# Radar Remote Sensing in the Delta Region

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

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***Jet Propulsion Laboratory, California Institute of Technology***

# Remote Sensing for Levee/Dam Safety Programs

**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)

# *Overview of Radar Remote Sensing*

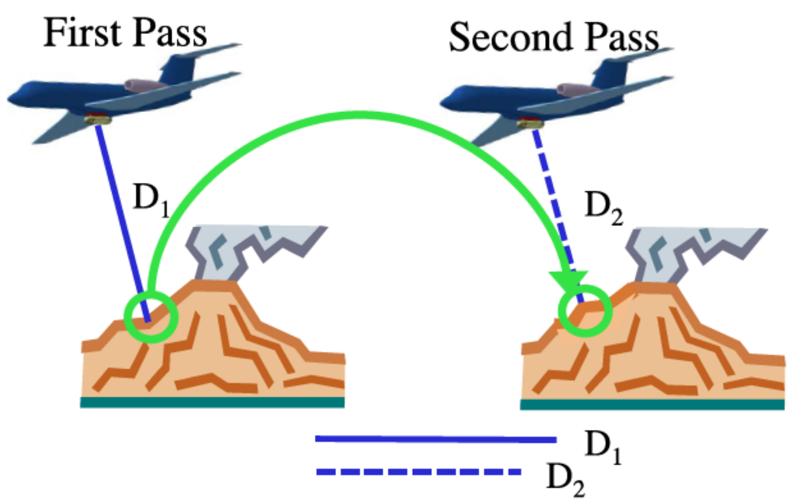
# Radar Remote Sensing

Radar remote sensing is used to support a wide range of science topics and an increasing number of applications that derive from the science. Although radar imaging is not the same as photogrammetry or visual surveys, there are certain applications for which it can provide information that is not readily available through other means.

Microwave-band 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 (orientation) 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.

**Differential Interferometry (DINSAR)**




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

$\lambda =$ wavelength of radar

# Radar Remote Sensing

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Microwave-band 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 Remote Sensing

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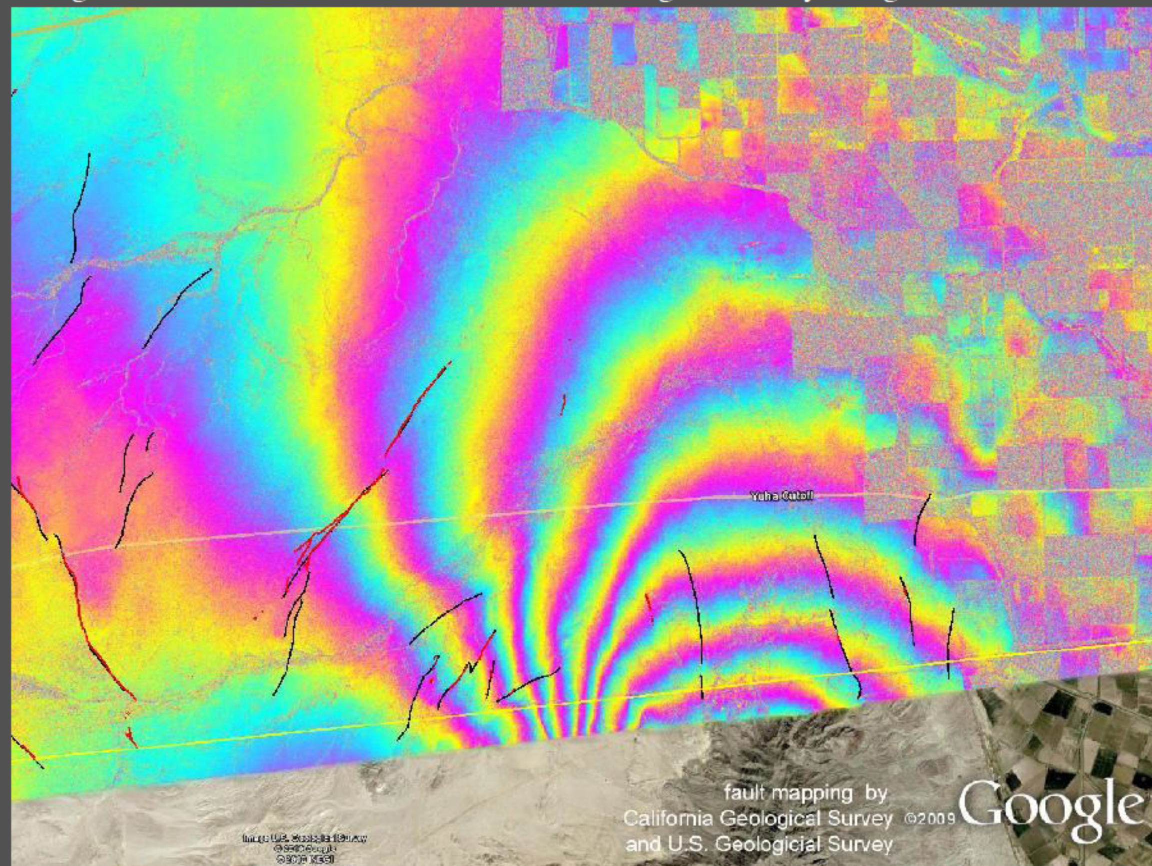
Sacramento Delta / false color UAVSAR POLSAR image / 7 m resolution

# Example: Earthquake Fault Slip

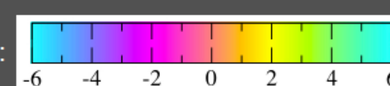
## Baja Earthquake, April 2010

This UAVSAR DifInSAR image, covering the time period from October 21, 2009 to April 13, 2010, shows ground deformation that is largely a result of the April 4, 2010 earthquake in Baja California. Black lines indicate interpreted faults, and red lines show where surface rupture was confirmed by geologists in the field.

Image credit: NASA JPL/USGS/California Geological Survey/Google




Relative surface shift in centimeters:



# *Monitoring the Levees of the Sacramento-San Joaquin Delta with the UAVSAR Radar*

# Radar Remote Sensing of the California Levees

NASA APPLIED SCIENCE PROJECT

## Monitoring Levees and Subsidence in the Sacramento-San Joaquin Delta

**STUDY PERIOD: Ongoing since JULY 2009**

***Jet Propulsion Laboratory*** *(Cathleen Jones, Sang-Ho Yun, Scott Hensley)*

***Ca. Department of Water Resources, FESSRO*** *(Joel Dudas)*

***USGS*** *(Gerald Bawden)*

***HydroFocus, Inc.*** *(Steve 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.**

Photo credit: Tom Williams, Gerald Bawden, Cathleen Jones

**Method:**

**The levees are monitored monthly for changes using UAVSAR. We are working to also obtain the general subsidence on all the islands from the monthly UAVSAR data.**

## Optimized Radar Remote Sensing for Levee Health Monitoring

FUNDING: DHS SCIENCE AND TECHNOLOGY DIRECTORATE (Dr. Bruce Davis)

ASSOCIATED FUNDING: NASA and CA. DEPT. OF WATER RESOURCES

***Jet Propulsion Laboratory*** *(Dr. Cathleen Jones)*

***Rensselaer Polytechnic Institute*** *(Civil Engineering Dept., Dr. Victoria Bennett, Dr. Tarek Abdoun)*

**Study Objectives:**

**Optimize methodologies to use existing satellite and airborne radar assets to monitor levee health in order to prevent disasters and more efficiently respond to emergency situations.**

- **Develop and validate the capability to efficiently use radar remote sensing for levee status monitoring and emergency response in order to incorporate it into the decision-making process before it is needed in an emergency.**
- **Partnership with end-users and beneficiaries is critical to developing useful methods and products.**

**Study Partners:**

**Sacramento Office of Emergency Services**
**California Dept. of Water Resources, Division of Flood Management**

**Study Areas:**

1. **California's Sacramento-San Joaquin Delta (build on the work done in a NASA multi-year study)**
2. **New Orleans (RPI partner's instrumented levee test site with coverage from multiple radars)**

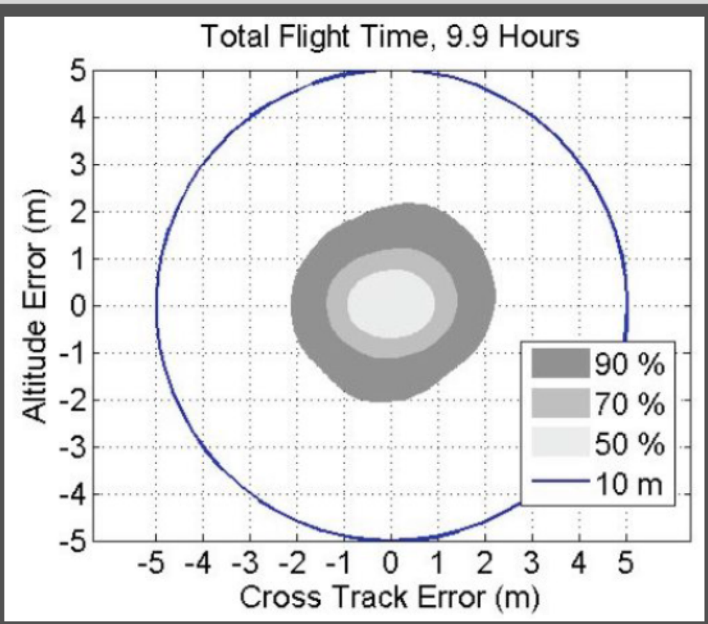
# UAVSAR

## NASA Airborne L-band Radar for Differential Interferometry

The UAVSAR system combines control of the radar instrument with the aircraft flight path and is designed for repeat track interferometry. UAVSAR has several unique features to allow high precision differential interferometry from an airborne platform:

1. Precision autopilot to maintain the flight track within a 10 meter tube around the desired track.
2. Phased array antenna plus adaptive steering to maintain pointing direction of the radar beam.

| Parameter | Value |
|---|---|
| Frequency | L-Band 1217.5 to 1297.5 MHz (23.8 cm wavelength) |
| Bandwidth | 80 MHz |
| Resolution | 1.67 m Range, 0.8 m Azimuth |
| Polarization | Full Quad-Polarization |
| ADC | 12 bit ADC; 180 MHz sampling frequency |
| Waveform | Nominal Chirp/Arbitrary Waveform |
| Antenna Aperture | 0.5 m range/1.5 m azimuth (electrical) |
| Azimuth Steering | Greater than ±20° |
| Transmit Power | > 3.1 kW |

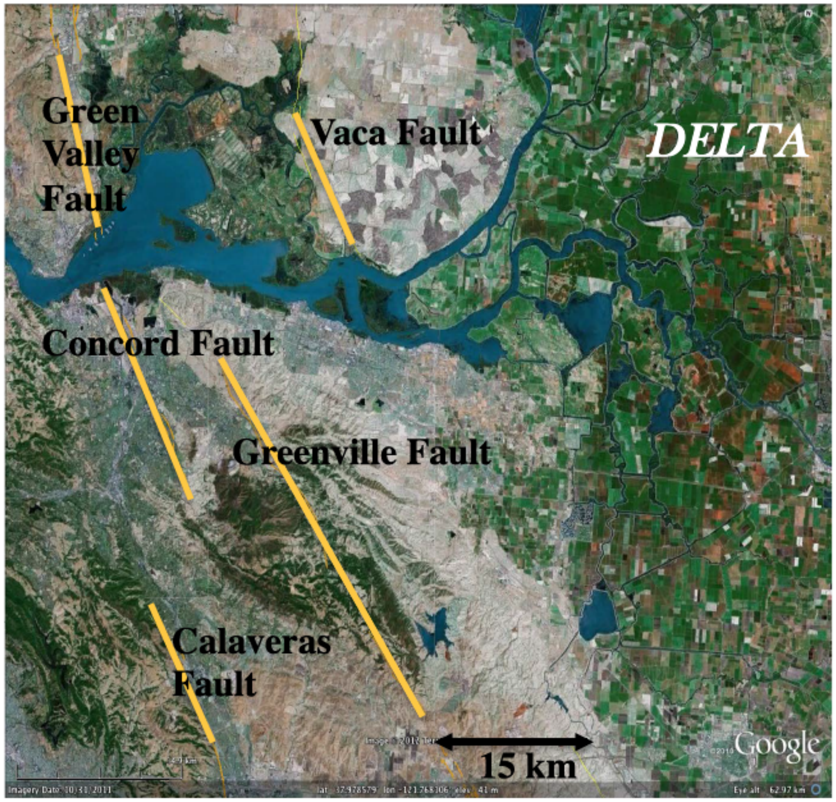


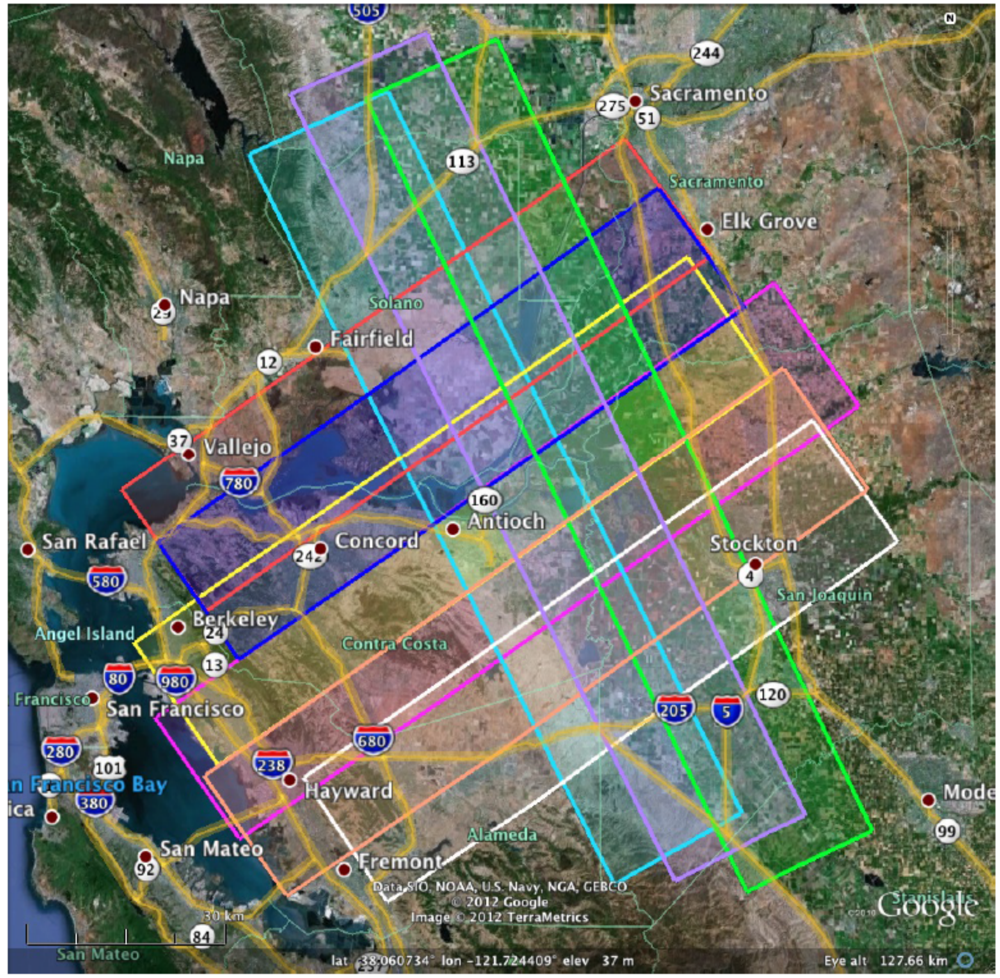
# UAVSAR

## Sacramento-San Joaquin Delta Coverage

***UAVSAR was used to image the entire Sacramento-San Joaquin Delta and Suisun Marsh along nine overlapping flight lines to observe each levee from at least three different directions.***

***We have completed 35 flights since July 2009.***



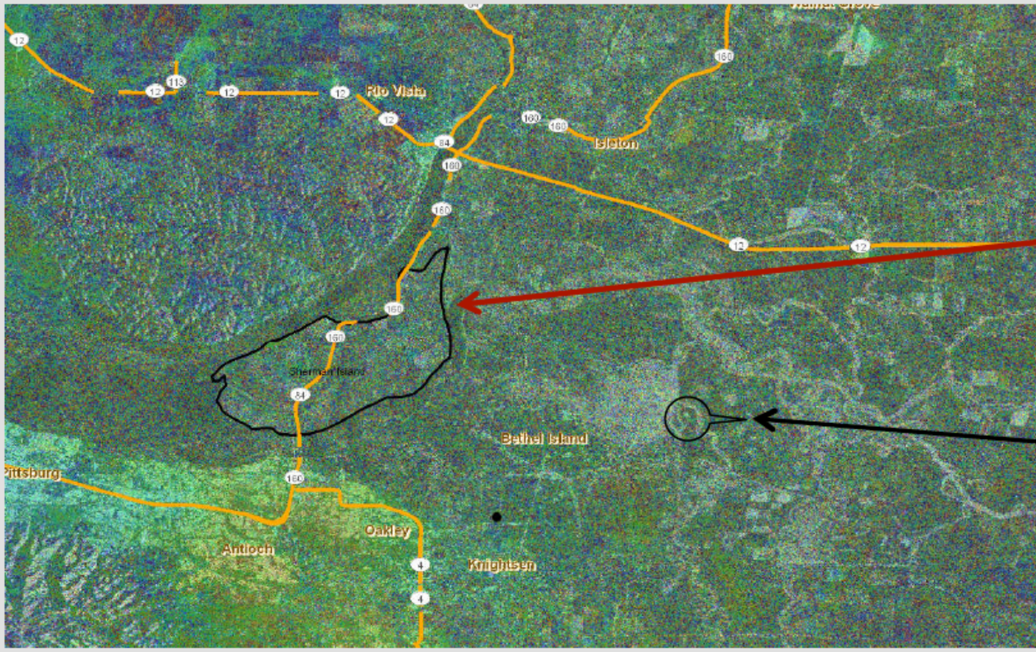



# Delta Islands and Levees

## UAVSAR Multi-polarization Image

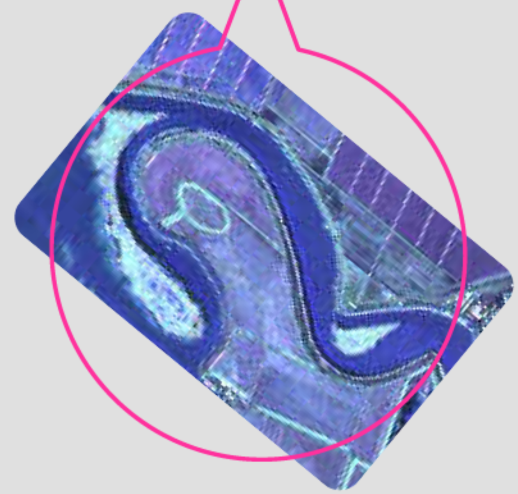
# Radar Remote Sensing

## COMPARISON BETWEEN HIGH AND LOW RESOLUTION RADARS




Satellite image of the delta (European Space Agency ERS instrument) – 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.*

