Workshop

New Remote Sensing Techniques for 3D Forest structure Mapping and Wildfire Modeling

Valencia, May 21-22, 2024

Project FireMode: from point clouds to fire behavior simulation

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The project

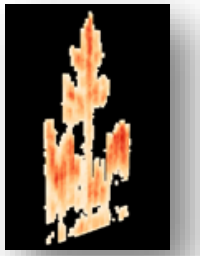
Spectral and Structural 3D Mapping of Mediterranean Fuels for Forest Fire Behavior Modelling (**FireMode**) [PID2020-117808RB-C21]

Call: Programa Estatal de I+D+i Orientada a los Retos de la Sociedad, 2020

Duration: Sept. 2021 – Sept. 2024 (extension)

Main goal: to explore and evaluate the incorporation of 3D structure variables derived from LiDAR point clouds, as well as fuel moisture content values from multispectral remote sensing devices into the new physics-based fire behavior models, and the simulation of different scenarios of propagation of wildfires in Mediterranean forests

Context



Project **ForeStructure** (2014-2016) [CGL2013-46387-C2-1-R]: Characterisation of forest structure by integrated analysis of methods based on LiDAR, terrestrial laser scanning and imagery

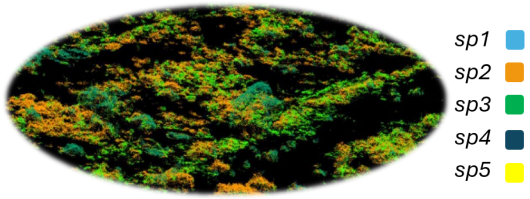
- Definition of 80 permanent plots in Sierra de Espadán and data aquisition (2015)
- Developing ALS *full-waveform* processing tools
- Modeling structure and fuel variables from ALS (discrete and FW) and TLS
- Classification of forest structural typologies using ALS and MS images

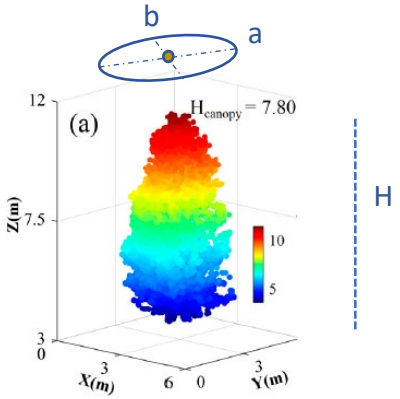
Project **FIRMACARTO** (*FIRe MAnagement CARtographic TOols*) (2017-2020) [CGL2016-80705-R]: Analysis and assessment of forest structure parameters from LiDAR and other emergent techniques for modeling fuel potencial

- Characterize understory vegetation with ALS *full-waveform*
- Forest species composition (ALS and TLS)
- Analysis of TLS location and density for prediction of forest structure

Rationale

From point clouds to fire behavior simulation





Data

- LiDAR
- UAV
- TLS
- Satellite
- Meteo
- DTM

Classification → Species → Estimation (H, a, b, DBH) → Allometric equations → **Bulk density**

Modeling → **LFMC**

Slope

Inputs Fire Behavior Models

- **Wind**
- **RH**
- **Bulk density**
- **LFMC**
- **Slope**

Bulk Density describes the density of fuel in a stand.
It is defined as the mass of available fuel per volume unit.

Rationale

From point clouds to fire behavior simulation

Inputs Fire Behavior Models

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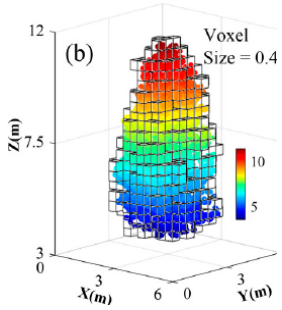
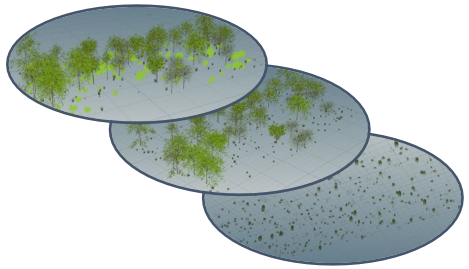


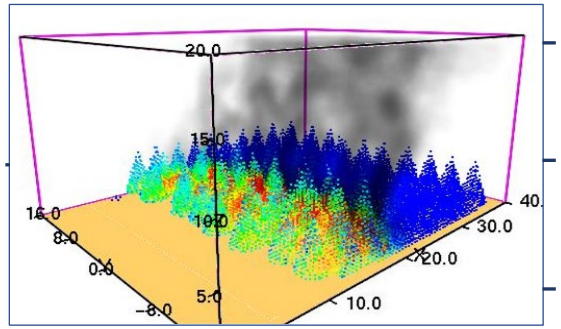


Voxelization

Creation of scenarios

Modifying
- Input variables
- Forest structure

Fire Dynamics Simulator



- **Rate of Spread**
- **Flame length**
- **Burnt dry matter**

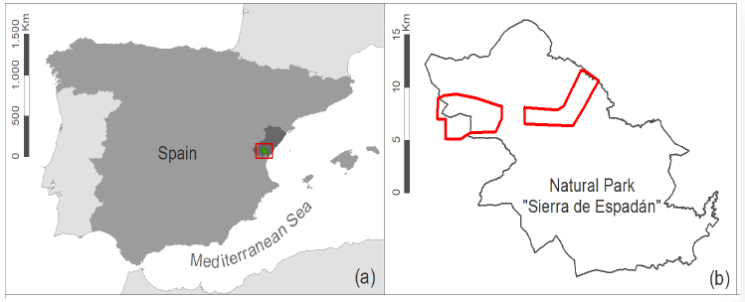
Bulk Density describes the density of fuel in a stand.
It is defined as the mass of available fuel per volume unit.

