Levee Monitoring with Radar Remote Sensing

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Outline of Presentation

1. **Overview of radar remote sensing**
2. **Surface change detection with Differential Interferometric Radar Processing**
3. **Study of the Sacramento - San Joaquin levees**
4. **Mississippi River Levees during the Spring 2011 floods**

FEMA, the USACE, and numerous state and local entities currently monitors thousands of dams and thousands of miles of levees throughout the United States.

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

- **providing *consistent monitoring* across all sites**
- **enabling *rapid data collection* over large areas to give a snapshot of conditions at many sites at the same time**
- ***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**
- **imaging areas that are *difficult* to *access* on the ground**

Atchison County, Missouri (6/6/2011)

Radar Remote Sensing
Overview

Radar remote sensing is used to support a wide range of science investigations including geology, vegetation mapping and biomass measurement, archeological research, soil moisture mapping, and cold land processes. It is also used to support applications such as monitoring aquifer discharge/refill, land subsidence, landslides and debris flows, land use classification, and, more recently, emergency response for a wide variety of natural or technological disasters.

Radar can…

1) See through clouds, smoke, haze.
2) Image the surface of the Earth day or night in any light conditions.
3) Tell where there is standing water.
4) Determine the type of surface based upon physical and electrical characteristics.
5) Determine whether the surface changed properties (i.e., seep developed, equipment was moved, water level dropped)
6) Detect changes in hard targets that don't move a lot.
7) Detect very small scale (few millimeters) change in the position of hard targets.

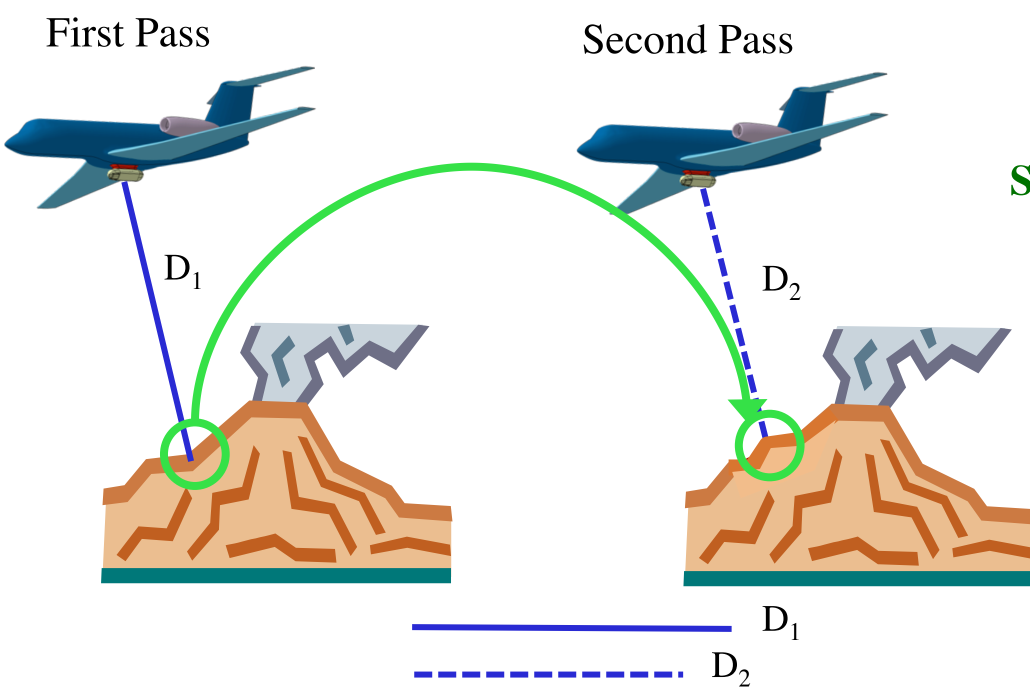
Radar cannot…

1) Take a photograph.
2) Identify a specific object and find it elsewhere in the scene if it is moved a long distance.
3) See below the surface by more than a few centimeters and then only when the surface is dry.
4) Reliably detect and quantify ground-level change of objects below large trees, for all currently operational satellite-based radars.
5) Do chemistry – radar can differentiate objects based upon physical properties (i.e., upright, dielectric properties) but not chemical properties (chlorophyll content, i.e., poison ivy vs. raspberry bush).

Radar Repeat Track Interferometry

Measurement of Surface Deformation

"Differential Interferometry," aka DInSAR or Repeat Track Interferometry, is a special implementation for change detection, where two images of the same location made at different times are coherently compared to detect small-scale changes. *Only the relative change is detected with DInSAR, not the surface height. Only change along the line-of-sight is detected.*



Surface deformation causes the distance to the feature on the ground to change, which is measurable as a change in phase of the radar return.

$$\Delta\phi = \frac{4\pi}{\lambda}\left(D_2 - D_1\right)$$

$\lambda =$ wavelength of radar

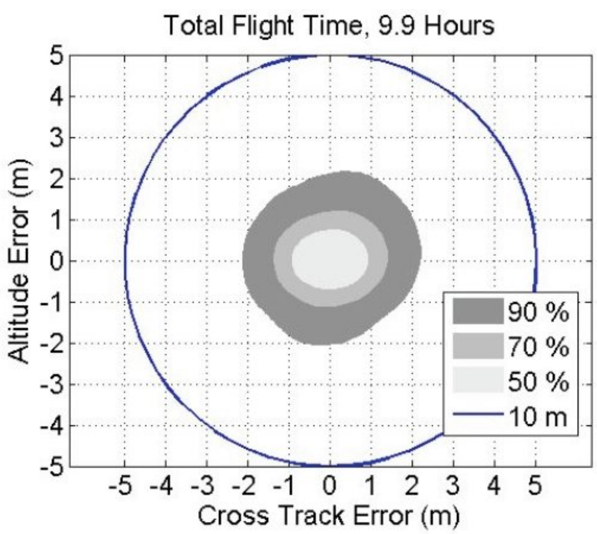
EXAMPLE: Using SAR to measure a volcano's surface deformation : The radar measures the distance D_1 to a point on the volcano on the first pass and the distance D_2 on a second pass taken after the volcano has undergone some deformation of the surface. The difference can be measured to ~5 millimeter level at L-band (1.26 GHz).

UAVSAR (Uninhabited Aerial Vehicle Synthetic Aperture Radar)

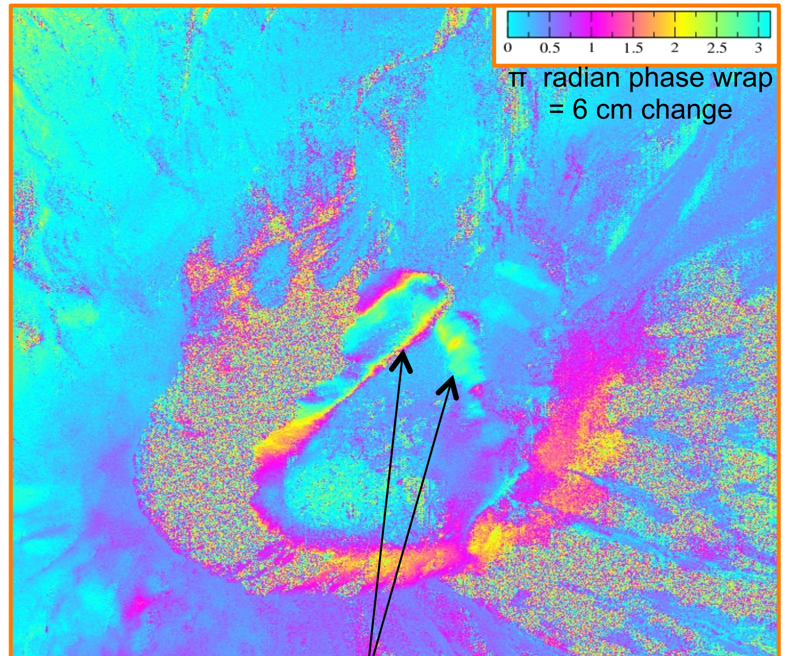
NASA's Airborne Radar for Repeat Track Differential Interferometry

The UAVSAR L-band (23.8 cm wavelength) radar is housed in a pod flown on the NASA G-3 platform, shown here in flight over Edwards Air Force Base, California.

The Precision Autopilot System was designed and developed at Dryden Flight Research Center to provide < 5 meter repeat track capability.



