The Use of High Resolution LiDAR to Predict Carbon on a Tree-by-Tree Basis

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Introduction

Forests worldwide store a tremendous amount of carbon, yet a forest's ability to sequester carbon varies greatly depending on forest stand age, tree density, structure, species composition, and climate. This variability has traditionally confounded estimates of forest carbon storage at large scales. In the past decade LiDAR (Light Detection and Ranging) has facilitated such estimates by providing valuable three-dimensional point clouds with information about forest height and structure that relate directly to carbon density.

For the most part, large area-based estimates of forest carbon density are derived from secondary canopy-structure variables detected by low resolution LiDAR. In contrast, this current study seeks to estimate carbon on a tree-by-tree basis, using medium-high resolution LiDAR. To that end we have developed a novel algorithm for detecting and measuring individual trees from a detailed LiDAR point clouds (a process called *segmentation*). Over 200,000 trees from the Penobscot Experimental Forest of central Maine will thus be segmented, and structural measures will be extracted for each. These measurements will then be used to predict the biomass, and hence carbon content, of each tree using allometric equations. Summing the tree-level values will produce area estimates of carbon density with greater precision than that of traditional methods.

Outline

Goal: Generate carbon mass estimates for each tree in the forest based on structural characteristics. Three steps are required to accomplish this.

(1)- Implement a novel algorithm for identifying and separating individual tree canopies from LiDAR point clouds (i.e., segmentation).

(2)- Separate coniferous from deciduous trees based on canopy shape, laser penetration, and laser reflectance

(3)- Estimate carbon mass for each tree using height, canopy area, and species group using allometric equations already developed.

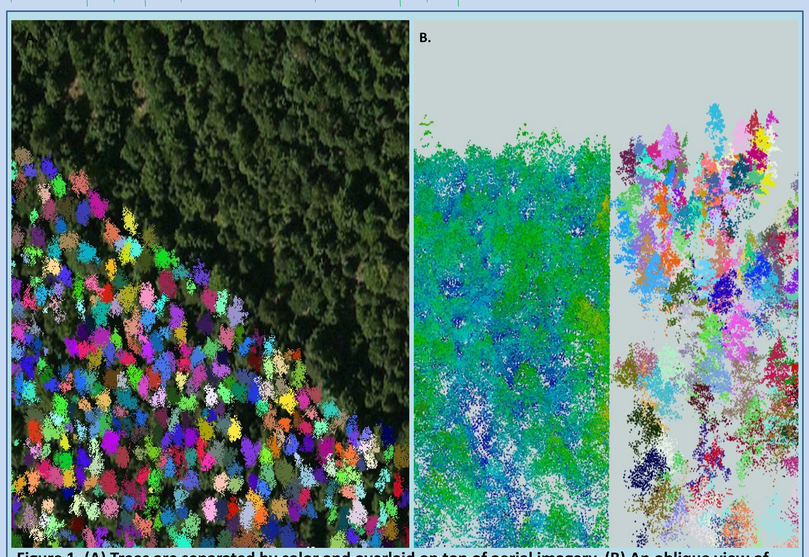

Figure 1. (A) Trees are separated by color and overlaid on top of aerial imagery. (B) An oblique view of two point clouds. The left is colored by elevation, the right by tree.

1-Developing A Tree Segmentation Algorithm

The segmentation algorithm (i.e., isolating individual trees) begins with raw LiDAR point clouds and proceeds as follows:

(1) The forest point cloud is first split into vertical layers. (2) For each layer, clustering algorithms are used to group nearby points. (3) A polygonal buffer is then placed around each group; and those buffers are overlain on top of one another similarly to a Venn-Diagram. Areas of greater overlap (local maxima) indicate the presence of a tree's center of mass. (4) Once tree centers are located, all polygon buffers touching that center are extracted, and erroneous polygon buffers are removed. (5) Layers are then merged back together to obtain the tree's three dimensional shape. Any points inside this shape are then clipped out of the point cloud. Figure 2 shows the algorithm workflow.

