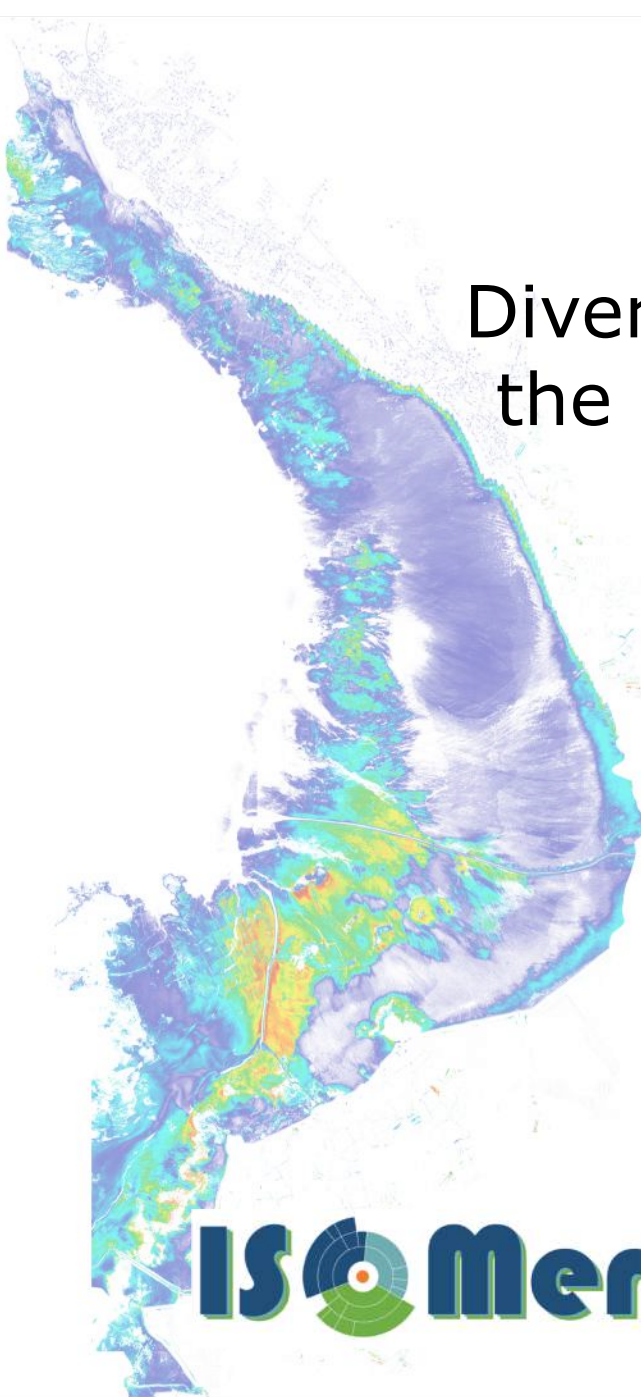
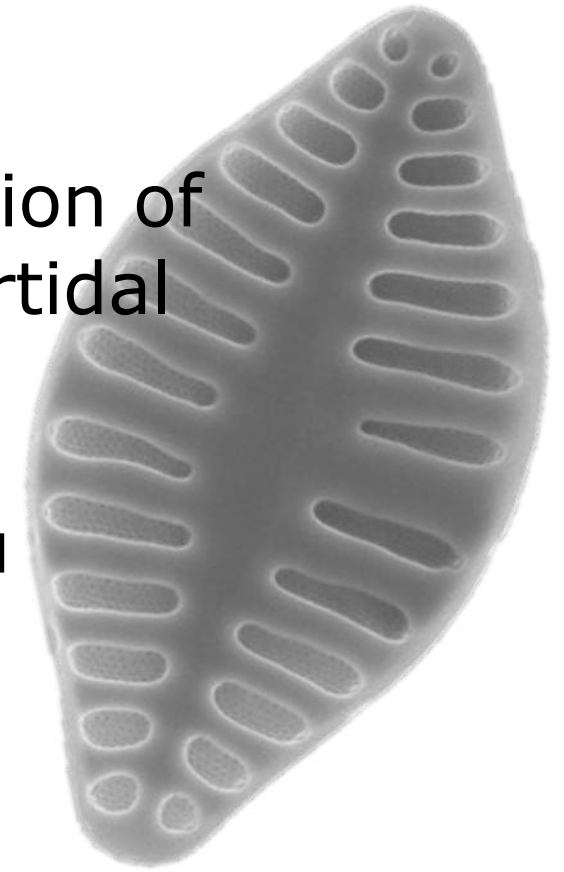




Diversity, biomass and primary production of the microphytobenthos inhabiting intertidal mudflats

Vona Méléder and Patrick Launeau
Nantes Université
16 Decembre 2022



Context

Intertidal mudflats (estuary & bay) = highly productive ecosystems

- Habitats for organisms (feeding, nursery, spawning ground, ...)
- Local activities (aquaculture, tourism, ...)
- High anthropogenic pressure



Context

Intertidal mudflats (estuary & bay) = highly productive ecosystems

- Habitats for organisms (feeding, nursery, spawning ground, ...)
- Local activities (aquaculture, tourism, ...)
- High anthropogenic pressure



This productivity is mainly supported by microphytobenthos (MPB)



Context

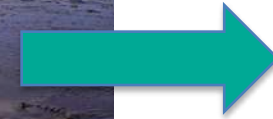
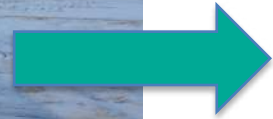
- The microphytobenthos (MPB):

- Is constituted of billions of microalgae cells
- Form biofilm during low tide
- Color the surface of the sediment
- Mainly diatoms, but also euglena and cyanobacteria



Context

- The microphytobenthos (MPB):



Difficulty of access

How to assess MPB
Diversity,
Biomass and
Primary Production
at the ecosystem level

?

Context

- The microphytobenthos (MPB):

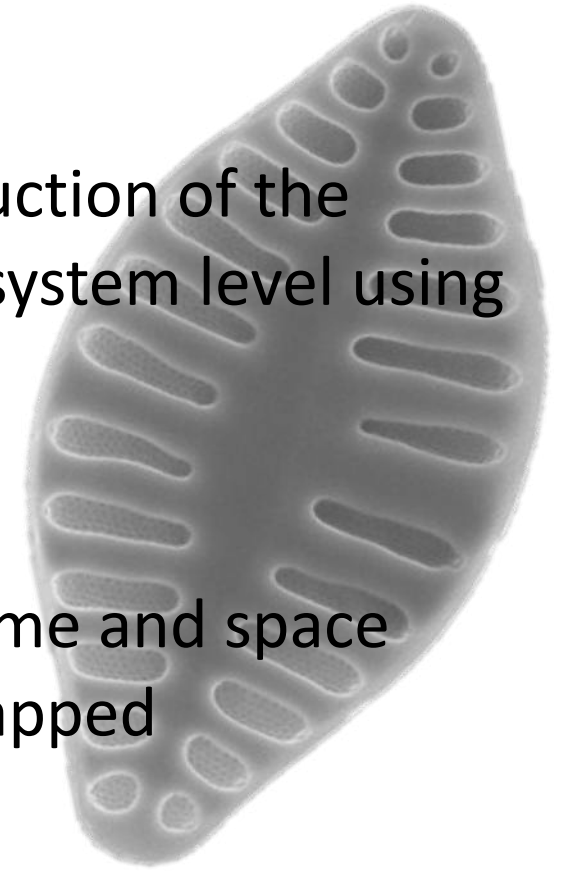
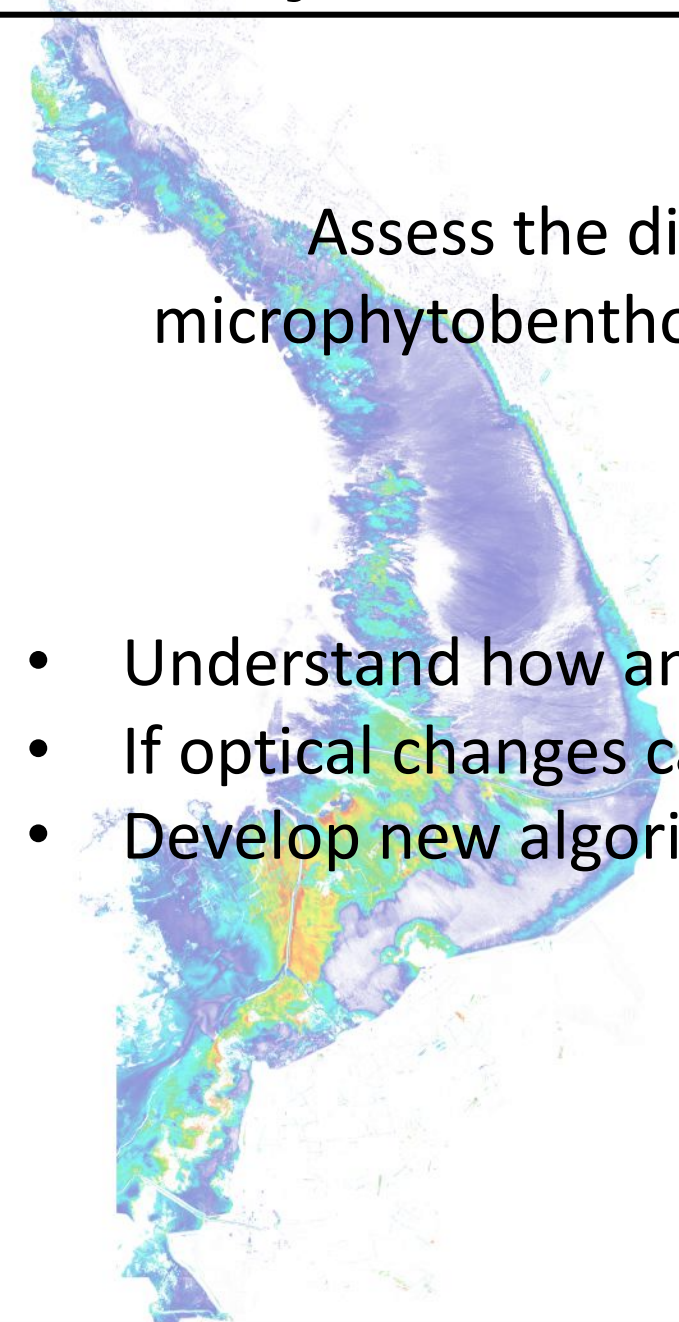


Remote Sensing approach

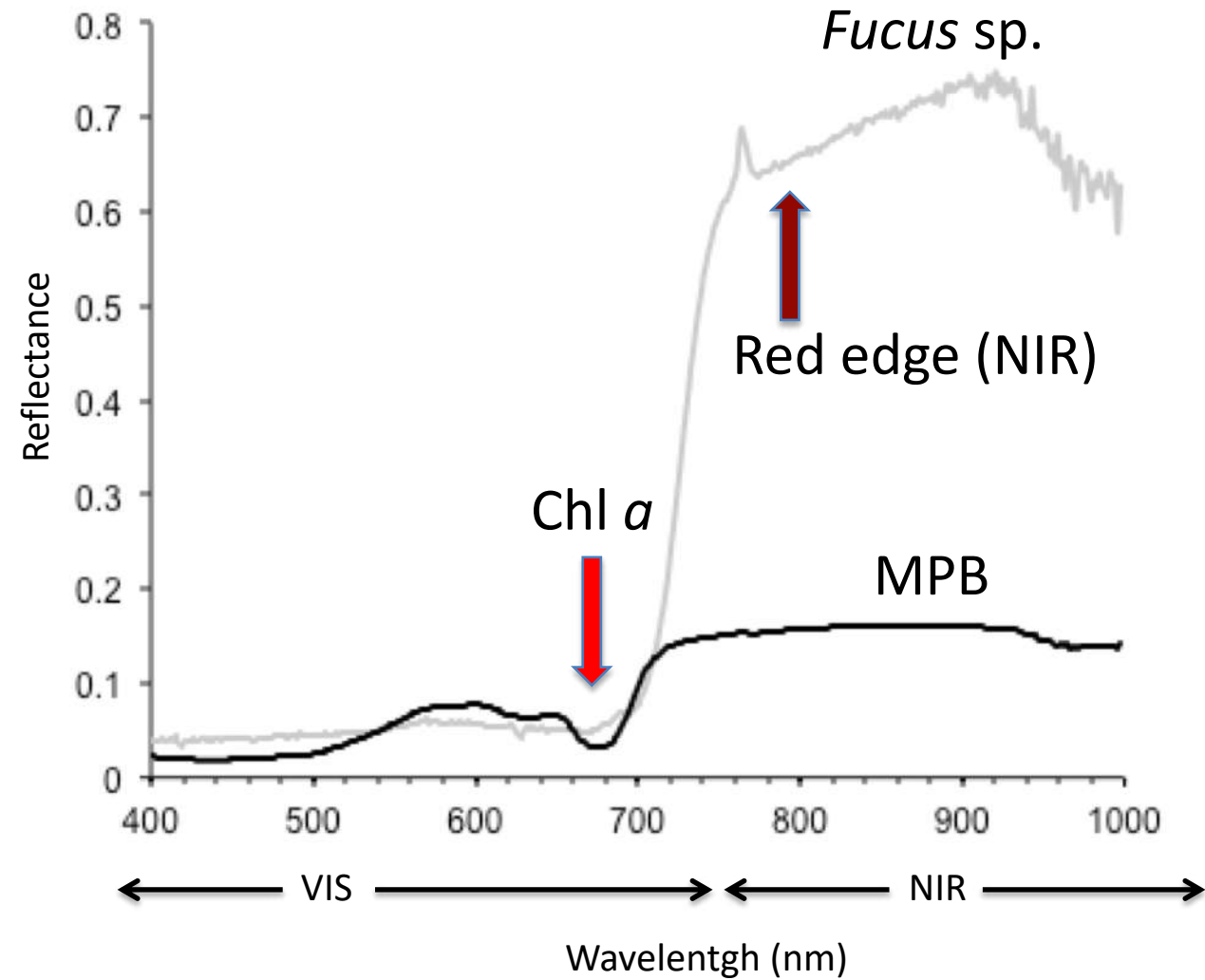
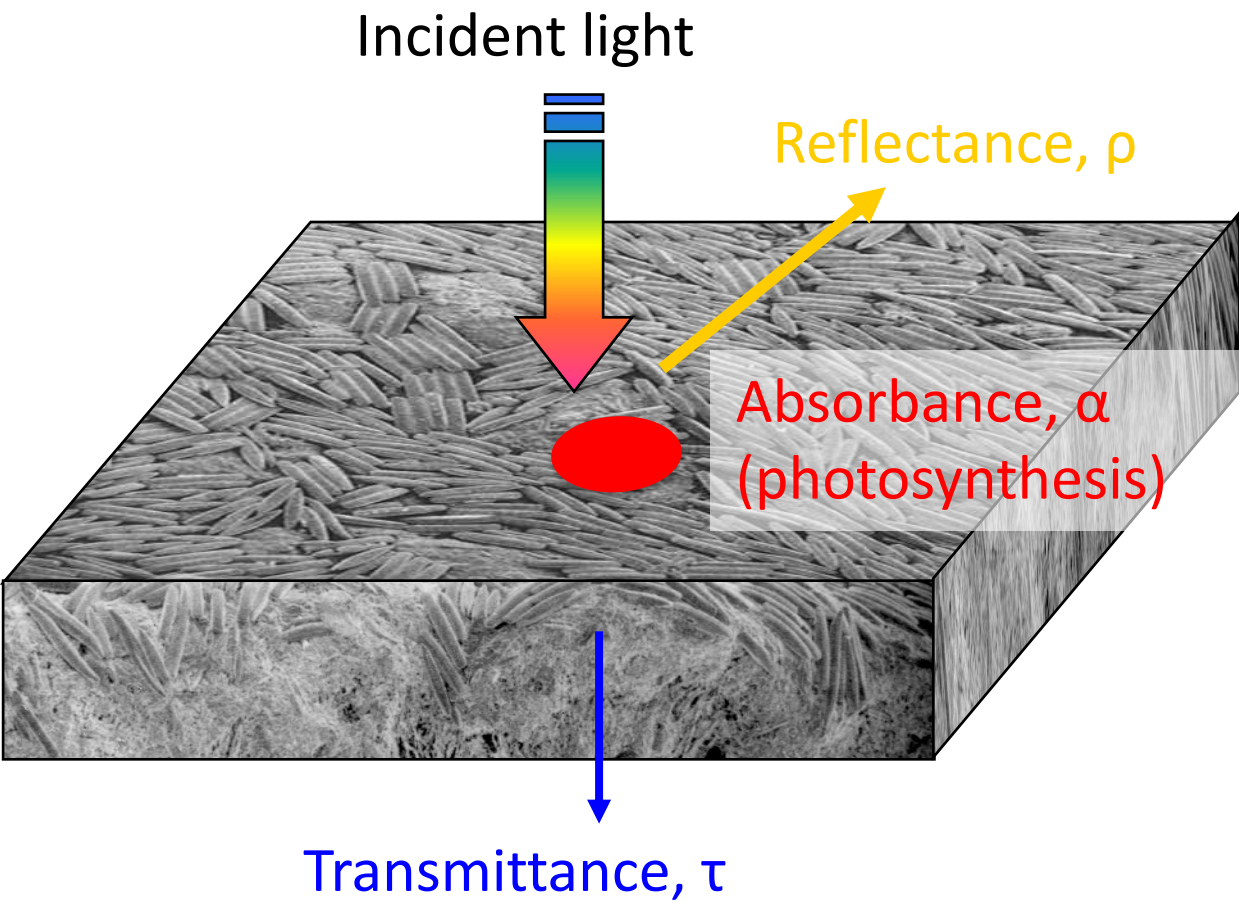
Main Objective

Assess the diversity, the biomass and the primary production of the microphytobenthos inhabiting intertidal mudflats at the ecosystem level using remote sensing approaches

- Understand how and why MPB optical properties change in time and space
- If optical changes can be detected by sensor imagers to be mapped
- Develop new algorithms to be applied to images to map MPB

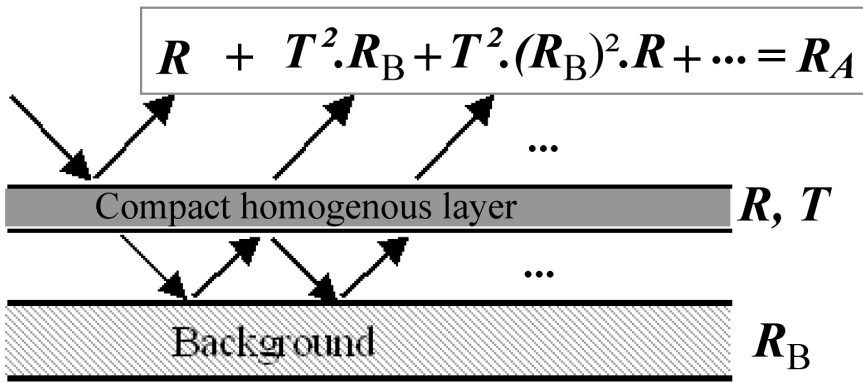


MPB spectrum



Estimation of the optical properties of biofilm

By spectroradiometry, from a radiative transfert model MPBOM (Kazemipour et al. 2011), modified by Launeau et al. 2018

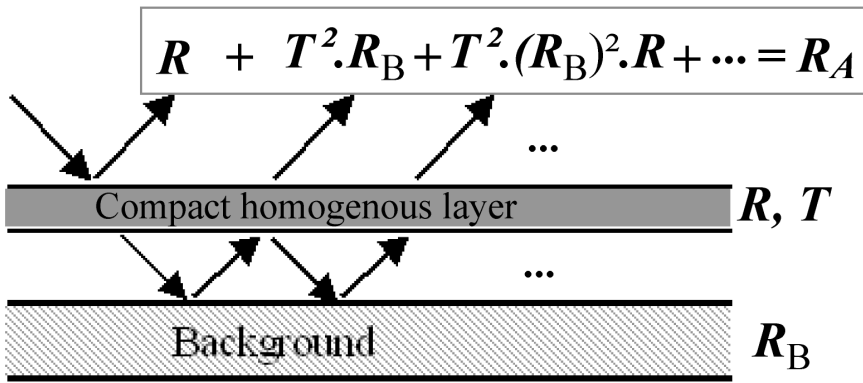


With

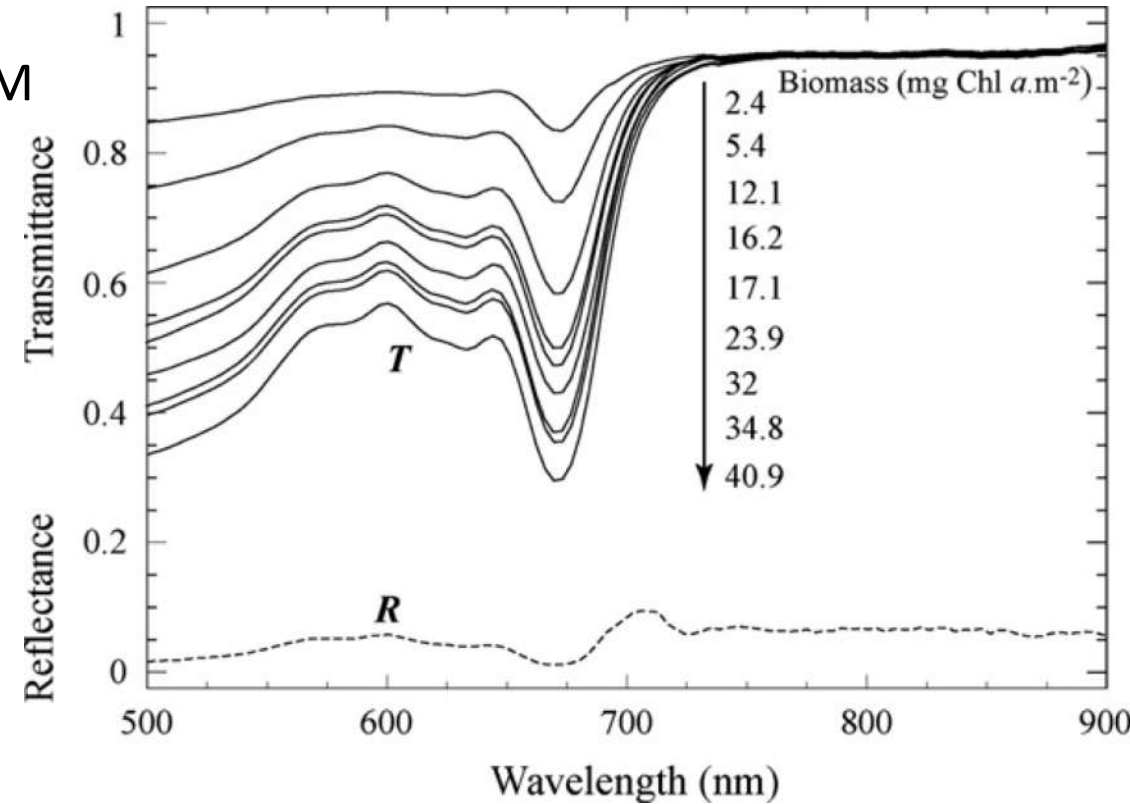
- R_A : measured reflectance
- R_B reflectance of the background

