Seasonal dynamics of mesopelagic organic particles in the subpolar North Atlantic

Learning from the crosstalk between biogeochemical Argo float measurements and PISCESv2 simulations

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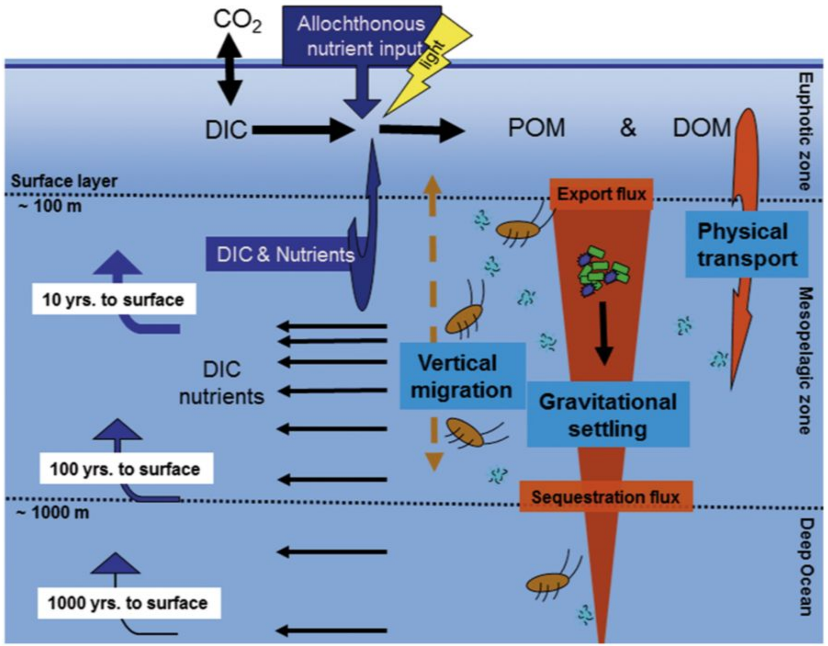
Mesopelagic layer POC cycling



Passow & Carlson 2012

- Removes 80-90% of the sinking flux of **particulate organic carbon** (POC) exported from the surface
- POC inputs are consumed by zooplankton and bacteria and eventually respired to CO_2
- Amount of POC removed by each pathway at a given depth determines sequestration time before it returns to the surface as CO_2 + inorganic nutrients
- But **mesopelagic POC budgets are extremely uncertain**

Kwon et al. 2009; Burd et al. 2010; Giering et al. 2014; Boyd et al. 2019

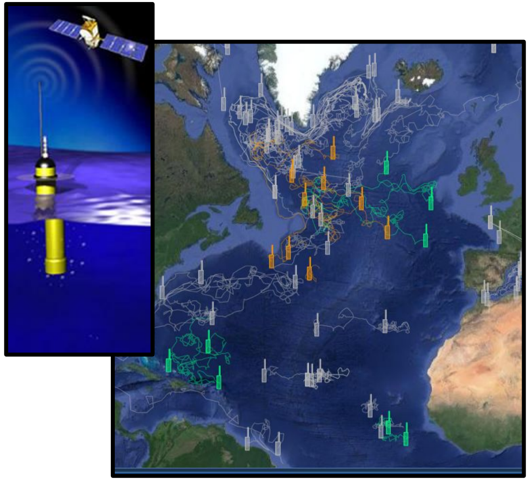
The ORCAS project

ORganic **CA**rbon **S**equestration in the ocean: constraining model predictions with novel high-resolution observations

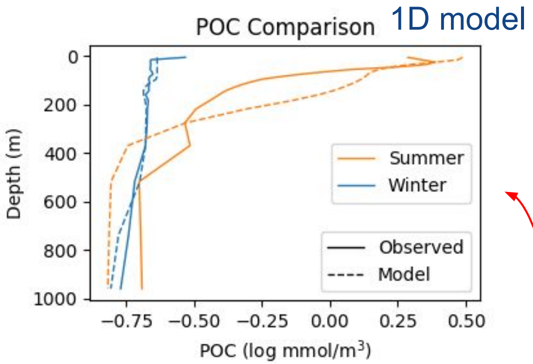
Hypothesis:

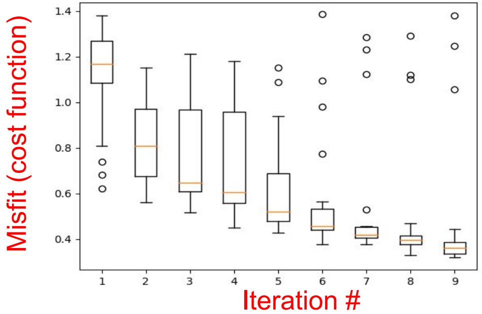
“We can use observations of mesopelagic particles made by autonomous drifting robots (biogeochemical Argo floats) to optimize the parameters that control POC cycling in a biogeochemical model and to constrain mesopelagic POC budgets”

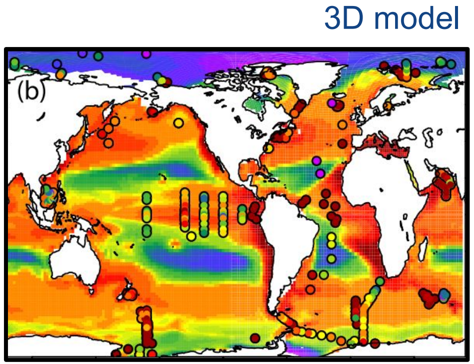
ORCAS approach



Robotic measurements of ocean particles (bgc-Argo floats, 0-1000 m)







Improving estimates of organic carbon sequestration.

Reducing model-data misfit through **parameter optimization** (genetic algorithm)

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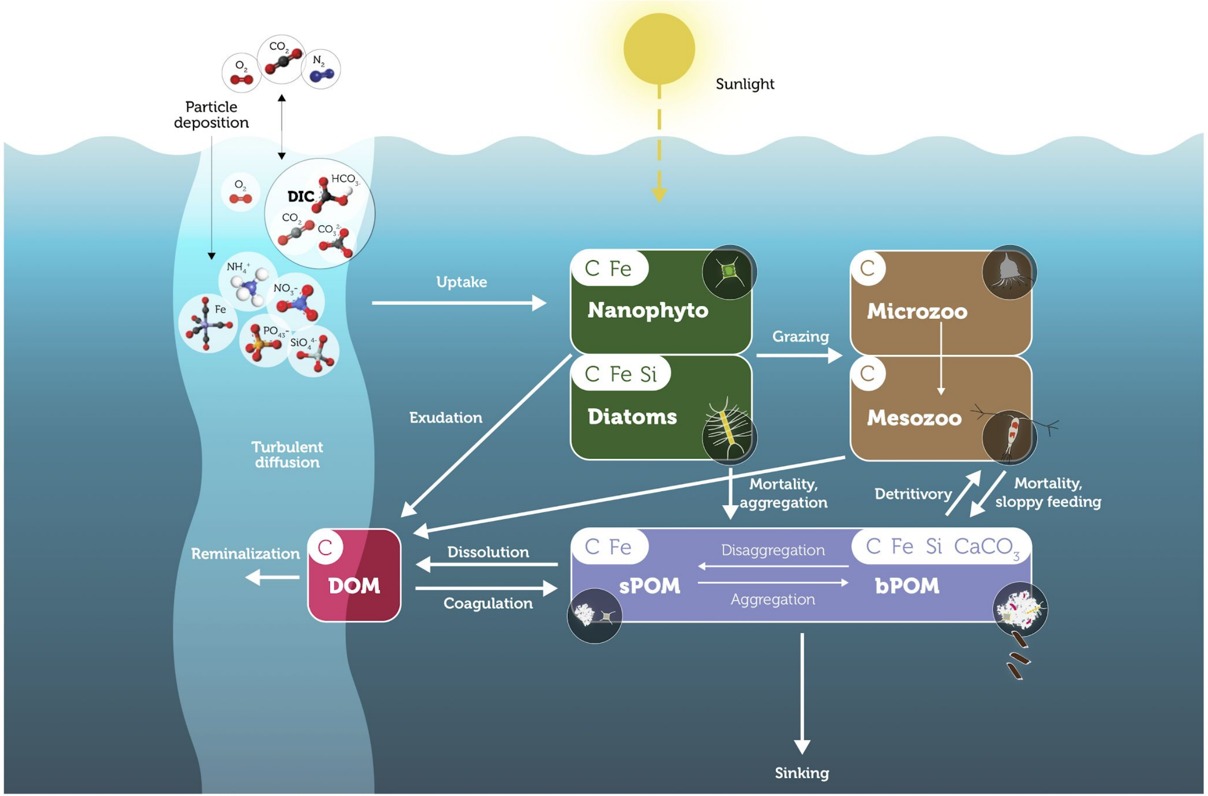
Ocean biogeochemistry model: PISCES (v2)