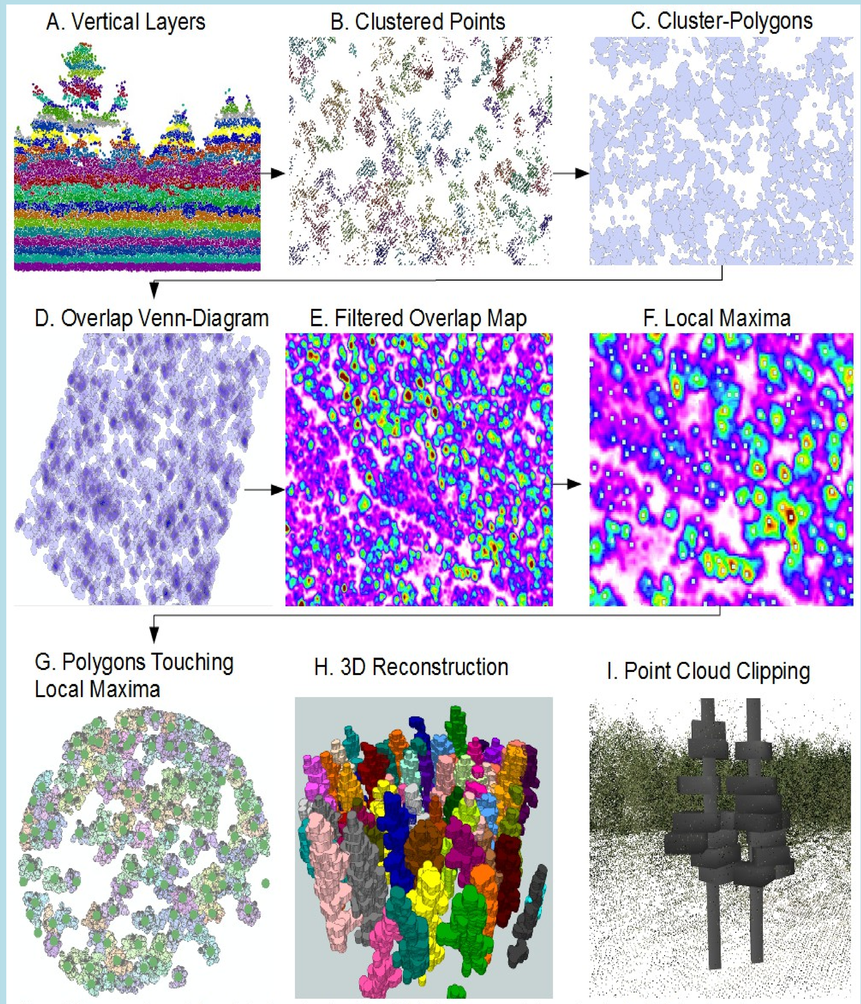

Figure 2. Illustrates the work flow of the detection algorithm. (A) The forest canopy is layered vertically. (B) Points in each layer are clustered. Each cluster is assigned a color. (C) Half-meter polygonal buffers are places around each cluster. (D) Polygons are stacked back on top of one another. Overlaps are counted and areas of greater overlap are shown in darker blue. (E) Overlaps are rasterized and filtered to create an overlap map. (F) Local maxima are detected from the overlap map. (G) Polygon buffers which touch local maxima are isolated. (H) Layered strata are reconstructed three dimensionally. (I) The 3D shapes are used to clip points out of the point cloud.

2-Detect Tree Species

Since carbon content varies considerably by tree species, it was necessary to separate trees into coniferous or deciduous groups.

A logistic regression model was developed using features gleaned from each tree's point cloud. These features include shape attributes such as height of densest point in the tree, average reflectance of the laser beam indicating whether leaves were broad and reflective or small and needle like(Fig. 3), and a measure of the laser's penetration to the ground beneath gauged the density of the tree canopy.

