Monitoring and Analysis of Surface Deformation with InSAR and Subsurface Data, San Joaquin Valley, California*

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Search and Discovery Article #41963 (2016)**
Posted December 12, 2016

*Adapted from oral presentation given at AAPG 2016 Pacific Section and Rocky Mountain Section Joint Meeting, Las Vegas, Nevada, October 2-5, 2016

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Abstract

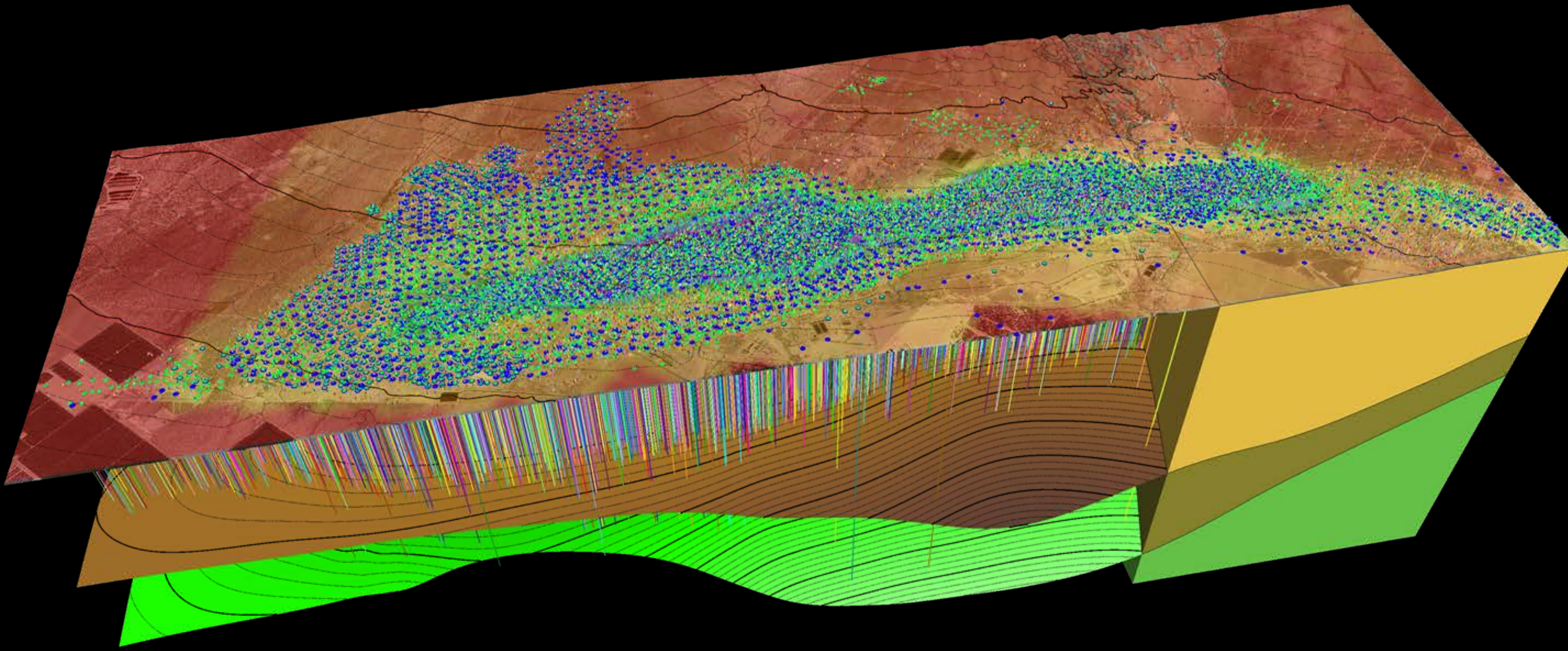
The potential for high density / high accuracy surface deformation (uplift and/or subsidence) information from oil field operations has significant financial, operational, and safety implications. This is especially acute in the San Joaquin Valley of California where heavy oil production, and water and steam injection, are often from very shallow reservoirs (<1000 feet below surface). Continuous advances in the collection and processing of Interferometric Synthetic Aperture Radar (InSAR) data make it an ideal tool for monitoring entire fields, analogous to millions of GPS stations measuring surface movements of just millimeters semi-daily. However, the true value of InSAR data is revealed when the data are fully integrated in a diverse contextual environment. This must necessarily include temporal records of production and injection data, and can include surface infrastructure, subsurface geologic models, well trajectories and even microseismic and tilt meter data. The temporal component is paramount in this integration. We present a case history spanning nearly twenty years around a producing field in the central San Joaquin Valley. We see long-term subsidence patterns that can clearly be related to fluid production, plus pockets of local uplift related to over-injection. We present detailed 4D analyses of the correlation between these diverse temporal and spatial datasets. Furthermore, we assess forward modeling with simple geomechanical models to quantify and predict injection performance. Careful integration of InSAR data can yield benefits for operators, including:

- Planning injection interventions
- Fewer well integrity issues
- Savings on drilling costs
- Better targeting and monitoring of injection campaigns

Reference Cited

Geertsma, J., 1973, A Basic Theory of Subsidence Due to Reservoir Compaction: The Homogeneous Case: Verhandeliger Kon. Ned. Geol. Mijhbouwk, v. 28, p. 43-62.

Monitoring & analysis of surface deformation with InSAR & subsurface data, San Joaquin Valley, California



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***Pieter Bas Leezenberg & Arjan Tabak*, SkyGeo**

