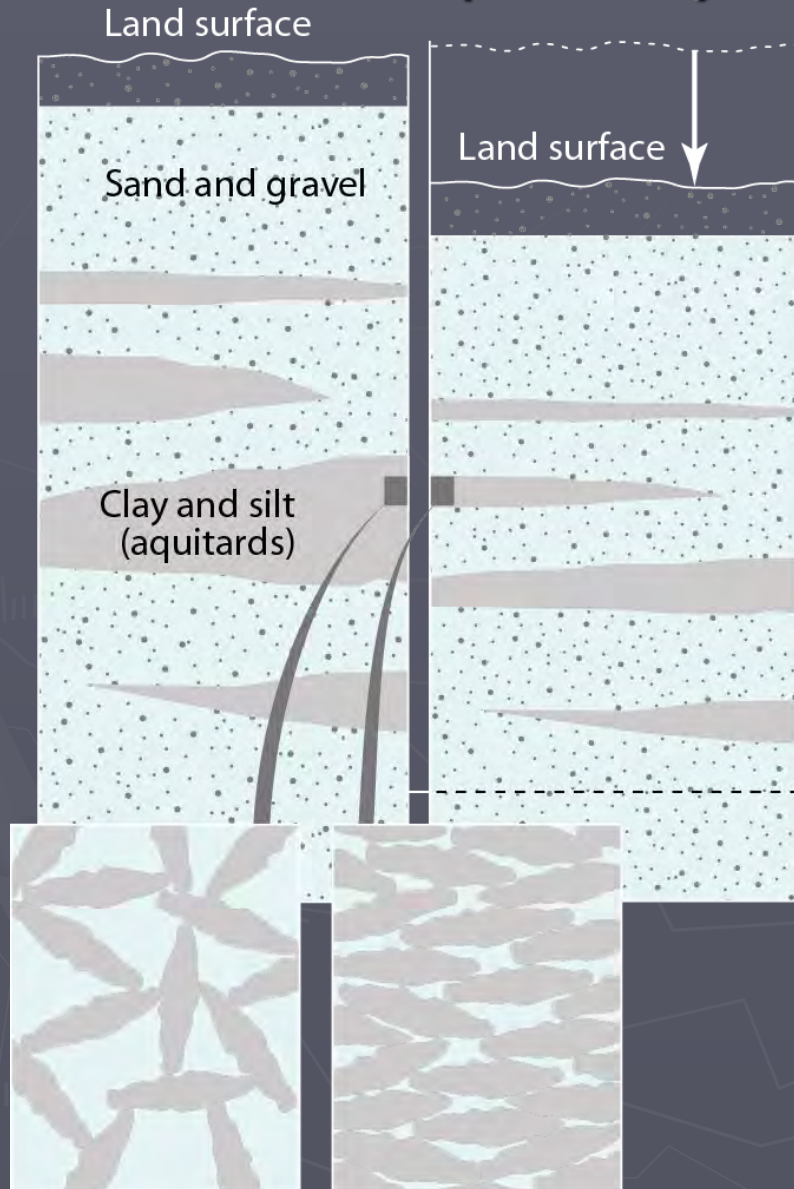


Land Subsidence Monitoring, San Joaquin Valley

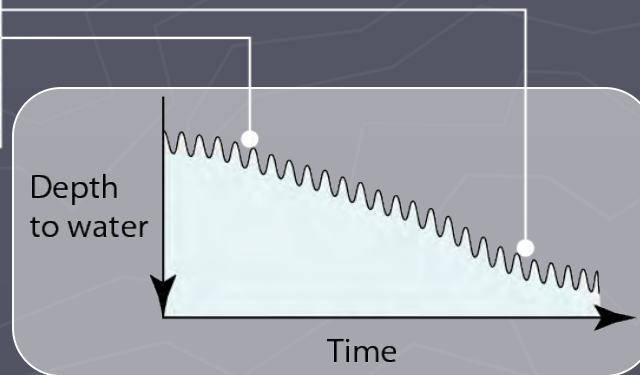
Michelle Sneed
California Water Science Center
U.S. Geological Survey
October 2, 2018



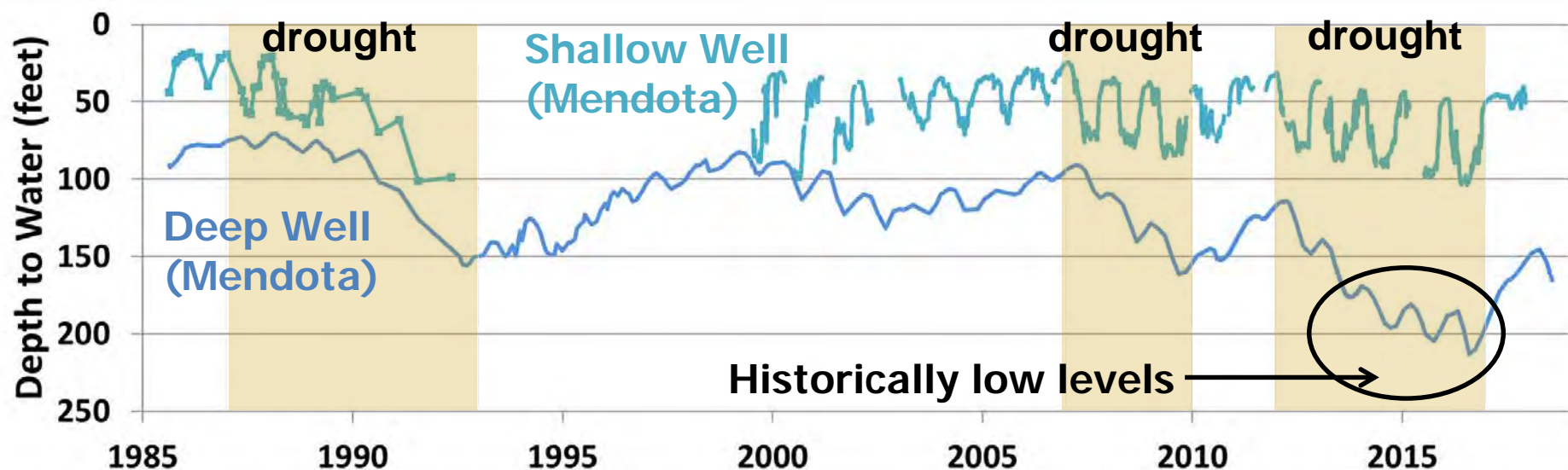
Land Subsidence in the San Joaquin Valley Aquifer-System Compaction



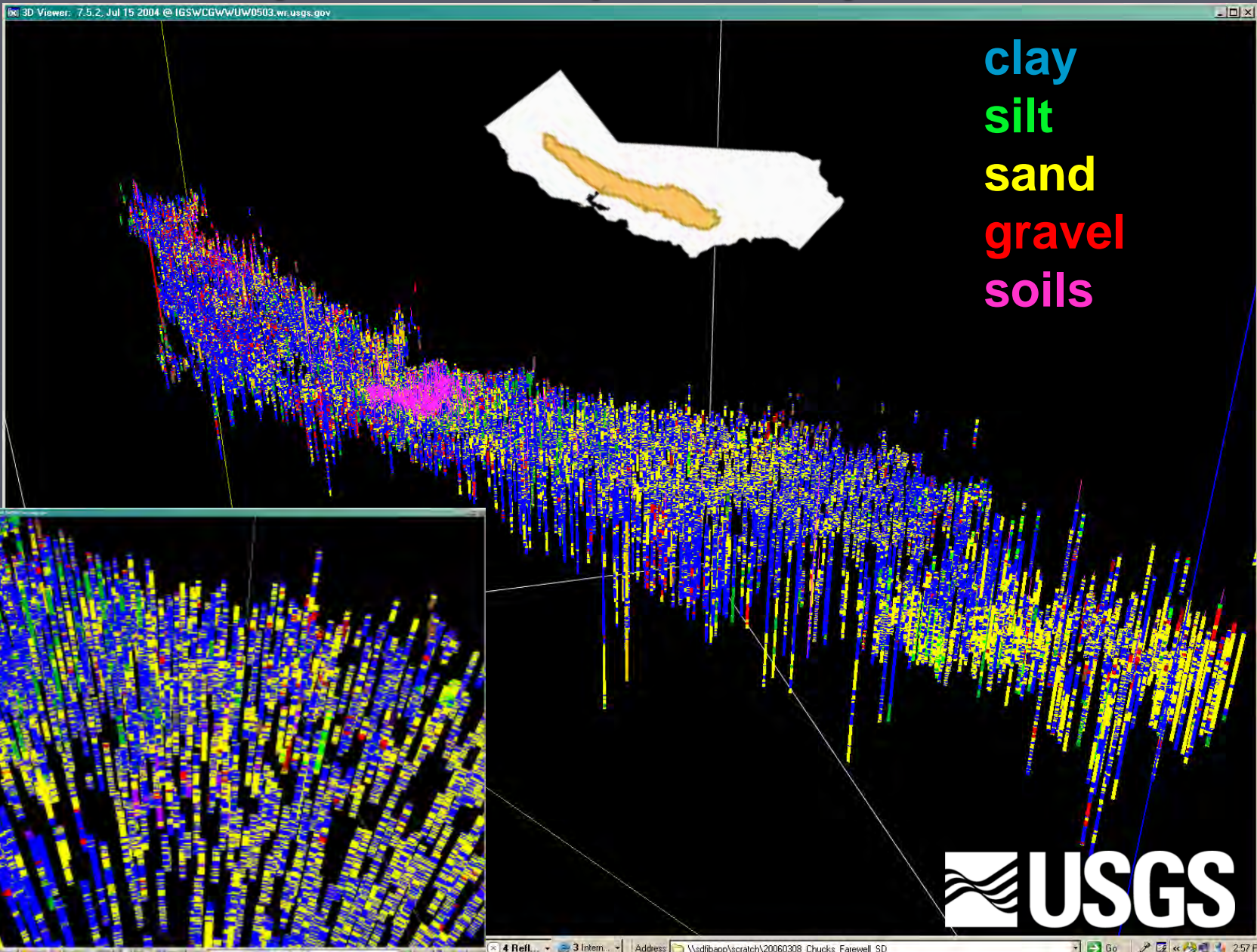
- ▶ Concentrated in the fine-grained deposits (clays/silts)
- ▶ Inelastic (permanent) compaction occurs when the critical head is exceeded
- ▶ Critical head \approx previous lowest groundwater level
- ▶ Storage capacity is reduced