*Subsidence*

*and*

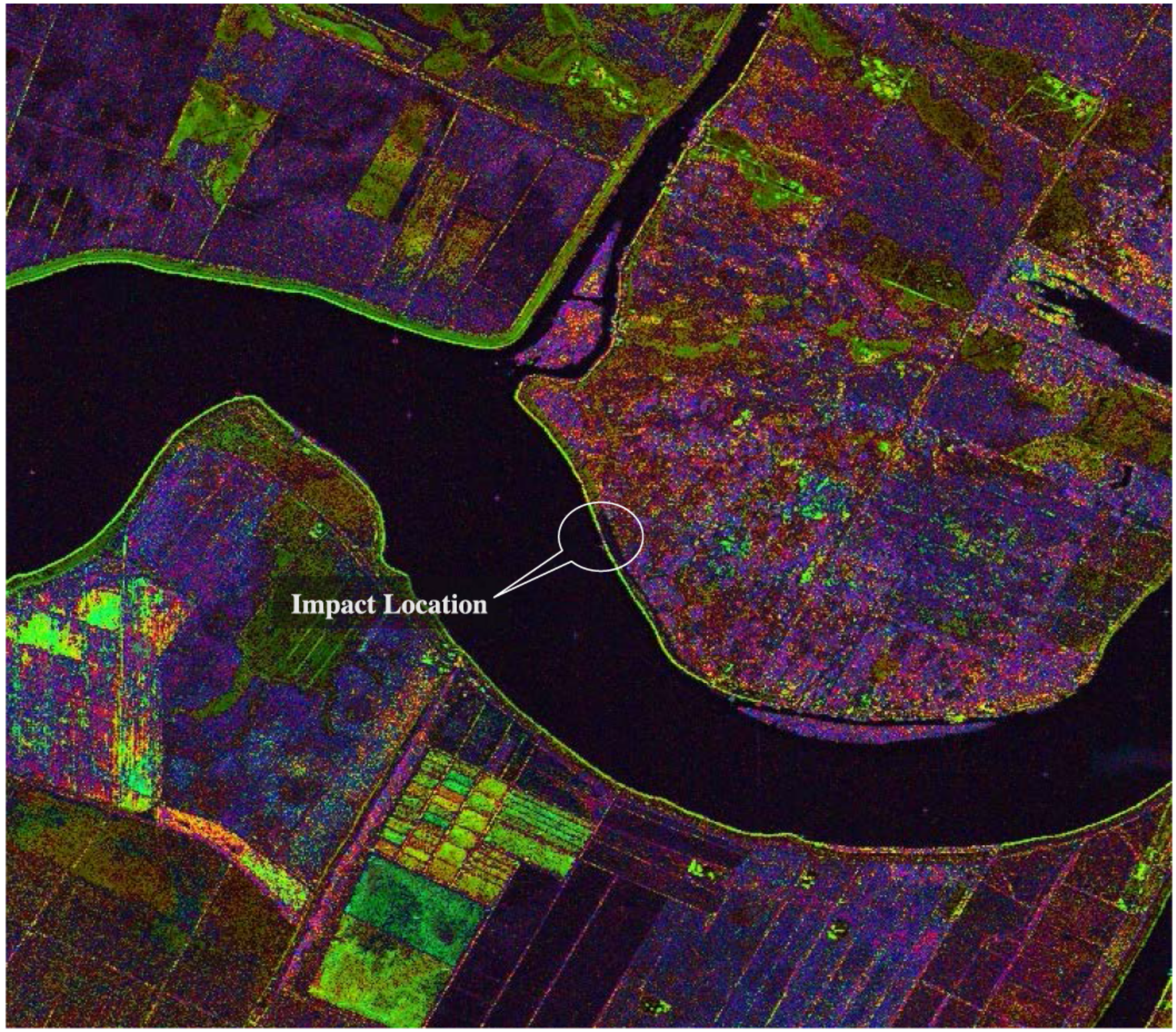
*Deformation*

# Bradford Island Levee Damage

## SHIP IMPACT IN 2009

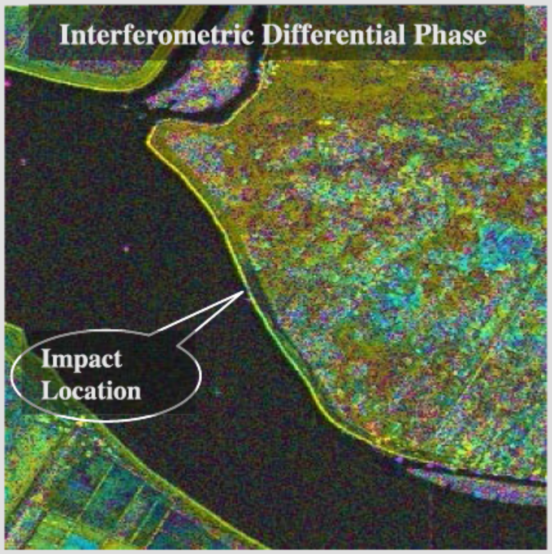
**On August 28, 2009 a ship rammed the north levee on Bradford Island. This image was made from an interferogram between UAVSAR data collected on July 17 and Sept. 10, so evidence of the impact and repair are seen in the data.**

