Shoal Tracker – A new satellite-based approach to monitor shoal development and migration
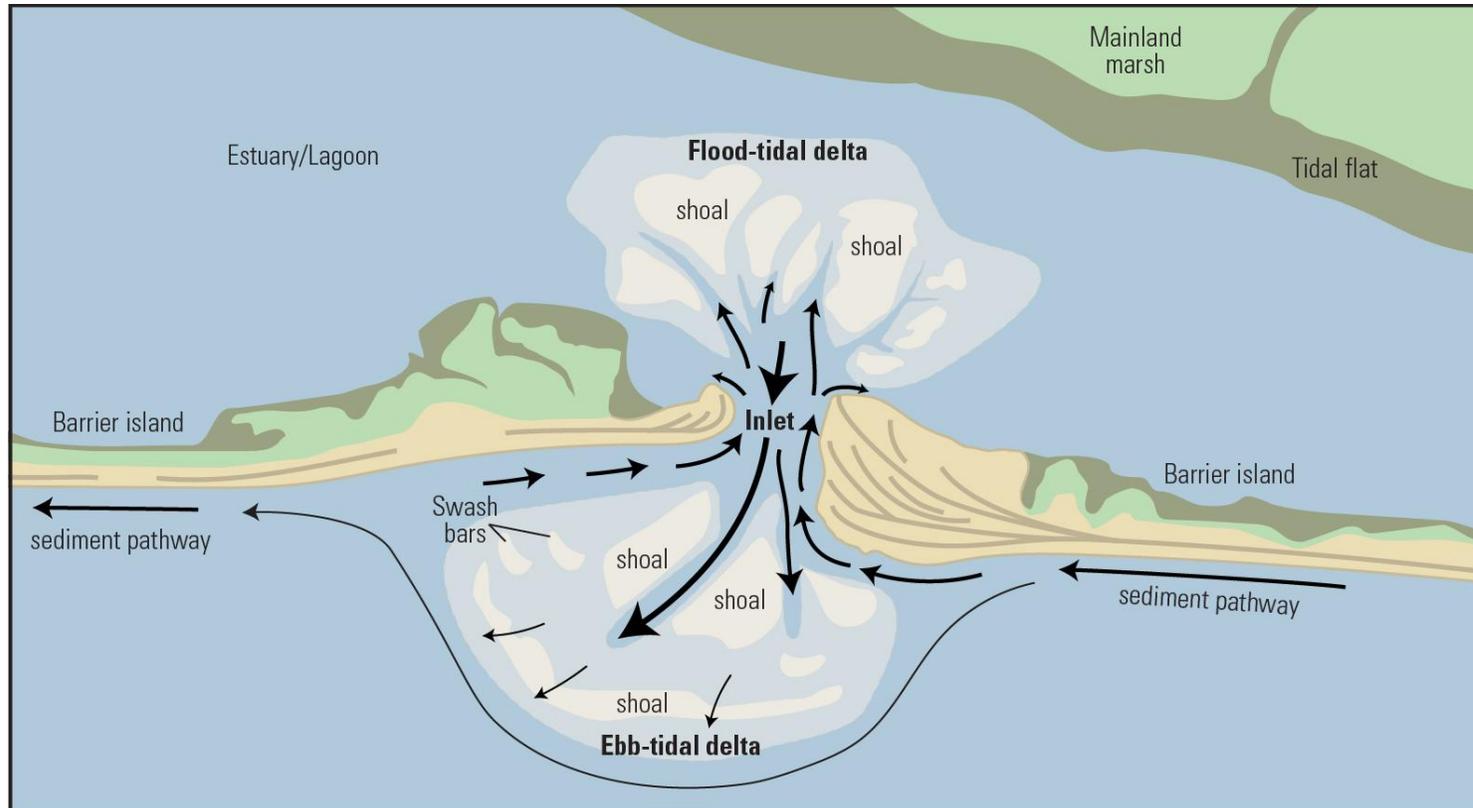
Copeland Cromwell[1,2], Adams, P.[1], Ostojic, A.[2], Shawler, J.[2], McPherran, K.[2], Conery, I.[2], and Brown, S.[2]

1. University of Florida - Dept. of Geological Sciences
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Shoals are shallow sand bodies ubiquitous to barrier islands and inlets.


USGS, 2021

- Morphologically complex with shoals occurring within and landward and seaward of the inlet.

- Altered by the interactions of waves, tidal exchange, and sediment supply.

- Can migrate as these conditions change or inlet configuration becomes hydraulically inefficient.

The influence of these systems on sediment delivery and inlet dynamics make them important on engineering timescales.
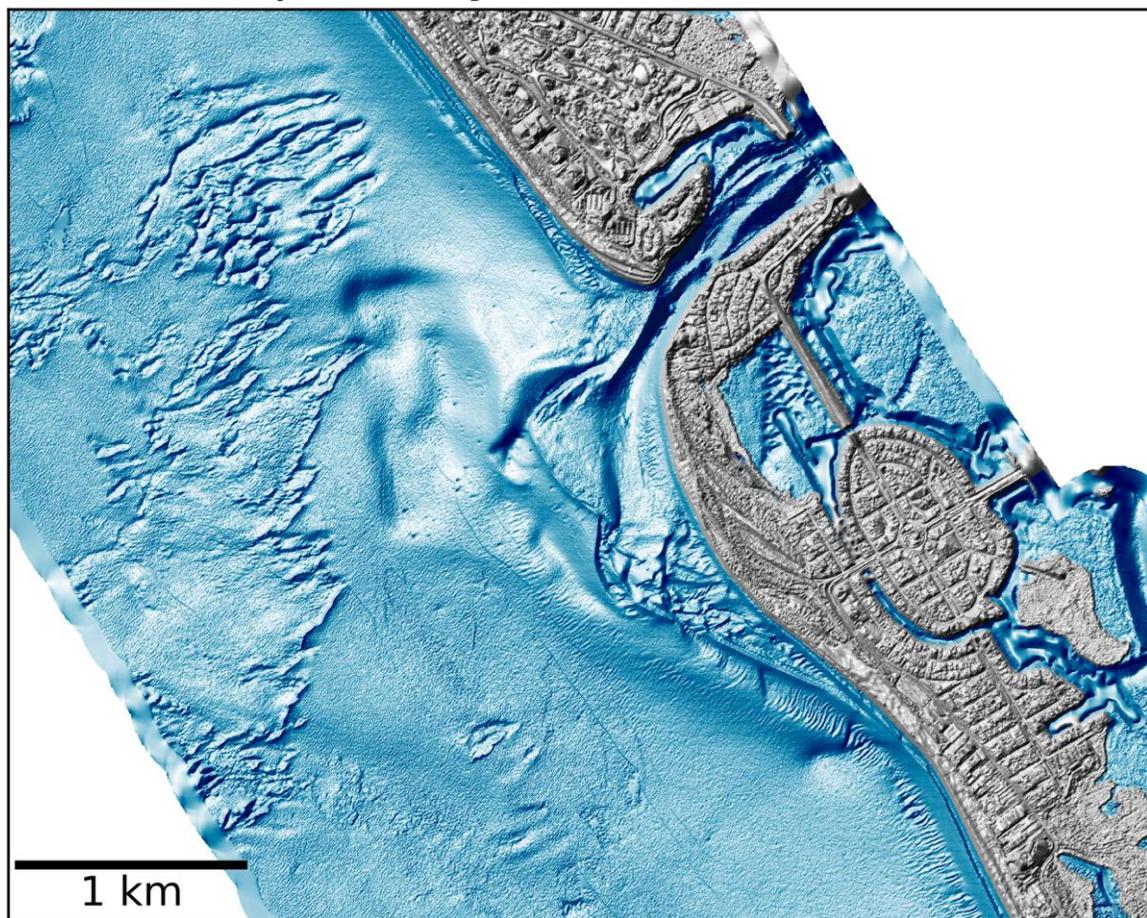

Tidal Prism vs.
Measured Ebb Delta Volume
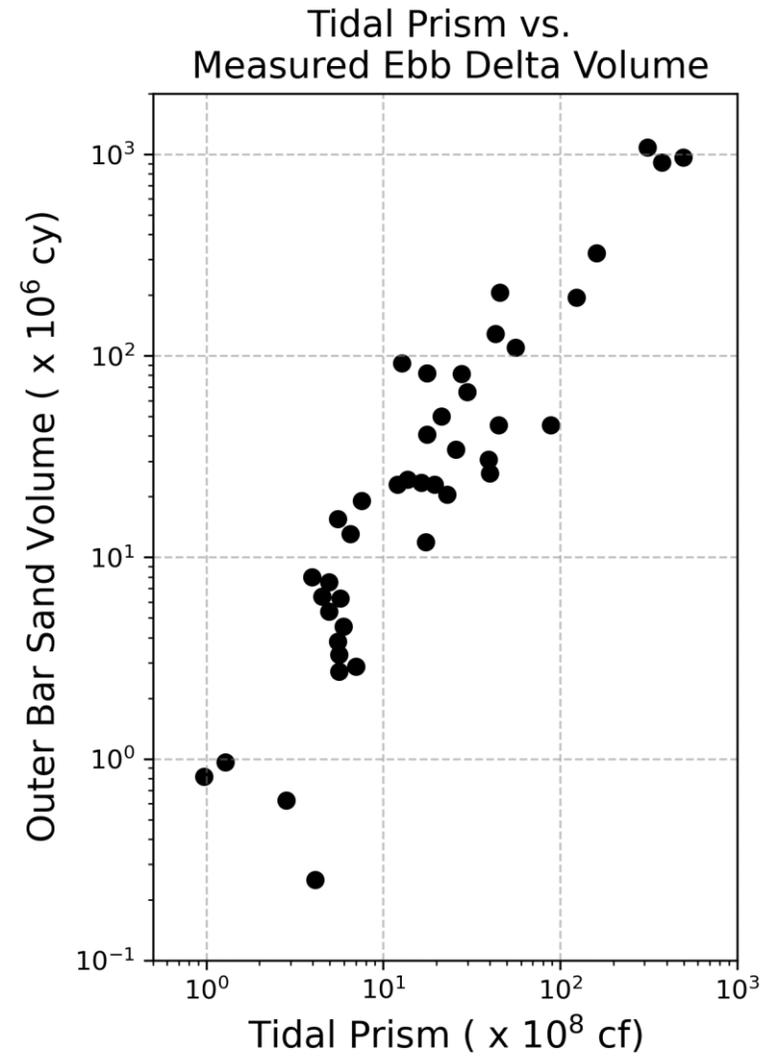
Modified from Walton and Adams, 1976

