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TAKING THE PULSE OF OUR PLANET FROM SPACE

EUMETSAT ECMWF EUSPA

CalValFLEX Barrax-2020 Field Campaign: protocols, instrument intercomparisons, and uncertainty analysis

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According to the **FLEX Mission Requirement Document (ESA, 2016),** to provide reliable estimates - uncertainties below 30% - on the photosynthesis efficiency:

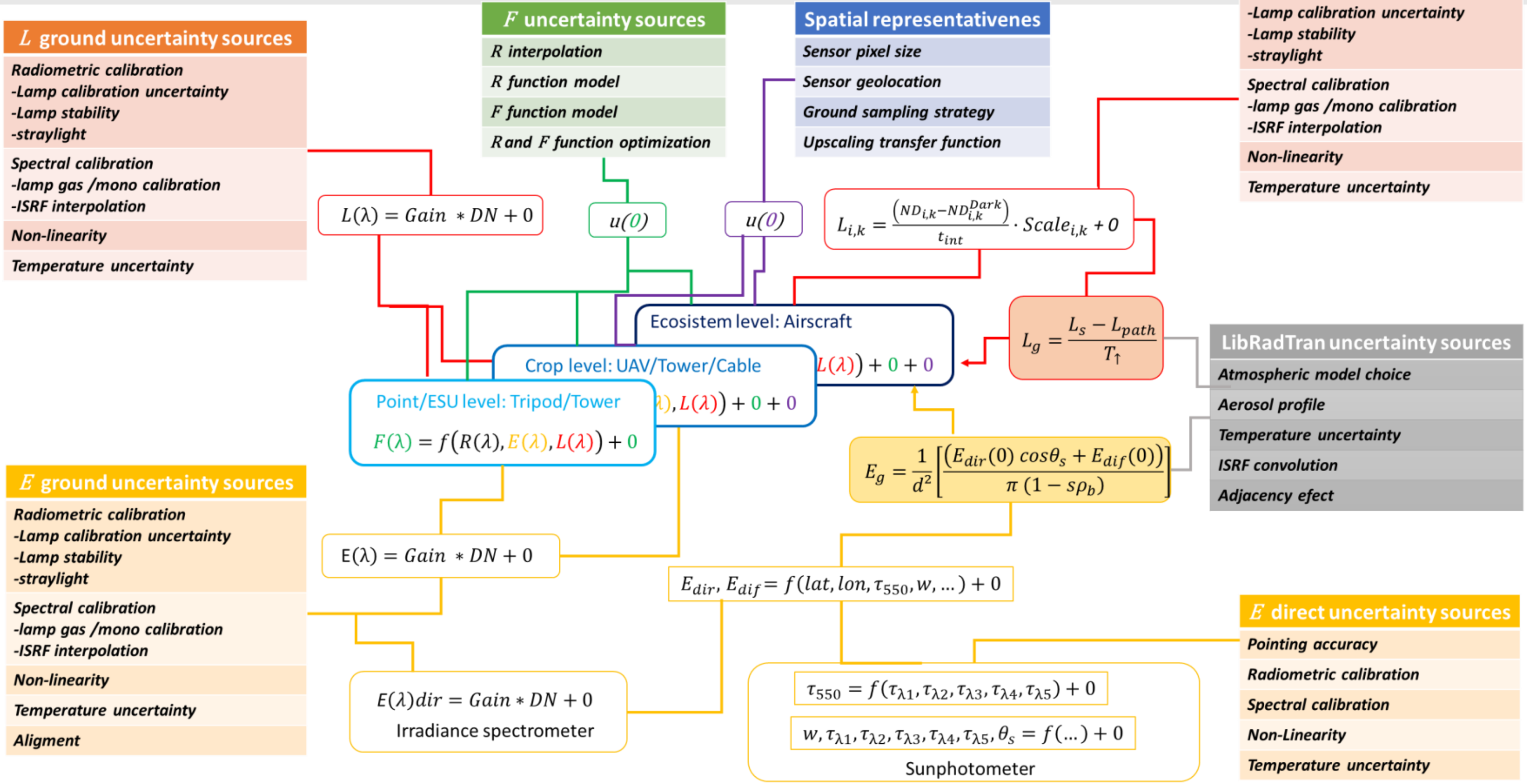
- **Fluorescence emission** requires an **uncertainty ~ 10%**
- **Solar irradiance** requires an **uncertainty ~ 10%**
- **Apparent reflectance uncertainty ~ 1%**

Ground measurements have associated **uncertainties and variances** mainly related**:**

1. Instrument performance and calibration
2. Retrieval algorithm error propagation
3. Natural variability of Cal/Val site (spatial and atmospherical)

source: Alonso et al. (2015). Development of a cal/val strategy from FLEX products v1.2.

