DEVELOPMENT OF A MATHEMATICAL MODEL FOR 3D-DYNAMICS OF PERSISTENT ORGANIC POLLUTANT IN THE EAST CHINA SEA

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Abstract

A three-dimensional/high-resolution transport model for persistent organic pollutants (ECS-POPs) has been developed to assess quantitatively the dynamics of POPs in the East China Sea (ECS). The ECS-POPs is coupled with an ocean circulation model and includes the POPs concentration in four types of media: air, seawater, phytoplankton, and detritus, in which air concentration is used as a boundary condition. In addition to the advection and diffusion by ocean currents and turbulences, the ECS-POPs also includes the diffusive flux of POPs through sea surface, phytoplankton uptake of POPs, vertical sinking of phytoplankton and detritus, detritus production by phytoplankton mortality, and decomposition of detritus. The phytoplankton information is from monthly satellite chlorophyll a data. In this study, we used the ECS-POPs to examine the seasonal variability of PCB153 whose air concentration was available in the literature. The model results presented a remarkable seasonal variability in the PCB153 concentration in three media. Concentrations of both dissolved and particulate PCB153 were high in winter and low in summer. In costal regions where the chlorophyll a concentrations are high, the horizontal and vertical distributions of dissolved and particulate PCB153 concentrations are strongly affected by the uptake of phytoplankton. To understand what factor mostly controls the seasonal variability in the PCB153 concentrations in the ECS, several sensitivity experiments were carried out. It was clarified that the change of water temperature is the major factor controlling the seasonal variation in the air-sea flux of POPs as well as the spatial distribution of POPs in the ECS. The model-based yearly mass balance of PCB153 in the ECS indicated that most of the atmospheric input PCB153 are removed outside the ECS by the ocean currents or accumulated to the sea bottom by vertical sinking.

Introduction

Global contamination by persistent organic pollutants (POPs), such as PCBs, and its impact on wildlife and ecosystem have been of concern over the last decade. Understanding of the global fate of POPs is an important issue. The deep ocean has been considered to be one candidate for the final sink of POPs. However, the dynamics of POPs inside the ocean has not yet been well understood. Numerical modeling studies(1) suggested that not only the horizontal advection and diffusion by currents and turbulences but also the vertical transport of POPs by the phytoplankton, which absorbs POPs and sinks to the deep water as detritus, are important to understand their dynamics inside the ocean. Up to now, most numerical modeling of POPs was based on a simple box model that was oriented to understand the processes. To know the spatial distribution of POPs in the ocean, a three-dimensional transport model for POPs based on realistic topography and ocean currents is necessary.

The final objective of this study is to assess quantitatively the POPs dynamics in the East China Sea (ECS), a marginal sea surrounding by China, Korea, and Japan. Based on an ocean circulation model that provided flow field and turbulence parameters, we developed a three-dimensional high-resolution transport model for the POPs, in the ECS (ECS-POPs). As the first application of ECS-POPs, we examined the seasonal variability of PCB153 whose air concentration was available in literature.

Model description

The POPs model includes four compartments (Gas phase POPs, Dissolved phase POPs, Phytoplankton POPs, and Detritus POPs) that are linked by some physical and biochemical processes, as shown in Fig 1. Gas phase POPs dissolve into the surface ocean through diffusive air-water exchange from the atmosphere to the ocean. In the ocean, a part of dissolved phase POPs are absorbed by the phytoplankton and the others are decomposed. The phytoplankton POPs is involved three processes: phytoplankton uptake, natural mortality, and vertical sinking. The natural mortality of phytoplankton transformed phytoplankton POPs into detritus POPs. A part of detritus POPs are then transported to the deep water by vertical sinking of detritus, and the others are transformed into dissolved phase POPs by decomposition. The POPs model is coupled with a three-dimensional ocean circulation model[3] that is based on the Princeton Ocean Model and can reproduce well the seasonal variations of current fields in the ECS. The velocity vectors in January are shown in Fig.2.