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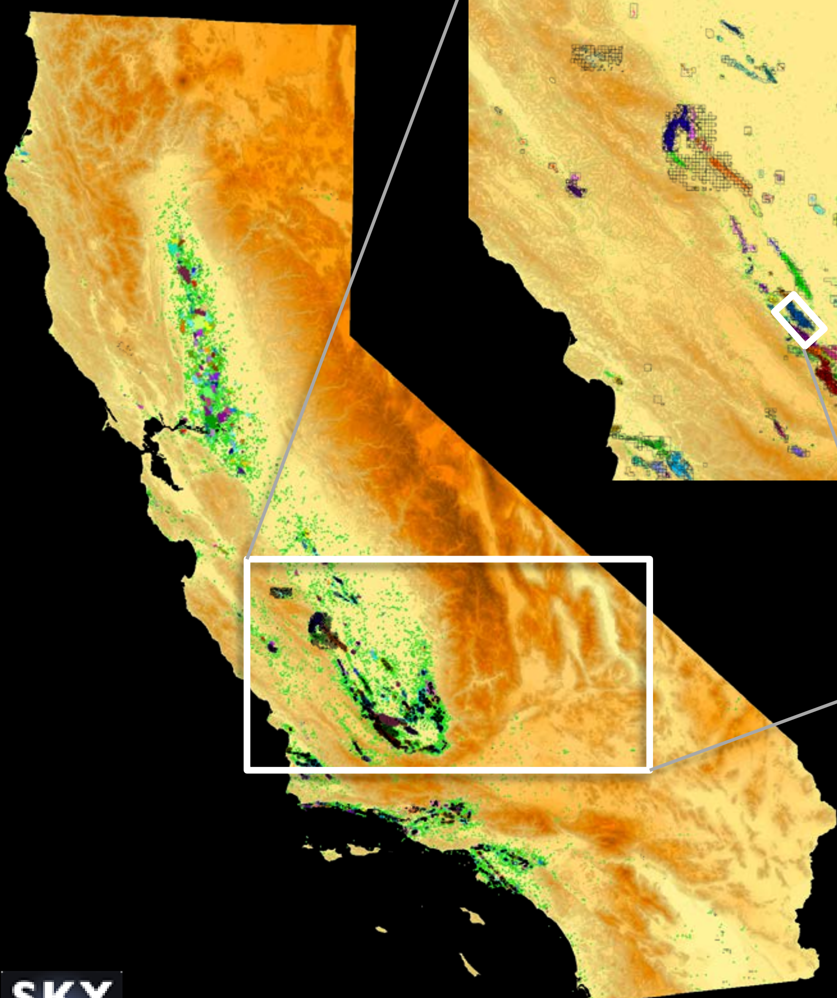
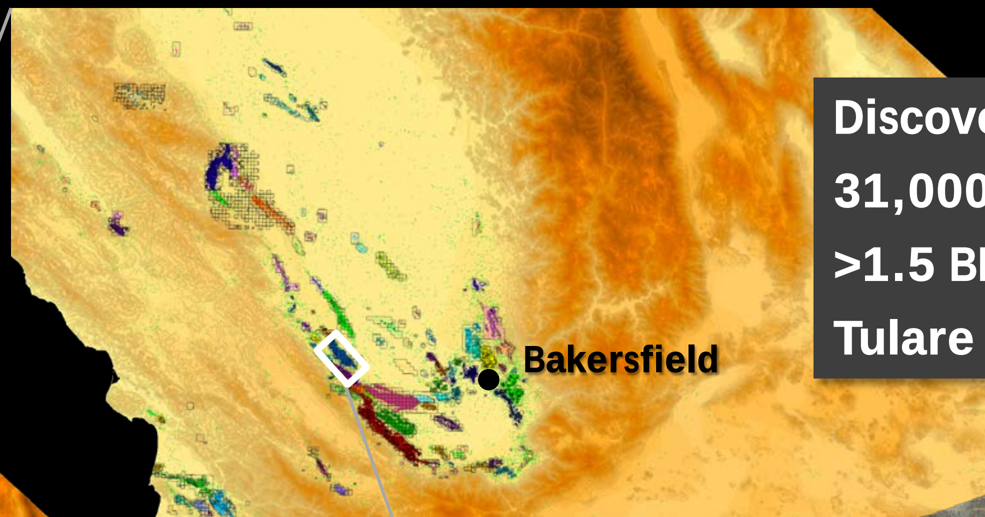
Summary

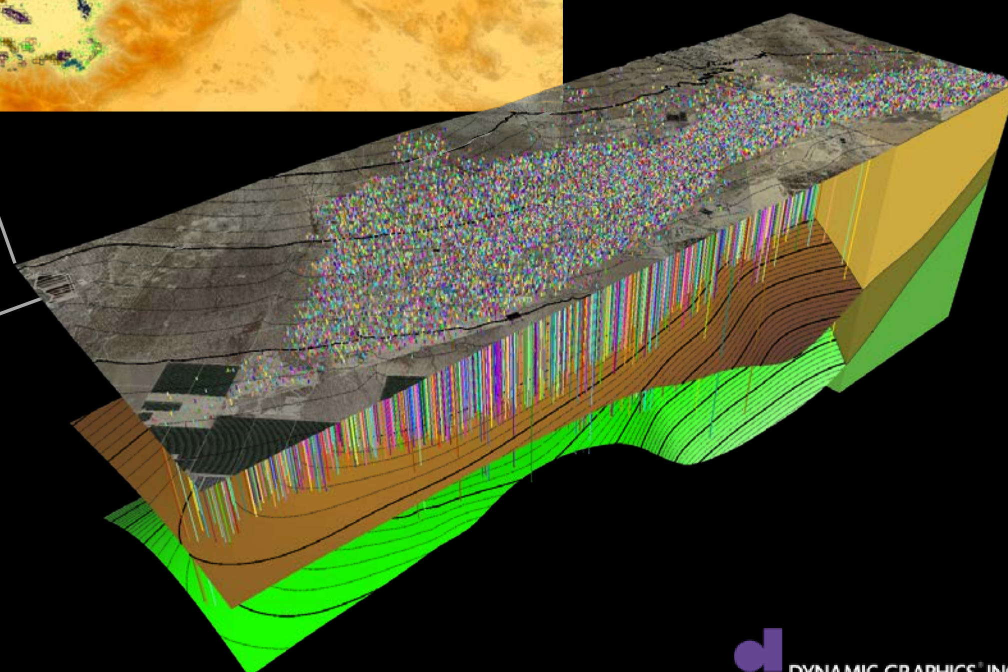
- InSAR data:
  - measures ground deformation over time
  - widely available, not restricted by access issues
  - high spatial and temporal resolution → surveillance
- Publicly available well data analyzed to reveal field history
- Integrated into 4D dataset analyzed for deformation history
- Long-term subsidence quantitatively related to production
  - Agrees with simple geomechanical forward models
- Localized uplifted related to injection
  - Short-period, timely InSAR actionable for operators

Setting





- Discovered 1911
- 31,000+ wells
- >1.5 BBL produced
- Tulare & Diatomite Fms

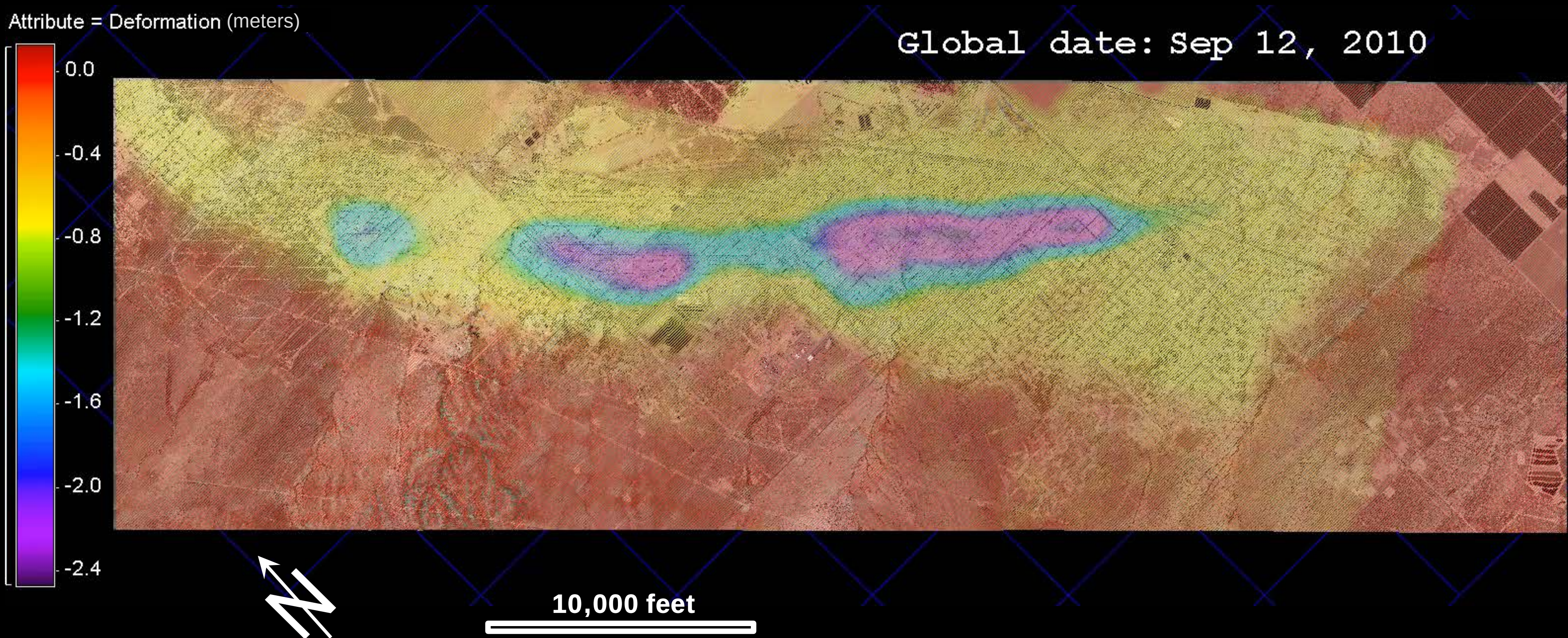


Data / sources

DATA	SOURCE
InSAR data 2003-2010, 2012-2015	**SkyGeo (*commercial*)**
Well Locations	California DOGGR
Production, injection histories	California DOGGR
Digital Elevation Model (DEM)	USGS SDTS
Subsurface horizons	Published maps, DOGGR
Infrastructure (roads etc.)	Kern County Online Mapping
Imagery	Google