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



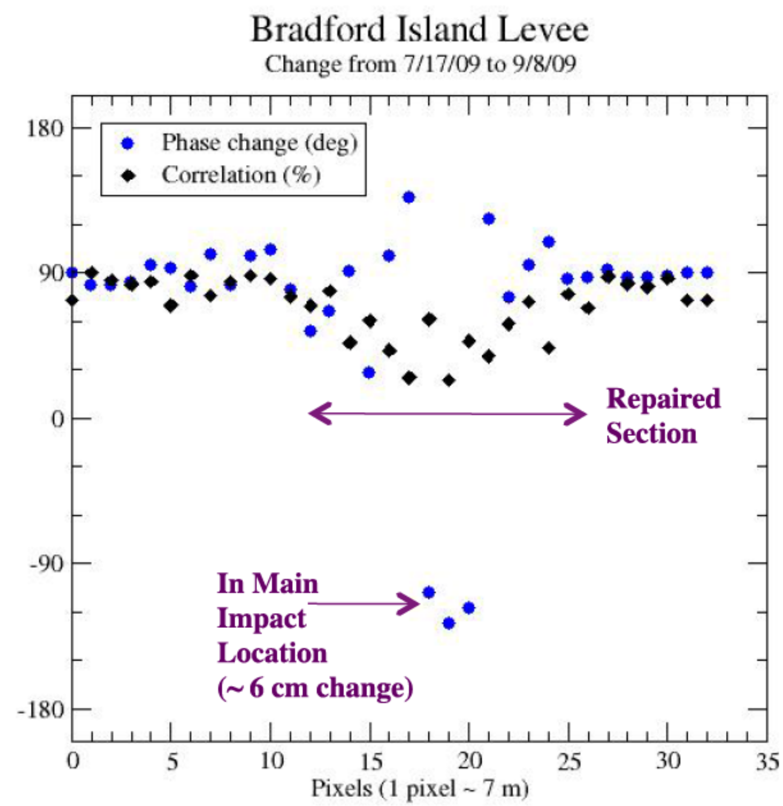
# Bradford Island Levee Damage

## DINSAR MEASUREMENT OF DEFORMATION





PRE-IMPACT TO POST- IMPACT LEVEE CHANGE

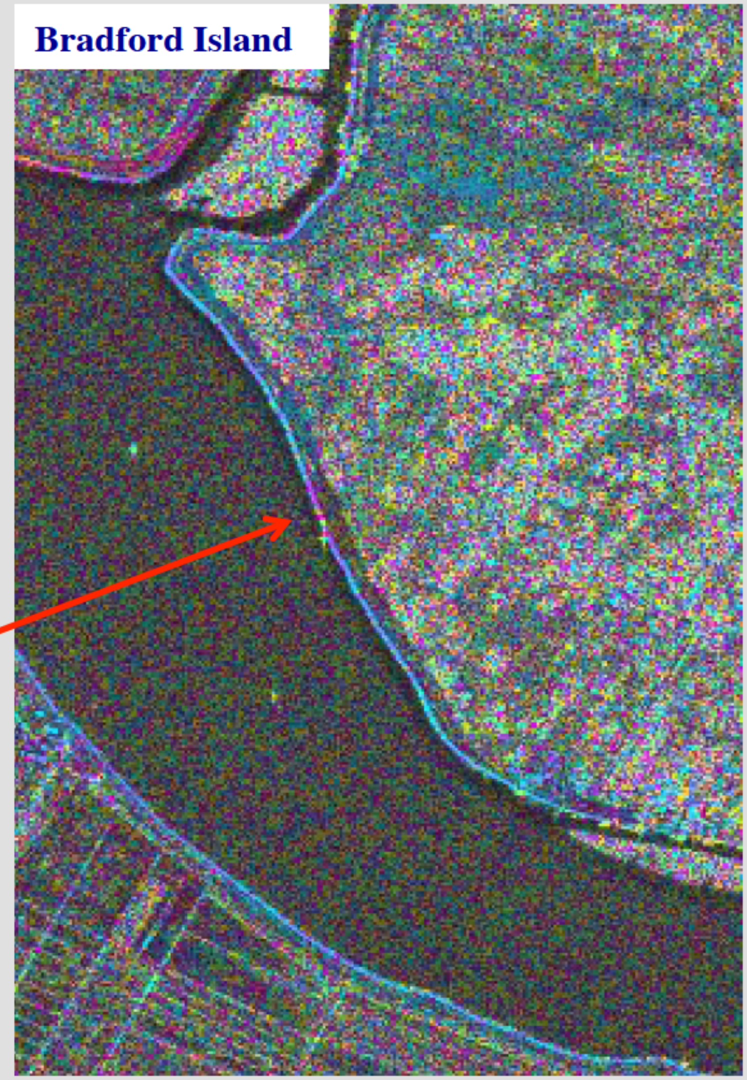


# Bradford Island Levee Damage

## Post-Impact Settling along the 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.***

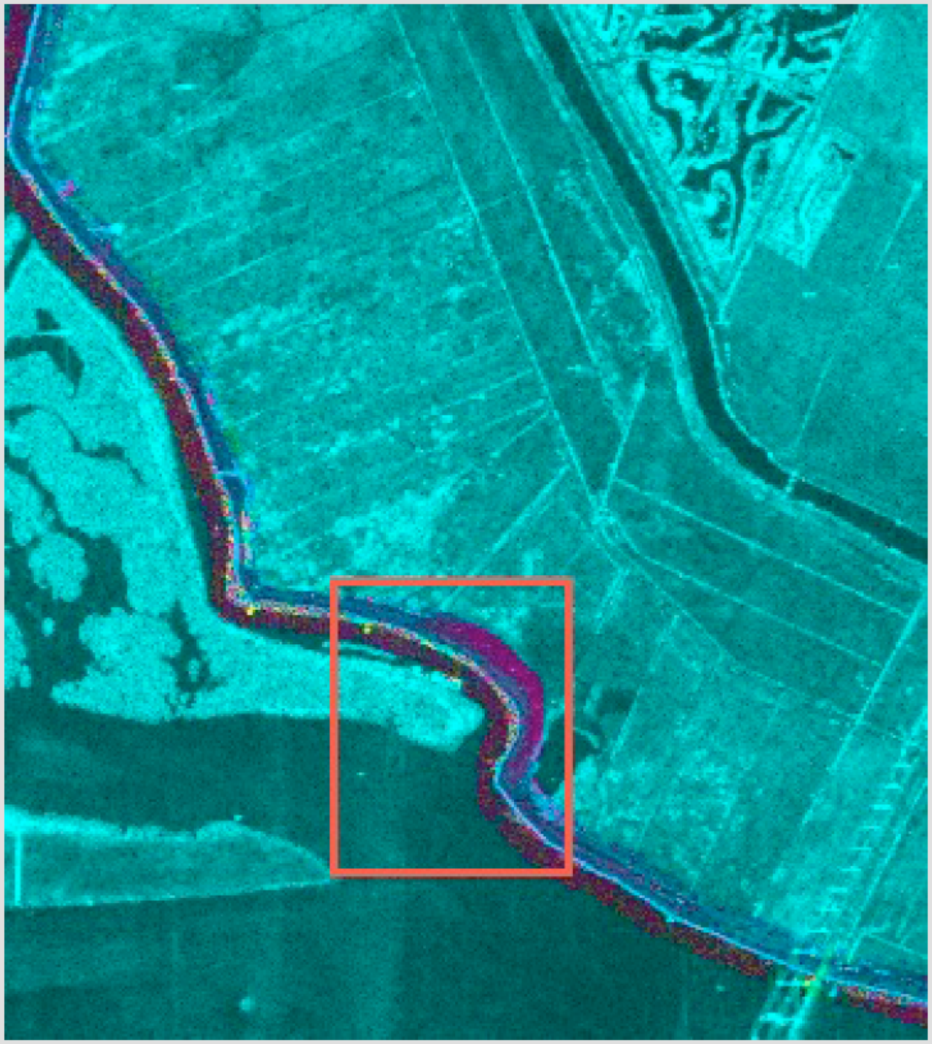

*Change along repaired section of the levee*

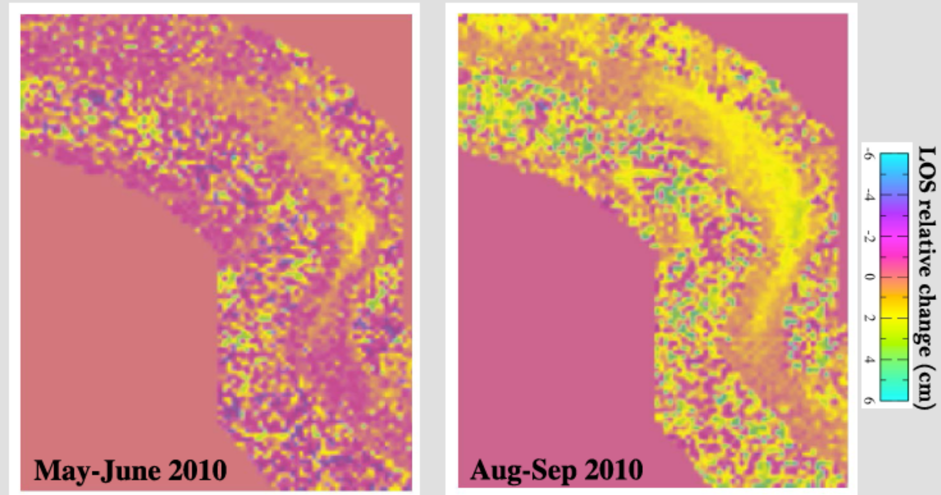


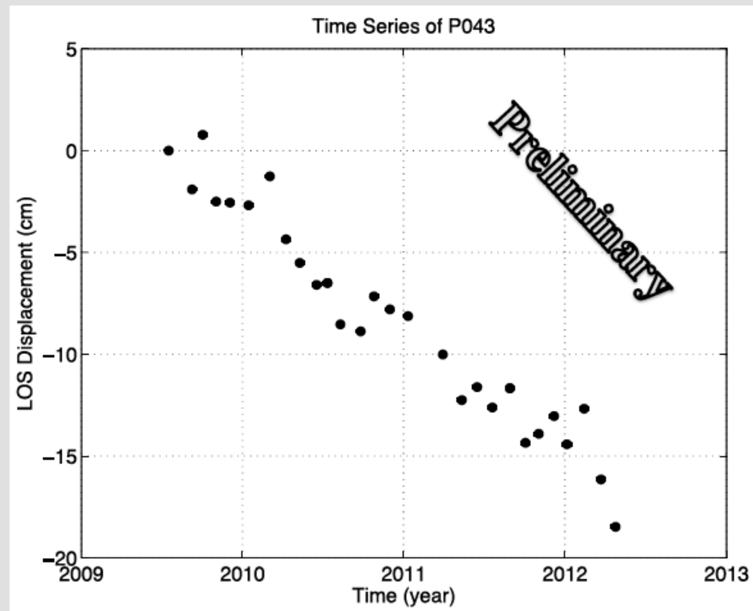