Barnegat Inlet, NJ
Watercraft Counts
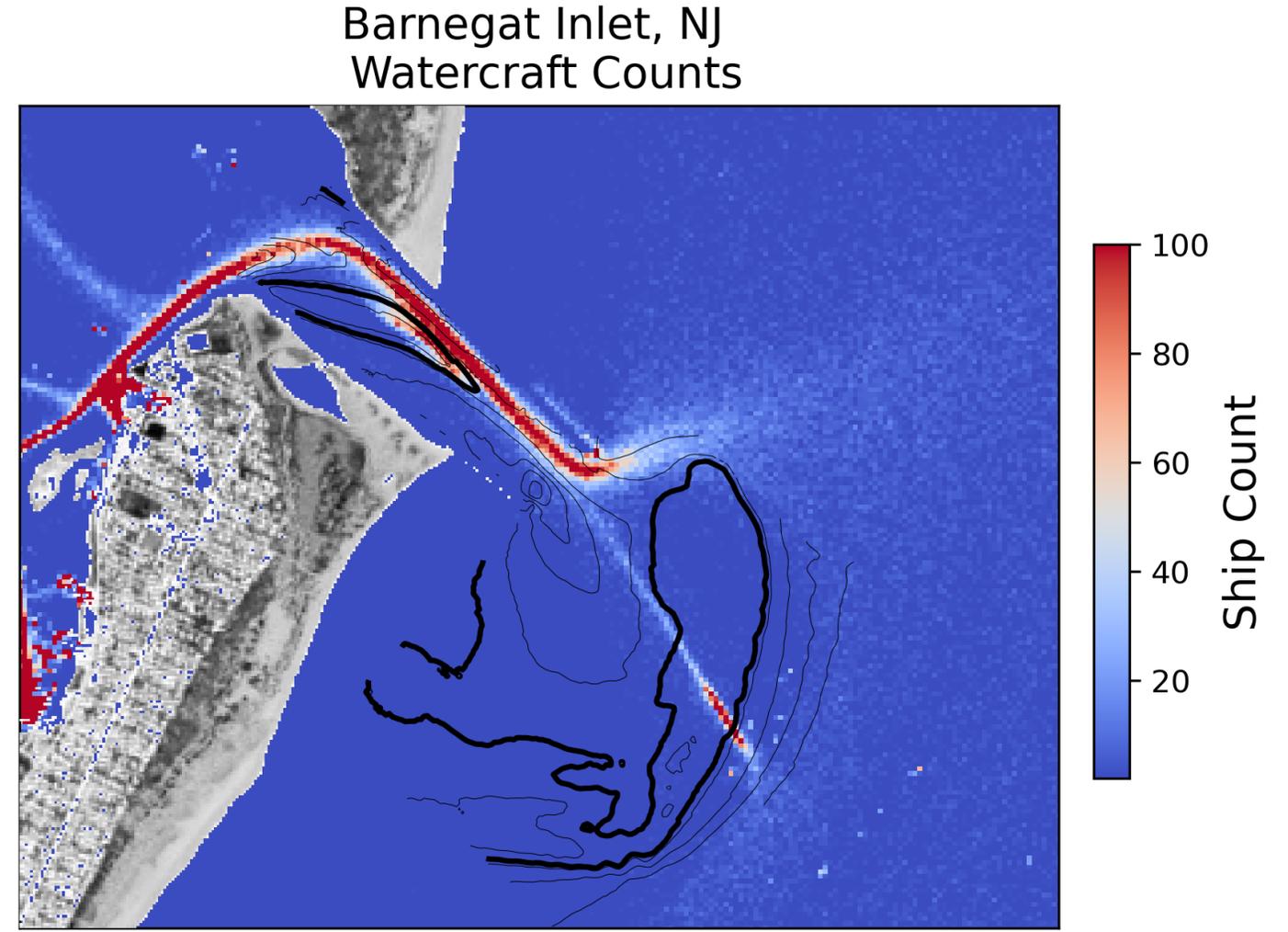
NOAA, 2025; AIS Data from 2021-2022

Conventional shoal monitoring relies on bathymetry and topobathy lidar collections.

Topobathy at New Pass, FL

1 km

Benefits of conventional surveys:

- Provide high-accuracy, high spatial resolution data for determining channel depths and hazards.

- Can determine shoal and ebb-tidal volumes for dredging and nourishment.

- Existing workflows are available to automatically identify features.
  - shoals, channels, and sandbars

A full understanding of shoal and ebb-tidal evolution are limited when using these datasets.

Topobathy at New Pass, FL

1 km
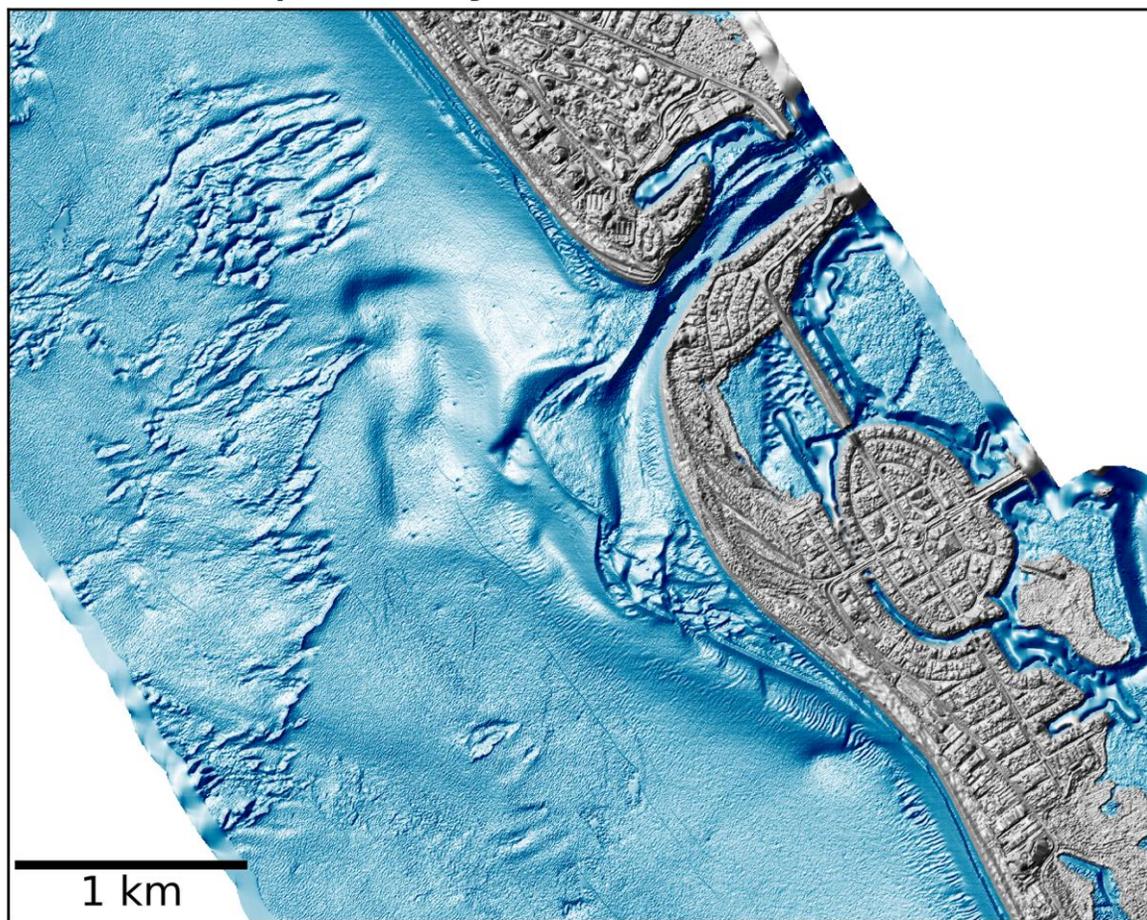
Limitations of conventional surveys:

- Are costly which often limits spatial coverage and collection frequency.
  - Commonly applied ~annually at authorized navigation channels

- In areas of rapid migration, shoal and ebb-tidal delta evolution may not be fully characterized.
  - Undetected hazards
  - Incomplete understanding of the sediment budget and littoral system

