Modeling of Light Intensity and Phytoplankton Dynamics in Tokyo Bay Using Monitoring Dataset

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ABSTRACT

We collected and analyzed monitoring data sets in Tokyo Bay, including measurements of detailed time series of vertical profiles of water quality for one year period to enhance modeling of light intensity and phytoplankton dynamics in the bay. We modeled the relationship among PAR and chlorophyll $a$. Suspended sediment mostly originated from rivers was modeled and calibrated and its effect on light extinction coefficient was investigated so that computational results became consistent with the field data. In this research, an appropriate method for estimation of light extinction coefficient as a function of chlorophyll $a$ and suspended sediment concentrations in a numerical model is proposed and examined.

KEY WORDS: Numerical model; Photosynthetically Active Radiation (PAR); phytoplankton dynamics; Tokyo Bay.

INTRODUCTION

Tokyo bay is a semi-enclosed embayment with a narrow mouth restricting the water exchange through the mouth (see Fig. 1). The bay is one of the most polluted bays in the world and the resultant hypoxia or anoxia is a serious water quality problem for more than 40 years, causing mortality of benthic animals and decline in fishery in the bay. Although many attempts to consider measures against the problem have been made using numerical models, their reliability was often reduced because of poor reproducibility of temporal and spatial variation in phytoplankton dynamics.

Koibuchi et al. (2000) revealed that primary production in the bay is mostly controlled by light intensity and the depth of the density interface because the shortage of nutrients rarely occurs in the bay, except that of silica. This implies that there is a possibility of improving reproducibility of phytoplankton dynamics on the basis of enhanced modeling of light intensity. Therefore, the objectives of the present study are to develop an enhanced model for photosynthetically active radiation (PAR) coupling with a hydrodynamic and a modified version of detailed ecosystem model by Sasaki and Isobe (1999) and to establish an improved predictive model for phytoplankton dynamics consistent with field observation.

The data set (Koibuchi et al., 2000) of water quality includes vertical profiles of physical and biogeochemical parameters continuously recorded at three stations in Tokyo Bay. The mean water depths at each station are: 15.0 m at Tokyo Light House (TLH), 14.5 m at Chiba Light House (CLH) and 22.0 m at Keiyo Sea Berth (KSB) (see Fig. 1). Koibuchi and Isobe (2007) analyzed phytoplankton blooming mechanism in Tokyo Bay using the data set. They described that the increase of chlorophyll $a$ was observed almost simultaneously at the three stations (see Fig. 1). According to their observations, even if the nutrients are consumed during blooms, their concentrations in the water column often remain higher than nutrient half saturation constants of phytoplankton. Thus the key factor of phytoplankton blooms is solar radiation and depth of the density interface governing the euphotic zone in the water column. Bouman et al. (2010) observed and analyzed the water quality parameters in Tokyo Bay to find the environmental controls on phytoplankton production. They indicated that water turbidity may not co-vary with pigment biomass and thus the attenuation coefficient of PAR may not be a simple function of chlorophyll $a$ concentration. However they proposed three formulas dependent on the location of their observation stations. In their formula the light extinction coefficient is a function of chlorophyll $a$ concentration only. Quinlan (2003) observed the light intensity and other water quality parameters in Suwannee Estuary (Gulf of Mexico) from April, 1998 until April, 2001. In his study four conversion factors are considered to determine the light extinction coefficient, light attenuation due to sea water, chlorophyll $a$, colored dissolved matter (CDM) and tripton (non-algal suspended solids). In a similar study performed in Solent Estuary (UK) by Iriarte (2004), river flow explained the highest percentage of the variability in the light extinction coefficient $k$, which shows the strong effect of suspended sediment on light penetration. Ichikawa et al. (2007) and Kishi et al. (1981) proposed a nonlinear formula for estimation of $k$ as a function of chlorophyll $a$ concentration for Shinji and Nakaumi Lagoons and Mikawa Bay, respectively. The formulas described above are summarized in Table 1 where $C_{chl-a}$ stands for chlorophyll $a$ concentrations $[\text{mg/m}^3]$, $k_2$ is light attenuation due to suspended solids $[1/\text{m}]$, $C_{CDM}$ is concentration of colored dissolved matter $[\text{mg/m}^3]$ and TSS is total suspended sediment $[\text{g/m}^3]$. 

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