

# A numerical study on the vertical transport of microplastics influenced by biological processes

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A numerical study on the vertical transport of microplastics influenced by biological processes

(生物過程を考慮した浮遊マイクロプラスチックの鉛直輸送に関する数値的研究)

区分：甲

### 主論文の要約

Marine microplastics have been collected mainly by horizontally towed nets near the sea surface and the suspended amount has been measured. This is because polyolefin polymers such as polyethylene and polypropylene have a lower density than seawater and can drift in the ocean for long periods, so it seemed reasonable to limit the observation layer to the ocean surface layer. However, recent observations have revealed that high concentrations of microplastics, comparable to those in the sea surface, can be observed in the subsurface layer at depths of several tens of meters. This is because suspended microplastics of polyolefin increase their density and settle down due to biological processes such as biofouling and absorption into aggregates by phytoplankton. In this study, we clarified the vertical transport process of suspended microplastics in a system assuming ocean turbulence and biological process, the absorption into aggregates.

This thesis is composed of four Chapters. Chapter 1 introduces the background of this study as in the previous paragraph, then followed by Chapters 2 and 3 explaining the modeling studies in detail, and finally by Chapter 4 which summarizes the results from the present study.

In Chapter 2, we quantified the settling velocity of buoyant marine microplastics absorbed into phytoplankton (especially diatom) aggregates, which are heavier than seawater. The two-dimensional numerical particle tracking model (PTM) was developed to describe these particles and their interaction in ocean turbulence. In this PTM, every phytoplankton and aggregate particles have an aggregation radius determined through trial and error. When microplastic and phytoplankton particles approach closer than this radius, a single aggregate particle containing these particles was produced. In the case of high phytoplankton concentrations commonly observed in spring/fall blooms and red tides, the suspended microplastics absorbed into phytoplankton aggregates settle down at a vertical velocity higher than  $O(10^{-5}-10^{-4})$  m/s

typically observed in the actual ocean. On the other hand, only the equilibrium between the rise velocity of buoyant microplastic particles and vertical diffusion due to ocean turbulence could not reproduce the observed vertical distribution of microplastics. Therefore, it is suggested that buoyant microplastics would be absorbed into phytoplankton aggregates and settle down in the actual ocean. Also suggested is a feedback loop in which settling velocities of phytoplankton aggregates containing microplastics depend on microplastic concentrations in the surrounding water.

In Chapter 3, we interpreted the results of an observation at the coastal ocean, where high concentrations of suspended microplastics were not located near the sea surface but just above the seasonal thermocline (pycnocline). In general, a high concentration area of phytoplankton (subsurface chlorophyll maximum; SCM) is formed in the vicinity of the thermocline in the coastal ocean. Therefore, it is suggested that the SCM is related to form the subsurface plastic maximum (SPM). The SCM is formed around the pycnocline, where both light intensity and nutrients from the bottom layer are abundant significantly, and phytoplankton aggregation frequently occurs in the vicinity of the SCM. Therefore, we assumed that the large amount of microplastics are absorbed into aggregates around SCM and develop SPM around the pycnocline. To investigate the relationship between SCM and SPM, the life cycle of phytoplankton (Nutrient-Phytoplankton-Detritus cycle; NPD cycle) was incorporated into the PTM developed in Chapter 2. To reproduce the NPD cycle, we used the Lagrangian marine ecosystem model by Kida and Ito (2017). Their model represents the growth of phytoplankton ingesting nutrients (this means transformation from N particle to P particle), conversion to detritus due to mortality (from P to D), and return to nutrients due to decomposition of detritus (from D to N), respectively. In this study, a surface mixed layer with the pycnocline as the lower boundary was set in the PTM to reproduce the SCM. The temporal variation of the number of NPD particles in the PTM showed a quasi-steady state 10 days after the start of the calculation. Similar to the real ocean, the SCM was formed just above the pycnocline in the model, and microplastic particles were trapped by phytoplankton aggregates around there. However, in the present model, suspended microplastic particles smaller than 200  $\mu\text{m}$  remained at the top of the surface mixed layer, and as a result, the SPM around the pycnocline was not clearly formed. In the real ocean, it is suggested that microplastics, especially those suspended near the sea surface, are released into the air with wave-induced spray emission. If this is the case, microplastics cannot remain in the surface mixed layer unless they are absorbed into phytoplankton aggregates.