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Annual Variation of Salinity in the Neighbouring Seas of Korea

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韓國周邊 海洋鹽分의 年變化

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Abstract: We study the annual variation of salinity at the sea surface and at 30m depth in the neighbouring seas of Korea by the harmonic method. The analysis is based on the monthly salinity data at 182 stations collected regularly by the Fisheries Research and Development Agency during 15 years (1961~1975). The annual mean salinity in the West Sea is lower than that in the East Sea. In the South and East Seas, the amplitude of annual salinity variation decreases and the phase delays with the downstream distance of the Tsushima Current. The salinity at 30m has a higher mean, a smaller amplitude and a delayed phase than the corresponding ones at the surface. The annual variations of salinity in the South and East Seas are caused mainly by the annual variations of the local precipitation and that of the fresh water discharge from the Yangtze River.

要約: 수산진흥원에서 15년간(1961~1975) 정기적으로 관측한 한국주변 182정점의 염분 자료에 대한 조화분석을 통하여, 한국 주변 동·서·남해표면과 30메타층 염분의 연변화를 분석하였다. 서해 염분의 연평균은 동해에서보다. 낮으며 남해와 동해에서는 대마난류의 하류방향으로 갈수록 염분 연변화의 진폭이 줄어들고 위상이 지연된다. 30메타층의 염분은 표면염분에 비하여 평균치는 높으나, 년교차의 폭이 작고 위상이 지연되고 있다. 한국 주변남해와 동해염분의 연변화는 주로 국지적 강우량 및 양자강담수 유출의 계절적인 변화 때문에 일어난다.

INTRODUCTION

The annual variation of salinity depends primarily on the evaporation and precipitation in an open sea and on the ice formation and melting at high latitueds (Defant, 1960; Neumann, 1972; Dietrich *et al*, 1980). The annual variation of salinity in the neighbouring seas of Korea, however, depends mainly on the seasonal variations of precipitation and river runoffs.

In this paper we study the annual variation of salinity at the sea surface and at 30m depth in the neighbouring seas of Korea by the harmonic method. Our analysis is based on monthly salinity data which had been routinely collected by the Fisheries Research and Development Agency (FRDA) during the period of 1961 to 1975 at 182 stations (FRDA, 1979). The oceanographic stations of the FRDA and the numbers of month with available mean salinity data at each station are shown in Fig. 1 of Kang and Jin (1984). Although a similar study was already made by Hong (1967), our work is useful because the number of stations included in our analysis is more than three times of 56 statoins used by Hong (1967). Furthermore, our analysis gives a comparison between

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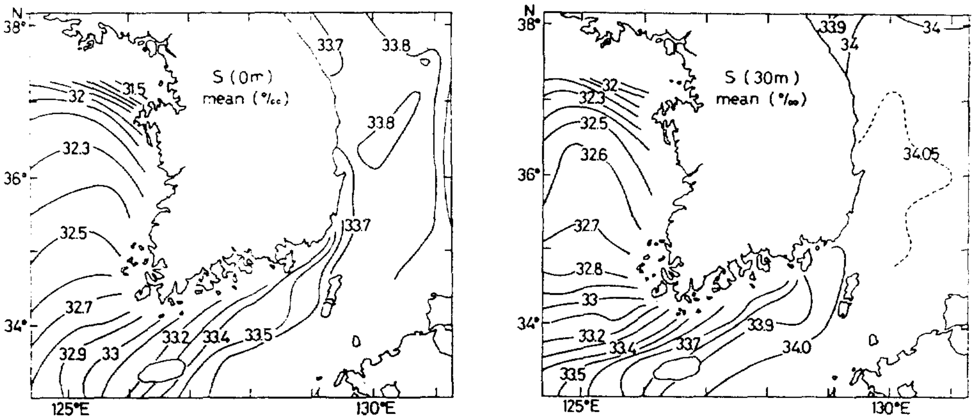

Fig. 1. Annual mean salinity at the sea surface and at 30m.

the salinity variations at the sea surface and at 30m. We also discuss the physical processes responsible for the observed salinity variations.

