Sujet de thèse

Vers une modélisation parcimonieuse de la biogéochimie océanique basée sur des indicateurs clés pour des projections décennales robustes en Méditerranée

Towards parsimonious data-driven modelling of the ocean biogeochemistry for robust decadal projections in the Mediterranean Sea

Scientific context

In order to answer the ever-increasing number of scientific questions related to biogeochemical cycles (particularly the carbon cycle) and the dynamics of the planktonic network in the ocean, or to attempt to reproduce certain biogeochemical characteristics observed in situ, biogeochemical models (which here refers to models based on size classes, functional groups, traits or species) have seen their complexity increase almost continuously over the last few decades. This increase in complexity takes different forms depending on the model, with a very large number of variables for models based on the diversity of living organisms including several dozen planktonic groups, or an increase in the number of processes represented and/or the formulations that represent them. Furthermore, modelling the flexibility of stoichiometry within planktonic organisms is also accompanied by a significant increase in the number of state variables. Moreover, these biogeochemical models are coupled to (or forced by) marine circulation models, or even integrated into model chains that also include an explicit representation of other components of the earth system. Performing multi-decadal simulations (including climate projections) using these highly complex integrated models poses two types of difficulties:

(i) it requires very substantial computing resources, which can be a handicap for quantifying uncertainties (especially via ensemble approaches), for exploring a diversity of scenarios for the 21st century, or for any other application requiring a large number of simulations

(ii) an excessive level of complexity may prove unnecessary depending on the objective pursued, especially as the carbon footprint of the simulations produced by these complex models is not negligible.

In this context, the identification of the 'right level' of complexity, particularly for the biogeochemical component of these integrated models, becomes a major issue. This level of complexity and the simplification expected from it necessarily depend on the scientific question studied or the ecological indicators to be estimated, and therefore on the variables and time scales of interest, but also on the quantity of information contained in the available observations. The literature already proposes a significant number of methods for simplifying dynamic models, which consist of either (i) breaking down the initial food web into sub-modules with few interactions between them, (ii) aggregating state variables or processes in order to obtain a reduced model whose structure may potentially differ from the original model, (iii) exploiting the potential presence of different time scales within the processes involved, either in a classic "manual" manner, (iv) simplifying the mathematical expressions of the original equations, or (v) identifying the variables and processes that govern the dynamics of the system and removing those variables or processes that are deemed to have little influence, which can be done through a sensitivity study, optimisation, or other methods.

Objectives of the thesis

This thesis is part of the MEDIATION[1] project which aims to develop methodological developments to (i) define the level of complexity required for modelling chains to assess the response of ecosystems to various scenarios, (ii) quantify the uncertainty of the models and the projections they provide, and (iii) reduce the execution time to explore a larger number of scenarios.

The main objective of this thesis is first to explore two main ways to reduce the computation time of the Eco3M-MED biogeochemical model (Baklouti et al., 2021) when used in a modelling chain such as the one already set up for the Mediterranean (e.g. Pagès et al., 2020) or in the enriched versions of other compotnets of the earth system as envisaged in the MEDIATION project. The more parsimonious model(s) resulting from this first step should allow for the estimation of uncertainties, for example by means of ensemble methods (Garnier et al., 2016) on some key indicators that will be identified in the framework of this thesis.

- The first pathway aims to develop one or more simplified versions of the Eco3M-MED model, at least one of which would retain the mechanistic foundations of the model and its explanatory capabilities. The objective is to build on one or more existing methods, without excluding modifications to make it better adapted to the objective pursued. In the best case, the method adopted will be sufficiently generic to be able to benefit other biogeochemical models, and in particular the other models involved in the MEDIATION project.

---

1 The MEDIATION project «"Methodological developments for a robust and efficient digital twin of the ocean" is led by L. Debreu (INRIA), F. Dumas (SHOM) and P. Marchesiello (IRD) and is founded by the PPR-OCEAN for 5 years (2022-2027).

- The second approach will explore the possibility of optimising the calculation time linked to the transport, by the hydrodynamic model, of the biogeochemical variables associated with a single organism. In the current flexible stoichiometry models, these concentrations are advected independently by the hydrodynamic model, which has the consequence of inducing inconsistency as soon as the advection pattern is not linear, in addition to unnecessarily increasing the calculation costs. The objective is therefore to propose, on the basis of already sketched paths, an advection scheme for the concentrations associated with the same organism which is of the same order as the initial scheme but which combines gains in consistency and calculation time.

Implementation and tools

The research carried out in the framework of this thesis will use the Eco3M-Med biogeochemical model in different configurations, i.e. coupled to a hydrodynamic model (NEMO or CROCO depending on the configuration) in a vertical 1D configuration and in a 3D configuration at the Mediterranean basin scale. Prior to the simplification of the model, a first step will consist of identifying key observable indicators from field data, and evaluating the original model on these indicators in order to make the necessary modifications if necessary. The programming of the simplification method and the advection scheme will be done in Fortran 90-95 while Python will be used for the post-processing of the simulations.

Expectations and perspectives

This thesis should make it possible to obtain one or more models that are significantly faster in their execution while maintaining, at least for one of them, their biogeochemical rationality and the mechanistic bases of the original model. The performance of this model will be evaluated using data acquired in the Mediterranean over a period of one to two decades over the period 2000-2020 and compared with that of the original model. If these are sufficient, this model should eventually be used for the Mediterranean basin-wide climate projections envisaged in the MEDIATION project, including a quantification of the uncertainties.

Working context

The candidate will be supervised by M Baklouti (AMU/MIO) and P Brasseur (CNRS/IGE). He/she will be mainly located at the MIO (Luminy campus, Marseille), and will spend some time at the IGE (Grenoble). A close collaboration is envisaged with E Arnaud, A Vidard, E Blayo, L Debreu (INRIA/AIRSEA) for the first part and with P Marchesiello (IRD/LEGOS) and F Dumas (SHOM) for the second.
The thesis will start on 1 October 2023.

Profil sought

The successful candidate will have a background in oceanography (or environmental sciences), and/or a good command of numerical methods (model reduction, sensitivity analysis, PDE resolution). Knowledge/experience in 3D numerical modelling in oceanography (or environmental sciences), and a good knowledge of Fortran and Python languages as well as of the Linux environment are also expected.

Contacts

melika.baklouti@univ-amu.fr, pierre.brasseur@univ-grenoble-alpes.fr

References

Baklouti M, Pagès R, Alekseenko E, Guyennon A, Grégori G (2021) On the benefits of using cell quotas in addition to intracellular elemental ratios in flexible-stoichiometry Plankton functional type models. Application to the Mediterranean Sea, Progress in Oceanography, 197, 102634.

Garnier F., Brankart J.-M., Brasseur P. and Cosme E., 2016: Stochastic parameterizations of biogeochemical uncertainties in a 1/4° NEMO/PISCES model for probabilistic comparisons with ocean color data, J. Mar. Systems, 155, 59-72, https://doi.org/10.1016/j.jmarsys.2015.10.012

Pagès R, Baklouti M, Barrier N, Ayache M, Sevault F, Somot S, Moutin T (2020). Projected Effects of Climate-Induced Changes in Hydrodynamics on the Biogeochemistry of the Mediterranean Sea Under the RCP 8.5 Regional Climate Scenario. Frontiers in Marine Science, 7, 10.3389/fmars.2020.563615