ADWR's Land Subsidence Monitoring Program

Interferometric Synthetic Aperture Radar (InSAR)

Brian D. Conway

Hydrology Division

Geophysics/Surveying Unit

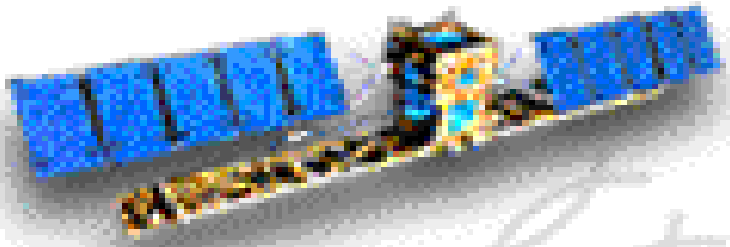
ARIZONA
DEPARTMENT
OF WATER
RESOURCES

Image courtesy of the Canadian Center for Remote Sensing

SUBSIDENCE
AREA

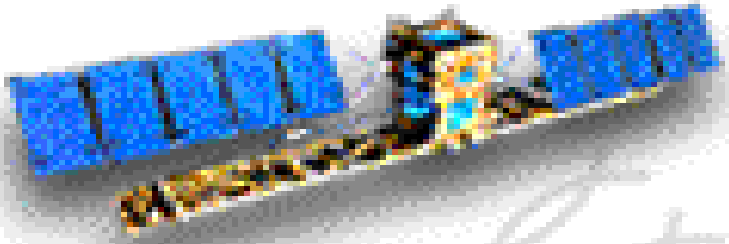
E INDIAN RIDGE RD
EARTH FISSURE
HAZARDOUS CONDITIONS
AHEAD
Brenda's
Realty

EARTH
FISSURES
POSSIBLE
25
MPH

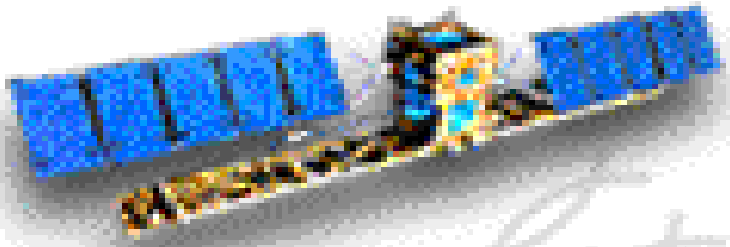


Topics Discussed

1. What is Land Subsidence (Land Subsidence 101)
2. Brief history of ADWR's land subsidence monitoring program.
3. Discuss SAR and InSAR technology.
4. Discuss the applications of InSAR for land subsidence monitoring and other projects.
5. Why surveyors should be concerned about land subsidence.



Geophysics/Surveying Unit

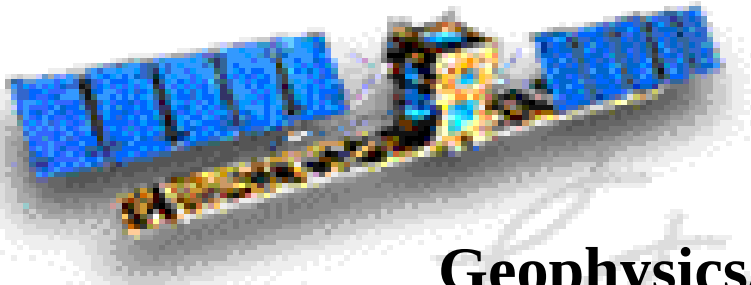


Geophysics/Surveying Unit

- **Gravity surveying for aquifer storage monitoring.**

Geophysics/Surveying Unit

- **Gravity surveying**

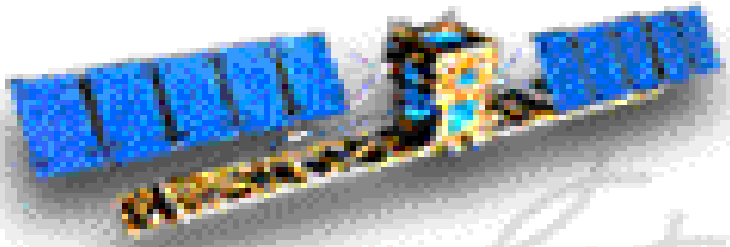


Geophysics/Surveying Unit

- **Gravity surveying for aquifer storage monitoring.**
- **Gravity surveying for depth-to-bedrock modeling and water-in-storage estimates.**

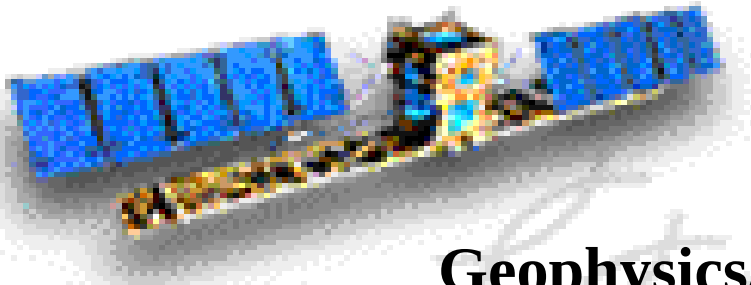
Geophysics/Surveying Unit

- **Gravity surveyin**
- **Gravity surveyin estimates.**



Geophysics/Surveying Unit

- **Gravity surveying for aquifer storage monitoring.**
- **Gravity surveying for depth-to-bedrock modeling and water-in-storage estimates.**
- **Gravity surveying to obtain hydraulic parameters for use in groundwater models.**



Geophysics/Surveying Unit

- **Gravity surveying for aquifer storage monitoring.**
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- **Collect, process, and analyze InSAR data for land subsidence monitoring.**

Geophysics/Surveying Unit

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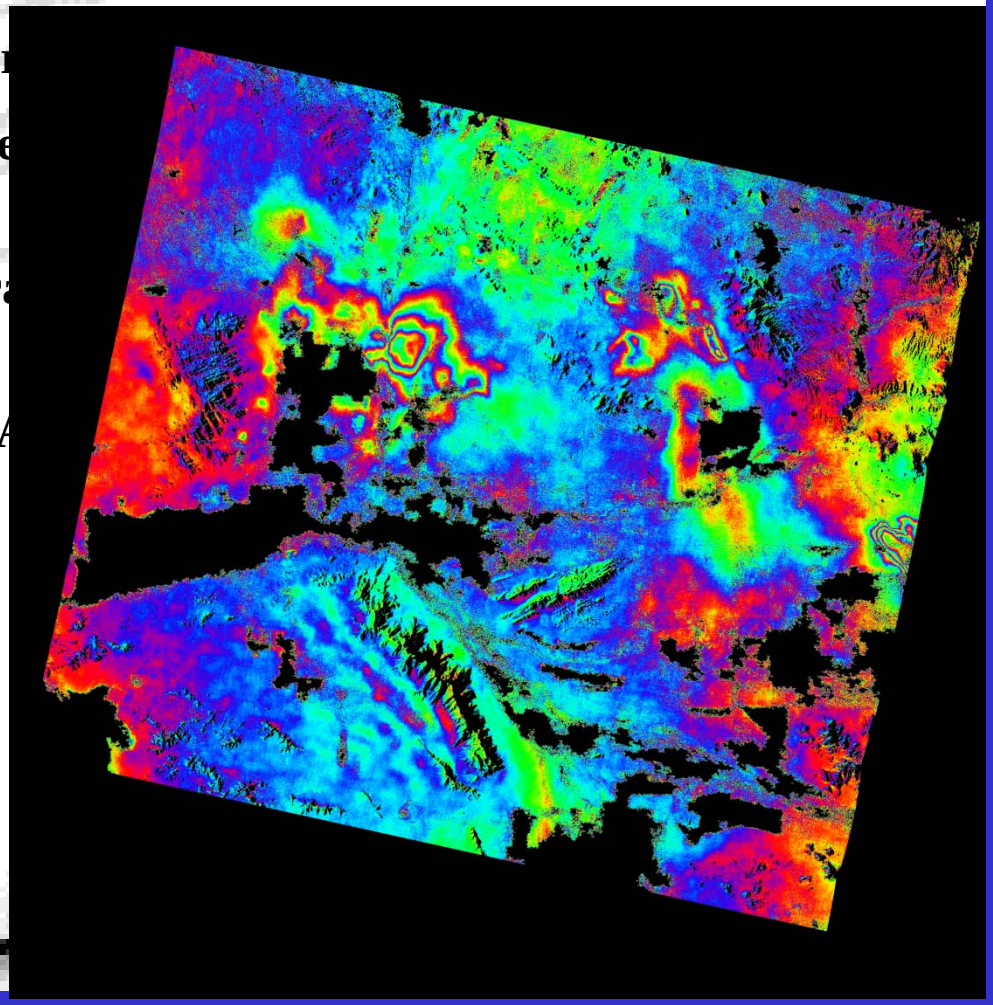


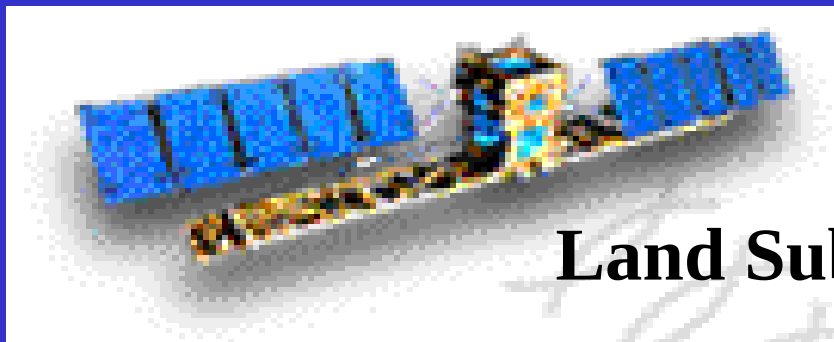
Geophysics/Surveying Unit

- **Gravity surveying for aquifer storage monitoring.**
- **Gravity surveying for depth-to-bedrock modeling and water-in-storage estimates.**
- **Gravity surveying to obtain hydrologic parameters for use in groundwater models.**
- **Collect, process, and analyze InSAR data for land subsidence monitoring.**
- **GPS surveying to support land subsidence monitoring, aquifer storage monitoring, WQARF program, transducer program and other ADWR programs.**

Geophysics/Surveying Unit

onitoring.

modeling and water-in-storage



Land Subsidence 101

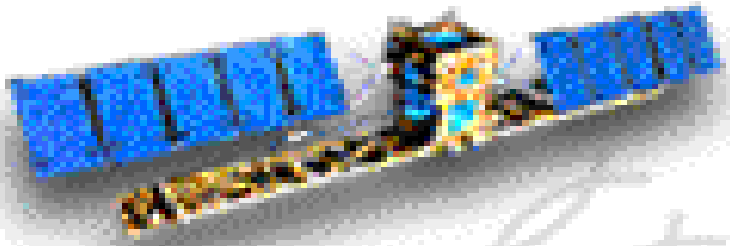
- Land subsidence is the lowering of the land-surface from changes that take place underground.

Human activities that cause land subsidence:

- The Pumping of water, oil and gas from reservoirs beneath the ground
- Dissolution of limestone aquifer (Sinkholes)
- Collapse of underground mines
- Drainage of organic soils and initial wetting of dry soils (hydrocompaction)

The Process of Land Subsidence

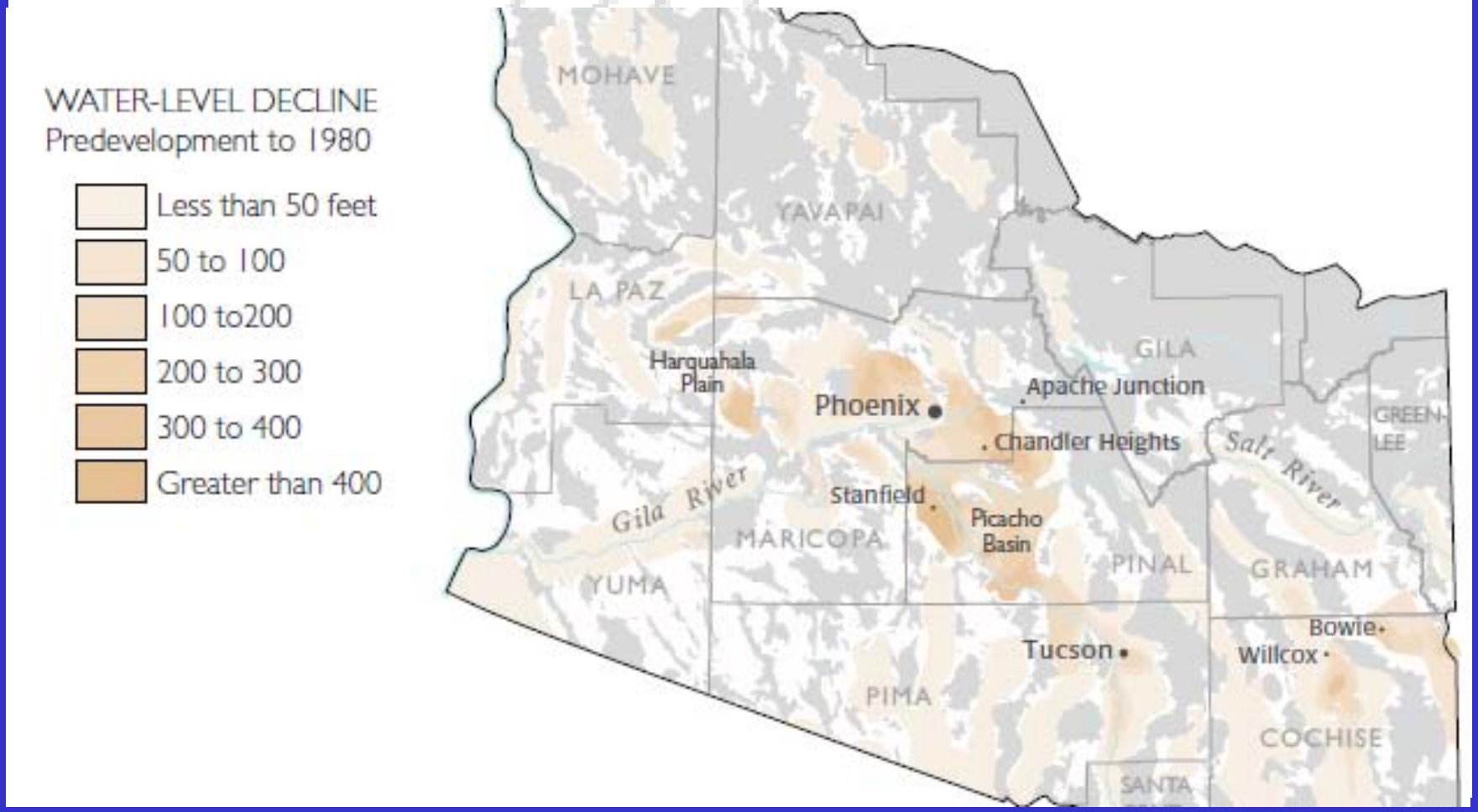
- Water is removed from pore spaces between grains of sand and gravel.
- Smaller grain material (silt and clay) are found in these pore spaces
- As the water is removed from the pore spaces, the water pressure is lowered, resulting in the drainage of water from the clay and silt.
- The reduced water pressure creates a loss of support for the clay and/or silt materials, resulting in compression and compaction.
- Subsidence Has Occurred.



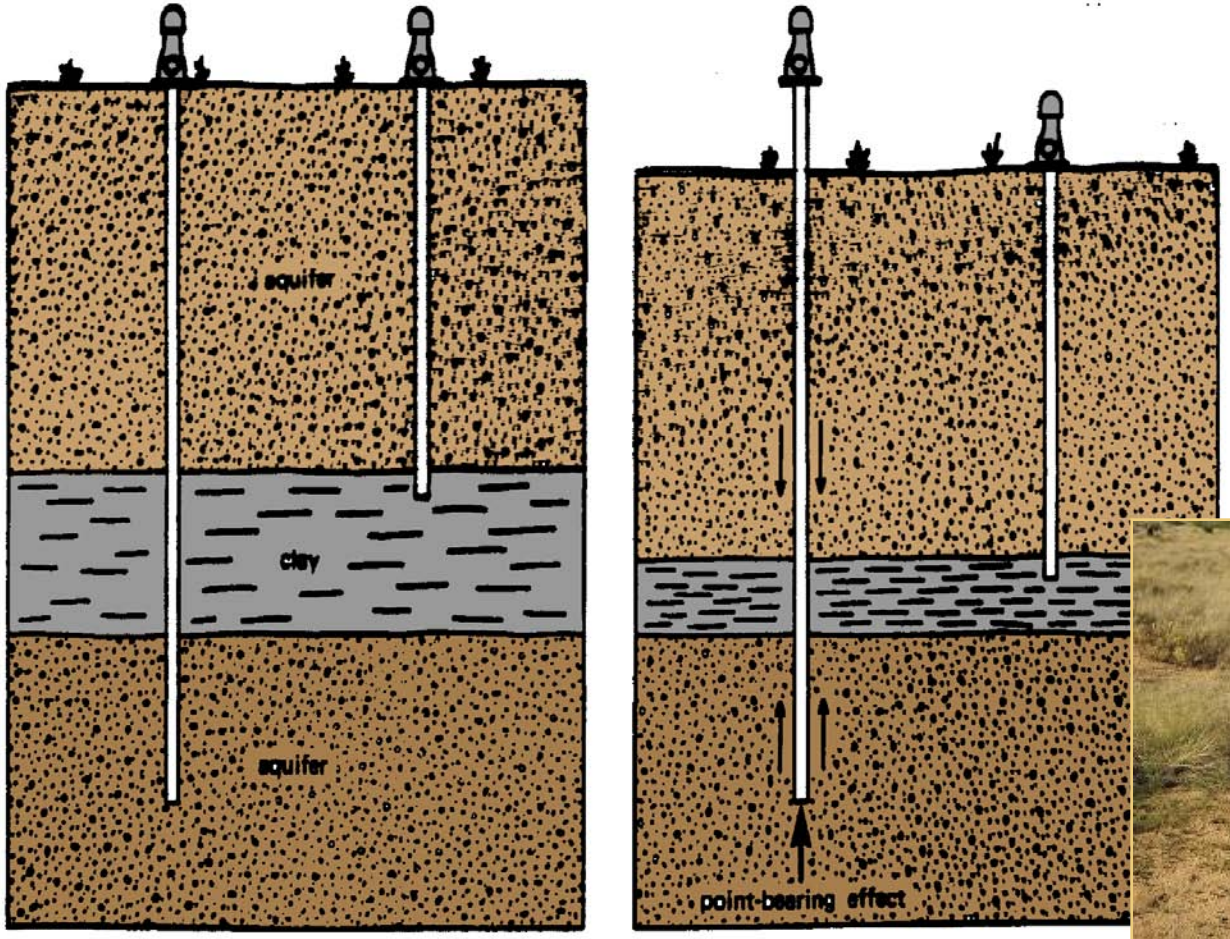
Subsidence within Arizona is due to the historical groundwater withdrawal (pumping) of aquifer systems.

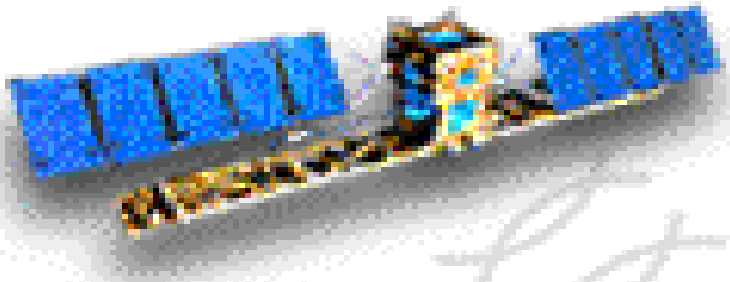
- Groundwater levels have dropped as much as 400 feet in areas around Arizona since the 1900's.
- The geologic composition of the basins of Arizona consists of gravel, sand, clay, salt, and silt.

Change in Groundwater Levels in Central and Southern Arizona Between 1900 and 1980



Land Subsidence and Groundwater Withdrawal

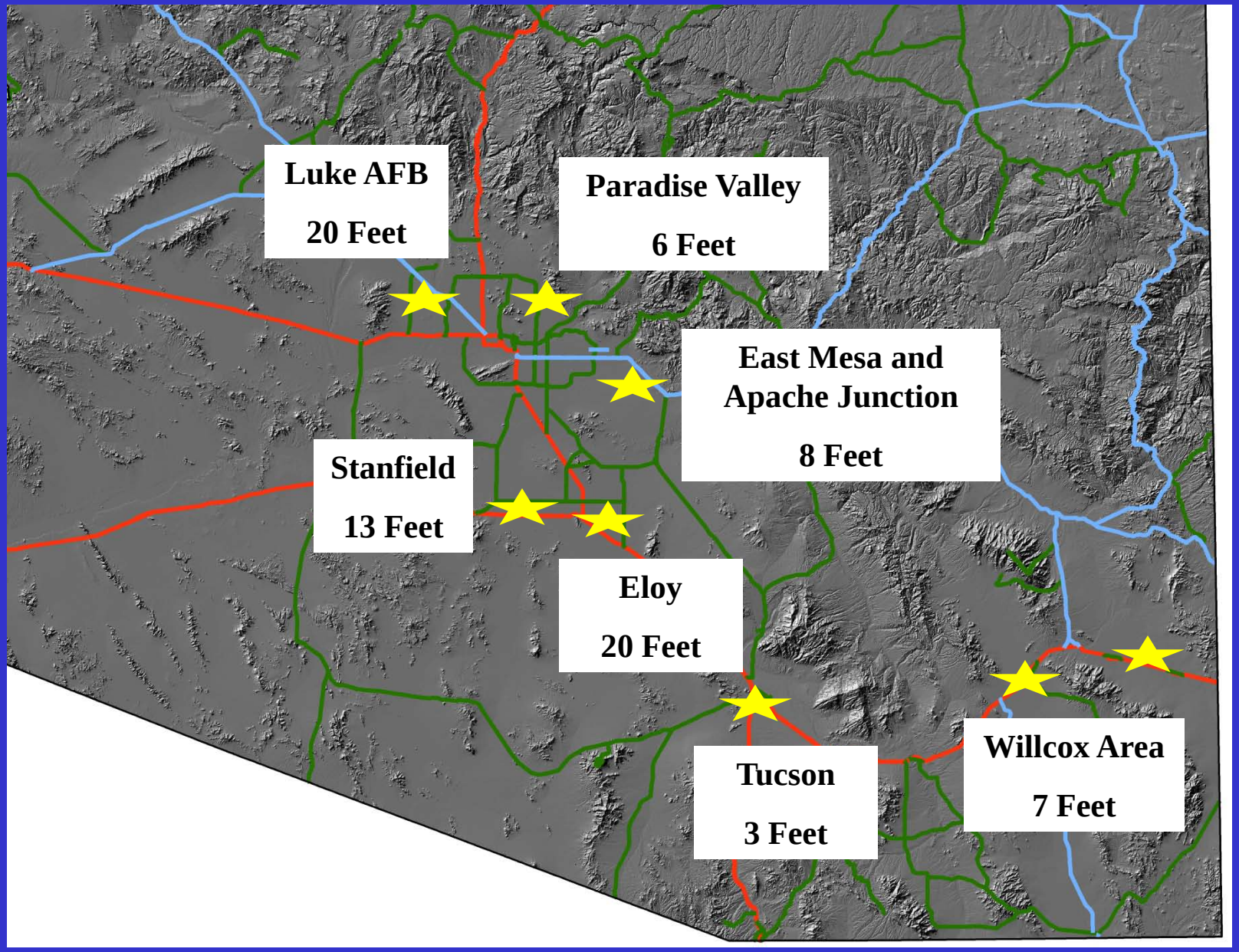


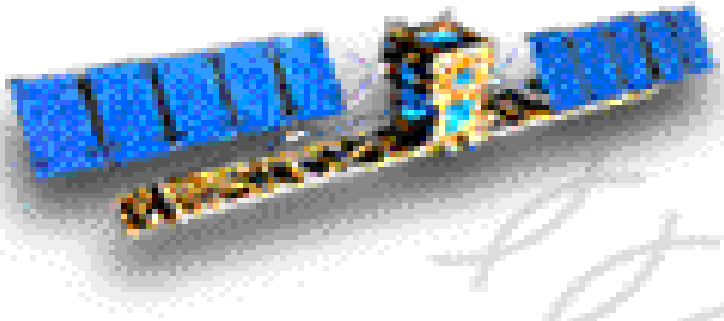


Where Has Subsidence Occurred?

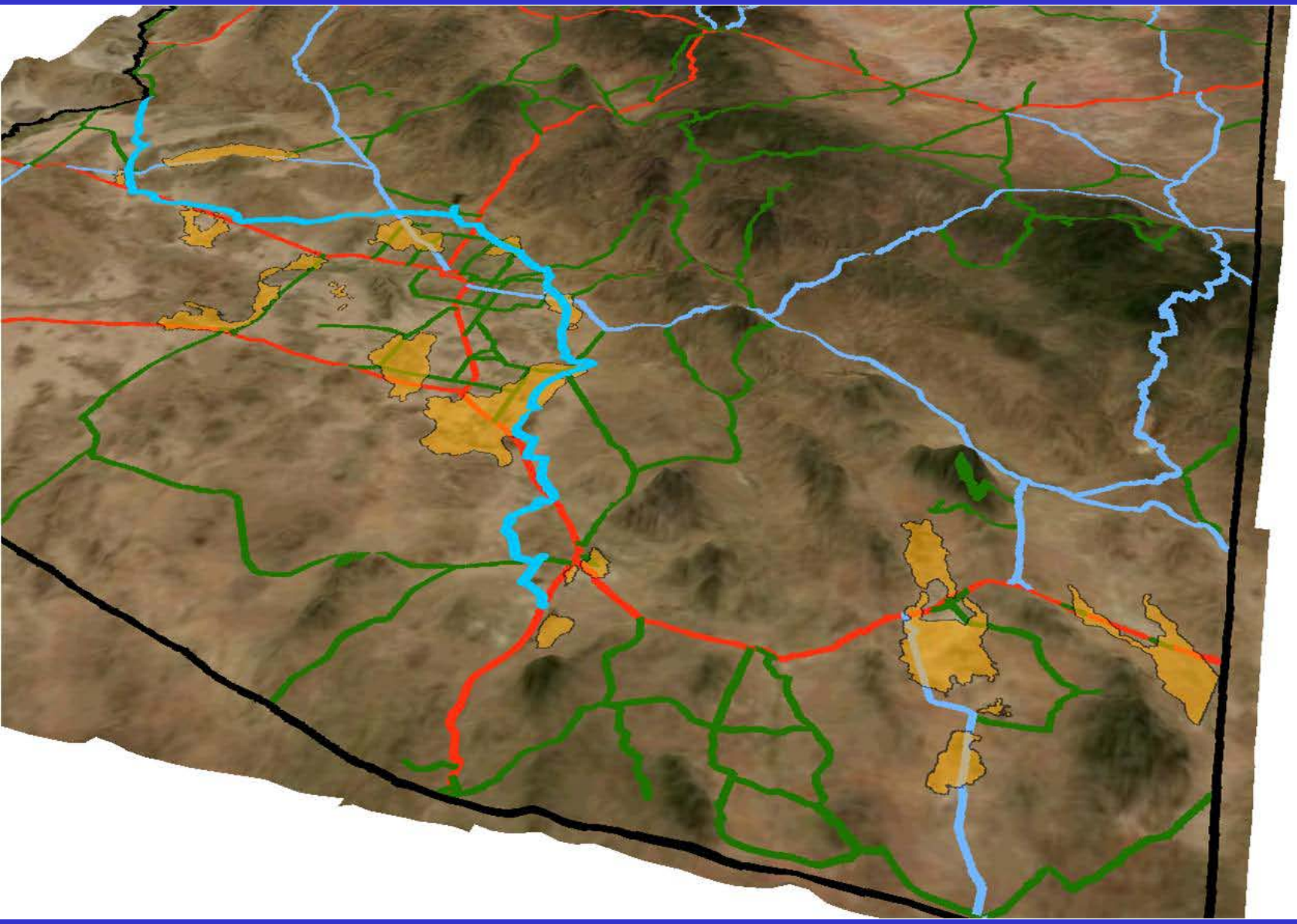
And How Much?

Where and How Much?



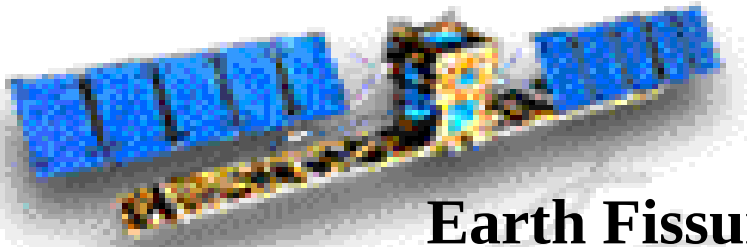


Aerial Flight of Land Subsidence Areas throughout Central and Southern Arizona



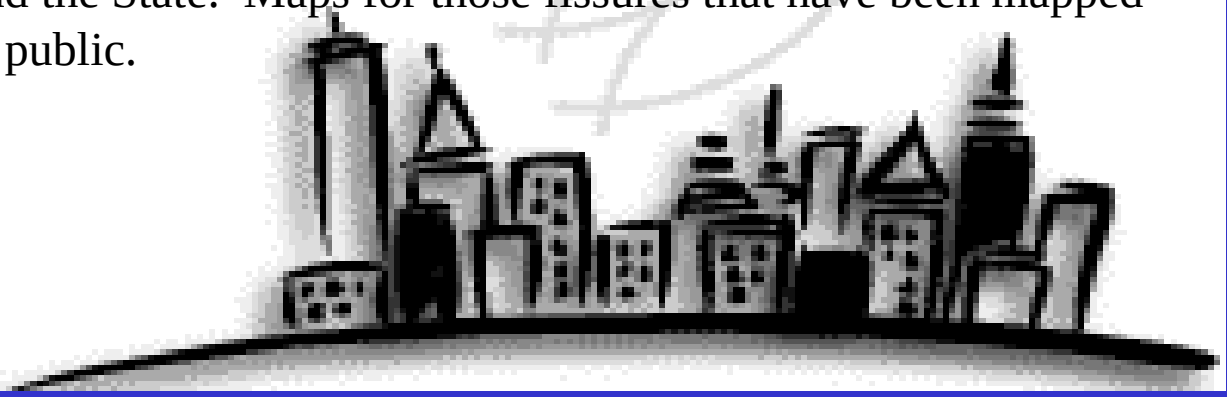
Problems Caused by Land Subsidence and Earth Fissures

- Damage to infrastructure (CAP canal, highways, sewer and water lines) and private property.
- Expenses incurred to mitigate land subsidence and earth fissures.
- Changing the natural slope of the floodplain (areas that did not flood now flood).
- Severe or even fatal injuries to people and livestock.
- Loss of groundwater storage and possible change to the hydraulic properties of the aquifer.



Earth Fissure Development

- Earth Fissures are the result of subsidence.
- Earth Fissures develop near bedrock and areas that transition between different types of geological material.
- Earth Fissures start out as hairline cracks but can open up at the surface with the interaction of surface water flow.
- Limited knowledge on the science of earth fissures.
- Arizona Geological Survey is in the process of identifying and mapping all the earth fissures around the State. Maps for those fissures that have been mapped are available to the public.

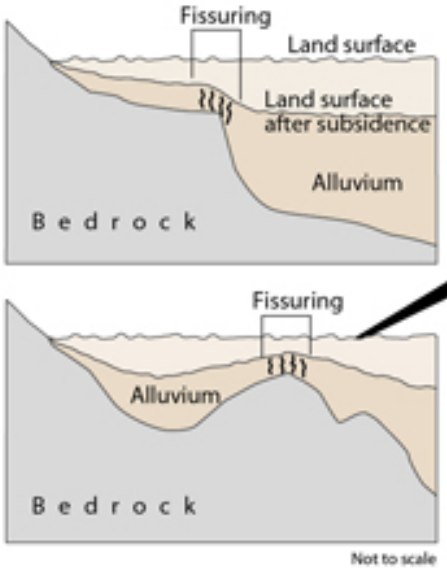


Earth Fissure Development

Earth Fissure Formation by Differential compaction

As the land surface subsides, alluvium stretches and eventually fails, generally in a region of abrupt change in alluvium thickness.

Fissures are concentrated in areas where the thickness of the alluvium changes, such as near the margin of basins or where bedrock is near the surface.



Lateral stresses induce tension cracking.

Surface water infiltrates, dissolving the natural cement bonding the soil, connecting hairline cracks, and further eroding and enlarging the fissure.

Fissure progressively enlarges, capturing surface runoff, sediment, and debris. Eventually vegetation establishes itself, creating a line of vegetation along the trace of the fissure.

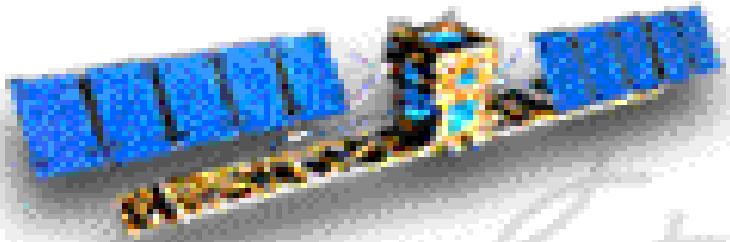
Modified from Galloway et al., 1999

Queen Creek Earth Fissure July 2007

Cochise County Earth Fissure July 2010

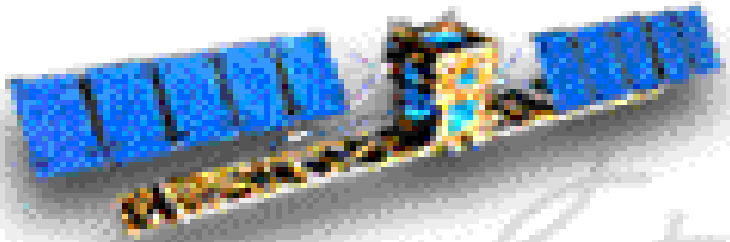
Red Mountain Loop 202/Apache Trail Earth Fissure

Red Mountain Loop 202/Apache Trail Earth Fissure



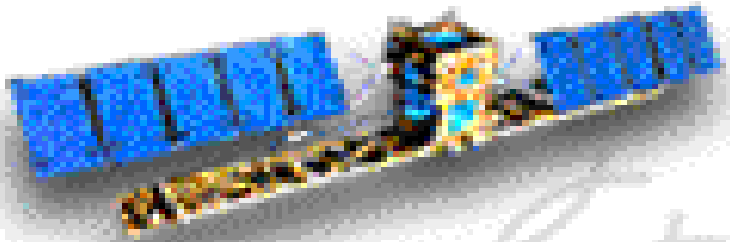
ADWR'S LAND SUBSIDENCE MONITORING PROGRAM

- ADWR's authority to collect or require the collection of land subsidence and/or earth fissure data is established in statutes and rules related to:
- Determining whether a subsequent Active Management Area (AMA) should be established (in part) to reduce the impacts of land subsidence or fissures.
- Determining whether new non-exempt or recovery wells in AMAs or other wells used for inner-basin groundwater transfers may cause unreasonable increasing harm due to regional land subsidence.
- Determining if subsidence or fissures are a potential concern for regulated dam projects.



ADWR'S LAND SUBSIDENCE MONITORING PROGRAM

- In 1997 numerous non-exempt wells were proposed in the Apache Junction and Luke Air Force Base areas, both areas noted for significant historic land subsidence and earth fissuring.
- Concerns over the potential for the new wells to cause unreasonable increasing harm led to a Directorate level decision to begin a land subsidence monitoring program.
- ADWR's first subsidence monitoring involved static GPS measurements near wells and over small sub-regional networks in the Hawk Rock area of eastern Maricopa and western Pinal Counties in 1998.

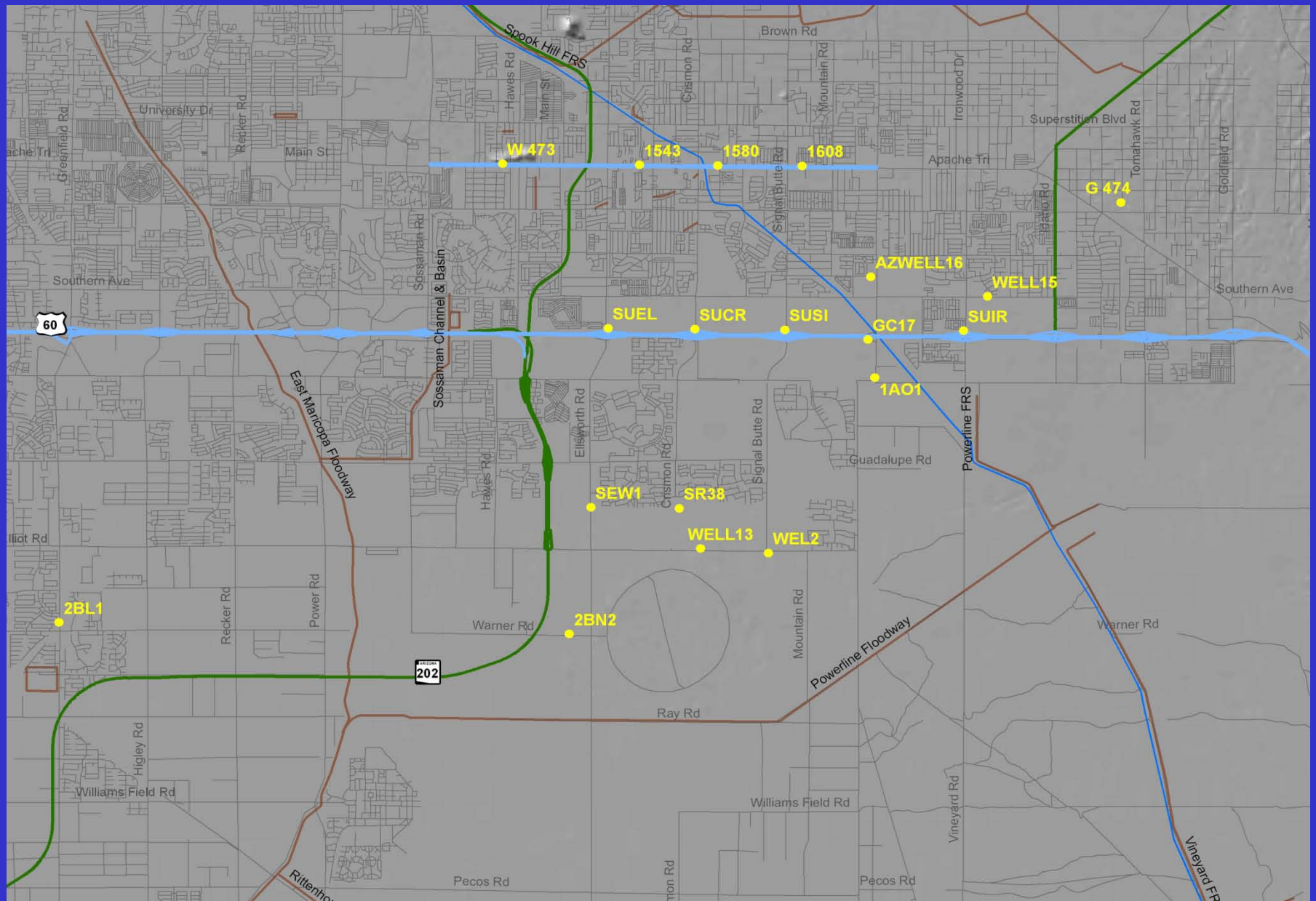


ADWR'S LAND SUBSIDENCE MONITORING PROGRAM

- In the late 1990's INSAR technology became recognized as a reliable and cost effective tool to provide regional-scaled land subsidence data, and ADWR soon began to utilize this information along with survey grade GPS
- Quickly migrated to emphasis on SAR/InSAR, with GPS support in 2001.
- Center For Space Research grant (ADWR funded) to collect InSAR data.
- Awarded $1.3 million NASA grant in 2002 to further develop ADWR's InSAR program for the next three years.
- By 2008, ADWR identified and monitored more than 16 land subsidence features around Central and Southern Arizona.

