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論 文

The oceanic condition of the Tsushima Warm Current region in the southern part of the East Sea (Sea of Japan) In June, 1996

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ABSTRACT: *Oceanic conditions of the Tsushima Warm Current (TWC) region in the southern area of the East Sea (the Japan Sea) are examined using data obtained from a CREAMS (Circulation Research of the East Asian Marginal Seas) cruise in June 1996. In 1990s, a lower temperature appears in 1996 and in this period, two branch of the TWC exist and the first branch of the TWC flows inshore of the Japanese coastal region compared to that in the other years, especially in the shallower water layer at less than about 200 m. The TWC cored with the higher salinity (>34.6 psu) is clearly observed over the continental shelf zone in the Japanese coastal region and offshore and identified by geostrophic calculation. Intrusion of the TWC into the East Sea through the Korea Strait (the Tsushima Strait) makes the density structure in the water column change and the water mass in the TWC region is unstable based on Brunt-Vaisala frequency.*

KEY WORDS : *Tsushima Warm Current, East Sea, Geostrophic calculation, Brunt-Vaisala frequency*

1. Introduction

In the southern part of the East Sea, the Tsushima Warm Current (TWC) enters the East Sea (Japan Sea) through the Korea Strait (the Tsushima Strait), and shows complicated behaviors like meandering and eddy formation under the moving process along the Korean-Japanese coastal regions and offshore (Fig. 1). The TWC, water with a higher temperature and higher salinity, is characterized from other water masses in the East Sea because of its water properties and it may have an influence on oceanic conditions in its moving regions.

According to the previous studies (Suda and Hidaka, 1932; Moriyasu, 1972, Kawabe, 1982; Yarichin, 1991), the TWC has one or more branches after it passes the Korea Strait and is considered an important factor on the variation of oceanic conditions in the southern part of the East Sea. These studies also suggest that the TWC shows seasonal and yearly fluctuations. In particular, the second branch of the TWC is formed between June and August (Kawabe, 1982) and higher salinity water of more than 34.6psu spreads widely in the southern part of the East Sea (Lee and Cho, 2000). Therefore, study of the TWC distribution in June adds useful information to the analysis of the varied oceanic conditions related to the TWC's variation in the East Sea. The spread of the TWC, relatively high-temperature and high-salinity water compared to other water masses in the East Sea, may lead to changes in the oceanic conditions of the East Sea. Actually, to investigate the effect of the TWC on oceanic conditions in the East Sea, we need detailed information about the fluctuation characteristics of the TWC. However, it is difficult for scientists to study oceanic conditions in the East Sea because of variable oceanic and atmospheric factors and so on. Also, a theory on the TWC's branching and its influence on oceanic phenomena is not yet clearly known.

In this study, we use data from a CREAMS (Circulation Research of the East Asian Marginal Seas) cruise performed in the southern part of the East Sea for the examination of oceanic conditions of the TWC in the southern part of the East Sea in June 1996 when a lower temperature phenomenon appeared.

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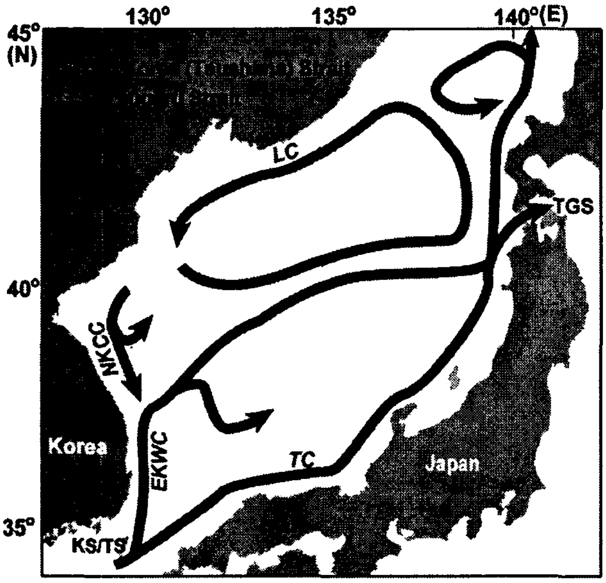

