The OCEAN (Ocean Color EarthCARE ANalysis) project

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Objectives & Approach

OCEAN: Ocean Color EarthCARE Analysis

24 months feasibility study approved by **ESA** within *the EARTHCARE+ INNOVATION - EXPRO+ Innovation program* (ESA 4000147849/25/I-AG)

OCEAN proposes to evaluate and document the feasibility of deriving in-water EarthCARE products:

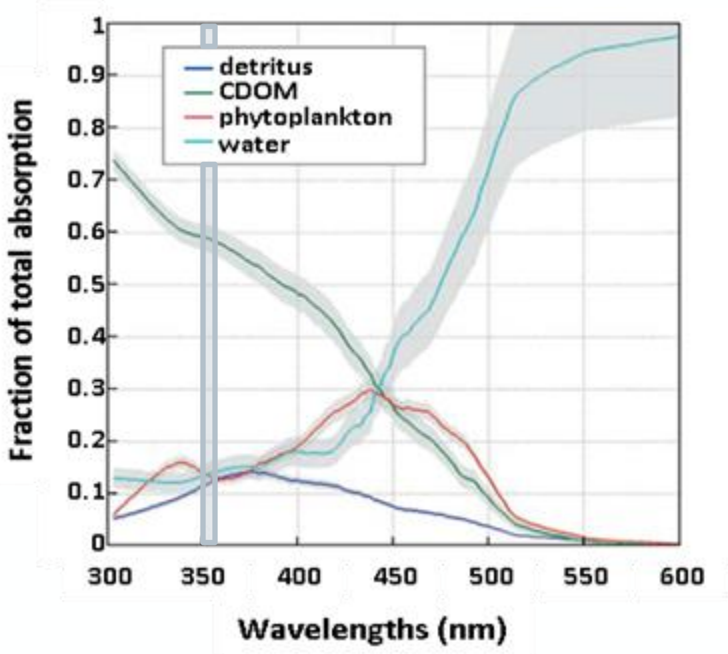
- Lidar parameters:
  - Attenuation coefficient (**K_L**)
  - Backscatter coefficient ($\boldsymbol{\beta^{par}_{wat}}$)

- Ocean Colour parameters:
  - Diffuse attenuation for downwelling irradiance (**K_d**)
  - Hemispheric particulate backscatter coefficient (**b_{bp}**)

- Bio-geochemical parameter:
  - Chromophoric Dissolved Organic Matter (**CDOM**)

$$K_d = -\frac{d \ln E_d}{dz}$$

$$b_{bp} = 2\pi \int_{\pi/2}^{\pi} \beta^{par}_{wat}(\theta) \sin(\theta)\, d\theta$$



In the UV, ***CDOM*** *is the most relevant contributor to the light absorption →* ***K_d*** *is used as a proxy of CDOM light absorption.*

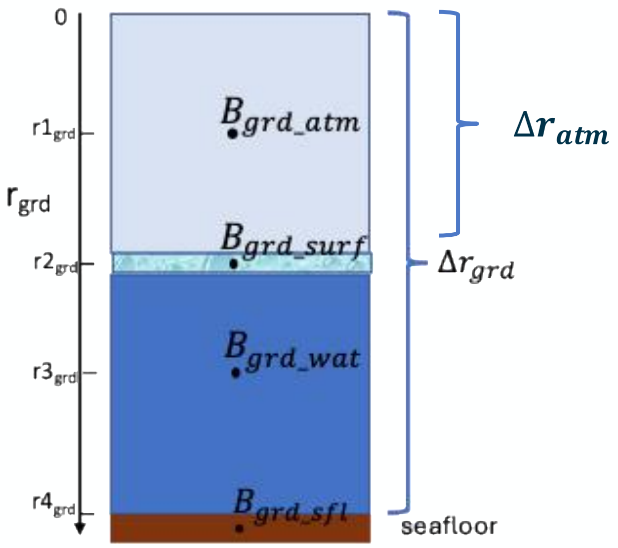
Objectives & Approach

ATLID integrated attenuated backscatter:
ATLID attenuated backscatter summed over 3 bins around the assumed surface (11% vertical crosstalk, *do Carmo et al. 2021*) and multiplied by the bin thickness Δr_{grd}

Mie (M) $A_M(r_{grd}) = \{B_{atmM} + B_{srfM} + B_{watM}\} T_A^2(r_{atm})$

Rayleigh (R) $A_R(r_{grd}) = \{B_{atmR} + B_{srfR} + B_{watR}\} T_A^2(r_{atm})$

Cross (X) $A_X(r_{grd}) = \{B_{atmX} + B_{srfX} + B_{watX}\} T_A^2(r_{atm})$



- $T_A^2(r_{atm})$ estimated with L2 ATLID products
- B_{atmY} estimated using the information in the bins above the ground bin and multiplied by Δr_{atm}
- No seafloor contribution
- $B_{srfM} = \frac{\rho}{4\pi\sigma^2\cos^4\theta}\exp\left(-\frac{\tan^2\theta}{\sigma^2}\right)$ $B_{srfR} = 0$ $B_{srfX} = 0$

Objectives & Approach

Rayleigh (R)

$$B_{watR} = f \cdot \frac{T_{srf}^{dn} T_{srf}^{up}}{n^2} \cdot \int_0^\infty \beta_{wat}^{mol} \cdot T_{wat}^2(r) dr \quad \Rightarrow \quad K_L = f \cdot \frac{T_{srf}^2}{n^2} \cdot \frac{\beta_{wat}^{mol}}{2B_{watR}}$$

- Assuming complete extinction of the signal in the bin
- $T_{wat}^2(r) = e^{-2K_L r}$ vertically homogenous extinction
- $T_{srf}^{dn} = T_{srf}^{up} = T_{srf}(\phi, \theta, u, v)$ from wind and surface modelling
- Pure seawater backscatter coefficient β_{wat}^{mol} known
- Negligible depolarization from molecular (Brillouin) scattering
- Refractive index $n(T, S)$ known
- spectral response function ratio $f \approx 1$
  (G-J. van Zadelhoff and J. Smith, personal communication)

Mie (M)

$$B_{watM} = \frac{T_{srf}^{dn} T_{srf}^{up}}{n^2} \cdot \int_0^\infty f_C(r) \cdot \beta_{wat}^{par}(r) \cdot T_{wat}^2(r) dr \quad \Rightarrow \quad \beta_{wat}^{par} = B_{watM} \cdot \frac{n^2}{T_{srf}^2} \cdot 2K_L(1+\delta)$$

$$f_X(r) = 1 - f_C(r) \qquad \delta = \frac{f_X}{f_C}$$

⚠ Signal dominated by the high surface reflectance

Objectives & Approach

Cross (X)

$$B_{watX} = \frac{T_{srf}^{dn} T_{srf}^{up}}{n^2} \cdot \int_0^\infty \left[f_X(r)\beta_{wat}^{par}(r) + 2\left(f_C(r)\beta_{wat}^{par}(r) + \beta_{wat}^{mol}\right)\int_0^r \gamma(r')dr' \right] \cdot T_{wat}^2(r)dr$$

Assuming $\gamma(r')$ vertically homogeneous: $\int_0^r \gamma(r')dr' = \gamma r$

depolarization by forward multiple scattering

$$\Rightarrow \quad B_{watX} = \frac{T_{srf}^2}{n^2} \cdot \left[\frac{\delta}{1+\delta} \frac{\beta_{wat}^{par}}{2K_L} + \frac{\left(\beta_{wat}^{par}/(1+\delta) + \beta_{wat}^{mol}\right)\gamma}{2{K_L}^2} \right]$$

γ from literature or derived through MC

If all three signals have sufficient SNR, K_L, β_{wat}^{par}, and δ can be retrieved.

