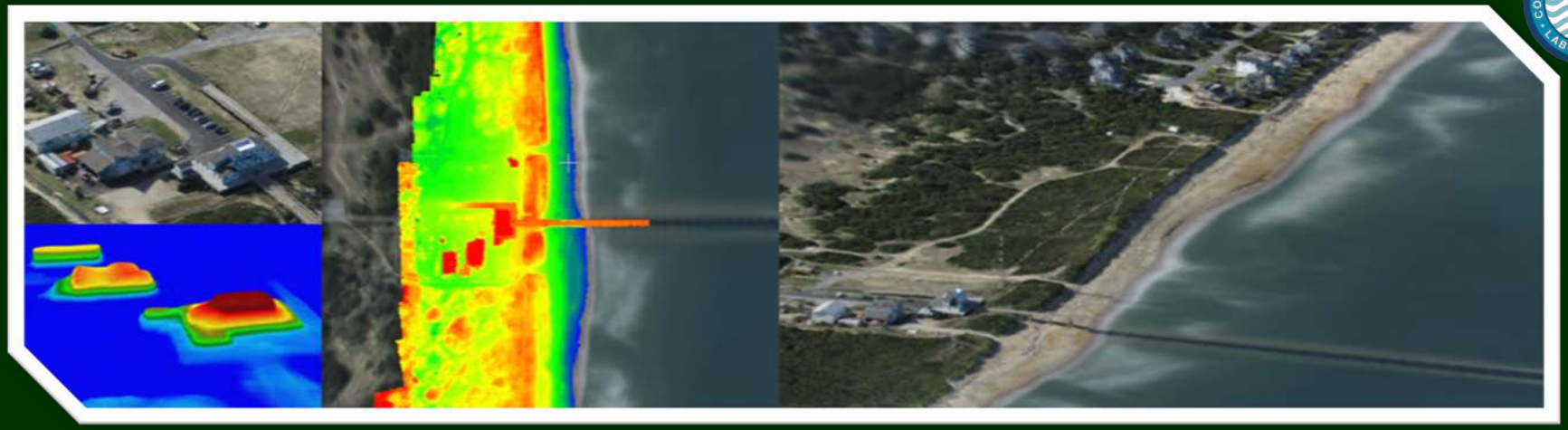

Coastal Remote Sensing at the FRF

Kate Brodie, Ph.D. Research Oceanographer
Richie Slocum Cormorant Analytics/Pathways Intern
Nick Spore, M.S. Research Engineer

Coastal Ocean Data Systems Program (CODS)
Coastal Field Data Collection Program (CFDC)
Ports of Debarkation: Assessment & Upgrade (POD:A&U)
Coastal Inlets Research Program (CIRP)

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Coastal Remote Sensing at the FRF

Mission -- Advancing coastal science and engineering through observational research utilizing:

1) collection and analysis of long-term oceanographic and morphologic data at the Field Research Facility,
2) assessment of model results and observational techniques, and
3) development of observational equipment and collection methodologies.

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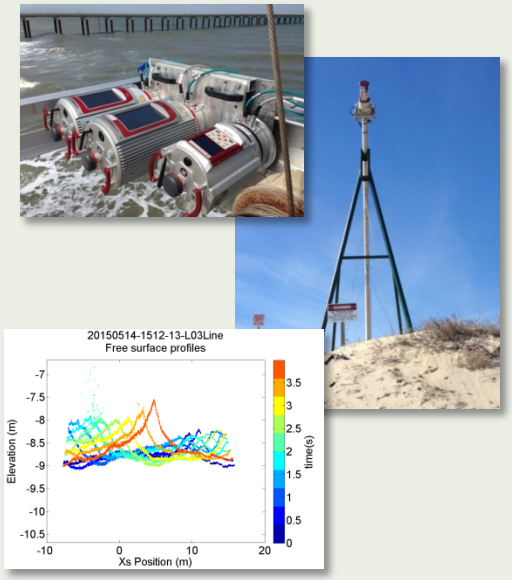
Talk Overview

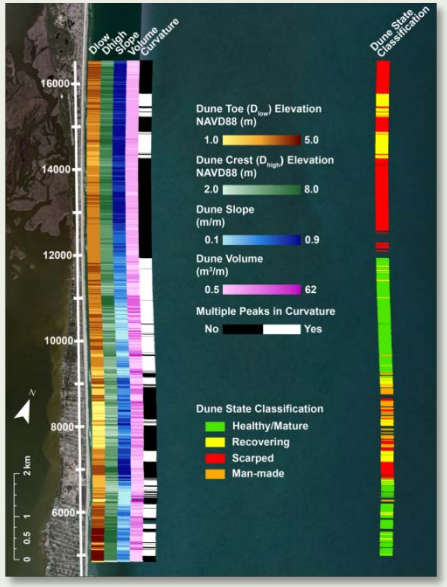
Basic Research

- Lidar observations of wave processes



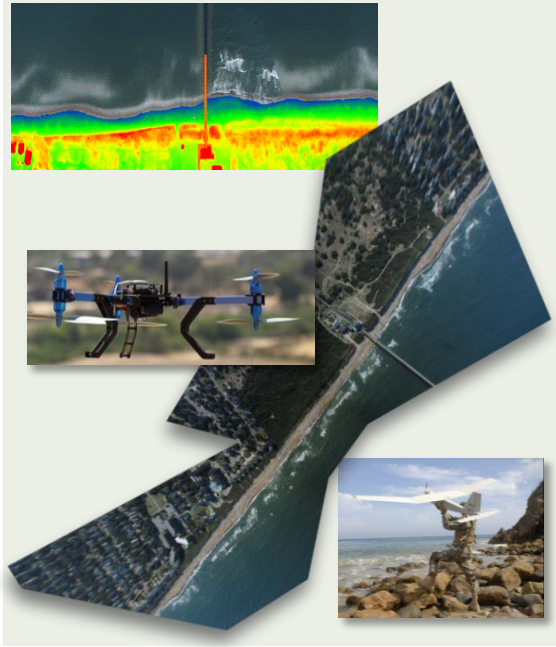
Applied Research

- Automated Dune-state classification



Technology R&D

- sUAS for coastal mapping



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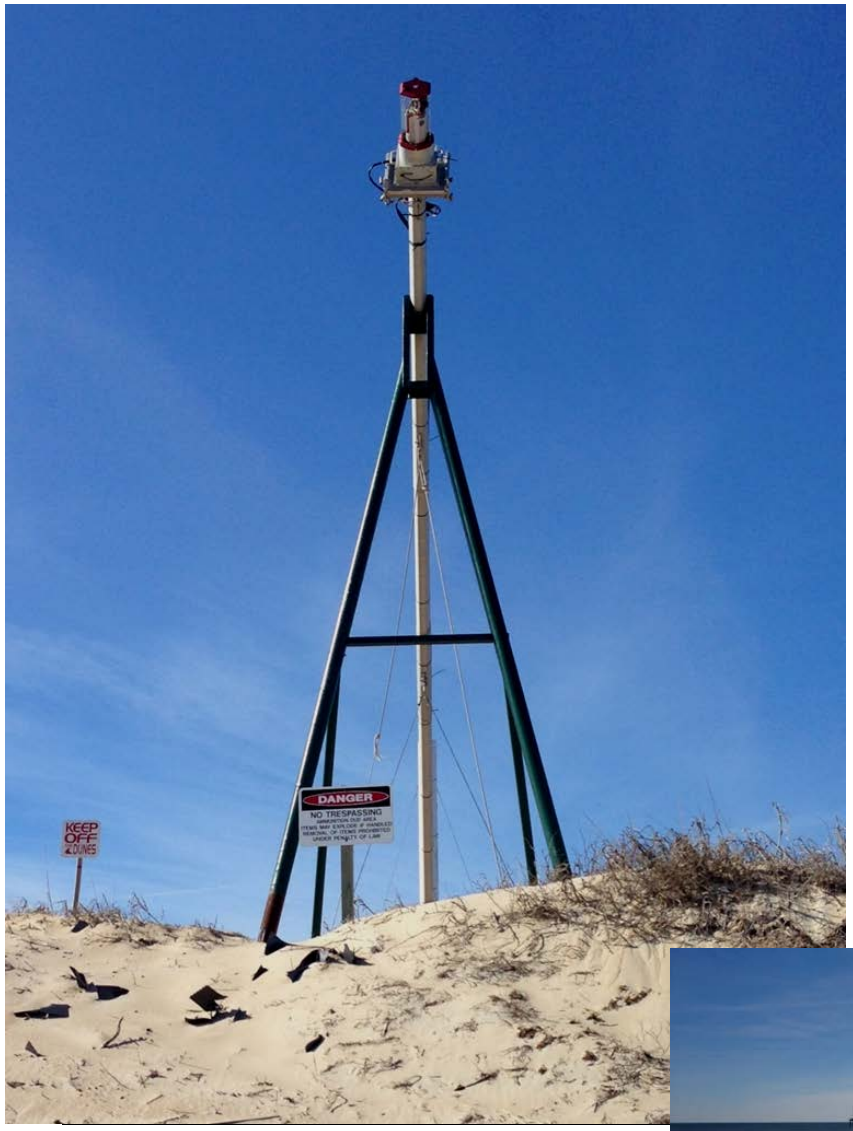
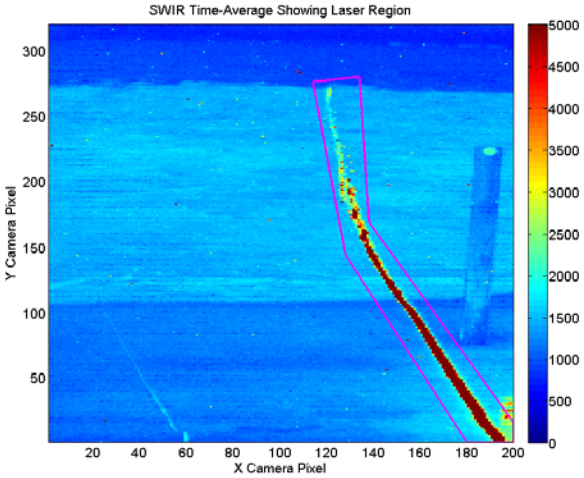
Stationary Dune Lidar