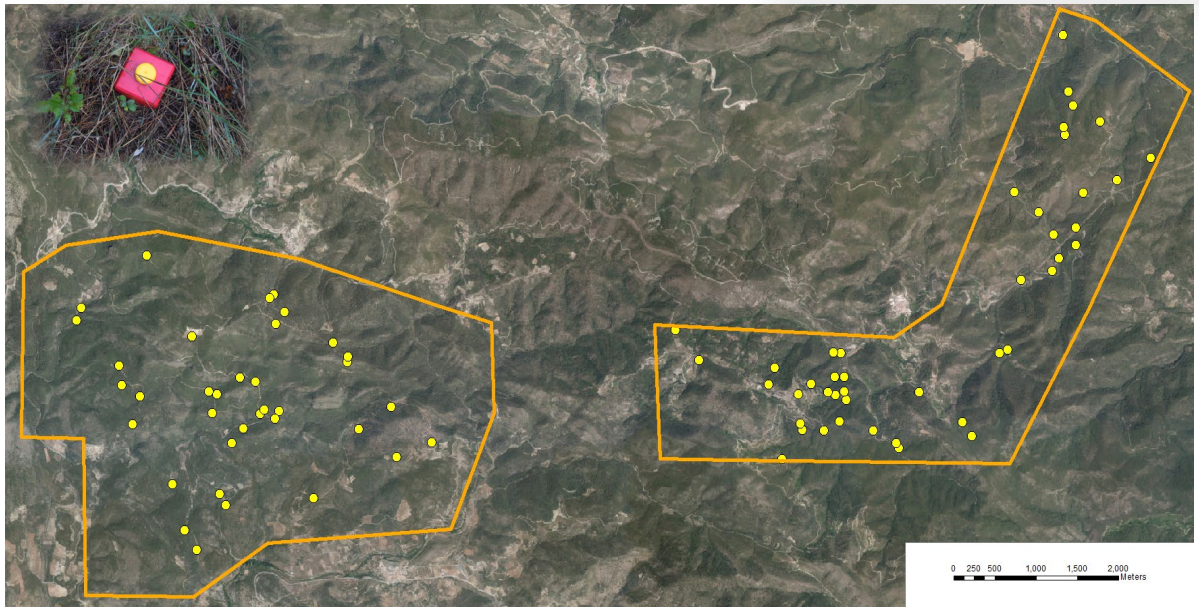
Objectives

- ✓ To **adapt data and fuel variables** from ALS, TLS and SfM (UAV) for their input in physical 3D fire behavior models at voxel level
- ✓ To develop methods for the **classification of structural patches and** shrub **species** based on 3D data from LiDAR/UAV/TLS and spectral information from satellite and UAV imagery
- ✓ **Modeling live fuel moisture content** in Mediterranean forests by using multispectral, meteorological and field data at 2 scales: (1) satellite-based images, and (2) multispectral laser scanner
- ✓ To analyze the effect of system (voxel resolution,…) and environmental parameters (fuel moisture, bulk density, wind,…) in fire behavior variables (spread rate, flame size, burnt dry matter,...) (**sensitivity analysis**)
- ✓ To identify **3D spatial fragmentation indices** and to analyze their **effect in fire behavior** >> mapping 3D fragmentation for fire prevention

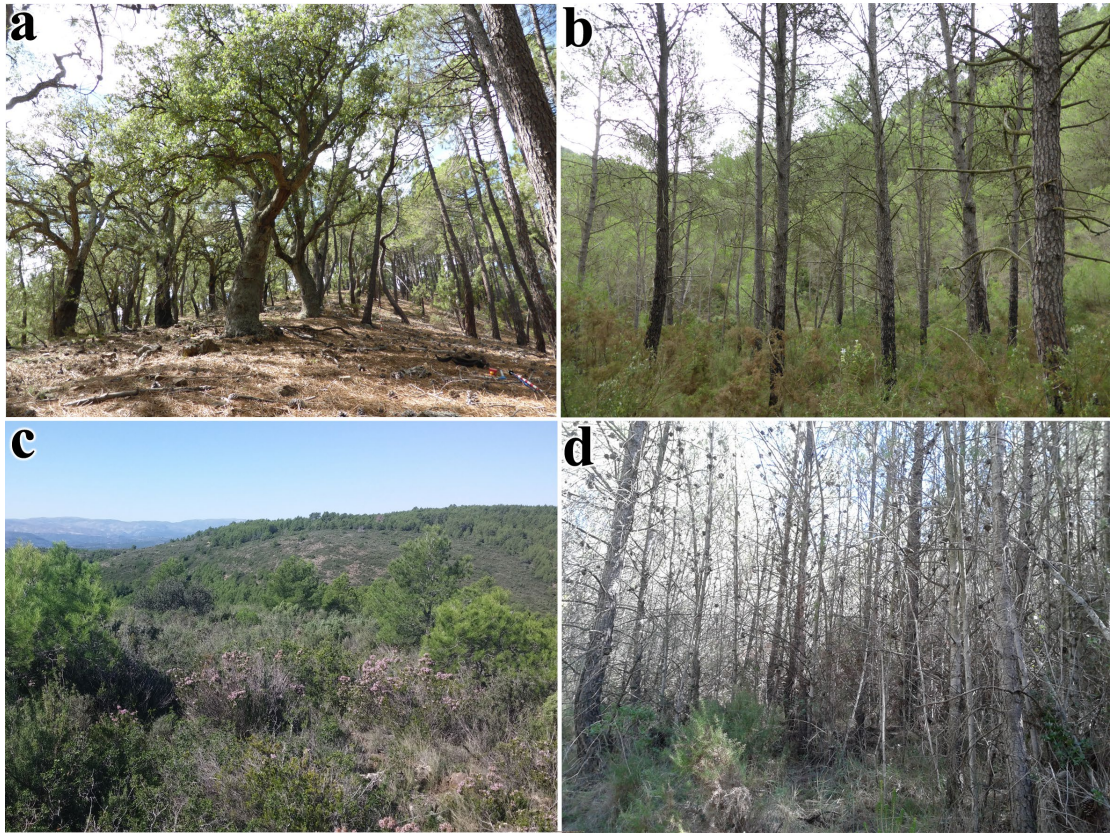
Study Area

Sierra de Espadán: In Sept. 2015, standard forest inventory measurements (DBH, tree heights, N. of trees) were collected in 80 field plots 15m radius, as well as descriptive information. In June 2022, same measurements were repeated in 27 plots.





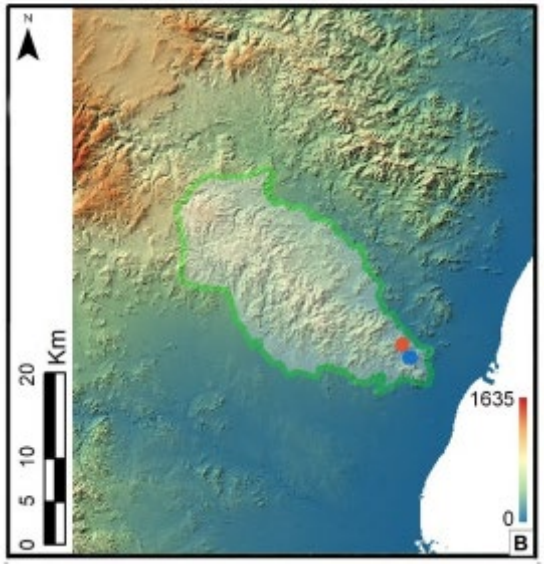
The dominant tree species are *Pinus halepensis*, *Pinus pinaster* and *Quercus suber*. Shrubs and high herbaceous species (*Quercus faginea*, *Ilex aquifolium, Genista scorpius, Erica sp, Juniperus phoenicea, etc.*



Study Area

Sierra Calderona: Two campaigns, in July 2020 and June 2022. Shrub position, height and crown size and were measured in smaller plots.