The high intensity of the surface reflection prevents the use of Mie channel
→ additional assumptions are necessary

$$\delta = \begin{cases} 2K_d(532) & \text{if } K_d(532) < 0.15\ m^{-1} \\ 0.3 & \text{otherwise} \end{cases}$$

Behrenfeld et al. 2013

$$\frac{\delta}{(1+\delta)} \approx 1.6K_d$$

Behrenfeld et al. 2022

Rayleigh channel: K_d and Chl-a

- Ground bin selected with FM `featuremask`

- Data selected using the following flags and masks:
  - No bad retrievals / fully Rayleigh attenuated bins
  - No clouds or thick aerosol in the bin above surface
  - Ocean
  - Ice-free conditions
  - Signal-based surface detection

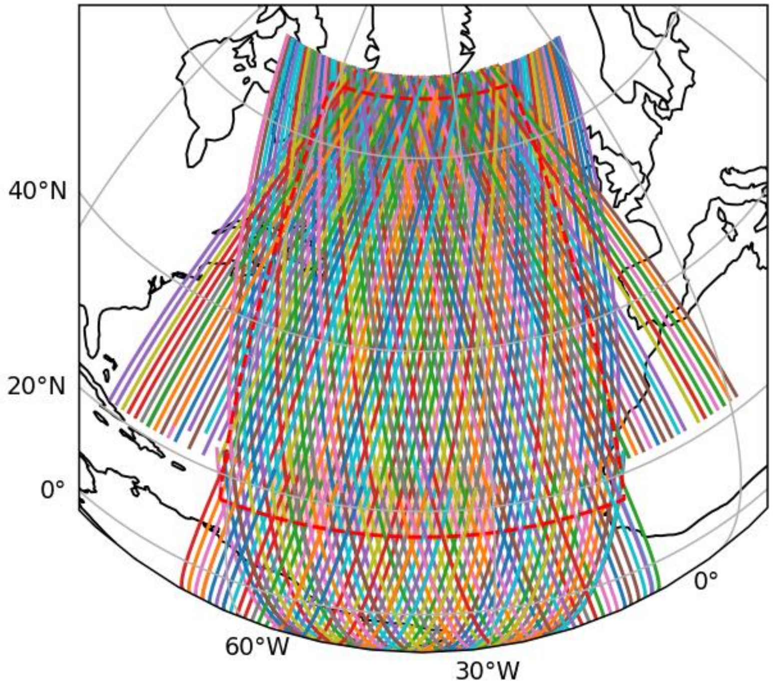
- Signal integrated over 100 measurements (including non-selected)

- In-water signal calculated as:

$$B_{watR} = \frac{A_R(r_{grd})}{T_A^2} - B_{atmR}$$

- T_A^2 and B_{atmR} calculated using:
  - FM: `surface_rayleigh_tau`
  - EBD: `particle_optical_depth_355nm` (high resolution)
  - EBD: `rayleigh_backscatter_355nm_model`

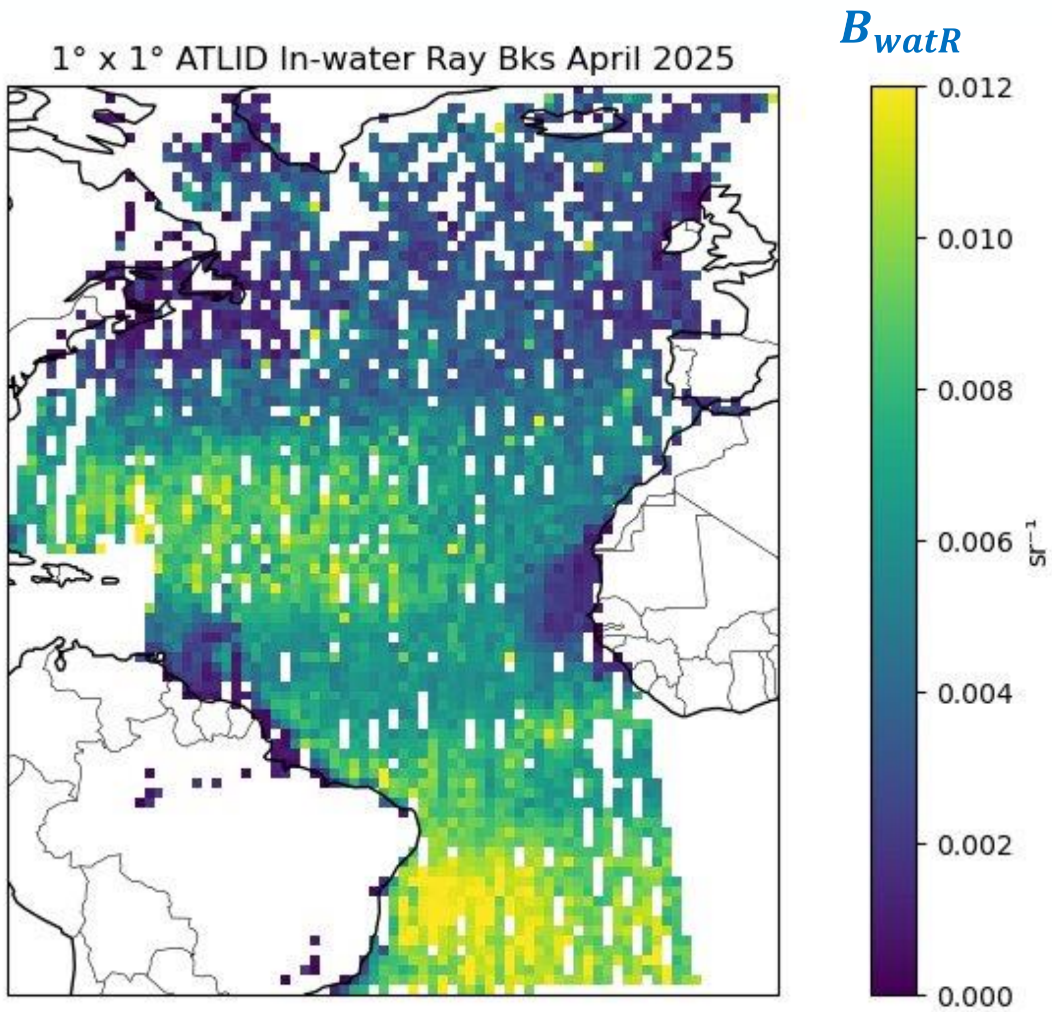
Test on baseline BA for April and September 2025

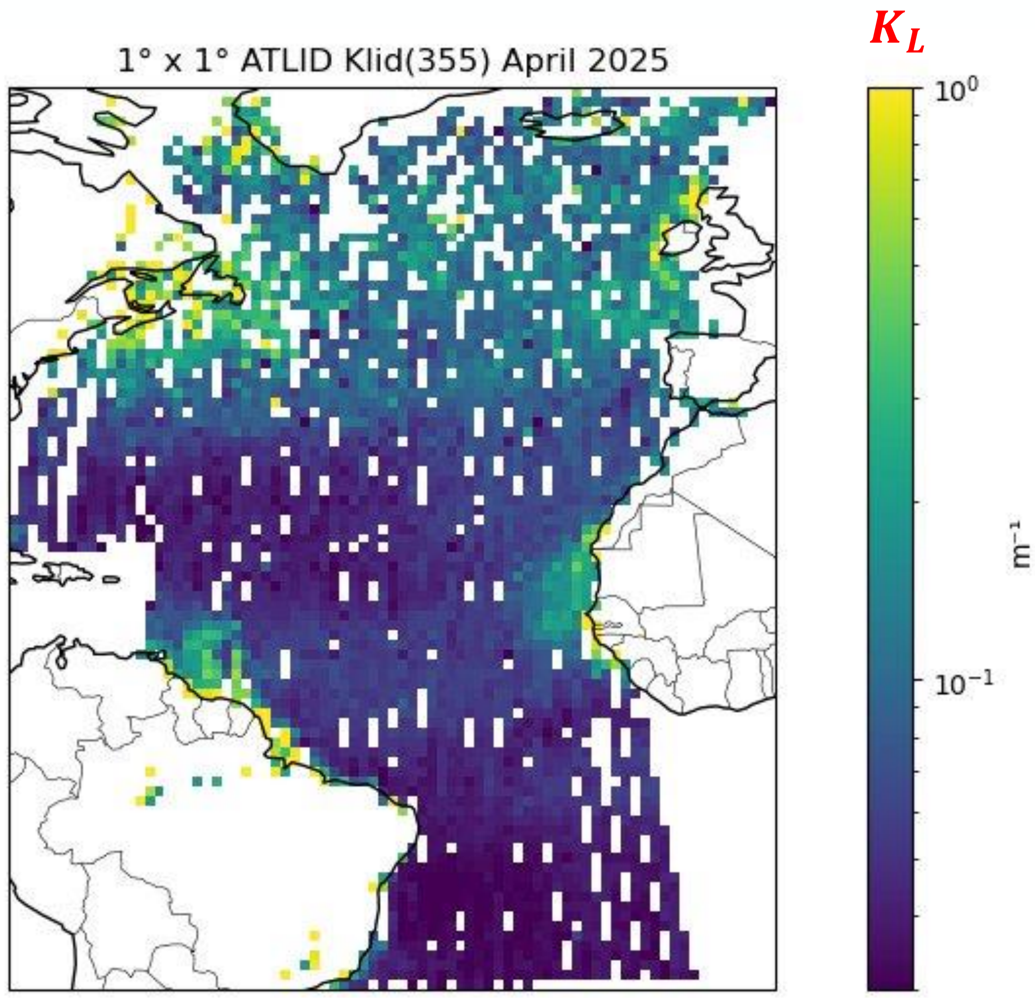


$$K_L = f \cdot \frac{T_{srf}^2}{n^2} \cdot \frac{\beta_{wat}^{mol}}{2B_{watR}} \quad \Rightarrow \quad K_L \sim K_d \quad \Rightarrow \quad K_d = 0.0239 + 0.149 \cdot Chl{-}a^{0.767}$$