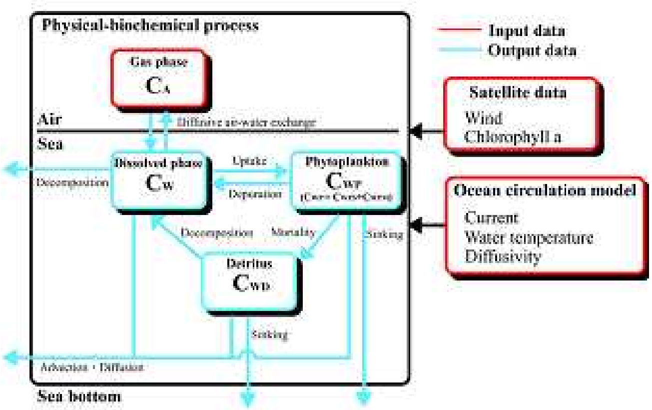

Fig 1. Schematic of the POPs model

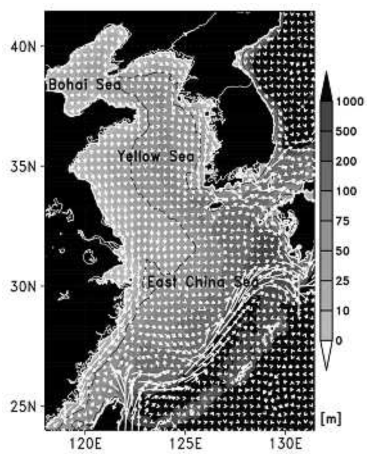

Fig 2. Model domain and bathymetry. Velocity fields in January were superimposed by vectors.

Fig. 2 shows the model domain and bathymetry, which includes the East China, Yellow, and Bohai Seas. The grid size is 1/18 degree and there were 20 levels in the vertical. Monthly satellite chlorophyll *a* (Sea WiFS) and wind stress (ERS1/2) are used to obtain the phytoplankton biomass and to calculate the diffusive air-water exchange flux, respectively. Target compound in this study is PCB153 that is one of the most bioaccumulation isomer of PCBs and dominant in the ecosystem of the ECS. Among initial and boundary conditions, concentrations of dissolved, phytoplankton, and detritus phase PCB153 were set to 0 pg m^{-3}, while concentrations of gas-phase PCB153 were set to 2.08 pg m^{-3} [(3)] that is the source of POPs in our model ECS.

Results and discussion

The model results showed a remarkable seasonal variability in dissolved and particulate PCB153 concentrations that are high in winter (Fig. 3) and low in summer (Fig. 4). The surface flux by diffusive air-water exchange is higher in January than in July (Figs. 3a and 4a). The high surface flux area in January is mainly formed in coastal regions from China to Korean Peninsula (Fig. 3a). Associated with the high surface flux, concentrations of dissolved and particulate PCB153 were also higher in January than in July (Figs 3b, 3c, 4b, and 4c). Interestingly, in coastal regions where concentrations of chlorophyll *a* are high, dissolved PCB153 concentrations are lower but particulate PCB153 concentrations are higher (Figs. 3b and 3c). This would be due to the uptake of dissolved phase PCB153 by phytoplankton. Consequently, the sinking flux also becomes high in coastal regions by vertical transport of particulate PCB153. To examine what is the most important factor controlling the seasonal variability in PCB153, we conducted several sensitivity experiments, in which the temporal variation of only one parameter was removed while that of the others was kept. According to the results (not shown), the temporal change in water temperature fields contributes most to the seasonal variability in PCB153. This can be caused by the variation of Henry's law constants with water temperature, which results in the direct change of the surface flux and indirect change in the concentrations of dissolved and particulate PCB153. We also estimated the yearly mass balance of PCB153 in the ECS. Atmospheric input by diffusive air-water exchange is about 35 kg per year, in which 19 kg are removed by horizontal advection outside the ECS and 16 kg are accumulated to the bottom of ECS by vertical sinking.

This study is a first step toward the realistic simulation of the POPs transport in the ECS. Our future effort will take account of following effects: (1) temporal and spatial variations of the POPs concentration in the atmosphere, (2) river inputs, (3) POPs concentrations at the open boundaries, and (4) dry and wet depositions.

Acknowledgements

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References.

(1) Dachs J., Eisenreich S. J., Baker J. E. Ko F. X., and Jeremiason J. D. Environ Sci Tecnol 1999:33: 3653.

(2) Jaward F. M., Zhang G., Nam J. J., Sweetman A. J., Obbard J. P., Kobara Y., snd Jones K. C. Environ Sci Tecnol:2005:39:8638.

(3) Guo X., Hukuda H., Miyazawa Y., and Yamagata T. J Phys Oceanogr 2003:33:146.

