

## Observation on Temperature, Salinity and Density in- and out of Owase Bay

Yoshihiko SEKINE and Takayuki OKUBO

<sup>\*</sup>Faculty of Bioresources, Mie University

### Abstract

Temperature, salinity and density fields in- and out of Owase Bay were observed on 12–15 in July 1991. The temperature and salinity fields were observed by CTD installed on the Training Vessel Seisui-Maru of the Faculty of Bioresources of Mie University. It is resulted that a coastal water less than 33 psu in a surface layer shallower than 5 m exists up to about 8 km offshore from the Sabaru-Jima (Sabaru Island) in the Owase Bay, forming a coastal front. Influence of coastal water on the oceanic condition off Owase Bay is suggested. A warm water core with no horizontal change in salinity at a depth of 10 m is observed at 3 km southeast of Toga-shima (Toga Island).

**Key words:** Coastal front, Coastal oceanography and Owase Bay

### Introduction

Owase Bay is located on eastern coast of the Kii Peninsula (Fig.1). As the Kuroshio flows offshore of the Owase Bay, the warm and saline Kuroshio water sometimes approach to an eastern coast of Kii Peninsula, forming a warm water tongue or warm water stream<sup>1)</sup>. Oceanic condition of Owase Bay is characterized by two effluents of warm water from thermal electric power plant and fresh water from water-power generation. The volume transport of these effluents is significant and simple estimation assuming a constant effluent of  $50 \text{ m}^3 \text{ sec}^{-1}$  gives that all of the water in the Owase Bay is completely replaced by effluent of water for every 20 days.

There is a few observation on the velocity fields in the Owase Bay. It is reported by Sugimoto<sup>2)</sup> that the tidal current in Owase Bay is relatively weak and constant outflow averaged over 25 hours is about  $5 \text{ cm sec}^{-1}$ . However, Sekine and Yamada<sup>3)</sup> pointed out by eight observations at a depth of 3 m in periods from July 1990 to August 1992 that relatively large velocity more than  $10 \text{ cm sec}^{-1}$  is observed in summer, while the velocity in spring is less than  $5 \text{ cm sec}^{-1}$ . It is also shown by Sekine and Yamada<sup>3)</sup> that there exists no significant velocity difference between the spring tide periods and neap tide periods.

Results of several hydrostatic observations in Owase Bay have been reviewed by Sugimoto<sup>2)</sup>. After April in 1986, several routine observations in Owase Bay have been carried out by Owase City Office.

