

Importance de l'étalonnage de la chaîne de traitement : application à la télédétection des propriétés optiques de biofilms littoraux par ULM.

Patrick LAUNEAU^{1*}, Vona MELEDER², Manuel GIRAUD¹, Farzaneh KAZEMIPOUR³

^{1*}Nantes Université, CNRS, UMR 6112, Laboratoire de Planétologie et Géosciences, F-44000 Nantes,
patrick.launeau@univ-nantes.fr, manuel.giraud@univ-nantes.fr

²Nantes Université, Institut des Substances et Organismes de la Mer, ISOMer, UR 2160, F-44000
Nantes, vona.meleder@univ-nantes.fr

³ UMR MISTEA-INRAe, 2 place Pierre Viala, 34060, Montpellier, farzaneh.kazemipour@inrae.fr

Matériel

But :

Mesurer l'efficacité d'utilisation de la lumière (LUE) à partir de l'absorption de Xanthophylles pour en déduire une production primaire de vase

Rappel :

Expérimentation en laboratoire
Modèle Optique du MicroPhytoBenthos
Limitation par variabilité des supports

Chaîne de traitement :

Sensibilité du capteur
Calibration usine
Correction atmosphérique
Retrait du bruit
Ajustement du gain

Application à 3 échelles (pixels de 30 cm, 50 cm et 100 cm) :

Réflectance et indices de sélection d'un biofilm
Coefficient d'absorption
Dérivée seconde

Conclusion – contribution au projet Horizon Europe REWRITE

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**



CPER 2014-2020 R16
Mer - Environnement - ville et territoires
Opération: **Suivi et Surveillance de l'Environnement en Pays de la Loire (S2E-PdL)**



Plateforme
Autonomie
Vitesse
Altitude
Fauchée
Pixel dir. vol
Temps intégration

UAV (drone)
30 minutes
0,7 à 35 km/h
20 à 140 m
6,5 à 46 m
0,3 à 7,6 cm
3,6 à 756 ms

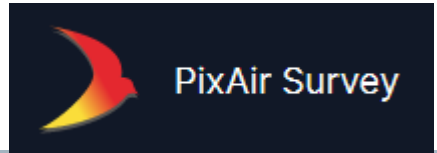
ULM ou AVION
4 (disque) à 7 heures
(80)150 à **240 km/h**
600 à **3500 m**
215 à **1272 m**
33 à 189 cm
3,6 à 45 ms



PIMA



Avion CTLS 100 ULM classe 3

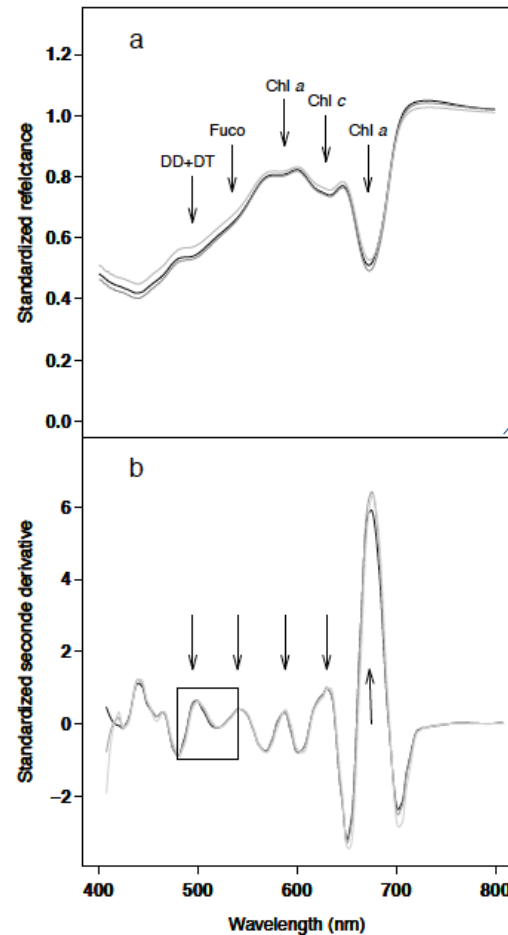


Britten Norman Islander

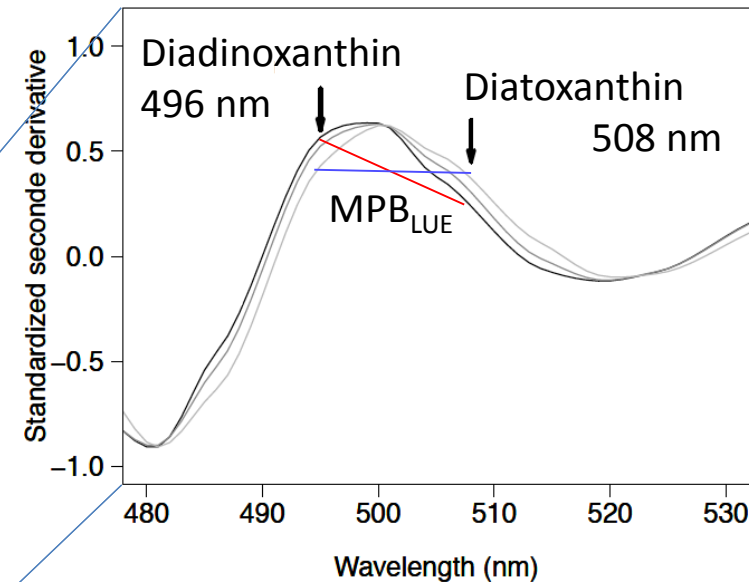
But :

Mesurer l'efficacité d'utilisation de la lumière (LUE) à partir de l'absorption de Xanthophylles pour en déduire une production primaire de vasière

Biremis lucens



Microphytobenthos primary production estimated by hyperspectral reflectance.
Méléder, V., Jesus, B., Barnett, A., Barillé, L., & Lavaud, J. (2018). PloS one, 13(5), e0197093



$$MBP_{LUE} = \delta\delta_{496} / \delta\delta_{508}$$

- L'exploitation de dérivée seconde nécessite une bonne qualité spectrale

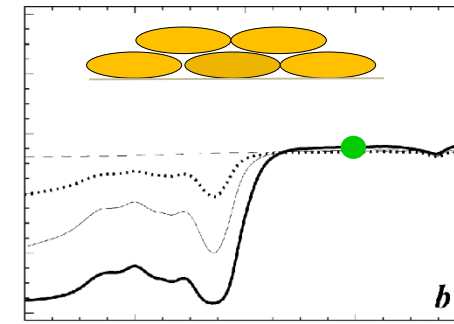
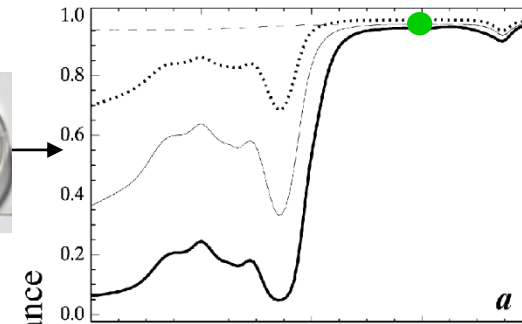
Rappel :
Expérimentation en laboratoire
Thèse Farzaneh Kazemipour-Ricci

Dépôts sur filtres en polycarbonate



0,2 mm par pixel = spectroscopie VPIR tous les 0,04mm²

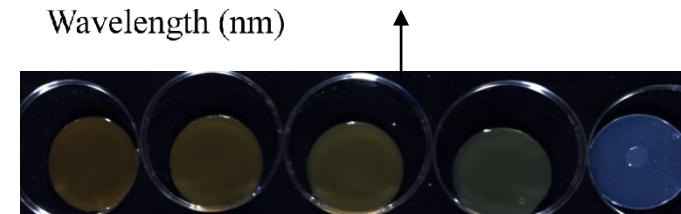
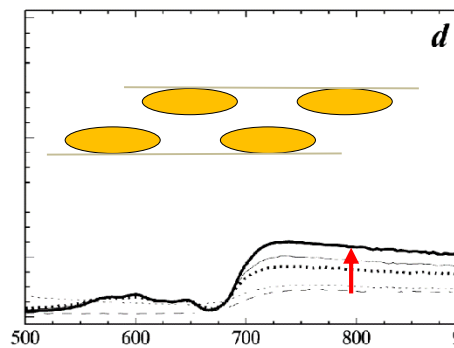
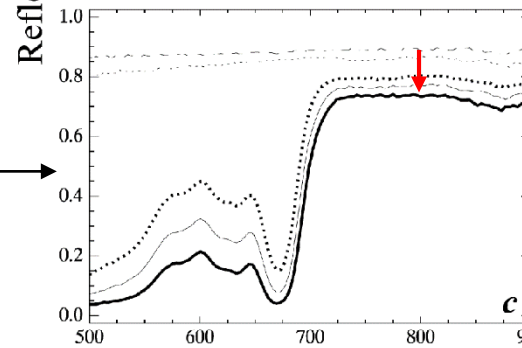
La réflectance ne change pas dans le PIR comme avec le MPB



Suspensions dans un gel d'agarose



La réflectance change avec la densité de cellules dans le PIR comme avec les feuilles ou les macroalgues (non compatible avec MPB)



Rappel :
 Modèle Optique du MicroPhytoBenthos
 pour la séparation entre biofilm et support

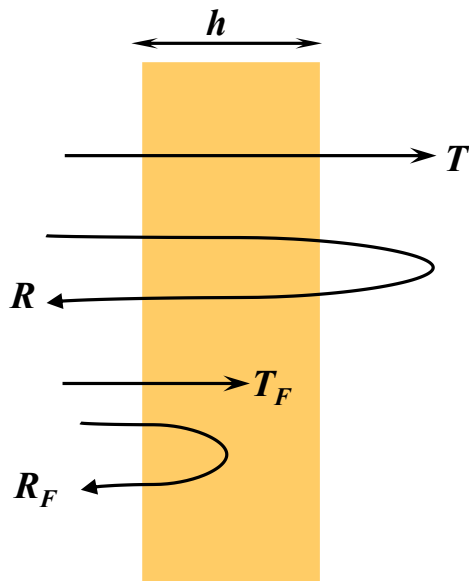
Microphytobenthos biomass mapping using the optical model of diatom biofilms: Application to hyperspectral images of Bourgneuf Bay.

Kazemipour F., P. Launeau, V. Méléder (2012) RemoteSensing of Environment, 127, 1–13

Microphytobenthos Biomass and Diversity Mapping at Different Spatial Scales with a Hyperspectral Optical Model.

