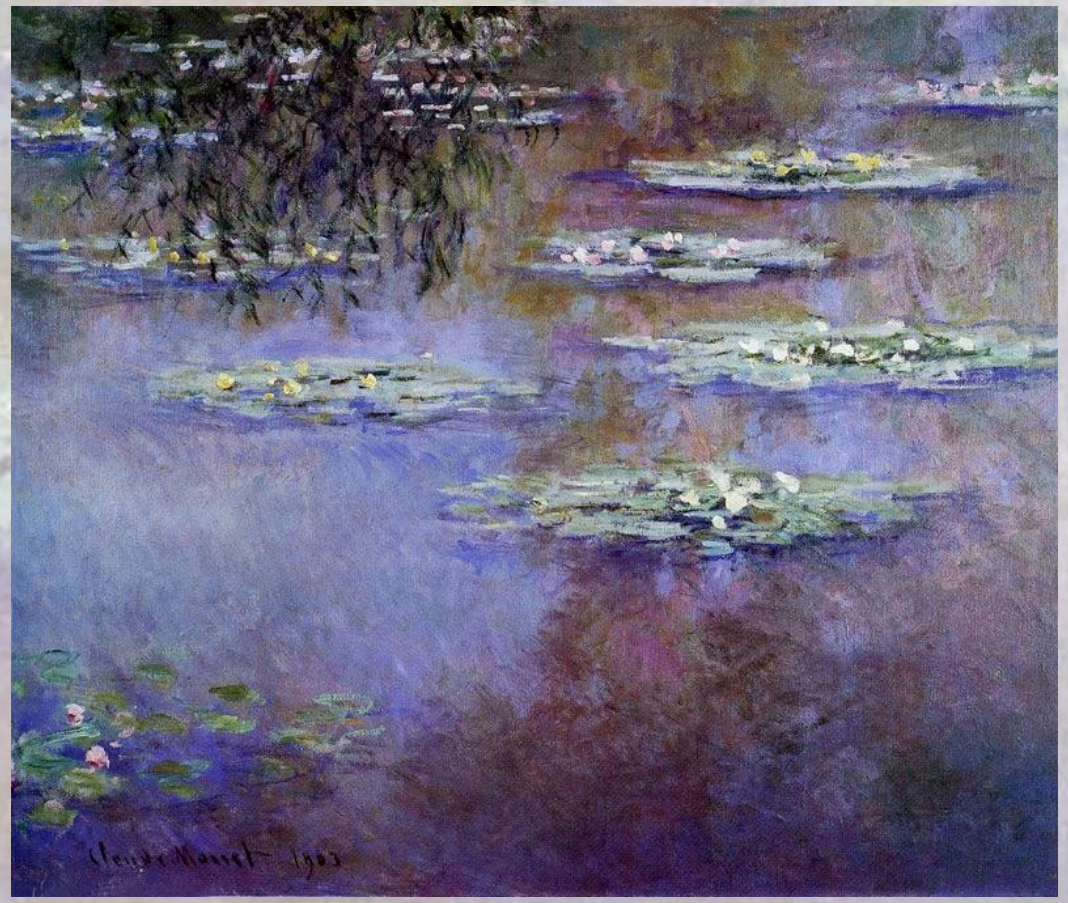
Radiative transfer model validation with BGC-Argo float data

Atmospheric and in-water components for the Mediterranean sea



Claude Monet (1840-1926)
Waterlillies, 1903
Dayton Art Institute, Ohio

Elena Terzić

Athens, October 2019

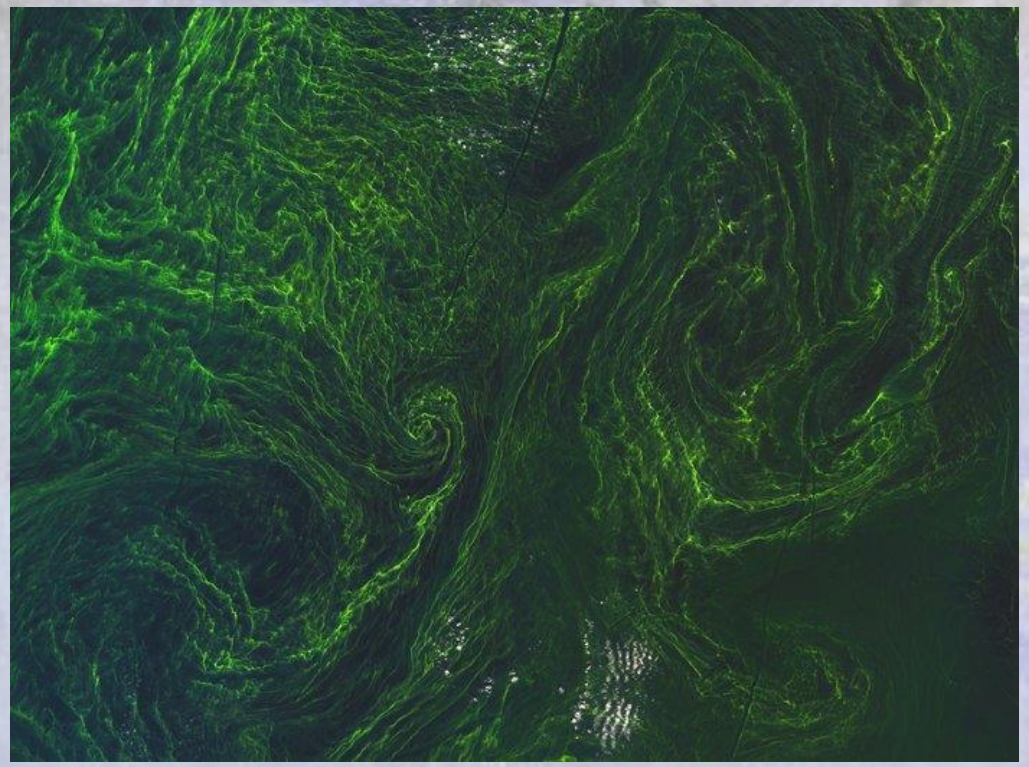
Outline

1. Introduction
2. Methods
3. Results 1 – Atmospheric component
4. Results 2 – In-water simulations
5. Conclusions and future directions

1. Introduction

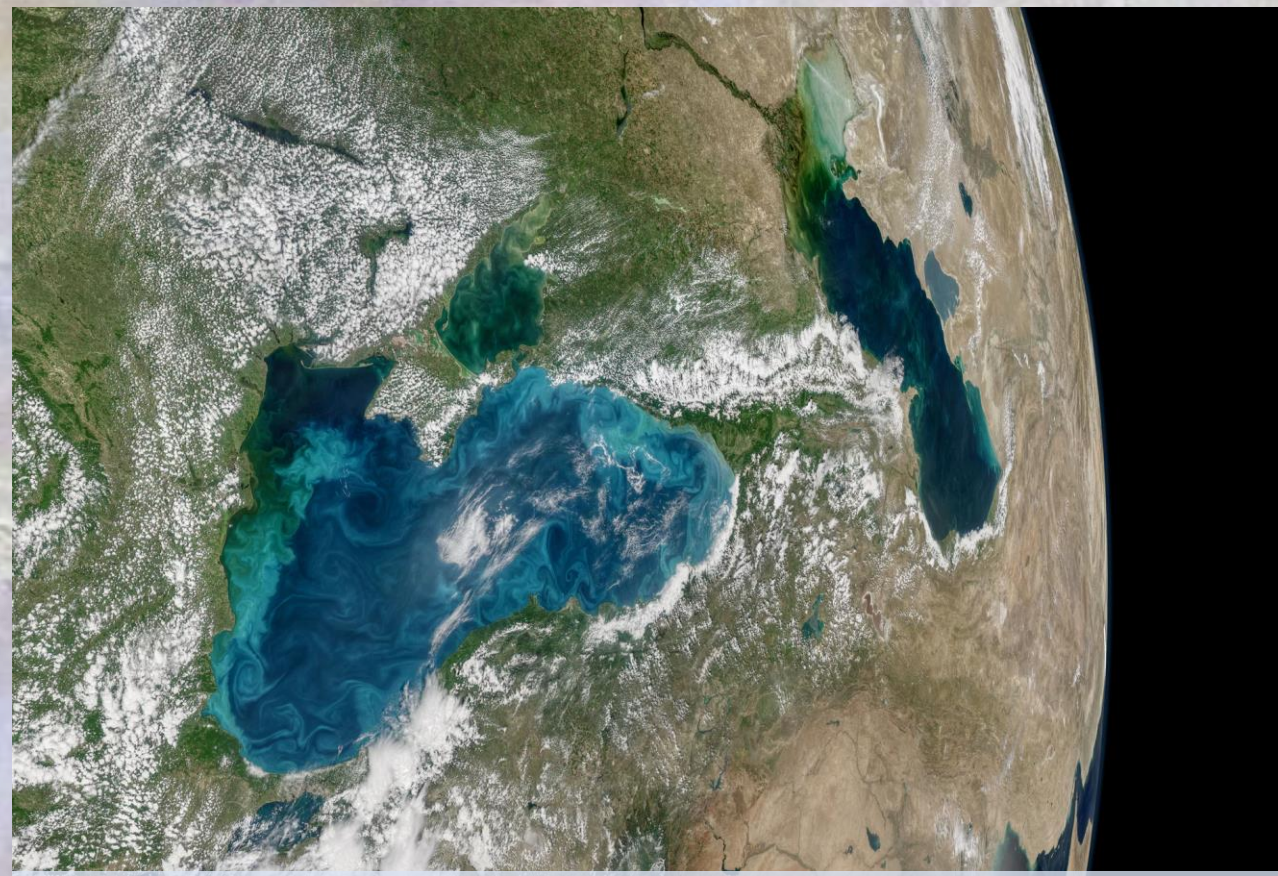
- A foreword on ocean colour
- Bio-optical anomalies in the Mediterranean sea

Phytoplankton from space ...



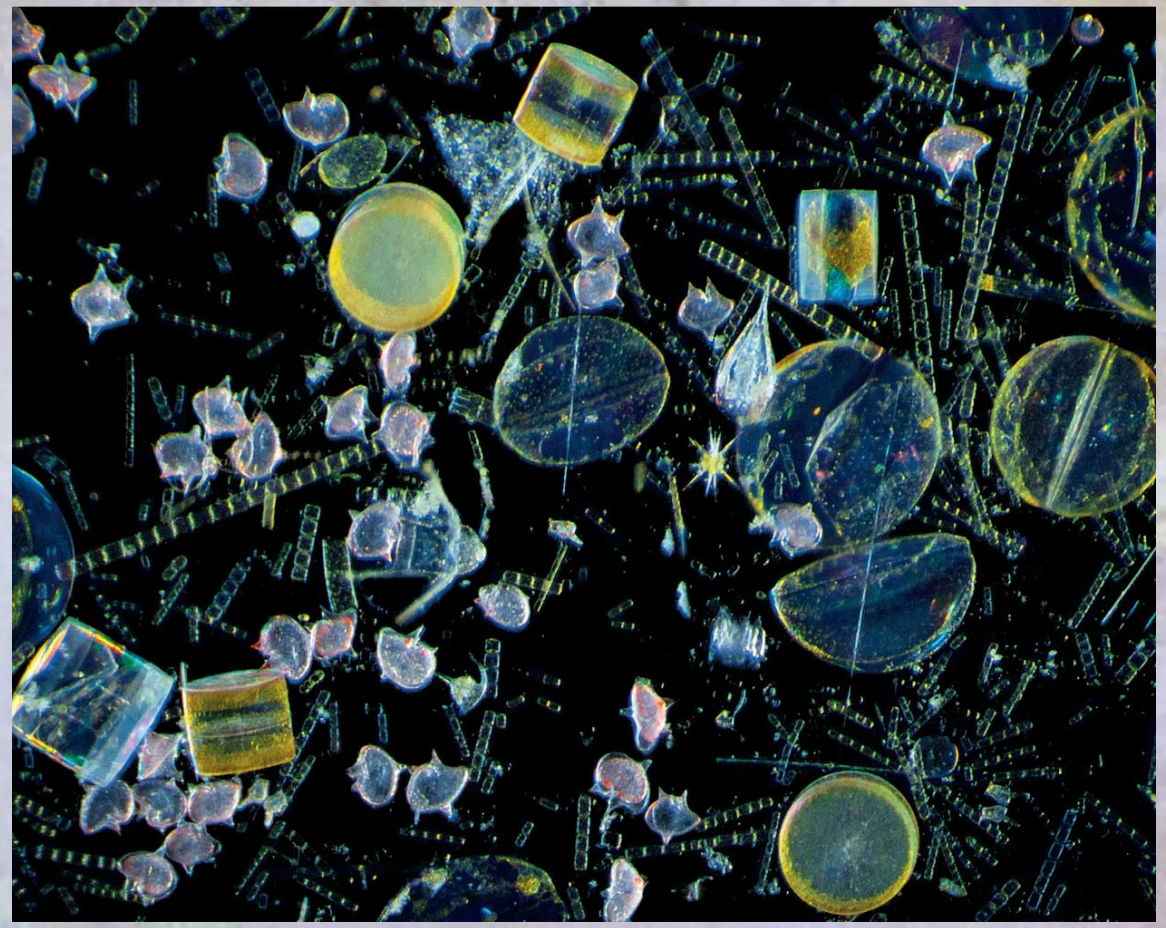
Top: Harmful algal bloom in the central Baltic Sea (September 2015)
Photograph: Sentinel 2

Right: Coccolithophore bloom in the Black Sea (June 2014)
Photograph: MODIS Aqua

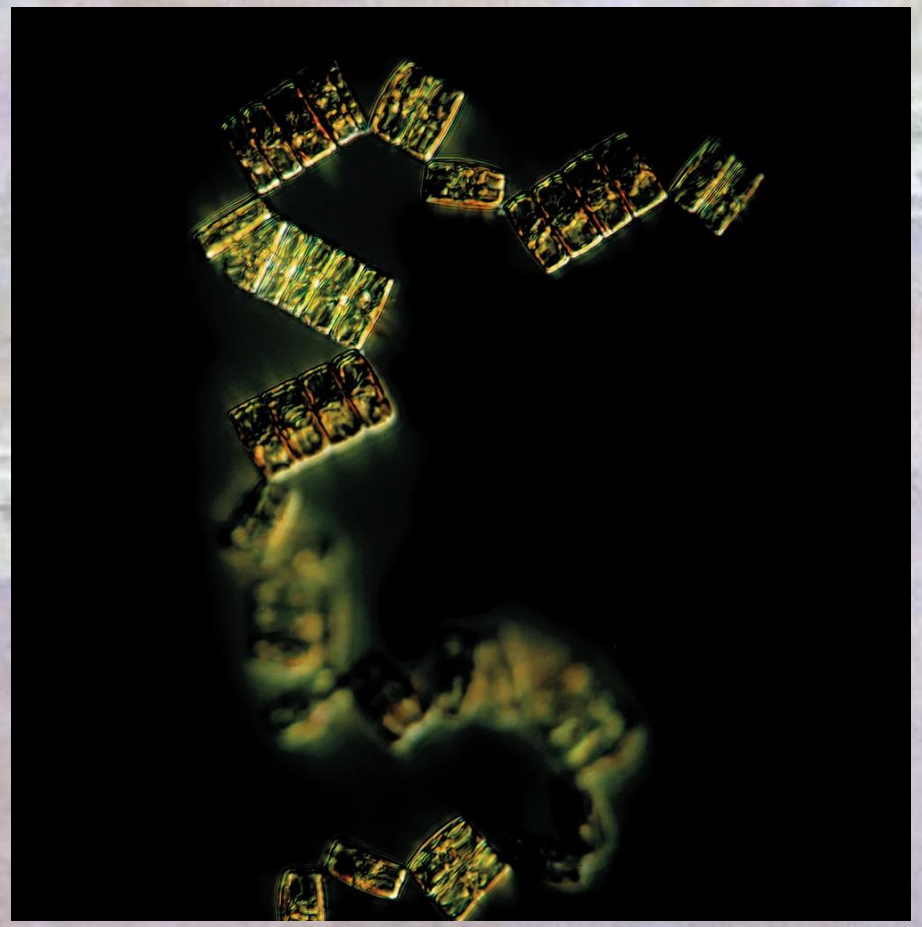


By inspecting the ocean **COLOUR** we can get a grasp on the **composition** of the water body.

Phytoplankton under a microscope ...



