Foredune Classification and Storm Response: Automated Analysis of Terrestrial Lidar DEMs

Kate Brodie & Nick Spore
ERDC-CHL-COAB

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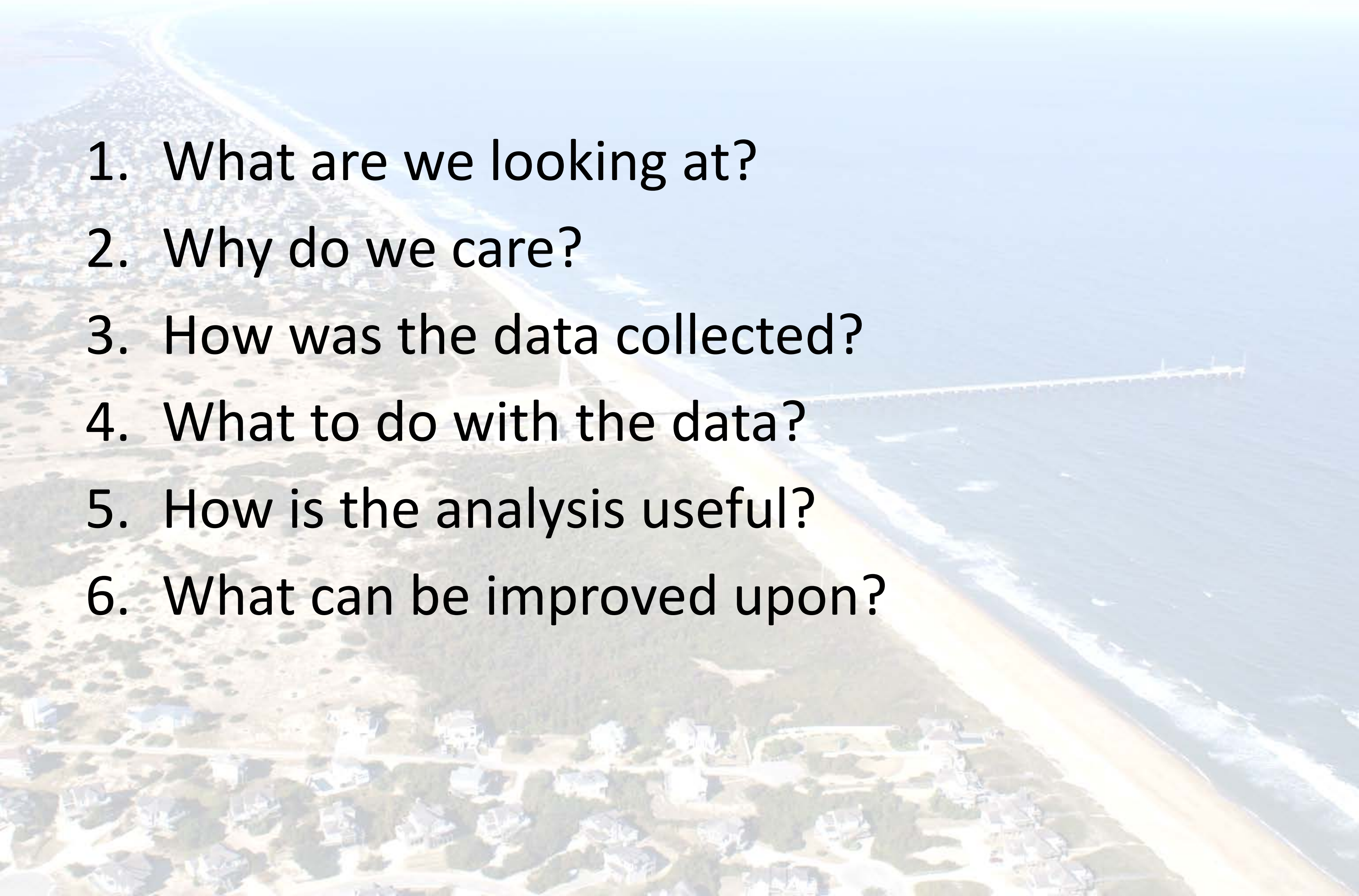
“Understanding and Working with Nature”

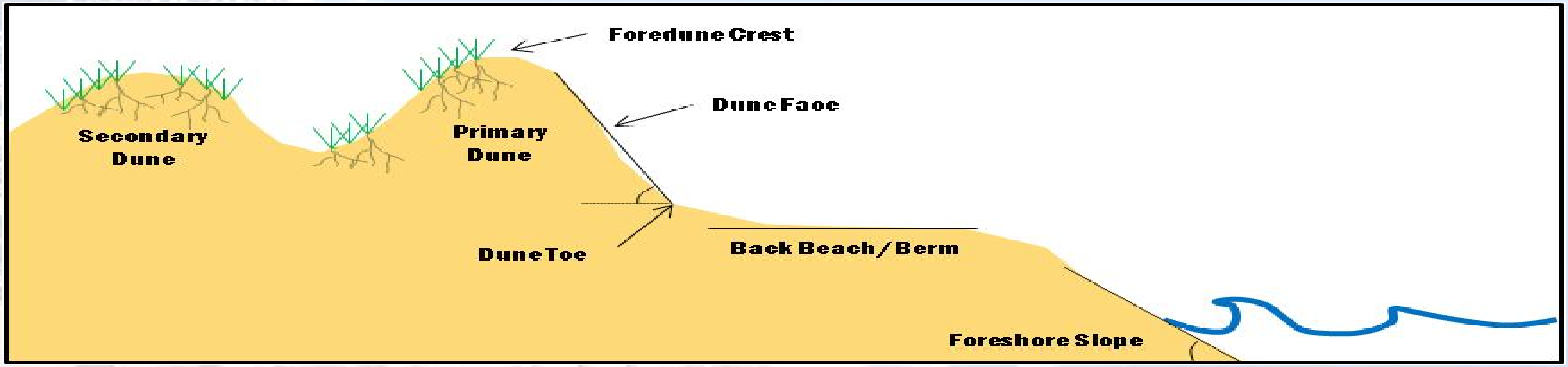
Outline



1. What are we looking at?
2. Why do we care?
3. How was the data collected?
4. What to do with the data?
5. How is the analysis useful?
6. What can be improved upon?

