# North-South Discrepancy in the Contributors to CB153 Accumulation in the Deep Water of the Sea of Japan

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## Purpose

Polychlorinated biphenyls (PCBs) are highly toxic and readily accumulated by marine mammals owing to their lipophilicity, which detrimentally impacts the immune system, thus posing a critical risk to the marine ecosystem (Friedman and Selin, 2016; Jepson et al., 2016). The deep-water environment and its ecosystem are becoming the ultimate sinks for PCBs. The Sea of Japan (SoJ) is a semi-closed marginal sea in the northwestern Pacific Ocean, and characterized by its marked bathymetric isolated geography. The average depth of the sea is approximately 1667 m, and the maximum depth is approximately 3800 m (Gamo et al., 2014). The bowl-shaped bathymetry separates its intermediate and deep water masses from the adjacent seas and confines the effect of flows through the straits to the upper 200 m (Isobe, 2020). The SoJ is a possible candidate for PCB sinks due to the heavy human activities around the sea. The semi-enclosed topography of the sea isolates deep water from the surrounding oceans, which is conducive to PCB accumulation in deep water.

Clarifying the accumulation of PCBs and their mechanisms is important for the conservation of deep-sea ecosystems and fishery resources in marginal seas. In this study, we established a three-dimensional high-resolution hydrodynamic-ecosystem-PCBs coupled model and targeted at the SoJ to examine the accumulation of PCBs in the deep sea. The relative contributions of physical and biological processes to the vertical transport of PCBs are therefore quantitatively discussed.

## Methods

We use the three-dimensional hydrodynamic-ecosystem-PCBs coupled model to depict the accumulation of CB153 in deep water, which has been successfully applied to the northwestern Pacific Ocean (Yang et al., 2022). The hydrodynamic module provides daily water temperature, current velocity in three directions, and the horizontal and vertical eddy diffusivity coefficients. The ecosystem module provides the daily biomass and the related biological parameters such as the mortality rate of phytoplankton, and the decomposition rate and sinking velocity of the detritus. We included dissolved and particulate-bound PCBs in the PCBs module, and the concentration of particulate-bound PCBs depends on the concentrations of phytoplankton and detritus. Mass exchange processes include advection and diffusion, biogeochemical processes, and air-sea exchange.

CB153 was selected as the target compound in this study. The initial values for the dissolved, phytoplankton, and detritus phases of CB153 concentrations in the ocean were set to zero. Under the climatological data of the physical, ecosystem module, and the climatological concentration of

atmospheric CB153, the PCB module was solved offline using these modules and integrated over 21 years.

## Results

The annual mean distributions of the dissolved and particulate CB153 concentrations are different (Figure 1). The concentration of dissolved CB153 in the sea surface decreases from the southern area (~0.5 *pg* $L^{-1}$) to the northern area (~0.3 *pg* $L^{-1}$) (Figure 1a). The CB153 concentration in the 50 m layer is lower than 0.3 *pg* $L^{-1}$ in the western Japan Basin (Figure 1b). However, there is a significantly high concentration (~0.7 *pg* $L^{-1}$) distributed in the middle layer from 100 to 600 m depth in the Japan Basin (Figure 1c–f), which is approximately twice that in the upper 100 m layer. The CB153 concentration in the deep layer (600–1500 m, ~0.5 *pg* $L^{-1}$) is lower than that in the middle layer (100–600 m) but is higher than that in the upper 100 m layer, and this pattern is uniformly distributed across the SoJ (Figure 1g, h). The concentration of dissolved CB153 showed a three-layer structure from the sea surface to the deep layer, which allows us to divide the SoJ into three layers: the surface layer (0–100 m), intermediate layer (100–600 m), and deep layer (600 m to the bottom).

The vertical distribution of dissolved CB153 along 131°E section shows that the dissolved concentrations exhibit significant seasonality in the surface layer (Figure 2). From spring to autumn, the surface concentration is significantly higher (~0.7 *pg* $L^{-1}$) and lower (~0.4 *pg* $L^{-1}$) in the southern and northern areas of the SoJ, respectively (Figure 2b–d). However, the dissolved concentration is higher in the northern region (~0.5 *pg* $L^{-1}$) than in the southern area in winter (~0.4 *pg* $L^{-1}$) (Figure 2a). The spatial discrepancy of the atmospheric CB153 concentration and the water with high CB153 concentration inflow from the East China Sea to the SoJ via the Tsushima Warm Current contribute to the difference between the south and north SoJ.

