Development of a Multiscale Monitoring and Health Assessment Framework for Effective Management of Levees and Flood-Control Infrastructure Systems

Award Number 70NANB10H018

Joint-Venture:
Rensselaer Polytechnic Institute
(M. Zeghal, T. Abdoun and B. Yazici)
and
Geocomp (A. Marr)

NIST Civil Infrastructure Showcase

March 13-14, 2014

Joint-Venture Research Team

Rensselaer Polytechnic Institute

- M. Zeghal: System Identification and Health Assessment (project leader)
- T. Abdoun: Field Monitoring, Testing and Sensor Development
- B. Yazici: Remote Sensing and Radar Technology
- V. Bennet: Field Sensors and Monitoring (project manager)

Geocomp

- A. Marr: Monitoring Strategies and Decision tools
- D. Ha: Field sensors and Data transfer
- R. Nyren: Data Collection and Management

Measurand (Contractor)

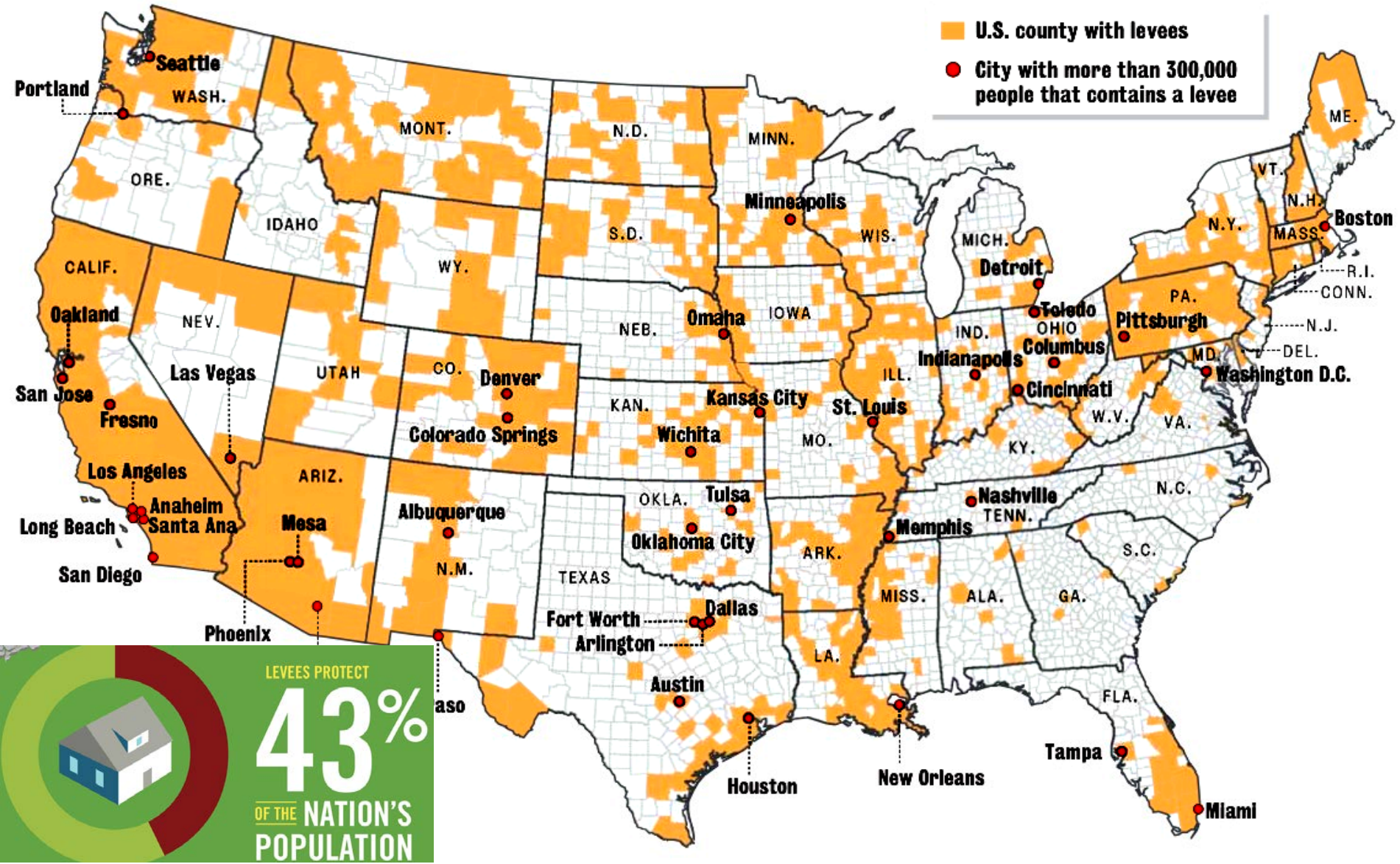
- L. Danisch: Shape-acceleration-pore pressure sensing array
- J. Bond: GPS sensors

www.Measurand.com

Overview

- Motivation & Introduction
- Vision and project overview
- Sensing Tools:
  - Remote (InSAR)
  - Field (GPS, SAP)
- Data management and analysis
  - *i*Central
  - Global-Intermediate-Local health assessment
- Concluding remarks

Introduction:Levees Everywhere



ASCE
AMERICAN SOCIETY OF CIVIL ENGINEERS

2013 REPORT CARD for America's INFRASTRUCTURE

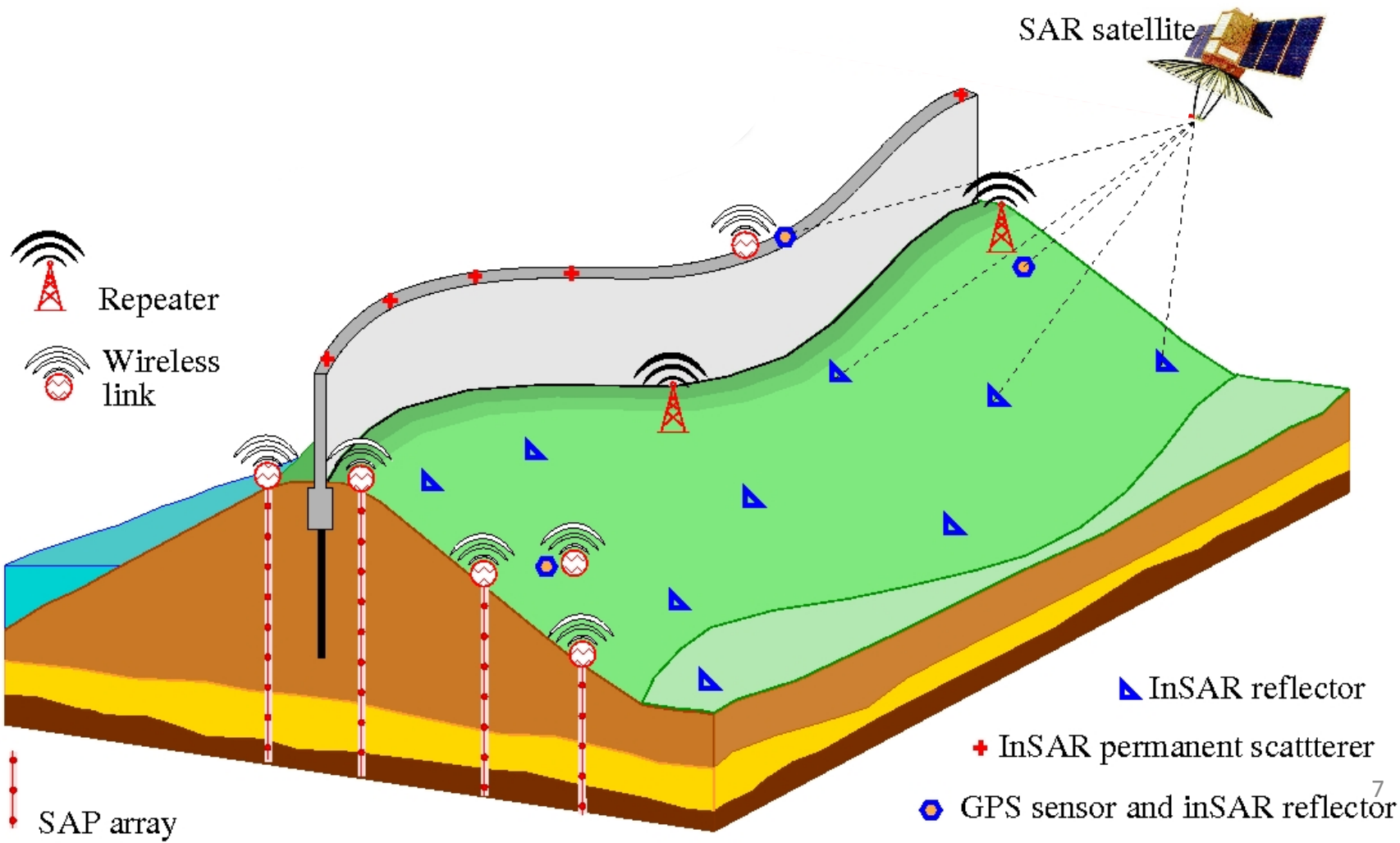
DAMS **D**

LEVEES **D-**

AVERAGE

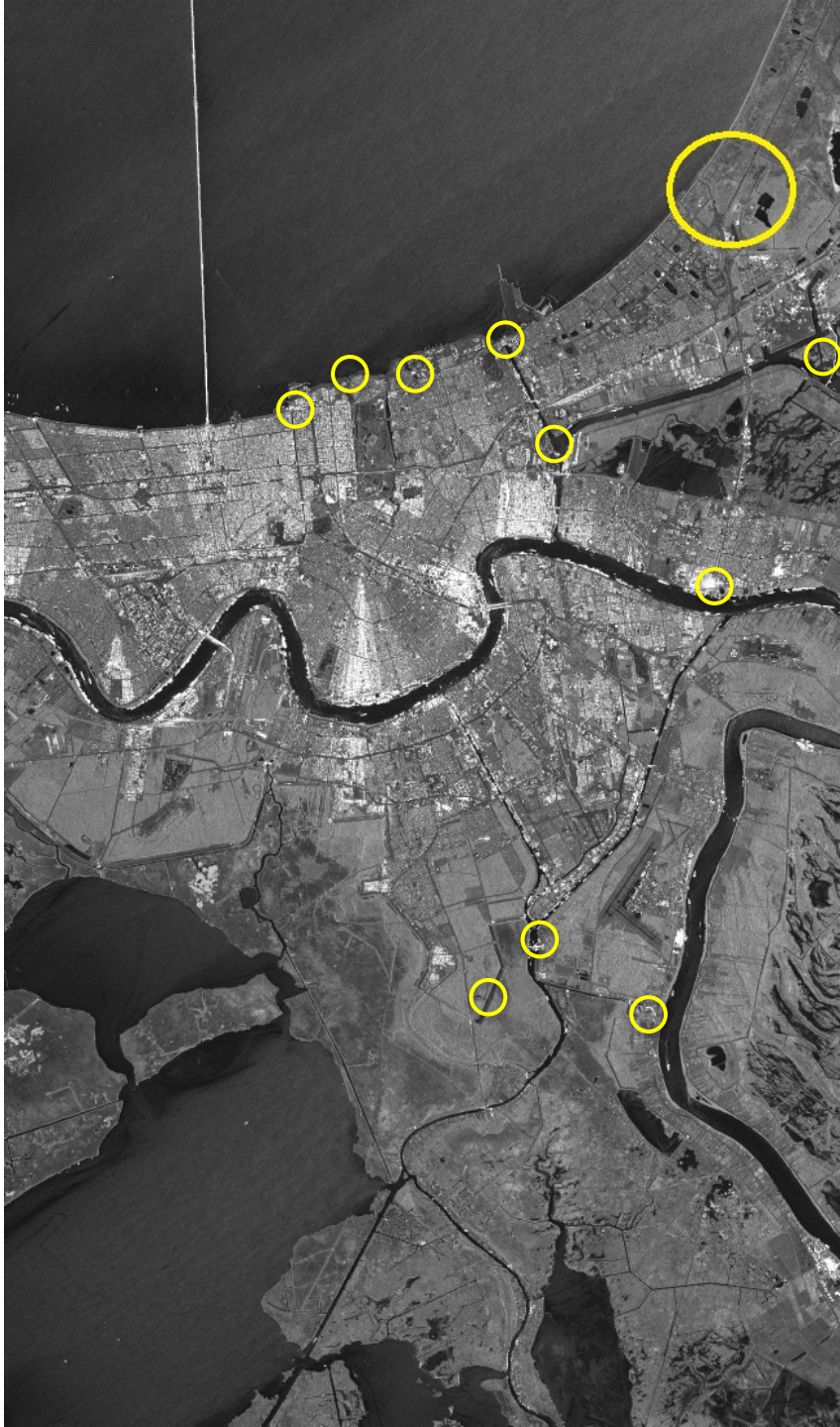
ACCEPTABLE

Vision


SAR satellite
Repeater
Wireless link
InSAR reflector
InSAR permanent scattterer
GPS sensor and inSAR reflector
SAP array

Remote Sensing: Objectives

- Monitor large areas (e.g., New Orleans levee network, 1000s of km^2 coverage) and spot locations
- Estimate deformation / rate of deformation in levee structures with mm accuracy
- Achieve a meter/pixel resolution for observed area



Remote Sensing: SAR Technology

Generates (using 2 or more SAR Interference images):

