Estimation of Tropical Forest Structure Using the Full Waveform Lidar from ICESat

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Introduction

The Amazon basin contains the world's largest continuous tropical forest constituting 40% of the remaining area for this ecotype and is made up of heterogeneous canopies and forest communities with unique assemblages of tree species, complex vegetation dynamics and history, and high biodiversity. Forest structural components include canopy geometry and tree architecture, size distributions of trees, and are closely linked with ecosystem functioning. The dynamic processes of growth and disturbance are reflected in the structural components of forest. Large footprint lidar has been used to estimate biomass in tropical and temperate forests, primarily through the correlation with field measured height, basal area, and plot biomass estimates. However, in tall-stature forests height loses much of its correlation with basal area, so the height-biomass curve becomes asymptotic and is associated with greater error at large biomass values. Use of lidar in such an analysis also does not include estimations of other stand level structural properties.

Background

Geometric Series in Forest Stands and Generation of Synthetic Forests and Canopies

Forests that are believed to be at or near a steady state are often modeled using a "q ratio" approach, in which the ratio between the number of trees in successive diameter classes is roughly constant (Meyer and Stevenson 1943). The first formal expression of the q ratio was made by the French forester de Liocourt (1898), who used the term to describe the "quotient of dimunition" or rate of change between numbers of trees in successive diameter classes, i.e.

$$q = N_j / N_{j+1}$$

where N_j is the number of trees in the j^{th} diameter class. Later authors emphasized the prevalence of a constant q, which gives rise to an exponential diameter distribution (Meyer 1943, Keller et al. 2001). Although iterative techniques are often used to calculate the number of trees in different diameter classes, exact algorithms to generate the number of trees, basal area, and biomass for different diameter classes have recently been developed (Ducey and Gove, in press).

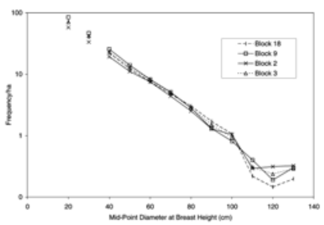


Figure 1. An example of the geometric series between DBH size classes in a forest from four 100 ha plots in Tapajos National Forest, Para, Brazil (Keller et al. 2001).

Method and Results

We used full lidar waveforms from ICESat GLAS to estimate forest stand structure. We developed a 3D canopy model that uses trunk or crown diameter distributions and allometric equations of associated crown depth and canopy height to generate a synthetic canopy. Using geometric series of tree size distributions, we generated thousands of synthetic vegetation profiles. These synthesized forest canopy profiles were rapidly and efficiently compared with lidar waveforms and matches identified using least squared difference.

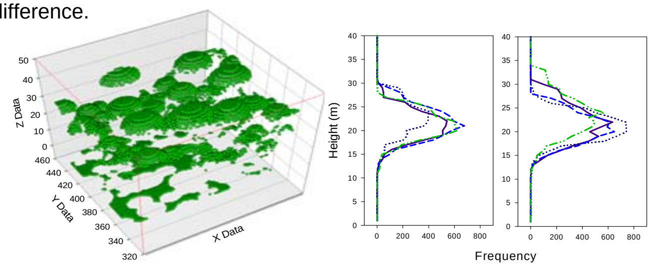


Figure 2. Example of crowns developed using a crown detection algorithm and allometric equations. Location of each crown in three-dimensions is used to calculate the canopy profile. Canopy height is presented for each square meter for a 100 by 100 meter plot. Synthetic canopy profiles generated using a crown edge detection algorithm (Palace et al. 2008) 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 plots of 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.

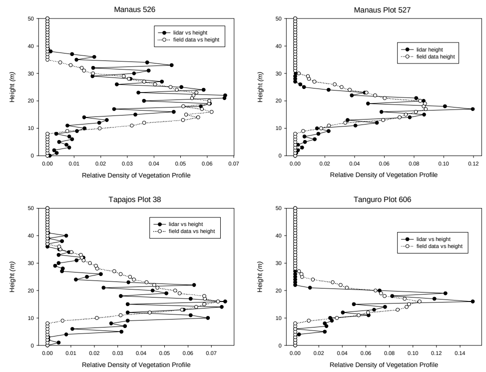
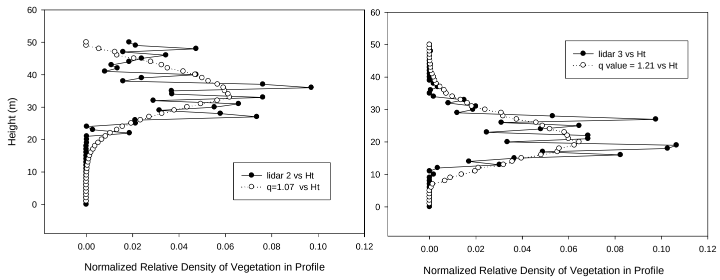


Figure 3. Synthetic profiles (derived from field data (dbh) and allometric equations using ellipsoids to generate canopy structure) compared with GLAS lidar waveforms plotted as relative density.



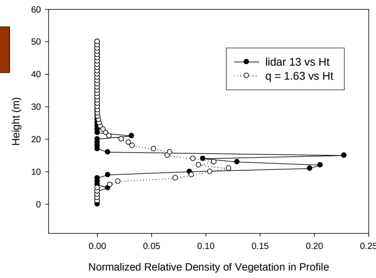


Figure 4. Comparison of GLAS lidar waveforms and the best fit synthetic vegetation profile using least square differences. Synthetic profiles were generated with our three dimensional canopy model. Each synthetic vegetation profile is generated using a geometric series, in this case De Liocourt values (q).

Summary and Future Work

The approach offered here uses a novel technique of simulating forest canopies to more accurately extract information about the complex structure of tropical forests from GLAS Lidar data that can be missed in simple height to biomass relationships. Preliminary results in Amazonia indicate that detailed tropical forest structural information can be estimated from GLAS using our 3D model.

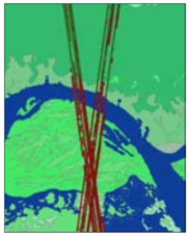


Figure 5. Generated q-values plotted across the landscape. The red marks high q-values indicating secondary vegetation or no vegetation. These GLAS footprint paths cross the Amazon River floodplain in the image on the right. Dark green is forest vegetation.

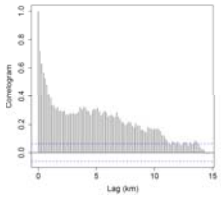


Figure 6. A plot of the spatial autocorrelation of 95%ile height for a typical 150km segment of a GLAS line (1000 waveforms at 150m sampling interval). This result indicates reasonable spatial coherence at kilometer-scales and beyond. Given the typical separation of GLAS lines in our study area (<5 km), this suggests good viability of kriging estimates, which will form a basis of a full "kriging with covariates" analysis that will incorporate relationships with MODIS data.

References

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