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Stratification Variation of Summer and Winter in the South Sea of Korea

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한국 남해의 여름과 겨울철 성층 변동

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ABSTRACT : *In order to illustrate the variation of stratification and to know the effects of the temperature and the salinity on the stratification in the South Sea of Korea, the stratification parameter defined as potential energy anomaly (PEA, V(J/m^3)) introduced by Simpson and Hunter (1974) was used. The oceanographic data were obtained in August 1999 and February 2000 by National Fisheries Research and Development Institute (NFRDI). V in August is generally high in offshore and low in near shore. However, in February, V in the near shore is higher than that of the offshore due to the vertical temperature gradient between surface and bottom layer caused by the expansion of South Korean Coastal Waters (SKCW). In summer, the increase of the atmospheric heating acts on the stratification as the buoyancy forcing. In most cases, the effect of the temperature on the stratification is stronger than that of the salinity. The temperature effect is predominantly due to the extent of the intrusion of Tsushima Warm Current into the study area. However, at stations where V is high the effect of the salinity is also significant. In winter, V is very low due to the decrease of the buoyancy forcing, but some stations show the relatively high V due to the expansion of SKCW and salinity in winter unlike that in summer makes the stratification weak.*

KEY WORDS : Stratification, Temperature, Salinity, South Korean Coastal Waters, Tsushima Warm Current.

요 약 : Simpson and Hunter (1974)의 포텐셜 에너지 anomaly(V)를 이용하여 한국 남해의 여름과 겨울철 성층 변동 및 수온과 염분이 성층의 강도에 미치는 영향을 분석하였다. 수온 및 염분은 국립수산과학원이 1999년 8월, 2000년 2월에 실시한 정선 관측 자료이다. 8월(여름)은 남해의 외해측에서 V 값이 높게 나타나는 반면, 2월(겨울)의 경우 연안역 가까운 곳에서 높게 나타났다. 8월은 대기의 가열 현상 및 쓰시마난류의 유입 등이 V가 증가하는 주요 인자이며, 2월은 대기 냉각 및 남해연안수의 확장이 표·저층간의 성층의 세기를 변화시키는 요인으로 작용한다. 전 시기에 걸쳐 수온이 염분보다 성층의 세기 변화에 큰 영향을 미치며, 8월에는 수온과 염분이 성층의 세기를 증가시키는 작용을 하는 반면, 2월에는 염분이 성층의 세기를 감소시키는 작용을 한다.

핵심용어 : 성층, 수온, 염분, 한국 남해 연안수, 쓰시마난류

1. Introduction

In general, oceanic stratification which means density distribution of the fluid in the gravity field is formed by the increase of the sun's radiation (heat flux), the input of fresh-water or low-saline water (net fresh water) from the land (buoyancy forcing hereafter), and the decrease of the wind speed.

Stratification-destratification phenomenon (namely SD phenomenon) and the strength of stratification affect the material transfer between the upper and the lower water mass. Studies on the mechanism of SD phenomenon have been done in many areas (Simpson and Hunter, 1974; Simpson and Bowers, 1979; Choi and Hong, 1997; Garret et al., 1978; Xing and Davies, 1998; Bisagni, 1999; Bisagni, 2000). The concept of stratification parameter was introduced to understand the strength of

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stratification quantitatively in the Irish Sea (Simpson and Hunter, 1974), although it has been used basically to locate positions of tidal fronts. They constructed an energy argument and estimated the amount of energy to mix a stratified column by calculating the difference in the potential energy of the water column before and after mixing. The energy calculated is what is required to mix the stratified column. On the basis of the calculation, many works have been done in many areas (Simpson and Hunter, 1974; Simpson and Bowers, 1979).

