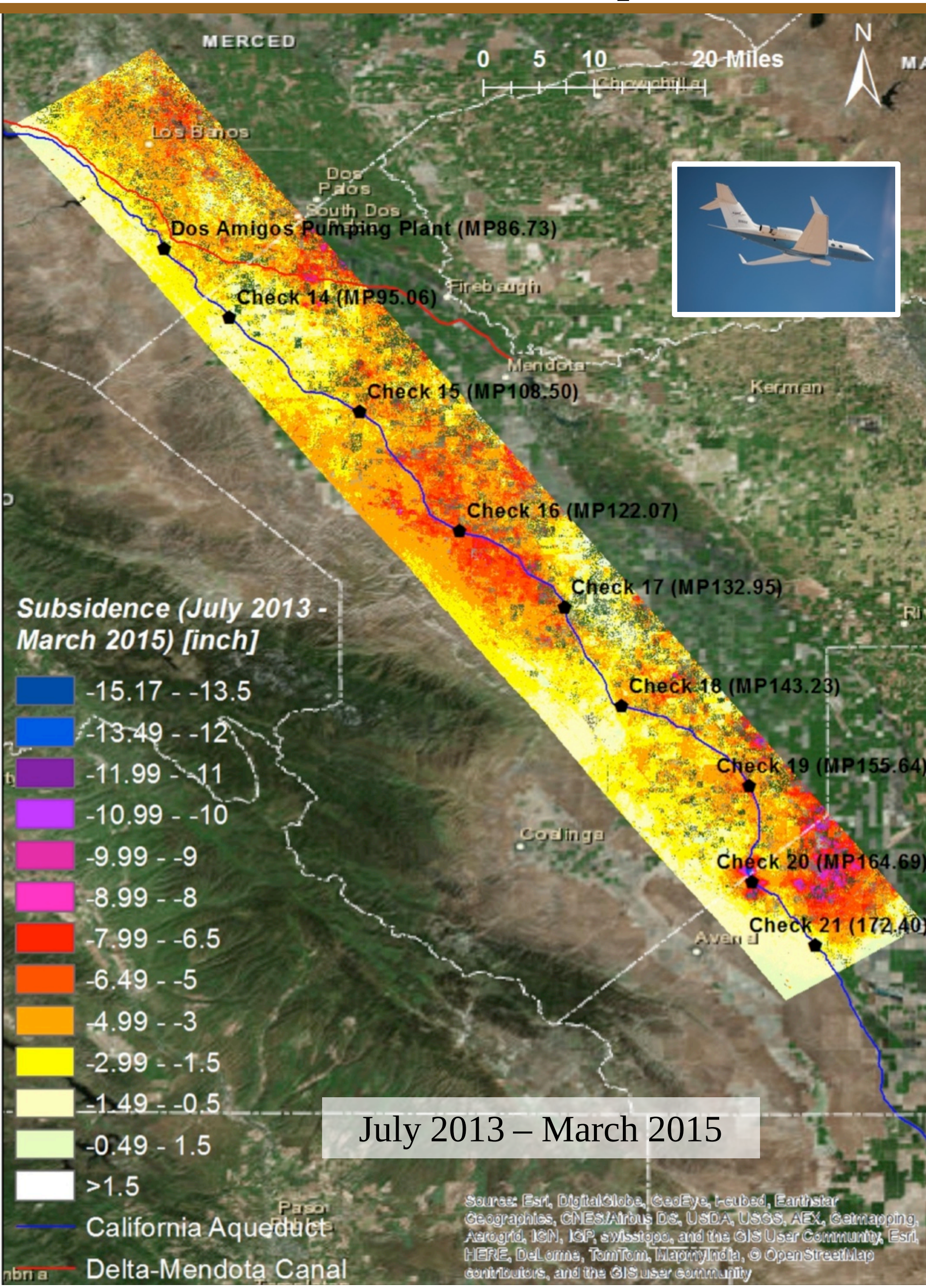


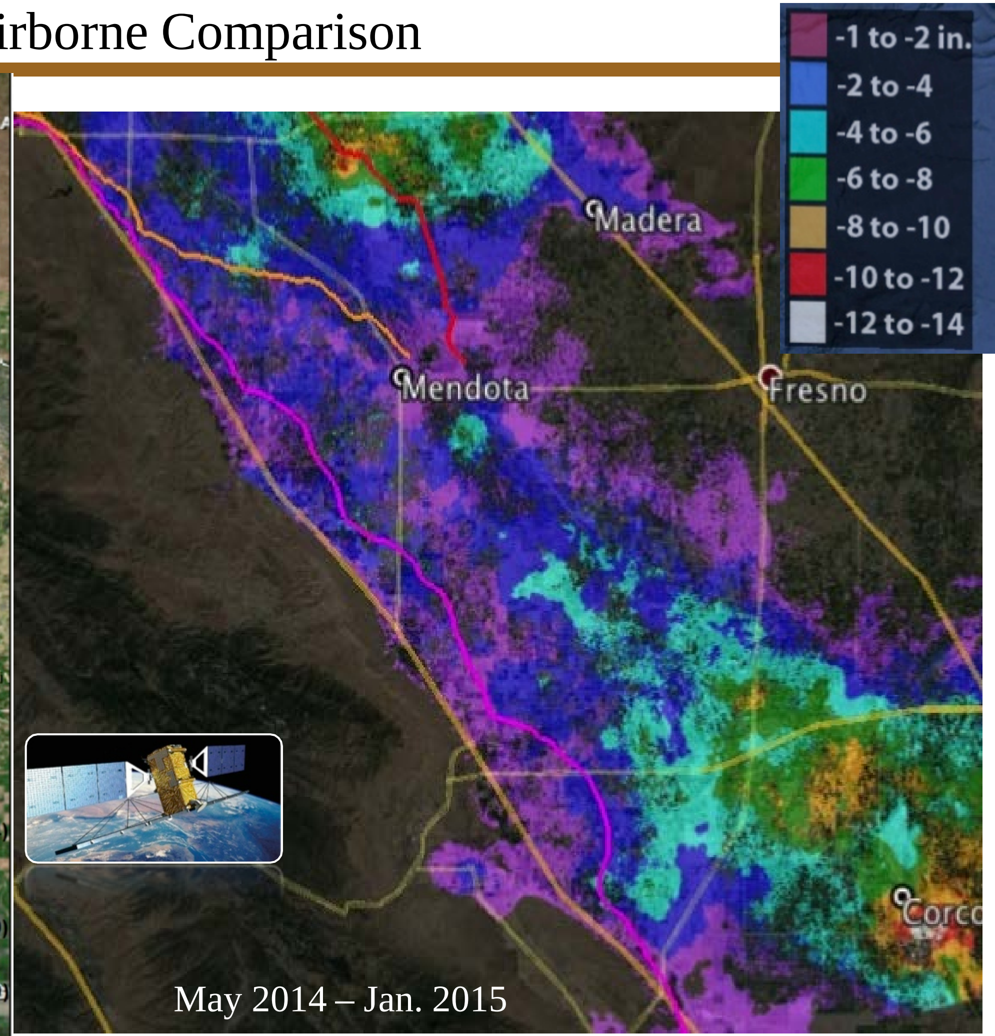
PALSAR Subsidence 2007-2011
Legend
California Aqueduct
Delta-Mendota Canal
High Speed Rail route
-10 to -20 cm
to -30 cm
to -40 cm
to -50 cm
to -60 cm
to -70 cm
to -80 cm
to -90 cm
to -100 cm
to -110 cm
to -120 cm
< -120 cm
Merced
Madera
Mendota
Salinas
Dinuba
Hanford
Visalia
Porterville
Delano
Deformation (cm)
20070105 (ref)
20080525 (cm)
20110303 (cm)
20070708 (cm)
Google earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2014 Google
Image Landsat
Data LDEO-Columbia, NSF, NOAA
40 km
N


SacDelta
Hayward
Modesto
San Jose
Merced
Fresno
Bakersfield
UAVSAR
Base
© 2016 Google
Image Landsat
Data LDEO-Columbia, NSF, NOAA
Data MBARI
98 km
Google earth
Imagery Date: 4/9/2013 lat 36.467826° lon -119.732984° elev 81 m eye alt 385.93 km

