Joint Airborne Lidar Bathymetry Technical Center of Expertise: Coastal Engineering and Environmental Product Expansion

US Army Engineer Research and Development Center,
Molly Reif: Environmental Laboratory (EL)
Lauren Dunkin: Coastal Hydraulics Laboratory (CHL)

Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX), Kiln, Mississippi

Ecosystem Restoration Learning Series

November 29, 2011

US Army Corps of Engineers
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Outline

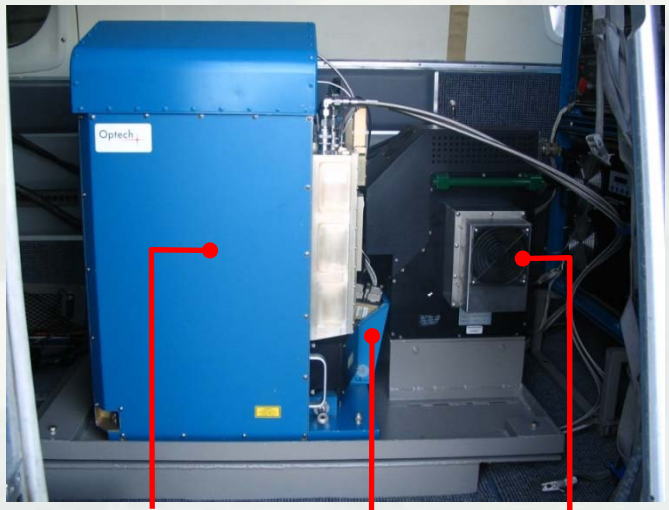
- Joint Airborne Lidar Bathymetry Technical Center of Expertise
  - Survey system and new sensor development
- National Coastal Mapping Program – NCMP
  - Acquisition Scheme
  - 2012 planned surveys
  - NCMP Products
- Environmental Applications
  - Land cover, invasive species, site characterization, stamp sands, SAV
- Coastal Engineering Applications
  - Coastal vulnerability and storm damage assessment, shore protection and navigation projects, inlet features, models, and regional sediment management
- Summary

Joint Airborne Lidar Bathymetry Technical Center of Expertise

JALBTCX

- **Operations**
  - USACE
  - Navy
- **Technology Evolution**
  - Coastal Measurements & Data Usage
  - Sensors & Systems
  - NOAA

CHARTS



Optech SHOALS-3000 Integrated Laser System

DuncanTech-4000 RGB camera

Itres CASI-1500 Hyperspectral Imager

Bottom Aircraft Port

<u>System Specifications</u>

3,000 Hz Pulse Rate (hydro)

20,000 Hz Pulse Rate (topo)

1 Hz Digital camera (~35 cm pixel)

CASI-1500 Hyperspectral Imager

- 1500 cross-track pixels
- 380 – 1050 nm wavelength
- 1 m pixel w/ 36 spectral bands

CHARTS

COMPACT HYDROGRAPHIC AIRBORNE RAPID TOTAL SURVEY

Applanix DSS 322

- **22.2 megapixel (5436 X 4092)**
- **~ 5 cm / pixel (at 400m)**
- **Color (VIS) or Color IR (CIR)**
- **Includes POS / AV**

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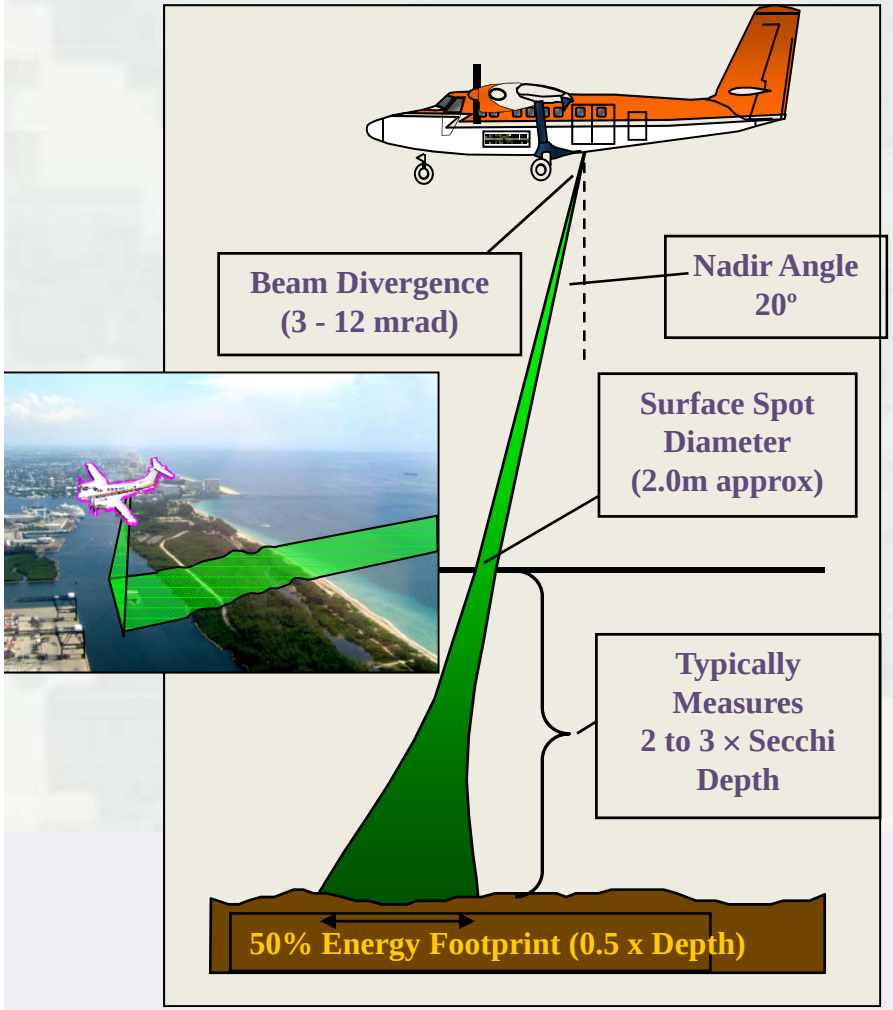
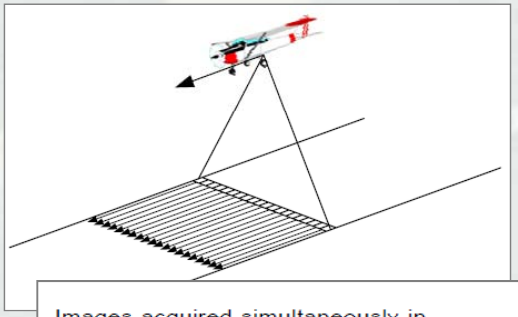
Lidar and Hyperspectral 101

Optech SHOALS Lidar: 3k Hz Pulse Rate (hydro, green laser)
20k Hz Pulse Rate (topo, NIR laser)

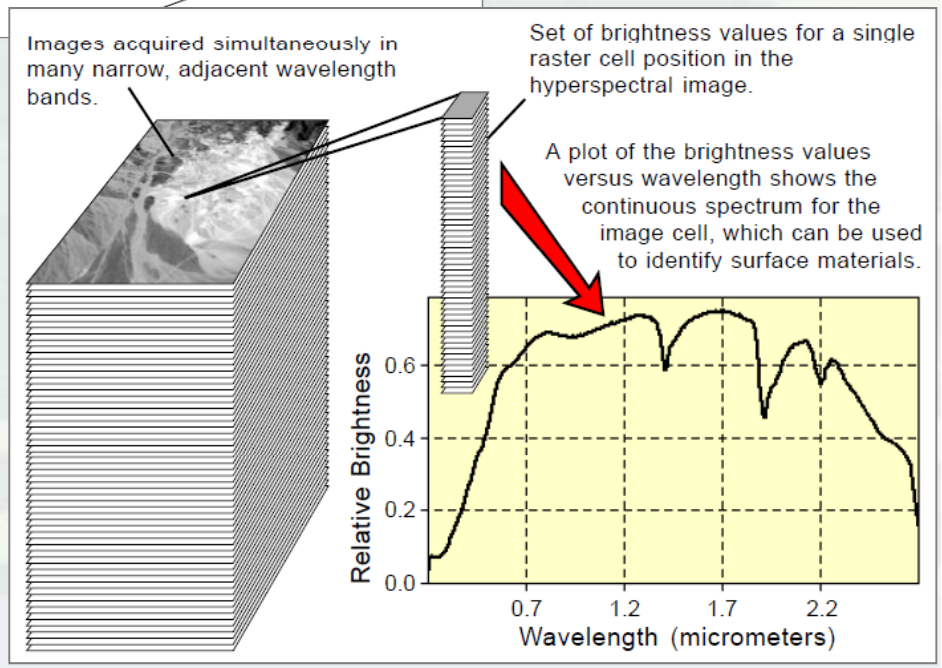


*The system on the plane receives the returned laser energy, in which the **return time is used to estimate elevation/depth**.*

Itres CASI-1500 Hyperspectral Imager

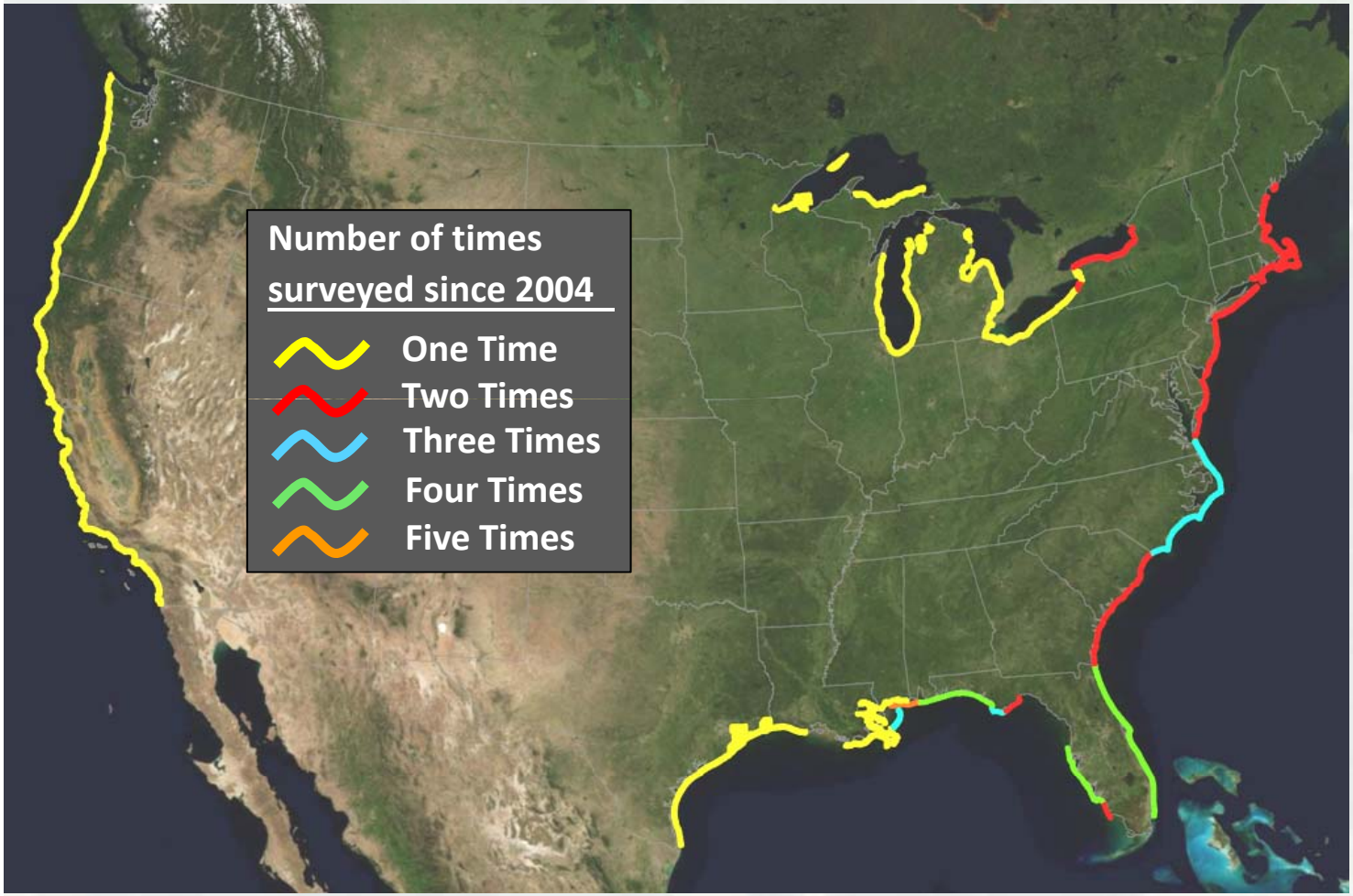


1500 cross-track pixels
380 – 1050 nm wavelength
1 m pixel w/ 36 spectral bands



*Hyperspectral sensors measure light reflected in many narrow, contiguous spectral bands across the electromagnetic spectrum. Due to the narrow bandwidth they can **capture unique spectral signatures** of objects on the earths surface.*

National Coastal Mapping Program



- Funded by USACE Headquarters
- Initiated FY2004
- Collect lidar elevation and imagery data in support of engineering and research
- Focus on sandy shorelines

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NCMP 2012 planned survey areas

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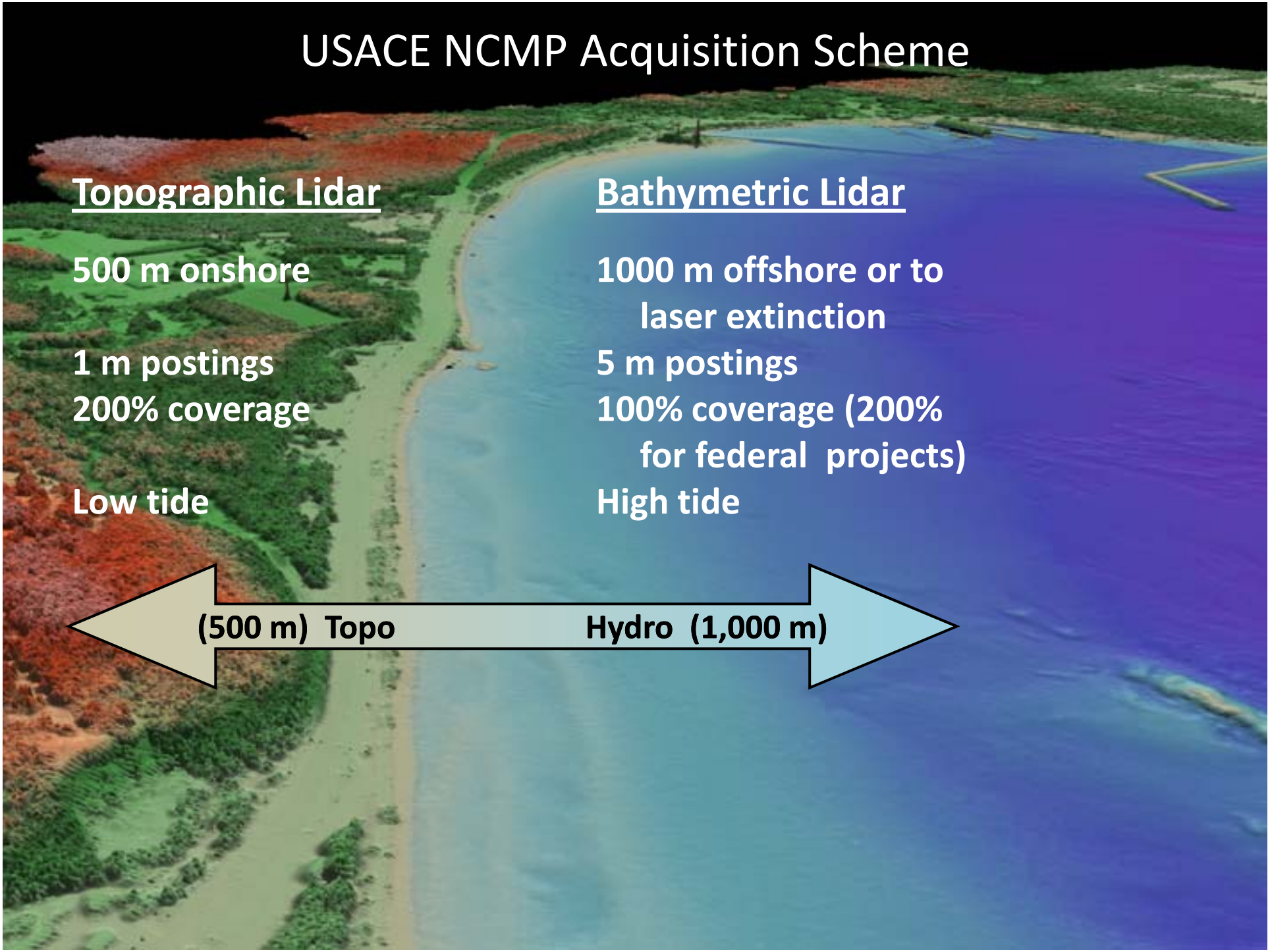
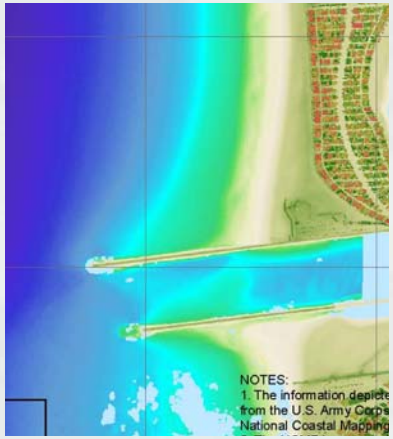