Launeau, P., Méléder, V., Verpoorter, C., Barillé, L., Kazemipour-Ricci, F., Giraud, M., Jesus, B. and Le Menn. E. (2018) Remote Sens., 10, 716; doi:10.3390/rs10050716

Simplifier les calculs : Comme la réflectance propre d'un biofilm est négligeable :



$$R = R_F = 0$$

Le calcul de T à partir de l'observation de la réflectance apparente R_A et de celle du support R_B se simplifie en :

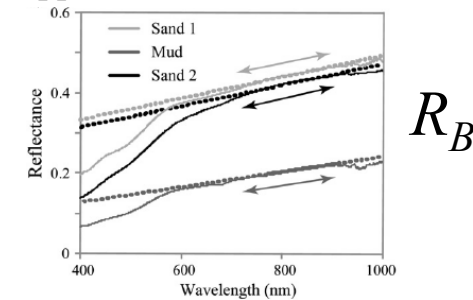
$$T^2 = \frac{(R_A - R)(1 - R.R_B)}{R_B} \xrightarrow{R \approx 0} T = \sqrt{\frac{R_A}{R_B}}$$

Et

$$T_F = \left[\frac{(1 - \eta^2 . R_F^2) . T}{\eta} \right]^{0.5} \xrightarrow{R \approx 0} T_F = \sqrt{\frac{T}{\eta}}$$

$$\eta = R_F + T_F \xrightarrow{R \approx 0} \eta = T_F$$

$$\eta = \sqrt{\frac{T}{\eta}} \quad \eta^3 = T$$



D'où, sans méthode itérative, nous avons directement :

$$\alpha = -\ln(\eta) \xrightarrow{R \approx 0} \alpha = -\ln(\sqrt[3]{T}) = -\ln\left(\sqrt[6]{\frac{R_A}{R_B}}\right)$$



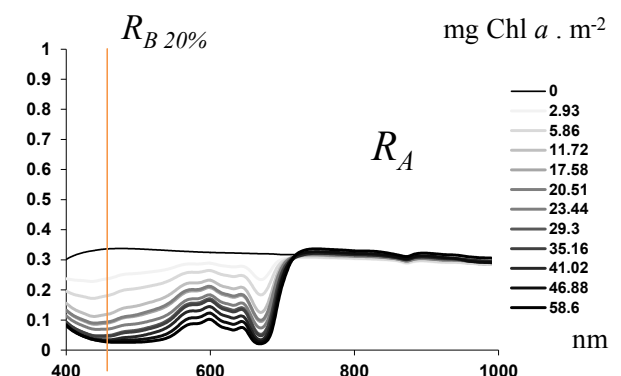
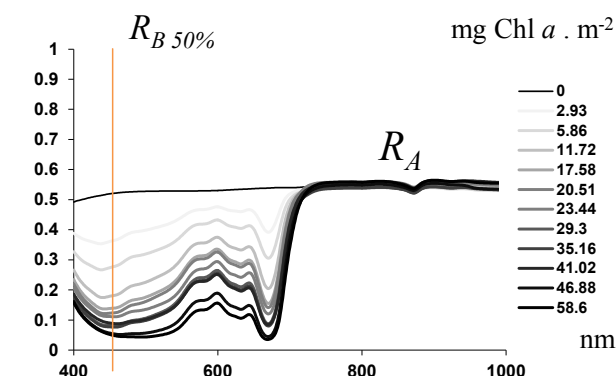
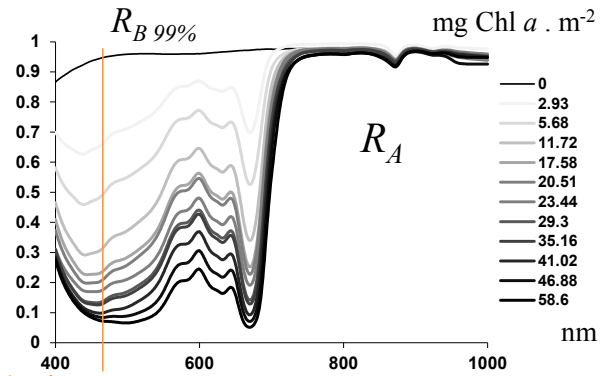
➤ simulation

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

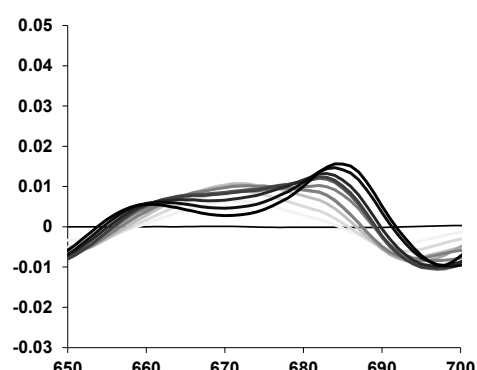
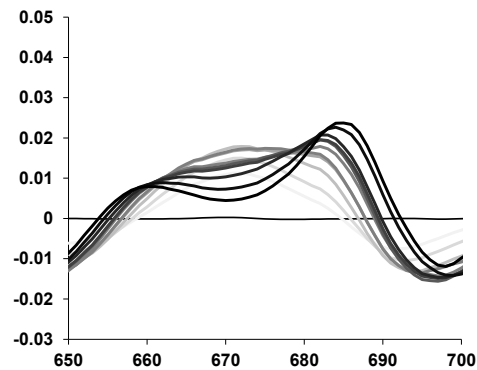
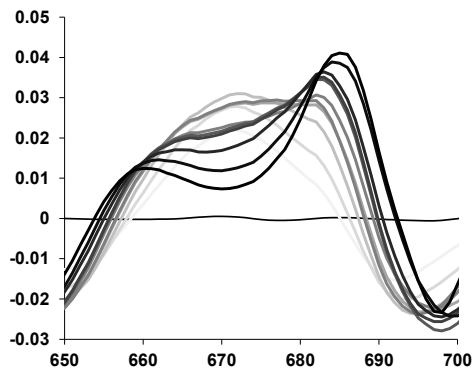
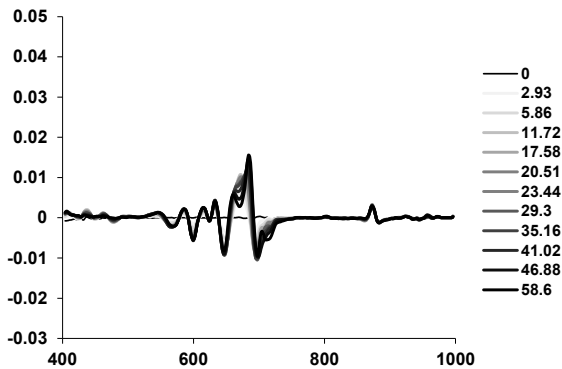
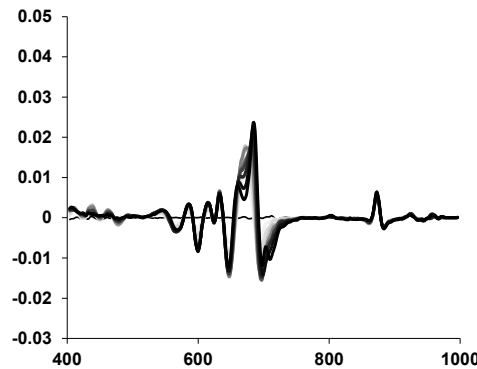
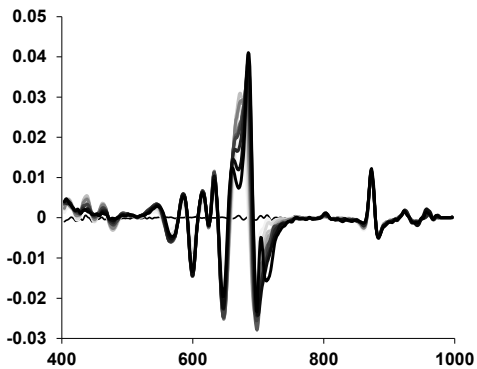
Mélange simple de supports Mélange intime de pigments

Rappel :

Réflectances et dérivées secondes de réflectances varient avec le support



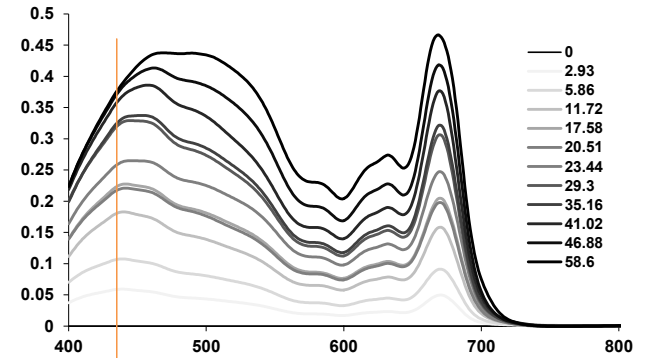
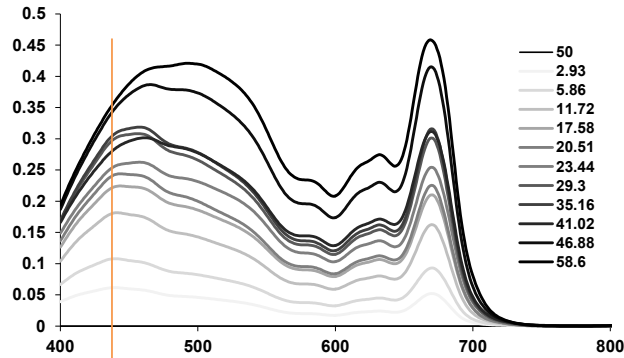
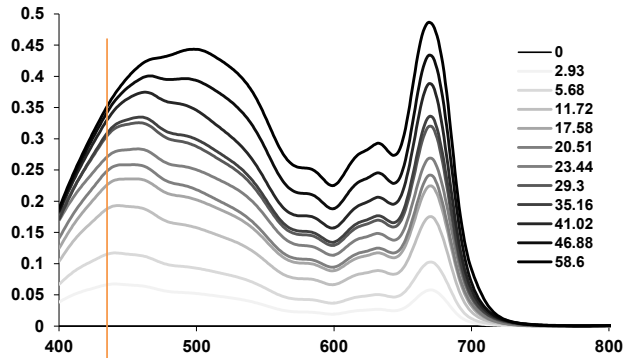
Biais induit par halogène



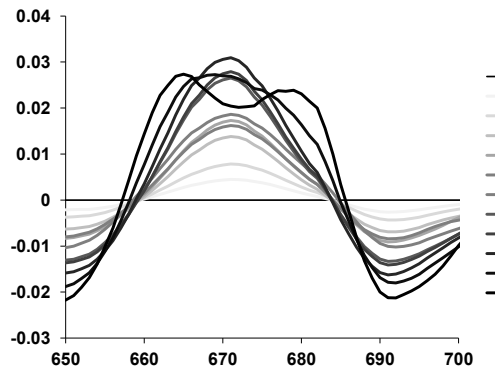
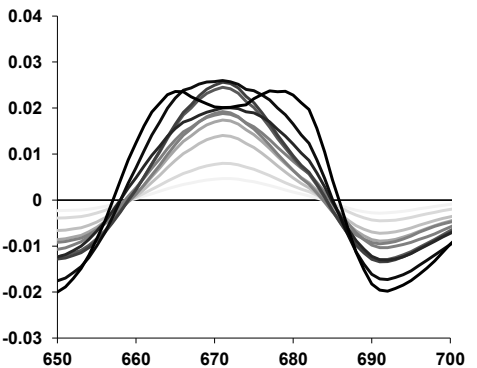
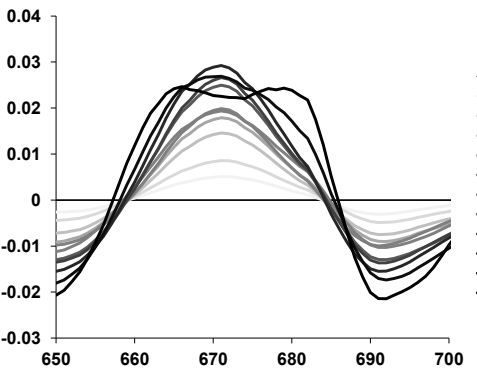
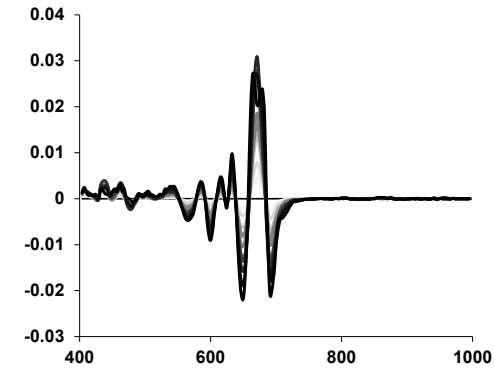
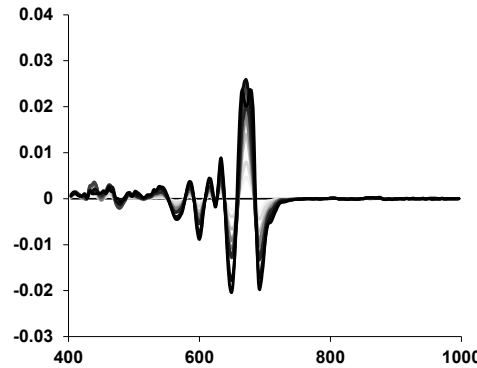
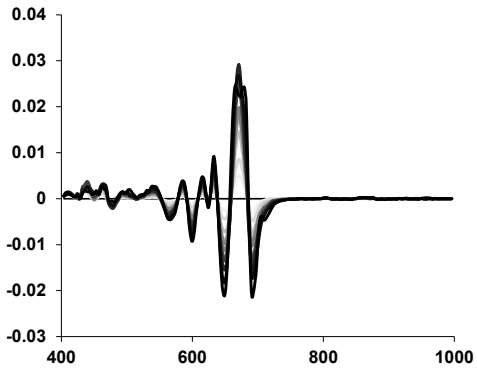
Rappel :

