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Methodological developments for monitoring the estimation of flammability indicators using airborne hyperspectral images in a Mediterranean forest context

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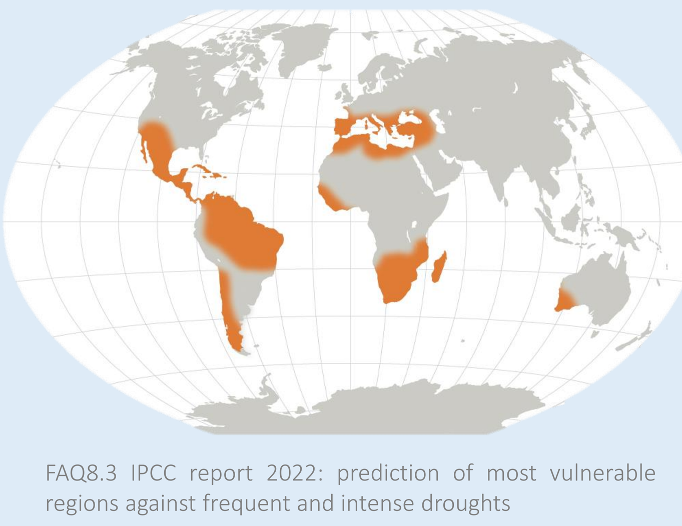
CONTEXT

Global Warming and Mediterranean Ecoregion

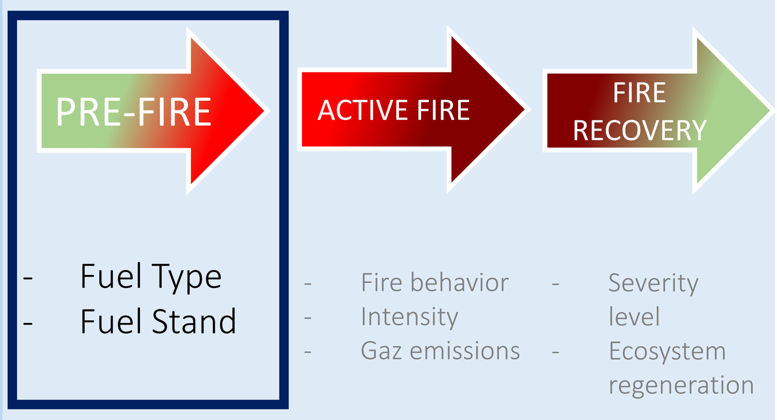
- Mediterranean ecoregion is a **biodiversity hotspot** with «drought higth risk » as stated by IPCC.
- **Savanna ecosystem** (about 20% of continental surfaces) is one of Mediterranean habitat that offers an important biodiversity because of its landscape mosaic.
- Even if **regular wildfires** take part of the regeneration of this Mediterranean ecosystem, the effects of Global Warming are affecting fire regime with more intensity and longer droughts.
- Coupling with anthropogenic pressures, fires are and will be **bigger and more frequent** in future years.



FAQ8.3 IPCC report 2022: prediction of most vulnerable regions against frequent and intense droughts

« Fire disturbance continuum »

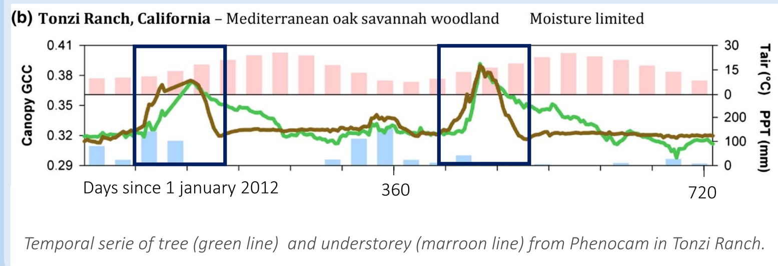
From Veraverbeke, 2018



- Fire prevention (**pre-fire** phase) requires an accurate knowledge of fuel stand and **fire risk monitoring**.
- **Modelisation** is mainly focused on fire behavior (active-fire phase) but is limited by the lack of spatial precision of the information on vegetation conditions.
- Fuel stand is generally assessed either by empirical approaches (spectral index) or by quantitative estimations through modelisation
- The challenge by pre-fire modelisation is to take into account the fuel stand behavior throughout the entire phenological cycle and to improve its spatial resolution

State of art

- Fuel stand estimations at the end of **spring** provide information on potential fire season tendency (Huesca et al., 2009)
- Spring (begining of fire-season) studies are scarce and challenging in **open forests** due to the **mixed** spectral signals of under and overstory .