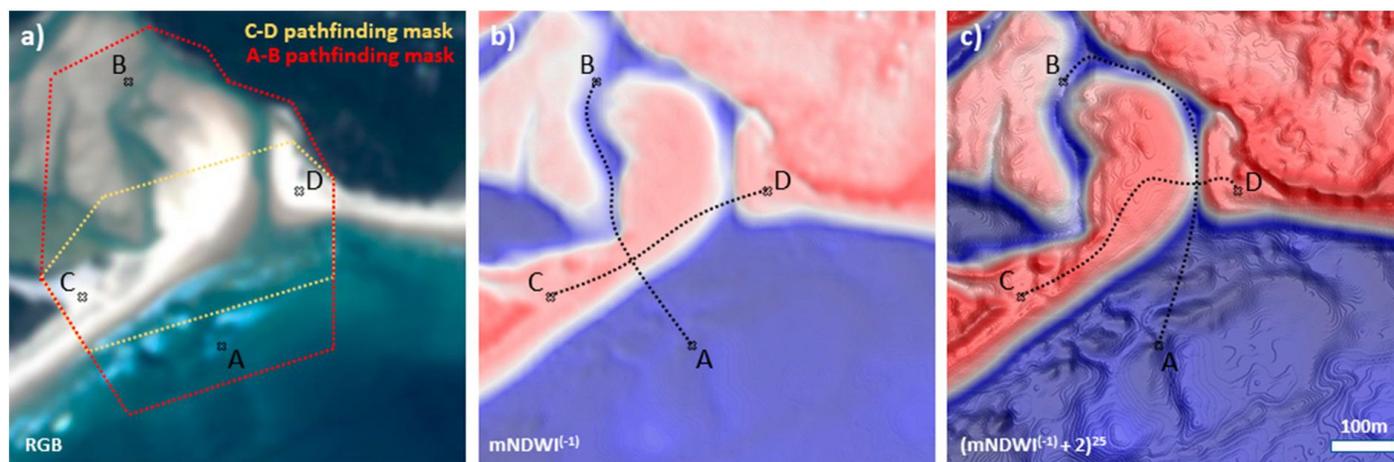# Satellites present new opportunities to characterize ebb-tidal features.
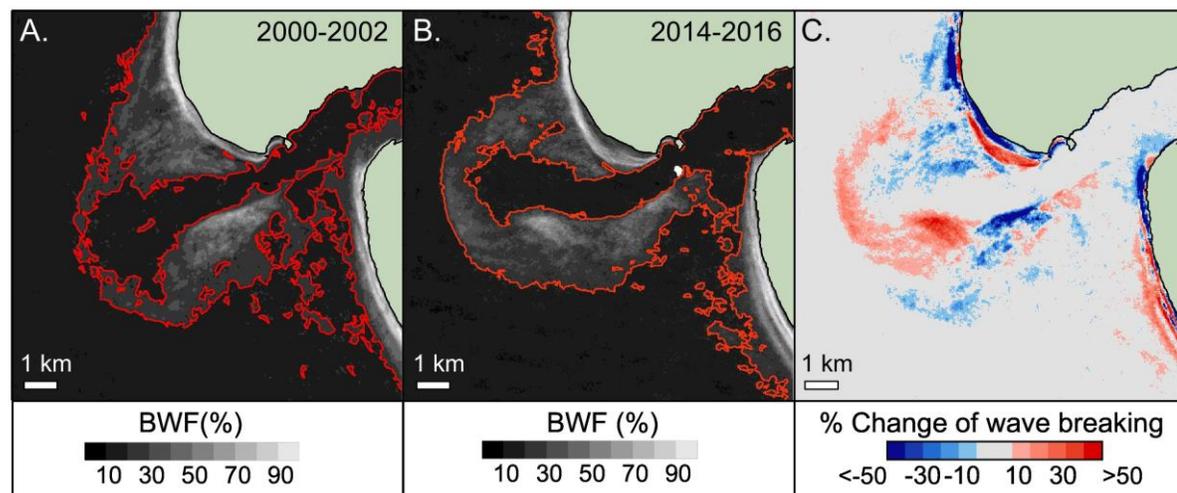
Ford and Dickson, 2017; BWF = Broken Wave Frequency

Heimhuber et al., 2021; Inlet tracking

Advantages of Satellite Imagery
- Satellite images frequently (~5 days) observes coastal environments.
- Easily applied at many sites
- Cost-effective

Previous Satellite Approaches
- Wave breaking used to detect shallow shoal positions
- Multispectral indices used to infer inlet location- may be useful in detecting shoal positions
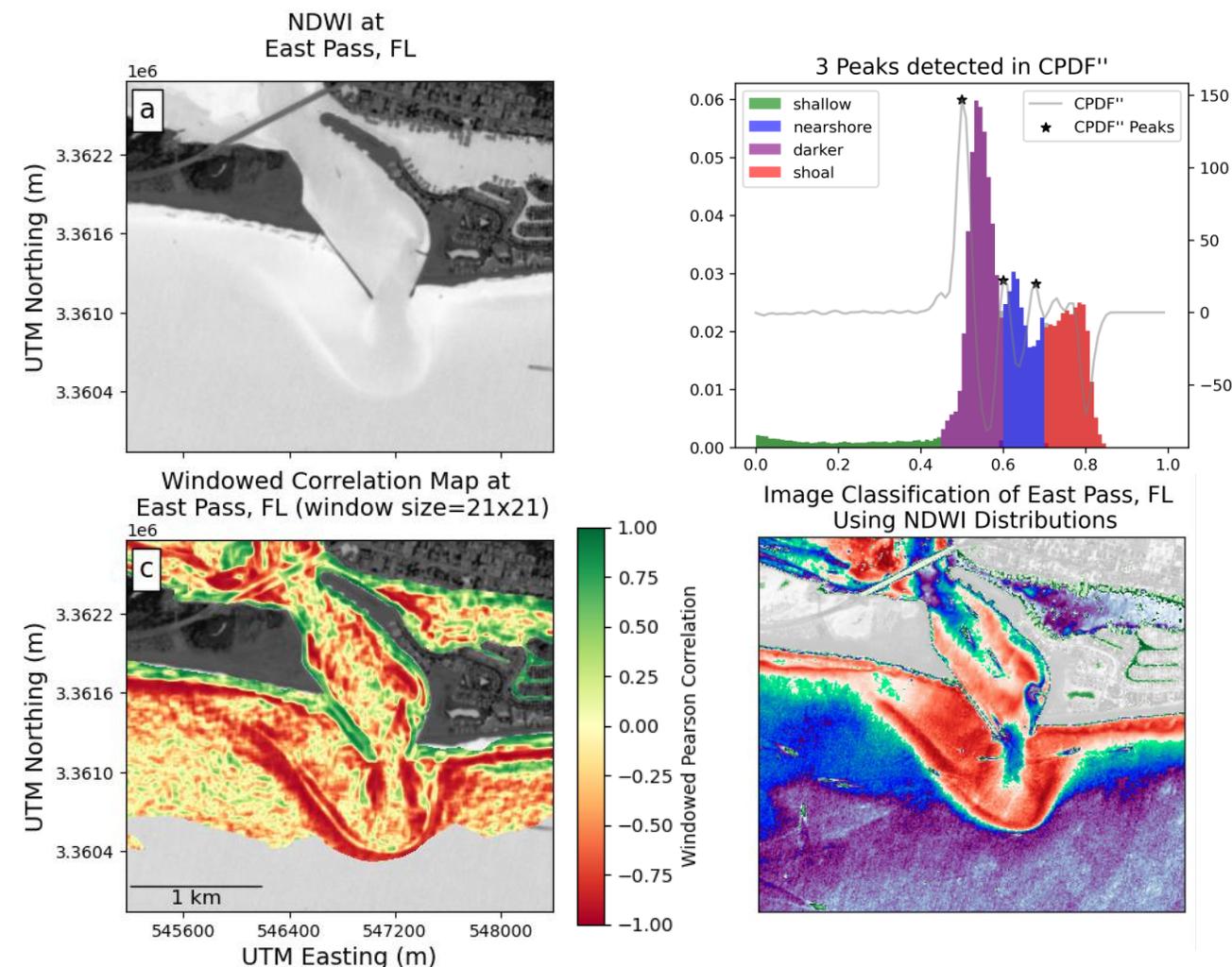- Satellite-derived bathymetry

The normalized differenced water index (NDWI) from satellites is correlated with bathymetry and morphologic zone.

NDWI at East Pass, FL

3 Peaks detected in CPDF''

Windowed Correlation Map at East Pass, FL (window size=21x21)

Red & Green indicate good correlations

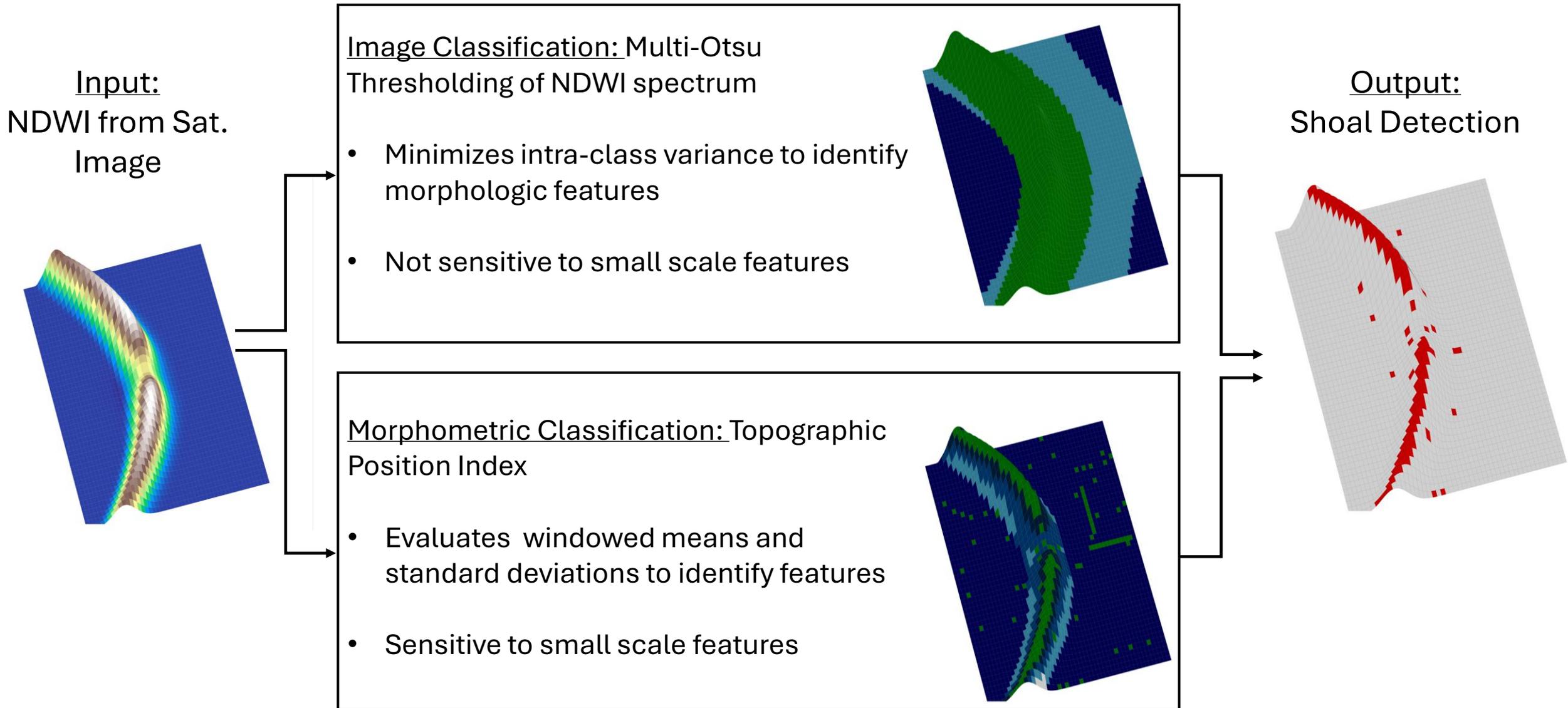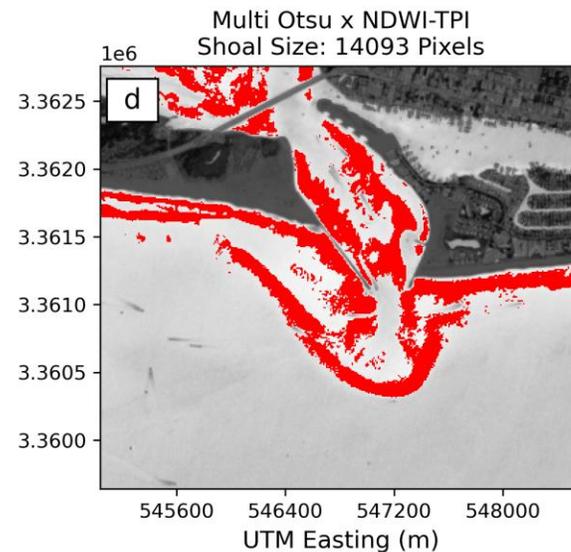Image Classification of East Pass, FL Using NDWI Distributions

