Land subsidence measurements using airborne radar

Impact to water conveyance infrastructure in the San Joaquin Valley

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Remote Sensing for Monitoring Water Infrastructure

The Vision: Widespread, Rapid Identification for Targeted Response

The California Dept. of Water Resources and numerous other state, local, and federal groups currently monitor thousands of miles of levees and aqueducts throughout California. This infrastructure serves both as flood protection barriers and water conveyance infrastructure.

Remote sensing can augment ground-based and visual surveys of these structures by:

- **enabling *rapid assessment* of large areas to give a snapshot of conditions at many sites at the same time**
- **providing *consistent monitoring* across all sites**
- **imaging areas that are *difficult to access* on the ground**
- ***detecting* areas that *change* by small amounts or in subtle ways**
- **providing information during *emergency response***

Sacramento/San Joaquin Delta, CA

UAVSAR

NASA Uninhabited Aerial Vehicle Synthetic Aperture Radar for Airborne Sciences

Why use an Airborne Instrument?

Image Resolution & Signal Strength

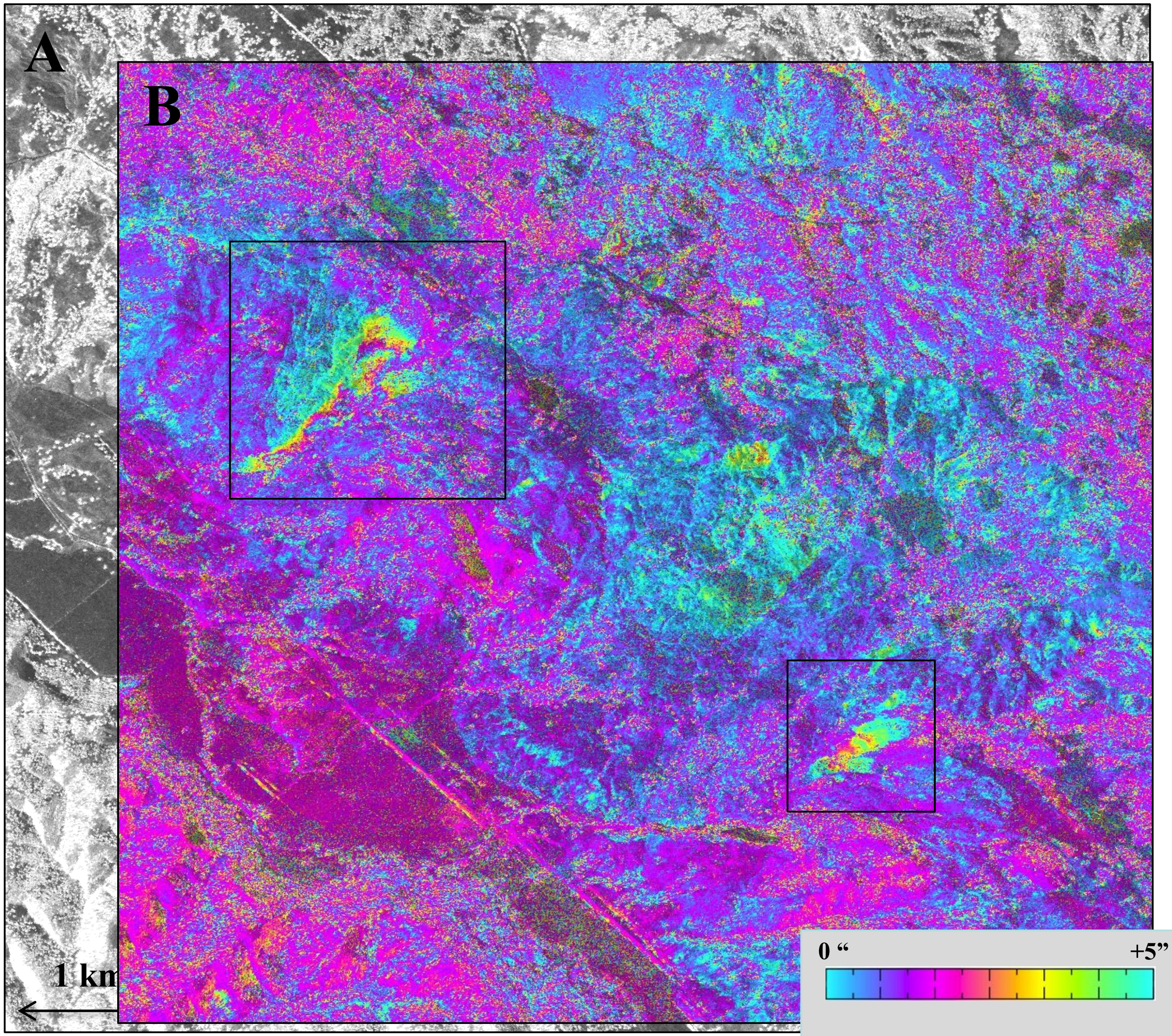
Parameter	Value
Frequency	L-Band 1217.5 to 1297.5 MHz (10” [23.8 cm] wavelength)
Resolution	5.6’ x 3.3’
Operational Altitude	41,000 feet
Swath Width	14 miles
Polarization	Quad-Polarization (HH, HV, VH, VV)
Repeat Track Accuracy	± 16’
Transmit Power	> 3.1 kW

Radar Interferometry (InSAR)

SAN ANDREAS FAULT, CENTRAL CALIFORNA (NORTH OF PARKFIELD)

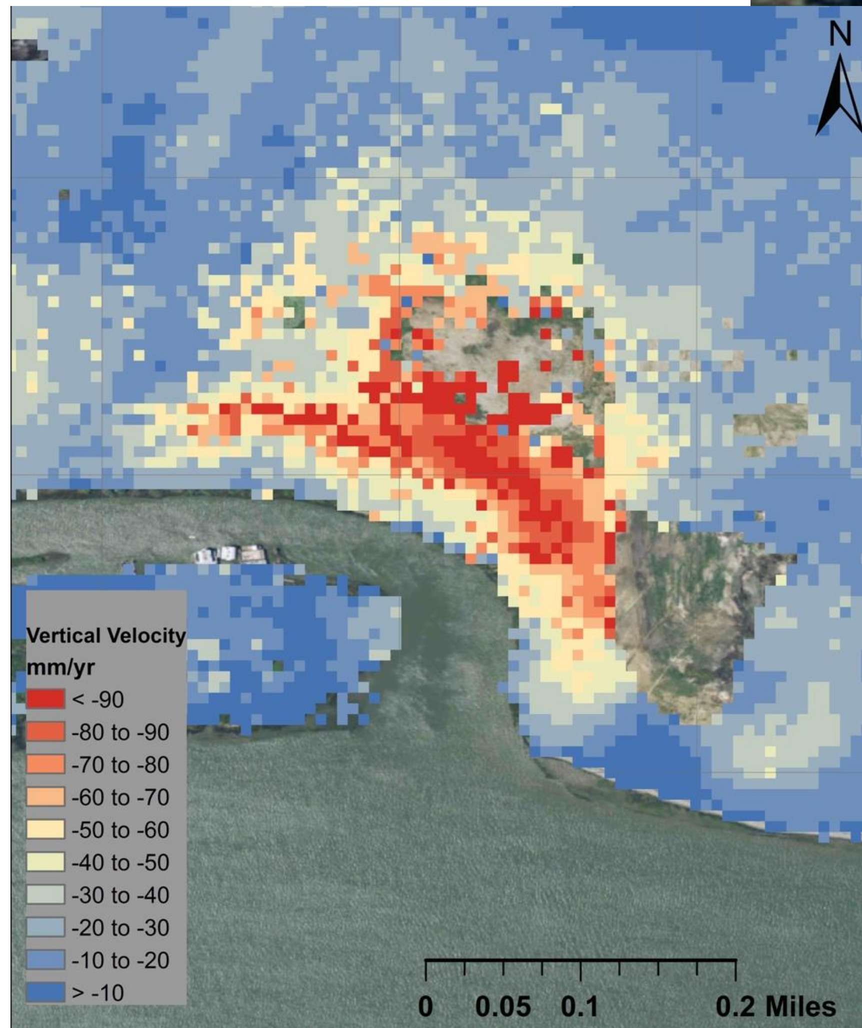
Intensity

Interferogram



Earthen Levee in the Sacramento Delta:


N
0
0.05
0.1
0.2 Miles


N
Vertical Velocity
mm/yr
< -90
-80 to -90
-70 to -80
-60 to -70
-50 to -60
-40 to -50
-30 to -40
-20 to -30
-10 to -20
> -10
0
0.05
0.1
0.2 Miles

Central Valley Subsidence Measured from Aircraft

Subsidence Reports

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."

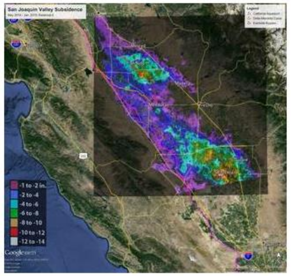
Sinking land, known as subsidence, has occurred for decades in California because of excessive groundwater pumping during drought conditions, but the new NASA data show the sinking is happening faster, putting infrastructure on the surface at growing risk of damage.

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.