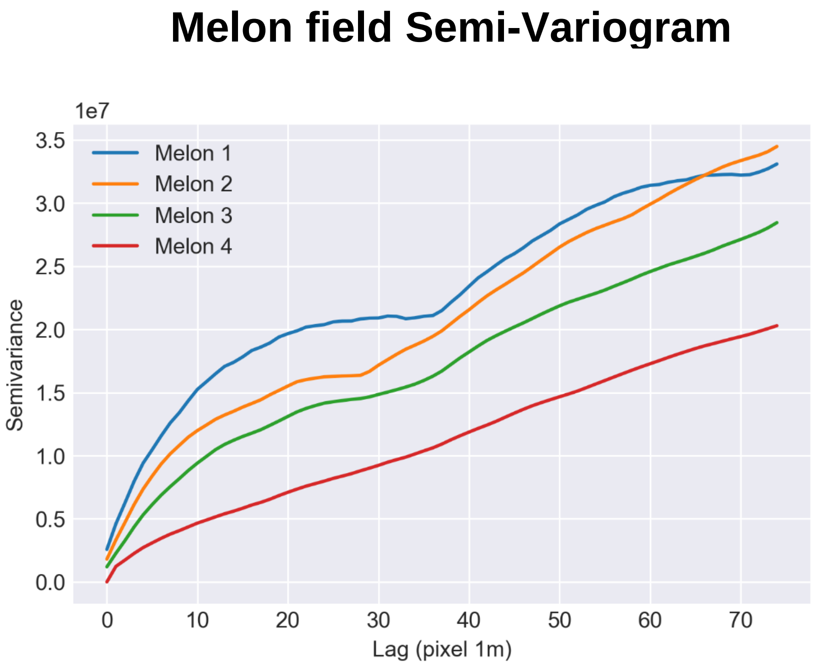
Multiple sources of error



1. Cal/val site spatial variability

- Cal/Val site should be **previously well characterized** (detailed maps ~ soil type, meteorological conditions).
- An **UAV** or **aircraft system** should be used to **characterize** the **Cal/Val site spatial heterogeneity** (~actual vegetation).
- **Ground sampling strategy** should be **defined based** on the **spatial heterogeneity** analysis (number of sampling points and sampling strategy).

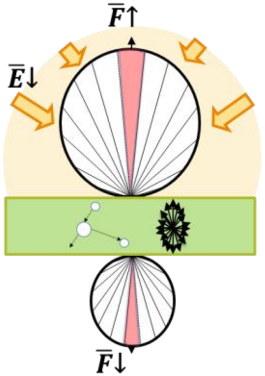
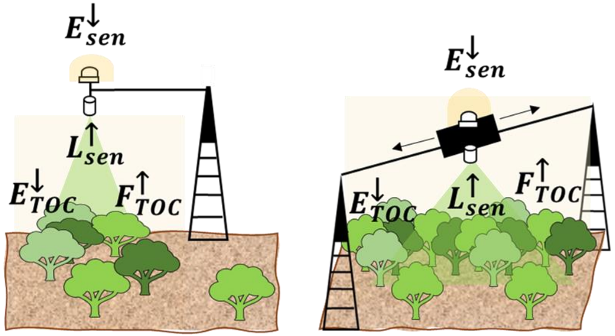
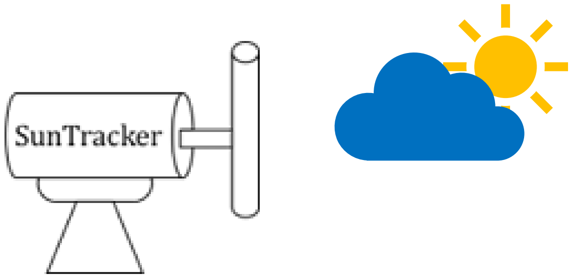
❑ *Spatial heterogeneity characterization*



- CASI hyperspectral sensor
- **Simple ratio** vegetation index

- Should be used to determine the optimal sampling distance between observations ~ **sampling strategy**.

