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Intermittent outflow of high-turbidity bottom water from Tokyo Bay in summer*

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Abstract: An intermittent outflow event of high-turbidity bottom water from Tokyo Bay was observed in summer 1987. As the Kuroshio front approaches to the coast, the intermediate water in Tokyo Bay with the same density of Kuroshio water increases its thickness and the high-turbidity surface and bottom waters in Tokyo Bay are pushed out offshore into the surface and intermediate layers of shelf water, respectively. Such events are thought to happen frequently in summer.

1. Introduction

The intermittent outflow of high-turbidity bottom water from Tokyo Bay in summer has been spoken by local fishermen and some ocean researchers. However, the detailed observation on such outflow of high-turbidity bottom water from Tokyo Bay has not been carried out because such a phenomenon is highly intermittent.

We were fortunately able to observe such intermittent outflow of high-turbidity bottom water from Tokyo Bay in the cruise of KT-87-9 by R/V Tansei-Maru, Ocean Research Institute, University of Tokyo. We will show the result of our observation and discuss on the mechanism and the significance of such intermittent outflow of high-turbidity bottom water from Tokyo Bay in this paper.

2. Observation

The field observation was carried out in Tokyo Bay (Fig. 1) by R/V Tansei-Maru from 2 July to 7 July 1987. The horizontal variations in surface (5 m below the sea surface) water temperature and salinity were continuously measured with use of thermistor and salinometer along the track of R/V Tansei-Maru. The vertical profiles of water temperature, salinity, dissolved oxygen and beam-transmittancy were observed as quickly as possible with use of the OCTOPUS system (ISHIMARU *et al.*, 1984). The OCTOPUS observations were carried out three times at the mouth of Tokyo Bay, from Stn. 8 to Stn. 15 on 3 July, from Stn. 17 to Stn. 29 on 4 July and from Stn. 30 to Stn. 39 on 7 July. The OCTOPUS observation was also carried out in Tokyo Bay from Stn. G-3 to Stn. G-28 on 6 July.

3. Results

Figure 2 shows the vertical distributions of water temperature, salinity, density, beam-transmittancy and dissolved oxygen from the head of Tokyo Bay to the Kuroshio water. The density stratification is well developed in Tokyo Bay and the main pycnocline exists at about 10 m below the sea surface. The water in Tokyo Bay is vertically divided into three layers, that is, the surface water with high water temperature (>21°C), low salinity (<32), low density in sigma t (<22), low transmittancy (<10 %), and high dissolved oxygen (>80%) which exists between 0 m and 10 m below the sea surface, the intermediate water with moderate water temperature (19–20°C), moderate salinity (33–34), moderate density (23–24), moderate transmittancy (20–40%) and moderate dissolved oxygen (50–80%) which exists between 10 m and 30 m below the sea surface, and the bottom water with low water temperature (<19°C), high salinity

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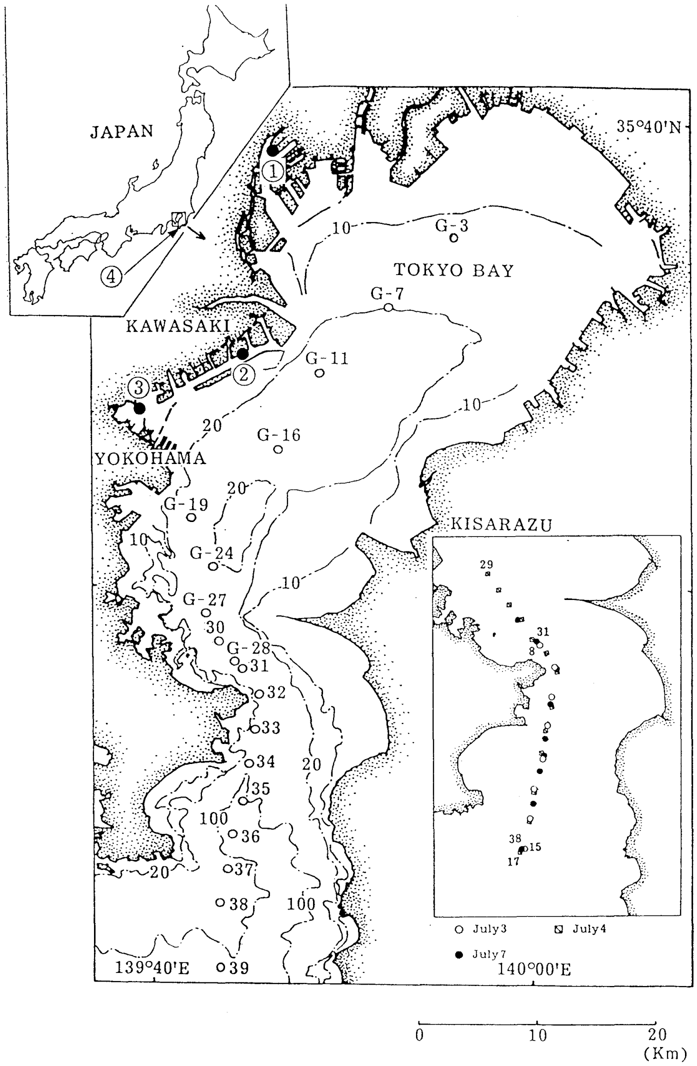