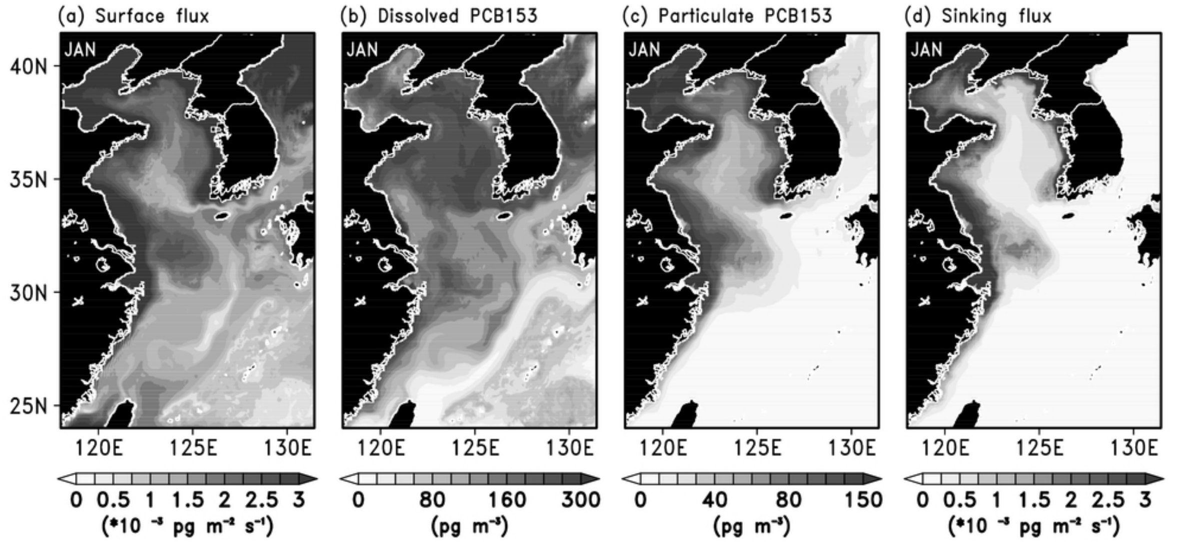

Fig 3. Horizontal distributions of (a) the surface flux of PCB153 from the atmosphere to the ocean, (b) dissolved PCB153 concentrations in the surface, (c) particulate PCB153 concentrations in the surface, (d) sinking flux of PCB153 to the sea bottom, in January.

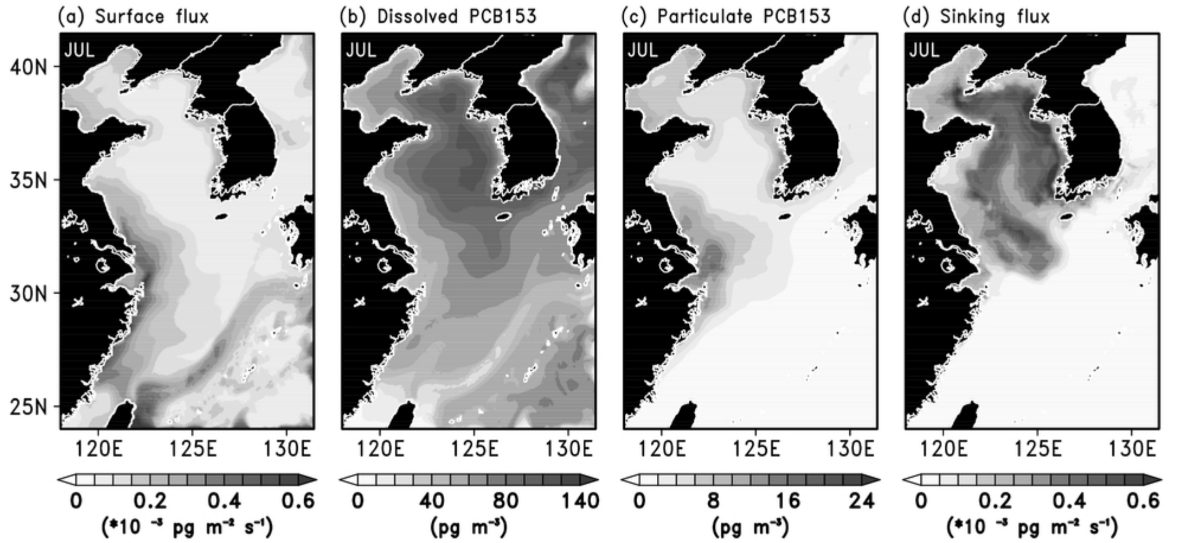

Fig 4. The same as Fig 3, except for in July. The shade scale is different from Fig 3 to show clearly the spatial structure.