Monitoring Land Subsidence With Static GPS Surveys

Hawk Rock GPS Network in East Mesa/Apache Junction Area, Maricopa/Pinal Counties



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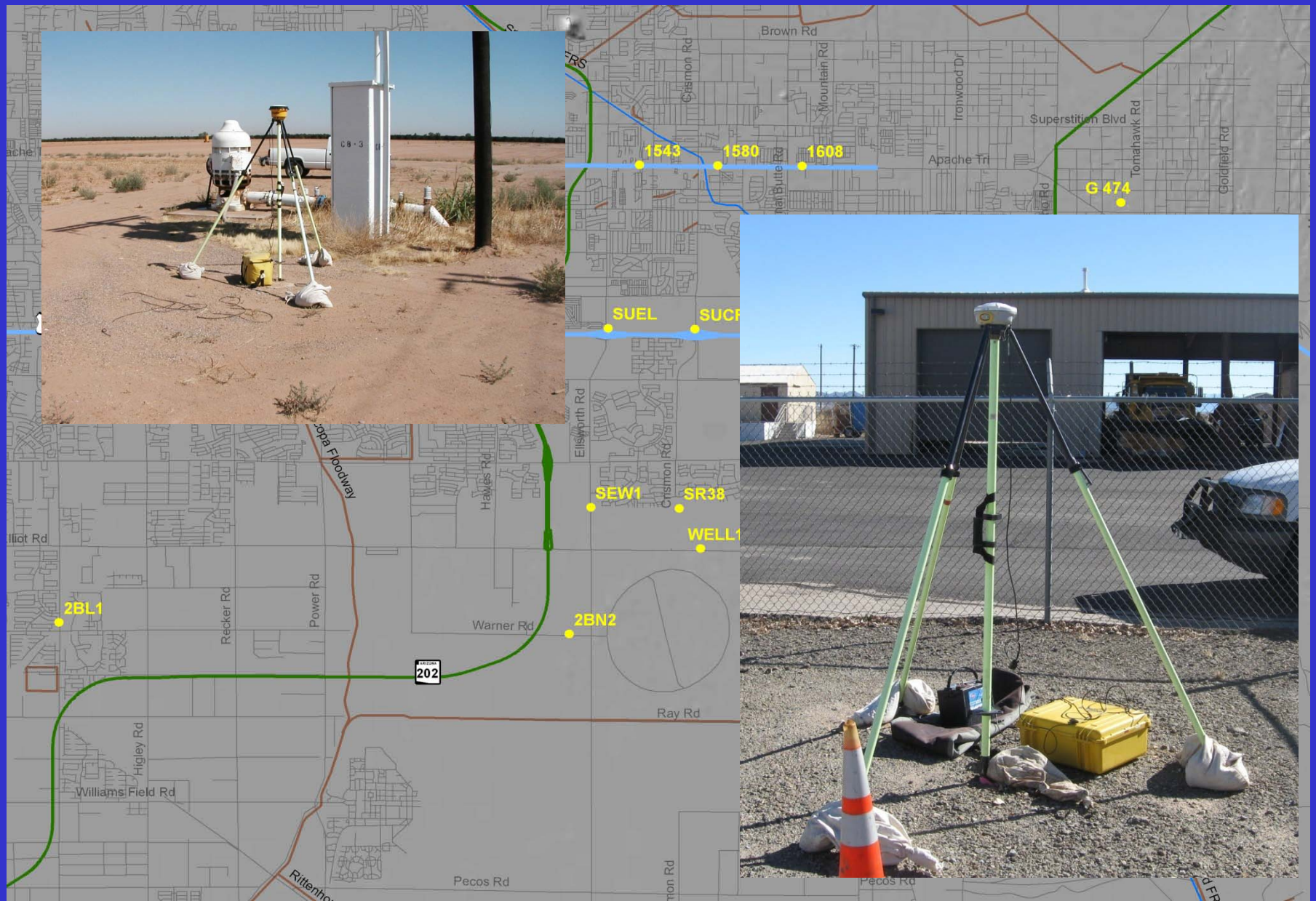
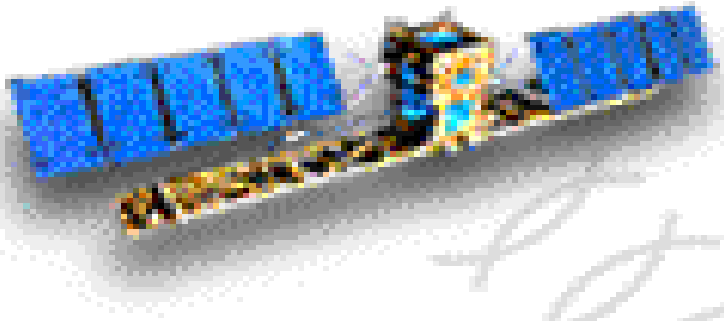
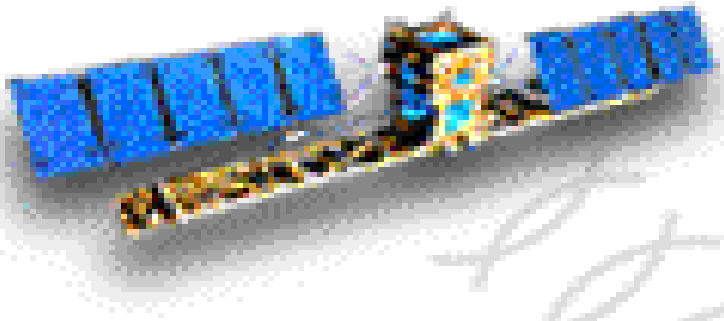


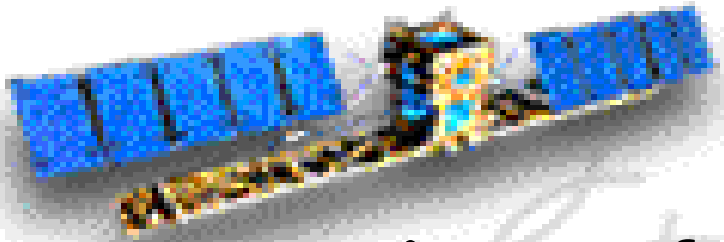


ADWR InSAR Program

Used For Land Subsidence Monitoring

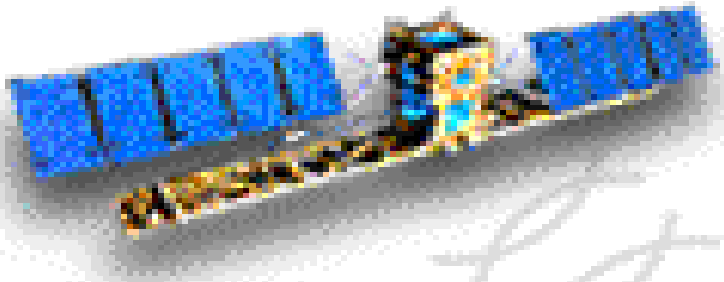


Differential SAR Interferometry (DiffSAR)

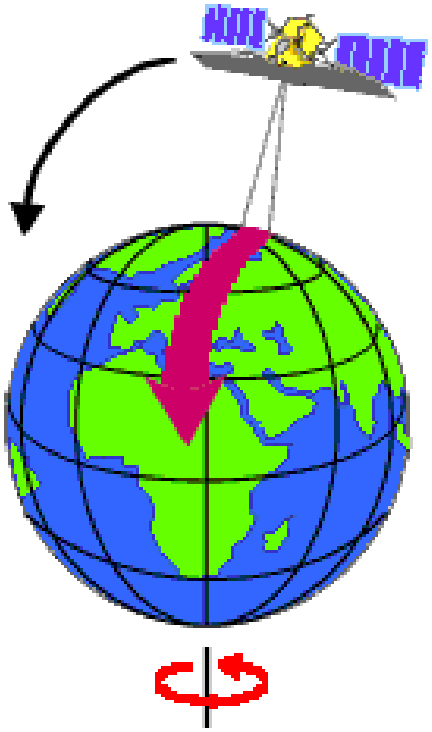


Measuring Surface Motion from Space

- Surface motion can arise from a variety of phenomena
  - Earthquakes
  - Underground excavation
  - Groundwater withdrawal
  - Hard target motion
- “Conventional” techniques have a variety of drawbacks
  - Only discreet spatial measurements
  - Expensive
- Civil space borne SAR technology has shown excellent success in producing ground motion measurements with differential interferometry (DiffSAR)



SAR SATELLITE CHARACTERISTICS



- Active sensors (day/night/clouds)
- Near Circular, Polar Orbit
- Period approx. 100 minutes (4.5 miles/sec)
- Approx. 800 km altitude
- Approx. 14 orbits/day
- Repeat cycle 8-46 days
- Need to be tasked

Relevant Satellite SAR Missions

Satellite	Dates	Sponsor	Band	Repeat Orbit
ERS-1	1991-2000	Europe	C	35 Days
JERS-1	1992-1998	Japan	L	44 Days
ERS-2	1995-2011	Europe	C	35 Days
Radarsat-1	1995-2007	Canada	C	24 Days
Envisat	2002-	Europe	C	35 Days
ALOS	2004-2011	Japan	L	46 Days
TerraSAR-X	2005-	Germany/Astrium	X	10 Days
Radarsat-2	2007-	Canada/MDA	C	24 Days
Sentinel-1	2013	Europe	C	12 Days
DESDynI	2018?	USA	L	8 Days

- **Cannot perform InSAR across different satellite platforms except for ERS 1/2.**
- **Shorter repeat orbit periods results in less overlap between adjacent tracks.**
- **L-band penetrates vegetation, C/X-band are unable to penetrate all vegetation.**
- **TerraSAR-X provides higher resolution imagery as compared with other missions.**

****** User must have strategy to transition from one platform to the next ******

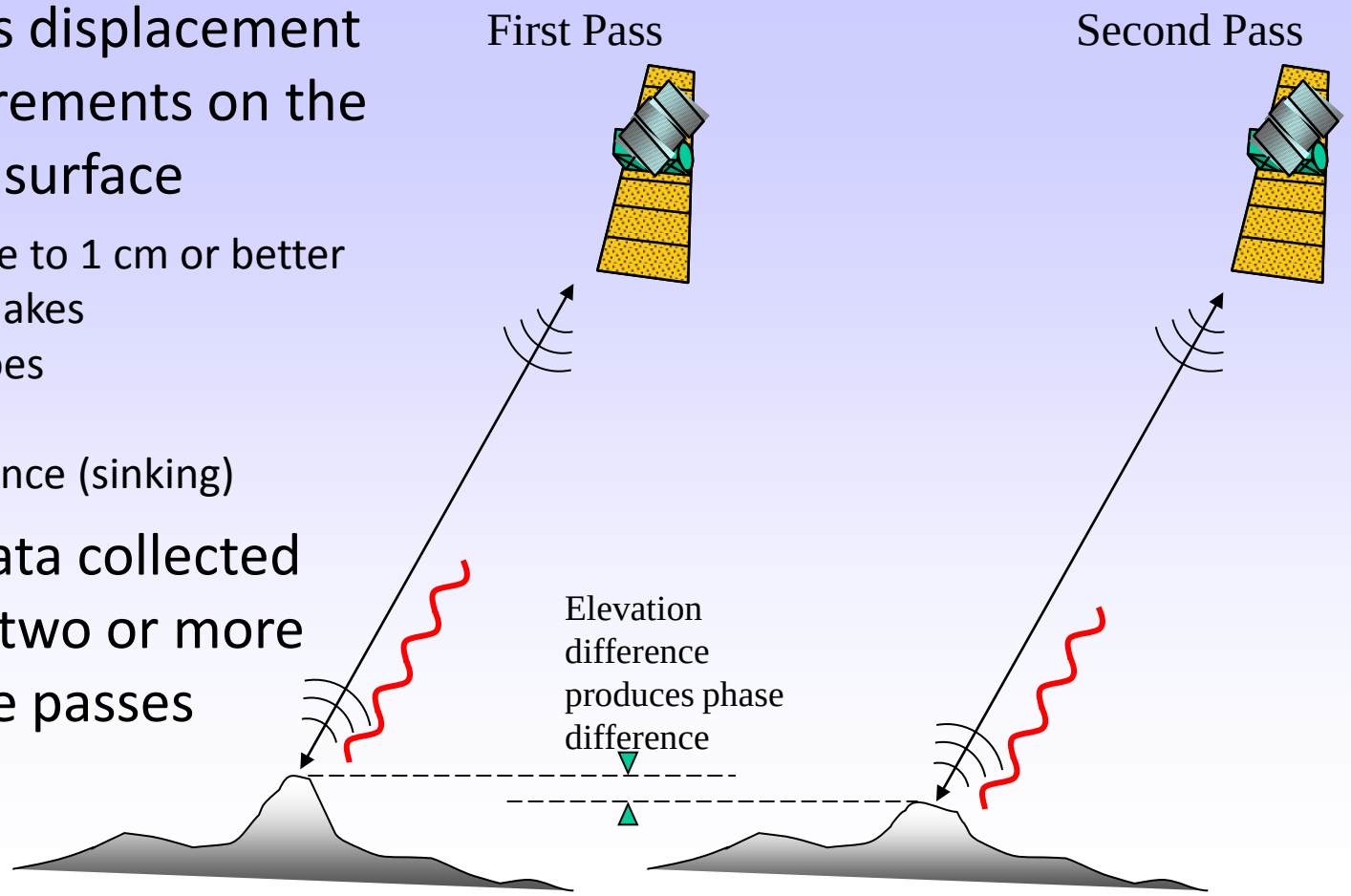
- **Continue acquiring data from older platform while acquiring data from newer mission.**
- **Careful selection of imaging modes.**

Synthetic Aperture Radar Interferometry (DiffSAR)

Enables displacement measurements on the Earth's surface

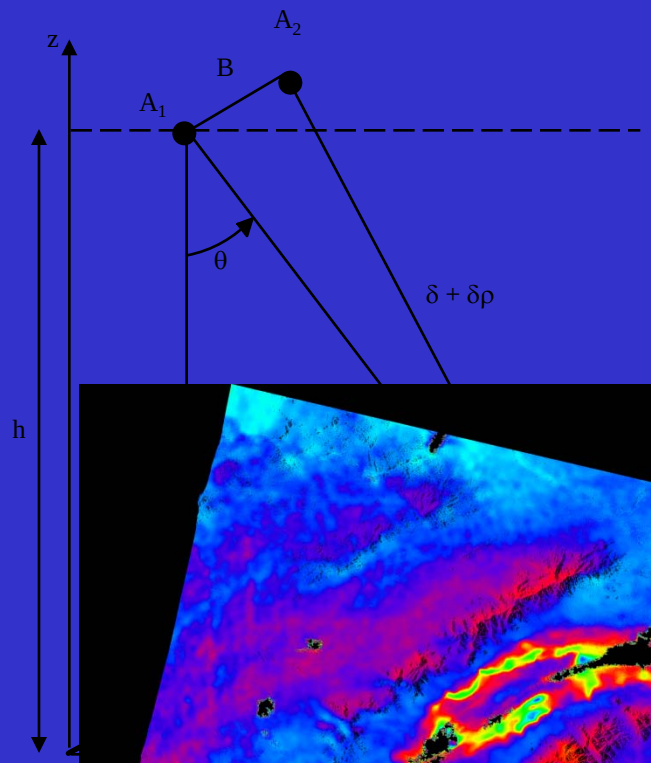
- Accurate to 1 cm or better
- Earthquakes
- Volcanoes
- Ice
- Subsidence (sinking)

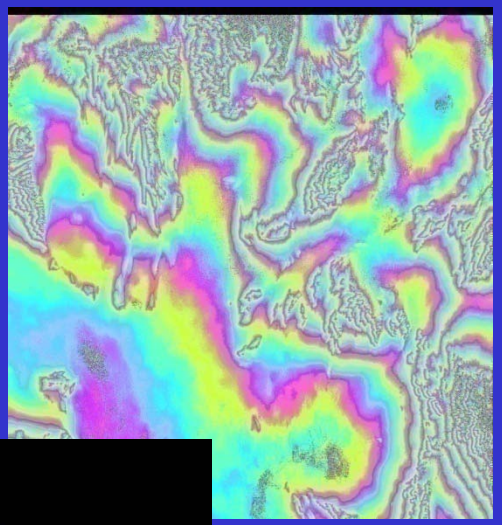
Uses data collected during two or more satellite passes

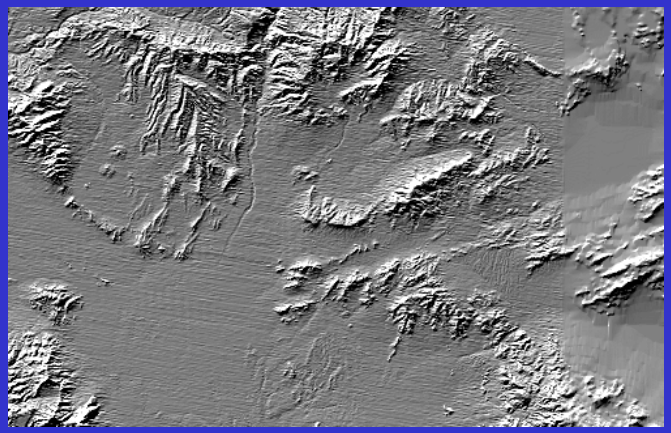


Slide Courtesy of the Vexcel Corporation

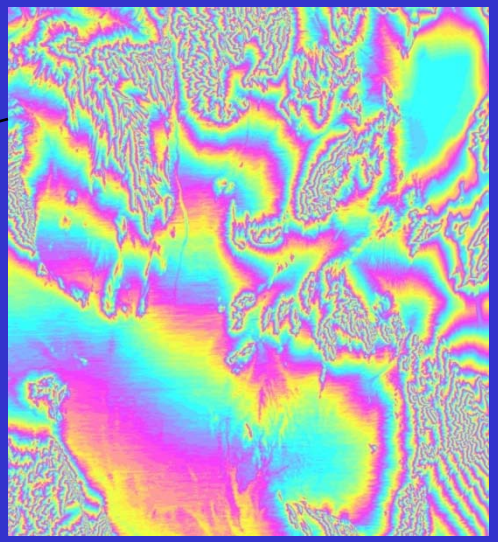
2-pass ERS, 11 month separation

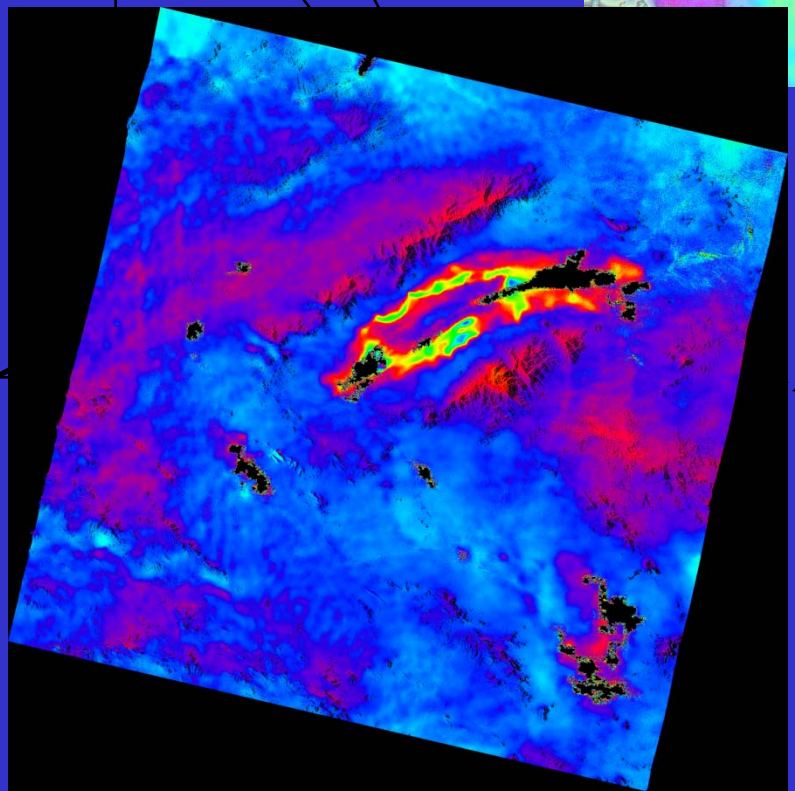


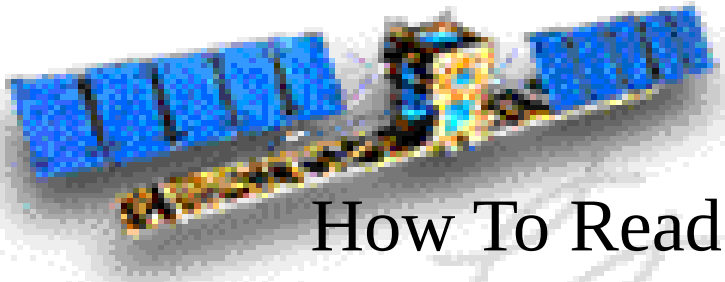




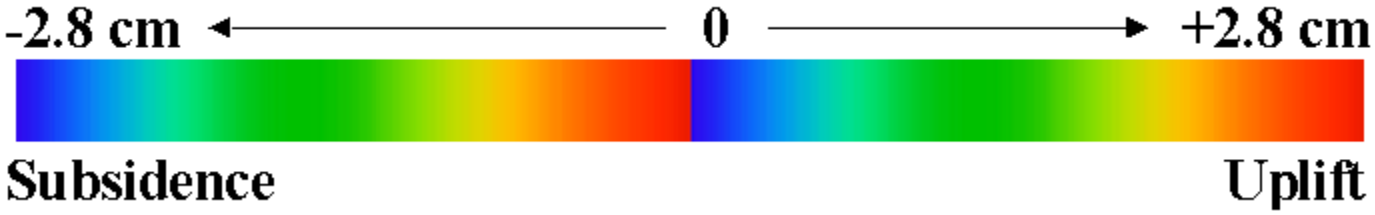
Simulate Phase from DEM







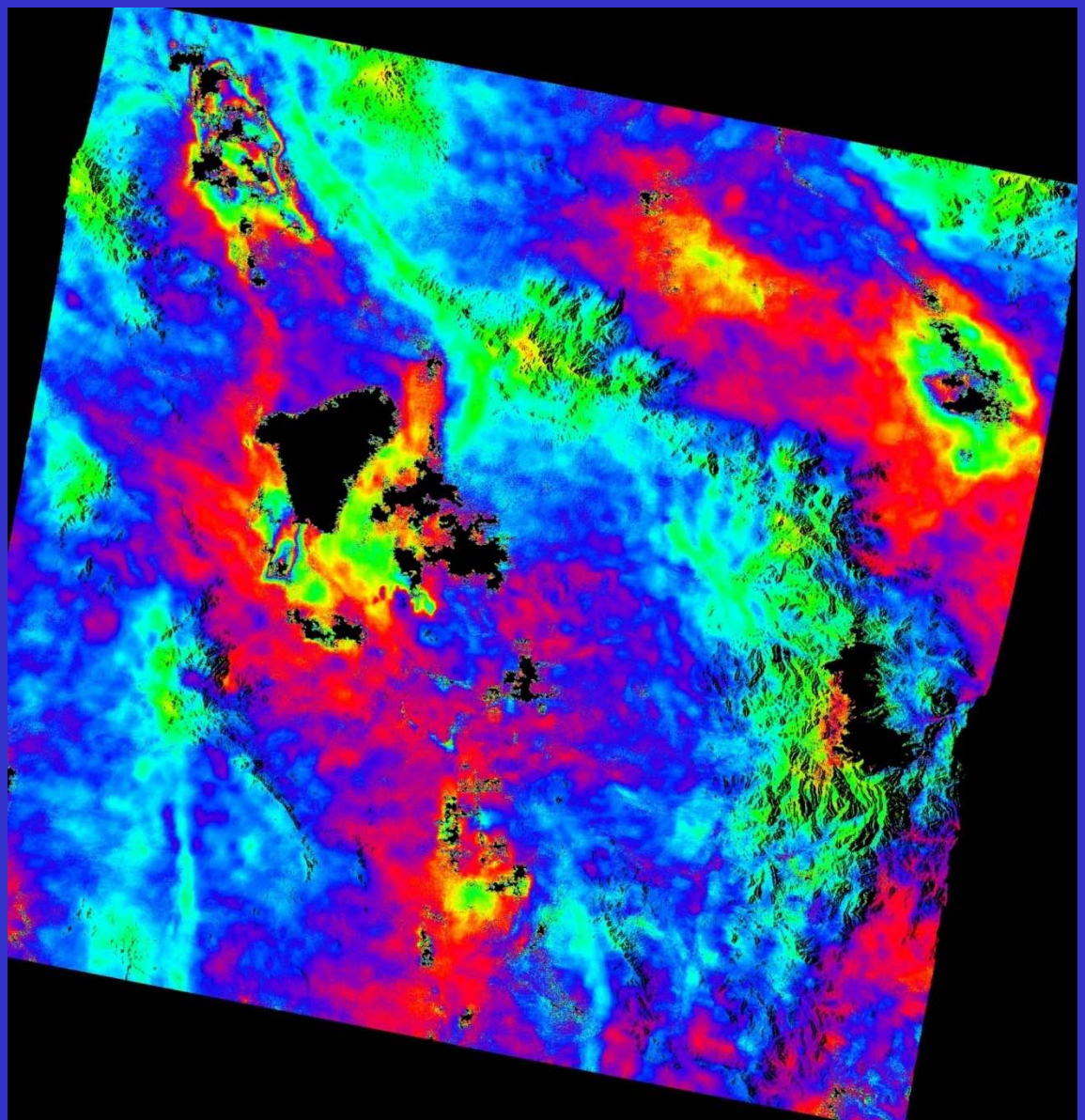
How To Read An Interferogram
Explanation of the Interferogram Color Sequence



- Start on the outside of the color fringe pattern
- Count the number of color cycles to the center
- Each color cycle represents 2.8 cm of deformation (uplift or subsidence)

Do You See Any Areas of Deformation?

05/20/2008 to 10/07/2008 EnviSat Time-Series, Cochise County in Southeastern Arizona



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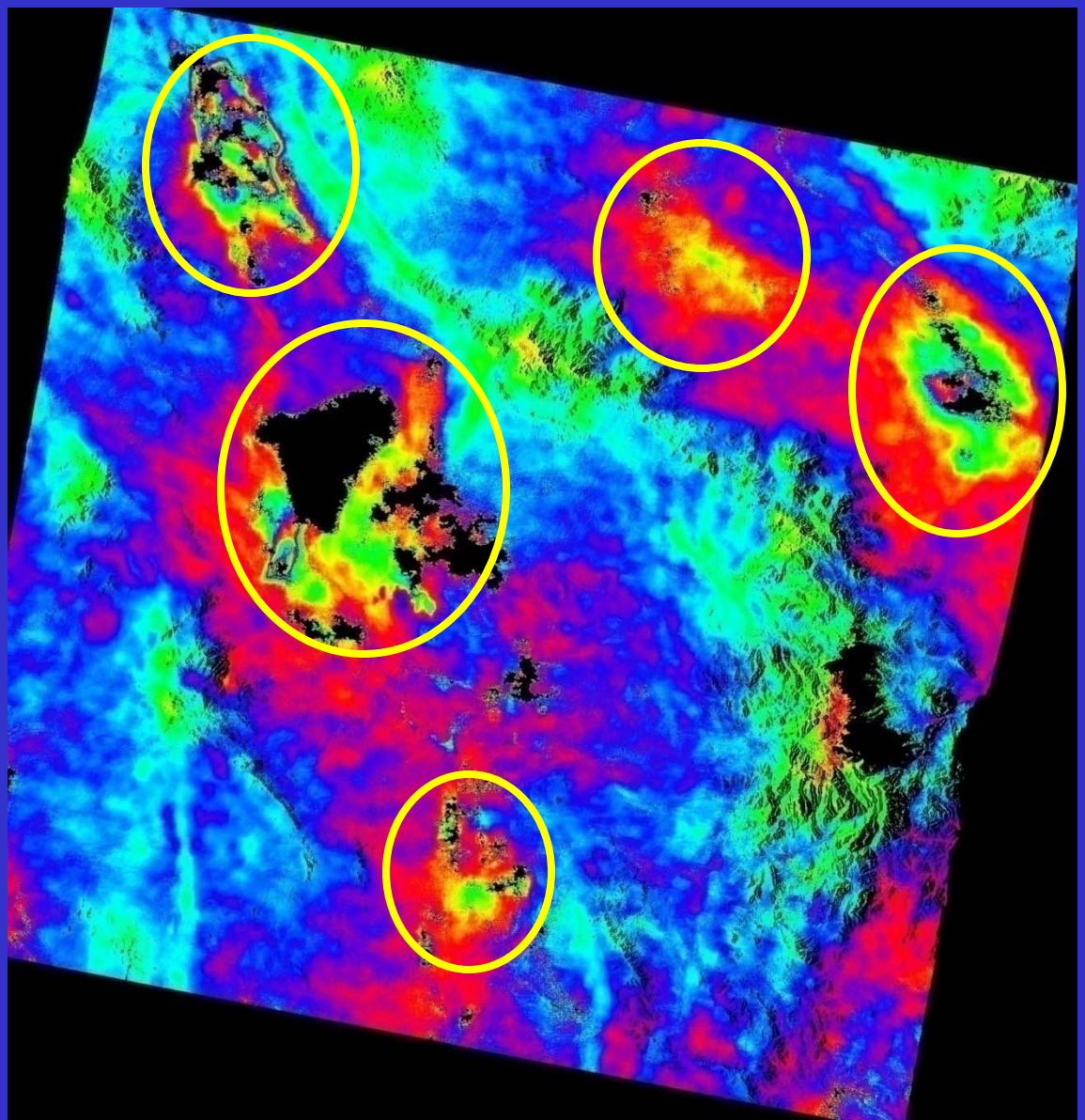
Is It Subsidence or Uplift?



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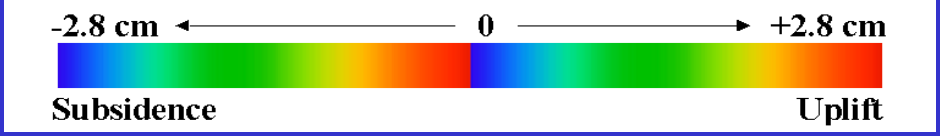

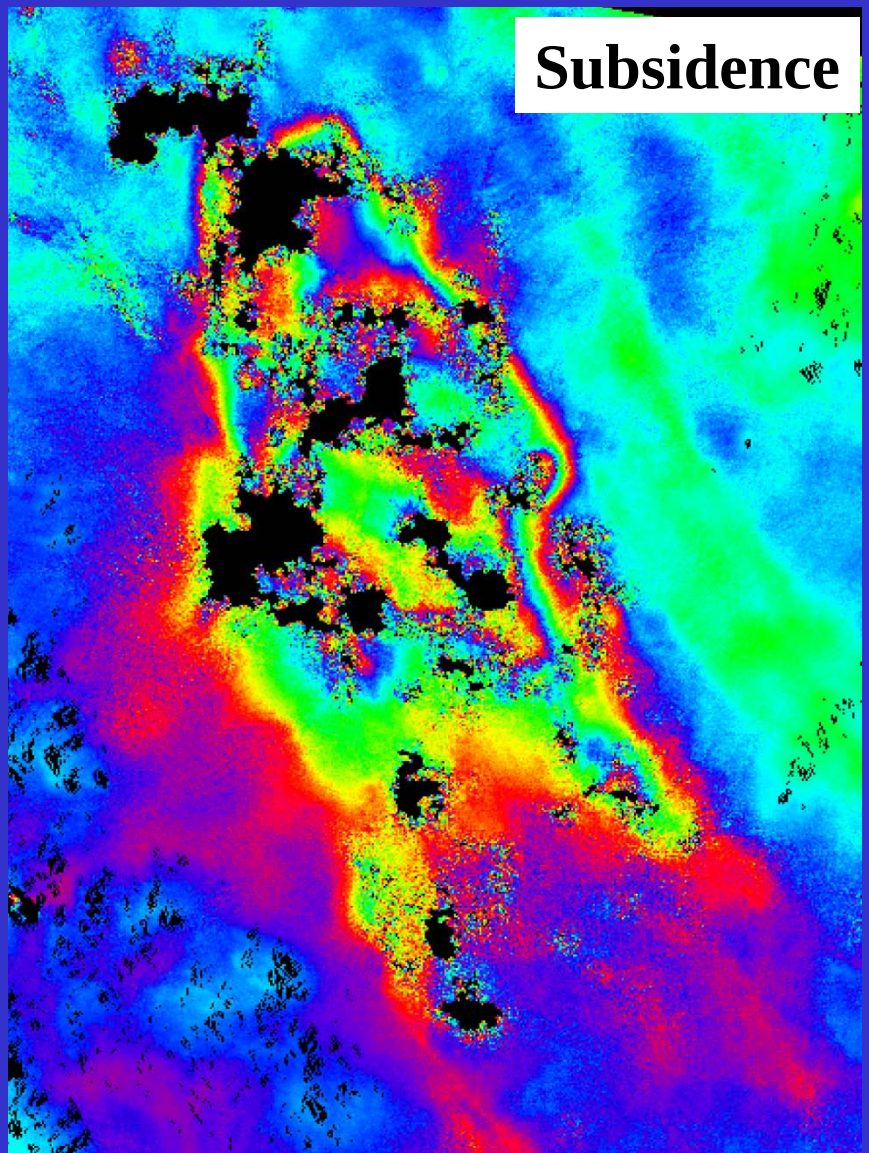

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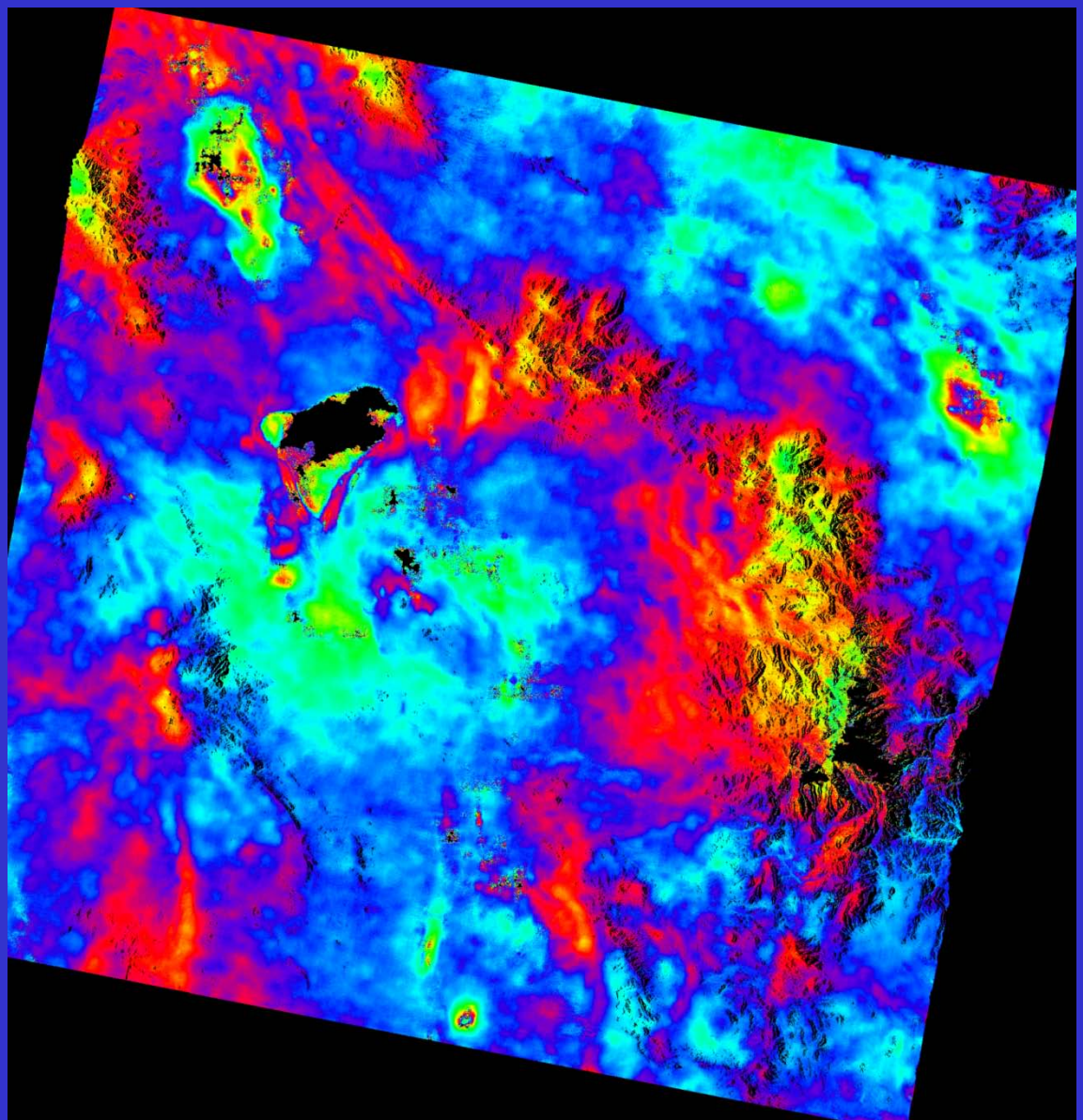

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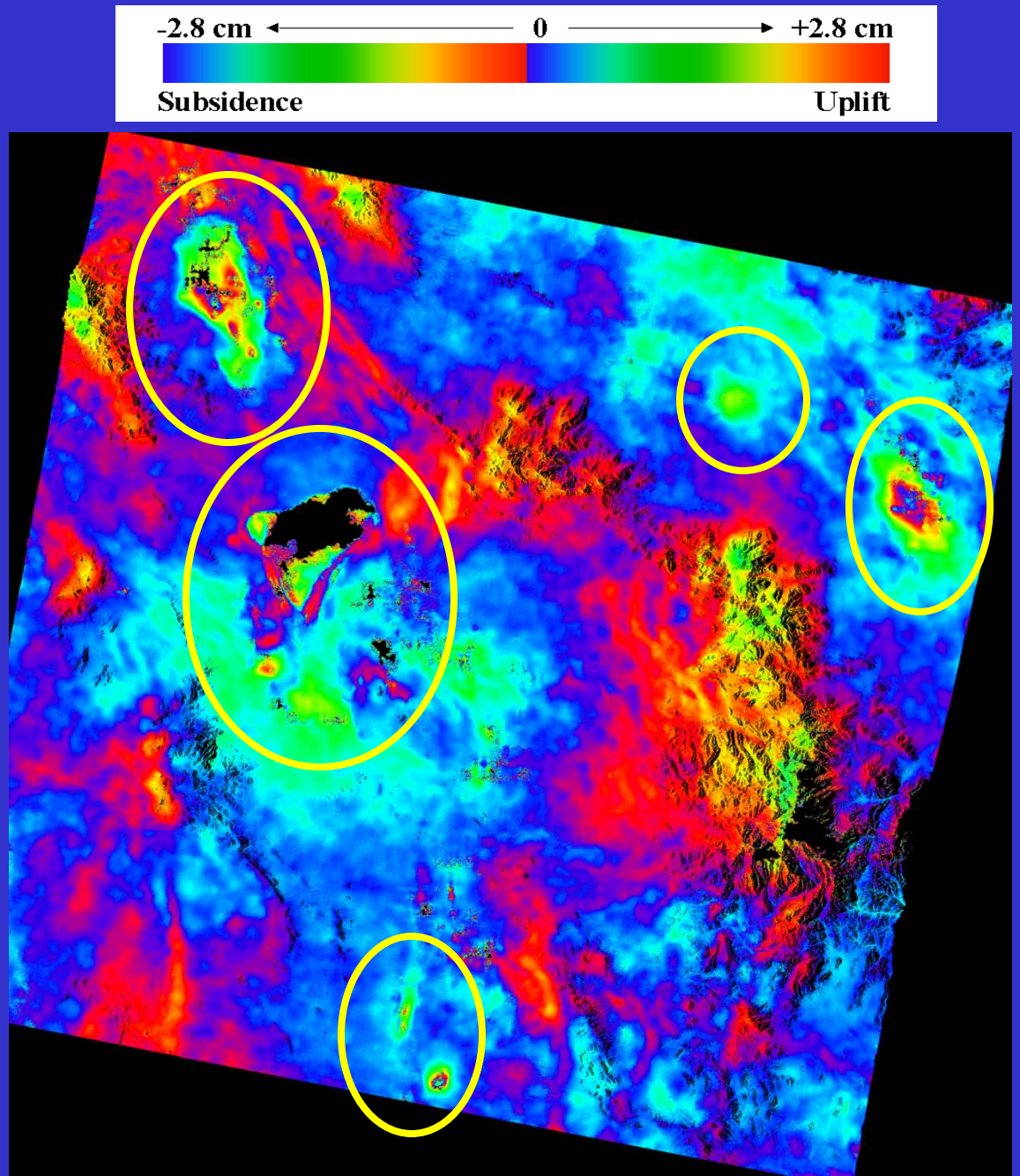
Is It Subsidence or Uplift?



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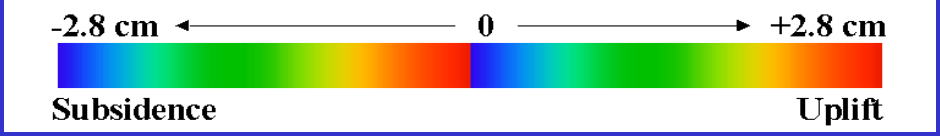
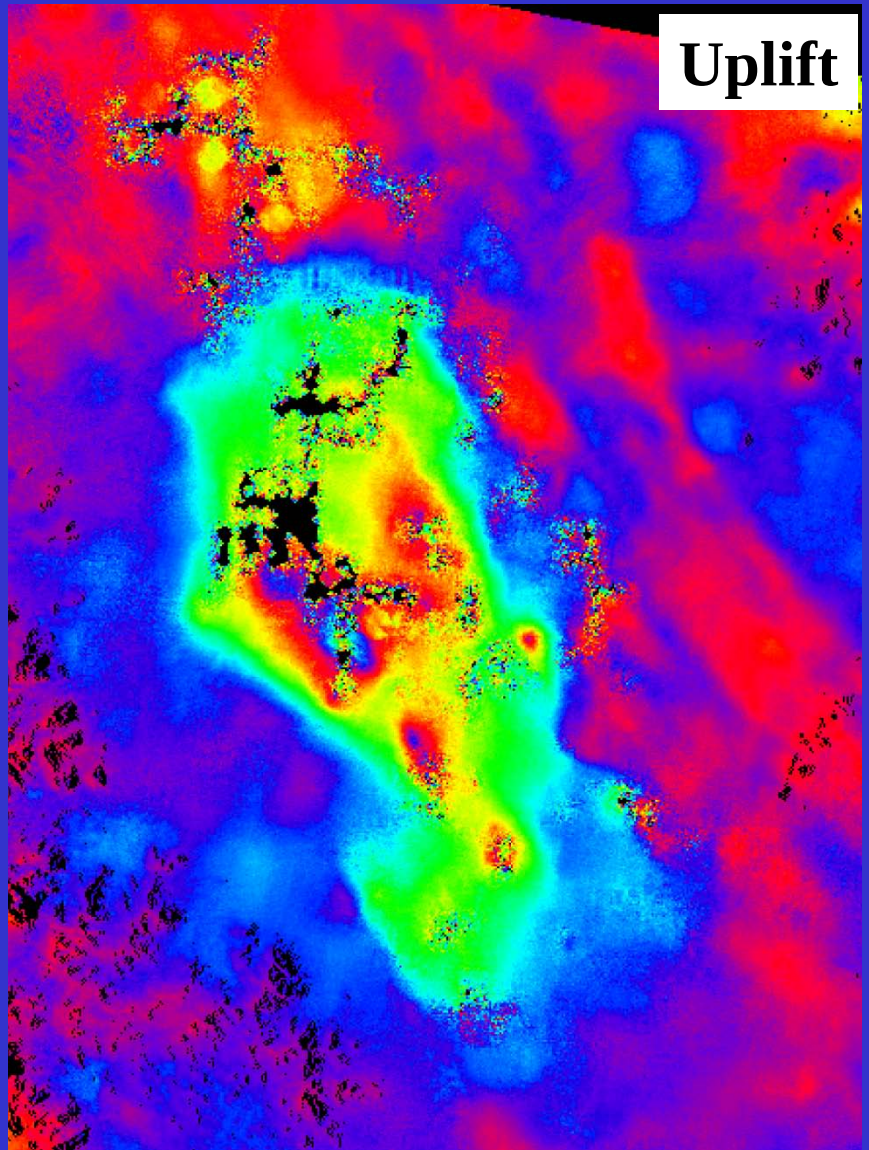
Is It Subsidence or Uplift?