...integrated in 3D / 4D

Total deformation (movie)



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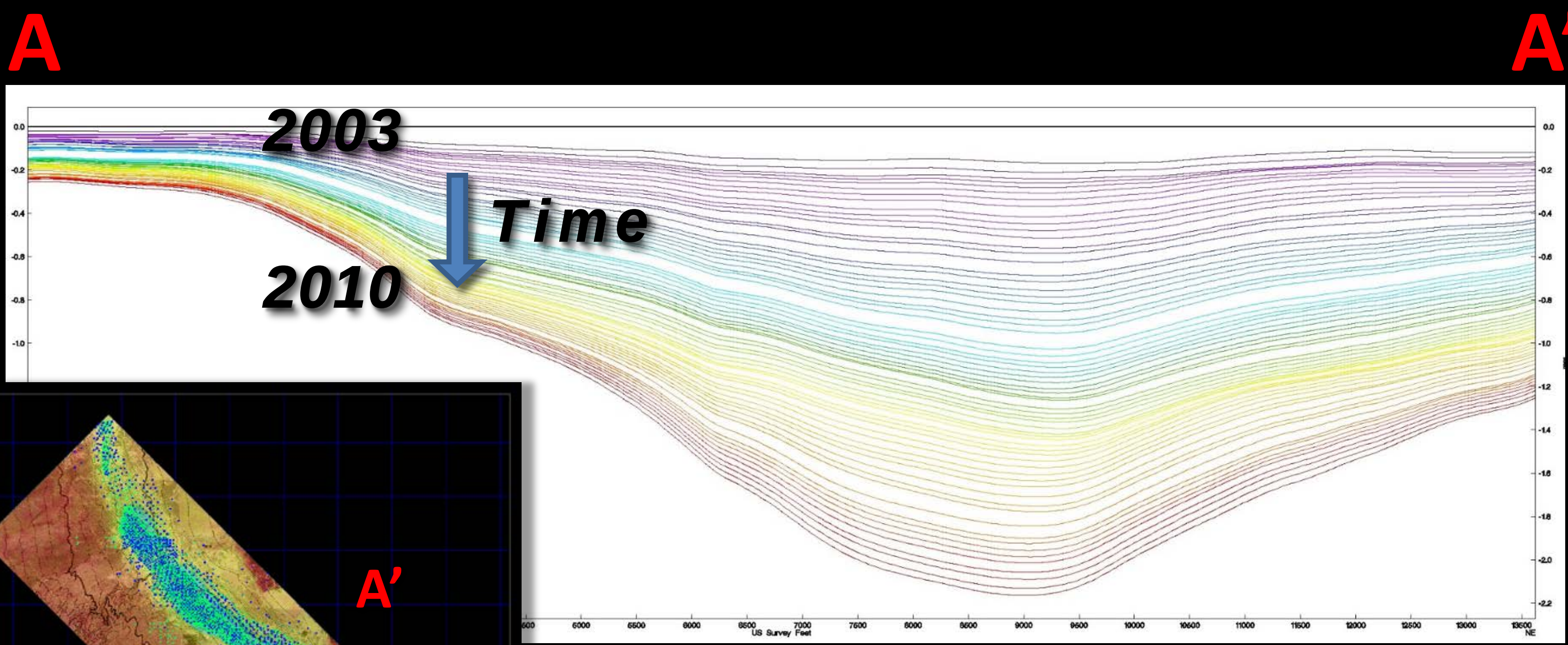
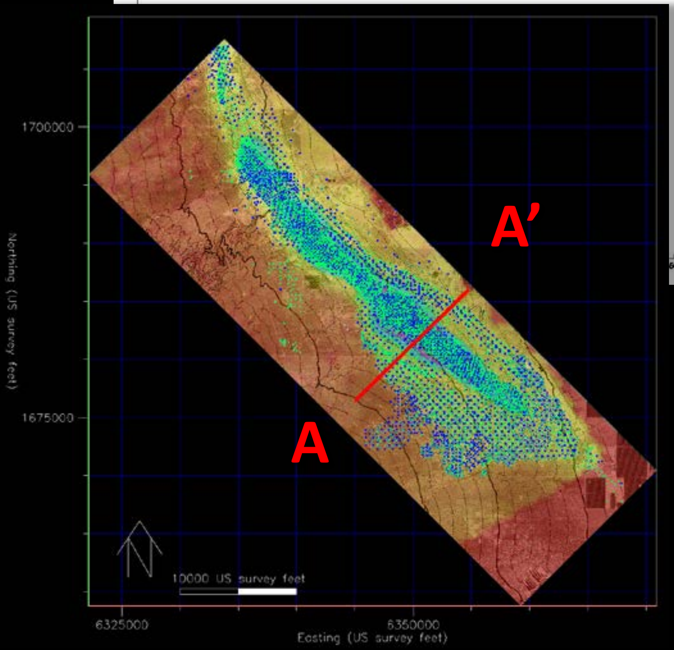
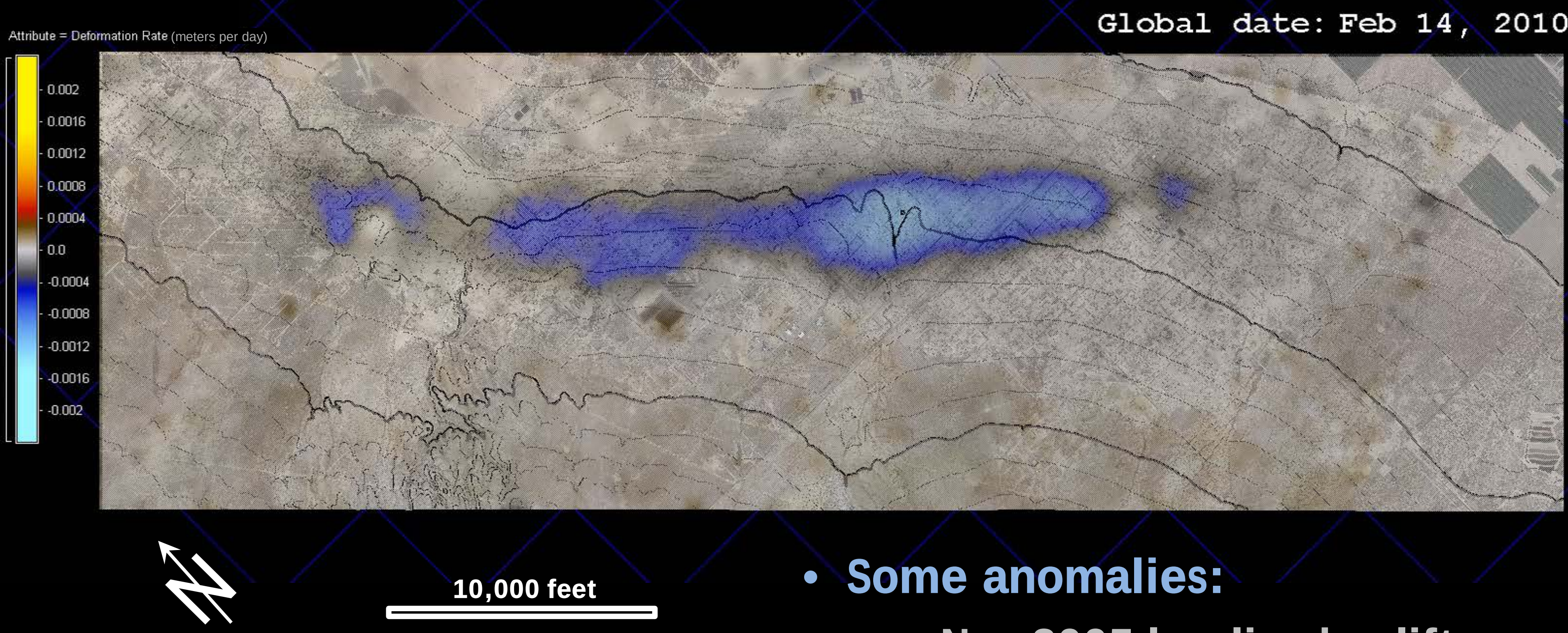
Deformation over time