Aumont et al. 2015

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Biogeosciences
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KEY NEW FEATURE IN PISCES

Variable reactivity of particulate organic matter in a global ocean biogeochemical model

Olivier Aumont[1], Marco van Hulten[2], Matthieu Roy-Barman[2], Jean-Claude Dutay[2], Christian Éthé[1], and Marion Gehlen[2]

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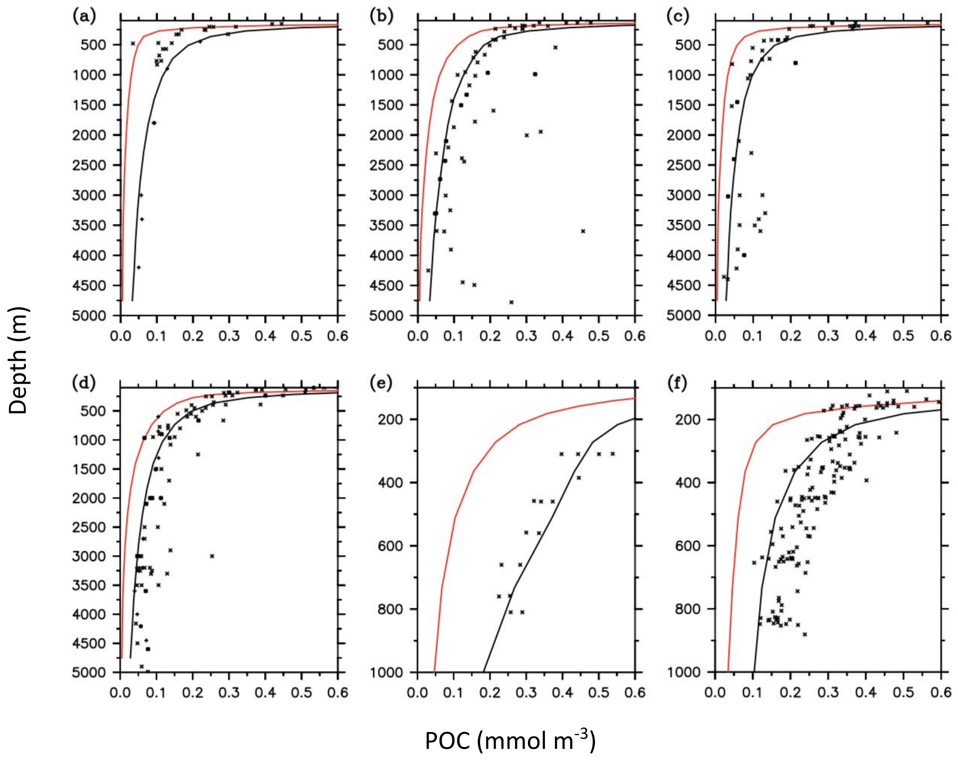
Variable POC reactivity greatly improved PISCES-observations fit



"Figure 4. Modelled and observed total POC concentrations (µM) in different regions of the ocean: (a) western, (b) oligotrophic, and (c) eastern North Atlantic Ocean; (d) Hawaii; (e) northwestern, (f) northeastern, [...] Pacific Ocean. The continuous lines are concentrations averaged over the region [...] **without (in red)** and **with the reactive continuum (RC) parameterisation (in black)**. The black speckles are observations in the respective regions from Druffel et al. (1992) and Lam et al. (2011, 2015b)."

Aumont et al. 2017

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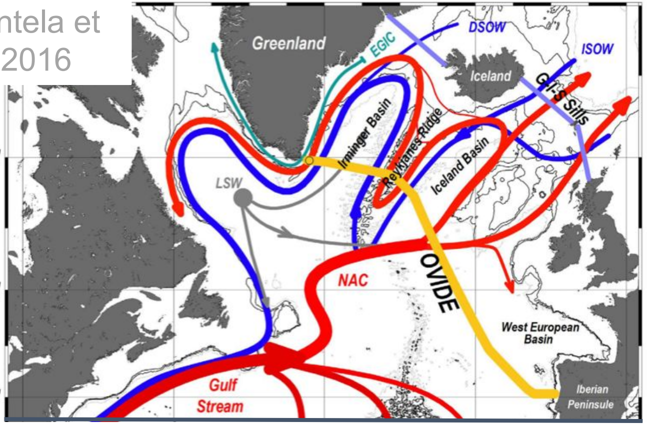
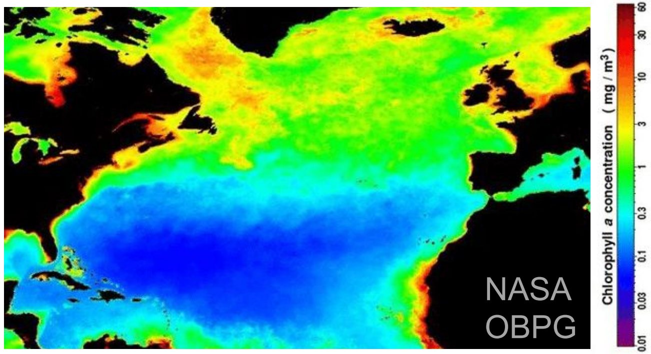
Study area: Subpolar North Atlantic