Groundwater Level Declines

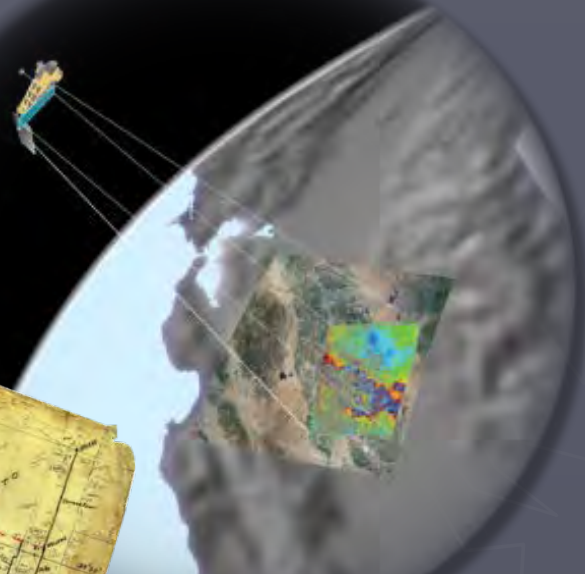


Clay-Rich Aquifer Systems



Subsidence Monitoring

- ▶ Can result in early detection
- ▶ Provides a measure of water-resources sustainability within relevant planning horizons
- ▶ Produces data needed for subsidence management



Subsidence Measurements: Space and Time

Spatial Resolution

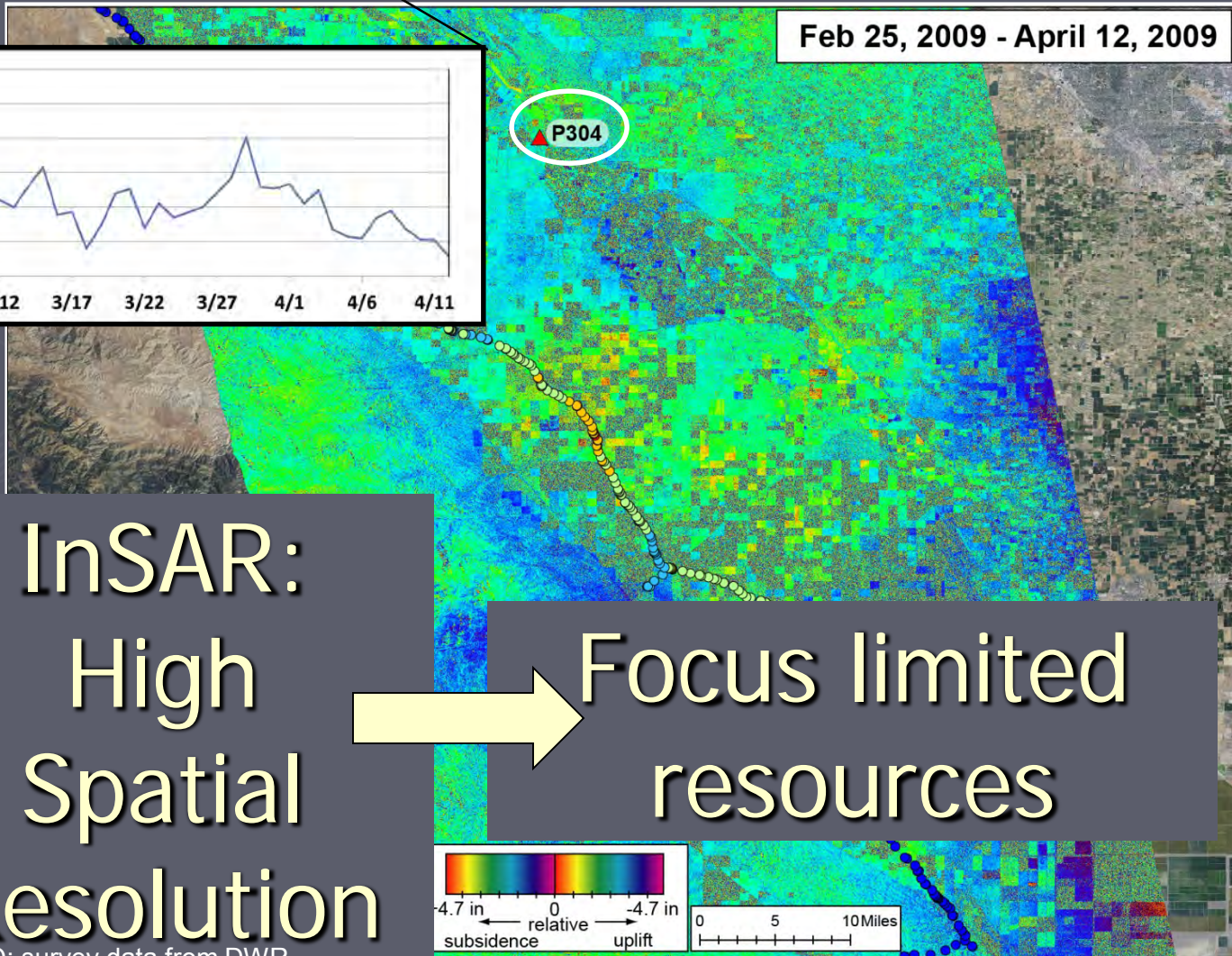
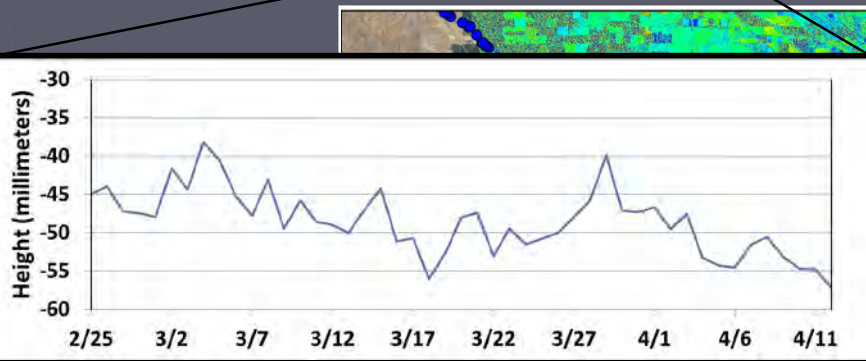
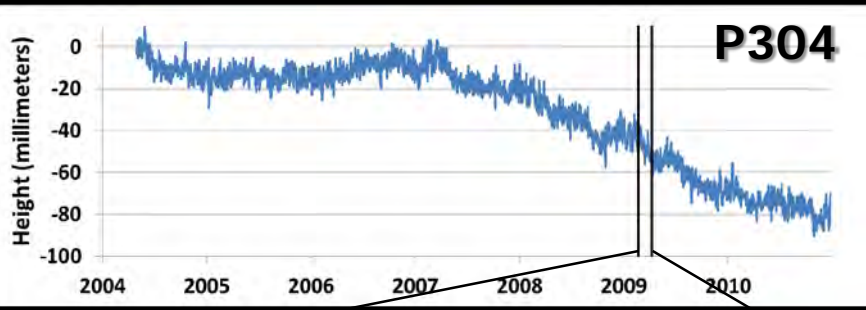
- One to Several Points
 - Borehole Extensometer*
- 10's of Points
 - Spirit Leveling
 - GPS (RTK/static/continuous)
- 1000's-1,000,000's of Points
 - InSAR (space and airborne)
 - LiDAR
 - Radar Altimetry

Temporal Resolution

- <Several measurements/year
 - Spirit Leveling
 - GPS (RTK, Static)
- Several measurements/year
 - InSAR (space and airborne)
 - LiDAR
 - Radar Altimetry
- 1000's measurements/year
 - Borehole Extensometer*
 - GPS (continuous)

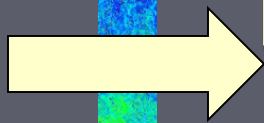
* Measures aquifer-system compaction

← CGPS: High Temporal Resolution



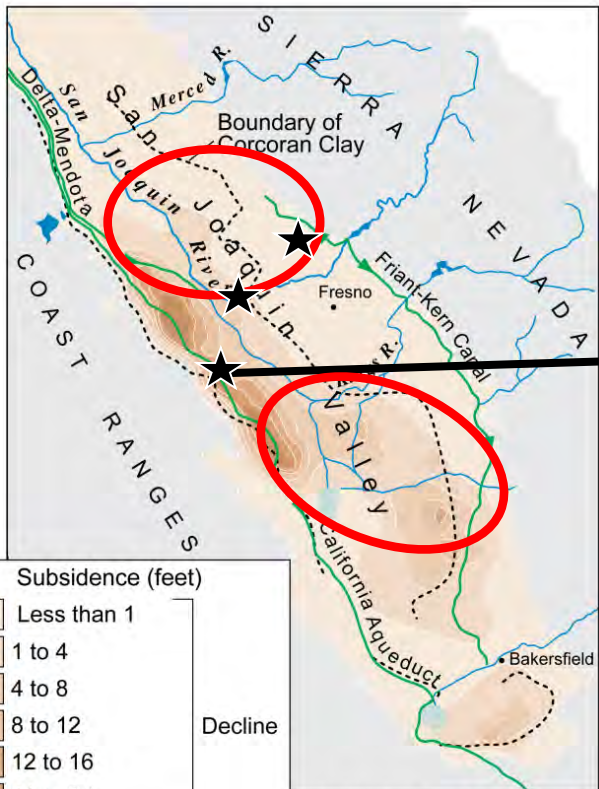
InSAR:
High Spatial Resolution

Focus limited resources

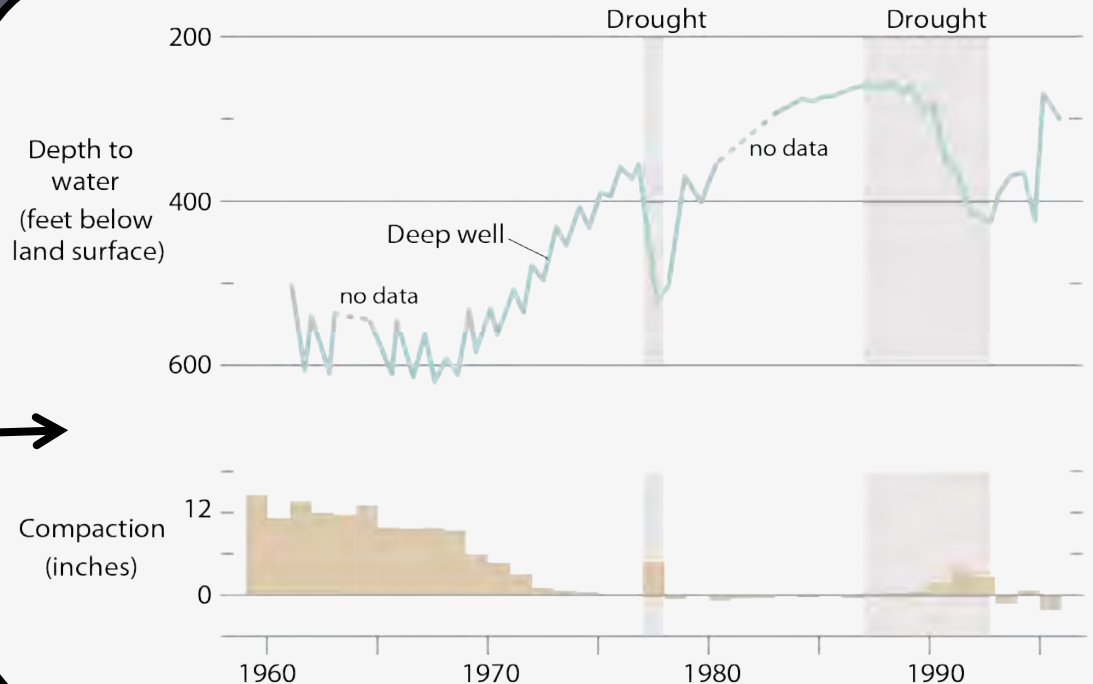


Subsidence History

Extensive withdrawal of groundwater caused widespread subsidence (1920s-1970)