Seuls les coefficients d'absorptions α sont indépendantes des supports

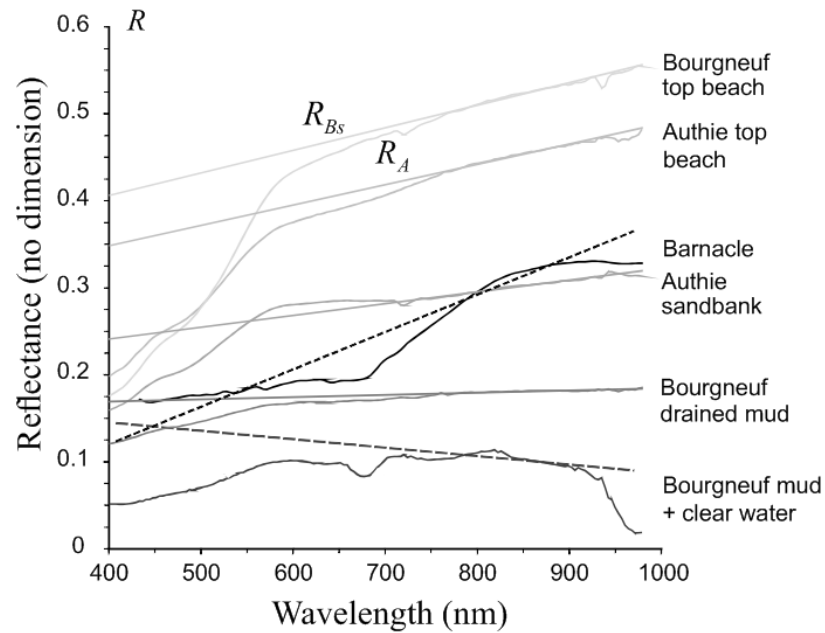
$$\alpha = -\ln \left(\sqrt[6]{\frac{R_A}{R_B}} \right)$$



Biais induit par halogène



Rappel :
Limitation par variabilité des supports



Microphytobenthos biomass mapping using the optical model of diatom biofilms: Application to hyperspectral images of Bourgneuf Bay.

Kazemipour F., P. Launeau, V. Méléder
(2012) RemoteSensing of Environment, 127, 1–13

Microphytobenthos Biomass and Diversity Mapping at Different Spatial Scales with a Hyperspectral Optical Model.

Launeau, P., Méléder, V., Verpoorter, C., Barillé, L., Kazemipour-Ricci, F., Giraud, M., Jesus, B. and Le Menn. E.
(2018) Remote Sens., 10, 716; doi:10.3390/rs10050716

La contribution du support des biofilms peut être estimée par l'observation de l'intervalle de 750 nm à 920 nm

Vases et sables dessinent une droite de 600 nm à 920 nm

Balanes et pellicule d'eau en surface fausse la pente PIR

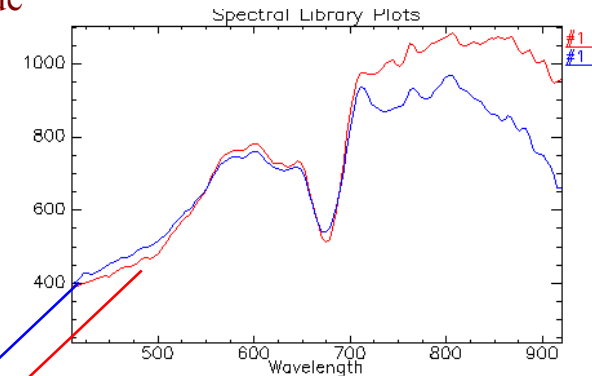
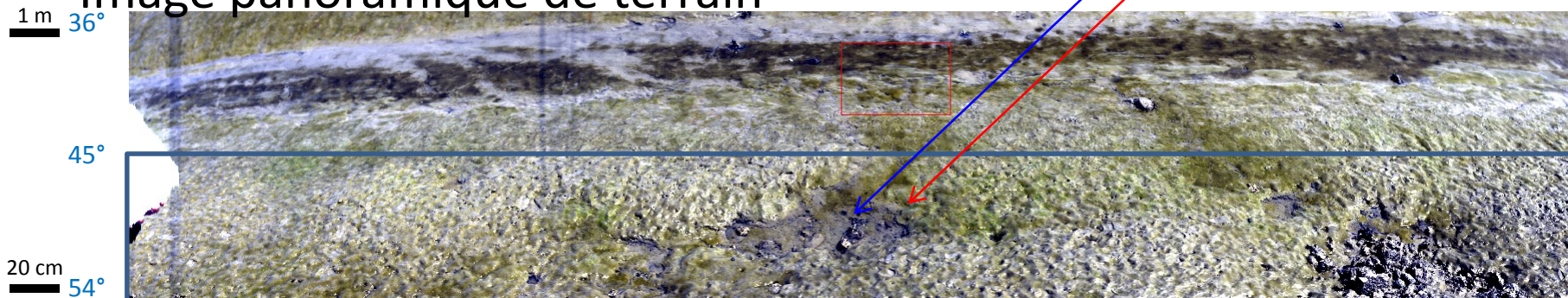
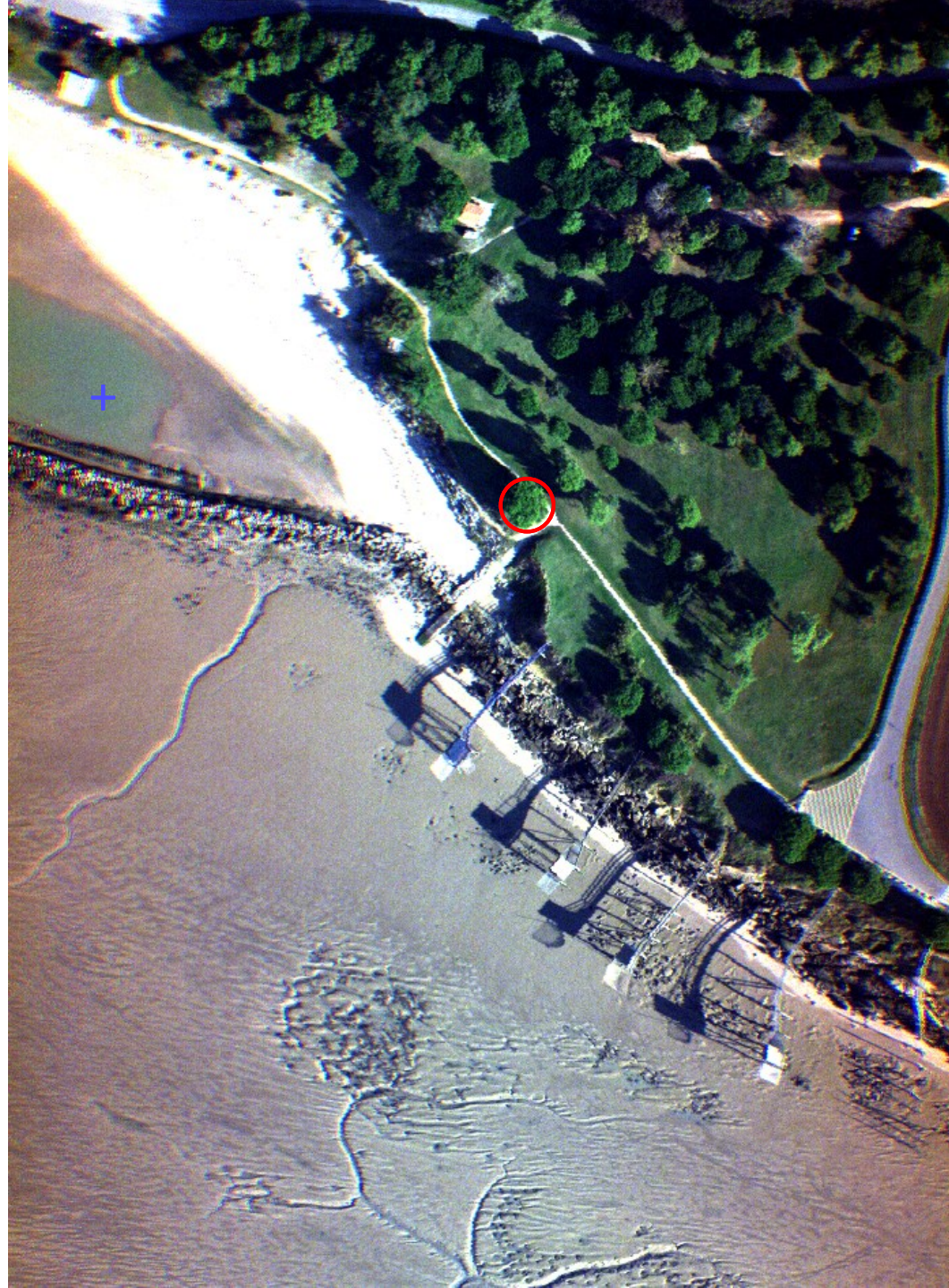
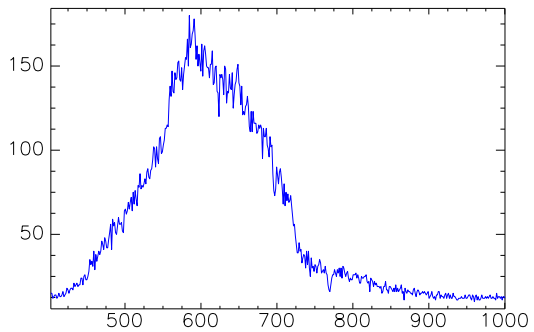
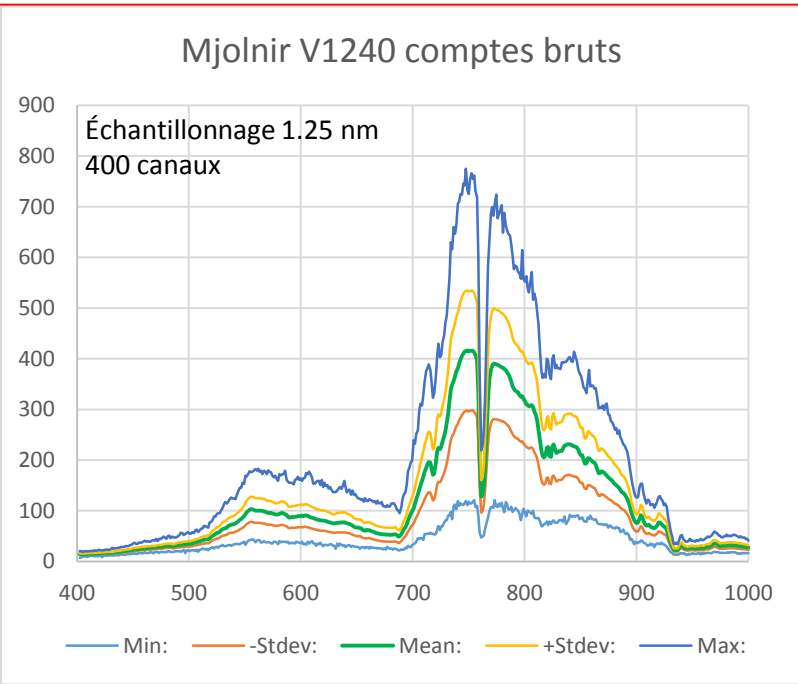