Fontela et al. 2016

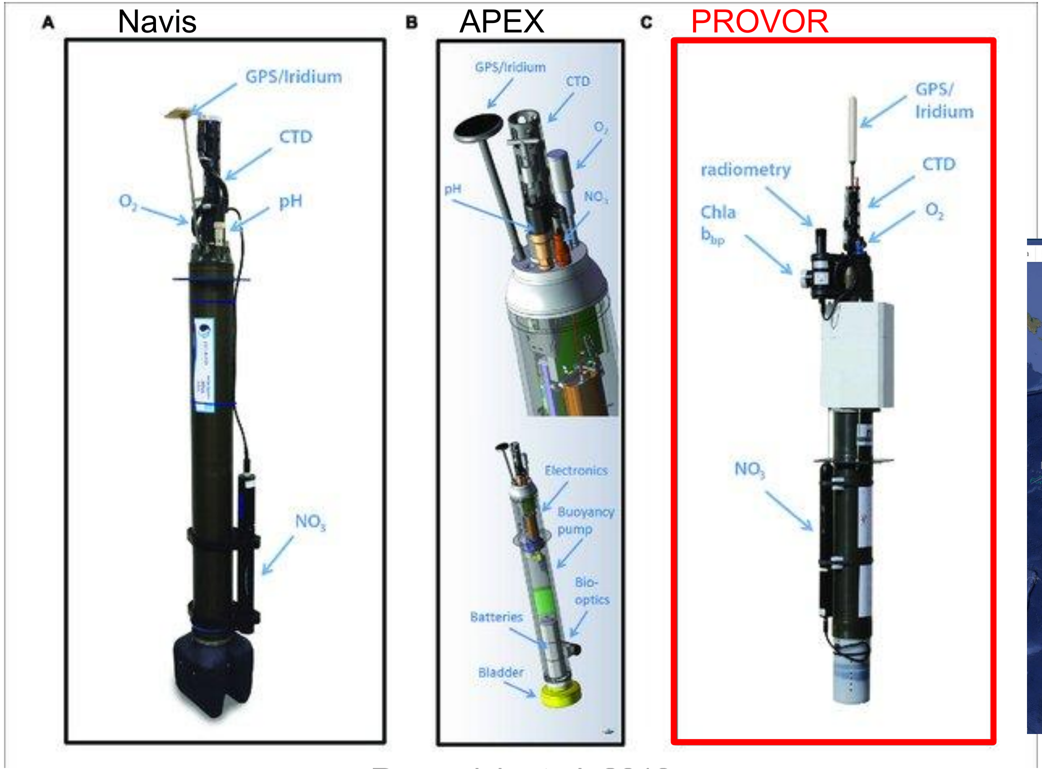




- Cyclonic subpolar gyre (45-65 ºN) associated with a large scale upwelling
- Marked seasonality: strong surface heat loss in winter triggers deep mixing and convection, which replenishes surface with nutrients
- Spring stratification triggers intense phytoplankton blooms (~15% of global ocean net photosynthesis) and efficient gravitational POC export events (fast gravitational sinking of large aggregates)
- Additional POC supply mechanisms are at play over the seasonal cycle: zooplankton diel and seasonal migration, physical transport (detrainment and subduction)...

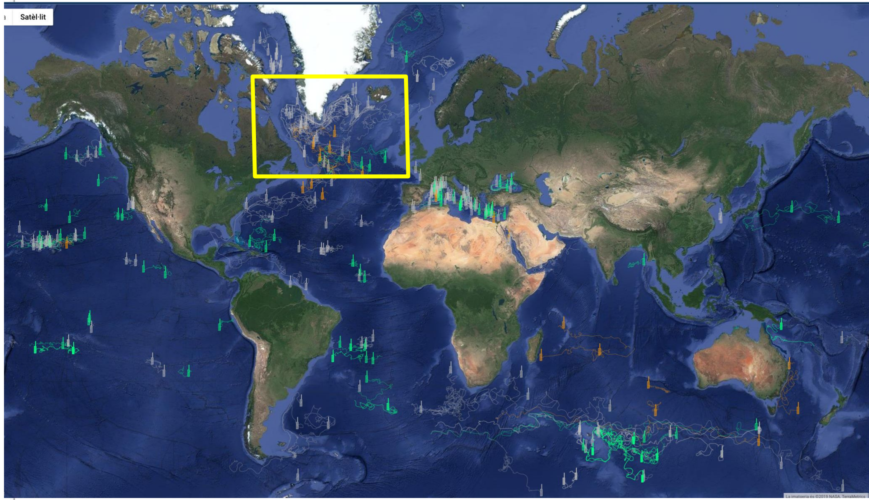
Dall'Olmo et al. 2016; Boyd et al. 2019; Brun et al. 2019; Resplandy et al. 2019

Observations: bgc-Argo floats



Roemnich et al. 2019

- Coriolis global data assembly center
  +
- BOPAD-Prof dataset from Organelli et al. 2017



http://www.oao.obs-vlfr.fr/maps/en/

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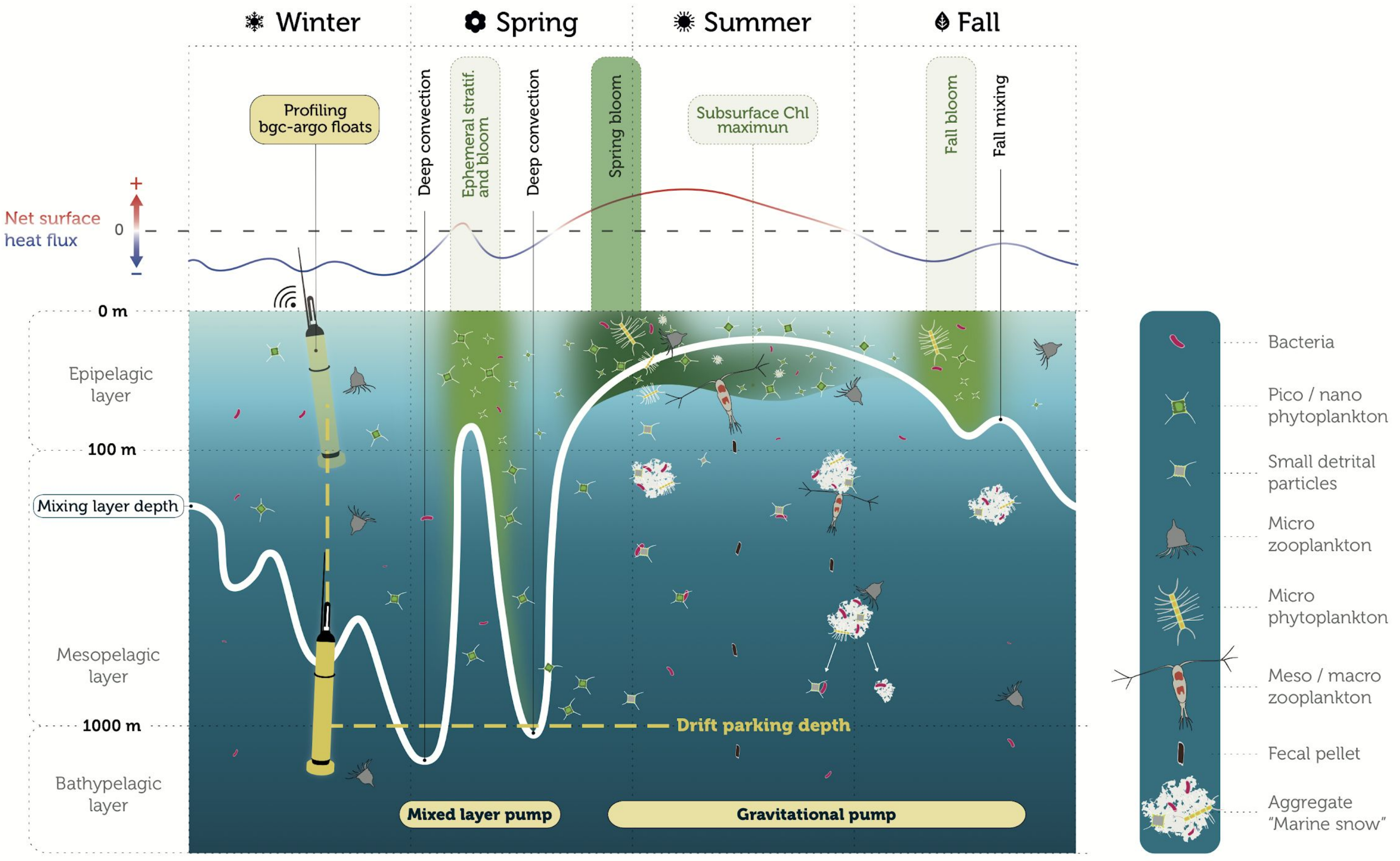
Bio-optical sensors mounted on bgc-Argo floats provide accurate, robust and non-invasive measurements of mesopelagic particles every ≤ 10d