Motivation

- Foredunes = Nature-based defensive infrastructure (especially along developed coastlines)



- Accurate storm-response and subsequent re-growth predictions → critical to assess resiliency and vulnerability
- Understanding and enhancing benefits of nature-based infrastructure post-Sandy (USACE)
- Classification = understand current state pre/post-storm and useful for decision makers

Motivation

Process Feedbacks


erosion by waves

Coastline Dynamics

- erosion by waves
- geologic framework
- sediment supply
- storm magnitude/frequency
- beach/nearshore morphology
- barrier island response to sea level rise


vegetation deposition

Aeolian Processes

- fetch-controlled sediment supply
- wind speed
- sediment size & type
- vegetation
- moisture content


sand fencing

Management

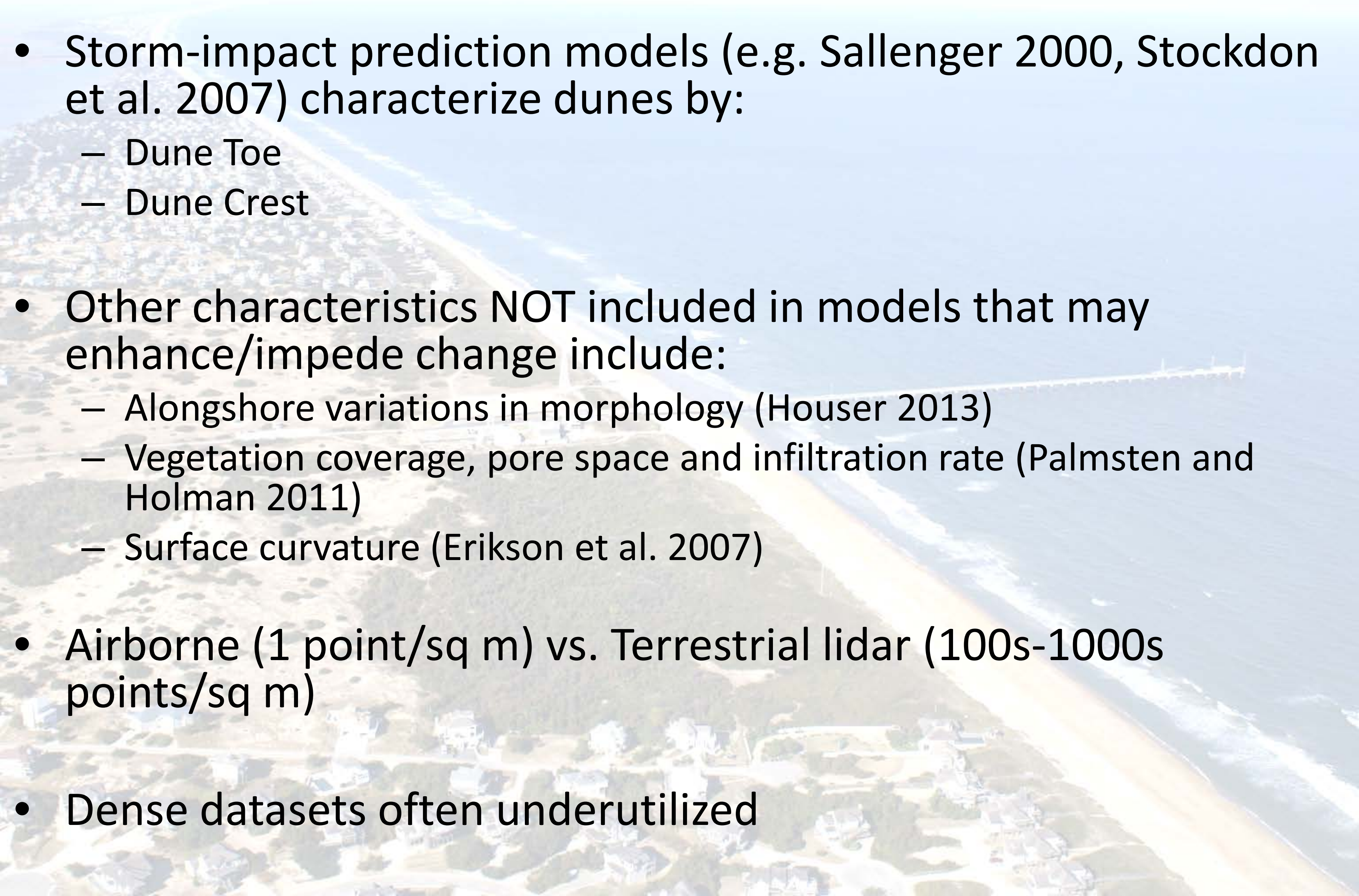
- anthropogenic sediment supply
- dune engineering
- planting vegetation
- sand fencing
- beach nourishment
- engineering structures

Foredune Form

Physical Features

- Profile Slope
- Height
- Width
- Vegetation Density
- Curvature
- Alongshore Continuity

Motivation



- Storm-impact prediction models (e.g. Sallenger 2000, Stockdon et al. 2007) characterize dunes by:
  - Dune Toe
  - Dune Crest

- Other characteristics NOT included in models that may enhance/impede change include:
  - Alongshore variations in morphology (Houser 2013)
  - Vegetation coverage, pore space and infiltration rate (Palmsten and Holman 2011)
  - Surface curvature (Erikson et al. 2007)

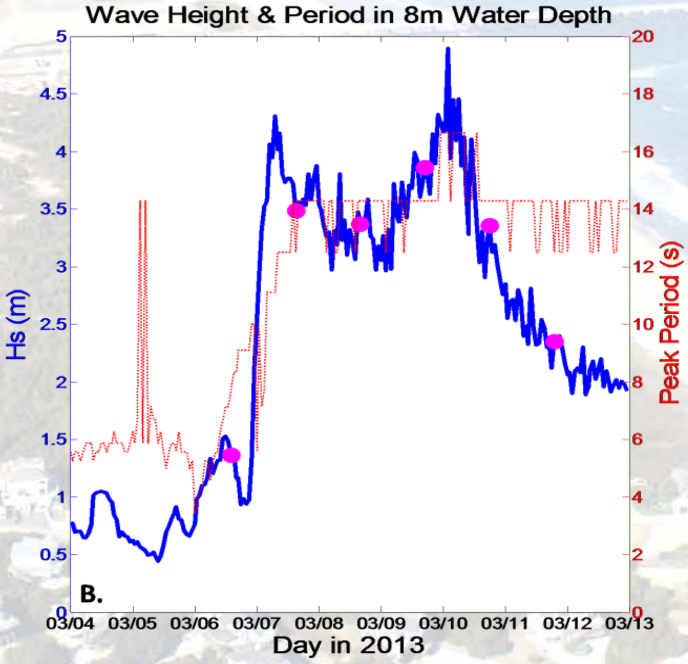
- Airborne (1 point/sq m) vs. Terrestrial lidar (100s-1000s points/sq m)