Fig. 1. Main surface currents in the East(Japan)Sea. Abbreations for the main currents are as follows; TC : the Tsushima Warm Current, LC :the Liman Current, EKWC : the East Korean Warm Current, and NKCC : the North Korean Cold Current (Yurasov and Yarichin, 1991; Senjyu, 1999)

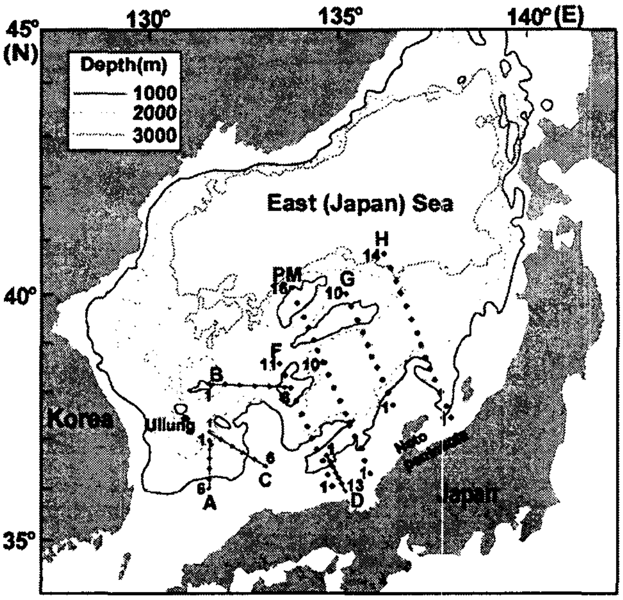

Fig. 2. The map showing studied lines and bathymetry in the East Sea. Numerals indicate number of station. Lines A -D indicate observation lines of CREAMS in June of 1996. Lines F, PM, G, and H represent observation lines of JMA.

2. Data and methods

2.1 Data

In this study, we use the data obtained during the CREAMS cruise in the southern part of the East Sea from June 10th to June 20th 1996 (all locations and topographic features are given in Fig. 2). Temperature (℃), salinity (psu), and dissolved oxygen (*ml/l*) were measured by CTD (Mark B type, Neil Brown) and the Rosette water sampler was used to calibrate the concentration level of salinity and dissolved oxygen.

The findings from the CREAMS cruise alone are insufficient for the analysis of the TWC's oceanic conditions in the southern part of the East Sea. Accordingly, temperatures measured by the Japan Meteorological Agency (JMA) in June of 1996 and the mean temperature averaged during the period from 1966 to 1995 in the East Sea, 30° X 30° resolution, by the Japan Sea National Fisheries Research Institute (JSNFRI) are used for areas the CREAMS cruise didn't cover in the study area (Fig. 2).

2.2 Methods

For this study, we use salinity data as an indicative factor of the TWC.

High-salinity, a distinctive feature of the TWC, is used as an indicative factor for the TWC's northern boundary (Uda, 1934; Ogawa, 1971; Moriyasu, 1972; Hong and Cho, 1983) and horizontal and vertical distribution of the TWC (Isoda, 1995; Lee and Cho, 2000). By high-salinity water in this study, we mean a concentration of salinity greater than 34.6psu derived from the vertical distribution of hydrological data. High-salinity water adds useful information for interpreting the distributions of temperature, density, dissolved oxygen, geostrophic current and water stability in the study area.

We analyzed temperatures measured at 100m of PM line from 1990 to 1999 to know the recent tendency of temperature variations in the study area and consequently found that the lower temperature phenomena appeared in 1996.

To investigate the average oceanic conditions and most suitable layer for the study of the TWC's oceanic conditions in the East Sea in June of 1996, horizontal distributions of the mean temperature at depths of 0m, 50m, 100m, and 200m from data by JSNFRI are drawn. Vertical sections of temperature, salinity, density, and dissolved oxygen along each observation line of the CREAMS cruise are prepared. Then, high salinity greater than 34.6psu based on vertical sections of observation data is selected as an indicator of the TWC.

Geostrophic currents are calculated to investigate the structure of the currents in the study area. As current data by field measurement is not enough to investigate current fields, currents in the study area are estimated by the geostrophic method. The reference level is 500m and this level is established based on seasonal variation in the upper layer and the density distribution that the isopycnal surface (sigma-t =27.4) runs parallel to the isobaric surface. The seasonal variation in the southern part of the East Sea occurs mainly in the upper 300m (Ohwada and Yamamoto, 1966) and the influence of the TWC is limited in the upper 400m (Yasui et al., 1967). In this study, we focus on current structure in the upper 500m with regards to the water column's seasonal variation and the TWC's variation in the East Sea.

