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The Fluctuation Characteristics of the Water Mass and the Current Structure of the Southeastern Region of The East Sea

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To investigate characteristics of water masses and current structures around Noto Peninsula located in south-east coastal region of the East Sea, observation results of CREAMS (Circulations Research of the East Asian Marginal Seas) cruise and data report of oceanographic observation (Japan Meteorological Agency) in June, 1995 and 1996 were used. Water mass showing characteristics of Tsushima Warm Current (TWC) exists over the continental shelf. The depth is shallower than 200 m and its width and thickness are 190 km and 200 m, respectively. Minimum level of dissolved oxygen occurred at the layers of maximum salinity. In the current structure, a noteworthy phenomenon is that the positions of the high-salinity water (more than 34.6 psu) match well with the distributions of the southwestward flow. In June of 1995 and June of 1996, a southwestward flow were separated into two parts along line C and line G. Current directions derived from the temperature and salinity match well with the distributions of the geostrophic currents in the vertical sections. The isothermal lines and the isohaline, which exist horizontally along the coastal area of the Japan, change abruptly at the frontal area of the Noto Peninsula, then turn toward the center of the East Sea. The dynamic depth anomalies centering around the region far northwest of the Noto Peninsula were relatively high, compared to those of other regions. The isopycnic surface (sigma-t, 25.8) existed near the surface in the central part of the East Sea, but, at the depth of 100 m, the isopycnic surface was found in the coastal waters.

Key words: Tsushima warm current, Wasaka bay, Noto peninsula, water masses, current structure

Introduction

The East Sea (also known as The Sea of Japan) is adjacent to the northwest region of the Pacific Ocean. The characteristics of the East Sea are similar to those of the Mediterranean Sea; its maximum depth is approximately 3700 m (mean depth: 1600 m), and it is surrounded by straits with depths shallower than 200 m. The upper layer of the East Sea is occupied by Tsushima Warm Currents (TWC), which are characterized by high temperature and a high level of salinity. The water mass in the intermediate and bottom layers of the East Sea are isolated from those of the open sea by topographic effects. Therefore, phenomena occurring in the East Sea may be considered as smaller versions of those that occur in the open sea. In the East Sea, the East Korean Warm Current (EKWC) shows characteristics similar to those of the Western Boundary Current, and a polar front is formed around a boundary between the low-temperature and low-salinity northern region and the high-temperature and high-salinity southern region (Choi *et al.*, 1995).

The East Sea borders the following bodies of water: the East China Sea, the North Pacific, the Sea of Okhotsk (through the Korean Strait, also known as the Tsushima Strait, the Tsugaru Strait, and the Soya Strait). Noteworthy is the fact that the TWC, which flow into the East Sea through the Korean Strait, play an important role in the transportation of heat and larvae (Ogawa, 1983).

The East Sea is an important place for the growth of marine organisms, and its oceanic conditions

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have great influence on marine ecosystems. Due to the instability of the EKWC, the oceanic conditions in the East Sea are affected by the fluctuations of the moving paths of the TWC, polar fronts, and warm eddies. In particular, warm eddies play an important role in spreading the surface water of the East Sea from its southern coastal region to its interior region (Isoda, 1994).

However, the fluctuation characteristics of the meandering TWC and the warm eddies in the East Sea are not yet known due to the instability of the TWC. Data analyses based on field measurements and experiments using numerical models have been performed to understand these phenomena (Kim and Yoon, 1999; Seung and Kim, 1993). Recently, observations using argos buoys have been attempted (Lee *et. al.*, 1997).

In particular, the moving paths and features of the TWC branch along the shallow oceanic regions around Japan change every year. Hideaki (1999) showed that the moving paths and features of the TWC in the coastal regions of Japan were not constant.

In the present paper, the characteristics of water masses and current structures around the Noto Peninsula located in the southeastern coastal region of the East Sea were studied by using the observation results of a CREAMS (Circulations Research of the East Asian Marginal Seas) cruise and the data reports of oceanographic observations (Japan Meteorological Agency) from June of 1995 and June of 1996.

Data and Methods

Data

This study used data obtained from a CREAMS cruise off the Wakasa Bay of Japan in June of 1995 and June of 1996 (see Fig. 1). The research vessel was the Kakuyo-maru (Nagasaki University). Temperature, salinity, density, and level of dissolved oxygen were measured by CTD (Mark III B type, Neil Brown), and the Rosette water sampler was used to correct the concentration levels of salinity and dissolved oxygen.

The above-stated CREAMS cruise did not cover the entire southeastern part of the East Sea. Therefore, the findings from the cruise alone were

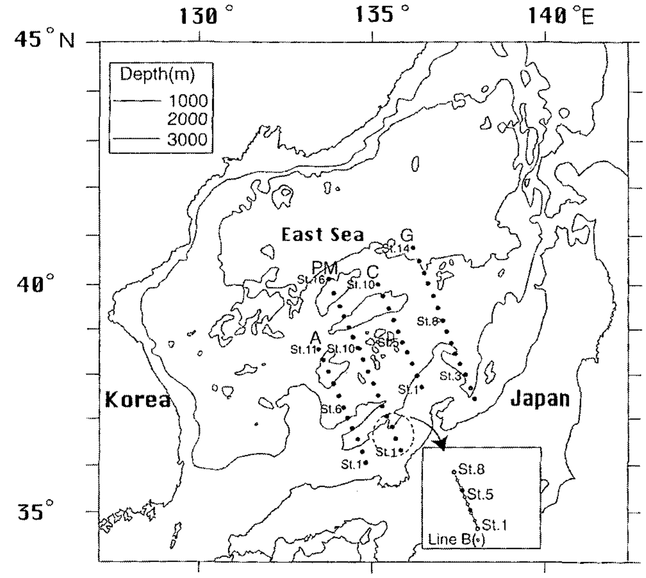

Fig. 1. The map showing studied lines and bathyme-try in the East Sea.
(Line A, PM, C, G: observation lines of Japan Meteorological Agency(JMA))
(Line B: cruise of CREAMS(Circulation Research of the East Asian Marginal Seas) in June of 1995 and June of 1996)

insufficient for this study. Accordingly, the temperature and salinity measured at four serial oceanographic stations, in which JMA (Japan Meteorological Agency) performed CTD observa-tions in 1995 and 1996 were used for this study.

Methods

Results of the CREAMS cruise

To investigate the oceanic conditions, the origins, and the levels of stability of the water masses around the Wakasa Bay, which is located in the southeastern part of the East Sea, the researchers drew up vertical profiles of temperature (T, ℃), salinity (S, psu), density (sigma-t), dissolved oxygen (D.O, mℓ/ℓ), and D-T, T-S, and T-D.O diagrams based on the data measured on June in 1995 and June in 1996.

Results of the JMA data

The TWC enter into the East Sea through the Korean Strait, then divide into several branches. One of these branches flows along the Japanese coast and shows complicated phenomena, due to the effects of topography, the instability of water masses, and so forth. The horizontal distributions of temperature and salinity measured at a depth of 100 m in June of 1995 and June of 1996 were drawn to investigate the characteristics of water masses and current structures in the southeastern area of the East Sea.

To discover the characteristics of spatio-temporal variations of the water masses, T-S diagrams from four serial oceanographic stations were prepared in accordance with the observation periods and stations. After the TWC pass the Korean Strait, they manifest spatio-temporal variations, with several meanderances and eddies. These variations significantly affect the marine life in the East Sea. In particular, the current patterns in the eastern and the southern regions around the Noto Peninsula are shown differently (Hideaki, 1999). Therefore, geostrophic currents, without tidal currents, were calculated to discover the characteristics of the current fields by fluctuations of TWC in the regions around the Noto Peninsula. No motion level (also known as the reference level, depth of 700 m) was established from density distribution. Horizontal distributions of the dynamic depth anomaly (unit: dynamic meters) in the regions around the Noto Peninsula were prepared in order to observe the surface topography.

The horizontal distributions of depth, temperature, and salinity where isopycnic surface equals sigma-t, 25.8, which is density in central part of the water mass of core type were given to investigate the movement patterns and spreading of the TWC in southeastern part of the East Sea.

