Aplicación del LiDAR full-waveform en la modelización de propiedades de combustibilidad de la cubierta arbórea y el sotobosque

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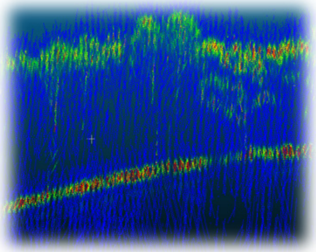
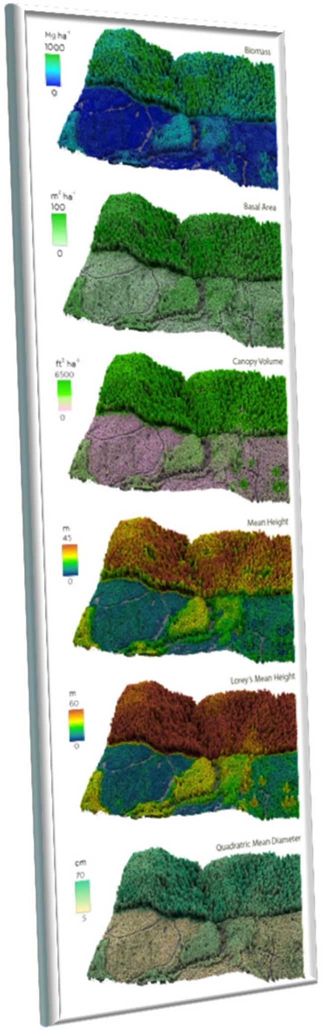


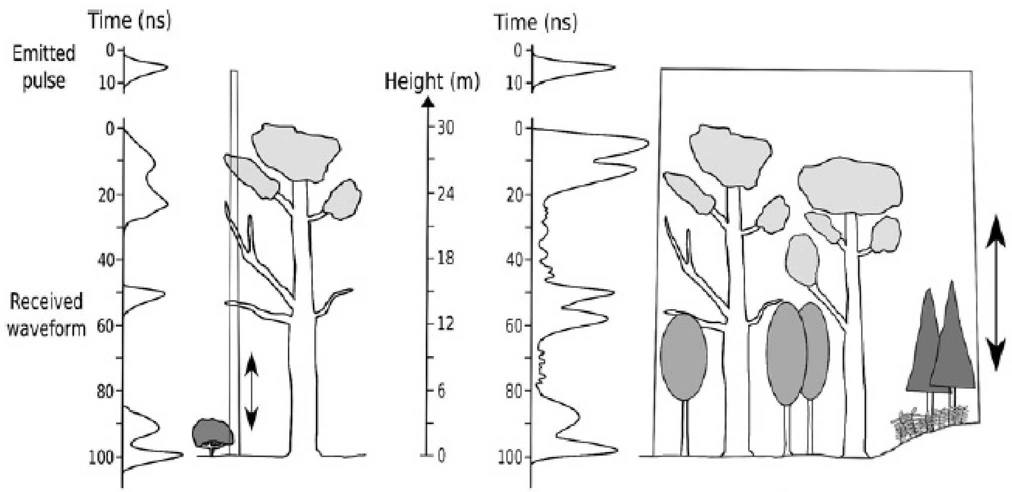
Contents



Introduction

- **Fuel properties** have been **sucessfully modeled** in different ecosystems using discrete airborne LiDAR systems (**ALS**), but has some **limitations** to characterize understory vegetation due to **canopy and pulse densities, footprint size, etc.**

small-footprint (0.2–3 m) **large-footprint** (10–70 m)

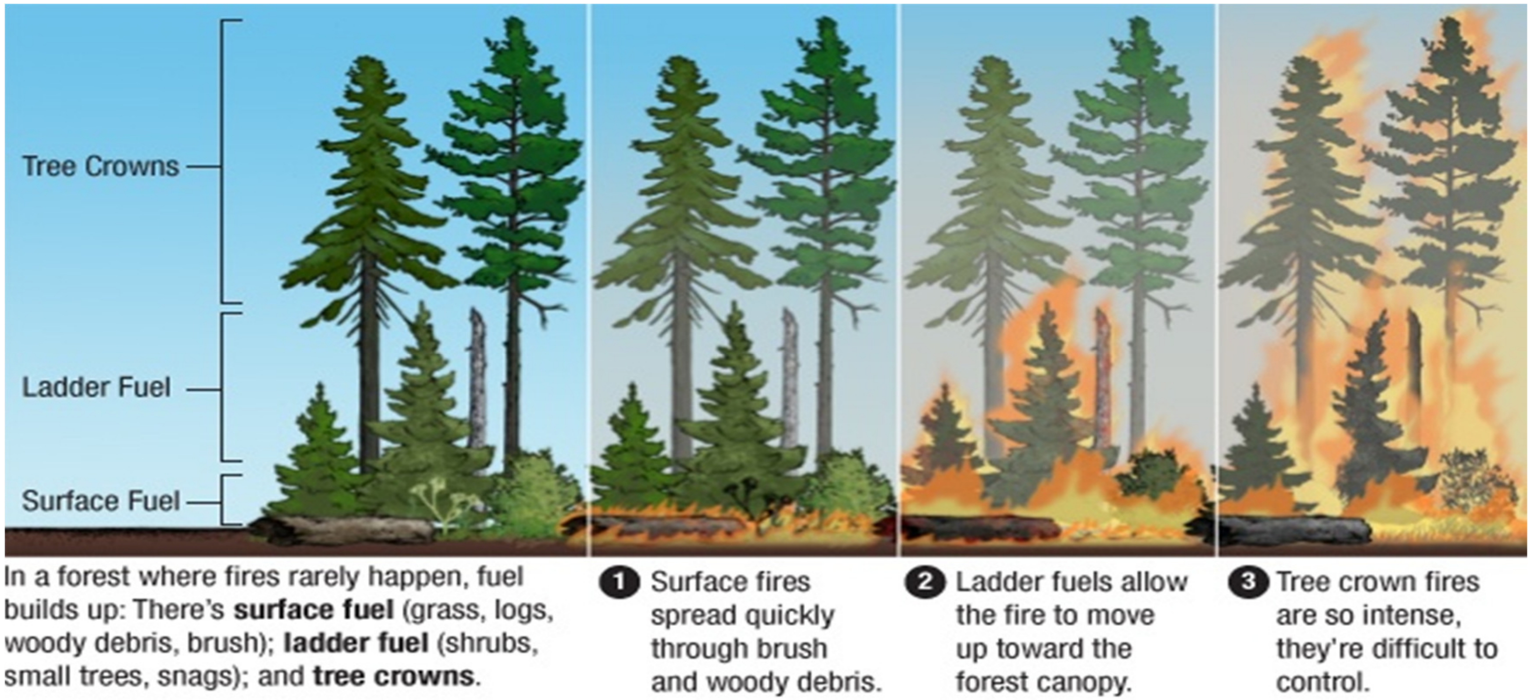


a *Mallet, C., and F. Bretar. 2009* b

Trade-off between spatial resolution and vertical penetration

Introduction

- Height, cover, and structure of **understory vegetation** are key drivers of fire behavior through **surface fuel** and **ladders fuel**, which are main responsible of **rate of spread** (*Keane, 2014*) and **crown fires** (*Molina et al., 2011*), respectively



