Examination of Tropical Forest Canopy Profiles Using Field Data and Remotely Sensed Imagery

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Abstract

Structural properties of forests are closely linked with ecosystem functioning. One such forest structural component is canopy depth or canopy profile. This is defined as the vertical distribution of foliage. Knowledge of canopy profiles is important in understanding gap formation and dynamics, light penetration, and surface roughness; all important parameters in ecological models that are demographic, physiological, or physical in nature. Our analysis compares field based data of canopy profile with estimates derived from remotely sensed images for an undisturbed forest in the Tapajos National Forest, Para, Brazil (3.08 S°, 54.94 W°). We used a handheld laser rangefinder to estimate canopy depth by pointing it directly up in the canopy. We sampled along multiple transects (6 km total) obtaining approximately 20 points every 50 meters and from this data we developed canopy profiles. In addition to our ground based methods, we developed a crown detection algorithm that used high resolution satellite image data. In this work we have further developed the algorithm to examine canopy depth. The algorithm utilized two allometric equations that relate crown width to the top of the canopy and bottom of the canopy. Automated analysis of IKONOS imagery allowed us to also estimate the frequency of crown at various heights. Ability to estimate canopy profiles and forest structural properties in vast areas of the Brazilian Amazon using IKONOS imagery is vital to enhancing our understand of the regional carbon balance.

Crown Detection Algorithm

Local maximum filtering has proven accurate in estimating the number of trees using the assumption that the brightest local value represents the characteristic of a single crown. Local minima value finding has been used to detect the area between two crowns, using the assumption that the darker image values are created by shadows between crowns.

Our algorithm combines local maximum and minima finding methods. It introduces three new concepts in crown detection analysis. These are the analysis of ***iterative local maximum analysis***, a ***derivative threshold*** that ends ordinal transect analysis, and the ***removal of previously analyzed pixels*** from further analysis. Our algorithm simultaneously estimates multiple canopy structural parameters, rather than just the number of trees per hectare.

