Influence of rainforest architectural and biological diversity on C assimilation along an elevation gradient in Hawaii

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Outline

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2. Primary research questions
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6. Micro-climate measurements
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Overview

• Carbon accumulation in plants is a major component of the global carbon cycle (~15 Pg C/year). Carbon dynamics will be altered by future climatic changes, including changes in temperature and precipitation.

• Carbon models have not included detailed 3-D maps of forest foliage distribution. Course scale estimates indicate that the inclusion of foliage profiles could result in ~50% differences in calculated GPP.

• Little understanding of the role architectural diversity vs. biological diversity may play in carbon dynamics, and especially under different environmental conditions. However, recent technological advancements are now making new research questions feasible.
Overarching research questions

• How does the inclusion of detailed forest structure alter modeled rates of forest C assimilation?

• How do architectural and biological diversity interact to define carbon assimilation under different temperature-precipitation regimes?
Approach

- Airborne LiDAR
- Micro-climate measurements
- Photosynthesis response curves

- 3-D LAD map
- 3-D micro-climate model
- 3D photosynthesis model

- Methodological hypotheses
- Ecological hypotheses
RS – LiDAR / hyperspectral fusion

Waveform light detection and ranging

Fig. 1. Schematic of CAO Alpha System sensor head package and onboard control systems.
Fig. 8. Sample spectral images (0.45 m pixel size) of (a) radiance and (b) atmospherically-corrected reflectance. Insets show example radiance and reflectance spectra from indicated circle for wavelengths spanning 367-1052 nm.
Fig. 9. Sample LiDAR first surface (vegetation and ground) image of same area shown in Fig. 8. Tall trees are shown in blue with progressively shorter vegetation in green and red. Also shown are the extracted waveform and a pseudo-waveform from canopy pixel in the black circle.
Surface topography

Image courtesy of Ty Kennedy-Bowdoin and the CAO
Max canopy height

Image courtesy of Ty Kennedy-Bowdoin and the CAO
Example. Vertical forest leaf area density profile (red = high, blue = low, black = no biomass)

Note voids in taller stature forest vertical profiles
Data fusion — waveform + hyperspectral

Fig. 6. Example ray tracing results for in-flight fusion of CAO hyperspectral imaging and LiDAR data.
Research site:
Laupahoehoe, “Big island”, Hawaii
Study transect location and description

Fig. 1. Proposed study area in Laupahoehoe experimental forest, Hawaii. (A) Study area and soil age; (B) Tree height (m); (C) Elevation classes; and (D) mean (std. dev.) tree height (m).
Tree max canopy height distributions along the elevation transect

T1: 1010 - 1040 m
T2: 1110 - 1140 m
T3: 1210 - 1240 m
T4: 1310 - 1340 m
Changes in texture or horizontal architectural diversity
Definitions — moving beyond tree height

Forest stature = height

Vertical profiles

Ex. Waveforms

1

2

Low diversity

High diversity

Architecture = understory biomass distribution

Definitions — moving beyond tree height

Forest stature = height

Vertical profiles

Ex. Waveforms

1

2

Low diversity

High diversity

Architecture = understory biomass distribution
Definitions

Forest heterogeneity – both in stature and architectural complexity
Site locations

- The identification of study sites within the transect has the goal of sampling across both the elevation gradient and the dominant types of forest architecture.

Input data:
1) Max canopy height
2) Forest architecture type
3) Canopy height variation
4) Elevation
However, forest structure is complex in three dimensions and varies along the elevation gradient.

So, leads to questions of:

1) What is forest architecture?
   a) New data types and resolutions require new metrics and definitions.

2) How to define/quantify?
   a) Plan to transition common community population diversity metrics to forest architectural diversity.

3) Categorical or continuous metrics?
   a) Determines statistical analyses and sampling designs.
Approach 1: Categorical approach to quantifying forest architecture

Height independent forest architectural categories

Foliage density (% total LAD)*

* In all cases, the summed area equals 100% vertical profile leaf area density (LAD).
Architecture classified based on max LSU probability

A=Red
B=Green
C=Blue
D=Yellow
E=Purple
F=Magenta

Results from classification over study area

<table>
<thead>
<tr>
<th>Arch Type</th>
<th>Pixels</th>
<th>%</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>25068</td>
<td>36</td>
</tr>
<tr>
<td>B</td>
<td>31135</td>
<td>45</td>
</tr>
<tr>
<td>C</td>
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<td>D</td>
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<td>E</td>
<td>8963</td>
<td>13</td>
</tr>
<tr>
<td>F</td>
<td>2352</td>
<td>3</td>
</tr>
</tbody>
</table>
Canopy height variation

- Canopy height variation is defined as the difference in canopy height between a specified pixel (different scales) and the mean canopy height across 30 m sections of elevation gradient (i.e., 1000 – 1030 m) within the study transect.