Source: U.S. Forest Service. Credit: Adam Cole, Nelson Hsu / NPR

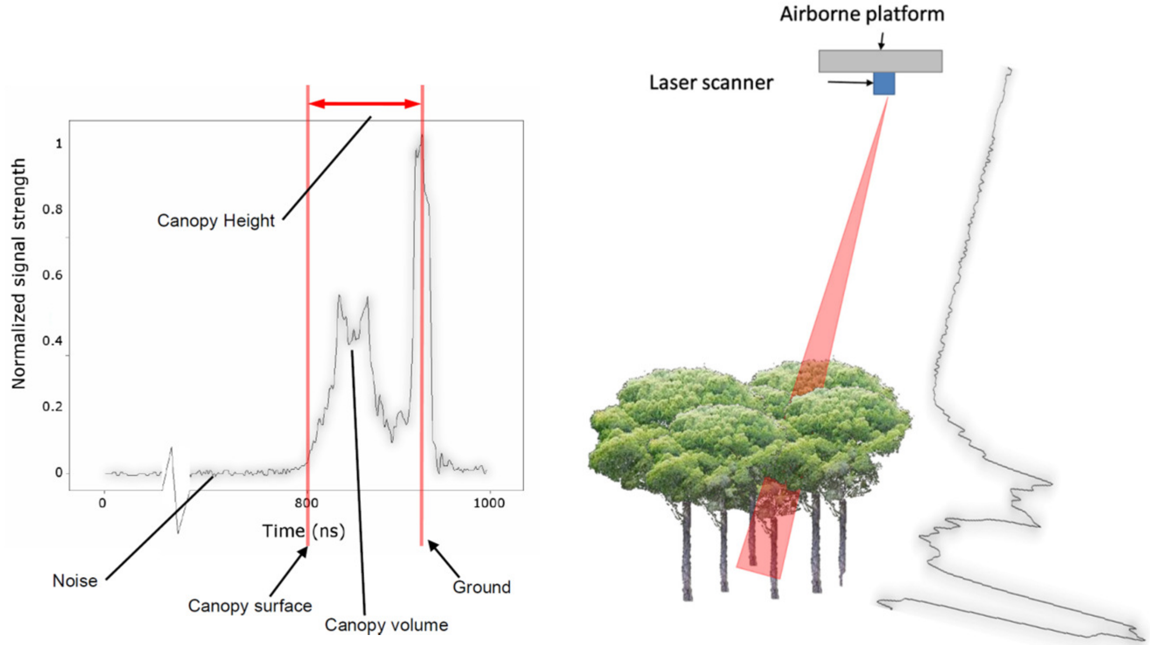
Introduction

- **Full-waveform ALS** data register more detailed information in different vertical strata compared to discrete ALS

The laser pulse interacts with vegetation and terrain, a return wave is generated, which is formed by differences in: (1) elevation; (2) % of pulse intercepted at each level of vegetation/soil; (3) reflected energy from the different contacted surfaces.

The complete return signal is registered, digitized and stored (64, 128 or 256 registers/bins)

A main limitation of full-waveform data is that requires a more **complex data processing**



Pirotti F, 2011

Objectives

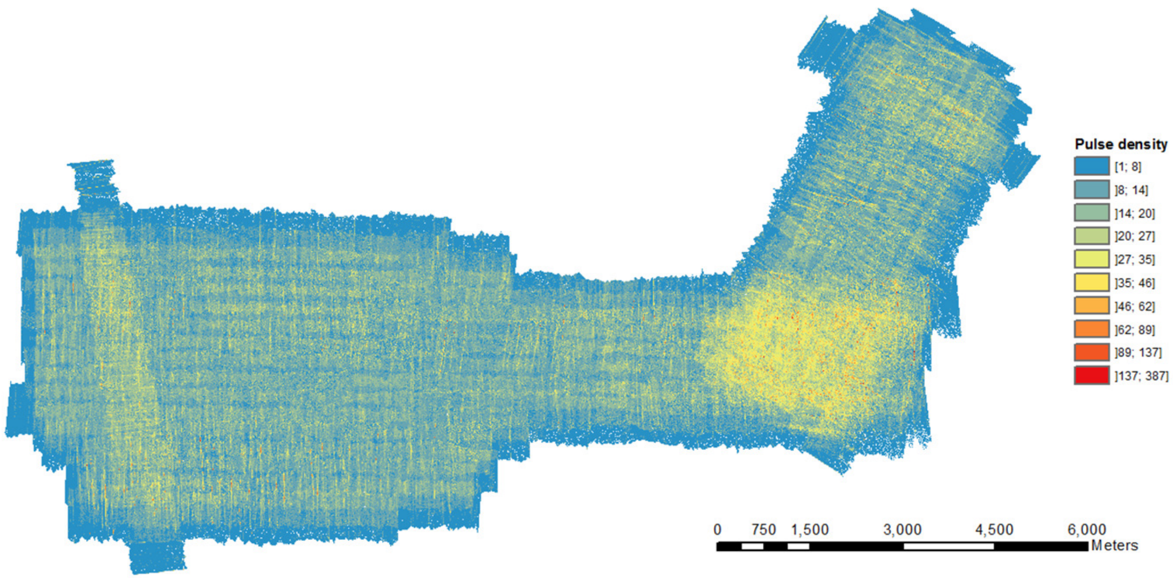
- Evaluation of full-waveform LiDAR data to estimate canopy **fuel variables in Mediterranean forest**
- Explore the capacity of FW-ALS data to **characterize understory vegetation** (volume, cover, mean and maximum height)
- **Assessment of specific metrics** in prediction models of understory vegetation properties
- Present a **new software tool** to calibrate and process FW LiDAR data

Data *(ALS)*

	Espadán
Date	16/09/2015
Sensor	LM6800
Pulse frequency	300 kHz
Average flight altitude	600-820 m
Waveform storage	80-160-240 bins
Temporal sample spacing	1 ns
Point density	≥ 11 m^{-2}
Wavelength	1550 nm
Pulse Length	3.5 ns
Pulse Width (TSS)	0.15 m
Beam Divergence	≤ 0.5 mrad
Scan Angle	± 18º
Footprint	0.24 m
Intensity detection	16 bit/return

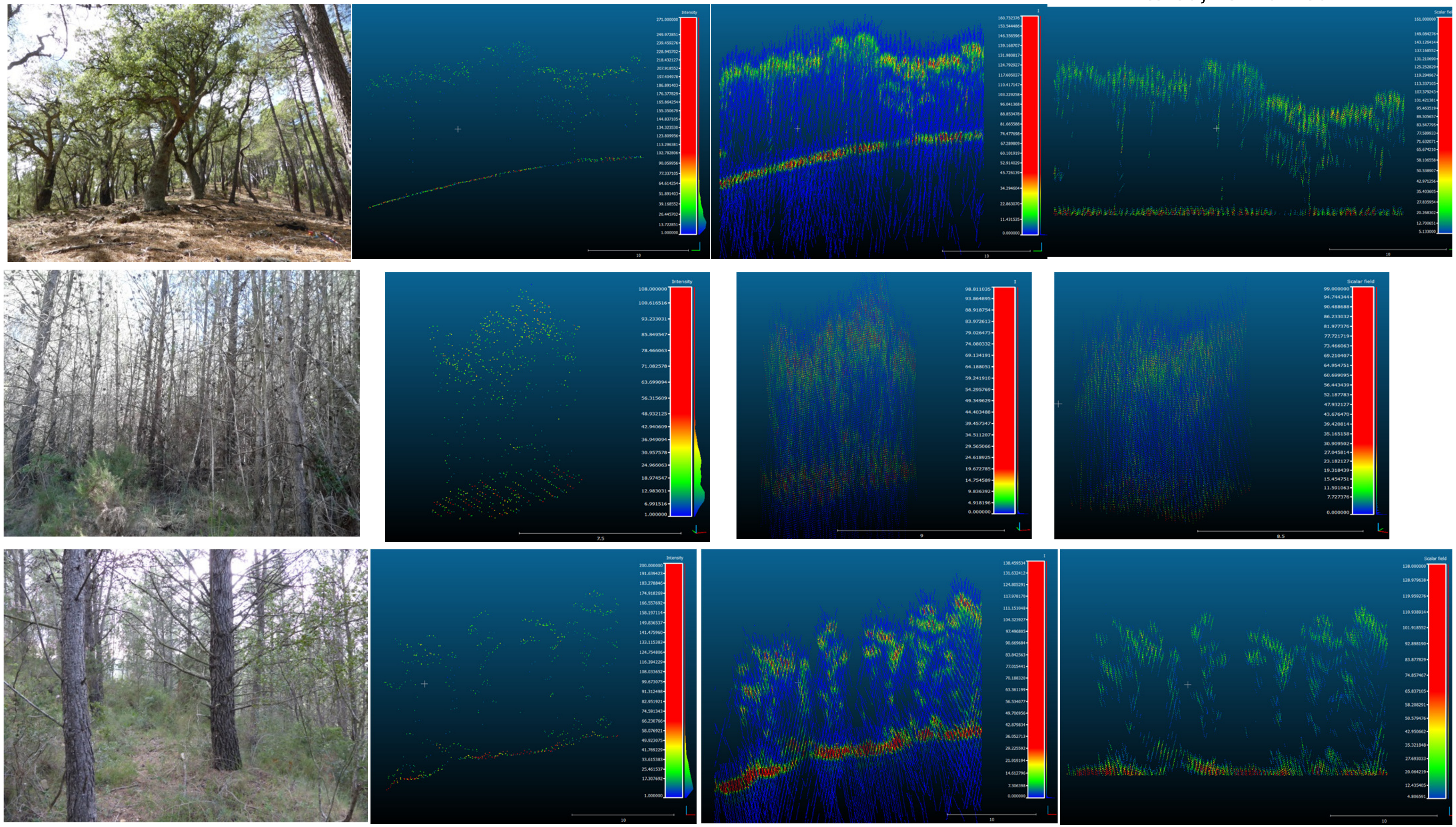
Sierra de Espadán (3742 ha)