Fig. 1. Observation stations by R/V *Tansei-Maru* in Tokyo Bay. Broken line shows the depth contour and numbers show the depth in meter. Numbers in the circle show the observation stations of sea level. ① Tokyo, ② Kawasaki, ③ Yamanouchi and ④ Mera.

(>34), high density (>24), low transmittancy (<20%) and low dissolved oxygen (<50%) which exists between 30 m and 50 m below the sea surface.

On the other hand, the Kuroshio water which exists in the surface layer around Stn. 39 is characterized by the highest water temperature (>23°C), high salinity (>34), moderate density (23–24), high transmittancy (>70%) and high dissolved oxygen (>90%).

Figure 3 shows the day-to-day variations in vertical distributions of transmittancy around the mouth of Tokyo Bay. There is no high-turbidity (low transmittancy) water (hereafter it is referred to as H.T.W.) along the shelf slope at Stns. 2, 3 and 4 on 3 July but H.T.W. whose transmittancy is smaller than 40% exists between 40 m and 50 m depth around Stns. 21 and 22 on 4 July. H.T.W. exists between 40 m and 90 m depth along the shelf slope on 7 July. Figure 4 shows the day-to-day variation in vertical profile of transmittancy at the shoulder of the shelf

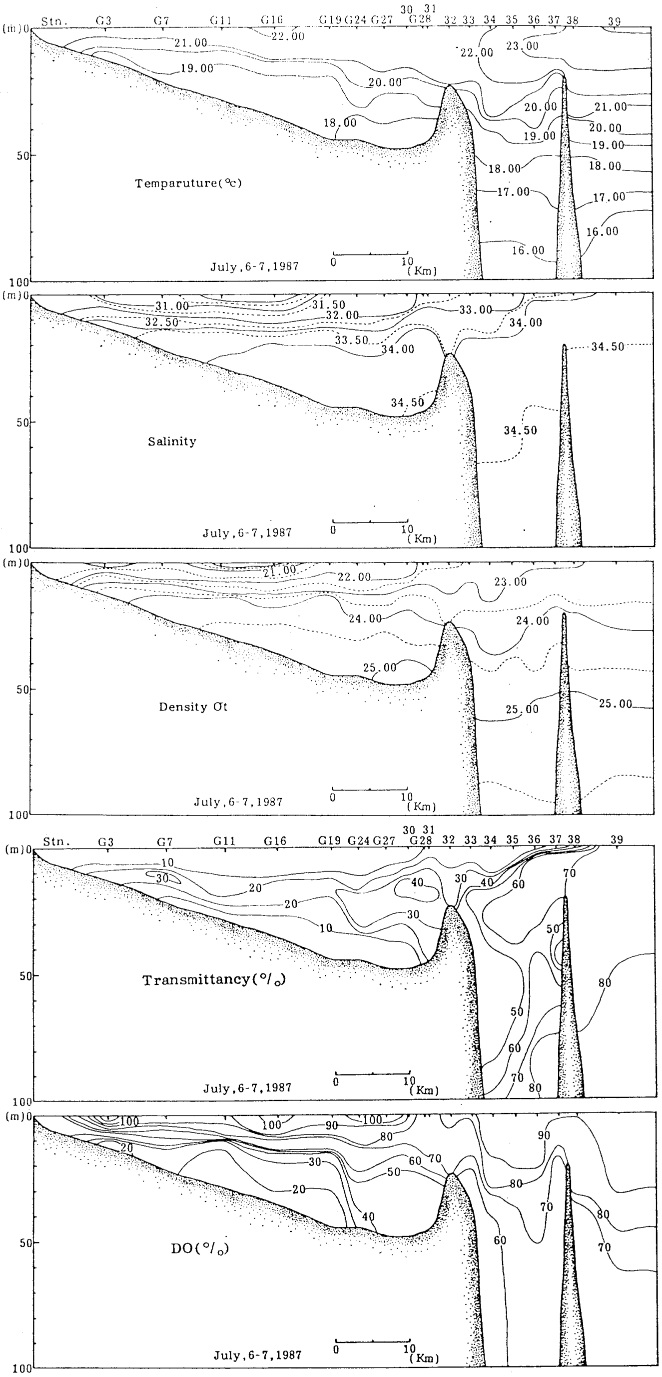

Fig. 2. Vertical distributions of water temperature, salinity, density, beam-transmittancy and dissolved oxygen along the center line of Tokyo Bay on 6-7 July 1987.

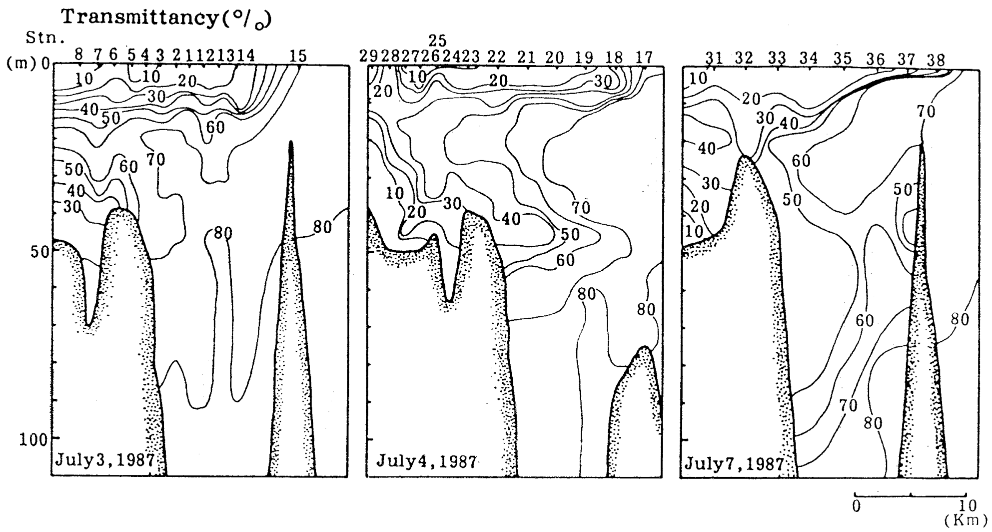