Results and Discussion

Characteristics of spatio-temporal distributions of water masses

The vertical distributions of temperature, salinity, density and dissolved oxygen were measured from samples taken in the southeastern part of the East Sea in June of 1996, as shown in Fig. 2. In Fig. 2, Shaded areas represent water mass of core type. In this figure, water mass are relatively homogeneous, nearly the same temperature and salinity. Water mass of core type existed over the continental shelf, the depth of which is shallower than 200 m. In Fig. 2, the water mass showing the core type is marked with shaded color, and it has the following measurements: width, 190 km; thickness, 200 m. The offshore boundary of water mass of core type was formed around St. 4 and 5, and the depth became sharply deeper toward offshore. The inclination of the thermocline was toward the continental shelf, from St. 5 and St. 6.

The water mass of the core type shown in Fig. 2 is considered to be that of the TWC. The TWC moving along the coast of the Japan are known to exist between March and August (Kawabe, 1982). Hong and Cho (1983) considered the maximum-salinity layer in the summer as a central part of the TWC. However, the moving path and period of the TWC are not constant (Hideaki *et al.*, 1999). It is considered that the TWC, which move over the continental shelf, the depth of which is shallower than 200 m, show characteristics of a coastal trapped current. After the TWC pass the Noto Peninsula, they are separated from the continental shelf and the continental slope, then flow northeastwards (Hideaki *et al.*, 1999).

The minimum layer of the dissolved oxygen below 5.1 mℓ/ℓ exists below the depth of 70 m offshore of St. 5.

To investigate the distribution of dissolved oxygen and to divide the distribution waters into several types according to their vertical structures, Hong and Cho (1983) selected the following observation stations with different vertical profiles: (1) waters around the Korean Strait where the TWC enter the East Sea, (2) waters where the TWC occupy the East Sea, and (3) waters in the northern part of the East Sea that the TWC does not influence. In Fig. 2, the layer where the concentration of dissolved oxygen was low matched well with the layer showing a salinity maximum in an area shallower than 200 m. It seems that this phenomenon occurs because the waters in the upper layer of the East China Sea, which is shallower than 100 m, enter into the coastal regions of Japan along the continental shelf by the topographical effects of the Korean Strait, which has depth less than 200 m, with the mean depth of about 110 m. Hong and Cho (1983) suggest that the water with a low level of dissolved oxygen originating from the TWC, which is older than the water of the East Sea proper, moves horizontally in the middle layer of

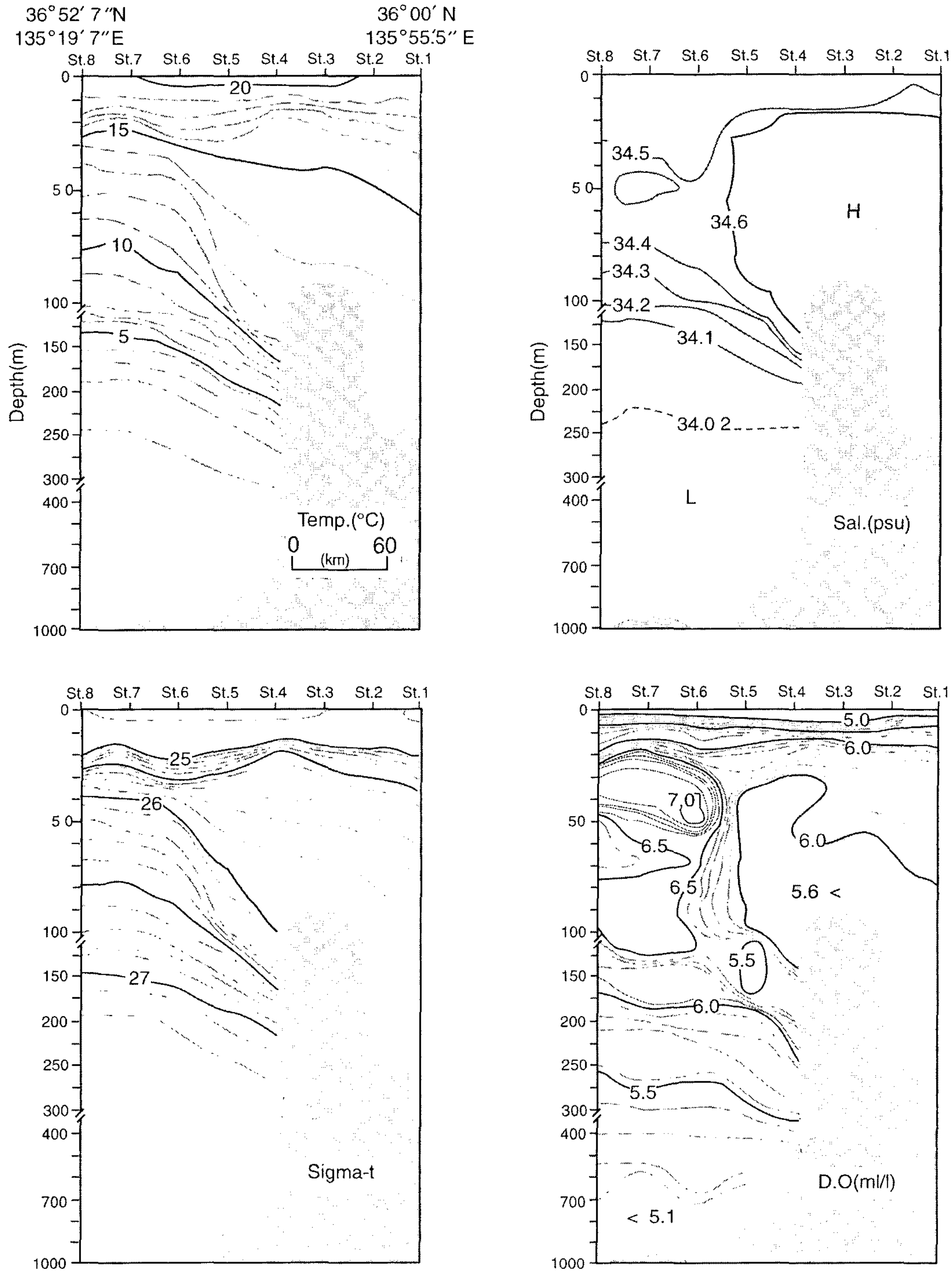

Fig. 2. Vertical distributions of temperature(℃), Salinity(psu), Sigmat-t, dissolved oxygen(mℓ/ℓ) at line B in June 14, 1996.

the water, where the concentration of dissolved oxygen is high. They indicate that the minimum level of dissolved oxygen occur frequently at the layers of maximum salinity.

To discover characteristics of water mass showing distribution of core type, D-T, T-D.O and T-S diagrams at St. 3 were prepared in Fig. 3. Shaded areas represent temperature, salinity, density and dissolved oxygen in the layer of salinity maximum (more than 34.6 psu). Especially, concentration level of dissolved oxygen in salinity maximum layer was lower than that in offshore, at the same depth. It seems that low level of dissolved oxygen at inner shelf match well with the result of Hong and Cho

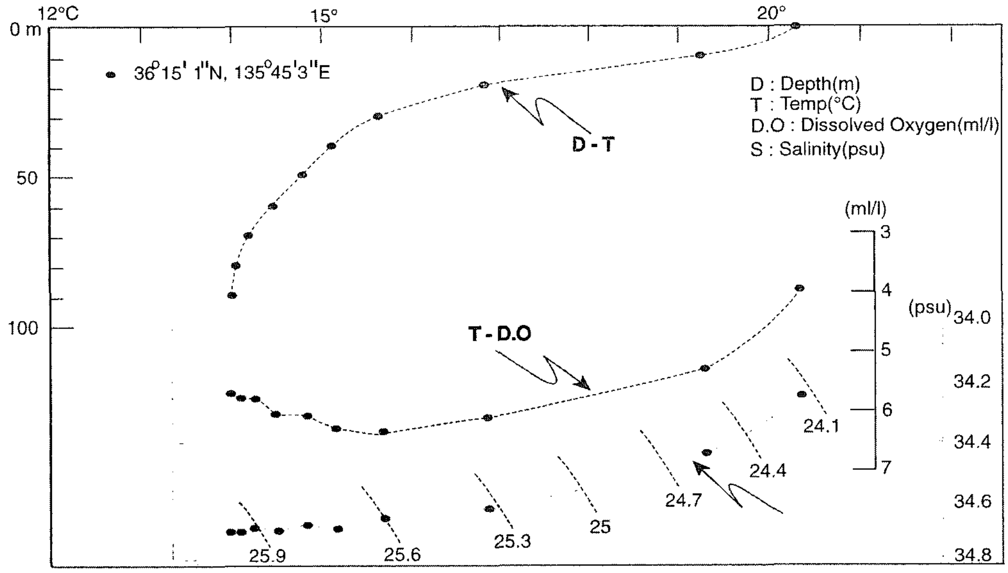

Fig. 3. D-T, T-D.O, T-S diagrams at st. 3 of line B in June 14, 1996.

