

## Seasonal Variations in Oceanic Structures In- and off Ise Bay

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### Abstract

Seasonal variations in frontal structure in- and off Ise Bay are examined by use of observational data during the period from 1985 to 1989 obtained by Aichi Fisheries Research Institute and Fisheries Research Institute of Mie. Monthly mean temperature, salinity and density along central region in- and off Ise Bay are discussed with reference to their time change at six fixed points. It is shown that amplitude of seasonal change in sea surface temperature (SST) is more than 20°C in Ise Bay but it is about 10°C off the bay. The horizontal temperature difference (HTD) shows maximum just off the Irago Strait, baymouth of Ise Bay. However, horizontal difference in salinity (HSD) shows maximum in- and out of the Irago Strait. It should be noticed that a cold water in summer and a density maximum are formed in a deep area at the Irago Strait. This deep area at the Irago strait, which is separated from the Pacific Ocean by a sill of Kami-Shima, locates at the tip of the coastal front and its topographic effect possibly generates a characteristic seasonal change in temperature, salinity and density of Ise Bay.

**Key words:** coastal front · river discharge and the Ise Bay

### 1 Introduction

There have been many observations on the oceanic conditions of Ise Bay<sup>1-4)</sup>. Although areas of these studies are confined to in Ise Bay, the oceanic structures in- and off Ise Bay were investigated by our previous studies<sup>5,6)</sup>. In these studies<sup>5,6)</sup>, seasonal variations in temperature, salinity and density were examined by use of the observational data during the period from 1985 to 1989 supplied by Fisheries Research Institute of Mie<sup>7)</sup> and by Aichi Fisheries Research Institute<sup>8)</sup>. It has been pointed out by the previous studies<sup>5,6)</sup> that the seasonal change in temperature and salinity pattern of Ise Bay is not sinusoidal but step-like between winter pattern and summer pattern. The change from winter pattern of temperature (salinity) to summer pattern occurs abruptly in May (April). The opposite changes from summer pattern to winter pattern of temperature and salinity occur concurrently in October. Furthermore, in winter, the vertically coherent density maximum, which forms a thermohaline coastal front by the effect of cabellings, is detected in the Irago Strait.

However, since the emphasis of these studies<sup>5,6)</sup> is placed on spatial change in horizontal and vertical distribution of temperature, salinity and density, time change at a fixed point has not been fully discussed. As a succeeding study on the oceanic conditions of Ise Bay, seasonal variations in temperature, salinity and density at some fixed points along a central region of Ise Bay are examined in the present paper with special reference to the formation of coastal fronts. To know both spatial and time changes in- and off Ise Bay is strongly needed for future quantitative studies by use of numerical models.

## 2 Data

Fig. 1 shows observational stations of temperature and salinity used in analyses of the present study. These stations were selected to see representative seasonal variation in- and off of Ise Bay. As for observed stations shown by the coupled closed circles in the bay, average of observational data at two stations are discussed to include local changes across the central section of Ise Bay. Monthly observational data of temperature and salinity at the stations shown in Fig. 1 during the period from 1985 to 1989 are used to calculate the monthly mean data and their standard deviation (STD). Density ( $\sigma_t$ ) is calculated from temperature and salinity data and its monthly mean value and STD are also discussed.

