Land Subsidence, Groundwater Levels, and Geology in the Coachella Valley, California

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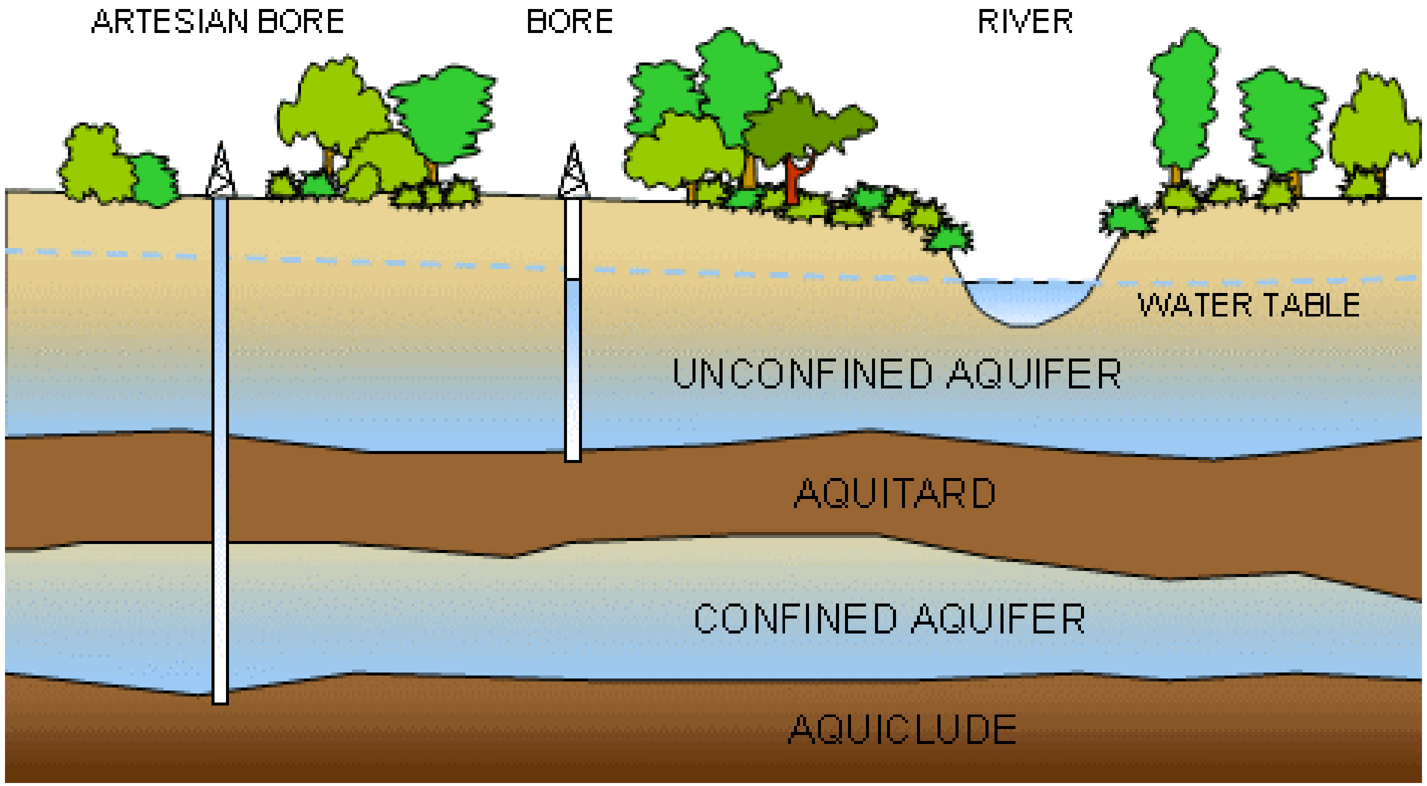
Outline

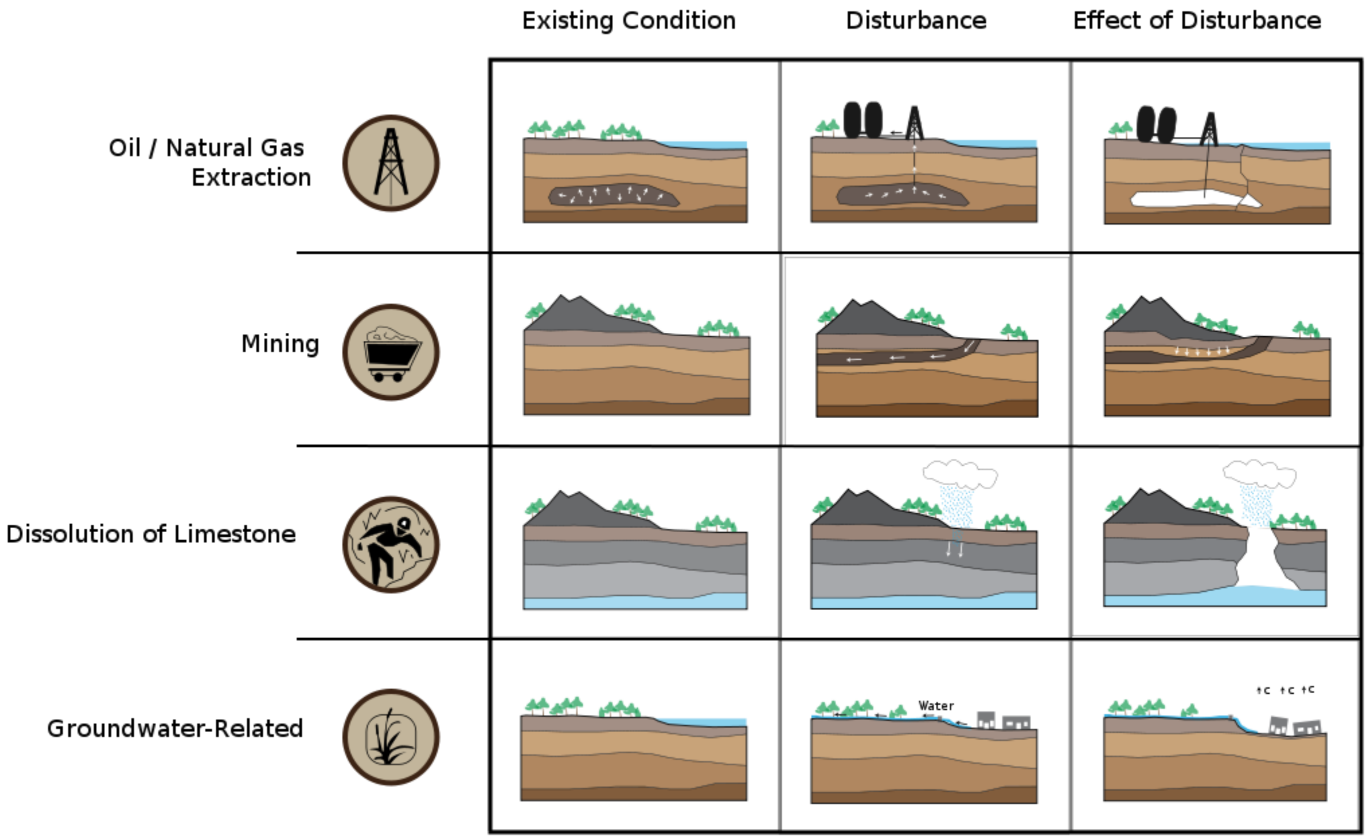
- Introduction: Basic Hydrology of Groundwater Systems
- Geology and Hydrology of Coachella Valley
  - Past Groundwater Studies in Coachella Valley USGS
- How InSAR and GPS are used to Monitor Land Subsidence
- 3 major Land Subsidence area in the Coachella Valley
- Results of first Interferogram
  - Problems

Introduction

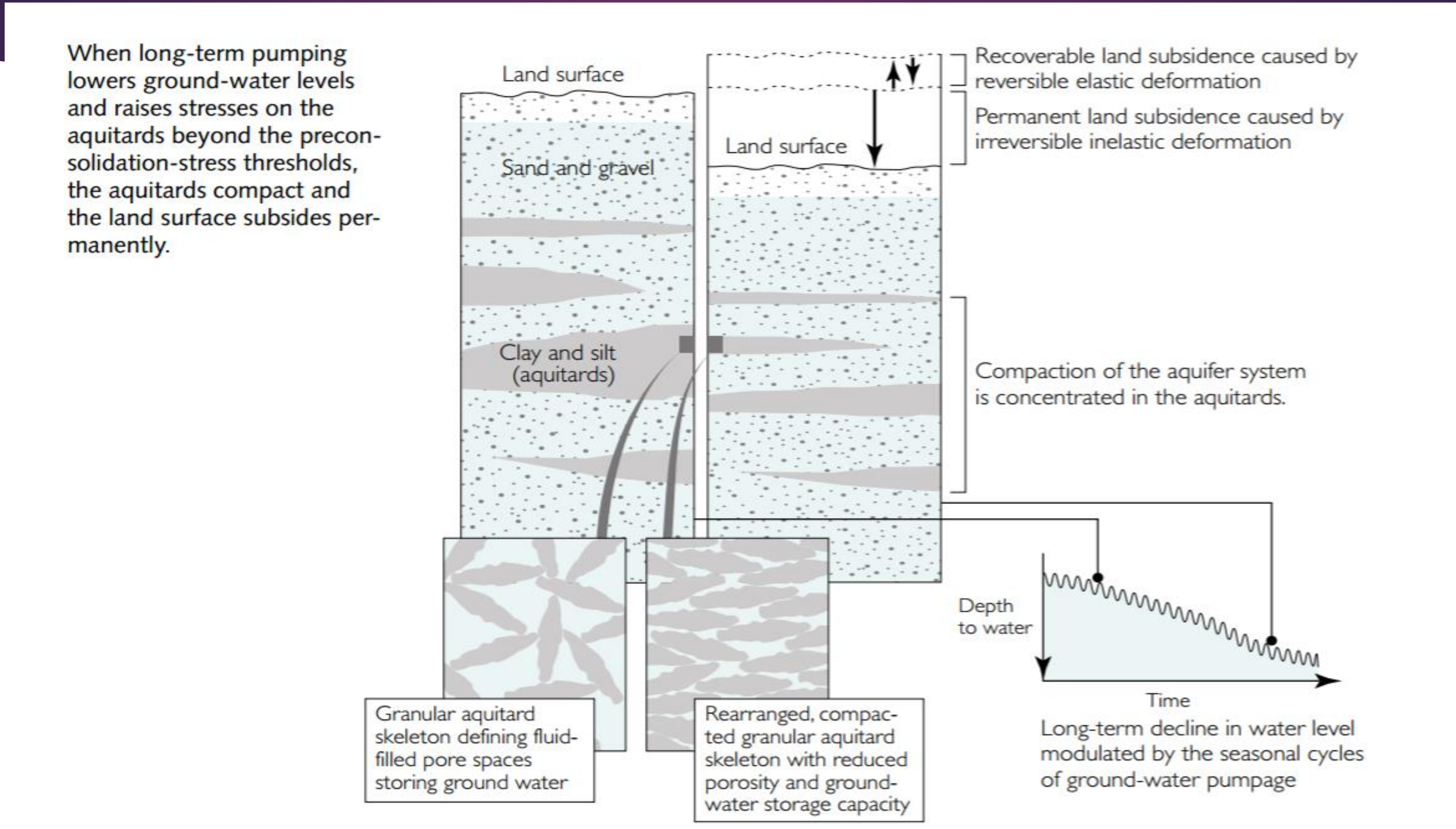
- Aquifers: Are underground layers of permeable rocks or unconsolidated materials such as gravel, sand or silt that are saturated with water
  - Contributes water to a well or springs
- Aquitards: a bed of low permeability sediments such as clays that restricts hydraulic conductivity
- Land subsidence: the gradual settling or sudden sinking of Earth's surface due to subsurface movement of materials