Subsidence in Central Valley

Spaceborne / Airborne Comparison



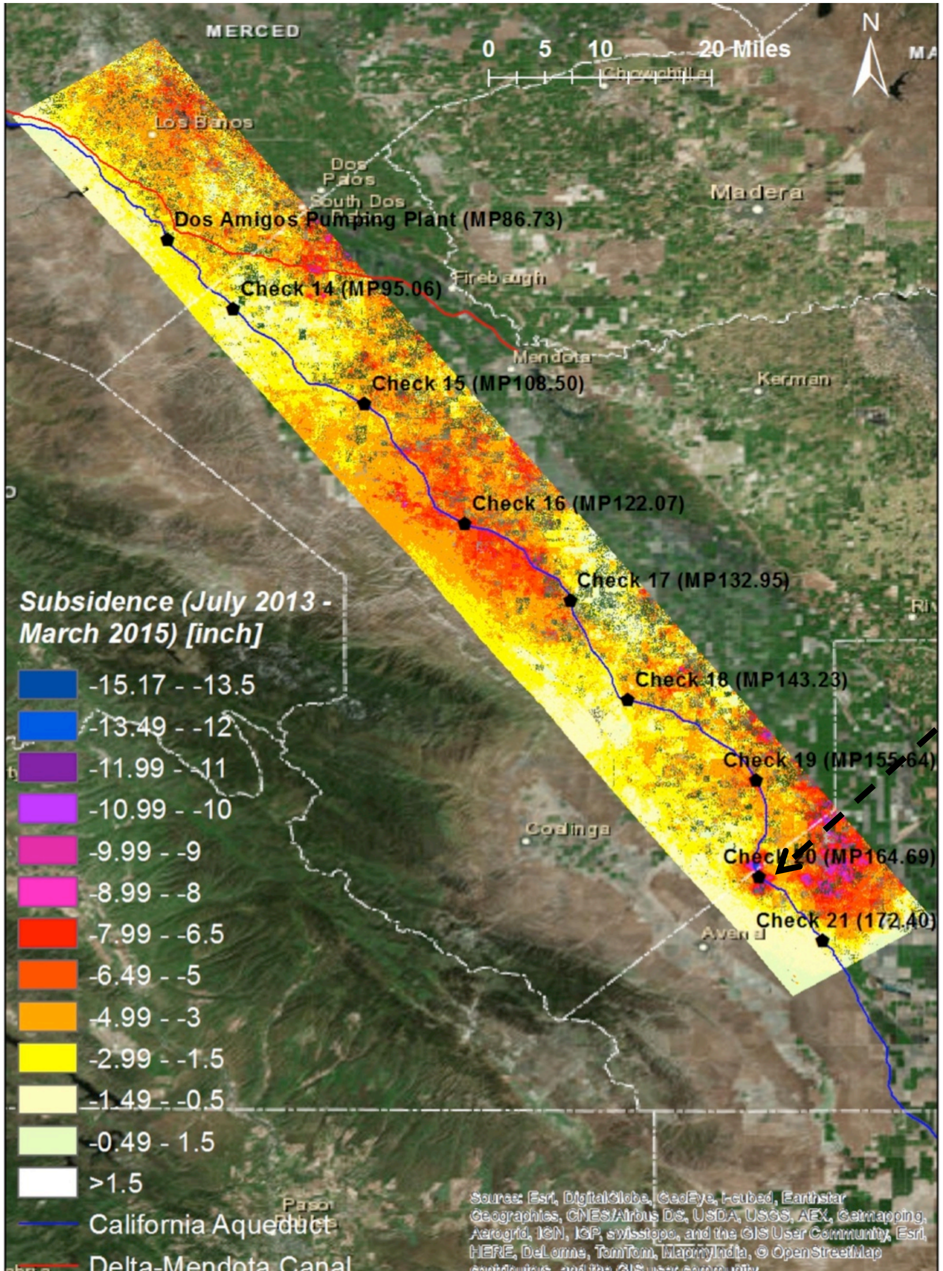


Progress Report: Subsidence in the Central Valley, California (Farr, Jones, Liu, 2015)

Difference:

1. *Different time periods*
2. *Spatial smoothing of spaceborne data*

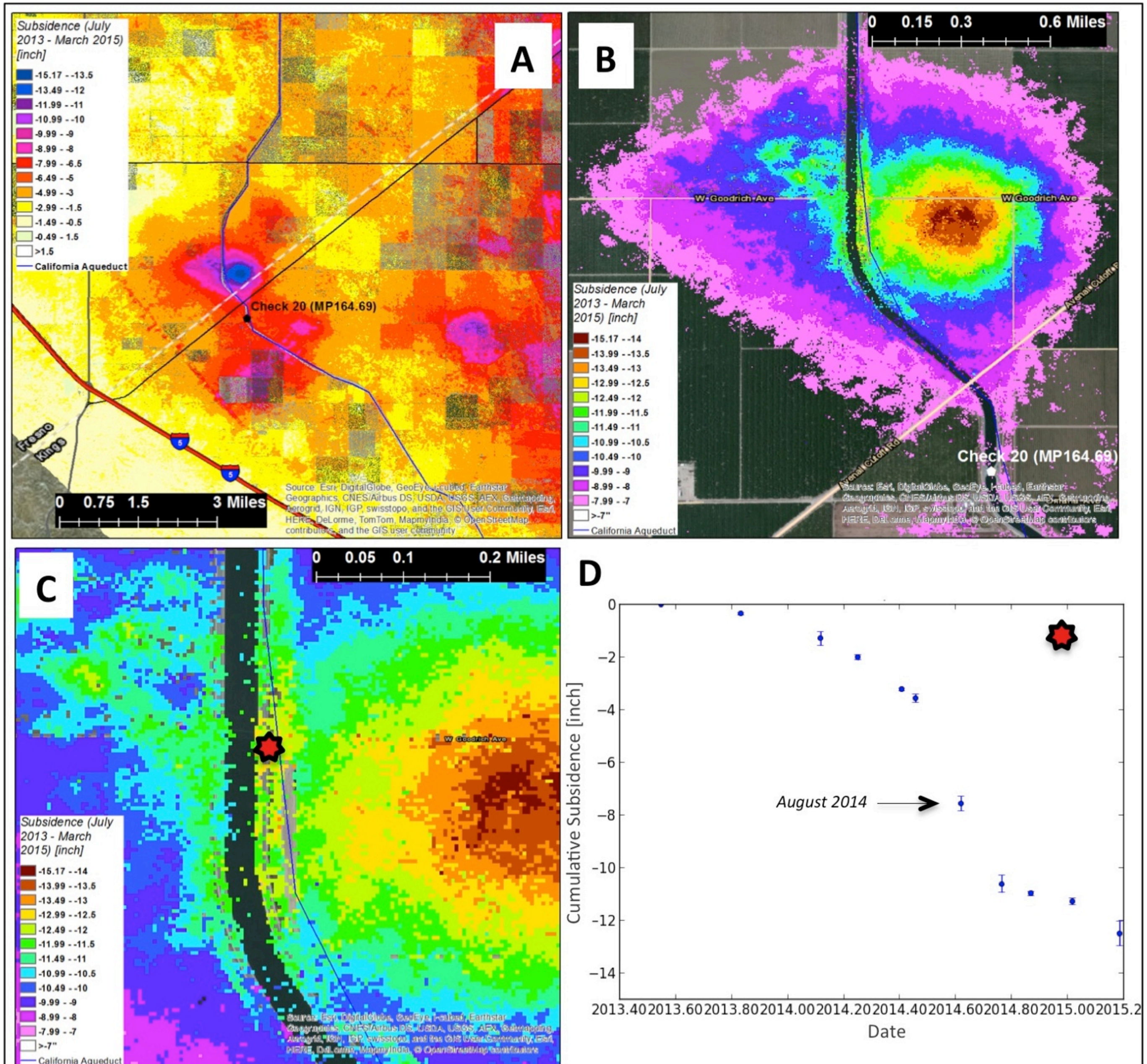
Subsidence Along the California Aqueduct



New Subsidence Hot Spot

Progress Report: Subsidence in the Central Valley, California (Farr, Jones, Liu, 2015)

Subsidence Along the California Aqueduct: Hotspot

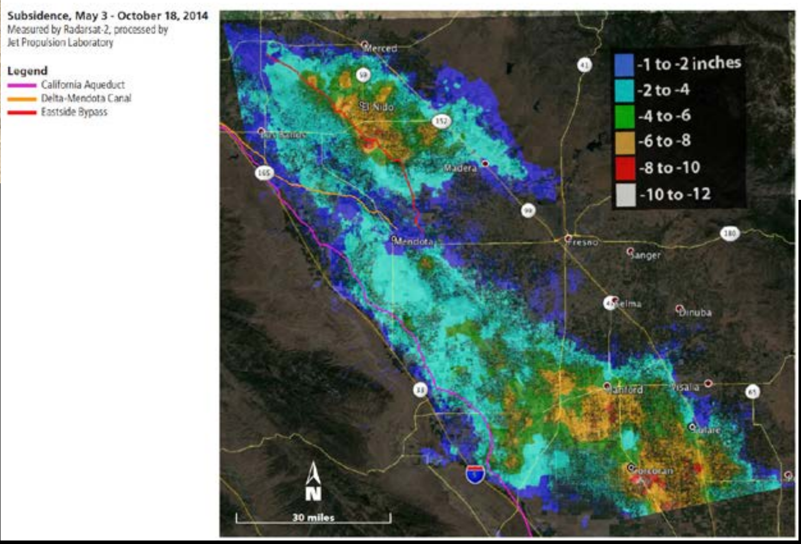


- A single well or cluster of wells can cause rapid subsidence of the aqueduct.
- Aqueduct subsided up to ~13" in < 2 years, and ~8" in 4 months
- 1.3 miles of the aqueduct subsided over 8"

