해양환경안전학회 제10권 제1호, pp. 55~59, 2004. 06. 30. (ISSN 1229-3431)
Journal of the Korean Society of Marine Environment & Safety

Temperature Inversion off Wasaka Bay in the East Sea, June of 1995 and 1996

Chung-Il Lee* · Kyu-Dae Cho** · Jong-Hwui Yun***

[1]Research Center for Ocean Industrial and Development, Pukyong National University, Busan 608-737, Korea
**Dept. of Oceanography, Pukyong National University, Busan 608-737, Korea
** Dept. of Maritime Police Science, Korea Maritime University, Busan 606-791, Korea

요 약 : 1995년과 1996년 6월에 실시된 CREAMS 항해 관측 자료를 이용하여 Wasaka bay 연안역의 수온역전 현상을 조사하였다. 수온역전현상은 대부분 20m 이천의 상층부에 위치하였으며, 특히 쓰시마난류와 연안수와의 경계역 부분에 형성되었다. 쓰시마난류는 고온·고염분수의 특징을 가지며, 이러한 고수온은 경계역 부분에서 수온역전 현상을 초래하여 밀도 역전현상을 일으키는 작용을 하는 반면, 고염분은 밀도를 증가시켜 주는 작용을 하여 수온역전에 따른 밀도역전현상을 막아주는 역할을 한다.

핵심용어 : 동해, 수온역전, 밀도역전, 열전선, 수온약층

Abstract : *Temperature inversion off Wasaka Bay in the East Sea was studied using data measured on a CREAMS cruise in June of 1995 and 1996. Temperature inversion occurred mainly at the upper layer of the thermocline at a depth of no more than 20 m and around the thermal front between the TWC and the coastal waters of Japan. At some stations, temperature inversion had an influence on density inversion, while, in some other stations, high salinity water prevented density inversion.*

KEY WORDS : Temperature inversion, Wasaka Bay, East Sea, density inversion, Thermocline, Thermal front

1. Introduction

Temperature inversions are often found in the coastal waters of Korea and the ocean adjacent to Japan (Nagata, 1968, 1979; Kim et al., 1982; Kim and Yug, 1983; Cho and Park, 1990). They are mainly caused by sea surface cooling, cold water mass advection by wind-driven current, coastal upwelling and mixing effect in ocean front where the thermal structure is complicated and isothermal lines are rugged (Collins et al., 1968; Nagata, 1968, 1979; Thadathil and Gosh, 1992).

In seas adjacent to the Korean Peninsula, temperature inversions are commonly occurred during winter and summer seasons (Kim and Cho, 1982; Kim et al., 1982). In winter season, temperature inversions are commonly occurred in mixed layer by heat loss from sea surface, while in summer season, off east and west Cheju Island and the Korean Strait, it is connected with the interaction between the Tsushima Warm Current (TWC) and coastal waters in South Sea of Korea (Cho and Park, 1990).

The TWC, characterized by high temperature and high salinity, enters the East Sea via the South Sea of Korea and the Korea Strait. At this time temperature inversions occur along the ocean fronts and mixed regions between the TWC and the coastal water masses. Kato and Asai (1983) and Han (1998) reported that the TWC plays an important role in heat transportation into the East Sea, and heat transportation by the TWC in the East Sea is more than 60% of total heat transport through the sea surface. In particular, there is a branch of the TWC off Wasaka Bay in the southern part of the East Sea, and according to the result of Hase et al. (1999), the moving path of the TWC off Wasaka Bay varies year by year. This has particular effects on oceanographic conditions off Wasaka Bay (Hase et al., 1999; Lee and Cho, 2000). Lee et al. (2003) reported that the higher-temperature water in the TWC influences the vertical structure of sound speed off Wasaka Bay.

In this study, temperature inversion phenomena off Wasaka Bay in the area of activity of the branch of the TWC are illustrated using data measured during Circulation Research of the East Asian Marginal Seas (CREAMS) cruises in June of 1995 and 1996.

---

* 대표저자 : leeci@mail1.pknu.ac.kr, 051)620-6211
** 정회원, kdcho@mail1.pknu.ac.kr, 051)620-6211
*** 정회원, jhyun@mail.kmaritime.ac.kr, 051)410-4279

2. Data and method

Temperature, salinity and density data at intervals of 1m are used to illustrate temperature inversion off Wasaka Bay (Fig. 1). These data were obtained by a CTD, Mark Ⅲ-B type, with instrument precision of ±0.005℃. Fig. 2 illustrates the procedure adopted in establishing the temperature inversion stations. If temperature difference (ΔT) obtained from (T2-T1) is greater than 0.1 ℃, the station is defined as temperature inversion station.