CALDERA OF MOUNT SAINT HELENS

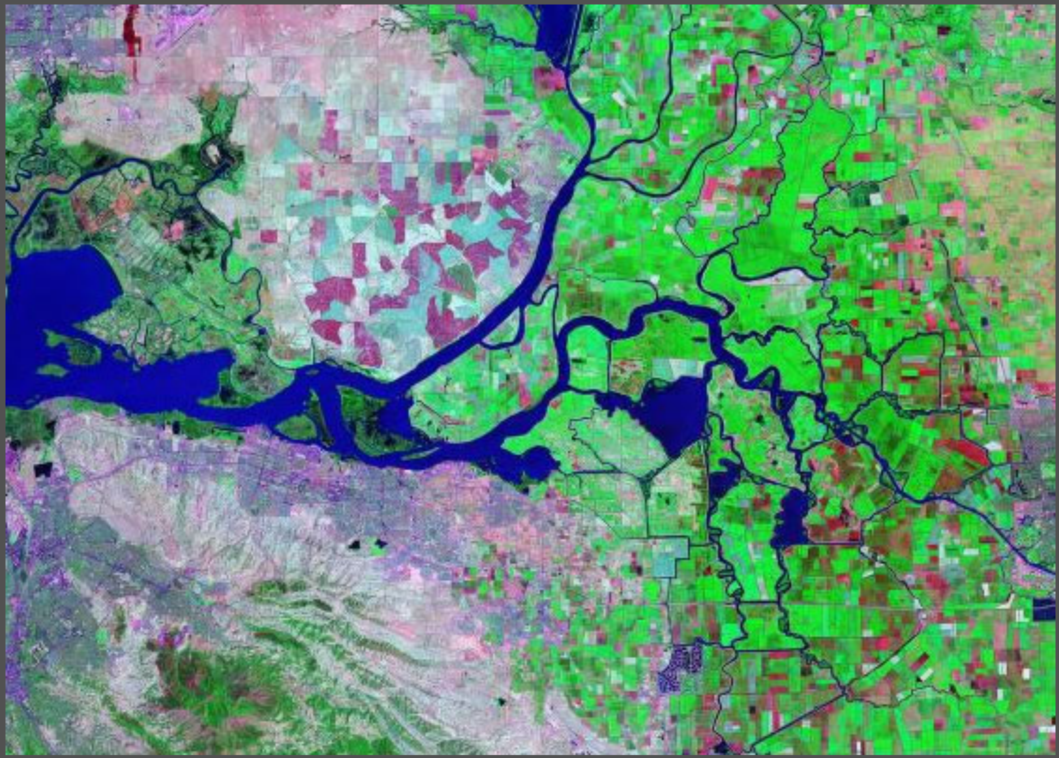


We can readily detect motion of the glaciers within the Mt. St. Helens caldera even with only a 4 hour repeat time.

$$\dot{\rho} = \frac{\lambda\phi}{4\pi\Delta t} = \frac{0.24}{4 \cdot 0.174} = 0.344\frac{m}{day}$$

The Sacramento-San Joaquin Delta

Critical Infrastructure: The Levees



- Over 60 reclaimed islands surrounded by 1100 miles of levees
- Most islands lie below mean sea level.
- Collects run-off from approximately 2/3 of the state via the Sacramento and San Joaquin rivers.
- Supplies water to ~2/3 of the residents of California and to almost all of the agriculture of the Central Valley.

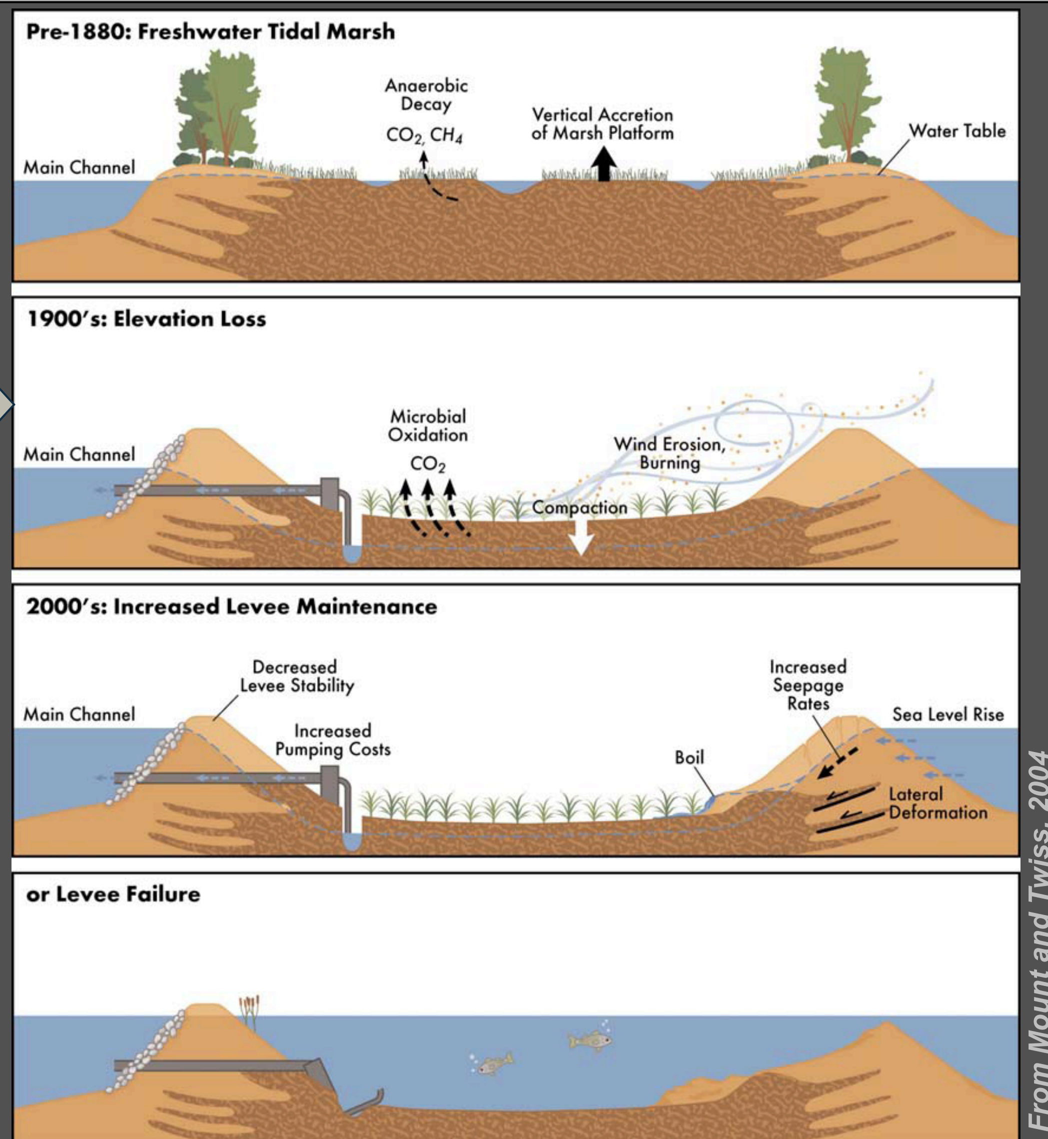
THE DELTA IS THE MOST CRITICAL WATER RESOURCE IN CALIFORNIA.

The Delta at Risk
Subsidence Mechanisms

Levees are at risk from constant hydrostatic pressure because of subsidence.

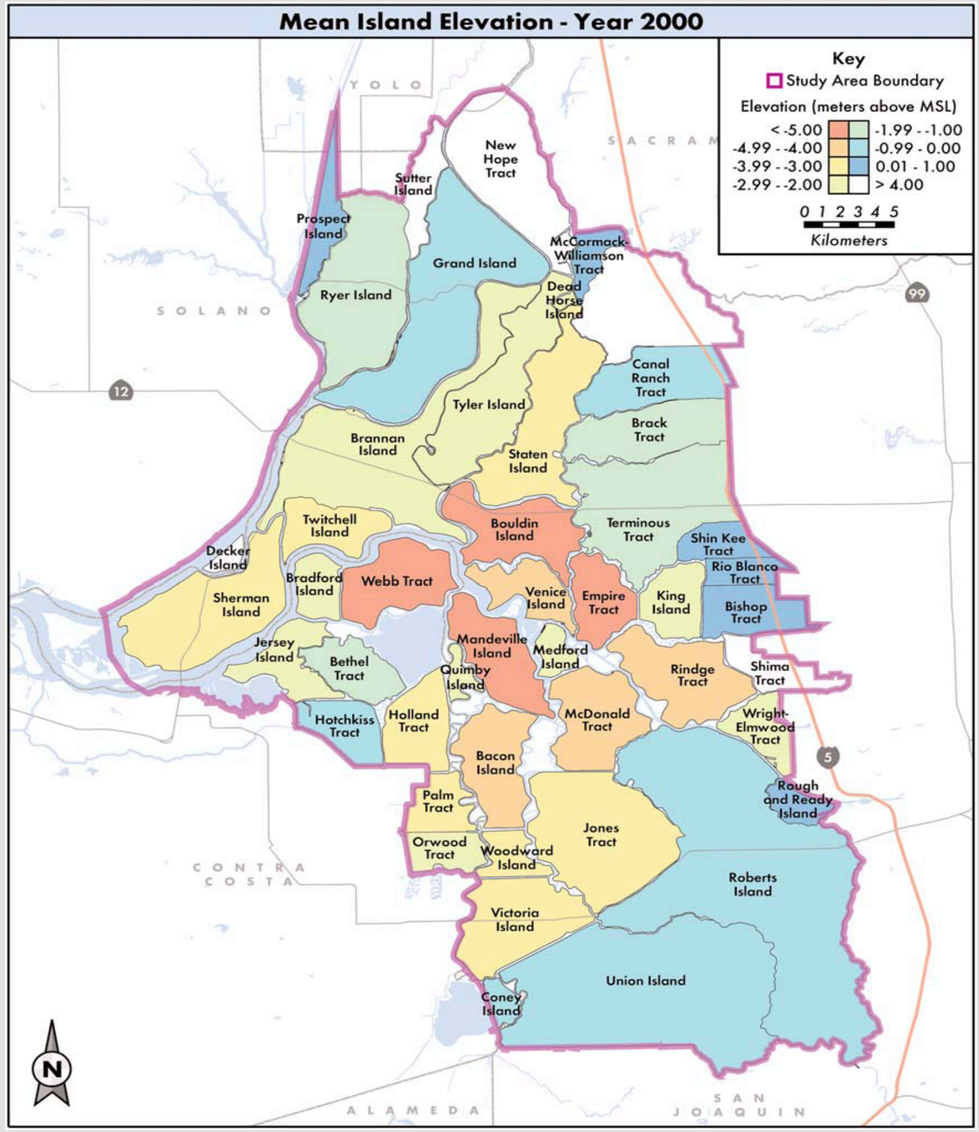
Conceptual diagram illustrating evolution of Delta islands due to levee construction and island subsidence.