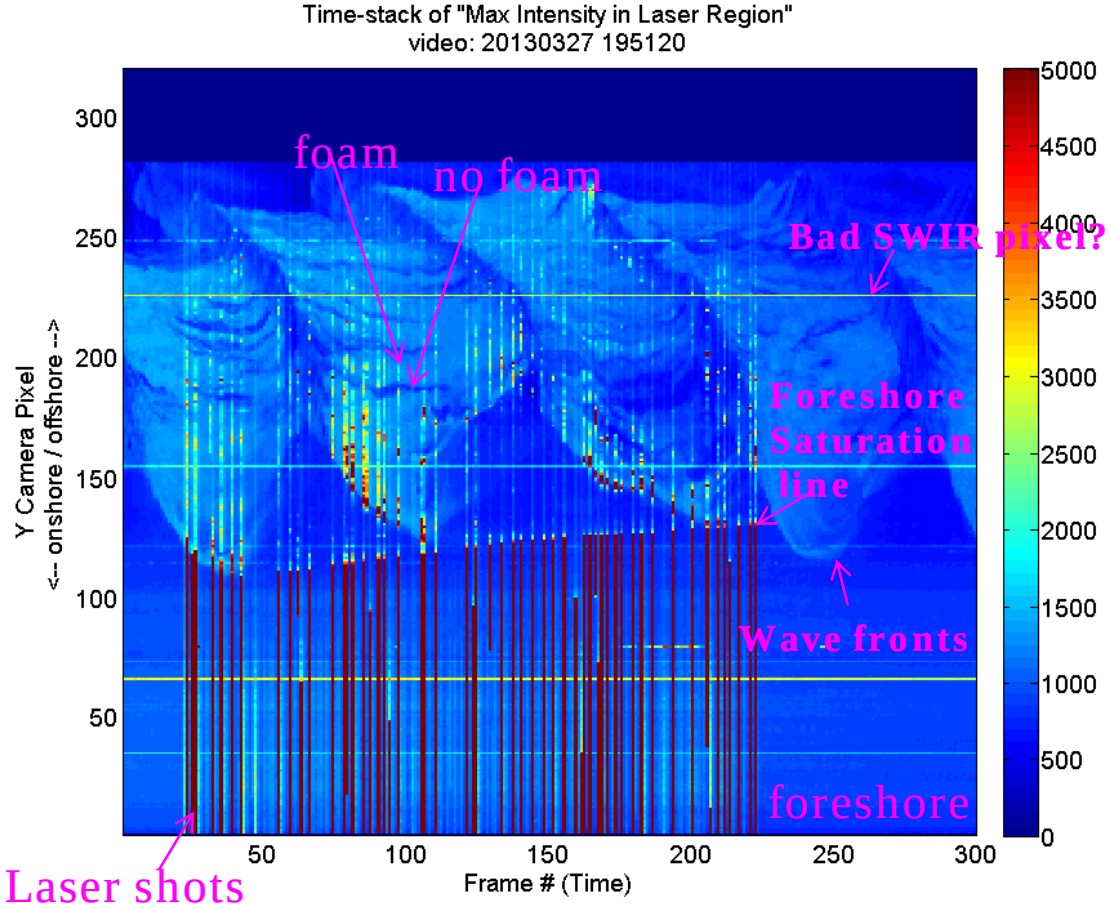


- Provides observations of:
  - Inner surf zone wave height & spectra
  - Mean water level
  - Runup elevations
  - Foreshore beach profile (hourly & wave by wave) & 3D morphology
- Riegl VZ-1000 Terrestrial Lidar Scanner
  - 1550 nm light
  - Reflects off of relict foam, active wave breaking, and steep faces of non-breaking waves
  - Drawbacks:
    - Platform stability
    - Attenuated in heavy rain; noisy in fog/light rain
    - No returns from flat mirror like surfaces (bounces away from scanner)
    - Shadowing behind tall wave faces

Imaging of Riegl's VZ-1000 on Water Surface

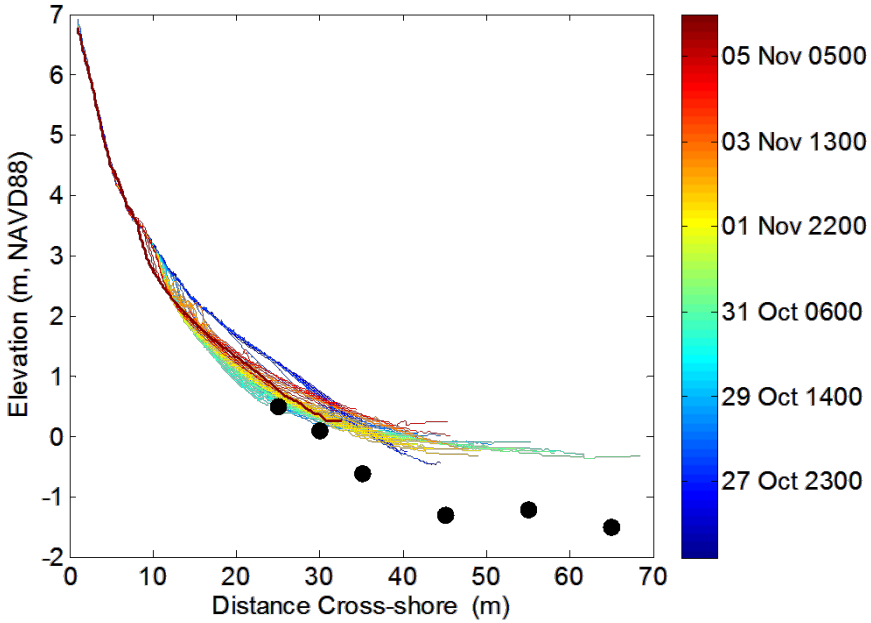
- Imaged VZ-1000 (1550nm) on water surface using SWIR camera (800-2500 nm) to investigate source of returns



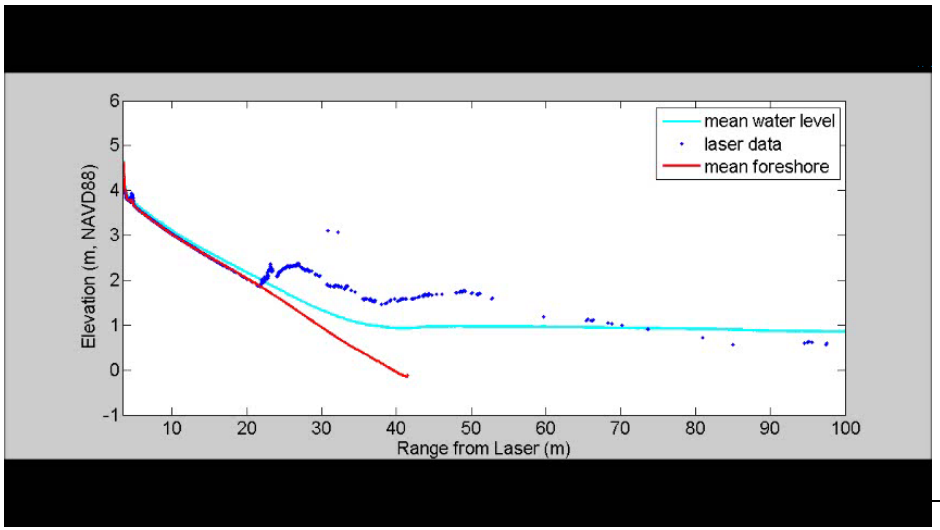


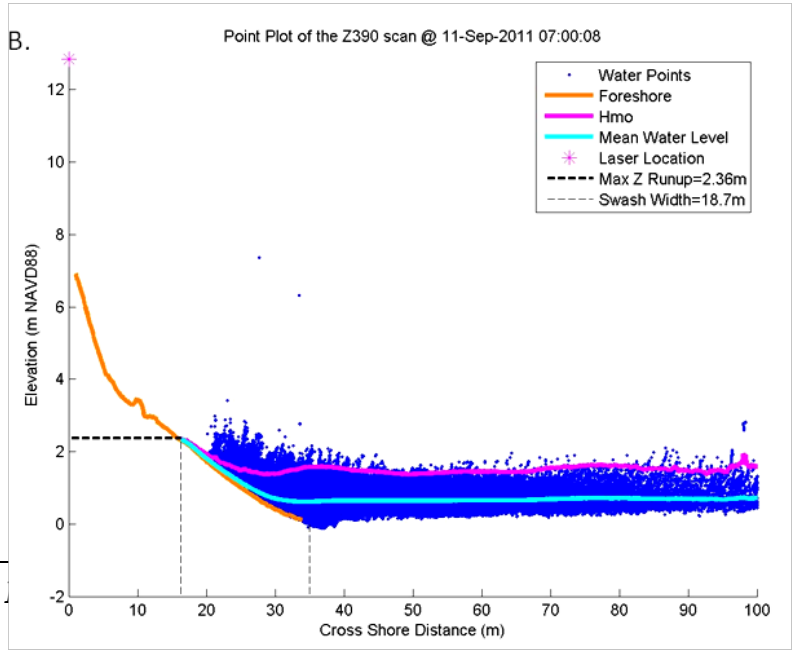
SWIR data courtesy ERDC-GRL

Stationary Dune Lidar

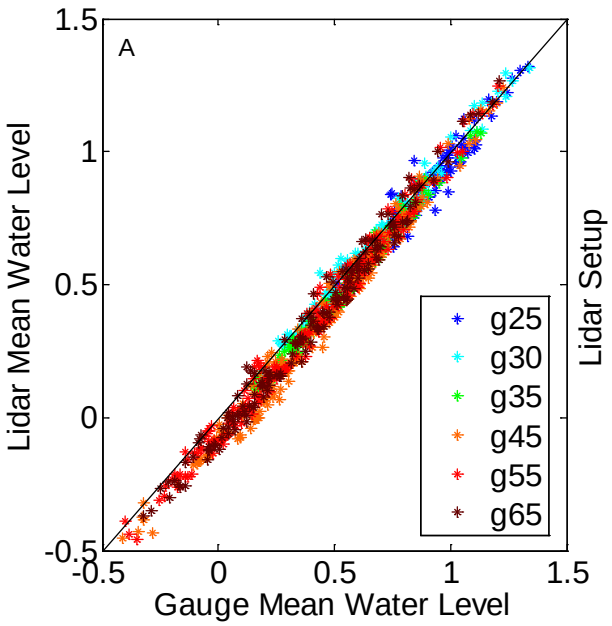


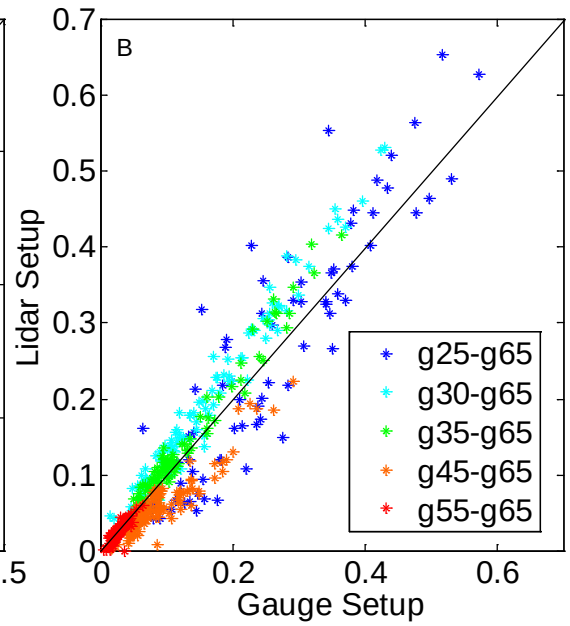
- Evaluated performance of Riegl z390i terrestrial scanner for wave & water level observations in the inner surf relative to paros pressure gauges (Raubenheimer & Elgar)
  - Beam width: 0.3 mrad
  - Angular resolution 0.02 degrees in vertical
- Problems:
  - Continuous bed level measurements were not available for all pressure gauges