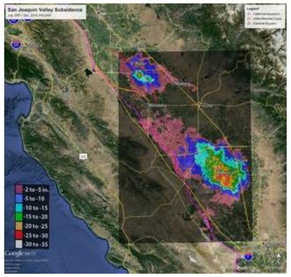
Using multiple scenes acquired by these systems, the JPL researchers were able to produce time ...ns, as well as profiles showing how subsidence varies

...use of multiple satellites and aircraft to map subsidence in ... we're all facing," said JPL research scientist and report ...pply the California DWR with information they can use to ...'s like the old saying: 'you can't manage what you don't

...nk 13 inches (33 centimeters) in just eight months -- ...n. One area in the Sacramento Valley was sinking ...s) 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

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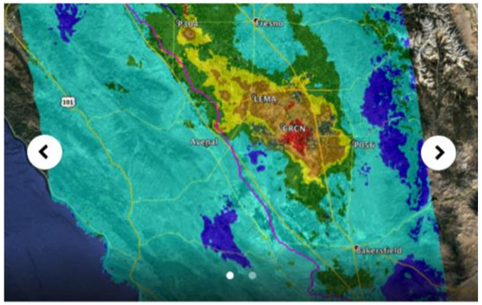
NEWS | FEBRUARY 28, 2017

NASA Data Show California's San Joaquin Valley Still Sinking



Total subsidence in California's San Joaquin Valley between May 7, 2015 and Sept. 10, 2016, as measured by ESA's Sentinel-1A and processed at JPL. Two large subsidence bowls are evident, centered on Corcoran and southeast of El Nido, with a small, new feature between them, near Tranquility. Credit: European Space Agency/NASA-JPL/Caltech/Google Earth
› Larger view

Fast Facts:

- For nearly a century, groundwater pumping from Central California wells has caused some land to subside.

- Subsidence is an ongoing issue for state water managers.

- JPL is using radar remote sensing to identify areas that are subsiding fastest.

Groundwater Pumping Causing Subsidence, Damaging Water Infrastructure

Since the 1920s, excessive pumping of groundwater at thousands of wells in California's San Joaquin Valley has caused land in sections of the valley to subside, or sink, by as much as 28 feet (8.5 meters). This subsidence is exacerbated during droughts, when farmers rely heavily on groundwater to sustain one of the most productive agricultural regions in the nation.

Long-term subsidence is a serious and challenging concern for California's water managers, putting state and federal aqueducts, levees, bridges and roads at risk of damage. Already, land subsidence has damaged thousands of public and private groundwater wells throughout the San Joaquin Valley. Furthermore, the subsidence can permanently reduce the storage capacity of underground aquifers, threatening future water supplies. It's also expensive. While there is no comprehensive estimate of damage costs associated with subsidence, state and federal water agencies have spent an estimated $100 million on subsidence-related repairs since the 1960s.

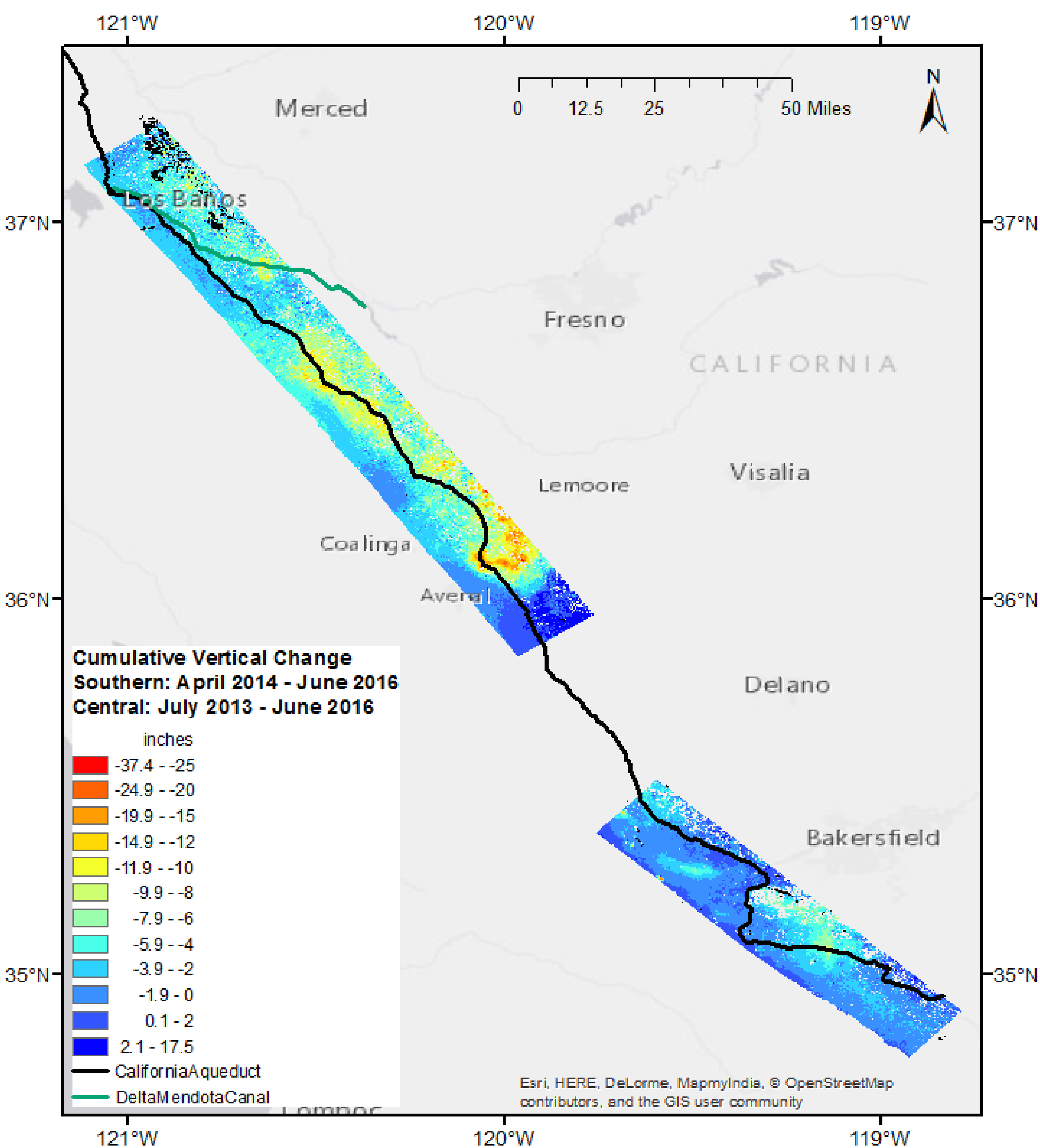
To determine the extent to which additional groundwater pumping associated with California's current historic drought, which began in 2012, has affected land subsidence in the Central Valley, California's Department of Water Resources (DWR) commissioned NASA's Jet Propulsion Laboratory, Pasadena, California, to use its expertise in collecting and analyzing airborne and satellite radar data. An initial report of the JPL findings (Aug. 2015) analyzed radar data from several different sensors between 2006 and early 2015. Due to the continuing drought, DWR subsequently commissioned JPL to collect and analyze new radar images from 2015 and 2016 to update DWR on the land subsidence.

How much sinking?

Several trouble spots identified in the first report continue to subside at rates as high as 2 feet (0.6 meters) a year. Significant subsidence was measured in two subsidence bowls located near the towns of Chowchilla, south of Merced; and Corcoran, north of Bakersfield. These bowls cover hundreds of square miles and continued to grow wider and deeper between May 2015 and Sept. 2016. Maximum subsidence during this time period was almost 2 feet (0.6 meters) in the Corcoran area and about 16 inches (41 centimeters) near Chowchilla. Subsidence also intensified near Tranquility in Fresno County during the past year, where the land surface has settled up to 20 inches (51 centimeters) in an area that extends 7 miles (11 kilometers). Subsidence in these areas affects aqueducts and flood control structures.

Farr, Jones, Liu, 2015, 2017

Subsidence along the California Aqueduct



Subsidence Impact to California Aqueduct – First View

First reported to the state in October 2014

InSAR shows an area of subsidence centered less than ½ mile from the California Aqueduct.

Analysis showed that subsidence in this area accelerated greatly starting in Summer 2014.

Near the center of the subsidence bowl is a pumping facility for extraction of water.