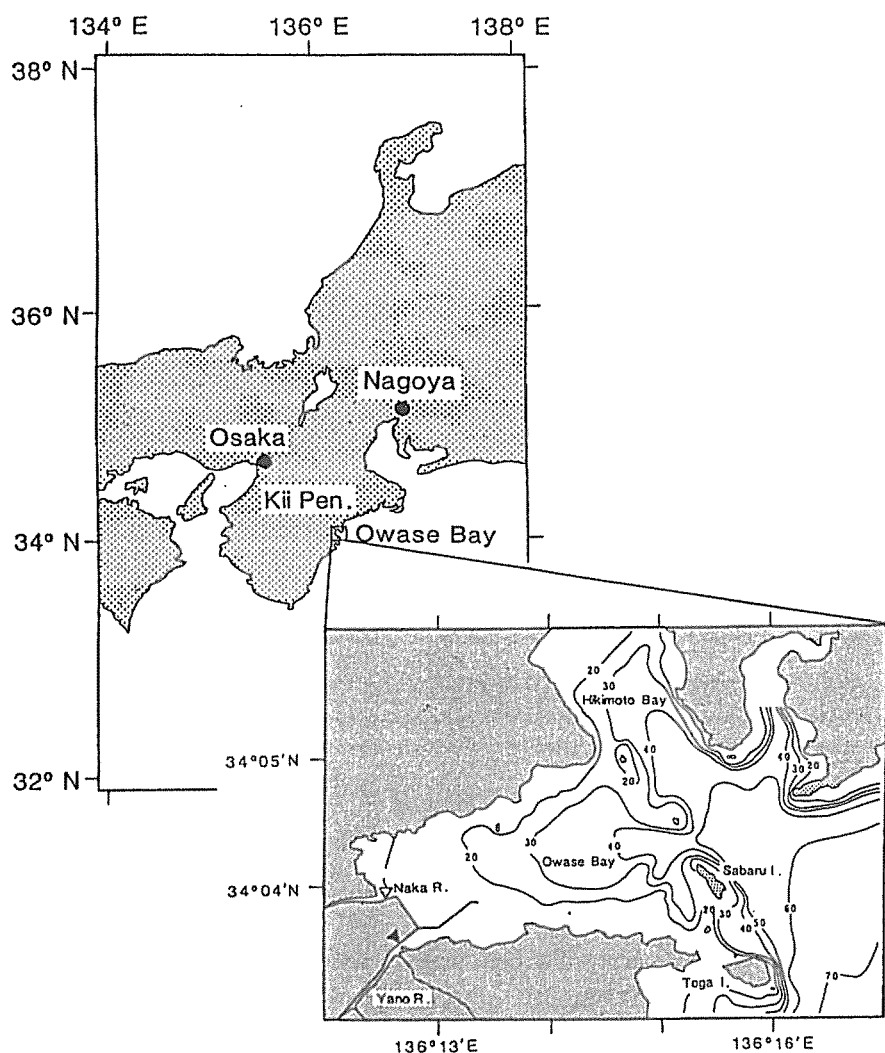


Fig. 1 Location and geometry of Owase Bay. Locations of two effluents, warm water from thermal electric power plant (▲) and fresh water from water-power generation (△), are shown. Depth contours (in meter) are also shown.

Sekine et al.<sup>4)</sup> and Nakagawa et al.<sup>5)</sup> analyzed the temperature, salinity and density data observed in thirteen observations during the periods from April 1986 to September 1991. It is shown by Sekine et al.<sup>4)</sup> that effluents of fresh and thermal water spread to a center of the bay or to a baymouth in periods of ebb and low water, while expansion of effluents tends to be confined to an innermost of the bay in flood and high water periods. Nakagawa et al.<sup>5)</sup> pointed out that almost of the effluents are confined to surface layer shallower than a depth of 3 m, and that during constant large effluent of fresh water, low density water spreads in a surface layer and effluent of thermal water intrudes below the less saline water. However, because there is no concentrated observations off Owase Bay, details of the oceanic condition

off Owase Bay is not well-known up-to-date. As a first observation off Owase Bay, concentrated observation off Owase Bay is made in middle July 1991 by use of the Training Vessel Seisui-Maru of Mie University. Main results of the observation are presented in the present paper.

### Observation

Observations were carried out in period from 12 to 15 in July 1991 by use of the Training Vessel Seisui-Maru of Mie University. Observational stations of CTD are shown in Fig. 2. After observing the coastal front in- and out of Ise Bay<sup>6)</sup>, we began to make CTD observations on 12 July at station 10 of A-line (Fig. 2b). In next, CTD observations were made along B-line from nearshore to offshore and along C-line from offshore to nearshore. After staying a day in Owase Bay, CTD observations on 14 July were made at stations 1–51 shown in Fig. 2a. CTD observation along D-line were made on 15 in July.

