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Seasonal Variations in Vertical Distribution of Temperature, Salinity and Density In- and off Ise Bay

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Abstract

Seasonal variations in vertical distribution of temperature, salinity and density in- and off Ise Bay are examined by use of observational data during the period from 1985 to 1989 obtained by Aichi Prefectural Fisheries Experimental Station and by Fisheries Research Institute of Mie. Monthly mean vertical maps and those of their standard deviations along three lines along west, central and east of Ise Bay are presented. It is found that the formation and decay of the thermocline occurs abruptly in May and October, respectively. Vertical temperature inversion is observed in the bay from Nov. to Mar. of the next year. The vertically coherent density maximum is detected in January at the Irago Strait, which shows the formation of coastal thermohaline front. Estuarine front with a thin layer thickness less than 5 m is formed in July and its vertical diffusion of less saline water from October is shown to have a much influence on the seasonal variation of the oceanic structures in- and off Ise Bay.

Key words: Castal front, river discharge and the Ise Bay

1 Introduction

In the Part I[1] of this study, the seasonal variations in the horizontal distributions of temperature, salinity and density fields in Ise Bay are discussed with special reference to the formation of the coastal front. The following characteristics are pointed out by Part I[1] of this study:

(1) The horizontal difference in sea surface temperature (SST) in- and out of Ise bay is largest in spring and smallest in summer to autumn. Although no prominent spatial change in SST is detected in summer, a horizontal temperature difference more than 3°C is formed at depths from 10 m to 30 m.

(2) The salinity fields are strongly influenced by the river discharge in summer. The horizontal difference in sea surface salinity (SSS) is very large (more than 12 psu) in summer, but it is very small in winter (about 3 psu). As the less saline water is confined to a shallower layer less than 10 m, horizontal salinity difference at depths deeper than 10 m is very small in all seasons.

(3) Because density depends on salinity in Ise Bay, density distribution is similar to salinity distributions in all seasons. In particular, low densty water diluted by river discharged water is found in out of Ise Bay, which suggests that the coastal water diffuses in wider area off Ise Bay. The density maximum is found at the Irago Strait in spring and the occurrence of the cabbeling is suggested.

However, since the discussion is based on the horizontal distribution of the temperature, salinity and density, the details of vertical distribution has not been considered in Part I[1]. As a succeeding study on the

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seasonal variations of oceanic conditions of Ise Bay, the vertical structures of the temperature, salinity and density of in- and off Ise Bay are studied and their monthly mean maps will be presented in the following. In particular, as Ise Bay is relatively shallow (Fig. 1a), larger vertical change is expected. Furthermore, since the Ise bay is characterized by the relatively large river discharge[2], vertical diffusion and/or advection of the river discharged water are suggested to have much influences on the seasonal change of the oceanic conditions.

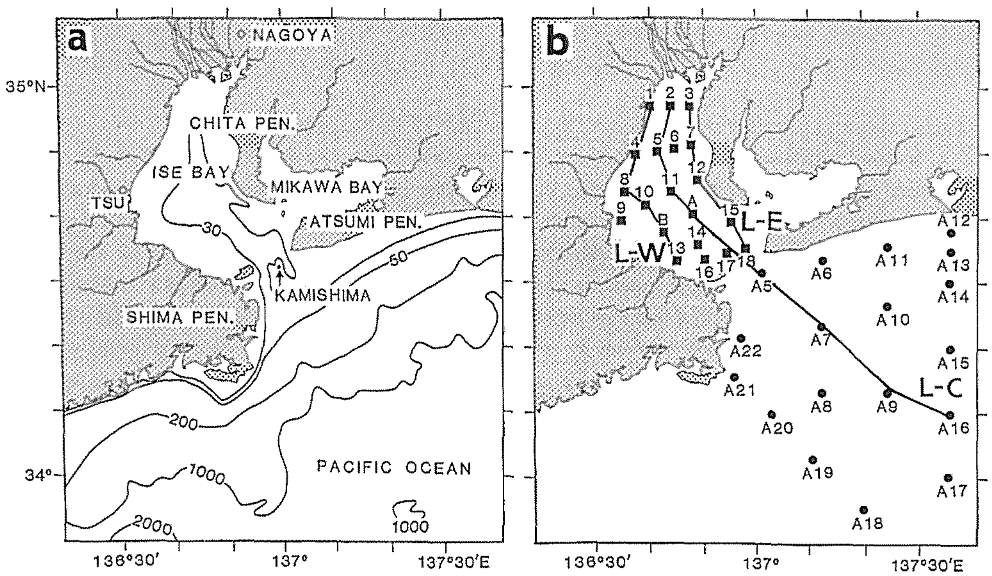

Fig. 1. (a) Depth contours (in meter) of Ise Bay. (b) Locations of observational stations of Aichi Prefectual Fisheries Experimental Station (closed circles) and by Fisheries Research Institute of Mie (closed squares). Three lines shown by L-W, L-C and L-E are adopted to present the vertical distributions of temperature, salinity and density.

2 Data

Fig. 1b shows all the observational stations of Aichi Prefectural Fisheries Experimental Station[3] and those of Fisheries Research Institute of Mie[4]. The temperature and salinity data have been observed monthly at these observational points. The horizontal distribution of temperature, salinity and density at these stations was presented by Part I[1]. In the present analysis, three observational lines are adopted and their vertical distribution is discussed. Namely, L-E, L-C and L-W are adopted to see the eastern region of Ise bay, central region and the western region, respectively. Main vertical feature of Ise Bay is discussed along L-C. As the effect of Coriolis force on the horizontal distribution is suggested in Part I[1], the other two lines are set to see the difference in vertical structure in the western and eastern regions of the bay.

The observational data during the period from 1985 to 1989 are used to present the monthly mean vertical distribution of temperature, salinity and density. Here, density (σ t) is calculated from the temperature and salinity data. Standard deviations (STD) are also calculated and they will be also shown.

3 Results

The monthly mean map of vertical temperature distribution along L-C and their standard deviation are shown in Figs. 2 and 3, respectively. In winter, vertivally homogeneous temperature with a weak temperature inversion is detected in the bay, which is formed in November and held upto May. Because this temperature inversion is formed after the decay of the seasonal thermocline, the temperature inversion is generated by the surface cooling. As for STD of the temperature (Fig. 3), it is found that the deviation in the outer bay is relatively large in December and January, but it is small in February to March. It is indicated that the STD of temperature becomes small as the winter mixed layer develops sufficiently.

In spring, similar temperature distribution to winter is observed in March and April, however a seasonal thermocline develops abruptly in May. This sudden change is noticed in the sense that the total pattern of vertical temperature distribution is abruptly changed from vertically homogeneous winter pattern to horizontally homogeneous summer pattern. By the warming of surface layer, the horizonal temperature difference is weakened gradually. The thermocline in outer bay is aslant in May, but it becomes horizontal in June. In outer bay, vertical mixing in the surface layer to a depth of 10 m is detected from July to September, while surface mixed layer in the bay is relatively thin.

Larger STD of temperature at depths 30–60 m at the out of the bay is found in July to September (Fig. 3), while larger STD of temperature exists in deeper region in October to November. In particular, largest SDT is found at off of the Irago Strait in September. These large SDT is due to the difference in development of mixed layer and/or in location of the current axis of the Kuroshio[5]. Abrupt decay of the seasonal thermocline occurs in October. Together with the abrupt change in May, it is resulted that the seasonal change of Ise bay is not gradual but abrupt. Maximum of the bottom temperature of 21°C is detected in October. Further development of the mixed layer is found in out of Ise Bay in November and December.