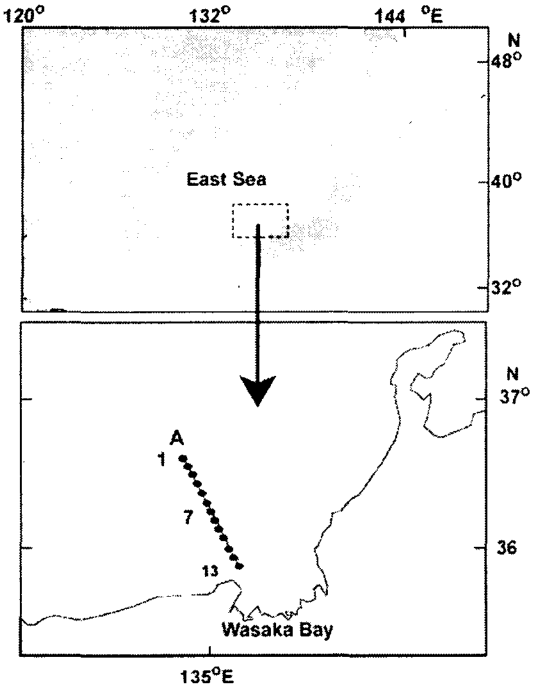


Fig. 1. The map showing study area in the East Sea. Line A represents the observation line of CREAMS and numerals indicate station number.

Temperature T1 and depth D1 of the upper end of the inversion layer (temperature minimum), and the temperature T2 and depth D2 of the lower end (temperature maximum) were read (Fig. 2).

Temperature inversions occurring below sea surface at a depth of less than 5 m were not considered because of potential error break which may occur during the warming-up stage of the CTD. Futhermore, if the thickness (ΔD) is less than 2 m based on the data interval (1 m), then temperature inversion is not defined in this study.

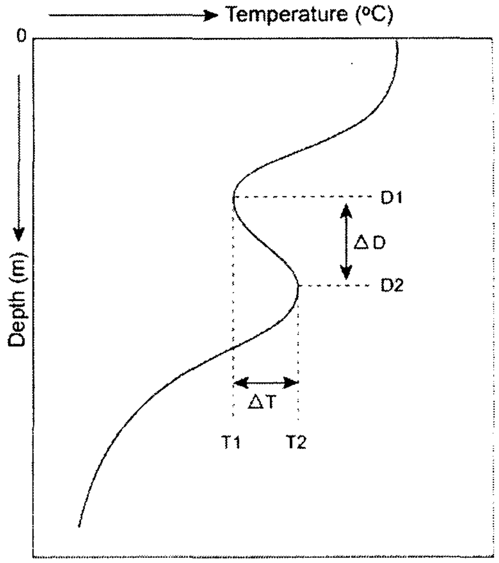


Fig. 2. A schematic temperature (℃) profile with inversion.

To find the temperature inversion and vertical structure of temperature in stations where temperature inversion occurs, a vertical profile of temperature, temperature section and salinity and density sections were prepared for the density inversion and effect of temperature and salinity on density structure.

3. Results and discussion

3.1 Vertical structure of temperature inversion

According to the results of Hase et al. (1999), Lee and Cho (2000) and Lee et al. (2003) in Wasaka Bay, the TWC flow at a depth of less than 200 m along the coastal waters of Japan shows the characteristics of a coastal trapped current, and it is characterized by a core of salinity higher than 34.40 psu. These results are clear markers of the oceanographic conditions in the TWC region off Wasaka Bay in 1995 and 1996. In

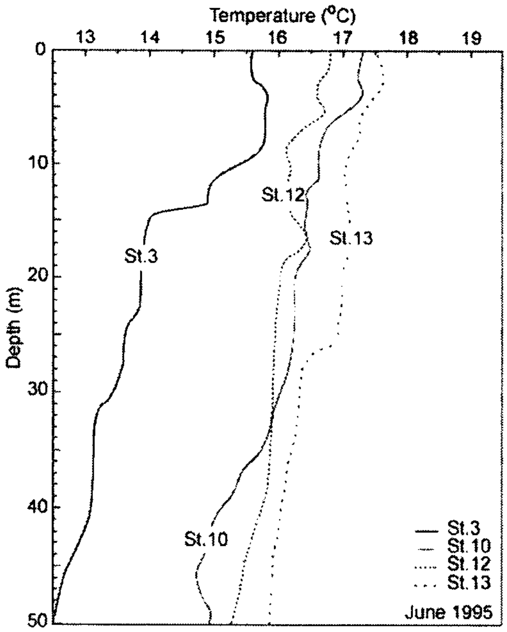


Fig. 3. Temperature profile at stations where temperature inversion occurs in June 1995.

