Linking sun-induced fluorescence and photosynthesis in a forest ecosystem

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Objectives

- To analyse the link between sun-induced fluorescence (F) and photosynthesis modeled with a biophysical model (BESS) coupling atmospheric and canopy radiative transfer processes in a forest ecosystem using high resolution hyperspectral data.

i) To retrieve spatialised maps of F687 and F760 using SFM;

ii) To retrieve spatialised maps of plant traits using RTM inversion;

iii) To evaluate the possibility to use these traits to drive the modeling of GPP using the BESS model;

iv) To analyse the spatial relation between measured F and modeled GPP.

Study Site

Hardt Forest, 47.821102 N 7.455386 E

- Mid-latitude mixed forest
- Broadleaves/Conifers
  - *Carpinus betulus* L.
  - *Quercus petraea* (Matt.) Liebl.
  - *Quercus robur* L.
  - *Acer campestre* L.
  - *Tilia* L.
  - *Pinus sylvestris* L.
  - *Larix decidua* (Mill.)
- Relative variability in terms of forest development stages

Data Acquisition
Ground Measurements

- Calibration and validation (Cal/Val) spectral measurements over artificial targets (n=9)
- Species composition (%) (n=14)
- Leaf chlorophyll content (µg cm^{-2}) (n=21)
- Leaf Area Index (m^2 m^{-2}) (n=14)
- Top-of-canopy spectral measurements (ρ and F) using high-resolution portable spectroradiometers (Ocean Optics, Dunedin, USA) (n=9)

View angle: nadir

Field of view: 25 °

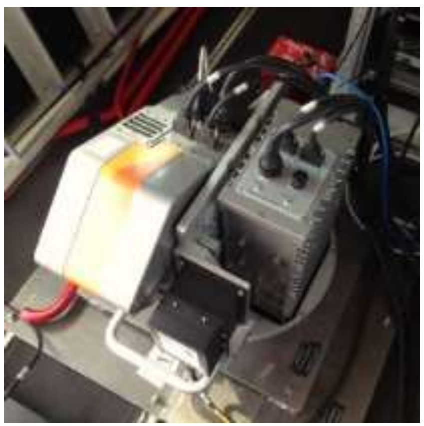
Obs. diameter: ~2 m

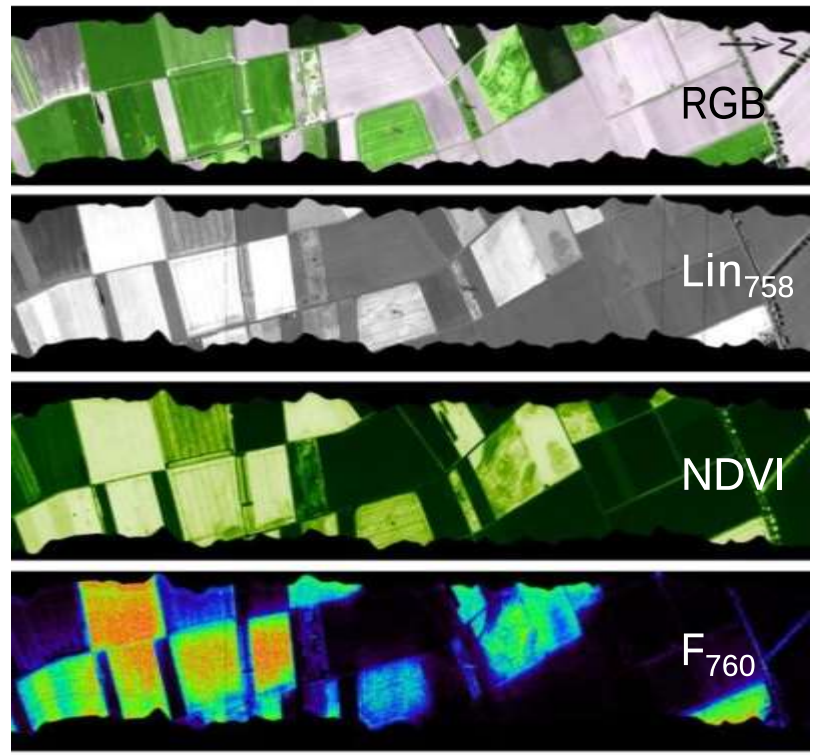
Data Acquisition

Airborne Data: the FLEX airborne demonstrator HyPlant

- First imaging spectrometer to allow mapping F over large areas
- FLEX-like module to retrieve both red and far-red F

HyPlant

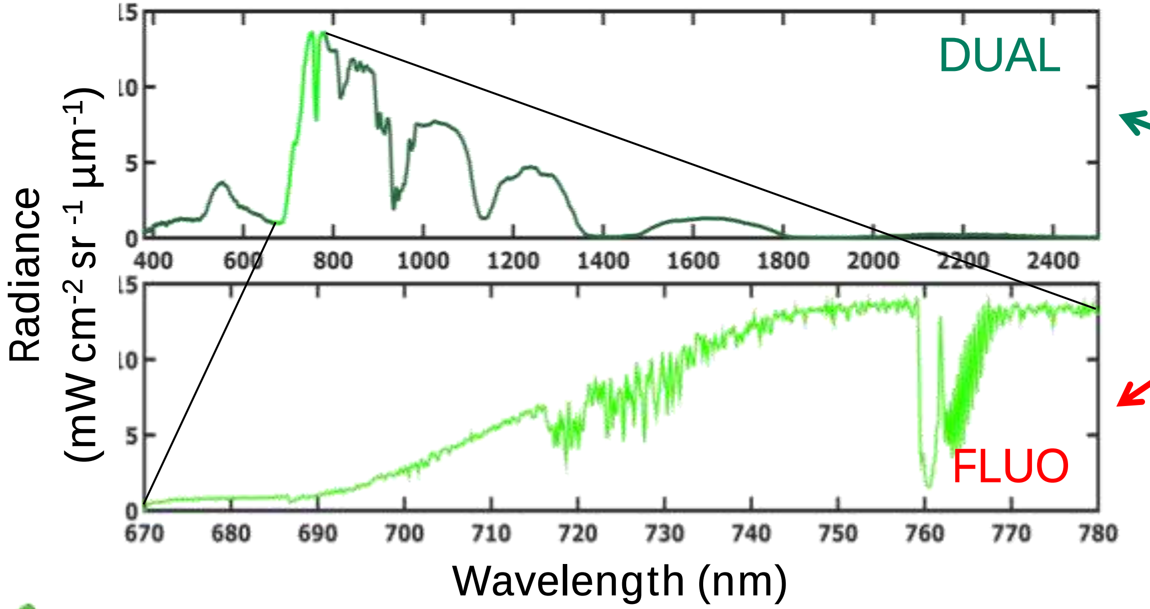


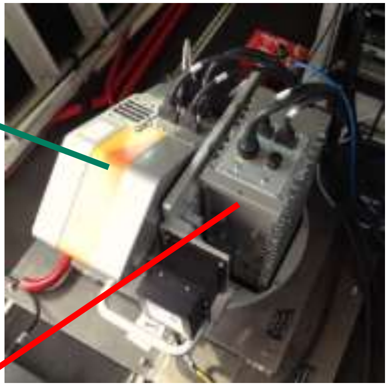


[Rascher et al., Global Change Biology, 2015]

