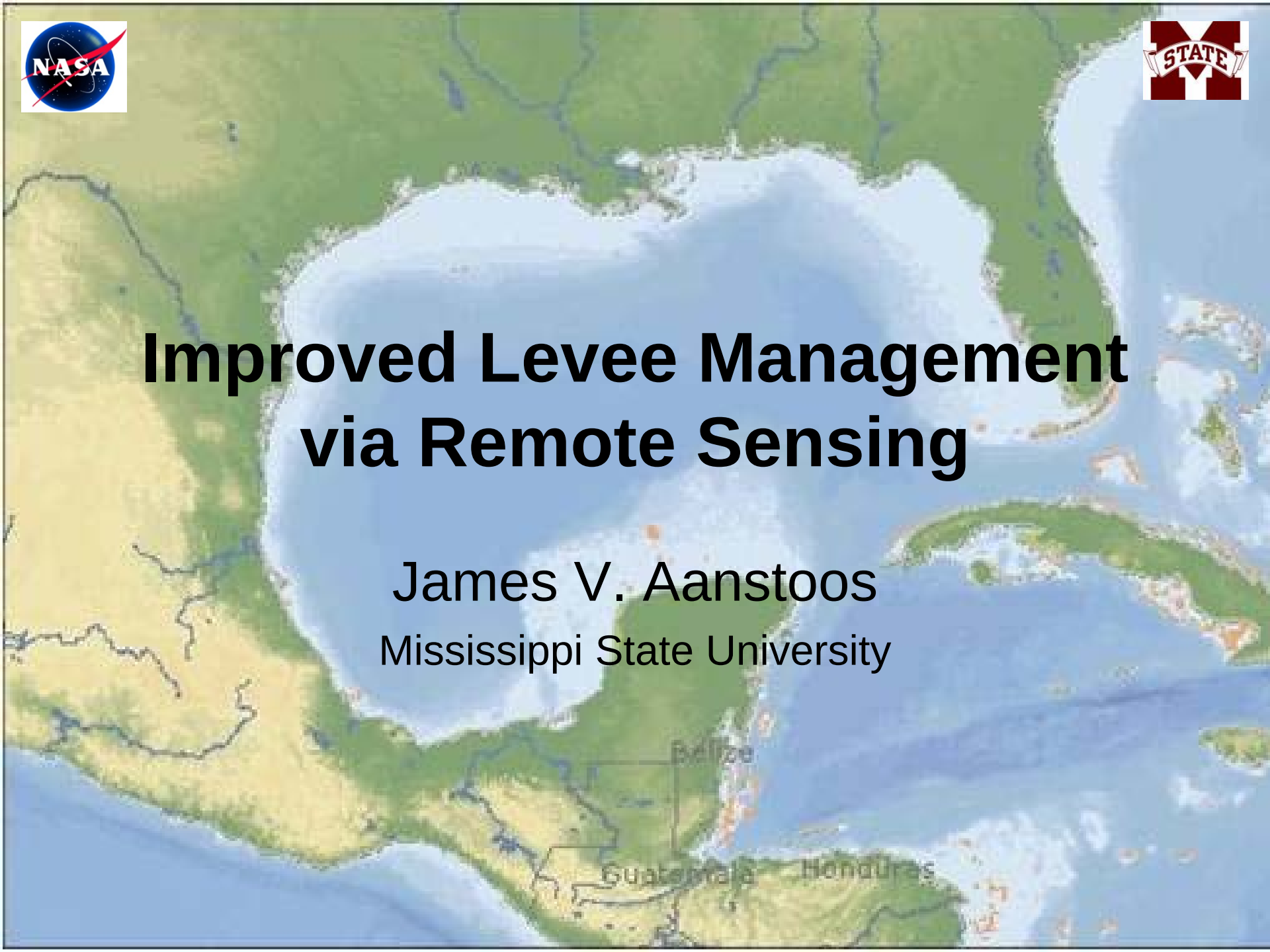


Improved Levee Management via Remote Sensing

James V. Aanstoos

Mississippi State University

Project Personnel

- **Geosystems Research Institute (GRI), Mississippi State University:**
  - Dr. James Aanstoos (Principal Investigator)
  - Dr. Rodrigo Nobrega -- Lalitha Dabbiru (Research Associates)
  - Matthew Lee (grad student)
- **Engineer Research and Development Center (ERDC), US Army Corps of Engineers:**
  - Mr. Joseph Dunbar - Dr. Lillian Wakeley
- **NASA Jet Propulsion Laboratory:**
  - Ms. Yunling Lou

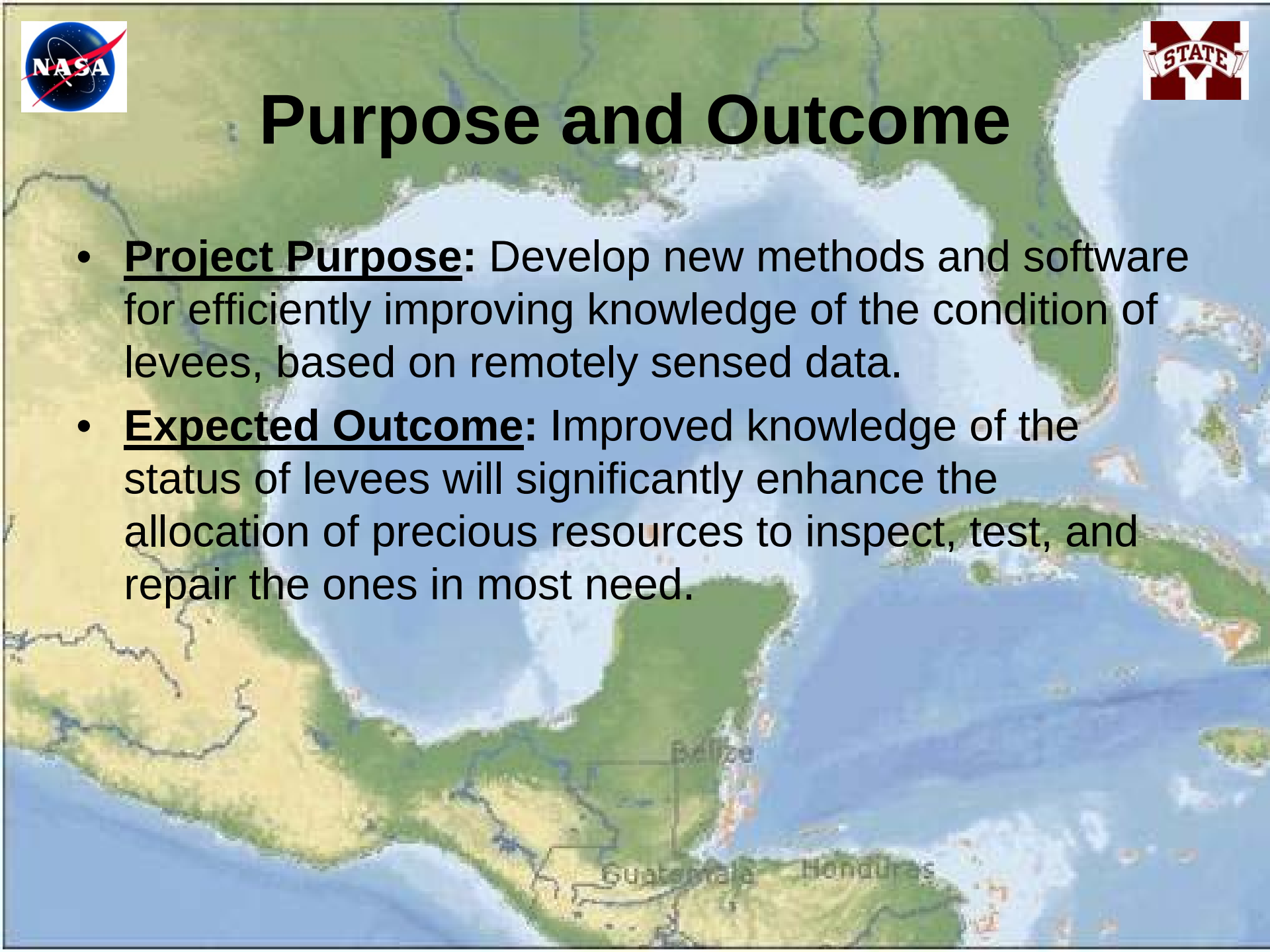
Need

- 100,000 miles of dams and levees nationwide
- National Committee on Levee Safety recommends*
  - "expand the existing federal National Levee Database (NLD) to include inventory and inspection... of all levees"
- No funds have been allocated for extending the inspection portion of this work beyond the small subset of these levees which are managed by the Corps of Engineers.

* 2009 report to Congress

Purpose and Outcome

- **Project Purpose:** Develop new methods and software for efficiently improving knowledge of the condition of levees, based on remotely sensed data.
- **Expected Outcome:** Improved knowledge of the status of levees will significantly enhance the allocation of precious resources to inspect, test, and repair the ones in most need.



Objective

The objective of this research is to develop a new method of using remotely sensed data to support levee condition assessment and screening procedures in an efficient and cost-effective manner based on the use of synthetic aperture radar.

Technical Approach

The objectives of this effort will be met by executing the following major tasks:

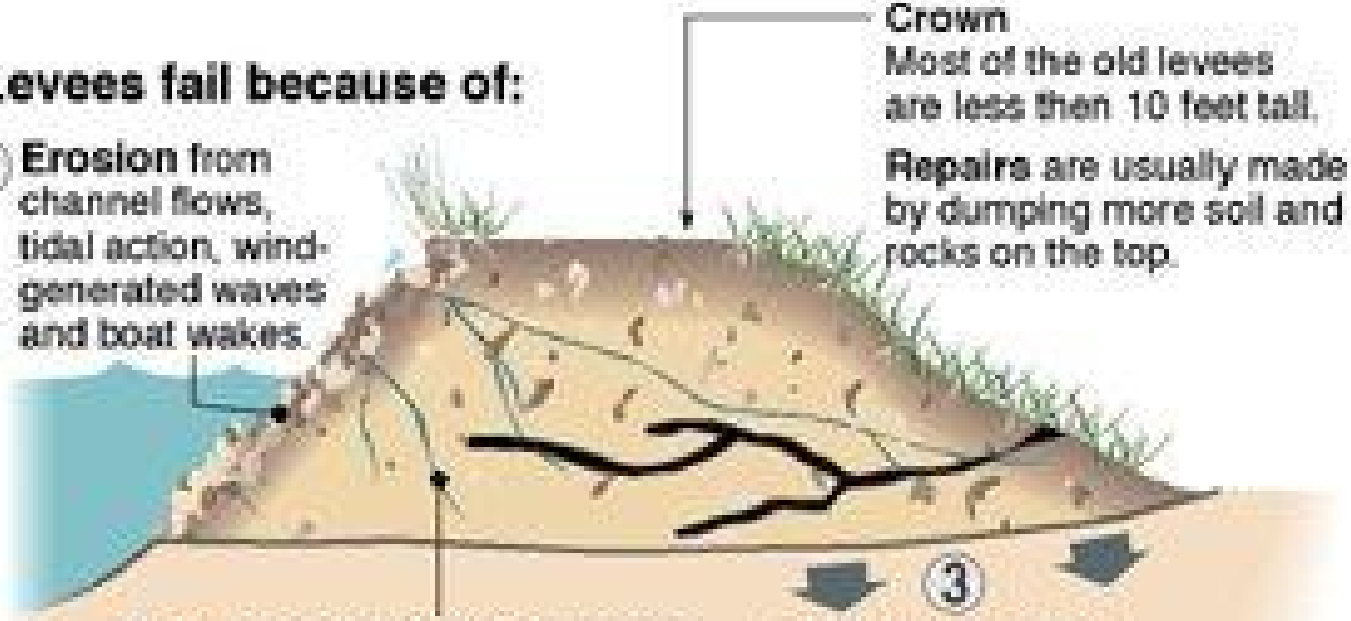
1. Remotely Sensed Data Collection
2. Data exploration and analysis
3. Ground Truth Inspections
4. Classification algorithm development and testing