Temporal serie of tree (green line) and understorey (marroon line) from Phenocam in Tonzi Ranch.

From Brown, 2016

The objective is to estimate biochemical and structural variables of woody vegetation in open Mediterranean forests based on a hybrid method during biomass peak phenophase when the two vegetation layers are active

VARIABLES

Fuel Type

LAI
Leaf area index

Vegetation type

→ leaf area relative to a surface unit.
→ Variable without unit correlated to foliar density of a vegetative system at different scales: tree, population, stand, ecosystem, biome
→ **Essential climate variable** for observing and monitoring climate change effects (GCOS Global Climate Observing System, 2011).

Fuel spatial distribution

Maps of species or plant functionnal type classification and canopy cover (CC) to estimate fuel spatial continuity

Fuel Stand

LFMC
Live Fuel Moisture Content

Hydric

- Leaf water concentration accessible with:
→ **EWT** : Equivalent Water Thickness
- This concentration must be normalized with respect to the structure of the vegetation defined by:
→ **LMA** : Leaf Mass per Area

$$LFMC\,(\%) = \frac{EWT - LMA}{LMA} \times 100$$

Pigments

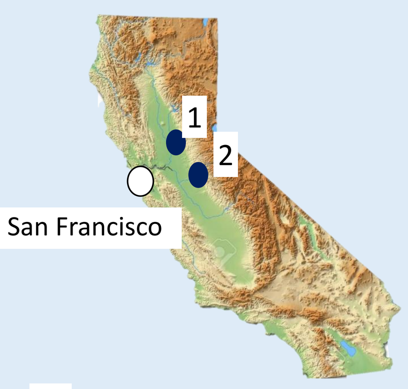
Physiologic

Hydric stress → changes of chlorophylls concentration [Cab] and carotenoïds [Car] + reduction of intercellular spaces occupied by air in the mesophyll
= changes in spectral behaviour

DATA

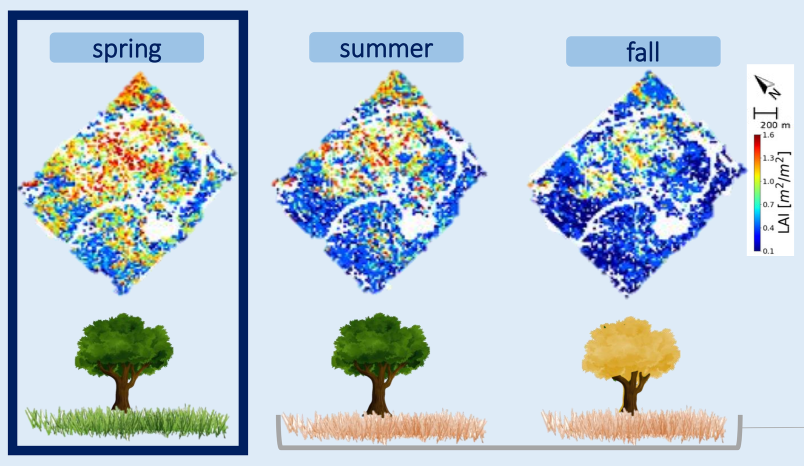
Study site

1 - Tonzi Ranch
2- San Joaquin Experimental Range



Measures of the functional and structural vegetation traits

These 2 sites are Mediterranean savannas (**Tree Grass Ecosystem** = TGE) where hyperspectral airborne data were performed since 2006 (AVIRIS CLASSIC). Coupled with these overflights, field data was collected by the CSTARS laboratory as part of a NASA-University of Davis – California project for the HyspIRI mission. These field bio-physio-chemical measurements will serve as calibration and validation data.