To investigate the variations of stability level in the TWC region, Brunt-Vaisala frequency (N^2 (sec^{-1})) representing the vertical stability of water mass is calculated by the following numerical formula (Knauss, 1997).

$$N^2 = gE = g\left(\frac{1}{\rho}\frac{\delta\rho}{\delta z} - \frac{g}{c^2}\right)$$

where is the in situ density (kg/m^3), g gravity (9.8 m/sec^2), and the velocity (m/sec) of sound in seawater, which is a function of temperature, density, and pressure. In general, N^2 has a positive value (+) when water masses are stable due to density differences between water masses in the vertical direction. On the other hand, N^2 has a negative value (-) when water masses in the vertical direction have nearly the same density, or are unstable due to density inversion.

3. Results and Discussion

3.1 Distribution of the Tsushima Warm Current

Fig. 3 shows the horizontal distribution of the mean temperature in June from 1966 to 1995 at depths of 0m, 50m, 100m, and 200m. In this figure, at 0m, 50m and 100m, the boundary between cold water masses in the northern part and warm water masses in the southern part of the East Sea, especially, the TWC's meandering, is shown clearly at 100m. But, at 200m, the horizontal distribution of temperature is nearly homogeneous except in regions around Ullung Island and along the Japanese coastal waters where they are supposed to be affected by the TWC. According to the previous studies, the TWC shows seasonal variation in the upper 300m (Ohwada and Yamamoto, 1966), but in this study, the bottom depth of the TWC seems to be limited in the upper 200m except for some regions in the East Sea.

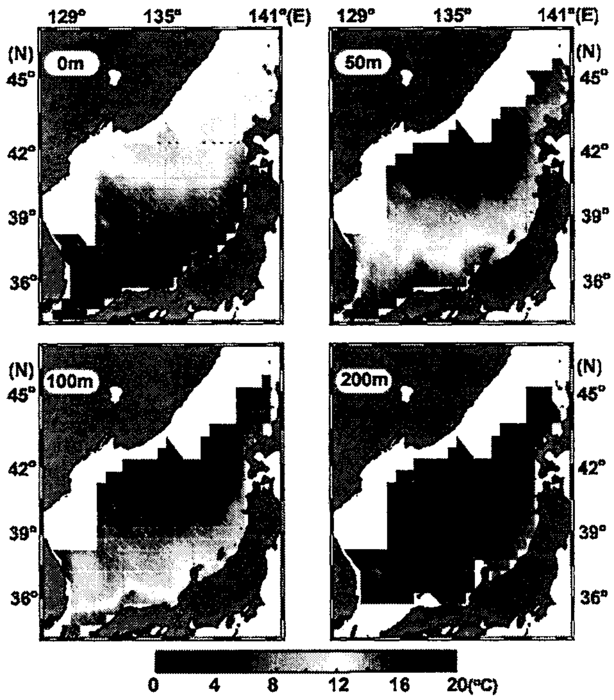

Fig. 3. Mean temperature(℃) in June from 1966 to 1995 in the East Sea.

Vertical sections of temperature (℃), salinity (psu), density (sigma units), and dissolved oxygen (*ml/l*) are prepared to investigate the characteristics of water masses (Figs. 4a - 4d and Fig. 5). In Fig. 3a, water masses that are relatively high in temperature (higher than 13℃), have high salinity (greater than 34.6psu) and low dissolved oxygen (5.5 - 6.0*ml/l*) as compared with adjacent water masses, exist at layers shallower than 200m. This high-salinity water is considered to be the TWC along the continental shelf in the coastal region of Japan. In particular, this water mass is characterized clearly from adjacent water masses by salinity higher than 34.6psu and exists in the subsurface of line B (Fig. 4b), line C (Fig. 4c), and line D (Fig. 4d). In Figs. 4a-4d, low concentration levels (5.5-6.0*ml/l*) of dissolved oxygen compared to adjacent water masses exist at the layer of maximum salinity greater than 34.6psu. This phenomenon may be considered to be a property of the TWC in the East Sea.