Subsidence rates and the dominant subsidence mechanism varies from island to island with the soil type. In high peat soils, the dominant subsidence mechanism is aerobic microbial oxidation, which releases CO_2 as a by-product.



The Islands of the Sacramento – San Joaquin Delta
Land Elevation

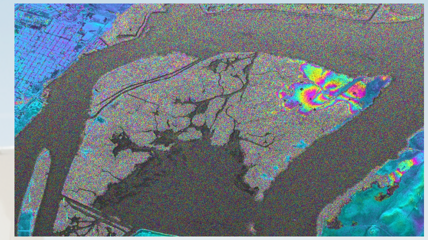
Twitchell Island, California



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.

Radar Remote Sensing of the Sacramento Delta Levees
A NASA Applied Science Project

Monitoring Levees and Subsidence in the Sacramento-San Joaquin Delta

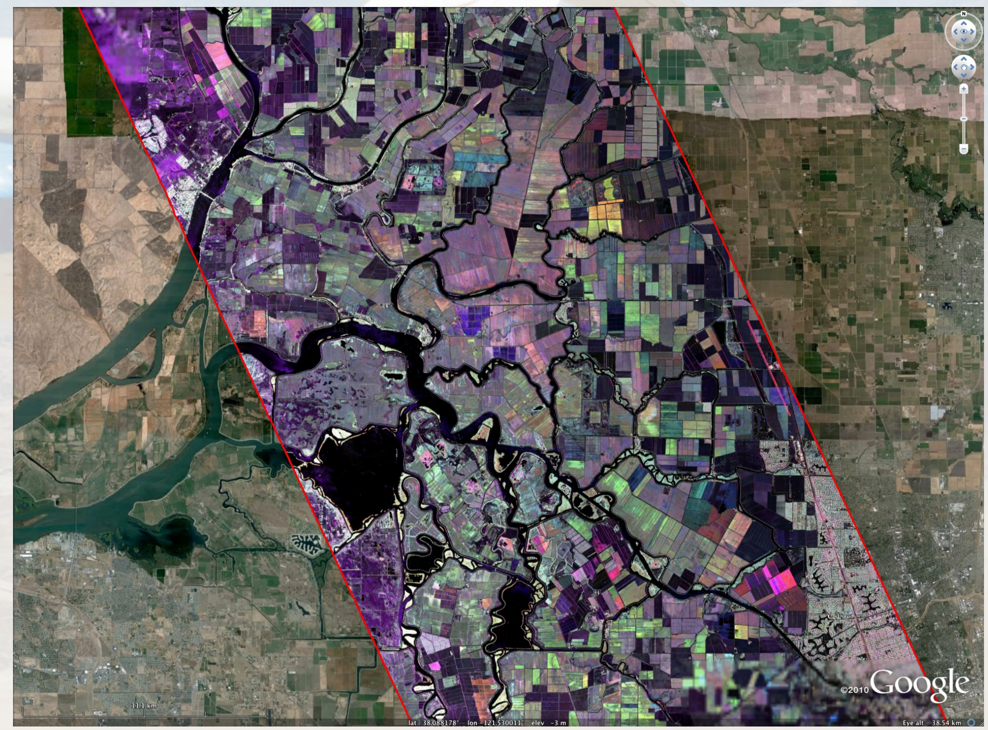


Jet Propulsion Laboratory *(Cathleen Jones, Sang-Ho Yun, Scott Hensley)*
Ca. Department of Water Resources, Delta - Suisun Marsh Office *(Joel Dudas)*
USGS, California Water Science Center *(Gerald Bawden)*
Hydrofocus, Inc. *(Steven Deverel)*

Objectives:
Provide an *independent and verifiable* source of information with the *spatial extent* needed to cover the 1100 miles of levees within the Sacramento Delta, with sufficient *ground resolution* and *temporal frequency* to detect changes indicative of potential levee failure.

Method:
The levees are monitored monthly for changes using normal DifInSAR. We will use Persistent Scatterer InSAR (PSInSAR) techniques to measure subsidence from the monthly UAVSAR data.

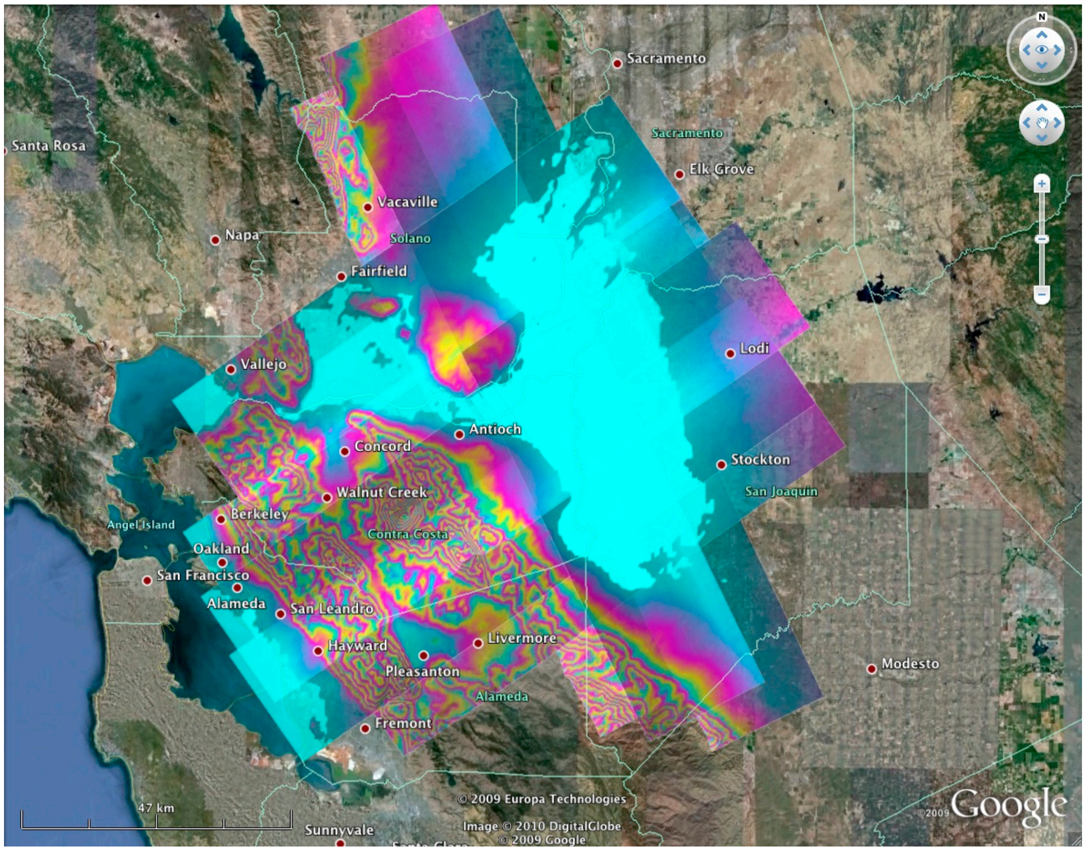
9 UAVSAR flight lines are collected ~ monthly to image all locations in the Sacramento Delta from 3-4 different look directions.

