Journal of Tokyo University of Fisheries, Vol. 89, pp. 25-35, 2003

Outflow and Inflow of Suspended particles at the Mouth of Tokyo Bay

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(Received August 29, 2002)

Abstract: The movement of the water mass off Kannon-zaki is influenced significantly by tidal variations. During the flood tide, seawater with a low temperature, high salinity, and low turbidity flows to the north especially through the bottom layer. During the ebb tide, seawater with a high temperature, low salinity and high turbidity flows to the south through both the surface layer and the bottom layer. On the other hand, the movement of the water mass off Futtsu-misaki corresponds to the tidal current. During the flood tide, high turbidity seawater flows to the northwest through the bottom layer. During the ebb tide, seawater with high temperature and high turbidity in the surface layer, and seawater with low temperature, high salinity, and low turbidity in the bottom layer flows to the southeast. The outflow and inflow of suspended solids during the one day were as follows. Off Kannon-zaki in June, there were outflows of 7.3 kg/m^2/day through the upper layer, and inflows of 11.3 kg/m^2/day through the lower layer. On the other hand, off Futtsu-misaki in September, there were outflows of 7.2 kg/m^2/day through the upper layer, and inflows of 4.9 kg/m^2/day through the lower layer. At the mouth of Tokyo Bay, the exchange rate of suspended solids in the upper layer was higher than that in the lower layer. Notably, the difference was much larger on the Kannon-zaki side. Thus it is considered that turbid seawater at the mouth of Tokyo Bay flows out through the upper layer, part of it reaches the open sea, and the rest returns through the lower layer to the inner bay area.

Key words: *Tokyo Bay, Turbidity, Suspended particles, Exchange rate*

Introduction

The turbidity of Tokyo Bay started to increase from the 1950's and reached a maximum in the early 1970's, and then decreased slightly with the implementation of various waste-water regulations[1]. Even at present, however, the turbidity is extremely high in the region to the north of Kannon-zaki and Futtsu-misaki because of particulate organic matter coupled with eutrophication. The distribution and characteristics of turbidity in the bay have been detailed for various component factors [2, 3], however, the balance of turbidity-causing materials, namely of suspended particles, has not been investigated in detail.

In order to understand the balance of suspended particles in Tokyo Bay, which is the origin of turbidity, it is necessary to accurately estimate (1) load from the rivers, (2) quantity of sediment precipitated to the bottom of the sea, (3) quantity of outflow and inflow around the bay, and (4) quantity of increased organic particles. Concerning (1), Ishiwatari [4]estimated that the particle load from the rivers amounted to 10^5 tons annually. Concerning (2), Matsumoto[5]estimated the average rate of sedimentation of particles in the inner part of Tokyo Bay to be 0.18 g/cm^2 yr. As for (3), there are reports by Matsumoto et al. [6], Matsuike et al. [2], Yanagi et al. [7], and Yanagi et al. [8]. Matsumoto et al. [6] reported that the suspended material outflow and inflow at the mouth of the bay took place by the residual current and the exchange of seawater by the tidal oscillation and that the exchange rate of seawater was 8-10% . Matsuike et al. [2] found that low turbidity water outside the bay flowed in through the lower layer off the Boso Peninsula and high turbidity water inside the bay flowed out through the upper layer off the Miura Peninsula. Yanagi et al. [7] found an intermittent outflow phenomenon of high turbidity bottom water through repeated observations of the turbidity along the Uraga Channel. They estimated the settling rate of the water mass along the slope of the continental shelf to be 40 m/day. In addition, Yanagi et al. [8] found a high turbidity layer developed on the shelf slope at the mouth of Tokyo Bay, which exhibited a significant seasonal change. Concerning (4), Ogura [9] investigated the seasonal change of particulate organic carbon (POC) and dissolved organic carbon (DOC) inside the bay. However, there is no research in regard to the outflow and inflow of suspended particles at the mouth of the bay and also no quantitative investigation about the increase of organic particles inside the bay.

In order to obtain quantitative information concerning

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(3), we set up observation stations off Kannon-zaki and Futtsu-misaki, which are at the mouth of Tokyo Bay. We investigated the dependence of turbidity on the tidal change and calculated the amount of outflow and inflow of suspended particles at the mouth of the bay.

Observations

The observations were carried out by the RT/V Seiyo-maru (167 Gt) of Tokyo University of Fisheries. Two stations (Stas. A and B) were set up near the mouth of Tokyo Bay (Fig. 1). Station A was located at 1.5 km off Kannon-zaki and west side of the Uraga Channel (water depth of 33 m) (35 ° 14.7 ′ N, 139 ° 45.7 ′ E). Station B was located at 3.8 km off Futtsu-misaki and east side of the Uraga Channel (water depth of 30 m) (35 ° 16.6 ′ N, 139 ° 46.7 ′ E). The observation periods for each station Sta. A and Sta. B were from 14:00 on June 1 to 15:00 on June 2, 1989 and from 13:30 on September 26 to 14:30 on September 27, 1989, each for 25 hours for off Kannon-zaki and off Futtsu-misaki, respectively. Further, for comparison with data seaward of the mouth of Tokyo Bay Sta. C (35 ° 8.95 ′ N, 139 ° 47.8 ′ E) was set off Kanaya and observations at Sta. C were performed at 16:00 on June 2 and at 16:40 on September 27.

