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

Sacramento Delta / false color UAVSAR POLSAR image / 7 m resolution

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Central Valley Flood Protection Board

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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.

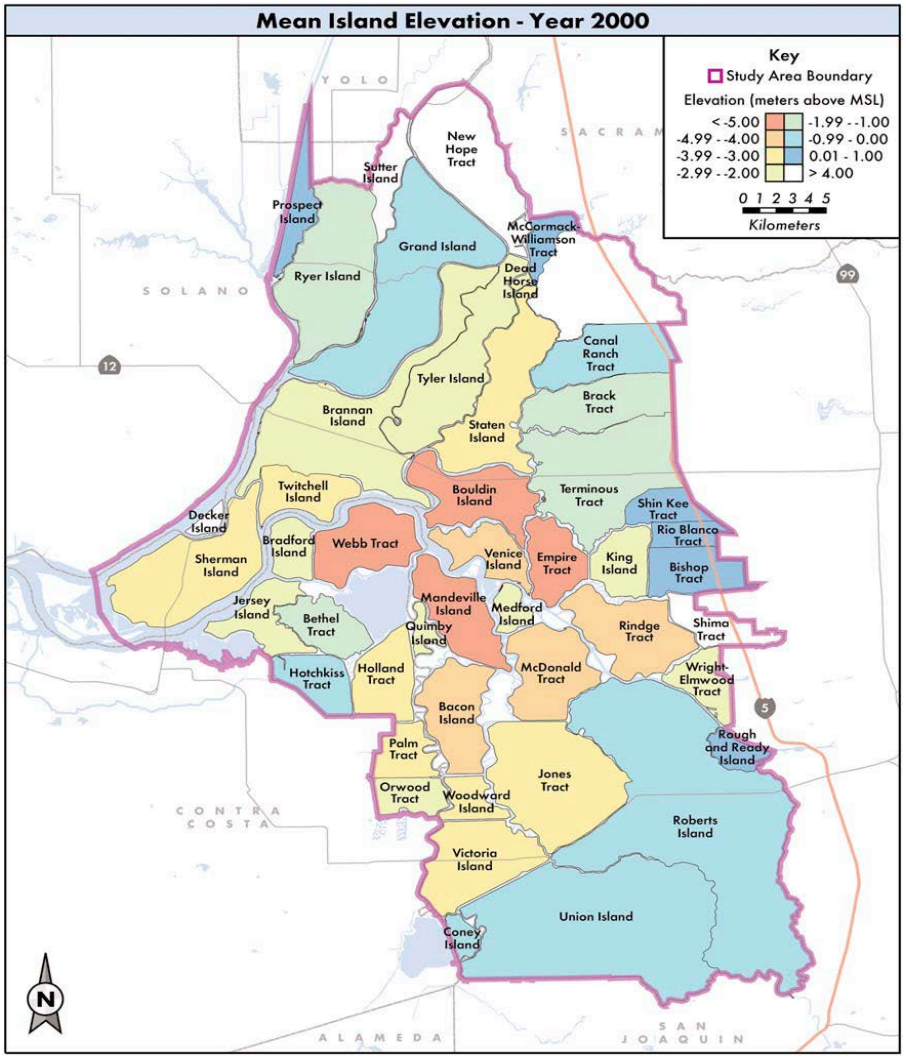
Remote sensing can augment ground-based and visual surveys by:

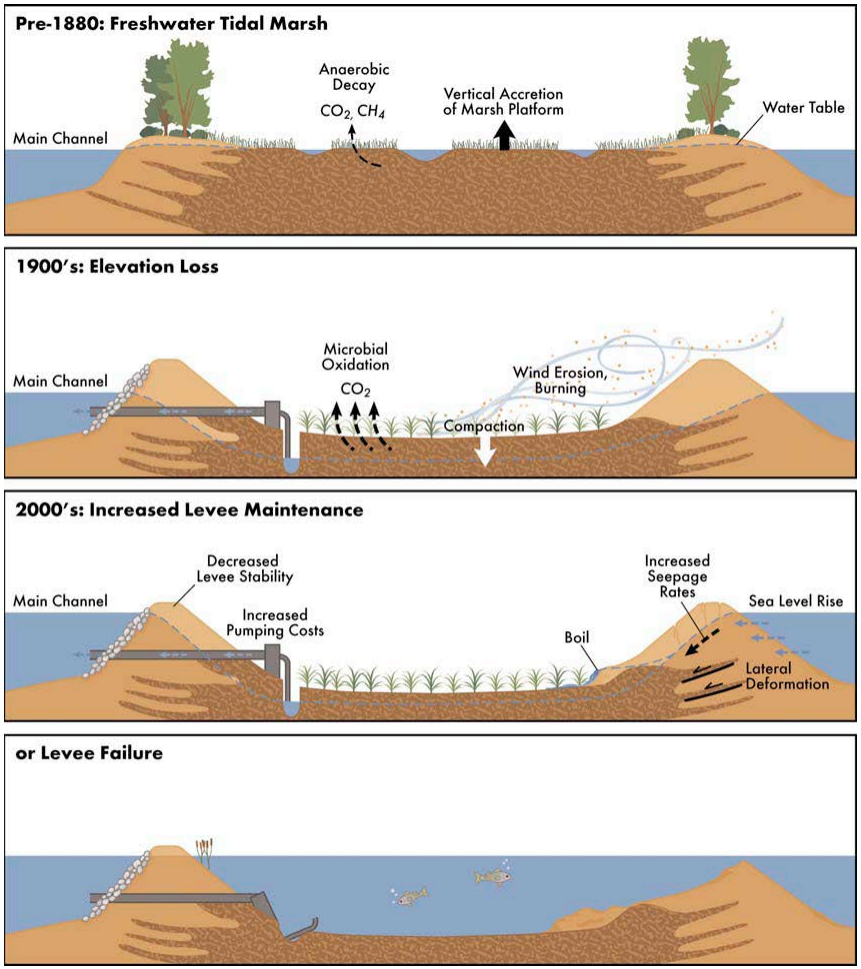
- **enabling *rapid assessment* of large areas to give a snapshot of conditions at many sites at the same time**
- **providing *consistent monitoring* across all sites**
- **imaging areas that are *difficult to access* on the ground**
- ***detecting* areas that *change* by small amounts or in subtle 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

Subsidence in the Sacramento-San Joaquin Delta

An ongoing and long-term issue





From "Subsidence, Sea Level Rise, and Seismicity in the Sacramento – San Joaquin Delta," Jeffrey Mount and Robert Twiss, San Francisco Estuary & Watershed Science, March 2005.

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 i**

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

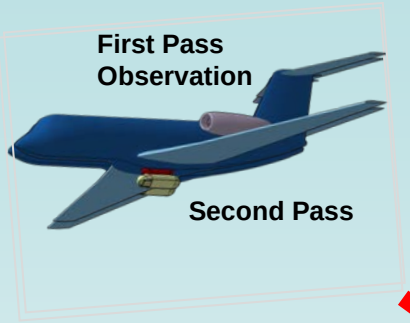
4)Detect standing water.

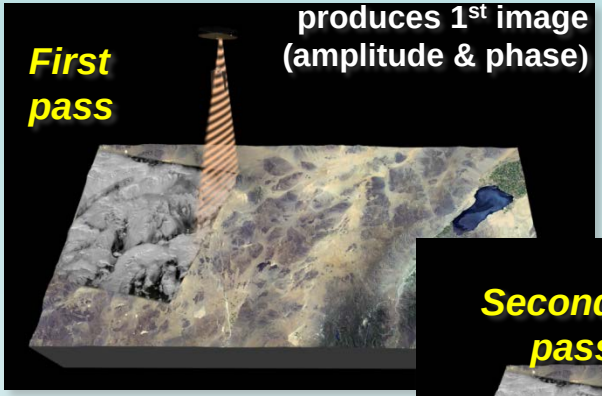
5)Determine surface type.

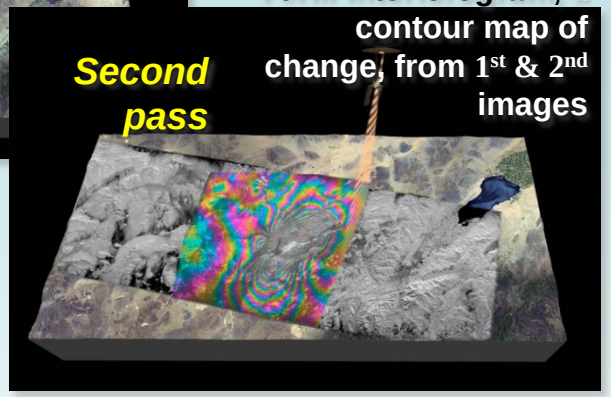
6)Identify surface change.

7)Detect very small scale (few millimeters) movement of the ground.