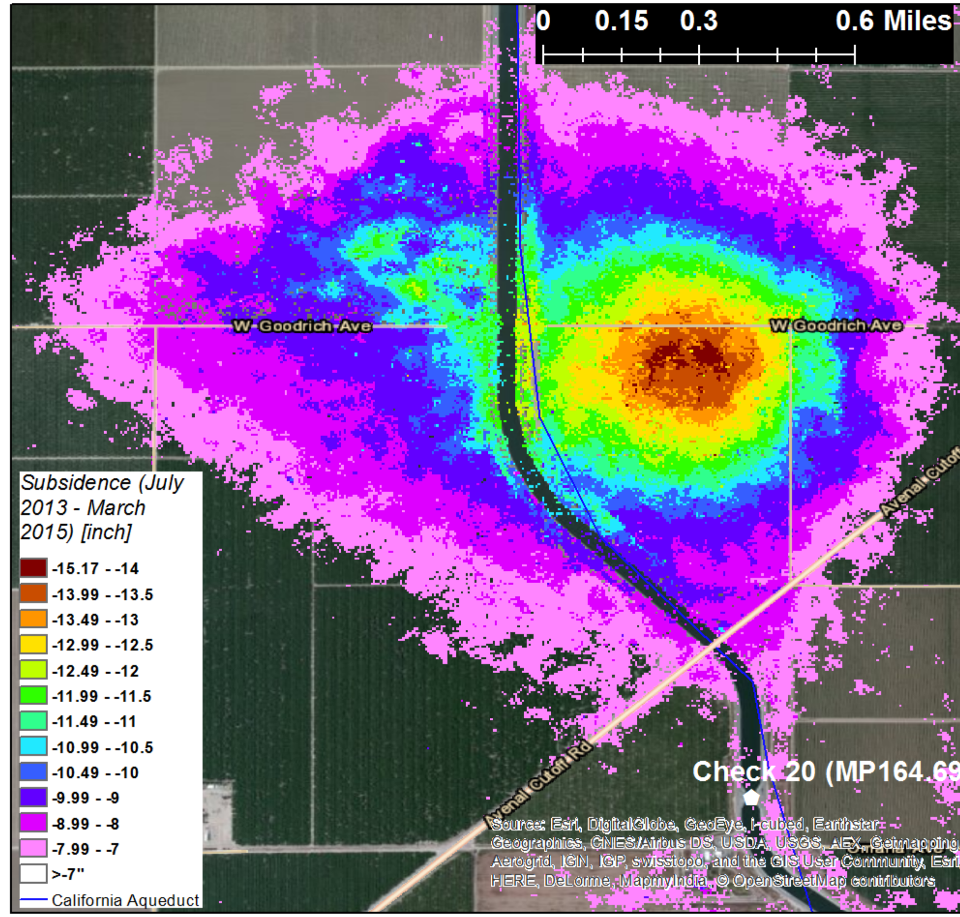
The bowl extended beyond the aqueduct and caused >8″ of subsidence along a 1.3 mile stretch of the aqueduct, with a maximum of about 13″ subsidence.

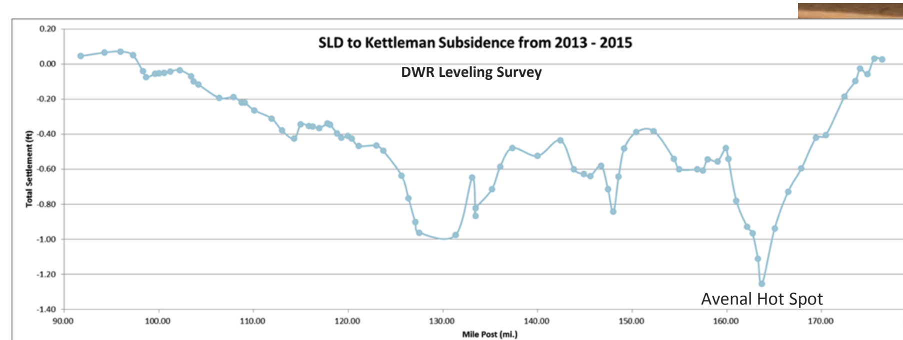
Land cover in this area is agricultural orchards. The CA/DWR team was not aware of this area of subsidence until this product was delivered to them.

The subsidence values measured with remote sensing techniques shown in the legend were validated by field survey techniques.

The subsidence measurement was georegistered for easy reference by monitoring/response agency officials.

This product was distributed to California Department of Water Resources as a product easily incorporated into their GIS for operational decision making.

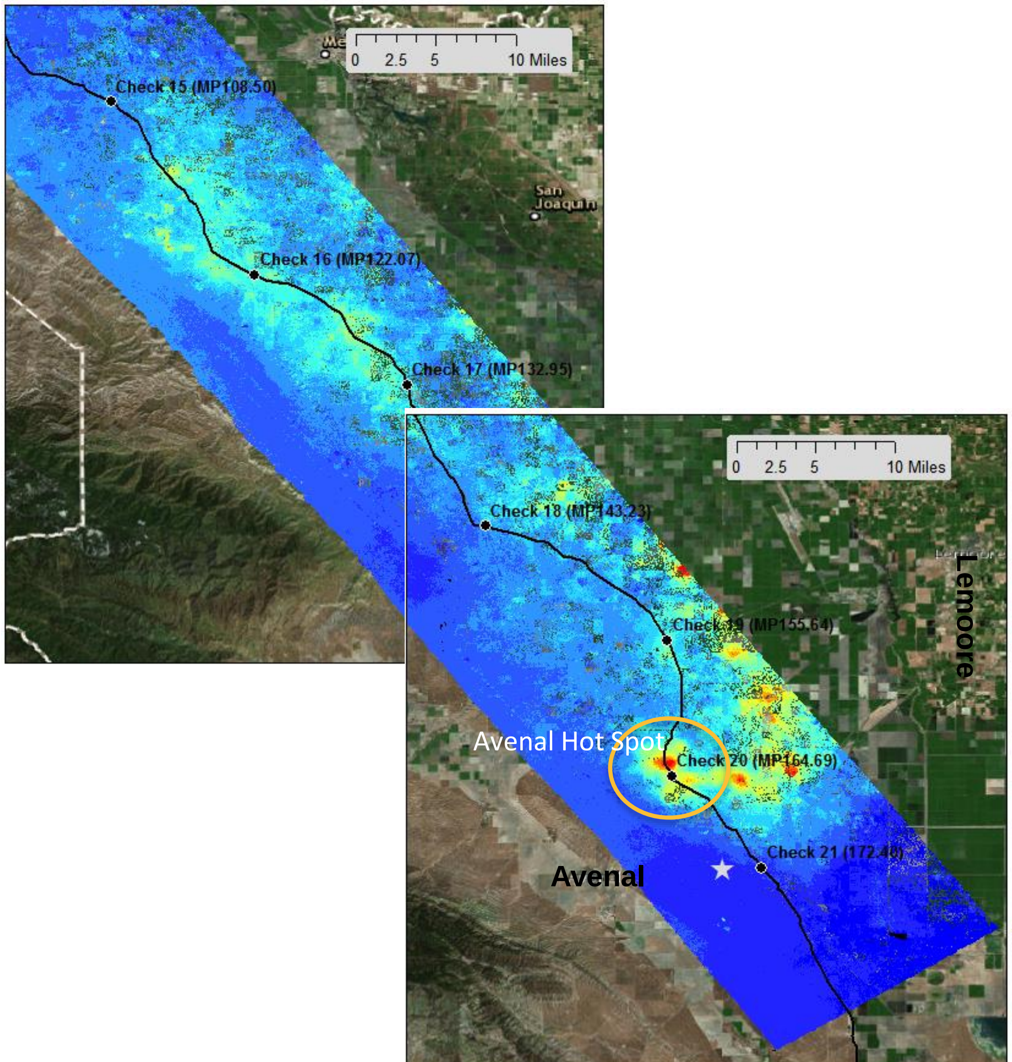




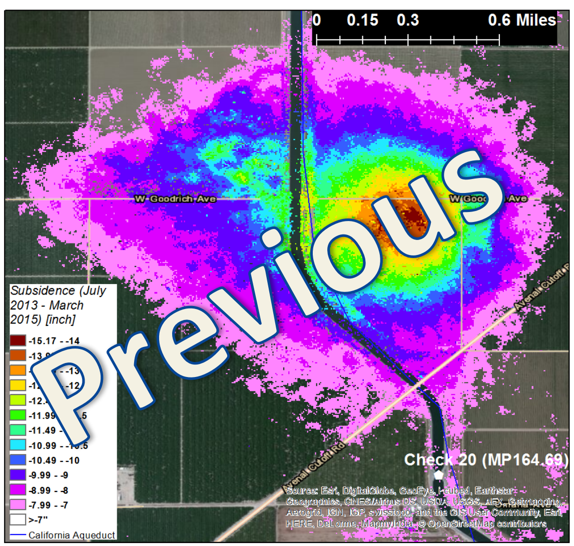
Continuing View:

July 2013 – June 2016

Overview, Cumulative Elevation Change



Avenal Subsidence Hot Spot



NOTE CHANGE IN SCALE

- Previously had seen 13” max subsidence of the aqueduct in July 2013 - March 2015.

owed 25”

