TREE AND CROWN HEIGHT ASSESSEMENTS OF A MARITIME PINE FOREST AT PLOT LEVEL USING A FULLWAVEFORM ULTRAVIOLET LIDAR PROTOTYPE

Tristan Allouis [a,*], Student Member, IEEE, *Sylvie Durrieu* [a], *Juan Cuesta* [b], *Patrick Chazette* [b], *Pierre H. Flamant* [b], *Pierre Couteron* [c]

[a] Cemagref / AgroParisTech, UMR TETIS, Montpellier, France
[b] Institut Pierre Simon Laplace, LMD / LSCE, Palaiseau / Gif sur Yvette, France
[c] Institut de Recherche pour le Développement, UMR AMAP, Montpellier, France
* Corresponding author. E-mail address: tristan.allouis@teledetection.fr

1. INTRODUCTION

Lidar (light detection and ranging) is an active technique based on the emission and reception of laser pulses. It enables surface relief measurement, as passive techniques do, but also provides additional information on the vegetation structure inside and below the canopy. It is commonly used in the forestry research field to characterize tree or stand heights [1], total volume and spatial organization of vegetation material [2]. These data can be used as inventory data for forestry management and as model input data for ecological applications. The lidar system parameters (laser beam divergence, laser wavelength, measurement repetition rate, waveform digitization frequency) and flight parameters (altitude, speed) have an impact on the recorded backscattered signals and on the way the forest is sampled (laser footprint size, distance between footprints). These parameters must therefore be chosen related to the scale of observation, the needed precision and the amount of data to be managed.

The aim of this study is to determine the potential of a new lidar prototype with an ultraviolet (UV) laser and a medium footprint (2.4 m diameter) [3] to provide forest structure information at plot level.

2. MATERIAL

2.1. Lidar system

The lidar prototype is a profiler based on the LAUVA (Airborne UltraViolet Aerosol Lidar) initially developed by the Commissariat à l'Énergie Atomique (French Atomic Energy Commission) and the Centre National de la Recherche Scientifique (National Center for Scientific Research) for atmospheric applications [4]. The system was modified for canopy measurements. The laser beam footprint has a 2.4 m diameter for a 300 m flight altitude. Such footprint size is in between conventional small footprint topographic lidars and large footprint experimental systems, providing respectively 15 cm to 1 m and 10 m to 70 m footprint diameters [5] [6]. The UV wavelength was chosen for its ability to characterize the atmosphere, while providing adequate eye safety. The lidar emits high energy pulses (17 mJ versus < 0.2 mJ for commercial near infrared topographic lidars) to obviate the difference in vegetation response regarding the wavelength. Actually, reflectance and transmittance of vegetation in the UV wavelength are lower than in the near infrared wavelength traditionally used in earth surface observation lidars. The fullwaveform backscattered signal is recorded with a 100 MHz sampling rate witch provides a vertical measurement precision of 1.5 m.

The lidar was embedded on an ultra-light aircraft (ULA) for rapid deployment and flexibility of flight plans. The ULA flies at about 30 m/s, and the lidar operates at 20 Hz during one second every two seconds. Considering that the laser footprint diameter is 2.4 m, we get sequences of continuous measurements along 30 m profiles every 30 m.

2.2. Study site

The experiment took place on the Landes forest (Landes of Gascony) in southwestern France (44° 10' N, 1° 12' W). It is the largest Maritime pine (*Pinus pinaster*) forest in Europe. With a planted area of about a million hectares it is a major economic pole in France with 30,000 jobs related to forestry and wood transformation.

The lidar flew on three different stands of about 1.2 km^2 each in the Mimizan commune: a young plantation, a middle-aged plantation and a mature naturally regenerated stand. For each stand, reference field data were acquired in measuring both the tree total height and the crown base height of each tree within a square plot of 30x30 m (Table 1).