Image panoramique de terrain

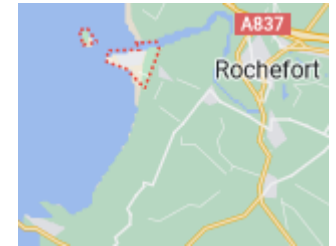


Chaine de traitement : Sensibilité du capteur

hmat01b_02_Mjolnir_V1240_SN5014_raw.hypex



Port des Barques



V1240 16 octobre 2020

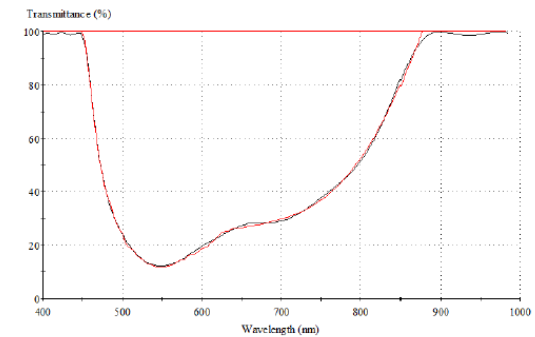
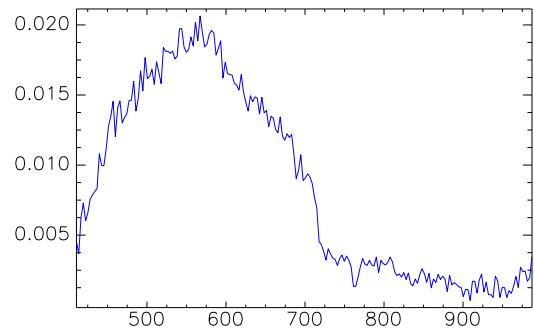
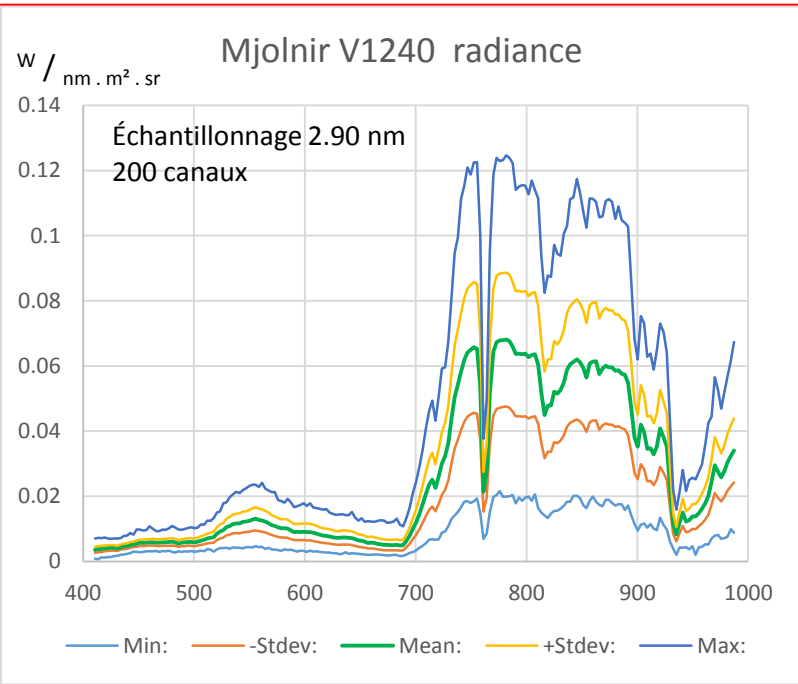


Figure 17. Transmittance curve of the entrance filter of Mjolnir.

Frameperiod = 10000
Integration time = 7938
EQ = 0
FOVexp = 0
bands = 468

Chaine de traitement : Calibration usine

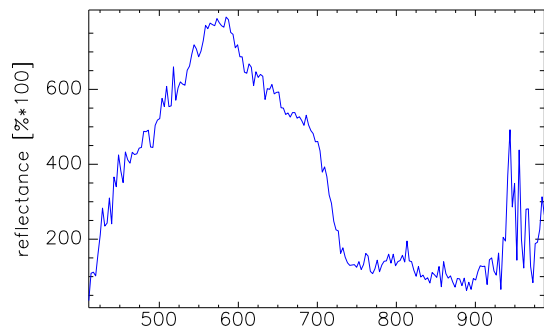
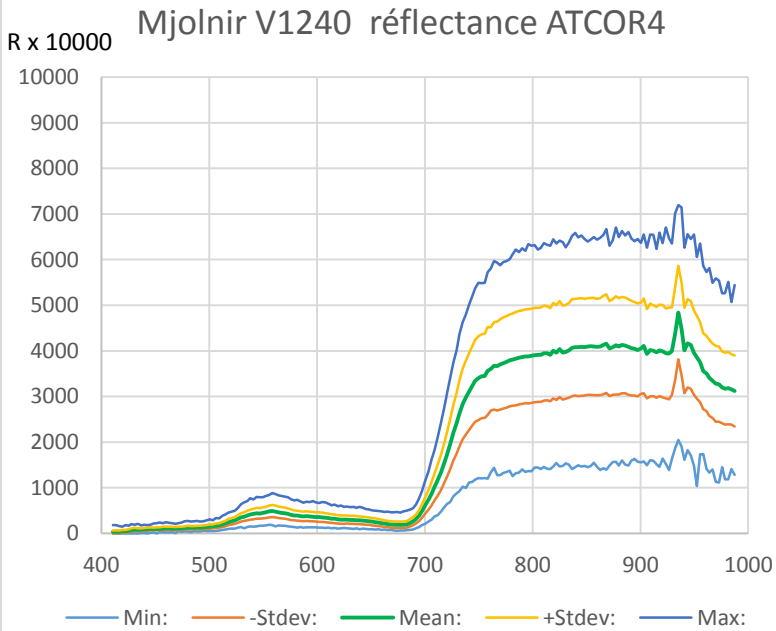
hmat01b_02_Mjolnir_V1240_SN5014_raw_rad_
keystone_smile_spectralbinningx2_bsq_float32.img



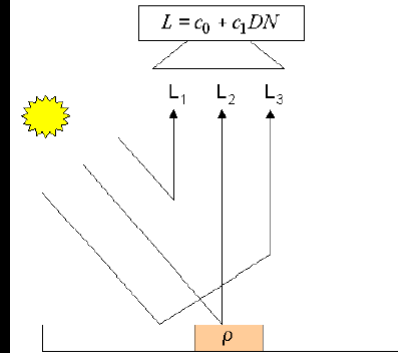
V1240 16 octobre 2020

Chaine de traitement : Correction atmosphérique

hmat01b_02_Mjolnir_V1240_SN5014_raw_rad_
keystone_smile_spectralbinningx2_bsq_atm.bsq



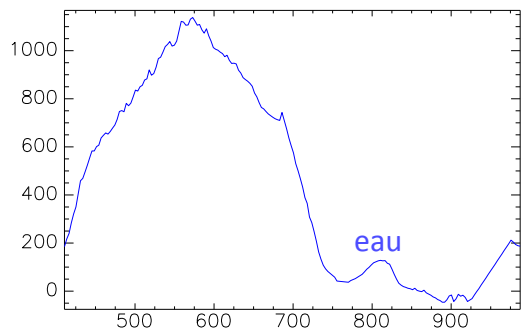
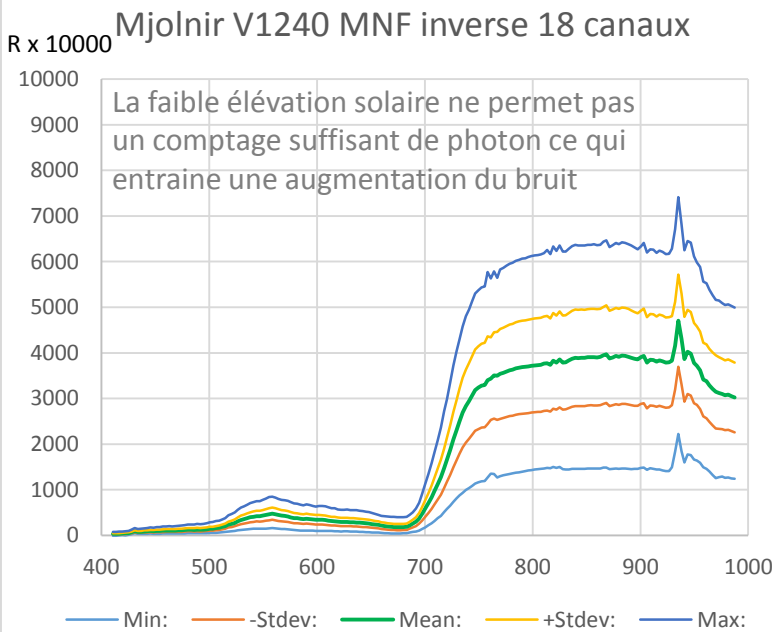
PARGE ATCOR 4



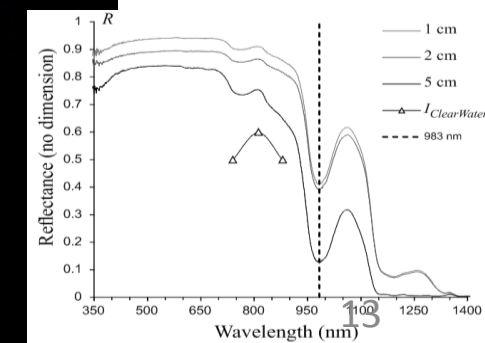
V1240 16 octobre 2020

Chaine de traitement : Retrait du bruit

hmat01b_02_Mjolnir_V1240_SN5014_raw_rad_
keystone_smile_spectralbinningx2_bsq_atm_
MNF inverse 18

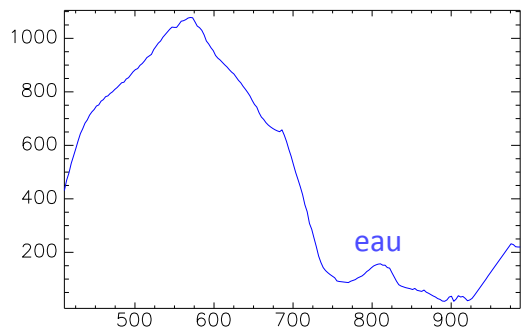
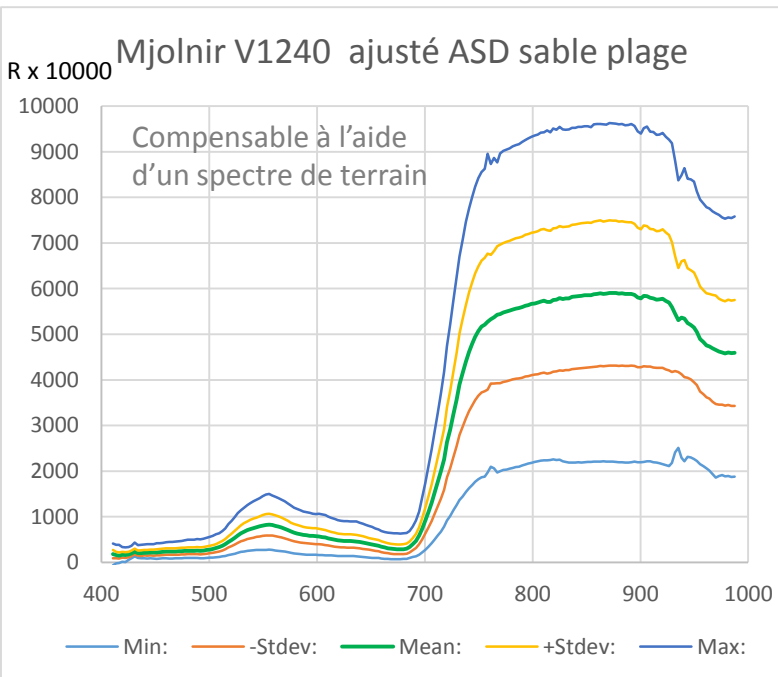


V1240 16 octobre 2020

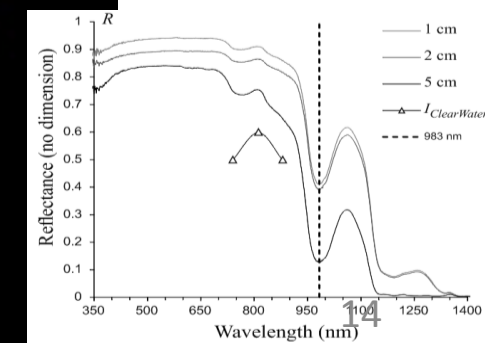


Chaine de traitement : Ajustement du gain

hmat01b_02_Mjolnir_V1240_SN5014_raw_rad_
keystone_smile_spectralbinningx2_bsq_atm_
MNF inverse ajustement ASD