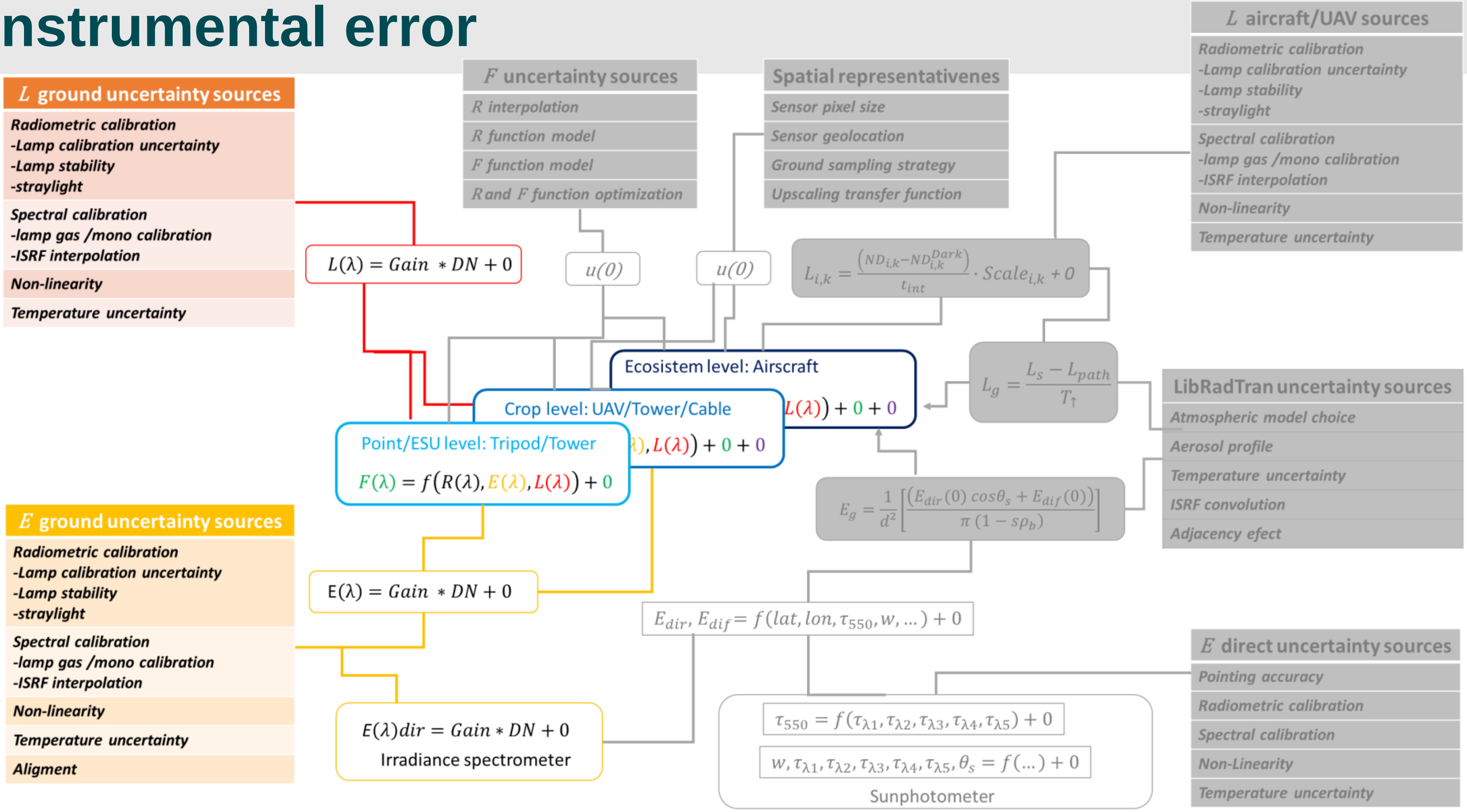
❑ *Ground sampling strategy at elementary sampling unit level*

Leaf	TOC	Atmospheric characterization
		
Biophysical + Physiological	Biophysical + Physiological + Geological	Diffuse and direct incoming radiation

❑ **Multisensor and measuring scale approach**

❑ **Objective: combine leaf and TOC measurements to obtain an integrated value of <u>apparent reflectance</u> and <u>fluorescence</u> over a 300 x 300 area ~ FLEX pixel**

2. Instrumental error



3. Retrieval algorithm error

- ❑ **Spectral fitting ~ retrieve complete SIF spectrum**
- ❑ **Intrinsic algorithm error (minimization function)**

We should consider:

- Differentiate between **systematic** and **random errors**
- Consider the **correlation between input parameters**
- Covariance between the parameters and measurements errors

- ❑ Monte Carlo versus derivative approach

Final uncertainty (U_{final})

Apparent reflectance and **fluorescence** final uncertainty is defined as:

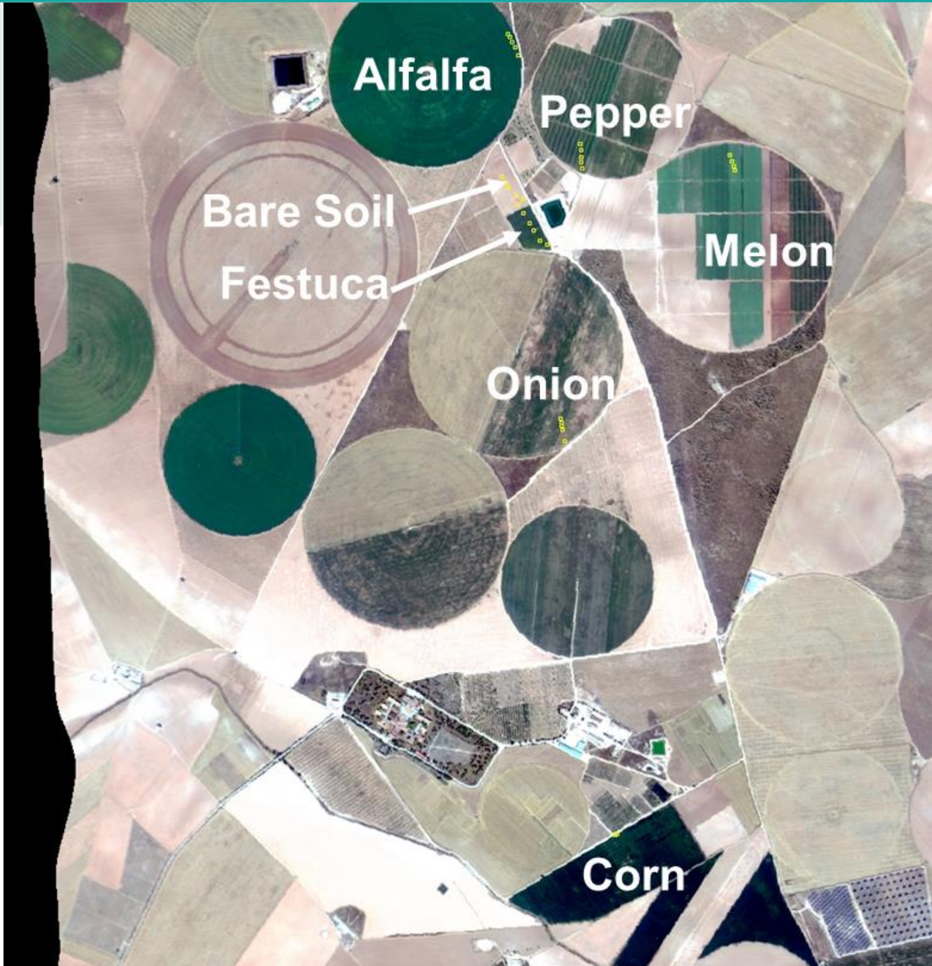
$$U_{final} = \sqrt{(u_{instruments})^2 + \left(u_{representativity}\right)^2 + (u_{retrieval})^2}$$

- ❑ Summation in quadrature of **independent uncertainty error sources**
- ❑ Final uncertainty should be provided as **extended uncertainty** at **95%** confidence interval.

Las Tiesas experimental farm, Barrax (Spain)

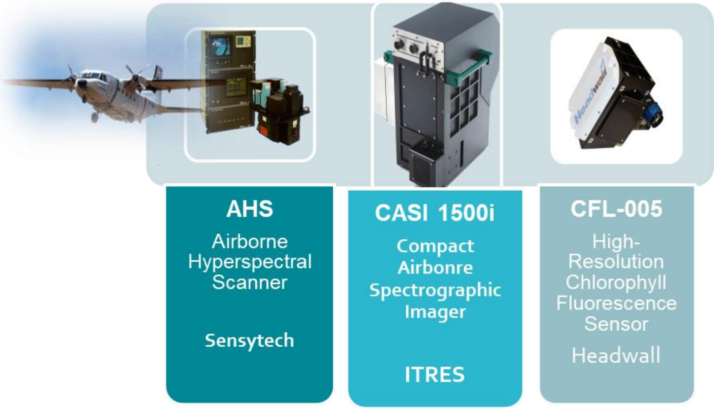
- **ESUs size:** 2m x 2m, which corresponds to the spatial resolution of the CFL airborne hyperspectral sensor.
- **Crops selected**: Melon (M), Pepper (P), Alfalfa (Al), Corn (C), and Onion (O).
- **Reference surfaces:** Festuca (F) and Bare Soil (BR).