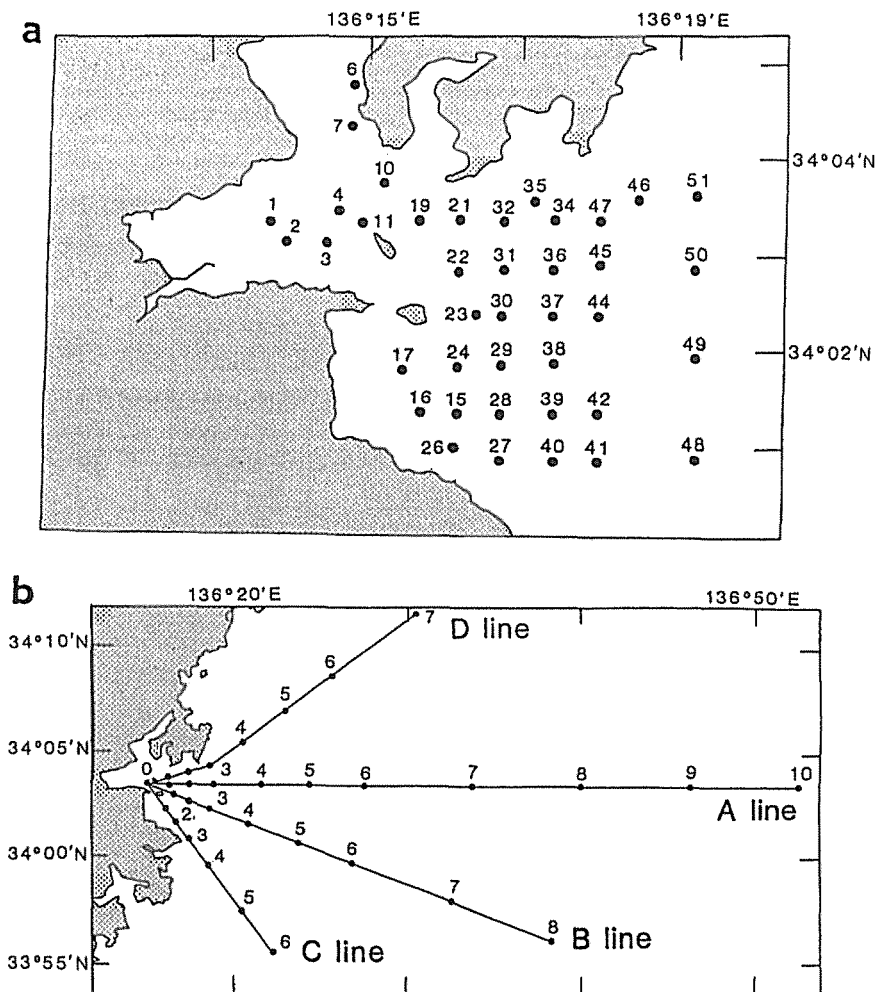


Fig. 2 Observational stations of CTD in the Owase Bay (a) and offshore area (b)

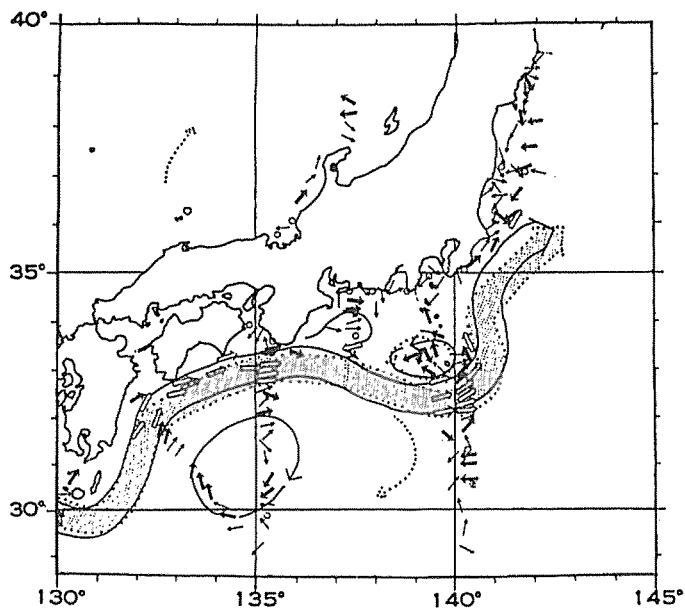


Fig. 3 Main path of the Kuroshio during the observation (after, Prompt Report published by Japan Hydrographic Agency, 1991). Solid arrows and dashed arrows show main Kuroshio path in period of from 3 to 17 in July and from 19 June to 3 July, respectively.

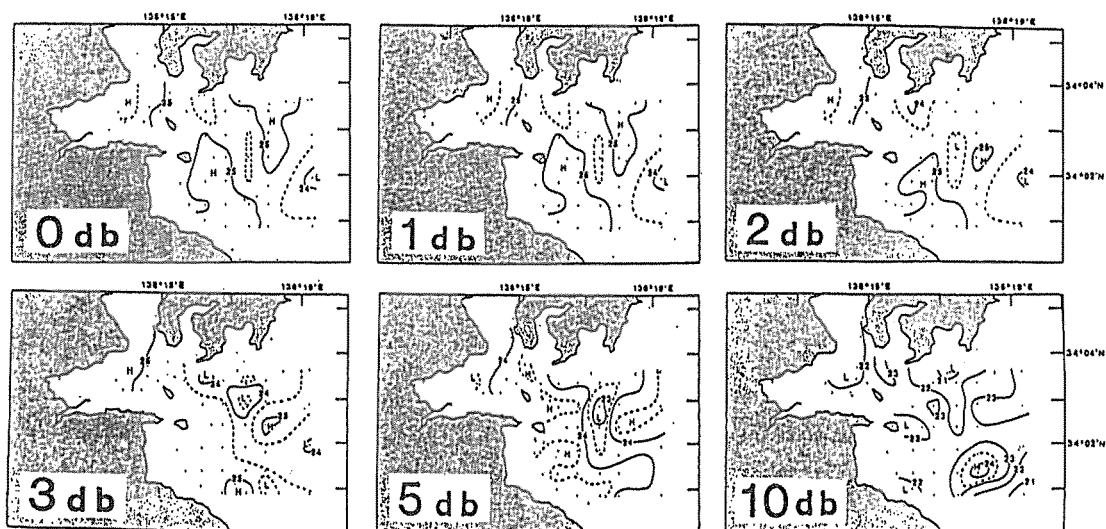


Fig. 4 Horizontal distribution of temperature (°C) at six levels.