Progress Report: Subsidence in the Central Valley, California (Farr, Jones, Liu, 2015)

Subsidence Reports

Figure 15: Preliminary Image of Relative Land Surface Displacement, San Joaquin Valley - May to October 2014.



http://water.ca.gov/waterconditions/index.cfm

Aug. 19, 2015

NASA: California Drought Causing Valley Land to Sink

As Californians continue pumping groundwater in response to the historic drought, the California Department of Water Resources today released a new NASA report showing land in the San Joaquin Valley is sinking faster than ever before, nearly 2 inches (5 centimeters) per month in some locations.

The report, *Progress Report: Subsidence in the Central Valley, California*, prepared for DWR by researchers at NASA's Jet Propulsion Laboratory, Pasadena, California, is available at:

http://water.ca.gov/groundwater/docs/NASA_REPORT.pdf

"Because of increased pumping, groundwater levels are reaching record lows -- up to 100 feet (30 meters) lower than previous records," said Department of Water Resources Director Mark Cowin. "As extensive groundwater pumping continues, the land is sinking more rapidly and this puts nearby infrastructure at greater risk of costly damage."

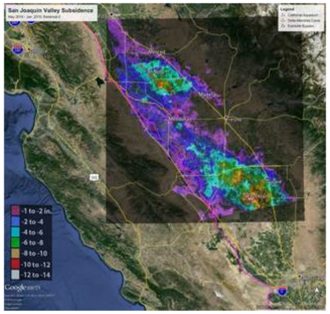
Sinking land, known as subsidence, has occurred for decades in California because of excessive groundwater pumping during drought conditions, but the new NASA data show the sinking is happening faster, putting infrastructure on the surface at growing risk of damage.

NASA obtained the subsidence data by comparing satellite images of Earth's surface over time. Over the last few years, interferometric synthetic aperture radar (InSAR) observations from satellite and aircraft platforms have been used to produce maps of subsidence with approximately centimeter-level accuracy. For this study, JPL researchers analyzed satellite data from Japan's PALSAR (2006 to 2010); and Canada's Radarsat-2 (May 2014 to January 2015), and then produced subsidence maps for those periods. High-resolution InSAR data were also acquired along the California Aqueduct by NASA's Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) (2013 to 2015) to identify and quantify new, highly localized areas of accelerated subsidence along the aqueduct that occurred in 2014. The California Aqueduct is a system of canals, pipelines and tunnels that carries water collected from the Sierra Nevada Mountains and Northern and Central California valleys to Southern California.

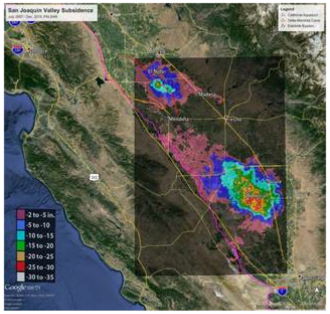
Using multiple scenes acquired by these systems, the JPL researchers were able to produce time histories of subsidence at selected locations, as well as profiles showing how subsidence varies over space and time.

"This study represents an unprecedented use of multiple satellites and aircraft to map subsidence in California and address a practical problem we're all facing," said JPL research scientist and report co-author Tom Farr. "We're pleased to supply the California DWR with information they can use to better manage California's groundwater. It's like the old saying: 'you can't manage what you don't measure'."

Land near Corcoran in the Tulare basin sank 13 inches (33 centimeters) in just eight months -- about 1.6 inches (4 centimeters) per month. One area in the Sacramento Valley was sinking approximately half-an-inch (1.3 centimeters) per month, faster than previous measurements.



Total subsidence in California's San Joaquin Valley for the period May 3, 2014 to Jan. 22, 2015, as measured by Canada's Radarsat-2 satellite. Two large subsidence bowls are evident, centered on Corcoran and south of El Nido.
Credits: Canadian Space Agency/NASA/JPL-Caltech



Total subsidence in California's San Joaquin Valley for the period June 2007 to Dec. 2010 as measured by Japan's PALSAR satellite. Two large subsidence bowls are evident, centered on

http://www.nasa.gov/jpl/nasa-california-drought-causing-valley-land-to-sink

Sentinel-1 Coverage