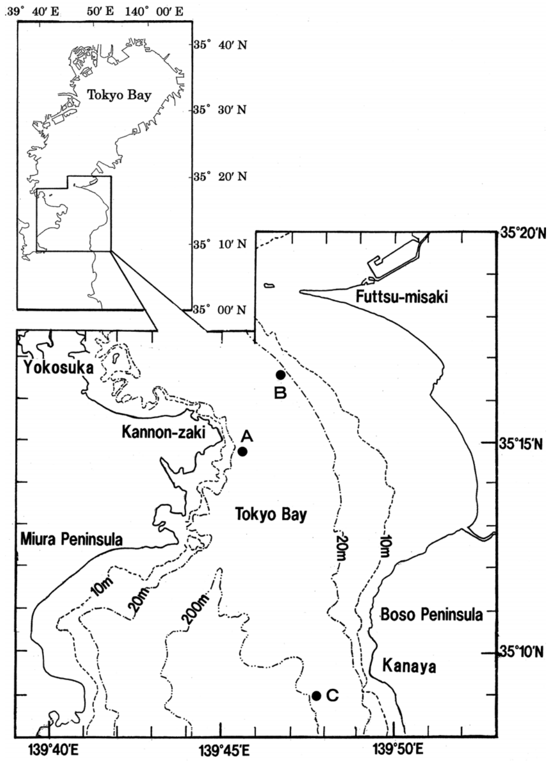

Figure 1. Observation stations at the mouth of Tokyo Bay. Symbols A and B indicate observation stations off Kannon-zaki and off Futtsu-misaki, respectively. Symbol C is a comparison point.

Measurements were performed for current velocity, water temperature, salinity, turbidity, suspended solids (SS), and ignition loss (IL). A self-recording current meter (Aanderaa, Inc. RCM-4S type) was used for the measurement of current velocity. The current meter was lowered from the anchored ship to a depth of 5 m and 20 m, and the measurement was performed over the 25 hour duration. The measurements of water temperature, salinity, and turbidity were performed with a multi-parameter water quality meter, TS-WQ-2 type (Tsurumi Seiki, Inc.). This meter was lowered every 3 hours from the ship, and the perpendicular distribution of the parameters from the surface to the bottom layer was measured. A turbidity sensor attached to the multi-parameter water quality meter was an optical nephelometer. The amount of suspended solids (SS, mg/l) was determined by sampling seawater by a Van Dorn water sampler, filtering through a Millipore filter (type HA, pore size; 0.45 μm) under reduced pressure, drying at 70 ℃ for 2 hours, and weighing the sample. After determining SS, the ignition residue was determined by placing the sample in a platinum crucible, heating the crucible in a muffle furnace at 500 ℃ for 4 hours, and weighing the residue. The percent content of organic matter in the total suspended solids was determined by the following equation.

$$IL = \left(1 - \frac{m_i}{m_s}\right) \times 100$$

where IL indicates ignition loss (%), m_i and m_s is the weight of the residue in the crucible and the weight of the suspended solids, respectively.

It has been established that the relationship between the turbidity (ppm) measured by an optical nephelometer and amount of suspended solids (SS; mg/l) is linear [for example 2)]. However, the slope of the equation is not constant because the average particle size and particle density depends on the dominant species of phytoplankton in the sea region[10)]. Also, it is not reasonable to apply the conventional conversion from the turbidity to the concentration of Kaolinite to the estimation of the amount of suspended solids in the actual ocean. In the present study, a regression line, as a conversion equation, was obtained by applying the least-squares method for the relationship between the measured turbidity data and the amount of suspended solids (SS) at Tokyo Bay (Fig. 2). The relationships are expressed as follows for June and September of 1989;

June, 1989: $Y = 0.614X - 0.346$, $(r = 0.846)$

September, 1989: $Y = 0.533X + 2.329$, $(r = 0.667)$

where Y is the turbidity (ppm) and X the SS (mg/l). These relationships will be used for the conversion of turbidity to the amount of suspended solids.

