Enhanced Coastal Mapping Using Lidar Waveform Features

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Lidar waveform features

Chapter 2
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 and ingested into GIS?
• Are they useful?
Animation of waveforms in transect across a marsh
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Metric Name</th>
<th>Computation Time (μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w$</td>
<td>Width</td>
<td>14.8</td>
</tr>
<tr>
<td>$A$</td>
<td>Amplitude</td>
<td>0.7</td>
</tr>
<tr>
<td>$w/A$</td>
<td>Pulse aspect ratio</td>
<td>17.6</td>
</tr>
<tr>
<td>$AUC$</td>
<td>Area under curve</td>
<td>0.8</td>
</tr>
<tr>
<td>$AUC_r$</td>
<td>Area under curve: R/L ratio</td>
<td>17.8</td>
</tr>
<tr>
<td>$\beta_t$</td>
<td>Slope trailing edge</td>
<td>37.9</td>
</tr>
<tr>
<td>$\beta_r$</td>
<td>Slope ratio</td>
<td>38.4</td>
</tr>
<tr>
<td>$\sigma_w$</td>
<td>Standard deviation</td>
<td>0.9</td>
</tr>
<tr>
<td>$\mu_w$</td>
<td>Mean</td>
<td>0.7</td>
</tr>
<tr>
<td>$n_{50}$</td>
<td>Median</td>
<td>9.3</td>
</tr>
<tr>
<td>$\hat{n}$</td>
<td>Mode</td>
<td>0.6</td>
</tr>
<tr>
<td>$\gamma_1$</td>
<td>Skewness</td>
<td>8.2</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>Kurtosis</td>
<td>8.2</td>
</tr>
<tr>
<td>$\Gamma_1$</td>
<td>Pearson's 1st skewness coefficient</td>
<td>7.2</td>
</tr>
<tr>
<td>$\Gamma_2$</td>
<td>Pearson's 2nd skewness coefficient</td>
<td>12.3</td>
</tr>
<tr>
<td>$R_G^2$</td>
<td>Goodness-of-fit of Gaussian</td>
<td>850.3</td>
</tr>
</tbody>
</table>
Gridded waveform features in GIS

- Gridded echo width
- Gridded skewness
- Gridded kurtosis
- Gridded AUC

Gridded AUC
Results of regressions of $\Delta Z$ on waveform metrics ($R^2$)

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

<table>
<thead>
<tr>
<th>Regression</th>
<th>Little Pamet</th>
<th>Great Island</th>
<th>Moors</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta Z$ on width and median</td>
<td>0.55</td>
<td>0.75</td>
<td>0.54</td>
<td>0.61</td>
</tr>
<tr>
<td>$\Delta Z$ on width and mean</td>
<td>0.55</td>
<td>0.75</td>
<td>0.53</td>
<td>0.61</td>
</tr>
<tr>
<td>$\Delta Z$ on width and mode</td>
<td>0.55</td>
<td>0.74</td>
<td>0.54</td>
<td>0.61</td>
</tr>
<tr>
<td>$\Delta Z$ on width and goodness-of-fit of Gaussian</td>
<td>0.56</td>
<td>0.80</td>
<td>0.56</td>
<td>0.64</td>
</tr>
<tr>
<td>$\Delta Z$ on PC1 and PC2</td>
<td>0.55</td>
<td>0.73</td>
<td>0.53</td>
<td>0.60</td>
</tr>
</tbody>
</table>
Generating Relative Uncertainty Surfaces from Waveform Features

\[ \Delta Z = 17.383 - 1.254w - 0.718\mu_w + 0.051w\mu_w \]

1. Point cloud in delimited text format and waveform corresponding to each point in marsh sites
2. Waveform feature extraction
3. Delimited text file, X, Y, waveform_feature1, waveform_feature2, ...
4. Regression equations from Parrish et al. (2013)
5. Estimate \( \Delta Z \)
6. Delimited text file: X, Y, est. vert. error (abs value)
7. Rescaling to [0,1] (arbitrary, unitless range)
8. Interpolate (IDW) to 1 m "relative uncertainty" grid
9. Import into ArcGIS with imagery and other layers for analysis
Pamet marsh
Relative uncertainty surface

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

Rogers et al., 2014
Use case #2 of lidar waveform features: Predicting salt marsh vegetation biophysical parameters

\[ y = 0.18x - 2.12 \]
\[ r = 0.73 \]

- $S. \ alterniflora$ samples
- $\text{all other species}$

Rogers et al., 2014
Vegetation Height (cm)

Waveform Width (ns)

y = 69.59x - 873.78

r = 0.82

Rogers et al., 2014
Proportion Vegetation Area (m^2) vs Waveform Width (ns)