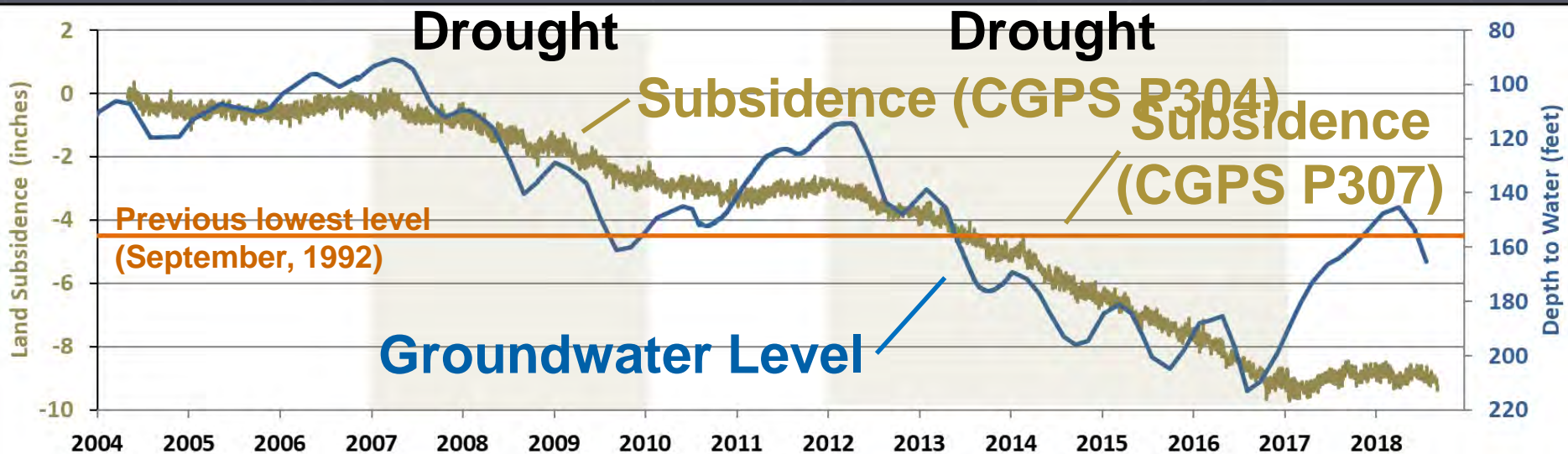
Land subsidence 1926-70



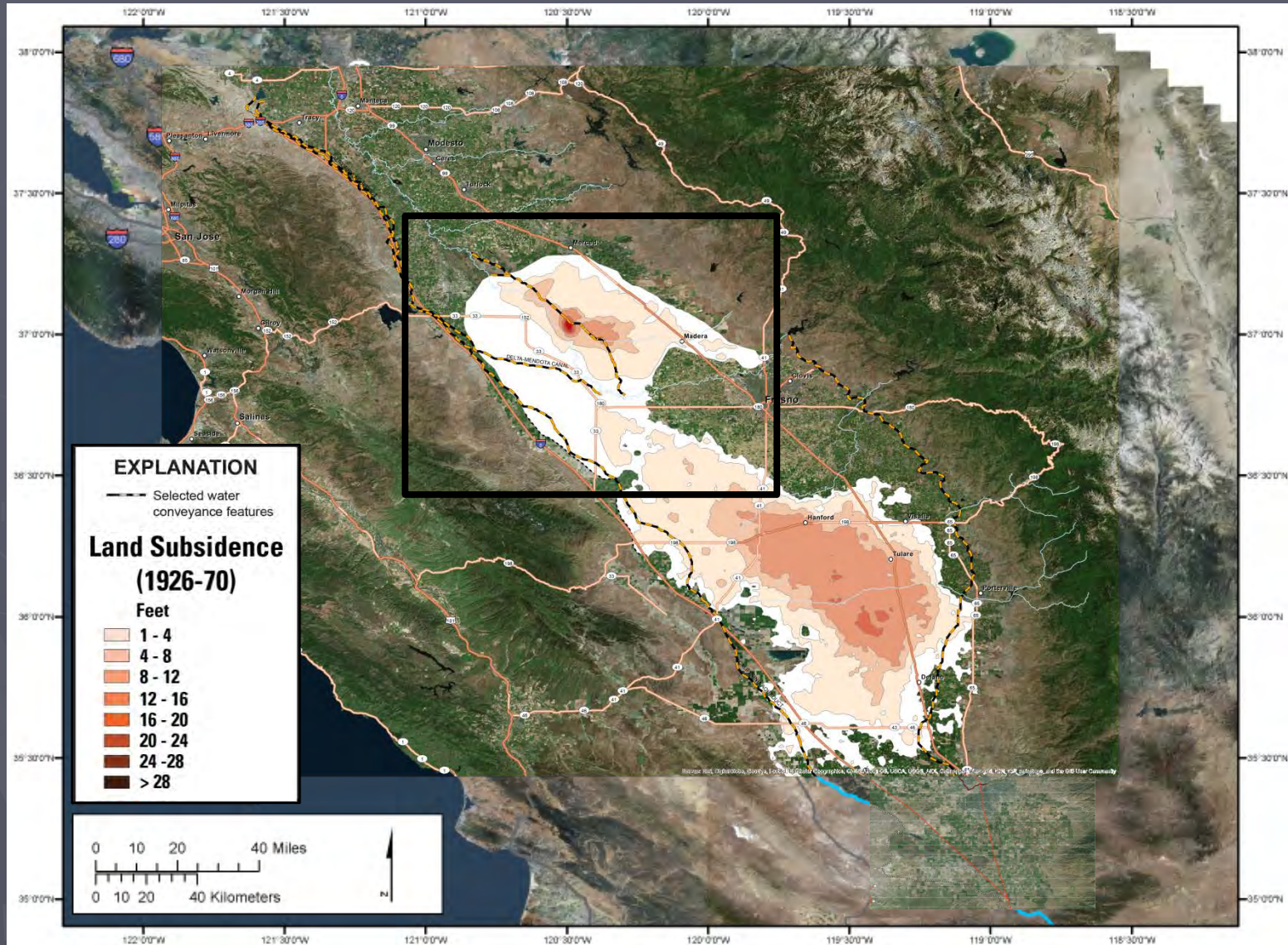
Surface-water deliveries caused widespread recovery and slowing or cessation of subsidence, except when deliveries were curtailed and groundwater pumping increased to meet demand

Recent Subsidence

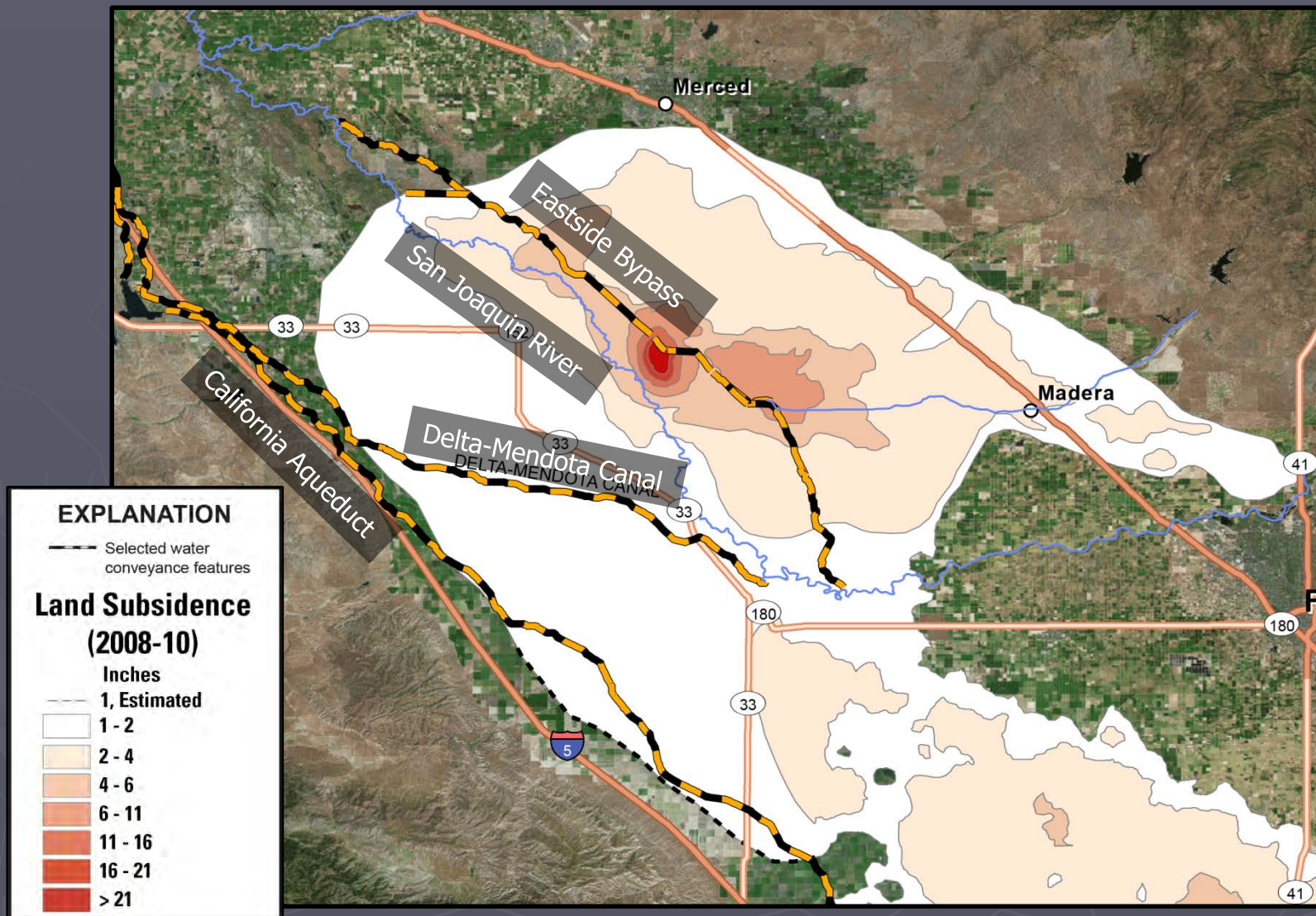
- ▶ Renewed subsidence concern during the 2007-09 drought initiated investigations
 - Reduced surface water importation
 - More reliance on the groundwater resources
 - As it turns out...this is not just a problem during droughts for some areas with limited surface-water access