Technical Approach

1. Data collection
    1.1 Develop collection plan: choose sites /dates, ancillary data
    1.2 UAVSAR Flight 1 collection; Flight 2 collection
    1.3 ASTER multispectral image data
2. Data exploration: compute statistics, visualize. Identify anomalies
3. Ground site visits (guided by data anomalies) and soil measurement
4. Classification algorithm development
    4.1 polarimetric SAR data relation with soil moisture variability
        4.1.1 Texture-based features
        4.1.2 H-A-alpha based features (Polsar pro)
    4.2 Interferometric algorithms to map subsidence
    4.3.Refine and test algorithms

Delta levee construction

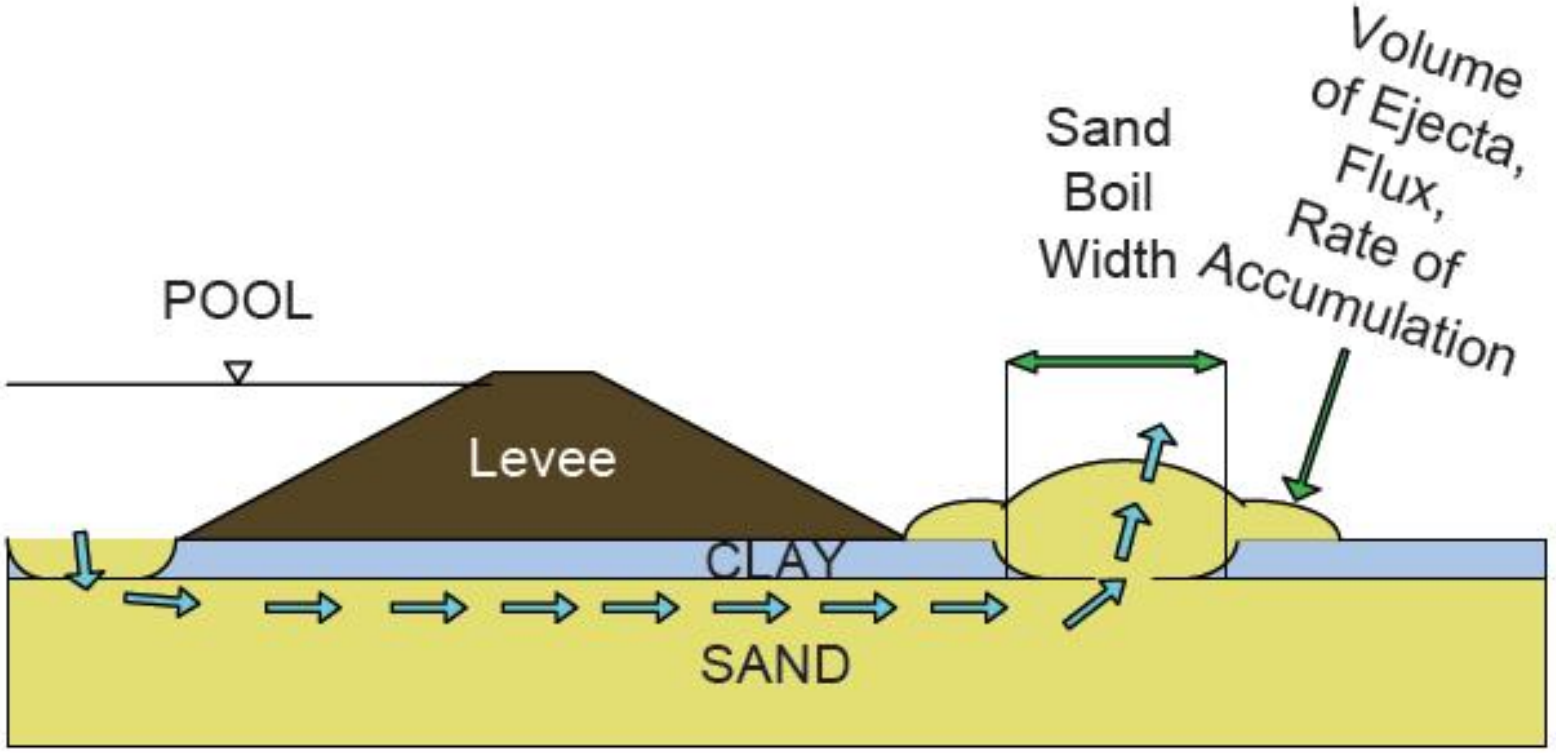
Most of the Delta's 100-year-old levees are made of the loose sand and peat soil that was dredged to deepen or create sloughs and channels. The resulting below-sea-level islands have been mainly used for farming and ranching.



Source: California Department of Water Resources

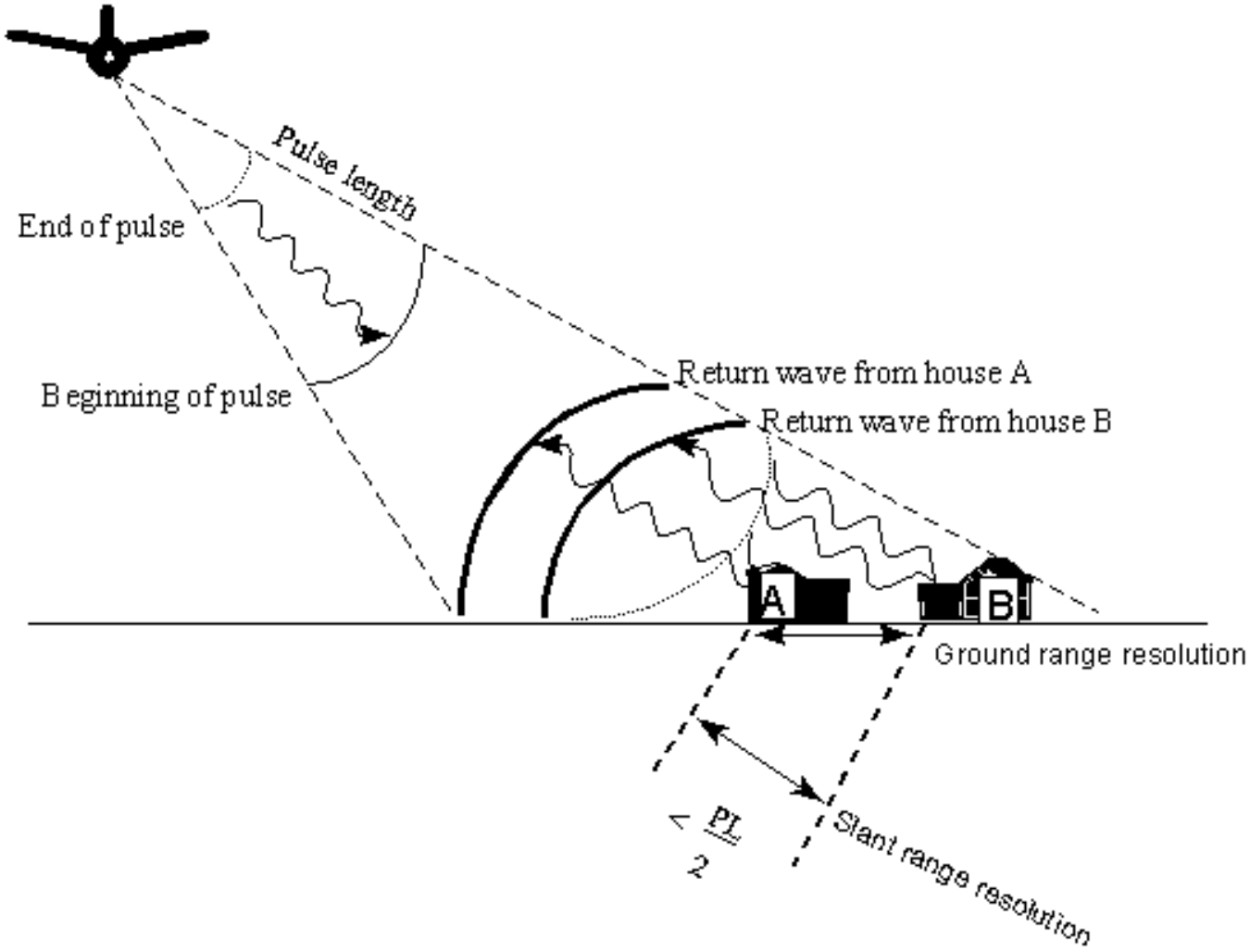
TIMES

Sand Boils



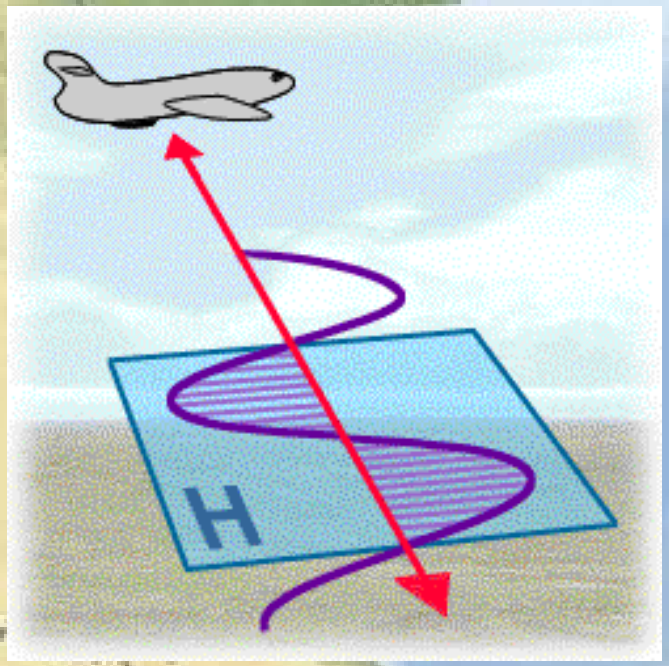
Hynes (2007)

Imaging RADAR Geometry

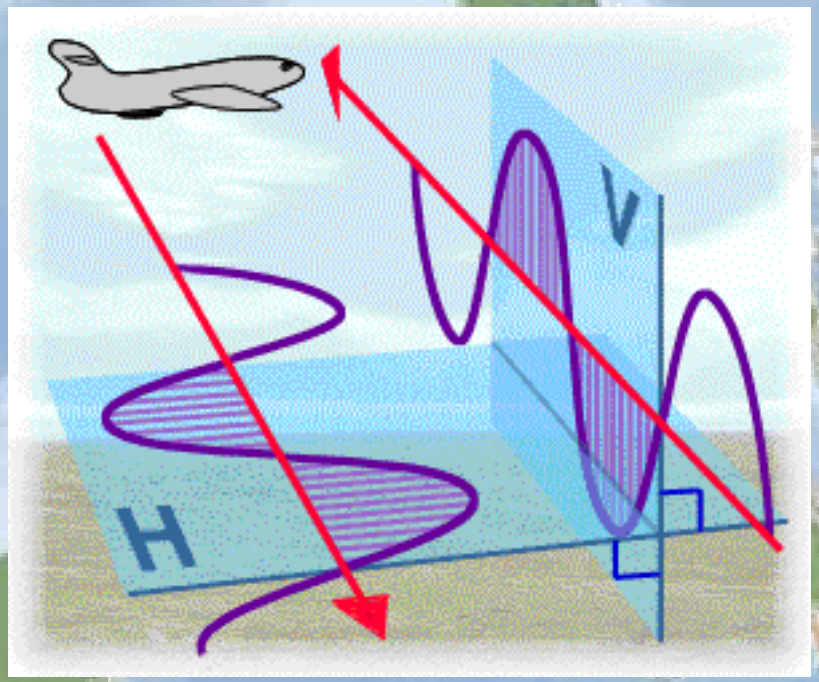


Dependence of range resolution on pulse length
(after Lillesand and Kiefer, 1994)