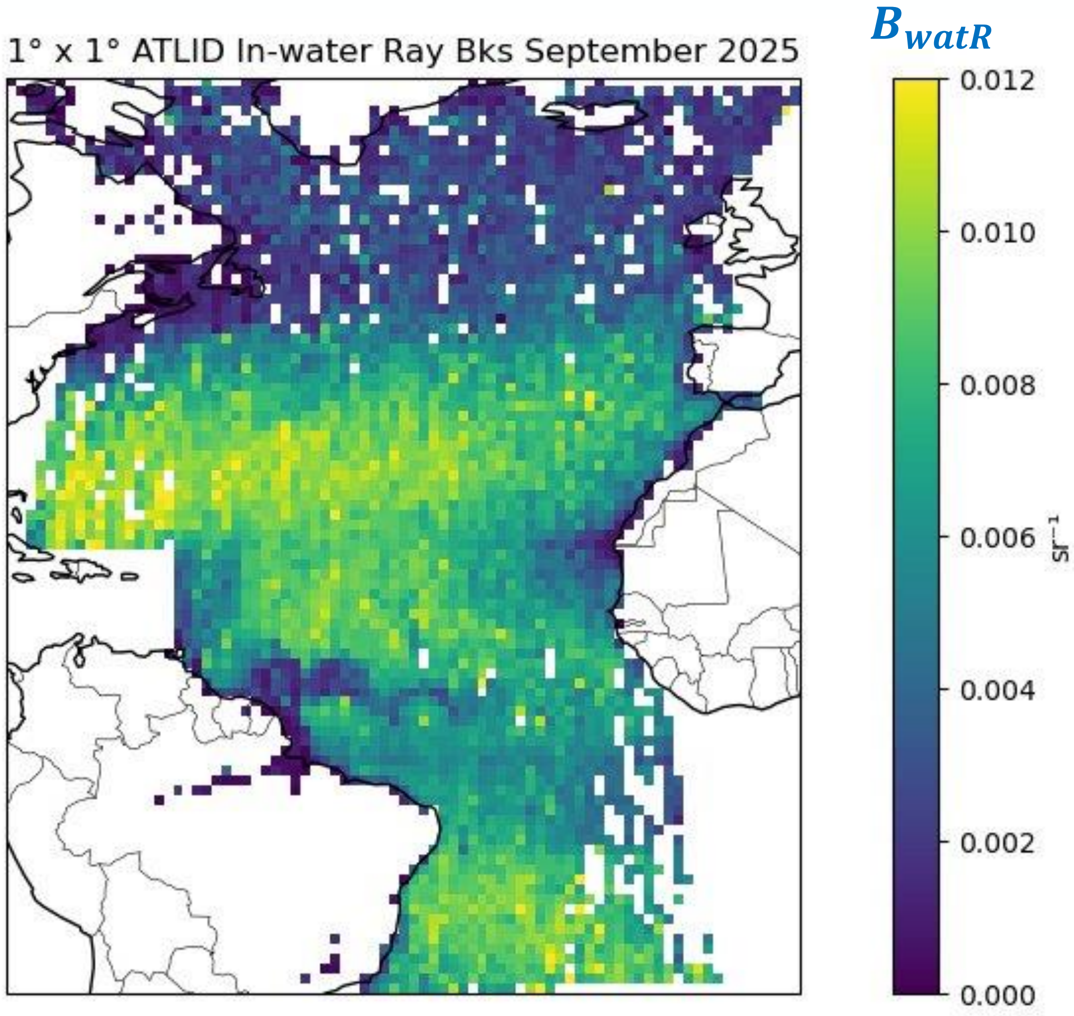
Case 1 waters, Morel and Maritorena 2001

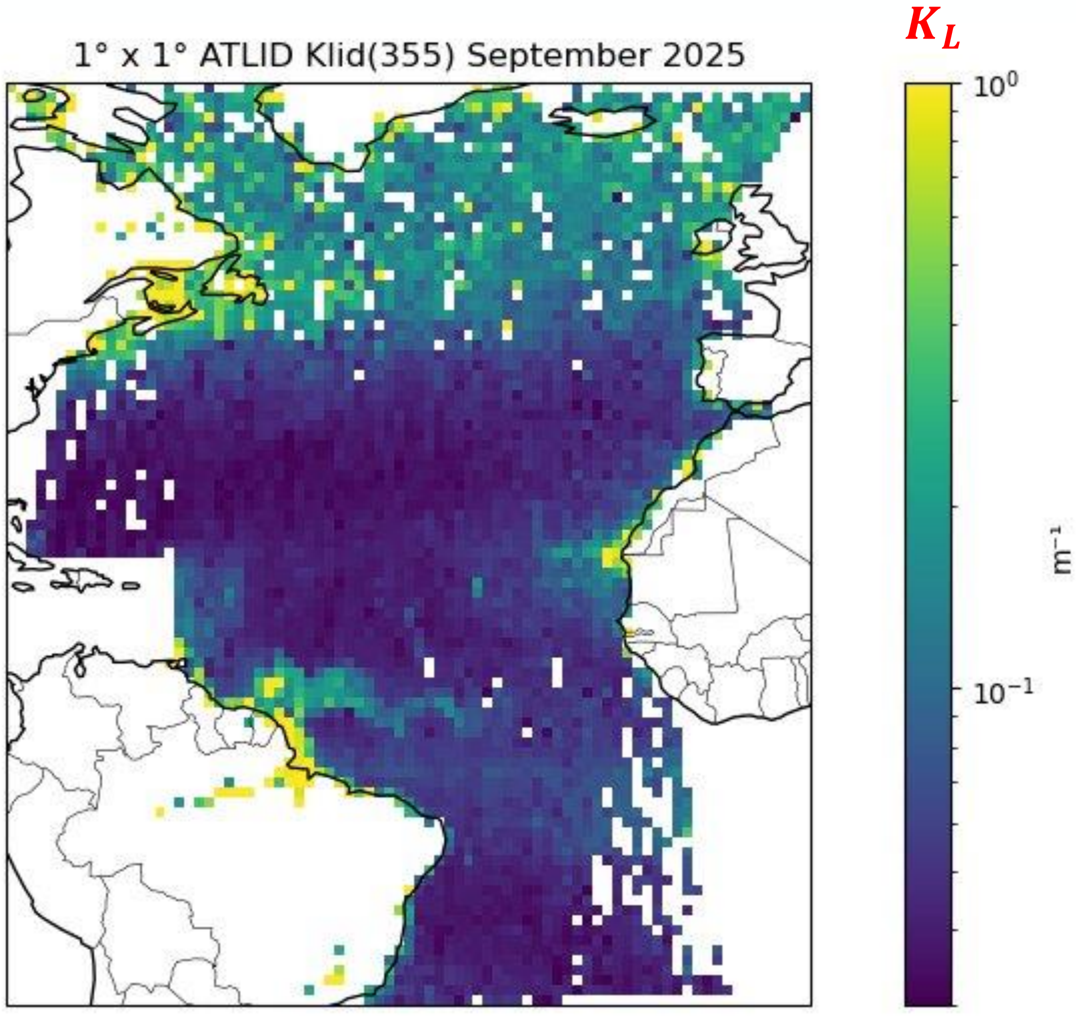
ATLID B_{watR} and K_L (1x1 degree average, April 2025)



