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Seasonal Variation of Heat Content in the Neighbouring Seas of Korea

Yong Q. Kang
Department of Oceanography, National Fisheries University of Pusan, Pusan 608, Korea

韓國 周邊 海洋 貯熱量의 季節的 變動

姜容均
釜山水產大學 海洋學科

Abstract: Seasonal variations of heat content in the neighbouring seas of Korea are estimated from the bimonthly normals of seawater temperature in the upper 300m for 15 years (1961~1975) at 192 stations. The heat is seasonally stored mainly in the upper 100m layer in the East Sea and in the whole water column in the West and South Seas of Korea. The annual range of heat content changes in the West Sea is almost the same as that in the East Sea. The annual phase of heat content variation lags behind that of sea surface temperature variation by one to three months. Due to the seasonal advections of heat by currents and winds, the annual amplitude of heat storage rate in the neighbouring seas of Korea is much larger than that of incoming radiation.

要約: 한국주변 192개 정점 표층 300m의 15년간(1961~1975) 격월 수온자료를 사용하여 해양이 보유(방출)하는 영량의 계절적인 변동을 추정하였다. 동해에서는 100m 이내의 표층에서 계절적인 열의 보관과 방출이 일어나며, 수심이 얕은 서해와 남해에서는 거의 전 수심에 걸쳐서 계절적인 열 보유량 변동의 연교차는 서해와 동해가 비슷하나, 열보유량 변동은 표면수온에 비하여 연주기 위상이 1내지 3개월 늦다. 해류와 계절풍에 의한 열이송으로 인하여 한국주변 해양 저열량의 시간적 변화의 연진폭은 태양복사에너지의 연진폭보다 훨씬 크다.

INTRODUCTION

The oean, due to it. large heat capacity, plays an important role in moderating the climate (Kang, 1983, 1984a). The excess heat gained in summer is stored in the upper layer of the ocean and is returned to the atmosphere in winter. As demonstrated quantitativety by Kang (1984b), the heat content and its change rate in the ocean are important in determining the exchange of heat across the sea surface by sensible and latent heats. Due to proximity to seas, the seasonal variational variation of air temperature in coastal regions of Korea is significantly modified by the annual variation of sea surface temperature (Kang, 1984c).

The seasonal storages of heat in the East China, the Yellow, and the Japan Seas depend not only on local flux of heat across the sea surface but also on advections of heat by ocean currents and prevailing winds (Kang, 1985). In the Japan Sea, the seasonal storage rate of heat, inferred from the heat budget, is larger than the seasonal variation of incoming radiation (Maizuru Marine Observatory, 1972). In this paper, I present the maps for seasonal variation of heat content in the neighbouring seas of Korea, which are estimated from the seasonal variations of temperature in the upper 300m of the seas.

DATA AND METD

The heat content in the neighbouring seas of Korea is computed from the bimonthly normals of sea water temperature for 15 years (1961~1975) in the upper 300m (or the whole water column in shallow regions) of 192 stations. The temperature data was taken from the publication by Fisheries Research and Development Agency of Korea (1979). In regions shallower than 300m, the heat content is computed from the temperature data in the whole water column. The 12 standard depths in the upper 300m layer are 0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, and 300m.

The annual variation of sea water temperature is limited in the upper 100m or so, and the annual range of temperature variation decreases exponentially with depths (Dietrich et al, 1980, p. 186). The e-folding depths for annual variation of water temperature at each station is determined by fitting the root-mean-square (RMS) amplitudes of temperature variation in the upper 100m to an exponential function

$$A(z)=A_o \exp(-z/z_e), \qquad (1)$$

where $A(z)$ is the RMS amplitude, z the depth, A_o a constant, and z_e an e-folding depth.

The heat content, Q, per unit area in the upper 300m of each station and month is computed by the trapezoidal integration of

$$Q=\int_{o}^{300m} \rho C_p T(z)\,dz, \qquad (2)$$

where ρ is the density of sea water, C_p the specific heat, and $T(z)$ the temperature in Celsius. At stations shallower than 300m, the integration was done from the bottom to the sea surface.

