Quantification of uncertainty in above-ground biomass estimates derived from small-footprint airborne LiDAR

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Introduction

Lidar

Individual tree detection

Tree height

Allometry

Tree-level AGB

Aggregation

Plot-level AGB

Error from Lidar-measured tree height

Error from allometric modeling

Error from tree detection: omission and commission
Research questions

• What are the errors in estimating AGB from LiDAR remote sensing?

  Remote sensing: lidar-derived tree height, tree detection errors
  Allometric modeling: model parameters, model residuals

• Which error sources contribute the most to the uncertainty in the AGB at different spatial scales?
Materials

Field data:
- FIA dataset for CA
- 8429 trees in 146 sample plots in the Lassen National Forest

<table>
<thead>
<tr>
<th>Attribute</th>
<th>min</th>
<th>mean</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (m)</td>
<td>2.13</td>
<td>12.20</td>
<td>61.57</td>
</tr>
<tr>
<td>DBH (cm)</td>
<td>5.08</td>
<td>25.01</td>
<td>206.80</td>
</tr>
</tbody>
</table>

LiDAR data:
- The Lassen National Forest
  9 measurements/m²
- Another 51 LiDAR holdings
Methods

Tree height for individual trees
Tree identification and crown delineation

1. Lidar tiles
   - Point classification
   - Generation of DTM
     - Height normalization
     - Building removal
     - Generation of raw CHM
     - Dynamic smoothing of raw CHM

2. Crown size
   - Kernel size
   - Gaussian sigma

3. Tree height
   - Local maxima
     - Watershed segmentation
     - Height
     - Coordinates

4. Delineation of tree crowns
   - Tree linkage
Tree height measurement

RMSE = 2.05m
Bias = -0.23m
An allometric model that relates tree height to AGB

A tree in FIA data

GlobAllomeTree database

Adding errors according to the published $R^2$

A distribution of AGB

Point estimate of AGB
Height-based allometric equation

\[ AGB_i = \exp(\beta H_i + \varepsilon_i) \]

\[ \text{Var}(AGB_i) = f(H_i) = \text{comp}(H) + \text{comp}(\beta) + \text{comp}(\varepsilon) \]

\[ \text{var}(AGB_{\text{tree}}) \approx \left( \frac{dg}{dH} \right)^2 \text{var}(H - \hat{H}) + \left( \frac{dg}{d\beta} \right)^2 \text{var}(\hat{\beta}) + \left( \frac{dg}{d\varepsilon} \right)^2 \text{var}(\hat{\varepsilon}) \]
Uncertainty in tree-level AGB

Tree-level uncertainty

Coefficient of variation

Uncertainty decomposition
Methods

The plot-level estimation that considers omission and commission errors
Uncertainty in omission and commission errors

Stem map and canopy height model (at 0.25m resolution)

Detection rate: 61%
Commission rate: 25%
A correction to the LiDAR-detected AGB

\[
AGB_{\text{plot}} = \sum_{i=1}^{n} AGB_{\text{tree},i} - \sum_{c=1}^{m} AGB_{\text{tree},c} + \sum_{o=1}^{l} AGB_{\text{tree},o}
\]

\[
\text{Var}(AGB_{\text{plot}}) = \sum_{i=1}^{n} \text{Var}(AGB_{\text{tree},i}) + \text{Var}(AGB_{\text{plot},o} - AGB_{\text{plot},c})
\]
Modeling omission and commission

Fitted OMCOM

AGB before and after correction
Uncertainty in plot-level AGB

Uncertainty increases with AGB  Coefficient of variation  Uncertainty Decomposition
Mapping of AGB and uncertainty at 30m resolution
Application to the California

- Summarization of AGB and its uncertainty according to 61 CA WHR types.

- By WHR type, “Sierran Mixed Conifer” forests were found to have the highest AGB and lowest error (351 Mg/ha, CV 0.43), and “Barren” lands have the lowest AGB and highest error (48 Mg/ha, CV 1.71).
Conclusions

• We found that from tree to plot level, the allometric model constituted the largest proportion of the total uncertainty in biomass.

• The proportion of the uncertainty associated with remote sensing errors was larger in lower AGB forests, but decreased as AGB increased.

• This conclusion suggests that it may be more worthwhile to devote future research efforts into reducing uncertainties in allometric equations than into remote sensing techniques.
• All of our datasets have been archived at ORNL DAAC, and we shall release the spatially explicit AGB across CA along with uncertainty, at both tree and plot levels.

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