ARTESIAN BORE
BORE
RIVER
WATER TABLE
UNCONFINED AQUIFER
AQUITARD
CONFINED AQUIFER
AQUICLUDE

Land Subsidence



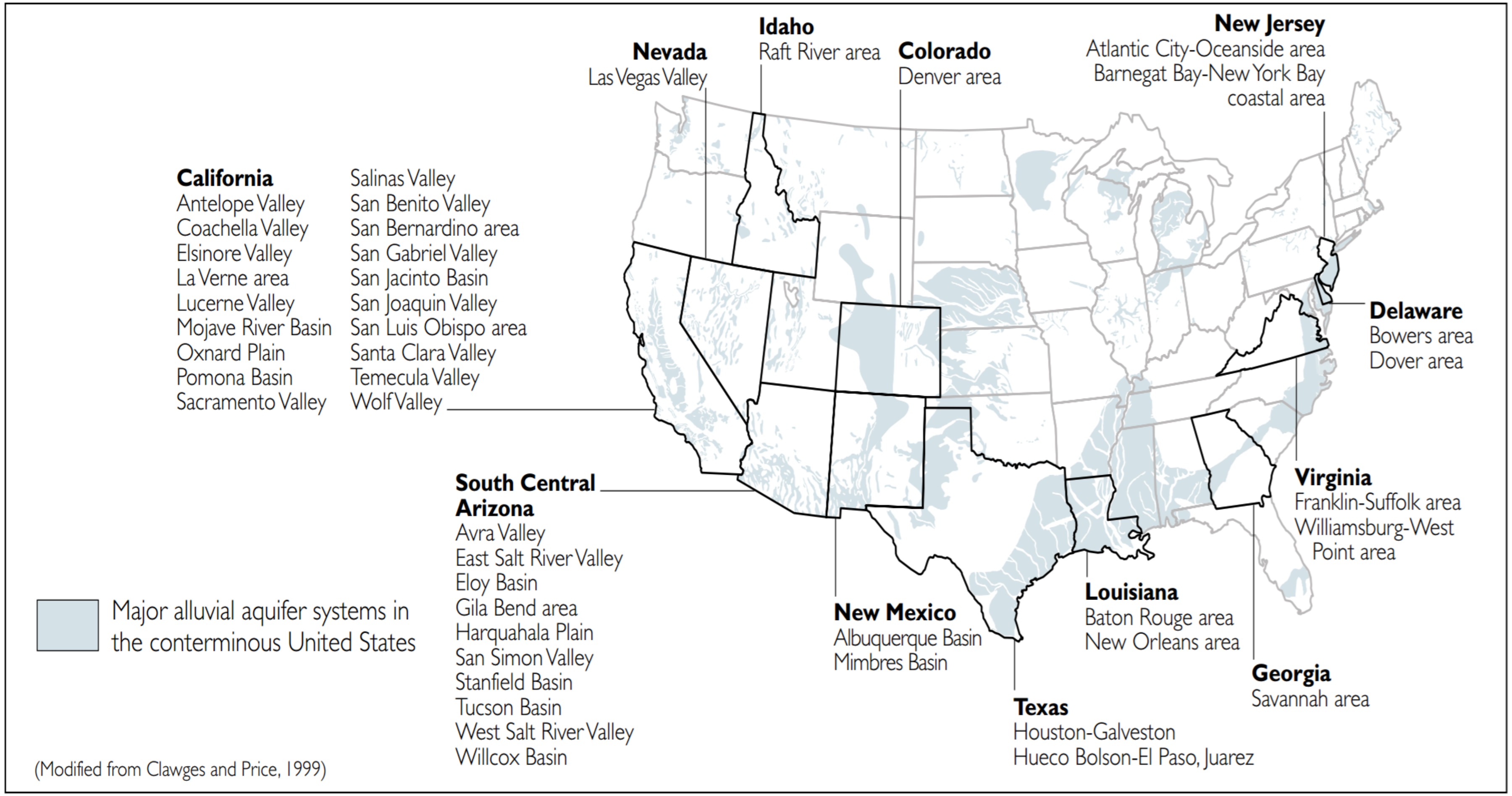
USGS


When long-term pumping lowers ground-water levels and raises stresses on the aquitards beyond the precon-solidation-stress thresholds, the aquitards compact and the land surface subsides per-manently.
Land surface
Sand and gravel
Clay and silt (aquitards)
Land surface
Recoverable land subsidence caused by reversible elastic deformation
Permanent land subsidence caused by irreversible inelastic deformation
Compaction of the aquifer system is concentrated in the aquitards.
Depth to water
Time
Long-term decline in water level modulated by the seasonal cycles of ground-water pumpage
Granular aquitard skeleton defining fluid-filled pore spaces storing ground water
Rearranged, compac-ted granular aquitard skeleton with reduced porosity and ground-water storage capacity

USGS

Problem and Prevention

- Problem: Exploitation of underground water without the consideration of recharging the system causing land subsidence
- This subsidence can cause permanent damage to the water resource due to the deformation to the aquifer system
- Changes the hydrology of fluids underground
- Prevention: Regulation of groundwater pumping limits the amount of water that can be used from the aquifer system
  - Recharging the aquifer system will allow the system to rebound



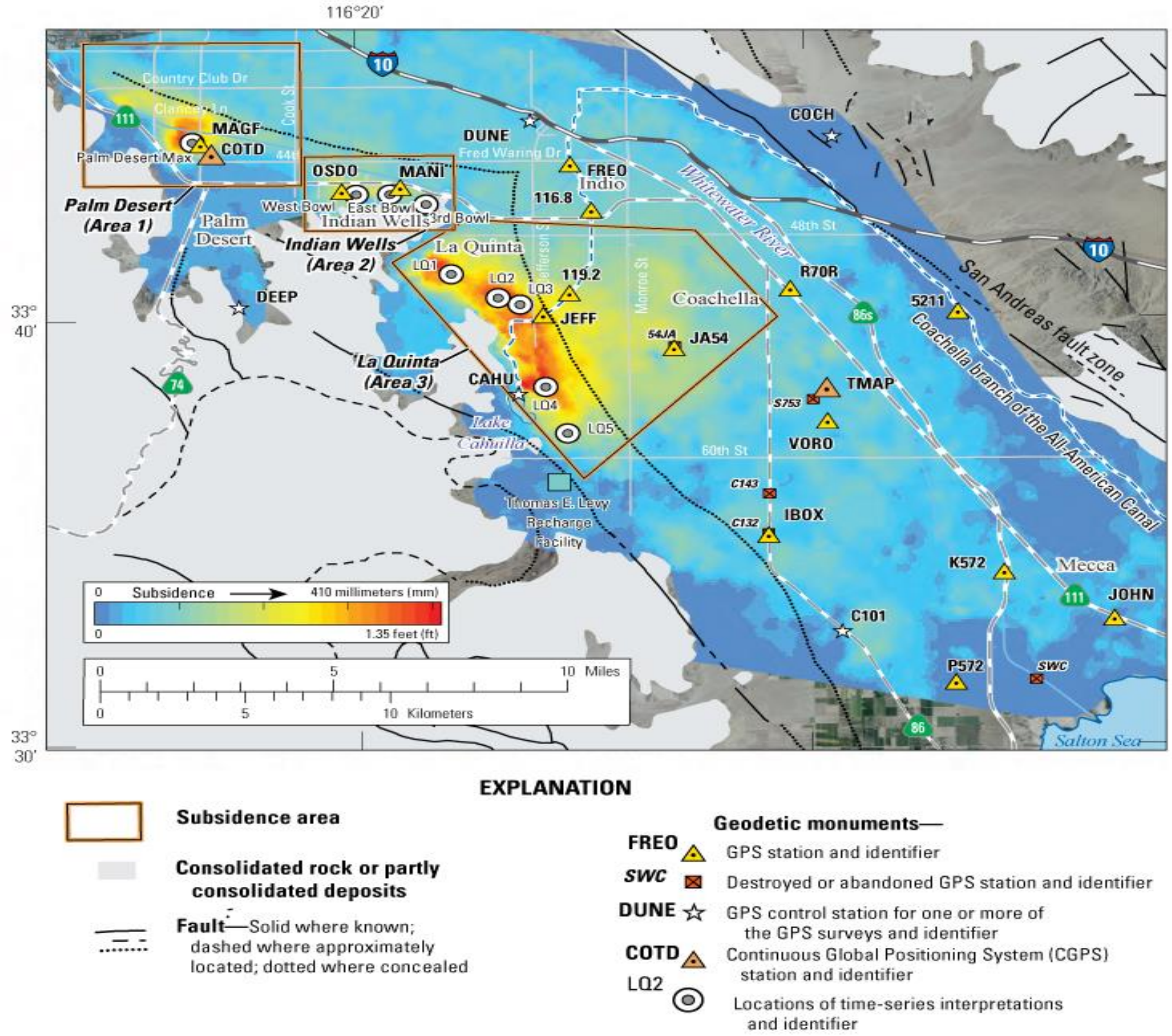
Studies of subsidence in the Santa Clara Valley (Tolman and Poland, 1940; Poland and Green, 1962; Green, 1964; Poland and Ireland, 1988) and San Joaquin Valley (Poland, 1960; Miller, 1961; Riley, 1969; Helm, 1975; Poland and others, 1975; Ireland and others, 1984) in California established the theoretical and field application of the laboratory derived principle of effective stress and theory of hydrodynamic consolidation to the drainage and compaction of aquitards. For reviews of the history and application of the aquitard drainage model see Holzer (1998) and Riley (1998).

