Surface Deformation from Satellite Data and Applications to Geothermal Assessment, Exploration and Mitigation in Imperial Valley

Mariana Eneva (Imageair Inc.)

PIER 2007-2009

- **Title:** *Application of InSAR to the Detection of Surface Deformation in the Geothermal Fields of Imperial Valley, CA*
- **CEC Manager:** Pablo Gutierrez
- **Method:** InSAR = Interferometric Synthetic Aperture Radar
- **Specific Application:** PSInSAR = "Permanent Scatterers" InSAR (works in agricultural areas !)
- **Subcontractor:** TRE Canada Inc. (best PSInSAR technique)
- **Data** - from the Salton Sea geothermal field:
    - Satellite radar data – Radarsat 2006-2008, from the Alaska Satellite Facility (ASF)
    - On the ground - leveling (from CalEnergy) and GPS (from PBO)
- **Results:** Displacements in the line-of sight (LOS) from ascending and descending images
- **Post-processing:** Decomposition into vertical and horizontal components

Study Area: Salton Sea geothermal field (SSGF)

Study area ~ 100 sq. km

79 leveling benchmarks (CalEnergy)

S-1246 – reference benchmark for leveling measurements

GPS stations

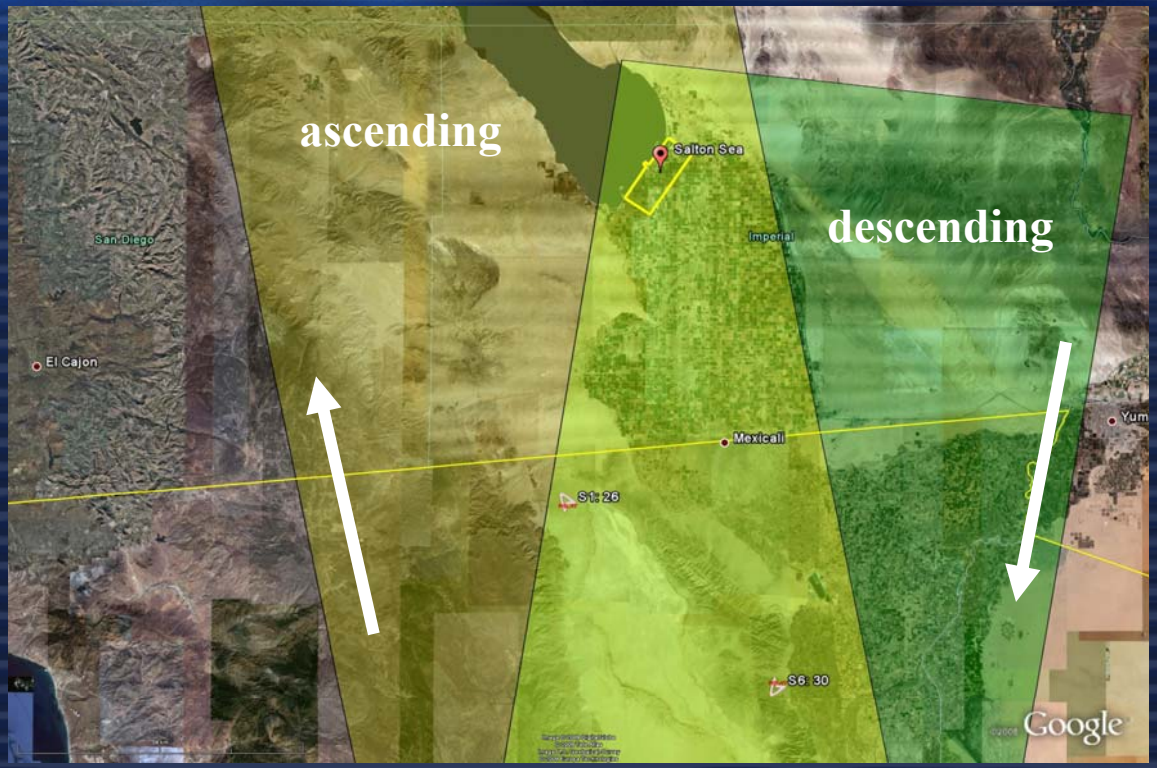
Between –50 and +10 mm/yr

Most between –30 and 0 mm/yr

S-1246: subsides at –19 mm/yr

Imageair, Inc.

PSInSAR at SSGF



Radarsat - 1 data (Canadian), from Alaska Satellite Facility

- **18 ascending, 21 descending**
- **May 2006 – March 2008**

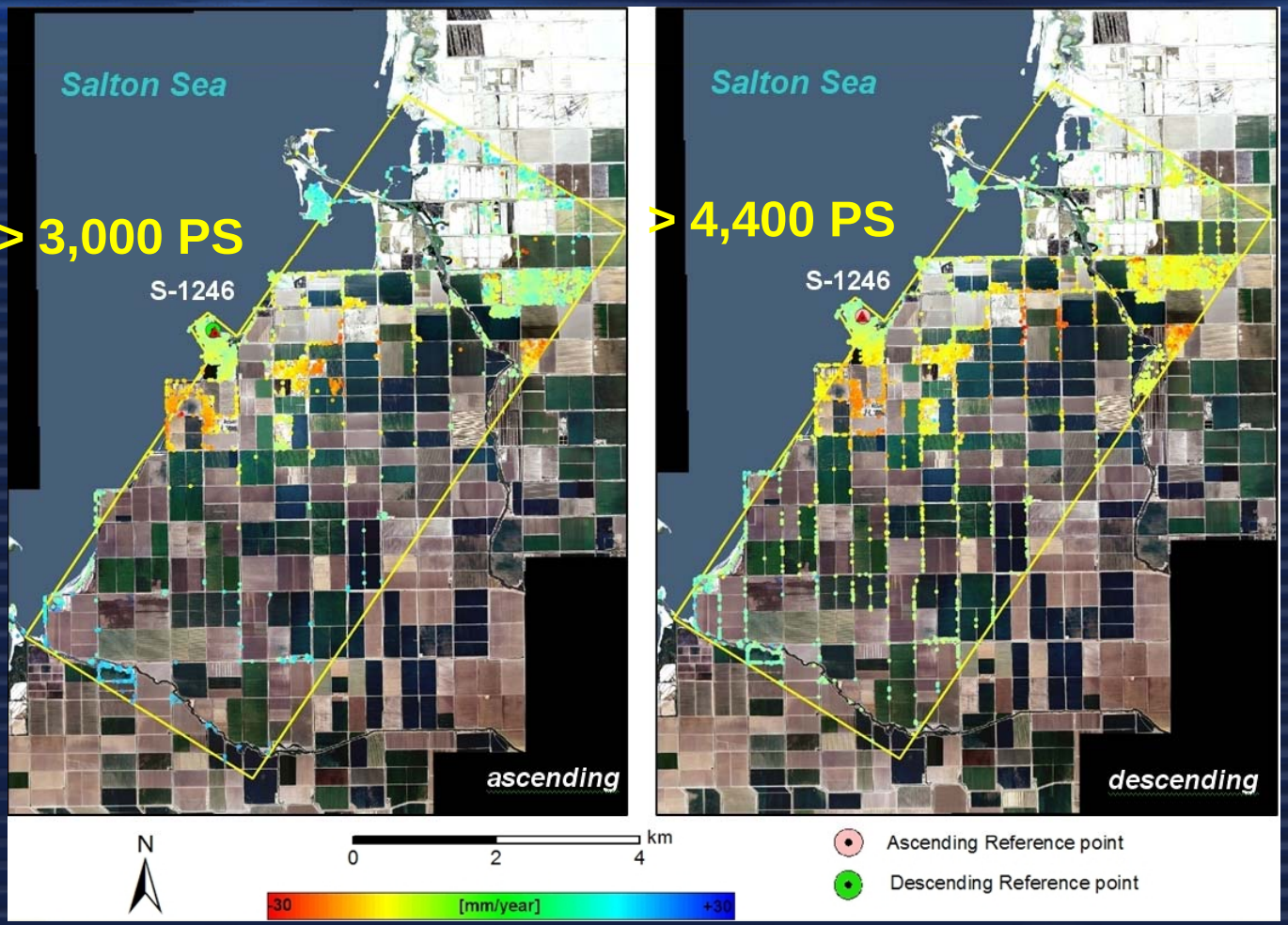
Imageair, Inc.