Bishop et al. 2009;
Lacour et al. 2019;
Claustre et al. 2019;
Briggs et al. 2020



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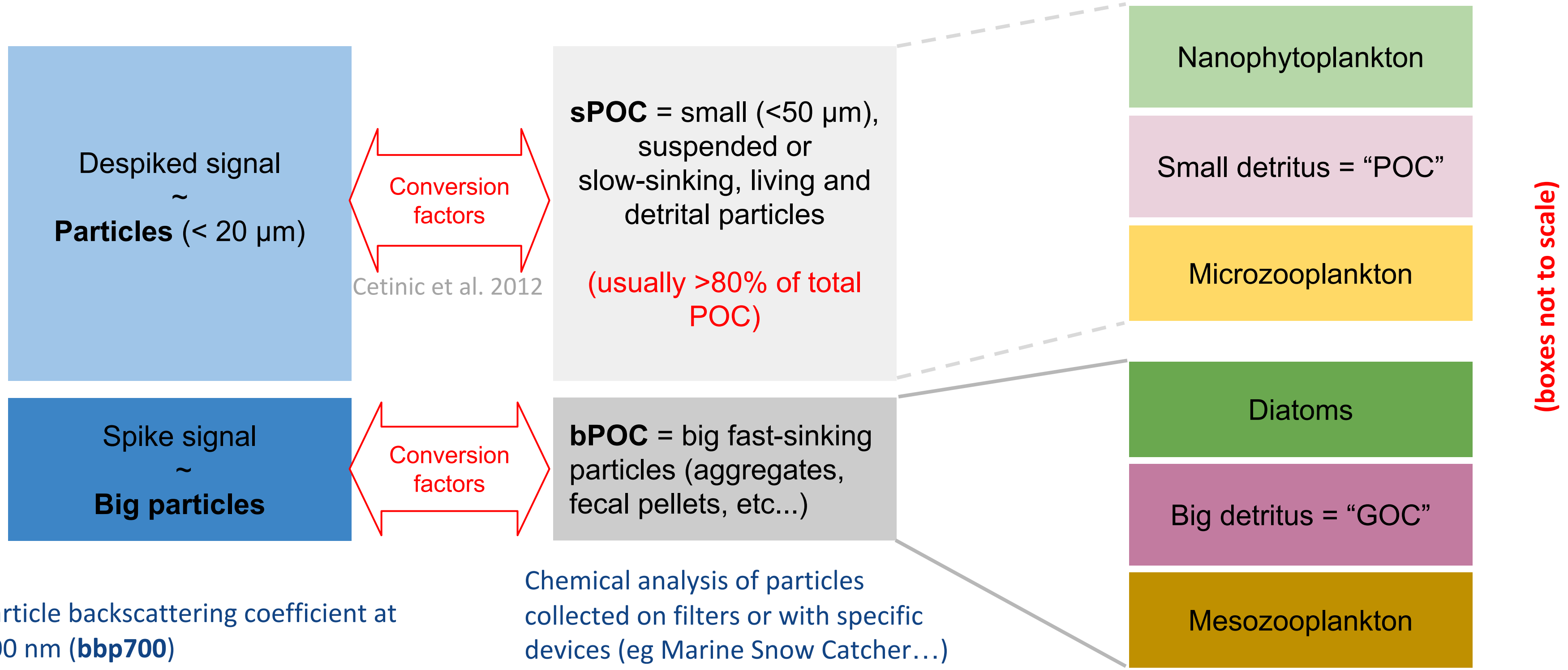
Inspired by Dall'Olmo et al. 2016

Additional challenge: comparing different "POCs"

bgc-Argo bio-optics

Traditional POC

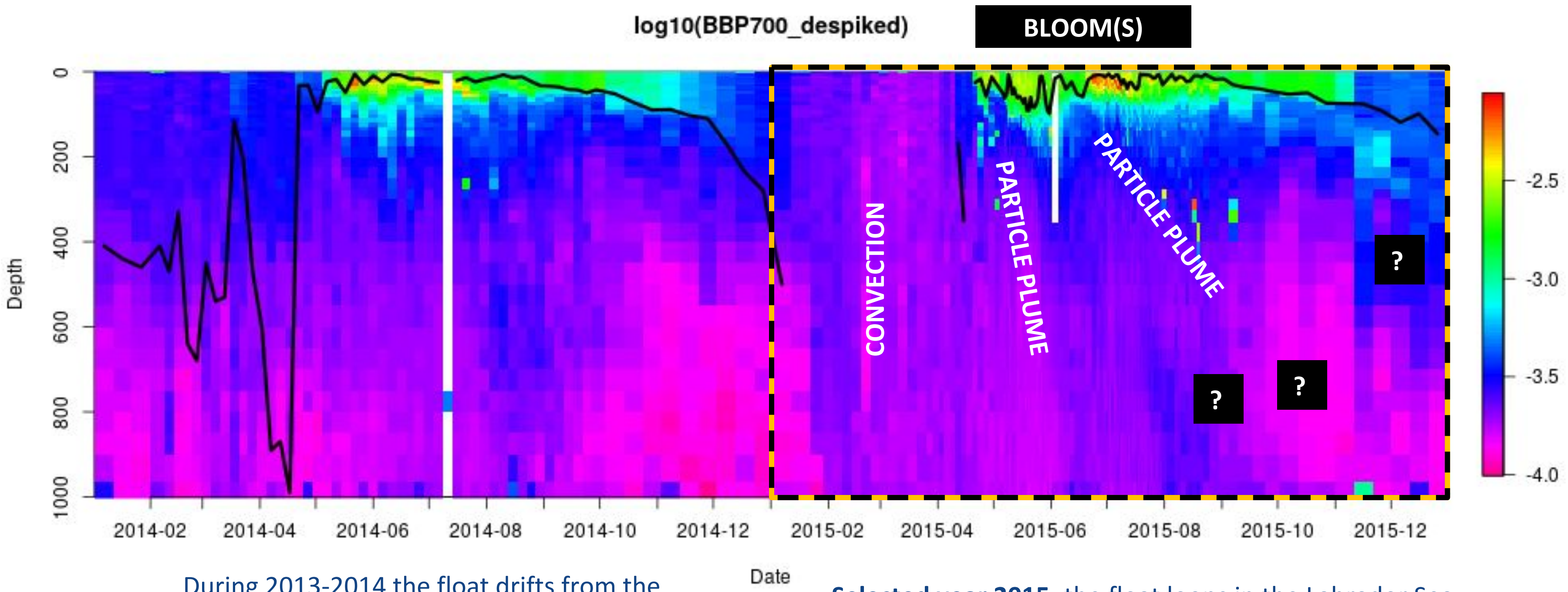
PISCES tracers



Particle backscattering coefficient at 700 nm (**bbp700**)

Chemical analysis of particles collected on filters or with specific devices (eg Marine Snow Catcher…)

Case study: Labrador Sea (float 6901486)



During 2013-2014 the float drifts from the Irminger Sea to the Labrador Sea

Selected year 2015: the float loops in the Labrador Sea. Similar seasonal cycles observed on 2 following years, during which the float remains in the Labrador Sea before dying.