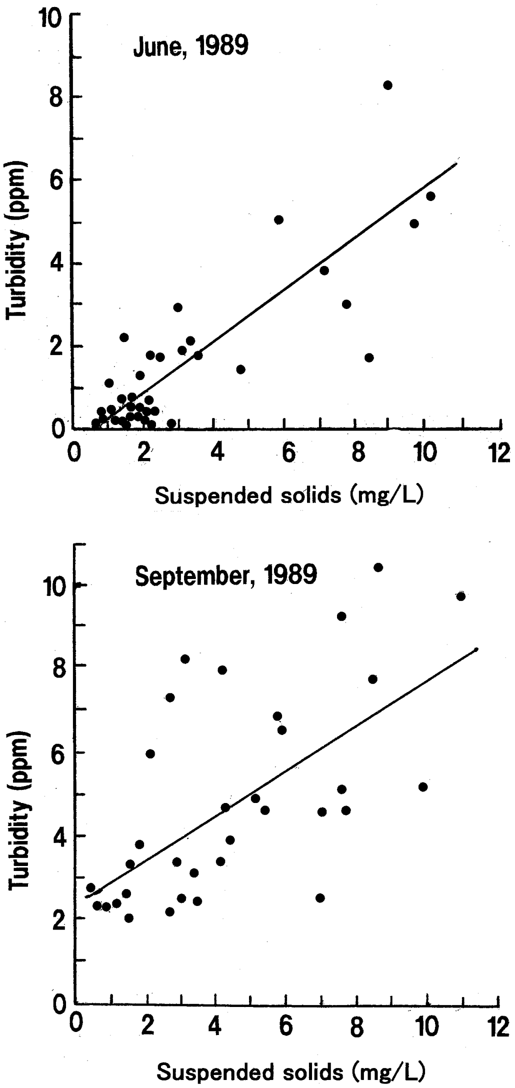

Figure 2. Relationship between suspended solids (SS) and turbidity (ppm).
The upper graph shows the relationship for June 1989 off Kannon-zaki and the lower graph for September 1989 off Futtsu-misaki, Tokyo Bay.

Results and Discussion

Fluxes of the water mass and turbidity off Kannon-zaki

Figure 3 shows the time variation at station A of the tidal level, the northward and eastward components of the current velocity at 5 m, the northward and eastward components of the current velocity at 20 m, and the water temperature, salinity, and turbidity. In Fig. 3a the tidal levels are shown on the observation dates using data for the Yokosuka Port near off Kannon-zaki. At Yokosuka Port, the lower high tide (L.H.) and higher high tide (H.H.) were at 15:38 on June 1 and 2:29 on June 2, respectively, and higher low tide (H.L.) and lower low tide (L.L.) were at 21:02, June 1 and 9:39, June 2, respectively.

The relationship between the tidal levels and the current velocity was examined. At 5 m (Fig. 3b), the southward component of the velocity was large during the ebb tide, and northward component was large during the flood tide, showing a standard oscillation. The eastward component of the velocity is small in comparison with the northward component. The current velocity at 20 m (Fig. 3c) also closely corresponded with the change of tide, namely a southward current during the ebb tide and a northward current during the flood tide. This trend closely approximates the case at 5 m. The cross-correlation coefficient between the tide and the northward component at 5 m and 20 m were calculated. The maximum positive coefficients were 0.46 at 5 m when the delay of tide is 260 minutes, and 0.89 at 20 m when the delay of tide is 180 minutes, respectively.

The relationship between the characteristics of the water mass and the tides was examined. As shown in Figs. 3d and 3e, at the lower high tide (L.H.), high temperature and low salinity water was found in the surface layer, while low temperature and high salinity water was found from 25 m to the bottom. During the ebb to the higher low tide (H.L.), high temperature and low salinity water occurred in the surface layer and low temperature and high salinity water near the bottom layer disappeared. After that, there was no substantial change in the water temperature and salinity until the higher high tide (H.H.). On the other hand, during the ebb from the higher high tide (H.H.) to the lower low tide (L.L.), the water temperature markedly increased below 15 m and the salinity decreased. At the lower low tide (L.L.) the water temperature was 18.5 ℃ and the salinity was 32.5-33.0 psu. When the tide changed to the flood tide, the water temperature markedly decreased to a minima of 17℃ and the salinity increased to a maxima 33.5 psu.