Stratification also affects directly biological processes and material transfers between the upper and the lower layer in the ocean. The existence of stratification limits new production in continental shelf seas (Chen et al., 2001). The growth of phytoplankton is partly dependent on stratification (Eilertsen, 1993; Townsend et al., 1992). Studies on the creation and maintenance of stratification, also, have been done so far in many aspects. The creation and maintenance of stratification have a close relationship with factors such as heat flux, wind speed, and tidal current (Choi and Hong, 1997; Garret et al., 1978; Xing and Davies, 1998; Bisagni, 1999; Bisagni, 2000). Masuda et al.(1999) suggested that stratification caused the change of Kuroshio current path. Guo et al.(2000) reported the effect of stratification on shelf edge flow. The understanding of stratification needs to tackle the propagation and the analysis of internal waves (Liu et al., 1985).

In order to acquire the knowledge of stratification in the South Sea of Korea quantitatively, Simpson and Hunter's (1974) equations were used. The strength and the distribution of stratification can be calculated by the equations. In a point of oceanographic view, the study area is the sea showing quite a complex characteristics because of advection, expansion, mixing, and diffusion among water masses. The variation of water masses may influence on the strength and the distribution of stratification. Since Simpson and Hunter's equations compute the strength of stratification by using density values at depths, results calculated by the equations will reflect the influence of the variation on stratification. The sea water density depends not only on the temperature but also on the salinity, the structure of temperature and salinity of the water will affect stratification respectively.

The aims of this paper are to illuminate the distribution and the strength of stratification during summer and winter in the South Sea of Korea and the effect of water temperature (temperature) and salinity on the variation of stratification.

2. Data and methods

2.1. Oceanographic Data

The data set obtained by National Fisheries Research and Development Institute (NFRDI) in August 1999 and February 2000 for this study were used to know the strength and the distribution of stratification in the South Sea of Korea. All of the cruises have been done by NFRDI along seven observation lines in the study area. The data obtained with CTD casts are consist of temperature (℃), salinity (psu), and density (σ_t). Fig. 1 shows the locations of NFRDI stations of the study area.

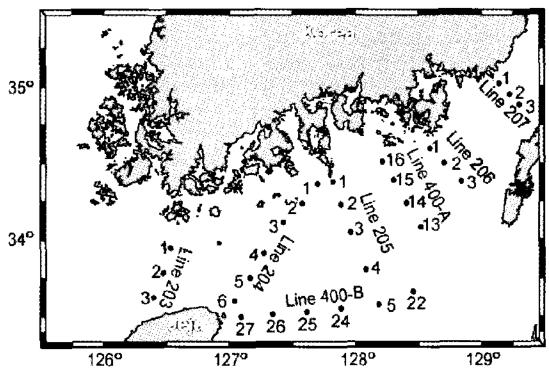

Fig. 1. Map showing the locations of oceanographic stations.

2.2. Meteorological Data

The monthly average air temperature, the monthly average wind speed and total precipitation in August 1999 and February 2000 were used in the monthly data report issued by Korea Meteorological Agency (KMA). Note that the monthly average air temperature was used because there were no heat flux data. It is better, of course, to use the meteorological data observed at the same time with the ocean data. The local data of five weather stations (Busan, Ulsan, Mokpo, Yeosu and Jeju) near the study area were used.

2.3. Methods

Calculation of stratification parameter

In order to know strength of stratification, stratification parameters on each station were calculated by the following equations. Stratification parameter or stratification index can be defined as potential energy anomaly (PEA, V (J/m^3), Simpson and Hunter, 1974). It is the difference in the potential energy of the water column before and after mixing, in other words, the amount of energy required to mix a stratified column by the stratification.

$$V = \frac{1}{h}\int_{-h}^{0}(\rho - \overline{\rho})gz\,dz \quad (J/m^3) \quad (1)$$

$$\overline{\rho} = \frac{1}{h}\int_{-h}^{0}\rho\,dz \quad (kg/m^3) \quad (2)$$

Where h is the water depth, ρ is the density (kg/m^3), g is the gravity acceleration (m/s^2), and z is defined as positive up (m). For a vertically mixed system, $V = 0$, and for increasingly stable stratification, V becomes negative. When $V < 0$, tidal stirring and mixing due to wind stress bring about positive change in V (Simpson and Bowers, 1981). V in each month was represented as bar graph and contour at the same time.