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5’x25’, so
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flow here
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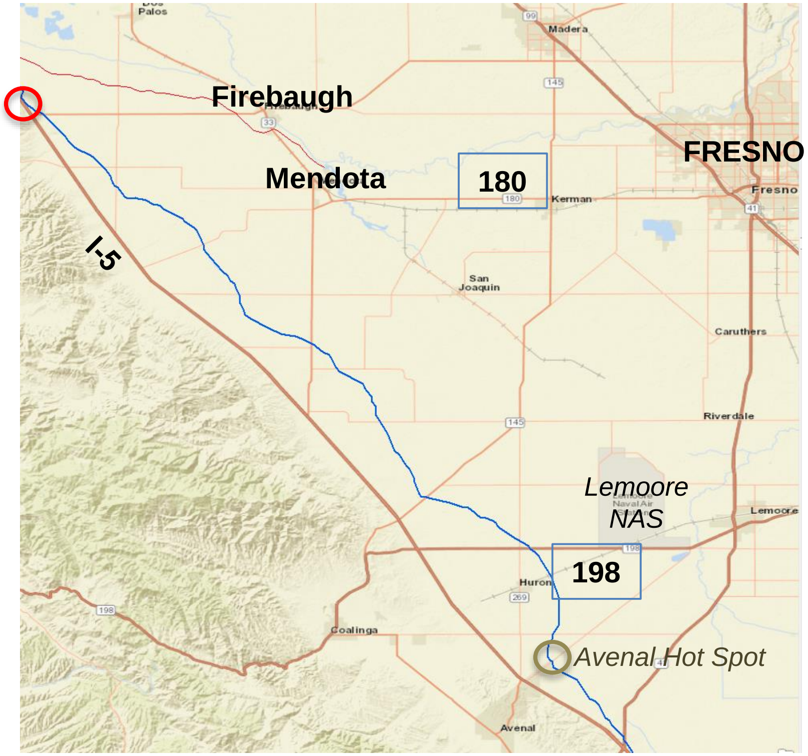
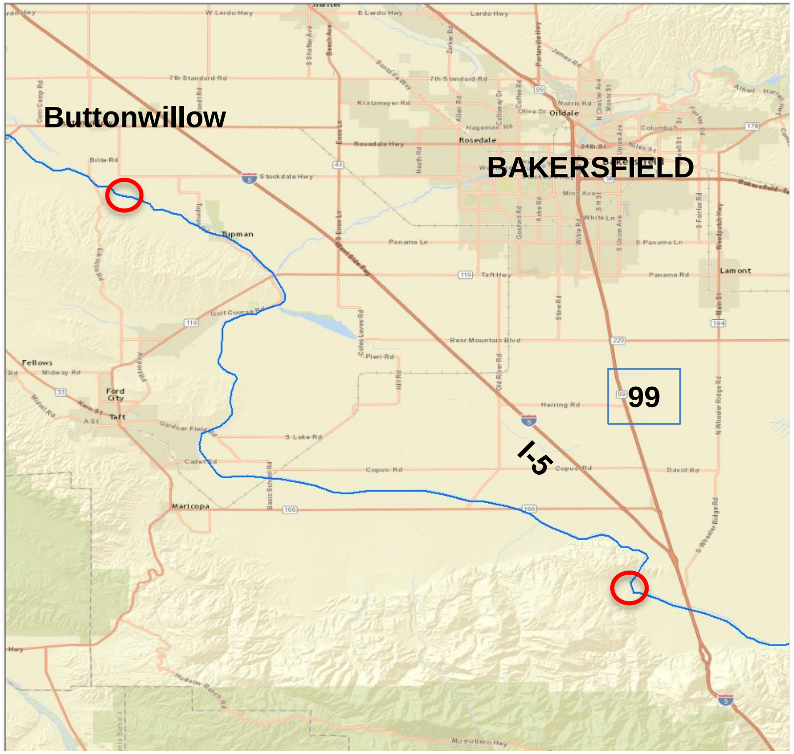
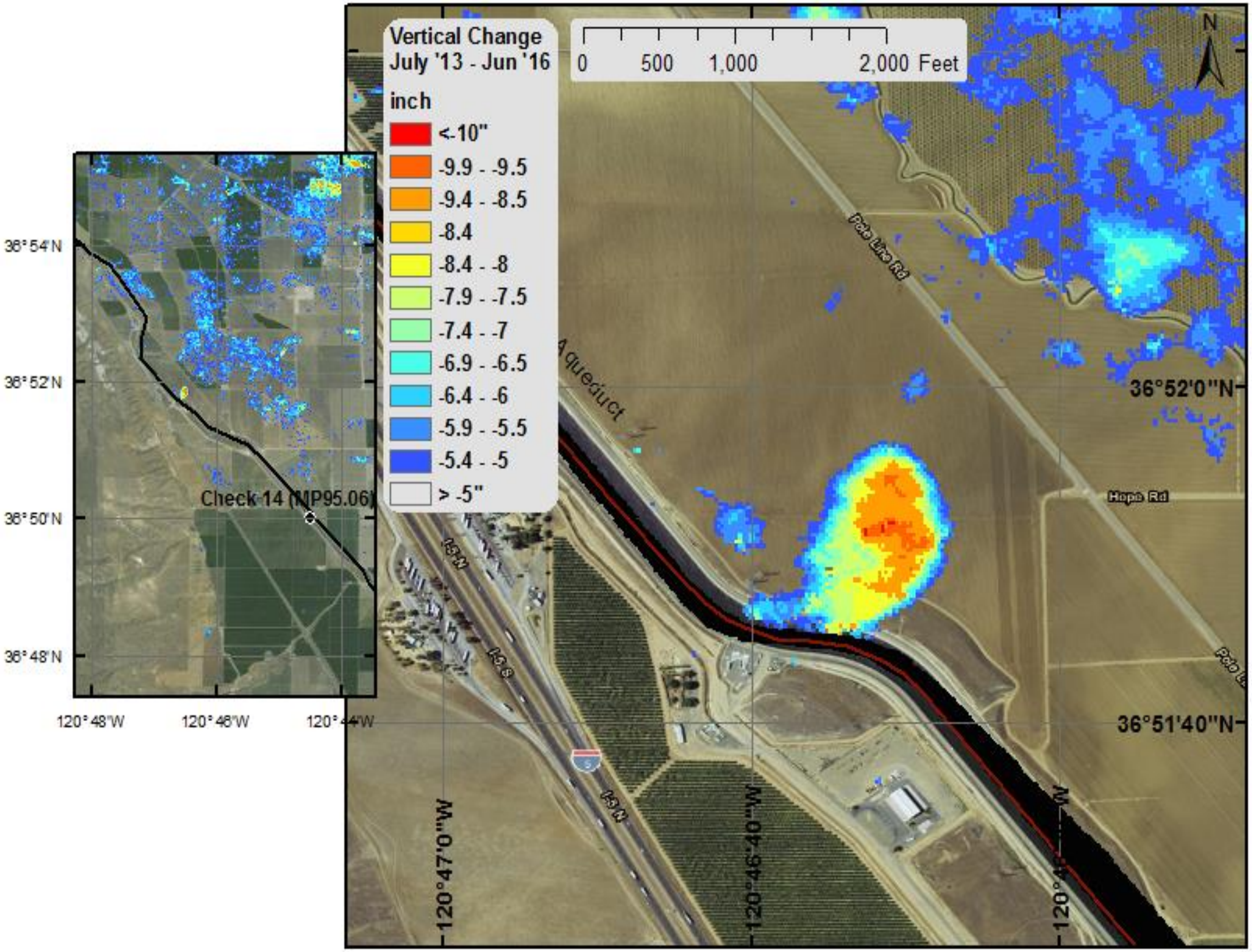
Search for similar incipient or small 'hot spots' along the aqueduct:

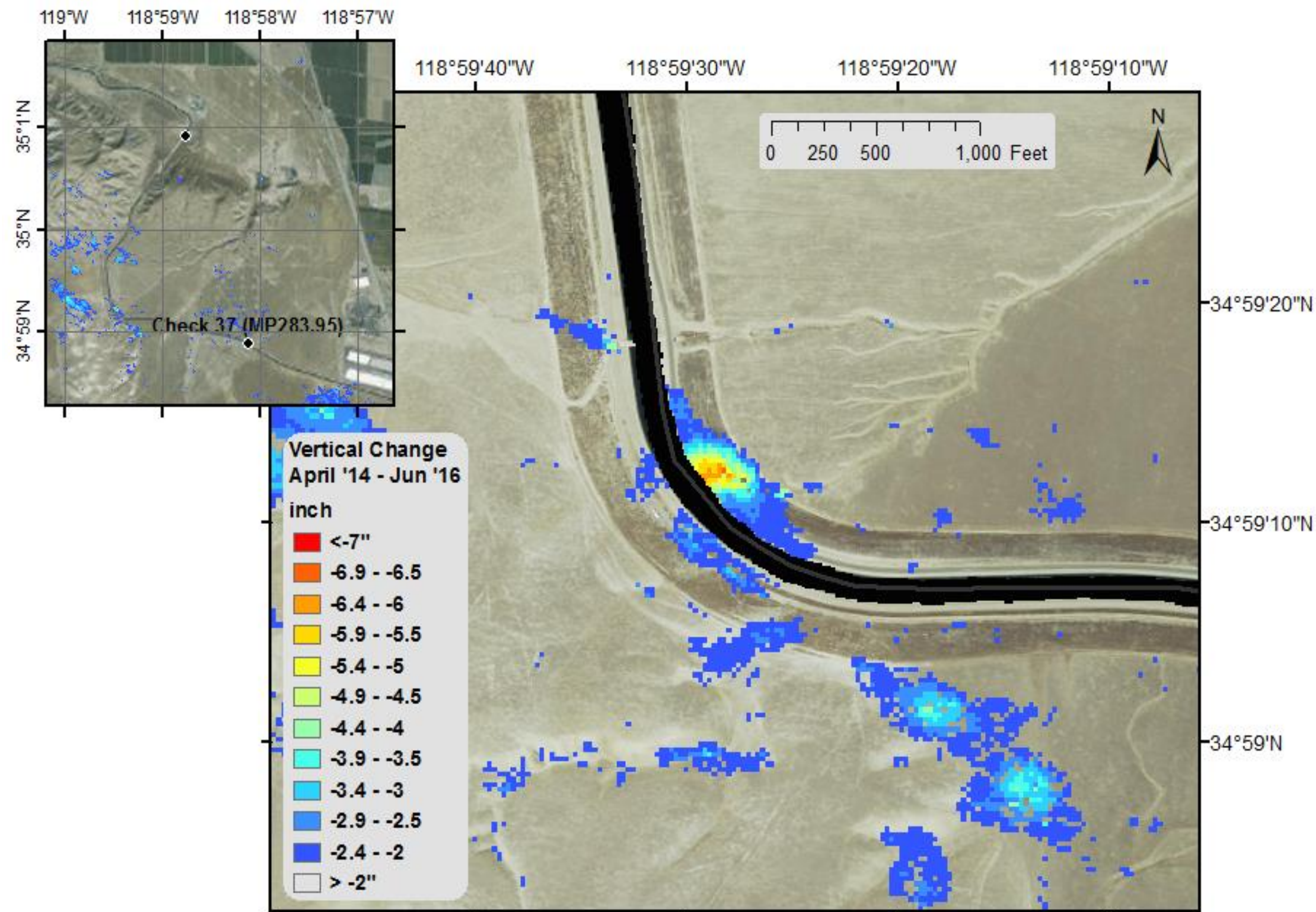




New small hot spot along the California Aqueduct

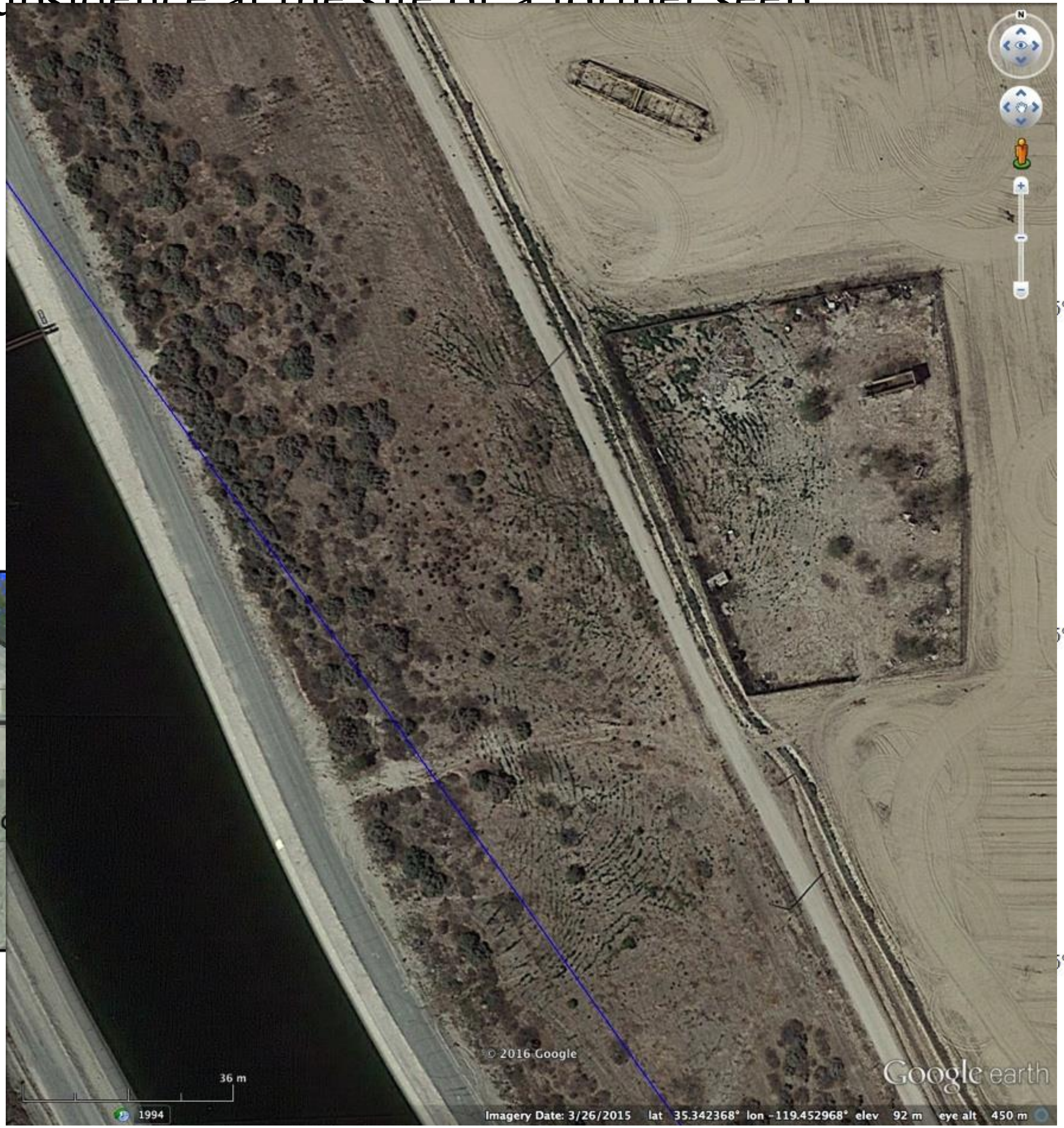


…and another directly on the aqueduct…

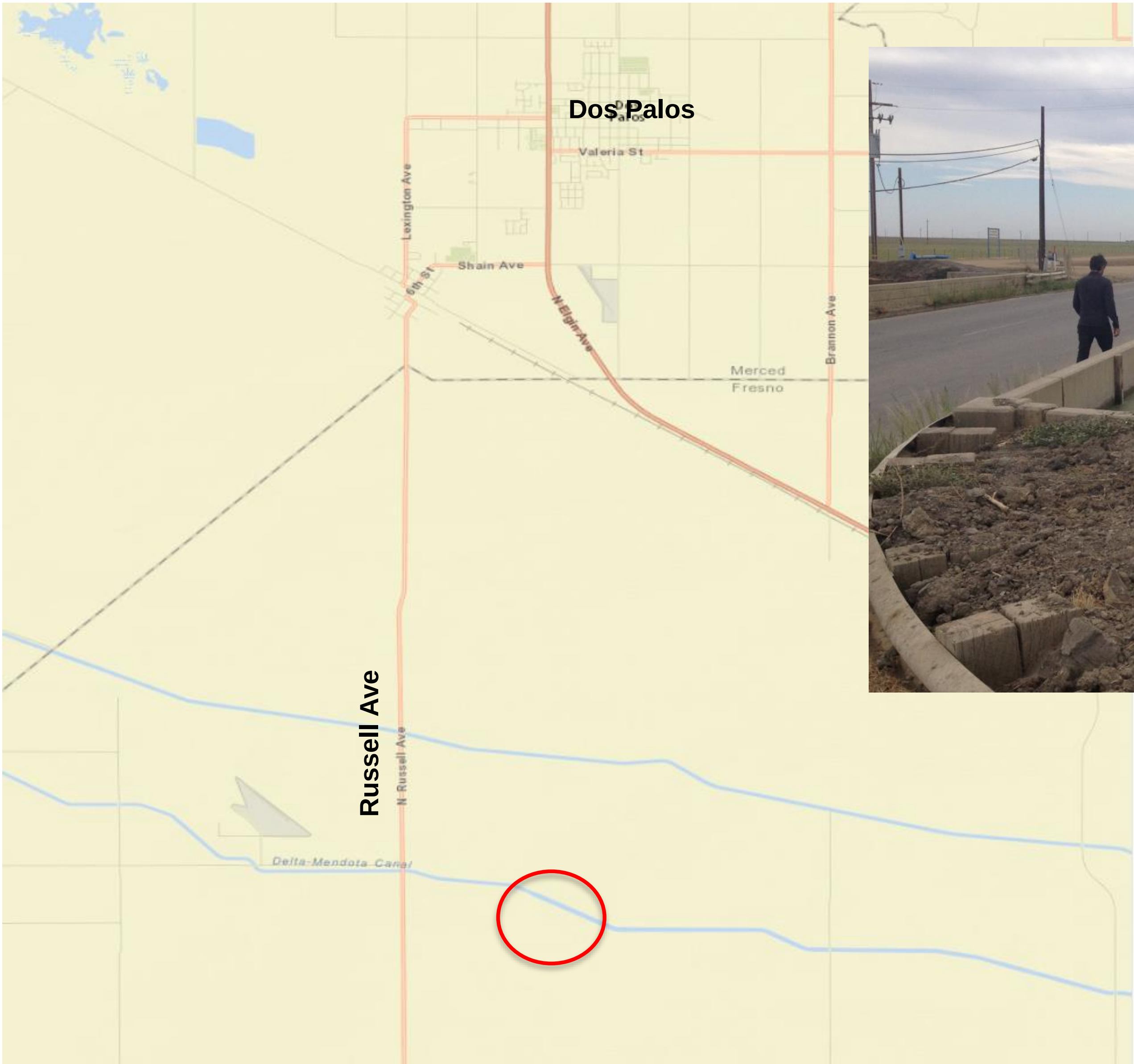


Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community
Esri, HERE, DeLorme, TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