- digital elevation maps
- surface deformation

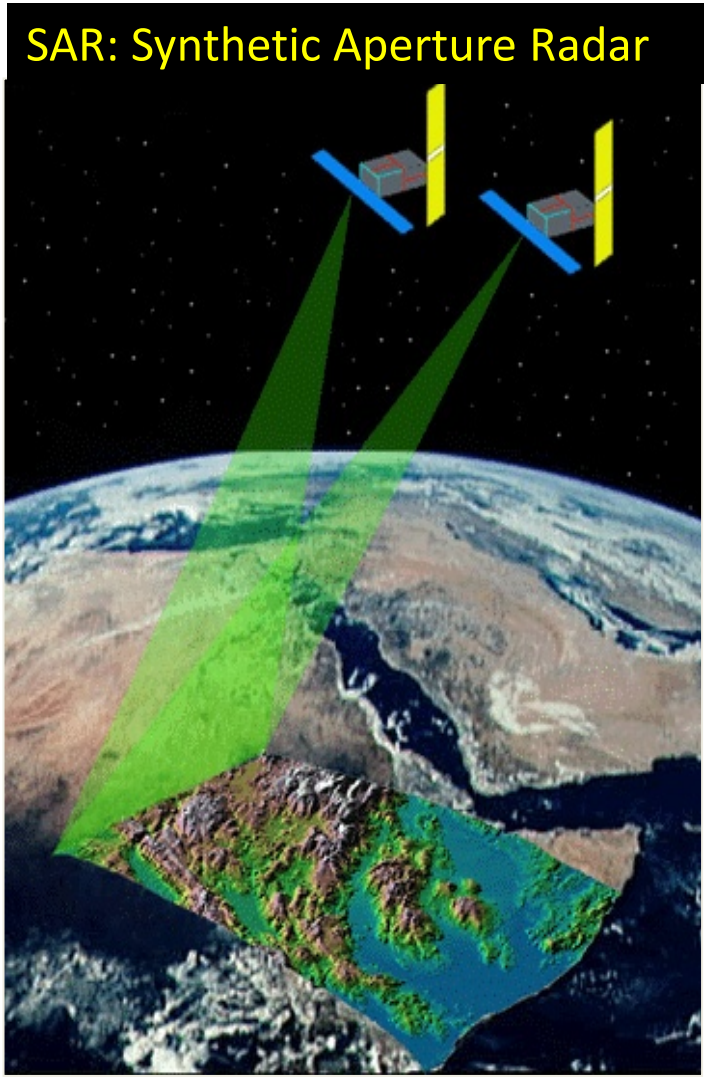


Image courtesy H. Zebker

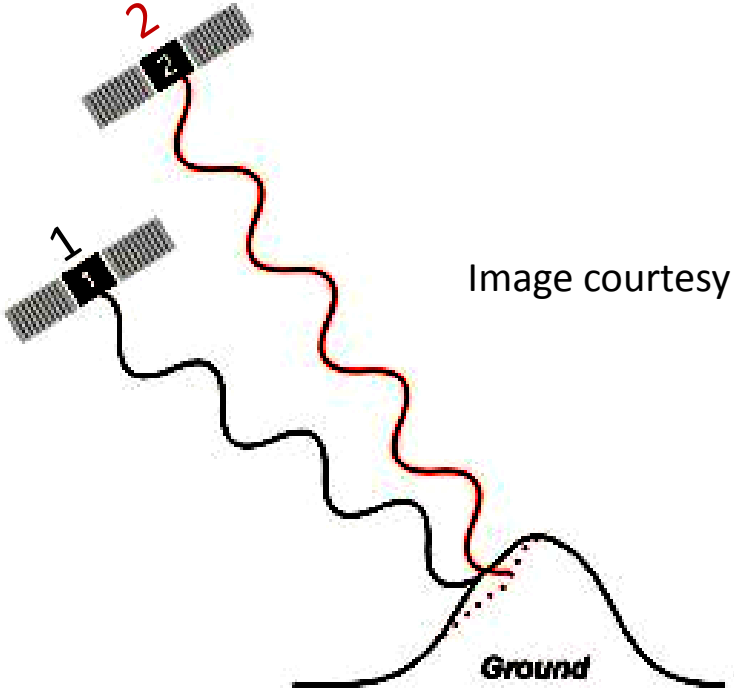
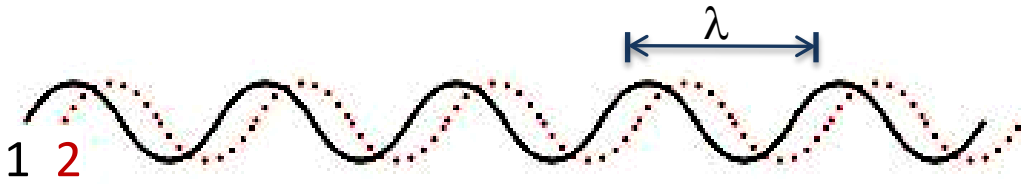
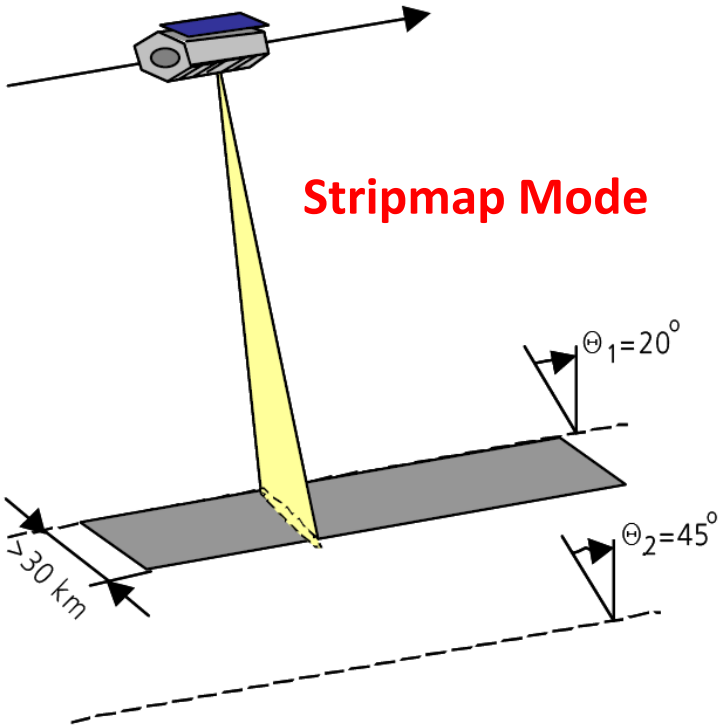
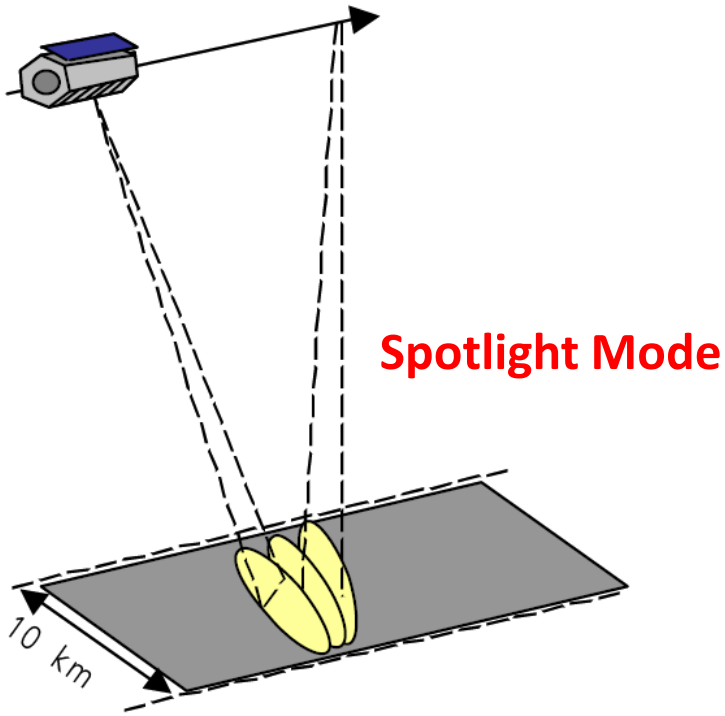


Image courtesy of Fugro



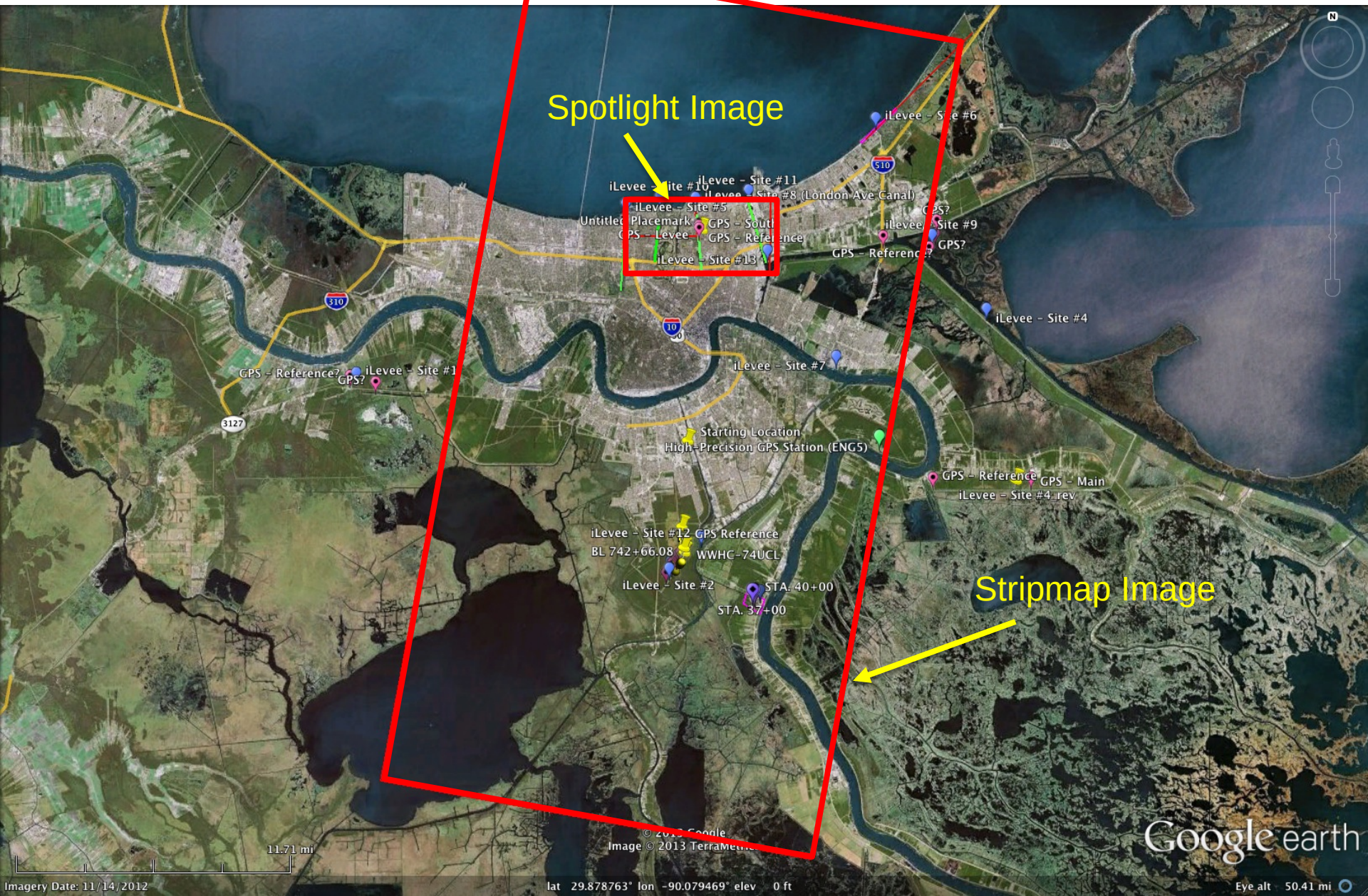
Satellite: TerraSAR-X



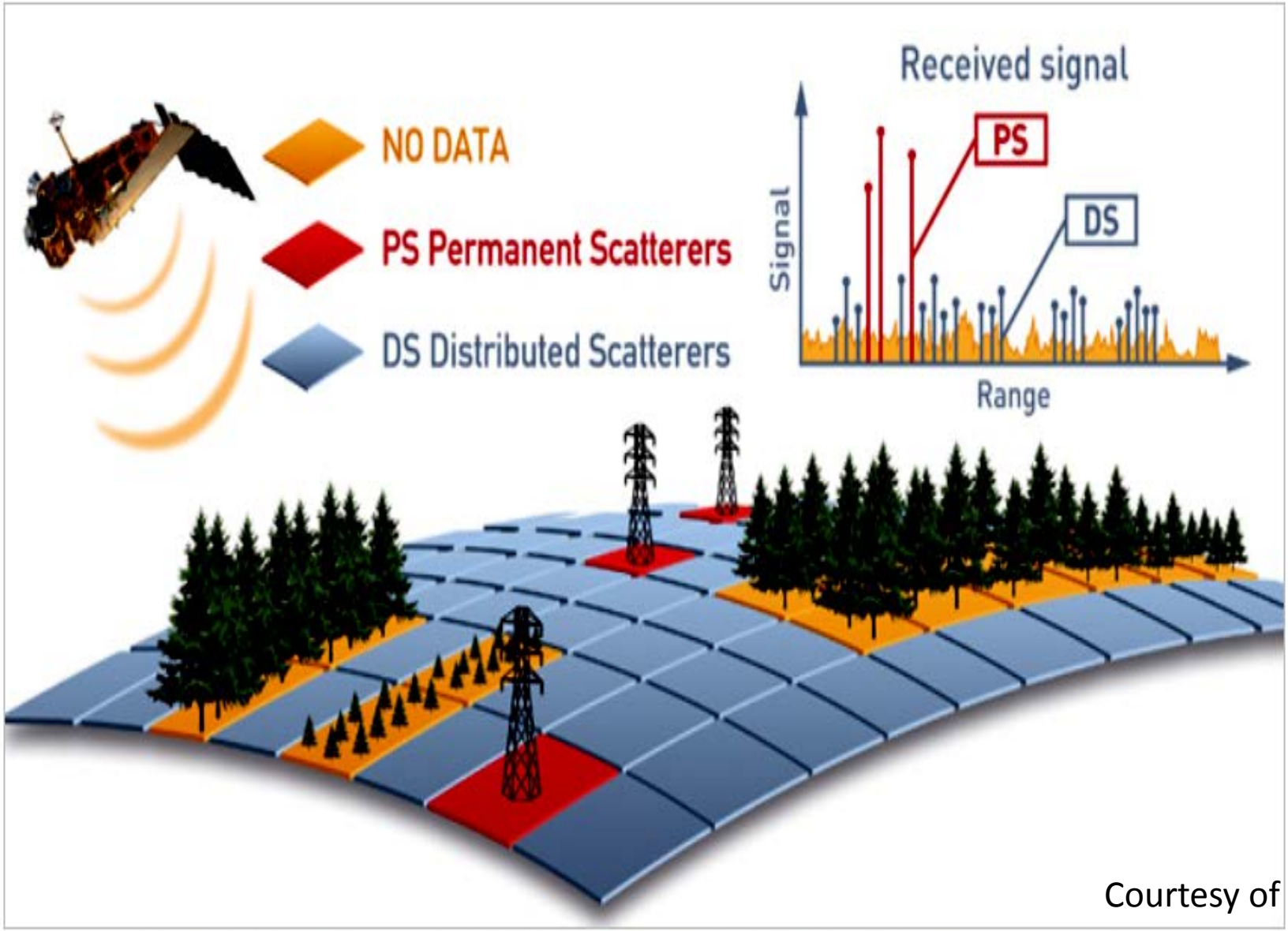


Characteristic	Stripmap Mode	Spotlight Mode
Swath width	30 km	10 km
Acquisition length	Max. 1650 km	5 km
Full performance incidence angle range	20°-55°	20°-55°
Azimuth resolution	3 m	1 m
Ground range resolution	1.7 - 3.5 m	1.5 - 3.5 m

TerraSAR-X: New Orleans Data



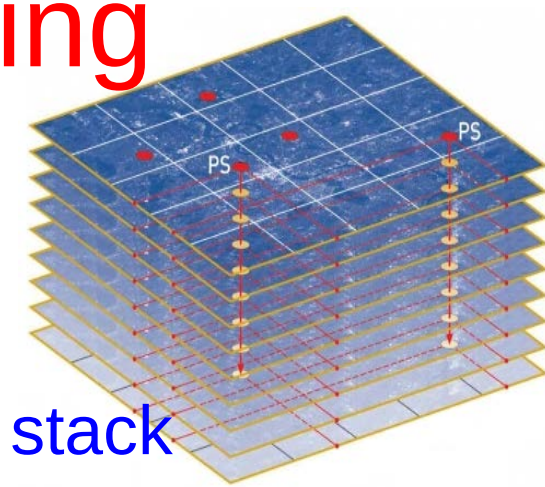
Scatterers and Analysis



Courtesy of TRE

Schematic showing the distribution of PS and DS over a typical AOI with SqueeSAR™ analysis.