USGS

Geology of the Coachella Valley

- Coachella Valley is 65 miles long and covers an area of 400 miles, communities involved are Palm Springs, Palm Desert, Indio, and Cochella
- The region depends on the ground water for their agriculture and their domestic water supplies since the 1920's
- Due to over pumping of ground water the water declined 50 feet between the early 1920's and 1940's
- Water pumping was reduced due to the limited availability which allowed the system to recover in the 1950's
- Since the 1970's over pumping has resumed due to the increasing needs of the communities and the lack of imported water available

Sneed, 2014;USGS



Sneed, 2014;USGS

How GPS is Used to Measure Ground Subsidence

- GPS survey were done to find the three dimensional position of the monuments in the geodetic monitoring network
  - Studies using GPS have been conducted in the Coachella region in 1996, 1998, 2000, 2005, and 2010
  - Began in 1996 with 17 geodetic monuments to determine the horizontal positions
  - Survey in 2010 used 24 geodetic monuments
- At the monuments the groundwater levels were measured looking at the seasonal fluctuation as well as the long term effects of pumping
  - Vertical crust motion did not contribute much to the elevation changes

Sneed, 2014;USGS

Results from GPS stations

- Looking at the groundwater levels near GPS stations water levels show seasonal fluctuations but the general trend shows a steady decline in water levels from 1995 to 2010
- Near the COCH station in the northeastern part of the region noticeable long term effects of water level declines
- The southwestern part near C101 and P572 measured in 2005 show slowing of declining water levels
- Water level recovery can also be seen in the southcentral and the southeastern parts of the geodetic network that started in 2008
- This is due to the increase imported water to the Thomas E. Levy Recharge Facility reducing the amount of pumped water and recharging the aquifer systems by recharge ponds
- Locations in recovery are K572, JOHN, K70, and G70

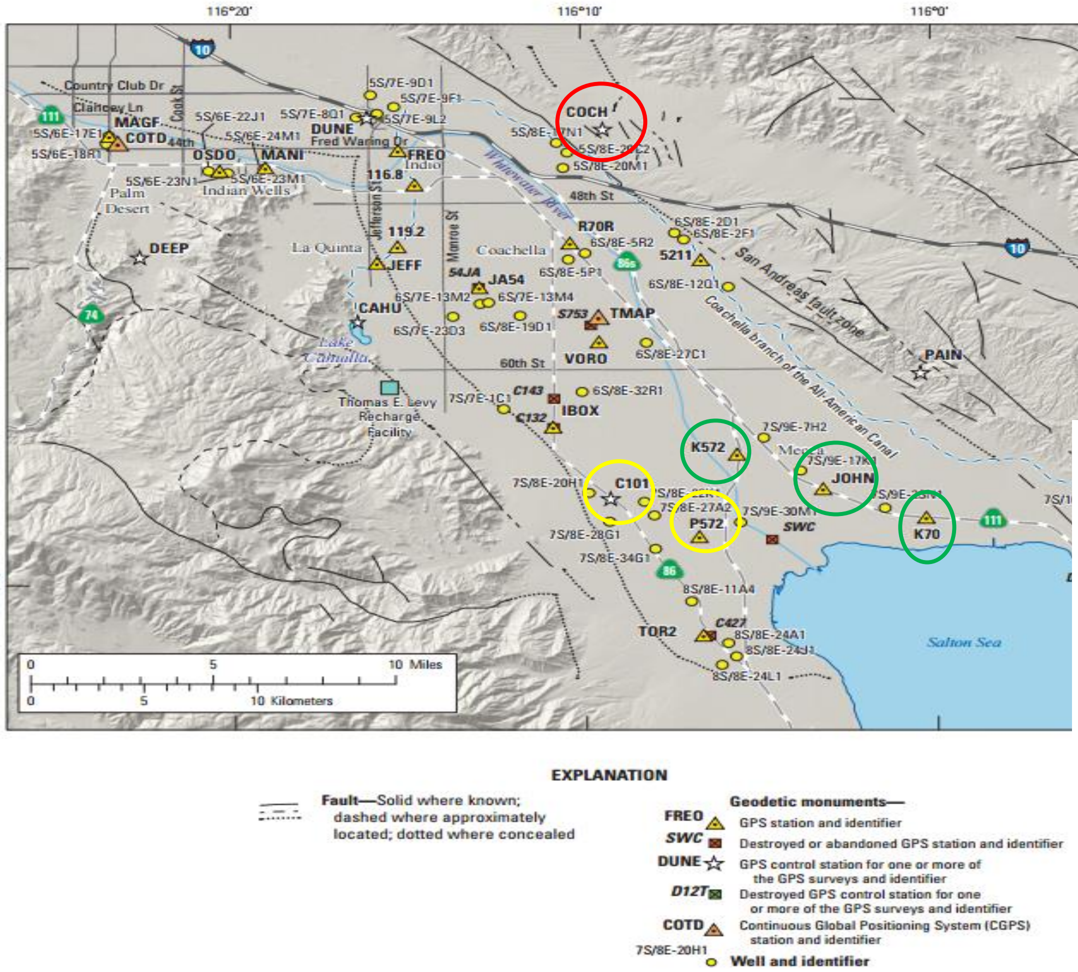


Figure 3. Network of Global Positioning System (GPS) stations and wells used to monitor vertical changes in land surface and groundwater levels, respectively, in the southern Coachella Valley, California.

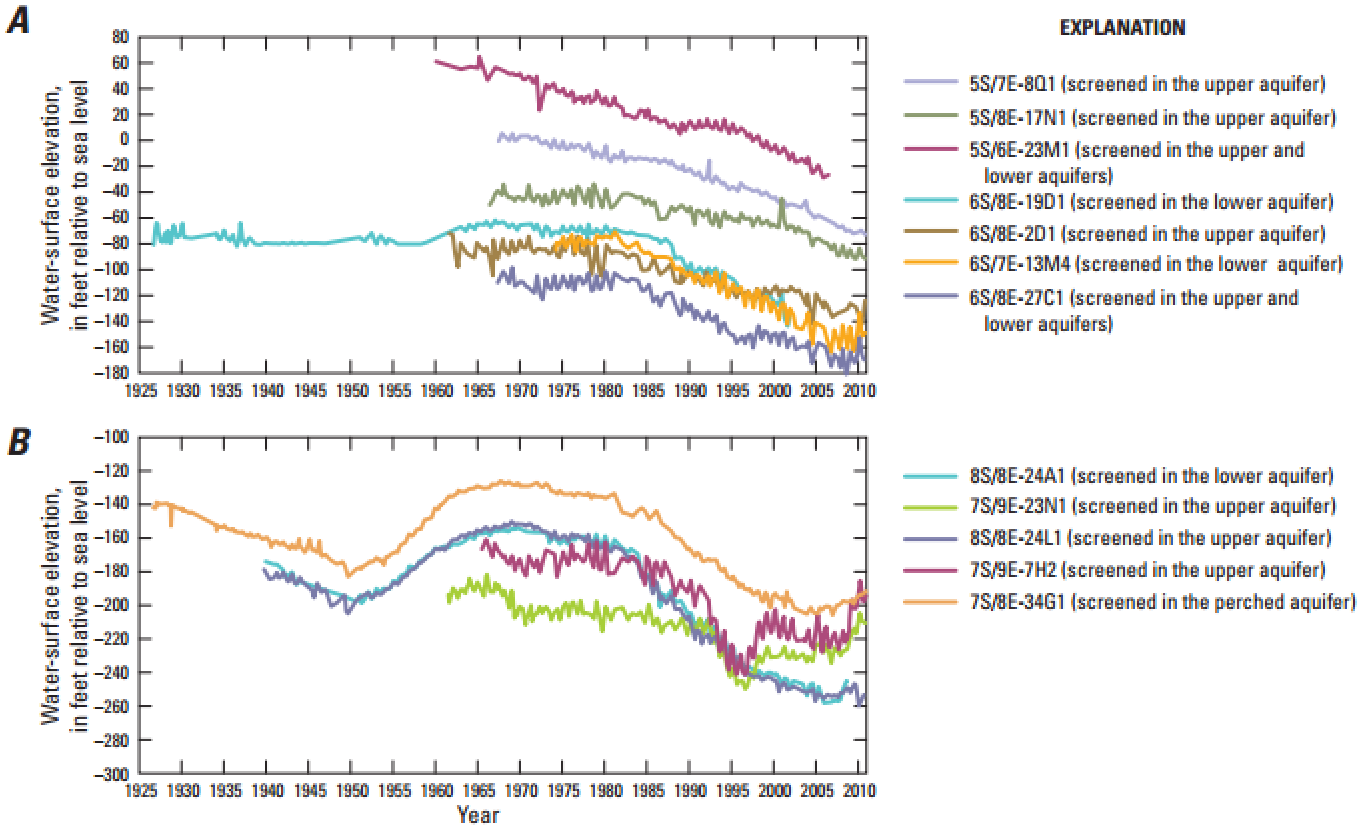


Figure 5. Water-surface elevations, 1925–2010, for wells in *A*, the northern and central parts of the subsidence monitoring network; and *B*, the southern part of the subsidence monitoring network. See *figure 3* for the locations of wells.