- Long-term steady subsidence with time
- Numerous departures, uplifts etc.

Deformation rate (movie)



- **Some anomalies:**
  - **Nov 2005 localized uplift**
  - **June 2008 localized uplift**

Quantifying deformation vs. fluids

InSAR Data

InSAR data
13.2 million data points

2003-09-14 to 2010-09-12, pseudo-monthly sampling
64 time-steps

Average deformation in each polygon

Compute deltas and rates

Structure Data

DEM, Top Lower Tulare Sand & Belridge Diatomite surfaces

Simple structural model

Make 500 x 500 ft (~6 acre) polygons covering AOI, aligned
3,465 polygons

Deformation and production / injection in geometrically consistent dynamic object
11 attributes
64 time-steps
2,700 polygons

Well / Fluid Data

DOGGR Access databases: Monthly Production & Injection
31,850 wells

Trim wells to InSAR time range:
8,698 producers
5,283 injectors

Convert to barrels, compute daily rate. QC

For each polygon & InSAR time-step, sum production & injection

Compute deltas, rates, and net

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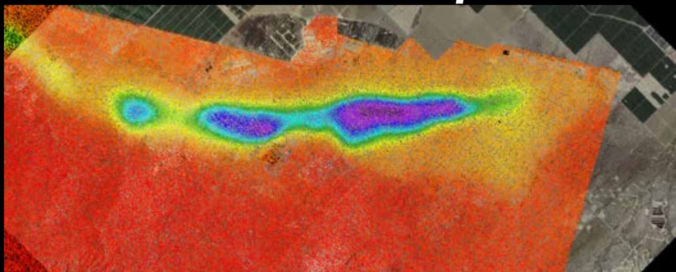
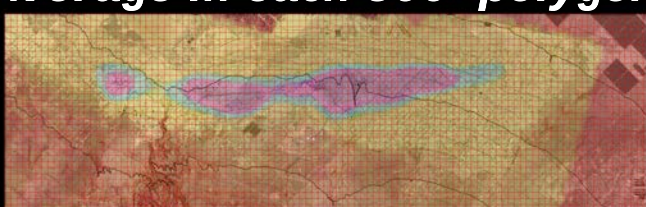
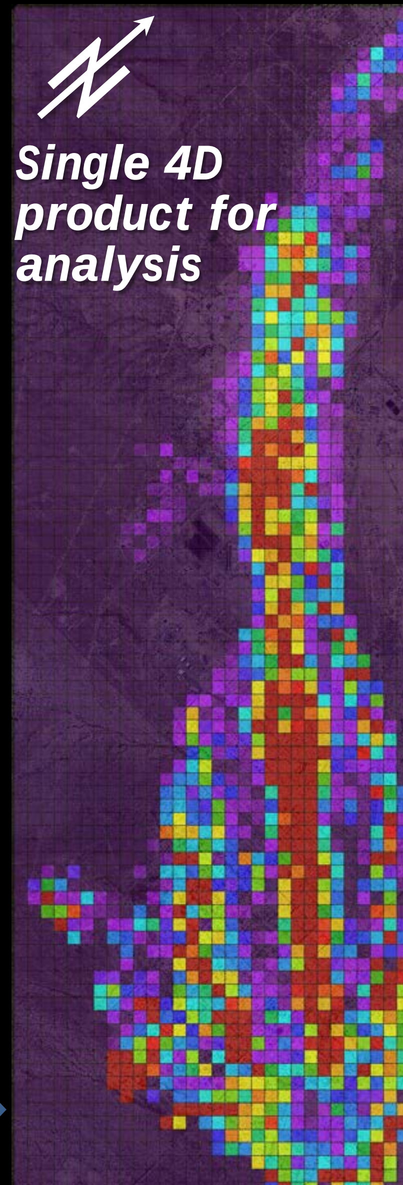
13.2 million data points