USACE NCMP Acquisition Scheme
Topographic Lidar
500 m onshore
1 m postings
200% coverage
Low tide
Bathymetric Lidar
1000 m offshore or to laser extinction
5 m postings
100% coverage (200% for federal projects)
High tide
(500 m) Topo
Hydro (1,000 m)

NCMP Product Evolution

2004

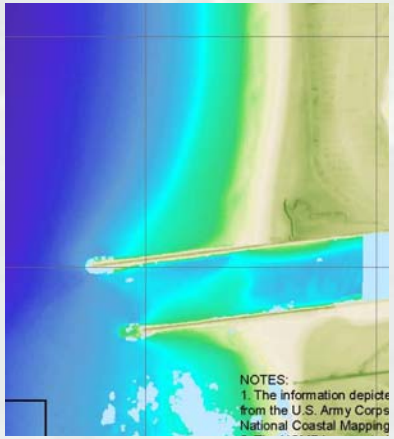
- ASCII xyz
- NAVD88 0 Shoreline
- RGB Mosaics

2005



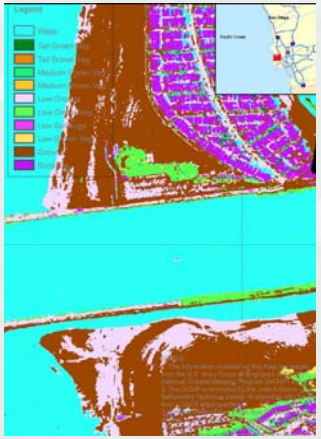
- Bathy/Topo DEM

2006



- LAS Format Topo
- Bare Earth DEM

2007-2009



- Hyperspectral Mosaics
- Laser Reflectance
- Land Cover Classification

Geographic Coordinates
NAVD88 Vertical Datum or IGLD85

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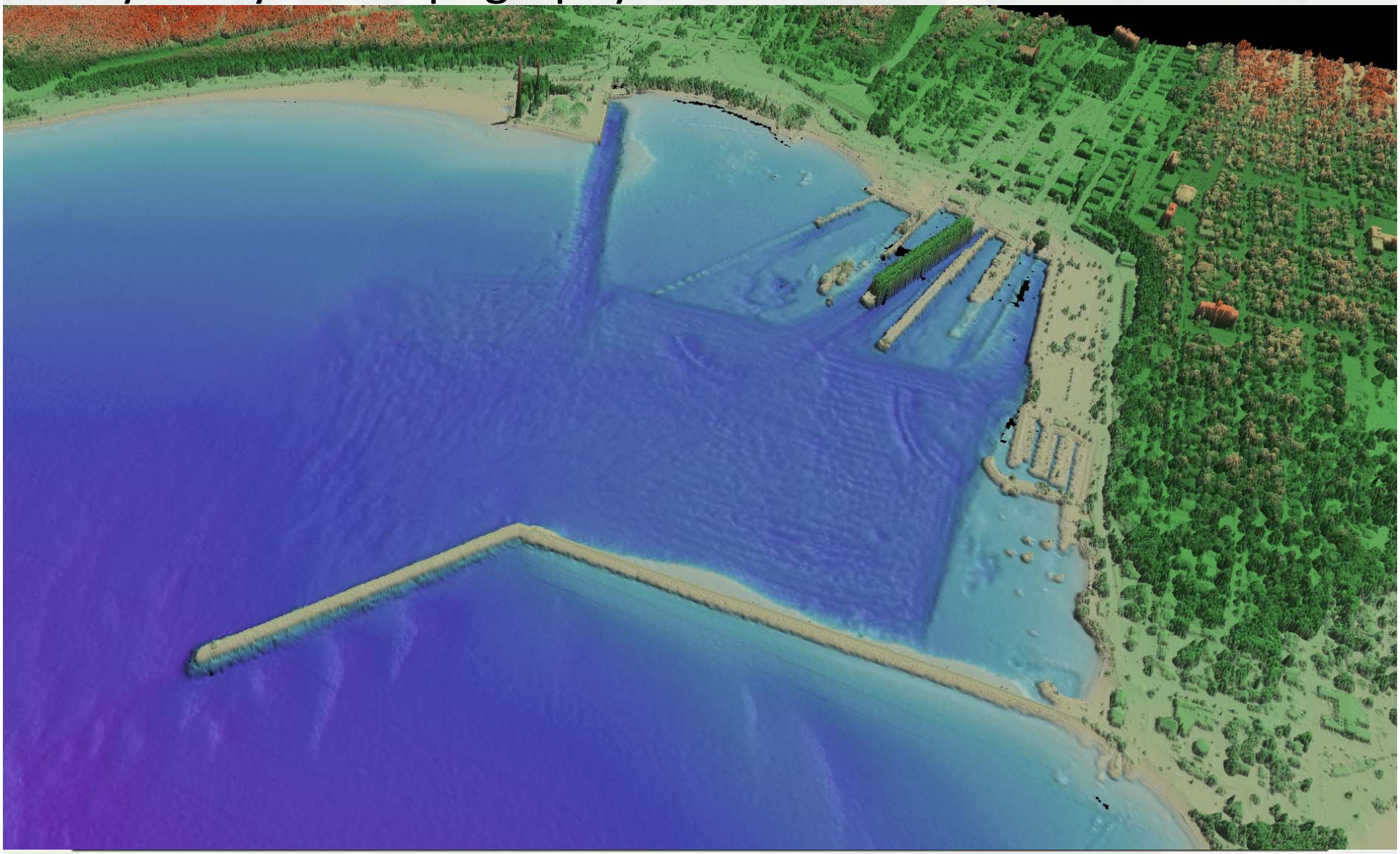
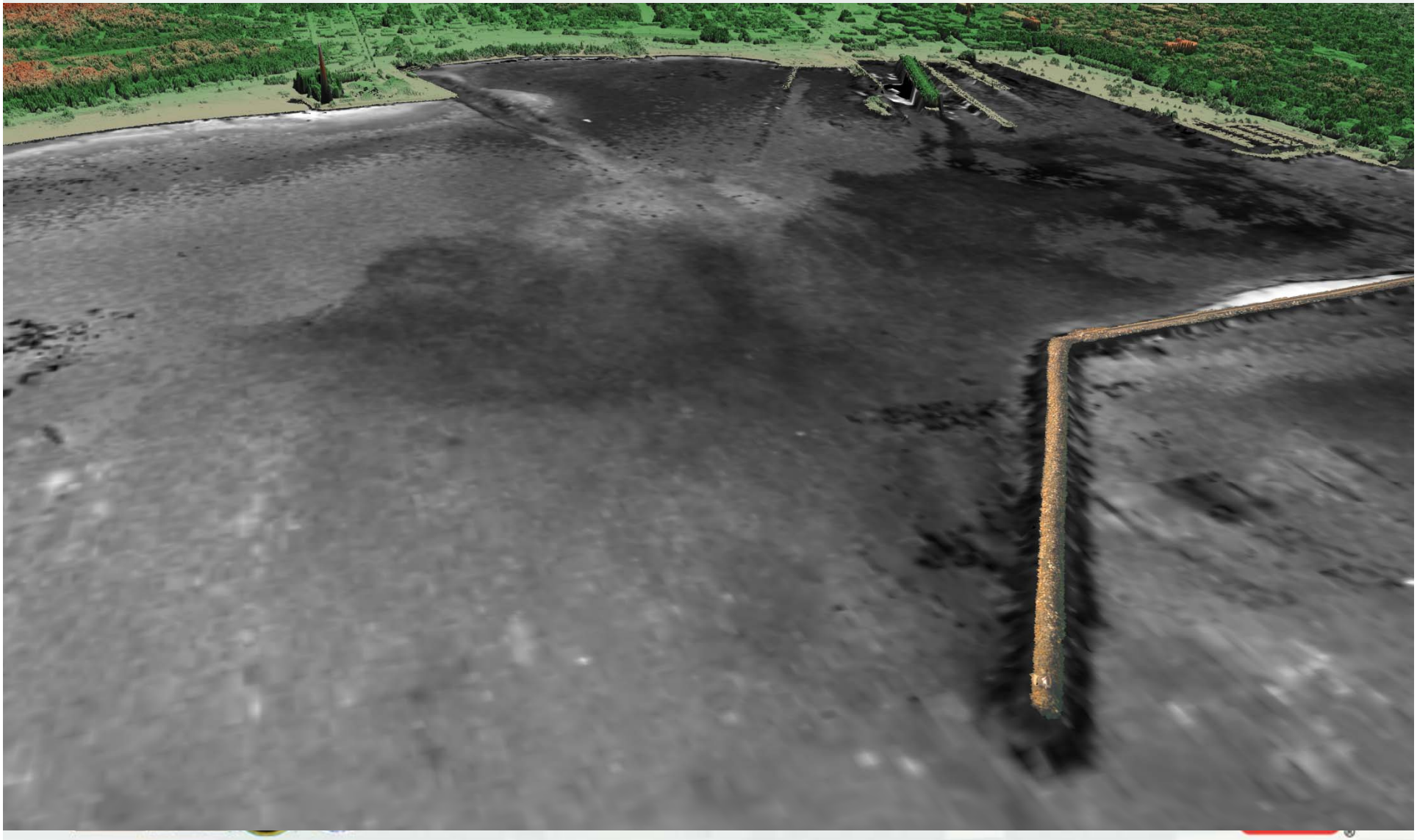
Bathymetry and topography



Marquette Harbor, MI

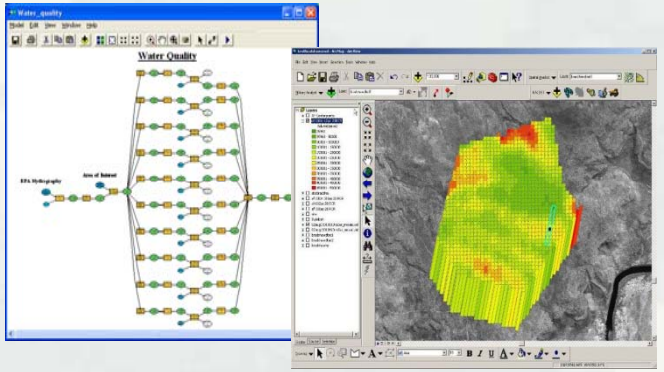
Laser imagery

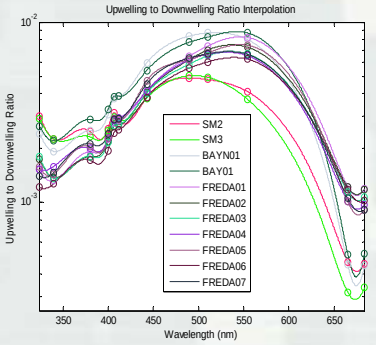


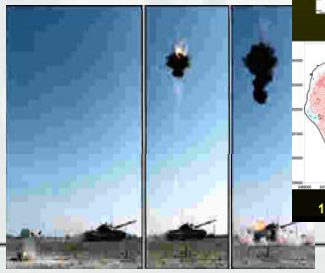
Aerial photography

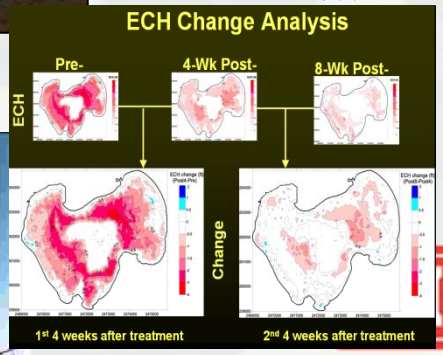
EL - Environmental Systems Branch

- **MISSION:** Identification, mapping, and modeling of environmental conditions in support of diverse military and civil requirements. Development of environmental sensing, characterization, and monitoring capabilities necessary to quantify environmental site conditions. Model development for the prediction and visualization of dynamic environmental characteristics for civil and military applications.









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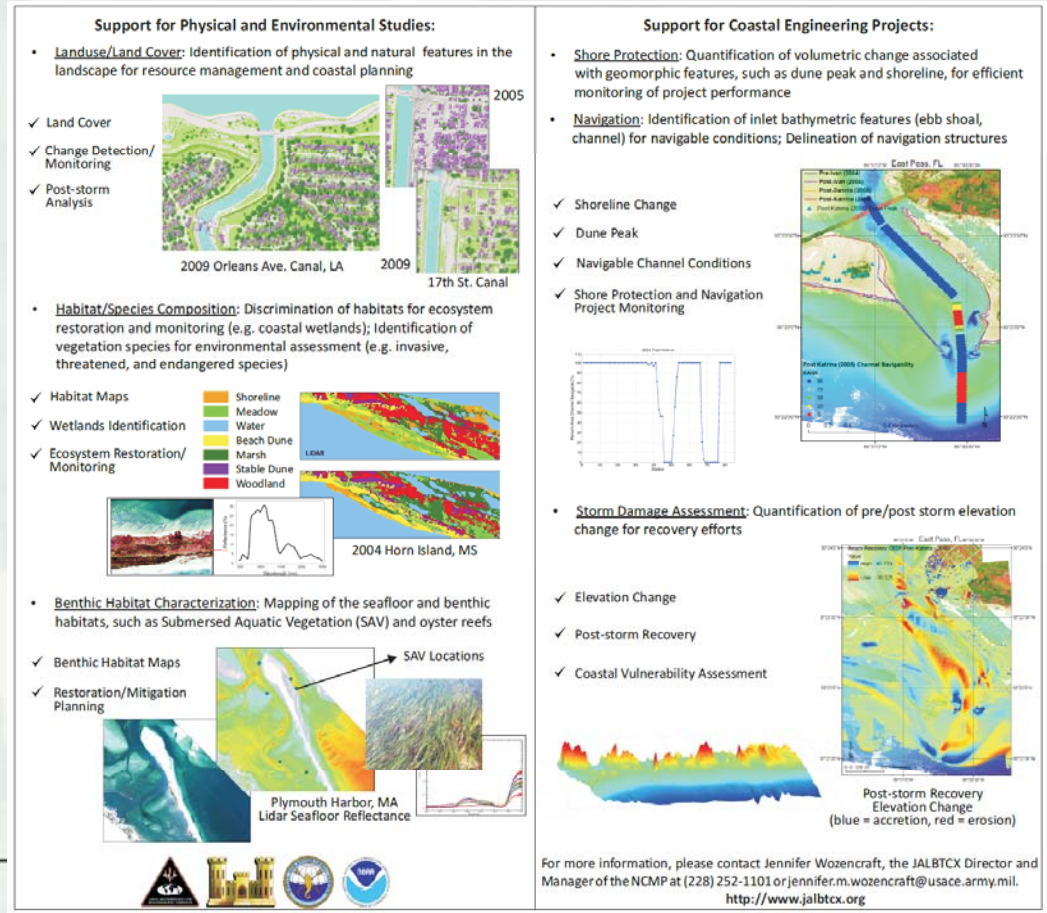
EL and JALBTCX

- **GOAL**: identify/expand environmental data products, utilizing (1) imagery resources of JALBTCX and (2) environmental expertise in EL to address environmental/geospatial needs of the coastal districts.

