From Drought to Flood:

Radar-based Monitoring of California's Aqueducts and Levees

Cathleen E. Jones

Jet Propulsion Laboratory, California Institute of Technology

"One Water LA" Educational Initiative – 14 April 2016

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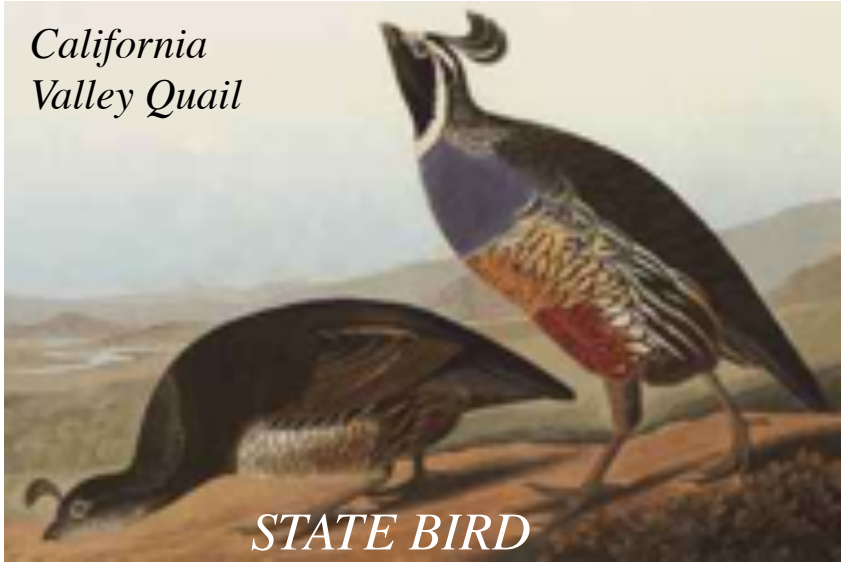
CALIFORNIA


California
Valley Quail
STATE BIRD

California Poppy
STATE FLOWER

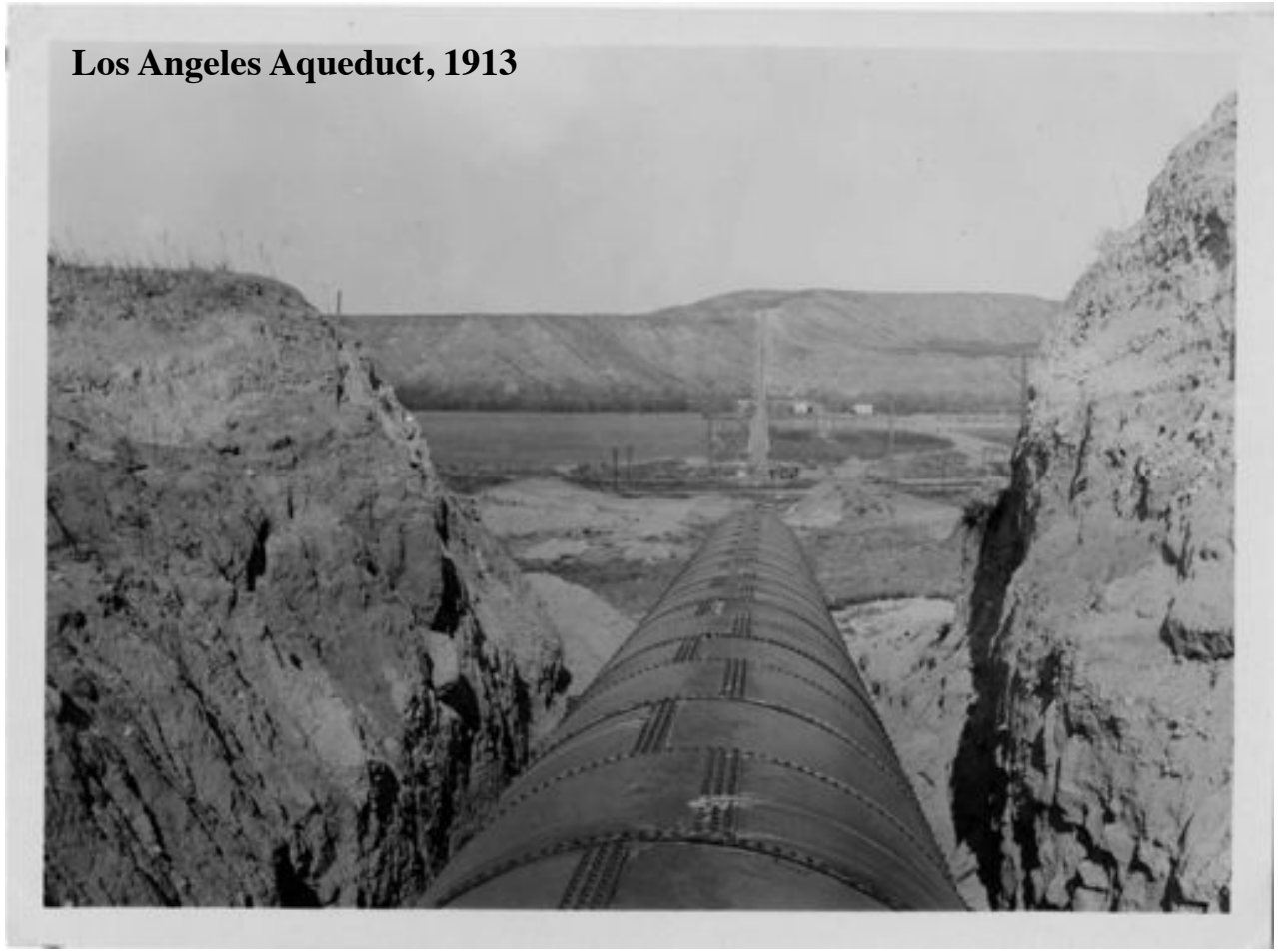
Gold
STATE MINERAL

Saber-toothed
Tiger
STATE FOSSIL

CALIFORNIA

Whiskey is for drinking, and water is for fighting.

SOURCE UNKNOWN



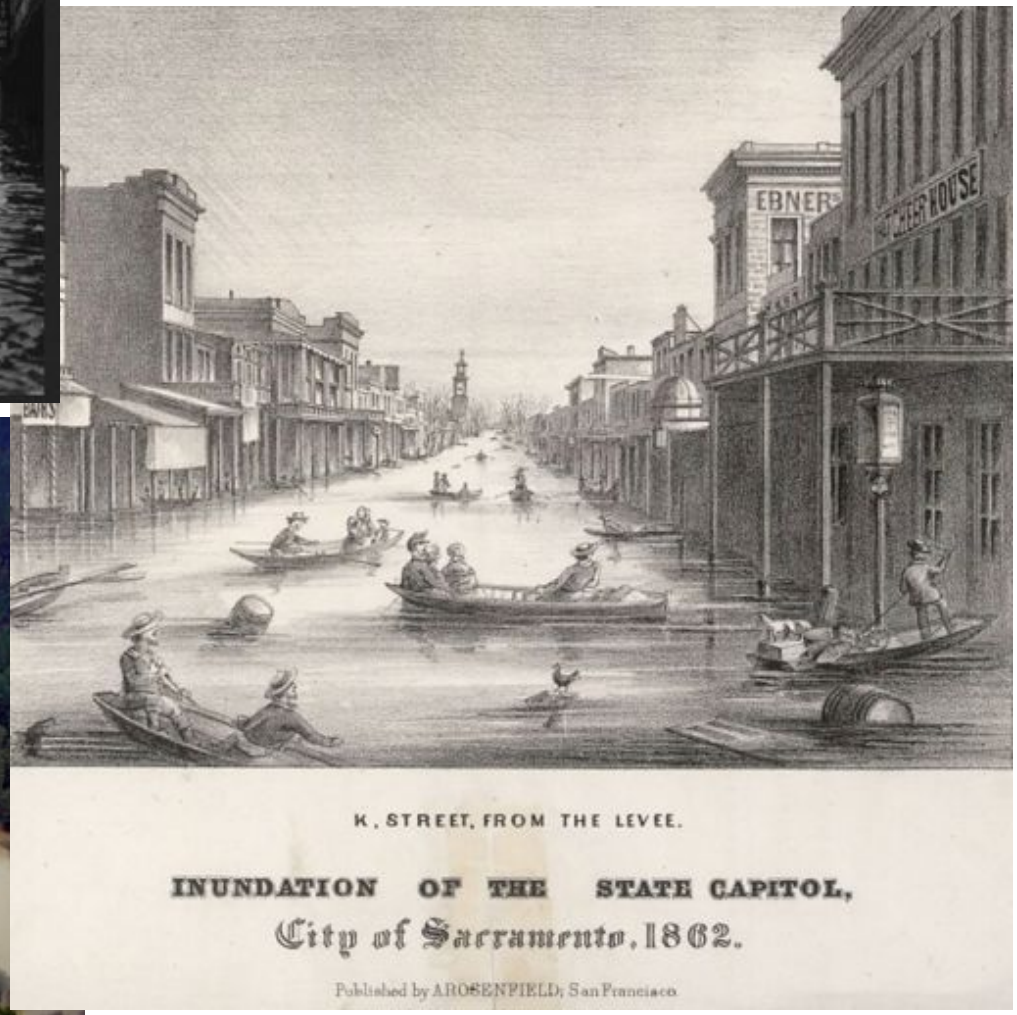
UC Riverside Libraries Digital Collections
cuwr_huber_641_2300 http://digilib.ucr.edu/items/show/2089 http://digilib.ucr.edu/files/original/26ec49d04adf3c9ee380bb1ff7ad2fc4.jpg

CALIFORNIA FLOODS

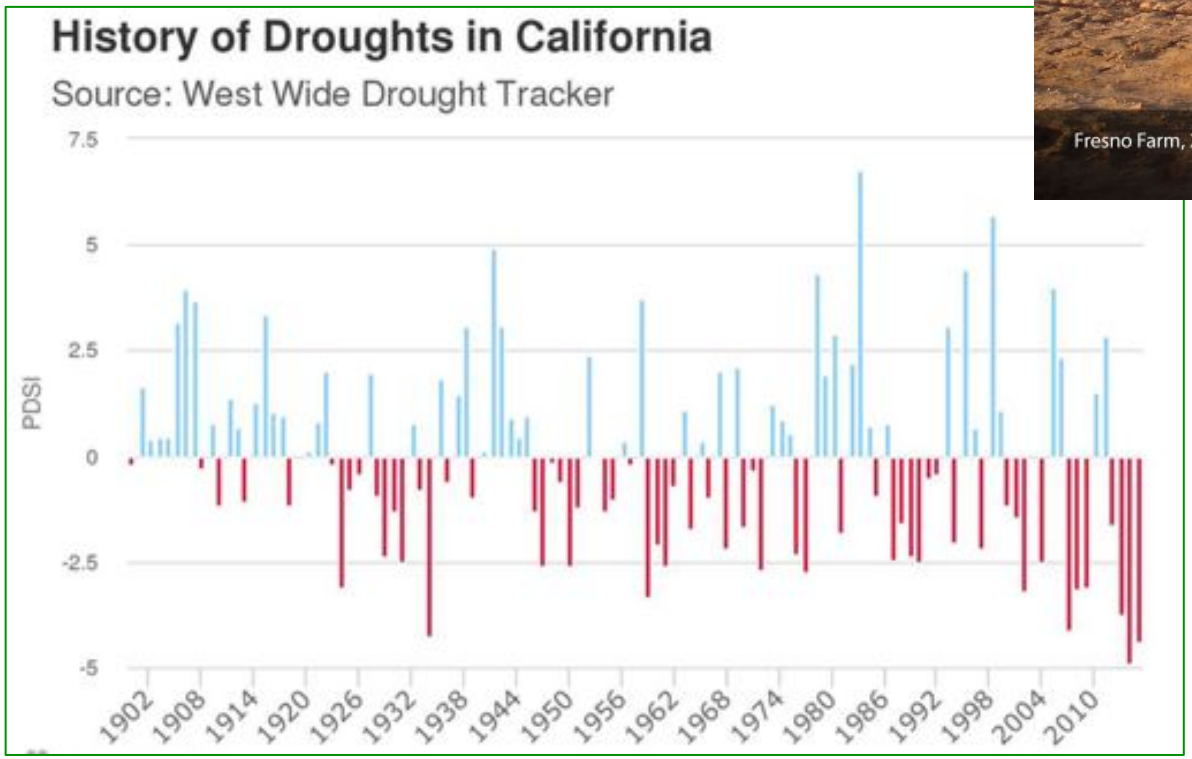
1862, Anaheim

Source: Anaheim Public Library

1986, Guerneville



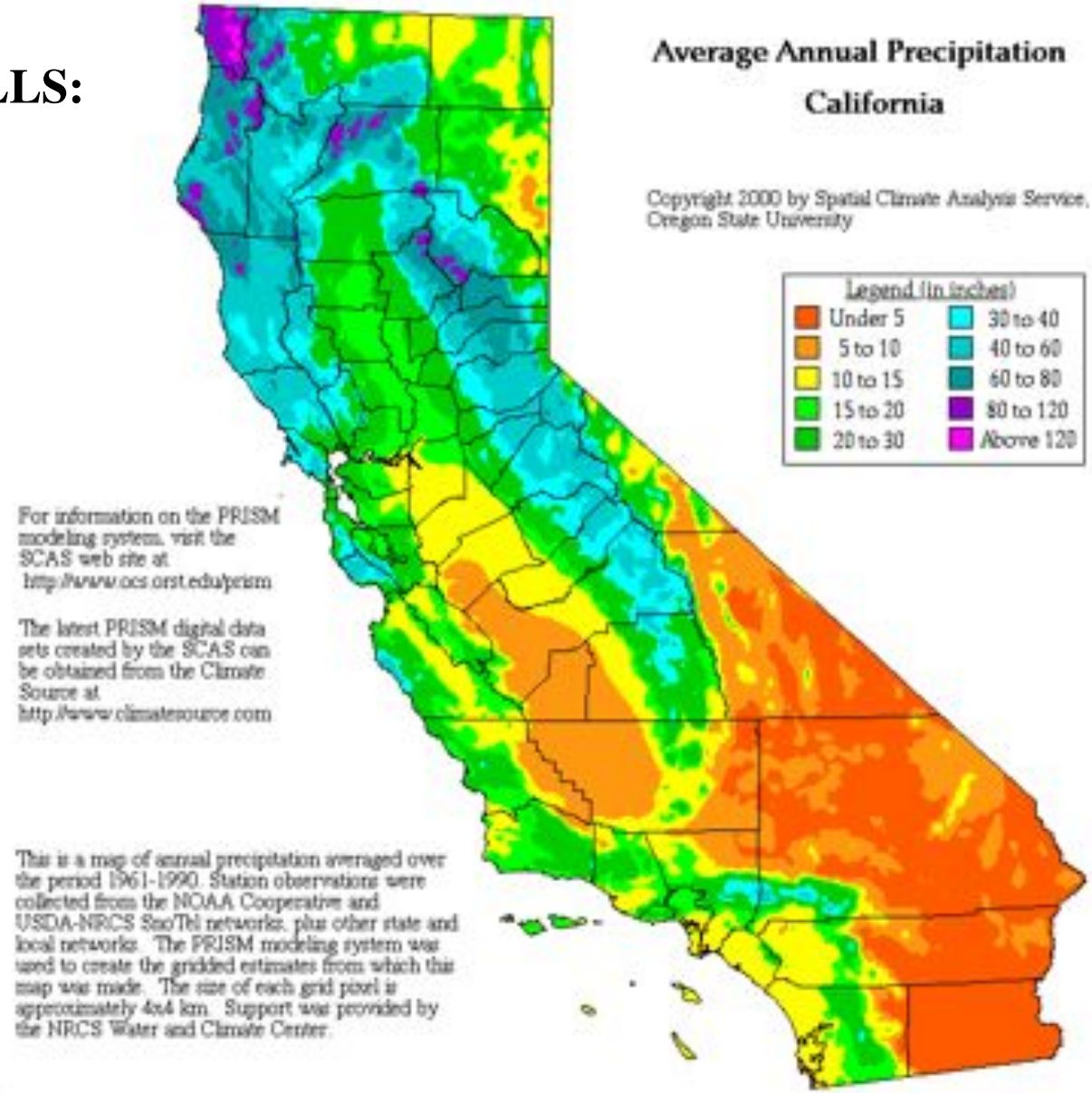
CALIFORNIA DROUGHTS



California Water – The Great Mismatch

WHERE RAIN/SNOW FALLS:

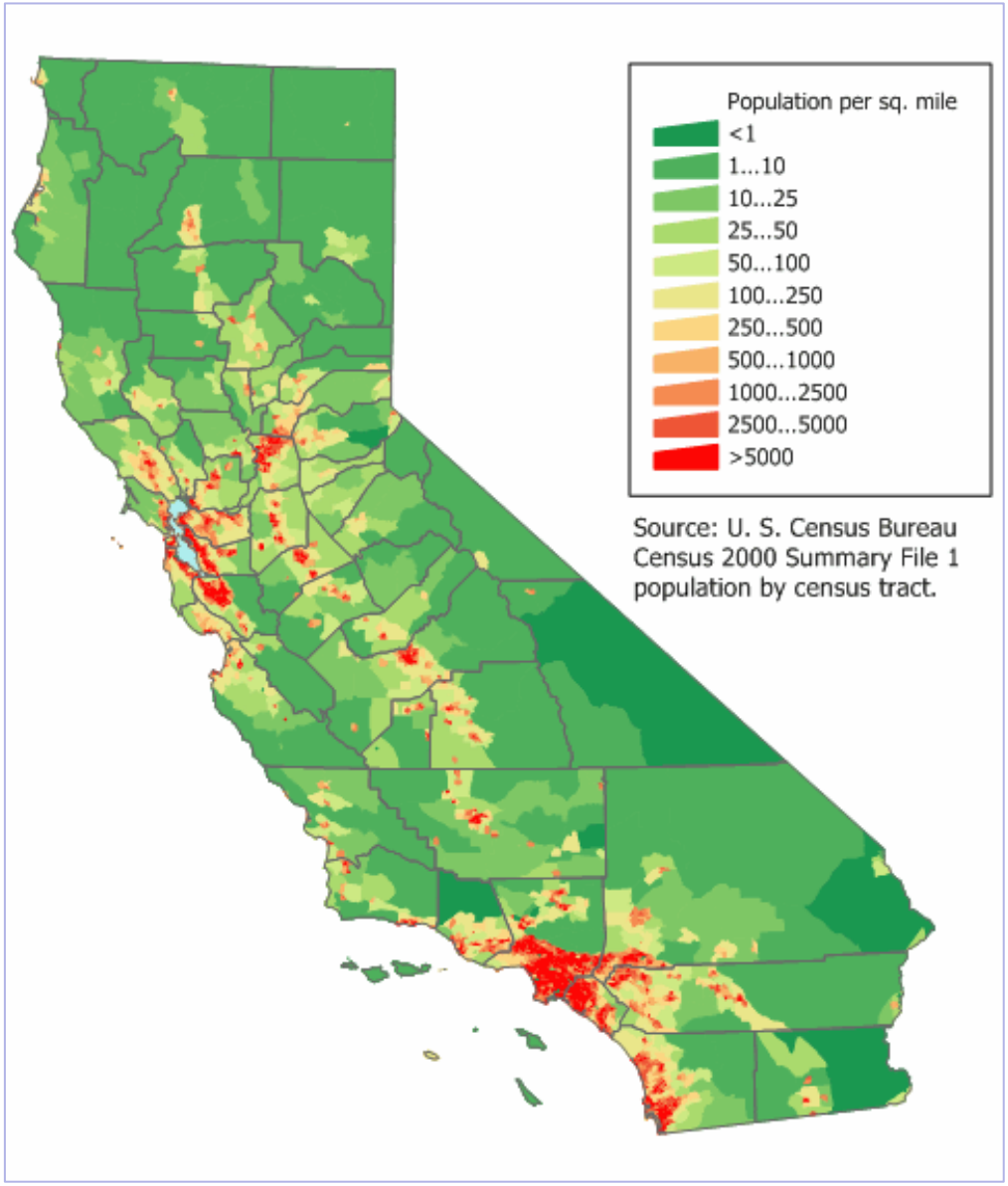
75% of precipitation occurs in upper 1/3 of the state



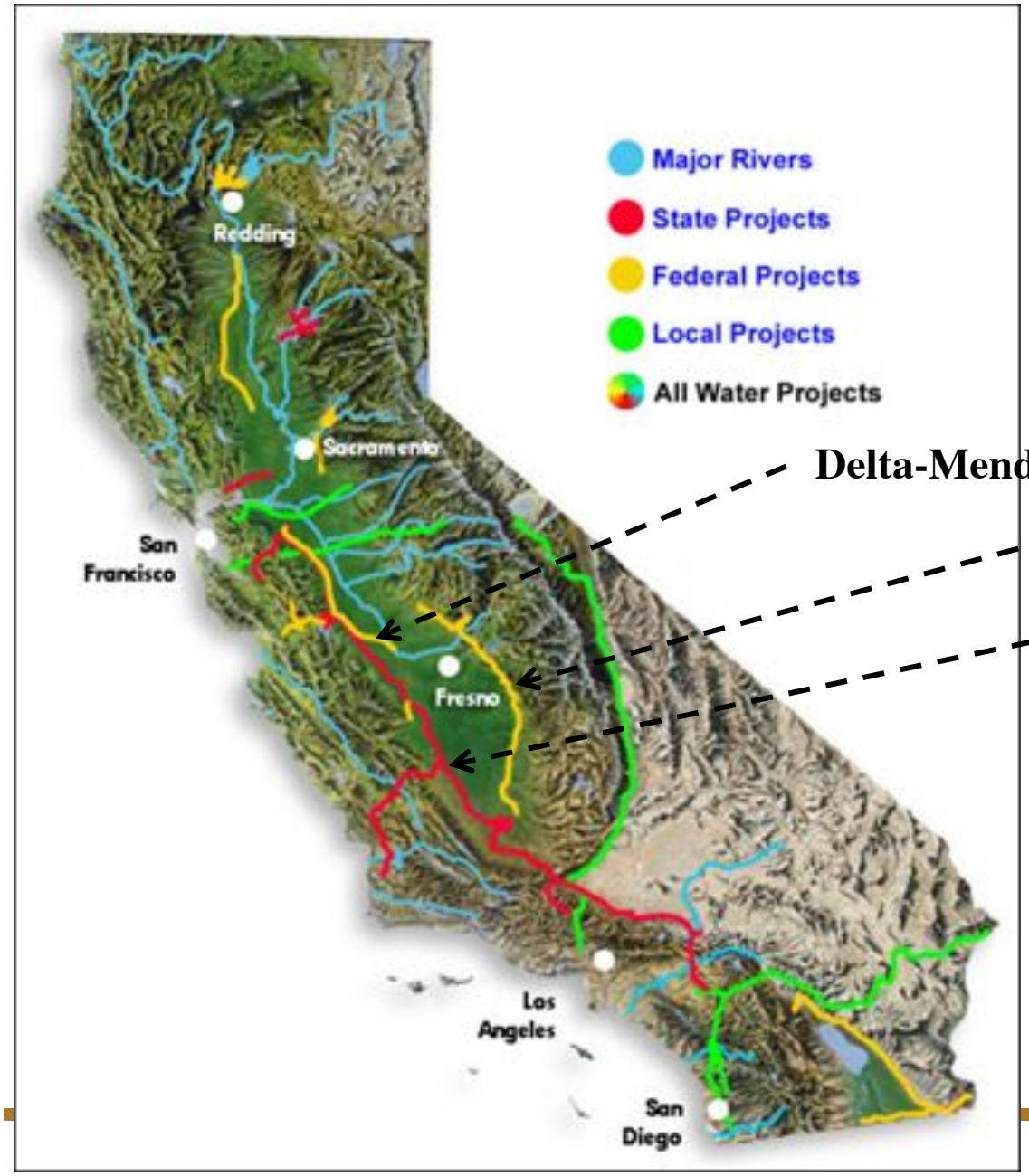
California Water – The Great Mismatch

WHERE PEOPLE LIVE:

80% of water usage occurs in lower 2/3 of the state



California Water Capture & Conveyance



- Dams, levees, and canals serve dual uses of water supply and flood protection.
- Dams supply hydroelectric power.

- Largest single user of electricity in the state is the State Water Project, used to move water over the mountains into southern California.

The Fall-Back: Groundwater Withdrawal

GROUNDWATER BASINS:

30% - 60% of water demand is met through groundwater withdrawal

Central Valley Agriculture & Historic Ground Subsidence

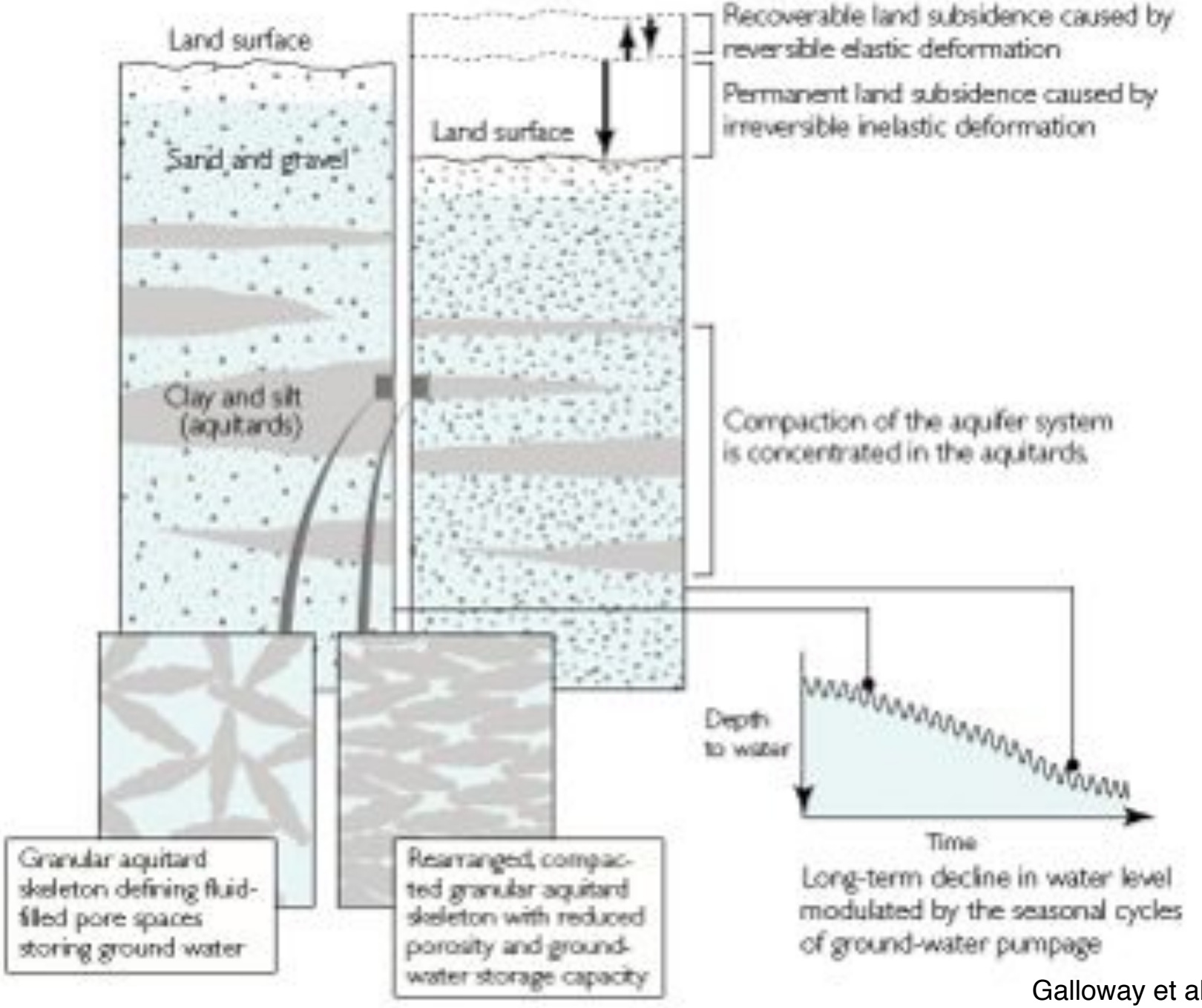
Today California produces:

- 50% of U.S. vegetables, nuts, fruit
- 21% of U.S. milk supply
- 23% of U.S. cheese

Expansion of Irrigated Cropland, 1950-2000

Giannini Foundation Special Report 04–1

Hydrology 101: Aquifer compaction



Galloway et al., 1999

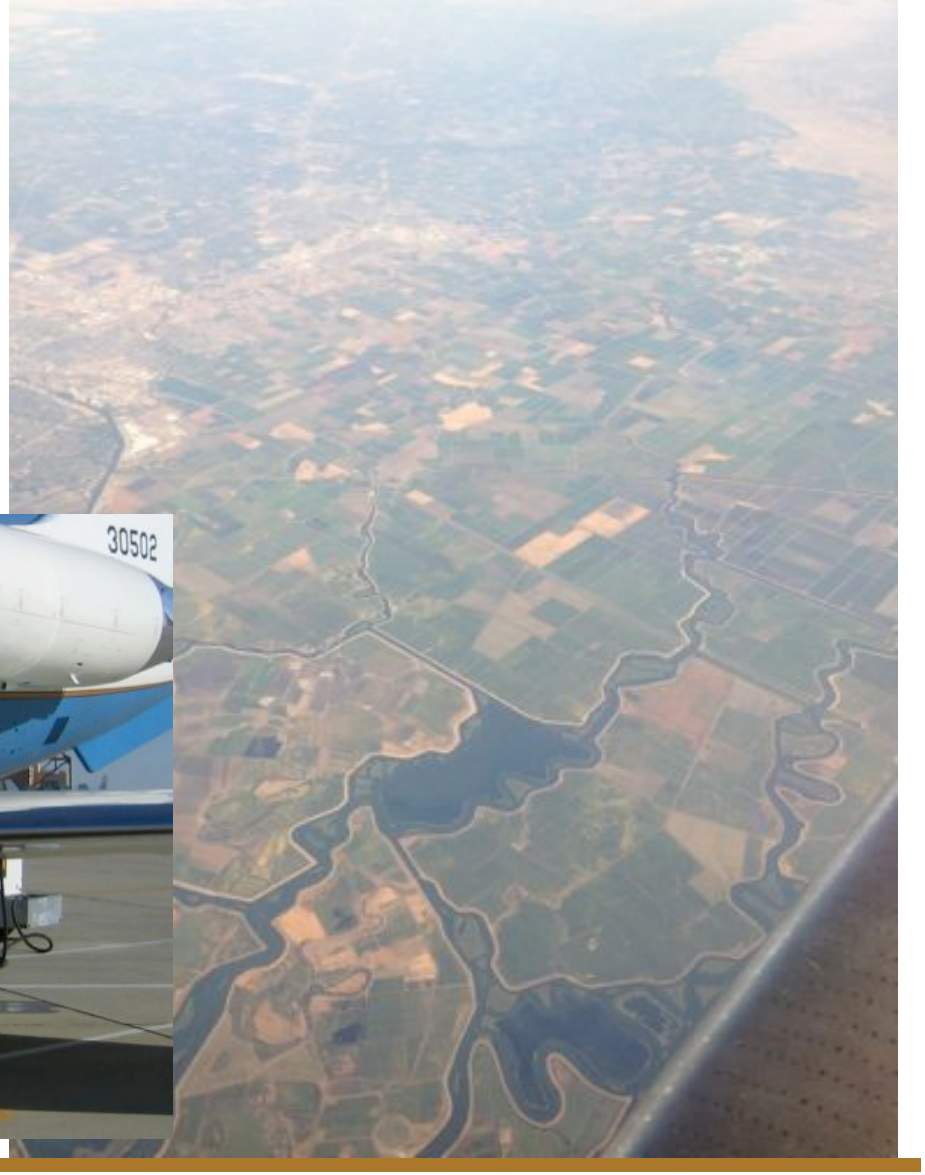
How I Got Involved in the State's Water Problems

Scott Hensley, Cathleen E. Jones
2007
UAVSAR, Dryden Flight Research Center

March 2007
NASA
Airborne Science
Flight
Integration and
Test

Scott Hensley, Cathleen Jones, Roger Chao
2007
UAVSAR, Dryden Flight Research Center

View of the Sacramento Delta from the UAVSAR G3 Aircraft

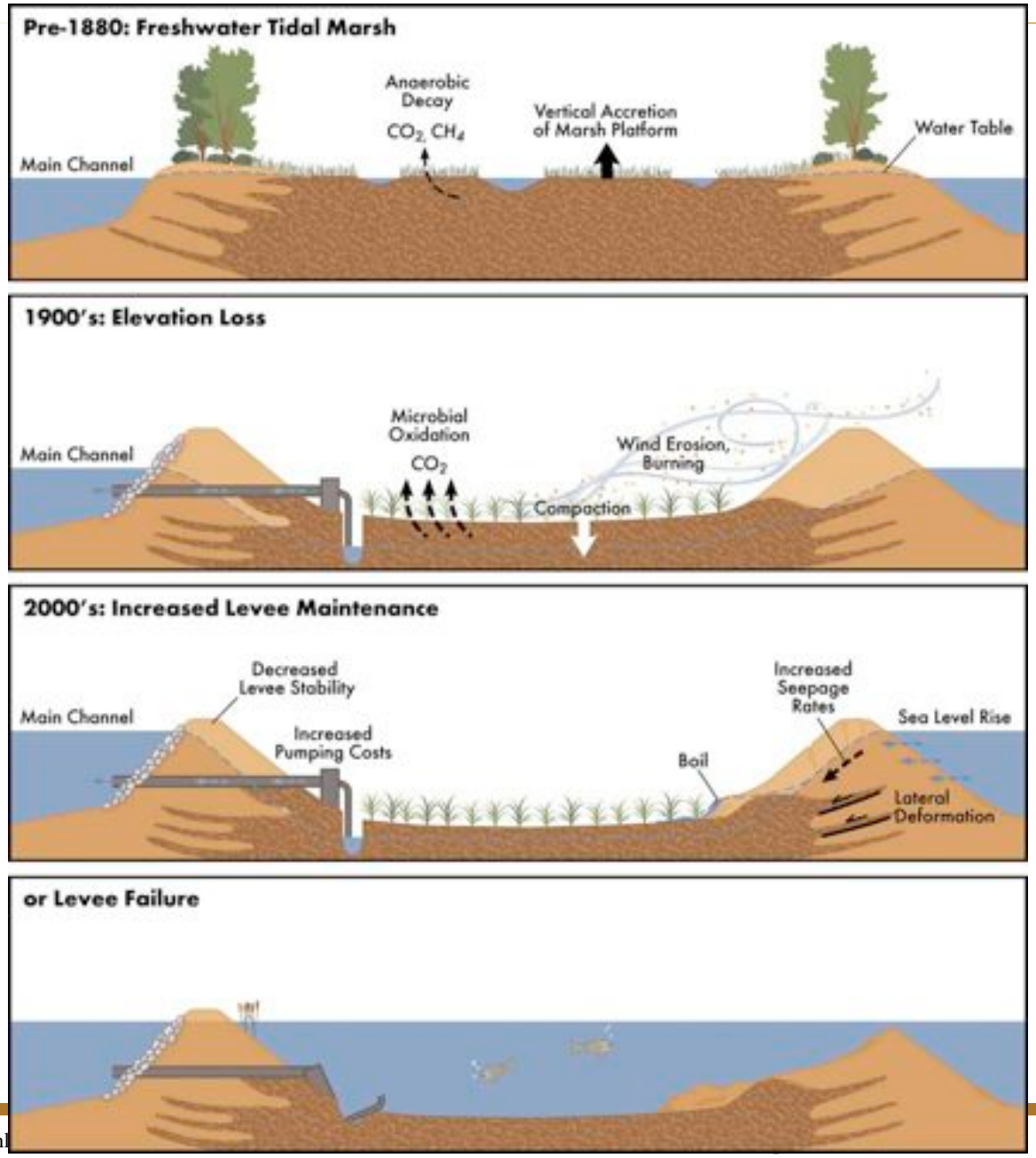


The Water Hub of the State: Sacramento Delta

- Over 60 reclaimed islands surrounded by 1100 miles of levees
- Most islands lie below mean sea level.
- Collects run-off from approximately 2/3 of the state via the Sacramento and San Joaquin rivers.
- Supplies water to ~2/3 of the residents of California and to almost all of the agriculture of the Central Valley.