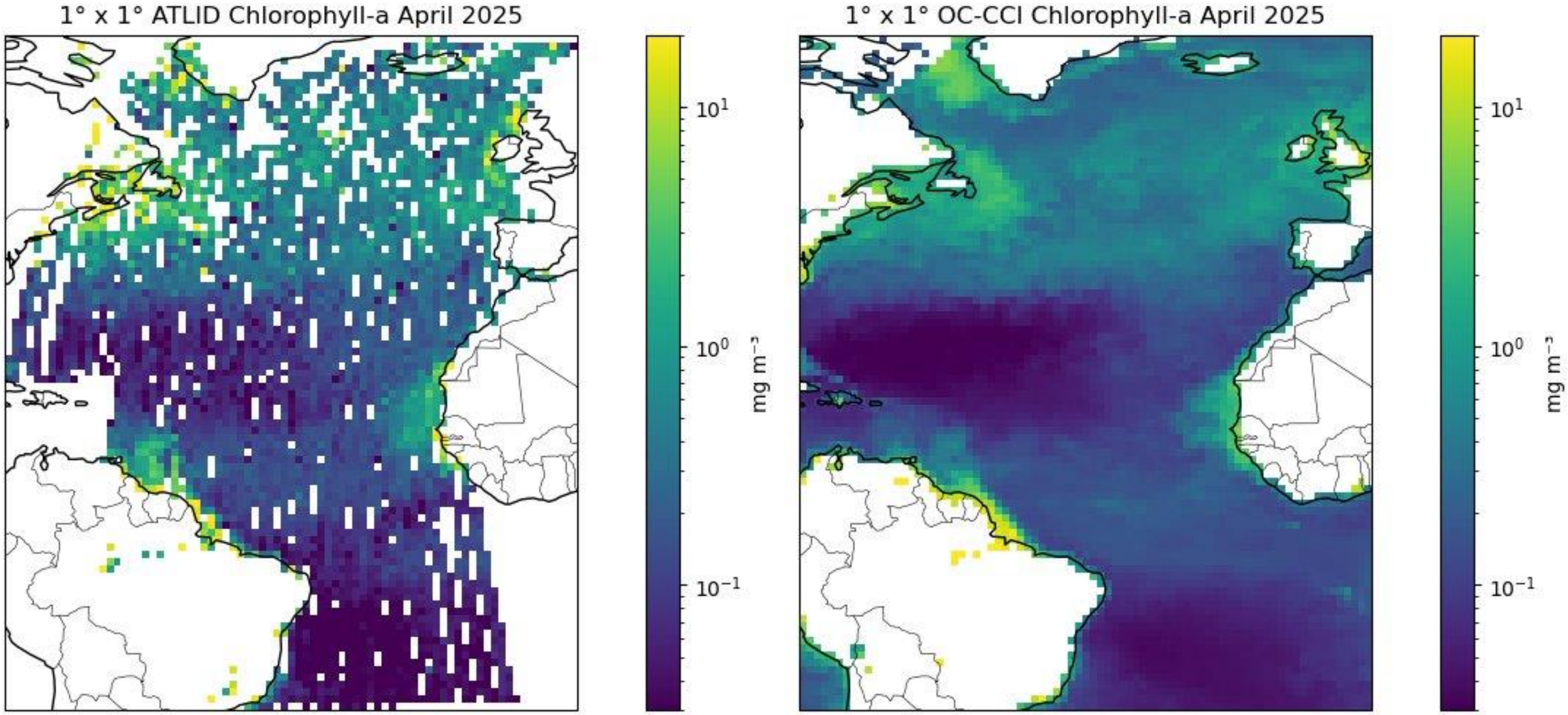


ATLID B_{watR} and K_L (1x1 degree average, September 2025)

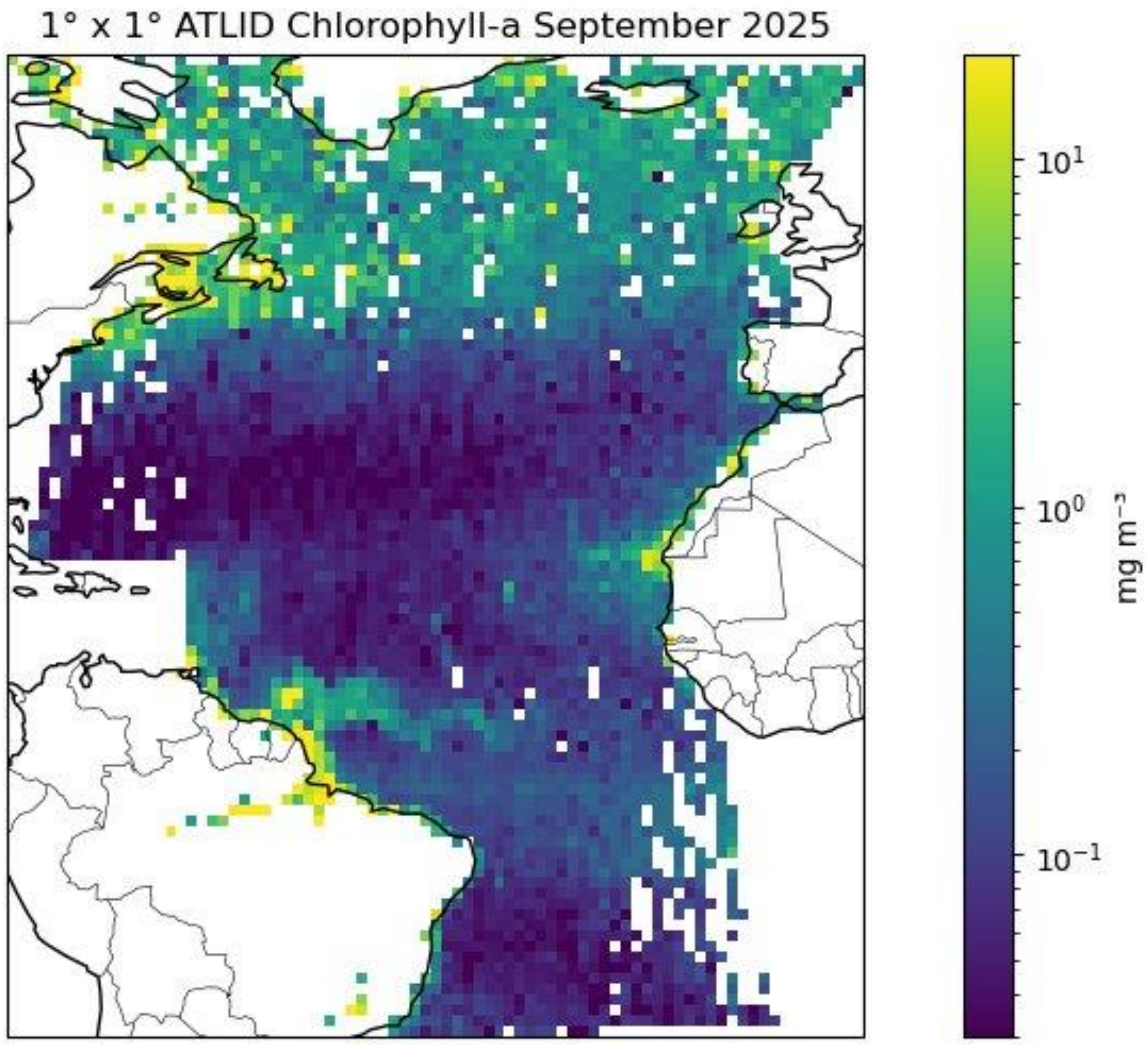


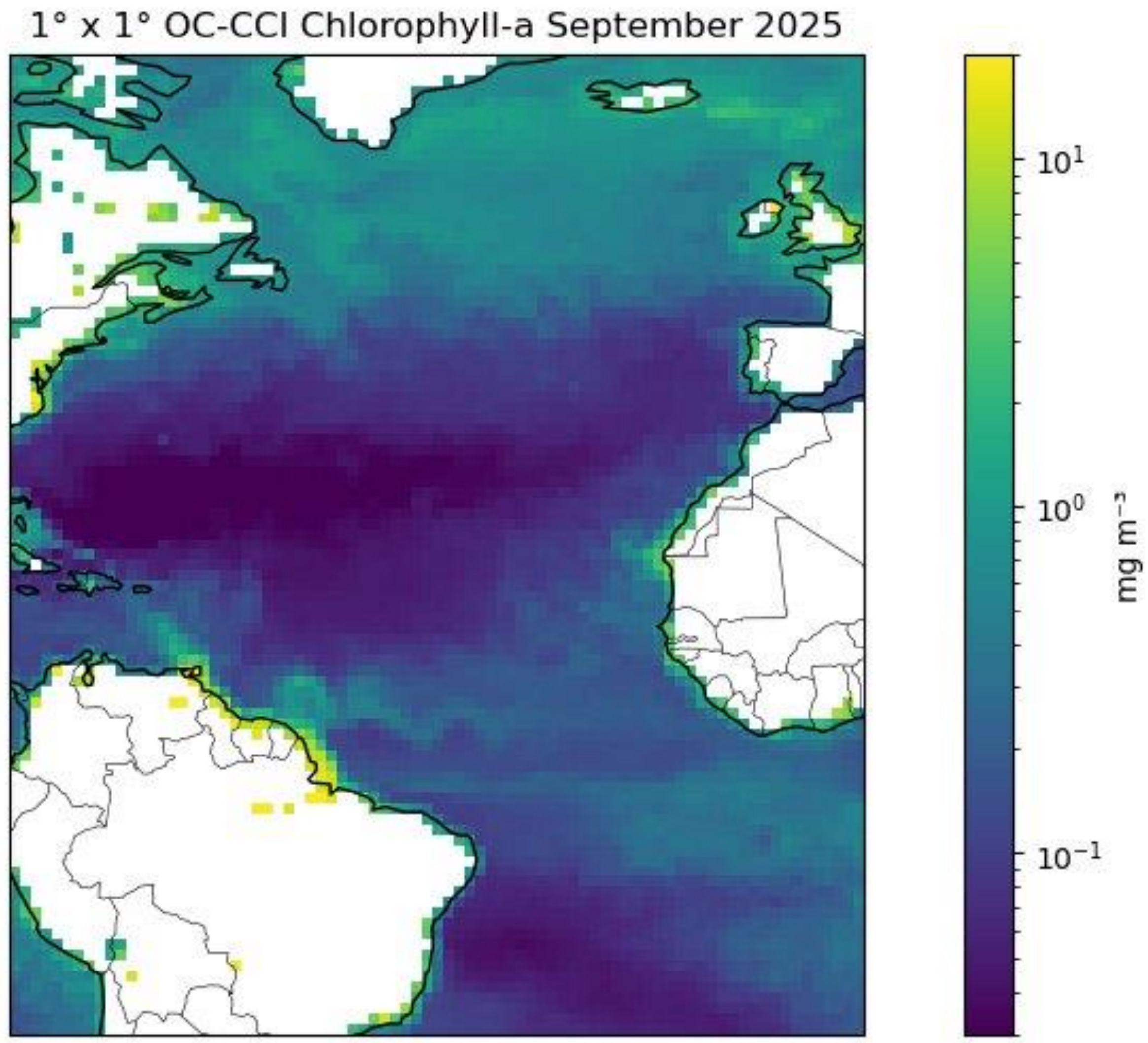


Chl-a: ATLID vs OC-CCI (1x1 degree average, April 2025)