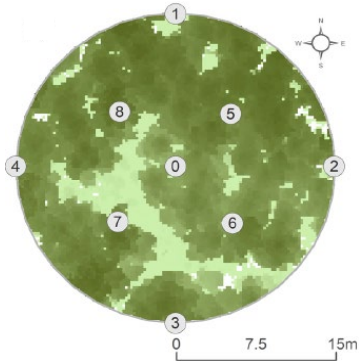
Scattered *Pinus halepensis* and Mediterranean shrub species: *Cistus, Genista, Quercus coccifera, Pistacia lentiscus, Juniperus oxycedrus, Salvia rosmarinus,* etc.



Data sets

TLS and SALCA

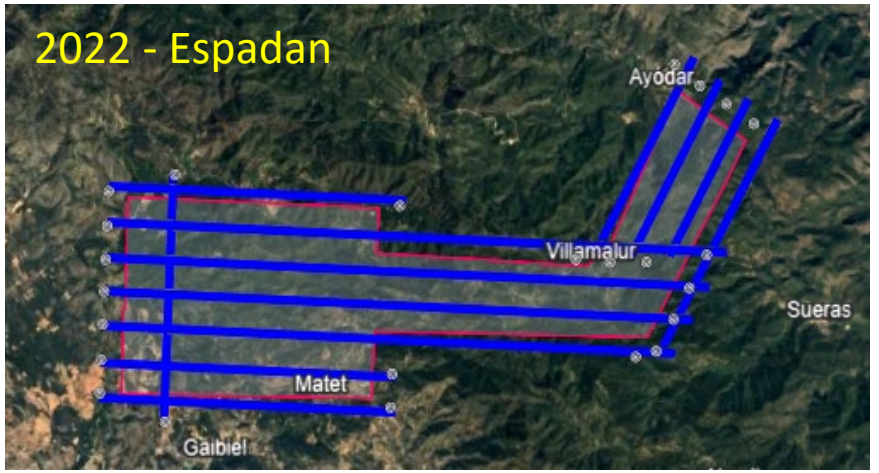
FARO Focus 3D 120
Trimble TX8

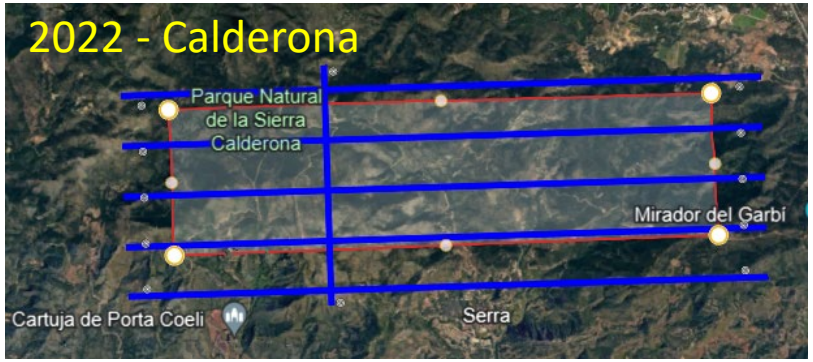


UAV (RGB & NIR)

DJI Inspire 2
Micasense RedEdge MS camera

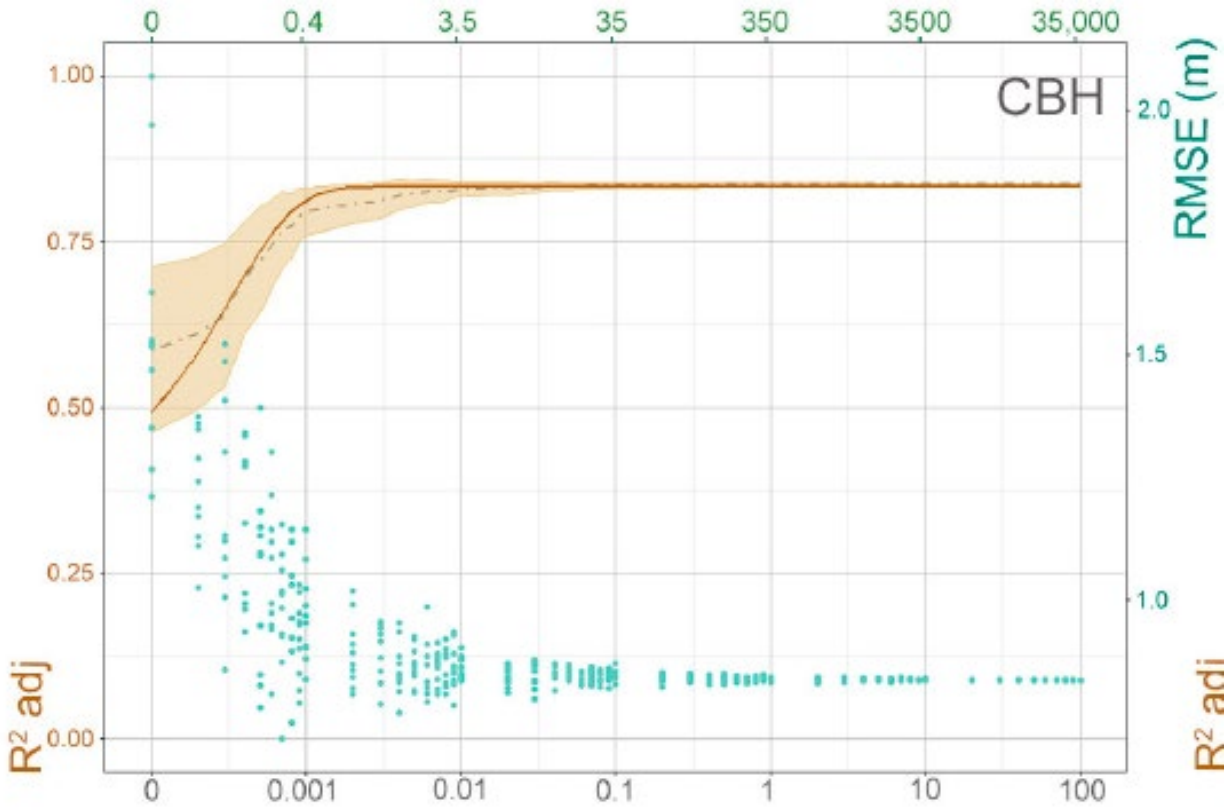
ALS (discrete & full-waveform)





Results: point density

Variation of TLS point density and its effect estimating forest structure variables