In this study, in order to examine the effects of temperature and salinity on V respectively, V was computed in three different ways. Averaged temperature and salinity of the water columns were used through the process of the density calculation. And then V was recalculated by equations (1) and (2) with the density computed by averaged temperature and salinity. So three types of V were produced. For simply explanation three types of notations will be used in this paper. V_{tot} represents V calculated by using all temperature and salinity profiles. V_{tem} and V_{sal} show the effect of temperature and salinity, respectively. These were also represented as bar graph and contour monthly at the same time.

3. Results

3.1 Stratification in August 1999 and February 2000

In August (Fig. 2), higher air temperature, weaker wind speed and greater precipitation compared to those in February may increase atmospheric heating and buoyancy forcing. In particular, air temperature and precipitation between August and February at five weather stations showed a sharp difference compared to wind speed.

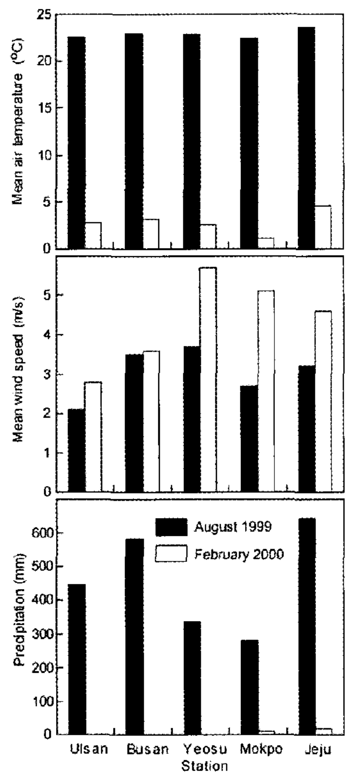

Fig. 2. Variation of mean air temperature (top), mean wind speed (middle) and precipitation (bottom) in August 1999 (■) and February 2000 (□) at weather stations on Ulsan, Busan, Yeosu, Mokpo and Jeju.

V_{tot} in August was high in the offshore, and low in the near shore (Fig. 3). In the figure, V_{tot} along the offshore in the whole area showed the similar value. The maximum value is 836 J/㎥ at 205-05. The minimum is 53 J/㎥ at 204-02. As shown in the figures, salinity, as well as temperature, played an important role in increase of stratification, and V_{tem} and V_{sal} were higher in the offshore.

However, V_{tot} in February unlike August was very low in the whole area and stratification strength in the near shore was greater than that in the offshore (Fig. 4). The maximum value is 27 J/㎥ at 204-03. The minimum is -7 J/㎥ at 400B-25. Unlike August, higher value of stratification parameter existed only in the near shore of lines 204, 205 and 400. The difference of the temperature and the salinity between the upper and the lower layers in these areas might cause the stratification and it will be discussed in session 4.2. The distribution pattern and strength of V_{tem} was similar to those of V_{tot}. Also, the regions where V_{tot} was high were predominantly affected by the temperature. Unlike summer (August 1999), effect of salinity on the stratification is negative, that is, salinity makes the strength of stratification weak.

