Can AEOLUS estimate ocean color parameters?
Aeolus+ Innovation AEOLUS Ocean Colour (AOC)

Jamet, C. [1], E., Belakebi-Joly[2], F. Poustomis[2], E. Lecuyer[1], X., Mériaux[1], Q., Cazenave[3], J., Delanoë[3] and C., Flamant[3]

[1] LOG, ULCO, France

[2] NOVELTIS, France

[3] LATMOS, France

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NO UNFORTUNATELY

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General objectives

- Derivation of Ocean Color parameters from Aeolus

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    - particulate attenuated backscatter $\boldsymbol{\beta_p}$
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  - **ocean optical parameters** related to ocean optical properties
    - diffuse attenuation coefficient $\boldsymbol{K_d}(355)$
    - particulate backscattering parameter $\boldsymbol{b_{bp}}(355)$

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  - **ocean optical parameters** related to ocean optical properties
    - diffuse attenuation coefficient $K_d(355)$
    - particulate backscattering parameter $b_{bp}(355)$

  - **biogeochemical parameters** related to marine biogeochemical cycles
    - coloured dissolved organic matter CDOM
    - particulate organic carbon POC
    - phytoplankton carbon C_{phyto}

General objectives

- Derivation of Ocean Color parameters from Aeolus
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Principle of the algorithm

HSRL capabilities of ALADIN

$$S_M(z) = K_{Ray}\left[\frac{A}{(nH+z)^2}\right](C_1\beta_M + C_2\beta_P)\left[exp\left(-\int_0^z K_L(z')dz'\right)\right]^2.(T_A)^2$$

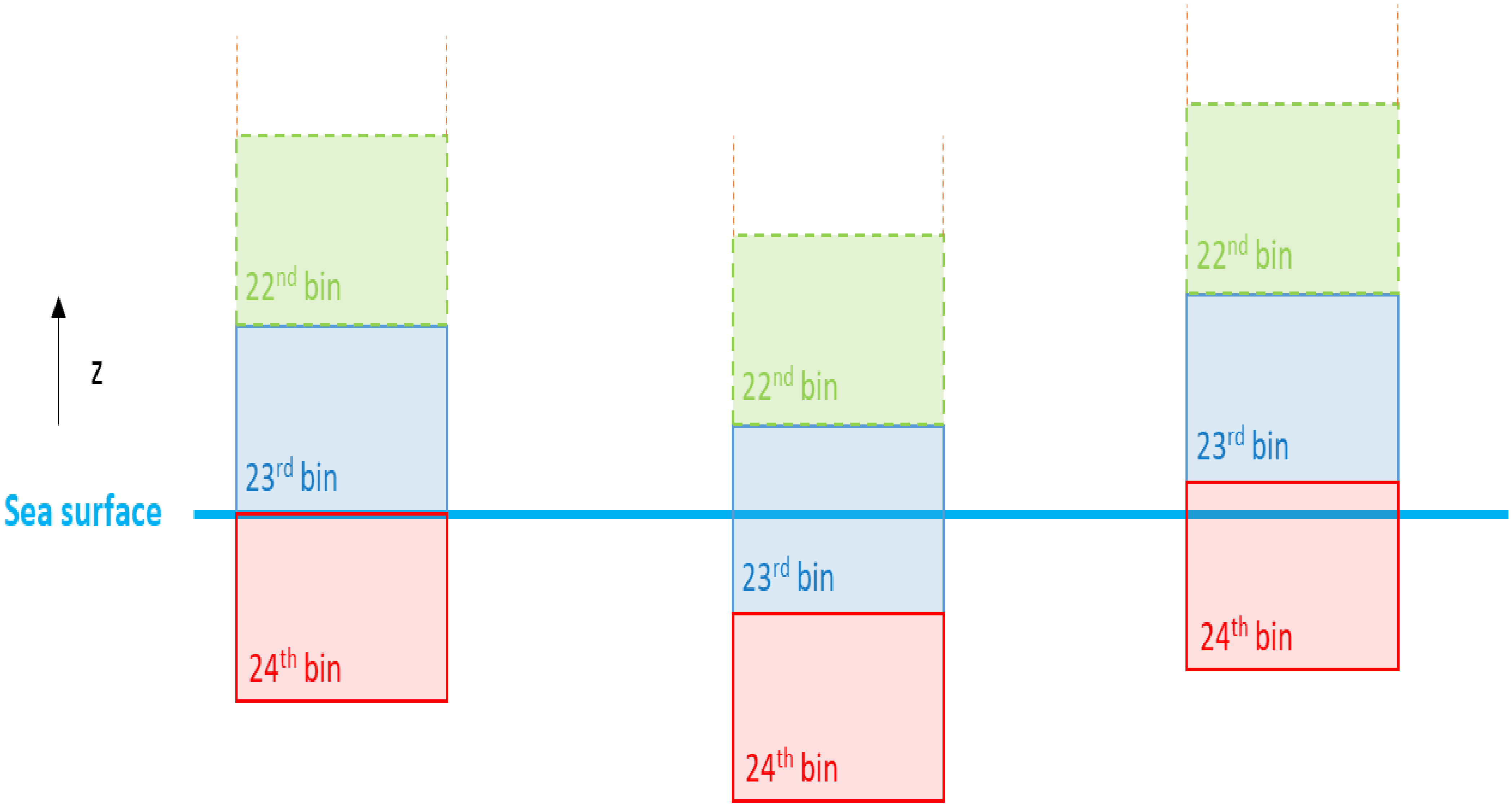
$$S_P(z) = K_{Mie}\left[\frac{A}{(nH+z)^2}\right](C_4\beta_M + C_3\beta_P)\left[exp\left(-\int_0^z K_L(z')dz'\right)\right]^2.(T_A)^2$$

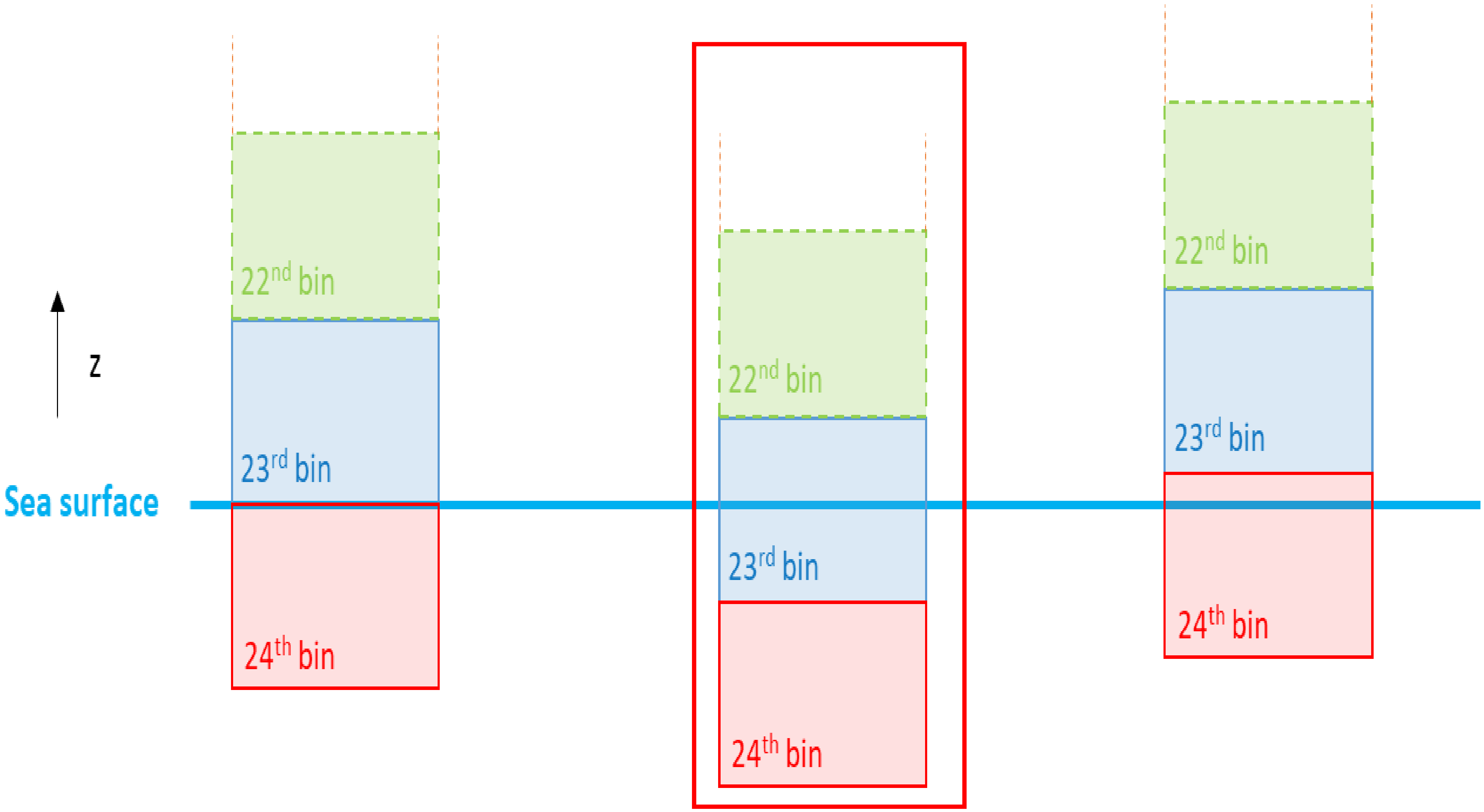
$$\boldsymbol{\beta_P = \beta_M \frac{(K_{Ray}C_1 - S_R K_{Mie}\,C_4)}{(S_R K_{Mie}\,C_3 - K_{Ray}C_2)}}$$

with $\frac{S_M(z)}{S_P(z)} = S_R$

β_M a constant

$C_1 = 1.14,\ C_2 = 1.64,\ C_3 = 1.3,\ C_4 = 1$ (Collaboration with Alain Dabas from Meteo-France)


z
Sea surface
22nd bin
23rd bin
24th bin
22nd bin
23rd bin
24th bin
22nd bin
23rd bin
24th bin



