Optimisation of biogeochemical model parameters using BGC-ARGO profiling floats

Quentin Hyvernat

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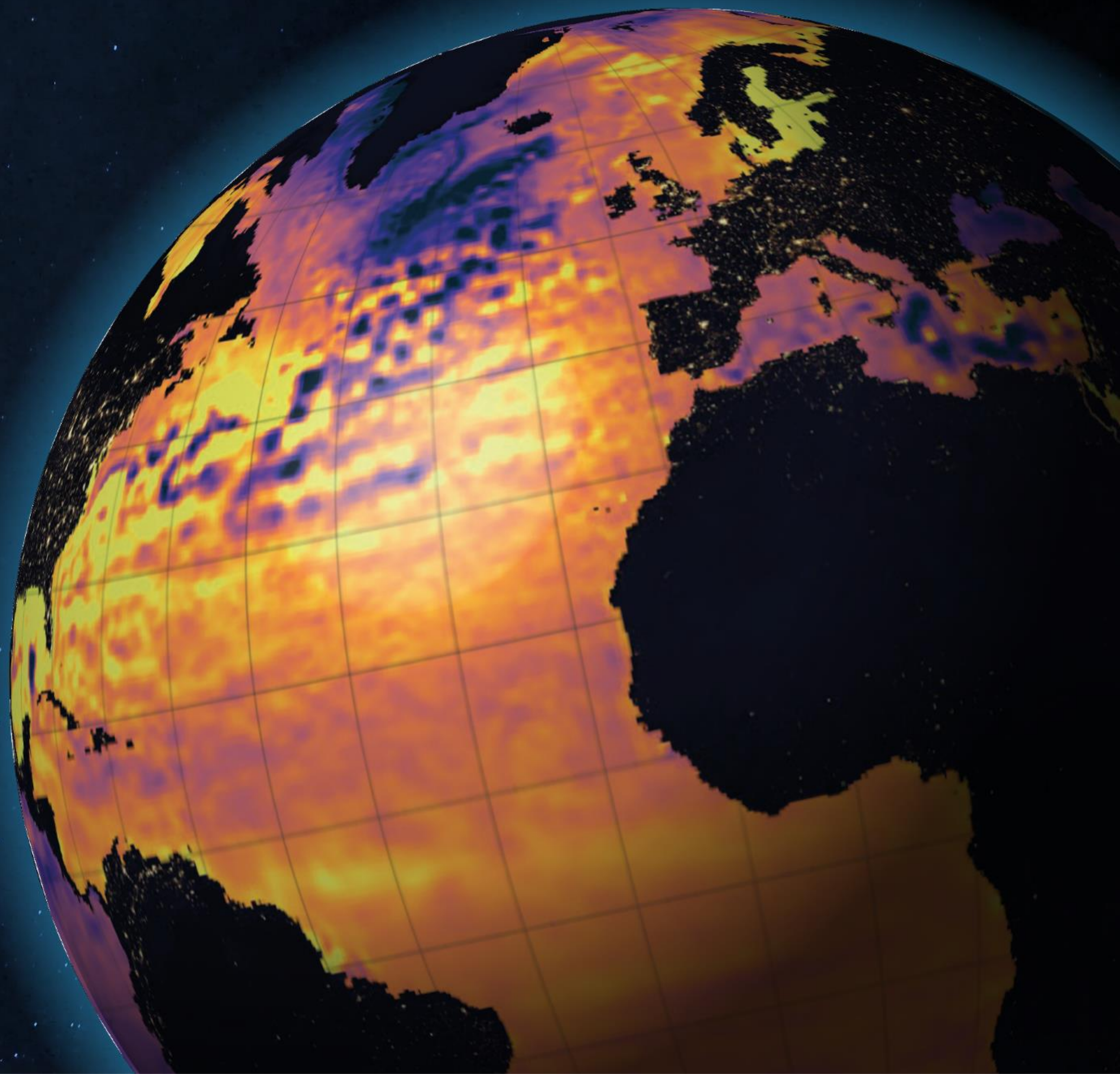


OceanPredict

SYMPOSIUM OP'24

In partnership with unesco Intergovernmental Oceanographic Commission

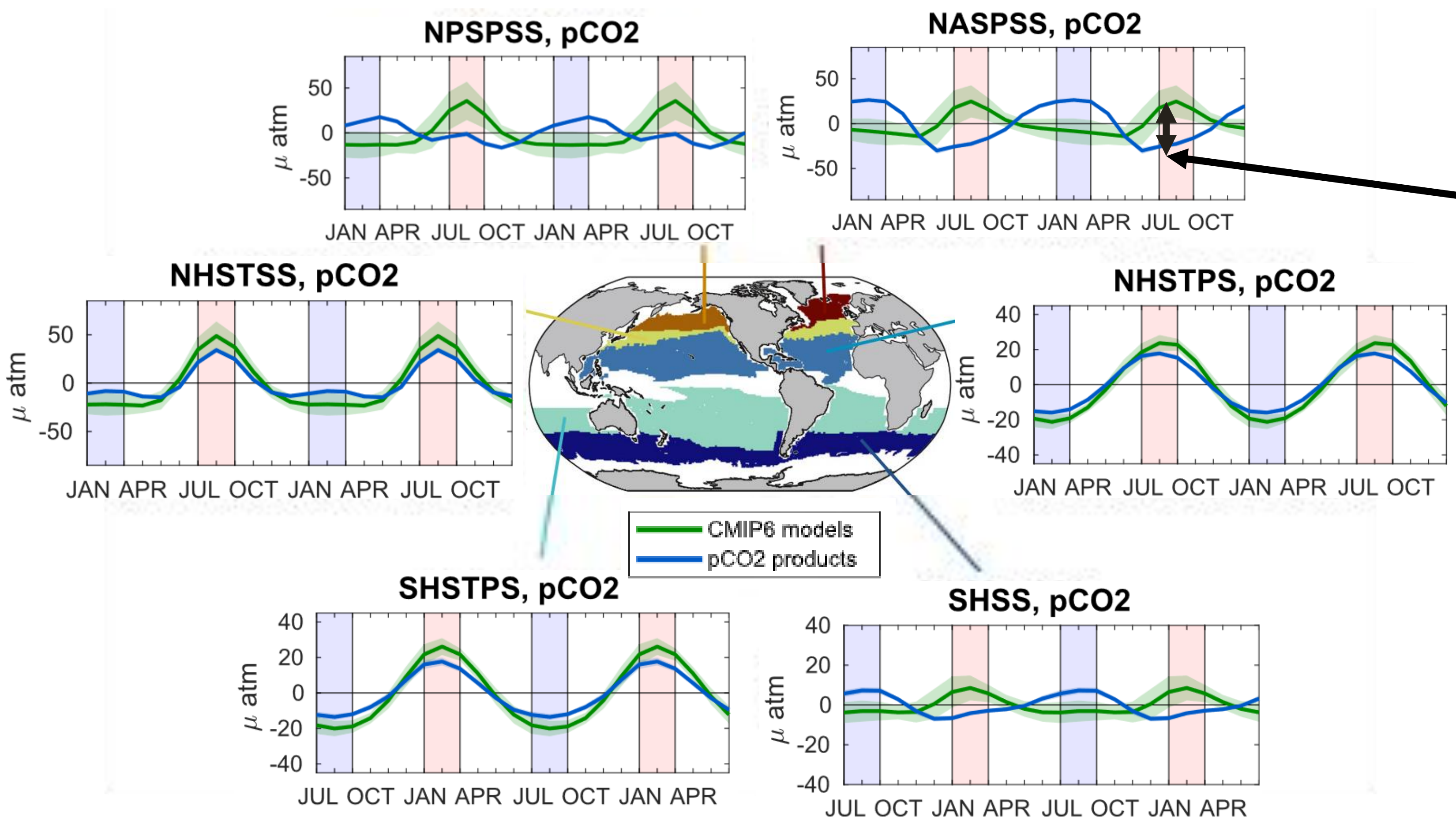
2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Optimisation of biogeochemical model parameters using BGC-ARGO profiling floats

- **Quentin Hyvernat**, Alexandre Mignot*, Elodie Gutknecht, Giovanni Ruggiero, Coralie Perruche, Guillaume Samson, Hervé Claustre*, Fabrizio D'ortenzio*

*PhD supervisor

CONTEXT



Large gap between observations and models !