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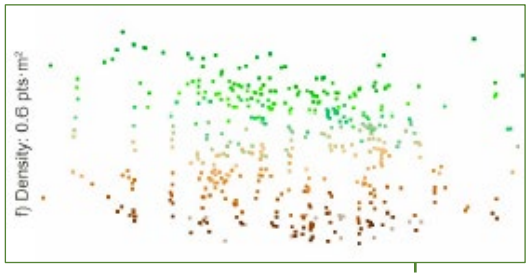
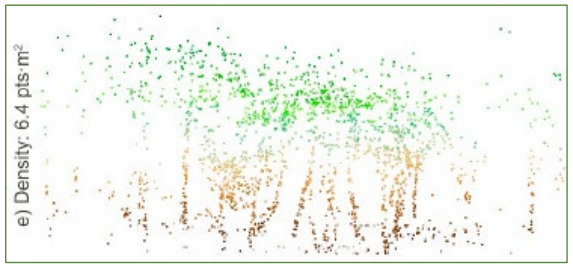
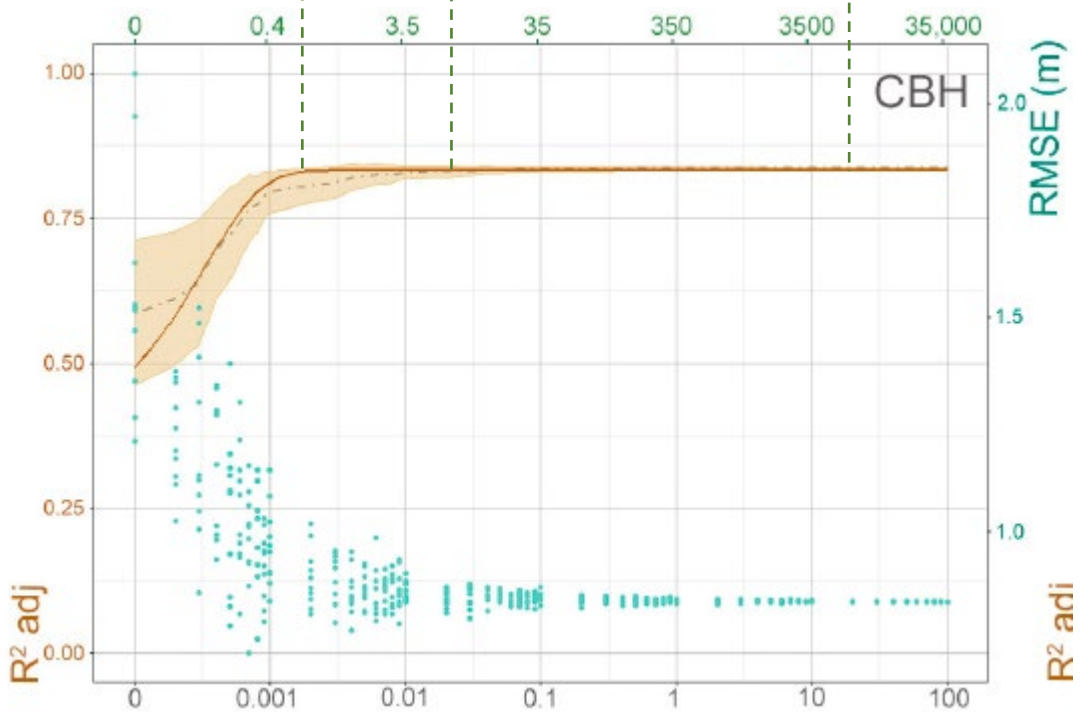
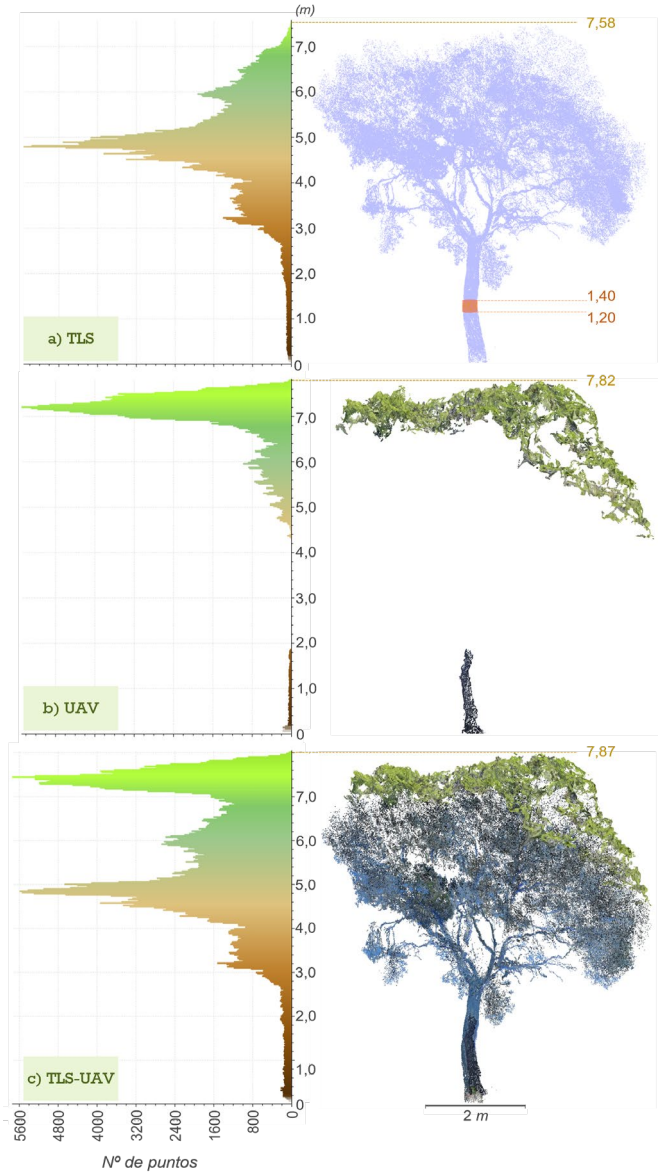






- The use of very high TLS point densities is not necessary to estimate some forest structure and fuel variables
- This is relevant thinking in the use of low-cost mobile scanners

Results: integration TLS-UAV



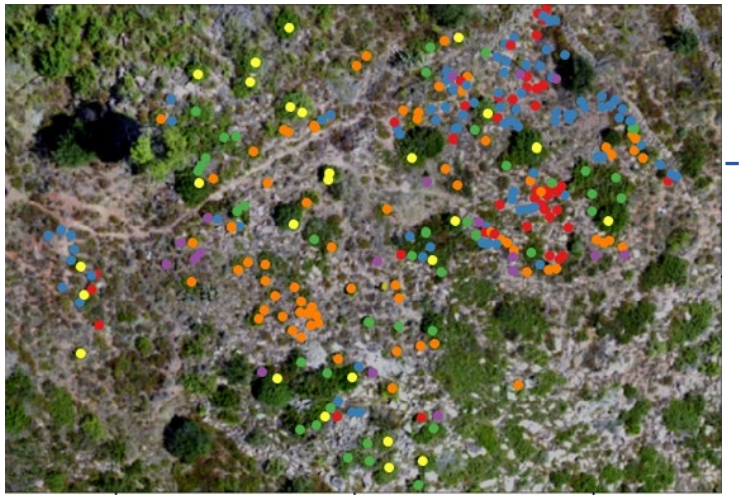
Estimation of structure variables and complementarity of TLS-UAV point clouds

