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Seasonal Variation of Surface Temperatures in the Neighbouring Seas of Korea

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韓國周邊 海洋表面水温의 季節的 變化

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Abstract: The seasonal variation of sea surface temperatures (SST) in the neighbouring seas of Korea was studied performing the harmonic analysis of the monthly mean SST data of 15 years (1961~1975) at 182 stations routinely collected by the Fisheries Research and Development Agency. The mean SST in the West Sea (Yellow Sea) is lower than that in the East Sea (Sea of Japan) whereas the annual range of SST in the West Sea is much larger than that in the East Sea. The maximum SST occurs between mid August and early September. The seasonal variation of SST in the seas of Korea is influenced by incoming radiation and heat advections by ocean currents and winds.

要約: 15년간 (1961~1975) 182정점에서 정기적으로 관측된 수산진흥원 자료를 조화분석함으로써 한국주변해양 표면수온의 계절적 변화를 연구하였다. 서해 평균수온은 동해에서보다 낮으나, 서해수온의 년교차는 동해에서보다 훨씬 크다. 한국주변해양의 최대 표면수온은 8월 중순부터 9월 초순 사이에 나타난다. 본 논문에서는 한국주변해양 표면수온의 년변화에 대한 물리적 원인을 규명하고, 특히 태양복사 에너지뿐만 아니라 해류와 기류에 의한 열의 이류가 표면수온에 미치는 영향을 고찰하였다.

INTRODUCTION

The sea water temperatures in the neighboring seas of Korean Peninsula have been regularly measured since 1961 by the Fisheries Research and Development Agency (FRDA). In spite of the continuous and systematic data collection, most previous studies on the sea water temperatures were limited to the harmonic analysis of temperature at coastal stations (Gong, 1968; Lim, 1972; Kim, 1983), or to the mapping of sea water temperatures of selected months (Kang, 1971; Marizuru Marine Observatory, 1972; FRDA, 1979). A comprehensive representation of the seasonal temperature variations of the off-shore waters of Korea has not yet been reported, perhaps, due to the uneven coverage of the data in time.

In this paper we study the seasonal variations of the sea surface temperature (SST) by the harmonic method, and discuss the physical mechanisms responsible for the SST variations.

DATA AND METHOD OF ANALYSIS

Monthly normals of SST data averaged over 15 years (1961~1975) were published by the FRDA (1979). The averages of monthly SST, however, are unevenly spaced in time.

Our analysis is based on the data at 182 stations by FRDA (1979), shown in Fig. 1.

We represent the SST by a harmonic function $\hat{T}$ given by

$$\hat{T}(t) = \bar{T} + T_1 \cos(\omega_1 t - \varphi_1) + T_2 \cos(\omega_2 t - \varphi_2), \quad (1)$$

where $\bar{T}$ is the mean SST, T_1 and T_2 the amplitudes of the annual and semi-annual vari-

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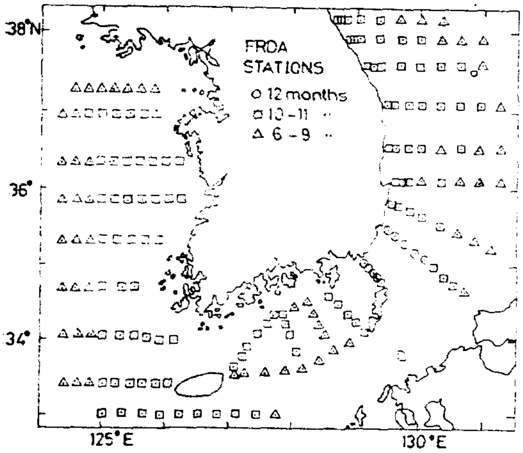

Fig. 1. Oceanographic stations of the FRDA. The numbers of month with available SST data at each station marked by triangles, squares and circles are 6 to 9, 10 to 11, and 12 months, respectively.

ations, respectively, ω_1 and ω_2 the angular speeds, 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. Eqn. (1) can be written as

$$\hat{T}(t)=x_1+x_2\sin\omega_1 t+x_3\cos\omega_1 t+x_4\sin\omega_2 t+x_5\cos\omega_2 t, \tag{2}$$

where $X=(x_1,x_2,x_3,x_4,x_5)=(\bar{T},\ T_1\sin\varphi_1,\ T_1\cos\varphi_1,\ T_2\sin\varphi_2,\ T_2\cos\varphi_2)$.