- Dense datasets often underutilized

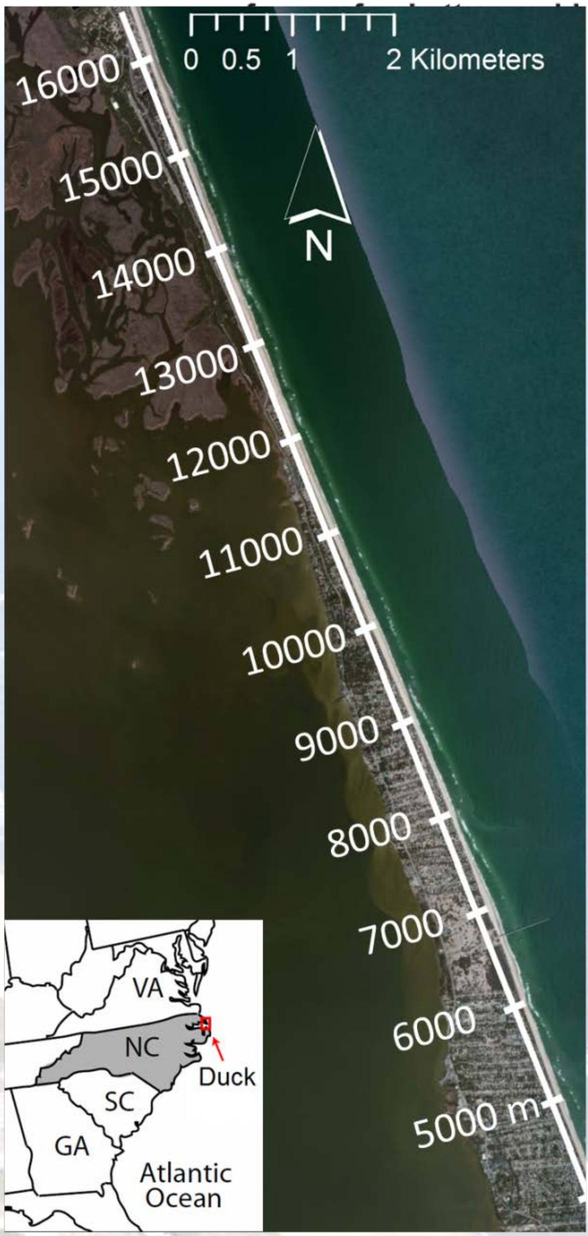
Methodology - Survey

- Mobile terrestrial lidar surveys performed daily along 11km stretch of coastline during 6-day Nor’easter
- Coupled with X-band radar to produce time-averaged images of radar intensity (i.e. wave breaking)
- Centered around low-tide for maximum foreshore exposure and personnel safety
- Largest waves on March 10: Hs = 4.8 m at 16 sec

Coastal Lidar and Radar Imaging System (CLARIS)