RADAR Polarization



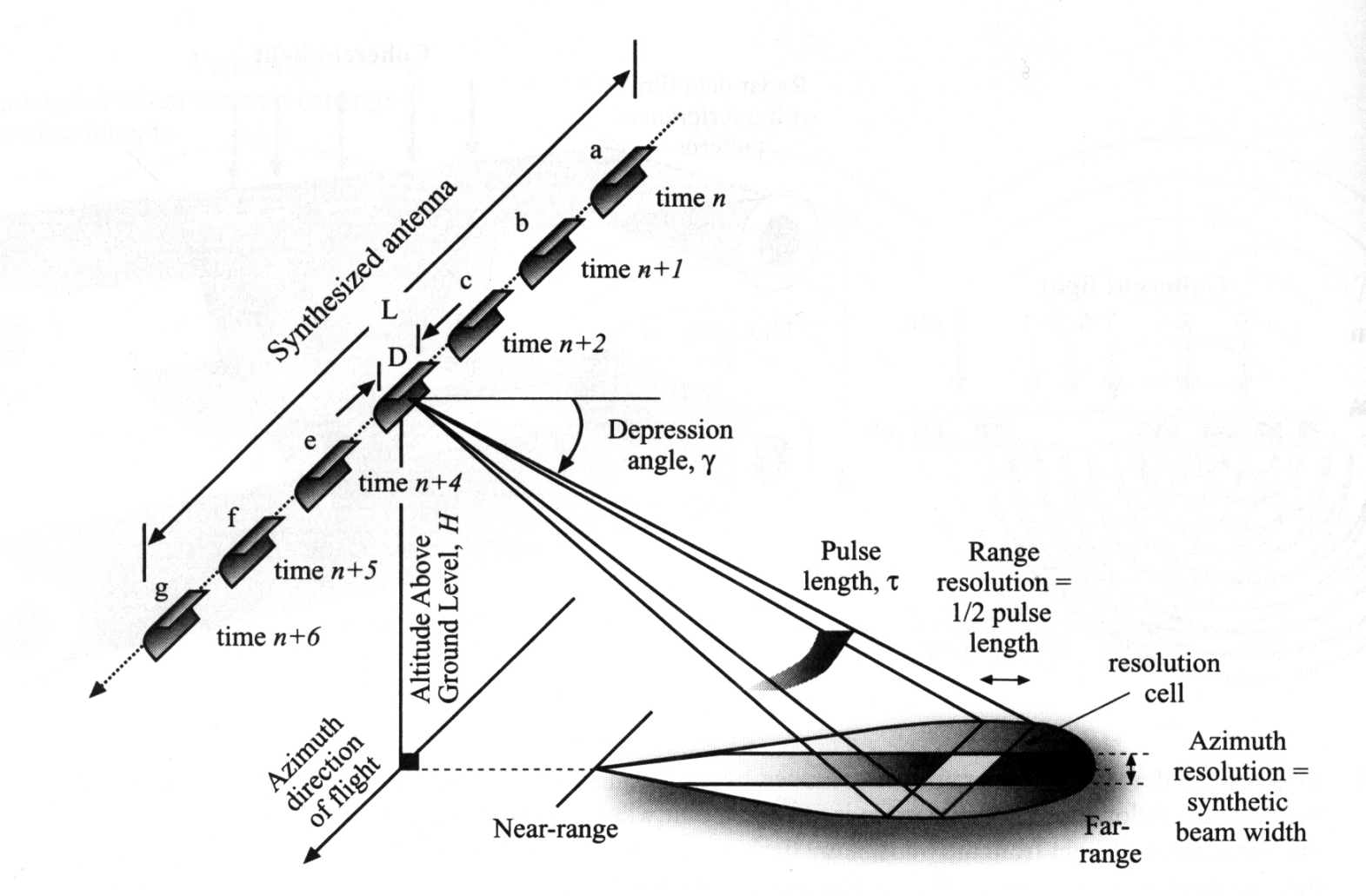
An airborne radar operating in the "Horizontal transmit - Horizontal receive" or HH polarization mode.



An airborne radar operating in the "Horizontal transmit - Vertical receive" or HV polarization mode.

[Canada Centre for Remote Sensing: http://ccrs.nrcan.gc.ca]

RADAR (SAR)


Synthesized antenna
L
D
a
b
c
e
f
g
time n
time n+1
time n+2
time n+4
time n+5
time n+6
Depression angle, γ
Altitude Above Ground Level, H
Azimuth direction of flight
Pulse length, τ
Range resolution = 1/2 pulse length
resolution cell
Azimuth resolution = synthetic beam width
Near-range
Far-range

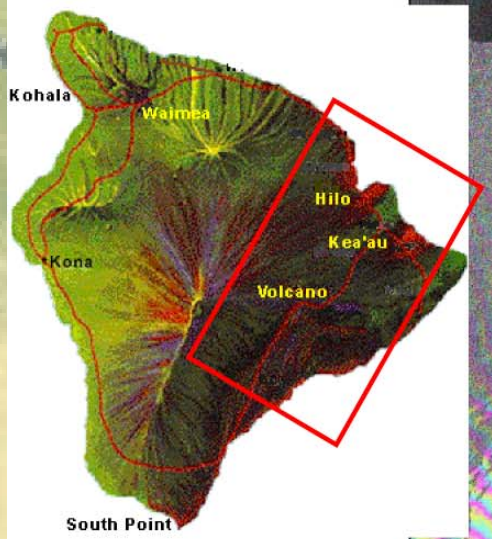
InSAR Phase calculation

$$E_1 = e^{j\phi_{scatterer}} e^{-j\frac{4\pi r_1}{\lambda}}$$

$$E_2 = e^{j\phi_{scatterer}} e^{-j\frac{4\pi r_2}{\lambda}}$$

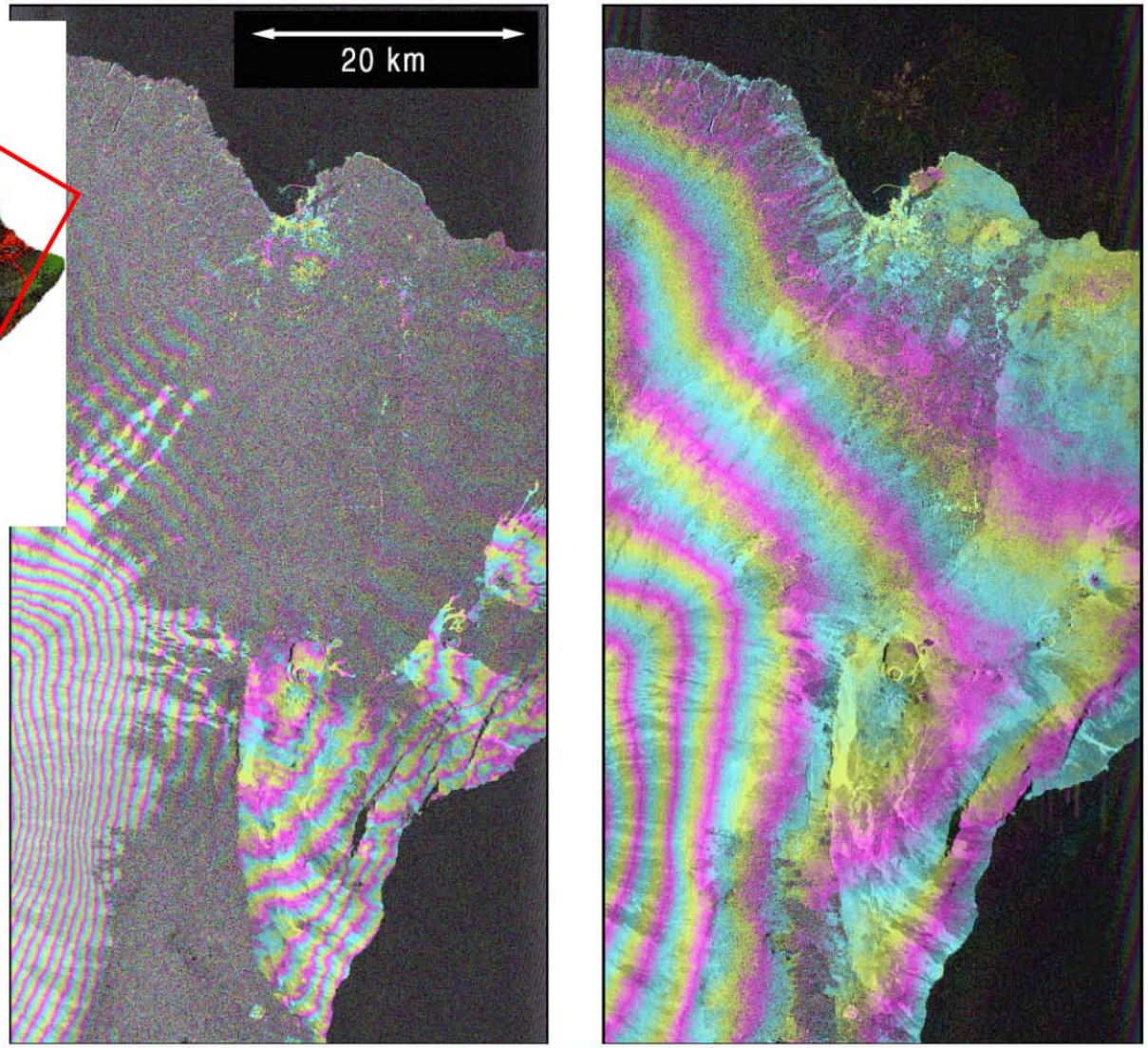
$$E_1 E_2^* = e^{-j\frac{4\pi(r_1 - r_2)}{\lambda}}$$

or, simply, $\phi = \frac{4\pi}{\lambda}(r_1 - r_2)$



C-Band λ = 5.6 cm

L-Band λ = 24 cm

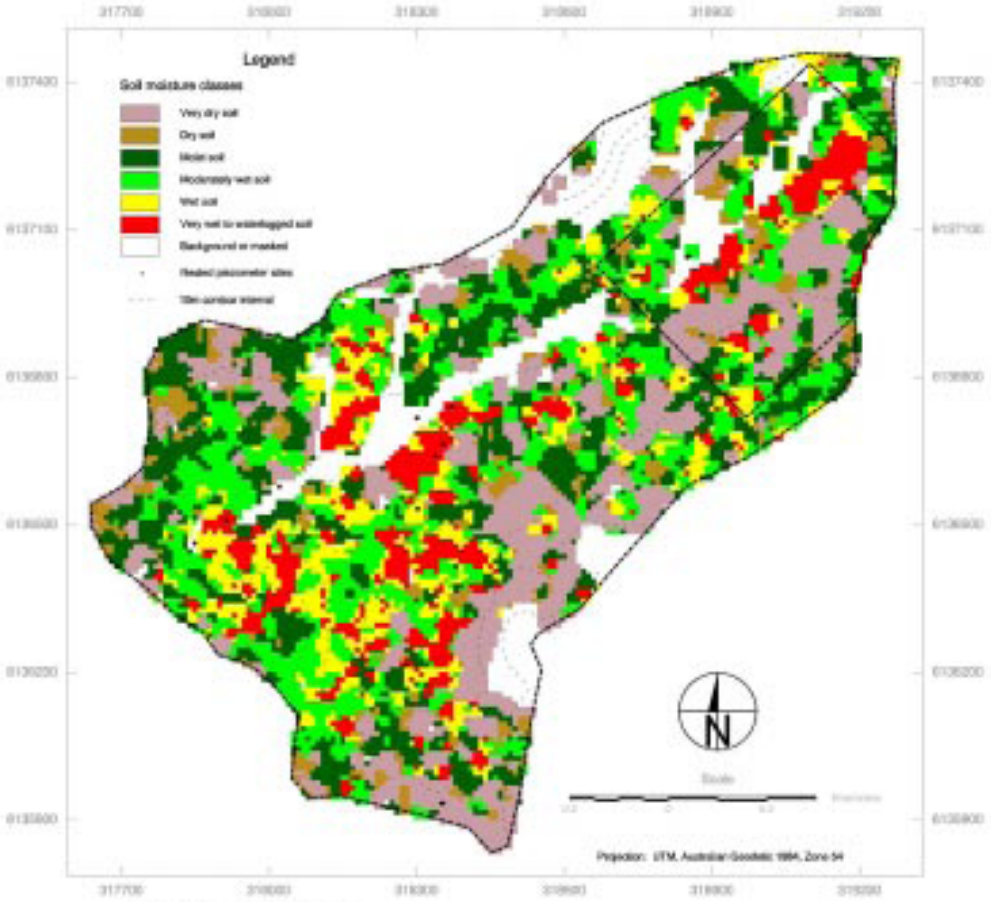


L-band greatly improves correlation

Data acquired by SIR-C Space Shuttle Mission, April/October 1994

1 Cycle of Interferometric Phase

RADAR derived soil moisture: Herrmann's catchment study area, Mt Lofty Ranges



Produced by: CSIRO Land & Water, Adelaide
Date: July 1999
Data Source: Compiled by D.A. Bruce from polarimetric analysis of airborne RADAR (AIRSAR) data acquired September 1993 by NASA/JPL and resampled to 10 m pixel size

CSIRO LAND and WATER

D. Bruce, P. Davies and R. Fitzpatrick, 1999: Validating Soil Moisture Estimates from Polarimetric Radar Using GIS Models : further results from the 1993 AIRSAR mission to Australia.

