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Behavior Analysis of the Open Ocean Water Mass in the Seto Inland Sea via Lagrangian Particle Tracking

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The open ocean water mass has affected the water quality of the Seto Inland Sea. In this study, the entering path and behavior of the open ocean water mass were analyzed using a three-dimensional flow simulation and Lagrangian particle tracking. The analyses revealed that the entering paths changed significantly, depending on the path of the Kuroshio Current. The entering of open ocean water may affect the water quality and primary production not only in the Kii Channel adjacent to the Pacific Ocean but also in other sea areas, including Harima Nada and Osaka Bay.

INTRODUCTION

Understanding the exchange of water with the open ocean is crucial for managing the water quality in enclosed sea areas. The Seto Inland Sea (SIS) is the largest semi-enclosed sea in Japan, with a water area of approximately 23,200 km^2, an average depth of 38 m, and a complex coastline (Fig. 1). The SIS consists of 12 sea areas (bays, nadas, and channels) and is connected to the Pacific Ocean through two channels: the Bungo Channel and the Kii Channel.

Owing to industrial development and population growth in the SIS, pollutant loads from land areas have increased, and eutrophication has become a serious problem. To address this issue, the inflow of pollutant loads from the land has been reduced under strict regulations. As a result, the concentrations of nitrogen and phosphorus have decreased, and the frequency of red tides has also declined. Nutrient concentrations have recently decreased significantly, resulting in oligotrophication, which has raised concerns about aquatic organisms and fishery resources (Abo and Yamamoto, 2019). Therefore, in recent years, measures have been taken to increase nutrient concentrations in seawater in several sea areas of the SIS to increase primary production and fishery productivity. To achieve this goal, it is essential to understand the origins and dynamics of nutrients in the sea. Previous studies have shown that the water quality of the SIS varies greatly, depending on the water mass entering from the open ocean (Takashi et al., 2006; Kobayashi and Fujiwara, 2008). Leng et al. (2023) conducted a three-dimensional numerical simulation and estimated that 61% of the dissolved inorganic nitrogen in the SIS originated from the open ocean. Therefore, the influence of open ocean water is significant, and clarifying the characteristics and behaviors of open ocean water is important for assessing the potential limitations of water quality management in the SIS.

Three-dimensional numerical simulations in the SIS have been conducted (e.g., Chang et al., 2009; Ubara et al., 2021; Leng et al., 2023). However, many of these studies neither included the Pacific Ocean in their computational domains nor considered the influence of the Kuroshio Current. Some studies included the Pacific Ocean in the computational domain but used one-way nesting. Using this method, the disturbances occurring in the small domain are not projected onto the large domain, and the interactions between the two domains cannot be considered. Sakamoto et al. (2016) developed a model that analyzed the SIS and the Pacific Ocean without nesting techniques; however, the spatial resolution was slightly rough and did not accurately reproduce the shapes of the straits. Therefore, the model may not have correctly represented the flow within the SIS.

Based on the above background, we conducted a flow simulation without nesting techniques in the SIS–Pacific Ocean region using a three-dimensional flow model with a high-resolution unstructured grid that can represent complex coastal and straight topographies at a high resolution. Using the flow simulation

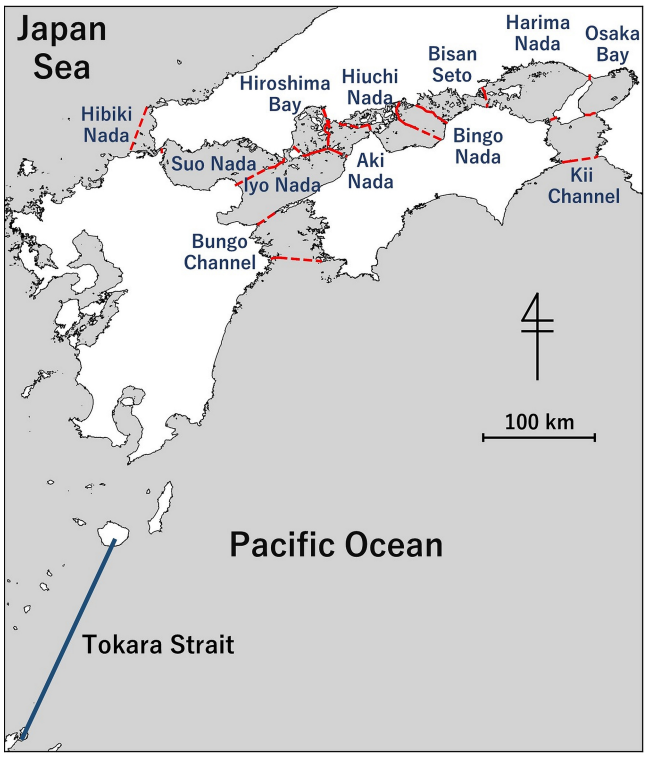

Fig. 1 Bodies of water and watershed areas of the Seto Inland Sea and surrounding areas

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KEY WORDS: Seto Inland Sea, numerical simulation, SCHISM, Lagrangian particle tracking, open ocean water, Kuroshio Current.