$$NDWI = \frac{Green - NIR}{Green + NIR}$$

- Variations in NDWI are strongly correlated with variations in bathymetry.
  - Implies morphometric approaches can be applied to satellite NDWI imagery.

- NDWI cumulative probability distribution curves separate morphological zones.
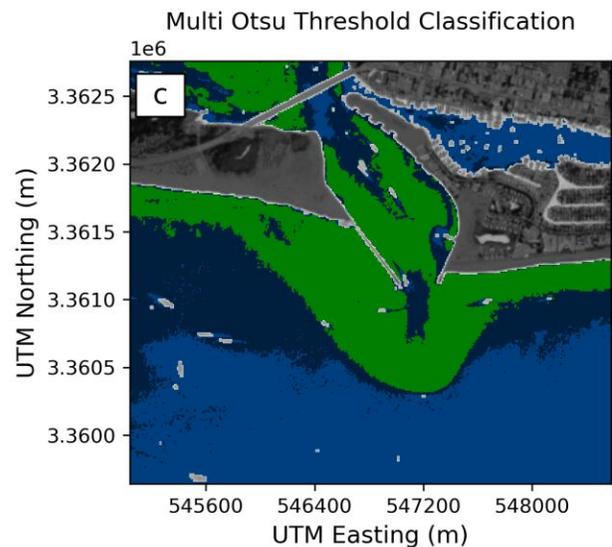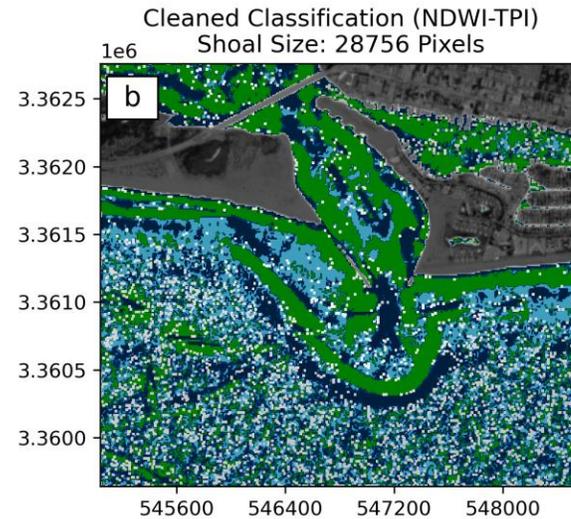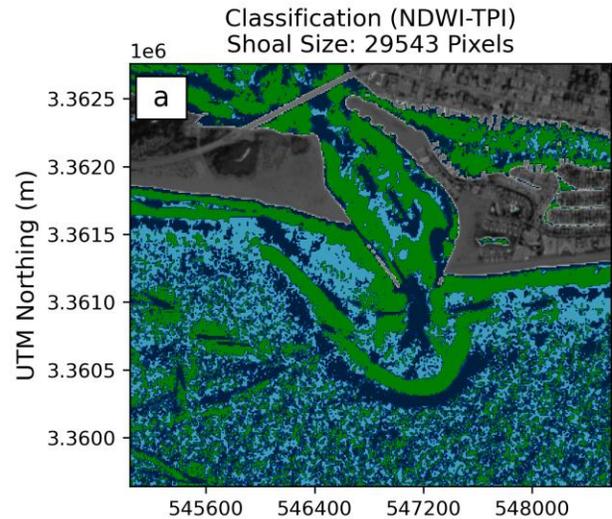 - Identifies shoals, deep and shallow water

Implies a joint image classification and morphometric workflow could identify shoals.

Input:
NDWI from Sat. Image

Image Classification: Multi-Otsu Thresholding of NDWI spectrum

- Minimizes intra-class variance to identify morphologic features

- Not sensitive to small scale features

Morphometric Classification: Topographic Position Index

- Evaluates windowed means and standard deviations to identify features

- Sensitive to small scale features

Output:
Shoal Detection

Implies a joint image classification and morphometric workflow could identify shoals.

Classification (NDWI-TPI)
Shoal Size: 29543 Pixels

Cleaned Classification (NDWI-TPI)
Shoal Size: 28756 Pixels

Multi Otsu Threshold Classification

Multi Otsu x NDWI-TPI
Shoal Size: 14093 Pixels

<u>Goal:</u> Iterative application to images to highlight regions where shoals are common.
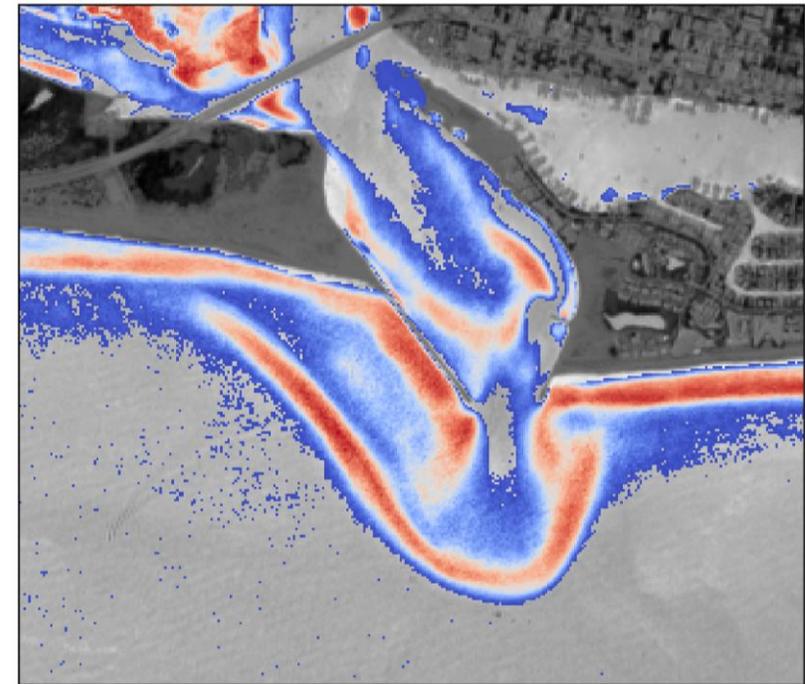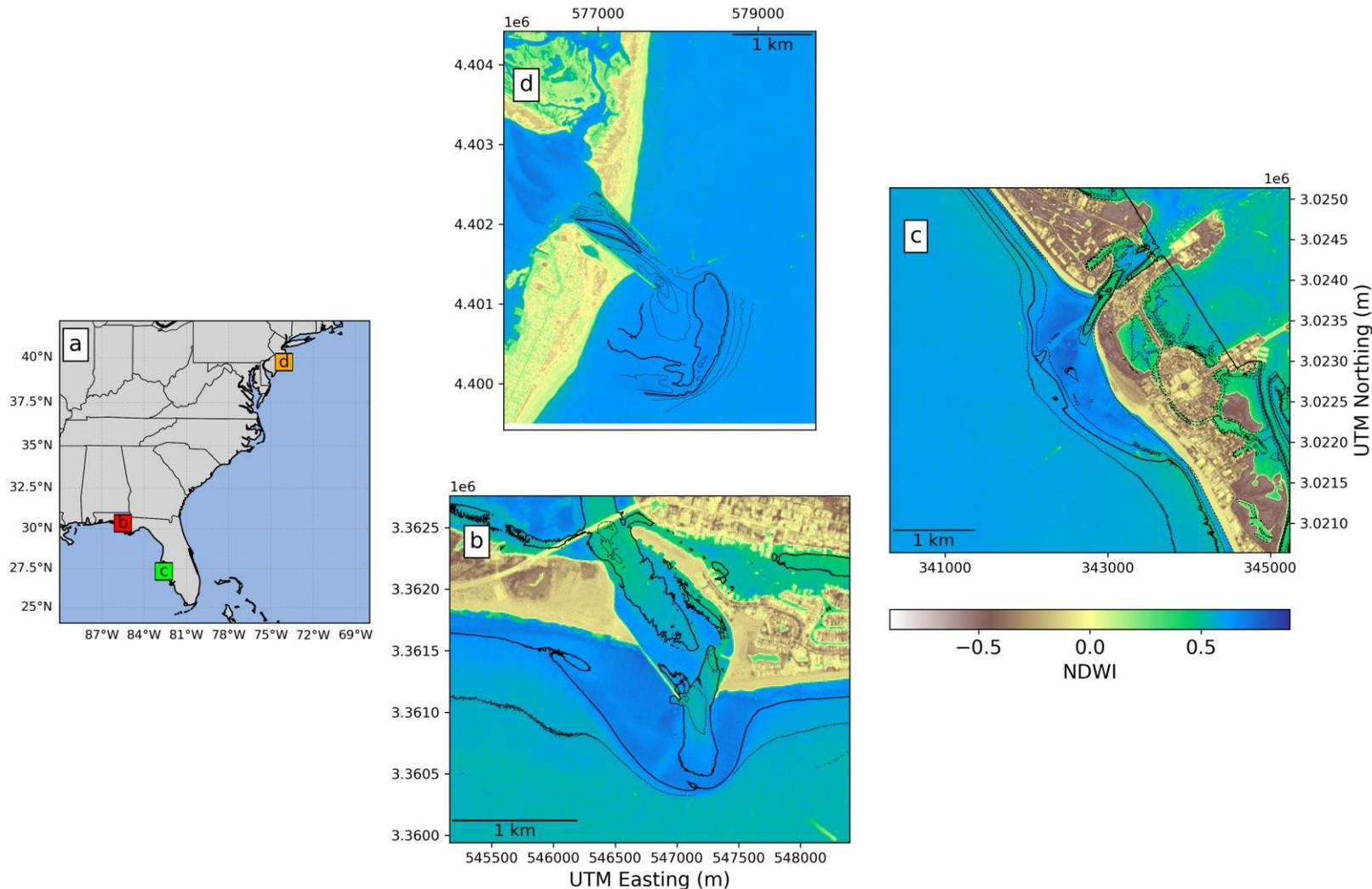