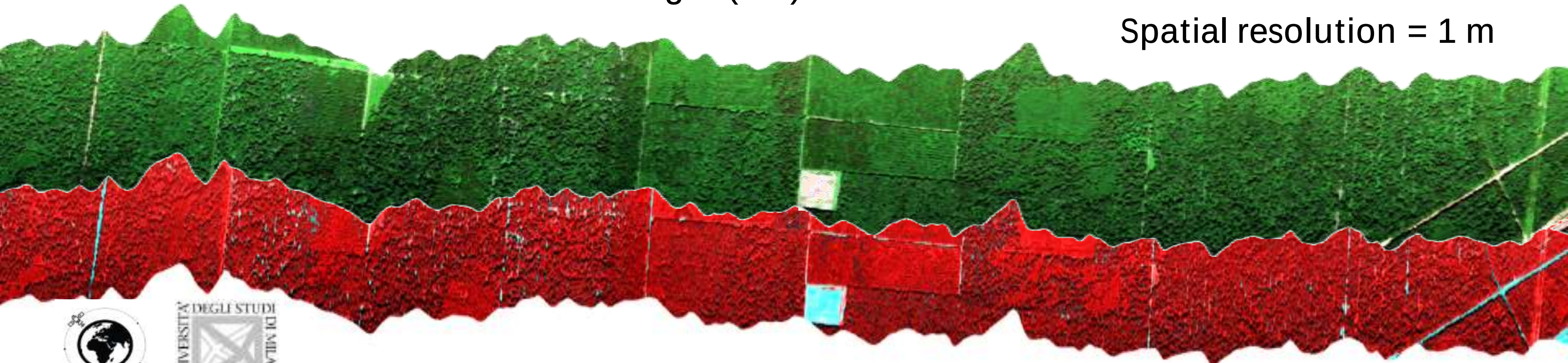
Data Acquisition

Airborne Data: the FLEX airborne demonstrator HyPlant





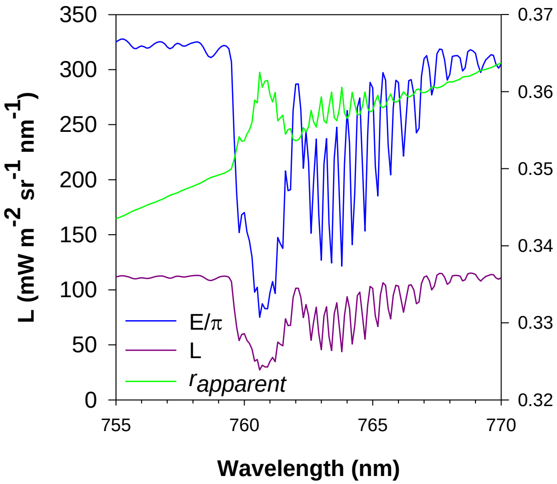
Spatial resolution = 1 m

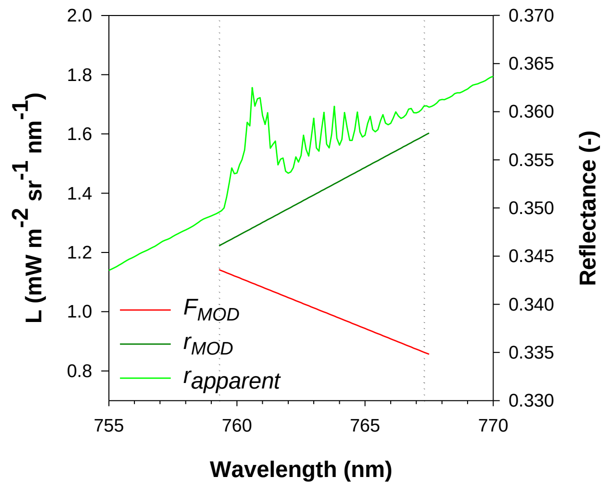


Methods

i) Sun-Induced Fluorescence Retrieval using SFM

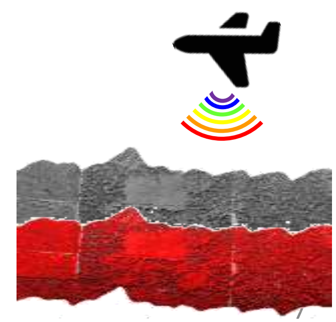
$$L(\lambda) = \boxed{\frac{r_{MOD}(\lambda)\, E(\lambda)}{\pi}} + \boxed{F_{MOD}(\lambda)}$$





