Spatial difference of spring phytoplankton bloom dynamics in the Japan Sea

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Onset and magnitude of spring phytoplankton bloom impact higher trophic levels in the ocean. In previous, relationship between mixed layer depth and euphotic layer depth is considered as the key factor to onset of the bloom (critical depth hypothesis, CDH), but in recent, importance of turbulent mixing in surface layer is focused (critical turbulence hypothesis, CTH). In the Japan Sea (JS), onset of spring bloom is heterogeneous: chlorophyll *a* (Chl-*a*) concentration reaches maximum in April in the south, and it does in May in the north. This heterogeneity has been explained by the CDH in the previous studies, but the role of the turbulence mixing has not been considered. In this study, we aimed to explain this spatial difference in timing of bloom based on the mechanism of bloom, the CDH and the CTH.

For understanding the mechanisms, we calculated the weekly and monthly climatological values of mixed layer depth (MLD) from historical water temperature and euphotic layer depth (ELD), net heat flux (NHF), wind stress (WS), nitrate concentration, and satellite-derived sea surface chlorophyll *a* (Chl-*a*) concentrations. Additionally, ecosystem model based on NEMURO was constructed. This model added turbulence as the physical parameter: it is weak at the surface when NHF is positive. Onset of spring bloom was defined as when increase rate of Chl-*a* concentration was more than twice compared to the previous week.The JS was divided by temperature at 50 m depth and temporal variation of Chl-*a* concentration into four regions, the southern part (South), the subpolar front region (SFP), the northwestern region (NW), and the northeastern region (NE).

First, onset of spring bloom was not different among the areas. The Chl-*a* concentration began to increase at the timing when the NHF changed from negative to positive. This result supports CTH and lowering of the turbulence mixing is the controlling factor of onset of the spring phytoplankton bloom in the JS. Particular, in the SFP, the MLD is always shallower than the ELD during winter, but rapid increase of Chl-*a* concentration occurred: CDH is not supported in the SFP. The results from the ecosystem model support the CTH as well as the observations. When the turbulence mixing in surface layer was cancelled in the model, the beginning of spring bloom delayed, but when the turbulence was deal with as realistic, the onset of bloom was reproduced well in the model.

Second, the timing of peak of the bloom was not homogeneous as same as the previous study: it delayed in the NE. Since the onset of bloom was synchronous all over the JS, this results indicated that phytoplankton growth rate is different among the ocean. The growth of phytoplankton is controlled by temperature and nutrient concentrations as well as the light condition, but in the model, the difference of former two parameters did not affect the timing of peak. On the other hand, it was effected by the depth of mixed layer. In the NW, winter mixed layer was deeper than the other three regions, and our model indicated that phytoplankton vertically transported by this deep mixing to the layer with low light level in the NW. This phenomenon supports CDH.

In conclusion, we succeed to revise the dynamics of spring bloom in the JS based on the CTH as follows: the onset of phytoplankton bloom is controlled by the turbulence mixing, and its development is controlled by the degree of mixing as well as the turbulence.

Keywords: spring bloom, critical turbulence hypothesis, critical depth hypothesis