1. Titre :

Study of the biological carbon pump in the Southern Ocean and North Atlantic by a multi-tracer approach (^{234}Th, elemental, isotopic and lipid composition of suspended matter). (Biopump)

Unité de recherche et éventuellement l'équipe d'accueil :

Laboratoire des Sciences de l'Environnement Marin (LEMAR), UMR 6539.

Research teams: Chibido, Discovery, Panorama

2. Encadrement et contact pour les candidats qui souhaitent des informations :

Supervisor : P. Pondaven (HDR)

Co-supervisor : F. Planchon

Contact : F. Planchon

3. Vos coordonnées : dont email(s) de contact

Contact : F. Planchon

Tel : 02 98 49 86 25

Email : frederic.planchon@univ-brest.fr

4. Contexte, objectifs et intérêts scientifiques :

The exchange of CO_2 between the atmosphere and the ocean is an important process of the global carbon cycle and a key component of the Earth climate (Gruber et al., 2009; Sigman and Boyle, 2000). One process by which the ocean is able to remove CO_2 from the atmosphere and keeps it isolated over long periods is the biological carbon pump (BCP) (Volk and Hoffert, 1985). The BCP is a complex set of mechanisms that transfer organic carbon previously fixed by the biological activity in the surface to the ocean interior and even to the sediment (Boyd et al., 2019). Despite large scientific interest over the past few decades, the magnitude of this process still remains largely uncertain, and global estimates, ranging from 5 PgC yr^{-1} (Henson et al., 2011) to 15 PgC yr^{-1} (Laws et al., 2011), have an uncertainty range as large as the total amount of anthropogenic CO_2 emitted yearly (Friedlingstein et al., 2019). This uncertainty highlights the need for a better understanding of the BCP, which still has significant gaps. Filling these gaps is particularly relevant in the current context of climate change and will allow obtaining realistic predictions of its future evolution (Siegel et al., 2016).

The scientific questions around the BCP primarily concern the spatial and temporal coverage of in-situ observations that are still scarce for many ocean areas. This is particularly the case for the Southern Ocean, which is recognized as an important area of atmospheric CO_2 uptake, both natural and anthropogenic (Gruber et al., 2019). In the Southern Ocean, the majority of studies have focused on high productivity areas located near subantarctic islands (Crozet, Kerguelen, South Georgia) and the Antarctic continent (Peninsula) (Morris et al., 2007; Planchon et al., 2015; Savoye et al., 2008). In comparison, other biogeochemical provinces, including the subtropical zone, the circumpolar current frontal zone, or the high-nutrient, low-chlorophyll Antarctic zone (HNLC zone), have received much less attention even though the BCP have proven to be particularly efficient in some of these areas (Planchon et al., 2013). Scientific issues also concern the modes of transfer and transformation of

organic carbon. These pathways can be multiple and are governed by both the characteristics of phytoplankton communities that influence the sedimentation (calcified, silicified species) as well as interactions with higher trophic levels (micro-, meso-, macrozooplankton, bacteria) that contribute to transport/modify/degrade the organic matter as it transits through the water column (Boyd et al., 2019). This set of factors has been shown to be particularly variable in space and time and affects both the intensity and efficiency of the BCP.

In line with these issues, this PhD project intends to focus on the functioning of the BCP in two regions of the world ocean, the Southern Ocean (Indian sector) and the North Atlantic (Subarctic zone, Porcupine Abyssal Plain site). The objectives are to establish the relevant metrics to describe the export flux of organic carbon from the base of the photic layer to the upper mesopelagic zone (intensity, surface export and mesopelagic transfer efficiency) and to estimate the associated macronutrient fluxes (N/P/Si) to determine the biogeochemical impact of the biological pump (Lemaitre et al., 2016). In addition, we will also focus on the modes of transformation (bacterial degradation, grazing and excretion by zooplankton) and the nutritional quality (long-chain polyunsaturated fatty acids content) of the organic matter present at the surface and in the mesopelagic zone (Remize et al., 2021). To meet these objectives, the methodology employed will be based on a multi-tracer approach including the ^{234}Th deficit method for estimating export fluxes at different depth horizons from the base of the photic layer to the upper mesopelagic zone, combined with a detailed study of the elemental (C, N, P, BSi, $CaCO_3$, lithogenic material), isotopic ($\delta^{13}C$, $\delta^{15}N$) and lipid (fatty acids) composition of the size-fractionated suspended material (1-5 µm, 5-50 µm, >50 µm). This set of parameters will allow to evaluate the carbon export dynamics considering different scenarios of settling particles, to study the role of silicified and calcified organisms, and finally to characterize the transformation pathways of organic matter and their impact on the nutritional quality of the suspended matter. This methodology will be implemented in the framework of three international research programs dedicated to the study of the Southern Ocean and the North Atlantic: the ANR SWING project (South-West Indian Geotraces section, cruise conducted in Jan.-March 2021), the SOCARB project (funded by LEFE-CYBER, cruise scheduled in Jan-Feb 2023, Indian sector of the Southern Ocean) and the ANR APERO project (cruise scheduled in June-July 2023, North Atlantic, PAP site). As part of this PhD, the participation to the two sampling campaigns planned in 2023 is required.

This PhD project includes collaborations with different national (LOCEAN, C. Ridame; MIO, S. Jacquet) and international (CSIR, South Africa, S. Thomalla, T. Ryan-Keogh; University of Seville, Spain, M. Villa-Alfageme) laboratories in order to obtain complementary parameters related to the biological pump (net primary production, mesopelagic remineralization flux, export flux using the ^{210}Pb-^{210}Po method). Short stays in these partner laboratories could be considered.

5. Résumé du projet :

The exchange of CO_2 between the atmosphere and the ocean is an important process in the global carbon cycle and a key component of the earth climate. The biological carbon pump (BCP) is one of the processes that control this exchange. The BCP consists of a complex set of mechanisms that transfer carbon in organic form and associated biogenic elements (N/P/Si) from the surface layers to the interior ocean and even to the sediment. Despite a strong scientific interest during the last decades, the magnitude of this process and the pathways of transfer and transformation of organic carbon within the water column are still largely uncertain and still represent a major scientific challenge. In line with these general issues, this PhD intends to focus on the characteristics of the BCP in two oceanic regions considered as important areas of atmospheric CO_2 uptake (natural and anthropogenic), the Southern Ocean and the North Atlantic. The objectives are to establish the

characteristics of the biological pump for the element carbon (export flux, surface export efficiency and mesopelagic transfer), for the organic matter components (N, P) and for the biominerals associated with silicified (BSi) and calcified (CaCO3) organisms. In addition and as it can be deduced from the isotopic ($\delta^{13}C$, $\delta^{15}N$) and lipid (fatty acids) composition of organic matter, we will constrain the transformation pathways and the nutritional quality of the suspended matter present at the surface and transferred to the mesopelagic zone. This PhD project will be carried out in the framework of three international programs dedicated to the study of the Southern Ocean (ANR SWINGS project and LEFE-CYBER SOCARB project) and the North Atlantic (ANR APERO project) and will involve participation to two sampling campaigns at sea (Southern Ocean and North Atlantic).

6. Partenariat, éventuellement international :

This PhD project will be conducted in collaboration with national and international research laboratories in relation to the different research programs concerned:

- The CSIR (South Africa, S. Thomalla, T. Ryan-Keogh) for the ANR SWINGS project.
- The LOCEAN (France, C. Ridame) and the MIO (France, S. Jacquet) for the SOCARB project.
- The University of Sevilla (Spain, M. Villa-Alfageme) for the project APERO.

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