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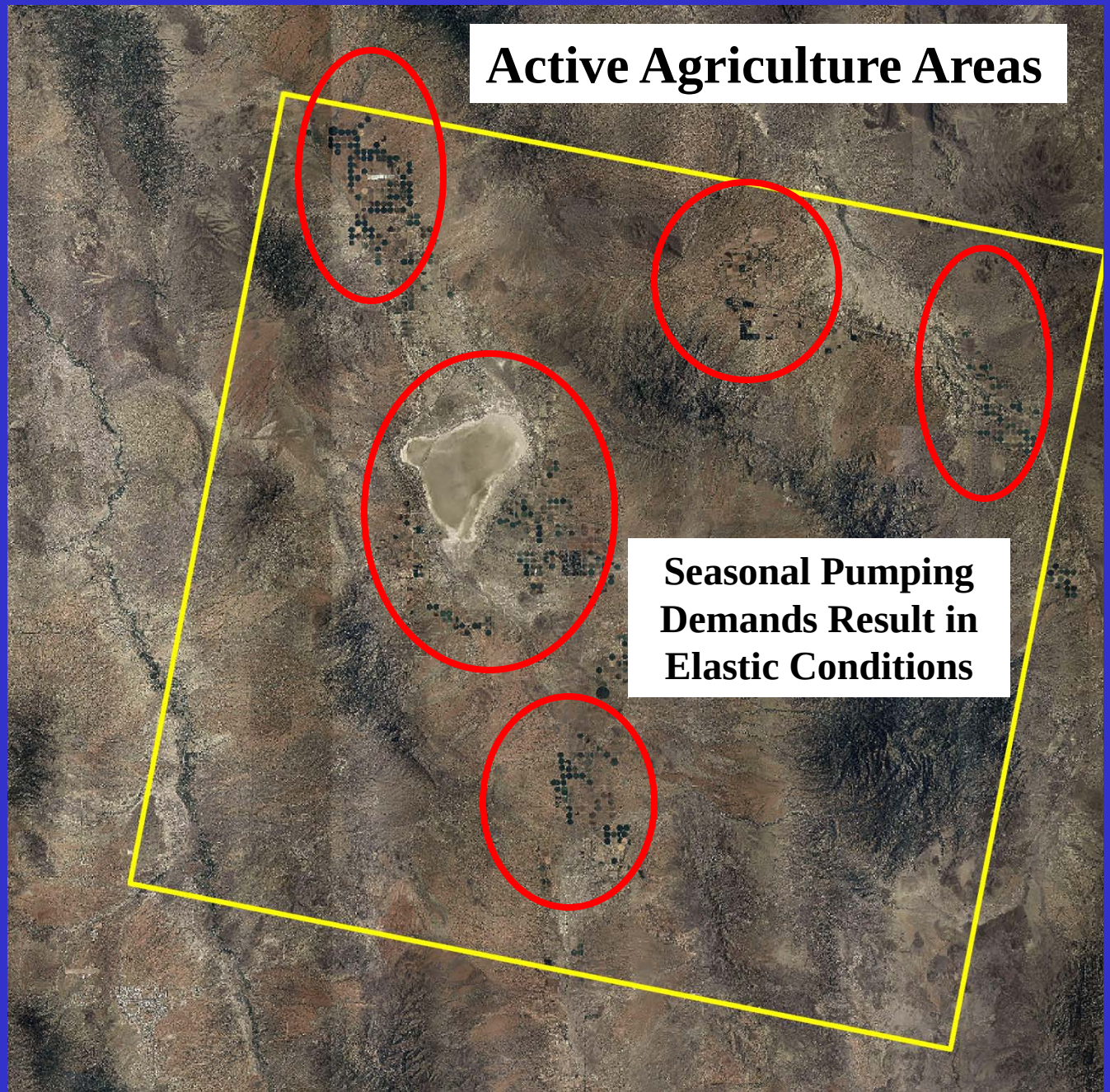
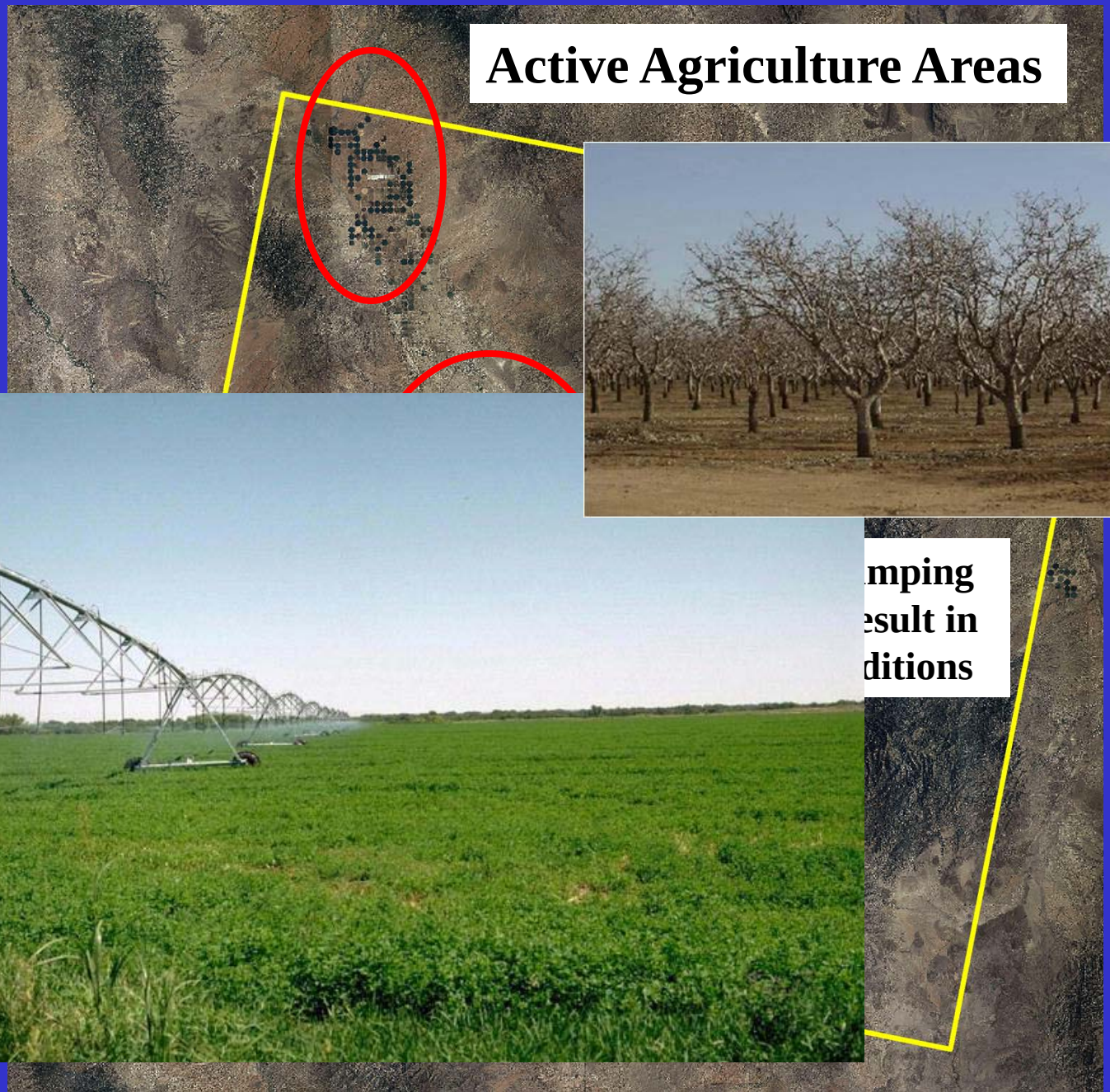
Why Subsidence and Uplift?



Why Subsidence and Uplift?



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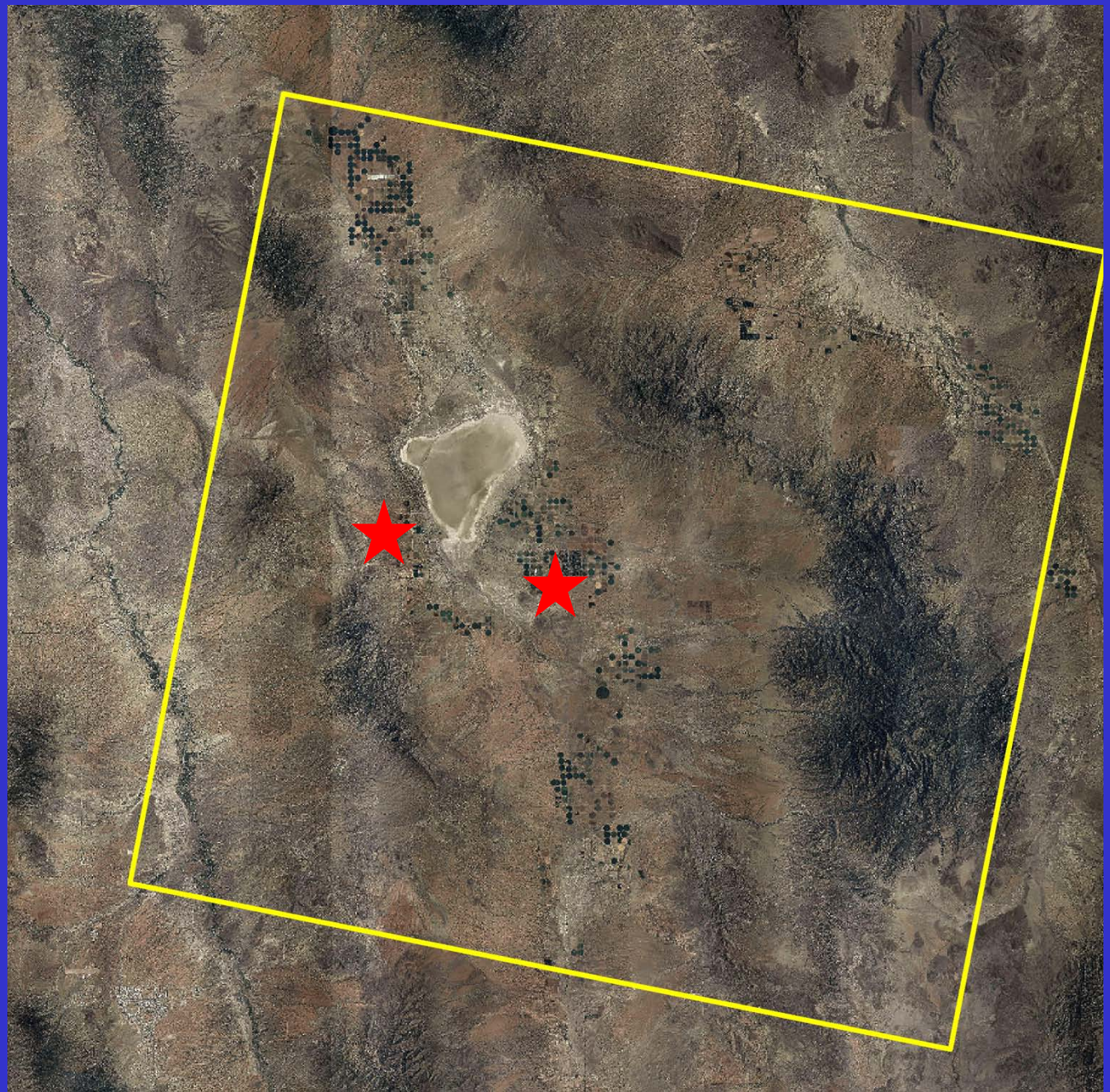
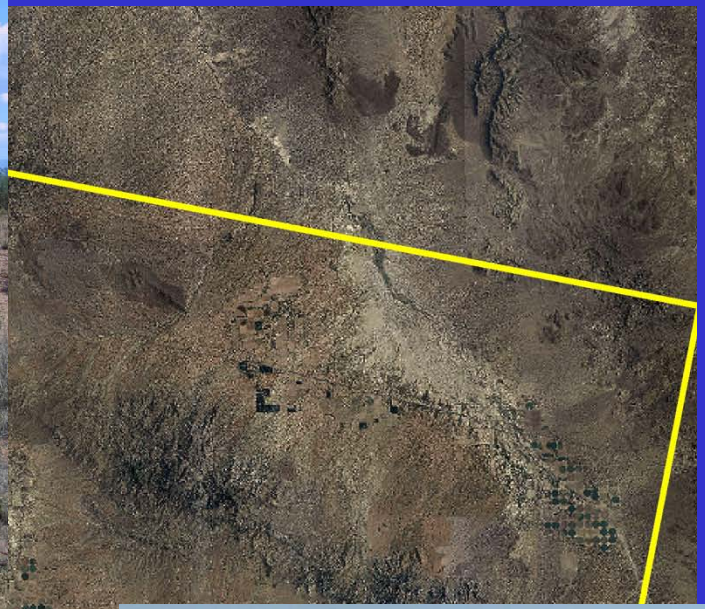
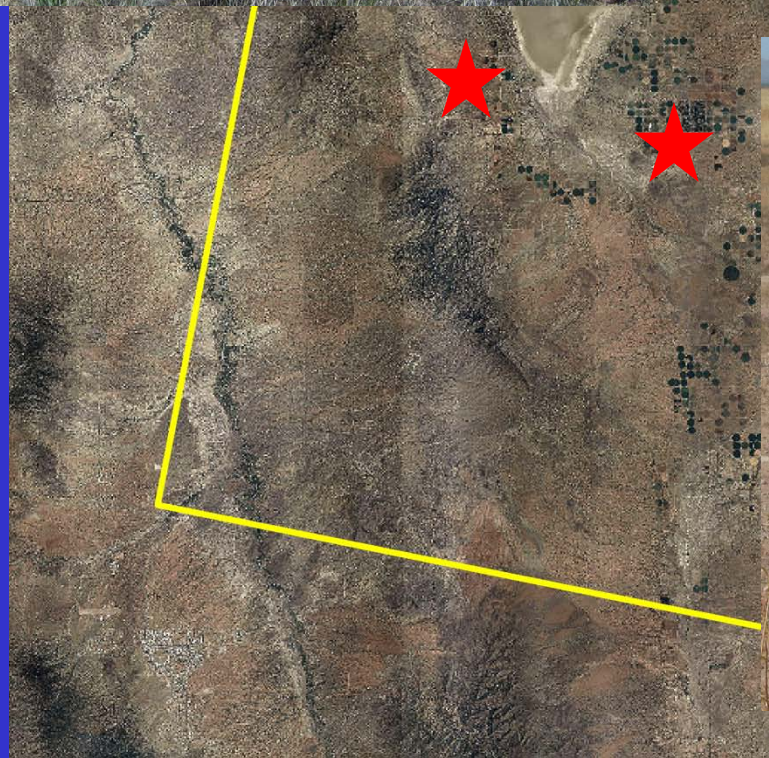
Evidence of Land Subsidence



Evidence of Land Subsidence





Land Subsidence Monitoring In Arizona Using InSAR

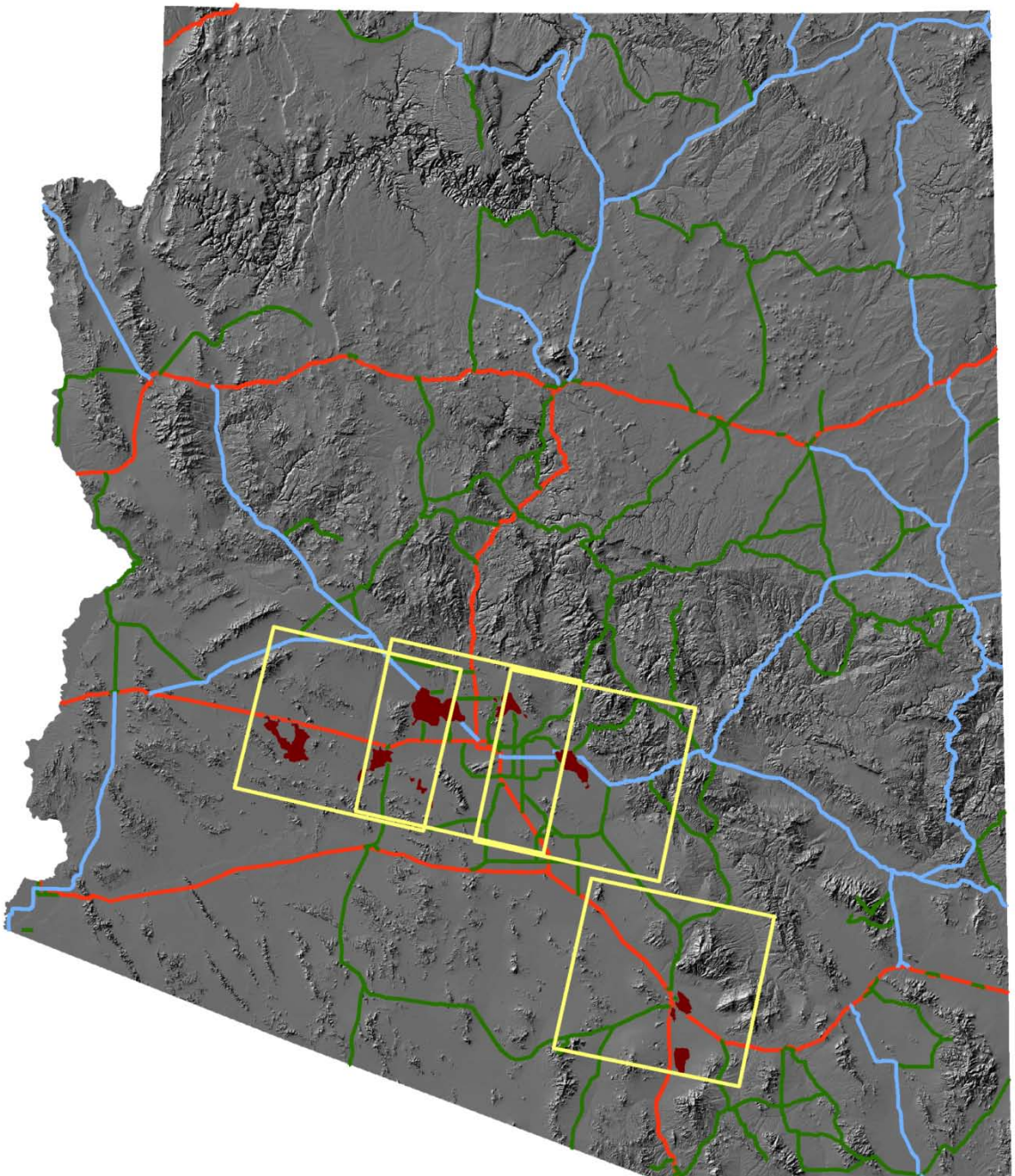
Started Looking At:

Phoenix and Tucson Metropolitan Areas

Using Four Satellite Frames

Identified Nine Subsidence Features

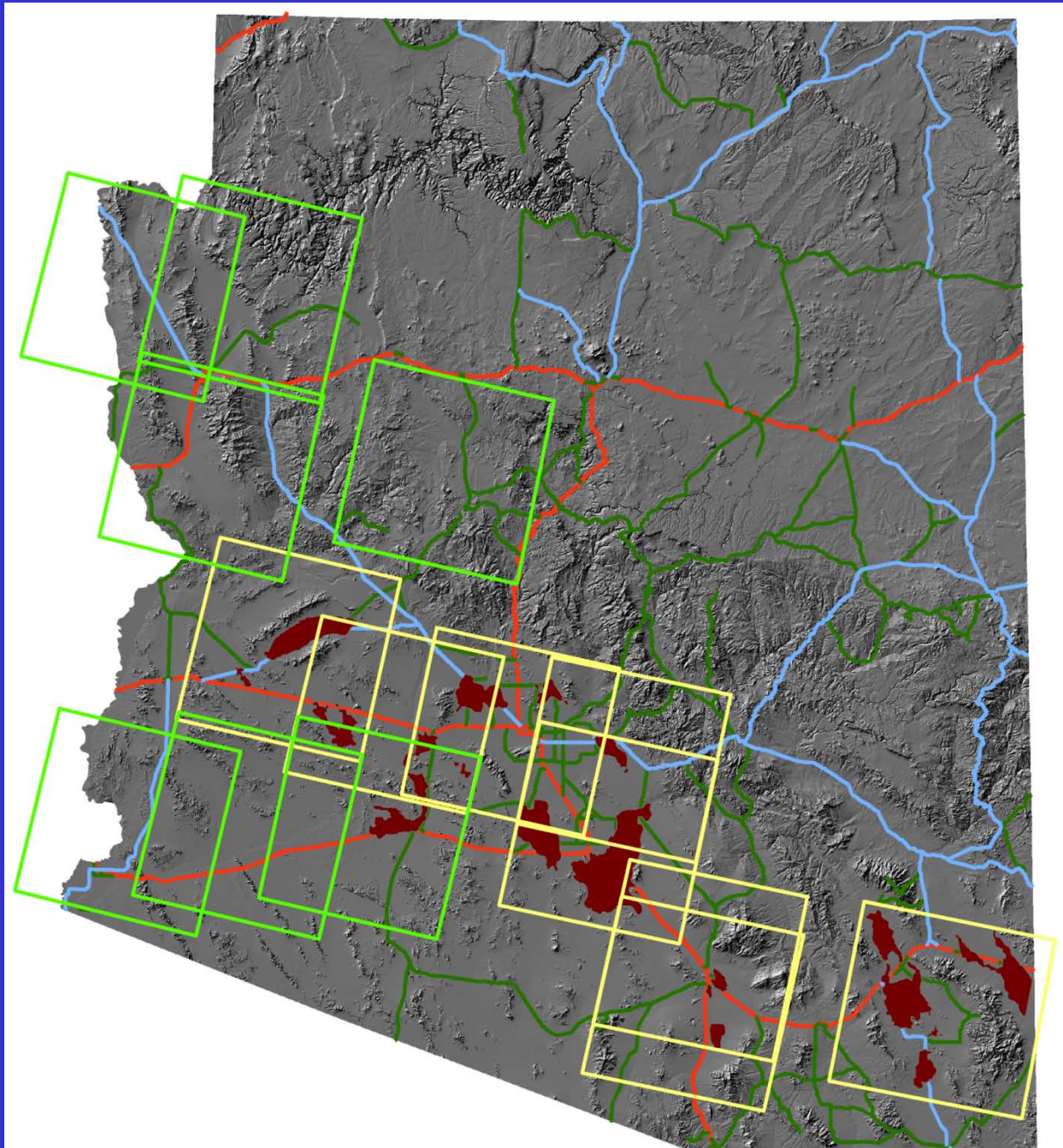
Started to monitor and collect InSAR data every month

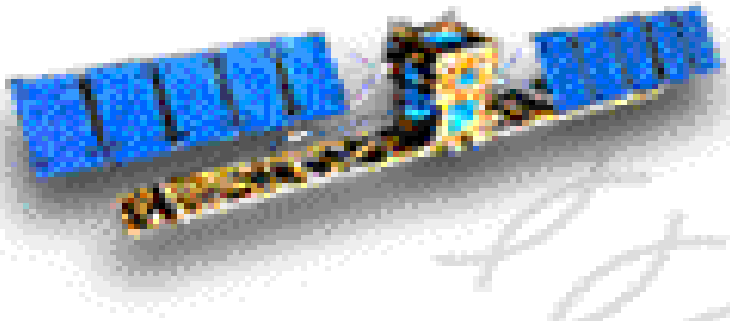


Land Subsidence Monitoring In Arizona Using InSAR

Expanded InSAR program through cooperative efforts and external funding.

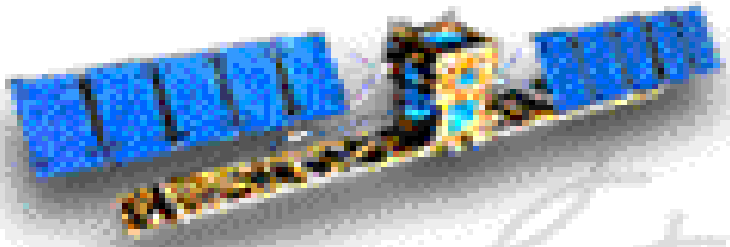
ADWR currently collects seven InSAR frames a month and have identified more than eighteen land subsidence features in Central and Southern Arizona





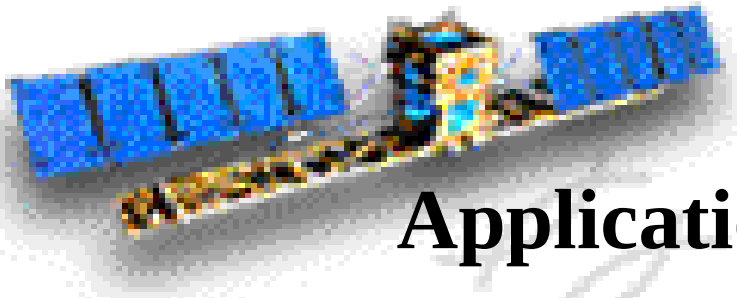
ADWR InSAR Program

Applications of InSAR



Cooperators Who Contribute to the ADWR InSAR Program

- Flood Control District of Maricopa County
- Pinal County Flood Control District
- Arizona Department of Transportation
- Arizona State Land Department
- Central Arizona Project
- Metropolitan Domestic Water Improvement District
- Salt River Project
- Community Water Company
- City of Scottsdale
- Cochise County

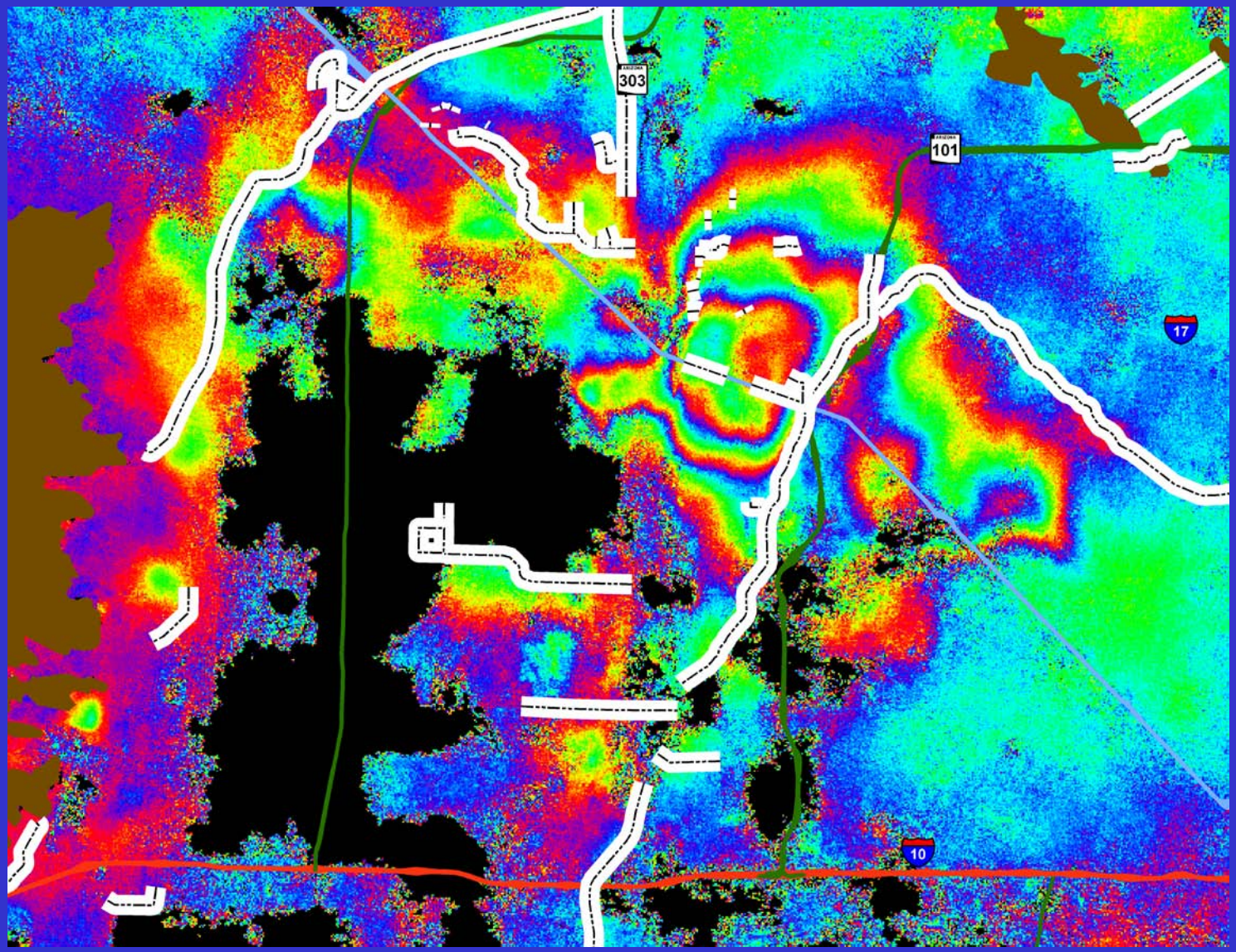


Applications of InSAR

- **Land subsidence monitoring.**
- **Monitoring seasonal deformation (subsidence and uplift).**
- **Monitoring natural and artificial recharge events.**
- **Geological mapping and investigations.**
- **Locating earth fissures and areas where conditions may exist for earth fissure formation.**
- **Dam mitigation and land subsidence modeling.**

InSAR Used For Land Subsidence Monitoring and Modeling Along A Flood Control Structure

FCDMC McMicken Dam, White Tank Mountains, 03/08/2004 To 02/11/2008



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InSAR Used For Land Subsidence Monitoring and Modeling Along A Flood Control Structure

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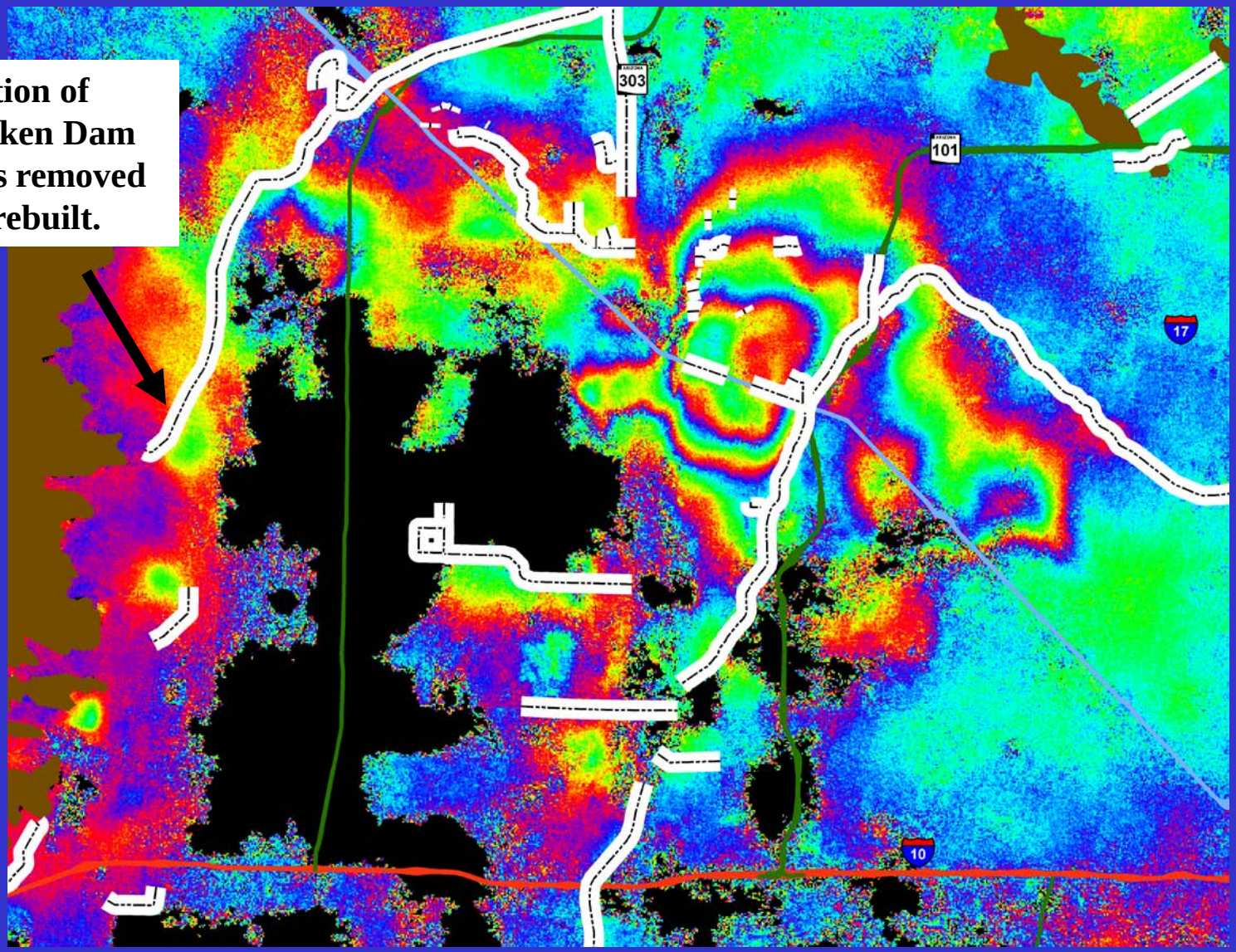

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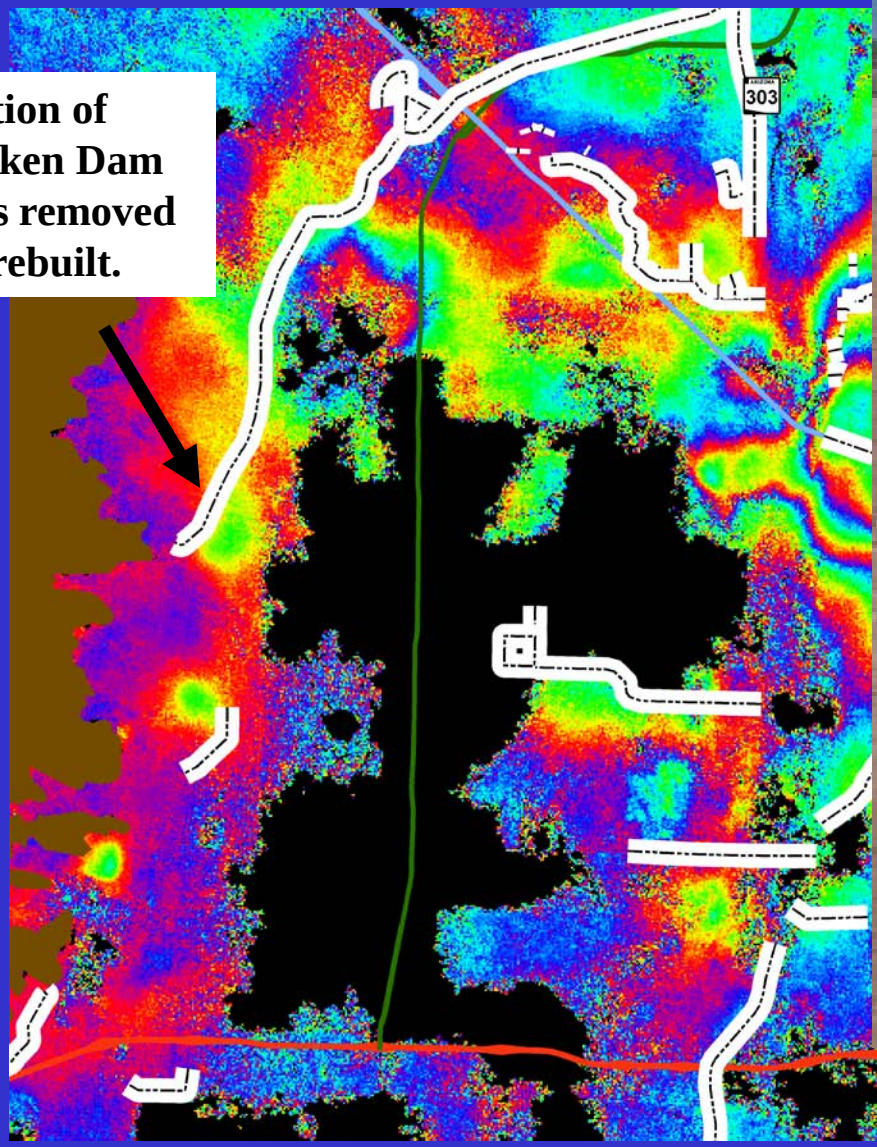
InSAR Used For Land Subsidence Monitoring and Modeling Along A Flood Control Structure

FCDMC McMicken Dam, White Tank Mountains, 03/08/2004 To 02/11/2008

Portion of McMicken Dam that was removed and rebuilt.



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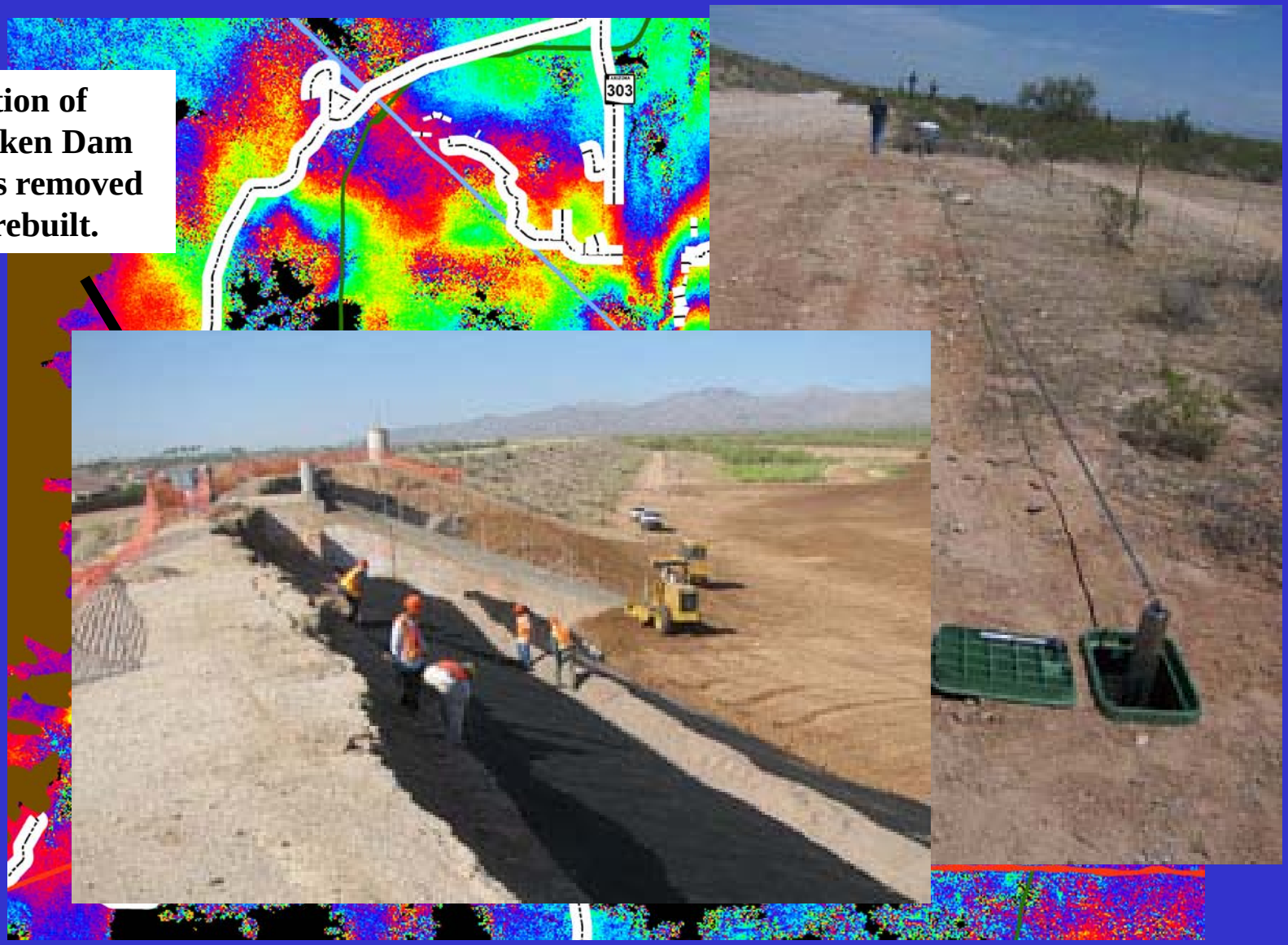

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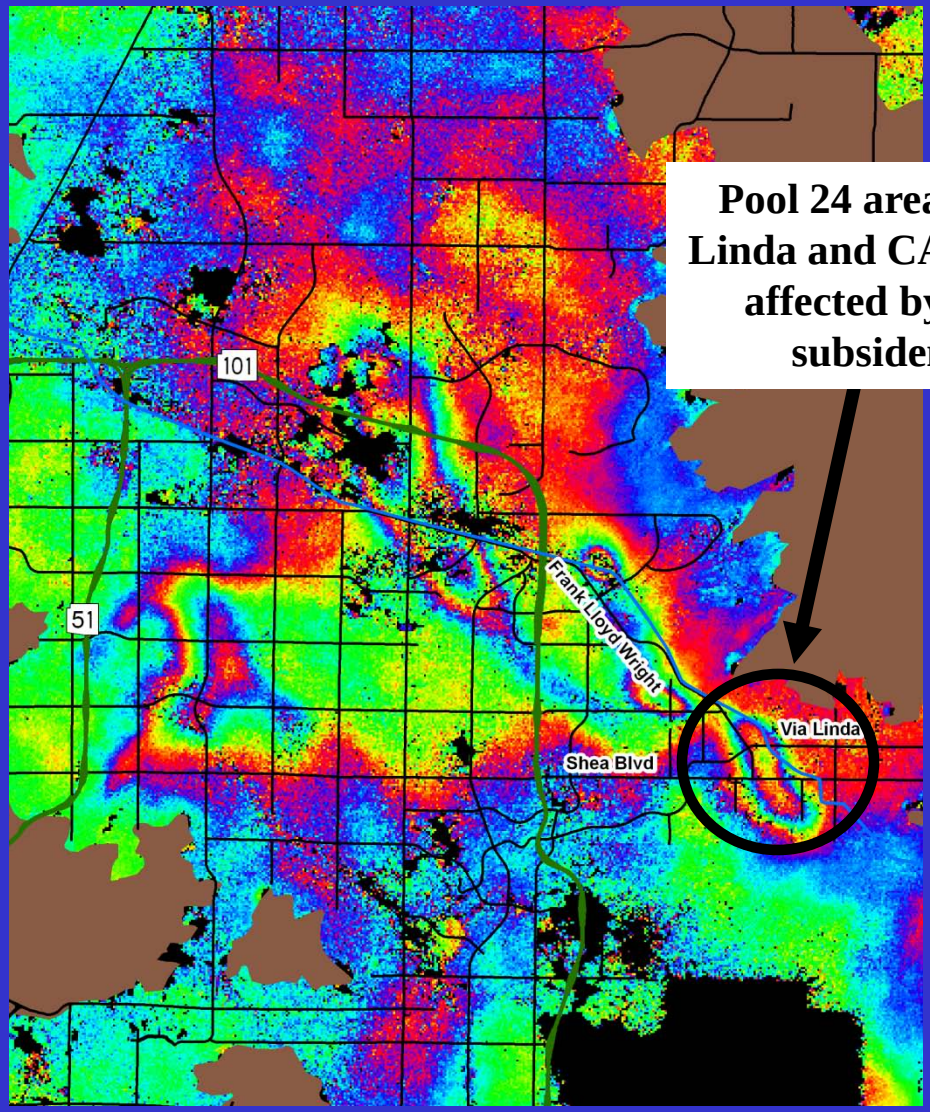
InSAR Used For Land Subsidence Monitoring and Modeling Along the Central Arizona Project Canal

CAP Canal Pool 23 and 24 Areas, NE Phoenix/Scottsdale, 07/10/1992 To 10/30/2000



Pool 24 area at Via Linda and CAP Canal affected by land subsidence

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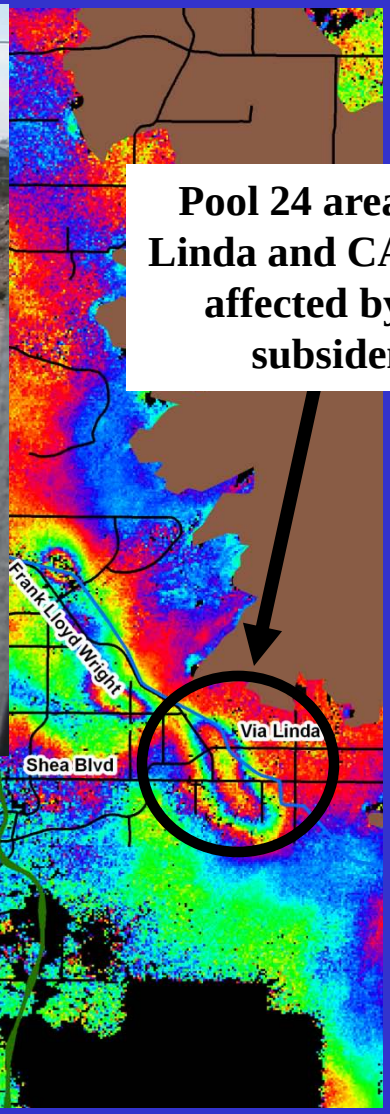
InSAR Used For Land Subsidence Monitoring and Modeling Along the Central Arizona Project Canal