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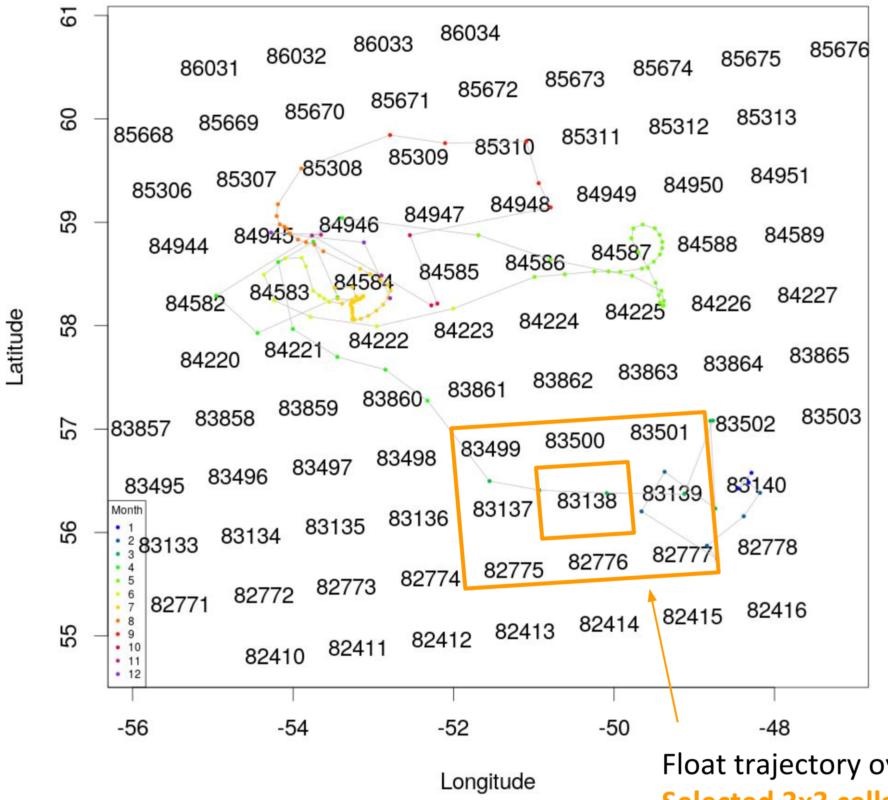
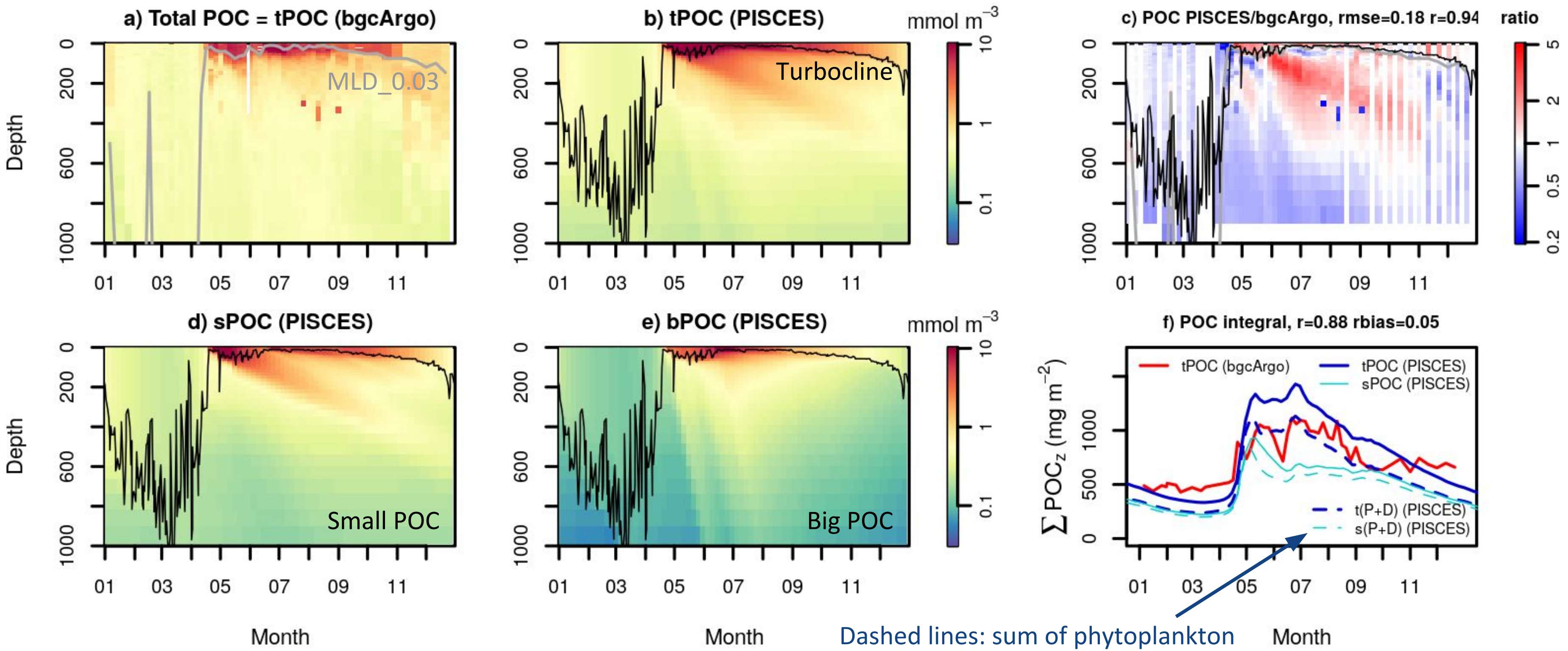
PISCES 1D offline simulations



- Simulations matching 1 natural year of bgc-Argo float observations.
- PISCES forced with NEMO-derived dynamical fields from OMIP2 6th cycle (ORCA1 L75 grid).
- Grid cell selected based on best match between MLD observed by floats (defined with a range of criteria) and turbocline depth simulated by NEMO (kz > 5e-4 $m^2 s^{-1}$).
- Nutrients restored towards annual climatology below 300 m depth.
- Simulations run for 10 repeating years to stabilize seasonal cycles (usually happens within ≤5 years).

Float trajectory overlaid on NEMO (ORCA1) grid.
Selected 3x3 cells centered on best MLD-turbocline match.

POC seasonality in bgc-Argo vs. PISCES 1D



(Reminder: tPOC = sPOC + bPOC)

Dashed lines: sum of phytoplankton and detritus, excluding zooplankton

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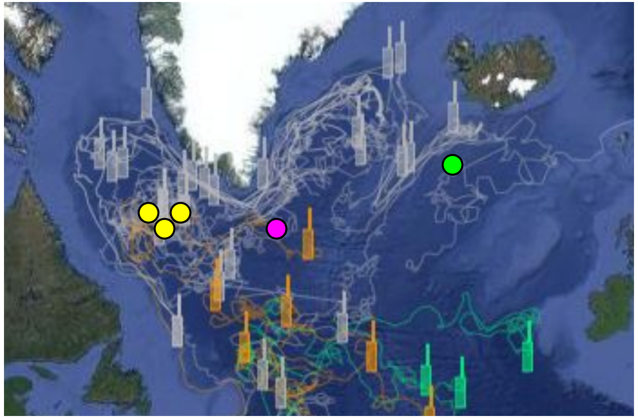
POC seasonality in bgc-Argo vs. PISCES 1D

- PISCES captures reasonably well the timing and magnitude of the spring-summer bloom, **but**…
  - Overestimates sPOC export (slow-sinking POC plumes) through upper mesopelagic.
  - Underestimates sPOC concentration in the lower mesopelagic.

- Both mismatches are too large to be explained by variations in bbp700 vs. POC conversion factors (Cetinic et al. 2012; see also Organelli et al. 2018)

- Similar mismatch patterns are consistently observed in other locations (i.e. for other float-year time series) in the subpolar North Atlantic: Labrador and Irminger seas and Iceland Basin.



- What processes explain the mismatch?