UAVSAR

UAVSAR Instrument

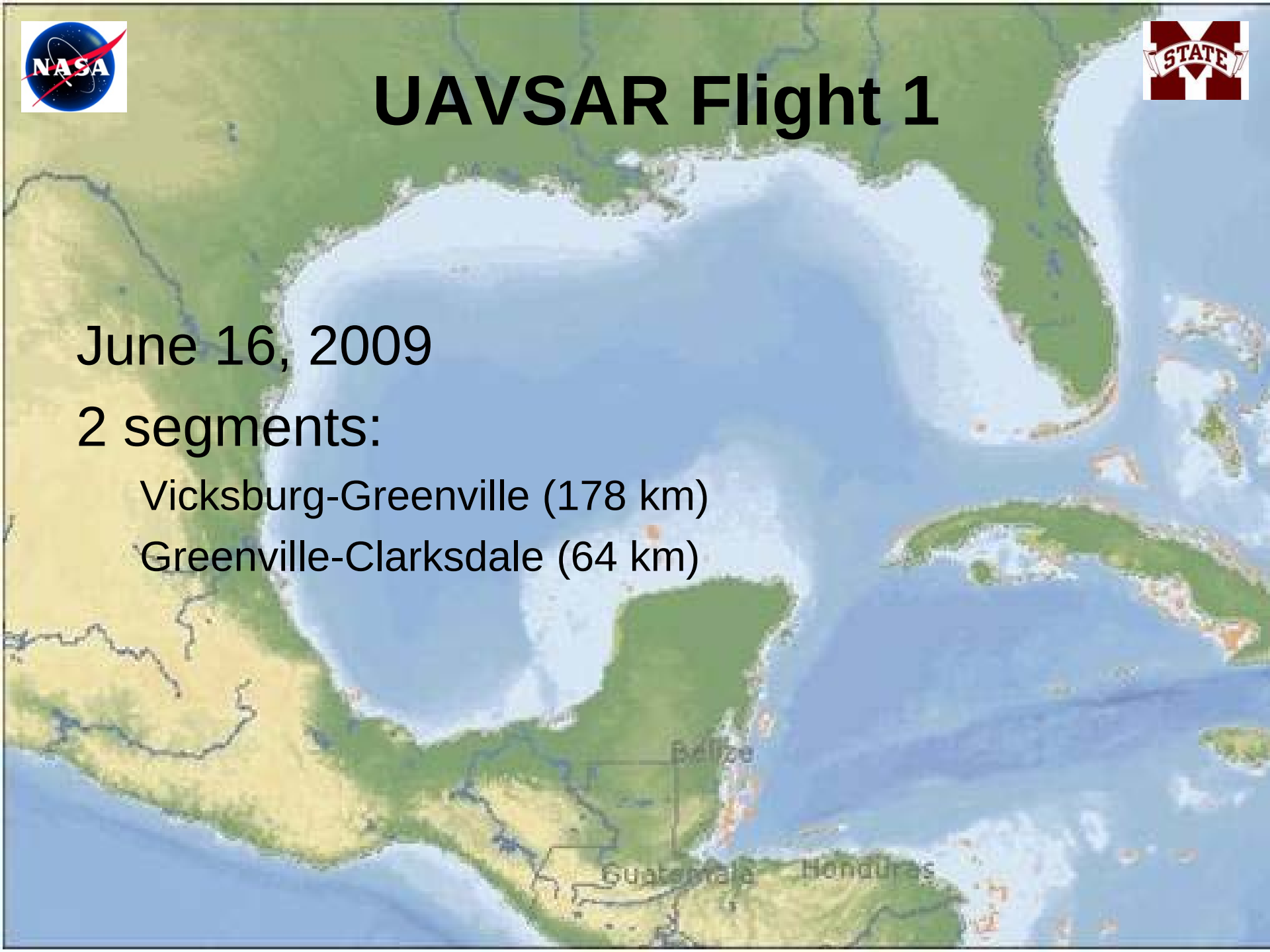
Parameter	Value
Frequency	L-band
Bandwidth	80 MHz
Range Resolution	1.8 m
Polarization	Full Quad-Polarization
Raw ADC Bits	12 baseline
Waveform	Nominal Chirp/Arbitrary Waveform
Antenna Dimensions	0.5 m range/1.5 azimuth
Azimuth Steering	Greater than ±20°
Power	> 2.0 kW
Polarization Isolation	<-20 dB

UAVSAR Flight 1

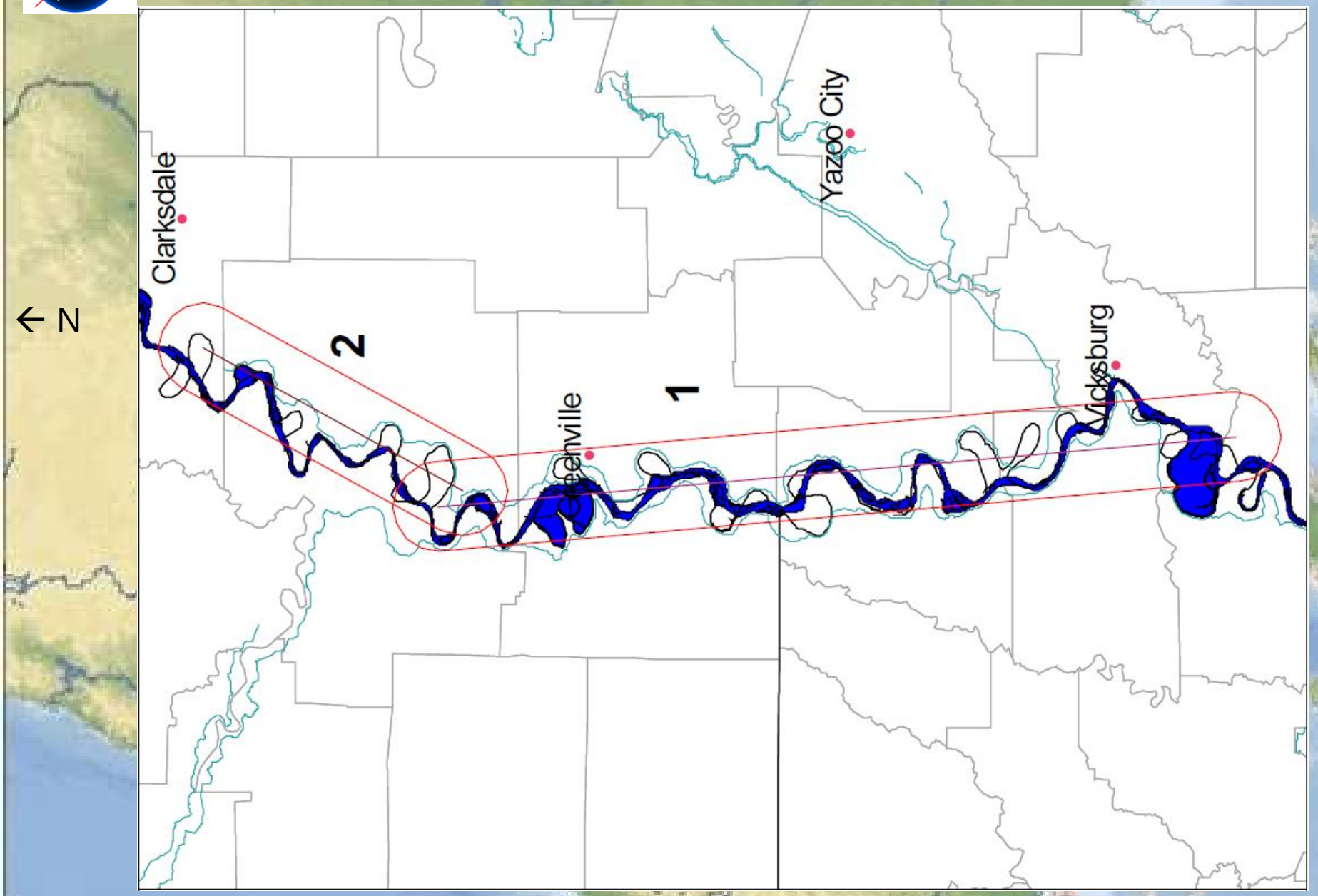
June 16, 2009

2 segments:

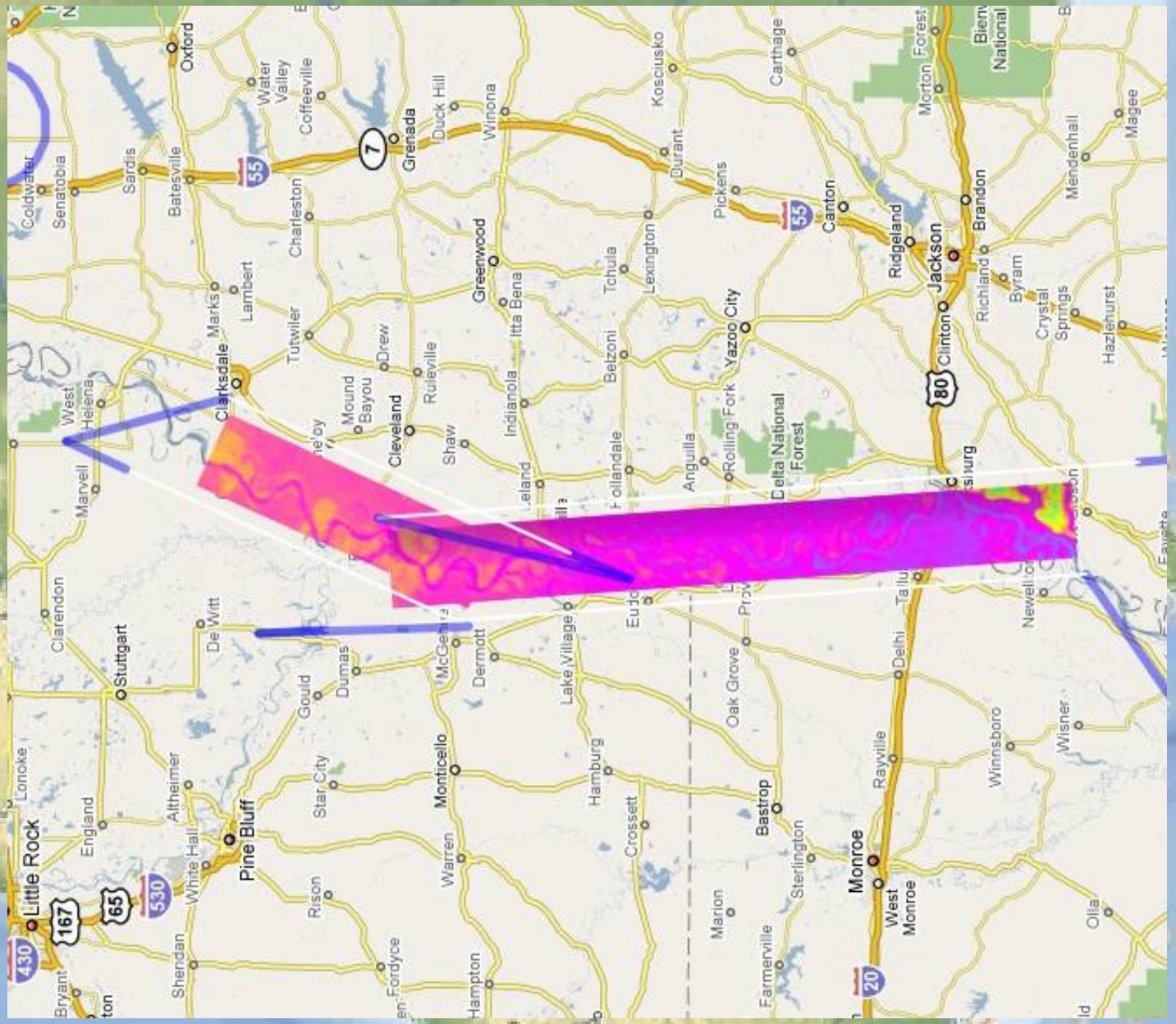
- Vicksburg-Greenville (178 km)
- Greenville-Clarksdale (64 km)