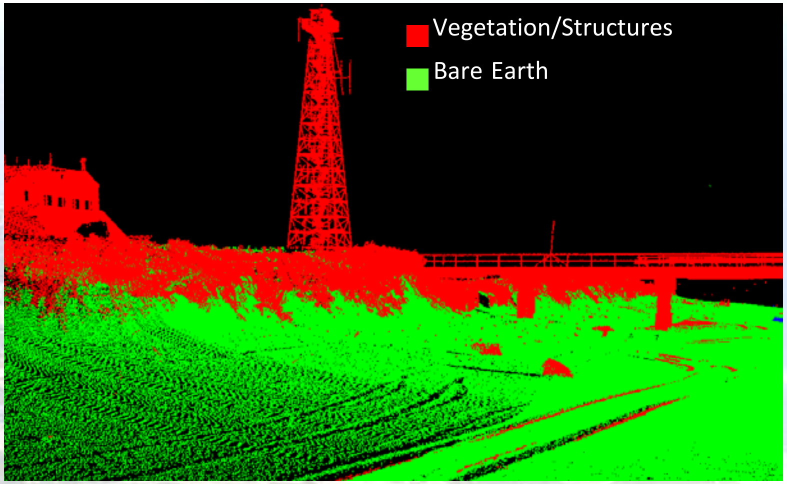


Nor’easter Storm Conditions



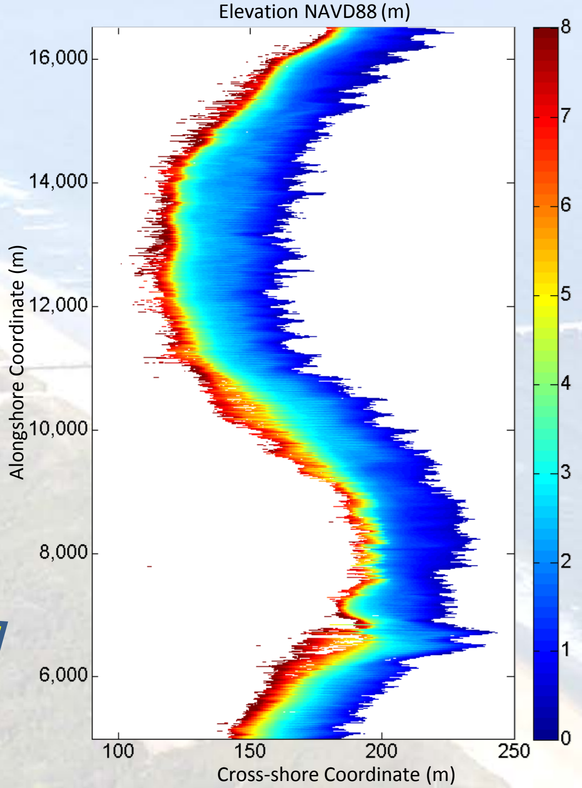
Study Site: Duck, NC

Methodology – Data Processing



1. Point cloud rectification and filtering

2. Bare-earth DEM at 50 cm resolution

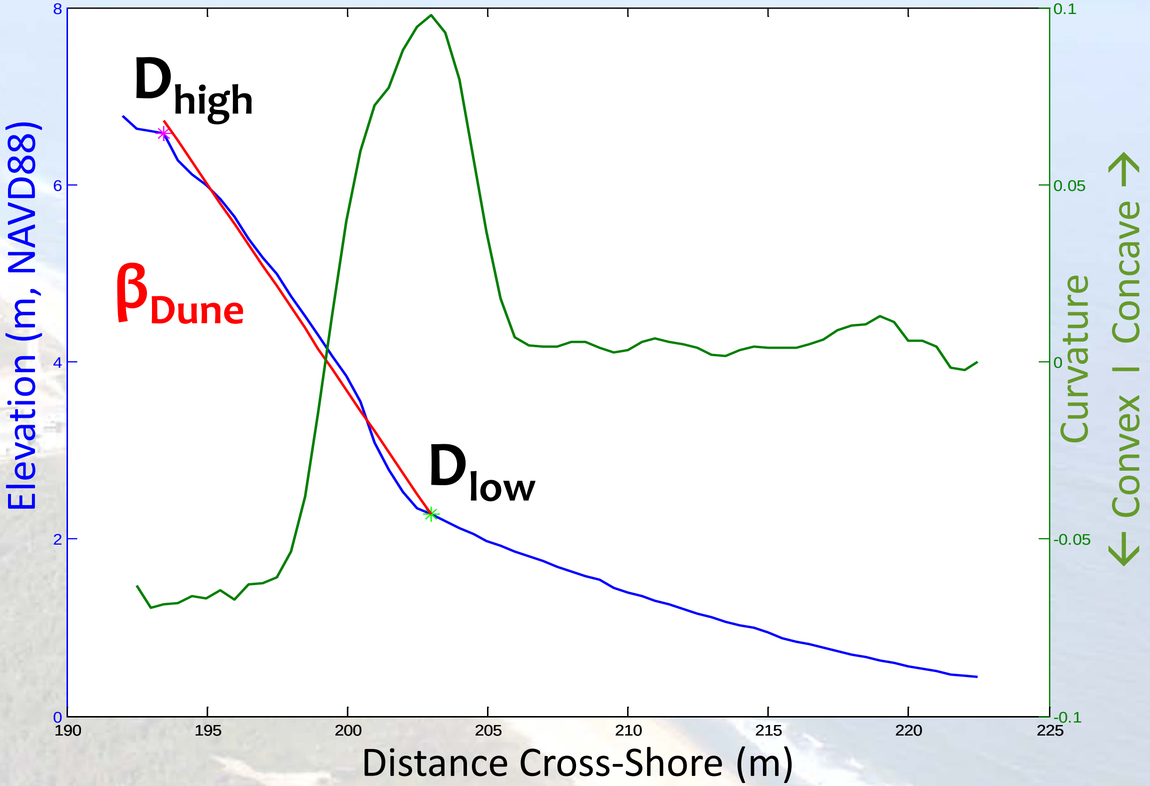


3. DEM rotated and translated into local alongshore/cross-shore coordinate system

4. Dune feature identification/ classification at every 0.5m transect

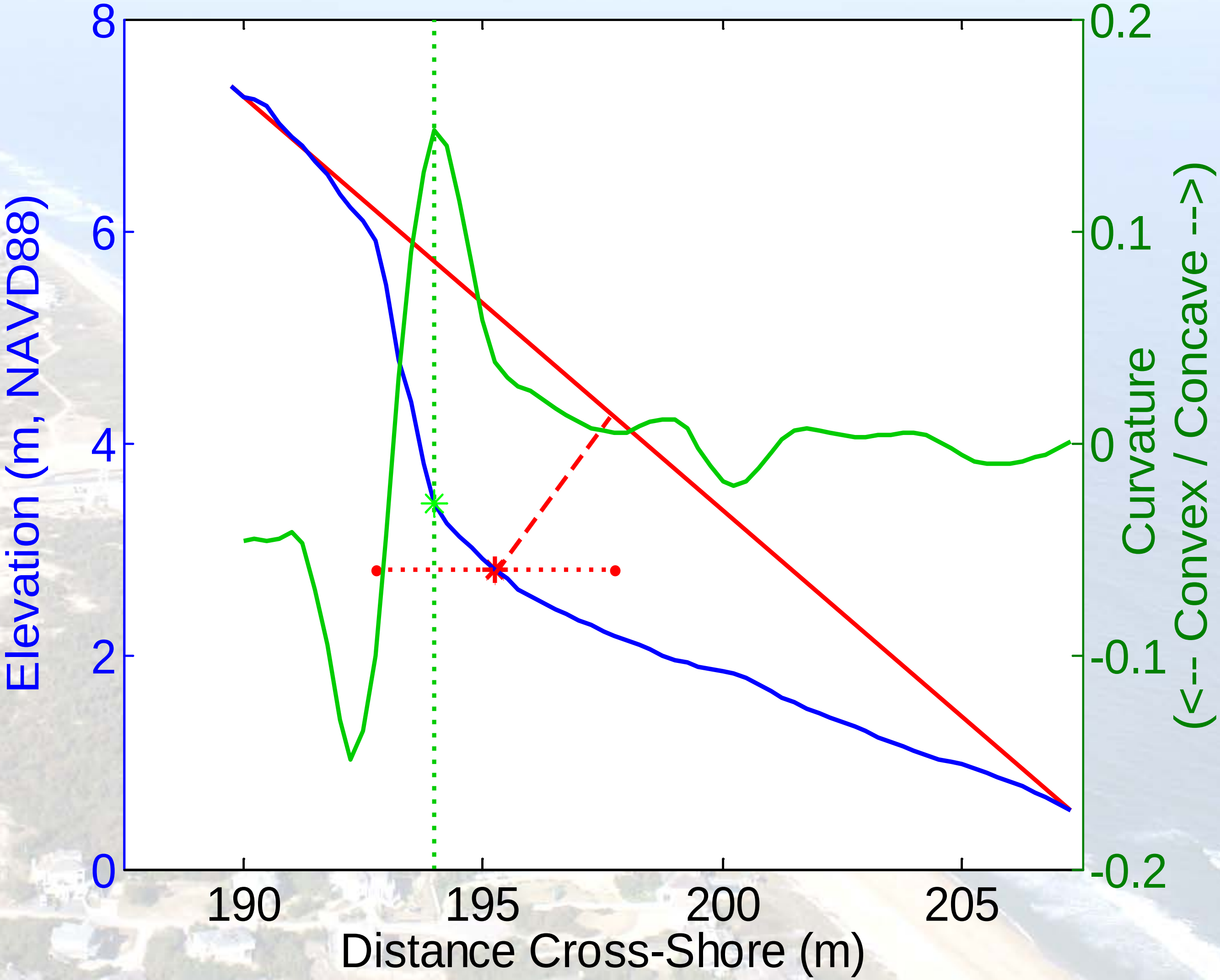
Dune Features

- Cross-shore Profile Curvature (κ_{pks})
- Dune Toe (D_{low}) Elevation
- Dune Crest (D_{high}) Elevation
- Dune Slope (β_{Dune})
- Dune Volume (V_{dune})