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24th bin
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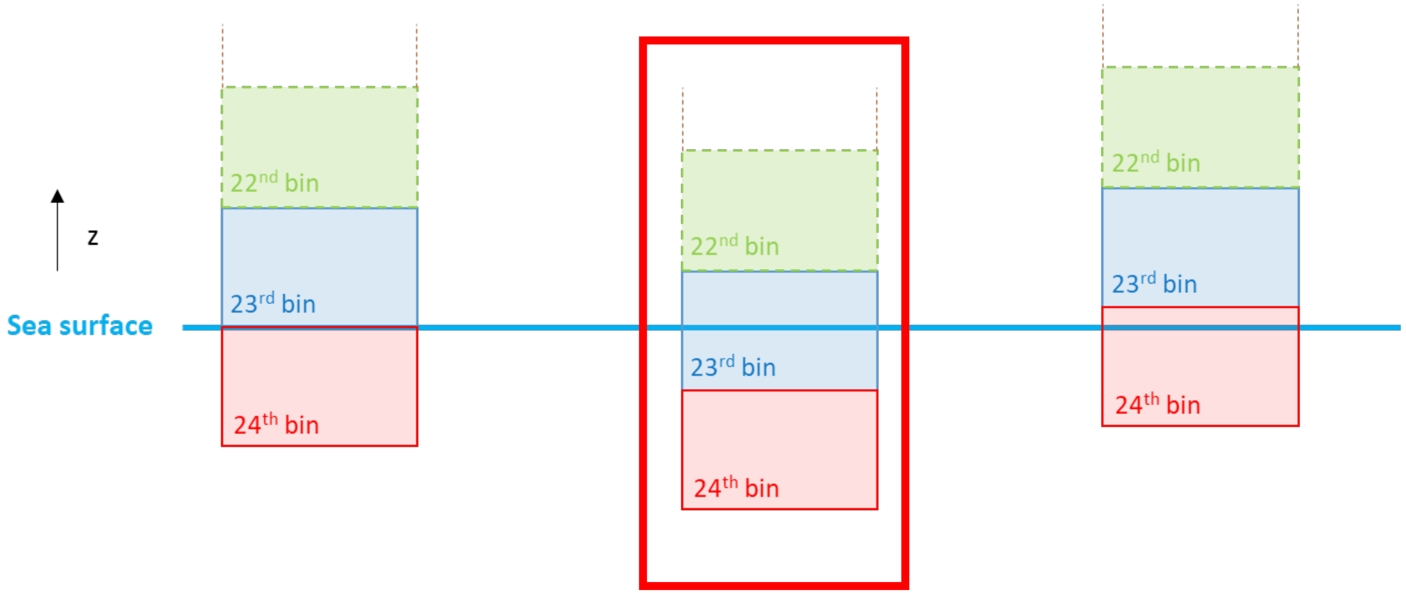
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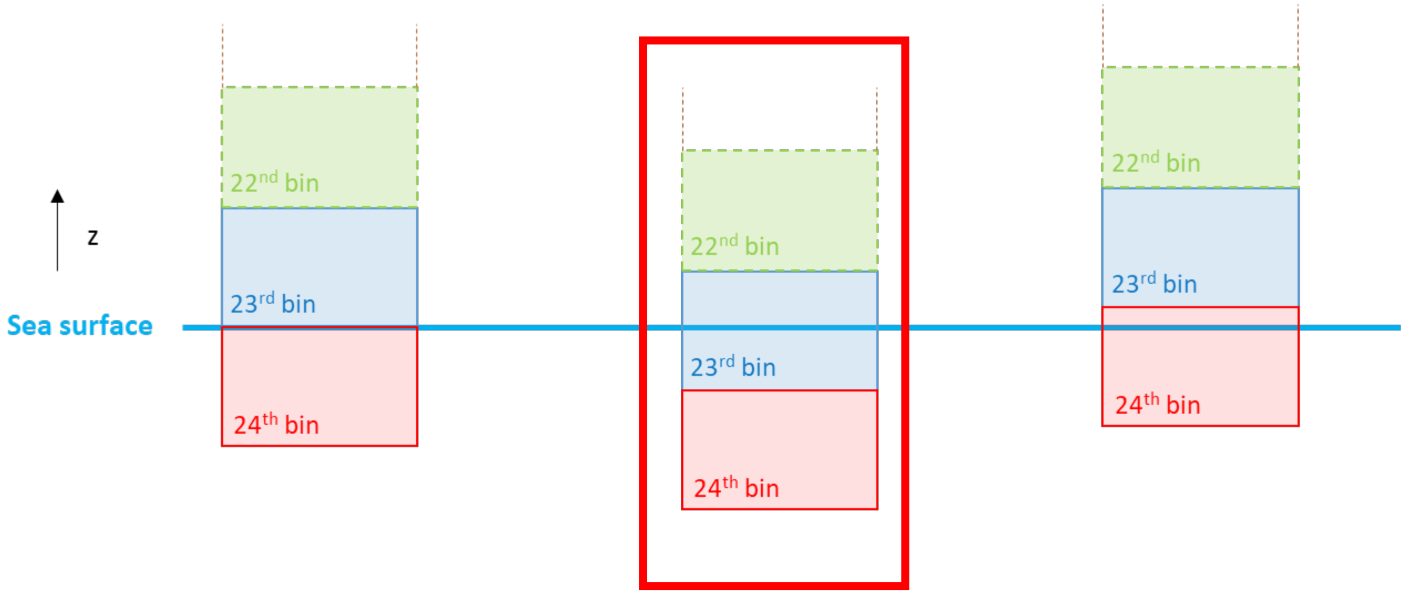
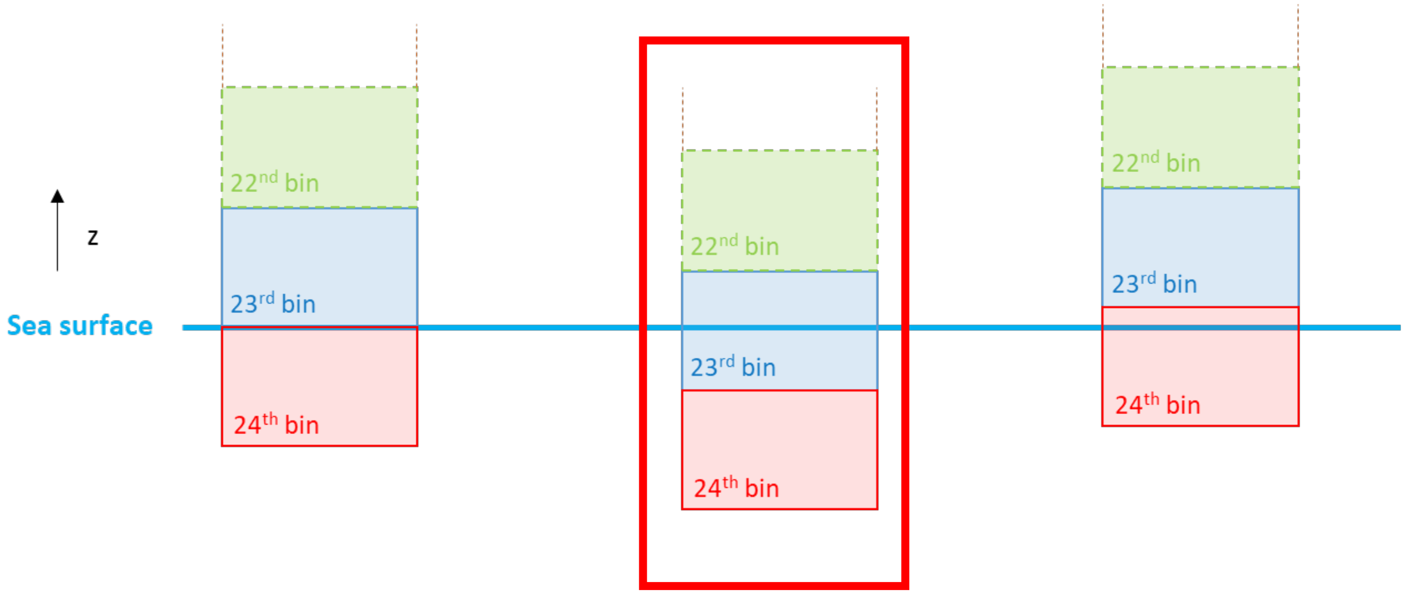


$$S(23) = S_{atm}$$

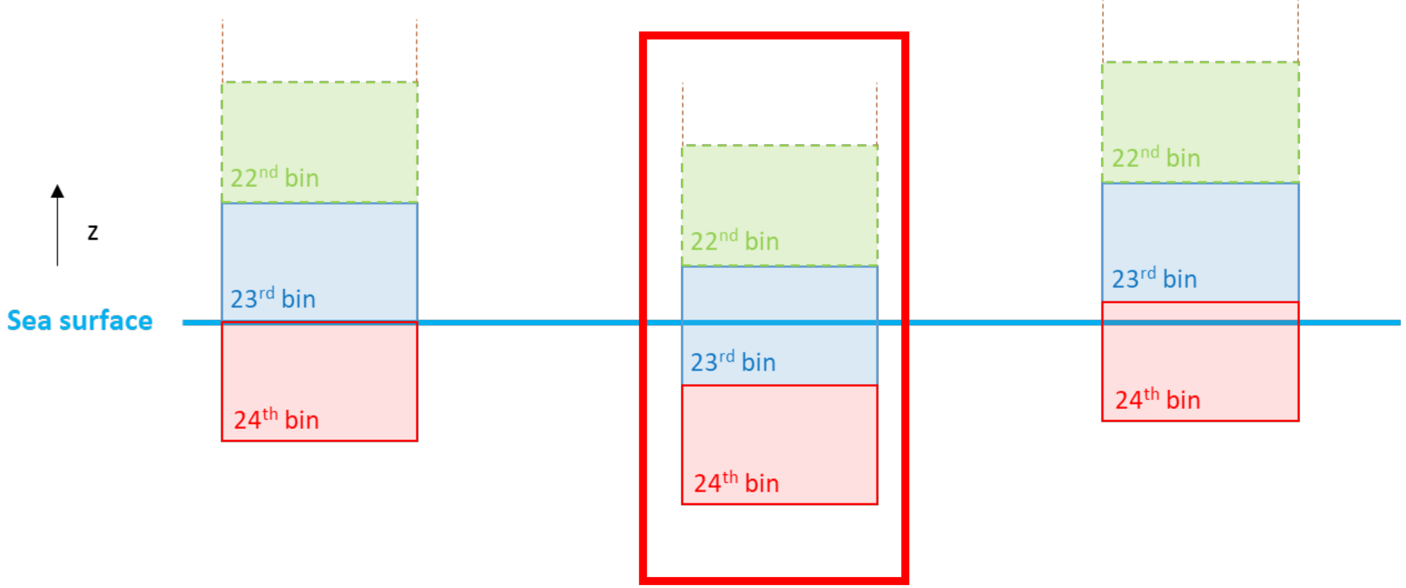
Correction using bin 22 with the hypothesis of an homogeneous atmosphere between 0 and 1 km altitude



$$S(23)=S_{atm}+S_s$$

Correction using bin 22

$\approx$ 0 for observation angle of 35°

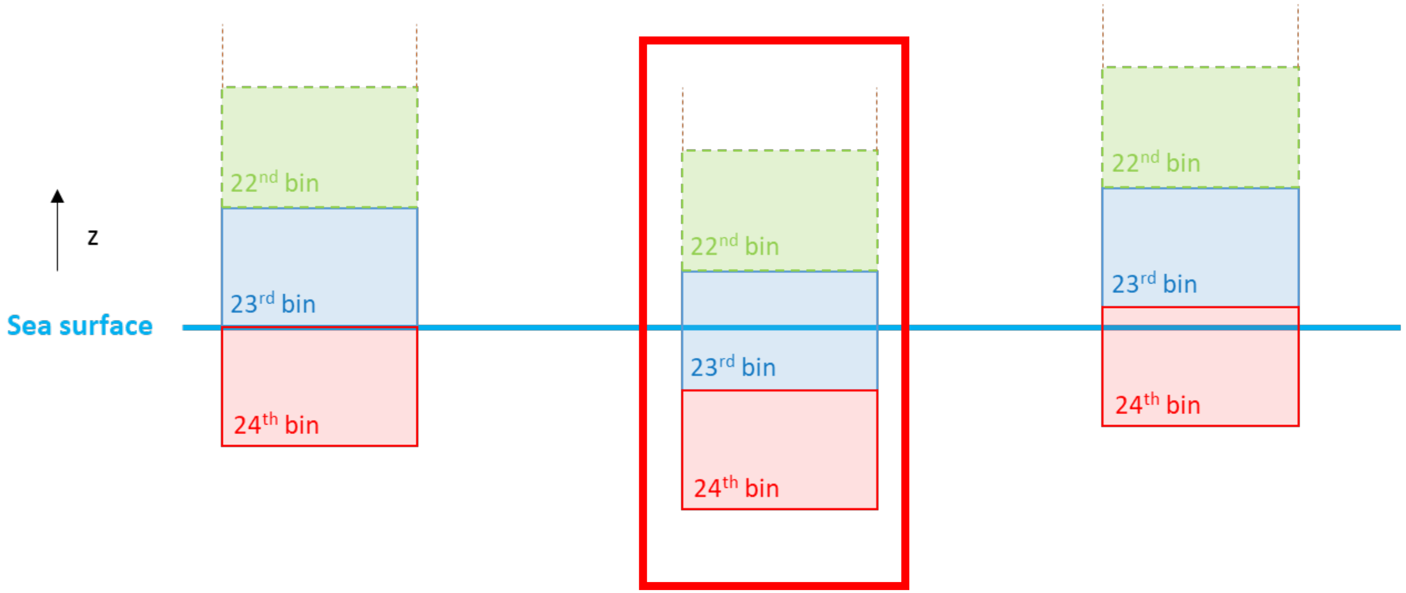


$$S(23)=S_{atm}+S_s+S_{wc}$$

Correction using bin 22

$\approx$ 0 for observation angle of 35°

$\approx$ 0 for low surface winds (<3 $m.s^{-1}$)



$$S(23) = S_{atm} + S_{s} + S_{wc} + S_{w}$$

Correction using bin 22

≈ 0 for observation angle of 35°

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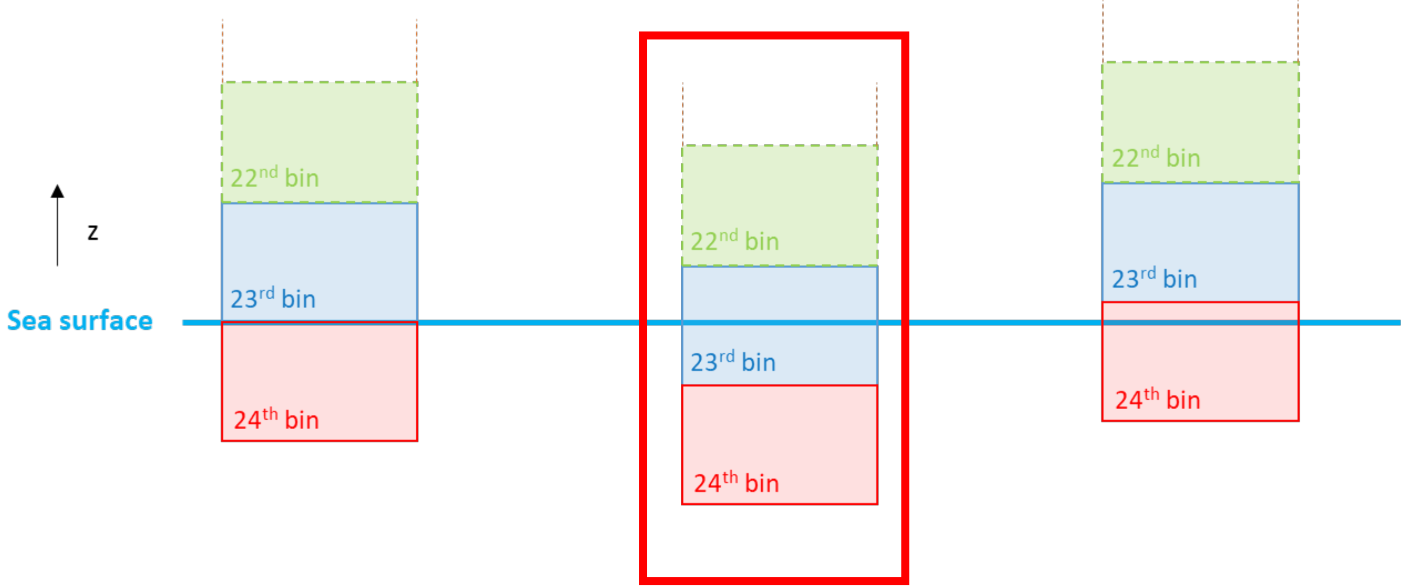
Oceanic signal



$$S(23) = S_{atm} + S_s + S_{wc} + S_w$$

Correction using bin 22

≈ 0 for observation angle of 35°

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Oceanic signal

$$\beta_P = \beta_M \frac{(K_{Ray} C_1 - S_R K_{Mie} C_4)}{(S_R K_{Mie} C_3 - K_{Ray} C_2)}$$