Flight planning



Flight planning



General Study Area

N
W E
S

Map Composition:
- UAVSAR (Lines 1 and 2)
- USGS Digital Raster Graphics 1:250.000

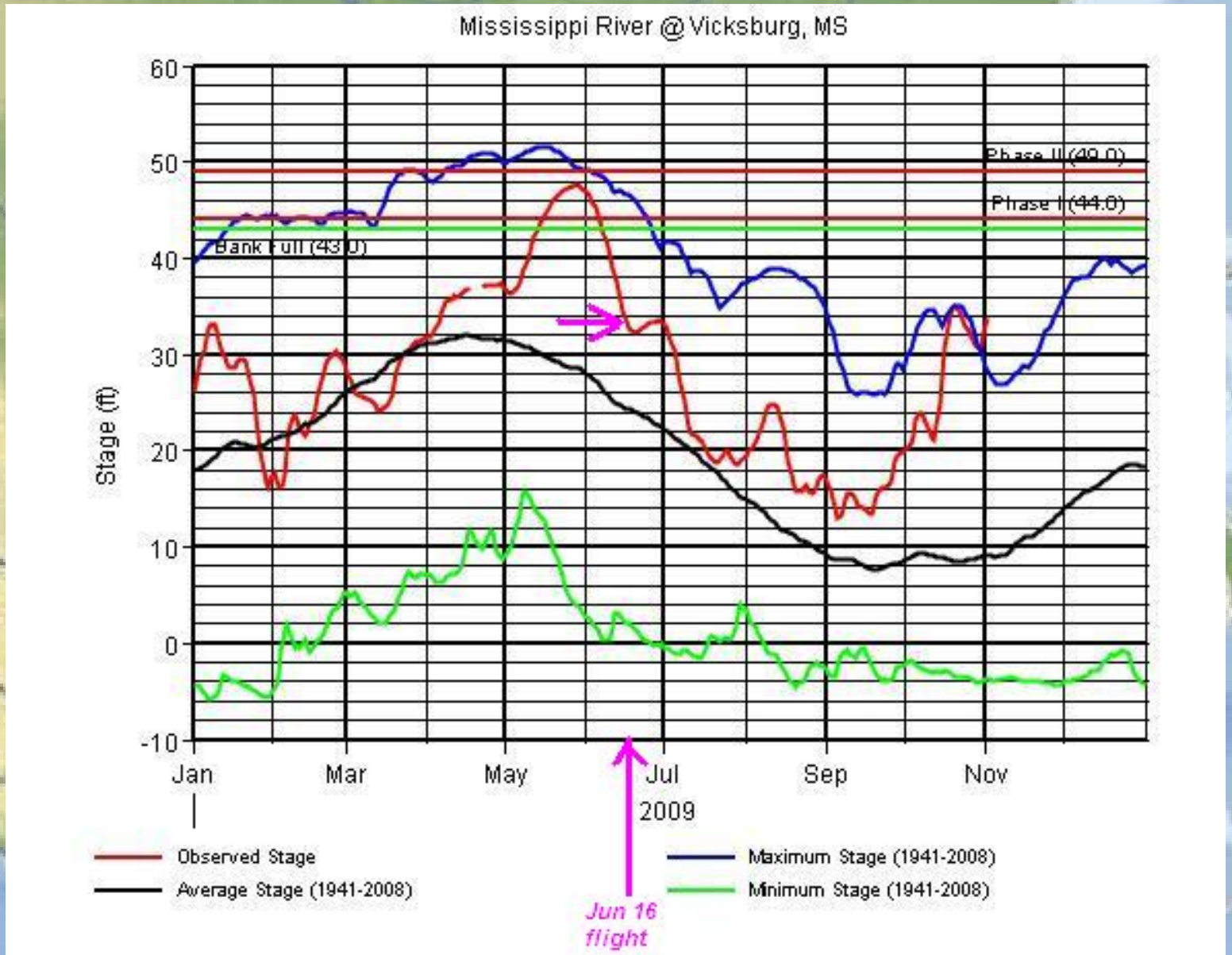
Geographic Coordinate System
WGS-84

Scale:

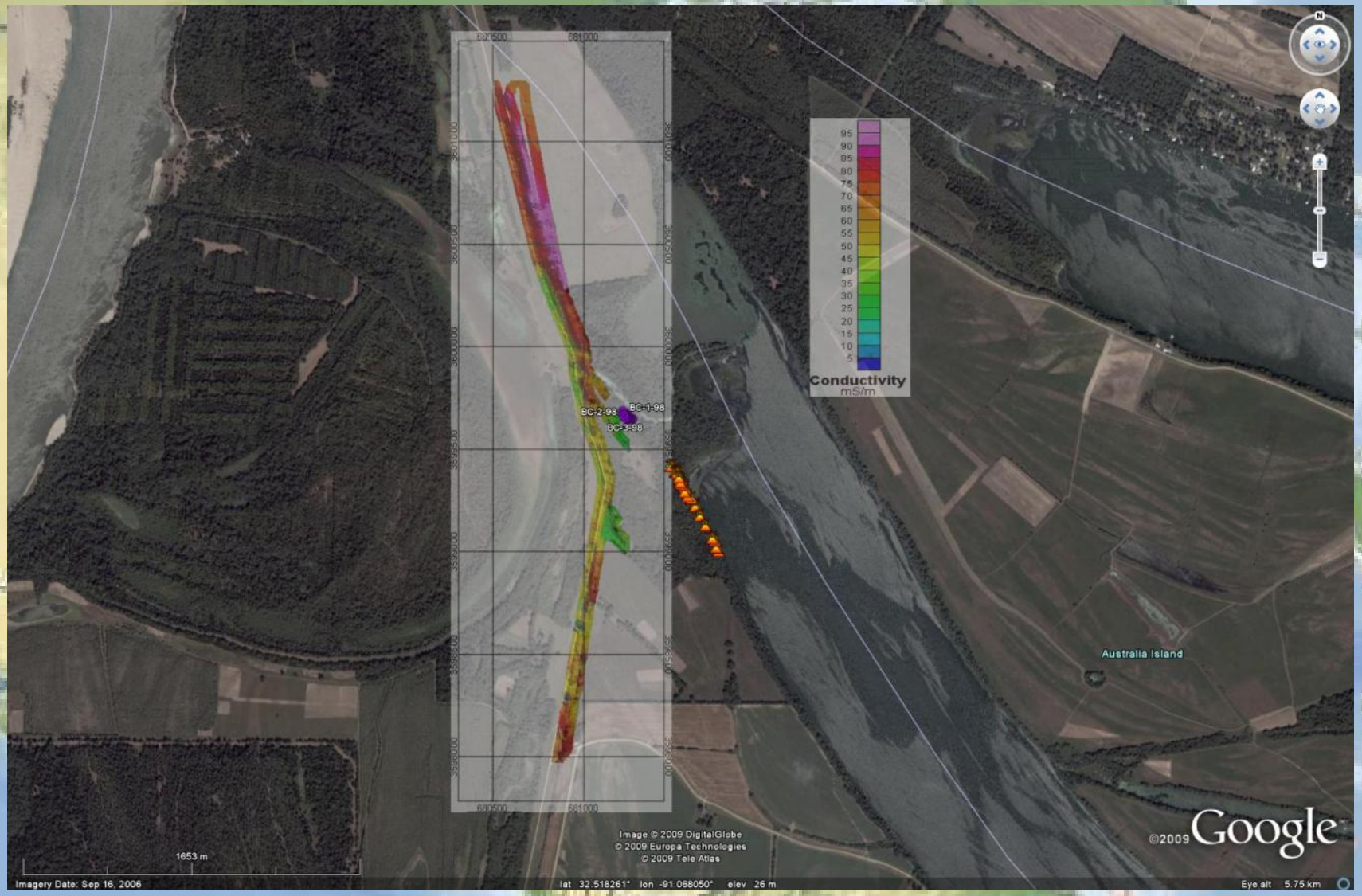
0 5 10 20 30 Miles

OBSERVATIONS:

River Stage


Mississippi River @ Vicksburg, MS
Stage (ft)
60
50
40
30
20
10
0
-10
Jan
Mar
May
Jul
Sep
Nov
2009
Phase II (49.0)
Phase I (44.0)
Bank Full (43.0)
Observed Stage
Average Stage (1941-2008)
Maximum Stage (1941-2008)
Minimum Stage (1941-2008)
Jun 16 flight

Ground “Truth” Data:
Buck Chute Levee at Eagle Lake, MS



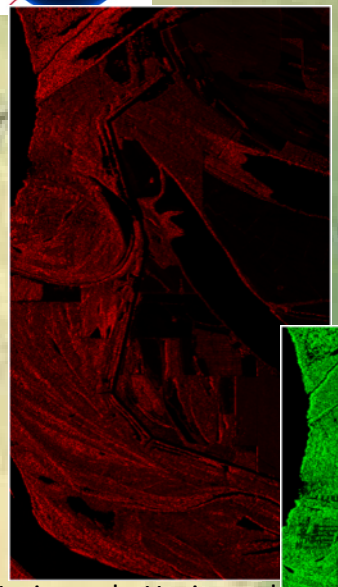
Buck Chute Levee Site Visit 2009

Buck Chute Levee Site

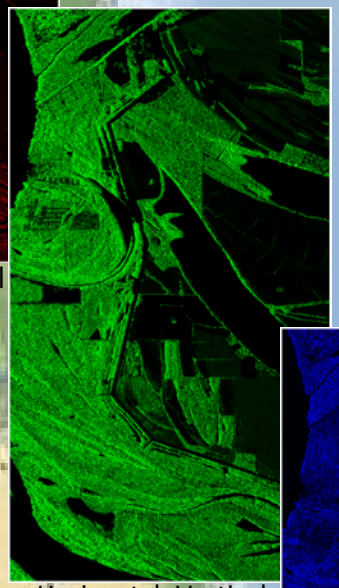
RGB Optical image 2007 National Agriculture Imagery Program - NAIP