- Heterogeneous montaneous area with high slopes
- *P. halepensis, P. pinaster, Q. suber, Q. coccifera, E. arborea, Erica sp.,…*



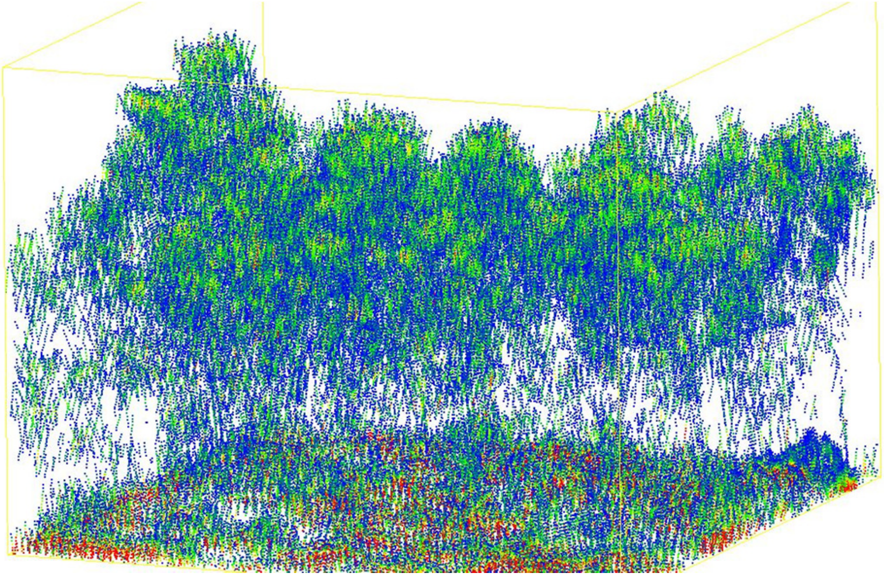
LiDAR pre-processing

Discrete lidar | **Raw FWF** | **Filtered, normalized FW**

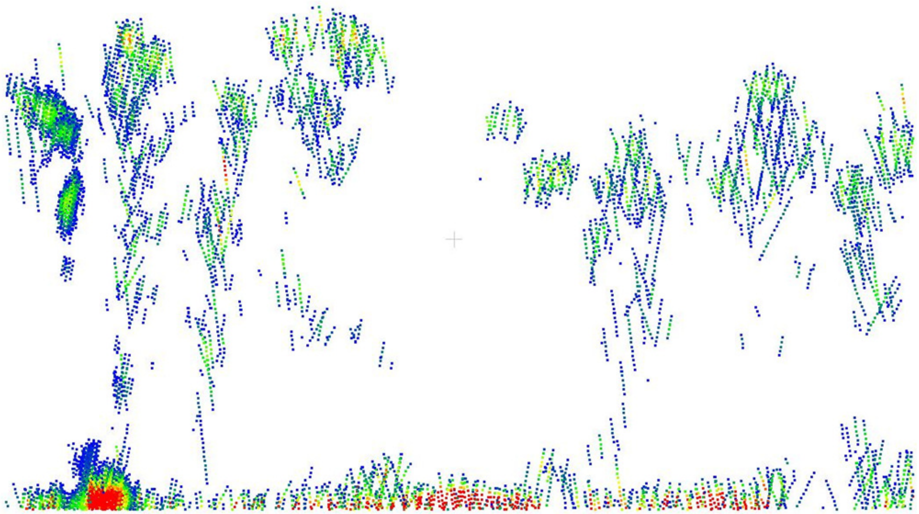


LiDAR full-waveform pre-processing

Detail of full-waveform data (filtered and normalized)



Detail of full-waveform profile (filtered and normalized)

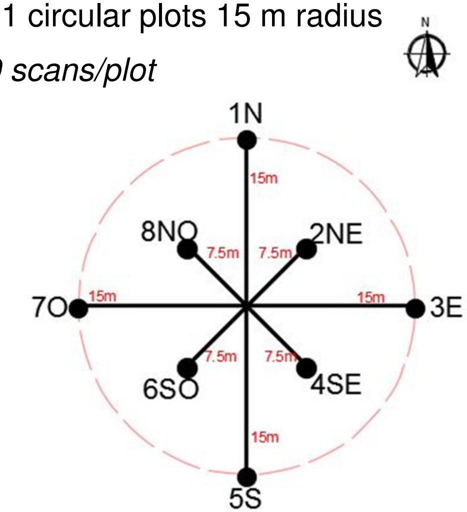


Data *(TLS)*

Specification	Value
Sensor	FARO FOCUS 3D 120
Accuracy	± 2 mm at 25 m
Range	0.6–120 m
Pulse frequency	97 Hz
Scan angle	Horizontal: 300°
	Vertical: 360°
Wavelength	905 nm
Beam divergence	0.19 mrad