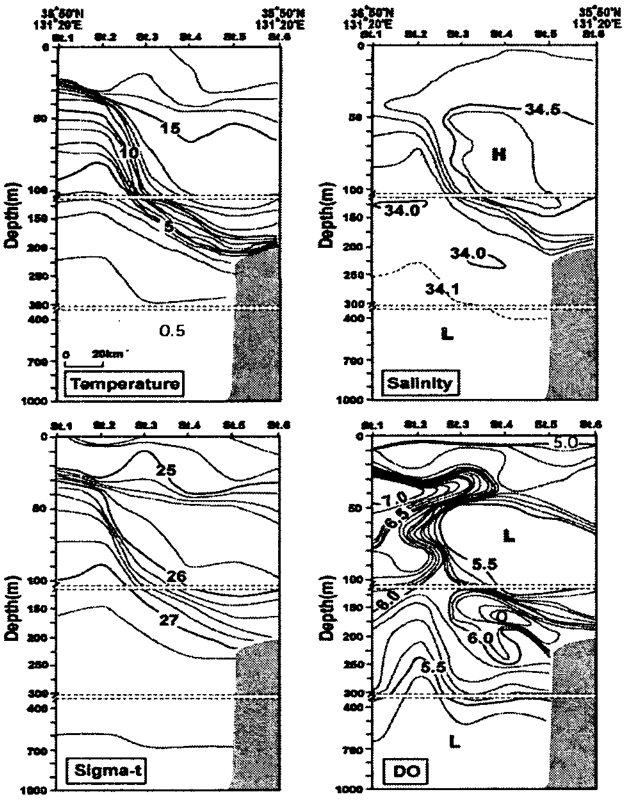

Fig. 4a. Vertical section of temperaure(oC), alinity(psu), sigma-t and dissolved oxygen(ml/l) along line A in June, 1996.

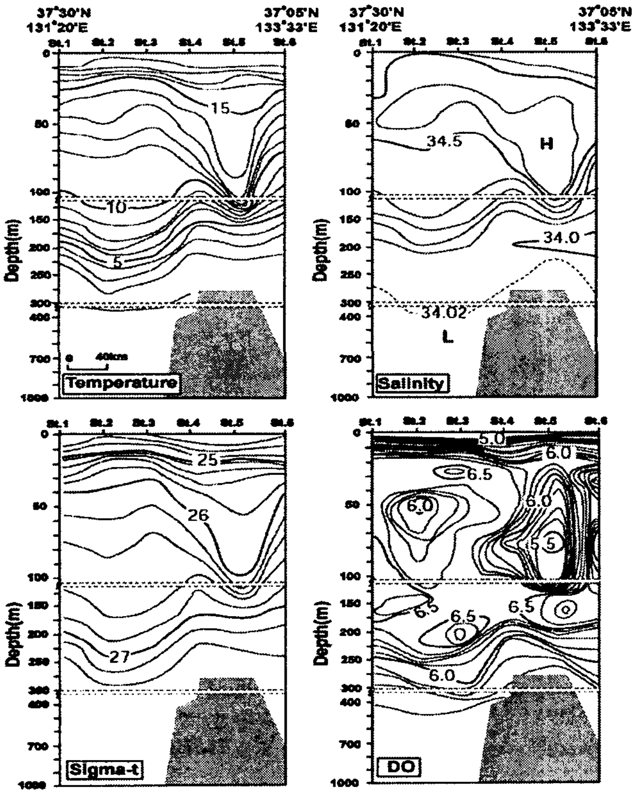

Fig. 4b. Continued along line B.