Main Kuroshio axes during the observational period are shown in Fig. 3. Main axis is approaching to the Kii Peninsula and relatively strong influence of the Kuroshio is expected.

### Results

Horizontal distribution of temperature at the observational area of stations 1–51 (Fig. 2a) is shown in Fig. 4. At sea surface, temperature is rather homogeneous with a weak horizontal change from 23.5 °C to 25.5 °C. The vertical change in temperature is weak in upper layer shallower than 3 m, however, lower temperature is detected at a depth of 10 m, which suggests the formation of seasonal thermocline. It should be noted that a warm water core is observed at a depth of 10 m in southeastern area of the observational field. Horizontal distribution of salinity is shown in Fig. 5. Less saline water less than 32 psu occupies upper layer in the Bay, which spatially corresponds to the layer shallower than the seasonal thermocline. Relatively saline water more than 33.5 psu occupies under the seasonal thermocline. It is suggested that seasonal thermocline is accompanied by seasonal isohaline. Because the warm core found at 10 m (Fig. 4) shows no clear salinity change, this warm core is not considered as a warm water from the Kuroshio, of which further discussion will be made in section 4.

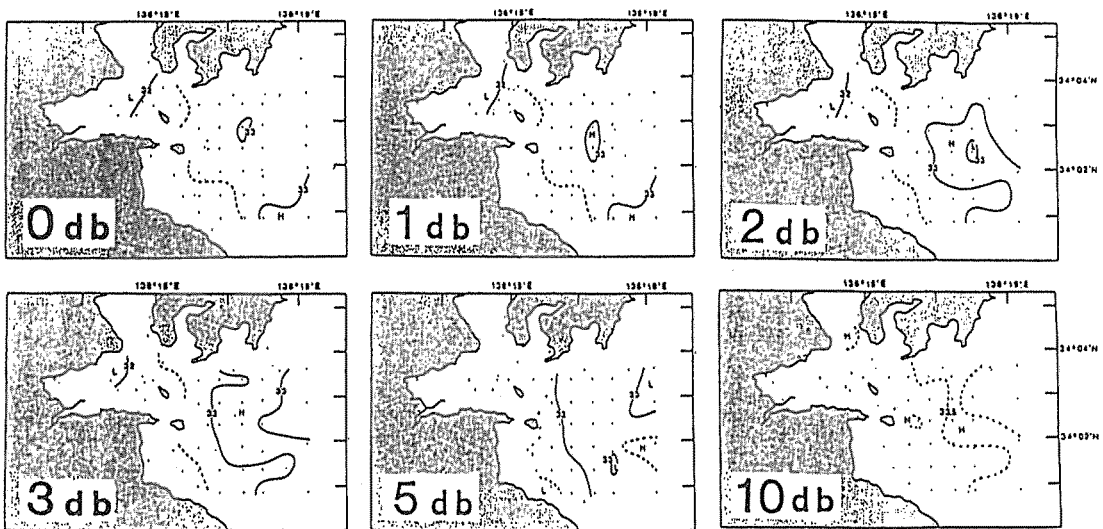


Fig. 5 Horizontal distribution of salinity (psu) at six levels.

Density ( $\sigma_t$ ) is calculated from the observed temperature and salinity data by use of the formula proposed by UNESCO<sup>®</sup>. Observed density fields (Fig. 6) also show the existence of the vertical density gradient corresponding to seasonal thermocline and halocline. In a surface layer shallower than 3 m, density mainly depends on salinity. However, because of very weak horizontal change in salinity under the seasonal thermocline, density depends on temperature at a depth of 10 m.

