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Enhanced coastal mapping using lidar waveform features

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Enhanced Coastal Mapping Using Lidar Waveform Features

Christopher Parrish, Jeffrey Rogers, Larry Ward, and Jennifer Dijkstra

15th Annual JALBTCX
Airborne Coastal Mapping & Charting Workshop
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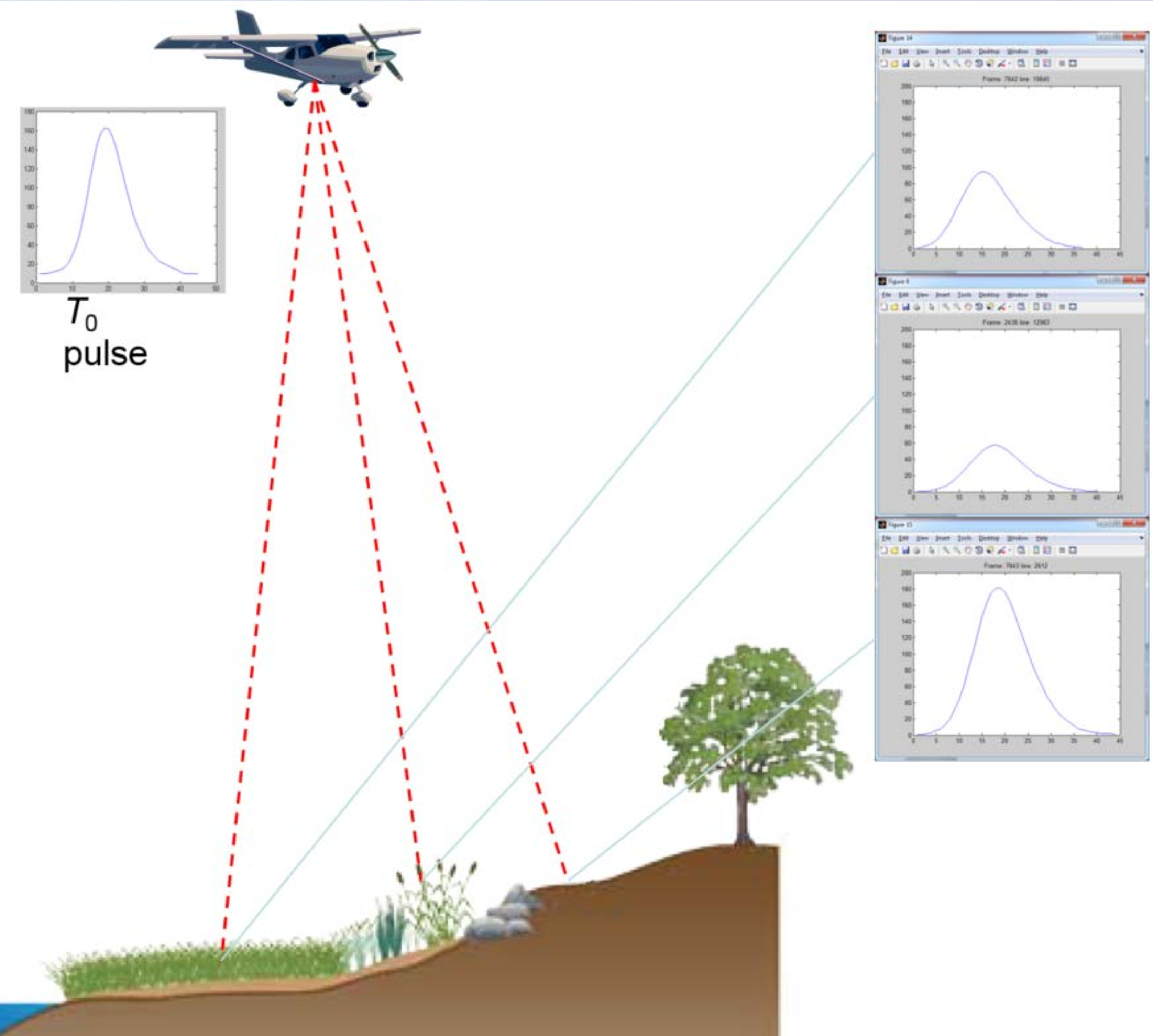
Recall from last year's JALBTCX presentation:

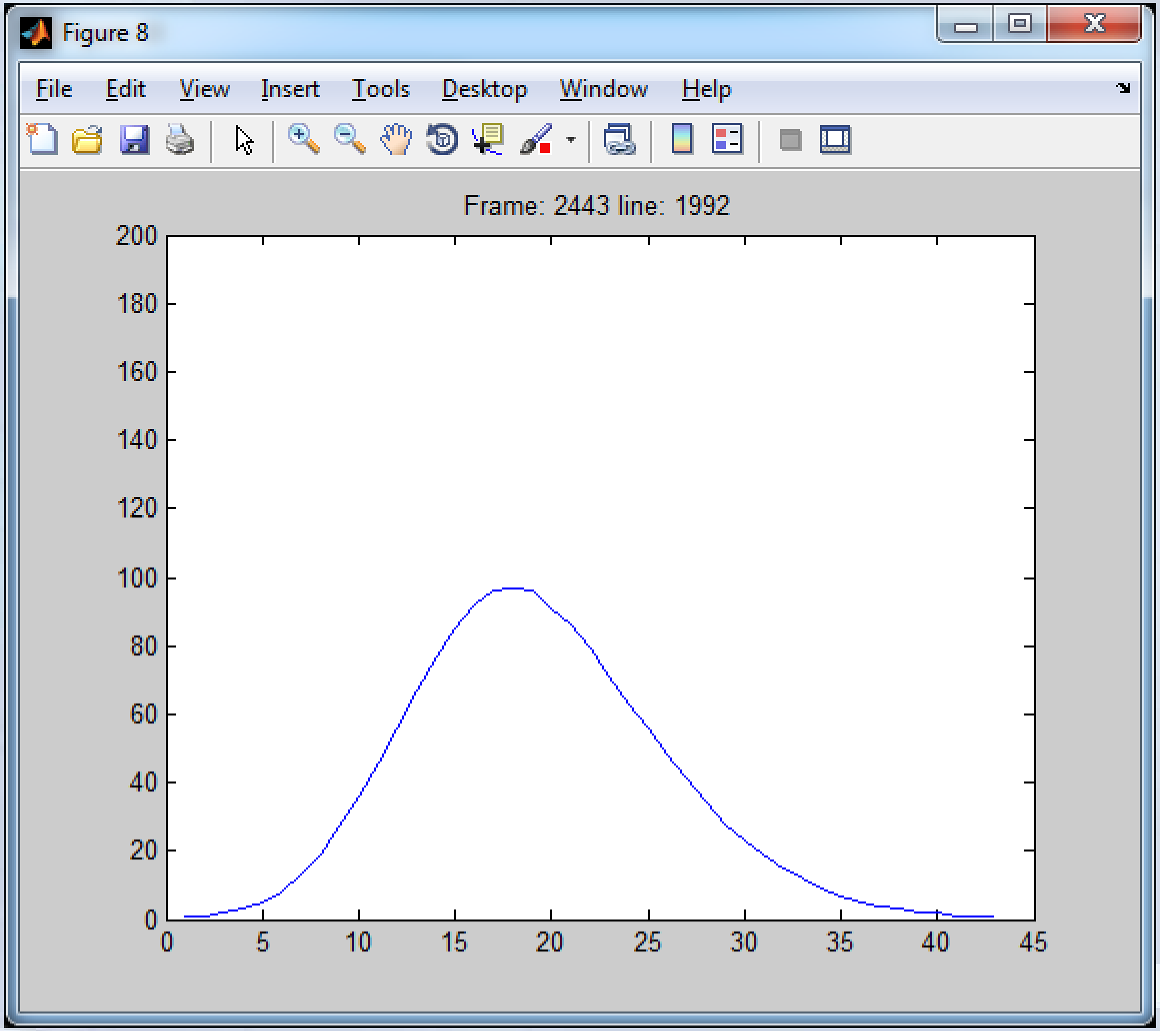
Simple, shape-based waveform features



Questions

- Are there simple, shape-based features that characterize the waveforms?
- Can they be computed in real-time?
- Can they be gridded an ingested into GIS?
- Are they useful?