THE DELTA IS THE MOST CRITICAL WATER RESOURCE IN CALIFORNIA.

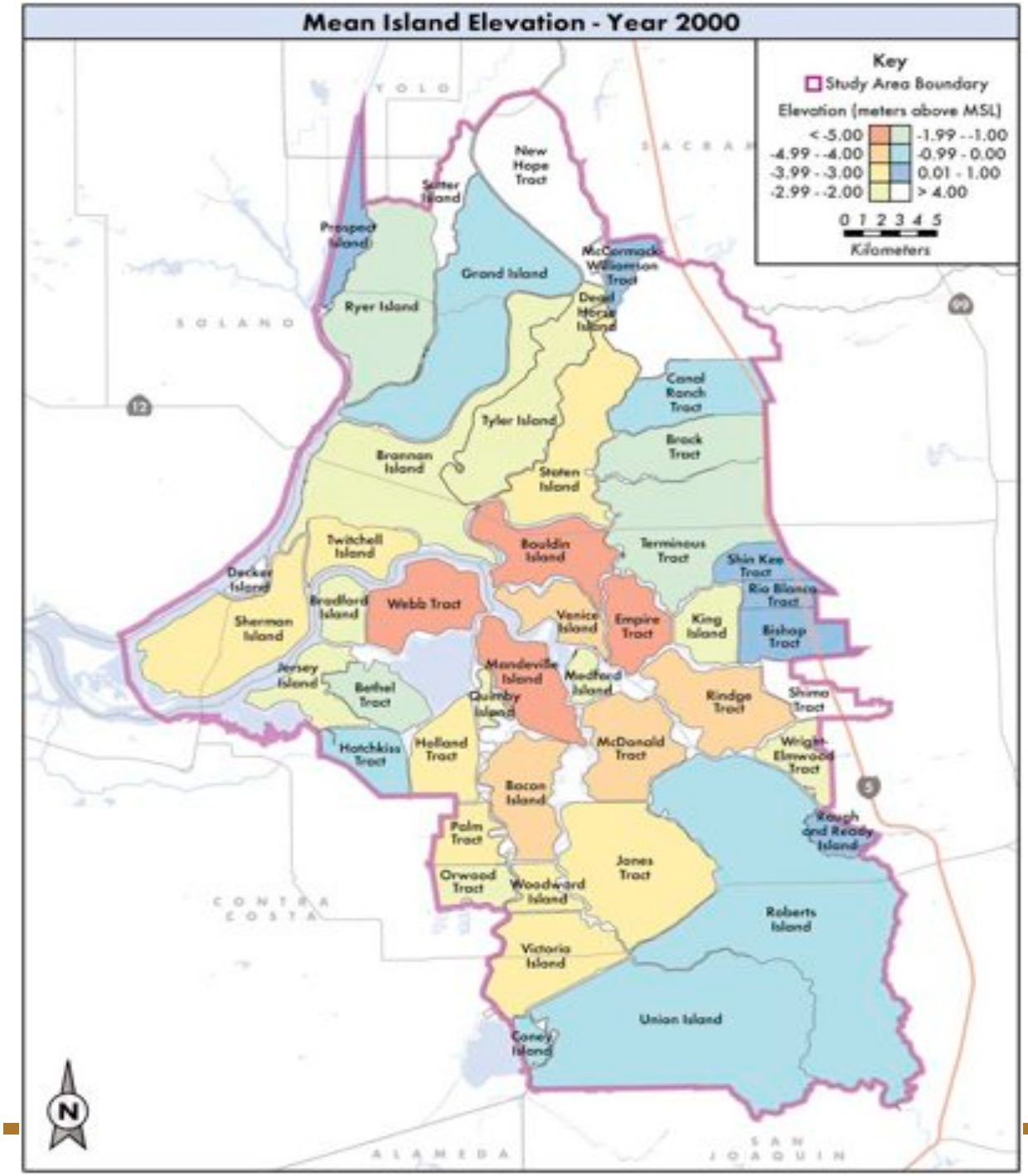
Causes of Subsidence in the Delta

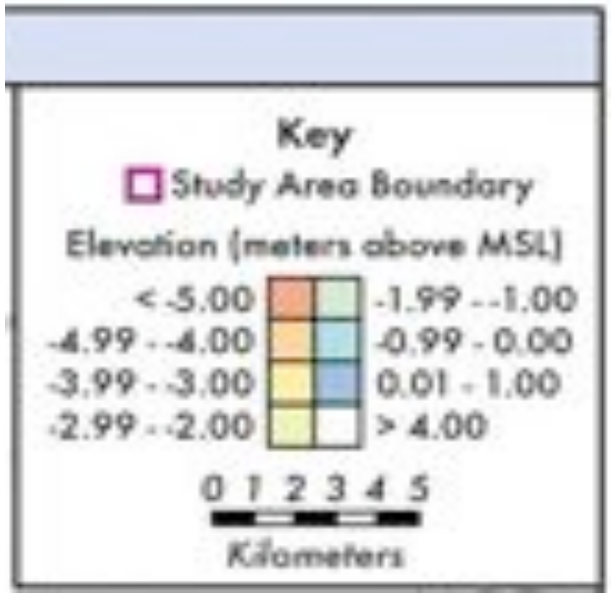


From "Subsidence, Sea Level Rise, and Seismicity in the Sacramento – San Joaquin Delta," Jeffrey Mount and Robert Twiss, San Francisco Estuary & Watershed Science, March 2005.

Natural Delta:
Anaerobic Oxidation of Soil (balanced by accretion from vegetation decay)

Today's Delta:
Aerobic Oxidation of Soil (from dewatering, or lowering water table to make soil suitable for agriculture)

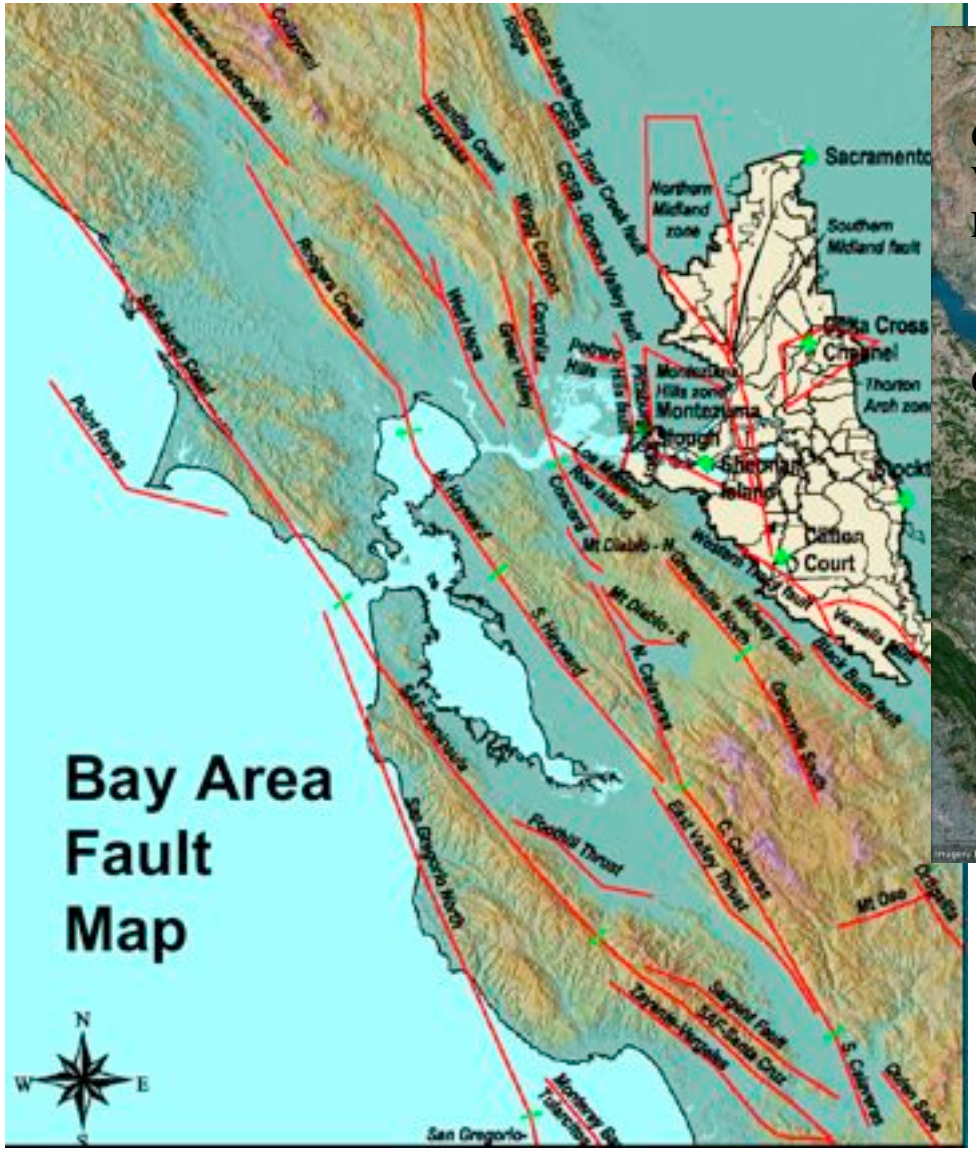


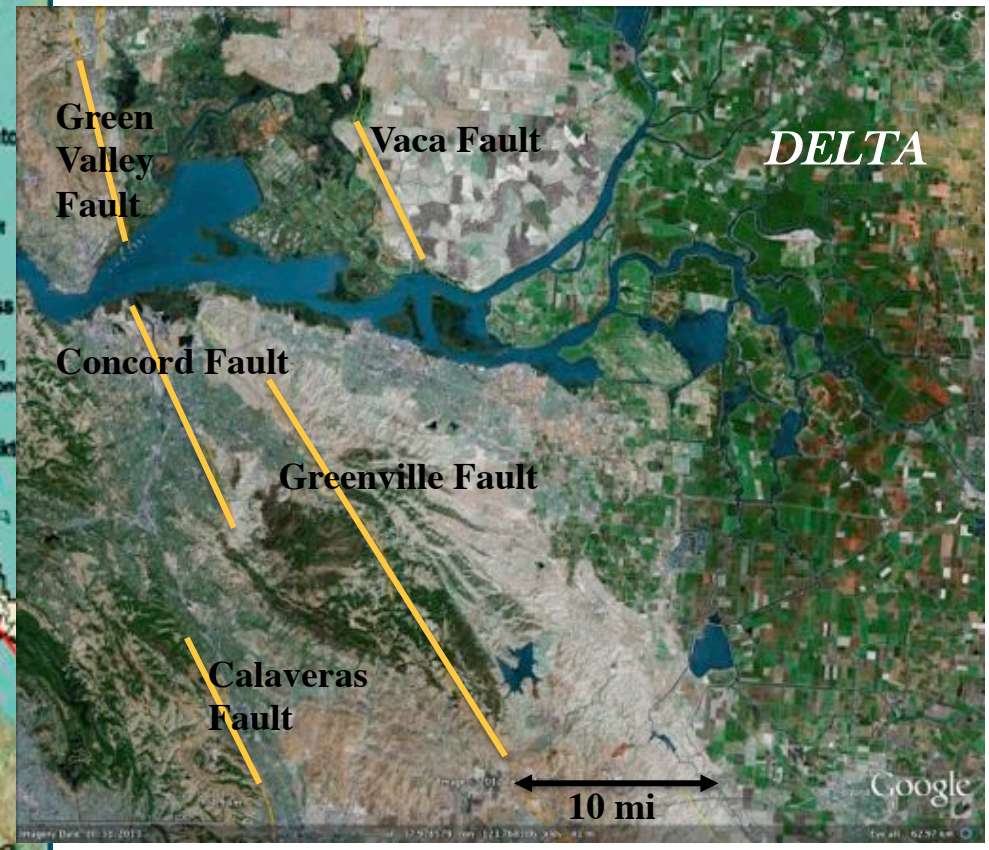


All but a few islands now lie below mean sea level.

All are encircled by levees to prevent flooding.

Geological Setting





Close proximity to the major California fault networks in the San Francisco Bay area

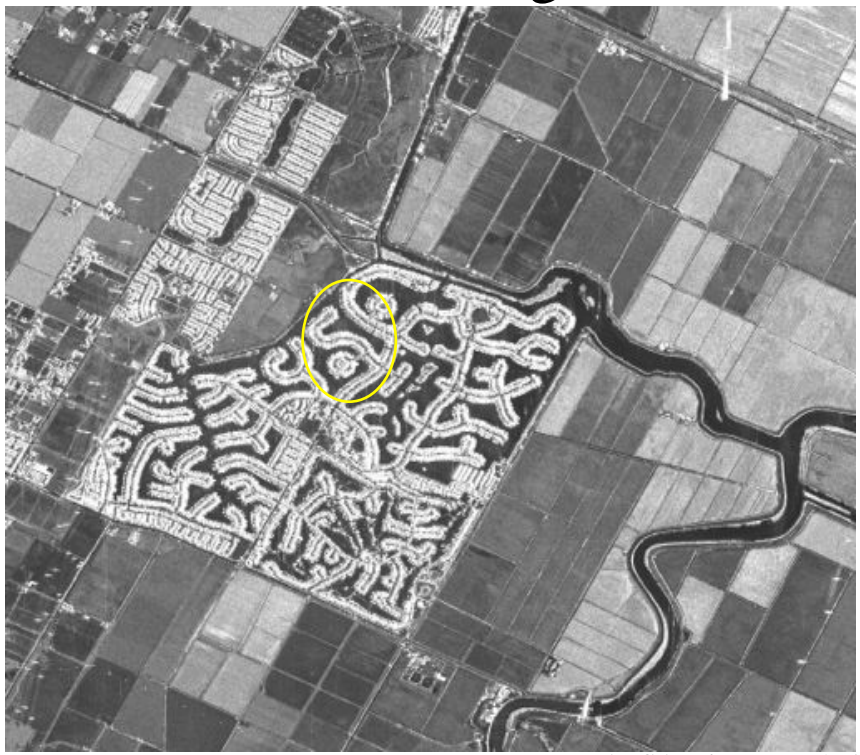
NASA/JPL UAVSAR Airborne Radar

Radar Remote Sensing

Radar imaging ≠ photogrammetry or visual surveys

Optical Image

Radar Image



UAVSAR / 7 m resolution

Discovery Bay, California

Polarization – Horizontal (H) and Vertical (V)

Red = HH, Blue = VV, Green = HV

Sacramento Delta / false color UAVSAR POLSAR image / 7 m resolution

Soil: HH & VV

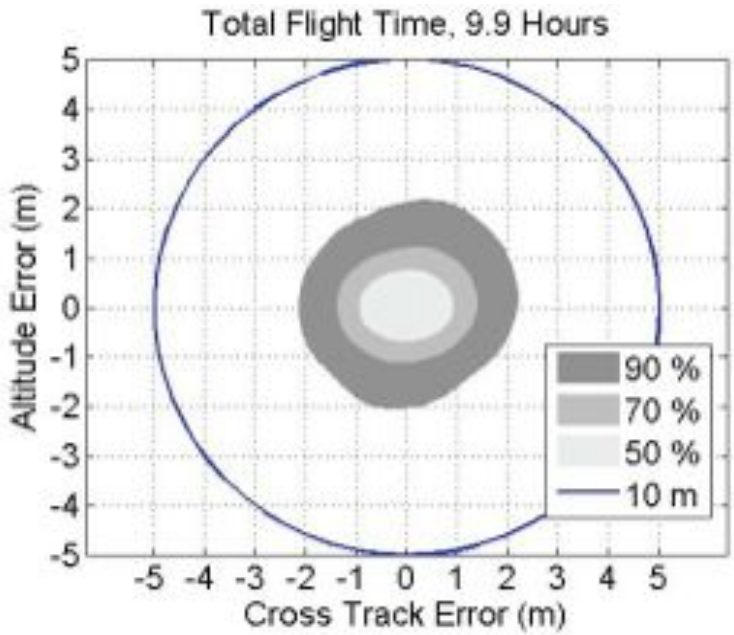
Water: VV

Vegetation: HV

Saturated Soil: HH + VV -> VV

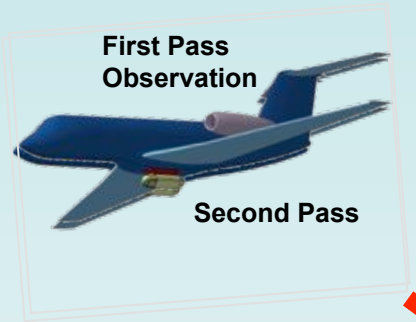
UAVSAR Capability: Repeat Track Flight Accuracy

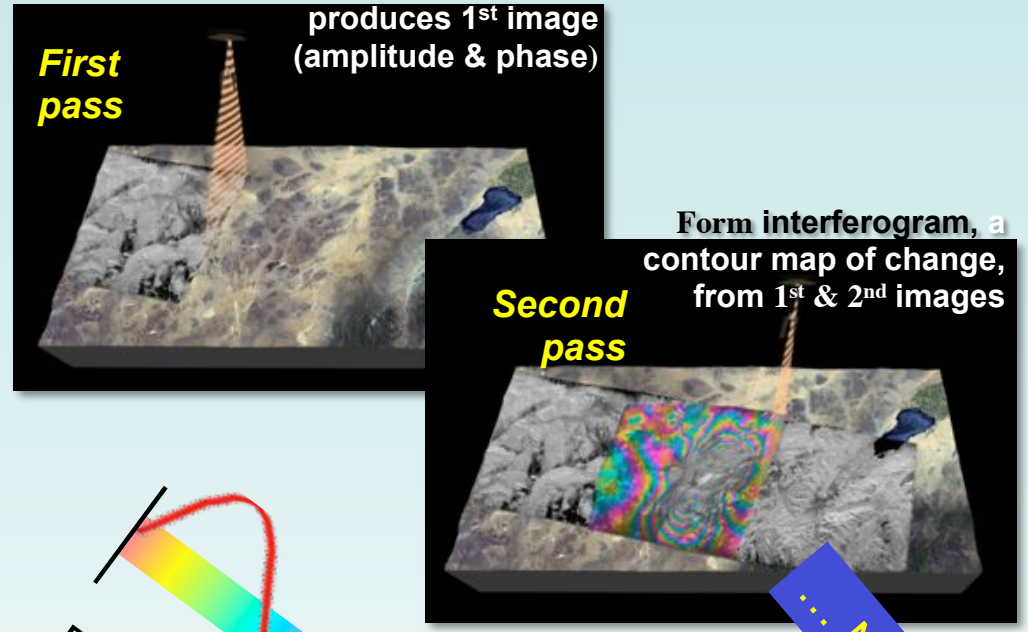
Parameter	Value
Frequency	L-Band 1217.5 to 1297.5 MHz (23.8 cm wavelength)
Resolution	1.7 m Slant Range, 1.0 m Azimuth
Operational Altitude	12.5 km
Swath Width	22 km
Polarization	Quad-Polarization (HH, HV, VH, VV)
Repeat Track Accuracy	± 5 meters
Transmit Power	> 3.1 kW
Radiometric Calibration	1.2 dB absolute, 0.5 dB relative
Noise Floor	-47 dB average



The Precision Autopilot System was designed and developed at Armstrong Flight Research Center to provide < 5 meter repeat track capability. Typically we achieve < 2 m accuracy.