SAR Data Processing



Previously available tools

PSInSAR

- Multiple interferograms obtained from a stack of radar images (at least 15)
- Poor/no estimates of elevation and displacement rate from grass covered levees

SqueeSAR™

- Pre-Processing + PSInSAR
- low spatial density of measurement points
- signal-to-noise ratio (SNR) of grass covered levees still low

SAR Data Processing: New Development

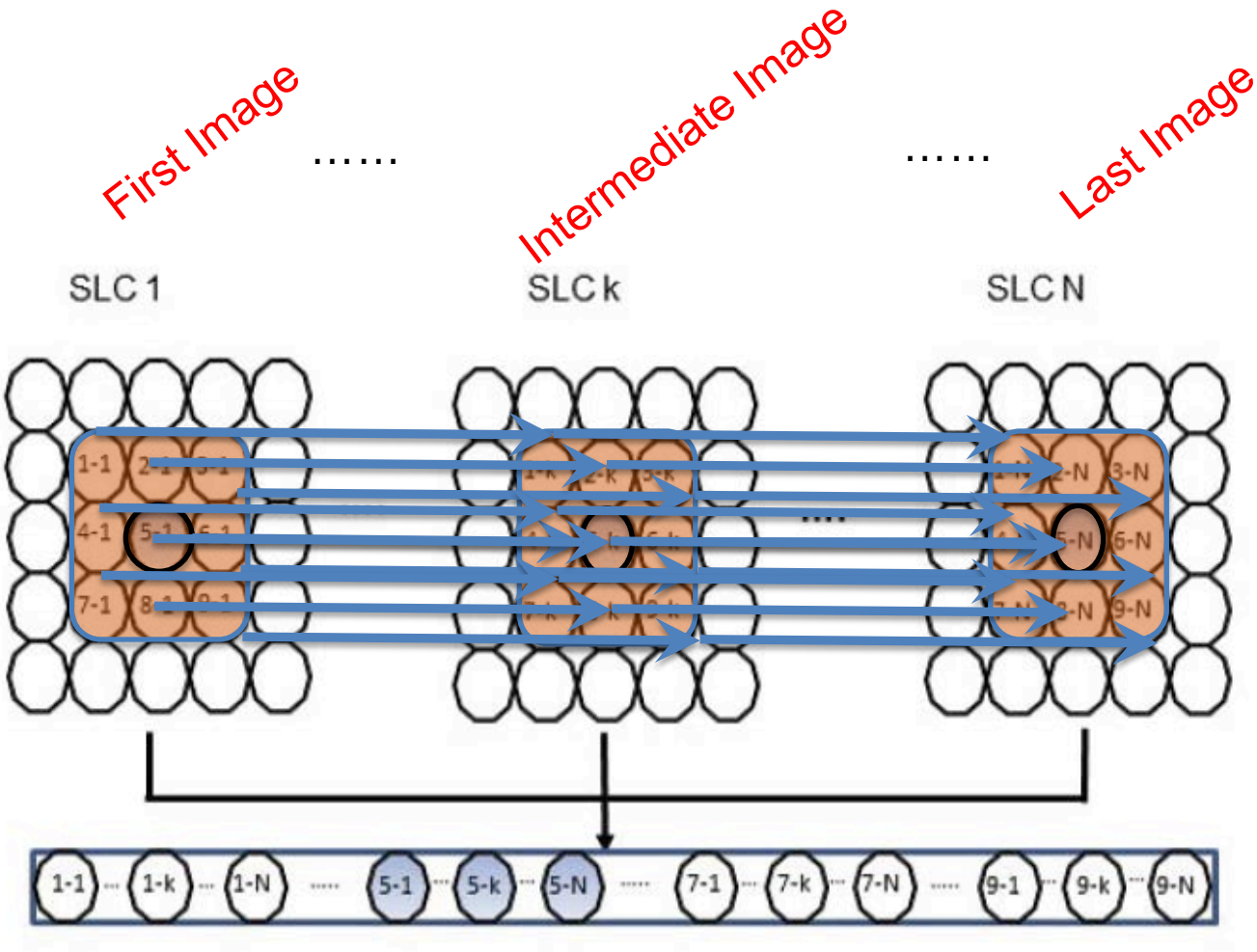
Enhanced SqueeSAR™:

- uses ***prior*** knowledge of the elevation of high quality scatterers (e.g., reflectors)
- Improved coherence of (grass scatterers) displacement estimates

Joint Scatterer InSAR (JSInSAR) :

- takes advantage of information provided by neighboring pixels
- increases number of useful measurement points and improves quality of estimated settlement

Joint Scatterer InSAR



KS Test

Used for coherence values of 0.4 to 0.75

Joint Scatterer Model

London Ave Canal (iLevee - Site#8)


Displacement rate
PSInSAR™
(42 images)
-8 ~ -10
-5 ~ -8
-3 ~ -5
-1 ~ -3
0 ~ -1
mm/year


Displacement rate
SqueeSAR™
(42 images)
-8 ~ -10
-5 ~ -8
-3 ~ -5
-1 ~ -3
0 ~ -1
mm/year

Point A on side of levee

Point B on levee wall

Displacement rate

JSInSAR

(42 images)