LOS deformation rates at PS points

GRC 2009 Proceedings

Eneva, M.[1], G. Falorni[2], D. Adams[1], J. Allievi[3], and F. Novali[3]

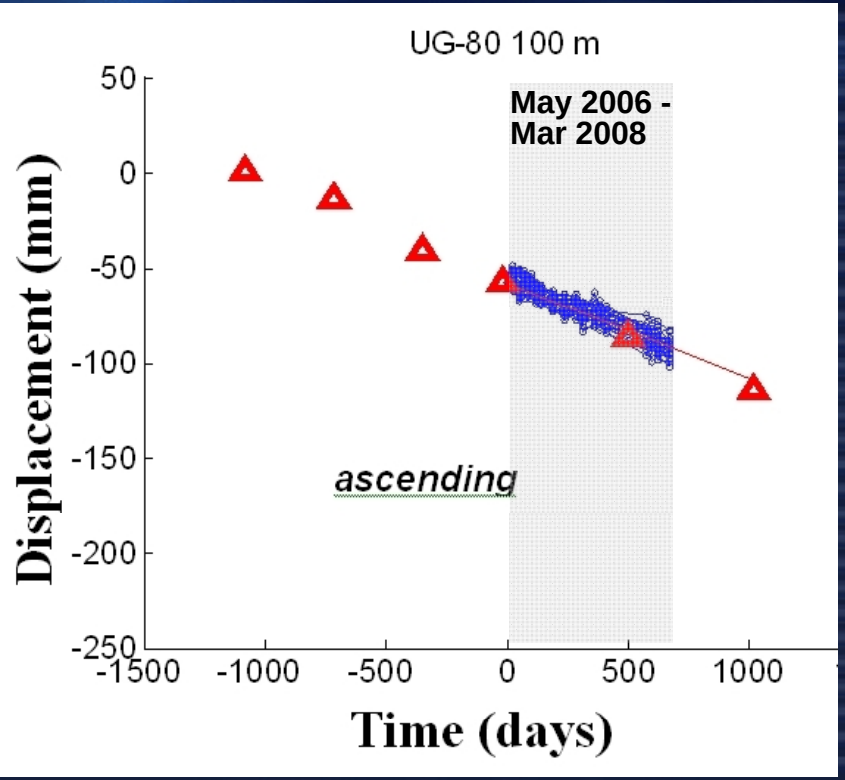
[1]Imageair, Inc., [2]TRE Canada, Inc., [3]TRE s.r.l., Italy



TRE provided these PS locations and the deformation time series

Imageair, Inc.

Comparison of leveling and PSInSAR observations



Leveling measurements (vertical movements only)

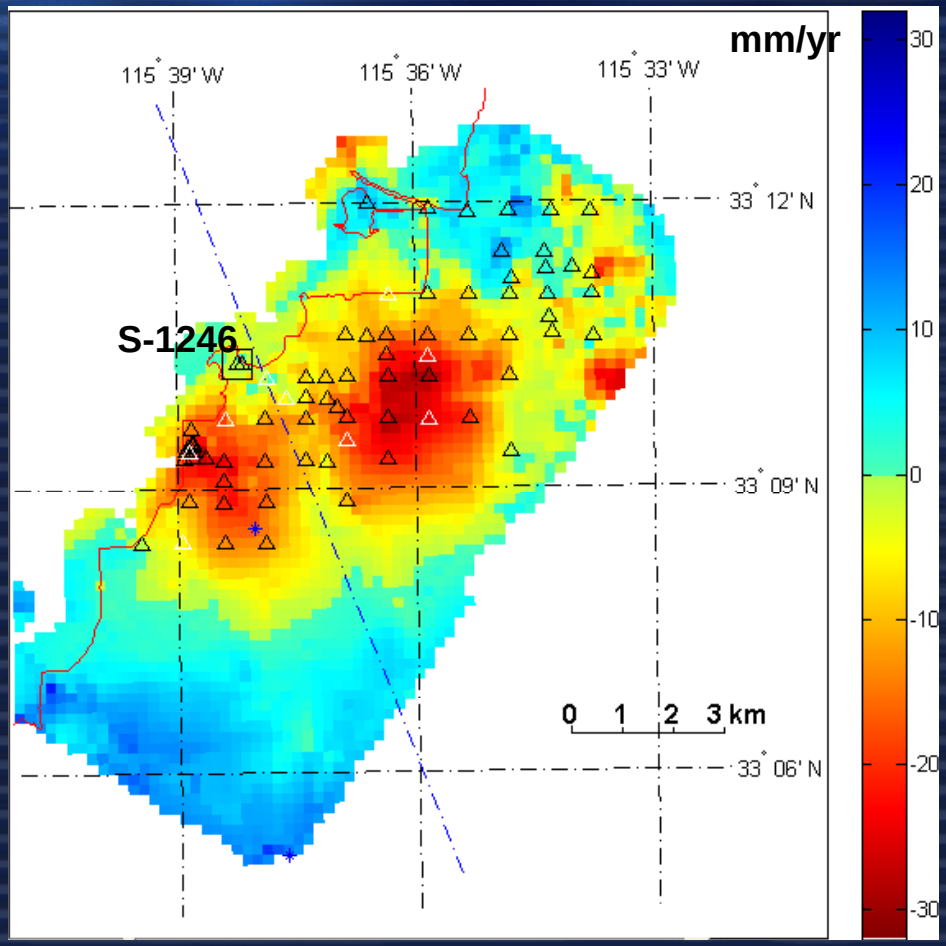
Leveling measurement projected onto LOS assuming only vertical movement

Deformation at PS points within 100 m of benchmark

Imageair, Inc.

Interpolation from PS points

GRC 2010 Eneva, M.[1] and D. Adams[1]
Proceedings [1]Imageair Inc.