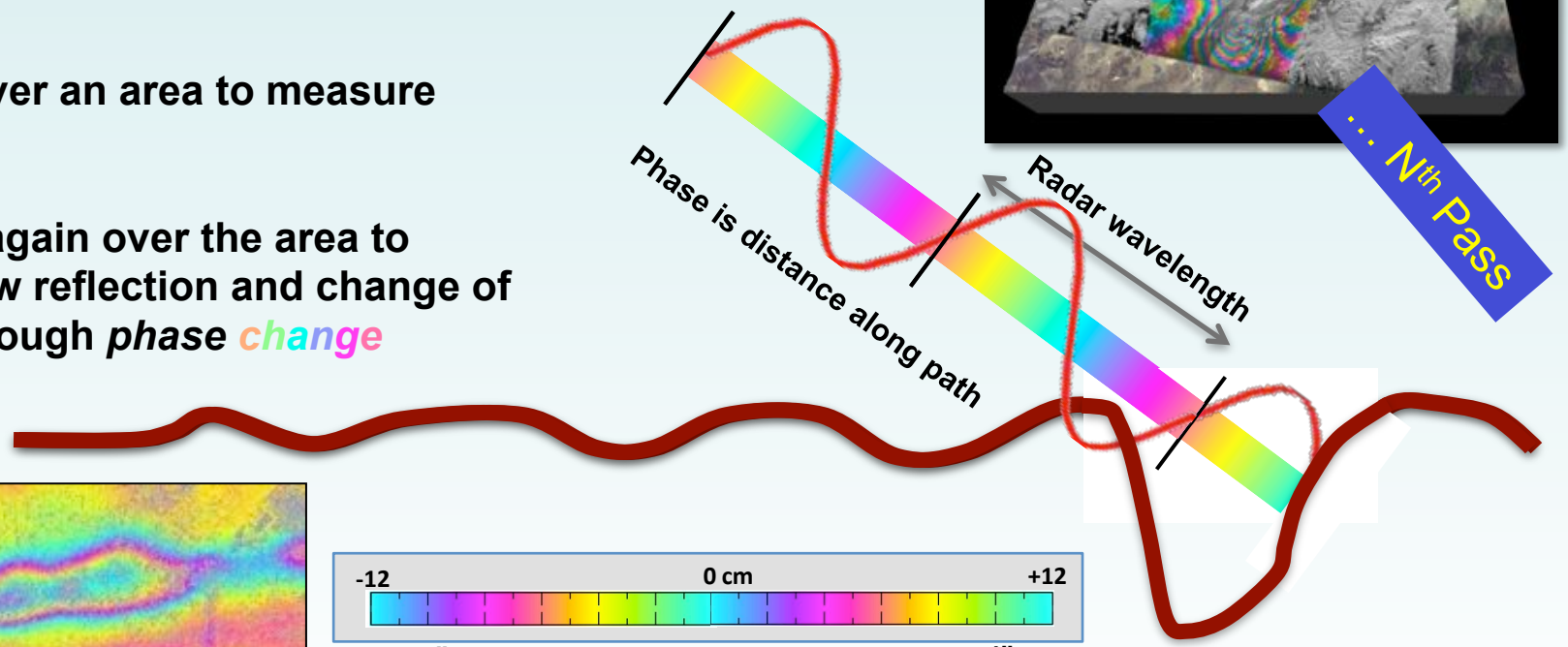
Radar Interferometry for Measuring Surface Deformation

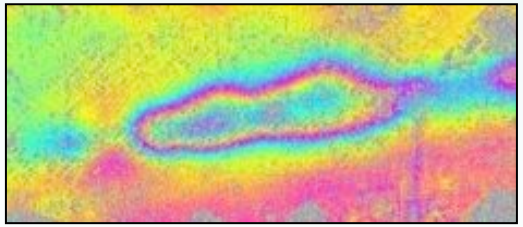


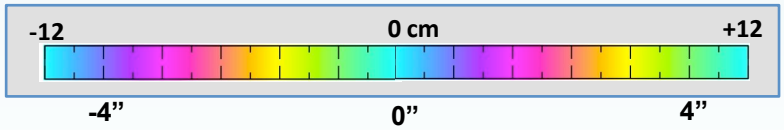


Radar flies over an area to measure reflection

Radar flies again over the area to measure new reflection and change of distance through *phase change*







UAVSAR: 12 cm per color wrap

UAVSAR Capability: High Resolution

Sacramento Delta Islands

->

Resolve the levees

->

Monitor their movement

Levee Threats / Levee Status

Radar Remote Sensing Capabilities

Seepage

Cracks

Sand Boils & Sinkholes

Slope Instability

Subsidence

Photo credit: Tom Williams, Gerald Bawden, Cathleen Jones, Joel Dudas

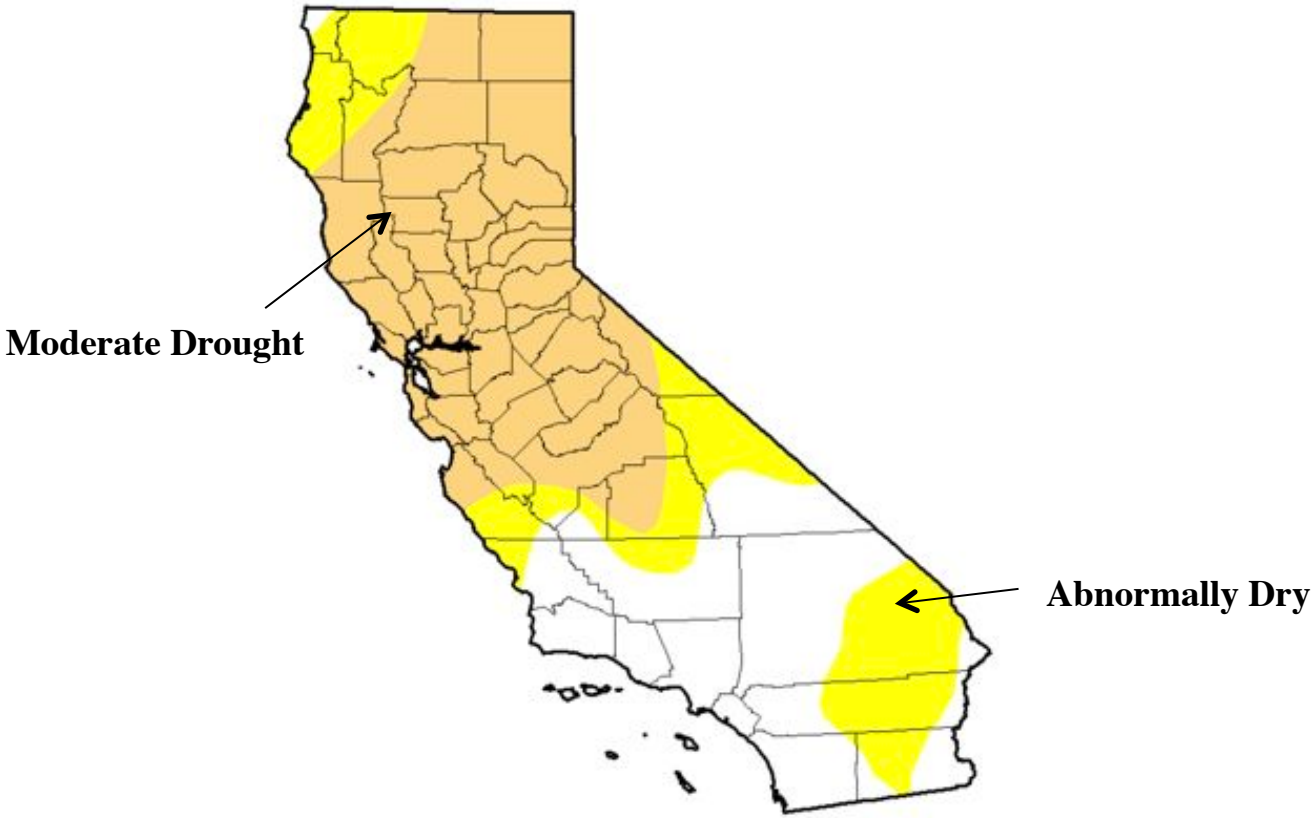
The Drought, Groundwater Pumping, & The California Aqueduct

Cathleen E. Jones (JPL)

The Current Drought

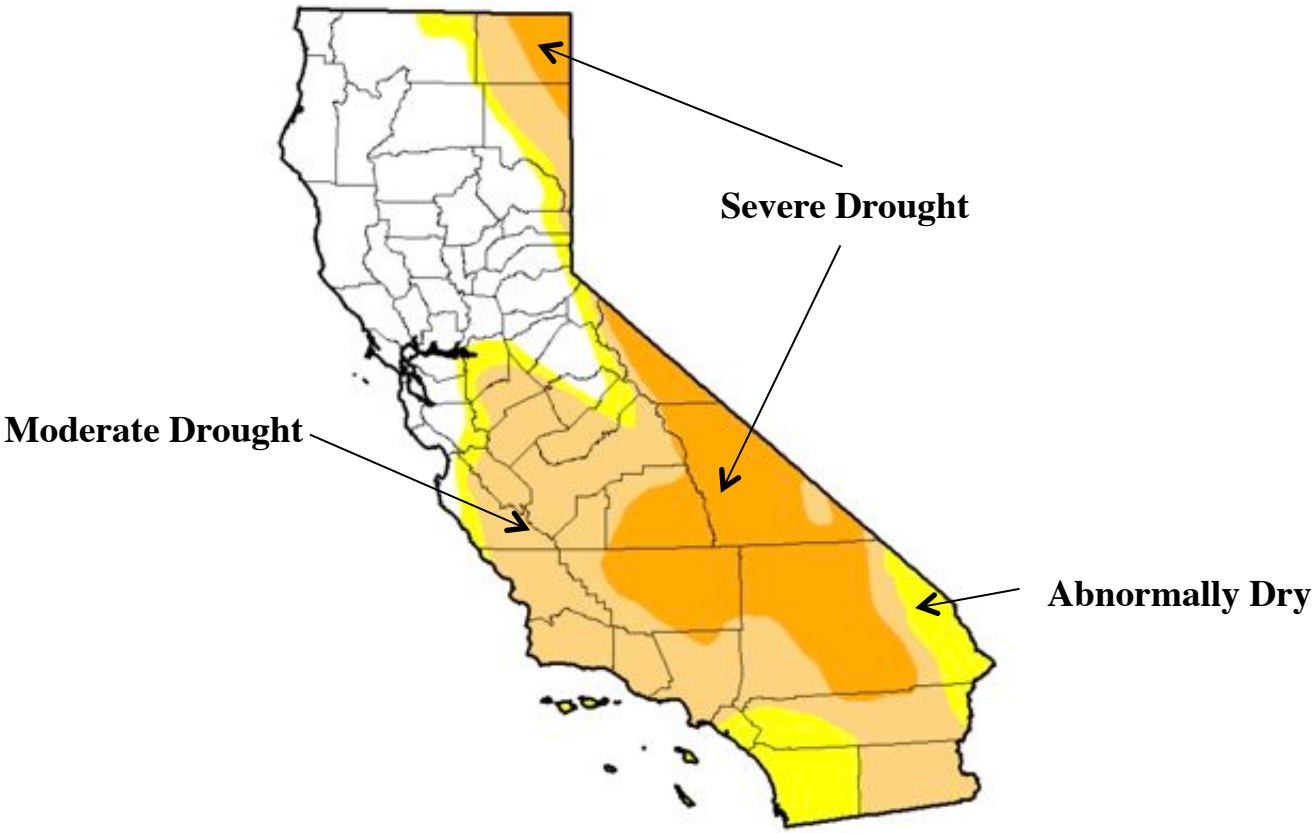
California Water Year:
Oct. 1 – Sept. 30

