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Comparison of two light attenuation parameterization focusing on timing of spring bloom and primary production in the Baltic Sea

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ABSTRACT

The physical–biogeochemical coupled model HMB–ERGOM is used to investigate the effects of light attenuation on the timing of spring bloom (TSB) in the Baltic Sea. When light attenuation was not included, the predicted TSB was earlier than observed values in shallow areas (<50 m) and the predicted primary production tended to be lower, especially in the open-sea areas. Tuning the value of related parameters could not resolve these two discrepancies simultaneously. In the present study, a new light attenuation parameter was introduced to incorporate the effects of inorganic suspended particulate matter (SPM) using bathymetry depth and vertical turbulent diffusivity. A variable optimal photosynthesis irradiance in ERGOM was replaced with a constant value. The new parameterization led to improvement in three aspects of modeled results: nutrients and chlorophyll concentrations, TSB, and primary production. However, insufficient light utilization and under-estimation of primary production in some coastal regions remain problematic. The present study demonstrates the possibility of examining the potential impacts of inorganic SPM without explicitly coupling a complicated SPM model and highlights the importance of inorganic SPM modulating TSB in shallow areas. The new parameterization could be used to examine spatial variation of TSB in the Baltic Sea.

1. Introduction

The 3D physical–biogeochemical coupled model HBM–ERGOM is currently providing operational service for the Baltic Sea (Wan et al., 2011, 2012b). A previous assessment showed that the model could effectively capture the observed general seasonal patterns and vertical distribution of the targeted variables: dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP) and chlorophyll *a* (Chl), but the modeled TSB was earlier than observations in shallow areas (depth <50 m) and the modeled primary production was generally lower than the observed values, especially in open-sea regions (Wan et al., 2012b). Maar et al. (2011) also found that the ERGOM underestimated the primary production in the Baltic Sea.

To resolve the discrepancy in TSB, we increased the parameter value of optimal photosynthesis irradiance in ERGOM (unpublished), which led to better estimates for the TSB, but worse performance in the modeled primary production, i.e., much lower than the observed values. Conversely, decreasing the value of the irradiance parameter led to better estimates of primary production, but worse performance in the predicated TSB and nutrient concentrations, i.e., the predicted TSB was much earlier than the observed values and the predicted nutrient concentrations in winter in coastal areas were also much lower. Therefore, the discrepancies cannot be resolved by parameter optimization, which implied some mechanistic problems with the light attenuation parameterization in ERGOM (Neumann, 2000). Previous model validation conducted by Neumann et al. (2002) did not find the problems with the predicted TSB (too early) and nutrient concentrations in winter (too less) in shallow areas, because their validation mostly focused on three offshore stations in the relatively deep Baltic proper and the observed data for validation were too sparse to resolve the TSB.

One of the major differences between shallow coastal waters and deep offshore waters is inorganic suspended particulate matter (SPM), which could be important for photosynthesis process. However, the inorganic SPM was not included in the ERGOM. In fact, it is well noted that the SPM affects the underwater light conditions which in turn play a crucial role in predicting the TSB (Xu et al., 2005; Allen et al., 2007; Arndt et al., 2007; Tian et al., 2009). The addition of a sub-model to simulate the dynamics of SPM explicitly will increase the complexity of the model system, as the SPM model usually include several state variables (Soulsby, 1997; Puls et al., 1997; Pleskachevsky et al., 2005; Gayer et al., 2006). In the present study, we propose a procedure to feature the impact of SPM on light attenuation. In this new procedure, the SPM is a function

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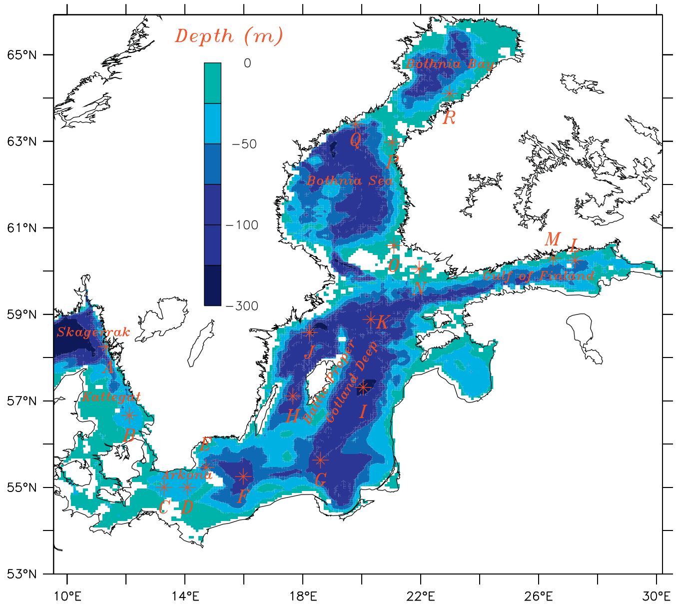

Fig. 1. Topography of the Baltic Sea (unit: m) and location of time-series observational stations A–R (*).

of bathymetry depth and vertical turbulent diffusivity. Meanwhile, we replaced the less common variable optimal photosynthesis irradiance in the ERGOM (Garrada et al., 1983; Stigebrandt and Wulff, 1987) with a constant value.