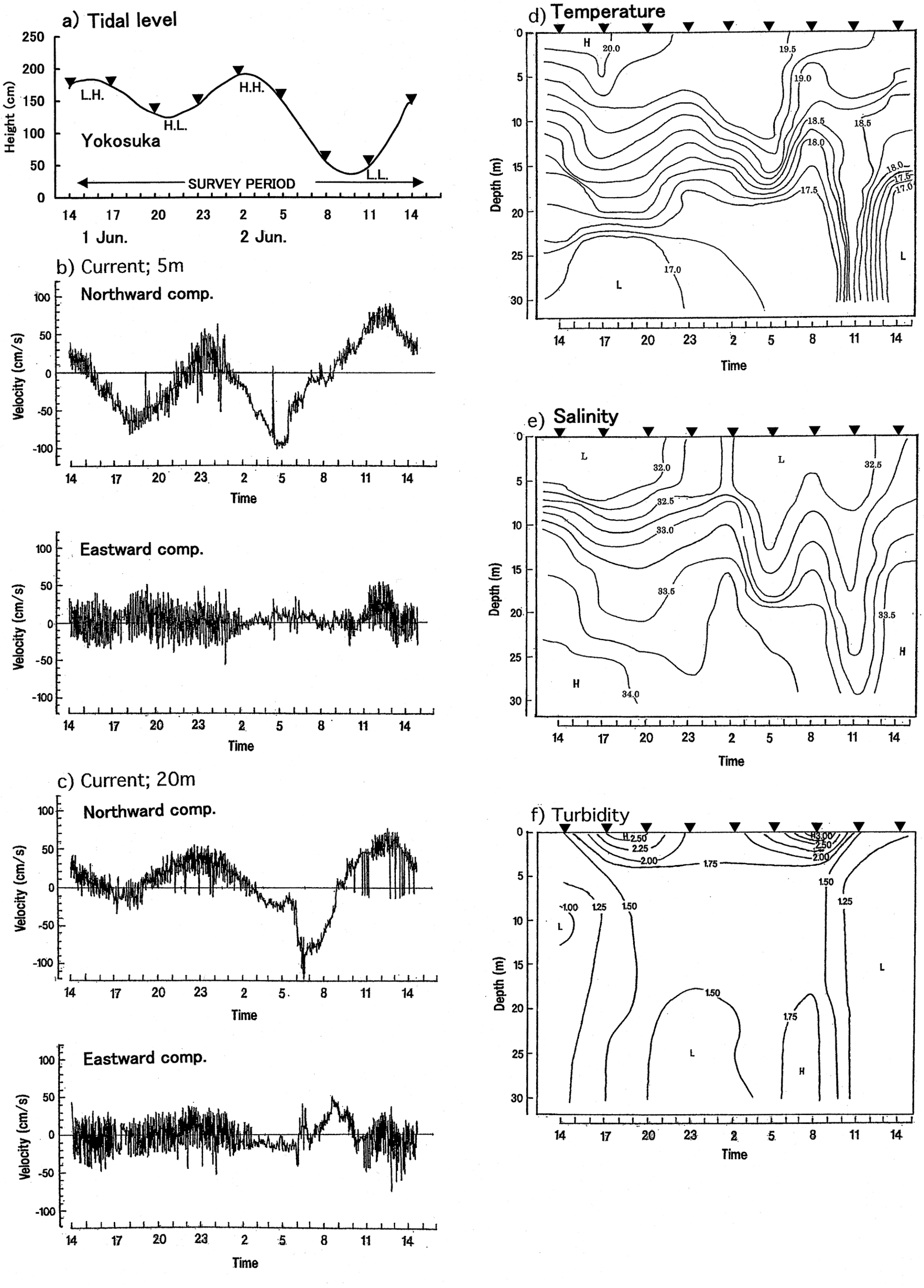

Figure 3. Variations of tidal level, northward and eastward components of current velocity at the depth of 5m and 20m, temperature, salinity, and turbidity off Kannon-zaki.
The symbols ▼ indicate the observation times. H.H., L.H., H.L., and L.L. are higher high tide, lower high tide, higher low tide, and lower low tide, respectively.

The change of turbidity (Fig. 3f) also closely agreed with the change of tides. The turbidity increased during the ebb from the lower high tide (L.H.) to the higher low tide (H.L.), and seawater with a high turbidity (2.5 mg/l) appeared in the surface layer. Also, seawater with a turbidity of 1.5 mg/l was widely found at depths from 10 to 25 m. During the flood from the higher low tide (H.L.) to the higher high tide (H.H.), the turbidity of the surface layer decreased to 1.9 mg/l within a short time (from 23:00 to 2:00). On the other hand, the turbidity change was small and water of relatively low turbidity was found at 5 to 30 m. During the ebb tide from the higher high tide (H.H.) to the lower low tide (L.L.), the turbidity rapidly increased for both the surface layer and the bottom layer, resulting in 3.3 mg/l in the surface layer and more than 1.75 mg/l in the bottom layer below 20 m.

In summary, it was found that during the flood tide seawater with a low temperature, high salinity, and low turbidity flows to the north especially through the bottom layer. During the ebb tide, seawater with a high temperature, low salinity, and high turbidity flows to the south through both the surface and the bottom layers. In particular, seawater with a high turbidity flows out of the bay at a high velocity and also within a short period of time between the higher high tide (H.H.) and the lower low tide (L.L.).

Fluxes of the water mass and turbidity off Futtsu-misaki Figure 4 shows the time variation at station B of the tidal level, the northward and eastward components of the current velocity at 5 m, the northward and eastward components of the current velocity at 20 m, and the water temperature, salinity, and turbidity, respectively. Fig. 4a shows the tidal level on the observation dates using data for the Yokosuka Port. At Yokosuka Port, higher high tide (H.H.) and lower high tide (L.H.) were at 15:48 on September 26 and 3:05 on September 27, respectively. Higher low tide (H.L.) and lower low tide (L.L.) were at 21:34 on September 26 and 9:36 on September 27, respectively.

At 5 m and 20 m, the southward component of the current was large during the ebb tide, and the northward component was large during the flood tide (Fig. 4b and 4c), corresponding well with the tide levels. The eastward component was large during the ebb tide and the westward component was small during the flood tide. Namely, strong flows occur to the southeast during the ebb tide and to northwest during the flood tide, showing a standard oscillation. The cross-correlation coefficient between the tide and the northward component at 5 m and 20 m were calculated. The maximum positive coefficients were 0.81 at 5 m when the delay of tide was 180 minutes, and 0.78 at 20 m when the delay of tide was 150 minutes, respectively.

The relationship between the characteristics of the water mass and the tides was examined. As shown in Figs. 4d and 4e, at the higher high tide (H.H.), the highest temperature and the lowest salinity water during the observation period was observed in the surface layer. The water temperature decreased and the salinity increased with the depth of water, reaching 21.0 ℃ and 34.0 psu in the bottom layer. At the higher low tide (H.L.) the high temperature water in the surface layer disappeared. At the lower high tide (L.H.) both the temperature and salinity were uniform below the depth of 10 m. At the lower low tide (L.L.) low salinity water was observed in the surface layer, and low temperature water was observed again in the bottom layer below the depth of 20 m (Figs. 4d, 4e).