January 2012



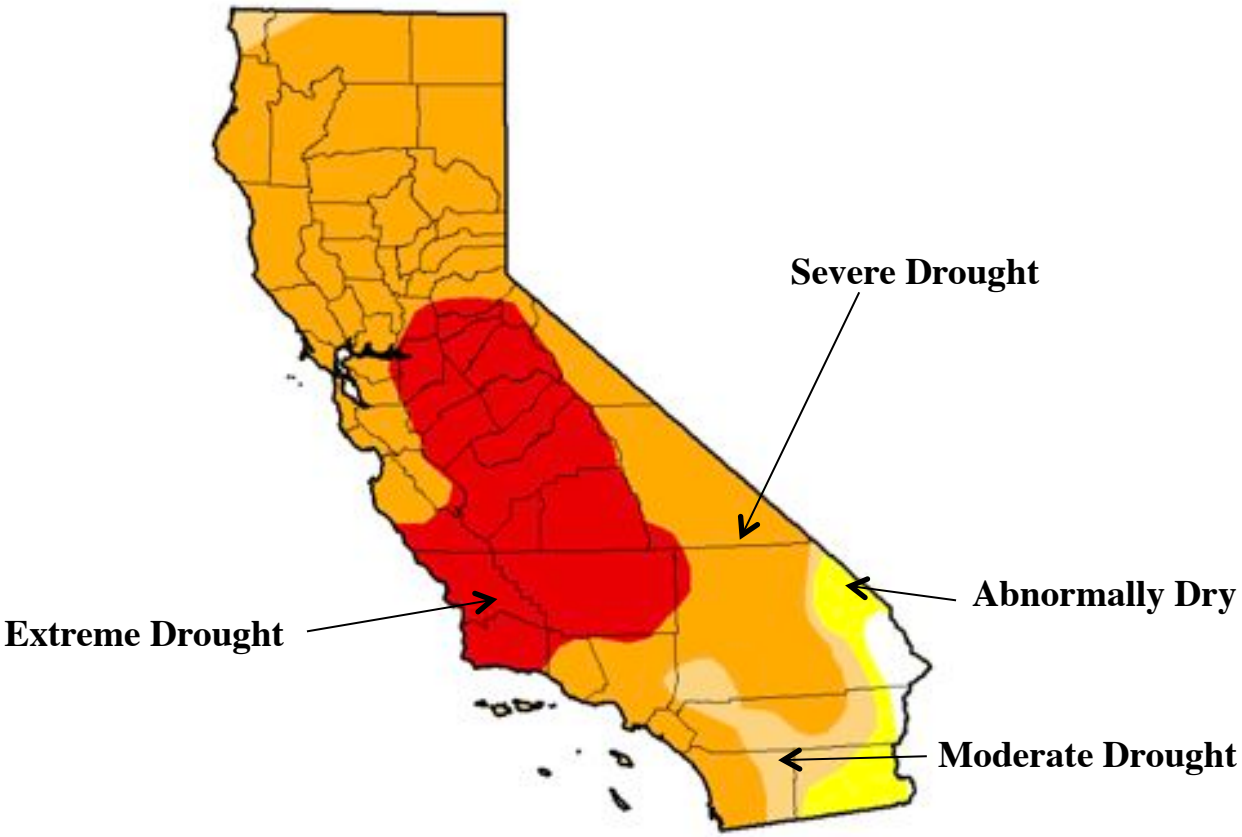
The Current Drought

January 2013



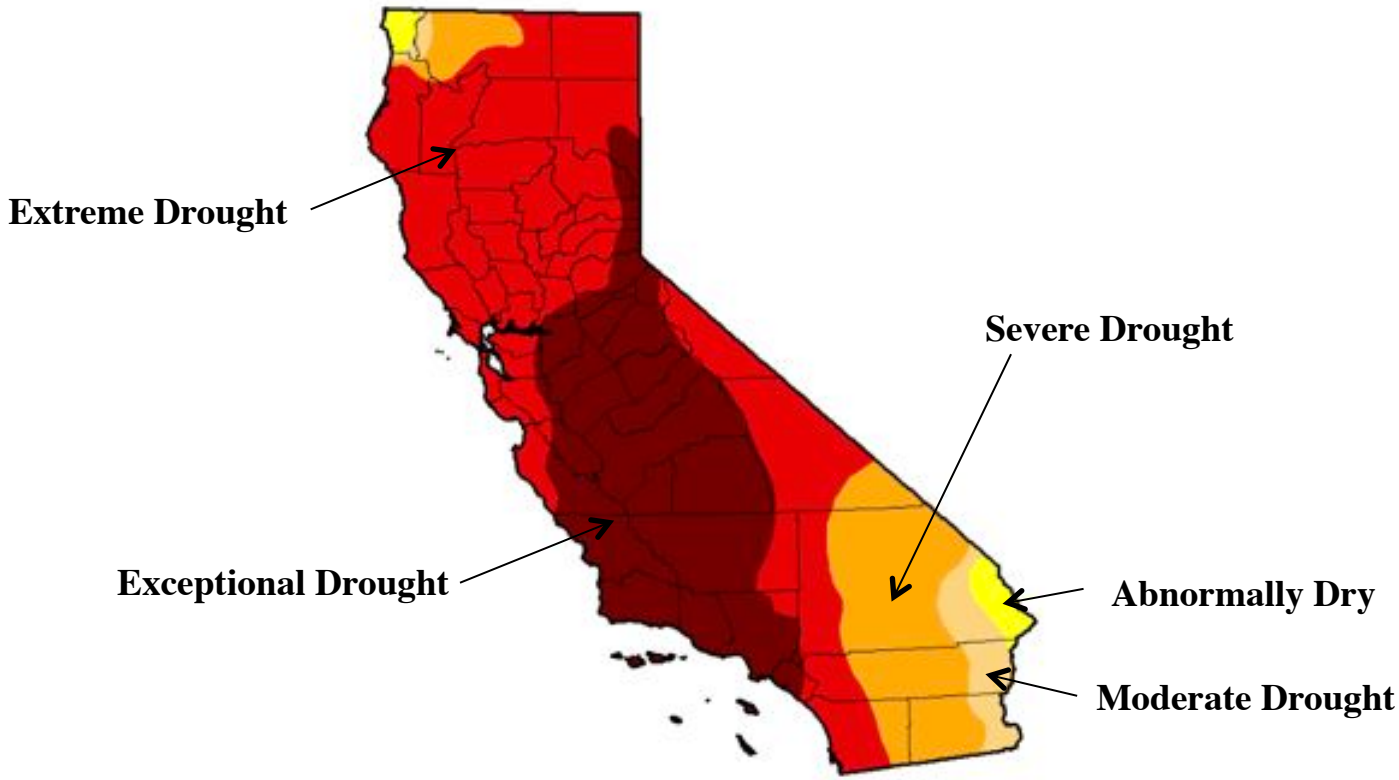
The Current Drought

January 2014



The Current Drought

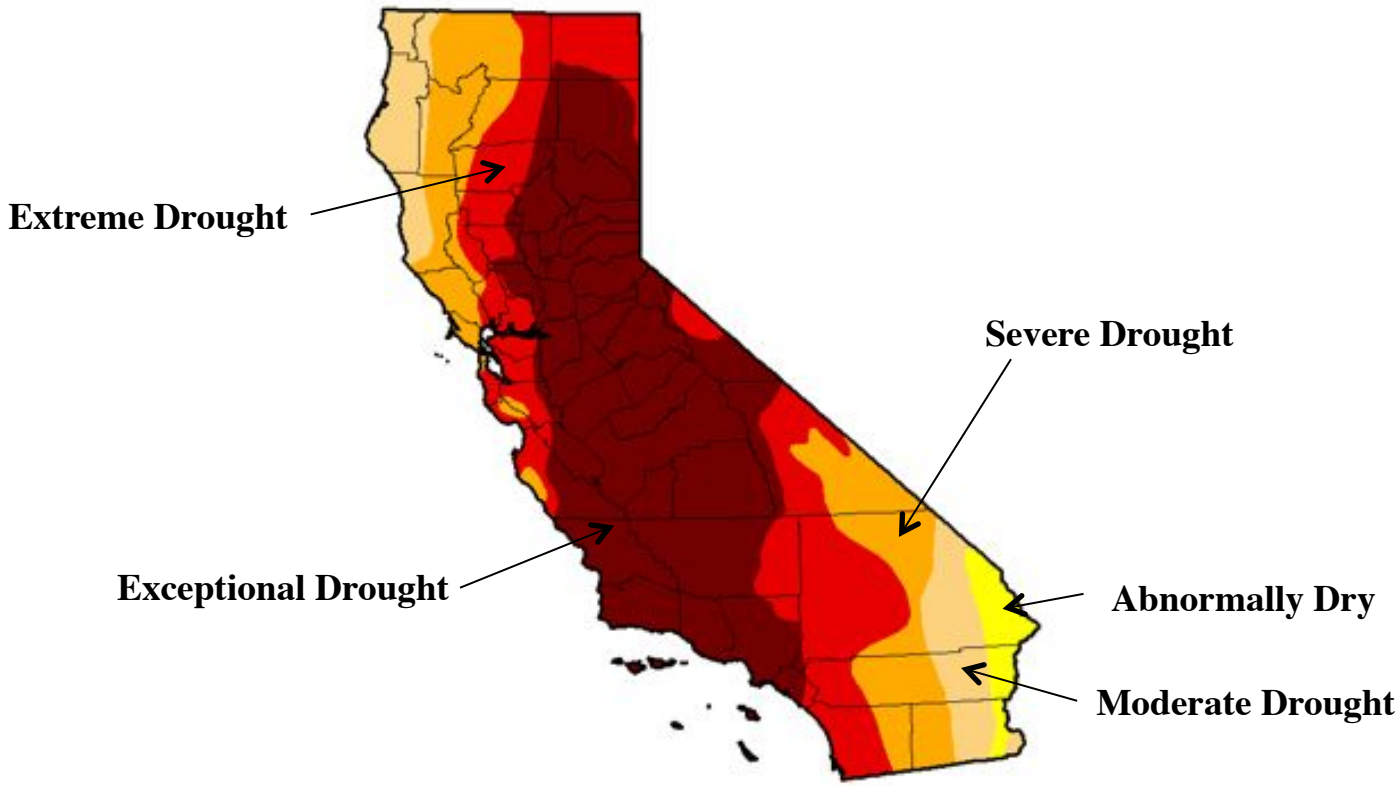
January 2015



Snowfall: 5% of Annual Average

The Current Drought

January 2016



The Current Drought – April 5, 2016

U.S. Drought Monitor

California

Download:

View drought planning resources

April 5, 2016

(Released Thursday April 7, 2016)

Valid 8 a.m. EDT

Statistics type: Traditional Percent Area

Export table:

Week	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current 2016-04-05	3.55	96.45	90.58	74.37	55.25	31.68
Last Week 2016-03-29	3.55	96.45	90.58	72.82	55.25	34.74
3 Months Ago 2016-01-05	0.00	100.00	97.33	67.55	69.07	44.84
Start of Calendar Year 2015-12-29	0.00	100.00	97.33	67.55	69.07	44.84
Start of Water Year 2015-09-29	0.14	99.86	97.33	92.36	71.08	46.00
One Year Ago 2015-04-07	0.15	99.85	96.11	93.44	66.60	44.32

Estimated Population in Drought Areas: **34,230,554**

View More Statistics

Intensity:

- D0 (Abnormally Dry)
- D1 (Moderate Drought)
- D2 (Severe Drought)
- D3 (Extreme Drought)
- D4 (Exceptional Drought)

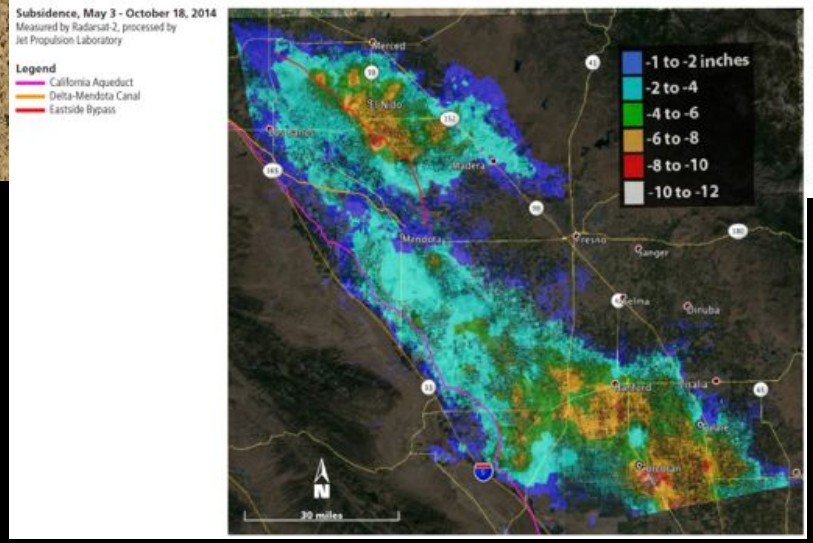
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author(s):

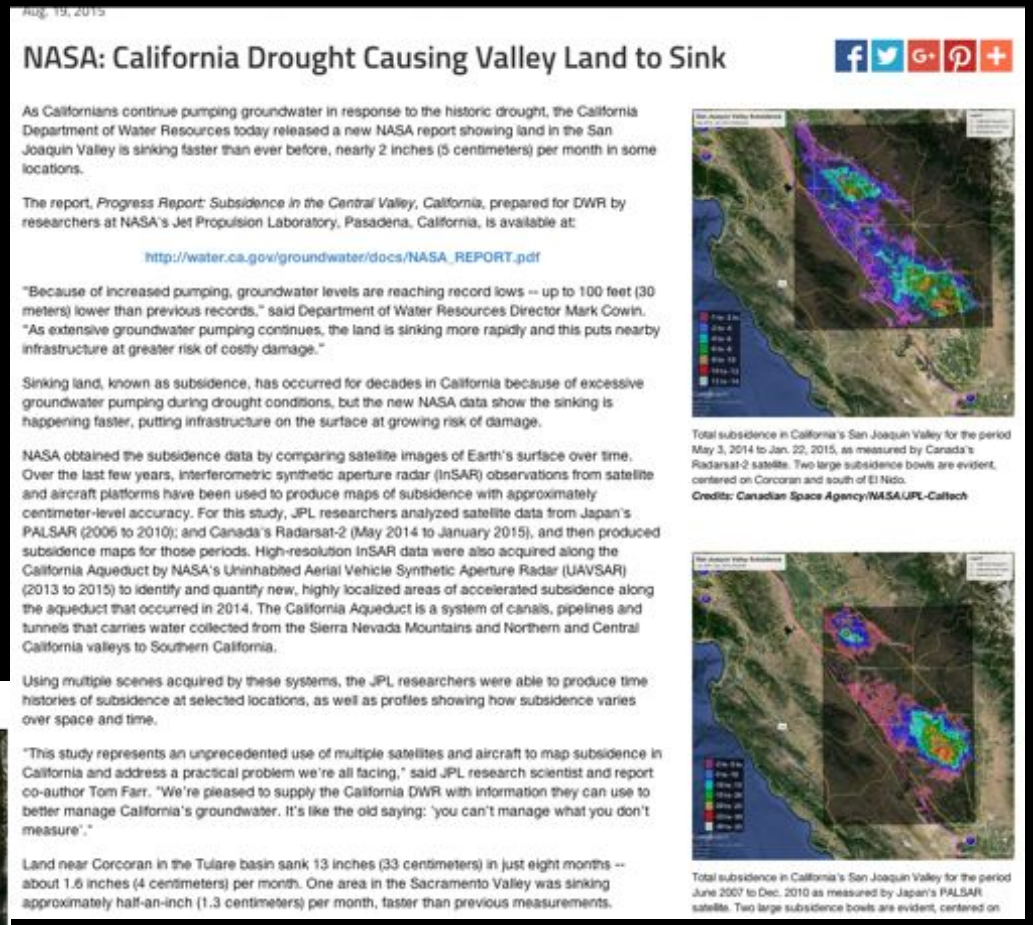
Richard Tinker, NOAA/NWS/NCEP/CPC

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.

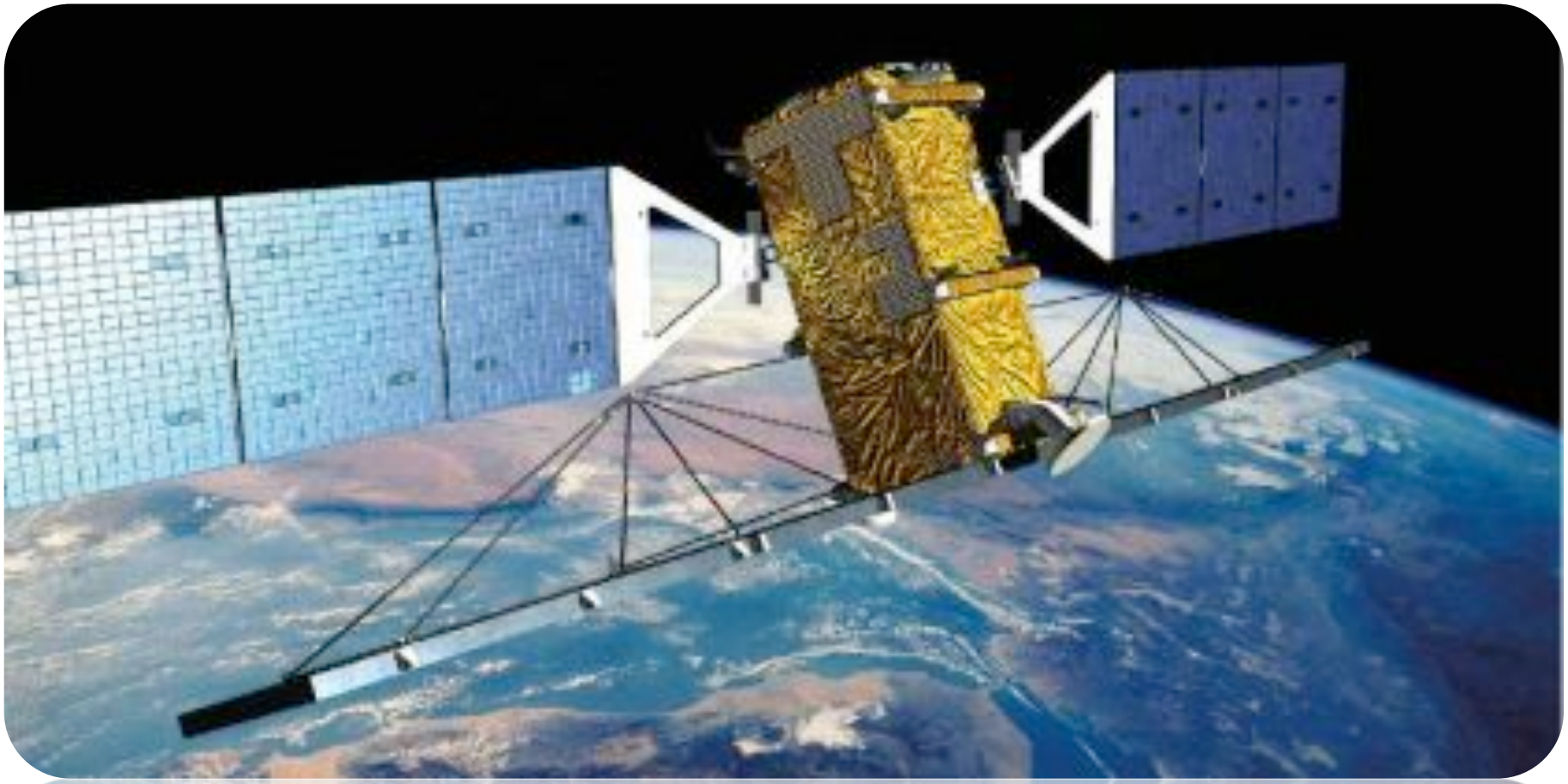
Total subsidence in California's San Joaquin Valley for the period May 3, 2014 to Jan. 22, 2015, as measured by Canada's Radarsat-2 satellite. Two large subsidence bowls are evident, centered on Corcoran and south of El Nido.
Credits: Canadian Space Agency/NASA/JPL-Caltech

