InSAR Land Subsidence Monitoring

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Subsidence from Space

- Groundwater is becoming a more important part of water resources
- But knowledge of the groundwater level is not uniformly available
- Wells provide some monitoring capability, but there are political and practical difficulties
- Interferometric Synthetic Aperture Radar (InSAR) can provide information on groundwater levels by measuring surface deformation caused by withdrawal and recharge of aquifers
- Subsidence also causes problems for infrastructure such as roads, aqueducts, and trains
- We are developing information products for water managers, the public, and hydrologists including animations, maps of ‘hot spots’, pixel histories, and regional maps of subsidence
- Most of the work has been done for the Central Valley and LA basin, but we are also processing data for other basins and coastal areas of California
Hydrology 101: Aquifer compaction

- Granular aquitard skeleton defining fluid-filled pore spaces storing ground water
- Rearranged, compacted granular aquitard skeleton with reduced porosity and groundwater storage capacity

- Recoverable land subsidence caused by reversible elastic deformation
- Permanent land subsidence caused by irreversible inelastic deformation

Compaction of the aquifer system is concentrated in the aquitards.

- Depth to water
- Time: Long-term decline in water level modulated by the seasonal cycles of ground-water pumpage
InSAR 101

1st pass: Measures reference phase ($\Phi_0$) for each pixel for time ($t_0$).

2nd pass: Measures phase ($\Phi_1$) or each pixel time ($t_1$).

Interferogram shows the phase difference ($\Phi_1 - \Phi_0$) for each pixel during time interval ($t_1 - t_0$).

One radar wavelength represented by phase ($\Phi$) in radians.

Pixel moves half wavelengths between 1st and 2nd satellite pass.

Line of sight.
<table>
<thead>
<tr>
<th>Satellite</th>
<th>dates</th>
<th>resolution (m)</th>
<th>swath (km)</th>
<th>incidence angles</th>
<th>minimum revisit (days)</th>
<th>band*/pol</th>
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<td>100</td>
<td>25°</td>
<td>35</td>
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<td>15-45°</td>
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<td>CVV, CHH</td>
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<td>40-350</td>
<td>10-60°</td>
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<td>L-quad</td>
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<td>350</td>
<td>15-60°</td>
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<td>L-quad</td>
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</tbody>
</table>

* wavelengths: X ~ 3 cm, C ~ 5 cm, L ~25 cm
May 2014 - January 2015
Subsidence from Radarsat-2

Legend
- California Aqueduct
- Delta-Mendota Canal
- Eastside Bypass
- Friant-Kern Canal

Google earth
Image Landsat / Copernicus
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Data MBARI
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
ARIA is a collaboration between JPL and Caltech to exploit radar and optical remote sensing, GPS, and seismic observations for hazard science and response.

ARIA investigates the processes and impacts of earthquakes, volcanoes, landslides, fires, subsurface fluid movement and other natural hazards by applying modern geodesy, merged with geophysical and geotechnical modeling.

As populations grow, response to natural disasters is becoming an increasingly important part of link between science and society. We are developing tools to use the growing volume of data to save lives and reduce the risk of natural hazards.
Subsidence along the California Aqueduct
Avenal Subsidence Hot Spot

- Previously had seen 13” max subsidence of the aqueduct in July 2013 - March 2015.

  - By June 2016 the same location showed 25” max subsidence of the aqueduct.
  - 4.7 miles of the aqueduct subsided > 10”.
  - InSAR averages over an area of ~25’x25’, so maximum at a point location is probably higher.
  - DWR calculated that the aqueduct flow here is reduced by 20% from initial construction values, 8350 ft$^3$/s > 6650 ft$^3$/s.

NOTE CHANGE IN SCALE

- Previously had seen 13” max subsidence of the aqueduct in July 2013 - March 2015.
Monitoring LA Basin

Range Displacement (cm)

Time Line


Paul Lundgren, Vince Realmuto, JPL
Monitoring LA Basin

Paul Lundgren, Vince Realmuto, JPL