Monitoring Forests Dynamics Using Lidar

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Background: Global Change

Human and natural drivers of climate change:

- The increases in greenhouse gas concentrations and aerosols (IPCC, 2007)
- Land use and land cover change

Spaceborne and airborne remote sensing provide the capability to monitor global and regional changes

(Figure adapted from IPCC 2007)

(Figure adapted from Lefsky, 2010)
Background: Carbon Dynamics

Climate change contributes to year-to-year changes in carbon cycling within the ecosystems.

We need information from both wood and leaves of vegetation:
- Above-ground biomass—carbon stock
- Leaf area index—carbon-fixing machinery

(Figure adapted from http://www.esd.ornl.gov/iab/iab2-2.htm)
Lidar Applications: 3D City and Urban Modeling

All possible reflective terrain objects can be distinguished from the high-resolution three-dimensional geo-referenced Lidar point cloud data, including bare-earth, buildings, bridges, vehicles, trees and other non-ground features. (Upper Left) Image Credit: University of Texas at Dallas

(Lower Left) Lidar Digital Elevation Model (DEM) in Harris County, Texas USA. Image Credit: Satellite Imaging Corporation.
Lidar Applications: Biodiversity and Wildlife Management

Lidar systems are used in mapping animal habitats, by mapping the distribution of vegetation structure, vegetation composition and terrain.

(Top) Singing male Black-throated Blue Warbler at Hubbard Brook, NH. (Lower left) Interior of northern hardwoods forest at Hubbard Brook. (Lower right) Female Black-throated Blue Warbler and young at nest located in the shrub layer.

Map of predicted Black-throated Blue Warbler habitat quality.

Lidar Applications: Forest Dynamics

1) Natural Disturbances:
   - Wildfires;
   - Pine Beetles;

Photos are from: http://www.treehugger.com/clean-technology/the-pine-beetles-deadly-march.html;
http://harvardforest.fas.harvard.edu/personnel/web/aellison/favoritelinks/icestorm.html; Brian Lockhart, USDA Forest Service.

(Image Credit: JFSP Final Reports, 2012)
1) Natural disturbances (continue):
- Ice Storm;
- Winter Storm;
- Floods;
- Drought, etc.

Lidar Applications: Forest Dynamics

2) Human activities

Overview

• A short, general introduction to lidar remote sensing of vegetation
• Airborne lidar sensing of vegetation
• Retrieval of forest structural parameters using the Echidna Ground-Based Lidar at field sites in New England
How a Lidar Works....

Lidar (Light Detection And Ranging)

(Adapted from Slides by Dr. Alan Strahler)
How a Lidar Works....

The laser fires a pulse....

(Adapted from Slides by Dr. Alan Strahler)
How a Lidar Works....

wavefront

scattering of pulse

that is scattered by the target....

(Adapted from Slides by Dr. Alan Strahler)
How a Lidar Works....

and moves back toward the detector....

(Adapted from Slides by Dr. Alan Strahler)
How a Lidar Works....

wavefront detector senses return pulse and is sensed and recorded....

(Adapted from Slides by Dr. Alan Strahler)
How a Lidar Works....

distance determines travel time

detector senses return pulse

by time (distance) and intensity

(Adapted from Slides by Dr. Alan Strahler)
Lidar Remote Sensing Systems

Categories & features:

– Spaceborne / Airborne / Ground-based:
  e.g. GLAS / LVIS / EVI

– Discrete-return vs. Full-waveform
  e.g. REIGL, LEICA and FARO etc
  v.s. SLICE, LVIS, EVI etc

Picture adapted from: Omasa K et al. J. Exp. Bot. 2006;58:881-898
Discrete Return Lidar System: e.g. First/Last Return

- This type of lidar returns the distance and intensity of the first or first and last scattering events
- Usually small footprint (< 1 m from aircraft)
- Provides canopy height, terrain elevation
This type of lidar samples the entire return waveform to give a full return.

- Usually larger footprint (15–30 m from aircraft)
- Provides details of canopy scattering as well as canopy height, terrain elevation.
Airborne Lidar Sensing of Vegetation
Small Footprint Discrete Return Lidar

The left figure shows
1) the three-dimensional distribution of discrete-return lidar data from within a 25-m footprint;
2) the vertical distribution of these returns.

Large Footprint Full-waveform Lidar --- SLICE (Scanning Lidar Imager of Canopies by Echo Recovery)

(Figure adapted from Blair, B. and Harding, D, NASA/GSFC.)
Large Footprint Full-waveform Lidar --- LVIS (Laser Vegetation Imaging Sensor)

- LVIS — NASA NIR aircraft lidar, 15- to 30-m diameter footprint
- Canopy Height Profile
  - RHxx = Relative Height above the ground at which xx percent of the signal has been returned
  - Colors are RH25, RH50, RH75, RH100 (canopy top)
  - Vertical distribution of foliage
Direct Retrievals from Return Waveforms

There are direct retrievals of various metrics near Washington DC as an example from the Laser Vegetation Imaging Sensor (LVIS).
La Selva Biomass

R² : 0.87
RMSE: 22.6 Mg/ha

Biomass derived from statistical inference using lidar and some ground data in Costa Rica.