Particulate back-scattering coefficient b_{bp}

$b_{bp} = 2.\chi\pi\beta_P$

Sensitivity studies

1. No M1 calibration bias. No cross-talk. Bin only in ocean
2. M1 calibration bias. No cross-talk. Bin only in ocean
3. M1 calibration bias. Cross-talk. Bin only in ocean
4. M1 calibration bias. Cross-talk. Bin partly in ocean (no atmospheric correction, no consideration of wind)
5. M1 calibration bias. Cross-talk. Bin partly in ocean (atmospheric correction, no consideration of wind)
6. M1 calibration bias. Cross-talk. Bin partly in ocean (atmospheric correction, consideration of wind)

- BASELINE 11

Validation exercise

- BGC-ARGO (Claustre et al., 2022) : $b_{bp}(700)$
- **Match-ups exercise:**
  - July 2019 – October 2020
  - Cloud-free AEOLUS obs. using SEVIRI cloud mask

Cloud mask

- It should be verified thoroughly that no cloud will impact the analysis

  › **Use of the SEVIRI Cloud Mask:**

  › Temporal resolution: 15 minutes

  › Spatial resolution: about 4 x 4 km^2

  › Spatial coverage: latitude -90 : 90 , longitude -90 : 90

  › Pixel categorization:

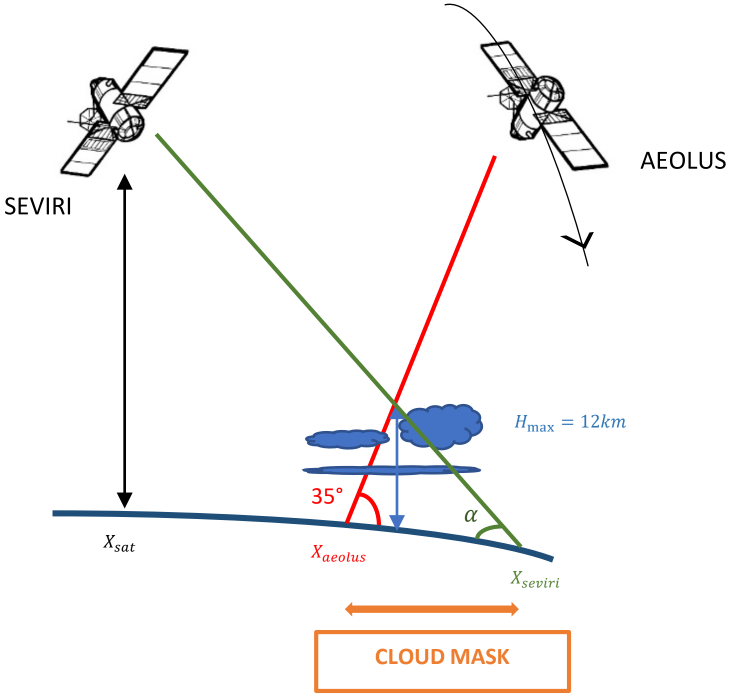
    → 0 = clear sky over water,

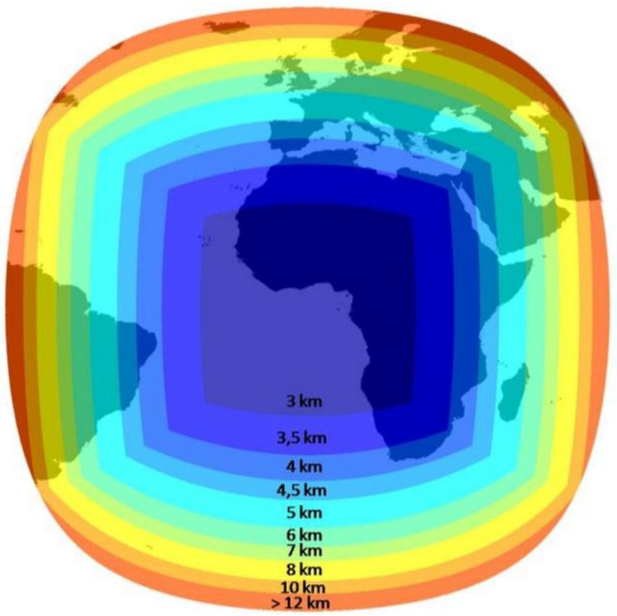
    → 1 = clear sky over land,

    → 2 = cloud,

    → 3 = not processed

  › View angle: variable

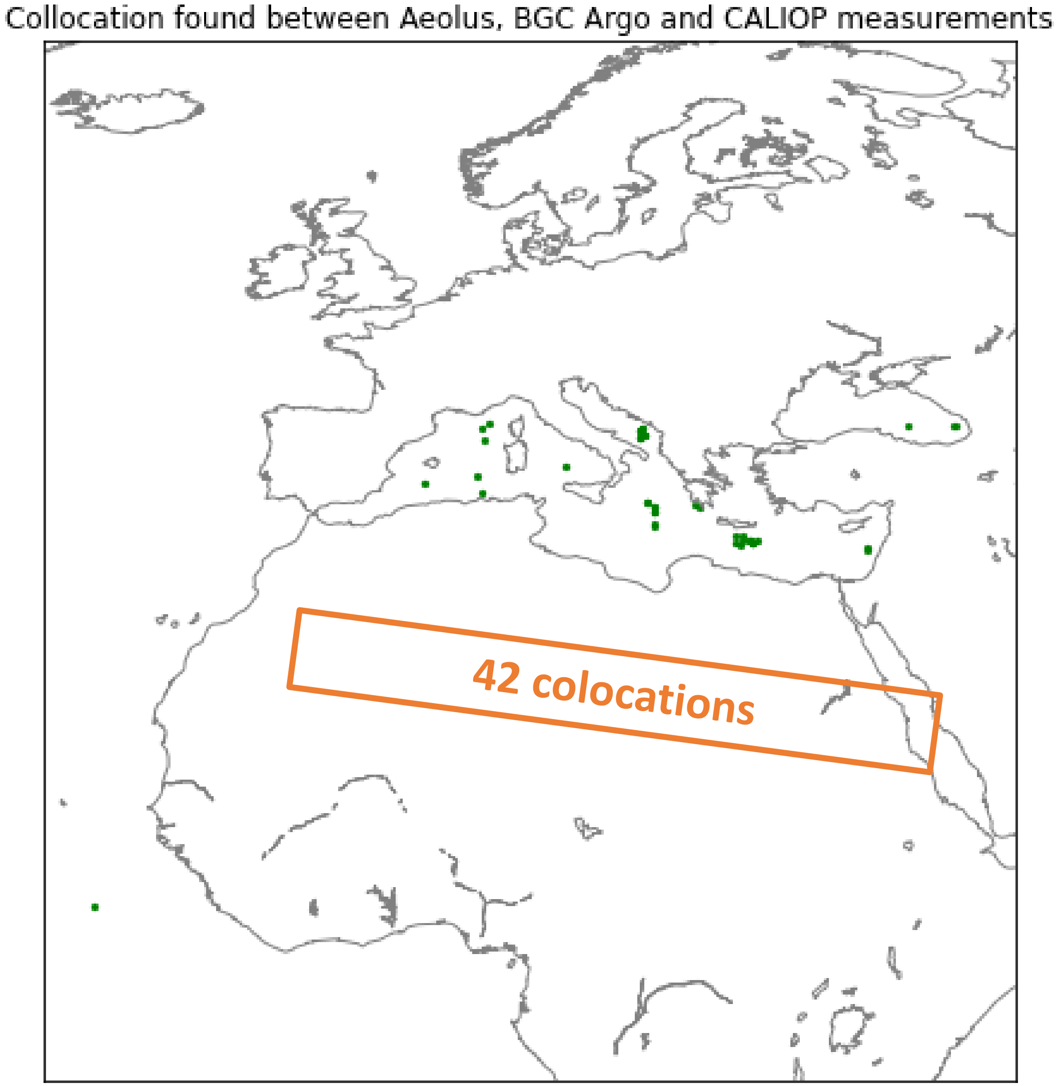




Spatial resolution and coverage of the SEVIRI instrument
Source : https://www.soda-pro.com/

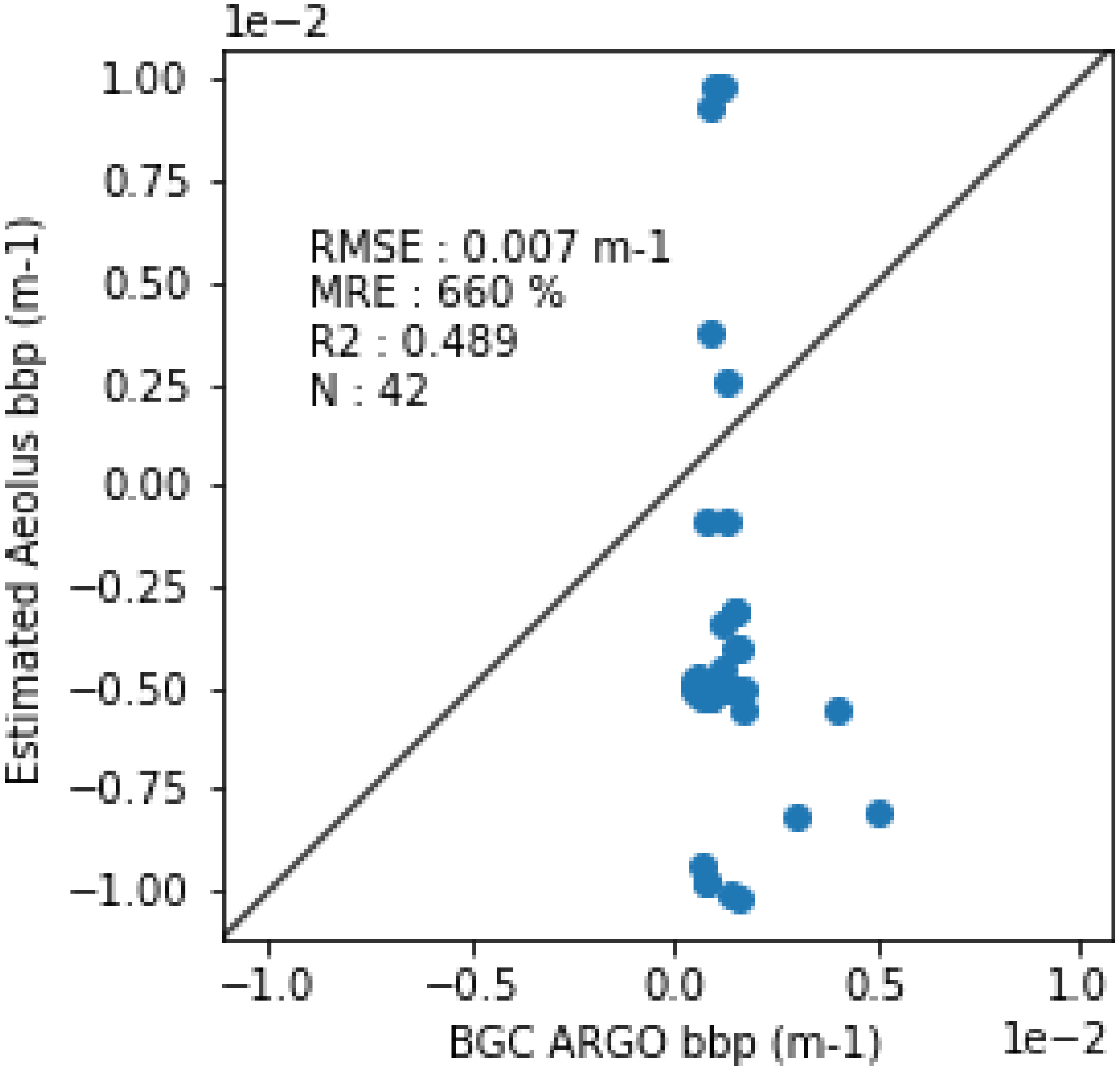
Validation exercise

- BGC-ARGO (Claustre et al., 2022) : $b_{bp}(700)$
- **Match-ups exercise:**
  - July 2019 – October 2020
  - Cloud-free AEOLUS obs. using SEVIRI cloud mask
  - Time difference : +/- 24h
  - Distance difference :
    - If SST < 15 °C, +/- 15 km
    - If SST > 15°C, +/- 50 km



M1 calibration bias. Cross-talk. Bin partly in ocean (no atmospheric correction, no consideration of wind)