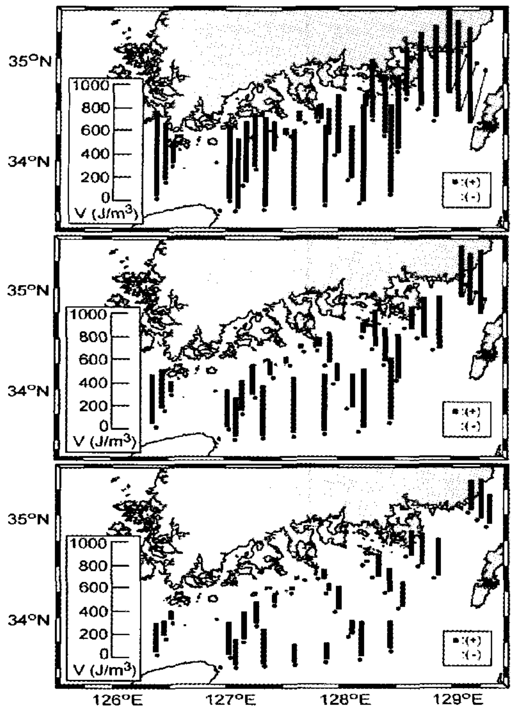

Fig. 3. Distribution of potential energy anomaly (PEA, J/m3) in August 1999 (top: PEA, middle: PEA calculated using average temperature values, bottom: PEA calculated using average salinity values).

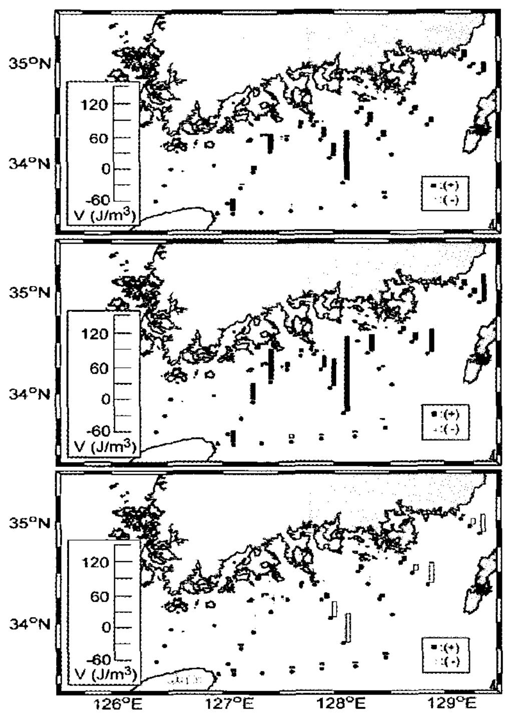

Fig. 4. Distribution of potential energy anomaly (PEA, J/m^3) in February 2000 (top: PEA, middle: PEA calculated using average temperature values, bottom: PEA calculated using average salinity values).

4. Discussion

4.1. Summer (August 1999)

The effect of temperature was more apparent than that of salinity in August 1999. In the area between line 204 and line 205, stations 25 and 24 along line 400-B, the effect of the salinity was weaker.

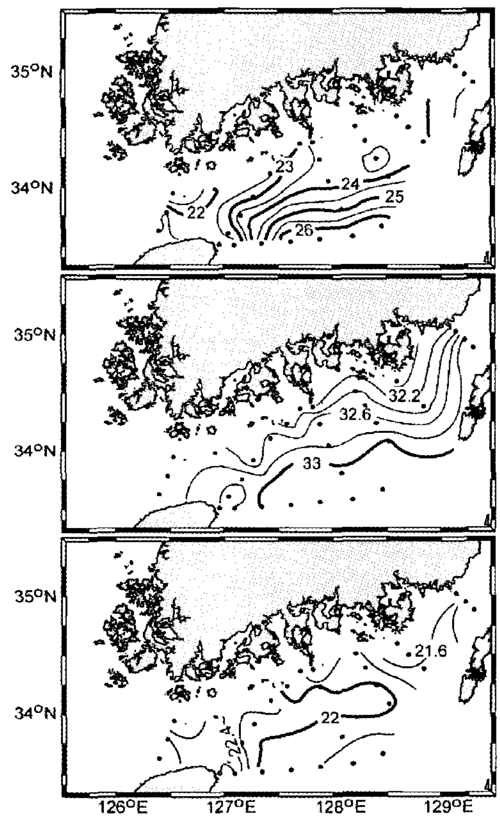

Fig. 5. Horizontal distributions of temperature (a), salinity (b), and density (c) at the surface in August 1999.