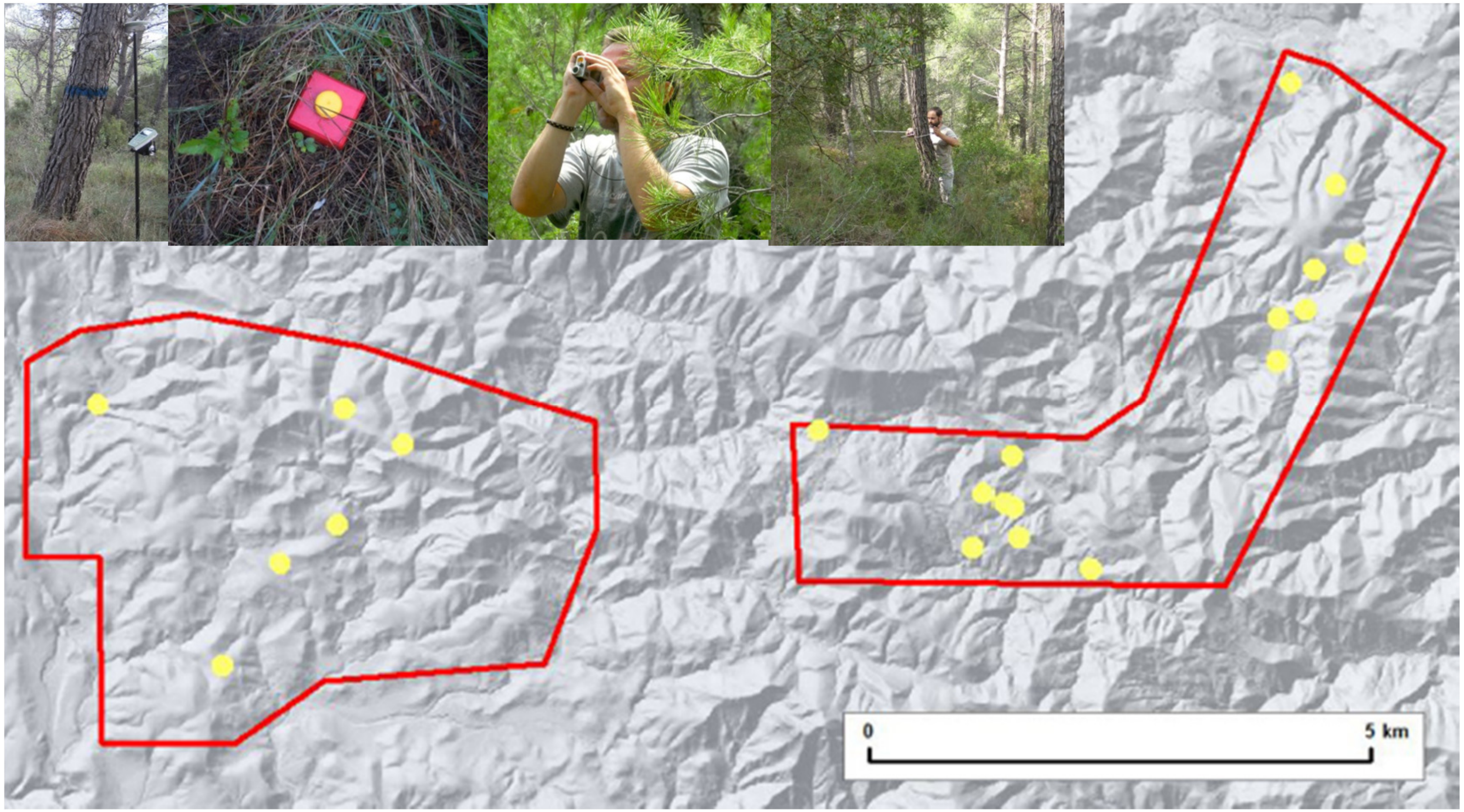
Sierra de Espadán (3742 ha)

- 21 circular plots 15 m radius
- *9 scans/plot*

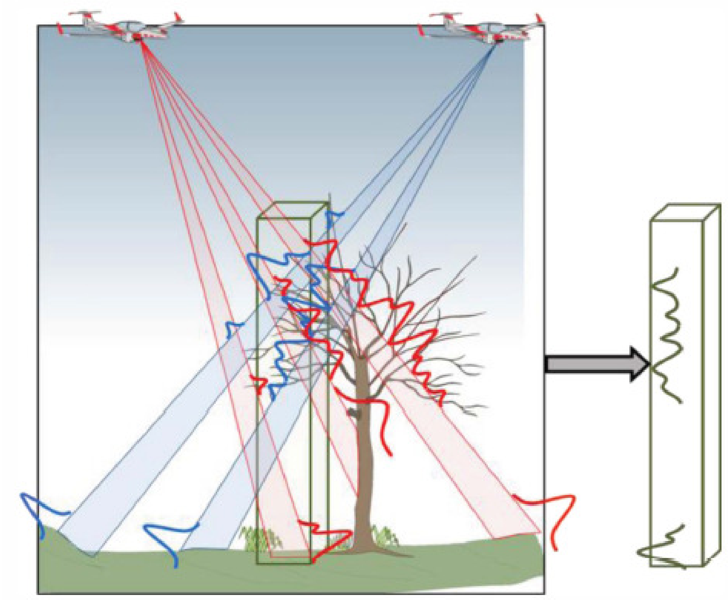


Field data

Sept. 2015,standard forest inventory measurements (DBH, height and N. trees, species description, etc.) Dominant species: *P. halepensis, P. pinaster, Q. suber, Q. coccifera, E. arborea, Erica sp.*,…



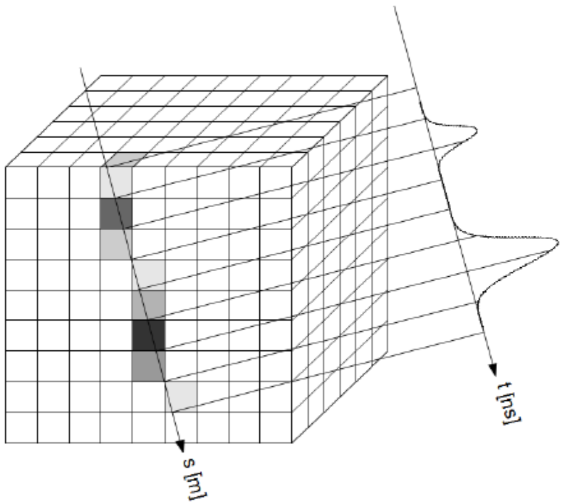
Full-waveform processing



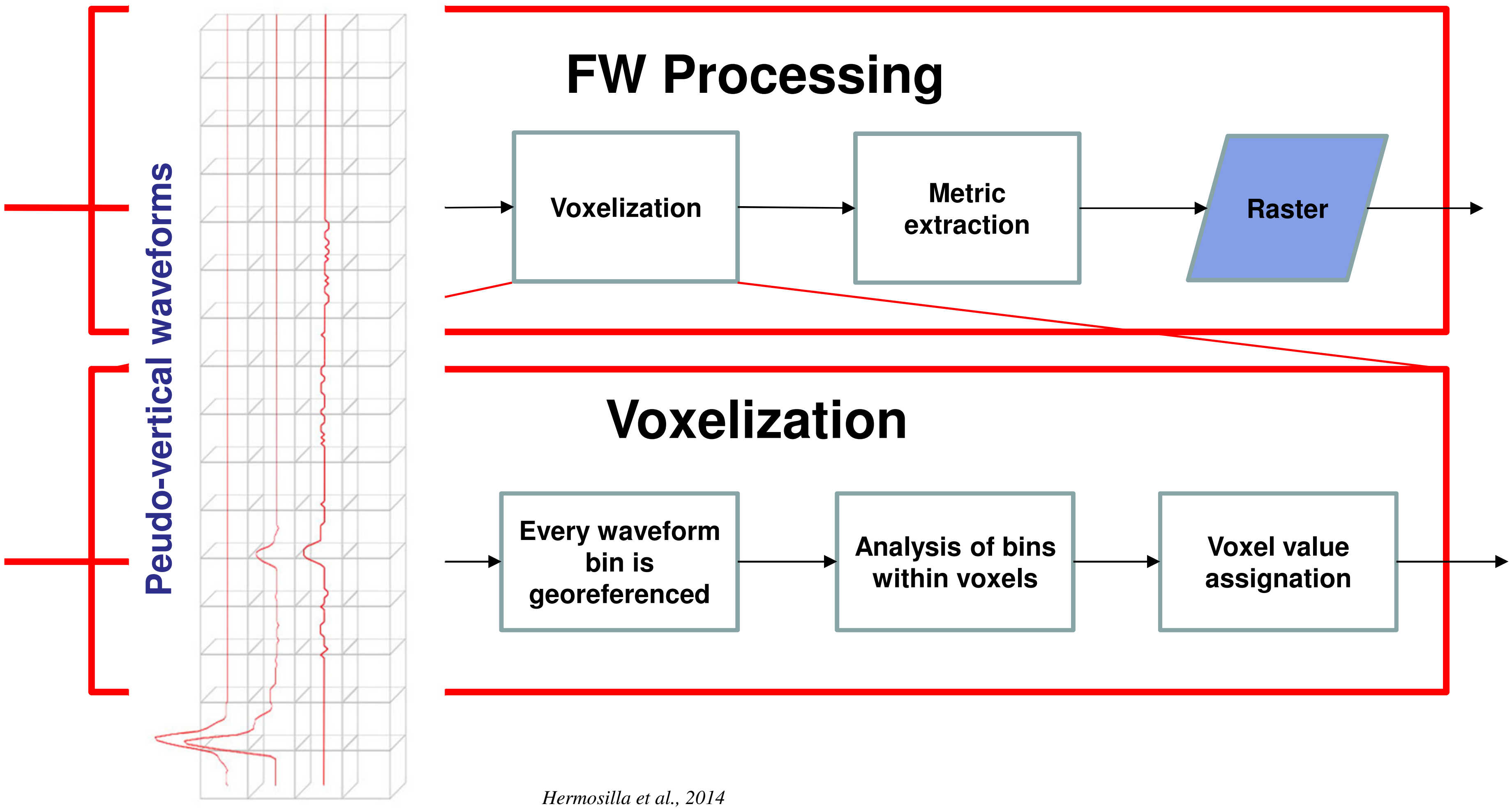
From Wong et al., 2013

In small-footprint systems, due to off-nadir scanning angles and various trajectories traveled by the pulses in overlapping strips the extracted full-waveform LiDAR pulse does not register truly vertical information