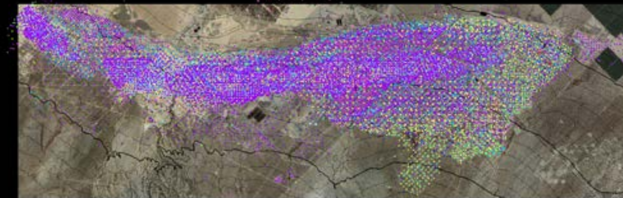
Gridded surfaces

Average in each 500’ polygon





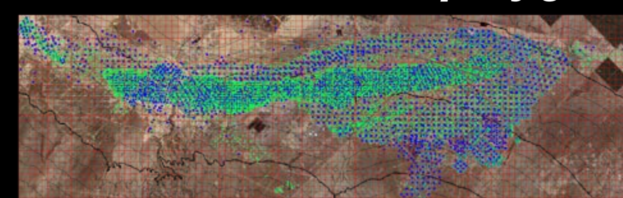
31,850 wells



8,698 producers

5,283 injectors

Sum in each 500’ polygon



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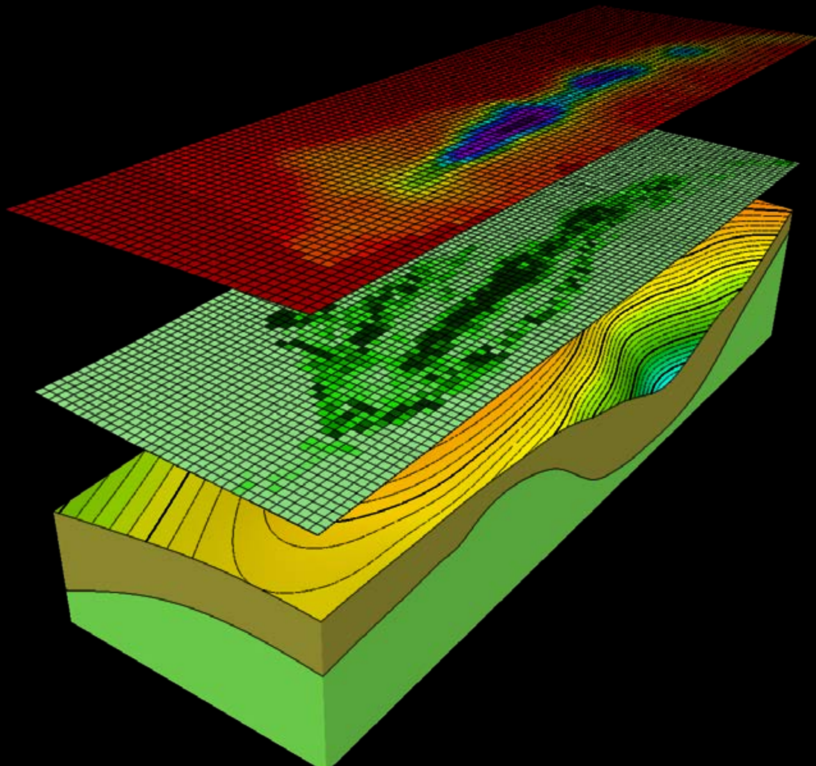
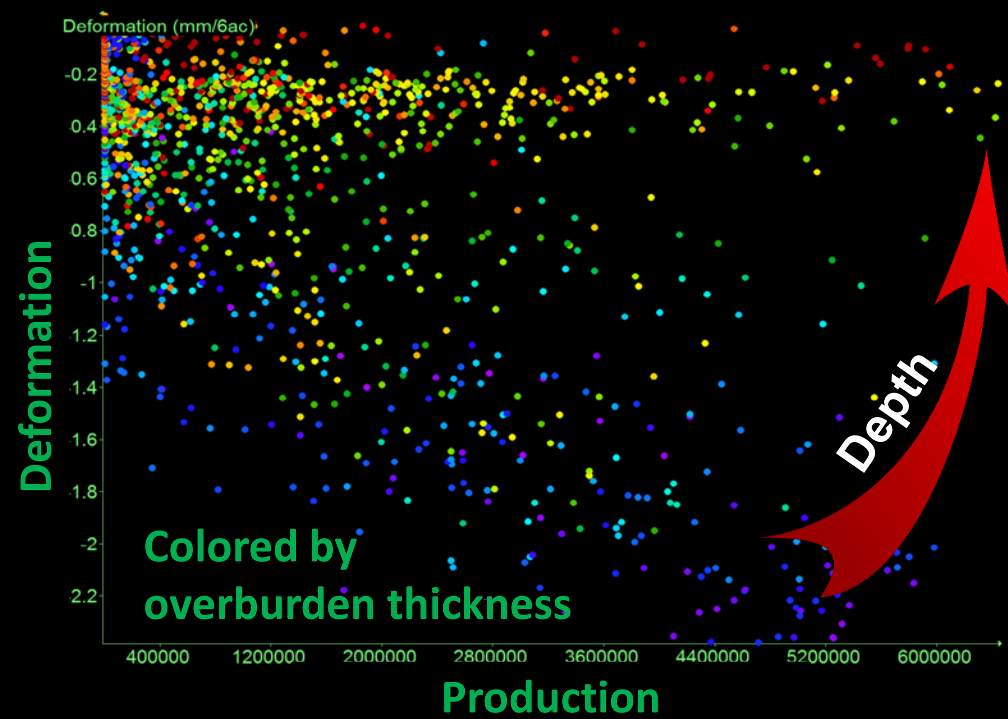
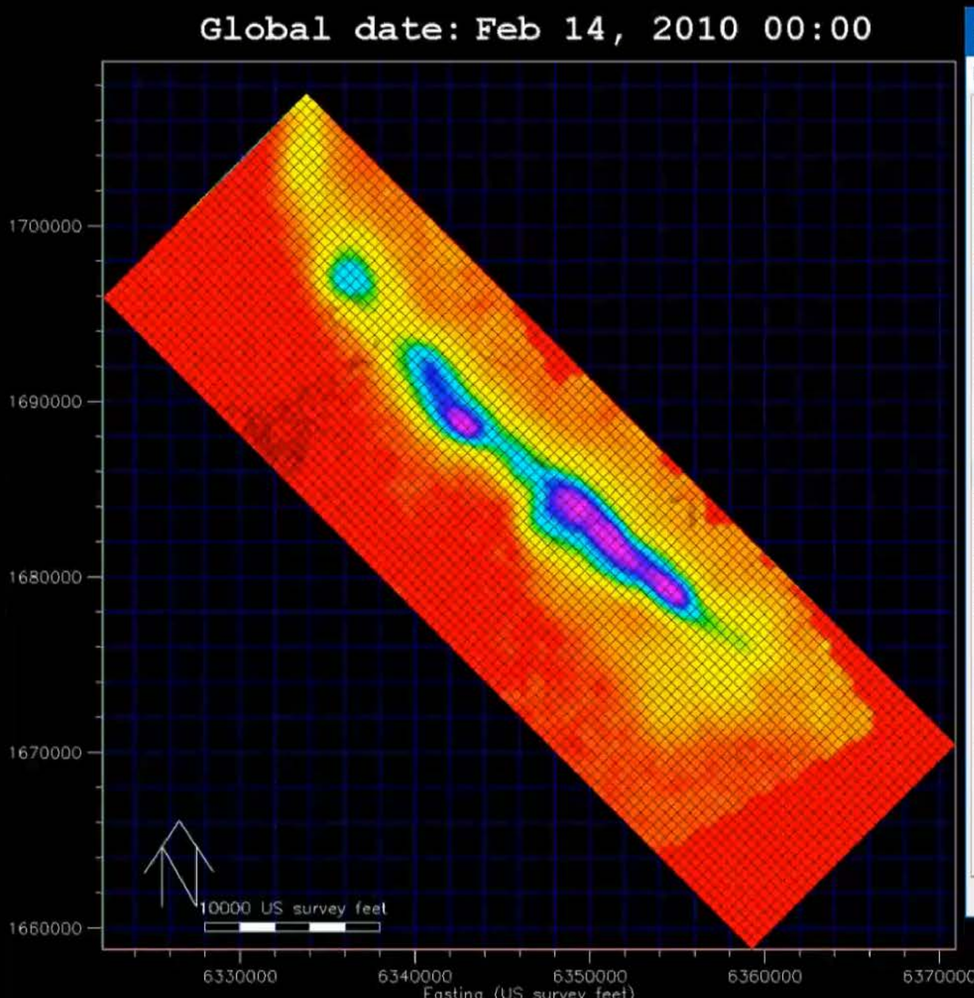
Deformation versus production