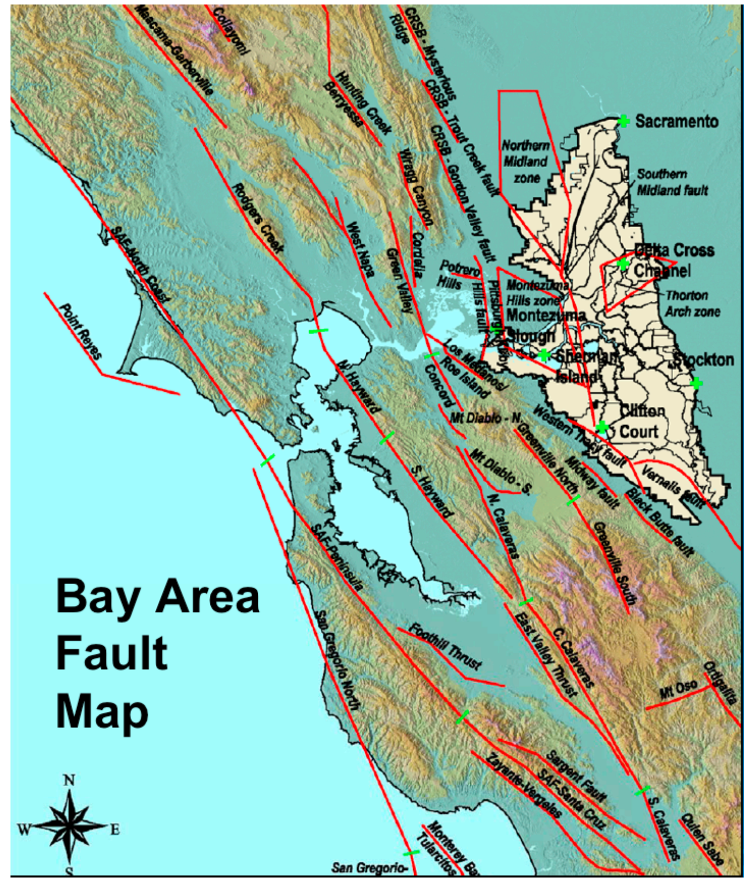


Radar Remote Sensing of the Sacramento Delta Levees

UAVSAR Flight Lines, Image Swaths, and Nearby Fault Lines

UAVSAR flights image the entire delta from 3 different directions 10-12 times per year to detect changes in the levees and measure subsidence rates.





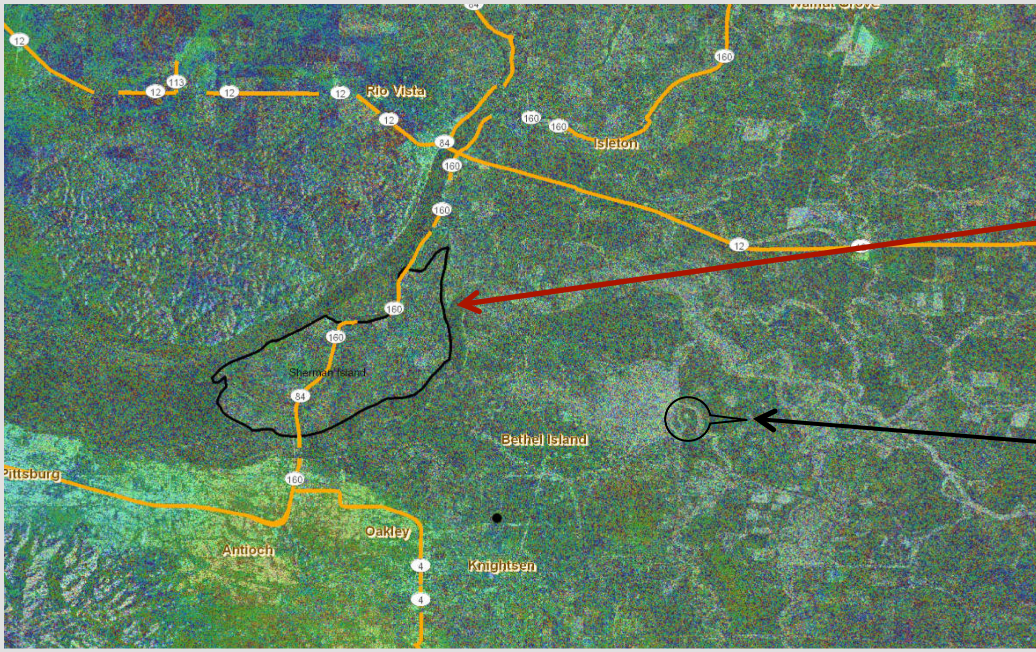
We have completed 32 flights since July 2009.

Radar Remote Sensing of the Sacramento Delta Levees

Radar Image of Delta Islands

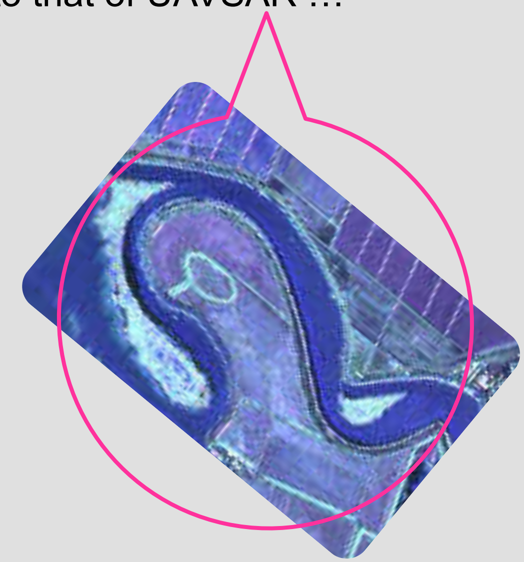
Radar Remote Sensing of the Sacramento Delta Levees

Comparison between Satellite and Airborne Image Resolution



Satellite image of the delta – resolving the levees is not feasible.

… compare feature resolution to that of UAVSAR …



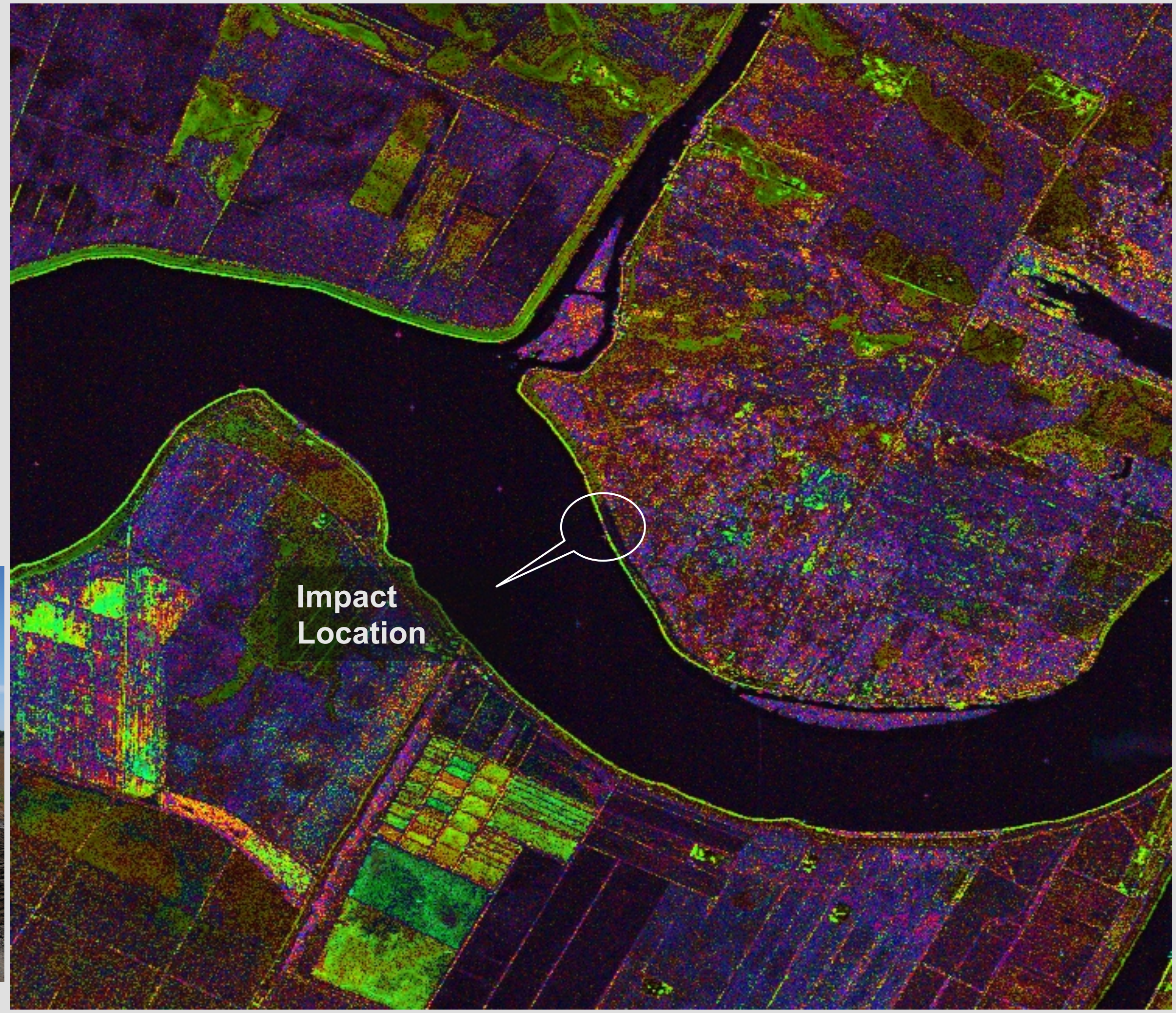
=> Levee monitoring requires fine spatial resolution, which is becoming available with more advanced radar instruments.

