Impact of the Operational Yodogawa Great Barrier on Stratification in Osaka Bay from a High-Resolution Circulation Model of the Seto Inland Sea

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Density stratification is a major driver of the baroclinic effects that determine ocean circulation patterns. Seawater density is influenced by temperature, salinity, and pressure. In the open ocean, where freshwater inputs are minimal, temperature largely explains baroclinic currents. However, in coastal zones, salinity variability, mainly driven by freshwater discharges, significantly impacts density and can outweigh the influence of temperature.

The Yodogawa Great Barrier, constructed in 1983 approximately 10 km upstream of the Yodo River mouth in Osaka (Seto Inland Sea, SIS), is a weir with six vertically adjustable gates. According to Matsumiya et al. (2009), the heights of the two regulating gates and four main gates are controlled between O.P. + 3.6 m (for river discharges below 120 m³/s) and O.P. − 4.0 m (for discharges exceeding 3000 m³/s), where O.P. represents Osaka's lowest low-water level.

This study incorporates the Yodogawa Great Barrier's hydraulic structure into a high-resolution unstructured grid-based SIS circulation model (Jeong and Lee, 2023). The gate heights were adjusted based on river discharge input from the Yodo River. Two scenarios—one with the operational weir and one without (open-channel case)—were simulated to assess the weir's impact on salinity stratification near the river mouth. The simulation period was July 2018, including the torrential rains of July 5, during which the Yodo River's discharge peaked at ~6000 m³/s.

In the open-channel case, freshwater was directly discharged into the bay, forming strong and extensive stratification, extending over 20 km from the river mouth (Figure 1a). Conversely, the operational weir regulated freshwater discharge, trapping it upstream and resulting in weaker, less extensive stratification (Figure 1b). Over time, surface-layer freshwater influenced the entire Osaka Bay in both scenarios. However, the weir operation delayed the ocean's response and altered the horizontal and vertical salinity distributions in the bay.

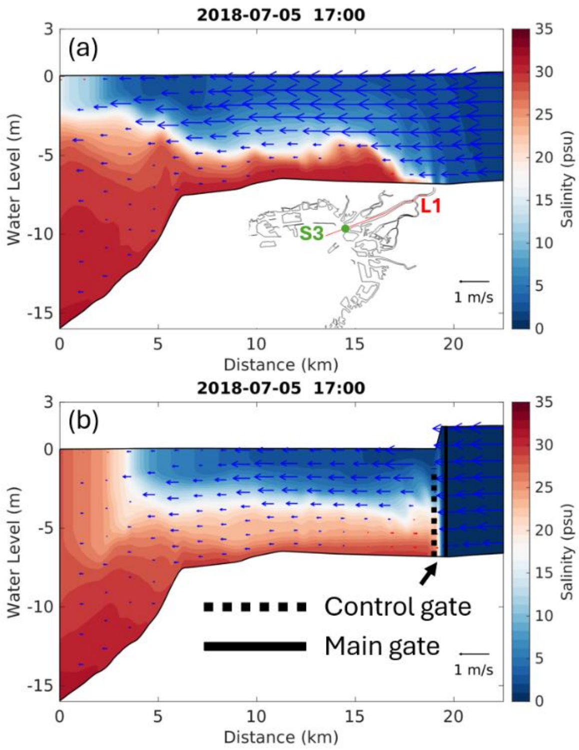

Figure 1. Cross-sectional view (L1) of salinity and currents during the heavy rainfall event of 2018 for (a) the open-channel case and (b) operational-weir case.