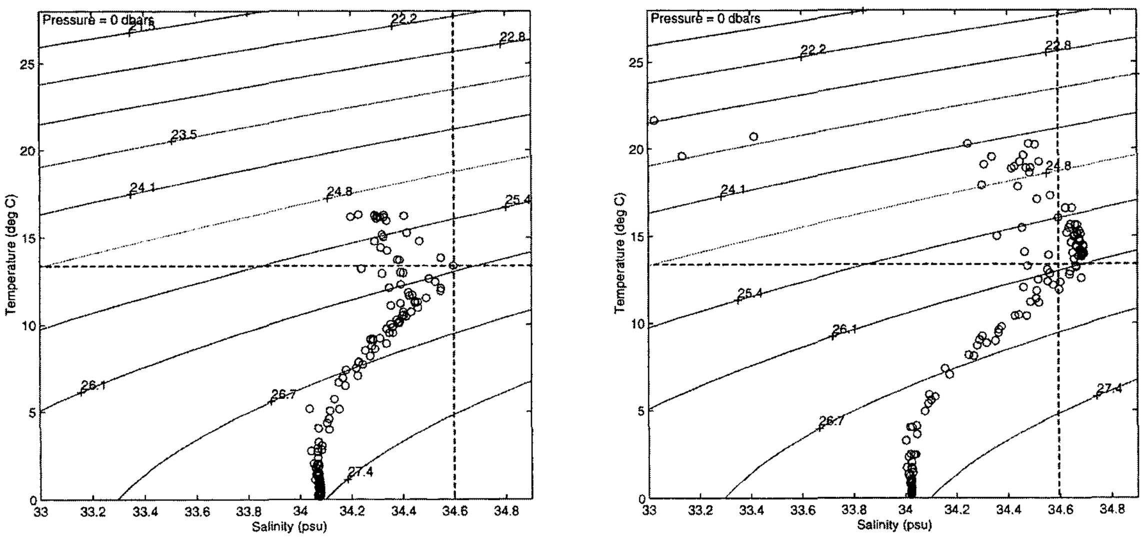

Fig. 4. T-S diagrams of water masses observed at line B during cruise of CREAMS in June, 1995(left) and 1996(right).

(1983).

Fig. 4 shows the T-S diagrams for the results of the CREAMS cruise in observation line B conducted in June of 1995 and June of 1996. Dashed lines indicate water masses that are like the core type shown in Fig. 2, that is, water masses with high temperature (≥13℃) and high salinity (≥34.6 psu). This figure shows the formation of high-temperature and low-salinity water masses in the upper layer centering around the intersection of dashed lines.

The place where the CREAMS cruise was carried out is located around the Wasaka Bay; thus, the cruise does not represent the entire southeastern area of the East Sea. Accordingly, to learn the characteristics of the spatio-temporal variations of the water masses and the current structures of the studied area, the temperature and salinity measured at four serial oceanographic stations, at which the JMA conducted CTD observations in 1995 and 1996, were used.

Figs. 5(a) and 5(b) show T-S diagrams of four serial oceanographic stations of the JMA in June of

1995 and June of 1996. Dashed lines indicate water masses with high temperature (higher than 10℃) and high salinity (higher than 34.6 psu). Four serial oceanographic stations are distributed from adjacent area to Korean Strait to north and south area of Noto Peninsula.

TWC that are characterized by high salinity (higher than 34.6 psu) can be seen for the first time in April at line A along the four observation lines. At the same time, the water mass in the upper layer begins to increase in temperature and decrease in salinity. In general, as the current moves northward, its salinity decreases, and the depth at which maximum salinity occurs becomes shallower. It seems that after the TWC pass through the narrow Korean Strait, the warm currents become thinner, and its width gradually becomes broader (Hong and Cho, 1983).

After April, the high-salinity water (above 34.6 psu) still existed, and this phenomenon, which is related to the high temperature and the low salinity of the water masses in the upper layer, continued until October. The occurrence of this phenomenon was delayed as time went by and the higher the latitude . It seems that these variations in time and space are due to the northeastward flow of the TWC along the coast of Japan.

In general, phenomena that are related to the high temperature and the low salinity of water masses in the upper layer occur in the summer. However, in this study, such water masses were already formed or were in the initial stage of formation by April. CTD measurements were not conducted at line C in February of 1995 nor at line