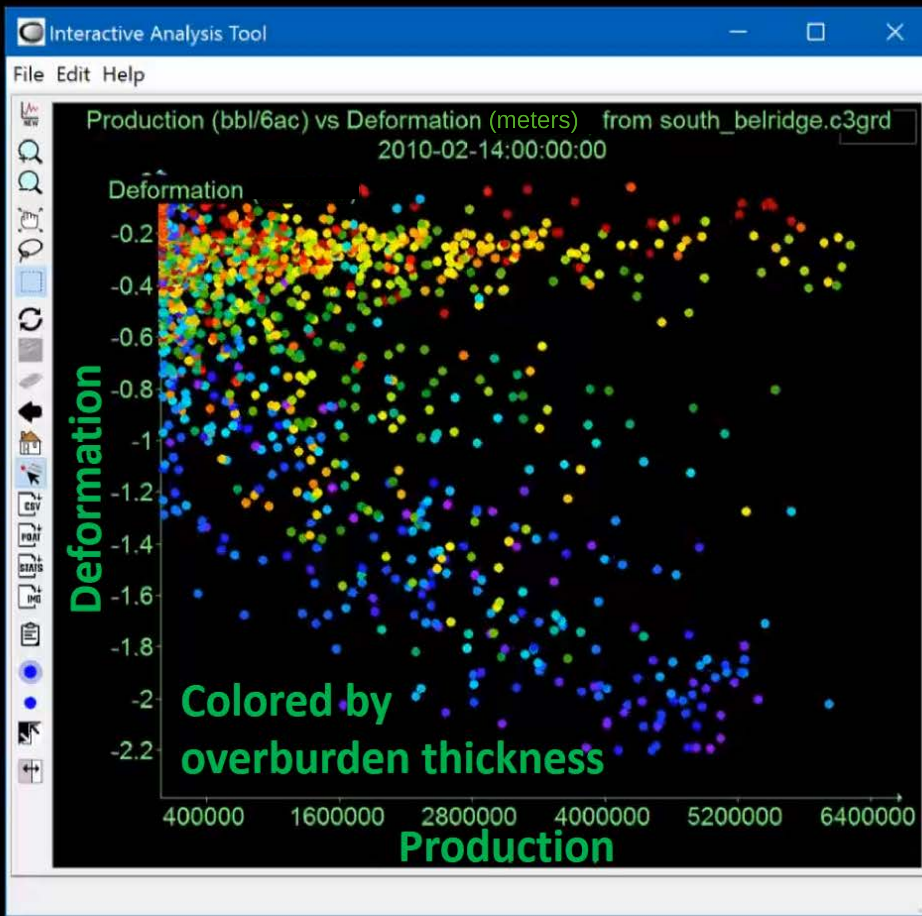




- Deformation related to production
- Depth dependence

Deformation versus production (movie)





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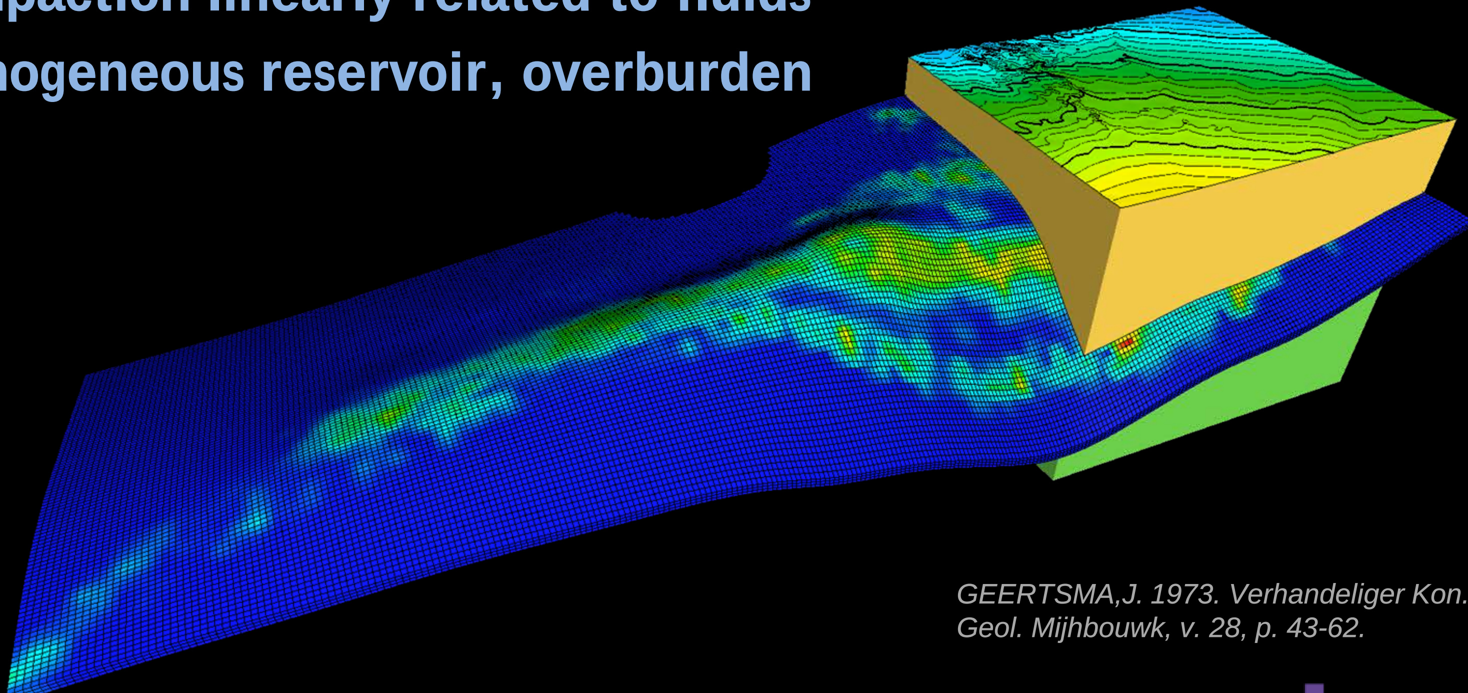
Geomechanical forward model

- Simple cellular model of Tulare Formation
- Geertsma formulation used to predict displacement
- Assumptions:
  - Compaction linearly related to fluids
  - Homogeneous reservoir, overburden



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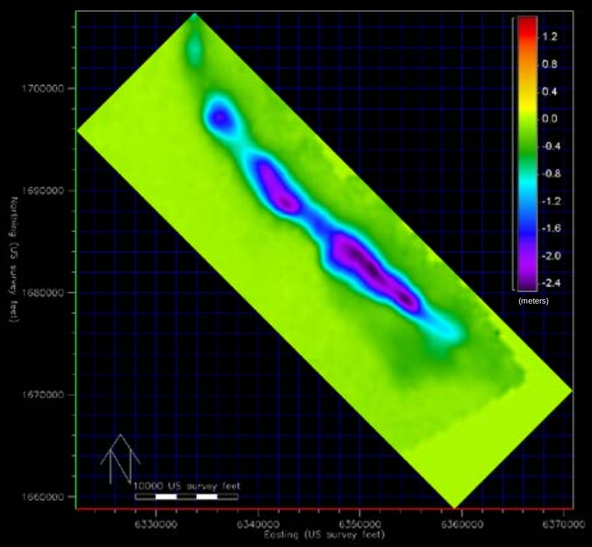
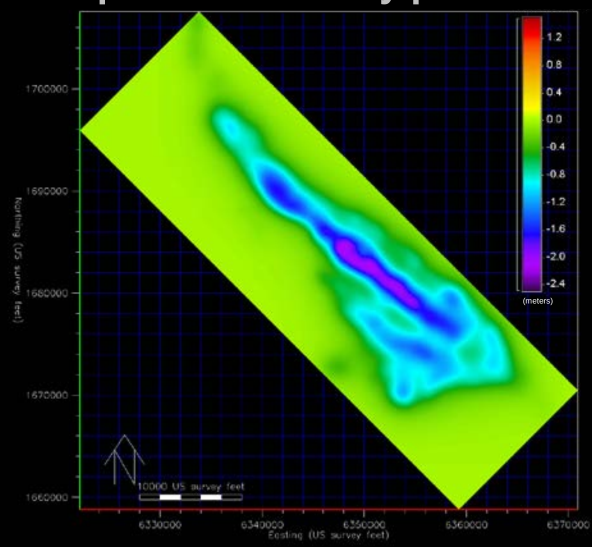
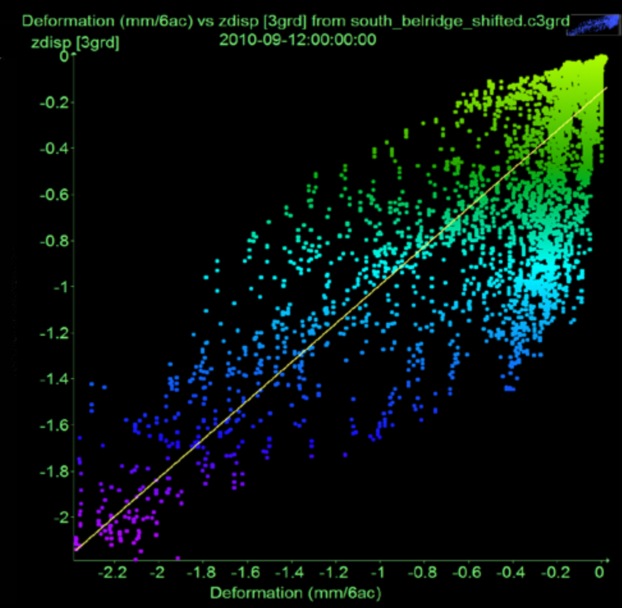
Geomechanical forward model