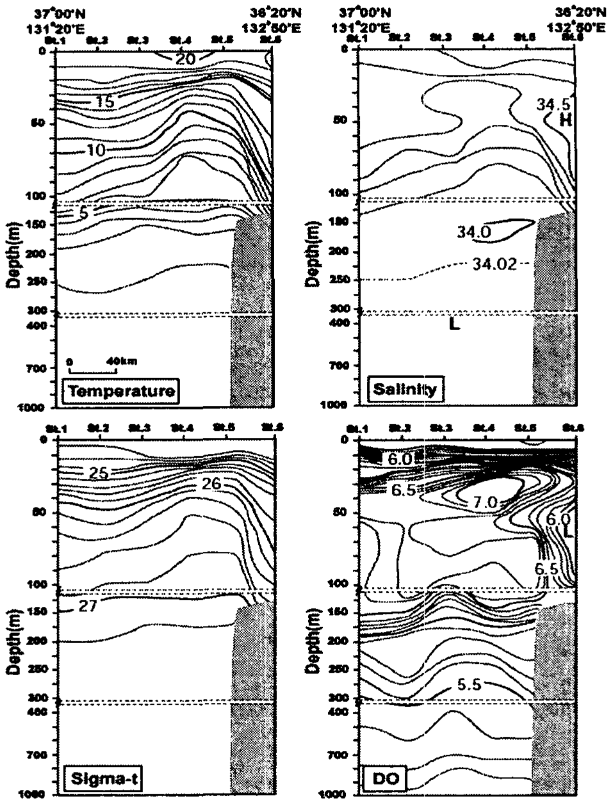

Fig. 4c. Continued along line C.

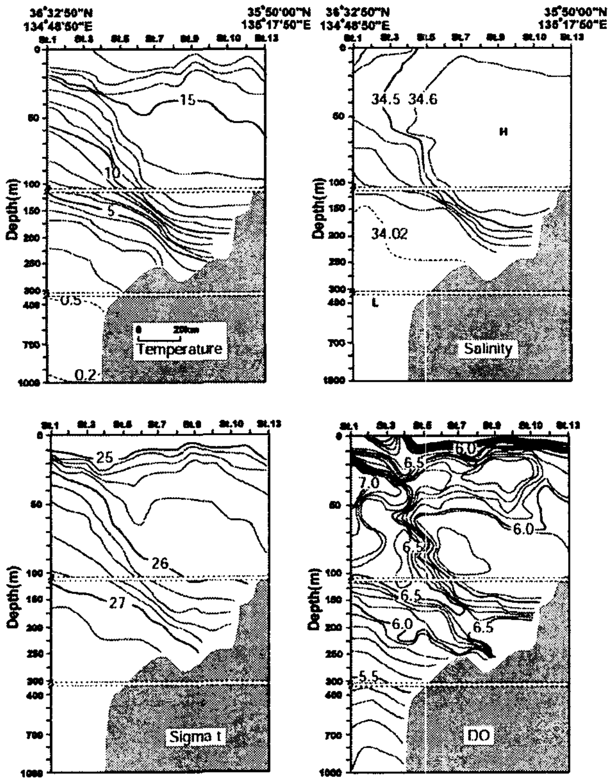

Fig. 4d. Continud along line D.

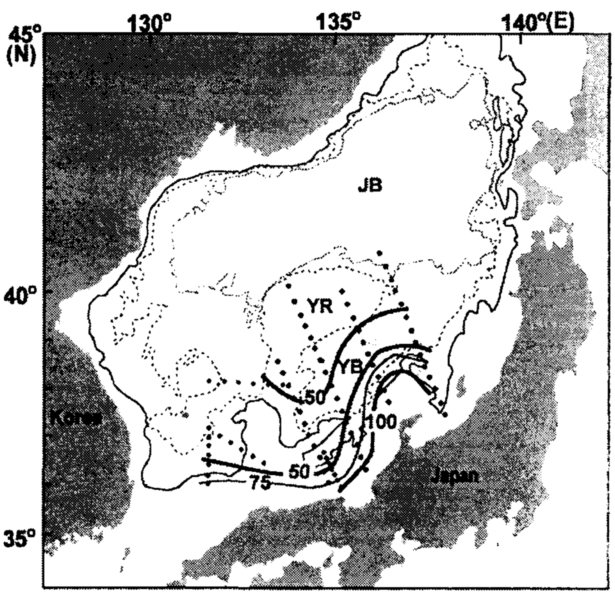

Fig. 5. Distributions of depth(m) where sigma-t equals 25.9. JB, YR, and YB indicate Japan Basin, Yamato Rise, and Yamato Basin respectively.