Can a biogeochemical model be optimised to represent seasonal variations in pCO2 ?

Seasonal Variability of the Surface Ocean Carbon Cycle: A Synthesis

Keith B. Rodgers[1,2], Jörg Schwinger[3], Andrea J. Fassbender[4], Peter Landschützer[5], Ryohei Yamaguchi[6], Hartmut Frenzel[4,7], Karl Stein[1,2], Jens Daniel Müller[8], Nadine Goris[3], Sahil Sharma[1,9], Seth Bushinsky[10], Thi-Tuyet-Trang Chau[11], Marion Gehlen[11], M. Angeles Gallego[10], Lucas Gloege[12,13], Luke Gregor[8], Nicolas Gruber[8], Judith Hauck[14], Yosuke Iida[15], Masao Ishii[16], Lydia Keppler[17], Ji-Eun Kim[1,2], Sarah Schlunegger[18], Jerry Tjiputra[3], Katsuya Toyama[16], Pradeebane Vaittinada Ayar[3,11], and Antón Velo[19]

Biogeochemical models still have many weaknesses

Biogeochemical processes are described by empirical relationships: a mathematical formulation involving one or more parameters :

- The values of biogeochemical parameters primarily are mainly derived from laboratory experiments and are therefore rarely based on in situ observations (Fennel et al.2019).

- A single set of parameters may not be representative of the many biogeochemical diversities found in the global ocean (Schartau et al.2017).

Materials : Particle filter

The aim is to explore the parameter space of the NEMO-PISCES model to find out whether it is able to reproduces the seasonal cycle observed by the floats.

All parameters of a biogeochemical model affect the behavior of the model, largely due to complex non-linear interactions between parameters

A global sensitivity analysis approach for marine biogeochemical modeling

C. Prieur[a], L. Viry[a], E. Blayo[a,*], J.-M Brankart[b]

[a] Univ. Grenoble Alpes, CNRS, Inria, Grenoble INP *, LJK, Grenoble 38000, France
[b] Univ. Grenoble Alpes, CNRS, Grenoble INP *, IGE, Grenoble 38000, France

→ We perturb the reference value (REF) of all parameters except those related to the Redfield ratio. The perturbation range is [REF*0.01,REF*1.99].

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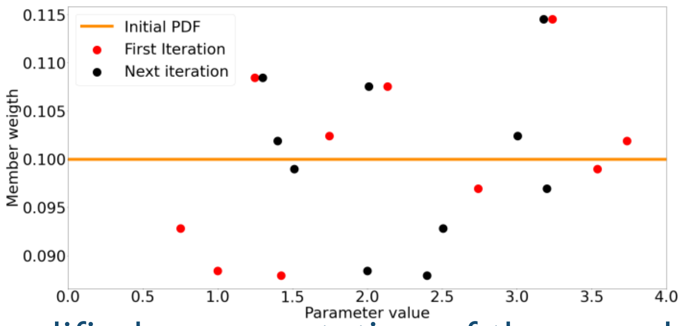
Particle Filter suitable for non-linear systems (Mattern et al. 2013)

Particle filter-based data assimilation for a three-dimensional biological ocean model and satellite observations

Jann Paul Mattern,[1,2] Michael Dowd,[1] and Katja Fennel[2]



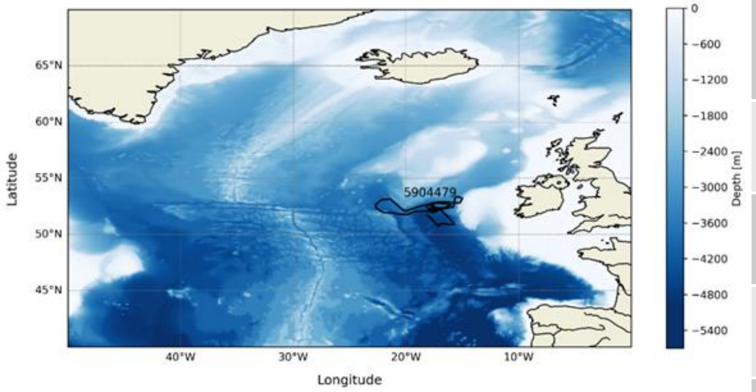
Simplified representation of the sampled space of a parameter for multiple iterations

Can we inform all parameters ?

Can we reduce uncertainties in parameter values?

Have these parameters been independently informed??

