AIRBORNE UV LIDAR FOR FOREST PARAMETER RETRIEVALS

Xiaoxia Shang*, Patrick Chazette, and Julien Totems

*Laboratoire des Sciences du Climat et de l'Environnement, CEA-CNRS-UVSQ, 91191 Gif-sur-Yvette Cedex, France, *Email: xiaoxia.shang@gmail.com*

ABSTRACT

A full-waveform UV lidar performed airborne measurements over several temperate and tropical forests sites. The structural and ecological parameters (canopy height, quadratic mean canopy height and apparent foliage) were extracted from lidar backscattered profiles. The aboveground carbon and leaf area index are also evaluated from lidar measurements.

1. INTRODUCTION

Representing 80% of the continental biospheric carbon, forests play a crucial role in Earth's carbon cycle by absorbing carbon dioxide from the atmosphere and storing it into biomass. They are also important sources and sinks for several atmospheric chemical species (e.g. volatile organic compounds, ozone). Both energy and chemical component fluxes between the low troposphere and the biosphere remains however largely unknown. What is clear is that it crucially depends on forest properties such as living biomass, composition and spatial structure. Measuring the three-dimensional vegetation structure of forests is thus essential to address this issue, as such structure contains a substantial amount of information about the state of development of plant communities and their potential to interact with the low troposphere. Active remote sensing instruments, including lidar and radar, can peer through the forest canopy down to the ground level. In particular, a dedicated lidar can provide a full description of the forest vertical structure (including canopy top, tree crown base height and understory structures) [1][2]. A full-waveform lidar with a large footprint can reliably extract the vertical structure of an optically thick tropical rainforest [3].

2. METHODOLOGY

The full-waveform UV lidar ULICE (Ultraviolet LIdar for Canopy Experiment), developed in our laboratory as a spaceborne demonstrator, performed airborne measurements over varied temperate and tropical forest biomes. Its main characteristics are given in Table 1. The use of UV spectral domain (355 nm) leads to a significant reduction of the multiple scattering effects, compared to near infrared wavelengths, in the forest structures. Depending on the sampled site, ULICE has 2 operation modes: the *classic* mode for temperate forests, and *tropical* mode for tropical forest. Their footprints diameters at the ground are ~2 m or ~10 m, respectively, for a flight altitude of ~300 m above the ground level.

The lidar system was embedded on an Ultra-Light Aircraft (ULA) as shown in Figure 1. It is coupled with an ancillary instrument which provides the position and the attitude information of the ULA to derive the angle between the lidar line of sight and the nadir direction. The principle of the canopy lidar measurement is shown in Figure 2, along with a schematic lidar backscattered profile showing forest vertical structures.

Table 1. Main characteristics of ULICE (Ultraviolet LIdar for Canopy Experiment).

	Characteristics	ULICE *classic*	ULICE *tropical*
Emitter	Wavelength	355 nm	
	Mean energy per pulse	~7 mJ	
	Pulse duration	~6 ns	
	Pulse repetition frequency	1–100 Hz	
	Beam diameter	20 mm	
	Maximum beam divergence	9 mrad	40 mrad
Receiver	Reception diameter	150 mm	
	Reception optical density	adjustable	
	Filter bandwidth	0.3 nm	10 nm
	Total field of view	5 mrad	33 mrad
	Detector	Photomultiplicateur	
	Detection mode	Analog	
Acquisition	Sampling frequency	100-500 MHz	
Global	Weight of the optical head	~20 kg	
	Weight of the electronics	~15 kg	
	Electric supply (2×12V batteries)	24 V/~400 W	

Figure 1. Photo of ULICE onboard ULA.

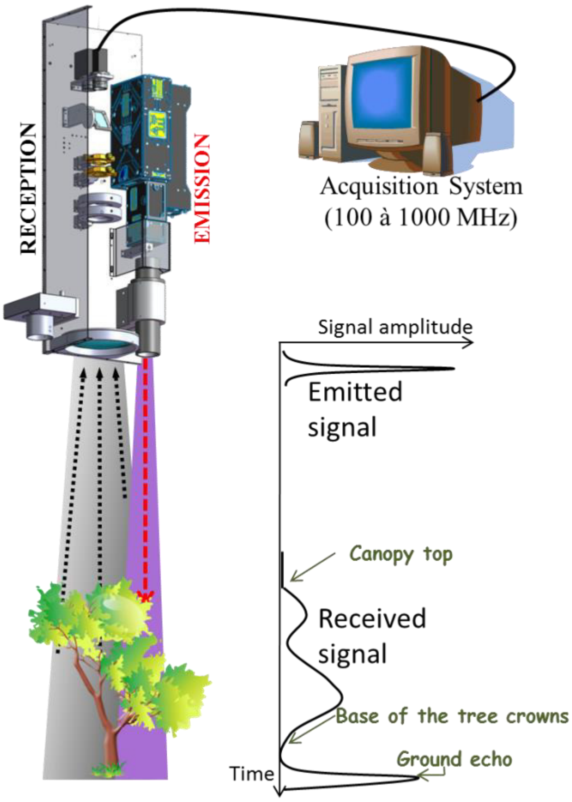

Figure 2. Principle of the canopy lidar measurement.