Figure: Heatmap of shoal occurrences at East Pass, FL

This workflow is tested at sites with different environmental characteristics

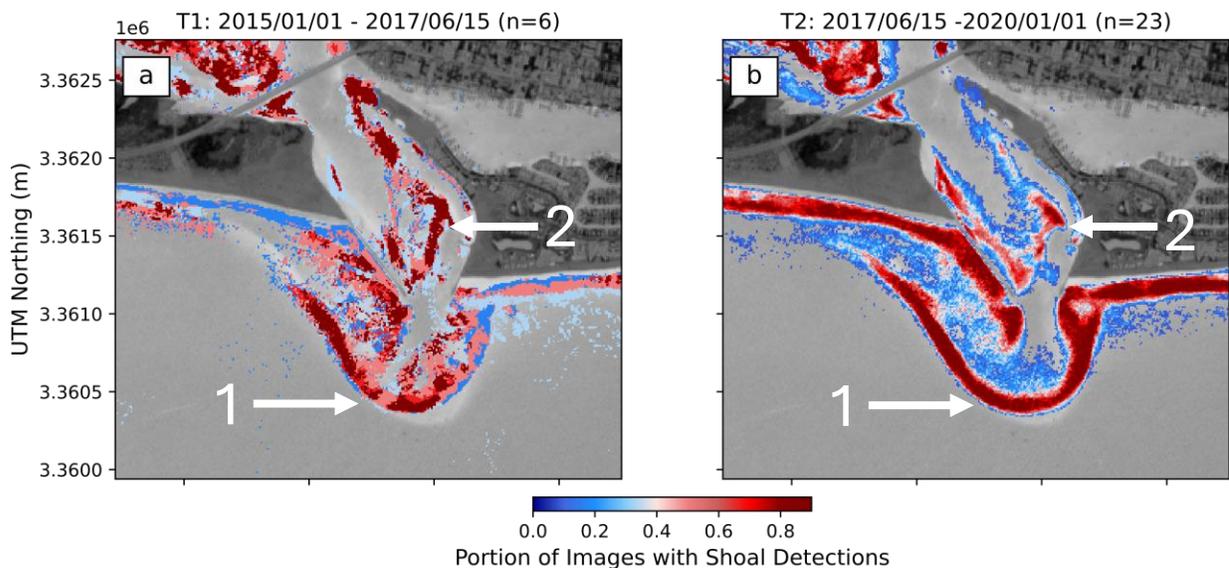

Shoal Tracker applied at:
1. Barnegat Inlet, NJ
2. New Pass, FL
3. East Pass, FL

These sites have different:
- ETD characteristics
- Wave characteristics
- Water clarity

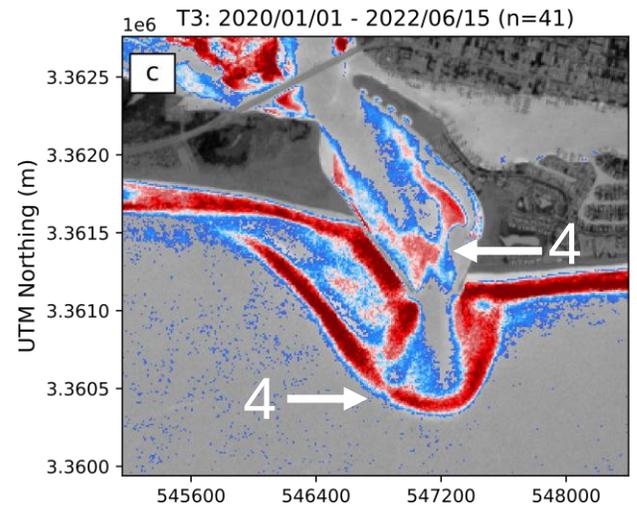Figure: NDWI satellite imagery of 3 study areas overlain with bathymetric contours
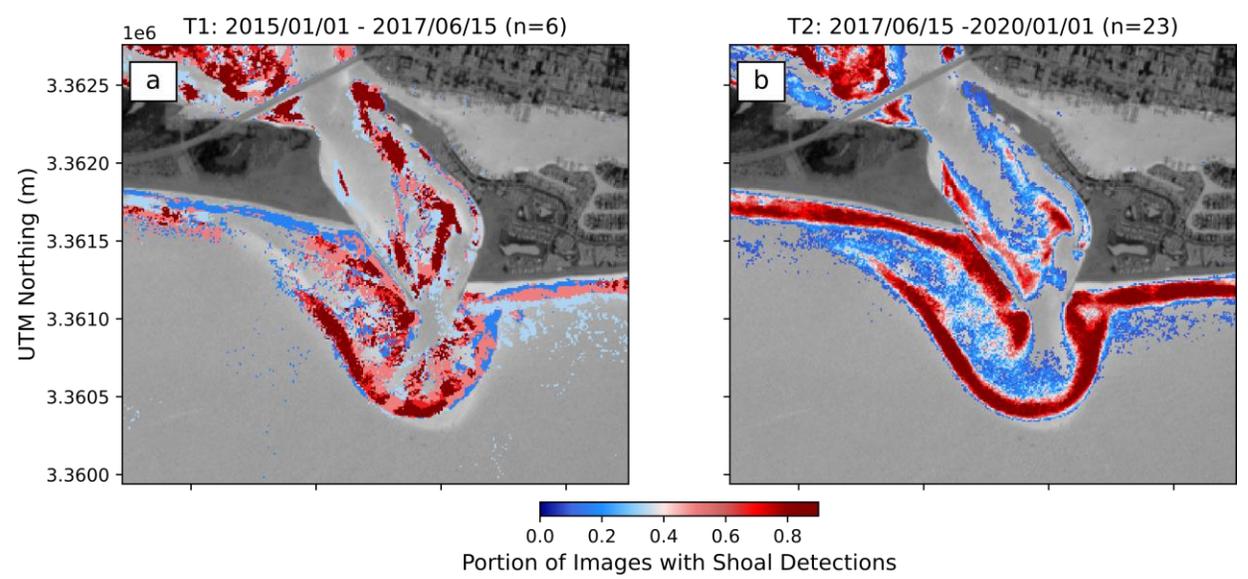
Shoal Tracker application at East Pass, FL highlights ETD migration and dredging of navigation channels.

T1: 2015/01/01 - 2017/06/15 (n=6)

T2: 2017/06/15 -2020/01/01 (n=23)

UTM Northing (m)

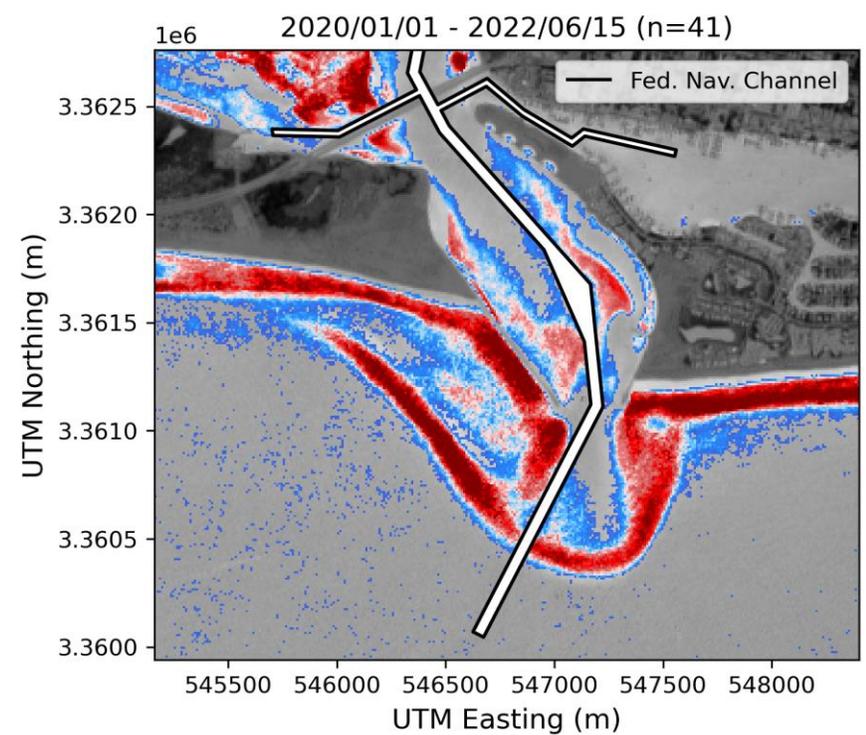Portion of Images with Shoal Detections

T1 and T2 show:
1. A westward skewed, concentric ETD complex.
2. Well-defined channel-margin bars (MB).