Figs. 4 and 5 show the monthly mean vertical temperature distribution along L-W and L-E and their STD, respectively. It is suggested that warmer water exists along L-E except for the inner most surface layer of the bay in late spring to early autumn. The temperature difference between L-E and L-W is relatively small in inner most of the bay and it becomes large in the bay mouth. As is suggested in Part I[1], warmer water of the Kuroshio has a tendency to flow in along the eastern coast. So warmer water on L-E is associated with its intrusion into the bay. Conversely, the warmer water on L-W in late spring to early autumn is confined to a surface layer shallower than 3–4 m, which is due to the river discharge. It should be noted that such a warm water is not detectd on L-E. This contrast is discussed again together with the salinity fields.

STD of temperature along L-W and L-E (Fig. 5) shows that maximum STD of temperature greater than 2°C exists in innermost of the bay in July by large river discharge. It is suggested that there exists a remarkable difference in the area and/or temperature of the discharged water. In the bay, relatively large STD of temperature is found at the bottom layer along L-W, which is associated with vertical temperature inversion (Fig. 4). This large STD is detected in all seasons except for May.

Fig. 6 show the monthly mean map of salinity distribution. In winter, halocline is relatively weak in the bay and vertically homogeneous salinity is observed at the bay mouth and out of the bay. The salinity increases as we go out from the bay. In April, the strong halocline develops innermost of the bay. This halocline is identical with the estuarine front made by river discharged water. This front is enhanced gradually and it is maintained upto September. It should be noted that this estuarine front is confined to an inner region from the

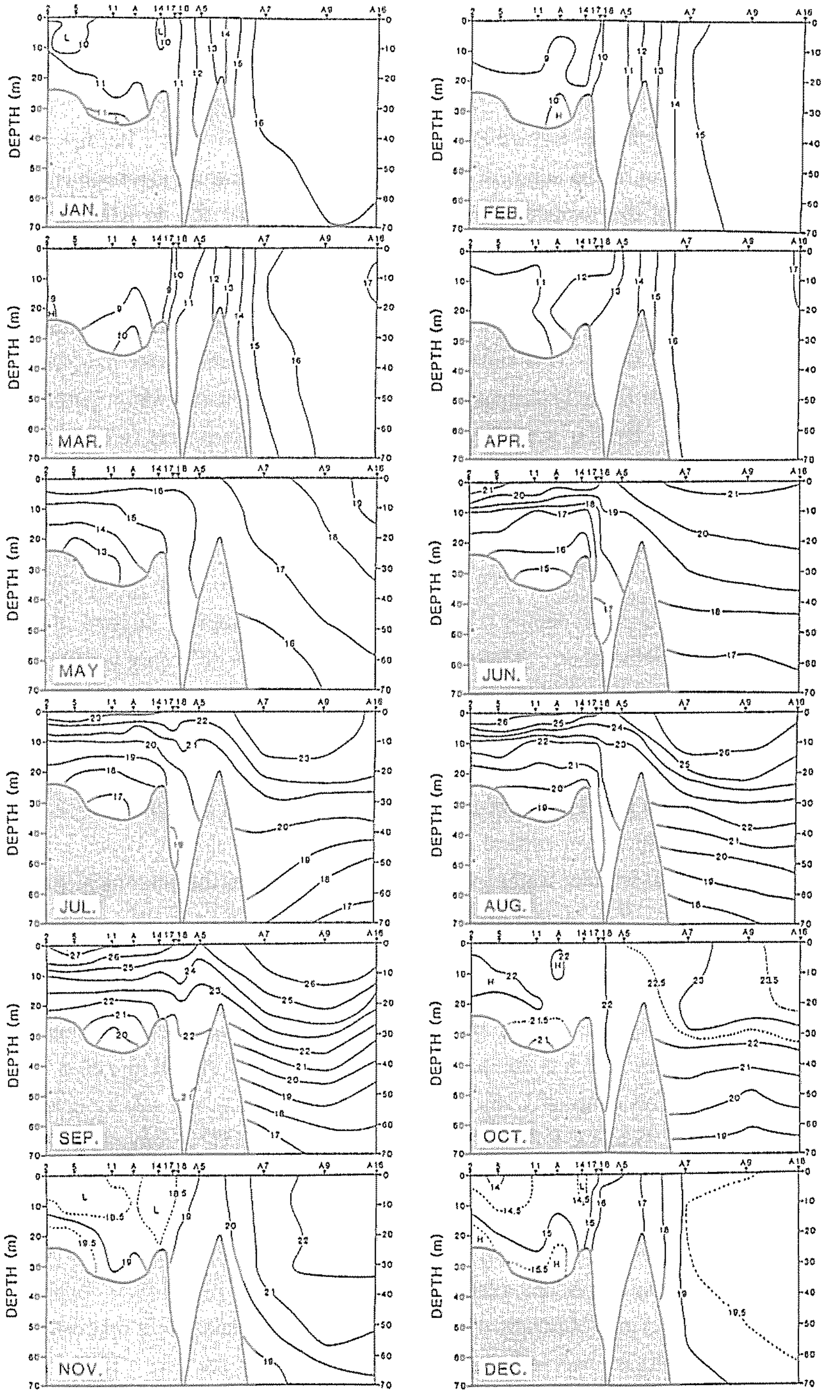

Fig. 2. Monthly mean vertical temperature distributions (°C) along L-C.

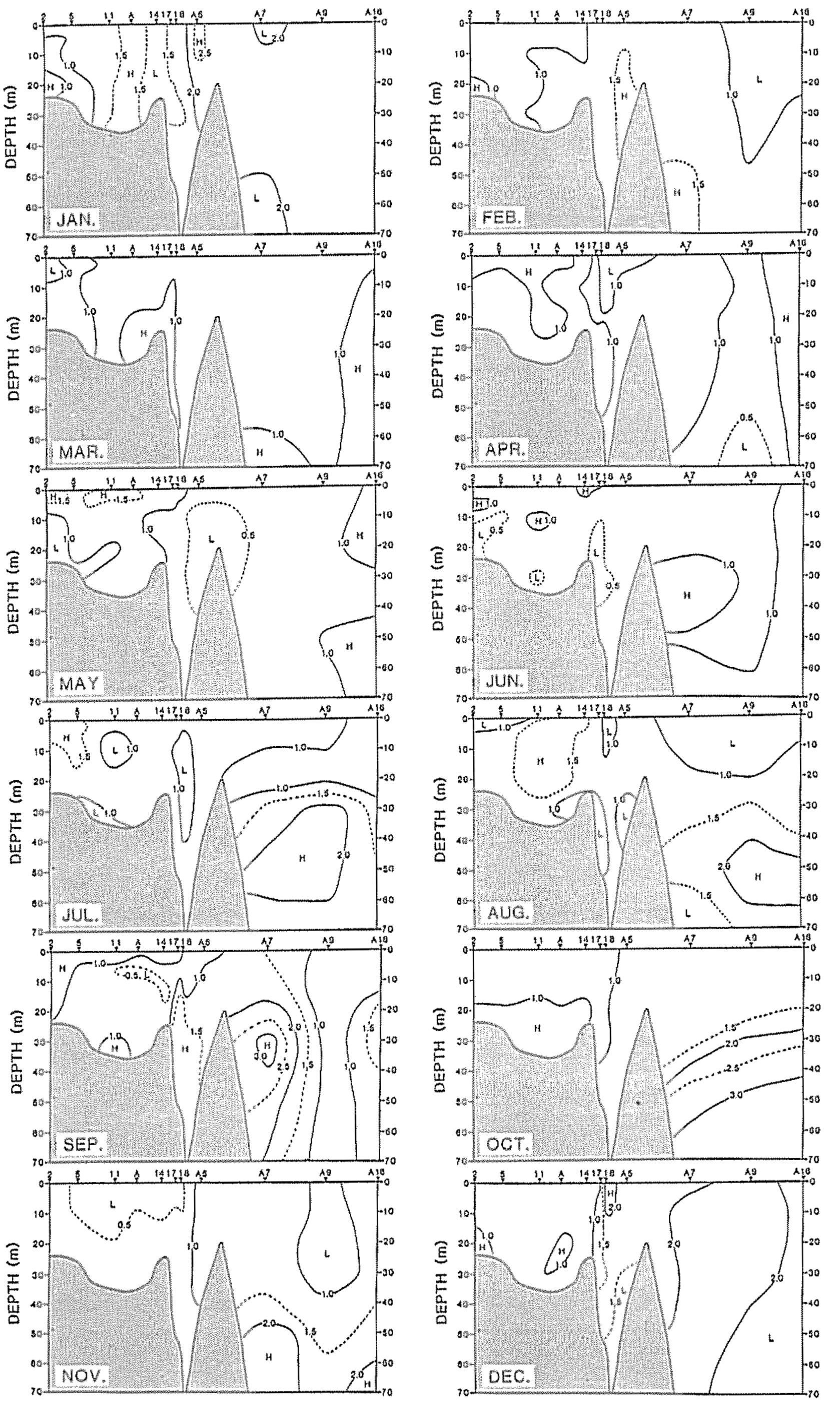

Fig. 3. Vertical distribution of standard deviation of temperature from monthly mean velue along L-C shown in Fig. 2.