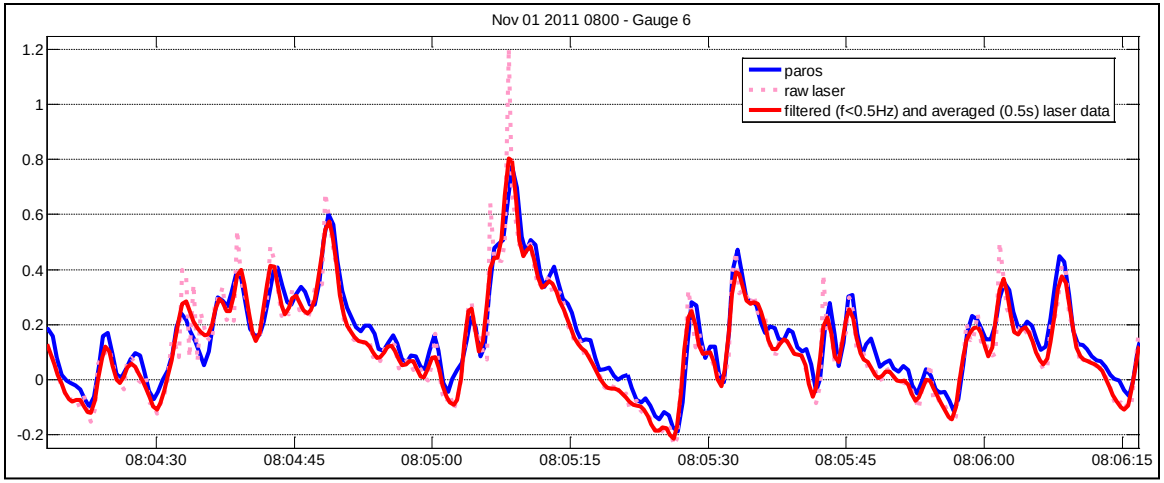


Water Level Comparison Statistics



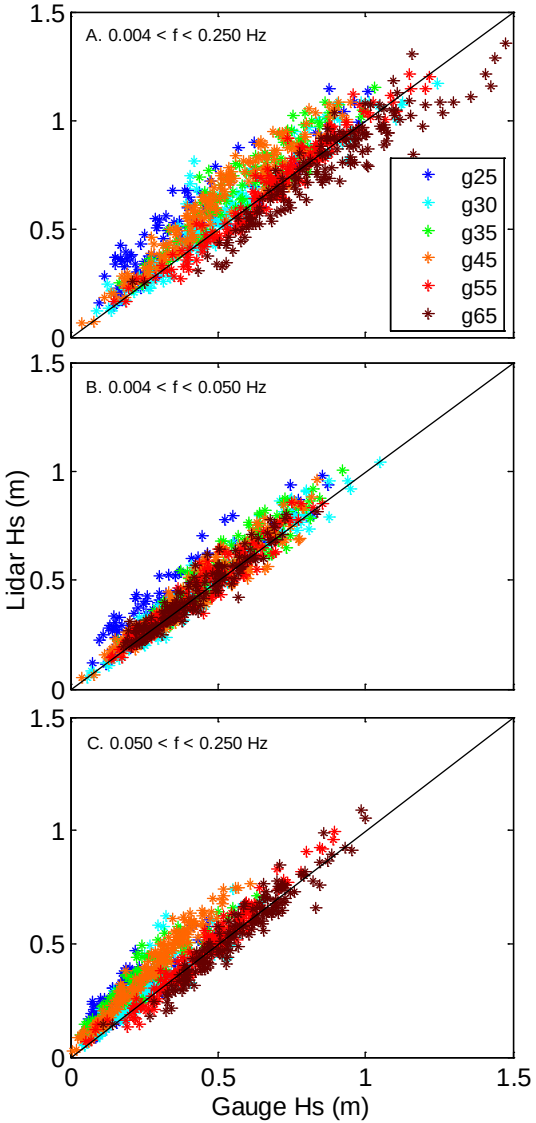


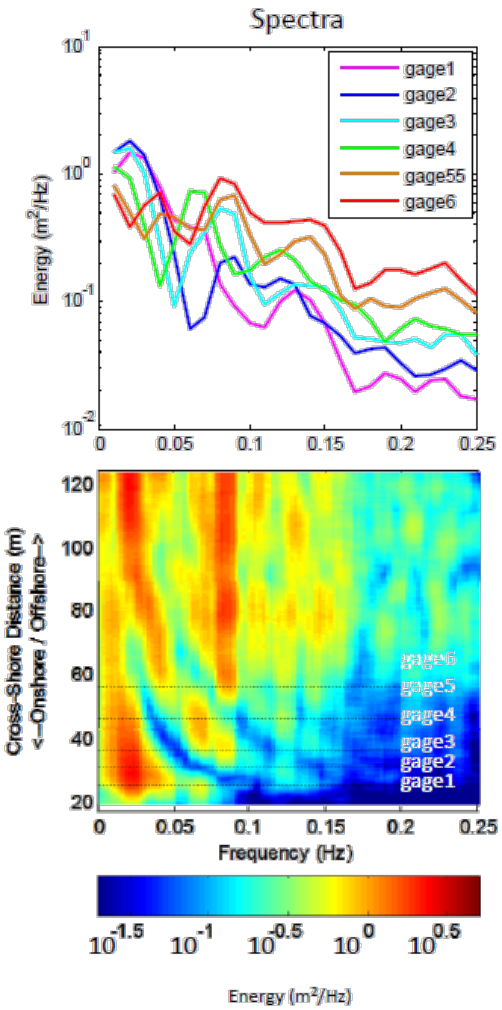
	r^2	rmse (m)	bias (m)	slope
Mean Water Level	0.98	0.05	-0.07	1.1
Setup	0.92	0.03	-0.01	1.1
Hs (total)	0.85	0.09	0.12	0.9
Hs (infragravity)	0.91	0.03	0.03	1.0
Hs (sea-swell)	0.87	0.07	0.08	0.9
Hs (sea-swell) g25	0.77	0.06	0.10	0.9
Hs (sea-swell) g30	0.84	0.06	0.04	1.0
Hs (sea-swell) g35	0.88	0.05	0.09	1.1
Hs (sea-swell) g45	0.96	0.04	0.03	1.3
Hs (sea-swell) g55	0.97	0.04	-0.04	1.1
Hs (sea-swell) g65	0.93	0.05	-0.06	1.1
** all p-values <<0.001*				

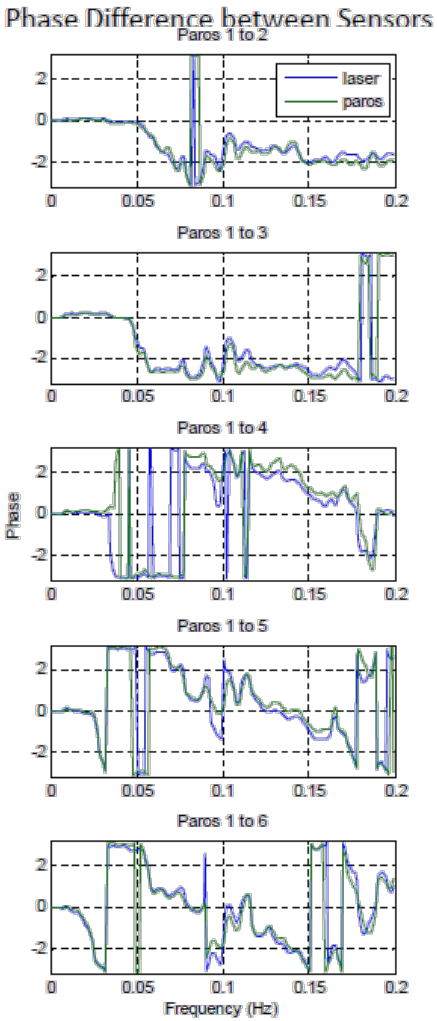


Brodie, K.L., B. Raubenheimer, S. Elgar, R.K. Slocum, and J.E. McNinch, in review. Lidar and pressure measurements of inner-surf zone waves and setup. JTECH.

Wave Height Comparison Statistics



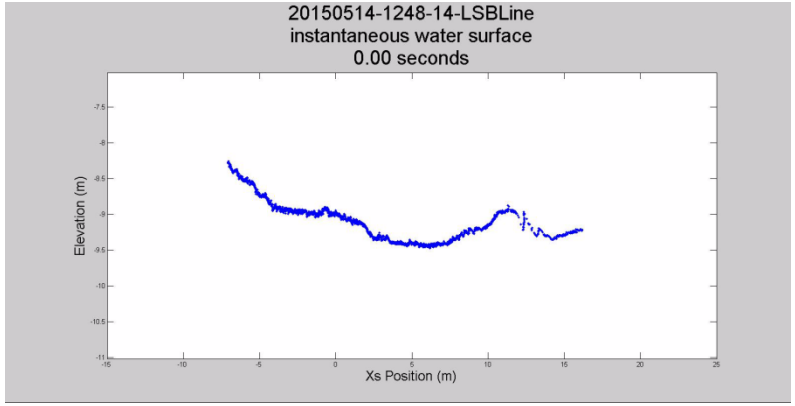


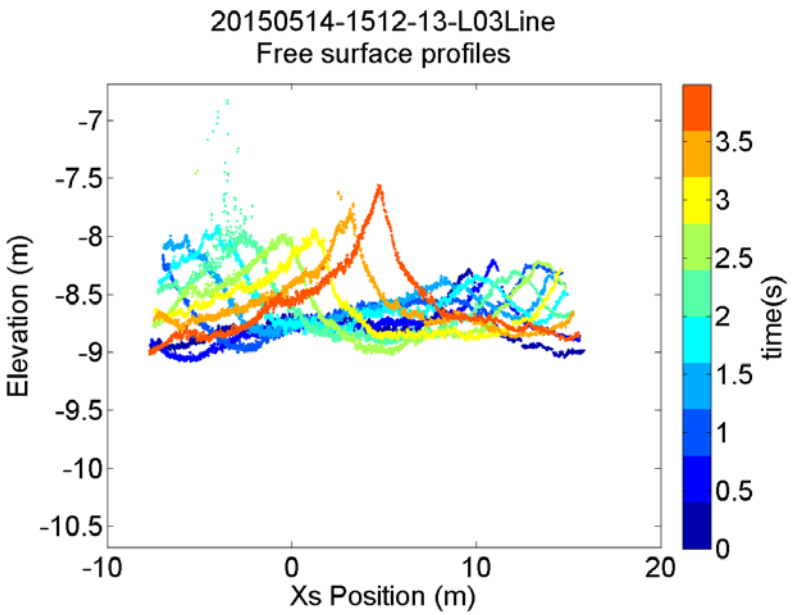


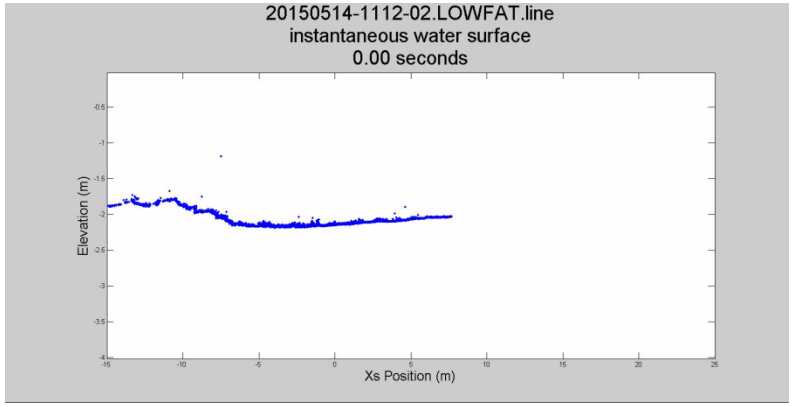
Quantifying wave shape

- Two Recent experiments
  - Riegl VZ-1000 & z210 from CRAB
    - Coupled with in-situ altimeters, advs, pressure sensors
      - Wave heights
      - Bubble depth penetration
      - Suspended sediment
    - How does wave breaking shape effect sediment transport at the bed and water column visibility
  - Full waveform Riegl VZ-1000, VZ-4000, VZ-6000 from CRAB & Tower
    - Performance of different scanners on water surface at low grazing angles and nadir looks

