Circulation of the Seto Inland Sea Revealed by Particle Tracking Experiments with a High-Resolution Circulation Model

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Riverborne debris can pose physical and chemical threats to coastal ecosystems and infrastructures, especially those near fisheries, aquaculture, or shipping zones where the potential for damage is more critical. Therefore, cleanup campaigns are needed when the volume of debris substantially increases during extreme events, such as typhoon passages and heavy rainfall.

In July 2018, a heavy rainfall event occurred with a precipitation of 1,800 mm over the Chugoku and the Shikoku regions, Japan, causing natural hazards, such as landslides and floods. Hiroshima Prefecture also experienced large floods and sediment discharge from rivers to adjacent seas due to severe heavy rainfall. Riverborne debris is discharged into the coastal Seto Inland Sea (SIS). Subsequently, collection campaigns were conducted spanning more than a month to ensure the safety of oyster farming rafts and other coastal infrastructures.

A particle tracking model called OpenDrift was applied to model the trajectories of buoyant particles over 183 days (6 months from 2 May to 1 November 2018). The particle tracking model utilized seawater circulation in the SIS calculated from a high-resolution unstructured grid-based SIS circulation model.

The analysis was conducted from two perspectives: one focused on the long-term perspective, investigating the spatial patterns of particles originating within the SIS, and the other analysing changes in particle distribution following circulation when meteorological conditions varied.

The initial positions of the particles at the surface layer were evenly distributed across the entire SIS at 2 km intervals (black circles in Figure 1A). The coloured particles represent the final locations after 183 days. In contrast to their initial positions, the last distribution of the particles exhibited broad dispersal over 6 months.

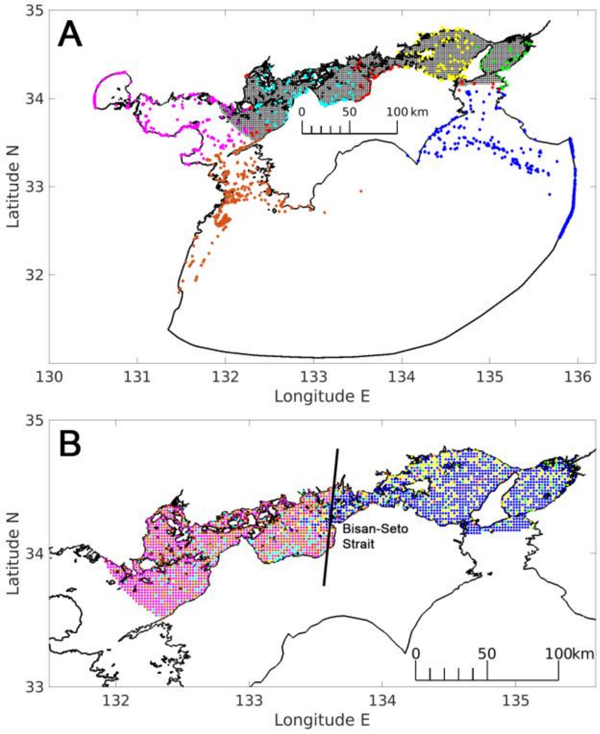

Figure 1. Particle tracking model results at the surface layer (0 m). (A) Initial positions of the particles (black circles) and the last positions of the particles after 183 days, grouped by colour. (B) Original positions of the grouped particles.

The coloured particles were traced back to their original positions to investigate the spatial distribution of their origin (Figure 1B). These particles were divided into two distinct groups from the Bisan-Seto Strait boundary, indicating that surface debris discharged into the western side of the SIS do not generally traverse the Bisan-Seto Strait. Consequently, the debris either remained on the western side for six months or was transported out of the SIS through the Bungo Channel. In contrast, particles on the eastern side were swiftly transported and reached the open boundary of the SIS model, while those on the western side struggled to exit the SIS.

