

# Using Sentinel-2-based metrics to characterize the sun-induced fluorescence spatial heterogeneity

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# Heterogeneity study motivation

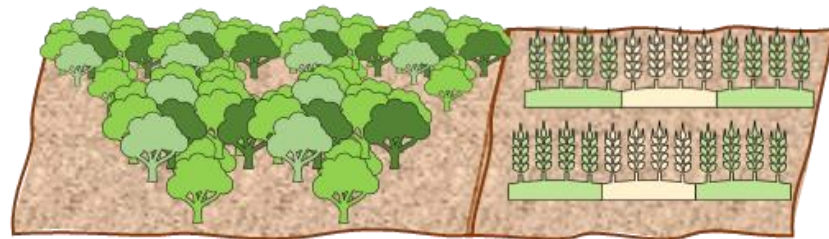
## SENSECO Working Group 1 objectives

- Objective 1.1 **To identify scalable leaf-to-canopy biophysical and biochemical traits** that can be derived from optical data, and to **evaluate the accuracy** that can be conserved **when upscaling**.
- Objective 1.2 **To provide clear, evidence-based guidelines of scaling protocols**, in terms of measurement protocols and data treatment; this ensures consistent, reproducible, and comparable results across Europe (Objective 4.4).
- Objective 1.3 **To provide a theoretical scaling assessment by means of RTMs** that enable the coupling of the RT of biochemistry-leaf-canopy drivers and giving feedback to the modelers for improving RTMs scaling functionality and for across spectral domain approaches (Objective 3.2).

# Sun Induced Fluorescence (SIF)

## Applications

- Actual photosynthetic capacity
- Improve GPP models
- Monitor vegetation dynamics
- Early stress detection



but...

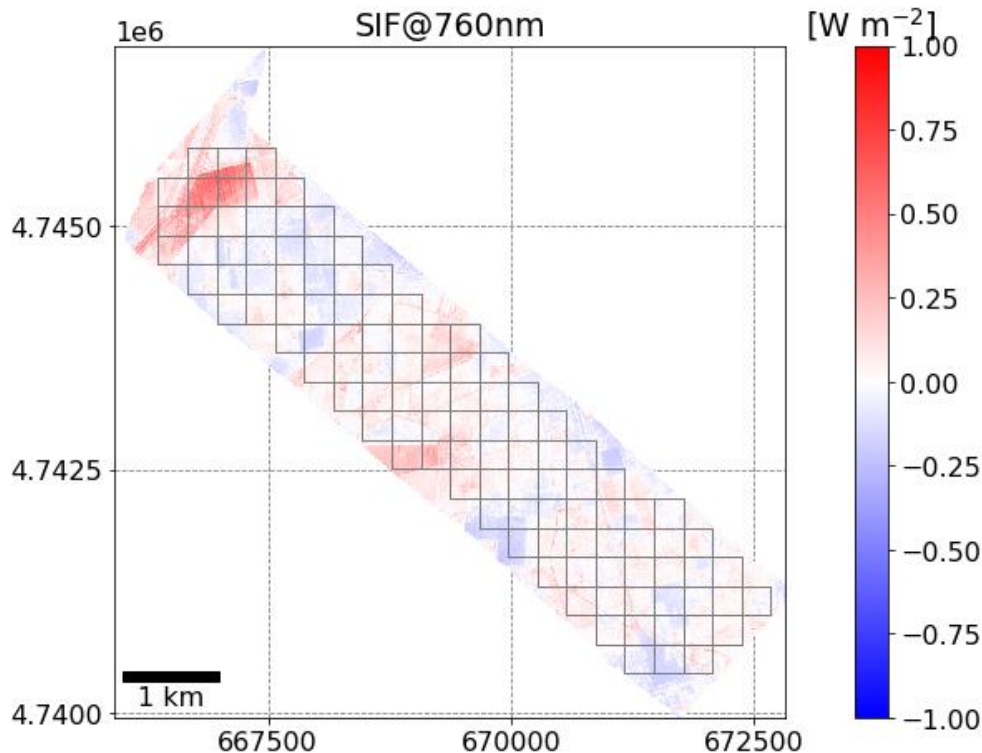
- **Highly dynamic:** land cover, phenology, temperature, water/nutrient availability...



# Sun Induced Fluorescence (SIF)

## Course spatial resolution:

- GOME-2 (40x80 km<sup>2</sup>)
- GOSAT (10 km diameter)
- OCO-2 (1.29 x 2.25 km<sup>2</sup>)
- TROPOMI (3.5 x 5.5 km<sup>2</sup>)
- FLEX (300 x 300 m)
- HyPlant (4.5 x 4.5 m)



HyPlant image example (4.5 x 4.5 m)

# Objective

In order to use fluorescence for the remote monitoring of vegetation:

- Characterize SIF **spatial heterogeneity** at FLEX spatial resolution (300x300m).
- We propose to use Sentinel-2 L2a surface reflectance based metrics.
- We will evaluate both **spatial heterogeneity methods** and **veg.indices / biophysical parameters**.

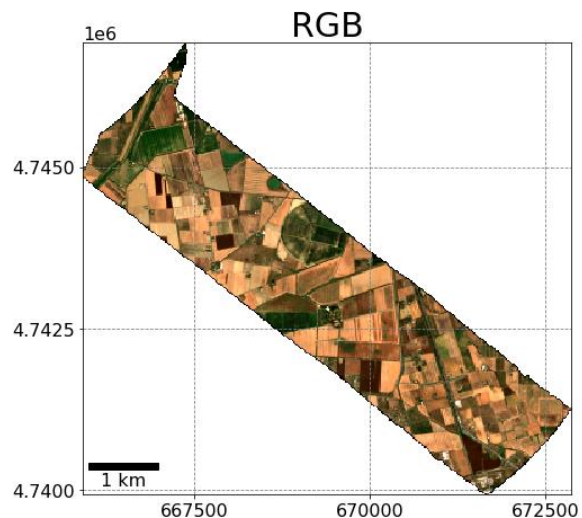
# Spatial heterogeneity

**Spatial heterogeneity** can be defined as **complexity** or **variability** of a system property (parameter) in **space and/or time**.