Ground Subsidence Measurement through InSAR

- Uses two SAR scenes that are measured at different times on the same area to find the differences between the two
- Able to produce a interferogram that shows relative ground-elevation change
- Quality of the interferogram can be affected due to vegetation, Coachella being an agricultural area use general farming methods such as plowing and tilling of fields create large changes
- Other than the agricultural areas within the Coachella Valley InSAR is able to provide good results due to the relatively flat and arid areas

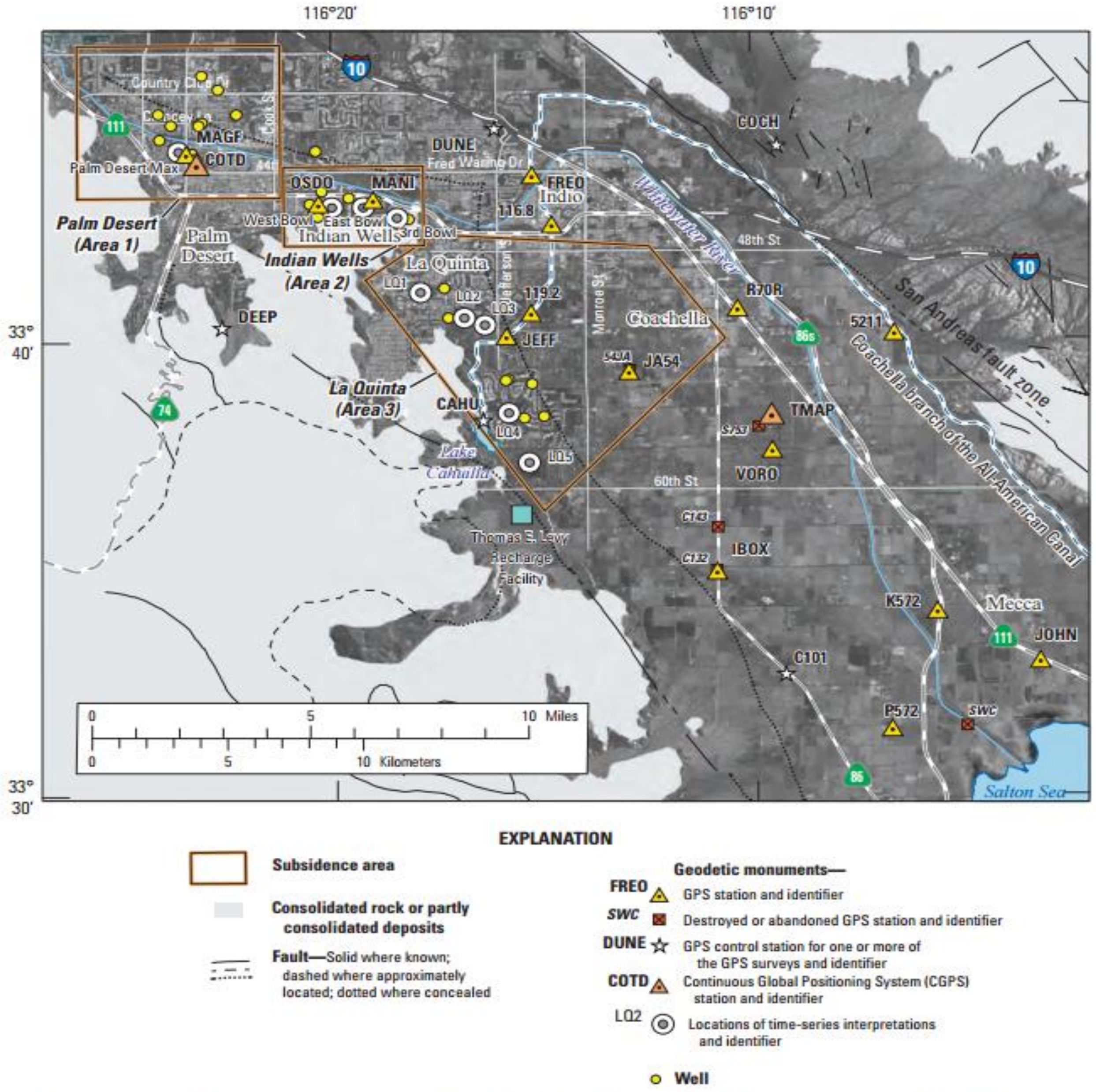
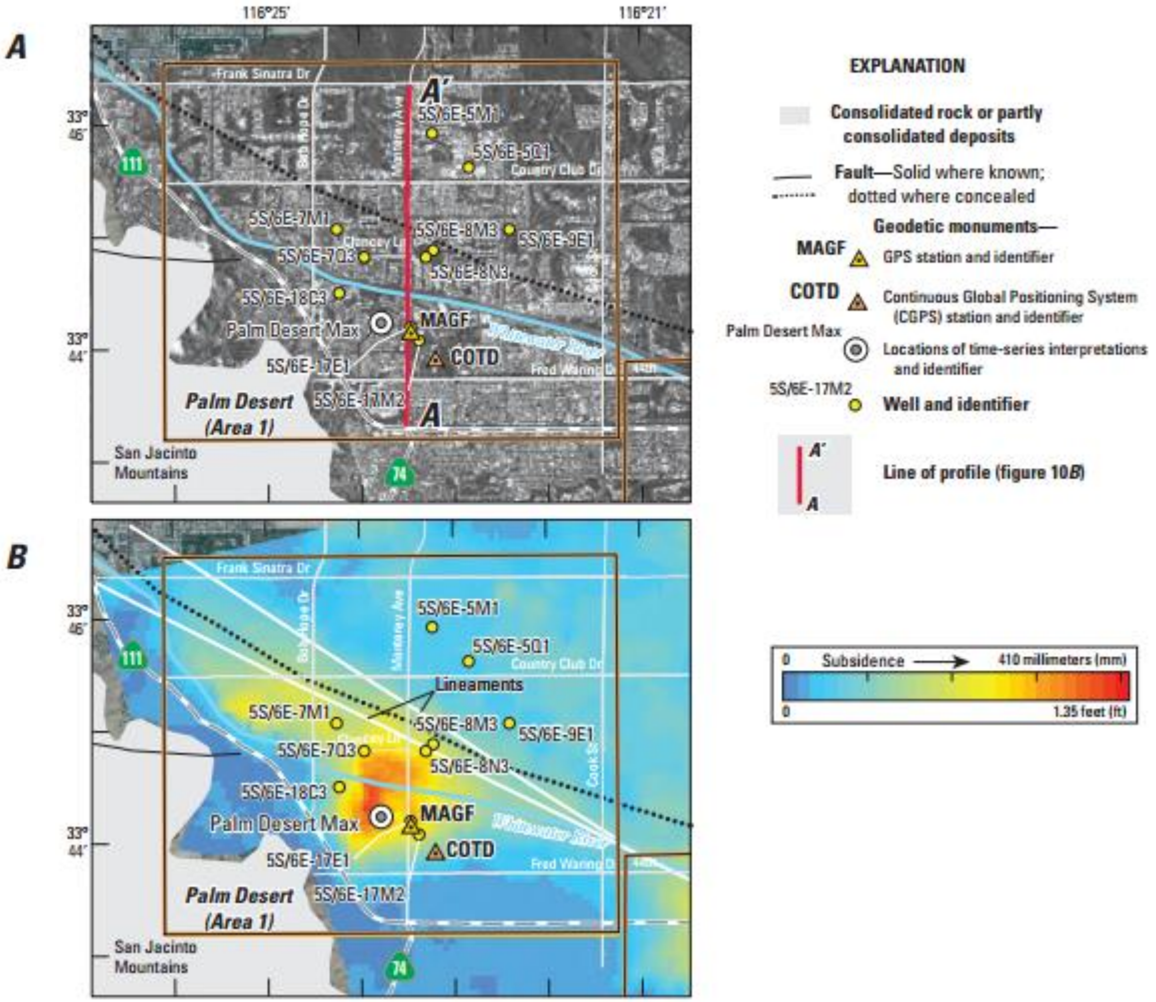


Figure 7. Land-surface features, consolidated rock, Global Positioning System (GPS) stations, two Continuous Global Positioning System (CGPS) stations, three areas of subsidence, and selected roads and wells, Coachella Valley, California.

Results from InSAR

- Palm Desert
  - Subsidence was constant from April 1993 to September 2010
  - Maximum subsidence magnitude was 600 mm (1.97 ft) between June 1995 and September 2010
  - This averages 40 mm per year between the 15 years
  - The San Jacinto and Santa Rosa Mountains which outcrop consolidated rock reduce land subsidence in the southwest
  - Urban areas within Palm springs face the most land subsidence



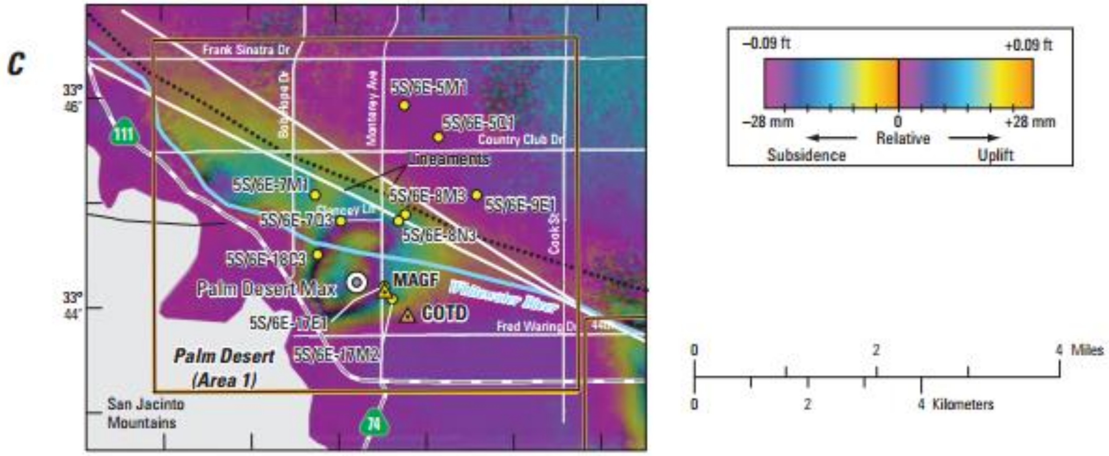


Figure 9. Palm Desert subsidence area (Area 1), Coachella Valley, California, showing one Global Positioning System (GPS) station, one Continuous Global Positioning System (CGPS) station, consolidated rock, and selected roads and wells overlain on *A*, an amplitude image showing land-surface features; *B*, a stacked and kriged interferogram depicting subsidence during June 27, 1995–September 19, 2010 (excluding November 8, 2000–November 30, 2003); and *C*, a conventional interferogram depicting subsidence during June 1, 2008–March 8, 2009.