Diatom and dinoflagellate bloom in Toba Bay



Diatoms in chains (*Thalassionema nitzschioides)*

The Mediterranean Sea

Bio-optically anomalous region

Insufficiently accurate global relationships for BGC parameters retrieval from Rrs (blue-to-green ratio) → large errors on their estimates

$$log_{10}(\boldsymbol{chl}\ a) = a_0 + \sum_{i=1}^{4} a_i \left(log_{10}\left(\frac{\boldsymbol{R_{rs}}(\lambda_{blue})}{\boldsymbol{R_{rs}}(\lambda_{green})}\right)\right)^i$$

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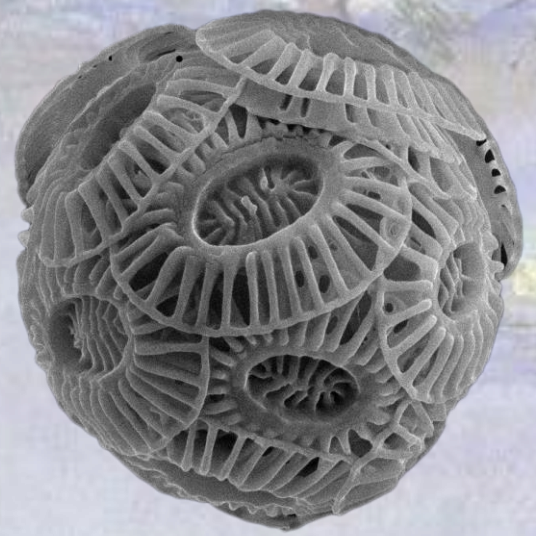
Possible **causes**:

- **phytoplankton community structure** (cell size, pigment packaging, pigment composition, photophysiology) – e.g. *presence of prymnesiophytes* affects phytoplankton absorption (a_{ph}) and the particulate backscattering signal (b_{bp})

The Mediterranean Sea



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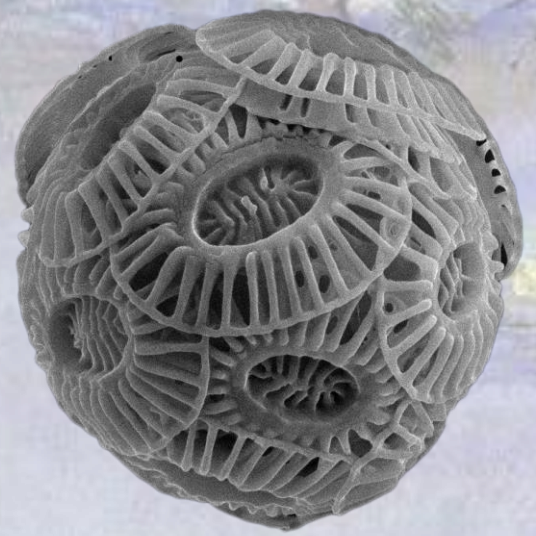

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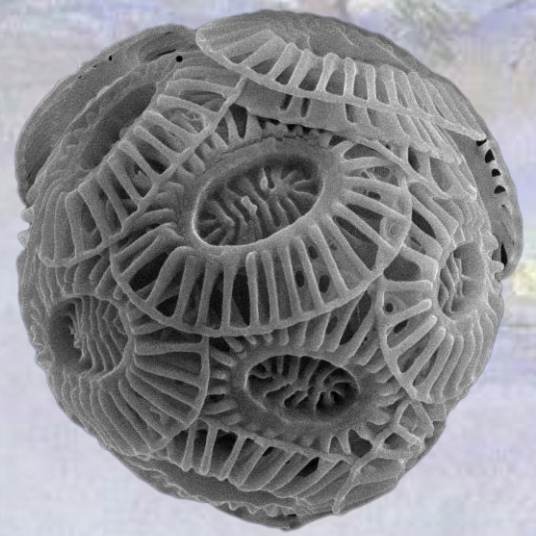
The Mediterranean Sea



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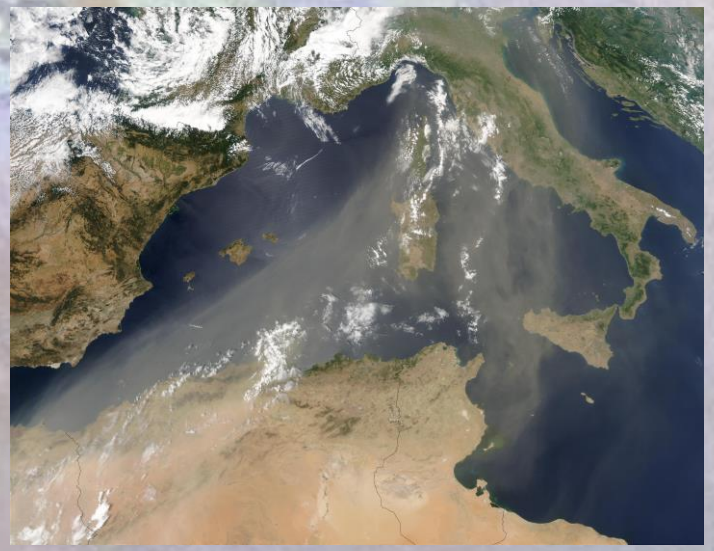
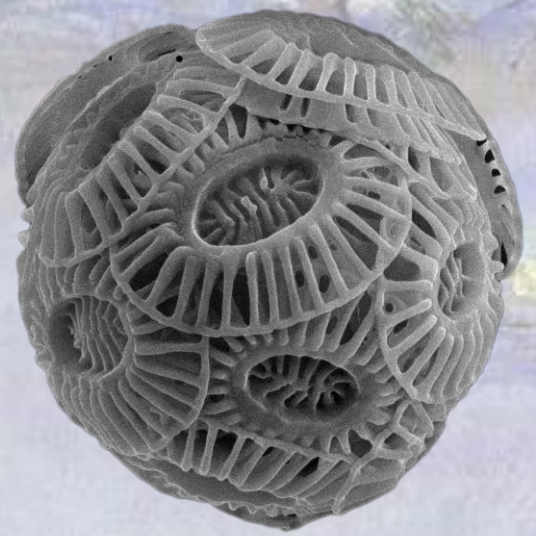


The Mediterranean Sea



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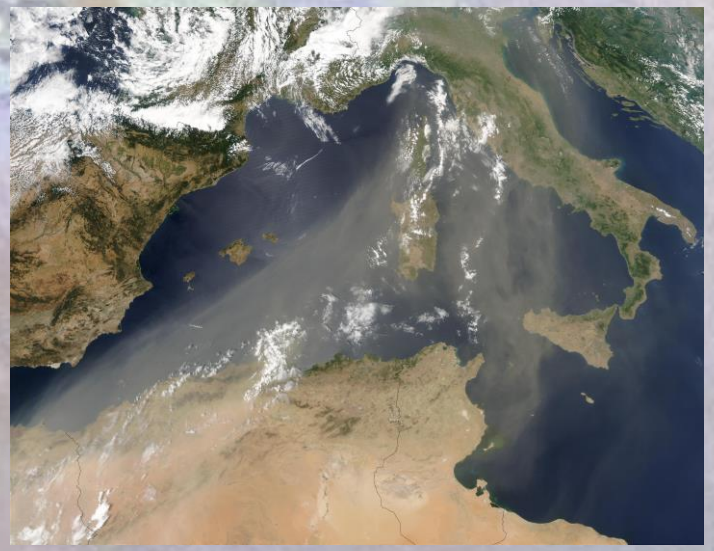
- excess/deficit of **non-algal** (biogenous or mineral) **particles** (influencing a_{NAP} and b_{bp}) – e.g. *Saharan dust deposition events*
- excess/deficit of **CDOM** (influencing a_{CDOM})



2. Methods

- BIOPTIMOD – project description
- BIOPTIMOD – Atmospheric and in-water radiative transfer models
- BGC-Argo floats

BIOPTIMOD

CMEMS-MED-MFC
Mediterranean Biogeochemistry modelling system

Initial Condition:
[MEDAR/MEDATLAS, NODC-OGS and Med-CarbSys]

Physical variable fields:
daily 3D fields of U, V, T, S, ssh, Qsw from NEMO3.6

Boundary Conditions:
1. seasonal profiles of N,P, O, DIC, Alk in the Atlantic buffer zone from MEDAR/MEDATLAS, NODC-OGS and Med-CarbSys;
2. climatological values of N, P, O2, DIC, Alk at the Open Boundary of the Dardanelles Strait from literature after tuning;

Land and atmosphere forcing for nutrients, DIC and alk:
1. yearly and monthly climatological discharges for 39 rivers (Perseus D4.6 dataset);
2. seasonal estimates for N and P atm. deposition

Observations:
1. daily Ocean Colour surface Chlorophyll maps at 1km horiz. resolution
2. daily NO3, Chl and O2 profiles from BGC-Argo floats (pre-operational)

OGSTM – Transport model
[free surface and Z*]

$$\left.\frac{\partial \boldsymbol{C}}{\partial t}\right|_{tra} = -\boldsymbol{v}\cdot\nabla\boldsymbol{C} + \nabla(K\nabla\boldsymbol{C})$$

BFM – biogeochemical model
[C, N, P, Si, Chl cycles; 51 state variables; 4 phytoplankton, 4 zooplankton, 1 bacteria groups]

$$\left.\frac{\partial \boldsymbol{C}}{\partial t}\right|_{bio} = \boldsymbol{R}_{bio}(\boldsymbol{C}, T, PAR, wind)$$

3DVarBio – data assimilation
[variational scheme with decomposition of B, update of 4 phytopl. groups]

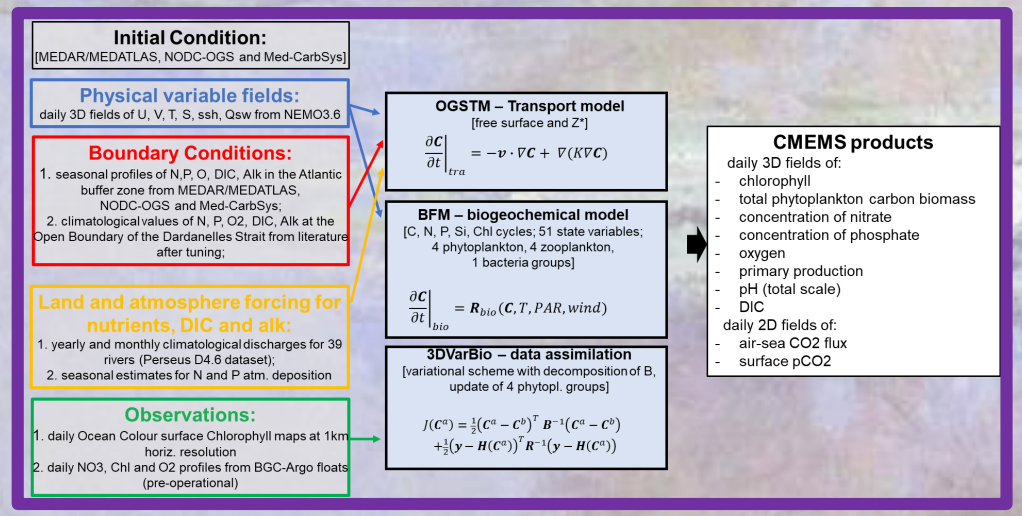
$$J(\boldsymbol{C}^a) = \tfrac{1}{2}(\boldsymbol{C}^a - \boldsymbol{C}^b)^T \boldsymbol{B}^{-1}(\boldsymbol{C}^a - \boldsymbol{C}^b) + \tfrac{1}{2}(\boldsymbol{y} - \boldsymbol{H}(\boldsymbol{C}^a))^T \boldsymbol{R}^{-1}(\boldsymbol{y} - \boldsymbol{H}(\boldsymbol{C}^a))$$

CMEMS products
daily 3D fields of:
- chlorophyll
- total phytoplankton carbon biomass
- concentration of nitrate
- concentration of phosphate
- oxygen
- primary production
- pH (total scale)
- DIC

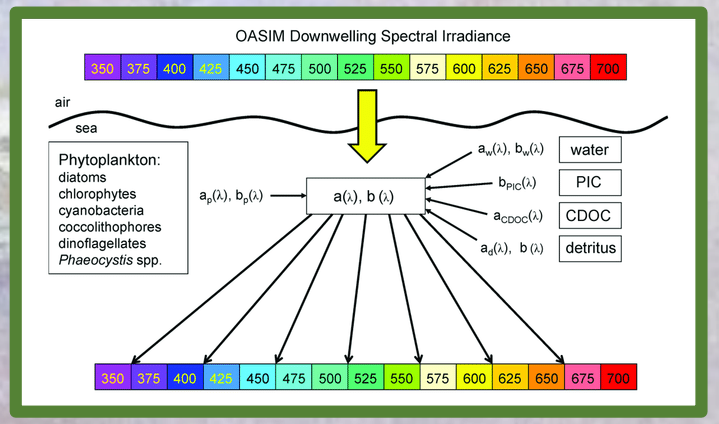
daily 2D fields of:
- air-sea CO2 flux
- surface pCO2

BIOPTIMOD

CMEMS-MED-MFC Mediterranean Biogeochemistry modelling system



New multi-spectral three-stream radiative transfer model



Linking spectral light propagation to biogeochemical variables through inherent optical properties (IOPs)

BIOPTIMOD

Data acquisition in the Mediterranean Sea: BOUSSOLE, **BGC-Argo**, satellites for:

- Model forcing
- Variable constraints
- Data assimilation
- Model output valdation

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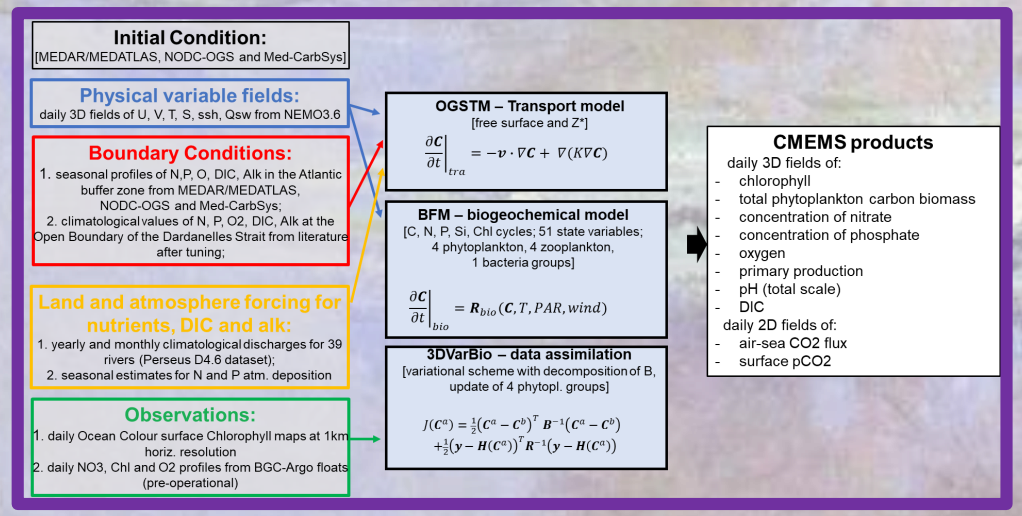

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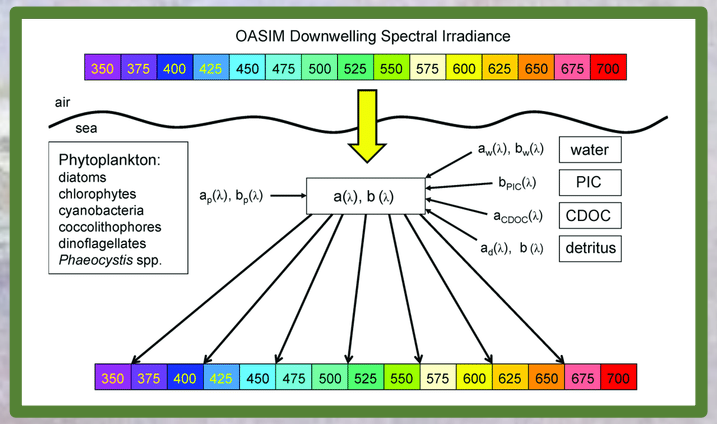