CRAB Lidar Experiments







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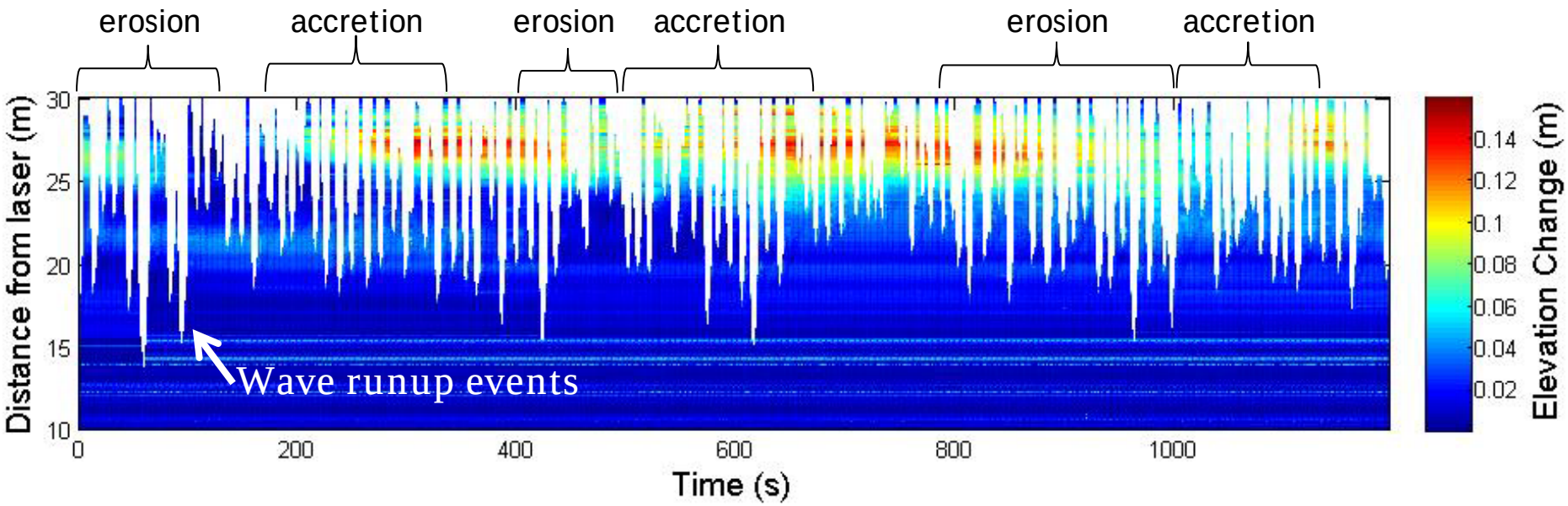
Wave-by-wave Morphology Change

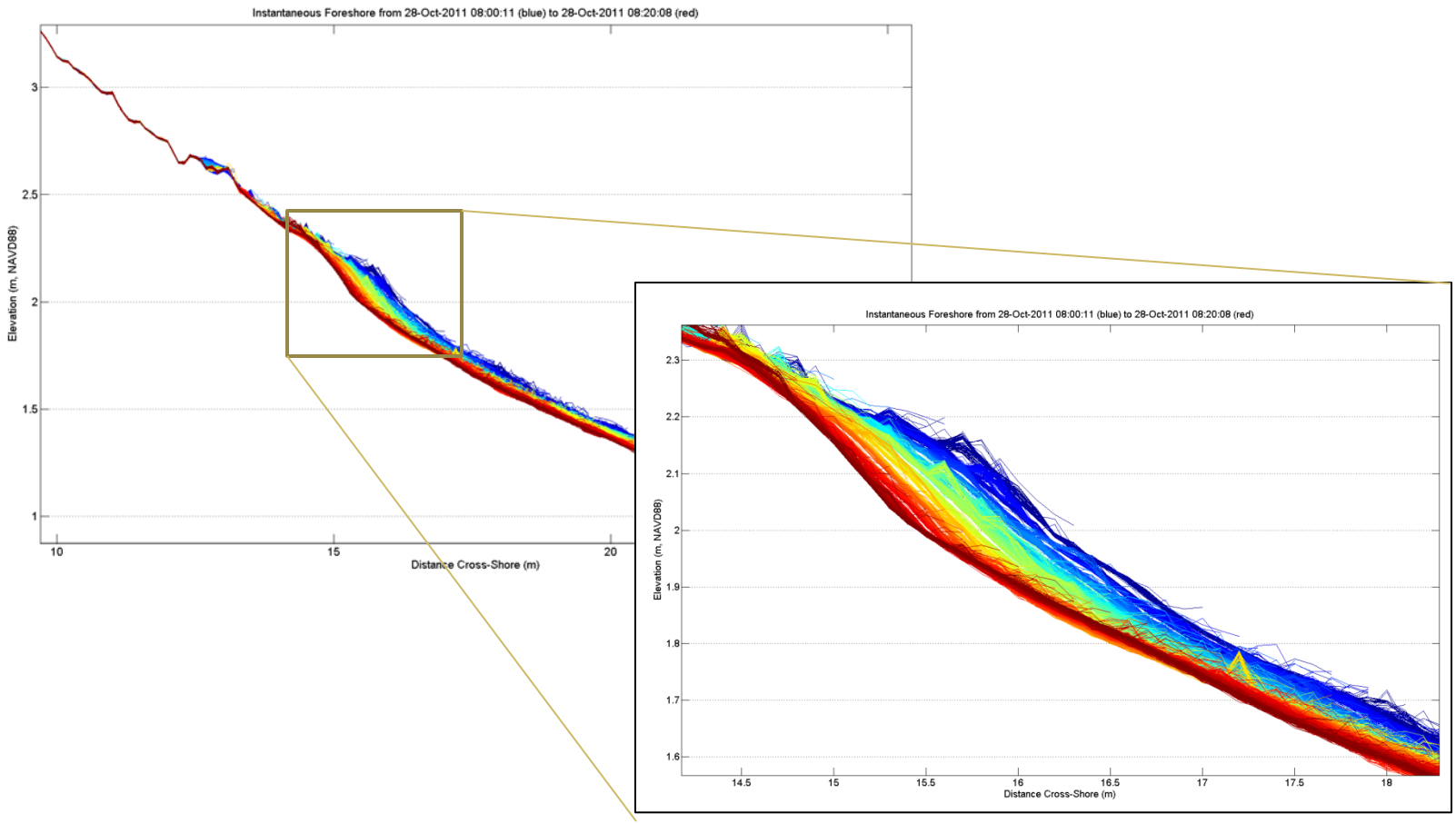
- Wave-by-wave foreshore evolution

Time-stack of elevation change relative to minimum foreshore over 20minutes

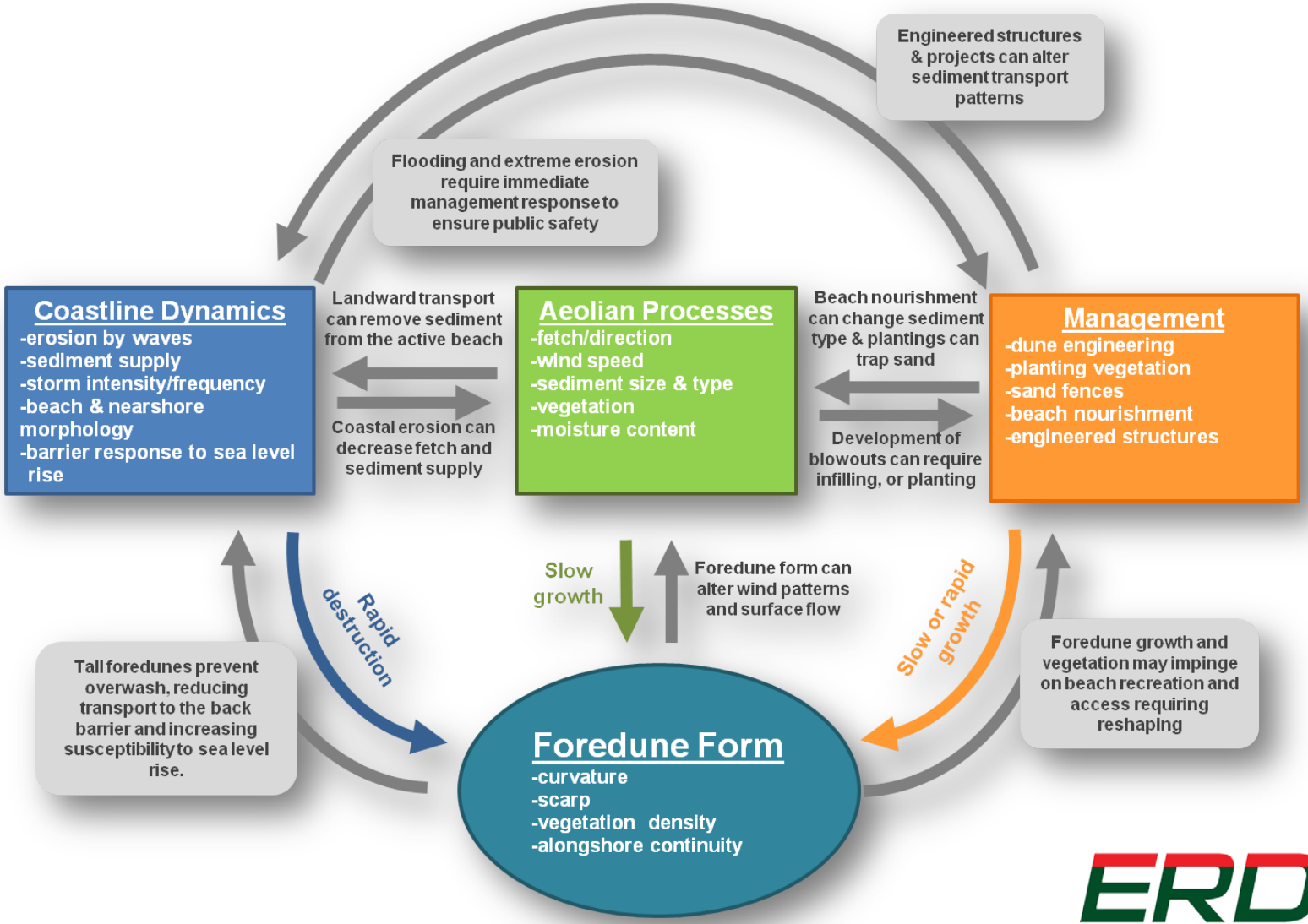


Data can now be collected at the same resolution as numerical models are run → improved skill assessment and physics understanding