The objective of this manuscript is to compare the modeled results with and without the new procedure on light attenuation. If the updated model significantly improves the modeled TSB, it will be a useful tool to investigate the spatial and temporal dynamics of spring bloom and nutrients in the Baltic Sea.

2. Models, data and methods

2.1. Physical model

The physical model is the HIROMB-BOOS ocean circulation model (HBM) (Berg and Poulsen, 2012). The source code used in this study is tagged as MyOV2. HBM is based on the primitive geophysical fluid dynamics equations for the conservations of volume, momentum, salt and heat. The wind, air pressure, air temperature, humidity, evaporation/precipitation and cloud cover are taken into account in the parameterizations of surface boundary conditions. Water levels of tides and surges and monthly climatology of temperature and salinity are imposed as outer lateral boundary conditions. River runoff is included as an inner lateral boundary condition. The model is set up to cover both the Baltic Sea and the North Sea though. our targeted area is only the Baltic Sea (Fig. 1). The model setup and configuration are the same as Wan et al. (2011).

2.2. Ecosystem model

The applied version of ERGOM is similar to the original version by Neumann (2000), Neumann et al. (2002), and Conkright et al. (2002). ERGOM originally adopted Redfield ratio for the phytoplankton stoichiometry. Wan et al. (2011) documented that a non-Redfield ratio is more suitable in the Baltic Sea than the Redfield ratio. Moreover, Wan et al. (2012a) demonstrated that a spatially variable N/P ratio is closer to the real phytoplankton stoichiometry in the Baltic Sea than a fixed non-Redfield ratio. The rest values of model parameters are based on Neumann (2000) with minor changes (Wan et al., 2011).

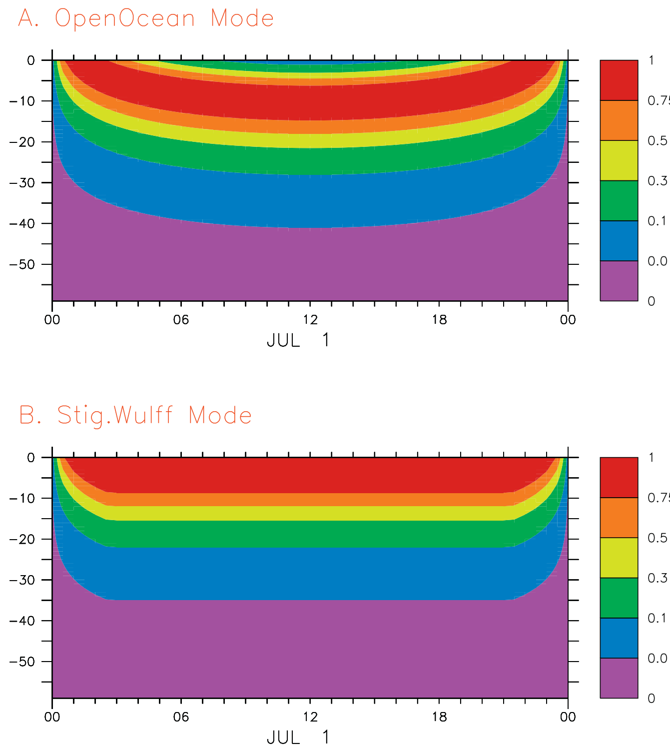

Fig. 2. Vertical profiles of light limitation efficient from two parameterization of light attenuation defined in Section 2.3. Horizontal axis stands for a typical summer day (July 1), unit: hour; vertical axis stands for depth, unit: m.

2.3. Parameterization of light attenuation

ERGOM adopts the relation of light limitation to photosynthesis according to Steel (1962):

$$r_L = \frac{I}{I_{opt}} \exp\left(1 - \frac{I}{I_{opt}}\right), \quad (1)$$

where r_L, I, I_{opt} stands for light limitation, irradiance intensity and optimal photosynthesis irradiance, respectively. Irradiance intensity I depends on surface irradiance I_s and light attenuation coefficient k:

$$I = I_s \exp(-k \cdot z), \quad (2)$$

where z is the depth.

ERGOM assumes I_{opt} is adjustable and dependent of I_s (Garrada et al., 1983; Stigebrandt and Wulff, 1987):

$$I_{opt} = \max(0.25 I_s, I_{\min}), \quad (3)$$

where $I_{\min}$ is a constant of minimum optimal photosynthesis irradiance. Comparing the variable I_{opt} in Eq. (3) with the constant I_{opt} of Steel (1962), the variable I_{opt} can turn an overly irradiance depressing photosynthesis to an optimal irradiance. Even though Eq. (3) moves the light condition at the sea surface to favor photosynthesis, it reduces the light utilization in the whole water column as shown in Fig. 2 which compares the profiles of light limitation between two parameterizations on a typical summer day.

ERGOM assumes:

$$k = k_w + k'_c \cdot C \quad (4)$$

where k is the total light attenuation coefficient, k_w is the light attenuation coefficient of pure water, and k'_c is the percentage of light attenuation attributed to organic SPM, and C is the concentration of organic SPM. Now we try to include the inorganic SPM in Eq. (4). Without introducing too much complexity of SPM modeling, we