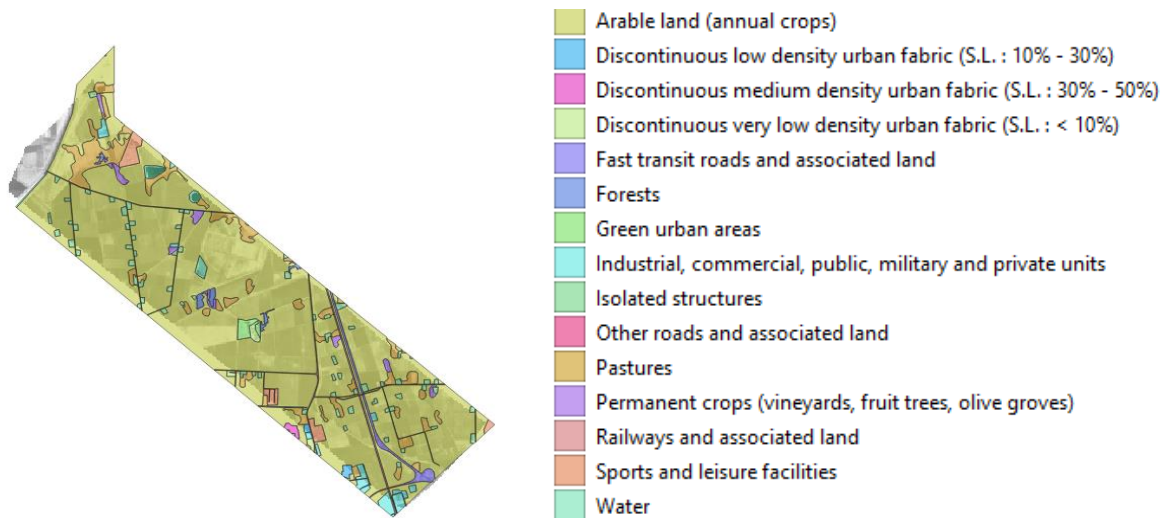
- **Complexity** refers to **qualitative parameters** (i.e., land cover)
- **Variability** refers to **quantitative parameters** (temperature, water content, nutrients, biomass, NDVI, chlorophyll content etc.)

# Study case

- Agricultural area
- Braccagni, Italy
- FLEXSense campaign activities (ESA Contract No. 4000125402/18/NL/NA).



Hyplant RGB image



Urban Atlas 2018 (Copernicus Land Service)

# Data set

## HyPlant airborne sensor

Type	Initial spectral and spatial resolution	re-sampled
<b>F760</b>	4.5 m 26 bands around the O2B (SFM)	5 m 1 channel (760 nm)
<b>F687</b>	4.5 m 14 bands around the O2B (SFM)	5 m 1 channel (687 nm)
<b>Reflected radiance</b>	4.5 m 626 bands	20 m (~S2) 13 channel

## Retrieved Veg. Indices and Biophysical traits

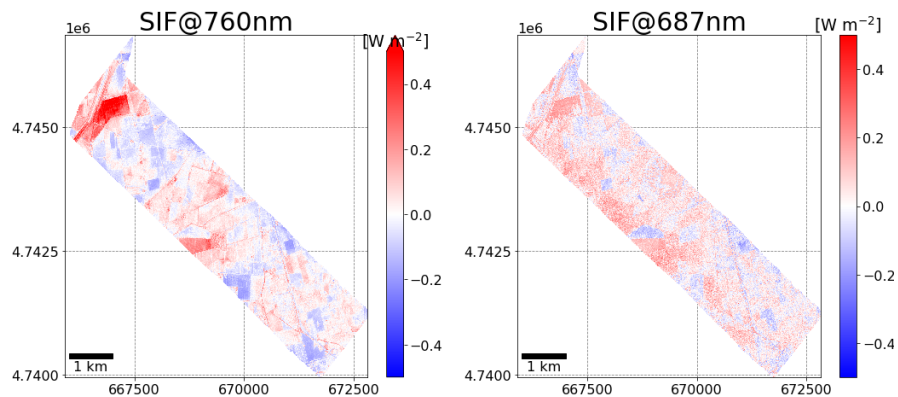
Vegetation indices	Resolution
NDVI, NIRv, ChIRE, EVI, MSI	5 m
Biophysical traits	Resolution
LAI, fAPAR, fCover, Chl	5 m



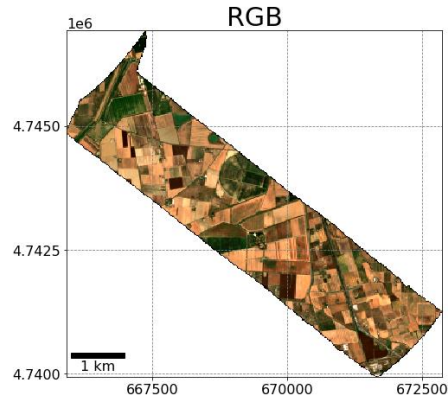
# Data set

## Copernicus land Monitoring service

Type	Initial spectral and spatial resolution	re-sampled mimic S2
Land-use type	Minimal Mapping unsit 0.25 ha 1 channel	5 m 1 channel



**Hyplant F760 and F687**



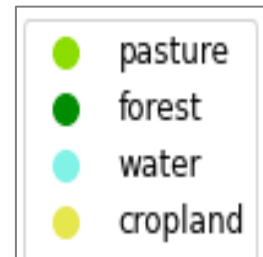
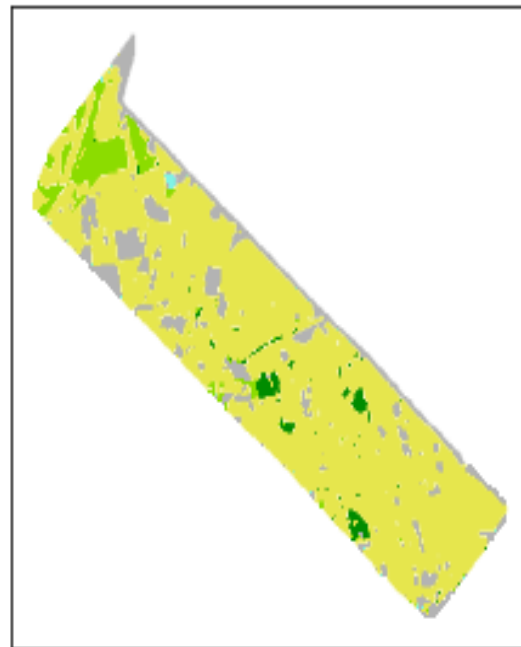
**Hyplant RGB**