Approach 2: looking for a continuous metric
Does canopy height explain forest architecture?

- If canopy height (continuous variable) explains forest architectural type (categorical variable) I can locate my study plots along continuous gradients (elevation and deviation) versus replicating within a categorical variable.

- 300 points were randomly selected across the study transect and data exported to JMP.

- Mean canopy height significantly differed between dominant forest architectural categories.
Does elevation correlate with mean canopy height and/or height deviation?

If mean canopy height and/or deviation is significantly related with elevation then fewer variables are necessary to consider when selecting study sites.

1000 points were randomly selected across the study transect and data exported to JMP.

Elevation explains max canopy height but does NOT explain height deviation.
Max height vs. height deviation

Max canopy height

Canopy height deviation
Study site selection

Based on results only elevation and canopy height deviation are necessary gradients to sample for my study sites. I used a stratified random sampling method to identify low, mean and high deviation sites (10 m spatial resolution) within 3 elevation study zones.
Micro-climate measurements

- Direct and Diffuse PAR (400 - 700 nm) – directly limits photosynthesis
- Wind speed – controls leaf transpiration rates
- Humidity – controls leaf transpiration rates
- Temperature – controls rates of enzyme catalysis
- Leaf water balance not measured as all rainfall is > 3000 mm yr⁻¹ (not limiting)

\[ \text{PAR} + \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_2\text{O} \ (\text{e.g., sucrose}) + \text{O}_2 \]
Top of canopy micro-climate

- Top of canopy weather stations are running simultaneously at low and high elevations of the transect. Data is collected every 30 seconds. Direct and diffuse PAR measurements will be collected at each location.
PAR: direct and diffuse dynamics

High arch. diversity

Low arch. diversity
Diffuse / Direct PAR

Important component of forest structure PAR interactions
Direct and diffuse PAR penetrate forest interiors differently

\[ \frac{B}{A} = \text{clearness index} \]

Isotrophic

Anisotrophic
How to make a shade ring - not as simple as it looks.

- Ring angle = latitude,
- PAR sensor position follows Earth polar axis,
- Offset varies with solar track; solstice = most severe offset,
- Sensor track positioned true North (solar noon – highest sun elevation),
- Post processing models used to remove isotropic (sunny) and anistrophic (cloudy) errors resulting from the shade ring obscuring the sky.
Interior forest micro-climate

- Movable array (4 units) located randomly within study sites and location shifted weekly.
- Data collected same time scale as climate stations.
- Sensors calibrated with climate stations.
Micro-climate and photosynthesis measurements
Litterfall measurements
Forest architecture measurements
Photosynthesis measurements

- 4-6 study sites per elevation zone will be selected based on canopy access. These will be used to set up traverses for in situ photosynthesis measurements throughout the upcoming year.

- Measurements will be made on the 5-8 dominant LAI species per site.

- Primary measurements will be photosynthesis under ambient conditions of PAR, temp and rH. A smaller number of PAR and temp response curves will be made for each species.

- For each photosynthesis measurement the following data will be recorded.
  - Day
  - Time of day
  - Precise spatial location
  - Species
  - Individual max height
  - Estimated leaf age (young, mid or old)
  - All standard LiCOR 6400 output information
Canopy access
Modeling approach

• Structural model dealing with 201,600,000 LAD “basketballs”.

• Interior forest micro-climate will be modeled at a time scale of 1 minute throughout the study transect normalized to the top of canopy weather stations.

• Half of the interior forest micro-climate measurements will be used to parameterize the model and the other half to validate.

• Photosynthesis will be modeled using microclimate, structural location and climate station measurements as input data. The influence of species differences vs. forest architecture on total C assimilation will be quantified and compared.
Present status

- Fabricating and calibrating interior forest microclimate array,
- Fabricating and calibrating direct/diffuse PAR sensor system,
- Collecting vertical leaf profile data for LiDAR calibration,
- Rigging traverse locations,
- Calibrating and installing top of canopy climate stations.
- Prepping for a seasonal cycle (aka., year) of measurements starting ~January 2009.
Some acknowledgements

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