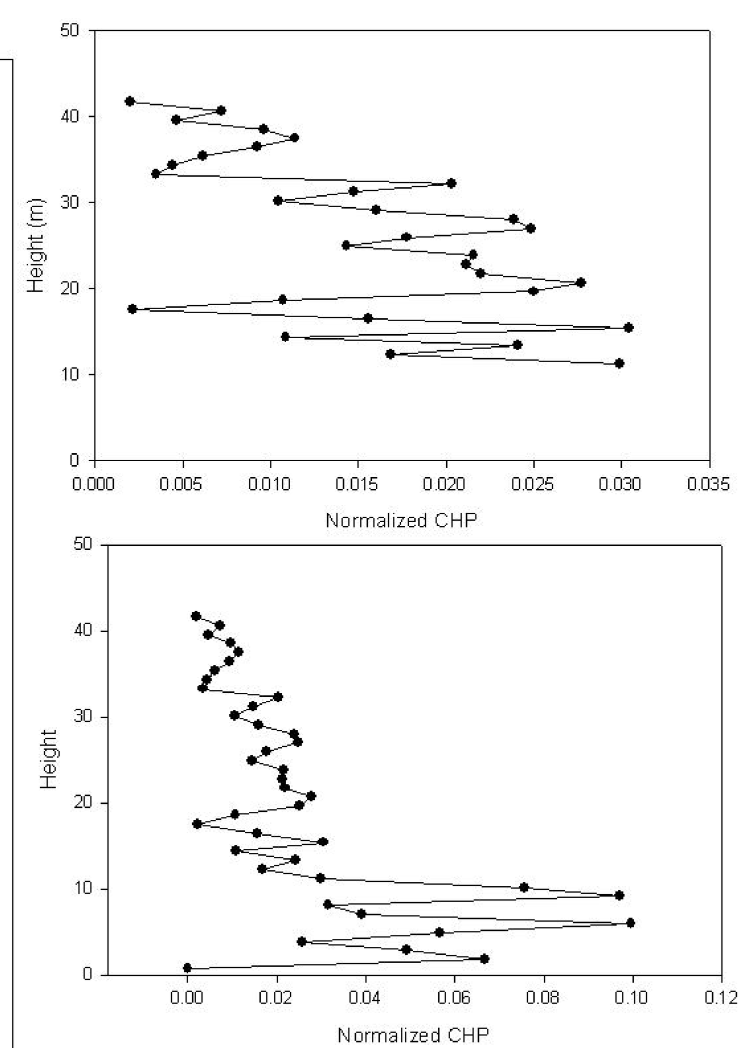
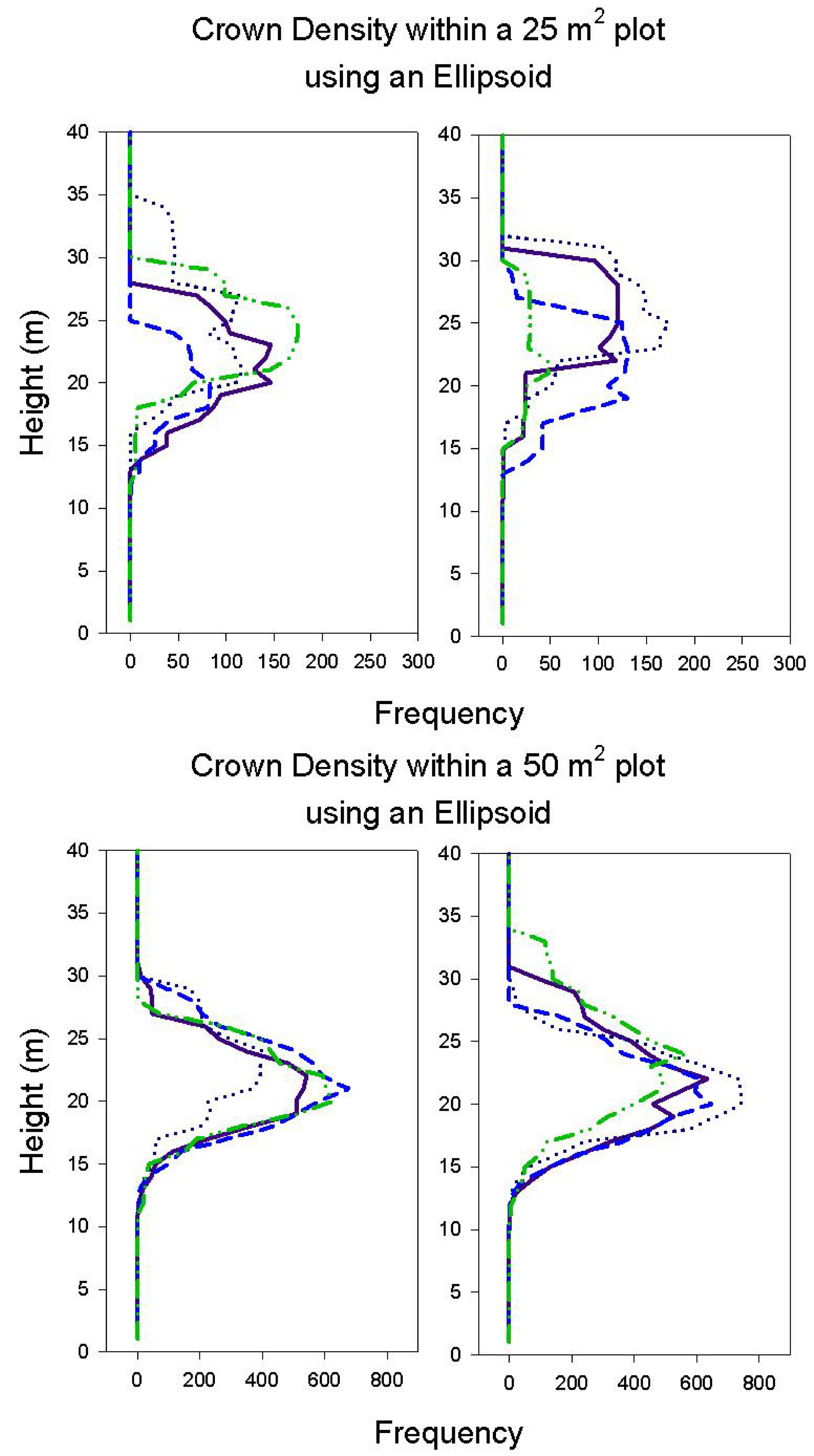


Figure 1 a-b. Normalized canopy height profile (CHP) for a waveform in the Tapajos National Forest from GLAS LIDAR (Michael Lefsky). a – removal of normalized CHP < 10 m. b – all normalized CHP information.