**Land-use type**



15 classes



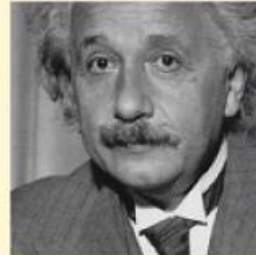
4 classes

# Narrowing the data set

## Structural similarity index matrix (SSIM)

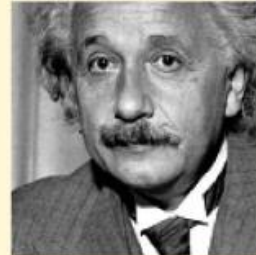
- Determine similarity between two images considering both **quantitative values** and the **spatial distribution** pattern.

Example compare **Mean square error (MSE)** and **Structural similarity index matrix (SSIM)**



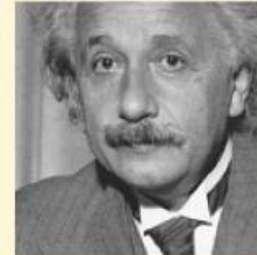
MSE=0, SSIM=1

(a)



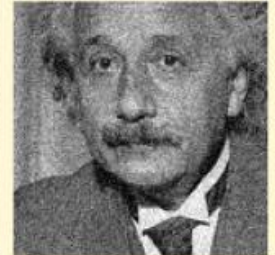
MSE=306, SSIM=0.928

(b)



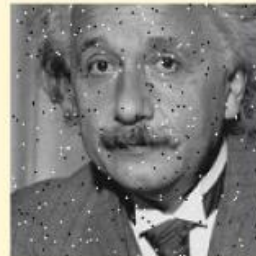
MSE=309, SSIM=0.987

(c)



MSE=309, SSIM=0.576

(d)



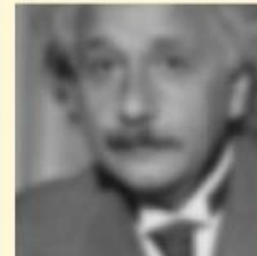
MSE=313, SSIM=0.730

(e)



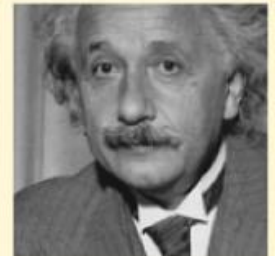
MSE=309, SSIM=0.580

(f)



MSE=308, SSIM=0.641

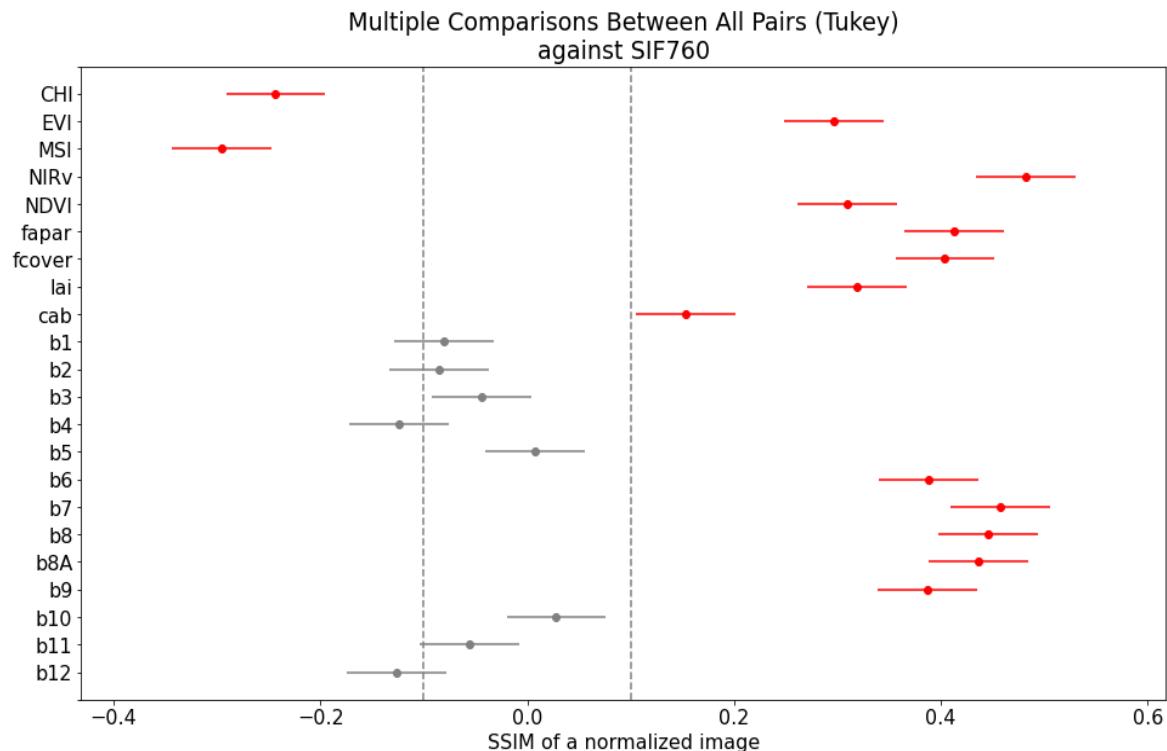
(g)



MSE=694, SSIM=0.505

(h)

# Narrowing the data set



Understanding SSIM index:

0	No correlated
-1	negatively correlated
+1	Positively correlated
Tukey test ~ statistically significant ( $p < 0.05$ )	

Selected indices/retrieved parameters/S2 bands:

- CHI, EVI, MSI, NIRv, NDVI, fapar, fcover, lai, cab, b6, b7, b8, b8a, b9.

