SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Organic Particle Export, Remineralization and Advection in the North Atlantic mesopelagic layer
Computer Project Account:	spesiccf
Start Year - End Year :	2023 - 2023
Principal Investigator(s)	Etienne Tourigny
Affiliation/Address:	Barcelona Supercomputing Center – Earth Sciences Department Plaça Eusebi Güell, 1-3, 08034 Barcelona (Spain)
Other Researchers (Name/Affiliation):	Yohan Ruprich-Robert, Martí Galí, Joan Llort, Andrea Orihuela, Vladimir Lapin, Saskia Loosveldt, Valentina Sicardi, Raffaele Bernardello, Elif Yilmaz, Miguel Castrillo

Summary of project objectives

(10 lines max)

This activity takes place in the context of the Spanish National MICINN project OPERA (Organic Particle Export, Remineralization and Advection in the North Atlantic mesopelagic layer). Advances in observation of ocean particles with autonomous robots (biogeochemical Argo boats) and a recent key development in the representation of small particles in a state-of-the-art ocean biogeochemistry model (PISCESv2) now enable comprehensive estimates of mesopelagic particulate organic carbon (POC) cycling pathways. The aim of the OPERA project is to quantify mesopelagic particulate POC budgets and constrain their sources of uncertainty, including (1) biological processes represented in PISCESv2, (2) meteorological forcing of upper-ocean mixing and temperature, which exert a strong control on plankton productivity, and (3) the long-neglected role of the horizontal advection of suspended particles. The resources requested in this ECMWF special computing project will enable us to perform all the simulations planned in the OPERA project.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

A number of scientific-technical issues which required more time than initially anticipated have delayed progress, which explain why the computational resources have not all been used (35,4 M SBU out of 65M requested) during the 2023 period, although some were used in 2024. Significant time was required to develop the Auto-NEMO workflow manager suite using the Autosubmit software. The NEMO/PISCES namelists parameters had to be revised and adapted when upgrading to NEMO version 4.0.6, which is significantly different from the 3.6 version used up to now by the BSC. Also, porting the model to the ECMWF HPC2020 supercomputer required some time to accomplish. The development of "phyto restoring" took a considerable amount of time and effort. Finally, we were not able to perform the simulations with NAO+ and NAO- perturbed forcings due to lack of time. Instead we are currently doing an analysis of interannual variability by comparing years of NAO+/- during the period 1958-2019.

Experience with the Special Project framework

The overall experience with the Special Project framework is very positive.

Summary of results

(This section should comprise up to 10 pages, reflecting the complexity and duration of the project, and can be replaced by a short summary plus an existing scientific report on the project.)

We successfully performed the spinup simulations forced by the JRA-55 atmospheric reanalysis as well as the simulations with restoring the surface POC field of the model. We have also performed the sensitivity experiments by perturbing these processes in our model within a range of realistic observed values. As explained above we were not able to perform the NAO+/NAO- perturbed forcing experiments.

We have analysed the Annual contribution of ocean BGC and physical processes to small POC budgets (as shown in Figure 1). This allowed us to identify the regions and subregions characterized by distinct processes such as gravitational sinking, vertical diffusion, fragmentation, etc.