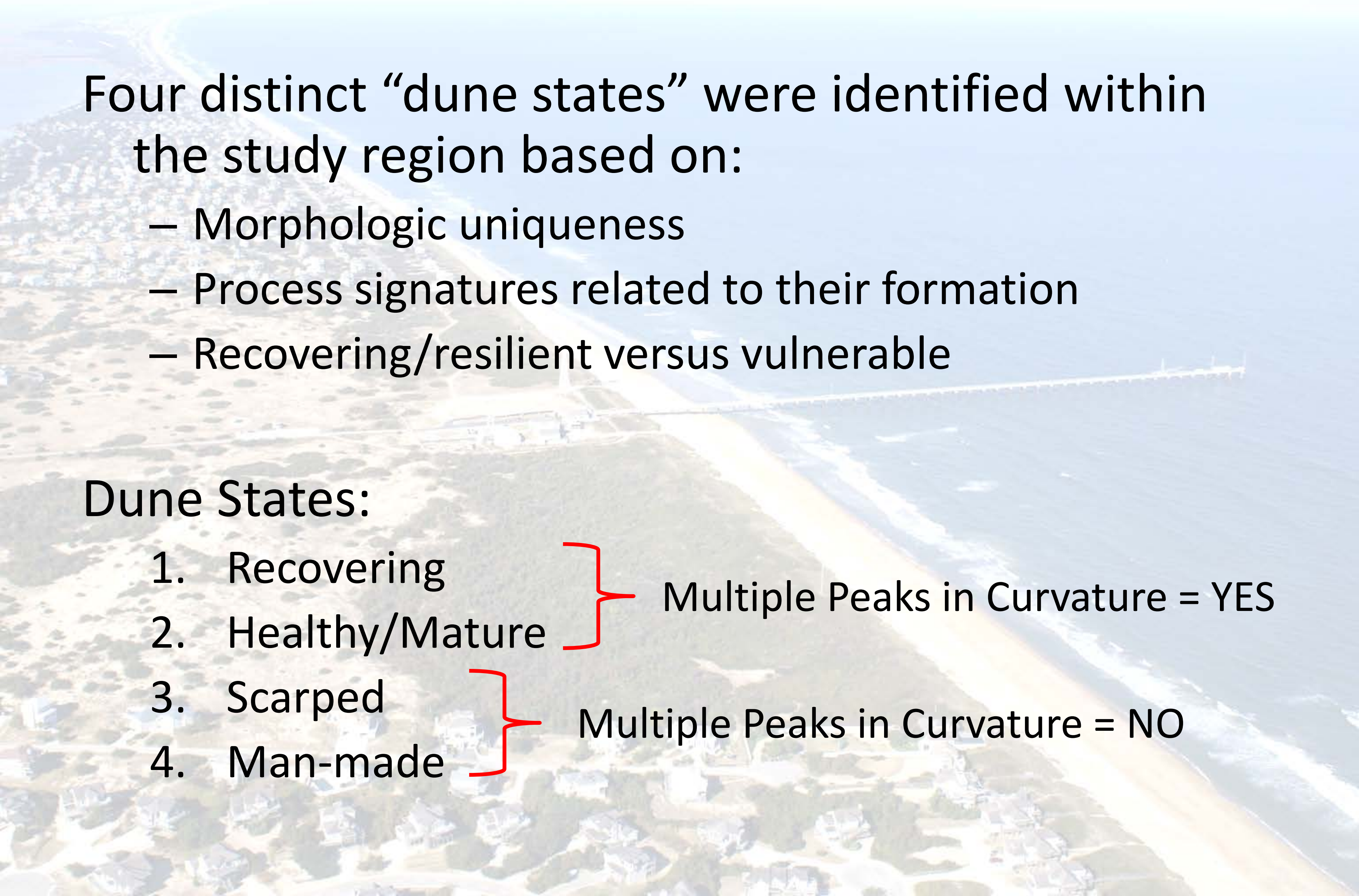


Feature Extraction

1. Fit “sheet”
2. D_{low} 1st guess
3. Refine guess
4. Define D_{high}
5. Fit β_{Dune}
6. Calc V_{dune}
7. Assess κ_{pks}
8. (Future…use point data for veg density/ structural presence)



Classification



Four distinct "dune states" were identified within the study region based on:

- Morphologic uniqueness
- Process signatures related to their formation
- Recovering/resilient versus vulnerable

Dune States:

1. Recovering
2. Healthy/Mature

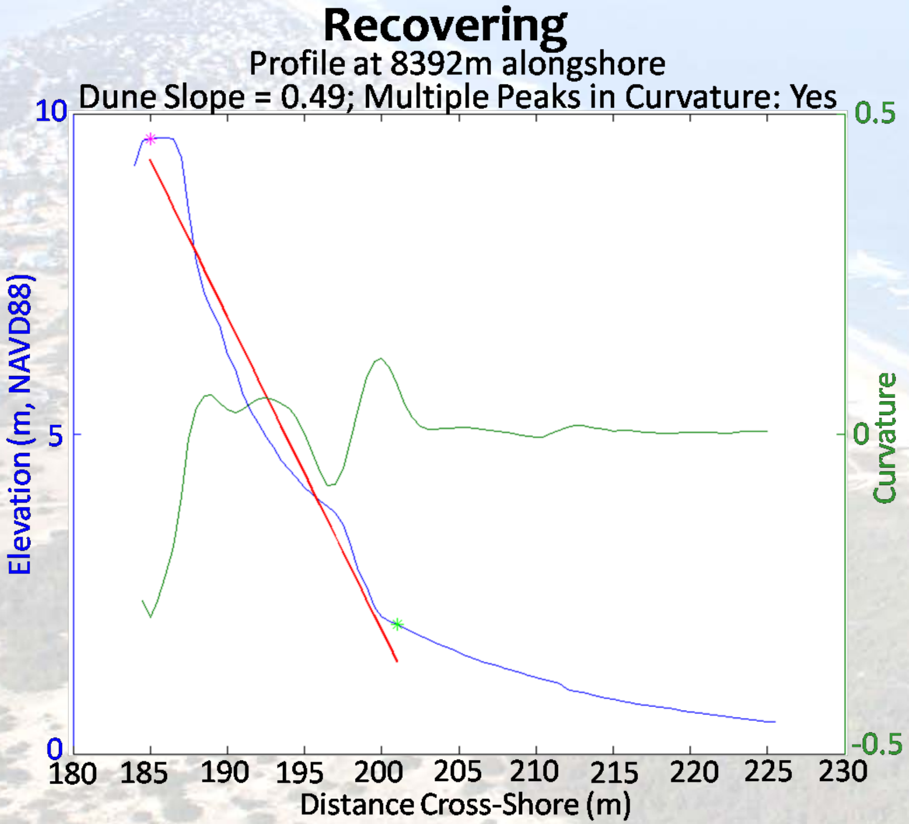
Multiple Peaks in Curvature = YES

3. Scarped
4. Man-made

Multiple Peaks in Curvature = NO

Classification

- Both recovering and healthy dunes are defined by $\kappa_{pks} > 0$ (i.e. multiple peaks in curvature)
- Indicative of active Aeolian processes (Thom and Hall, 1991)



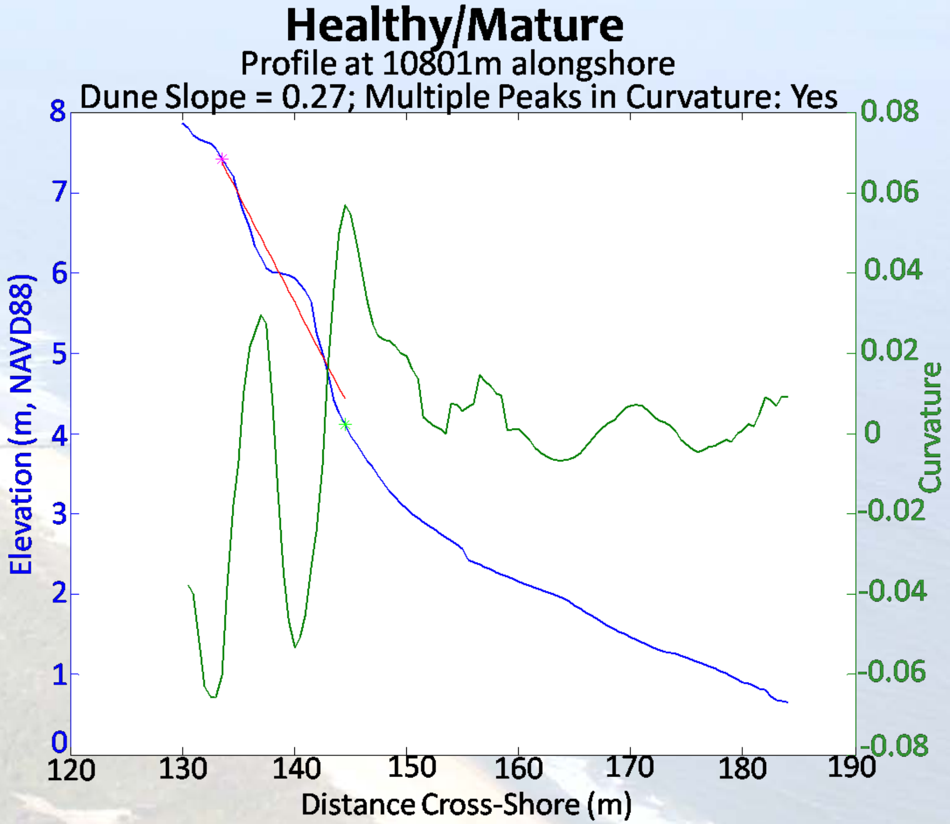
Recovering

Profile at 8392m alongshore

Dune Slope = 0.49; Multiple Peaks in Curvature: Yes

- Incipient dune forms near dune toe (Hesp 2002) while upper dune face remains steep indicating recent wave attack

