AUTONOMOUS MONITORING OF CARBONATE CHEMISTRY, MARINE REFLECTANCE, AND BIO-OPTICS DURING SHIP TRANSIT

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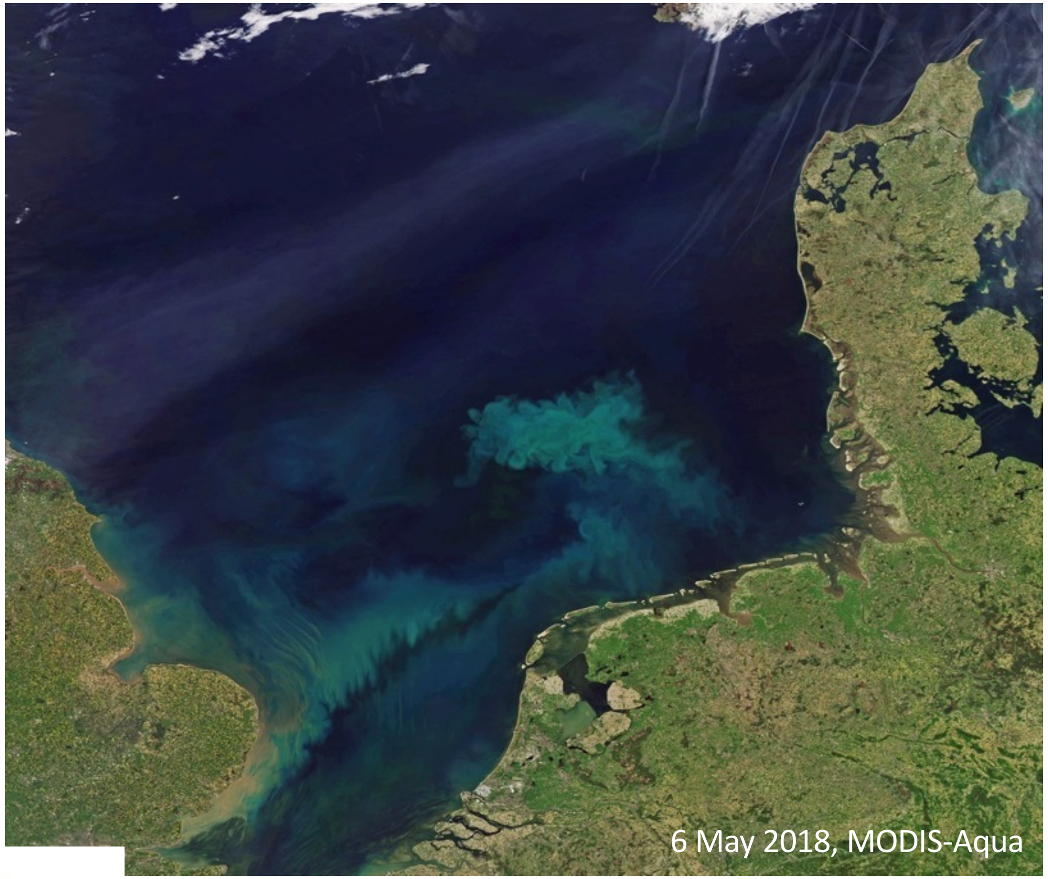
COASTAL OCEAN & SHELF SEAS : SINKS FOR ATMOSPHERIC CO_2

CO_2 sink of ~0.4 Pg C/year[1] or ~ 20% of global ocean CO_2 sink



$FCO_2 = f(\mathbf{pCO_{2,sea}} - pCO_{2,atm})$

with f(wind speed, temperature, salinity,..)

High spatiotemporal variability in $pCO_{2,sea}$ due to complexity and strong dynamics of physical & biogeochemical processes

Overall objective: set up a carbon budget for the North Sea area based on in situ and remote sensing observations.

[1] Roobaert et al. (2024)

SHIP-BASED UNDERWAY SYSTEM

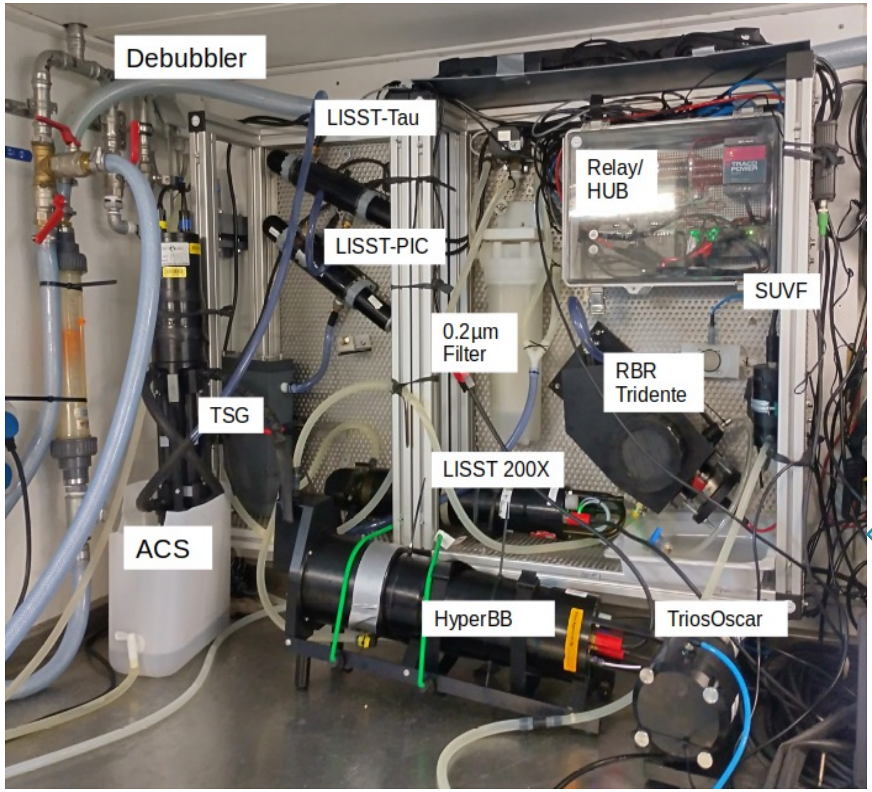
For measurement of pCO_2, marine reflectance, and bio-optics

ICOS INTEGRATED CARBON OBSERVATION SYSTEM VLIZ

Marine reflectance $\rho_w(\lambda)$

Autonomous hyperspectral above-water radiometry system, **DALEC** instrument

RV Simon Stevin is an **ICOS Ocean Station** providing standardized and open data of greenhouse gas observations (e.g., pCO_2) using a ship-based underway flow-through system.



Semi-Autonomous uNderway near-real-Time HYperspectraL Optical Properties PackagE (**ATHYLOPE**)

We extended the underway ICOS flow-through system with measurements of:

- Hyperspectral marine reflectance (DALEC)
- Hyperspectral Inherent Optical Properties (IOPs): $a(\lambda)$, $c(\lambda)$, $b_b(\lambda)$ (AC-S, HyperBB)
- Single-wavelength c (LISST-Tau), b_b (Tridente)
- Cross-polarized light scattering (LISST-PIC)
- Fluorescence of Chl-a and CDOM (Tridente, SUVF)
- Particle size distribution (LISST-200X)
- Temperature, salinity (TSG)