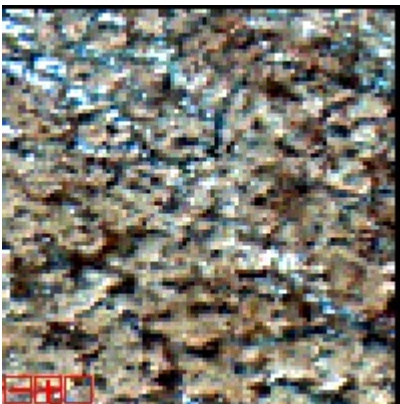


V1240 16 octobre 2020

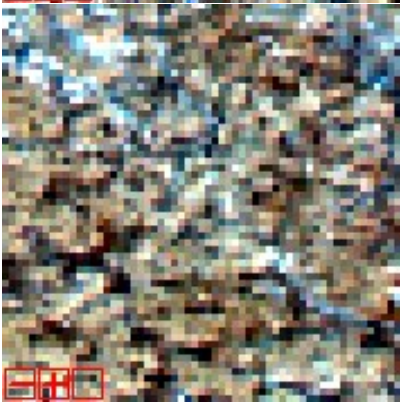


Reflectance R

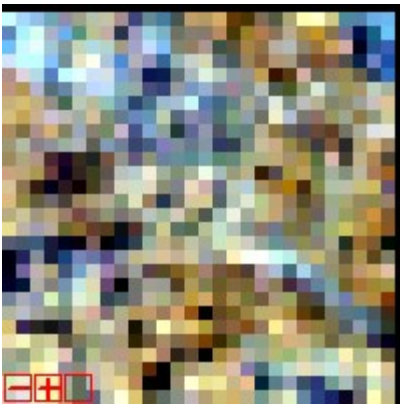
98 x 99
0.3 m



59 x 59
0.5 m



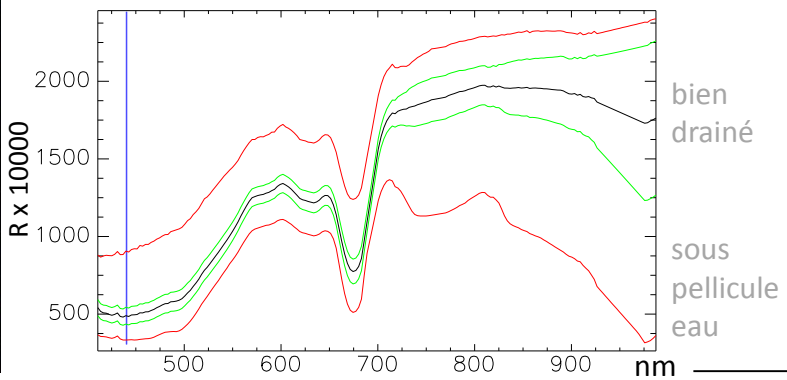
29 x 29
1.0 m



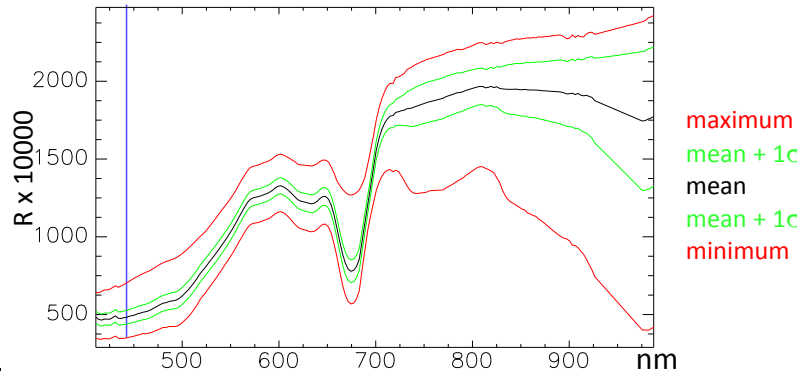
visible (r,v,b)

Diffusion croissante de l'atmosphère dans le bleu

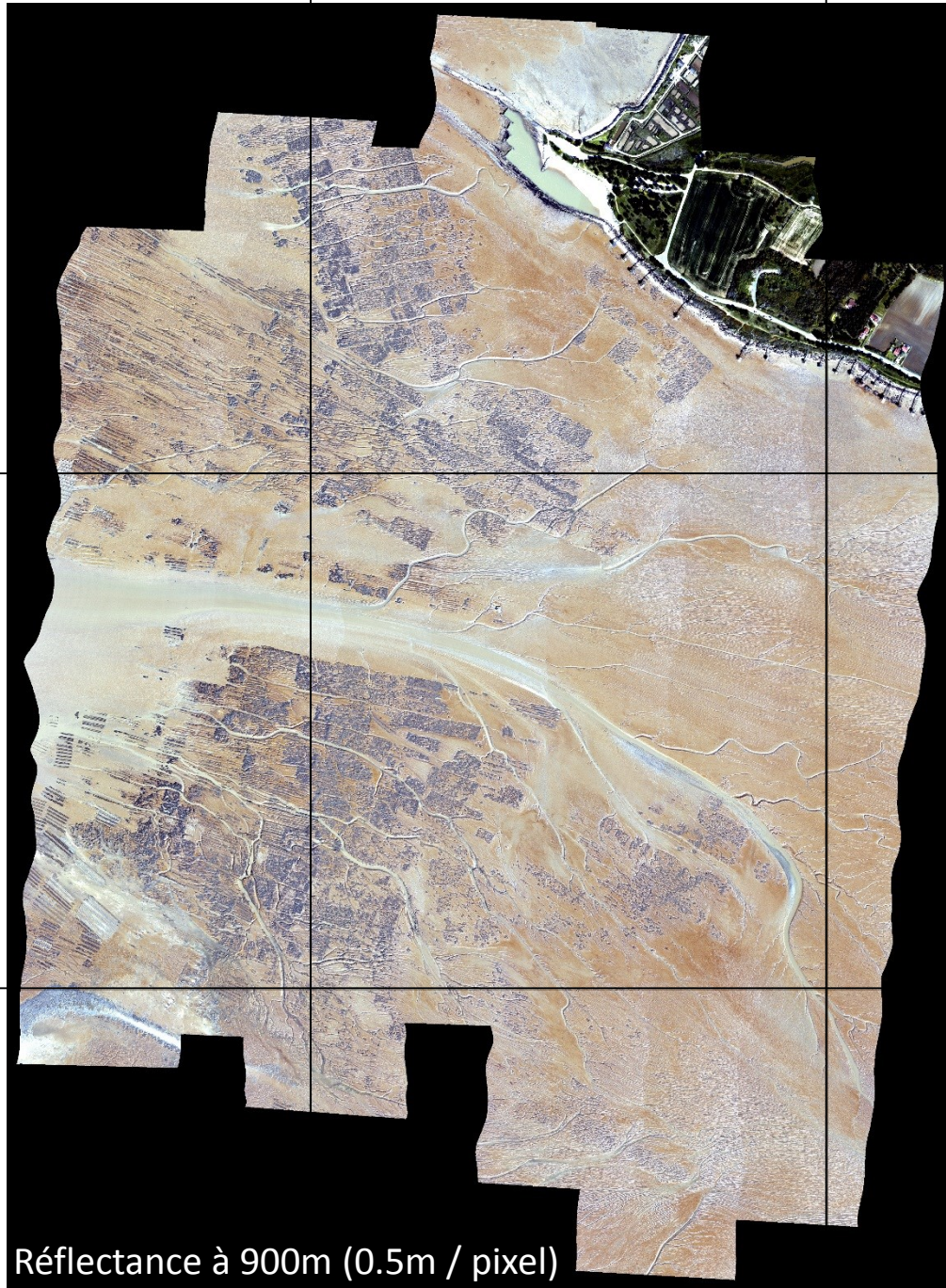
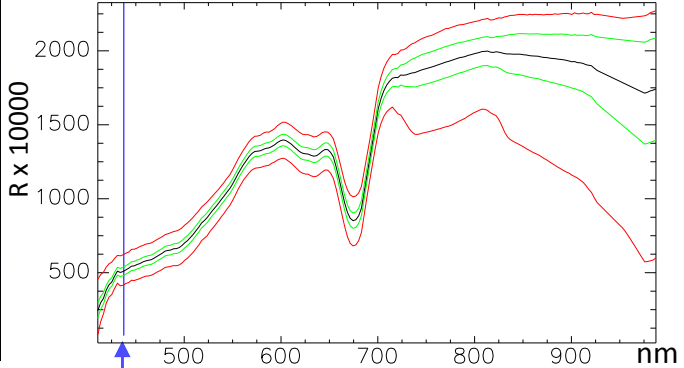
Altitude 600m



Altitude 900m



Altitude 1800m



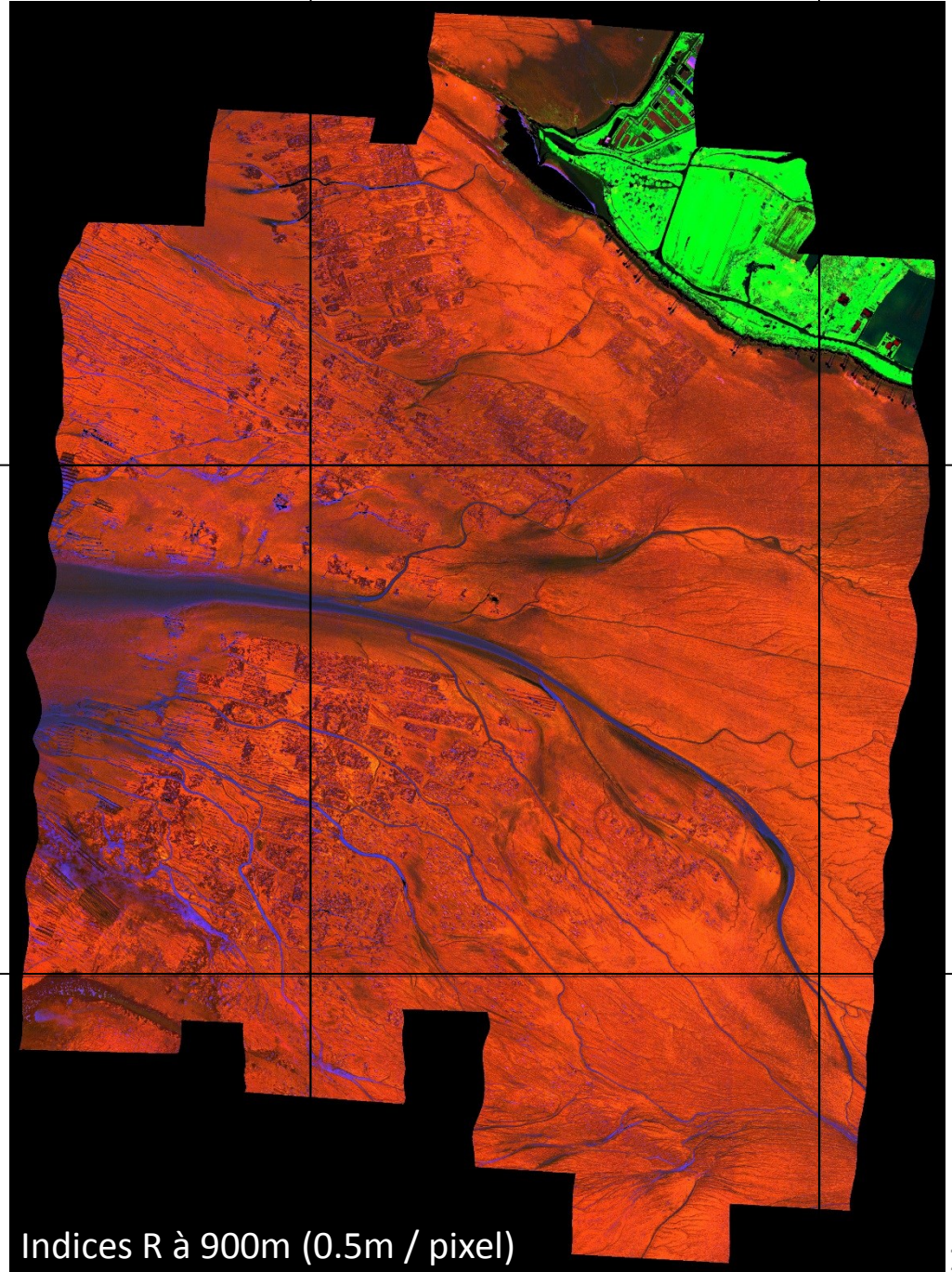
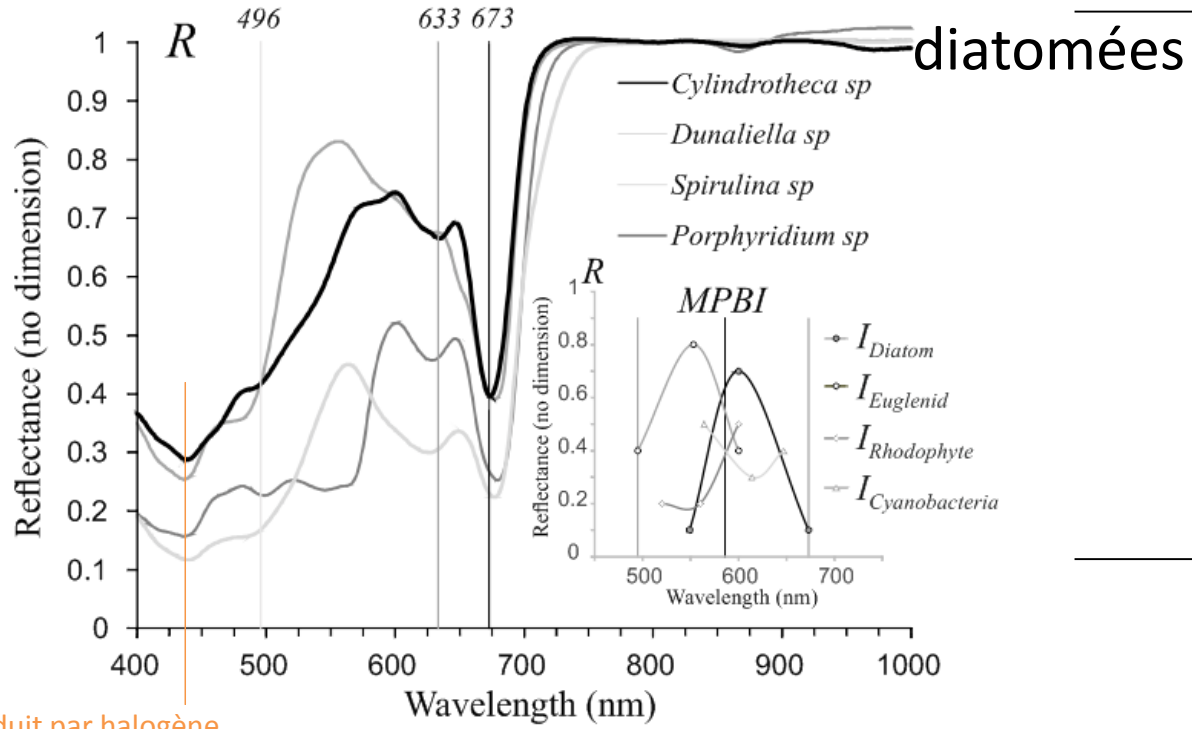
Réflectance à 900m (0.5m / pixel)

