Assessment of ICESat-2 ATL08 Canopy Height Estimates for Tropical Forests in the Americas

Juan Fernandez-Diaz[1], Mariya Velikova[1], and Craig Glennie[1]

[1]University of Houston

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Abstract

A secondary mission objective of NASA's Ice, Cloud and Land Elevation Satellite-2 (ICESat-2) is to derive vegetation heights that can be used to refine estimates of above-ground biomass at a global scale [1] & [2]. In this work we assess the accuracy of ICESat-2 derived canopy height (CH) retrieval in dense, late-succession, tropical forests in Mexico, Belize, Guatemala, Honduras, Costa Rica and Brazil. Over 28,000 ICESat-2 ATL-08 canopy height estimates (CHe) are compared against equivalent metrics derived from spatially coincident linear-mode high density airborne lidar (HDL) data obtained over a variety of forests exhibiting different structural characteristics and underlying terrain conditions. Our preliminary results indicate that in these high closure forests the ATL08 canopy height estimates (CHe) differ to the airborne lidar canopy heights (CHr) over a very wide range. The 5 to 95 percentile errors range between an underestimation of negative 26 m to an overestimation of 27 m; with an interquartile range (IQR) between -14 to 0.25 m. When the samples are stratified using the (CHr) into 5 meter classes (5-10, 10-15, . . . , 40-45 m), the IQR of the canopy heigh estimation errors grows exponentially in relation to the CHr (1.25e^0.057 ; R2=0.97), while the median for each class decreases linearly at a rate of -0.174m/m (R2 = 0.88). When the ATL08 CHe are normalized to the reference CH the median of the errors exhibit a mostly uniform behavior around an underestimation level of 16.4% . By analyzing the behavior of other ATL08 parameters such as the terrain elevation and top of canopy elevations (both absolute elevations above the ellipsoid) as a function of the CHr, it is apparent that the gradual underestimation of the vegetation height is due to the inability of the ICESat-2 sensor and algorithms to accurately detect the terrain under these dense late-succession tropical forests.

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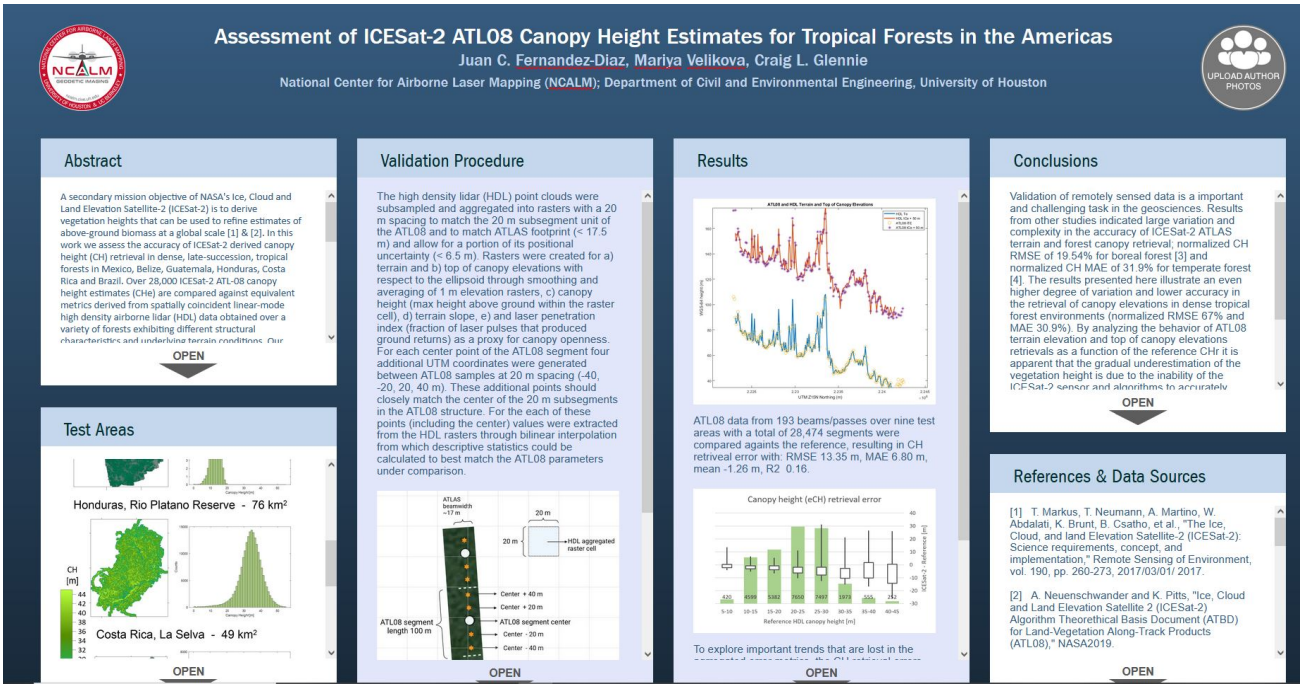
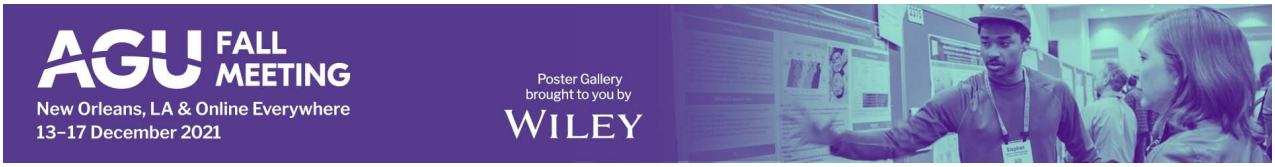