# Methods used to define spatial heterogeneity

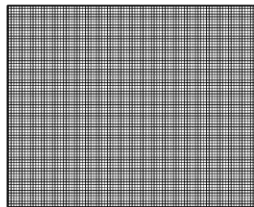
- **S2-based methods**

- Local Moran's
- Spatial heterogeneity coefficient (Land cover map)
- Sub-pixel variance

- **SIF predicted methods**

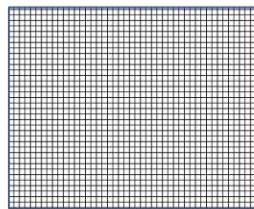
- Multiregression

**HyPlant**  
Reflected radiance  
4.5 x 4.5 m



**Resampled S2**

Spectrally  
20 x 20 m

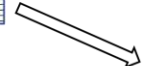
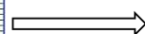
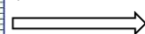
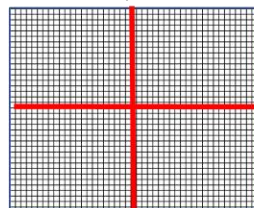


**Retrieval veg**  
indices and  
biophysical traits



**Patching FLEX**

300x 300 m



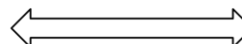
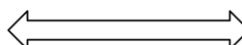
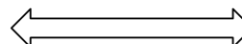
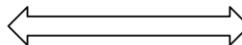
Local Moral

Spatial heterogeneity  
Coeff

Sub-pixel variance

Multiple regression

**Evaluation**



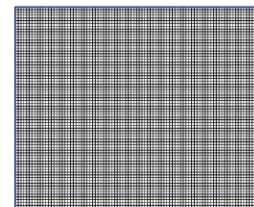
Local Moral

Spatial heterogeneity  
Coeff

Sub-pixel variance

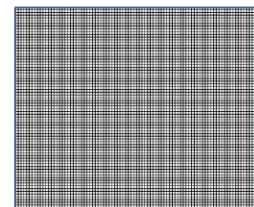
Multiple regression

**HyPlant**  
F687 and F760  
4.5 x 4.5 m



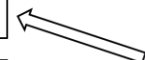
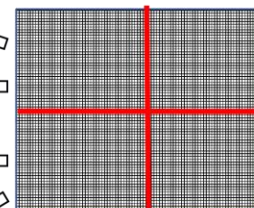
**Resampled**

5 x 5 m



**Patching FLEX**

300x 300 m



# S2 based methods

## Local Moran's I method (Anselin, 1995)

### Input data S2 based model

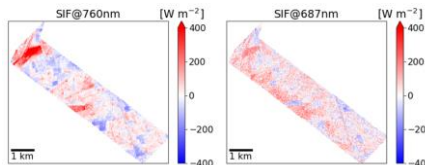
S2



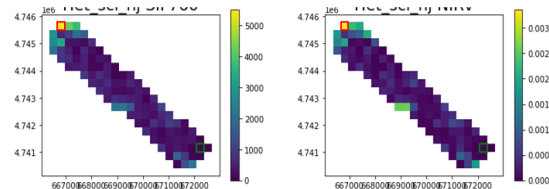
Veg.  
Indices

Biophysical  
Traits

### Reference data

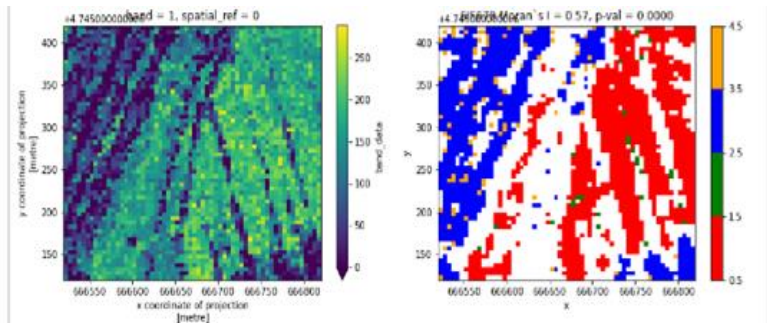


### Output: SIF and S2 heterogeneity maps



## Heterogeneity

### Example F687



	HL
	LL
	LH
	HH
	No class

- percentage of subpixels belonging to the “no class” type over the total number of subpixels in a 300x300 FLEX patch
- Range from [0-1], where 0 corresponds to low heterogeneity and 1 to high heterogeneity

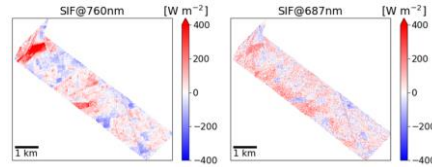
# S2 based methods

## Spatial heterogeneity coefficients (Land cover map – Zao & Fan 2018 )

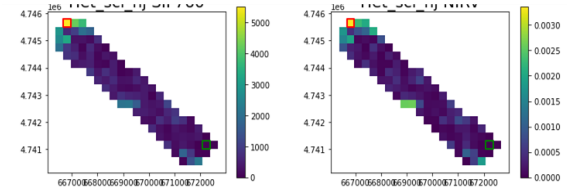
### Input data S2 based model



### Reference data



### Output: SIF and S2 heterogeneity maps



## Heterogeneity

- Combine **land-use variance** and **entropy** within each 300x300 FLEX patch.
- High values determine higher heterogeneity and lower values lower heterogeneity.