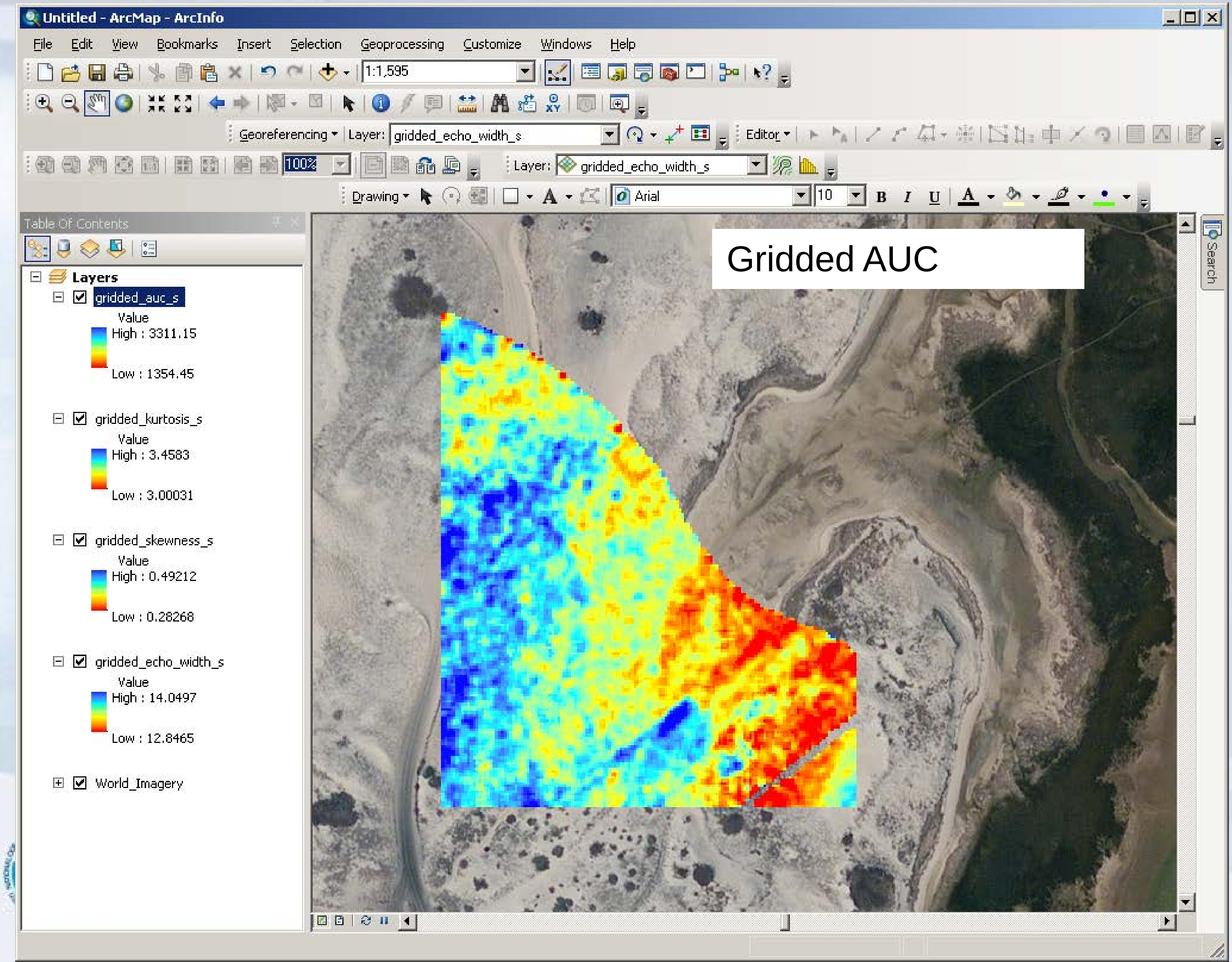
Animation of waveforms in transect across a marsh



Waveform Features & Computation Times

Symbol	Metric Name	Computation Time (μs)
w	Width	14.8
A	Amplitude	0.7
w/A	Pulse aspect ratio	17.6
AUC	Area under curve	0.8
AUC_r	Area under curve: R/L ratio	17.8
β_t	Slope trailing edge	37.9
β_r	Slope ratio	38.4
σ_w	Standard deviation	0.9
μ_w	Mean	0.7
n_{50}	Median	9.3
$\hat{n}$	Mode	0.6
γ_1	Skewness	8.2
β_2	Kurtosis	8.2
Γ_1	Pearson's 1st skewness coefficient	7.2
Γ_2	Pearson's 2nd skewness coefficient	12.3
R_G^2	Goodness-of-fit of Gaussian	850.3

Gridded waveform features in GIS



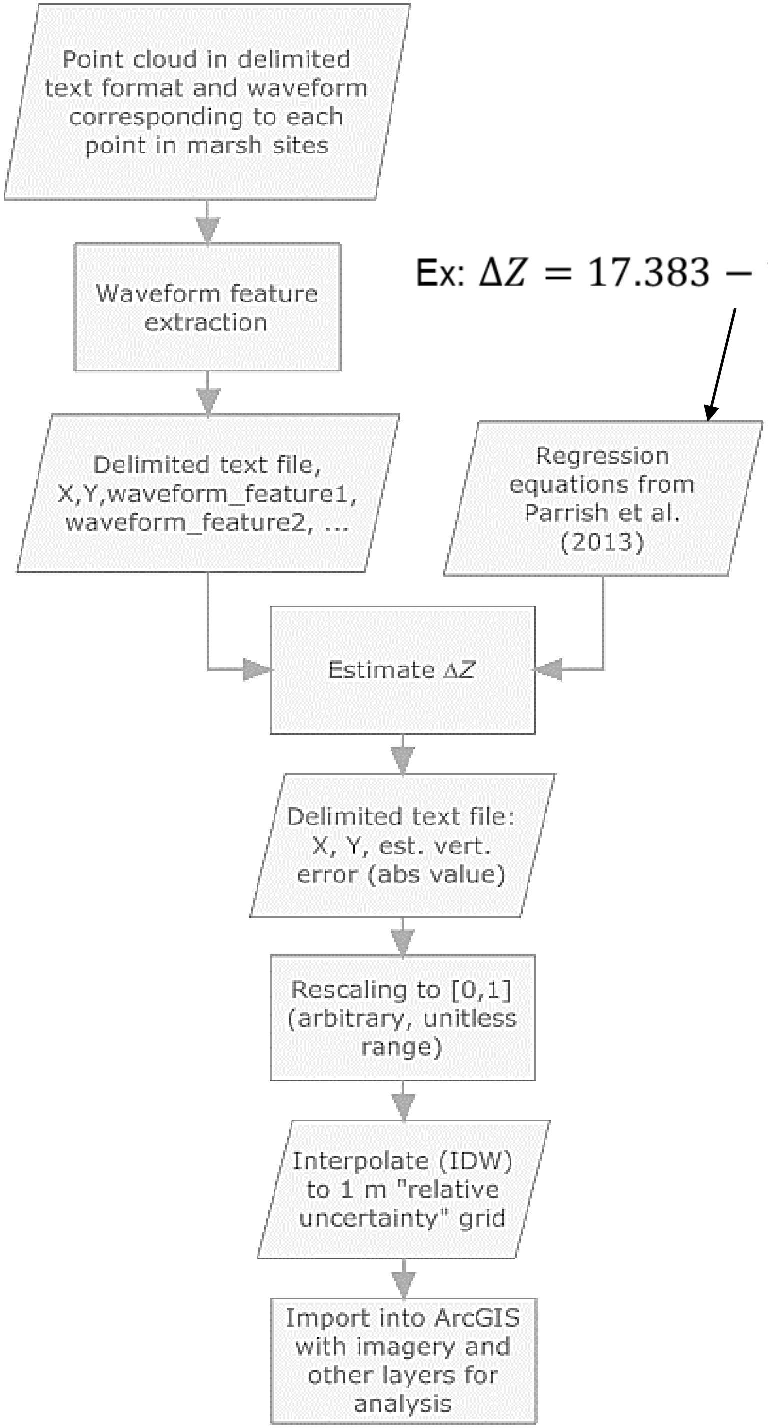
Results of regressions of ΔZ on waveform metrics (R^2)

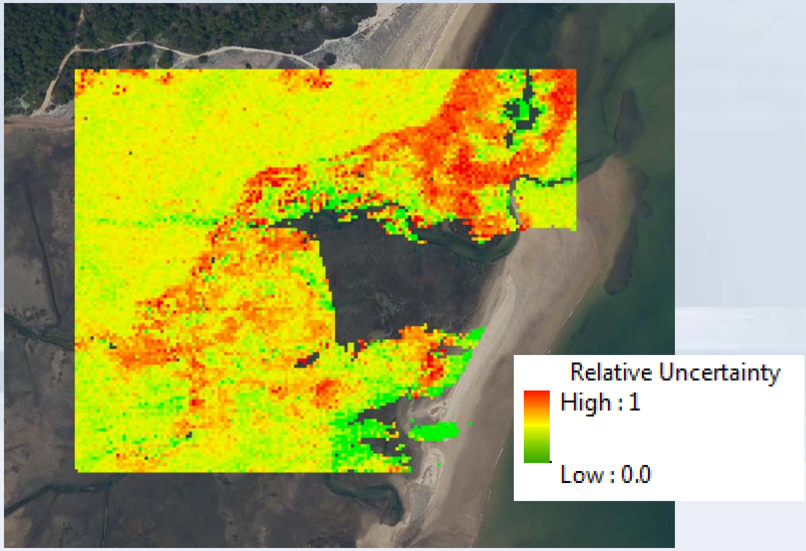
Metric	Little Pamet	Great Island	Moors	Mean
Width	0.55	0.72	0.53	0.60
Standard deviation	0.55	0.73	0.42	0.57
Mean	0.27	0.27	0.04	0.19
Median	0.27	0.28	0.04	0.20
Mode	0.24	0.29	0.02	0.18
Goodness-of-fit of Gaussian	0.15	0.54	0.01	0.23

Regression	Little Pamet	Great Island	Moors	Mean
ΔZ on width and median	0.55	0.75	0.54	0.61
ΔZ on width and mean	0.55	0.75	0.53	0.61
ΔZ on width and mode	0.55	0.74	0.54	0.61
ΔZ on width and goodness-of-fit of Gaussian	0.56	0.80	0.56	0.64
ΔZ on PC1 and PC2	0.55	0.73	0.53	0.60