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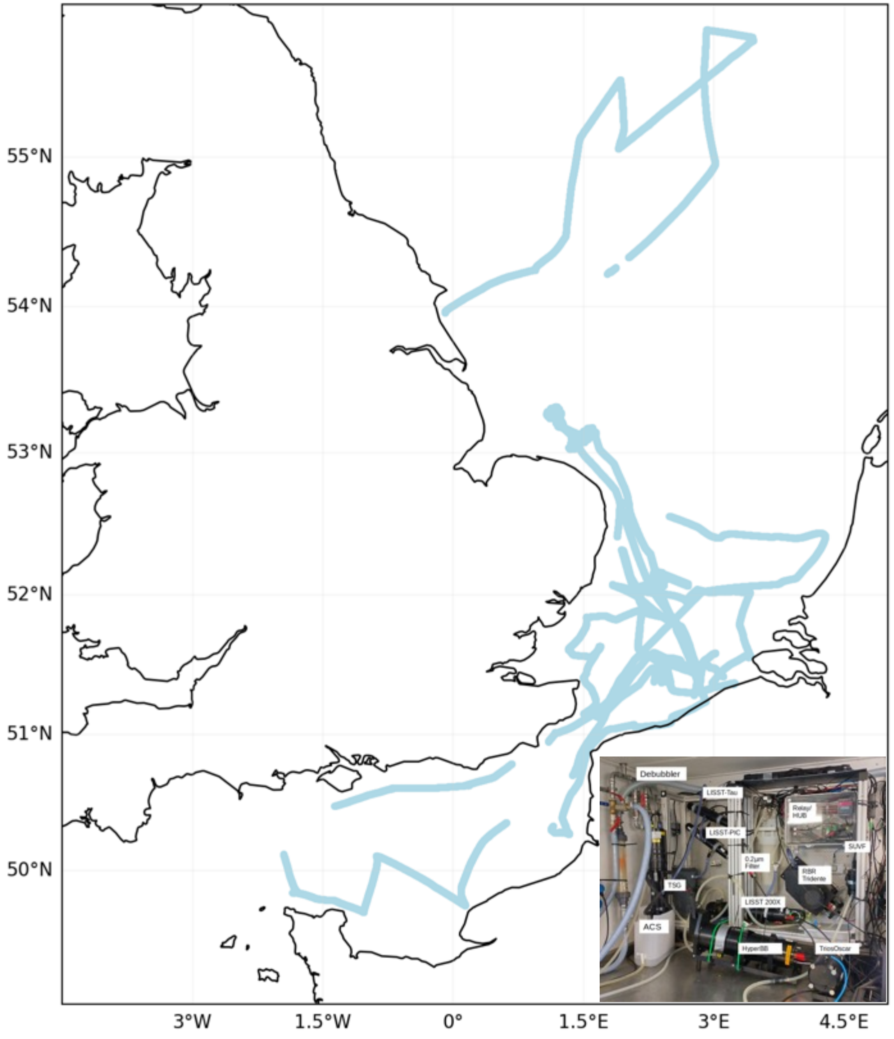
DATA COLLECTION

Four cruises in different seasons: 24 days at sea since May 2024

ANTHYLOPE sampling points: 19 344



ANTHYLOPE data is logged with **Inlinino**[2] (A Modular Software Data Logger for Oceanography).

[2] Haentjens and Boss, 2020.

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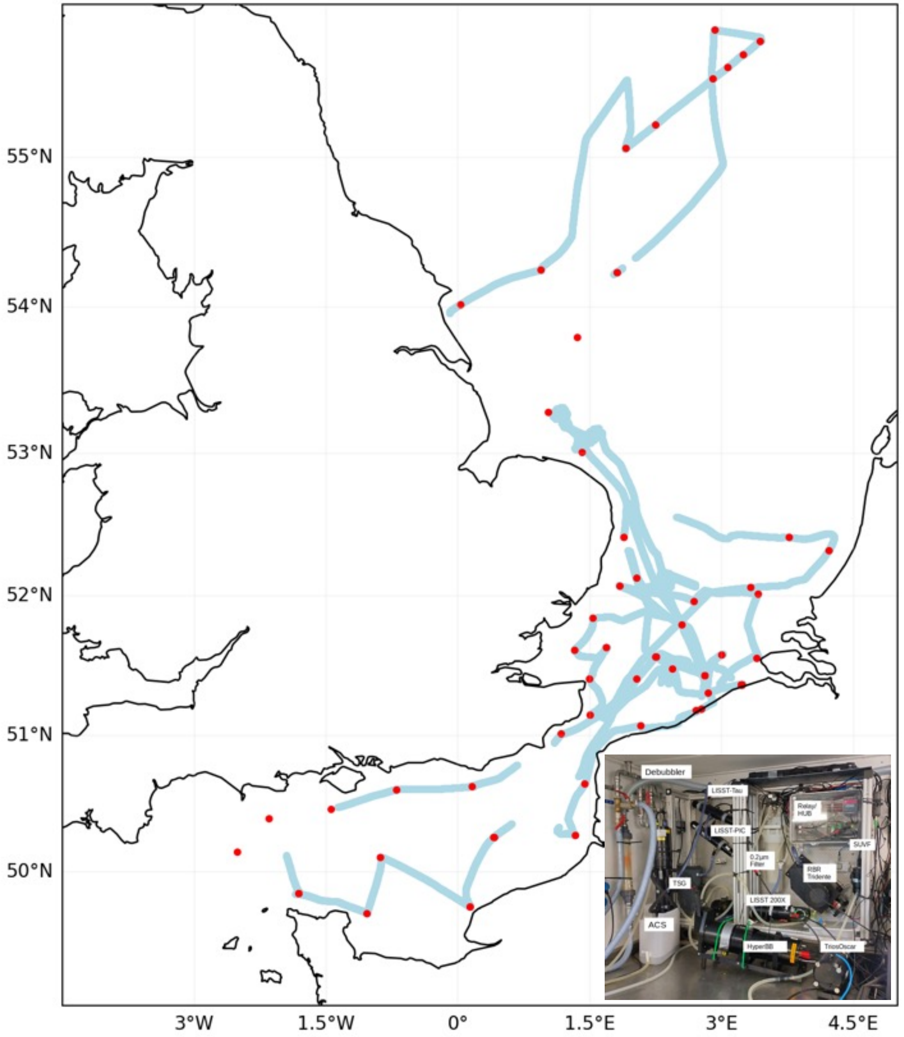

Discrete sampling stations: 70

Water filtrations for the analyses of:

- SPM (POM, PIM)
- POC, PIC
- HPLC pigments
- Scanning Electron Microscopy
- $a_p(\lambda)$, $a_{phy}(\lambda)$, $a_{det}(\lambda)$ (spectrophotometric)
- DOC

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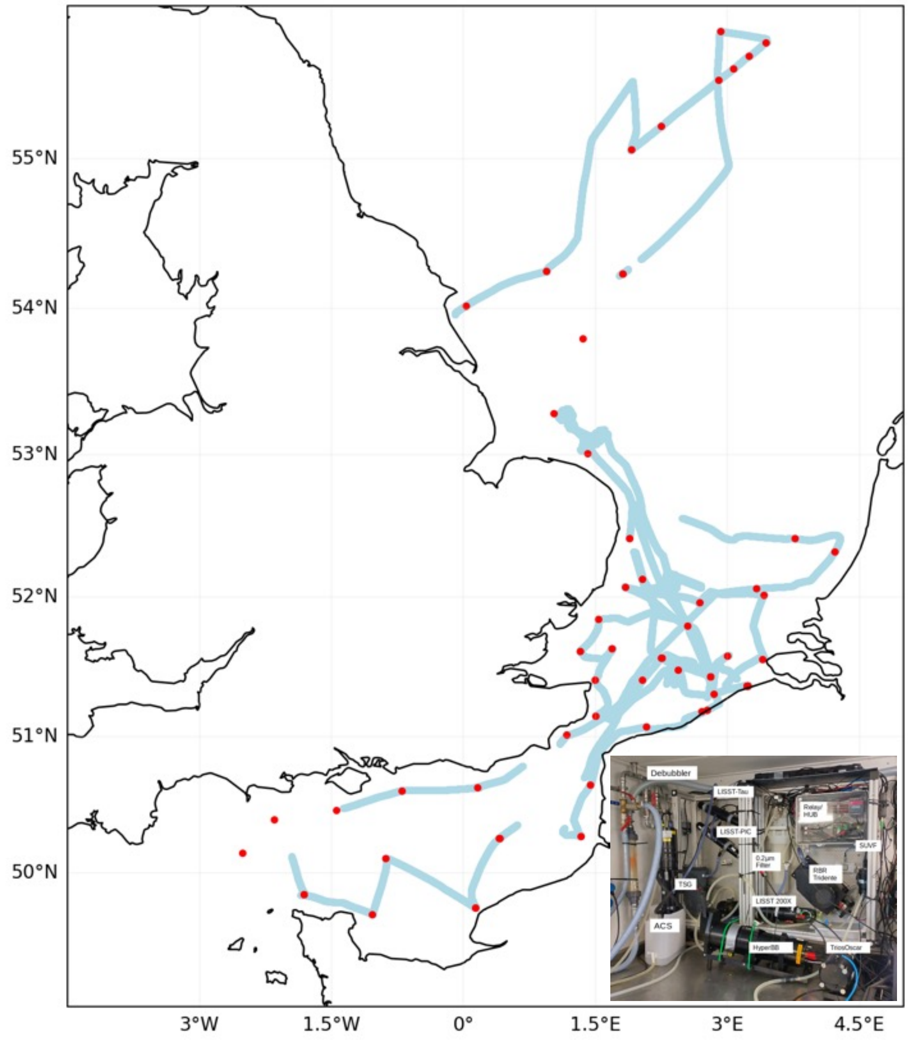