Structure parameter	System	R^2	RMSE
Height	TLS	0.89	0.75m
	UAV	0.88	0.78m
	Fusion	0.90	0.69m
Biomass	TLS	0.91	42.2kg
	UAV	0.70	65.4kg
Volume	TLS	0.91	35.9dm^3
	UAV	0.82	54.3dm^3
	Fusion	0.92	32.7dm^3

- Similar TLS/UAV results for Height estimation
- but not in the case of Volume or Biomass
- Combining both slightly improves the predictions

Species classification

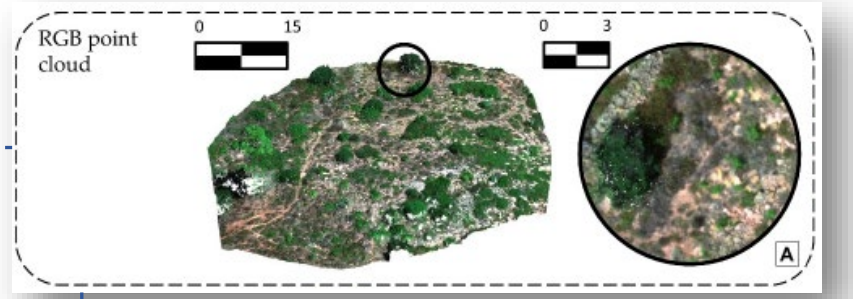
Field location & identification of species



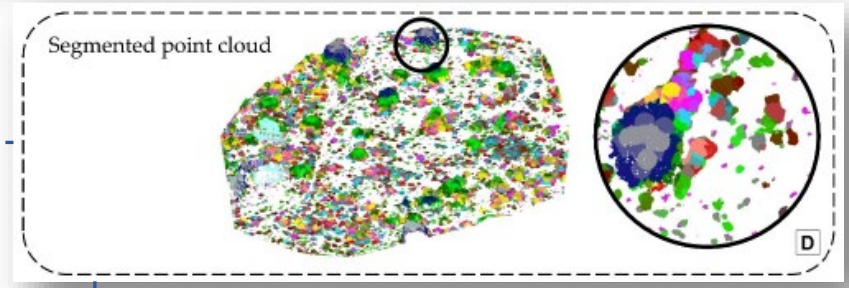
- *Genista scorpius* (L.) DC.
- *Cistus monspeliensis* L.
- *Quercus coccifera* L.
- *Anthyllis cytisoides* L.
- *Chamaerops humilis* L.
- *Pistacia lentiscus* L.

Classification of shrub species from UAV point clouds

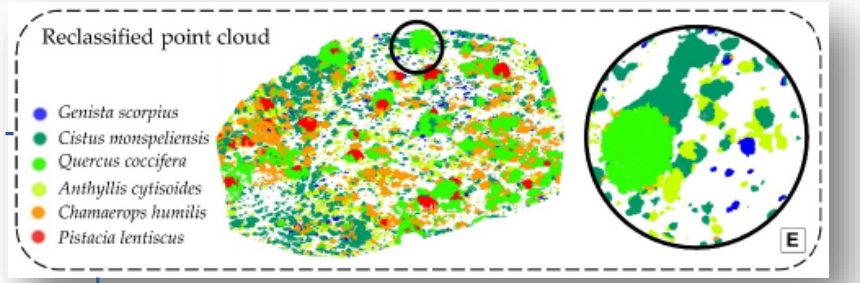
Image acquisition & point cloud generation



Feature extraction & segmentation



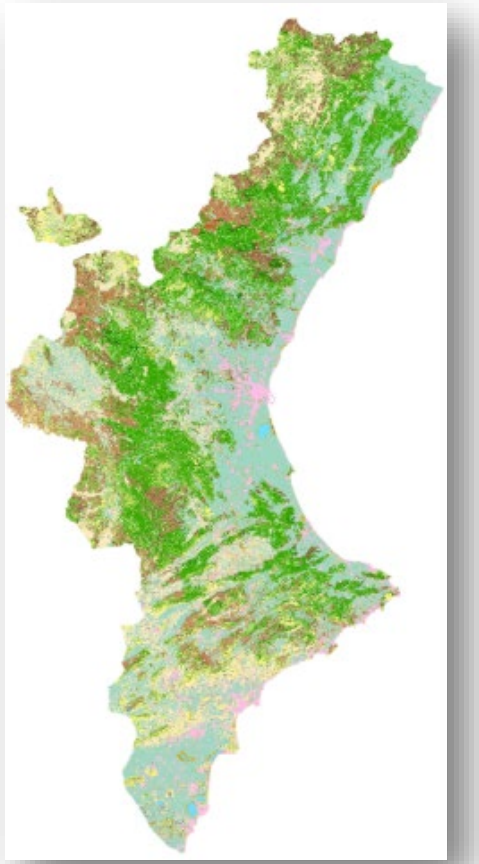
Shrub species classification



Estimation of structure and fuel variables

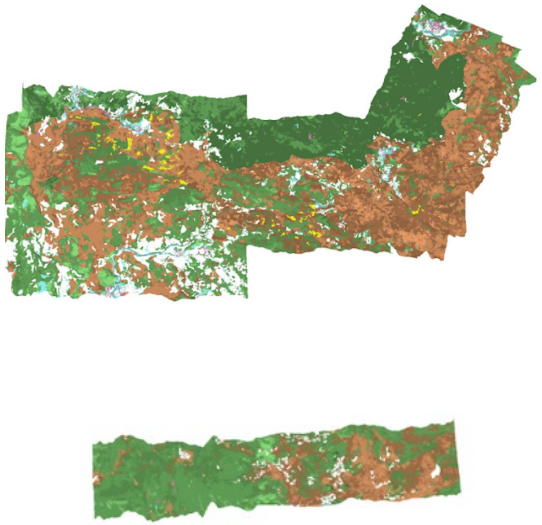
Fuel characterization

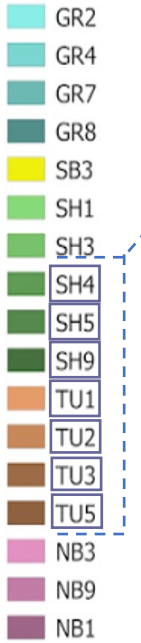
Mapa de Modelos de Combustible (ICV) based on Scott & Burgan Fuel Models, 2005