CAP Canal Pool 23 and 24 Areas, NE Phoenix/Scottsdale, 07/10/1992 To 10/30/2000

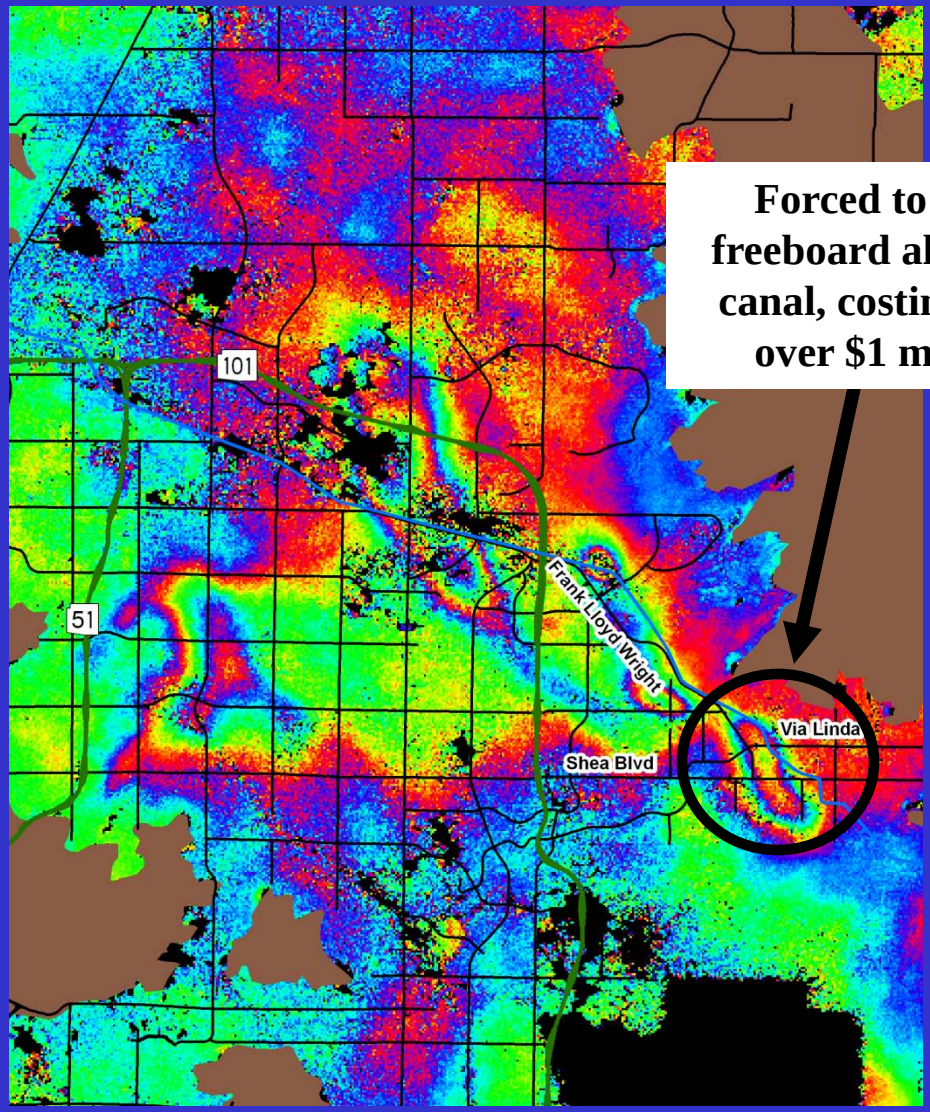


Pool 24 area at Via Linda and CAP Canal affected by land subsidence

© ESA 1992 - 2000

InSAR Used For Land Subsidence Monitoring and Modeling Along the Central Arizona Project Canal

CAP Canal Pool 23 and 24 Areas, NE Phoenix/Scottsdale, 07/10/1992 To 10/30/2000



Forced to raise freeboard along the canal, costing CAP over $1 million

© ESA 1992 - 2000

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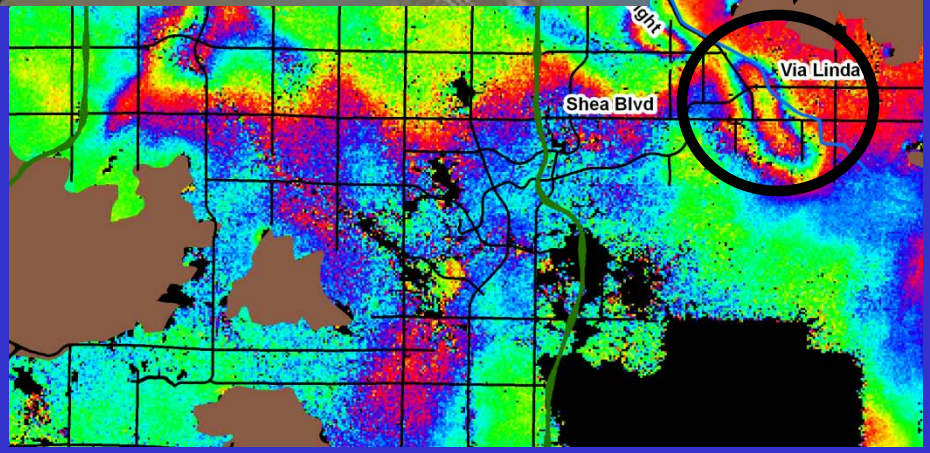

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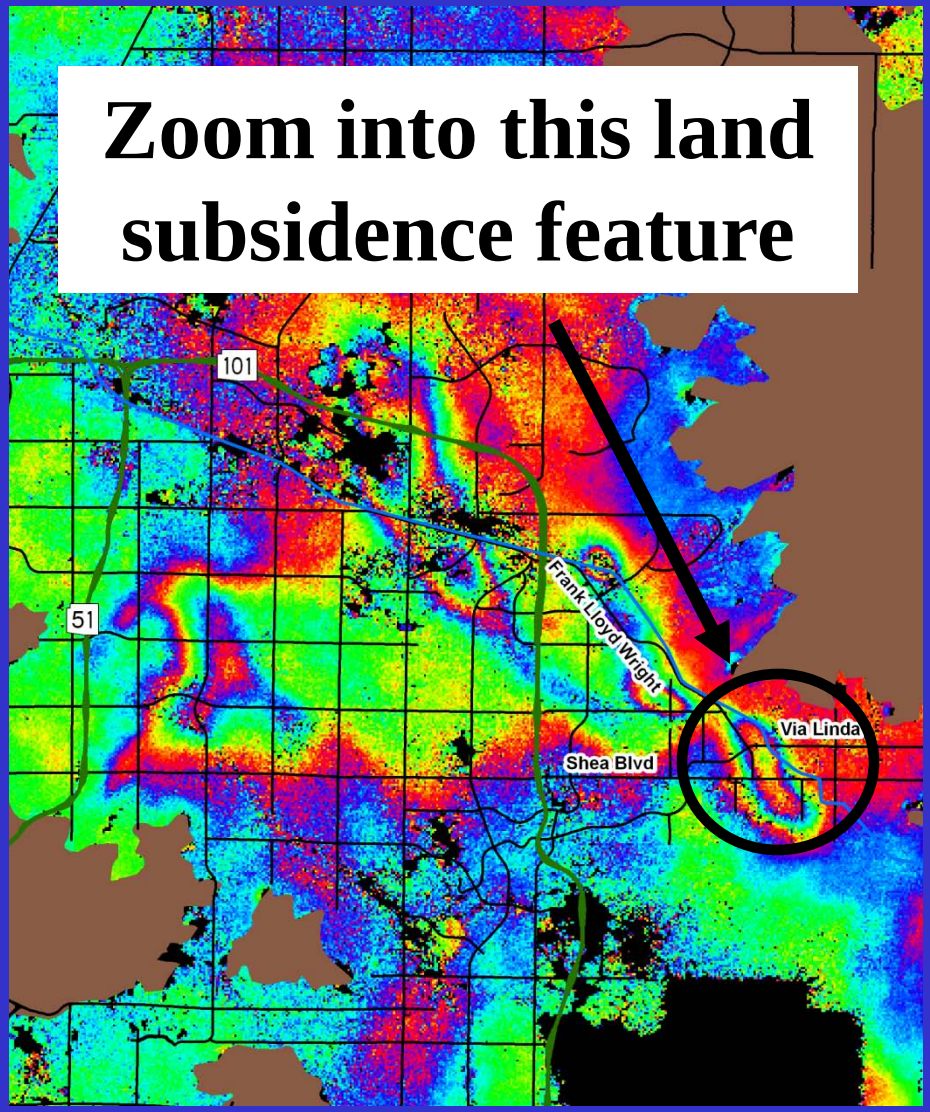

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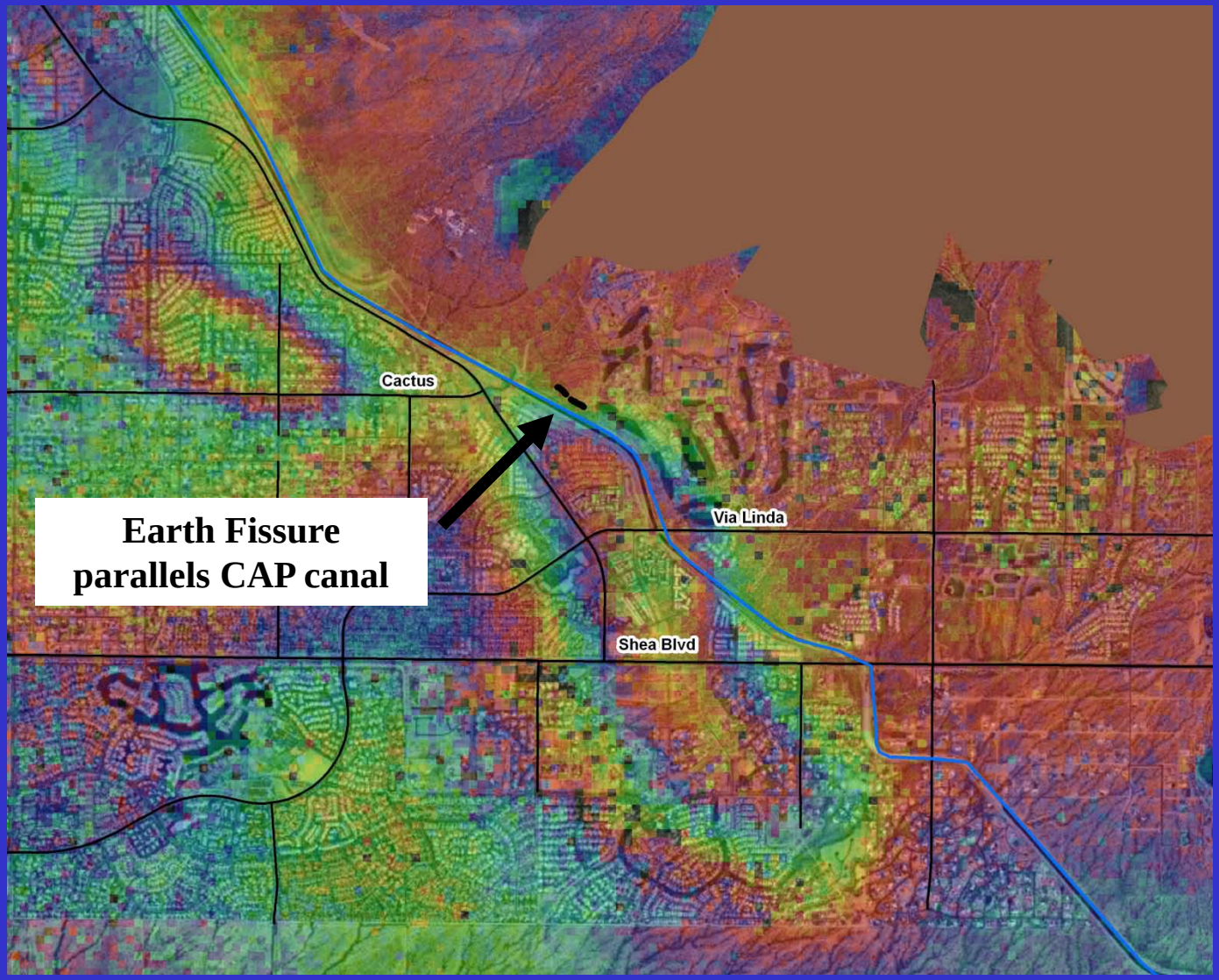

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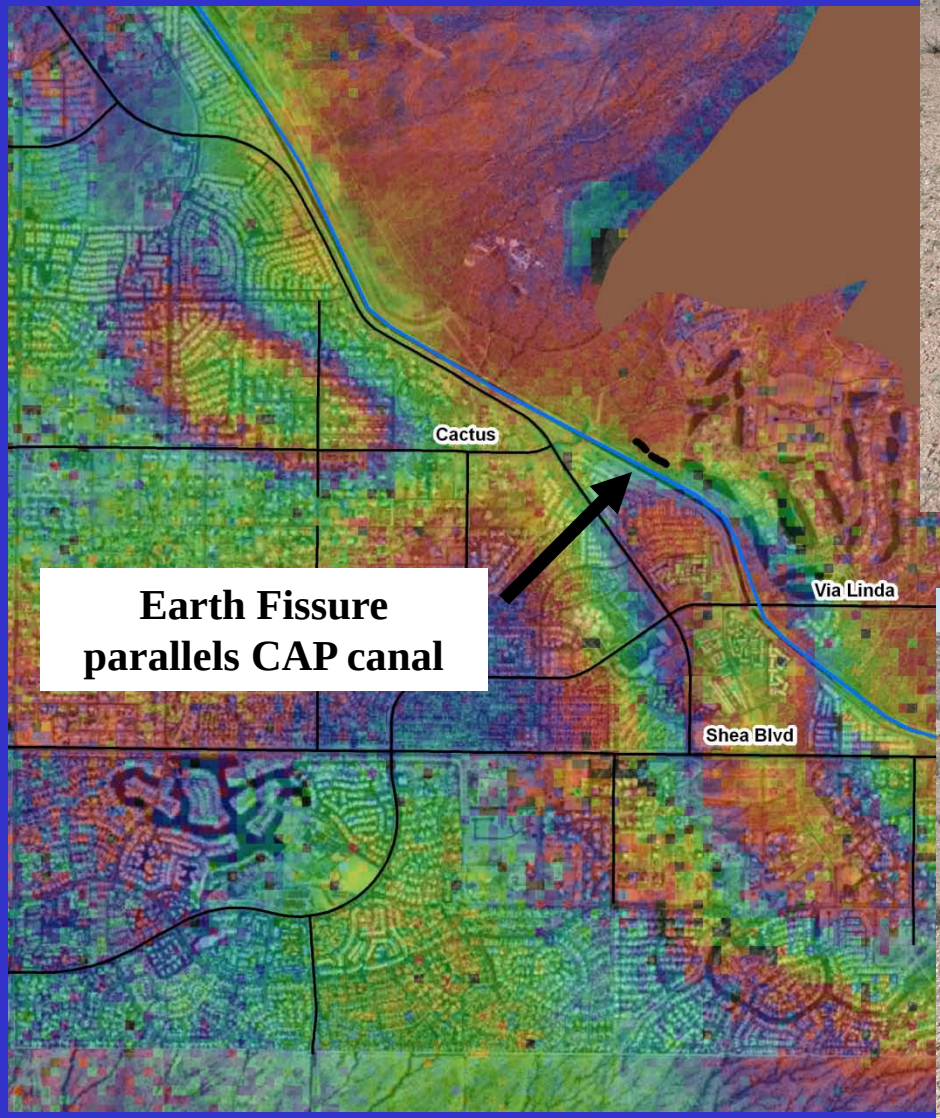
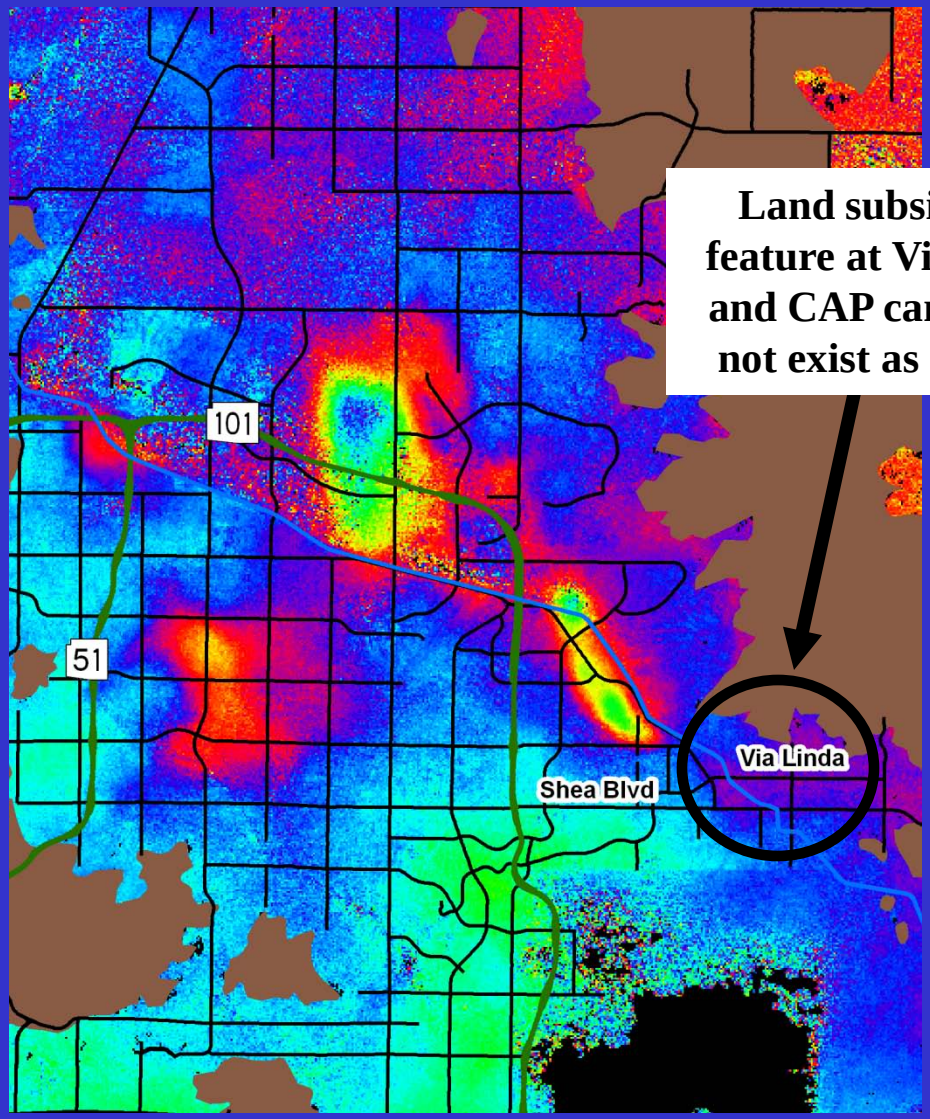
InSAR Used For Land Subsidence Monitoring and Modeling Along the Central Arizona Project Canal

CAP Canal Pool 23 and 24 Areas, NE Phoenix/Scottsdale, 07/10/1992 To 10/30/2000



InSAR Used For Land Subsidence Monitoring and Modeling Along the Central Arizona Project Canal

CAP Canal Pool 23 and 24 Areas, NE Phoenix/Scottsdale, 02/11/2008 to 02/15/2010



Land subsidence feature at Via Linda and CAP canal does not exist as of 2010

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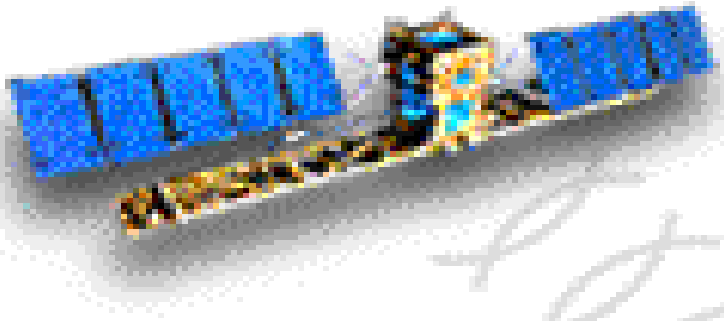
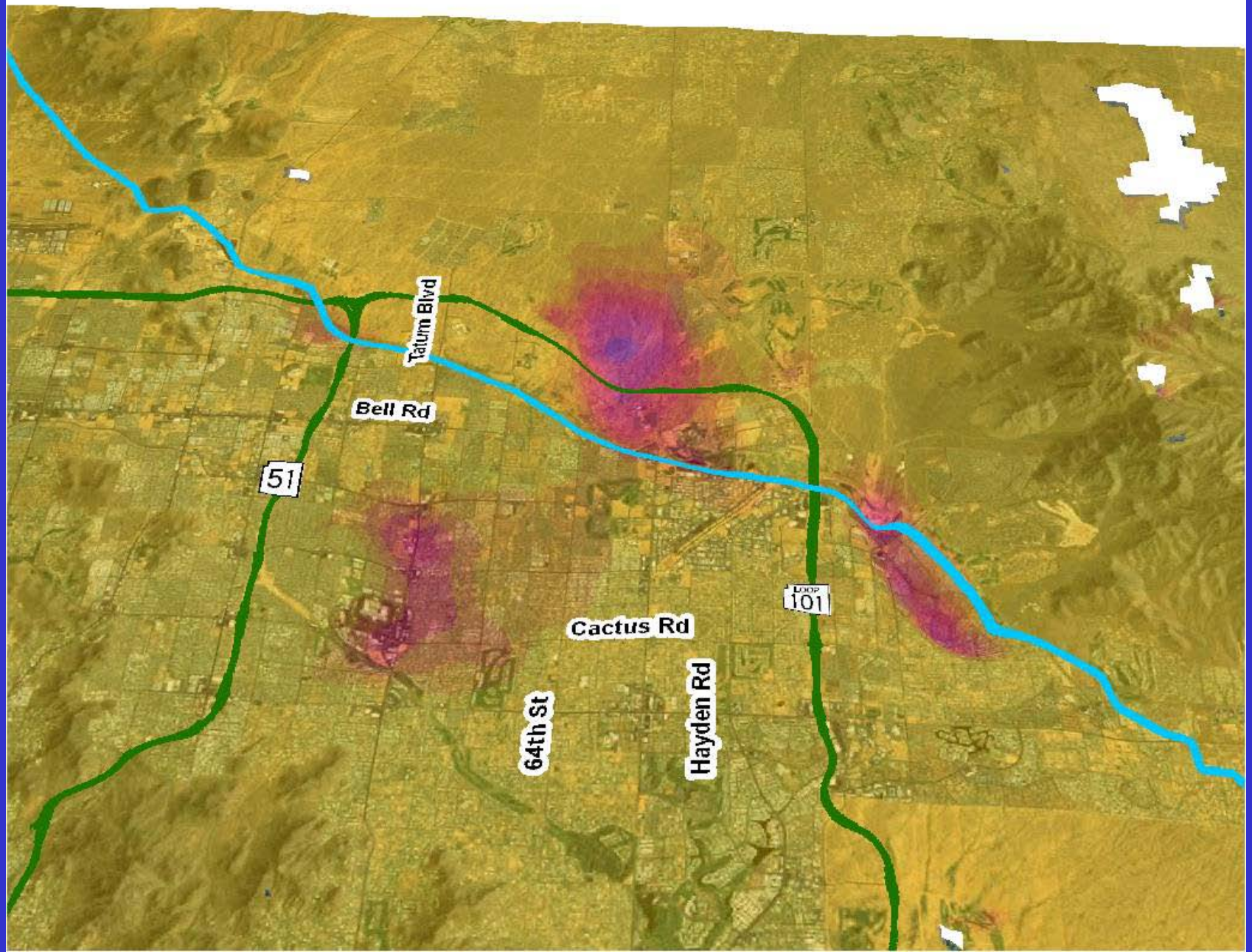
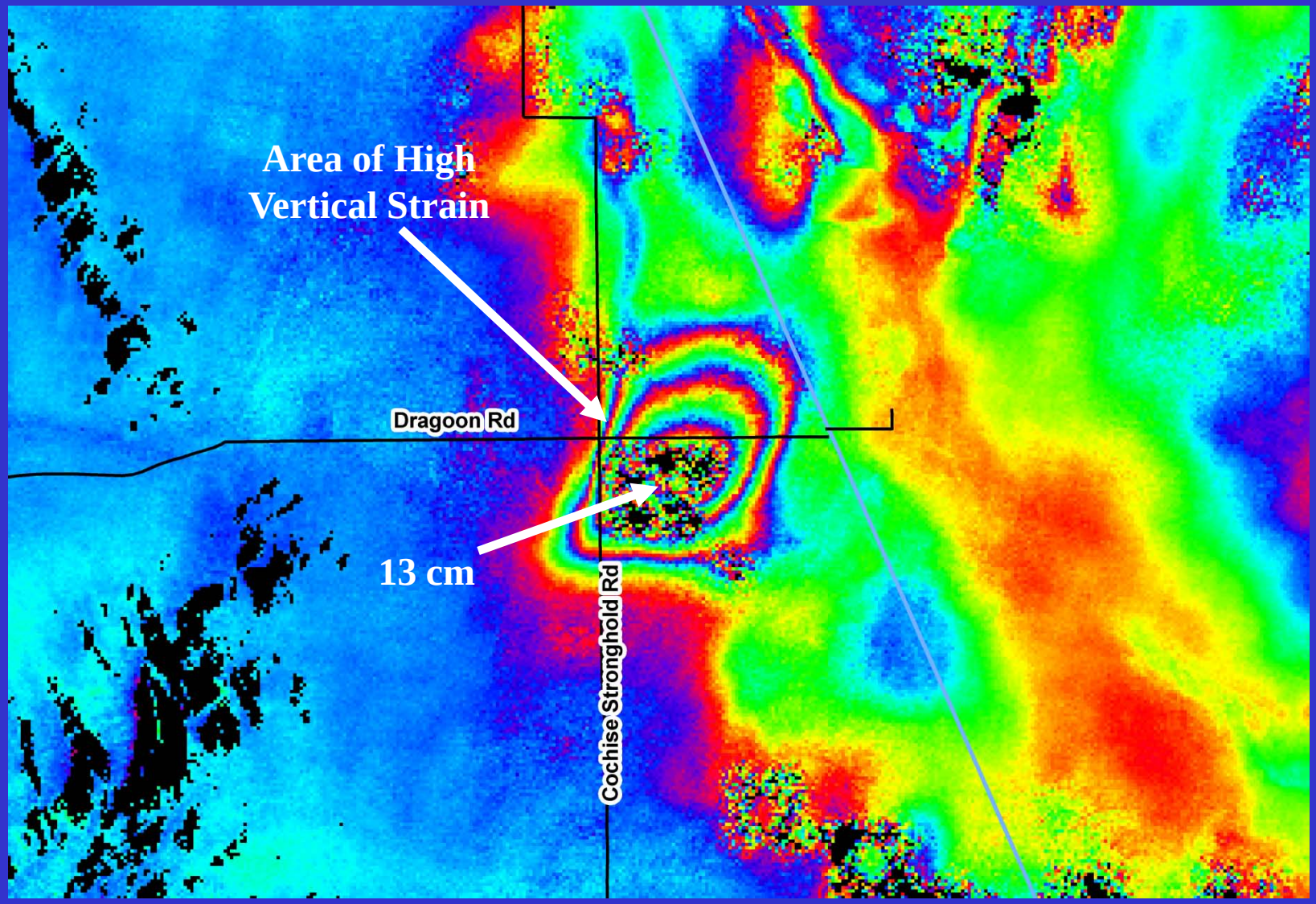


Virtual View of Land Subsidence for the Northeast Phoenix/Scottsdale Area in Maricopa County


Tatum Blvd
Bell Rd
51
Cactus Rd
101
64th St
Hayden Rd

InSAR Used For Earth Fissure Monitoring

Willcox Basin/Cochise County, 10 miles southwest of the Town of Willcox 01/20/2009 To 01/05/2010



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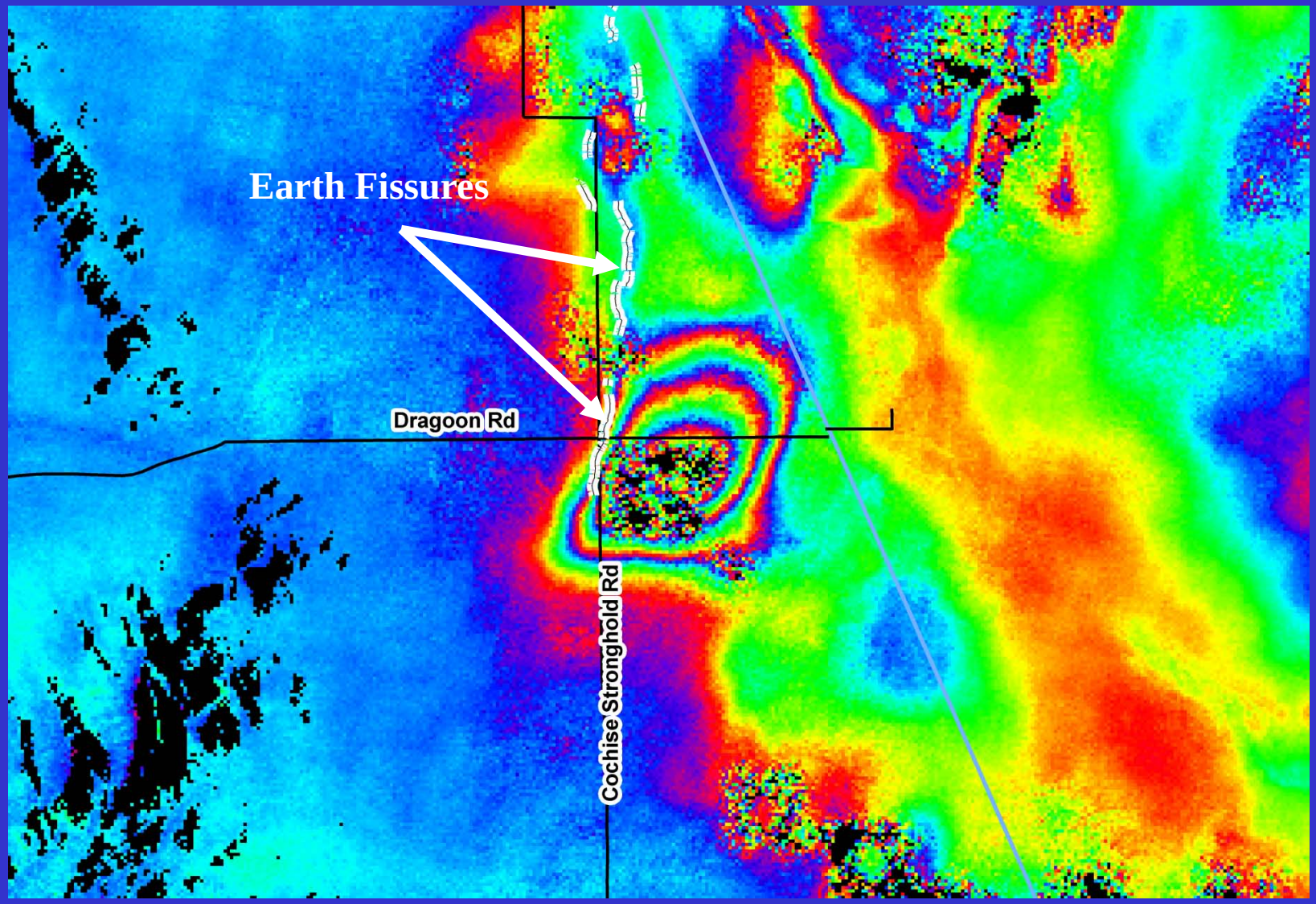
InSAR Used For Earth Fissure Monitoring

Willcox Basin/Cochise County, 10 miles southwest of the Town of Willcox 01/20/2009 To 01/05/2010



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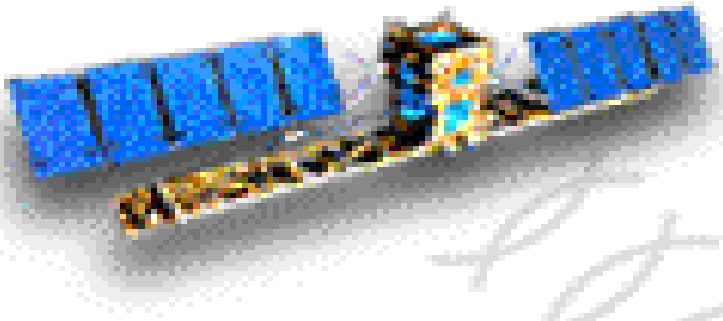
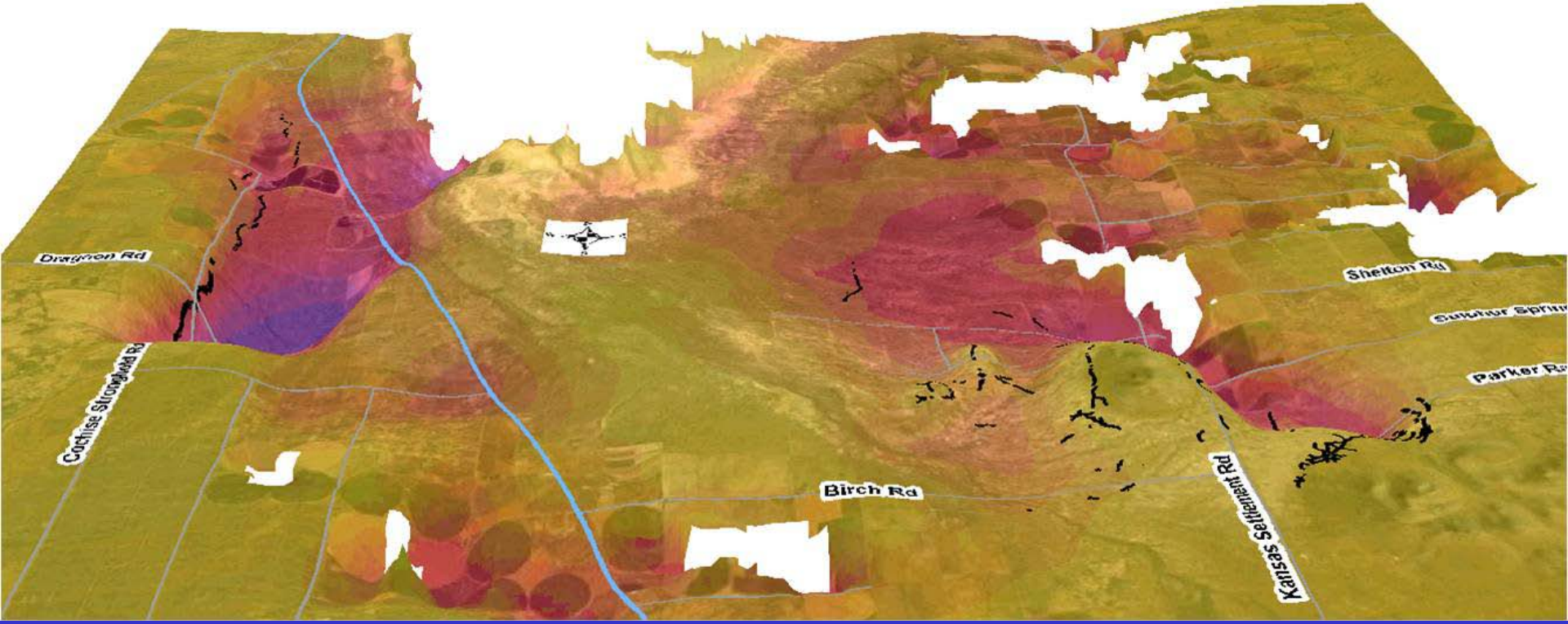


Enhanced 3D View

Land Subsidence in Southern Willcox Basin


Dragoon Rd
Cochise Stronghold Rd
Birch Rd
Kansas Settlement Rd
Shelton Rd
Parker Rd

InSAR Used For Monitoring Artificial Recharge and Associated Uplift

CAP Tonopah Recharge Facility, Tonopah, Maricopa County

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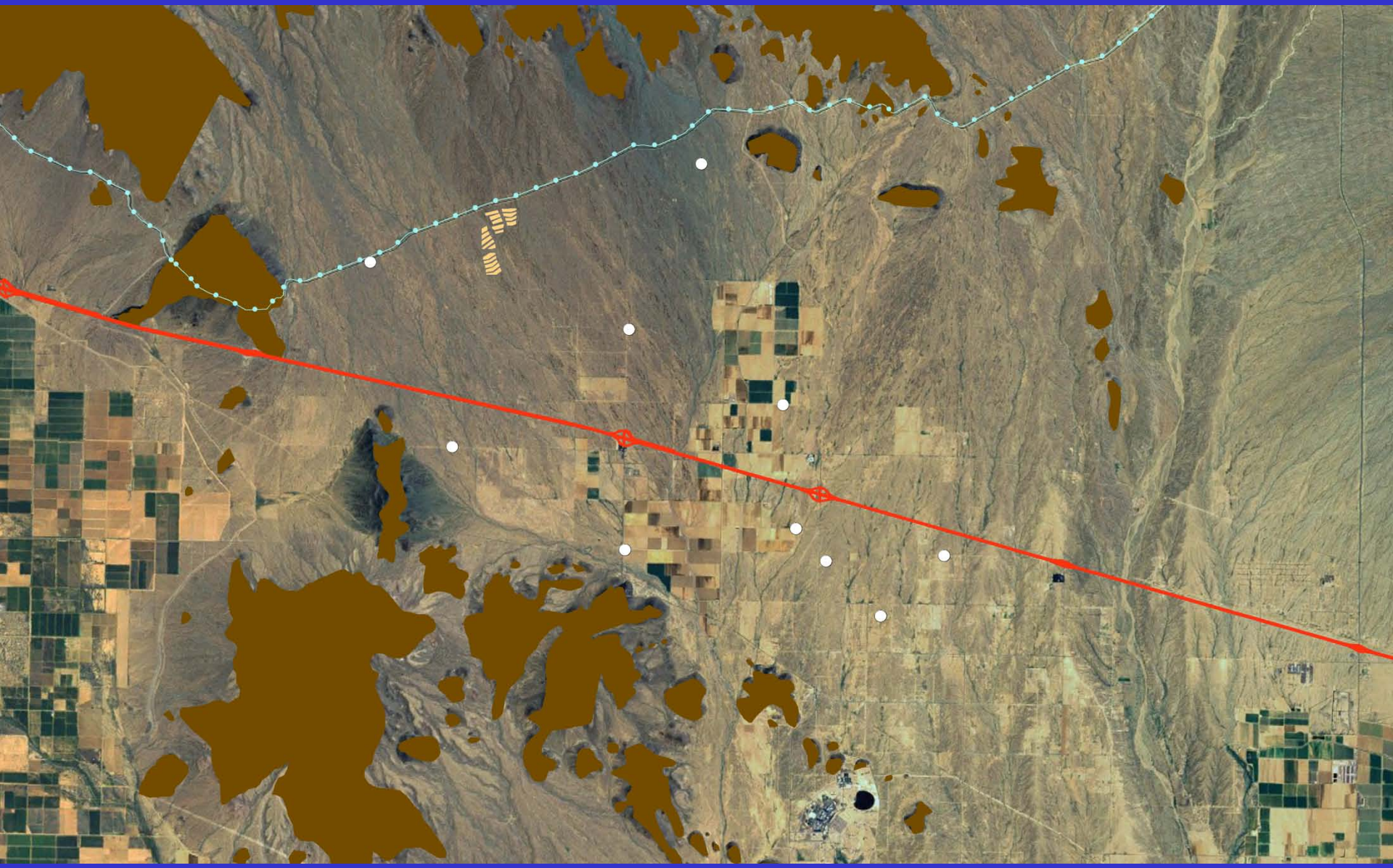
InSAR Used For Monitoring Artificial Recharge and Associated Uplift

CAP Tonopah Recharge Facility, Tonopah, Maricopa County



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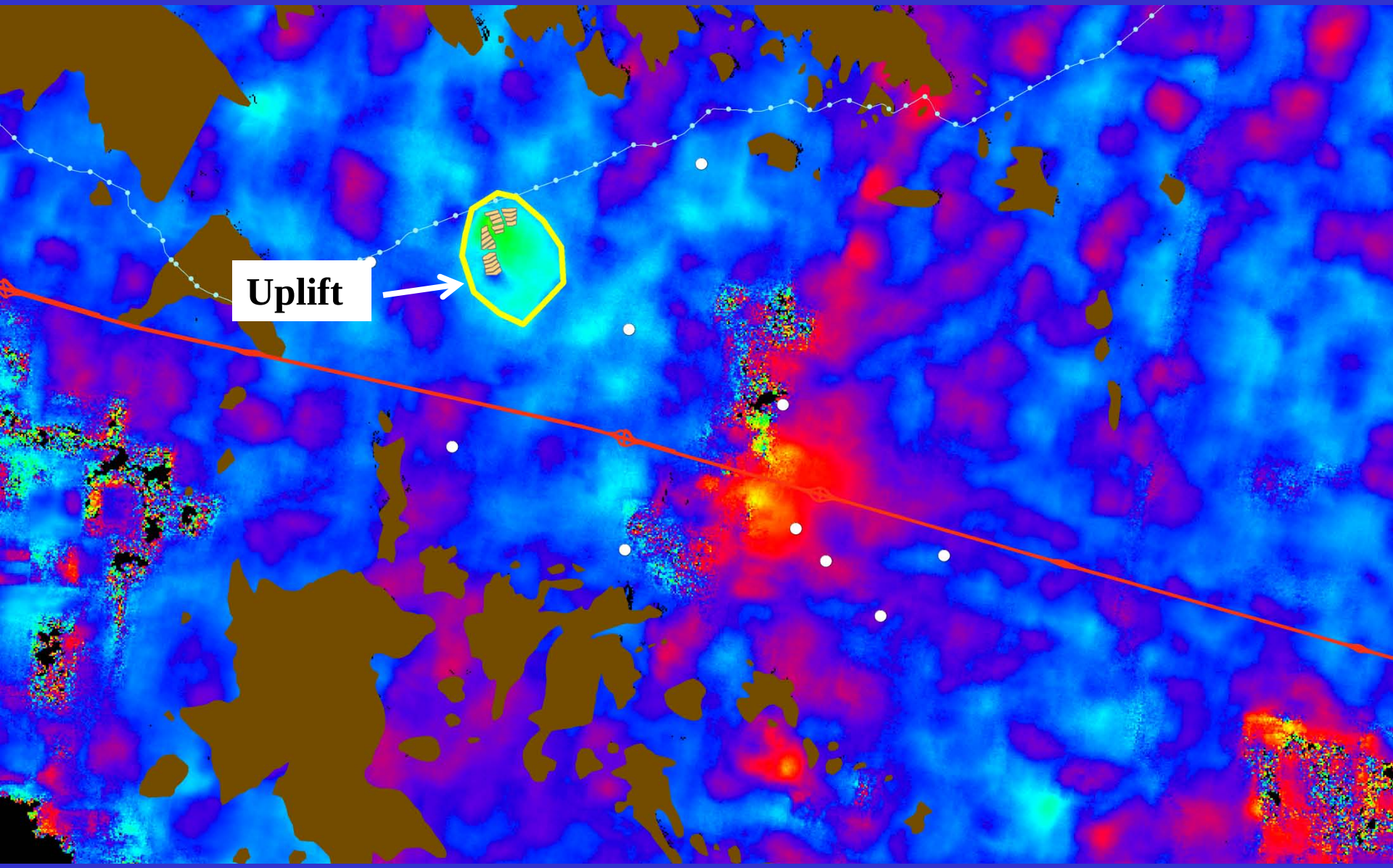
InSAR Used For Monitoring Artificial Recharge and Associated Uplift