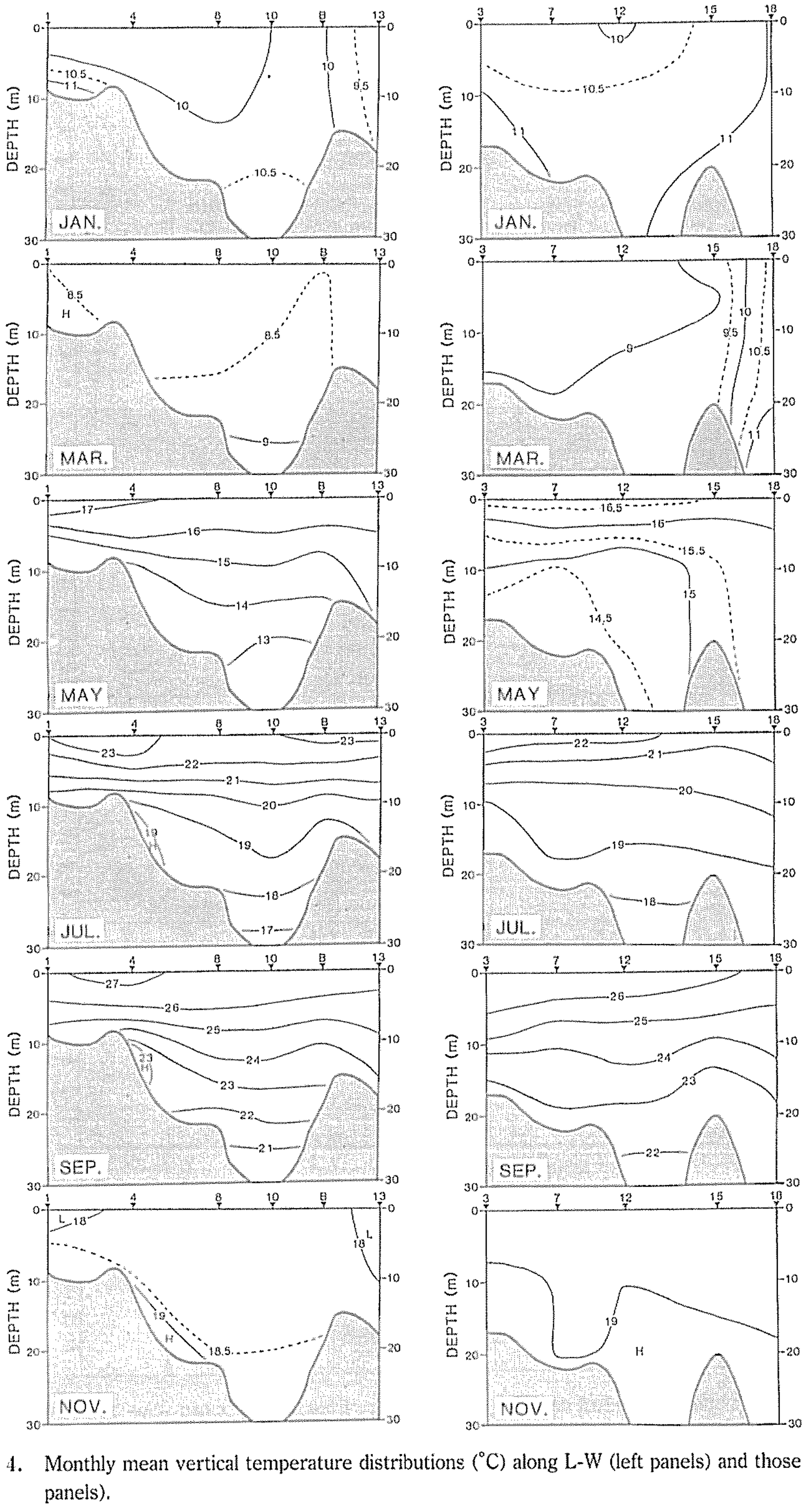

Fig. 4. Monthly mean vertical temperature distributions (°C) along L-W (left panels) and those along L-E (right panels).