*Campaign for instrumental test during COVID period



yellow dots indicate ESUs measurements

UAV & Aircraft



Irradiance & Atmosphere

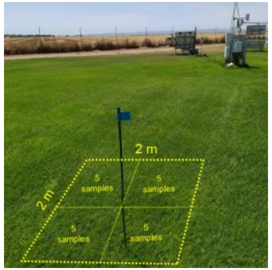
Leaf

FluoWat

Independent of retrieval methods

Top of Canopy

ASD



FLoX

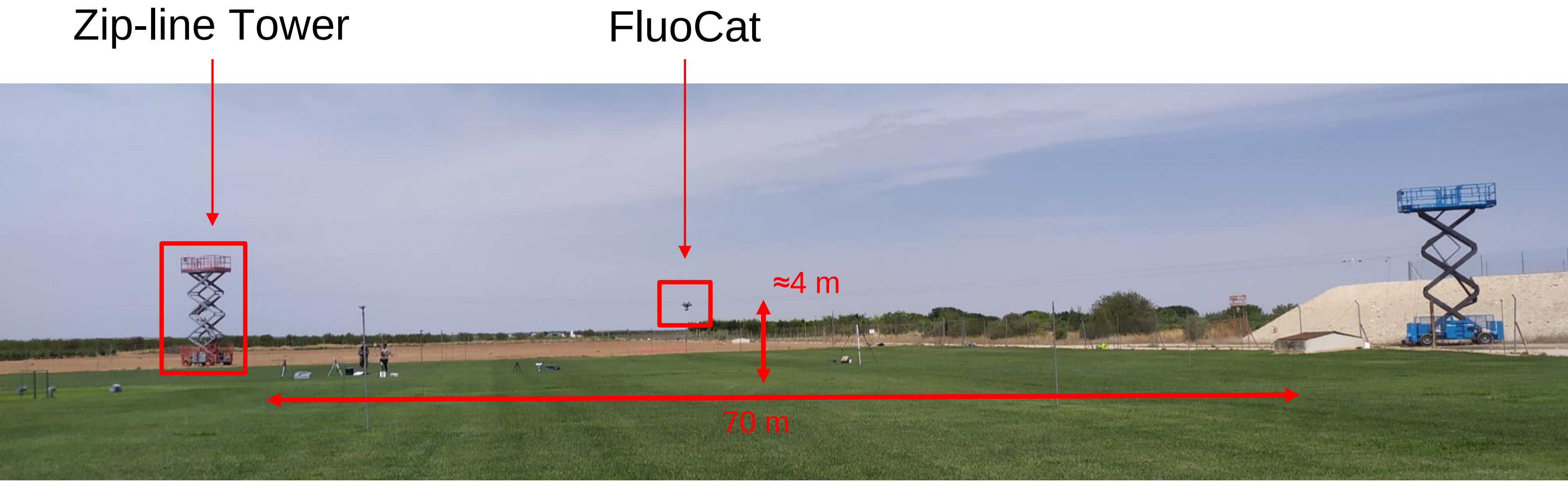
Piccolo – FluoCat system

FluoCat system

- **Autonomous platform over a zip line**

- Instrumentation (one trigger for all):
  - **Piccolo: Fluorescence + VNIR**
  - MAIA S2: Multispectra camera w/ Sentinel-2 bands
  - TeaX Thermal Capture Fusion: FLIR Tau 2 + Sony RGB
  - Environmental sensor: Pressure, Humidity, Temperature

Instrumentation interchangeable with the UAV system



- **Programmable:**
  - start/stop locations
  - number of stops
  - number of cycles
  - delay between cycles
  - Manual control through wireless console
  - Auto recharge when battery is low.
  - Automatically resumes task.

Piccolo's footprint: ~1.75 m at 4 m height

✓ **Spatial representativity low height**

✓ **No atmospheric correction needed**

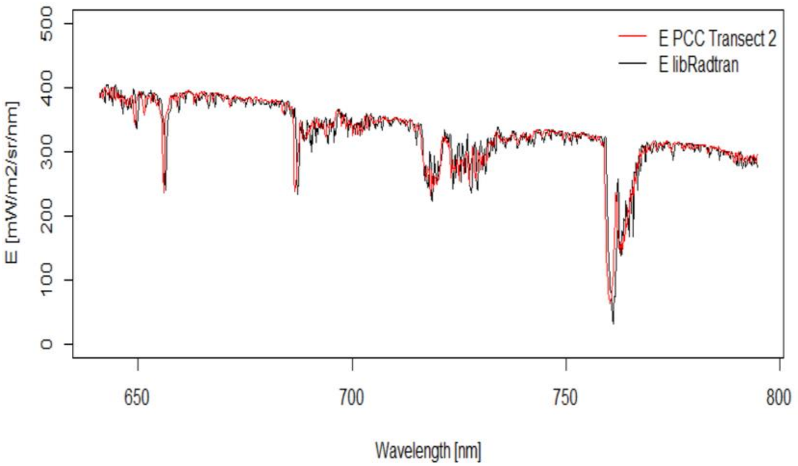
FluoCat measurement protocol

- ❑ Melon field
- ❑ 1 defined transect (70 m)
- ❑ 4 repetitions ~ rounds ⇒ R1, R2, R3, R4
- ❑ 8 stops points over vegetation (~15 measurements at each stop point)