Fig. 3. Day-to-day variations in vertical distributions of beam-transmittancy at the mouth of Tokyo Bay from 3 to 7 July 1987.

slope, that is, at the mouth of Tokyo Bay. The water of low transmittancy exists in the surface layer and that of high transmittancy below the 10 m depth on 3 July, but the vertical profile of transmittancy drastically changes next day. The water of low transmittancy exists between 40 m and 50 m depth on 4 July and there is no change in vertical profile of transmittancy above 25 m depth and below 70 m depth. The subsurface H.T.W. exists between 40 m and 90 m depth on 7 July.

Figure 5 shows the day-to-day variation in density distribution along the same vertical section of Fig. 3. The Kuroshio water whose transmittancy is larger than 70 % and whose density is between 23.5 and 24.0 (shown by dotted area in Fig. 5) exists at the intermediate layer of Stn. 4 around the mouth of Tokyo Bay, and the bottom water of Tokyo Bay whose transmittancy is smaller than 40 % and whose density is between 24.5 and 25.0 (shown by inclined full line area in Fig. 5) at the bottom layer of Stn. 6 on 3 July. The thickness of Kuroshio water in the intermediate layer of Tokyo Bay increases around Stn. 26 on 4 July from Figs. 3 and 5. At the same time, the bottom water of Tokyo Bay appears on the shoulder of the shelf slope around Stn. 21 on 4 July. The density distribution on 7 July is rather different from those on 3 and 4 July, and