Estimation of the optical properties of biofilm

By spectroradiometry, from a radiative transfert model MPBOM (Kazemipour et al. 2011), modified by Launeau et al. 2018



Kubelka et al. (1948)
formalism:

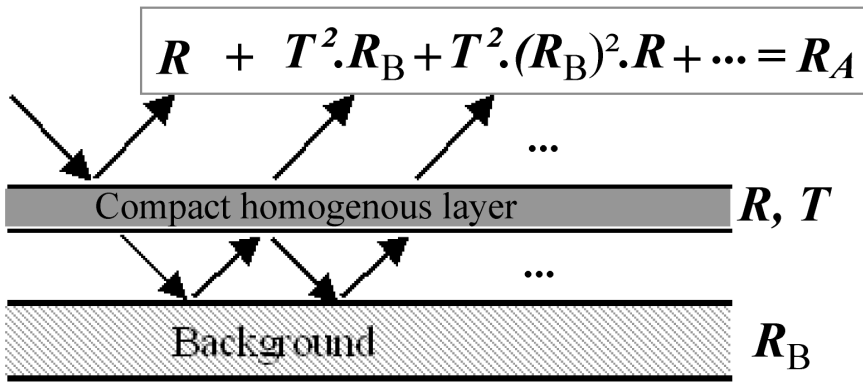


With

- R_A : measured reflectance
- R_B reflectance of the background

Estimation of the optical properties of biofilm

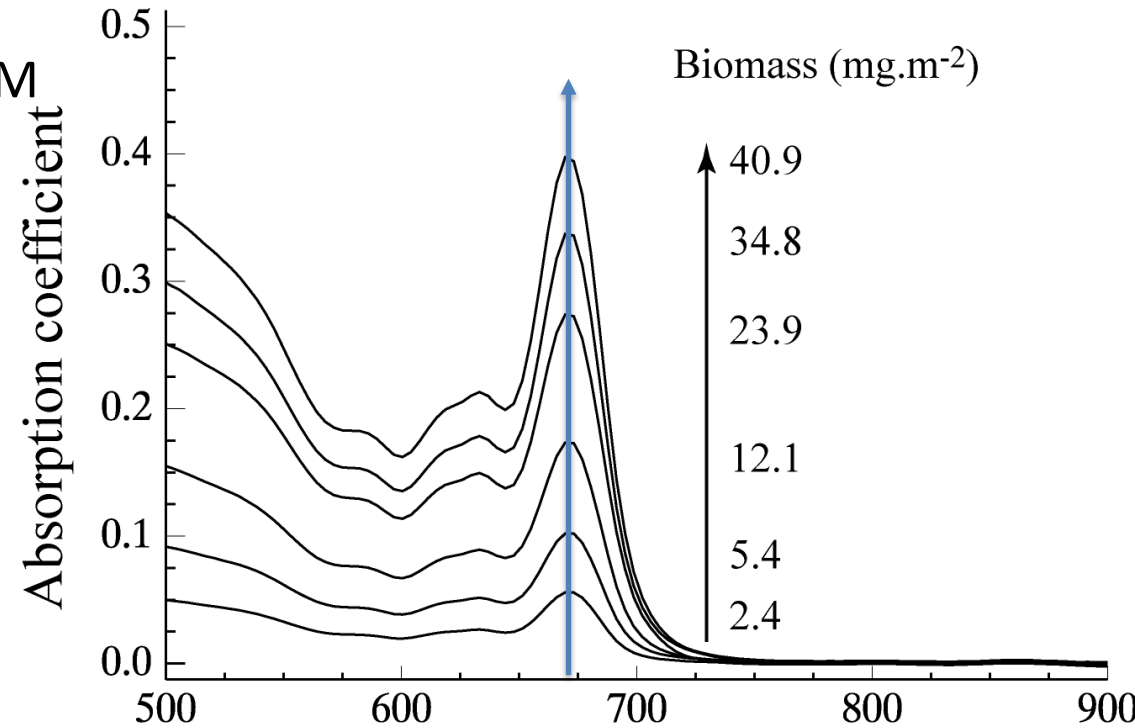
By spectroradiometry, from a radiative transfert model MPBOM (Kazemipour et al. 2011), modified by Launeau et al. 2018



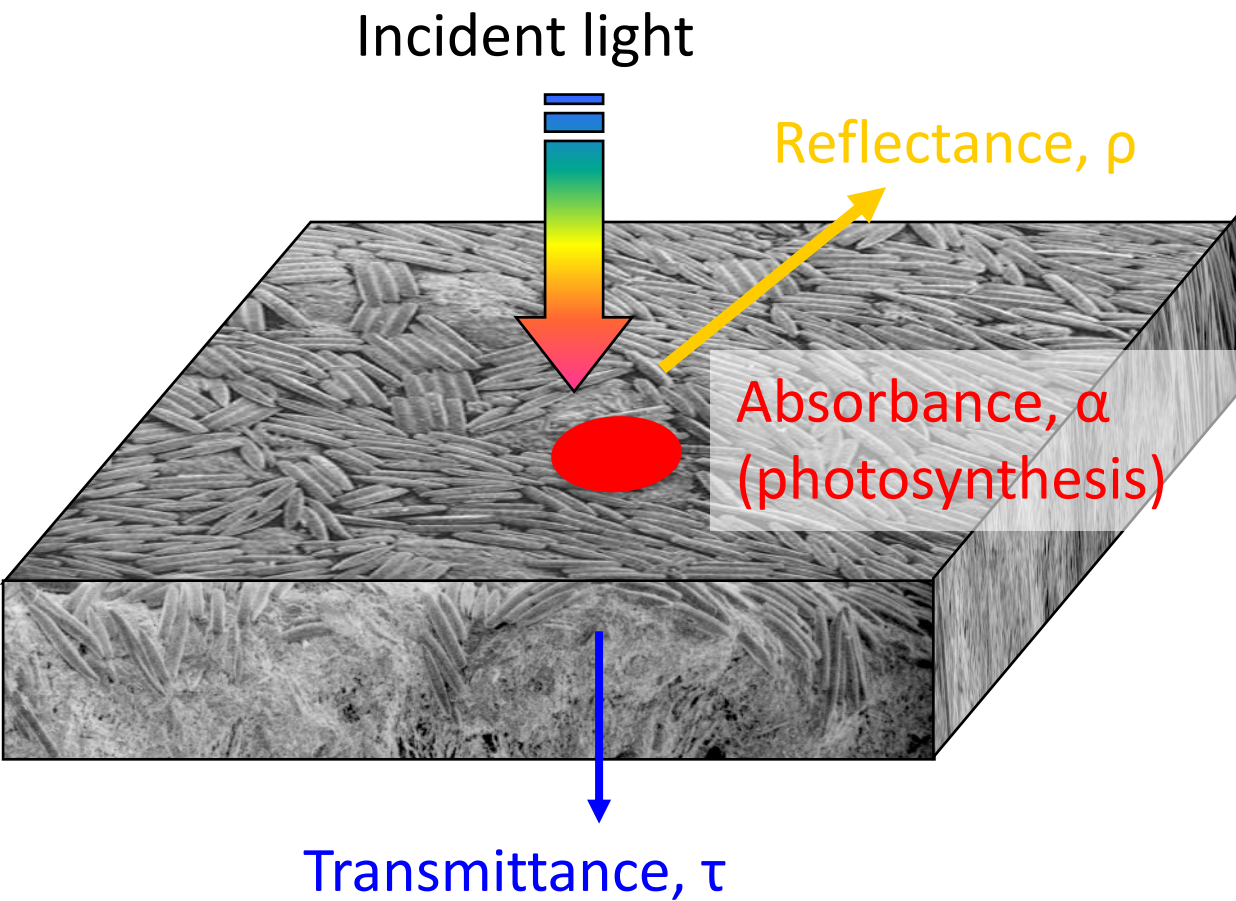
$$\alpha = -\ln \left(\sqrt[6]{\frac{R_A}{R_B}} \right)$$

With

- R_A : measured reflectance
- R_B reflectance of the background



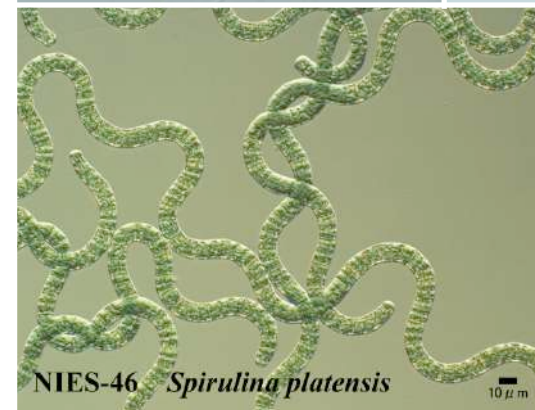
Diversity effect



Green strain
Dunaliella tertiolecta



Brown strain
Entomoneis paludosa

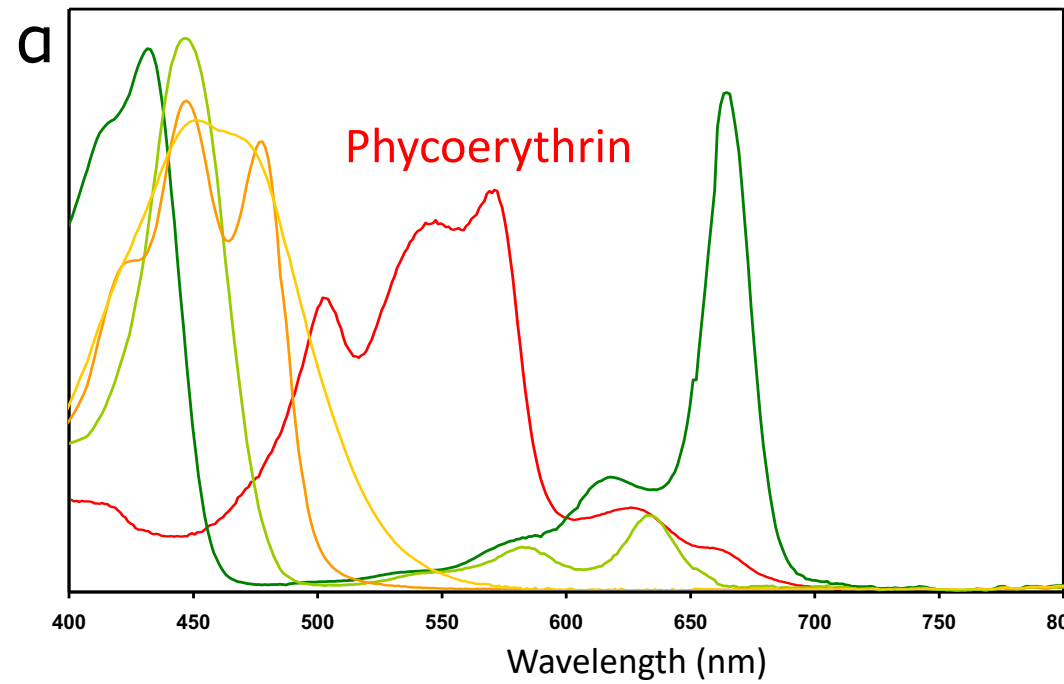
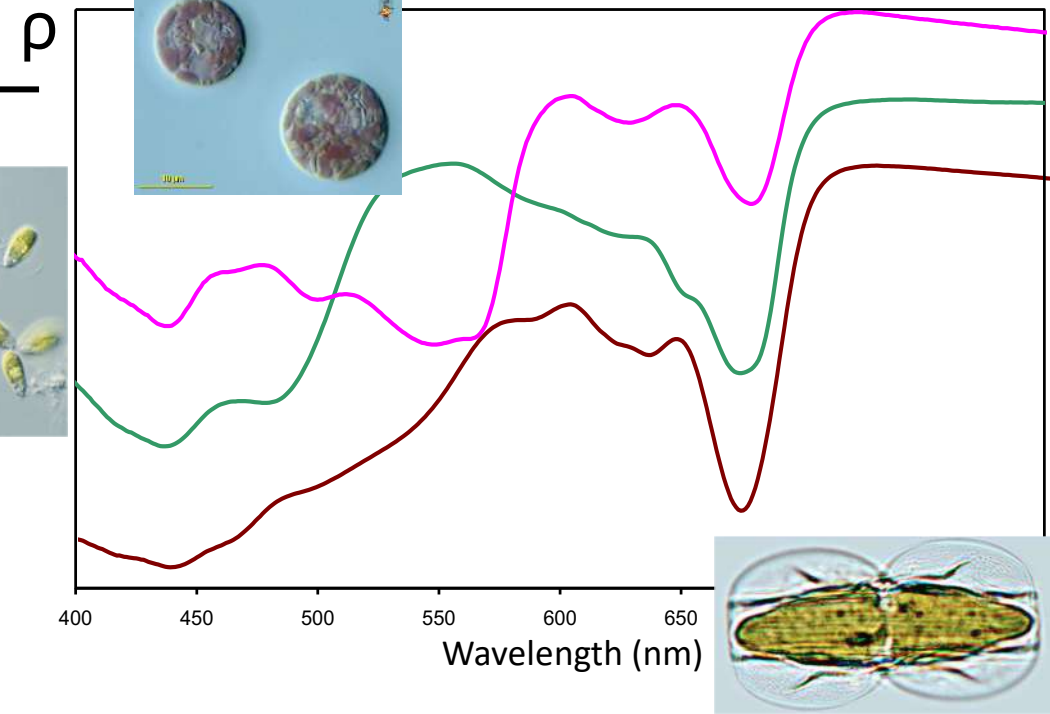
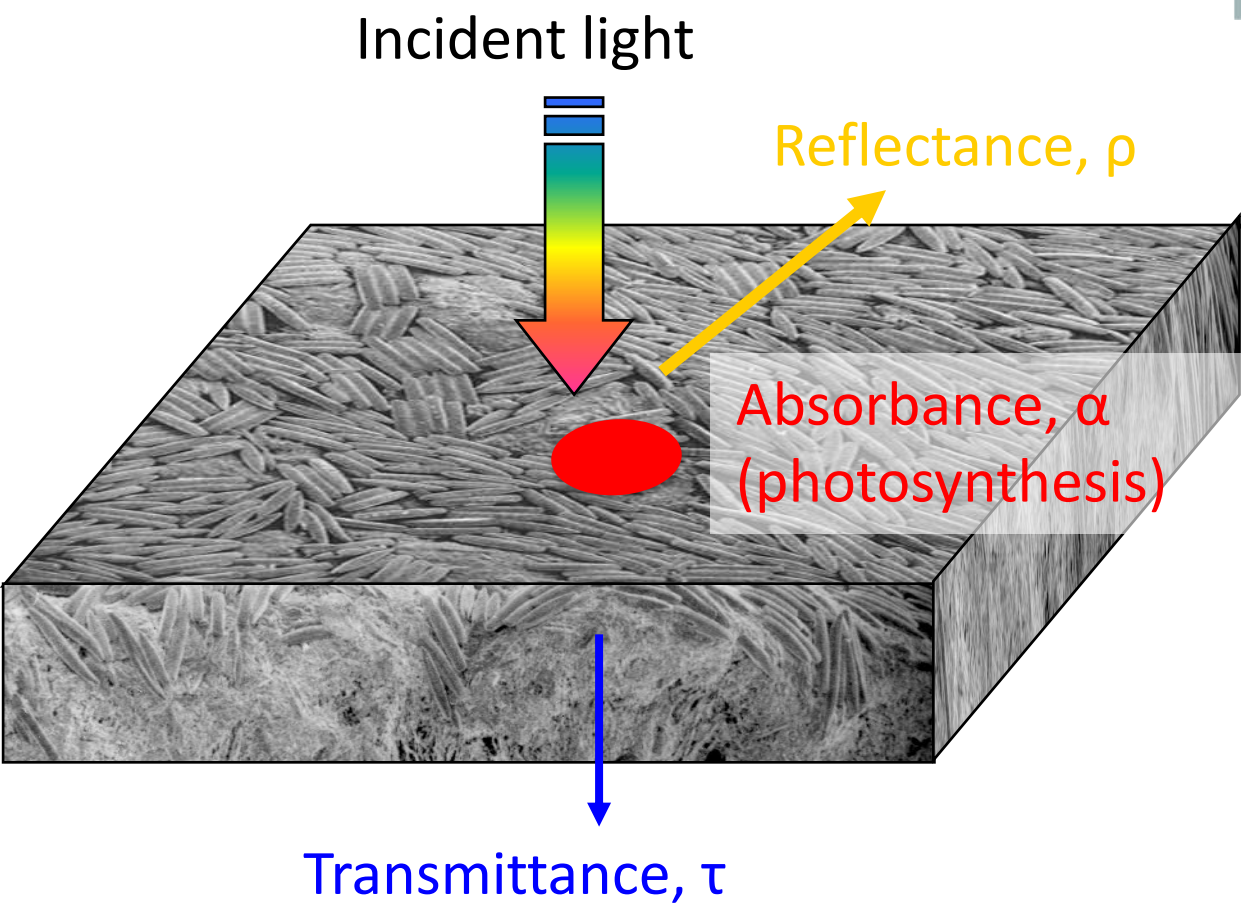


Blue strain
Spirulina platensis

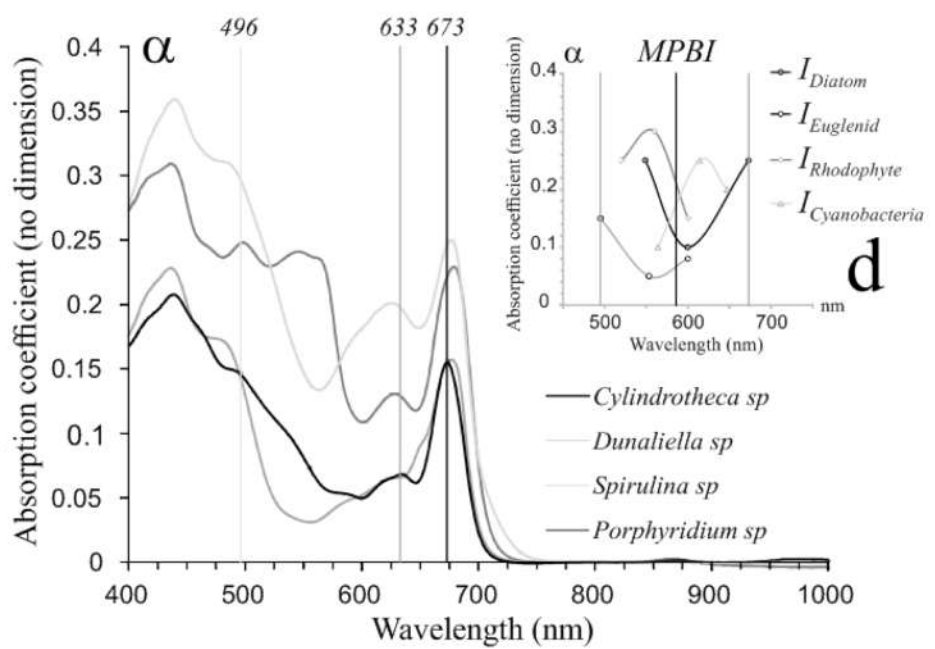
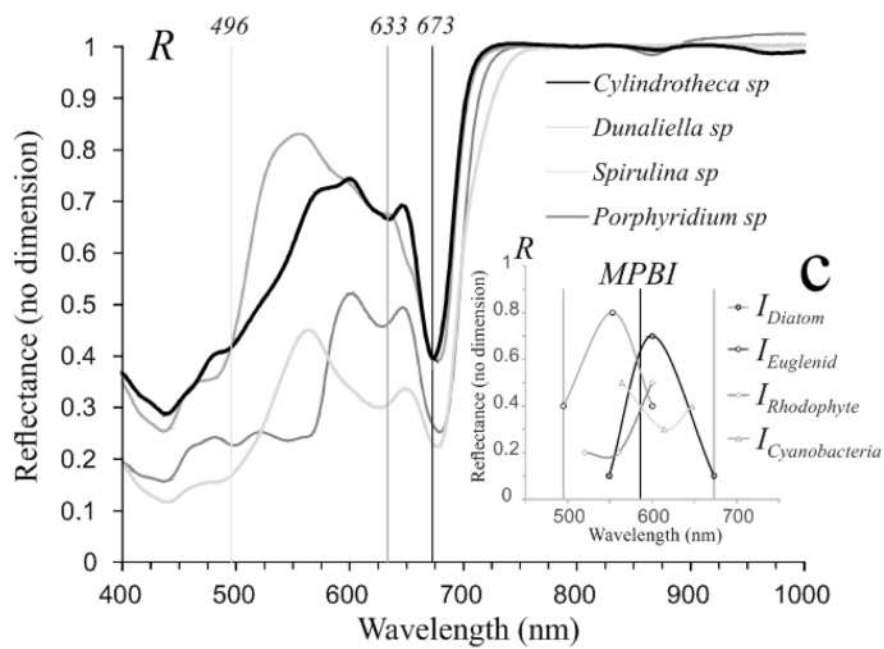
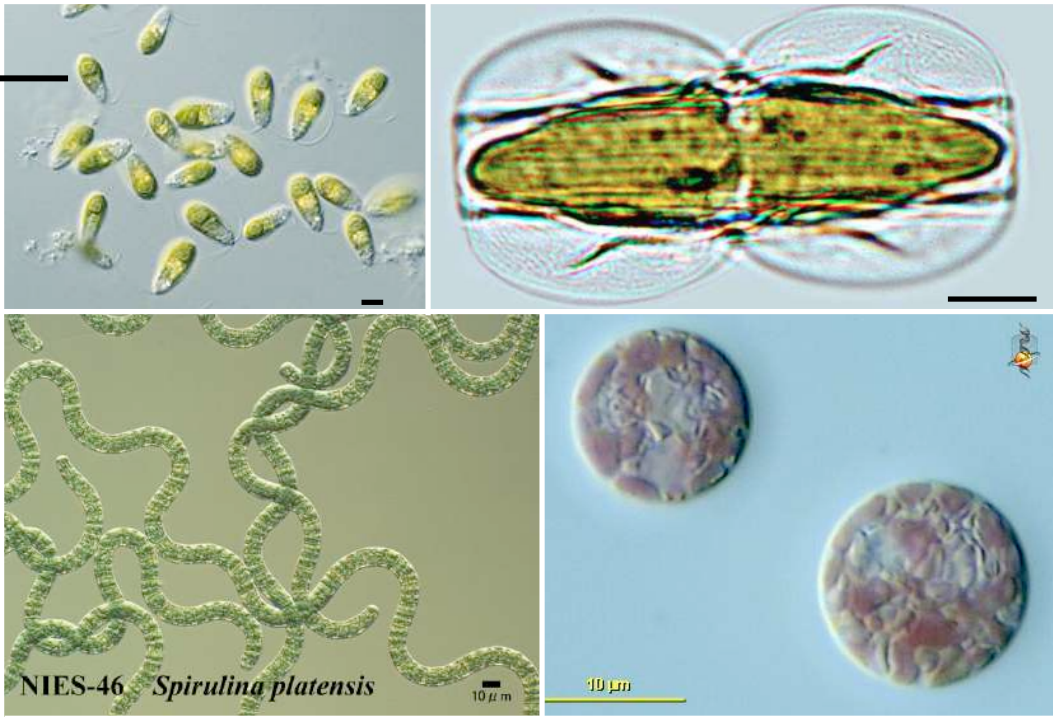