- Environmental Applications:
  - Site Characterization
  - Environmental Monitoring
  - Habitat Identification
  - Ecosystem Restoration Planning
  - Emergency Response/Recovery



Hyperspectral and Lidar Fusion

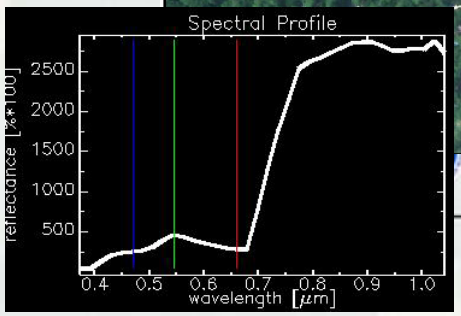
- Target features spectrally with hyperspectral and structurally with lidar through image fusion

Northern tip of Hunting Island, SC, 2010

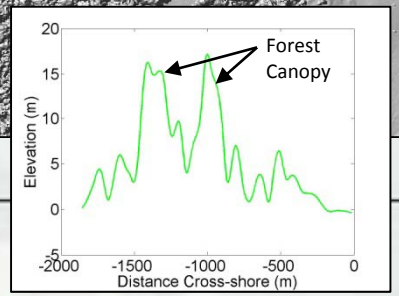
CASI hyperspectral, RGB

1m topo lidar hillshade

Fusion of hyperspectral and lidar



Forest Spectra



Elevation profile

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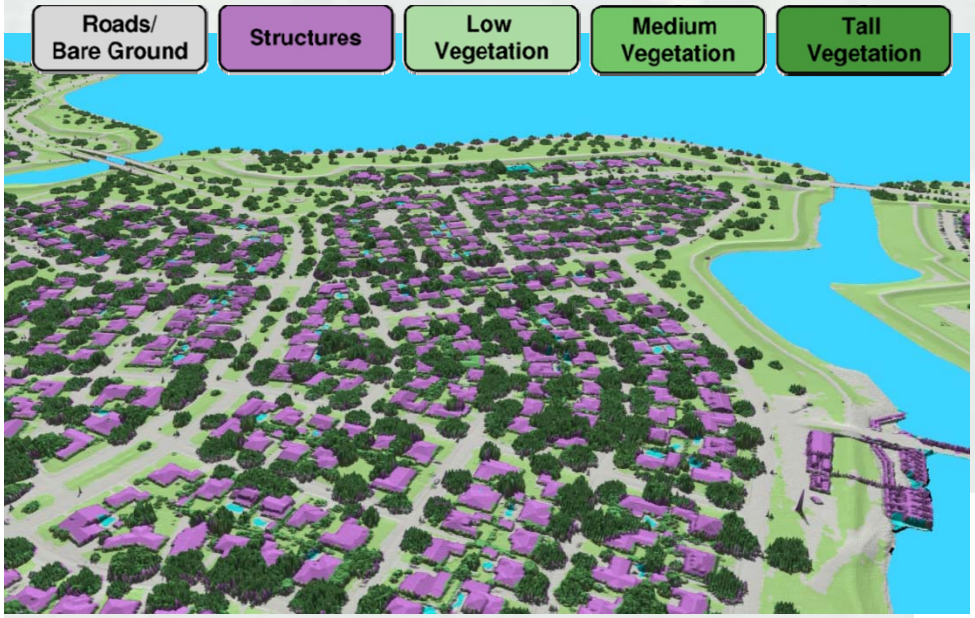
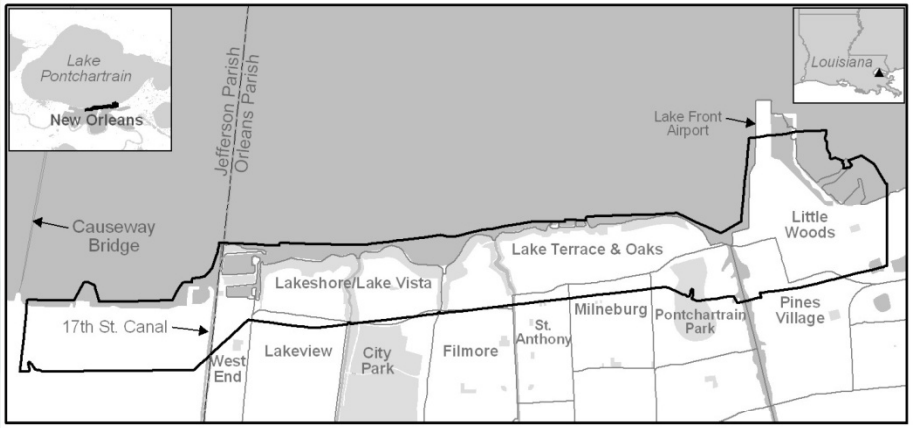
Post-Storm Land Cover, Elevation, and Volume Change Assessment

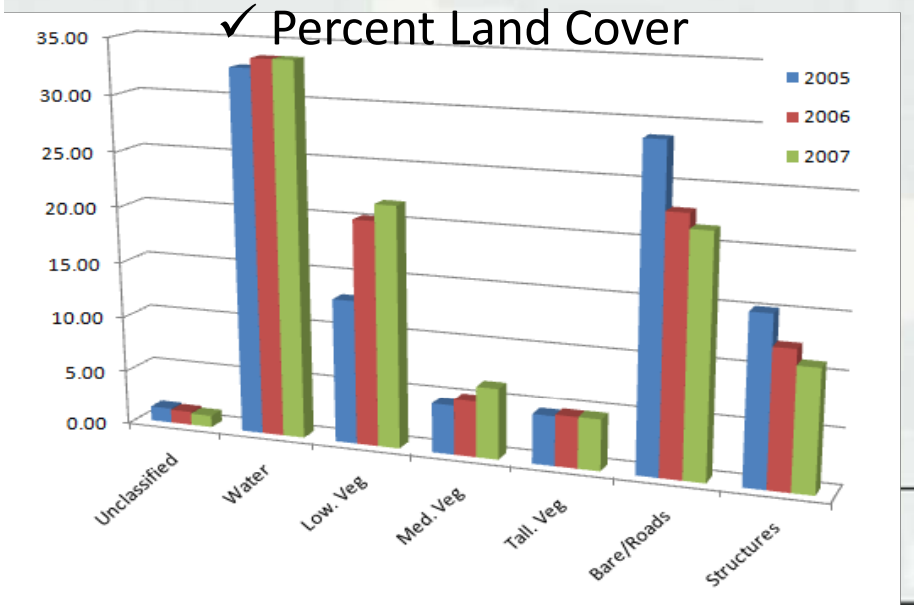


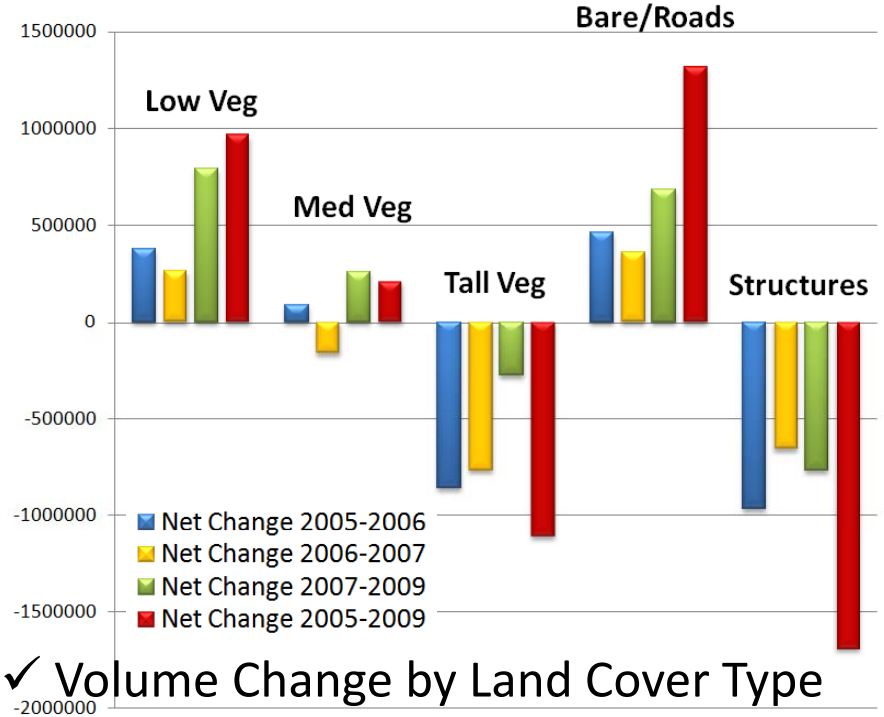


✓ Elevation Change

	2005-2006 Loss	2005-2006 Gain	Net Change
Elevation (km²)	-2.21	+2.17	-0.04
% Elevation	-6.55	+6.43	-0.12
Volume (m³)	-8.1×10^6	$+6.5 \times 10^6$	-1.6×10^6
% Volume	-25.97	+20.75	-5.22

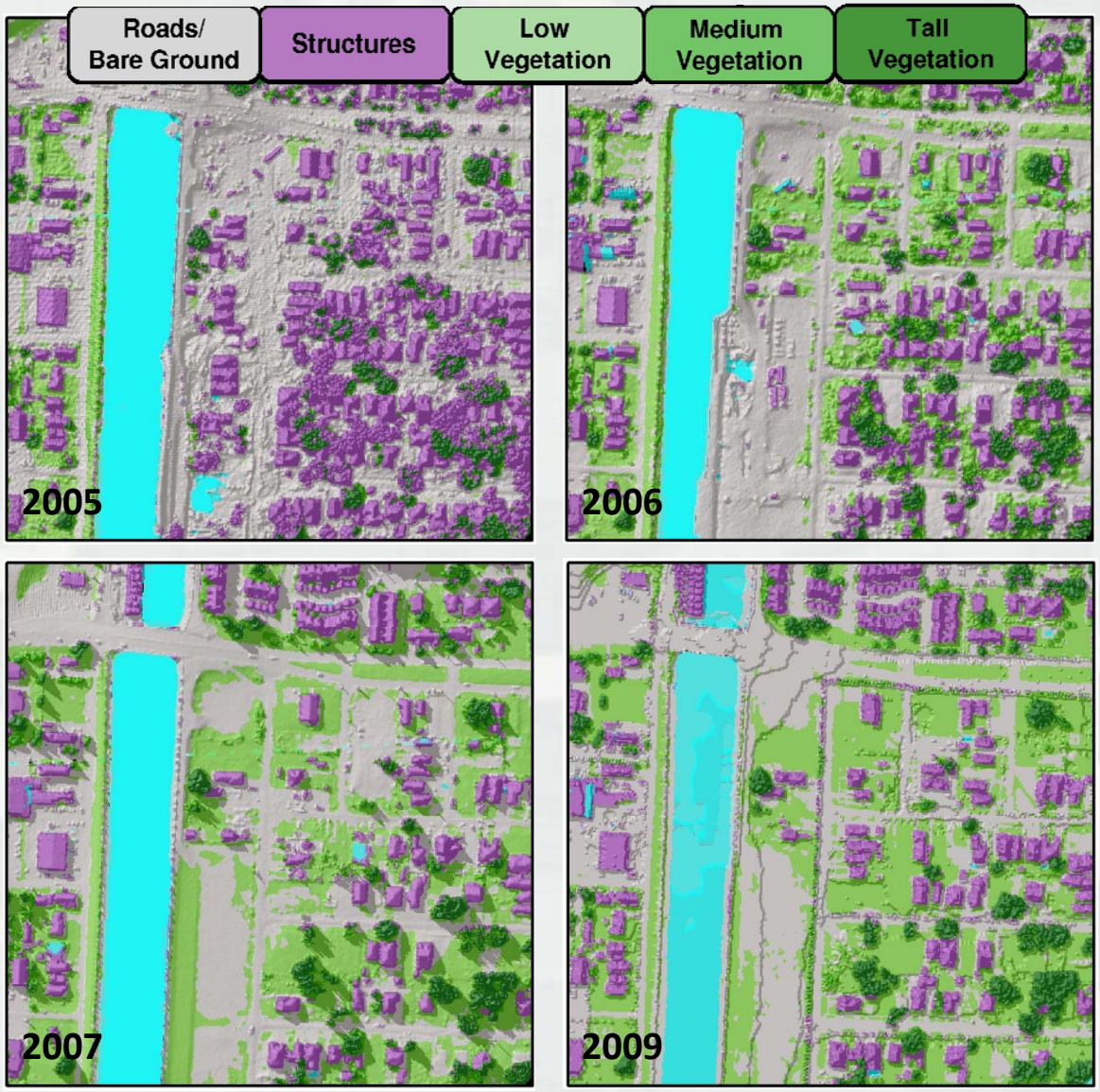
✓ Percent Land Cover





✓ Volume Change by Land Cover Type

Landscape changes



Reif, M., C.L. Macon, and J.M. Wozencraft. 2011. Post-Katrina Land-Cover, Elevation, and Volume Change Assessment along the South Shore of Lake Pontchartrain, Louisiana, U.S.A. *Journal of Coastal Research: Special Issue 62 – Applied Lidar Techniques* [Pe'eri & Long]: pp. 30-39.