Materials : Observations



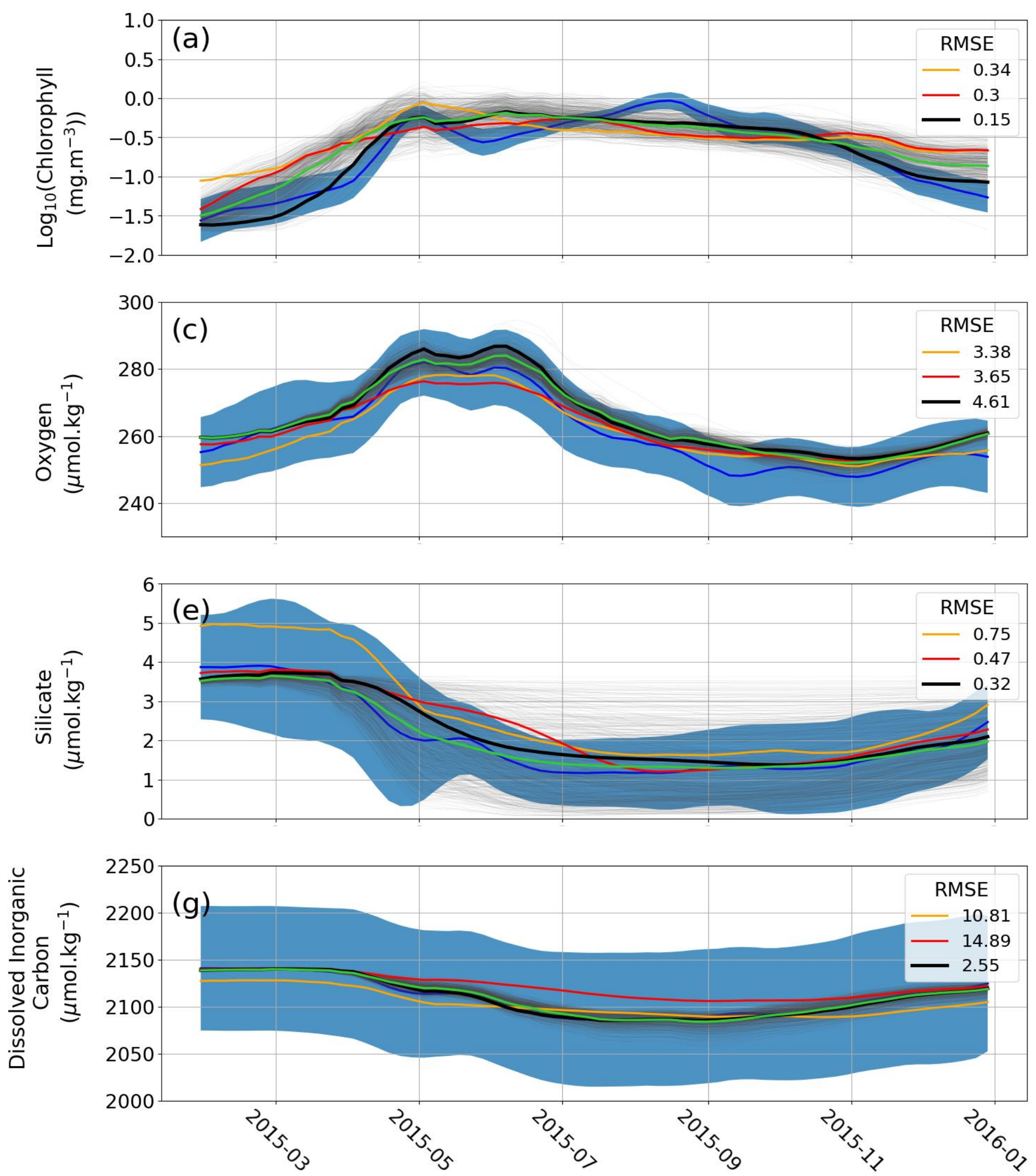
Float trajectory

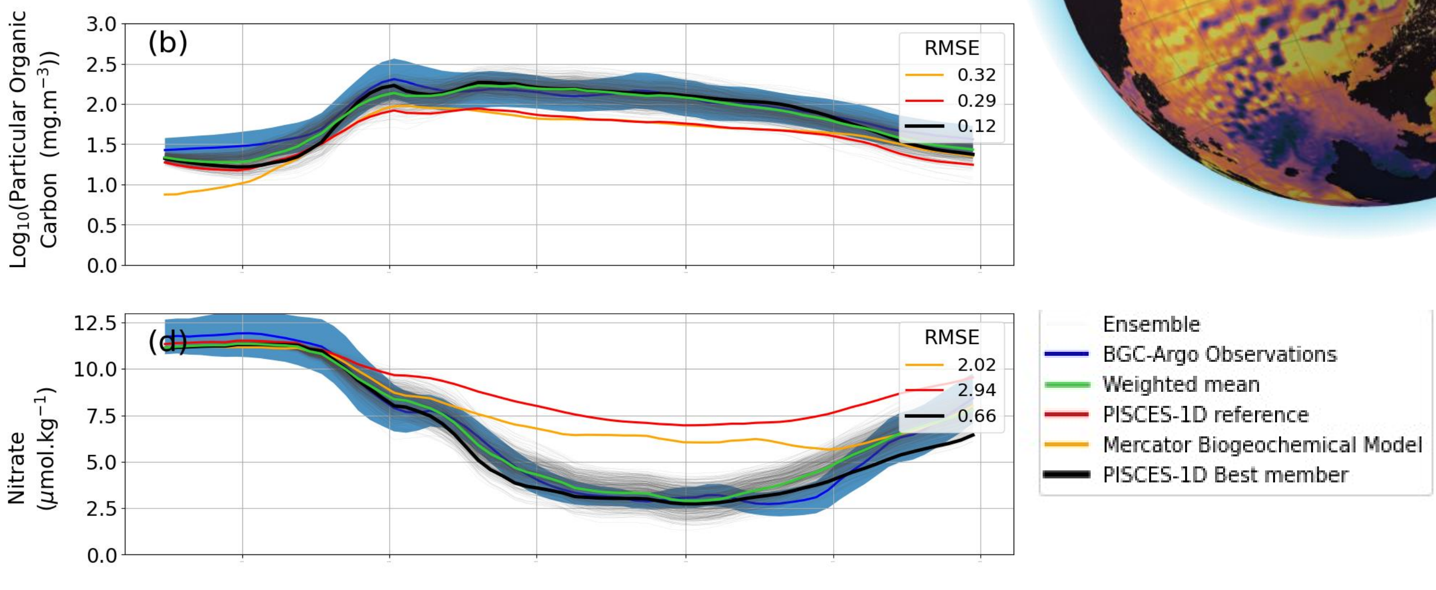
Variables	Source	20 Metrics
Chla*	O	$Chl_{prod.\ Layer}$ | H_{DCM} | Chl_{DCM}
POC*	O	$POC_{prod.\ Layer}$ | POC_{meso}
O_2*	O	$O_{2\ prod.\ Layer}$ | $O_{2\ meso}$ | $O_{2\ min}$ | $HO_{2\ min}$
NO_3*	O/NN	$NO_{3\ Prod.\ Layer}$ | $NO_{3\ meso}$ | $H_{nitracline}$
SiO_3^{2-}*	NN	$SiO_3^{2-}{}_{prod.\ Layer}$ | $SiO_3^{2-}{}_{meso}$
DIC*	NN	$DIC_{prod.\ Layer}$ | DIC_{meso}
PO_4*	NN	$PO_{4\ prod.\ Layer}$ | $PO_{4\ meso}$
Alk*	NN	$Alk_{prod.\ Layer}$ | Alk_{meso}
pH	NN	$pH_{prod.\ Layer}$ | pH_{meso}
pCO_2	NN	$pCO_{2\ surface}$

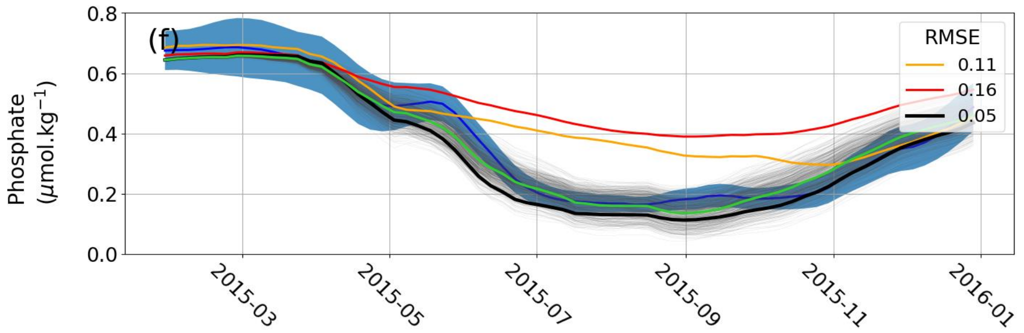
(O) : Observed (NN) : Neural Network
*Assimilated variables

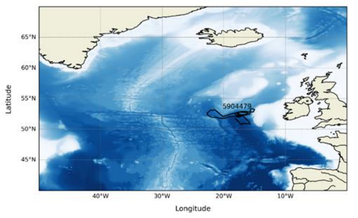
Bittig et al., 2018, Mignot et al., 2023

Results : Optimisation of biogeochemical model - 1D







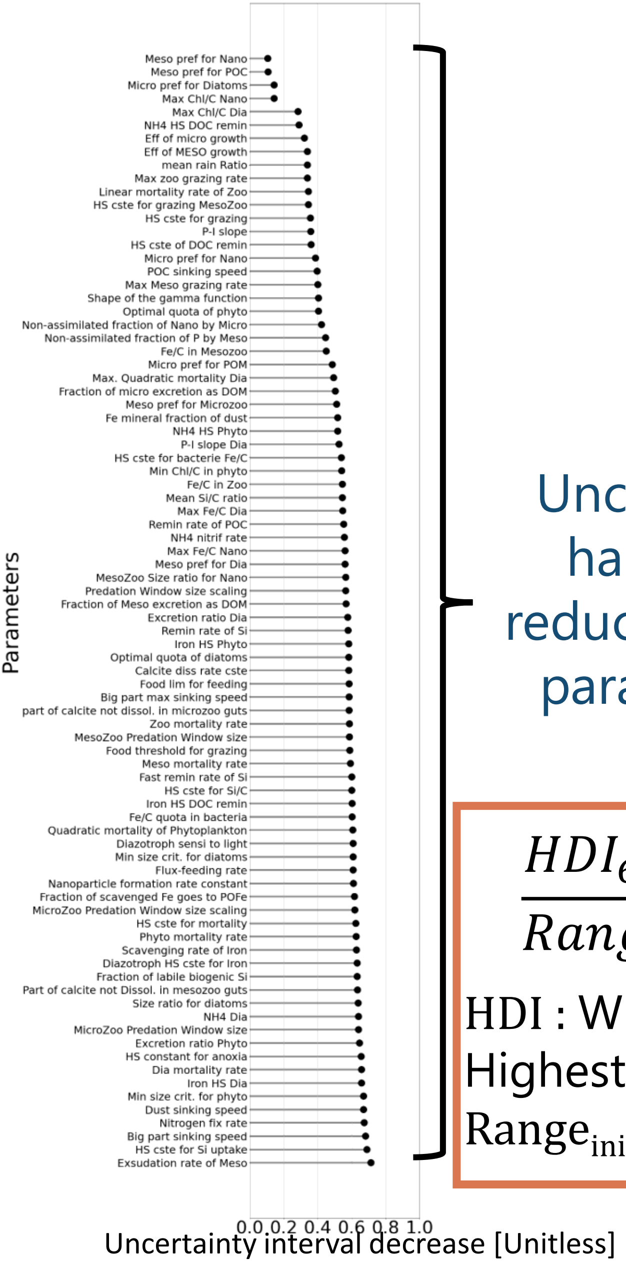


Float trajectory

Our best member simulates an increase in photosynthesis and primary production :