The coefficient vector X can be found by minimizing the squared error function E given by $E=\sum_t[T(t)-\hat{T}(t)]^2$, where the summation applies only for the month with available observed SST, $T(t)$. The minimization condition, $\partial E/\partial x_i$ $(i=1$ to $5)$ yields 5 linear equations for 5 knowns, $x_i (i=1$ to $5)$. The resultant equations can be written in a matrix equation as

$$AX=B. \tag{3}$$

The elements of the matrix A and the vector B are given by $A_{ij}=\sum_t f_i(t)f_j(t)$, $B_i=\sum_t T(t) f_i(t)$, where $(f_1,f_2,f_3,f_4,f_5)=(1,\sin\omega_1 t,\cos\omega_1 t,\sin\omega_2 t,\cos\omega_2 t)$. The coefficient vector X in equation (3) can be found by numerical method (e.g., Connor and Brebbia, 1976, p. 83). The mean, amplitude and phase are computed from X by $\bar{T}=x_1$, $T_1=\sqrt{x_2^2+x_3^2}$, $\varphi_1=\tan^{-1}(x_2/x_3)$, $T_2=\sqrt{x_4^2+x_5^2}$, $\varphi_2=\tan^{-1}(x_4/x_5)$.

The method of harmonic analysis discussed above can be effectively applied for the time series with data gaps. Fig. 2 shows the harmonic fitting (solid curves) of the unequally spaced monthly SST data (dots) at two stations.

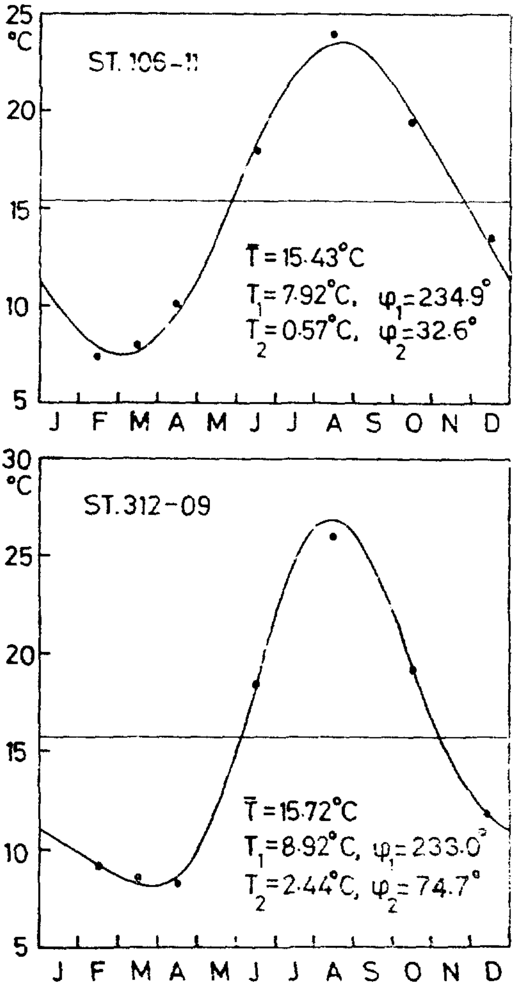

Fig. 2. Harmonic curve fits based on irregulary spaced SST data (dots) at FRDA Station 106-11 and at Station 312-09. Fitted curves in °C of the upper and lower figures are $T(t)=15.43+7.92\cos(\omega_1 t-234.9°)+0.57\cos(\omega_2 t-32.6°)$ and $T(t)=15.72+8.92\cos(\omega_1 t-233.0°)+2.44\cos(\omega_2 t-74.7°)$, respectively.

RESULTS

The distribution of mean SST is shown in Fig. 3. The mean SST in the West Sea (the Yellow Sea) is about 3°C lower than that in the East Sea (the Sea of Japan) at the same laitudes. In the South Sea the mean SST increases with distance from the coast. The mean SST at the vicinity of coast is generally lower than that in off-shore regions.

Fig. 4 shows the amplitudes of annual SST variation. The annual amplitudes of 8 to 10.5°C in the West Sea are much larger than those of 5 to 8°C in the East and South seas.

The phases of annual SST variation are mapped in Fig. 5, showing that the maximum annual SST in the seas of Korea occurs between Angust 18 (228°) and September 3 (242°). The phase of annual SST variation in the West Sea is from 228 to 238° and that in the East Sea is from 232 to 242°. This means that the maximum SST in the West Sea leads that in the East Sea by approximately 4 days.