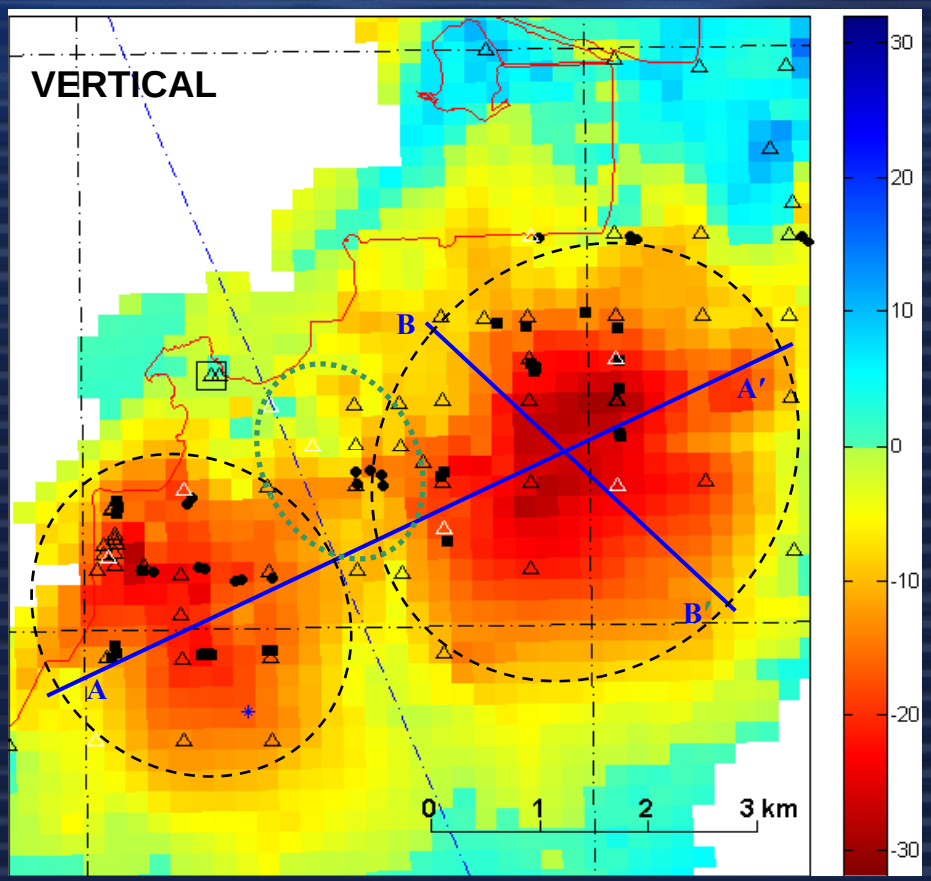
Vertical Deformation Rates - relative to S-1246

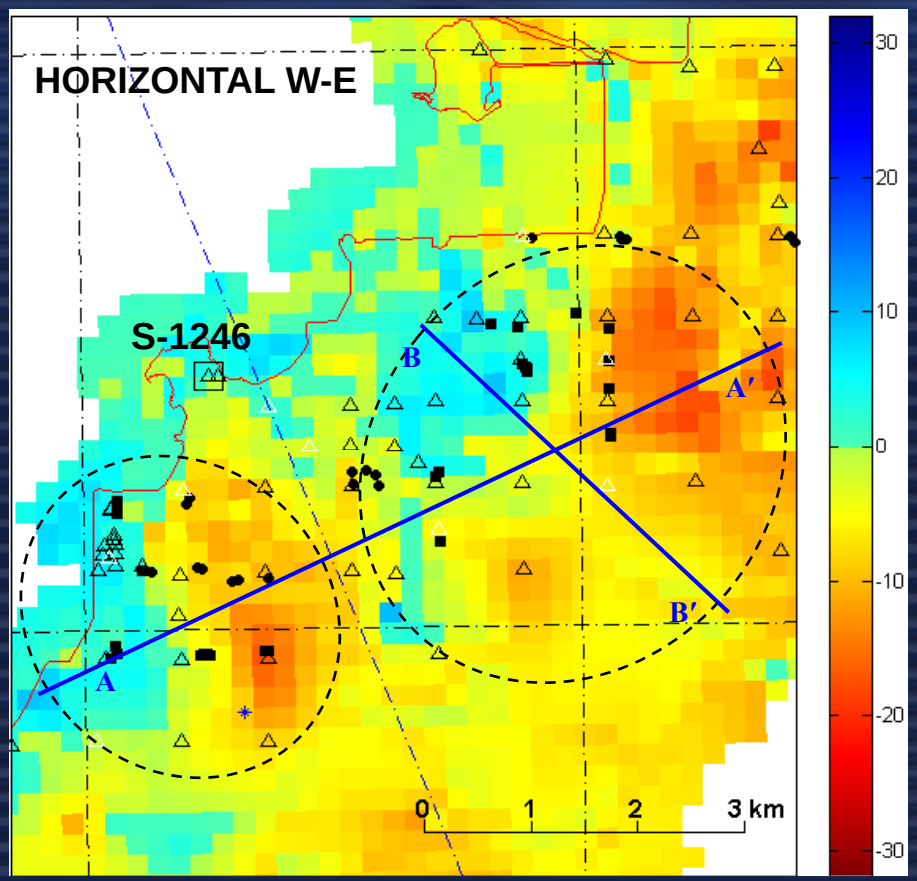
"warm" colors = subsidence, "cold" colors = uplift, gray circles = PS points

Imageair, Inc.

Vertical and horizontal deformation

GRC 2010 Eneva, M.[1] and D. Adams[1]
Proceedings [1]Imageair Inc.



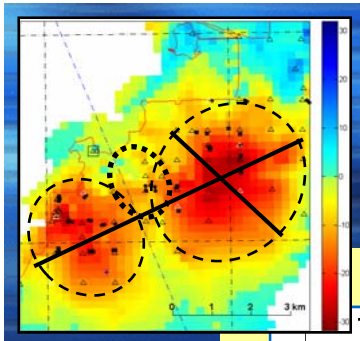


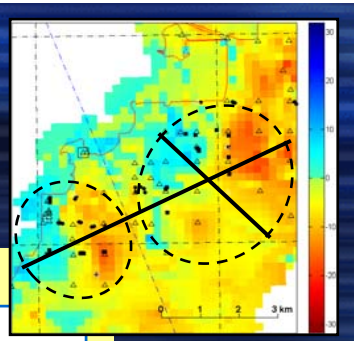
warm colors = subsidence
cold colors = uplift

warm colors = west
cold colors = east

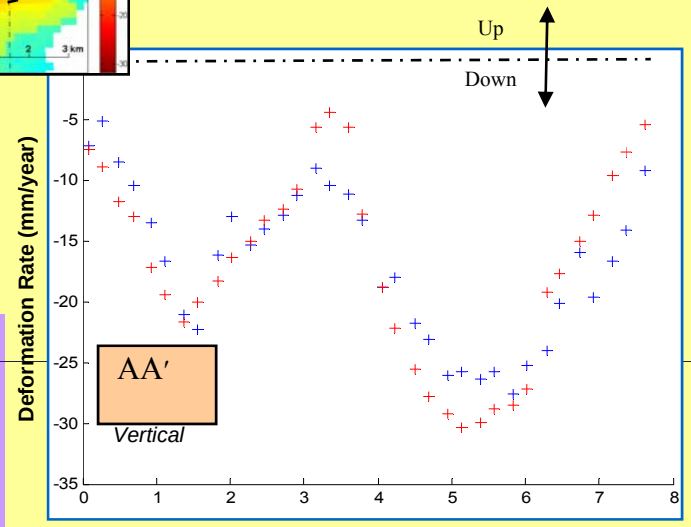
Imageair, Inc.