InSAR observed deformation



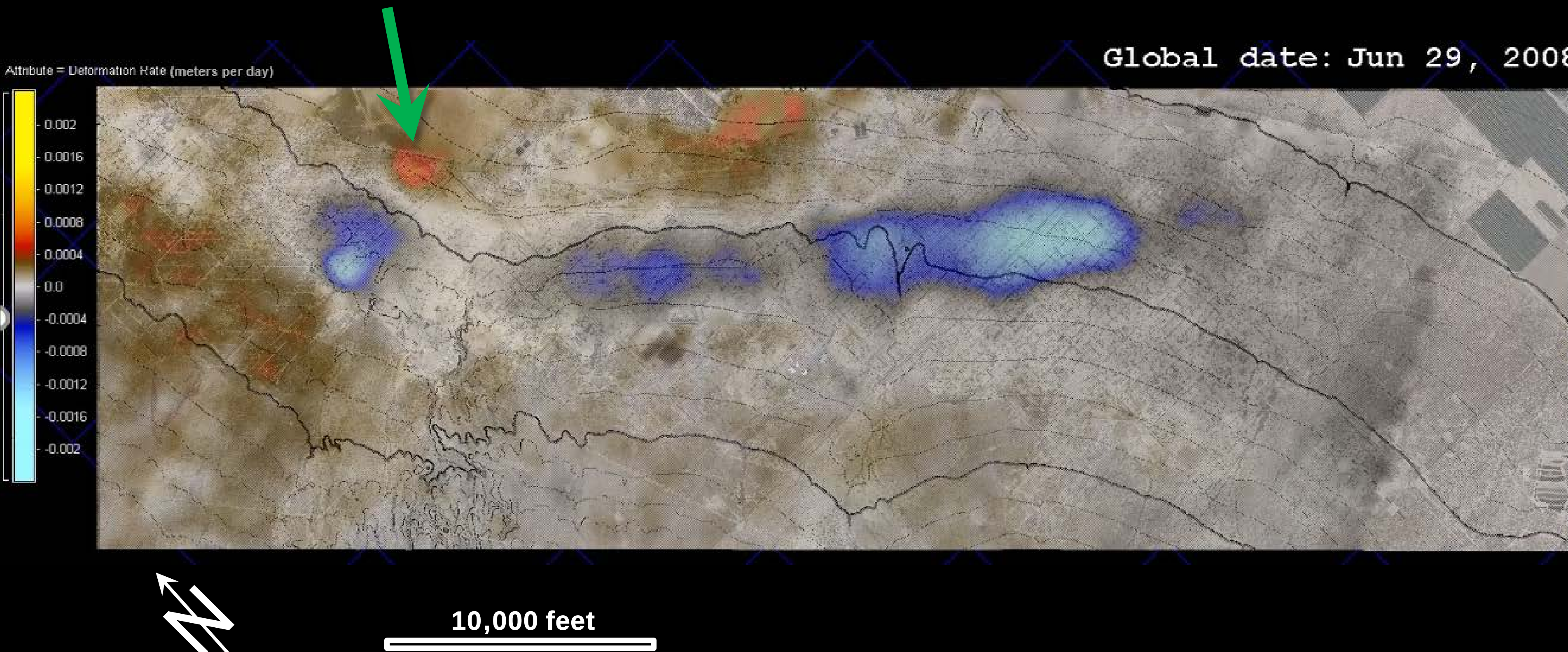
Compaction scaled by production

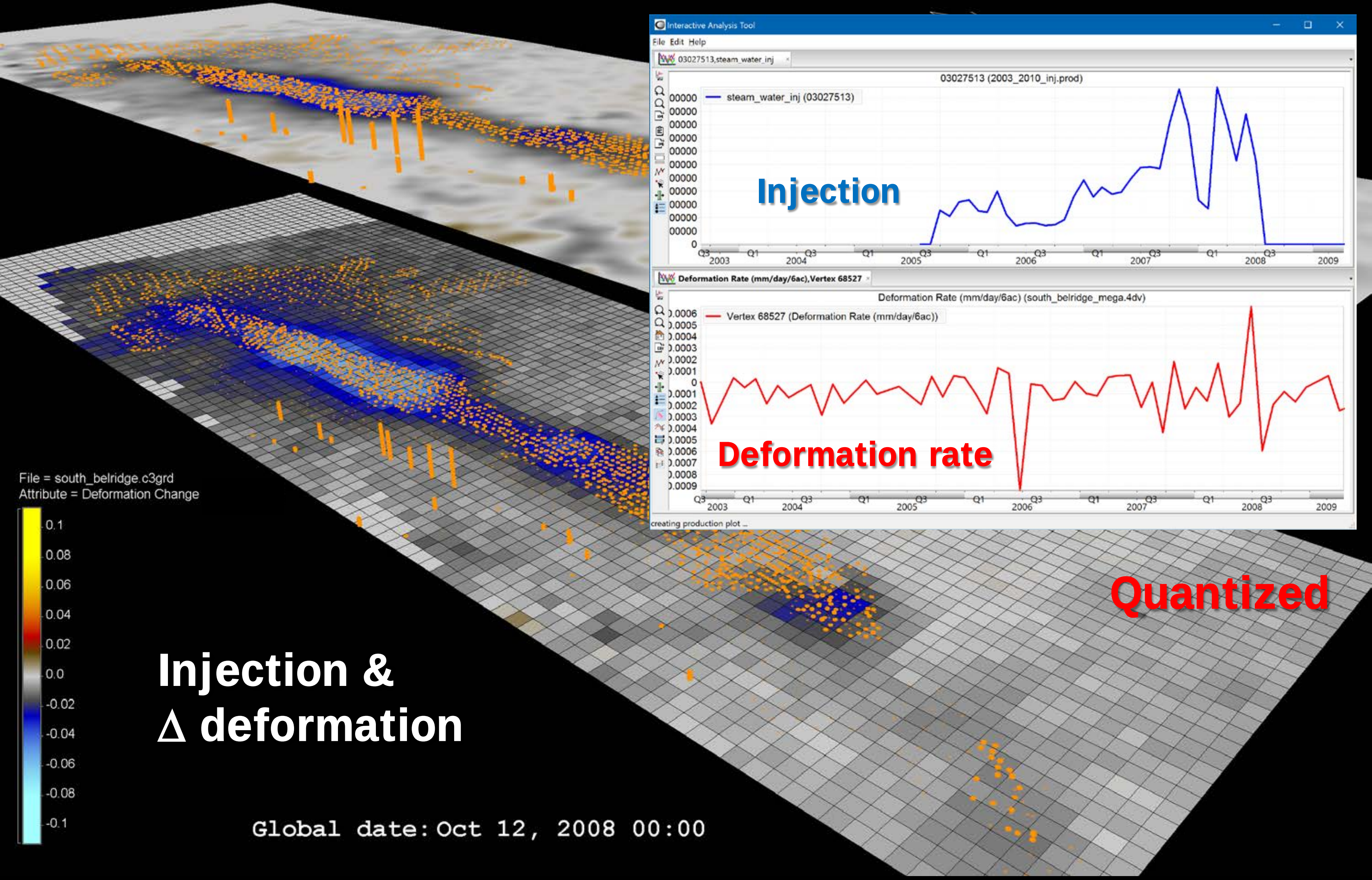




- **First-order match**
- **Heterogeneities not considered:**
  - **Overburden, reservoir compressibility, detailed structure, deviated well paths, injection etc.**
- **Further work could invert for reservoir properties etc.**