→ Compute **POC budgets**

POC budgets in PISCES

d[POC]/dt = production - consumption + sinking + transport

"sources"

Mort2POC = Phytoplankton and zooplankton mortalities

Z1NoAssim = Unassimilated fraction of microzooplankton food ingestion

GOC2POC = Bacterial breakdown of big POC aggregates

DOC2POC = DOC aggregation due to Brownian motion, shear and differential settling

Z2FragmGOC = big POC fragmentation by filter-feeding mesozooplankton

"sinks"

Z1IngestPOC = Microzooplankton POC ingestion

Z2ff_IngestPOC = POC ingestion by filter-feeding mesozooplankton

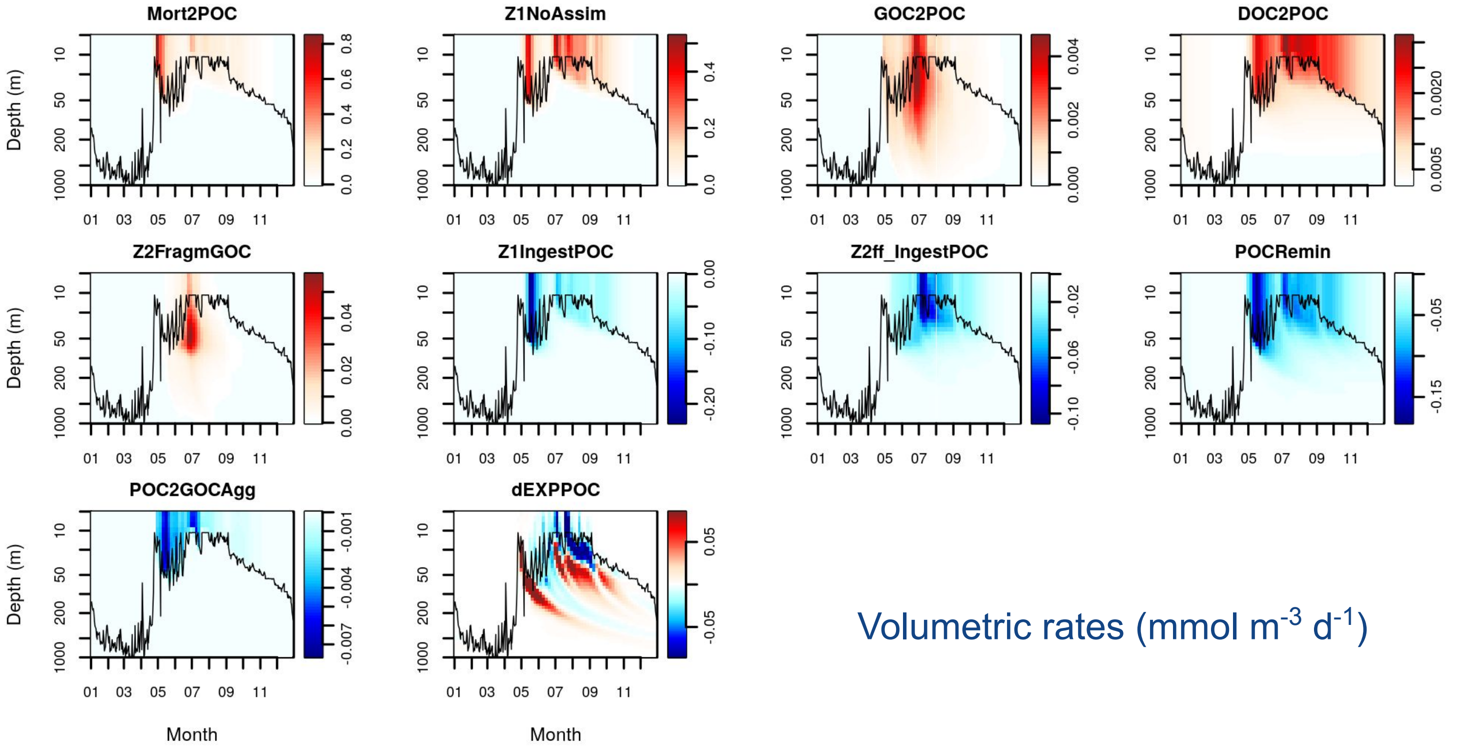
POCRemin = POC degradation (to DOC) and subsequent remineralization

POC2GOCAgg = Aggregation of small POC into large aggregates

dEXPPOC = Net gravitational POC sinking (input - output)

Not analyzed (yet)

sPOC budgets in PISCES



Volumetric rates (mmol m^{-3} d^{-1})

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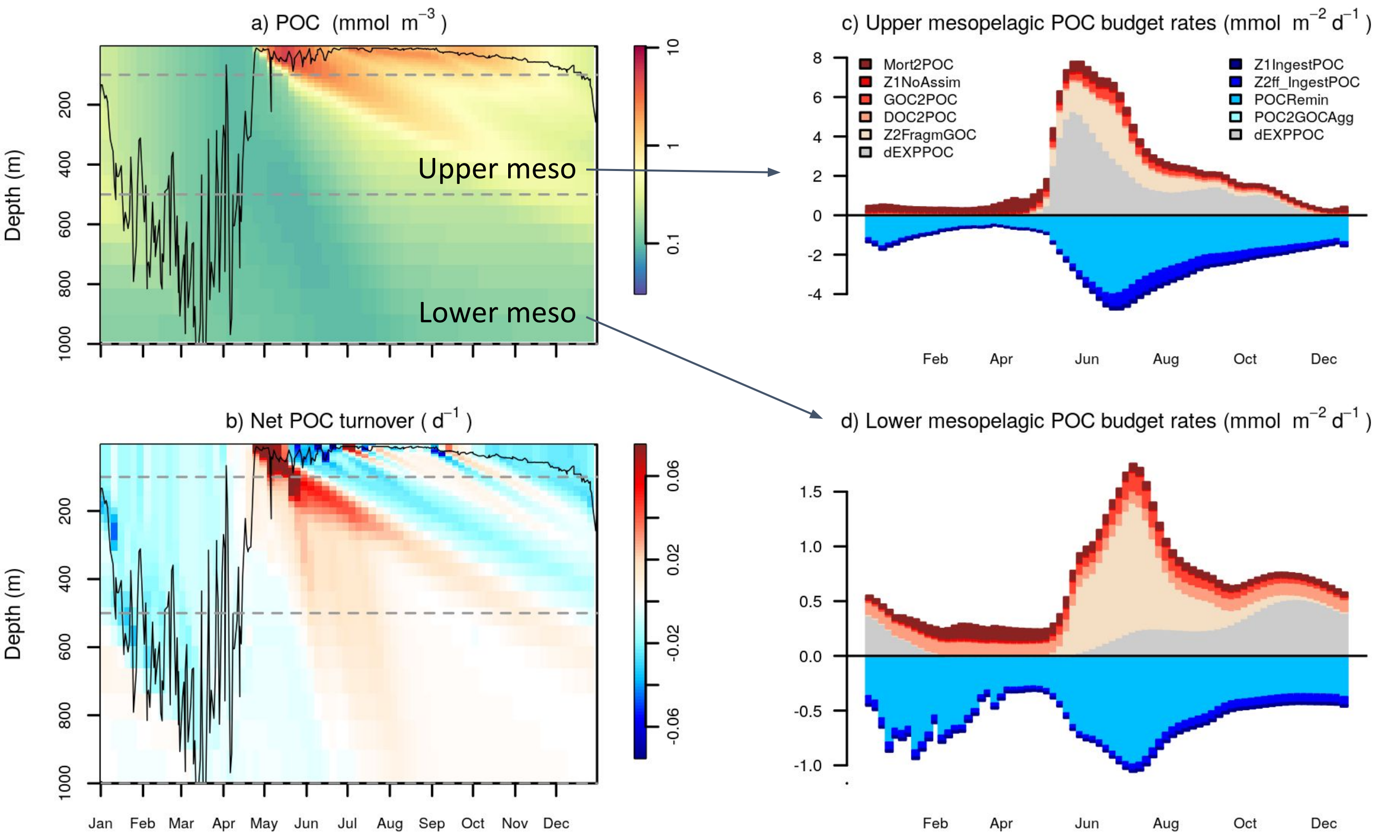
sPOC budgets in PISCES



Processes controlling mesopelagic sPOC in PISCES

Main budget terms		PISCES parameters
Inputs:		
• Gravitational sinking	→	**wsbio, m d^{-1}** (sPOC sinking speed)
• bPOC fragmentation "cross-section") by mesozooplankton	→	**grazflux, m^2 mol^{-1}** (flux feeding
Outputs:		
• Degradation	→	**xremip, d^{-1}** (specific degradation rate of freshly produced POC at the base of the mixed layer)