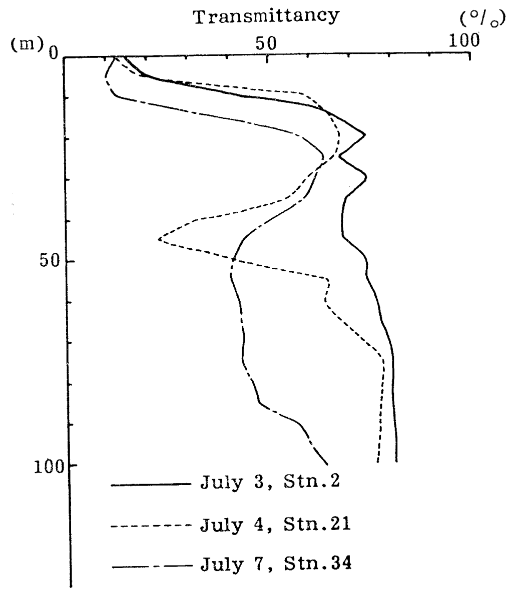

Fig. 4. Day-to-day variations in vertical profile of beam-transmittancy at the shoulder of Tokyo Bay from 3 to 7 July 1987.

the bottom water of Tokyo Bay whose density is between 24.5 and 25.0 and whose transmittancy is smaller than 50 % exists along the shelf slope.

4. Discussion

The temporal variations in density and transmittancy distributions from 3 to 4 July, which

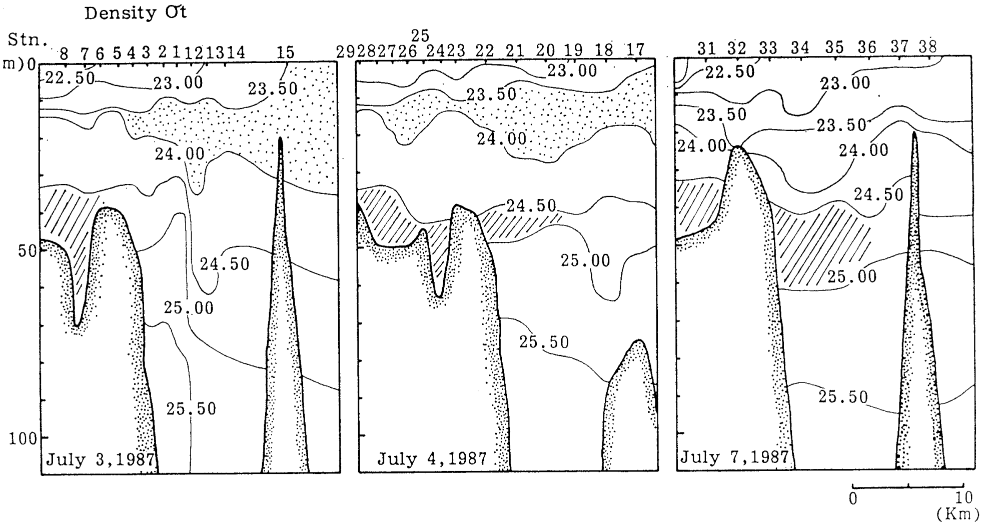

Fig. 5. Day-to-day variations in vertical distribution of density at the mouth of Tokyo Bay from 3 to 7 July 1987. Dotted area shows the Kuroshio water and shadow area the bottom water of Tokyo Bay.