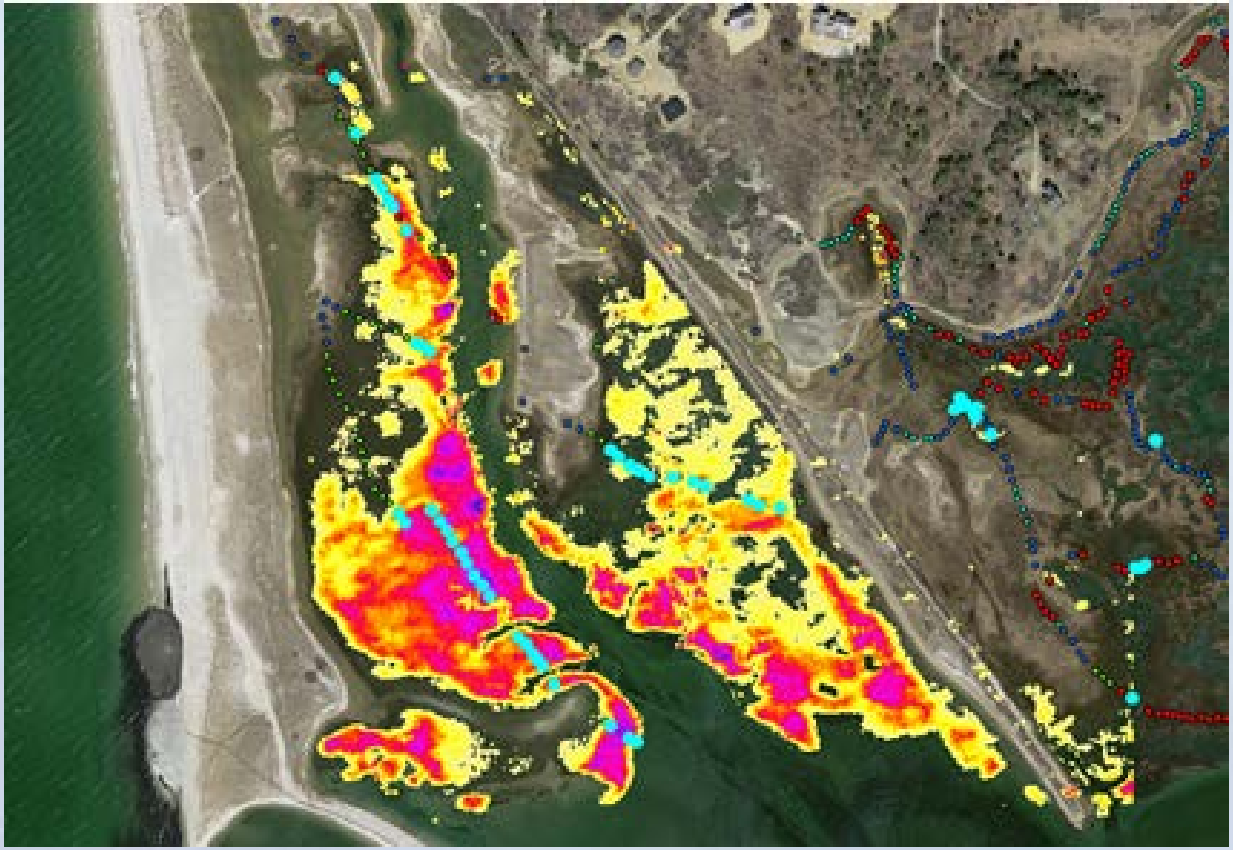
Generating Relative Uncertainty Surfaces from Waveform Features

Ex: $\Delta Z = 17.383 - 1.254w - 0.718\mu_w + 0.051w\mu_w$





Pamet marsh
Relative uncertainty surface



Circles = field sample sites
Blue = TF *Spartina alterniflora*

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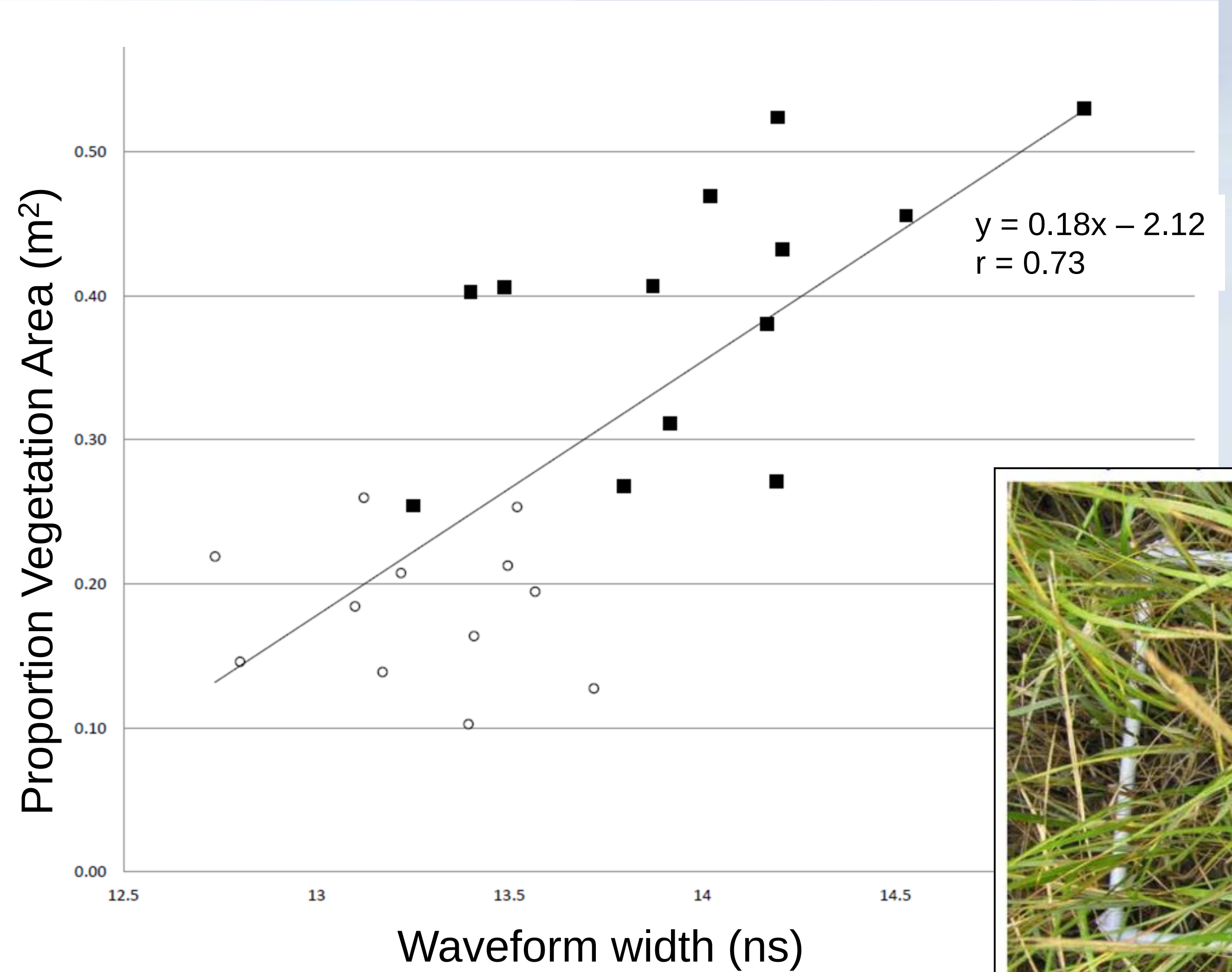
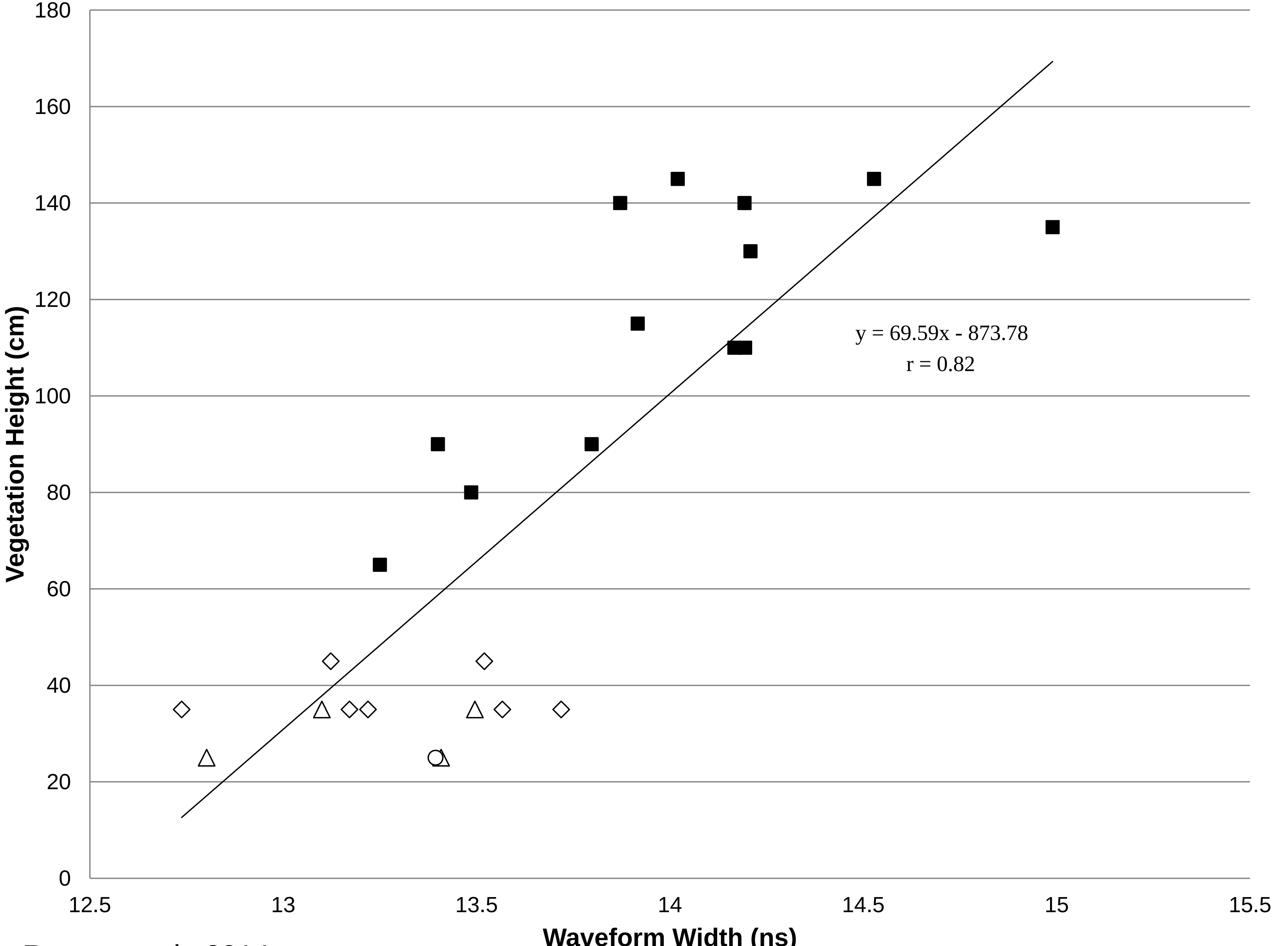
Rogers et al., 2014