Radar Remote Sensing of the Sacramento Delta Levees

Damaged Levee Detection and Monitoring

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.

We have monitored this site monthly since the repair to look for shifts and settling.

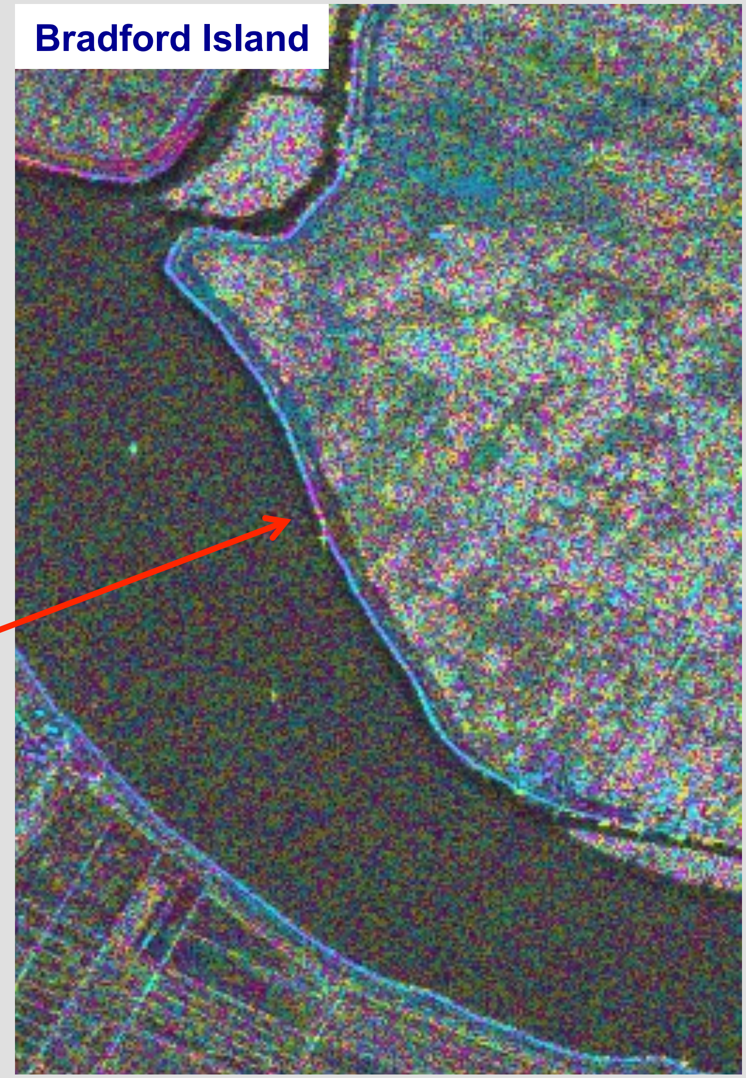


Radar Remote Sensing of the Sacramento Delta Levees

Post-repair settling along levee crown

The DInSAR change map formed from images collected in July 2009 and a year later in July 2010, show that the post-repair settling extended all along the length of the repair site.

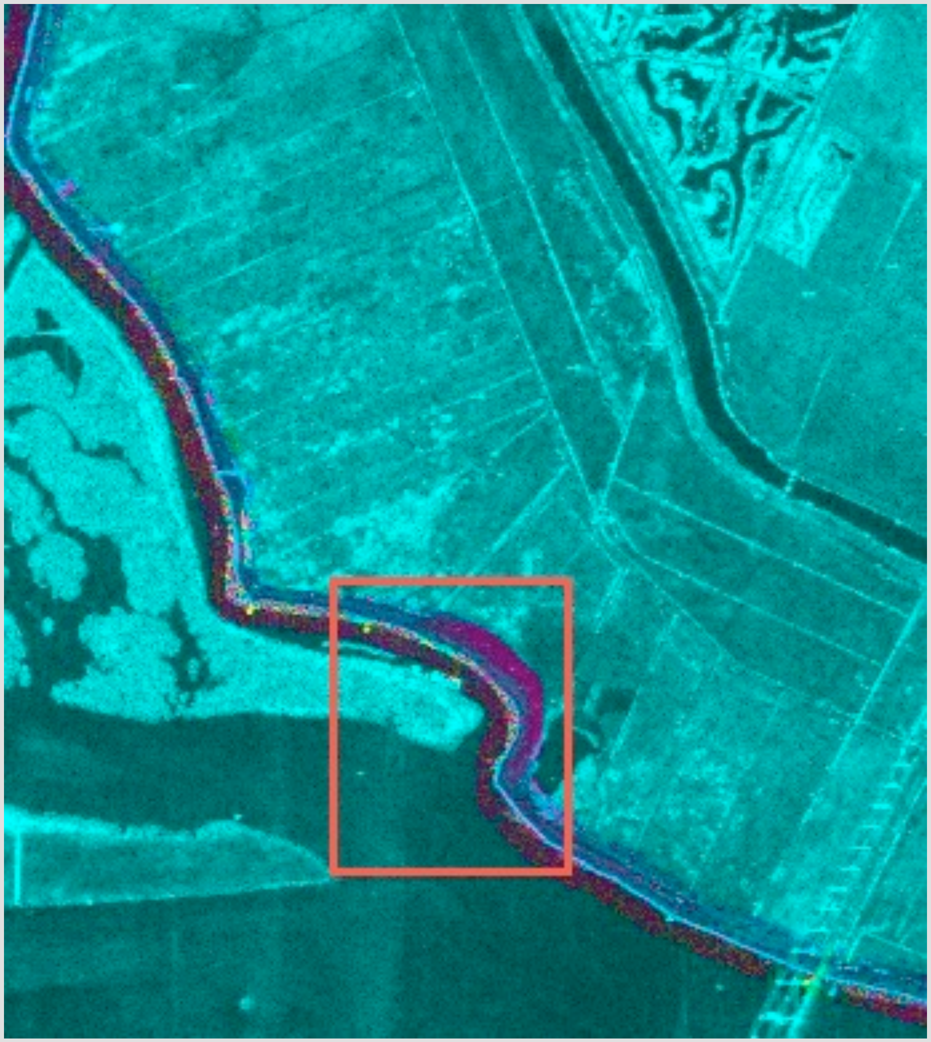
Change along repaired section of the levee