The amplitudes of semi-annual SST variations (Fig. 6) are less than 2°C. The semi-annual amplitudes in the West Sea are larger than those in the East and South seas. The phases of the semi-annual SST are not shown because the amplitude is low (less than 2°C) and phase distribution does not show any systematic pattern. The semi-annual amplitudes are much smaller than annual ones, but the magnitude of semi-annual amplitude can be a 'measure' of the distortion of SST from a simple sinusoidal variation, as can be noted by comparing SST variation at two stations in Fig. 2.

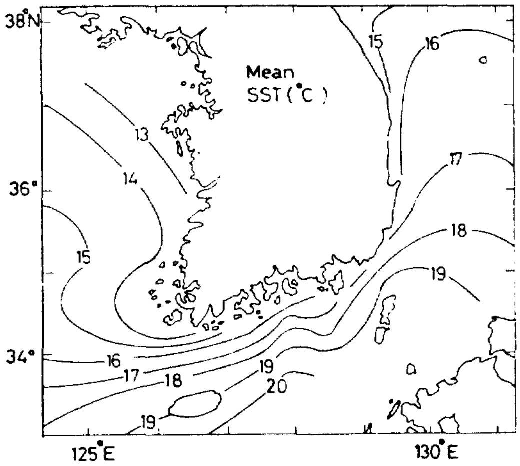

Fig. 3. The mean SST (°C) distribution.

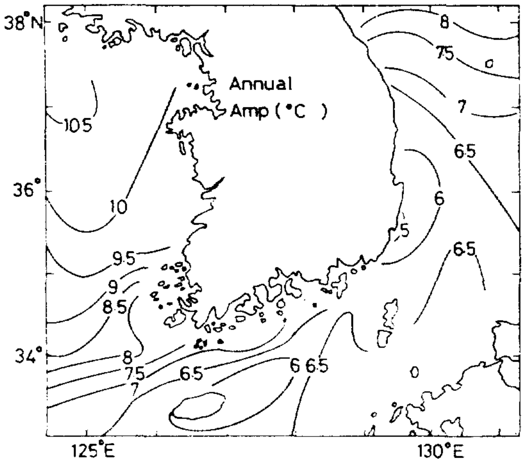

Fig. 4. Amplitude (°C) of annual SST variation.

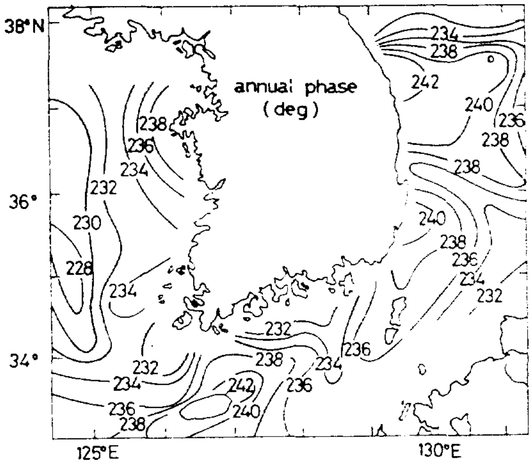

Fig. 5. The phase of annual SST variation. The phase of 240° means that the maximum SST occurs on September 1.

DISCUSSION AND CONCLUSIONS

The annual variation of SST depends primarily on the annual variation of the incoming radiation. In the seas adjacent to Korea, however, the SST is significantly influenced by the heat advected by the Asian Monsoon and ocean

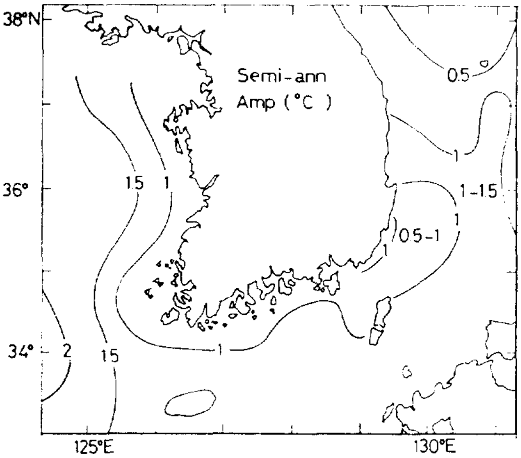

Fig. 6. The amplitude (°C) of semi-annual SST.