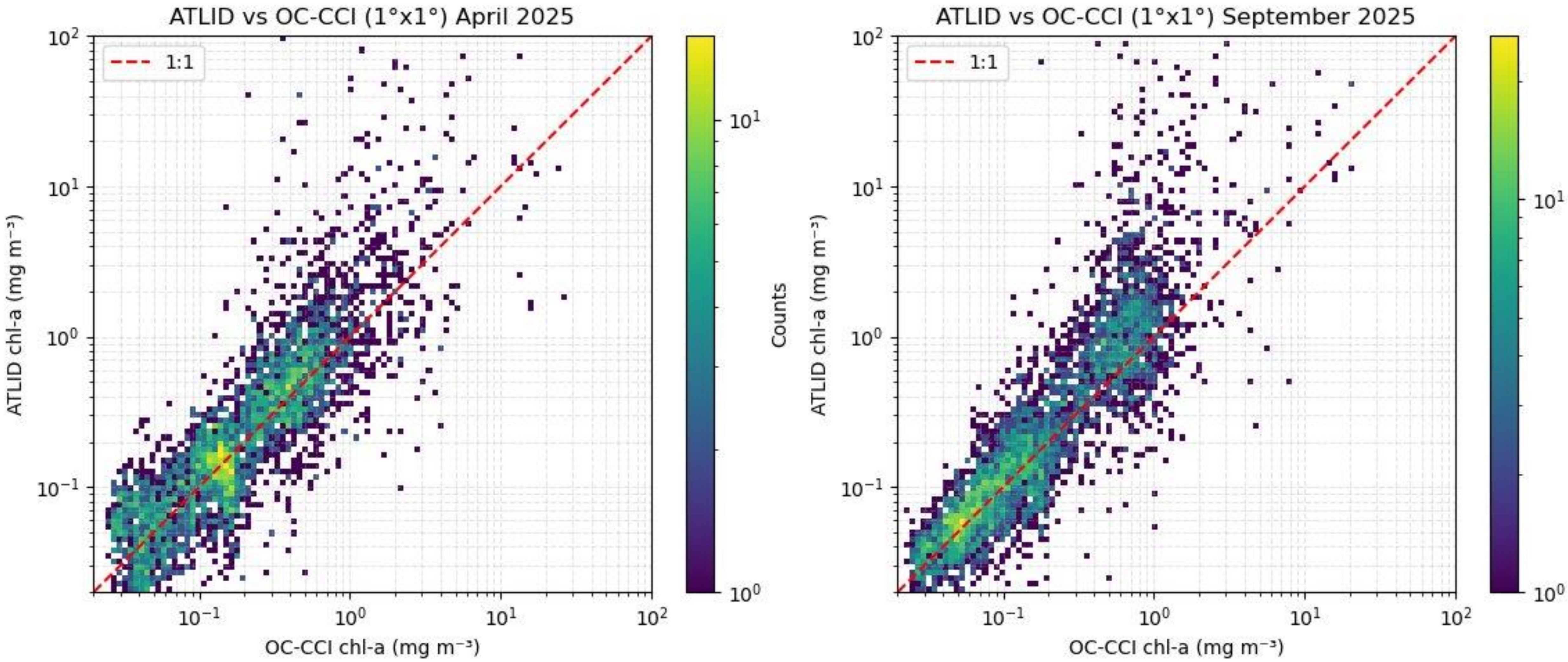


Chl-a: ATLID vs OC-CCI (1x1 degree average, September 2025)