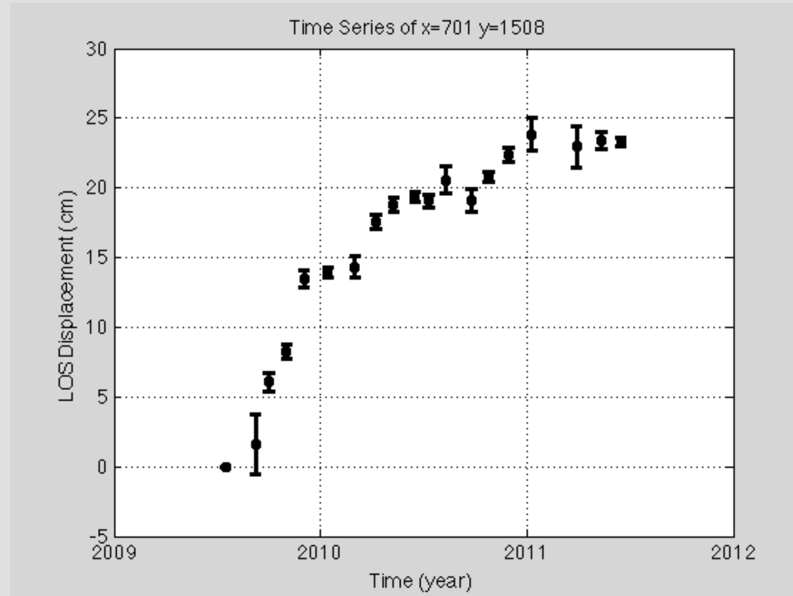


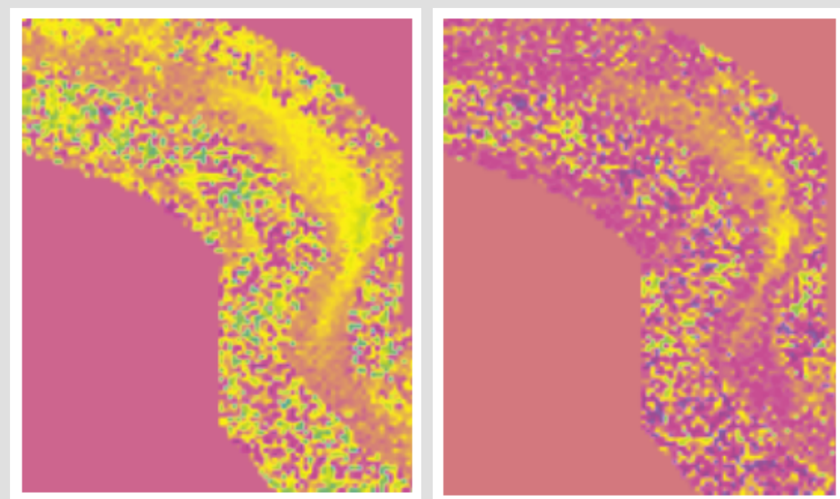
1 year temporal baseline 7/2009 - 7/2010

Radar Remote Sensing of the Sacramento Delta Levees

Subsidence along toe behind repaired levees



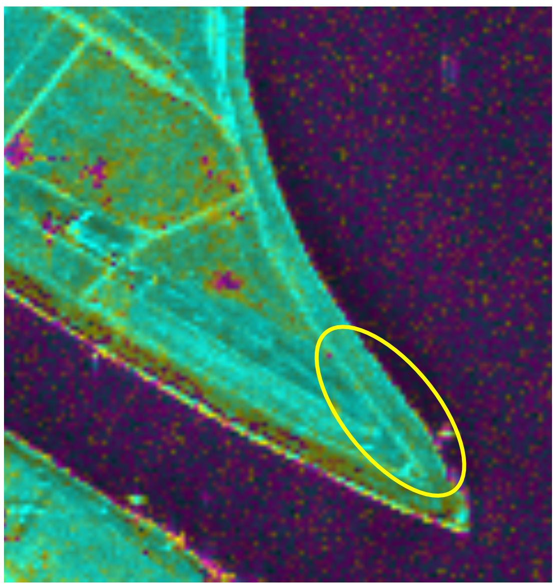




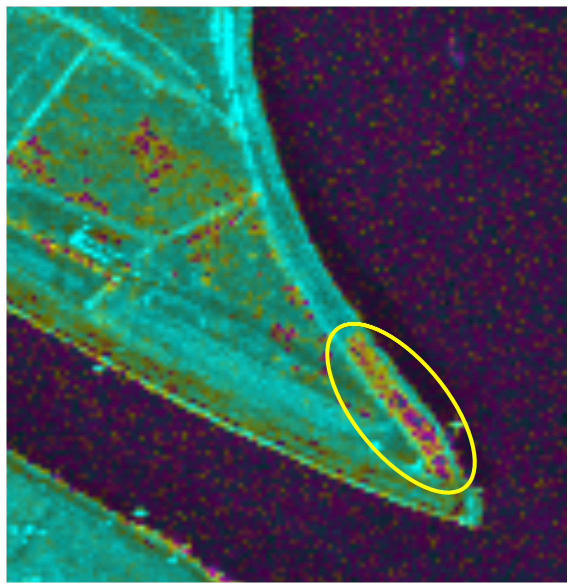
Levee Seep Detection

A seep through a levee on Twitchell Island developed between July 2010 and June 2011. This is detected in the repeat pass images collected at high and low tide with the UAVSAR L-band radar. There was no change observed along the levee during the high/low tidal cycle in 2010, but a large change was seen in the same location the following year.

July 2010

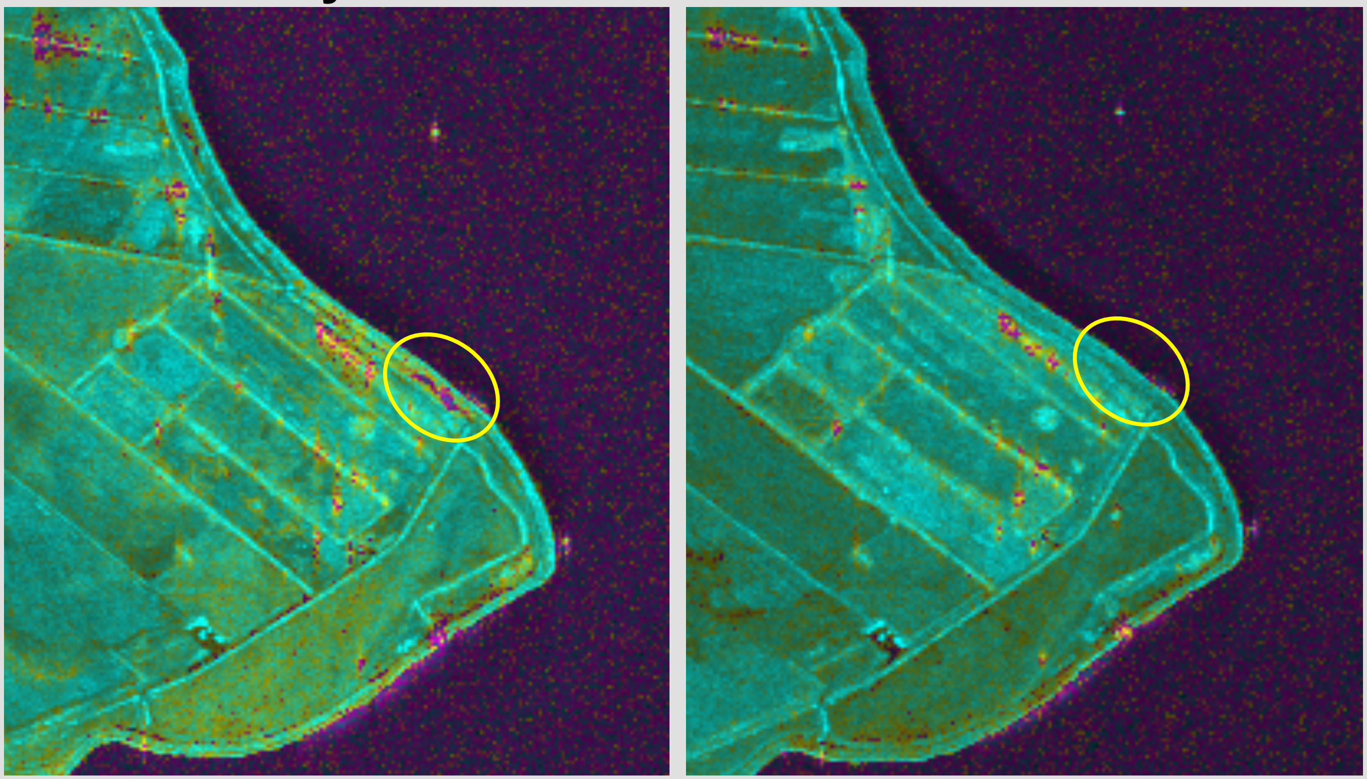


June 2011



A seep that had been present in 2010 was repaired in May 2011. The seep was identified the repeat pass data in 2010 but not seen following the repair in 2011.