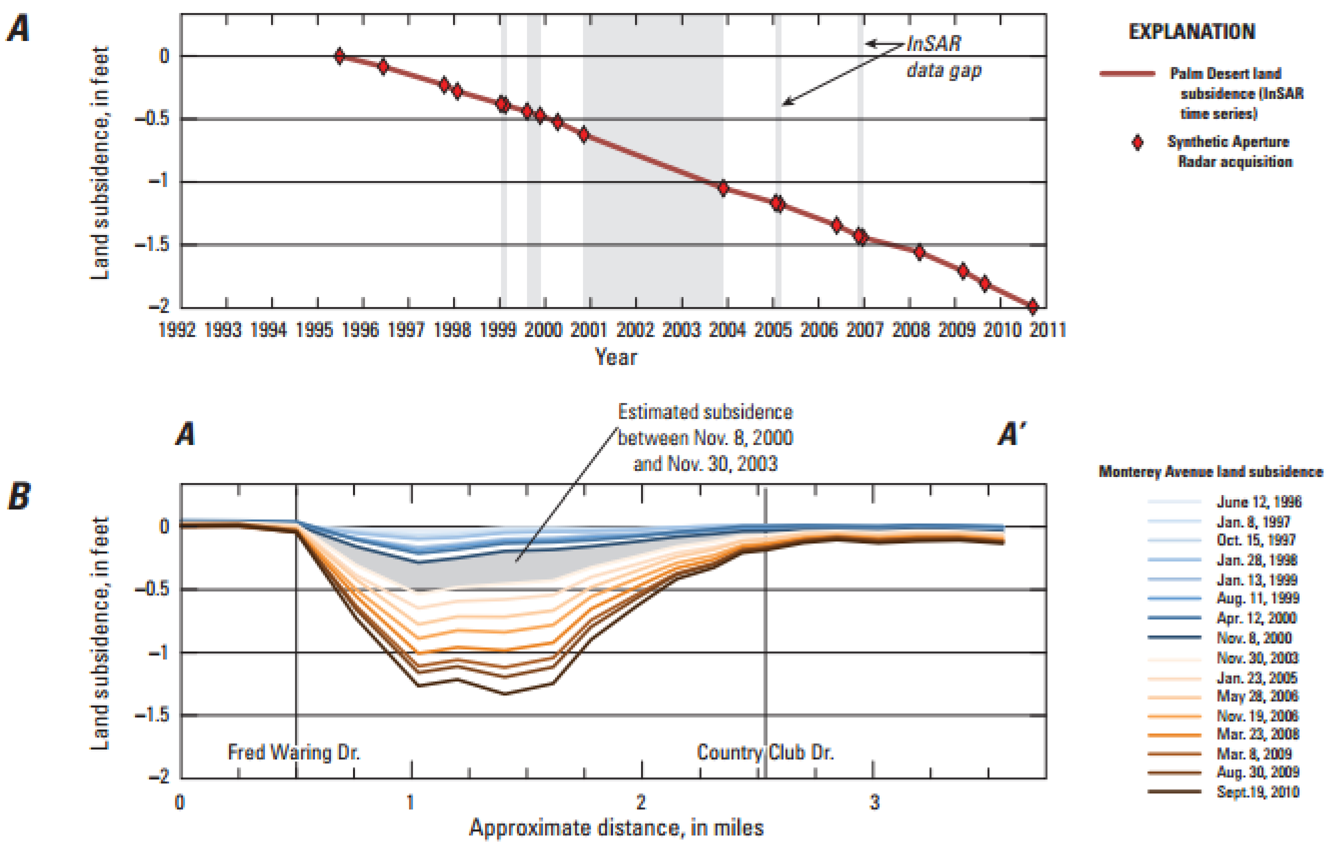
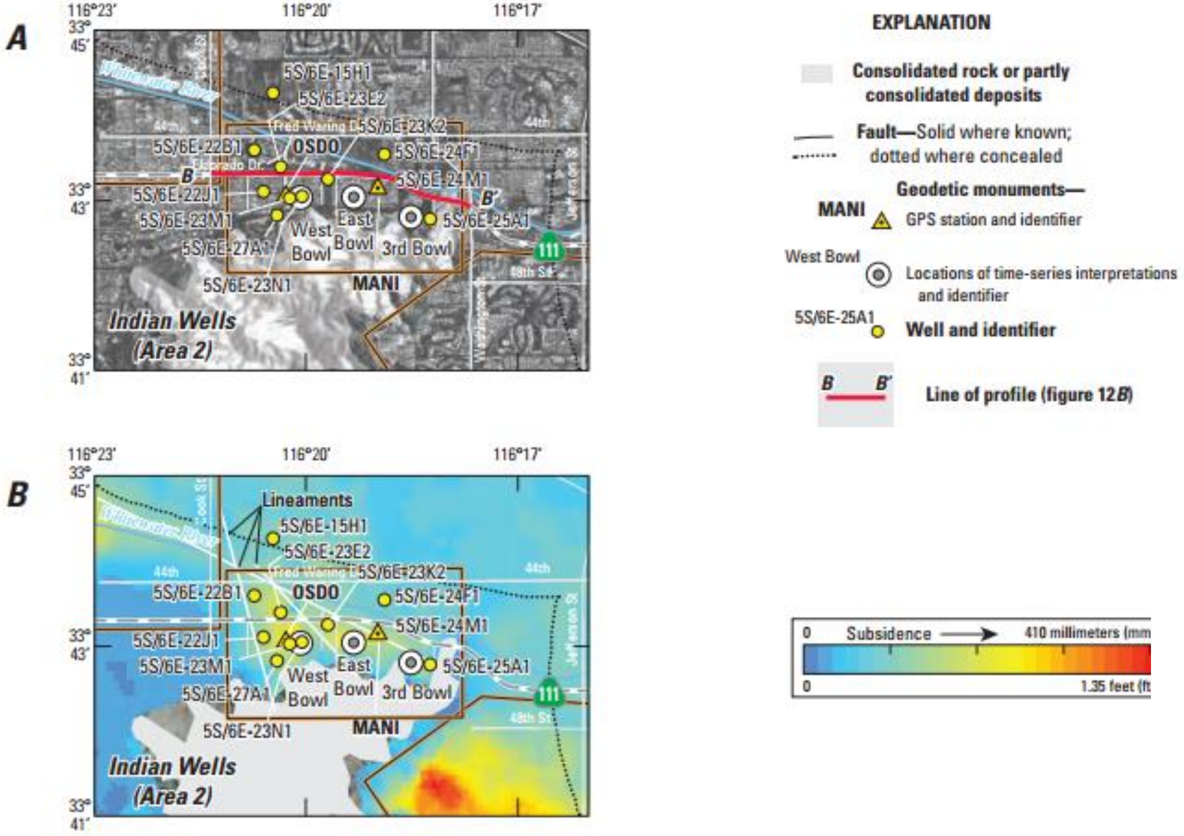
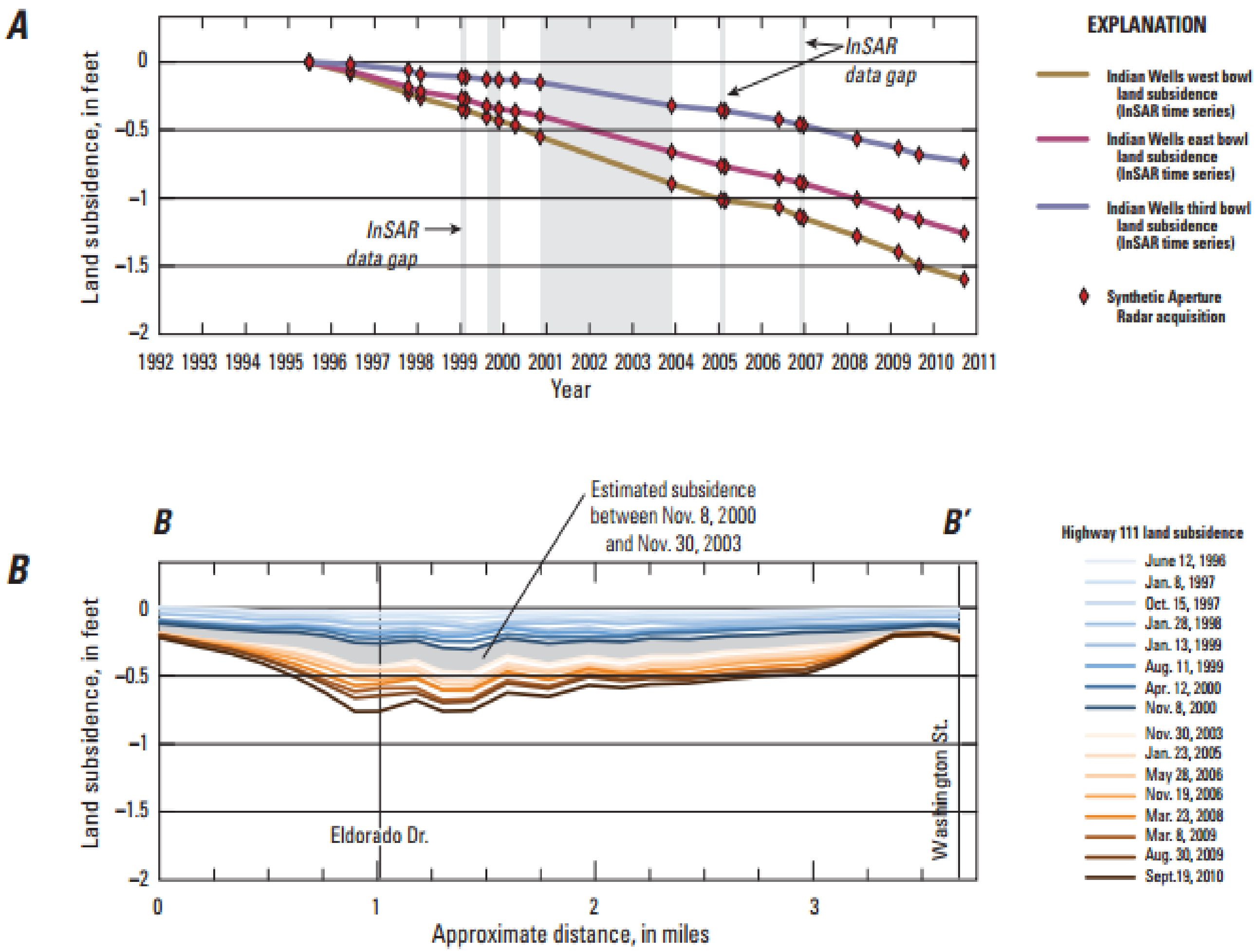