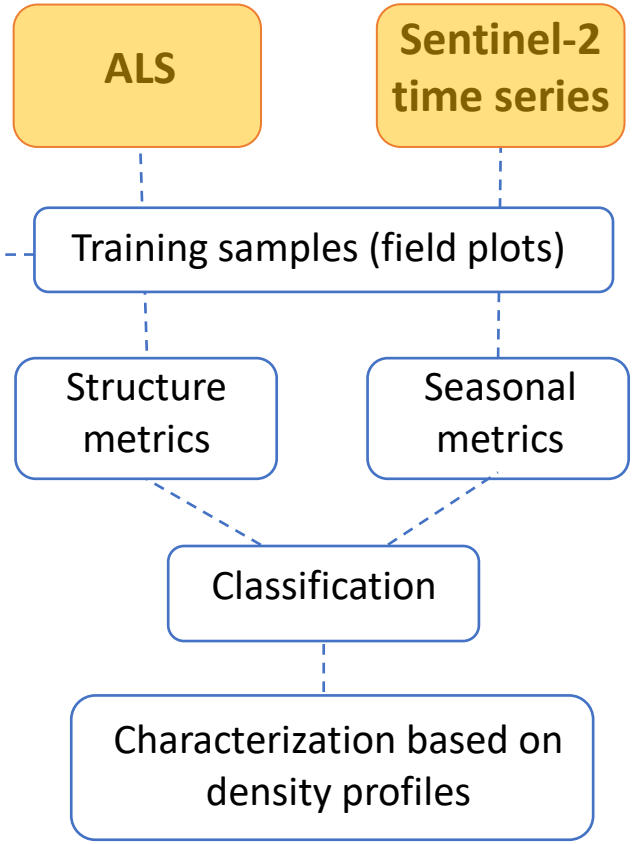


Characterization of fuel models

Fuel Map of Espadan & Calderona



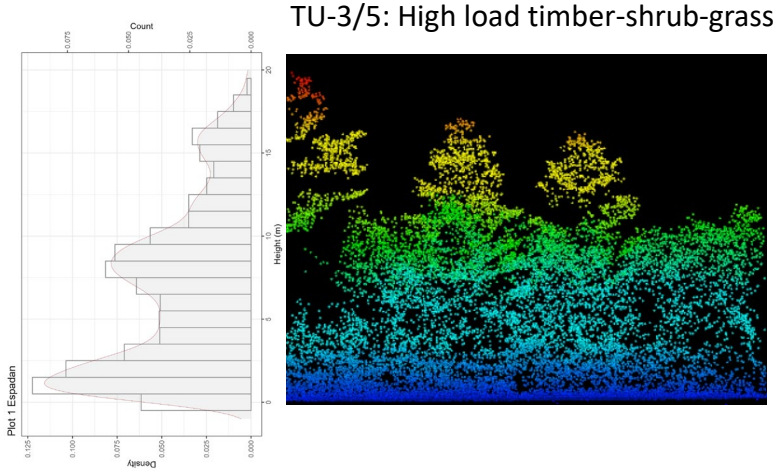




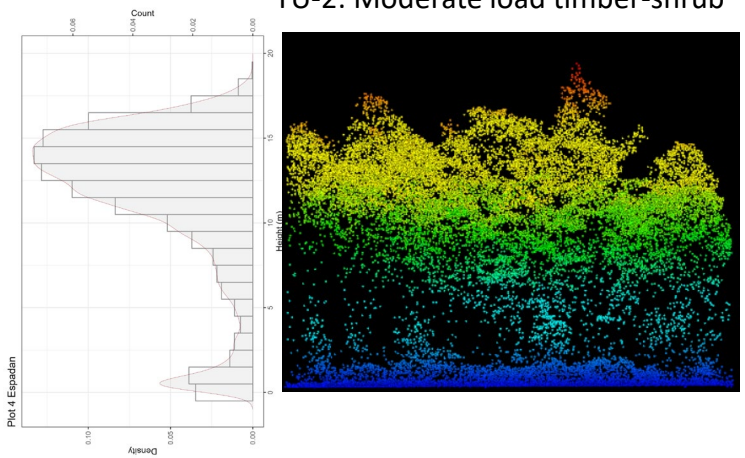
Fuel characterization

Characterization based on density profiles (ALS)