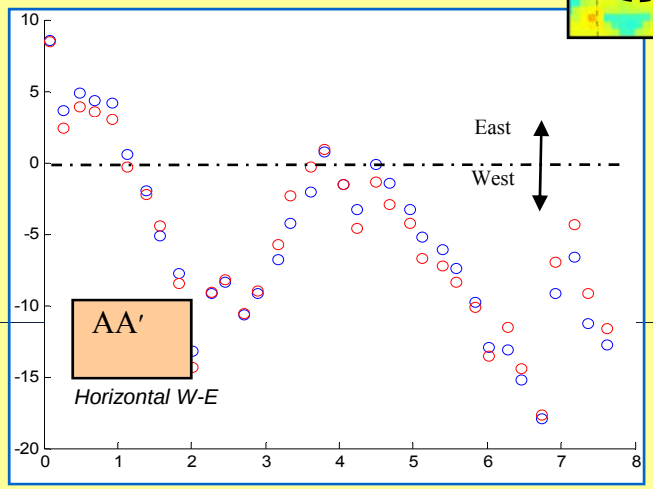
Deformation profiles



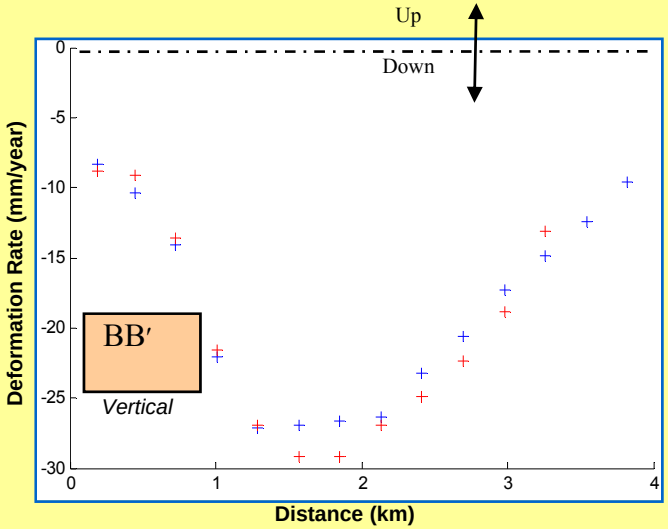


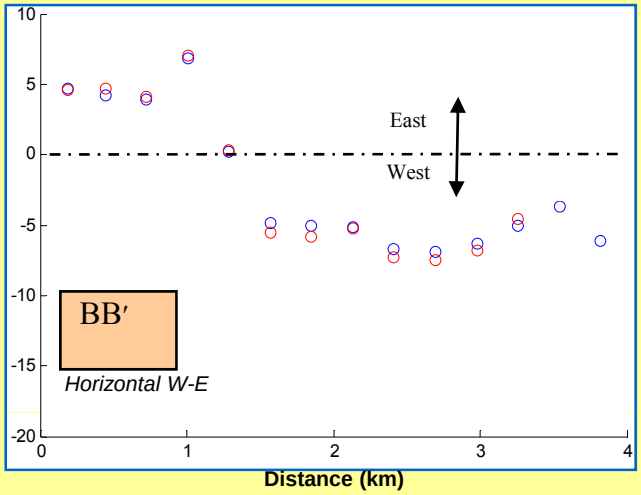
VERTICAL





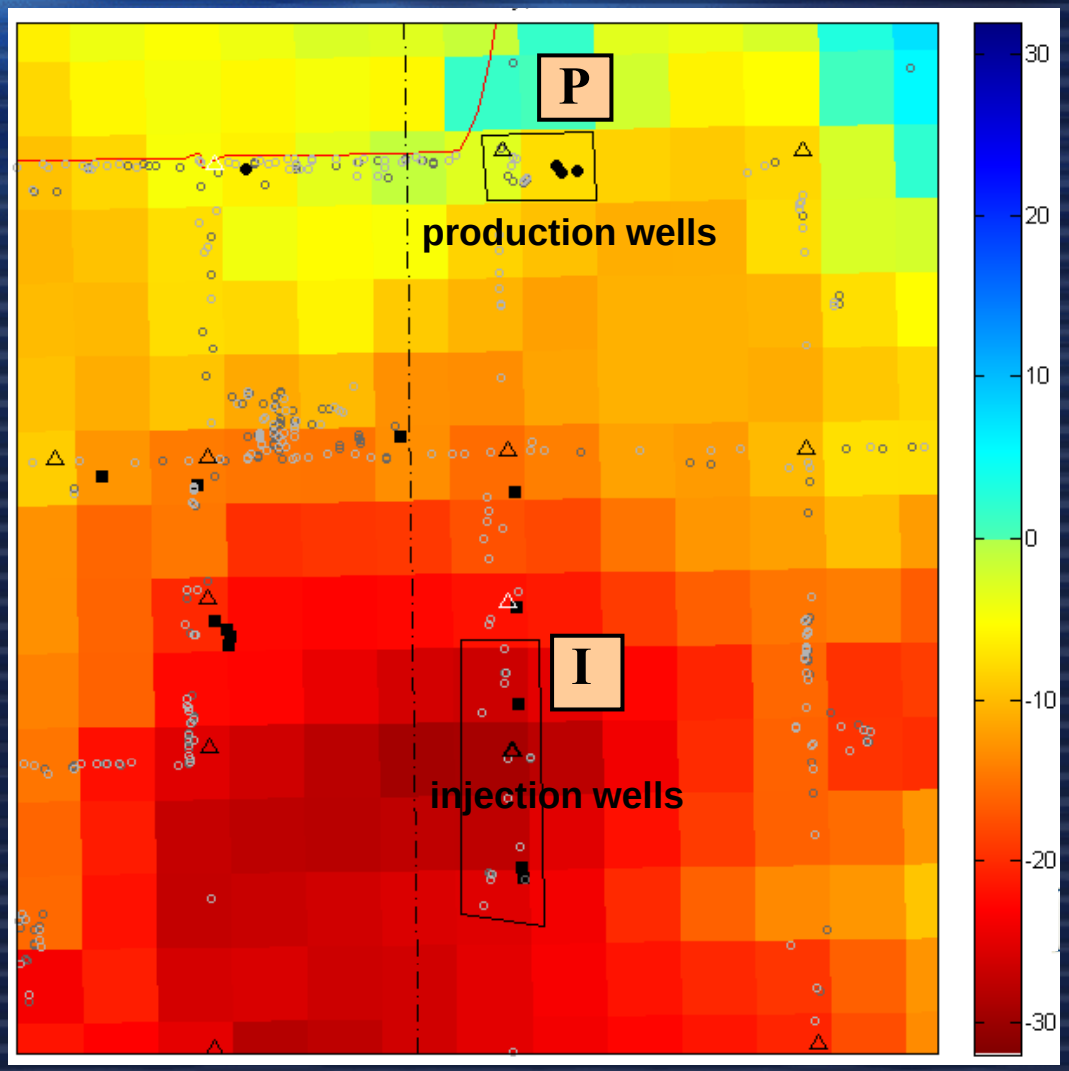
HORIZONTAL W-E

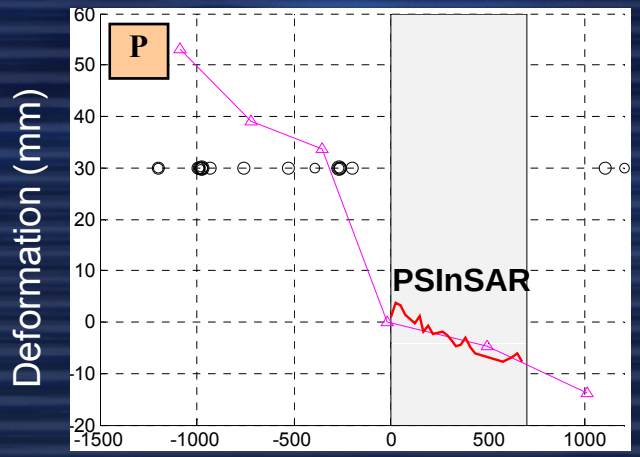


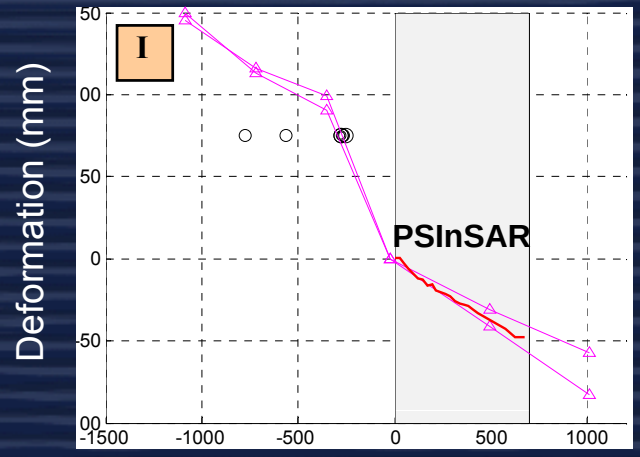


Imageair, Inc.