Total number of land cover types of each subpixel included in a pixel

$$C_{sh} = \sum_{i=1}^N p_i \times E_i \times \sigma_i^2$$

$$= - \sum_{i=1}^N p_i^2 \ln(p_i) \frac{\sum_{m=1}^{n_i} (x_m - \mu)^2}{n_i}$$

$p_i$  = Ratio of the  $i$ -th land cover type in a pixel

$n_i$  – total number of subpixels included in the  $i$ -th type

$x_m$  –  $m$ -th pixel value which is include  $n$   $i$ -th type

$\mu$  – Mean value of total subpixels that are included in one pixels



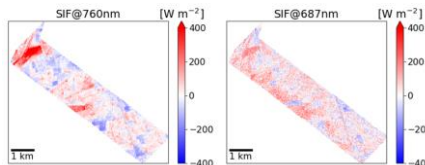
# S2 based methods

## Subpixel variance

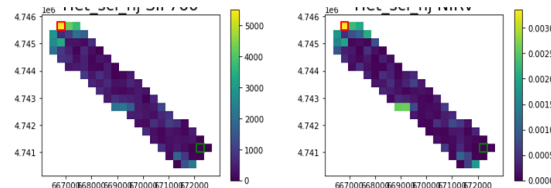
### Input data S2 based model



### Reference data



### Output: SIF and S2 heterogeneity maps



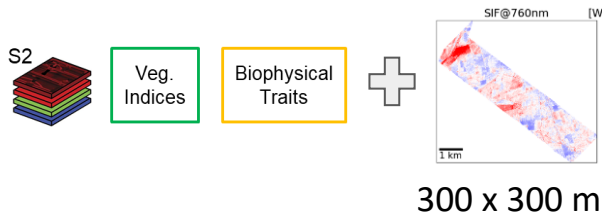
## Heterogeneity

- **Standard deviation** over the total number of subpixels in a 300x300 FLEX patch.
- High values determine higher heterogeneity and lower values lower heterogeneity.

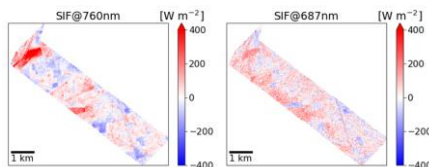
# SIF predicted methods

## Multiple regression

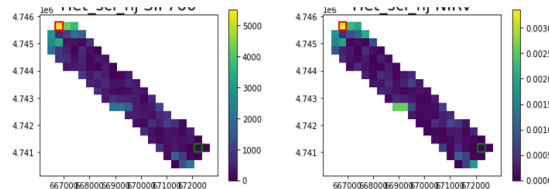
### Input data S2 based model



### Reference data



### Output: SIF and S2 heterogeneity maps

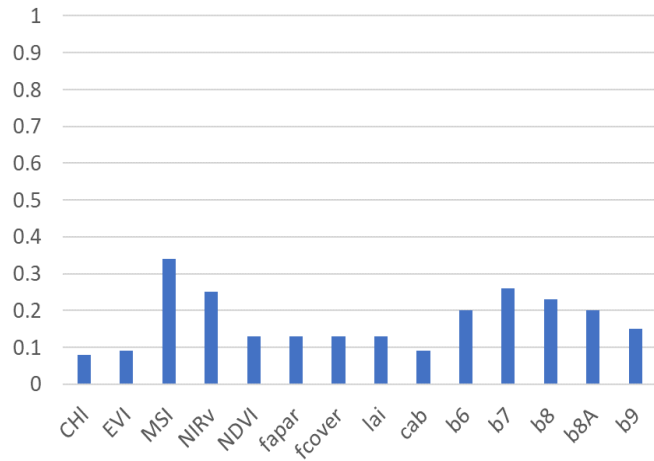


## Heterogeneity

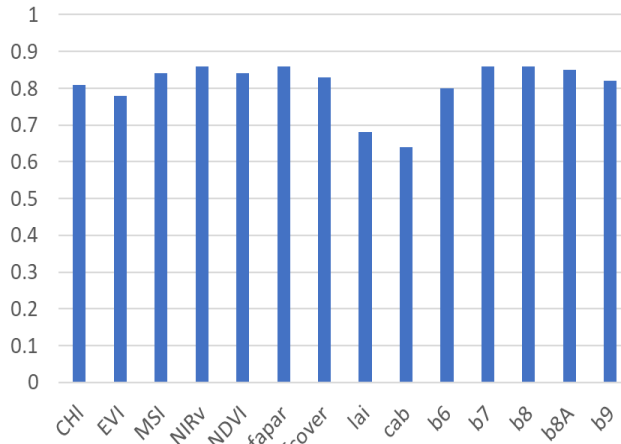
- **Standard deviation** over the total number of subpixels in a 300x300 FLEX patch.
- High values determine higher heterogeneity and low values lower heterogeneity.

