IDYPOP

Impact de la DYnamique à petite et moyenne échelles sur le devenir des Particules exportées dans l'Océan Profond

Impact of the meso and submesoscale dynamics on the fate of exported particles in the deep ocean

Research teams : LEMAR/IUEM – LOPS/IUEM (Université Bretagne Occidentale).

Technopôle Brest Iroise, 29280 Plouzané, France

Supervisor : Laurent Mémery (LEMAR) , laurent.memery@univ-brest.fr ; (33) 2 98 49 88 97

Co-supervisor : Jonathan Gula (LOPS) : Jonathan.gula@univ-brest.fr

Adrian Martin (NOCS, Southampton, UK) : adrian.martin@noc.ac.uk

Preliminary remark: The study is strongly inter disciplinary. It is driven by issues in marine biogeochemistry (Biological Carbon Pump), but is clearly oriented towards problems in ocean physical dynamics at meso and submesoscales.

Scientific background

The Earth climate deeply depends on atmospheric concentrations of greenhouse gases, such as CO_2. The CO_2 flux towards the ocean is partly regulated by biological activity (photosynthesis). A variable ratio of the biogenic matter produced at the surface is exported towards the deep ocean where it is almost entirely oxidized. Along with dissolved carbon production, this oxidation takes place at variable depths, which constrains the time during which CO_2 is isolated from the atmosphere (between several months up to tens, or hundreds, of years). It is therefore fundamental to correctly describe the processes driving the transport and the transformation of this export biogenic matter in the water column in order to better quantify the carbon storage in the ocean.

Mostly through particles, the export flux is historically estimated from observations using sediment trap moorings at depths from 200 to 3000 m during periods of several days to one/two years (with a time resolution from several hours to a week). These observations are interpreted using a very simple underlying statement: the collected matter comes vertically from the surface, e.g. the ocean is one-dimensional. Yet, not only the ocean is a tridimensional fluid (with a strong horizontal component), which is variable with time, but it is inherently turbulent (fig. 1).

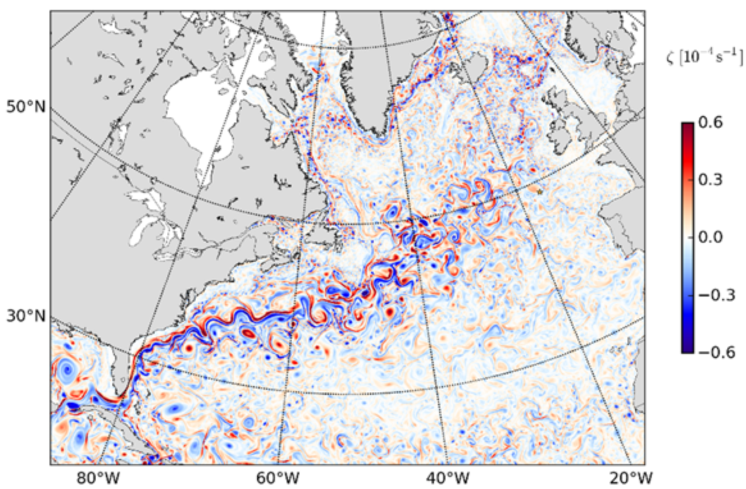


Figure 1: Relative vorticity at the ocean surface in a simulation of the North Atlantic Ocean.

The ocean has a very energetic mesoscale (horizontal scale about 30 -200 km) and submesoscale (1-30 km) eddy field. Meso and submesoscale eddies can convey particles on long distances and modify their vertical and horizontal distributions. In fact, sediment traps sample a more or less large and heterogeneous area of the ocean surface.

Furthermore, the meso- and submesoscale currents play an important role as they not only create a very strong heterogeneity on the particle production at the surface (fig. 2), but they also drive the vertical velocities that control for the most part exchanges between the surface layer and the ocean interior. Submesoscale instabilities act on average to restratify the mixed-layer, which could potentially inhibit vertical exchanges. However the very large vertical velocities generated at the submesoscale fronts and filaments are very efficient to flux tracers through the base of the mixed-layer, such that the net impact of submesoscale currents may be to enhance both upward nutrient inputs into the surface layer (fertilizing effect on primary production), and tracer and particle subduction from the surface layer to the interior (export). This result remains to be carefully quantified in fully realistic conditions and under different dynamical regimes. The impact on tracer subduction may depend on the type of mesoscale and submesoscale processes dominating the upper ocean dynamics.