- Increased concentrations of : POC, Chla, O_2
- Decreased in concentrations of : DIC, PO_4, NO_3, SiO_3^{2-}

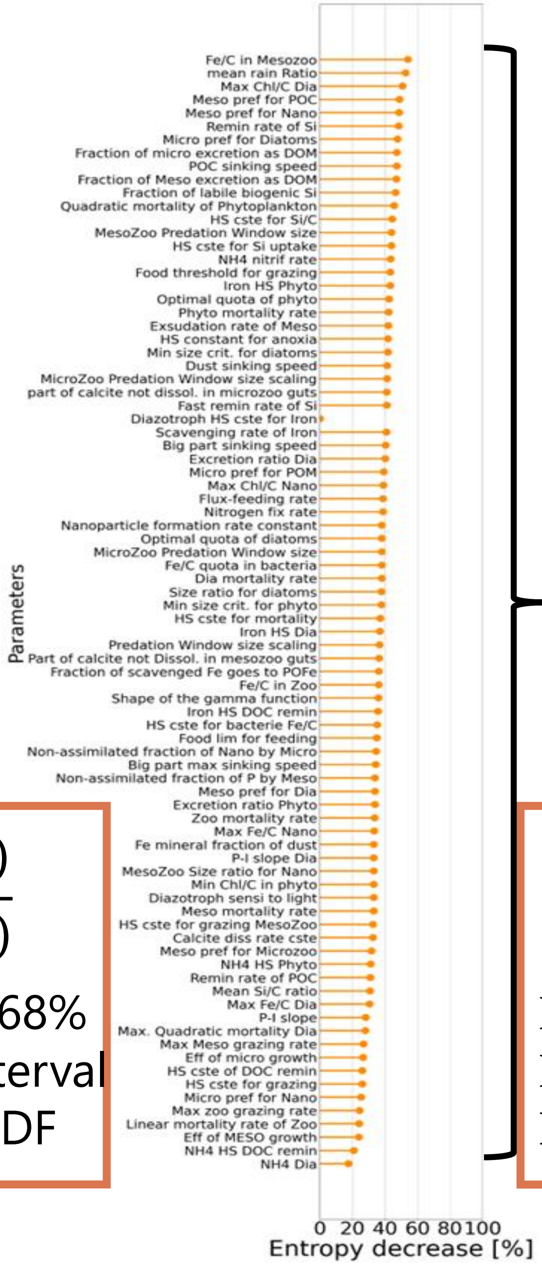
Results : Optimisation of biogeochemical model - 1D



Uncertainty has been reduced on all parameters

$$\frac{HDI_{68\%}(P_{final})}{Range(P_{initial})}$$

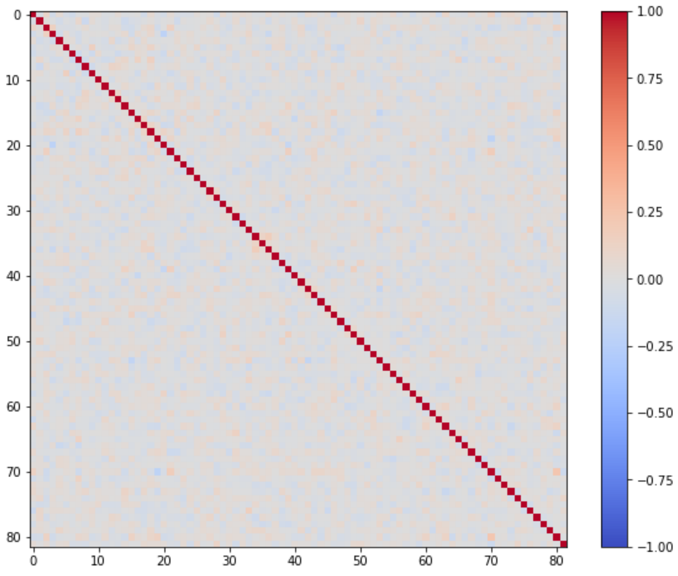
HDI : Width of the 68% Highest Density Interval
$Range_{initial}$: Initial PDF



All parameters have received information

$$1 - \left(\frac{H(P_{final})}{H(P_{initial})}\right)$$

H : Entropy of the PDF
$P_{initial}$: Initial PDF
P_{final} : Final PDF

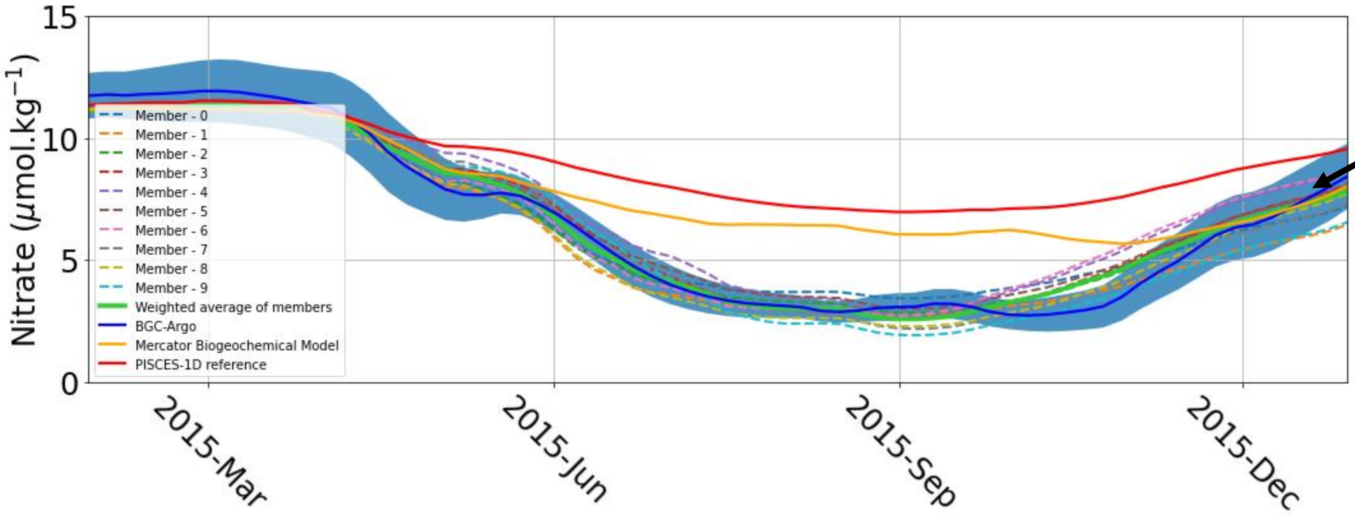


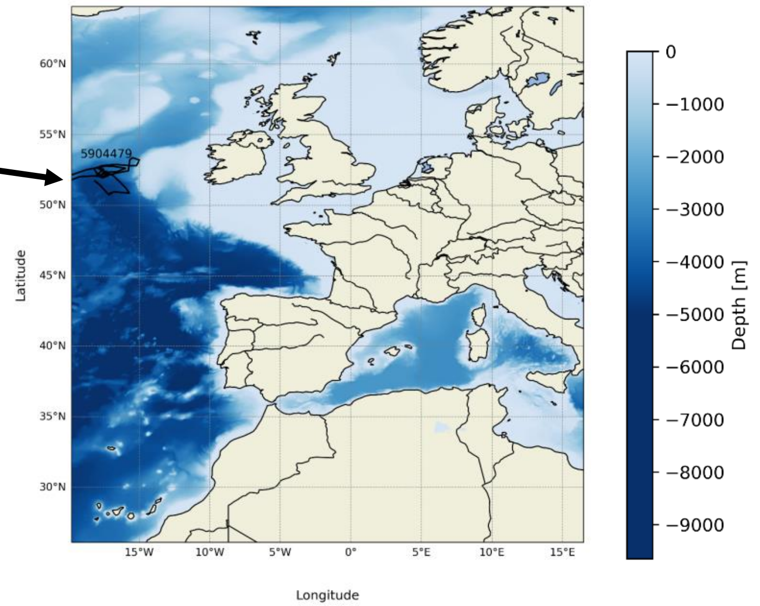
All parameters were independently informed