METHOD OF ANALYSIS

The data used are the monthly normals of salinity averaged over 15 years (1961~1975) at 182 stations (FRDA, 1979). We represent the salinity as a harmonic function $\hat{S}(t)$ given by

$$\hat{S}(t)=\bar{S}+S_1\cos(\omega_1 t-\phi_1)+S_2\cos(\omega_2 t-\phi_2), \quad (1)$$

where $\bar{S}$ is the mean salinity, S_1 and S_2 the amplitudes of the annual and semi-annual variations, respectively, ω_1 and ω_2 the angular frequencies, ϕ_1 and ϕ_2 the phases, and t the time from January 1. We considered the annual and semi-annual components only, because the higher harmonics are not persistent and their amplitudes are negligibly small. The 5 unknowns, $\bar{S}$, S_1, S_2, ϕ_1 and ϕ_2, are determined by minimizing the squared error function E given by

$$E=\sum_t [S(t)-\hat{S}(t)]^2, \quad (2)$$

where the summation is applid only to the months with available salinity data, $S(t)$. Since the months with available data are unevenly spaced in time, the mean salinity $\bar{S}$ cannot be determined by means of an arithmatic averaging of the available data. The harmonic fitting method we used, however, yields the mean salinity even for unevenly spaced data. The details of the harmonic method we used are described by Kang and Jin (1984).

MEAN, AMPLITUDE, AND PHASE

The annual mean salinities at the sea surface and at 30m are shown in Fig. 1. The mean salinities at the sea surface are 31.5 to 32.7‰ in the West Sea (the Yellow Sea), 32.7‰ to 33.6‰ in the South Sea, and 33.7‰ to 33.9‰ in the East Sea (the Japan Sea). The mean salinity in the West Sea is about 1 to 2‰ lower than that in the East Sea. The mean salinities at 30m are 0.2 to 0.5‰ higher than those at the sea surface. The mean salinity in the East Sea is almost uniform whereas that in the West Sea shows a strong spatial variability.

Fig. 2 shows the annual amplitudes of salinity at the sea surface and at 30m, respectively. The annual amplitudes of surface salinity are 1.0 to 1.9‰ in the South Sea, 0.7 to 1.3‰ in the East Sea, and less then 0.5‰ in the West Sea. The amplitudes at 30m depth are reduced to 50 to 60‰ of those at the sea surface. The amplitudes in the South

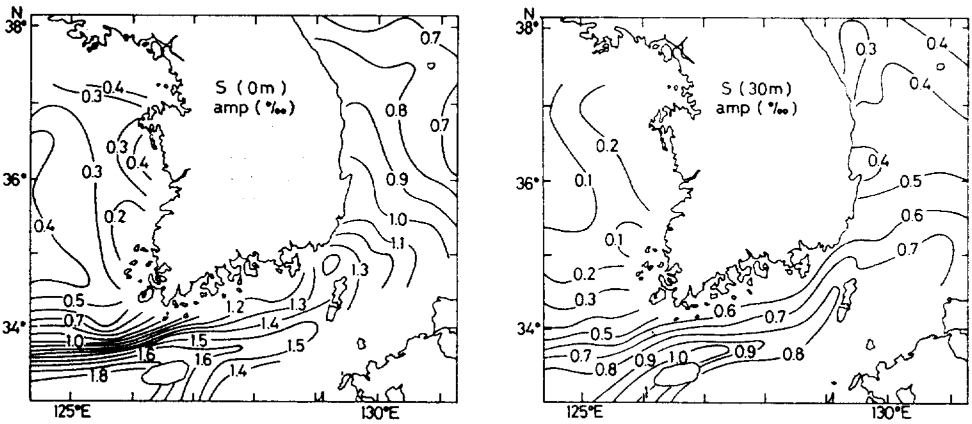

Fig. 2. Amplitudes of annual salinity variation at the sea surface and at 30m.