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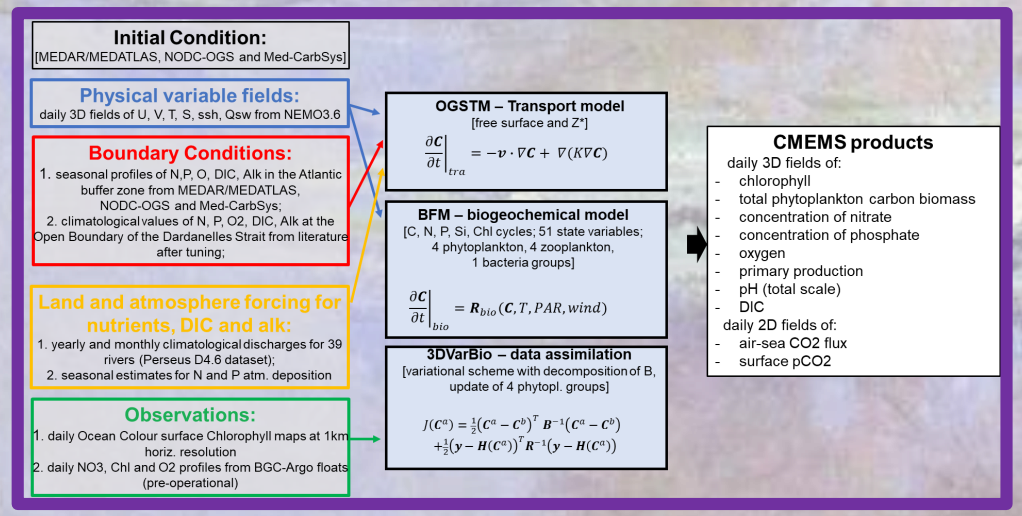

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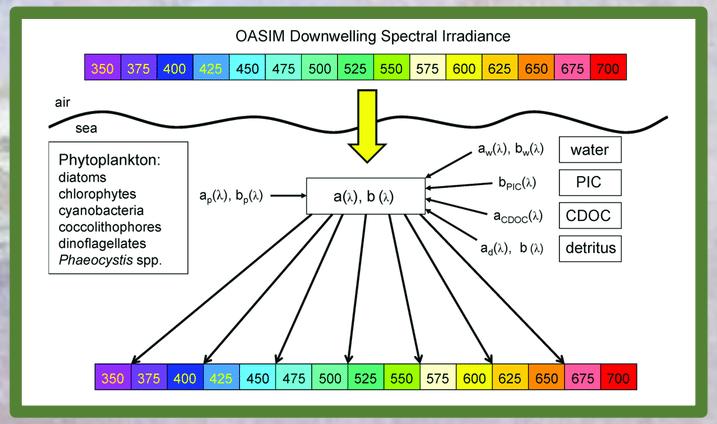

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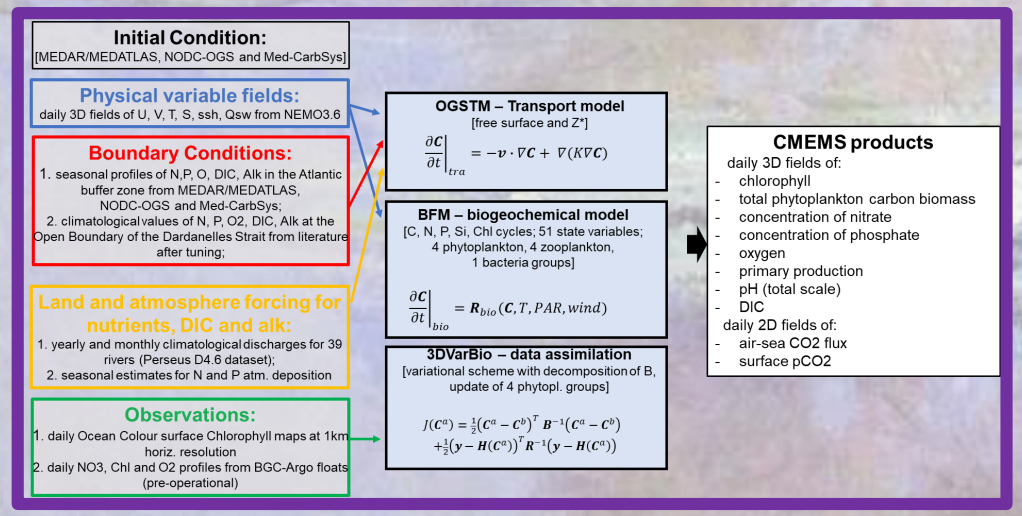

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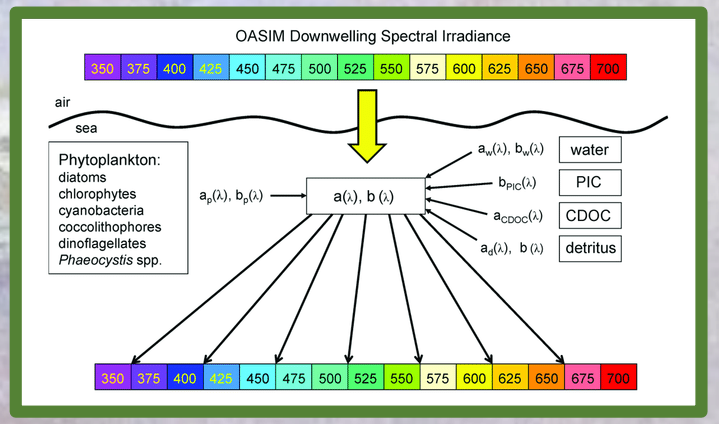
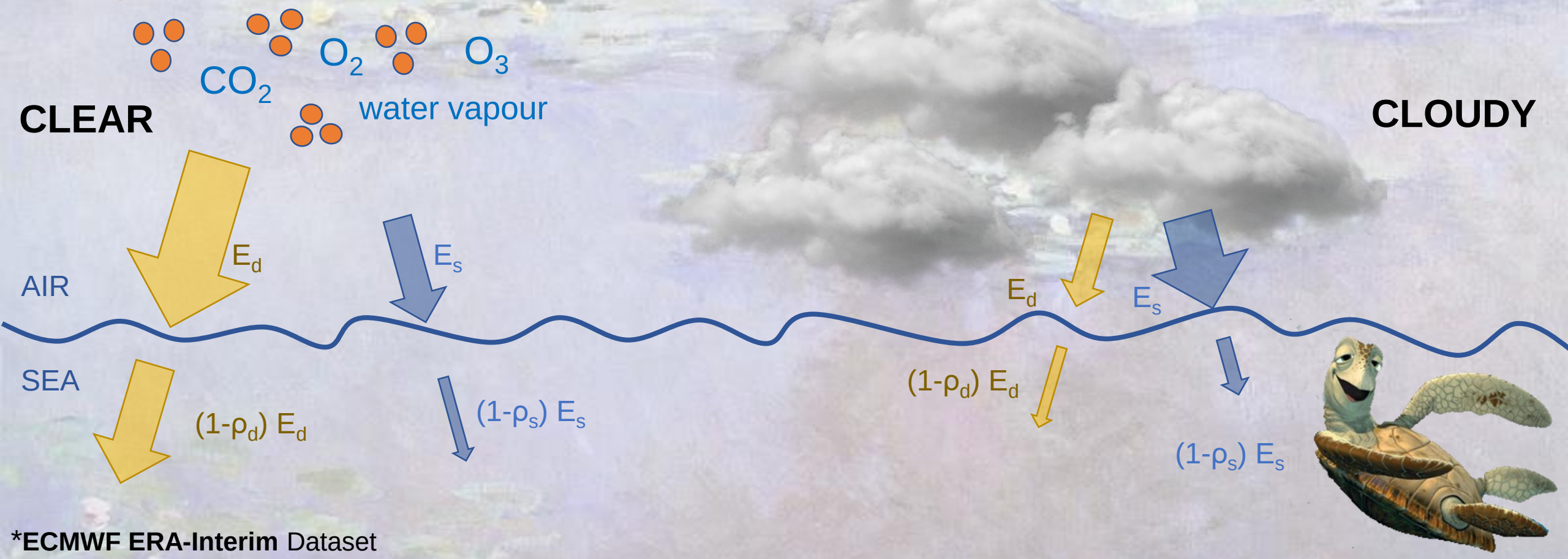


More info on the whole modelling chain, as well as on data assimilation, at 9:40 (G. Cossarini) and 10:40 (P. Lazzari)

OASIM – atmospheric RTM

Scattering and/or absorption by **aerosols**, **gases**, **clouds** *

350	375	400	425	450	475	500	525	550	575	600	625	650	675	700



***ECMWF ERA-Interim** Dataset

In-water RTM

Output → $R_{rs}(\lambda) = \frac{E_u}{Q \cdot E_d}$ (link to satellites)

SEA

$(1-\rho_d)\ E_d$

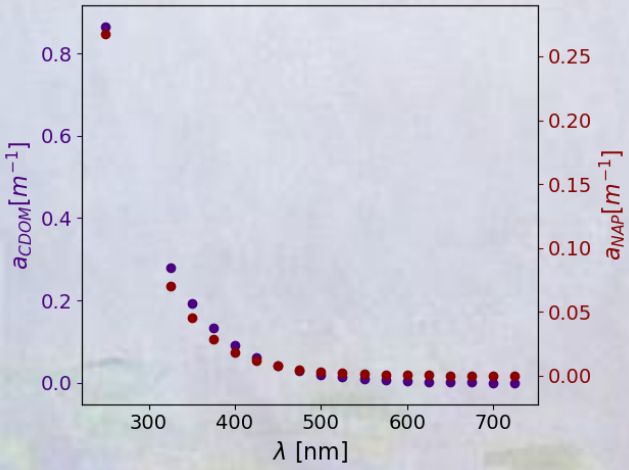
$(1-\rho_s)\ E_s$

$(1-\rho_d)\ E_d$

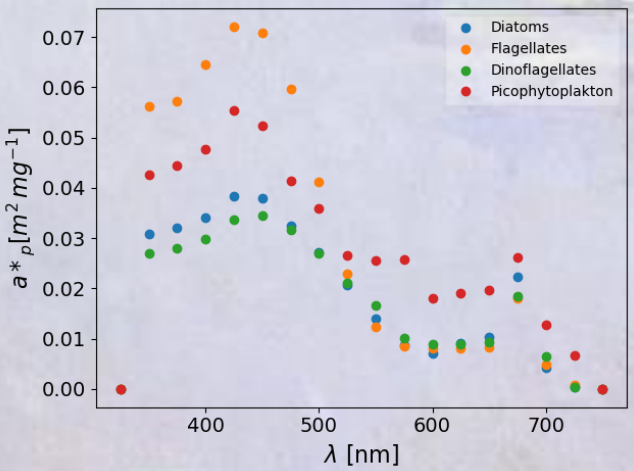
$(1-\rho_s)\ E_s$

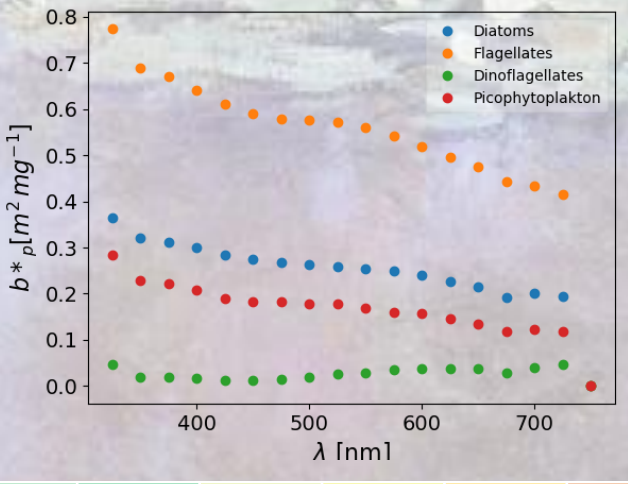
Eu (λ)
upwelling irradiance

CDOM and **NAP**

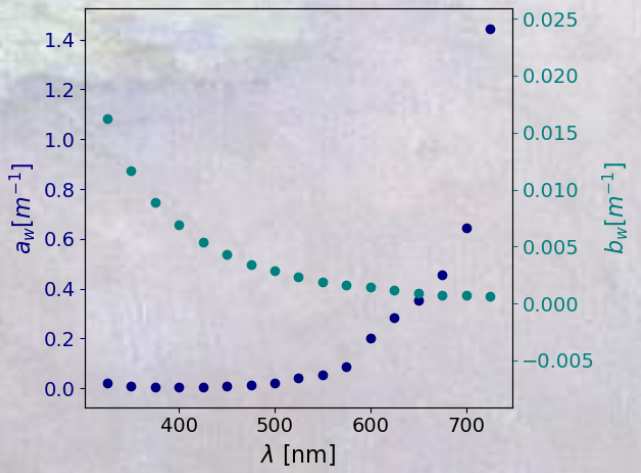


PHYTOPLANKTON





WATER



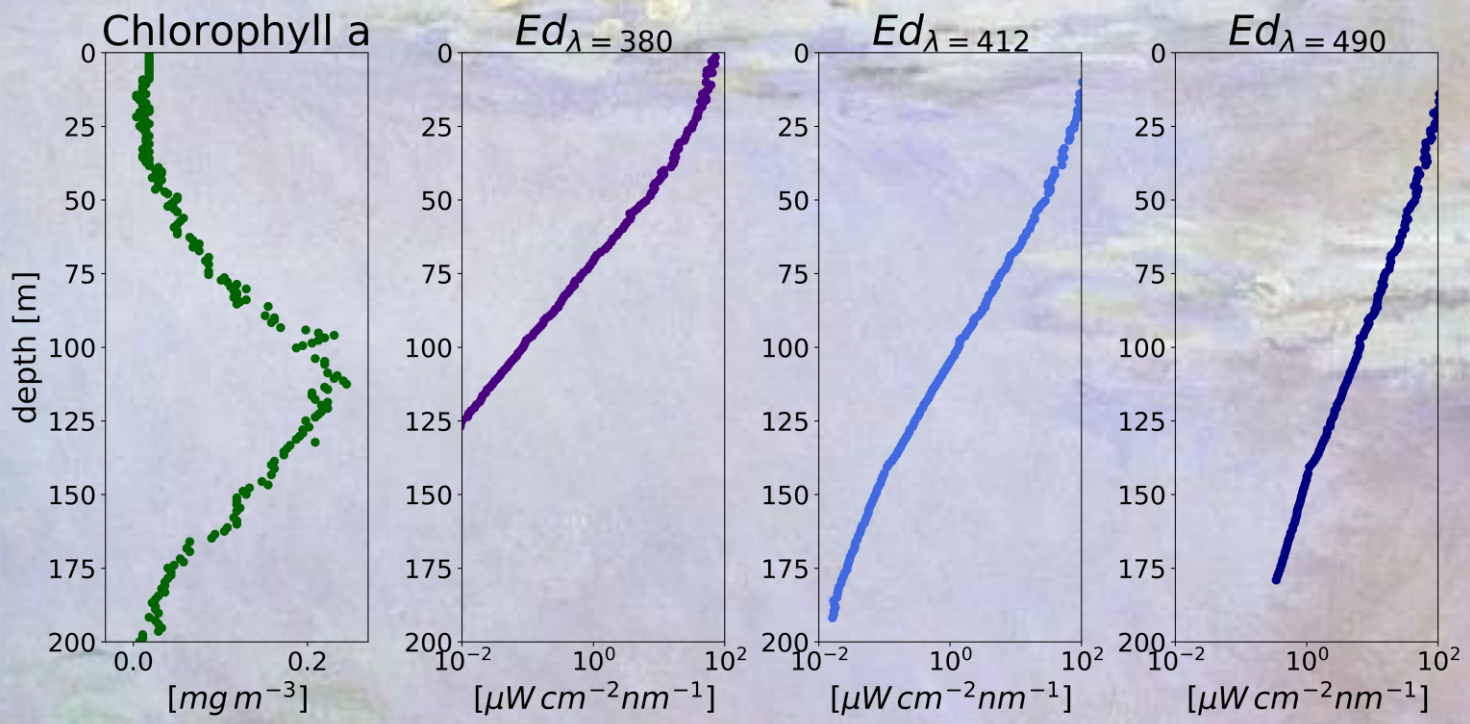
350	375	400	425	450	475	500	525	550	575	600	625	650	675	700

How can we use BGC-Argo floats?