*1 year temporal baseline 7/2009 - 7/2010*

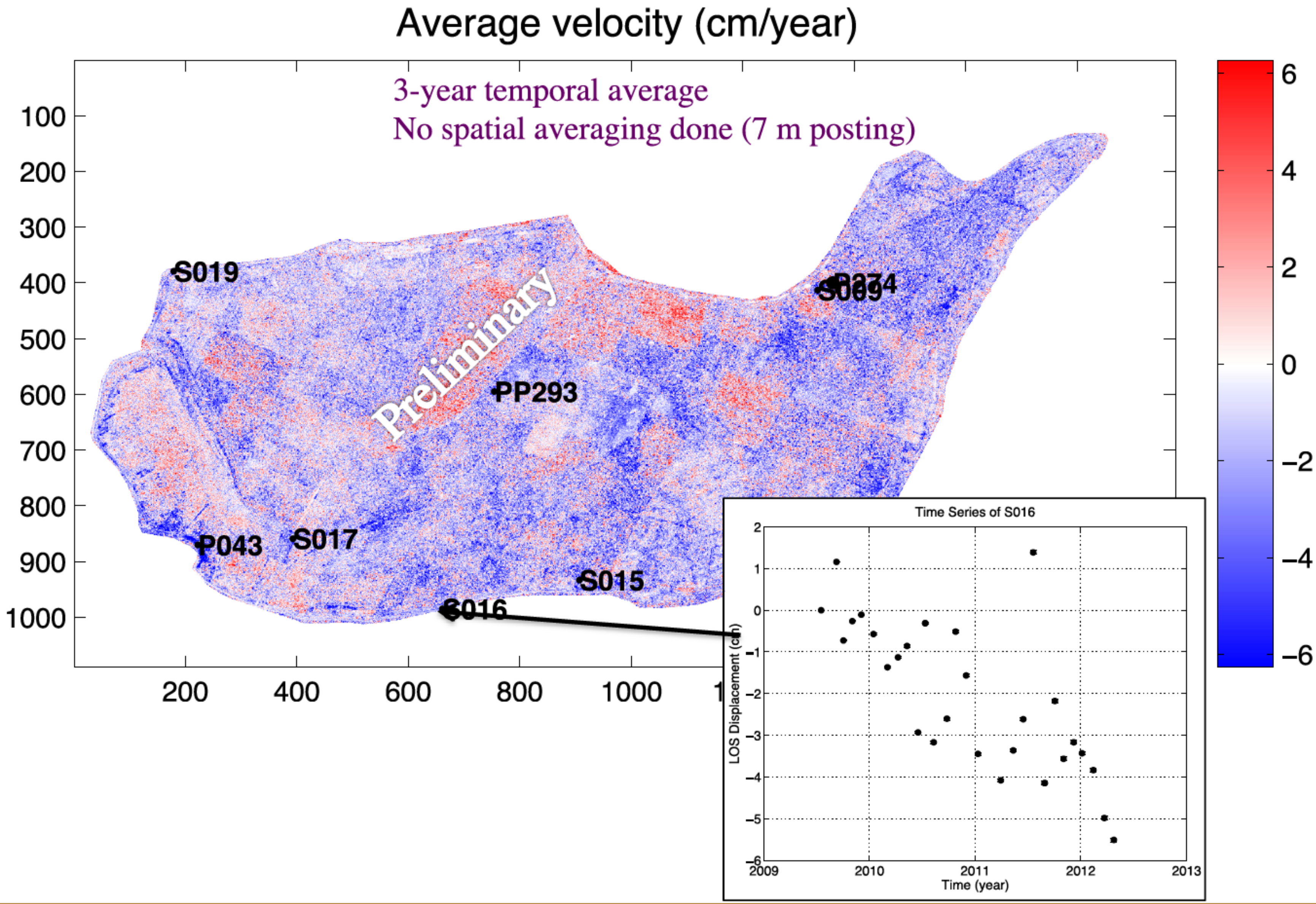
# Subsidence Behind New/Repaired Levees

## SHERMAN ISLAND SET-BACK LEVEE





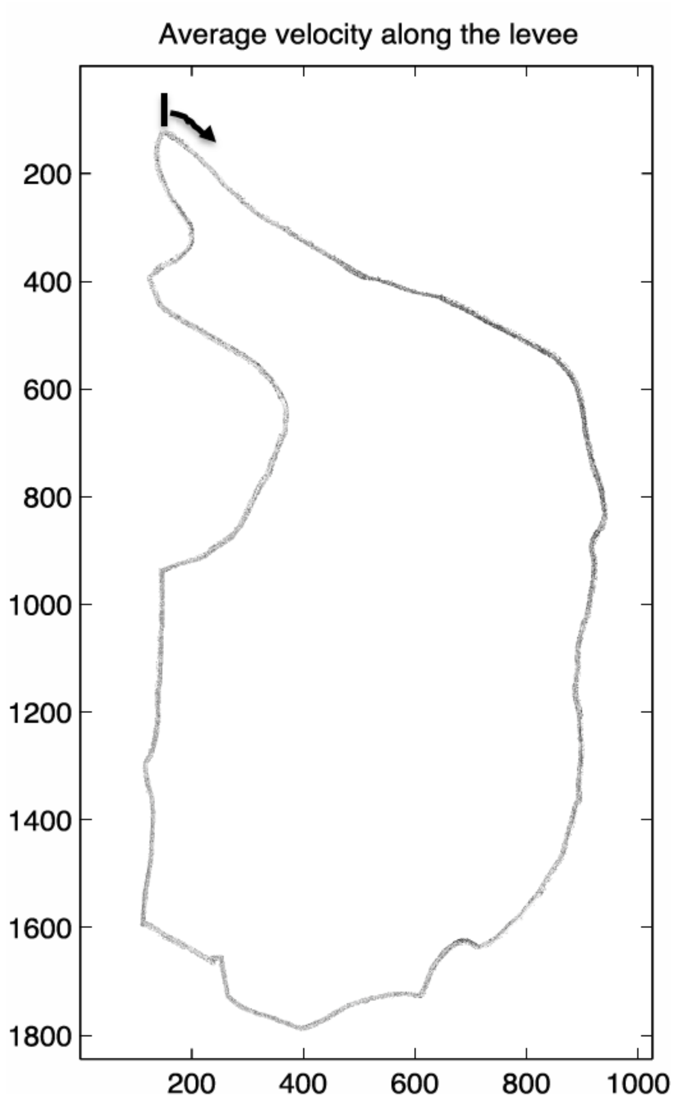



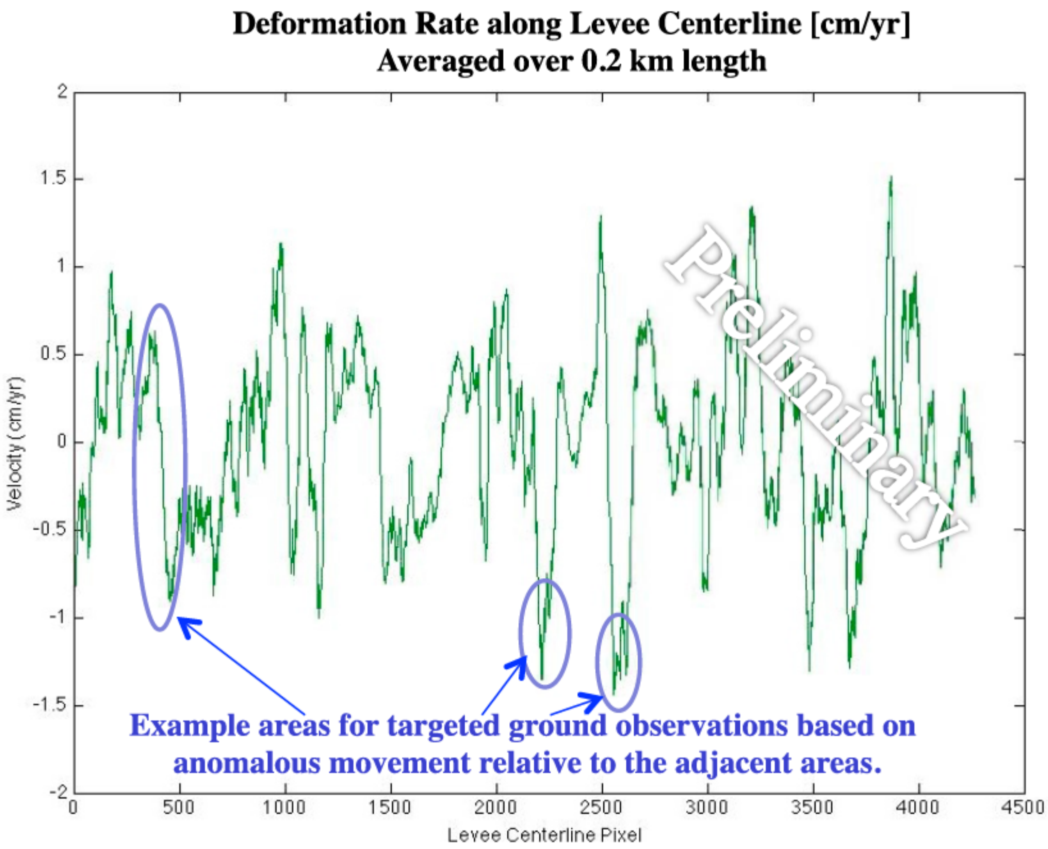


Average velocity (cm/year)
3-year temporal average
No spatial averaging done (7 m posting)
Preliminary
S019
PP293
P043
S017
S015
S016
100
200
300
400
500
600
700
800
900
1000
6
4
2
0
−2
−4
−6
Time Series of S016
LOS Displacement (cm)
Time (year)
2009
2010
2011
2012
2013