# Results

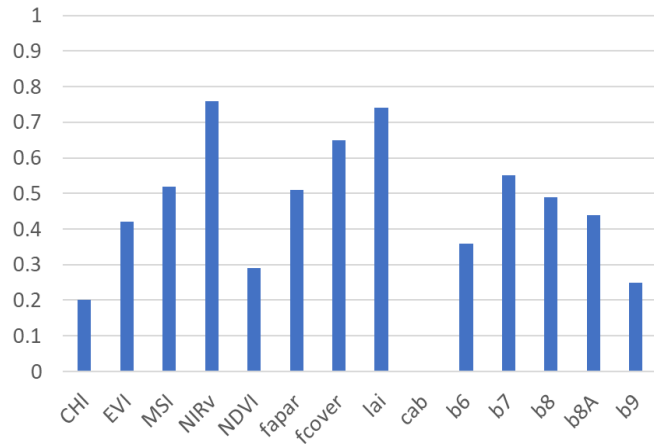
Local Moran's



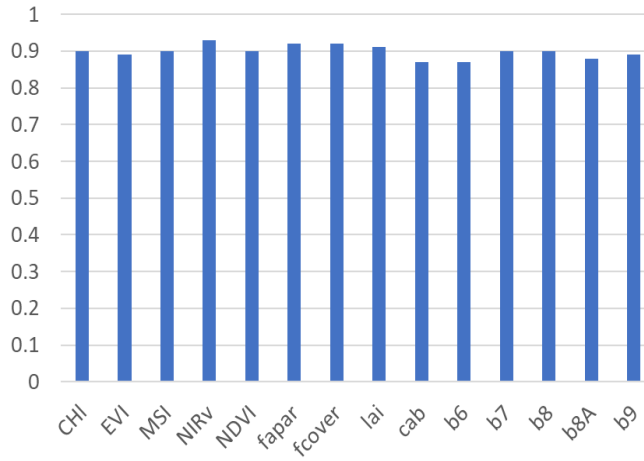
Spatial heterogeneity Coeff



Subpixel variance



Multiple regression



## R² S2 and SIF heterogeneity maps ( $p < 0.05$ )

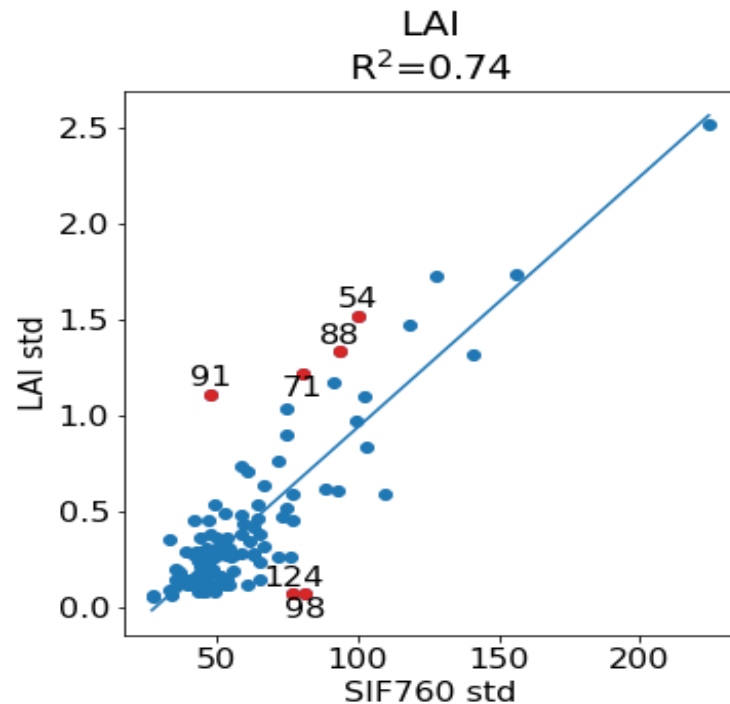
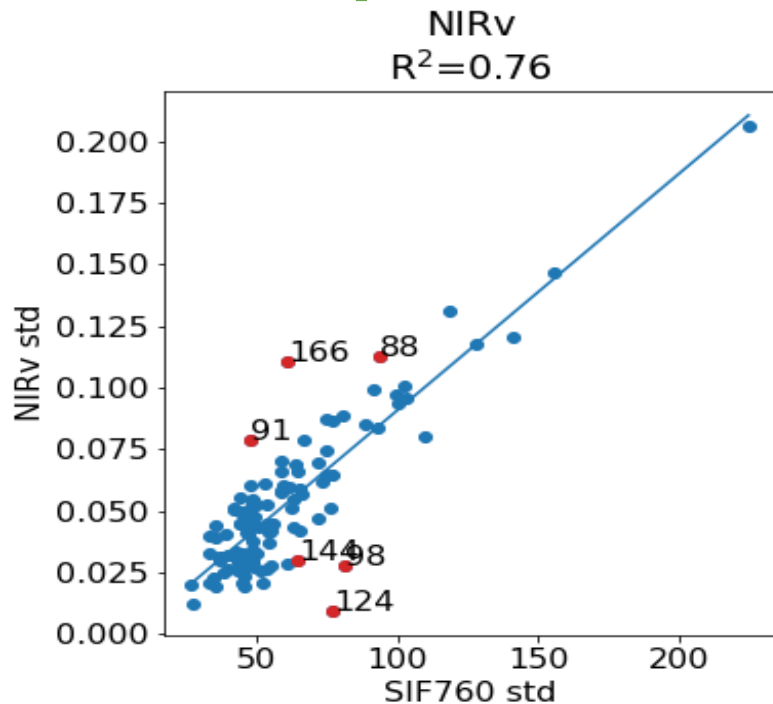
Methods ranking:

1. Multiple regression
2. Spatial heterogeneity Coeff
3. Subpixel variance
4. Local Moran

Subpixel variance:

- NIRv
- LAI
- fcover

# Outliers: Subpixel variance



**Outliers are defined as:**

- top 6 RSME

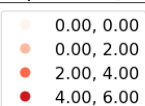
**Future work:**

- Identify outliers
- Consistency (91, 88, 98, 124)



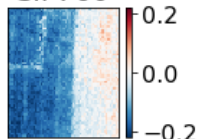
## Results (understand outliers)

SIF760 outliers ['NIRv', 'fapar', 'b7']

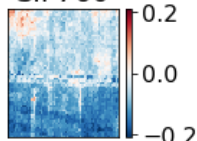


SIF760

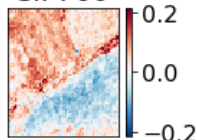
px\_ID=124  
SIF760



px\_ID=77  
SIF760

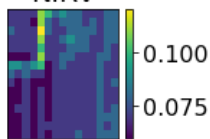


px\_ID=144  
SIF760

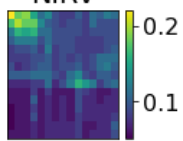


NIRv

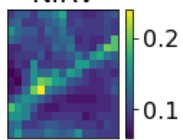
px\_ID=124  
NIRv



px\_ID=77  
NIRv

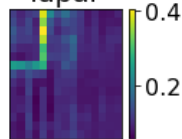


px\_ID=144  
NIRv

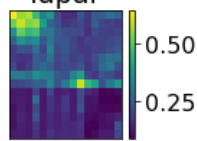


fAPAR

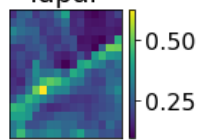
px\_ID=124  
fapar



px\_ID=77  
fapar

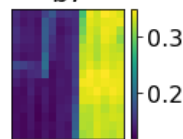


px\_ID=144  
fapar

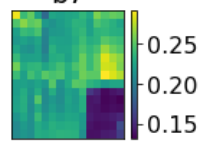


B7 (red-edge)