Sandboils

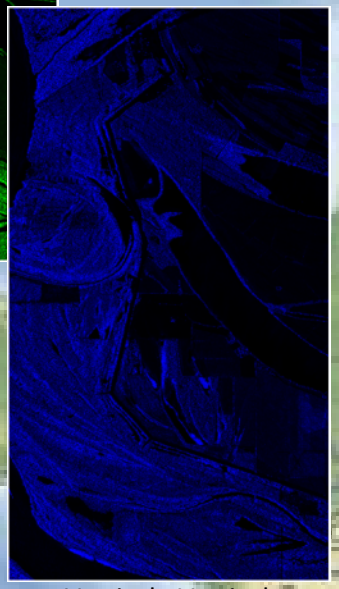
UAVSAR Data, Buck Chute vicinity



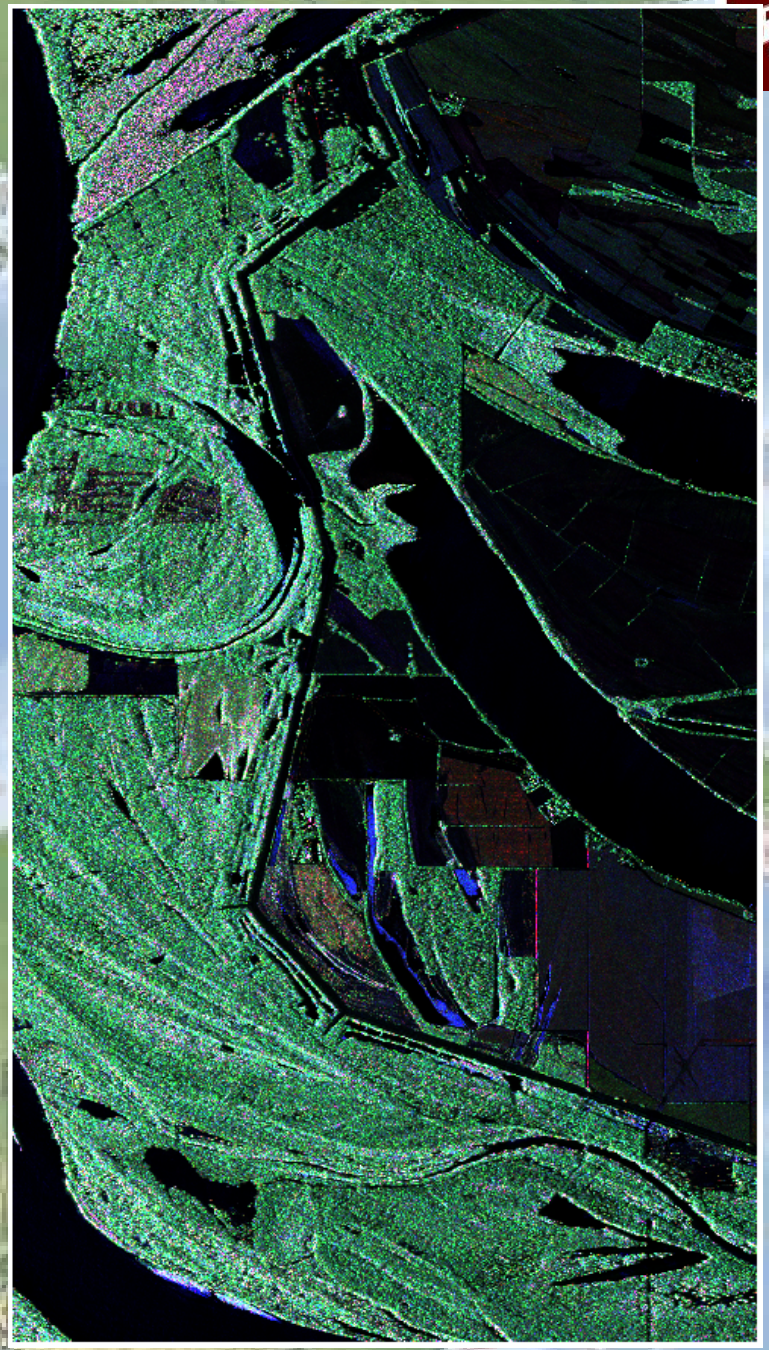
Horizontal - Horizontal



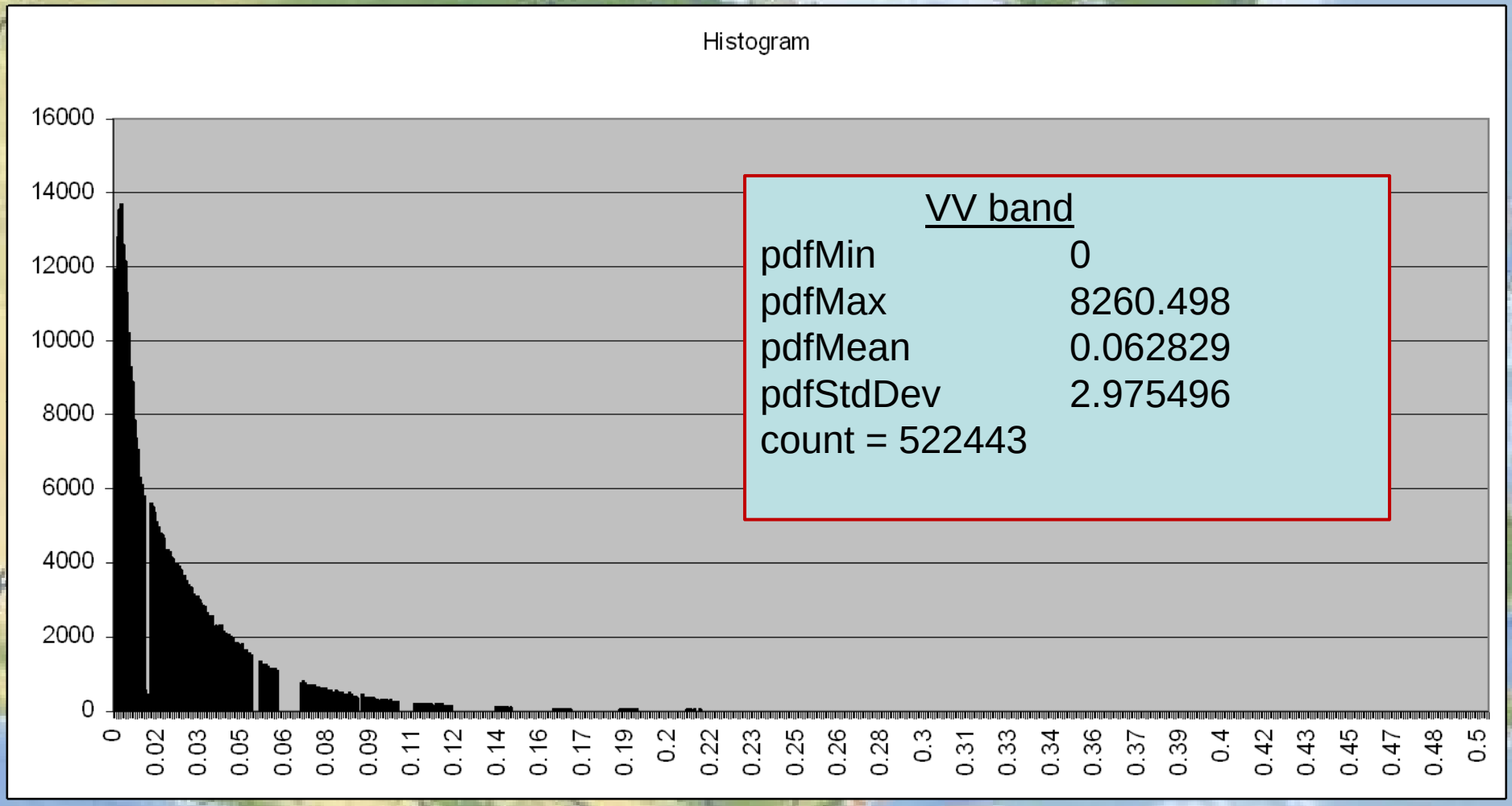
Horizontal -Vertical



Vertical - Vertical

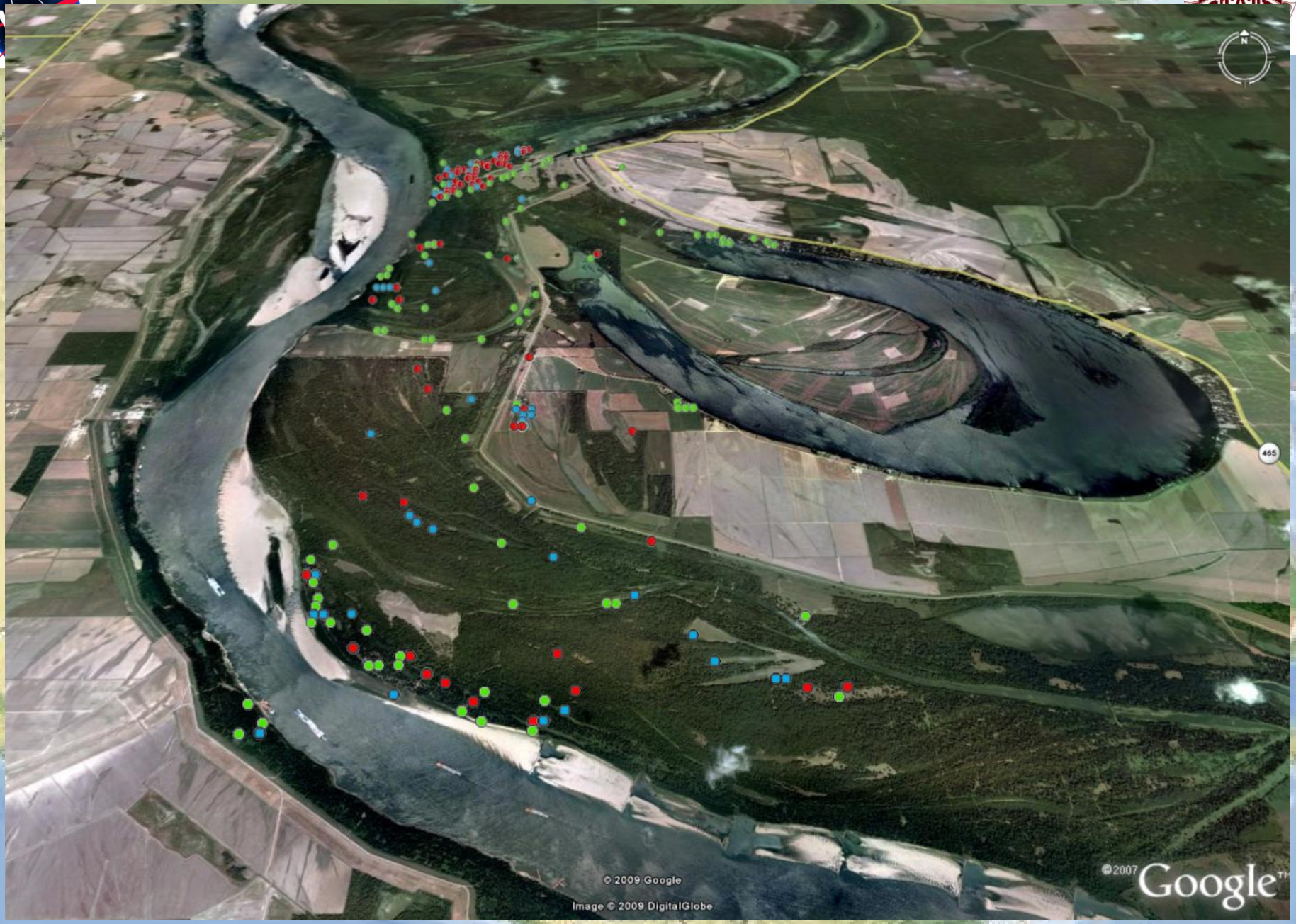


Histograms

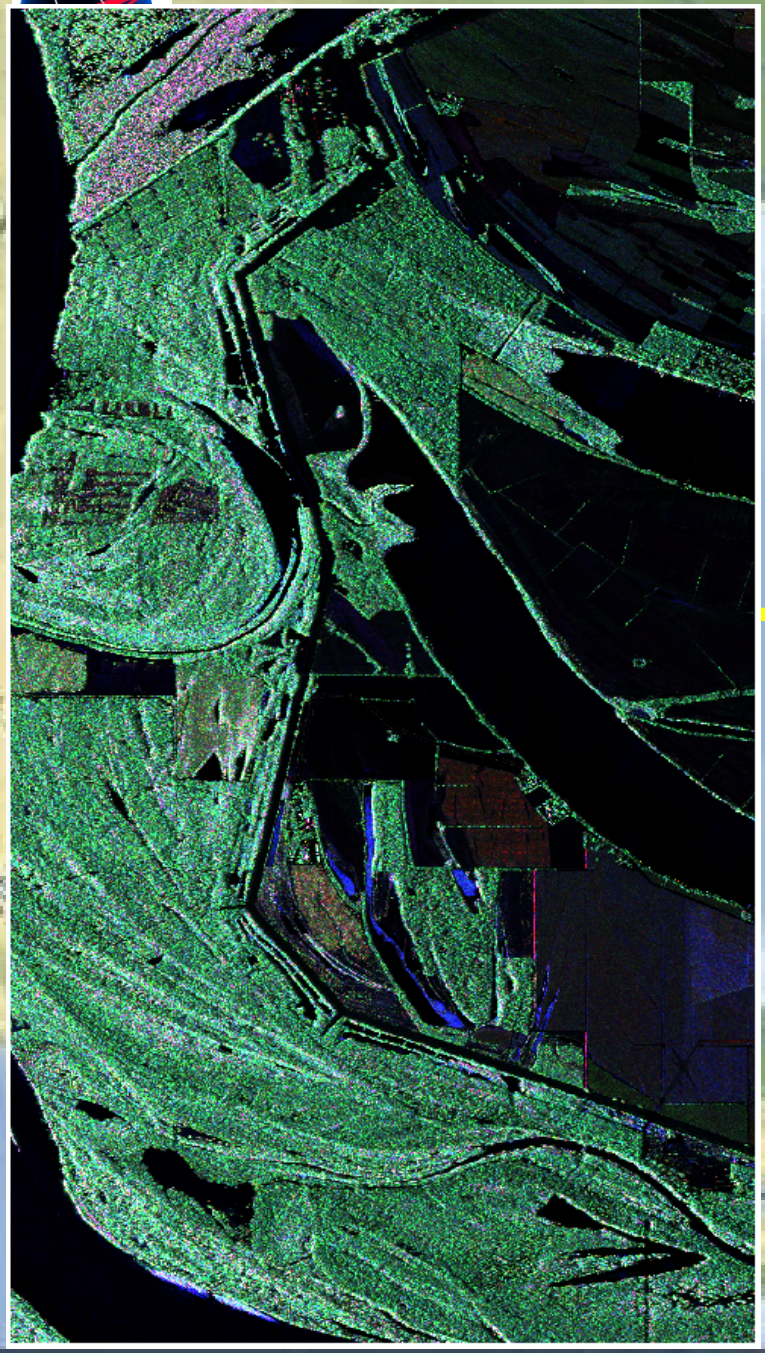


VV Backscatter magnitude (32-bit floating point values)

