Clarification of the Generation Mechanism for Blue Tide Distribution Using 3D Hydrodynamics and Ecological Model, and Satellite Images of Tokyo Bay

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Abstract

In order to figure out the generation mechanism of blue tide occurrence including upwelling, blue tide distribution taken from satellite images was estimated by using the estimation model of blue tide which we developed based on observation result of optical properties in Tokyo Bay and numerical simulation by 3-dimensional hydrodynamics and ecological model. By incorporating the information from the results of both satellite image analysis and numerical simulation, the upwelling area was identified by using the estimated blue tide reflectance and the calculated result of dissolved oxygen (DO) by numerical simulation. Furthermore, the detailed processes of upwelling in the vertical cross-section was identified by simulating the upwelling of anoxic water from trenches.

Keywords – Blue tide, GOCI satellite, 3-dimentinal hydrodynamics and ecological model

1 Introduction

Blue tides, upwelling of anoxic waters and blue color of surface water, have been a serious environmental problem in Tokyo Bay. Blue tides often cause mass fish and shellfish mortality. It is important to improve the technology for monitoring the behaviour of blue tides and to resolve its generation mechanism, in order to predict blue tides occurrences in the future. Although studies on clarification of blue tide generation mechanism have already been carried out using numerical simulations, there is still a problem on its accuracy, particularly in simulating the upwelling processes in Tokyo Bay which has a complicated geography since there are many trenches by landing-back. In addition, the pattern and processes of upwelling were clarified in the previous studies using satellite images of temperature which assumed that the area with low temperature water masses is where upwelling occurs (Ueno et al., 1992). However, it is difficult to assume the blue tide area by low temperature water masses as the distribution of blue tide occurs because it is impossible to identify whether sulfide is included in the upwelling area or not.

In this study, field observations were carried out to elucidate the optical properties of blue tides.

Based on the optical properties, the estimation model of blue tides from satellite images was developed to determine the behaviour of blue tide distribution. Furthermore, numerical simulation using 3-dimensional hydrodynamics and ecological model which links the information between the satellite image and the simulation results were carried out to understand the upwelling process.

1 Field observation

Field observation was carried out at the head of Tokyo Bay. Blue tide observed on 30th August, 2011. Spectral upward radiance and downward irradiance in the blue tide area were measured with submersible radiometers (TriOS Optical Sensors; RAMSES ACC/ARC). Remote sensing reflectance was calculated from the radiometer measurements.

2 Results

2.1 Optical properties of Blue tide

The result of observed remote sensing reflectance is shown in Fig. 1. The reflectance for the blue tide significantly increased between 350 to 720nm, with the highest peak at 550nm. Compared with the reflectance for high turbidity region, the blue tide reflectance was significantly higher. Based on the results, it was found that blue tide has completely different optical properties from high and low turbidity regions in Tokyo Bay.

2.2 Estimation model of blue tide for satellite

The estimation model of blue tide was developed based on the optical properties determined during field observation and the use of satellite images.

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\text{Blue tide reflectance} = \frac{\text{Band}(555 \text{nm})}{\text{Band}(680 \text{nm})} - 0.006 \cdot \left| \frac{\text{Band}(680 \text{nm})}{\text{Band}(660 \text{nm})} \right| \quad (1)
\]

The model describes that the reflectance in band on the regions without blue tide should be less than zero. In order to calculate the blue tide reflectance, the bandwidth ratio at 680nm/660nm should be subtracted from the band at 555nm which has the highest reflectance in the bay. These two bands at 660nm and 680nm indicate the light absorption by chlorophyll in the spectral region and the chlorophyll fluorescence spectra, respectively. Since the model can show blue tide occurrences based on color strength, it will be helpful not only in the monitoring of the extent of distribution of blue tide but also in the identification of areas where upwelling occurs.

Figure 2 shows the satellite image, which was taken on 24th September, 2012, was made by the developed model. It was found that the estimated blue tide distribution expands from offshore region of Makuhari to offshore region of Urayasu. In addition, this result
denotes that the upwelling of the anoxic water was started from these two areas because the light reflectance of the blue tide was high.

2.3 Numerical simulation by 3-dimensional hydrodynamics and ecological model

Although it is possible to estimate the distribution of the generation mechanism of blue tide using the developed model, it is also valid to utilize incorporated results by both numerical simulation and the satellite image analysis.

In this study, DO was calculated by using a 3-dimensional model which employs hydrodynamics, circulating nutrients and low-order ecological model.

The fundamental equations are composed by the Navier-Stokes equation, the continuous equation with hydrostatic and boussinesq approximation, and the equations for the state of temperature, salinity and density. In this model, the z coordinate is used as vertical direction, while the k-l turbulent flow model (Mellor and Yamada, 1982) is used to derive the diffusion coefficient for the vertical direction. On the other hand, Smagoinsky model is used to derive the diffusion coefficient for the horizontal direction (Onozawa et al., 2007). In addition, growth rate of some phytoplankton species, light intensity, nutrients, and DO in the water were simulated by using three models: (1) the ecological model, (2) the bottom sediment model, and (3) the hydrodynamics model. This was supported by data from the detailed results of field observation which was done in 1999 (Koibuchi et al., 2007). In this study, the accuracy of results of the simulation have already been verified since the same parameters in the model were used by Saya et al. (2012).

Figure 3 illustrates the calculation result of surface DO during the blue tide event on 24 September, 2012. The upwelling of the anoxic water below 2.5 mg/l of DO concentration was distributed around the offshore region of Urayasu and the west side of the offshore region of Makuhari.

3 Discussion

Based on the result of Fig. 2 showing the higher light reflectance around the offshore region of Urayasu and the west side of the offshore region of Makuhari, it was found that the satellite image showing the blue tide occurrence is consistent with the estimation results of numerical simulation the upwelling area. Furthermore, in order to verify the reason of upwelling around the offshore region of Urayasu, DO concentration for the vertical cross section of the area was calculated, as shown in Figure 4. From the result, the anoxic water from the trench of the offshore region of Urayasu was rising to the surface water due to the continuous wind blew with 8 to 10 m/s starting on 23th September at 12:00 p.m. In addition, the DO calculation result showed that the upwelling of the anoxic water in the offshore region of Urayasu stopped on 25th September. Thereafter, based on the result of upwelling processes, eventually, blue tide event occurred around Tokyo port until 28th September.

4 Conclusion

In this study, we developed the estimation model for blue tide based on field observation resists of optical properties. The model can identify blue tide occurrences. Therefore, it can be useful to monitor the extent of the blue tide distribution and to identify the upwelling regions.

Based on the results of blue tide generation mechanism using temporal-spatial information from satellite images, complemented with continuous observation of DO concentration, and calculation results of 3-dimensional model for hydrodynamics, bottom sediment and ecosystem, the formation process of blue tide event on September, 2012 was due to continuous strong north wind over the area, which induced upwelling of anoxic water to the surface layer, resulting to upwelling in the offshore region of Urayasu and the offshore region of Makuhari at the same time.

References