Figures 2. a-b. Synthetic canopy profiles generated using a crown edge detection algorithm and an allometric relationship between crown width and both tree height and height to the bottom of the canopy. Ellipsoids were generated in three-dimensional space and grided plots of 25 m² or 50 m² were used to estimate frequency of crown location in a vertical profile. Each color on the graph represents a randomly selected plot within the study area.

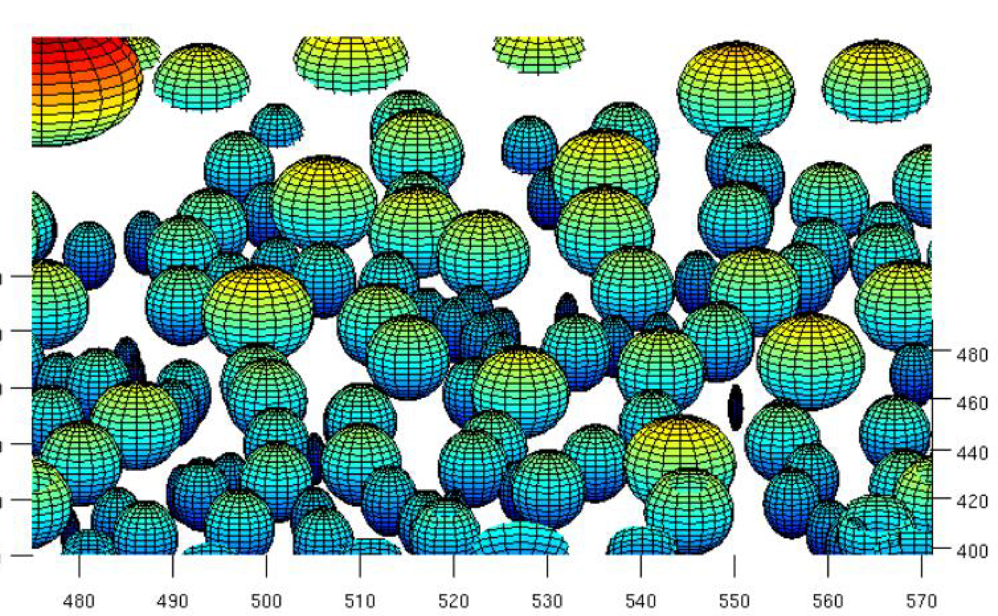
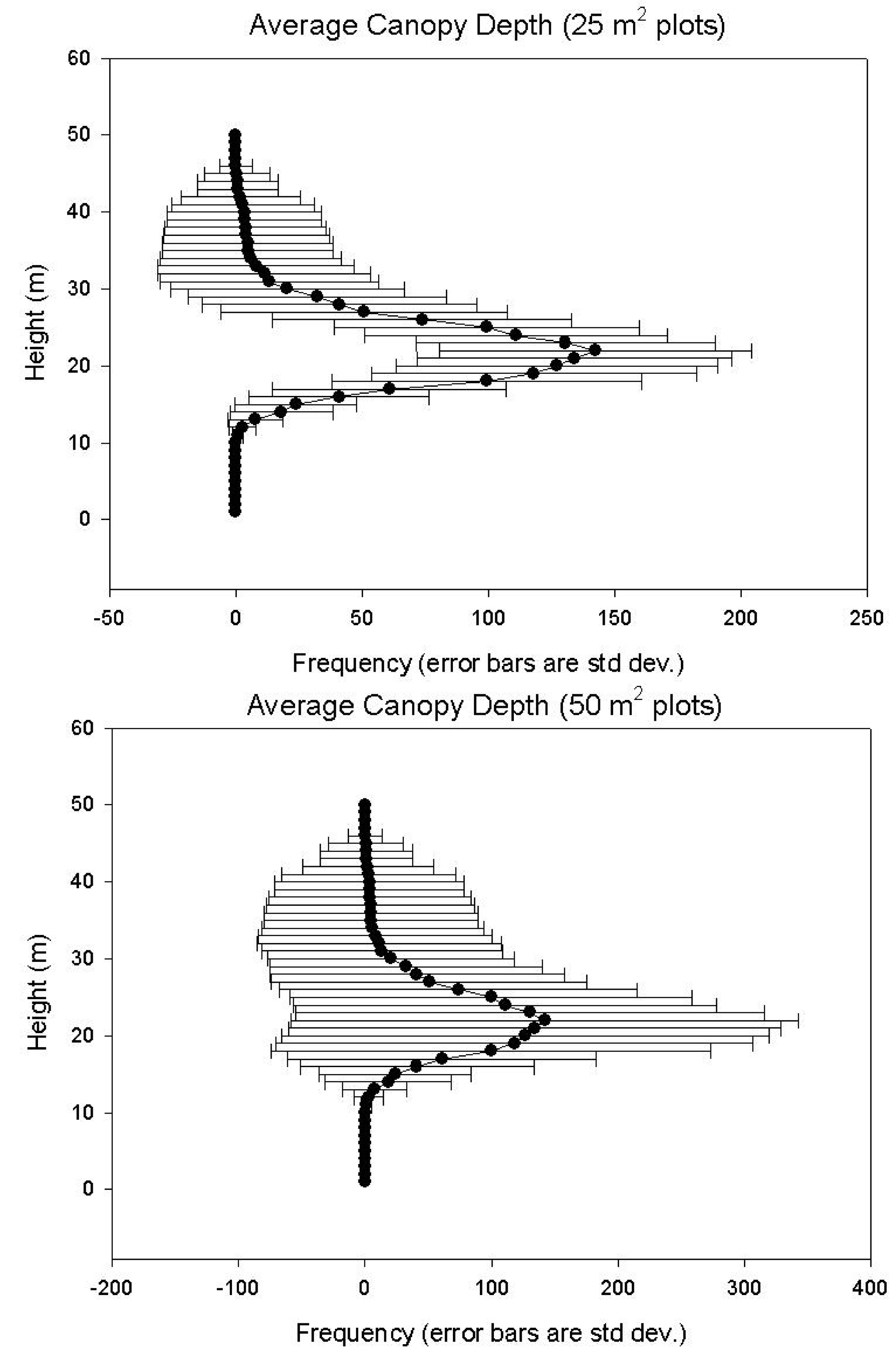
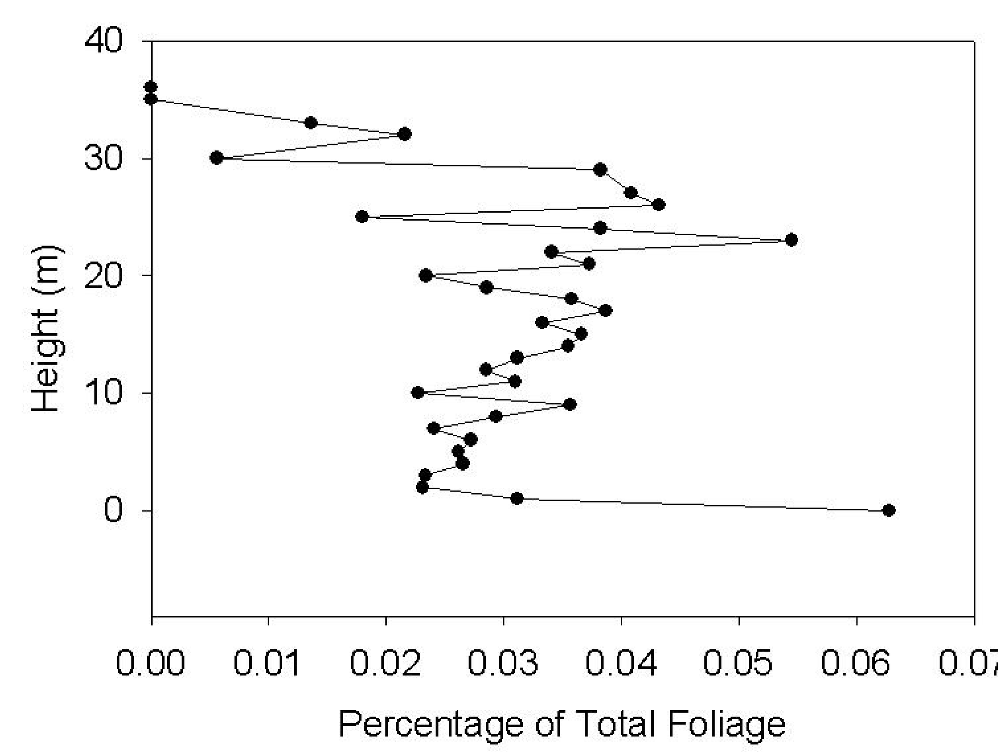