Short-term uplifts





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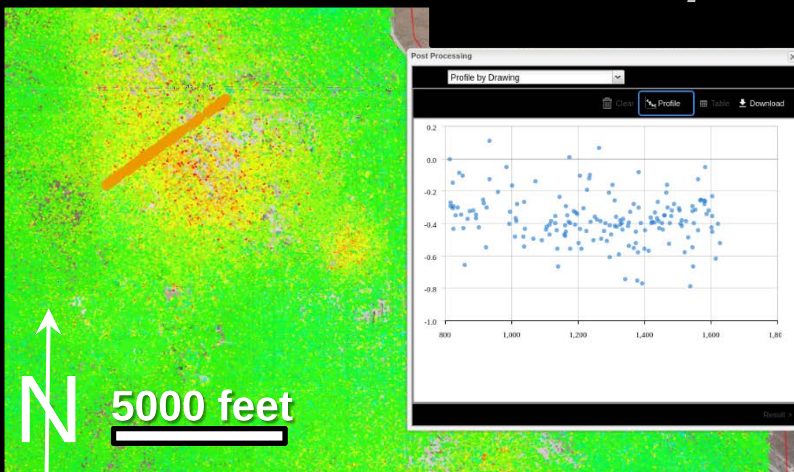
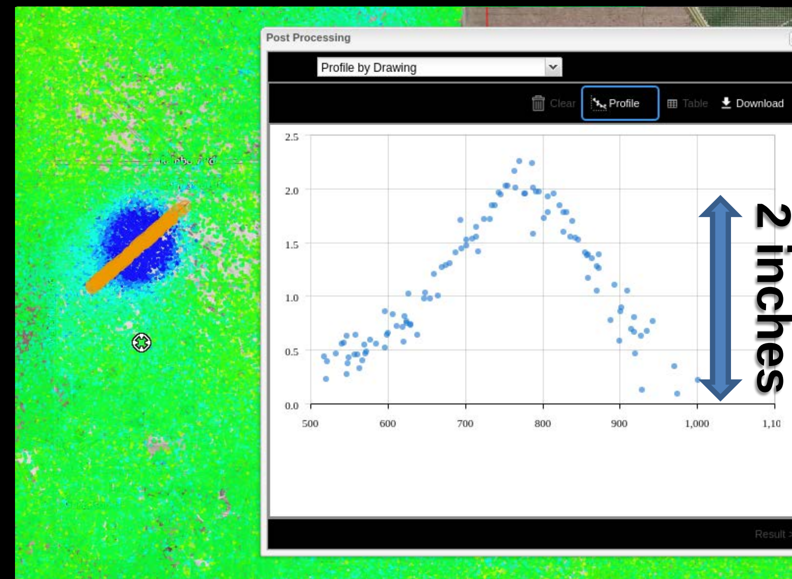
Localized short-term uplift

Red=subsidence; blue=uplift



22 day period



Following 11 day period

- Rapid localized uplift, quickly detected by InSAR
- Related to injection, shallow (~300 ft?) leakage
- Timely intervention (shut-in) prevented possible surface event

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Conclusions

- InSAR data:
  - Field-wide monitoring, long- & short- term signatures
- Value in integrating publicly available data
- Quantitative 3D/4D Integration environment allows rapid insights
- Long-term subsidence relates to production
  - Agrees with simple forward geomechanical models
  - Future work could capture more heterogeneities:
    - *Reservoir, overburden, temporal changes, deviated well paths*
- Localized uplifted related to injection
  - InSAR observations allow timely surveillance, hence intervention

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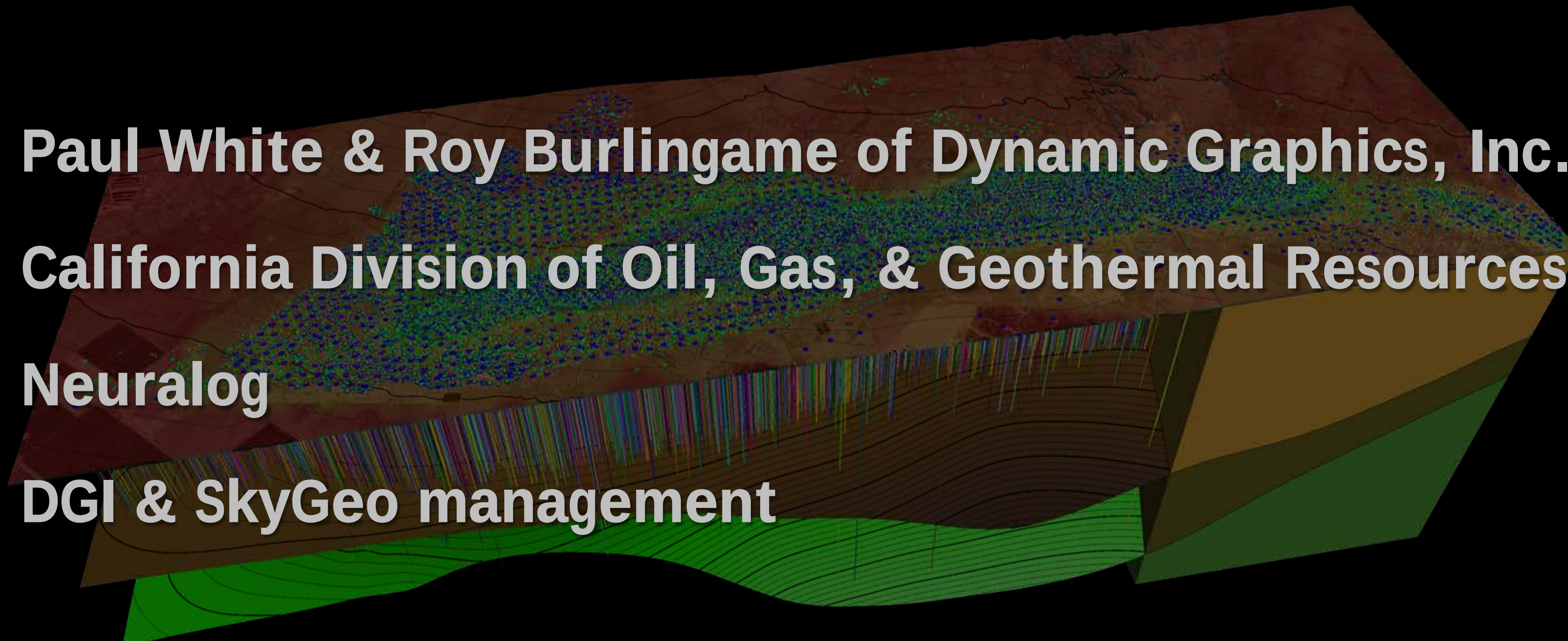
Acknowledgements



- Paul White & Roy Burlingame of Dynamic Graphics, Inc.
- California Division of Oil, Gas, & Geothermal Resources
- Neuralog
- DGI & SkyGeo management

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