Dataset description		
Biochemical	Chlorophylls and carotenoids pigment contents	• EWT • LMA
Structural	LAI derived from hemispherical photo processing	Forest Inventory

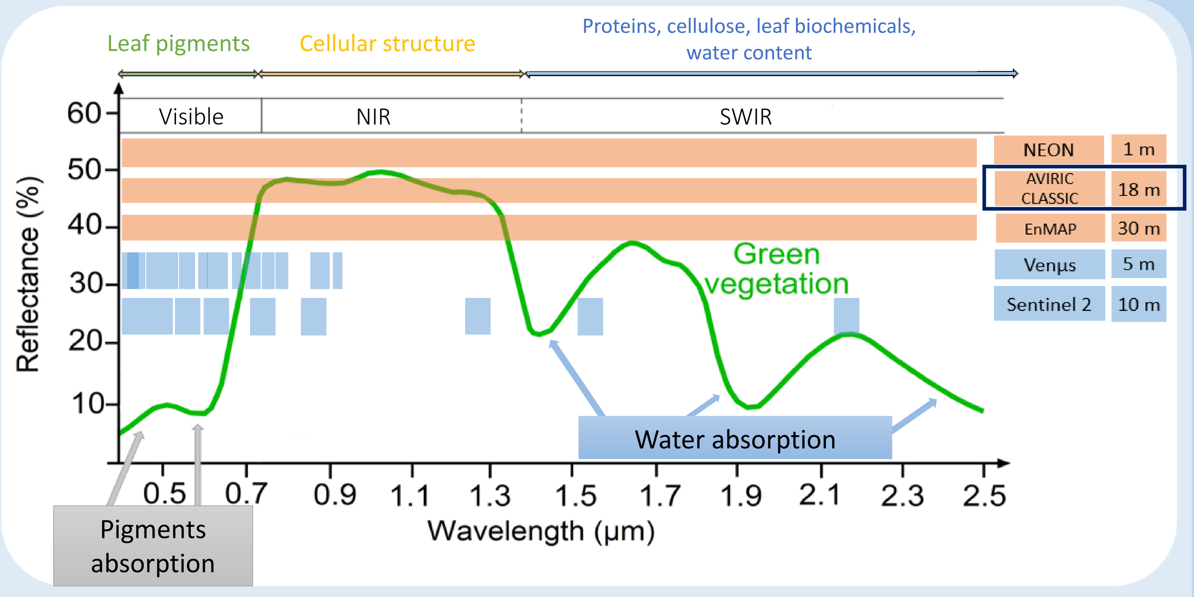
From Miraglio PhD 2021

Remote sensing

→ Hyperspectral airborne images are very useful because they allow to estimate most vegetation traits
→ Proof of local correlations between LFMC estimations from AVIRIS CLASSIC and LFMC from field (Roberts et al., 2006)

Dates		
Site	Image	Field data
SJER	20140407	LAI : 20140409-10
		Bio: 20140411
TZ	20140410	LAI: 20140415
		Bio: 20140410

AVIRIS Airborne Visible / Infrared Imaging Spectrometer



AVIRIS – CLASSIC products characteristics:

- Airborne data acquired at 4-20 km from the level of the sea
- Hyperspectral data with 224 contiguous spectral channels from 400 → 2500 nm
- Reflectance images (L2) resampled at 18 m

Limits:

- Coarse spatial resolution to estimate variables at tree scale : majority of mixed pixels composed of trees + background
- No systematic revisiting : fuel monitoring not possible

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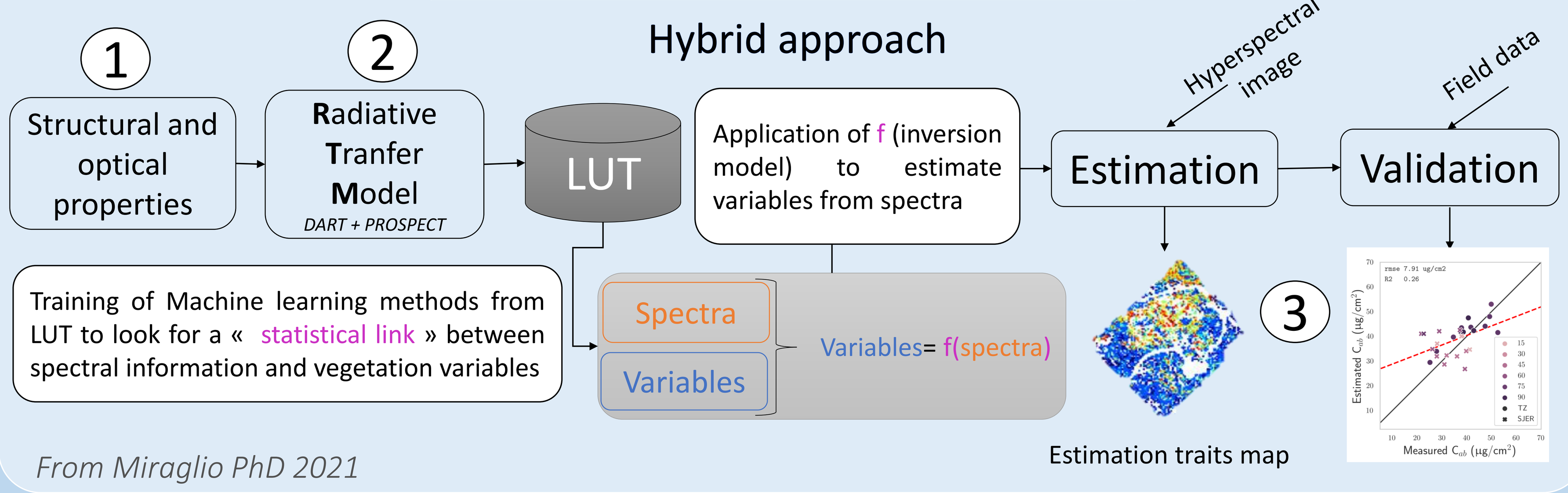
METHODOLOGY