Red strain
Porphyridium cruentum

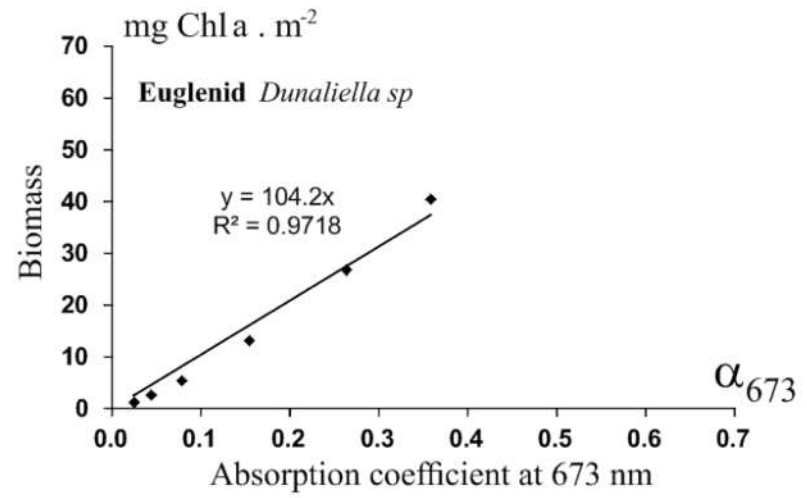
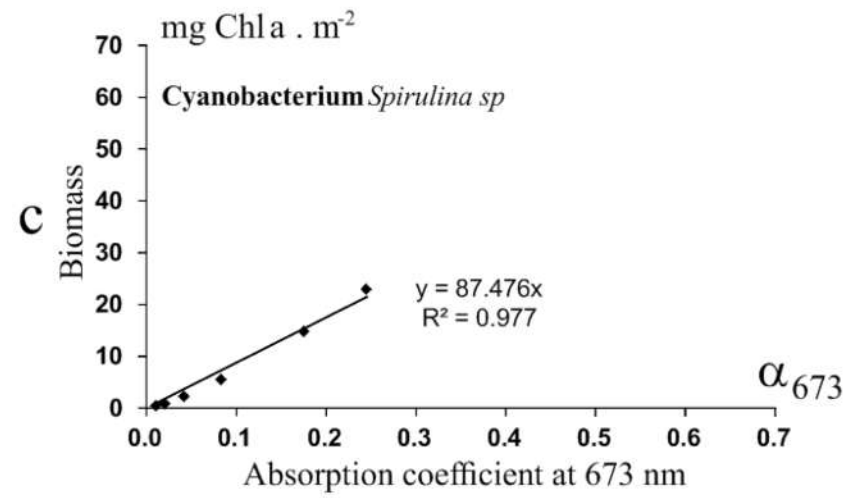
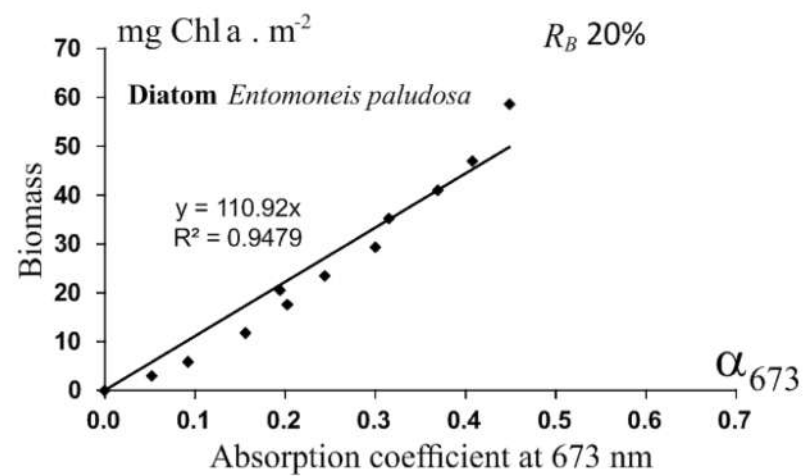
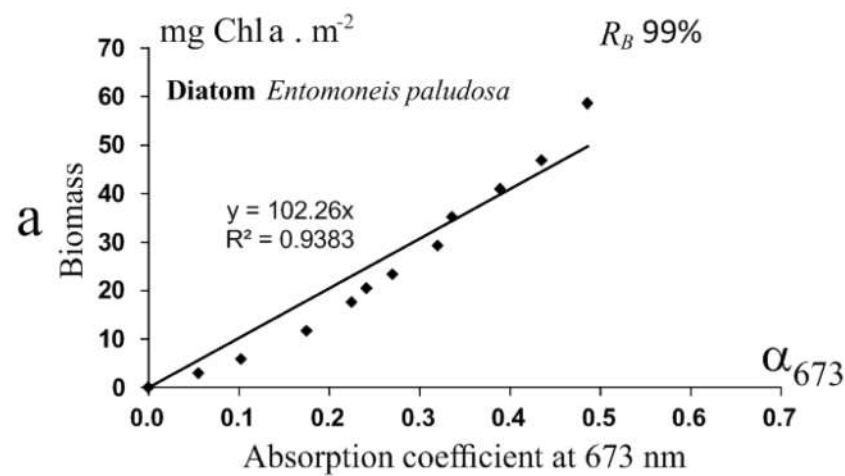
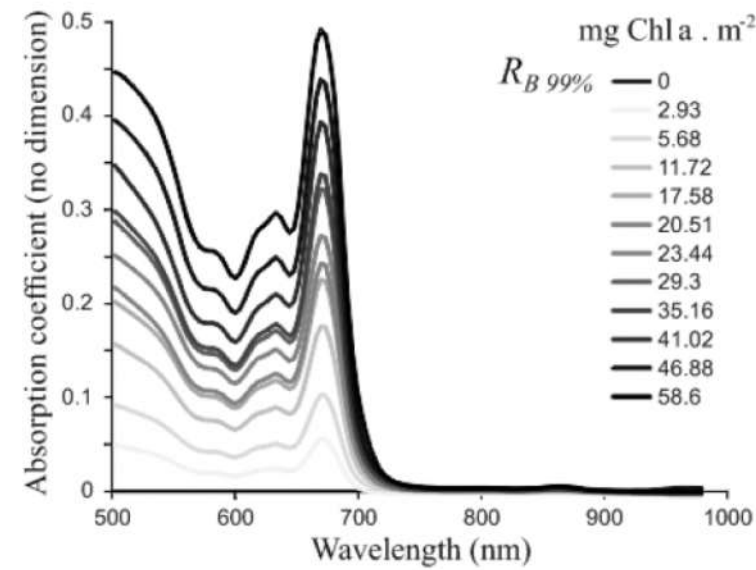
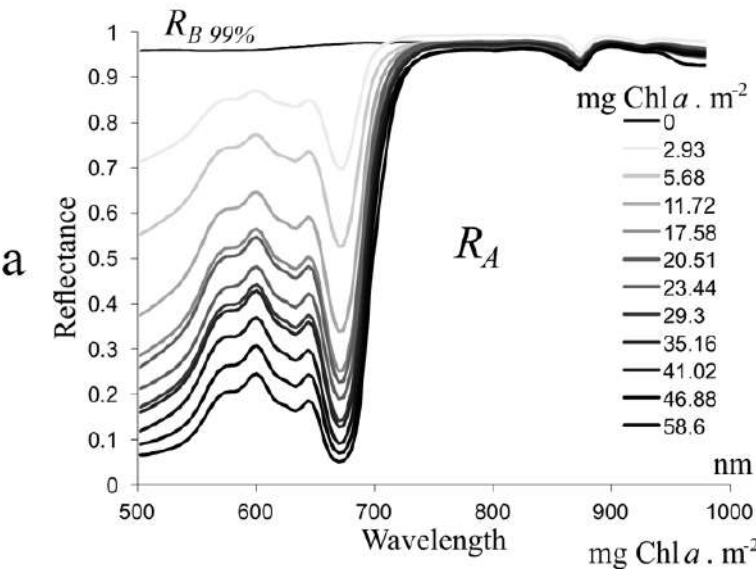
Diversity effect



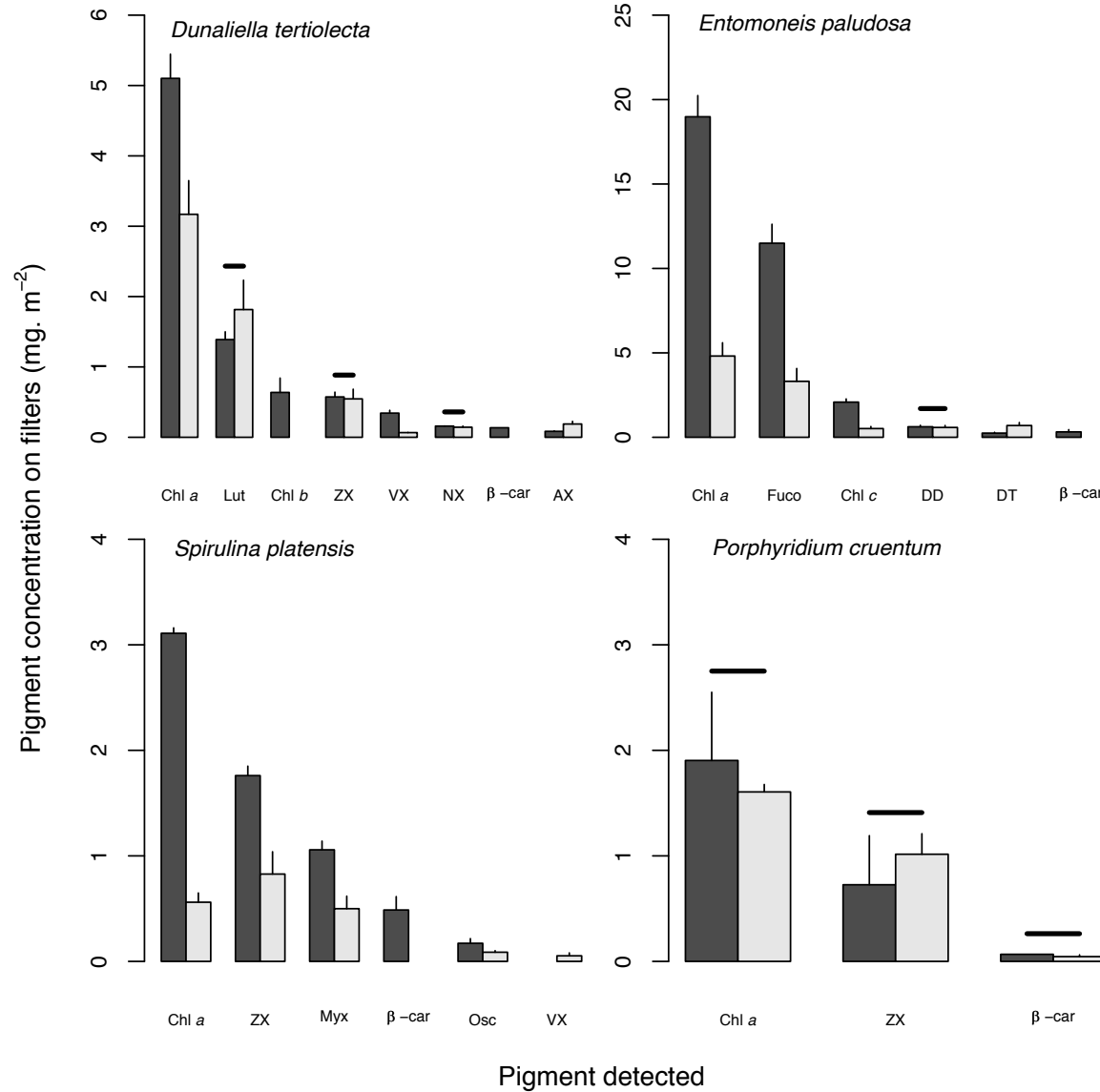
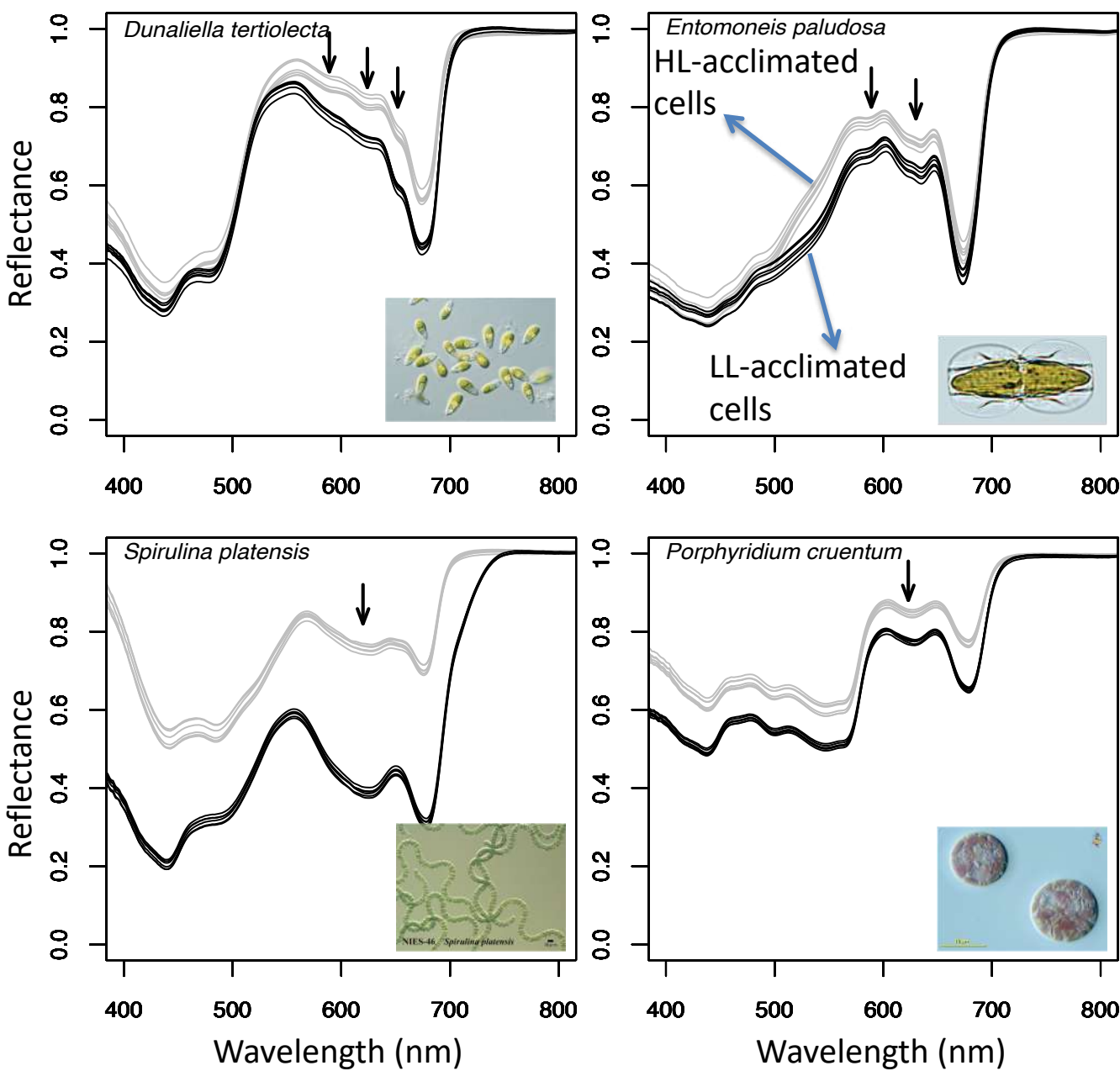
Diversity effect



Biomass effect

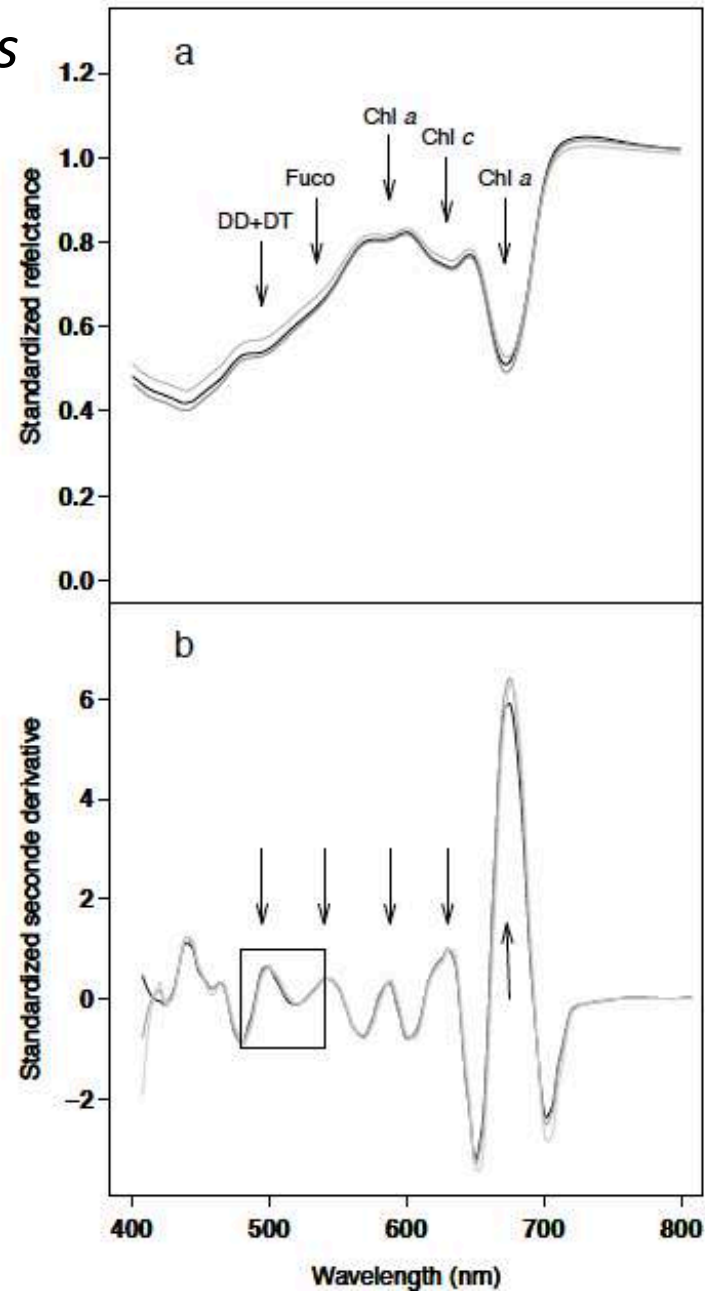


Ecophysiological effect (High Light vs. Low Light)

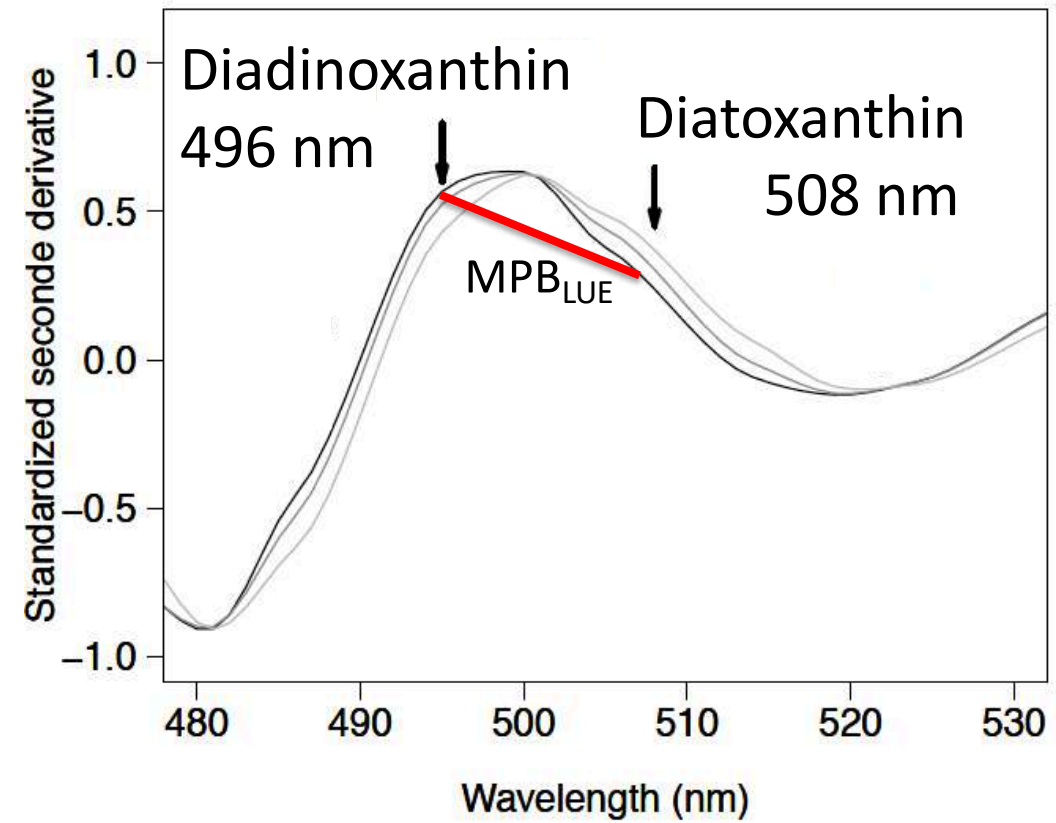


Estimation of the light use efficiency

- *Biremis lucens*



Xanthophyll cycle :