are shown in Figs. 3, 4 and 5, suggests that the Kuroshio water intrudes into the intermediate layer of Tokyo Bay and the bottom water of Tokyo Bay extrudes into the intermediate layer of the open ocean in turn. The mechanism of outflow of H.T.W. in the bottom layer of Tokyo Bay is considered in this section. Figure 6 shows the day-to-day variation in horizontal distribution of surface salinity along the observation lines which are shown in Fig. 1. The value of salinity 34 which is shown by the arrow in Fig. 6 denotes the Kuroshio front. The Kuroshio front exists at the northern position on 2 and 5 July and this means the Kuroshio water approaches to the coast. The Kuroshio front shifts southward on 3, 4 and 7 July. The response of the water in Tokyo Bay to such approaching of the Kuroshio front may be schematically represented in Fig. 7. Before approaching of the Kuroshio front to the coast, the water in Tokyo Bay is stratified in three layers, that is, surface, intermediate and bottom waters (Fig. 7a). When the Kuroshio front approaches near the coast, the Kuroshio water intrudes into the intermediate layer of Tokyo Bay because the Kuroshio water has the same density as that of the intermediate water in Tokyo Bay. Then the surface and bottom waters in Tokyo Bay are pushed off out of the bay (Fig. 7b). The intruding Kuroshio water is advected eastward (flows into the panel in Fig. 7b) and the surface and bottom waters pushed out of the bay are advected westward (flow from the panel in Fig. 7b) due to the Coriolis effect, and the intermediate water becomes thin and the surface and the bottom waters become thick along the observation section which is located in the western part of Tokyo Bay (Fig. 7c).

The situation on 3 July may correspond to Fig. 7a and that on 4 July to Fig. 7b. That on 7 July is considered to correspond to Fig. 7c of another event from Fig. 6 and Fig. 7 which will be shown in the followings.

We will examine the relation of such intermittent outflow of bottom water from Tokyo Bay to temporal variation of the mean sea level in Tokyo Bay. Figure 8 shows temporal variations of the mean sea level at 4 stations around Tokyo Bay. They were obtained by low-pass filtering of the sea level data every hour, which were observed by Japan Meteorology Agency with use of the tide-killer filter (HANAWA and MITUDERA, 1985) and adjusted by air pressure variation at Tokyo. There is a distinct positive anomaly peak of the mean sea level during this observation period from 2 July to 7 July, and the day of this anomaly peak (5 July) well coincides with the day of the approaching of the

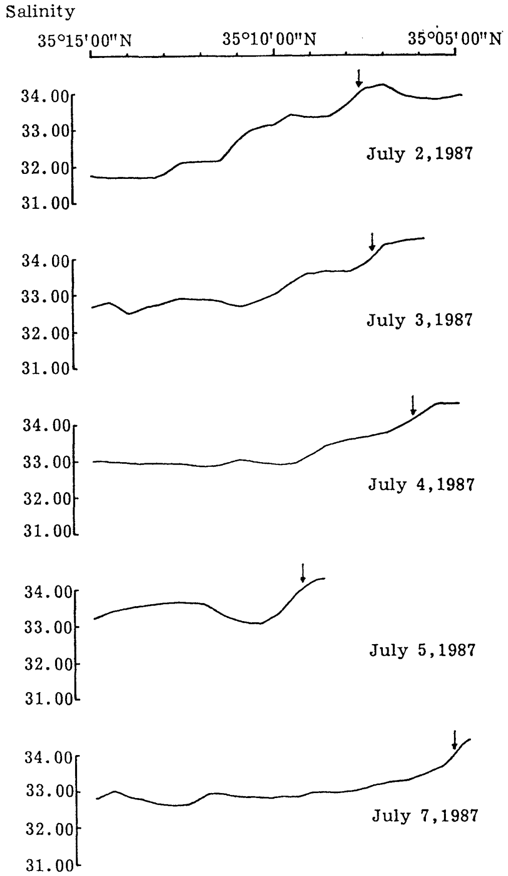

Fig. 6. Day-to-day variations in surface (−5 m) salinity distribution along the north-to-south observation line at the mouth of Tokyo Bay from 2 to 7 July 1987. Arrow shows the position of the Kuroshio front.

Kuroshio front to the coast (5 July) shown in Fig. 6. Such result suggests that the approaching of the Kuroshio front to the coast may be monitored by the temporal variation of the mean sea level in Tokyo Bay. Such positive anomaly peaks of the mean sea level can be frequently seen with the period of about a week in Fig. 8. Positive anomaly peak of the mean sea level may be generated by the strong wind blowing in the coastal sea, but there was no strong wind blowing in this period. Therefore, positive anomaly peaks of the mean sea level in Fig. 8 are mainly related to the approaching of the Kuroshio front to the coast and the outflow of bottom water from Tokyo Bay is considered to happen frequently in summer.