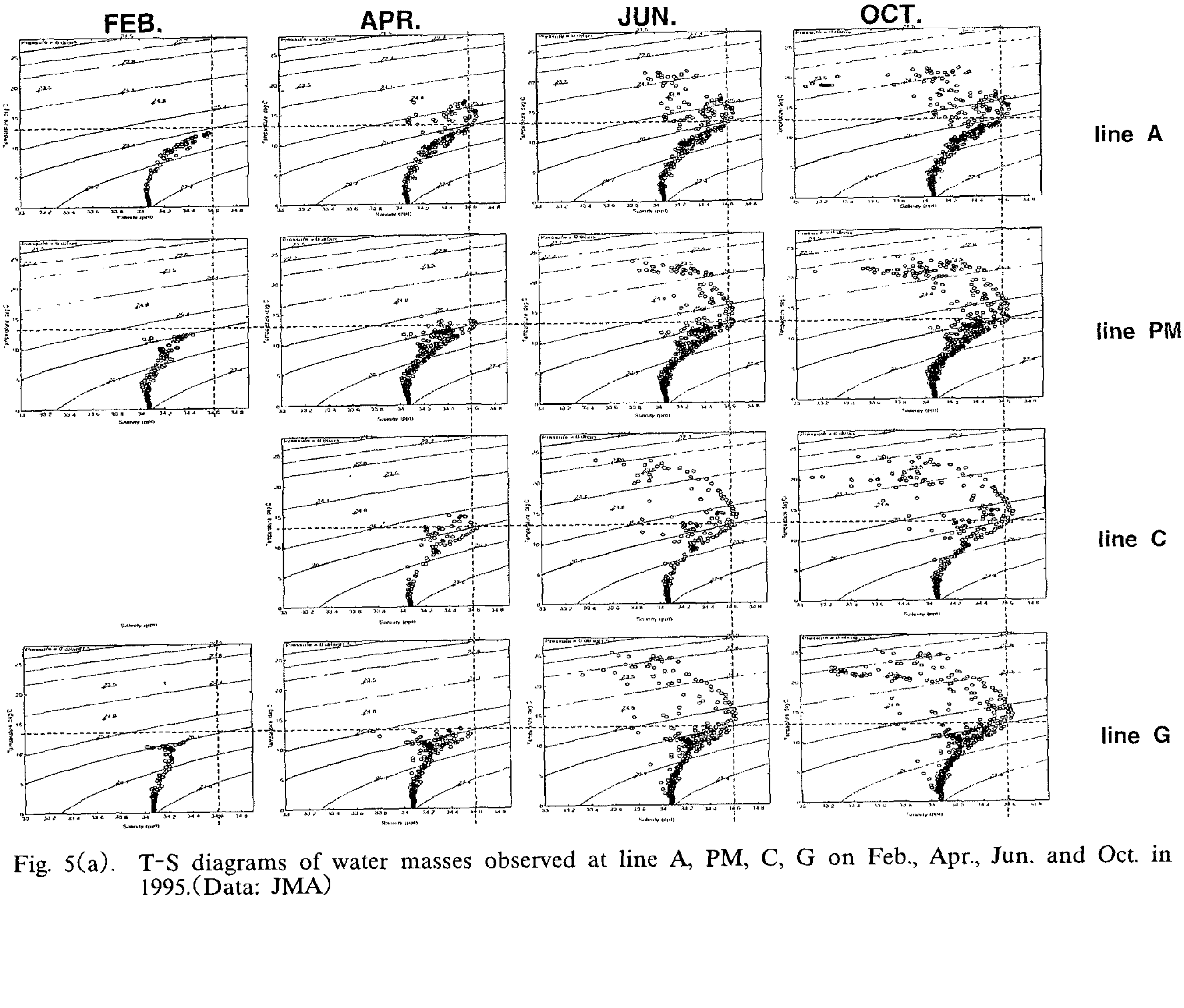

Fig. 5(a). T-S diagrams of water masses observed at line A, PM, C, G on Feb., Apr., Jun. and Oct. in 1995.(Data: JMA)

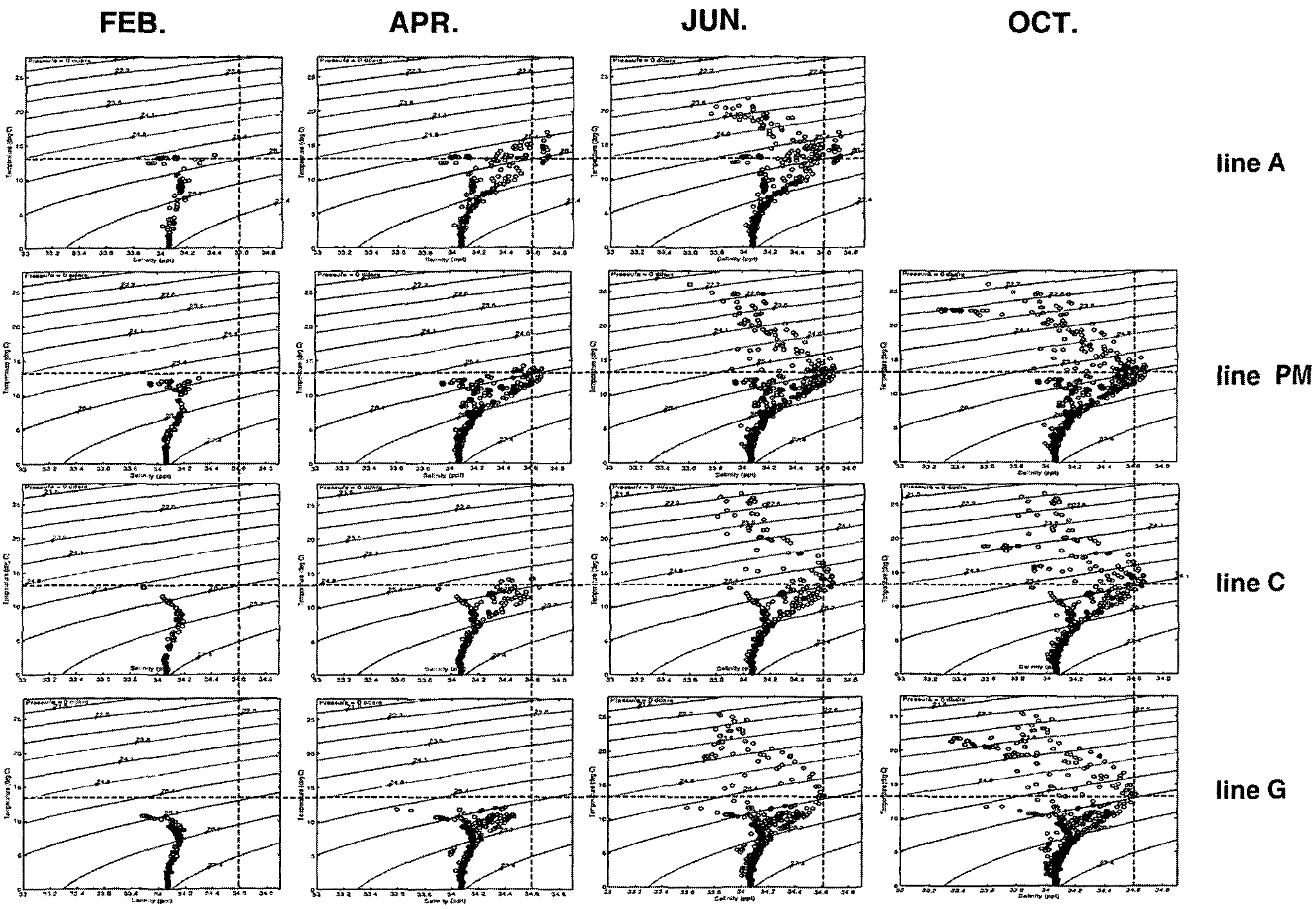

Fig. 5(b). T-S diagrams of water masses observed at line A, PM, C, G on Feb., Apr., Jun. and Oct. in 1995.(Data: JMA)

A in October of 1996. The surface waters of the TWC region in the East Sea show characteristics of high salinity in the winter, but those of low salinity in the summer. In the summer, the density of the surface layer changes because of seasonal variations in temperature and the appearance of low-salinity waters, and this change results in the seasonal variations of water types (Cho and Choe, 1988). Kim (1986) suggested that low-salinity water in th China Coastal Water (less than 32.2 psu) enters adjacent seas around the Cheju Island into the East Sea through the Korean Strait and has influence on formation of low-salinity water.

Characteristics of current structures

Fig. 6 shows the results of the ADCP (Acoustic Doppler Current Profiler) measurements carried out by CREAMS cruises in 1995 and 1996 (Hideaki *et al.*, 1999). Thermal fronts formed along the continental shelf, the depth of which is shallower than 200 m, and it seems that the TWC move along the isobathymetric line of coastal waters. However, the moving paths and fluctuation characteristics of the TWC are not constant and vary with primary factors related to bottom topography and the instability of the water masses. Therefore, investigations on the variation patterns of the TWC are required.

The vertical profiles of temperature, salinity, and geostrophic currents regarding the regions around the Noto Peninsula were prepared to investigate how TWC is changed (Figs. 7 and 8).

Fig. 7 shows vertical profiles of temperature and salinity at line PM in June of 1995 and June of 1996. The shaded areas in Fig. 7 indicates high-salinity water (above 34.6%), which is considered

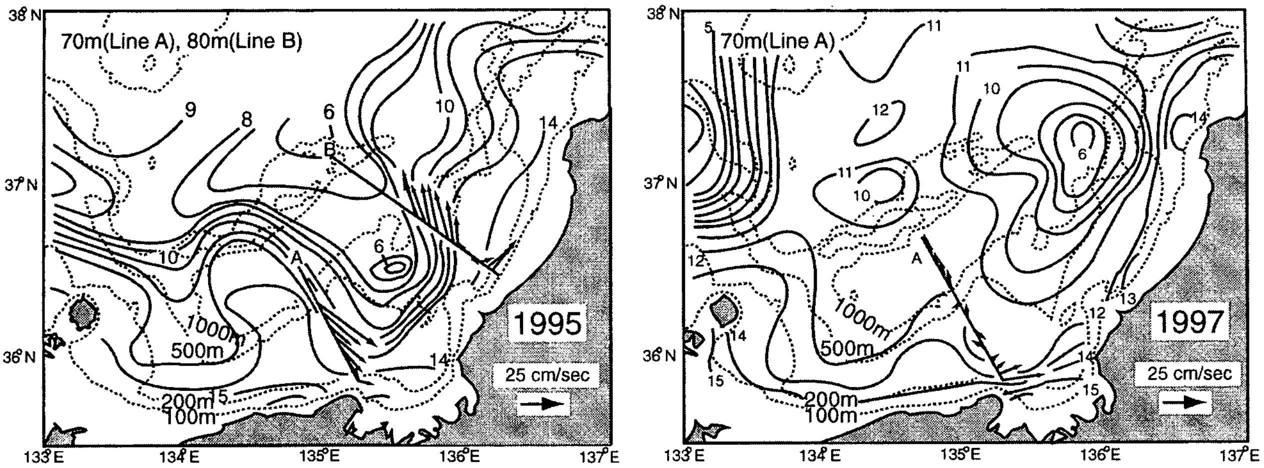

Fig. 6. Horizontal distributions of the diurnally averaged current at the intermediate depth in 1995(left) and 1997(right). Temperature distributions at 100 m depth in early June of 1995 and 1997 are superimposed, respectively.
Contour interval is 1.0℃. (Toon et al., 1999)

