Estimating canopy load and bulk density distribution using calibrated T-LiDAR indices

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Estimating canopy load and bulk density distribution using calibrated T-LiDAR indices

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Introduction

Canopy fuel structure is a driver of fire behavior which affects rate of spread, intensity and crown fire potential (Van Wagner 1977, Cruz *et al.* 2005). Physically sample it is not feasible on large samples of trees. At plot scale, the inventory-based is commonly used (Baldwin *et al.* 1997, Alexander *et al.* 2004). It combines a stem inventory, allometric equations for mass and cumulative vertical distributions to estimate bulk density profiles and load. This approach can be used to reproduce the 3D structure of fuel beds though a modelling approach (Pimont *et al.* 2016). However, the allometric equations of the inventory-based approach require time-consuming measurements for calibration, their performance can be highly variable among sites (e.g. Baldwin *et al.* 1997) and there is little validation of this method.

Remote sensing techniques have long been used to estimate quantities such as leaf area index (LAI). More recently, terrestrial LiDAR (Light Detection And Ranging) scanner, referred hereinafter as TLS, emerged as a promising tool to estimate leaf area distribution (Béland *et al.* 2011, 2014). This approach is based on the relative density of returns, which is defined as the proportion of returns in a given volume relatively to the number of laser pulses crossing this volume. LiDAR technology has also shown promises for the estimation of canopy fuel structure (Skowronski *et al.* 2011, Seielstad *et al.* 2011).

Herein, we present a method based on the calibration of relative density indices to estimate canopy bulk density. The original method is described in Pimont *et al.* (2015), applied to the estimation of leaf bulk density and corrected in Pimont *et al.* (2016). Here, we present results in the context of canopy fuel structure estimation. Some of the results incorporate a second campaign of TLS acquisitions done in 2015 that are still in progress.

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Material and methods

Plot description and inventory-based method

Four 12 m diameter contrasted plots were selected in a *Quercus pubescens* forest in the South-East of France. Maximum heights varied between 8 to 12 m and basal areas between 18 and 40 m^2 ha^{-1}. A stem inventory was carried out and 10 trees of various diameters at breast height were felled and cut in 1-m vertical sections. Leaves and 0-6 mm twigs were collected, oven-dried and weighted. Data was used to fit allometric equations for leaf and twig biomass and vertical distribution. The combination of these equations and the stem inventory in each plot were used to estimate bulk density profiles in each plot (Pimont *et al.* 2015).

LiDAR campaigns

We conducted two different measurement campaigns on the study site. The first one was done in 2013. A FOCUS 3D 120S (FARO Technologies Inc., Lake Mary, USA) TLS instrument was used in this study with a resolution of 43.8 million points per scan. Five scans were performed on each plot from the center and the four summits of the square inscribed in the circular plot (Pimont *et al.* 2015). Similar measurements were done in 2015 with a FOCUS 3D 130X. The main difference between the two TLS is the wavelength (905 nm for the 120S and 1500 nm for the 130X), the second being more adapted to separate leaf returns from wood returns using return intensity (Béland *et al.* 2014).

Calibration of biomass indices in spherical volumes

During each campaign, ten polystyrene balls (diameter 0.1 m) were placed at different locations in the canopy of each plot, to mark out the center of virtual spherical volumes. These volumes, referred to as Calibration Volumes (CV) are bounded by a 0.7 m diameter virtual sphere, that has the same center as the polystyrene target. Once the TLS scans were performed on a plot, the leaves and twigs inside the calibration volumes were collected, oven-dried and weighted.

TLS point clouds were used to compute relative density indices in each CV, using the polystyrene targets to identify CV locations in each point cloud. Several variants of these indices were introduced to account for occlusion, leaf orientation and filtered returns (Pimont *et al.* 2015). These indices were calibrated for biomass estimation, using leaf and twig mass weighted in CVs. On going work aims at separating leaf from wood returns to improve the accuracy of estimation.

Model application

Once calibrated, relative density indices can be computed at any location in the canopy to estimate local bulk density. To estimate bulk density at plot scale, calibrated indices were computed at all nodes of a virtual grid in each plot. The 3D distributions of estimated bulk density were integrated horizontally to estimate vertical bulk density profiles that could be compared to the ones obtained with the inventory-based method.

Results

Figure 1 shows a comparison between profiles of leaf bulk density estimated with the inventory-based method (black crosses) and the TLS method using scans done in 2013 and 2015, respectively in blue and green lines. They compared well together in terms of shape, canopy height, peak bulk density, etc. At this stage it is unclear if differences observed on plot 2 are due to the TLS or the inventory-based method. In the lower part of the canopy, it is likely that the TLS-based method overestimates bulk densities, because the model interprets trunk returns as if they were foliage.