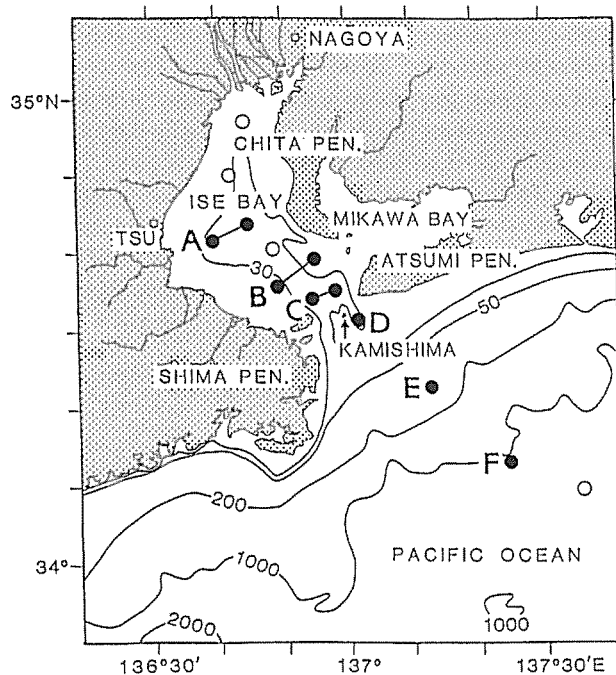


Fig. 1. Depth contours (in meter) of Ise Bay and locations of observational stations of temperature, salinity and density by Fisheries Research Institute of Mie (coupled two closed marks noted by A-C and two open circles in the Bay) and Aichi Fisheries Research Institute (closed marks noted by D-F and a open circle off F). Data at the stations shown by closed circles are used to see the seasonal variation in temperature, salinity and density, while those shown by open circle are used to see the vertical distribution of temperature, salinity and density.

## 3 Results

Fig. 2 shows seasonal variations in temperature at six observational stations shown in Fig. 1. Here, because the depth at the station B is less than 30 m, data for 30 m is not shown. Larger seasonal variation is detected in Ise Bay: annual variation range exceeds 20°C (12°C) at a surface (a depth of 30 m) of A, while it is less than 12°C (7°C) at a surface (a depth of 30 m) of F.

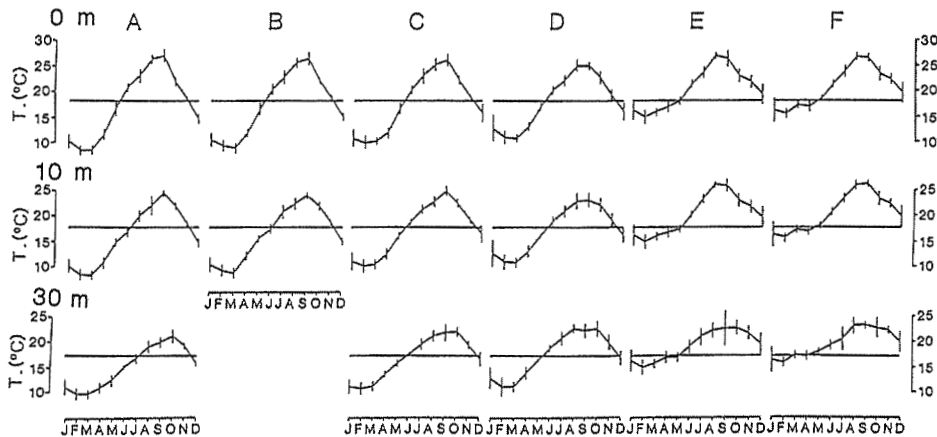


Fig. 2. Monthly mean temperature over 1985–1989 at the stations shown in Fig. 1 at depths of 0 m, 10 m and 30 m. Vertical bars in each graph show the standard deviation from monthly mean value.

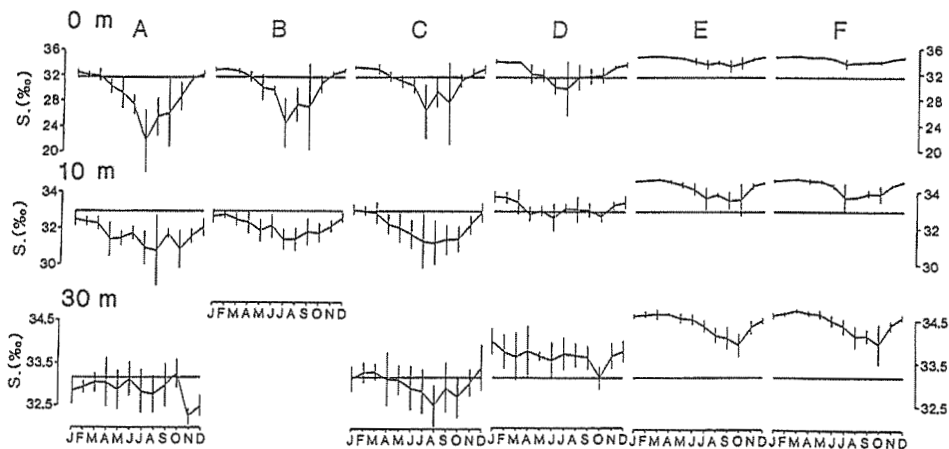


Fig. 3. Same as Fig. 2 but for salinity.