To avoid this, the construction of a **pseudo-vertical full-waveform** consists on the integration of the non-vertical waveforms registered from different flight trajectories, partitioning the vertical aboveground space into regular voxels (Hermosilla et al., 2014a)



Full-waveform voxelization

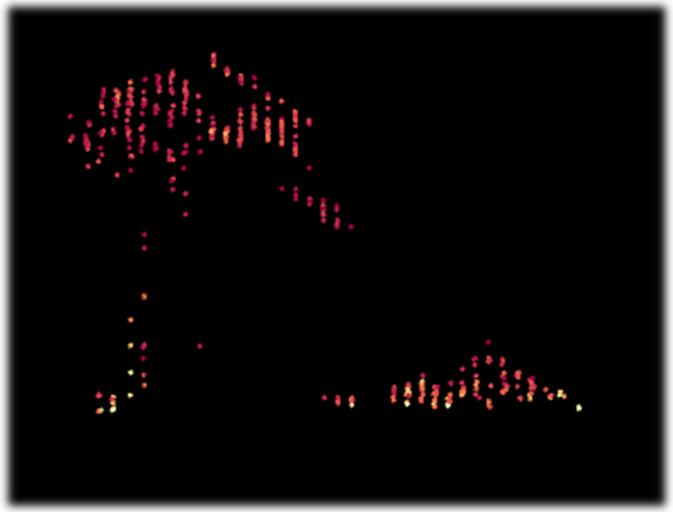


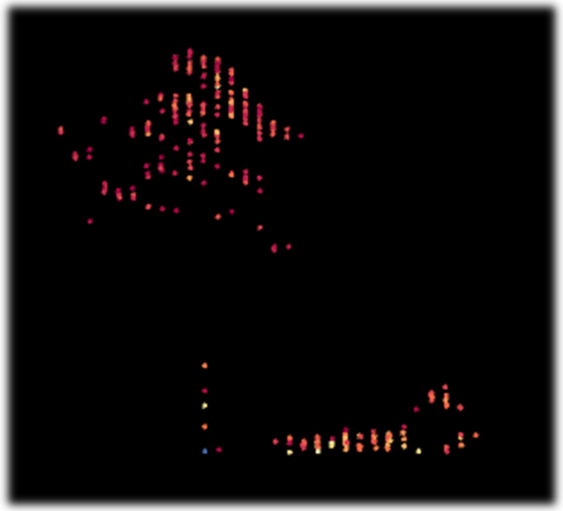
Hermosilla et al., 2014

LiDAR profiles: discrete vs full-waveform

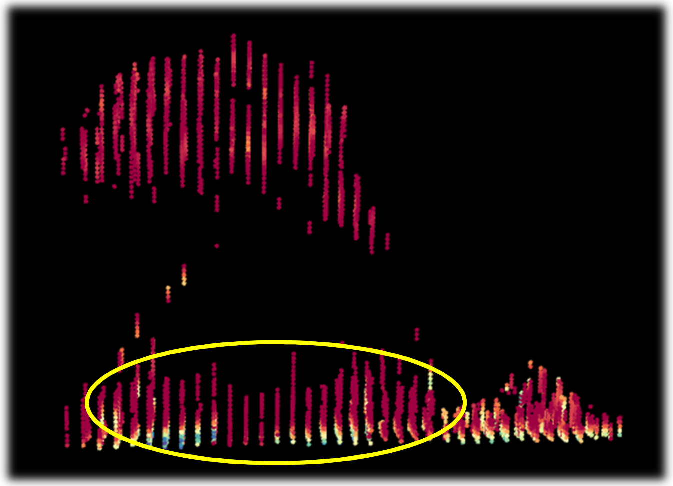
Sierra de Espadán

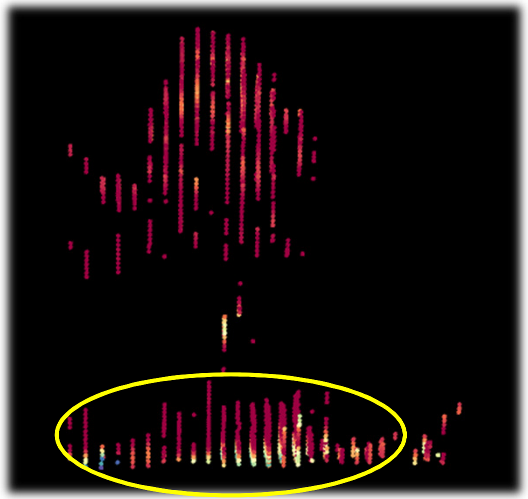
Discrete (intensity)





Full-waveform (intensity)



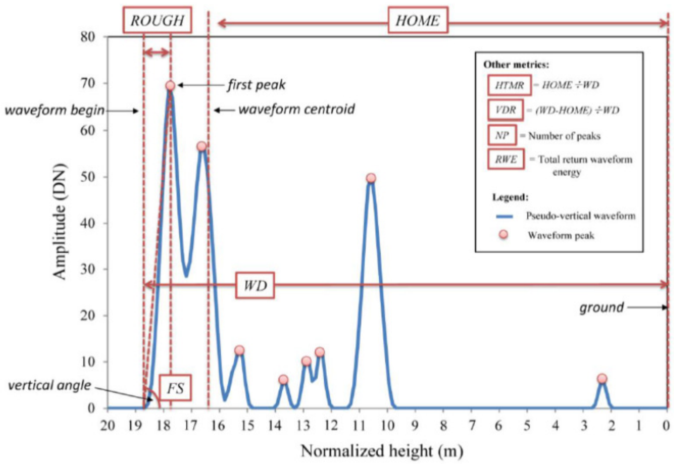


Understory vegetation

Full-waveform metrics (general)

Feature	Description
HOME	*height of median energy*
NP	*number of peaks*
WD	*waveform distance*
ROUGH	*roughness of outermost canopy*
HTMR	*height to median ratio*
VDR	*vertical distribution ratio*
RWE	*return waveform energy*
FS	*front slope angle*

Duong (2010)