$S(23\ or\ 24) = S_w$



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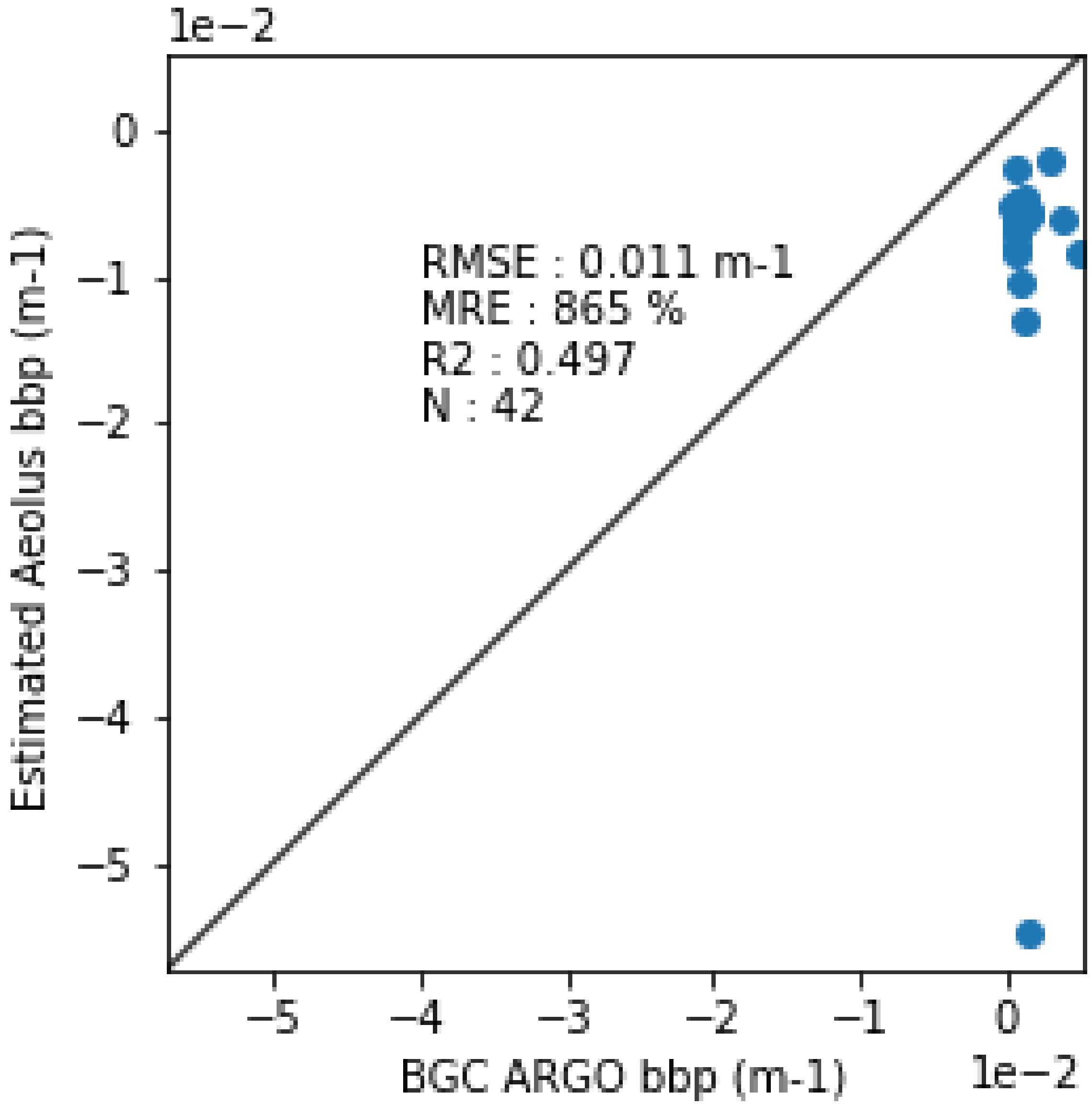
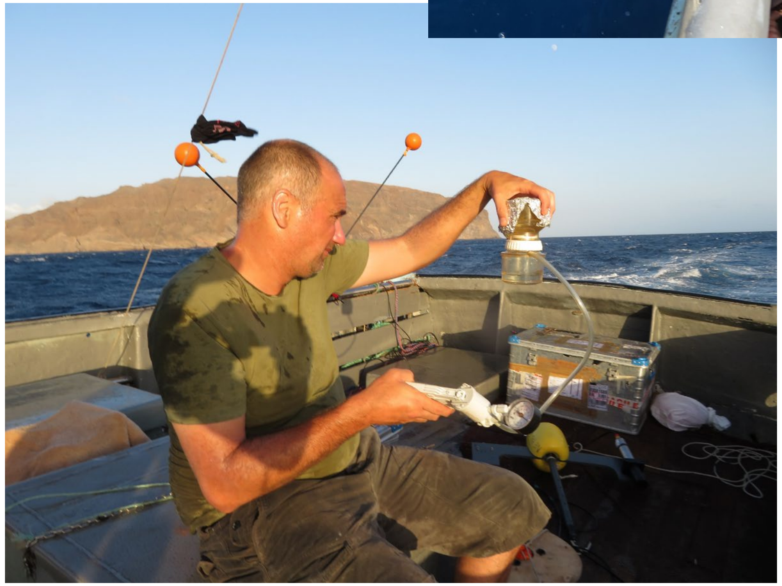
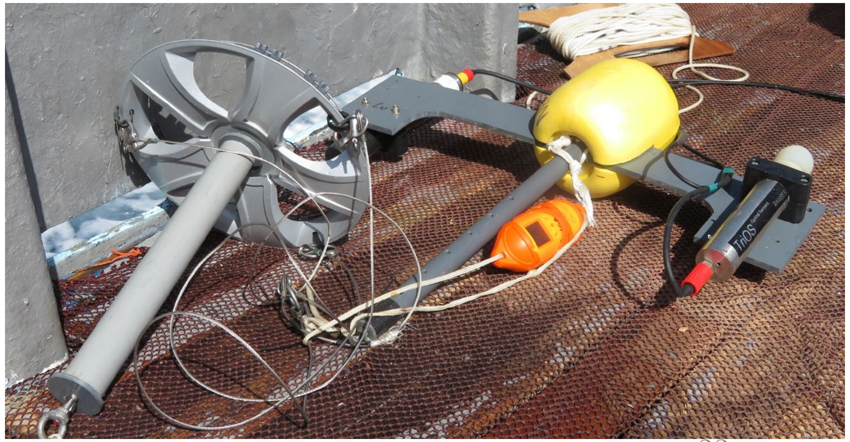
$$S_{atm}(23) = S_{atm}(22)\frac{altitude\_bin(23)}{height\_bin(23)}$$



Validation in Cabo Verde during the JATAC and CADDIWA campaigns

- 7-22 September 2021
- 6 days at sea
- Radiometry (Rrs) btw 350 and 900nm
- Diffuse attenuation coefficient K_d until 30m ($c<K_L<K_d$)
- Particulate back-scattering coefficients b_{bp} until 30m ($b_{bp} = 2.\chi\pi\beta_P$)
- Concentrations of CDOM (2m), chl-a (2-20m) and POC (2-10m)





Jamet et al. (in préparation)

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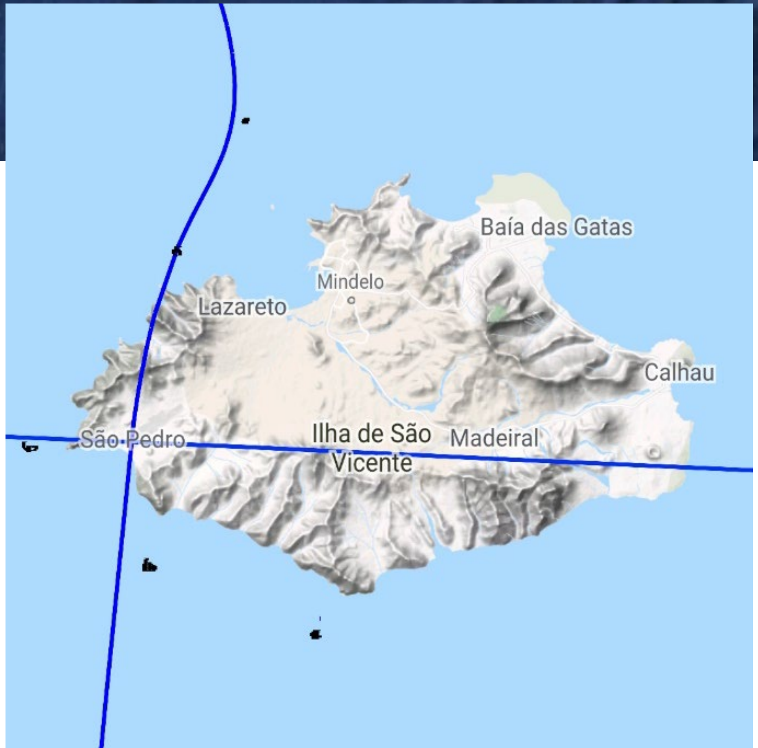

- Number of co-locations :

Lidar	Dates	# co-locations
ADM/AEOLUS	10-15-17-22 sept. 2021	9
LNG	10-17-18 sept. 2021	11

Jamet et al. (in préparation)

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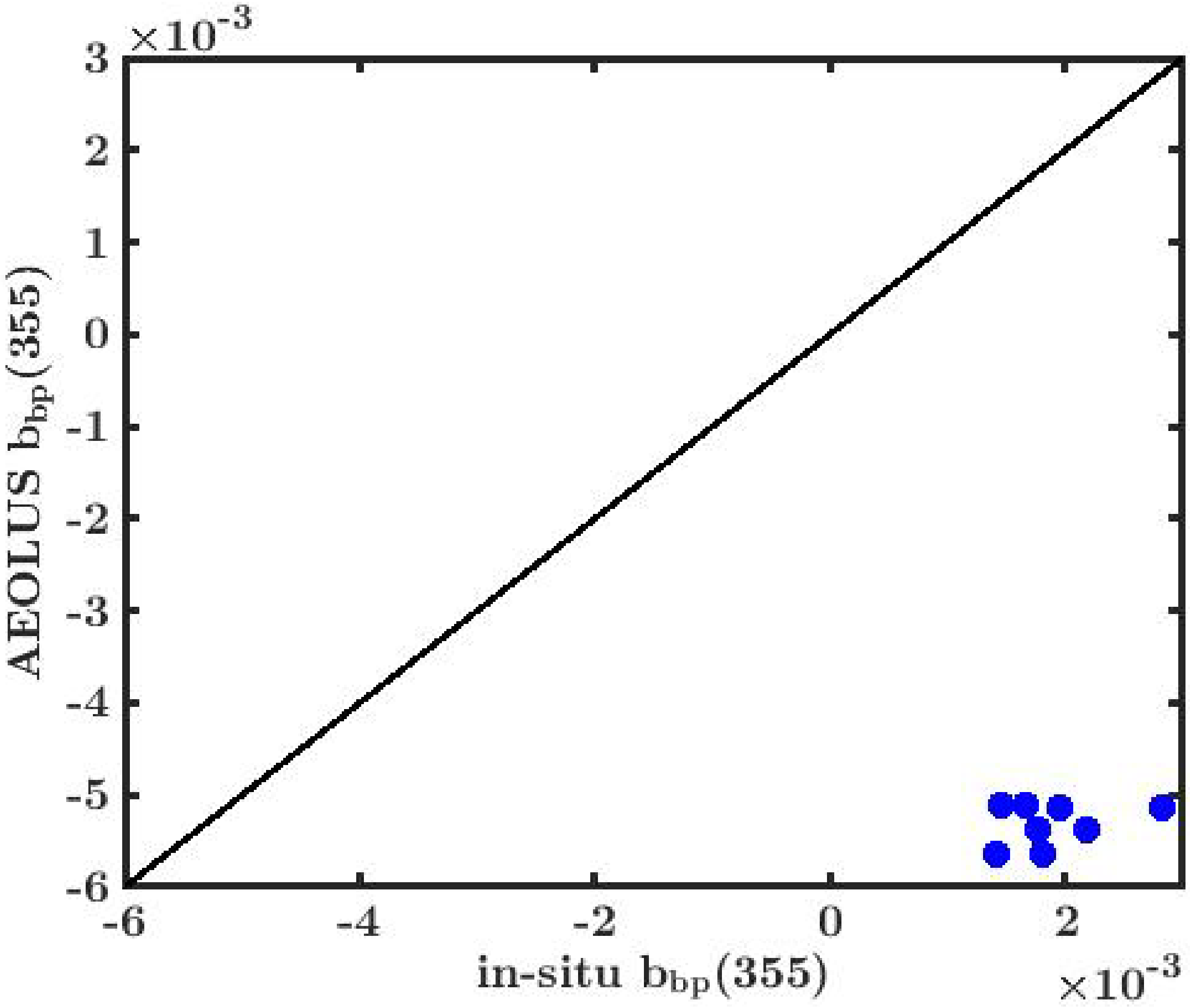

$$S_{atm}(23) = S_{atm}(22)\frac{altitude\_bin(23)}{height\_bin(23)}$$

Jamet et al. (in préparation)