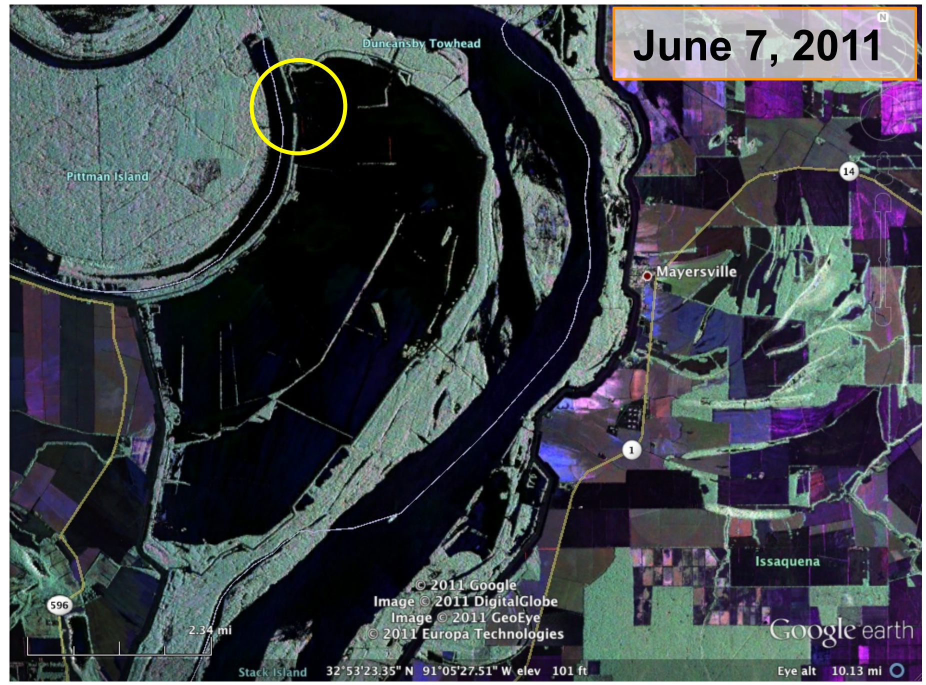
July 2010 | **June 2011**



Radar Remote Sensing of the Mississippi River Levees

Mississippi River Flood, Spring 2011

UAVSAR Radar Images of the Mississippi River near Greenville, MS



Levee failure location

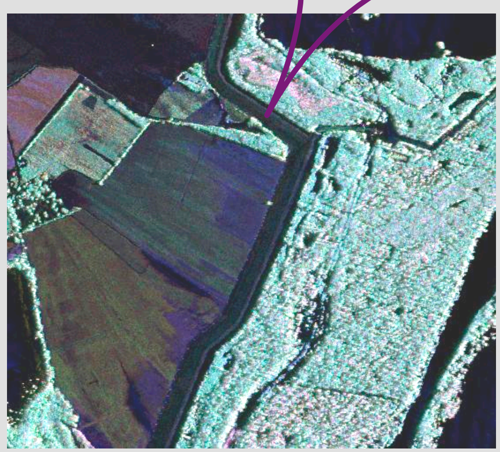
NASA DEVELOP student project
JPL, Fall 2011 – Spring 2012

Radar Remote Sensing of the Mississippi River Levees

Mississippi River Flood, Spring 2011

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

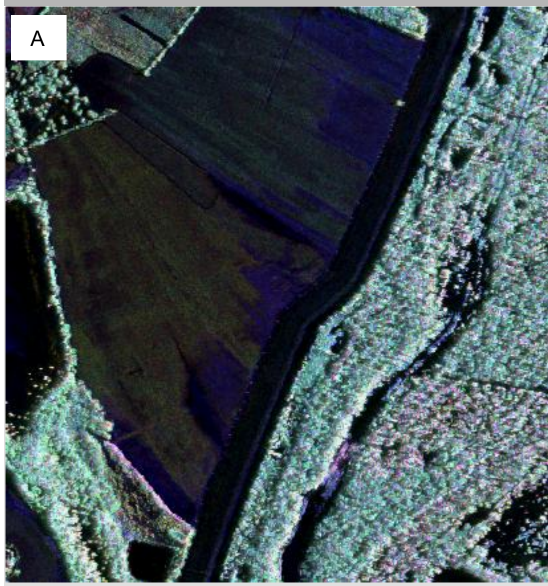
UAVSAR, combined polarizations



The radar images show that there is a seep through the levee along this section. We used the different polarization data to enhance detection of leaking sections of levees and to automatically classify high-likelihood seepage areas.

Radar Remote Sensing of the Mississippi River Levees

Automatic Classification to Locate Major Seeps



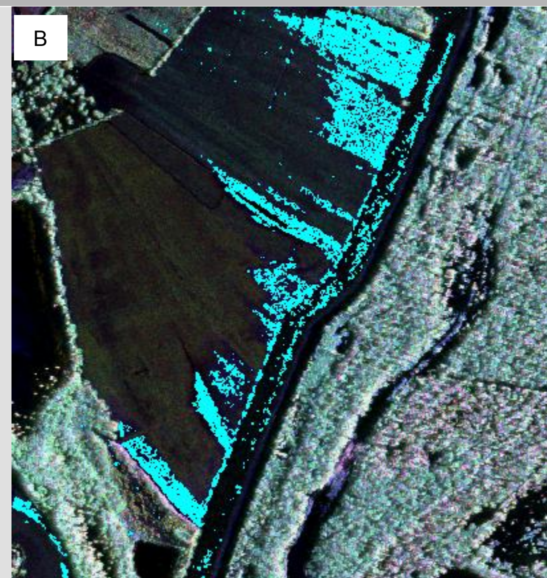
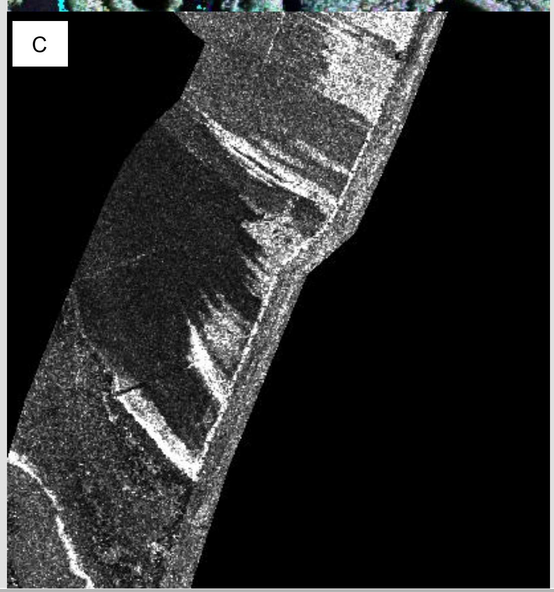
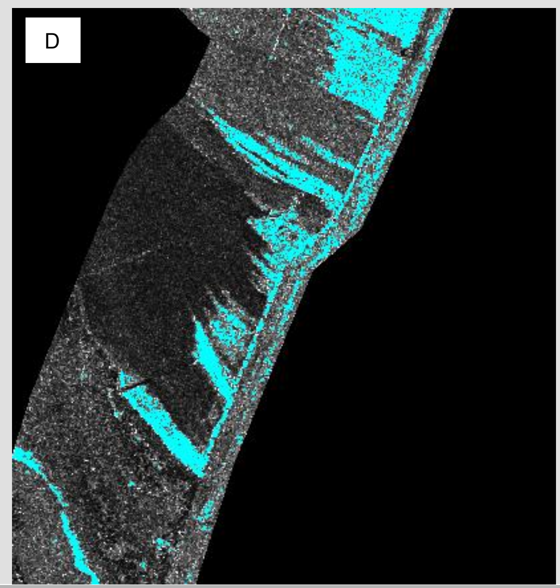


Image A is an RGB = HH, HV, VV color composite UAVSAR image of the area, image B is the same color composite with the high moisture class pixels(cyan) overlaid on top, image C is the VV/HH band ratio, and image D is the same band ratio image with the high moisture class pixels (cyan) overlaid on top.

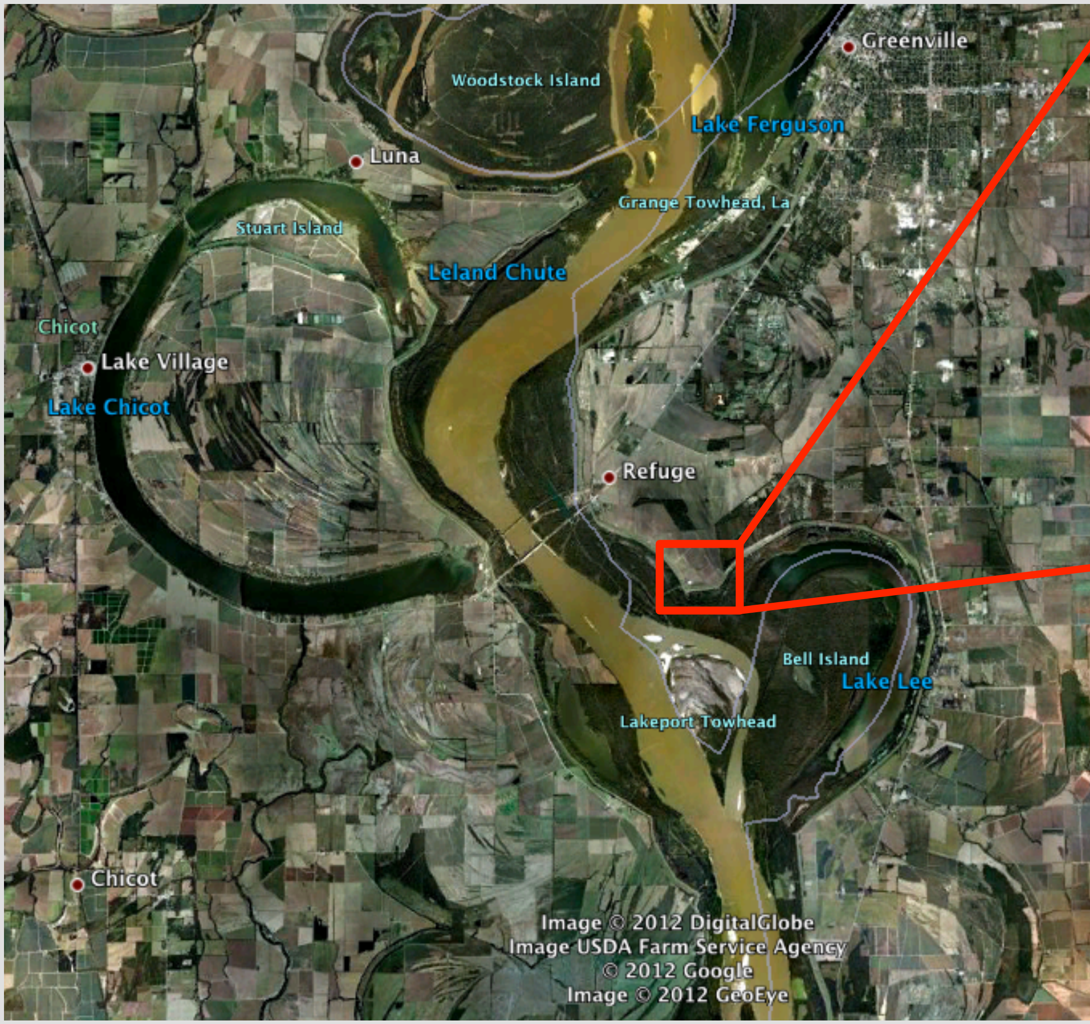
The levee is present in the images running from southwest to northeast. Deep purple striations in image A relate to lighter pixels in image C, as well as pixels in the increased moisture class (cyan).