Rapid Foreshore Evolution - Irene

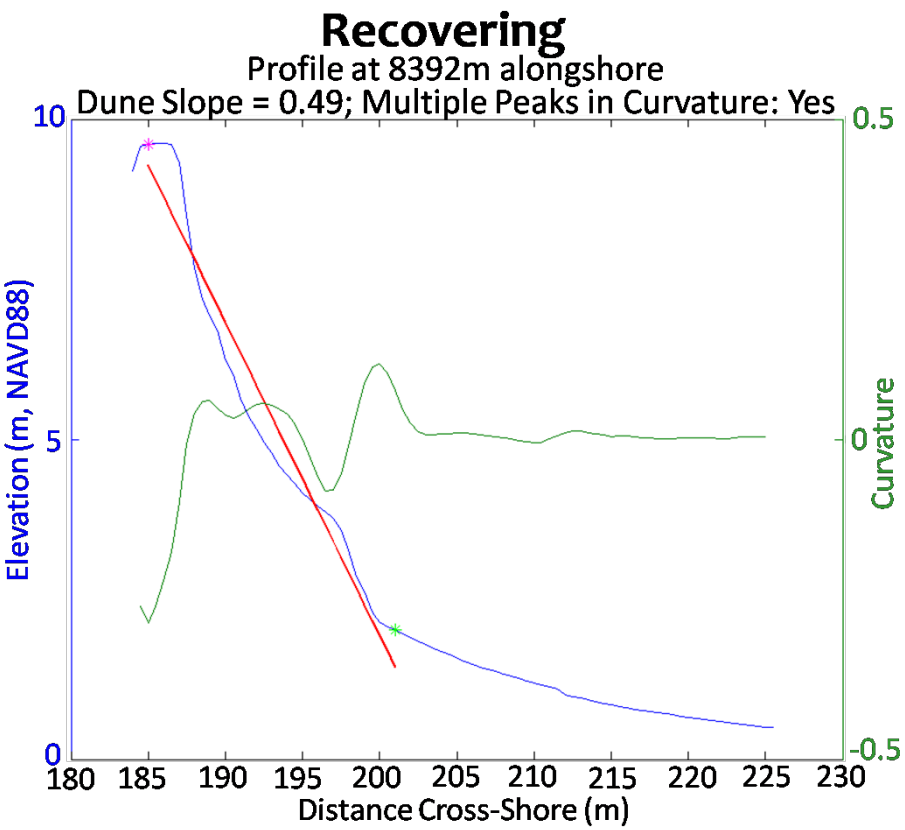


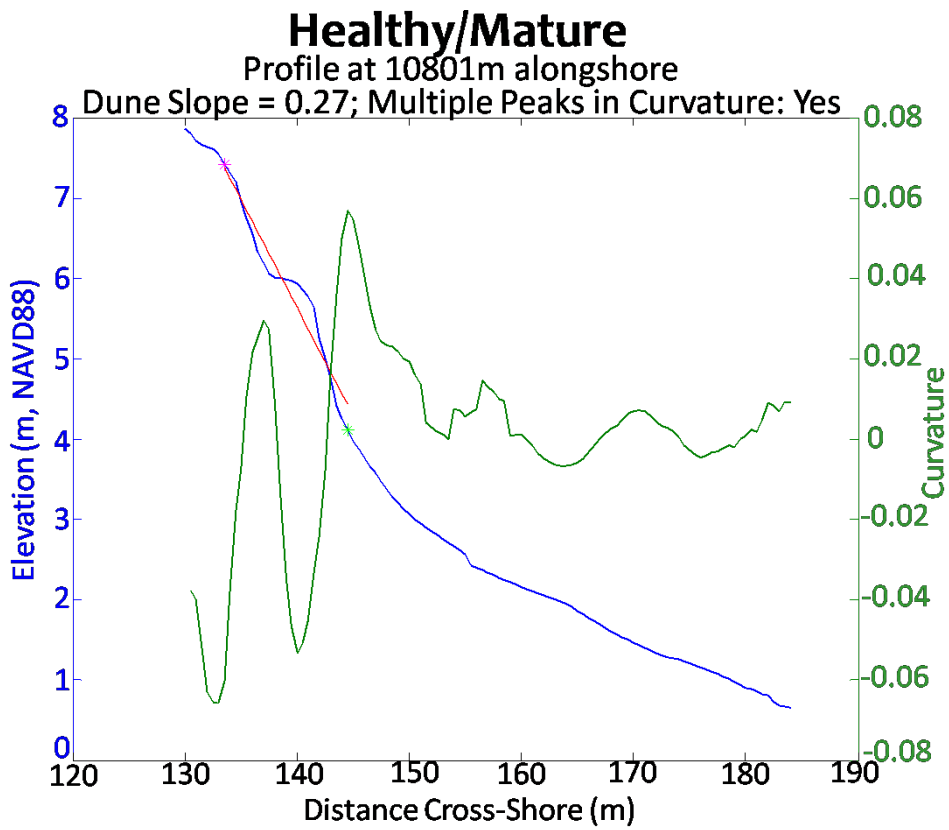
Coastal Foredune State



Coastal Foredune State

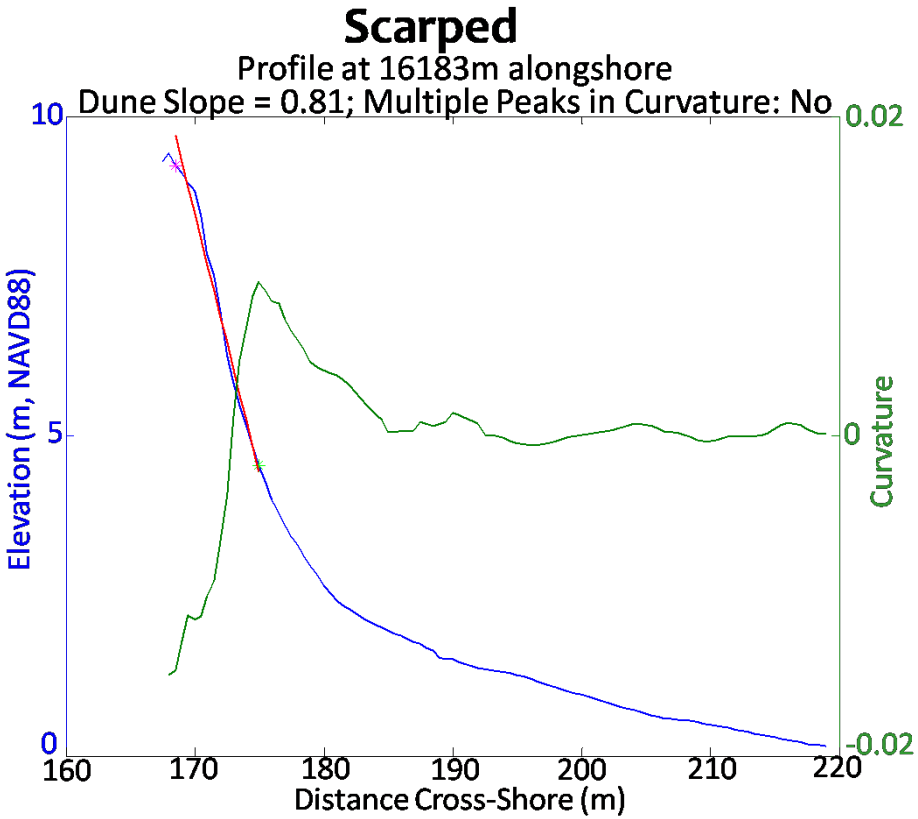
- Convex curvature indicative of active Aeolian processes (Thom and Hall, 1991)

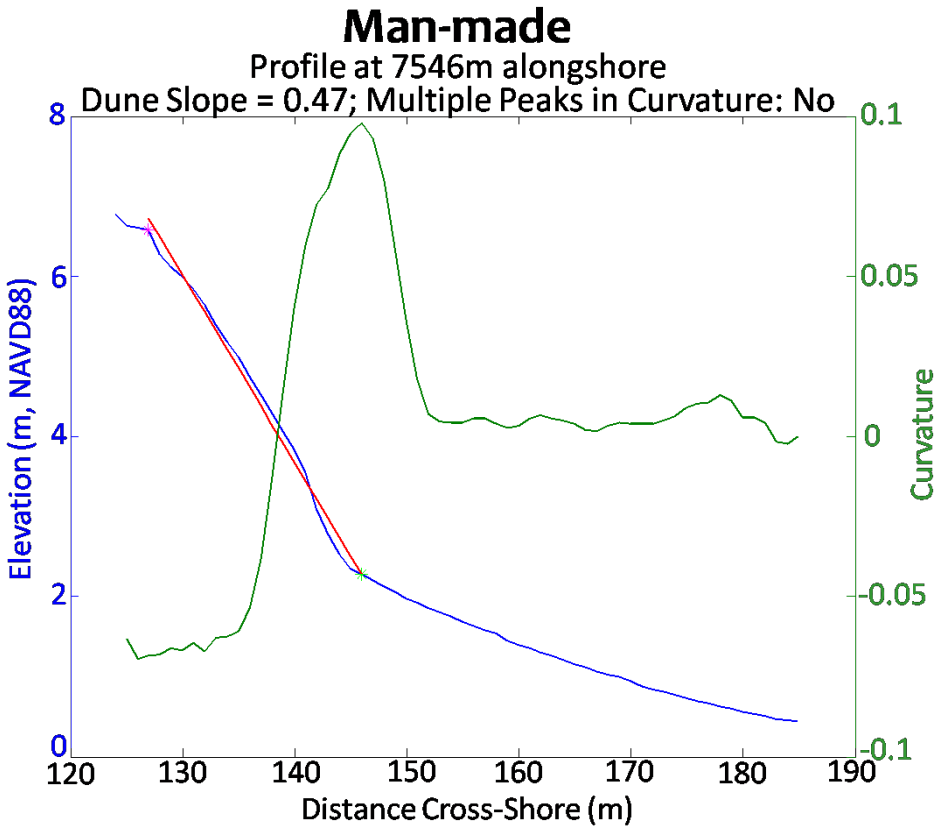




- Incipient dune forms near dune toe (Hesp 2002) while upper dune face remains steep indicating recent wave attack
- Prograding dune with high volume and shallower slopes closer to the angle of repose