Impact of the hypothesis

- Range of S_R
- Impact of the wind
- Homogeneity of the marine boundary layer

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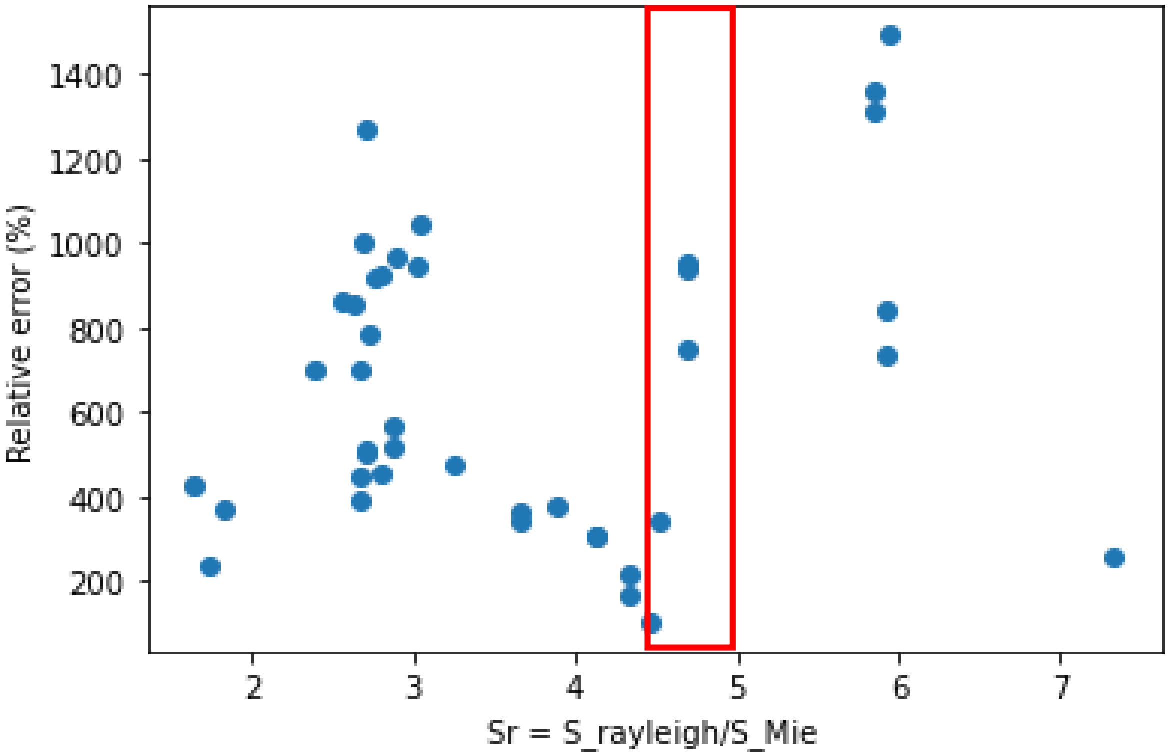
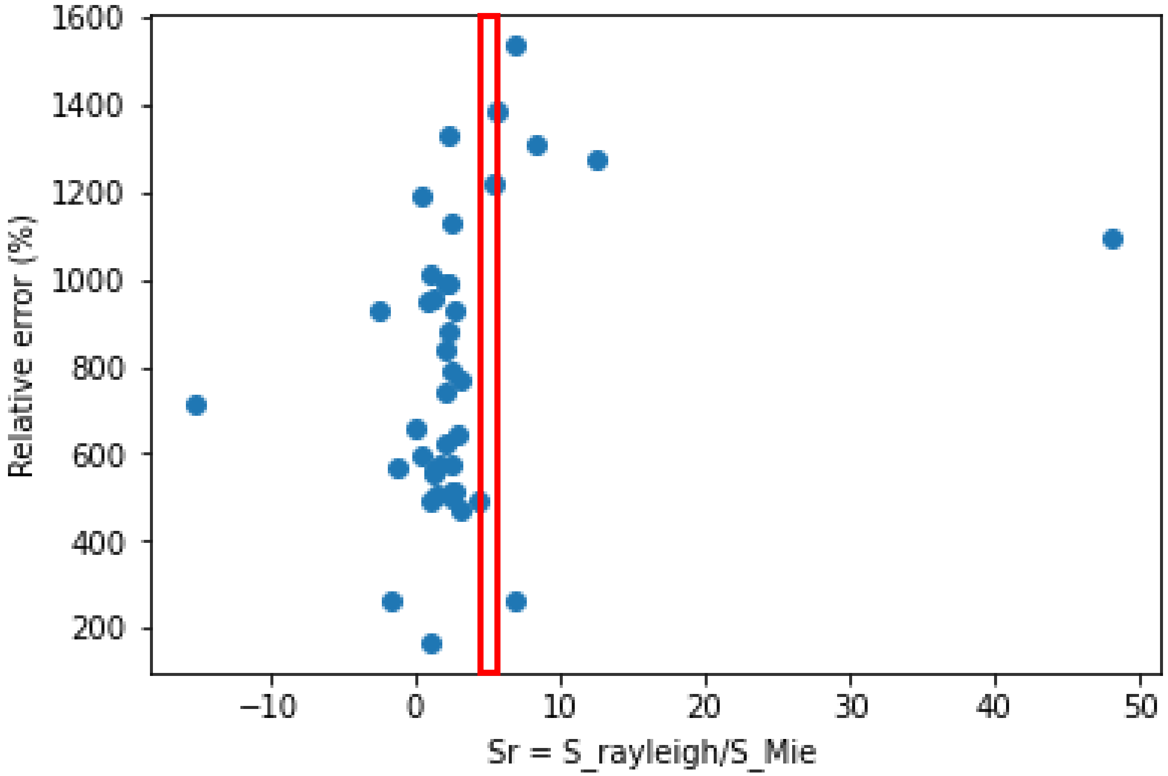
M1 calibration bias. Cross-talk. Bin partly in ocean (atmospheric correction, no consideration of wind)

$\beta_P > 0 \quad \Rightarrow \quad 4.5 < S_R < 5$



Without atmospheric correction

$\boldsymbol{S(23\ or\ 24) = S_w}$



With atmospheric correction

$\boldsymbol{S(23\ or\ 24) = S_{atm} + S_w}$

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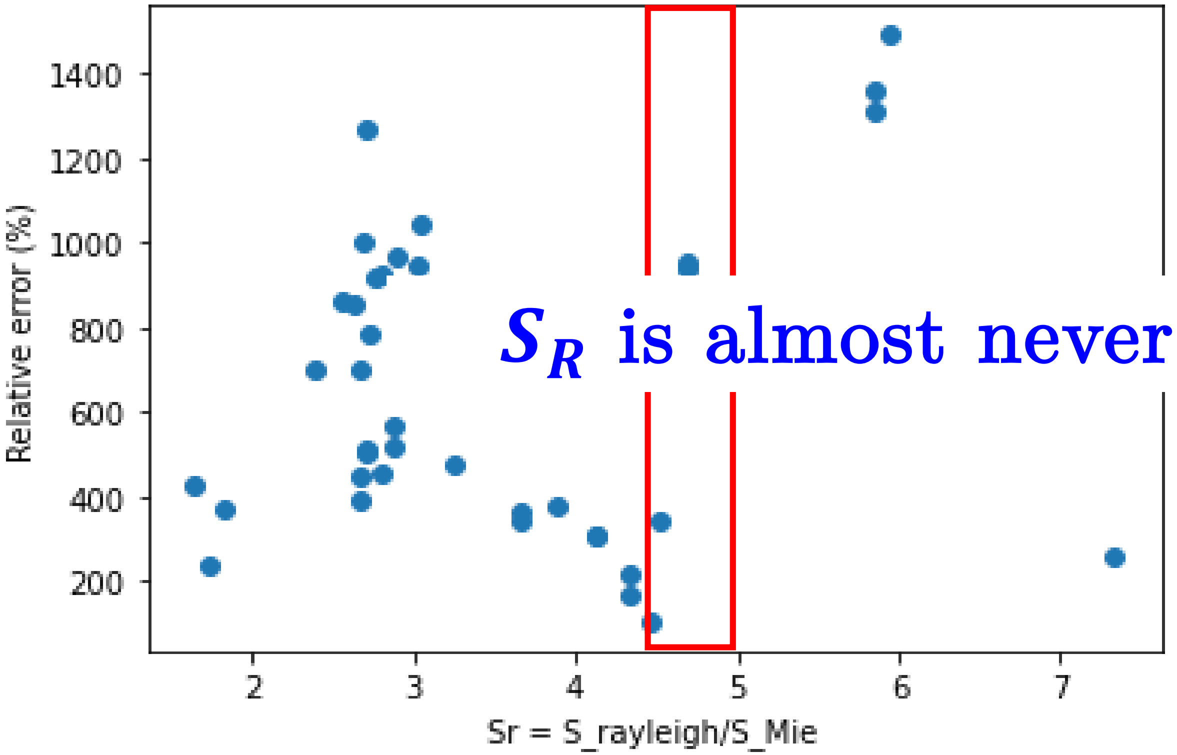
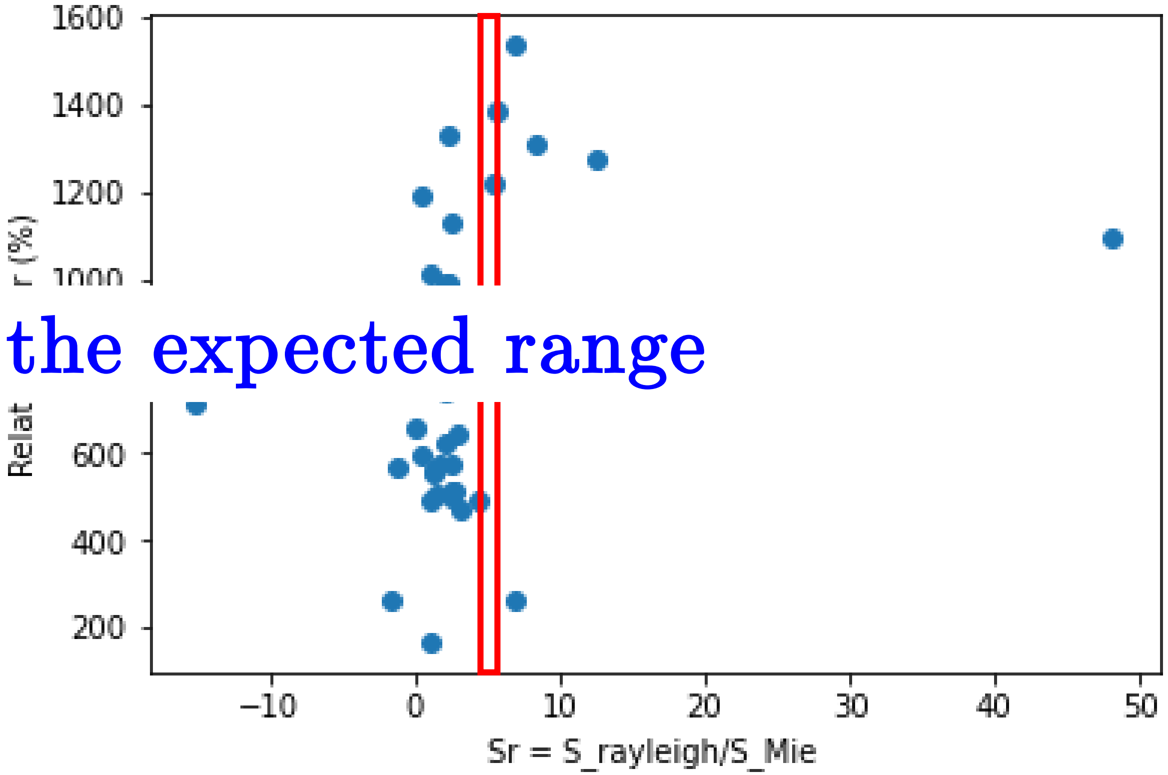


Without atmospheric correction

$S(23\ or\ 24) = S_w$

S_R is almost never in the expected range



With atmospheric correction

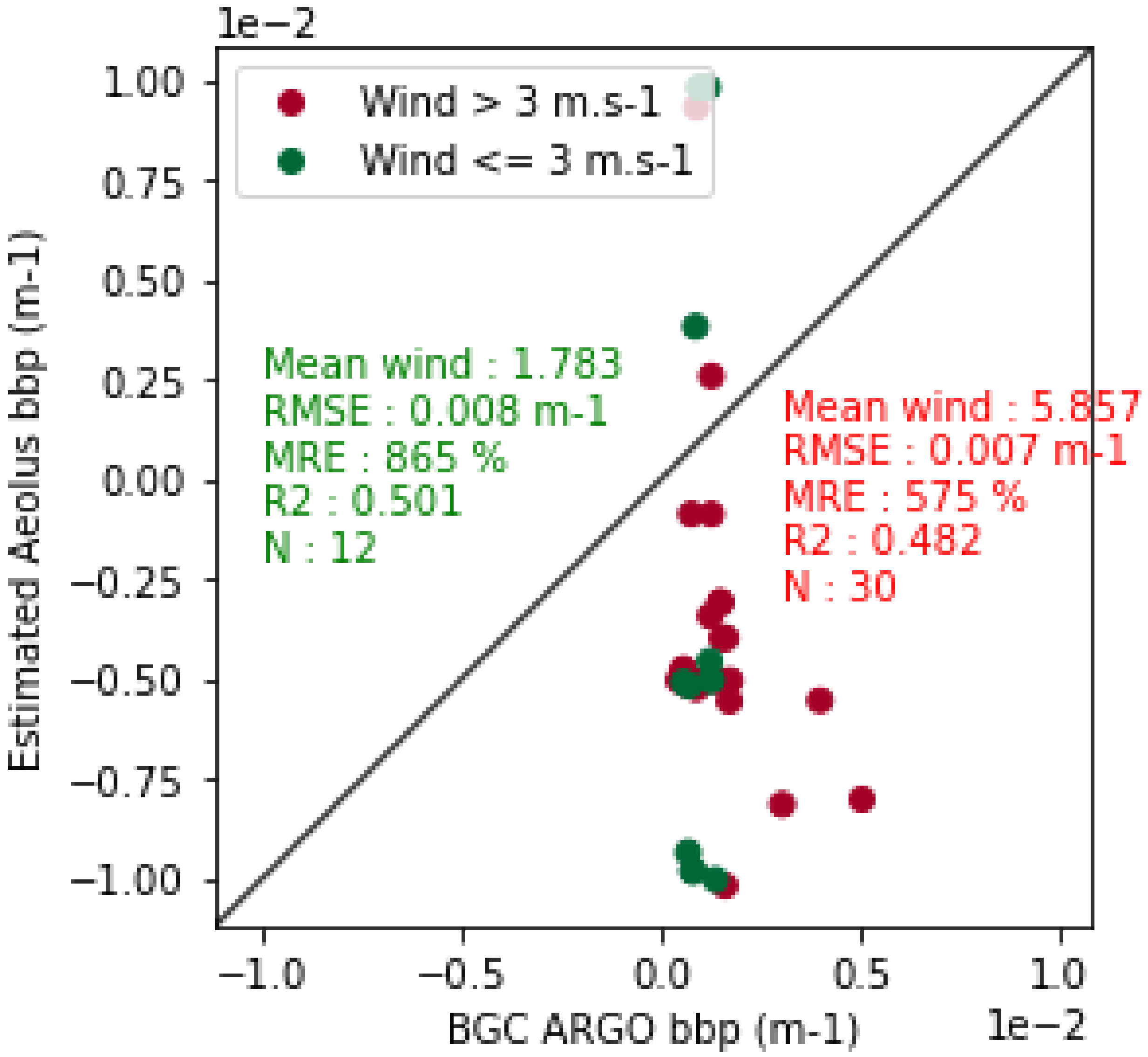
$S(23\ or\ 24) = S_{atm} + S_w$

Impact of the hypothesis

- Range of S_R
- **Impact of the wind**
- Homogeneity of the marine boundary layer

