Modeling in Apero: carbon Remineralization and Transfer, Investigating the heterotrophic Network Impact (MARTINI)

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Abstract :
The ocean plays a key role in biogeochemical cycles, particularly the carbon cycle, which impacts on climate. The **biological carbon pump** represents all the processes that regulate the transfer and transformation of biogenic carbon produced at the surface to the deep ocean. Observations show that the energy supply to the deep ocean, supplied by the biological pump, cannot compensate for the metabolic demand of the water column ecosystem. The ANR **APERO** project aims to constrain this biological carbon pump in a part of the ocean that has been poorly understood until now due to a lack of observations: the mesopelagic zone between 200 and 1000m. It is in this depth range that the carbon exported from the ocean surface is subject to the most intense attenuation, resulting from multiple and complex degradation processes. Carbon storage in the deep ocean depends very critically on the depth of remineralisation of this exported material. Since the 2010s, technological (platforms, sensors) and methodological (imaging, molecular biology) innovations have made it possible to explore the mesopelagic zone in a new and systematic way. It is on these achievements that APERO was built, based on an ambitious campaign in the North East Atlantic in June 2023 using two oceanographic vessels for 45 days.
The objective of the thesis is to describe the carbon fluxes during the APERO campaign and to quantify the processes regulating the attenuation of the export with depth by using a modelling approach. The focus will be specifically on two aspects: the description and understanding of **heterotrophic processes** constraining carbon fluxes between 200 and 1000m; the role of **eddies** (mesoscale: ~ 10-100 km) and **fronts** (sub-mesoscale: 1-10 km) on carbon production and fate in the deep ocean. These two elements are the central points of the sampling strategy of the APERO campaign.

Hypotheses and methodology
Two major assumptions have structured the APERO programme:

- Heterotrophic activity in the water column (responsible for the degradation of exported material) is strongly coupled to ecosystem diversity in the euphotic surface zone.
- The impact of small and medium scale, fully acknowledged for surface biological activity (primary and exported production), strongly constrains heterotrophic microbial biodiversity and zooplankton biodiversity in the meso-pelagic zone

Based on a rich variety of instrumental approaches (from the most classical to acoustics, imaging and molecular biology, accompanied by autonomous platforms - BGC Argo, gliders), APERO aims to verify these hypotheses during a dedicated cruise at the British PAP station (Porcupine Abyssal Plain: 16.5°W, 49°N) in the North East Atlantic.
The thesis is built around the use of a generic biogeochemical model PISCES, of intermediate complexity (used in IPCC simulations). It is characterised by a rather simple consideration of planktonic biodiversity and by a relatively complex dynamics of particles in the water column. Giving very satisfactory results in the productive surface layer, the processes in the mesopelagic zone are for the time being taken into account in a very simplified way, as are all the models used in climate simulations. One of the objectives of this thesis is to leverage the observations and experiments of APERO to better represent the degradation processes of biogenic matter in the water column. In addition to particles, the two compartments targeted are bacteria (not explicit in PISCES) and nekton/zooplankton.
The thesis will be carried out in three stages.

- *High resolution 3D 'baseline' simulation*. Using the ROMS/CROCO ocean circulation model, forcing the PISCES biogeochemical model, a high-resolution (~2 km) simulation of the Northeast Atlantic will be implemented. This simulation has a double objective: to provide a first high-resolution 3D description of the PAP area and contextualise the cruise, which is essential and extremely useful for the APERO community; to serve as a baseline simulation to estimate modifications/improvements of new parameterization.

- *Data and processes*. This stage is based on complementary work, in the framework of projects linked to APERO itself. Integrated directly into the APERO programme, the first work relates to the estimation of major carbon fluxes in the water column on the basis of the survey observations by inverse methods, which will make it possible, among other things, to constrain some of the parameters of PISCES. In parallel, in collaboration with the MIO (Marseille) within the framework of a Franco-German European project (MOOD), a study on the description of the functional biodiversity of bacteria will be carried out in order to better quantify their biodegradation activity within the particles. Finally, carried by LOCEAN, within the framework of an ANR project already funded, a study concerns the integration of the functional diversity of zooplankton/micronecton. Essential, this intermediate stage of synthesis aims at emphasizing the processes to be better parameterized or taken into account, because not included, in the PISCES model: this choice will be carried out by the PhD student in close relation with the researchers in charge of these studies.
- *High resolution 3D simulation with modified PISCES*. This simulation will allow to benchmark and quantify the modifications brought by updated parameterizations based on the considerations of the previous step. Sensitivity studies on certain parameters in a low-cost 1D vertical configuration could be considered at first

This thesis is an important outcome of APERO, providing an **integrated synthesis of the project**. One of the challenges of this work will be to reconcile the mismatch between **energy supply in the mesopelagic zone** and the **metabolic demand** of this zone. Specific attention is given to the **frontal and eddy scales**. Furthermore, beyond the thesis, these modifications in PISCES will be applied and evaluated in a global medium resolution (1/4°) configuration.

Scientific environment

This thesis will be carried out within LEMAR (Brest, France), for which the biological carbon pump is one of the priority themes. The modelling of biogeochemical cycles, coupled with ocean dynamics, is a central and well established activity. In addition, strong collaborations with ITM Atlantic have been developed on the use of AI in biogeochemical modelling (including data assimilation) and the PhD student will benefit from this collaboration. APERO, led by L. Memery, is a large-scale French ANR programme. Expertise on all aspects associated with the fate of biogenic matter in the water column is widely represented, and this thesis, considered as a synthesis of the project, will rely on the very strong dynamics within APERO.
APERO has a strong international component, with collaborations in many countries as part of the oceanographic cruise (Germany, USA, UK, Australia, Spain). It is part of the international consortium JETZON (https://jetzon.org/) and is closely linked to the American project EXPORTS, which visited the same area as APERO during a different period.

Candidate

The candidate should have a strong background in oceanography and biogeochemistry, and, if possible, expertise in modelling, or at least a strong affinity for the numerical approach. Although the project focuses on biogeochemical processes, the "mesoscale and sub-mesoscale ocean circulation" component is an important issue: the subject is highly interdisciplinary. An aptitude for communicating and exchanging with teams from different disciplines is an undeniable asset.