Identifying Secondary Forests in the Brazilian Amazon using Spaceborne Lidar

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1. Introduction

Lidar data have been shown to be helpful in discriminating secondary from primary forest, both alone and in combination with other sensors. Drake et al. (2002) used the Laser Vegetation Imaging Sensor (LVIS) to examine primary forests and secondary forests at 14, 22, and 31 years at La Selva Biological Station. Four waveform-derived metrics (lidar canopy height, height of median energy, height/median ratio, and ground return ratio) were evaluated. Secondary growth sites were virtually indistinguishable from older (22 and 31 years old) secondary forests with respect to the height/median and ground return ratios, but the height of median energy and height/median ratio enabled separation of secondary from primary forest regardless of the age of the former. Castillo et al. (2012) also used LVIS data to characterize secondary forests in Guanacaste, Costa Rica (a tropical dry forest site). Using only three return levels (heights at which the normalized cumulative return energy reached 50, 75, and 100% of the total energy reflected by the target) they were able to separate successional stages of secondary forest. A preceding study by almost the same team (Castillo-Núñez et al., 2011) found maximum canopy heights to be estimated reasonably accurately (RMSE = 1.3 m) by waveform lidar (using only the LVIS canopy elevations maximum canopy height) in the same tropical dry forest environment. Caughlin et al. (2016) estimated canopy cover and height associated with forest regrowth in Los Santos Province, Panama using a canopy height model derived from Carnegie Airborne Observatory-2 waveform data and the mean photosynthetic fraction derived from four Landsat Thematic Mapper images acquired near the same time as the lidar data.

A study of forest transition in the Amazon requires separation of primary from secondary forest. With optical data this is only feasible for a short period after the initiation of regrowth unless the area of prior clearing is known. In either case small clearings and subsequent secondary regrowth can be missed. Secondary growth mapping using maps of primary forest loss is, of course, limited to the accuracy and minimum mapping unit of those maps. Lidar data appear able to discriminate secondary from primary forest for decades after regrowth began, but their suitability for land cover and land use change studies has heretofore been limited by their necessarily limited coverage. That has now changed in the area of NASA spaceborne lidars.

2. Objective

Our overall objectives are to (1) use the Rural Environmental Registry (Cadastro Ambiental Rural - CAR), current MapBiomas classifications, stand maps from industrial partners, and our collaborator's expertise to identify classes of land use histories of interest, with a focus on disturbed areas that appear have recovered to secondary forests, and (2) use NASA spaceborne lidars (GEDI02B and ATL08 products) to develop a structurally-mediated identification and characterization of secondary forests in portions of the legal Amazon.

3. Methods

3.1 Study Area

We are initially focusing only on (1) areas of the Amazon that MapBiomas has classified as forests that were previously recorded as having been cleared in the CAR, and (2) known forest plantations.

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3.2 CAR

The CAR is an online, electronic land registry and is required for all private land properties in Brazil. In the CAR, the landowner (with assistance from a qualified technical professional or the government) reports to the state and federal governments the extent of each of these areas and where they are located within the property in question. As of May 2019, the number of registered properties was 5,983,649, which summed up to a total area of approximately 24 times the size of Germany, with 205 million hectares of original vegetation cover.

3.3 MapBiomas

The Brazilian Annual Land Use and Land Cover Mapping Project (MapBiomas) is a multi-institutional collaboration that has generated a Landsat-derived land use and land cover time series for Brazil, computed in Google Earth Engine. The products include 30 m land use and land cover maps, 28-layer image mosaics including spectral bands and indices, derived maps and statistics organized by biome from 1985.

3.4 Lidar Data

Metrics from GEDI (02B) and ICESat-2 (ATL08) are being used. 19 variables in GEDI02B (elev_lowest mode, toploc, botloc, Pgap (z, theta), cover, cover_z, pai, pai_z, pavd_z, Rh100, rhog, rhov, Rg, Rv, local_beam_elevation, Omega, Ross-G, LC, and Sensitivity) are in the modeling framework. There are 34 canopy variables in the ATL08 product, but we are only using relative height metrics, reducing that by 12. As such, the metrics used are canopy_h_metrics (25, 50, 60, 70, 75, 80, 85, 90, 95), h_canopy, h_mean_canopy, h_dif_canopy, h_min_canopy, h_max_canopy, canopy_openness, toc_roughness, h_canopy_quad, n_ca_photons, n_toc_photons, centroid_height, canopy_flag, Landsat_flag. The 91-day repeat of ICESat-2 is substantially reducing data availability in some persistently cloudy forests.