M1 calibration bias. Cross-talk. Bin partly in ocean (no atmospheric correction, consideration of wind)

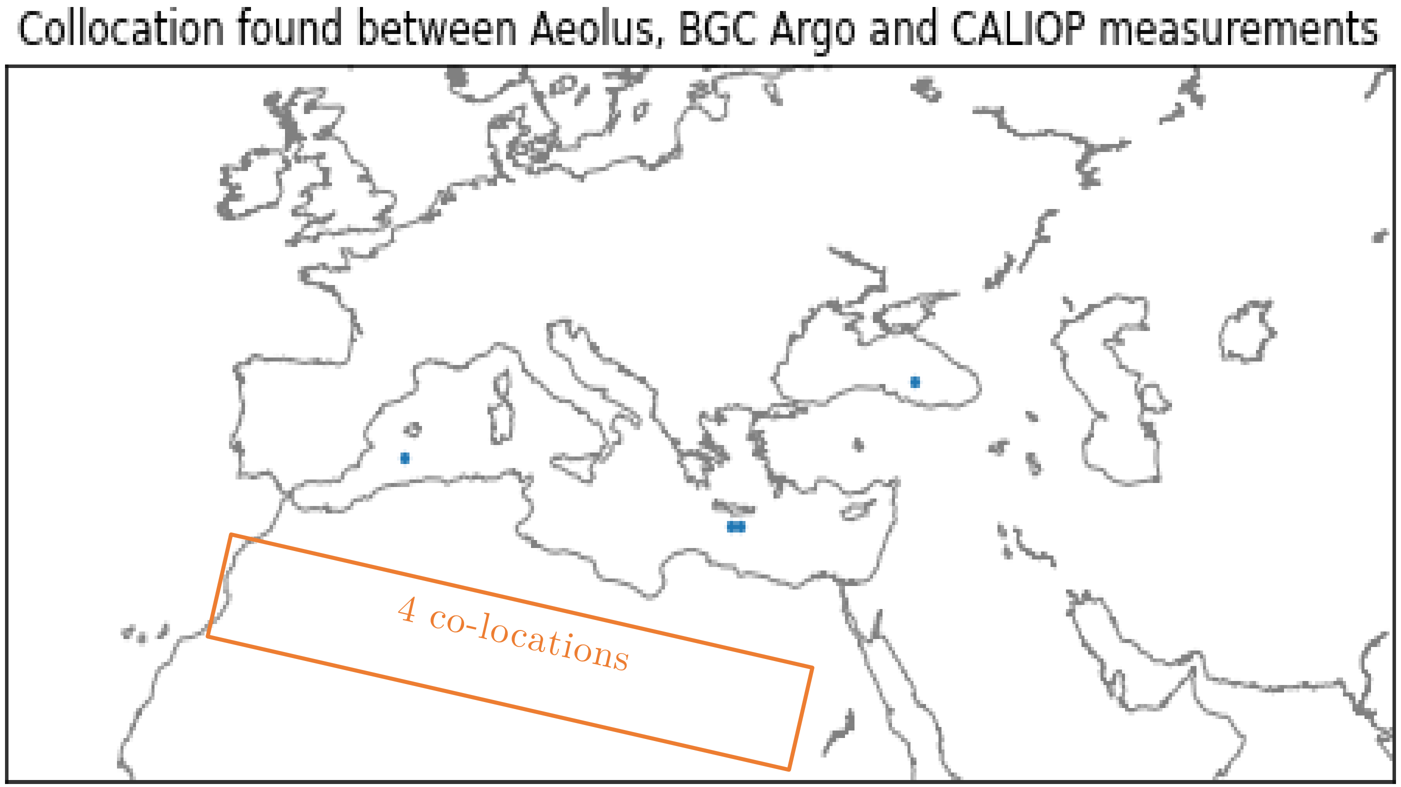
ERA5 reanalysis data used at the time and location of AEOLUS observations.



Impact of the hypothesis

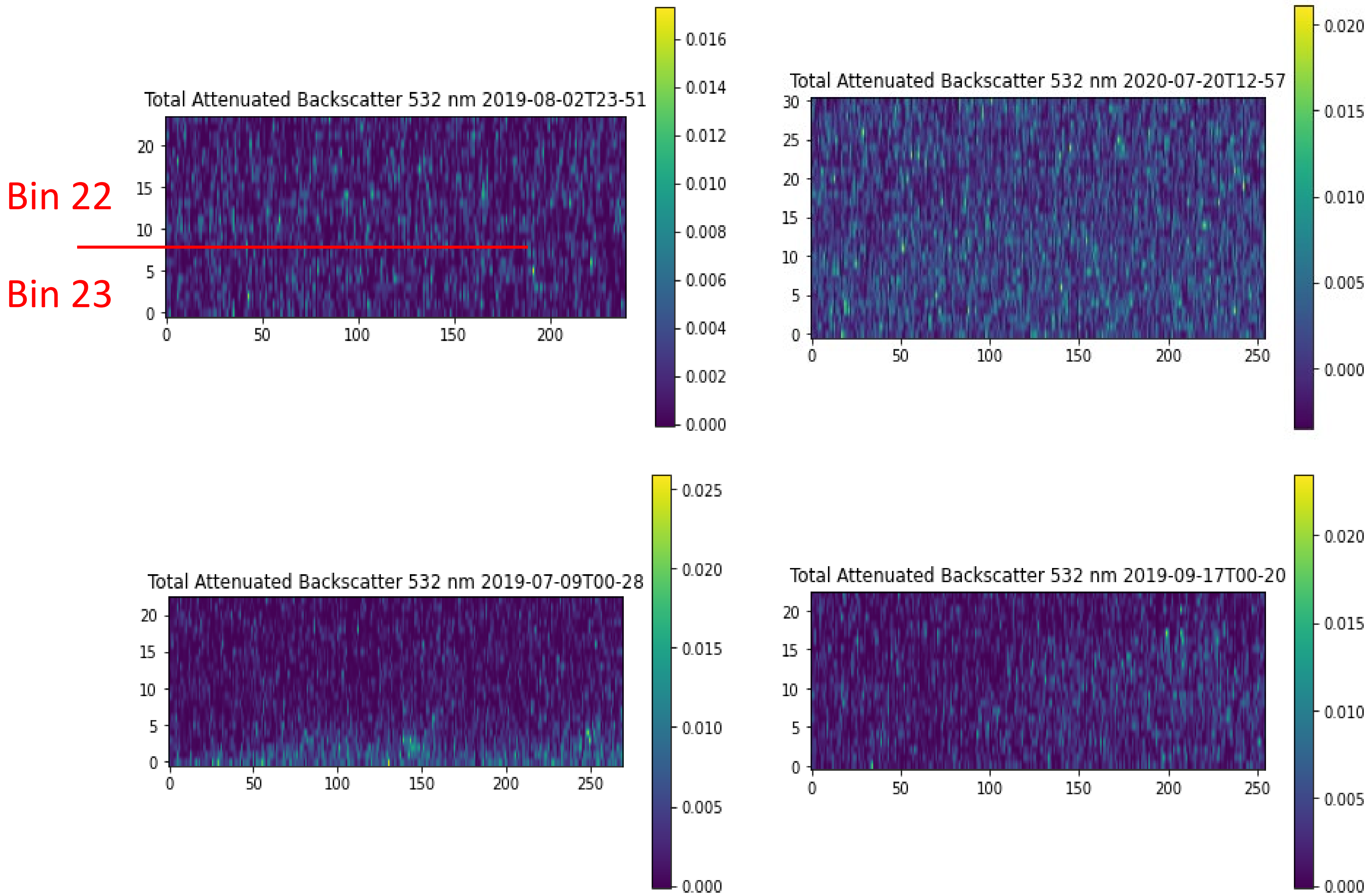
- Range of S_R
- Impact of the wind
- **Homogeneity of the marine boundary layer**

Hypothesis on the homogeneity of the lower atmosphere



	Obs 1	Obs 2	Obs 3	Obs 4
SP dist 1 (km)	99	3.5	26	54
SP dist 2 (km)	63	3.3	32	49
TP dist (h)	8:30	28:40	4:00	4:07

Hypothesis on the homogeneity of the lower atmosphere



	Observation 1		Observation 2		Observation 3		Observation 4	
	22nd bin	23rd bin	22nd bin	23rd bin	22nd bin	23rd bin	22nd bin	23rd bin
count	1440	240	3315	255	1620	270	1530	255
mean ($km^{-1}sr^{-1}$)	0.00172	0.0015	0.0016	0.0015	0.00398	0.00171	0.00242	0.00266
median ($km^{-1}sr^{-1}$)	0.00103	0.00076	0.00082	0.00095	0.003	0.00092	0.00173	0.00215
std ($km^{-1}sr^{-1}$)	0.00202	0.00177	0.00357	0.00356	0.00368	0.00216	0.00241	0.00237
abs relative difference (%)	12.79		6.25		57.03		9.91	
b_{bp} predicted	-0.00803		-0.00518		0.00931		0.00381	
relative error (%)	259.53		698.14		953.36		345.06	

Statistical summary of the total backscatter at 532 nm above the 4 co-locations studied with a comparison between backscatter values in the 22nd and the 23rd bin