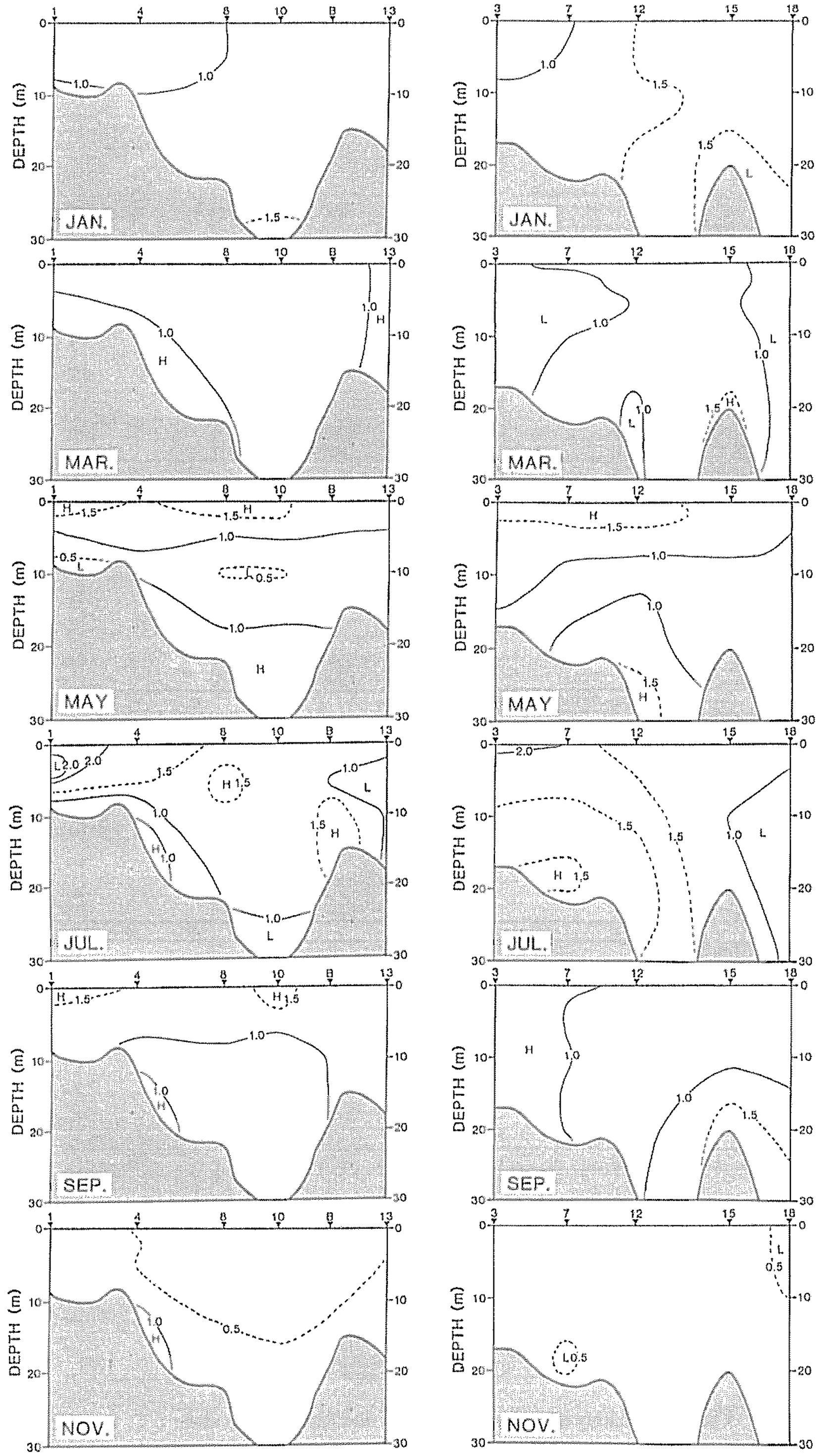

Fig. 5. Vertical distribution of standard deviation of temperature from monthly mean value along L-W (left panels) and those along L-E (right panels) shown in Fig. 4.

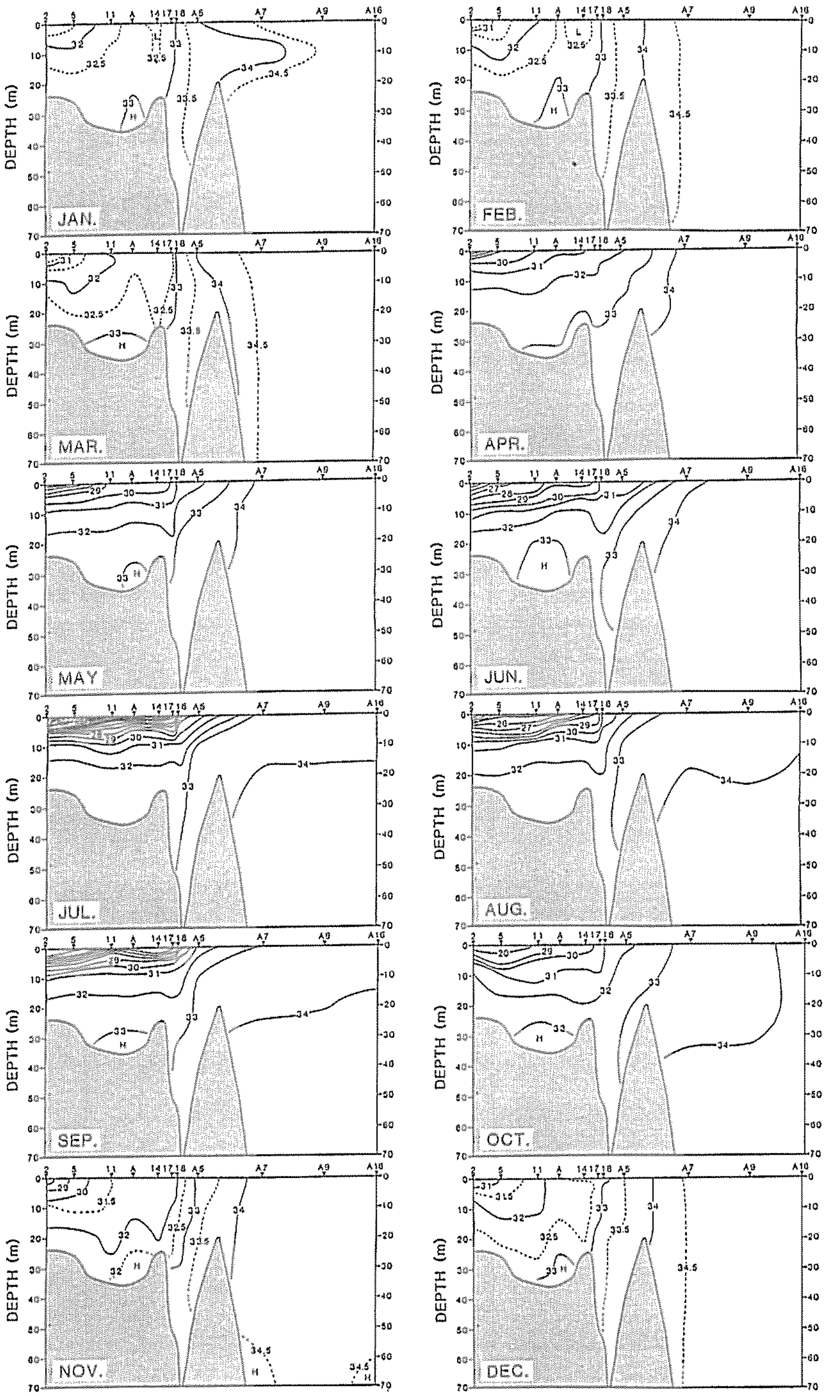

Fig. 6. Monthly mean vertical salinity distributions (°C) along L-C.

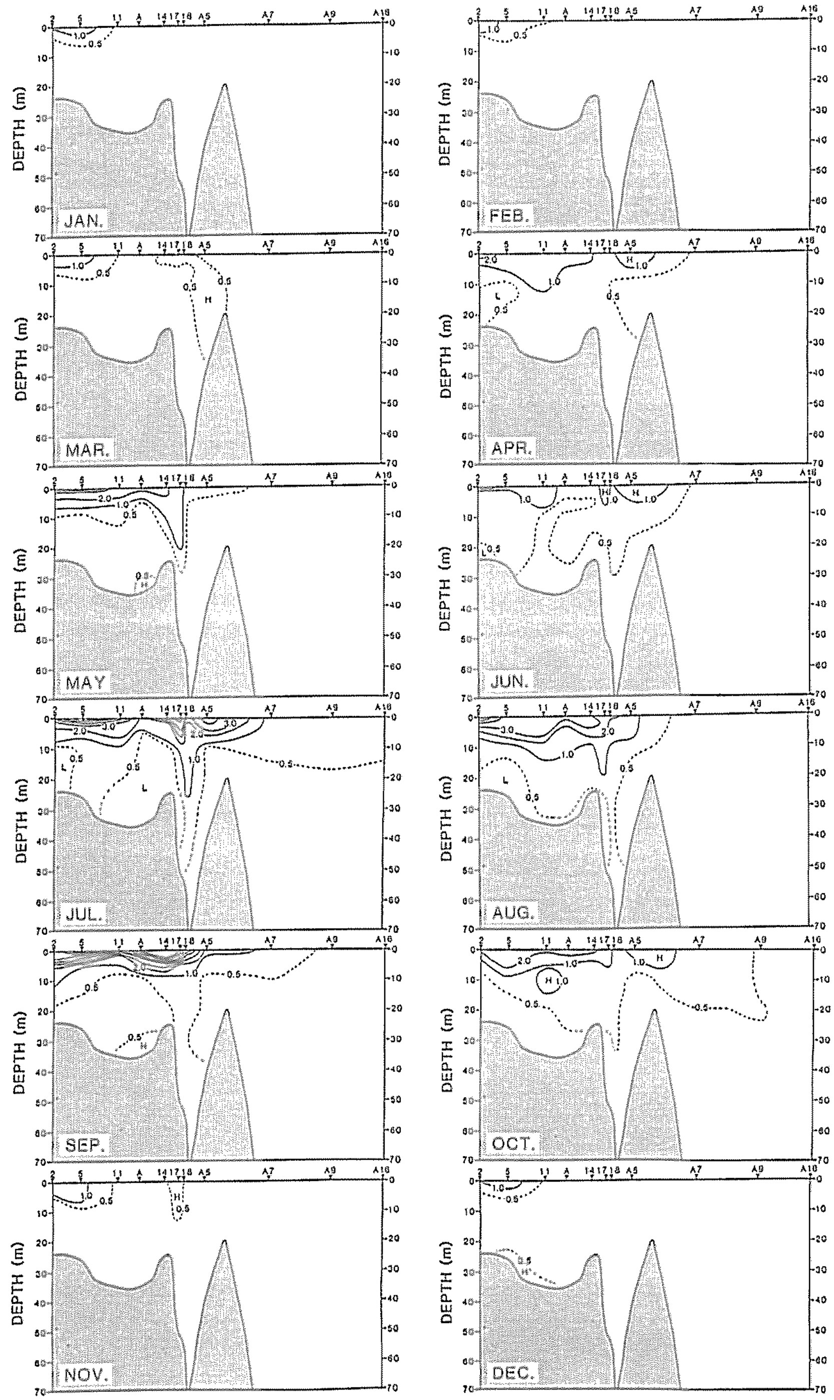

Fig. 7. Vertical distribution of standard deviation of salinity from monthly mean value along L-C shown in Fig. 6.