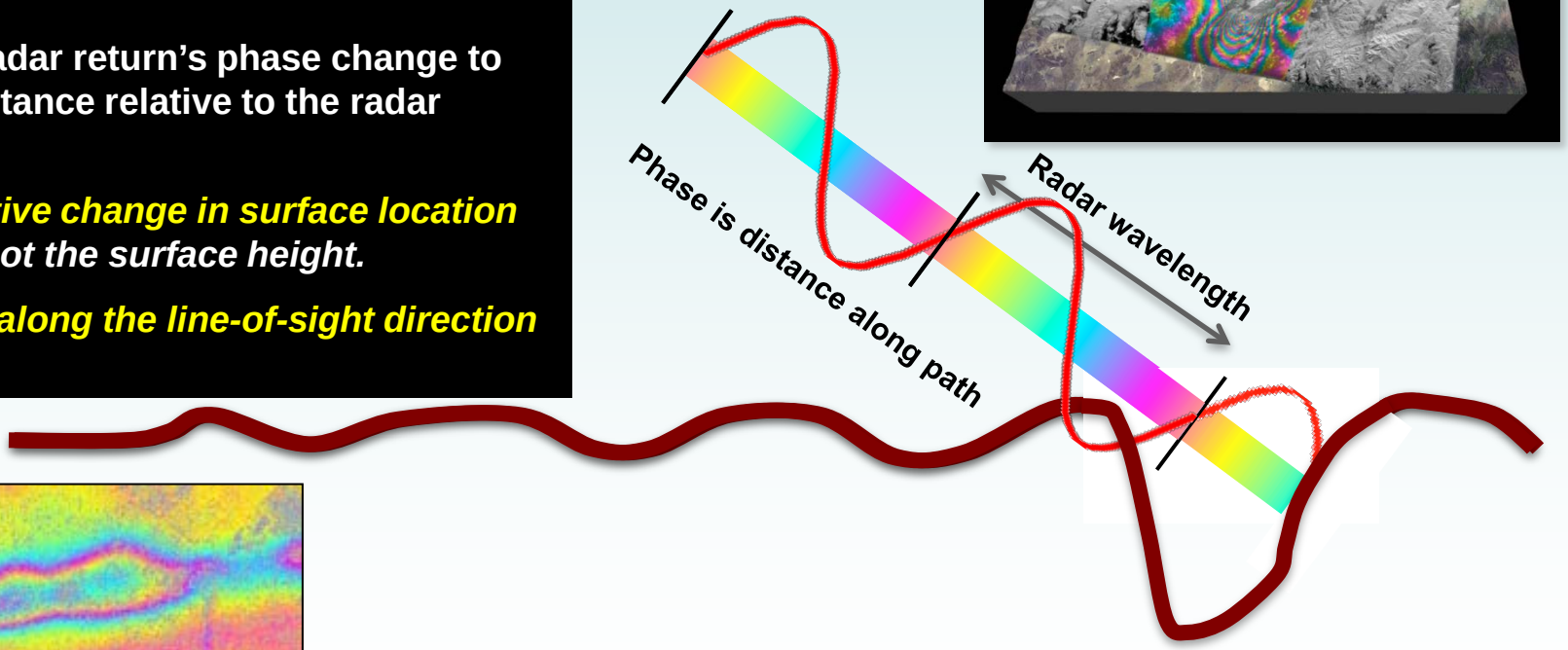
Radar Interferometry for Measuring Surface Deformation

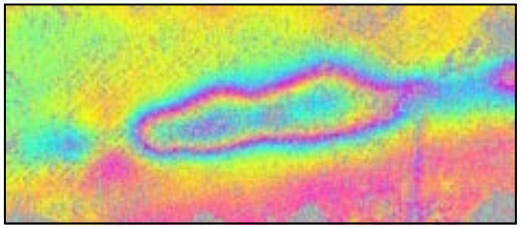






- Used for surface deformation & change detection.
- Relates the radar return's phase change to change in distance relative to the radar wavelength
- *Only the relative change in surface location is detected, not the surface height.*
- *Only change along the line-of-sight direction is detected.*





UAVSAR: 13 cm per color wrap

Levee Threats / Levee Status

Radar Remote Sensing Capabilities

Seepage

Cracks

Sand Boils & Sinkholes

Slope Instability

Subsidence

Photo credit: Tom Williams, Gerald Bawden, Cathleen Jones

Levee Health Indicator:
1. Movement

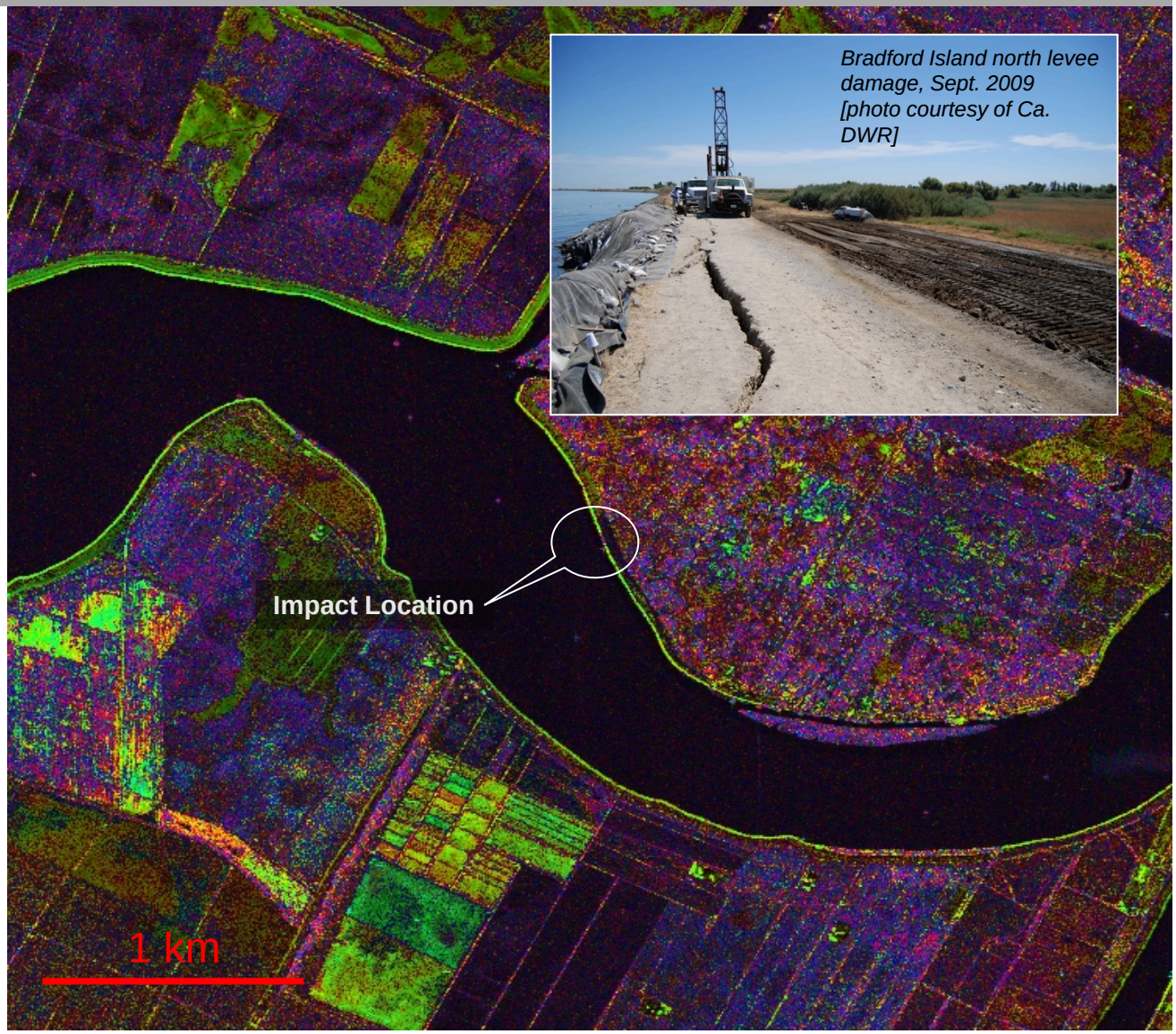

10 km
Bouldin
Bradford
Webb
Sherman
Mandeville
Jersey
Holland
Antioch
Google earth
Imagery Date: 6/9/2014 lat 38.057763° lon -121.633244° elev -5 ft eye alt 17.68 mi

Levee Damage from Impact

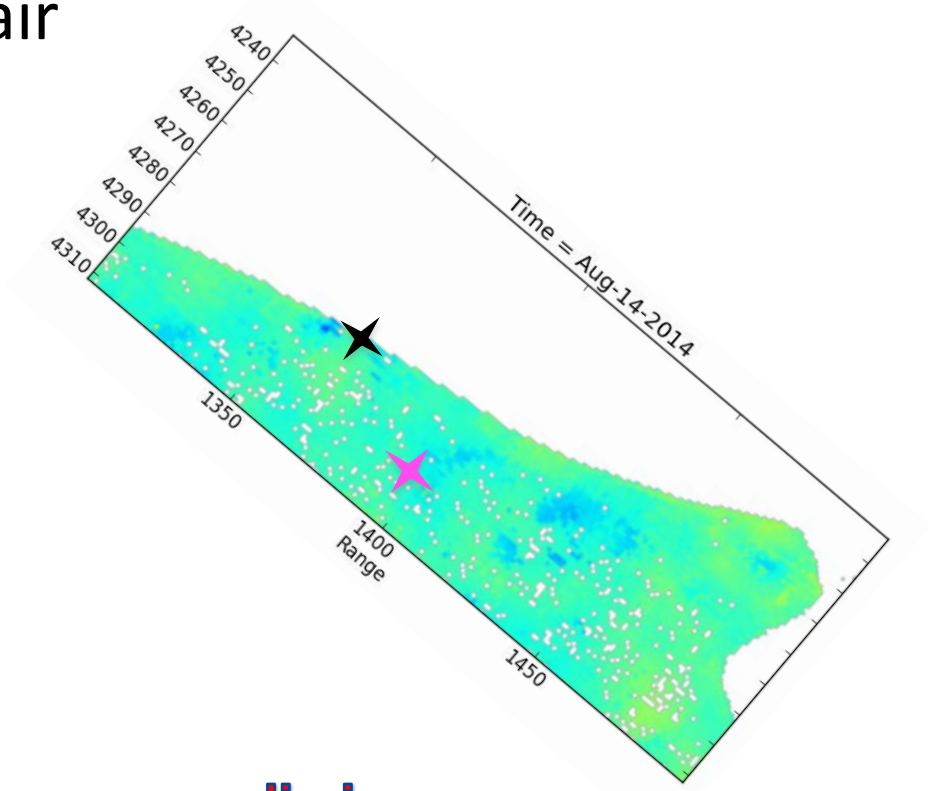
Example: Sacramento Delta, Bradford Island, 2009

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.