In particular, the vertical distribution shape of the temperature (10-14℃), salinity (34.6psu), density (t=26.0), and dissolved oxygen (5.5-6.0*ml/l*) centering around st.5 of line B (Fig. 4b) is a tongue-shaped distribution It seems that the tongue-shaped distribution shown in Fig. 4b is considered a warm eddy. Seung et al. (1990) consider the warm eddy of the tongue-shaped distribution formed around Ullung Island as a warm lens. According to the previous studies (Kang and Kang, 1990; Seung et al., 1990; An et al., 1994), wind and bottom topography around Ullung basin play an important role in the formation of a warm lens and the position of a warm lens is not fixed. This warm eddy is supported by a supply of warm water due to the northward movement of the TWC. It is believed that the warm eddy at 200m around Ullung Island shown in Fig. 2 is formed by the effect of a warm lens.

The isothermal line of about 10℃ is considered the southern boundary of the cold water in the East Sea and gives an important clue on the northern boundary of the TWC. The horizontal distribution of depth where the isopycnic surface equals sigma-t (25.9), which is the density of the central part of the TWC shown in Figs. 4a - 4d, is prepared for spread patterns of the TWC in the southern part of the East Sea in Fig. 5. In this figure, the isopycnic surface exists near the surface in the central part of the East Sea, but exists at the depth of 100m around the southwestern part of the East Sea and in the coastal waters along Japan. The depth of the isopycnic surface seems to become greater from the Yamato Rise located in the central part of the East Sea to the Yamato Basin. However, the distribution pattern of the TWC is not constant (Hong and Cho, 1983; Hase et al., 1999; Lee, 2003). Fig. 6 shows the horizontal distribution of temperature at 100m in the Japanese coastal waters in early June of 1995 and 1997. In Fig. 6, the TWC that flows along the Japanese coastal waters in a shallower water layer less than 200m, unlike Figs. 3a, 3b, 3d, is not shown clearly.

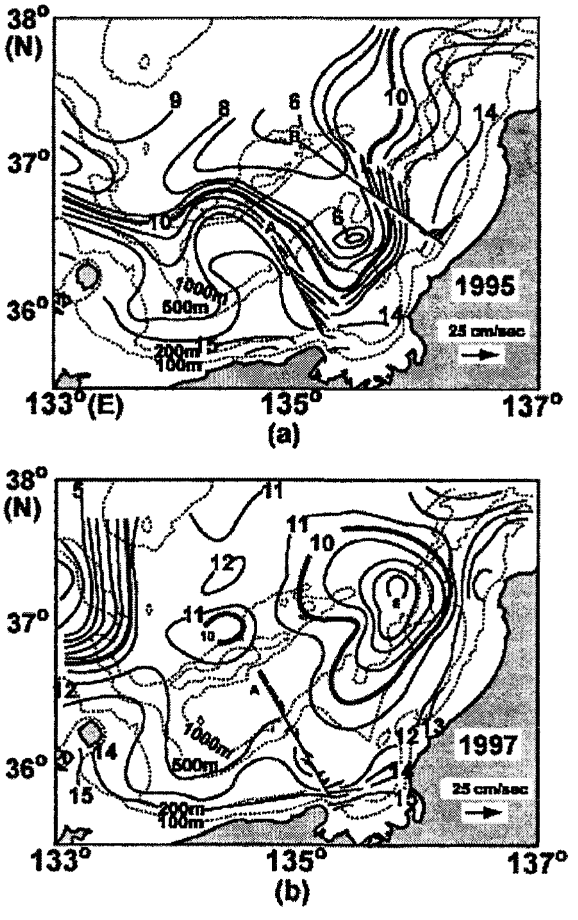

Fig. 6. Horizontal distributions of the diurnally averaged current at the intermediate depth (70m) in 1995 (a) and (68m) 1997 (b). Temperature distributions at 100m depth in early June, 1995 and 1997 referred to the Report of the Fisheries and Oceanographic conditions in the Japan Sea (Nihonkai Gyojyo-Kaikyo Sokuhou) by the Japan Sea National Fisheries Research Institute are superimposed. Contour interval is 1.0oC (Hase et. al., 1999).

The TWC flows inshore of the Japanese coastal region in early June of 1995 and 1996 compared to early June of 1997 and it seems that results in 1996 may be the middle stage between in 1995 and 1997, that is, the TWC is approaching the continental shelf in 1995 and 1996, but in 1997, flows offshore.