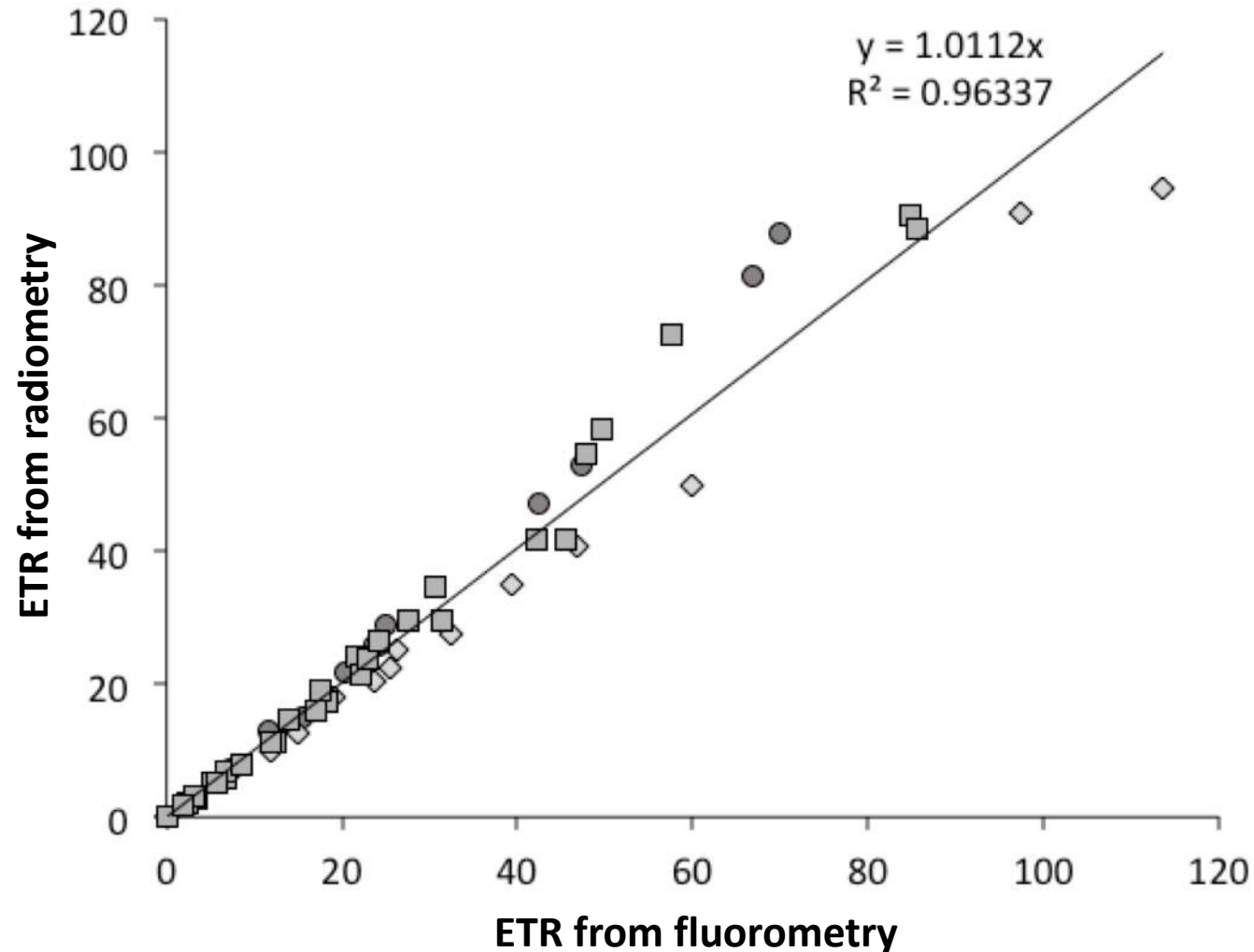


$$MPB_{LUE} = \delta\delta 496 / \delta\delta 508$$

Estimation of the light use efficiency AND primary production

- First step to the primary production estimation by spectroradiometry:

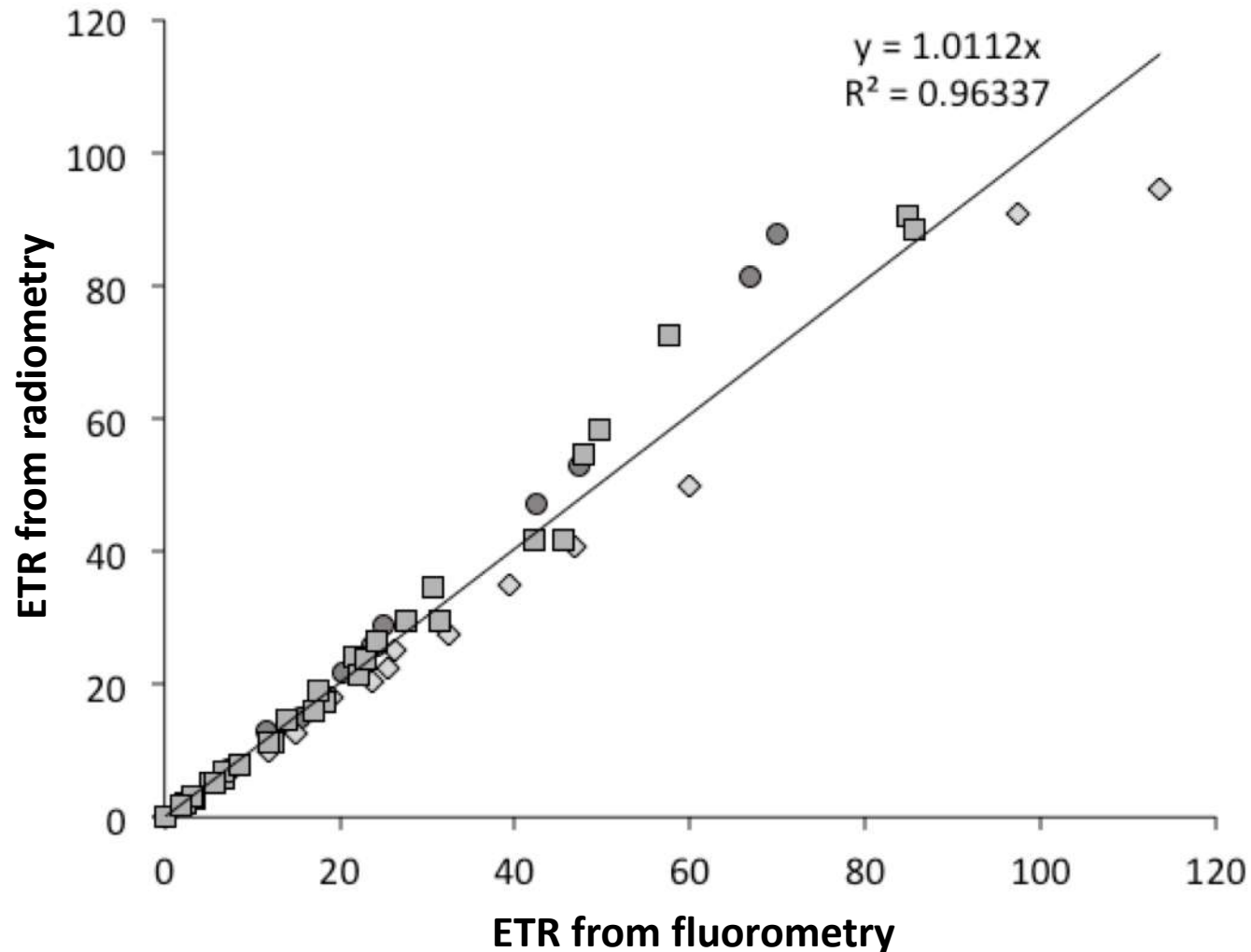
$$\text{Electron Transport Rate (ETR)} = \text{LUE} \times \alpha \times E$$



Estimation of the light use efficiency AND primary production

- First step to the primary production estimation by spectroradiometry:

$$\text{Electron Transport Rate (ETR)} = \text{LUE} \times \alpha \times E$$



What about CO₂ uptake ???



- Intertidal MPB

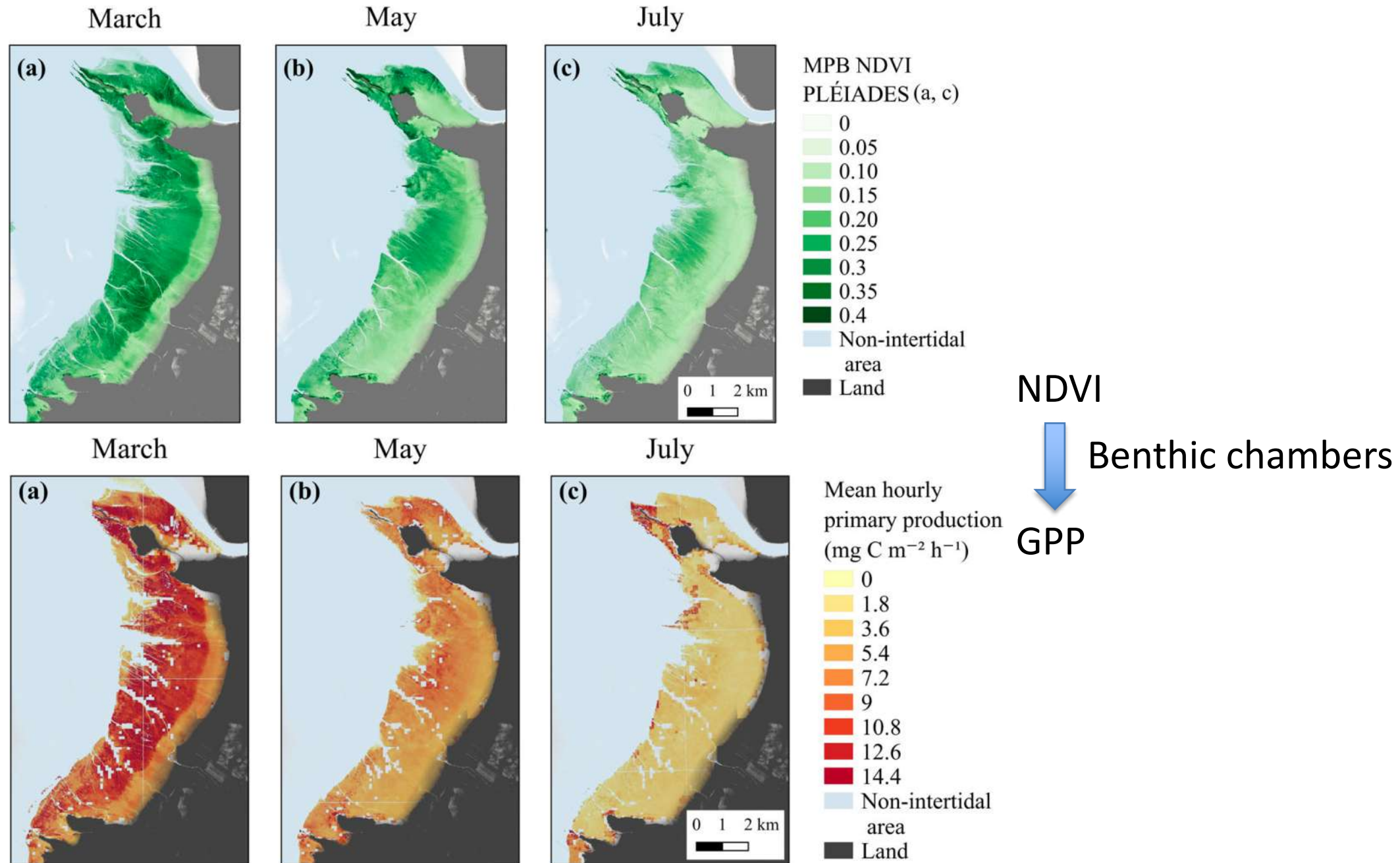


- Can be responsible for up to 17% of the ocean GPP although occupying only 0.03% of their surface
- In spite of their potentially high contribution to the Global Carbon Budget, their actual contribution remains unknown



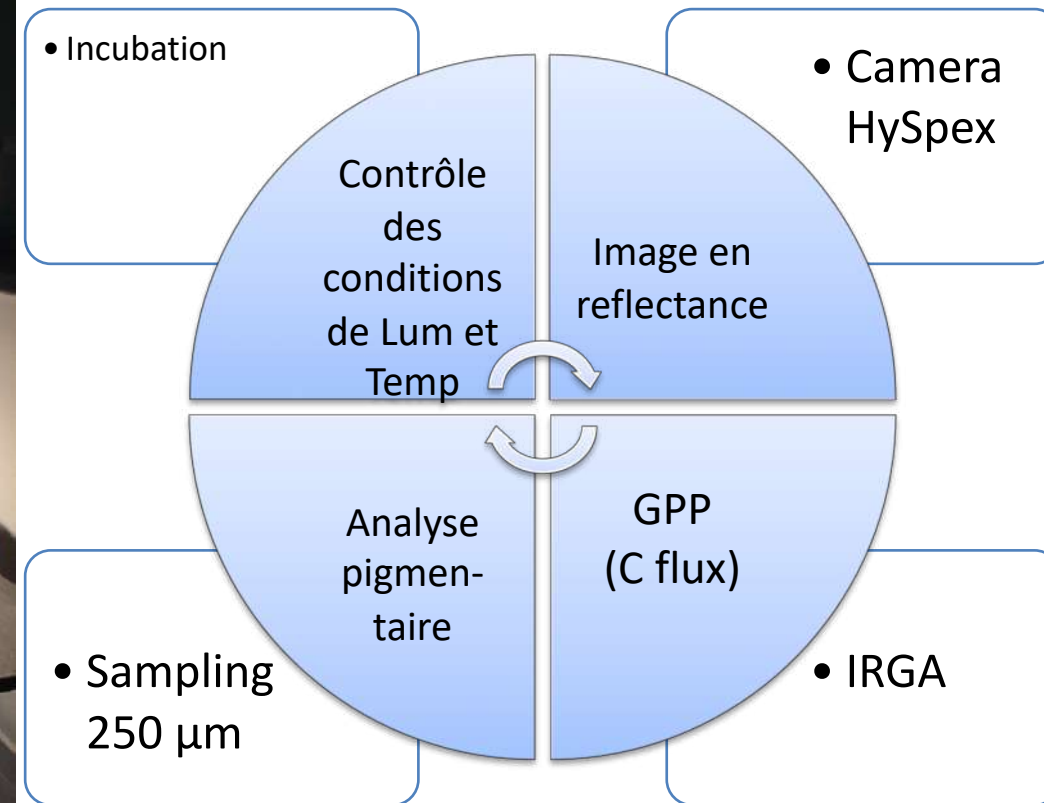
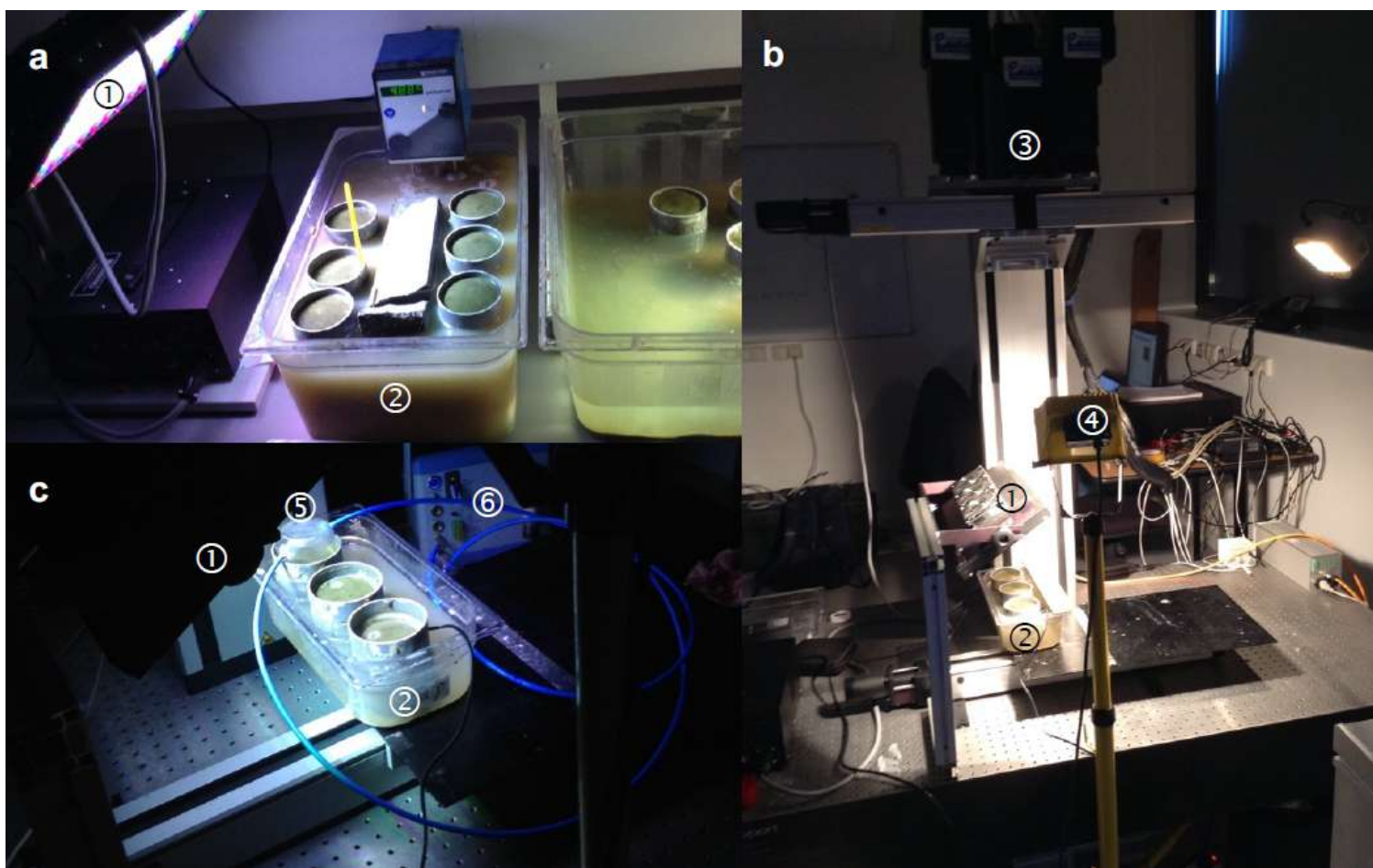
- OBJECTIVE : estimate the GPP by remote sensing

GPP mapping by multispectral remote-sensing



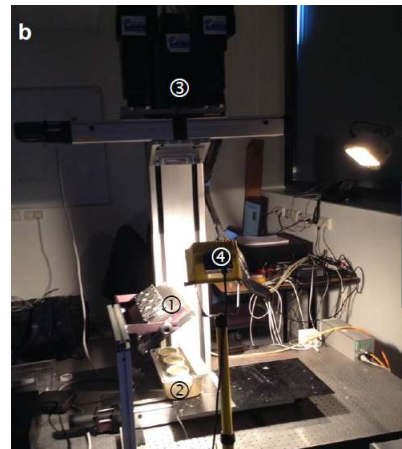
Etablissement des algorithmes en laboratoire (Thèse de Meng Zhang)

- Biofilms naturels (Avril et Octobre 2019, Janvier et Juillet 2020)
- Contrôle de la lumière et de la température : $0 - 2300 \mu\text{mol photon.m}^{-2}.\text{s}^{-1}$; 17°C , 25°C , 40°C
- Triplicats ; 2 heures d'incubation



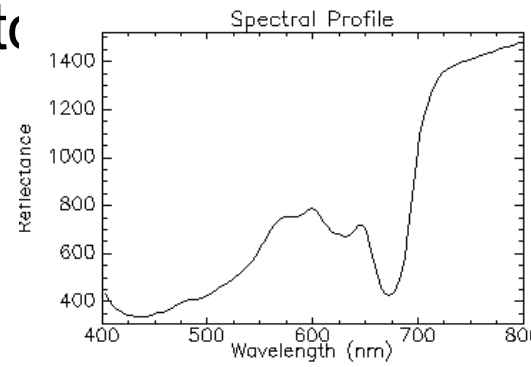
- Respiration mesurée pour chaque température, à l'obscurité

Etablissement des algorithmes en laboratoire

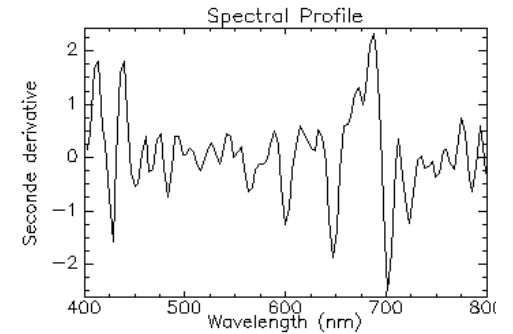
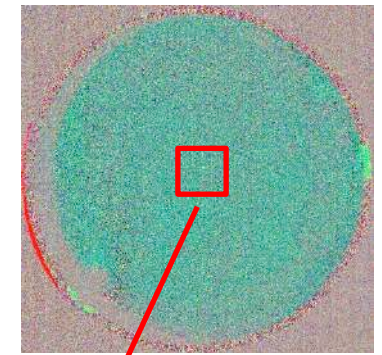


Process flowchart

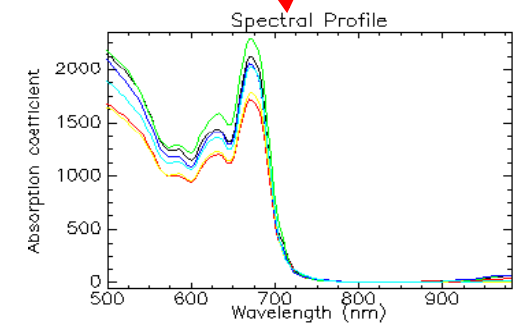
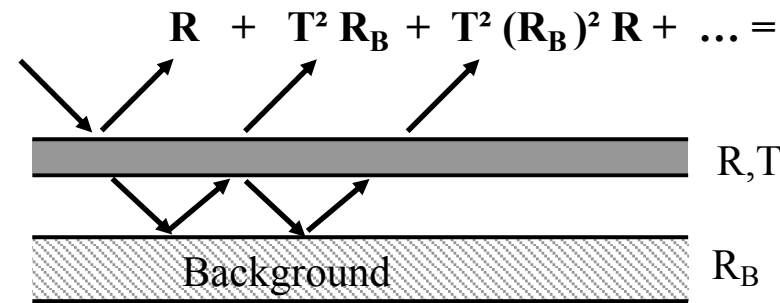
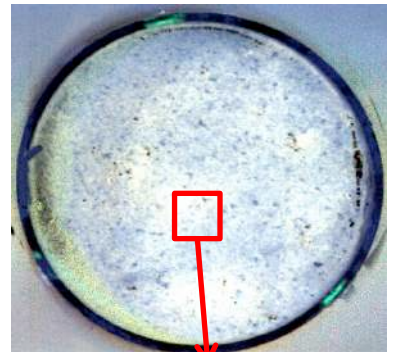
- Raw data
- Radiance
- raw Reflectance
- forward MNF
- inverse MNF
- Reflectance free of noise