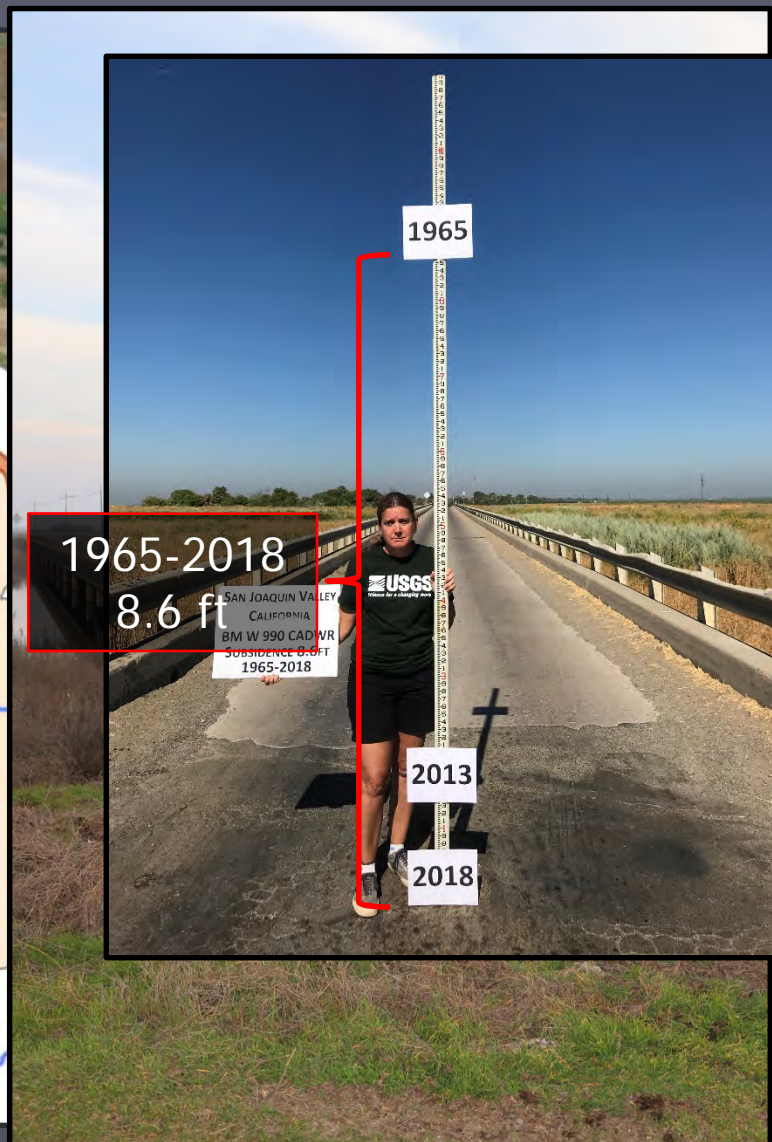
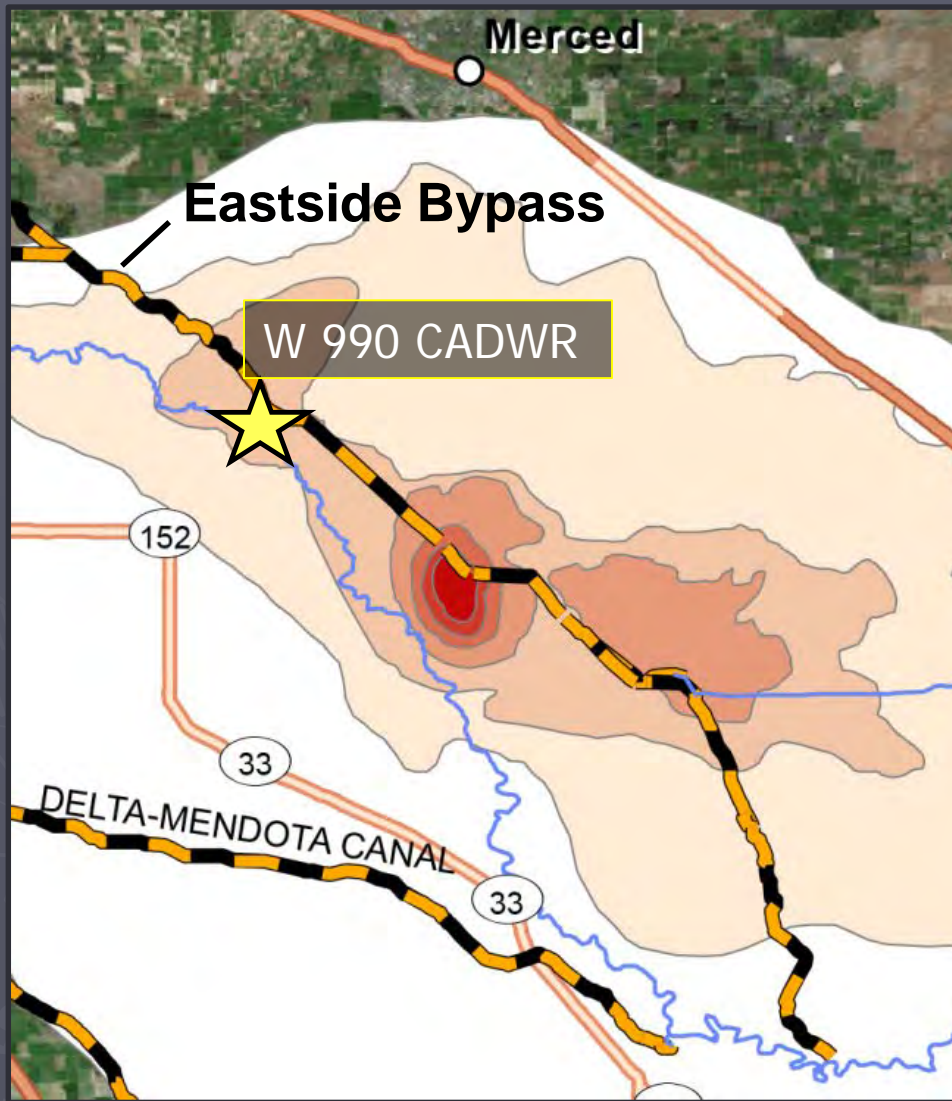
Historical Subsidence



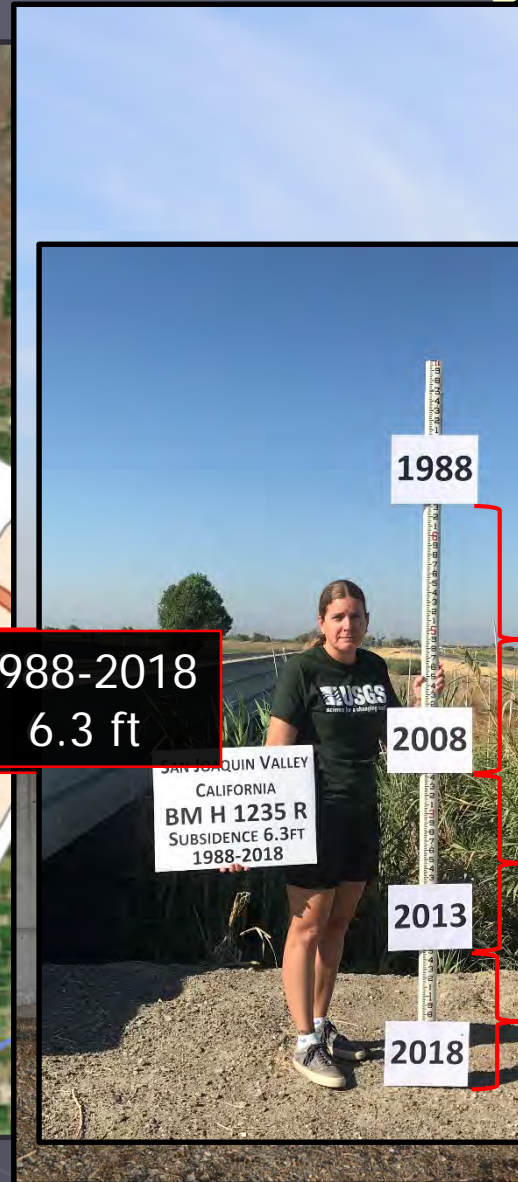
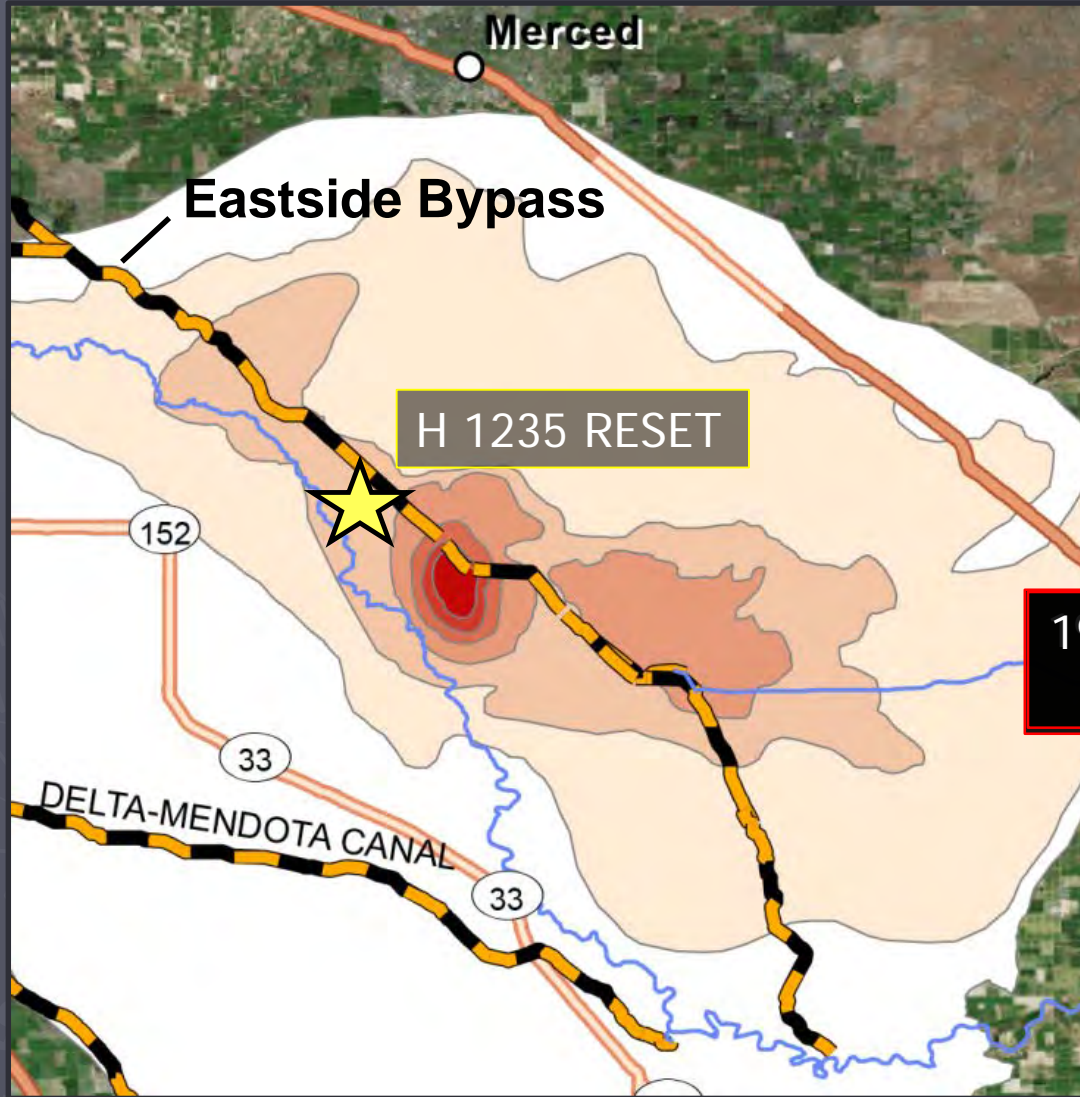
Water Conveyance Infrastructure