Coastal Foredune State

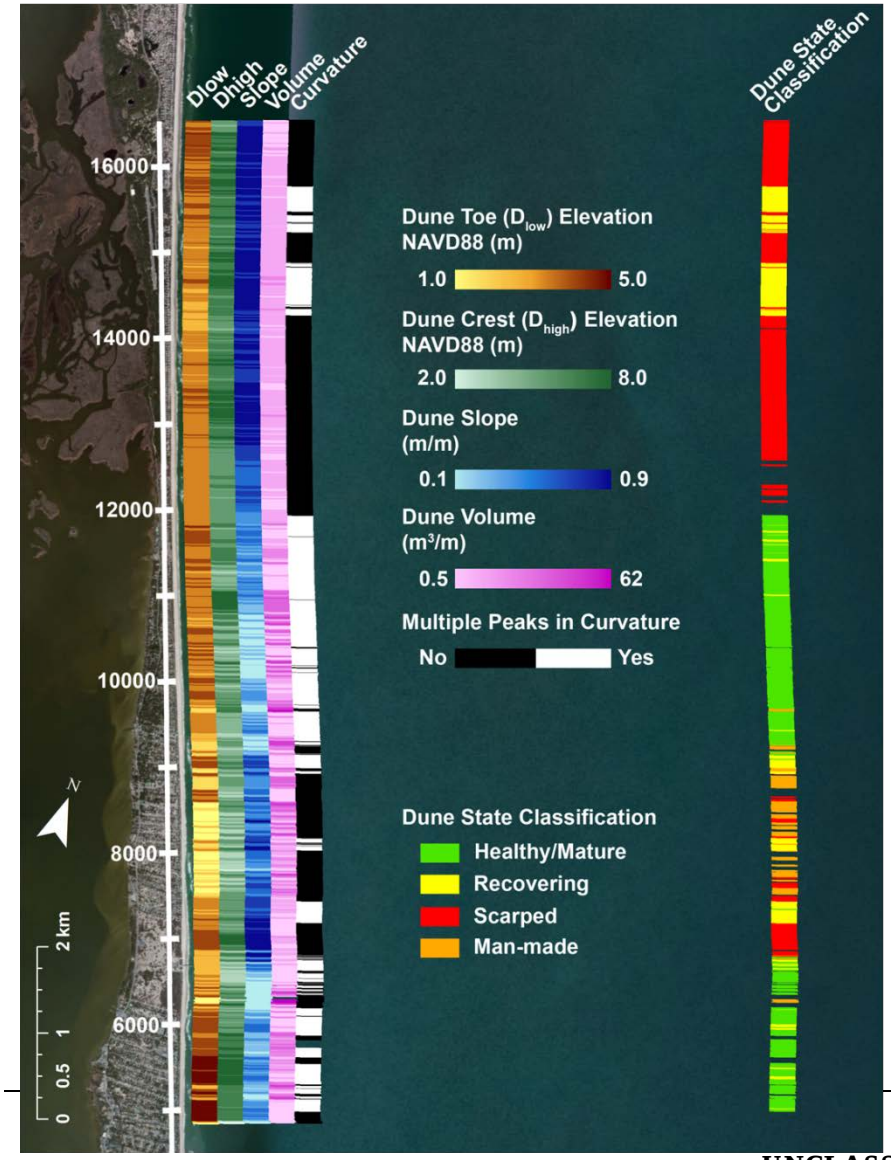




- Defined by steep slopes and low dune volume, indicative of recent scarping from wave attack
- No incipient dune present and often little to no recovery at the base of the dune

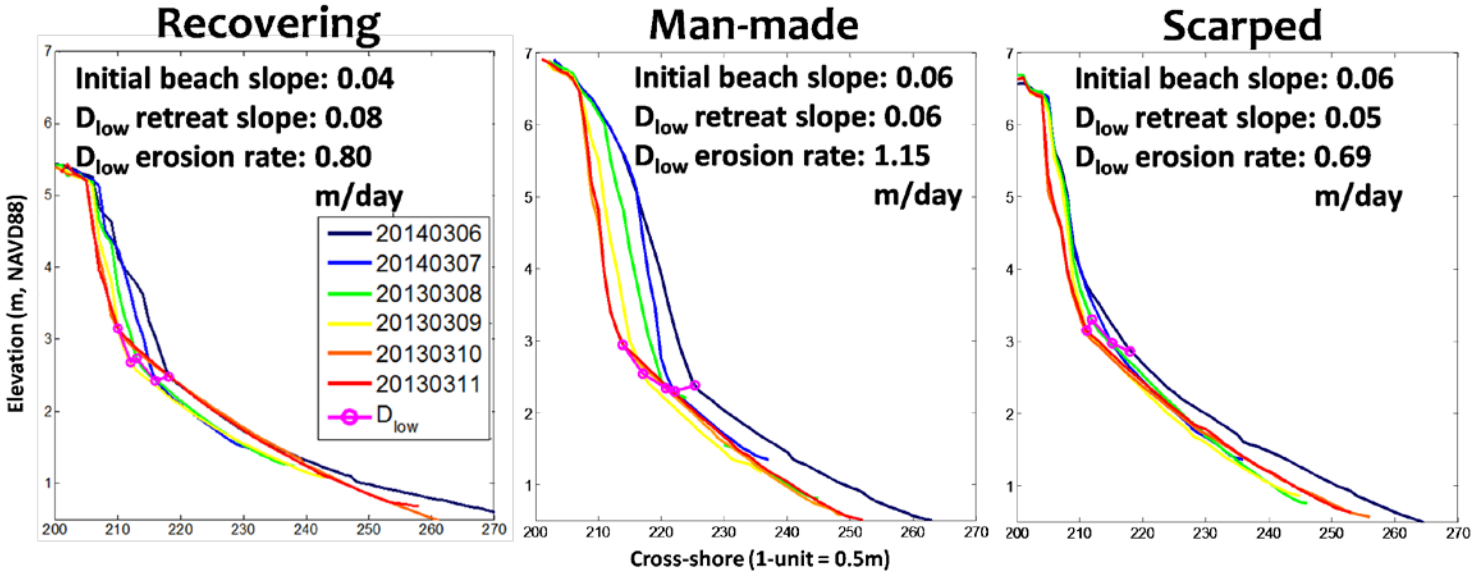
- Larger dune volume and shallower slope approaching angle of repose typically placed as an unconsolidated pile of sediment

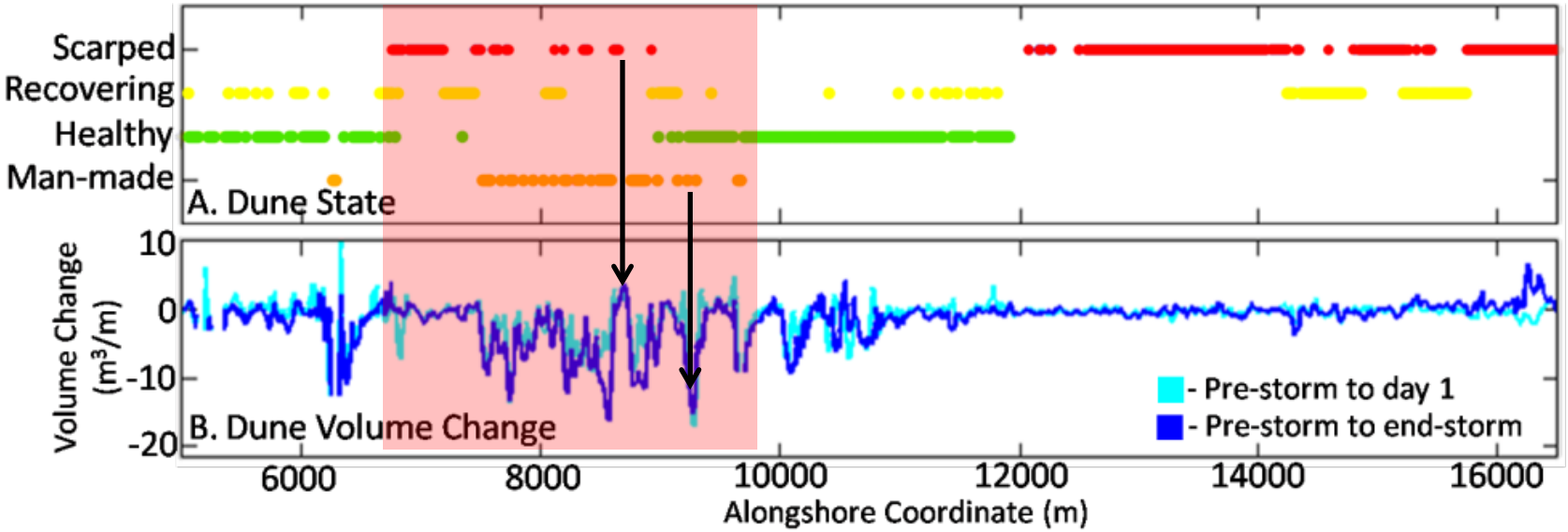
Coastal Foredune State



- Automated classification tool used to classify foredune state
- Dune state classifications can help coastal managers or engineers identify where natural recovery processes are occurring vs. where they need to be supplemented (plantings/sand fencing)
- Provides added information on physical processes occurring
- Can we adapt code to airborne data?
- Improve code using a Bayesian network for improved uncertainty

Linking Foredune State & Storm Response

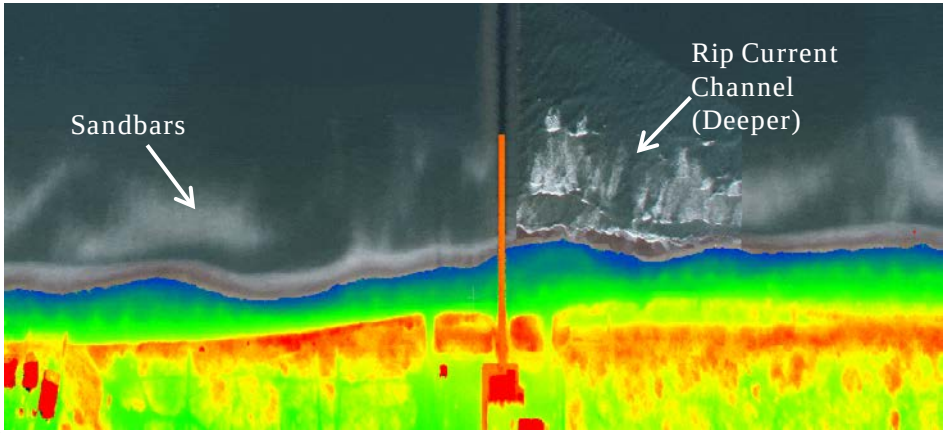




Coastal sUAS Mapper

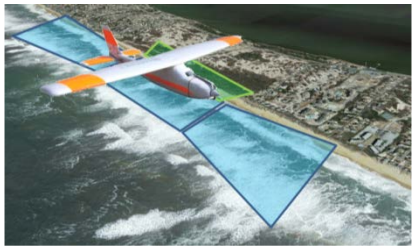
- Joint Military/Civil Requirement:
  - Ability to update coastal topography and bathymetry
    - In advance of approaching storms for improved storm assessment and inundation predictions
    - For improved battlespace awareness in clandestine surf operations