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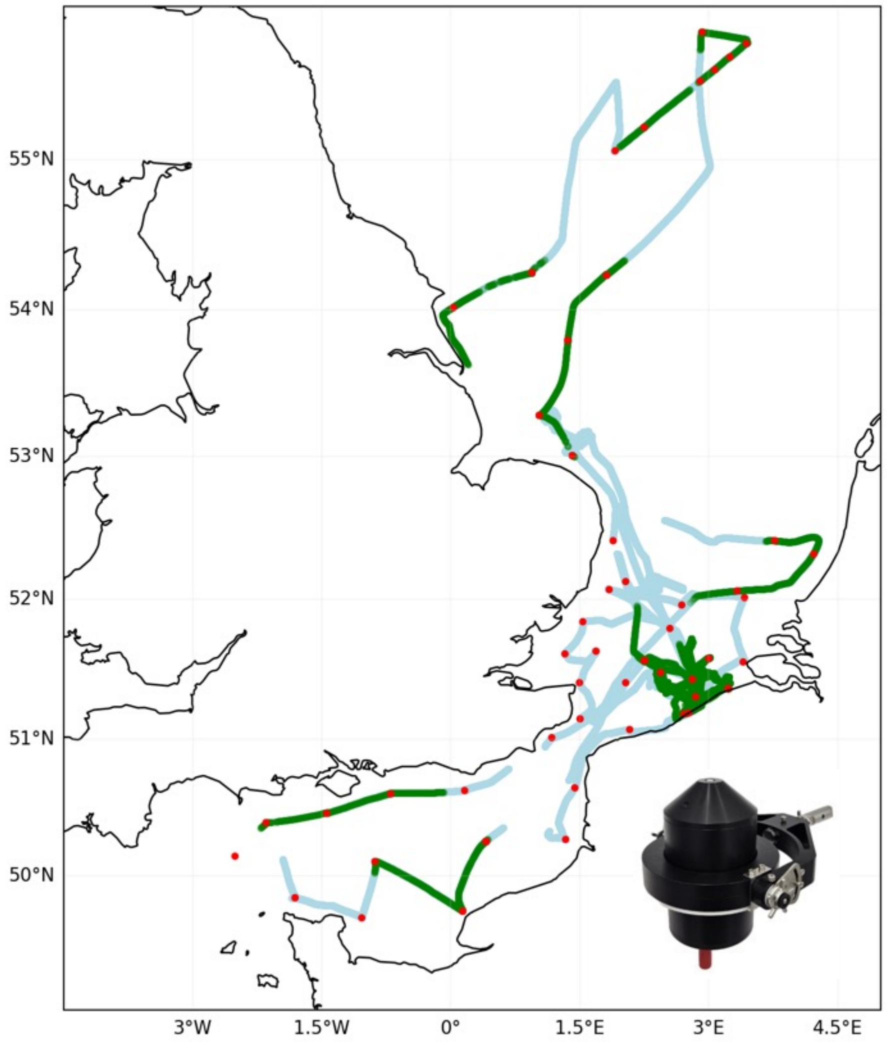
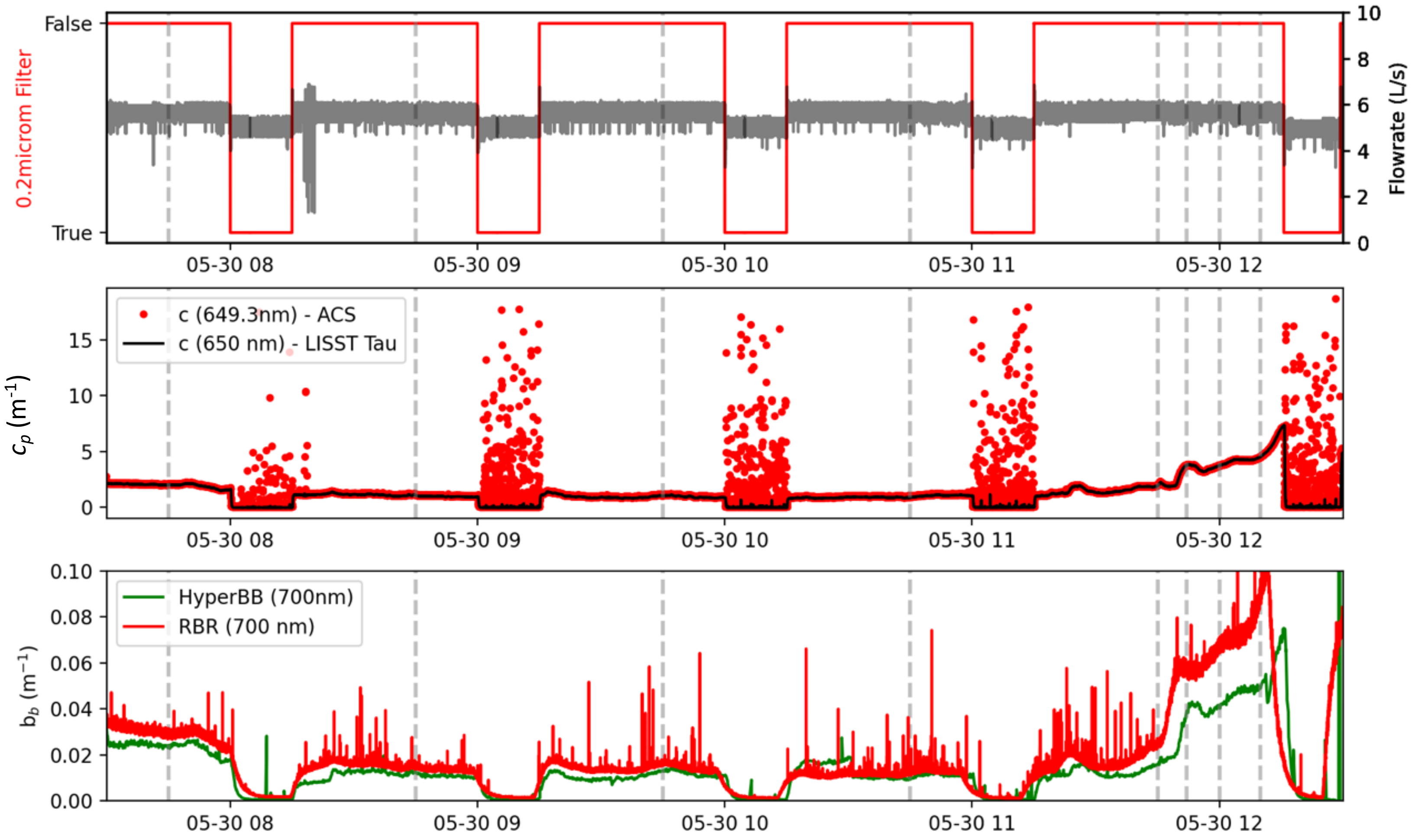
DALEC sampling points: 14 217 (8 074 QC'ed)



ANTHYLOPE PARTICULATE IOPS

$$\mathrm{IOP}_p(\lambda) = \mathrm{IOP}^{\mathrm{TSW}}(\lambda) - \mathrm{IOP}^{\mathrm{FSW}}(\lambda)$$

Using the 0.2μm filtered seawater (FSW)/unfiltered (TSW) differencing technique[3]