17th Street Canal New Orleans, LA

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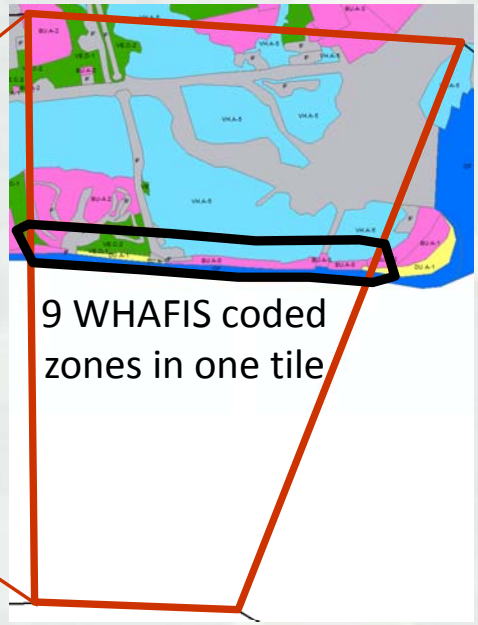
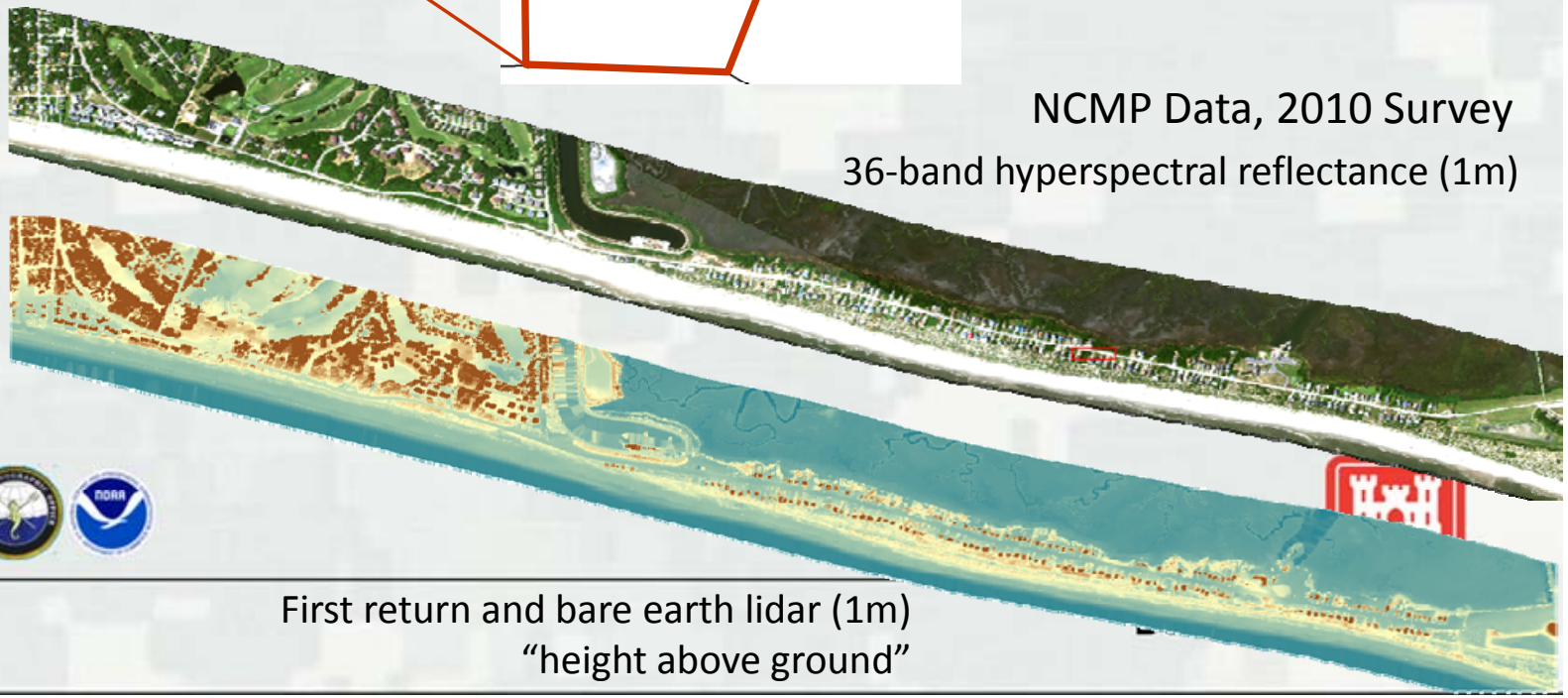
Pilot Coastal Classification: Brunswick County, NC

Caswell Beach, NC



9 WHAFIS coded zones in one tile



NCMP Data, 2010 Survey

36-band hyperspectral reflectance (1m)

First return and bare earth lidar (1m)

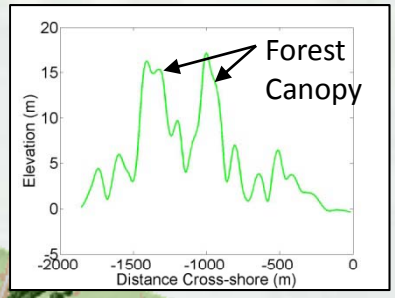
"height above ground"

Overland Wave Modeling

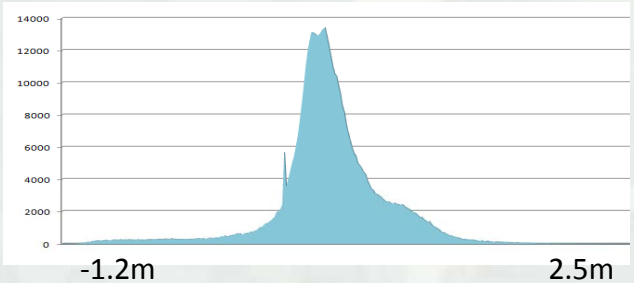
Transects (red) extend from the open coast, inland to the +20-ft contour. Each polygon is assigned WHAFIS code associated with a set of attributes to represent land use on the ground.

- As waves move inland they are affected by changes in topography and land use
  - Boils down to friction
- Lots of manual entering of data; tools such as Coastal Module WISE used to extract physical characteristics in GIS
- Transects drawn perpendicular to shore representing segments of coast with similar characteristics (spacing is variable depending on land use)

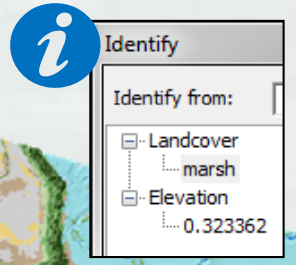
Coastal land cover classification

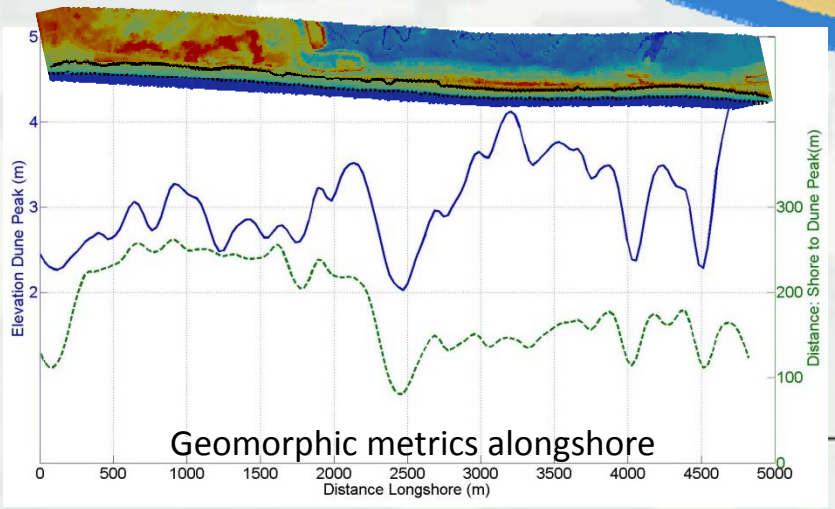


Marsh Elevation Distribution



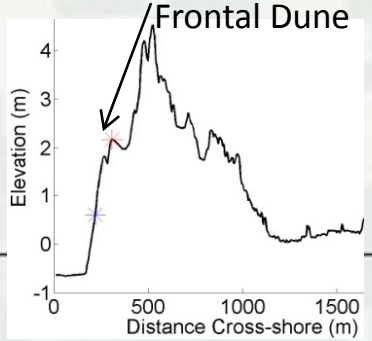
Landcover type	Manning n Value
bare/open	0.04
buildings/structures	0.07
grass/lawn	0.034
marsh	0.04
road/impervious	0.012
sand/beach	0.04
shrub	0.05
trees/forested	0.12
water	0.02



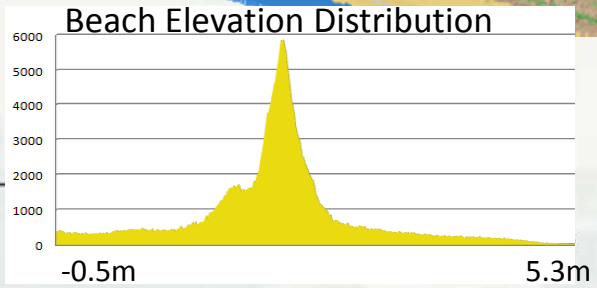


Geomorphic metrics alongshore

Primary Frontal Dune



Beach Elevation Distribution



Invasive species detection

- Spectrally and structurally target species of interest
- Emphasize changes in composition, structure and function in ecosystems caused by invasives

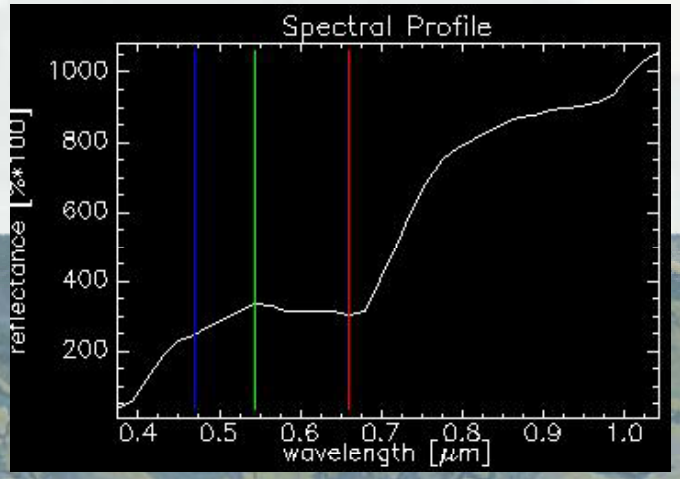
Times Beach, Buffalo NY, 2007

Emergent marsh dominated by *phragmites*

Wetlands Characterization

- Mapping Wetland Habitats
  - Spectrally and structurally target wetland species
  - Emphasize species pattern characterization and zonation related to elevation gradients
  - Wetland condition assessment

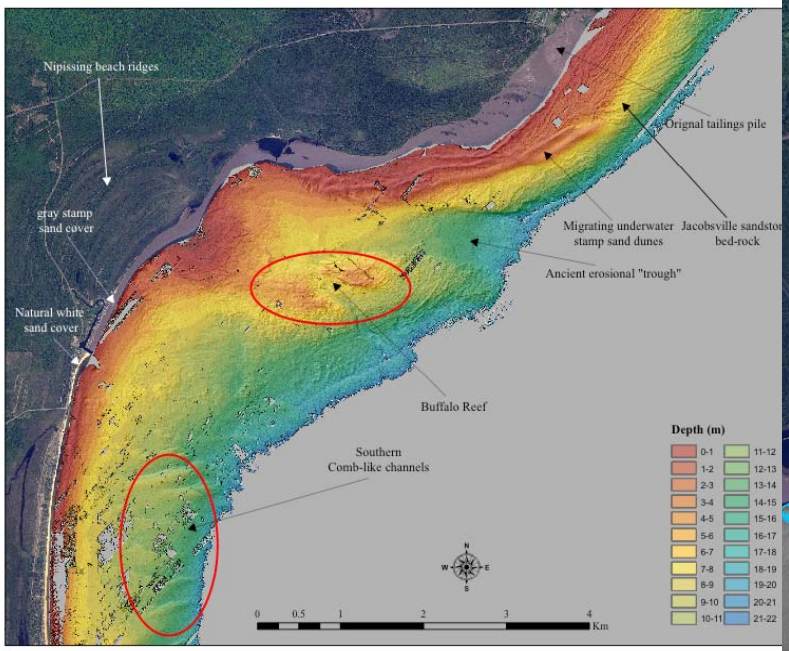
Marsh Spectra

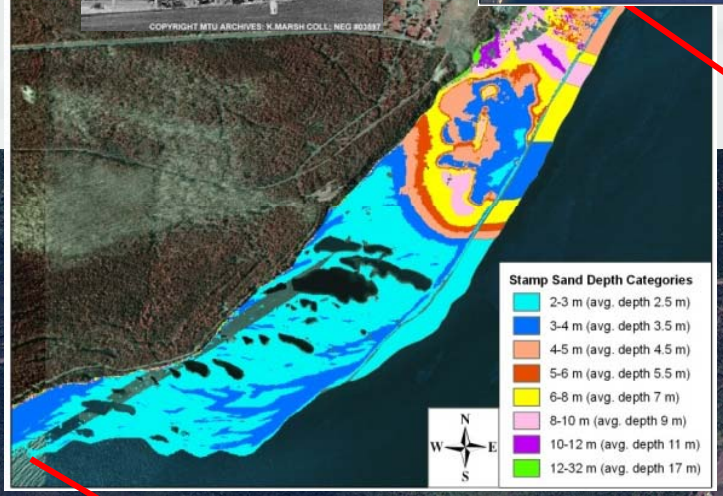


Edisto Island, SC, 2010; south of Jeremy Inlet

Stamp Sands Discrimination

Objective: classify lake bottom using hyperspectral/lidar reflectance. Map stamp sands distribution, estimate movement/loss of stamp sands to lake, and aid in reef restoration.





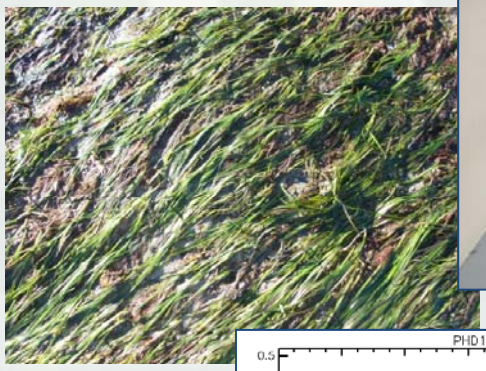
Dredging Operations and Environmental Research Work Unit:

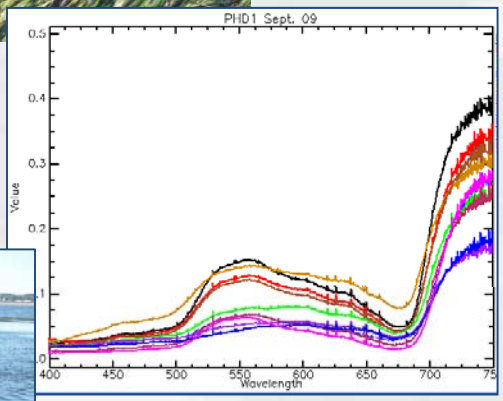
Use of Airborne Lidar and Hyperspectral Data to Detect and Discriminate SAV Species at Corps Dredging Sites

Purpose: evaluate and demonstrate the use of fused airborne hyperspectral and bathymetric lidar data to detect and discriminate species of estuarine SAV and macroalgae in two representative small-craft dredged harbors

Background: Dredging impacts to SAV vary by species; CWA lists SAV as a Special Aquatic Site; Mapping species is important for:

- Planning dredging operations
- Mitigating ecological damage
- Monitoring SAV





Submersed Eelgrass spectra, Plymouth Harbor, MA

PI: Bruce Sabol, EL

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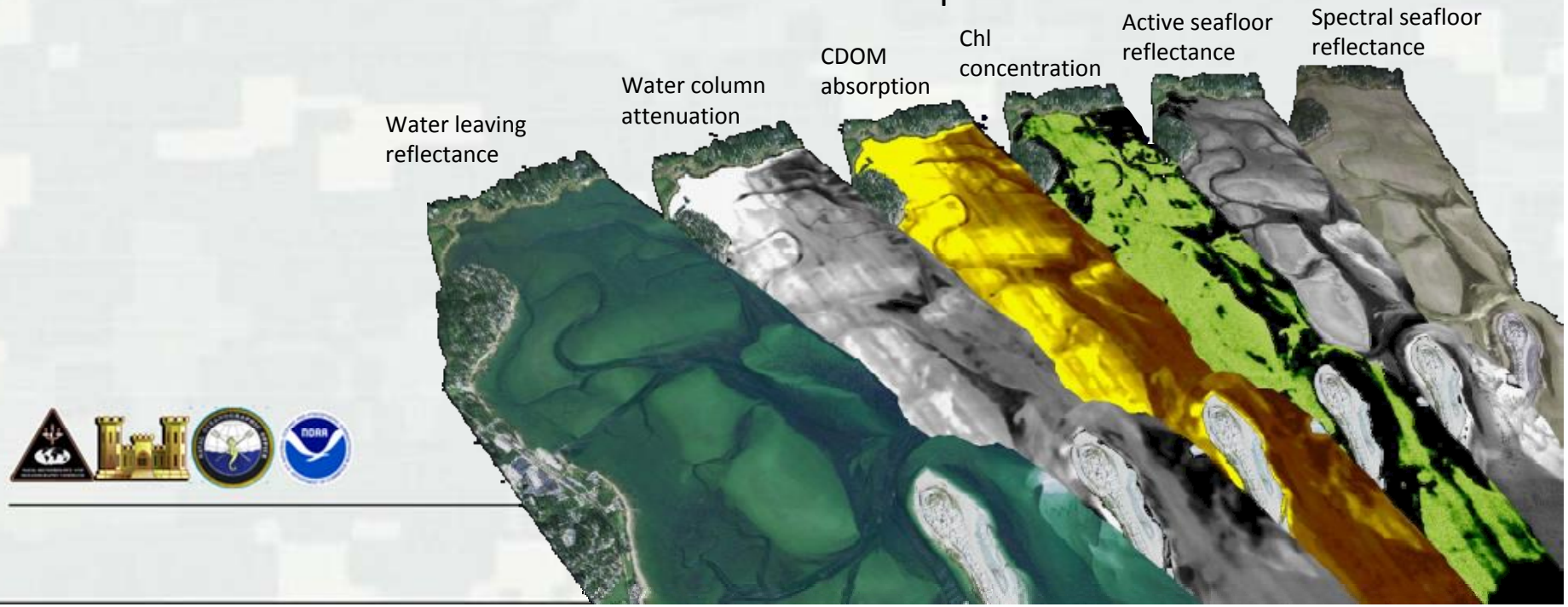
Image Processing Methods: Overall Approach

- Coastal Zone Mapping and Imaging Lidar (CZMIL) Data Processing System (DPS)
  - DPS with *Spectral Optimization* to characterize seafloor and water column
  - * Spectral curve fitting approach using radiative transfer theory to invert the hyperspectral image with lidar depth as a constraint for modeling water column constituents and estimating bottom reflectance
  - Classification of seafloor reflectance to solve for species



Results

Spectral Angle Mapper Classification Results: Optimized Bottom Reflectance

			Ground Truth	
Classified Image	Non-Veg	site BA	Site SG	Row total
Non-Veg	**12**	1	4	17
class 1 brown/red algae	0	**7**	0	7
class 2 seagrass	0	0	**17**	17
	12	8	21	**41**
Overall Accuracy (12+7+17)/41 = 87.8%				
Producer's Accuracy: Non-Veg (12/12)=100%; BA (7/8) = 87.5%; SG (17/21) = 81%				
User's Accuracy: Non-Veg (12/17)=70.6%; BA (7/7) = 100%; SG (17/17) = 100%				
** Note that a 5-meter buffer was applied to sites to account for GPS error (sampling locations around a GPS recording from a non-anchored boat, and raster spatial resolution accuracy (2-meters)*				
*** Non-Veg = non-vegetation; BA = brown/red algae; SG = seagrass*				
****Non-vegetation area total = 16.4 square kilometers*				
***** Brown/red algae area total = 0.4 square kilometers*				
***** Seagrass total vegetation = 0.85 square kilometers*				

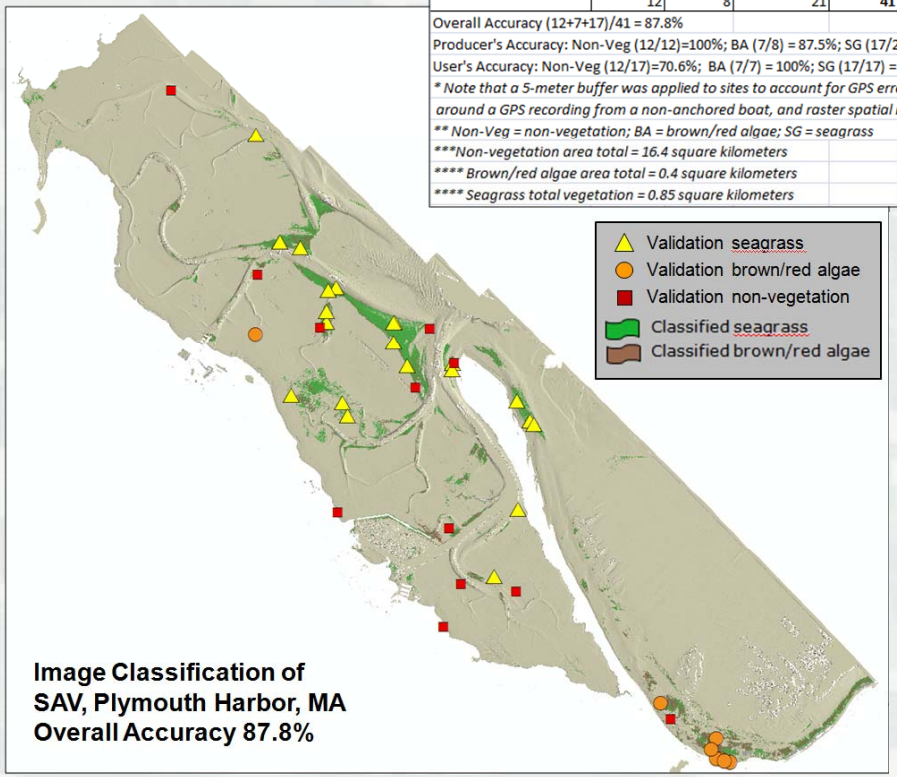


Image Classification of SAV, Plymouth Harbor, MA Overall Accuracy 87.8%

Air-Photo Classification Results

PLYMOUTH HARBOR			
		Training Data	
Delineation Data	SG Site	Non-SG Site	Row Total
In SG Poly	**25**	6	31
Outside SG Poly	14	**66**	80
Column Total	39	72	**111**
Overall Accuracy (25 + 66)/111 = 82%			
Producer's Accuracy: SG (25/39) = 64.1%; Non-SG (66/72) = 91.7%			
User's Accuracy: SG (25/31) = 80.6%; Non-SG (66/80) = 82.5%			
*** SG = seagrass; Poly = vector polygon delineated by the MDEP*			
**** SG poly area total = 3.0 square kilometers*			

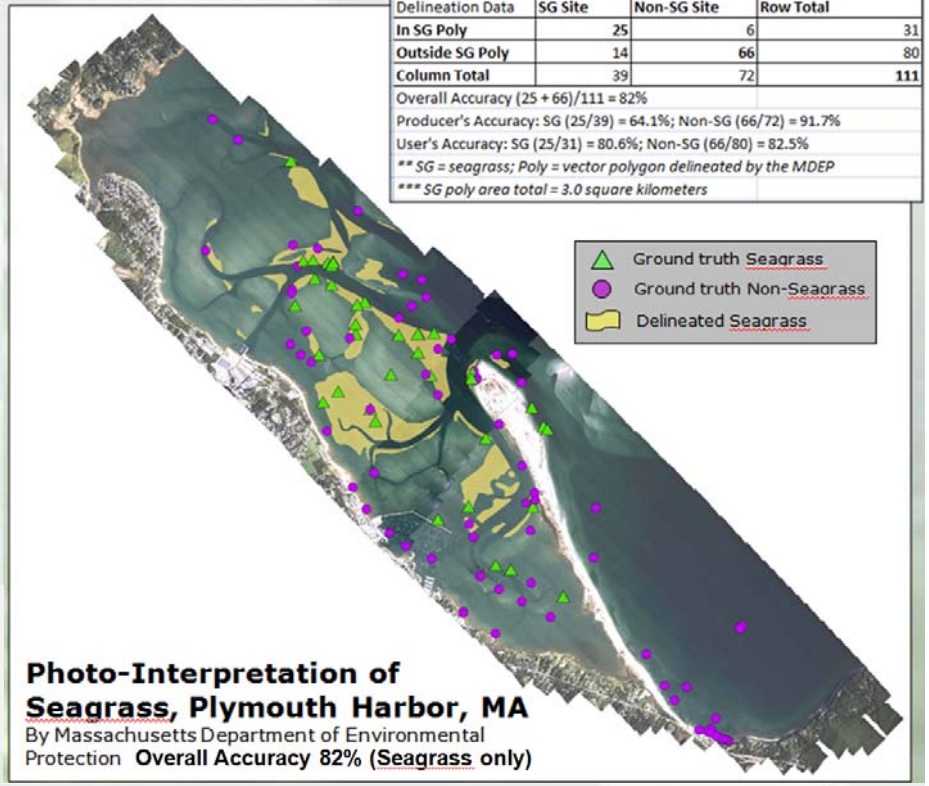


Photo-Interpretation of Seagrass, Plymouth Harbor, MA
By Massachusetts Department of Environmental Protection **Overall Accuracy 82% (Seagrass only)**

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ERDC/Coastal Hydraulics Laboratory

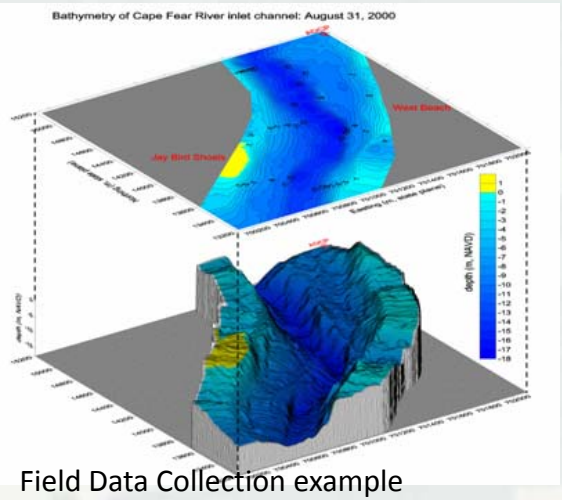
Hydraulic work focuses on understanding and improving USACE water-related projects including

- Navigation
- Flood risk management
- Hydraulic structures
- Reservoir operations

Los Angeles/ Long Beach Harbor Model

Coastal engineering work focuses on providing a better understanding of waves, currents, winds, and other natural shoreline forces

- Shore and beach erosion control
- Flooding and storm protection
- Coastal dredging
- Physical components of coastal environmental problems

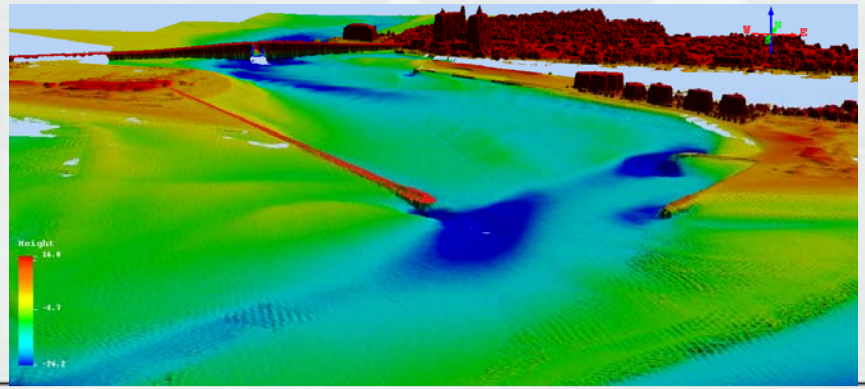


Field Data Collection example

BUILDING STRONG®

Coastal Engineering Branch

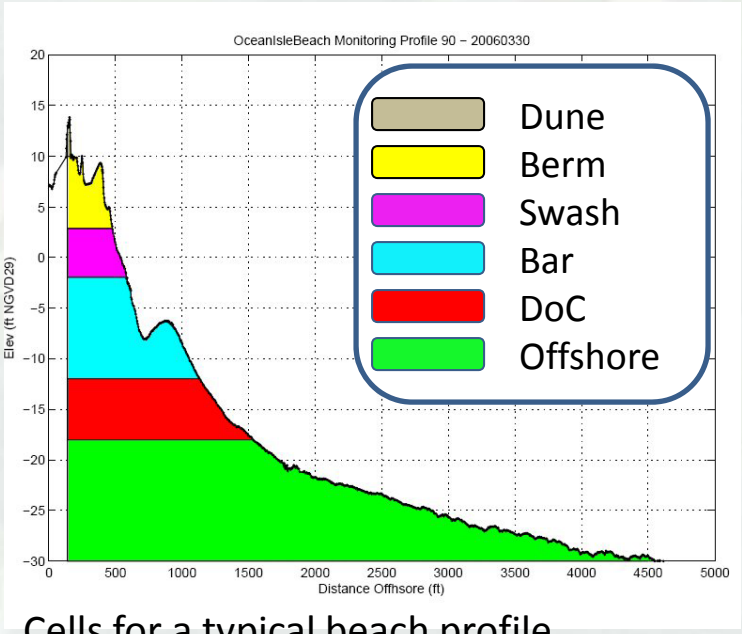
- Plan-execute-evaluate: coastal engineering studies and investigations
  - project planning and design,
  - performance monitoring and evaluation,
  - geologic and geomorphic analyses,
  - dredging and dredged material disposal problems
- Solve coastal & ocean problems: Coastal physical environmental, project specific, and regional scale studies, analyses, and data collection programs



CHL at JALBTCX

- Goal: Improve use of the JALBTCX data and collaboration within the coastal engineering field by
  - Development and expansion of coastal engineering data products and tools by utilizing lidar derived data products and resources at the JALBTCX and coastal engineering expertise in CEB to address coastal needs
    - Improve predictions of coastal vulnerability,
    - Storm damage assessment,
    - Shore Protection and Navigation Projects (condition & monitoring),
    - Regional Sediment Management (sediment budgets & pathways)

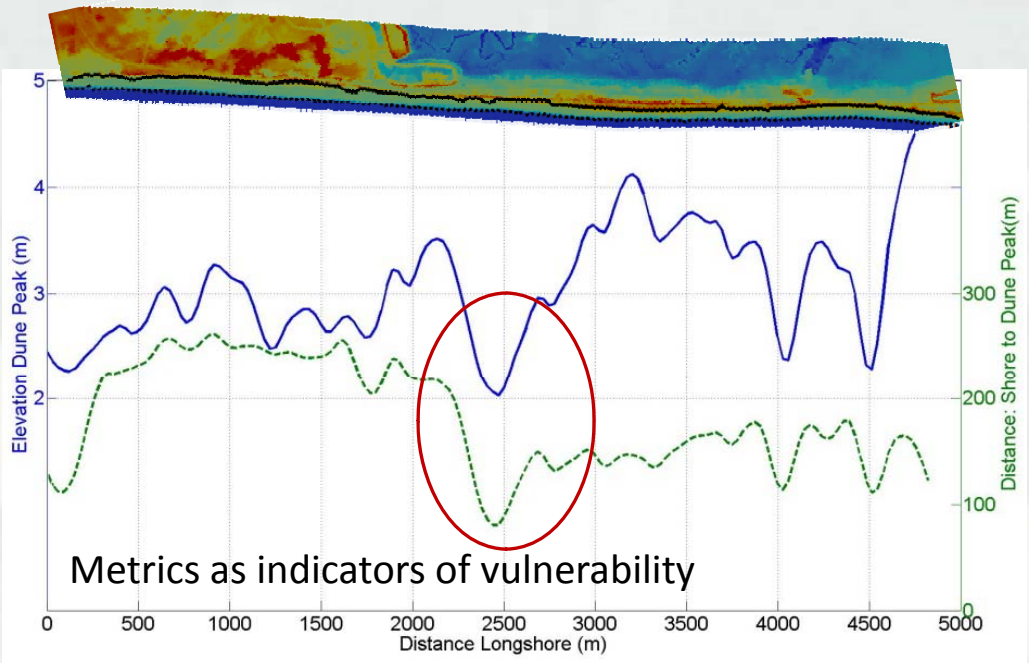
Coastal Vulnerability



Cells for a typical beach profile

- Wide beach and dunes
  - provide protection to upland infrastructure
  - valuable habitat