Figure 10. Land subsidence in the Palm Desert area (Area 1), Coachella Valley, California, during June 27, 1995–September 19, 2010, derived from interferograms shown in *appendix A* (including estimated subsidence for November 8, 2000–November 30, 2003): *A*, time series for the location of maximum subsidence; and *B*, profile along Monterey Avenue. See *figure 9A* for profile location.

Results from InSAR

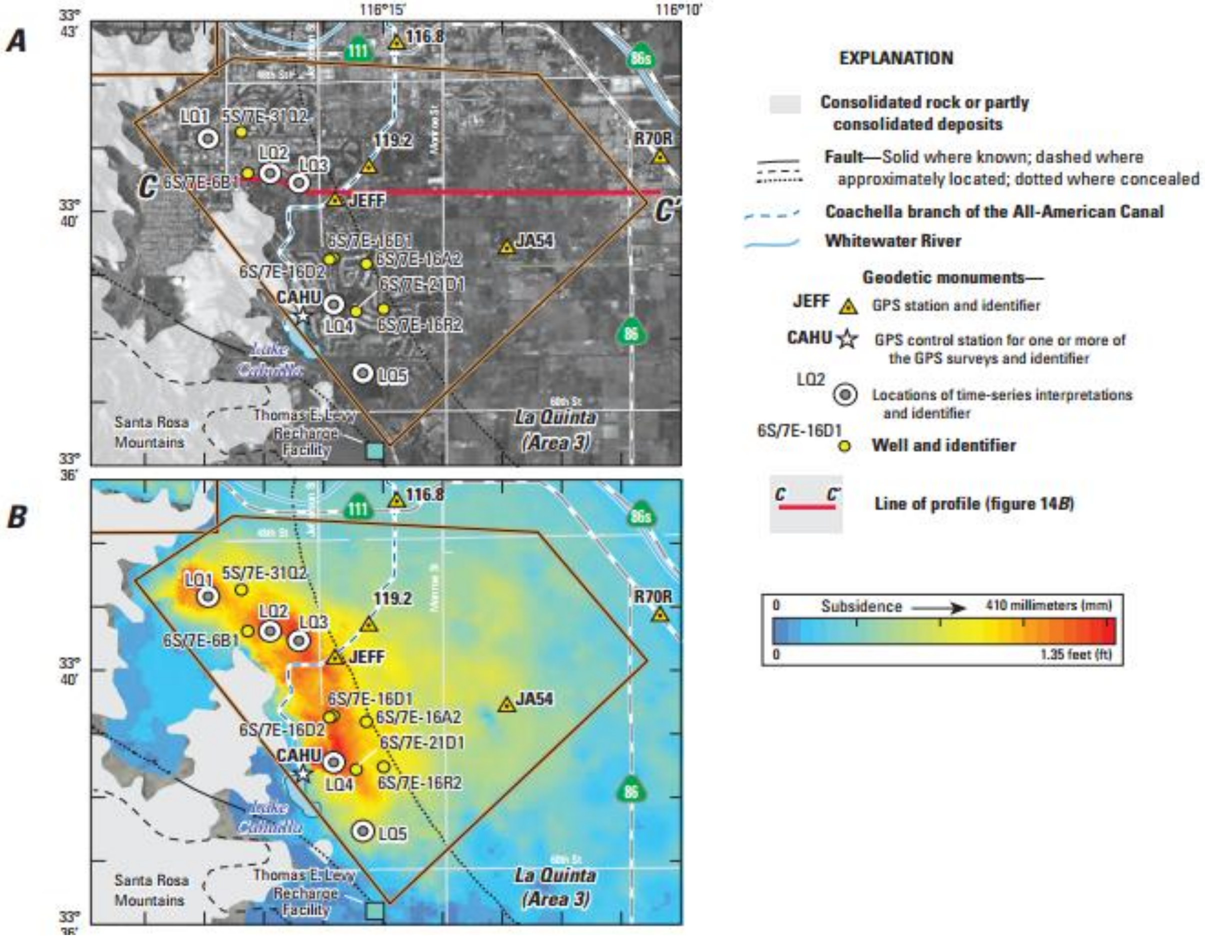
- The Indian Wells Area
  - 3 areas within this area shows subsidence all three areas show subsidence in urban land and golf courses
  - All the subsiding areas make a total of 8 km2
  - Time series between April 1995 and September 2010 show a maximum subsidence with a magnitude of 480 mm for the west side, 380 mm east side, and 220 mm 3rd bowl
  - Subsidence in the Indian well area has increased from 33 mm/ year to 35 mm/ year in the west bowl


A
B
116°23′
116°20′
116°17′
33° 45′
33° 43′
33° 41′
Whitewater River
5S/6E-15H1
5S/6E-23E2
5S/6E-23K2
5S/6E-22B1
OSDO
5S/6E-24F1
5S/6E-24M1
5S/6E-22J1
5S/6E-23M1
5S/6E-27A1
5S/6E-23N1
5S/6E-25A1
West Bowl
East Bowl
3rd Bowl
MANI
Lineaments
44th
48th St
111
Indian Wells (Area 2)
EXPLANATION
Consolidated rock or partly consolidated deposits
Fault—Solid where known; dotted where concealed
Geodetic monuments—
MANI GPS station and identifier
West Bowl Locations of time-series interpretations and identifier
5S/6E-25A1 Well and identifier
B B′ Line of profile (figure 12B)
0 Subsidence 410 millimeters
0 1.35 feet


A
Land subsidence, in feet
0
−0.5
−1
−1.5
−2
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
Year
InSAR data gap
InSAR data gap
EXPLANATION
Indian Wells west bowl land subsidence (InSAR time series)
Indian Wells east bowl land subsidence (InSAR time series)
Indian Wells third bowl land subsidence (InSAR time series)
Synthetic Aperture Radar acquisition
B
B
B′
Estimated subsidence between Nov. 8, 2000 and Nov. 30, 2003
Land subsidence, in feet
0
−0.5
−1
−1.5
−2
Eldorado Dr.
Washington St.
0
1
2
3
Approximate distance, in miles
Highway 111 land subsidence
June 12, 1996
Jan. 8, 1997
Oct. 15, 1997
Jan. 28, 1998
Jan. 13, 1999
Aug. 11, 1999
Apr. 12, 2000
Nov. 8, 2000
Nov. 30, 2003
Jan. 23, 2005
May 28, 2006
Nov. 19, 2006
Mar. 23, 2008
Mar. 8, 2009
Aug. 30, 2009
Sept.19, 2010

Results from InSAR

- La Quinta Area
  - All interferograms from 1993 to 2010 showed subsidence occurring in this area, and is presumed to be larger than reported before
  - This subsidence covers an area of 85 km2 and connects to the agricultural activity center of Coachella Valley, with a subsidence of 60 mm minimum
  - The InSAR data of this region is not complete since there was a gap that occurred in 2000 to 2003
  - Time series for the 4 maxima locations were within golf courses which ranged from 465 mm to about 600 mm