$$corr(P_i, P_j)$$

corr : Correlation
P_i : Parameter i
P_j : Parameter j

Results : Optimisation of biogeochemical model - 1D





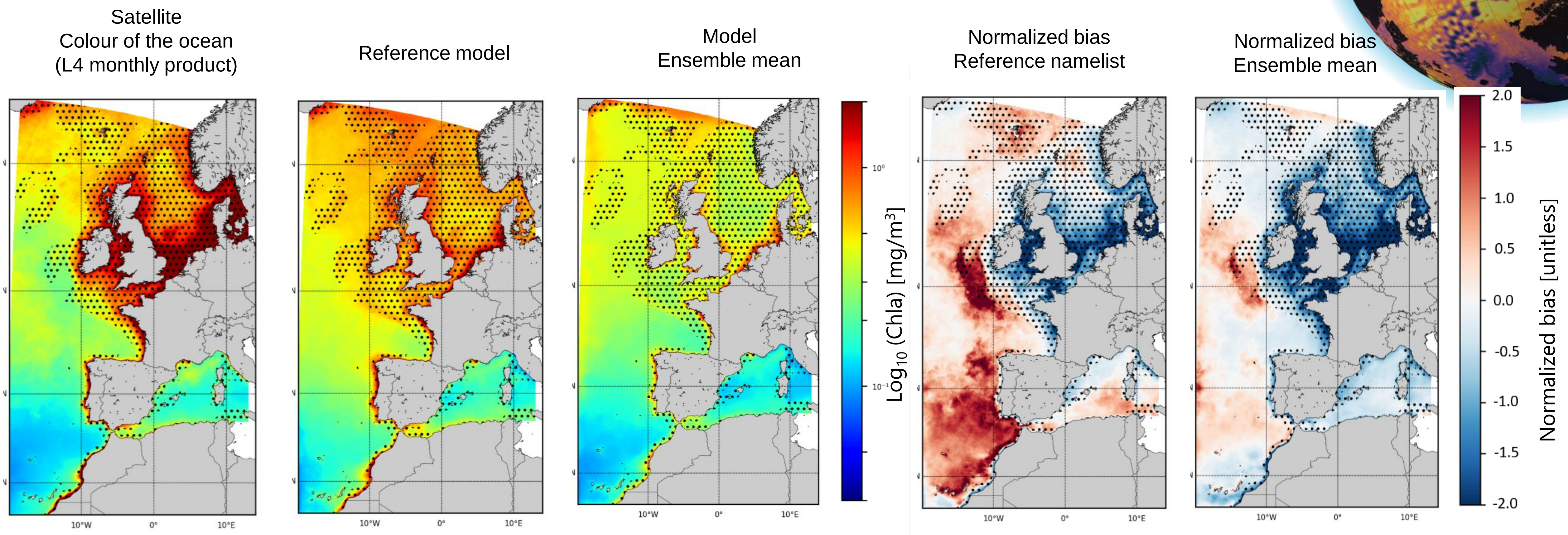
IBI domain

Metrics	Percentage improvement (Best member/Reference) (%)	Percentage improvement (ensemble average/reference) (%)
The average of the metrics in the productive layer.	-49.42	**-52.15**
Average of all assimilated metrics	-20.23	**-21.1**

- At the end of the 1D optimisation process, we selected the 10 ensemble members with the lowest RMSE values.

- We have used these ten separate parameter sets to **generate a set of ten 3D NEMO-PISCES simulations in the IBI region**, covering three years from 2021 to 2023.

Results : Optimisation of biogeochemical model - 3D



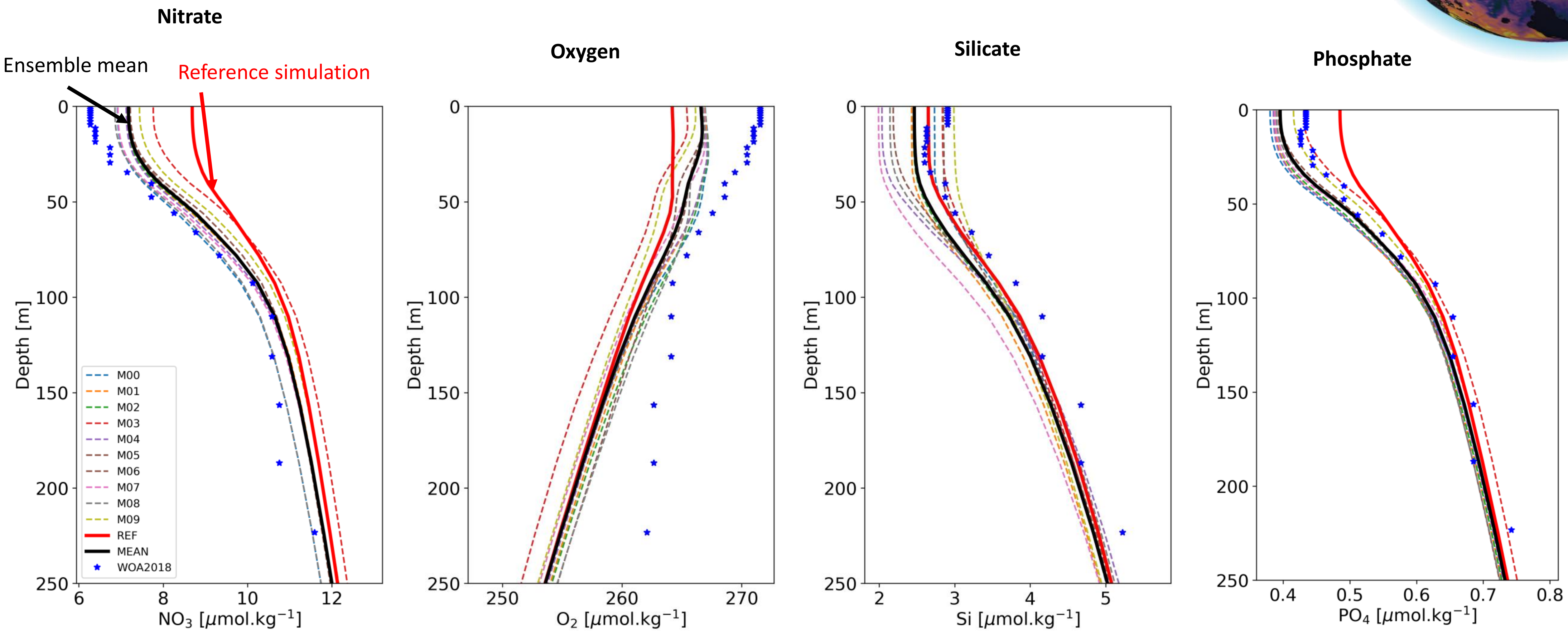
Mean normalised bias in the open ocean	
Reference parameter set	Ensemble average
0.639	**-0.001**

Optimised simulations improve representativeness in other bioregions.
The addition of 3D physical processes does not significantly degrade the results.