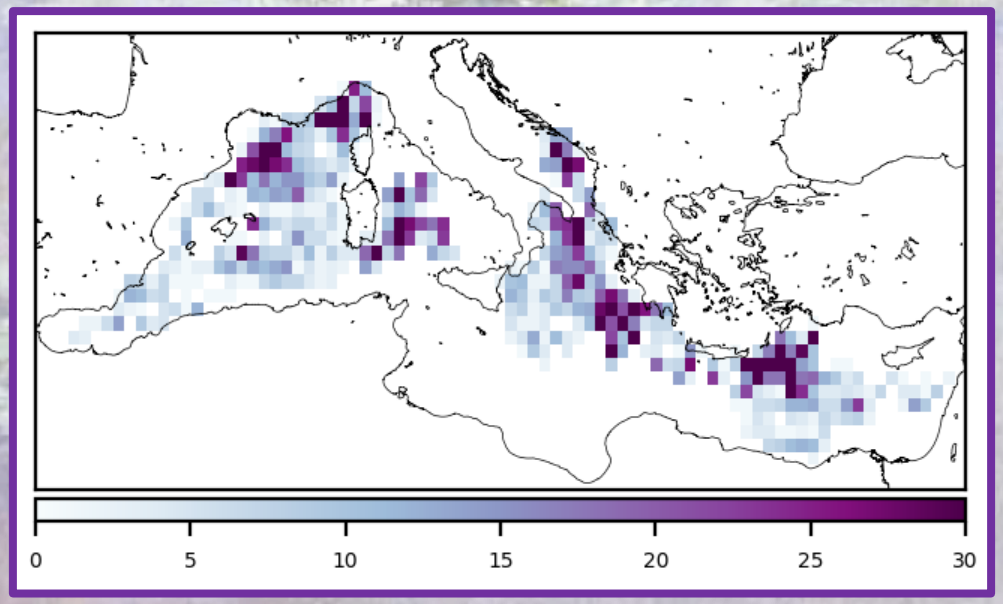
BGC-Argo floats

Period covered: 2012-2017

Variables:



6042 profiles

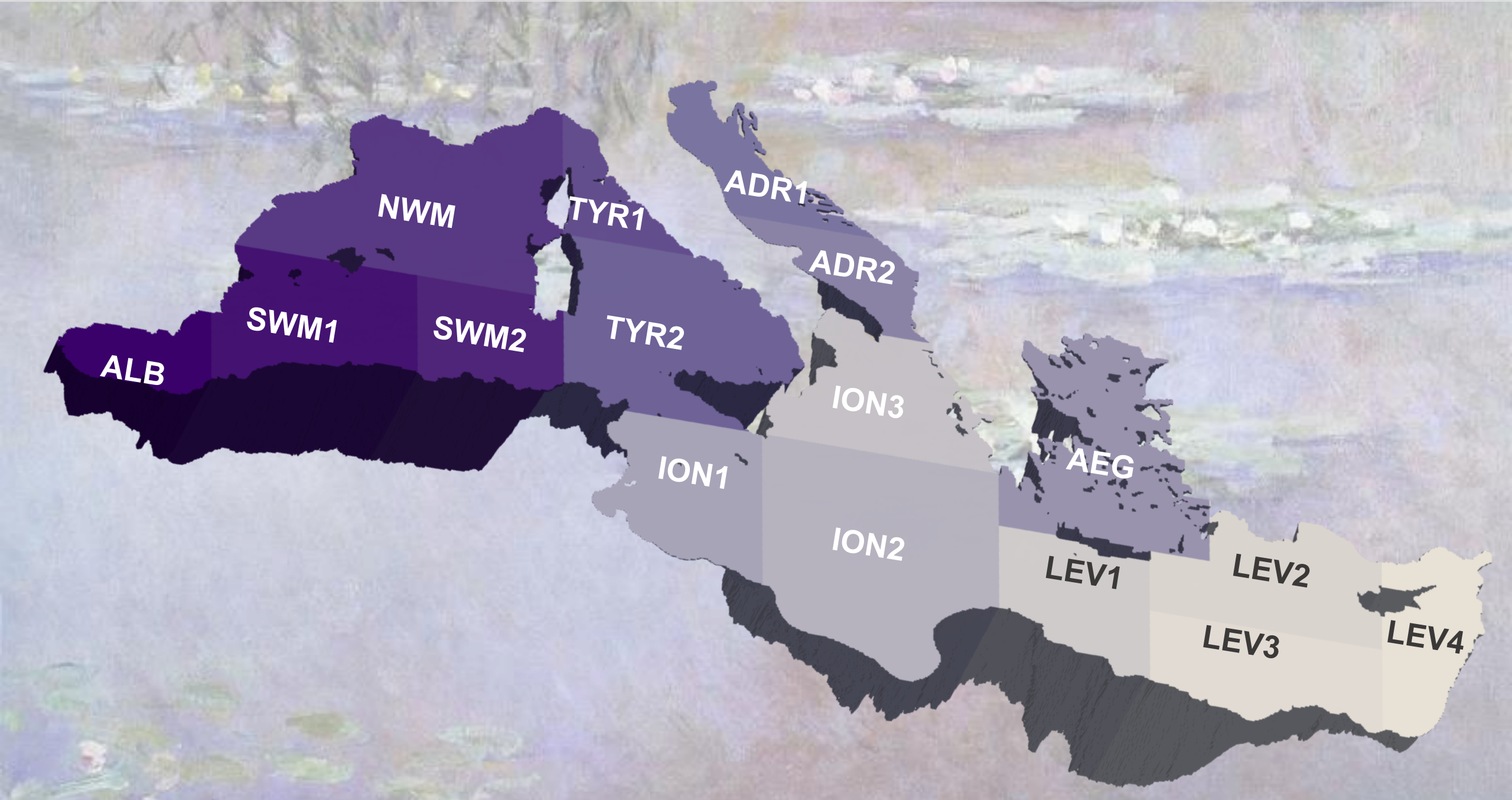


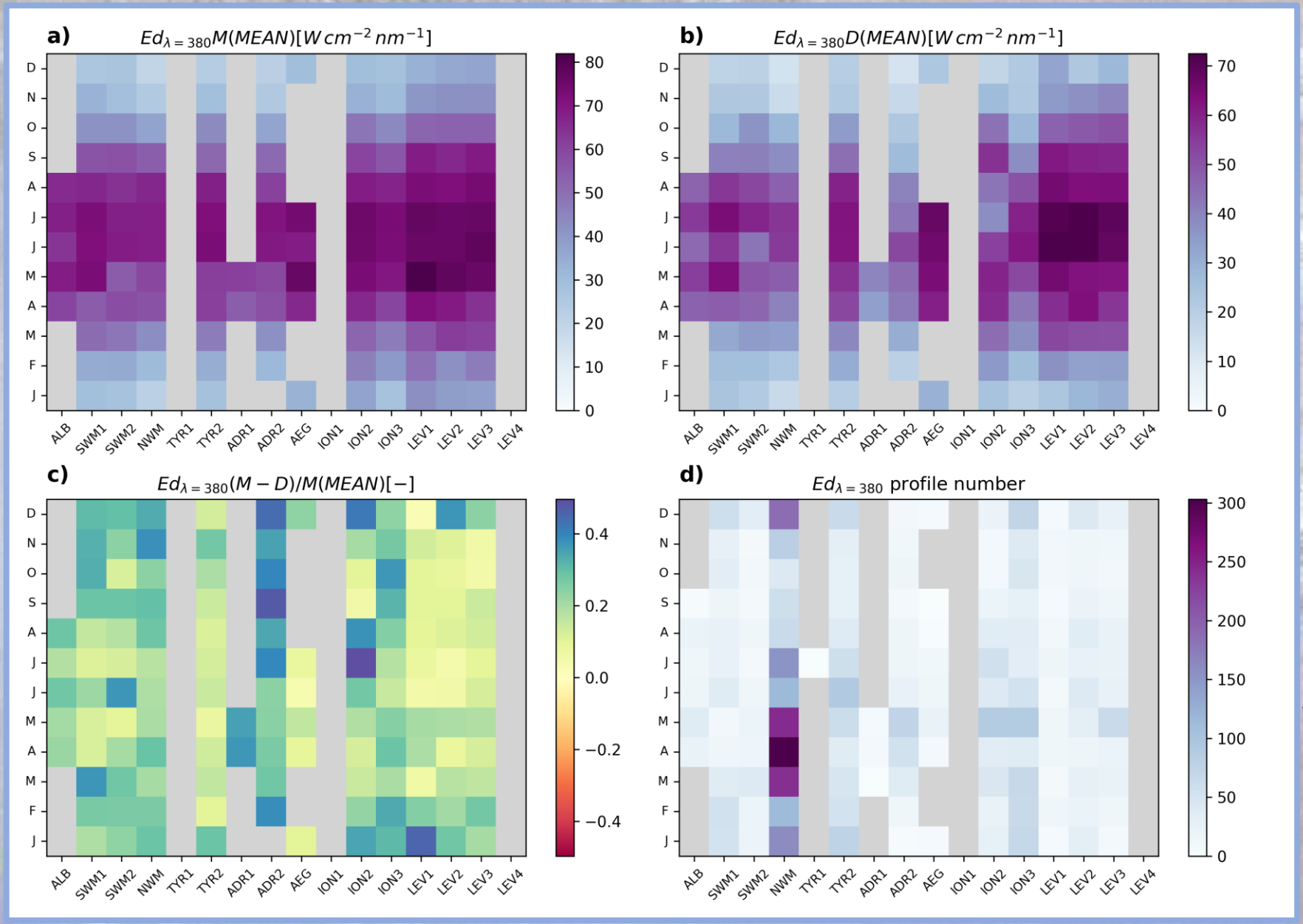
A Novel Near-Real-Time Quality-Control Procedure for Radiometric Profiles Measured by Bio-Argo Floats: Protocols and Performances

Emanuele Organelli,* Hervé Claustre,* Annick Bricaud,* Catherine Schmechtig,+ Antoine Poteau,* Xiaogang Xing,#,@ Louis Prieur,* Fabrizio D'Ortenzio,* Giorgio Dall'Olmo,&,** and Vincenzo Vellucci*

3. Results - 1

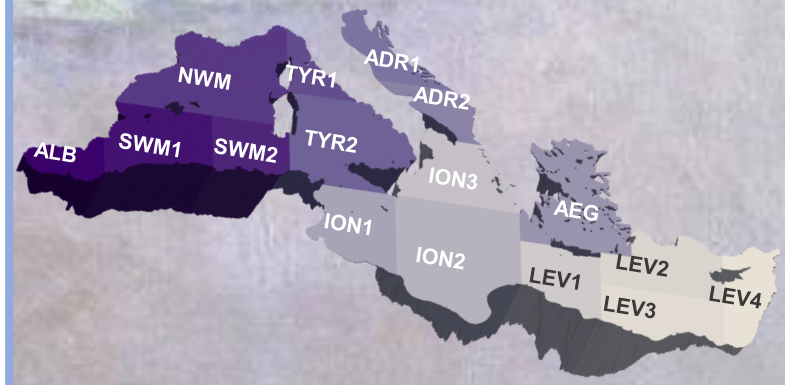
- Atmospheric model (OASIM) matchup

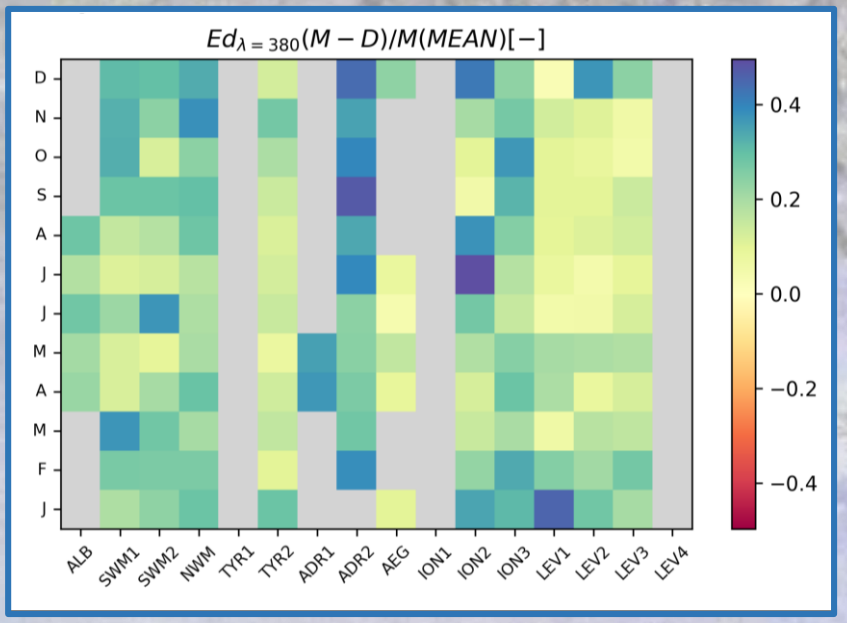

NWM
TYR1
ADR1
ADR2
SWM1
SWM2
TYR2
ALB
ION3
AEG
ION1
ION2
LEV1
LEV2
LEV3
LEV4

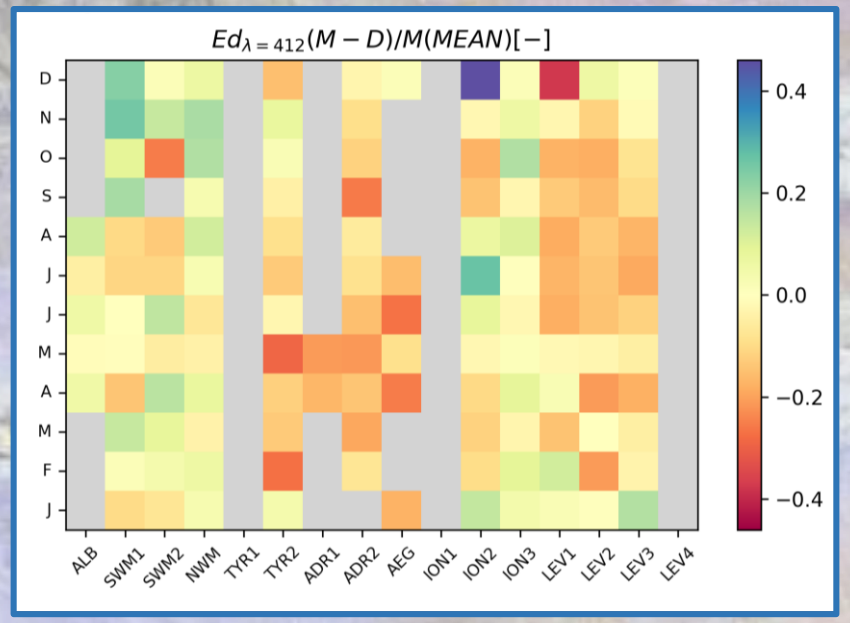


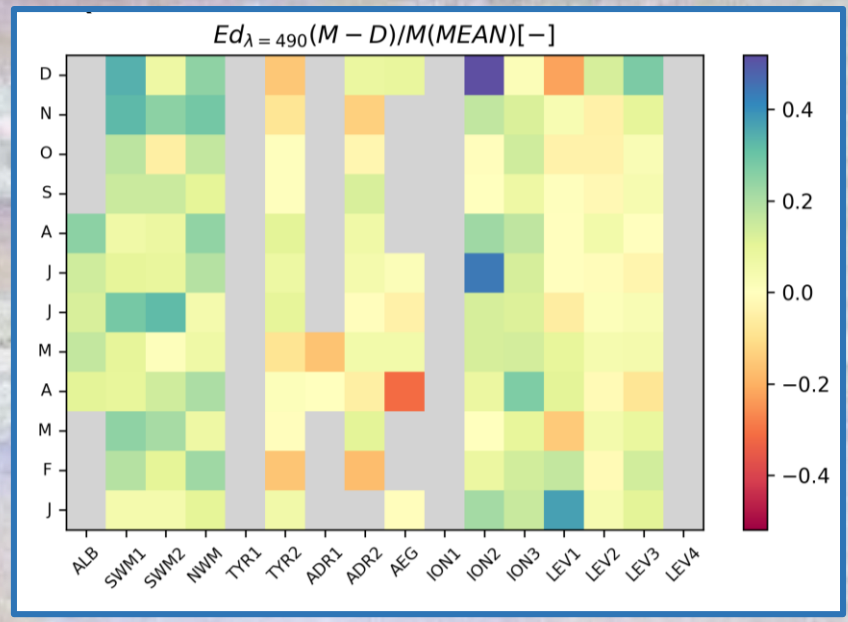
Top: Monthly mean per (16) sub-basins for model (M, left) and BGC-Argo data (D – right)

Bottom: Relative differences (left) and profile number per month per sub-basin(right)