-8 ~ -10

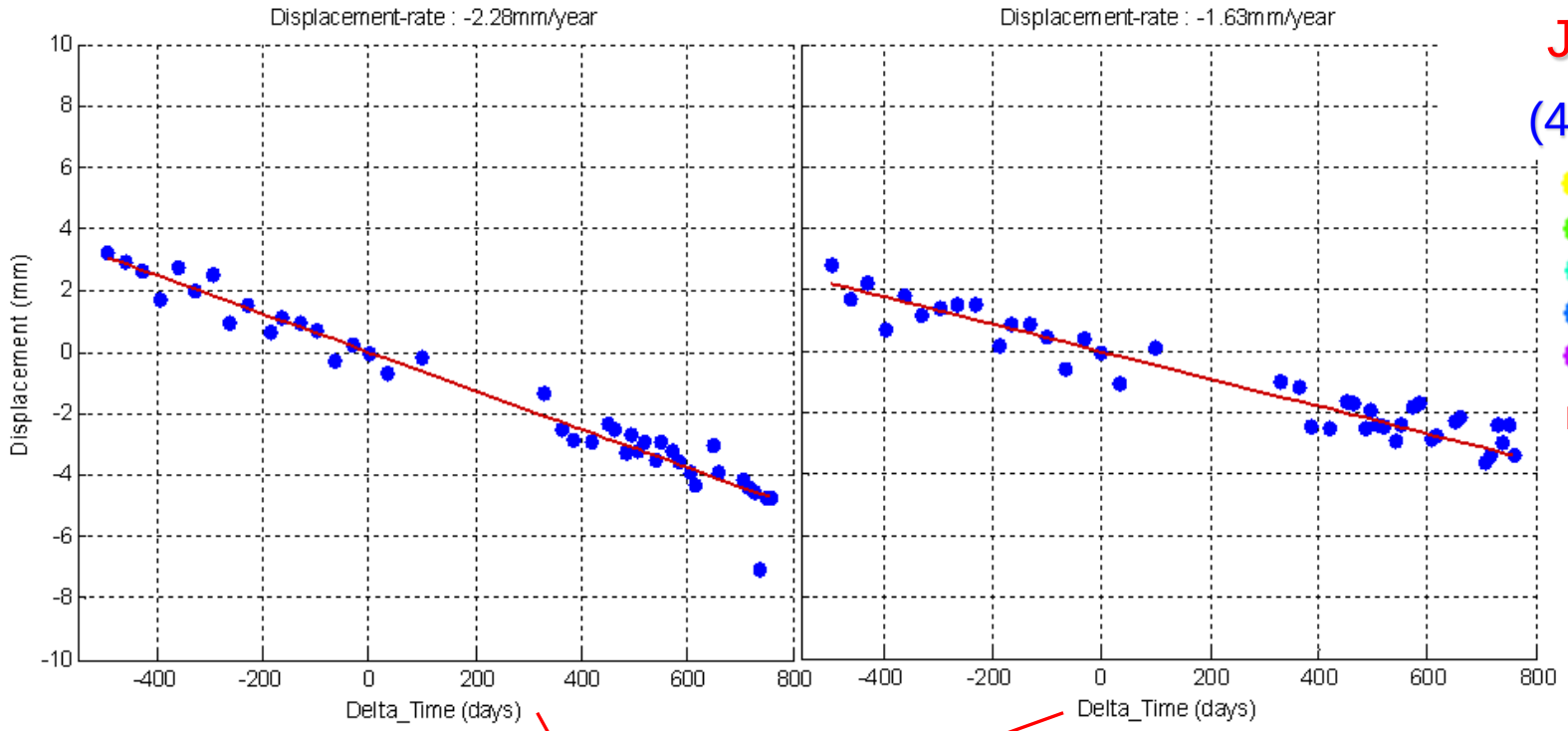
-5 ~ -8

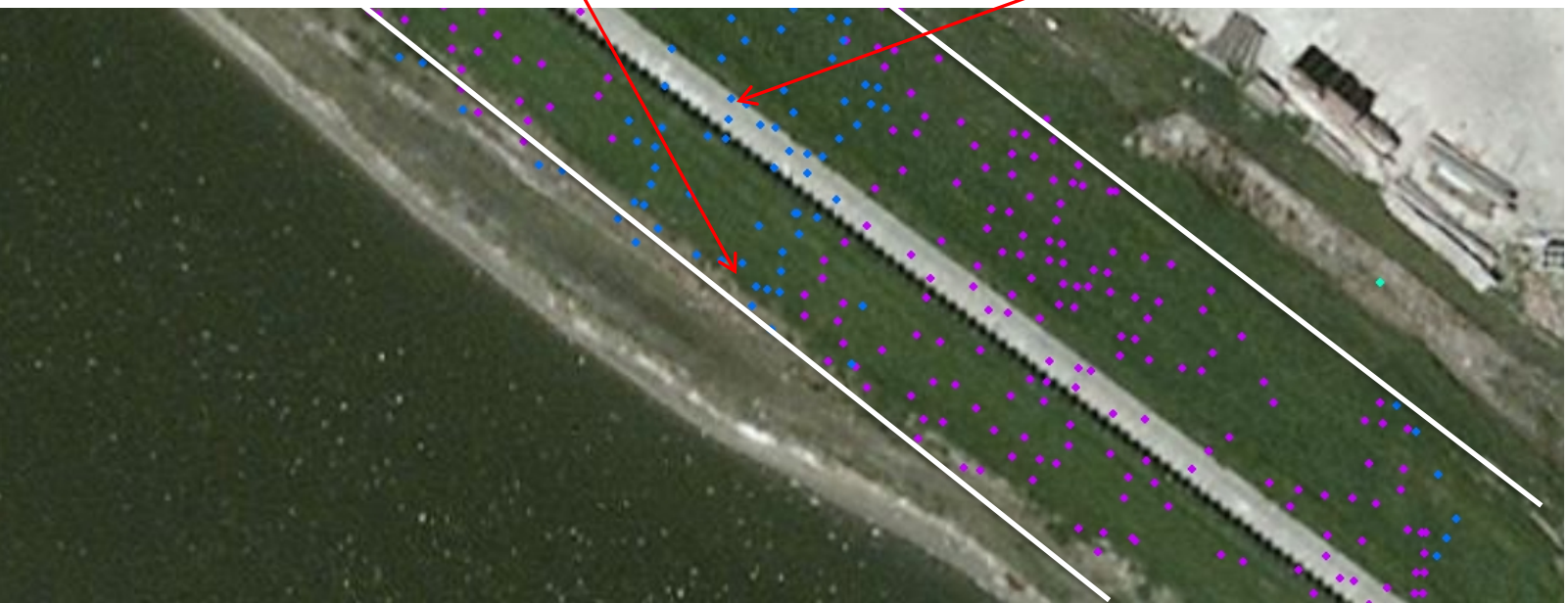
-3 ~ -5

-1 ~ -3

0 ~ -1

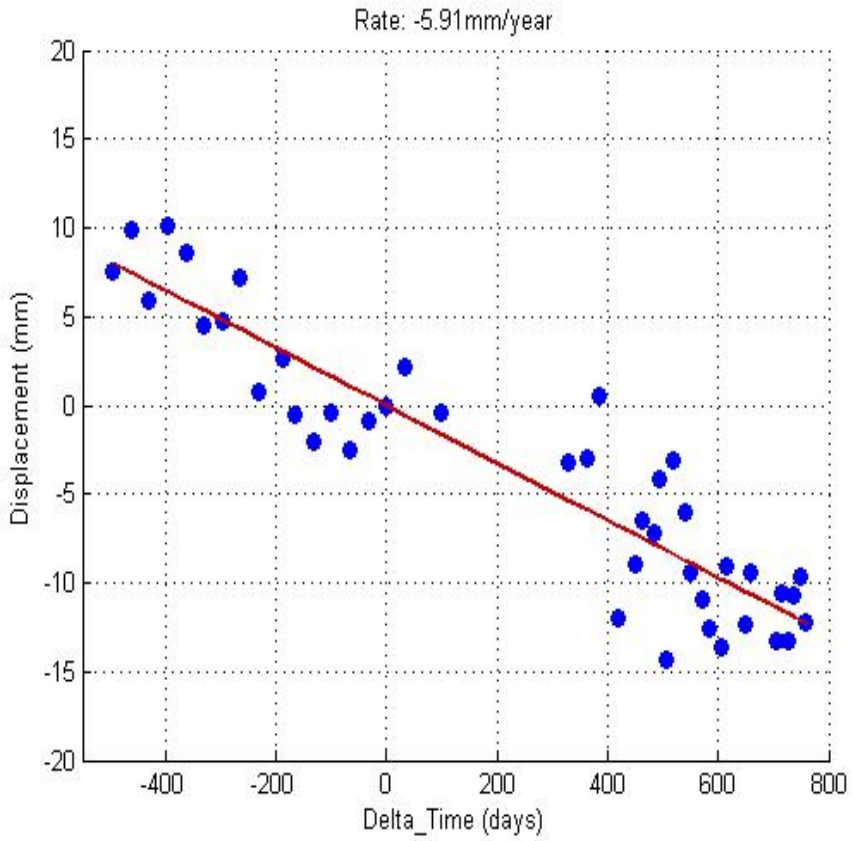
mm/year



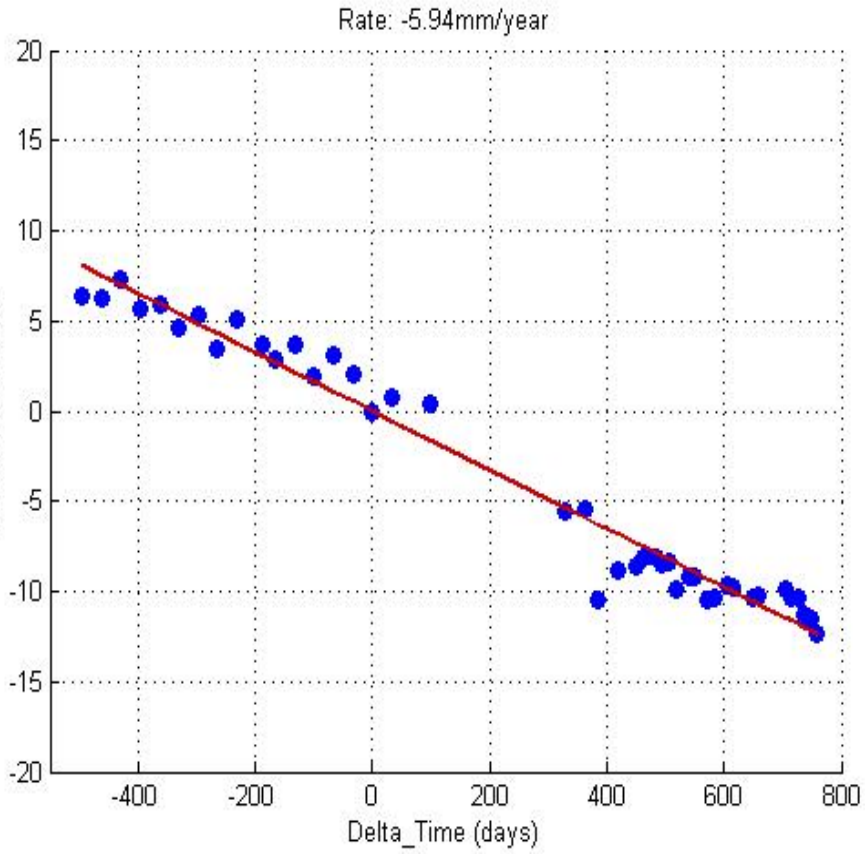


StripmapTerraSAR-X Data (42 images)

Comparison of displacement time series for a same point



PSInSAR : std: 2.83



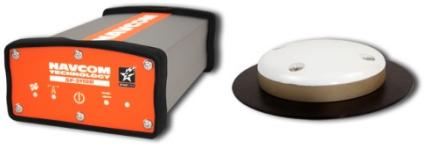
JSInSAR: std:1.21

Field Sensors: Cost Effective GPS

State-of-the-art GPS displacement sensors: more than **$10,000**

Alternative: low-cost GPS and software enhancement

Receiver	Price USD	Power
Hemisphere GPS: A100	$1795 (includes cables)	7 to 36 VDC, < 2 W @ 12 VDC, 150 mA @ 12 VDC
Hemisphere GPS: R100	$2495 (includes antenna and cables)	8 to 36 VDC, 3W, 250 mA @ 12 VDC
Javad: Alpha- G2, GrAnt antenna, 16 mB onboard data logger	$2815 (qty 100) $3730 (qty 1)	7 to 40 VDC, 3W, 225 mA @12 VDC
Septentrio: AsteRX1 Pro	$2775 with antenna and cables	5VDC, 1.2 W
NAVCOM: SF-2110	$2995 with antenna and cables	9 to 36 VDC, < 5W
NovAtel: FlexPak G2	$1390 with antenna and cables	12 VDC, 1.4 W

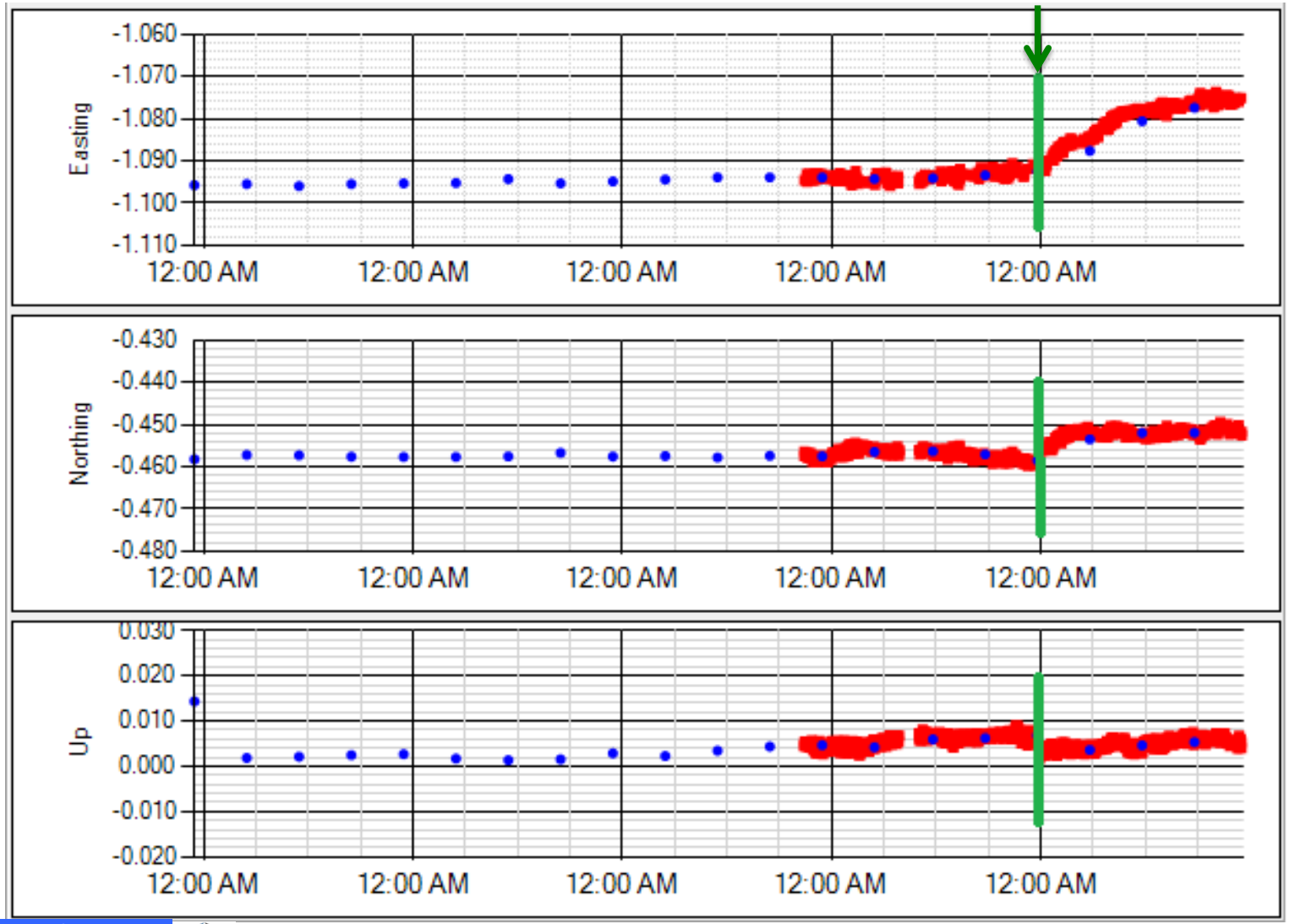


GPS
Displacement Test: $12,000 GPS

20 mm displacement introduced

- 12hour average
- individual measurements

± 2 mm accuracy

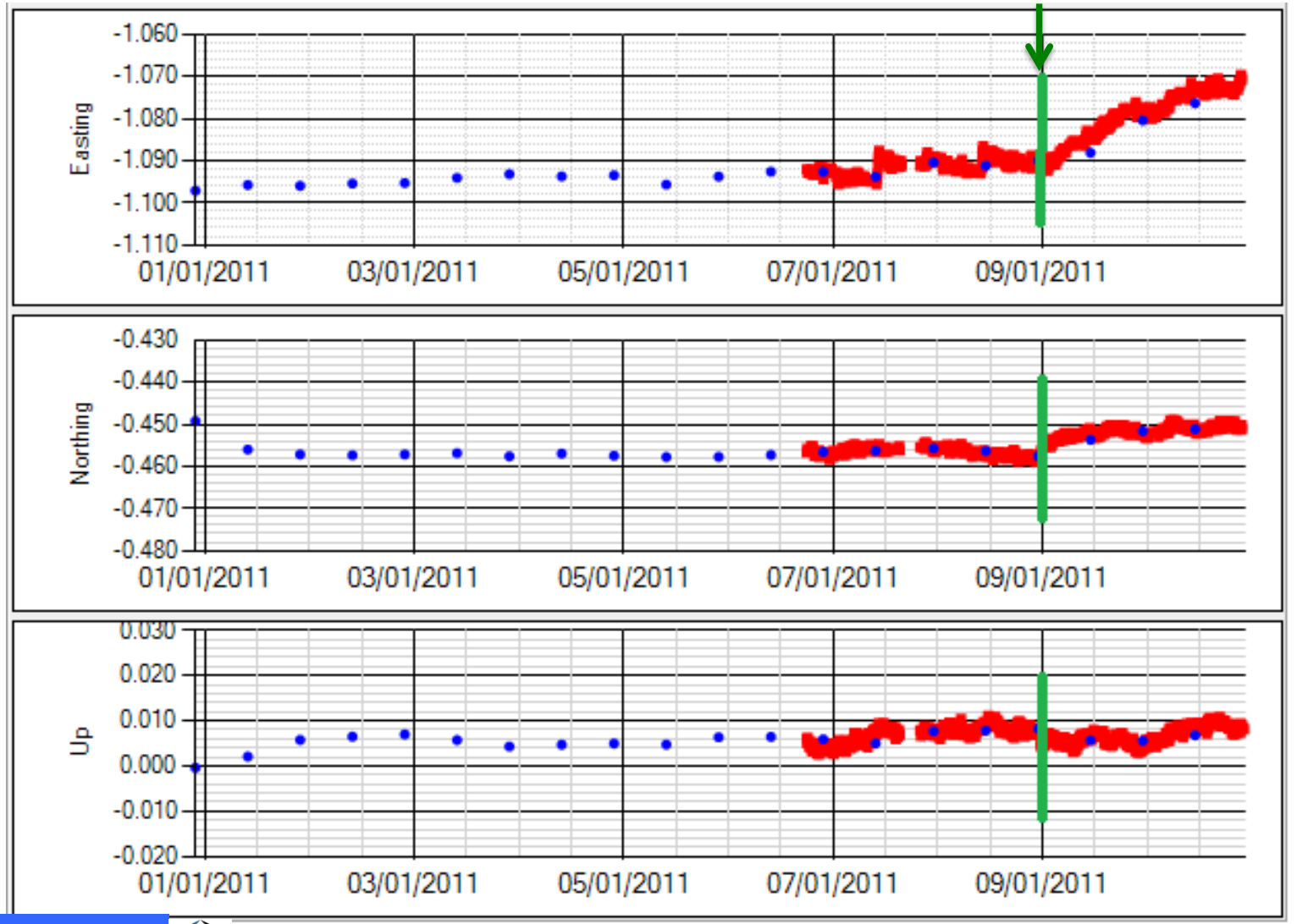


GPS
Displacement Test: Single Freq. NovAtel

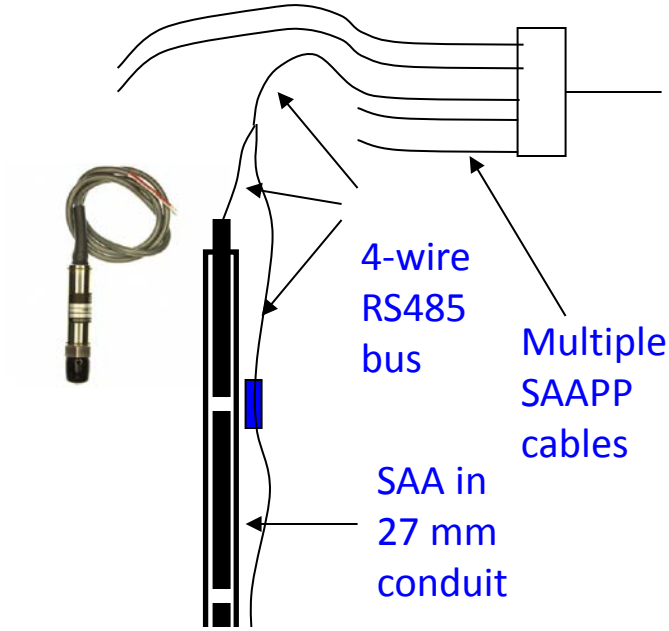
20 mm displacement introduced

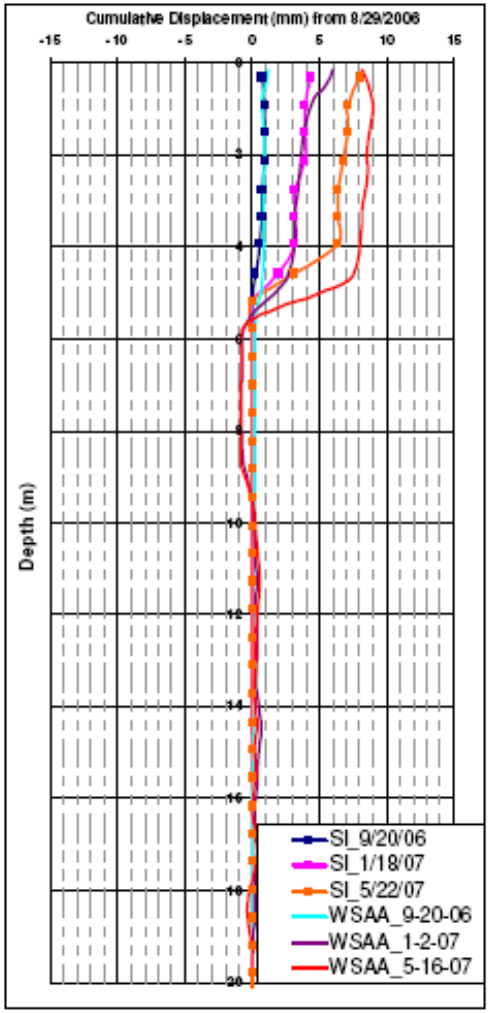
- 12hour average
- individual measurements