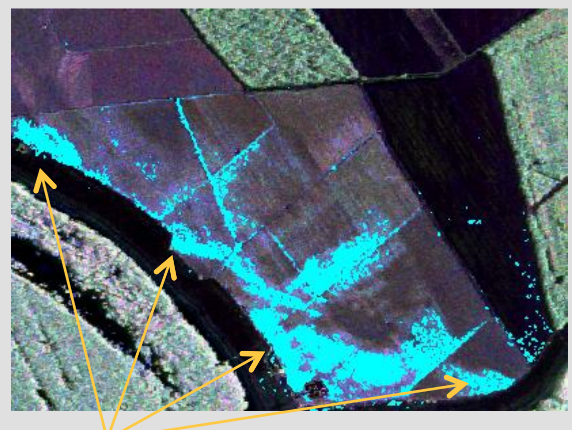




Radar Remote Sensing of the Mississippi River Levees

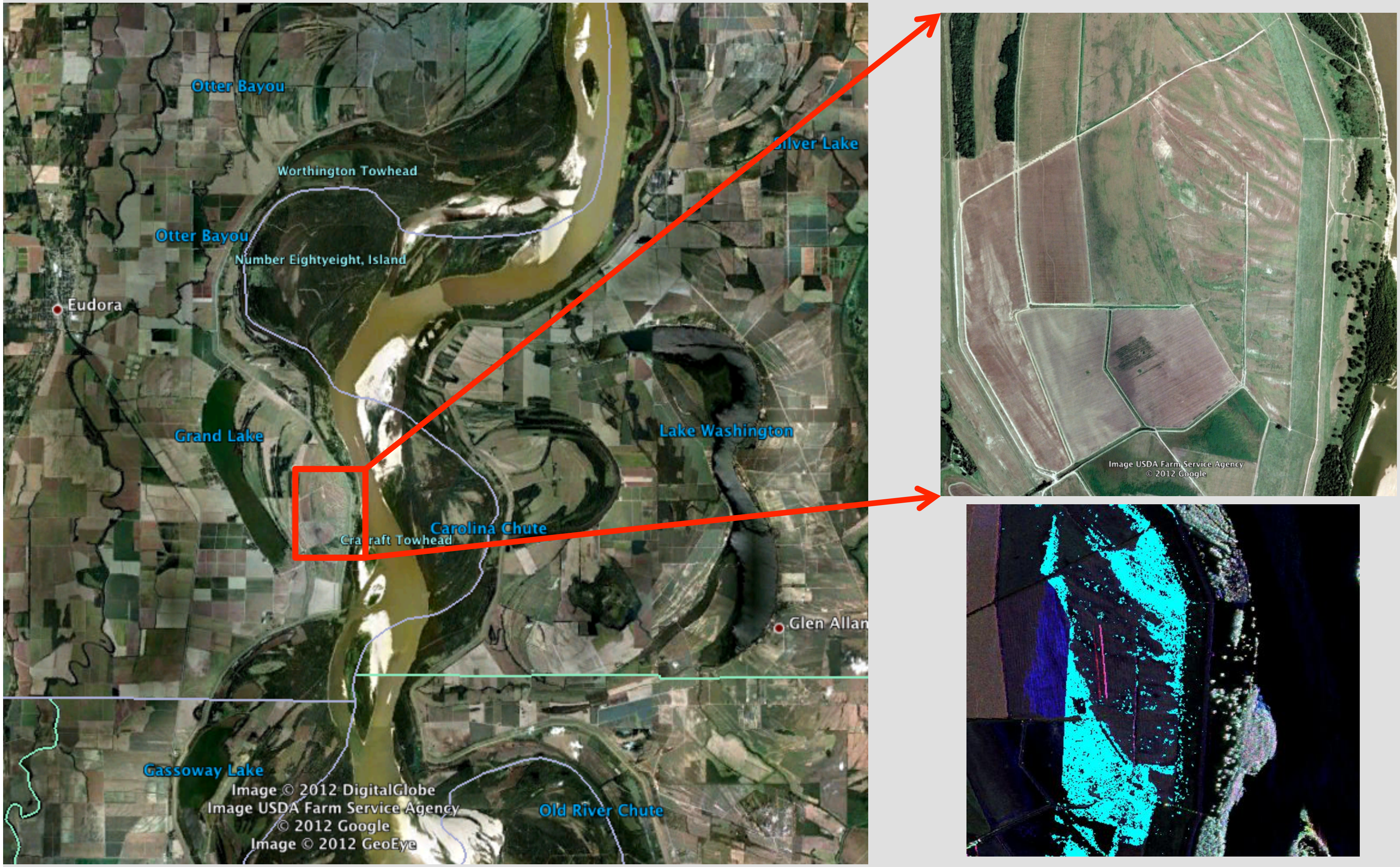
Automatic Classification to Locate Major Seeps



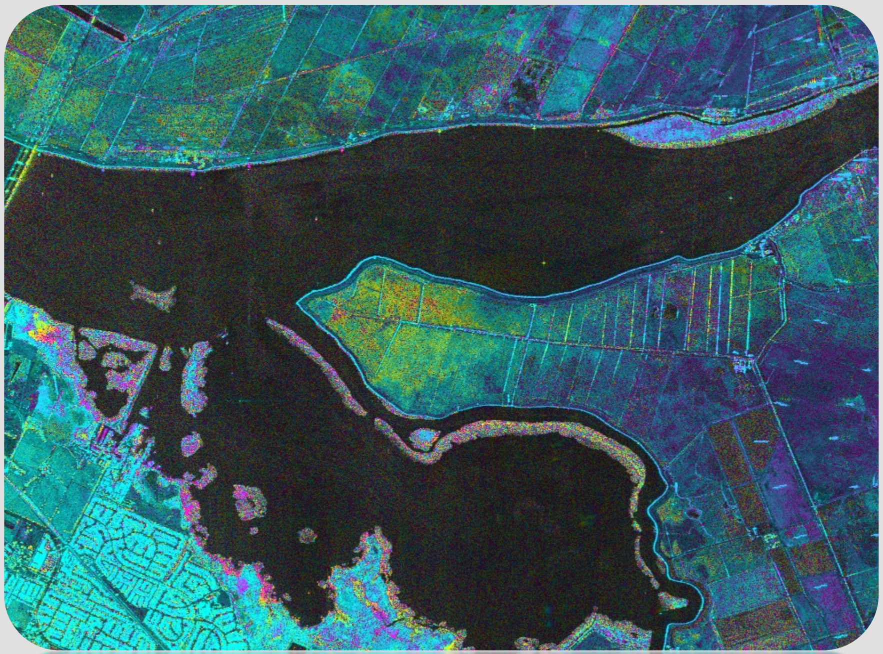


Major seepage through the levee

Radar Remote Sensing of the Mississippi River Levees
Automatic Classification to Locate Major Seeps



Radar Remote Sensing for Monitoring Levees
Conclusions



Radar remote sensing offers great potential for high resolution monitoring of ground surface changes over large areas at one time to detect movement on and near levees and for location of seepage through levees.

Our project to monitor levees in the Sacramento Delta and the Mississippi River has developed and demonstrated the knowledge base needed to monitor similar critical structures elsewhere, providing a needed asset for disaster management throughout the United States.

The next step is to take this from the research phase to a usable system employed by levee managers in a general safety program.