- Geomorphic Metrics
  - Automated feature extraction
    - Seaward most dune
    - Minimum wet/dry contour
  - Identify areas of vulnerability
    - Narrow beach width
    - Low elevations in dune line



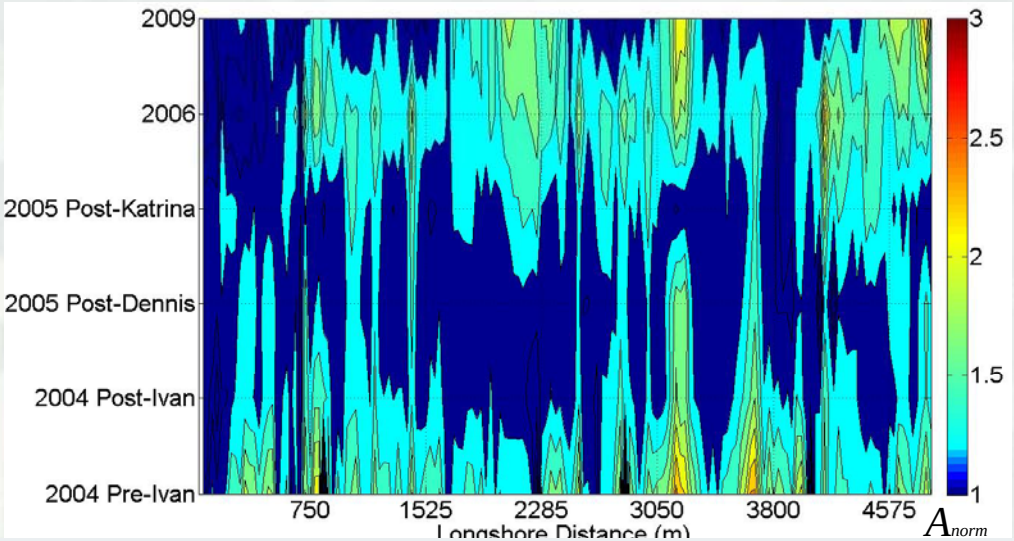
Metrics as indicators of vulnerability

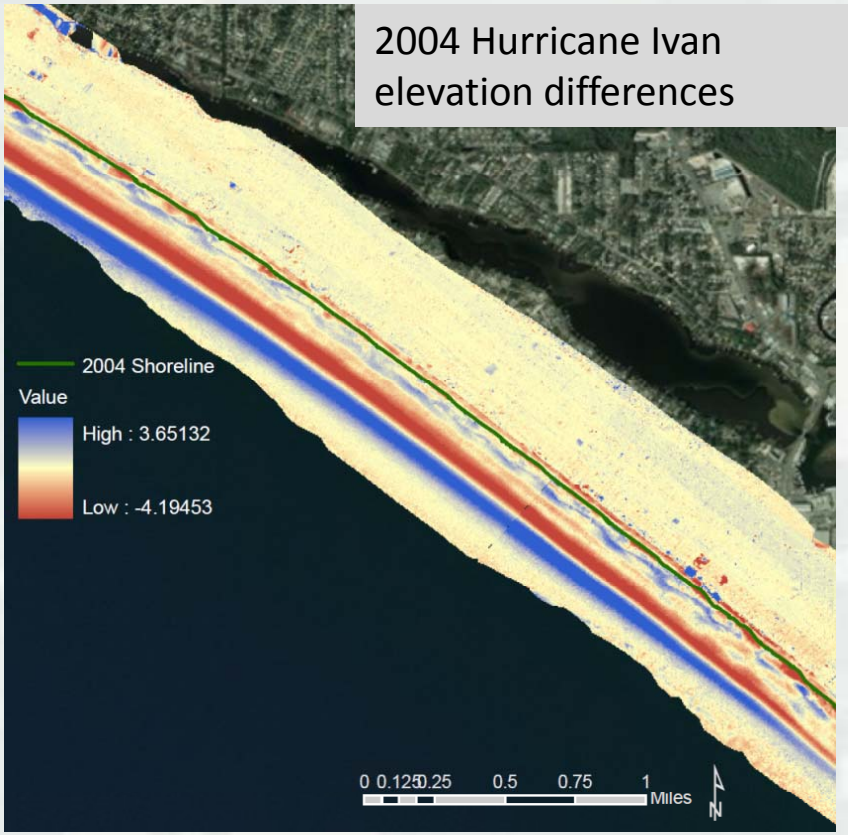
Storm Damage Assessment

- Multiple surveys provide a valuable means to compare pre- and post- storm assessments and to quantify recovery with repeat surveys of the same area

$$A_{norm} = \frac{A_{surveys}}{A_{base}}$$

Compare all surveys on a cell by cell basis to find minimum elevation



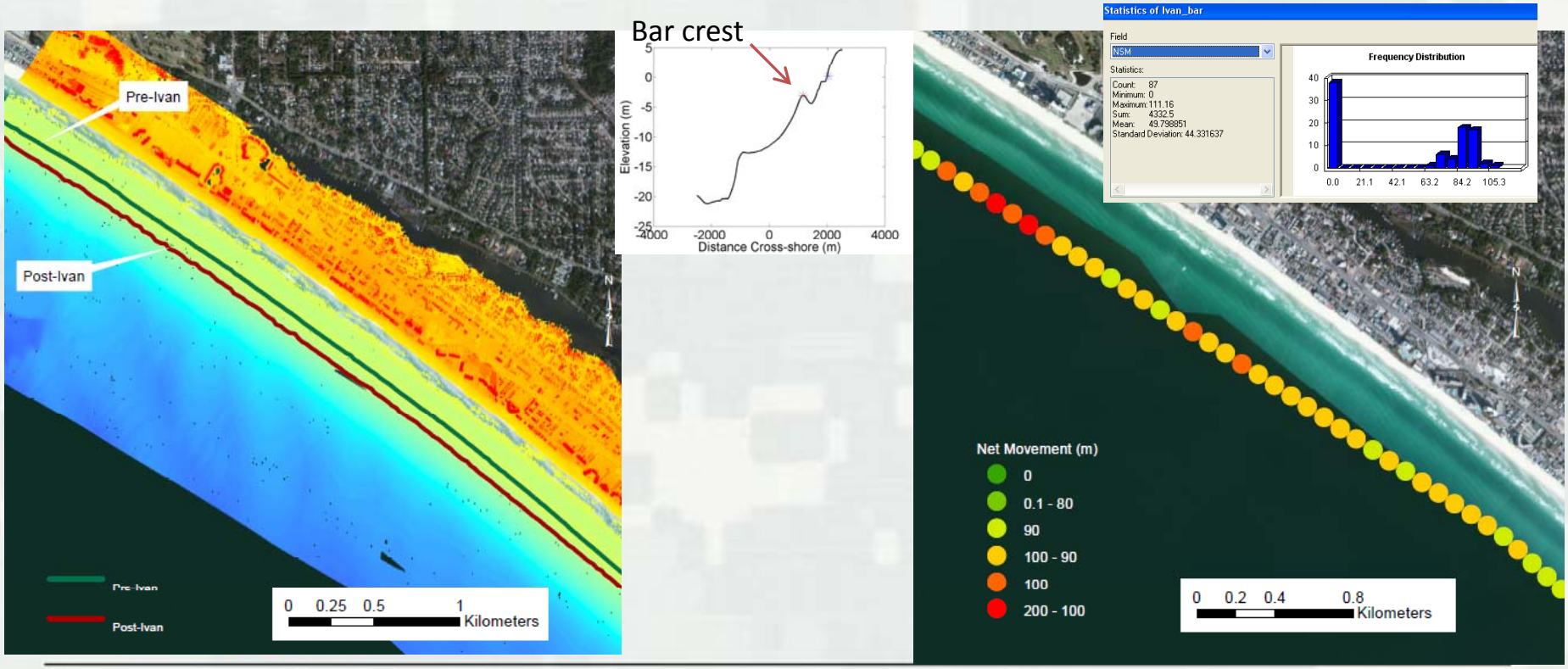


Seaward migration of nearshore bar

Multiple lidar surveys show areas that are close to minimum base elevation – indicator for vulnerability

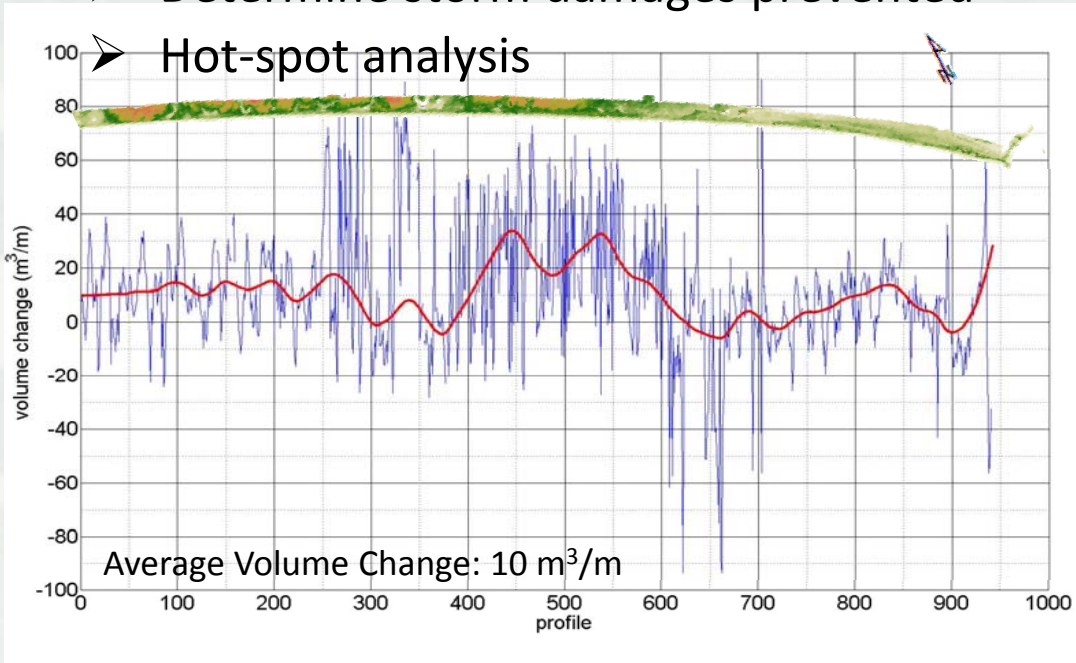
Storm Damage Assessment

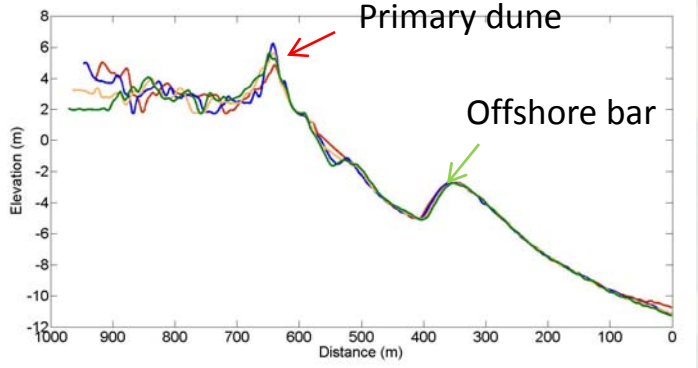
- Nearshore region highly dynamic during storm events
- Nearshore bars can provide added protection during storm events when waves break farther offshore and energy is dissipated
- Example – comparison of Pre- and Post- Ivan surveys show that the offshore bar migrated an average of 50 m offshore

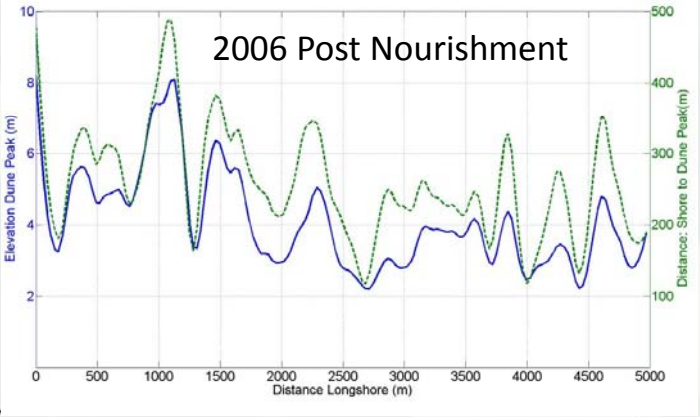


Shore Protection

- Beach Nourishment Projects
  - Placing sand on the beach provides recreational area, storm protection, environmental habitat
- NCMP data available to monitoring project performance
  - volumetric and contour change
  - Identifying re-nourishment requirements
  - Determine storm damages prevented
  - Hot-spot analysis



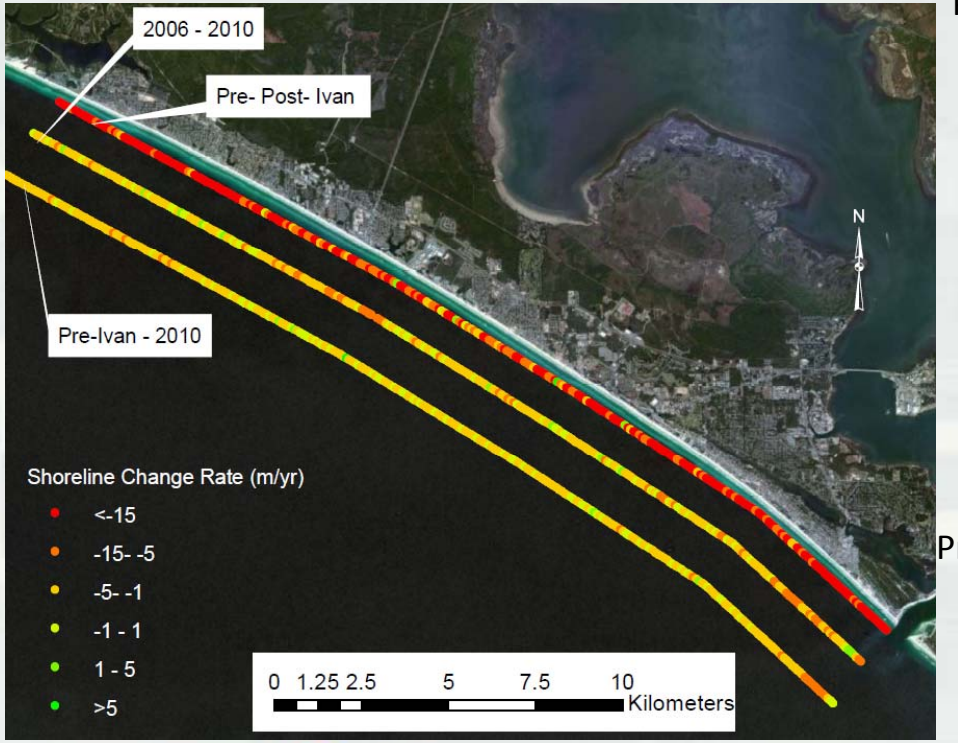




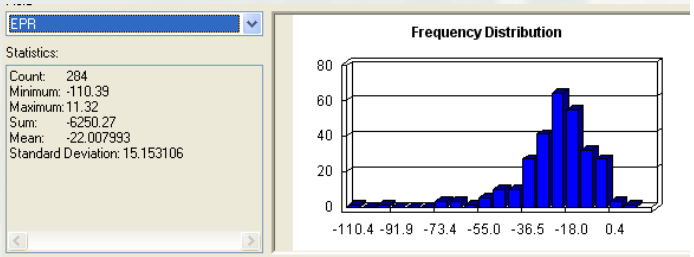
2006 Post Nourishment – 2005 Post Katrina