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

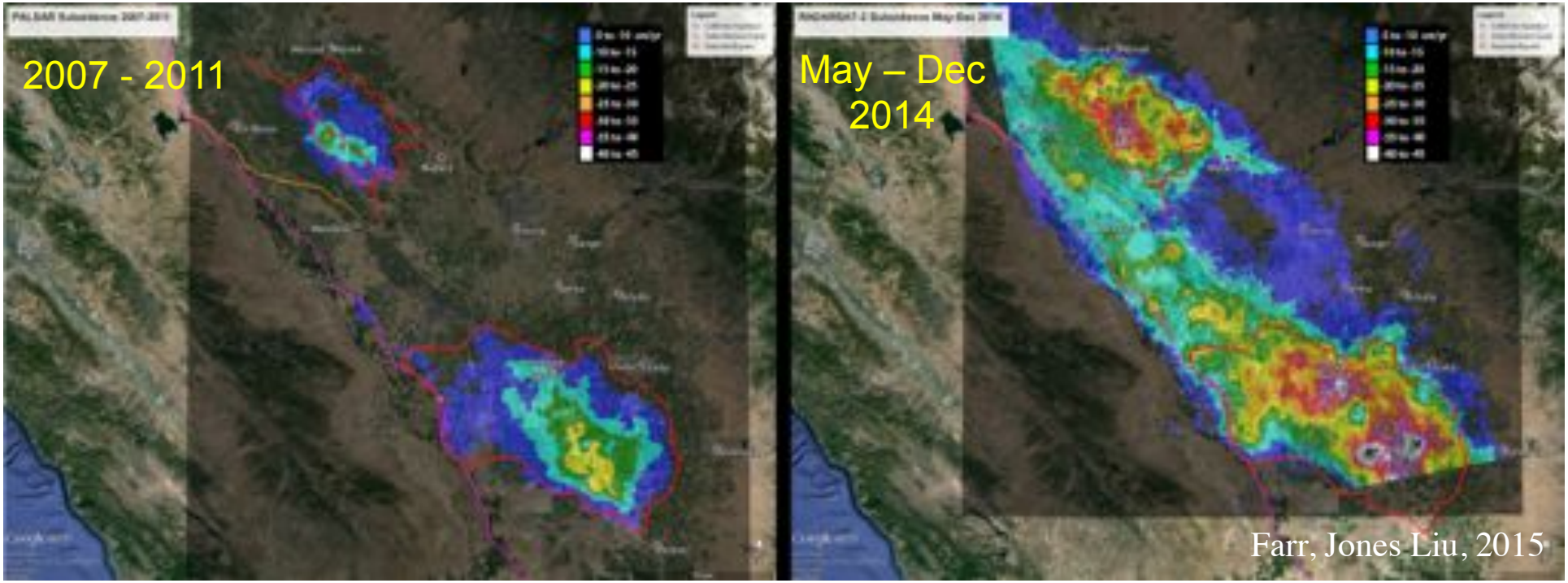
http://www.nasa.gov/jpl/nasa-california-drought-causing-valley-land-to-sink

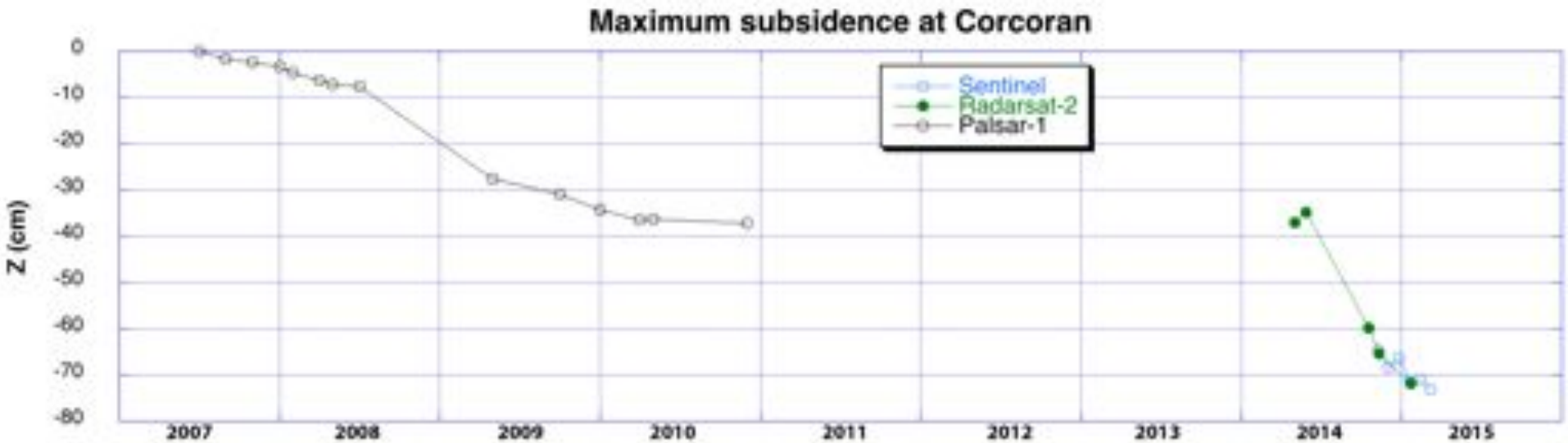
Farr, Jones, Liu, 2015

Central Valley Subsidence: Measured from Space



Central Valley Subsidence Rates

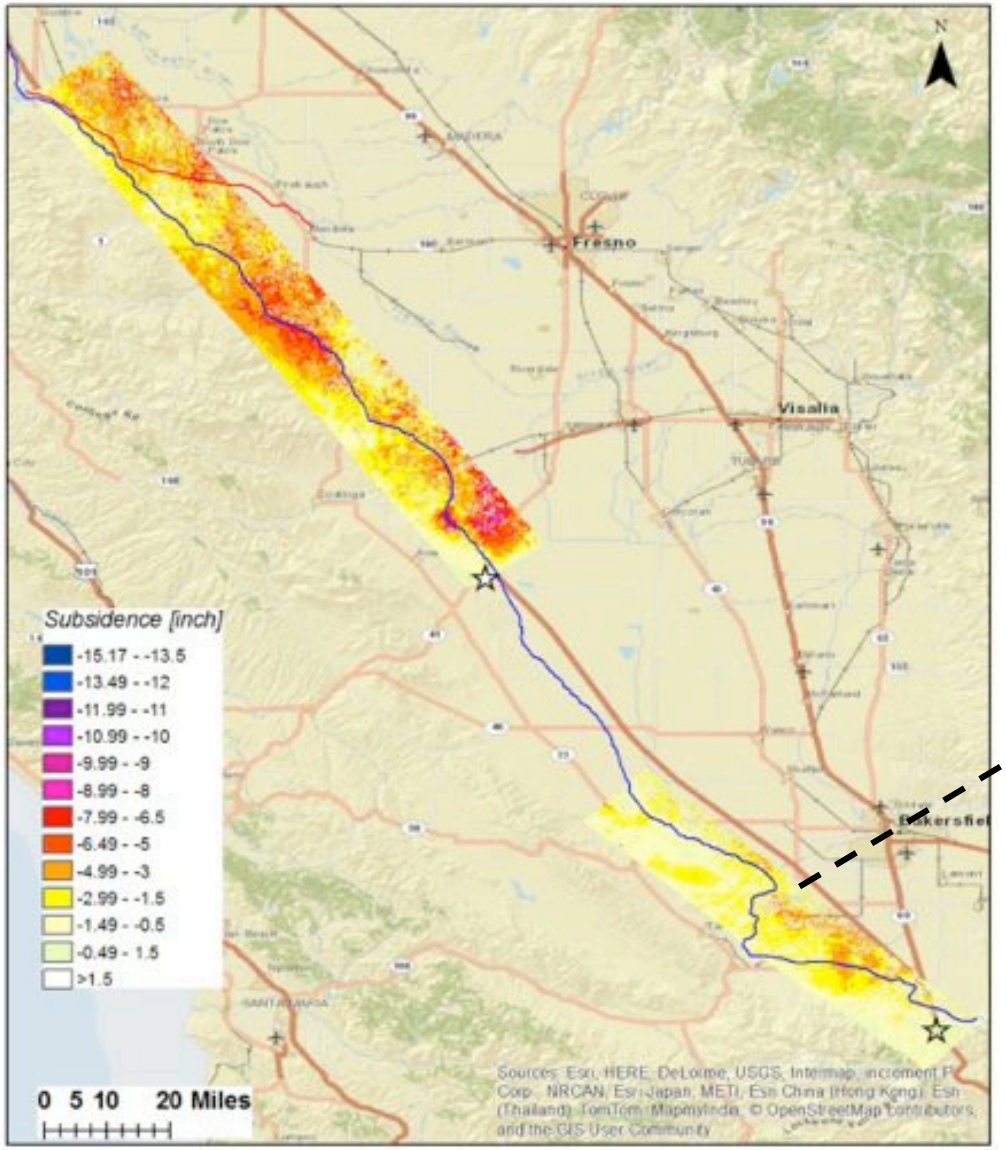




Central Valley Subsidence: Measured from Aircraft

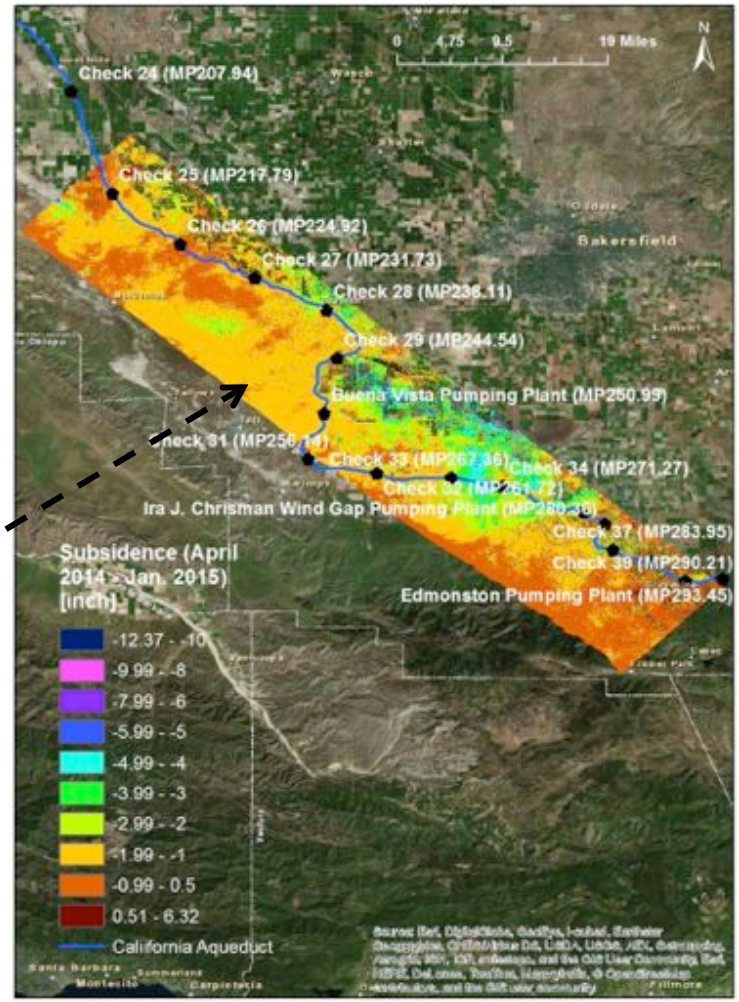
"Californiacentralvalley". Licensed under CC BY-SA 3.0 via Commons - https://commons.wikimedia.org/wiki/File:Californiacentralvalley.jpg#/media/File:Californiacentralvalley.jpg

Subsidence Along the California Aqueduct



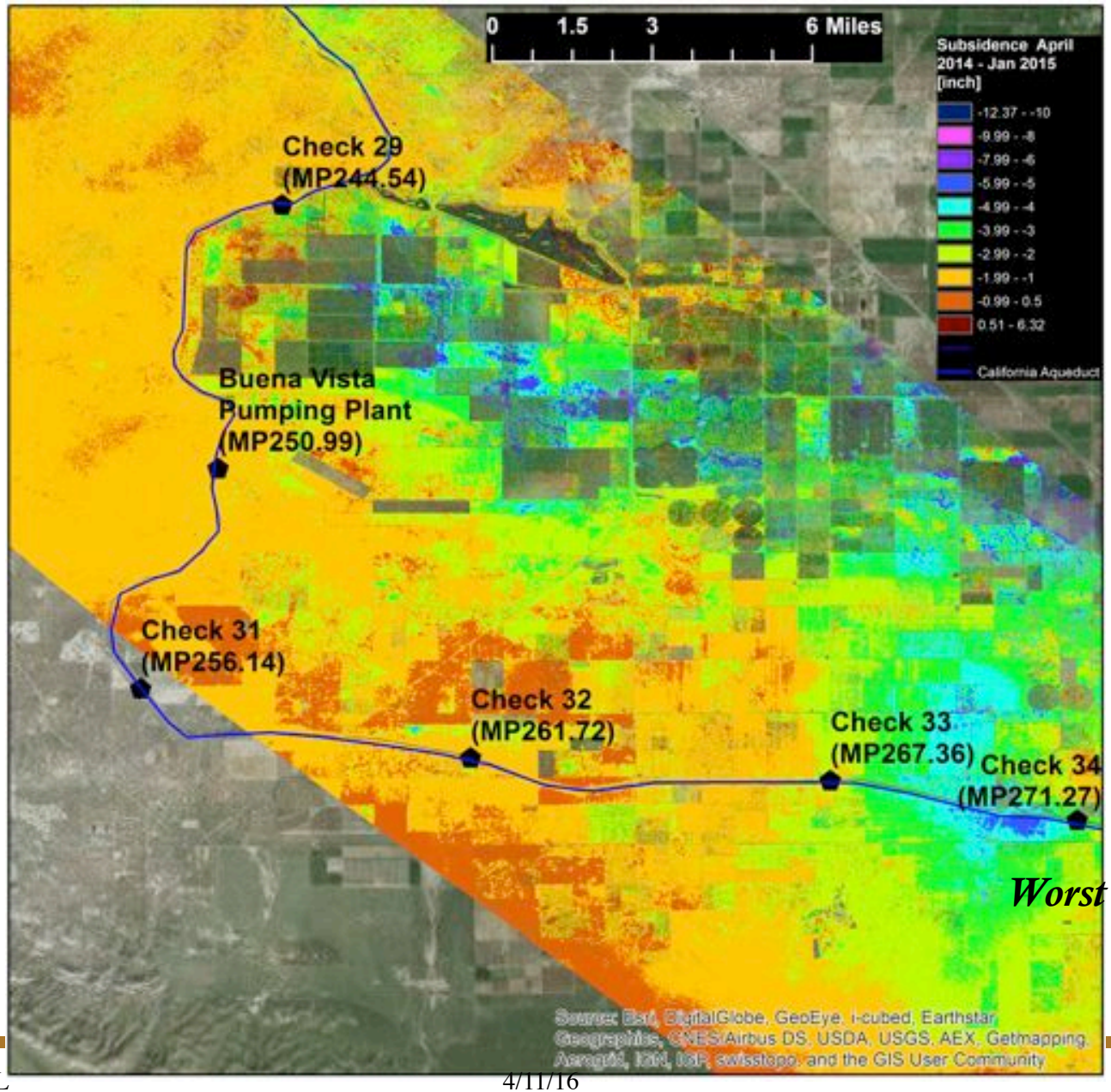
Progress Report: Subsidence in the Central Valley, California (Farr, Jones, Liu, 2015)

Aqueduct west of Bakersfield:



Subsidence Along the California Aqueduct

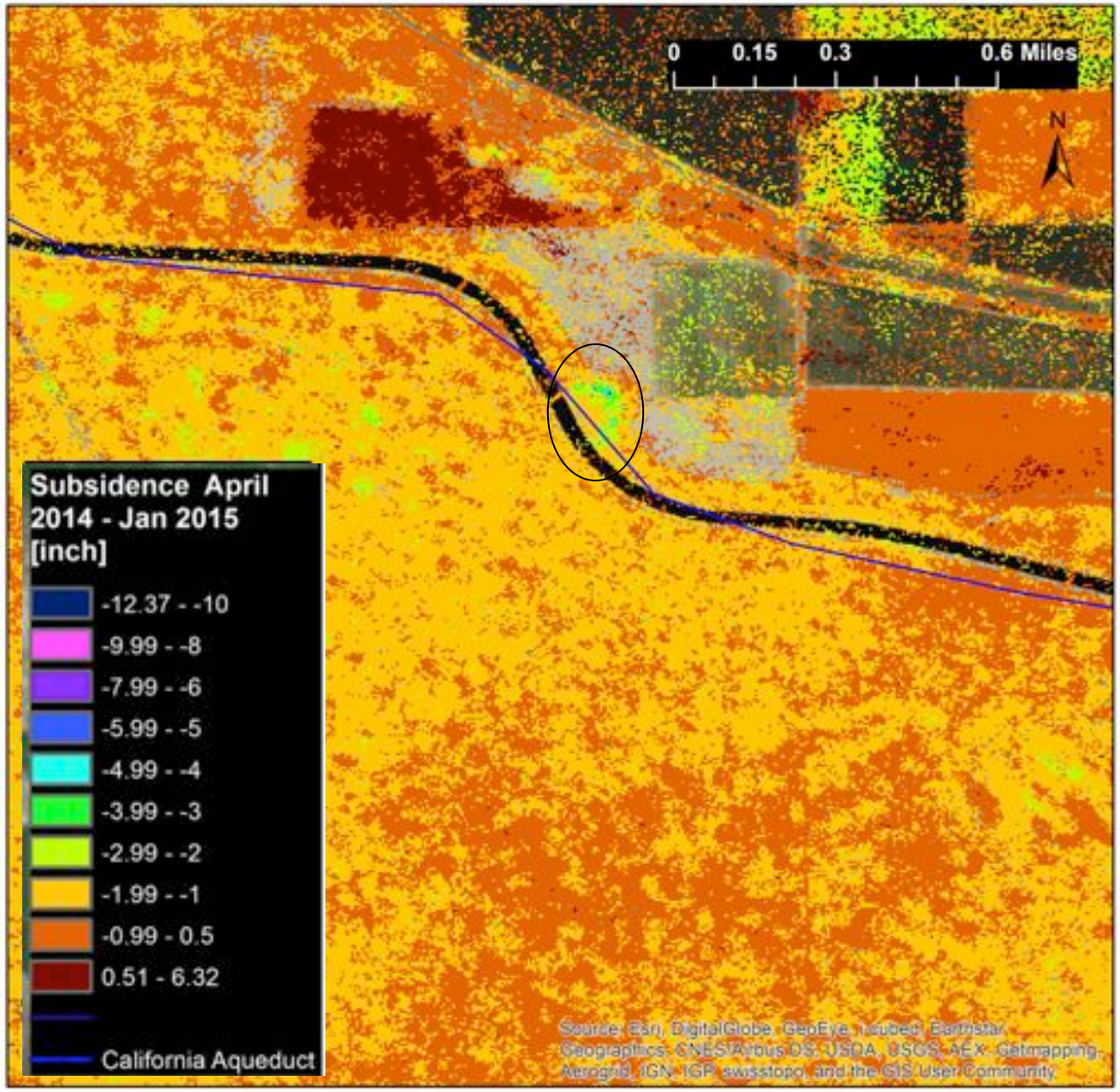
South Tulare Basin



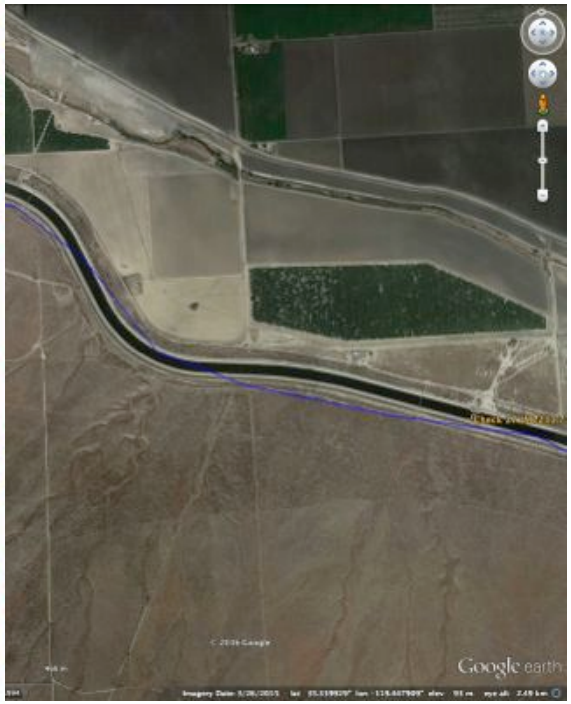
Worst large scale area

Subsidence Along the California Aqueduct

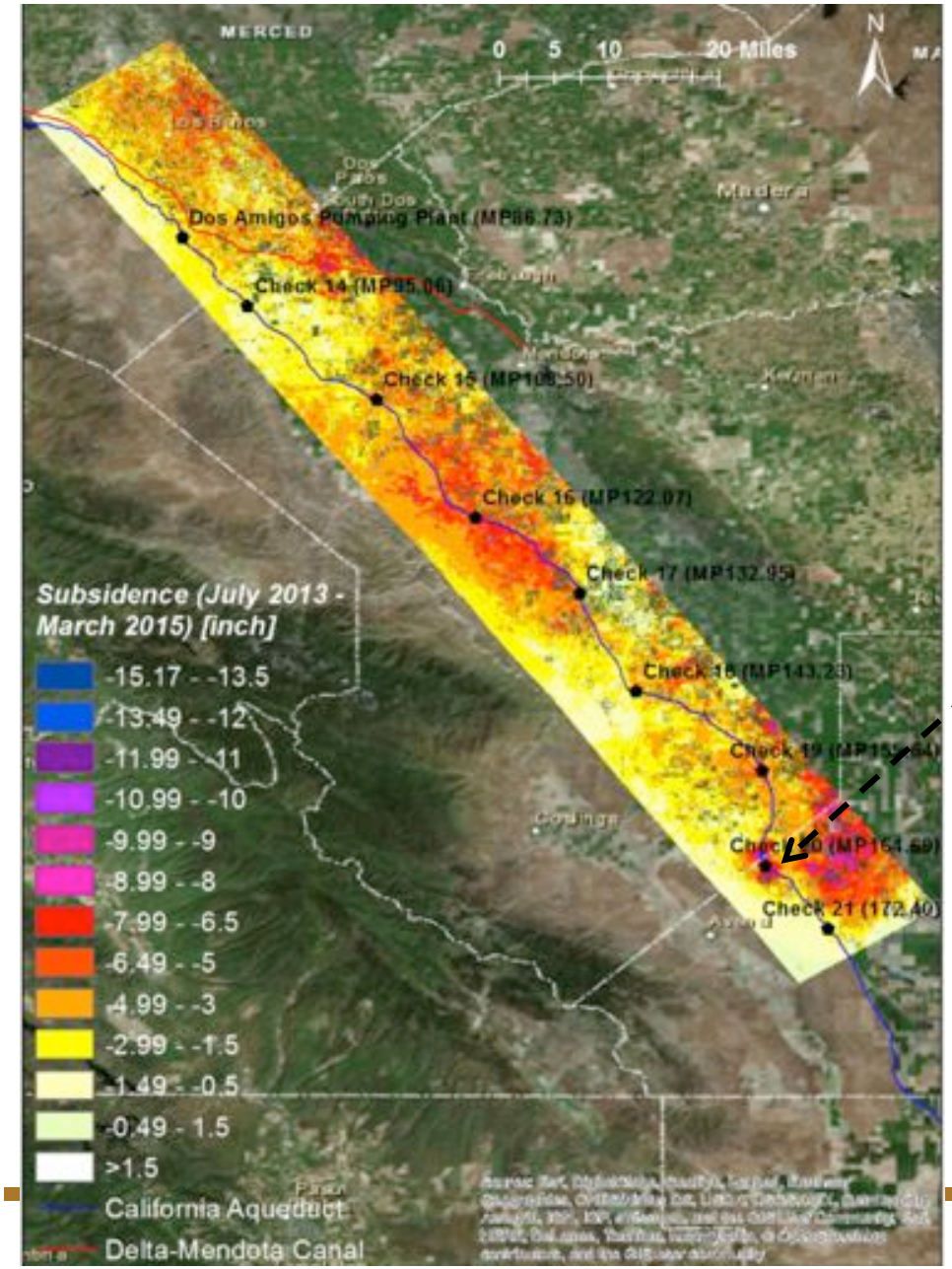
Small Area near Former Seep



Southeast of Buttonwillow



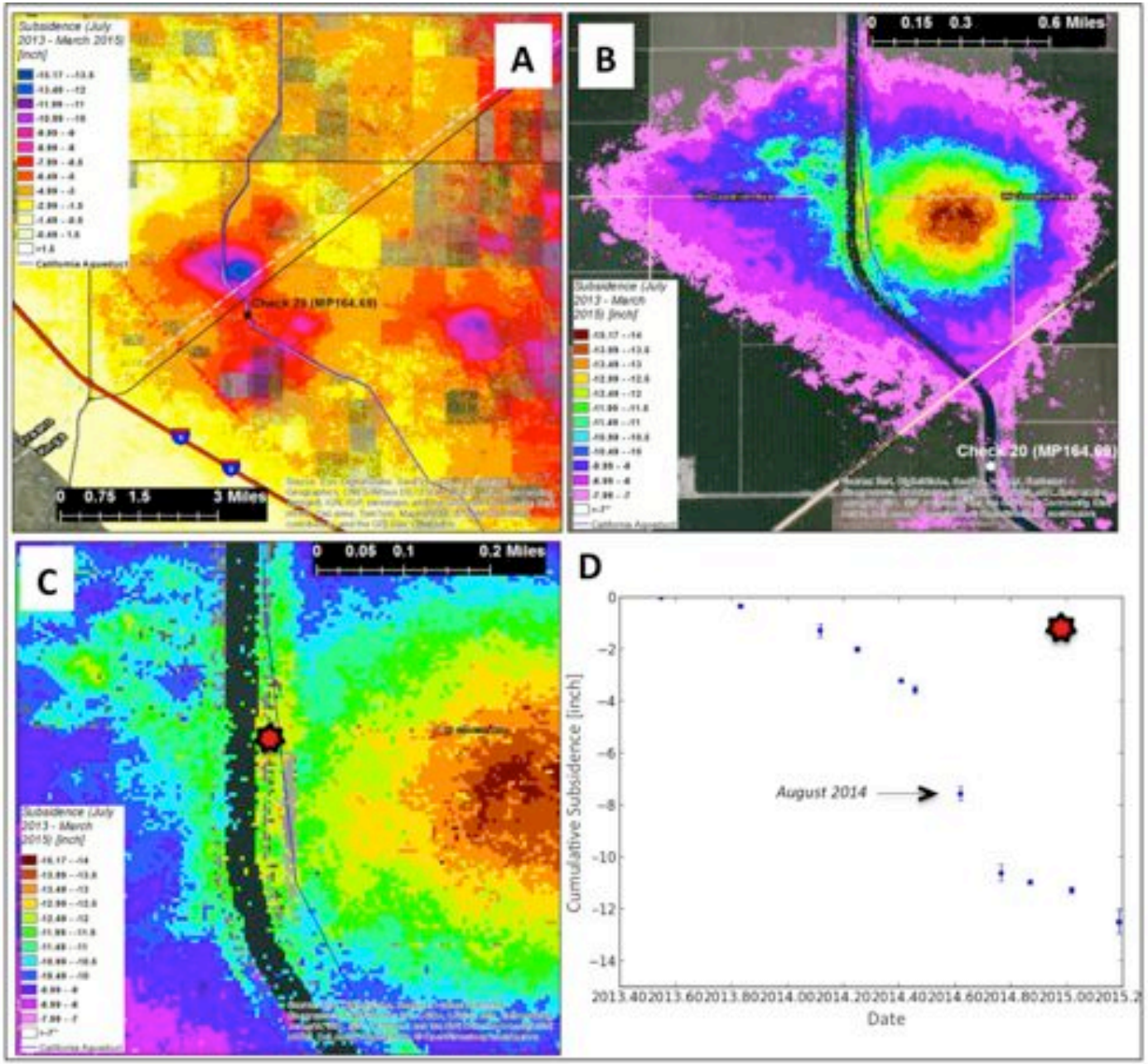
Subsidence Along the California Aqueduct – Central Section



New Subsidence Hot Spot

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

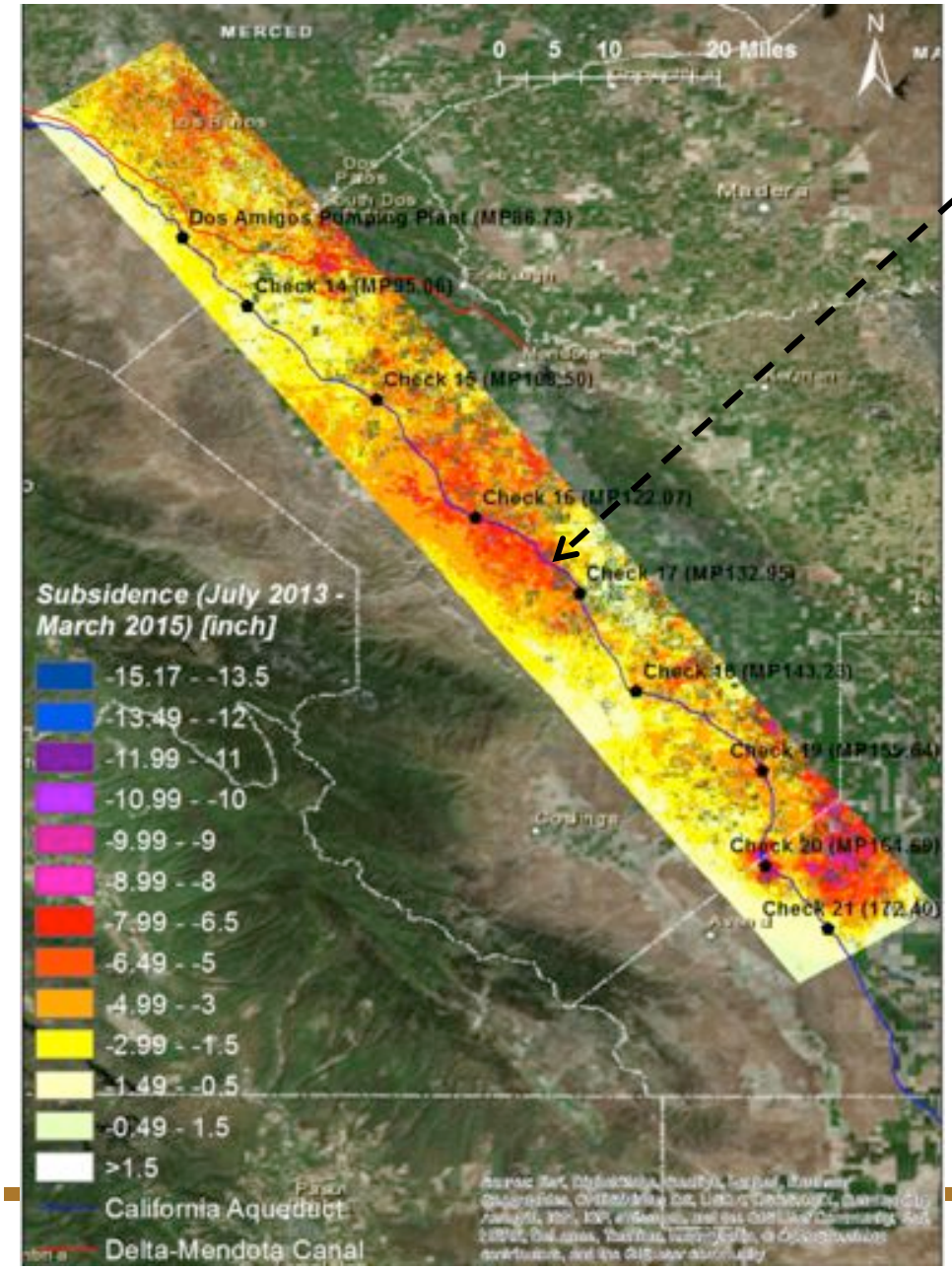
Subsidence Along the California Aqueduct
Worst Case Effect of Drought / Groundwater Pumping



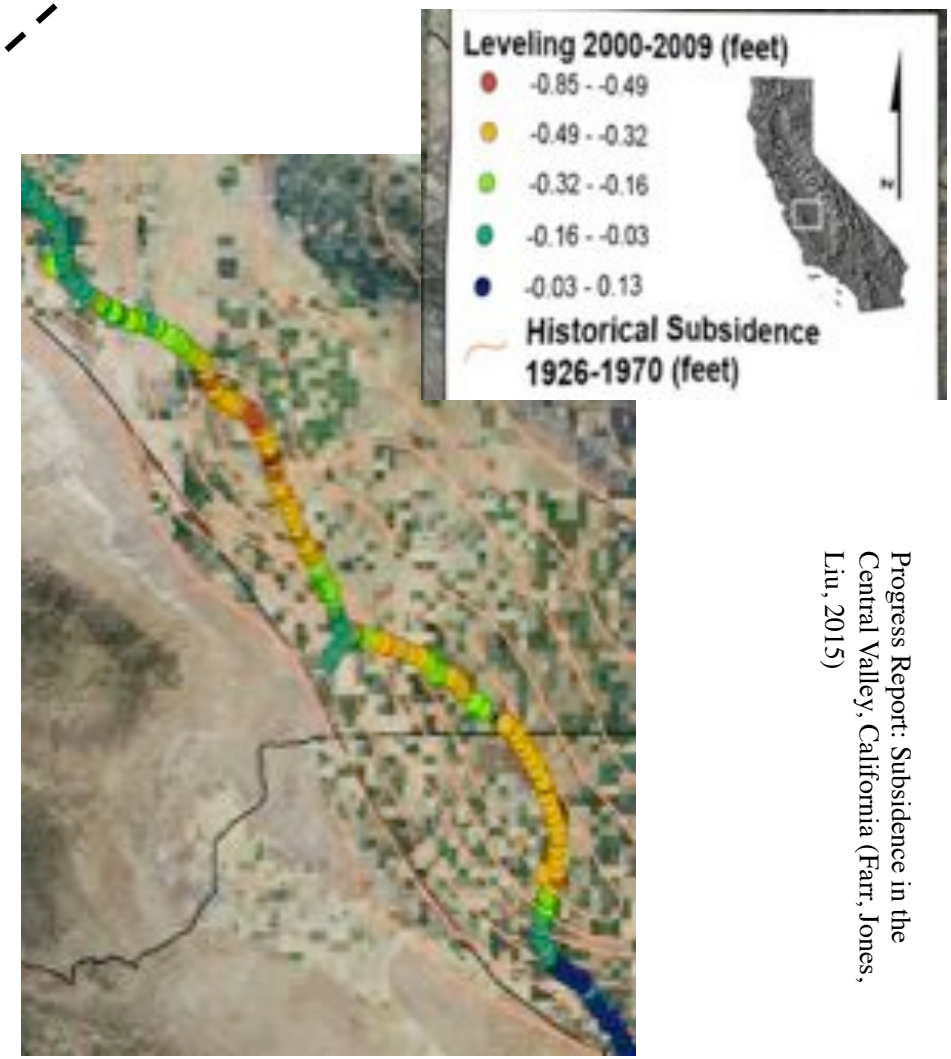
- A single well or cluster of wells can cause rapid subsidence of the aqueduct.
- Aqueduct subsided up to ~13” in < 2 years, and ~8” in 4 months
- 1.3 miles of the acqueduct subsided over 8”