characteristic of TWC, as can also be seen in Fig. 2. The position of the high-salinity water in the observation areas changed between 1995 and 1996. High-salinity water existed offshore and inshore centering around St. 9, but existed around St. 7 and St. 8. The horizontal position of the high-salinity water changed between 1995 and 1996, but existed nearly at the same depth. It seems that these distributions in the horizontal and vertical positions are related to variations in the moving paths of TWC influenced by the effects of the bottom topography and the instability of the water mass-generating eddies. It is assumed that the southwestward flow of geostrophic currents shaded areas are generated from the distributions of temperature and salinity in the layer where high-salinity water exists. To investigate currents without tidal currents in the observation lines, geostrophic currents were calculated.

The current structures around the Noto Peninsula are complicated. In particular, the spatio-temporal variations of eddies due to the meandering of the TWC were great in the regions around the Noto Peninsula (Isoda, 1994). To investigate the characteristics of the currents in the eastern and the southern regions of the Noto Peninsula, vertical distributions of the geostrophic currents were prepared at line PM (western region), line C (the Noto Peninsula), and line G (eastern region), using the data report of JMA from June of 1995 and June of 1996 (Fig. 8).

Shaded areas in Fig. 8 indicates a southwestward flow of the geostrophic current, normal to the vertical section. In this figure, a noteworthy phenomenon is that the positions of the high-salinity water (more than 34.6 psu) shown in Fig. 7 match well with the distributions of the southwestward flow shown in Fig. 8. That is, the TWC, showing characteristics of high-salinity water, flows southwestward along line PM. In June of 1995, a southwestward flow existed between St. 3 and St. 14 along line PM and were separated into two parts along line C and line G. In comparison, in 1996, the position of the geostrophic current was different from that in 1995 in line PM, except along lines C and G. As can be seen in Figs. 7 and 8, it seems that the variations in the current structures in the regions centering around the Noto Peninsula occur first at line C (the Noto Peninsula), and this phenomenon is due to the warm eddies that are related to the meandering of the TWC and the effects of bottom topography. In other words, the TWC, which flow along the coastal region through the Korean Strait, undergo significant change as it pass through the Noto Peninsula.

Figs. 9(a) and 9(b) show horizontal distributions of temperature and salinity at the depth of 100 m as of June, 1995 and June, 1996. Generally, the depth of 100 m in the East Sea is considered to be a depth indicative of the TWC (Cho and Choe, 1994;

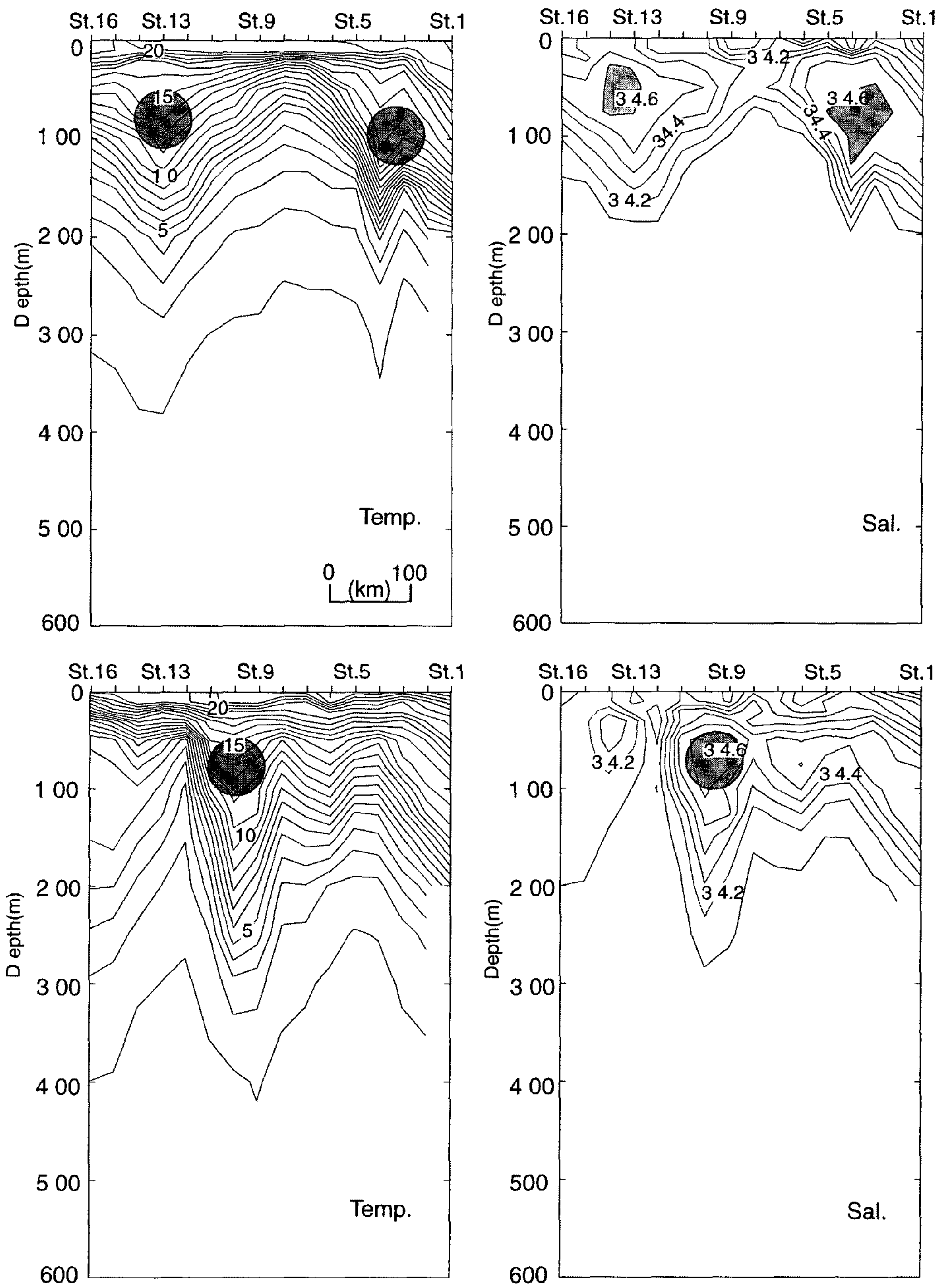

Fig. 7. Vertical distributions of temperature and salinity along line PM in June, 1995(top) and 1996(Bottom).

Kawabe, 1982).