Pirotti F, 2011

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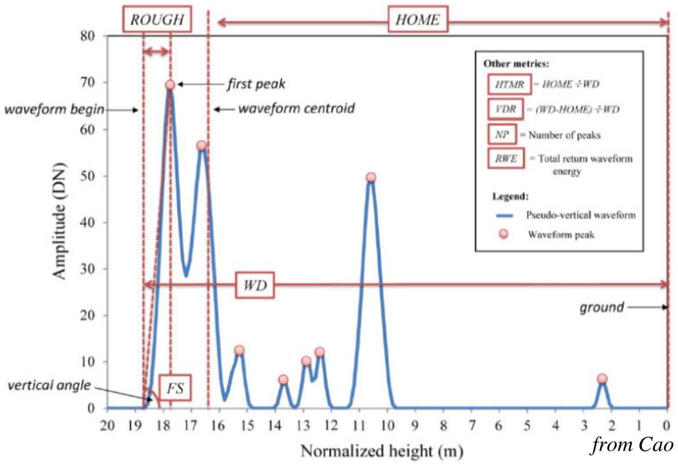
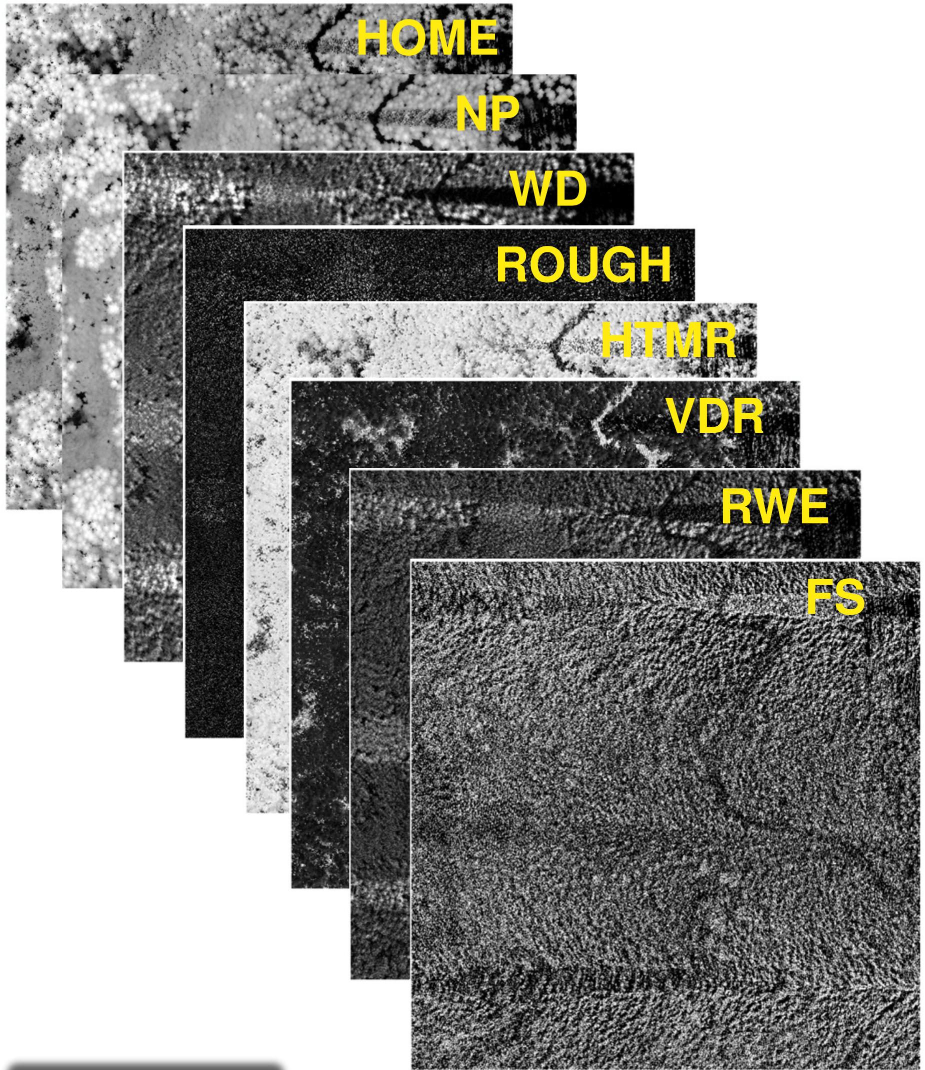


from Cao et al. (2014)

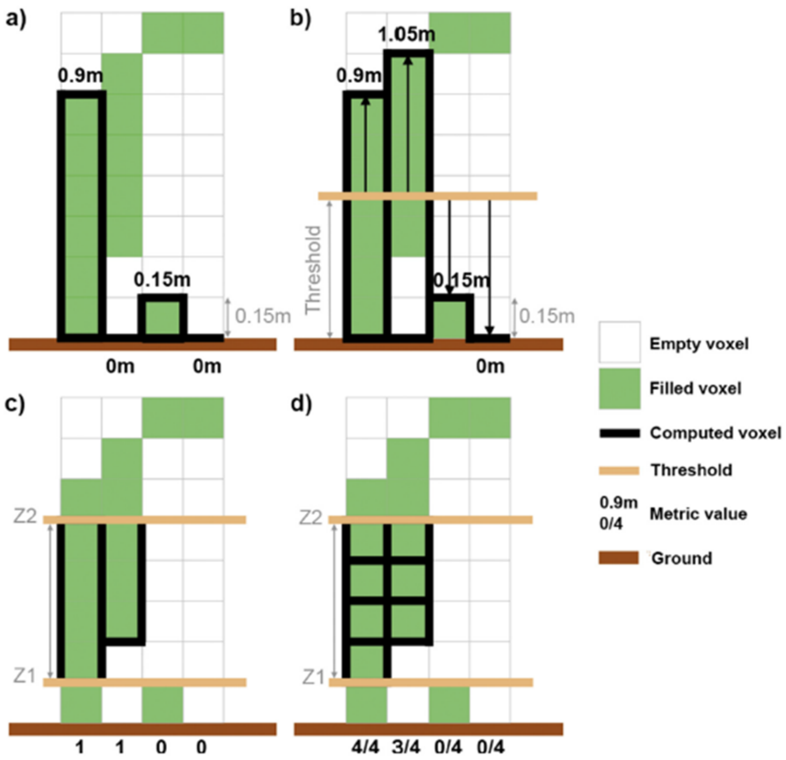


Full-waveform metrics (understory)

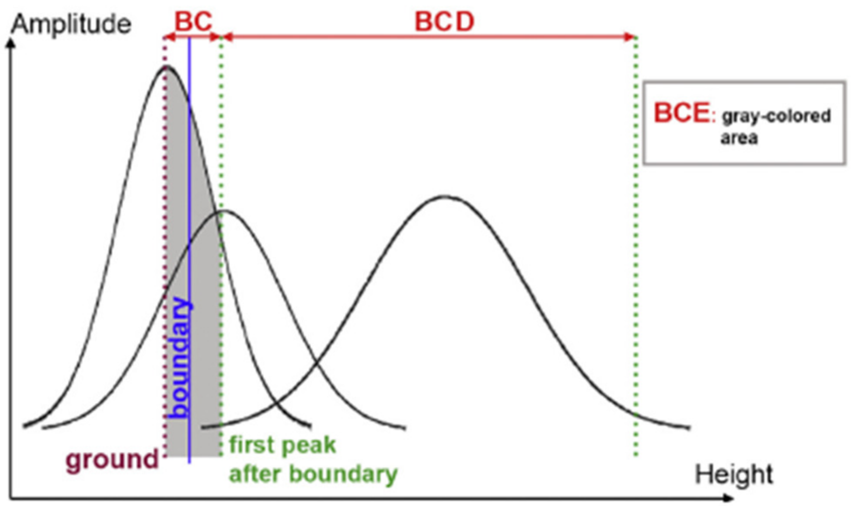
a) HFEV: Height at first empty voxel
b) HFEVT: Height at first empty voxel from threshold
c) FVU: Filled voxels at understory
d) NFVU: Filled voxels at understory divided by N. voxels

29 metrics. More detailed info in:

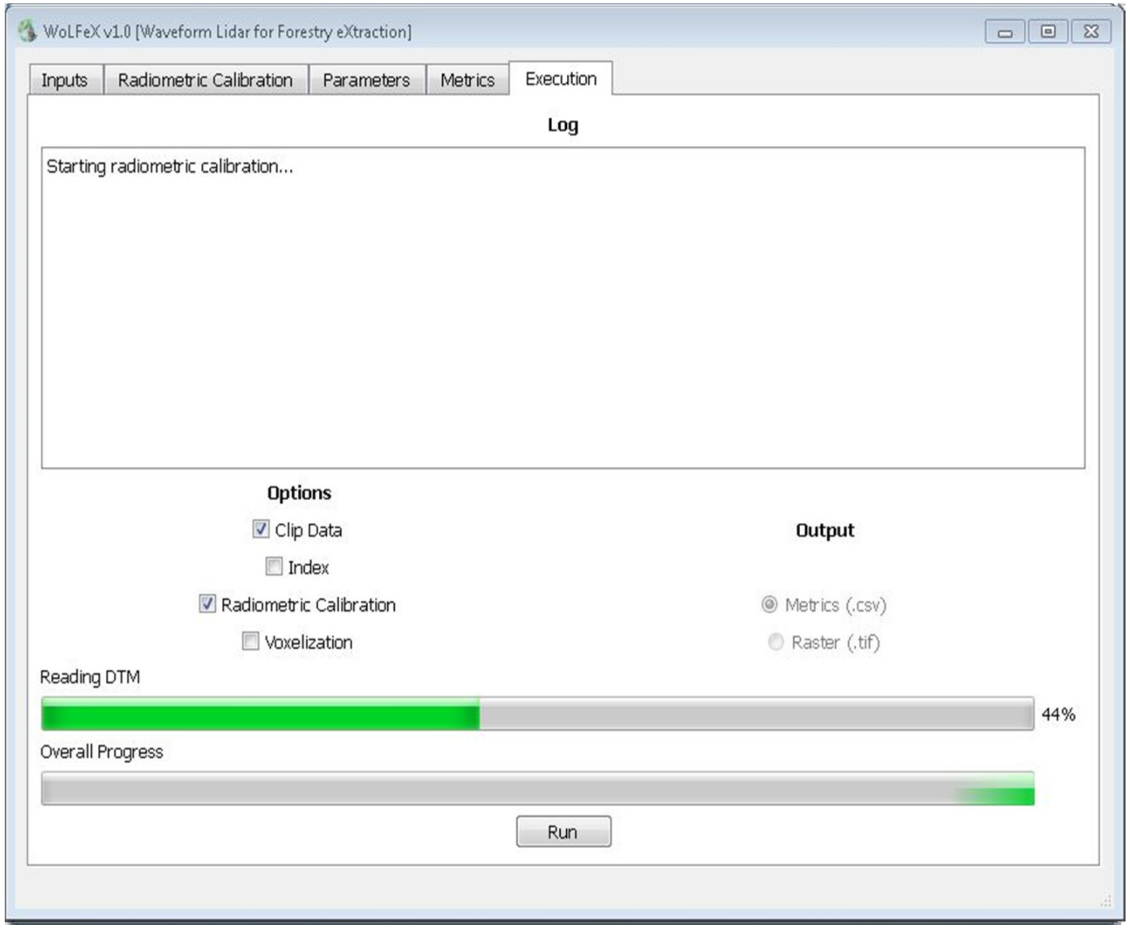
Crespo-Peremarch, P., Tompalski, P., Coops, N., Ruiz, L.A., 2018. *Characterizing understory vegetation in Mediterranean forests using full-waveform airborne laser scanning data*. ***Remote Sensing of Environment***, 217, 400-413.



a) BC: Bottom of canopy
b) BCE: Bottom of canopy energy
c) BCD: Bottom of canopy distance

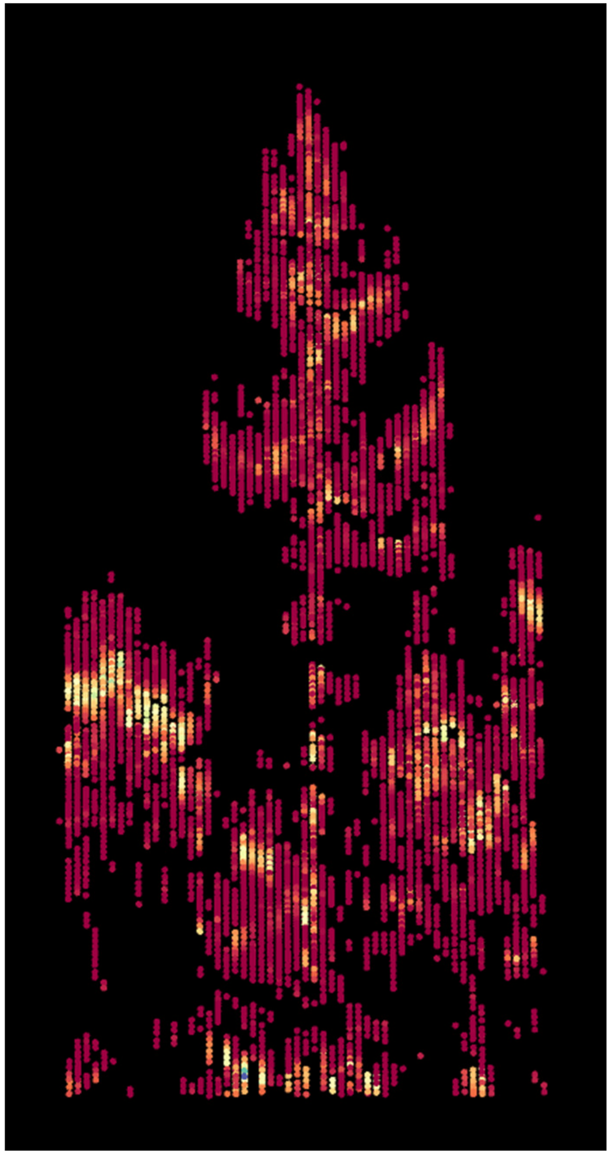


LiDAR full-waveform processing software tool

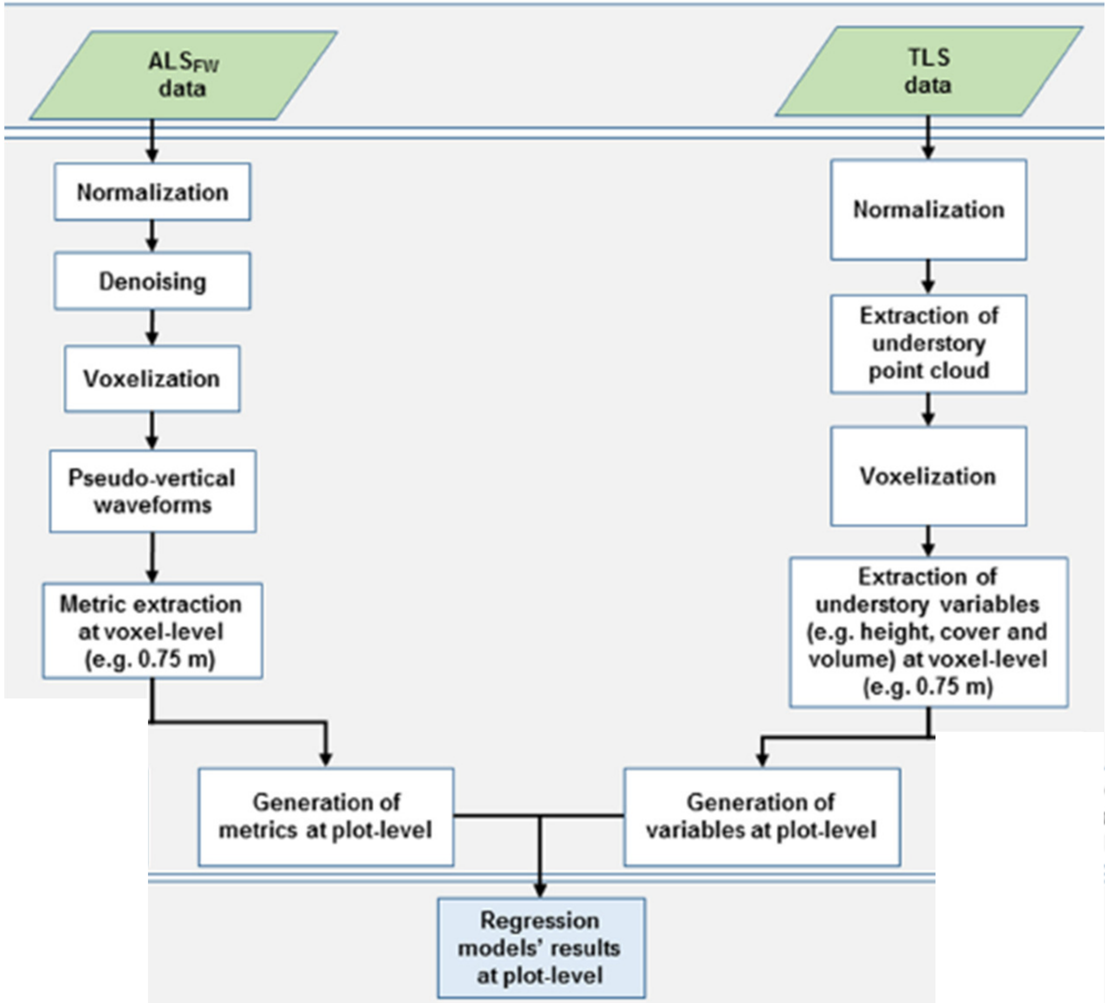


- Import, indexing, radiometric calibration and clipping
- Parameter optimization, voxelization
- Extraction of metrics, processing and analysis