3. METHOD

Lidar measurements were geolocated using both the position and the orientation of the system, measured by a differential GPS (DGPS) and an electronic flight instrument system (EFIS) respectively. The EFIS provides angles measurements with an accuracy of 0.5° and one EFIS measurement and five DGPS measurements are available for one 20 lidar shots sequence. Consequently, the (X, Y, Z) geolocation accuracy of a lidar spot is estimated to be about 5 m.

This low geolocating accuracy is not compatible with a study at tree level. Therefore, we chose to compare lidar and field measurements at plot level by summing the 20 successive backscattered signals, for a sequence of footprints located in each plot. This level of study also corrpesponds to traditional forest inventory field measurements level. In addition, the probability to obtain a ground echo within the waveform sum is increased. Each waveform sum was then transformed into reflectance profile according to an adaptation of the MacArthur and Horn equation [7]. This adapted equation transforms the backscattered lidar signal into the amount of cover per height class, while taking account of lidar signal attenuation inside the vegetation.

Finally, the location of the last reflectance profile peak is considered to correspond with the ground range (R_{ground}). The first reflectance profile point that exceeds the noise level is considered to correspond with the top of canopy range (R_{top}). The point situated before the strongest decrease of reflectance profile and between the last canopy increase and the ground peak is considered to correspond with the crown base range (R_{crown}). The distance between R_{ground} and R_{top} is assumed to be the plot mean total height. The distance between R_{ground} and R_{crown} is assumed to be the plot crown base mean height. These two heights are then compared to the reference data. To that aim, we calculated the mean total height and the mean crown base height for each plot.

4. RESULTS

Figure 1 shows lidar signals summed at plot level, derived reflectance profiles and plots average trees for the three different plots. We can see a good agreement between the average tree, the lidar signal variations and reflectance profile distribution.

Except for the crown base height of plot c, all the lidar derived heights are consistent with those calculated from field measurements (Table 2) considering that the lidar derived heights are given with a precision of 1.5 m (the waveform digitization frequency) and considering the standard deviations of field tree heights.

5. DISCUSSION AND CONCLUSION

We chose to sum waveforms of contiguous laser spots in order to produce 30 m long and 2.4 m wide footprints and perform a study at plot level. However, the reference plots are 30x30 m square. Consequently, the information held in a summed lidar waveform characterizes only a part of the plot. The increase in measurement errors, from young stand plot to mature stand plot, is probably linked to the lidar sampling strategy with regard to stand structure variability. Actually, trees in the young stand plot are plentiful (127 trees), planted in regular lines. On the contrary, the naturally regenerated stand plot held fewer trees (15 trees) with random position. A larger number of trees are then measured by the lidar in the young stand plot than in the mature stand plot. Consequently, measurements are more robust on the young stand plot. These results highlight the importance of the lidar sampling strategy in order to retrieve consistent heights measurements.

In depth analysis of these data will be performed in the future. To study the impact of the sampling strategy, the reflectance profiles derived from spot sizes of 30x2.4 m (presented in this study) and 30x4 m (obtained by flying the lidar at an altitude of 500 m) will be compared. We will also seek to extract the tree cover from the plot reflectance profiles. In addition, we will consider other statistics than the mean to compare field measurements with lidar derived metrics. Actually, the mean was suitable for this study because of tree height distribution homogeneity, but will not be suitable for multi-layered stands.

In spite of the previously discussed sampling bias, the results demonstrate the potential of this lidar prototype for tree heights estimation. This is promising for emergency inventory applications that can be facilitated by the rapid deployment and flexibility of ultra-light aircraft (ULA) in the case of storm or fire events. The obtained results will also be useful for designing systems for a future spaceborne lidar mission dedicated to forest measurements [8].

For future experiments, the EFIS accuracy will be improved to enable direct comparison between recorded waveform and field data (stand characteristics and topography). As the initial function of the LAUVA system was to measure atmospheric aerosols [9], the conception of a bi-function lidar for studying the forest response to atmospheric pollution is possible. The addition of a channel to study chlorophyll fluorescence is also considered for tree species recognition.