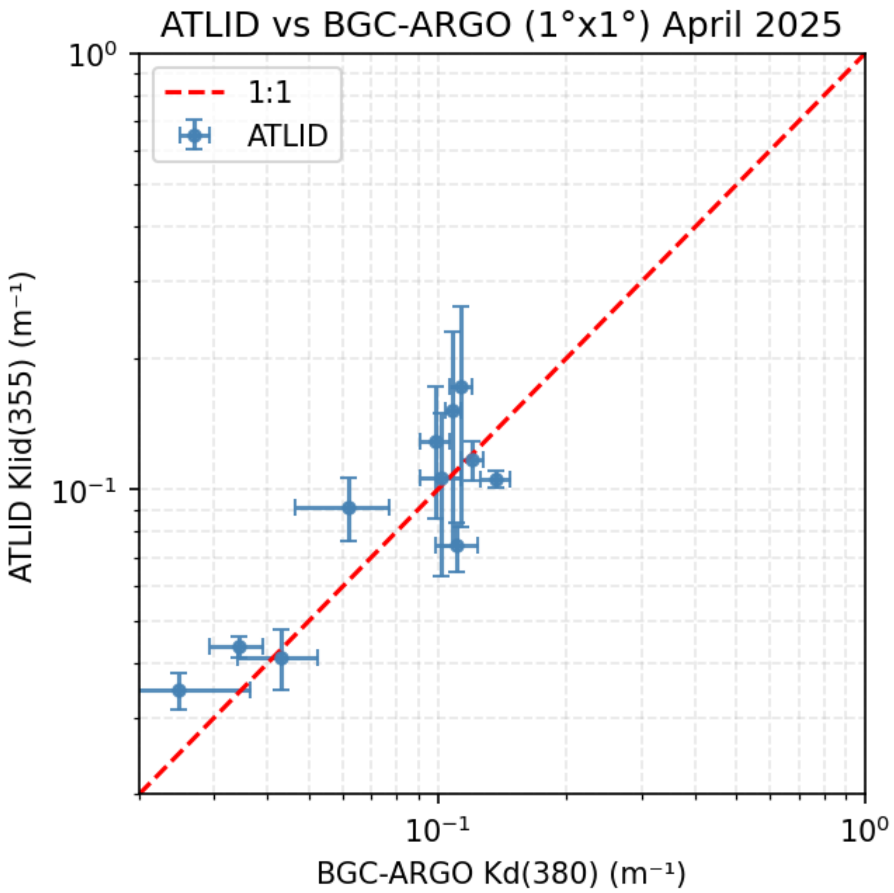


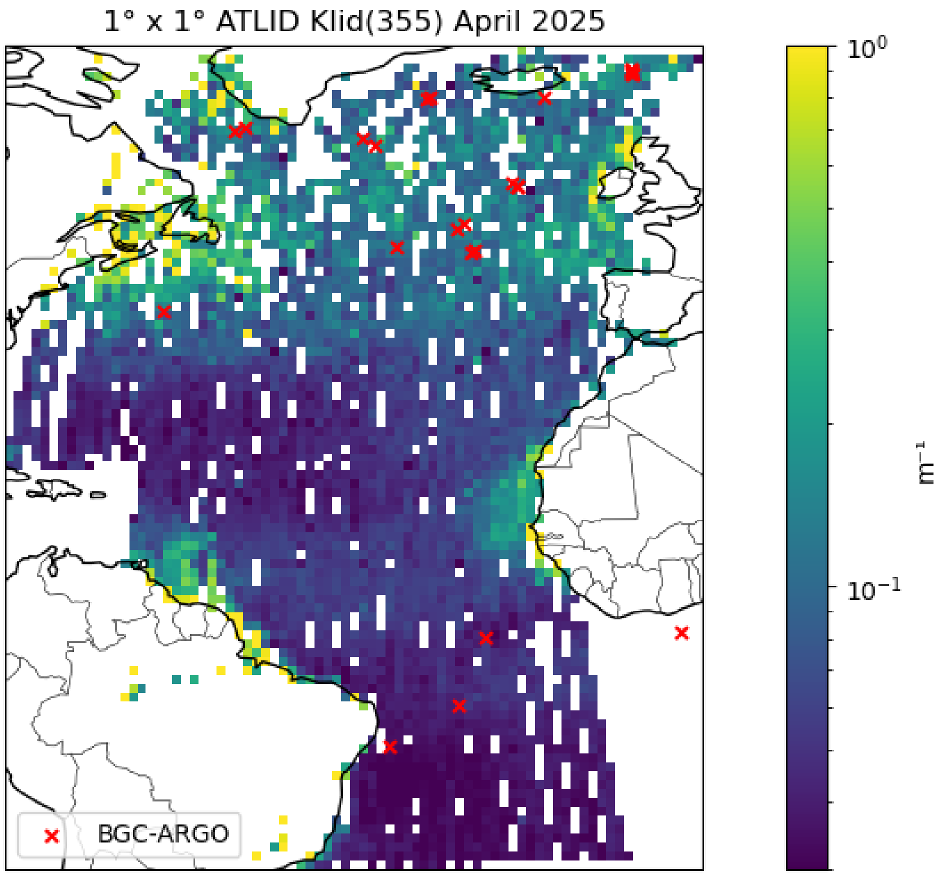
Chl-a: ATLID vs OC-CCI



K_d: ATLID vs BGC Argo

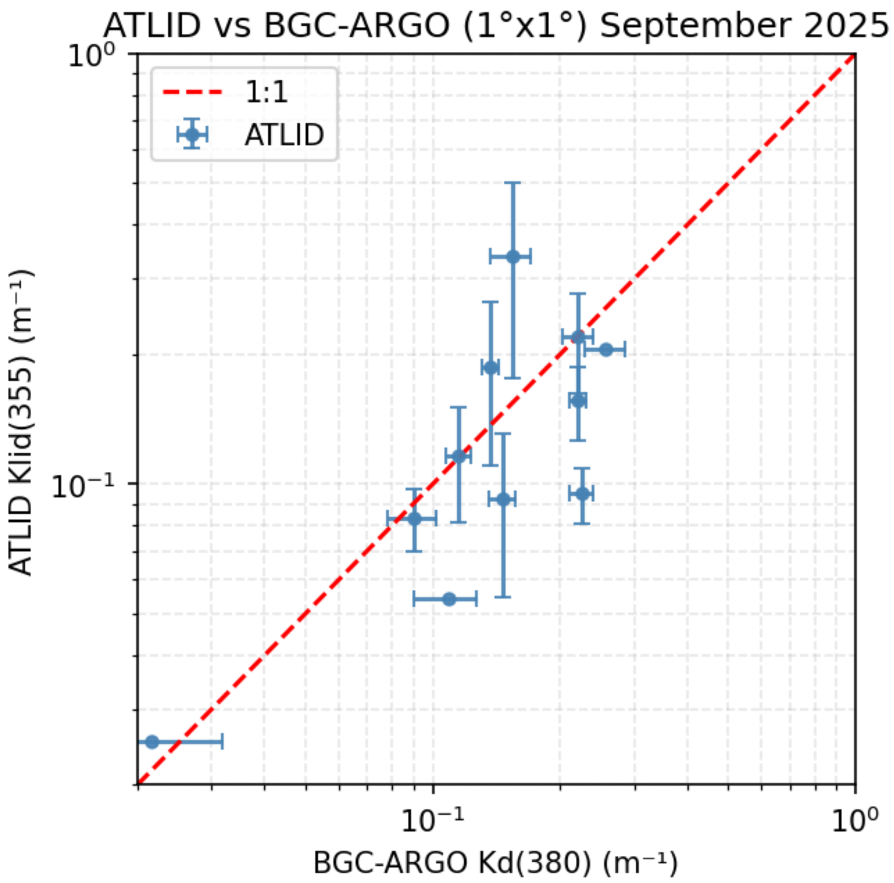
April 2025 (monthly averages vs point measurements)

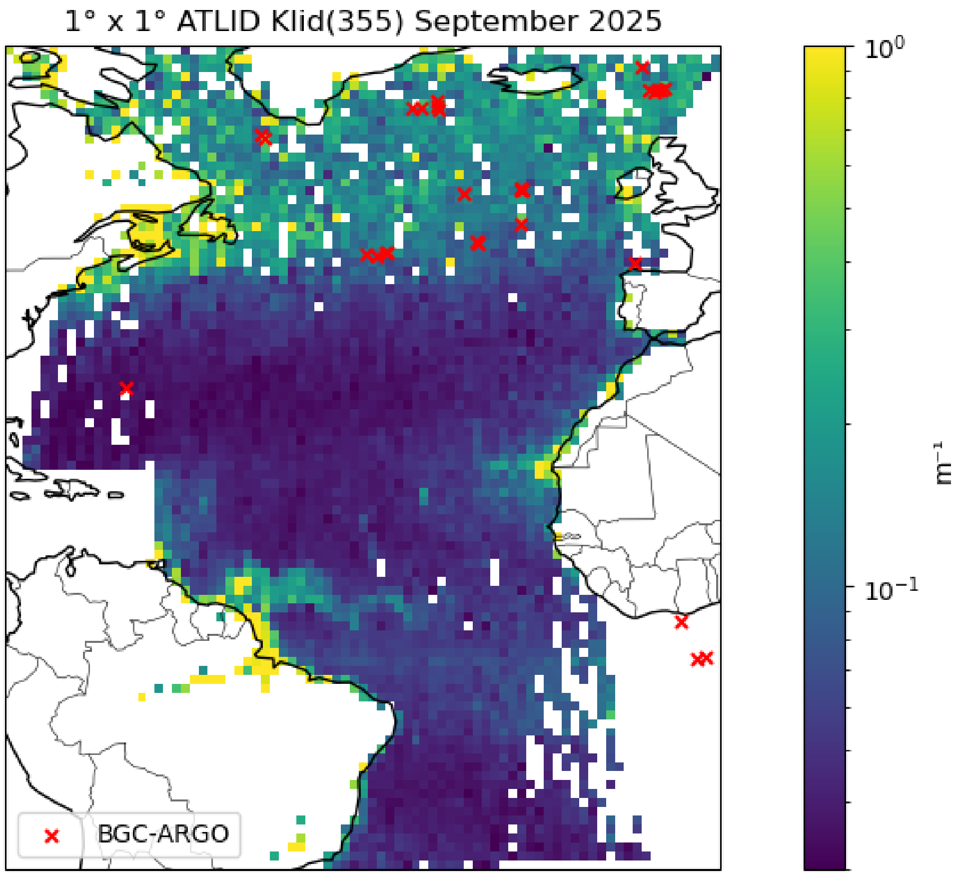




K_d: ATLID vs BGC Argo

September 2025 (monthly averages vs point measurements)





Cross polar channel: b_{bp}

- Ground bin selected with FM `featuremask`
- Data selected using the following flags and masks:
  - No bad retrievals / fully Rayleigh attenuated bins
  - No clouds or thick aerosol in the bin above surface
  - Ocean
  - Ice-free conditions
  - Signal-based surface detection
- Signal integrated over 100 measurements (including non-selected)
- In-water signal calculated as:

$$B_{watX} = \frac{A_X(r_{grd})}{T_A^2} - B_{atmX}$$

- T_A^2 and B_{atmR} calculated using:
  - FM: `surface_rayleigh_tau`
  - EBD: `particle_optical_depth_355nm` (high resolution)
  - NOM: `crosspolar_attenuated_backscatter` 2 bins over the surface

$$\beta_{wat}^{par} = 2K_L \frac{(1+\delta)}{\delta + \frac{\gamma}{K_L}} \left(\frac{n^2}{T_{srf}^2} B_{watX} - \frac{\gamma \beta_{wat}^{mol}}{2K_L^2} \right)$$