3. RESULTS

In order to characterize the forest biomes, the structural and ecological parameters are studied, such as the canopy height (CH), the aboveground carbon (AGC), and the leaf area index (LAI). Here we present some results for our sampling sites.

3.1 Structural parameters

Lidar backscatter profiles include a signature from vertical forest structures, which is dominant compared to the atmospheric contribution. Hence, the canopy height (CH) can be extracted as the distance between the first return at the upper surface of the vegetation and the last return at the ground surface, with a mean uncertainty of ~1.5 m. An example of lidar-derived CH is given in Figure 3. The vertical structure within the canopy is also important for forest studies, and can be extracted from lidar backscatter profiles as shown in Figure 4 for a tropical forest in the Réunion Island. The weighted height – quadratic mean canopy height (QMCH) – was used to evaluate the aboveground carbon by several authors [1][4][5], via the relationship found between the QMCH and the AGC as shown in Figure 5.

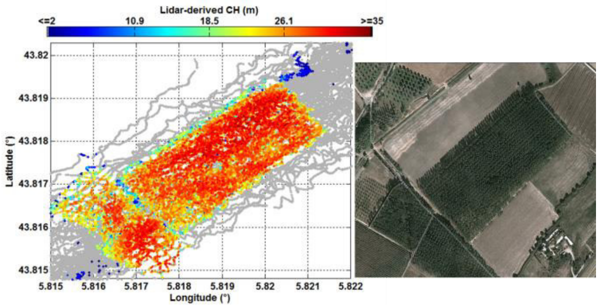

Figure 3. Canopy height (CH) of a plantation of poplar (the footprint diameter at the ground was ~2 m). The satellite view (Google Earth™) of sampled site is on the right.

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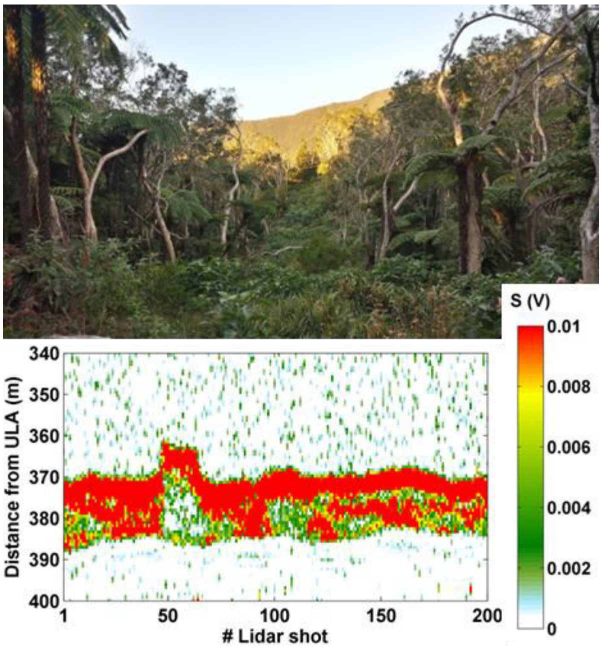

Figure 4. Upper panel: Photo of the sampled tropical forest. Bottom panel: Example of lidar signals over the tropical forest (the footprint at the ground was ~10 m).

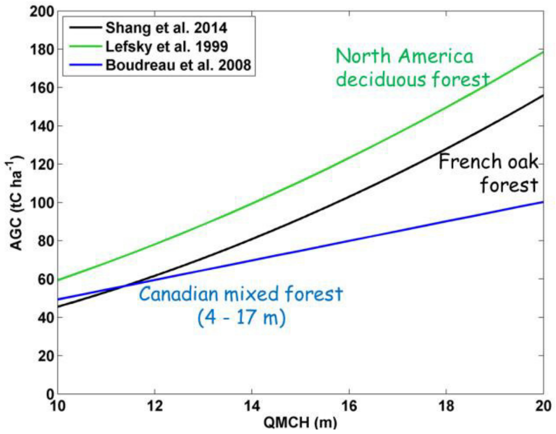

Figure 5. The relationships between QMCH and AGC published.