Time (hours) on 30 May 2024

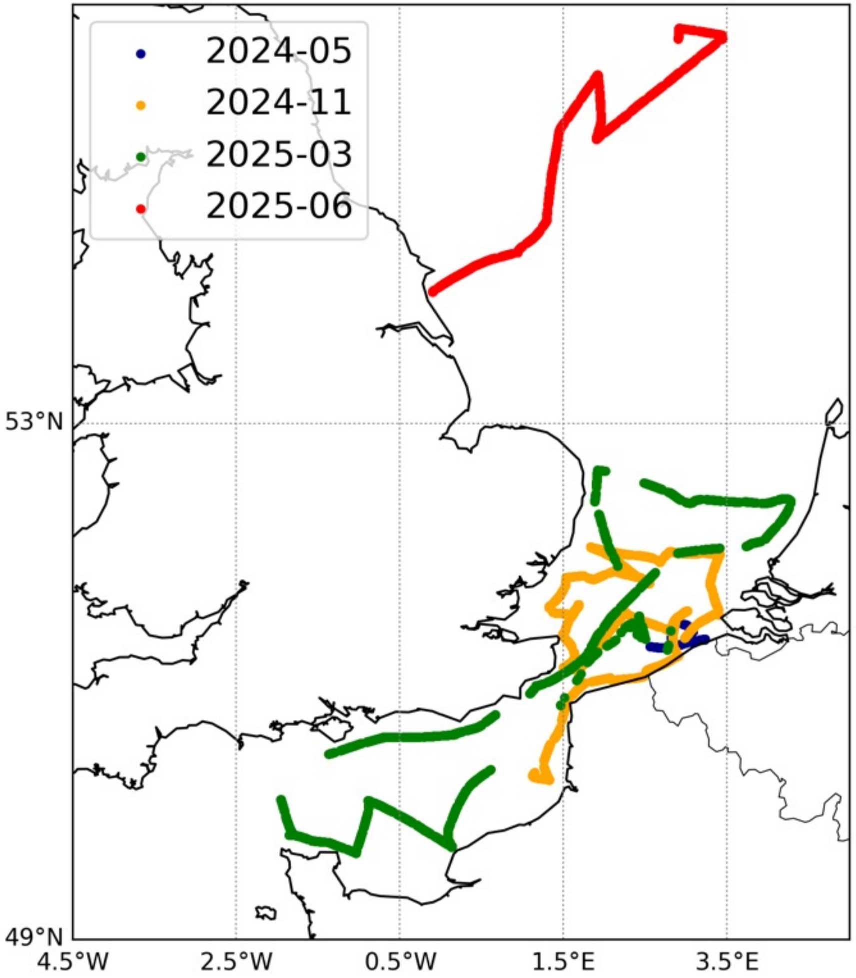
Filtering interval: ~10 min/hour

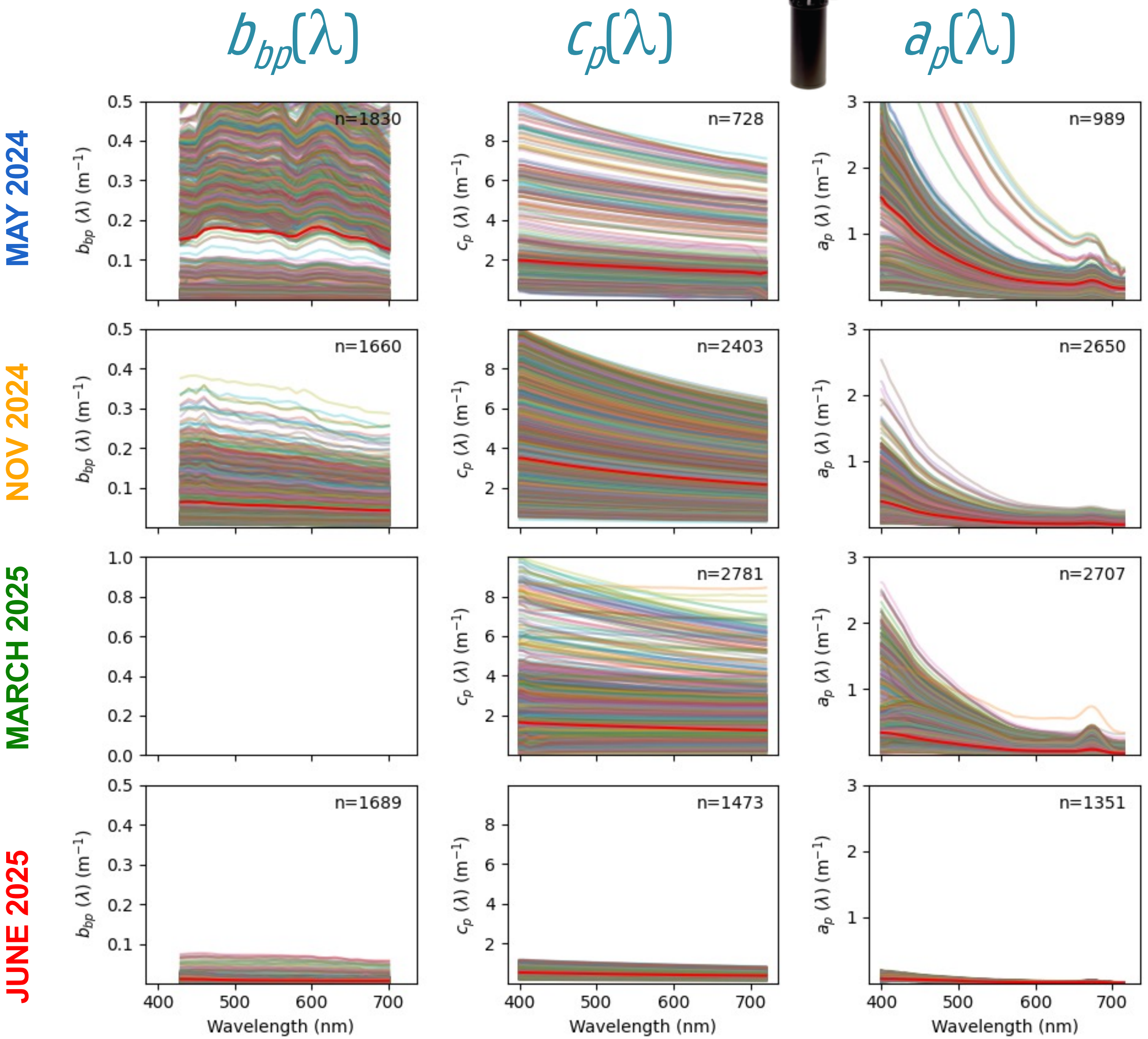
3-way valve switch & 0.2 μm filter

[3] Slade et al. (2010)

ANTHYLOPE PARTICULATE IOPS

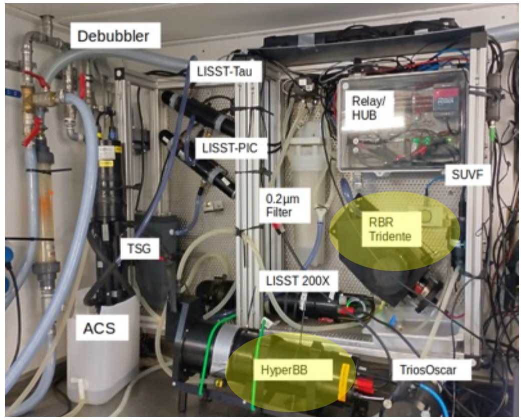
backscattering, attenuation, absorption:

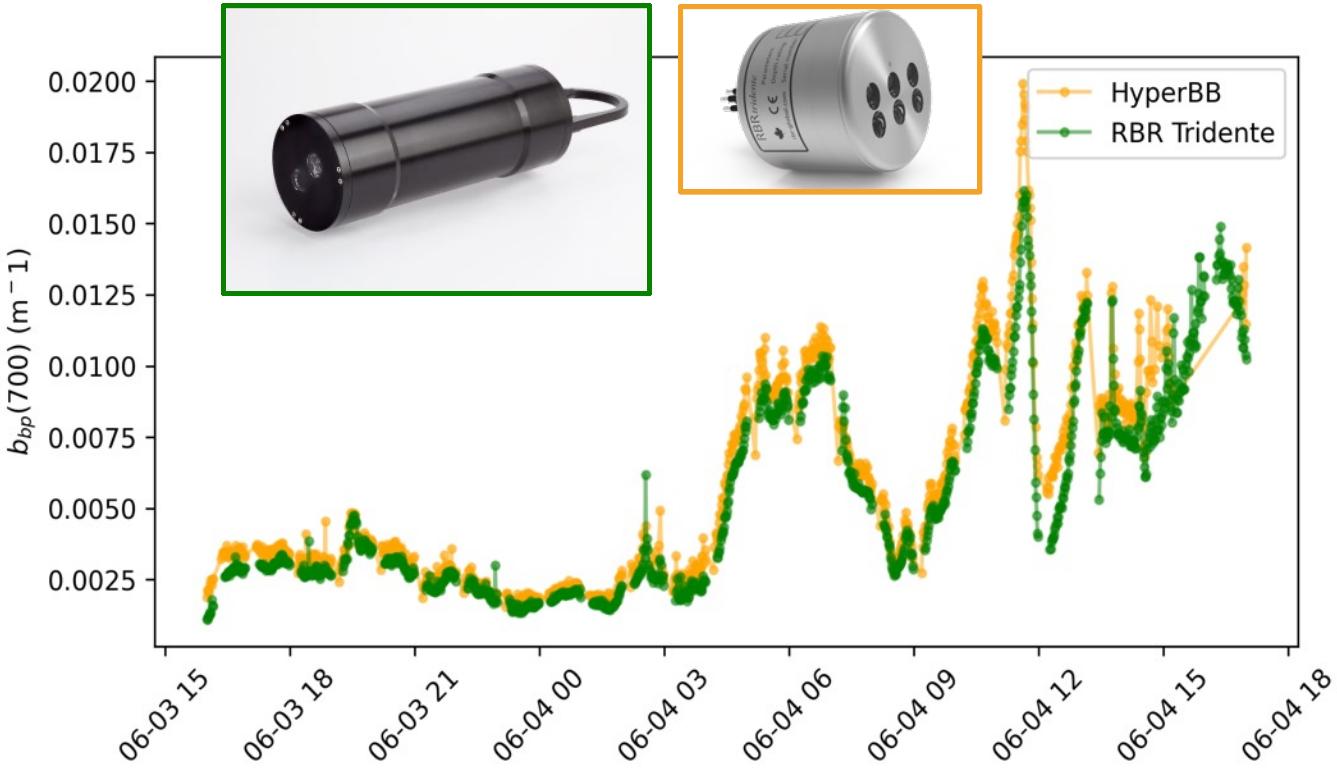




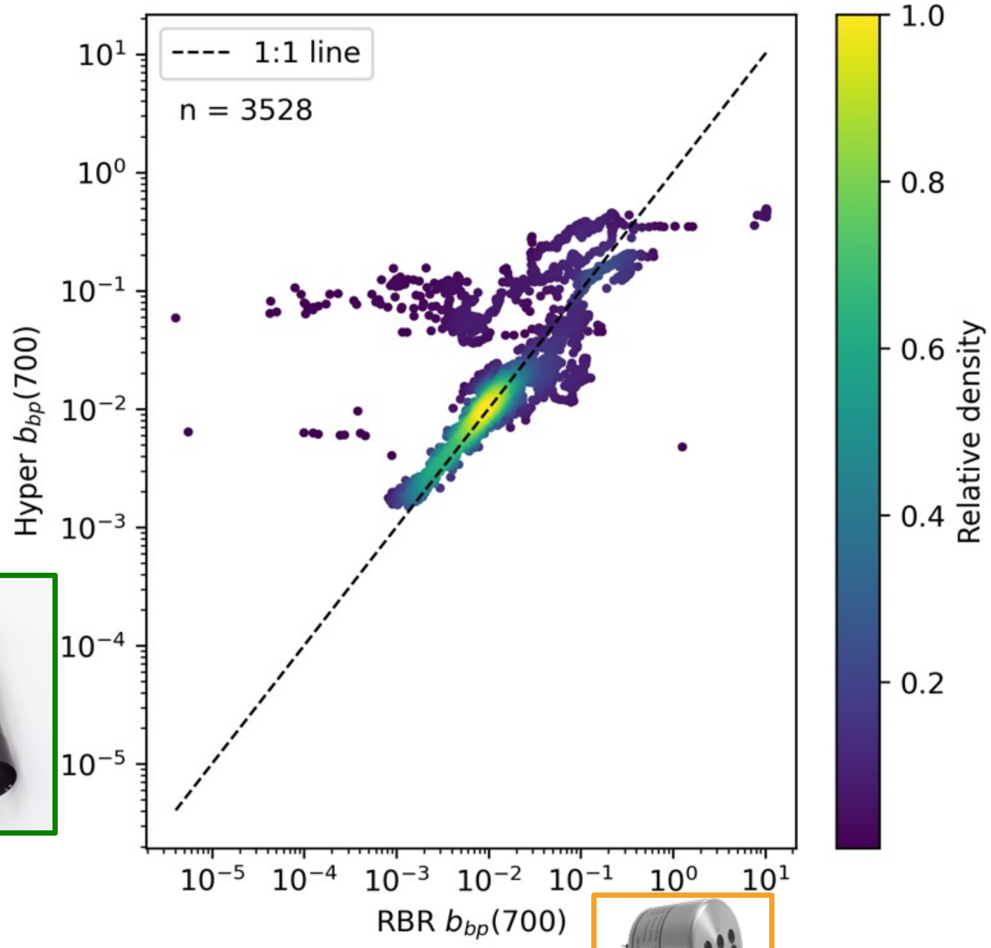
ATHYLOPE PARTICULATE IOPS

Consistency checks for b_{bp}(700nm)





Time (hours) in June 2025



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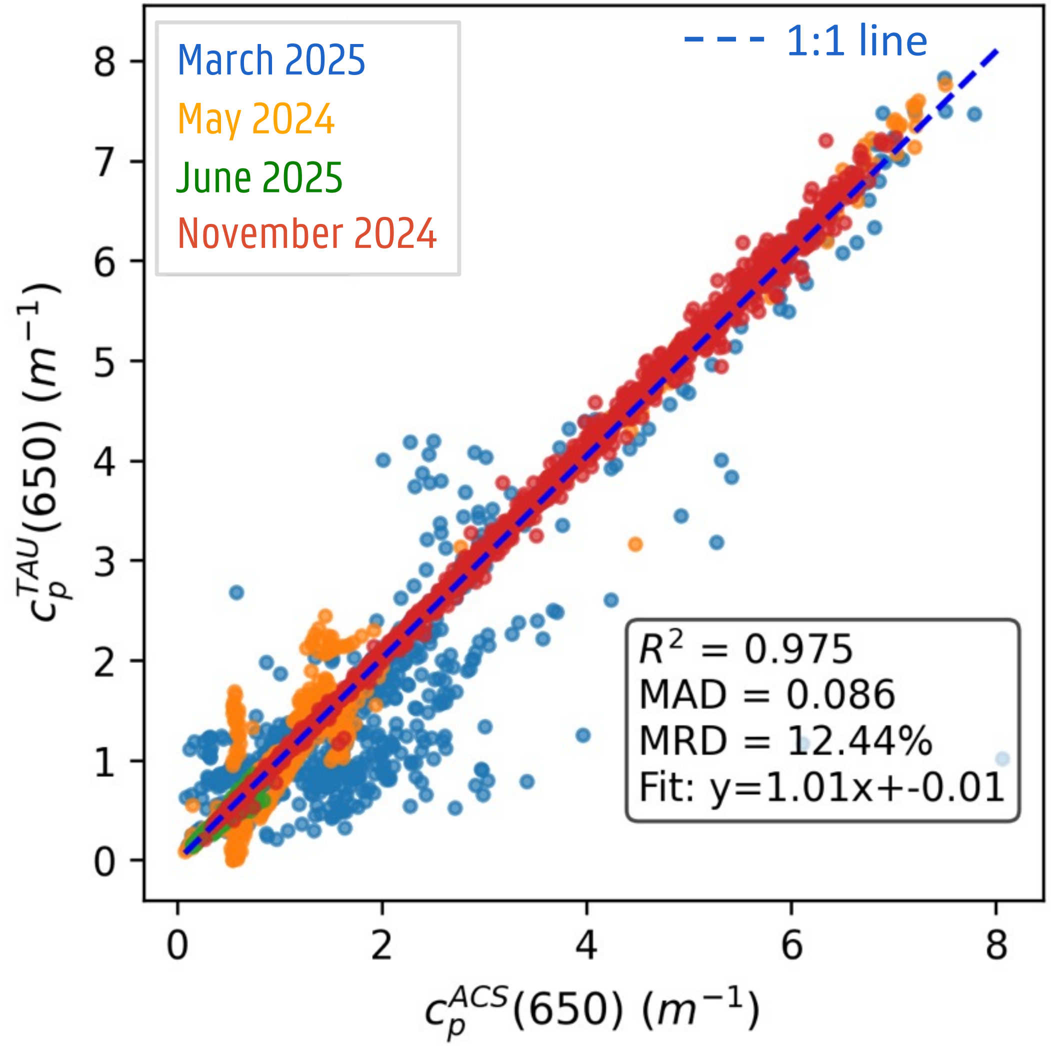
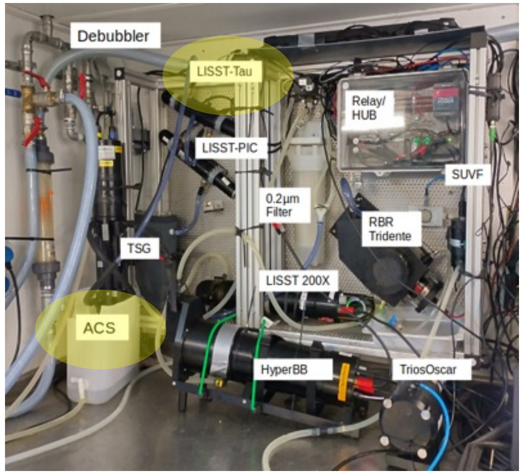
ATHYLOPE PARTICULATE IOPS

Consistency checks for c_p(650nm)





Differences in c_p(650nm) between instruments of 12% on average.