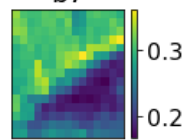
px\_ID=124  
b7



px\_ID=77  
b7

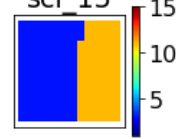


px\_ID=144  
b7

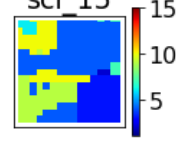


LandCover

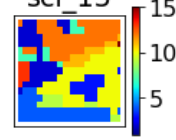
px\_ID=124  
scl\_15



px\_ID=77  
scl\_15



px\_ID=144  
scl\_15



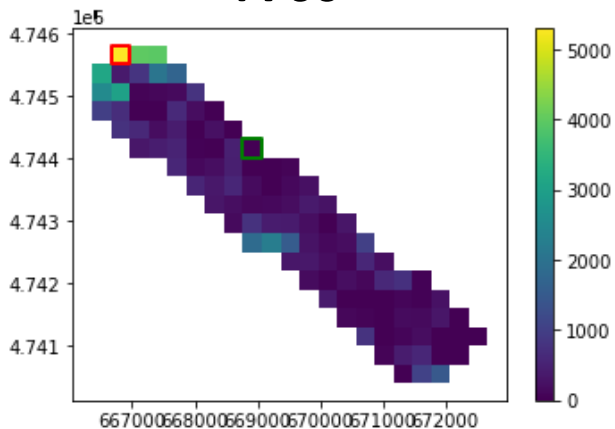
Low  
Heterogeneity

Medium  
Heterogeneity

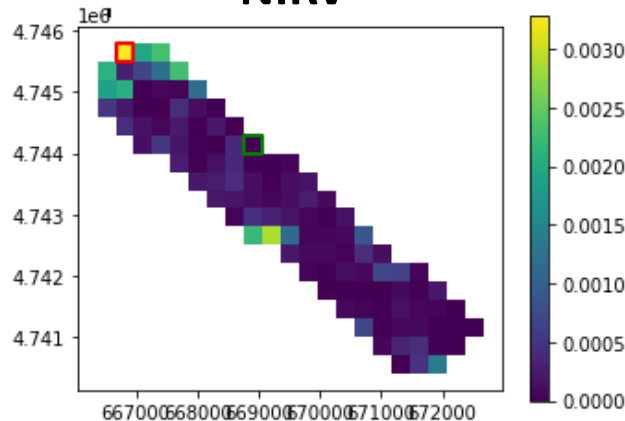
High  
Heterogeneity

# Heterogeneity Maps

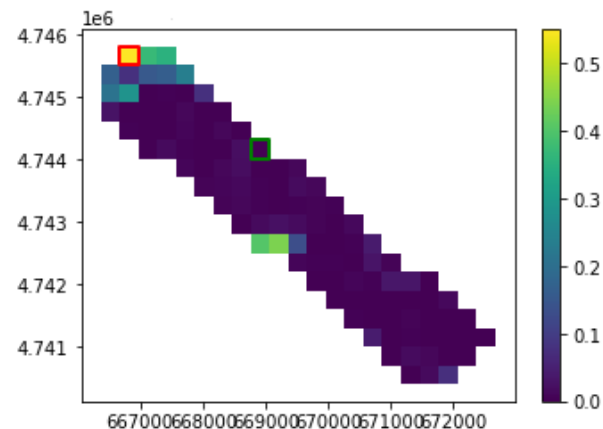
**F760**



**NIRv**



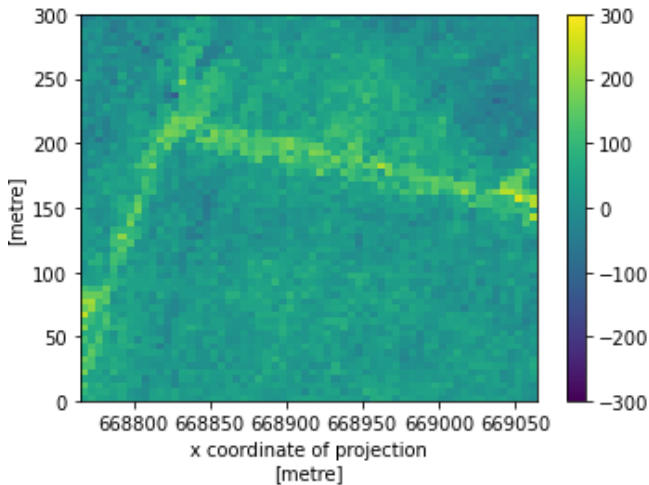
**LAI**



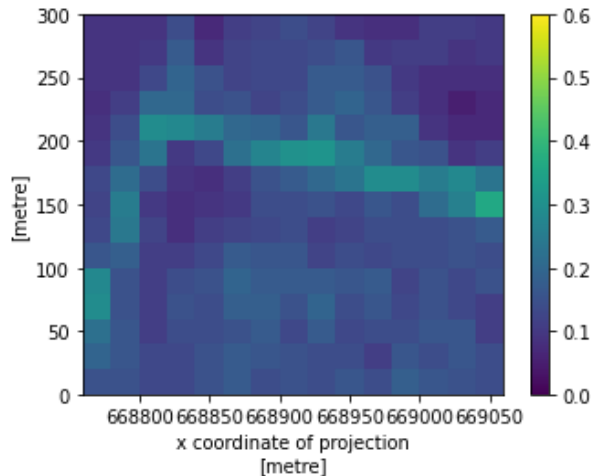
- Study area characterized by low heterogeneity
- Up corner higher heterogeneity