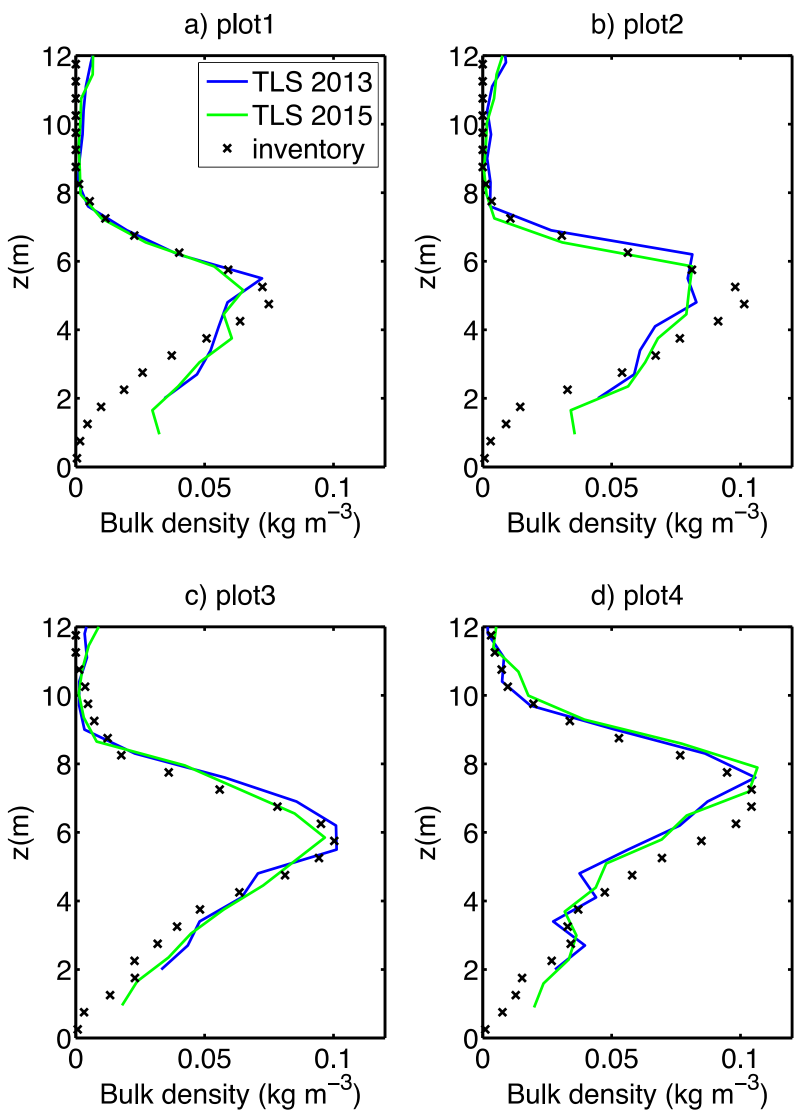

Figure 1: Leaf bulk density profiles estimated from TLS- and inventory-based methods using data from the 2013 and 2015 campaign. No separation is done between leaf and wood returns at this stage.

A similar methodology was applied to thin twigs, based on a calibration of relative density indices with twig biomass measured in calibration volumes. When compared to inventory-based-method profiles, this first attempt to estimate twig biomass with TLS showed a disappointing overestimation. This overestimation (by a factor 1.5 to 2) is explained by the fact that polystyrene balls were hanged to thin twigs, leading to an over-representation of twigs with regards to leaves in calibration volumes. We believe significant improvements should result from separation between leaf and wood returns.

Some work is still in progress to use return intensity to separate leaf and wood returns in the 2015 scans. Such separation was not possible with the 2013 scans, because leaf and wood returns showed similar intensity ranges at FOCUS 3D 120S wavelength (Pimont *et al.* 2015). We also developed a slightly different approach to remove wood returns in leaf biomass estimation, using RGB colors estimated for TLS returns by the camera incorporated in the FARO FOCUS 3D 130X. This first attempt estimated the proportion of leaf and wood returns in a spherical volume using the Excess Green index, an efficient index derived from RGB for plant segmentation (Guajardo *et al.* 2011). The method was evaluated in some spherical volumes containing wood only and performed correctly (reducing the estimation of leaf biomass in these volumes to near zero values). Figure 2 shows how leaf bulk density estimation was corrected when including leaf and wood separation, the black arrows illustrating the reduction of the estimated biomass in the lower part of the canopy, when removing trunk returns.