- Less dune volume compared to healthy dune due to steeper slope on upper dune face



Healthy/Mature

Profile at 10801m alongshore

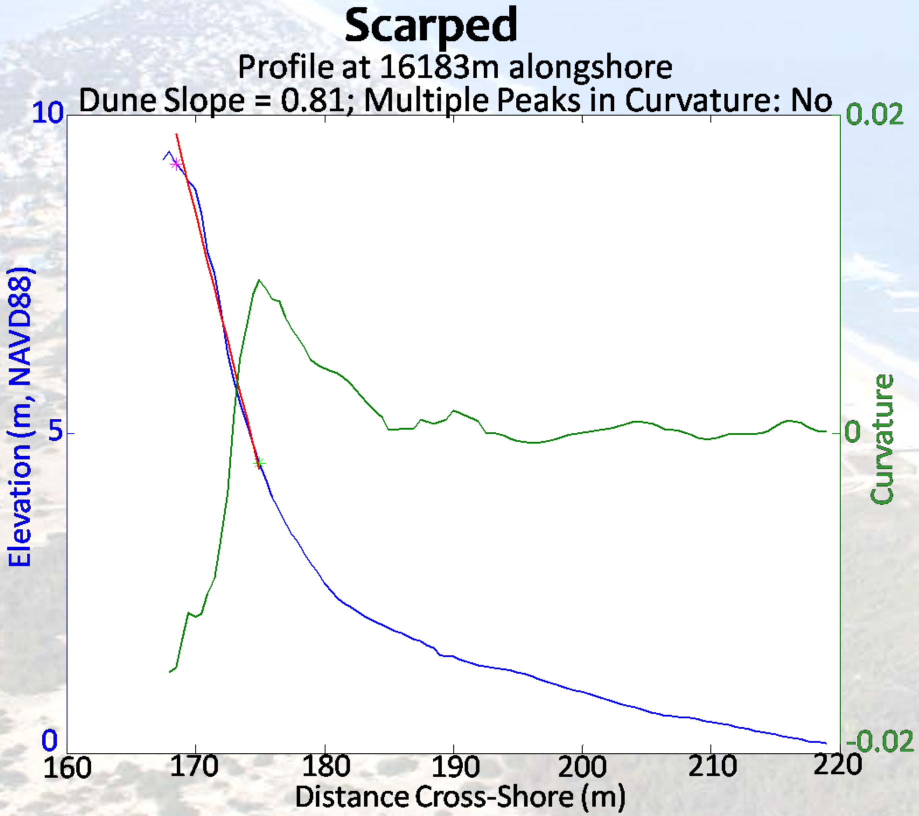
Dune Slope = 0.27; Multiple Peaks in Curvature: Yes

- Continual deposition and re-working by Aeolian processes yields shallower slopes closer to angle of repose for native sediment

- Longer time period since last storm-wave inundation allows for greater dune volumes and prograding foredune face

Classification

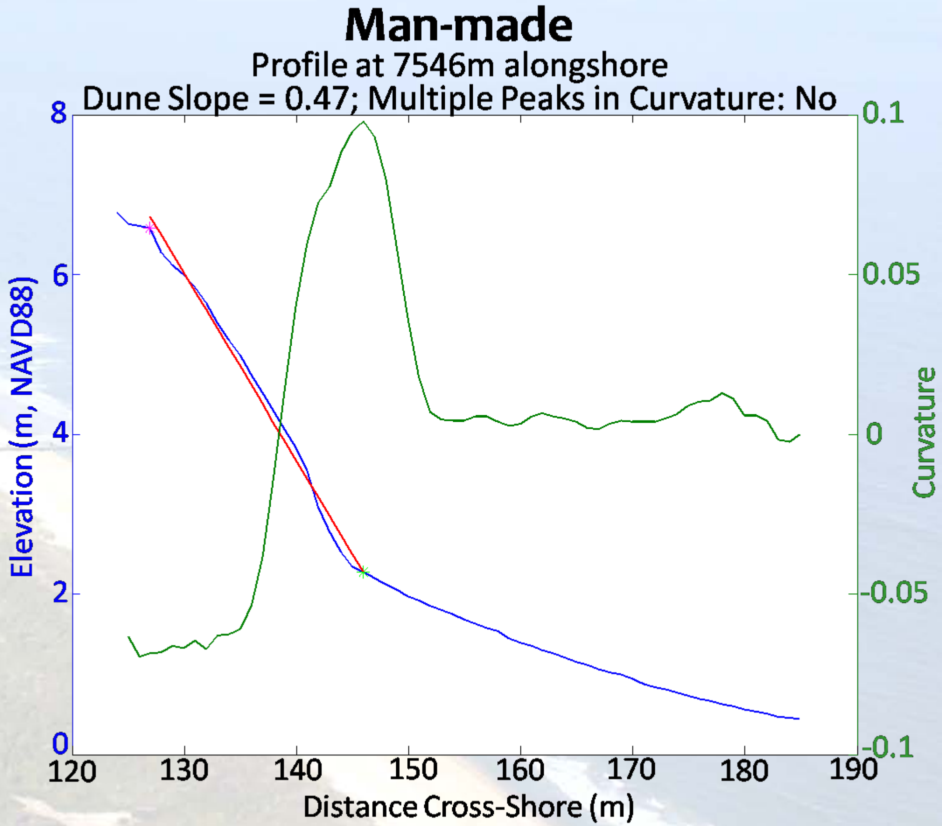
- Both scarped and man-made dunes are defined by $\kappa_{pks} < 0$ (i.e. NO peaks in curvature)
- Characterized by a more linear foredune face



