On relaxation of the influences of treated sewage effluent on an adjacent seaweed farm in a tidal strait

Introduction

Osaka Bay (OB) suffers from the anthropogenic loads from the densely populated hinterland, even though the water quality has been improved since 1980s. Tarumi Sewage Treatment Plant (TSTP) is a major wastewater treatment plant in OB near the narrow Akashi Strait (AS), where energetic tidal currents occur. The area around TSTP is well known for seaweed farming, in which the spores are quite vulnerable to density and nutrient conditions during the hatch in fall. The local government (Kobe City) has constructed a new western outfall in TSTP aimed at seasonal diversions of the effluent release in fall to reduce possible impact on the farm upon the claims from the local fishery. A previous study (Uchiyama *et al.*, 2018) concluded the western diversion operation successfully decreased the accumulation of TSTP effluents in the farm by on average ~28%, while the instantaneous effluent concentration was reduced to ~50%. However, the farmers are still demanding that the local government should further diminish TSTP influence. Therefore, in the present study, we conduct several high-resolution numerical model experiments with different operation scenarios suggested by the local government to provide qualitative engineering guidelines on the alternative discharge operations optimized for reducing TSTP influence on the seaweed farm.

Methodology

The assessment is performed using a quadruple nested JCOPE2-ROMS oceanic downscaling model in a high-resolution configuration (**Fig. 1**). The lateral grid size refinement occurs from ~10 km (JCOPE2) to 2 km (ROMS-L1), 600 m (L2), 100 m (L3), and further down to 20 m (L4). We take into account the surface momentum (wind), heat, and freshwater fluxes, tides, and major river discharge, etc, as realistically as possible. The sewage effluent is implemented in the ROMS-L4 model as an additional point source and 3D Eulerian passive tracer model of Uchiyama *et al.* (2014, 2018). The sewage effluent is applied to the coastal area near TSTP as a bottom-released freshwater plume at the volume rate of 180,000 m^3 d^{-1} for the baseline case (case 1) mimicking the standard operation. The first alternative (case 2) is simply a reduced discharged volume rate from 1.8×10^5 m^3 d^{-1} to 1.5×10^5 m^3 d^{-1}. In the second alternative (case 3), the effluent density is intentionally increased by mixing with 0.8×10^5 m^3 d^{-1} of the ambient seawater to suppress the buoyant plume from its immediate surfacing during the initial dilution.

Results and Discussion

The surface residual currents in **Fig. 2a** represent that strong tidal currents intrude into OB through AS. A pair of clockwise and counterclockwise rotating gyres are formed near AS; the former is in the south whereas the latter is just off TSTP. Two selected enlarged regions shown in **Fig. 2b-c** demonstrate the influences of man-made marine constructions in the red dotted boxes labeled with z1 and z2 in **Fig. 2a**. The complex residual current appears around the fishing pier (**Fig. 2b**). The breakwater provokes a bifurcation of the westward coastal residual current with noticeable velocity weakening (**Fig. 2c**). The time-averaged non-dimensional tracer (effluent) concentration c (color) and the seawater density (contours) at the surface are depicted in **Fig. 3**. Consistent with the residual current field (**Fig. 2a**), for the baseline case shown in **Fig. 3a**, the mean effluent concentration c is mostly distributed in the alongshore direction near TSTP. Similar to the c distribution, slight decreases in the surface density occur because of the fresh effluent discharge from the western diversion outfall. The effluent concentration and density surface deviations observed for Case 2 are generally consistent although with opposite signs (**Fig. 3b**). The surface density ρ slightly increases around TSTP due to the reduced fresh effluent, while c is diminished. By contrast, the adjusted effluent density with the unchanged total tracer flux (Case 3) does not result in obvious changes in ρ and c (**Fig. 3c**). **Fig. 4a** shows the net cumulative tracer in the seaweed farm for three cases. **Fig. 4b** investigates that the released flux reduction of 16.7% ($1.8 \times 10^5\, m^3 d^{-1} \rightarrow 1.5 \times 10^5\, m^3 d^{-1}$) at the diversion outfall in Case 2 results in a 25.4% reduction ($2.01 \times 10^4\, m^3 \rightarrow 1.50 \times 10^4\, m^3$) in the time-averaged effluent accumulation in the farm relative to Case 1 (black curve), while the reduction in Case 3 is subtle ($\Delta Q_{31} \sim 0$, red curve). Although Case 3 was believed to be a favorable operation option claimed by the government and seaweed farmers, the model solidly declines it and suggests simply reducing the discharge.

