Microscale spatial variability of plankton and new closure ecosystem models coupled with a 1D physical model

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Recent development of measurement technologies allows us to investigate microscale distributions of plankton. For instance, Doubell et al. (2009) employed the microstructure profiler TurboMAP-L equipped with a laser fluorescence probe and observed highly intermittent spatial variability of phytoplankton at a mm scale. The phytoplankton distributions acquired by the laser probe were patchier and more intermittent than those obtained concurrently by a conventional light emitting diode (LED) probe that resolves a cm scale. However, 1-m averaged profiles were consistent for both probes. This indicates that the intense fluorescence peaks are not noise signals but are due to highly concentrated phytoplankton aggregates. The results from high-resolution in situ observations demonstrate that microscale plankton communities and organic/inorganic particles play a vital role in ocean ecosystem dynamics. It has thus become urgent to develop a new ecosystem model which takes the observed microscale variability into account.
Mandal et al. (2014) developed a simple nutrient-phytoplankton (NP) ecosystem model by applying the closure approach, which decomposes each variable (N, P) into mean (N_0, P_0) and fluctuating component (N', P'). The NP closure ecosystem model consists of five variables: mean N_0 and P_0, variance $<N'^2>$ and $<P'^2>$, and covariance $<N'P'>$, where angle brackets denote ensemble averaging. To evaluate the magnitude of fluctuating components in the ecosystem, Mandal et al. (2014) defined a non-dimensional parameter $\beta = B/A^2$, where $A = N_0 + P_0$ is the total mean and $B = <N'^2> + <P'^2> + 2<N'P'>$ is the total variability. Mandal et al. (2014) performed dimensionless time-series simulations and found that the growth of P_0 was enhanced under high variability (high β) conditions. Subsequently, Priyadarshi et al. (2016) developed a new nutrient-phytoplankton-zooplankton (NPZ) closure model. The results of dimensionless time-series analyses showed that zooplankton biomass increased with increasing variability; on the other hand, phytoplankton biomass decreased. This suggests that trophic transfer in the food chain becomes more efficient under high variability conditions. However, these analyses excluded the effect of physical processes, for instance diurnal/seasonal variation of solar insolation, water movement, and stratification. To investigate the impact of microscale variability on ocean ecosystem dynamics, it is necessary to couple the closure ecosystem models with physical models.
We implemented the NPZ closure ecosystem model in a 1D water column physical model, General Ocean Turbulence Model (GOTM), using the same method as the physical-biological coupling by Mandal et al. (2016). GOTM is a public domain model (http://www.gotm.net) which is freely available to the community and reproduces reasonable seasonal cycle of stratification and vertical diffusion in the open ocean. The results of annual simulations showed that microscale variability led to the enhancement of Z_0 growth after the spring bloom of P_0. However, P_0 and Z_0 were rapidly depleted in spring when β is greater than or equal to 1 since Z_0 grazing was too fast under high variability conditions. Dynamics of Z_0 is sensitive to the covariance $<P'Z'>$, implying that the combination of phytoplankton aggregates and zooplankton communities impacts ocean ecosystem dynamics. We will present the outcomes from this 1D mixed layer simulations.

キーワード：NPZモデル、クロージャー生態系モデル、微細構造、GOTM
Keywords: NPZ model, closure ecosystem model, microstructure, GOTM