The turbidity of the surface layer (Fig. 4f) was more than 4.0 mg/l, which is regarded as high, between the lower high tide (L.H.) and the higher low tide (H.L.), and then decreased during the ebb from the higher high tide (H.H.). At 10 m to 25 m, seawater with a turbidity of less than 2.5 mg/l was observed during the flood tide. On the other hand, below the depth of 25 m, seawater of a slightly higher turbidity was observed at the high tides.

In summary, off Futtsu-misaki the turbidity increased at the depth below 25 m and at the high tide. At the low tide, seawater of a high temperature and high turbidity was found in the surface layer, and seawater of low temperature, high salinity, and low turbidity was found in the bottom layer.

Estimation of suspended particles by inflow and outflow

We assume a cross section from the northeast to the southwest between the two observation stations, Kannon-zaki (Sta. A) and Futtsu-misaki (Sta. B). We also assume that the flow of seawater is perpendicular to this cross section, and calculate the inflow and outflow per 1 m^2 at the depths of 5 m and 20 m at these two observation stations. Over the course of one day, if we let the inflow to the bay be Q_f, and outflow from the bay be Q_e, the volume of the passing water can be expressed with the following equations:

$$Q_f = \Sigma V_f(t_i) \cdot \Delta t$$

$$Q_e = \Sigma V_e(t_j) \cdot \Delta t$$

where $V_f(t_i)$ is the northwest component of current velocity during the flood tide at the observation time t_i. $V_e(t_j)$ is the southeast component of current velocity during

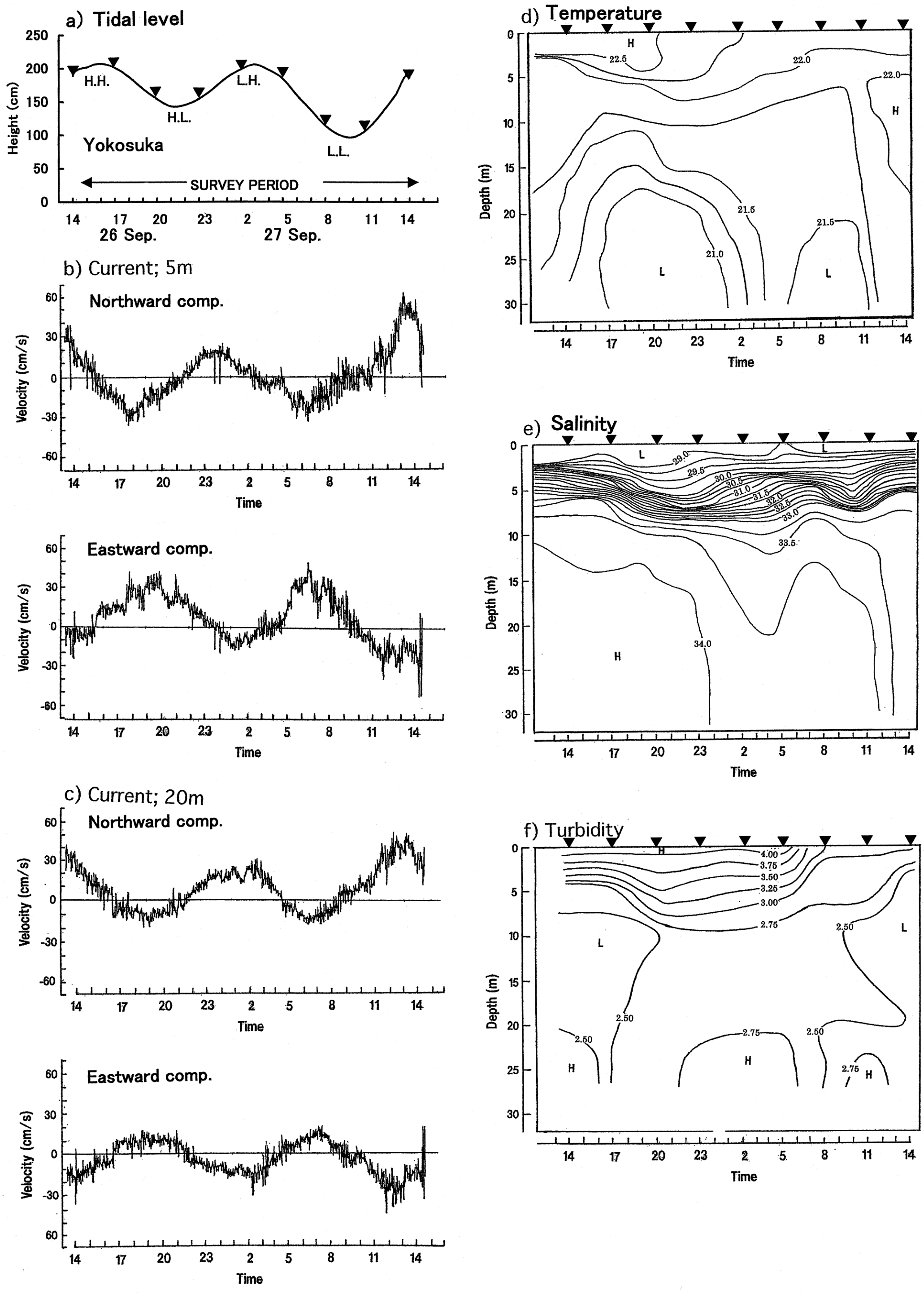

Figure 4. Variations of tidal level, northward and eastward components of current velocity at the depth of 5 m and 20 m, temperature, salinity, and turbidity off Futtsu-misaki.
The symbols ▼ indicate the observation times. The initials are as shown in Fig. 3.

the ebb tide at the observation time t_j, and Δt is the observation time interval. The estimates of the outflow and inflow of seawater over the course of one day (24 hours) are shown in Table 1. Data obtained from 14:00 on June 1 to 14:00 on June 2 off Kannon-zaki and those from 14:00 on September 26 to 14:00 on September 27 off Futtsu-misaki are used for the calculation.