Juan C. Fernandez-Diaz, Mariya Velikova, Craig L. Glennie
National Center for Airborne Laser Mapping (NCALM); Department of Civil and Environmental Engineering, University of Houston

Presented at:



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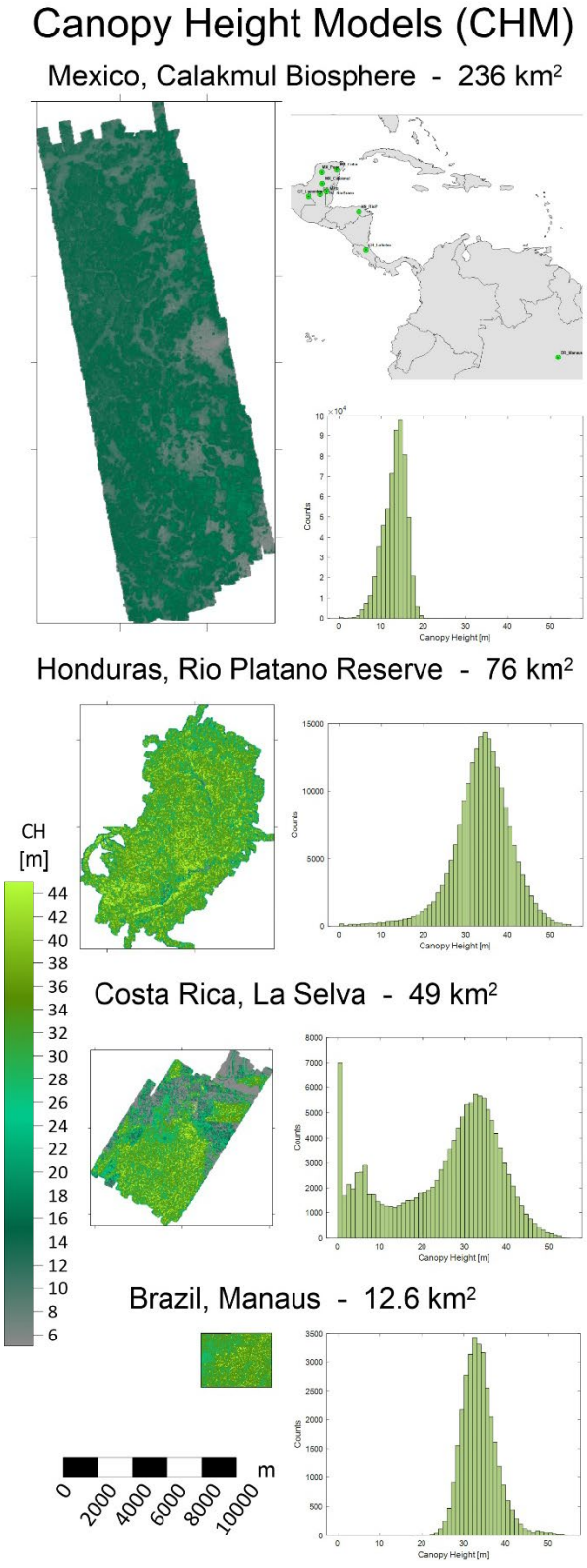
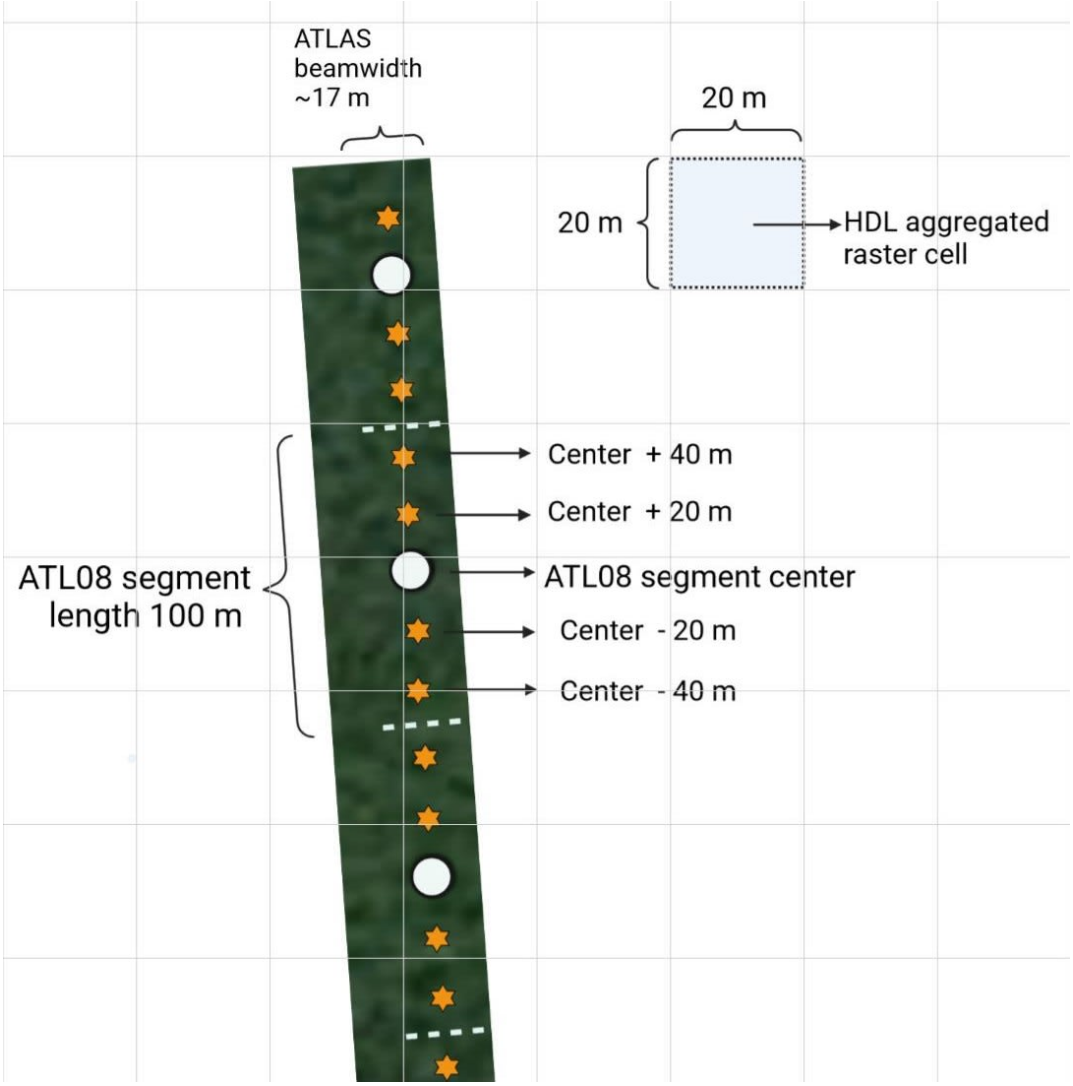
A secondary mission objective of NASA's Ice, Cloud and Land Elevation Satellite-2 (ICESat-2) is to derive vegetation heights that can be used to refine estimates of above-ground biomass at a global scale [1] & [2]. In this work we assess the accuracy of ICESat-2 derived canopy height (CH) retrieval in dense, late-succession, tropical forests in Mexico, Belize, Guatemala, Honduras, Costa Rica and Brazil. Over 28,000 ICESat-2 ATL-08 canopy height estimates (CHe) are compared against equivalent metrics derived from spatially coincident linear-mode high density airborne lidar (HDL) data obtained over a variety of forests exhibiting different structural characteristics and underlying terrain conditions. Our preliminary results indicate that in these high closure forests the ATL08 canopy height estimates (CHe) differ to the airborne lidar canopy heights (CHr) over a very wide range. The 5 to 95 percentile errors range between an underestimation of negative 26 m to an overestimation of 27 m; with an interquartile range (IQR) between -14 to 0.25 m. When the samples are stratified using the (CHr) into 5 meter classes (5-10, 10-15, …, 40-45 m), the IQR of the canopy heigh estimation errors grows exponentially in relation to the CHr (1.25e^0.057 ; R2=0.97), while the median for each class decreases linearly at a rate of -0.174m/m (R2 = 0.88). When the ATL08 CHe are normalized to the reference CH the median of the errors exhibit a mostly uniform behavior around an underestimation level of 16.4% . By analyzing the behavior of other ATL08 parameters such as the terrain elevation and top of canopy elevations (both absolute elevations above the ellipsoid) as a function of the CHr, it is apparent that the gradual underestimation of the vegetation height is due to the inability of the ICESat-2 sensor and algorithms to accurately detect the terrain under these dense late-succession tropical forests.