Scarped

Profile at 16183m alongshore

Dune Slope = 0.81; Multiple Peaks in Curvature: No



Man-made

Profile at 7546m alongshore

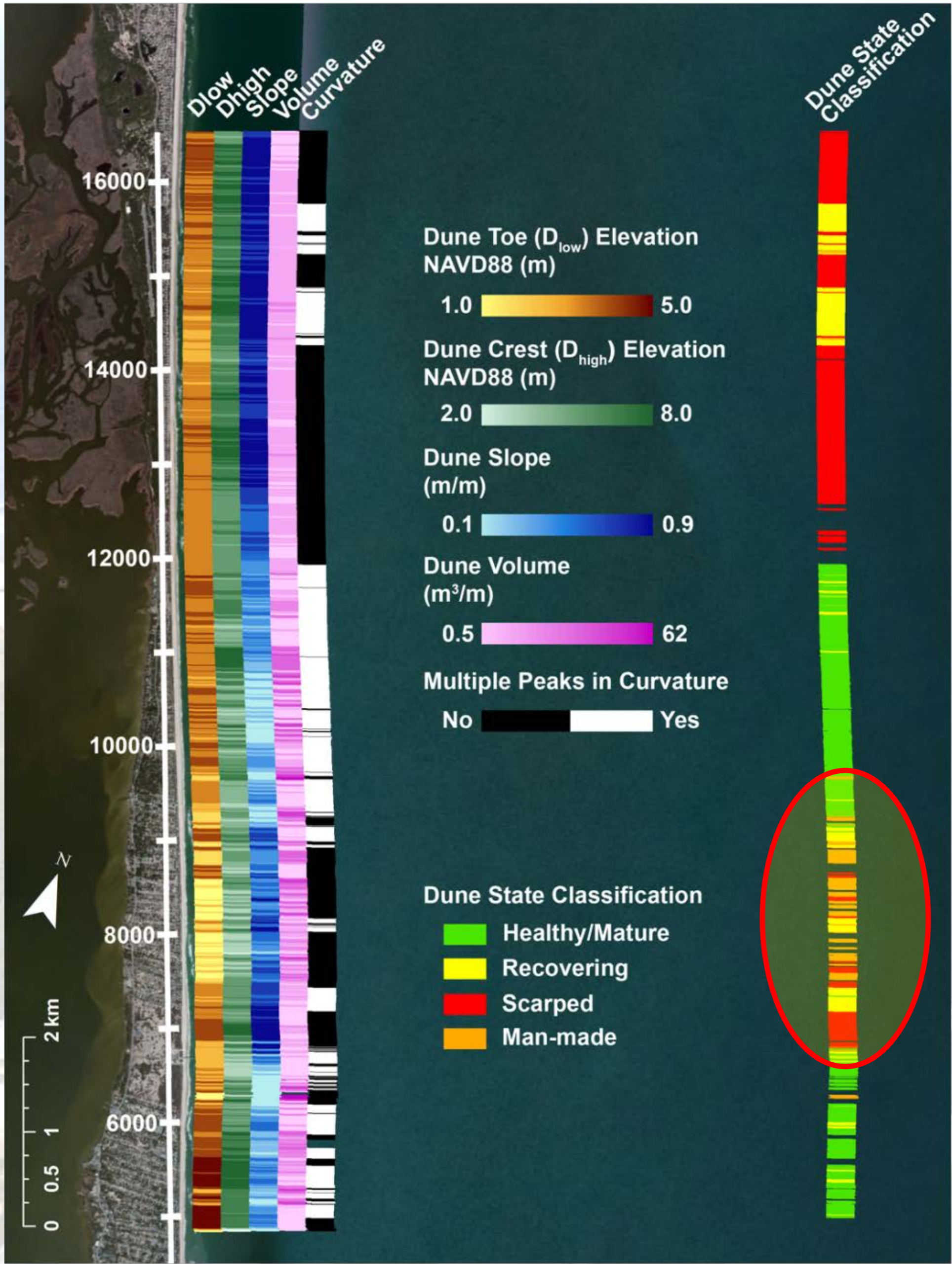
Dune Slope = 0.47; Multiple Peaks in Curvature: No

- Defined by steep slopes and low dune volume, indicative of recent scarping from wave attack
- No incipient dune present and often little to no recovery at the base of the dune

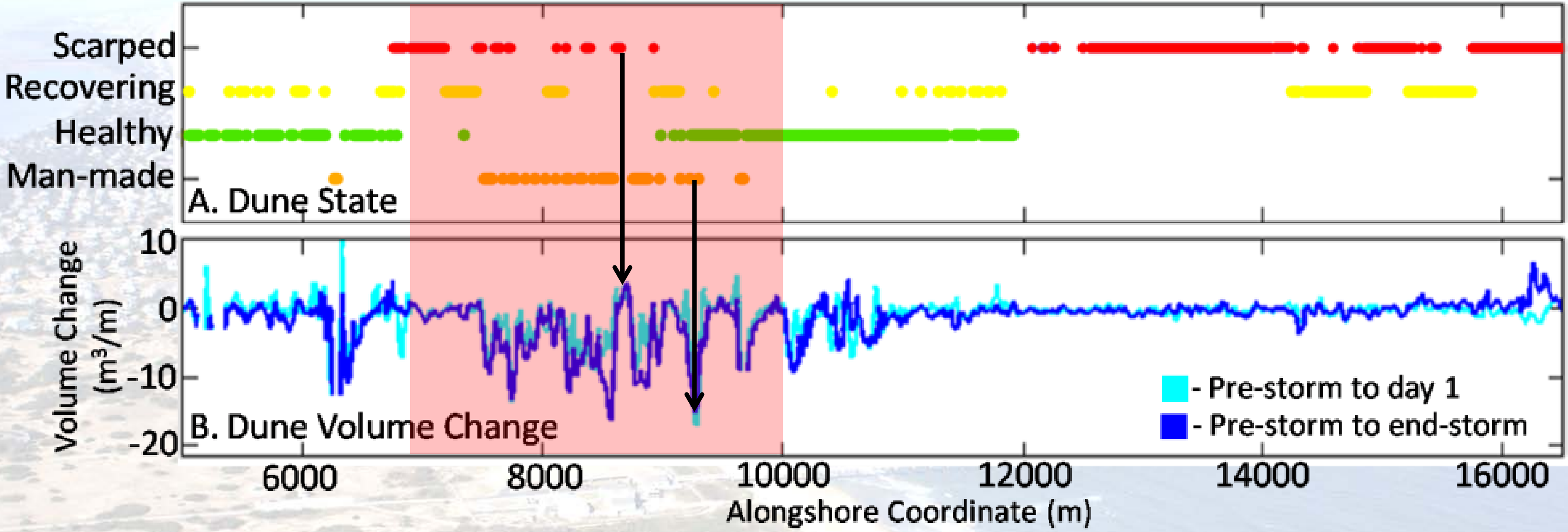
- Larger dune volume and shallower slope approaching angle of repose typically placed as an unconsolidated pile of sediment
- Dune toe elevation often lower due to beach scraping or pushing

Classification - Results

- Final product from classification routine useful for coastal engineers and managers to identify vulnerable areas
- Results were in-line with qualitative assessments of the study site
- Transitions are still poorly understood and need further investigation