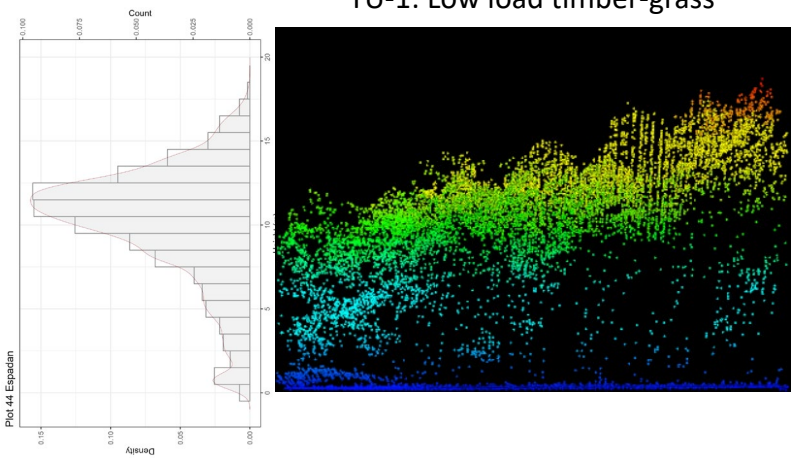
TU-3/5: High load timber-shrub-grass



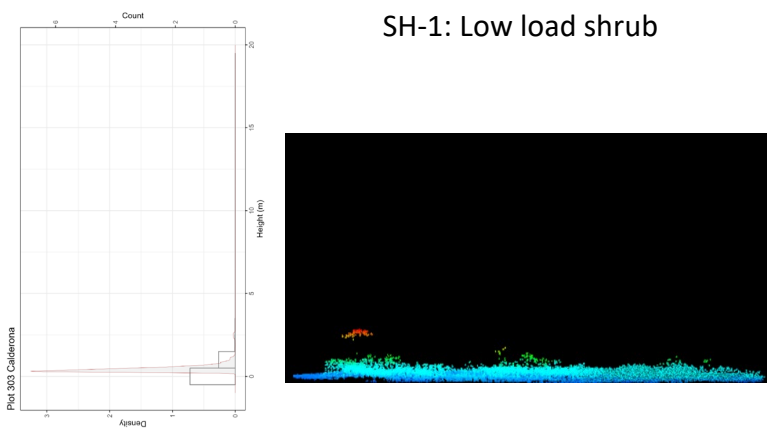
TU-2: Moderate load timber-shrub



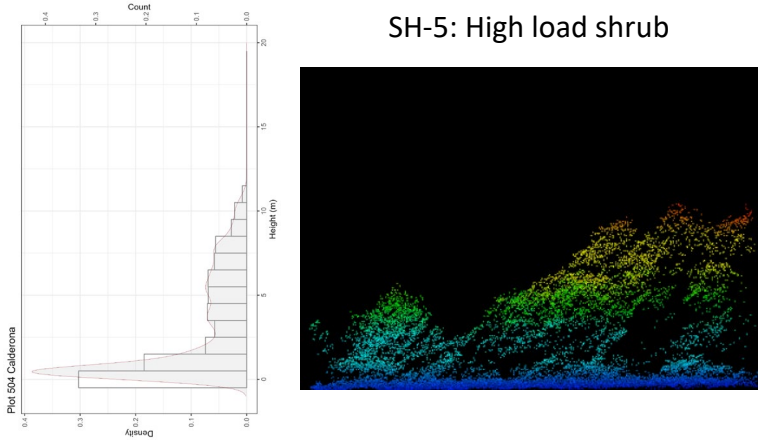
TU-1: Low load timber-grass



SH-1: Low load shrub



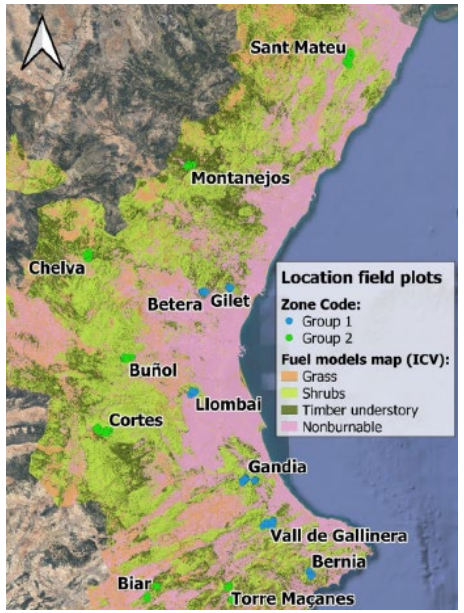
SH-5: High load shrub

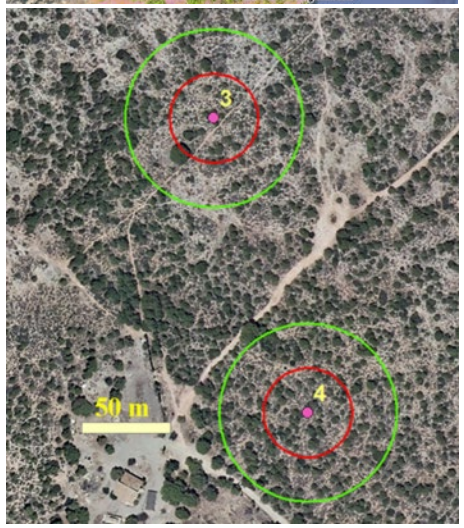


Gaussian decomposition, definition of number, size and density of vertical strata

Modeling life fuel moisture content

Field data collection



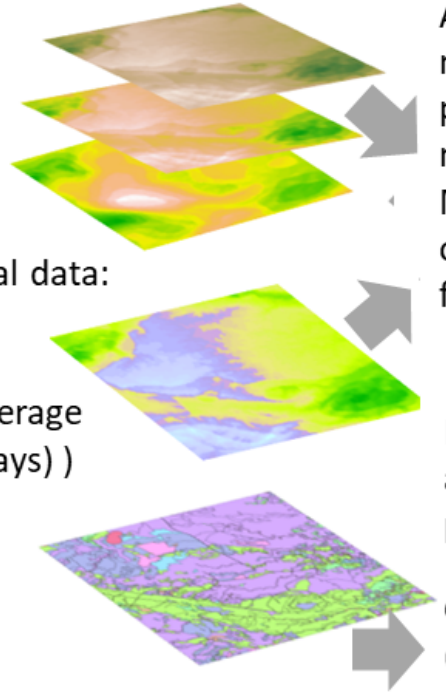


Processing and mapping

1) Sentinel-2A NDMI time series (Google Earth Engine)

2) Meteorological data: average daily temperature (60 days) and average wind speed (7 days))

3) Forest Map: Shrub or sparse Woodland areas



A) Linear regression model using LFMC in pooled locations for mixed vegetation in a Mediterranean area of Spain during the fire season

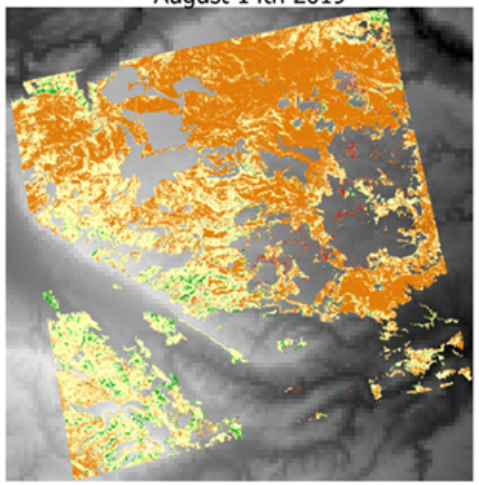
B) Cross-validation and testing in other plots

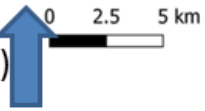
C) LFMC estimation in shrub areas (weighted average of shrub species-WAS)

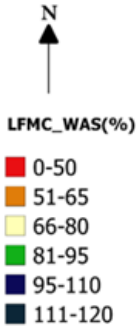
$$LFMC_{ij} \leftarrow \text{Average\_NDMI}_j + \text{NDMI}_{ij} - \text{T60}_{ij} - \text{W7}_{ij}$$

Live Fuel Moisture Content (LFMC) projection

August 14th 2019



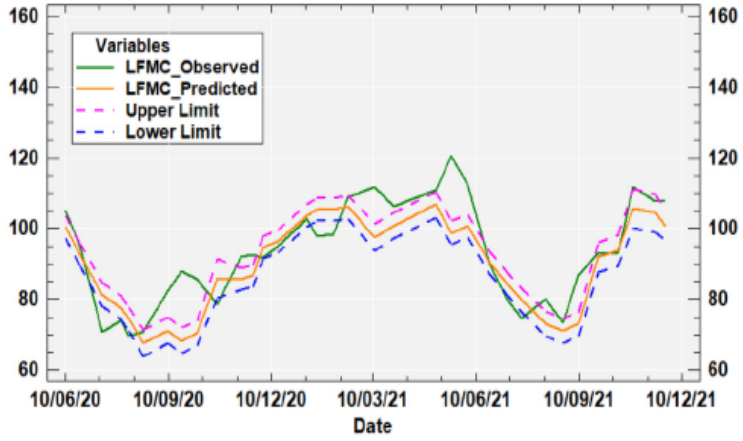




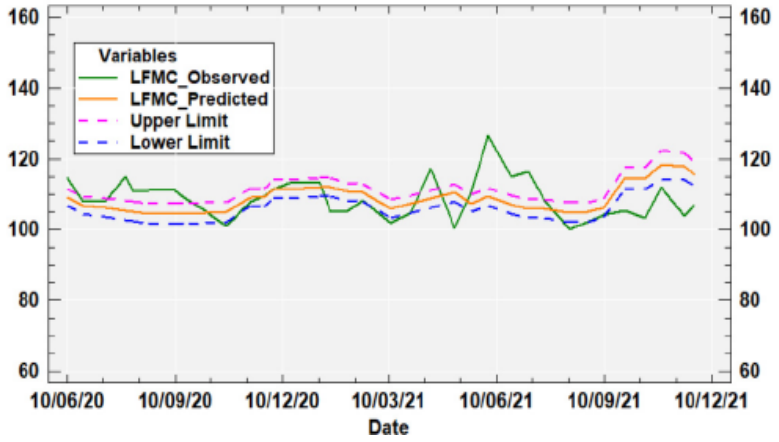
Modeling life fuel moisture content

Seasonal variations of observed (green) vs predicted (orange) in two plots of shrub (left) and trees (right).
Discontinuous lines show 95% of confidence level limits