currents. The heat advection by the warm currents, such as the Tsushima Current and the Yellow Sea Warm Current, in winter is larger than that in summer because the horizontal gradient of SST along the paths of currents in winter is larger than that in summer (Robinson, 1976). Hence the annual phase of heat advection by currents is almost out of phase from that of the incoming radiation. On the other hand the annual phase of heat advection by the Asian Monson is almost in phase with the incoming radiation because the northerly winter monsoon extracts heat from the sea surface whereas the southerly summer monsoon adds heat onto the sea. The annual average of heat advetion by the Asia Monsoon is negative because the winter monsoon is stronger than the summer monsoon and the meridional gradient of air temperature in winter is stronger than that in summer (Gorshkov, 1976).

Let $J(t)$ be the sum of incoming solar radiation and heat advections by currents and winds. By following the same argument as in Kang (1984), it can be shown that the mean, the amplitude, and the phase of the annual variation of SST are given by

$$\bar{T}=(\bar{J}/\sigma)^{\frac{1}{4}}+\theta \tag{4}$$

$$T_1=J_1/\sqrt{(4\sigma T_0^3)^2+(\omega_1 C)^2} \tag{5}$$

$$\varphi_1=\varphi_J+\tan^{-1}(-\omega_1 C/4T_0^3), \tag{6}$$

where $\bar{T}$ is the absolute mean temperature, T_1 and φ_1 the amplitude and phase of SST, respectively, $\bar{J}$, J_1 and φ_J are respectively the mean, the annual amplitude and the annual phase of $J(t)$, σ the Stefan-Boltzman constant ($\sigma=5.67\times10^{-8}Wm^{-2}K^{-4}$), θ the difference between the actual mean SST and the 'effective' mean SST, T_0, determined by the radiation balance, i.e., $\theta=T-T_0=35$°K (Goody and Walker, 1972, p. 49), and C the effective heat capacity of the ocean per unit area associated with an annual variation of seawater temperature.

The annual average of heat advection by the Tsushima Current and the Yellow Sea Warm Current are larger than zero, but that by the Asian Monsoon is less than zero. Therefore, according to equation (4), the heat advection by warm currents increases the mean SST whereas that by Asian Monsoon decreases the mean SST. Since the annual average of heat advection by the Yellow Sea Warm Current in the West Sea is smaller than that by the Tsushima Current in the East Sea, the mean SST in the West Sea is lower than that in the East Sea (Fig. 3). The relatively low mean SST within a few tens of kilometers from the coast is attributed, in part, to the predominance of the heat advection by the Asian Monsoon over that by the warm currents.

Eqn. (5) shows that the annual amplitude of SST is proportional to the amplitude of the sum of heat inputs by incoming radiation and heat advections. As mentioned above, the annual variation of heat advection by the Asian Monsoon is almost in phase with incoming radiation, but that by the warm currents is out of phase. The annual SST ranges of 10~21°C in the seas of Korea (Fig. 4) are larger than the corresponding values of about 10°C in the North Pacific at the same latitudes (Robinson, 1976). The large range of SST in the seas of Korea arises mainly due to the heat advetion by the Asian Monsoon.

The larger amplitude of SST in the West Sea than in the East Sea (Fig. 4) can be understood from the fact that the seasonal heat advection by the Yellow Sea Warm Current in the West Sea is smaller than that by the Tsushima Current in the East Sea. A particulary low amplitude of about 5°C near the southeast coast of Korea in the East Sea is asociated with an appearance of cold water masses in that region in summer (An, 1974).

The maximum SST in the neighbouring seas of Korea occurs between mid August and early September (Fig. 5). The maximmum SST in the West Sea occurs a few days before that in the East Sea. The shallowness of the West Sea may be one of the possible causes of a larger annual range and an earlier occurrence of the maximum SST, because the smaller the capacity, the larger the annual range and the earlier the phase (Kang, 1984).

The SST in the regions considered depends not only on incoming radiation but also on heat advections by winds and ocean currents. The heat advection by the Asian Monsoon decreases the mean SST and increases the annual range of SST. The heat advection by warm currents, such as the Tsushima Current and the Yellow Sea Warm Current, increases the mean SST and decreases the annual range of SST. The higher mean SST and smaller range of SST in the East Sea (the Sea of Japan) than in the West Sea (the Yellow Sea) are resulted mainly from the fact that the heat advection into the East Sea by the Tsushima Current is more pronounced than that into the West Sea by the Yellow Sea Warm Current.

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