Second derivative

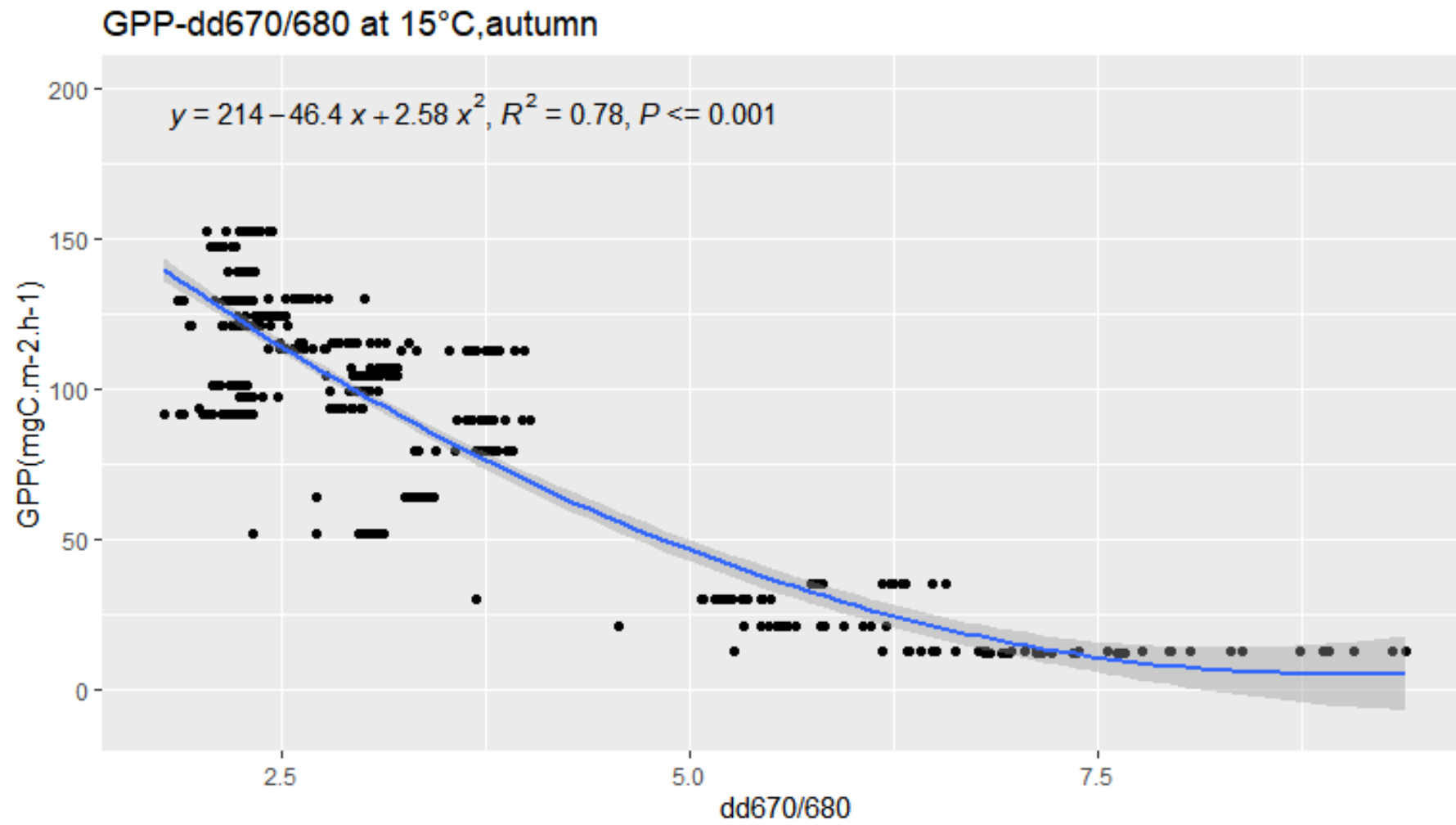


MPBOM



HySpex VNIR 1600
(400-1000nm)

Résultats préliminaires

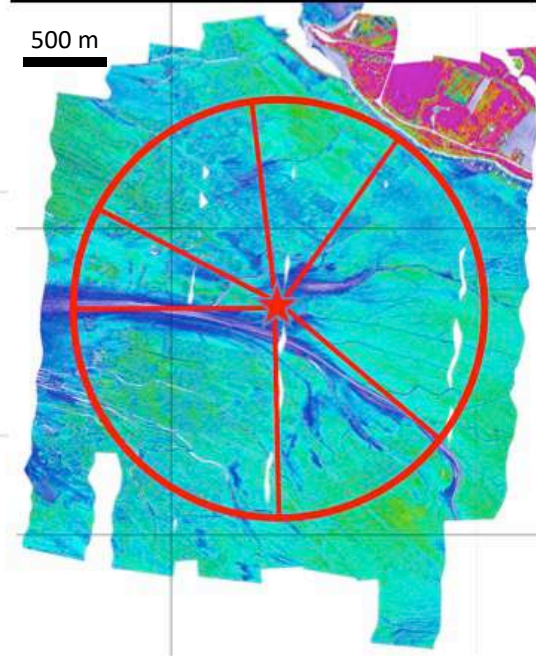
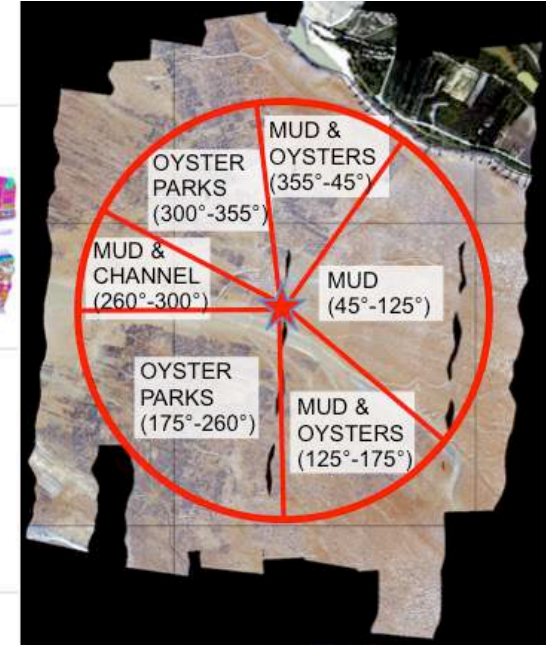
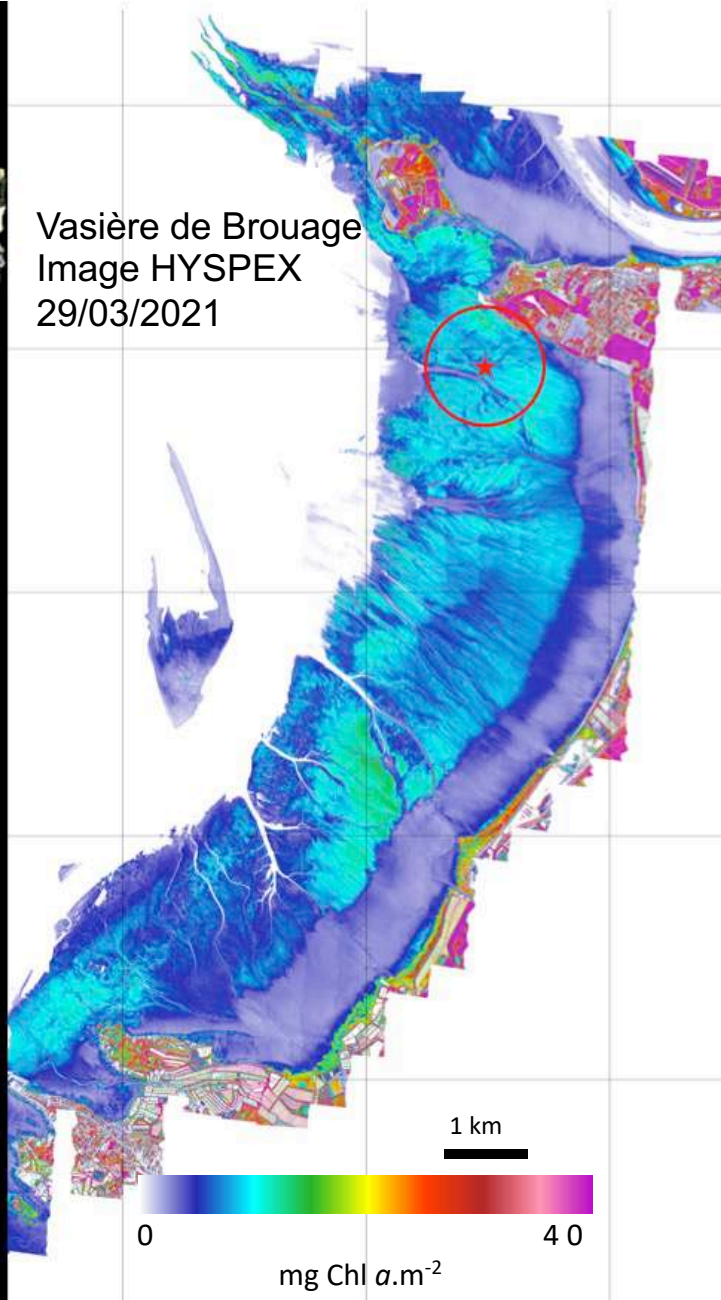




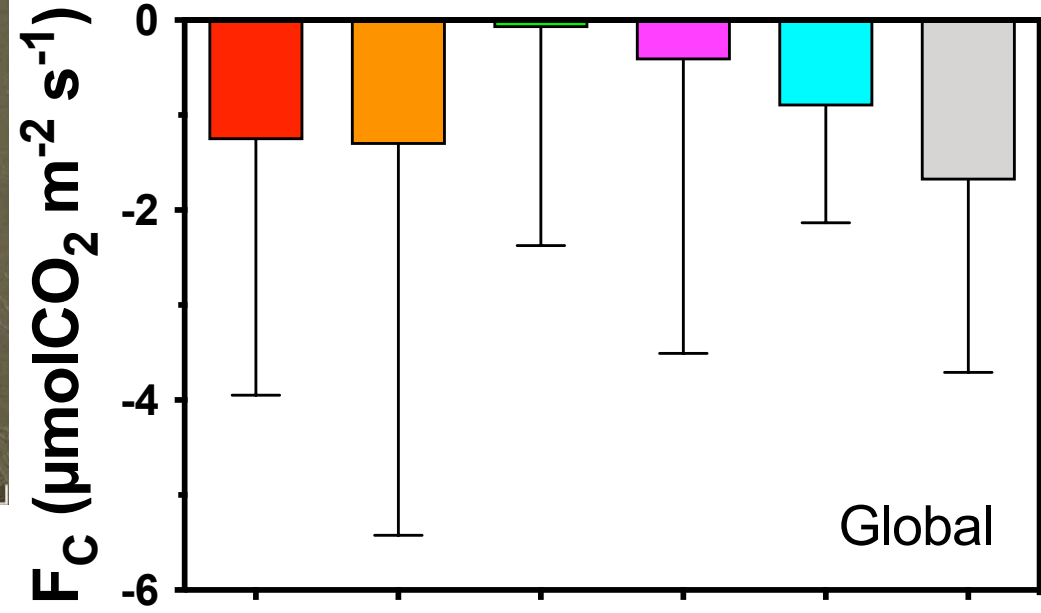
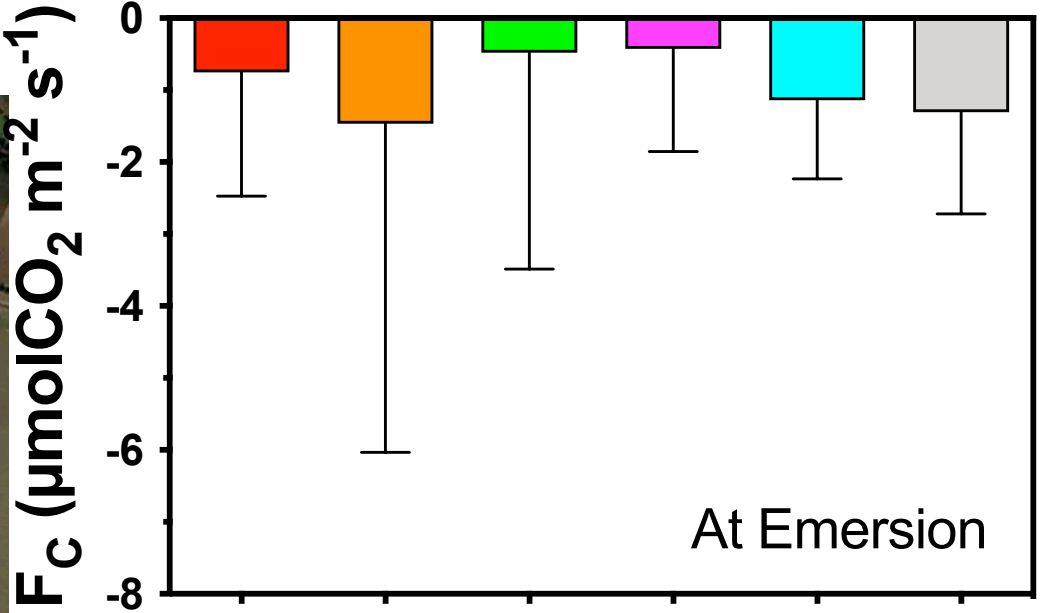
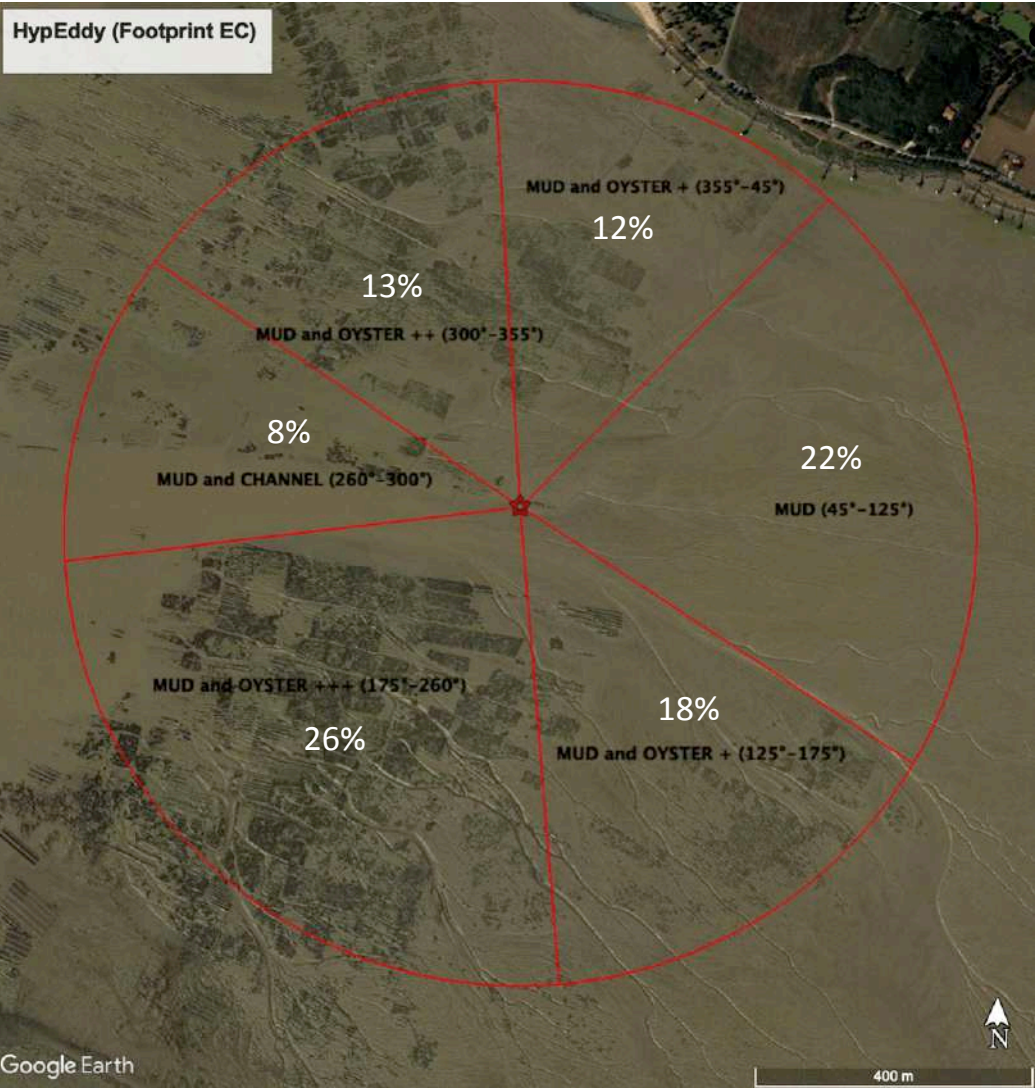
Flux de C par eddy-covariance atmosphérique et imagerie hyperspectrale



Vasière de Brouage
Image HYSPEX
29/03/2021



Résultats préliminaires



- M (45_125°)
- M&O+ (125_175°)
- M&O+++ (175_260°)
- M&C (260_300°)
- M&O++ (300_355°)
- M&O+ (355_45°)

HySpex
by neo

Mjolnir VS-620

	V-1240	S-620
Spectral range	400 – 1000 nm	970 – 2500 nm
Combined spectral range	400 – 2500	
Spatial pixels	1240	620
Combined spatial pixels	620	
Spectral channels and sampling	200 bands @ 3.0 nm	300 bands @ 5.1 nm
Combined spectral channels	490	
F-number	F1.8	F1.9
FOV	20°	20°
Combined FOV	20°	
Pixel FOV across/along	0.27/0.54 mrad	0.54/0.54 mrad
Combined Pixel FOV across/along	0.54/0.54 mrad	
Bit resolution (raw data)	12 bit	16 bit
Noise floor	2.3 e-	80 e-
Dynamic range	4400	10000
Peak SNR (at full resolution)	> 180	> 900
Max speed (at full resolution)	200 fps	100 fps
Power consumption*	50 W	
Dimensions (l-w-h)*	374 – 202 – 178 mm	
Weight*	~ 6 kg	

*Includes IMU/GPS and DAU – <6.5 kg including standard battery

APPLANIX APX-15/20 UAV



- Plateforme
- Autonomie
- Vitesse
- Altitude
- Fauchée
- Pixel dir. vol
- Temps intégration



Manuel Giraud et Guy Grunfelder



Avion CTLS 100 ULM classe 3

	UAV (drone)	ULM
Autonomie	30 minutes	4 (disque) à 7 heures
Vitesse	0,7 à 35 km/h	(80)150 à 200 km/h
Altitude	20 à 140 m	600 à 3500 m
Fauchée	6,5 à 46 m	215 à 1272 m
Pixel dir. vol	0,3 à 7,6 cm	33 à 189 cm
Temps intégration	3,6 à 756 ms	3,6 à 45 ms



Application du modèle

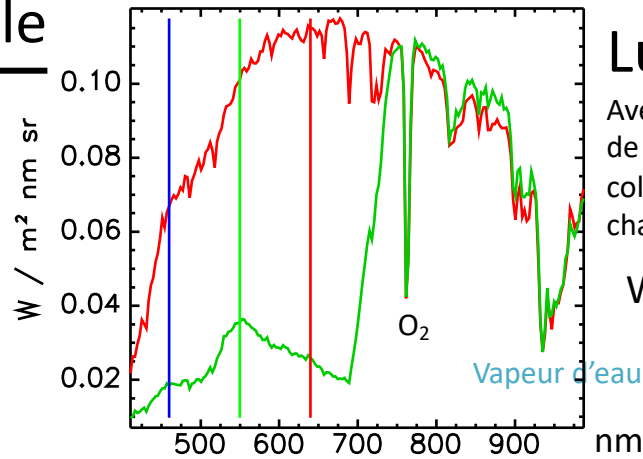
Une même visualisation pour 3 spectres



~369 hectares à 900m d'altitude

V1240 29 mars 2021

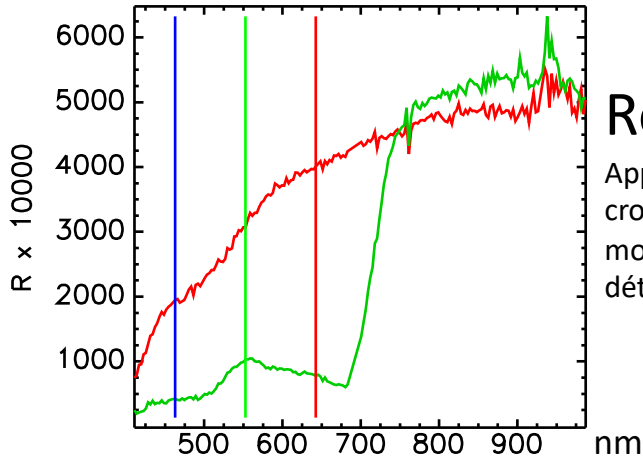
160 canaux
codés en entier



Luminance

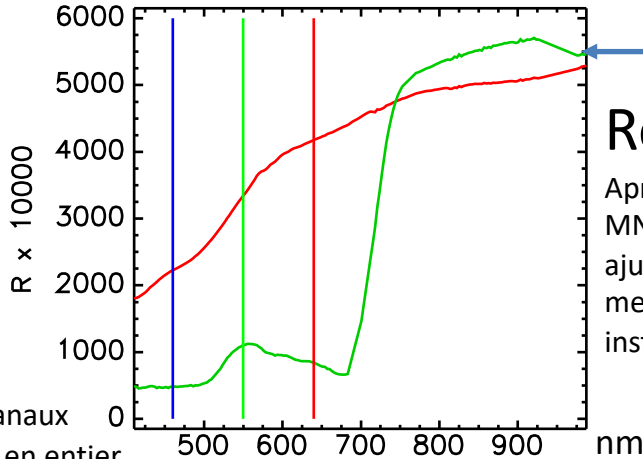
Avec mesure de l'épaisseur de l'atmosphère et de la colonne de vapeur d'eau en chaque pixel de l'image

$$W / \text{nm} \cdot \text{m}^2 \cdot \text{sr}$$



Réflectance

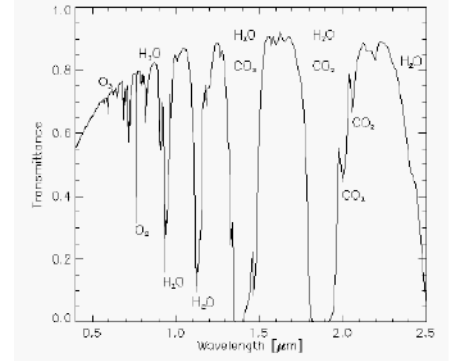
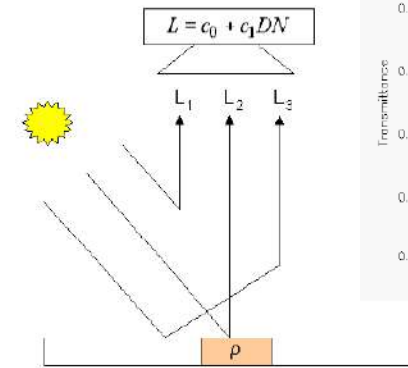
Apparente avec bruit croissant vers les extrémités moins sensibles des détecteurs