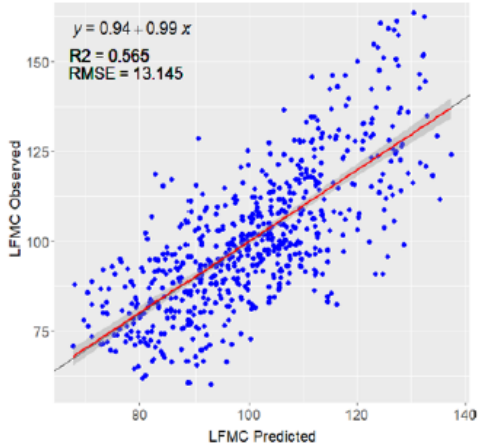
Shrub

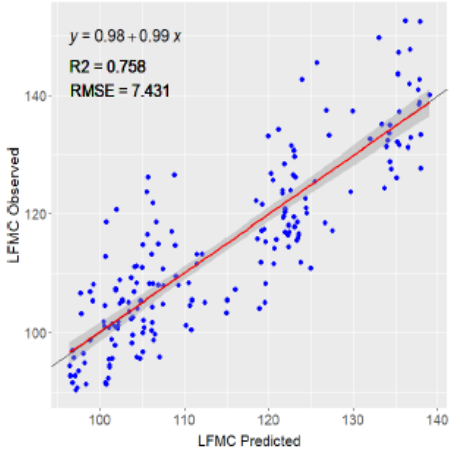


Trees



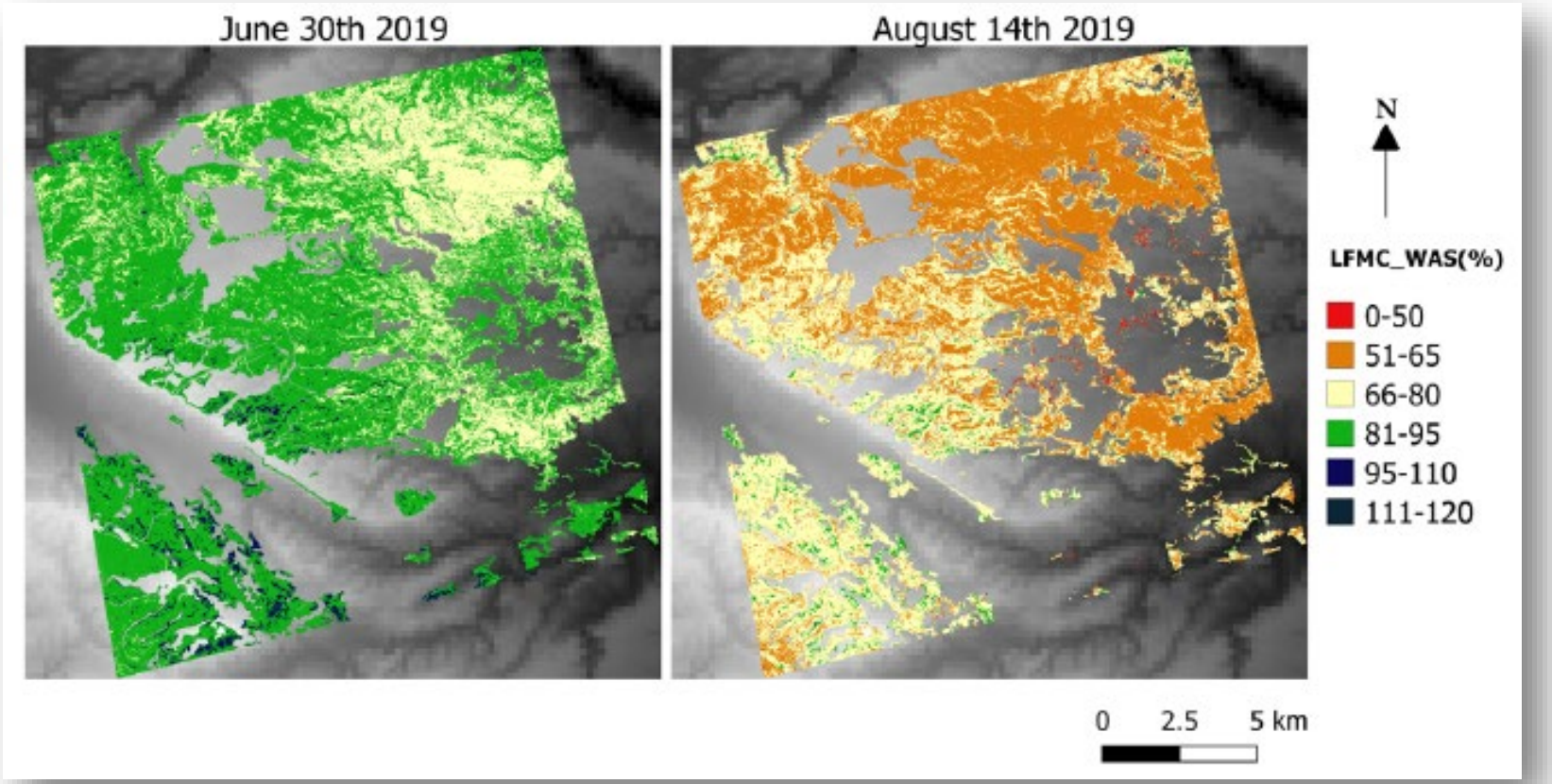
Predicted vs observed LFMC values: Shrub, group 1; Trees, group 1; Line y=x (black), regression line (red), grey area: 95% conf. level





Modeling life fuel moisture content

Example of estimated LFMC of forested areas in June and August



Simulating fire behavior

How forest structure properties affect fire propagation?

Simulated scenarios

Allow for a more complete testing of structural variables

Real scenarios (point clouds)

Provide a more realistic representation of the landscape

Sensitivity analysis

Fire Dynamics Simulator

Testing the effect of forest structure and 3D fragmentation conditions on fire behaviour

Mapping 3D forest fragmentation and structure from point clouds

Allowing to preview fire behavior and risk

Next steps

- ✓ To **complete sensitivity analysis** to assess the effect of forest condition and structure on fire propagation and risk.
- ✓ Identify and test **3D forest fragmentation indices**, measurable from point clouds, as indicators of wildfire risk.
- ✓ Continue **improving classification** of vegetation species and patches to be extended to broader areas with more diversity.
- ✓ **Validate** operative **models of LFMC** which can be used by our local administration in wildfire risk assessment.
- ✓ Introduce **deep learning and AI** methods to classify point clouds and to estimate forest fuel variables in a more efficient manner.

Thank you for your attention!

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