3.5 Finding Secondary Growth using MapBiomas and CAR data

The CAR data by themselves do not have secondary growth as a class. We are identifying secondary growth as CAR-identified forest loss that is forest on the 2019 MapBiomas classification. Neither the CAR nor MapBiomas is completely correct (otherwise we would not need to assess secondary forest growth with spaceborne lidar data), but with field verification by trained interpreters at the Universidade Federal de Lavras we are able to create a high-quality random but balanced sample of secondary forest growth, along with areas that have not been disturbed and those that have been disturbed but on which (secondary) forests have not been re-established.

3.5 Analysis

Classification is being conducted using random forests. We recently pioneered an iterative modeling framework approach in which each random forests model is run with an iterative bootstrapping approach to include all available in-bag training data while also using an out-of-bag sample for model evaluation. The result of this process is that each individual footprint or segment has 500 labels, enabling a *de facto* estimate of uncertainty at the segment or footprint level, as the strength of the assignment can be determined from the distribution of assigned classes. Classification accuracy is being assessed using standard methods.

4. Early Results

While the analyses are not yet complete, visualizations indicate some likelihood of success (Figure 1 and Figure 2). In Figure 1, the upper left shows actual ground hits for the “3L” beam of ICESat-2 ground reference track 1268 on June 20, 2019 (left track) and on December 20, 2018 (right track) for a small area in the western Amazon where secondary forest patches have been identified in the CAR. The lower left shows an enlarged CAR polygon with 3 highlighted ICESat-2 ATL08 samples. Samples A and B are outside the CAR polygon, with no known history of disturbance. Sample C is secondary forest. The right-hand side of the figure shows cumulative relative heights extracted from ATL08 data for the three samples.