Vertical distributions of observed temperature, salinity and density along A-line, B-line, C-line and D-line are shown in Figs. 7, 8, 9 and 10, respectively. As for A-line, uplift of isotherms of 15 °C and 14 °C is found near coast. Surface water less than 33 psu exists from coast to the station 5 (Fig. 2b), which

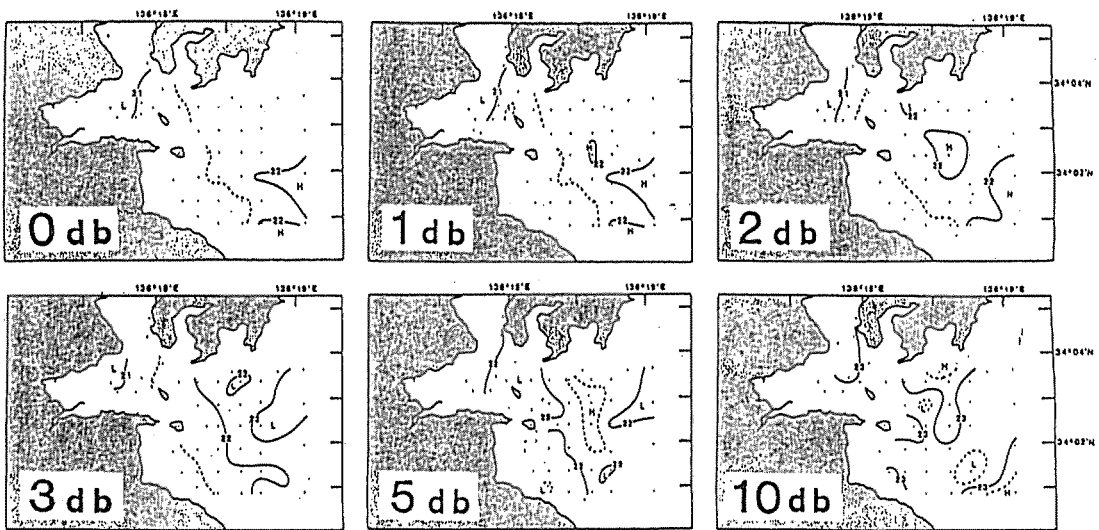


Fig. 6 Horizontal distribution of density ( $\sigma_t$ ) at six levels.

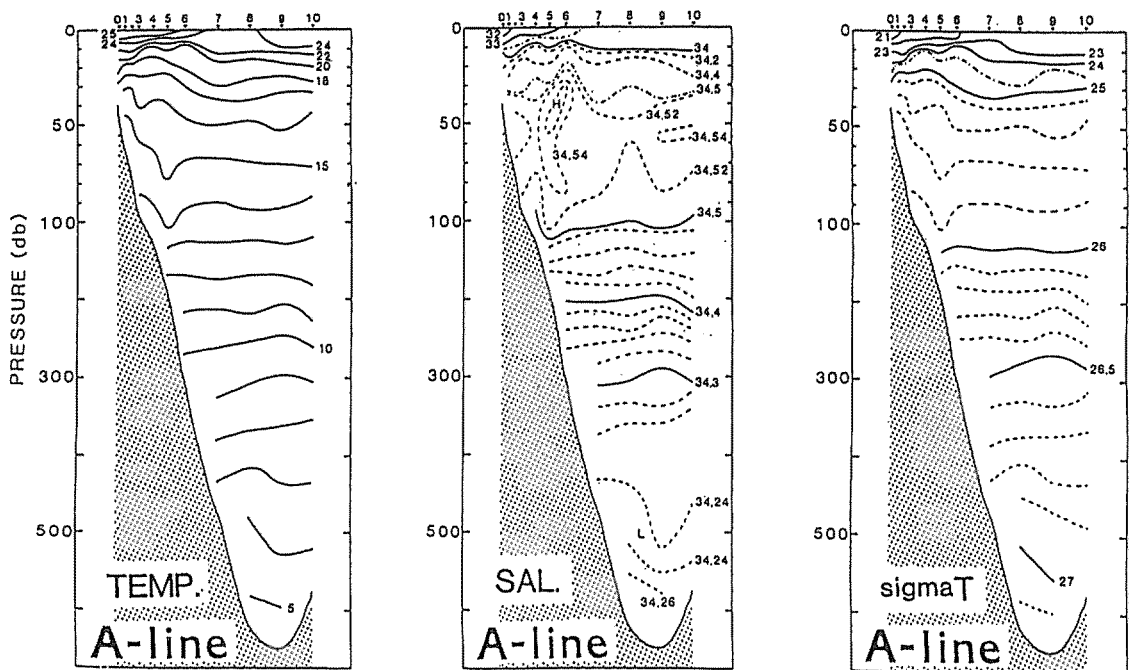


Fig. 7 Vertical temperature ( $^{\circ}\text{C}$ ), salinity (psu) and density ( $\sigma_t$ ) distribution along A-line.