Use case #2 of lidar waveform features:
Predicting salt marsh vegetation biophysical parameters

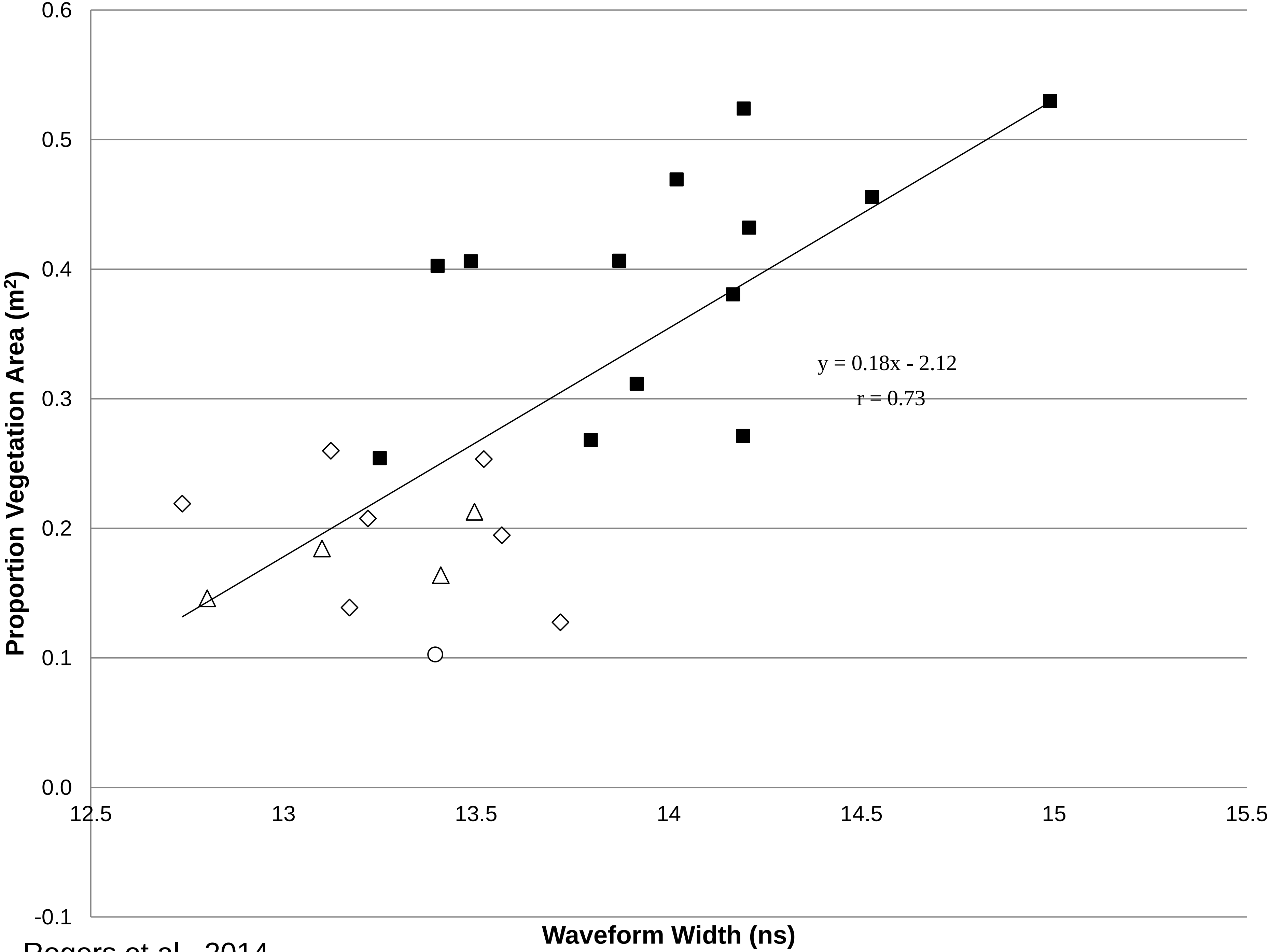
■ = *S. alterniflora* samples
○ = all other species



Rogers et al., 2014



Rogers et al., 2014



Rogers et al., 2014

Predicting salt marsh vegetation biophysical parameters

Results of correlations (*r*) of biophysical parameters on waveform metrics for all vegetation species and the subset of S. alterniflora. Gray shaded cells have a *p* value <0.05 (df =24).

	Width		Sample Skewness		Amplitude		Waveform Standard deviation		Pearson's 1st Skewness	
Parameters	**All**	***S. alterniflora***	**All**	***S. alterniflora***	**All**	***S. alterniflora***	**All**	***S. alterniflora***	**All**	***S. alterniflora***
Photographic Vegetation Height	**0.82**	**0.75**	**0.54**	0.17	**0.57**	0.17	**0.73**	**0.78**	0.36	0.37
Planimetric Obscuration	**0.47**	0.14	**0.56**	0.33	**0.71**	**0.62**	0.10	0.30	0.10	0.20
Quadrat Stem Density	**0.58**	**0.66**	**0.63**	0.35	**0.73**	0.00	0.35	**0.48**	**0.39**	0.00
Quadrat Biomass Density	**0.41**	0.20	0.30	0.22	**0.53**	0.14	0.17	0.22	0.00	0.14
Proportion Vegetation Area (25cm	**0.73**	**0.57**	**0.45**	0.00	**0.39**	**0.61**	**0.62**	**0.46**	0.37	0.24
Proportion Vegetation Area (10cm	**0.49**	0.14	0.28	0.14	0.26	0.28	0.33	0.00	0.22	0.00

National Oceanic and Atmospheric Administration

Rogers et al., 2014

Predicting salt marsh vegetation biophysical parameters

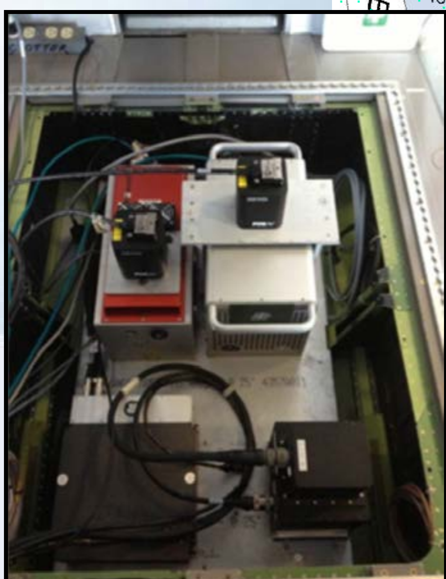
Results of multiple linear regressions (R^2) of biophysical parameter with waveform metrics. Bold with underline represent improved results.

	Waveform Width and Sample Skewness	Waveform Width and Amplitude	Waveform Width and Waveform STDV	Sample Skewness and Amplitude	Sample Skewness and Waveform STDV	Amplitude and Waveform STDV
Vegetation Height	0.68	**<u>0.72</u>**	0.68	0.38	0.57	**<u>0.74</u>**
Planimetric Obscuration	0.32	0.53	0.49	0.53	0.36	0.51
Quadrat Stem Density	0.47	**<u>0.6</u>**	0.38	0.58	0.42	**<u>0.6</u>**
Quadrat Biomass Density	0.18	0.32	0.27	0.32	0.05	0.29
PVA (25 cm)	0.54	0.54	0.54	0.23	0.42	0.47