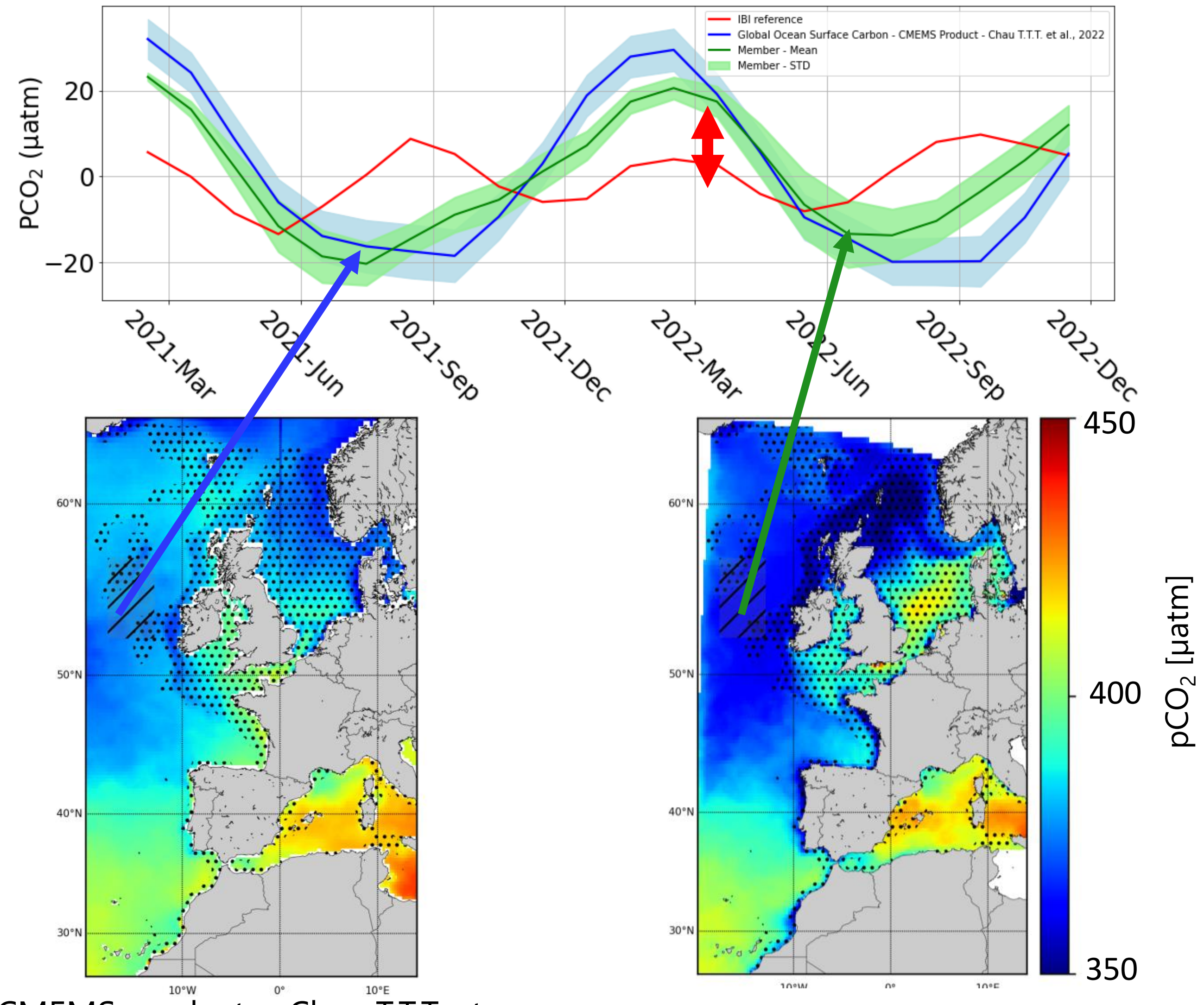
Results : Optimisation of biogeochemical model - 3D

Climatology from WOA2018

Average vertical profiles for 2019-2021 at 15°W, 55°N

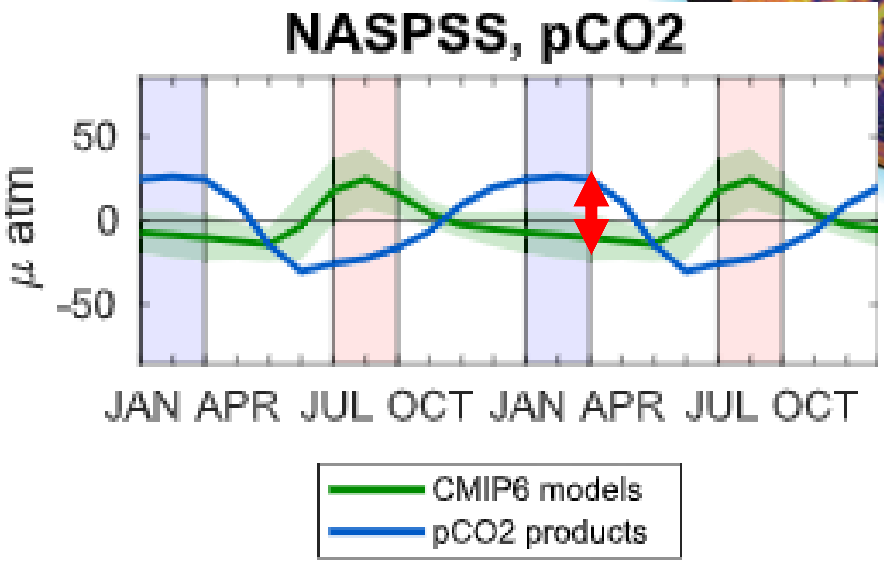


Results : Optimisation of biogeochemical model - 3D



CMEMS product - Chau T.T.T. et al., 2022
2021-2023

Optimised simulation



Seasonal Variability of the Surface Ocean Carbon Cycle: A Synthesis

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Our ensemble produces the correct phenology of pCO_2 and provides an estimate of the uncertainty.

Perspective and conclusion

To summarize :

- Development of an ensemble method for parameter optimization of biogeochemical model.
- The optimized 1D simulation achieves a 35% improvement in representing the observerd seasonal cycle compared to the reference simulation.
- The implementation of optimized parameters in the NEMO-PISCES 3D model leads to better regional results compared to the NEMO-PISCES 3D simulation using reference values. It can also correctly simulate seasonal variations in pCO_2 and estimate uncertainties.

Perspective :

- Use other sets of observations to optimise the continental shelf too.
- We will apply this method to multiple BGC-Argo observations in different bio-regions to produce an optimised global biogeochemical model.

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Interested in postdoctoral opportunities

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Thank you!

Results : Optimisation of biogeochemical model - 3D

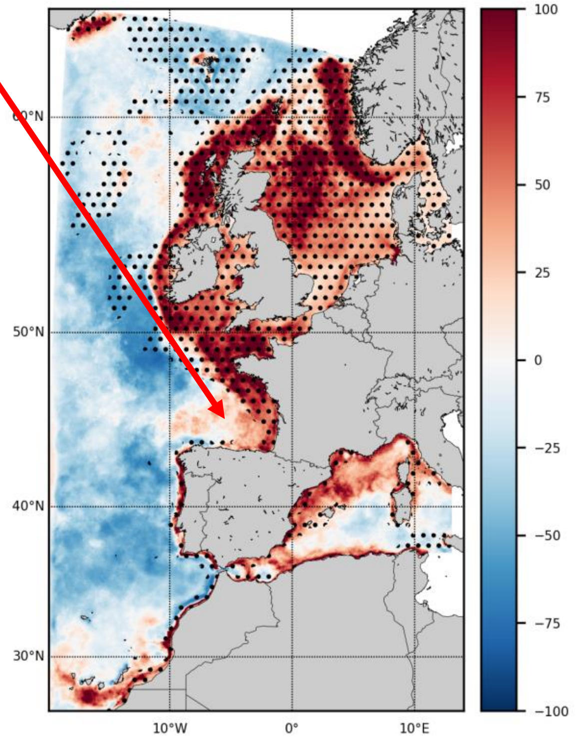
Percentage difference between the Mean Absolute Error (MAE) of ensemble members and the reference simulation