Larger seasonal variation is also found in sea surface salinity (SSS) (Fig. 3). Seasonal variation range of SSS at A is larger than 10 psu, while that of F is less than 1 psu. In contrast to this, horizontal difference in seasonal range of salinity is relatively small at a depth of 30 m: the range at A is 1 psu and that of F is 0.8 psu. As for A and C, clear seasonal cycle is not detected at a depth of 30 m by significant STD. Because this level locates below the bottom of estuarine front which develops from innermost of the bay to Irago Strait<sup>5,6)</sup>, it is supposed that seasonal variation is relatively weak and influence of the interannual difference of upper layer is more essential. As for E and F, salinity minimum with relatively large STD is detected in summer to autumn. This is due to the formation of mixed layer, in which surface less saline water is advected to deeper layer by strong vertical mixing.

Seasonal change in density ( $\sigma_t$ ) is shown in Fig. 4. Because the seasonal change in SSS is significant,

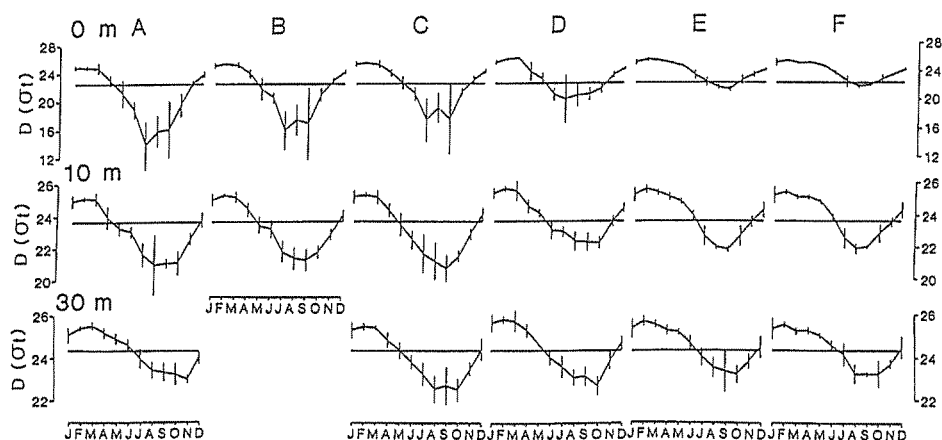


Fig. 4. Same as Fig. 2 but for density ( $\sigma_t$ ).

seasonal cycle in surface density shows close resemblance to salinity. At a depth of 10 m, salinity minimum in summer is much smoothed than that of SSS. Conversely, winter maximum at a depth of 10 m becomes more significant than that of SSS. This tendency is more prominent at B and C. It is pointed out that there exists a difference in winter maximum of salinity and density: winter salinity maximum is found in January, but that of density is in February and March. Since decrease in temperature is clear in February to March (Fig. 2), density maximum in February to March is due to cooling in winter. At a depth of 30 m, a similar annual cycle of density to those of 10 m are seen, which is different from those of salinity. Clear annual cycle of density is

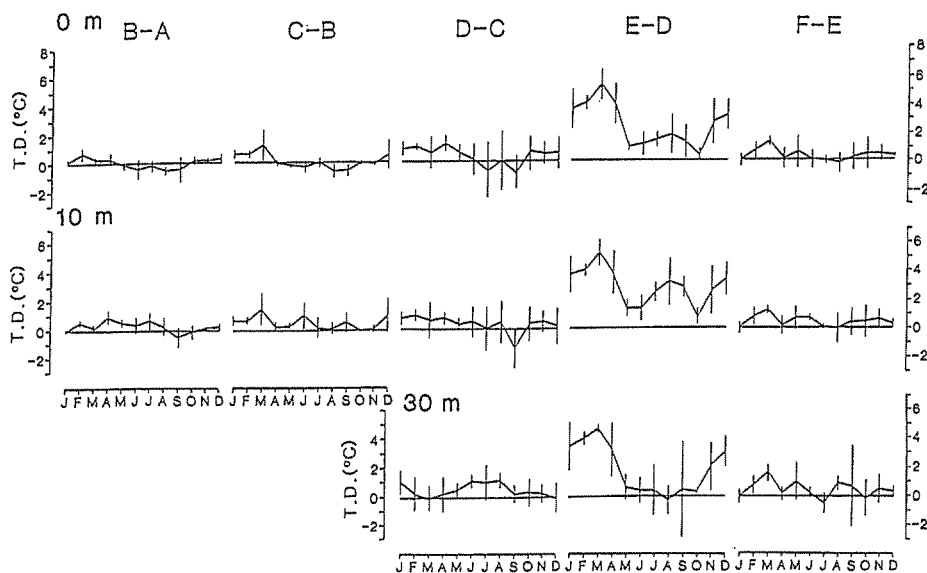


Fig. 5. Monthly mean horizontal temperature difference (HTD) between two neighboring stations shown in Fig. 1 at depths of 0 m, 10 m and 30 m. Vertical bars in each graph show their standard deviation from monthly mean value.