Horizontal distributions of temperature and salinity were matched with each other. The arrow marks in Figs 9(a) and 9(b) simply signify the direction of the currents derived from the temperature and salinity match well with the distributions of the geostrophic currents in the vertical sections shown in Fig. 8. In this figure, a thermal front between 10~15℃ formed near the coastal area of the Japan in 1995, but at around 39°N in 1996. The

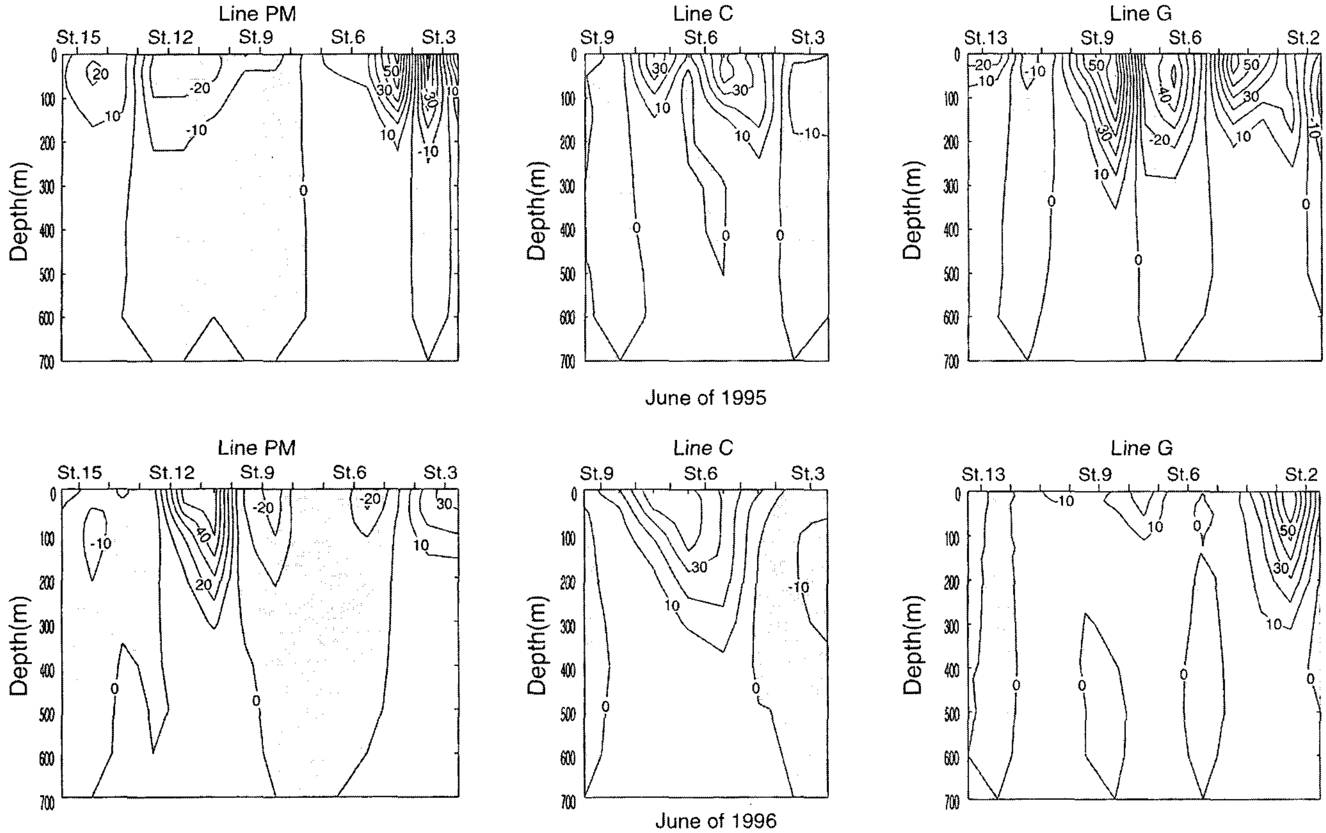

Fig. 8. Vertical distributions of geostrophic currents along lines PM(left), C(middle) and G(right) in June of 1995(top) and June of 1996(bottom). Shaded areas represent southwestward currents(unit: cm/sec).

noteworthy phenomenon in this figure is the change in the distribution of the isothermal lines and the isohaline in the region around the Noto Peninsula. The isothermal lines and the isohaline, which exist horizontally along the coastal area of the Japan, change abruptly at the frontal area of the Noto Peninsula, then turn toward the center of the East Sea. It seems that the topographic effects of the Noto Peninsula influences the distributions of the current structures.

The horizontal distributions of the dynamic depth anomaly on the four serial oceanographic stations located around the Noto Peninsula in June of 1995 and June of 1996 were prepared to investigate horizontal flow patterns of currents influenced by of the sea surface (Fig. 10). The dynamic depth anomalies centering around the region far northwest of the Noto Peninsula were relatively high, compared with those of other regions. This suggests that the height of the sea surface in these areas is higher than that in the adjacent areas, and anticyclonic current flows may exist. These results corroborate well with the results shown in Fig. 8. Noteworthy is the fact that distributions of the dynamics depth anomalies are matched well with isobathymetric lines. This suggest that topography has influence on eddies.

The horizontal distributions of depth, temperature, and salinity where the isopycnic surface equals sigma-t, 25.8, which is density in the central part of the water mass of the core type shown in Figs. 2 and 3, were given to investigate the spread patterns of the TWC in the southeastern area of the East Sea (Figs. 11(a) and 11(b)). The isopycnic surface existed near the surface in the central part of the East Sea, but, at the depth of 100 m, the isopycnic surface was found in the coastal waters. Variations in the depth at which the isopycnic surface lay

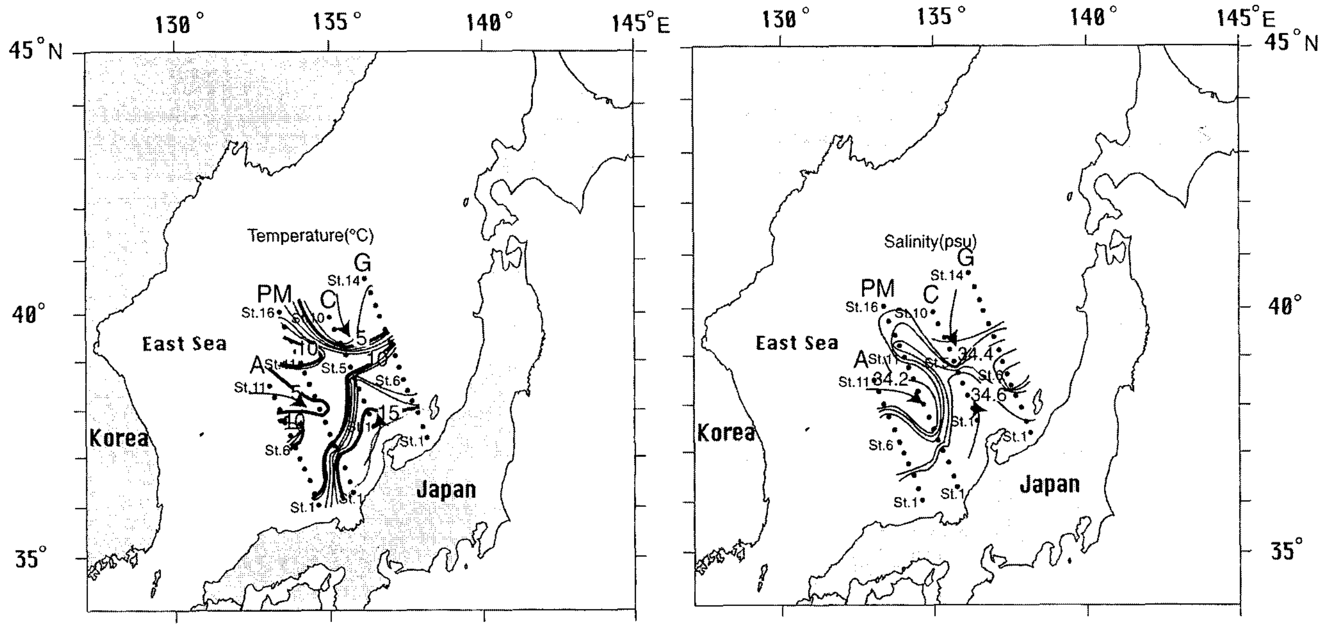

Fig. 9(a). Horizontal distributions of temperature and salinity at 100 m in June of 1995.