	Observation 1		Observation 2		Observation 3		Observation 4	
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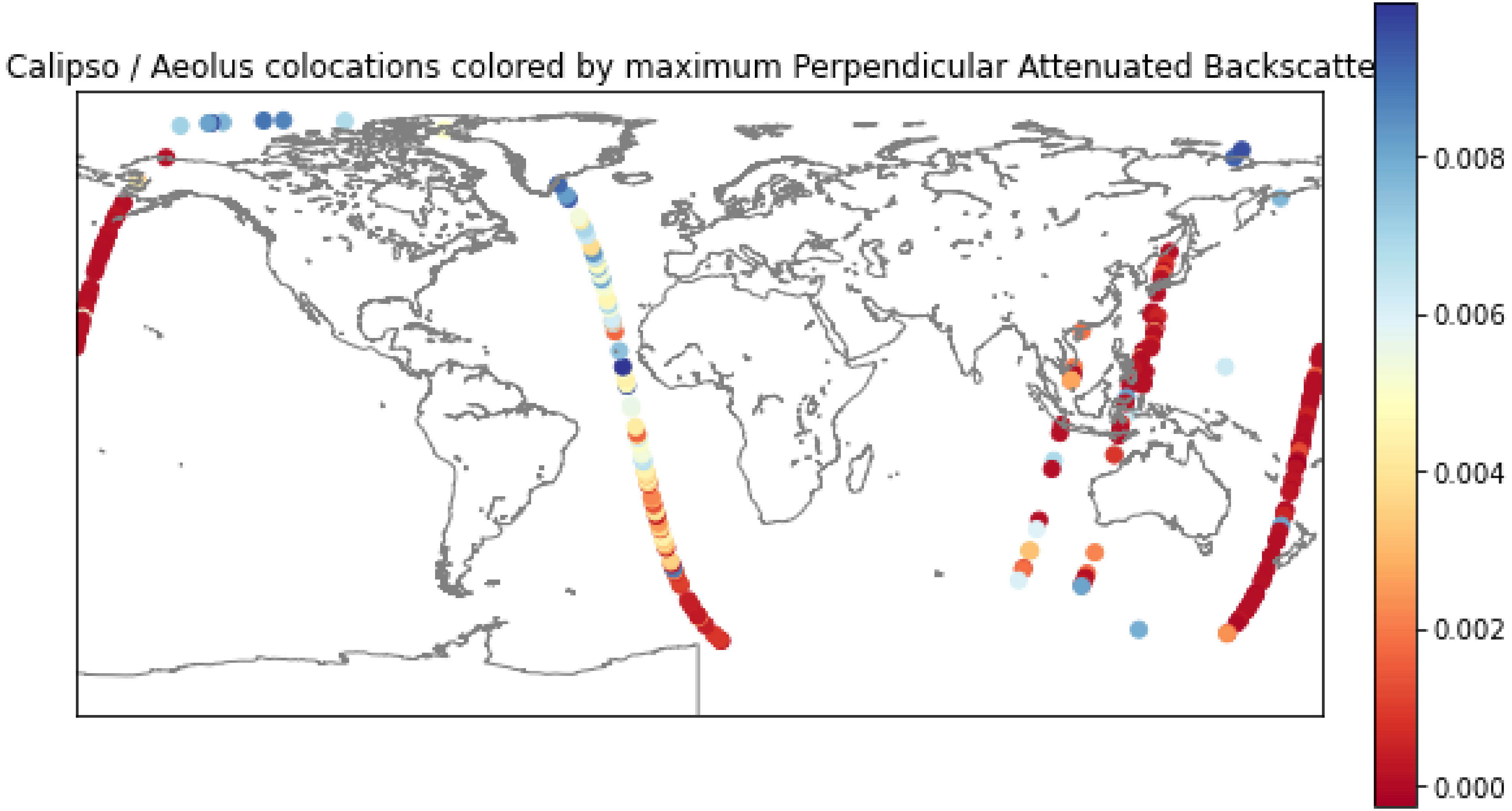
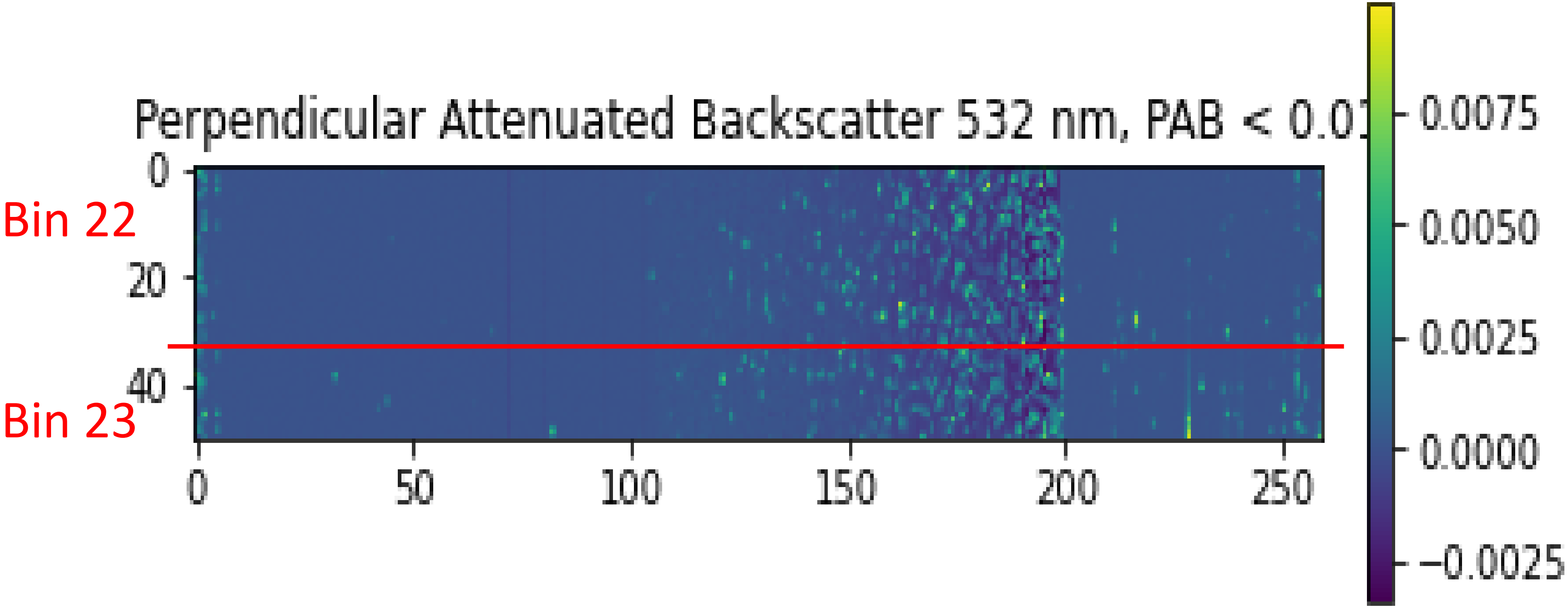
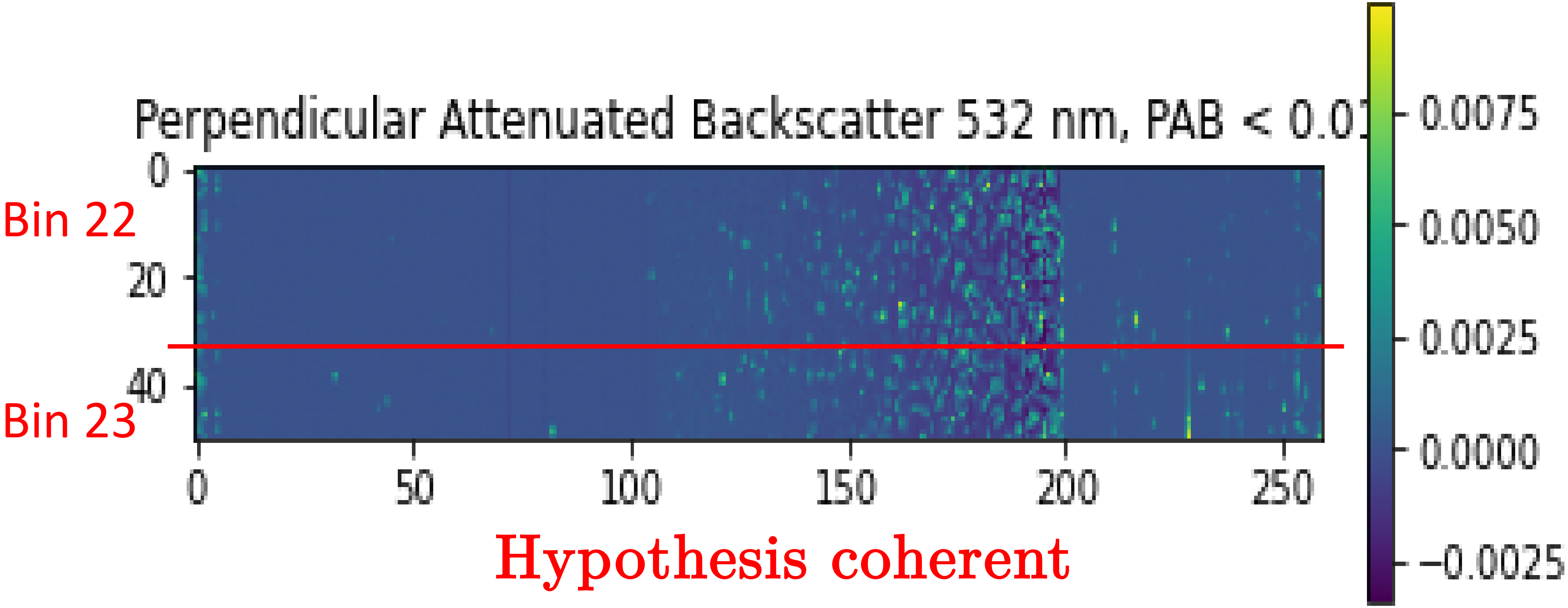
Hypothesis acceptable for 3 out of 4 observations

- 259 observations found without clouds between ALADIN and AEOLUS





Mean absolute difference (%)	3.89
Median absolute difference (%)	1.30
Std of absolute difference (%)	7.64
Max absolute difference (%)	64.37
Min absolute difference (%)	0.02
Count	259



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Conclusions and Perspectives

- **Use of HSRL capabilities to develop an oceanic algorithm**
  - Estimation of the particulate back-scattering coefficient $b_{bp}(355)$
  - Use of bin #23 : partly in atmosphere, partly in ocean, interface air-sea
  - Correction of atmosphere using bin #22
  - Validation in open ocean waters and Cabo Verde coastal waters

  →Only negative values of $b_{bp}(355)$: not physical

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  - Hypothesis of homogeneous lower atmosphere
  - Impact of wind
  - Range of validity on S_R

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  - Hypothesis of homogeneous lower atmosphere
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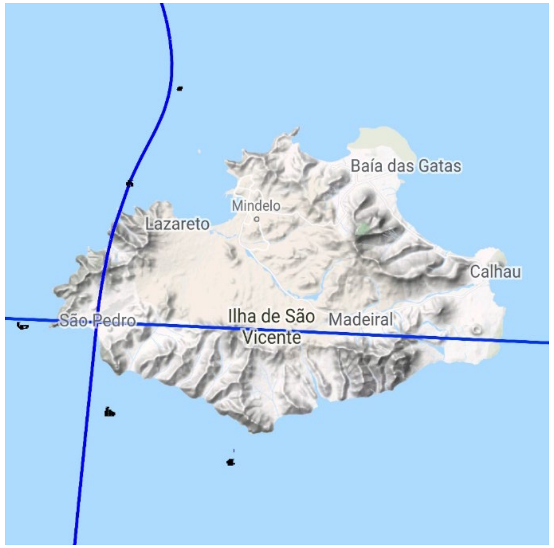
- **Main causes :**
  - Vertical resolution
  - SNR too low

Perspectives

- Perspectives :
  - Applying HSRL algorithm to LNG airborne lidar



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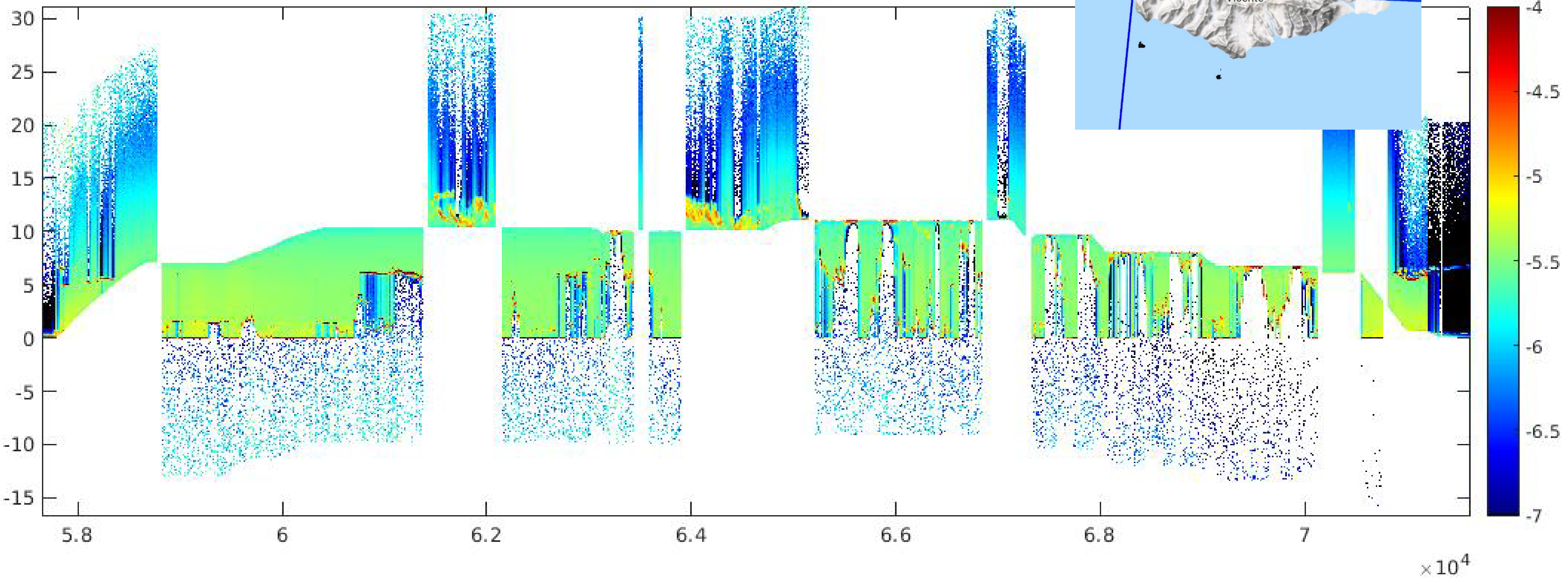

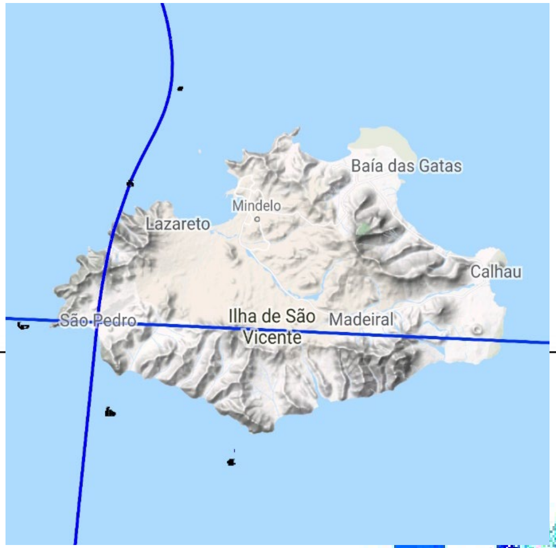

Attenuated backscatter lidar return signal at 355 nm in the Rayleigh channel

Perspectives

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  - Applying HSRL algorithm to LNG airborne lidar
  - Development of an algorithm using only the Mie channel

Perspectives

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  - Applying HSRL algorithm to LNG airborne lidar
  - Development of an algorithm using only the Mie channel
  - Simulation of AEOLUS-2 with ocean capabilities (cross-polarization)