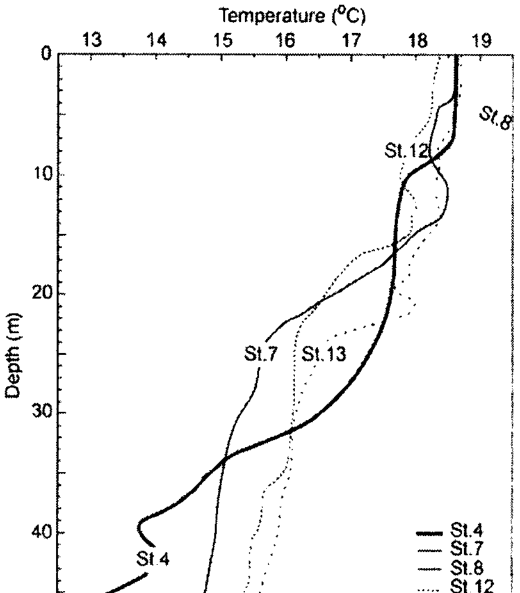


Fig. 4. Temperature (℃) profile at stations where temperature inversion occurs in June 1996.

this study, based on the results of Hase et al. (1999), Lee and Cho (2000) and Lee et al. (2003), the vertical profile for temperature inversion is established for a depth of 50 m from sea surface. Fig. 3 and Fig. 4 show vertical profiles at stations along Line A where temperature inversions occur.

In June 1995, temperature inversion occurred at Sts. 3, 10, 12 and 13 and they were recorded at a depth of less than 20 m for the most part except St. 10 (Fig. 3). Temperature with depth at St. 3 is lower than that in Sts. 10 and 12. According to the results of Lee and Cho (2003), the main axis of the TWC moves below Sts. 10 and 13 and as a result, temperature difference apparently occur at different stations.

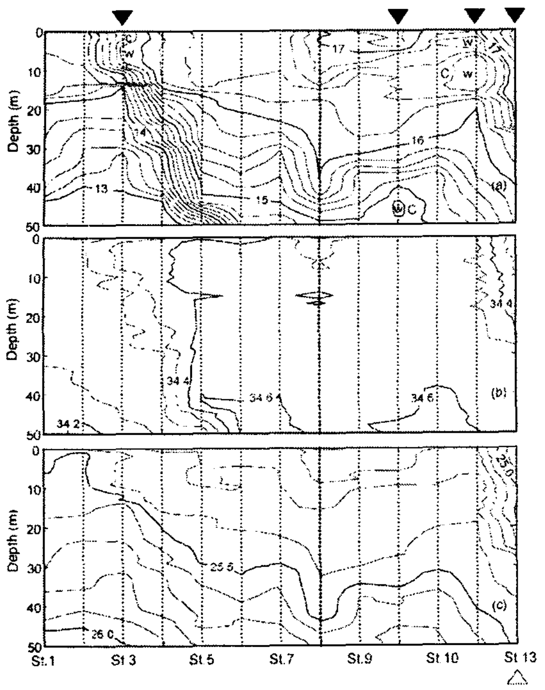
In June 1996, temperature inversion occurred at Sts. 4, 7, 8, 12 and 13 and vertical profiles of temperature are more complex when compared to those of 1995 (Fig. 4).

Temperature inversion in June 1995 and 1996 occurred mostly in the upper layer of thermocline, and this phenomenon differs from that off east Cheju where the TWC flows. This means that temperature inversion off east Cheju occurred at depth below 40 m for the most part. These differences will be discussed in detail in the next session.

3.2 Vertical distribution of temperature, salinity and density

Figs. 5 and Fig. 6 show the vertical distribution of temperature, salinity and density between sea surface and a depth of 50 m and these figures describe the detail of the vertical structure of water column. In these figures, the black inverted triangles at the top of the figure represent those stations where the temperature inversion occurred, and the clear triangles at the bottom of the figure are symbols for density inversion.