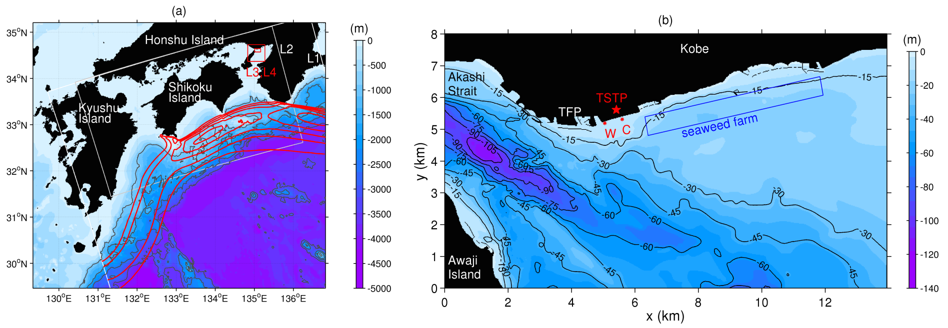

Figure 1. (a) ROMS-L1-L4 domains. (b) ROMS-L4 domain with bathymetry in color (m). The blue box is the seaweed farm area; red star is the location of TSTP; the red dots are the two outfalls (W: western diversion, C: central).

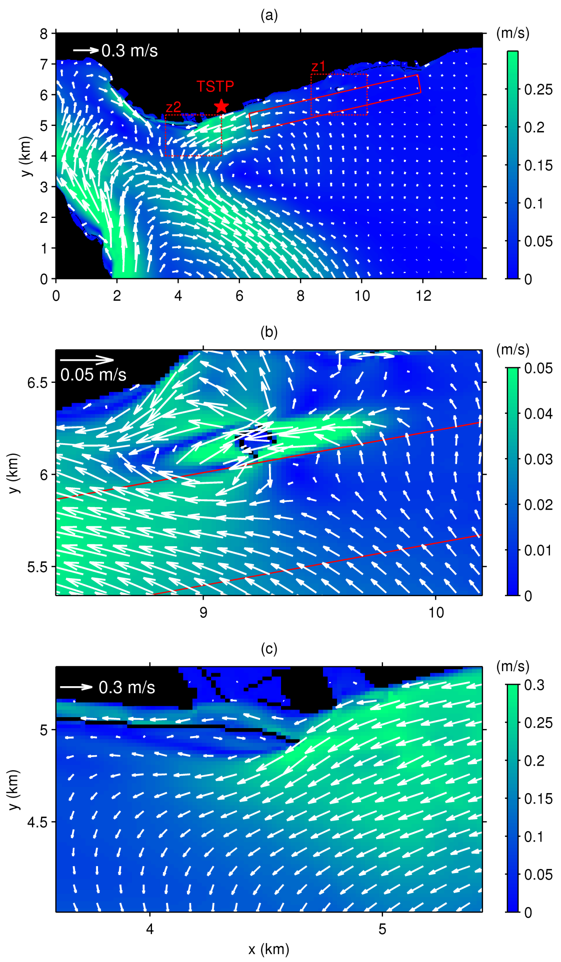

Figure 2. (a) Time-averaged surface velocity vectors (white arrows) on their own magnitude (color). (b) Same as (a) but for the enlarged region shown by the red dotted box (z1) in **Figure 2a**. (c) Same as (a) but for the enlarged region shown by the red dotted box (z2) in **Figure 2a**. The red solid box shows the seaweed farm area.