Retrieval of forest structural parameters using the Echidna Ground-Based Lidar at field sites in New England
Study Area

New England 2007, 2009
Harvard and Howland Forests
1 conifer stand at each location

## Motivation for Forest Change

<table>
<thead>
<tr>
<th>Site Location</th>
<th>Dominant Tree Species</th>
<th>Motivation for change</th>
<th>Change Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Howland Forest (ME)</td>
<td>Red Spruce, Hemlock</td>
<td>Shelterwood cutting recovery</td>
<td>2007-2009</td>
</tr>
</tbody>
</table>

December 2008 ice storm damage In Harvard Forest, MA.  
(Left photo adapted from http://harvardforest.fas.harvard.edu/personnel/web/aellison/favoritelinks/icestorm.html)  
Shelterwood stand openings in Howland Forest, ME.
Echidna® Validation Instrument (EVI)

- Ground-based, scanning, full-waveform lidar operating at a 1064 nm wavelength
- Return pulse digitized at 7.5 cm to 140 m range
- Space around EVI is fully sampled.
- Developed by Australia’s CSIRO
Forest Field Measurements

- Crown Diameter
- DBH
- Crown Height
- Tree Height

Stem map

[Images of field measurements and equipment]
EVI Scans vs. Manual Tree Measurements

E.g. In one field plot with 20m radius, with about 140 sampled trees.

3-4 people in a group, 2-3 hours.  VS.  2 people in a group, 40 minutes.
EVI Data Projection (Equal-angle)

Image shows the mean waveform using an “Equal-angle projection” of the data cube recorded at Harvard Forest Hemlock plot.

Forest Structure Retrieval with EVI

(Figure adapted from Seidel et al., 2011)
### Change in forest structural parameters, 2007–2009

<table>
<thead>
<tr>
<th>Parameters(^1)</th>
<th>Harvard Forest</th>
<th>Howland Forest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hemlock Site</td>
<td>Shelterwood Site</td>
</tr>
<tr>
<td></td>
<td>2007</td>
<td>2009</td>
</tr>
<tr>
<td>Mean of DBH(^2) (m)</td>
<td>Field</td>
<td>0.26 ± 0.01</td>
</tr>
<tr>
<td></td>
<td>EVI</td>
<td>0.25 ± 0.01</td>
</tr>
<tr>
<td>Stem density (tree/ha)</td>
<td>Field</td>
<td>953 ± 59</td>
</tr>
<tr>
<td></td>
<td>EVI</td>
<td>921 ± 79</td>
</tr>
<tr>
<td>Basal area (m(^2)/ha)</td>
<td>Field</td>
<td>54.65 ± 6.03</td>
</tr>
<tr>
<td></td>
<td>EVI</td>
<td>51.21 ± 3.54</td>
</tr>
<tr>
<td>Above-ground biomass (ton/ha)</td>
<td>Field</td>
<td>260.9 ± 16.56</td>
</tr>
<tr>
<td></td>
<td>EVI</td>
<td>235.3 ± 17.29</td>
</tr>
<tr>
<td>EVI regression LAI</td>
<td>Field</td>
<td>4.52 ± 0.22</td>
</tr>
<tr>
<td>EVI CMTH (m)</td>
<td>Field</td>
<td>22.63 ± 0.35</td>
</tr>
<tr>
<td>LVIS RH100 height (m)(^3)</td>
<td>Field</td>
<td>23.89 ± 0.40</td>
</tr>
<tr>
<td>Field canopy height (m)</td>
<td>Field</td>
<td>23.24 ± 0.65</td>
</tr>
<tr>
<td>Dominant species</td>
<td>Hemlock; White Pine</td>
<td>Hemlock; Red Spruce</td>
</tr>
</tbody>
</table>

\(^1\) Standard errors based on values of plots, n=5.
\(^2\) Data sets only contain trees with DBH≥10cm.
\(^3\) LVIS data were collected in 2003 and 2009.
From 2007 to 2009, the right map shows the difference between the two canopy height models at the 1-ha Harvard Hemlock site.
Conclusions

- The Echidna Validation Instrument (EVI) can detect forest growth over a period as short as two years.
- EVI can identify disturbance to the forest from a damaging event such as an ice storm.
- The changes in forest through EVI retrievals were validated by direct field measurements.
Future Directions

- Continue to develop and extend 3-D reconstructions of forest stands derived from merging multiple EVI scans
- Provide virtual direct measurement of biomass (carbon stock) and LAI (carbon-fixing machinery)
- Link 3-D reconstructions to airborne and spaceborne lidar for calibration and validation of structural retrievals
Movie in New England Forest Stand
People involved in EVI Lidar Program

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Questions?