CAP Tonopah Recharge Facility, Tonopah, Maricopa County 02/25/2006 To 06/10/2006



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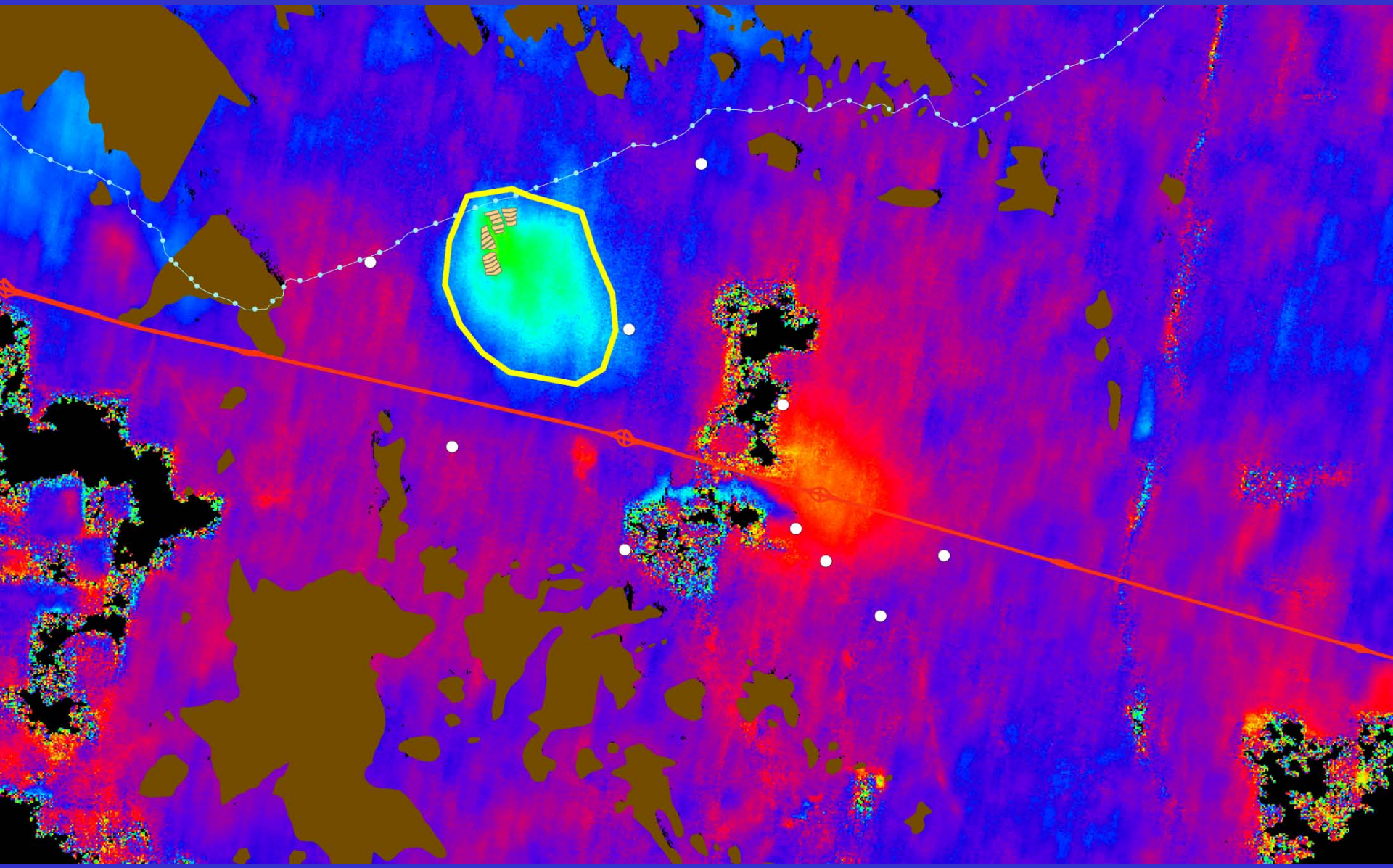
InSAR Used For Monitoring Artificial Recharge and Associated Uplift

CAP Tonopah Recharge Facility, Tonopah, Maricopa County 02/25/2006 To 10/28/2006



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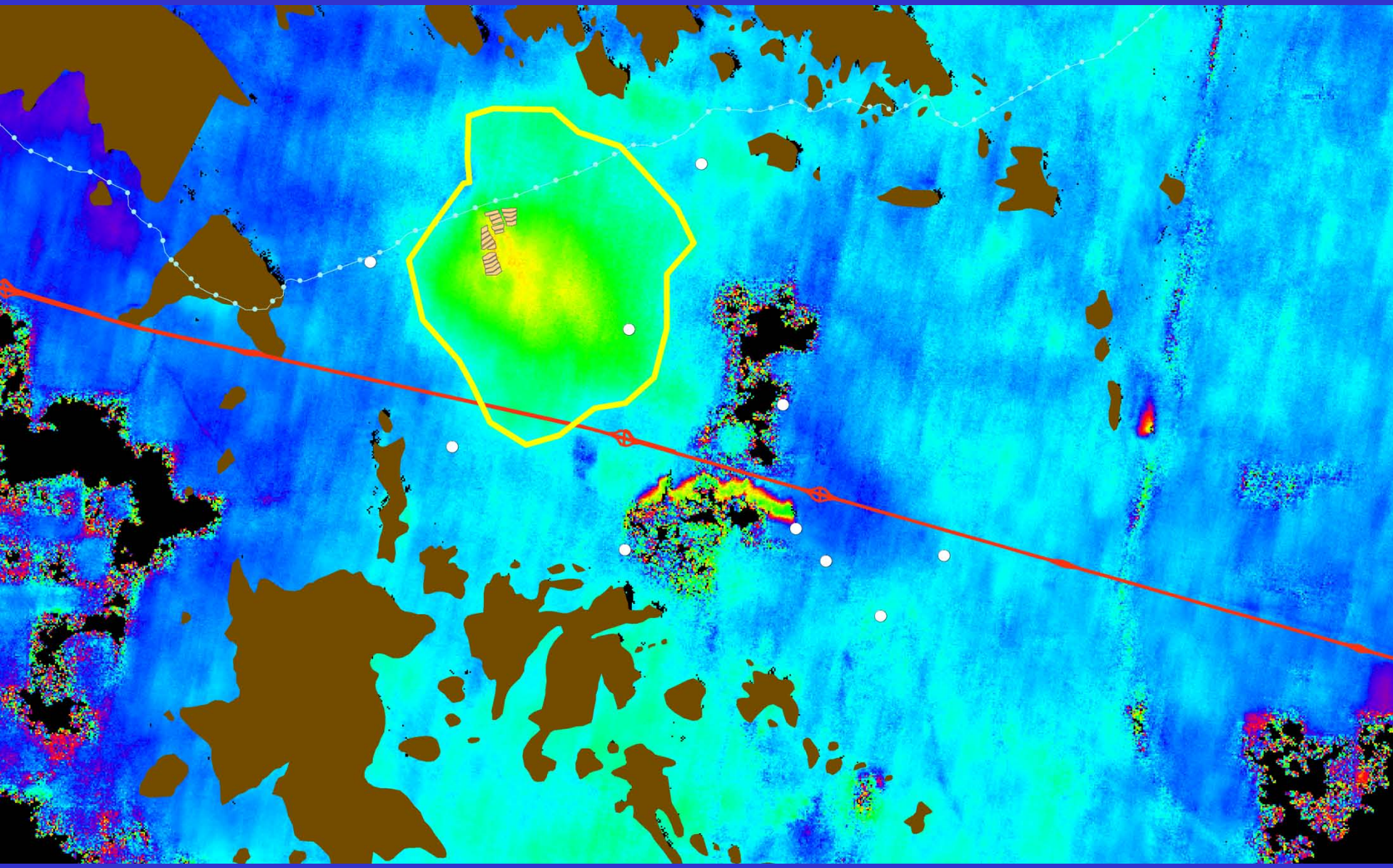
InSAR Used For Monitoring Artificial Recharge and Associated Uplift

CAP Tonopah Recharge Facility, Tonopah, Maricopa County 02/25/2006 To 12/02/2006



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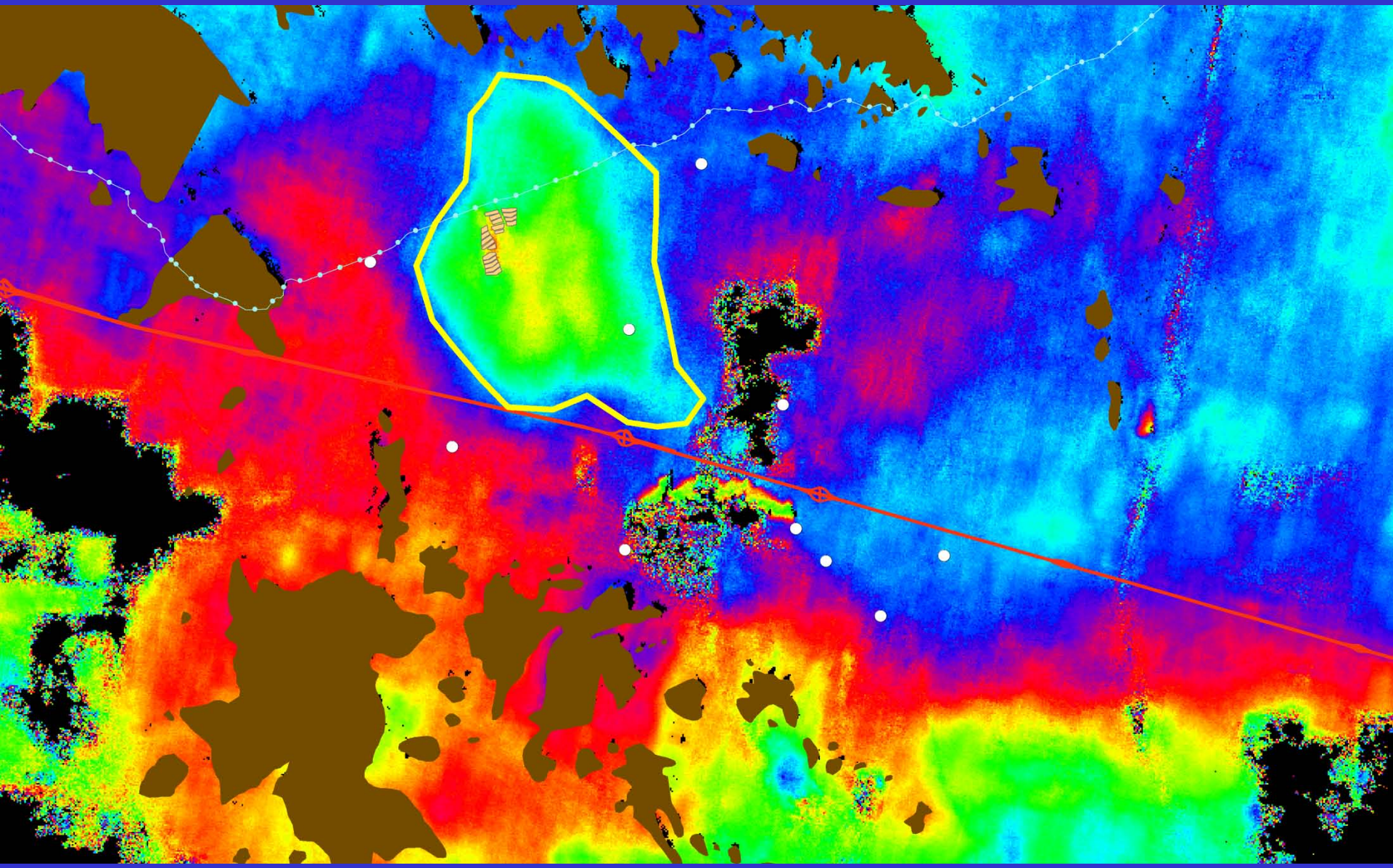
InSAR Used For Monitoring Artificial Recharge and Associated Uplift

CAP Tonopah Recharge Facility, Tonopah, Maricopa County 02/25/2006 To 08/04/2007



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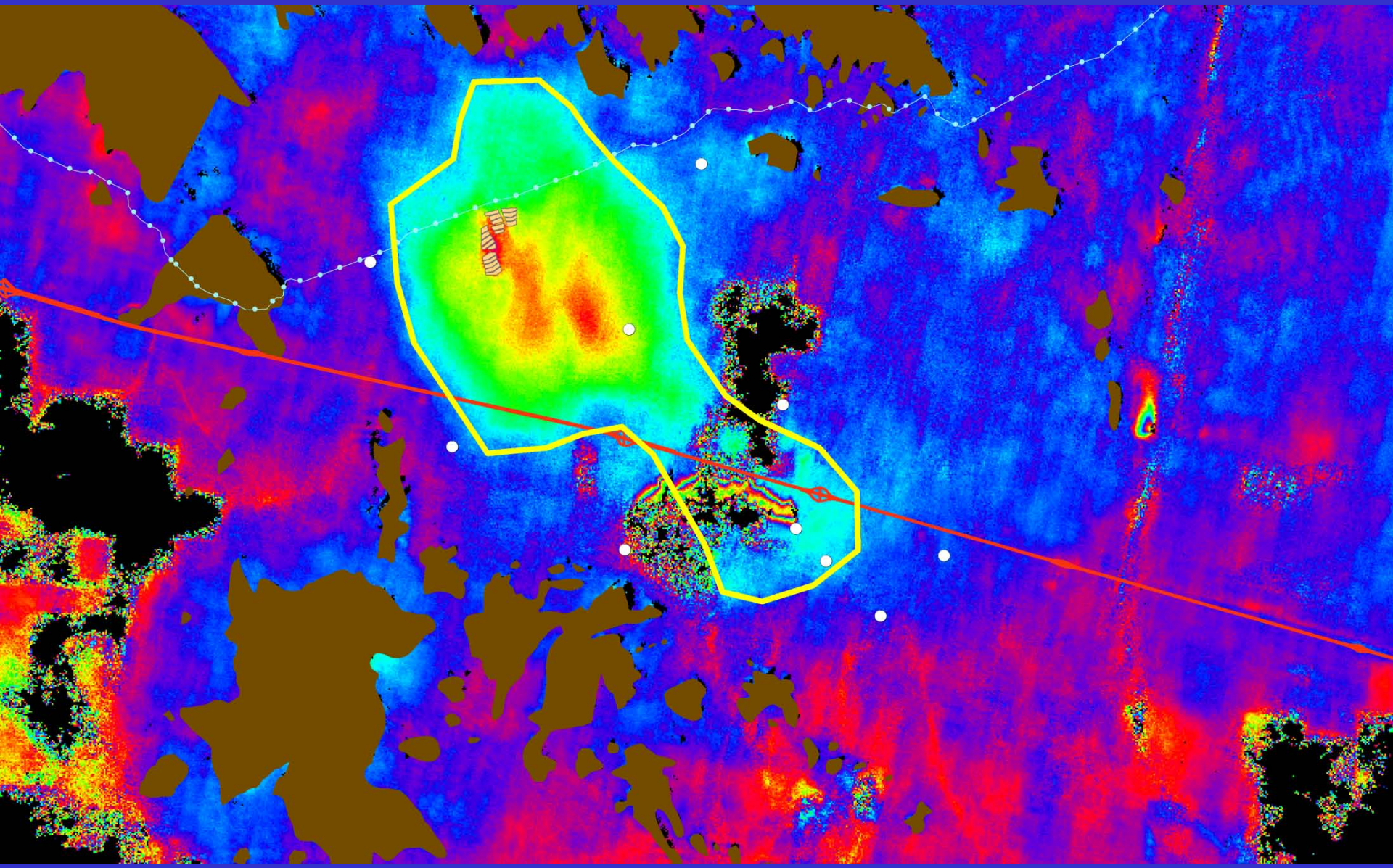
InSAR Used For Monitoring Artificial Recharge and Associated Uplift

CAP Tonopah Recharge Facility, Tonopah, Maricopa County 02/25/2006 To 11/17/2007



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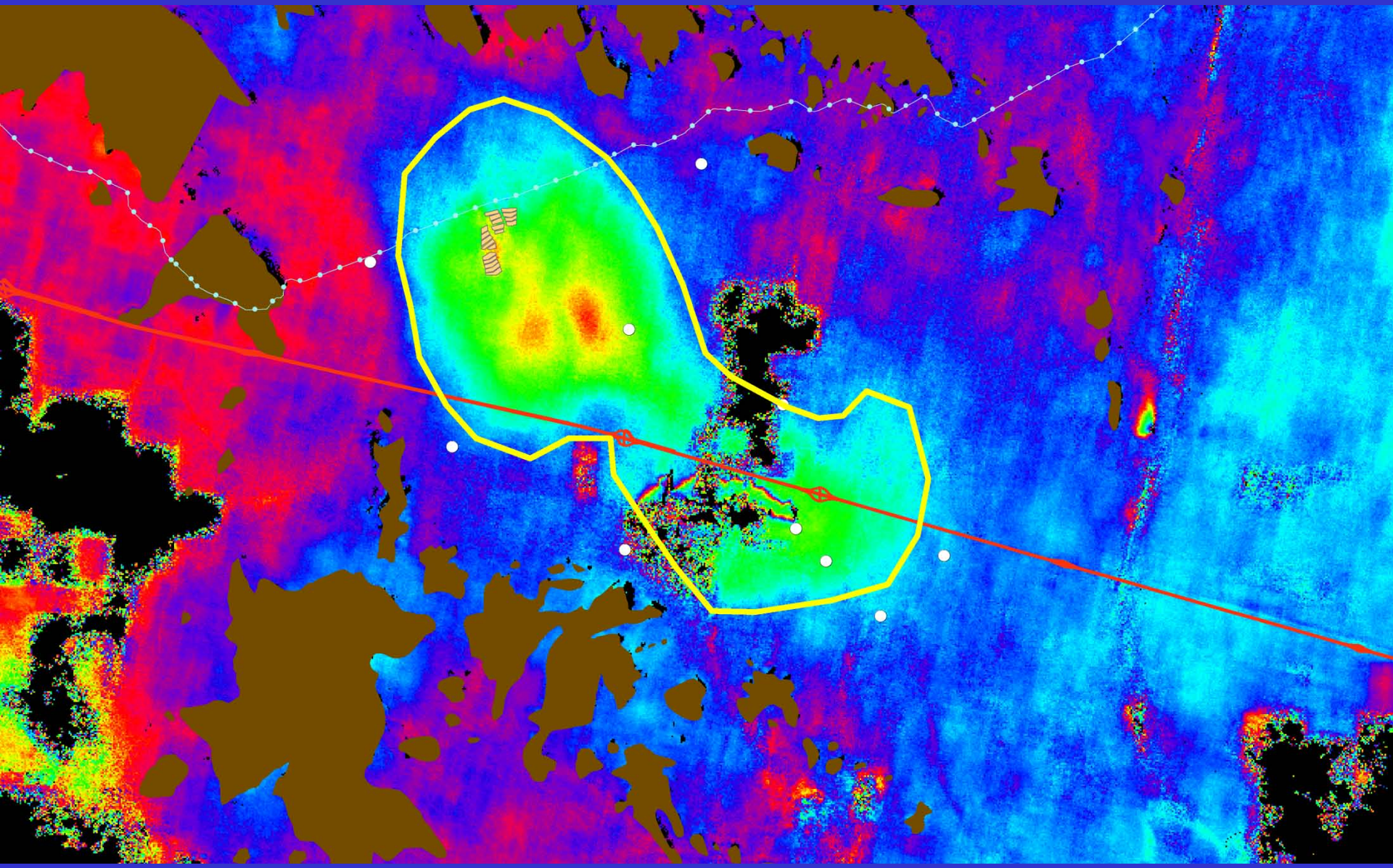
InSAR Used For Monitoring Artificial Recharge and Associated Uplift

CAP Tonopah Recharge Facility, Tonopah, Maricopa County 02/25/2006 To 01/26/2008



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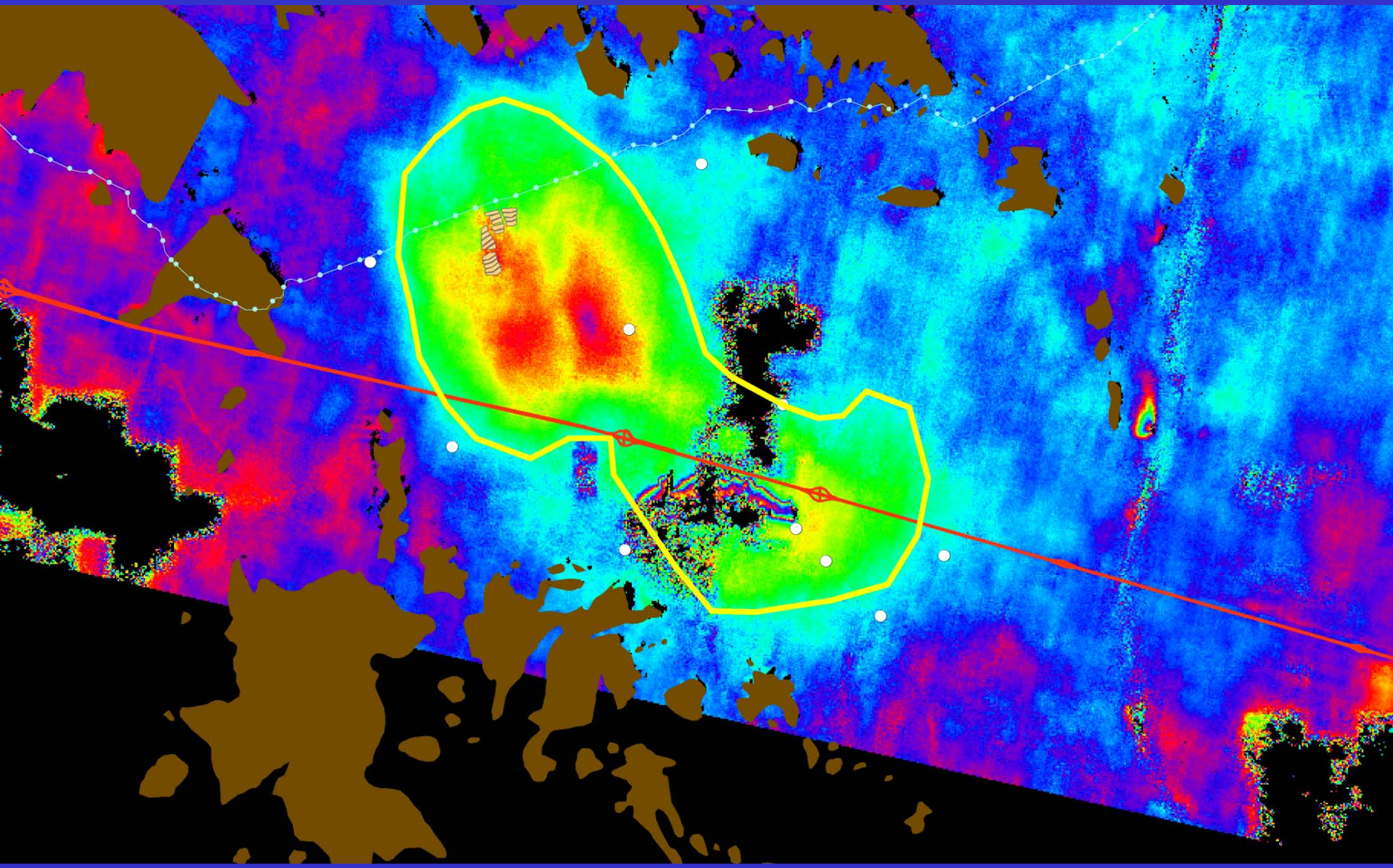
InSAR Used For Monitoring Artificial Recharge and Associated Uplift

CAP Tonopah Recharge Facility, Tonopah, Maricopa County 02/25/2006 To 04/05/2008



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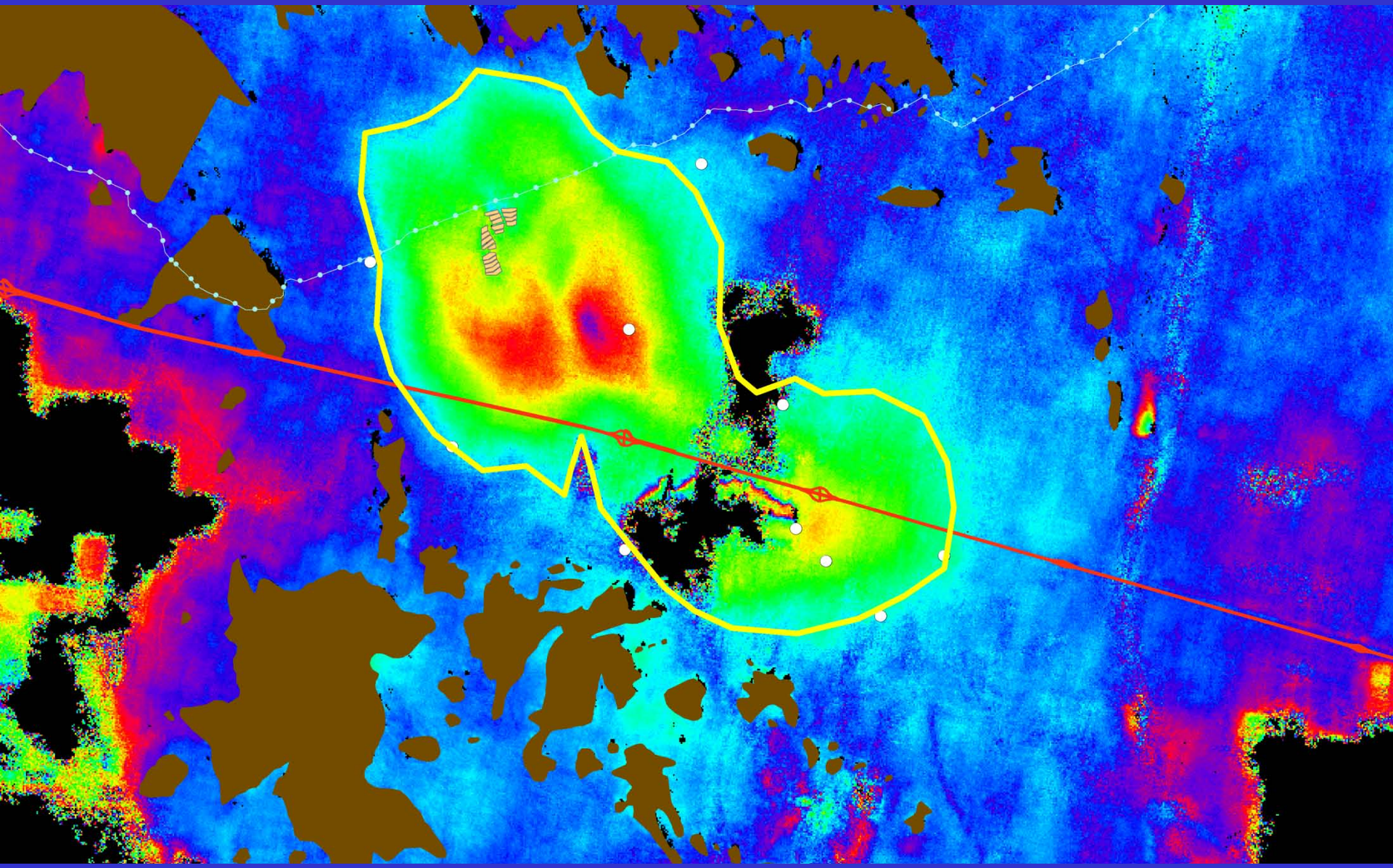
InSAR Used For Monitoring Artificial Recharge and Associated Uplift

CAP Tonopah Recharge Facility, Tonopah, Maricopa County 02/25/2006 To 11/01/2008



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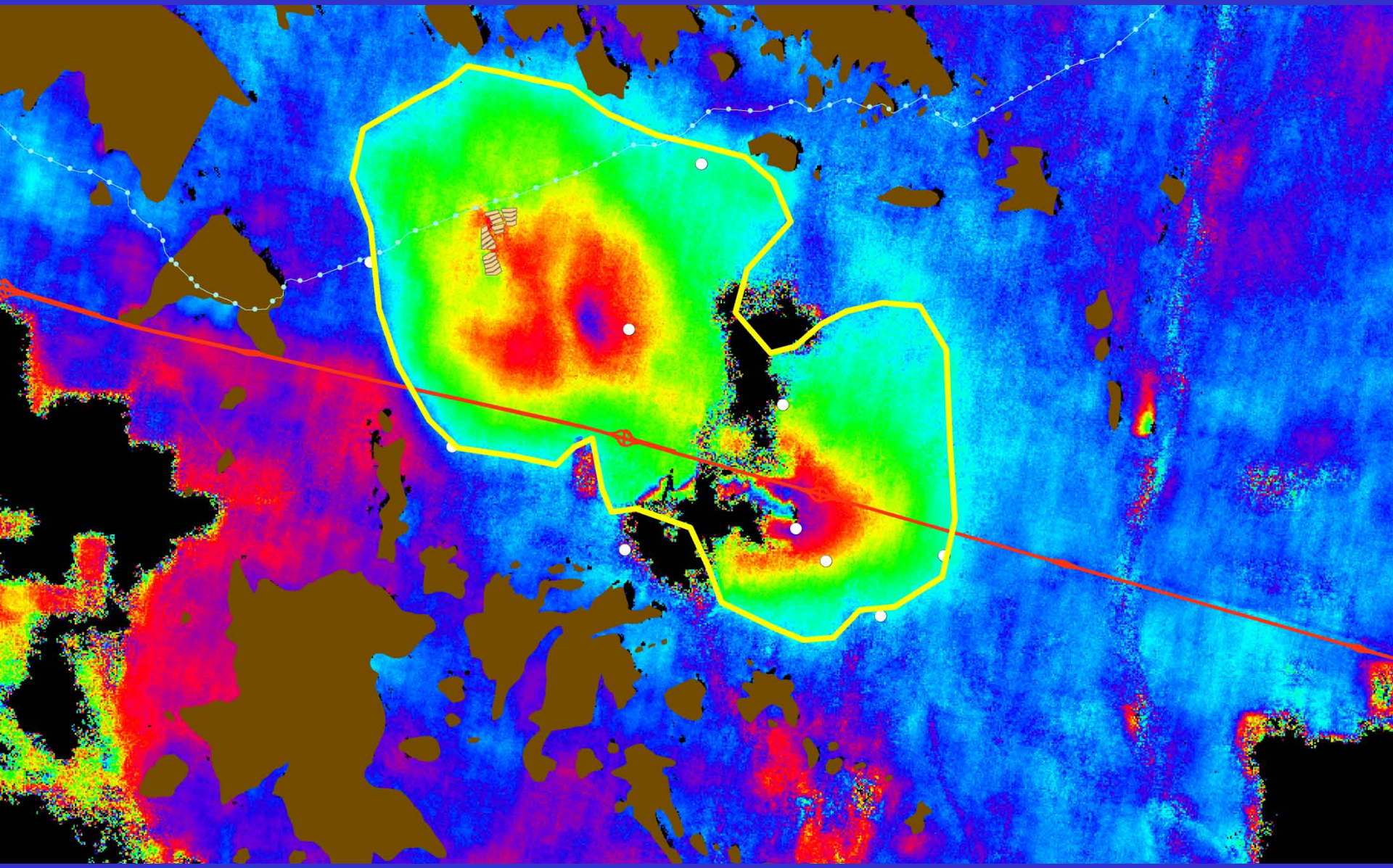
InSAR Used For Monitoring Artificial Recharge and Associated Uplift

CAP Tonopah Recharge Facility, Tonopah, Maricopa County 02/25/2006 To 01/10/2009



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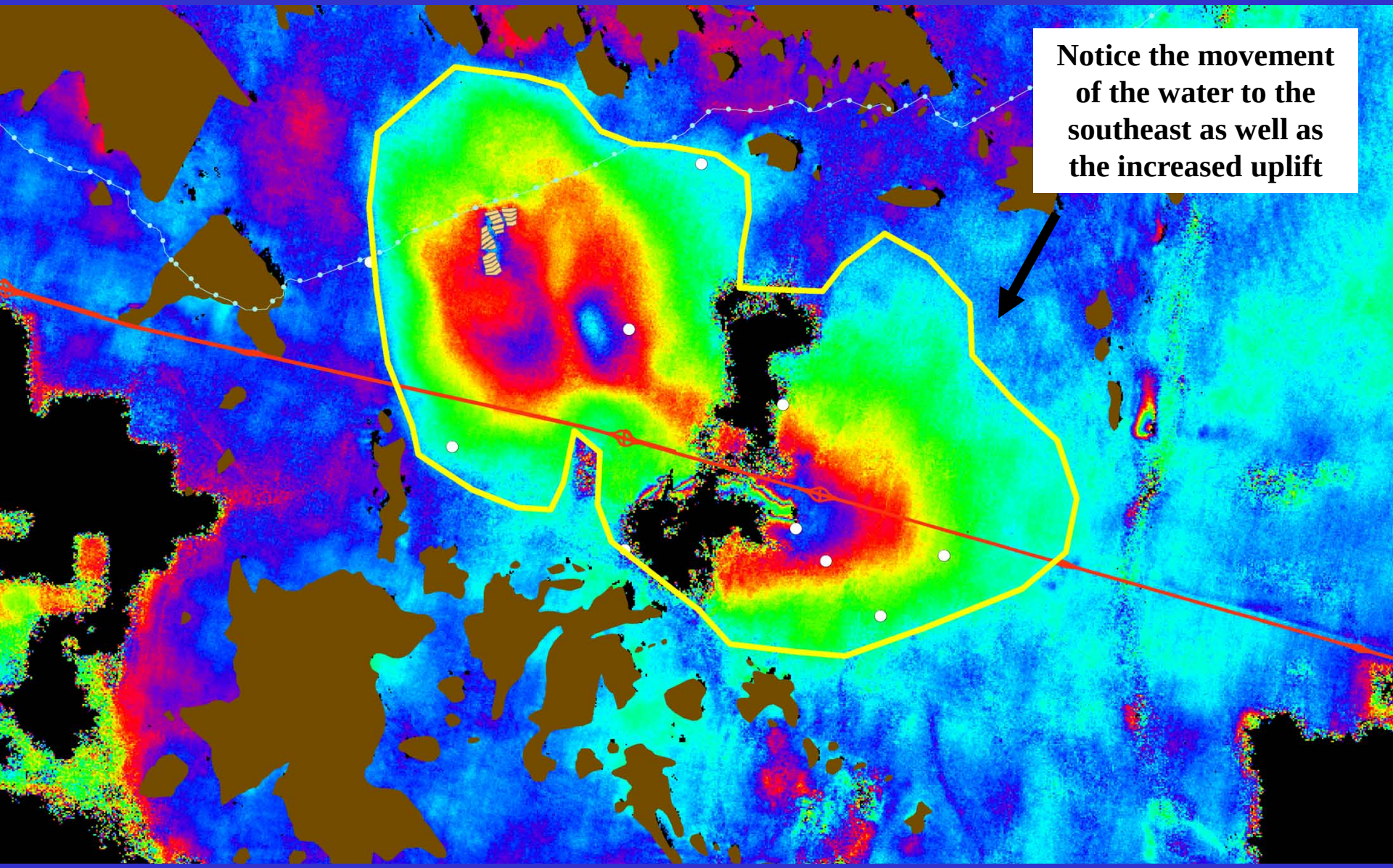
InSAR Used For Monitoring Artificial Recharge and Associated Uplift

CAP Tonopah Recharge Facility, Tonopah, Maricopa County 02/25/2006 To 11/21/2009



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InSAR Used For Monitoring Artificial Recharge and Associated Uplift

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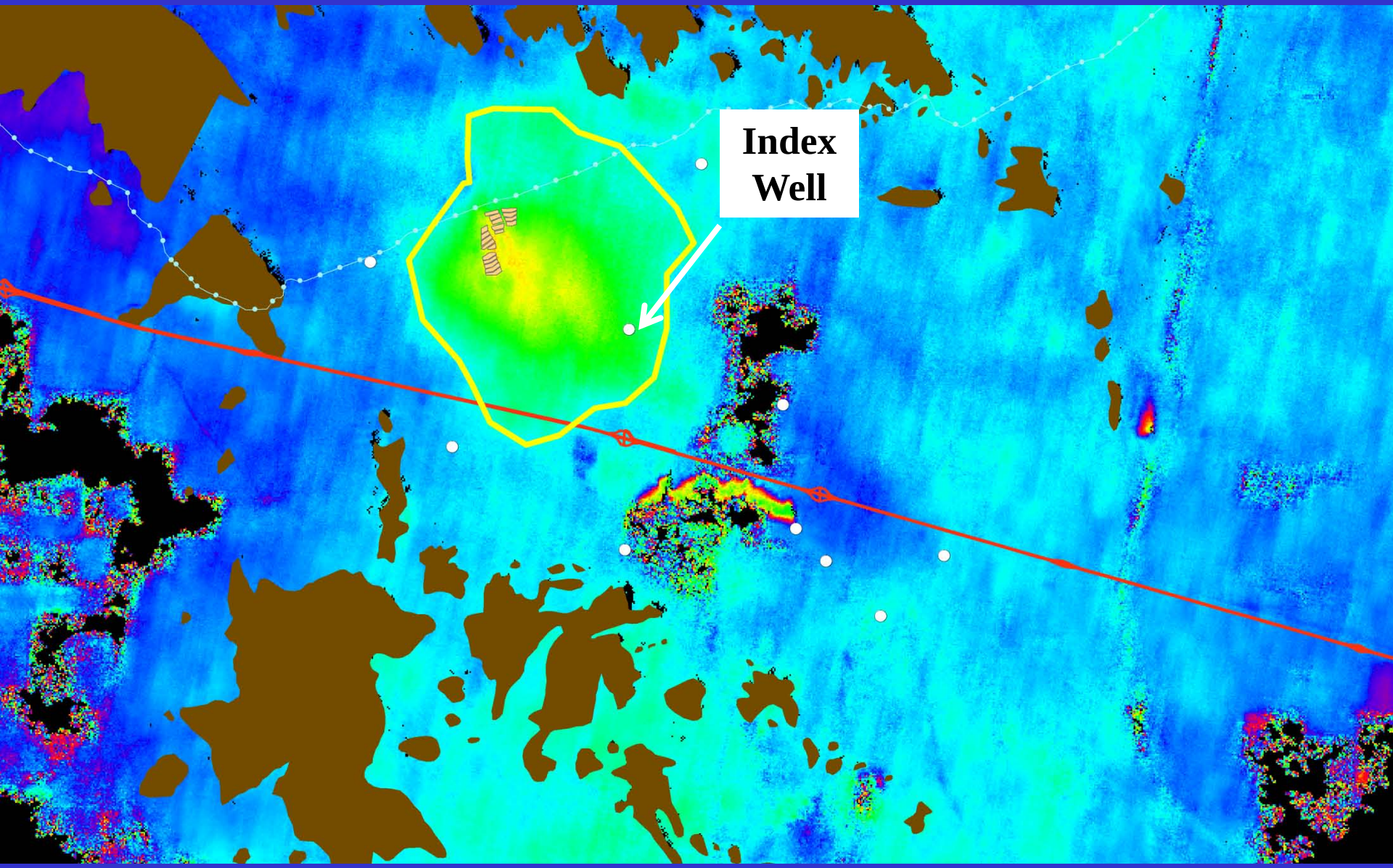

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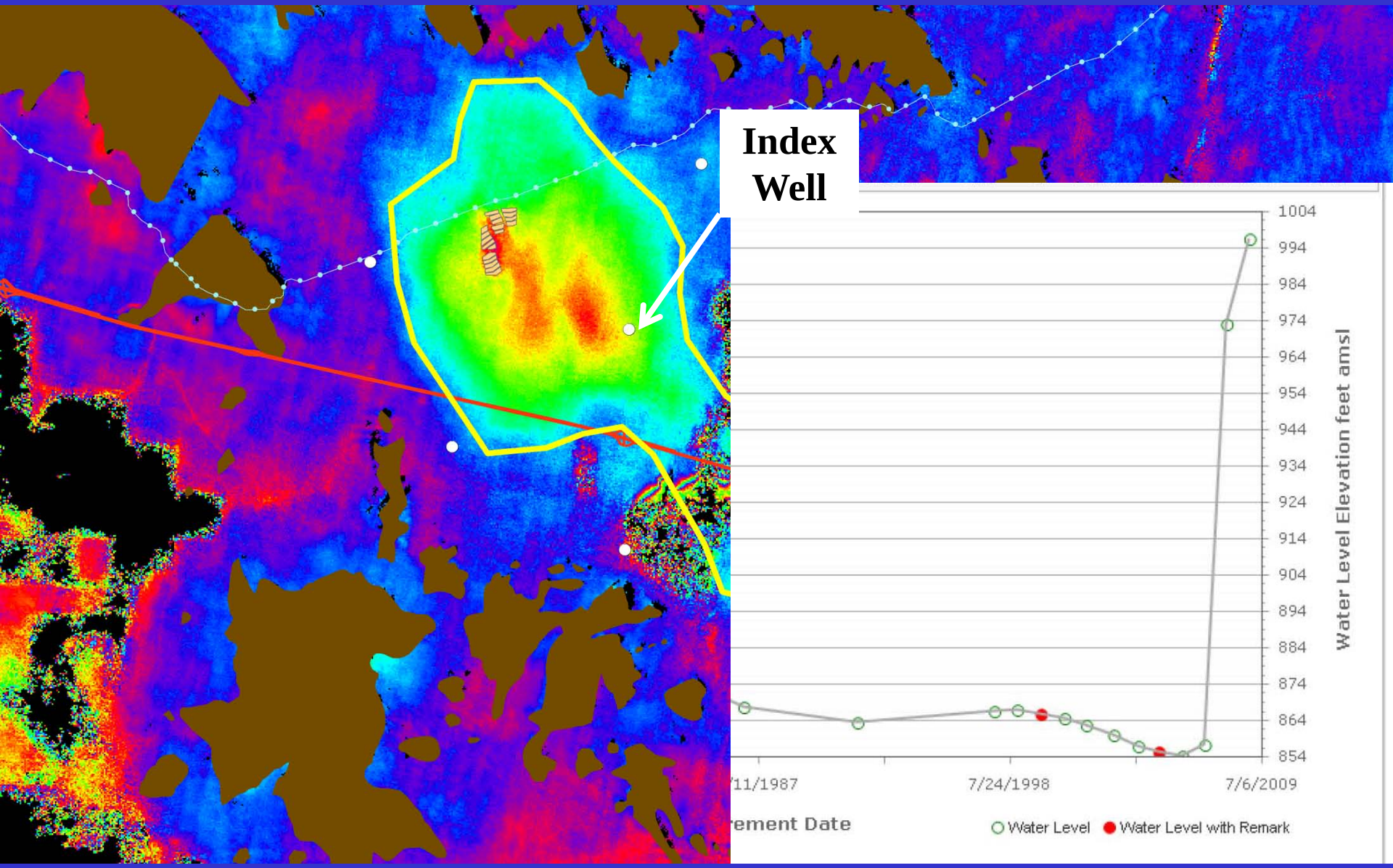
CAP Tonopah Recharge Facility, Tonopah, Maricopa County 02/25/2006 To 11/17/2007