Réflectance

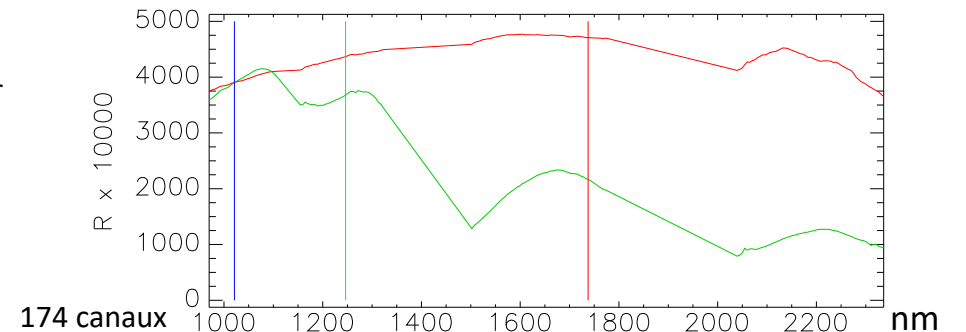
Après retrait du bruit par MNF inverse et par ajustement à un pixel de mesure du bruit instrumental résiduel

ATCOR 4 - for Airborne Remote Sensing Systems



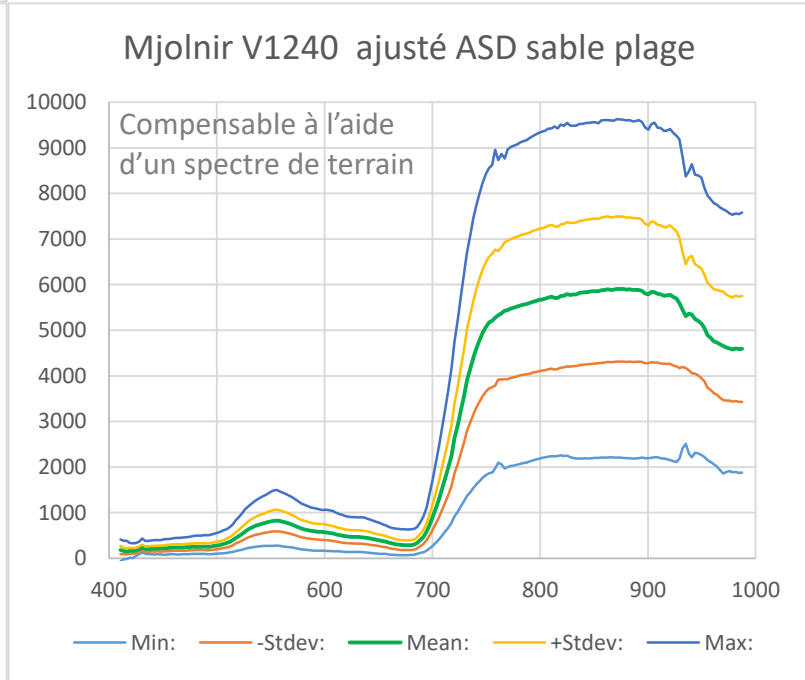
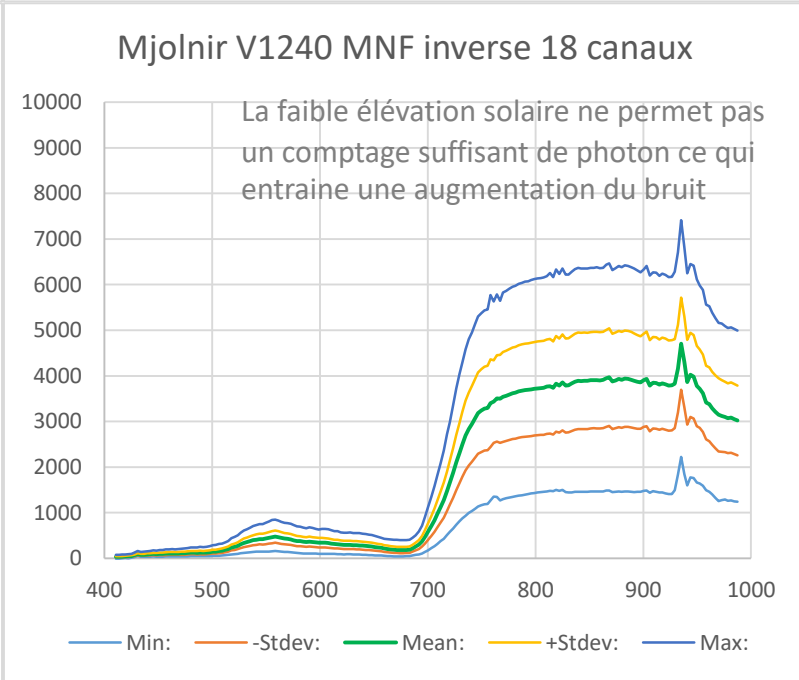
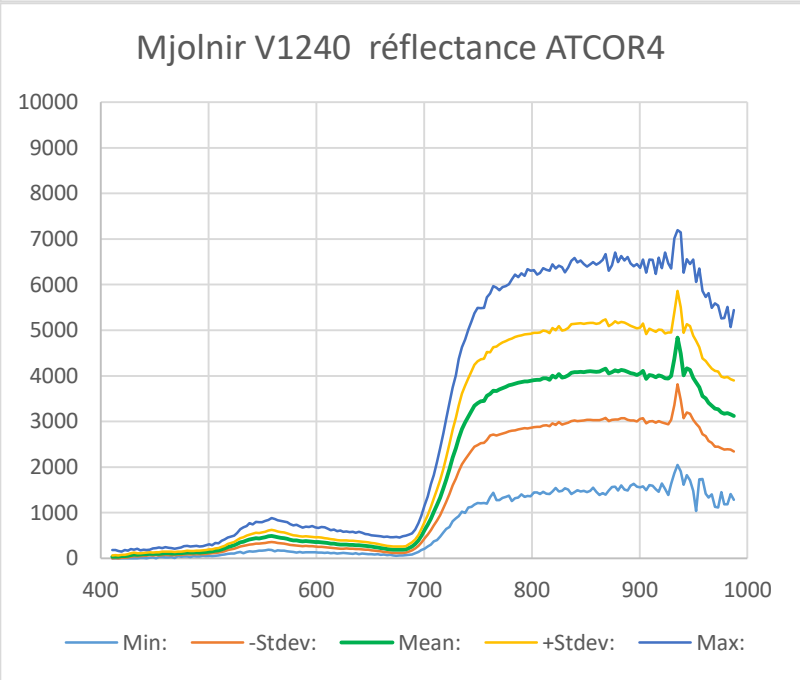
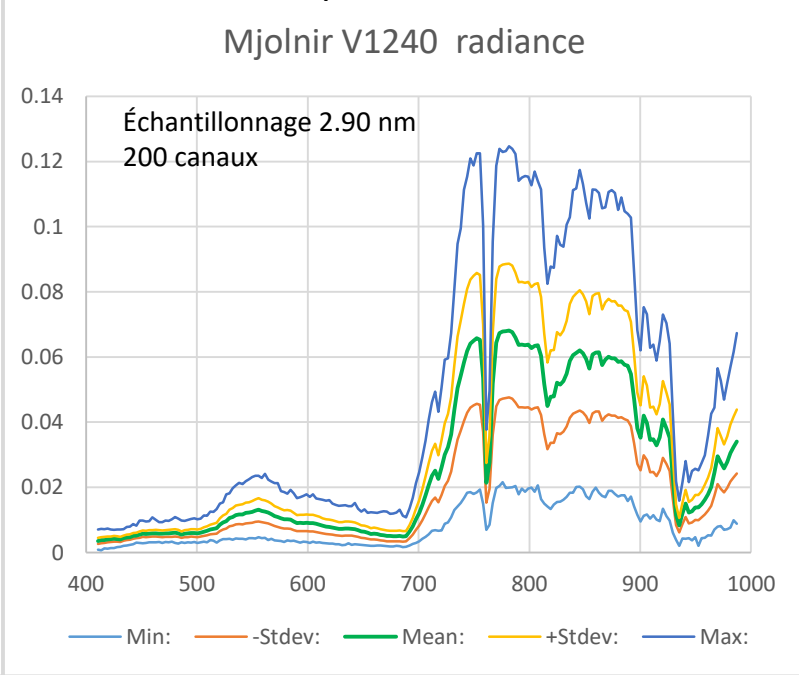
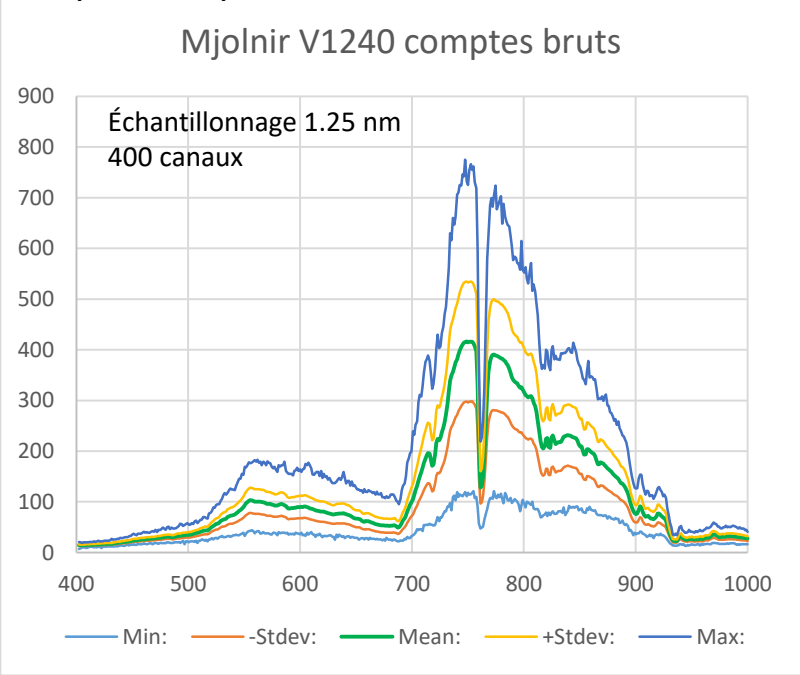
ReSe
APPLICATIONS

Figure 2.2: Schematic sketch of solar radiation components in flat terrain.
 L_1 : path radiance, L_2 : reflected radiance, L_3 : adjacency radiance.



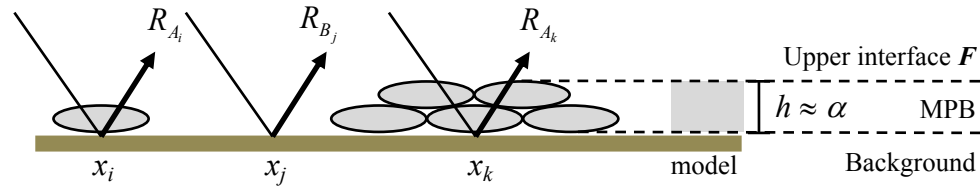
174 canaux

Exemple d'acquisition V1240 du 16 octobre 2020 avec chaine complète de traitement



Application du modèle à des supports naturels

L'estimation de la biomasse par un pic α à 673 nm est très dépendante du support (background B)

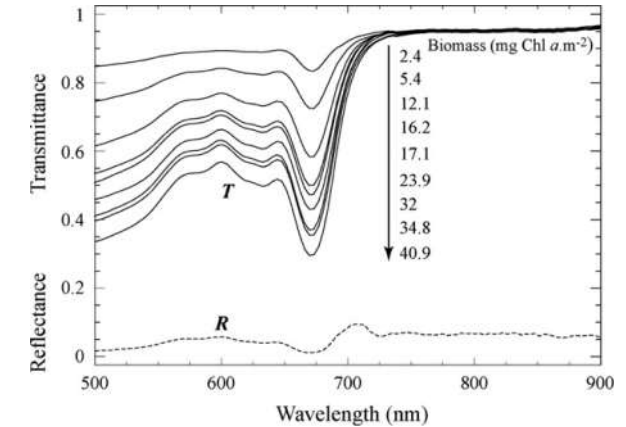


Calcul du coefficient d'absorption

$$\alpha = -\ln\left(\sqrt[6]{\frac{R_A}{R_B}}\right)$$

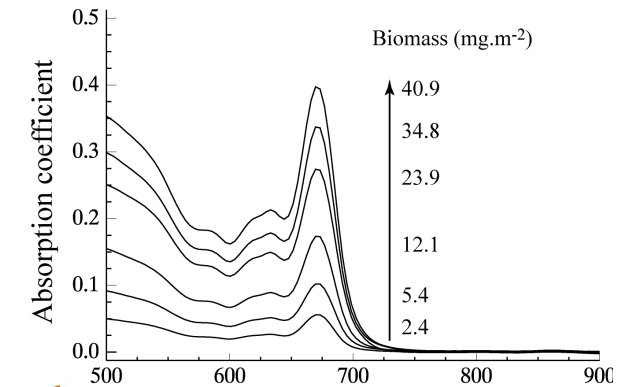
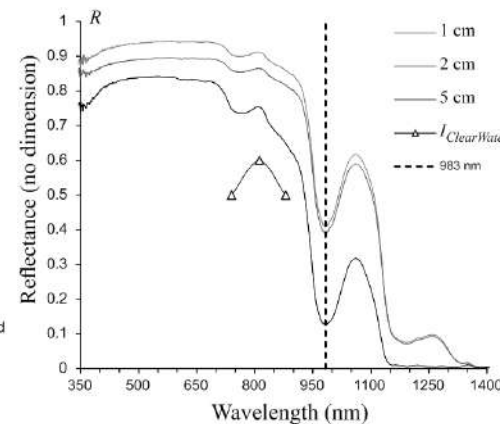
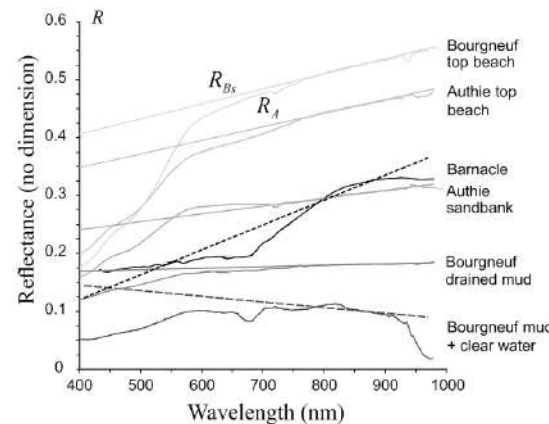
et réciproquement

$$\frac{R_A}{R_B} = \exp(-\alpha)^6$$



Estimation du support sur l'intervalle 750-920 nm de translucidité des biofilms par une droite

$$R_{Bj} = R_{Bi} \cdot \frac{\sum_{\lambda=750}^{920} R_{Bj}}{\sum_{\lambda=750}^{920} R_{Bi}}$$



Estimation complète du support

Séparer somme des n réflectances des supports opaques

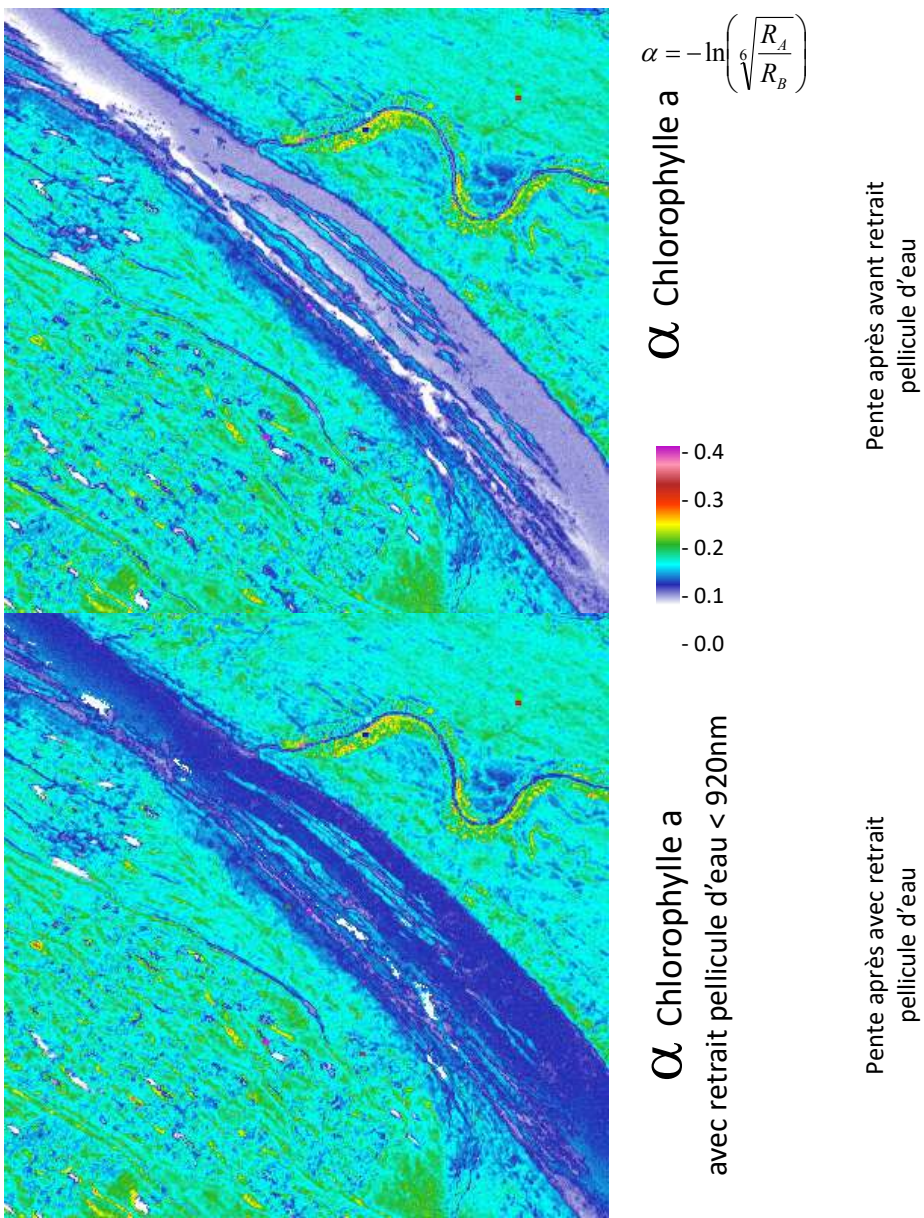
$$R_{Amn} = \left(\sum_{j=1}^n R_{Bj} \right) \cdot \exp\left(-\sum_{i=1}^m \alpha_i\right)^6$$

du produit (somme de log) des m coefficients d'absorption des biofilms $\pm$ eau claire de surface

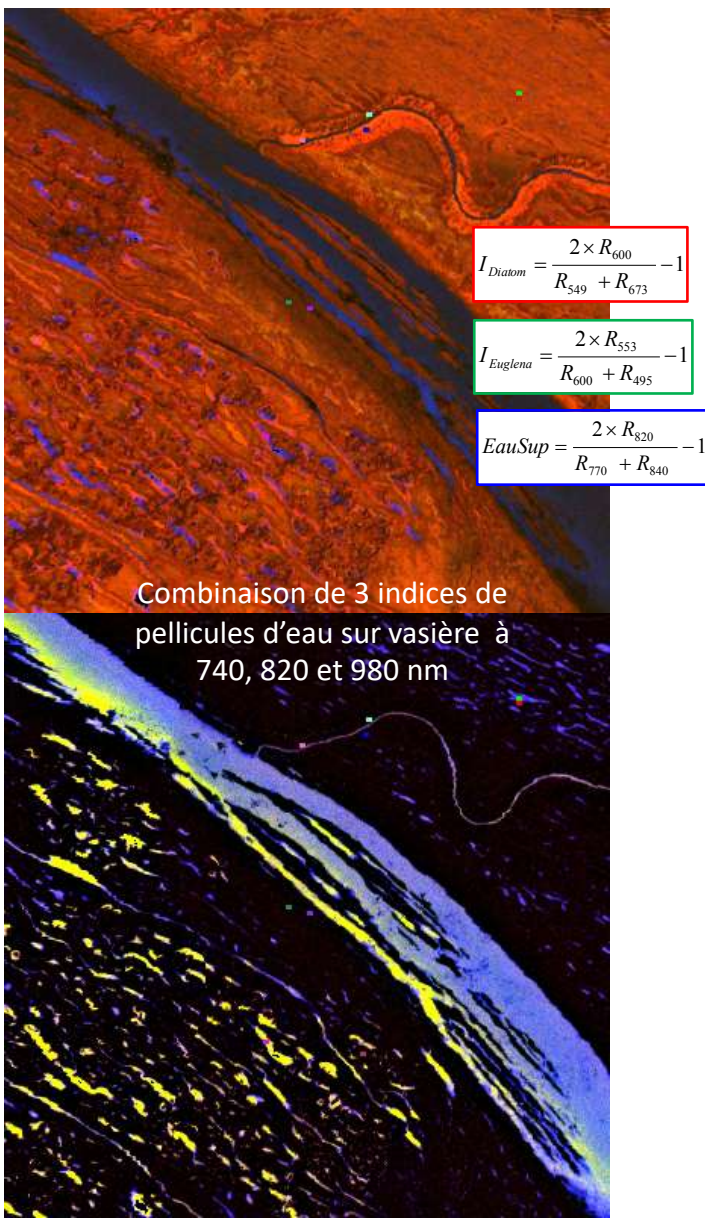
➤ Identification du support de 750 à 2450 nm en projet pour 2023

