Horizontal two-dimensional pattern formation of chlorophyll-a in ecosystem model with vertical mixing process

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In the Toyama Bay, chlorophyll-a in the surface layer of a few meters increases in the rainy season of Jun to July, while forming the counterclockwise pattern (cf. Fig.1). This characteristic distribution is considered to be found in the relationship between oceanic physical processes (advection and diffusion) and ecosystem in the Toyama Bay. However, the formation and development mechanism are not revealed in detail. Then, we investigate the mechanisms of pattern formation using a satellite image, ocean observation data, and physics-ecosystem modelling.
Especially, we focus on the vertical mixing process and the inflow of nutrient from the river.
In this study, we used the NPZ model as an ecosystem model, including the advection and diffusion terms as ocean physical processes. This three-dimensional system was solved by finite differential method. The horizontal oceanic area is 100 km x 100 km referring to extention of the Toyama Bay and the resolution is 2km x 2km. For the model calculation, we employed a horizontal diffusive coefficient of 10 (m^2/s) and performed a cyclonic circulation as flow fields. Also vertical diffusive coefficients are in the range of 10^{-5} to $10^{-2}(m^2/s)$.
The experiments are carried out for macro and micro plankton, and several values of grazing rate coefficient showing a relationship between the predictor-pray of planktons as the ecosystem parameters.
In this numerical experiment, assuming the inflow of nutrient from rivers, we set up a situation where the concentration of nutrient increases from below the model area and analyse the transition.
We also analyzed by using COMS-GOCI satellite image to understand development of chlorophyll-a pattern in the actual situation in the Toyama Bay and to compare it with numerical experiment.
The data is from April to September of 2010 to 2014 and data from April to October 1, 2015 (lacking only for July 2012).
In the numerical experiment without vertical diffusion, the counter-clockwise spiral pattern was formed in all zooplankton parameter. This pattern gradually collapsed, and then the amount of phytoplankton in the model area changed uniformly(cf. Fig. 2). After that, a spiral pattern was appeared again only in micro zooplankton parameter.
The counterclockwise spiral pattern in the surface layer in the three-dimensional model with the vertical diffusion.
The concentration of phytoplankton was lower in the three-dimensioal case than that in the two-dimensional case, however, because the nutrient supplied on the surface layer was carried to the deep layer by the vertical mixing.
It was found there were cases where the spiral pattern was formed to the lowest layer and cases where it was not formed, depending on the zooplankton parameters and the magnitude of vertical diffusion.
From these experiments, the formation of the spiral pattern in Toyama Bay is assumed nutrient supplied from a river is transferred to a counterclockwise flow field, and then phytoplankton consume its nutrient. We found that for the abundant nutrient in the bay, the spiral pattern was formed with active interactions of predator-prey between plankton.
In satellite image analysis, chlorophyll-a concentration distribution in Toyama Bay was classified into 4 patterns. : firstly high concentration in the offshore area, secondly high concentration on the coast, thirdly high concentration part developed from near Kurobe river estuary toward Toyama Bay, fourthly spiral

pattern.
For the fourth spiral pattern, we showed the possibility to explain the mechanism of the formation in the numerical experiment.
Moreover, for the formation of a spiral pattern, we suggest that spring water in the Kurobe River with the rich nutrient are carried in counterclockwise circulation field in the Toyama Bay. Furthermore we plan to investigate the above described items in three-dimensional model research.

Keywords: chlorophyll-a, ecosystem model, Toyama Bay, two dimensional pattern, Vertical mixing

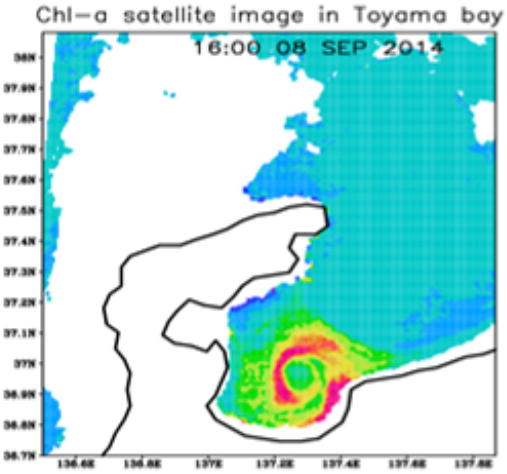

Figure.1
Chlorophyll-a concentration distribution in COMS-GOCI satellite.

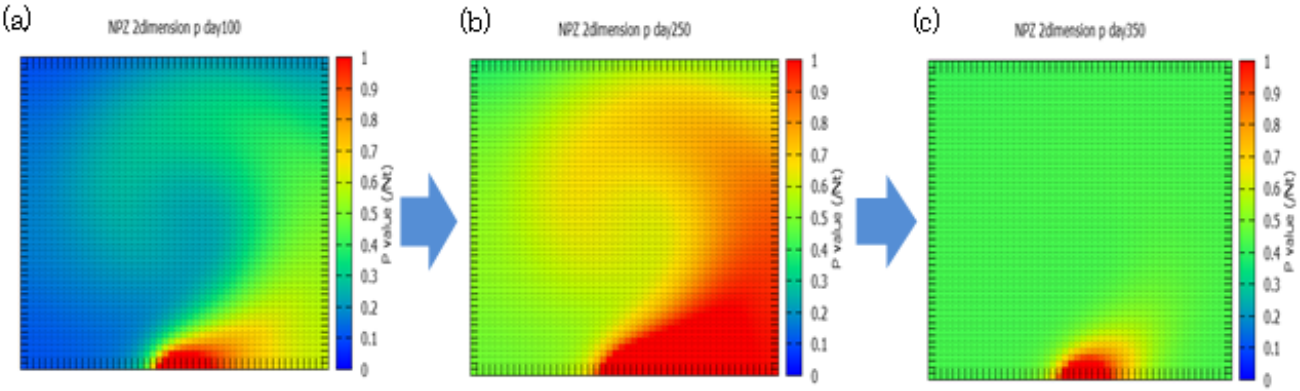

Figure.2
Transition of the phytoplankton concentration distribution in numerical experiment.
(a) Distribution of 100 days
(b) Distribution of 250 days
(c) Distribution of 350 days