- Solution:
  - sUAS multi-rotor/fixed wing
  - wide field of view camera
  - topography from multi-view stereo photogrammetry
  - bathymetry from a wave kinematics inverison model (e.g. cBathy)



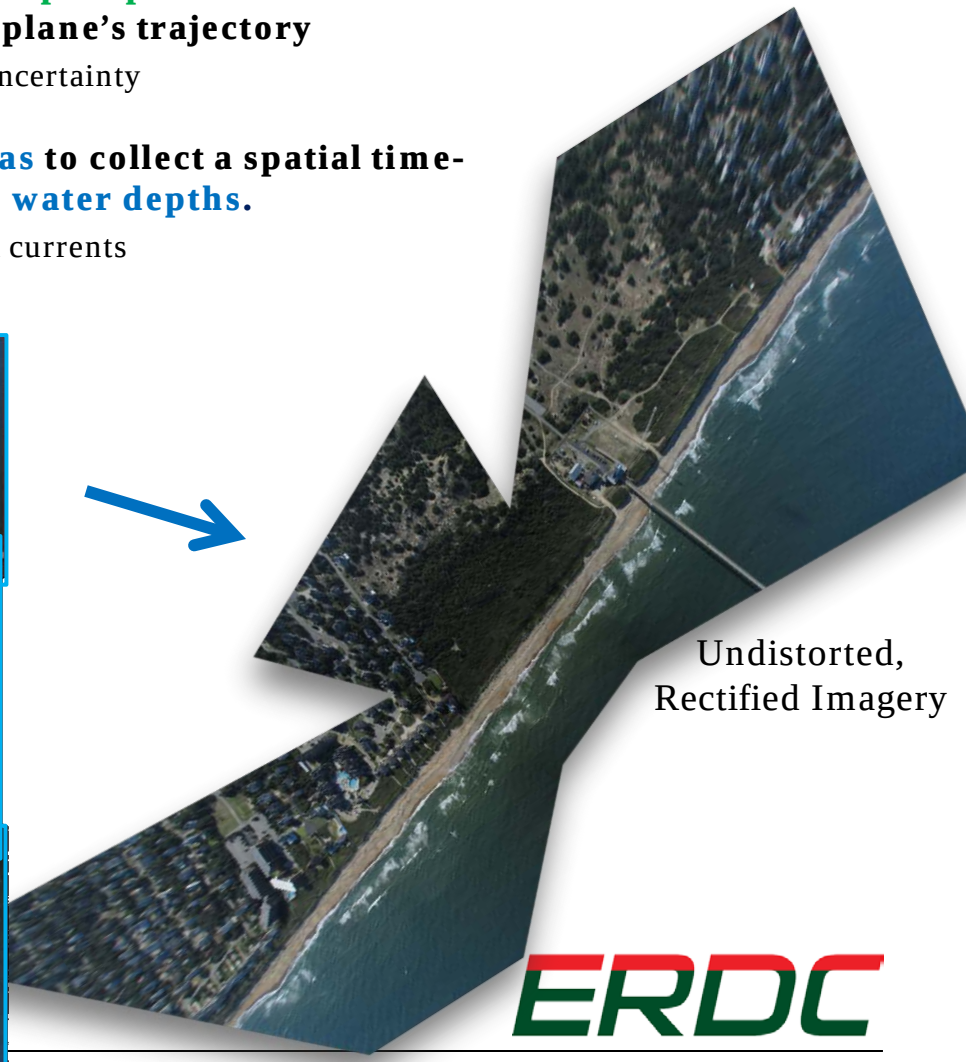
Coastal sUAS Mapper – Technical Approach

- **Landward looking camera generates 3D topographic point cloud of beach and surrounding infrastructure, as well as the plane's trajectory**
  - Developing robust error propagation for point cloud uncertainty
- **Trajectory used to rectify ocean looking cameras to collect a spatial time-series of moving, breaking waves for surf-zone water depths.**
  - Bathymetric inversion and optical flow for depths and currents



Conceptual diagram of sensor view

Raw Imagery



Undistorted, Rectified Imagery

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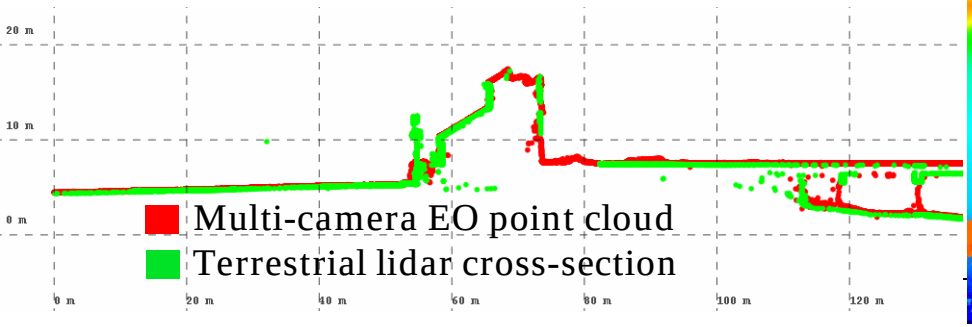
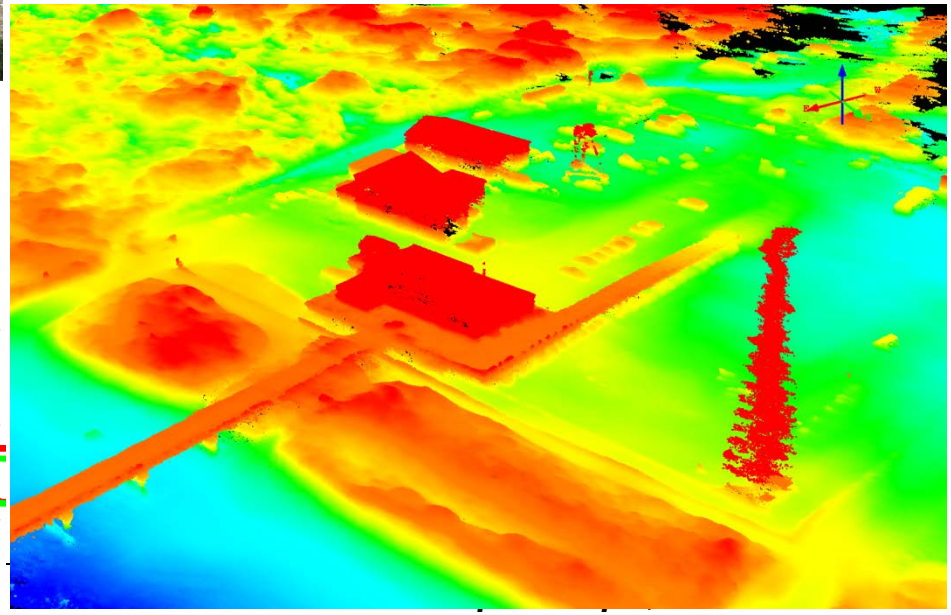
Coastal sUAS Mapper - Topography

- Multi-view Stereo Photogrammetry
- Collects elevation data with photo-realistic texture
- High resolution; FRF oceanside property = 150 million points
- 3D EO point cloud scence & DEM generation

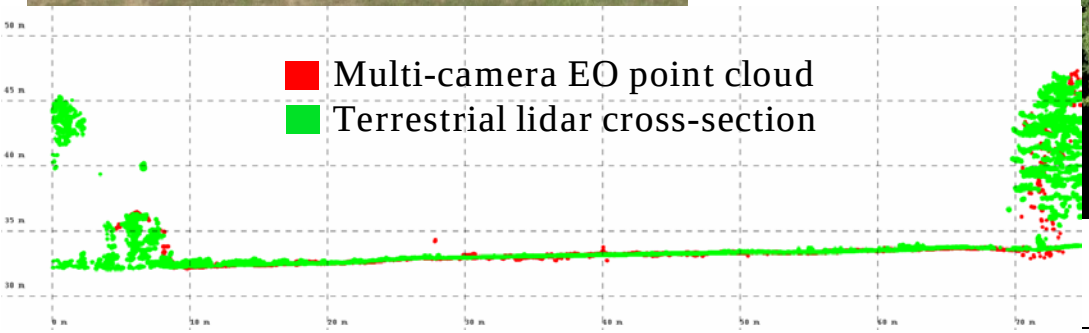
- 10-15 cm error compared to terrestrial lidar scanner





Coastal sUAS Mapper - Topography

- Collaborated with NGA at Corbin, VA remote sensing test site
- Target pad deployed for Rural Juror Exercise to assess point cloud absolute and relative accuracies from a wide array of sensors



SFM vs Terrestrial Lidar comparison

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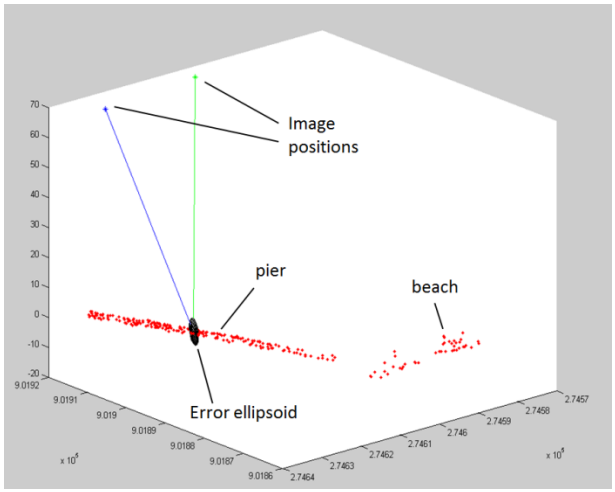
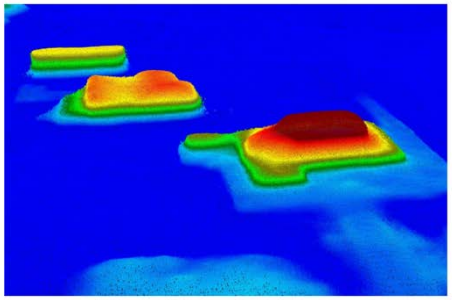
Software Comparisons & Error Propogation

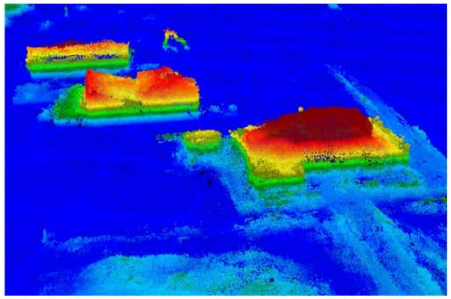
- EO derived point clouds provide an exciting and potentially low-cost data solution for the community.
- Compare existing software for point cloud generation from EO imagery.
- Assess the usability as well as qualitative and quantitative aspects of the output.
- Current EO software solutions provide little to no predicted accuracy on final point cloud.