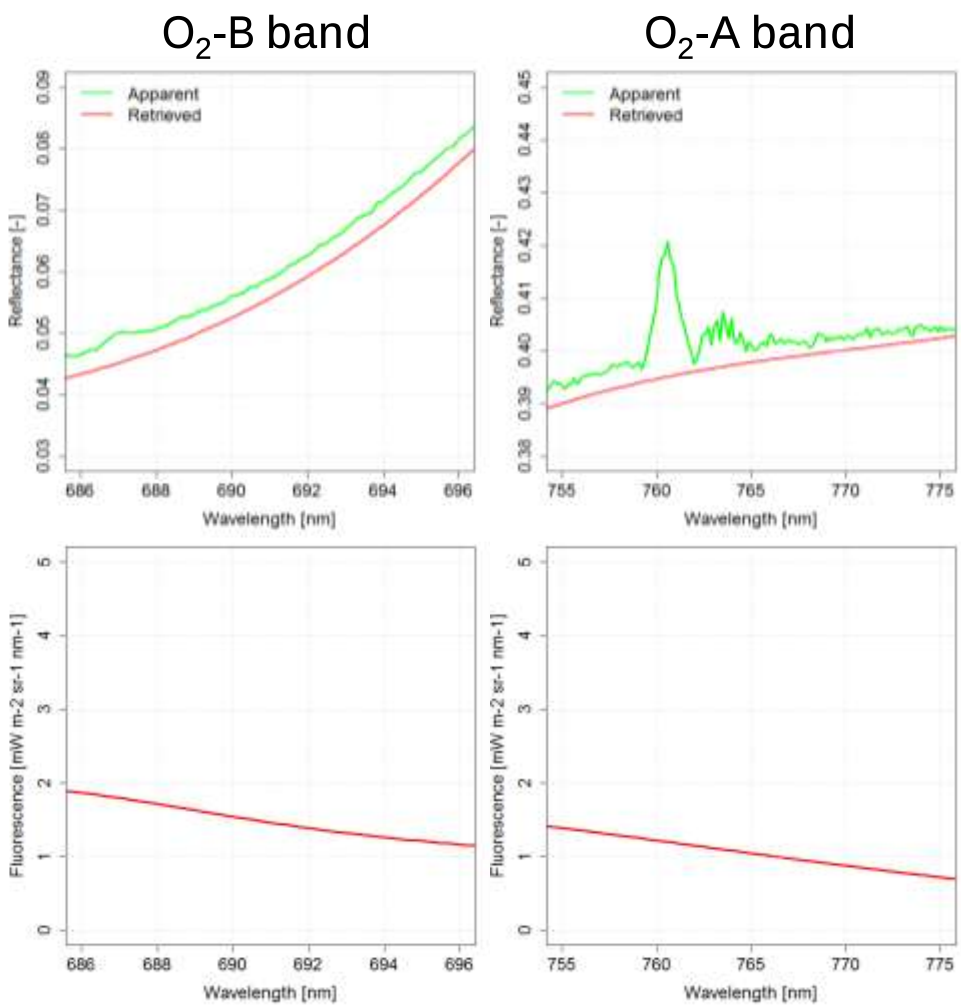
- Decoupling of the reflected and emitted fluxes that compose the measured signal to retrieve passive F
- Spectral Fitting Method: powerful technique based on the use of mathematical functions to model canopy reflectance and fluorescence spectra at different wavelengths

[Meroni et al., RSE, 2010]
[Cogliati et al., RSE, 2015]



Methods

i) Sun-Induced Fluorescence Retrieval using SFM

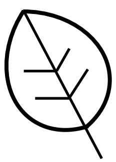


- Modeling of the F spectrum using a pseudo-Voigt function
- Modeling of the reflectance spectrum using a 3rd order polynomial function

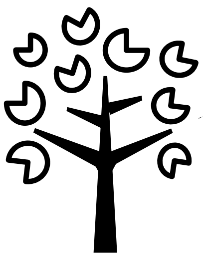
- Estimation of F687 in the spectral range 674-700 nm
- Estimation of F760 in the spectral range 759-767 nm

Methods
ii) Plant traits retrieval through RTM inversion

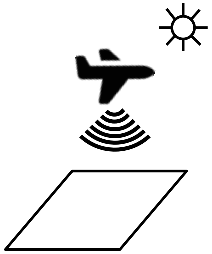
- INFORM (Invertible Forest Reflectance Model) [*Atzberger et al., 2000]*



Leaf chlorophyll content
Leaf dry matter content
Leaf water content
Leaf structural parameter

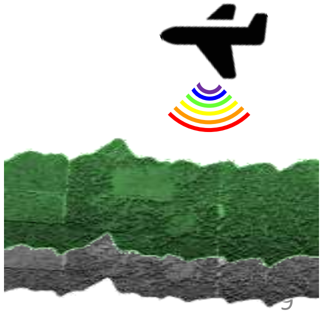


LAI of single trees
LAI of understory
Average leaf angle
Tree height
Crown diameter
Stem density



Sun zenith angle
Observer zenith angle
Relative azimuth angle
Fraction of diffuse radiation

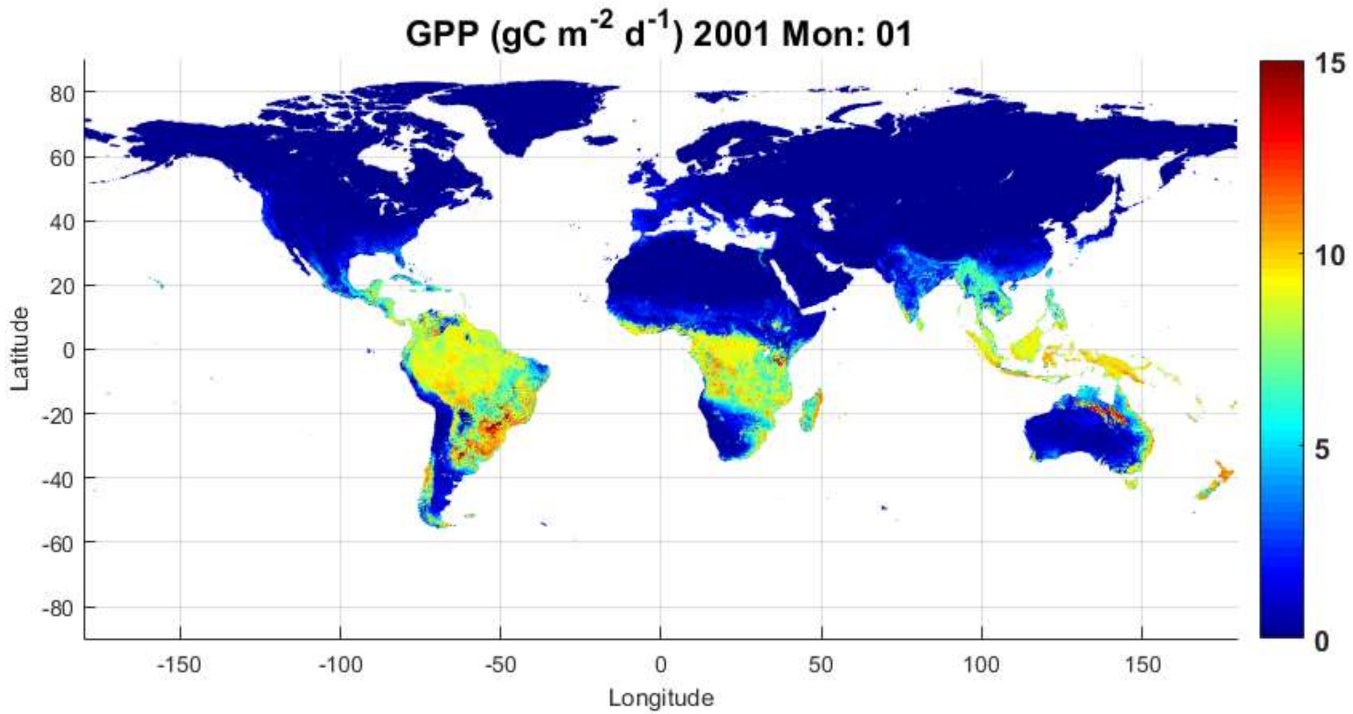
- Generation of 30000 simulated spectra
- LUT-based inversion of the model
- Optimisation of the inversion process:
  - Testing of different cost functions
  - Addition of gaussian noise
  - Multiple best solutions of the inversion