Perspectives

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  - Study of ATLID

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  - Simulation of AEOLUS-2 with ocean capabilities
  - Study of ATLID
    - Higher vertical and horizontal resolution
    - Cross-polarization
    - Need Cx values for ocean

Acknowledgments

- CNES for funding through the TOSCA program
- ESA for funding through the AEOLUS+-Innovation call
- The Ocean Science Mindelo Center (OSCM) for the help to organize this campaign and the use of their facilities: Pericles Silva, Ivanice Monteiro and Elizandro Rodrigues
- The captain and the fishermen of the Gamboa ship
- Alain Dabas and his team from Meteo-France for providing the Cx values for the ocean

Thank you for your attention

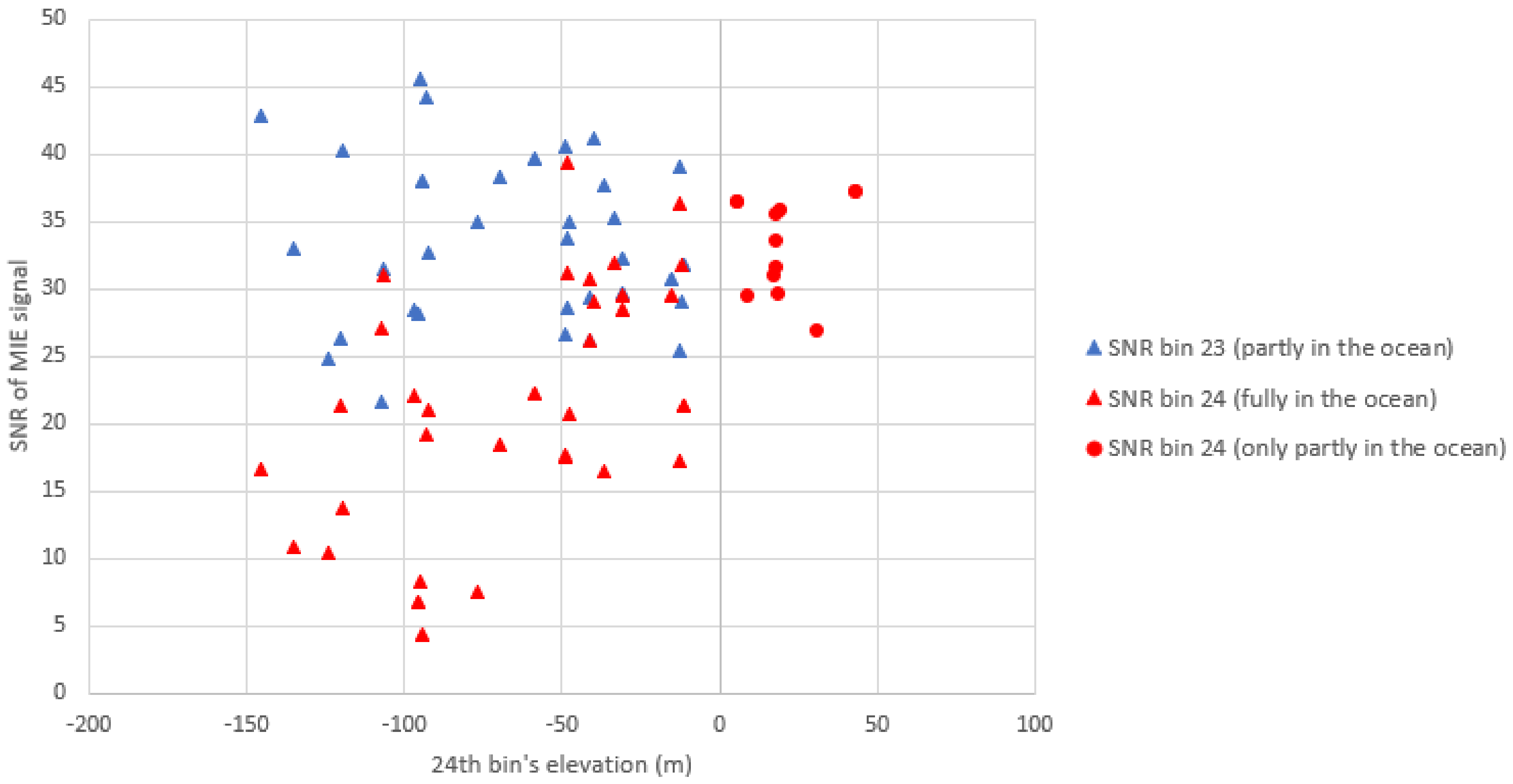
Merci

ευχαριστώ

General objectives

- Derivation of Ocean Color parameters from Aeolus
  - **lidar-derived optical parameters**
    - particulate attenuated backscatter $\boldsymbol{\beta_p}$
    - attenuation coefficient $\boldsymbol{K_L}$
  - **ocean optical parameters** related to ocean optical properties
    - diffuse attenuation coefficient $\boldsymbol{K_d}(355)$
    - particulate backscattering parameter $\boldsymbol{b_{bp}}(355)$
  - **biogeochemical parameters** related to marine biogeochemical cycles
    - particulate organic carbon $\boldsymbol{POC}$
    - phytoplankton carbon $\boldsymbol{C_{phyto}}$
    - coloured dissolved organic matter (**CDOM**)

➢ Potentials of these AOC products
  - ➢ Provide optical ocean properties in the UV
  - ➢ Study the diurnal variability of phytoplankton
  - ➢ Characterize the degradation of organic matter due to UV solar light, especially in Polar Regions.



$$\mathrm{SNR}(24) < \mathrm{SNR}(23)$$

General objectives

- **2 core goals**

- Demonstrate the Aeolus potential to measure subsurface ocean particulate backscattering and the diffuse attenuation coefficient parameters in the UV
- Assess Aeolus potentials to estimate biogeochemical parameters linked to ocean colour and the ocean carbon cycle: particulate organic carbon (POC), phytoplankton carbon (Cphyto) and coloured Dissolved Organic Matter (CDOM)

General objectives

• 2 core goals

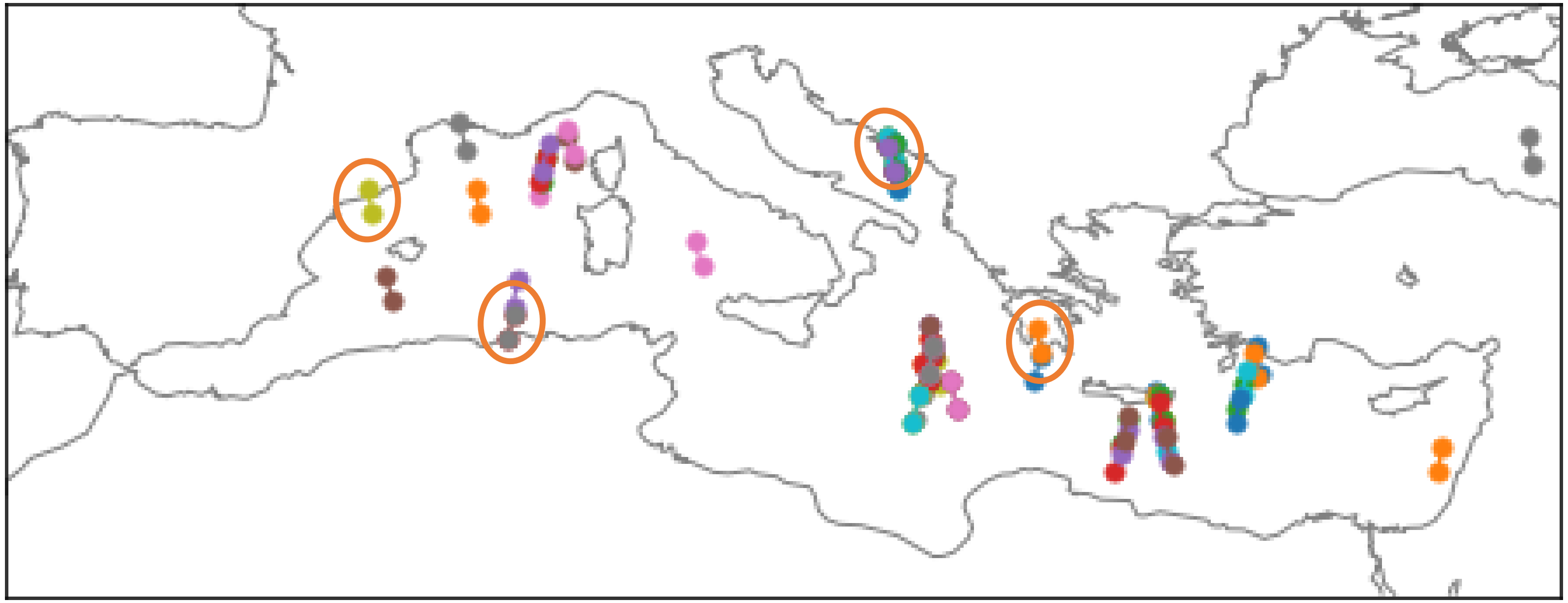
- Demonstrate the Aeolus potential to measure subsurface ocean particulate backscattering and the diffuse attenuation coefficient parameters in the UV
- Assess Aeolus potentials to estimate biogeochemical parameters linked to ocean colour and the ocean carbon cycle: particulate organic carbon (POC), phytoplankton carbon (Cphyto) and coloured Dissolved Organic Matter (CDOM)

• 6 Technical / Scientific objectives

- Development of a processing algorithm to generate Aeolus lidar-derived optical properties ($\beta_P(355)$ and $K_L(355)$) from the co-polar backscatter signal;
- Development of a processing algorithm to generate Aeolus ocean optical parameters ($b_{bp}(355)$ and $K_d(355)$) from the lidar-derived parameters;
- Development of a retrieval scheme to generate more added-value biogeochemical estimates related to ocean colour from Aeolus measurements (*POC*, *Cphyto* , *CDOM*), derived from the ocean optical parameters;
- Evaluation and validation of Aeolus ocean optical estimates compared to other space-borne products (albeit at other wavelengths) and *in situ* data;
- Evaluation and validation of Aeolus biogeochemical estimates against other products (space-borne products, in situ measurements, model simulations, etc.);
- Assessment of the benefits of ocean colour products derived from Aeolus measurements in terms of knowledge gain on the functioning of ocean ecosystems, in particular regarding the global carbon cycle.

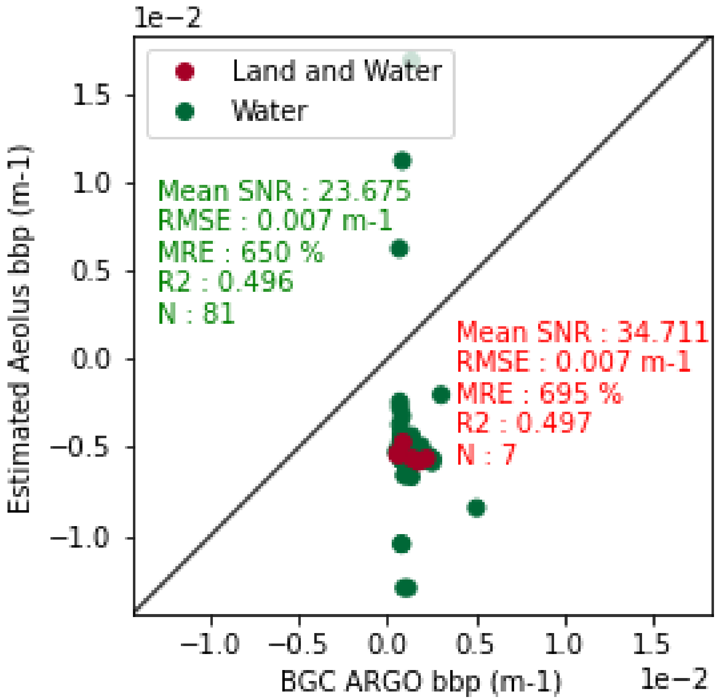
Validation of AOC products

- M1 calibration bias. Cross-talk. Bin partly in ocean (atmospheric correction, no consideration of wind)
  - AEOLUS observations affected by the ground

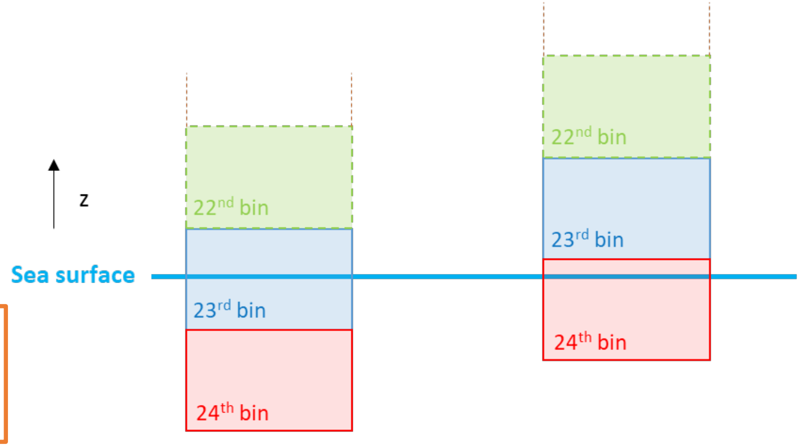


Validation of AOC products

- M1 calibration bias. Cross-talk. Bin partly in ocean (atmospheric correction, no consideration of wind)
  - › Global results of b_{bp} retrievals



$$S_{atom}(23) = S_{atm}(22)\frac{altitude\_bin(23)}{height\_bin(23)}$$



AEOLUS observations partly on ground removed in the algorithm