Time series: vert. deformation from leveling, mean vert. deformation from PSInSAR, earthquakes



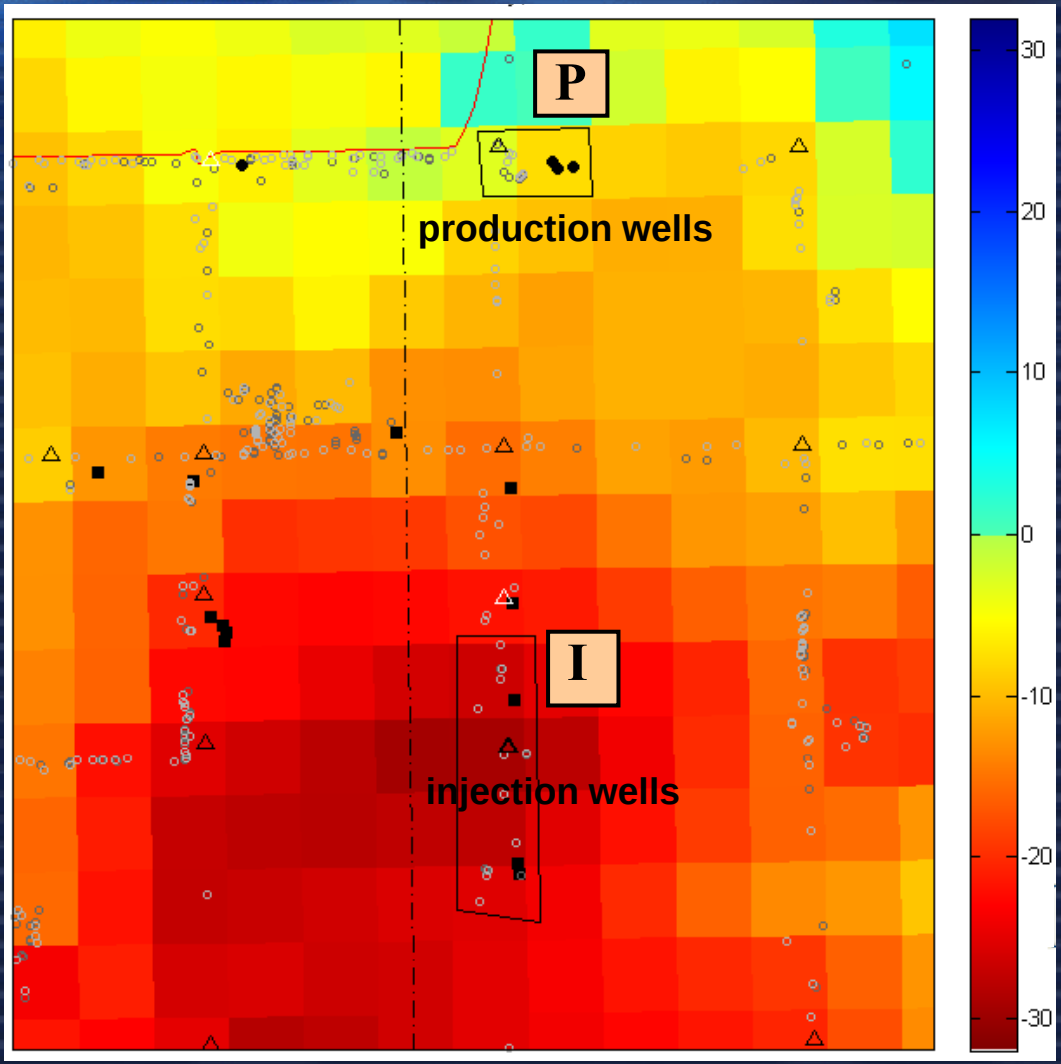


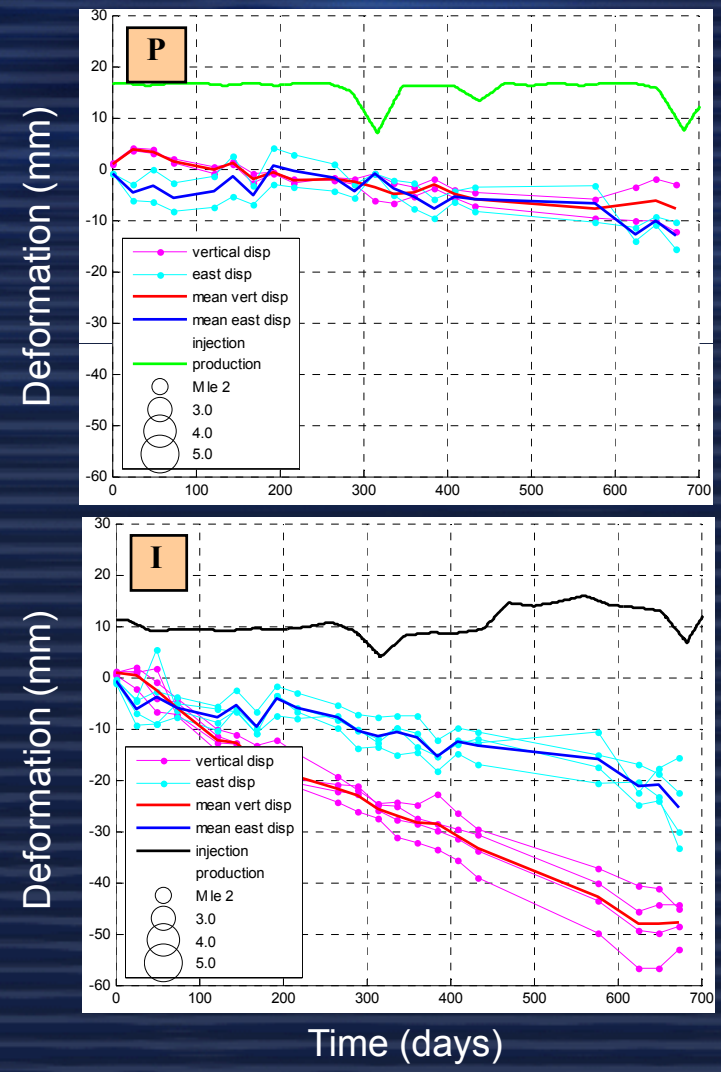


Time (days)

Imageair, Inc.