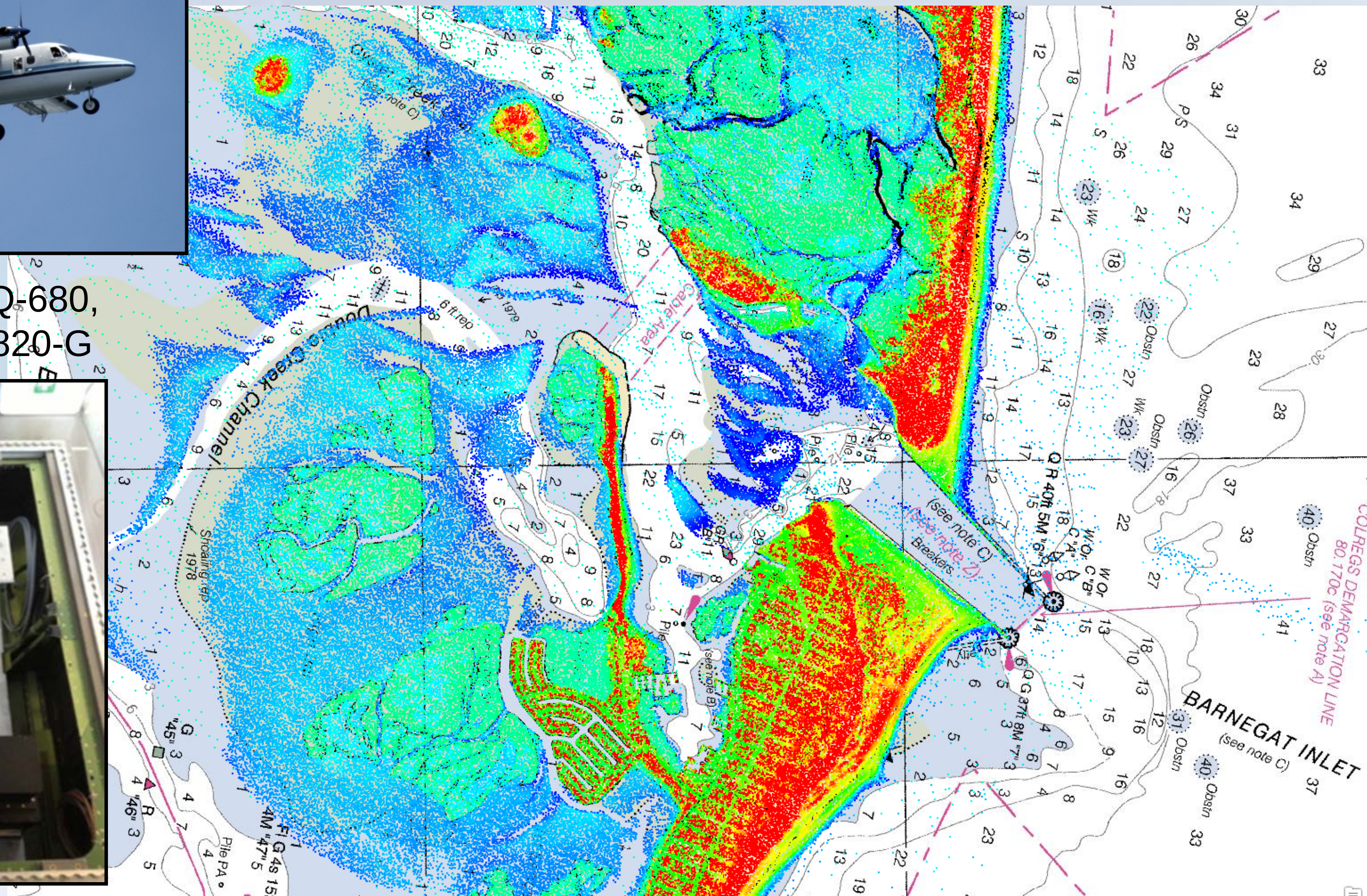
Can we extend this to topo-bathy lidar and benthic habitat mapping?

DeHavilland Twin Otter (DHC-6)

Left: Riegl LMS Q-680,
Right: Riegl VQ-820-G



Sept 2013 NOAA/NGS data of Barnegat Inlet



Riegl waveform features

- Waveform features included as standard output from “V-line” systems and provided via LAS ExtraBytes

1. “Reflectance”
   - Ratio of signal amplitude to amplitude of signal from a white reference target at same range, given in dB

$$A_{dB} = 10 \cdot \log_{10}\left(\frac{P_{echo}}{P_{DL}}\right)$$

$$\rho = A_{dB} - A_{dB,ref}(R)$$

2. Pulse Shape Deviation
   - Measure of the discrepancy between the digitized waveform *y*[*n*] and a stored, system-specific reference pulse, *p*[*n*]

$$\delta = \sum_{n=0}^{N-1} |y[n] - p[n]|$$

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Pfennigbauer, M. and A. Ullrich, 2010. Improving quality of laser scanning data acquisition through calibrated amplitude and pulse deviation measurement. *Proc. SPIE Defense, Security, and Sensing*, pp. 76841F-76841F.

Pre-Processing Steps

- No rigorous radiometric calibration (e.g., inversion of radiative transfer model) to solve for true bottom reflectance
- Instead, we apply some simple radiometric balancing to remove salient artifacts in mosaics of ρ_{rel} (or other gridded waveform features)
- Procedure
  - For each flightline and each waveform feature, compute the mean, μ_i, and standard deviation, σ_i
  - Pick one flightline that has good contrast and average “brightness” to be the reference
  - Normalize histograms of other flightlines, as follows

$$r' = \frac{\sigma_{ref}}{\sigma_i}\left(r - \mu_i\right) + \mu_{ref}$$

Example:
Preprocessed “reflectance” layer

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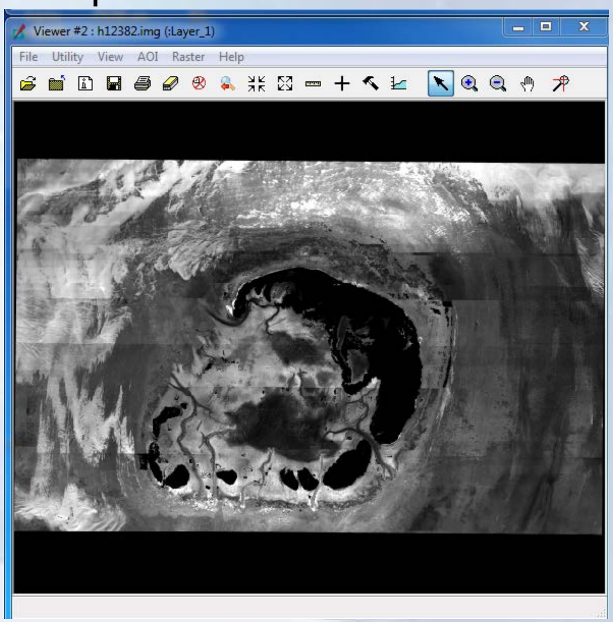
Something else you can do…

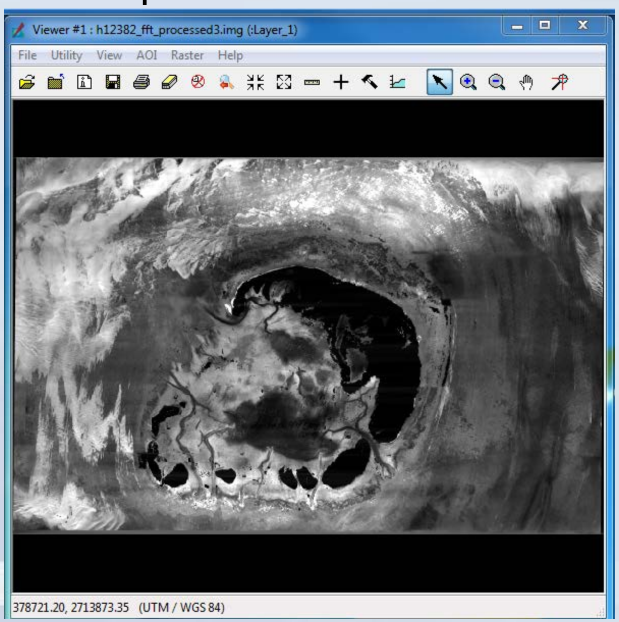
- Remove any remaining artifacts (e.g., seamlines between swaths) from waveform feature mosaics in the frequency domain using ERDAS Imagine

Input



- $f(x,y) \xrightarrow{\mathcal{F}} F(u,v)$
- Notch filter to remove frequency components corresponding to seamlines
- $F_c(u,v) \xrightarrow{\mathcal{F}^{-1}} f_c(x,y)$

Output



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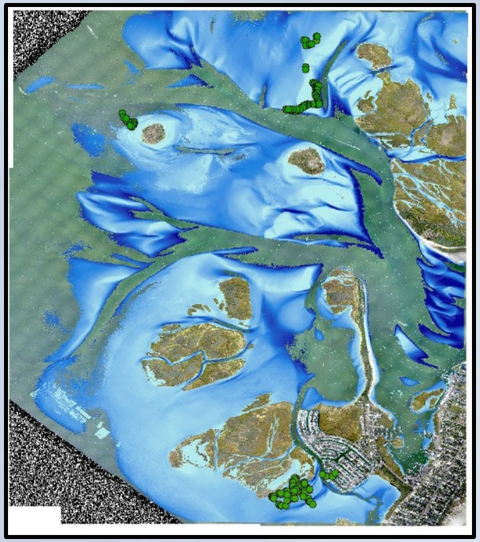
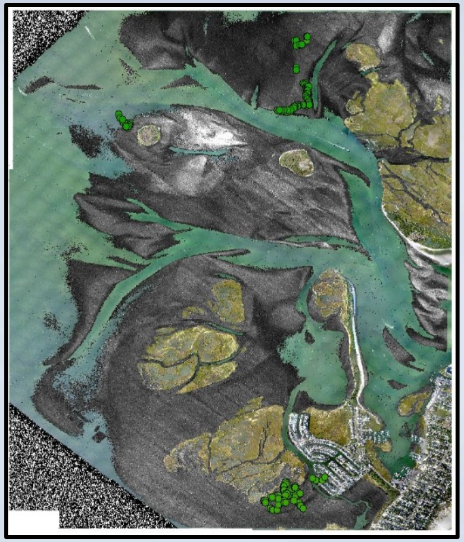
Data Layers