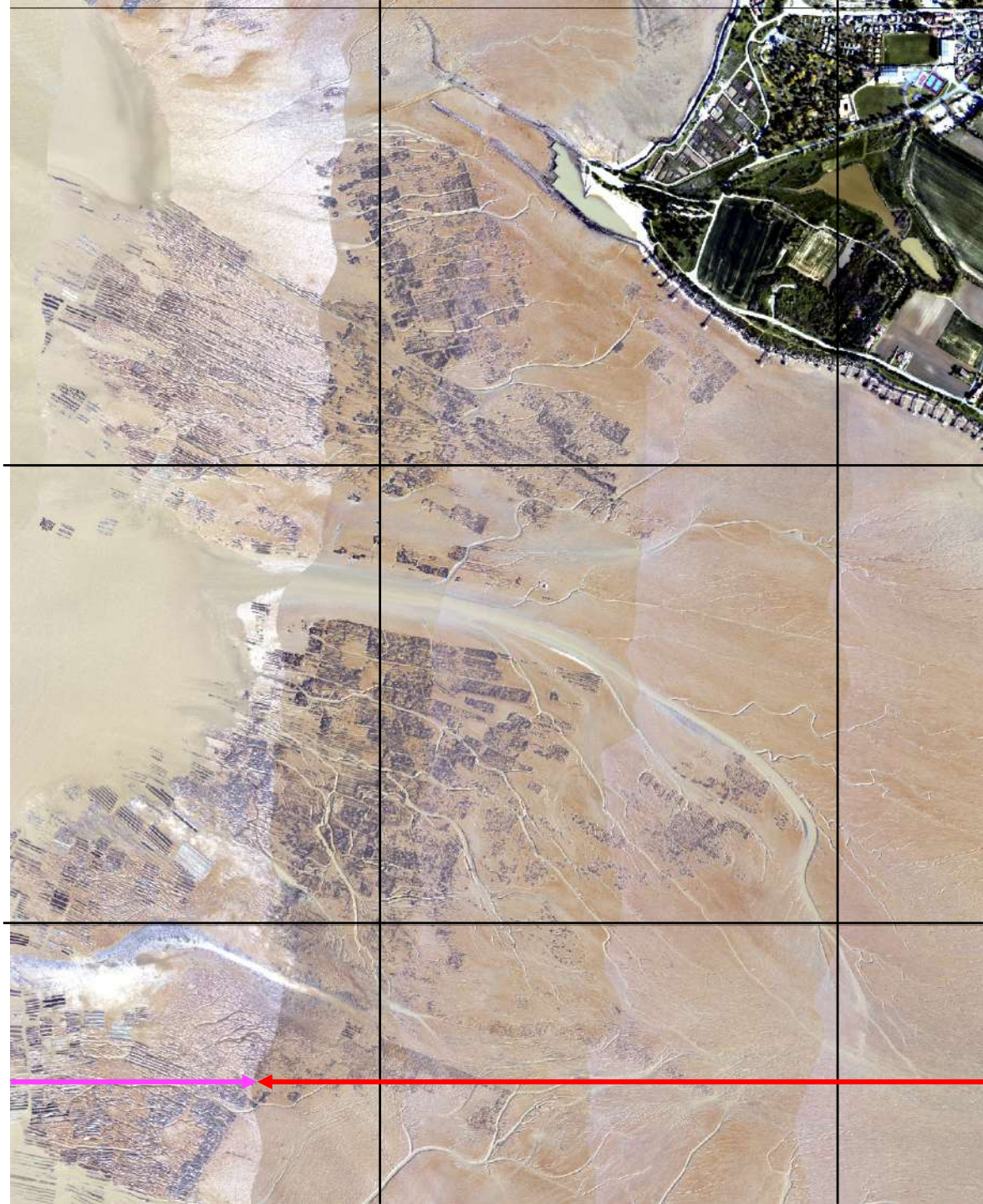
Application du modèle à des supports naturels

Estimation du support sur l'intervalle 750-920 nm de translucidité des biofilms par une droite



Sélection du MPBT par combinaison d'indices

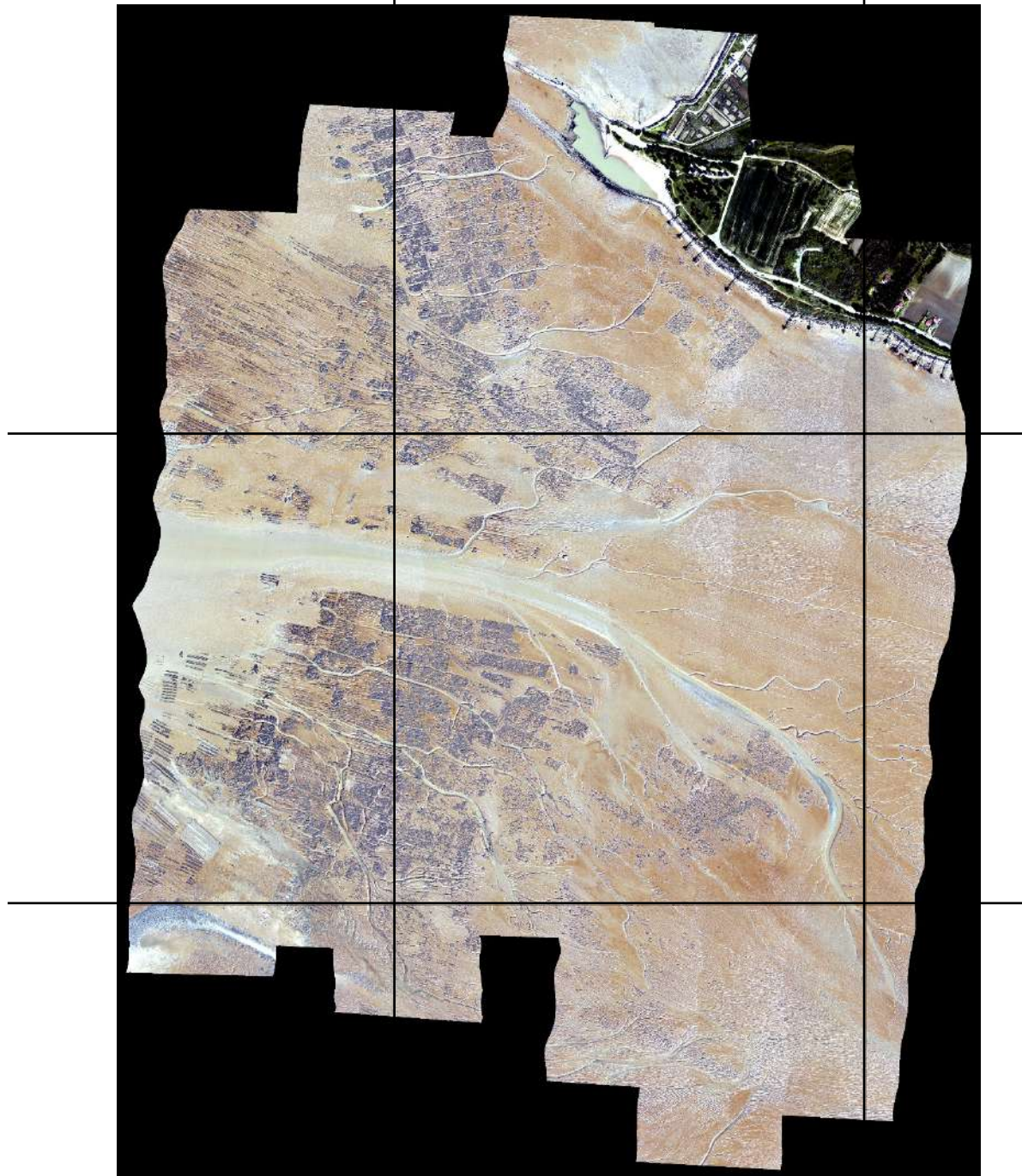




Réflectance à 1800m (1m / pixel)

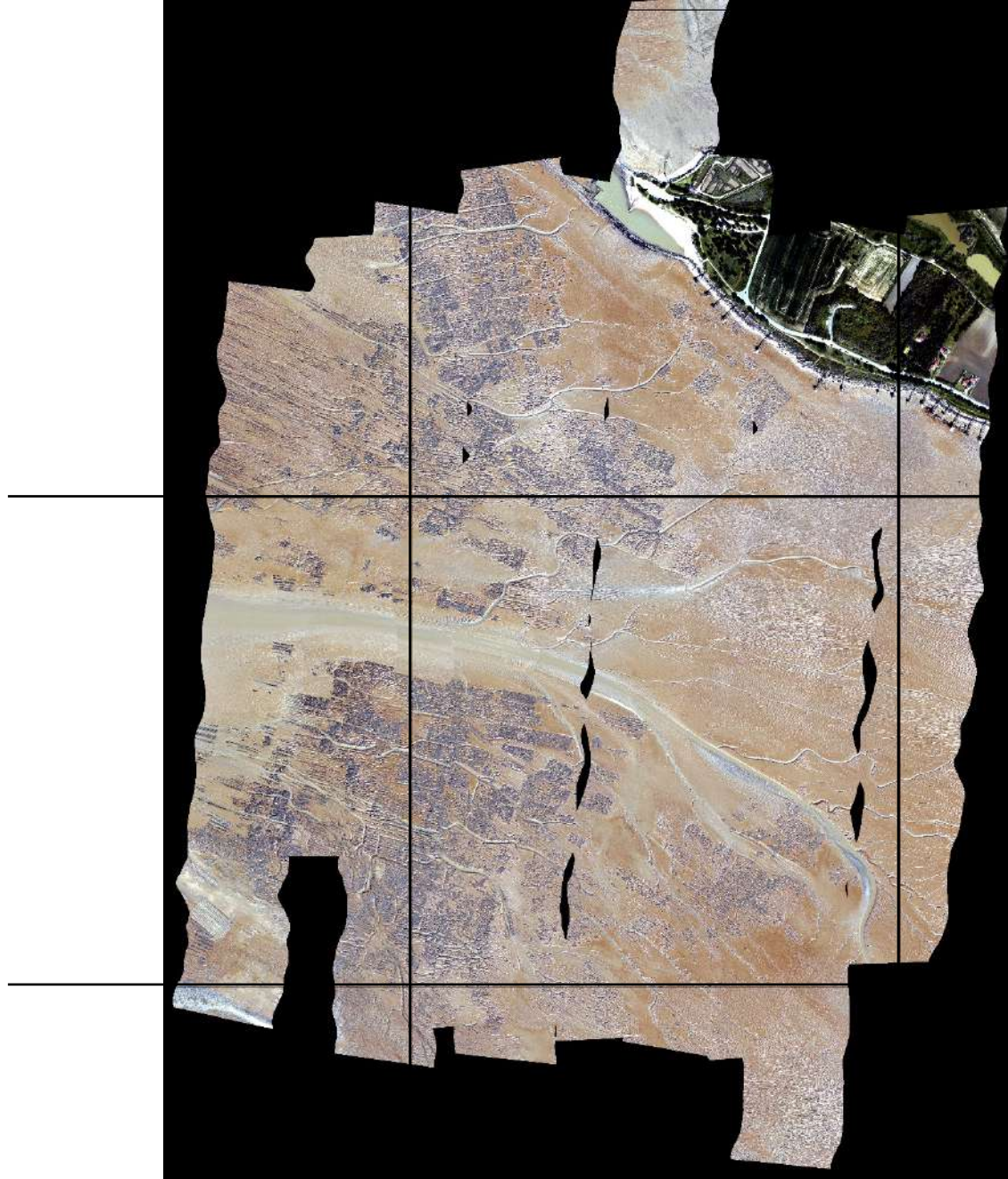
Lignes faites après 900 et 600m
En fin de marée

Lignes faites avant 900 et 600m
En début de marée



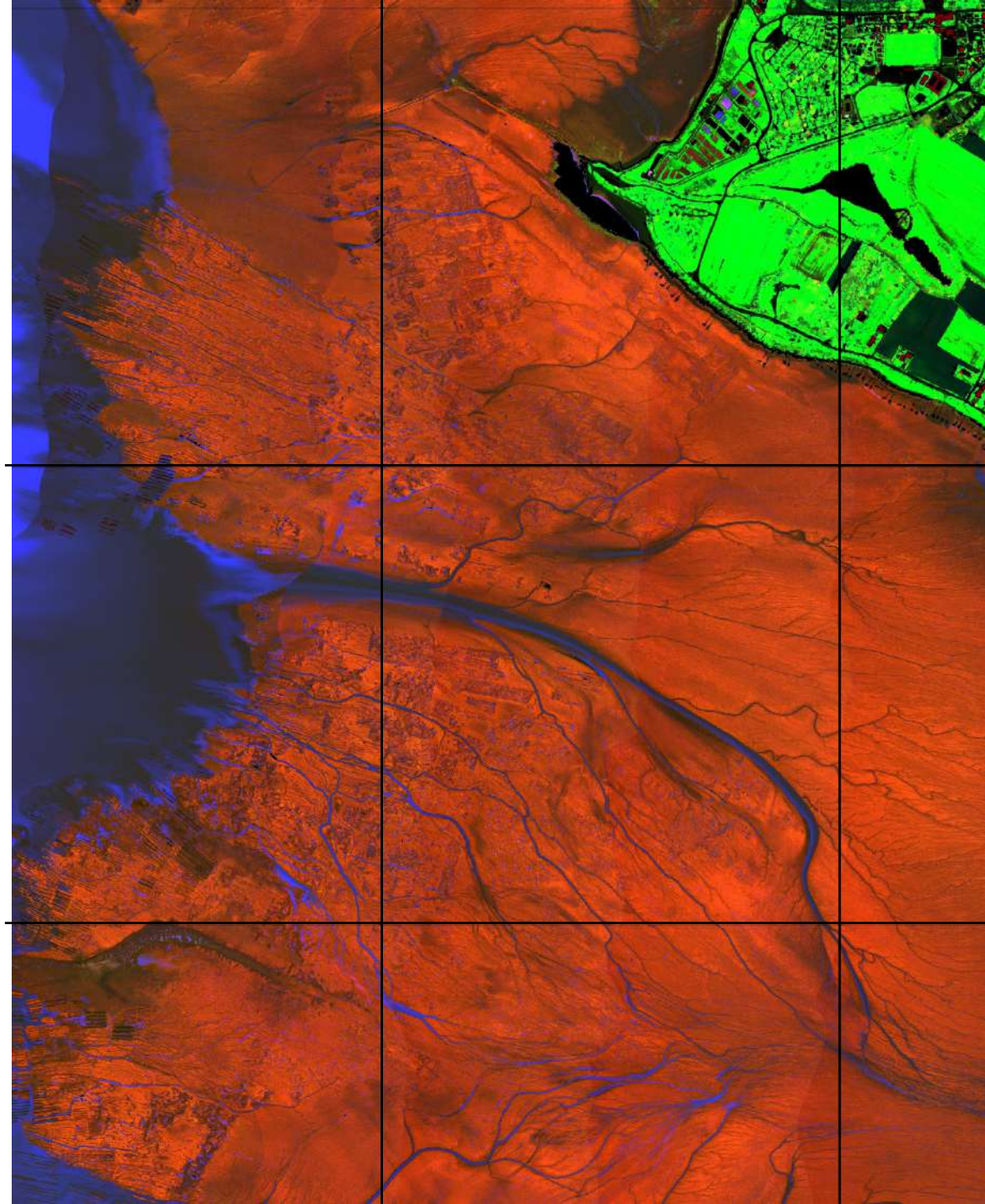
Réflectance à 900m (0.5m / pixel)

Acquise après 1800m mais avant 600m



Réflectance à 600m (0.3m / pixel)

Acquise après 1800m et 900m

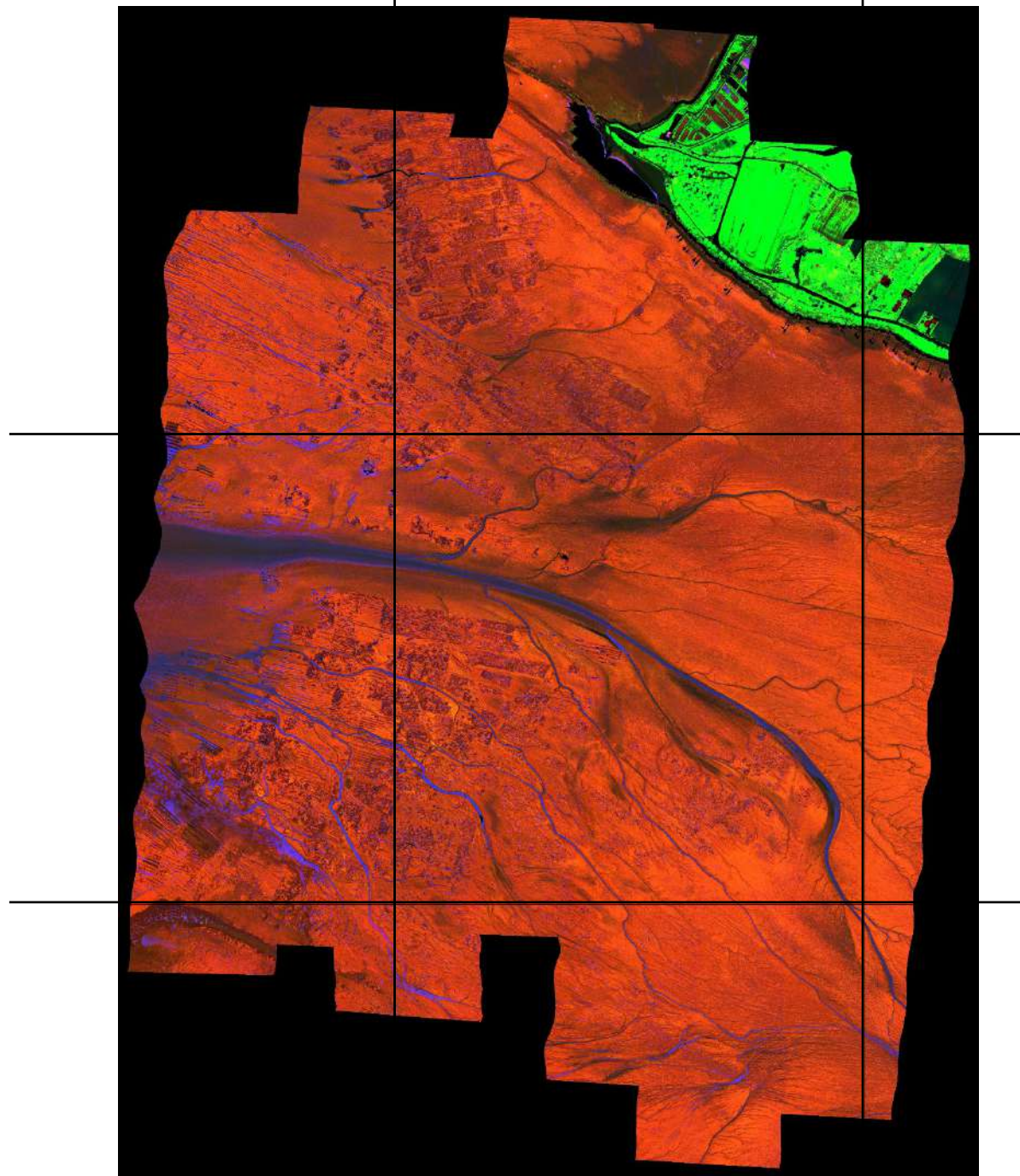


$$I_{Diatom} = \frac{2 \times R_{600}}{R_{549} + R_{673}} - 1$$

$$I_{Euglena} = \frac{2 \times R_{553}}{R_{600} + R_{495}} - 1$$

$$EauSup = \frac{2 \times R_{820}}{R_{770} + R_{840}} - 1$$

Réflectance à 1800m (1m / pixel)

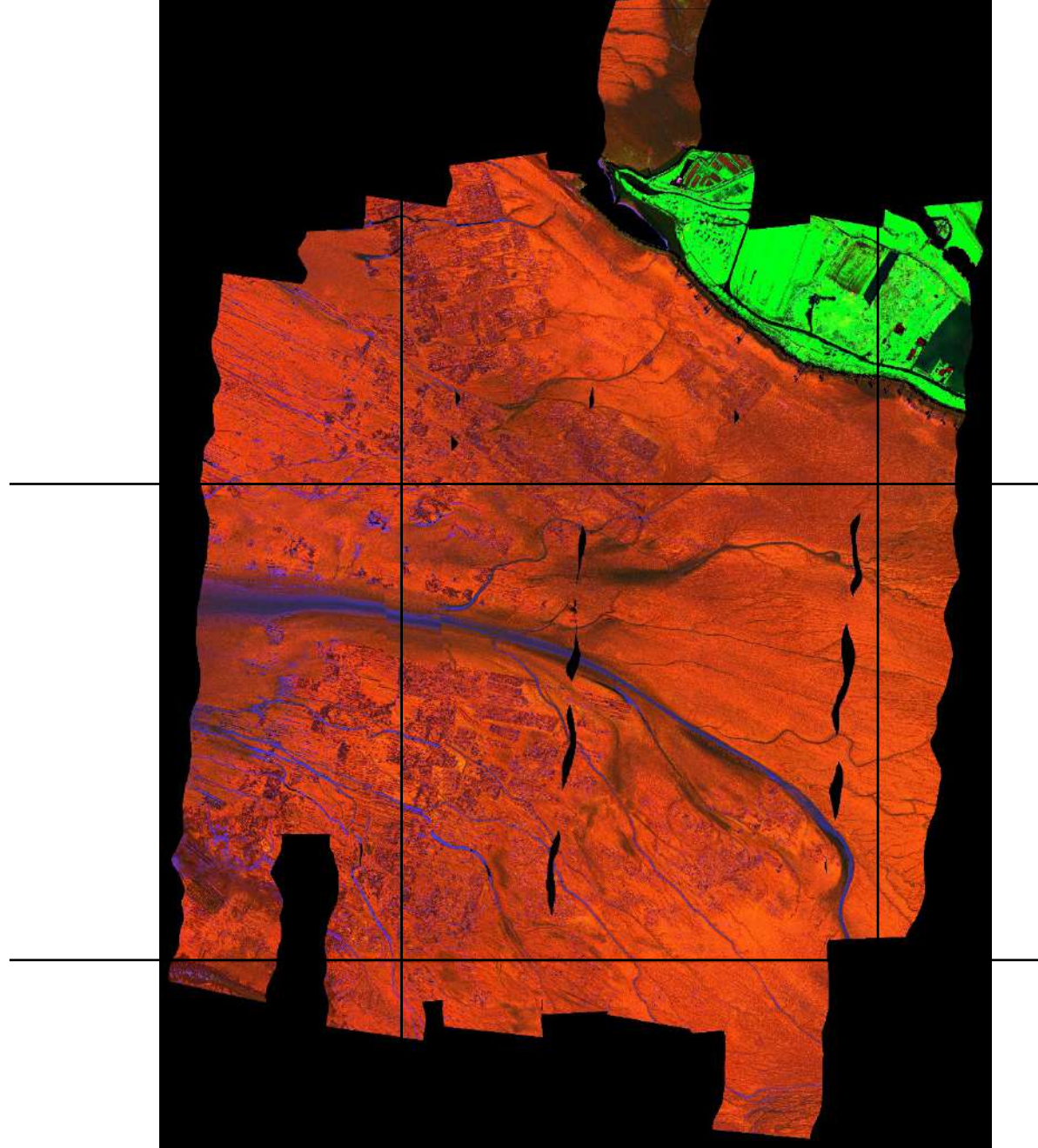


$$I_{Diatom} = \frac{2 \times R_{600}}{R_{549} + R_{673}} - 1$$

$$I_{Euglena} = \frac{2 \times R_{553}}{R_{600} + R_{495}} - 1$$

$$EauSup = \frac{2 \times R_{820}}{R_{770} + R_{840}} - 1$$

Réflectance à 900m (0.5m / pixel)