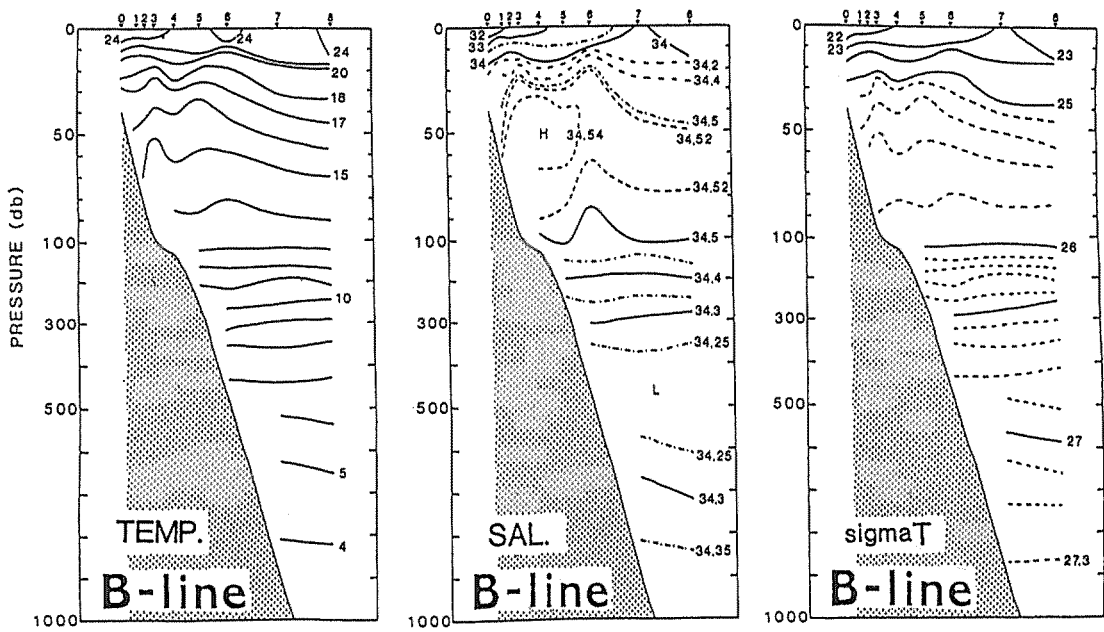


Fig. 8 Vertical temperature ( $^{\circ}\text{C}$ ), salinity (psu) and density ( $\sigma_t$ ) distribution along B-line.

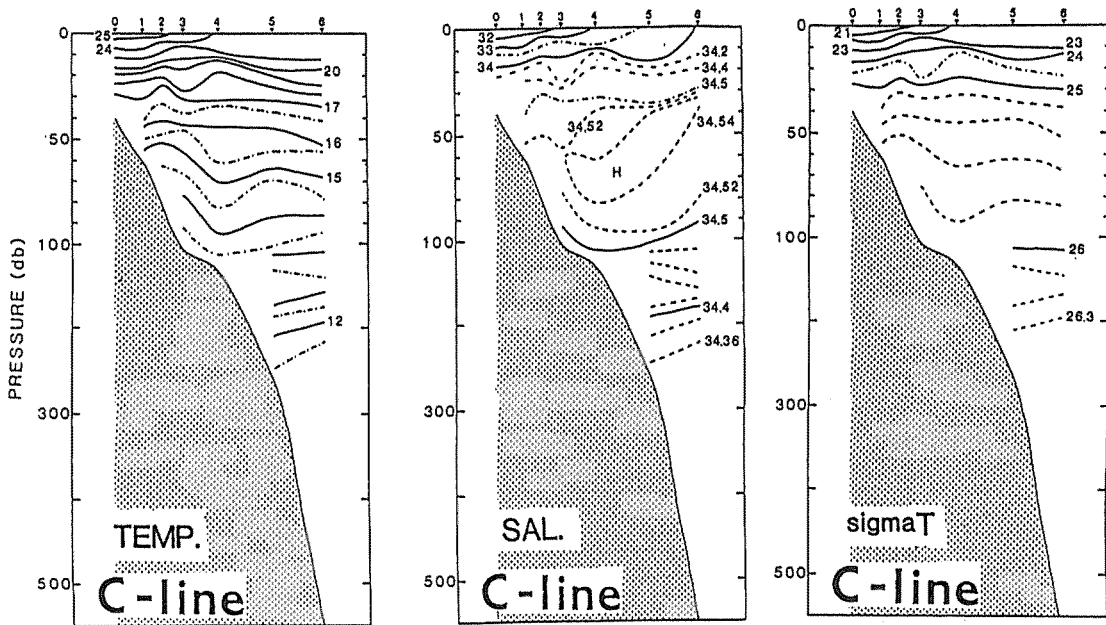


Fig. 9 Vertical temperature ( $^{\circ}\text{C}$ ), salinity (psu) and density ( $\sigma_t$ ) distribution along C-line.