In particular, in the case of 1996, lower temperatures in the southern part of the East Sea appear (Fig. 7). Fig. 7 shows a time series of mean temperatures at 100m of depth along the PM line from 1990 to 1999. The mean temperature incline decreases from 1990 to 1996, recording the lowest value in 1996, and then shows a tendency to increase. The result in Fig. 7 seems to be related to the distribution pattern of the TWC shown in Figs. 4a, 4c, 4d and Fig. 6. Temperature fields in the southern part of the East Sea may depend on the distribution pattern of the TWC and high-temperature water. When the TWC flows inshore of the Japanese coastal region like coastal trapped currents, the influence of the TWC on the temperature field in the southern part of the East Sea is considered to be small compared to the conditions in which the TWC spreads widely.

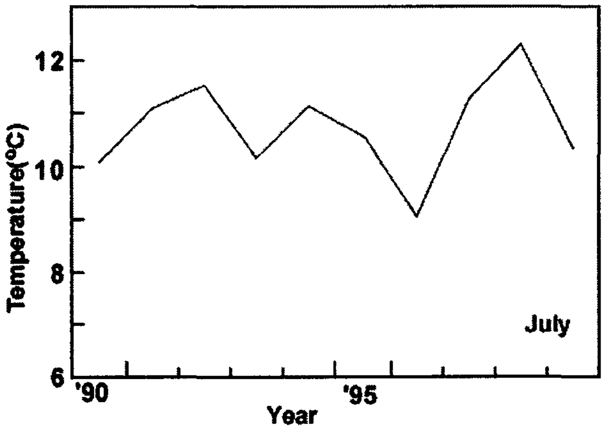

Fig. 7. Time-series of mean temperature in July at 100m along PM line.

3.2 Current fields and water stabilities in the TWC region

In order to investigate the characteristics of currents, a vertical section of geostrophic current is prepared, as shown in Fig. 8. The reference level is established from the density distribution shown in Figs. 4a - 4d.

Shaded areas in the figures indicate the flow out of the paper. Geostrophic currents are relatively strong at depths where the TWC flows along the coastal waters of Japan (sections A, C, and D) and offshore (section B). It seems that these results match well with the vertical distribution of observation data, as shown in Figs. 4a, 4c, 4d. It is noteworthy that in the case of section B, the position of geostrophic currents flowing southward and out of paper, matches well with that of the high-salinity water above 34.6psu shown in Fig. 4b. This branch seems to have originated from the East Korean Warm Current called the third branch of the TWC.

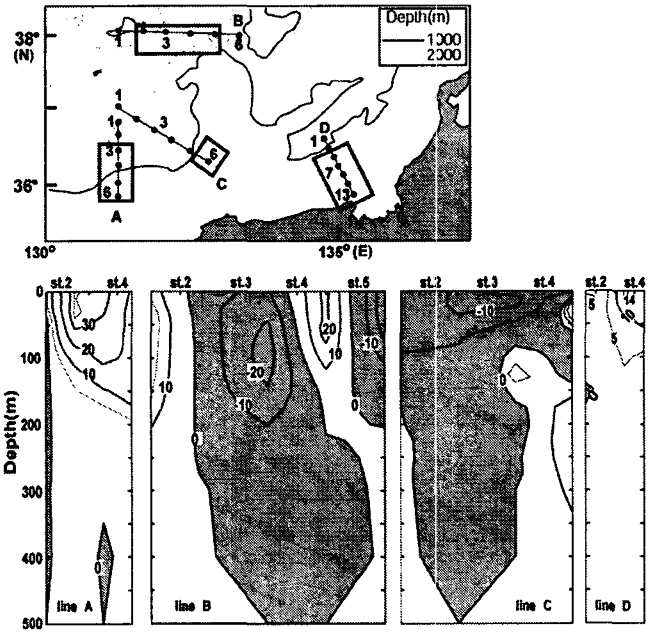

Fig. 8. - Top:

study area (rectangles indicate region where high salinity greater than 34.6psu exists),

- Bottom :

vertical section of geostrophic currents cm/sec) along each observation lines (shade areas represent flows out of paper).

The movement of the currents in waters where the TWC flows is very complicated (Hase et al, 1999). These complicated distributions in the current structure are closely related to the meandering of the TWC and the generation of eddies. In the case of the branch flowing along the coastal region of Japan, it moves along the continental shelf, the depth of which is shallower than 200m. It seems that this branch has the characteristics of the coastal trapped current (Figs. 4a, 4c, 4d and Fig. 6).