6. REFERENCES

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	Mean total height ± standard deviation (m)	Mean crown base height ± standard deviation (m)	Number of trees
Plot a (young)	9.5 ± 0.9	4.5 ± 0.8	127
Plot b (intermediate)	15.9 ± 1.1	10.3 ± 0.6	56
Plot c (mature)	21.9 ± 0.9	15.6 ± 1.1	15

Table 1. Tree plots characteristics.

	Lidar total plot height (m)	Total height error (lidar – field)	Lidar crown base plot height (m)	Crown base height error (lidar – field)
Plot a (young)	10.5	1	4.5	0
Plot b (intermediate)	16.5	0.6	9	-1.3
Plot c (mature)	21	-0.9	13.5	-2.5

Table 2. Tree heights extracted from reflectance profiles and their comparison with mean heights calculated from field measurements.

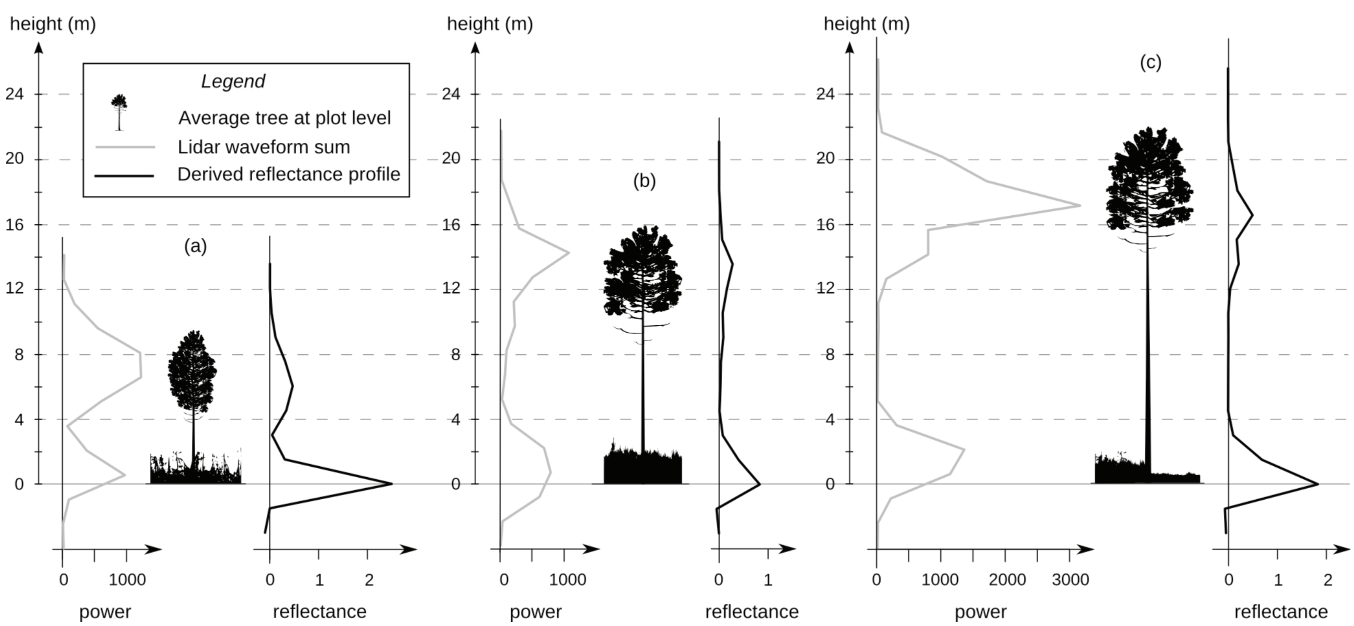

Figure 1. Lidar waveform sums (grey curves), derived reflectance profiles (black curves) and average trees at plot level derived from field measurements (black), for the three plots. The average trees are related to total mean height, base crown mean height, mean crown diameter and undergrowth distribution.