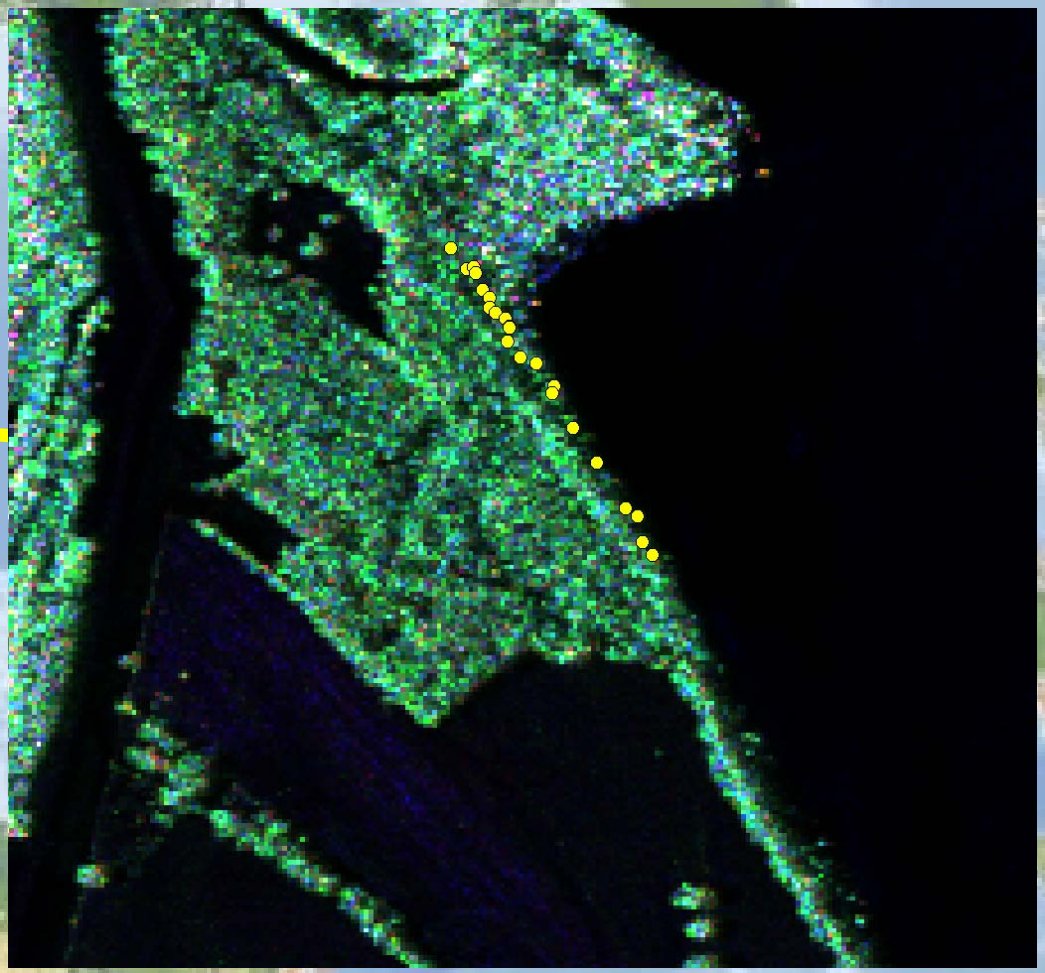
Maxima in HH, VV, HV



UAVSAR 32-bit (ESRI Arcgis - stretching using standard deviation)

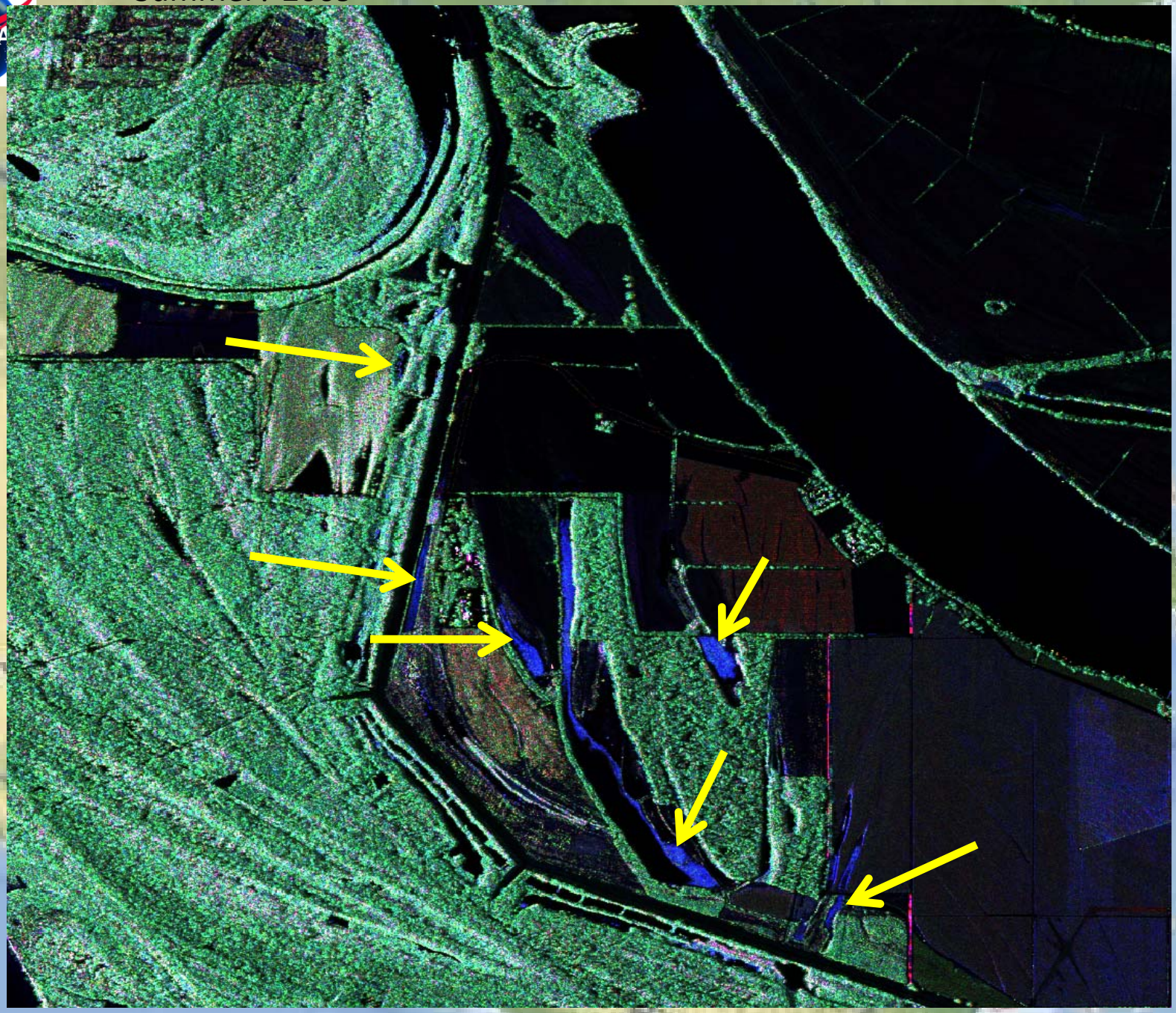


Sandboils



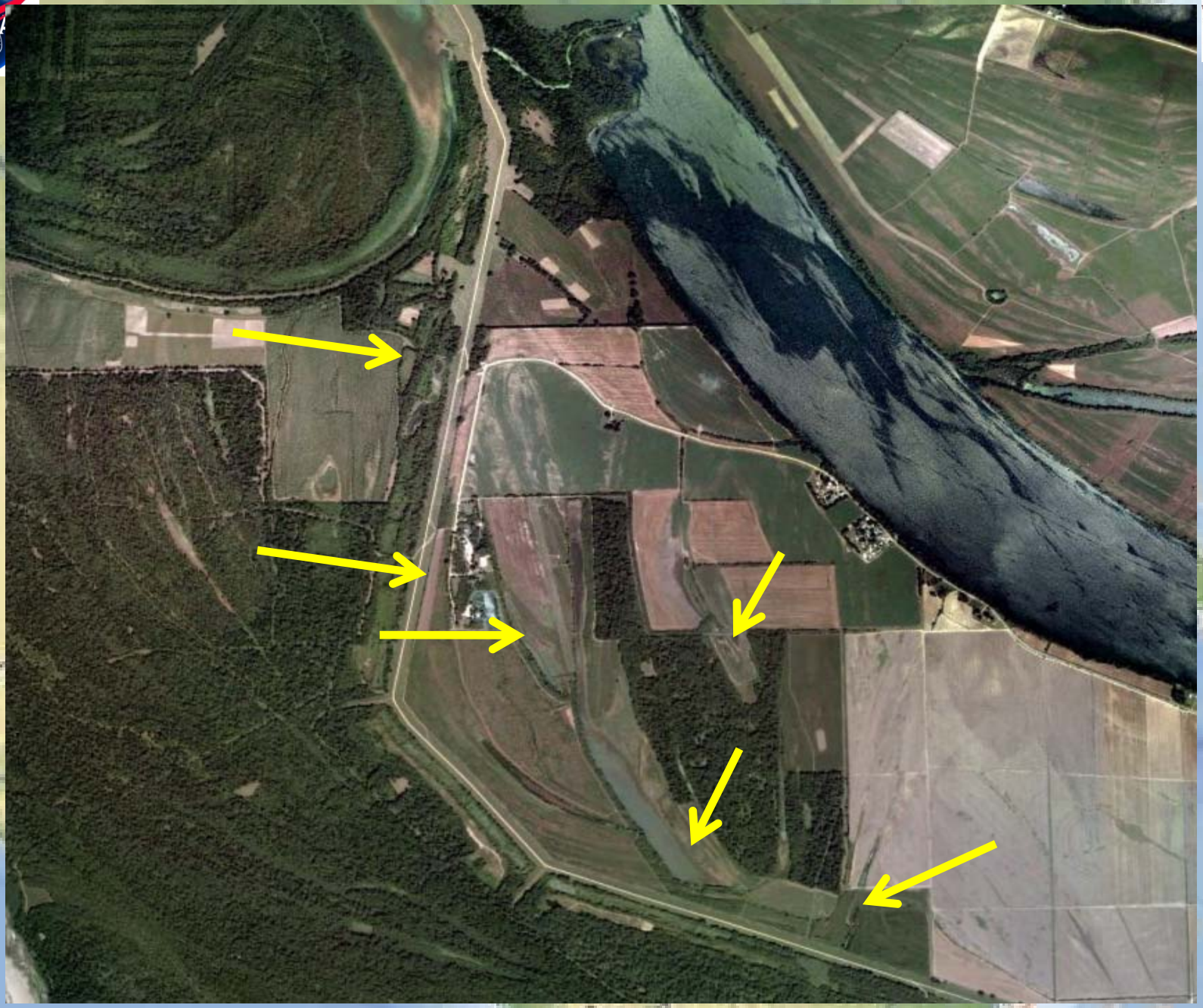
Statistical distance image for GLCM homogeneity feature in HV