# Surface Deformation Along Levee Centerlines

## SHERMAN ISLAND



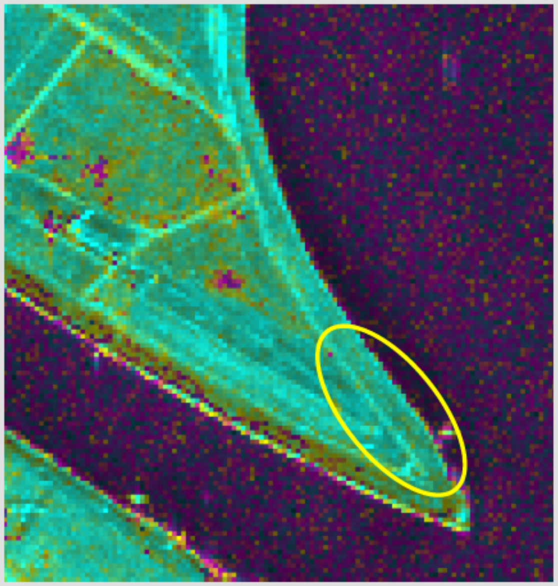
# *Detection of Seepage*

# Seep Detection Behind Levees

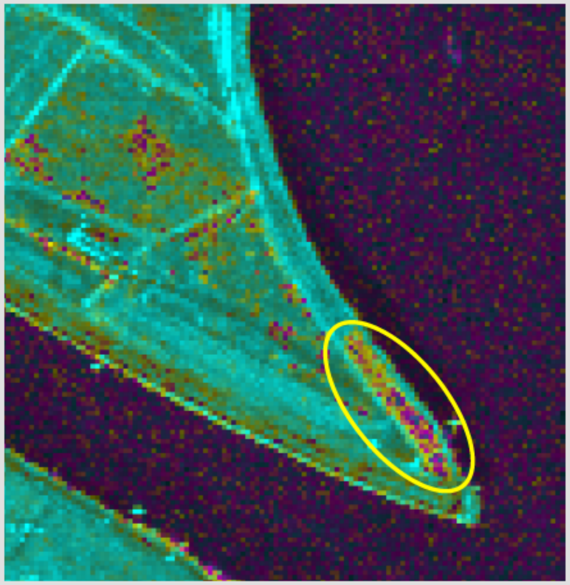
## TWITCHELL ISLAND – SEEP FORMATION

**A seep through the levee developed between July 2010 and June 2011. This is detected in the repeat pass interferometric correlation, measured with the UAVSAR L-band radar, which saw no change behind the levee during the high/low tidal cycle in 2010, but detected a large change the following year.**

**July 2010**



**June 2011**

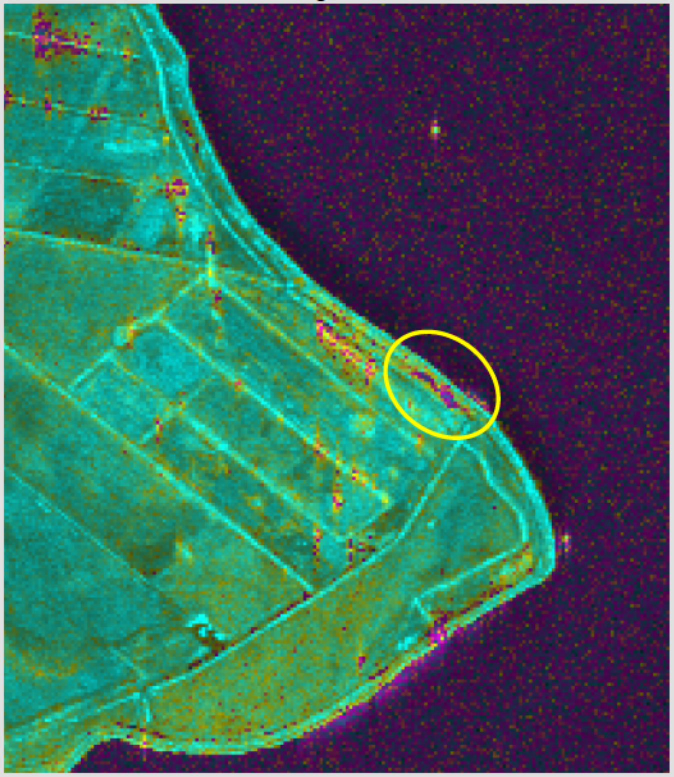


# Seep Detection Behind Levees

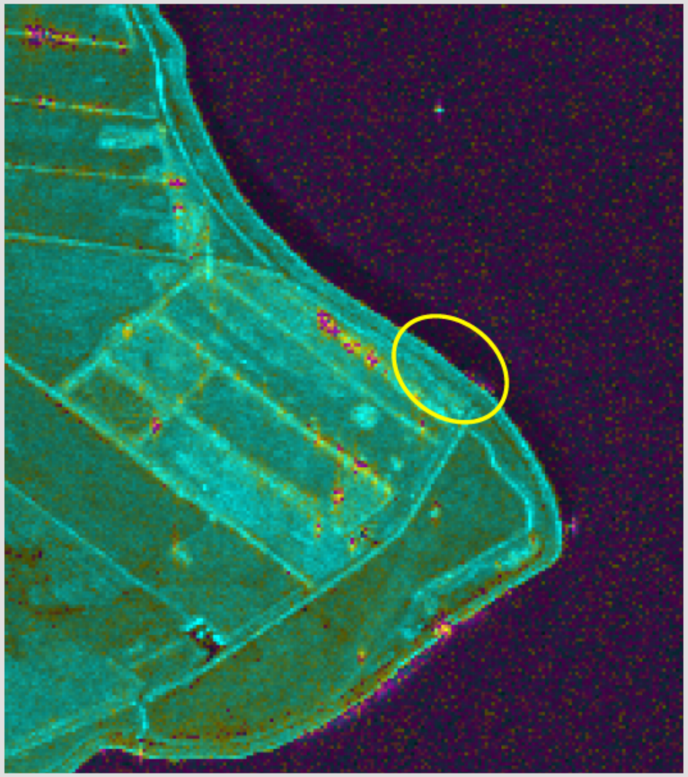
## TWITCHELL ISLAND – LEVEE REPAIR

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

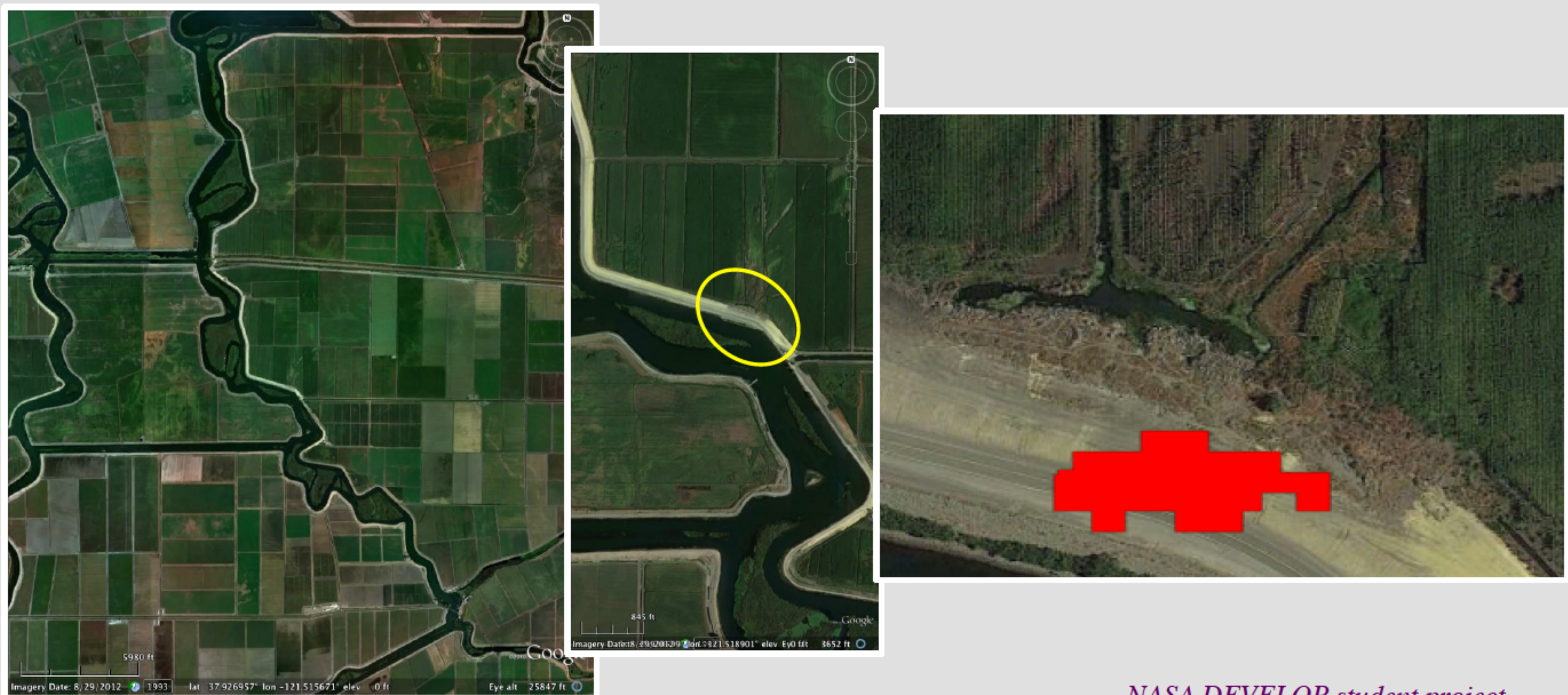
**July 2010**



**June 2011**



**We trained an automated classifier using the Twitchell Island Chevron Point seep and applied it to all of the Sacramento-San Joaquin high-to-low tide data sets. A number of other potential seeps showed up. We are working with J. Dudas (FESSRO) to determine true/false positive rates, with the goal of refining & understanding the limitations of the seep detection technique.**



