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

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Name

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（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）

Title

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Category

論　文　内　容　の　要　旨

Thesis Summary

Plastic debris fragmented to pieces smaller than 5 mm in the diameter is currently referred to as microplastics. Besides microplastics generated on land via degradation and fragmentation, plastic debris discharged into the ocean through various pathways was fragmented to microplastics in preserving the total mass (or volume, assuming a constant density) in the world's oceans. However, there may be a large gap between the total mass of plastic debris potentially released into the oceans and mass of ocean plastic debris including microplastics observed to date. This 'missing plastics' paradox is particularly evident in the size distribution of the observed microplastics especially for particle sizes below 300 μm in the diameter. There are several possible causes for a significant amount of missing microplastics. The causes given in previous studies were, for examples, small microplastics less buoyant insufficient for staying in the surface layer where they can be collected by surface net towing, ingestion by marine organisms and/or absorption into diatom aggregates, and further fragmentation to small microplastics passing through mesh opening of the net. The mesh size of neuston nets commonly used for microplastic observations is approximately 330 μm, and so there is a possibility that some of diatom species may pass through the mesh opening even if microplastics are absorbed into their aggregates.

In this study, we focus on phytoplankton (assuming diatoms) aggregates incorporated into biological processes, by which the phytoplankton causes aggregation that entraps the microplastics. The process results in an increase in density sufficient to divert the buoyancy of the microplastics vertically downward and thus transport them toward the bottom layer. The reason for focusing on this process is based on the results of vertical observations of microplastics along the Korean coasts in Song et al. (2018). Since most of the microplastics have a smaller density than seawater, it is reasonable to consider that most of them are floating at the sea surface. Nonetheless, in their observations, a large amount of microplastics were found even in the middle layer below the seasonal thermocline under conditions with wind speeds higher than 3 m/s. Since the vertical distribution could not be explained only by physical processes that reproduced turbulent mixing associated with wind waves, it was considered that transport by biological processes played a role to transport theses subsurface microplastics downward. The observed data were used to plot the distribution of particle size at depths, and it was confirmed that microplastics with a particle size smaller than 300 μm were widely distributed from the sea surface to the middle layer, regardless of wind speed. Furthermore, the results for wind speeds higher than 3 m/s showed that microplastics below this size were not existent at the sea surface, but had a maximum just above the thermocline. The suggestion is therefore that the subsurface chlorophyll maximum (SCM), which is frequently observed in coastal waters, is related to the formation of this subsurface plastic maximum (SPM) of the microplastic concentrations. The aggregation of phytoplankton occurs frequently around the SCM because a large amount of phytoplankton are suspended, and so we hypothesized that microplastics were also trapped around the SCM via absorption into the aggregates. In this study, therefore, we attempted to reproduce the horizontal and vertical

transport of microplastics using a numerical model to quantitatively examine the influence of biological processes on the vertical distribution of microplastics. A vertical two-dimensional model was employed in this study because the aggregation occurs in the model according to relative positions of phytoplankton and microplastic particles. All models developed in this study were particle tracking model (PTM) which reproduced the interaction between microplastics and phytoplankton particles.

First, to quantify the settling velocity of upward buoyant marine microplastics absorbed by phytoplankton aggregates, which are heavier than seawater, a PTM was developed to represent the motion and interaction of both particles in ocean turbulence. The model incorporates in silico phytoplankton, and phytoplankton particles located closer than the cohesion radius determined by trial and error form aggregate particles. Microplastic particles located inside the cohesion radius are absorbed by the aggregate particles. Assuming phytoplankton concentrations in this model to the extent observed in spring and fall blooms and red tides, phytoplankton aggregates reproduced the settling of microplastics with vertical velocity O (10-5 to 10-4) m/s, which is universally observed in oceans. On the other hand, only the equilibrium between the upward velocity of microplastic particles, which are not incorporated into aggregates, and the vertical diffusion due to ocean turbulence did not reproduce the abundance of microplastics observed in the sub-surface layer. Therefore, ocean-suspended microplastics are considered to settle toward the deeper layers in the real ocean by absorption into phytoplankton aggregates. A feedback loop was also suggested for the sedimentation rate of phytoplankton aggregates, which depends on the amount of microplastics in the surrounding environment. However, to confirm this loop, the effect of ocean circulation other than ocean turbulence alone and the formulation of settling velocity of phytoplankton aggregation containing microplastics of small specific gravity need to be reexamined.

Second, to investigate the relationship between SCM and SPM, we then incorporated the phytoplankton life cycle into the above model. Namely, the Lagrangian ocean ecosystem model developed by Kida and Ito (2017) was used to incorporate phytoplankton development, their mortality, and decomposition processes. This is a PTM that represents the behavior and morphological changes among nutrients (N), phytoplankton (P), and detritus (D) particles. In this study, we hypothesized that SCMs are formed when phytoplankton float at the depth where nutrients and light intensity are both sufficient for photosynthesis. Thereby, the stratification such that the surface mixed layer with 20-m thickness was bounded by the thermocline over the subsurface homogeneous layer was employed in the PTM to reproduce the SCM just above the thermocline. The temporal variation in the number of NPD particles in this PTM showed that a quasi-steady state was accomplished within 10 days after the begging of the calculation, which was the state that we analyzed. In the depth-time distribution of P particle numbers demonstrated that SCM (dense concentration of phytoplankton) was clearly formed just above the thermocline, as we observed in the nature. In the PTM results, it was found that the dense concentrations of aggregated P particles (hence, microplastics included) were also existent around the SCM. In the particle size distribution of microplastics at depths, it was confirmed that many microplastics smaller than 200 μm were suspended in the surface mixed layer. However, the SPM was not persistently confirmed in small microplastics just above the thermocline even in the case with wind speeds higher than 3 m/s. Nevertheless, the subsurface maxima of microplastics were observed in the model, suggesting that they were formed by the sedimentation process of sporadic aggregates. It was suggested that small microplastics drifted in the surface mixed layer are removed in the actual ocean unless they are absorbed in the phytoplankton aggregates.