Methods

iii) Modeling of GPP using the BESS model

- BESS (Breathing Earth System Simulator)
  [Ryu et al., 2001; Jiang & Ryu, 2016]



[Jiang & Riu, 2016]

Methods

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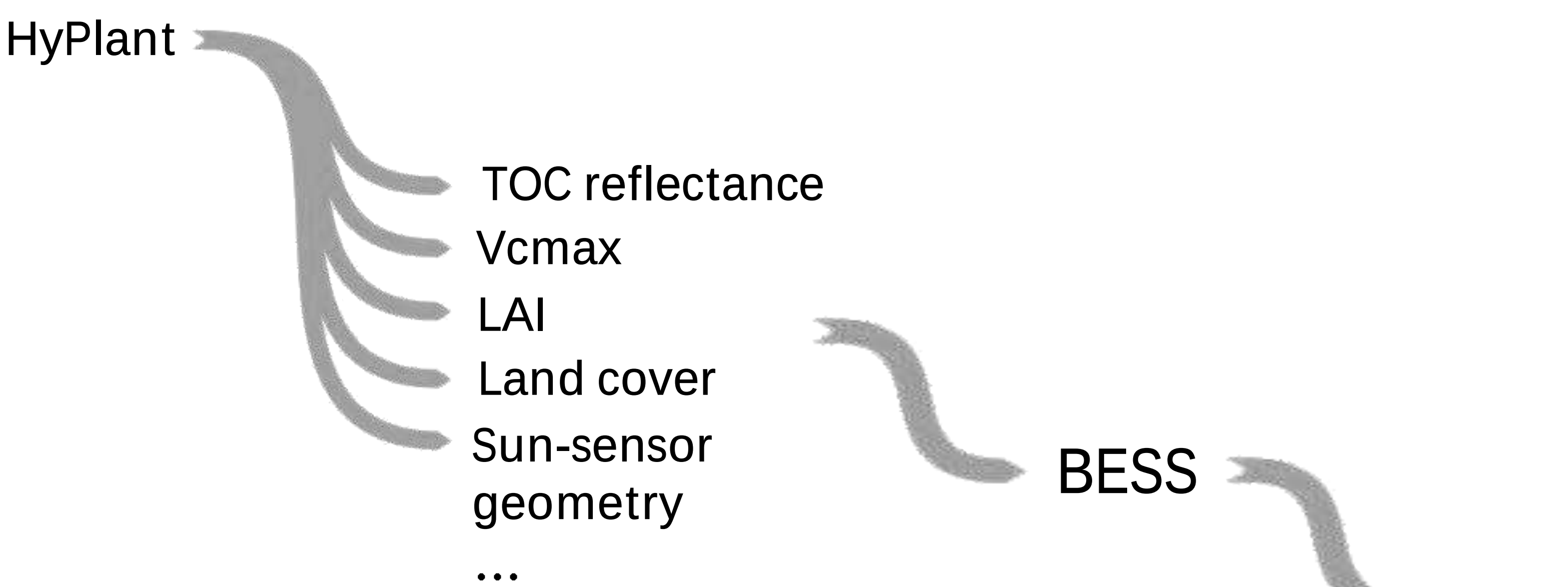
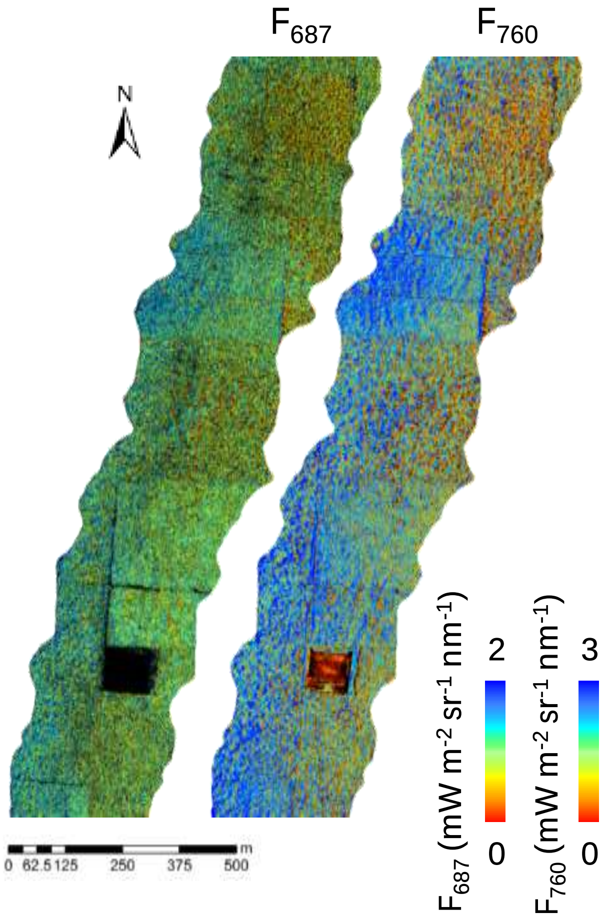
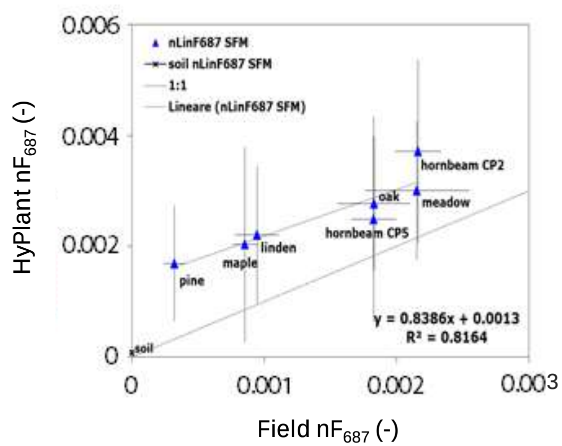
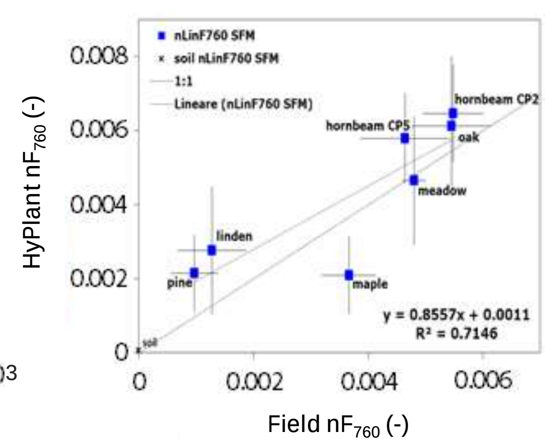