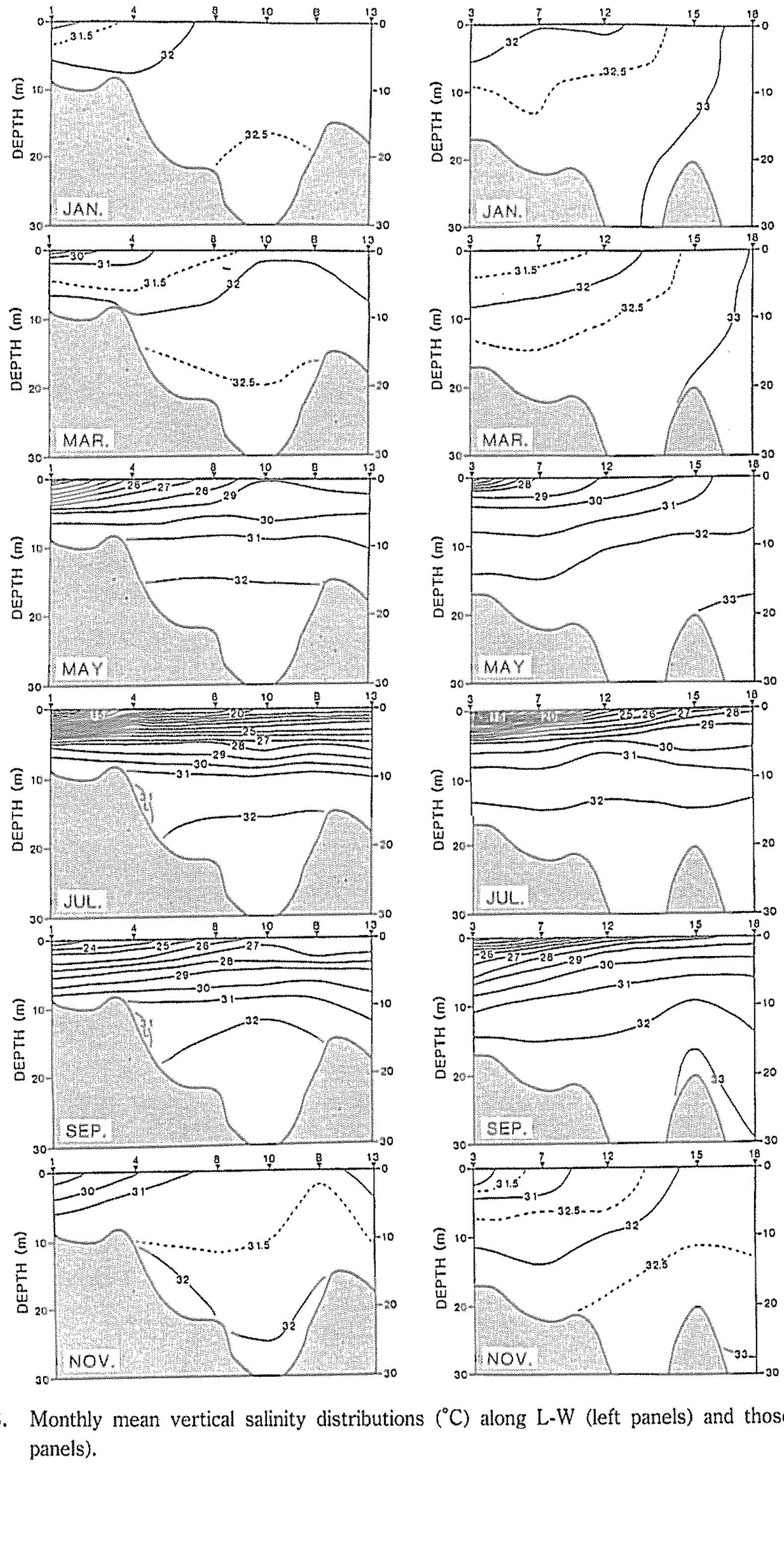

Fig. 8. Monthly mean vertical salinity distributions (°C) along L-W (left panels) and those along L-E (right panels).

Irago Strait and its thickness is less than 10 m. The isohaline of 34 psu runs vertically in late winter to June, but it runs horizontally in July to September. Because the less saline water less than 34 psu is not found in the Kuroshio region, the horizontal isohaline of 34 psu in July to September indicates the flow out of less saline water of the bay. Decay of the estuarine front begins in October. The vertical isohaline distributions are maintained upto March except for the offshore intrusion of the isohaline of 34 and 34.5 psu in January.

Fig. 7 shows the STD of salinity of each month. In winter, larger STD is detected in the surface layer in the innermost of the bay. The difference in the location and/or salinity of estuarine front is suggested in winter. Relatively large STD of the inner surface layer is found in spring to early autumn by large discharge of the river water. In particular, larger STD is found at the innermost surface layer and the tip of frontal region at stations A-A5 (Fig. 1b). The former innermost STD is due to the difference in diffusion and/or advection of less saline river discharged water and the latter large STD is mainly caused by the difference in the location of the estuarine front.

Fig. 8 shows the salinity distribution along L-W and L-E. In winter, relatively less saline water is found in L-W. However, total distributions with the less saline water in innermost surface layer and saline water in deeper layer near the bay mouth are equal with L-E. In contrast to this, remarkable differences between two observational lines are found in late spring to autumn: less saline water covers all the surface layer to a depth of 5 m along L-W, while frontal structure of less saline water to a depth of 5 m is detected along L-E. In particular, salinity differences between the two lines are clear in May and September, corresponding to the formation and decay periods of the estuarine front.

Fig. 9 shows the STD of salinity along L-W and L-E. In winter, relatively large STD exists in an innermost, which represents the difference in the distribution of the less saline water. In spring to autumn, prominent STD is found at the surface layer. Here, it should be noticed that the thickness of large STD layer along L-E is smaller than that of L-E, which is due to the difference in layer thickness of the less saline water in the surface layer (Fig. 8). However, larger STD at a surface layer in September is common to both the lines.

Figs. 10 and 11 show the monthly mean density (σt) and their STD along L-C. It is found that the density distribution has a close resemblance to that of salinity in the bay. However, in outer region of the bay, the density distribution is also influenced by temperature distribution. So the density fields along L-E and L-W has similar patterns to those of salinity shown in Fig. 6. In winter, the density maximum is detected at the Irago Strait, which indicates the formation of coastal thermohaline front. As the offshore intrusion of the isohaline of 34 and 34.5 psu in January (Fig. 6) suggests that the heavier water sinks to the bottom and/or intrudes outer region of the bay. Although the vertical temperature inversion was found in winter, the inversion of density is not detected.