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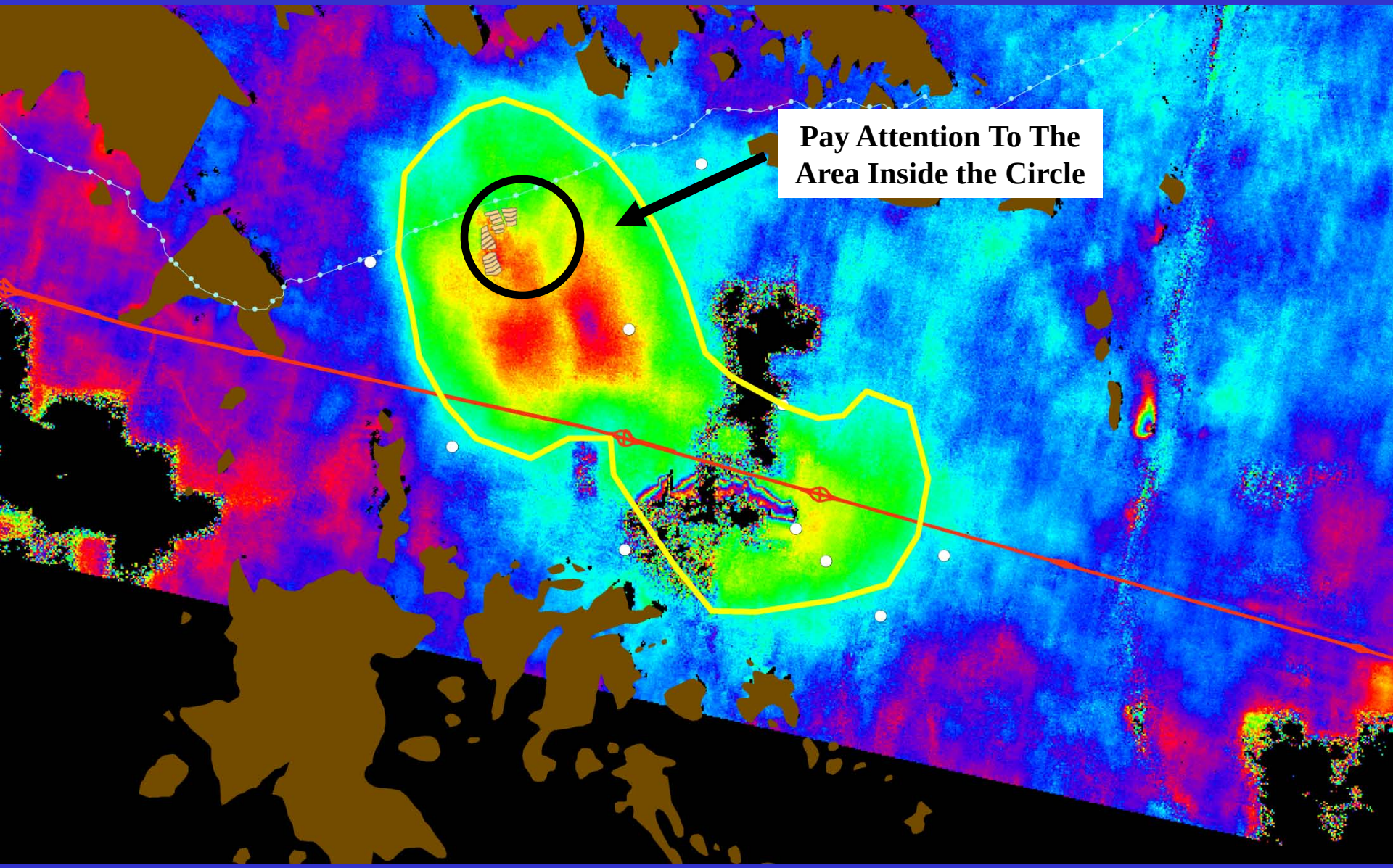
InSAR Used For Monitoring Artificial Recharge and Associated Uplift

CAP Tonopah Recharge Facility, Tonopah, Maricopa County 02/25/2006 To 04/05/2008



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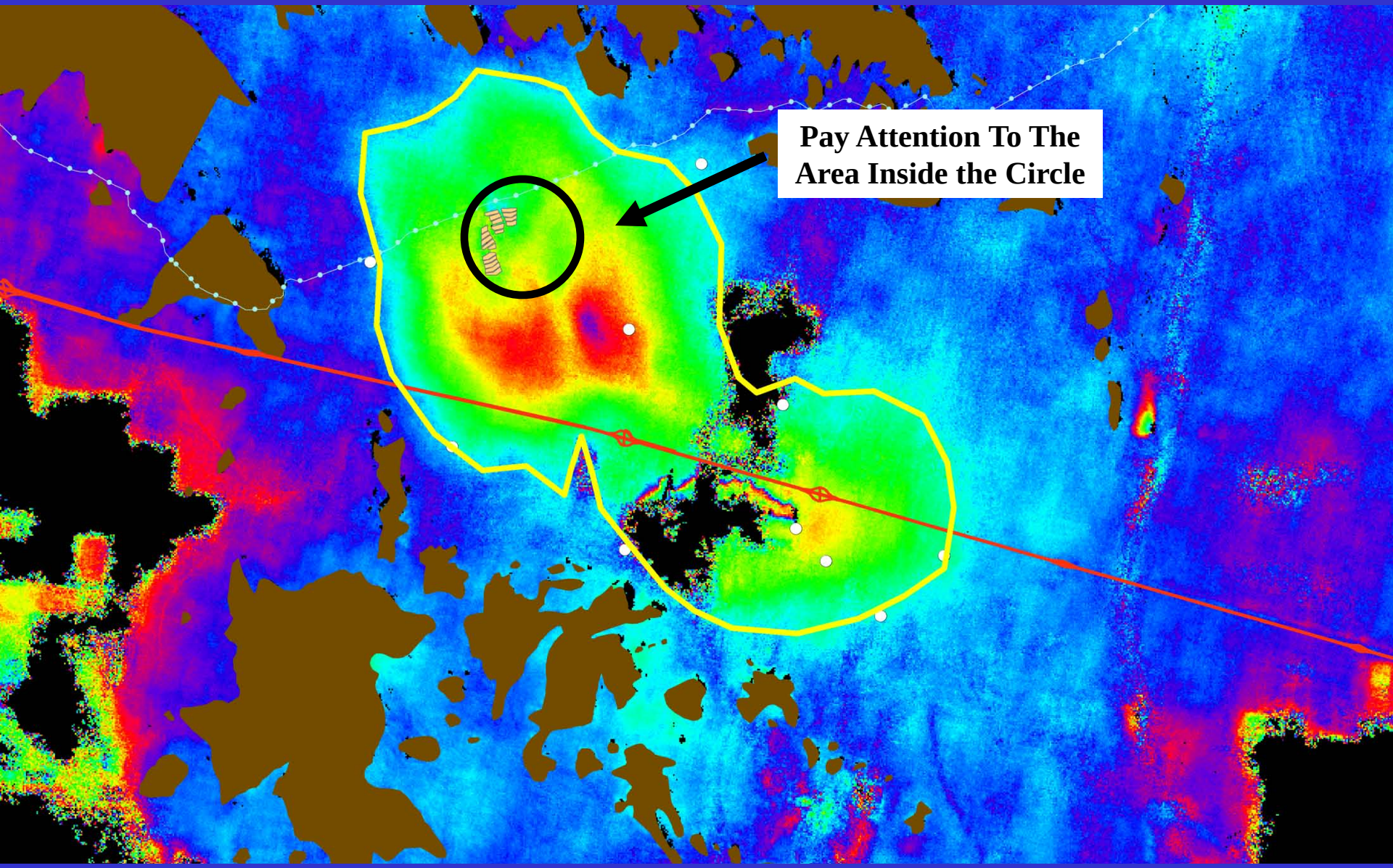
InSAR Used For Monitoring Artificial Recharge and Associated Uplift

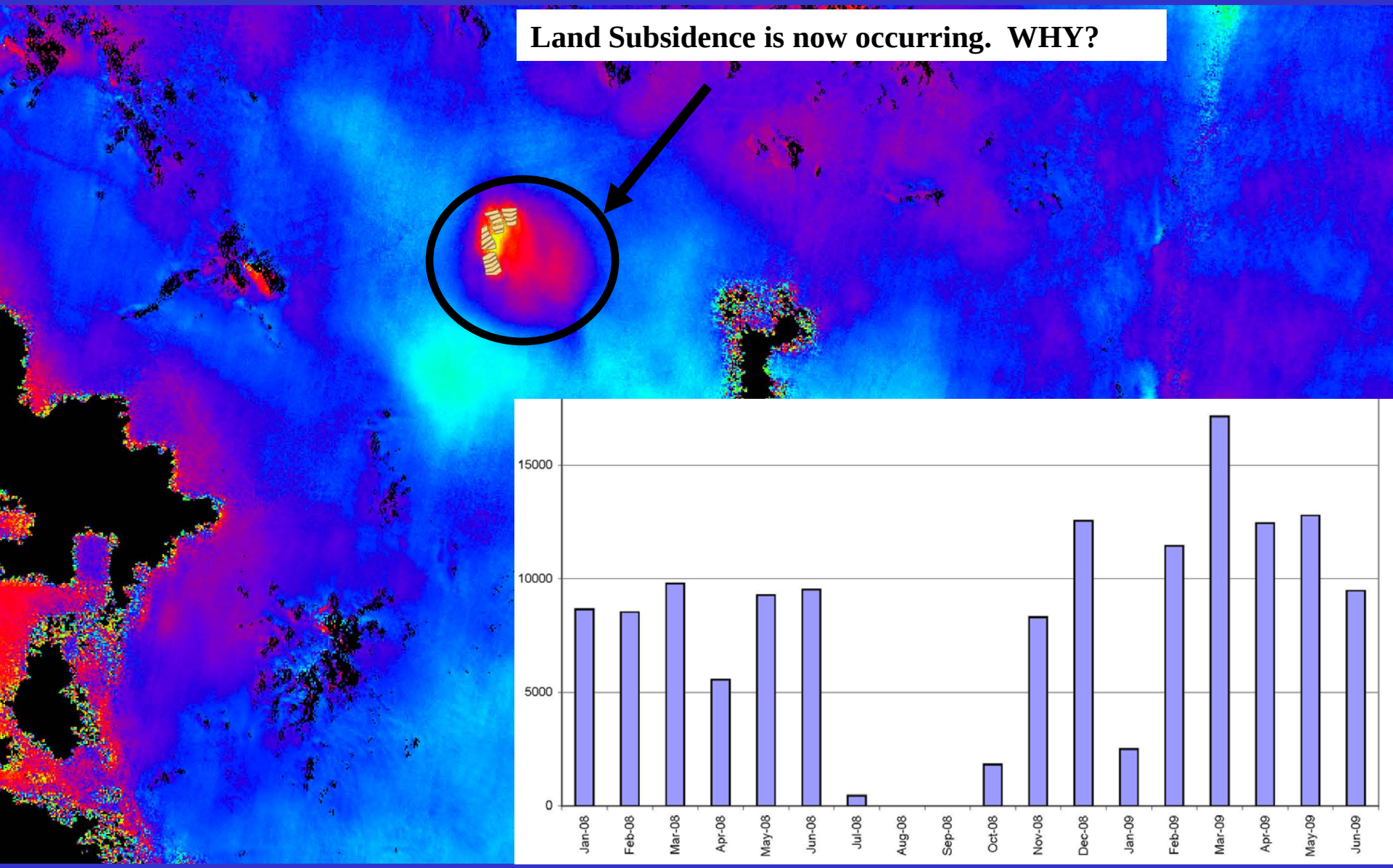
CAP Tonopah Recharge Facility, Tonopah, Maricopa County 11/17/2007 To 11/01/2008



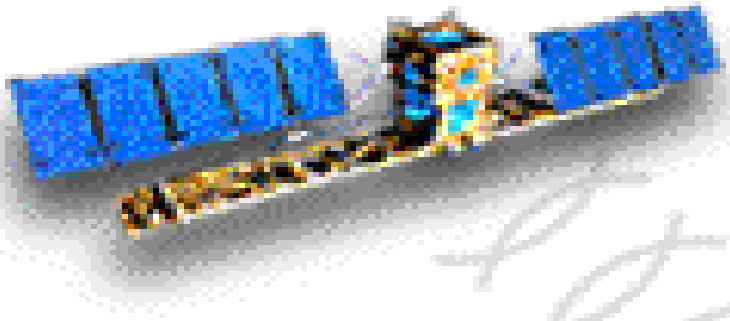
© ESA 2006 - 2009

InSAR Used For Monitoring Artificial Recharge and Associated Uplift

CAP Tonopah Recharge Facility, Tonopah, Maricopa County 02/25/2006 To 10/28/2006



© ESA 2006 - 2009

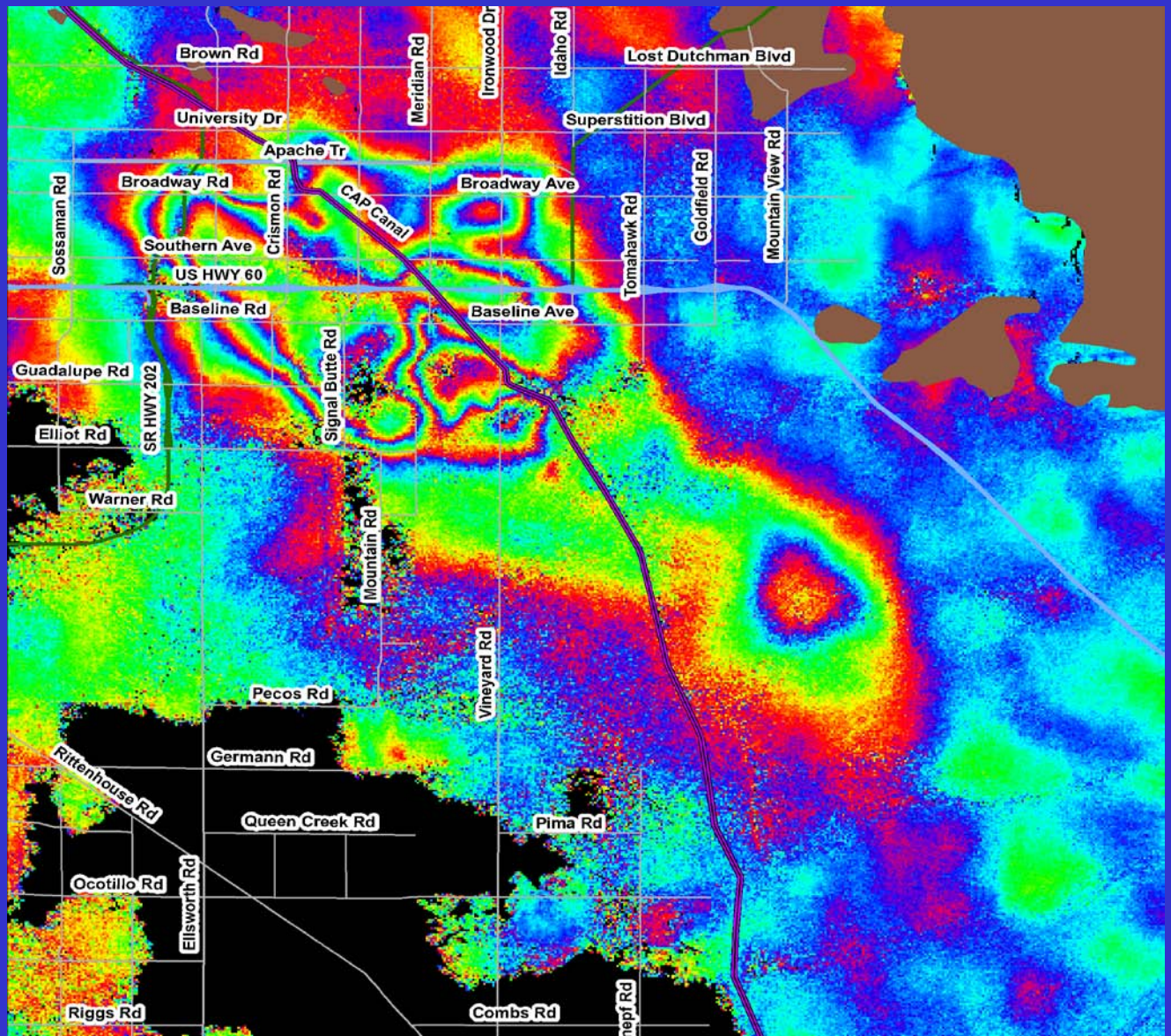


Applications of InSAR

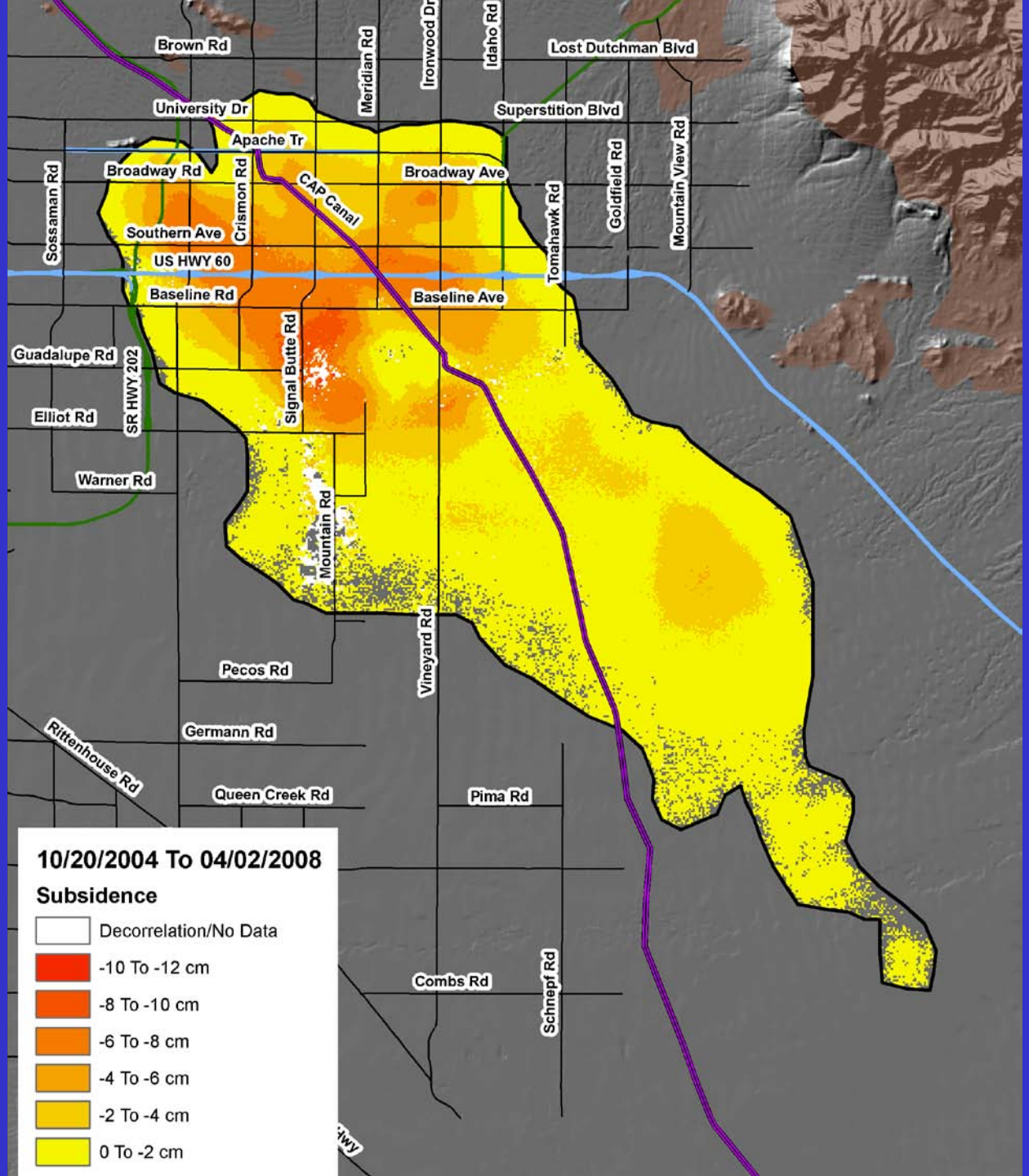
For Land Subsidence Monitoring

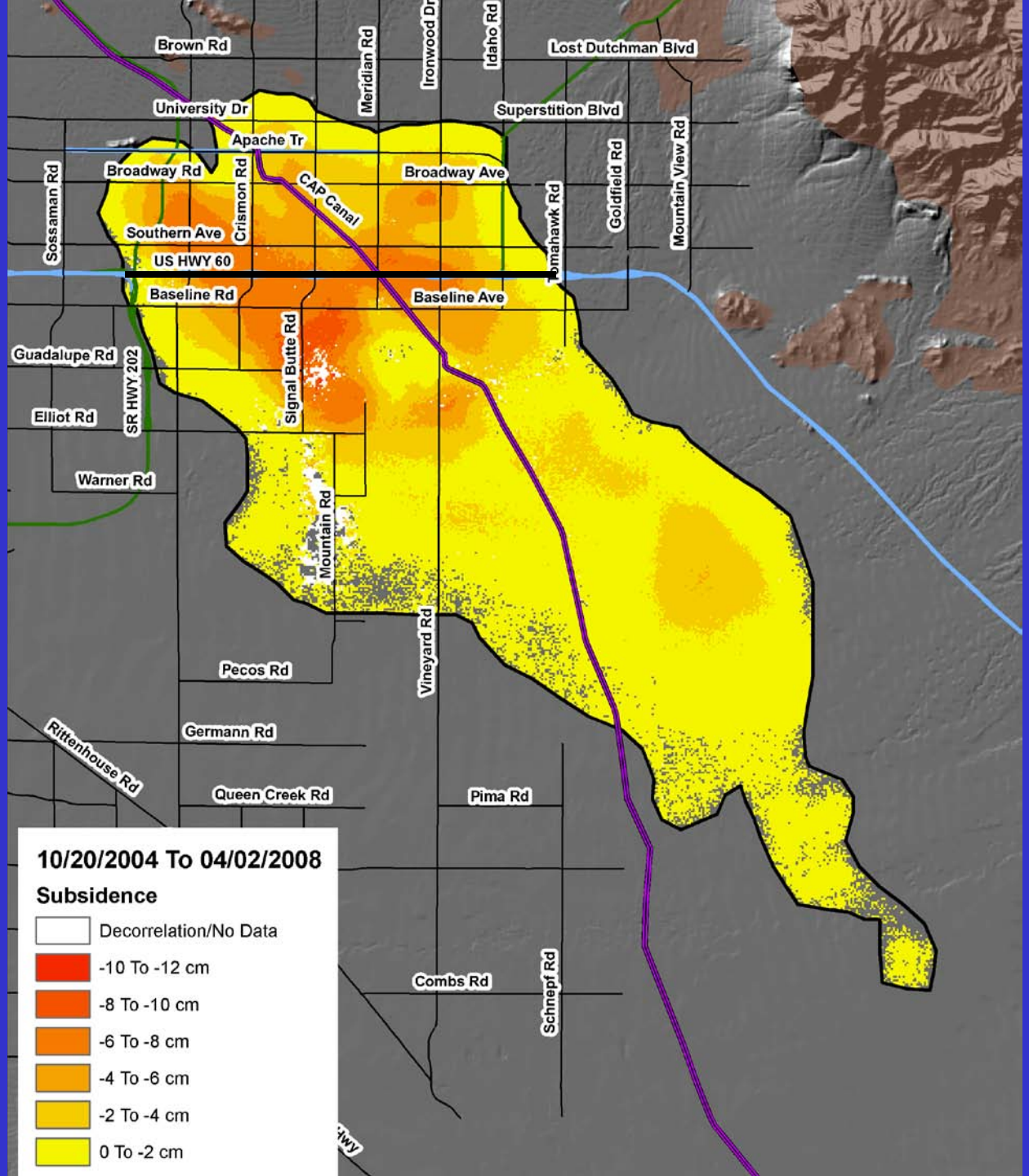
3.5 Year Time-Series Interferogram 10/20/2004 To 04/02/2008

Hawk Rock Land Subsidence Feature in East Mesa/Apache Junction Area, Maricopa/Pinal Counties



© ESA 2004 -2008


Brown Rd
Meridian Rd
Ironwood Dr
Idaho Rd
Lost Dutchman Blvd
University Dr
Superstition Blvd
Apache Tr
Broadway Rd
Broadway Ave
CAP Canal
Sossaman Rd
Crismon Rd
Goldfield Rd
Mountain View Rd
Tomahawk Rd
Southern Ave
US HWY 60
Baseline Rd
Baseline Ave
Guadalupe Rd
SR HWY 202
Signal Butte Rd
Elliot Rd
Warner Rd
Mountain Rd
Vineyard Rd
Pecos Rd
Germann Rd
Rittenhouse Rd
Queen Creek Rd
Pima Rd
Combs Rd
Schnepf Rd
10/20/2004 To 04/02/2008
Subsidence
Decorrelation/No Data
-10 To -12 cm
-8 To -10 cm
-6 To -8 cm
-4 To -6 cm
-2 To -4 cm
0 To -2 cm


Brown Rd
Meridian Rd
Ironwood Dr
Idaho Rd
Lost Dutchman Blvd
University Dr
Superstition Blvd
Apache Tr
Broadway Rd
Broadway Ave
CAP Canal
Sossaman Rd
Crismon Rd
Tomahawk Rd
Goldfield Rd
Mountain View Rd
Southern Ave
US HWY 60
Baseline Rd
Baseline Ave
Guadalupe Rd
SR HWY 202
Signal Butte Rd
Elliot Rd
Warner Rd
Mountain Rd
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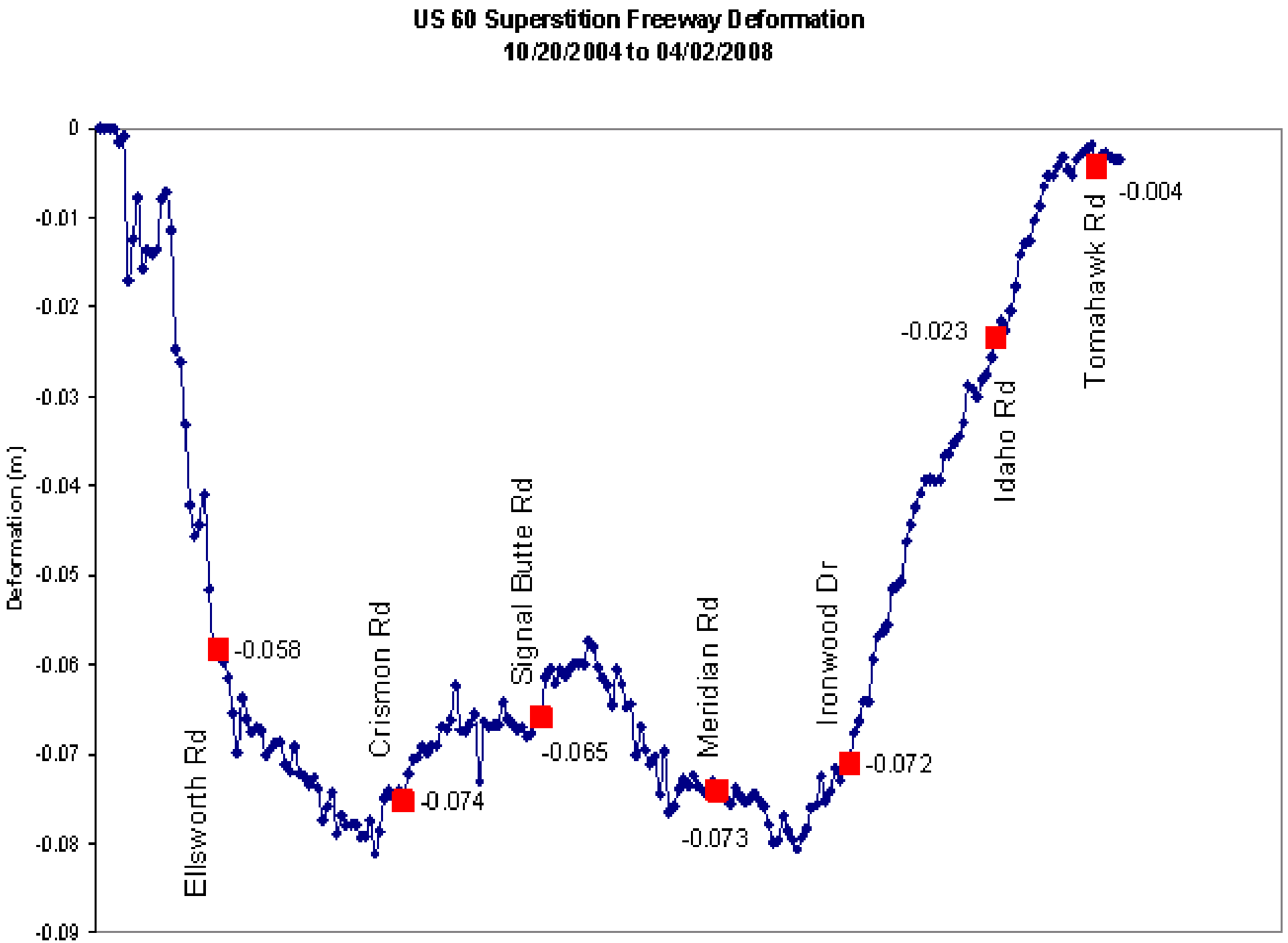
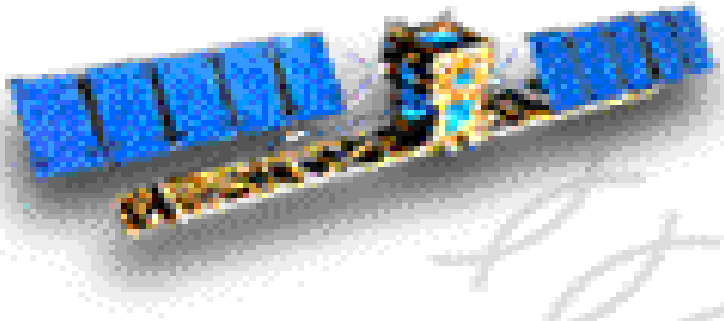
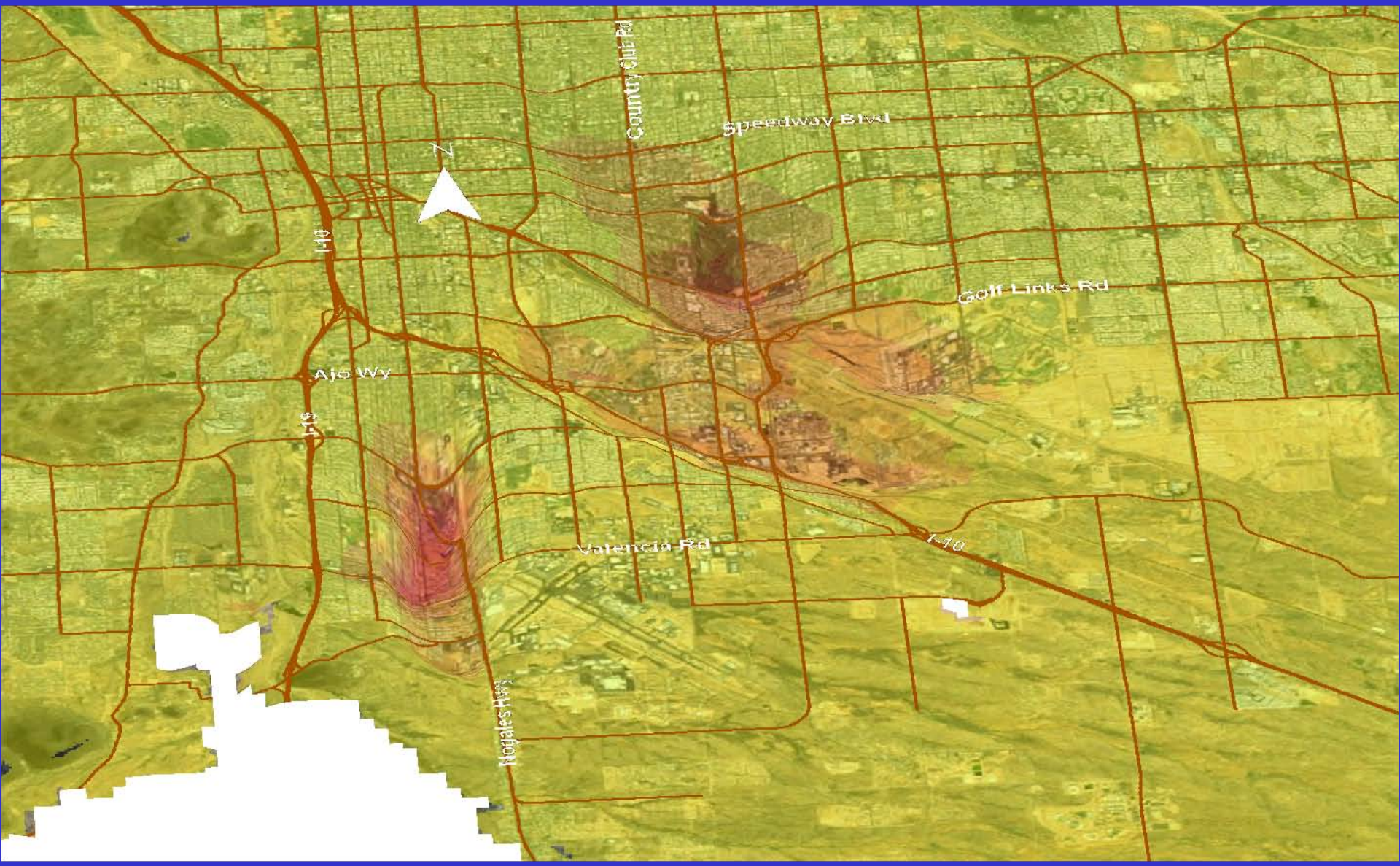
Queen Creek Rd
Pima Rd
Combs Rd
Schnepf Rd
10/20/2004 To 04/02/2008
Subsidence
Decorrelation/No Data
-10 To -12 cm
-8 To -10 cm
-6 To -8 cm
-4 To -6 cm
-2 To -4 cm
0 To -2 cm

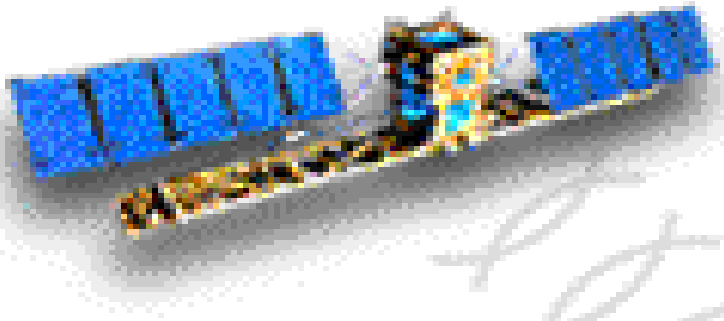

US 60 Superstition Freeway Deformation
10/20/2004 to 04/02/2008
Deformation (m)
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
Ellsworth Rd
-0.058
Crismon Rd
-0.074
Signal Butte Rd
-0.065
Meridian Rd
-0.073
Ironwood Dr
-0.072
Idaho Rd
-0.023
Tomahawk Rd
-0.004



Enhanced 3D View

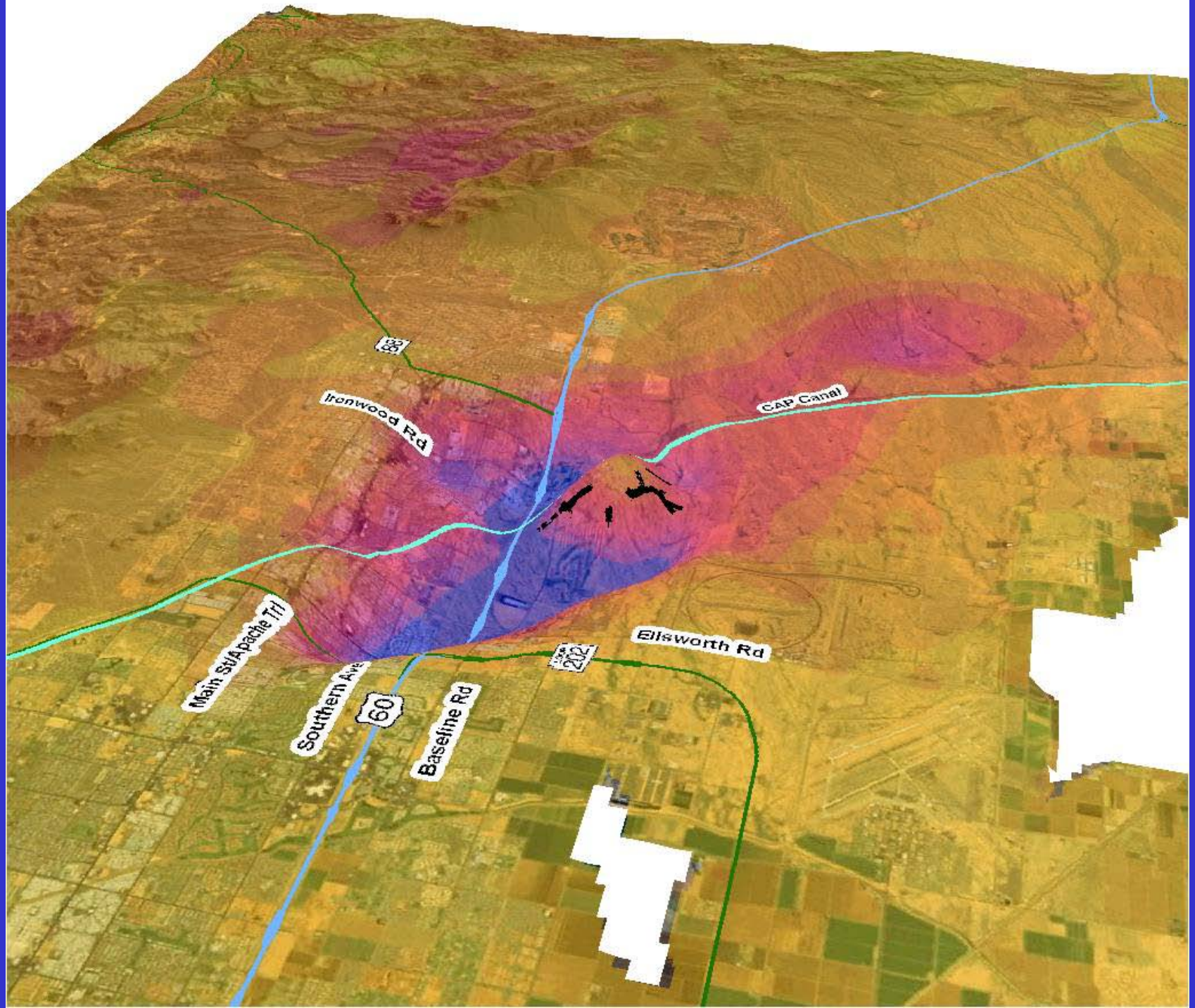
Land Subsidence for the Tucson Area

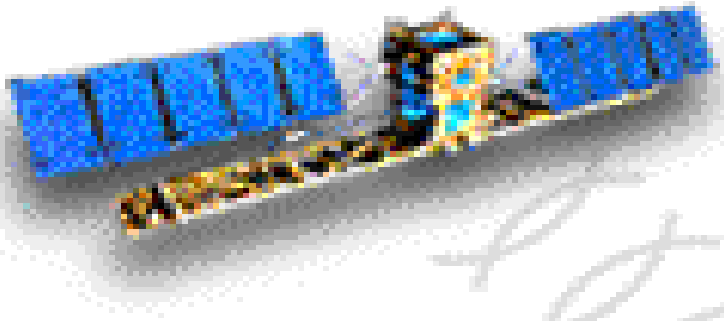

Country Club Rd
Speedway Blvd
N
I-10
Golf Links Rd
Ajo Wy
I-19
Valencia Rd
I-10
Nogales Hwy



Enhanced 3D View

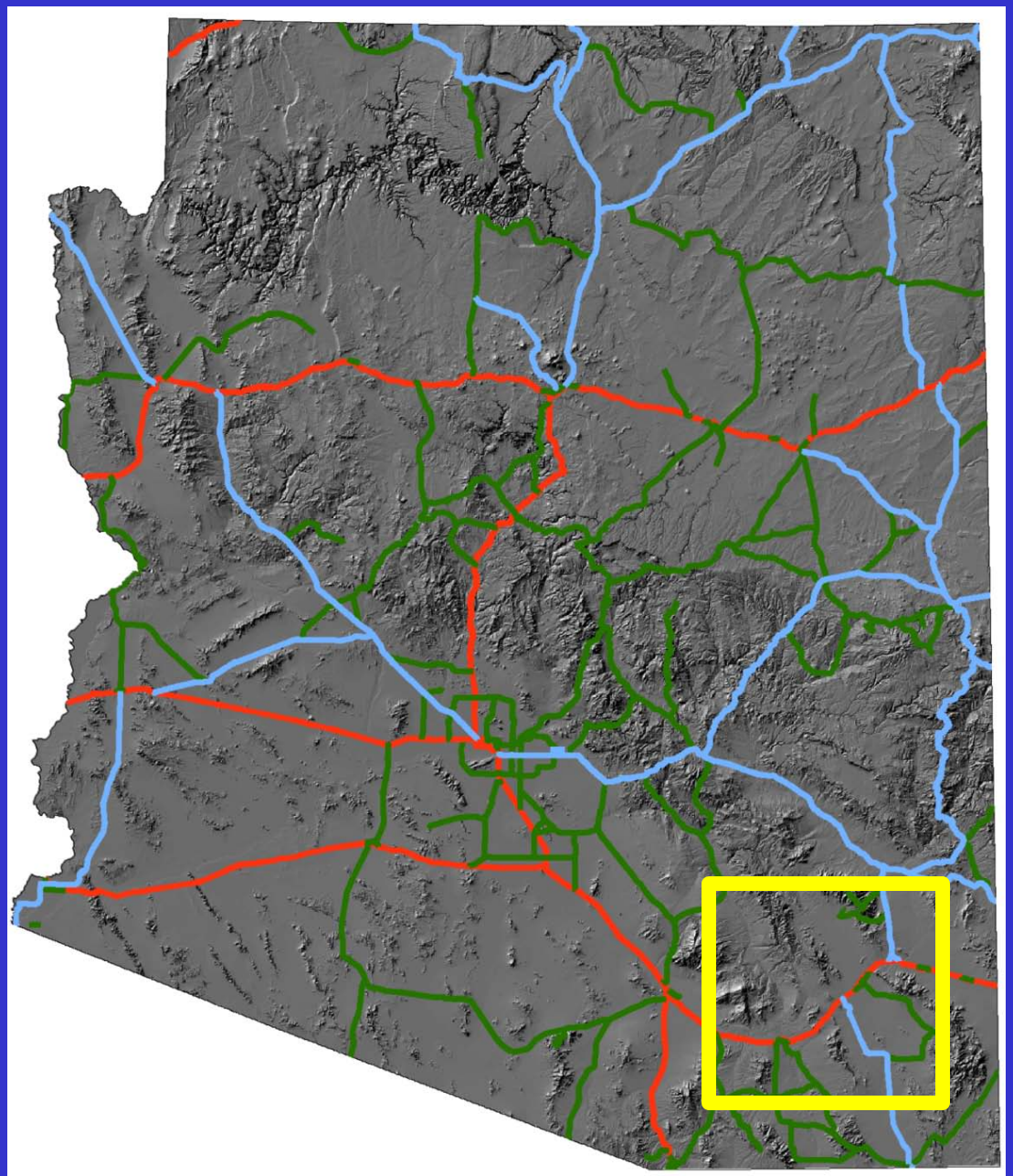
Land Subsidence for the Hawk Rock Area in Eastern Maricopa and Western Pinal Counties


Ironwood Rd
CAP Canal
Main St/Apache Trl
Southern Ave
60
Baseline Rd
Ellsworth Rd
202

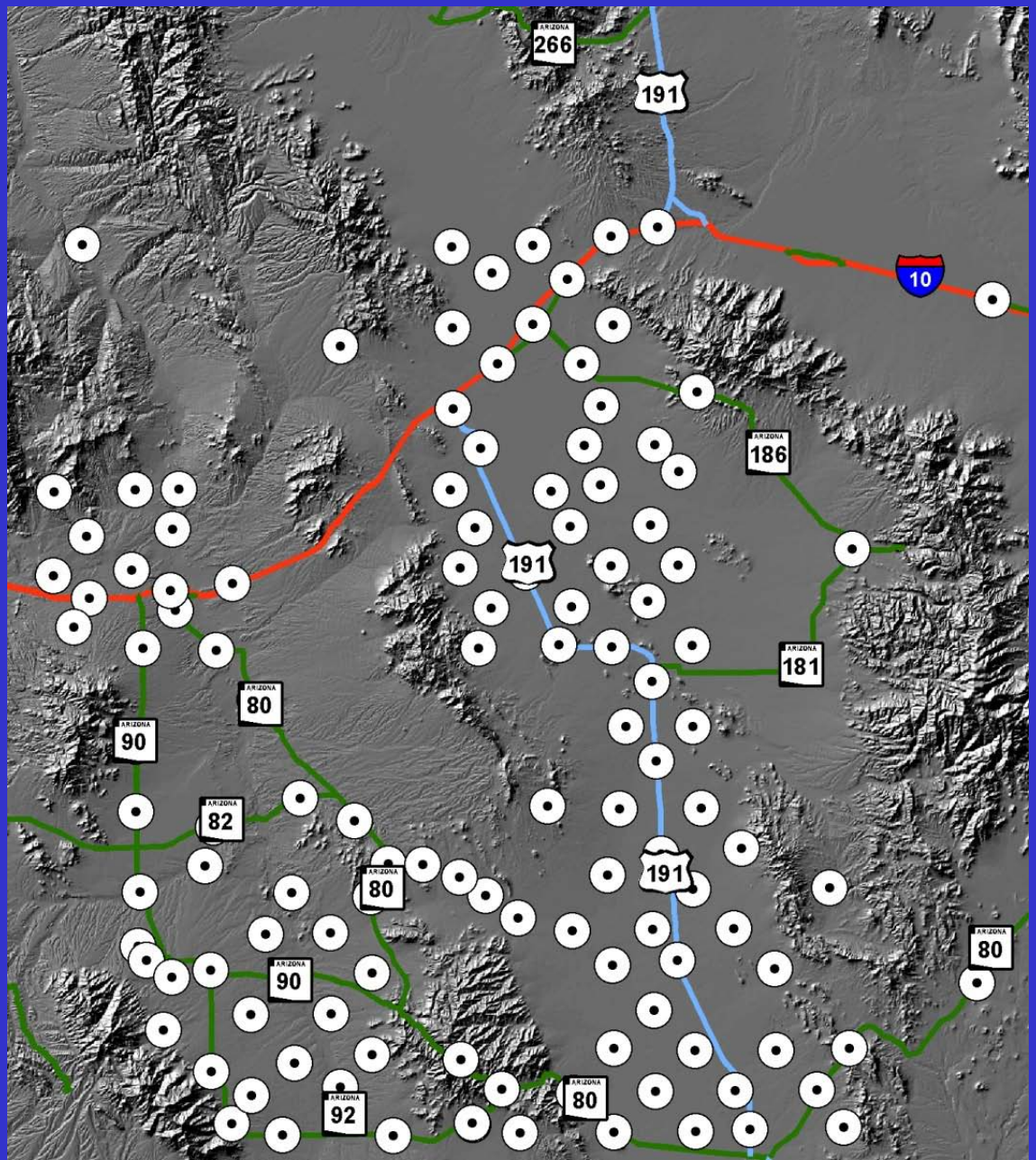


Why A Surveyor Should Know Where Land Subsidence is Occurring?