The high temperature (>24 ℃) and salty (>32.8) water from the south flowed into the study area (Fig. 5). This water may result in some effect on V_{tot}. The differences of the near shore and offshore V_{tot} were great.

In summer, Tsushima Warm current that is warmer and salty intrudes into South Korean Coastal Waters that is colder and less saline, or South Korean Coastal Water (SKCW) intrudes into Tsushima current.

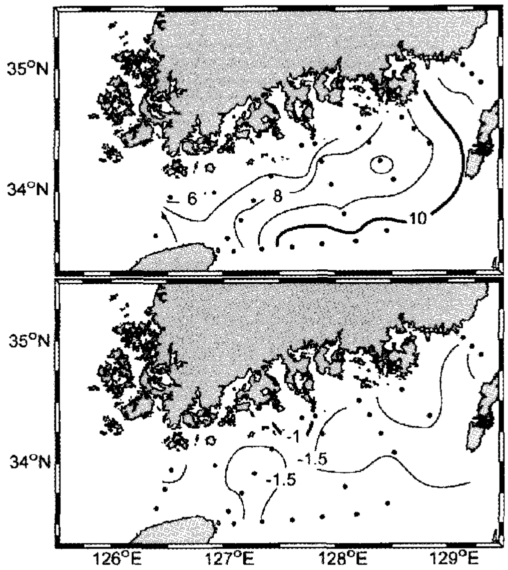

Fig. 6. Horizontal distributions of the differences between surface and bottom temperature (a), and salinity in August 1999.

These intrusions cause the temperature inversion phenomena (Cho and Park, 1990), and it may cause the increase in the strength of the stratification in some regions where the two different water masses meet can be stronger than the other areas due to the buoyancy forcing by the inversion phenomenon. In the figure, temperature difference in the offshore had greater than in the near shore because of intrusion of warm water through surface layer(Fig. 6).

4.2. Winter (February 2000)

Like summer, the effect of the temperature was more apparent in February 2000. The distribution of V_{tot} was similar to that of V_{tem}. However, the values of V_{sal} were almost negative at stations except for stations in the near shore. Therefore, it is concluded that salinity in February makes stratification weak. V_{tot} was higher in the near shore, in particular, it was high in the near shore of lines 204, 205 and 400-A. Higher V_{tot} in these areas matched the intrusion of higher density water (Fig. 7). According to the distribution of the temperature and the salinity at the surface, the cold and less saline water existed in the near shore.

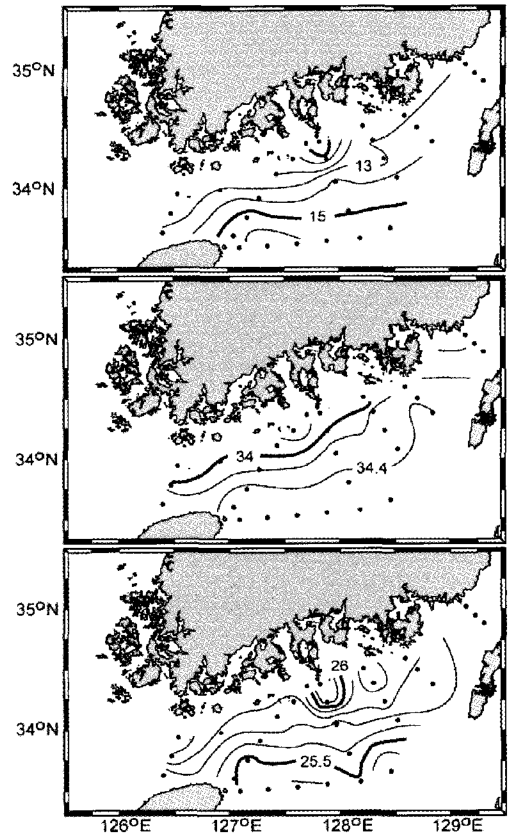

Fig. 7. Horizontal distributions of temperature (top), salinity (middle), and density (bottom) at the surface in February 2000.