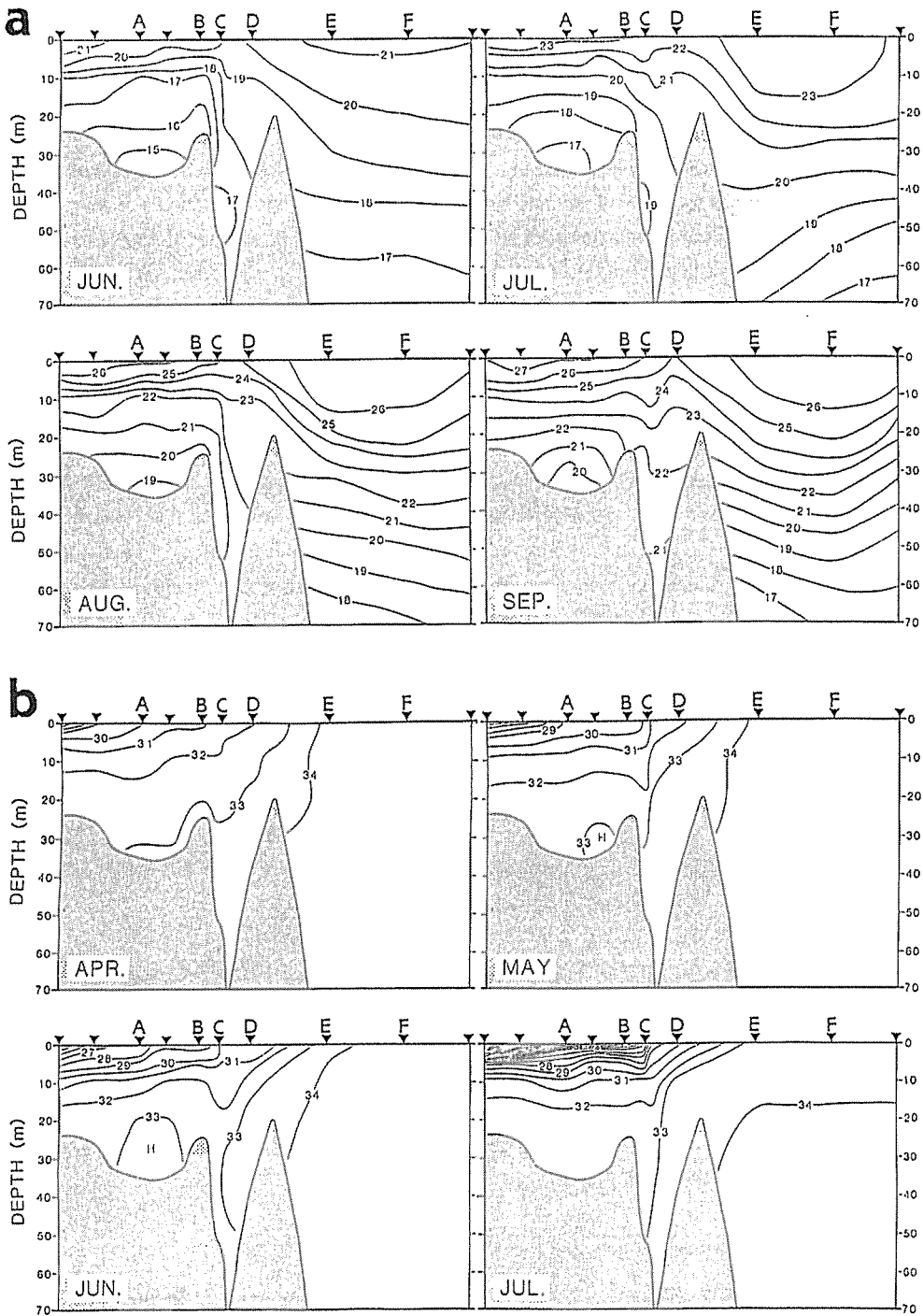


Fig. 6. (a) Monthly mean vertical distribution of temperature ( $^{\circ}\text{C}$ ) from June to September along the stations in central region in- and off Ise Bay shown in Fig. 1 and (b) that of salinity (psu) from April to July.

characterized by increase in winter and decrease in summer. On the whole, it is concluded that in Ise Bay, density depends on salinity in the surface layer but it depends on both salinity and temperature in deeper layer than the layer of estuarine front (halocline).

