Scaling Small-footprint Airborne Laser Waveforms to Simulate DESDynI waveforms for Vegetation Structure Characterization

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Abstract - In preparation for the NASA DESDynI mission, this research is focused on scaling-up small-footprint laser waveforms to simulate space-based laser waveforms. Specifically, the goal is to examine the accuracy and success of vegetation structure retrieval algorithms on large-footprint data. Previous studies where coincident small-footprint waveform lidar have overflown ICESat/GLAS ground tracks, the synthesis method for combining the small-footprint data into a large-footprint "spacelike" waveform works well. By synthesizing space-based waveforms from small-footprint airborne waveform lidar over various biomes, height retrieval errors can be estimated which will provide a foundation to develop new algorithms for the DESDynI mission and future NASA laser altimetry missions. Data from three airborne lidar campaigns across Texas and Mississippi were synthesized to create over 400 20 m diameter footprints for analysis. Preliminary results indicate maximum canopy height retrieval errors had an RSME of 1.12 m for footprints have sufficient canopy cover within the footprint (>40%). Additionally, large-footprint structure metrics such as canopy cover and RH50 were compared against airborne estimates of canopy cover and mean canopy height, respectively.

Purpose: assess the accuracy of space-based lidar to determine vegetation structure and height errors associated with different biomes

Airborne Lidar Data Acquisition Sites

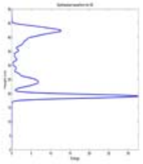
Freeman Ranch, Texas

Starr Forest, MS

Camp Shelby, MS

Methodology

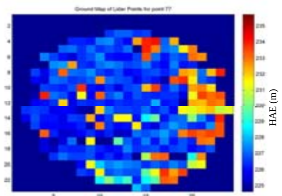
1/e² weighting



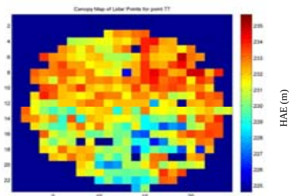
Each synthesized space-based waveform consisted of 400 – 1500 small-footprint waveforms.

Each small-footprint waveform is combined via Gaussian weighting to form a synthetic large-footprint waveform (20 m in diameter)

Locations were selected within the airborne lidar coverage and used as the centroid location of a large-footprint. From each centroid location, small-footprint laser waveforms were identified that fell within a 20 m diameter circle. The small-footprint waveforms for each simulation were then synthesized into one waveform using a Gaussian $1/e^2$ weighting as described in Neuenschwander et al. (2008).



Map of last returns from the small-footprint waveform data within a footprint. These elevations are iteratively processed to estimate the mean ground elevation for this footprint.

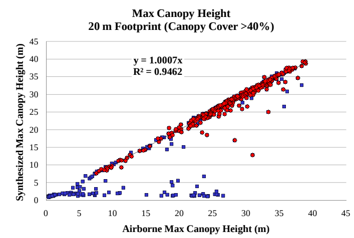


Map of first returns from the small-footprint waveform data within a footprint which represents the top of the canopy. The mean ground elevation is subtracted from the canopy map to estimate the vegetation height.

Derived Metrics

Airborne (small-footprint)	Simulated Space (large-footprint)
Ground: weighted mean of last returns classified as terrain points	**Ground:** mode of last peak
Canopy Cover: Ratio of first peaks > ground+(3 sigma of terrain points): total number of waveforms in footprint	**Canopy Cover:** Canopy energy / Total energy
Maximum Canopy: Maximum height of all first peaks	**Maximum Canopy:** 5% energy of leading edge on synthesized waveforms
Average Canopy: Mean canopy height of all waveforms	**RH50:** Relative height at 50% of returned energy
Canopy Variance: variance of canopy height from all waveforms	**RH75:** Relative height at 75% of returned energy

Q1. How accurately can we retrieve maximum canopy height from the synthesized space-based waveforms compared to the airborne small-footprint waveforms?



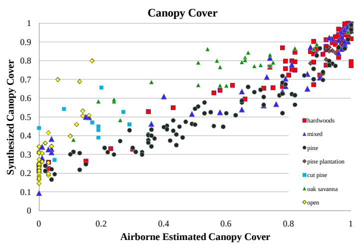
Blue points – all data
Red points - data points with canopy cover > 40%

This plot illustrates that there is a direct relationship between the small-footprint estimate and synthesized retrieved value except for two situations: 1) the laser energy does not penetrate to the ground in dense canopy and 2) not enough vegetation is present within the footprint to generate a signal that can be detected. When only points that return enough energy are analyzed (i.e. a canopy cover within the footprint > 40%) there is a strong direct relationship (R^2 =94).