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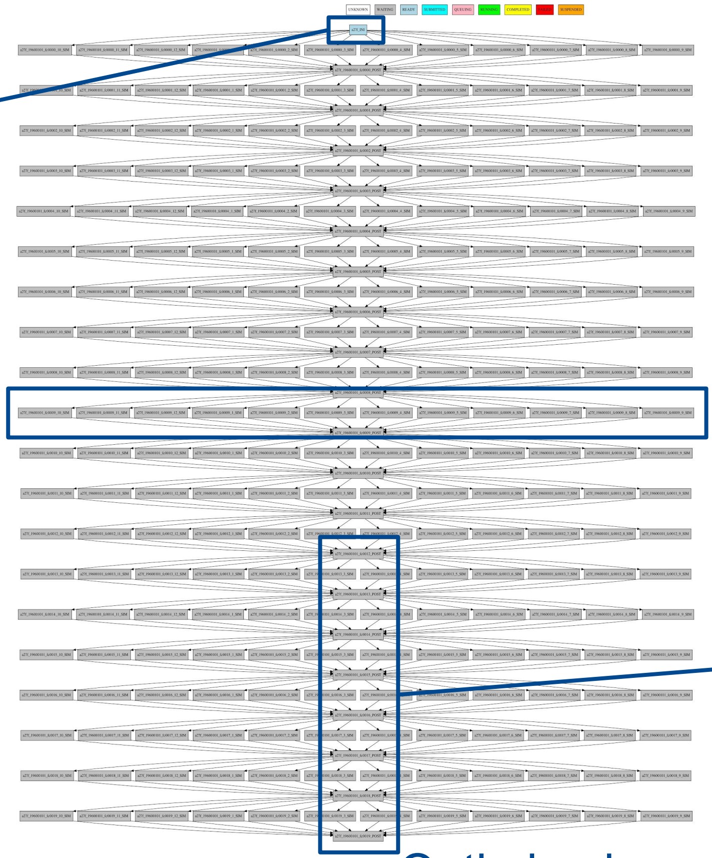
Parameter optimization: genetic algorithm (GA)

Initial simulation with default parameter set



Generation 1

Generation 2...

Individual simulations with different parameter sets

(50-100 sims / generation)

Calculation of cost + ‘Crossover’

Optimized parameter set

AUTOSUBMIT workflow manager

(Manubens-Gil et al. 2016)

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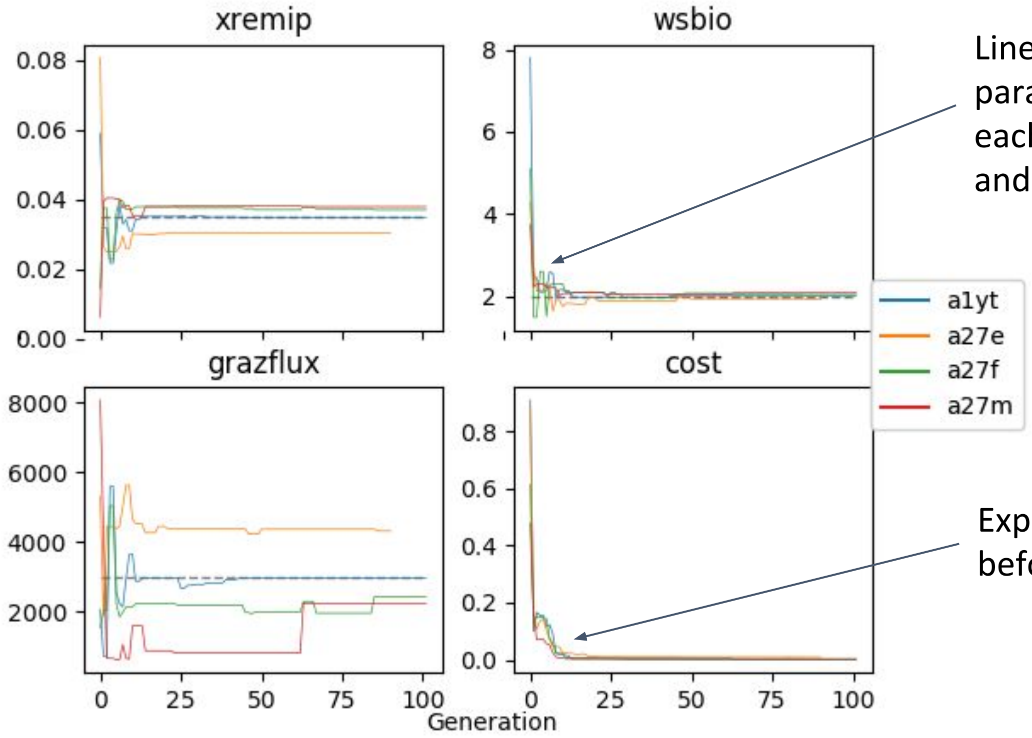
GA step 1: run against PISCES reference simulation with default parameters ("perfect model" approach)

Both **xremip** and **wsbio** converge towards default parameter values (known *a priori* in this experiment), which indicates these parameters can likely be optimized using POC observations.

In contrast, **grazflux** does not converge in all experiments. This parameter is likely difficult to optimize using only POC observations.