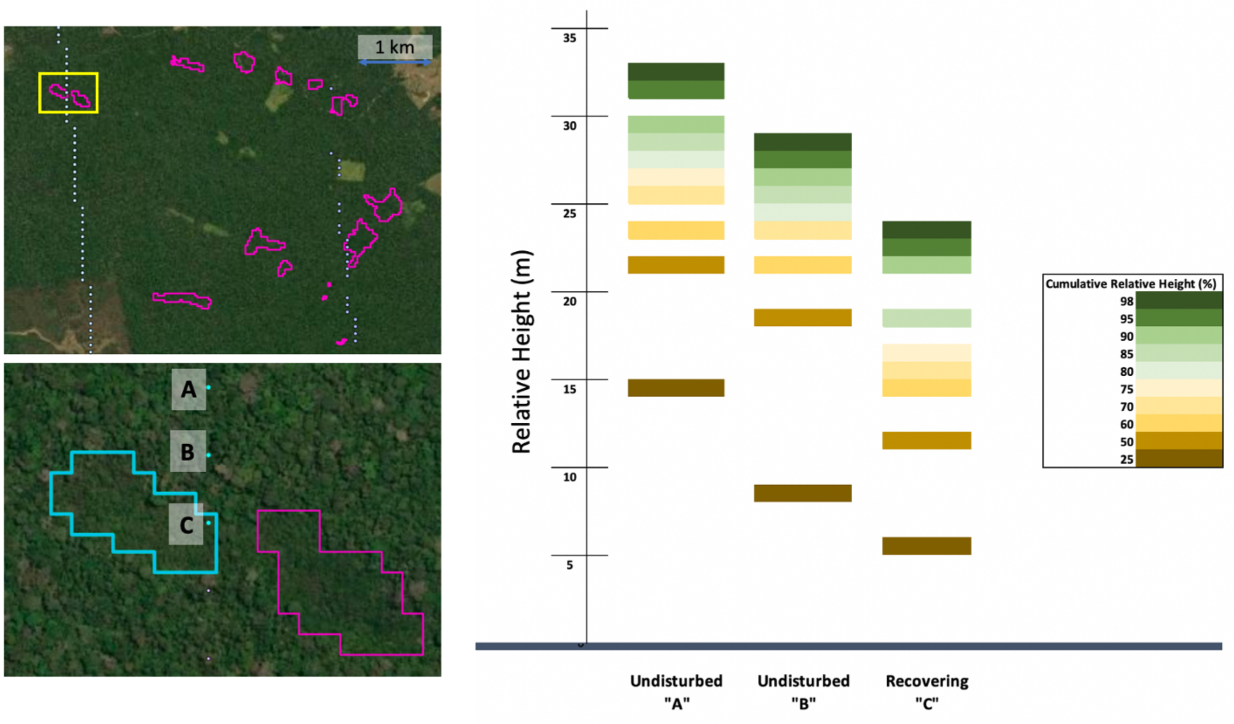

Figure 1. Examples of interactions between ICESat-2 and the CAR.

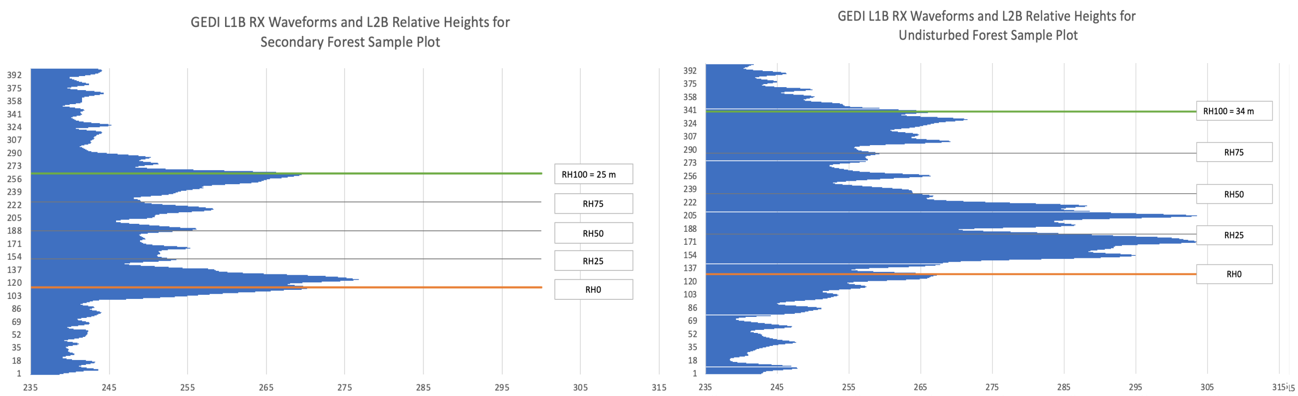

Figure 2. Examples of interactions between GEDI and the CAR.

Figure 2 shows specified shots chosen from ground hits for beam 0010 of GEDI ground reference track 3218 on July 8, 2019 in the western Amazon where secondary forest polygons from the CAR were supplemented with examples in surrounding undisturbed forest. Shown in this figure are extracted RX waveforms from the GEDI 1B product along with estimated relative heights from GEDI 2B.

References

Castillo, M, Rivard, B, Sanchez-Azofeifa, GA, Calvo-Alvarado, J, and Dubayah, R, 2012, Lidar remote sensing for secondary tropical dry forest identification. *Remote Sensing of Environment*, 121:132–143.

Castillo-Núñez, M, Sanchez-Azofeifa, and others, 2011, Delineation of secondary succession mechanisms for tropical dry forests using LiDAR. *Remote Sensing of Environment*, 115:2217–2231.

Caughlin, TT, Rifai, SW, Graves, SJ, Asner, GP, and Bohlman, SA, 2016, Integrating lidar-derived tree height and Landsat satellite reflectance to estimate forest regrowth in a tropical agricultural landscape. *Remote Sensing in Ecology and Conservation*, 2(4):190–203.

Drake, JB, Dubayah, RO, and others, 2002, Estimation of tropical forest structural characteristics using large footprint lidar. *Remote Sensing of Environment*, 79(2):305–319.