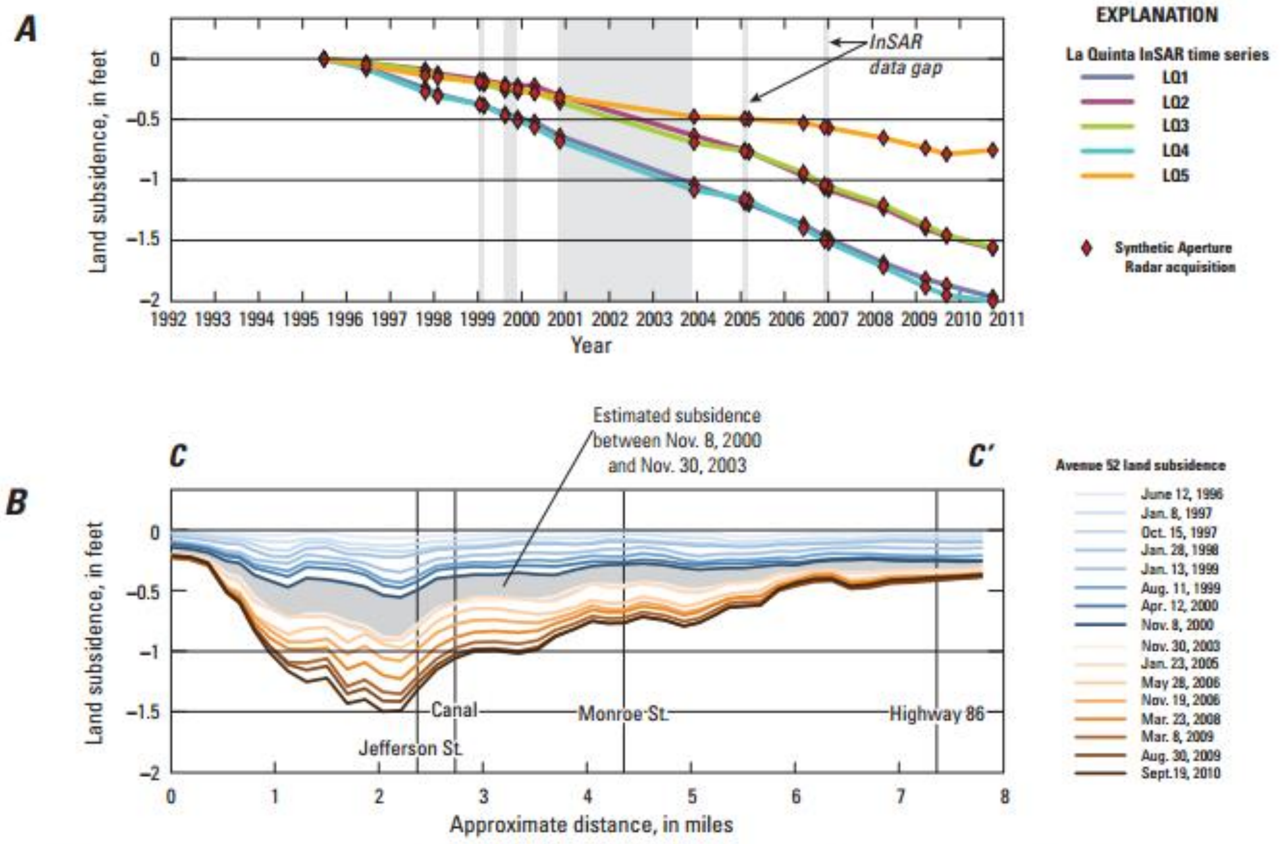


Figure 14. Subsidence in the La Quinta subsidence area (Area 3), Coachella Valley, California, during June 27, 1995–September 19, 2010, derived from interferograms shown in *appendix A* (including estimated subsidence for November 8, 2000–November 30, 2003): *A*, time series for five selected locations (four are maxima) during June 27, 1995–September 19, 2010; and *B*, profile along Avenue 52. See *figure 13A* for profile location.

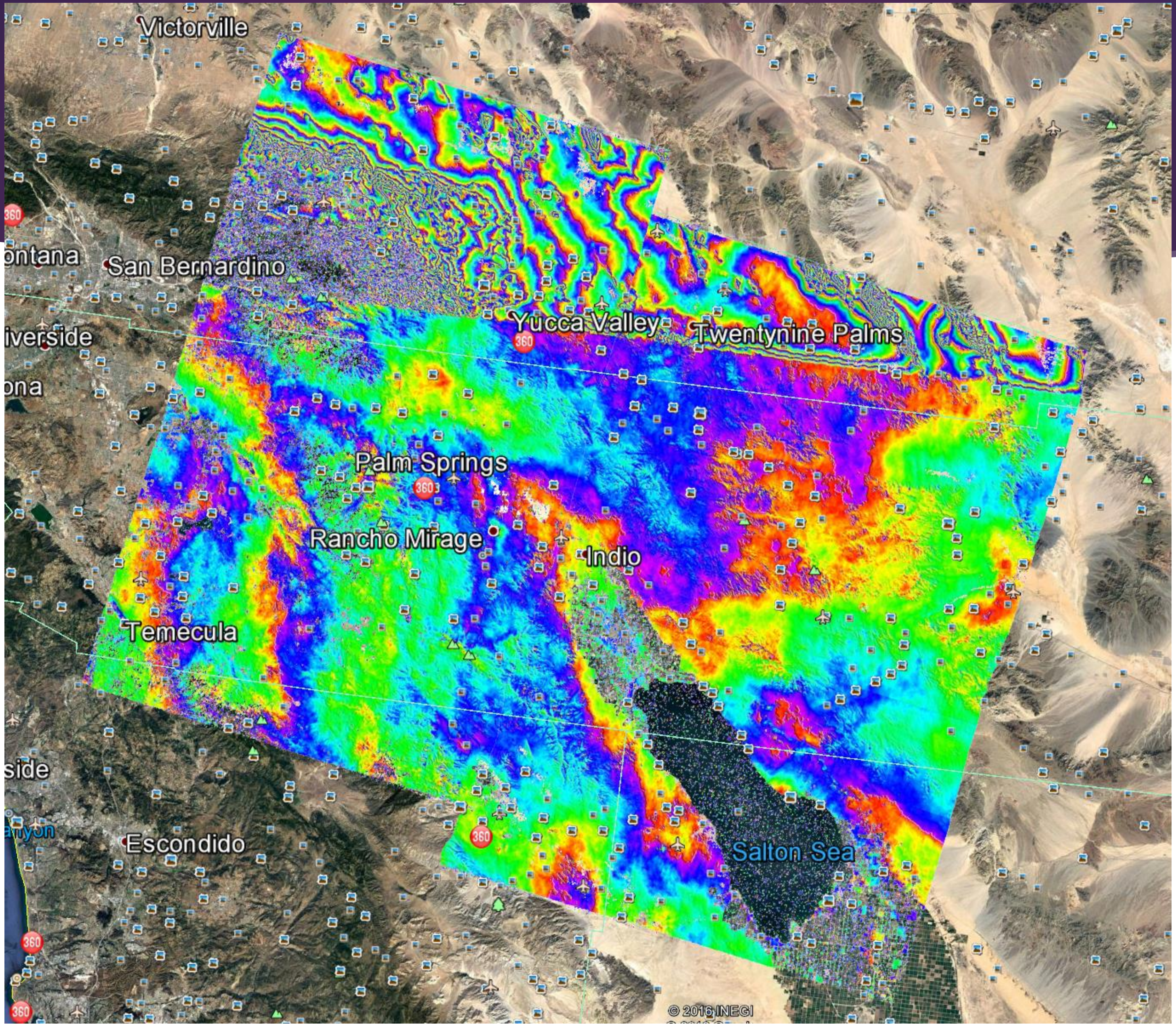
InSAR from Sentinel 1

- Sentinell-1 is a two satellite constellation, its main objective is monitoring Land and Ocean
  - Carries a C-band Synthetic Aperture Radar
  - Offers medium to high resolution imaging in all weather conditions as well as night imagery
  - Sentinel-1A - 03 April 2014
  - Sentinel-1B - 25 April 2016
- Some objectives it is being used for are
  - Climate change monitoring
  - Land monitoring of forests, water, soil and agriculture
  - Sea ice observations
  - Mapping oil spills
- Orbit types are sun- synchronous, near polar, and circular

ESA (European Space Agency)

Results

- Created an interferogram using a time delay of a year from June 14, 2015 to June 8,2016
- Used ncview to estimate the z value of the interferogram from the subsiding zone to the flat area resulted in a 42.07 mm subsidence within a year which is around the results found in the USGS paper
- This would mean that that the area is still subsiding at the same rate
- The area that showed the most subsidence is an area with many fields, the urban area shows lowest elevation and the fields that surround it shows subsidence however due to the agricultural activity fields with no vegetation show data


Victorville
ontana
San Bernardino
iverside
ona
Yucca Valley
Twentynine Palms
Palm Springs
Rancho Mirage
Indio
Temecula
side
Escondido
Salton Sea
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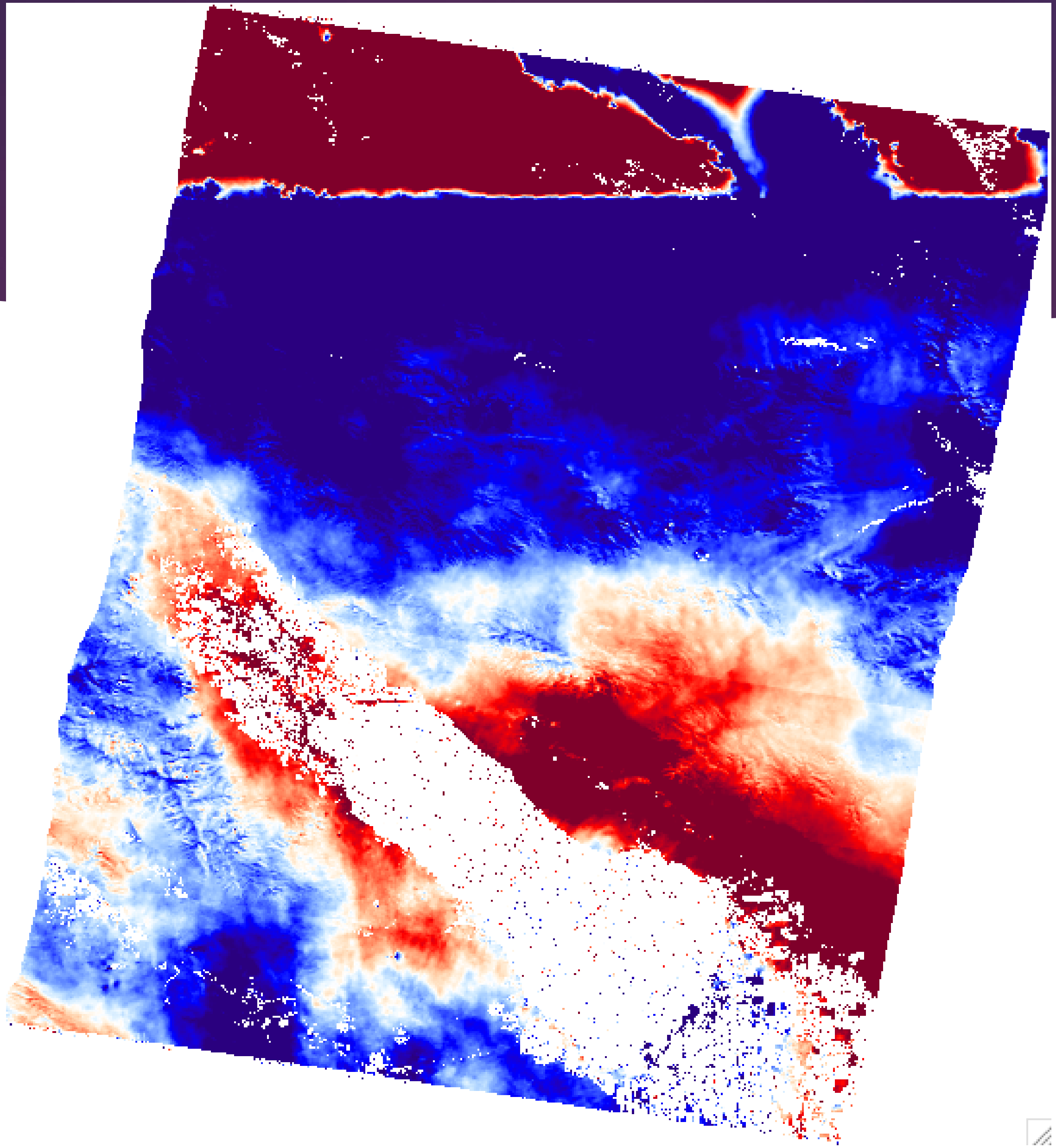