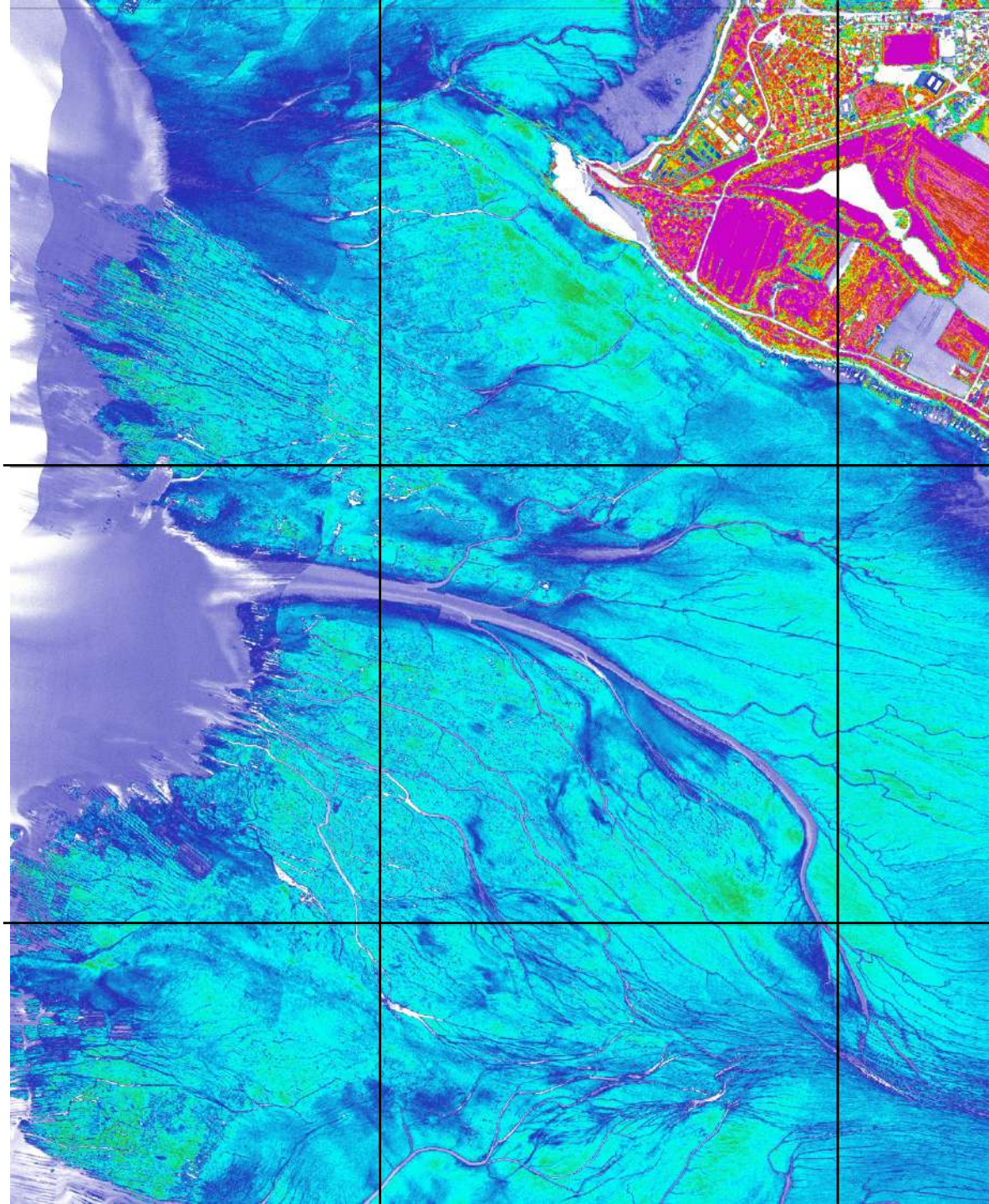


$$I_{Diatom} = \frac{2 \times R_{600}}{R_{549} + R_{673}} - 1$$

$$I_{Euglena} = \frac{2 \times R_{553}}{R_{600} + R_{495}} - 1$$

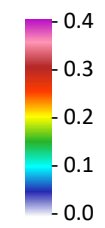
$$EauSup = \frac{2 \times R_{820}}{R_{770} + R_{840}} - 1$$

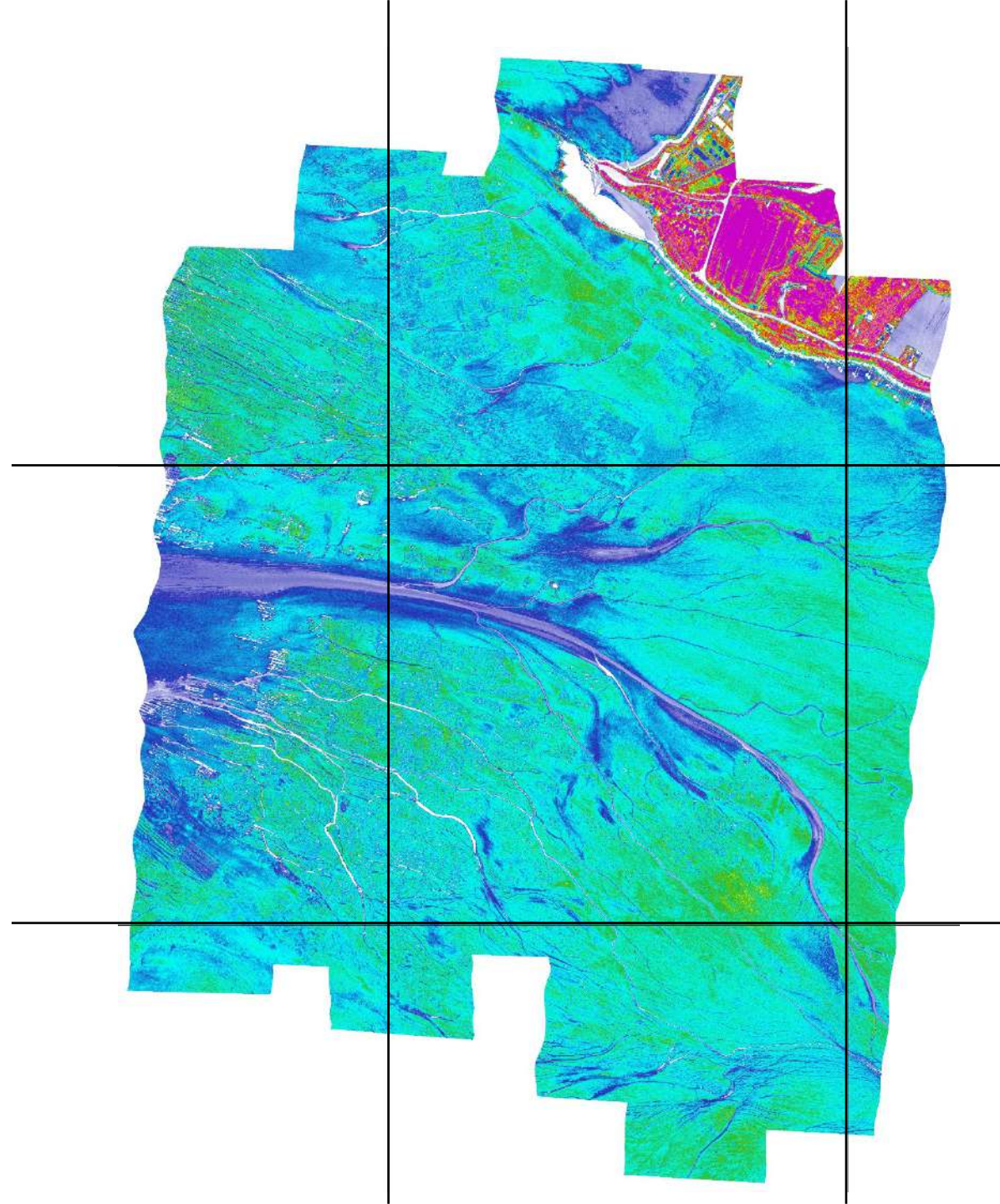
Réflectance à 600m (0.3m / pixel)



$$\alpha = -\ln\left(\sqrt[6]{\frac{R_A}{R_B}}\right)$$

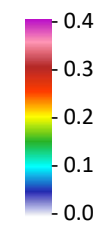
α à 1800m (1m / pixel)

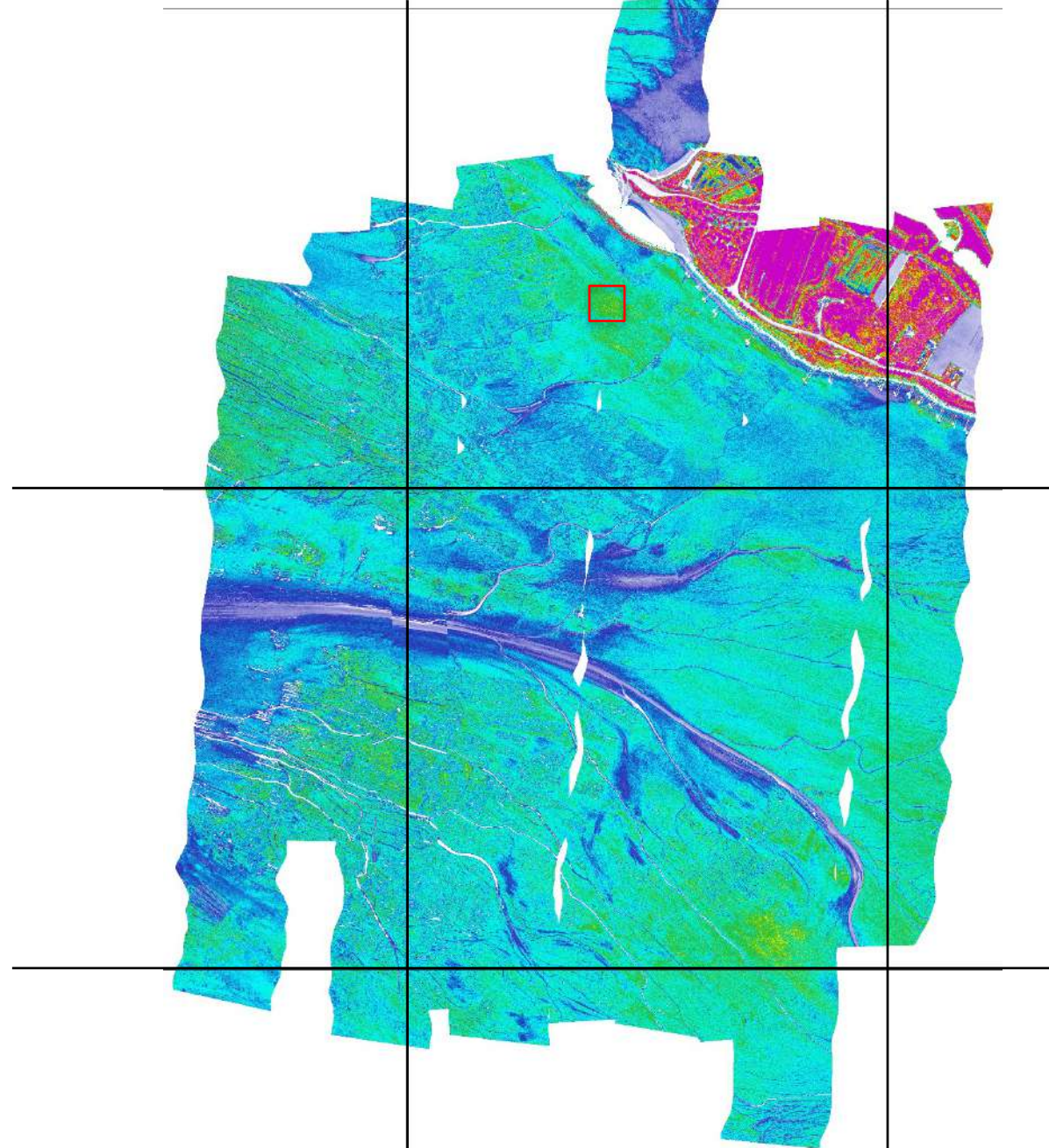




$$\alpha = -\ln\left(\sqrt[6]{\frac{R_A}{R_B}}\right)$$

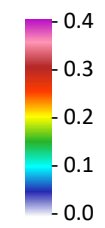
α à 900m (0.5m / pixel)





$$\alpha = -\ln\left(\sqrt[6]{\frac{R_A}{R_B}}\right)$$

α à 600m (0.3m / pixel)

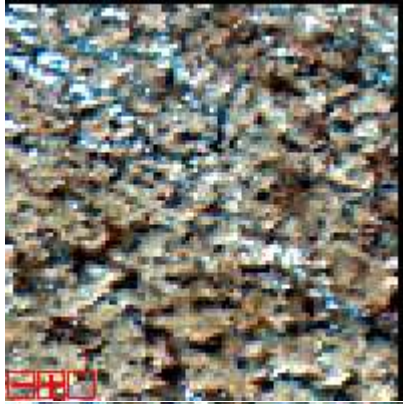


Simulation d'un pixel de 30 x 30 m vu à 600, 900 et 1800 m d'altitude

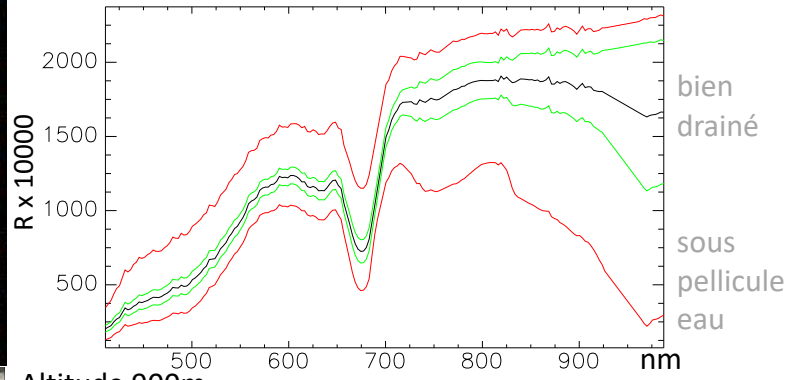
Reflectance R

Coefficient d'absorption α

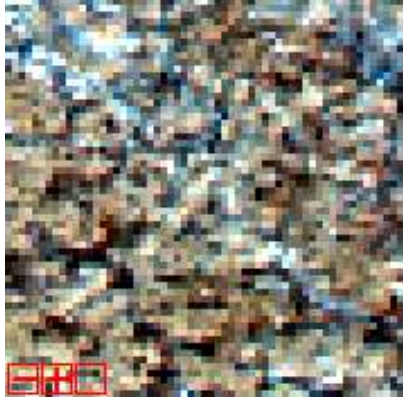
98 x 99
0.3 m



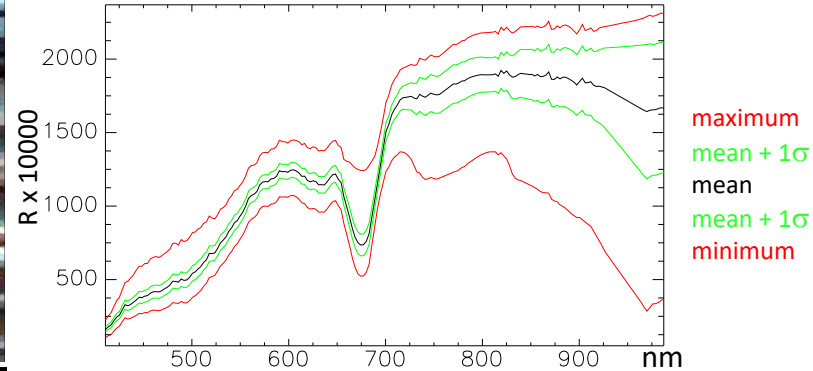
Altitude 600m



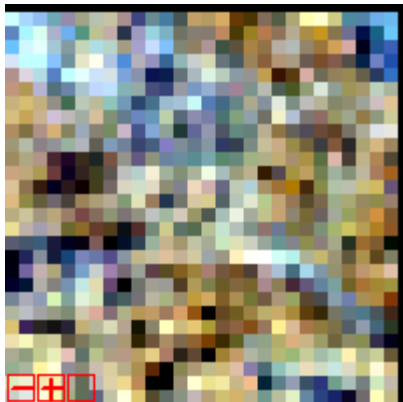
59 x 59
0.5 m



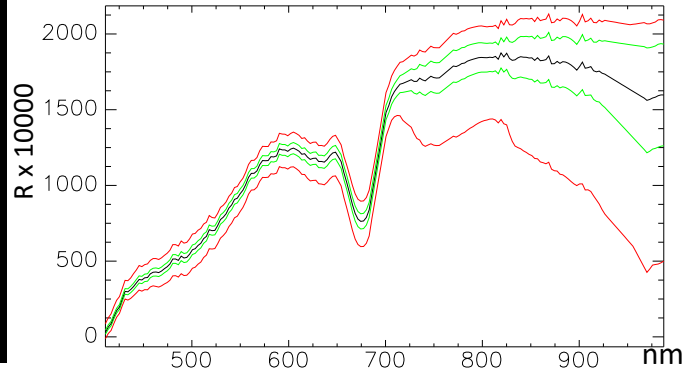
Altitude 900m



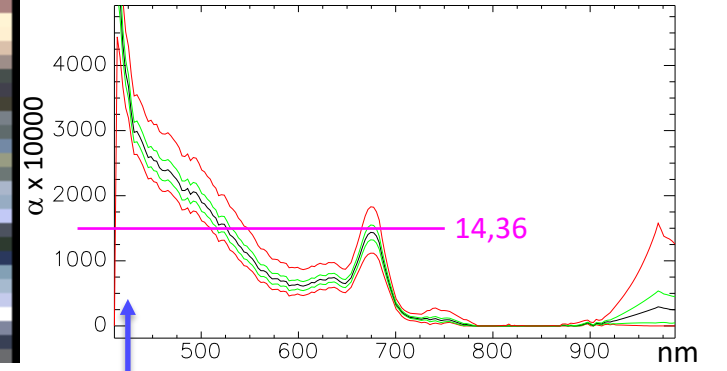
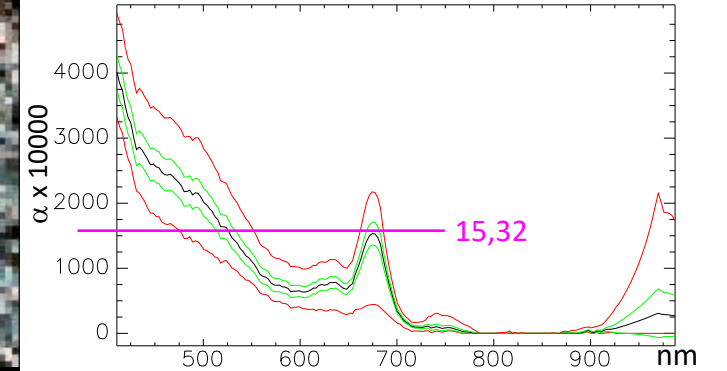
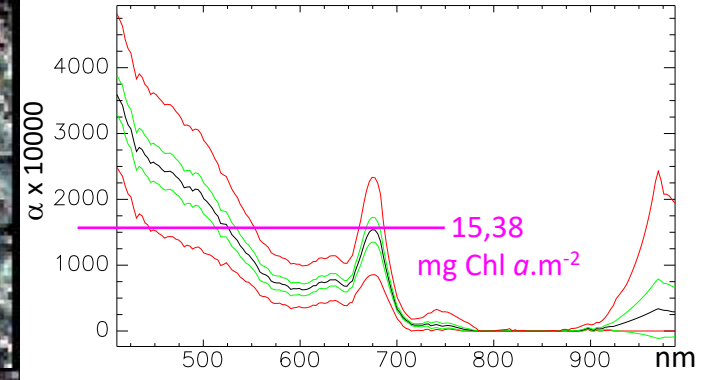
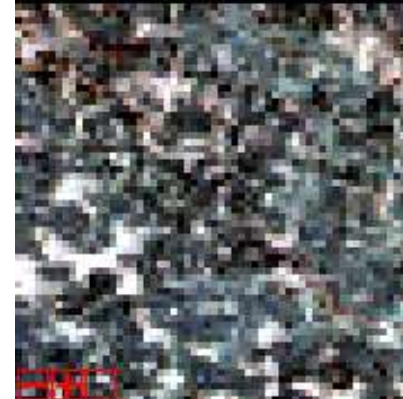
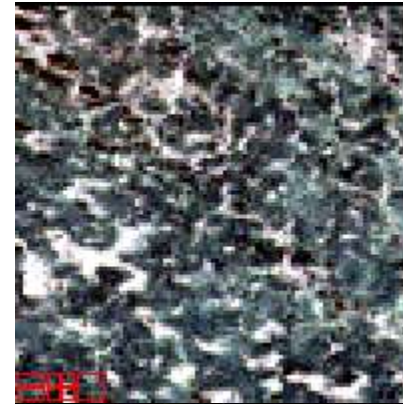
29 x 29
1.0 m



Altitude 1800m



Domaine visible (r,v,b)



Diffusion croissante de l'atmosphère dans le bleu

= Sous estimation de 7% à 1800m