± 2 mm accuracy



Shape-Acceleration-Pore Pressure Array

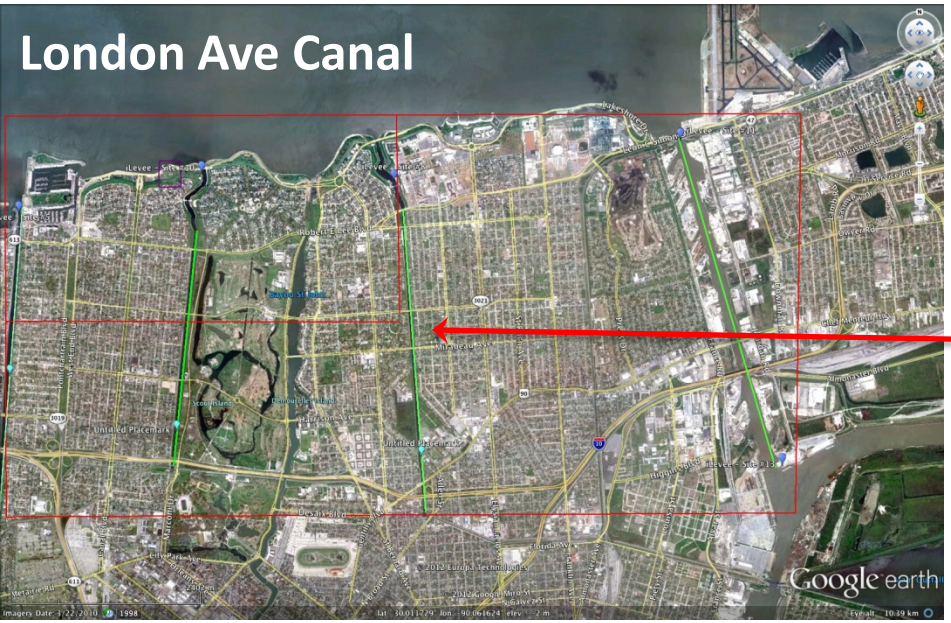




MEMs based

- 3D Accelerations
- Permanent displacements
- Pore pressure

Testbed: New Orleans (13 specific sites)

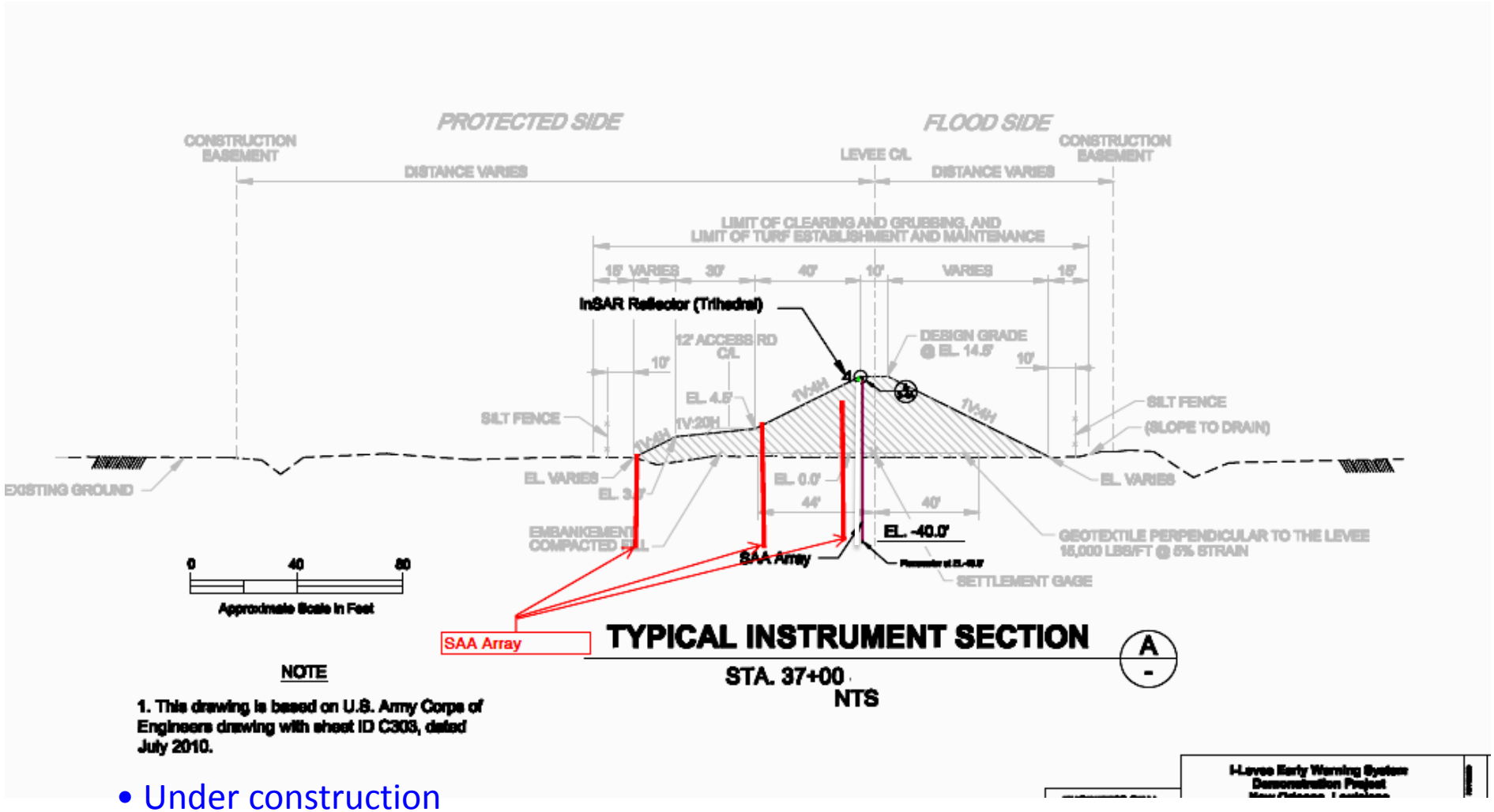


Site Descriptions:

1. London Ave Canal
   Potential for lateral movement during extreme weather event
2. Eastern Tie-In
   Levee section on Virgin Ground Settlement > 3’

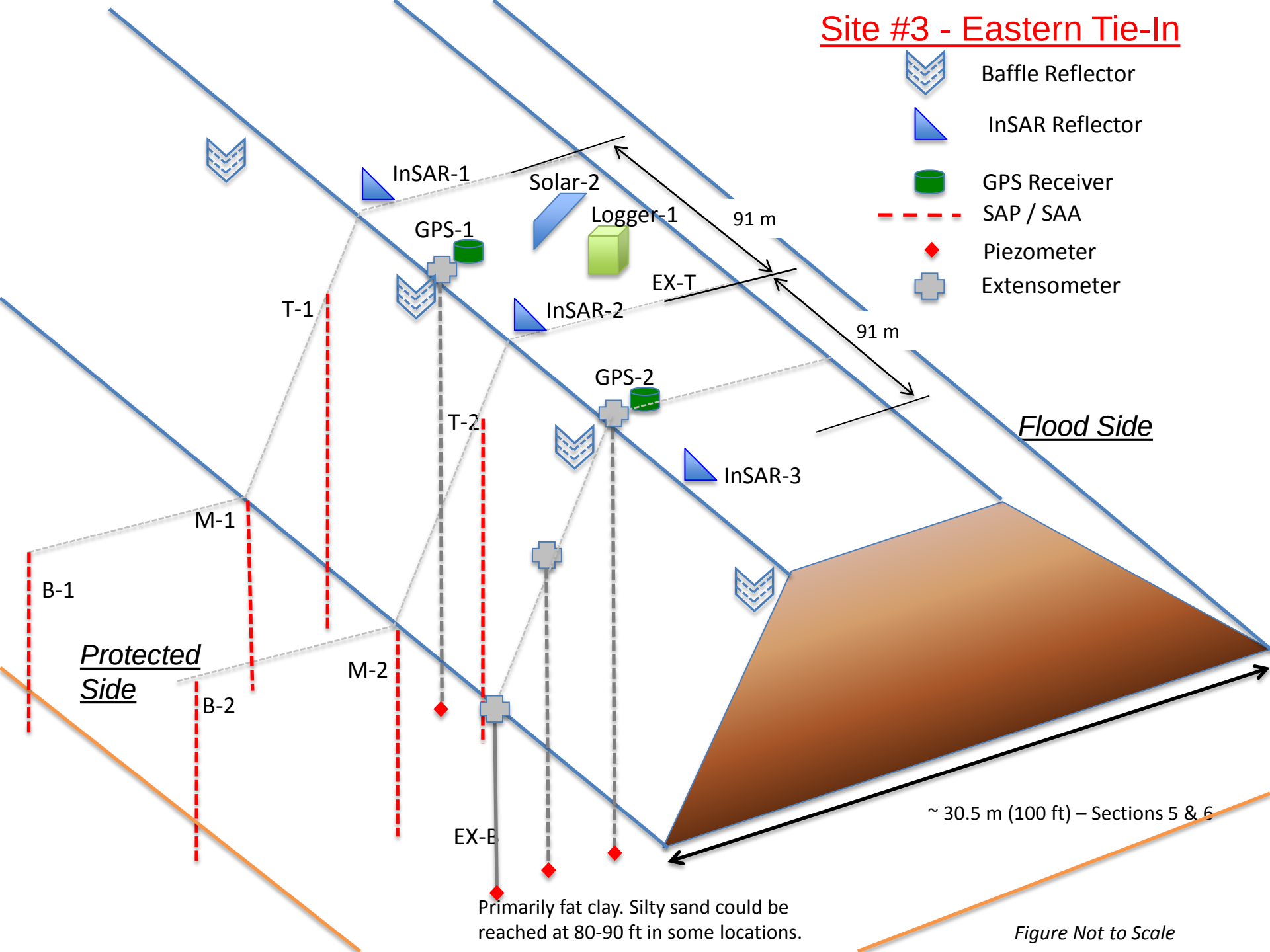
Site #3 – Eastern Tie-in Levee

Site #3 – Eastern Tie-in Levee



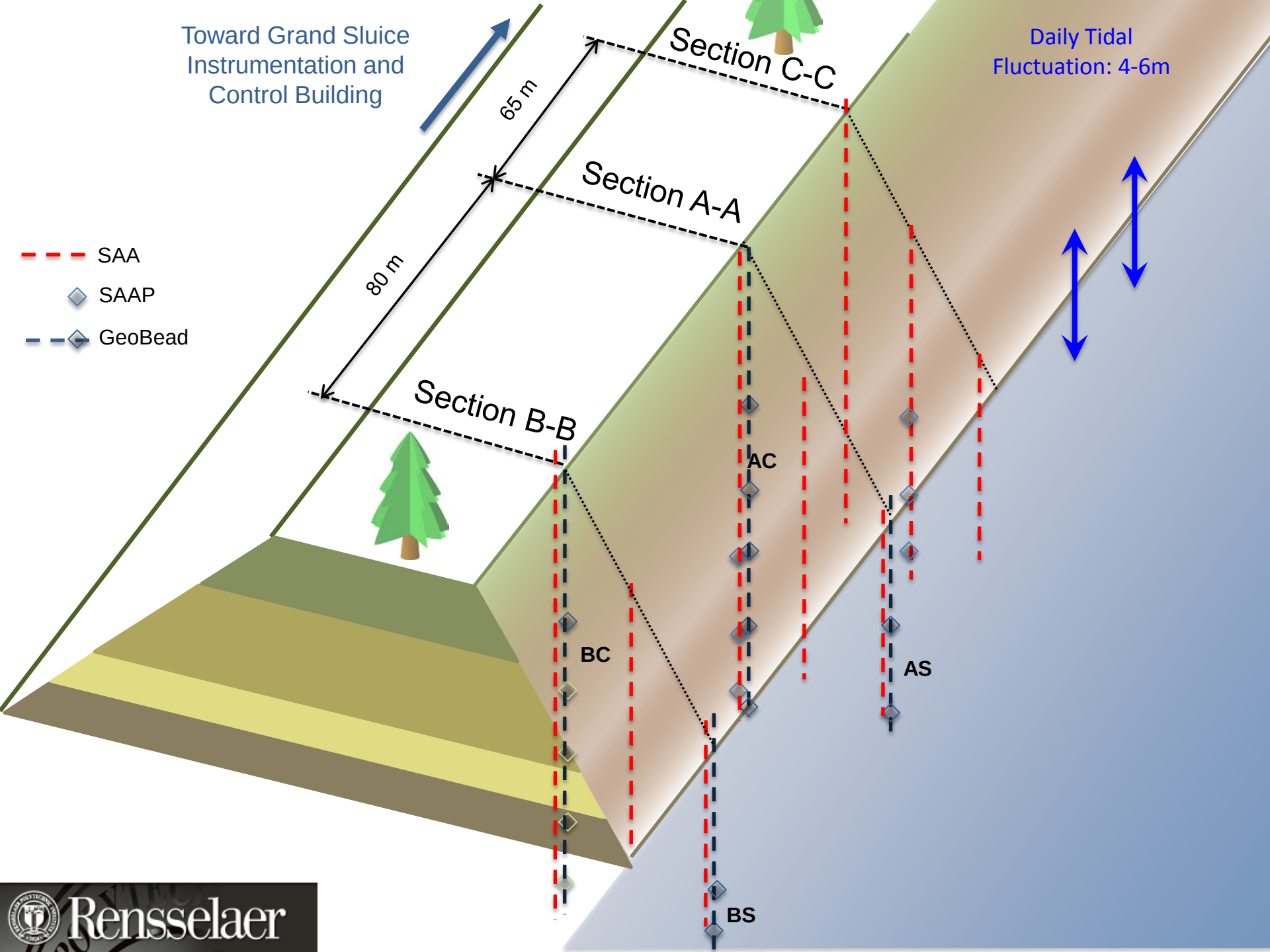
- Under construction
- Wick drains
- Potential lateral movement during construction

Eastern Tie-In: Levee section on virgin ground; Expected settlement > 3’