STD of the density has also a similar distribution to that of salinity, which is more clearly along L-W and L-E (Fig. 13). However, relatively large STD of density along L-C is found at an outer region of the bay. This large STD coincides with STD of temperature (Fig. 3) except for October. In October, decay of halocline commonly occurs abruptly and less saline water flows out from the bay (Fig. 6) and STD of salinity is small (Fig. 7). Although large STD of temperature is detected in October (Fig. 3), the density is mainly due to the salinity by the flow out of less saline water.

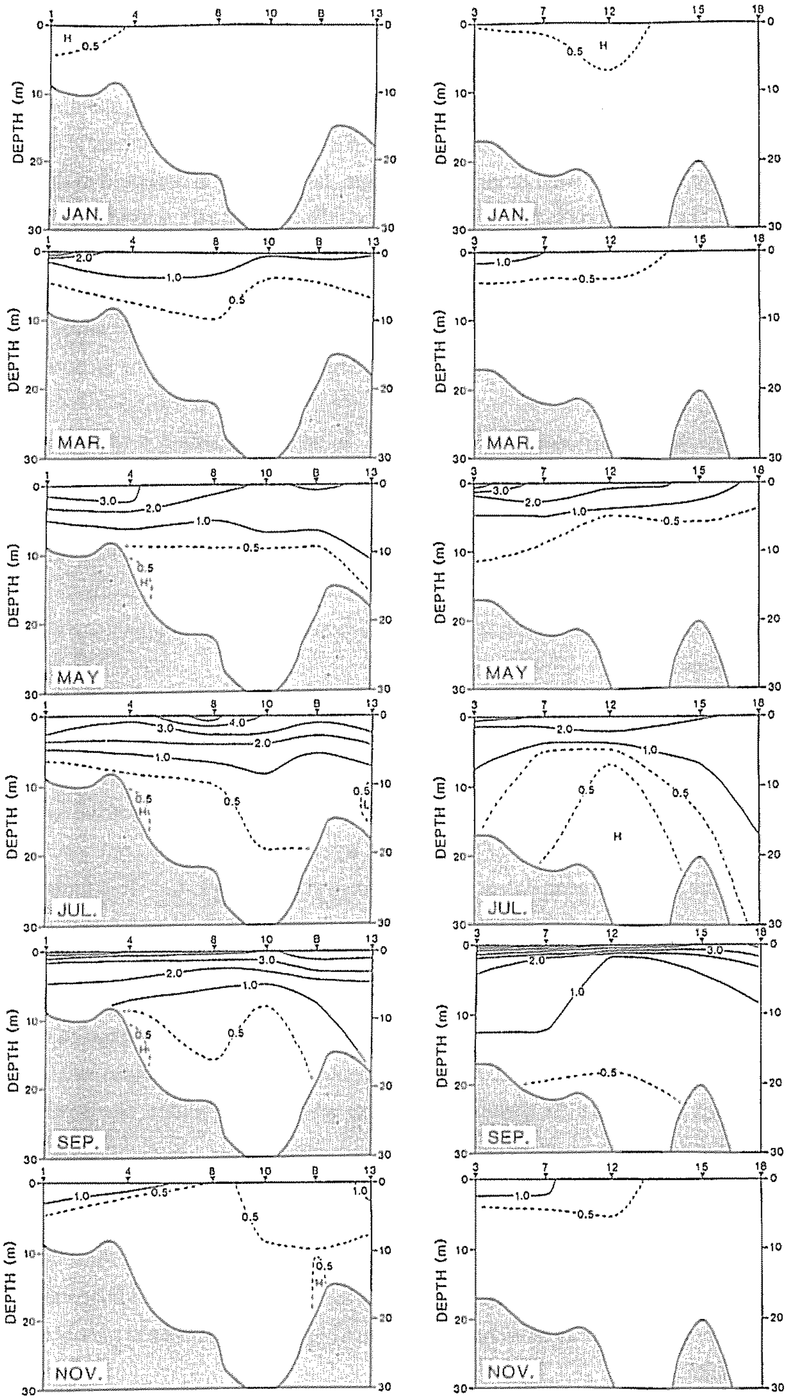

Fig. 9. Vertical distribution of standard deviation of salinity from monthly mean value along L-W (left panels) and those along L-E (right panels) shown in Fig. 8.

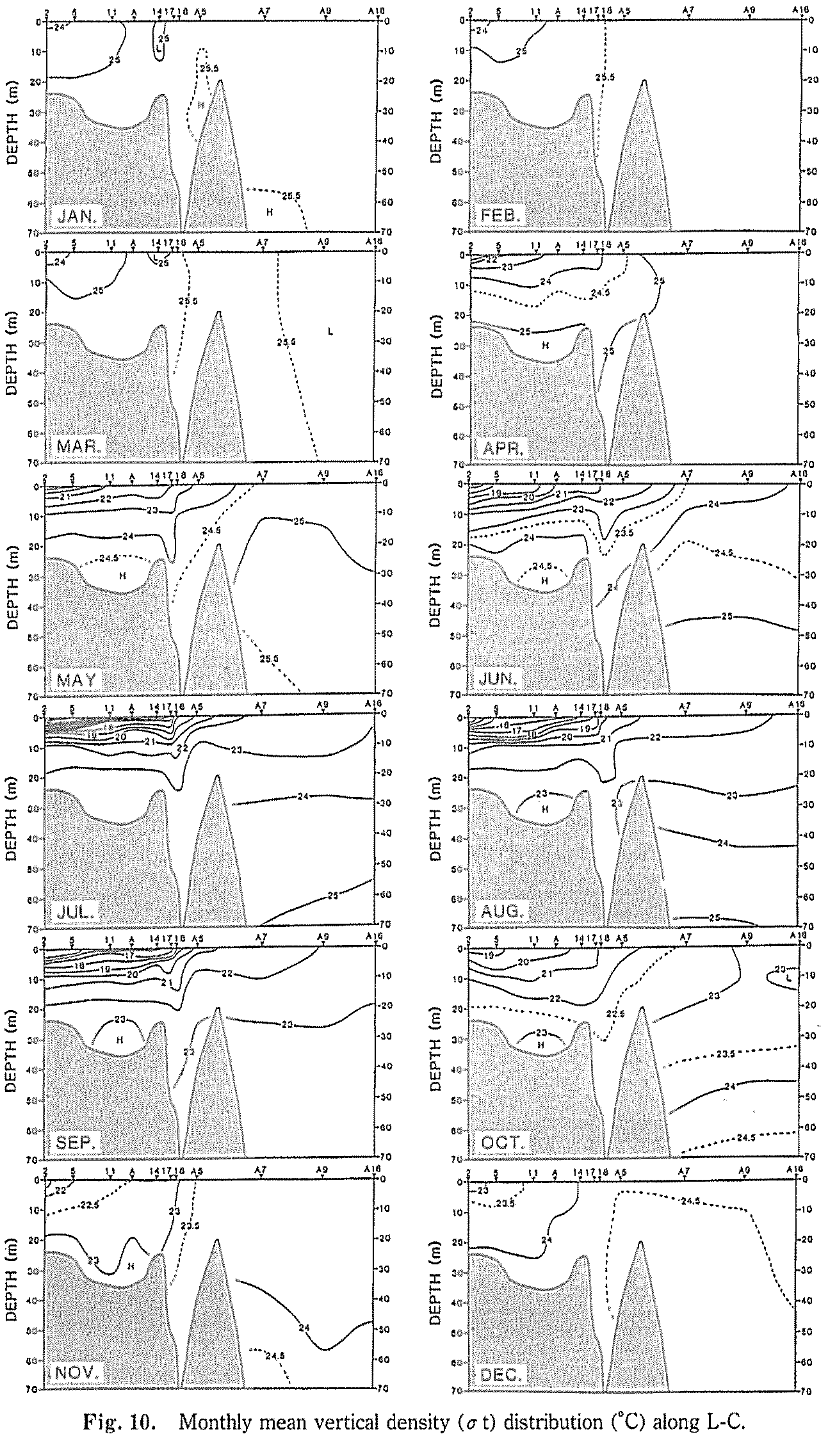

Fig. 10. Monthly mean vertical density (σ t) distribution (°C) along L-C.