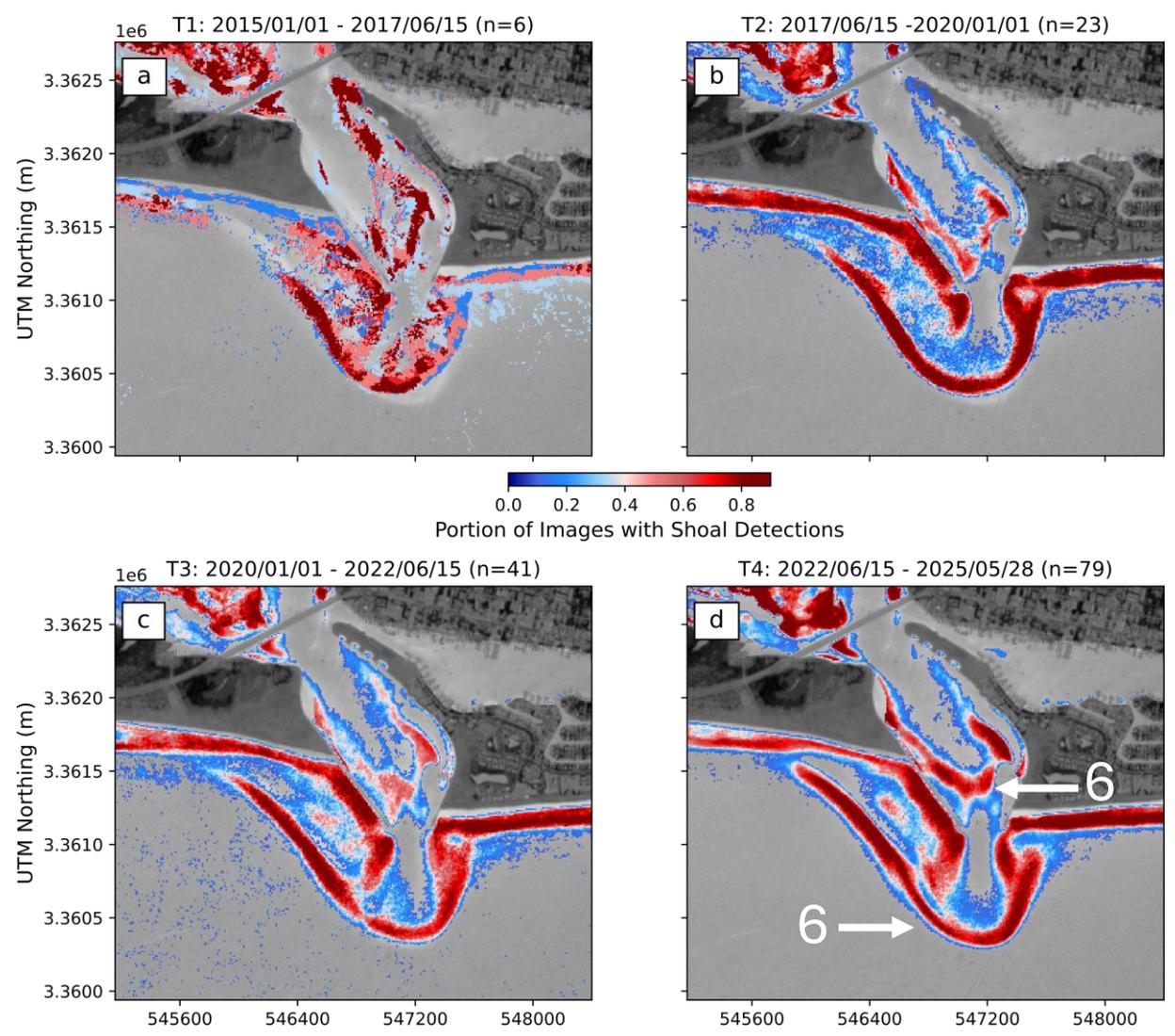# Shoal Tracker application at East Pass, FL highlights ETD migration and dredging of navigation channels.

T1: 2015/01/01 - 2017/06/15 (n=6)

T2: 2017/06/15 -2020/01/01 (n=23)

Portion of Images with Shoal Detections

T3: 2020/01/01 - 2022/06/15 (n=41)

T3 shows:
3. A more eastern skewed ETD complex.
4. Reduced shoal detections at the MB and delta consistent with the nav channel.

2020/01/01 - 2022/06/15 (n=41)

Fed. Nav. Channel

UTM Northing (m)

UTM Easting (m)

Shoal Tracker application at East Pass, FL highlights ETD migration and dredging of navigation channels.

T4 shows:
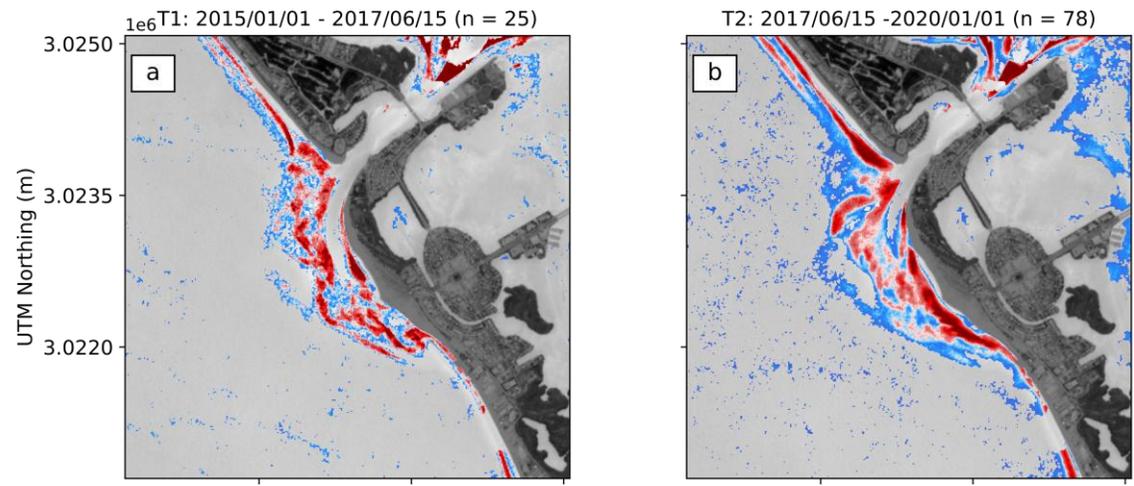5. Persistence in the eastern-skewed ETD.
6. Recovery of the MB and delta.

Shoal Tracker application at New Pass, FL highlights internal ETD reorganization and bar welding south of the channel.

T1: 2015/01/01 - 2017/06/15 (n = 25)

T2: 2017/06/15 -2020/01/01 (n = 78)

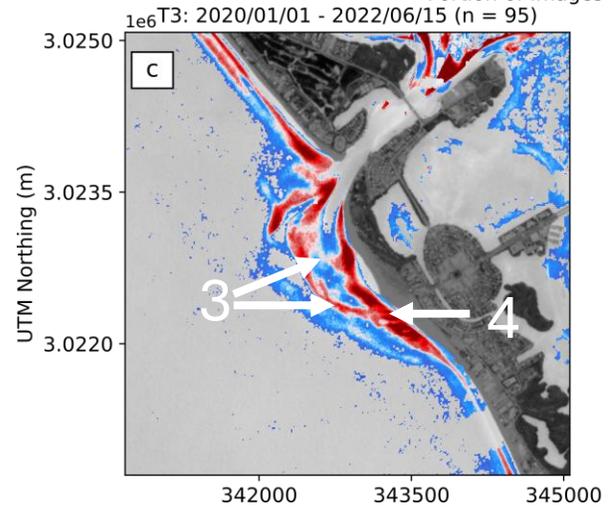Portion of Images with Shoal Detections
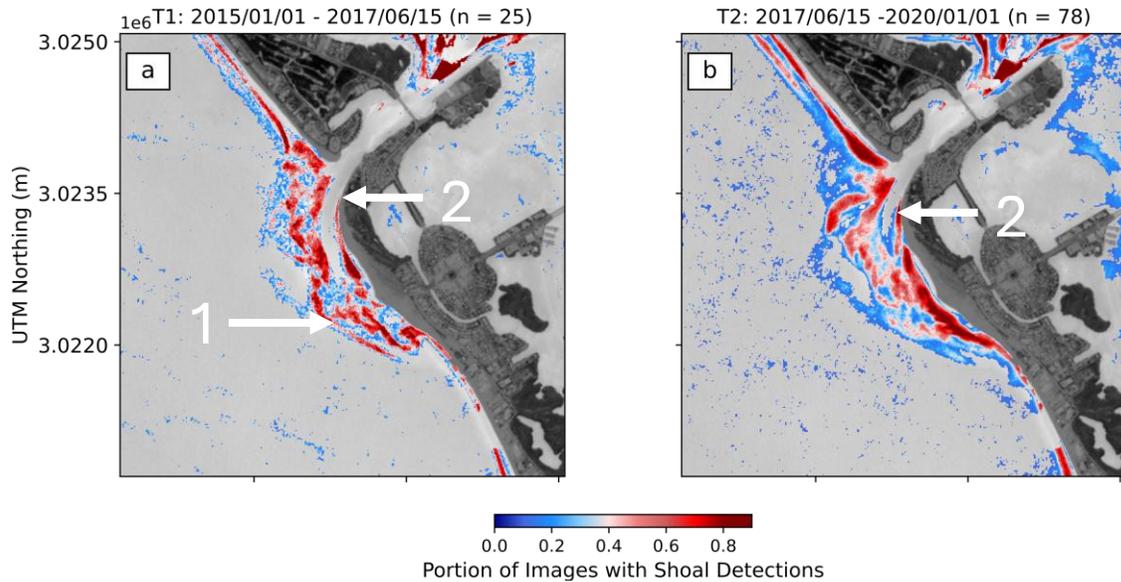
T1 and T2 show:

1. Well-defined bar complex
2. Clear inlet channel

Shoal Tracker application at New Pass, FL highlights internal ETD reorganization and bar welding south of the channel.
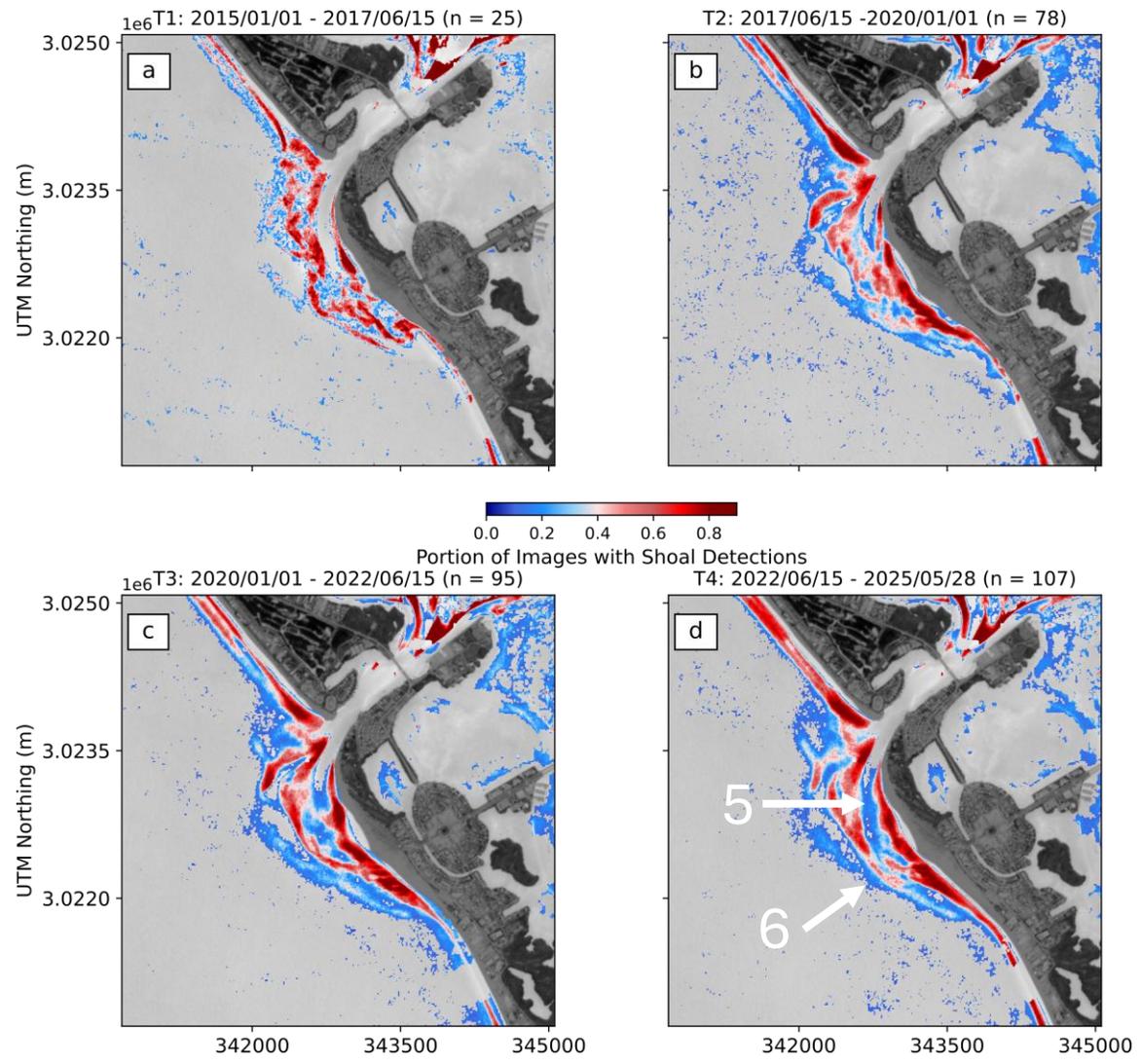

T1: 2015/01/01 - 2017/06/15 (n = 25)

T2: 2017/06/15 - 2020/01/01 (n = 78)

Portion of Images with Shoal Detections

T3: 2020/01/01 - 2022/06/15 (n = 95)

T3 shows:

3. Concentric shoals obstructing the channel
4. Margin bar welding along the southeastern ETD

Shoal Tracker application at New Pass, FL highlights internal ETD reorganization and bar welding south of the channel.

T4 shows:

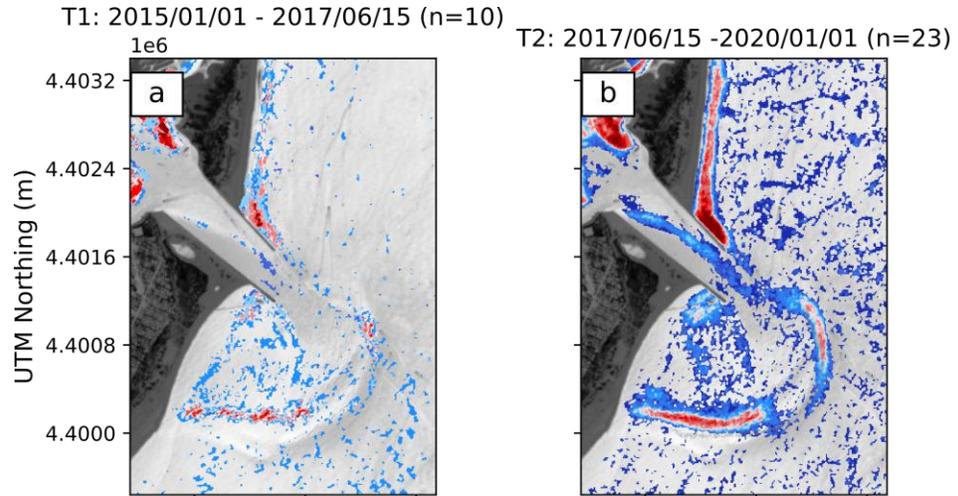5. A return to an unobstructed channel
6. Distal linear bars

Implies a joint image classification and morphometric workflow could identify shoals.

T1: 2015/01/01 - 2017/06/15 (n=10)

T2: 2017/06/15 -2020/01/01 (n=23)

UTM Northing (m)

Portion of Images with Shoal Detections
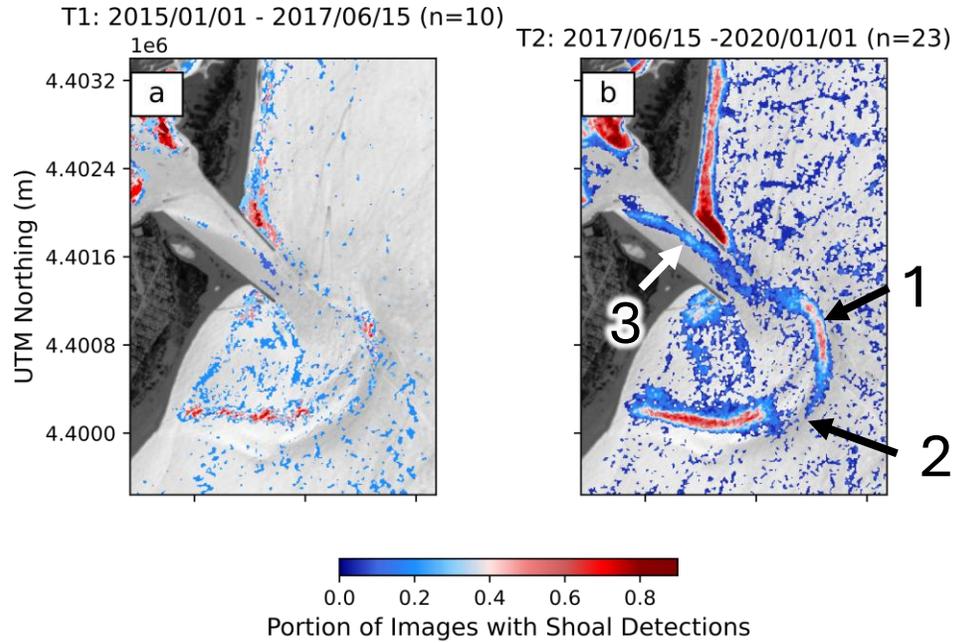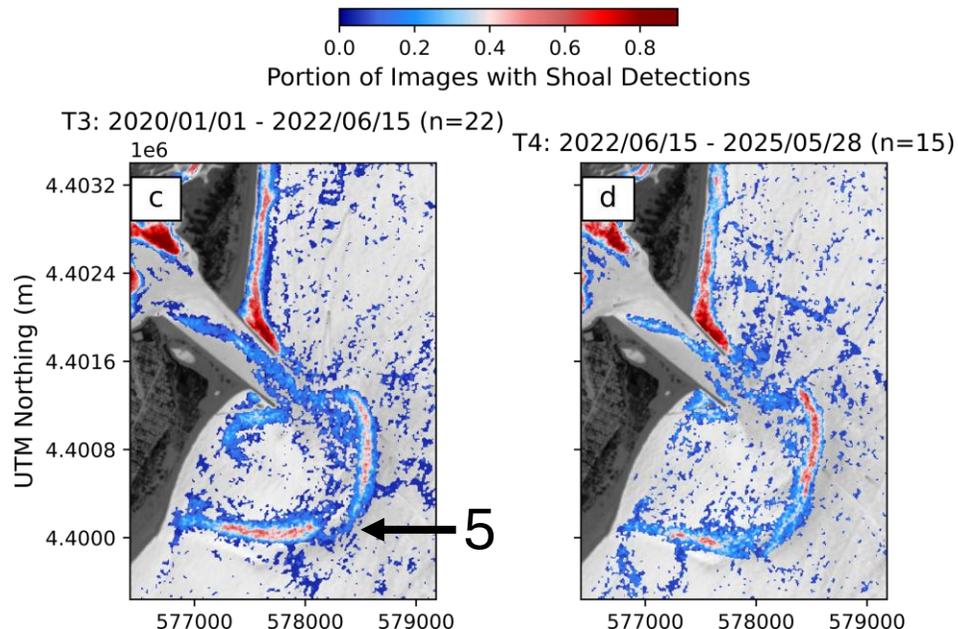
T1 and T2 show:

1. Well-defined concentric ETD
2. Clear break in the outer ETD.
3. A well-defined channel margin bar.

# Implies a joint image classification and morphometric workflow could identify shoals.

T1: 2015/01/01 - 2017/06/15 (n=10)

T2: 2017/06/15 -2020/01/01 (n=23)

T3: 2020/01/01 - 2022/06/15 (n=22)

T4: 2022/06/15 - 2025/05/28 (n=15)

Portion of Images with Shoal Detections

UTM Northing (m)

T3 and T4 show:

4. Alongshore expansion and cross shore compression of the outer ETD
5. Closure of the earlier ETD break

When compared against bathymetric data, Shoal Tracker results indicate high accuracy outputs.