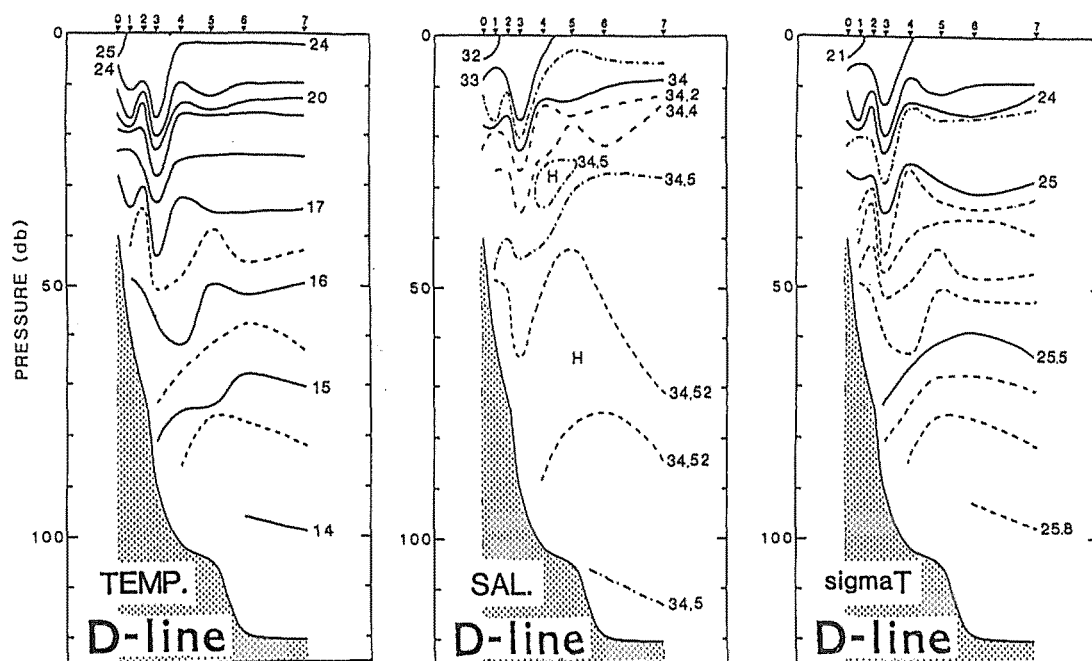


Fig. 10 Vertical temperature ( $^{\circ}\text{C}$ ), salinity (psu) and density ( $\sigma_t$ ) distribution along D-line.

indicates an outflow of the less saline water to an offshore area. A thick layer of saline water more than 34.5 psu is detected in depths from 30 m to 100 m. As this saline water has a temperature of  $16^{\circ}\text{C}$ – $18^{\circ}\text{C}$ , this water is considered as an associated water with subtropical mode water<sup>9)</sup>. Since the typical salinity of the subtropical mode water along  $137^{\circ}\text{E}$  ranges from 34.7 to 34.9 psu<sup>10)</sup>, decrease in salinity near the coastal area is inferred. Salinity minimum layer is observed at a depth of 500 m, which corresponds to a northern part of the salinity minimum layer formed by the ventilation of water in the subarctic circulation. Density almost depends on salinity in a coastal surface layer shallower than 20 m, however, density depends on temperature in the deeper layer. Because various horizontal gradient of pycnocline are observed, existence of internal wave and/or geostrophic flow are suggested.

Although maximum uplift of the isotherm is nearshore area in case of A-line, it shifts to offshore area along B-line and C-line. Significant horizontal gradients of isotherms and isohalines are observed in the surface coastal area of D-line (Fig. 10). As this gradient is formed by coastal water less than 33 psu, formation of the clear coastal front is suggested.

### Discussion

The observations on temperature, salinity and density in- and out of the Owase Bay have been carried out from 12 to 15 in July 1991 by use of the Training Vessel Seisui-Marui of Mie University. Here, we firstly discuss the warm core observed at a depth of 10 m (Fig. 4). As is noted before, this warm core has no clear salinity change, which indicates that this warm core is not considered as a warm water from the

Kuroshio. Conversely, because the salinity of warm water core of 33.5 psu is more saline than the coastal water with a salinity less than 32 psu (Figs. 7, 8, 9 and 10), the warm water core is not a coastal water. It is inferred from high temperature and no salinity change that the warm core is considered as a thicker area of effluent water discharged from the thermal electric power plant.