Table 1. Outflow and inflow of seawater off Kannon-zaki and off Futtsu-misaki. Q_f and Q_e indicate the inflow and outflow of seawater during one day (24 hours), respectively.

	Kannon-zaki(Jun.)		Futtsu-misaki(Sep.)	
	5m	20m	5m	20m
Q_f($\times 10^3 m^3$/day)	4.64	8.12	5.23	8.49
Q_e($\times 10^3 m^3$/day)	10.9	5.42	11.1	4.67

At both observation stations off Kannon-zaki and Futtsu-misaki, the main flow of seawater flowed out through the upper layer and flowed in through the lower layer. The present calculation was performed using the data taken in June off Kannon-zaki and the data taken in September off Futtsu-misaki, thus a direct comparison of the two data sets may not be possible. However, Tsuji[11, 12] investigated the residual current at the mouth of Tokyo Bay and reported that there was no substantial difference in the residual current between June and September. Furthermore, in the present investigation the maximum differences in the observed tide levels for in the June and September surveys were 153 cm and 108 cm, respectively. Since the difference was not so great, we made a comparison between the inflow and outflow data at both observation stations, assuming that the tidal flow was in similar conditions in June and in September. Outflow was larger on the Kannon-zaki side, and inflow was slightly larger for the lower layer on the Futtsu-misaki side. These observations agree well with the results of Nagashima and Okazaki [13].

The amount of inflow (P_f) and outflow (P_e) of suspended solids through the mouth of the bay for each hour is expressed with the following equation:

$$P_f = C(t_i) \cdot V_f(t_i) \cdot \Delta t$$

$$P_e = C(t_j) \cdot V_e(t_j) \cdot \Delta t$$

where $C(t_i)$ and $C(t_j)$ are the concentrations of suspended solids in a unit volume at the observation times.

Fig. 5 shows the outflow and inflow of suspended solids through the mouth of the bay as a function of time. Generally, the outflow of suspended solids is greater than

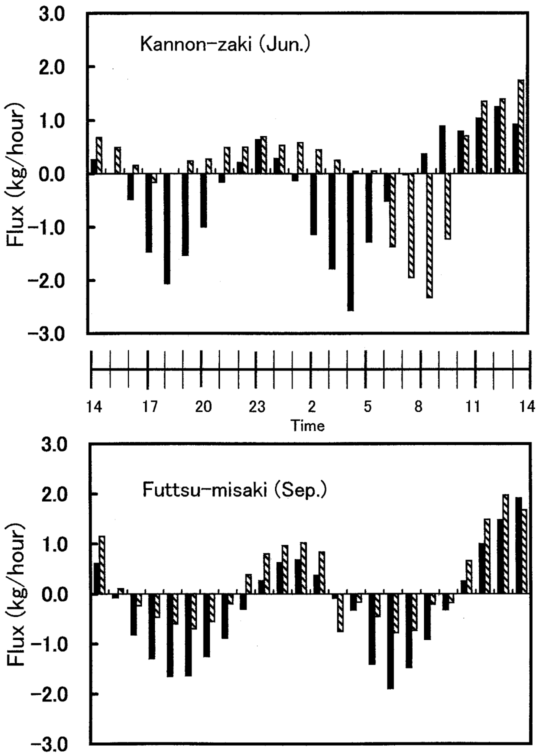

Figure 5. Time variation of the particle flux. Upper; Kannon-zaki, Lower; Futtsu-misaki. Solid bars and striped bars indicate the depth of 5 m and 20 m, respectively.

the inflow on the Kannon-zaki side. Off Futtsu-misaki, the outflow was prominent at the depth of 5 m and the inflow is remarkable at the depth of 20 m. The fluxes (S_e) over one day (24 hours) are calculated by the following equation:

$$S_e = \Sigma P_f - \Sigma P_e$$

The amount of suspended solids that passed outside the bay over the course of one day is shown in Table 2. Through the upper layer there were outflows of 7.3 kg/m^2/day on the Kannon-zaki side, and 7.2 kg/m^2/day on the Futtsu-misaki side. On the other hand, through the lower layer there were inflows of 11.3 kg/m^2/day on the Kannon-zaki side and 4.9 kg/m^2/day on the Futtsu-misaki side.

Again we cannot make a direct comparison of outflow and inflow of suspended solids between the two locations because the time of investigation was different for Kannon-zaki and Futtsu-misaki. However similar amounts of suspended solids flowed out through the surface layer of

Table 2. Outflow and inflow of suspended particles off Kannon-zaki and off Futtsu-misaki.
A positive value for Se indicates inflow, and a negative value indicates outflow.