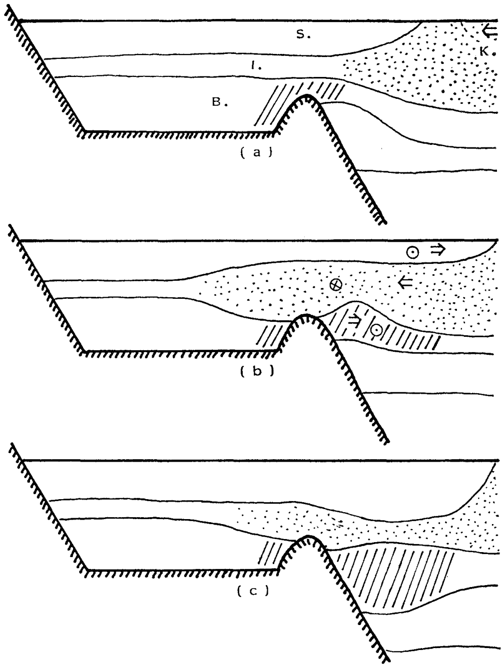

Fig. 7. Schematic representation of intermittent outflow of surface and bottom waters of Tokyo Bay related to the inflow of Kuroshio water. S, surface water of Tokyo Bay; I, intermediate water of Tokyo Bay; B, bottom water of Tokyo Bay; and K, Kuroshio water.

Our field data on the intermittent outflow of H.T.W. from Tokyo Bay are rather limited, but we believe that this report will be useful for planning the observation at the mouth of Tokyo Bay in the future. Moreover, the result of this paper will give a new idea on the water exchange through the mouth of Tokyo Bay in summer. We ourselves will clarify quantitatively the mechanism of intrusion of the Kuroshio water into the intermediate layer of Tokyo Bay and the role of such intermittent outflow of surface and bottom waters from Tokyo Bay to the water exchange between Tokyo Bay and the open ocean.

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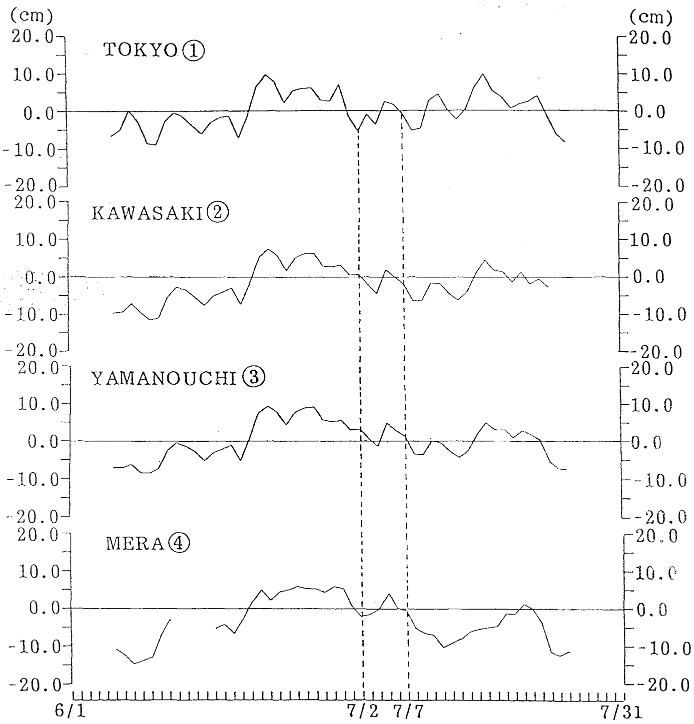

Fig. 8. Day-to-day variations of low-passed sea level at Tokyo ①, Kawasaki ②, Yamanouchi ③ and Mera ④. Observation stations are shown in Fig. 1. Zero means the mean sea level from 1 June to 31 July.

Ministry of Education, Science and Culture, Japan.

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夏季東京湾の高濁度底層水の間欠的流出

柳　哲雄・田丸浩之・石丸　隆・才野敏郎

要旨: 1987 年夏東京湾の高濁度底層水の間欠的流出現象を観測した。黒潮フロントが接岸すると，黒潮水は等密度の東京湾中層に流入し，高濁度の東京湾表層水と底層水は湾外に流出する。このような現象は夏季しばしば発生しているらしい。