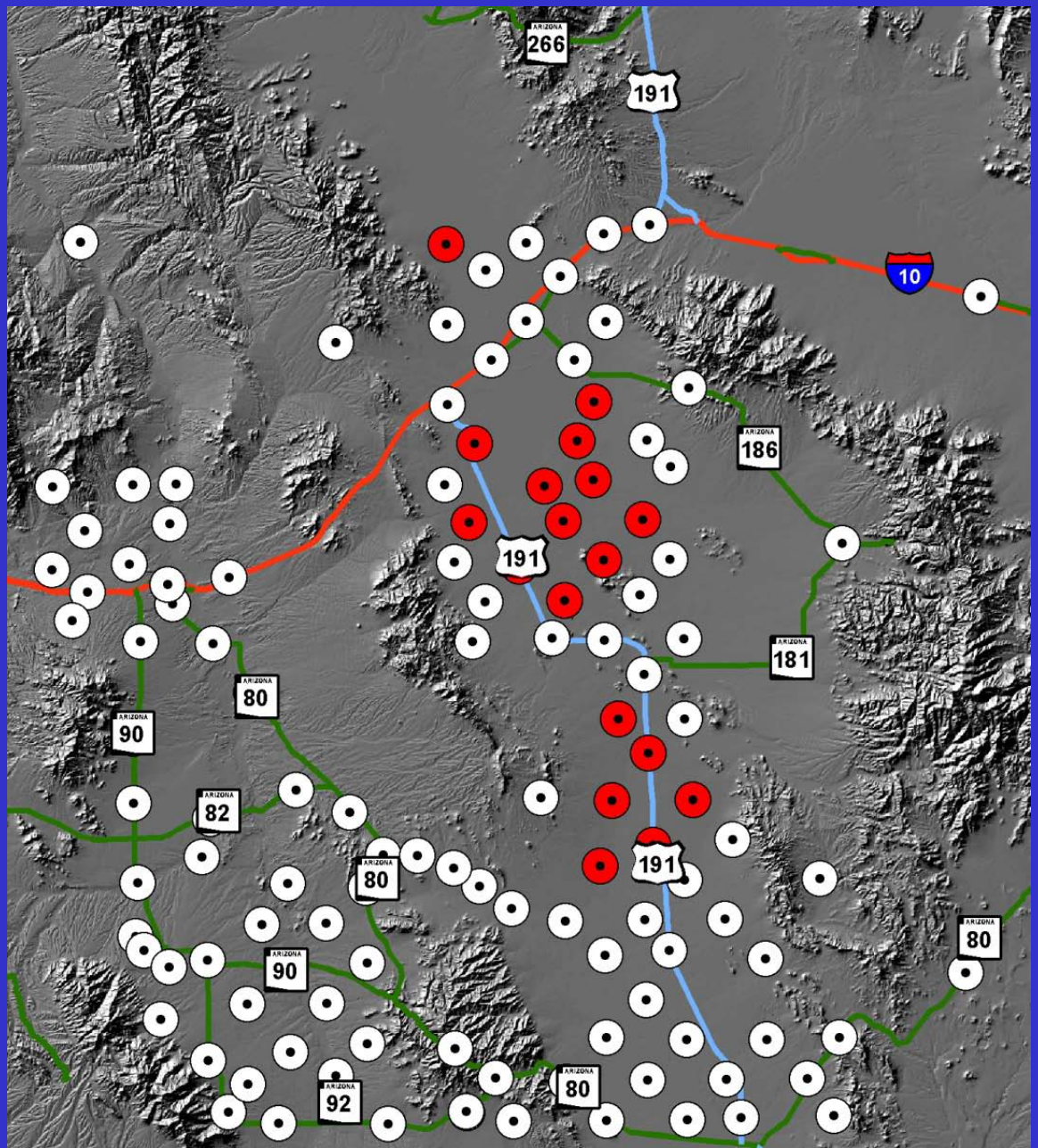
Why A Surveyor Should Know Where Land Subsidence is Occurring?
Cochise County Survey Control



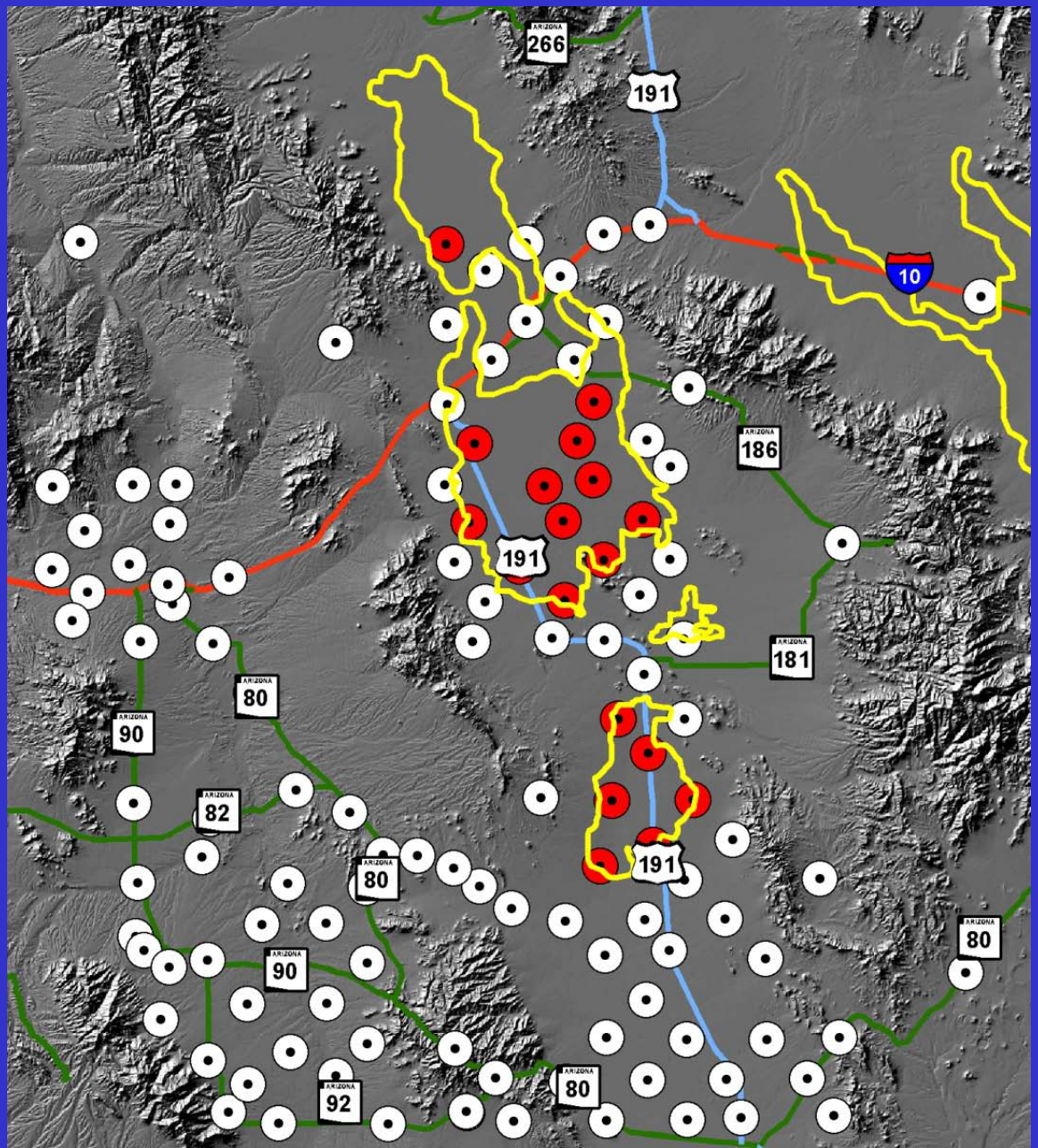
Why A Surveyor Should Know Where Land Subsidence is Occurring?
Cochise County Survey Control (White Dots)



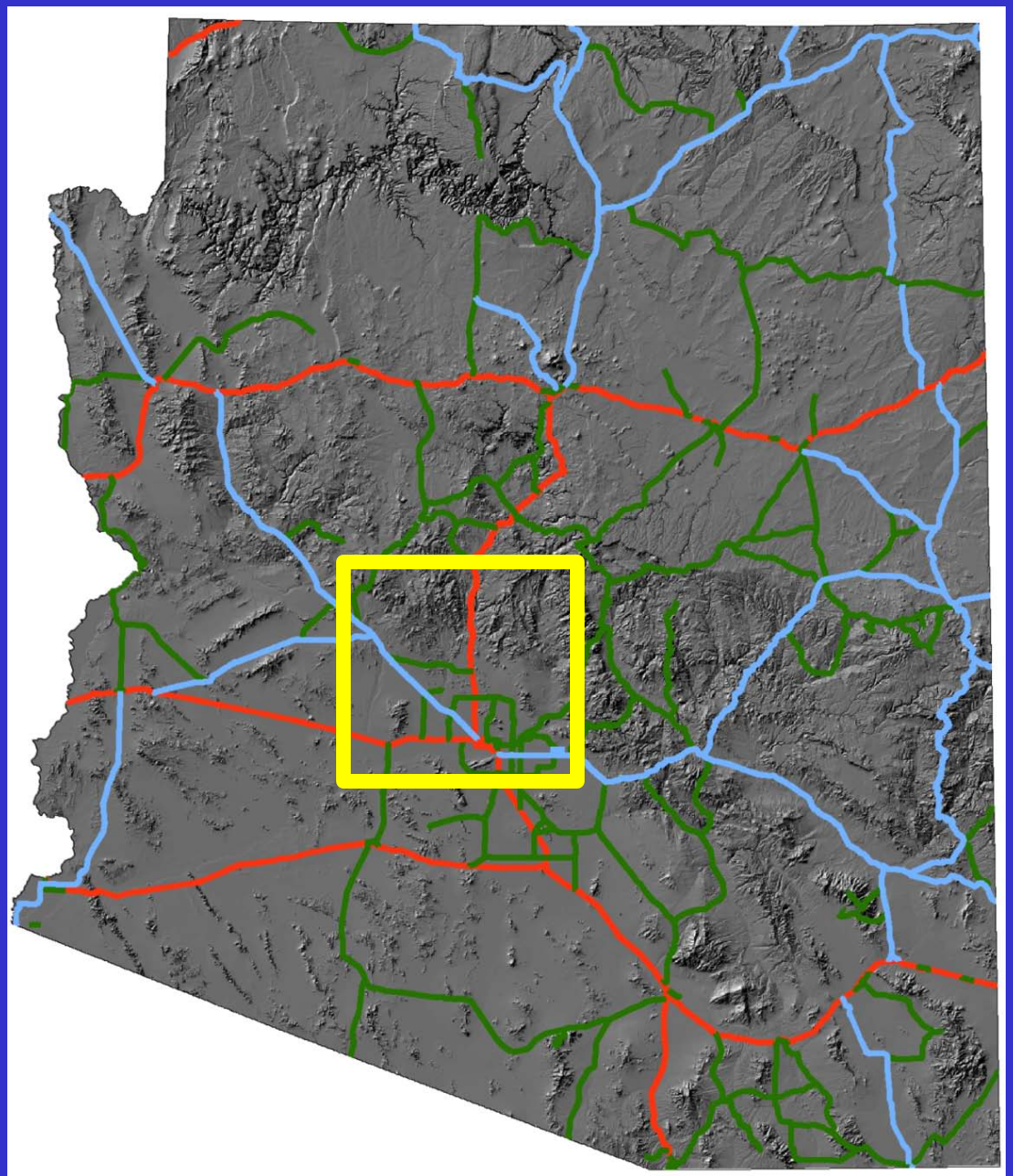
Why A Surveyor Should Know Where Land Subsidence is Occurring?
Cochise County Survey Control Affected By Land Subsidence (Red Dots)



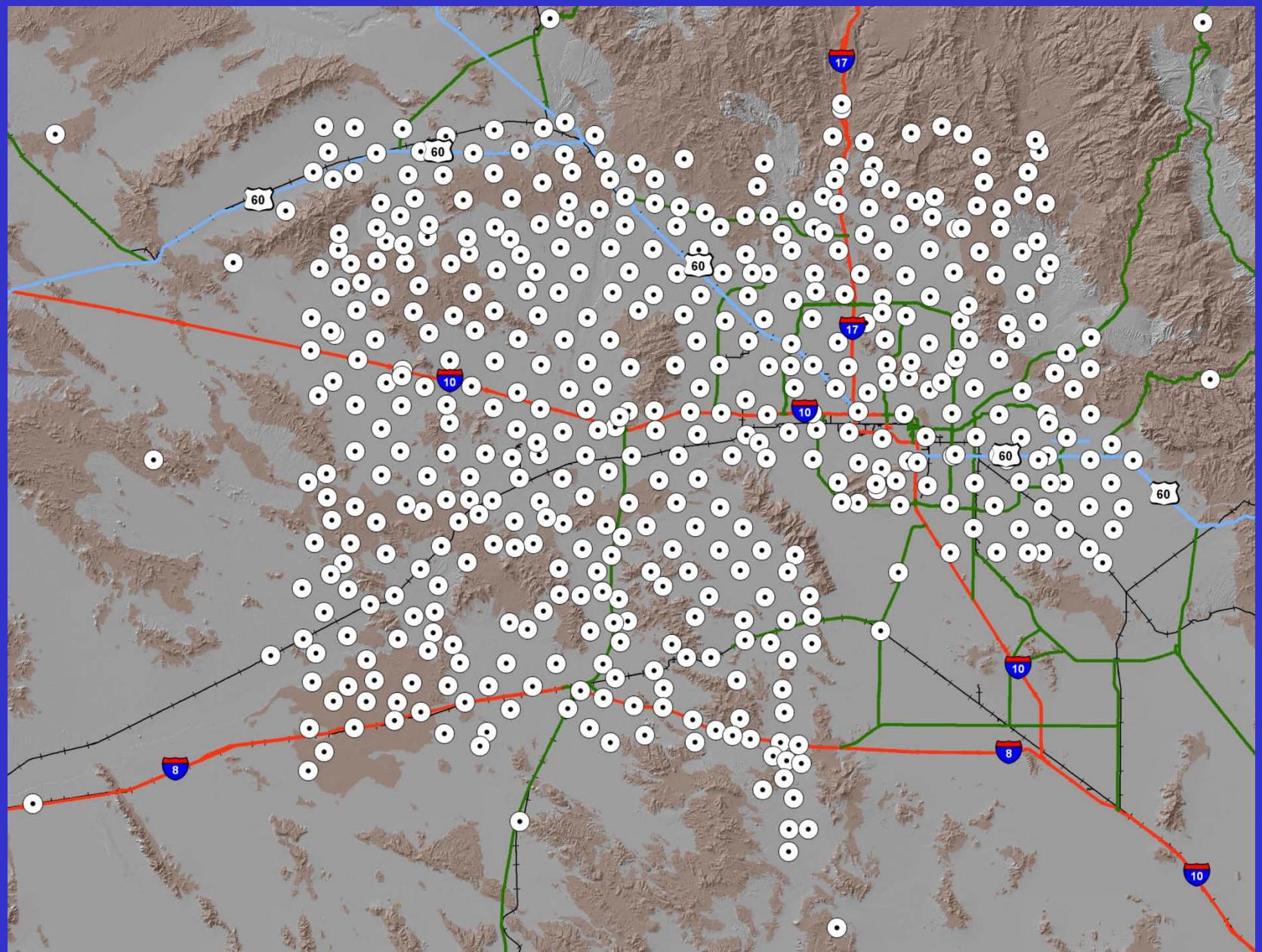
Why A Surveyor Should Know Where Land Subsidence is Occurring?
Cochise County Survey Control Affected By Land Subsidence (Red Dots)



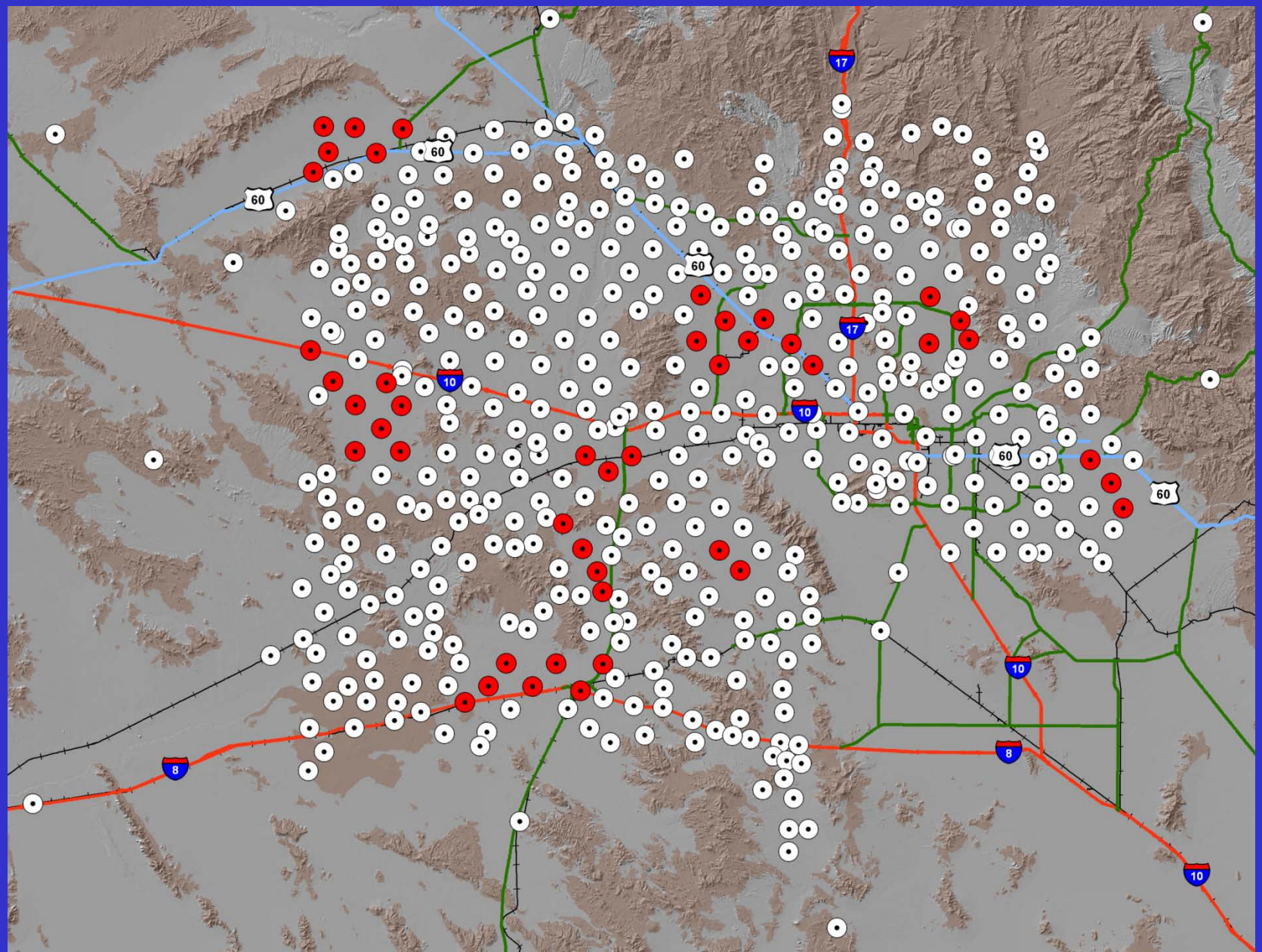
Why A Surveyor Should Know Where Land Subsidence is Occurring?
Maricopa County Survey Control



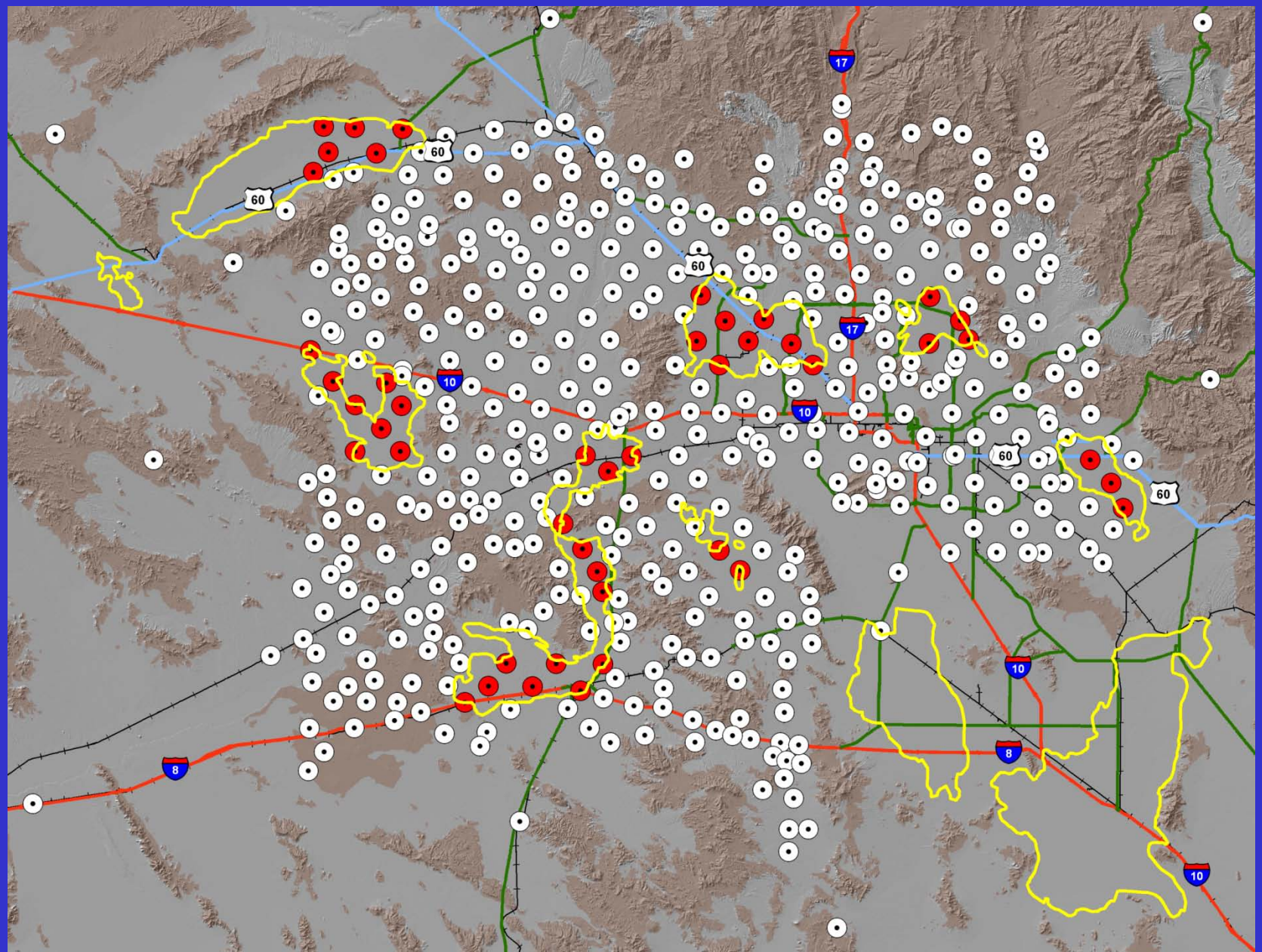
Why A Surveyor Should Know Where Land Subsidence is Occurring?
Maricopa County Survey Control (White Dots)



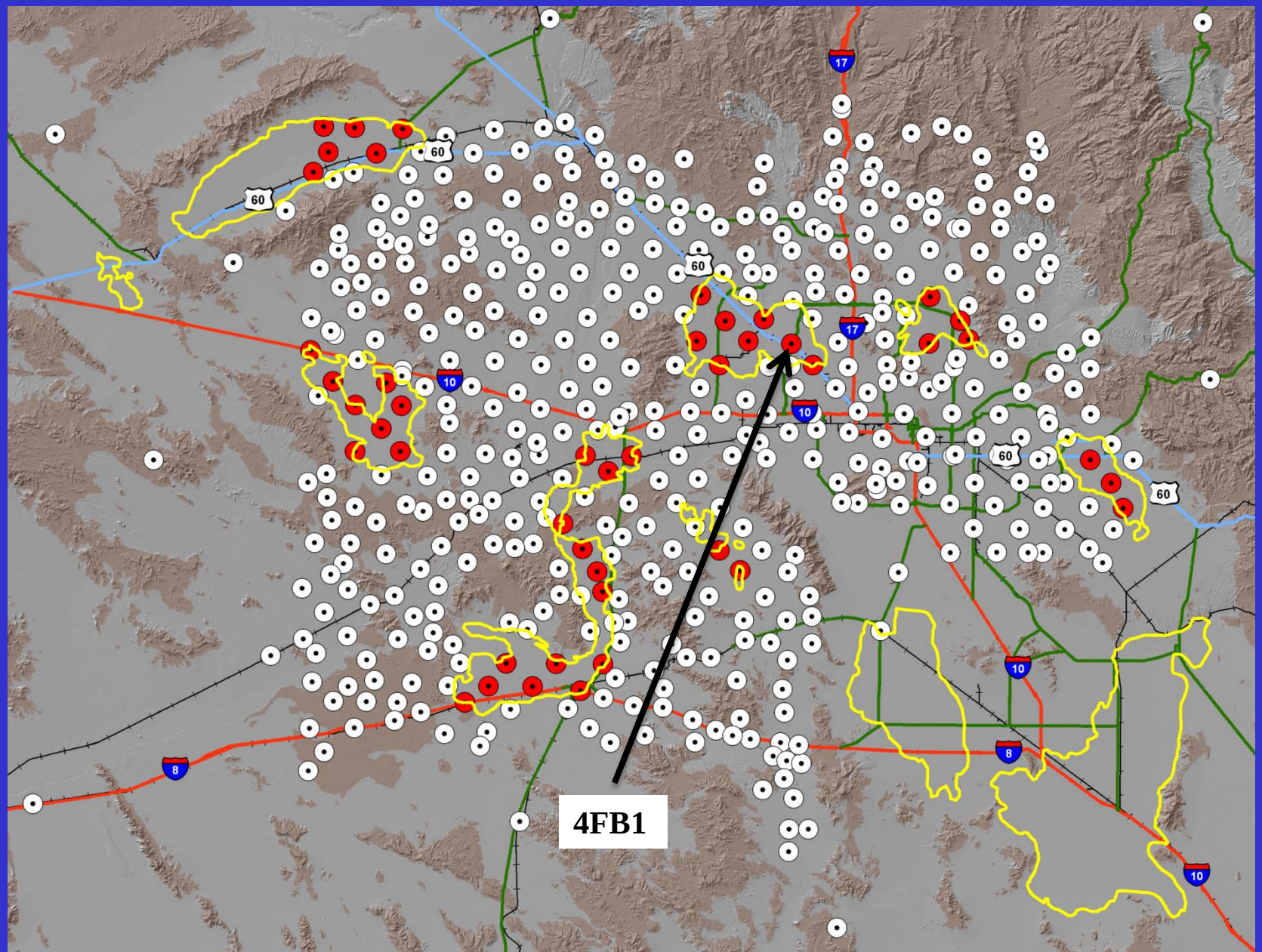
Why A Surveyor Should Know Where Land Subsidence is Occurring?
Maricopa County Survey Control Affected By Land Subsidence (Red Dots)



Why A Surveyor Should Know Where Land Subsidence is Occurring?
Maricopa County Survey Control Affected By Land Subsidence (Red Dots)



Why A Surveyor Should Know Where Land Subsidence is Occurring?
Maricopa County Survey Control Affected By Land Subsidence (Red Dots)



Why A Surveyor Should Know Where Land Subsidence is Occurring?
Maricopa County Survey Control Affected By Land Subsidence (Red Dots)