Time series: vertical and horizontal W-E deformation from PSInSAR , injection and production, earthquakes



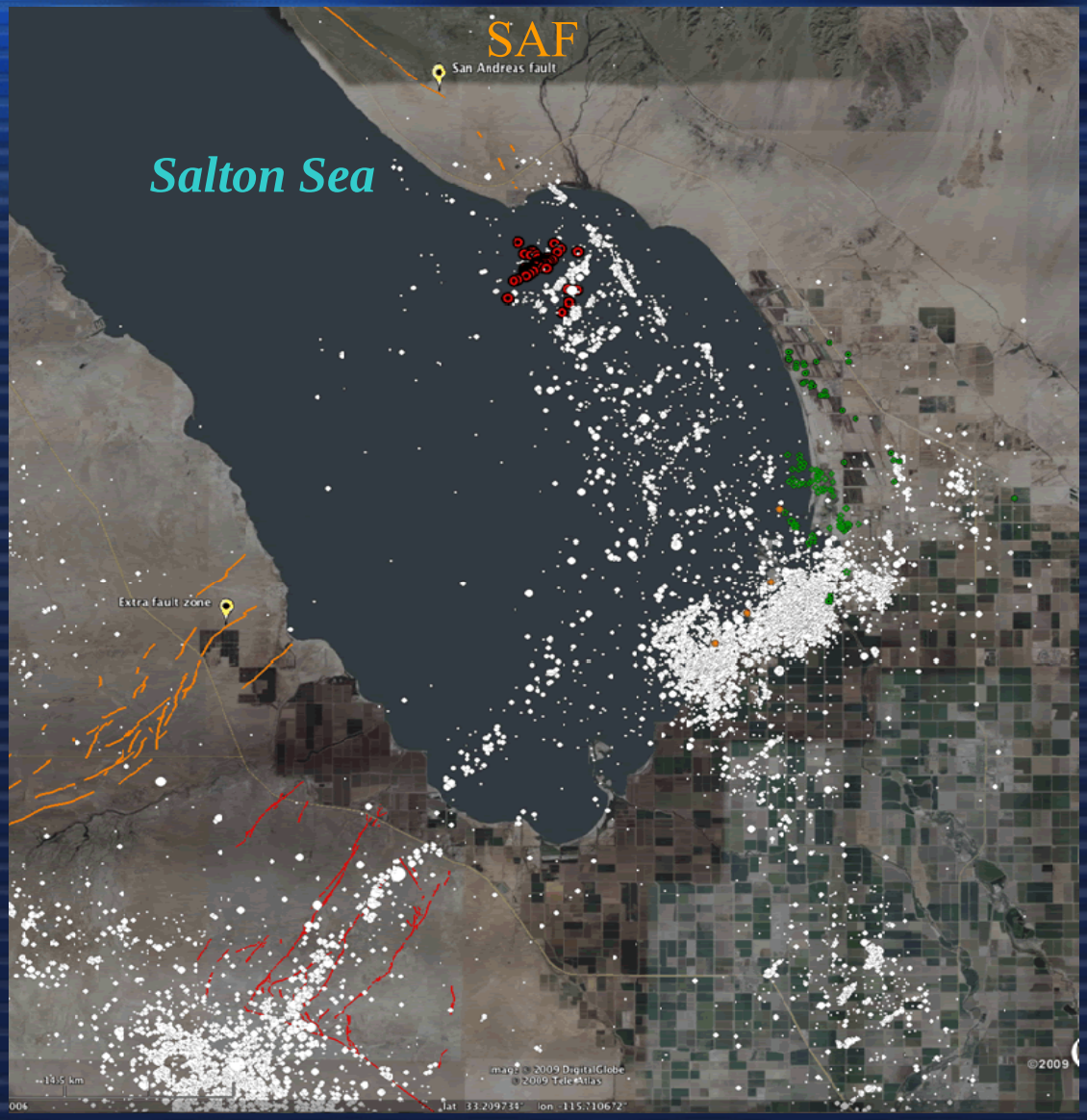


Imageair, Inc.

Possible causes for subsidence

- Regional tectonic deformation – extensional regime and subsidence (gradual)
- Local tectonic deformation
  - Gradual – e.g., related to local structures such as faults
  - Abrupt – e.g., earthquakes plus some short-term aseismic
- Geothermal activities
  - Temperature changes
  - Fluid withdrawal
  - Pressure changes
- Soil compaction or expansion related to levels of irrigation

Brawley Seismic Zone (BSZ)



From

http://www.cisn.org

BSZ:

Transitional zone between San Andreas and Imperial faults

No faults with obvious surface expression

SSGF:

Seismic swarms and accompanying aseismic slip

Most recent:

1981

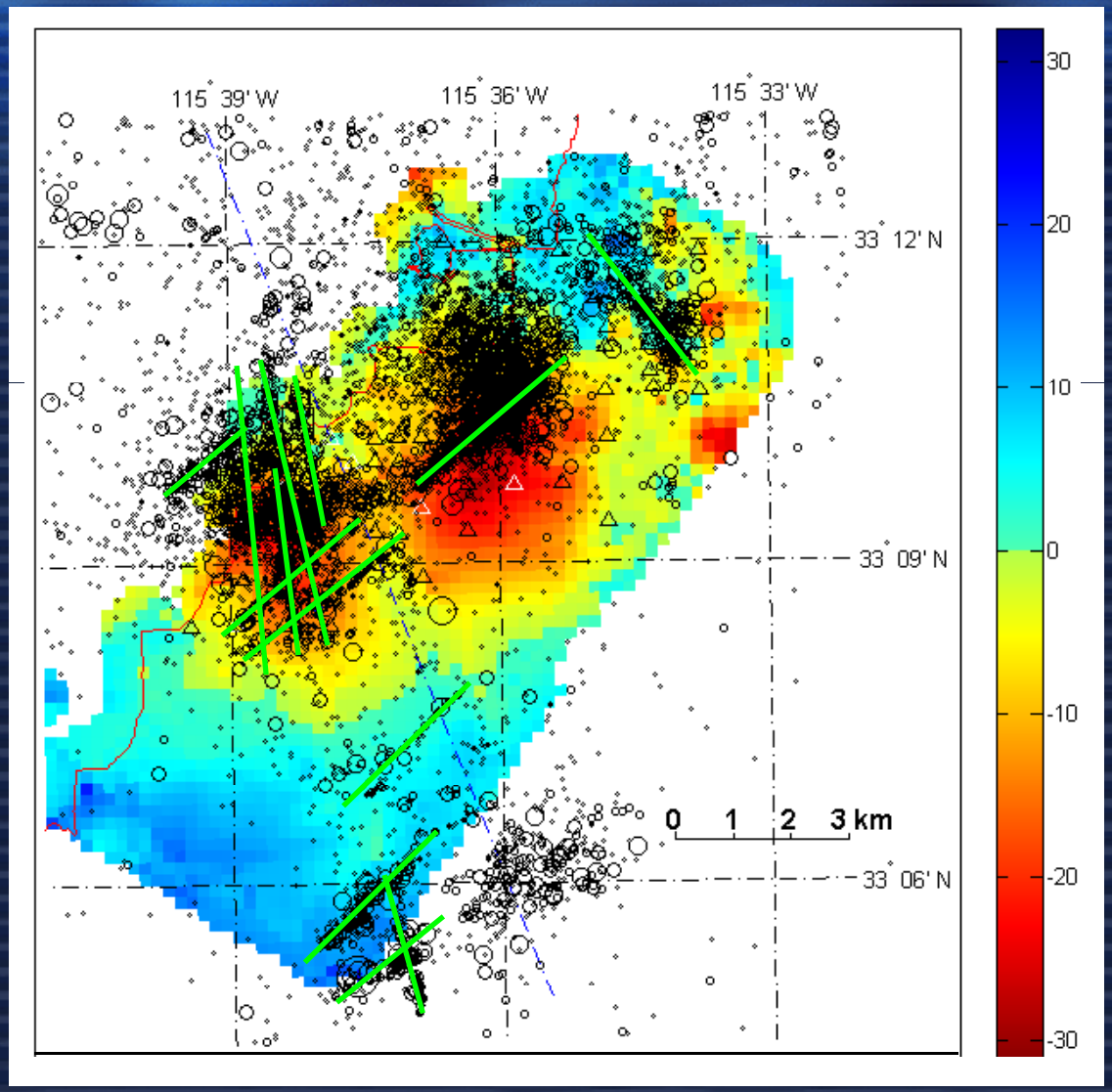
1989

1985

2005

Imageair, Inc.