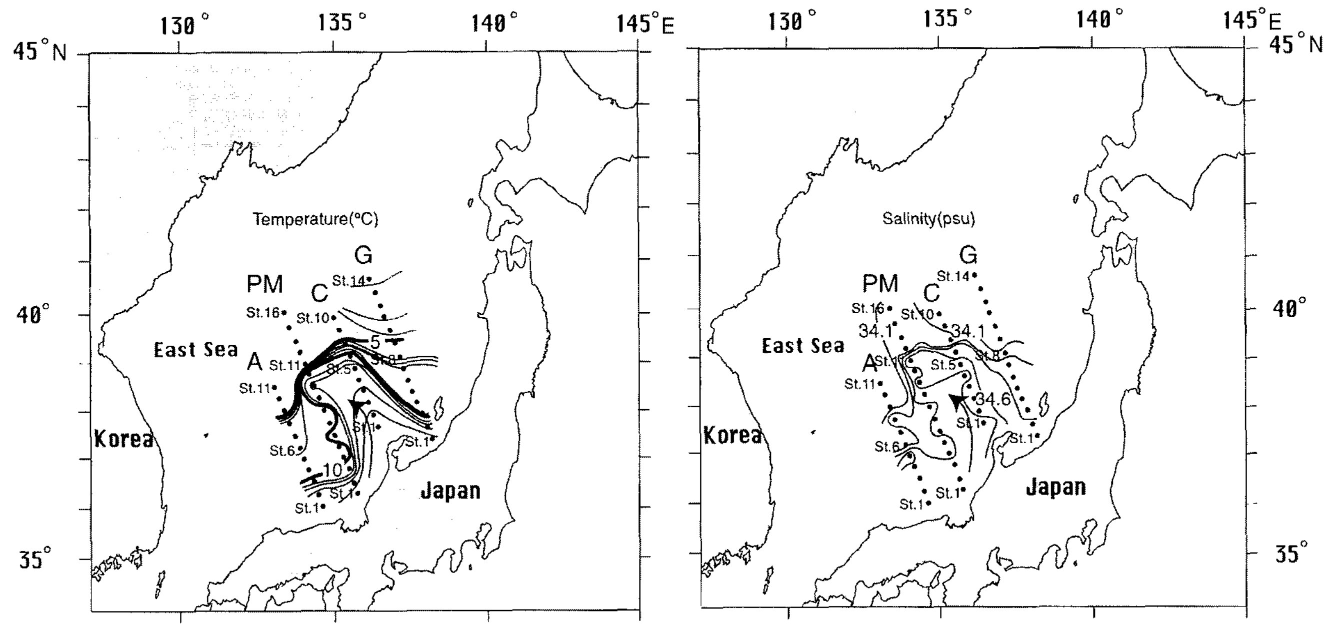

Fig. 9(b). Horizontal distributions of temperature and salinity at 100 m in June of 1996.

seem to become deeper from the Yamato Rise located in the central part of the East Sea to the Yamato Basin. It is considered that the TWC flow northeastward through deep basins in the coastal region of Japan by the topographical effect of the Yamato Rise, which has a depth of less than 500 m. This pattern was also shown well in the horizontal distribution of temperature. Temperature became higher in the coastal region of Japan centering around 14℃, but, offshore, the warm and cold water masses existed together (Figs. 11(a) and 11(b)). It seems that these phenomena are not related to

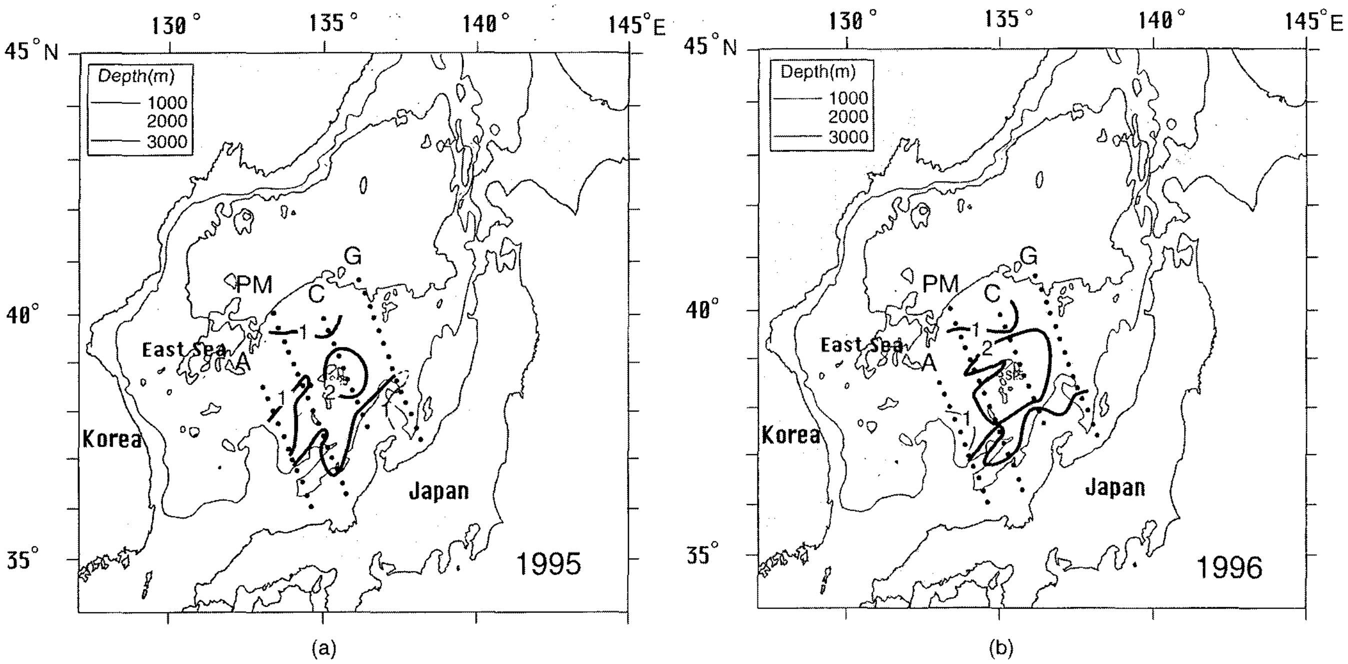

Fig. 10. Horizontal distributions of dynamic depth anomaly in June of 1995 and of 1996.(unit: dynamic meters).

changes in the water mass of the TWC. However, in the upwelling of the East Sea Proper Water or the downwelling of the TWC, and in the East Sea, warm and cold water masses are stable in relation to bottom topography (Tanioka, 1962).

Summary

To investigate characteristics of water masses and current structures around Noto Peninsula located in south-east coastal region of the East Sea, observation results of CREAMS (Circulations Research of the East Asian Marginal Seas) cruise and data report of oceanographic observation (Japan Meteorological Agency) in June, 1995 and 1996 were used.

Water mass of core type showing characteristics of Tsushima Warm Current (TWC) existed over the continental shelf. The depth was shallower than 200 m and it had the following measurements: width, 190 km; thickness, 200 m. Concentration level of dissolved oxygen in salinity maximum layer was lower than that in offshore, at the same depth. Minimum level of dissolved oxygen occurred at the layers of maximum salinity.

In the current structure, a noteworthy phenomenon is that the positions of the high-salinity water (more than 34.6 psu) match well with the distributions of the southwestward flow. That is, the TWC, showing characteristics of high-salinity water, flows southwestward along line PM. In June of 1995 and June of 1996, a southwestward flow were separated into two parts along line C and line G. It seems that the variations in the current structures in the regions centering around the Noto Peninsula occur first at line C (the Noto Peninsula), and this phenomenon is due to the warm eddies that are related to the meandering of the TWC and the effects of bottom topography. In other words, the TWC, which flow along the coastal region through the Korean Strait, undergo significant change as pass through the Noto Peninsula.