Secondly we should discuss the observational evidence that almost common vertical distribution of coastal water less than 33 psu is observed along A-, B- and C-lines, however, that of D-line is significantly different. Namely, thickness of coastal water along A- B- and C-lines decreases as the distance from the coast is increased, but the thickness has a maximum at station 3 of D-line and downward shift of the isotherms and isohalines are clear between stations 2 and 4 (Fig. 10). Because the observation along D-line was carried out two days later than those of A- B- and C-lines, there is a possibility of oceanic condition change during the two days. However, precipitation at Owase during the two days is not significant, such a large river discharge is not expected. If we assume that time change in the oceanic condition is weak, because the D-line is located near to the northern peninsula, it is indicated that the change in the thickness of the coastal front is caused by spatial change. Some different feature near the northern coast in the Owase Bay is suggested from horizontal distribution of temperature at a depth of 10 m (Fig. 4). However, it is difficult to draw firm conclusion, more concentrated observation is needed.

#### Acknowledgment

We would like to thank Captain I. Ishikura and all officers and crews of Seisui-Marui of Mie University for their skillful help in the observation. Thanks are extended to Mr. K. Kurifuji of Fisheries Section of Owase City Office, Messrs. Y. Takashiba and K. Noda of Environmental Section of Owase City Office for their help in the observation.

#### References

- 1) SEKINE, Y., T. ITOH and K. FUJITA. Warm water approach to eastern coast of Kii Peninsula (in Japanese with English abstract). *Bull. Coast. Oceanogr.* 28, 174–182 (1991).
- 2) SUGIMOTO, T. Kumano-Nada. In *Coastal Oceanography of Japanese Islands* ed. by H. KUNISHI. Tokai Univ. Press. pp.572–580 (1985).
- 3) SEKINE, Y. and F. YAMADA. Observation on sea level and velocity variation in Owase Bay. *Bull. Fac. Biores. Mie Univ.*, 15, 1–17 (1995).
- 4) SEKINE, Y., M. NAKAGAWA, K. KURIFUJI, K. NODA and Y. TAKASHIBA. Horizontal distributions of temperature and salinity in Owase Bay. *Bull. Fac. Biores. Mie Univ.*, 11 113–144 (1993).
- 5) NAKAGAWA, M., K. KURIFUJI, K. NODA, Y. TAKASHIBA and Y. SEKINE. Vertical distributions of temperature, salinity and density in Owase Bay. *Bull. Fac. Biores. Mie Univ.*, 12, 187–207 (1994).
- 6) SEKINE, S. KAWAMATA and Y. SATOH. Observation of coastal fronts in Ise Bay in early winter (in Japanese with English abstract). *Bull. Coast. Oceanogr.*, 29, 190–196 (1992).
- 7) Japan Hydrographic Department, Maritime Safety Agency. Prompt Report of Oceanic Condition (in Japanese). No.14 (1991).
- 8) UNESCO. Tenth report of the joint panel on oceanographic tables and standards. UNESCO Technical Papers

- in Marine Sci., No., 36 UNESCO, Paris (1981)
- 9) KAWAI, H. Hydrography of the Kuroshio Extension, in *Kuroshio : Its physical Aspect*, H. STOMMEL and K. YOSHIDA, eds. University of Tokyo Press, 235–352.
- 10) SUGA, T., K. HANAWA and Y. TODA. Subtropical Mode Water in the 137° E section. *J. Phys. Oceanogr.*, 19, 1605–1618 (1989)

## 尾鷲湾内外の水温，塩分，密度の観測

関根義彦\*，大久保孝之\*

\*三重大学生物資源学部

1991年7月中旬，尾鷲湾内外の水温，塩分および密度の観測を三重大学生物資源学部の練習船『勢水丸』に搭載のCTDを用いて行った。この観測で得られた水温，塩分および密度の水平および鉛直分布の結果を報告する。主な結果として，塩分値が33 psu 以下で海面から5 m 程度の厚さを持つ低塩分水が佐波留島の沖8 km 程度まで張り出していることが観測され，沖の海域への低塩分水の影響が示唆された。また，桃頭島の南東の約3 km には塩分変化を伴わない高温水が10 m の水深で観測された。