Periodic Leveling/GPS Surveys



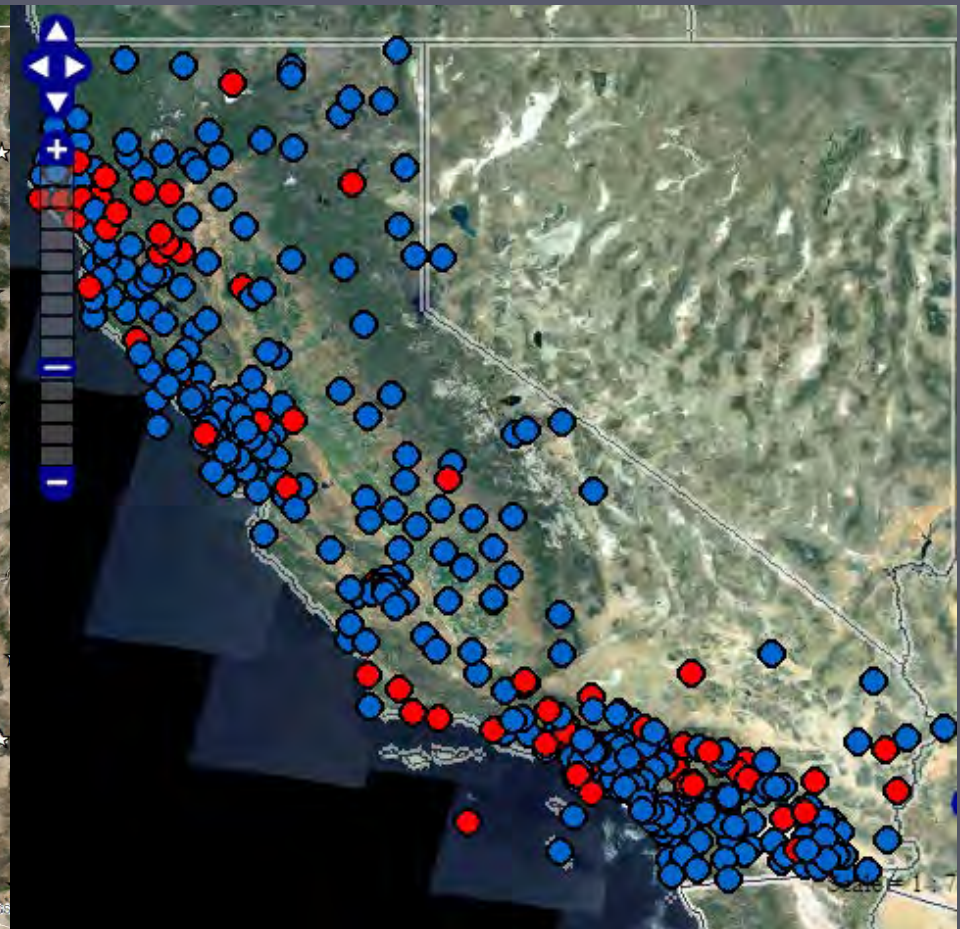
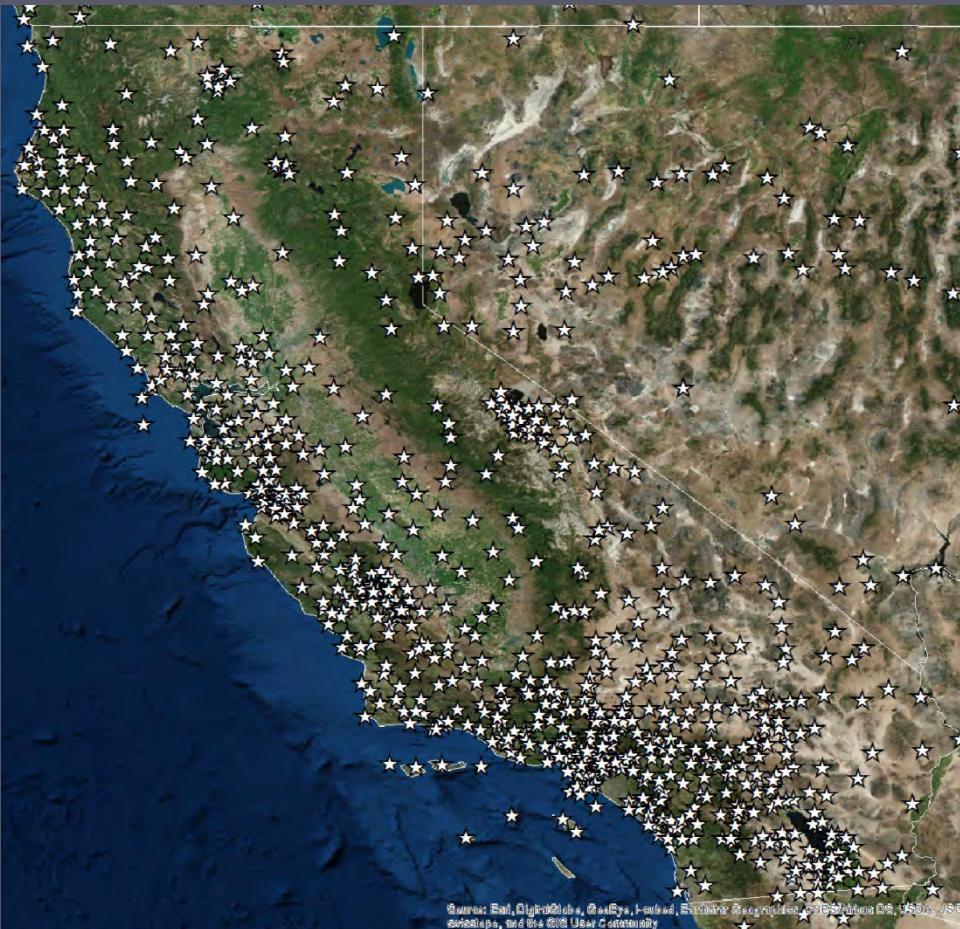
Periodic Leveling/GPS Surveys