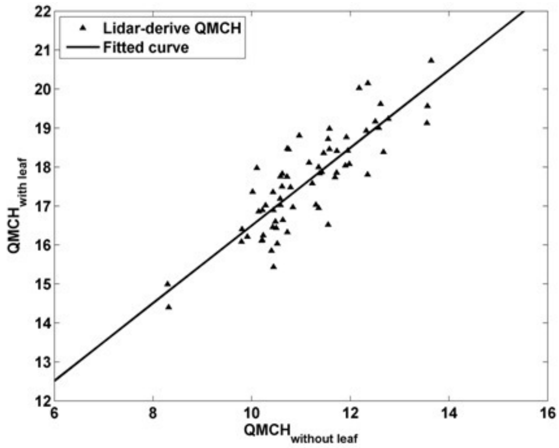

Figure 6. Comparison among the plot-level QMCHs, which are derived from experiments in summer (with leaf) and winter (without leaf). The relationship is found to be $QMCH_{with\ leaf} = 0.996 \times QMCH_{without\ leaf} + 6.5$ (r^2 ~0.7).

The effect of leaves on the AGC estimation was studied. By comparing the summer and winter lidar measurements for the same temperate forest site, we found that the different canopy structures imply a significant difference of the QMCH with a mean value ~6 m (Figure 6), which would lead to an AGC overestimation of ~50% in summer when using a calibration done in winter. This overestimation could be considered as a systematic bias and be corrected.

3.2 Ecological parameters

Lidar is also a powerful instrument to retrieve the leaf area index (LAI) [3] using the vertical profile of apparent foliage which informs on both the canopy density and the vertical distribution of leaf biomass along the profile. The lidar-derived forest optical thickness (FOT), depending on the canopy extinction coefficient, was found to get a linear relationship with the mean LAI derived from MODIS over a larger sample site of pin forest as shown in Figure 7. The lidar-derived LAI index seems to overestimate the LAI, because our lidar sampled only the forest area whereas the MODIS production integrated both forest and non-forest area for each considered pixel of 1 km × 1 km.

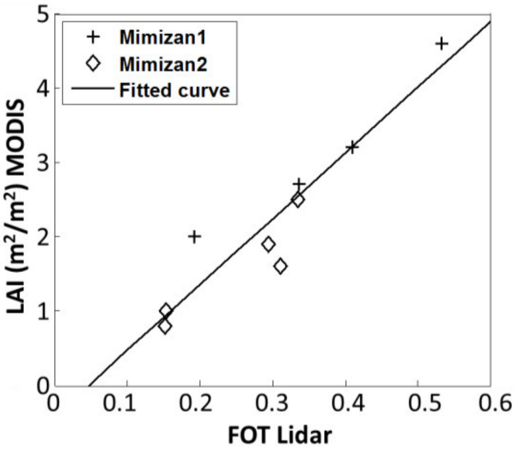

Figure 7. Comparison between FOT computed from lidar measurements and LAI estimated via MODIS for 9 pixels of 1 km × 1 km in a pin forest.

3.3 Application to forest type classification

Using the average values and variability of both CH and LAI, 7 tropical forest sites of the Réunion Island were classified.

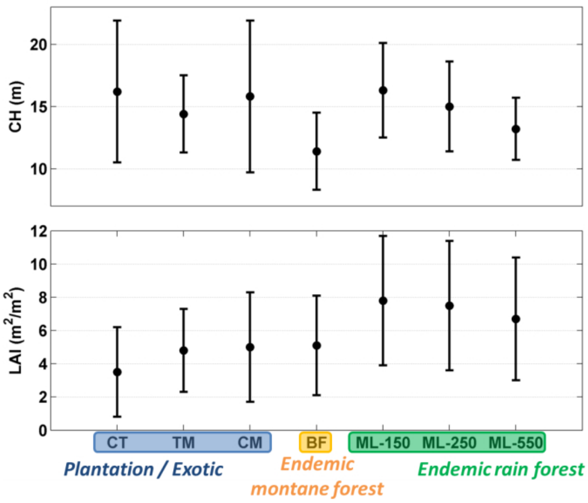

Figure 8. Mean (dot) and standard deviations (line segments) of canopy height and leaf area index for 7 tropical forest site: coastal (CT), Tamarind (TM), Cryptomeria (CM), Bélouve (BF), and Mare-Longue (ML-150, 250 and 550) sites. Measurements with CH < 5 m are not considered.

These tropical forests range from coastal to rain forest, including montane cloud forest. As shown in Figure 8 we can identify 2 groups: the endemic (montane/rain) forests and the planted/exotic forests.

4. CONCLUSIONS

Airborne lidar measurements were performed over several temperate and tropical forests sites, which allowed building a representative database of lidar vertical profiles. We extracted the structural and ecological parameters (canopy height, quadratic mean canopy height and apparent foliage) from lidar backscattered signal, and then evaluate the aboveground carbon and leaf area index. Even though UV lidar is not a good candidate for spaceborne missions due to the weak atmospheric transmission and the strong absorption by the vegetation in the UV domain, we confirm that the UV wavelength is a good candidate for airborne lidar measurements, and can be a very interesting reference for a spaceborne mission dedicated to forest studies at the global scale.

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