FINAL REPORT PROGRAM LEFE

Program LEFE/ CYBER	**SO-dust**: responses of phytoplankton to Patagonian dust input and anthropogenic changes in the future Southern Ocean	**Years 2021 - 2022**

PI: Marie BOYE, boye@ipgp.fr, Institut de physique du globe de Paris (UMR 7154)

Participating Laboratories: IPGP, ARTHERIS (CNRS UMR 6298), LEMAR (UMR 6539), LOCEAN (UMR 7159), IMEV (FR 3761), MIO (UMR 7294)

Contribution to: SOLAS, IMBER

Other funding sources: IDEX-Université Paris Cité

Context: Future projections indicate an intensification of Patagonian Fe-dust deposition in the Southern Ocean (SO), as well as acidification and warming of surface waters. However, the cumulative effects of these multifaceted changes on the phytoplankton community are not yet known, providing a major limitation for anticipating the future direction of the primary production in the SO.

Objectives: The SO-dust project aimed at evaluating the effects of anticipated anthropogenic changes (Fe dust input, pH, T) in the SO on the natural phytoplankton assemblage and on Antarctic key diatom species.

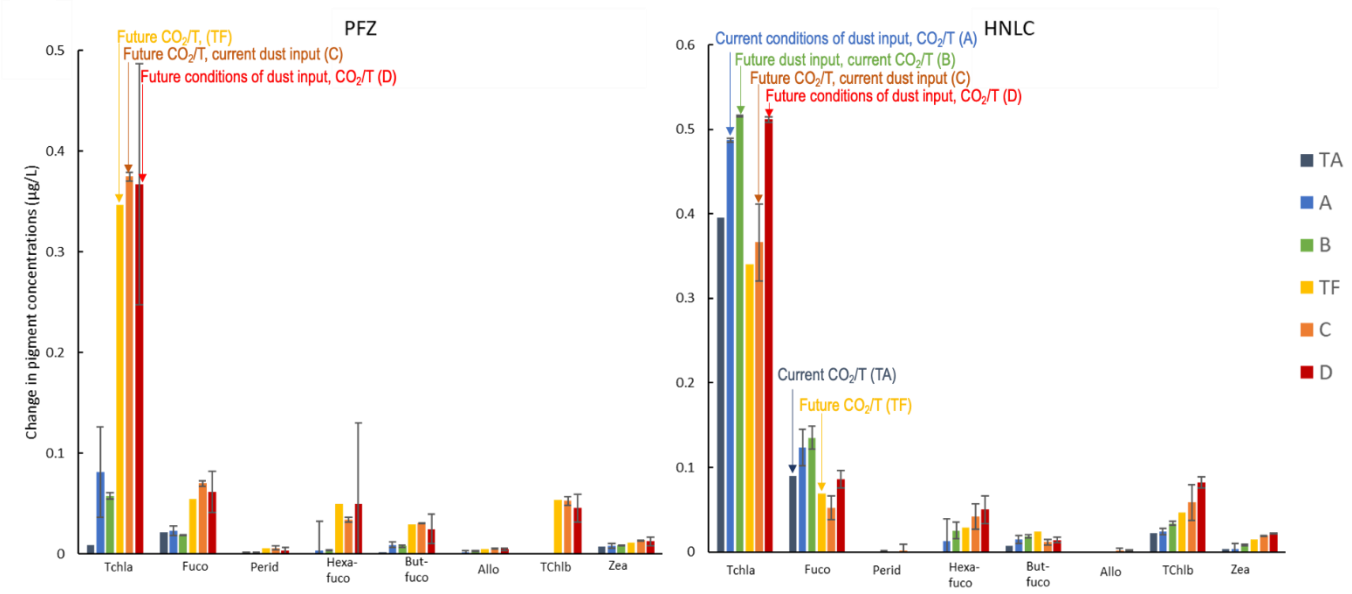
Main results: Onboard incubations were conducted during the Austral summer 2022 in the Indian sector of the SO aboard *R.V. Marion Dufresne* to test the impacts of anthropogenic changes projected to the 2100 horizon on the natural phytoplankton community in the Polar Frontal Zone (PFZ) and the HNLC area, where Fe is a limiting micronutrient, following a reduced factorial experimental design (with the input of dust as the target stressor, and ocean acidification and warming as a combined factor). Phytoplankton responses differed between biogeochemical provinces, mainly due to the variations in the diatom responses.

In the PFZ, the nano- (coccolithophorids) and pico- (cyanobacteria) phytoplankton growth and biomass were strongly stimulated under future warmer and more acidified conditions. Diatoms responded poorly to the addition of Fe dust alone, probably due to Si limitation during the post bloom summer period, when their biomass increased under warming and acidification, although much less than the smaller species (Figures 1 et 2).

In the HNLC area, future conditions also favoured smaller species (haptophytes and prochlorophytes) due to the cumulative positive effect of the multistressors. Fe dust input of increased the biomass of diatoms (mainly *F. kerguelensis*) under current T and pH conditions, probably due to the alleviation of Fe-limitation. In contrast, future conditions will put diatoms at a disadvantage compared to dust addition alone, likely due to the negative effect of acidification and warming counteracting the positive impact of Fe-dust input. In both provinces, future conditions could mainly benefit smaller species, while the relative abundance of phytoplankton biomass would not change under future SO, with diatoms still representing the largest biomass in the HNLC area and picophytoplankton in the PFZ during the austral summer. Future production of particulate organic carbon (POC) by photosynthesis was of the same order of magnitude as under current conditions in both areas. This suggests that primary production may not change in the future SO. However, the increase in the number and the length of long-chain diatoms observed in the HNLC area under future conditions may lead to an intensification of the biological gravitational pump and of POC export in the future.