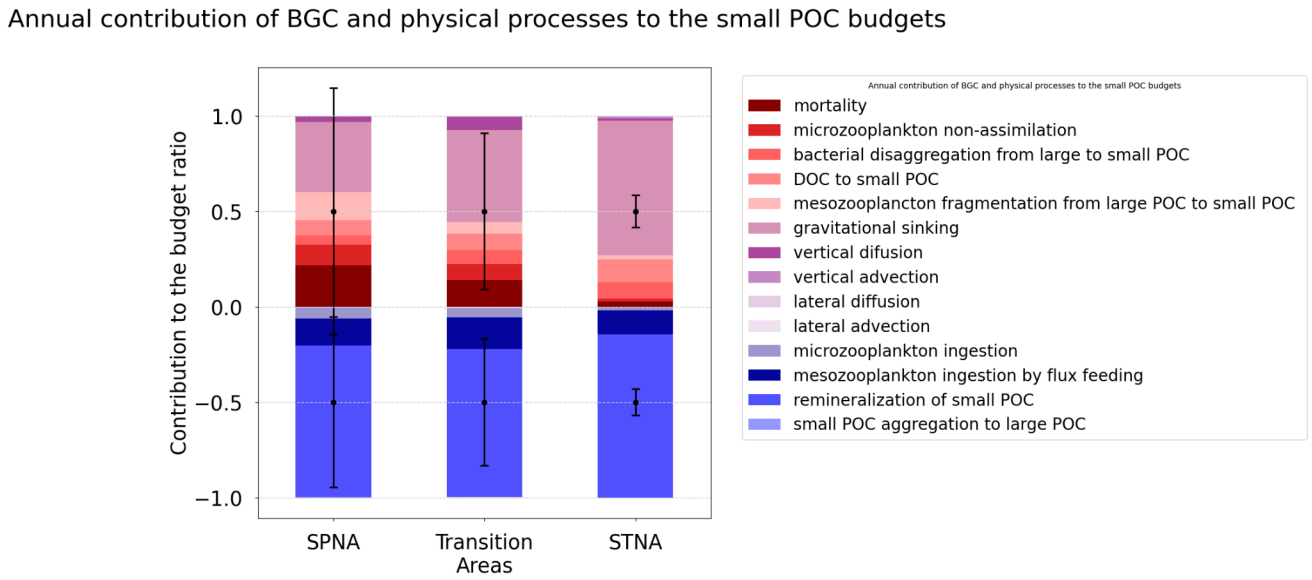

Figure 1: Normalized annual contribution (climatology of period 1998-2019) of all processes (production, consumption and transport) of POC in the mesopelagic layer in subpolar (SPNA), transition and subtropical (STNA) regions.

We have quantified the effect of surface restoring of NPP from satellite observations on simulated NPP (Figure 2) as well as compared POC concentrations in the model to observations based on estimates based on satellite data and BGC-Argo float data (Figure 3).

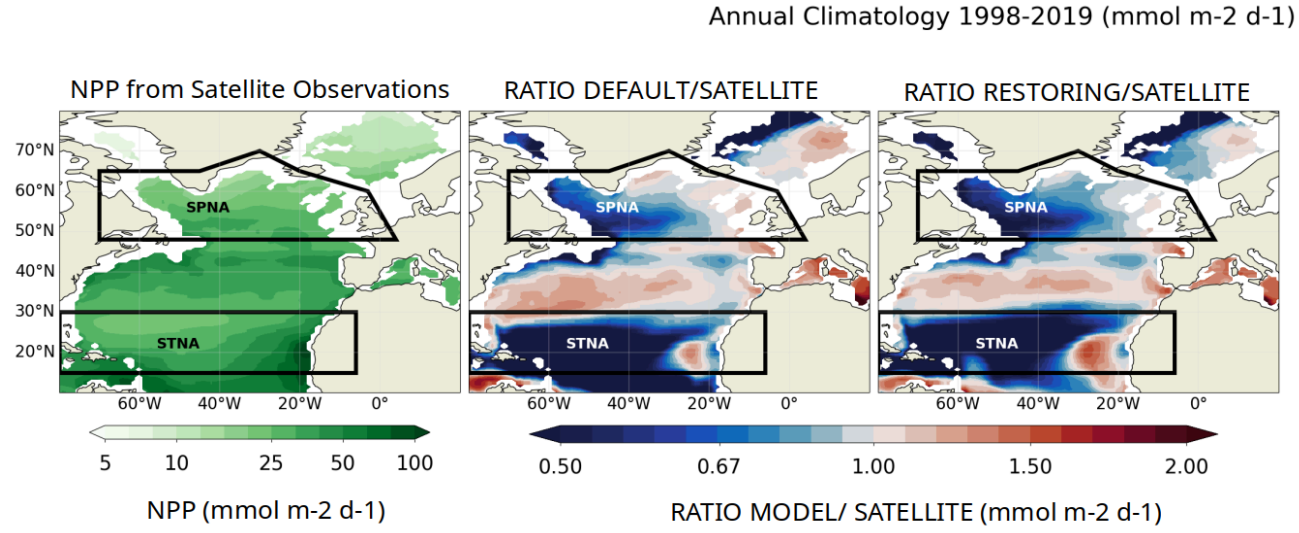

Figure 2: NPP from satellite observations (climatology of period 1998-2019) compared to model results without and with surface restoring.