In the Fig. 5, there are two thermal fronts on both sides of the Line A; the one is for a thermal front between St. 2 and St. 6 (mean temperature: 14-15 ℃), the other is for thermal front between St. 12 and St. 13 (mean temperature: 17 ℃). It seems that thermal fronts on both sides of Line A are formed by a boundary where the TWC meets with the bodies of water in the area studied, and the position of thermal fronts matches with the vertical distribution of salinity shown in the middle of the Fig. 5. Hong and Cho (1983) reported that a salinity contour line of 34.40 psu was the northern boundary of the TWC, and Lee and Cho (2000) suggested that salinity higher than 34.60psu was the index for the main axis of the TWC.

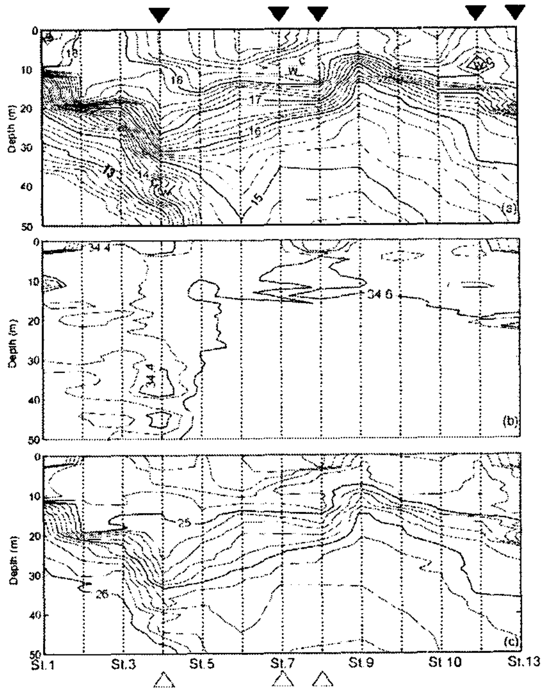


w: warm water, c: cold water

Fig. 5. Vertical sections of temperature (℃, (a)), salinity (psu, (b)) and density (sigma-t, (c)) in June 1995. The black inverted triangles are symbols for temperature inversion and the clear triangles are symbols for density inversion.

In the Fig. 5, the position of the thermal fronts corresponded exactly to that of the 34.40 psu salinity contour lines. In addition, temperature inversion shown in the Fig. 3 exists mainly around the stations at which thermal fronts are formed. This phenomenon agrees with the results of Nagata (1968, 1979): that is, temperature inversion occurs frequently at the boundary and the mixed water regions where the Kuroshio warm current meets with the Oyashio cold current. High salinity water also influences the vertical structure of density (see Fig. 5, bottom). However, it seems that the locations of density and temperature inversion at some stations do not match because of the compensation effect of high-salinity water above 34.40 psu.

In case of data for June 1996, the vertical structures of each factor shown in Fig. 6 differ from those for June 1995 (refer to Fig. 5). Thermal front is not clear compared to that specified in Fig. 5. In fact, two thermoclines appear in Fig. 6; one for a mean temperature 17℃ contour line between 10 m and 30 m along Line A, and the other for mean temperature 14℃ contour line between St. 1 and St. 5. Temperature inversion exists mainly in the upper layer of thermocline. High-salinity water above 34.60psu spreads widely compared to that shown in Fig. 5. Density inversion occurs at stations where temperature inversion occurs except at St. 12.



w: warm water, c: cold water

Fig. 6. Vertical sections of temperature (℃, (a)), salinity (psu, (b)) and density (sigma-t, (c)) in June 1996. The black inverted triangles are symbols for temperature inversion and the clear triangles are symbols for density inversion.

According to the results of Hong and Cho (1983), Hase et al. (1999) and Lee et al. (2003), the strength of the flow path of the TWC is not constant. Therefore, It is hypothesized that the boundary between the TWC and other water masses, and the location of temperature inversion may vary.

Studies of temperature inversion around the Korean Peninsula focus on the main events of the summer season and the winter season, and consider sea surface cooling, wind-driven current, and coastal upwelling as the major causal factors. In addition to these, the interaction between Tsushima Warm Current and Korea Coastal Waters is also important factor in formation of temperature inversion. Temperature inversion may cause the instability of water mass and it matches well with the result of Lee et al. (2003) showing the instability off Wasaka Bay.