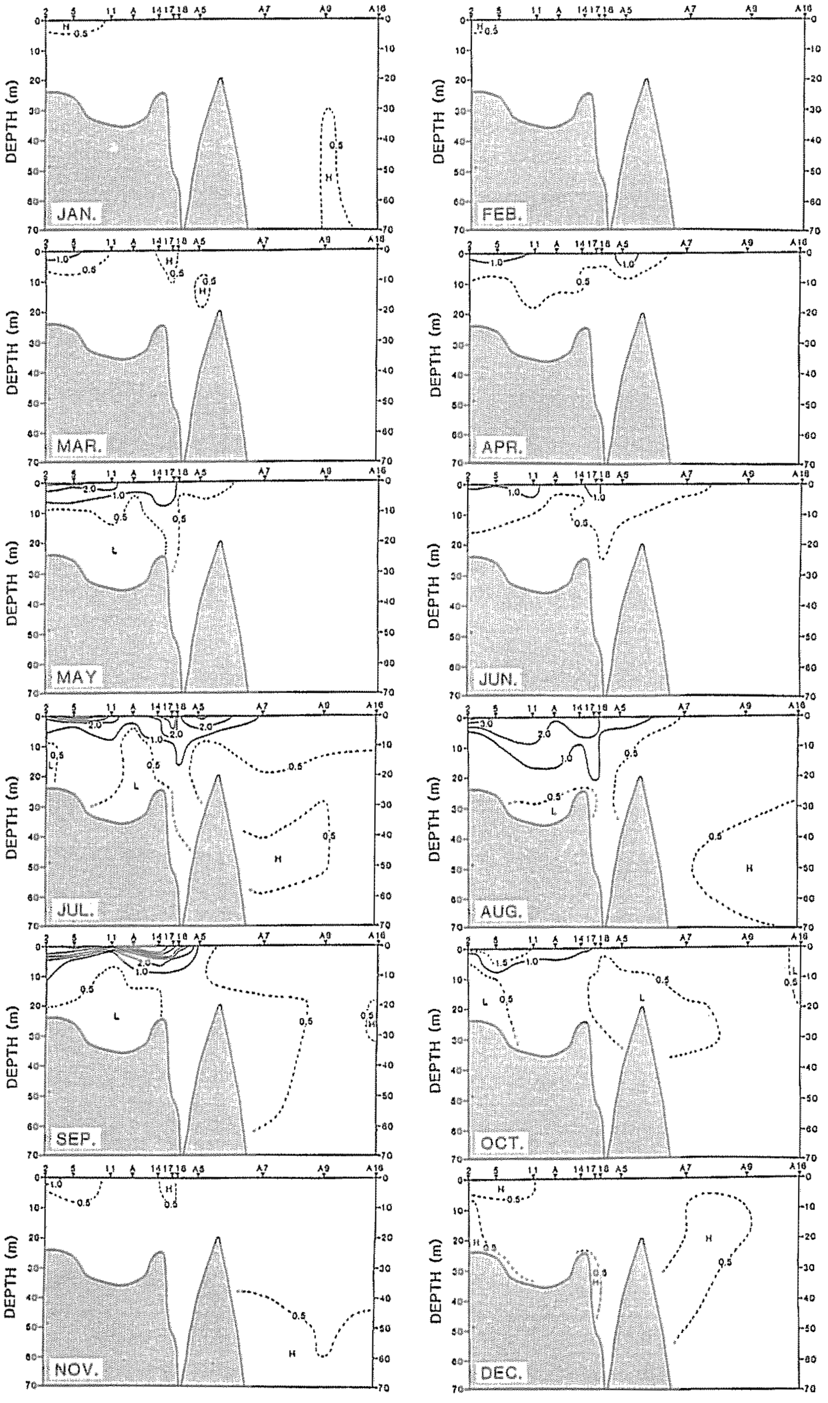

Fig. 11. Vertical distribution of standard deviation of density (σ t) from monthly mean value along L-C shown in Fig. 10.

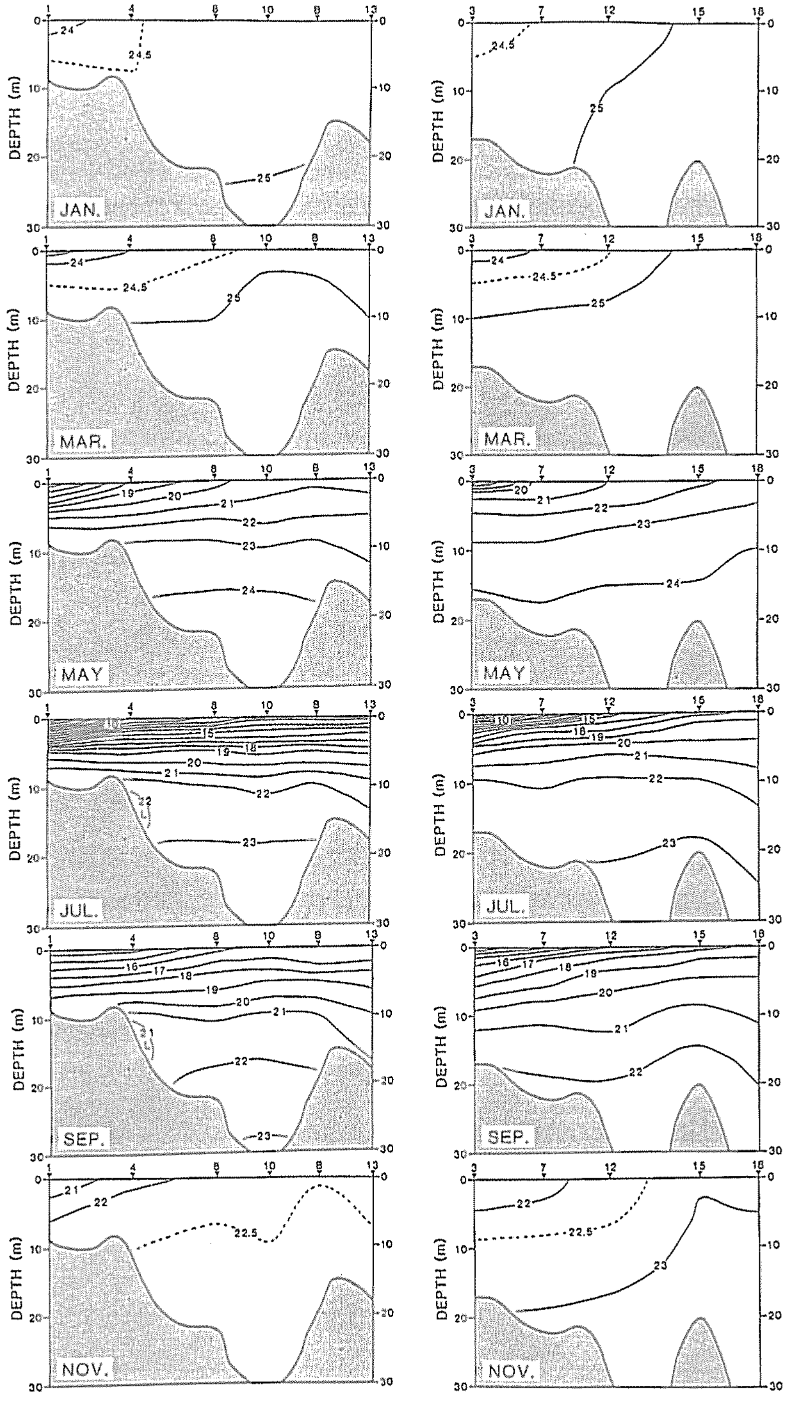

Fig. 12. Monthly mean vertical density (σt) distributions (°C) along L-W (left panels) and those along L-E (right panels).