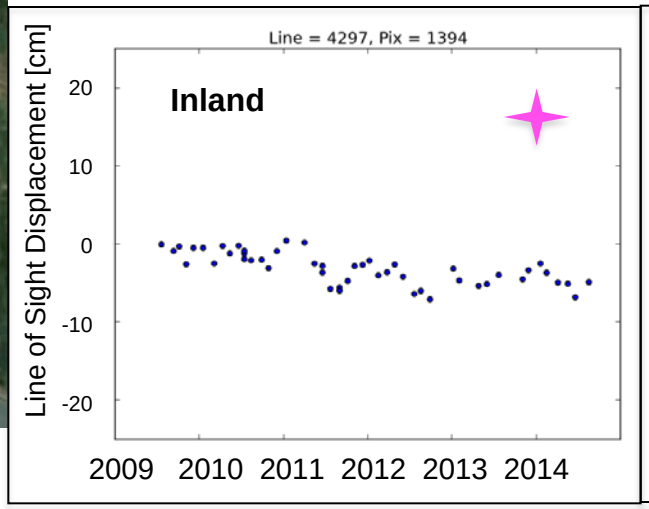
The plot shows a false color map overlaying the differential phase and correlation of the interferograms formed using the two data sets.

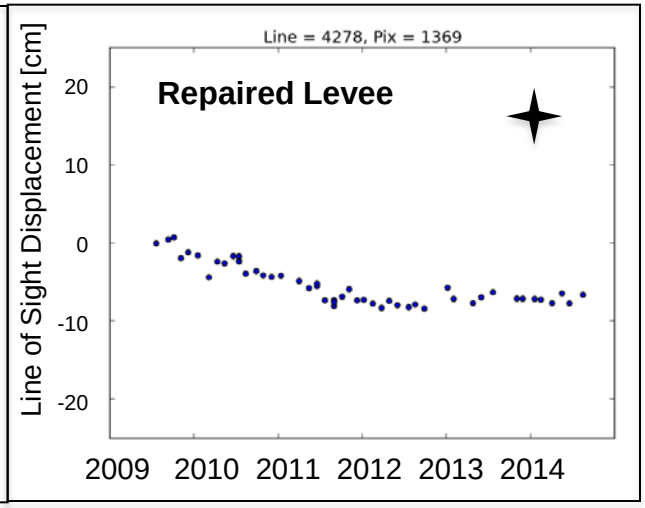


1. Bradford Island – Post Repair

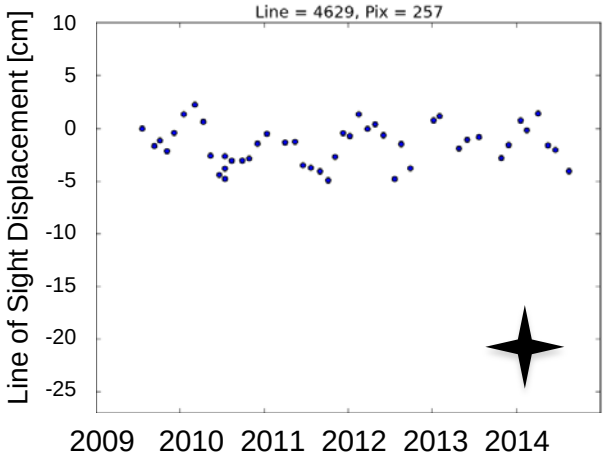


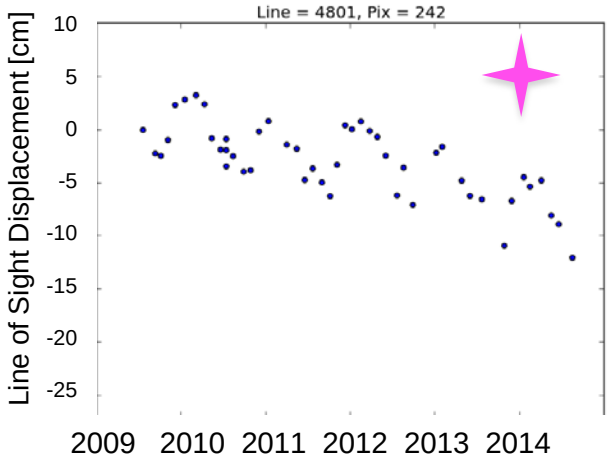
preliminary

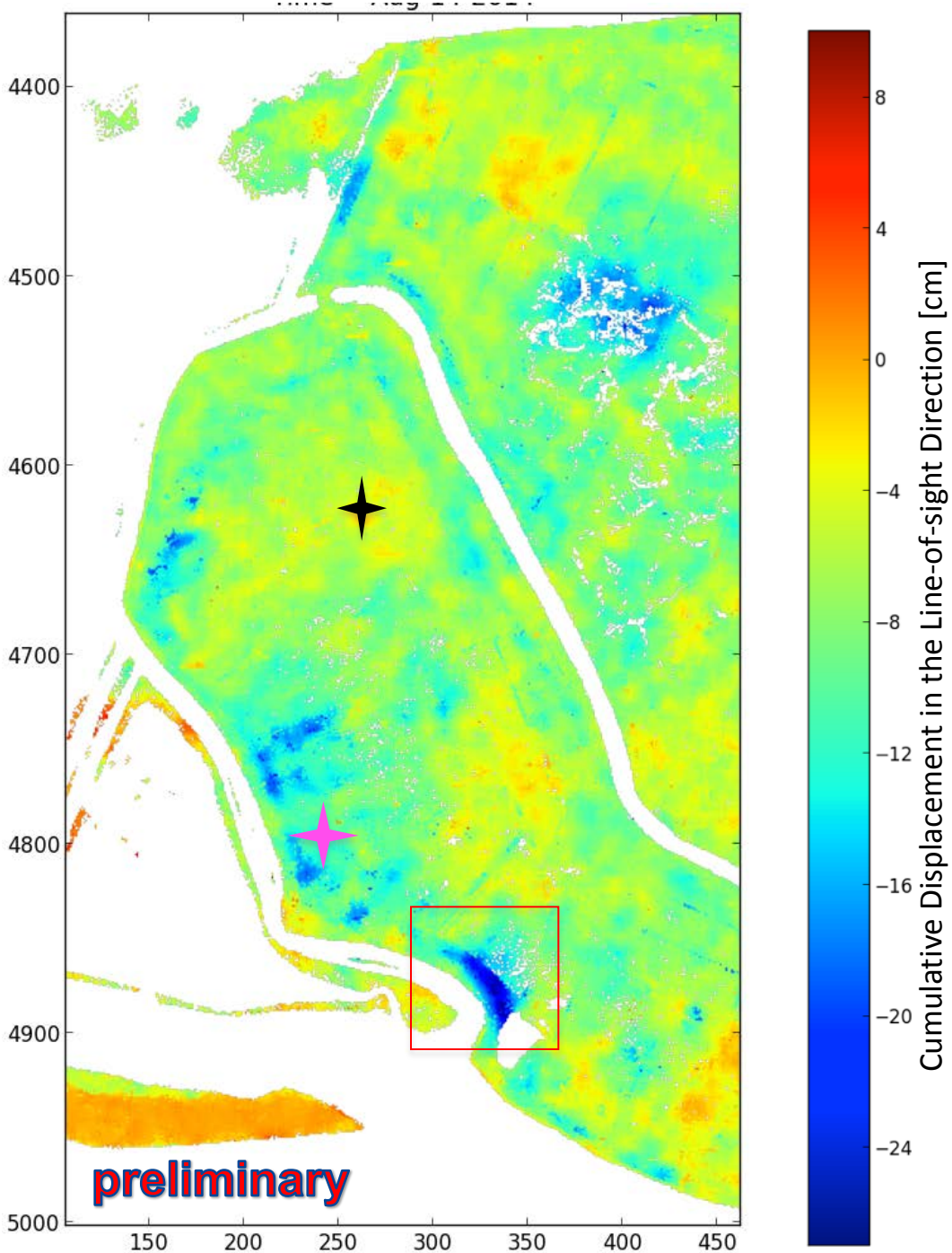




2. West Sherman - Inland

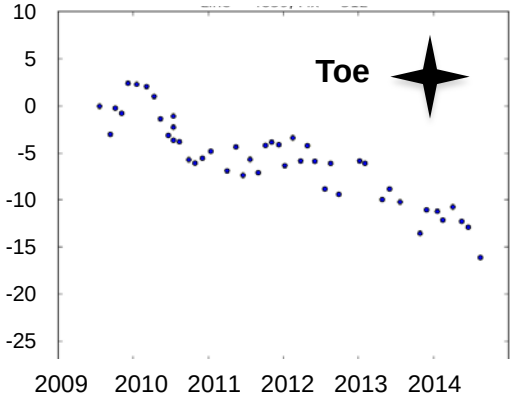


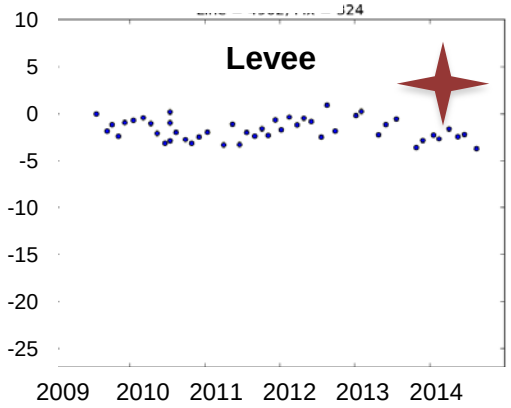


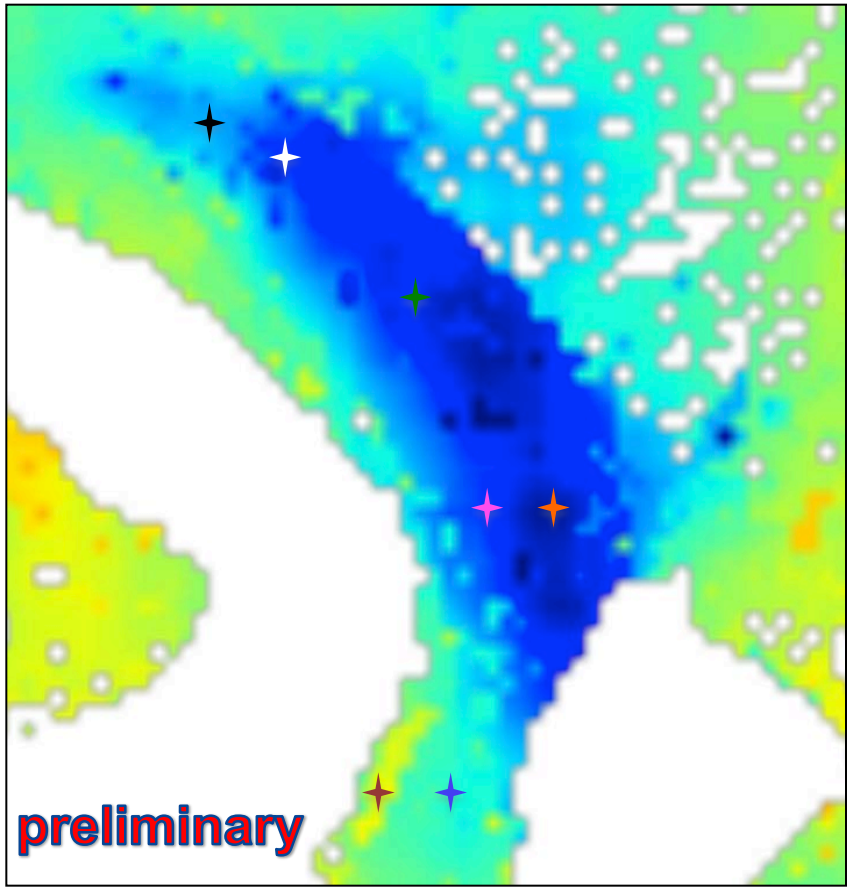


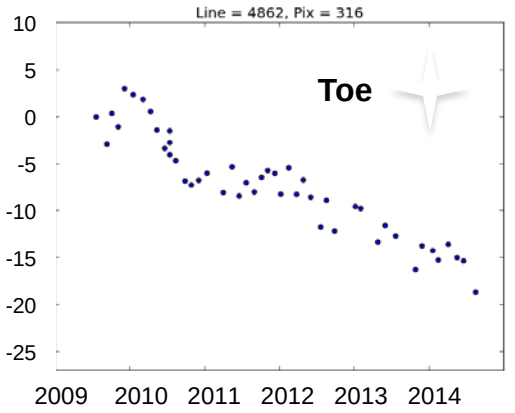
Sherman Setback Levee

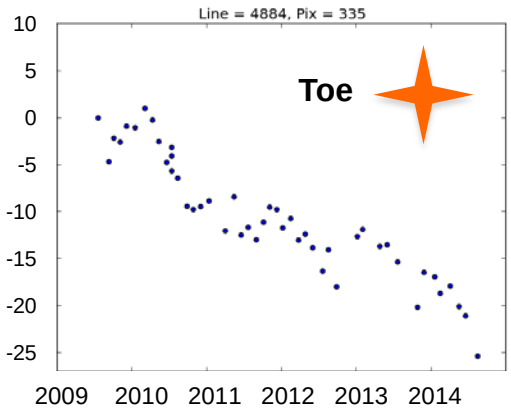
Cumulative Line-of-sight Displacement in cm

