Wastewater dispersal in Osaka Bay and Harima Nada using a multi-nested high-resolution ocean modeling

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Abstract

Anthropogenic land-derived materials in urban wastewater have been recognized to influence on the water quality and the marine ecosystem in Osaka Bay and Harima Nada, Japan. Towards a rigorous environmental assessment of these two semi-enclosed estuaries, a triple-nested high-resolution oceanic modeling framework based on ROMS is developed to investigate the dispersal and dilution of treated swage water effluent released from the subsurface nearshore outfall of Tarumi Sewage Treatment Plant near Akashi Strait. The effluent dispersal in the northeastern Osaka Bay is two-layered and highly reversible in the upper and lower layers due to stratification influenced by freshwater input mainly from Yodo River. The overall effluent load is in the dominant circulation direction of Seto Inland Sea encompassing the two estuaries, substantially controlled by Kuroshio. The estimated cumulative tracer flux for a four-month period is found to accumulate by about 75% in Osaka Bay, while merely 17% exits towards the Pacific.

Keywords - ocean downscaling, ROMS, urban wastewater effluent

1. Introduction

Osaka Bay (OB) and Harima Nada (HN) located off the densely populated Kobe and Osaka areas are encompassed in the northeastern part of Seto Inland Sea (SIS), Japan (Fig. 1). Complex shoreline topography with over 3,000 islands in SIS and riverine inflows play an essential role in formation of quite complicated tidal and estuarine circulations. Uchiyama et al. (2012) reported that the overall circulation in SIS is strongly affected by the seasonally varying Kuroshio path. The water quality, coastal marine ecosystem and aquatic resources in these estuaries are significantly influenced by anthropogenic sewage effluent and river discharges (e.g., Abo et al., 2012). Therefore, for a rigorous hydrodynamic and associated material dispersal modeling for these shallow estuaries, it is necessary to precisely account for boundary conditions to convey the SIS circulations to OB and HN, forcing conditions such as tides, river inputs, and surface wind, and the lateral topography and bathymetry as exactly as possible. To this end, an oceanic downscaling system in a triple nested configuration is developed to conduct a highresolution forward modeling of OB and HN with lateral grid spacing of 200 m. A particular attention is paid to dispersion of sewage effluent released from the subsurface nearshore outfall of Tarumi Sewage Treatment Plant (TSTP) near Akashi Strait (Fig. 1 middle) that is considered to be a potential source of nutrient loads to the inner OB attributed to the clockwise predominant current in SIS.

2. Numerical Model

The outermost boundary condition is provided by JCOPE2, an eddy-resolving, assimilative oceanic reanalysis product with a horizontal grid resolution, dx, of $1/12^{\circ}$ ($dx \approx 10$ km) to bring offshore signals inclusive of influences of Kuroshio into the ROMS-L1 model at dx = 2 km. The triply nested configuration (Fig. 1 left) based on ROMS (Shchepetkin and McWilliams, 2005) successively refines dx = 600 km (L2) to 200 m (L3). The L3 model consists of 800 × 560 horizontal grids with 32 bottom-following, stretched vertical σ -layers. The intermediate L1 and L2 results described in Uchiyama et al. (2012) are exploited for the lateral boundary conditions of the innermost L3 model with a bihourly update to account for high frequency tidal signals. The L3 grid relies on the high-resolution (at dx =50 m) dataset of the topography and the coastal embankments compiled by Japan's Cabinet Office. We use the hourly GPV-MSM product (JMA) for surface wind stresses and the COADS climatology for the other surface forcing. Monthly climatology of freshwater inputs from the 10 major rivers in L3 is taken into account. Sewage effluent is applied in L3 at the location of TSTP as a bottom-released fresh (buoyant) plume at the monitored hourly volume rate with a Gaussian initial dilution submodel to avoid undesirable non-hydrostatic effects. Eulerian passive tracer is additionally released at TSTP to track the effluent. The computational period is chosen for the four-month period from Aug. 1, 2009 to Nov. 29, 2009.



Fig. 1. (Left) ROMS-L1, L2 and L3 domains, (middle) ROMS-L3 domain, (right) blow-up of Osaka Bay and Yodo Line (red line).

3. Effluent Dispersal

Significant differences between the bottom and the surface layers are observed in the passive tracer concentration (i.e., wastewater effluent) released from TSPT. Initially, the tracer in the surface layer (the top-most σ -layer) is mainly transported toward OB and spread southward, whereas the prevailing transport occurs eastward in the bottom layer (the bottom-most σ -layer). On the 16th day, the tracer begins to emerge in the surface layer in the inner part of OB near the month of Yodo River and to subsequently flow westward (Fig.2a). Meanwhile the near-bed tracer has reached the inner bay (Fig.2b). This would be caused by an upwelling associated with an estuarine recirculation in the inner bay near Yodo River that has the largest freshwater input to OB. Once surfaced, the effluent is dispersed over the entire OB due to the mean near-surface flow in the WSW direction. This suggests that the estuarine recirculation is substantial to form a two-layered structure in the inner OB that plays a key role in three-dimensional effluent dispersion.



Fig. 2. Snapshots of the log₁₀-based normalized passive tracer concentration on Aug. 16, 2009, in (a) surface and (b) bottom layers.

4. Vertical Structure

Figure 3 (top panels) shows the monthly-averaged offshore (southwestward) velocity along the Yodo Line (Fig.1). As anticipated in Sec. 3, the lateral velocity in the northeastern OB is two-layered and reversible in the upper and the lower layers due to stratification (not shown) induced by the freshwater input. The interface between the offshore-directed surface current and the shoreward subsurface current is located approximately at 3-5 m deep, corresponding to the mixed layer depths computed with the KPP model. This recirculating reversal clearly leads to the upwelling of the near-bed effluent at the inner OB (Fig. 3 bottom). In week 1 of Aug., 2009, the tracer distributes in the vertical near the release site crossing the pycnocline to deeper than 40 m. In weeks 2 and 3, subsurface intrusion into the lower layer occurs off Kobe with onshore transport of the concentration maxima, and continuously disperses towards the inner bay. In weeks 3 and 4, the tracer surfaces by the upwelling associated with the estuarine recirculation, and then drifts back to the southwest in the upper layer.

5. Tracer Flux Budget

A tracer flux budget analysis is conducted at the three straits (*viz.*, Akashi, Kitan and Naruto). Predominant effluent transport is found to occur westward to HN at Akashi Strait, while in the southward direction to the Pacific at Kitan and Naruto Straits. The cumulative normalized tracer fluxes for the four month period are 1.04×10^6 m³ at Akashi, 1.63×10^6 m³ at Kitan, and 2.28×10^5 m³ at Naruto Strait, respectively. The estimated inventory reveals that 75% and 8% out of the total amount of the released sewage water in the four months are accumulated in OB and HN, albeit the rest (about 17%) disperses towards the Pacific through Kii Channel.

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Fig. 3. Cross-sectional plots of the monthly-averaged offshore (to the SW) velocity (top panels) and of the weekly-averaged normalized tracer concentration in Aug., 2009 (bottom panels). The while curves indicate the corresponding mixed layer depths.