Site #3 - Eastern Tie-In
Baffle Reflector
InSAR Reflector
GPS Receiver
SAP / SAA
Piezometer
Extensometer
InSAR-1
Solar-2
Logger-1
GPS-1
91 m
EX-T
InSAR-2
91 m
T-1
GPS-2
T-2
Flood Side
InSAR-3
M-1
B-1
Protected Side
M-2
B-2
EX-E
~ 30.5 m (100 ft) – Sections 5 & 6
Primarily fat clay. Silty sand could be reached at 80-90 ft in some locations.
Figure Not to Scale

Test-Bed: Field Sensors

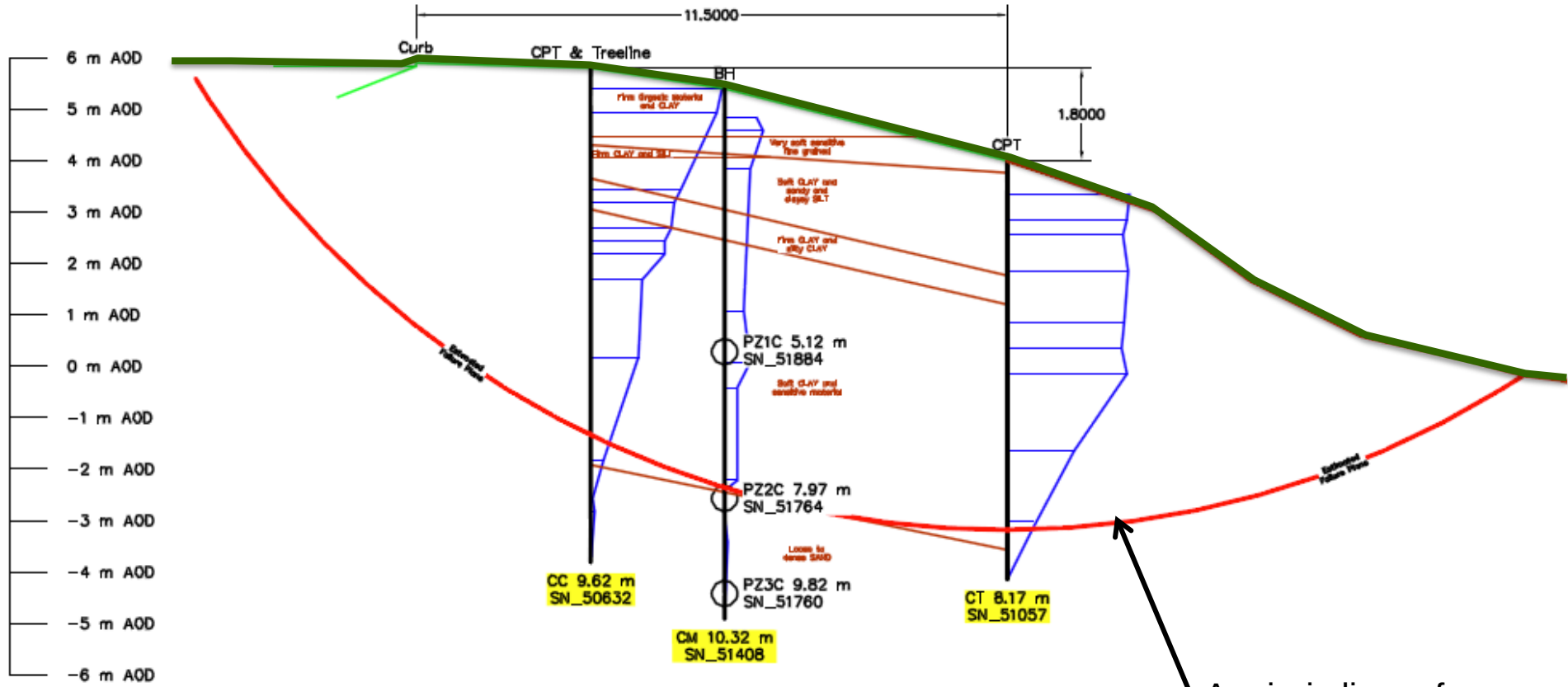
Testbed: Boston, UK Site (active levees)


Toward Grand Sluice
Instrumentation and
Control Building
65 m
80 m
Section C-C
Section A-A
Section B-B
Daily Tidal
Fluctuation: 4-6m
SAA
SAAP
GeoBead
AC
BC
AS
BS

Rensselaer

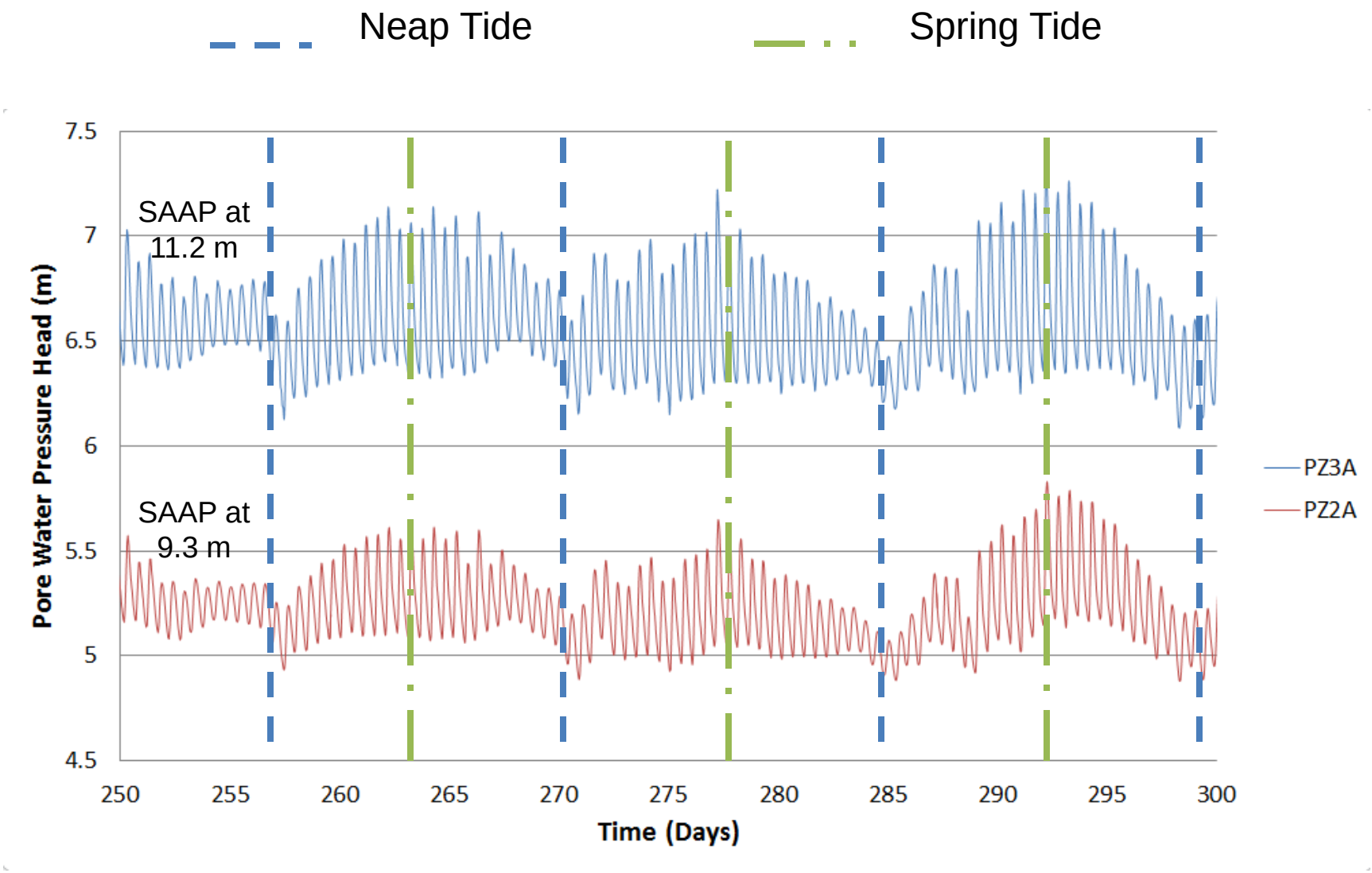
Section CC

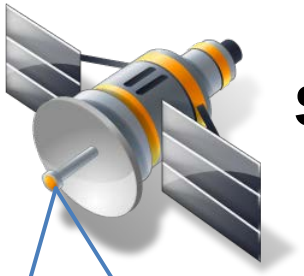
Field Measurements



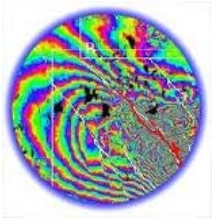
A priori slip surface near dense sand interface

SAAPs at Crest of Section AA



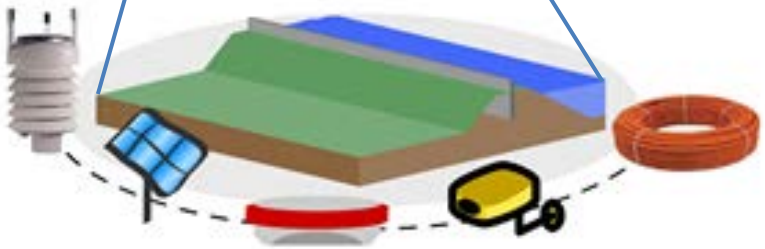


SAR Images

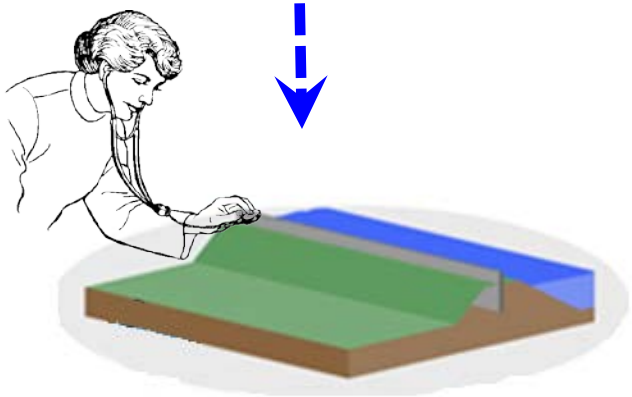


InSAR Processing

Levee



Local Sensor Network



Health Assessment

*i*SiteCentral™

Geocomp CORPORATION

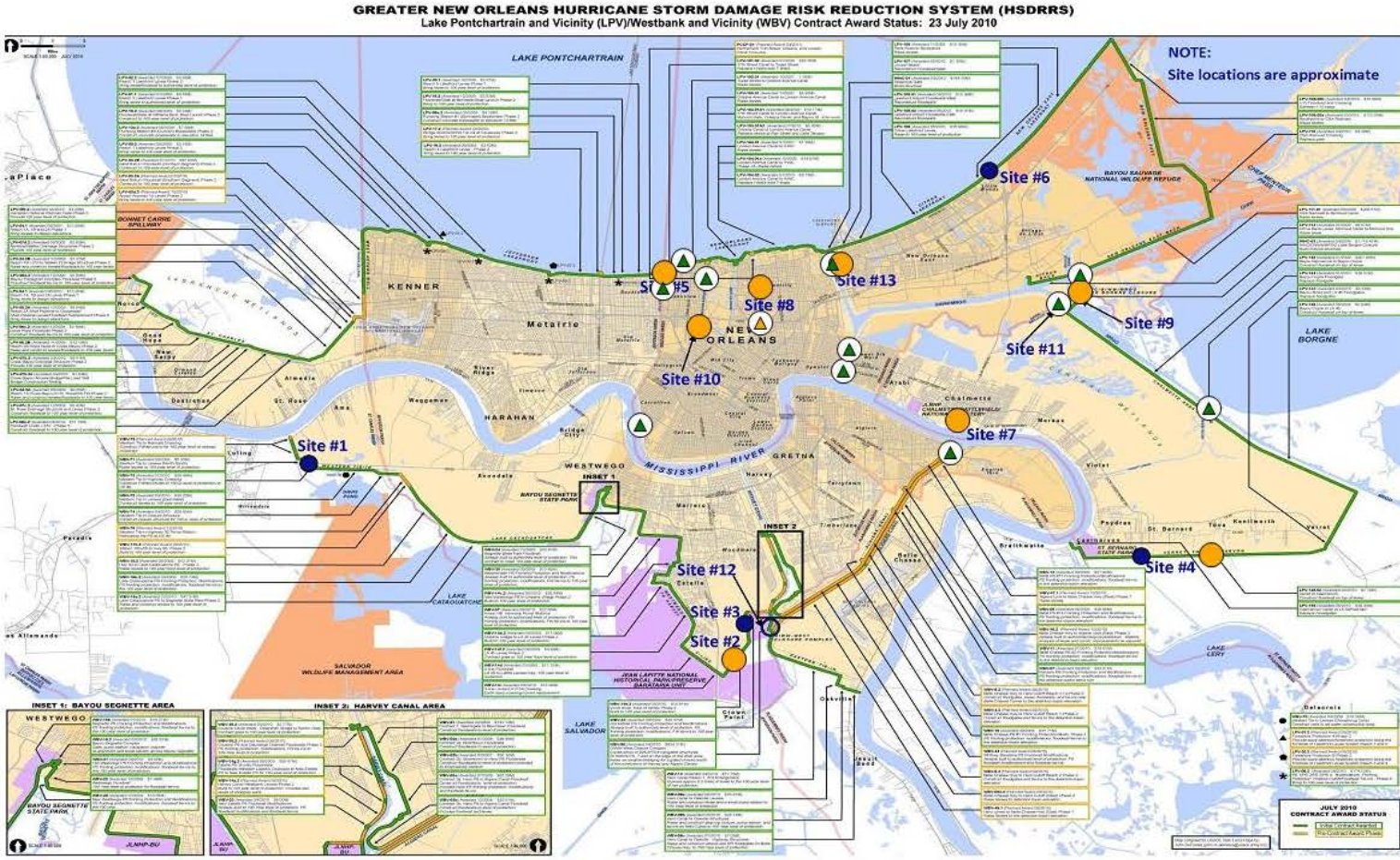
Show Message Board

iSite Central

TECHNOLOGIES TO MANAGE RISK FOR INFRASTRUCTURE

- View Data
  - Plan Views
  - Charts/Profiles
    - Interactive
    - Snapshot
    - Sensor Default
  - Reports
  - Readings Table
  - iSite Events
  - Documents
- Chart Builder
  - Define Charts
  - Define TimeSeries 4
  - Define ATS Charts
  - Define Tilt Charts
  - Define XY Charts
  - Define Profiles
    - Horizontal
    - Horizontal Tilt
    - Vertical
    - Vertical Tilt
  - Define Instantel Charts
- My Private Data
  - Charts