Shore Protection

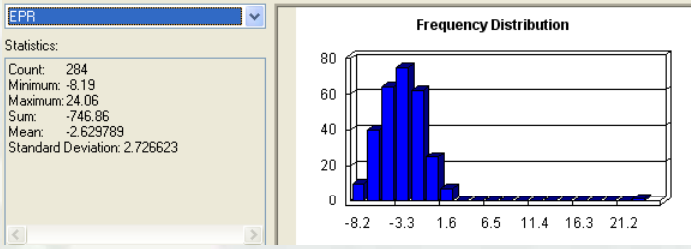
- Shoreline change
  - rates quantified by comparing multiple shorelines derived from lidar elevation data
  - Monitor fill placement and migration post-nourishment
  - Automated process that reduces manual delineation



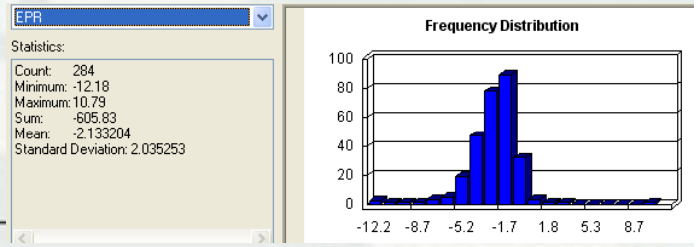
Pre- Post- Ivan



2006 - 2010



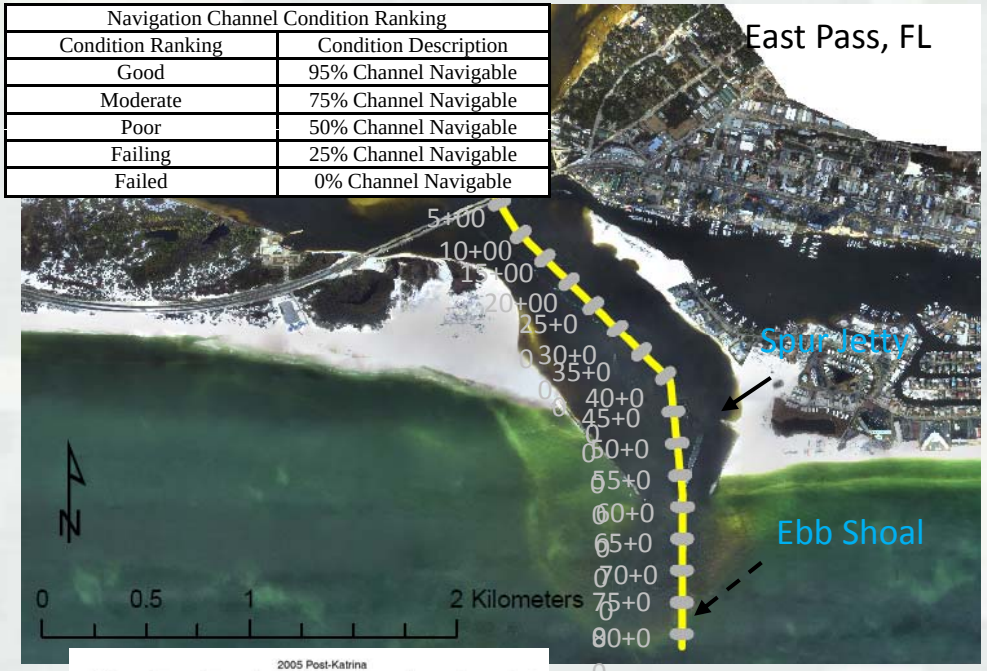
Pre-Ivan - 2010

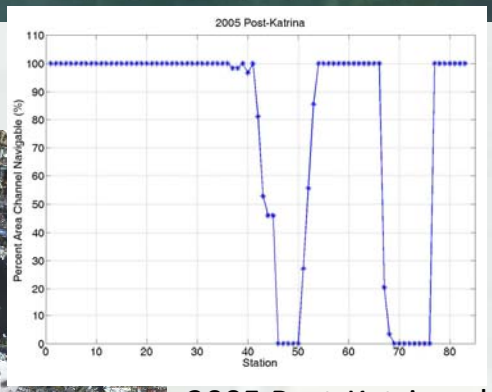


Navigation Projects

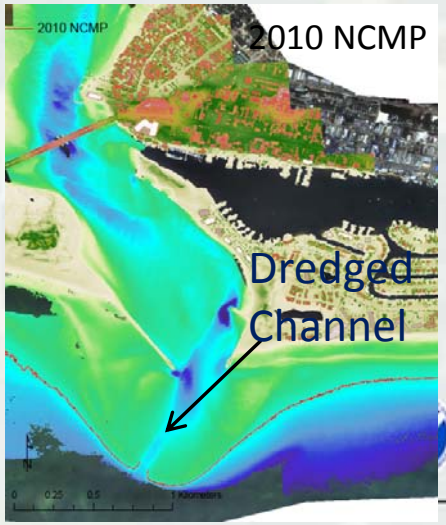
- Condition assessment of the navigation channel is vital to maintaining safe navigation through the inlet
- Automate channel condition assessment using bathymetric data
  - Channel availability ranked for each cross section to determine percentage of channel that is navigable

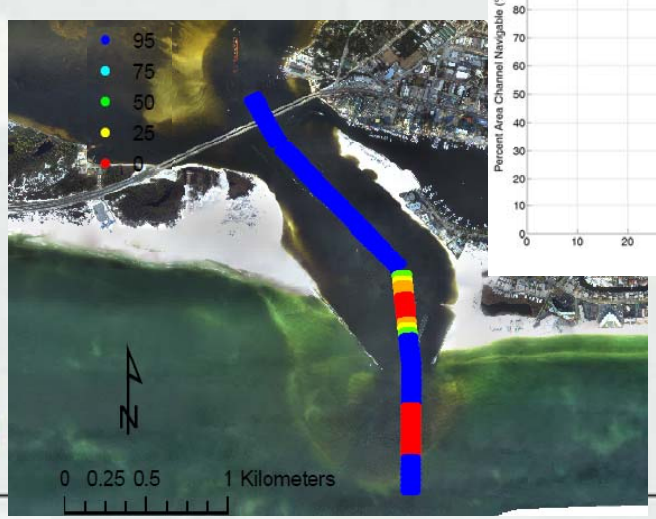
Navigation Channel Condition Ranking	
Condition Ranking	Condition Description
Good	95% Channel Navigable
Moderate	75% Channel Navigable
Poor	50% Channel Navigable
Failing	25% Channel Navigable
Failed	0% Channel Navigable





- Identify areas of concern after storm events and use multiple surveys to show migration of the channel





2005 Post-Katrina channel condition assessment of East Pass, FL

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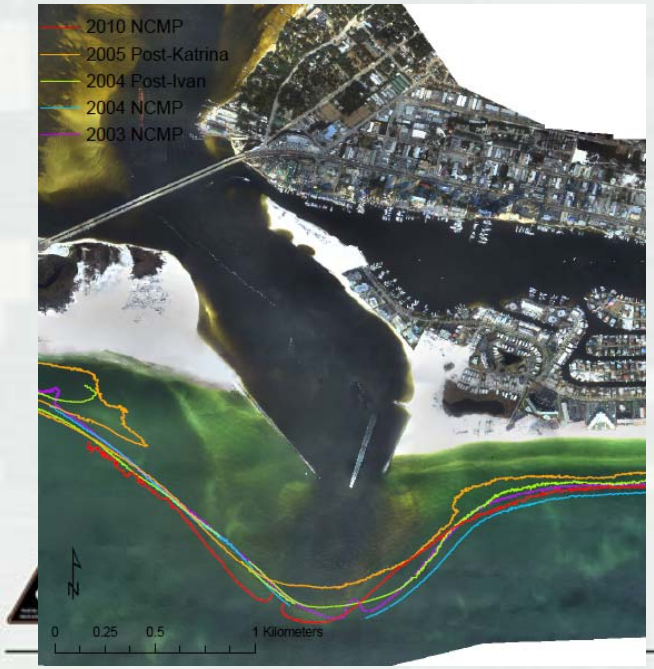
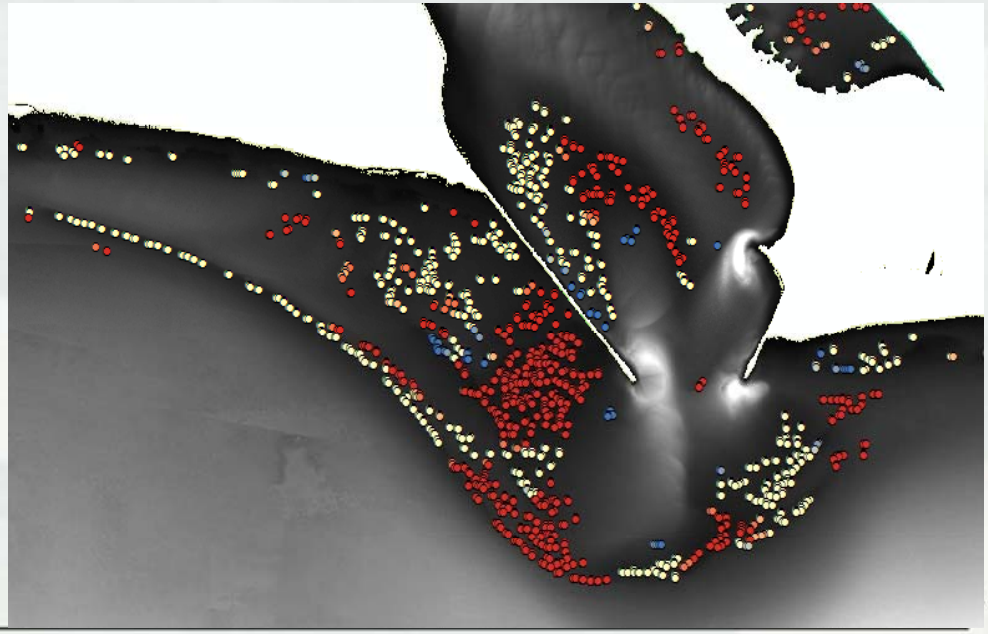
Inlet Features

- Coastal environment is highly dynamic with waves and currents acting as the primary driving force for changes in the nearshore area.
  - Inlet regions are particularly influenced by these forces which can cause migration of the ebb shoal
  - New methods/tools to delineate the ebb shoal feature in a semi-automated manner that would reduce the subjectivity and laborious process of manual digitization and provide valuable insight into sediment pathways and input into sediment budgets



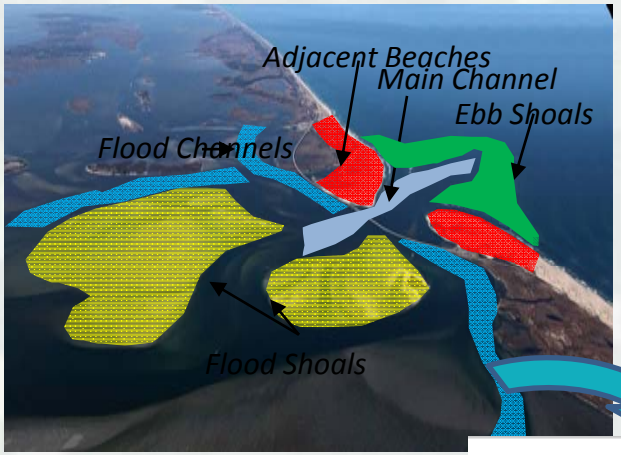
Migration of the East Pass, FL ebb shoal bounds



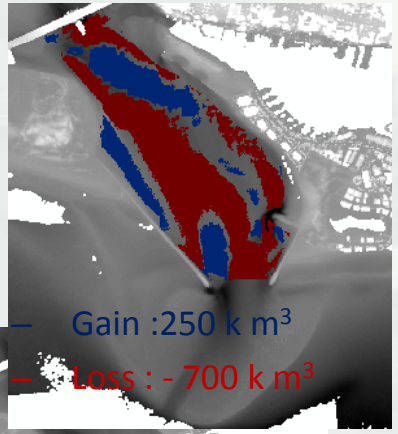
Hydrology- inverse depth to find sinks and cluster groups

Sediment Pathways & Budget

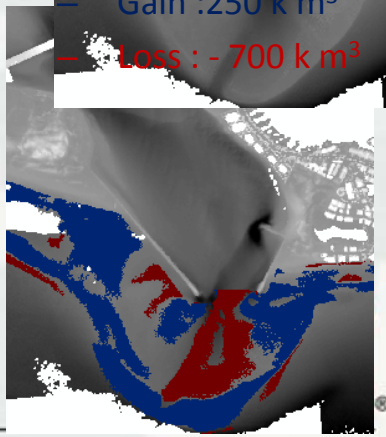
- Delineate morphological features of the shoal system
- Quantify amount of sediment entering/leaving system
  - Sediment budget
- Automated extraction of sediment volumes from bathymetric data to provide input into sediment budgets



Cells: Inlet and ebb shoal

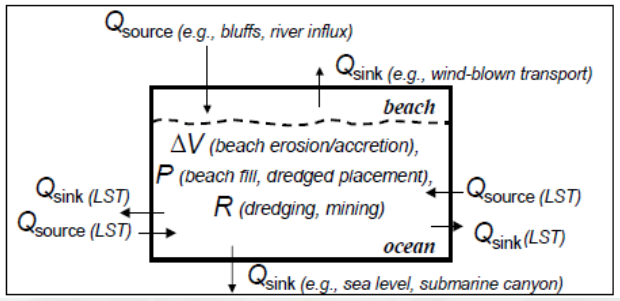


– Gain :250 k m³
– Loss : - 700 k m³



– Gain: 680 k m³
– Loss: -205 k m³

ERDC/CHL CHETN-XIV-3
June 2001



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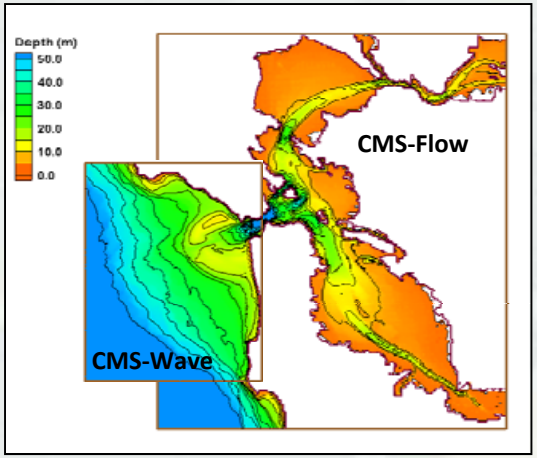
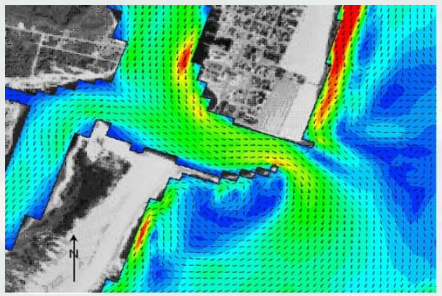
Models