Application :
 Une combinaison d'indices
 suffit à isoler les biofilms
 dominants des vasières

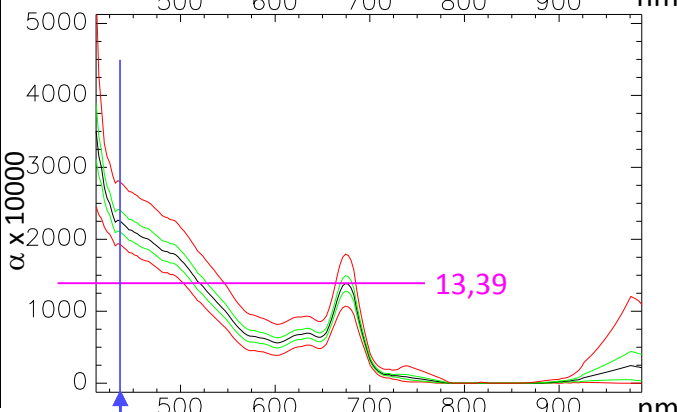
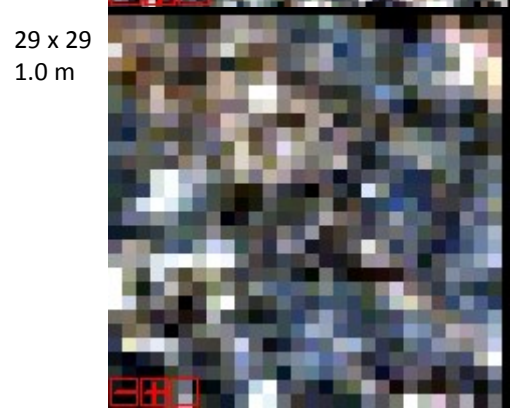
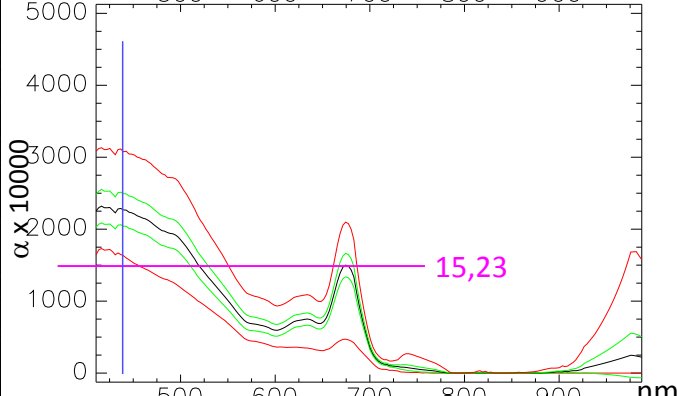
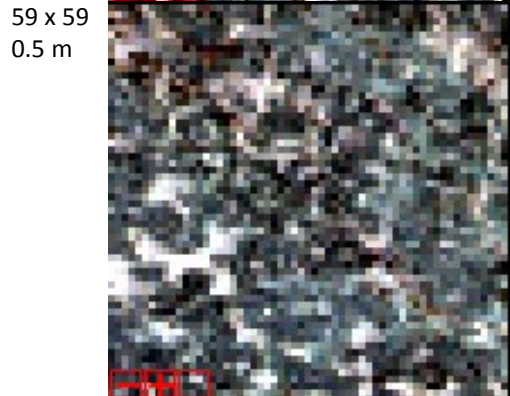
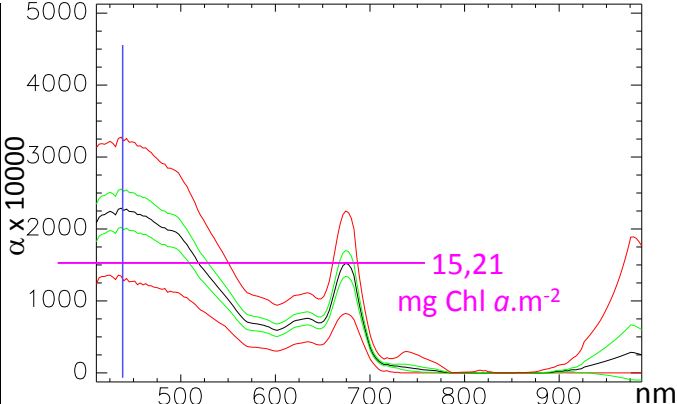
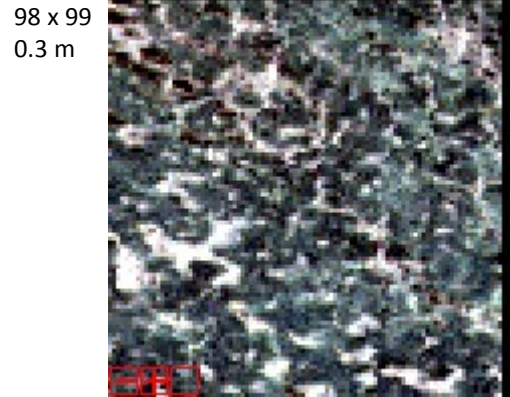
$$I_{Diatom} = \frac{2 \times R_{600}}{R_{549} + R_{673}} - 1$$

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

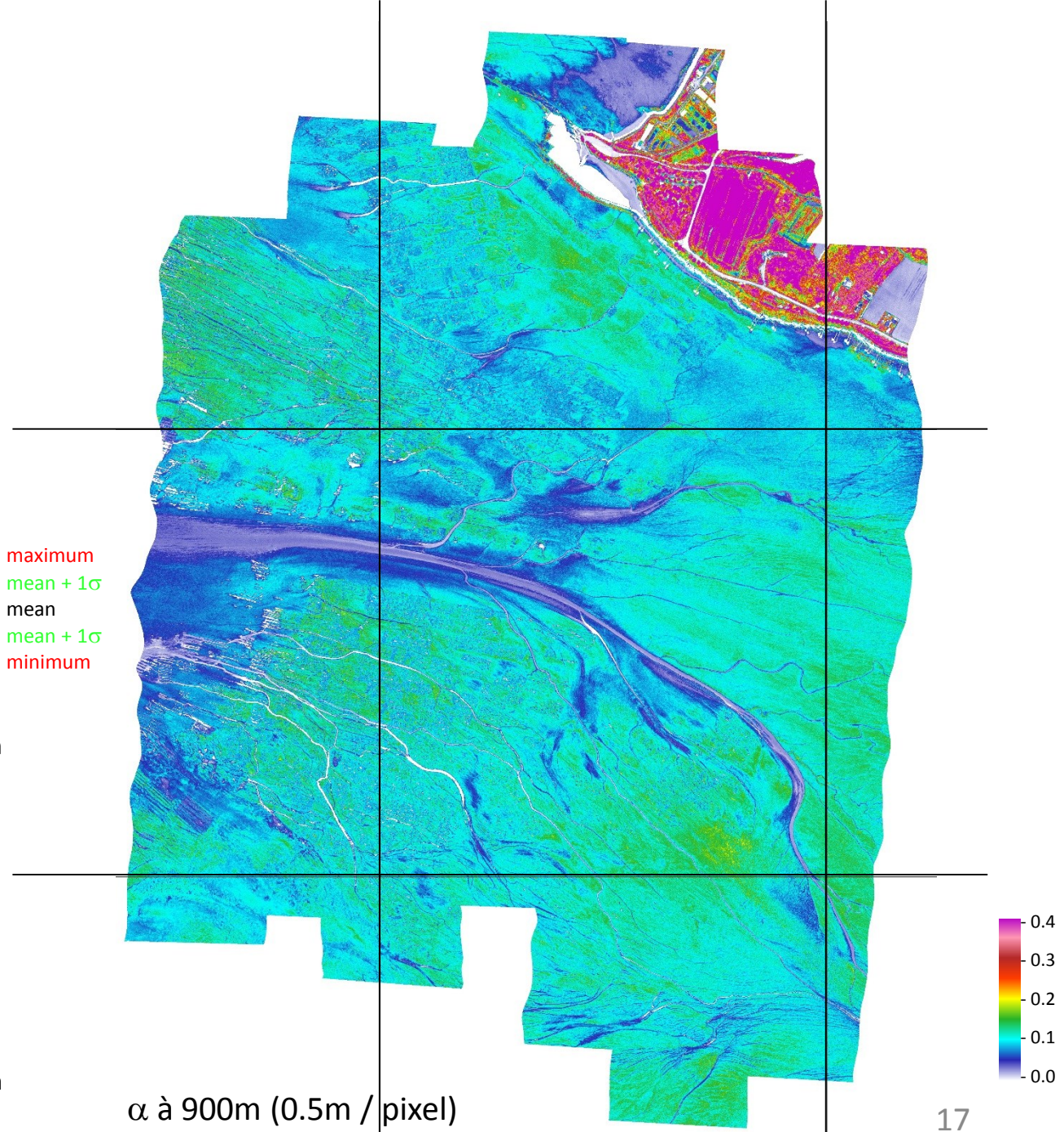
$$EauSup = \frac{2 \times R_{820}}{R_{770} + R_{840}} - 1$$