In order to see the seasonal variation in frontal structure of temperature, horizontal temperature difference (HTD) between two neighboring stations are shown in Fig. 5. Large HTD is found between D and E (E-D), which locates at offshore of Kami-shima (Fig. 1). In particular, large HTD at E-D is found in winter. It is supposed that large HTD at E-D is due to small heat content in the bay and its influence is more enhanced by vertical mixing in winter. Another maximum of HDT at E-D is detected in summer at depths of 0 m and 10 m, which is caused by the upwelling of cold water at the Irago Strait (Fig. 6a). Namely, sea surface temperature (SST) in the bay and outside of the Irago Strait are warmer than  $26^{\circ}\text{C}$ , however, SST at the Irago Strait is less than  $25^{\circ}\text{C}$ . Because this cold water has a larger horizontal temperature gradient, negative values HTD at B-A, C-B and D-C in summer are formed. The cold water exists in deep area of baymouth of Ise Bay that is separated from the Pacific Ocean by a sill of Irago Strait. It is thus suggested that the existence of this deep area causes characteristic seasonal change in temperature of Ise Bay.

Horizontal salinity difference (HSD) between the two neighboring stations are shown in Fig. 7. Relatively large HSD is found at D-C and E-D. At a depth of 10 m, weak negative HSD at C-B is found in late spring to autumn. Because this level locates at bottom layer of halocline and because thickness of the halocline is largest at the tip of coastal front, which is clearly seen by isohaline of 32 psu (Fig. 6b), salinity at a depth of 10 m is decreased toward innermost of the bay. This explains the negative HSD at these stations. It is also found that surface HSD maximum of E-D exists in summer, but that at a depth of 30 m is found in spring. Summer maximum of surface HSD is due to the offshore diffusion of less saline water from the estuarine front (Fig. 6b). It is also pointed out from Fig. 6b that spring maximum of HSD at a depth of 30 m is caused by outflow of less saline water formed by vertical mixing through the Irago Strait.

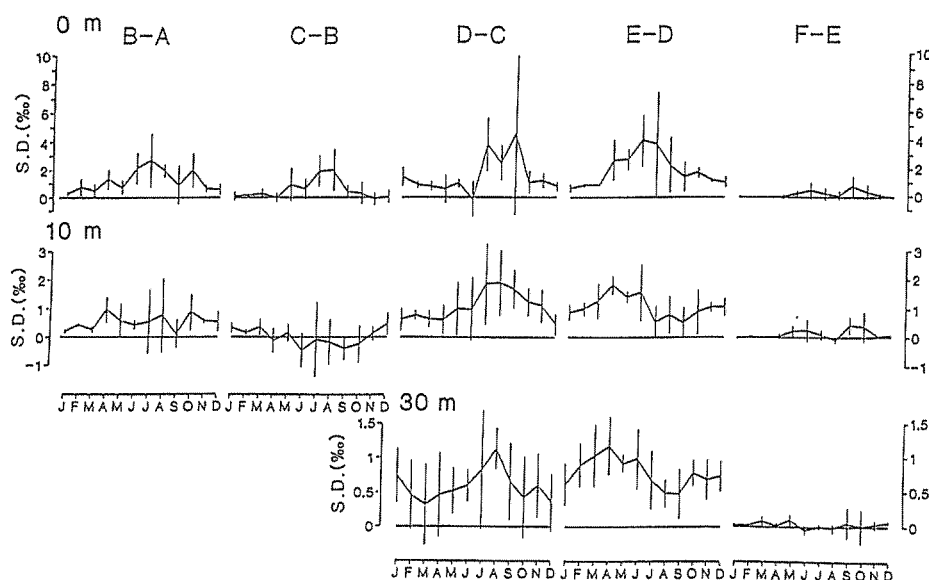


Fig. 7. Same as Fig. 5 but for horizontal salinity difference (HSD).