$$MAE = \frac{1}{n}\sum|x - y|$$

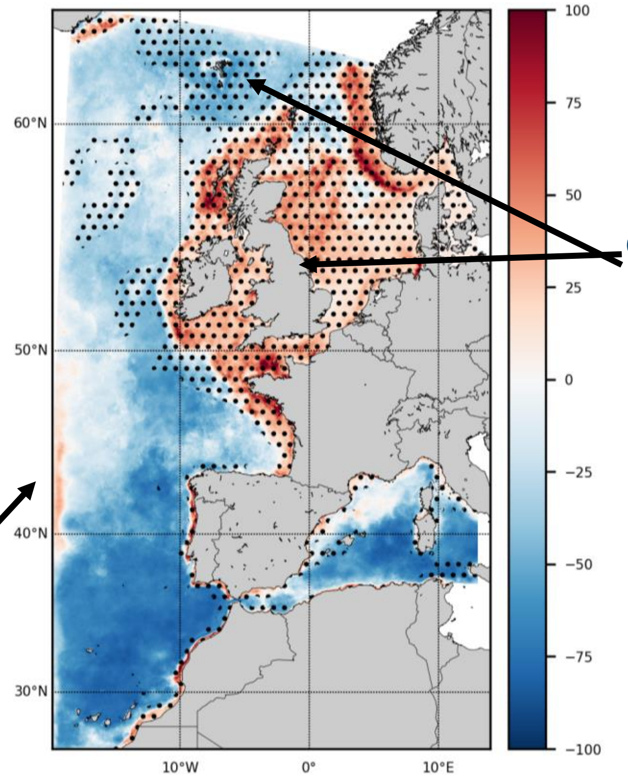
The **red color** indicates that the member performs **worse** in predicting Chlorophyll compared to the reference simulation

The **blue color** indicates that the member performs **better** in predicting Chlorophyll compared to the reference simulation

Worst member



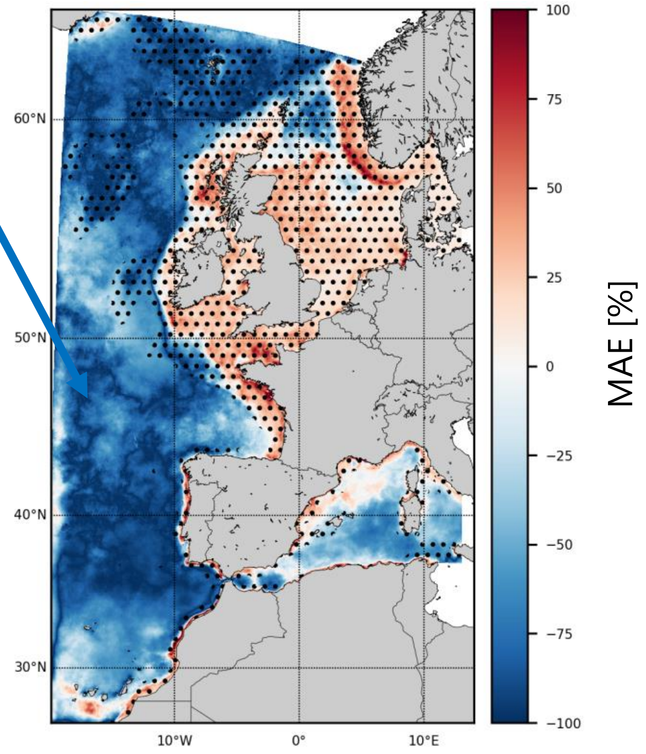
Ensemble mean



Coastal mask

Faulty boundary conditions

Best member



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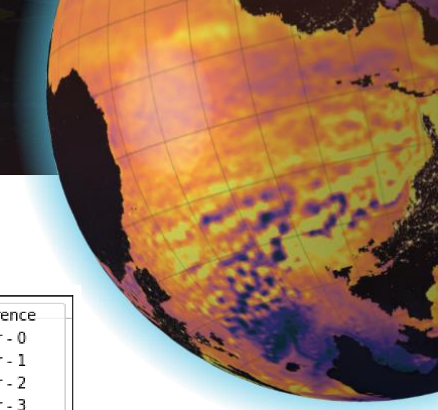
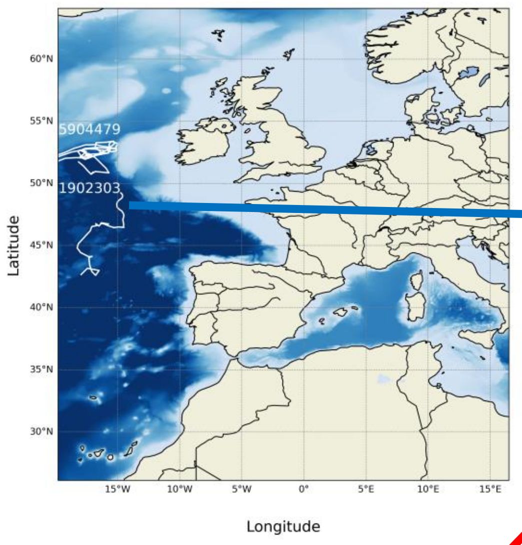
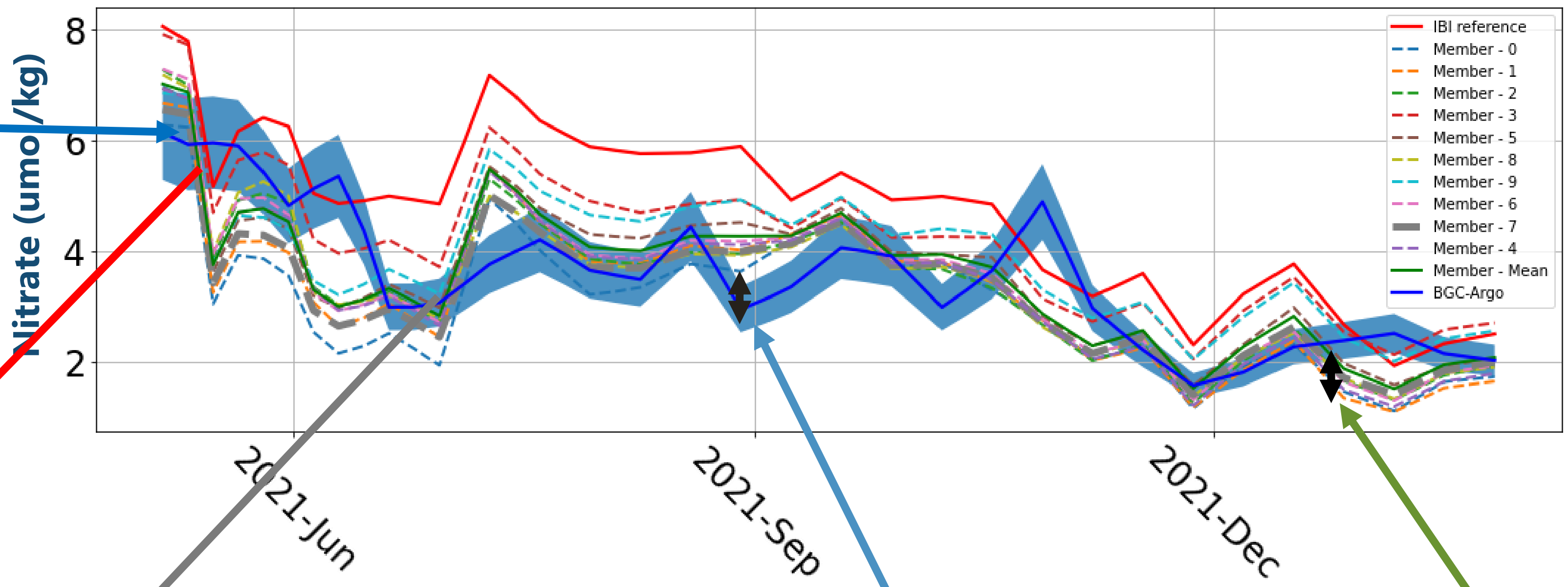
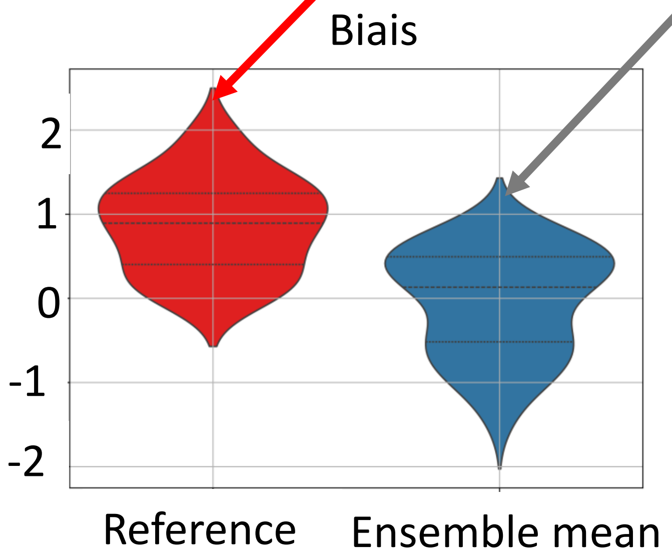