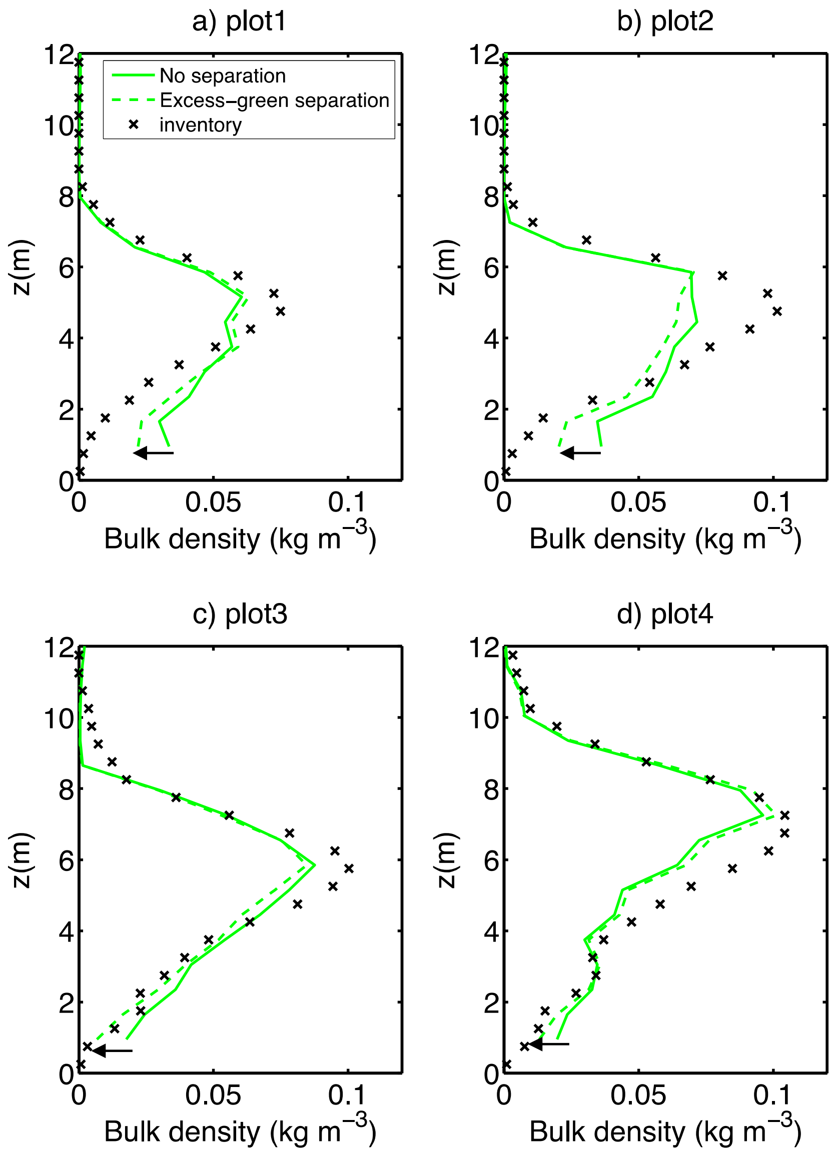

Figure 2: Leaf bulk density profiles estimated from TLS method without separation of leaf and wood returns (line green) and with Excess-green-based-leaf-and-wood separation (dashed green) using data of the 2015 campaign. The small black arrows illustrate the bulk density reduction when removing wood returns

Discussion and conclusion

Our method based on calibration of relative density indices (Pimont *et al.* 2015) yielded encouraging results. It was the first able to estimate leaf bulk density profiles in forestry plots using TLS, the previous work being limited to small trees or individual branches. The approach based on the Excess-Green index to remove wood returns is innovative and leads to promising results. Combined with an approach based on return intensity, we hope it would help to get more robust estimates of leaf biomass and distribution. Our first attempt to estimate twig biomass was not successful, but we hope that the progress in leaf and wood separation will lead to much better results.

Regarding the cost of measurement, the time required to calibrate our indices was about ten times faster that the time required to calibrate the inventory based methods. However, this time is not negligible (about 8 days to prepare the plot, to collect, oven-dry and weight the biomass, to identify the location of CV in scans, etc.). We expect that these coefficients will be relatively stable as they depend only on the distribution of foliage element at the spherical volume scale, that should not change much for a given species or group of species with similar morphologies. Variations of these coefficients are potentially predictable from foliage characteristics, such as surface to volume ratio or shoot properties (Pimont *et al.* 2009).

The method presented here is promising and has potential to become an efficient, operational methodology to estimate bulk density distribution and canopy load. It could be used in combination with airborne and space-borne remote sensing (that often requires ground measurements for calibration), for monitoring of ecosystem, or to provide data for physics-based fire models.

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