Harsh weather conditions in March 2025 : many bubbles cycled through the instruments, despite the integration of a debubbler.

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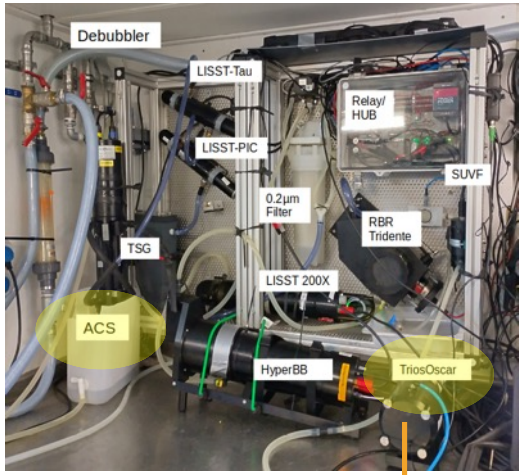
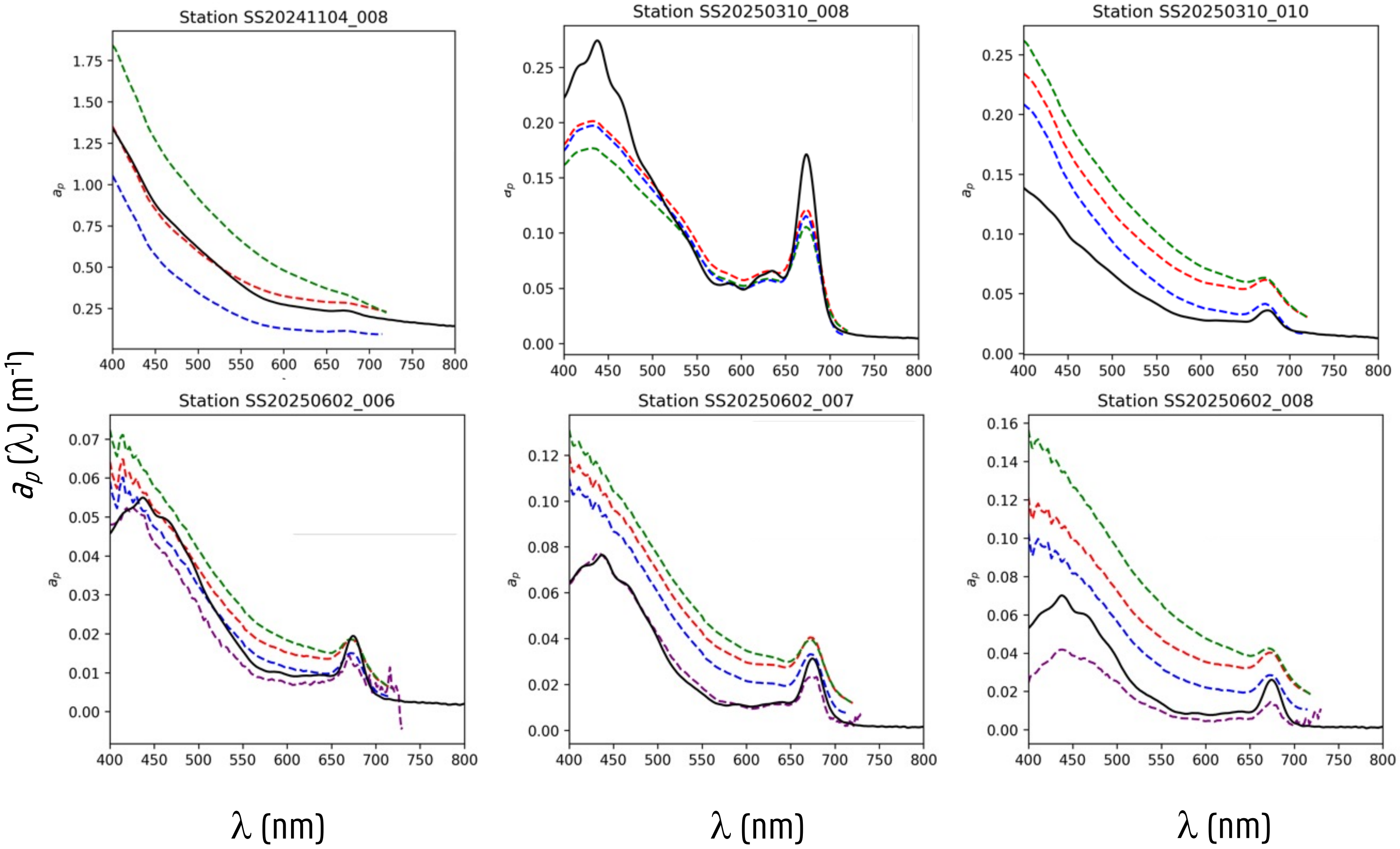
ATHYLOPE PARTICULATE IOPS

Consistency checks for $a_p(\lambda)$



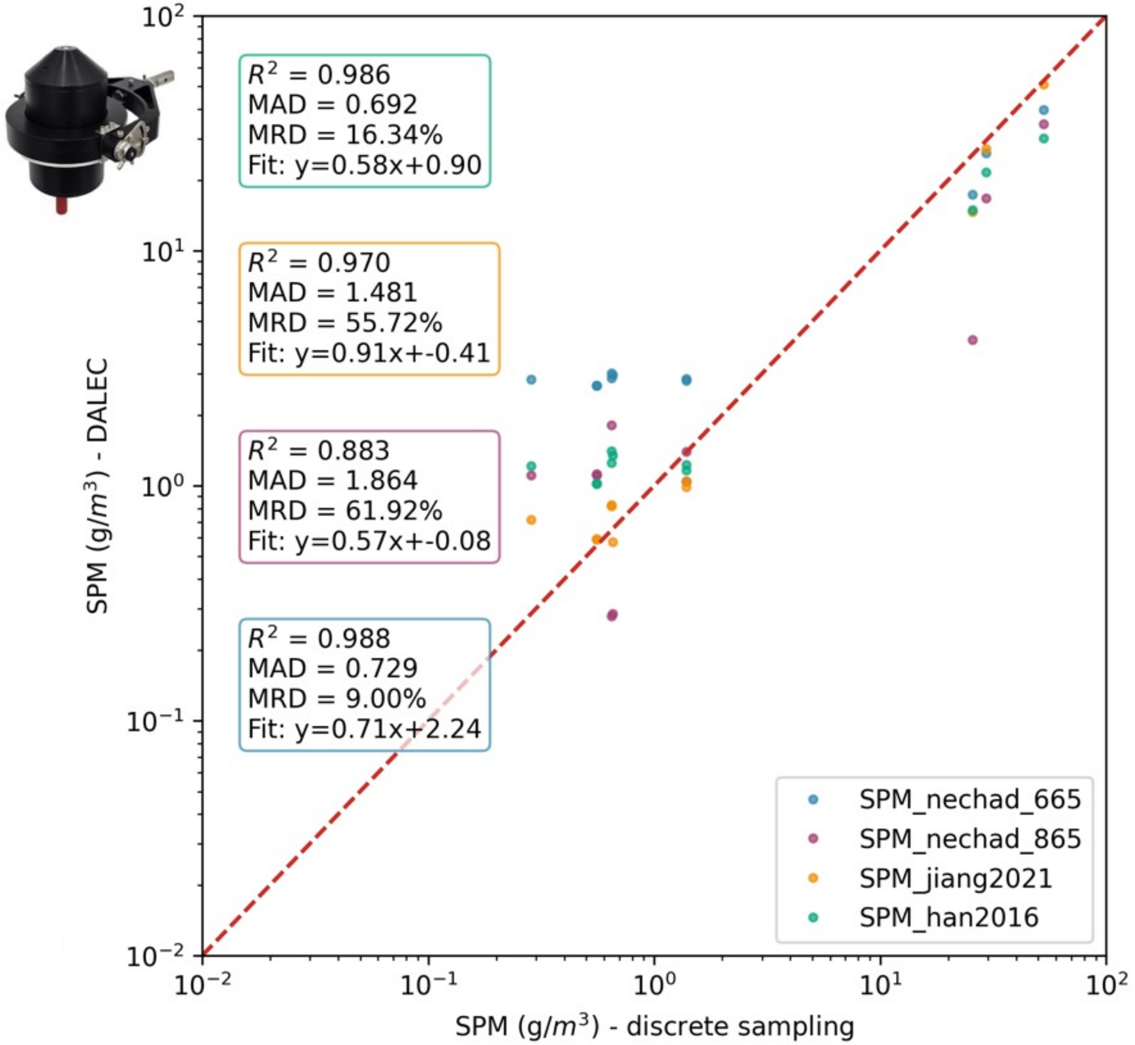


6/25 stations, comparing:

- Filter-pad spectro.
- ACS Rottgers et al. (2013) scattering correction
- ACS Rottgers et al. (2013) + optimized T corr.
- ACS Blended Rottgers et al. (2013) + Zaneveld (1994) (Boss and Bourdin in prep.)
- OSCAR (principle: Point Source Integrating Cavity Absorption Meter - PSICAM)

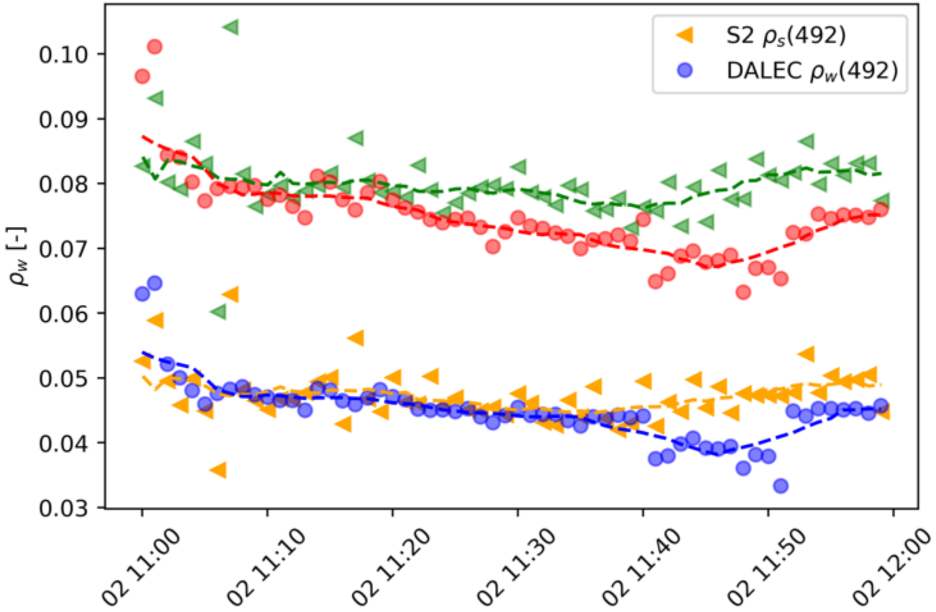
1) SPM ALGORITHM VALIDATION

Tested four RS algorithms for SPM in coastal waters



2) SENTINEL-2 REFLECTANCE VALIDATION

Using the DALEC above-water radiometry system

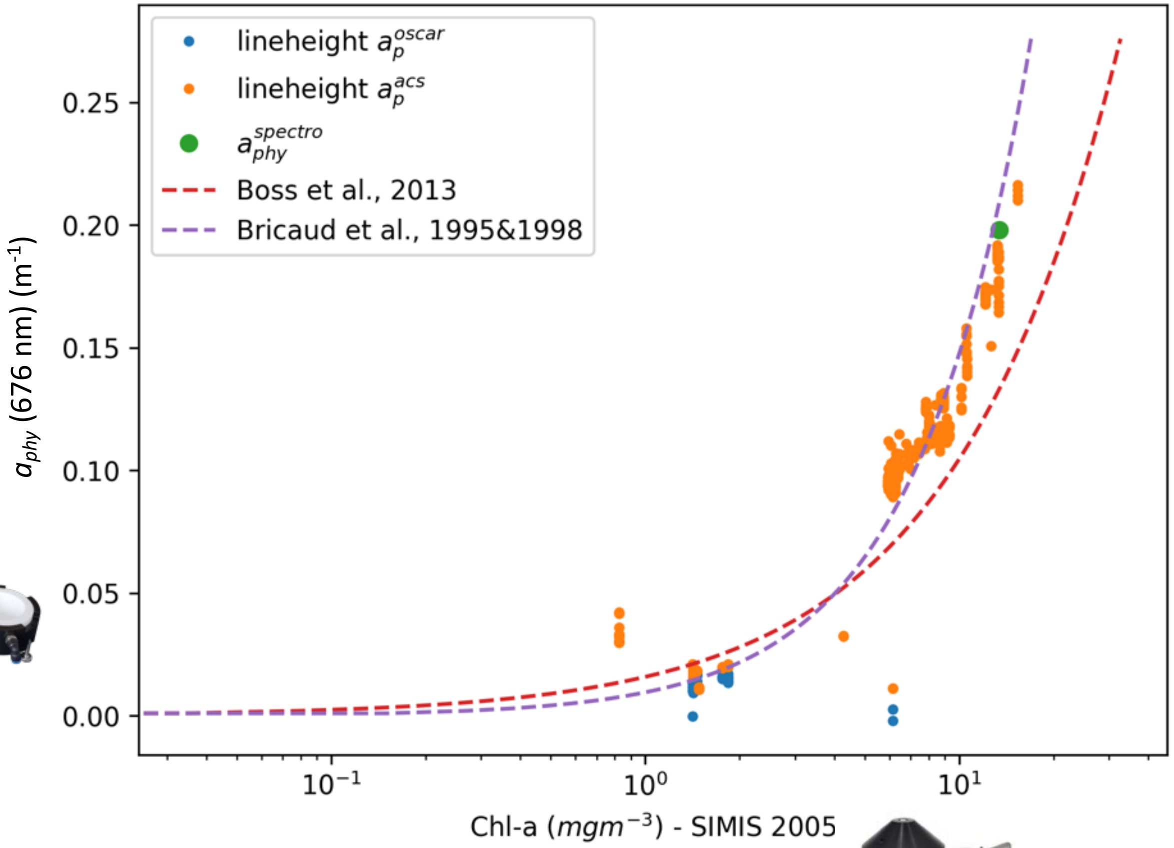


Good correspondence between marine reflectance retrieved from DALEC and Sentinel-2 satellite along ship transect.

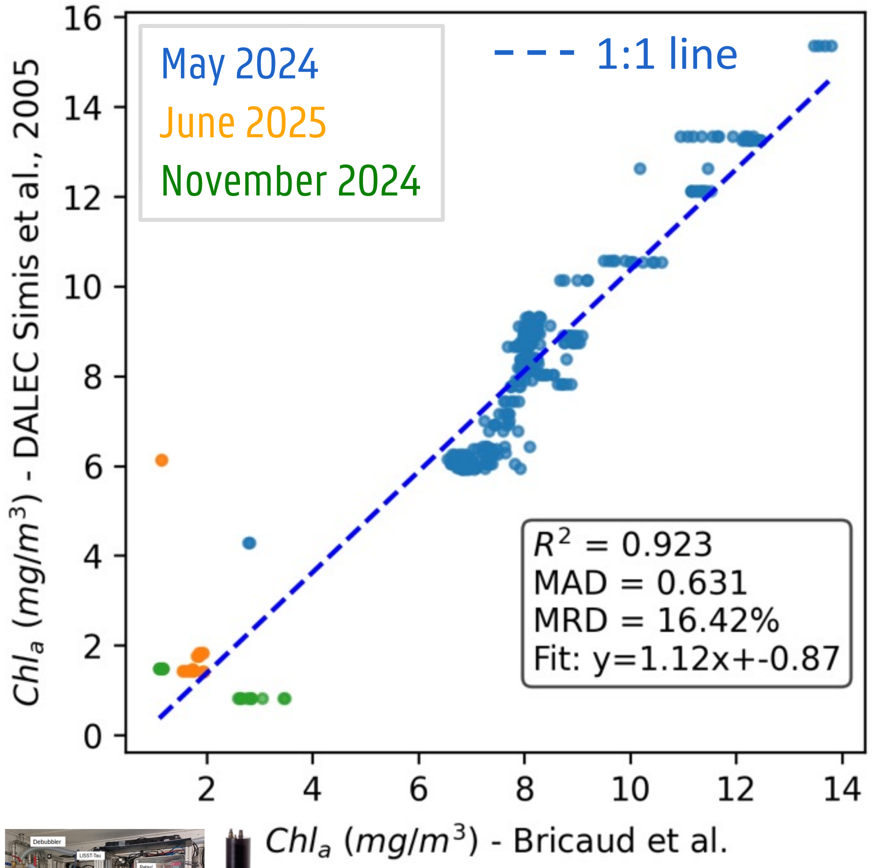
Jiang et al. (2021) two-step semi-analytical SPM retrieval algorithm seems to outperform the other SPM algorithms.