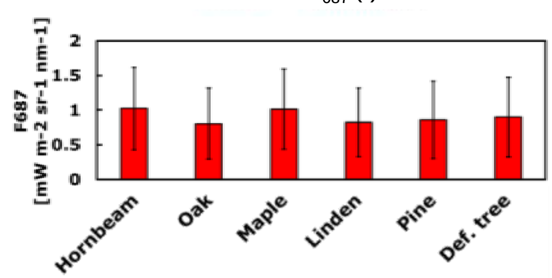
Results

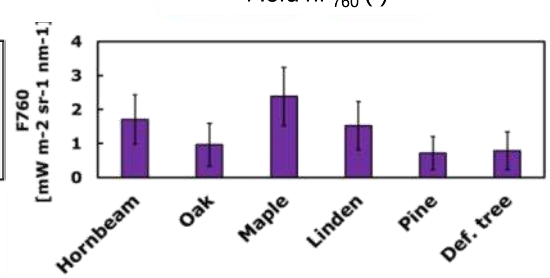
F_{687} and F_{760} retrievals





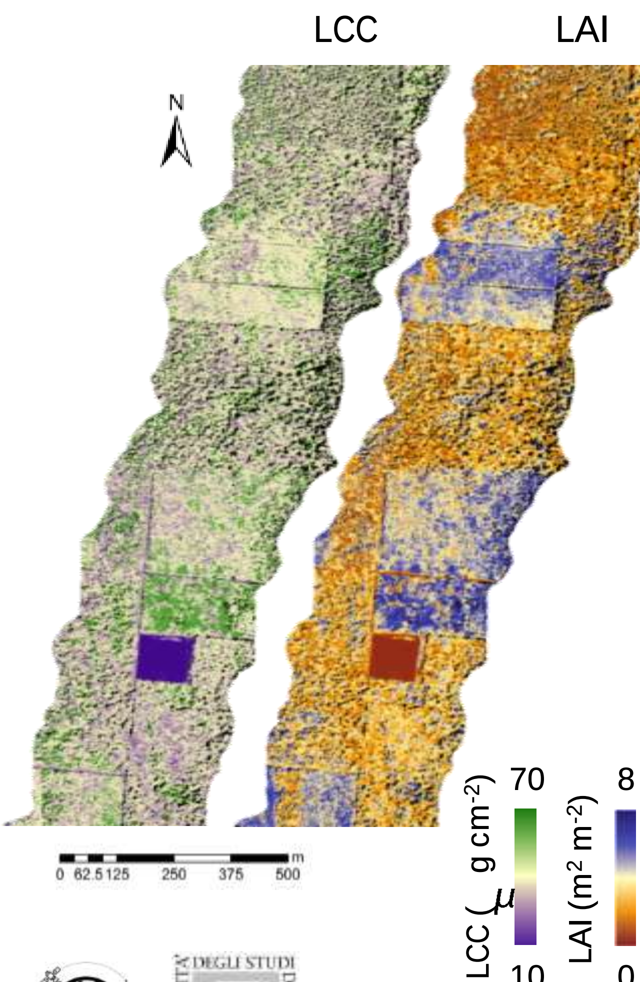


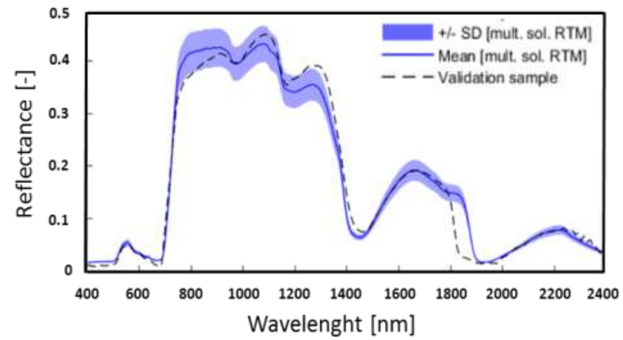


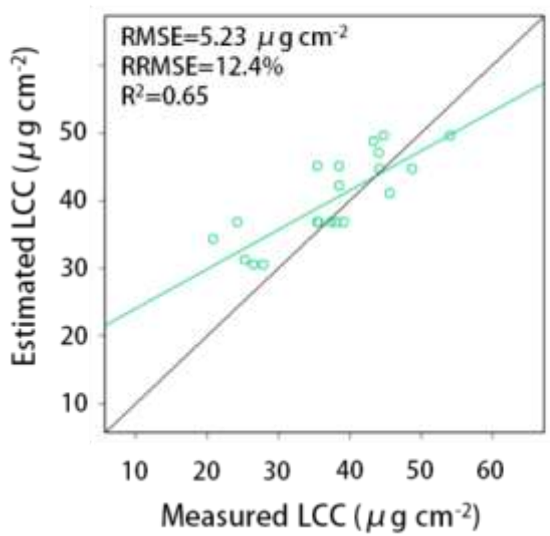


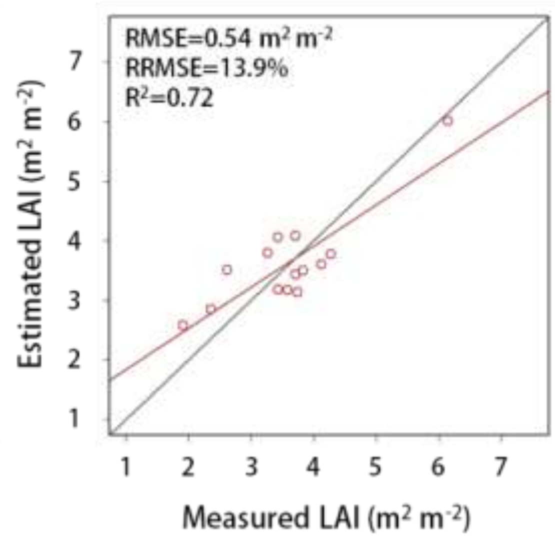
Results

Plant trait retrievals









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Results

Spatial relationship between F_{687}, F_{760} and GPP

BESS
modeled GPP