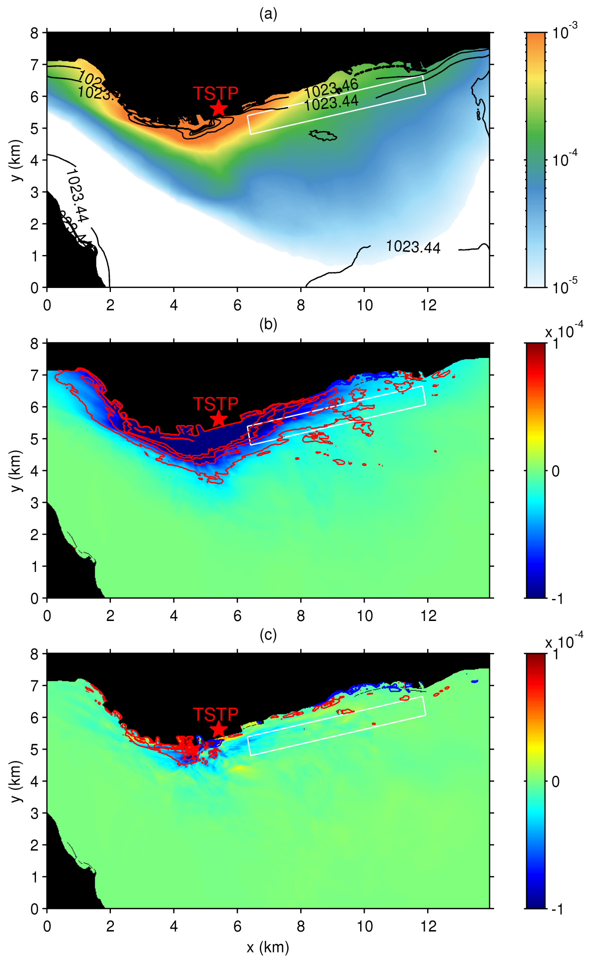

Figure 3. (a) Time-averaged passive tracer concentration, *c* (color, non-dimensional) at the surface for the baseline case (Case 1). The black contours denote the sea surface density at 0.02 kg m^{-3} intervals. (b) The differences in *c* (color, non-dimensional) and density (contours) between Case 2 and Case 1 (Case 2 – Case 1). The red and blue contours are positive and negative values (intervals: 0.001 kg m^{-3}). (c) Same as (b), but for Case 3 – Case 1.

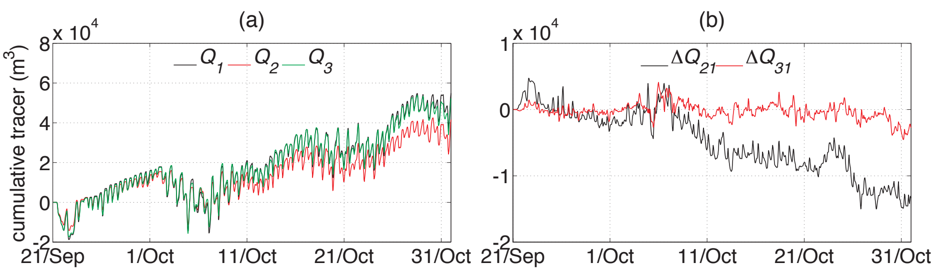

Figure 4. (a) Time series of the temporally cumulative net tracer fluxes stored in the seaweed farm area, Q_{farm} (m^3). (b) The temporal changes in the Q_{farm} (m^3) differences for each case. The black curve ΔQ_{21} is for Case 2 – Case 1, while the red curve ΔQ_{31} is for Case 3 – Case 1.

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