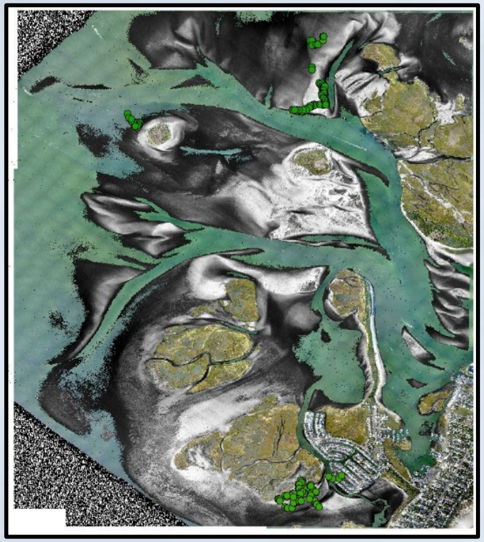
Aerial RGB Image



Bathymetry



Pulse Shape Deviation



Reflectance

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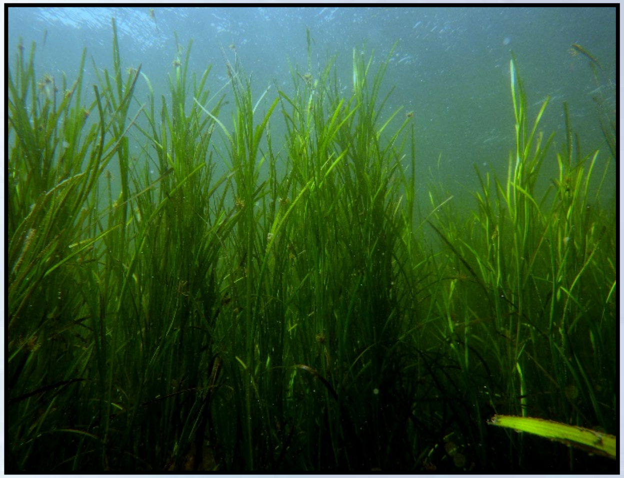
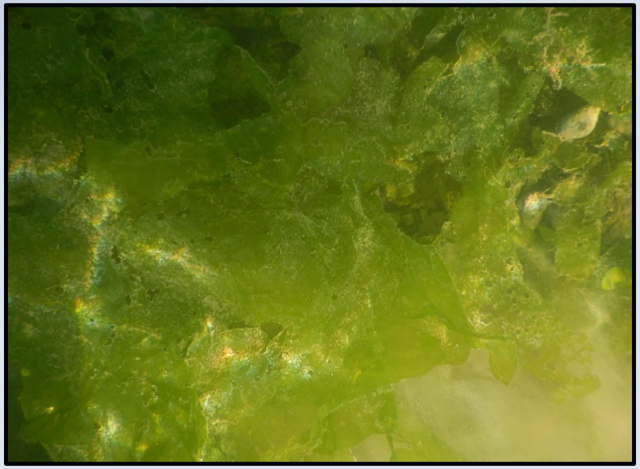
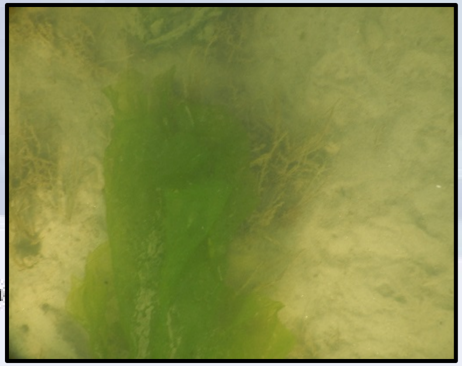
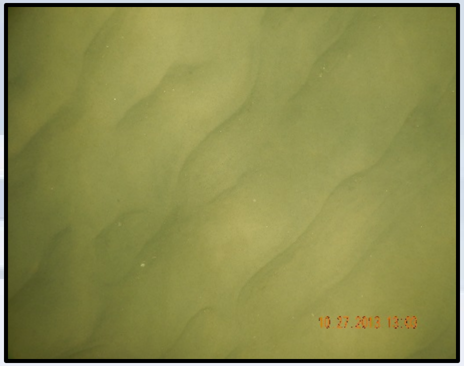
Benthic Habitats









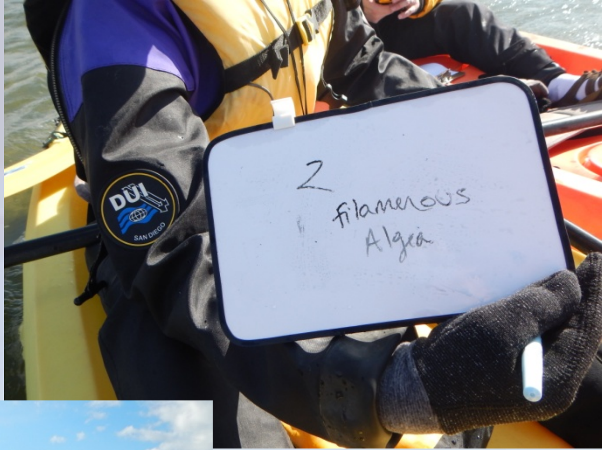
Seagrass

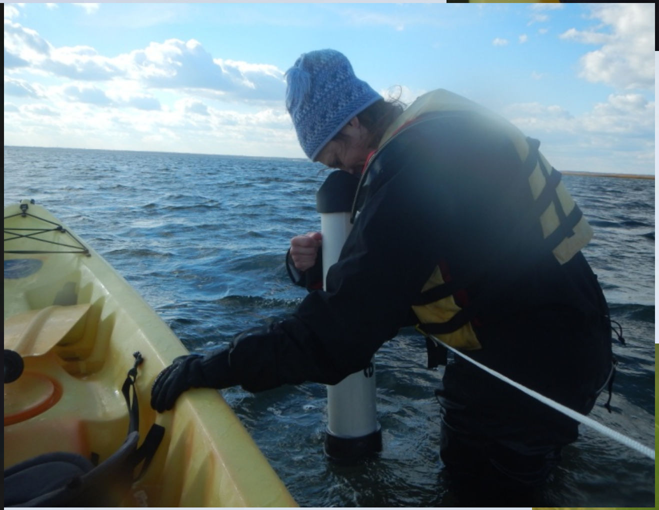
KEY INDICATORS
Water quality
Ecosystem health
Essential fish and shellfish habitat

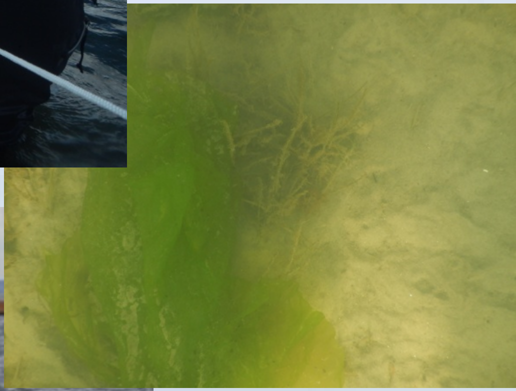
Eelgrass
Zostera marina

Widgeongrass
Ruppia maritima

Barnegat Bay Field Campaign: October 2013







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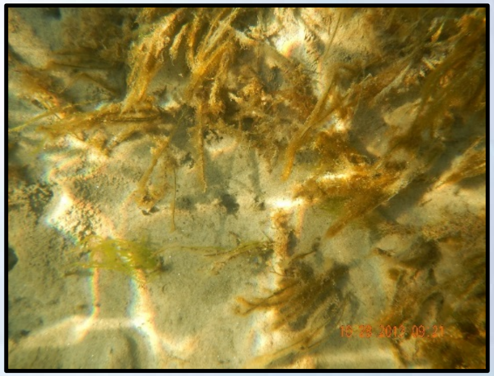
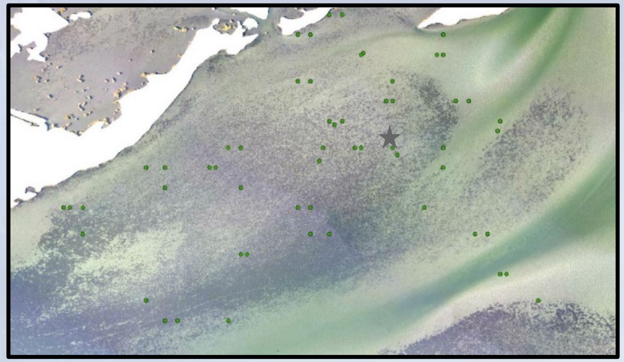
Sand and Macroalgae