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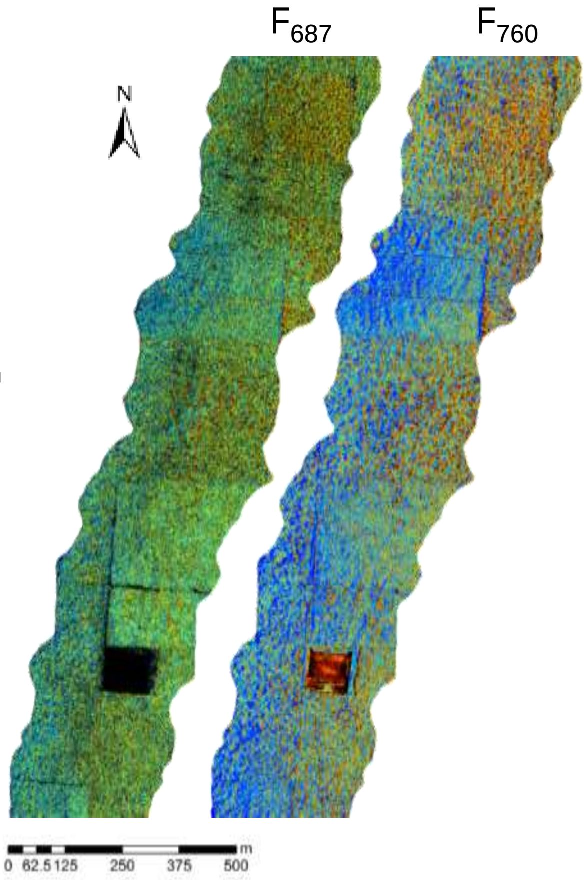
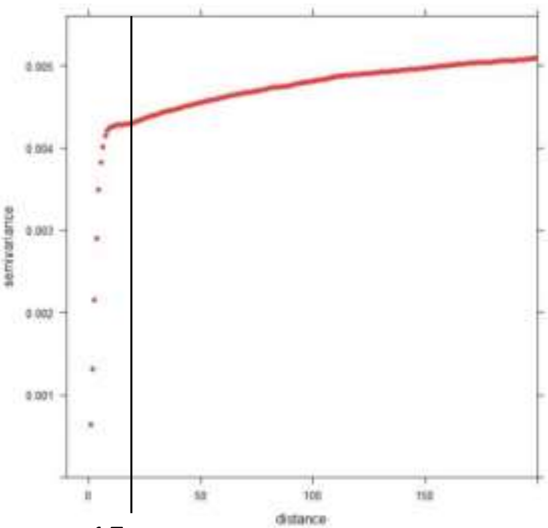


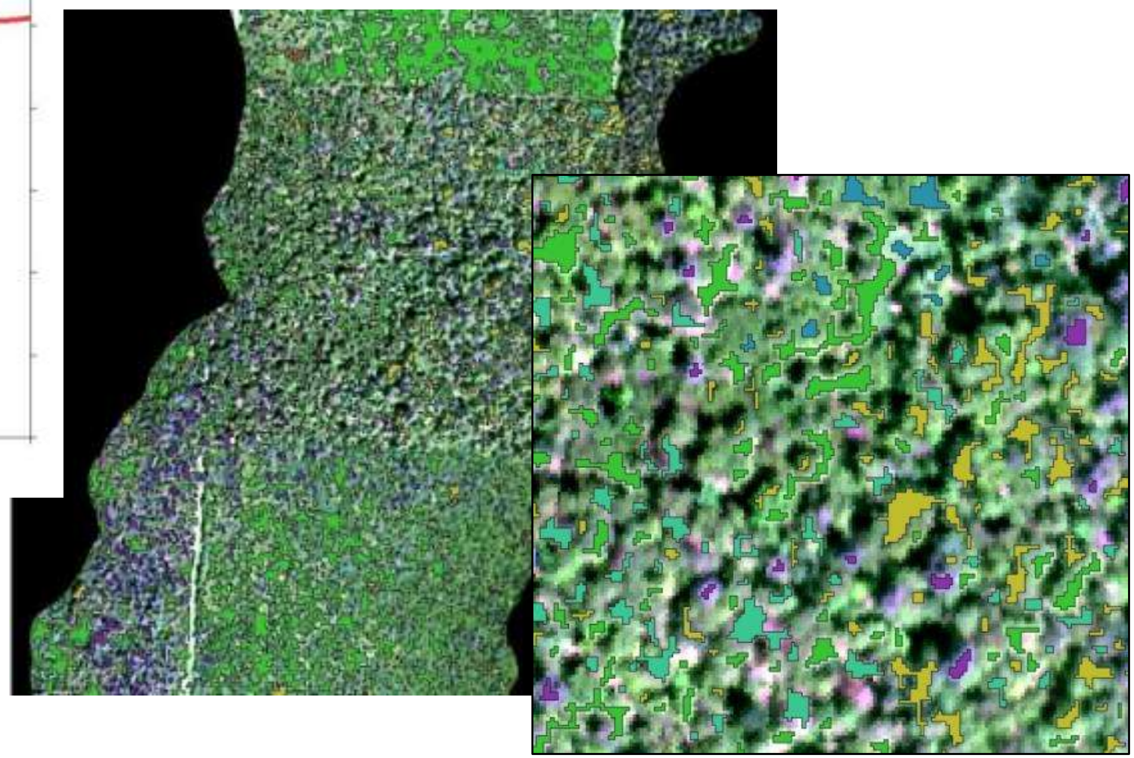
Results

Spatial relationship between F_{687}, F_{760} and GPP

- Analysis of spatial auto-correlation through variograms > detection of auto-correlation at crown level (<15 m)
- Aggregation of F_{687}, F_{760} and GPP at crown level in order to avoid spatial auto-correlation and to reduce noise