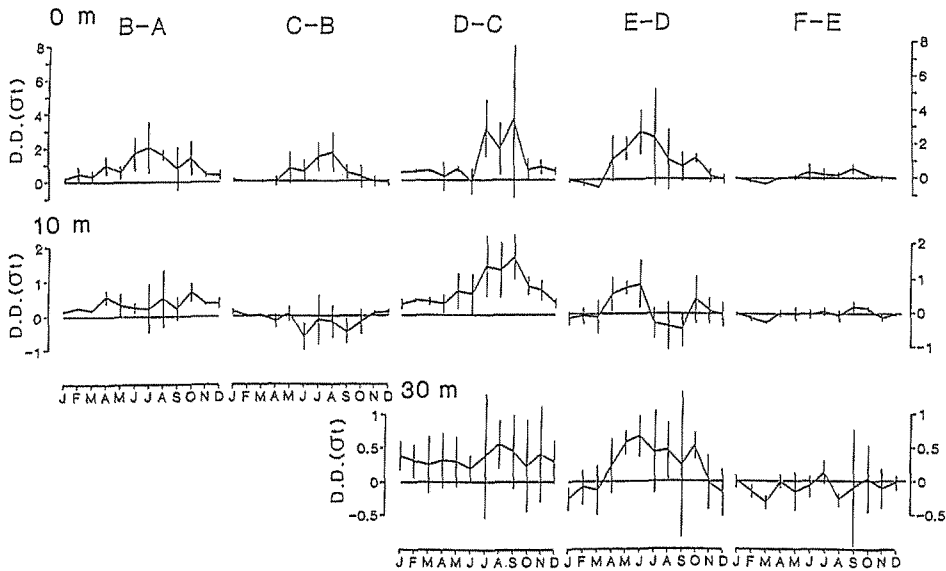


Fig. 8. Same as Fig. 5 but for horizontal density difference (HDD).

Horizontal difference in density (HDD) is shown in Fig. 8. At surface, seasonal cycles of HDD are almost similar to those of HSD. There exists some negative HDD: negative HDD at E-D and F-E are caused by the formation of density maximum at the Irago Strait by generation of cabelling<sup>5,6)</sup>. At a depth of 10 m, two negative HDD at C-B and at E-D are found in summer. Causes of these two negative HDD are common to those of HSD: negative HSD at C-B is caused by larger thickness of the coastal front. Negative HDD at E-D is attributed to the cold water appearance at Irago Strait in summer (Fig. 6a) and resultant positive HTD in summer (Fig. 5) yields the negative HDD.

#### 4 Discussion

Seasonal variations in horizontal temperature, salinity and density in- and off Ise Bay and their horizontal difference have been studied by use of observational data during the period from 1985 to 1989 obtained by Fisheries Research Institute of Mie<sup>7)</sup> and Aichi Fisheries Research Institute<sup>8)</sup>. It should be noted that a cold SST area is formed at the deep area at the Irago Strait in summer. As this area locates at the tip of the layer of coastal front with less saline water, this cold water is supposed to suppress the offshore extension of estuarine front of Ise Bay. It is thus suggested that deeper area at the Irago Strait is important for the seasonal cycle and it has a possibility to generate characteristic seasonal changes in the oceanic conditions of Ise Bay. Quantitative discussion on the topographic effect of the deep area is needed in the next stage of this study.

Recently, three detailed hydrographic observations on the coastal fronts of Ise Bay were made in December 1989 and November to December 1990<sup>9)</sup>. It has been demonstrated by these observations that during only three days, significant changes in oceanic front are observed. This result suggests that data analysis by use of more frequent observations are required to see more realistic seasonal variations of Ise Bay.

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## 伊勢湾内外における海洋構造の季節変化

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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年の水温塩分の海洋観測結果を用い、伊勢湾中央部の季節変化を調べた。水温の季節変化幅が湾内部では  $20^{\circ}\text{C}$  を上回るのに対し、湾外では  $10^{\circ}\text{C}$  程度である。水温の水平勾配は伊良湖水道沖で最大となるが、塩分の水平勾配は伊良湖水道内部と沖で最大となることを示した。伊良湖水道の深い海域は夏に低温域となり、冬には密度最大域が生じる。この深い海域は神島の浅瀬で外洋と分離しており、また、沿岸フロントの先端部に位置している。この深い海域の存在が伊勢湾特有の水温、塩分、密度の季節変化を生じる可能性を指摘した。