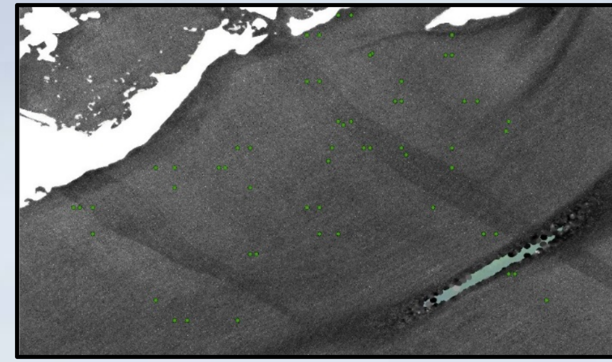
Camera Photo



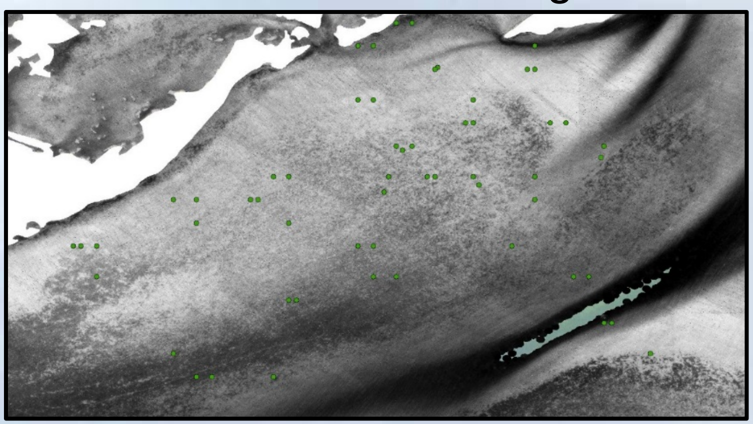
Aerial RGB Image



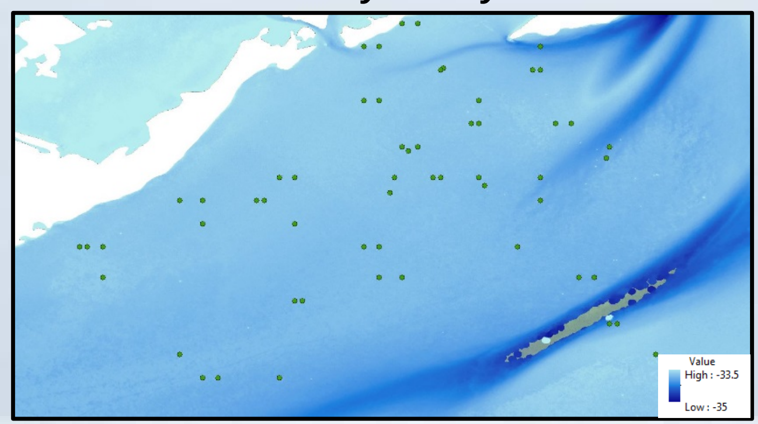
Pulse Shape Deviation



Reflectance Image

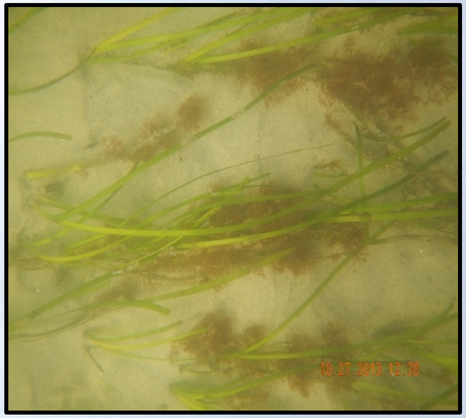


Bathymetry

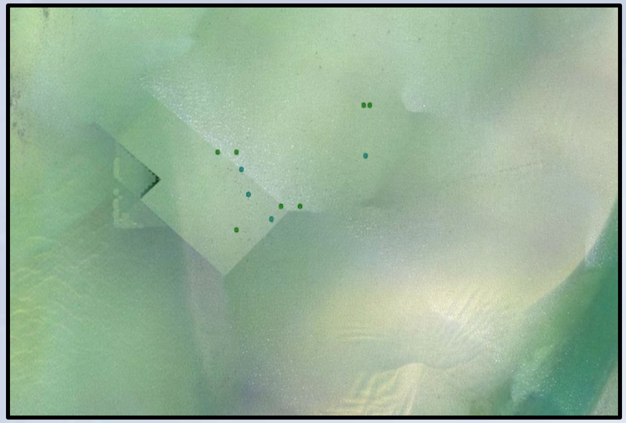


Sand and Eelgrass

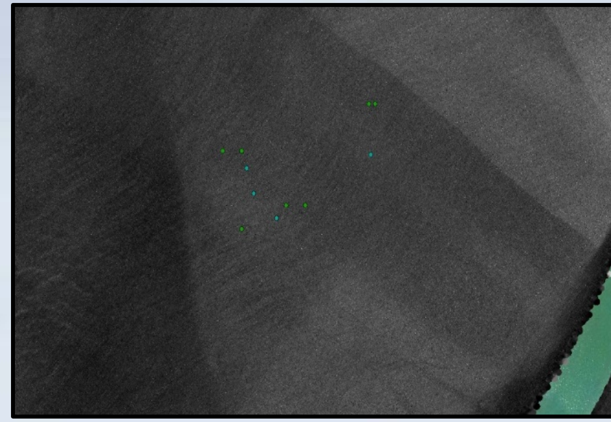
Camera Photo



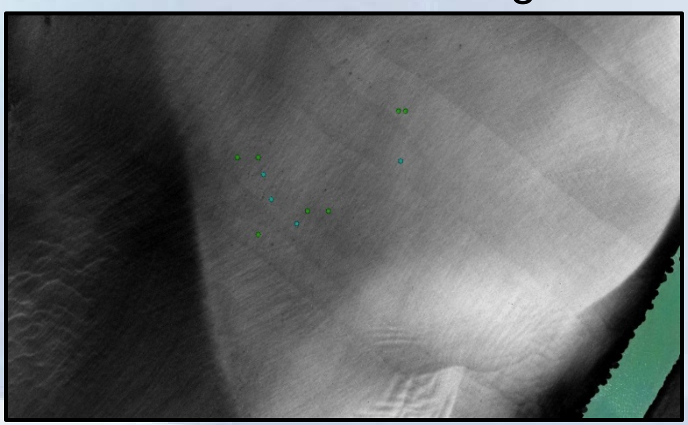
Aerial RGB Image



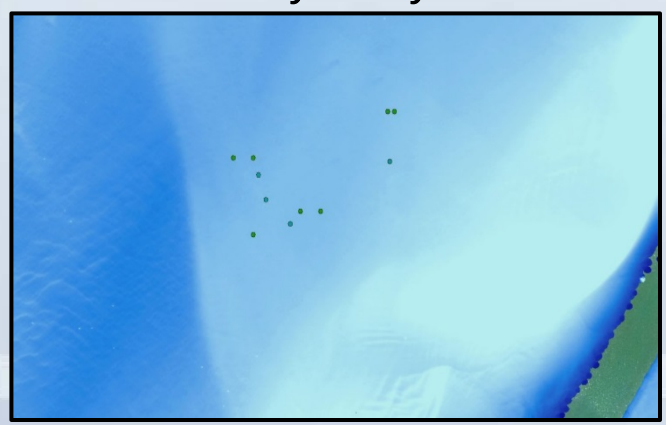
Pulse Shape Deviation



Reflectance Image



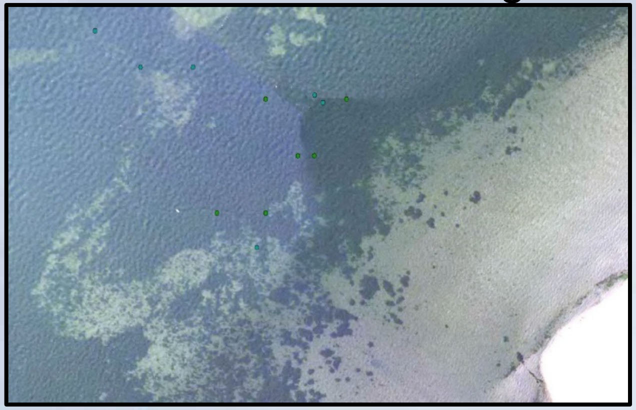
Bathymetry



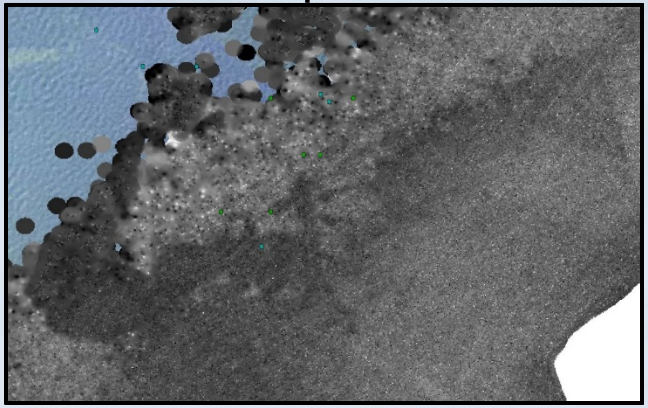
Eelgrass

Camera Photo

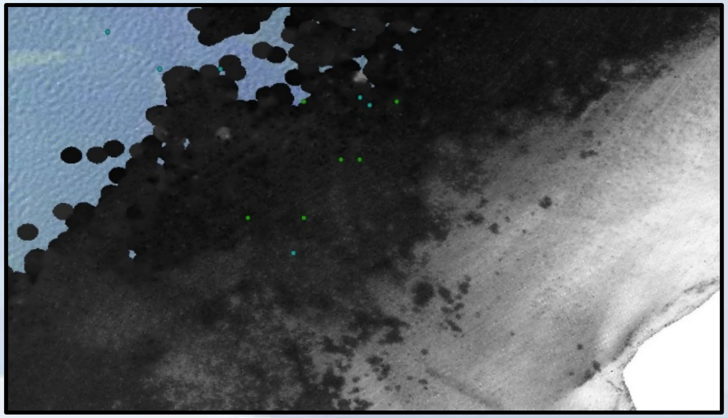
Aerial RGB Image



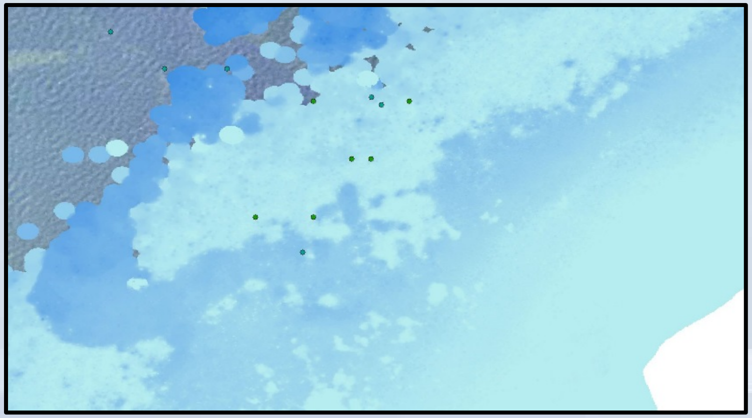
Pulse Shape Deviation



Reflectance Image

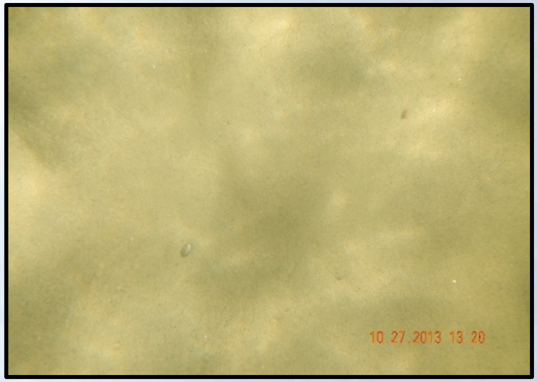


Bathymetry



Sand

Camera Photo



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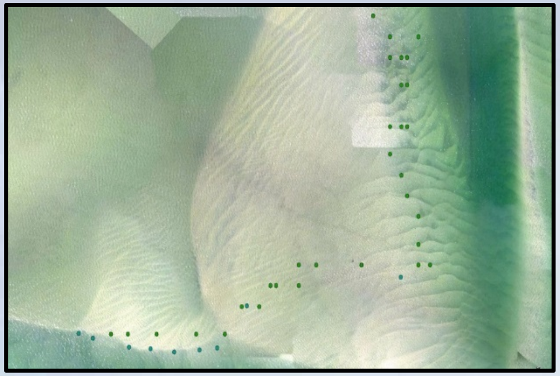
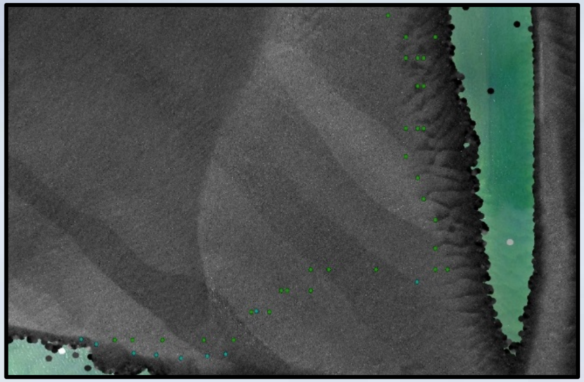
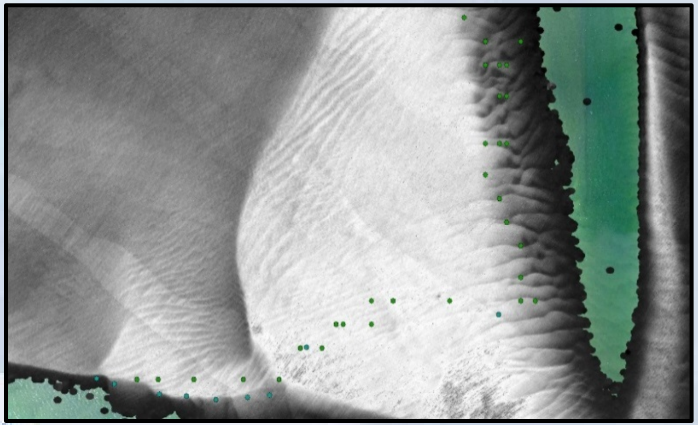


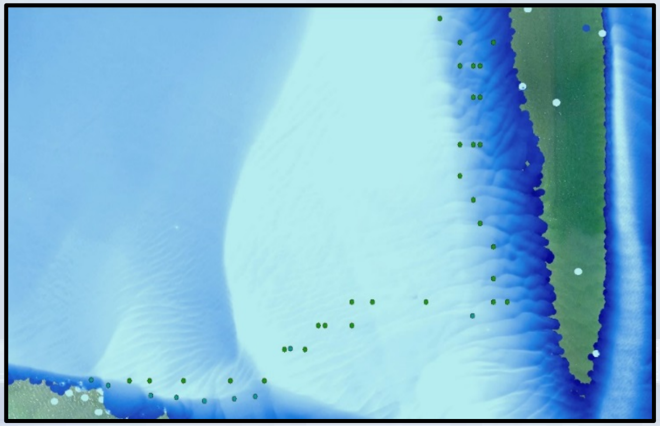
Pulse Shape Deviation



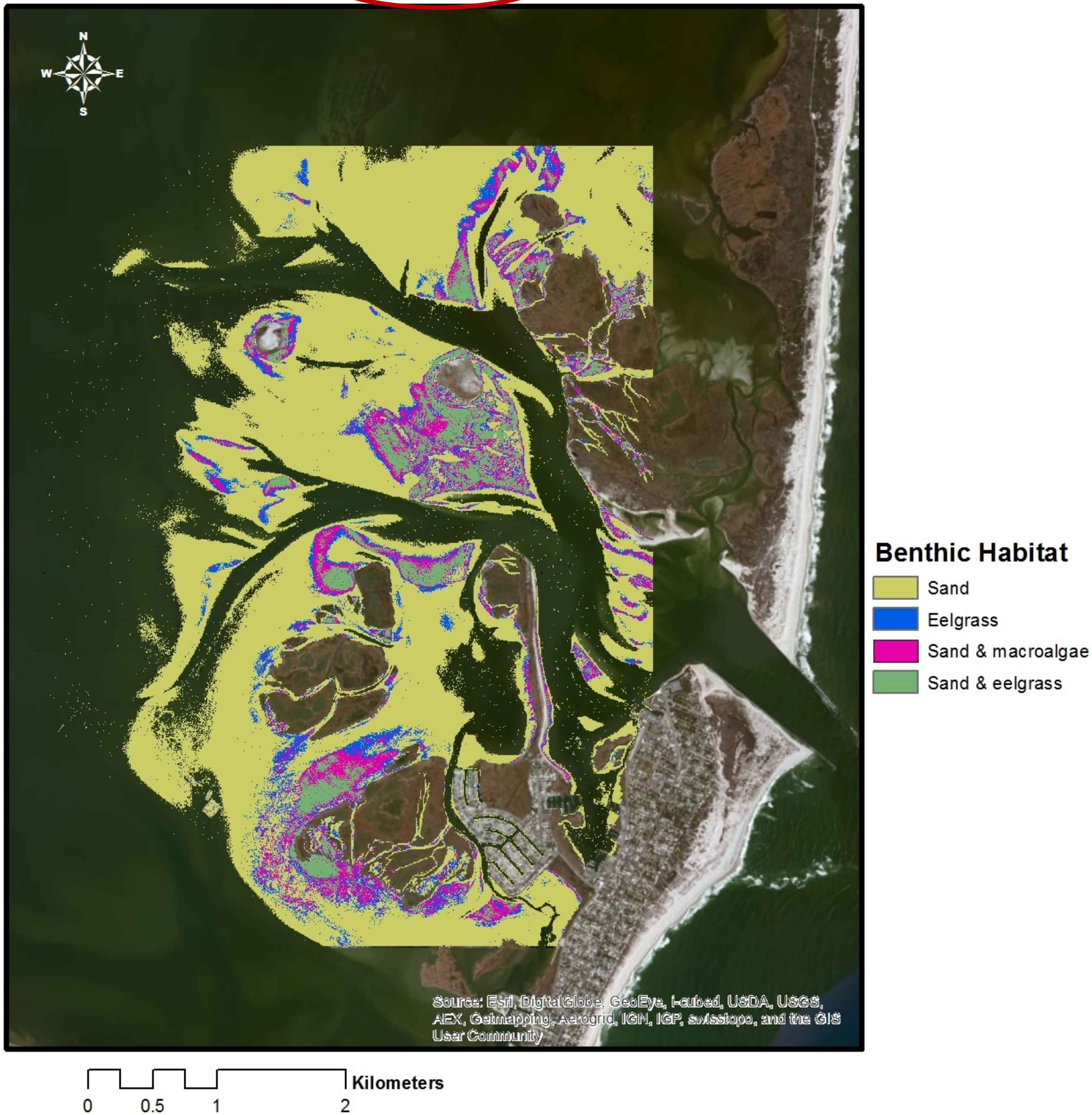
Reflectance Image



Bathymetry



Barnegat Bay: Preliminary Habitat Map