FW vertical profile



Processing flowchart



Results

(overall fuel variables)

Results of prediction models for canopy fuel variables (DENS: tree density; CH: canopy height; CBH: canopy base height; CFL: canopy fuel load)

	Adj. R^2	RMSE	nRMSE	CV
DENS	0,342	304,11 árb.ha^{-1}	12%	39%
CH	0,905	1,15 m	6%	9%
CBH	0,906	0,88 m	7%	15%
CFL	0,774	3,81 Mg.ha-1	10%	19%

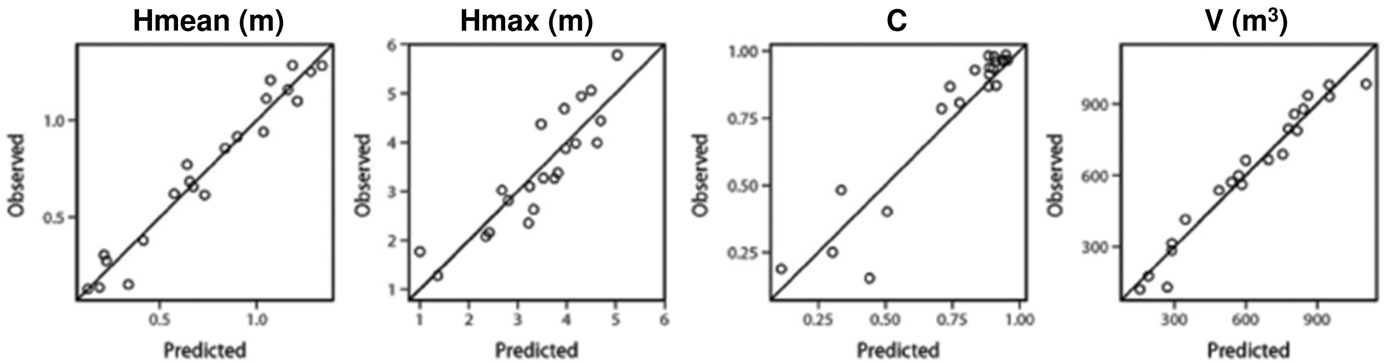
- Linear regression models
- Max. 3 independent variables (AIC)

Results

(understory vegetation)

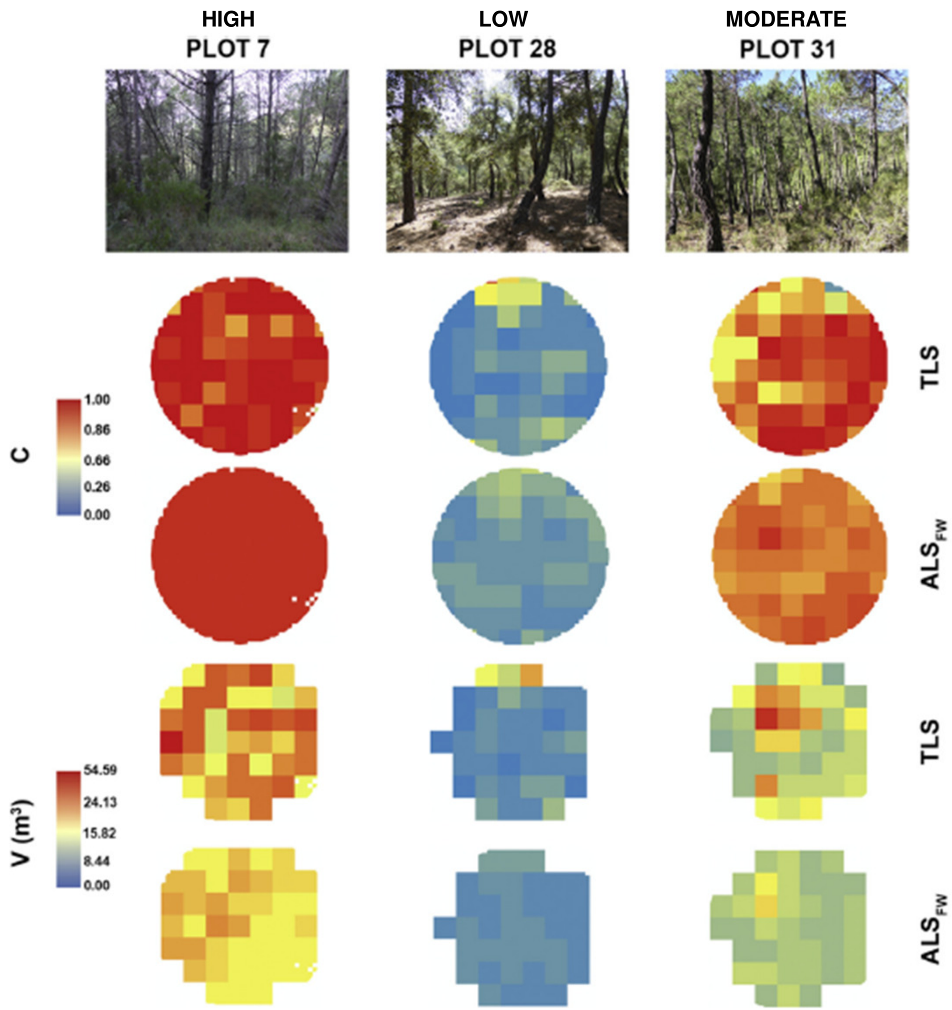
Results of prediction models for understory vegetation (MH: mean height; MaxH: maximum height; COVER: cover; VOL: volume)

	Adj. R2	**RMSE**	**nRMSE**	**CV**
MH	0,949	0,08 m	7%	11%
MaxH	0,758	0,52 m	12%	15%
COVER	0,871	0,09	11%	12%
VOL	0,951	56,49 m^3	7%	9%



Results

Comparative values of understory variables between **predicted** (ALS) and **reference** (TLS) on three example plots with low (28), moderate (31) and high (7) degrees of understory cover



Conclusions

- **Full-waveform** can be used to estimate canopy fuel variables in **Mediterranean forests**
- **Understory** cover, height and volume can be accurately predicted using **full-waveform** ALS
- The **most selected attributes** in the prediction of understory variables were those **specifically designed** for this purpose (based on filled and empty voxels)
- The new **software tool** presented fills a gap for radiometric calibration, voxelization and metrics extraction of **LiDAR full-waveform** files

remote sensing

IMPACT FACTOR 3.406

Special Issue

Applications of Full Waveform Lidar

Special Issue Editor*:*

Prof. Luis A. Ruiz
Universitat Politècnica de València

The purpose of this *Special Issue* is to bring the state-of-the-art in LiDAR FW applications with different system types, in the development of new processing methods, algorithms and tools, and in the integration of LiDAR with other sensors and data sets to optimize its performance. Review papers and research contributions are both welcomed.

Submission Deadline: 30 April 2019

Keywords
- Forest ecology and structure assessment
- Wildfire prevention and fuel estimates
- Urban classification
- Topographic applications
- Agricultural applications
- LiDAR full-waveform methods and software

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