The NGS Data Sheet

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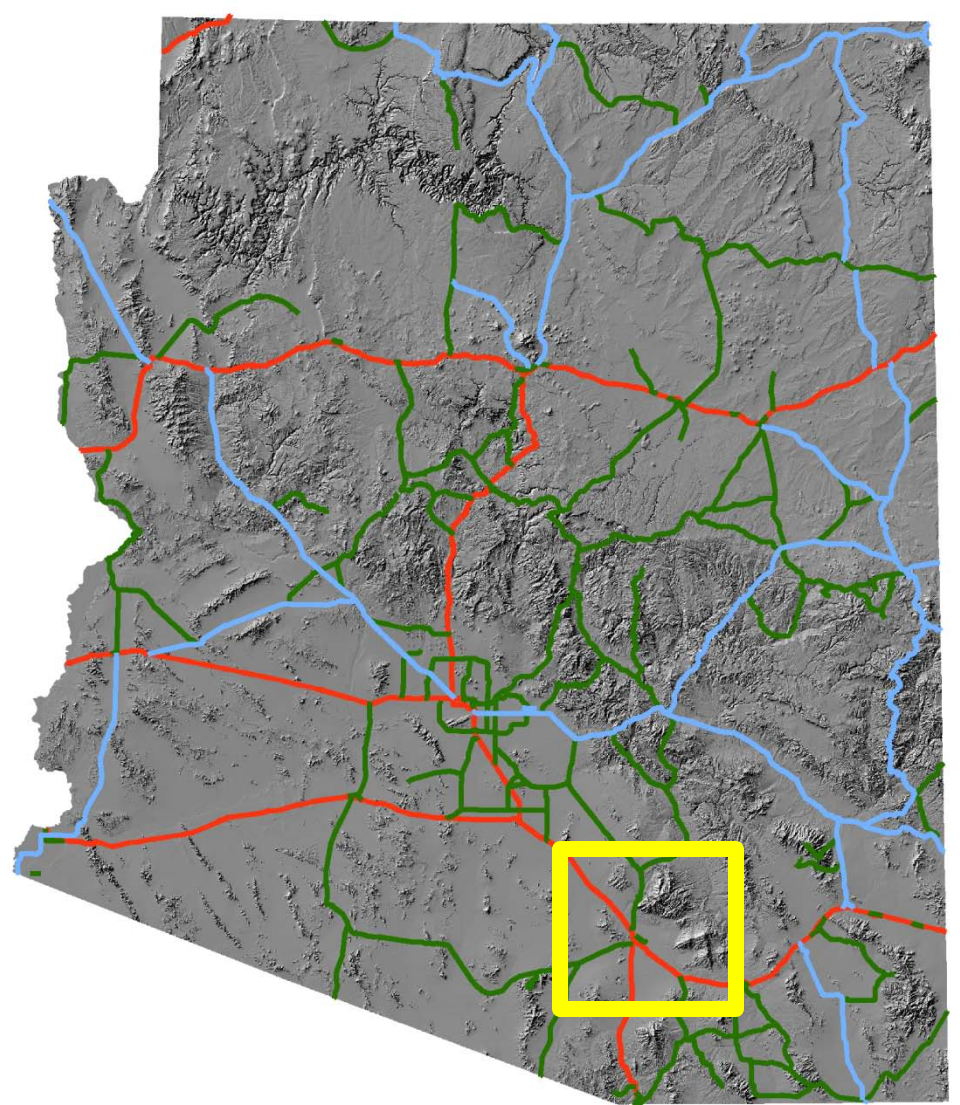
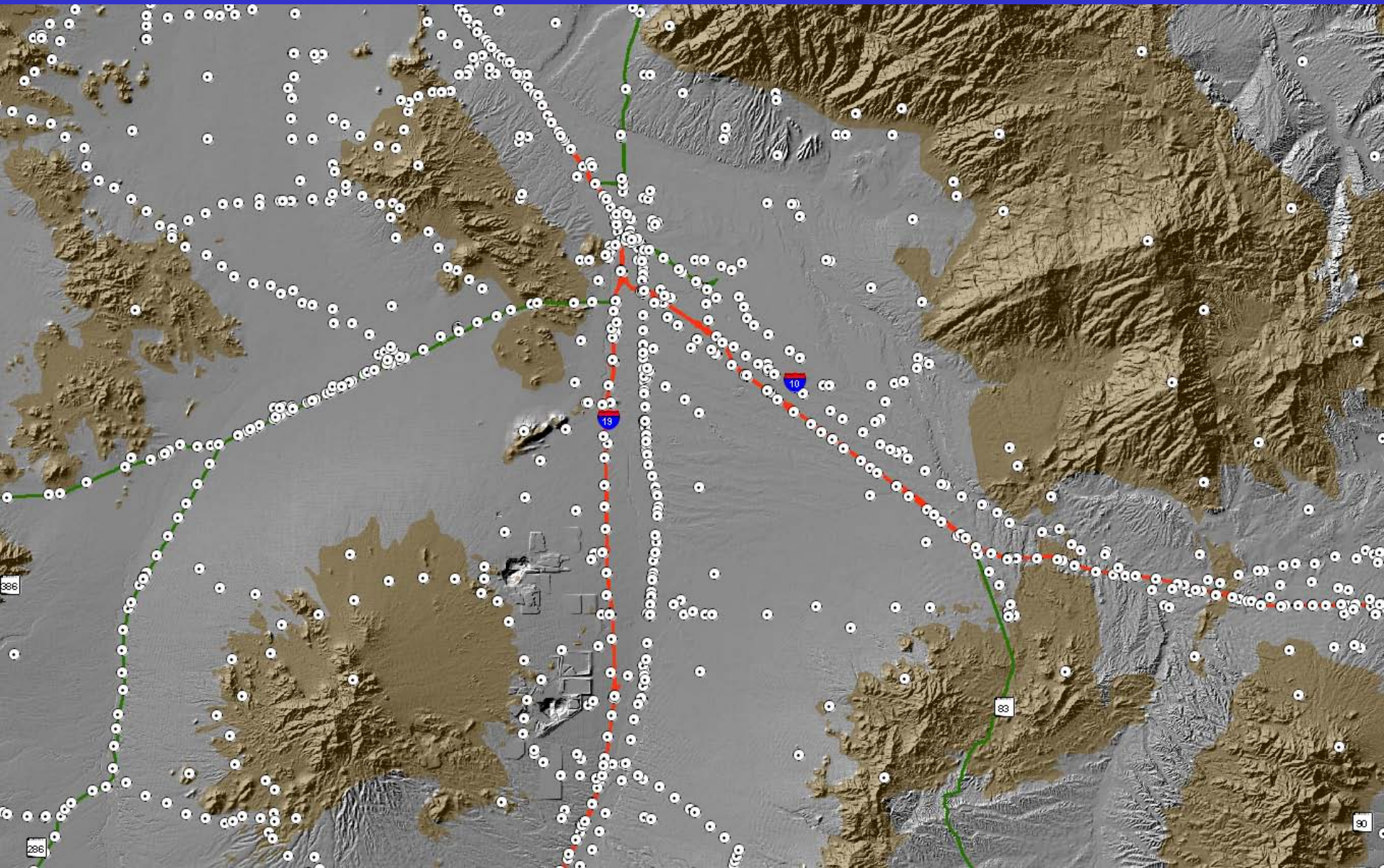
DATABASE =  ,PROGRAM = datasheet, VERSION = 7.82
1         National Geodetic Survey,   Retrieval Date = APRIL 16, 2010
 AJ3849 ***********************************************************************
 AJ3849  HT_MOD      -  This is a Height Modernization Survey Station.
 AJ3849  DESIGNATION -  4FB1
 AJ3849  PID         -  AJ3849
 AJ3849  STATE/COUNTY-  AZ/MARICOPA
 AJ3849  USGS QUAD   -  EL MIRAGE (1982)
 AJ3849
 AJ3849                        *CURRENT SURVEY CONTROL
 AJ3849  ___________________________________________________________________
 AJ3849* NAD 83(2007)-  33 35 50.38588(N)    112 21 02.02338(W)     ADJUSTED
 AJ3849* NAVD 88     -       345.97   (meters)    1135.1    (feet)  GPS OBS
 AJ3849  ___________________________________________________________________
 AJ3849  EPOCH DATE  -        2007.00
 AJ3849  X           -  -2,022,428.502 (meters)                     COMP
 AJ3849  Y           -  -4,918,821.679 (meters)                     COMP
 AJ3849  Z           -   3,509,505.916 (meters)                     COMP
 AJ3849  LAPLACE CORR-           0.69  (seconds)                    DEFLEC09
 AJ3849  ELLIP HEIGHT-         315.735 (meters)          (02/10/07) ADJUSTED
 AJ3849  GEOID HEIGHT-         -30.22  (meters)                     GEOID09
 AJ3849
 AJ3849  ------- Accuracy Estimates (at 95% Confidence Level in cm) --------
 AJ3849  Type    PID    Designation                     North   East  Ellip
 AJ3849  ___________________________________________________________________
 AJ3849  NETWORK AJ3849 4FB1                              0.78   0.69   1.18
 AJ3849  ___________________________________________________________________
 AJ3849
 AJ3849.The horizontal coordinates were established by GPS observations
 AJ3849.and adjusted by the National Geodetic Survey in February 2007.
 AJ3849
 AJ3849
 AJ3849                          STATION RECOVERY (2007)
 AJ3849
 AJ3849'RECOVERY NOTE BY MARICOPA CO DOT 2007 (BPD)
 AJ3849'FOUND THE MONUMENT IN GOOD CONDITION HOWEVER IT APPEARS IT IS
 AJ3849'SUBSIDING. WE PERFORMED FAST STATIC GPS AND IT SHOWS TO BE DOWN ABOUT
 AJ3849'0.30 FEET.
 AJ3849'
```

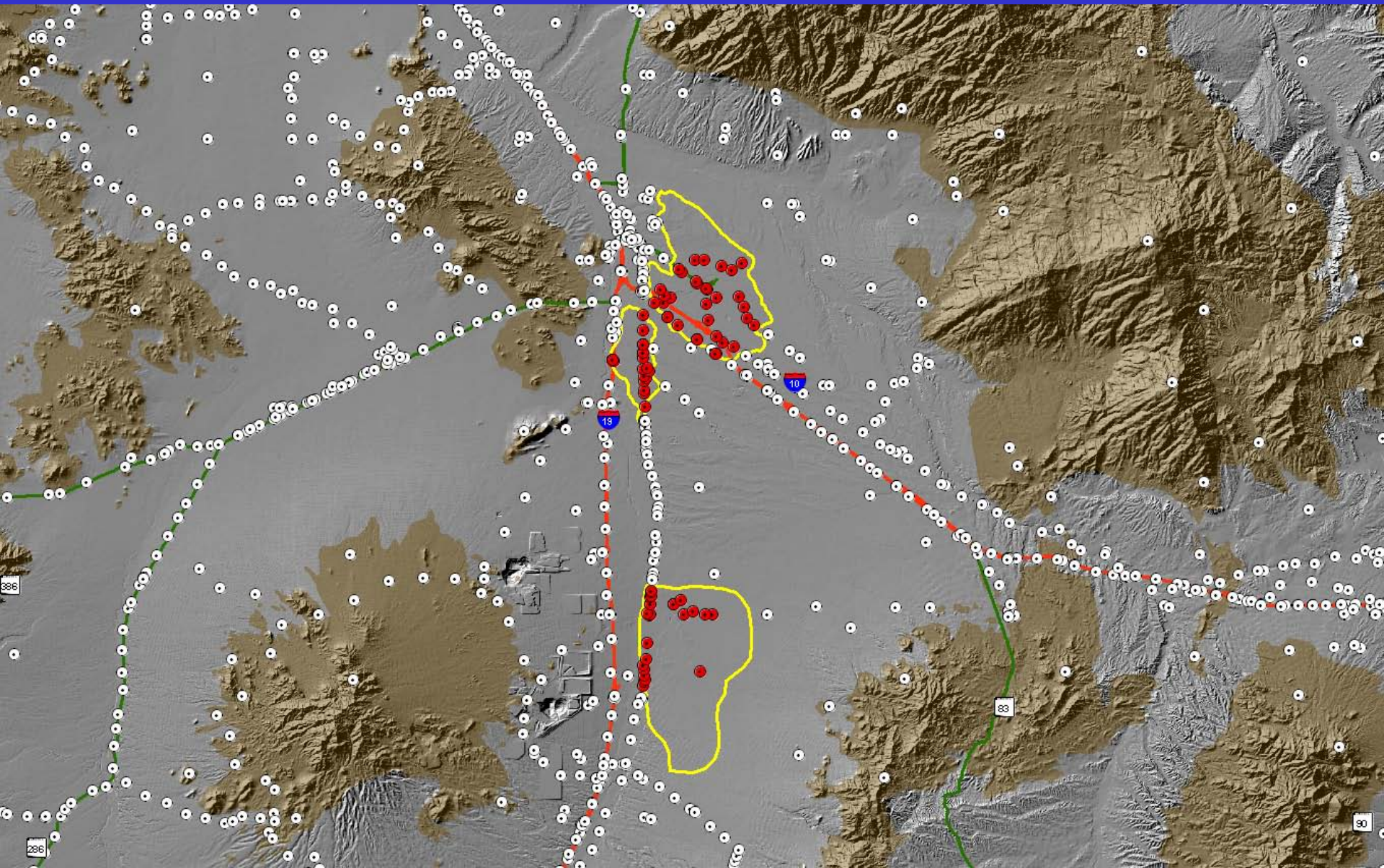
Why A Surveyor Should Know Where Land Subsidence is Occurring?
Pima County Survey Control



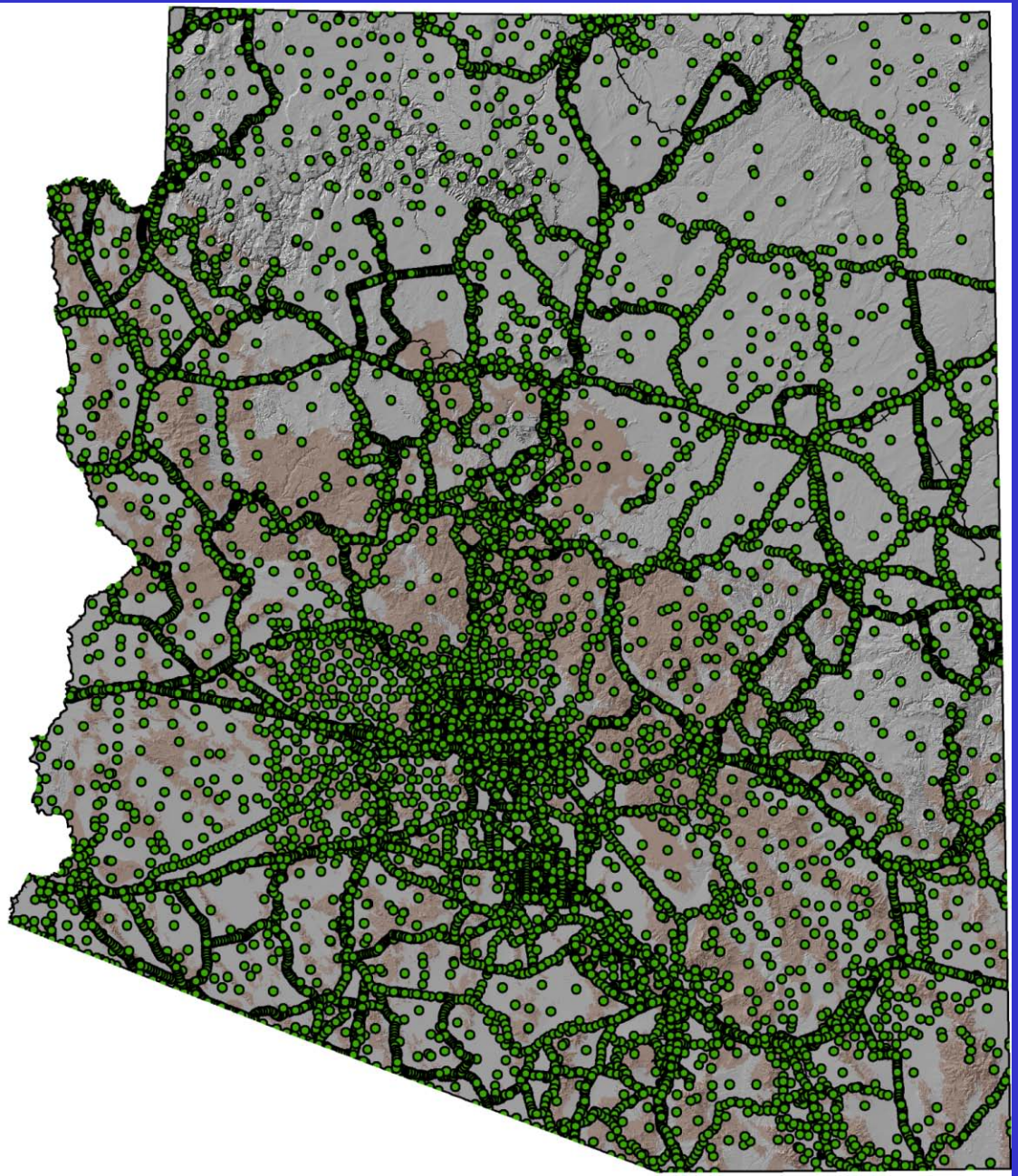
Why A Surveyor Should Know Where Land Subsidence is Occurring?
Pima County Survey Control (White Dots)



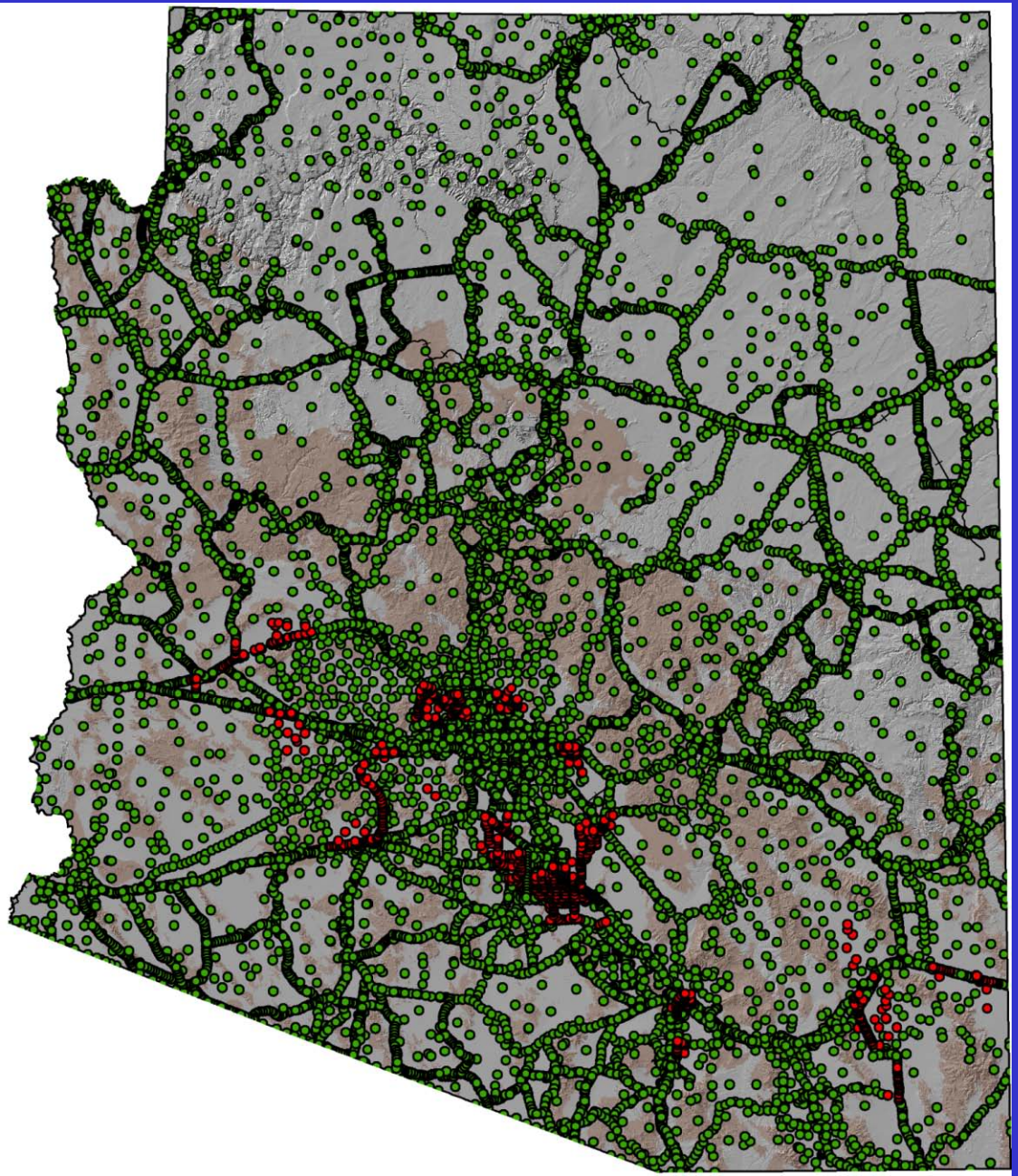
Why A Surveyor Should Know Where Land Subsidence is Occurring?
Pima County Survey Control Affected By Land Subsidence (Red Dots)



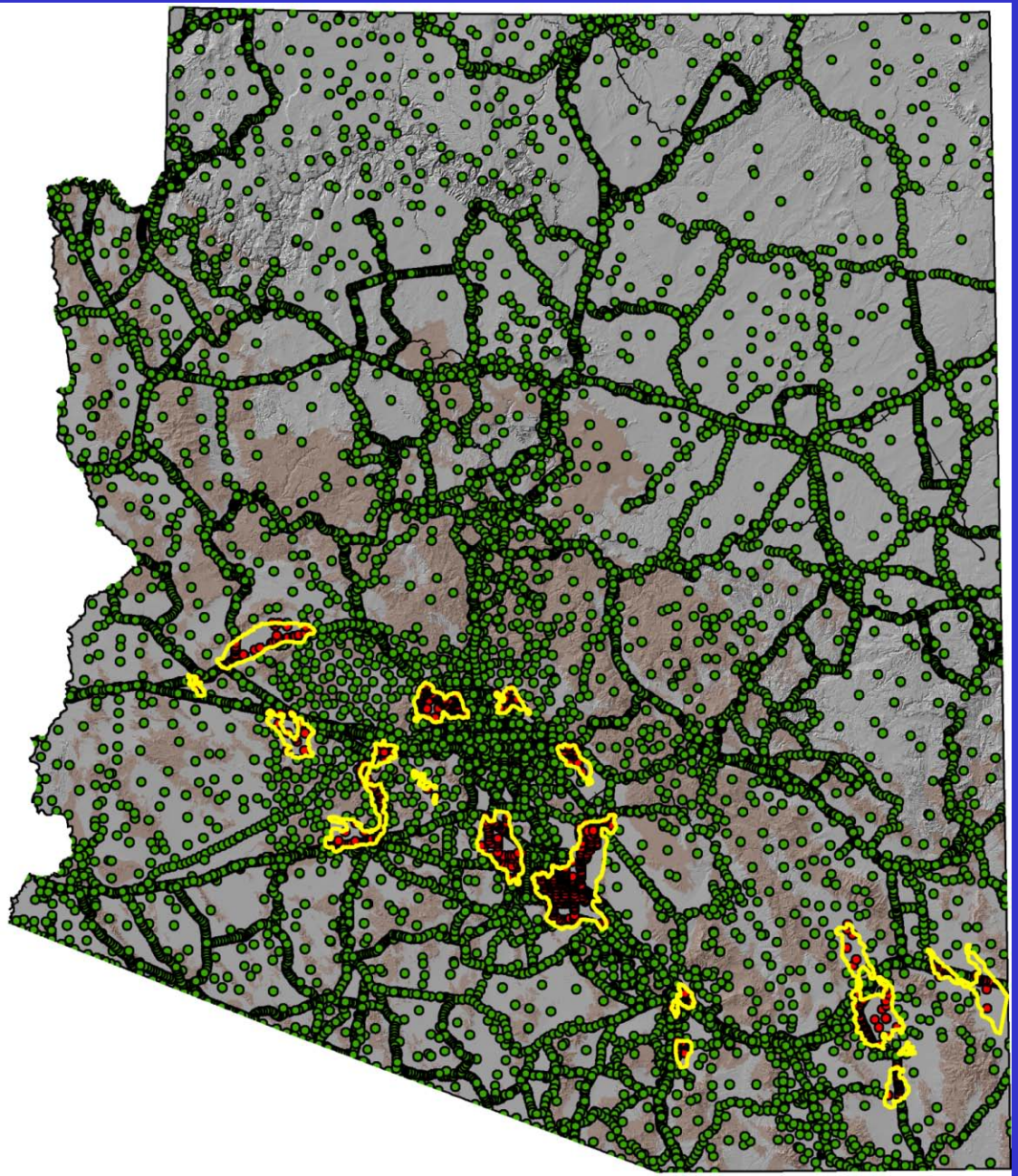
Why A Surveyor Should Know Where Land Subsidence is Occurring?
Arizona Survey Control According to the National Geodetic Survey (Green Dots)



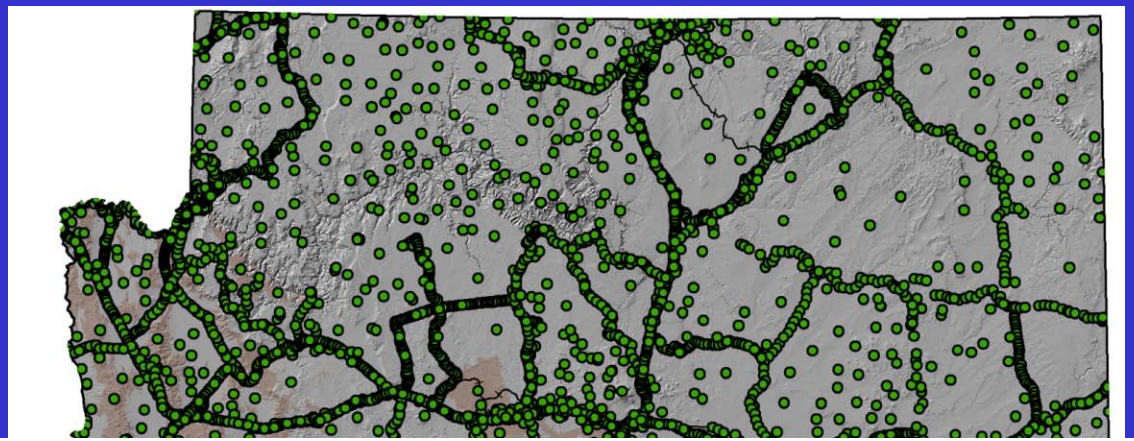
Why A Surveyor Should Know Where Land Subsidence is Occurring?
Arizona Survey Control Affected By Land Subsidence (Red Dots)



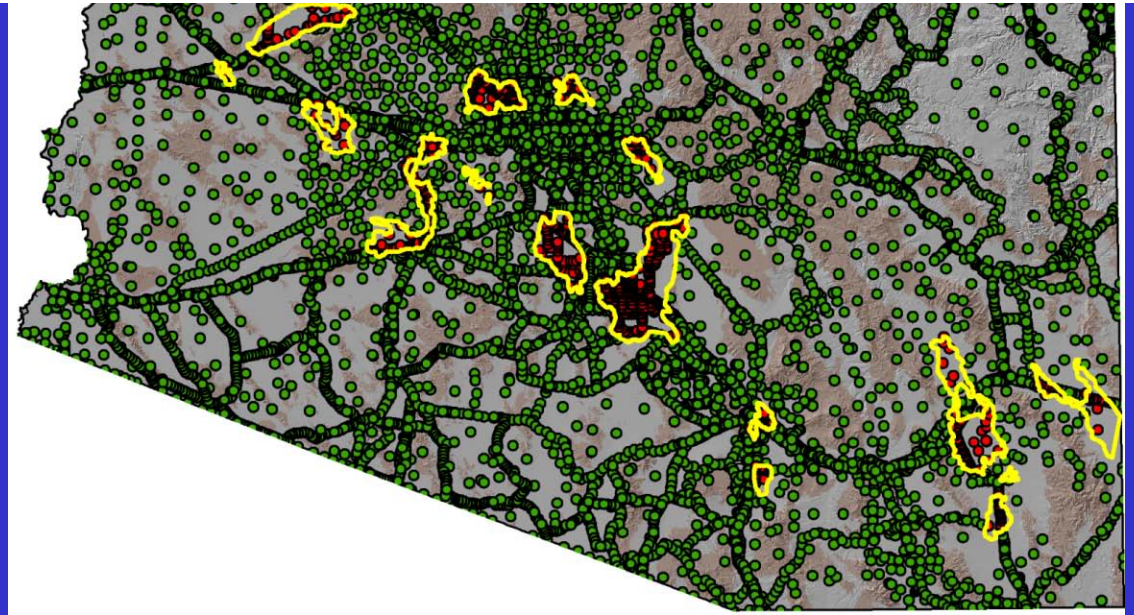
Why A Surveyor Should Know Where Land Subsidence is Occurring?
Arizona Survey Control Affected By Land Subsidence (Red Dots)

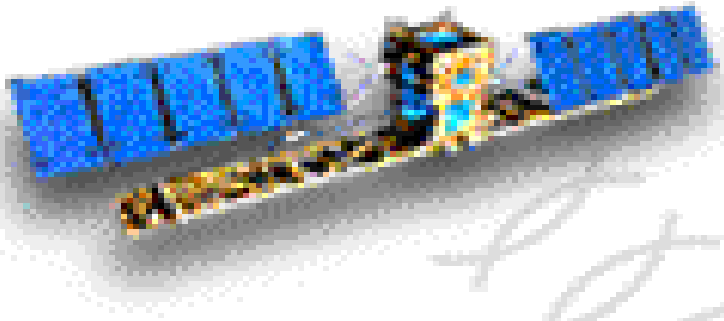


Why A Surveyor Should Know Where Land Subsidence is Occurring?
Arizona Survey Control Affected By Land Subsidence (Red Dots)



1,222 Survey Monuments Affected by Land Subsidence





Surveyed Elevations May Not Be Accurate

Old home elevations called into question

By Kyle Peveto The Beaumont Enterprise, Texas
Publication: The Beaumont Enterprise (Texas)
Date: Monday, February 16 2009

Feb. 16--Documents certifying the height of Southeast Texas properties above sea level may be as worthless as the homes flooded during Hurricane Ike.

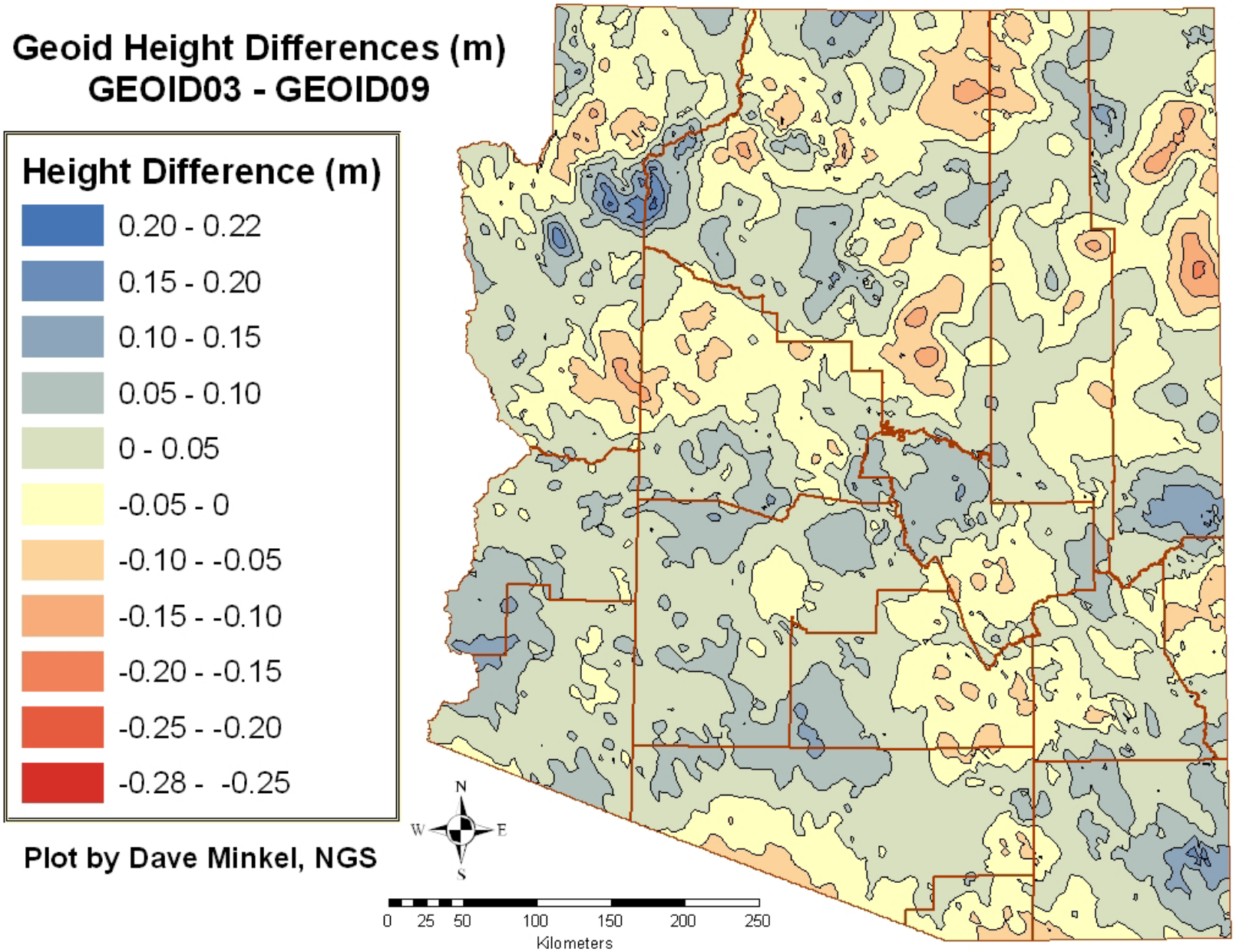
Elevation certificates, needed for new construction permits in flood zones and flood insurance applications, are based on decades-old government monuments that some property surveying experts say are unreliable and have been corrupted.

Surveyors "have to depend on these things, and that's what happened in this case, where the monument was inspected in 1959 for the last time, and in 1980, when local surveyors used it, there had been 3 feet of subsidence," Gilley said. "But nobody knew that.”

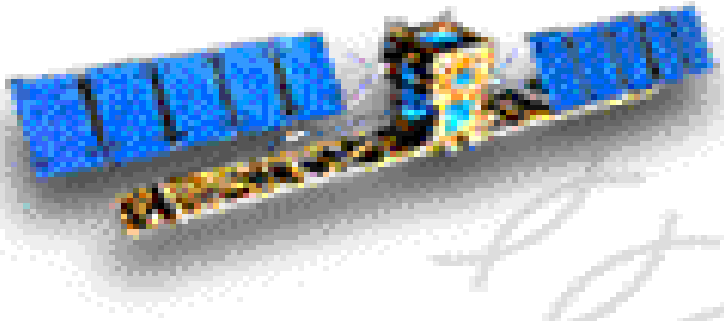
When Using NGS OPUS

- **Geoid 03 and Geoid 09 differ -0.28 to +0.22 meters in Arizona.**
- **The 0.5 meter variations could pose a problem for elevation certificates, especially in areas of little to no relief.**
- **Both Geoid 03 and Geoid 09 provide NAVD 88 heights, so the surveyor who uses OPUS determined orthometric heights should ALWAYS provide the client with the geoid model (e.g. NAVD 88 height as determined by Geoid 09).**

Geoid Height Differences (m)
GEOID03 - GEOID09



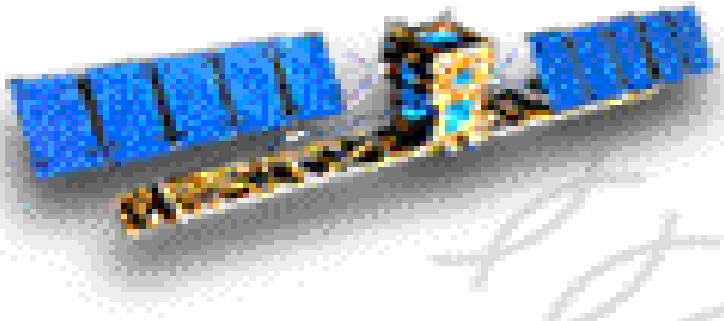
Plot by Dave Minkel, NGS



Floodplain Changed by Land Subsidence

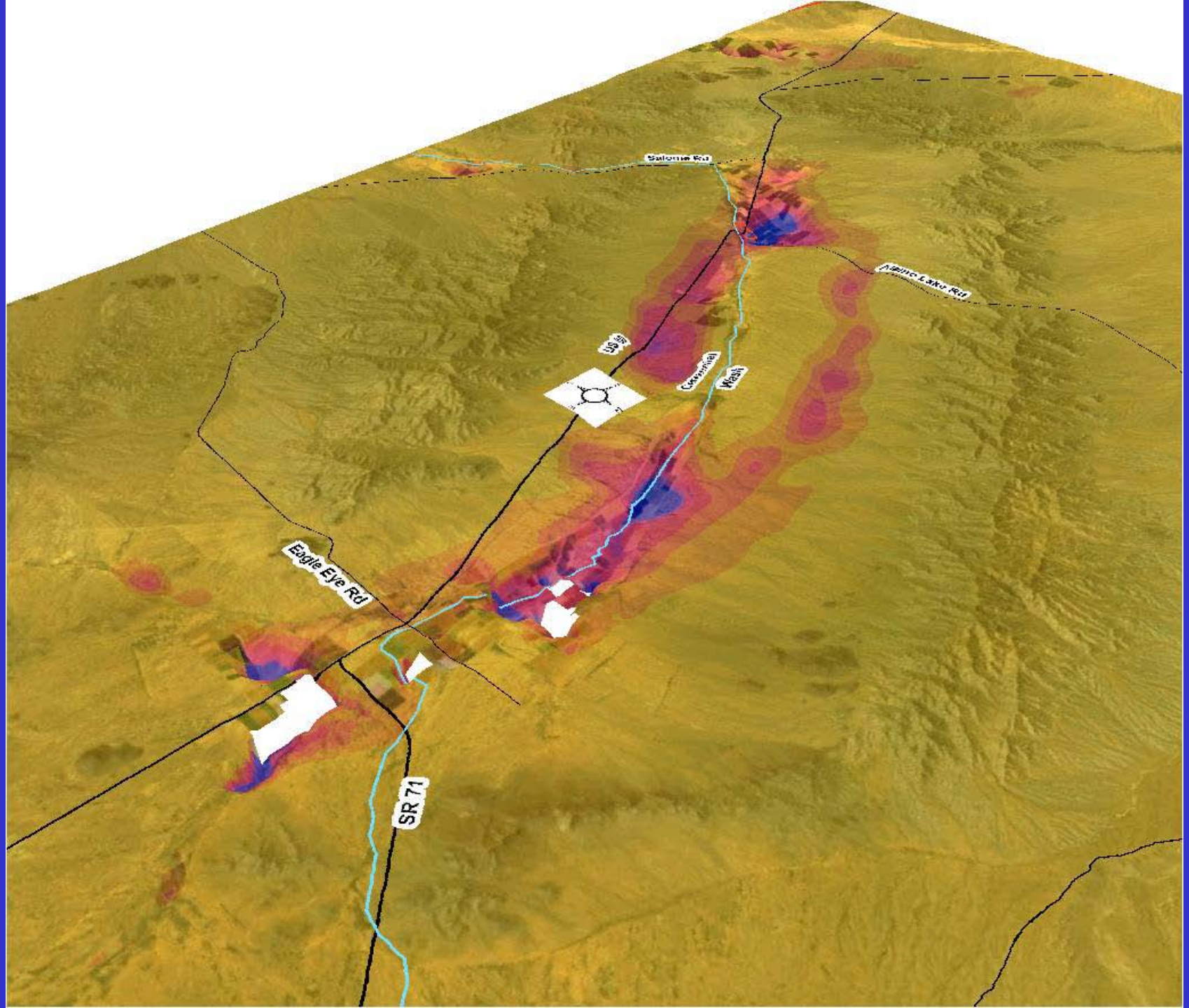
Floodplain Changed by Land Subsidence Centennial Wash in the McMullen Valley Maricopa and La Paz Counties

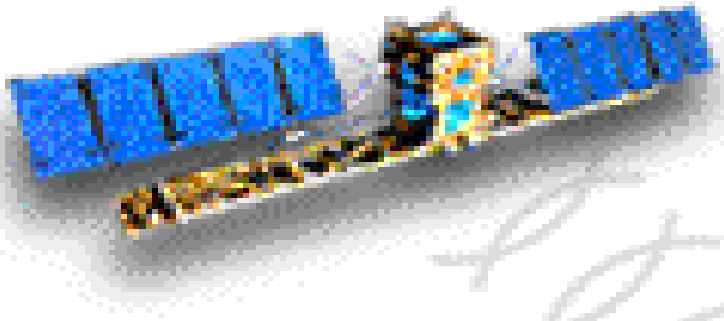
Town of Wenden Flooding January 2010
Photo Courtesy of La Paz County



Enhanced 3D View

Land Subsidence for the McMullen Valley


Salome Rd
Aguila Lake Rd
US 60
Centennial
Wash
Eagle Eye Rd
SR 71



Enhanced 3D View

Land Subsidence for the Town of Wenden

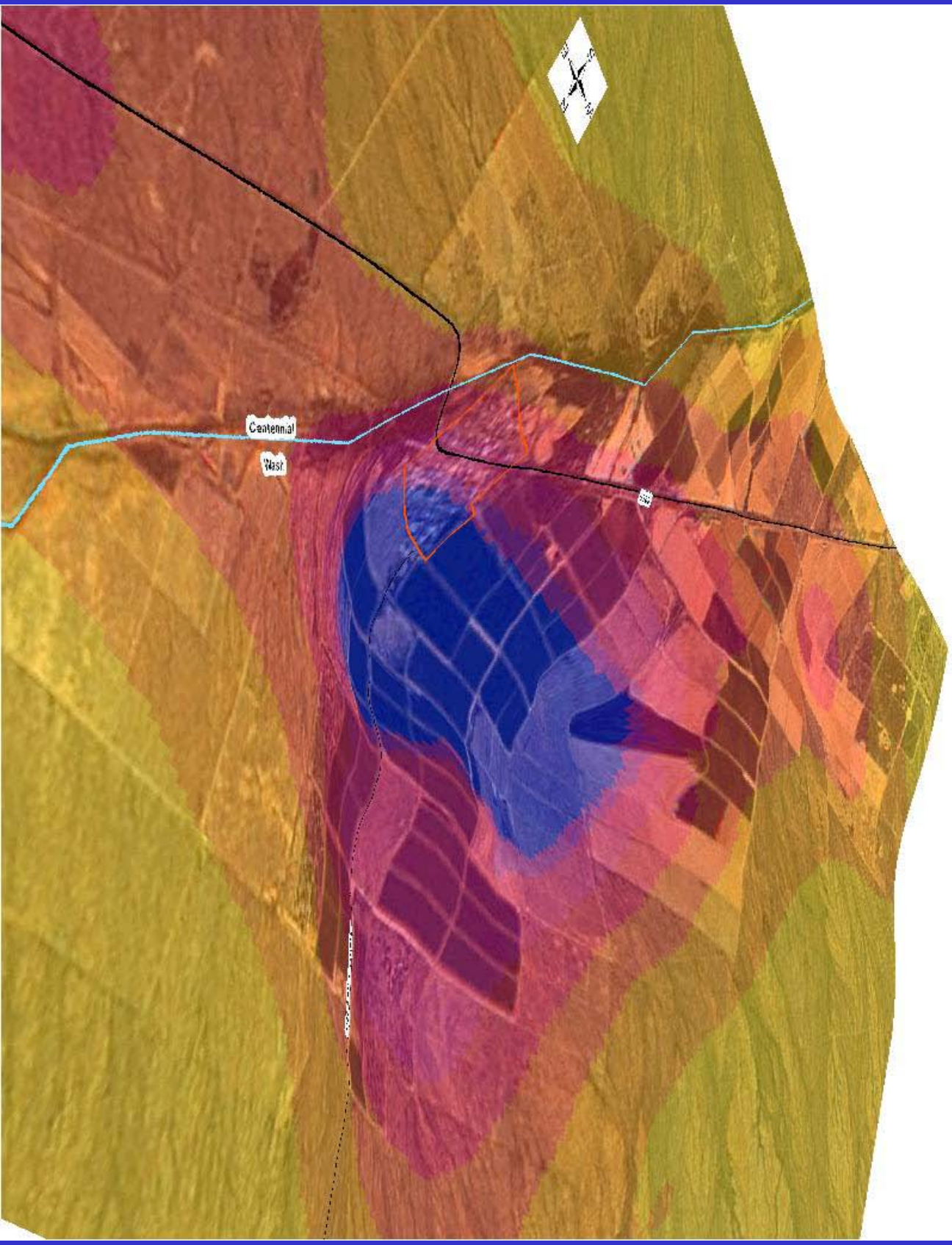

Centennial
West

Photo Courtesy of La Paz County

Photo Courtesy of La Paz County

Town of Wenden Virtual View Enhanced Land Subsidence February 2009 to February 2010

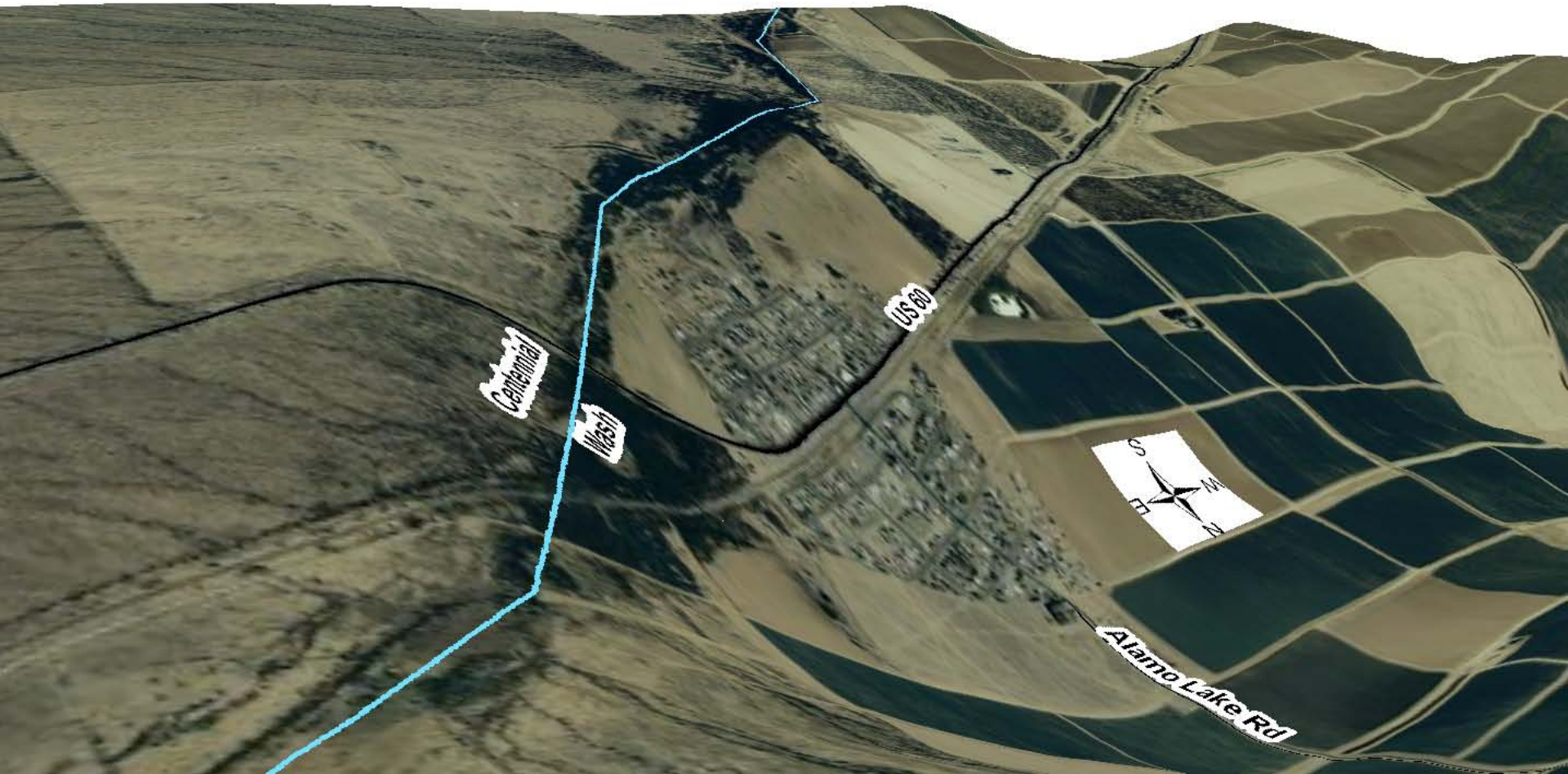
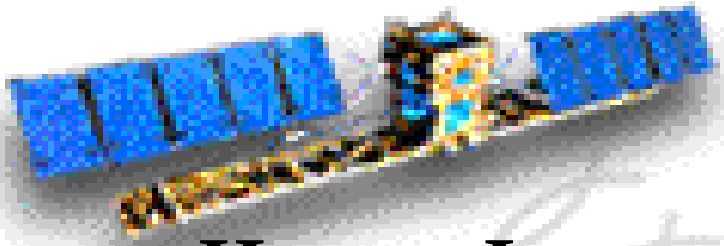
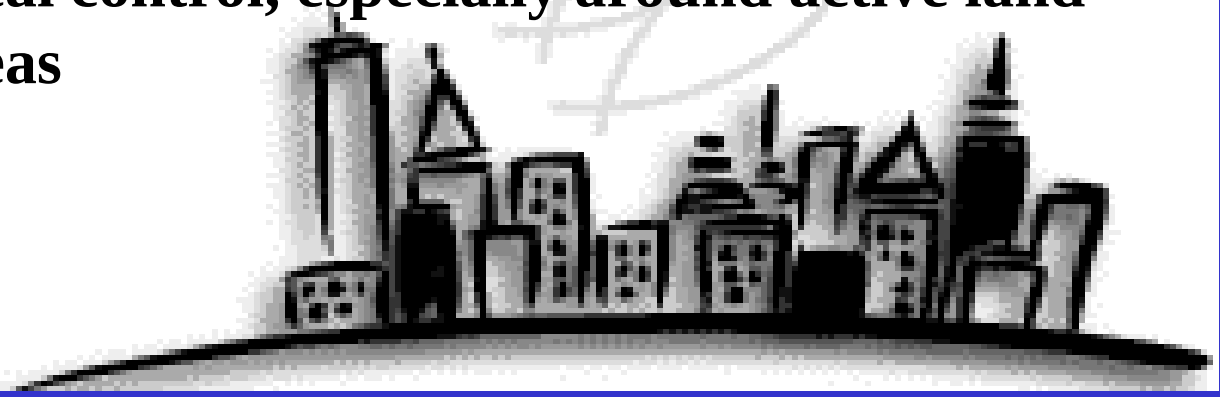


Photo Courtesy of La Paz County



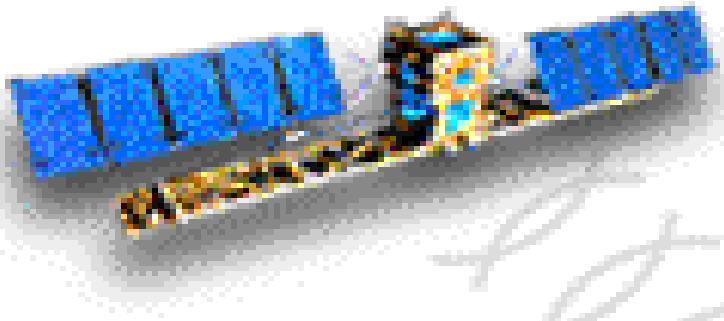
How to Improve Vertical Control

- **Investigate where active land subsidence areas exist and verify published survey monument elevations**
- **Utilize bedrock CORS for vertical control**
- **Install additional bedrock CORS throughout Arizona to improve vertical control, especially around active land subsidence areas**

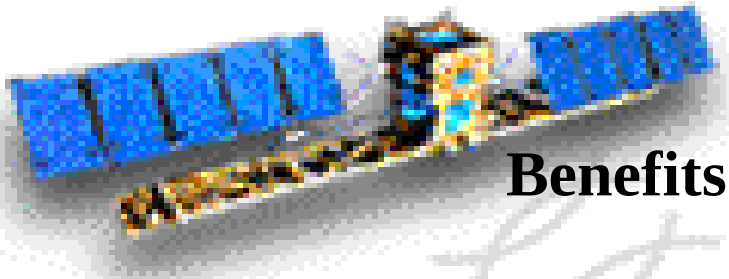


How to Improve Vertical Control

- Investigate whe
  verify publishe
- Utilize bedrock
- Install addition
  improve vertica
  subsidence area



Presentation Review

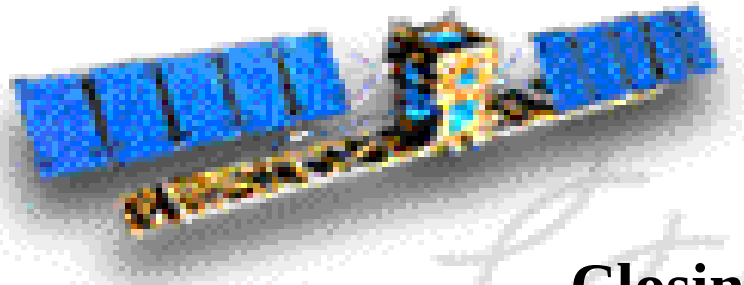


Benefits From InSAR

- Greatly improved land subsidence monitoring efforts across Arizona.
- Developed important partnerships with other State, County, and Local Agencies providing land subsidence data for their monitoring efforts.
- Developed and published land subsidence maps for the State of Arizona.
- Greatly improved awareness of land subsidence and the potential problems caused by land subsidence.

Land Subsidence and InSAR Review

- Subsidence is a significant problem in the Southwestern U.S.
- Land subsidence should be monitored on an annual basis to monitor existing features and to detect new areas of land subsidence.
- InSAR is a valuable resource for monitoring land deformation, both subsidence and uplift.
- Various Federal, State, County, and Local Agencies use InSAR for land subsidence monitoring.



Closing Remarks

- You should now have a better understanding about land subsidence and how it can be monitored on a regional and local scale.

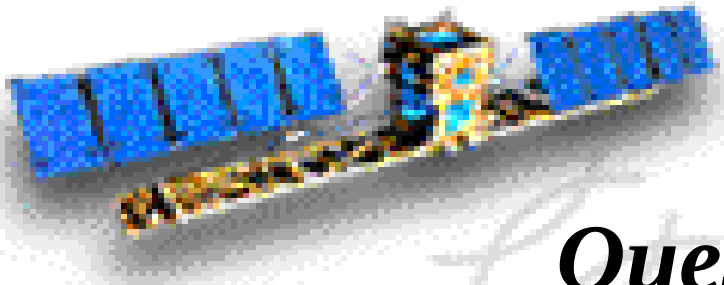
- Monitoring land subsidence using InSAR by hydrologist, geologists, surveyors, engineers, GIS professionals, floodplain managers, and scientists has increased dramatically over the past ten years.

Arizona Land Subsidence Group Workshop

Arizona Geology and Geohydrology Challenges in Alternate Energy Site Selection & Design

- One day workshop to provide attendees an overview of the subsurface ground conditions present in Arizona that would impact development of alternate energy sites

- Give attendees access to public and consultant geologic/geohydrologic experts who deal with unique Arizona subsurface conditions



Questions?

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