In the laboratory, monospecific cultures in HNLC-sampled waters showed on the contrary that future changes in the different stressors could have a neutral cumulative effect on the growth of the Antarctic diatom *F. cylindrus* and a positive cumulative effect on its POC production.

The SO-dust project clearly demonstrated that future predictions are biased when only a subset of multi-stressors is considered, stressing the need to develop more experiments to study the cumulative effects of multifaceted changes on phytoplankton, at the scale of the assemblage and key species, in order to better anticipate the impact of anthropogenic changes on the primary production in the SO. These experiments should be accompanied by the development of new multi-stressor parameterisations in biogeochemical models.



***Impact of Patagonian Fe dust input, T and pH on phytoplankton biomass in the Southern Ocean* in the PFZ (Figure 1, left) and HNLC areas (Figure 2, right).:** changes in phytoplankton pigment concentrations between day 0 and day 5 under different scenarios (A, B, C, D, TA and TF) in the PFZ (left) and HNLC areas (right). *Zeaxanthin* refers to cyanobacteria and prochlorophytes, *TChl b* to prochlorophytes, *alloxanthin* to cryptophytes, *19'-butanoyloxyfucoxanthin* to haptophytes and pelagophytes, *19'-hexanoyloxyfucoxanthin* to haptophytes, *peridinin* to dinoflagellates, and *fucoxanthin* to diatoms (Uitz *et al*., 2006).

Future of the project: This project has served as a basis for a larger proposal submitted to the ANR. It will be in the background of the SOPHYAC-Light project (PI K. Sellegri) financed by LEFE in 2024-2025 and of the SOPHYAC campaign (chief scientist M. Boye) on board the *R.V. Marion Dufresne* in December 2024/February 2025.

Publications:

Demasy C., M. Boye, B. Lai, P. Burckel, Y. Feng, R. Losno, S. Borensztajn, P. Besson (*in rev*.) Iron dissolution from Patagonian dust in the Southern Ocean: under present and future conditions. In revision at *Frontiers in Marine Science* (special issue Aerosol Deposition in the Ocean: Drivers and Biogeochemical Effects).

Demasy C., M. Boye, A. Delisée, J.F. Maguer, E. Moreau (*subm*.) Responses of phytoplankton to Patagonian dust input and anthropogenic changes in the future Southern Ocean. Submitted to *Limnology & Oceanography*.

Moreau E., M. Boye et *al.* (*in prep*.) Effects of multi-faceted environmental changes in the Southern Ocean on a key Antarctic diatom. In preparation for submission to *JGR Oceans*.

Communications:

Boye M., C. Demasy, A. Delisée, E. Moreau, R. Losno, P. Burckel, J.F. Maguer, K. Leblanc, M. Thyssen (2024) Responses of phytoplankton to Patagonian dust input and anthropogenic changes in the future Southern Ocean. *Ocean Sciences 2024 conference*, 18-23 February 2024, New Orleans, USA. *Poster*

Boye M., C. Demasy *et al.* (2022) Responses of phytoplankton to Patagonian dust input and anthropogenic changes in the future Southern Ocean. *SOLAS Open Science Conference*, 25-29 September 2022, Cap Town, South Africa. *Poster*

Demasy, C., Boye, M., Burckel, P., Monna, F., Losno, R. (2021) Solubility of trace metals from Patagonian dust in the future Southern Ocean. *AGU Fall meeting*, 13-17 December 2021, New Orleans, USA. *Poster*

Demasy, C., Boye, M. (2021) Solubility and bioavailability of Patagonian dust in the future Southern Ocean. *SOLAS-France meeting*, March 2021, online meeting. *Talk*

Demasy, C., Boye, M. (2021) Dissolution of Patagonian dust in the future Southern Ocean. *Blowing South: Southern hemisphere dust symposium*, 9-10 November 2021, online meeting. *Talk*

Theses:

Clément Demasy (2019-2023) Solubility and bioavailability of Patagonian dust in the future Southern. *PhD thesis*, Université de Paris Cité, IPGP, 266 pp.

Emma Moreau (March-September 2022) Biogeochemical impacts of anthropogenic changes in the future Southern Ocean on micro-algae and key Antarctic diatoms. *Master 2 thesis* (Chemistry engineering and water and environmental management, Université de Limoges) and *Engineering School end of study report* (water engineering and environment, ENSIL-ENSCI, Limoges), 51 pp.

Ambroise Delisée (September 2021-February 2022) Study of the biogeochemical impacts of anthropogenic changes in the Southern Ocean on the phytoplankton assemblages during onboard incubations. *Licence 3*, Fundamental and biomedical sciences, Université de Paris Cité, 35 pp.

Lucie Morin (July 2023) Analyzes of nutrient salts, alkalinity and cell counts in microalgae incubation experiments. 3rd year *engineering student* in water and environmental engineering at ENSIL-ENSCI (Limoges).