Regression line:
y = 0.18x - 2.12
r = 0.73

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).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Width</th>
<th>Sample Skewness</th>
<th>Amplitude</th>
<th>Waveform Standard deviation</th>
<th>Pearson’s 1st Skewness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
<td><em>S. alterniflora</em></td>
<td>All</td>
<td><em>S. alterniflora</em></td>
<td>All</td>
</tr>
<tr>
<td>Photographic Vegetation Height</td>
<td>0.82</td>
<td>0.75</td>
<td>0.54</td>
<td>0.17</td>
<td>0.57</td>
</tr>
<tr>
<td>Planimetric Obscuration</td>
<td>0.47</td>
<td>0.14</td>
<td>0.56</td>
<td>0.33</td>
<td>0.71</td>
</tr>
<tr>
<td>Quadrat Stem Density</td>
<td>0.58</td>
<td>0.66</td>
<td>0.63</td>
<td>0.35</td>
<td>0.73</td>
</tr>
<tr>
<td>Quadrat Biomass Density</td>
<td>0.41</td>
<td>0.20</td>
<td>0.30</td>
<td>0.22</td>
<td>0.53</td>
</tr>
<tr>
<td>Proportion Vegetation Area (25cm)</td>
<td>0.73</td>
<td>0.57</td>
<td>0.45</td>
<td>0.00</td>
<td>0.39</td>
</tr>
<tr>
<td>Proportion Vegetation Area (10cm)</td>
<td>0.49</td>
<td>0.14</td>
<td>0.28</td>
<td>0.14</td>
<td>0.26</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th></th>
<th>Waveform Width and Sample Skewness</th>
<th>Waveform Width and Amplitude</th>
<th>Waveform Width and Waveform STDV</th>
<th>Sample Skewness and Amplitude</th>
<th>Sample Skewness and Waveform STDV</th>
<th>Amplitude and Waveform STDV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation Height</td>
<td>0.68</td>
<td><strong>0.72</strong></td>
<td>0.68</td>
<td>0.38</td>
<td>0.57</td>
<td><strong>0.74</strong></td>
</tr>
<tr>
<td>Planimetric Obscuration</td>
<td>0.32</td>
<td>0.53</td>
<td>0.49</td>
<td>0.53</td>
<td>0.36</td>
<td>0.51</td>
</tr>
<tr>
<td>Quadrat Stem Density</td>
<td>0.47</td>
<td><strong>0.6</strong></td>
<td>0.38</td>
<td>0.58</td>
<td>0.42</td>
<td><strong>0.6</strong></td>
</tr>
<tr>
<td>Quadrat Biomass Density</td>
<td>0.18</td>
<td>0.32</td>
<td>0.27</td>
<td>0.32</td>
<td>0.05</td>
<td>0.29</td>
</tr>
<tr>
<td>PVA (25 cm)</td>
<td>0.54</td>
<td>0.54</td>
<td>0.54</td>
<td>0.23</td>
<td>0.42</td>
<td>0.47</td>
</tr>
</tbody>
</table>
Can we extend this to topo-bathy lidar and benthic habitat mapping?

Sept 2013 NOAA/NGS data of Barnegat Inlet

DeHavilland Twin Otter (DHC-6)

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

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

\[
A_{dB} = 10 \cdot \log_{10} \left( \frac{P_{echo}}{P_{DL}} \right)
\]
\[
\rho = A_{dB} - A_{dB,ref}(R)
\]
\[
\delta = \sum_{n=0}^{N-1} |y[n] - p[n]|
\]

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 $\rho_{rel}$ (or other gridded waveform features)
- Procedure
  - For each flightline and each waveform feature, compute the mean, $\mu_i$, and standard deviation, $\sigma_i$
  - Pick one flightline that has good contrast and average “brightness” to be the reference
  - Normalize histograms of other flightlines, as follows
    \[ r' = \frac{\sigma_{ref}}{\sigma_i} (r - \mu_i) + \mu_{ref} \]
Example:
Preprocessed “reflectance” layer
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.

\[
f(x, y) \xrightarrow{\mathcal{F}} F(u, v)
\]

- Notch filter to remove frequency components corresponding to seamlines.

\[
F_c(u, v) \xrightarrow{\mathcal{F}^{-1}} f_c(x, y)
\]
Data Layers

- Aerial RGB Image
- Bathymetry
- Pulse Shape Deviation
- Reflectance
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
Sand and Macroalgae

Camera Photo

Aerial RGB Image

Pulse Shape Deviation

Reflectance Image

Bathymetry

National Oceanic and Atmospheric Administration
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

National Oceanic and Atmospheric Administration
Sand

Camera Photo

Aerial RGB Image

Pulse Shape Deviation

Reflectance Image

Bathymetry
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


+ 2 more papers to be submitted to JCR SI