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Effect of airborne LiDAR pulse density on crown fuel modelling

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Abstract

Airborne LiDAR has been proven very useful to characterize 3D forest structure, being a revolution on data gathering at large scale. Previous studies have shown different success of LiDAR for crown fuel characterization at different laser pulse densities. However, most of the studies comparing the effect of laser pulse density used simulated data from a high pulse density dataset by decreasing the number of returns to different predefined levels. There are few studies comparing different laser pulse densities acquired from actual LiDAR flights performed at the same time, or within a short timelag, over the same area. In the present study, we analyze the effect of LiDAR pulse density on crown fuel parameter estimation from two airborne LiDAR datasets obtained in 2009 (1.5 p m^{-2}) and 2010 (0.5 p m^{-2}) in Valsaín, Sierra de Guadarrama (central Spain). Field data consisted of 30 circular plots (radius = 14.1 m) located in a Pinus sylvestris stand. Crown fuel load (CFL) and crown bulk density (CBD) were modelled with parametric (linear regression) and non-parametric (Random Forest) methods. Results indicate that higher pulse density did not improve models for CFL and CBD estimation, at least for the pulse densities compared in the present study, with R2 (pseudo-R2 for non-parametric models) ranging from 0.64 to 0.72 for CFL and 0.61 to 0.69 for CBD, depending on the modelling method used. Our study suggests that high density LiDAR data may not be required for estimating crown fuel parameters that are critical for fire behavior simulation.

Keywords: airborne laser scanner; LiDAR pulse density; crown bulk density; crown fuel load; *Pinus sylvestris*

Introduction

Free airborne LiDAR data at a low pulse density are becoming available in some countries (e.g. Spain) implying an increased used in forest monitoring. Airborne LiDAR has been proven very useful to characterize 3D forest structure, being a revolution on data gathering at large scale. Regarding forest fuels, previous studies have shown different success of airborne LiDAR for crown fuel characterization at different pulse densities (Riaño *et al.* 2003, Andersen *et al.* 2005). However, few studies compare different laser pulse densities acquired from actual LiDAR flights performed at the same time, or within a short time lag, over the same area. Most of the studies comparing the effect of laser pulse density used simulated data from a high pulse density dataset by decreasing the number of returns to different predefined levels (Gonzalez-Ferreiro *et al.* 2012, Jakubowski *et al.* 2013).

Crown fuel modelling from LiDAR data is of paramount importance, as it can provide spatially-explicit input data of fuel parameters that are critical for fire behavior simulation. The aim of the present study is to assess the effect of laser pulse density from two different airborne LiDAR dataset acquired within a short time lag (< 1 year) in the same study area on crown fuel load (CFL) and crown bulk density (CBD).

Material and methods

Study area and field inventory

The study site is located at Valsaín in Segovia, central Spain and comprises 7448 ha dominated by *Pinus sylvestris* Ait. natural stands. Altitude ranges from 1260 to 1995 m, with mean annual precipitation higher than 1000 mm and average minimum and maximum temperature of -1 ºC and 22 ºC, respectively.

Field measurements were performed in a set of 30 circular plots (radius=14.1 m). Plot locations were chosen to cover structural variability according to prior forest inventory (2010) and LiDAR data. Areas with disturbance or management activities during the time lag between field inventory and LiDAR data acquisition were excluded. Diameter at breast height (DBH) was measured in all trees thicker than 7.5 cm. Tree height and crown base height (CBH) were registered in 10 randomly selected trees per plot.

Allometric equations developed by Montero *et al.* (2005) for the same pine species and study area were used for foliar biomass estimation at tree level from DBH. Available crown fuel load at plot level was calculated as the foliar biomass in kg m^{-2}. Crown bulk density was calculated from crown fuel load, considering mean canopy length as mean tree height minus mean CBH at plot level. Descriptive metrics of the stand at summarize in Table 1.

Table 1. Summary statistics of stand variables and canopy fuels at the study plots.
N, stand density (stems ha^{-1}); G, basal area (m^2 ha^{-1}); Dg, quadratic mean diameter (cm); H, stand dominant height (m); N_{reg}, regeneration density (stems ha^{-1}); H_{reg}, regeneration height (m); Cov_{sh}, shrub cover (%); H_{sh}, shrub height (m); CFL, crown base height (m);CFL, crown fuel load (kg m^{-2}); CBD, crown bulk density (kg m^{-3}); SD, standard deviation.

Value	N	G	Dg	H	N_{reg}	H_{reg}	Cov_{sh}	H_{sh}	CBH	CFL	CBD
Min	240.2	18.8	15.6	11.2	0.0	0.0	0.0	0.0	1.2	0.47	0.04
Max	2273.5	74.6	44.9	32.3	4002.7	7.0	100.0	1.5	22.2	1.73	0.30
Mean	873.4	41.1	28.0	20.4	934.5	3.5	30.3	0.5	8.3	1.00	0.12
SD	490.8	12.5	9.1	5.6	1245.3	2.1	28.1	0.3	4.7	0.31	0.05

LiDAR data

Two LiDAR datasets with different pulse densities were used: i) LiDAR data with 1.5 p m^{-2} from a specific flight performed in 2009 for forest inventory in the study area; and ii) LiDAR data from the Spanish National Plan for Aerial Orthophotography (PNOA), performed with 0.5 p m^{-2} in 2010.