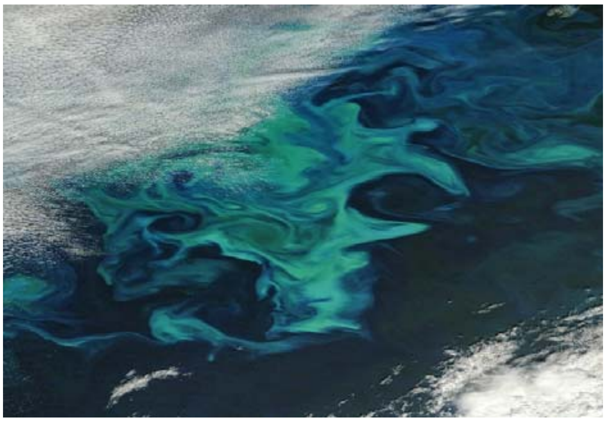
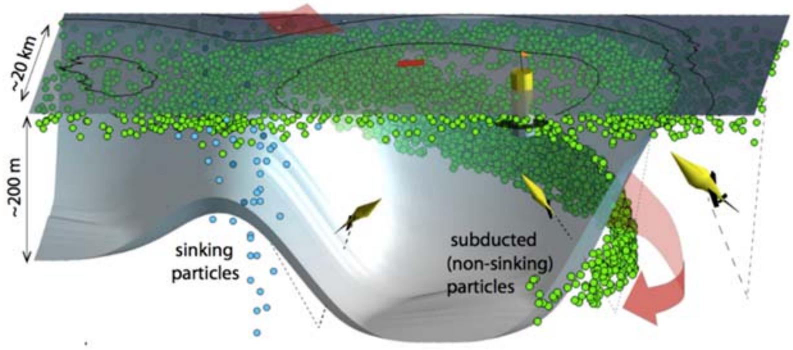


Figure 2: Phytoplankton bloom in the North Atlantic, south of Ireland, observed with the Terra NASA satellite.

This complexity is intensified by sinking rates varying by two orders of magnitude (from 10 to 500 m/day), the smallest being able to be advected on long distances before reaching the trap (fig. 3). Besides, these velocities lead to time lags between the surface source and the deep ocean. Finally, within the water column, particles interact (aggregation, breaking up, …), which implies that the size spectra, and thus the sinking velocities, vary with depth.

Figure 3: Diagram showing the impact of the advection generated by an eddy on the sinking of particles (from Denver et al, 2017)



Objectives

Based on a modelling approach, this work aims at exploring and quantifying the (de)correlation of the particle flux sampled in the traps in the deep ocean with the spatio temporal distribution of surface particles, generated by biological production. The estimation of the representativeness of a punctual observation of a sediment trap makes the general framework of this study (e.g. what is the surface ocean area sampled by a sediment trap and what is the time lag distribution between surface production and deep observation ?). Several more specific issues are addressed: what is the impact of small scale heterogeneity of the surface production and of the transport in the sub surface layers on the deep particle flux? How do interactions between particles and small - scale dynamics modify the particle dispersion and spectra at depth, compared to the particle distribution at the surface? Is it possible to regionalize the surface – deep (de)coupling of particle distribution in terms of the ocean dynamics and come up with relations between the characteristics of the surface turbulence regime and the particle dispersion and spectra at depth?

This work will rely on a high resolution (1 km) simulation of the North Atlantic and local simulations (~ 200 m), resolving the small scales. The basin scale simulation will help in defining the characteristics of different dynamical and biological production regimes (North-East Atlantic, African upwelling, Gulf Stream, Sargasso Sea, Labrador Sea, etc.), where high resolution local (~ 400x400 km) simulations of particle distributions will be considered. They will use a code of Lagrangian trajectories, suited for particles, e.g. taking into account behavior rules (sinking, particle interaction). In order to take into account the role of small scales on the surface heterogeneity of production and particle distributions, either empirical relationships linking particle size spectra and hydro-dynamical patterns (such as horizontal temperature gradients) will be used, or a simplified NPD (Nutrient – Phytoplancton – Detritus) model will be coupled to the circulation model. The particle interactions will possibly be considered with relationships of variable complexity: this will give some clues about the role of this particle dynamics on the decorrelation between the surface signal and the signal in the deep ocean.

Programs and collaborations

This study is directly linked to sea cruises on the Biological Carbon Pump (BCP), undertaken by a wide international community (US, UK, D, F, Es) during the years 2010s. It is more specifically focused on the North Atlantic ocean (French program APERO ***A****ssessing marine biogenic matter* ***P****roduction,* ***E****xport and* ***R****emineralisation : from the surface to the dark* ***O****cean* and US program EXPORTS*)*. Based on a strong collaboration between Southampton and Brest, the APERO cruise takes place at the British long - term observatory PAP (SW of Ireland). More generally, these cruises update the BCP concept by using new devices enabling to sample the ocean at very high resolution, not only for physical parameters (velocities, temperature, salinity), but also for several biogeochemical parameters, such as fluorescence (chlorophyll), particle concentrations and spectra (with optical devices): this modelling study is therefore strongly associated to in situ observations. Moreover, this work has potential impact on the use of surface satellite data (which give information on chlorophyll and particles with sea color data and mesoscale dynamics with altimetry data) in order to constrain the fate of carbon in the water column. Finally, this process study will make possible a better evaluation and the calibration of models used in Earth System simulations in the framework of Climate Change (IPCC).

About the applicant

This project is situated at the intersection of physical oceanography and biogeochemsitry, and makes the connection between modelling and observation. Therefore, the applicant should be open to inter disciplinary and group work. Excellent knowledge in oceanography, more specifically in physical oceanography, is mandatory. Moreover, he/she should have an expertise in scientific computing.