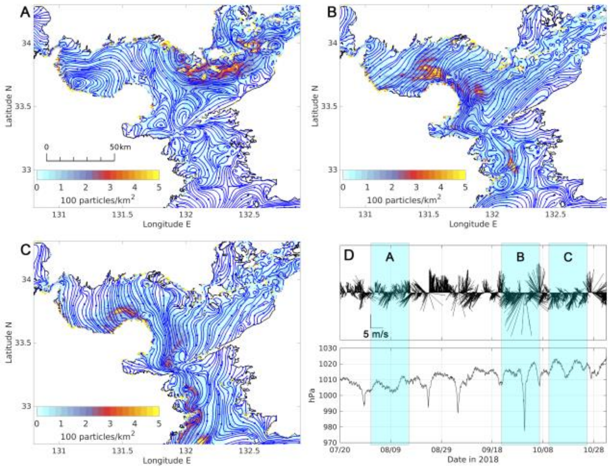

Figure 2. Particle density distribution and streamlines for 15 days in the surface layer (0 m) near the Bungo Channel (A) during ordinary conditions, (B) during typhoon passage, and (C) after typhoon passage. (D) Surface wind vectors (upper) and air pressure (lower)

The number of particles within each grid (1 km × 1 km) was counted for three distinct periods (15 days each): ordinary condition, typhoon passage, and post typhoon, as illustrated in Figure 2D. The particle density field depicted the regions where debris could exist with high probability during each respective period. Afterwards, streamlines were calculated using velocity vector fields. These streamlines exhibited continuous variations, reflecting external forcings such as tides and meteorological factors.

Figures 2 and 3 were generated by combining the aforementioned particle density fields with streamlines to elucidate the movements of particles based on varying meteorological conditions.

Due to the southwestward current fields by surface winds, Figure 2B reveals higher concentrations of particles along the western coastlines. Despite this, the majority of the particles still remained within the SIS. After two weeks, a significant number of particles were transported outside the SIS through the Bungo Channel, marking the first instance of such transportation in five months. This pattern is unusual under ordinary conditions, as the water volume flux through the Bungo Channel is inflow dominant (not shown here). The typhoon in September 2018 seemed to trigger outflow through the Bungo Channel, increasing the likelihood of particles escaping from the SIS.

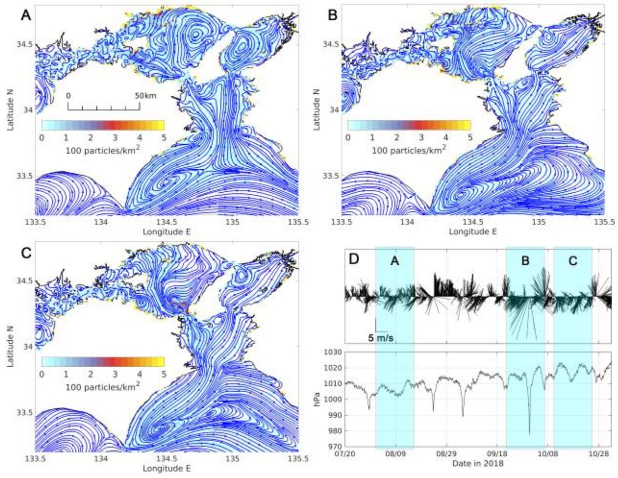

Figure 3. Particle density distribution and streamlines for 15 days in the surface layer (0 m) near the Kii Channel (A) during ordinary conditions, (B) during typhoon passage, and (C) after typhoon passage. (D) Surface wind vectors (upper) and air pressure (lower)

The eastern part of the SIS was analysed, as shown in Figure 3. During ordinary weather, one distinct circulation pattern developed in each basin (Figure 3A). However, the northeastern winds induced by the typhoon dissipated the existing circulations. Examining the particle density fields, it was difficult to identify high-density areas within the three analysed periods. This was because most of the particles had already been transported out of the SIS before August, as shown in Figure 1A, which was attributed to the strong outflow through the eastern channel, the Kii Channel.

If particles are transported outside, the outer costal cities could be contaminated instead of the cities inside the SIS. Therefore, it is important to proactively collect debris in the eastern part of the SIS before it becomes dispersed. For the western part, more effective collection can be conducted when a cleanup campaign focuses on the area where the particles were highly concentrated.