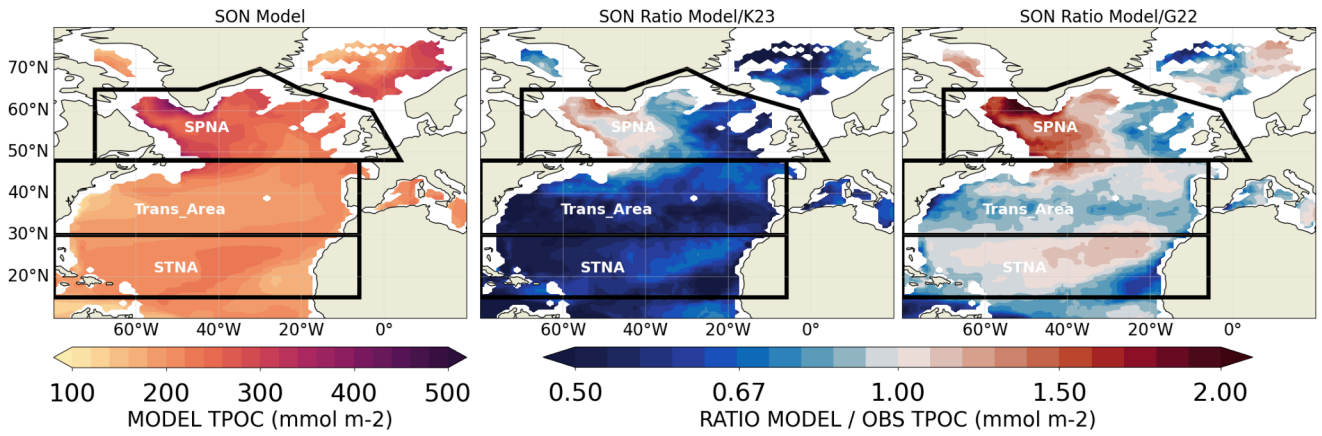

Figure 3: Maps of POC concentrations in the model (left) and the ratio to observations based on estimates based on satellite data and BGC-Argo float data (K23: Koestner et al., 2024; G22: Galí et al., 2022)

This special project has contributed to make a number of advances in the OPERA project : we have improved the understanding of POC dynamics in the mesopelagic layer in the North Atlantic. The mesopelagic ecosystem depends on biological transformation and physical transport of organic matter produced by photosynthesis in the superficial layers of the ocean. However, the lack of observations at appropriate temporal and spatial scales, as well as conceptual flaws, have historically hindered estimates of POC balances. In OPERA we have exploited the capacity of numerical models to estimate 3D balances of POC with high temporal frequency, comparing them to in situ data obtained from satellites and subaquatic robots. The main findings of OPERA are:

i. Small POC (SPOC, with size less than 100 µm) represents around 85% of total POC in mesopelagic waters. The majority of SPOC is formed of biodetritus.

ii. POC balances vary greatly depending on particle size. For large particles (>100 µm) sedimentation is compensated by bacterial remineralization and zooplancton ingestion in a period of several weeks.

iii. SPOC balances do not follow this classical paradigm and contributions from zooplancton activity (ingestion and excretion, fragmentation of large detritus) and transport from diffusion and advection dominate over gravitational contributions.

iv. SPOC balances show a marked latitudinal gradient. The subpolar zone is characterized by a strong seasonal cycle and interannual variability, which propagate from the epipelagic to mesopelagic ecosystem.

v. Contributions and consumption of SPOC in the subpolar zone are greater, more diverse and more variable than in temperate and tropical latitudes. Thus, SPOC balances cannot be closed in the timescale of weeks or months as they are non-stationary: they must be quantified in the annual timescale or greater. This uncertainty has historically impeded the study of POC balances and of mesopelagic metabolism.

Related to this project are a number of papers currently under preparation:

- Patterns and drivers of the mesopelagic POC budget in the North Atlantic Ocean in PISCESv2 (submission scheduled for October)
- Constraining POC budget uncertainties in NEMO4-PISCESv2 through sea surface restoring of remotely-sensed phytoplankton carbon biomass
- Assessing uncertainties in POC dynamics in the temperate North Atlantic using bio-optical glider observations and PISCESv2 and MEDUSA2.0 simulations

- Organic particle injection by deep convection in the northwest Atlantic subpolar gyre (submission planned November)

References:

Galí et al. 2022 doi.org/10.5194/bg-19-1245-2022
Falls et al. 2022 doi.org/10.5194/gmd-15-5713-2022
Koestner et al. 2024 doi.org/10.3389/fmars.2023.1197953

List of publications/reports from the project with complete references

Galí, M., Falls, M., Claustre, H., Aumont, O., & Bernardello, R. (2022). Bridging the gaps between particulate backscattering measurements and modeled particulate organic carbon in the ocean. Biogeosciences, 19(4), 1245-1275.

Falls, M., Bernardello, R., Castrillo, M., Acosta, M., Llort, J., & Galí, M. (2022). Use of genetic algorithms for ocean model parameter optimisation: a case study using PISCES-v2_RC for North Atlantic particulate organic carbon. Geoscientific Model Development, 15(14), 5713-5737.

M. Andrea Orihuela-García, Martí Galí, Yohan Ruprich-Robert, Vladimir Lapin, Saskia Loosveldt Tomas, Marga Samso. Mesopelagic Particulate Organic Carbon (POC): distribution, budgets, main drivers and uncertainties of model performance in the North Atlantic, 2024. Ocean Sciences Meeting, 18-24 February 2024, New Orleans, USA.

Galí, M., Yohan Ruprich-Robert. INFORME FINAL, PROYECTOS DE I+D+i. MODALIDADES "GENERACIÓN DEL CONOCIMIENTO" Y "RETOS INVESTIGACIÓN" 2019. OPERA (Organic Particle Export, Remineralization and Advection in the North Atlantic mesopelagic layer).

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

The results of this work will enable us to improve the OBGC representation in the next version of EC-Earth with an updated version of NEMO (4.2.2). This will be helpful for another special project spnltune, in which the PI is involved.