Test Areas


Canopy Height Models (CHM)
Mexico, Calakmul Biosphere - 236 km²
Counts
Canopy Height [m]
Honduras, Rio Platano Reserve - 76 km²
CH
[m]
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
Costa Rica, La Selva - 49 km²
Brazil, Manaus - 12.6 km²
0
2000
4000
6000
8000
10000
m

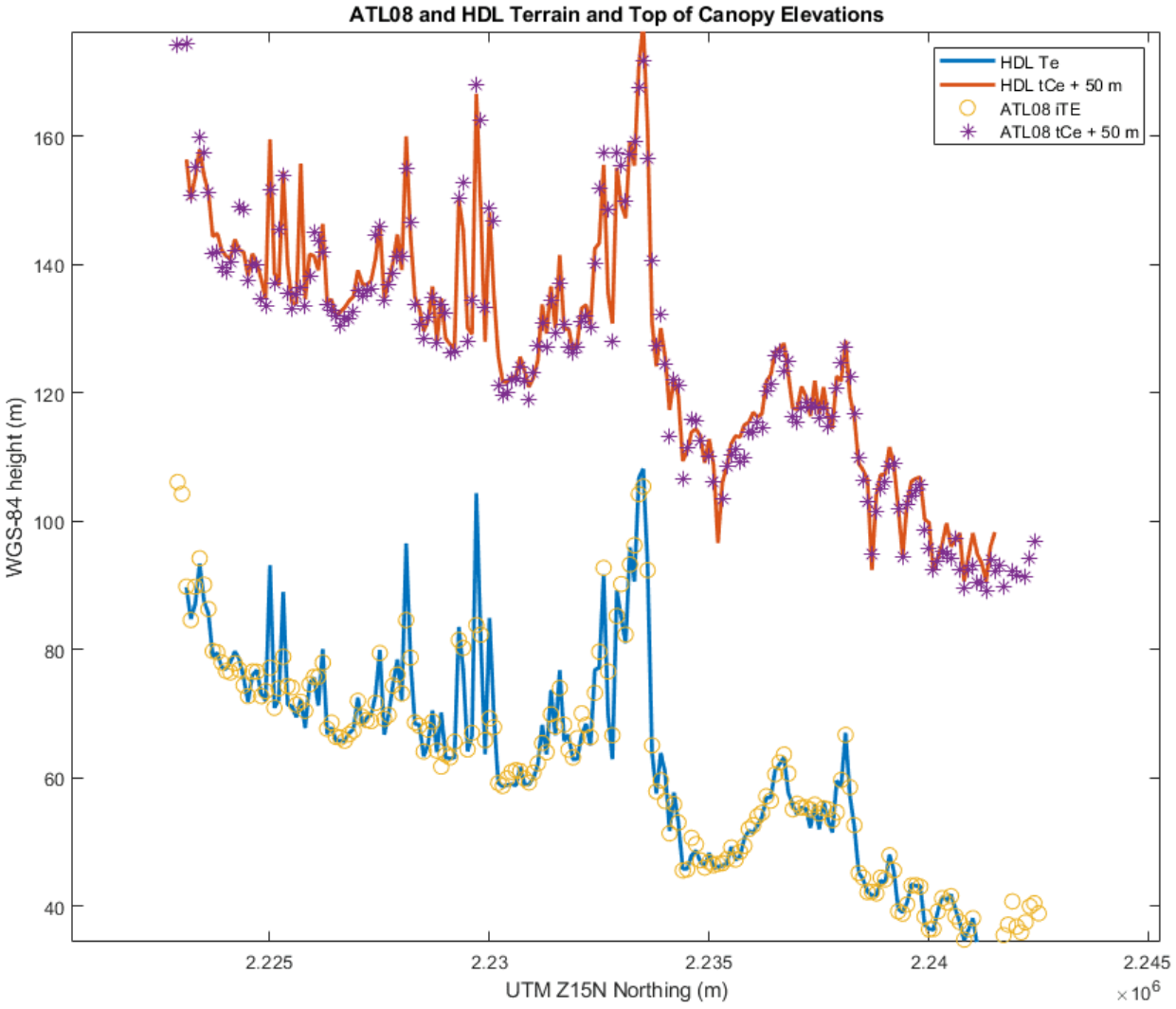
Validation Procedure

The high density lidar (HDL) point clouds were subsampled and aggregated into rasters with a 20 m spacing to match the 20 m subsegment unit of the ATL08 and to match ATLAS footprint (< 17.5 m) and allow for a portion of its positional uncertainty (< 6.5 m). Rasters were created for a) terrain and b) top of canopy elevations with respect to the ellipsoid through smoothing and averaging of 1 m elevation rasters, c) canopy height (max height above ground within the raster cell), d) terrain slope, e) and laser penetration index (fraction of laser pulses that produced ground returns) as a proxy for canopy openness. For each center point of the ATL08 segment four additional UTM coordinates were generated between ATL08 samples at 20 m spacing (-40, -20, 20, 40 m). These additional points should closely match the center of the 20 m subsegments in the ATL08 structure. For the each of these points (including the center) values were extracted from the HDL rasters through bilinear interpolation from which descriptive statistics could be calculated to best match the ATL08 parameters under comparison.