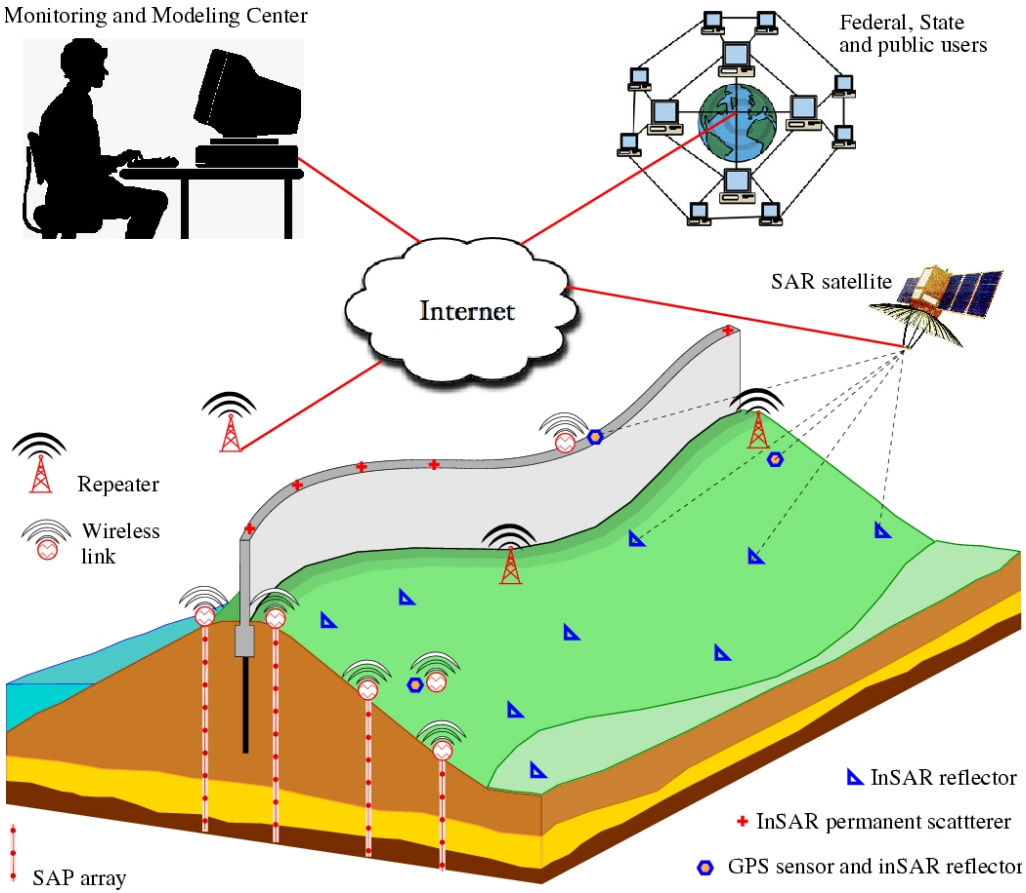
iLevee Instrumentation Sites
13 Sites in New Orleans



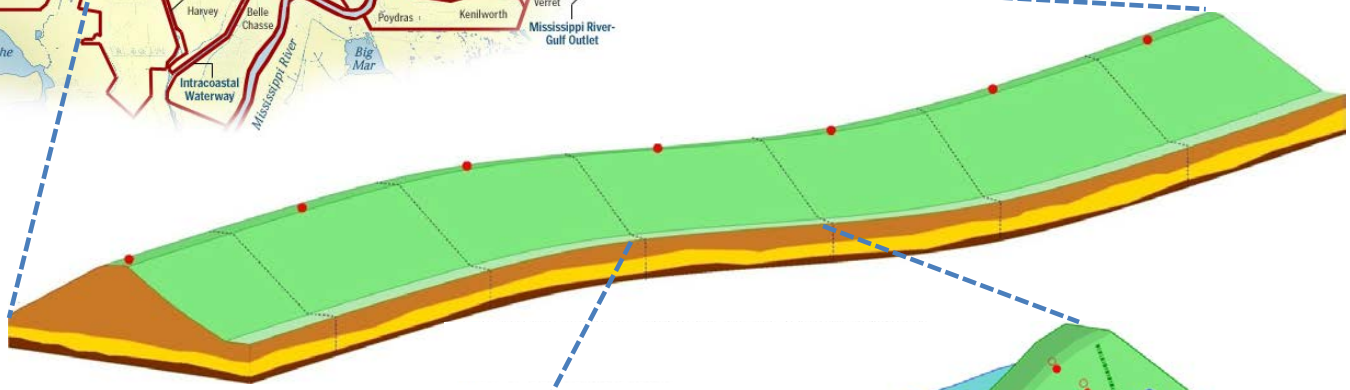
Health Assessment

Adaptive multi-scale:

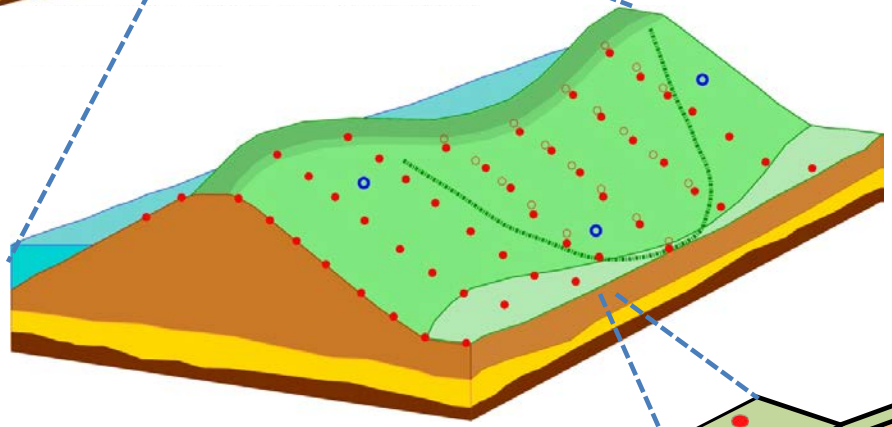
- Global
  - InSAR data (strip mode)
  - InSAR data (spotlight mode)
- Intermediate
  - InSAR data (spotlight mode)
  - GPS data
- Local
  - Shape-acceleration-Pore Pressure data
  - GPS data



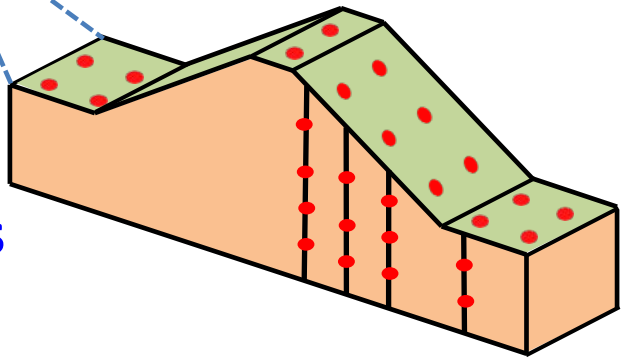
Global Analysis



Intermediate Analysis



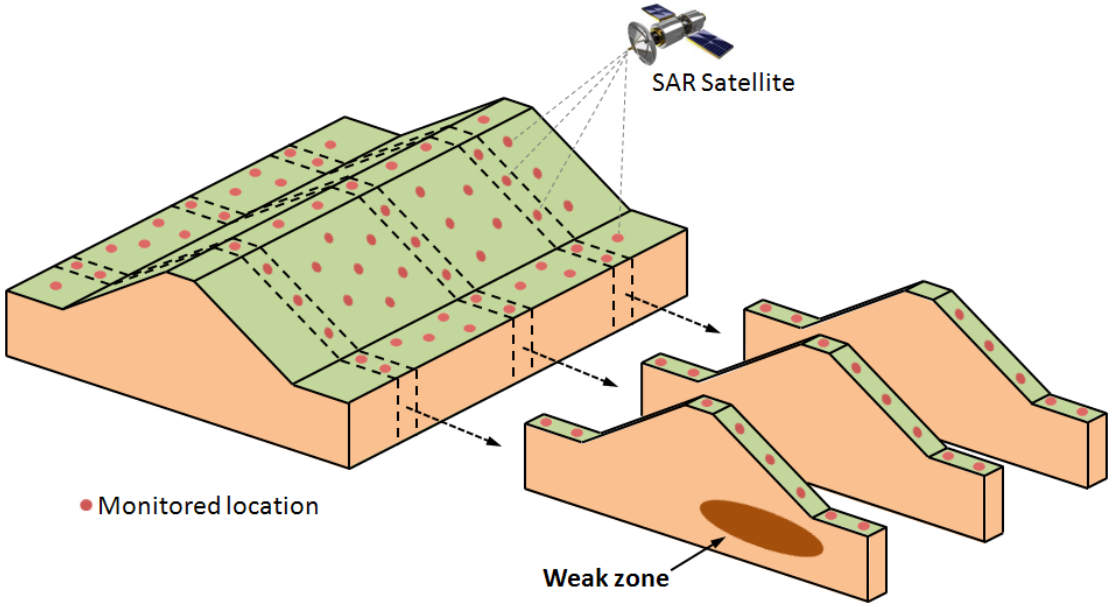
Local Analysis



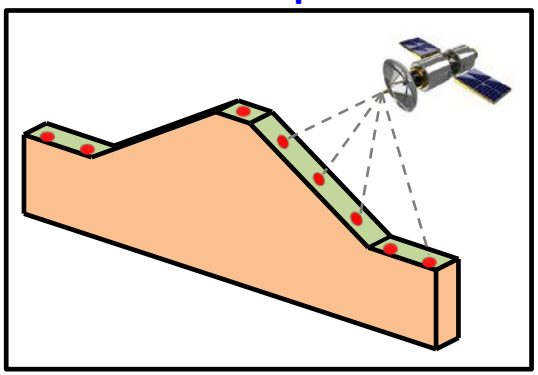
Health Assessment Rationale

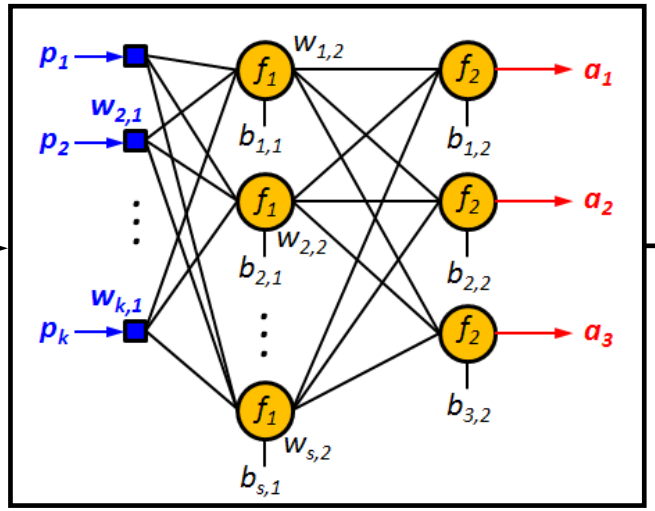
- Calibrated baseline levee **model**
  - a priori information
- Updated levee **models**
  - baseline model
  - new measurements
- Evaluation of **health status** and identification of damage (if any)
  - **discrepancies** between baseline and updated models
  - other information