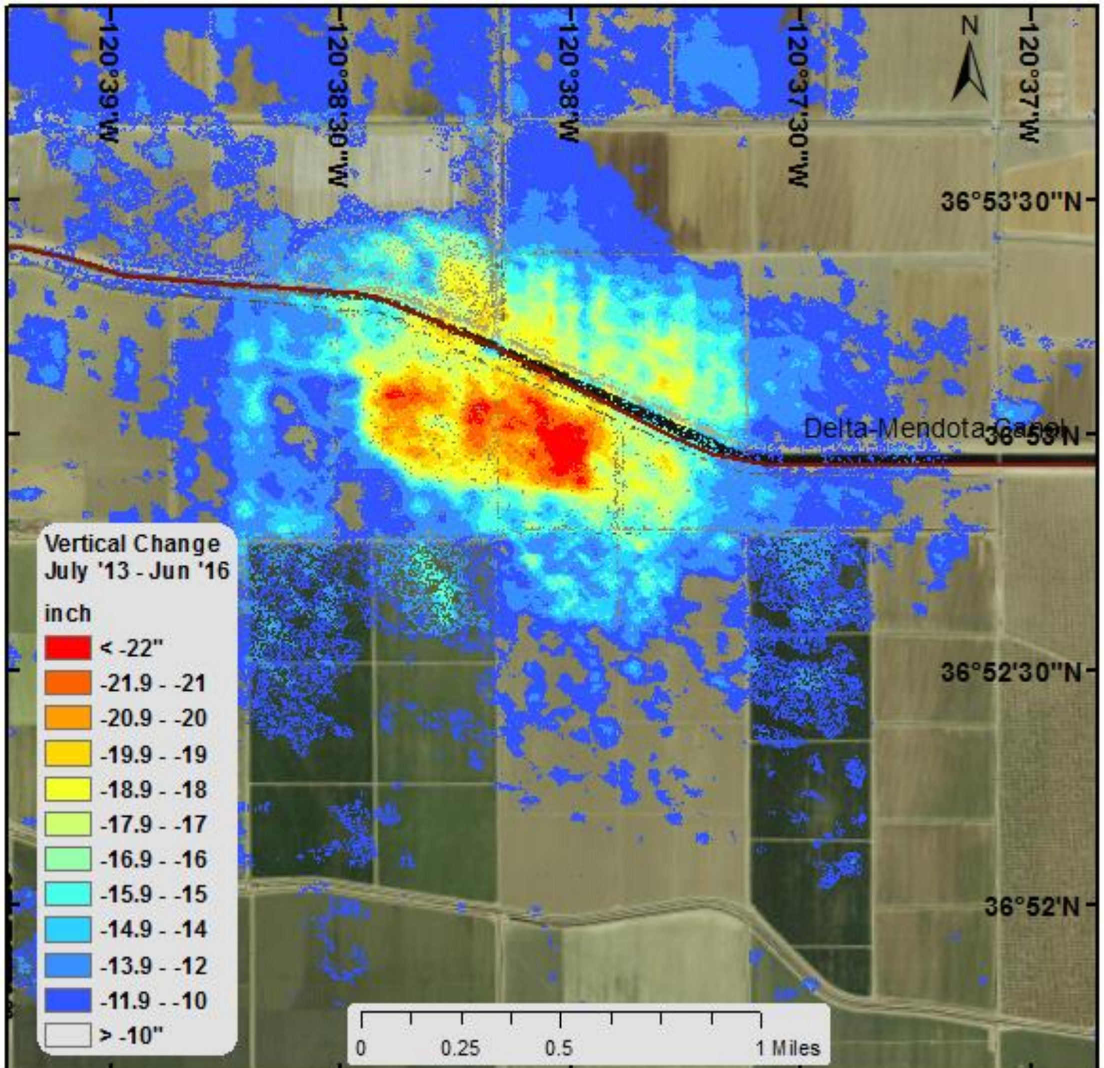
… and subsidence at the site of a former seep



Delta-Mendota Canal



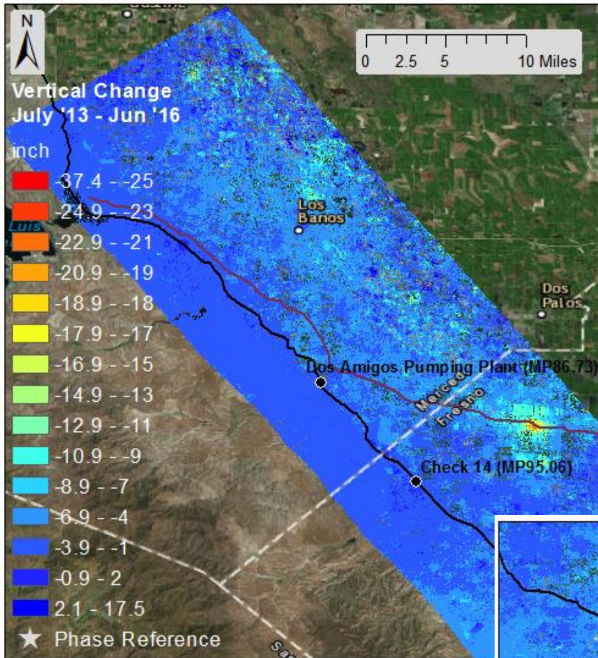
Delta-Mendota Canal, east Russell Ave. Bridge

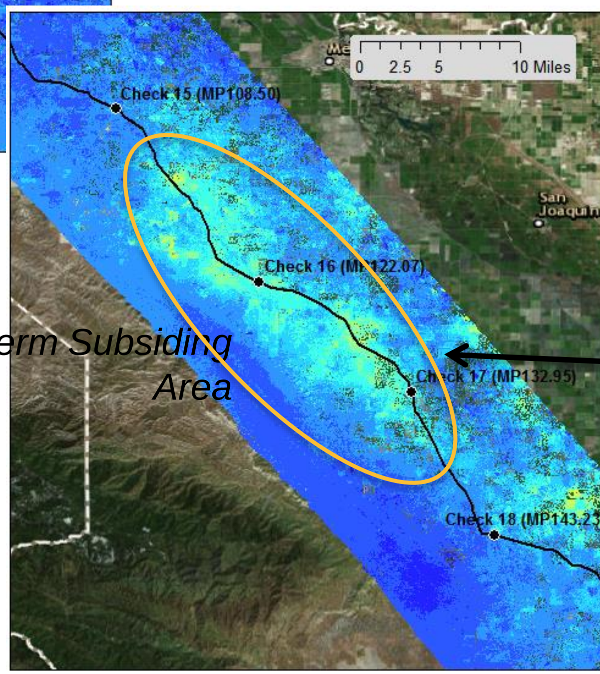


San Luis Field District

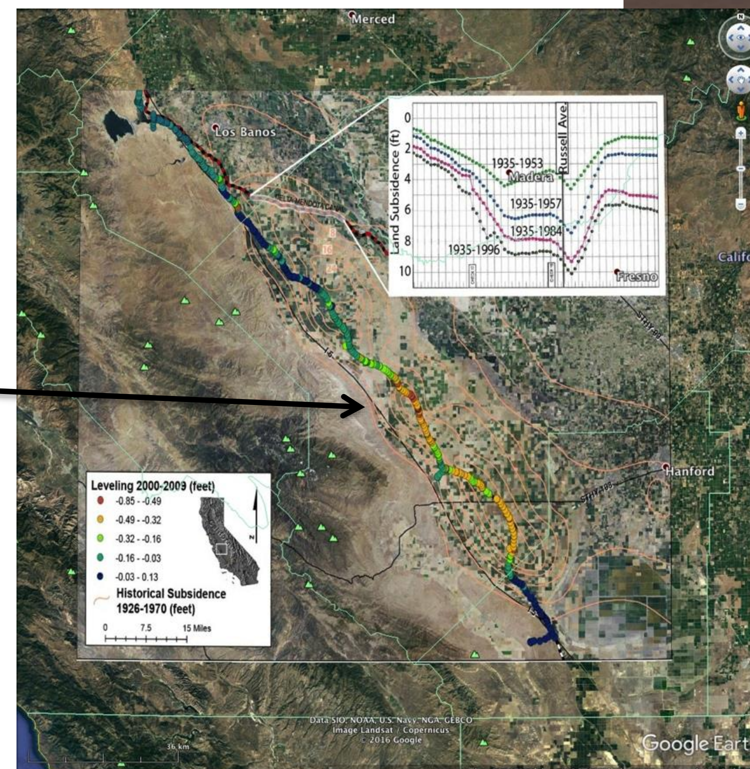
July 2013 – June 2016

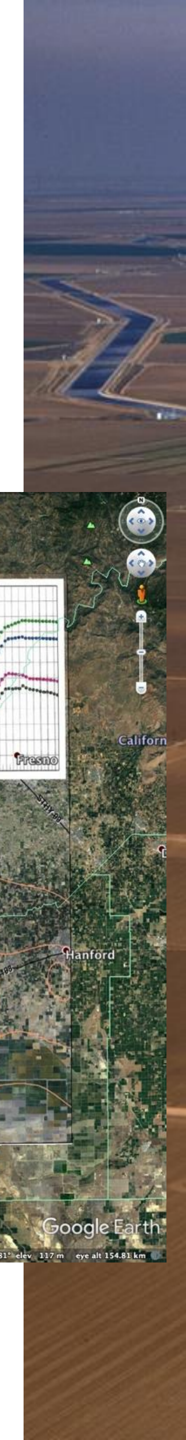
Overview, Large Scale Subsidence Along the California Aqueduct