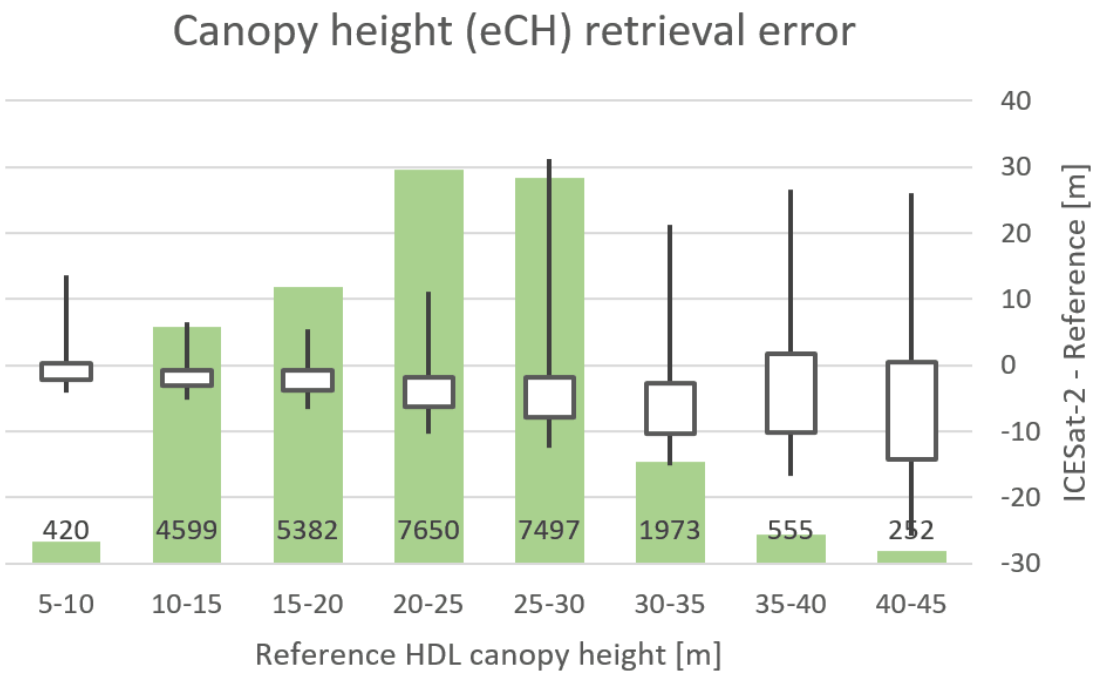


For each matching ATL08 segment and aggregated HDL metric, individual (per sample) retrieval errors were computed by subtracting the HDL reference values from the ATL08 values, from these per sample errors aggregated error metrics such as root mean square error (RMSE), mean absolute error (MAE), and coefficient of determination (R^2) were computed.

Results



ATL08 data from 193 beams/passes over nine test areas with a total of 28,474 segments were compared againts the reference, resulting in CH retriveal error with: RMSE 13.35 m, MAE 6.80 m, mean -1.26 m, R2 0.16.



To explore important trends that are lost in the agrregated error metrics, the CH retrieval errors were grouped by reference CH in 5 meter wide strata. As the reference CH increases, the size of the IQR increases exponentially (R2 = 0397) , while the median indicates a linear underestimation a rate of -0.174m/m (R2 = 0.88). When the ATL08 CHe are normalized to the reference CH the median of the errors exhibit a mostly uniform behavior around an underestimation level of 16.4% .

Conclusions

Validation of remotely sensed data is a important and challenging task in the geosciences. Results from other studies indicated large variation and complexity in the accuracy of ICESat-2 ATLAS terrain and forest canopy retrieval; normalized CH RMSE of 19.54% for boreal forest [3] and normalized CH MAE of 31.9% for temperate forest [4]. The results presented here illustrate an even higher degree of variation and lower accuracy in the retrieval of canopy elevations in dense tropical forest environments (normalized RMSE 67% and MAE 30.9%). By analyzing the behavior of ATL08 terrain elevation and top of canopy elevations retrievals as a function of the reference CHr it is apparent that the gradual underestimation of the vegetation height is due to the inability of the ICESat-2 sensor and algorithms to accurately detect the terrain under these dense forests. However, the results are encouraging in that the median of the relative errors of canopy heights seems to exhibit a uniform behavior that can be used to propagate uncertainty to models and algorithms that leverage ATL08 canopy data.