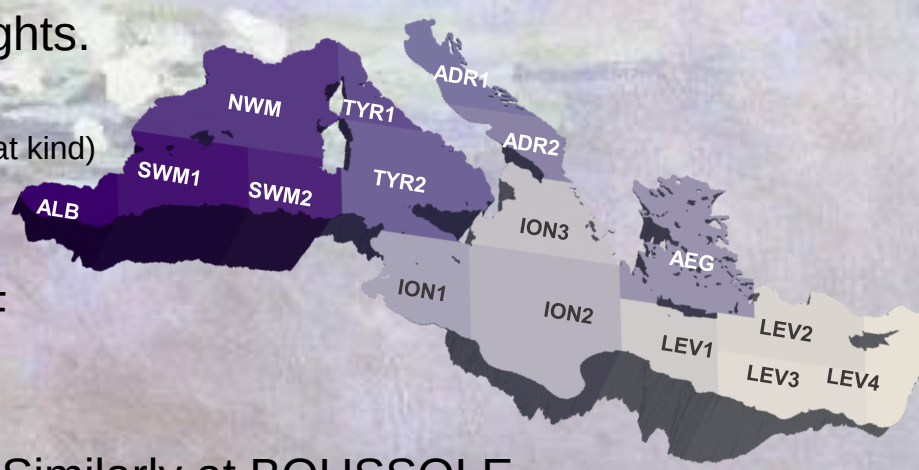




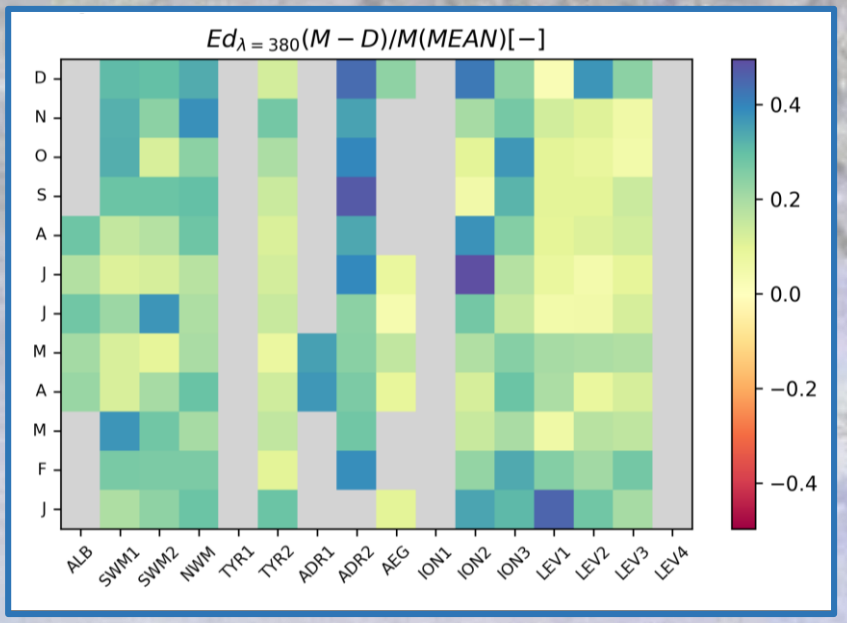
Up to 40% differences in the mean monthly values towards shorter wavelenghts.

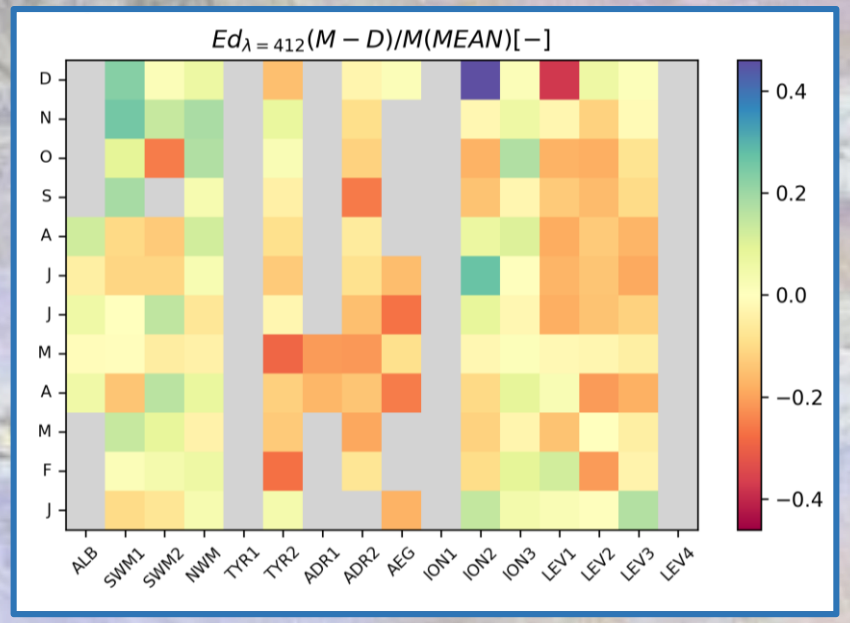
In agreement with findings of Organelli et al., 2016 (to our knowledge the only study of that kind)

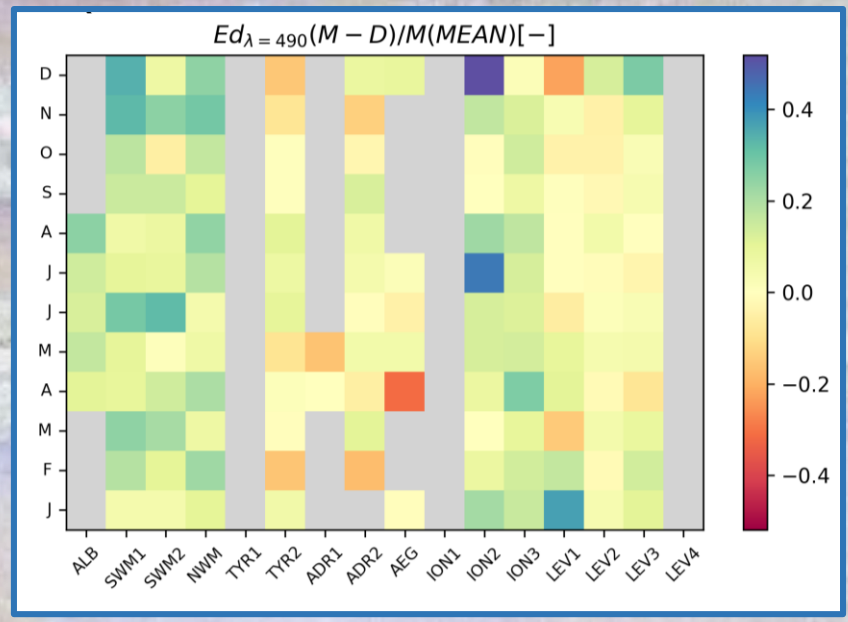
Range of variability possibly due also to **potential cloud overpasses during float's ascent** not captured in the cloud coverage data from ECMWF Era-Interim (and vice-versa) → future work



412 nm model underestimation → issue with the atmospheric correction? Similarly at BOUSSOLE



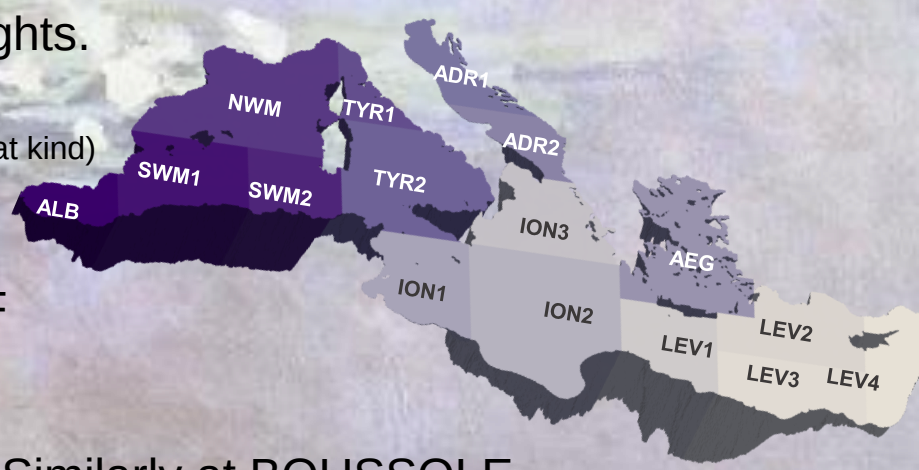




Up to 40% differences in the mean monthly values towards shorter wavelenghts.

In agreement with findings of Organelli et al., 2016 (to our knowledge the only study of that kind)

Range of variability possibly due also to **potential cloud overpasses during float's ascent** not captured in the cloud coverage data from ECMWF Era-Interim (and vice-versa) → future work



412 nm model underestimation → issue with the atmospheric correction? Similarly at BOUSSOLE

Remember that we are dealing with **less than 10%** of the total signal in the visible range of the spectrum!

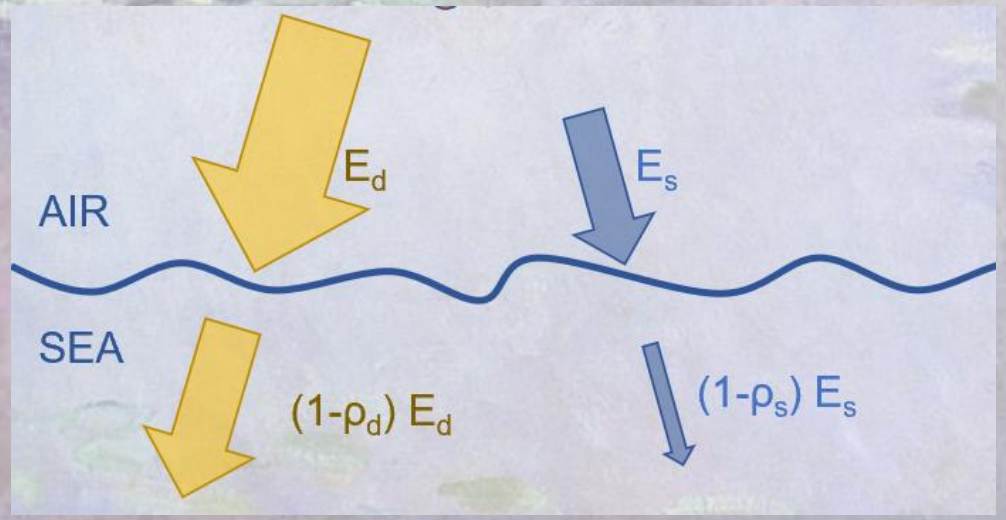
Possible improvements:

350	375	400	425	450	475	500	525	550	575	600	625	650	675	700

- **Increased spectral resolution** (< 25 nm bandwidth) to reduce the spectral variability in the blue!

- **Increased temporal resolution:** current model output every 2 hrs, BGC-Argo float acquisition at around local noon → considering 10-14 GMT values differs from the actual solar zenith θ!

- **Removal of high surface reflectance values** (ρ_d and ρ_s) : **average** 0.04 and 0.03, but maximum up to 0.99 → function of **wind speed**



4. Results - 2

- In-water model (OASIM) matchup
- IOP parameterizazions

How to link light and BGC?