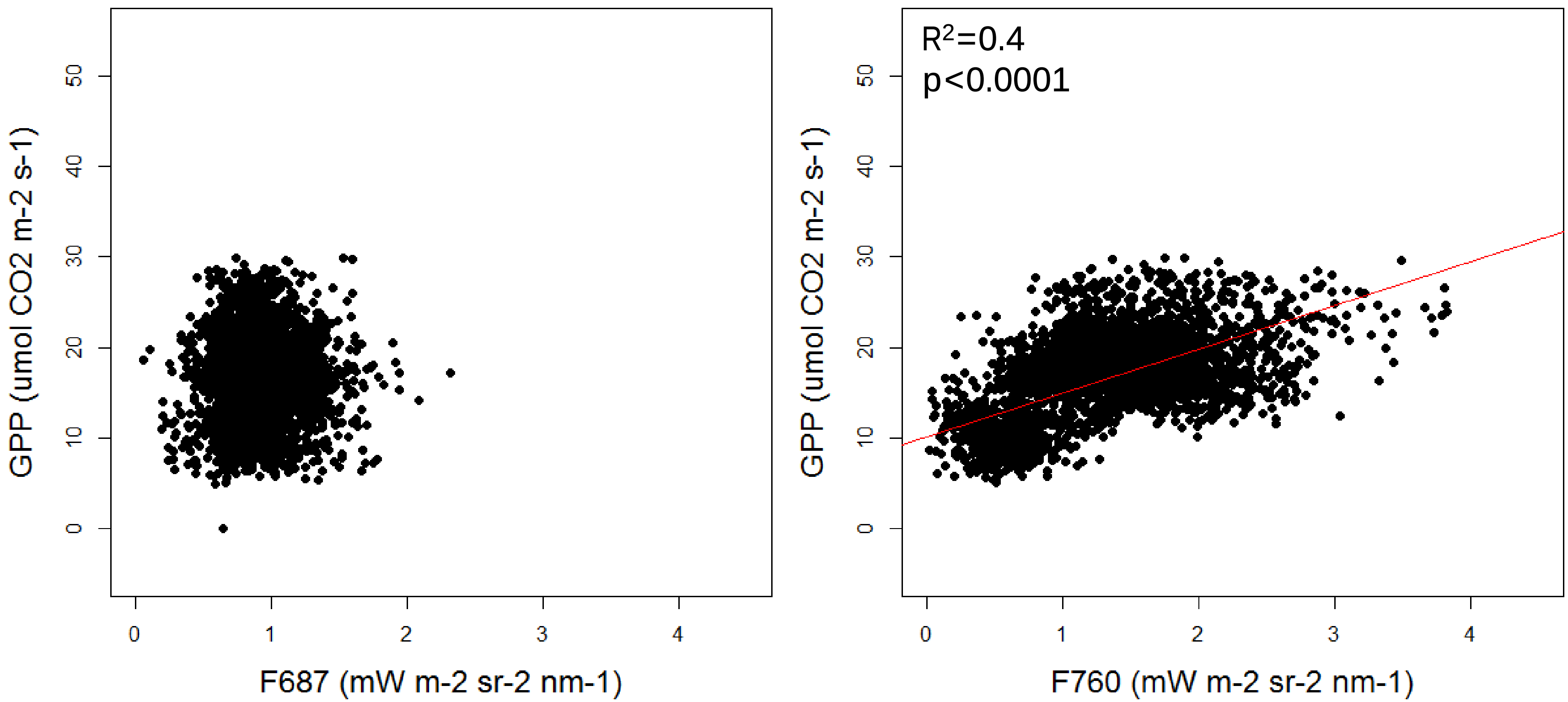


15 m



Preliminary Results

Spatial relationship between F_{687}, F_{760} and GPP



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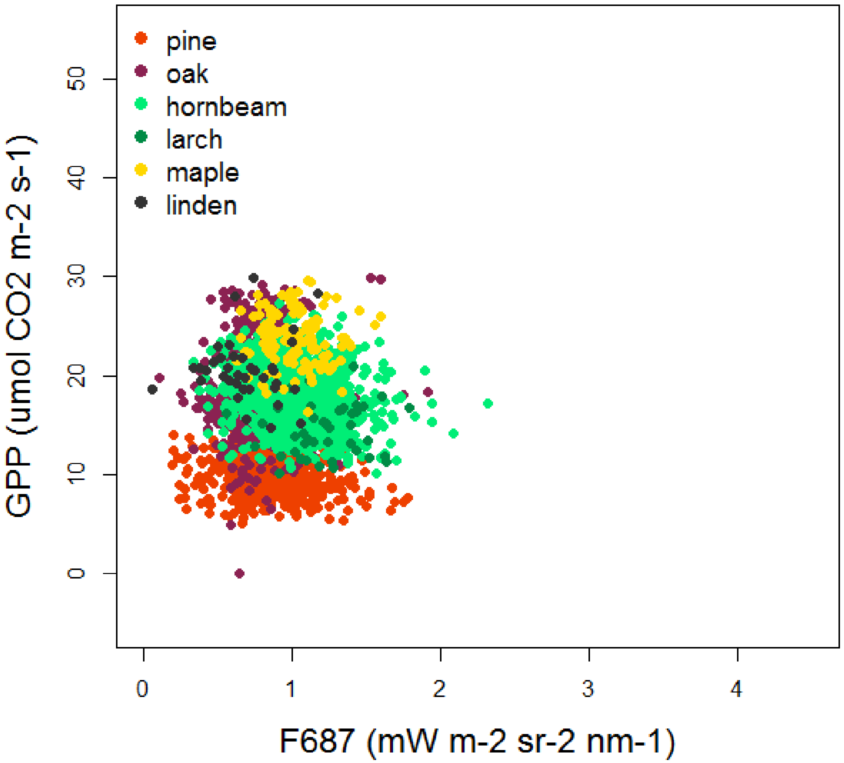