Local tectonics (faults, seismicity)



January 1981 to March 2010

1981 – 2005:
Relocated catalog (Lin et al., 2007)

2006 – present:
SCSN catalog

Imageair, Inc.

Question: What are the causes of the observed subsidence in the SSGF?

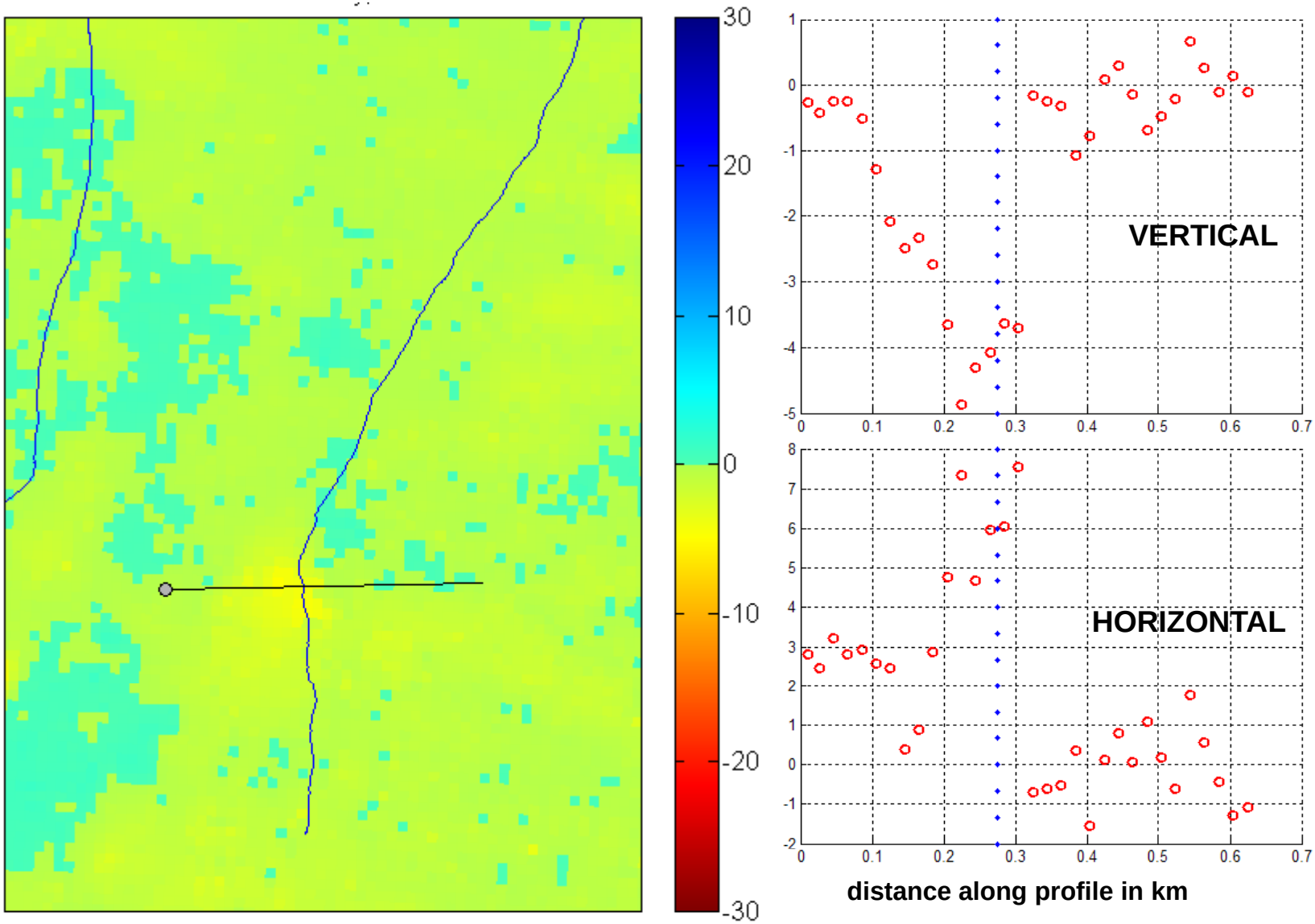
- CalEnergy - subsidence is NOT related to the geothermal operations, because:
  - Significant reinjection (75%-80%) at depth below 6000 ft
  - Production is rather deep - generally between 2000 and 6000 ft, and up to 9000 ft
  - A very small portion of the total KGRA is utilized at present
  - No significant fluid level or pressure changes are observed for the 30 years of operation
  - Therefore, subsidence must be only due to tectonics (regional and local)

Our PIER 2007-2009 project:

- Regional tectonic effect represents at most 10% of the deformation at the sites of maximum subsidence
- Question: Can all of the remaining deformation be accommodated by local tectonics?
  - No information on fluid level and pressure changes
  - No obvious surface expression of faults
  - Seismicity data
    - ❖Earthquake hypocenter locations
    - ❖Earthquake fault mechanisms
  - Deformation modeling from various fault scenarios
  - Modeling of contraction due to cooling

Imageair, Inc.

Example of a signal across a fault (not from SSGF)



Eneva et al., 2011 (GRC Transactions) - From a DOE project (2010-2011) with US Geothermal, San Emidio geothermal field in Nevada

Imageair, Inc.