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

Subsidence Along the California Aqueduct – Central Section



Historical Subsidence Area



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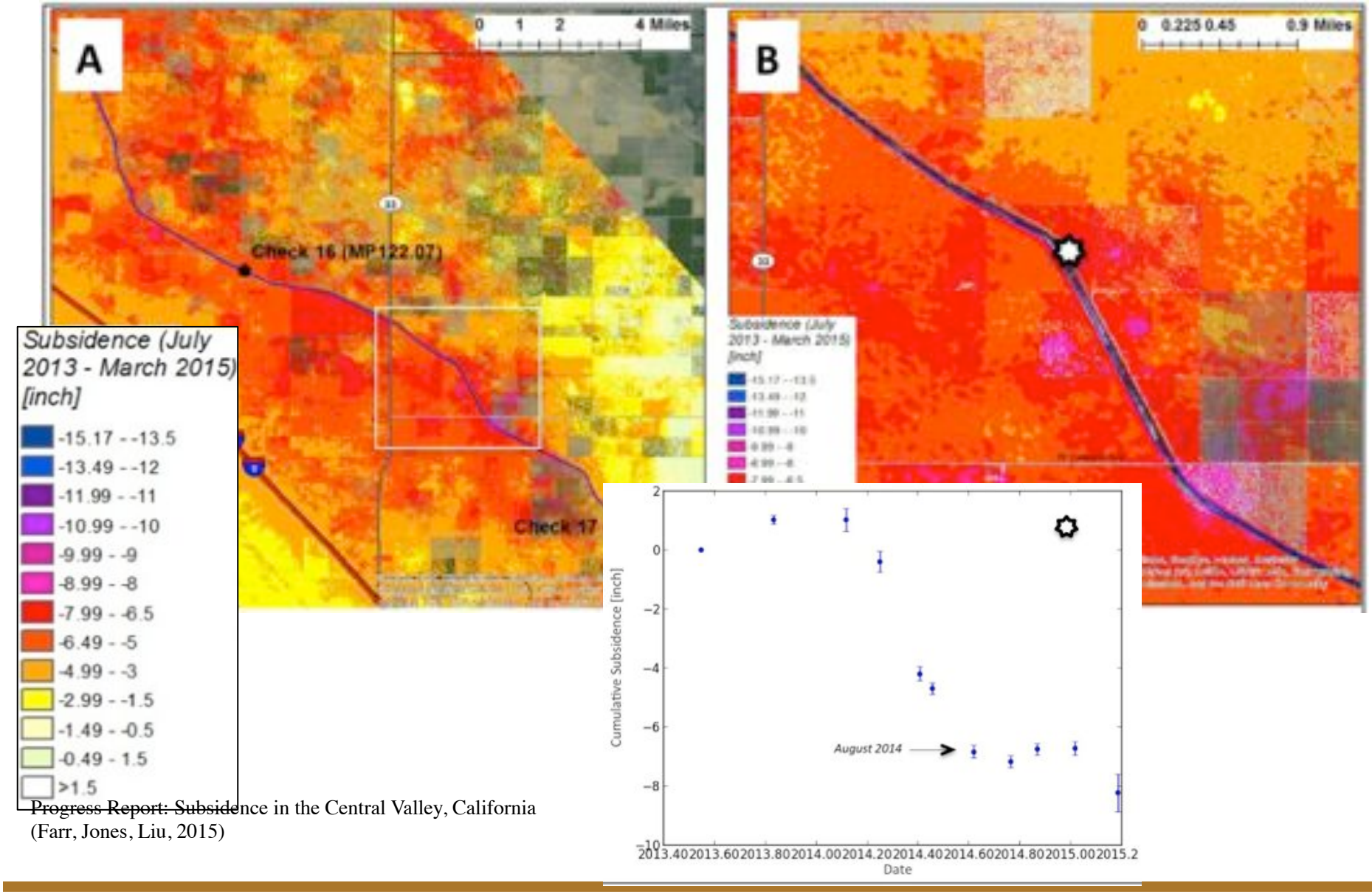

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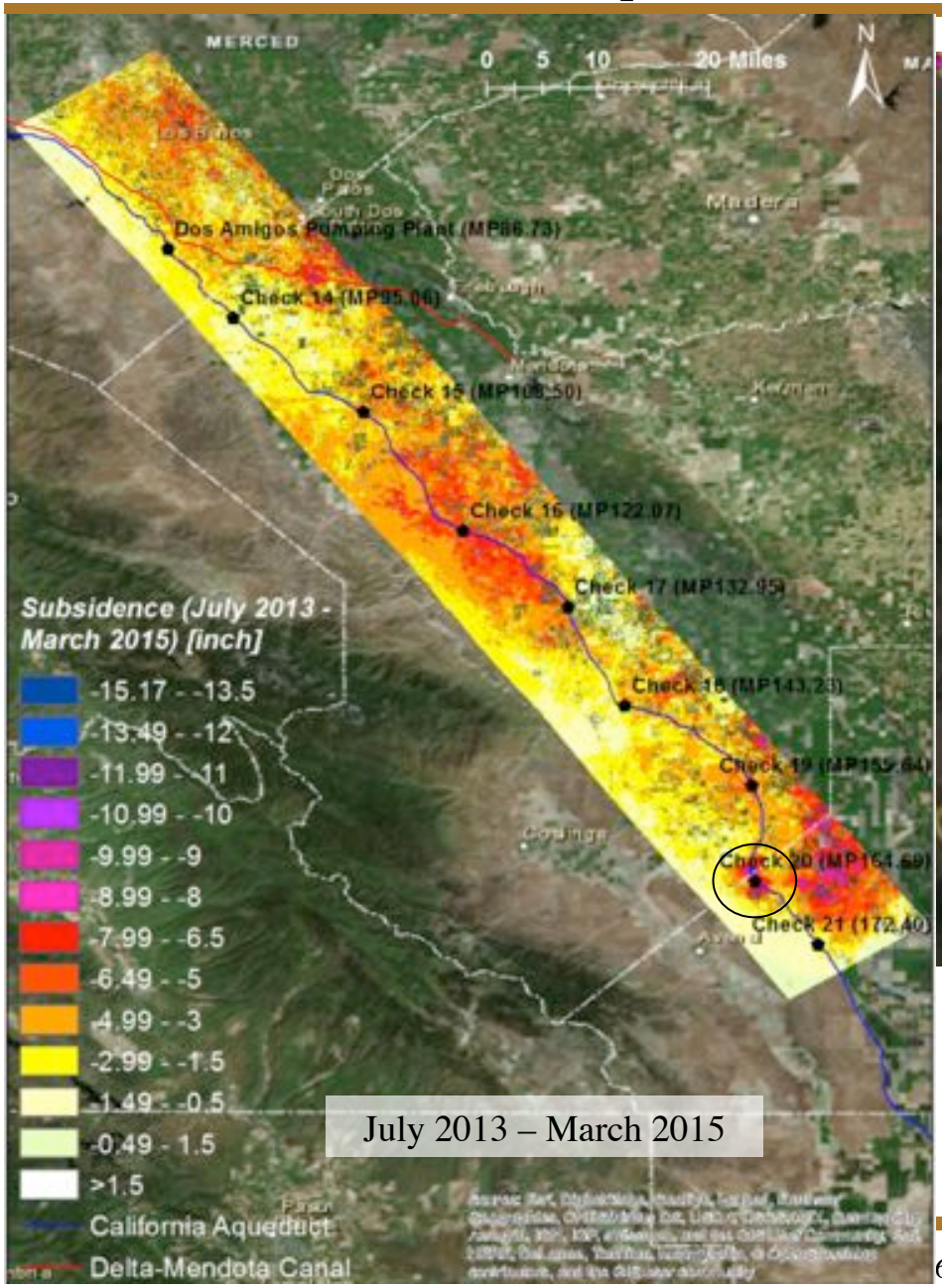
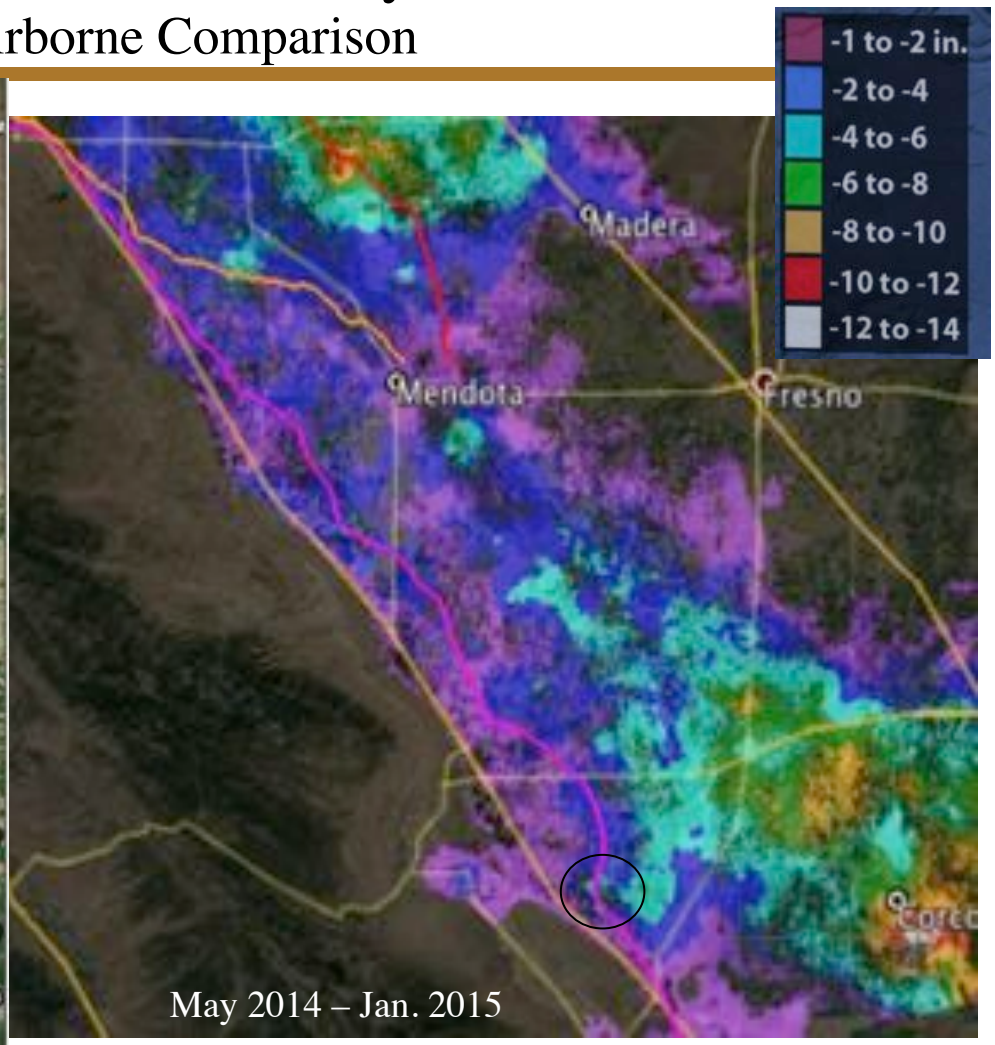
Subsidence in Central Valley

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*

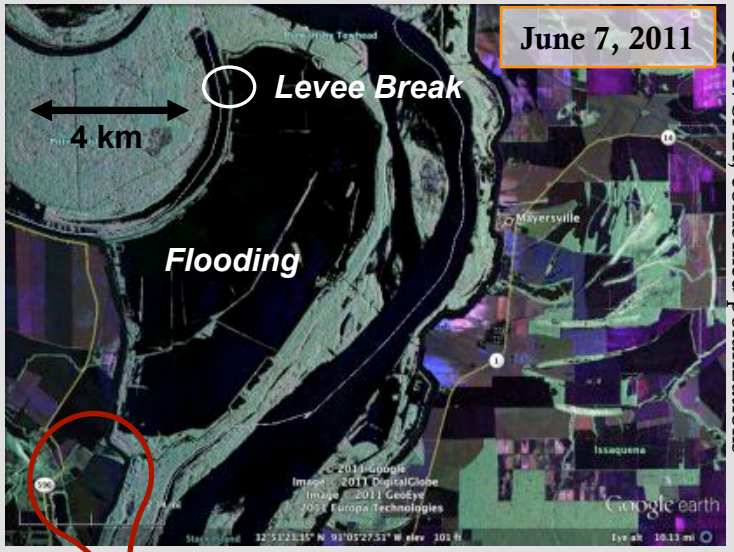
Radar-Based Seepage Detection

Seep Detection: Current Methodology

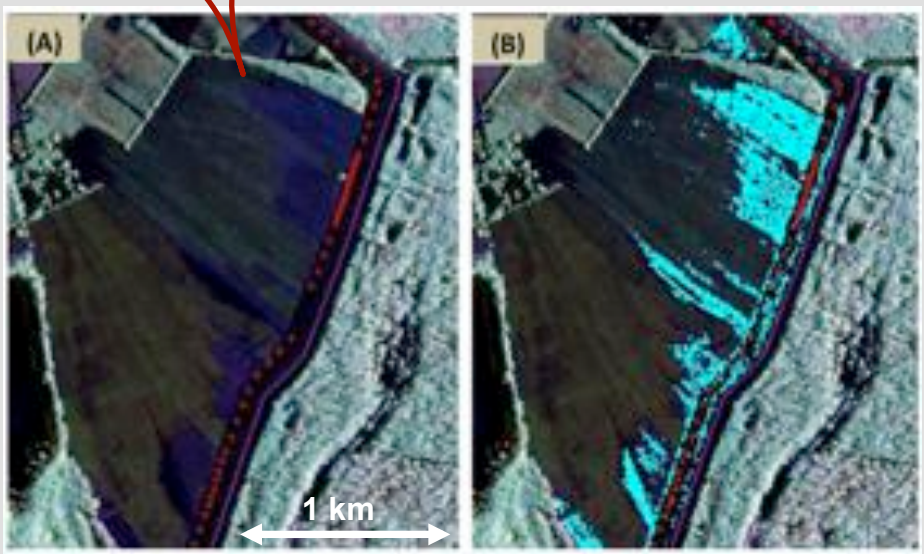
Multi-Polarization Based Detection of Seepage

Example: Mississippi River Flood, Spring 2011

NASA DEVELOP student project : JPL, Fall 2011 – Spring 2012



UAVSAR, combined polarizations

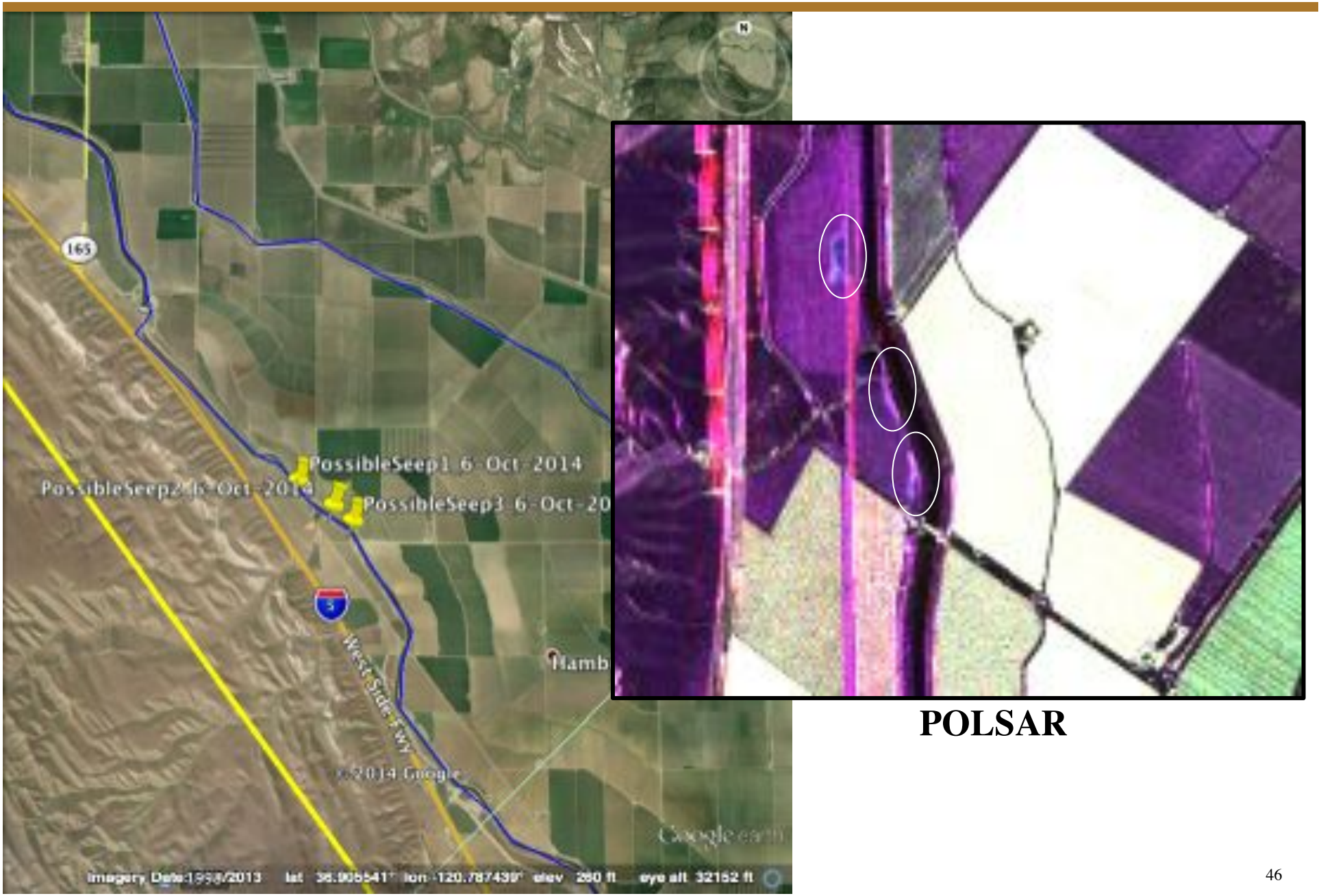


****** SINGLE IMAGE*** (POLSAR)***

The radar data indicates not only large area flooding but also where there is seepage through relief wells along the levee in this area.

We used the polarization-dependence of the radar return to enhance detection of leaking sections of levees and to automatically classify high-likelihood seepage areas.

Next: Seep Detection along the Aqueduct (Airborne SAR)



POLSAR

Radar-Based Seepage Detection – False Positives

SUMMARY
Remote Sensing from Space and High Altitude

- Groundwater is becoming a more important part of California's water resources
- Groundwater withdrawal can profoundly impact local areas
- Knowledge of the groundwater level is not uniformly available
- Interferometric Synthetic Aperture Radar (InSAR) gives:
  - Ground water state and dynamics
  - Impact to infrastructure