East Pass, FL Comparison Transects

New Pass, FL Comparison Transects

Barnegat Inlet, NJ Comparison Transects

Satellite Shoal vs Bathymetric Data

$R^2 = 0.90$

$R^2 = 0.87$

$R^2 = 0.95$

Accuracy assessments:
- Shoal Tracker is comparable to or outperforms other satellite feature extractions (e.g., CoastSat, VedgeSat, SDB)

- In many cases, error ~15 m (1.5 S2 pixels)

- Error is largely localized at areas with gentle slope breaks (northern New Pass)
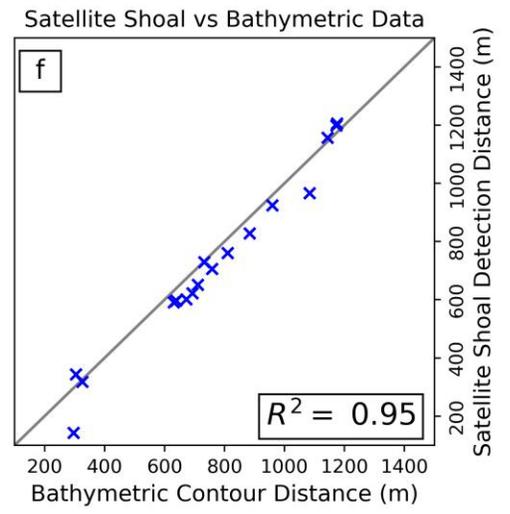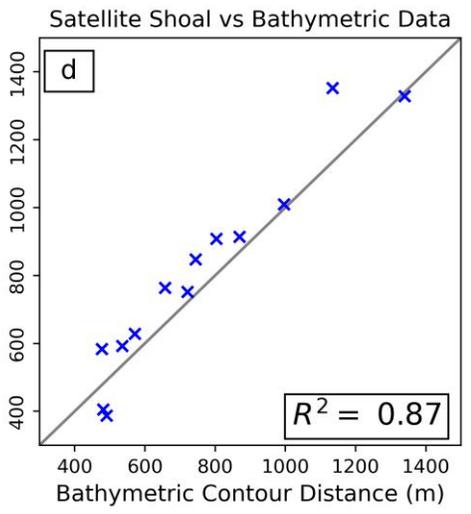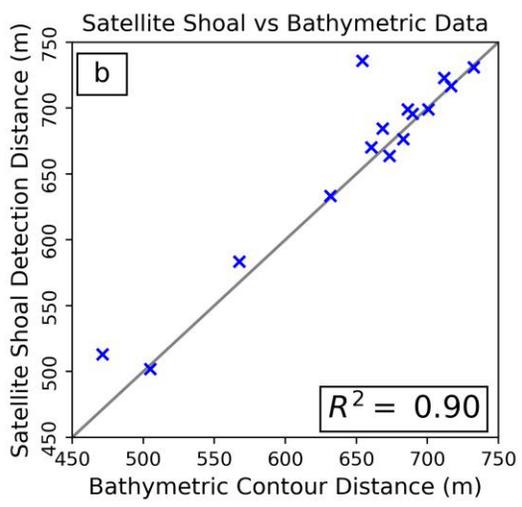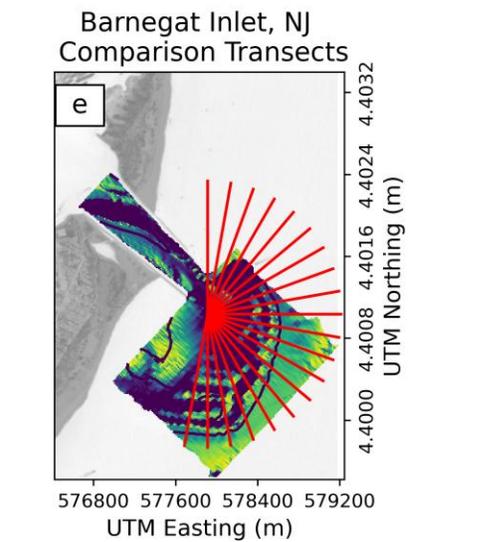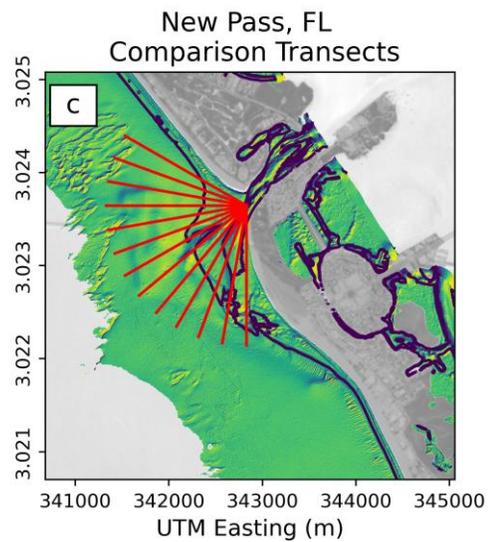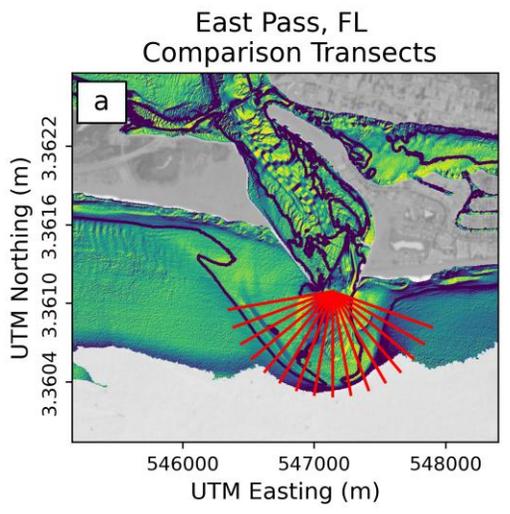
Shoal Tracker outputs and trends agree with bathymetric data, dredging, and conceptual models.

East Pass, FL
Comparison Transects

Satellite Shoal vs Bathymetric Data

2020/01/01 - 2022/06/15 (n=41)
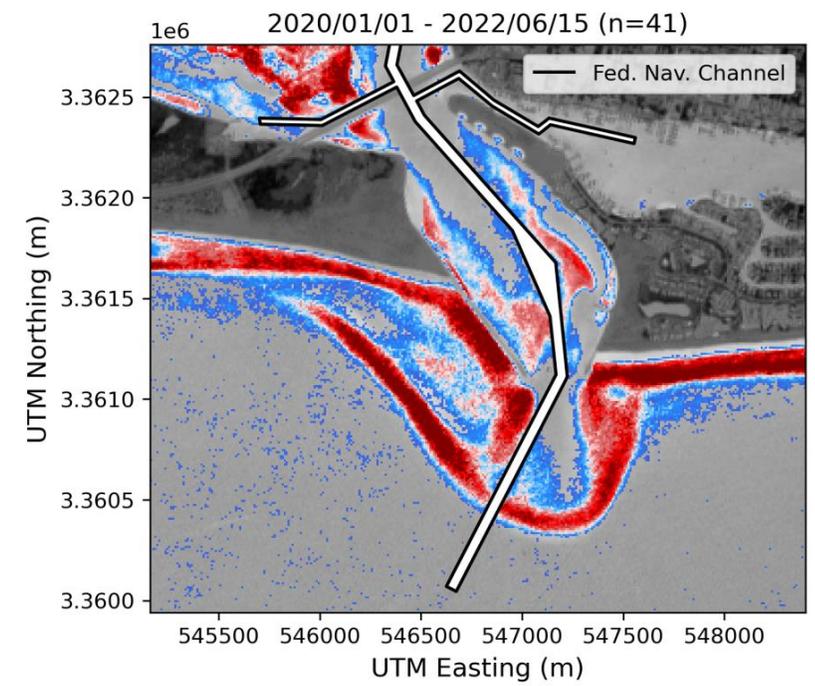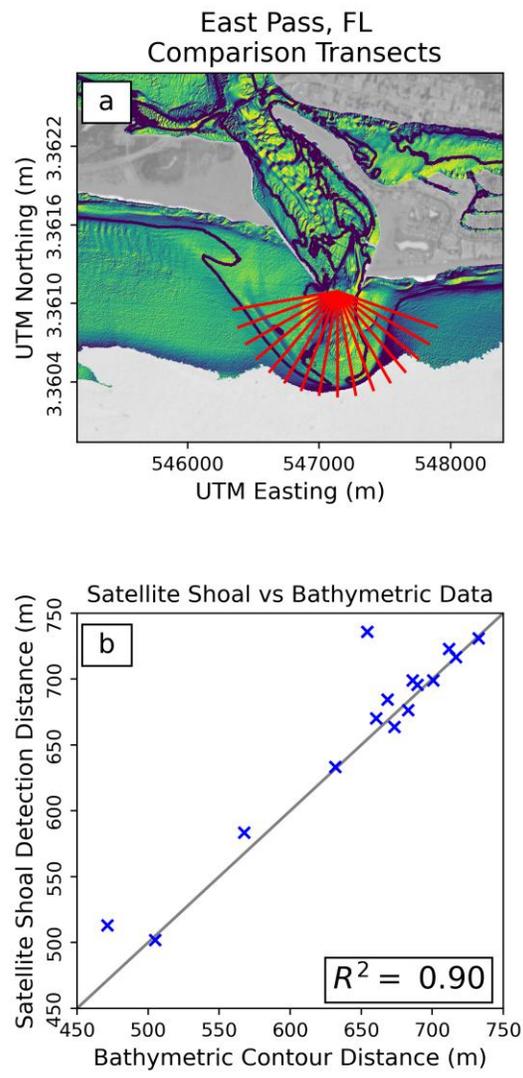
Shoal Tracker:
- Outputs yield low error (~15-30 m) when compared to bathymetric data.
- Identifies dredging activities along federal nav channels.
- Reveals trends which adhere to conceptual models of inlet evolution.

Indicate Shoal Tracker is capable of reliably revealing decadal trends in ETD evolution.

Questions?

Image Classification: Multi-Otsu Thresholding of NDWI spectrum

- Minimizes intra-class variance to identify morphologic features

- Not sensitive to small scale features

Morphometric Classification: Topographic Position Index

- Evaluates windowed means and standard deviations to identify features

- Sensitive to small scale features

Output:
Shoal Detection