Subsidence and Levee Movement in the Sacramento-San Joaquin Delta: Application of Radar Imaging to a Region-Wide Levee Assessment

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Remote Sensing for Monitoring Water Infrastructure
The Vision: Widespread, Rapid Identification for Targeted Response

The California Dept. of Water Resources and numerous other state, local, and federal groups currently monitor thousands of miles of levees and aqueducts throughout California. This infrastructure serves both as flood protection barriers and water conveyance infrastructure.

Remote sensing can augment ground-based and visual surveys by:

- enabling rapid assessment of large areas to give a snapshot of conditions at many sites at the same time
- providing consistent monitoring across all sites
- imaging areas that are difficult to access on the ground
- detecting areas that change by small amounts or in subtle ways
- informing a targeted monitoring program that can identify potential problem spots and/or provide continual monitoring of those sites to identify when/how they change
- providing information during emergency response

Sacramento/San Joaquin Delta, CA
Airborne Monitoring of the Sacramento-San Joaquin Delta
UAVSAR: NASA’s Uninhabited Aerial Vehicle Synthetic Aperture Radar

Project: Monitoring Levees and Subsidence in the Sacramento-San Joaquin Delta using UAVSAR

Funding Agencies: NASA Applied Sciences, Dept. of Homeland Security, CA DWR (FESSRO)

Study Period: Ongoing since July 2009

- Uses the NASA UAVSAR synthetic aperture radar
- ~50 flights since 2009, @ 6 week avg intervals
- Covers the Sacramento-San Joaquin Delta along 9 imaging tracks
Proximity to Major Faults

Bay Area Fault Map

- Vaca Fault
- Greenville Fault
- Concord Fault
- Green Valley Fault
- Calaveras Fault

DELTA

15 km
Shaken was stronger in the northern delta than the western delta! The bedrock of the Montezuma hills protected the western delta.
Radar imaging ≠ photogrammetry or visual surveys

Microwave-band Radar can…
1) See through clouds, smoke, haze.
2) Image day or night, in any light conditions.
3) Rapid, relatively high resolution, across large areas
4) Detect standing water.
5) Determine surface type.
6) Identify surface change.
7) Detect very small scale (few millimeters) movement of the ground.
Radar Interferometry for Measuring Surface Deformation

- Used for surface deformation & change detection.
- Relates the radar return’s phase change to change in distance relative to the radar wavelength
- Only the relative change in surface location is detected, not the surface height.
- Only change along the line-of-sight direction is detected.

First Pass Observation

First pass produces 1st image (amplitude & phase)

Second pass

Form interferogram, a contour map of change, from 1st & 2nd images

Phase is distance along path

Radar wavelength

UAVSAR: 13 cm per color wrap

Jones and Blom, AEG 2014
Levee Threats / Levee Status
Radar Remote Sensing Capabilities

Seepage

Cracks

Sand Boils & Sinkholes

Slope Instability

Subsidence

Photo credit: Tom Williams, Gerald Bawden, Cathleen Jones

State of California
Department of Water Resources
2012 Edition

012 05 18.indd - Levee_Threat_Monitoring_Guidelines.pdf
Subsidence in the Sacramento-San Joaquin Delta
An ongoing and long-term issue

On August 28, 2009 a ship rammed the north levee on Bradford Island. This image was made from an interferogram between UAVSAR data collected on July 17 and Sept. 10, so evidence of the impact and repair are seen in the data.

The plot shows a false color map overlaying the differential phase and correlation of the interferograms formed using the two data sets.
1. Bradford Island – Post Repair

![Map of Bradford Island with post-repair data](image)

- **Line of Sight Displacement [cm]**
  - **Inland**
  - **Repaired Levee**

*Preliminary*
2. West Sherman - Inland

Cumulative Displacement in the Line of Sight Direction [cm]

Line of Sight Displacement [cm]

2009 2010 2011 2012 2013 2014

2009 2010 2011 2012 2013 2014

preliminary
Sherman Setback Levee
Cumulative Line-of-sight Displacement in cm

2009    2010   2011   2012   2013   2014
Levee
Landside Slope
Toe

preliminary
3. Jersey Island

Water-Side Slope of Levee

40 m, water-side slope

Land-Side
3. Jersey Island, Blind Point Peninsula

Time = Aug-14-2014

Preliminary
4. Webb Tract

[Map and graph showing line of sight displacement in cm from 2009 to 2014, with a preliminary note on the map.]
6. Holland Tract

Loading the levee causes subsidence inland in some area – depends on soil type, which is highly heterogeneous.
Radar Imaging of Levee Status – Mandeville Island

Anomalous Levee Movement in a Localized Area

Mandeville

Inland

Levee
Change detection across a high/low tidal cycle can be used to identify some mid-sized seeps in areas where the soil moisture varies with the water level in the adjacent canals.
InSAR Applied to Other Critical Infrastructure
Example: California Aqueduct

Between Huron & Kettleman City

5/15/14 – 6/16/14
No subsidence at this location before 6/16

6/16/14 – 10/6/14

Eastern side of aqueduct subsided 6.5” +/- 1” at its maximum point in the period between 16 June 2014 and 6 Oct 2014 (112 days).

Center of bowl subsided 8” +/- 1” during same time period.
• High resolution L-band InSAR can definitely be used to identify movement & change on earthen levees.
• We achieve high accuracy by using long time series of frequent acquisitions to differentiate normal seasonal variability from long term trends.

Twitchell Island, California