1988-2018
6.3 ft

16 years	2.9 ft
4 years	0.6 ft
5 years	1.9 ft
8 years	3.3 ft
5 years	1.5 ft

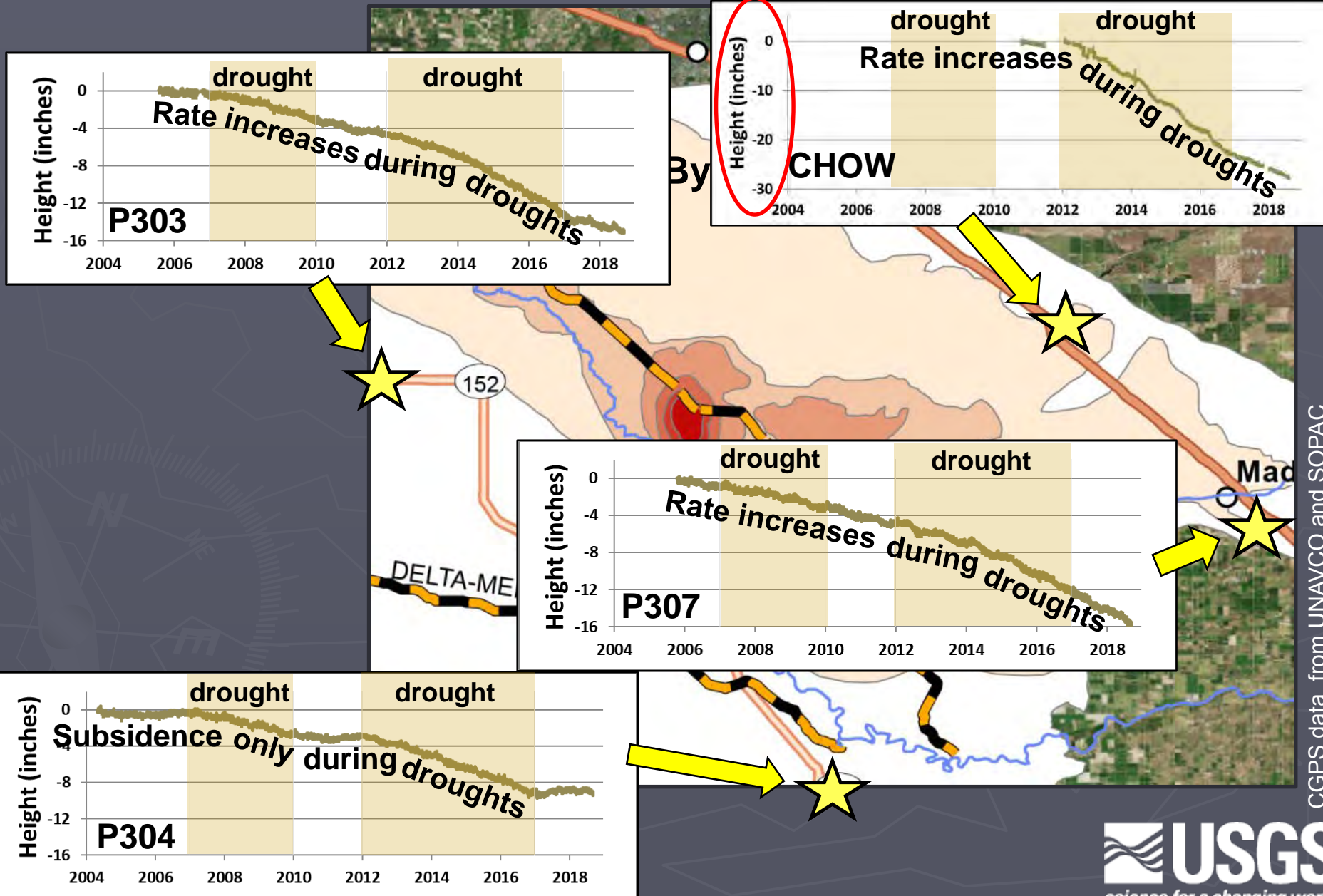
Continuous GPS Stations in CA



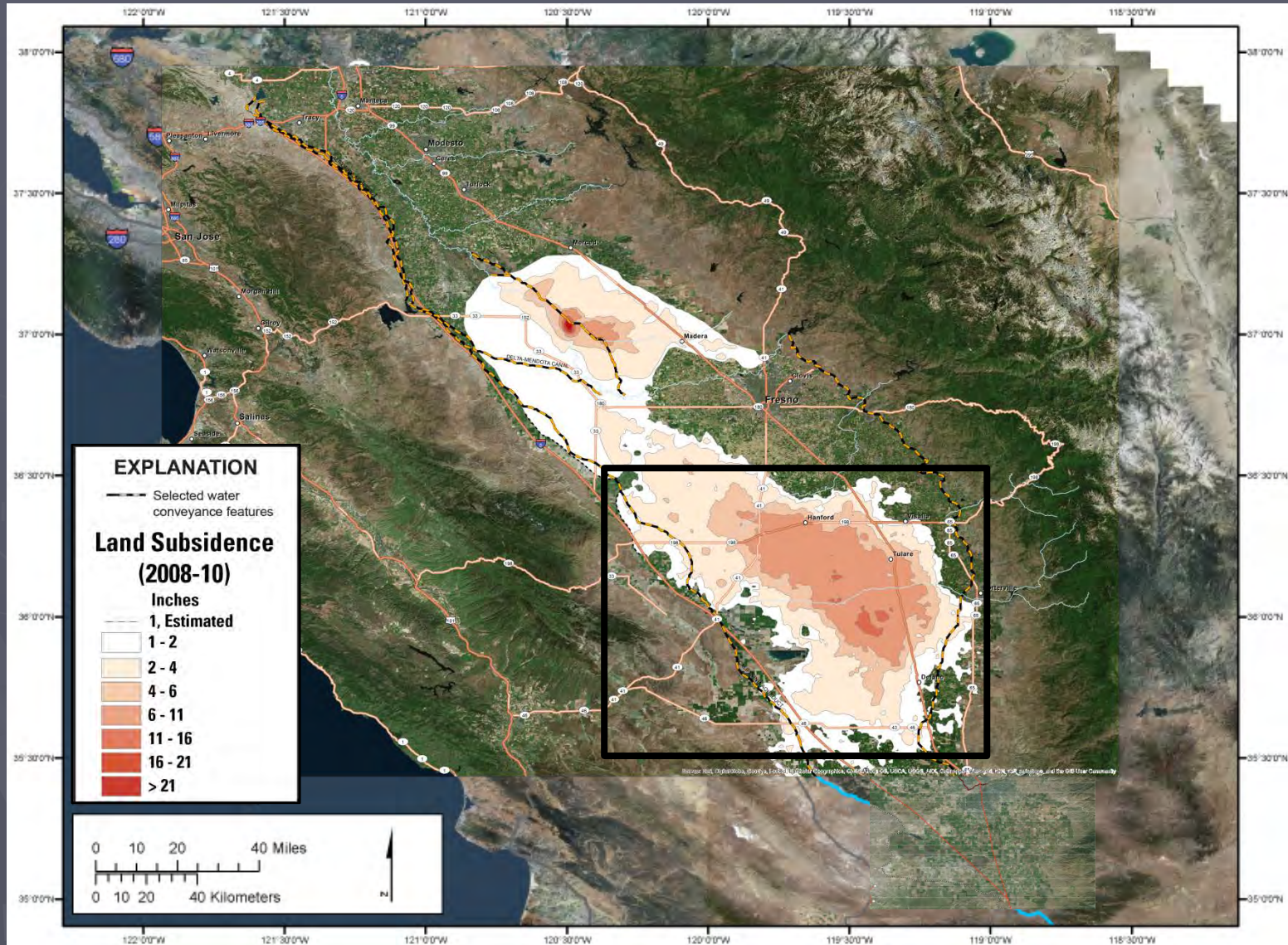
[http://www.unavco.org/
instrumentation/networks/
status/pbo](http://www.unavco.org/instrumentation/networks/status/pbo)