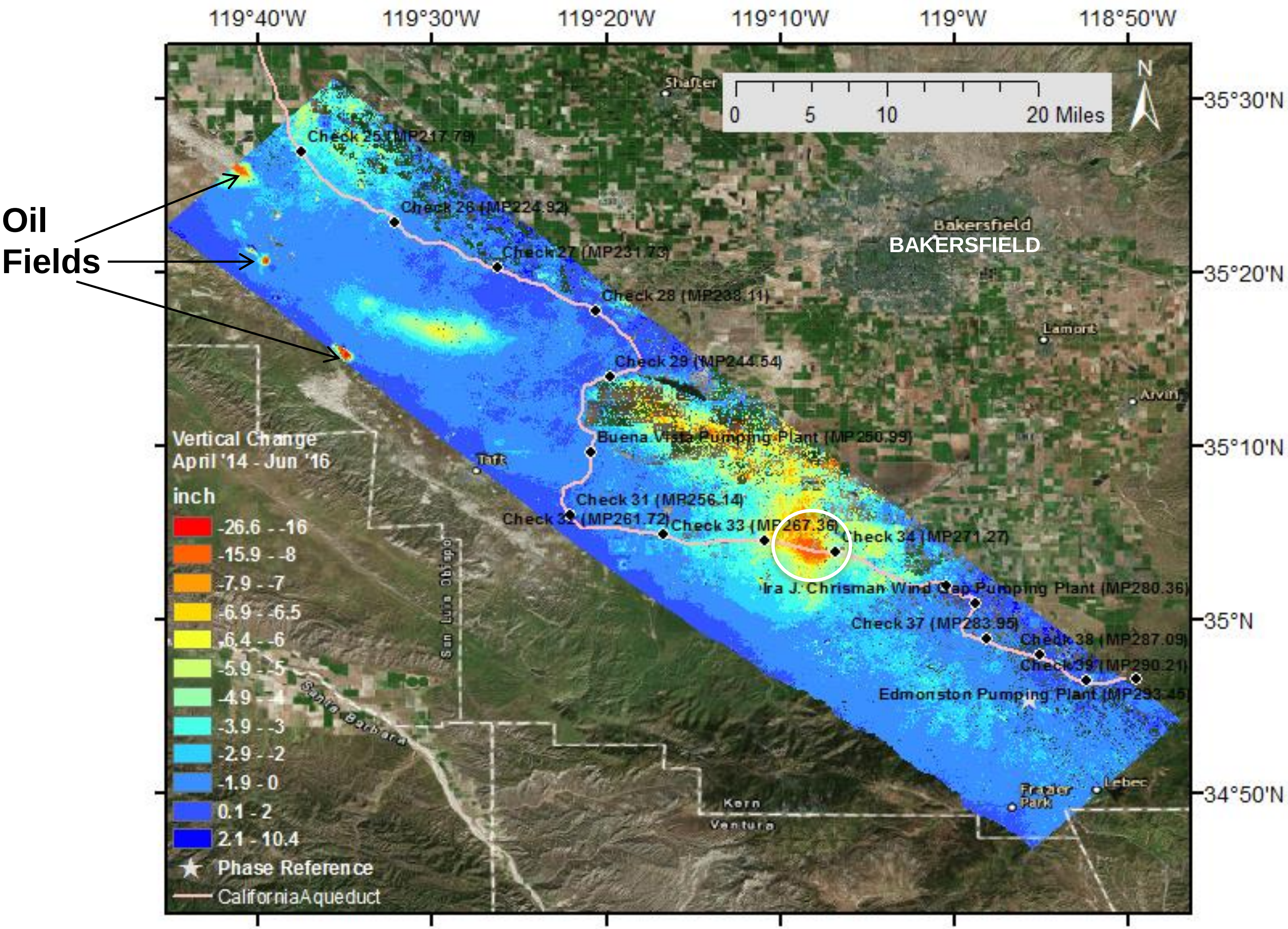
Long-term Subsiding Area



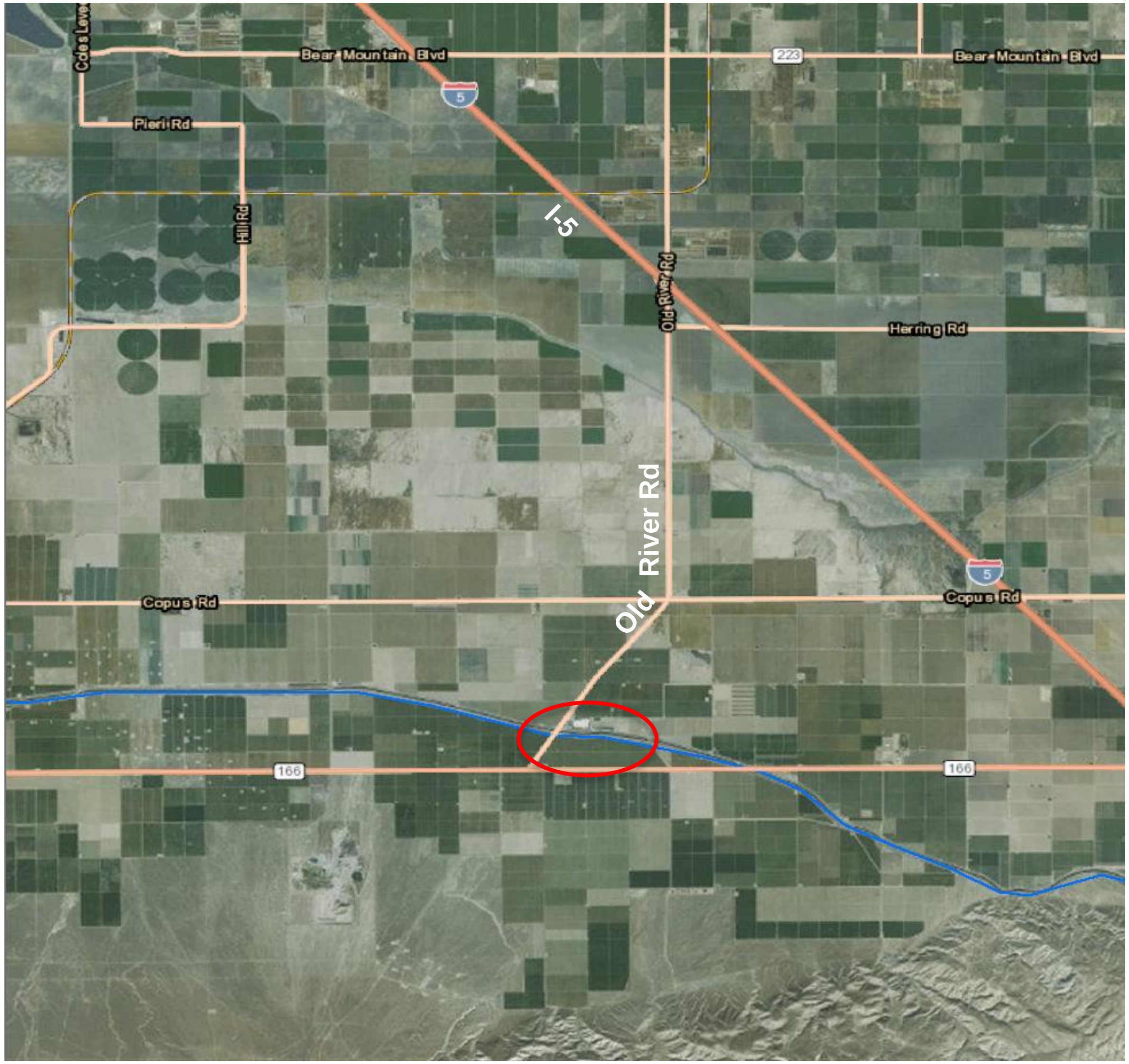


San Joaquin Field District

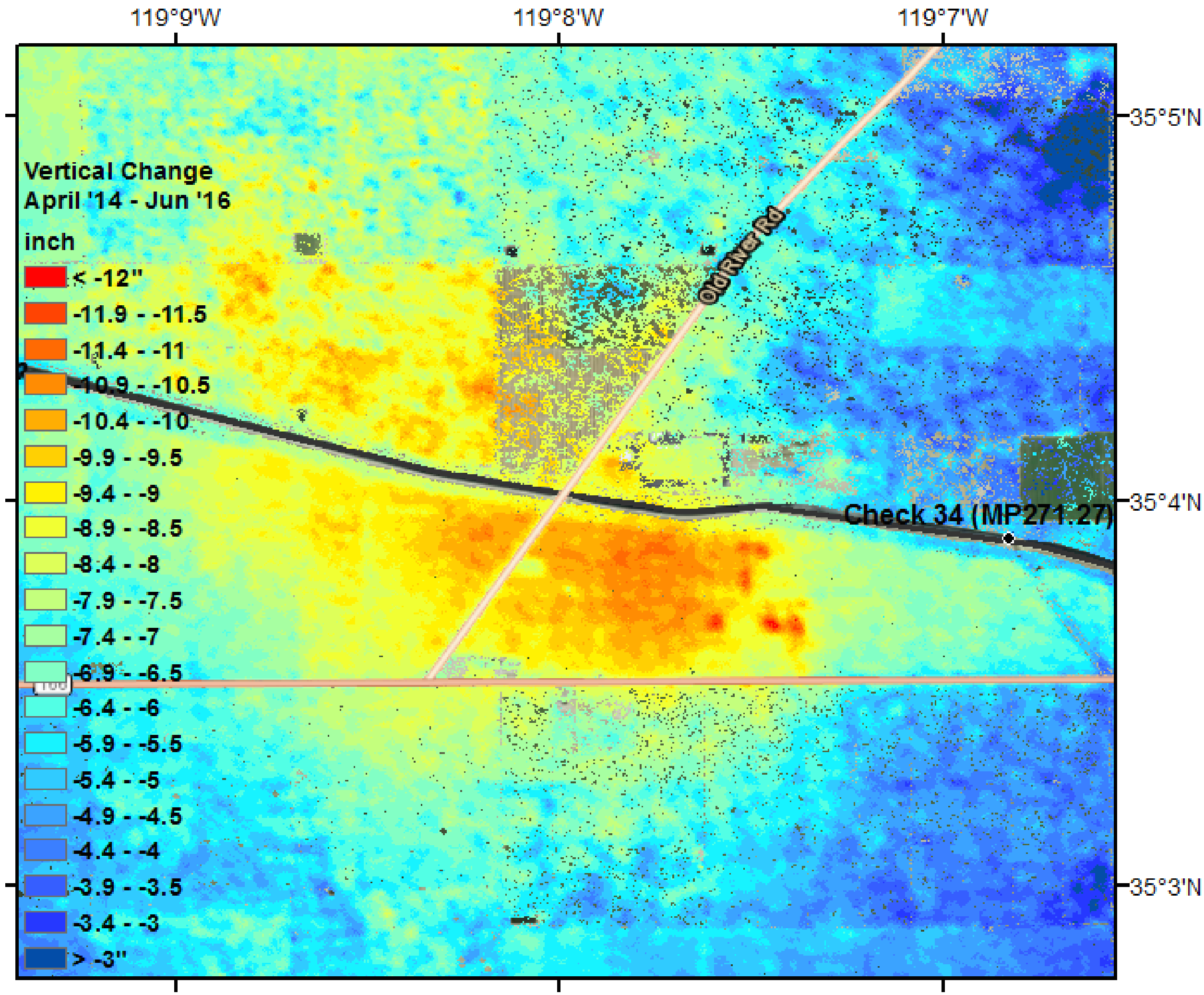
April 2014 – June 2016
Overview, Cumulative Elevation Change



Orchards near Old River Road



Ca. Aqueduct @ Old River Road & Maricopa Hwy



SUMMARY
Remote Measurement of Subsidence with Airborne Radar

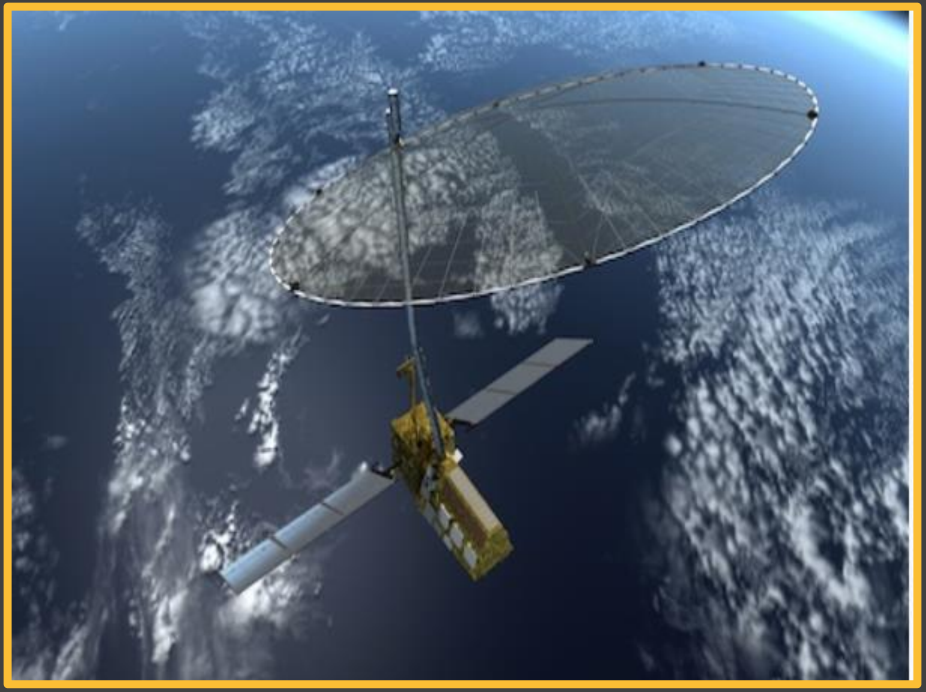
- Radar remote sensing with InSAR can be a game-changer for monitoring water storage, conveyance & flood control infrastructure.
- Airborne radar can be used to pinpoint problem areas on aqueducts & levees.
- Airborne radar can be used to identify potential or developing problems associated with changes in nearby areas.

NASA-ISRO Synthetic Aperture Radar (NISAR) Mission

UAVSAR: The NISAR Prototype Airborne Instrument

Today

2022+



NISAR Launch Dec. 2021
Repeat land coverage every 12 days
All NASA data are free

Applications – NASA-ISRO SAR ×

Secure https://nisar.jpl.nasa.gov/applications/#

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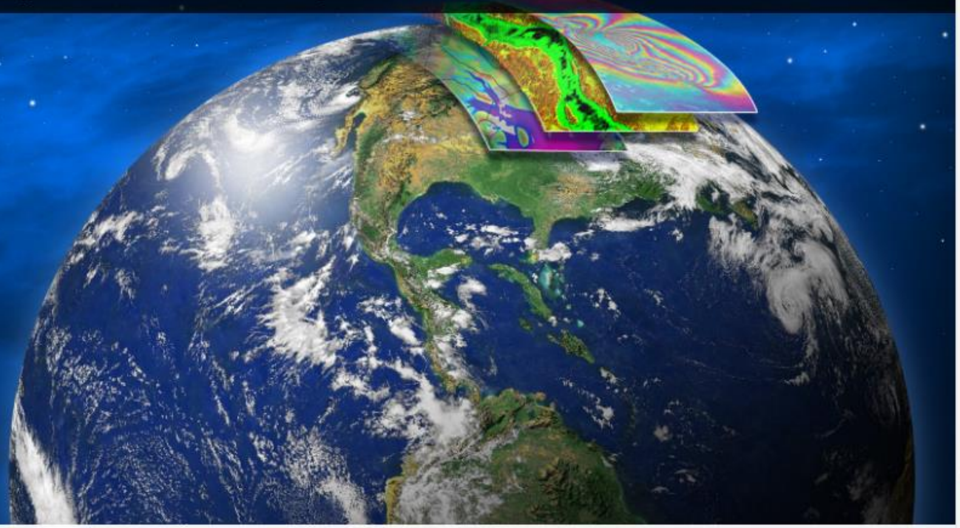

Applications

Share

NISAR will add a tremendous new data set to create new and greatly improve upon existing applications. By virtue of the planned frequent and regular sampling of some of the world's most hazard-prone areas, these data will be more