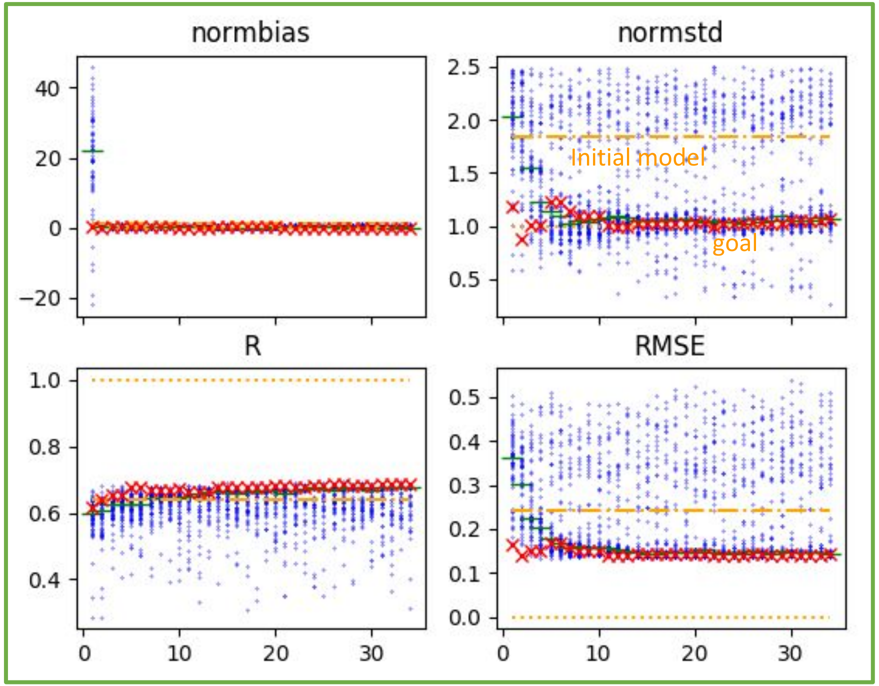


Lines show best parameter set in each generation and experiment

Four independent GA experiments

Experiments converge before 20 generations

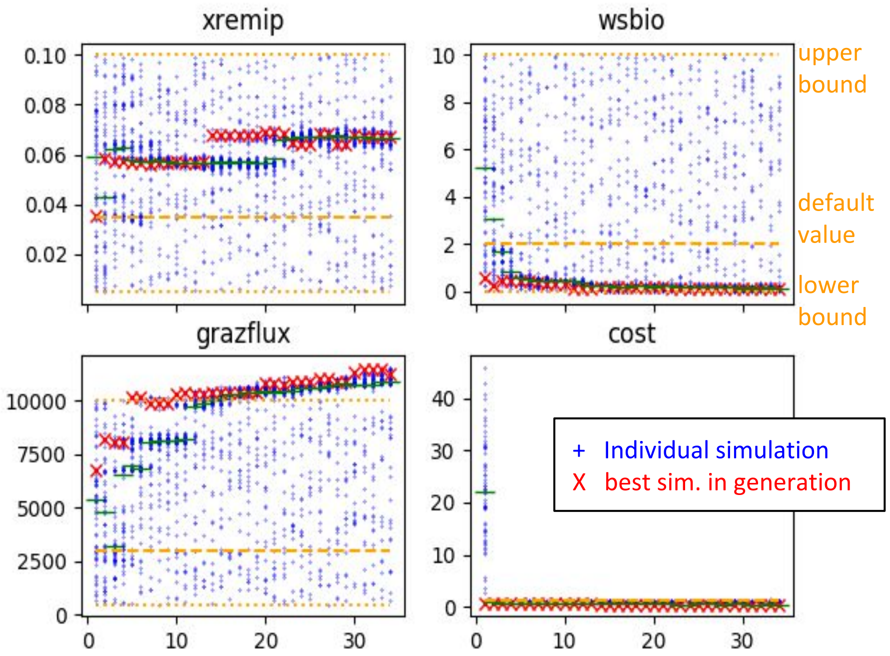
GA step 2: run against bgc-Argo observations



Components of the cost function

Jolliff et al. 2009

xremip/wsbio converge towards higher/lower values



In contrast, **grazflux** keeps increasing after >30 generations

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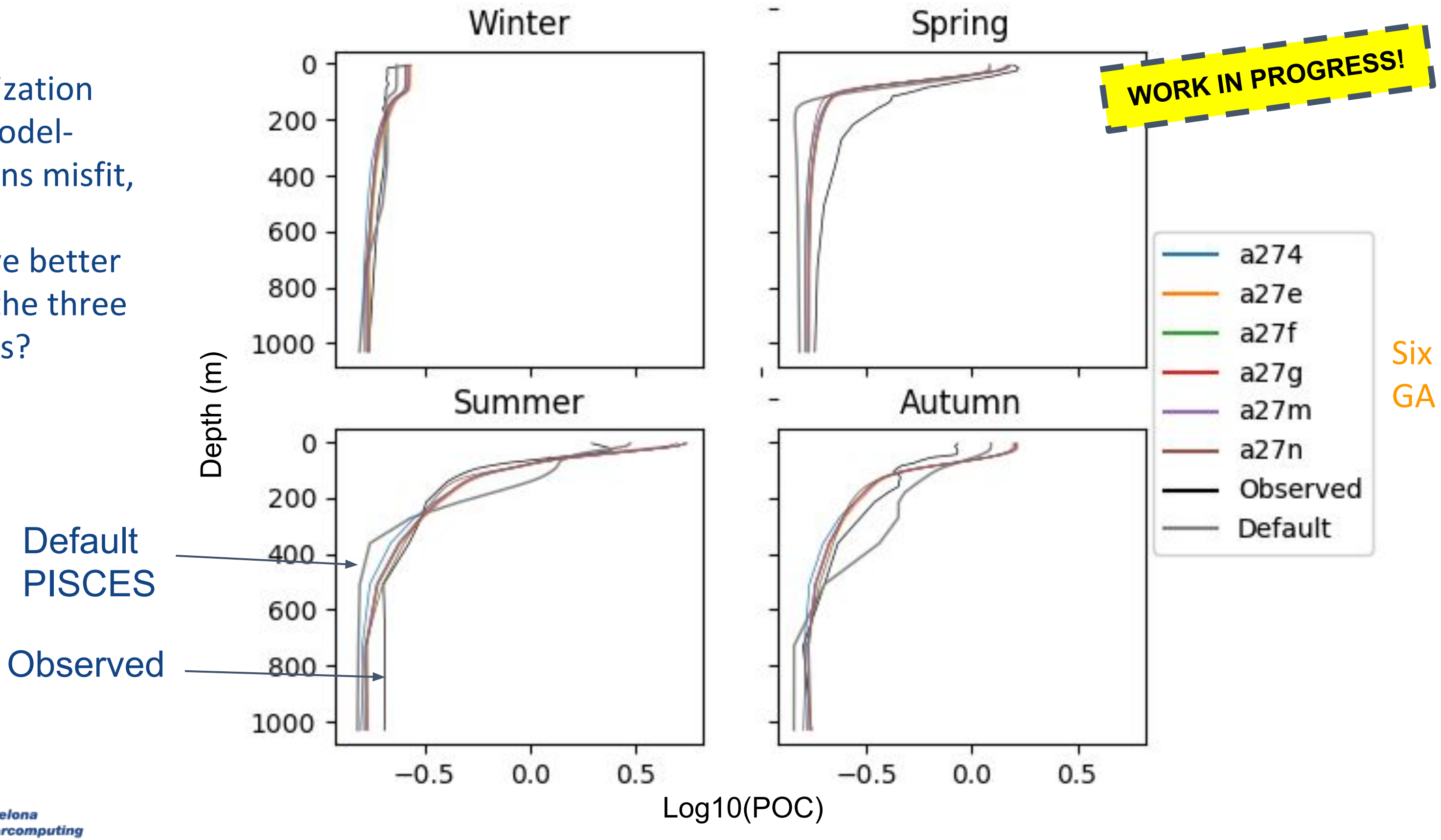
GA step 2: run against bgc-Argo observations

The optimization reduces model-observations misfit, **but**, how can we better constrain the three parameters?



Six independent GA experiments

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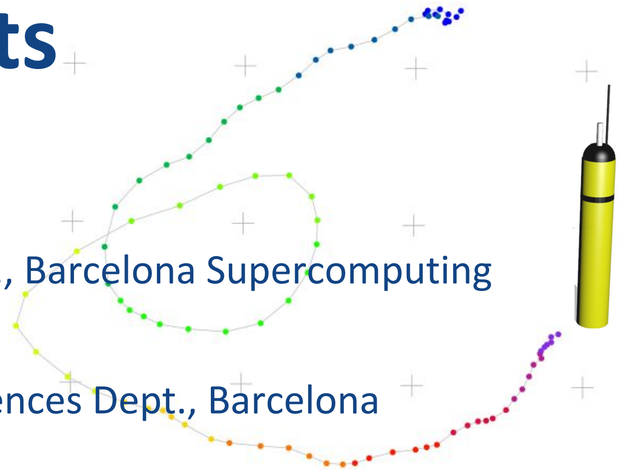
Summary and conclusions

- We performed PISCES 1D offline simulations in the subpolar North Atlantic, matching bgc-Argo float observations over 1-year periods (0-1000 m).
- PISCES captures the seasonality of epipelagic and mesopelagic POC concentrations, but consistently (1) overestimates small POC export plumes through the upper mesopelagic and (2) underestimates small POC concentration in the lower mesopelagic.
- PISCES-derived budgets suggest that the interplay between small POC sinking speed and breakdown rates and big POC fragmentation by flux-feeding zooplankton controls mesopelagic small POC dynamics over the seasonal cycle.
- We used a genetic algorithm to optimize PISCES parameters that control POC concentration and flux through the mesopelagic layer. Preliminary experiments suggest small POC sinking speed and degradation rates are more amenable to optimization than flux-feeding fragmentation.
- PISCES-derived POC budgets have to be further evaluated against other POC flux and metabolism measurements.
- Reducing uncertainty in estimation of POC from bio-optical variables will enable more accurate assessments.

Acknowledgements



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