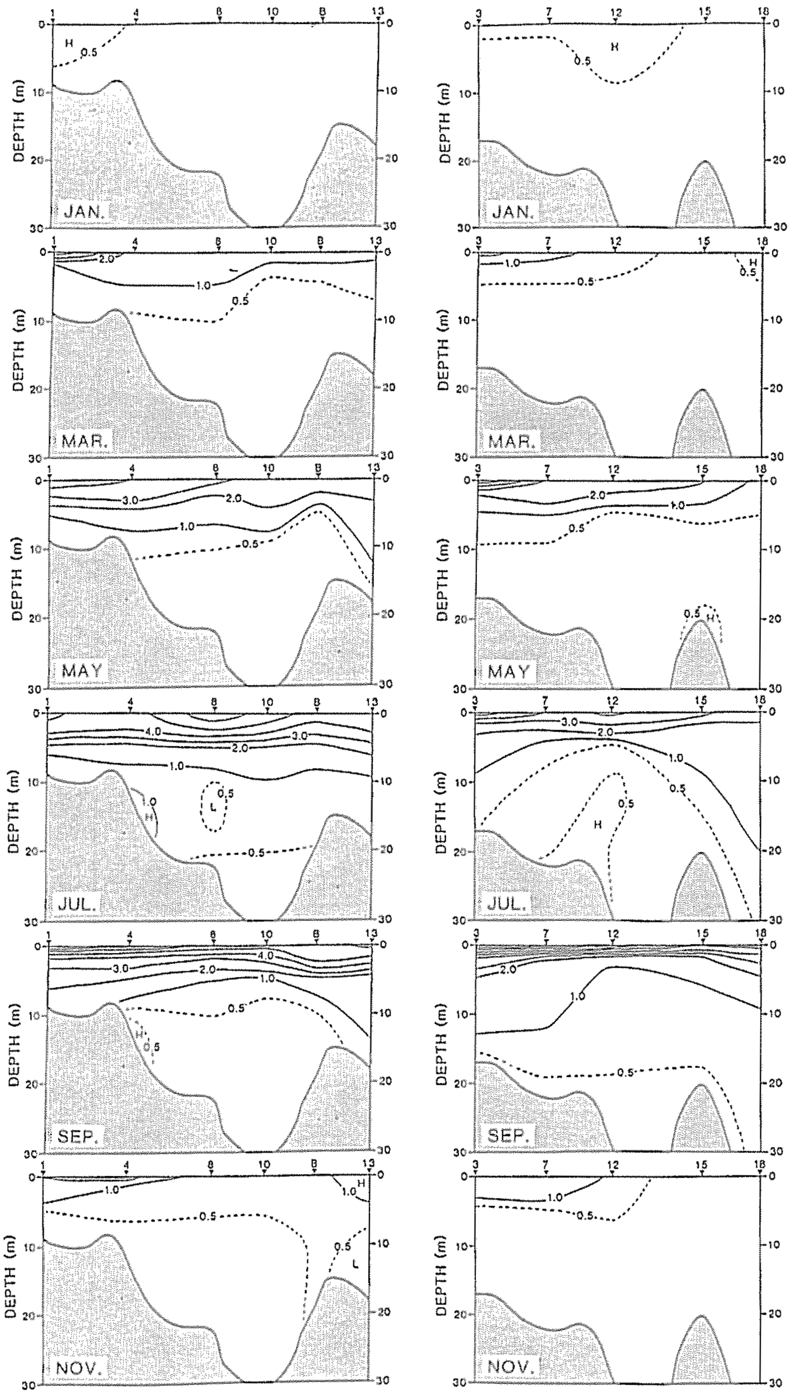

Fig. 13. Vertical distribution of standard deviation of density (σ t) from monthly mean value along L-W (left panels) and those along (right panels) shown in Fig. 12.

4 Summary

Seasonal variations in the oceanic conditions in- and off Ise Bay were examined by use of the historical data during the period from 1985 to 1989 observed by Aichi Prefectural Fisheries Experimental Station[3] and by Fisheries Research Institute of Mie[4]. The monthly mean vertical maps of temperature, salinity and density along three lines and those of their STD have been prsented. The main results are summarized as follows.

(1) It is found that although temperature fields in April show a winter temperature pattern with a vertically homogeneous structure, the seasonal thermocline is formed abruptly in May. On the other hand, decay of the thermocline occurs abruptly in October, while a summer temperature pattern with a clear thermocline is observed in September. The seasonal change in temperature distribution in Ise bay is not sinusoidal but step-like between winter pattern and summer pattern.

(2) Decay of estuarine front with a less saline water decays abruptly in October, which is coincides with the decay of thermocline. Weak halocline is detected in the bay from November to March. The seasonal change in salinity in Ise Bay is also step-like between winter and summer patterns. Estuarine front has a thin thickness less than 5 m and its vertical diffusion in autumn is shown to have a much influence on the seasonal cycle of oceanic structure of the Ise Bay.

(3) The density distribution has a close resemblance to that of salinity in the bay, however it is also influenced by temperature distribution in outer region of the bay. In January, the vertically coherent density maximum is detected at the Irago Strait, which indicates the formation of thermohaline coastal front.

Together with the horizontal distribution of temperature, salinity and density[1], gross features of oceanic structure of the Ise Bay have been clarified. It should be noted that the seasonal variation in temperature and salinity fields of Ise Bay is not sinusoidal but step-like. This evidence gives a new concept for the seasonal change of the bay. For example, the seasonal changes in the formation and decay of front structures are supposed to be very clear and they occur in a short time. Quantitative discussions on the abrupt change in the seasonal cycle should be needed in the next step of this study. The numeical modeling of the seasonal variation of Ise Bay is now performed and the results will be reported in another paper.

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References

1) SEKINE, Y., H. MIZUTANI and T. MOTOYA. Seasonal variation in temperature, salinity and density in- and off Ise Bay. Bull. Fac. Bioresources, Mie Univ., No. 8: 1–18 (1992).

2) UNOKI, S. Ise Bay and Mikawa Bay, II Physics. In Coastal Oceanography of Japanese Islands ed., H. Kunishi et al. (in Japanese), Tokai Univ. Press, 513–527 (1985).

3) Aichi Prefectural Fisheries Experimental Station. Prompt Ocean Report (Kaiyou Sokuhou) (in Japanese). From Report on 8–9 January 1985 to Report on 11–12 December 1989.

4) Fisheries Research Institute of Mie. Monthly Observations of the Bay (Senkai Teisen Kansoku Kekka) (in Japanese).

From Report on 8–9 January 1985 to Report on 6–7 December 1989.
5) SEKINE, Y., T. ITOH and K. FUJITA. Warm water approaches to the eastern coast of Kii Peninsula (in Japanese). Bull. Coast. Oceanogr. 28: 174–182 (1991)

伊勢湾内外における水温・塩分・密度の鉛直分布の季節変化

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伊勢湾内外における水温，塩分，密度の鉛直分布の季節変化を調べた。愛知県水産試験場と三重県水産技術センターによる1985年から1989年の海洋観測結果を用いて湾の西部，中央部，東部の３つの線に沿う水温，塩分，密度の月別平均鉛直分布およびその標準偏差分布図を提出した。結果として，水温躍層の形成と消滅がそれぞれ５月と10月に突然生じることが示された。伊勢湾内部では鉛直水温逆転層の形成が11月から翌年の５月まで認められた。鉛直方向に一様な密度極大域が１月に伊良湖水道でみられ，熱塩フロントの形成が認められた。７月に顕著な河口フロントが形成され，10月以降に生じる河口フロント消滅による低塩分水の鉛直移流拡散が湾内外の海洋構造の季節変化に大きな影響を及ぼすことが示された。