The variation of the TWC's moving path with time may lead the density structure of the water column to change because of the TWC's water properties , high-temperature and high-salinity water, and changes in water stabilities. Fig. 9 shows the vertical profile of the density gradient both in the TWC region (solid line) where the TWC flows under the sea surface and in the non-TWC region (dashed line) where the TWC doesn't exist. In Fig. 9, the vertical structure of density in the TWC region has a different pattern from that in the non-TWC region showing a typical pattern in the temperate zones. In the case of the TWC region, two pycnoclines exist and are considered to be formed by the advection of the TWC.

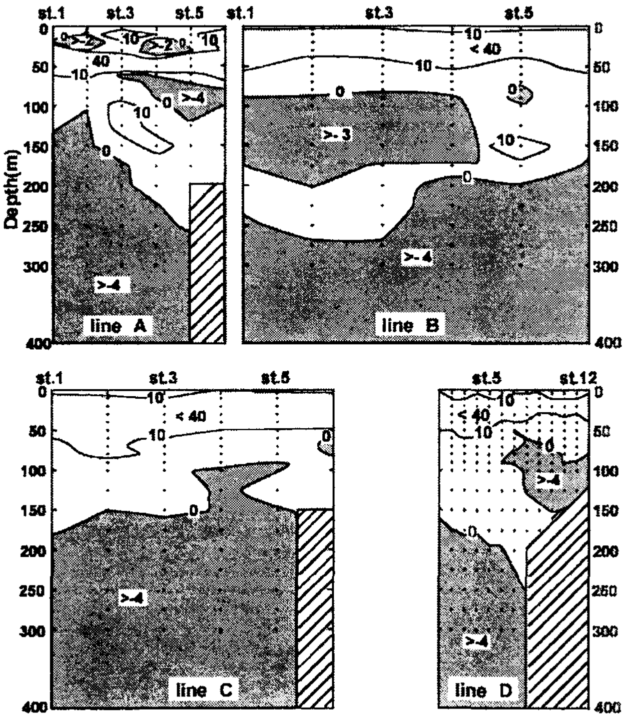

Fig. 9. Vertical section of Brunt Vaisala frequency (x 10^{-6} sec^{-1}) along each observation line in June, 1996. Shaded areas represent layers smaller than zero.

Vertical sections of N^2 along the lines A, B, C, and D are shown in Fig. 10. In the ocean, N^2, defining the strength of the density gradients and stability of the water column, is calculated. Shaded areas in the figures represent layers under unstable conditions and, in particular, these areas in the upper layer shallower than 200m match layers of the TWC with high salinity water

The stability of water masses is caused by a density inversion derived from the Ekman transport due to the effects of seasonal winds in summer and winter (Lim and Chang, 1969; Park, 1978; Kim and Cho, 1982). In particular, unstable conditions in the coastal waters located in the southeastern region of Korea are shown frequently in summer and this area is known as coastal upwelling (Lee, 1978; Park, 1978). That is, bottom cold water is upwelled onto the sea's surface, and water in the subsurface layer becomes unstable. According to the results of this study, it is noteworthy that the TWC is also a main factor making water masses in the East Sea unstable.

Summary

This study presented oceanic conditions in the Tsushima Warm Current region in the southern part of the East Sea (Sea of Japan) in June 1996 by using data from a CREAMS cruise.

A lower temperature phenomenon in the southern part of the East Sea appeared in 1996 between 1990 and 1999, and this phenomenon seems to be related to the distribution area of the TWC. In the period of this study, the first branch of the TWC which is known flowing along the Japanese coastal region exists more inshore of the Japanese coastal region compared to the other years, especially in the shallower water layer at less than about 200 m.

The TWC is also confirmed by the distribution of geostrophic currents and they are relatively strong at depths where the TWC flows along the coastal waters of Japan and offshore. Intrusion of the TWC into the southern part of the East Sea has influence on the vertical structure and stability of the water column.

The present paper analyzed snapshot data in 1996 when a lower temperature appeared and therefore is not sufficient for showing average conditions. Hereafter, the researchers will investigate mechanisms for the spatio-temporal variations of the TWC and their influence on long-term oceanic and fishing conditions.

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