AIR

SEA

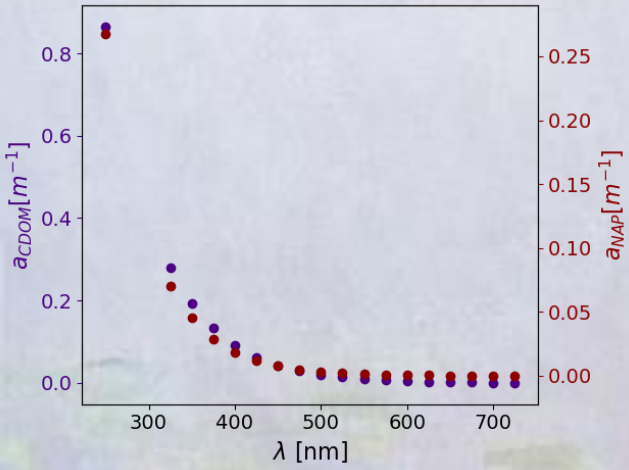
$(1-\rho_d)\ E_d$

$(1-\rho_s)\ E_s$

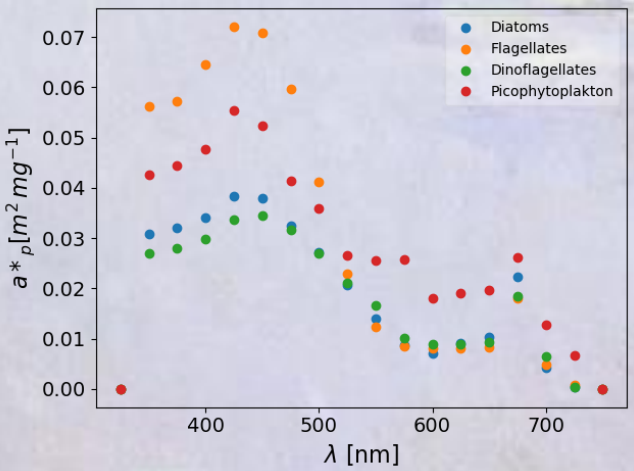
$(1-\rho_d)\ E_d$

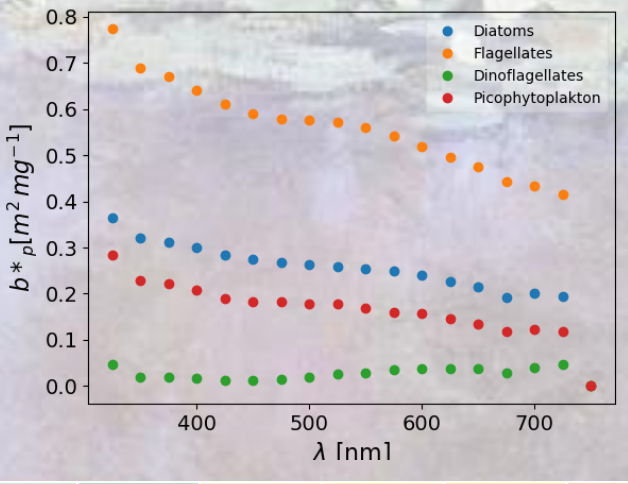
$(1-\rho_s)\ E_s$

CDOM and **NAP**

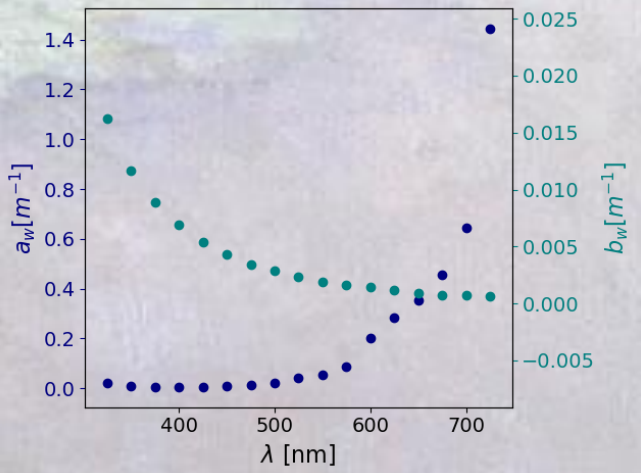


PHYTOPLANKTON



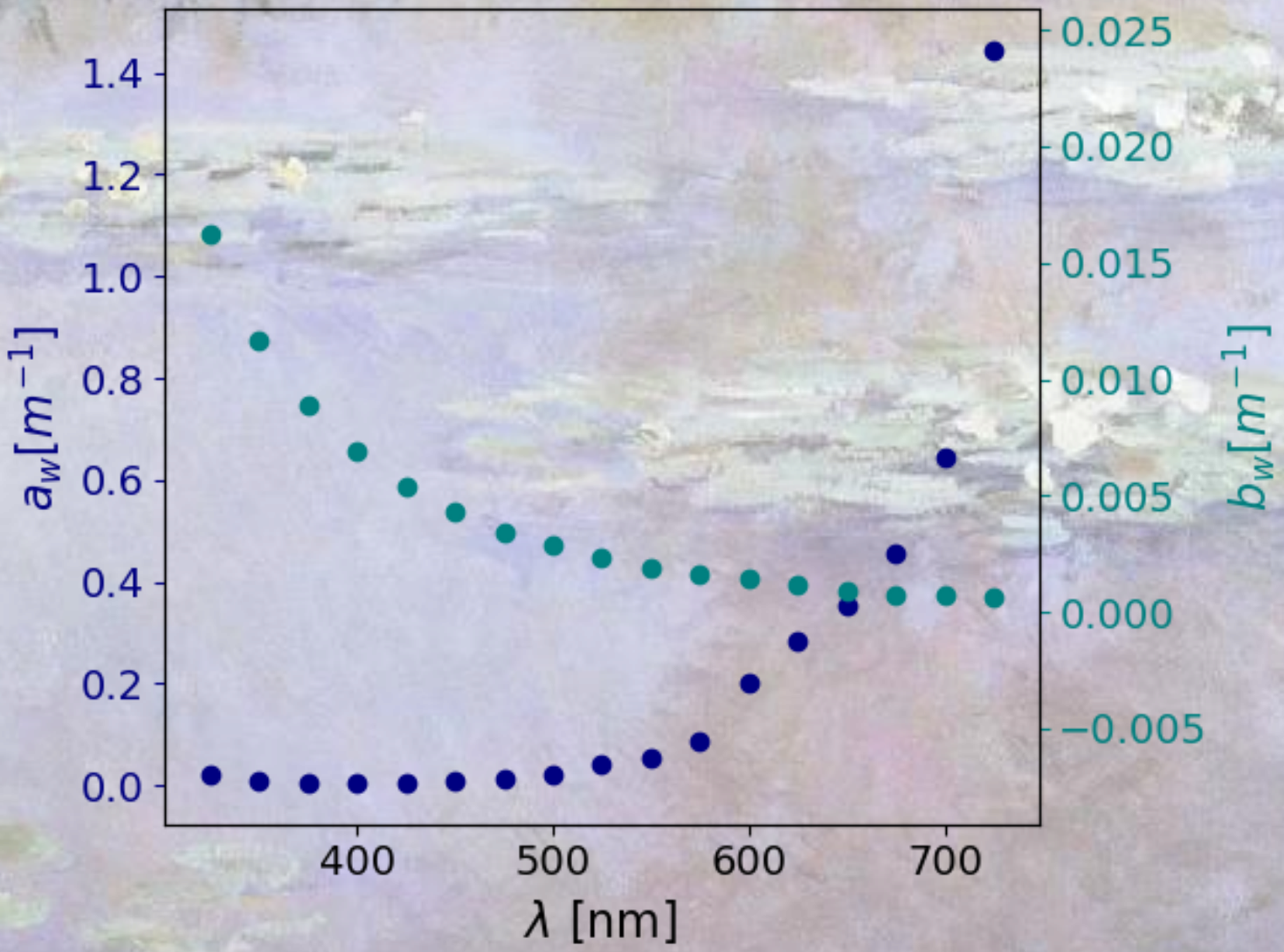


WATER

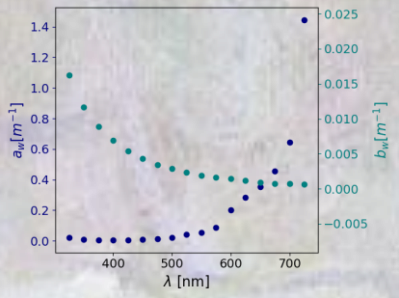


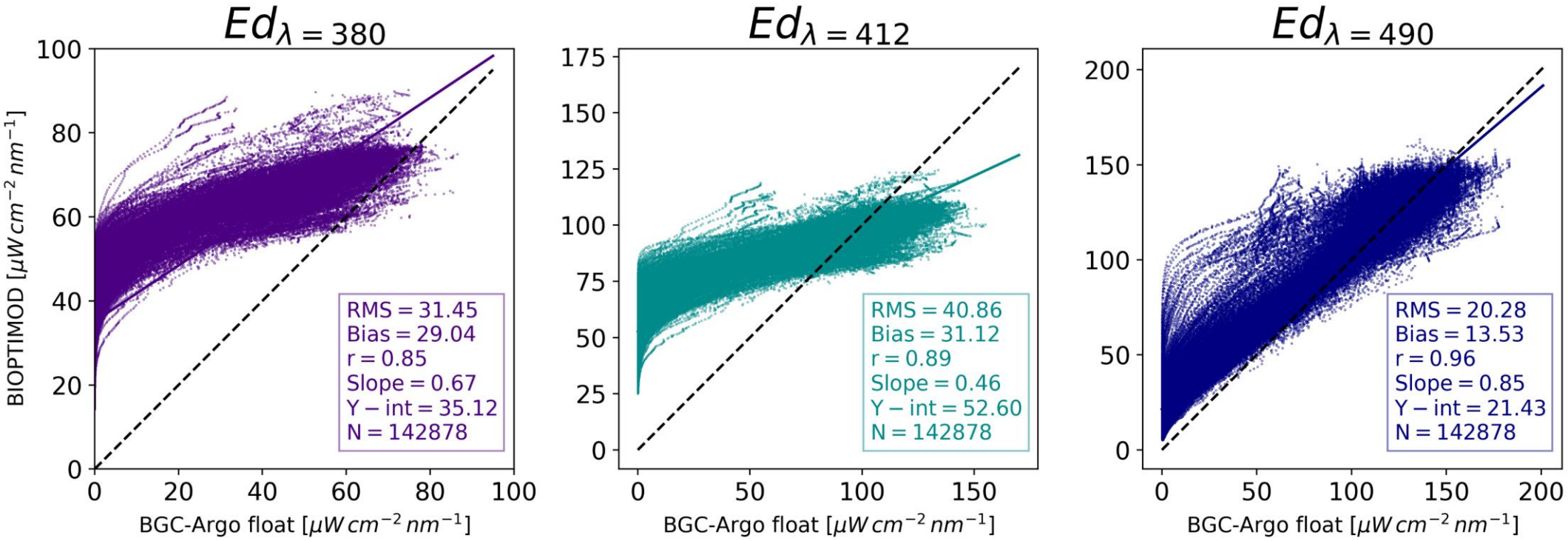
350	375	400	425	450	475	500	525	550	575	600	625	650	675	700

IOP-1: Pure water



IOP-1: Pure water



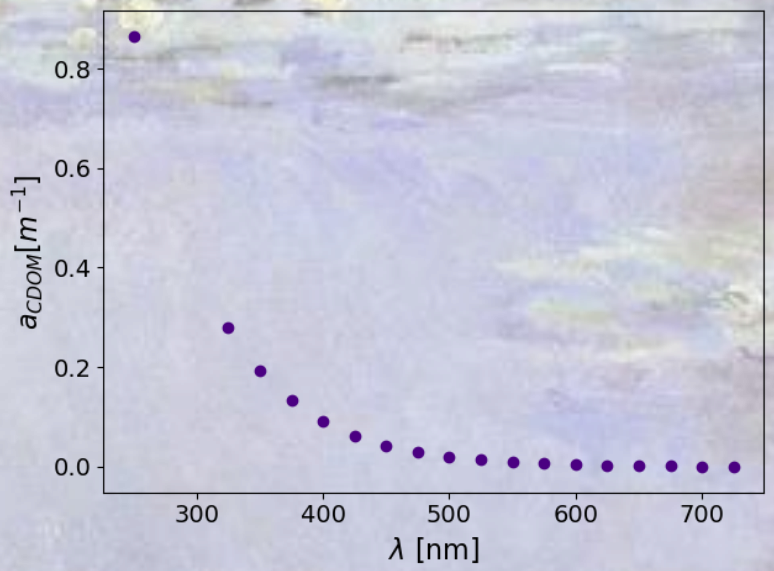


IOP-2: CDOM

Range of values*:
S 0.015 – 0.020 (mean 0.017)
a440: 0.01 – 0.05

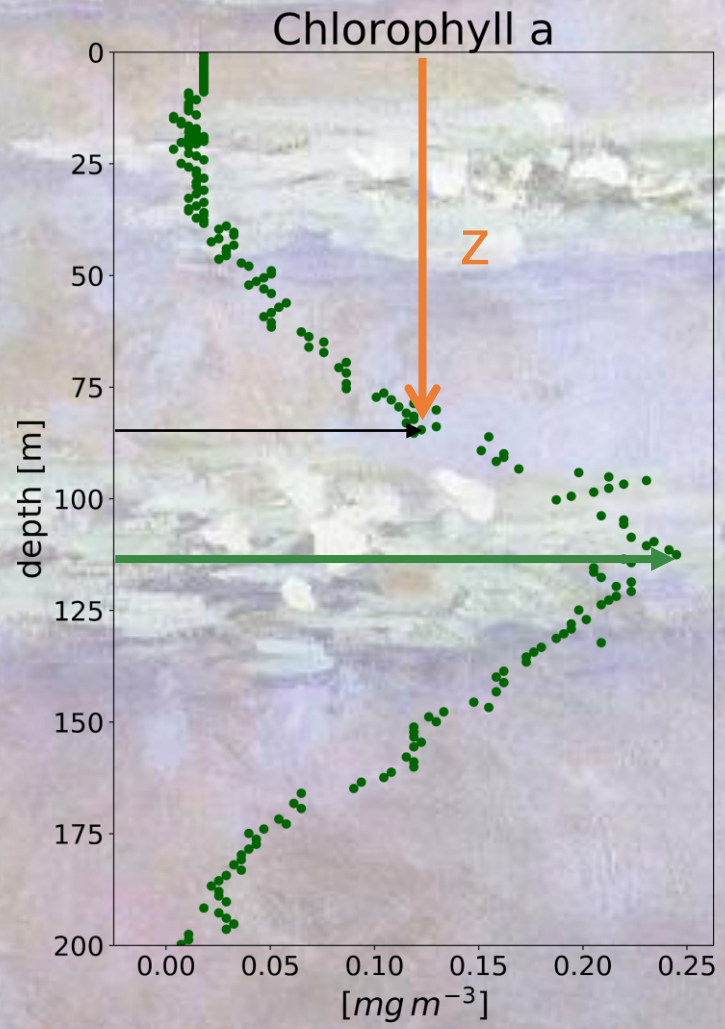
$$a_{CDOM} = a_{440} e^{-S\,(\lambda - 440)}$$

a (λ, z) [m^{-1}] =



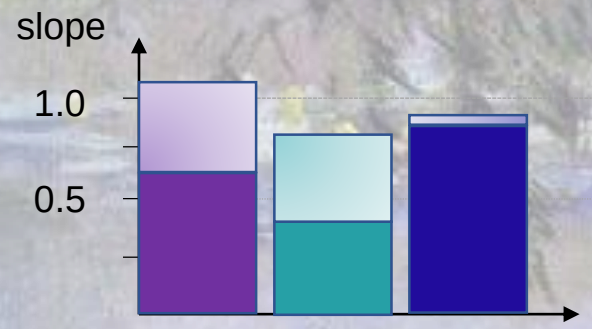
a (λ) [m^{-1}]

·

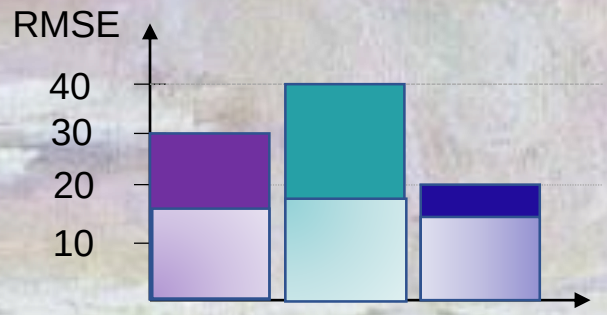


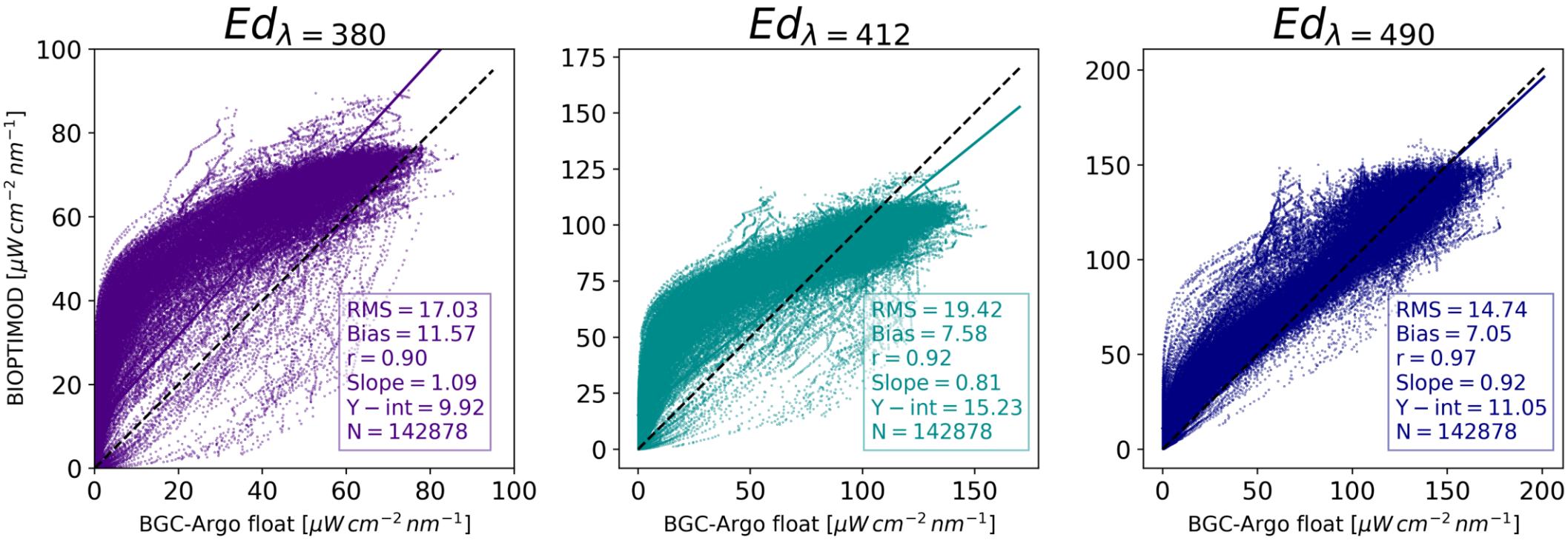
$$\frac{\text{CHL (z)}}{\text{CHLmax}}$$

*from Organelli et al., 2014 and Babin et al., 2003


slope
1.0
0.5

IOP-2: CDOM

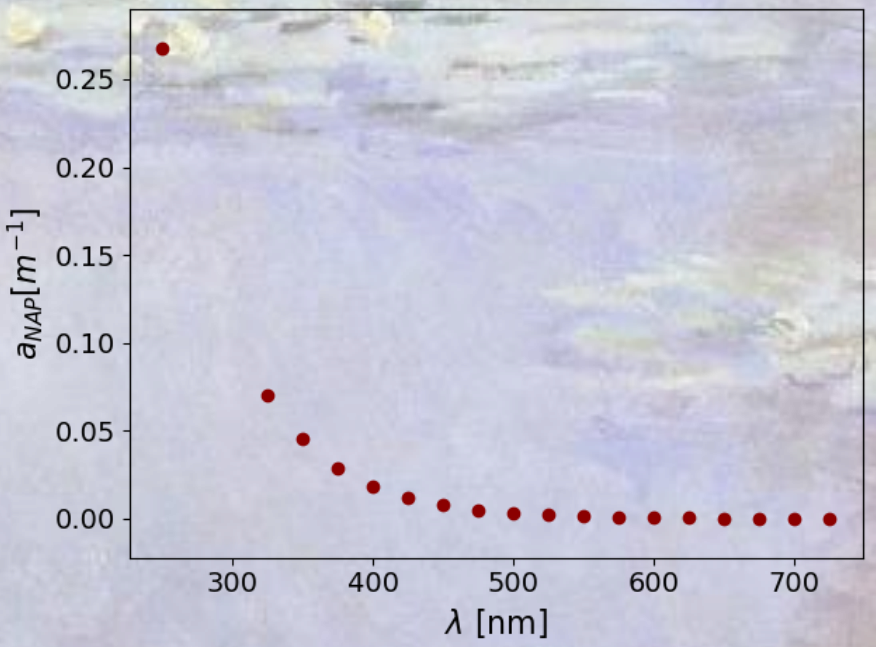

RMSE
40
30
20
10


$Ed_{\lambda=380}$
BIOPTIMOD [$\mu W\,cm^{-2}\,nm^{-1}$]
BGC-Argo float [$\mu W\,cm^{-2}\,nm^{-1}$]
RMS = 17.03
Bias = 11.57
r = 0.90
Slope = 1.09
Y − int = 9.92
N = 142878
$Ed_{\lambda=412}$
BGC-Argo float [$\mu W\,cm^{-2}\,nm^{-1}$]
RMS = 19.42
Bias = 7.58
r = 0.92
Slope = 0.81
Y − int = 15.23
N = 142878
$Ed_{\lambda=490}$
BGC-Argo float [$\mu W\,cm^{-2}\,nm^{-1}$]
RMS = 14.74
Bias = 7.05
r = 0.97
Slope = 0.92
Y − int = 11.05
N = 142878