Conclusions

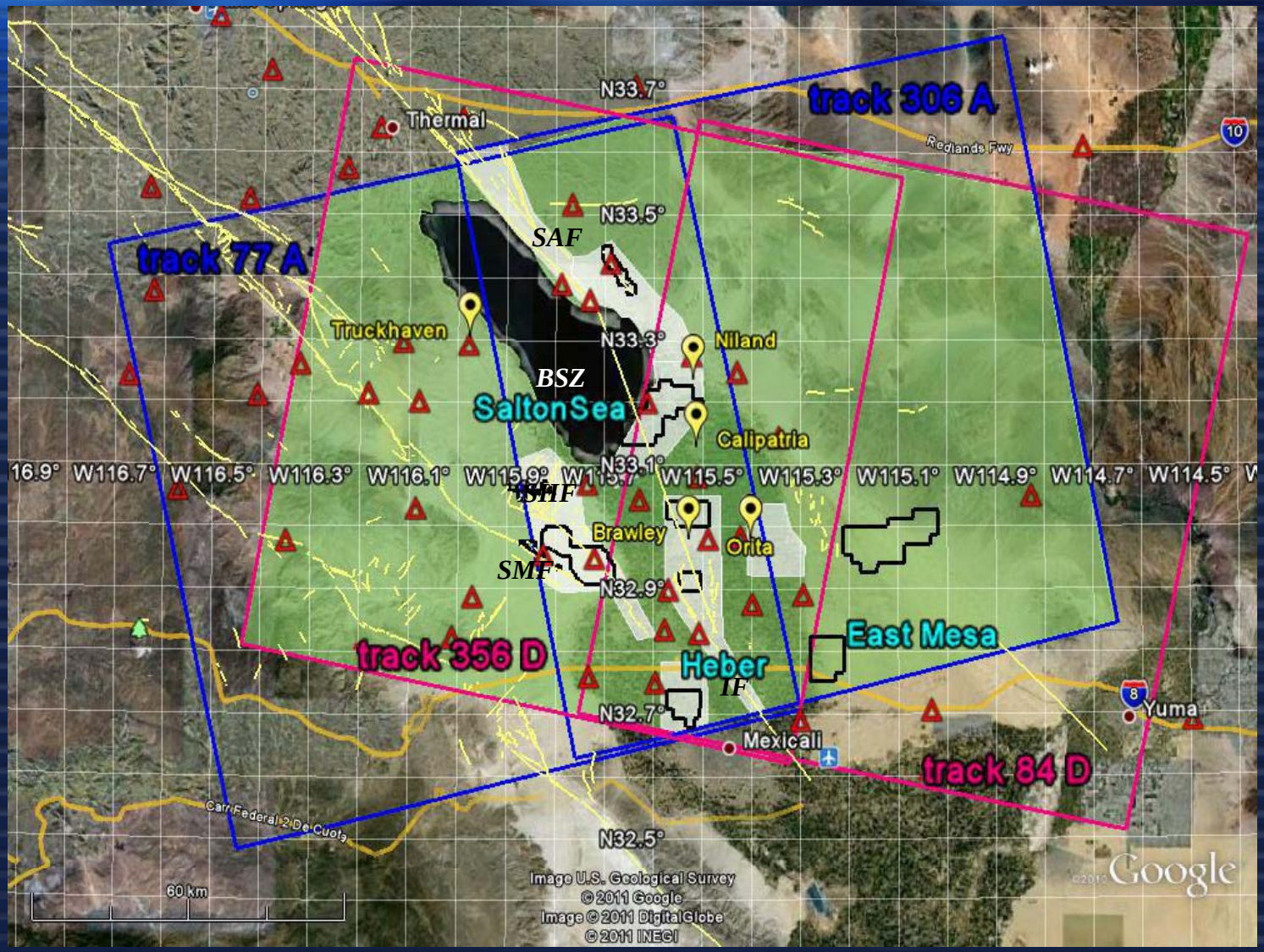
- InSAR can provide accurate and cost-effective monitoring of surface deformation over large areas
- In Imperial Valley – PSInSAR provides results amidst agricultural areas where conventional methods fail
- Leveling data and PSInSAR observations agree very well
- Distinct subsidence and corresponding horizontal movements are identified
- Uses:
  - **Assessment** (e.g., deformation prior to geothermal operations)
  - **Exploration** (e.g., locating faults and observing fault movements)
  - **Mitigation** (e.g., locations, amounts, and timing of injection and production)

Imageair, Inc.

GRDA: Current Project (2011-2013)

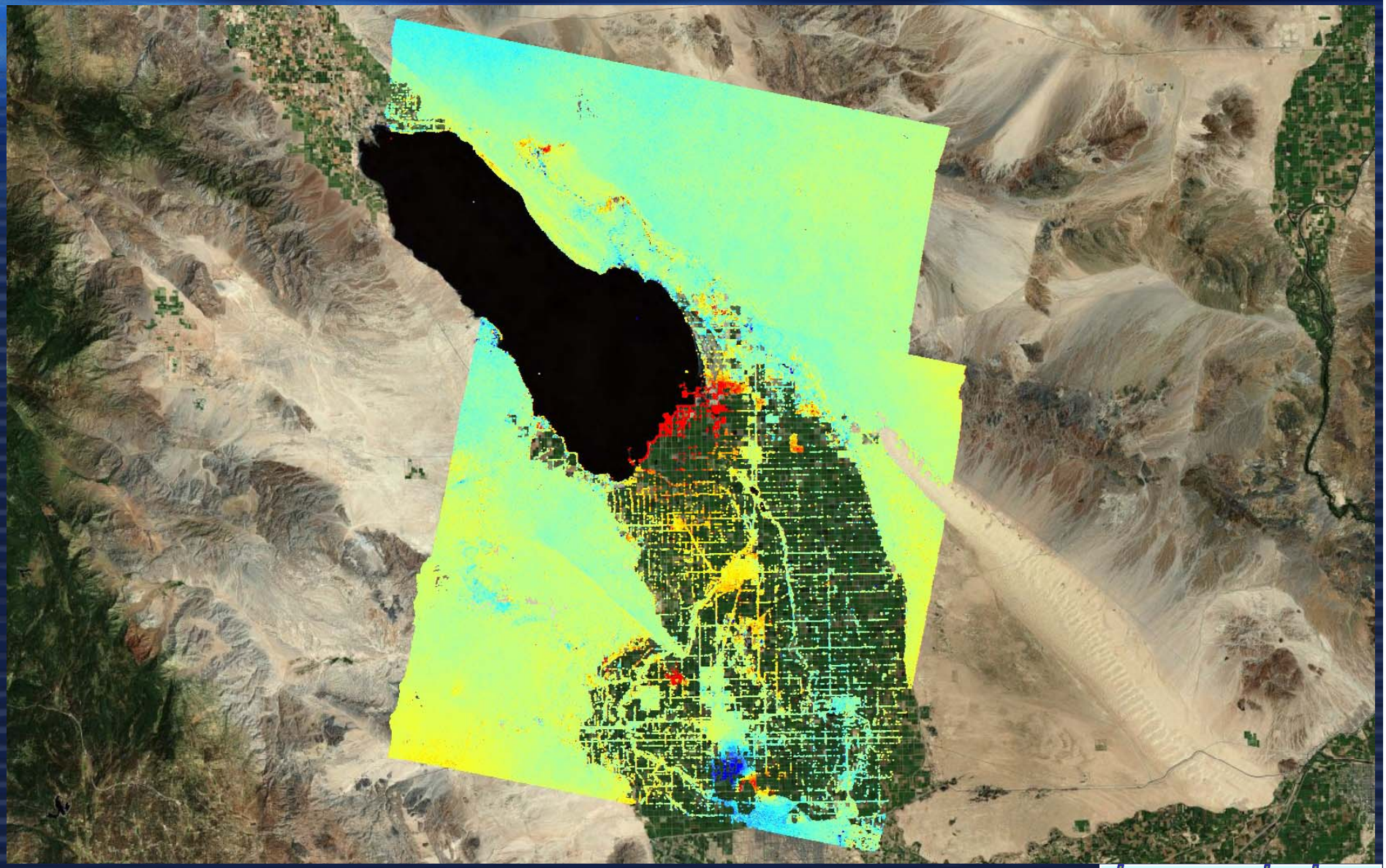
- CEC Manager: Cheryl Closson
- Title: Surface Deformation Baseline in Imperial Valley from Satellite Radar Interferometry (InSAR)
- Method: SqueeSAR (latest PSInSAR development from TRE)
- Data: From Envisat, 2003-2010

GRDA Study Areas – marked with white



Imageair, Inc.

SqueeSAR preliminary results 2003-2010



Imageair, Inc.