This issue brings to question **how much canopy cover within the laser footprint is required to create a vegetation return.** From the three data campaigns examined here, the amount varied. At Freeman Ranch (the wooded savanna), approximately 20% canopy cover was required. However, in pine dominated landscapes 35-40% canopy cover was required.

The computed error of maximum vegetation height retrievals with canopy cover > 40 % is 0.1 m , 1.11 m RMS.

Q2. Can we extract canopy cover from large-footprint waveforms?



This figure depicts the relationship between canopy cover as derived from the small-footprint data and canopy cover derived from the synthesized waveforms separated by landcover type. As listed in Table 1, canopy cover from the synthesized footprint is the ratio of integrated canopy energy to total integrated energy for the entire waveform.

As can be observed from this plot, different relationships are apparent with different landcover types. For example, canopy cover for hardwood vegetation yields a linear relationship (R2=0.90). In contrast, oak savanna has an logarithmic relationship (R2=0.83) and pine follows an exponential relationship (R2=0.86)

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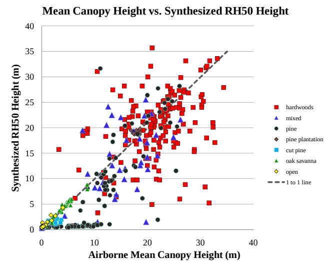
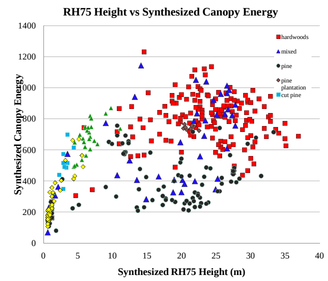
Q4. What physical height within the footprint do height metrics (e.g. RH50) correspond to?



Height metrics from large footprint waveforms are often used in the literature in a linear regression against above-ground biomass. For the Oak/Juniper savanna and open landcover classes, RH50 was strongly linearly related to mean canopy height. In addition, the RH50 height for pine plantation (i.e. pines that are managed for research purposes by Mississippi State University) corresponds to the mean canopy height of the trees within the laser footprint.

The RH50 height metric, however, did not correspond to mean canopy height for the hardwoods, mixed hardwoods/pine, and pine classes. This is likely due several factors including weak reflecting properties of pine. The hardwoods class also has a poor relationship between the RH50 derived height and the mean canopy height due to the high canopy cover for much of this landcover type and the difficulty in retrieving an accurate height.

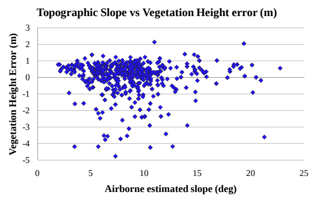
Q5: Can we separate landcover by large-footprint waveform parameters?

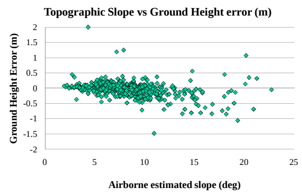


Of great desire is the ability to classify a space-based laser waveform into a landcover type based on its shape properties. For example, would it be possible to classify ICESat-1 or DESDynI waveforms as ice, ocean, or as terrestrial vegetation. Furthermore, could the terrestrial vegetation be identified as forest vs. savanna, or conifer vs. broadleaf.

This figure depicts waveform properties of Canopy Energy vs. RH95 height derived from each synthesized large-footprint waveform. From this figure, it is easy to identify clear groupings of landcover type based on these two waveform parameters. Additional variables that can be derived from the large-footprint waveforms could yield additional discriminatory power for general surface classifications.

Q3: Does topographic slope impact maximum vegetation height retrievals?





These figures depict the relationship between topographic slope and retrieved height error of both the ground and maximum vegetation heights. Height errors are the residuals between the airborne estimated value and the elevation derived from the synthesized waveforms. There appears to be a negative trend in ground height estimate as a function of topographic slope which is likely attributed to pulse broadening. This topographic effect subsequently enters the error for vegetation height retrievals, yet as can be observed in the figures, it is only a small portion of the vegetation height error.

Concluding Thoughts

1) Vegetation height retrievals with a 1 m RMS is possible from space-based platforms for temperate ecosystems.
2) Canopy cover can be estimated from waveform data over temperate ecosystems; however the relationship varies as a function of landcover type and is not linear.
3) A minimum amount of canopy cover within the footprint is needed to generate a canopy return. This ranges from 20 – 40% canopy cover and is landcover type dependent.
4) Properties from waveforms can potentially identify and classify landcover types.
5) Topographic slope plays a limited role in the recovered vegetation height errors.