Validation against independent BGC-Argo float





The average of the members recovers the observed phenology in an unbiased manner and with an uncertainty similar to the observations.

The percentage of observational error (use by the particle filter)	STD of members around the average of members
14 %	11 %

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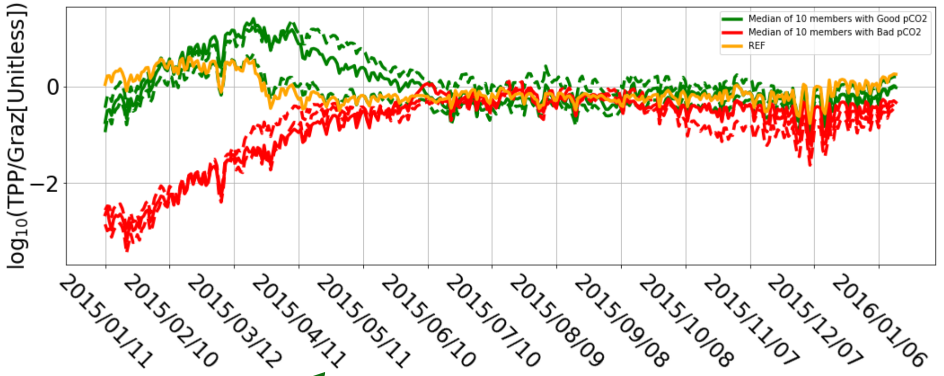
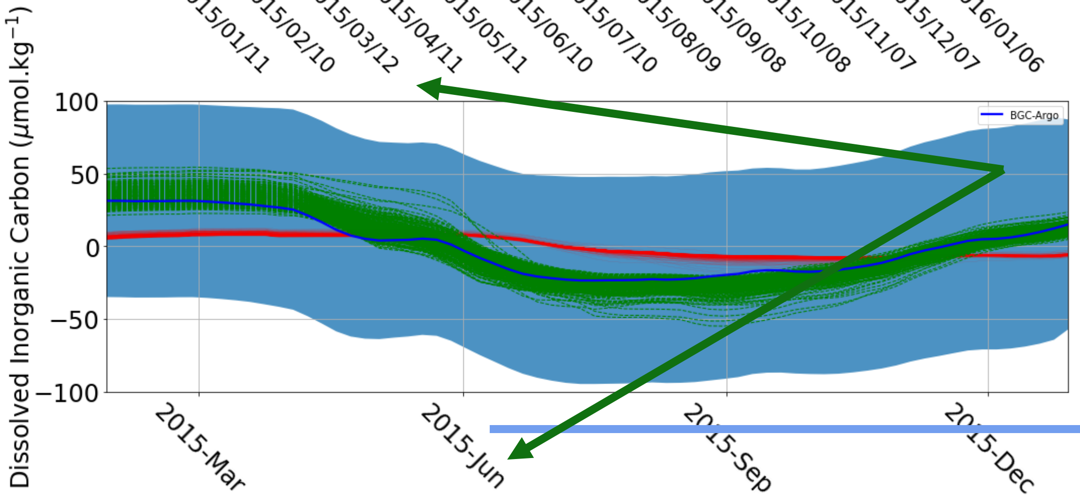
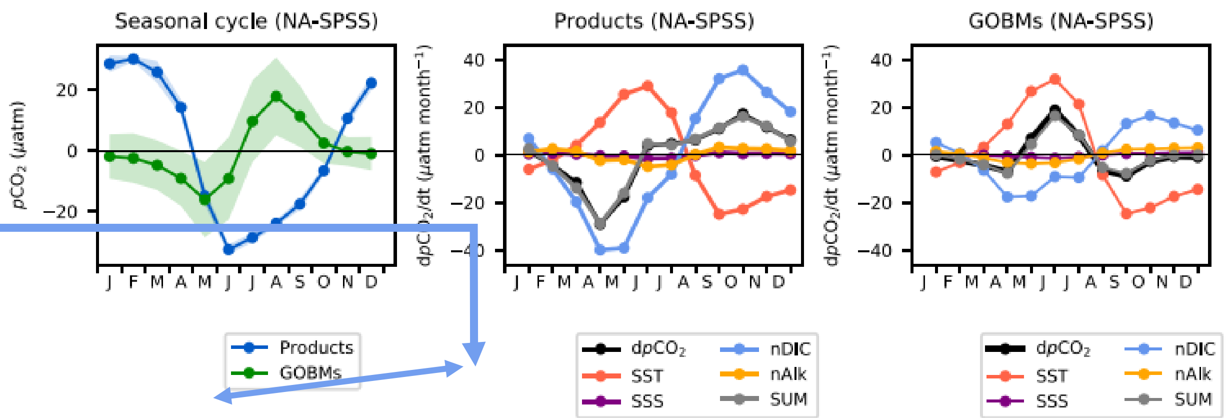
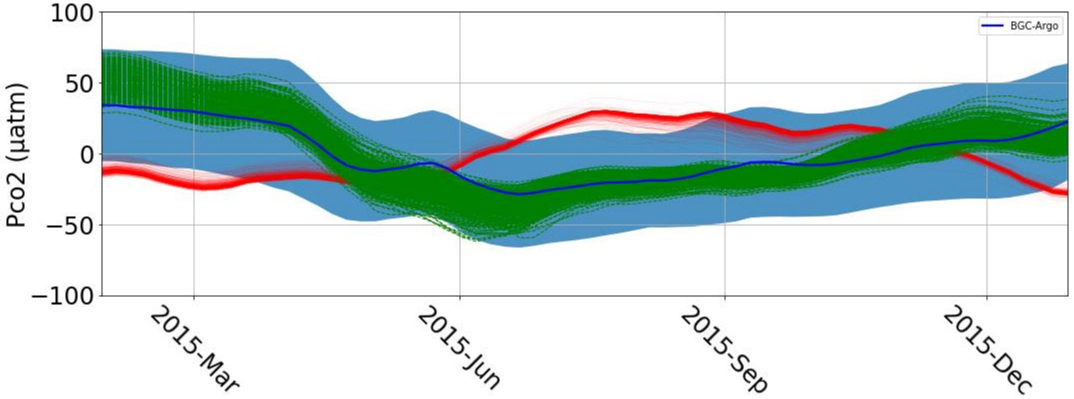


Par conséquent, l'augmentation de la P-I slope et de la constante de demi-saturation a permis d'augmenter le rapport en la production primaire et la prédation.
a permis d'accroître la production primaire. Ces effets ont pour conséquence de diminuer la concentration de DIC. Rodgers et al., 2023 montre d'ailleurs que la variabilité saisonnière produite par les modèles est trop faible, ce qui cause la mauvaise représentation de la pCO_2.







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