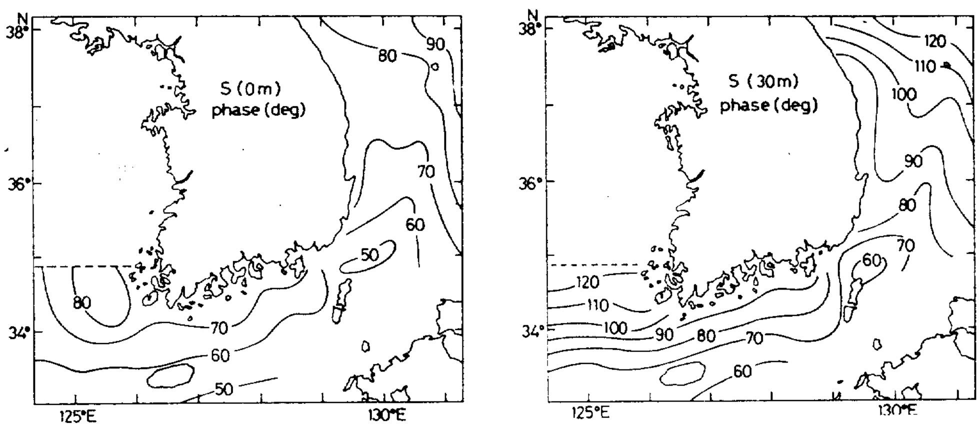

Fig. 3. Phases of annual salinity variation at the sea surface and at 30m referred to January 1. The phase of 60° means that the maximum salinity occurs on March 1.

Sea are maximal along a smooth curve connecting the Cheju and Tsushima Islands, and they decrease near the coast. The amplitudes in the East Sea decrease with the distance from Tsushima Island. Note that the decrease in amplitude with distance from Cheju to Tsushima Islands is small, but that in the East Sea is large.

The annual phases of salinity, referred to January 1, at the sea surface and at 30m are shown in Fig. 3. The phase angle of 60° in the figure represents that the salinity is maximum on March 1 and minimum on September 1. The phases in the West Sea, where the amplitudes are less than 0.5‰ at the sea surface and less than 0.2‰ at 30m, are not shown in Fig. 3. In the South Sea, the phase at the off-shore leads that near the coast. In the East Sea, the phase generally lags behind with the distance from Tsushima Island. The time lag in the annual salinity variation between Tsushima and Ullung Islands is one month at the sea surface and two months at 30m depth. The annual salinity variation at 30m lags behind that at the surface by 10 to 30 days.

The results for the semi-annual salinity variation are neglected in this paper because the amplitude is small (less than 0.5‰ at the surface and less than 0.2‰ at 30m) and the phase *distribution does not show any systematic pattern.*

DISCUSSION

The annal mean salinity in the neighbouring seas of Korea (Fig.1) is considerably lower than that of 34.5‰ in the Kuroshio region (Robinson, 1976). The annual evaporation in the Japan Sea, associated with the evaporative cooling of 72 Kcal $cm^{-2}yr^{-1}$, is 1.2 m/yr (Maizuru Marine Observatory, 1972). Since the annual precipitation is about the same as the annual evaporation, the local exchange of fresh water across the sea surface gives only a negligible effect on the annual mean salinity. The low salinity in the neighbouring seas of Korea is mainly due to fresh water discharge from rivers.

The influence of the fresh water discharge on the salinity of seawater can be estimated as follows. If a water mass with volume transport of V_1 and salinity of S_1 is mixed with another water mass with corresponding values of V_2 and S_2, then the salinity of mixed one becomes

$$S=(V_1S_1+V_2S_2)/(V_1+V_2). \tag{3}$$

If the fresh water discharge of 34×10^3 m^3/s from the Yangtze River (Dietrich *et al*, 1980, p. 197) were mixed with the seawater with salinity of 34‰ and volume transport of 1×10^6 m^3/s, the salinity would be decreased by 1.1‰. The low salnity in the Tsushima Current region is ultimately resulted due to fresh water discharge from the Yangtze River. In the Yellow Sea (the West Sea) the salinity is low due to fresh water discharges of the Huangho and many rivers along the western coast of Korea. Although the fresh water discharges of the Huangho and other rivers into the Yellow Sea are much smaller than that of the Yangtze, the mean salinity in the Yellow Sea is lower than that in the Tsushima Current region. This suggests that the residence or recycling time of seawater in the Yellow Sea is much longer than that in the Tsushima Current region.