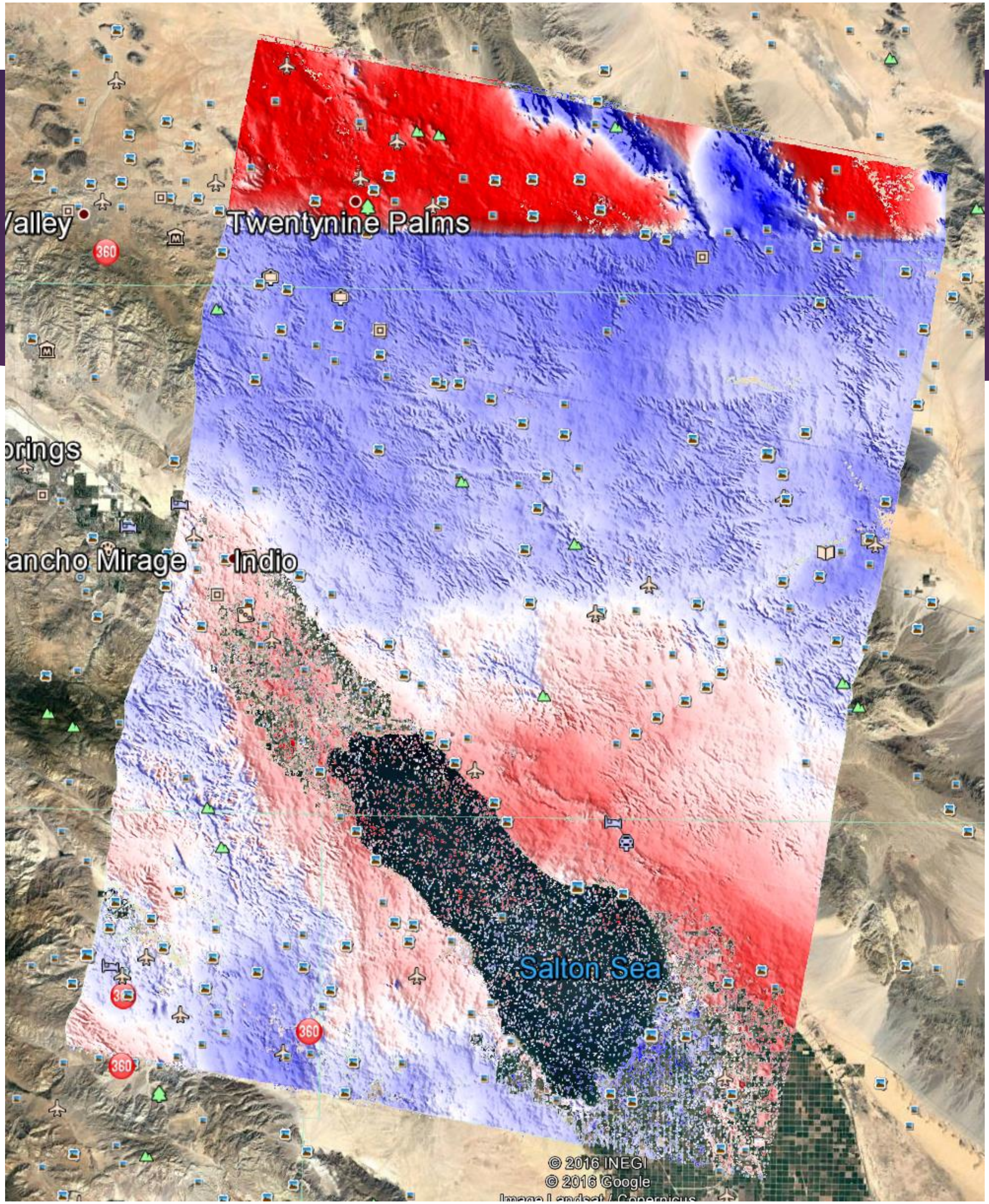
Twentynine Palms
Indio
Salton Sea
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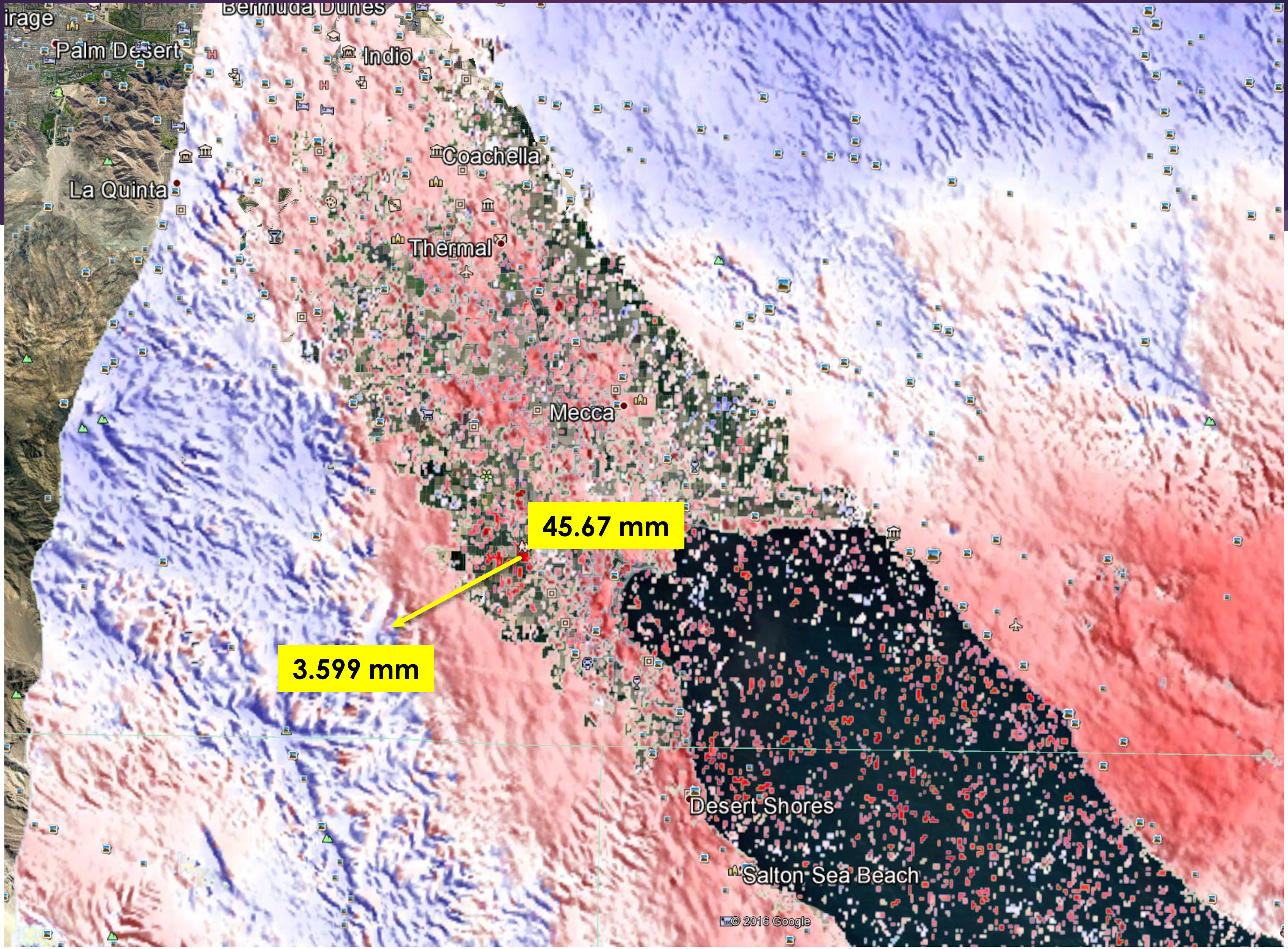
Bermuda Dunes
irage
Palm Desert
Indio
Coachella
La Quinta
Thermal
Mecca
45.67 mm
3.599 mm
Desert Shores
Salton Sea Beach
© 2016 Google


© 2016 Google
Google earth
1996
Imagery Date: 10/13/2016 lat 33.506845° lon -116.126858° elev -129 ft eye alt 9692 ft

Problems

- The top of interferogram is decorrelated
- Some areas of interest were covered in vegetation giving incoherent signals
- To fix some of the errors within the interferogram need to shorten the time delay possibly using 2 months
- Atmospheric errors
- Could attempt to try ascending satellite data

Sources

- Sneed, Michelle, Justin T. Brandt, and Mike Solt. "Land Subsidence, Groundwater Levels, and Geology in the Coachella Valley, California, 1993-2010." *Scientific Investigations Report* (2014): n. pag. Web. 15 Mar. 2017.
- U.S. Geological Survey California Water Science Center. "Current Land Subsidence in the San Joaquin Valley." *San Joaquin Valley Land Subsidence Monitoring Network | USGS California Water Science Center*. N.p., n.d. Web. 17 Mar. 2017.