Temperature (7-15℃) and salinity (33.9-34.4psu) in bottom layer can be estimated from Figs. 7 and 8. The water existing at the bottom showed the characteristics of SKCW reported by Na et al. (1990). They reported that SKCW of which the temperature was <11 ℃ and the salinity was from 34.0 to 34.2 was formed by the cooling in the winter, and then it expanded in sink or in drift by the northwesterly wind. Due to the existence of the SKCW in February 2000, the vertical gradient of the temperature between the upper and the lower layers occurred. Because of the gradient, the stratification was formed. On lines 204, 205 400-A, the temperature difference between surface and bottom layer was higher, and it seemed that this difference was by expansion of cold water. In the whole area, where SKCW existed, the difference of the temperature between the upper and the lower layers was relatively higher (Fig. 8).

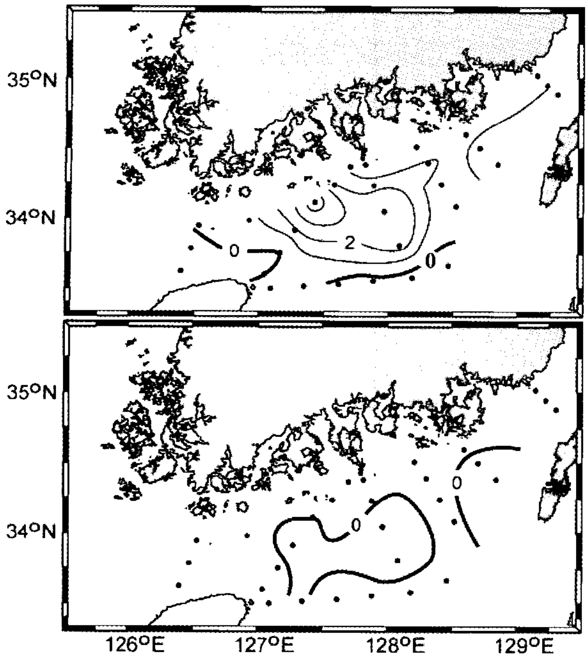

Fig. 8. Horizontal distributions of the differences between surface and bottom temperature (a), and salinity in February 2000.

In this study, the authors didn't consider the factors such as tidal current, heat flux, wind, fresh water. In particular, in case of South Sea of Korea, the water depth was mostly above 200 m, tidal current should be considered in the SD phenomenon. According to the previous studies, the strength of stratification was strongly dependent on the spring-neap tidal cycle in Deukryang Bay (Lee et al., 1996). Pingree et al. (1978) approached destratification from the point of view of the turbulent energy dissipation rate due to tidal flow on the continental shelf around British Isles. Simpson and Bowers (1981) also reported that tidal current was a significant factor of destratification on the continental shelf around British Isles. Therefore, the role of tidal current might be important in the South Sea of Korea.

The buoyancy forcing into the sea surface due to precipitation or fresh water runoff sometimes plays an important role in producing stratification in the local area. As shown in Fig. 2, precipitation between August 1999 and February 2000 may be considered as an important factor in stratification variation of summer and winter. For example, Garrett et al. (1978) reported that the river discharge in May of $3.1\times10^{3}\ m^{3}s^{-1}$ produces a buoyancy forcing to the Bay of Fundy equivalent to the heat flux of 200 W^{-2} over an area of about 10,000 km^{2}.

Further work is required to produce more reliable results of the stratification phenomenon in the South Sea of Korea. If other factors are considered in the further work with more quantitative results, the parametric study that estimates the relative importance of each factor could be enabled.

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