- Provide identified morphological parameters from the lidar elevation data and thematic characteristics from the hyperspectral data as input into numerical models to better facilitate analysis of areas that are vulnerable to erosion and surge from storm events
- CMS – Coastal Modeling System
  - Simulating waves, currents, water level, sediment transport, and morphology change at inlets
- STWAVE – Steady State spectral WAVE
  - Nearshore wind-wave growth and propagation
- GenCade
  - Shoreline change, long-shore sand transport, and morphology change at inlets



❖ *More powerful models require more accurate and extensive data sets for model input and for validation of model output.*

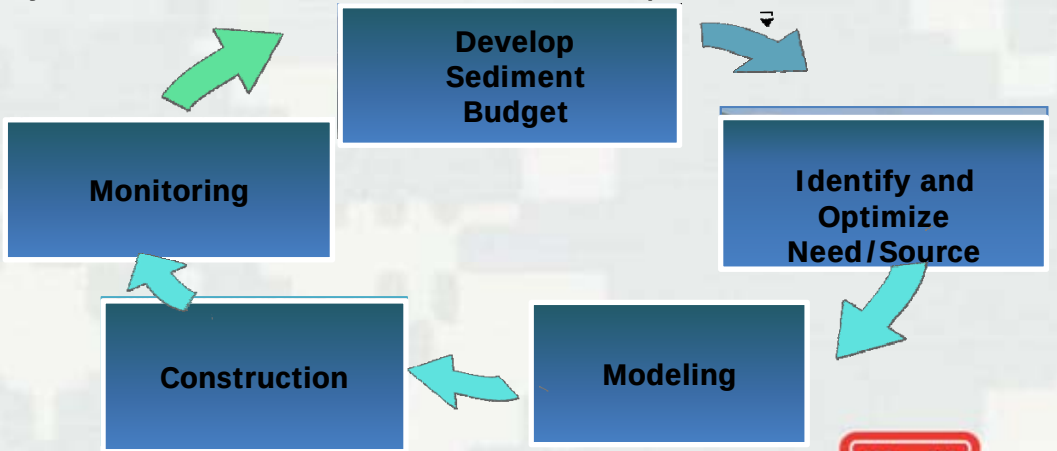


GENESIS + Cascade → GenCade

BUILDING STRONG®

Regional Sediment Management

- Iterative process that involves developing sediment budgets, identifying needs and sources, modeling changes, construction, and monitoring the project
- Beneficially manage sediment as a resource
- NCMP bathymetric and topographic data provides opportunity to refine sediment budgets and identify areas of viable fill material, provide high resolution data for input into models to determine the effects of changes to the inlet features (mining ebb shoal for beach fill material, changes in dredging, etc.), and monitoring the completed project to assess the functional performance



Summary

- National Coastal Mapping Program initiated in 2004 by HQ to provide high resolution lidar elevation and imagery along the sandy shoreline of the U.S. on a recurring basis
- JALBTCX performs operations, R&D in airborne bathymetric lidar in support of navigation, Regional Sediment Management, and environmental and coastal engineering applications to meet the requirements of USACE

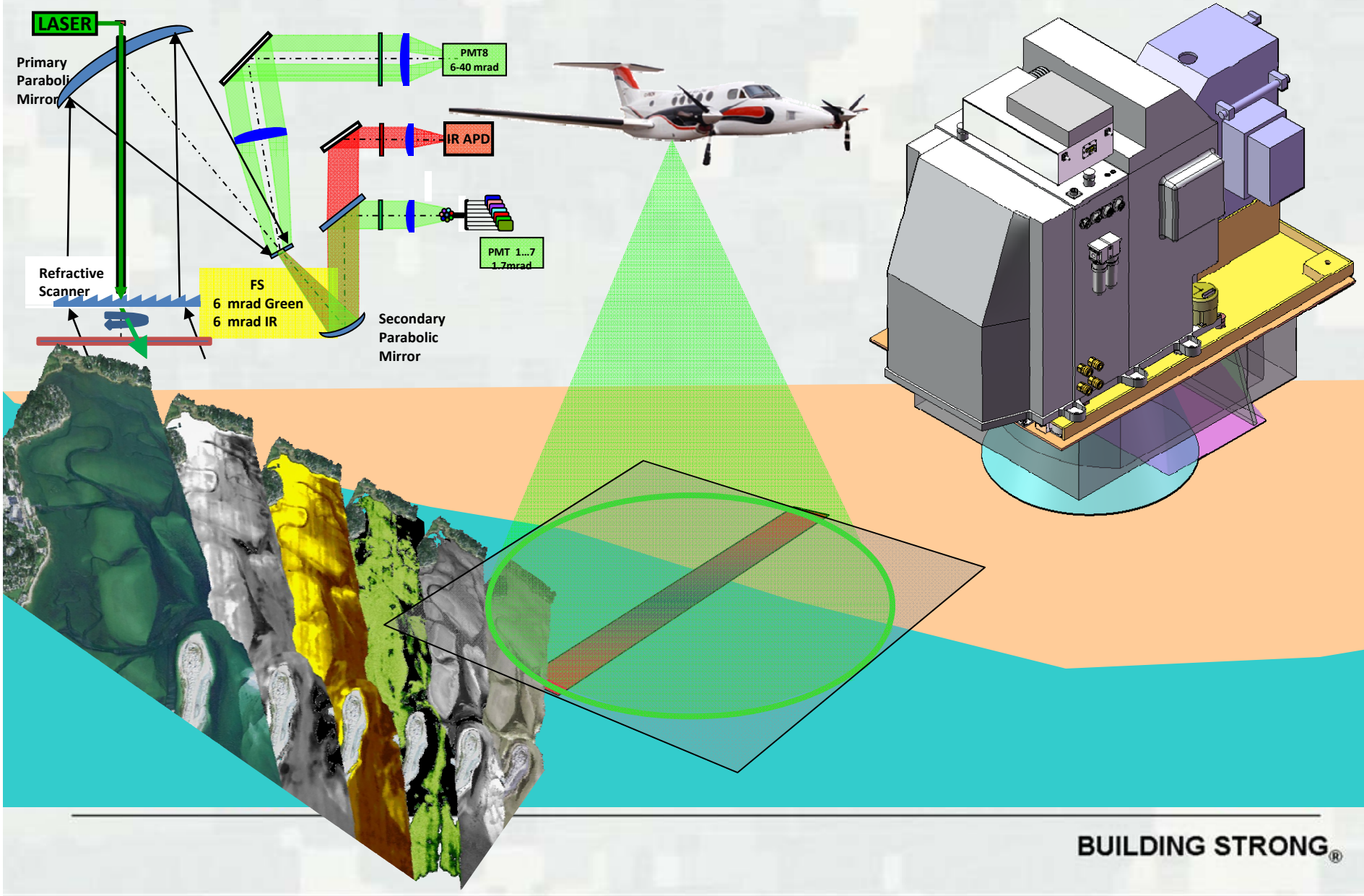
Environmental Applications:

- Site Characterization
- Environmental Monitoring
- Habitat Identification
- Ecosystem Restoration Planning
- Emergency Response/Recovery

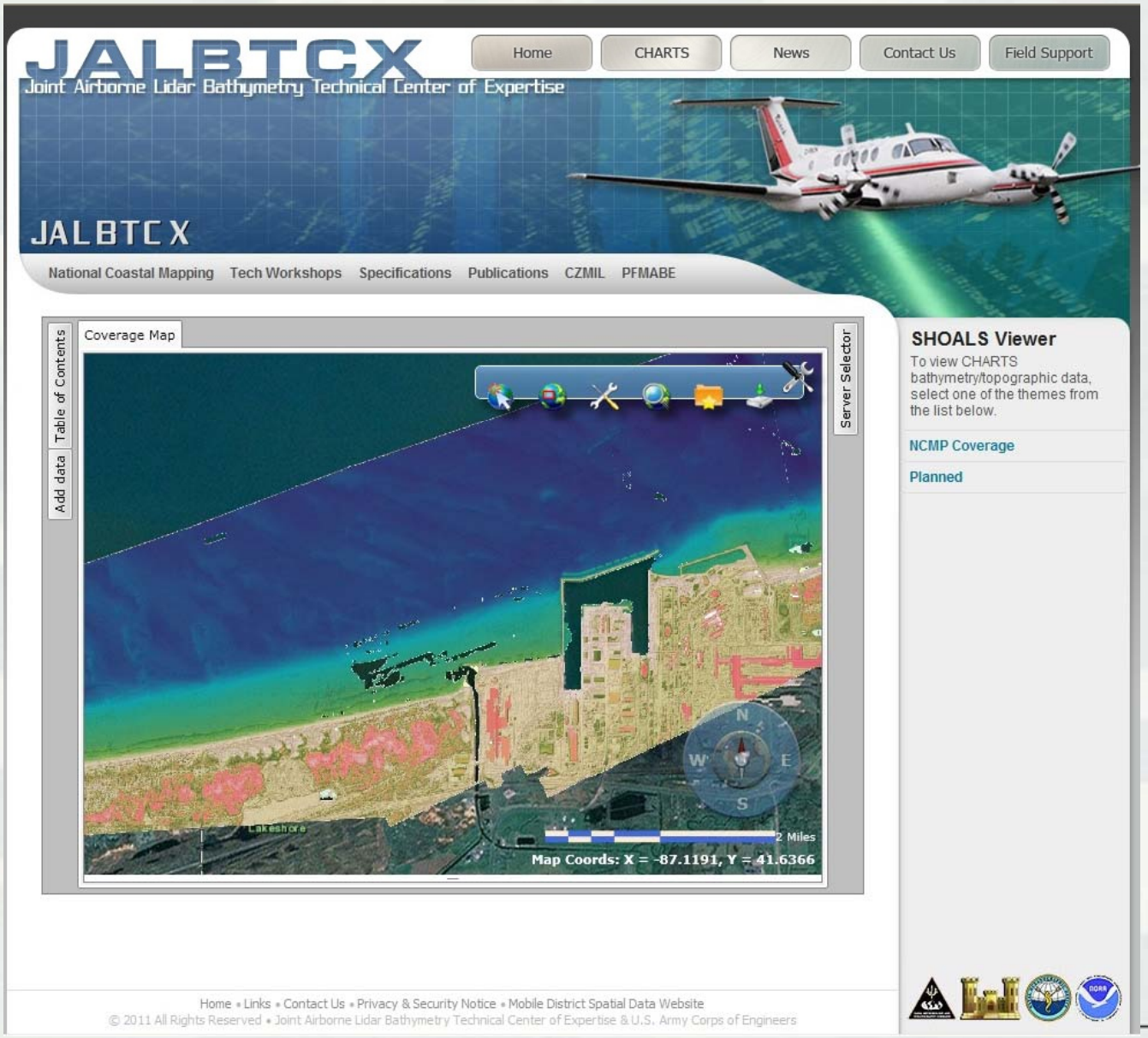
Coastal Engineering Applications:

- vulnerability before storms arrive
- Performance metrics for beach nourishment, channel and ebb shoal conditions
- Sediment pathways quantified from bathymetric data to provide input into sediment budgets
- Input into numerical models for morphological and coastal hazards analysis
- Standardize monitoring reports

CZMIL Coastal Zone Mapping and Imaging Lidar



Data Access



View CHARTS bathymetric/ topographic data

www.jalbtcx.org

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Thank you!

Joint Airborne Lidar Bathymetry
Technical Center of eXpertise

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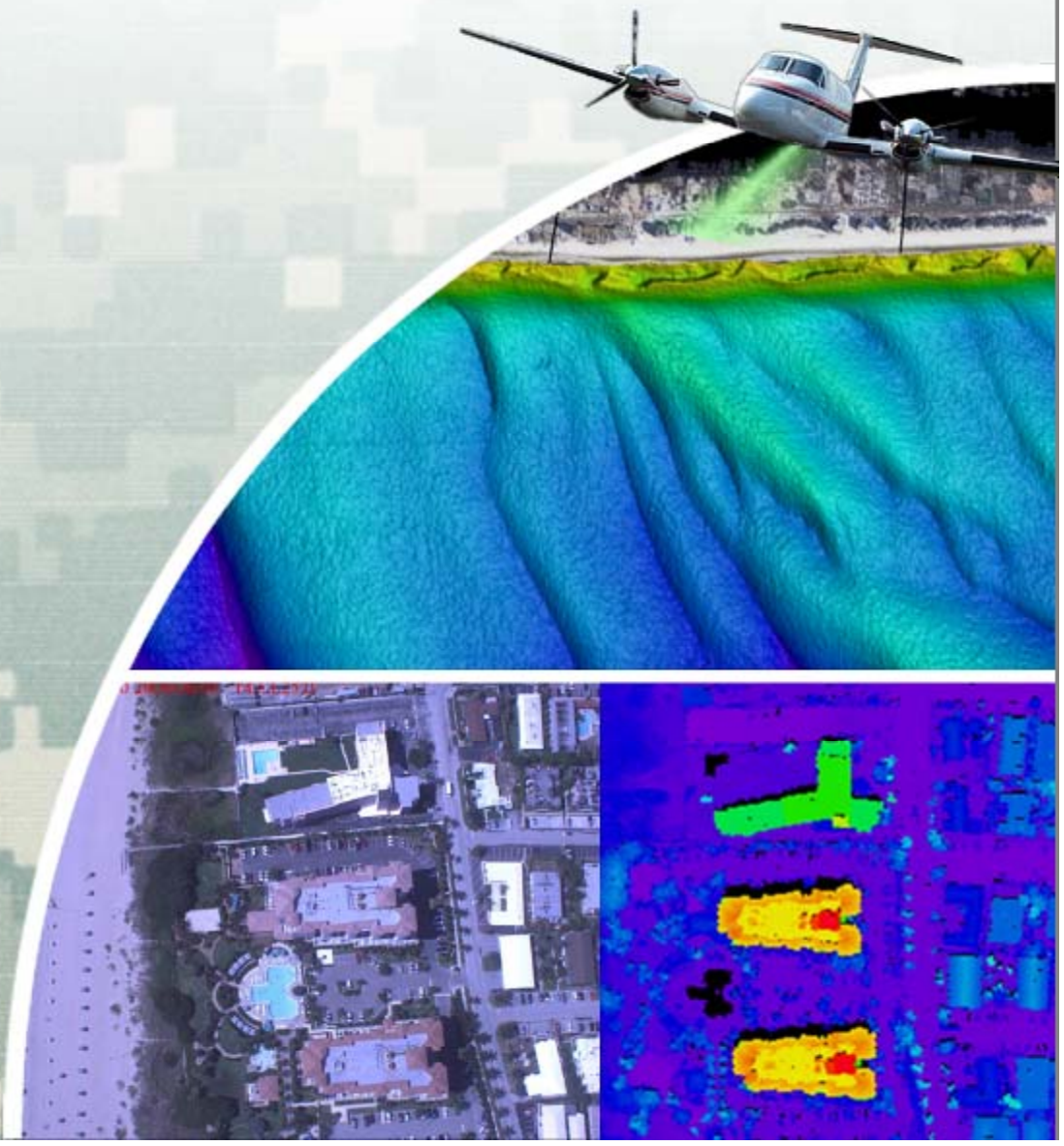

US Army Corps of Engineers
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