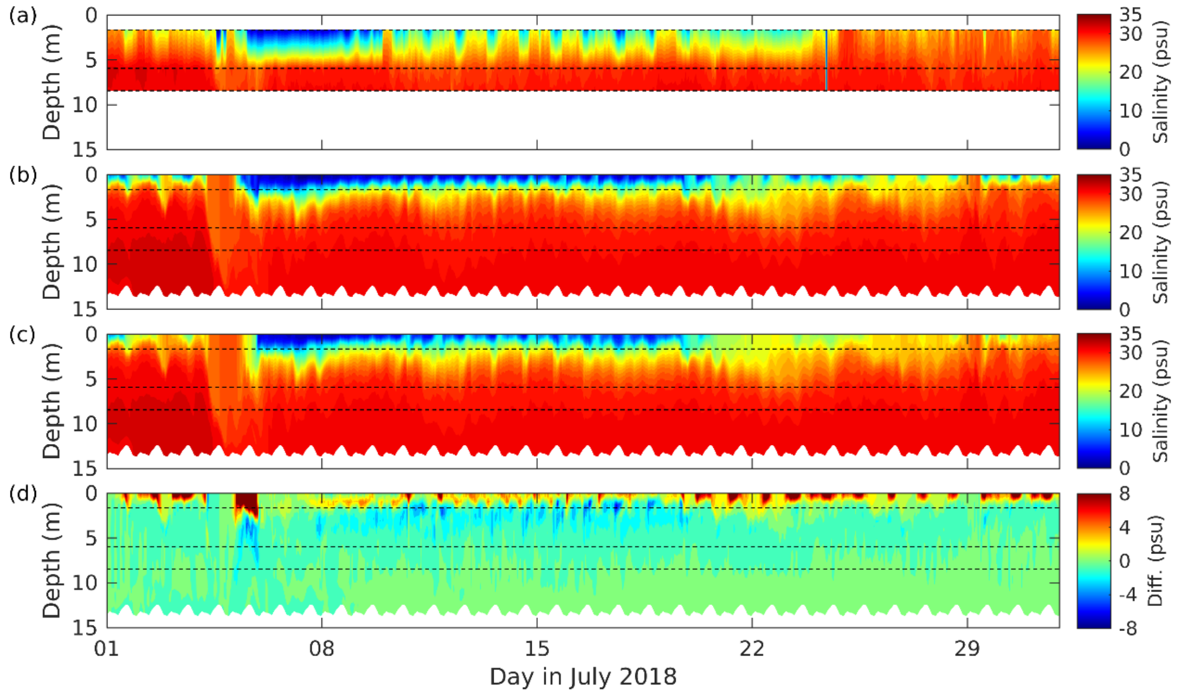

Figure 2. Salinity profiles at the Yodo River mouth (S3 in Figure 1) from (a) observations, (b) the open-channel case, (c) the operational-weir case, and (d) the difference between (b) and (c). Dotted lines indicate the depths of the salinity sensors.

The simulated profiles of salinity showed similar patterns to the observed profiles (as shown in Figure 2a-c). The salinity observation is achieved every hour using fixed sensors at 0.7, 5.0, and 7.5 m depths from C.D.L. (Kansai Airport Chart Datum Level = M.S.L. + 0.95 m) at S3 in Figure 1a.

The stratification, driven by freshwater discharge starting on July 5, primarily developed above a depth of 5 m. During the first week following the rainfall, tidal fluctuations in the stratification were slight, as local freshwater discharge dominated the region. However, as the discharge subsided, tidal patterns began influencing the formation of stratification. These trends were also reproduced in the model results.

The operational weir influenced the timing, magnitude, formation, and dissipation of stratification. Initially, closed gates delayed freshwater discharge, postponing stratification development (Figure 1). Controlled discharge rates subsequently increased surface salinity (where depth < 1.5 m) while reducing salinity in the middle layer (as shown in Figure 2d), weakening stratification during the discharge period (July 8–20). As discharge subsided after July 20, closed gates rapidly diminished stratification (Figure 2a, c), while the open-channel case retained stratification.

This study highlights the significant impact of river discharge regulation on oceanic conditions in narrow river mouths like the 300 m-wide Yodo River. While anthropogenic changes to ocean environments may not always be detrimental, understanding and predicting their potential effects is crucial for sustainable management of coastal and marine systems.

References:

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