The nonhomogeneous vertical distribution of small neutrally buoyant particles in a convective ocean-mixed-layer model

Université de Lille

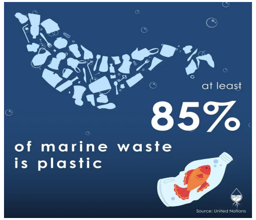
Luz Andrea SILVA TORRES.[1], Stefano BERTI[1], Enrico Calzavarini[1]

1 Univ. Lille, ULR 7512, Unité de Mécanique de Lille Joseph Boussinesq (UML), F-59000 Lille, France

Unité Mécanique Lille UML J. Boussinesq

We aim to study the transport and vertical concentration profiles of neutrally buoyant microplastics through direct numerical simulations of small particles in an inhomogeneous turbulent flow.

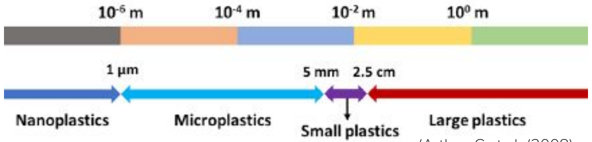
SCIENTIFIC CONTEXT



◆ Plastic pollution

- It is one of the biggest threats to the marine environment
- Microplastic transport is complex, involving biological, physical, and chemical processes across multiple scales.

◆ What are microplastics?



(Arthur, C et al. (2008)

◆ Neutrally buoyant particles

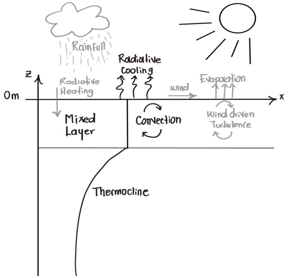
$$\rho_p = \rho_F$$

- They are particles whose density is equal to that of the surrounding fluid.
- Some of the most common plastics in the ocean have a density ratio (ρ_p/ρ_F) close to 1.

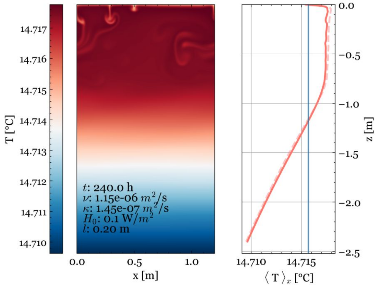
APPROACH AND MODEL

A model system for ocean Mixed Layer

Bhamidipati, N. et al (2020)

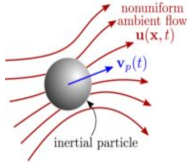


- The ocean Mixed Layer forms due to wind and surface radiation, leading to homogeneous seawater properties through mixing.
- We model this using a 2D convective mixed layer governed by the Boussinesq equations.



Particle dynamics

We use the Maxey-Riley-Gatignol equation that takes into account the effects of:



◆ Added mass force
◆ Buoyancy force
◆ Drag force

we derive a simplified **model for neutrally buoyant particle dynamics in a stratified flow:**

$$\dot{\mathbf{x}} = \mathbf{v}(\mathbf{x}(t), t)$$

$$\mathbf{v} = \mathbf{u} + \frac{2}{3}\tau_p \alpha (T - T_0)\left(\mathbf{g} - \frac{D\mathbf{u}}{Dt}\right)$$

where

$\tau_p = \frac{a}{3\nu}$: Particle response time

α : Thermal expansion coefficient for sea water

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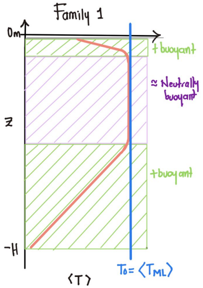
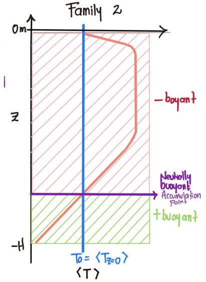
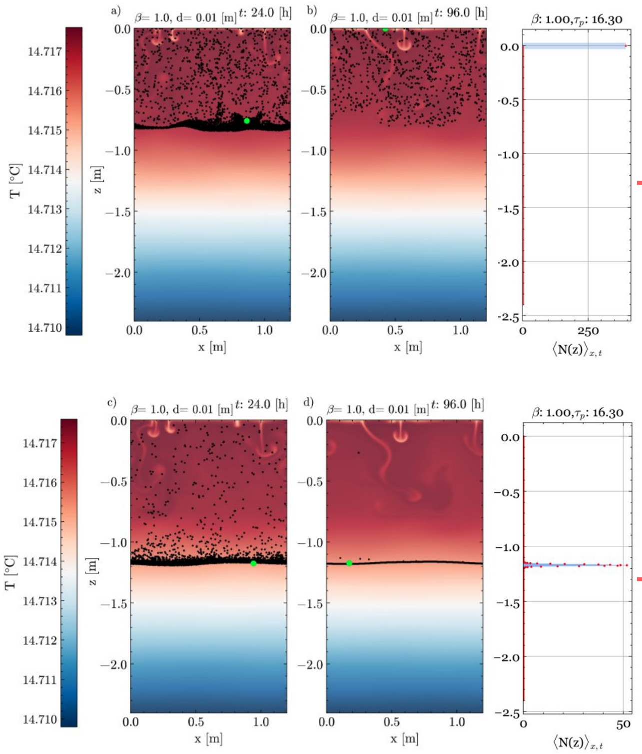
KEY RESULTS





Evolution of temperature field and particle distribution

Concentration profiles at steady state



The accumulation of particles is influenced by variations in water temperature

We derive a theoretical relation to predict the concentration profiles

We start with the conservation of particle mass

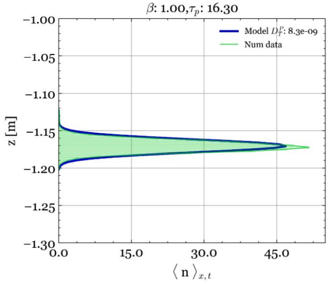
$$\frac{\partial n}{\partial t} + \nabla \cdot (n\mathbf{v}) = 0$$

For each quantity, we average over the x direction and decompose our quantities into mean and fluctuating components

$$\frac{\partial}{\partial t}\langle n\rangle_x - \frac{2}{3}\tau_p \alpha g \frac{\partial}{\partial z}\langle n\rangle_x \langle T - T_0\rangle_x - \frac{\partial}{\partial z}\left(D_T^P(z)\frac{\partial}{\partial z}\langle n\rangle_x\right) = 0$$

FInally we get:

$$\langle n\rangle_{x,t} = \frac{1}{\int_0^H e^{-\frac{2}{3}\frac{\alpha\tau_p g}{D_T^P}\int_0^{z'}\langle T-T_0\rangle_{x,t}dz'}dz}\, e^{-\frac{2}{3}\frac{\alpha\tau_p g}{D_T^P}\int_0^{z'}\langle T-T_0\rangle_{x,t}dz'}$$



The model accurately predicts particle concentration below the mixed layer, where gravity and eddy diffusivity control accumulation and distribution.