**Jones Tract**

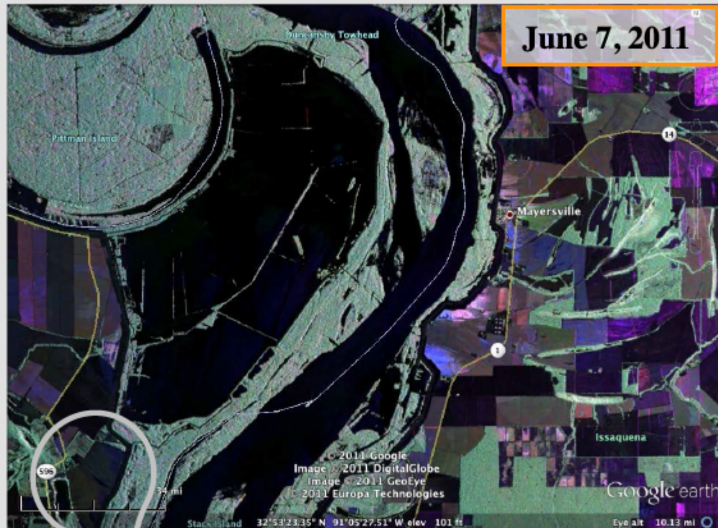
*NASA DEVELOP student project*
*JPL, Spring 2013*
*A. Madson, A. Thorstensen, P. San Juan*

# Radar Remote Sensing of the Mississippi River Levees

## Mississippi River Flood, Spring 2011

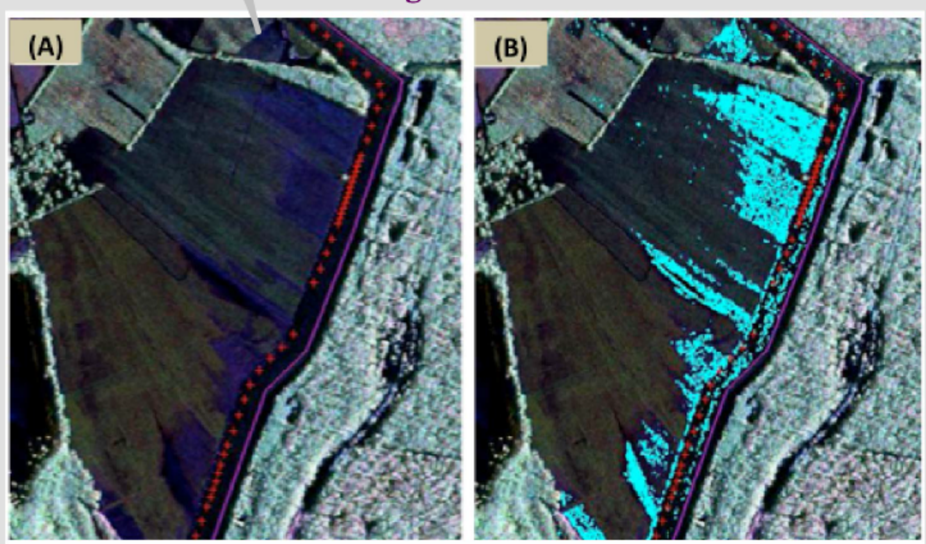
Homeland Security


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




UAVSAR, combined polarizations

**The radar data indicates there is seepage through relief wells along the levee in this area.**

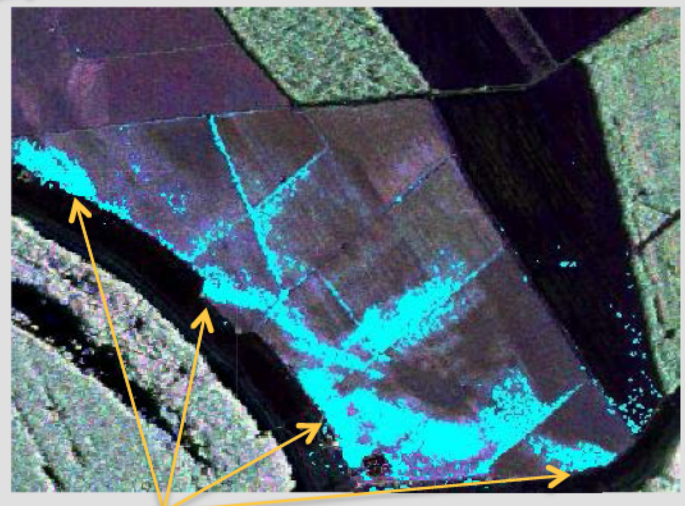



**We used the polarization-dependence of the radar return to enhance detection of leaking sections of levees and to automatically classify high-likelihood seepage areas.**

# Radar Remote Sensing of the Mississippi River Levees

## Unsupervised Classification to Locate Major Seeps

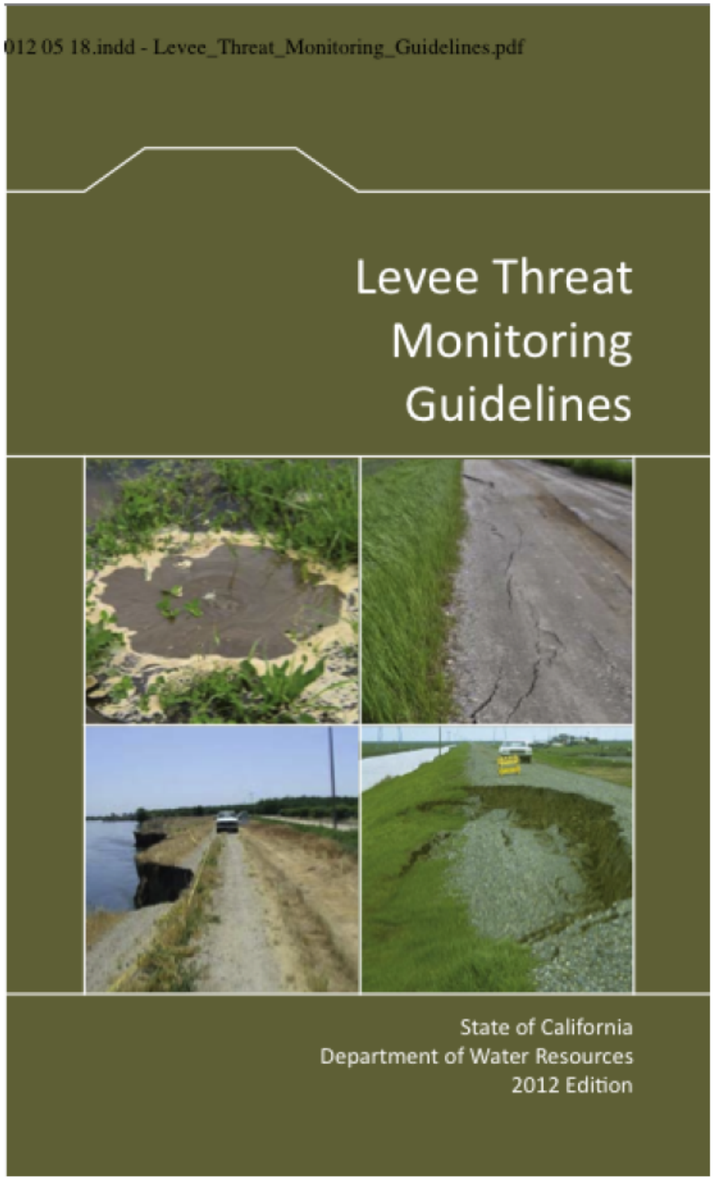




**Major seepage through the levee in areas without relief wells**

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

# Radar Remote Sensing of Specific Levee Threats




1. **Seepage**

   *We've had some success, mainly in detecting larger seeps. We can build on this to develop more sensitive classification methods.*