than a rich source of information to guide development of applications and their associated scientific studies. They will be a reliable source over the life of the mission for proactive planning for disasters, and will have a store of pre-disaster images available to rapidly and unambiguously understand what transpired in the disaster, leading to the development of actionable applications that could inform the government for consideration of future operational missions. Water resource monitoring, infrastructure monitoring, and other value-added applications will also be revolutionized by access to these data.

Hazards

Sinkholes and Cavern Collapse (PDF, 2.01 MB)
Volcanic Hazards (PDF, 1.62 MB)
Landslides (PDF, 1.25 MB)
Floods (PDF, 2.98 MB)

Applications White Papers:

Levees and Dams (PDF, 1.92 MB)
Fire Management (PDF, 1.78 MB)
Food Security (PDF, 1.01 MB)
Coastal Land Loss (PDF, 2.56 MB)
Drought and Groundwater Withdrawal (PDF, 3.06 MB)
Forest Resources (PDF, 2.02 MB)
Sinkholes and Cavern Collapse (PDF, 2.01 MB)
Oil Spills (PDF, 3.48 MB)
Oil, Gas, and Water Underground Reservoirs (PDF, 2.09 MB)
Flood Forecasting (PDF, 3.52 MB)
Volcanic Hazards (PDF, 1.62 MB)
Timber and Forest Disturbance (PDF, 2.7 MB)
Ice Sheets, Glaciers, and Oceans (PDF, 1.19 MB)
Landslides (PDF, 1.25 MB)
Subsidence (PDF, 2.58 MB)
Floods (PDF, 2.98 MB)
Marine Hazards (PDF, 1.44 MB)