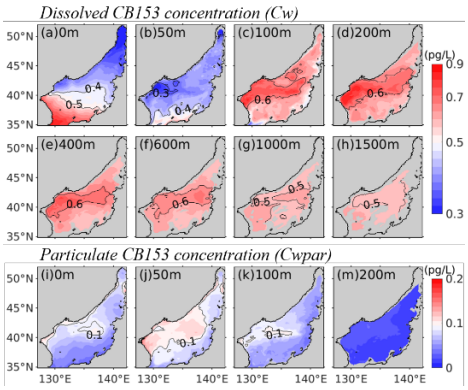


**Figure 1.** Horizontal distributions of annual mean concentrations of dissolved CB153 (a–h) and particulate CB153 (i–m) at different depths in the SoJ.

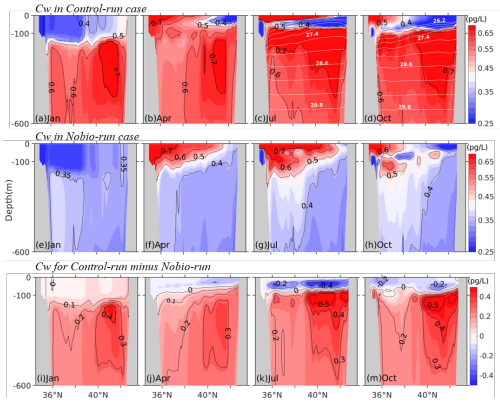


**Figure 2.** Vertical distributions of dissolved CB153 concentrations (*pg* $L^{-1}$) in (a–d) control-run, (e–h) nobio-run, and (i–m) the difference of dissolved CB153 concentration between the control-run and nobio-run (control-run minus nobio-run) in the upper 600 m along 131°E section in January, April, July, and October. The white solid lines in (c, d) denote the isopycnal lines.

The vertical distribution of dissolved CB153 in the deep layer of SoJ is controlled by a combination of physical and biological pumps. To clarify the role of physical processes on the vertical distribution of dissolved CB153 concentration in the SoJ, we examined the dissolved CB153 concentration on different density surfaces (isopycnals) (Figure 3). The dissolved CB153 above the σ1=27.5 isopycnal accumulated mainly in the area south of the subpolar front in the SoJ (Figure 3A). On the σ1=27.7 isopycnal, the dissolved CB153 concentration increases significantly in the subpolar front region between 100 and 120 m depth owing to the sinking and remineralization of detritus-bound CB153 at this depth.

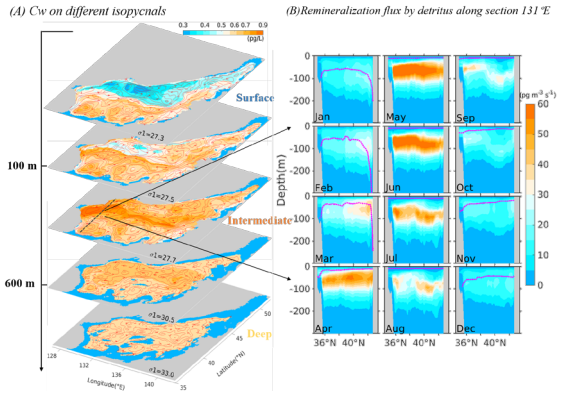


Figure 3. (A) Distribution of dissolved CB153 concentrations at different isopycnals. The red lines with arrows denoted the streamlines of the ocean current. The black dashed line denotes 131°E section. (B) Vertical distributions of the remineralization flux from January to December along 131°E section. The magenta dashed line denotes the depth of the surface mixed layer.

To investigate the effect of the physical process on the accumulation of CB153 in the intermediate and deep layers, we examined the vertical current velocity (*w*) and calculated the vertical advection flux of dissolved CB153 along the zonal cross section of 37°N. Positive and negative *w* alternately distributed along 37°N section. In summer, the downward *w* is prominent, especially in the western region (the Ulleung basin), where the large downward w is maintained from the surface layer to the layer below 1000 m. Correspondingly, the vertical advection flux of the dissolved CB153 distributes similarly to w, and shows significantly downward transport of dissolved CB153 in the Ulleung basin,

which results in the higher CB153 concentration accumulation in this region as compared to the Yamato basin. The vertical advection fluxes through the depths of 100 m and 600 m were integrated in the southern SoJ and both show negative values year-round. Therefore, the downward vertical advection in the southern SoJ is in favor of the accumulation of CB153 in the intermediate and deep layers in the southern SoJ.