IOP-3: NAP

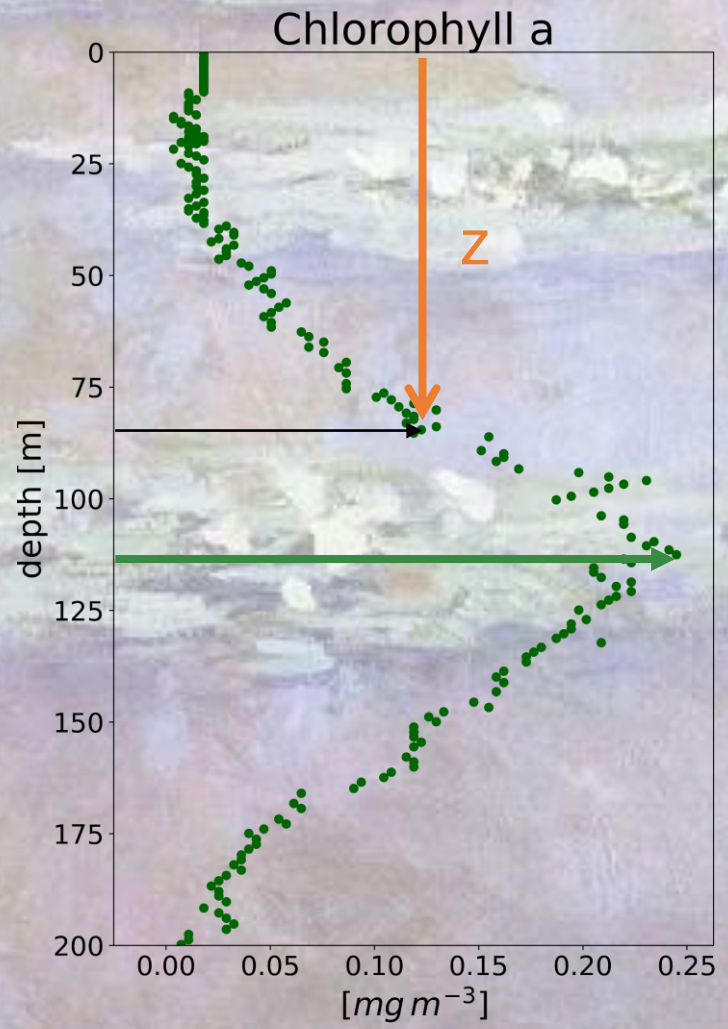
Range of values*:
S 0.0129
a440: 0.0087 – 0.8

$$a_{NAP} = a_{443} e^{-S(\lambda - 443)}$$

a (λ, z) [m^{-1}] = 

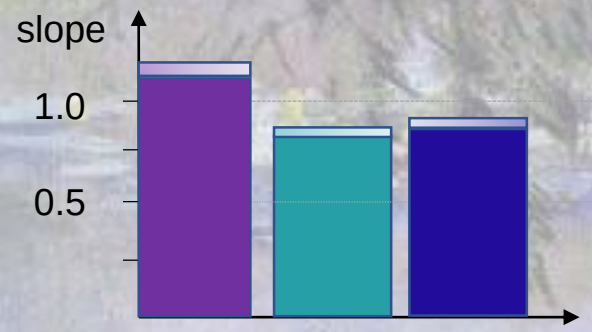
a (λ) [m^{-1}]

.

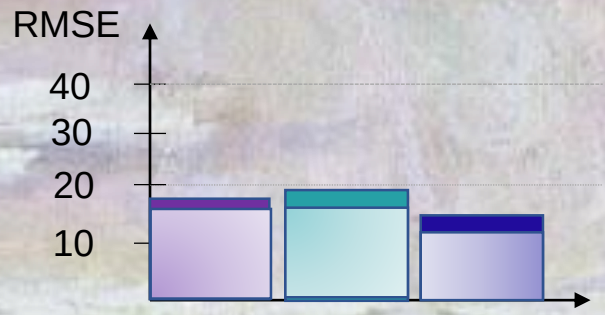


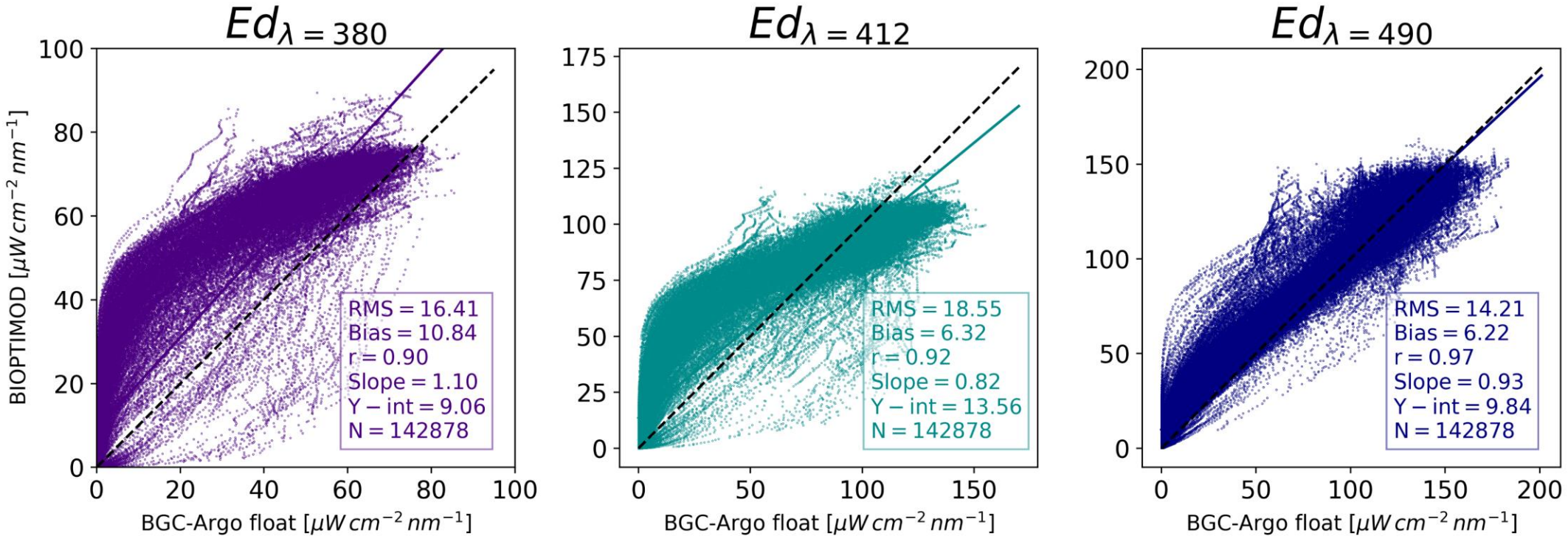
$$\frac{\text{CHL}(z)}{\text{CHLmax}}$$

*from Babin et al., 2003


slope
1.0
0.5

IOP-3: NAP


RMSE
40
30
20
10

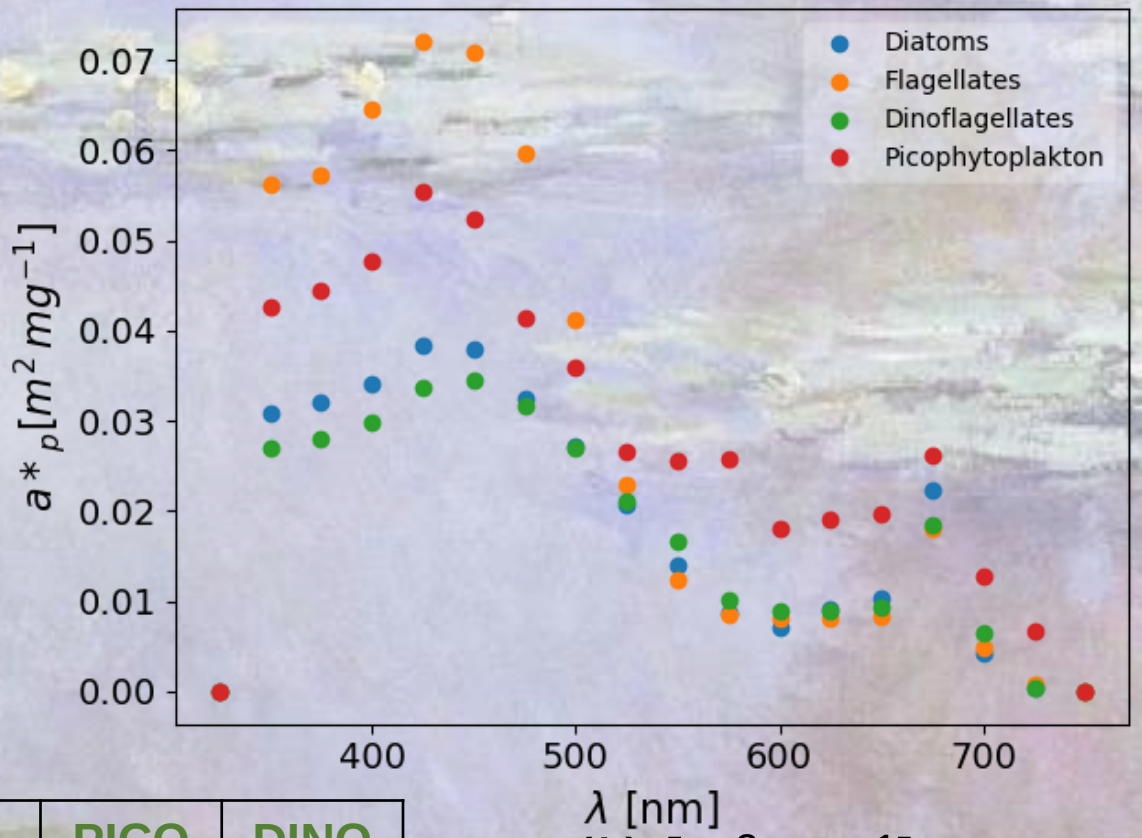

$Ed_{\lambda=380}$
BIOPTIMOD [$\mu W\,cm^{-2}\,nm^{-1}$]
BGC-Argo float [$\mu W\,cm^{-2}\,nm^{-1}$]
RMS = 16.41
Bias = 10.84
r = 0.90
Slope = 1.10
Y − int = 9.06
N = 142878
$Ed_{\lambda=412}$
BGC-Argo float [$\mu W\,cm^{-2}\,nm^{-1}$]
RMS = 18.55
Bias = 6.32
r = 0.92
Slope = 0.82
Y − int = 13.56
N = 142878
$Ed_{\lambda=490}$
BGC-Argo float [$\mu W\,cm^{-2}\,nm^{-1}$]
RMS = 14.21
Bias = 6.22
r = 0.97
Slope = 0.93
Y − int = 9.84
N = 142878

IOP-4: Phytoplakton

Input

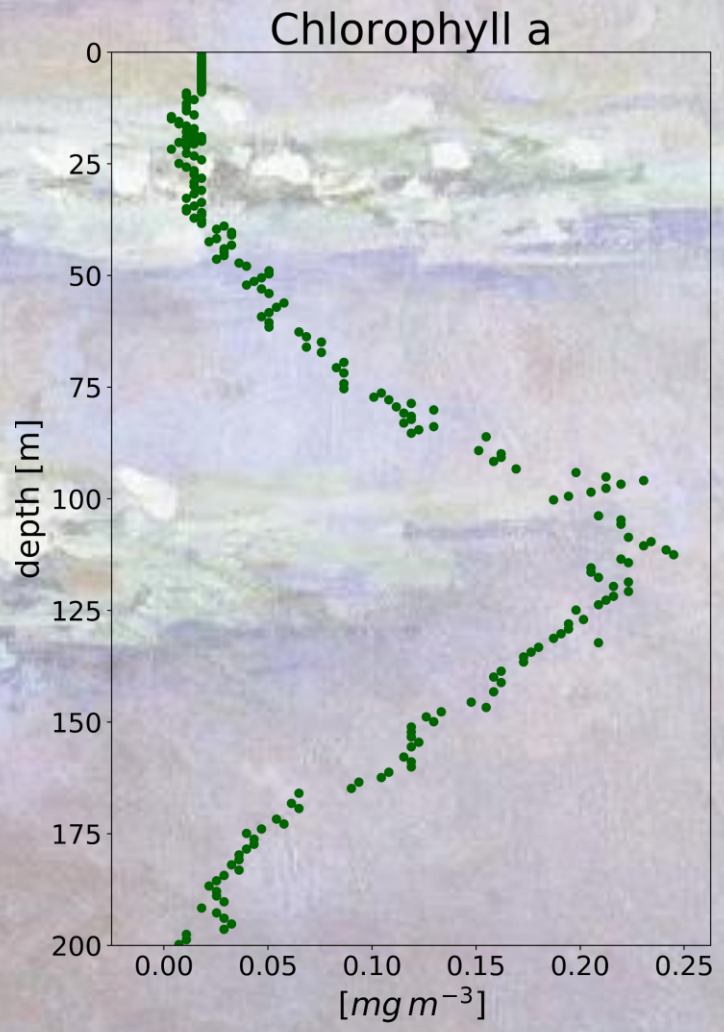
$$PFT_i = \sum_{i=1}^{n} x_i \, CHL \quad , where \sum_{i=1}^{n} x_i = 1.0$$

a (λ, z) [m^{-1}] =



a* (λ) [m^2 mg^{-1}]

·



CHL (z) [mg m^{-3}]

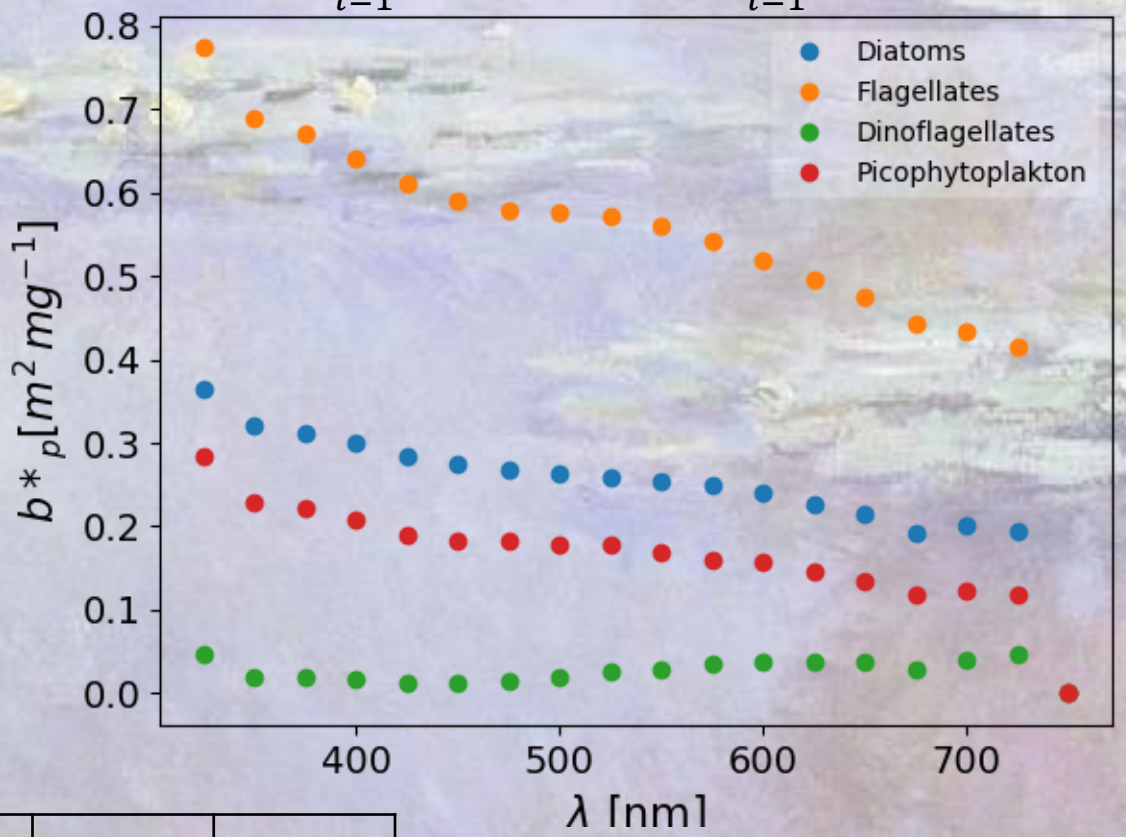
PFT	DIA	FLA	PICO	DINO
x_i	0.3	0.2	0.4	0.1