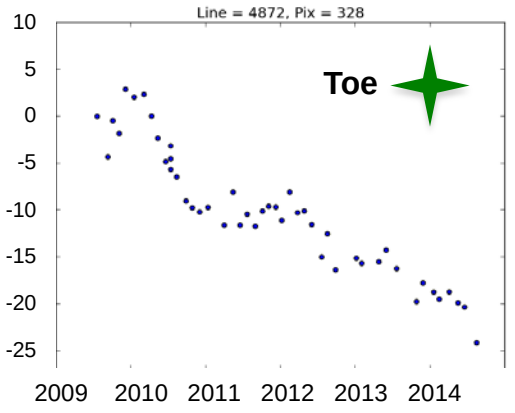


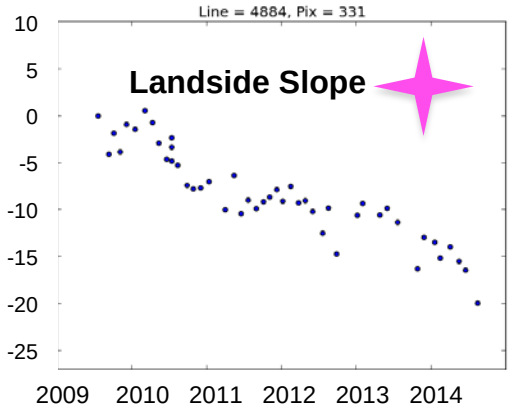


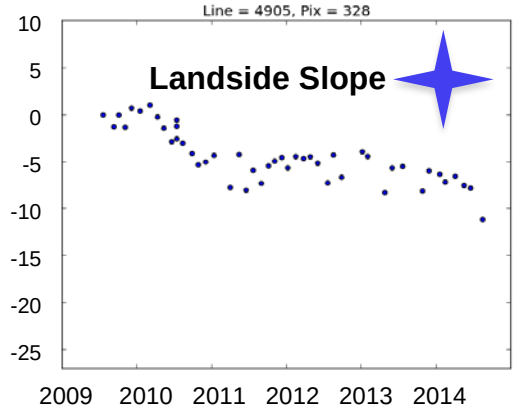




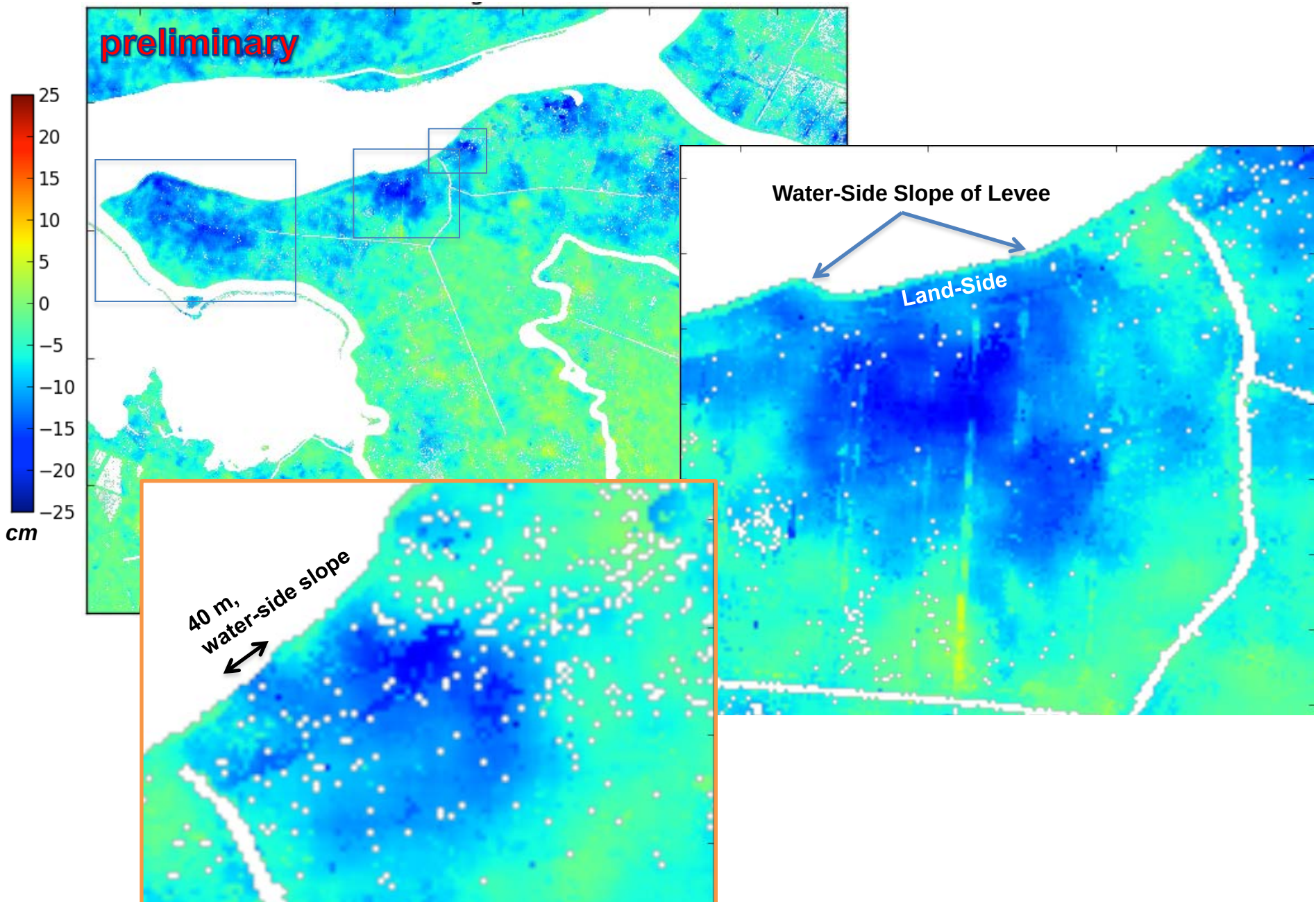




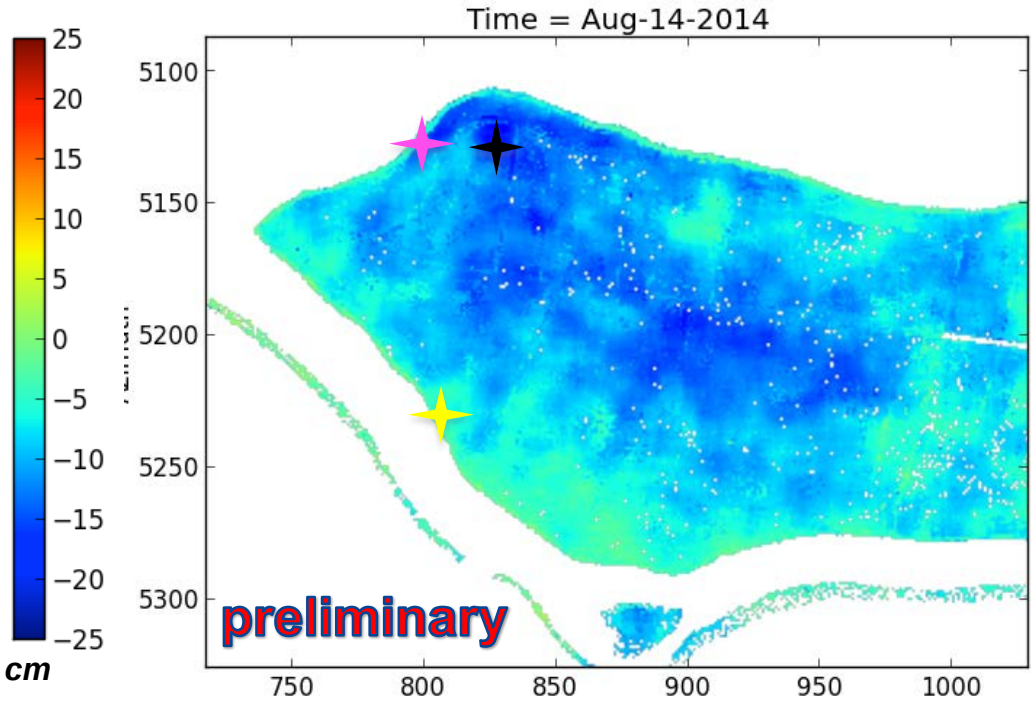


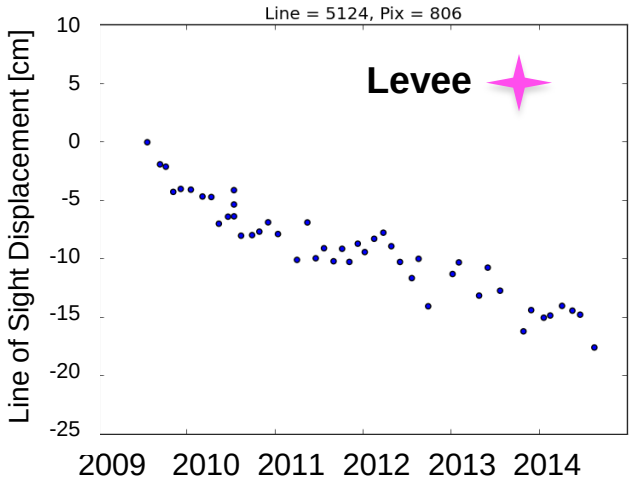


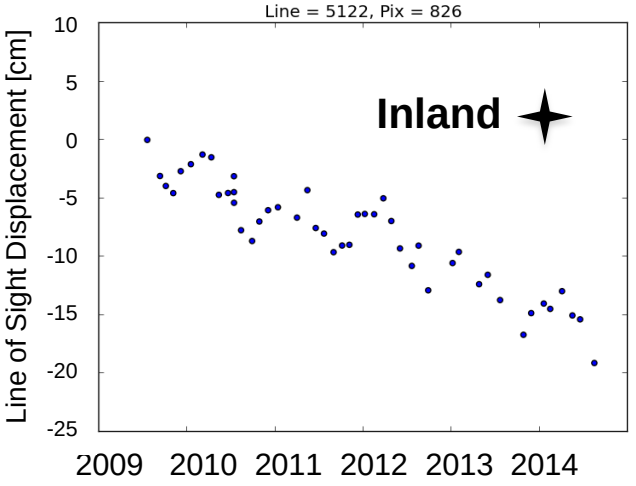