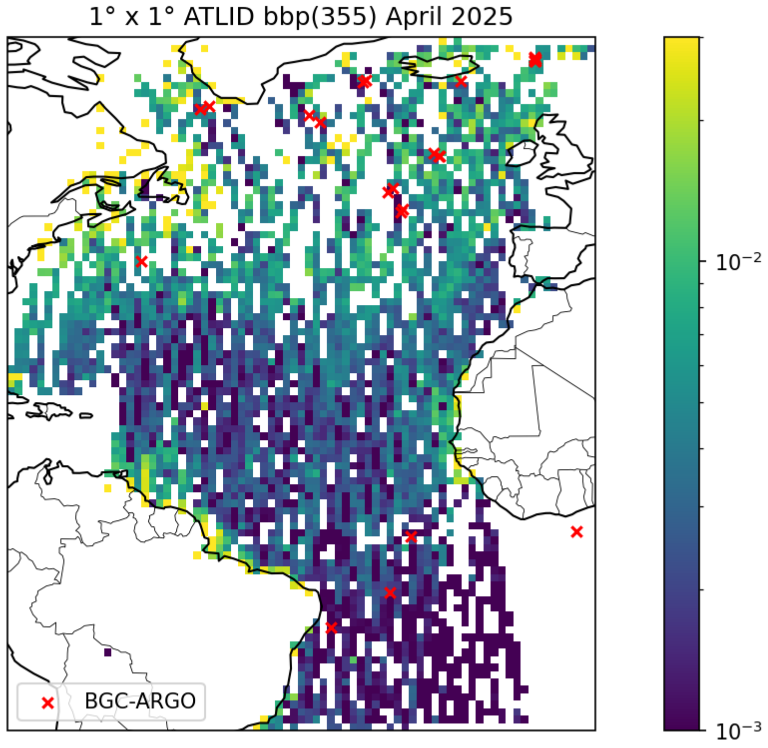
preliminary assumptions

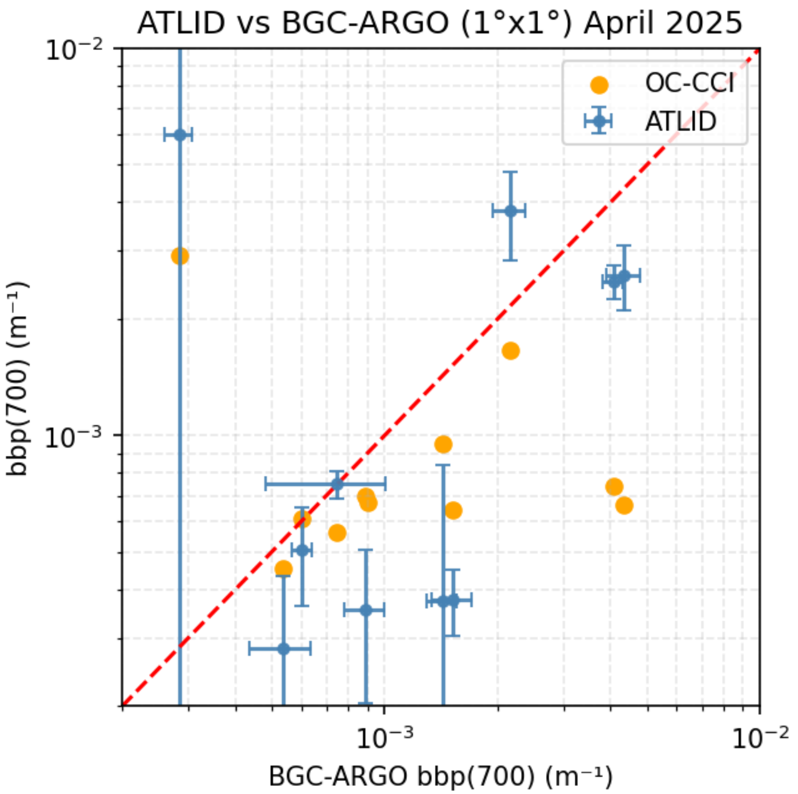
$\frac{\delta}{1+\delta} \approx 1.6 K_d(532)$	*Behrenfeld et al. 2022*
$K_d(532) = \frac{K_L(355)}{4} + 0.05$	355 → 490 nm: linear fit 490 → 532 nm: *Lu et al. 2016*
$\gamma = 2 \cdot 10^{-3}$ m^{-1}	*Churnside 2008* *Behrenfeld et al. 2022*
$\chi = 0.5$	*Lacour et al. 2020*

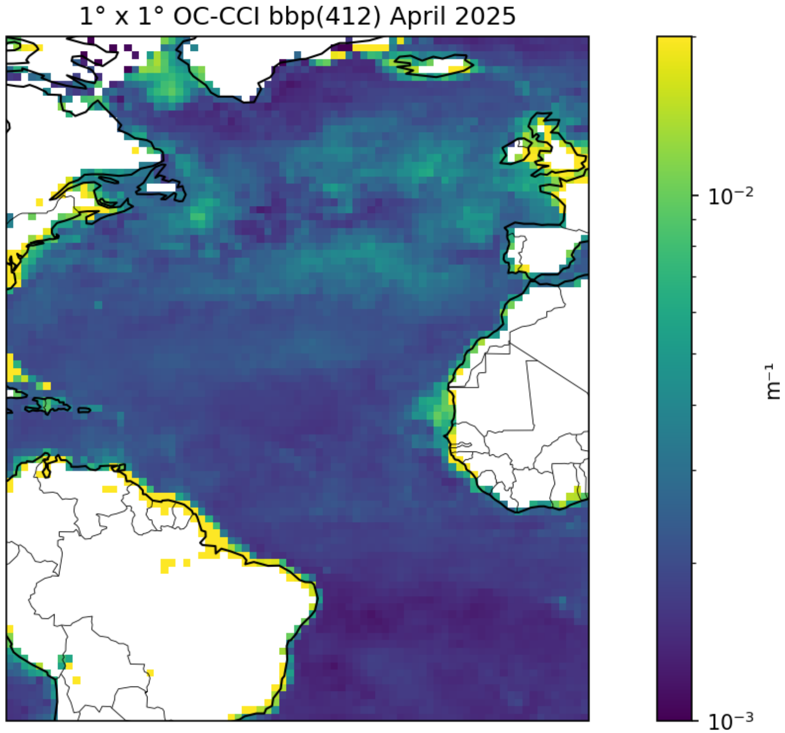
$$b_{bp} = 2\pi\chi\beta_{wat}^{par}$$

b_{bp}: preliminary results

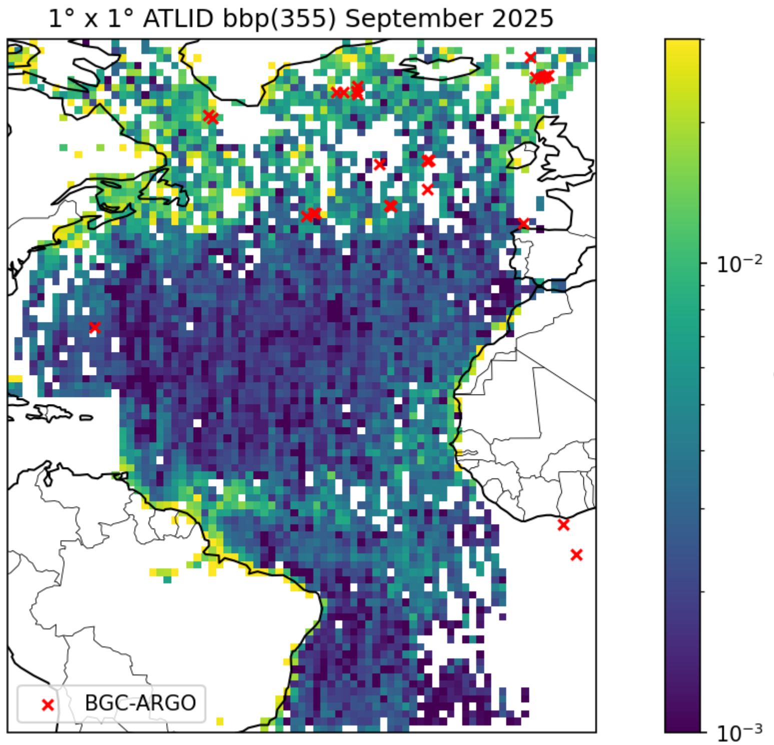
$$b_{bp}(\lambda) = b_{bp}(355)\left(\frac{355}{\lambda}\right)^{\eta}$$ with η from OC-CCI