# Lower heterogeneity

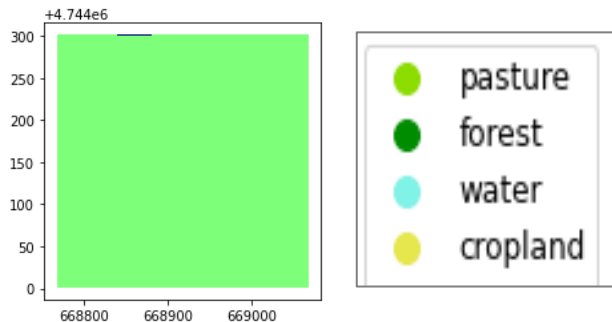
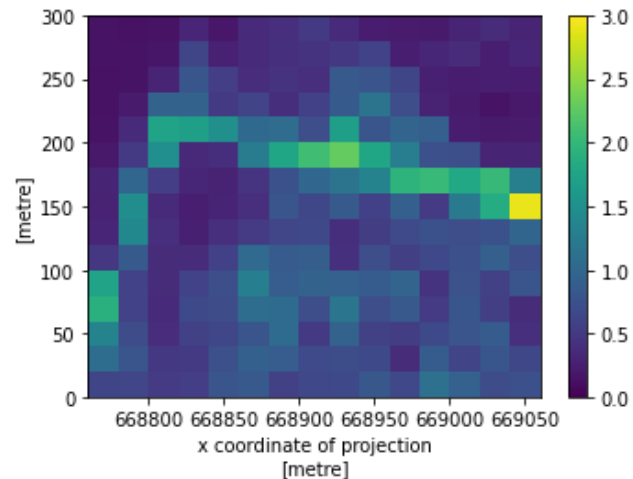
F760



NIRv



LAI

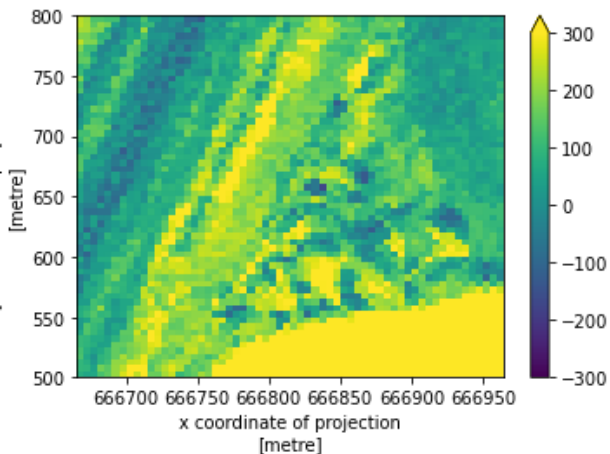


- Example low heterogeneity 300 x 300 FLEX pixel
- Pasture land cover type

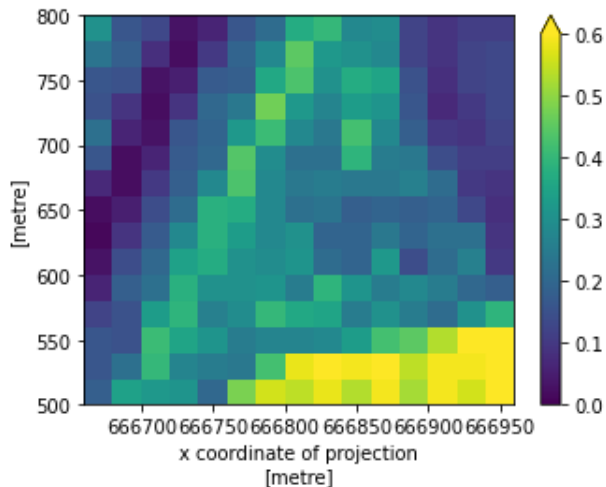


# Higher heterogeneity

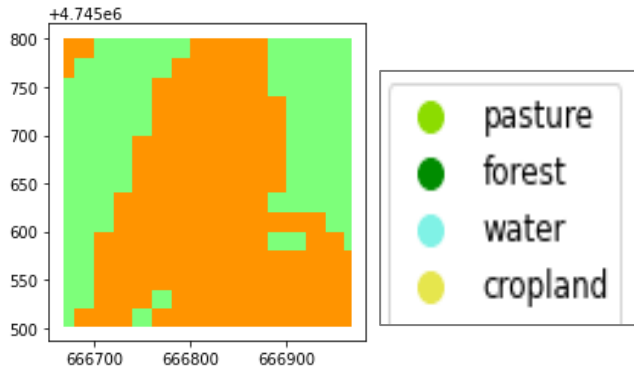
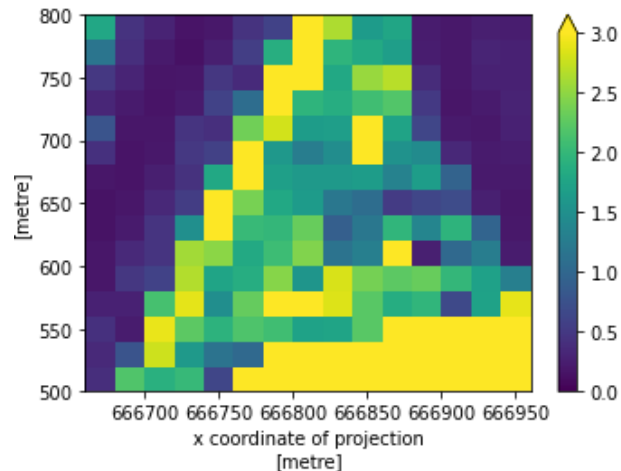
F760



NIRv



LAI



- Example low heterogeneity 300 x 300 FLEX pixel
- Pasture and crop land

# Conclusions

- **Satellite based fluorescence spatial heterogeneity** should be **considered** before using SIF to **understand/model vegetation dynamics**.
- **Subpixel variance heterogeneity model** provided reliable results and is simple to implement.
- **Vegetation indices/biophysical parameters** related to **canopy structure** (NIRv, LAI, fcover) better characterize fluorescence spatial heterogeneity.

## WG1 deliverable: guidelenes and protocols

Based on the present study results  
under elaboration in a joint manuscript!