The study area is located in the coastal waters of Japan in the East Sea and is the main path of the branch of the TWC. Unlike in the previous studies, data used in this study were gathered in early summer (June of 1995 and 1996), and also, temperature inversion occurs mainly in the upper layer of thermocline compared to the situation in the South Sea of Korea where temperature inversion occurs in the lower part of thermocline due to the advection of cold water mass or to the TWC.

The data presented and discussed in this study do not cover a wide area of the East Sea and, therefore, are not sufficient to describe the general phenomena of the East Sea. However, it is clearly shown in this study that temperature inversion occurs around the boundary between the TWC and other water masses, and thus provides some clues toward a more detailed description of the oceanographic conditions of the TWC region. Moreover, the advection of the TWC in the East Sea may suggest the generation of temperature inversion not only in summer and winter season but also in other seasons.

Summary

Studies for temperature inversion around the Korean Peninsula focus mainly on the main events in the coastal waters of Korea during the summer season and the winter season. In this study, temperature inversion off Wasaka Bay in the East Sea where the TWC's branch moves had been studied using the data from CREAMS cruise in June of 1995 and 1996.

The majority of the temperature inversion occurred around the boundary between the TWC and other water mass and in the upper layer of thermocline. Temperature inversion was caused by interaction between the TWC and the coastal waters of Japan in the East Sea. High-salinity water, a distinctive feature of the TWC, restrained the occurrence of density inversion by effect of temperature inversion.

Acknowledgments

This study was funded by the Korea Maritime Science

References

[1] Cho, K.D. and S.W. Park (1990), Inversion phenomena of temperature off East Cheju Island in Summer, 1986. Bull. Kor. Fish. Technol. Soc. 26(3), pp.265~274.

[2] Collinst, C.A., C.N.K. Mooers, M.R. Stevenson, R. L. Smith and J. G. Pattullo (1968), Direct current measurement in the frontal zone of a coastal upwelling region. J. Oceanogr. Soc. Japan, 24(6), pp.295~306.

[3] Han, I.S (1998), Heat supply in Tonghae by Tsushima Warm Current. Ms Thesis, Pukyong National University, Busan, Korea. pp.35.

[4] Hase, H., J.H. Yoon and W. Koterayama (1999), The current structure of the Tsushima Warm Current along the Japanese Coast. J. Oceanogr. 55, pp.217~235.

[5] Hong, C.H and K.D. Cho (1983), The northern boundary of the Tsushima Warm Current and its fluctuations. J. Oceanol. Soc. Korea, 18(1). pp.1~9.

[6] Kato, K. and T. Asai (1983), Seasonal variations of heat budgets in both the atmosphere and the sea in the Japan Sea. J. Meteor. Soc. Japan, 61, pp.222~238.

[7] Kim, H.J. and K.D. Cho (1982), Inversion phenomena of density in the Japan Sea. J. Oceanol. Soc. Korea, 17(2), pp.51~58.

[8] Kim, H.J., H.J. Yoon and S.K. Yang (1982), Inversion phenomena of temperature in the Yellow Sea. Bull. Kor. Fish. Soc. 18(2), pp.91~96.

[9] Kim, H. J. and S. S. Yug (1983), Inversion phenomena of temperature in the southern sea of Korea. Bull. Kor. Fish. Soc. 16(2), pp.111~116.

[10] Lee, C. I. and K. D. Cho (2000), The fluctuation characteristics of the water mass and the current structure of the southeastern region of the East Sea. J. Fish. Sci. Technol., 3(2), pp.97~110.

[11] Lee, C.I., K.D. Cho and S.W. Kim (2003), Variation of sound speed in the Tsushima Warm Current region of the East Sea. J. Kor. Fish. Soc. 36(2), pp.170~177.

[12] Lee, C.I., K.D. Cho and J.H. Yoon (2003), The oceanic condition of the Tsushma Warm Current region in the southern part of the East Sea (Sea of Japan) in June, 1996. J. Kor. Soc. Marine Envi. Safety, 9(2), pp.65~72.

[13] Nagata, Y (1968), Shallow temperature inversions in the sea to the east of Honshu. J. Oceanogr. Soc. Japan, 24, pp.103~114.

[14] Nagata, Y (1979), Shallow temperature inversions in the Pacific Ocean near Japan. J. Oceanogr. Soc. Japan, 35, pp.141~150.

[15] Thadathil, P. and A.K. Gosh (1992), Surface layer temperature inversion in the Arabian Sea during winter. J. Oceanogr. 48, pp.293~304.

원고접수일 : 2004년 03월 26일
원고채택일 : 2004년 06월 10일