3. Jersey Island

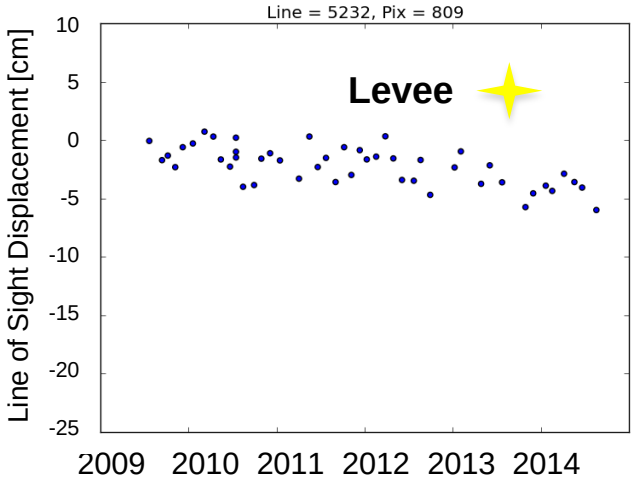


3. Jersey Island, Blind Point Peninsula

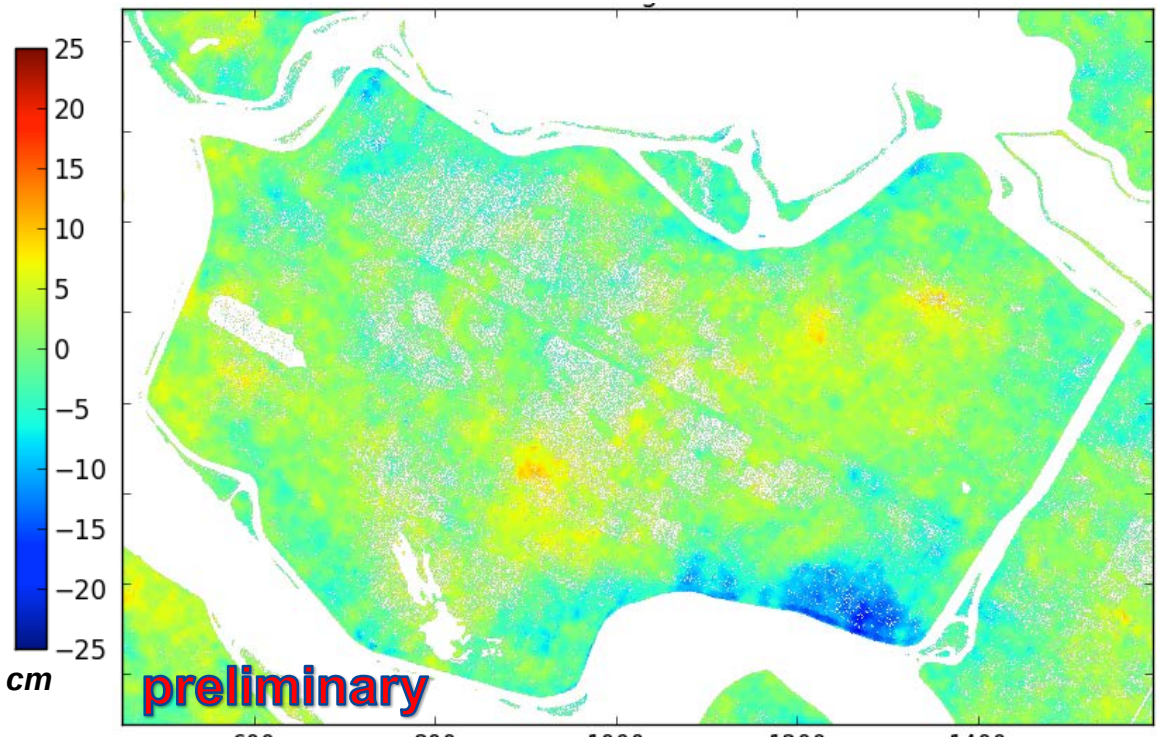


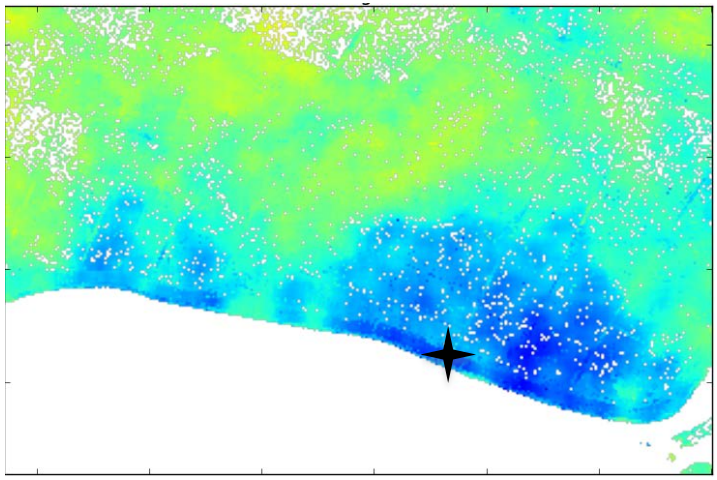


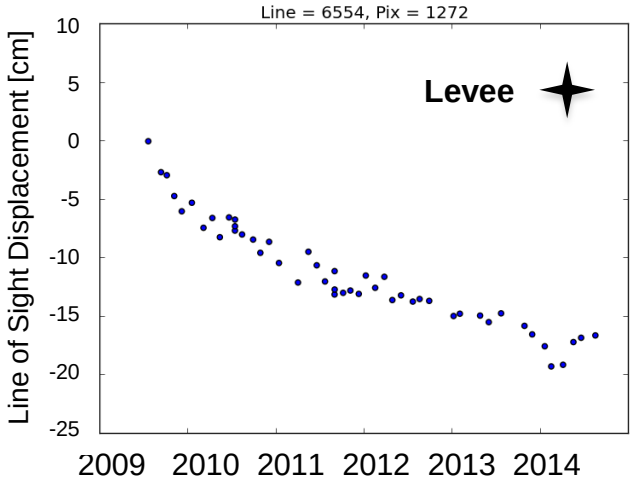




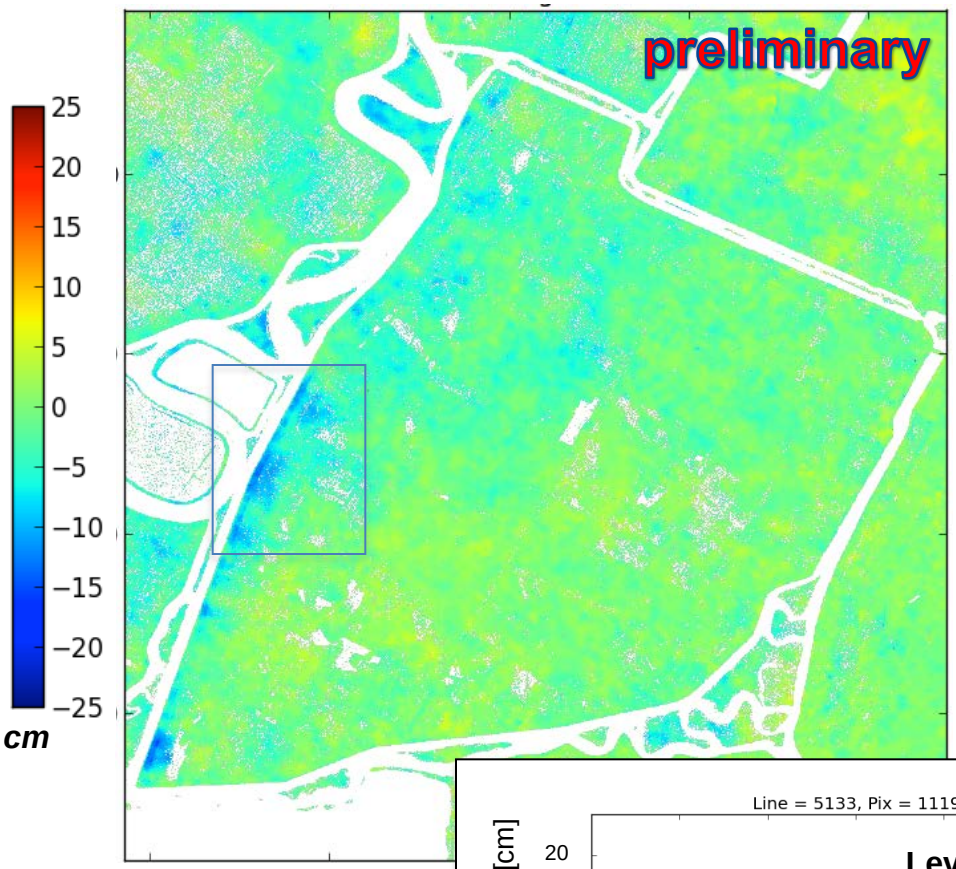