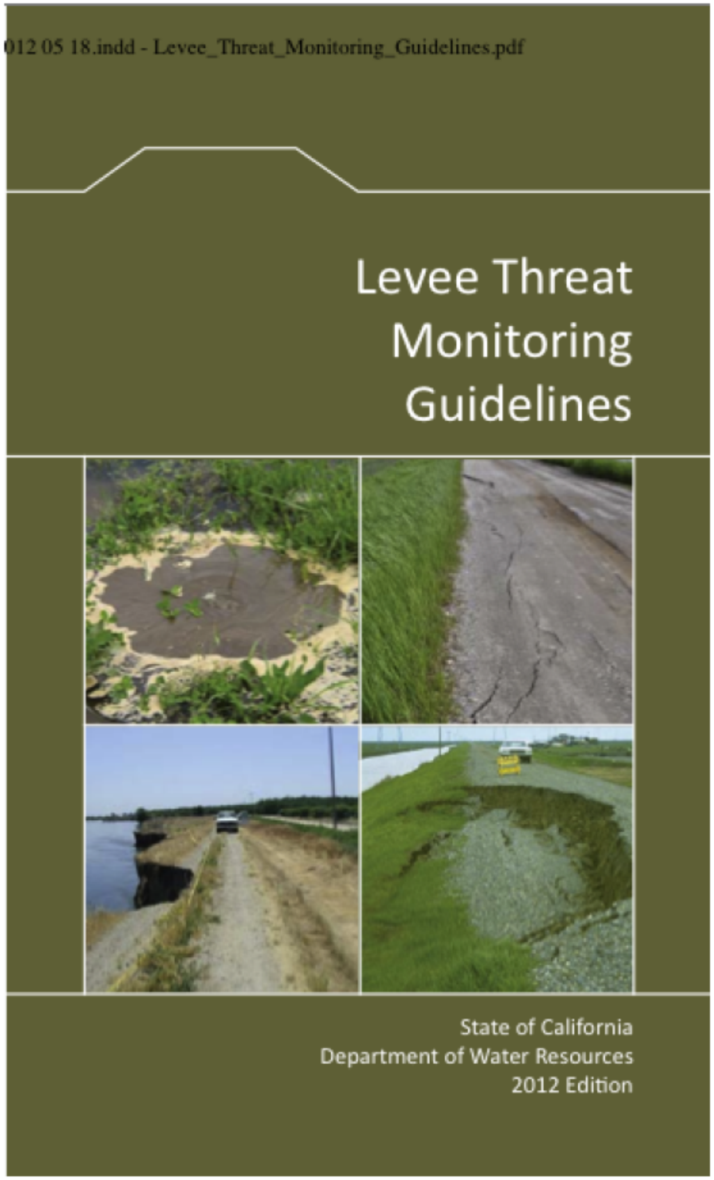
2. **Boils**

   *Small boils that surface in toe ditches can't be resolved from the water that is already there. We would detect boils surfacing away from other water as seepage and right now aren't able to distinguish small seeps from other false positives.*

3. **Cracking**

   *Possible if area is extensive enough.*

# Radar Remote Sensing of Specific Levee Threats




## 4. Sink Holes

*Not possible for small sink holes because of the UAVSAR radar imaging's spatial resolution. Large sink holes could be detected as for seeps.*

## 5. Slope Instability

*Can detect once slumping occurs.*

## 6. Erosion near the water line

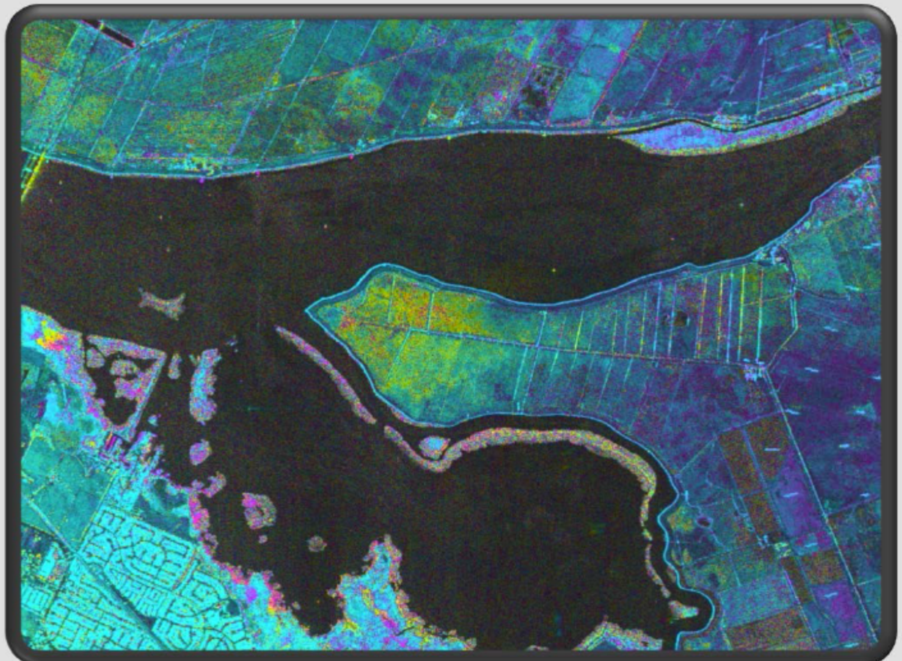
*There will be some difficulty in distinguishing this from water level changes. Needs investigation.*

## 7. Landside subsidence along levee toe

*Yes, especially with repeated acquisitions to discern a trend.*

# Radar Remote Sensing of Sacramento Delta Levees

CONCLUSIONS



Collaborators on work shown: Joel Dudas (Ca. DWR); Dr. Sang-Ho Yun, Dr. Scott Hensley, Austin Madson, Kevin O'Connell, Katrina Laygo, Andrea Thorstensen, Priscilla San Juan (JPL); Dr. Gerald Bawden (USGS); Dr. Steven Deverel (HydroFocus, Inc.)

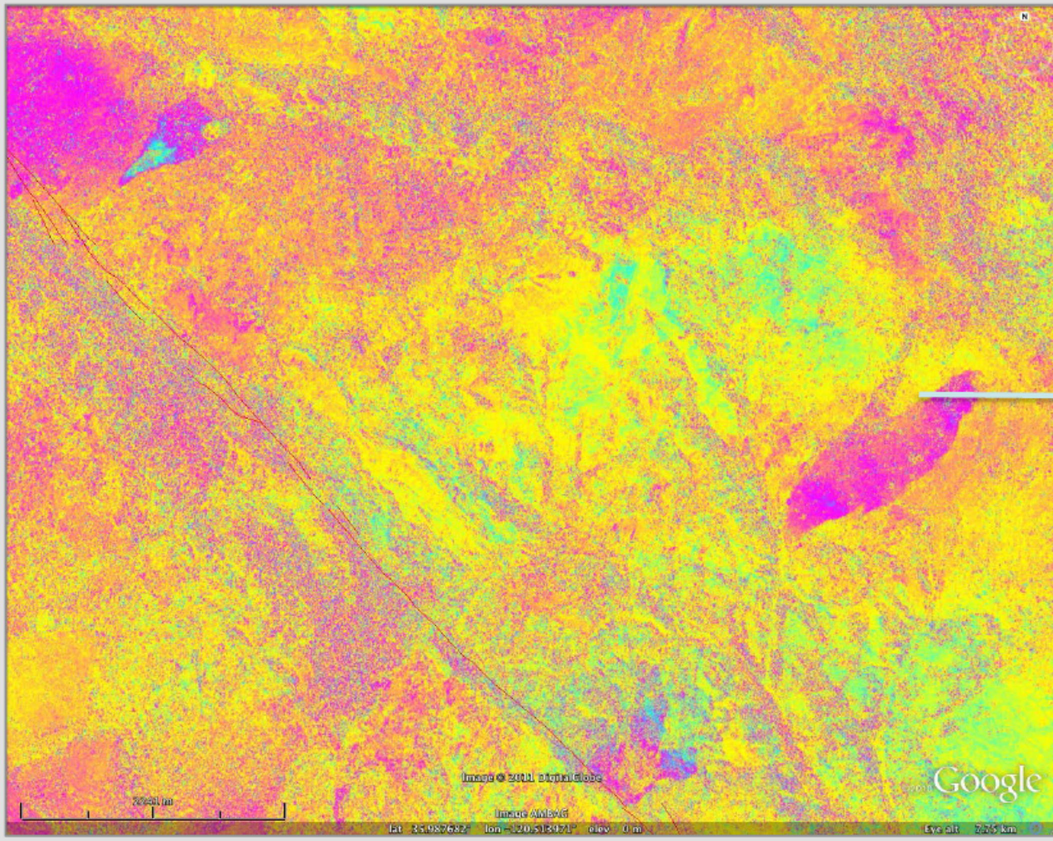
Radar remote sensing offers great potential for high resolution monitoring of ground surface changes over large areas at one time to detect movement on and near levees and for location of seepage through levees.

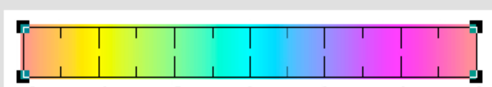
Through our DHS and NASA-funded projects to monitor levees in the Sacramento Delta and the Mississippi River, we are developing methods to use radar remote sensing to monitor levee health. These techniques are applicable to similar critical structures elsewhere, providing a needed asset for levee and dam disaster management throughout the United States.

The next step is to take this from the proof-of-concept research phase to a usable system employed by interested parties in a general safety program.

# Slow Creep Landslides

**189 days**
**5/11/2010 to 11/16/2010**




**427 days**
**5/11/2010 to 7/12/2011**