Coefficient d'absorption α



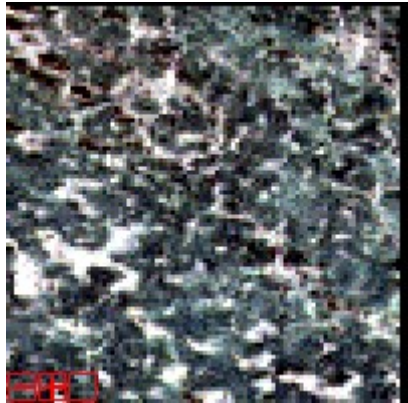
Diffusion croissante de l'atmosphère dans le bleu



α à 900m (0.5m / pixel)

Coefficient d'absorption α

98 x 99
0.3 m



59 x 59
0.5 m

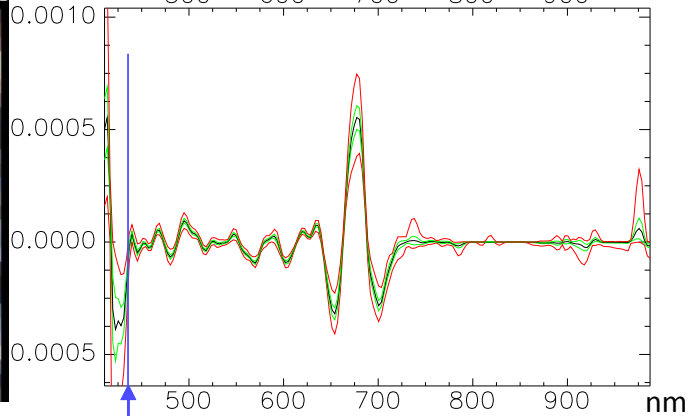
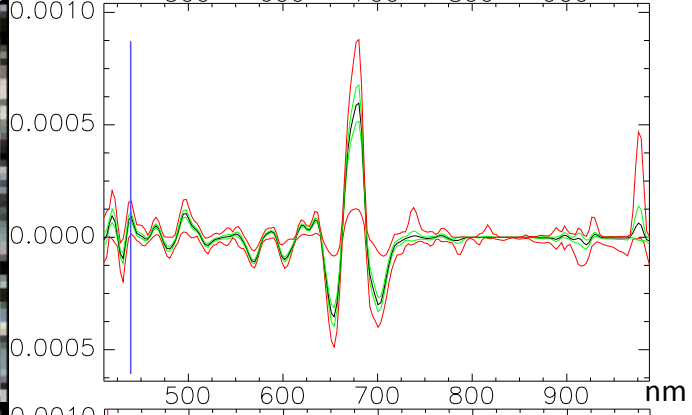
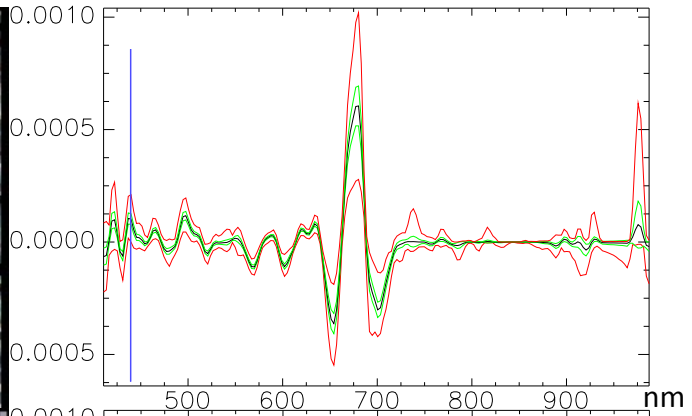


29 x 29
1.0 m

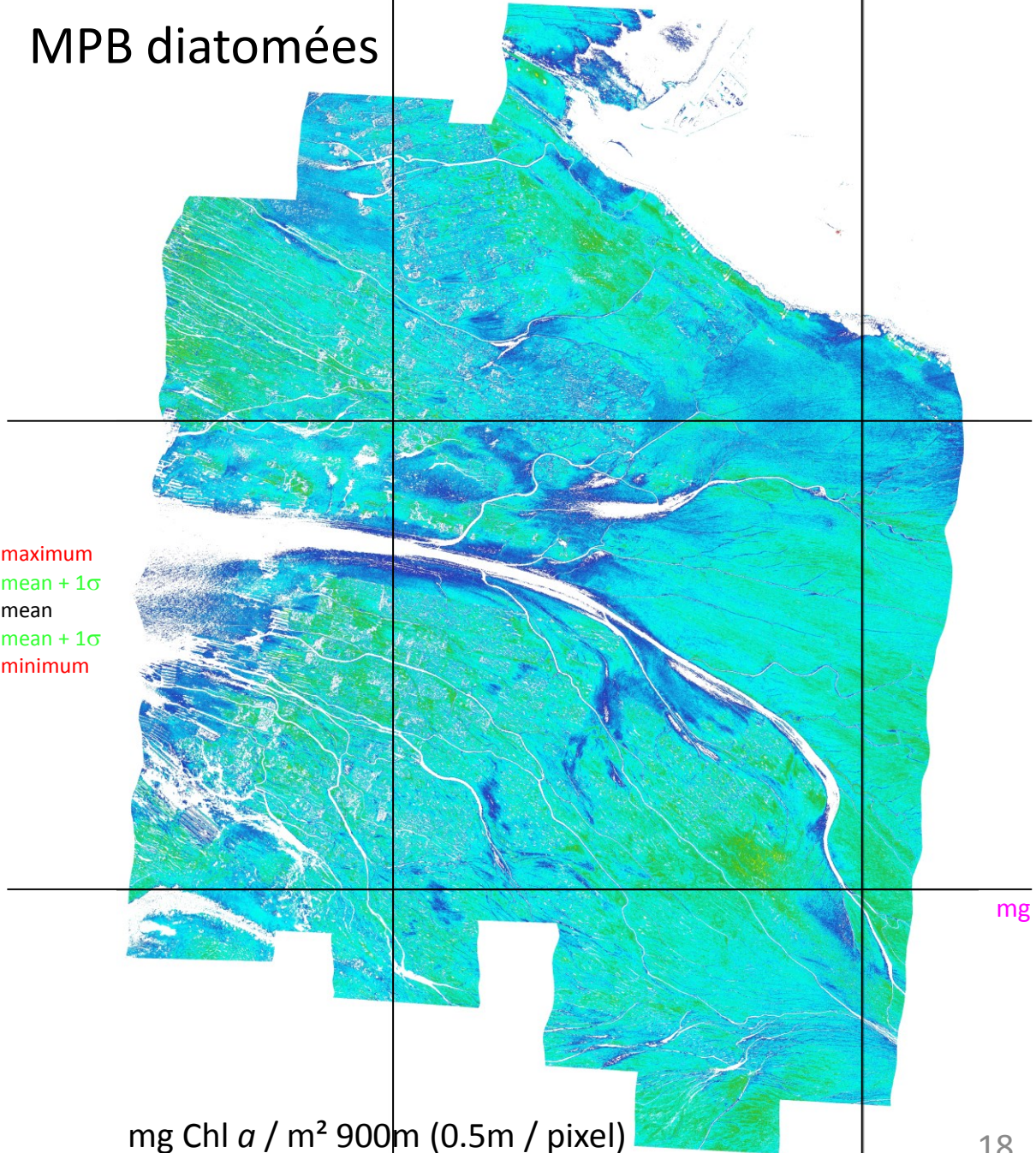


Diffusion croissante de l'atmosphère dans le bleu

$\delta\delta \alpha$

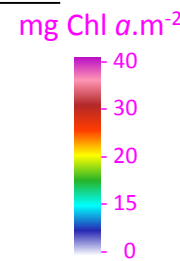


MPB diatomées



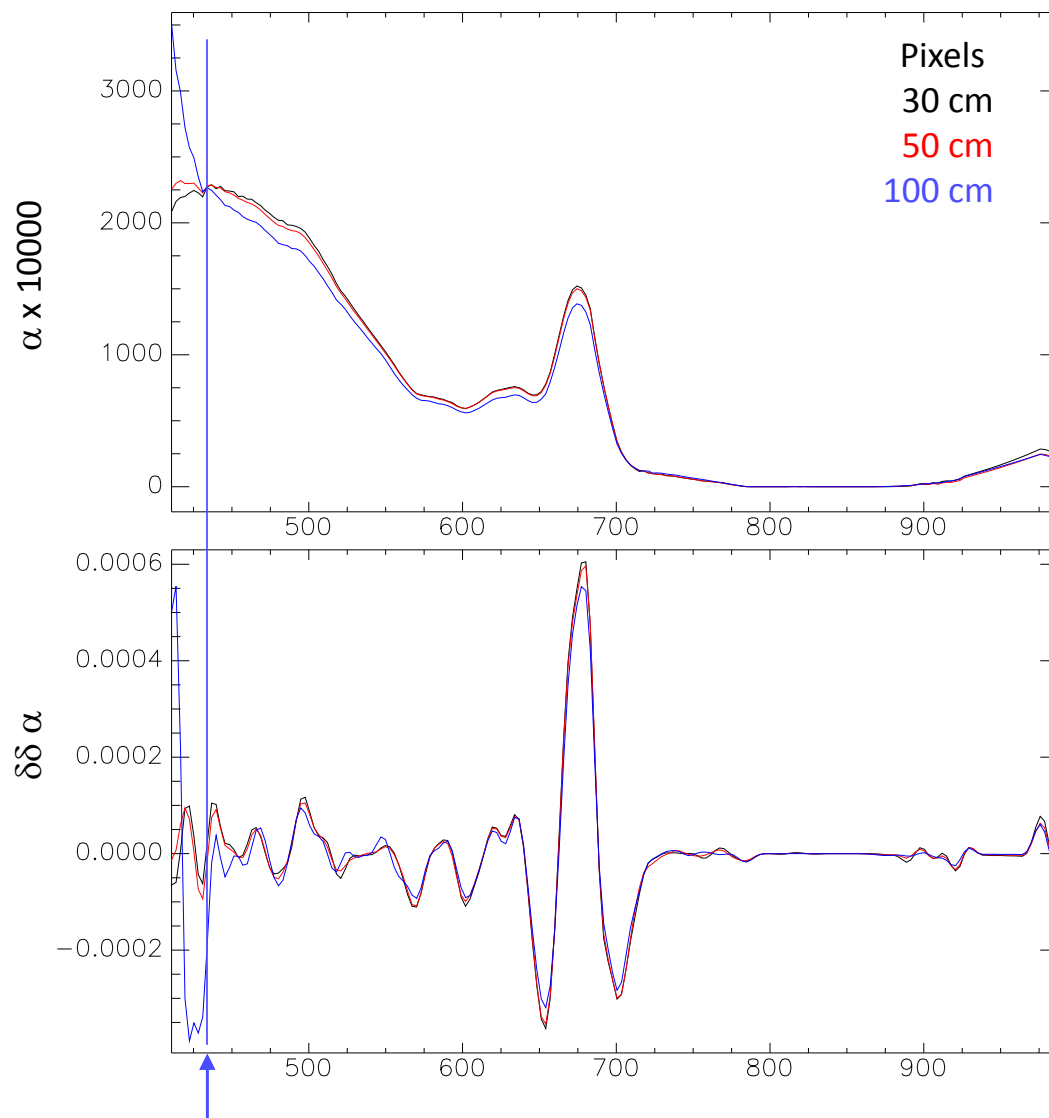
maximum
mean + 1 σ
mean
mean - 1 σ
minimum

mg Chl a / m² 900m (0.5m / pixel)