4. Webb Tract

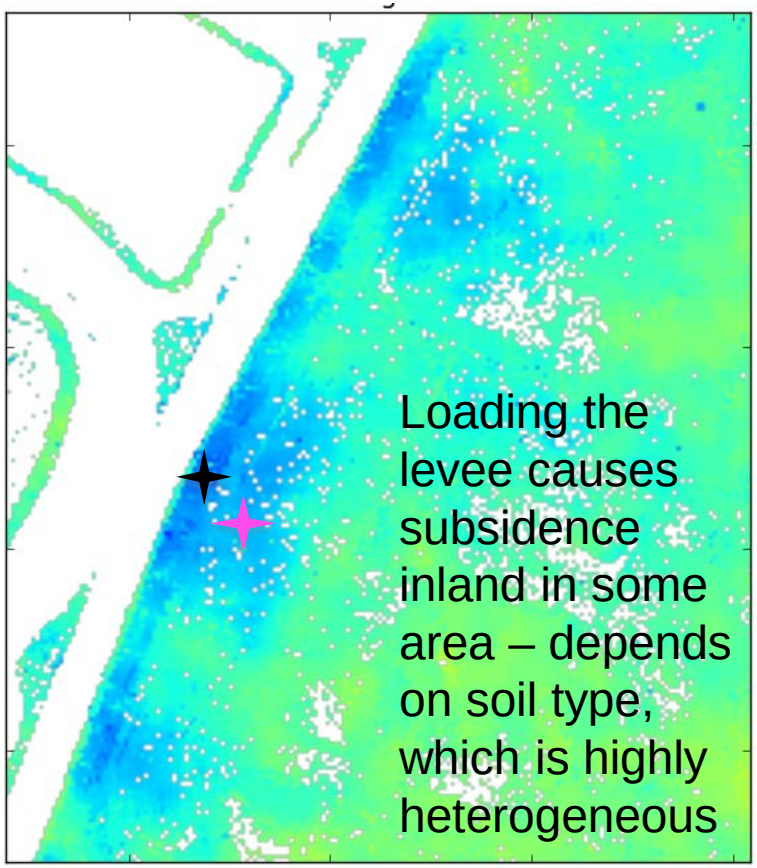

25
20
15
10
5
0
−5
−10
−15
−20
−25
cm
preliminary

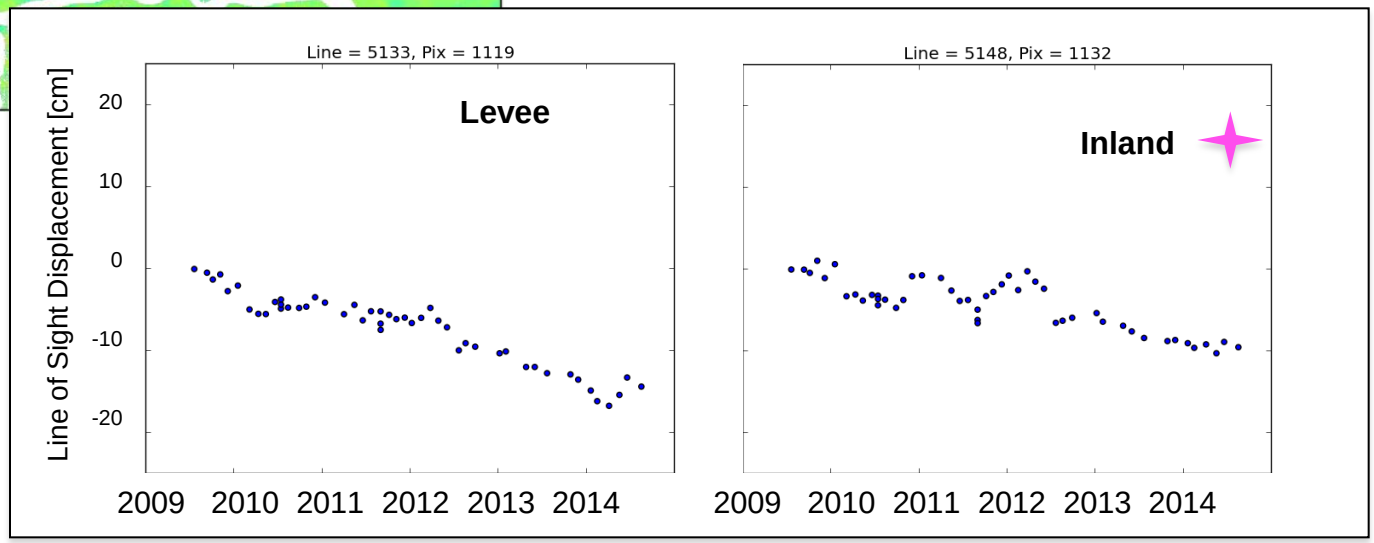



Line = 6554, Pix = 1272
Line of Sight Displacement [cm]
10
5
0
-5
-10
-15
-20
-25
2009
2010
2011
2012
2013
2014
Levee