IOP-4: Phytoplakton

Input

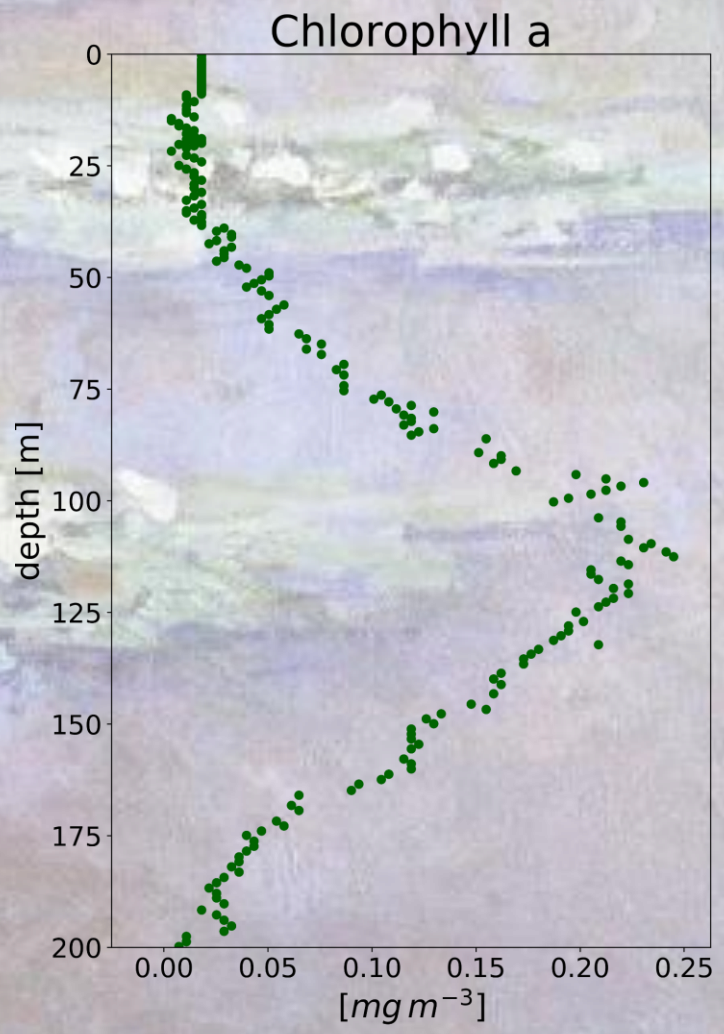
$$PFT_i = \sum_{i=1}^{n} x_i \, CHL \quad , where \sum_{i=1}^{n} x_i = 1.0$$

b (λ, z) [m^{-1}] =



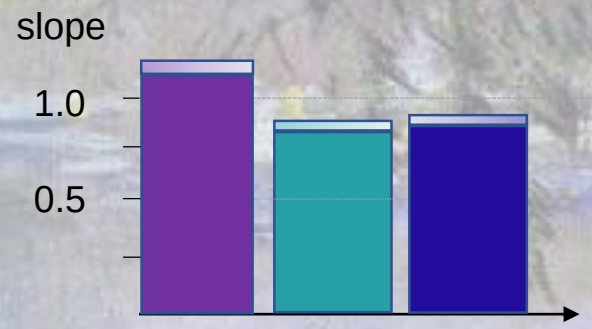
b* (λ) [m^2 mg^{-1}]

·

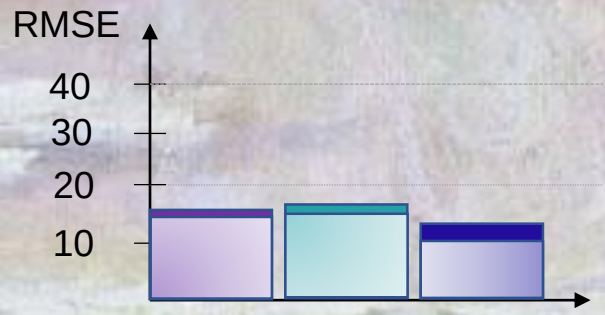


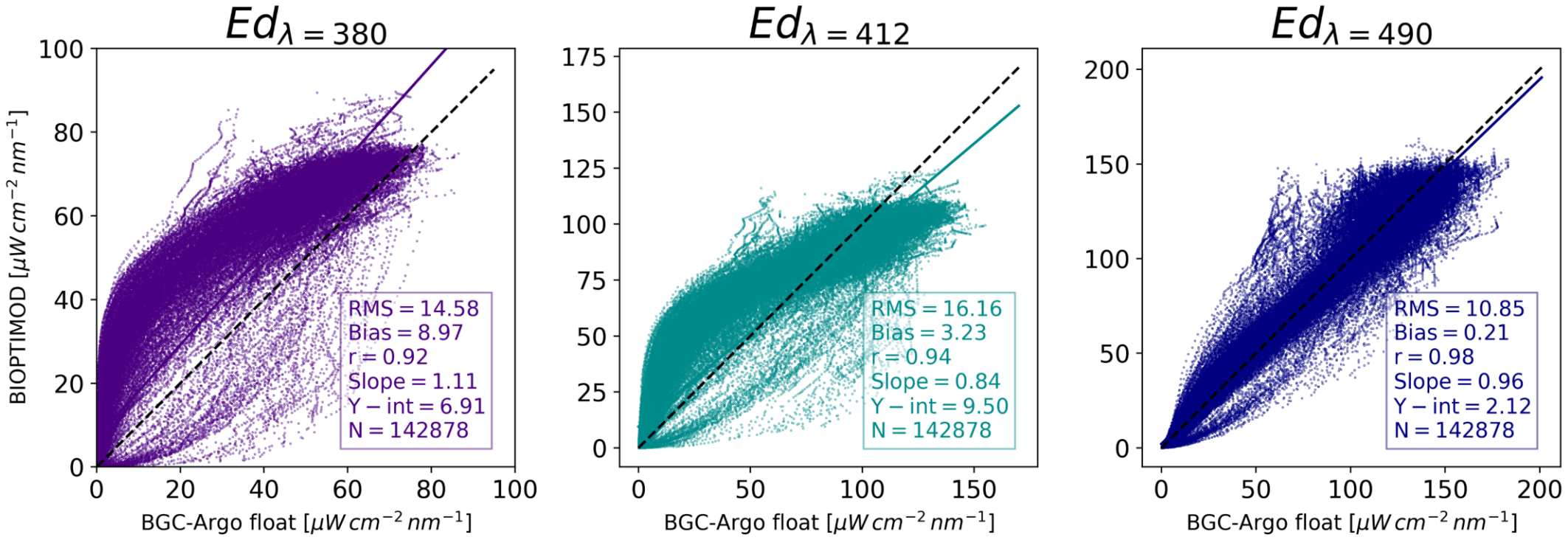
CHL (z) [mg m^{-3}]

PFT	DIA	FLA	PICO	DINO
x_i	0.3	0.2	0.4	0.1


slope
1.0
0.5

IOP-4: PFT


RMSE
40
30
20
10


$Ed_{\lambda=380}$
BIOPTIMOD [$\mu W\,cm^{-2}\,nm^{-1}$]
BGC-Argo float [$\mu W\,cm^{-2}\,nm^{-1}$]
RMS = 14.58
Bias = 8.97
r = 0.92
Slope = 1.11
Y − int = 6.91
N = 142878
$Ed_{\lambda=412}$
BGC-Argo float [$\mu W\,cm^{-2}\,nm^{-1}$]
RMS = 16.16
Bias = 3.23
r = 0.94
Slope = 0.84
Y − int = 9.50
N = 142878
$Ed_{\lambda=490}$
BGC-Argo float [$\mu W\,cm^{-2}\,nm^{-1}$]
RMS = 10.85
Bias = 0.21
r = 0.98
Slope = 0.96
Y − int = 2.12
N = 142878

5. Conclusions

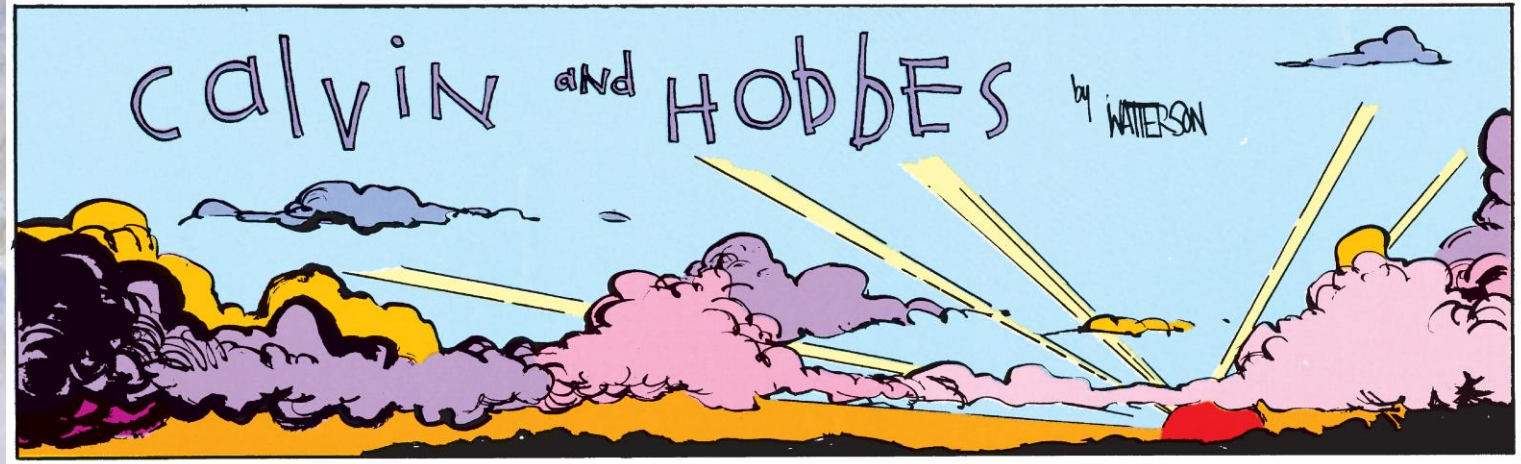
Summary of findings

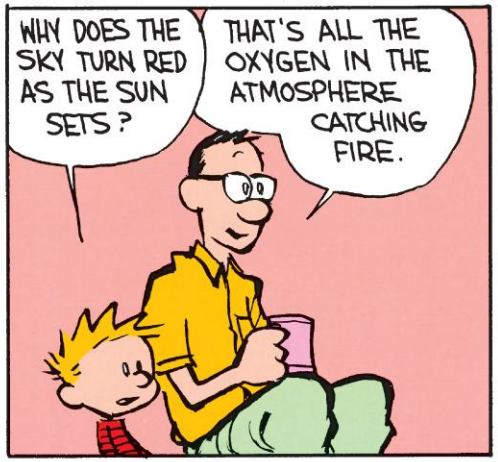
- **Atmospheric** RTM :
  - Up to 40% variability between model and data, largest at 380 nm
  - Further corrections are needed: increased spectral and time frequency, surface reflectance range of values
- **In-water** RTM:
  - Using **CHL** from floats for tracer-specific absorption spectra in order to simulate IOP depth variability shows encouraging results

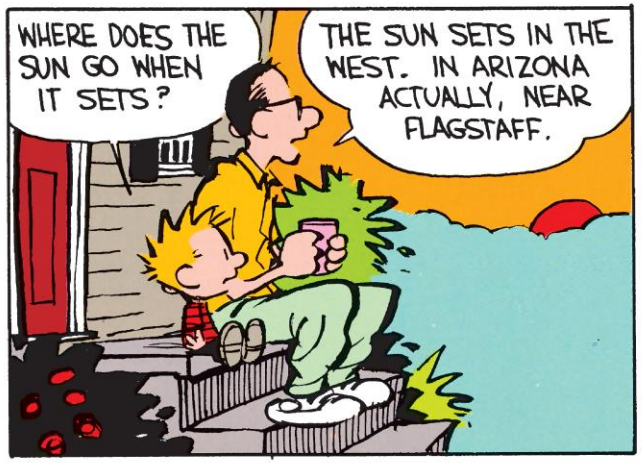
Next steps

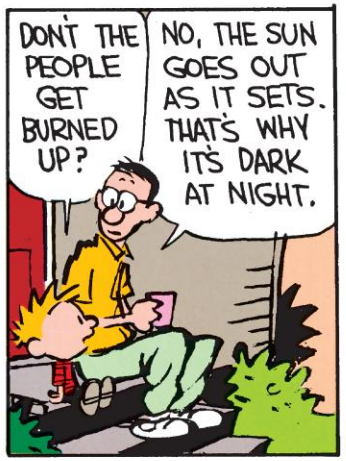
- Using further the BGC-Argo database:
  - Inclusion of **b_{bp}, CDOM** for IOP parameterization? → QC **data availability?**
- 1-dimensionsal coupling with BGC model
- Testing other IOP parameterizations (e.g. Di Cicco et al., 2017)
- **Possibly using hyperspectral floats in the future?**

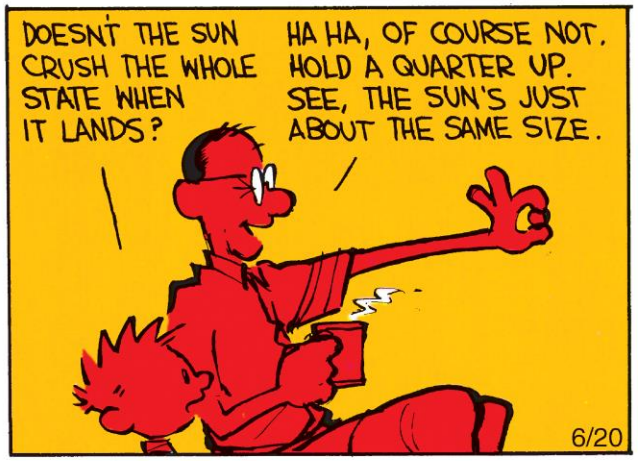
See poster 17 A.Jemai: Advancing hyperspectral radiometric observations on ARGO floats

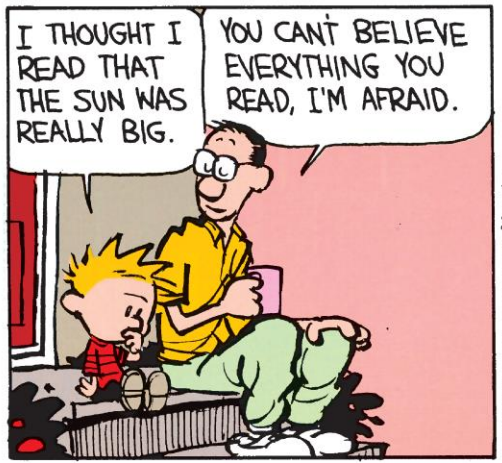
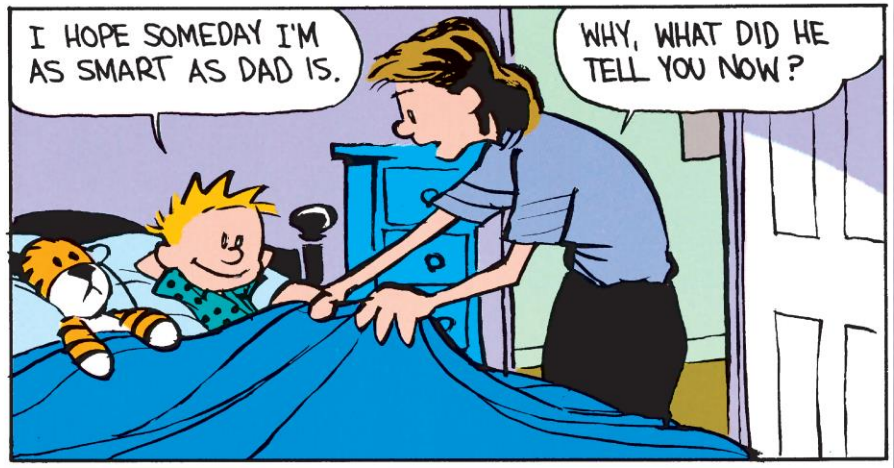








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