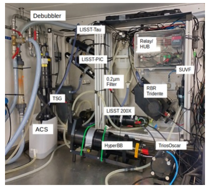
CHL-A ALGORITHM VALIDATION

a_{phy} (676nm) (from a_p line height) vs. ρ_w (DALEC)-based Chl-a



Chl-a (ATHYLOPE) vs. Chl-a (DALEC)





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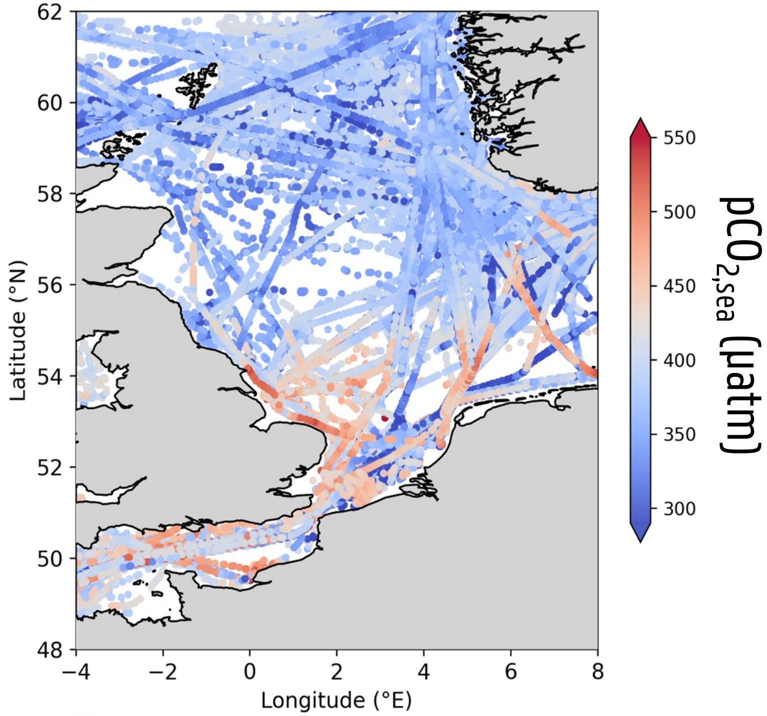
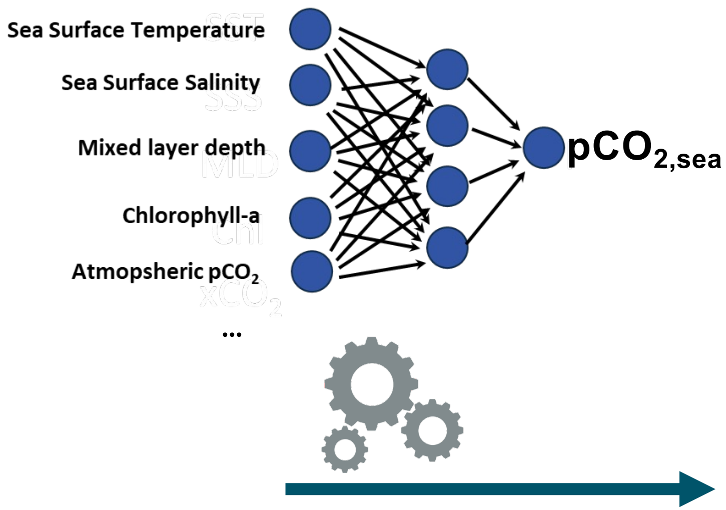
OBSERVATIONS TO SET UP THE NORTH SEA CARBON BUDGET

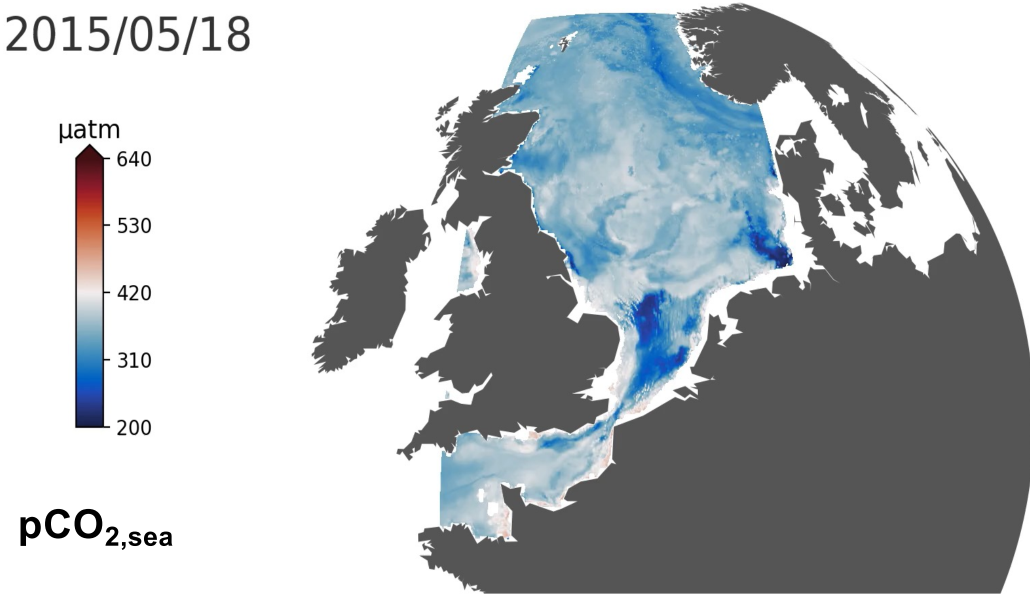
In situ pCO_2 + ATHYLOPE + DALEC

Develop/train a Neural Network method to estimate $pCO_{2,sea}$ that feeds on improved data products for particulate and dissolved carbon stocks and production (based on IOPs, marine reflectance, and ocean colour satellite data)





Self Organizing map - Feed Forward Neural Network (SOM-FFN) method[4]



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VLIZ

$pCO_{2,sea}$ at daily-weekly, 1km resolution

Test product provided by A. Van Langen Roson (VLIZ-MarSens PhD student, presenting on Tuesday 25/11)

[4] Landschutzer et al. (2015); Roobaert et al. (2024)

KNOWLEDGE GAPS AND PRIORITIES FOR NEXT STEPS

1 y

5 y

10 y

- Improve automation of the optical measurement systems
- Improve optical data processing and quality control
- Examine spatio-temporal variability in $pCO_{2,sea}$ and understand its physical, chemical, and biological drivers in coastal waters
- Improve algorithms for particulate and dissolved carbon stocks and production retrievals from IOPs, marine reflectance, and ocean colour satellite data
- Optimize (in situ and RS) observational strategy for marine carbon budgeting in coastal shelf seas
- Integration of optical measurements on other ICOS-Ocean stations
- Standardized and interoperable work flows for optical measurements and derived carbon variables

THANK YOU FOR YOUR ATTENTION!

Related OCFS presentations and IOCS posters:

- Castagna et al. : Retrieval of Particulate Inorganic Carbon (PIC) in the North Sea with the MTG/FCI geostationary sensor
- Keppens et al.: Influence of Marine Heatwaves on Coastal Carbon Cycling Using Machine Learning Reconstructions in the Belgian Coastal Sea
- Sun et al.: An Optical Sensor for Autonomous Detection of Particulate Inorganic Carbon (PIC) Concentration in Seawater
- Van Langen Roson et al.: Unraveling Biological Controls on Surface Ocean CO_2 from Ocean Colour Satellite Remote Sensing

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