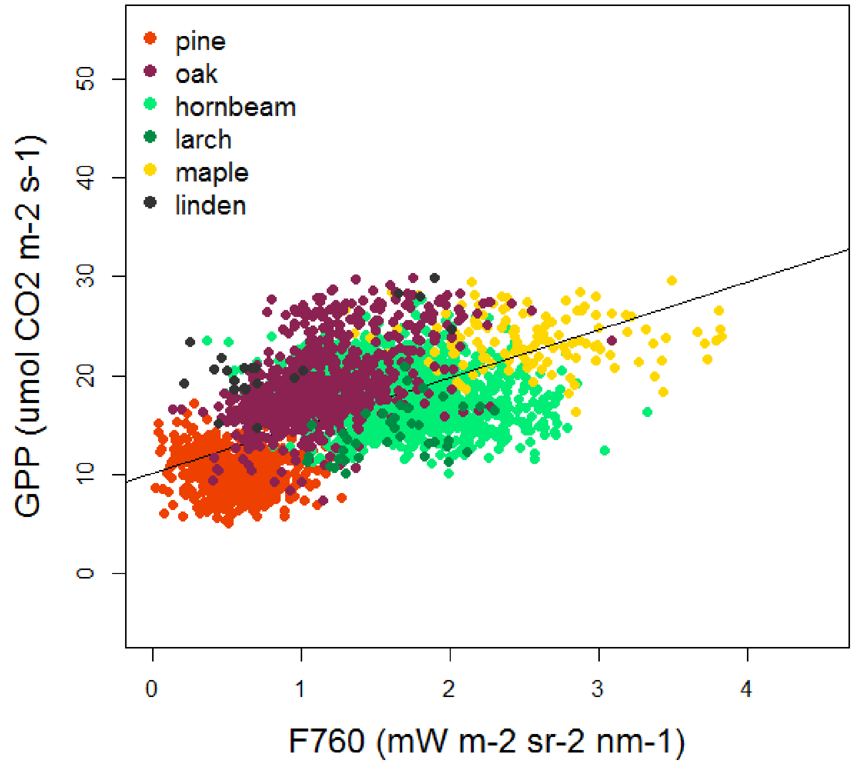

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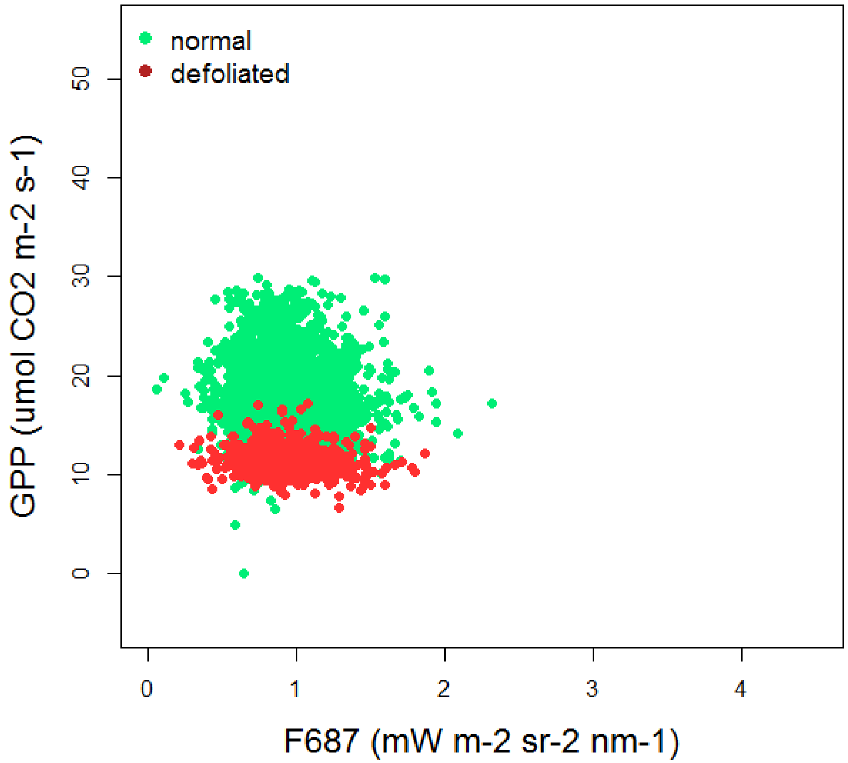
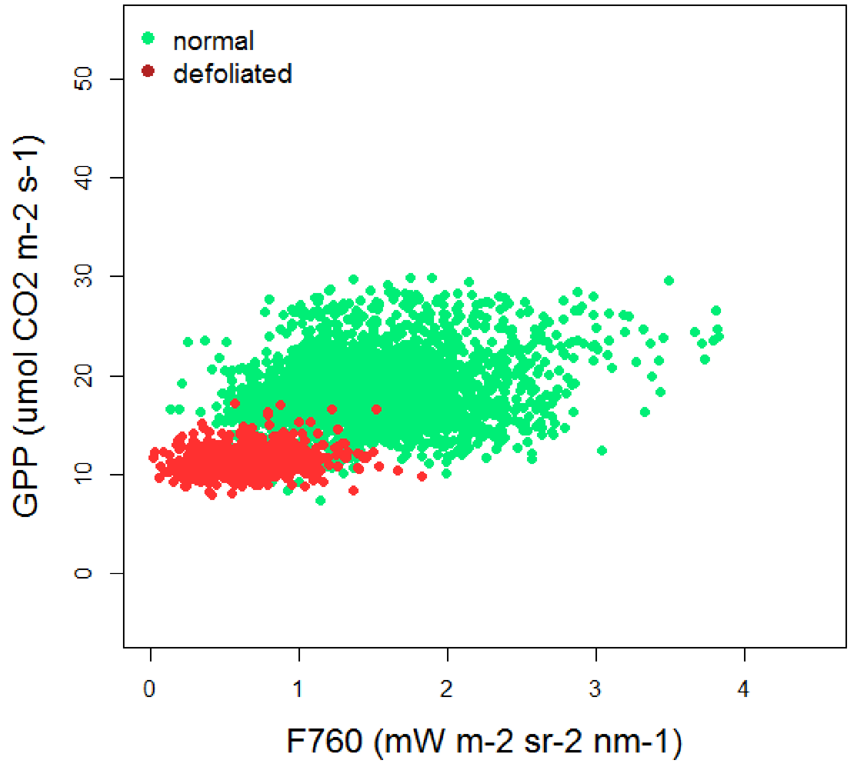




Concluding Remarks

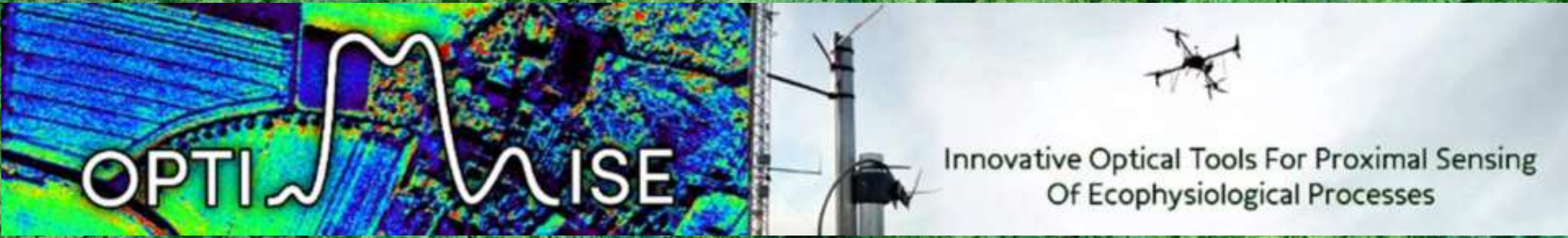
i) First validated maps of F_{687} and F_{760} were realised from high resolution airborne images in a forest area using SFM;

ii) Plant traits were accurately retrieved from VIS-NIR-SWIR airborne data through RTM inversion (R^2_{LCC}=0.65, $RMSE_{LCC}$=5.23 µg cm^{-2}; R^2_{LAI} =0.72, $RMSE_{LAI}$=0.54 m^2 m^{-2});

iii) For the first time, GPP maps over forest areas were obtained feeding the BESS model with plant traits derived from high resolution airborne images;

iv) GPP and F show consistent spatial patterns, however the interpretation of their relationship is not straightforward.

Importance of exploiting and integrating different data products to interpret the patterns observed in the measured fluorescence signal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Of Ecophysiological Processes

Thank you