LiDAR data were provided in LAS format files and processed using FUSION (McGaughey and Carson 2003) and QGIS software (QGIS Development Team 2014). Point clouds were classified in soil and vegetation returns. A ground surface model (DTM) was generated from soil returns at 2m resolution and used to normalized return height to soil level. LiDAR metrics were extracted from point clouds for both datasets at plot level (fig 1).

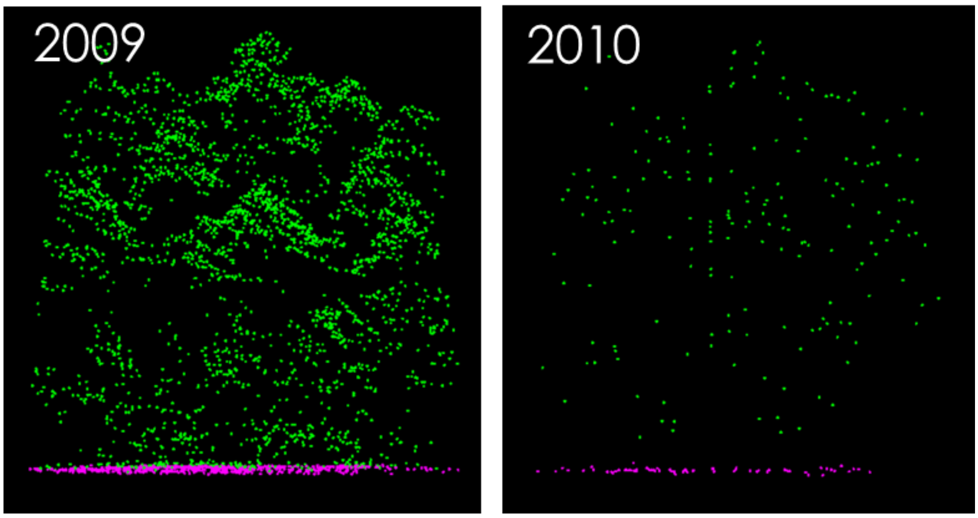

Figure 1. Example point clouds of the same plot from both LIDAR dataset: medium pulse density (2009) and low pulse density (2010)

Statistical analysis

The statistical methods for crown fuel modelling included parametric and non-parametric regression analysis. Models with linear, potential and exponential formulation were tested in parametric regression analysis. Models were fitted in R software, using stepwise as well as alternative combinations of LiDAR metrics. Final model selection was based on p-values of the input LiDAR metrics and the overall model significance, as well as adjusted R^2 and root mean squared error (RMSE) resulting from crossvalidation. Random Forest models (RF) were also fitted in R using an optimized method for input metric selection. The importance of the variables was used to identify the relative contribution of each LiDAR metric to RF models. Final model selection was based on pseudo-R^2, indicating the variability explained by the model, and RMSE resulting from crossvalidation.

Results and conclusions

Our results indicate that higher pulse density did not improve model performance for CFL and CBD estimation, at least for the pulse densities compared in the present study (Table 2). Both LiDAR datasets provided very similar results in terms of % of variance explained by the models and errors (RMSE), with R^2 (pseudo-R^2 for non-parametric models) ranging from 0.64 to 0.72 for CFL and 0.61 to 0.69 for CBD. In general terms, linear regression performed slightly better than RF, independently of the pulse density used.

Table 2. Comparison of goodness-of-fit for the models obtained to estimate crown fuel parameters from different LiDAR pulse densities and modelling approaches

Crown fuel model	LIDAR pulse density	Linear regression		Random Forest	
		adjusted R^2	RMSE	pseudo-R^2	RMSE
Crown fuel load (CFL)	Low density	0.724	0.159	0.682	0.173
	Medium density	0.713	0.162	0.638	0.185
Crown bulk density (CBD)	Low density	0.687	0.031	0.651	0.032
	Medium density	0.607	0.032	0.653	0.032

Our study suggests that models derived from low pulse density data provide a good performance for CFL and CBD estimation, and that high density airborne LiDAR may not be required for estimating crown fuel parameters that are critical for fire behavior simulation. Given the wide structure variability of the stand (Table 1), these conclusions may be generalized to forest areas with similar pine species, although more research is needed to confirm these results in different forest types.

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Presenter's bio

Eva Marino is a Forest Engineer graduated at Universidad Politécnica de Madrid (Spain). She got her PhD in 2011 working at INIA forest fire laboratory (Madrid, Spain). She joined Agresta S. Coop. in 2015, working in the development of tools and methods for 3D fuel structure modelling, vegetation monitoring after wildfire and fuel moisture prediction. Her research interests include fuel management, wildfire behavior modelling and forest fuel characterization, including the application of remote sensing technologies (imagery and LiDAR) and simulations.