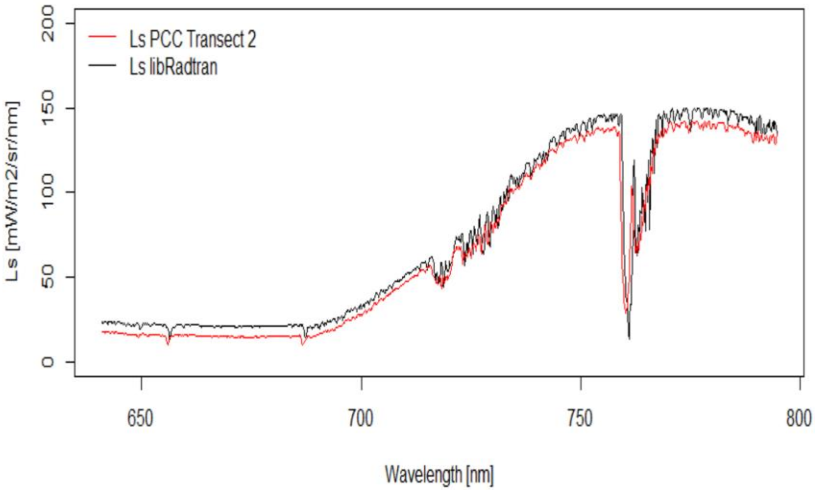
Instrument uncertainty

- ❑ Fluorescence module downwelling and upwelling radiance
- ❑ Comparison between Piccolo vs LibRadtran

Downwelling radiance



Upwelling radiance



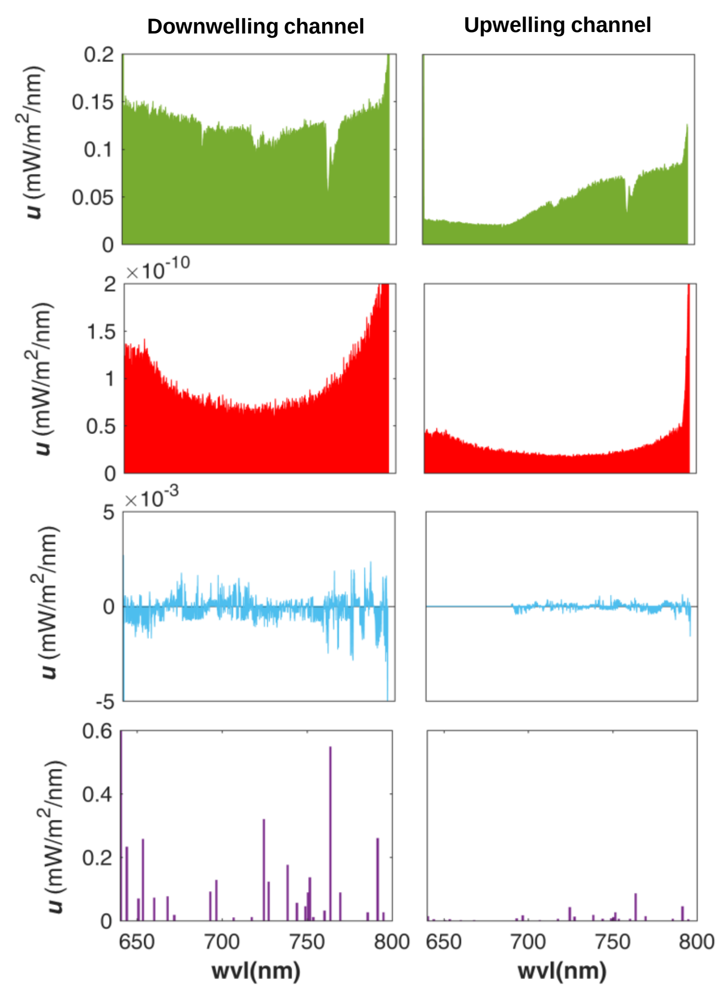
- Consistent **radiance values** between Piccolo measurements and LibRadtran simulations
- LibRadtran simulations can be used to verify spectral calibration
- **Systematic error do not dominate Piccolo measurements**

Instrument uncertainty

- **Fluorescence module downwelling and upwelling radiance**
  - Repeatability-noise (u_{rep})
  - Radiometric calibration (u_{rad})
  - Non-linearity ($u_{non-lin}$)
  - Spectral calibration (u_{spec})

- **Results:**
  - $u_{rad} < u_{non-lin} < u_{spec} < u_{rep}$
  - u_{rep} ↓ radiance > ↑ radiance

    ~ same stop point = captures small changes in illumination conditions but vegetation target is homogeneous.