	Kannon-zaki(Jun.)		Futtsu-misaki(Sep.)	
	5m	20m	5m	20m
Se (kg/m^2/day)	-7.3	11.3	-7.2	4.9

Table 3. Ignition losses of suspended solids off Futtsu-misaki.

	Flood		Ebb	
	5m	20m	5m	20m
IL (%)	67	55	67	55

both the sea regions and flowed in through the bottom layer off Futtsu-misaki.

The results of ignition loss of suspended solids from off Futtsu-misaki are shown in Table 3. The content of organic matter from the upper layer (5 m) and the lower layer (20 m) were 67 % and 55 %, during both flood tide and ebb tide, respectively. Namely, they were high in the upper layer and low in the lower layer. From the results, the amount of inflow and outflow of organic matter and inorganic matter during over a 24hr period were determined. In the upper layer, 4.8 kg/m^2/day of organic matter and 2.4 kg/m^2/day of inorganic matter flowed out, and in the lower layer 2.7 kg/m^2/day of organic matter and 2.2 kg/m^2/day of inorganic matter flowed in.

In the present investigation, fluxes were calculated based on the turbidity data obtained every three hours. Here we discuss the validity of calculating the flux for the one day based on observations every three hours. The Aanderaa current meter, which was used in the present investigation, has an attached water-temperature sensor, and data were collected every minute. We compare the data from the attached water-temperature sensor and water-temperature data collected every three hours. Fig. 6 shows the deviation of the water temperature from the average water temperature. The solid line shows the data with the Aanderaa current meter and the solid dots show the data collected every three hours. At 5 m off Kannon-zaki, they agree closely and the variation in temperature between the two estimates is minimal except for the temperature rise that happened at ca. 20 hours after the start of monitoring was not recorded by the measurements every three hours. We cannot determine the concentration of turbidity at that time. If we assume the turbidity at the time of the high water temperature after ca. 20 hours is twice the turbidity after 18 hours, the inflow at the lapse of 20 hours will be larger by 0.75 kg than the value calculated from the flux

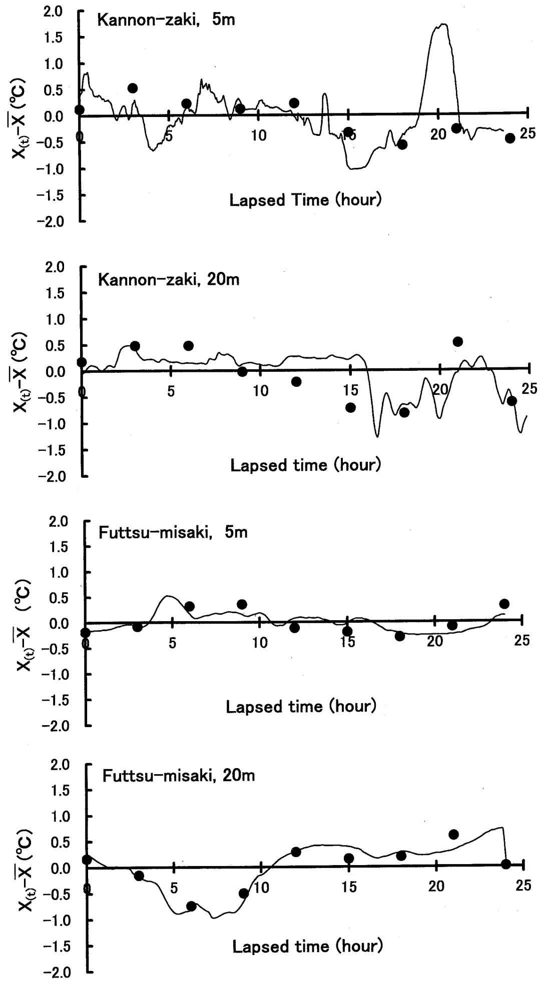

Figure 6. Comparison of water temperature variations at the depths of 5m and 20m off Kannon-zaki and off Futtsu-misaki.
Solid lines indicate the water temperature observed by the thermometer equipped Aanderaa current meter. Solid circles indicate the water temperature measured every 3 hours by a multi-parameter water quality meter. $X_{(t)}$ and $\bar{X}$ denote the temperature at the lapse of t minute and the average temperature during observation period, respectively.

measurements, resulting in a decrease of Se (refer to Table 2) by approximately 10 %. Nevertheless, the results taken every three hours detected the temperature deviation closely at the depth of 20 m off Kannon-zaki and off Futtsu-misaki. Therefore, it is considered that the calculated flux data on the whole are appropriate.

Exchange of turbid water In the previous section, only the inflow and outflow of suspended particles were examined. However, it is not clear how much water inside the bay is exchanged with the water outside the bay. Also it is not clear the amount of particulate matter exchanged through the exchange of water.