Horizontal distributions of temperature and salinity were matched with each other. Current directions derived from the temperature and salinity match well with the distributions of the geostrophic currents in the vertical sections. The noteworthy phenomenon is the change in the distribution of the isothermal lines and the isohaline lines in the region around the Noto Peninsula. The isothermal lines and the isohaline lines, which exist horizontally along the coastal area of the Japan, change abruptly at the frontal area of the Noto Peninsula,

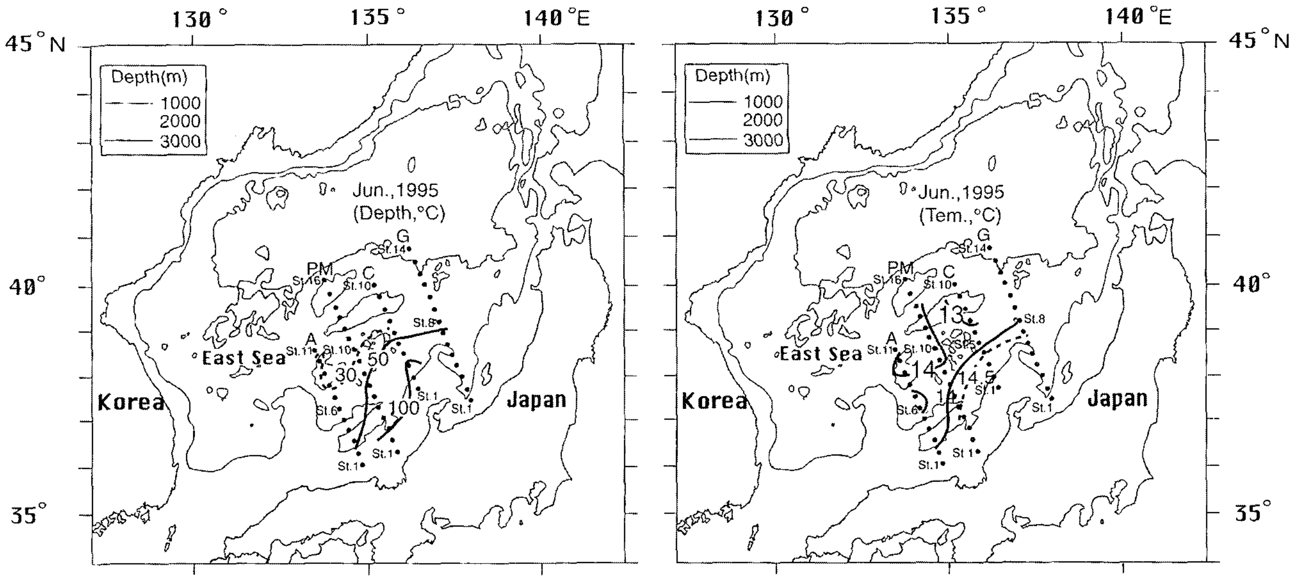

Fig. 11(a). Distributions of depth and temperature where sigma-t equals 25.8.

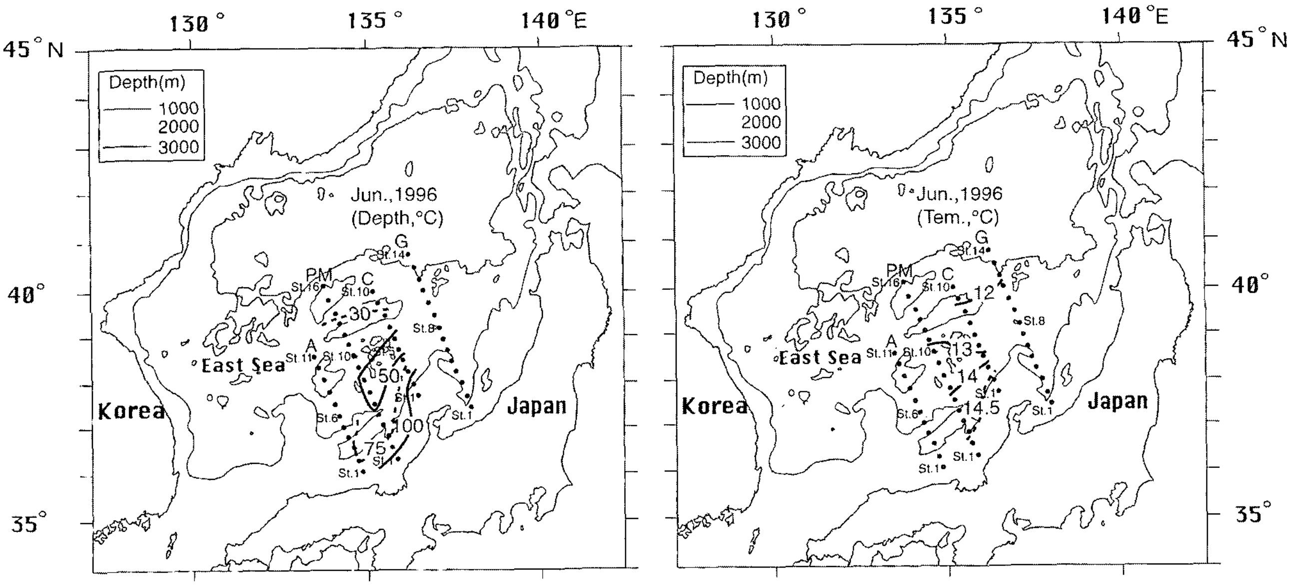

Fig. 11(b). Distributions of depth and temperature where sigma-t equals 25.8.

then turn toward the center of the East Sea.

The dynamic depth anomalies centering around the region far northwest of the Noto Peninsula were relatively high, compared with those of other regions. This suggests that the height of the sea surface in these areas is higher than that in the adjacent areas, and anticyclonic current flows may exist.

The isopycnic surface (sigma-t, 25.8) existed near the surface in the central part of the East Sea, but, at the depth of 100 m, the isopycnic surface was found in the coastal waters. Variations in the depth at which the isopycnic surface lay seem to become deeper from the Yamato Rise located in the central part of the East Sea to the Yamato Basin.

References

Choi, Y.K., Cho, K.D. and Yang, S.K. 1995. Oceanographic characteristics of the Japan Sea Proper Water-II. The Japan Sea Proper Water and Chimney. J. Korean Environ. Scienc. Soc., 4(2), 121~138.

Hong, C.H. and Cho, K.D. 1983. The relationship between the characteristics of dissolved oxygen and the Tsushima Current in the Japan Sea in summer. bull. korean fish. soc., 16(3), 291~297.

Hong, C.H. and Cho, K.D. 1983. The northern boundary of the Tsushima Current and its fluctuation. Journ. Oceanolo. Soc. Korea, 18(1), 1~9.

Hideaki, H. 1999. The Current structure of the Tsushima Warm Current along the Japanese Coast. J. Oceanogr. Soc. Japan, 55(2), 217~235.

Kim, C.H. and Yoon, J.H. 1999. A numerical modeling of the upper and the intermediate layer circulation in the East Sea, J. Oceanogr. Soc. Japan, 55, 327~345.

Kim, I.O. 1986. The study on the China Coastal Water in adjacent seas of Cheju Island. Cheju. Univ., thesis for a degree.

Cho, K.D. and Choe, Y.K. 1988. Seasonal variation of the water type in the Tsushima Current, Bull. Kor. Fish. Soc., 21(6), 297~306.

Lee, D.K., Lee, J.C., Lee, S.R. and Lie, H.J. 1997. A circulation study of the East Sea using satellite-tracked drifters, I. Tsushima Current, J. Korean Fish. Soc., 30, 1021~1032.

Kawabe, M. 1982. Branching of the Tsushima Current in the Japan Sea Part I. Data Analysis. J. Oceanogr. Soc. Japan, 38, 95~107.

Ogawa, Y. 1983. Seasonal changes in temperature and salinity of water flowing into the Japan Sea through the Tsushima Straits. Research Report of Japan Fisheries Oceanography Institute. 43, 1~8.

Seung, Y.H. and K. Kim. 1993. A numerical modeling of the East Sea circulation, J. Oceanol. Soc. Korea, 28, 292~304.

Tanioka, K. 1962. The Oceanographical conditions of the Japan Sea(II)-On the cold and warm water region and haline water-. Umi to Sora, 38(4), 115~128.

Isoda, Y. 1994. Warm Eddy Movements in the Eastern Japan Sea, J. Oceanogr. Soc. Japan, 50, 1~15.

Japan Meteorological Agency. 1997. Data report of oceanographic observation, No.86.

Japan Meteorological Agency. 1998. Data report of oceanographic observation, No.87.