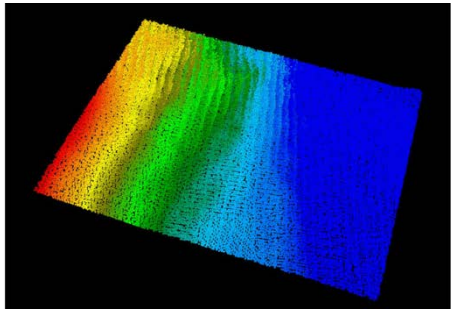
Initial Output of Error Ellipsoid for tie-points.

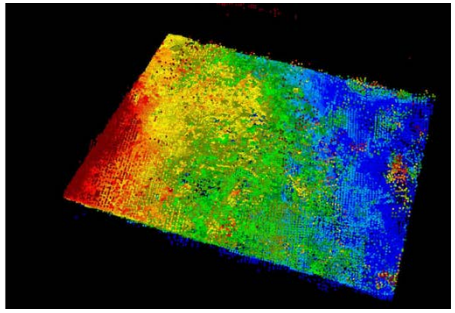


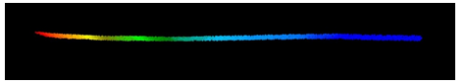
FRF - Photoscan Output



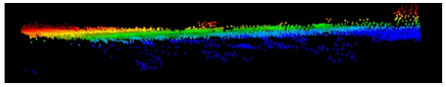
FRF - Pix4D Output





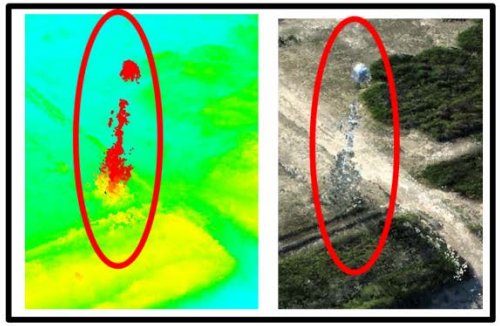


Beach - Photoscan Output



Beach - Pix4D Output

Tower - Photoscan Output



Tower - Pix4D Output

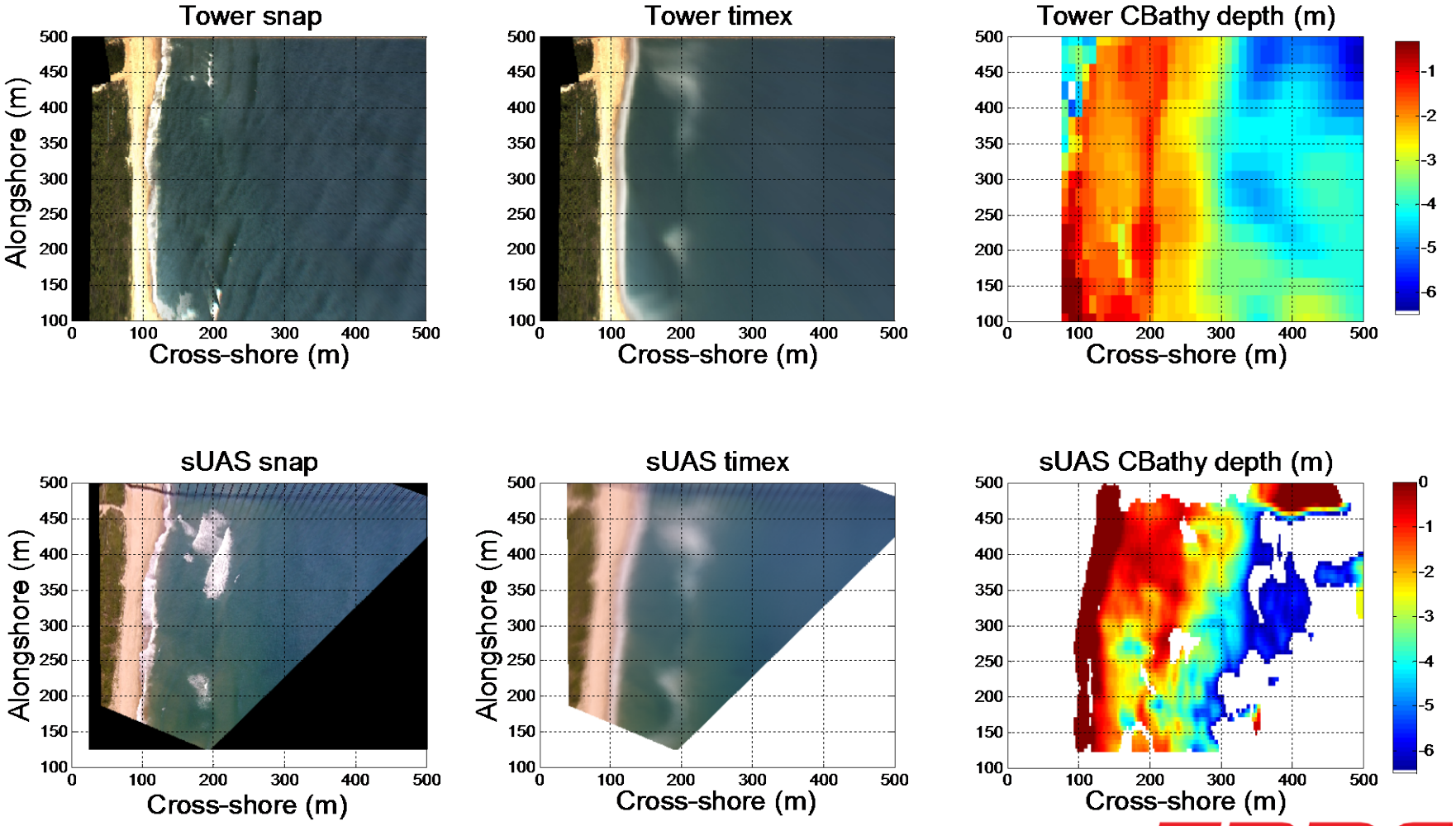
Coastal sUAS Mapper – Surf-Zone Mapping

- Example from FRF multi-camera prototype
- Wide field of view enables longer time-series of imagery with fewer gaps compared to existing cameras on sUAS platforms
- Note ability to cover wide stretch of coastline (10s of kilometers in one flight)

Coastal sUAS Mapper – Surf-Zone Mapping

- Example multi-rotor collect with 1 camera

Initial cBathy test from sUAS (MultiRotor)



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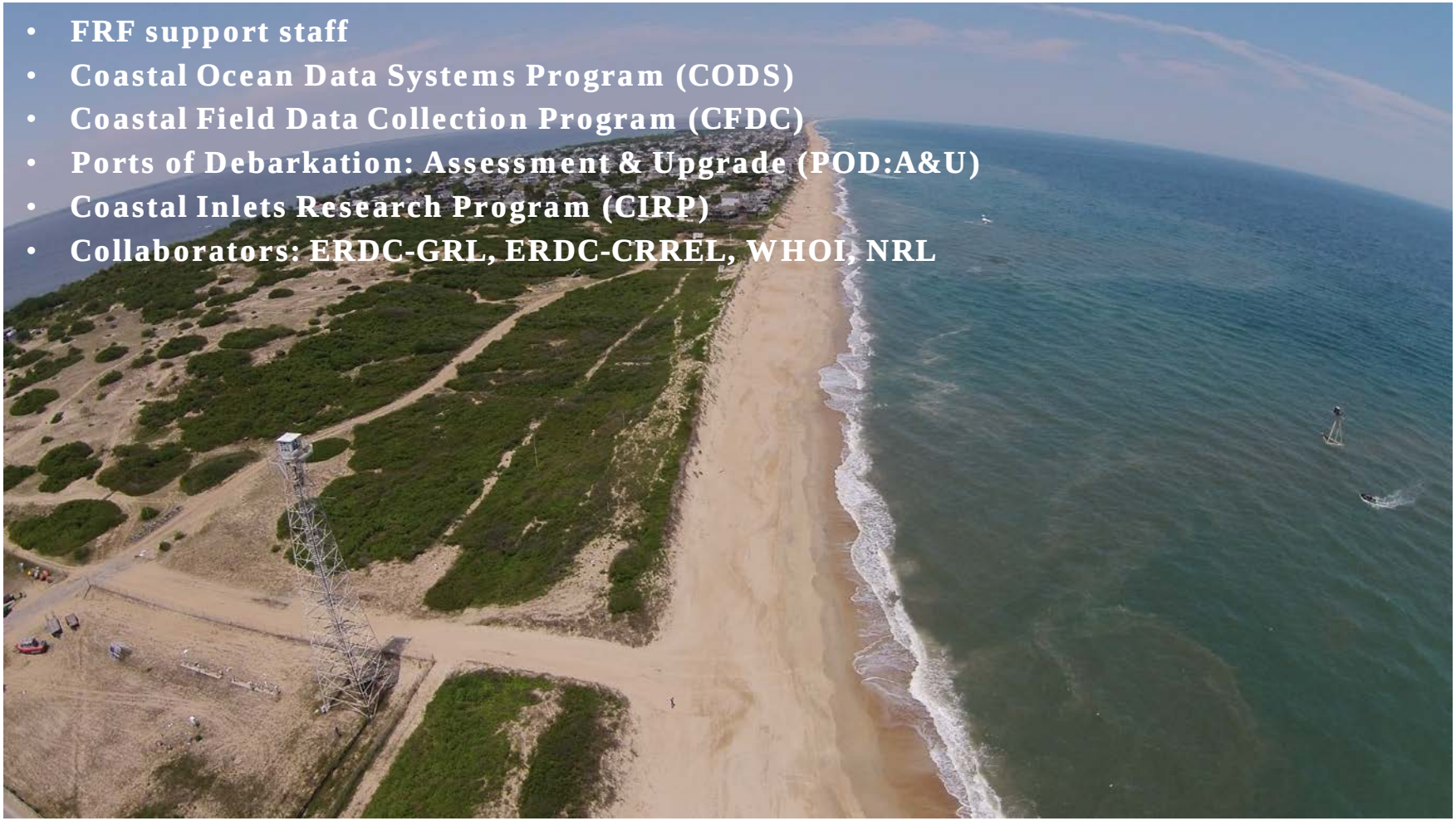
Acknowledgements



- FRF support staff
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- Coastal Field Data Collection Program (CFDC)
- Ports of Debarkation: Assessment & Upgrade (POD:A&U)
- Coastal Inlets Research Program (CIRP)
- Collaborators: ERDC-GRL, ERDC-CRREL, WHOI, NRL