Global Health Assessment

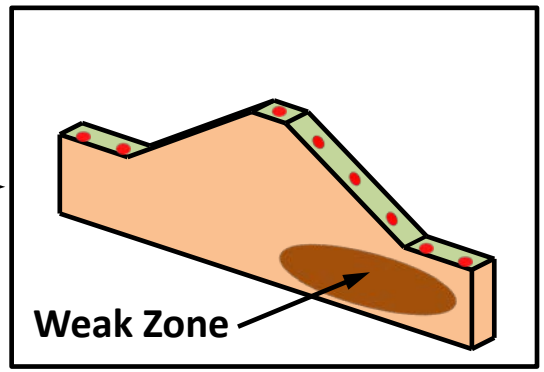


Monitored displacements





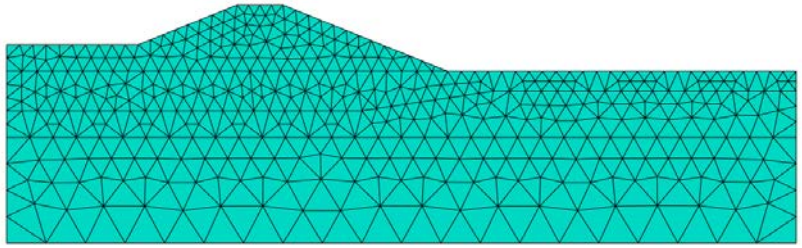
Output



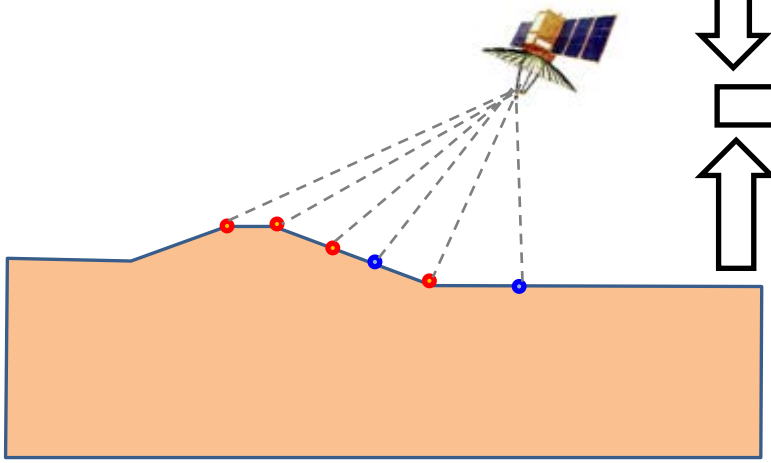
Neural Network

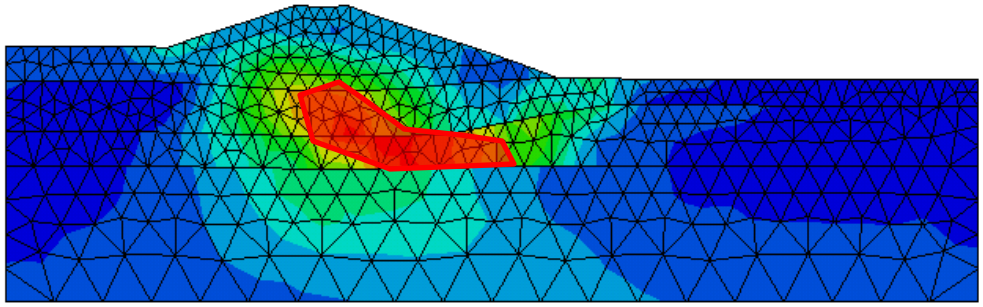
Rensselaer

Intermediate: Modeling & Localization



Initial Condition

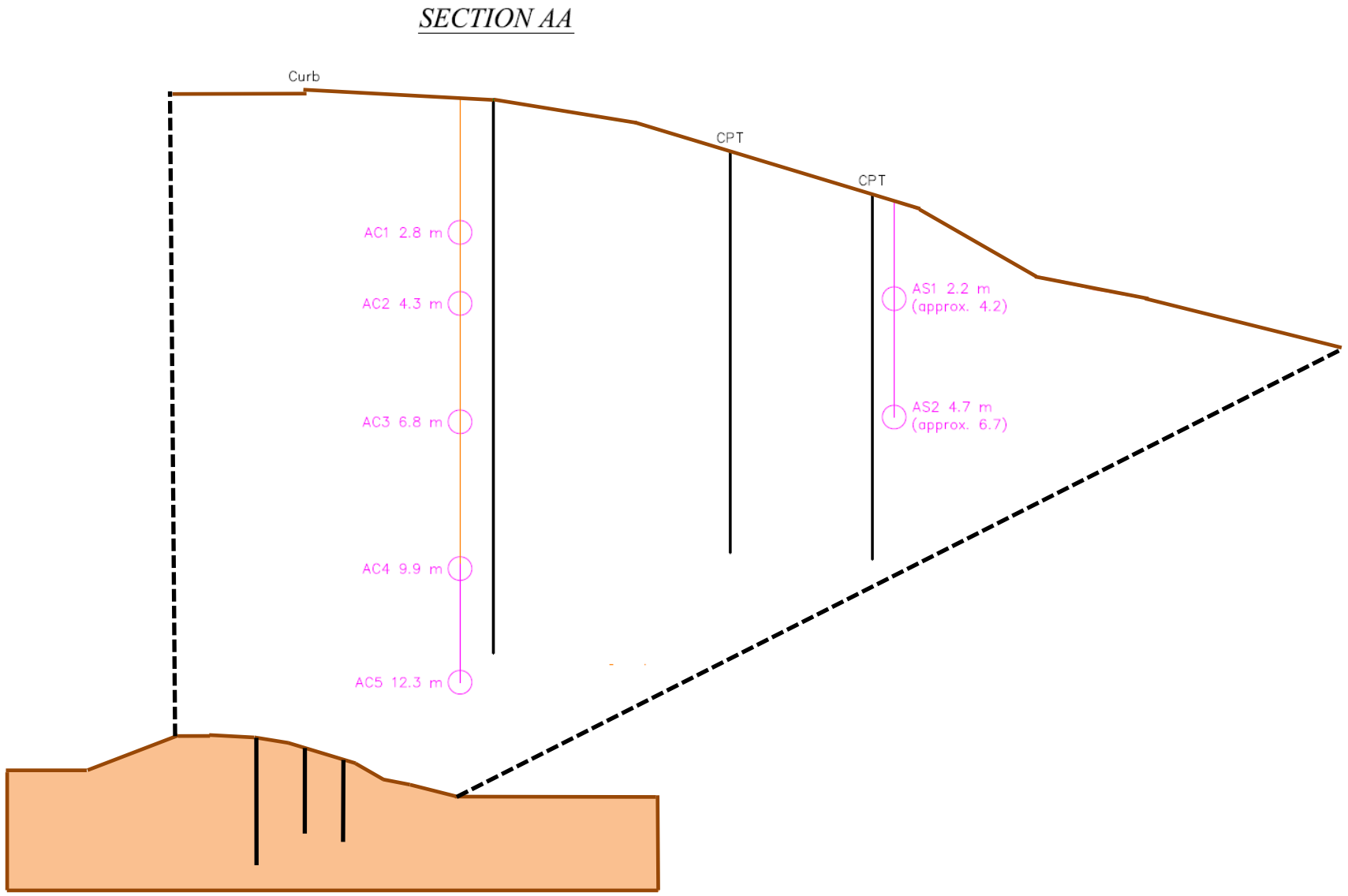




Updated levee condition

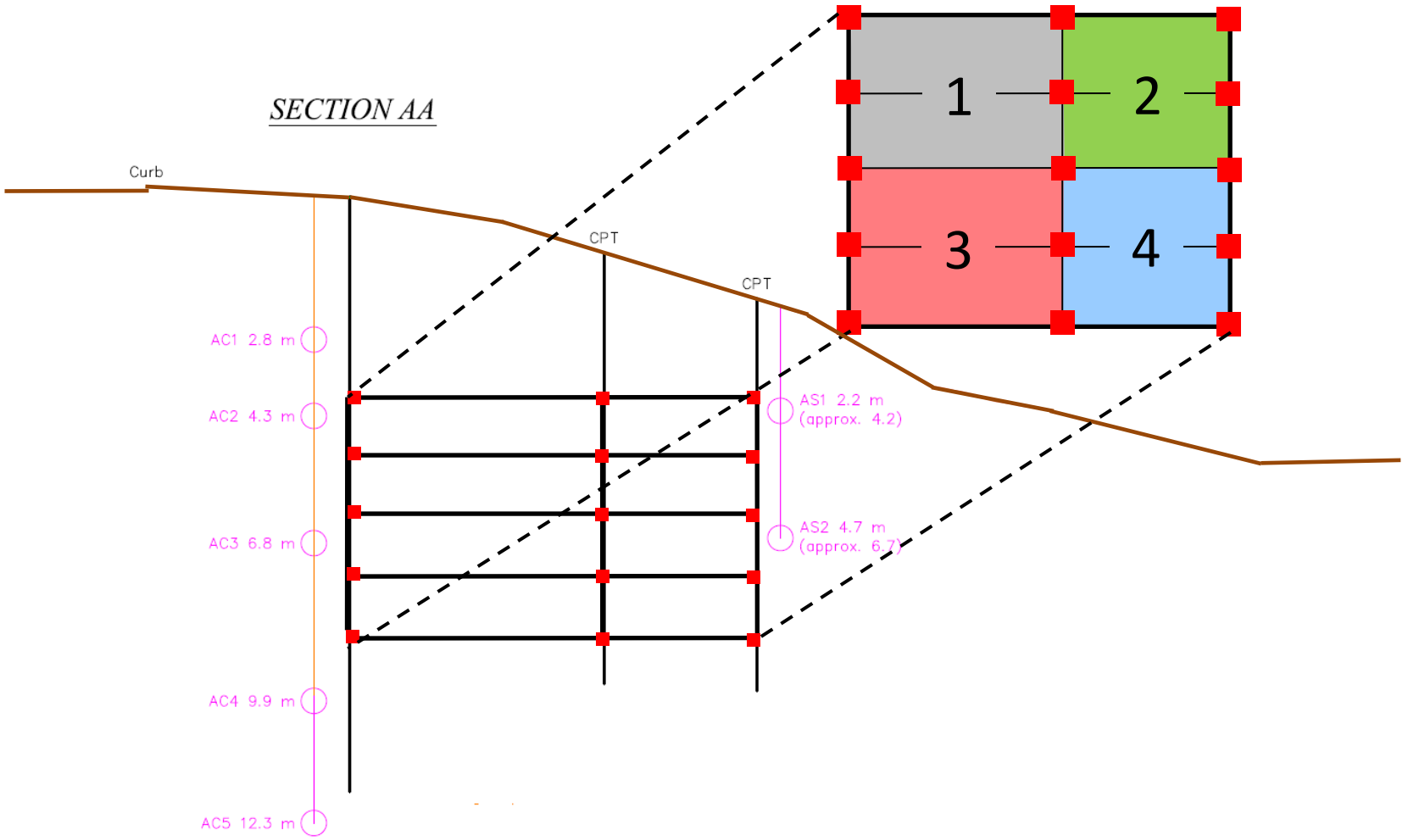
• Insar measurements • GPS measurements

Local Health Assessment

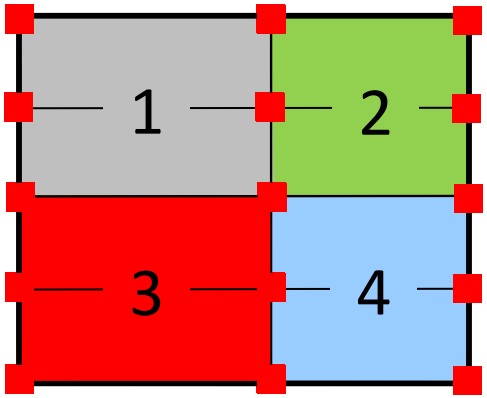


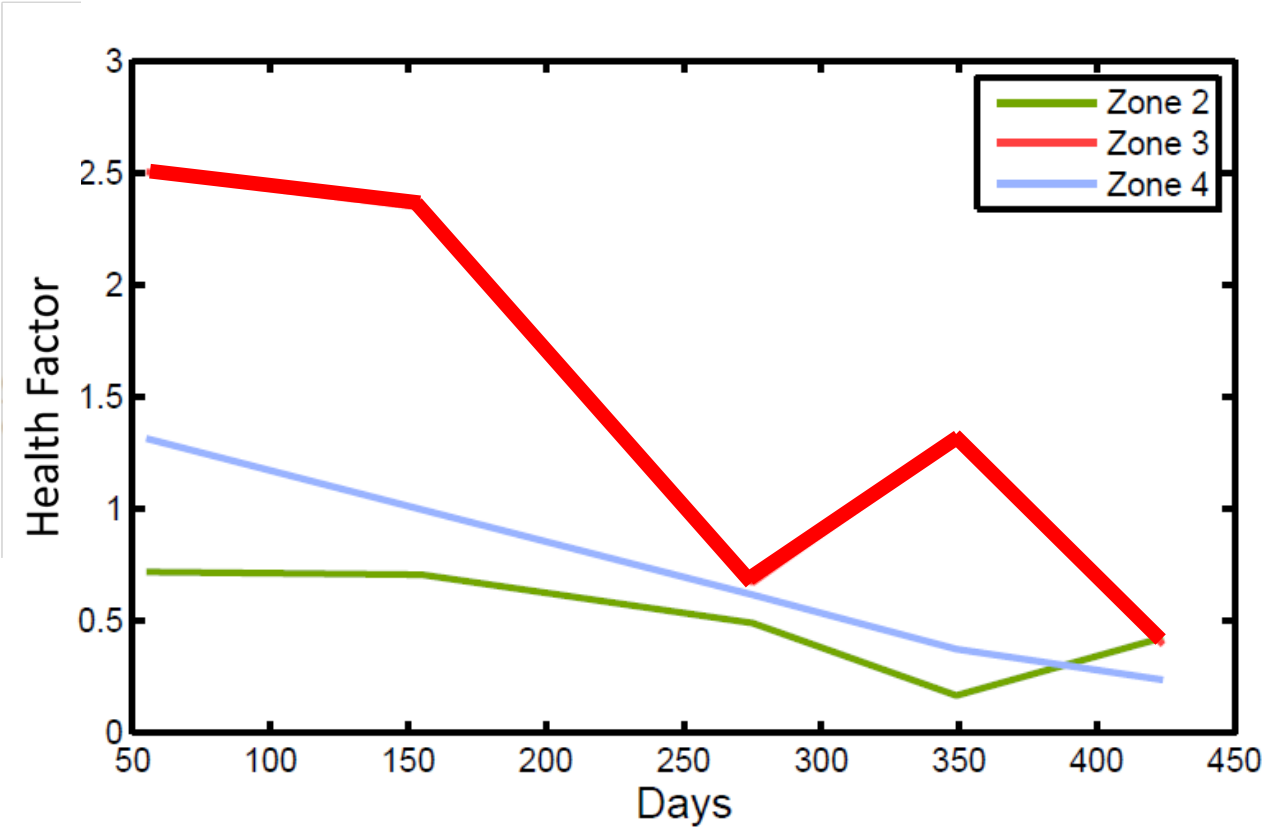
- Insar measurements
- GPS measurements
- SAAP Arrays

Local Health Assessment

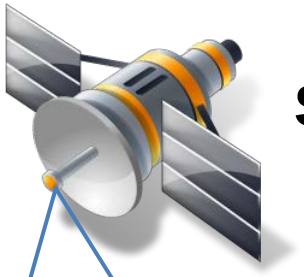


Local Health Assessment

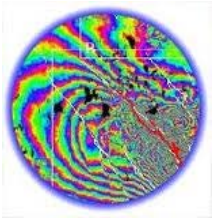




Material Zone 1 Material Zone 2 Material Zone 3 Material Zone 4

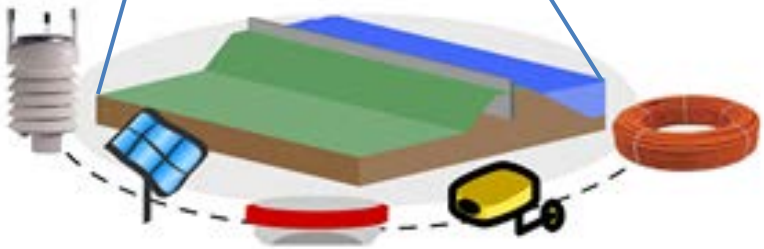


SAR Images



InSAR Processing

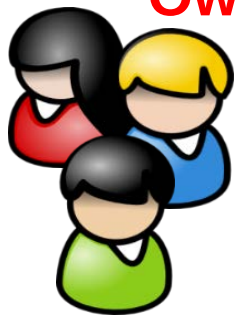
Levee



Local Sensor Network

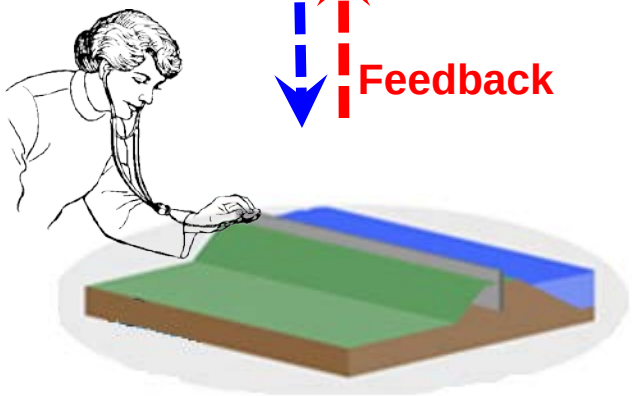
Operators

Owners



Regulators

Feedback



Health Assessment

Concluding Remarks

Health assessment framework:

- Sensing tools
  - Remote: **JSinSAR, Enhanced SqueeSAR**
  - Field: **GPS and SAP**
- **Global-Intermediate-Local** health assessment
  - Provides a evaluation of "current" levee condition
  - Provides amble time to implement required repairs before major events (hurricanes, floods, …)
  - Enhances resiliency of flood control levee systems
- Provides an automated monitoring and data collection program.