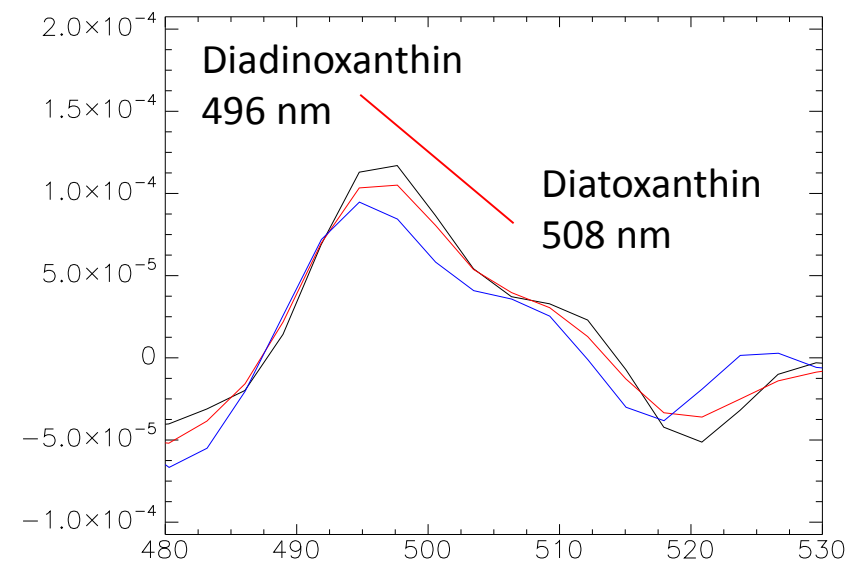
Conclusion le but est atteint :

Mesurer l'efficacité d'utilisation de la lumière (LUE) à partir de l'absorption de Xanthophylles pour en déduire une production primaire de vasière

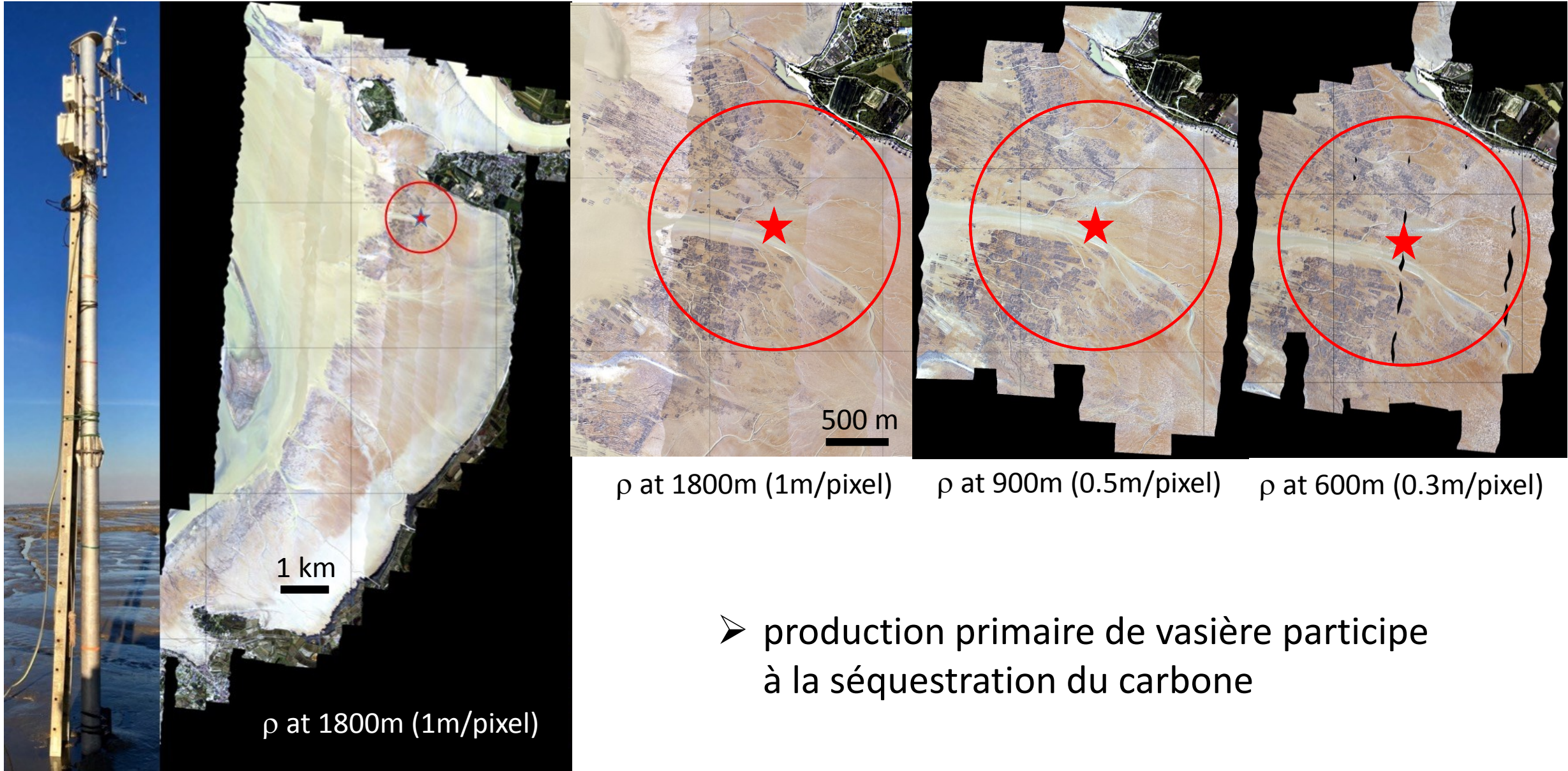


Chronologie des acquisitions

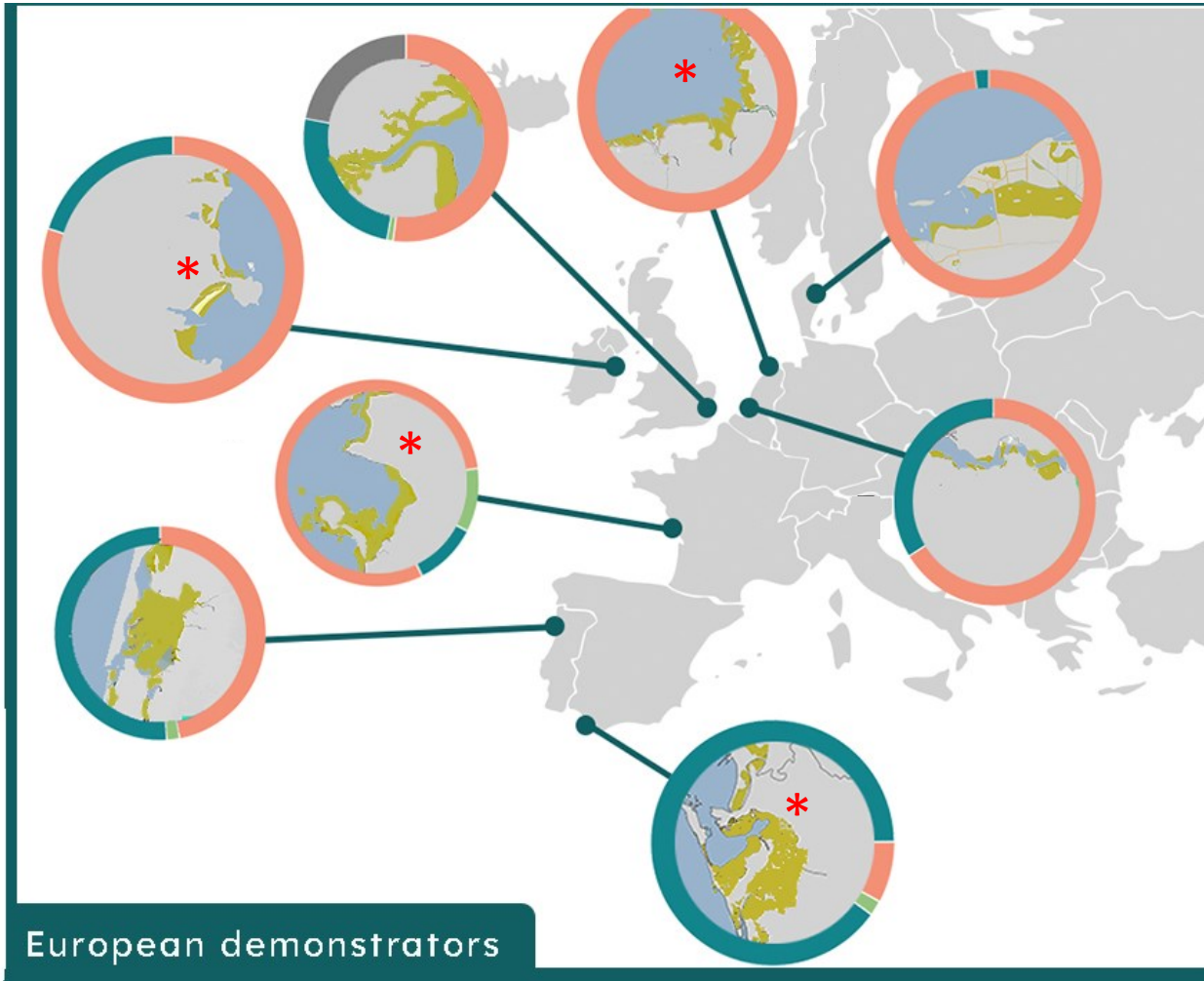
600 m
900 m
1800 m



Estimation des flux de CO₂ par couplage eddy-covariance et hyperspectral



- production primaire de vaseière participe à la séquestration du carbone



Demonstrators

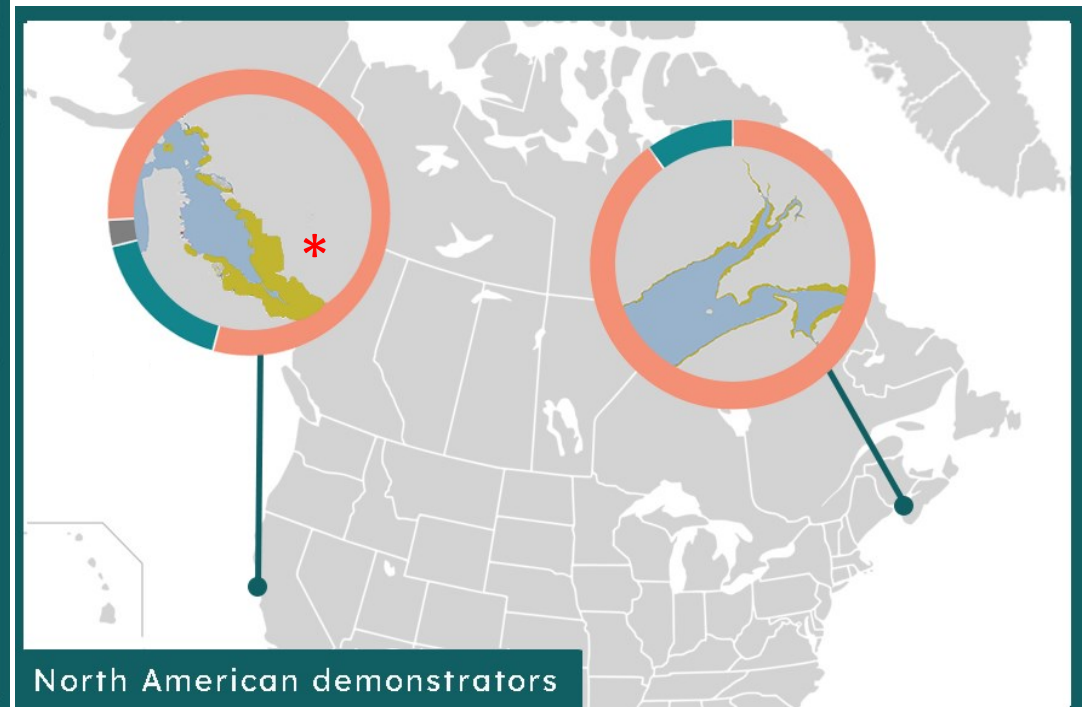


Habitats (%)

- Microphytobenthos
- Seagrass meadows
- Salt marsh
- Other

Areas

- Water
- Intertidal area
- Land



* Au moins une tour d'eddy-covariance avec imagerie hyperspectrale associée



REWRITE

**REWilding and Restoration of
InterTidal sediment Ecosystems
for carbon sequestration, climate
adaptation and biodiversity
support**

Starting in October 2023

2023-2028

@VonaMeleder



HORIZON EUROPE