<http://sopac.ucsd.edu/map.shtml>

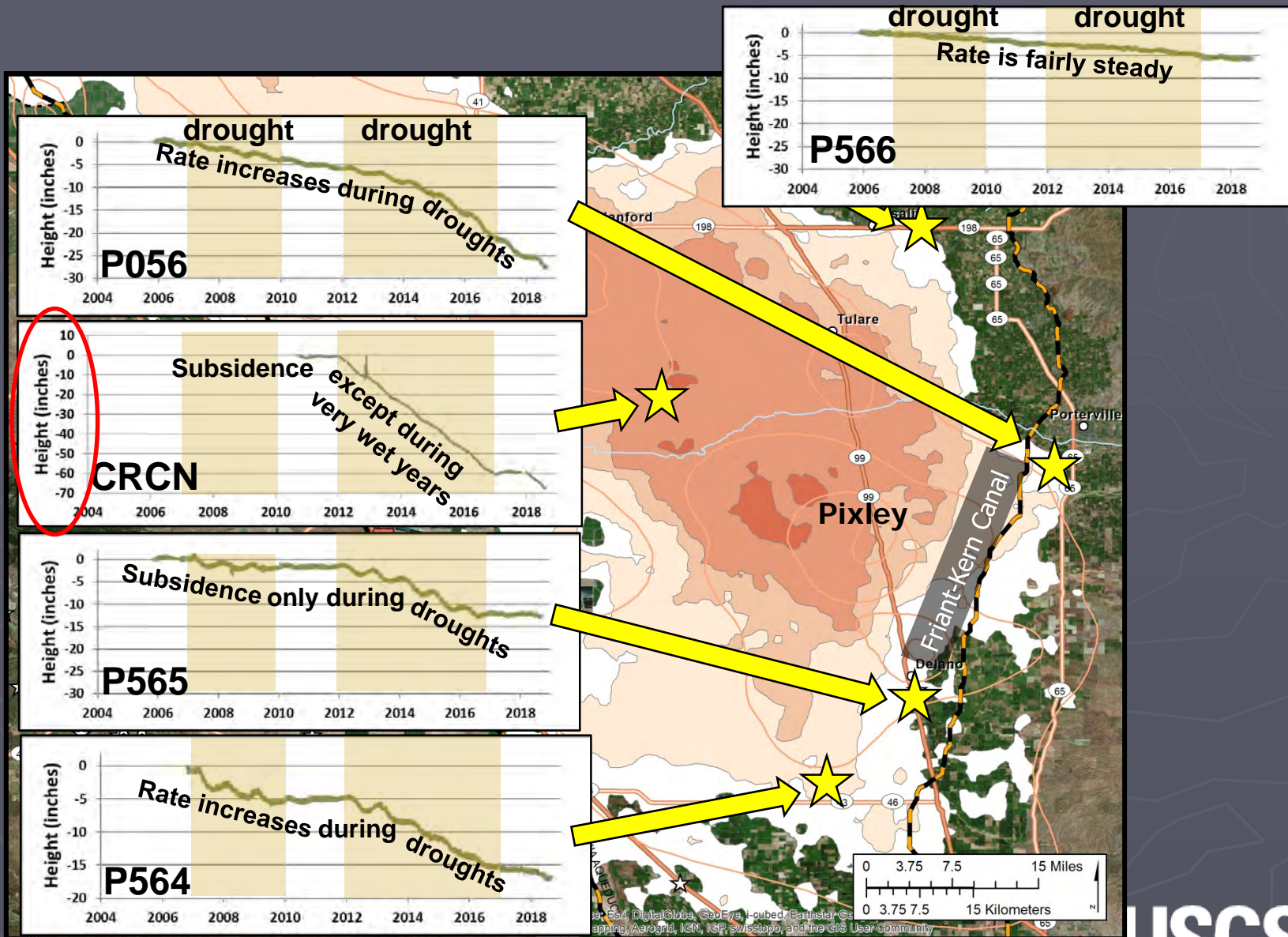
Continuous GPS Time Series



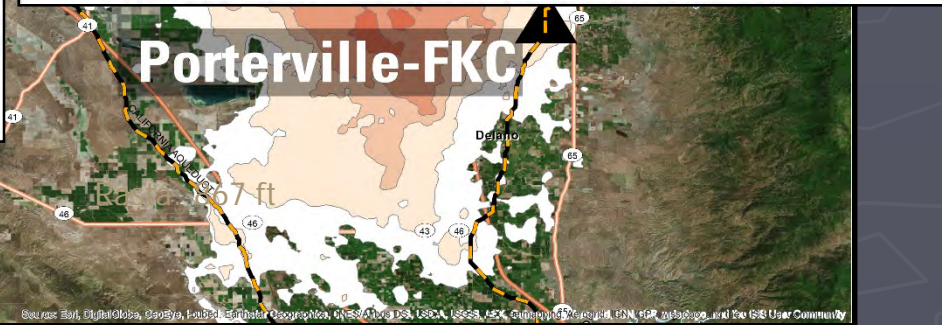
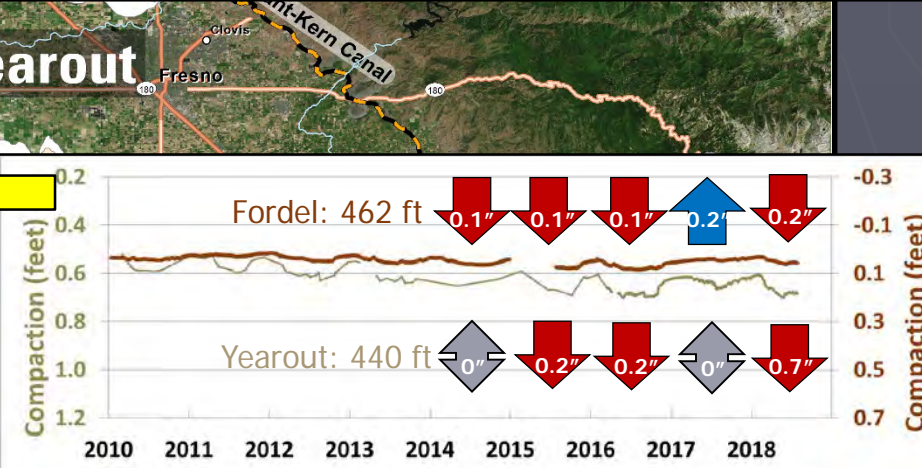
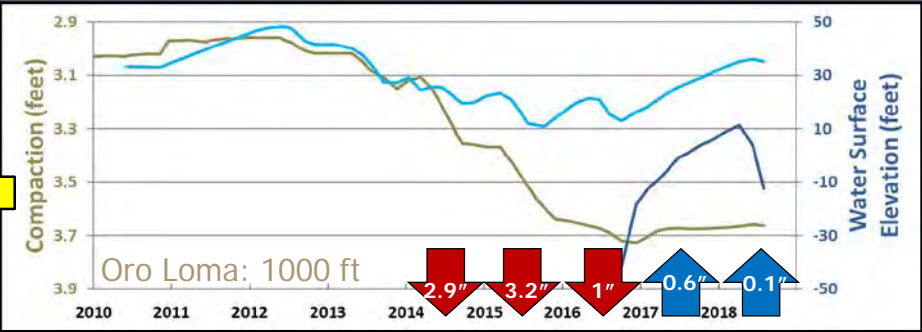
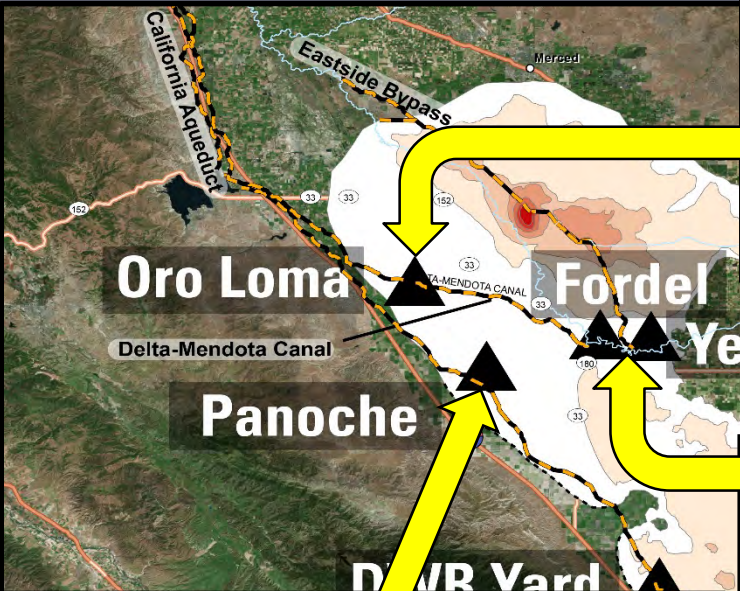
Recent Subsidence



Continuous GPS Time Series



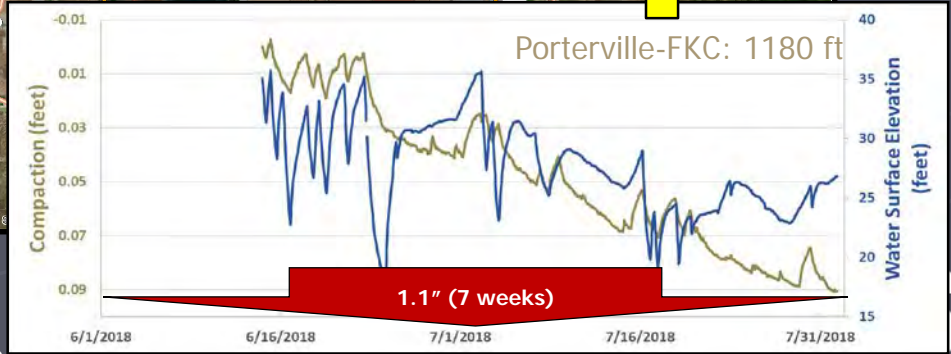
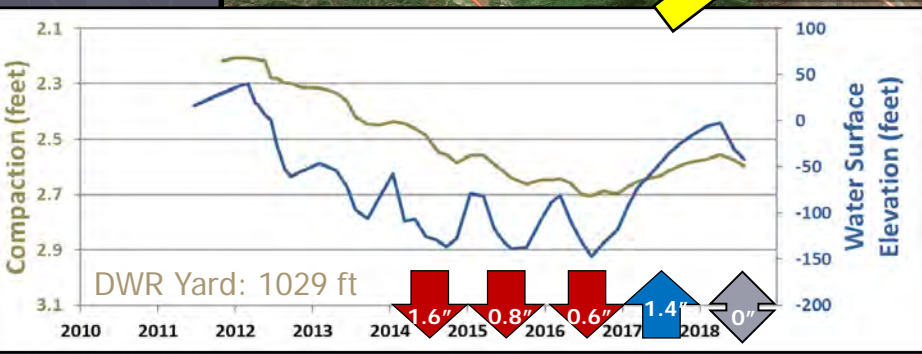
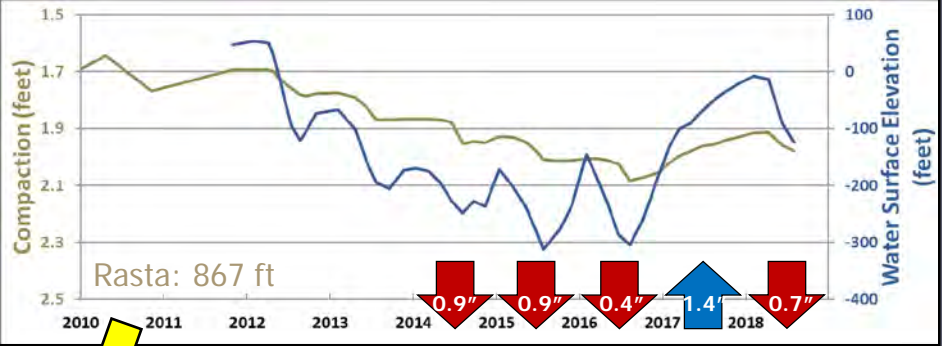
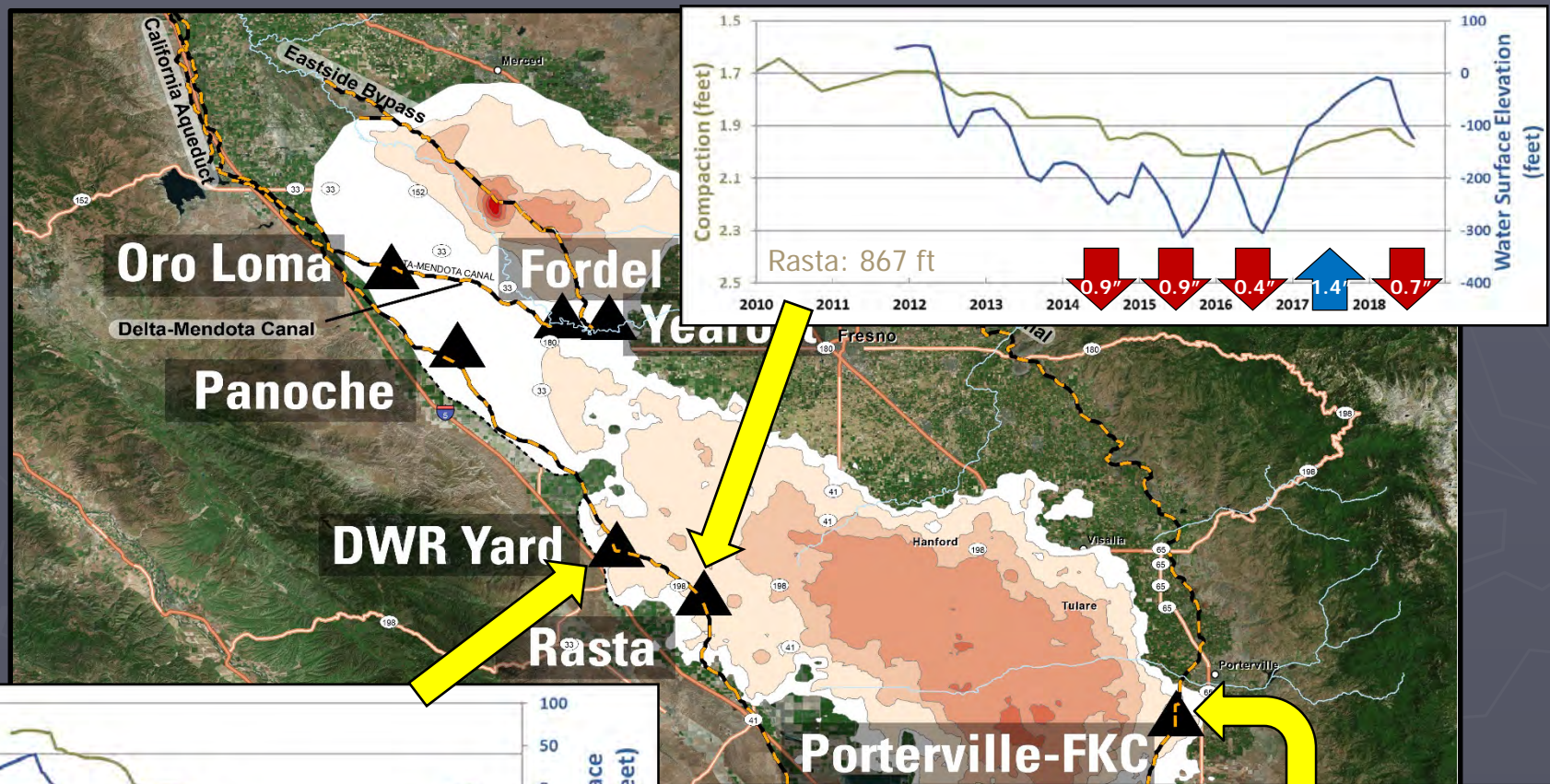
Continuous Compaction: Extensometers