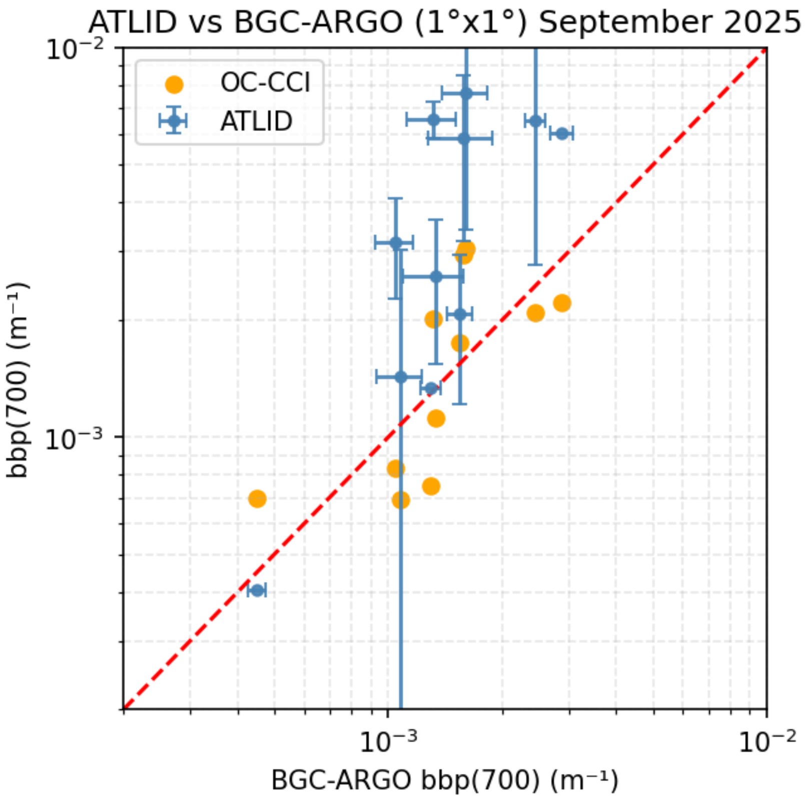


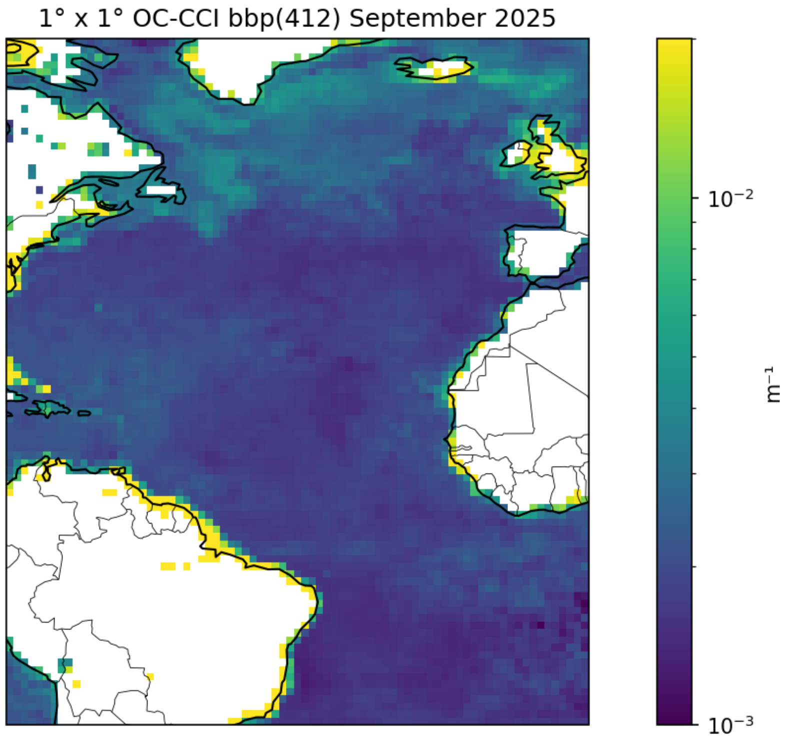




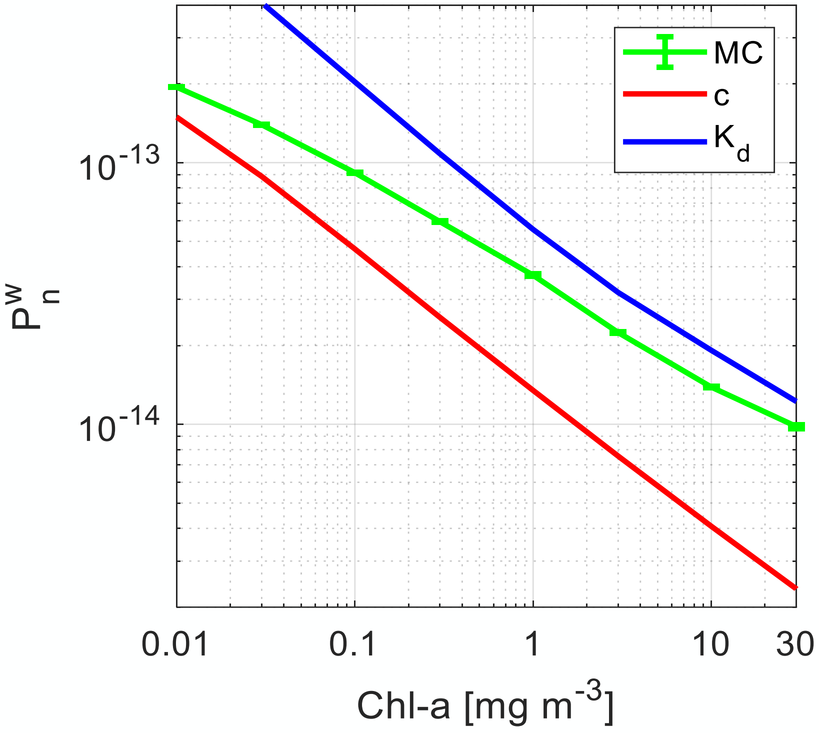
b_{bp}: preliminary results







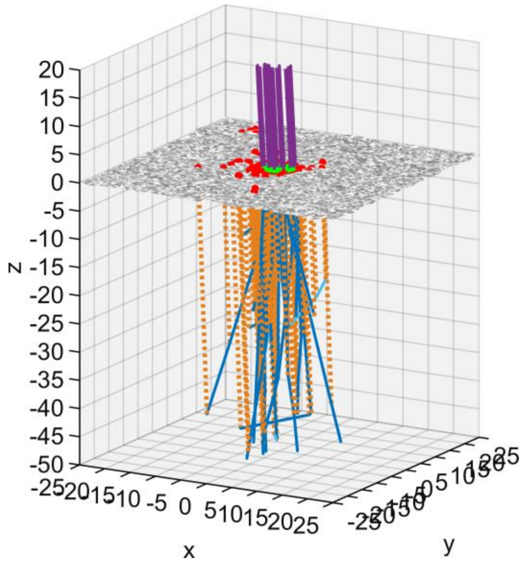
Next: Radiative Transfer Model



- The **green** curve obtained with the effective lidar attenuation coefficient (**K_L**)
- The **blue** and **red** curves correspond to the diffuse (**K_d**) and the beam (**c**) attenuation coefficient, respectively
- **K_L** is bounded between estimates based on **c** and **K_d**

Gordon 1982, unpolarized MC

Results point to **K_L** = **K_d** → simulations taking into account MS, polarization and HSRL are needed

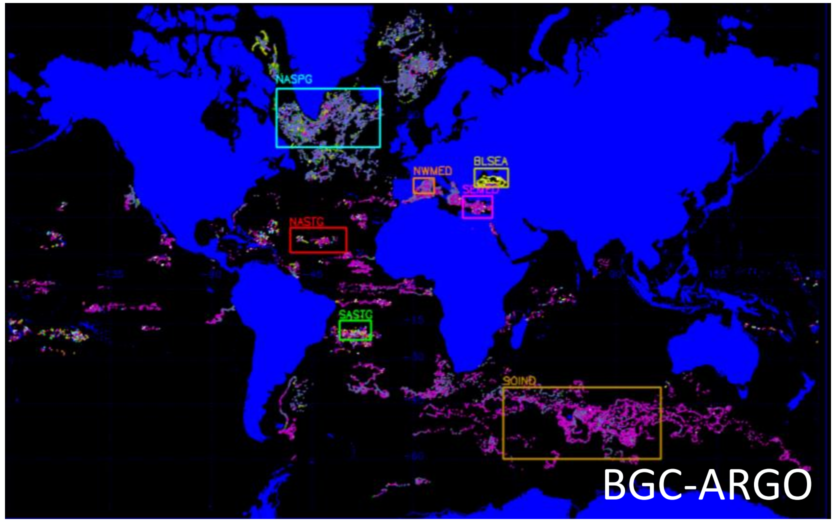


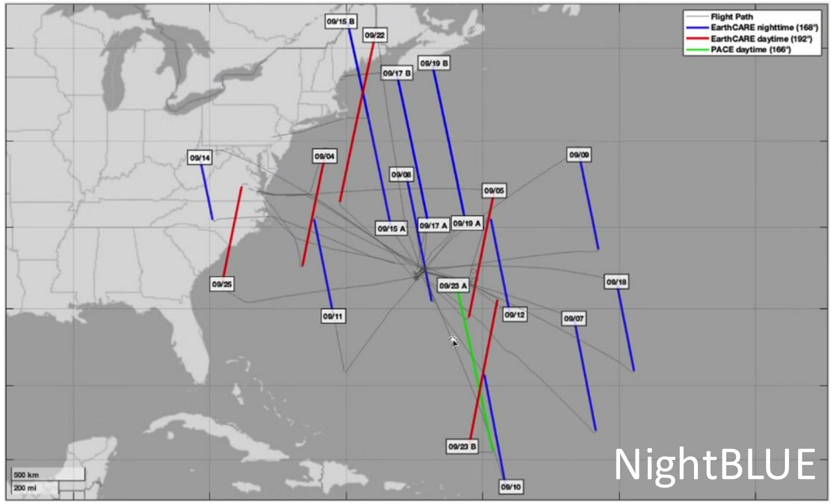
3D polarized Monte Carlo simulations will be used to:

- estimate **K_L** and analyze its dynamics
- find better parametrizations at 355 nm for γ and δ

Next

- ❑ Extend the analysis on a 12 month global dataset (BA baseline)
- ❑ Application of a K_L correction based on RTM results
- ❑ Exploitation of Cross polar and Mie channels using RTM results
- ❑ Statistical (specific ROIs) and global validation with BGC-ARGO float dataset
- ❑ Comparison between ATLID OCEAN products and NASA HSRL-2 measurements (NightBLUE campaign, September 2025)
- ❑ Analysis of the diurnal cycle



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Thank you for your attention