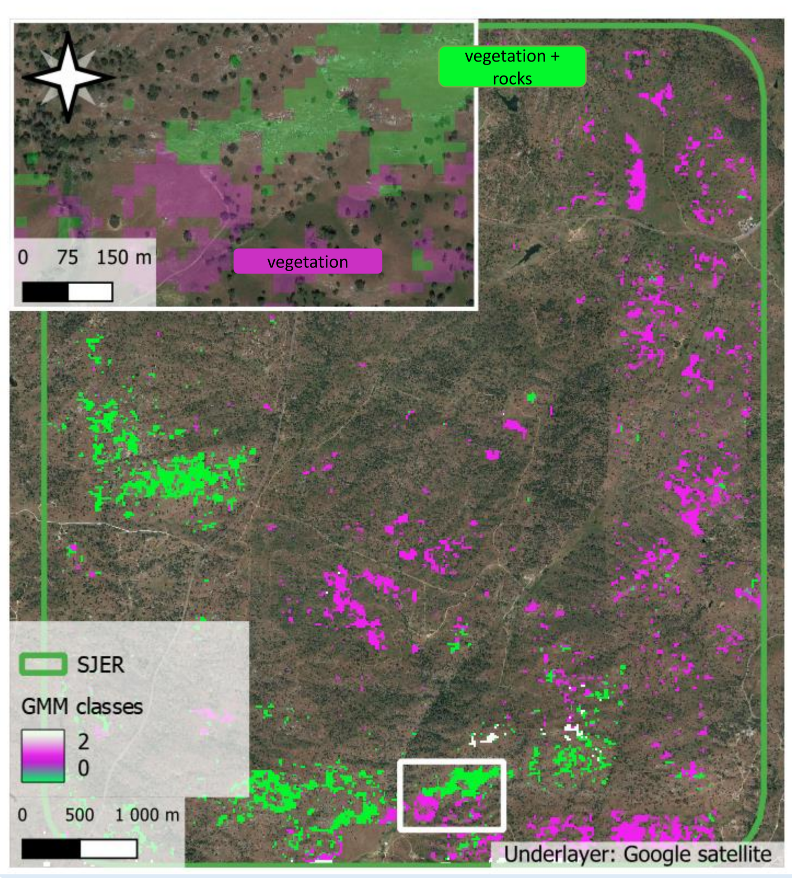
Hybrid approach

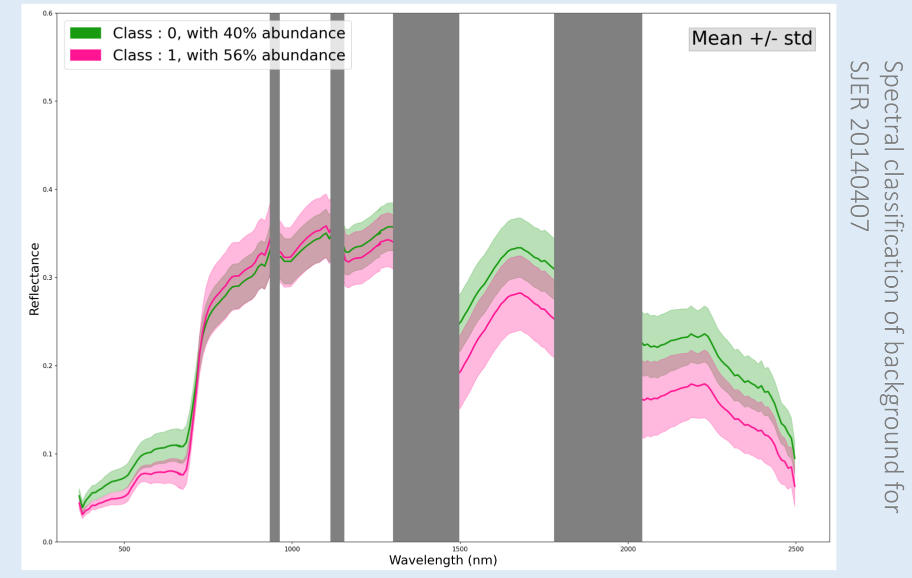


From Miraglio PhD 2021

1 Background spectral extraction and classification
from Démoulin (internship 2022)

Background classification with 3 components for SJER





→ Selection of the pixel with maximum proportion of background information (thresholding from MCARI2 image)
→ Selection of the addequate number of components from PCA applied on an image stack composed of 3 dates per year for different phenological periods
→ GMM classification and selection of number of classes

2 LUT generation with RTMs

CESBIO · DART

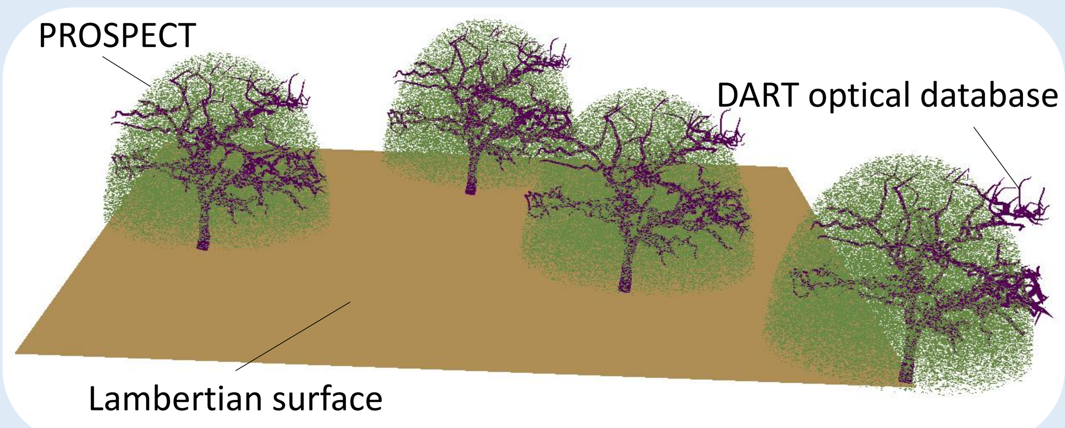
→ Simple Forest Representation with woody structure from LiDAR = DETAIL *(from Miraglio PhD 2021)*
→ Leaf reflectance obtained with PROSPECT implemented in DART
→ Background parameterized with AVIRIS CLASSIC spectra using classification from (1)
→ Design of Experiments generated for 700 combinations of [Cab], [Car], LAI, Average Leaf Angle, EWT, LMA, CC and background spectra

DART 30 scene from top view

Woody structure from LiDAR measurement made by Crystal Schaaf's University of Boston

DART parameters

Trees geometric properties		Scene size (m)	
Crown shape	Ellipsoid composed	CC10	45,95 x 45,95
Crown diameter	8m	CC30	26,5 x 26,5
Trunk height below canopy	2m	CC50	20,5 x 20,5
Trunk Height with the crown	6m	CC70	17,4 x 17,4
		CC90	15,3 x 15,3



3 Biophysical and structural vegetation traits estimation and validation: PHYTREE

→ Generation of Species mask (*Quercus douglasii* and/or *Quercus wislizeni* >50% of pixel)
→ Generation of Canopy Cover mask (CC >10%)
→ Comparaison of estimation performance with different machine learning algorithms (PLSR, RLR, RF, neural network …)
→ Validation criterion = comparaison of variables estimated with field data values (R^2, RMSE)

Canopy cover and species mask for SJER