Figure 3. Example of crowns developed using a crown detection algorithm and allometric equations. Location of each crown in three-dimensions is used to calculate the canopy profile.



Figures 4. a-b. Averaged synthetic canopy profiles generated as described in Figure 2. Figure 3 a is generated from 6400 25 m² plots in a 2 km by 2 km area located at Tapajos km 67. Figure 3 b is generated from 1600 50 m² plots in the same area. No trees smaller the 10 m in height are estimated due to allometric equations.



Figures 5. Field based foliage estimate through the canopy based on measurements using a laser rangefinder at Tapajos National Forest, using the equation below from Radtke and Bolstad, Can. J. For. Res. **31**: 410–418 (2001).

$$L(h_1, h_2) = \ln\left(\frac{n_{h_1}}{n_{h_2}}\right) \quad [2]$$

where n_{h_1} and n_{h_2} are the numbers of point quadrats whose height exceeded h_1 and h_2, respectively, $n_{h_1} \geq n_{h_2}$.

Canopy Profile Steps

Preprocessing
1. Modal, maximum, and minimum brightness values (DN) found
2. Moving window 3x3 averaging filter

Crown Detection
1. Local Maxima Analysis
2. Brightness value (highest to modal brightness values examined in an iterative step)
3. Local maxima seeds ordinate analysis

Ordinate Analysis
1. Ordinate analysis (series of DN values in straight line) radiates out in multiple directions from the local maxima or seeded pixel. Number of ordinates defined by user (64 in this study).
2. End ordinate when the next pixel DN value is 2 greater then current pixel
3. Ordinate may not proceed into previously determined crowns

Crown Determination
1. Two longest opposite ordinates determined (crown width)
2. Crown drawn as circle using radius of one-half of the longest crown width
3. DBH and Biomass estimate conducted based on crown width
4. Once a crown is determined, no new local maxima in that area may be analyzed

Canopy Profile Creation
1. Generate ellipsoids for each tree determined using allometric equations of height of tree and bottom of canopy.
2. Fill a three-dimensional matrix with ellipsoids
3. Generate averaged plots of 25 m² or 50 m² to estimate frequency of crown location in a vertical profile.

Summary

Initial work using synthesized canopy profiles could provide added ability to estimate forest structure in the Amazon when coupled with field data and other remote sensing products such as LIDAR.

There are obvious limitations in developing synthetic canopy profiles from IKONOS. The biggest limitation is that the remotely sensed data can not see the understory. In addition, allometric equations based on crown width to both height of a tree and height to the bottom of the canopy are rare yet necessary for creation of our synthetic canopy profiles.

Satellite based LIDAR is limited in availability to the general science community. Use of IKONOS to generate canopy profiles allows for forest structure to be determined spatially and this information can be used to parameterize ecological simulation models.

Use of height generated estimates of the forest canopy could aid in determining gap formation and disturbances regimes in Amazonian forests.

ACKNOWLEDGEMENTS
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