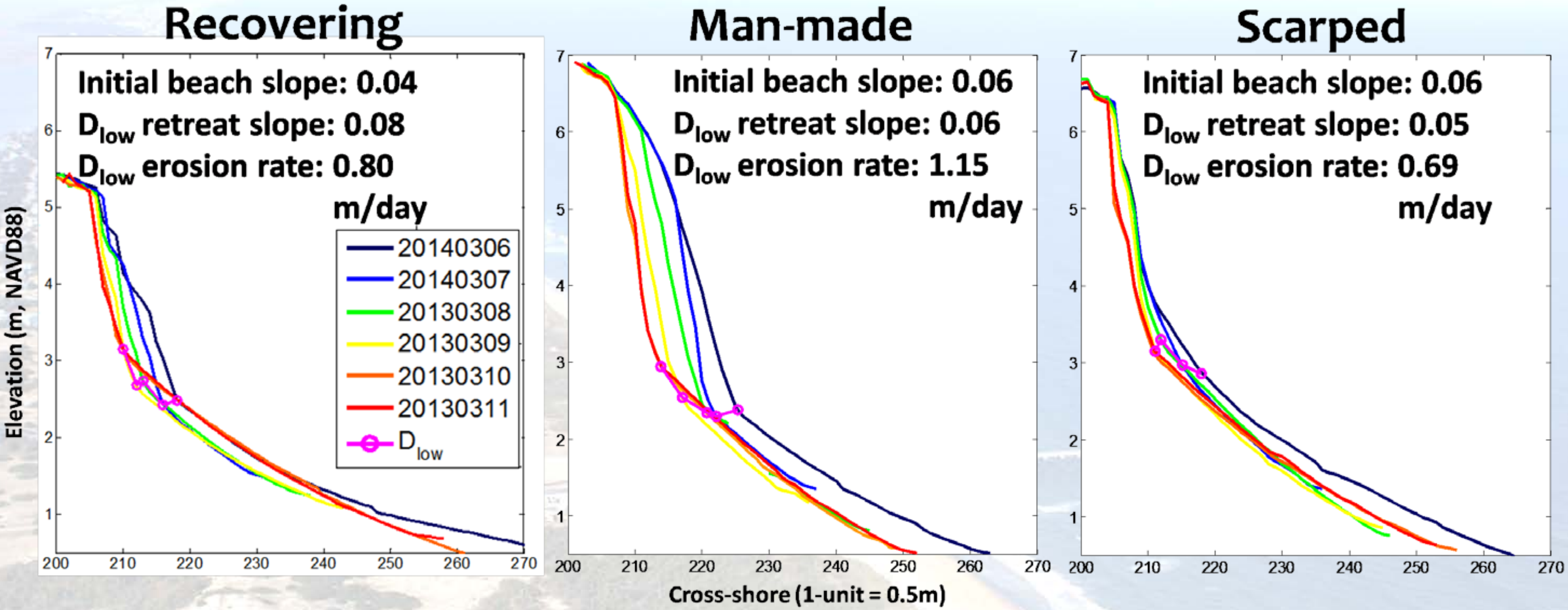


Storm Response



- Dune volume change clearly illustrates where wave attack to the foredune occurred within the study site vs. pre-storm condition
- Highest erosion rates coincide with the erosional hotspot, recently impacted 4 months prior by Hurricane Sandy; particularly the recently constructed man-made dunes

Storm Response

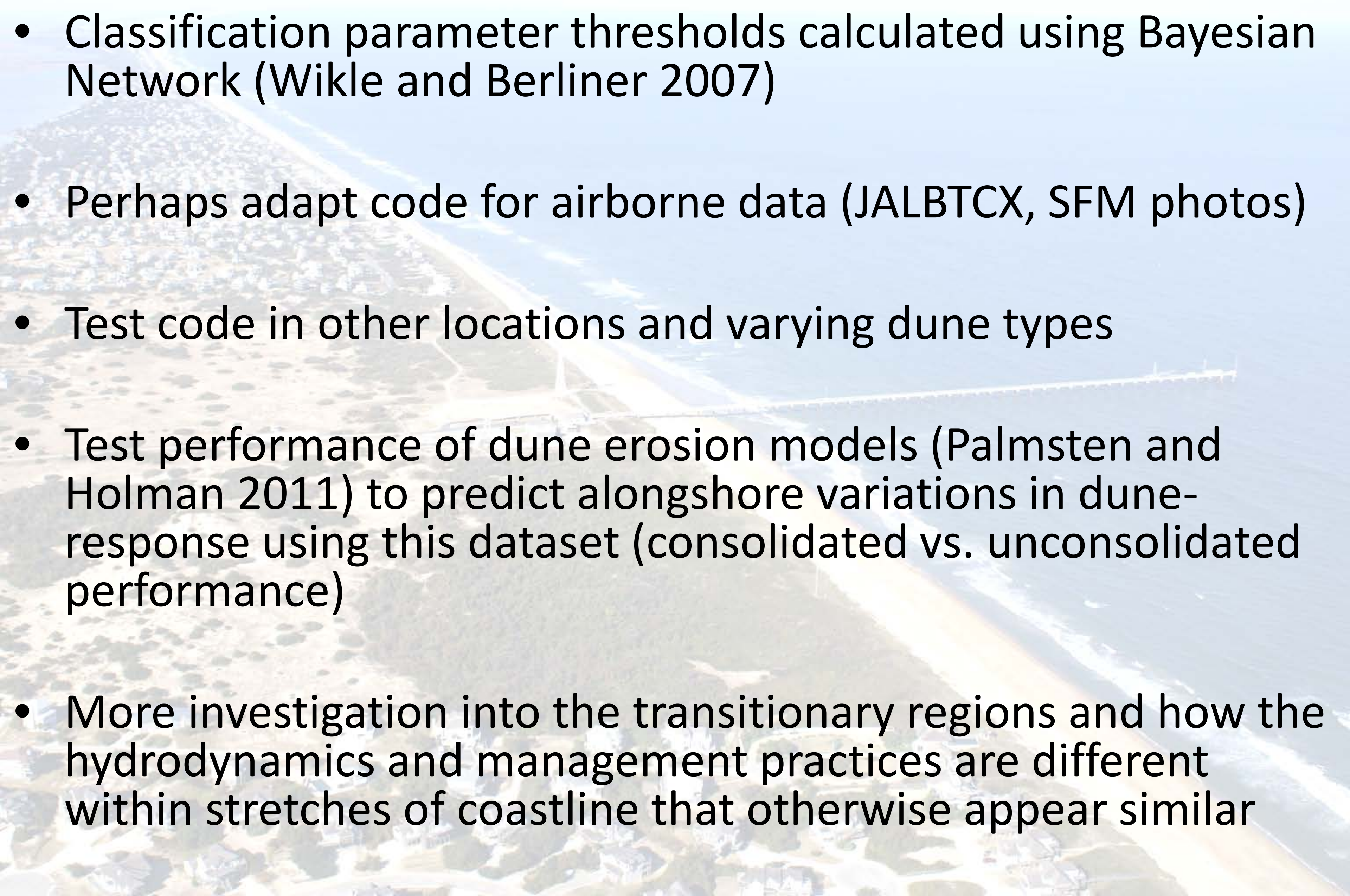


- All three dune types present in erosional hotspot and daily D_{low} erosion rates were calculated
- Recovering and man-made dunes experienced an initial drop in D_{low} elevation whereas scarped dunes retreat was directed upward
- **Hypothesis:** unconsolidated sediment present in both the incipient recovering foredune and the recently placed pile of sand by homeowners combined with lower D_{low} elevations yields higher erosion rates

Conclusions

- Subtle changes in curvature exploited to identify active Aeolian Transport
- Along with foredune slope and volume, useful for indicating “state” of dune
- Classification regime allows for rapid identification of resilient regions and useful for mitigation efforts
- Preliminary storm-response results indicate consolidation affects resiliency and magnitude of retreat
- Classification not necessarily linked to storms → more interested in recovery /resiliency
  - Which regions are recovering naturally vs. vulnerable

Future Work



- Classification parameter thresholds calculated using Bayesian Network (Wikle and Berliner 2007)
- Perhaps adapt code for airborne data (JALBTCX, SFM photos)
- Test code in other locations and varying dune types
- Test performance of dune erosion models (Palmsten and Holman 2011) to predict alongshore variations in dune-response using this dataset (consolidated vs. unconsolidated performance)
- More investigation into the transitionary regions and how the hydrodynamics and management practices are different within stretches of coastline that otherwise appear similar

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Questions??

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