Imasato[14] explained that there are three groups of methods for the quantitative assessment of exchanged seawater: (1) Box model method, (2) Flux model method, and (3) Lagrange's method. In the present investigation (2) Flux model method was adopted and the equation by Parker et al.[15] was used because it was considered to be most appropriate for the present observation method. Parker et al.[15] devised a model that evaluates the difference in the material concentration by the following mechanism. Seawater mixed in the bay flows out of the bay through the center of the channel and seawater outside of the bay flows in through both sides of the channel. The equation used to calculate the seawater exchange rate (r_w) based on material concentration is shown below.

$$r_w = \frac{(S_f - S_e)}{(S_o - S_e)}$$

where, S_f, S_e, and S_0 are the average salinity during the flood tide, during the ebb tide, and outside the bay, over the course of one day (24 hours), respectively. In the present case, the salinity outside the bay is that for Sta. C. The salinity in June at Sta. C was 32.7 psu at 5 m, and 34.2 psu at 20 m, respectively. In September it was 33.0 psu at 5 m, and 33.4 psu at 20 m, respectively.

When the exchange rate of seawater is determined, the salinity, which is a conservative property, is generally used as an indicator material. In Table 4 the exchange rate of seawater(r_w) derived from the salinity is shown. The exchange rate of seawater at both the observation stations off Kannon-zaki and off Futtsu-misaki was higher in the upper layer than in the lower layer. Thus, it was found that the high exchange rate in the upper layer off Kannon-zaki greatly contributed to the seawater exchange of the bay. Matsumoto et al.[6] performed vertical profiling measurements between Kannon-zaki and Futtsu-misaki. According to the data of Matsumoto, the exchange rate of seawater through the surface layer of Kannon-zaki was from 28 to 36 %, and that through the 20 m layer was 17 to 27 %. These are in good agreement with our results. On the other hand, the exchange rate of seawater through the surface layer off Futtsu-misaki was from -2 to 11 %, and that through the 20 m layer was -2 to 5 %, showing lower results than in our present investigation. The above difference in the exchange rates of seawater is considered to be due to the difference of observation points.

Table 4. Exchange rates of seawater (r_w) and suspended particles (r_p) at the mouth of Tokyo Bay.

	Kannon-Zaki (Jun)		Futtsu-misaki(Sep)	
	5m	20m	5m	20m
r_w	0.27	0.15	0.18	0.16
r_p	0.78	0.52	0.23	0.14

Additionally, we investigated the exchange rate of suspended particles during one day. Using the above equation for the exchange rate of seawater (r_w) and the amount of suspended solids, the exchange rate (r_p) of particles was investigated.

$$r_p = \frac{(T_f - T_e)}{(T_o - T_e)}$$

where, T_f, T_e, and T_0 are the average particle concentration during the flood tide, during the ebb tide, and outside the bay, over the course of one day (24 hours), respectively. In the present case, the particle concentration outside the bay is that for Sta. C. The suspended particle concentration in June at Sta. C was 1.3 mg/l at 5 m, and 1.1 mg/l at 20 m, respectively. In September they were 2.4 mg/l at 5 m, 2.3 mg/l at 20 m, respectively.

The exchange rate of suspended particles (r_p) at 5 m off Kannon-zaki showed 0.78, which was the highest. The lower layer showed lower results than the upper layer at both the observation stations. In both the upper and lower layer off Kannon-zaki, and in the upper layer off Futtsu-misaki, the exchange rate of suspended particles was much larger than the exchange rate of seawater. This is probably due to the loss of out-flowed suspended particles by sedimentation outside the bay, since the values for suspended particles are non-conservative. Namely, the difference between the exchange rate for non-conservative materials and the exchange rate of conservative materials is considered to be the loss rate for the non-conservative materials during one day. They flow out the bay or they are lost by sedimentation outside the bay, and will not return into the bay. Over the course of one day, the rate of particle loss off Kannon-zaki was 40-50 %, and approximately 5 % in the upper layer off Futtsu-misaki. From the results, it was estimated that the exchange rate of particles was lower than the exchange rate of seawater in the lower layer off Futtsu-misaki. This may be due to the low apparent exchange rate of particles because of the addition of particles by settling from the upper layer to the lower layer at the time of water exchange.

Acknowledgement

The authors wish to express their sincere appreciation to

Dr. Kuniaki Okuda of the Tohoku National Fisheries Institute, Fisheries Research Agency, for his detailed review of the paper. Also the authors express their deep appreciation to the captain of the RT/V Seiyo-maru and his crew at the Tokyo University of Fisheries for their cooperation during the present investigation.

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東京湾口部における懸濁粒子の流出入量

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観音崎沖の水塊の動きは潮汐に大きな影響を受けており，上げ潮時には特に底層付近において低温，高塩分，低濁度の海水が北方向へ流れ，下げ潮時には表層から底層にかけて，高温，低塩分，高濁度の海水が南方向へ流れる。富津岬沖の水塊の動きは，上げ潮時には底層において高濁度の海水が北西方向へ流れ，下げ潮時には表層で高温，高濁度の海水および底層で低温，高塩，低濁度の海水が南東方向へ流れる。懸濁物質は6月の観音崎沖では上層で7.3 kg/m^2/day流出し，下層で 11.3 kg/m^2/day 流入する。9 月の富津岬沖では上層で 7.2kg/m^2/day 流出し，下層で 4.9 kg/m^2/day 流入する。湾口における懸濁粒子の交換率は下層より上層で大きく，特に観音崎側でその差が大きい。すなわち，濁った海水は湾口の上層から放出され，その一部は湾外に流出し，また他の一部は下層部を通り再び湾内に戻されることが判る。

キーワード：東京湾，濁度，懸濁粒子，交換率