The monthly remineralization flux along the 131°E section is high from March to September but lower from October to the next January, and occurs mainly in the subsurface layer (Figure 3B). In summer and autumn, the magnitude of the flux is similar in the southern and northern SoJ, but the depth of detritus decomposition is greater in the northern region (60–140 m) than in the southern region (40–120 m). The magenta dashed line in Figure 3B indicates the monthly mixed layer depth (MLD). The MLD reaches a depth of 60 m in the majority of the SoJ from December to the next February, and is less than 10 m from May to September. In summer, the sinking of detritus is not affected by the strong stratification and brings the detritus-bound CB153 below the mixed layer. Meanwhile, the decomposition of detritus-bound CB153 induces the accumulation of a large amount of dissolved CB153 in the subsurface layer (60–120 m). With the increase of the MLD from October to December, the previously accumulated high concentration of dissolved CB153 in the subsurface layer is mixed with the lower concentration in the surface layer. Therefore, the dissolved CB153 in the subsurface layer is diluted with the surface mixed layer.

To investigate the relative contributions of physical processes and biological pump to the accumulation of CB153 in the intermediate layer of the SoJ, one sensitivity experiment was conducted. In this calculation (nobio-run), the initial and boundary conditions and the simulation time are the same as those in the control-run. However, biological processes related to CB153 are removed; therefore, only the dissolved CB153 was calculated by solving its advection and diffusion equations.

Compared to the results of the control-run (Figure 2a–d), the vertical distribution of dissolved CB153 along the 131°E section in the nobio-run exhibits significant differences in the layer below 100 m depth, and these differences in the southern and northern 131°E section are inconsistent (Figure 2e–h). The concentration difference between the control-run and nobio-run in the surface layer of the southern region is smaller (~-0.2 $pg\ L^{-1}$), which corresponds to the smaller increase of dissolved CB153 concentration in the deeper layer (~0.2 $pg\ L^{-1}$) of the southern region. Correspondingly, the contributions of biological processes to the accumulation of dissolved CB153 in the intermediate and deep layers in the northern area are approximately 70% and 60%, respectively, and this contribution is only 30% in the southern area.

## Future challenges

Many semi-enclosed fjords exist in the global oceans (e.g., the SoJ, the Norwegian Sea, and the Labrador Sea). The PCBs concentrations are usually higher in these seas than in the open ocean. The discussion of the relative contributions of oceanic biological pump and physical processes to the accumulation of PCBs in deep water of the SoJ can be naturally tested in other semi-enclosed fjords in the future. Such studies can deepen our understanding of the regulation and diversity of accumulation mechanisms among different semi-enclosed fjords and provide fundamental information for the study of deep-sea marine fishery resources.

## Publications

Min Yang, Xinyu Guo, Junyong Zheng, and Yasumasa Miyazawa. North-south discrepancy in the contributors to CB153 accumulation in the deep water of the Sea of Japan. Science of The Total Environment, Vol.939, 173599, 08, 2024.

## References


Friedman, C.L., Selin, N.E., 2016. PCBs in the Arctic atmosphere: determining important driving forces using a global atmospheric transport model. Atmospheric Chemistry and Physics 16, 3433–3448.

Gamo, T., Nakayama, N., Takahata, N., Sano, Y., Zhang, J., Yamazaki, E., Taniyasu, S., Yamashita, N., 2014. The Sea of Japan and Its Unique Chemistry Revealed by Time-Series Observations over the Last 30 Years. Monogr. Environ. Earth Planets 2, 1–22.

Isobe, A., 2020. Paleo-ocean Destratification Triggered by the Subduction of the Oyashio Water Into the Sea of Japan After the Last Glacial Maximum. Paleoceanography and Paleoclimatology 35, e2019PA003593.

Jepson, P.D., Deaville, R., Barber, J.L., Aguilar, À., Borrell, A., Murphy, S., Barry, J., Brownlow, A., Barnett, J., Berrow, S., Cunningham, A.A., Davison, N.J., ten Doeschate, M., Esteban, R., Ferreira, M., Foote, A.D., Genov, T., Giménez, J., Loveridge, J., Llavona, Á., Martin, V., Maxwell, D.L., Papachlimitzou, A., Penrose, R., Perkins, M.W., Smith, B., de Stephanis, R., Tregenza, N., Verborgh, P., Fernandez, A., Law, R.J., 2016. PCB pollution continues to impact populations of orcas and other dolphins in European waters. Sci Rep 6, 18573.

Yang, M., Guo, X., Ishizu, M., Miyazawa, Y., 2022. The Kuroshio Regulates the Air–Sea Exchange of PCBs in the Northwestern Pacific Ocean. Environ. Sci. Technol. 56, 12307–12314.