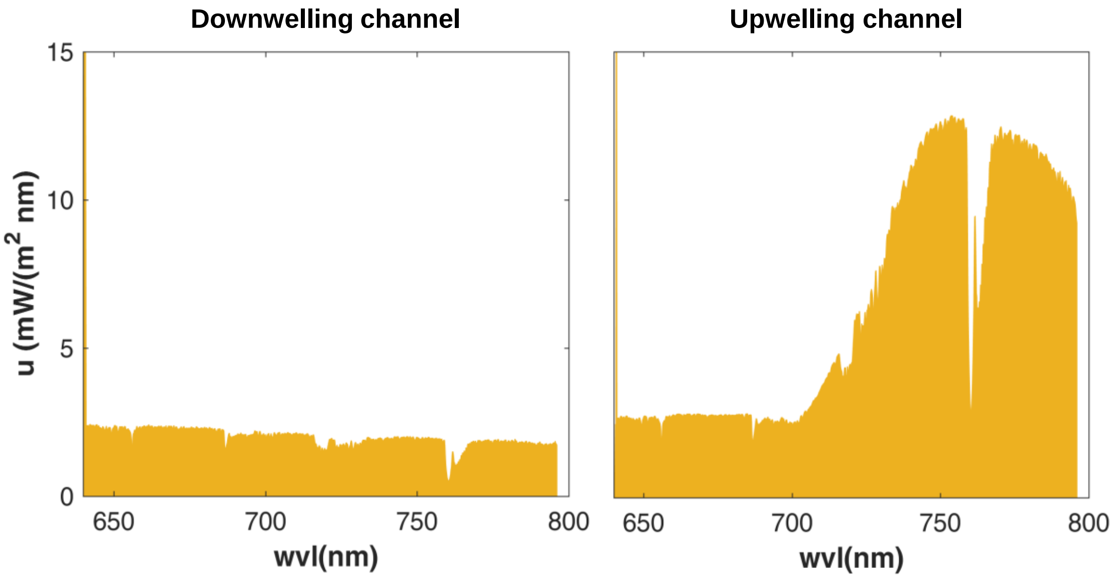
Representativity uncertainty

- **<u>Fluorescence module</u> downwelling and upwelling <u>reflected radiance</u>**

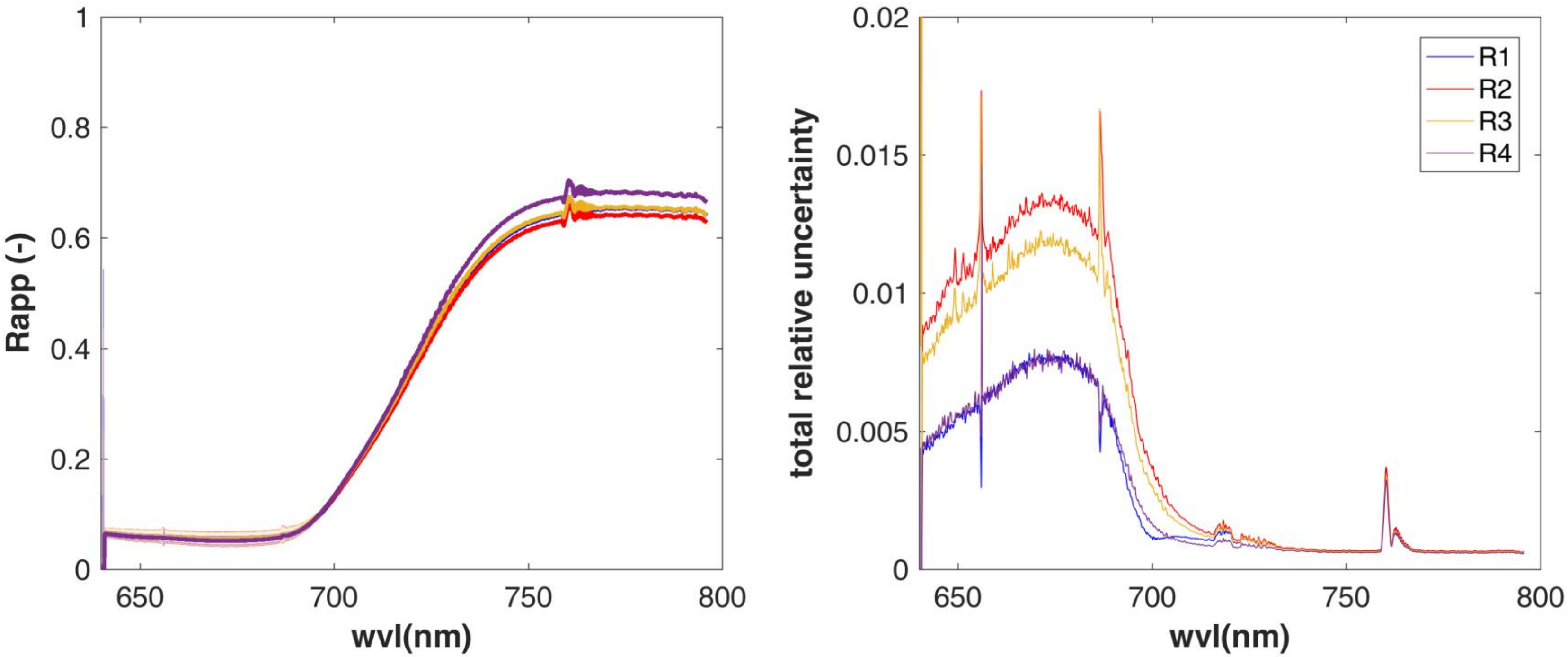
- **Results:**
  - $u_{representativity}$ ↓ radiance < ↑ radiance