The seasonal variations of heat content in the regions considered are studied by fitting the bimonthly normals of heat content at each station to a harmonic function

$$Q(t)=Q_0+Q_1\cos(\omega t-\phi_1)+Q_2\cos(2\omega t-\phi_2), \qquad (3)$$

where Q_0 is the mean of heat content, Q_1 and Q_2 the annual and semi-annual amplitudes, ϕ_1 and ϕ_2 the annual and semi-annual phases, and ω the annual angular frequency. The 5 parameters Q_0, Q_1, Q_2, ϕ_1, and ϕ_2 are determined by the method of harmonic analysis discussed by Kang and Jin (1984). The rates of seasonal storage and release of heat in the ocean can be studied without considering the mean value, Q_0.

Similarly, the sea surface temperature is fitted by an analogous harmonic function. The 'effective' depth of mixed layer, D, which is defined by the thickness of water column of uniform tem perature associated with annual variation of annual heat content change, is determined by

$$D=Q_1/(\rho C_p T_1), \qquad (4)$$

where T_1 is the annual amplitude of sea surface temperature.

RESULTS

Fig. 1 shows the e-folding depths assocciated with an exponential decrease of the RMS amplitude of temperature variation computed from the temperature data in the upper 100m. This figure shows that the e-folding depths are between 40 and 100m, and 100m, and the seasonal variations

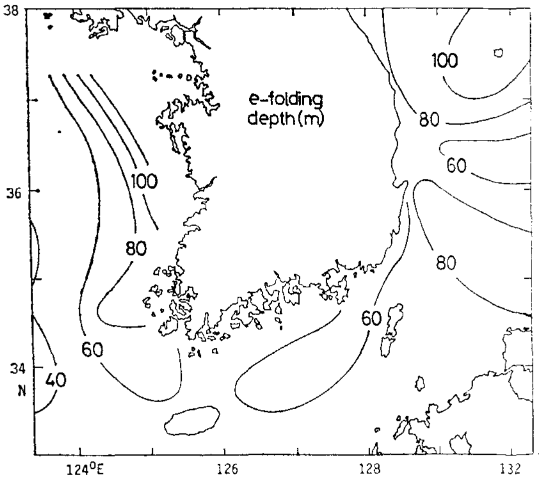

Fig. 1. e-folding depth (meters) for RMS amplitude of sea water temperature variation.

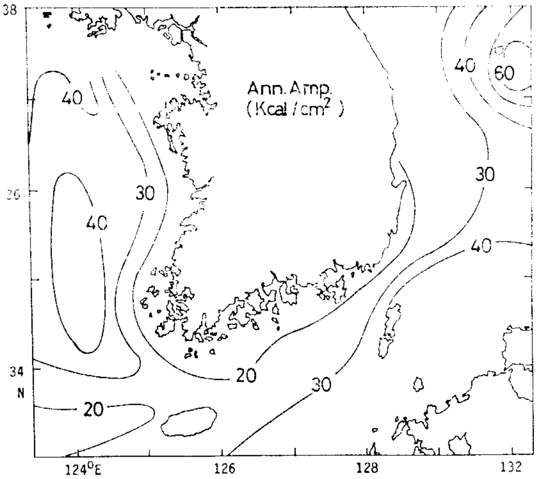

Fig. 2. Annual amplitude (Kcal/cm^2) of heat content variation.

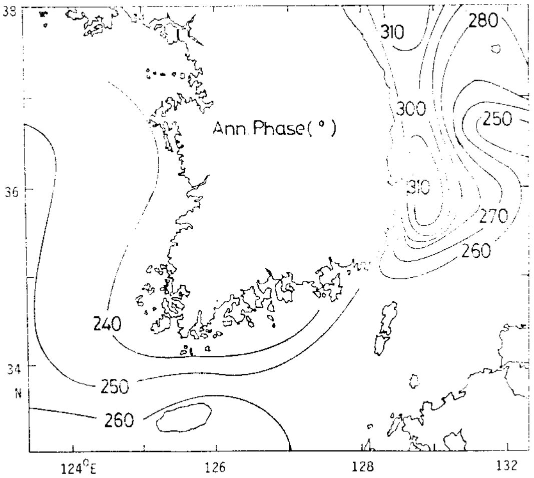

Fig. 3. Annual phase of heat content varition in degrees referred to January 1.

of seawater temperature in the neighbouring seas of Korea occur basically within the top 100m layer. A large magnitude of e-folding depth more than 100m in the coastal region of the Yellow Sea indicates that the temperature changes in a very shallow sea are almost uniform throughout the whole water column.