Next Steps & Future Direction

- Object-based classification of Barnegat Bay benthic habitats
  - eCog
  - Rule set based on texture of waveform features, depth, dist from shoreline
- EAARL-B / ALPS implementation
  - Great data set, acquired very shortly before and after Sandy
  - Pre- and post-Sandy => habitat change analysis
- (Jeff's dissertation work) Marsh elevation correction factors, computed as a function of waveform features, distance from shoreline, elevation relative to MHW
  - 2 more papers to be submitted to JCR SI

References

Parrish, C.E., J.N. Rogers, and B.R. Calder, 2014. Assessment of Waveform Shape Features for Lidar Uncertainty Modeling in a Coastal Salt Marsh Environment. *Geoscience and Remote Sensing Letters*, Vol. 11, No. 2, pp. 569-573.

Pfennigbauer, M. and A. Ullrich, 2010. Improving quality of laser scanning data acquisition through calibrated amplitude and pulse deviation measurement. *Proc. SPIE Defense, Security, and Sensing*, pp. 76841F-76841F.

Rogers, J.N., C.E. Parrish, L. Ward, and D. Burdick, 2014. Evaluation of Vertical Obscuration and Full Waveform Lidar to Predict Salt Marsh Vegetation Biophysical Parameters. *Remote Sensing of Environment* (in revision).

+ 2 more papers to be submitted to JCR SI