References & Data Sources

[1] T. Markus, T. Neumann, A. Martino, W. Abdalati, K. Brunt, B. Csatho, et al., "The Ice, Cloud, and land Elevation Satellite-2 (ICESat-2): Science requirements, concept, and implementation," Remote Sensing of Environment, vol. 190, pp. 260-273, 2017/03/01/ 2017.

[2] A. Neuenschwander and K. Pitts, "Ice, Cloud and Land Elevation Satellite 2 (ICESat-2) Algorithm Theorethical Basis Document (ATBD) for Land-Vegetation Along-Track Products (ATL08)," NASA2019.

[3] A. Neuenschwander, E. Guenther, J. C. White, L. Duncanson, and P. Montesano, "Validation of ICESat-2 terrain and canopy heights in boreal forests," Remote Sensing of Environment, vol. 251, p. 112110, 2020/12/15/ 2020.

[4] L. Malambo and S. C. Popescu, "Assessing the agreement of ICESat-2 terrain and canopy height with airborne lidar over US ecozones," Remote Sensing of Environment, vol. 266, p. 112711, 2021/12/01/ 2021.

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Data for seven of the nine test areas were collected by the National Center for Airborne Laser Mapping for investigators working on archaeological prospection in jungle enviorments. We acknowledge those investigators and their projects, whihc allowed for this value-added research.

The Costa Rica, la Selva dataset was collected by 3001 for the Volcan Barva TEAM and downloaded from OpenTopopgraphy https://doi.org/10.5069/G9P8491K.

Data for the Brazil, Manaus dataset is part of the 2019 dataset by dos-Santos, M.N., M.M. Keller, and D.C. Morton. LiDAR Surveys over Selected Forest Research Sites, Brazilian Amazon, 2008-2018. ORNL DAAC, Oak Ridge, Tennessee, USA. http://https://doi.org/10.3334/ORNLDAAC/1644