6. Holland Tract

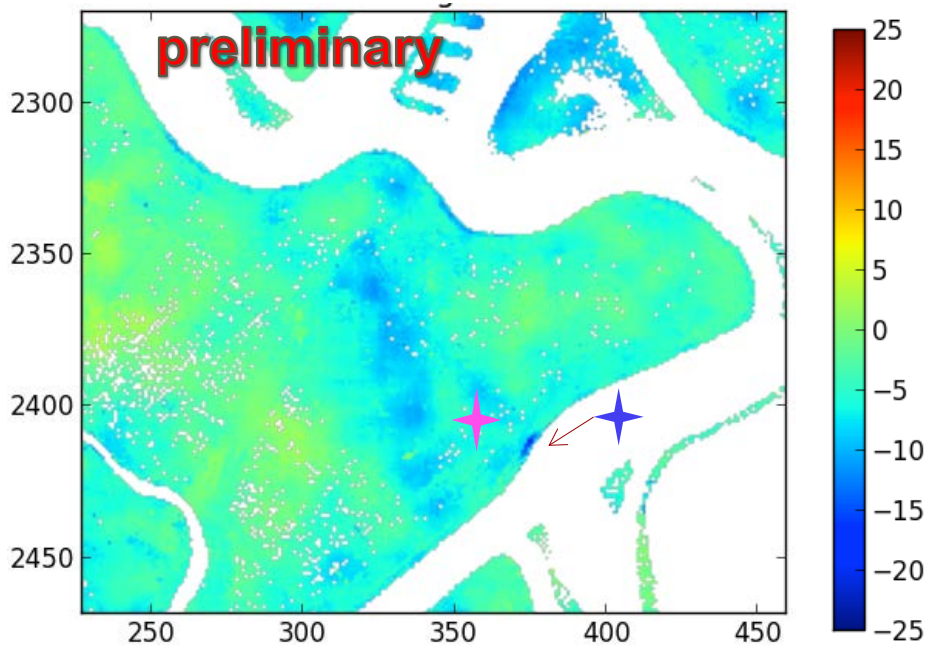


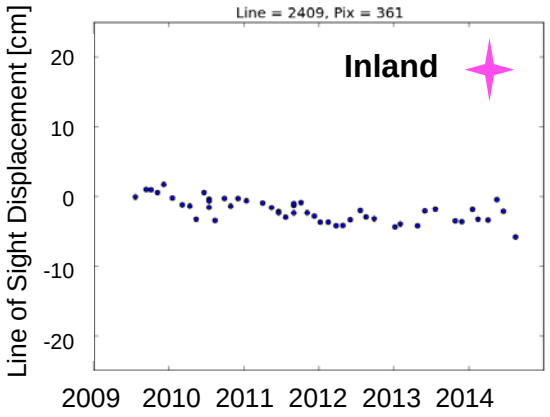


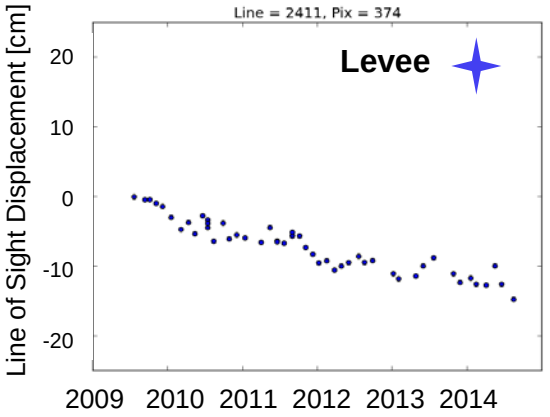


Radar Imaging of Levee Status – Mandeville Island

Anomalous Levee Movement in a Localized Area

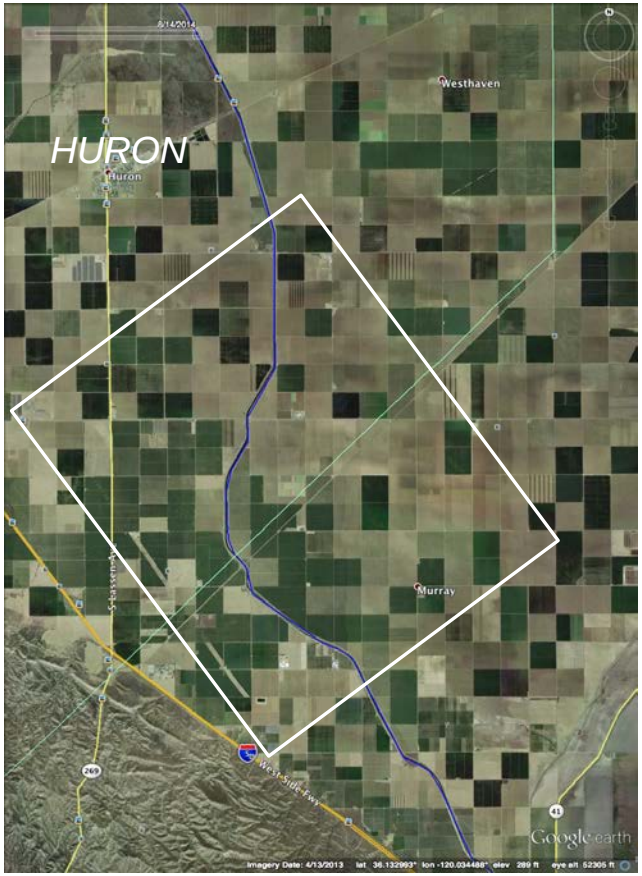


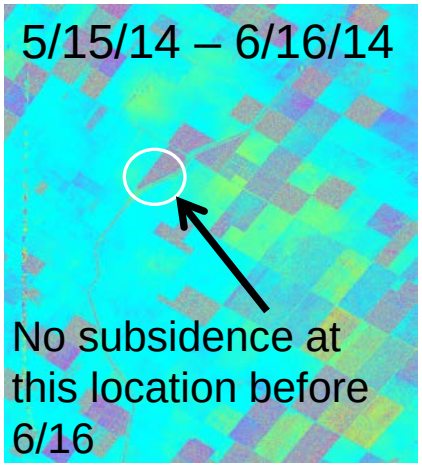


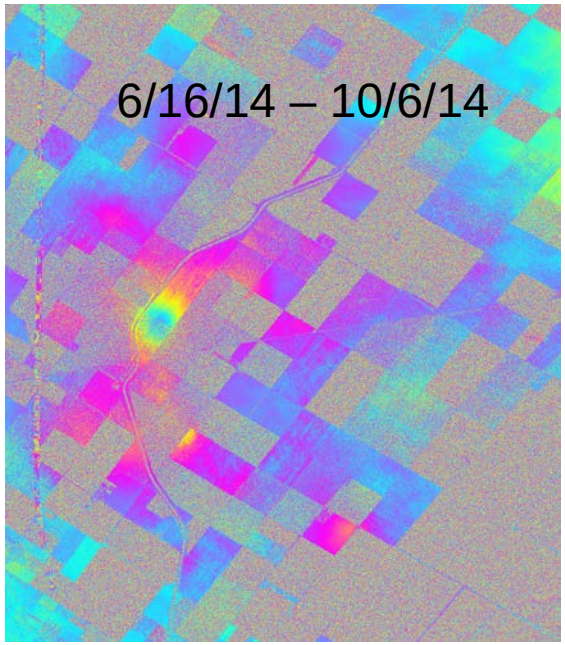


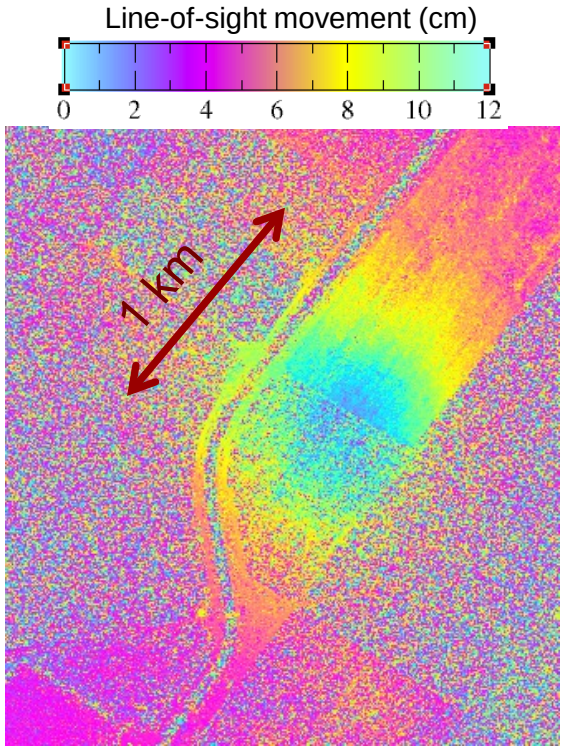
InSAR Applied to Other Critical Infrastructure
Example: California Aqueduct

Between Huron & Kettleman City









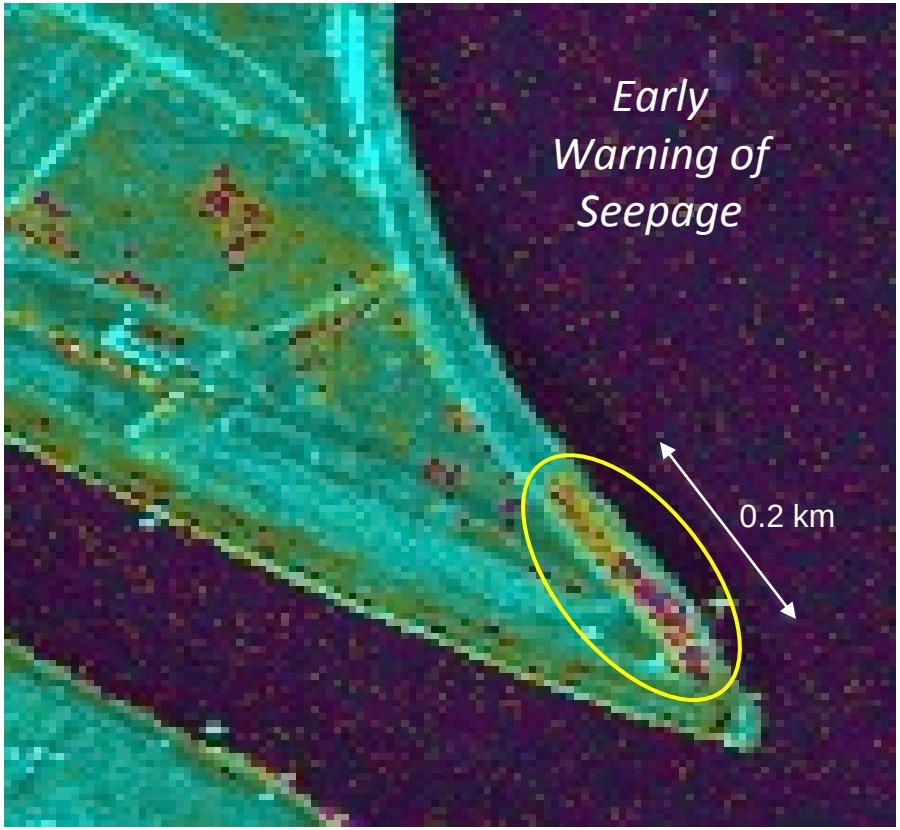
Eastern side of aqueduct subsided 6.5” +/- 1” at its maximum point in the period between 16 June 2014 and 6 Oct 2014 (112 days).

Center of bowl subsided 8” +/- 1” during same time period.

Levee Health Indicator: 2. Seepage

Identification of Seep Locations

Radar Change Detection to Locate Small Seeps

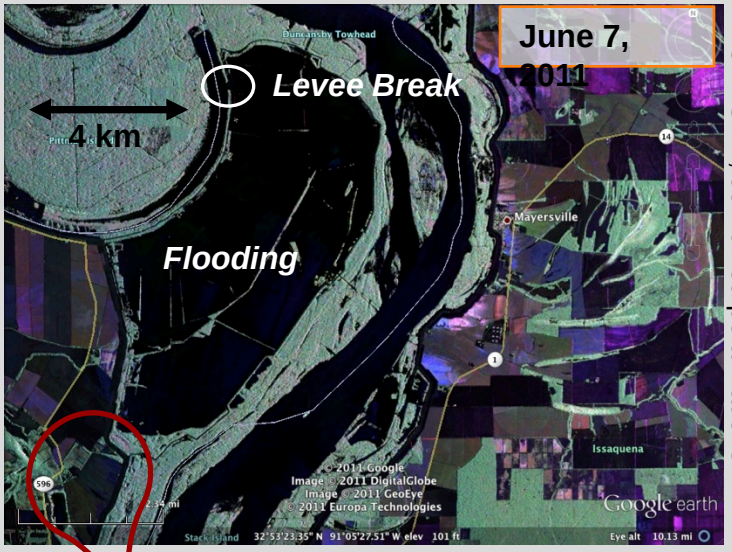


Change detection across a high/low tidal cycle can be used to identify some mid-sized seeps in areas where the soil moisture varies with the water level in the adjacent canals.

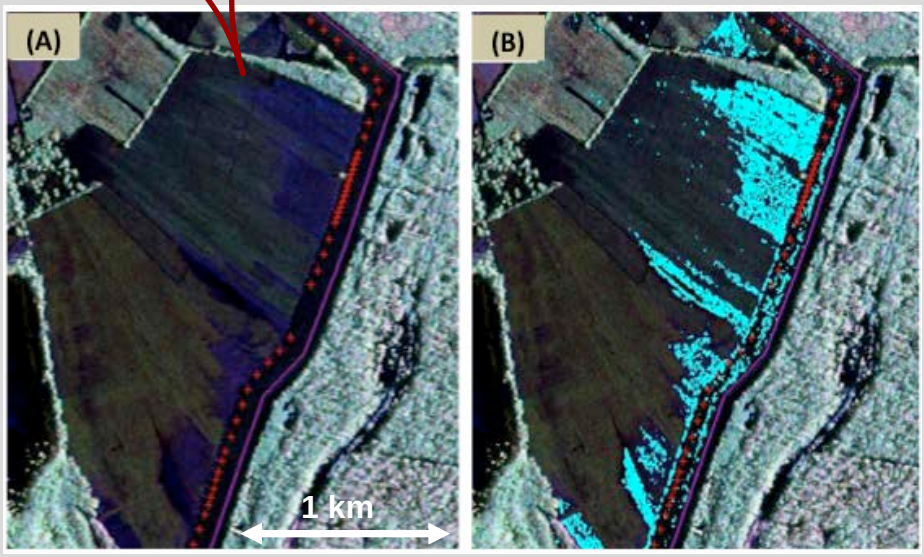
Radar Applied to Flooding and Major Seepage

Example: Mississippi River Flood, Spring 2011

NASA DEVELOP student project : JPL, Fall 2011 – Spring 2012



UAVSAR, combined polarizations



****** SINGLE IMAGE*** (POLSAR)***

The radar data indicates not only large area flooding but also where there is seepage through relief wells along the levee in this area.

We used the polarization-dependence of the radar return to enhance detection of leaking sections of levees and to automatically classify high-likelihood seepage areas.

Remote Sensing for Flood Response
Sacramento & Central Valley Levees

Preparedness & Response:

- **In Advance:**
  - **Determine where InSAR will work (line-of-sight, trees, etc.).**
  - **Acquire baseline images for critical or known risk areas.**
  - **Develop and integrate products under test scenarios.**
- **During an event:**
  - **Single image (POLSAR) can be used to find seepage in areas with high soil water content or with standing water.**
  - **InSAR can show movement, areas of major disruption.**

Radar Remote Sensing: A Game-Changing Levee Monitoring Tool

- **High resolution L-band InSAR can definitely be used to identify seepage, movement & change on earthen levees.**
- **In the Sacramento Delta, we achieve high accuracy in subsidence rate measurement by using long time series of frequent acquisitions to differentiate normal seasonal variability from long term trends.**
- **A simple assessment can identify areas where InSAR is likely to work, saving money and time.**
- **In a flood emergency, single pass, multi-polarization radar images can be used to identify seepage.**

Twitchell Island, California