Summer? 2009

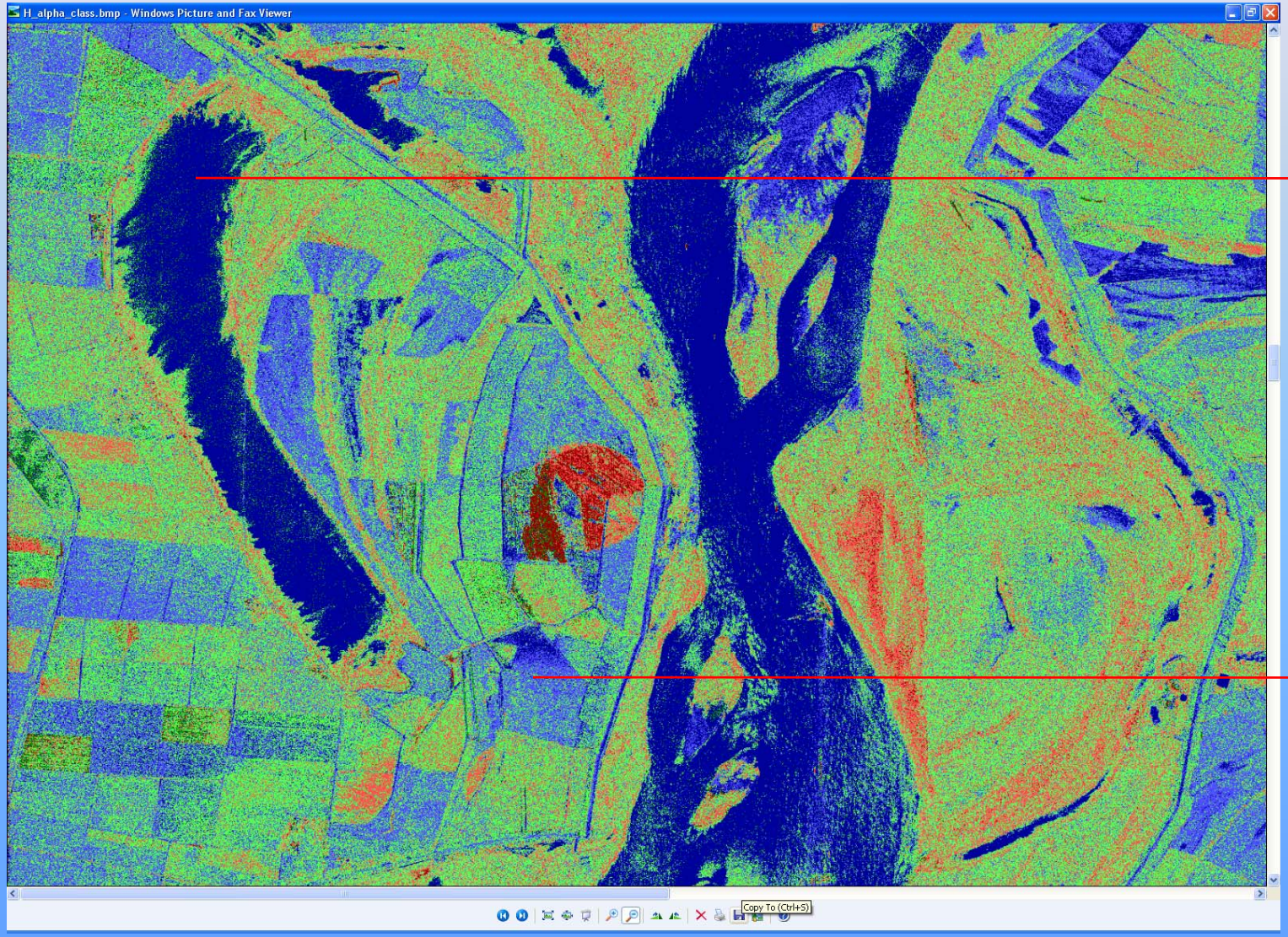


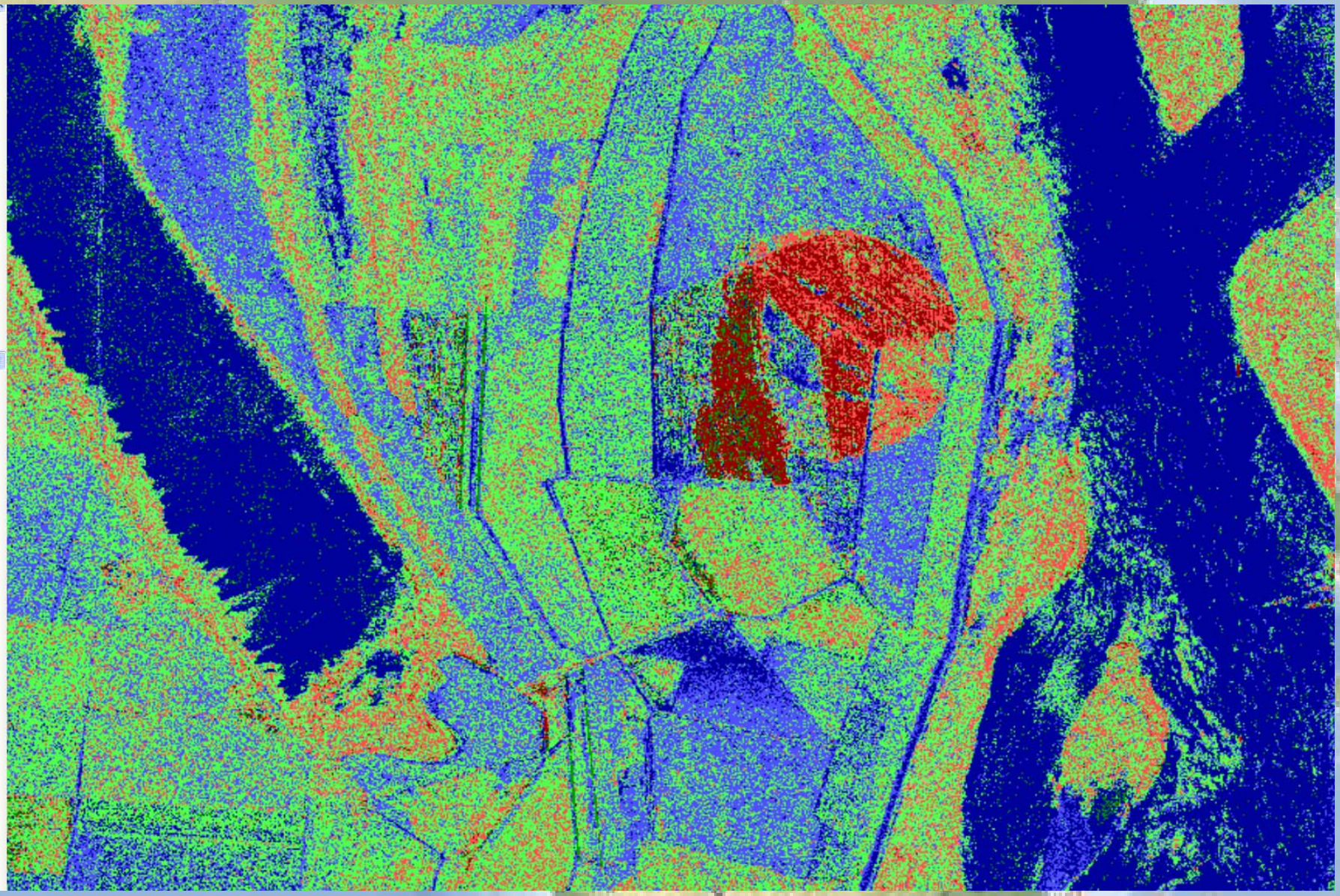
Fall/Winter 2004

Google Earth (June 2009)

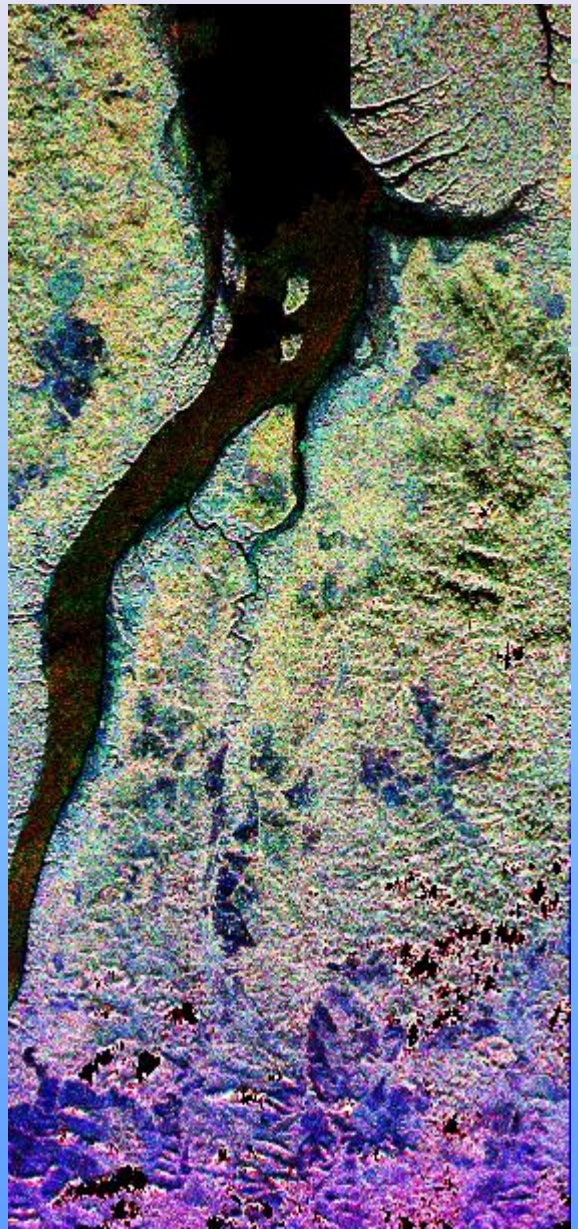


H-Alpha Classification





Thank you



PCA, LDA, S-LDA, MCDF

Posterior Probabilities / Scores

HH
HV
VV
Ancillary / Derived Features

Features from GLCM
Features from GLCM
Features from GLCM

Dimensionality Reduction
Dimensionality Reduction
Dimensionality Reduction
Dimensionality Reduction

Classifier
Classifier
Classifier
Classifier

Decision/ Score Fusion

Final Score / Decision

GLCM/GTSD Features:

Estimate texture (GLCM) at different angles (0, 45, 90, 135)

Energy, Variance, Correlation, Uniformity, Inverse Difference Moment, Entropy

Decision (L)/Score(C) Fusion:

$$C(L_i \mid x) = \sum_{j=1}^{n} \alpha_j p_j(L_i \mid x)$$

$$L = \underset{i \in \{1,2...C\}}{\arg\max}\ C(L_i \mid x)$$

Grey-Level Co-occurrence Matrix (GLCM)

- For a position operator *p*, we can define a matrix P_{ij} that counts the number of times a pixel with grey-level *i* occurs at position *p* from a pixel with grey-level *j*.
- For example, if we have three distinct grey-levels 0, 1, and 2, and the position operator p is “lower right”, the counts matrix P of the image

0 0 0 1 2
1 1 0 1 1
2 2 1 0 0
1 1 0 2 0
0 0 1 0 1

is $P =$

4 1 0
2 3 2
1 2 0

- If we normalize the matrix *P by the total number of pixels so that each element is between 0 and 1, we get a grey-level co-occurrence matrix C.*

Features extracted from the GLCM

$$f_{ENERGY} = \sum_i \sum_j [p(i,j)]^2$$

$$f_{CORRELATION} = \frac{\sum_i \sum_j (ij)p(i,j) - \mu_x \mu_y}{\sigma_x \sigma_y}$$

$$f_{VARIANCE} = \sum_i \sum_j (i-\mu)^2 p(i,j)$$

$$f_{HOMOGENEITY} = \sum_i \sum_j \frac{p(i,j)}{1+(i+j)^2}$$

$$f_{INERTIA} = \sum_i \sum_j (i-j)^2 p(i,j)$$

$$f_{ENTROPY} = -\sum_i \sum_j p(i,j) \log\{p(i,j)\}$$