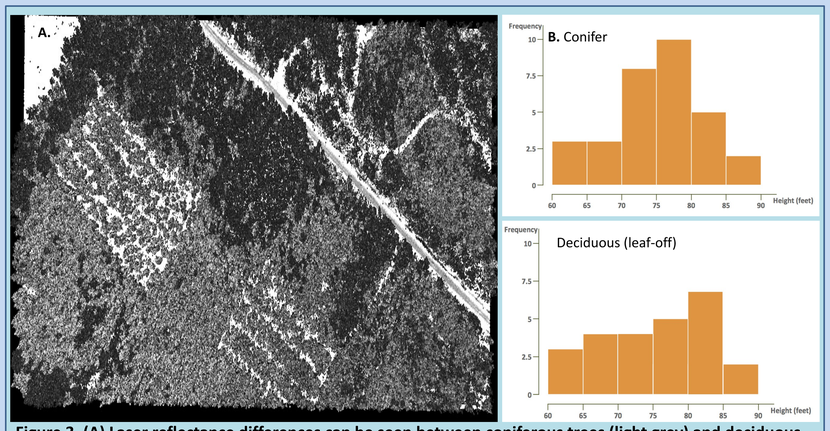

Figure 3. (A) Laser reflectance differences can be seen between coniferous trees (light grey) and deciduous (dark grey). (B) point density profile histograms illustrating primarily shape differences between guilds

3- Tree By Tree Carbon Estimates

Building on data collected in the previous steps, carbon estimates are made for each tree in the forest as follows.

Existing allometric equations provide carbon estimates for specific tree species, based on stem diameter and height. However only species group is known(conifer vs. deciduous), so with existing field data providing relative abundances of each tree species within groups, weighted model averaging is used to estimate carbon.

Many allometric equations use both stem diameter and tree height to estimate carbon content. Because LiDAR cannot directly measure stem diameter, a second set of averaged models are used to predict diameter from canopy projection area (Fig. 4a). With predicted stem diameter, measured height, and species group, an estimate of carbon mass can be made for each tree automatically. Finally, summing carbon mass from all individual trees produces a per-area estimate of above-ground carbon density.

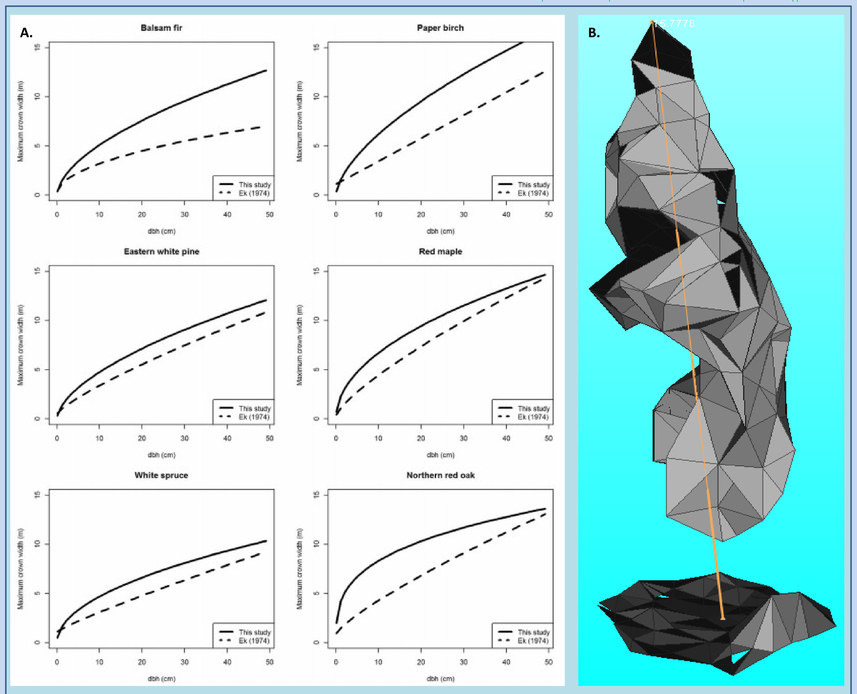

Figure 4. (A) Models for predicting stem diameter from canopy width for species found in the study area.
- Russell, Matthew B., and Aaron R. Weiskittel. "Maximum and largest crown width equations for 15 tree species in Maine." *Northern Journal of Applied Forestry* 28.2 (2011): 84-91.

(B) Three dimensional reconstruction of a segmented tree with a convex hull. Measurements such as height, canopy width, canopy projection area, and crown volume can be taken.

Data collected by:

NASA Goddard's LiDAR, Hyperspectral, and Thermal Imaging (G-LiHT) & Maine's Cooperative Forestry Research Unit & USFS Penobscot Experimental Forest