Data are preliminary and subject to revision
 Extensometer and water-level data from USGS and Luhdorff and Scalmanini Consulting Engineers



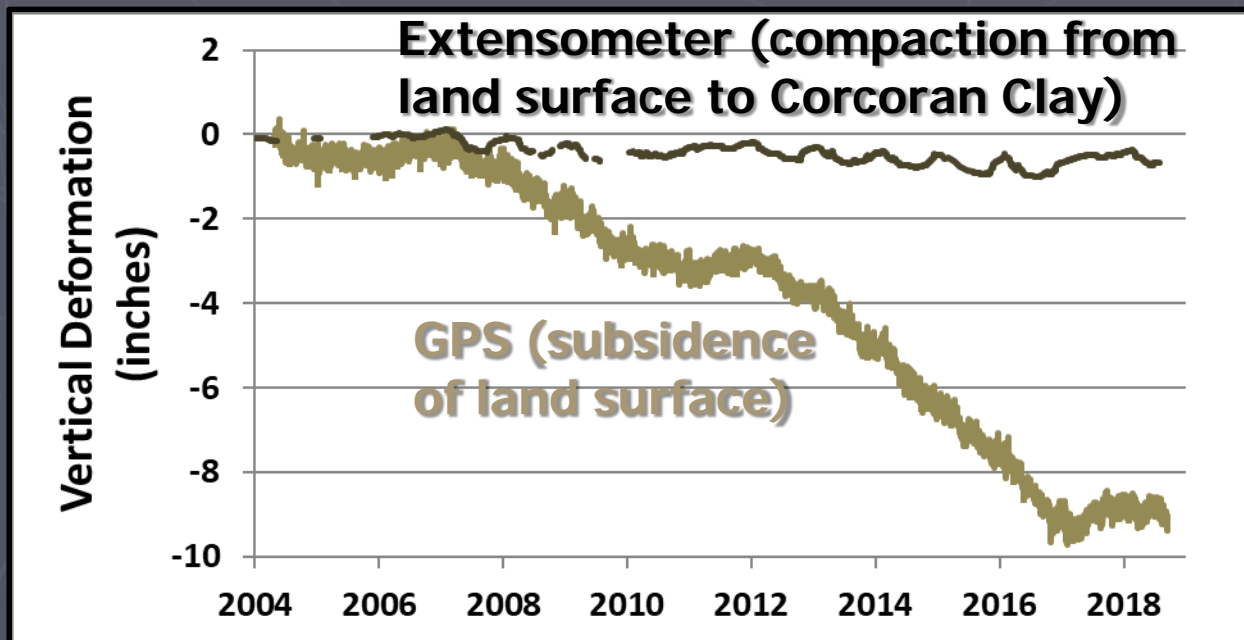
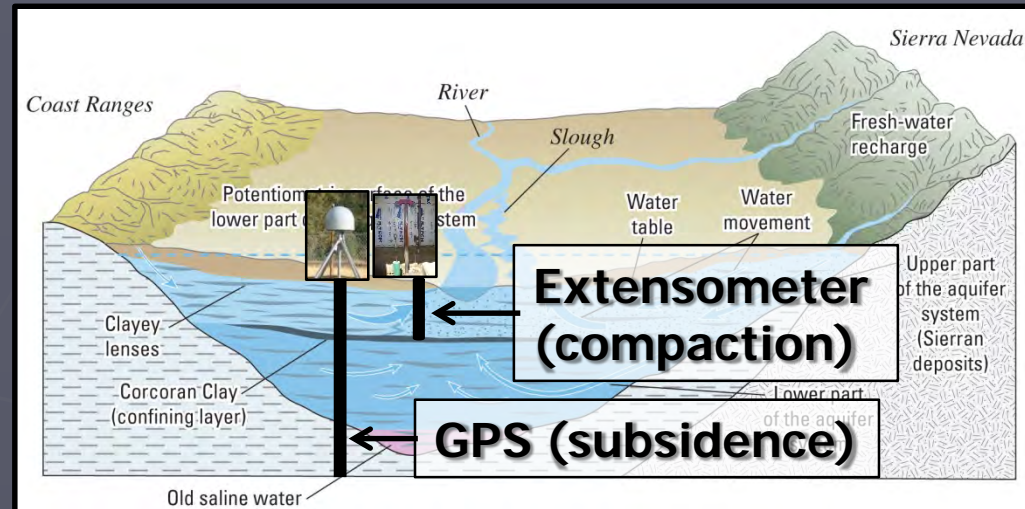
Continuous Compaction: Extensometers



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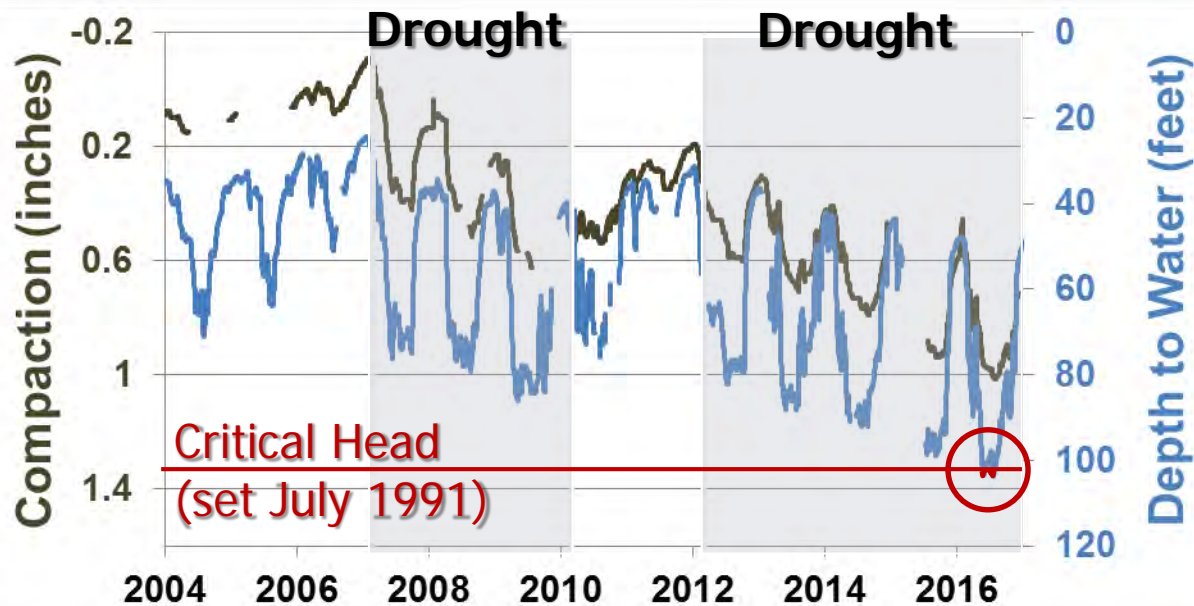
Compaction Depths (Mendota)

- ▶ Extensometer is anchored in the top of Corcoran Clay
- ▶ GPS reflects subsidence relative to the center of the Earth
- ▶ GPS measured much more deformation than the extensometer



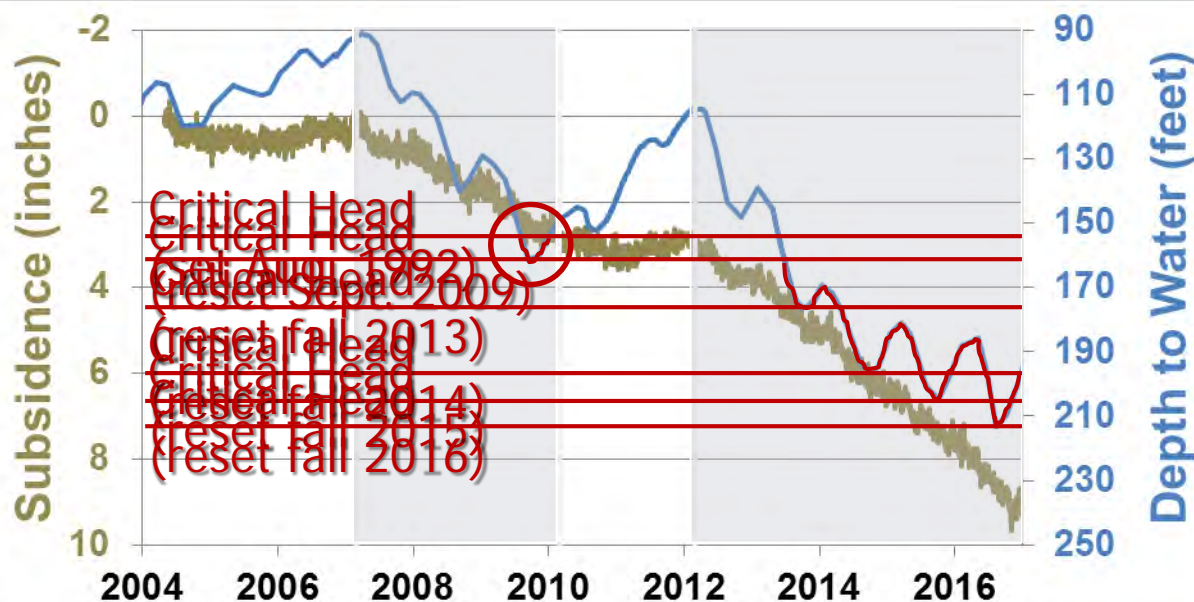
- **Conclusion:** most of deformation is occurring below the top of the Corcoran Clay

Recoverable or Permanent?



Compaction & Groundwater Levels above the Corcoran Clay

- Water levels have remained above the critical head except for short period in 2016
 - Likely mostly recoverable



Subsidence & Groundwater Levels below the Corcoran Clay

- Water levels have remained below the critical head
 - Likely mostly permanent



Subsidence Monitoring Summary

- ▶ Measuring subsidence/compaction AND groundwater levels is essential to understanding aquifer-system behavior
 - ▶ Estimate critical head and aquifer-system storage properties (model input)
- ▶ High spatial resolution of subsidence provided by InSAR data can help focus monitoring resources
 - ▶ Design ground-based networks to improve temporal resolution
- ▶ High temporal resolution of subsidence provided by continuous GPS or extensometers can help managers determine how various management strategies affect subsidence (decision support)
- ▶ Extensometers are the only measurement technique that will indicate depth intervals of compaction
 - ▶ Understanding compacting intervals is critical in subsidence management

Thanks!

For more information:

http://ca.water.usgs.gov/land_subsidence/