    ~ different stop point = captures vegetation target heterogeneity and illumination conditions are stables along the transect.

  - **Natural variability is of larger order than instrumental**

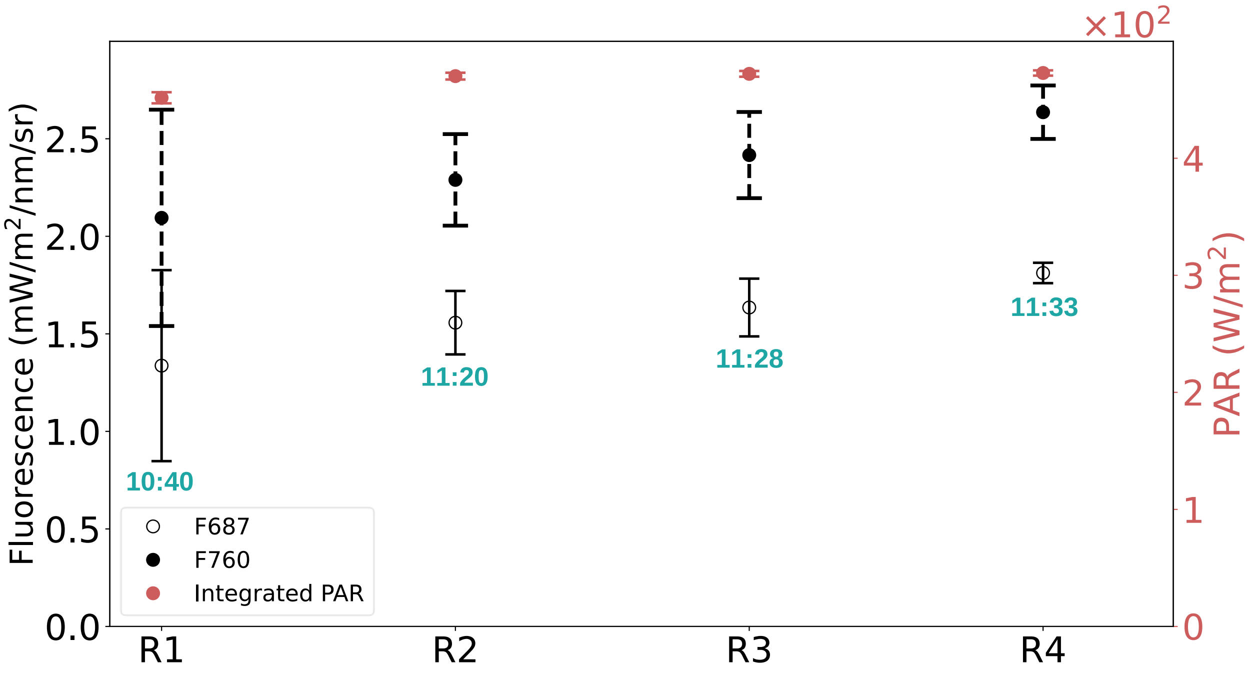


Fluo module: Apparent Reflectance (Rapp)



- ❑ Similar Rapp curves between transect rounds
- ❑ Higher uncertainty in red (low signal) wavelengths

Fluorescence



- ❑ Fluorescence uncertainty reflects the transect heterogeneity
- ❑ FluoCat is capable of capturing fluorescence 2nd order changes while adapting to PAR variation

*figure adapted from Moncholi-Estornell et al. in preparation

Conclusions:

- **Multisensor** approach to tackle spatial issues.
- **Spatial** heterogeneity **characterization** is **mandatory** ($u_{representativity} > u_{instrument}$).
- **Final product** should be a **fluorescence** and **apparent reflectance** value for a **300x 300 m** pixel + **confident interval**.
- A **rigorous statistical analysis** is mandatory (error characterization, error propagation).

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