The annual variations of the local flux of fresh water across the sea surface associated with precipitation and evaporation, that of the fresh water discharge from rivers, and also that of the horizontal salinity advection are responsible for the annual variation of salinity. In the regions considered, the local flux of fresh water across the sea surface decreases the salinity in summer during which the precipit ation is large and the evaporation is small (Kang, 1983). The situations are reversed in winter. The amplitude of salinity variation associated with local flux of fresh water across the sea surface is expected to be much smaller than that associated with the river runoffs. This can be inferred from the fact that the amplitude in the West Sea is much smaller than that in the South and East Seas (Fig. 2). The large amplitudes in the South and East Seas are resulted mainly due to an annual variation of river runoffs, especially that of the Yangtze River. The salinity advection depends not only on the fresh water discharge but also on the annual variation of currents in the regions considered (Kang, 1984). The variation of salinity associated with the advection and diffusion follows the equation

$$\frac{\partial S}{\partial t}+U\frac{\partial S}{\partial x}=K\frac{\partial^2 S}{\partial y^2}, \tag{4}$$

where x is the downstream distance, U the mean current, K the eddy diffusivity, and y the coordinate orthogonal to x. The boundary condition of a linear increase in salinity from $y=-b$ to $y=b$ on which is superimposed a periodic annual disturbance at $x=0$ with a maximum amplitude at $y=0$ and vanishing at $y=\pm b$ can be written as

$$S=A+By+C\cos\left(\frac{\pi y}{2b}\right)\cos(\omega_1 t) \quad \text{at} \quad x=0, \tag{5}$$

where A, B and C are constants. This boundary condition crudely approximates the situation for the annual variation of salinity, associated with the annual variation of fresh water discharge from the Yangtze River, at the upstream of the Tsushima Current. The solution of (4) and (5) is (Defant, 1961, p. 156)

$$S=A+By+C\exp\left(-\frac{\pi^2Kx}{4b^2U}\right)\cos\left(\frac{\pi y}{2b}\right)\cos\left[\omega_1\left(t-\frac{x}{U}\right)\right]. \qquad (6)$$

This solution shows that the amplitude decreases exponentially with x and the phase delays linealy with x by $\omega_1 x/U$.

Although the simple analytic solution (6) does not necessarily agree exactly with reality, it gives insights on the salinity variations in the regions considered. A rather rapid decrease of the amplitude in the East Sea from Tsushima to Ullung Island shown in Fig. 2 is resulted due to lateral diffusion of salinity and a widening of the width of the Tsushima Current. The phase of salinity variation delays with the downstream distance (Fig. 3). The fact that the delay of phase with downstream distance in the South Sea is smaller than that in the East Sea suggests that the current speed in the South Sea is faster than that in the East Sea. A particularly early occurrence of salinity variation in the Korea Strais is due to the local influence of fresh water discharge by the Nakdong River. A more pronounced phase delay at 30m than at the sea surface is resulted because the current speed at 30m is slower than that at the surface.

CONCLUSIONS

In this paper we presented the mean and annual variation of salinity in the seas neighbouring to Korea and discussed the associated physical processes. The mean salinity in the seas adjacent to Korea is lower than that in the open sea mainly due to fresh water discharge from rivers and the horizontal advections of low salinity water. The local flux of fresh water across the sea surface, associated with precipitation and evaporation, gives a significant influence on the annual variation of salinity, but its effect on the annual mean salinity is negligible. The mean salinity at the sea surface is 0.2 to 0.5‰ lower than that at 30m. Although the fresh water discharge into the Yellow Sea by the Huangho, the Han River, etc. is much smaller than that into the East China Sea by the Yangtze River, the mean salinity in the Yellow Sea is very low because the recycling time of seawater is relatively long in the Yellow Sea. The amplitude of annual salinity variation is largest in the South Sea, and it decreases gradually with the downstream distance of the Tsushima Current in the East Sea.

The amplitudes at the sea surface are 1.8‰ near Cheju Island, 1.4‰ near Tsushima and 0.8‰ near Ullung Island. The amplitudes at 30m are only about one half of those at the sea surface. In the West Sea the amplitudes at the sea surface and at 30m are less than 0.5‰ and 0.2‰, respectively. In the South and East Seas the phase of annual salinity variation shows a systematic delay with the downstream distance of the Tsushima Current. The delay in phase with distance in the East Sea is more rapid than in the South Sea because the current speed in the East Sea is slower than in the South Sea. The phase at 30m is delayed behind that at the sea surface, and the degree of delay increases with the downstream distance of the Tsushima Current in the East Sea. This suggests that the advection of low salinity at the sea surface is more rapid than that at 30m, because the current speed at the surface is faster than that at 30m. The annual variations of salinity in the neighbouring seas of Korea are caused mainly due to annual variations in the local fresh water flux across the sea surface and those in the fresh water discharge from the Yangtze River.

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