Fig. 2 shows the distribution of the annual amplitudes of heat content changes in the upper 300m (or in the whole water colnme in areas shallower than 300m). The annual amplitudes of heat content change are 20~40 Kcal/cm^2 in the West (Yellow) and South Sea and 20~60 Kcal/cm^2 in the East (Japan) sea. In shallow coastal regions the annual amplitude is less than 20 Kcal/cm^2.

Fig. 3 shows the annual phase of heat content change referred to January 1. The heat content in the West and South Seas are maximal from the beginning to the mid of September (240~260°). The phase of heat content in the East Sea shows a large spatial variability. In coastal regions within 30 miles from the east coast of Korea the heat content is maximal in early November (300~310°) whereas in offshore regions it is maximal from early September to the mid of October (250~290°).

The semi-annual amplitudes of the variation of heat content, shown in Fig. 4, are less than 5Kcal/cm^2 in the West and South Sea and between 5 and 20kcal/cm^2 in the East Sea. The magnitude of semi-annual amplitude is 10 to 30 percent of the annual amplitude. The semi-annual phase varies irregularly in space (figure not shown).

The seasonal variation of heat content generally lags behind that of sea suface temperature. Fig. 5 shows the difference between the annual phase of heat content and that of sea surface

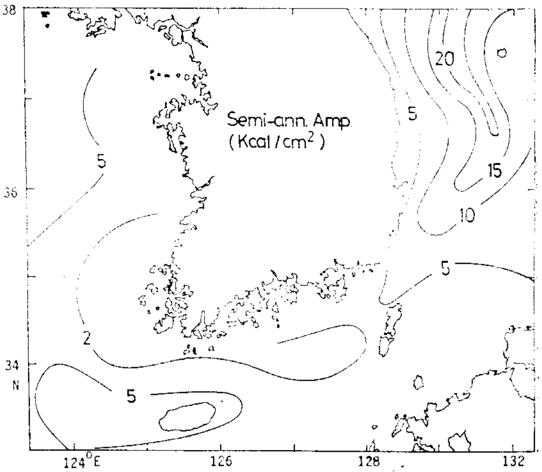

Fig. 4. Semi-annual amplitude (Kcal/cm^2) of heat content variation.

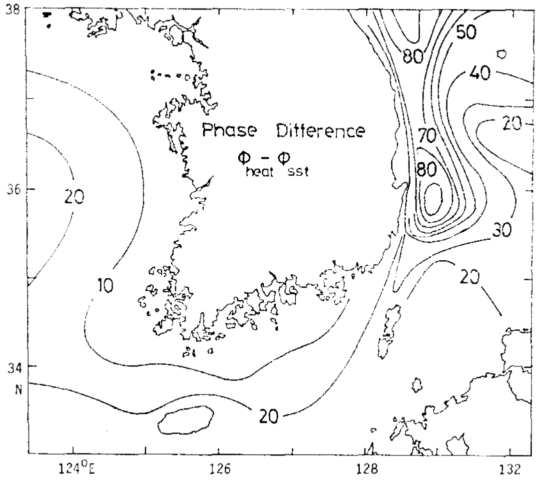

Fig. 5. Phase difference (degrees) between the annual variations of heat content and sea surface temperature.

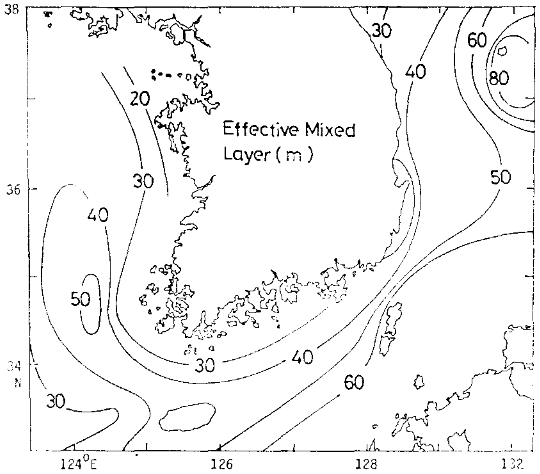

Fig. 6. Effective mixed layer (meters) associated with annual variation of heat content.

temperature. In the West and South Seas the phase difference is less than one month, and it generally increases with the distance from the coast. In the East Sea, on the other hand, the phase difference shows a pronounced spatial variability. In offshore regions over 50 miles from the east coast of Korea the phase difference is 20 to 50 days. However, a particularly large phase difference of about 3 months is found in a zone at distance about 20 miles from the east coast of Korea.

Fig. 6 shows the effective thickness of surface mixed layer computed by (4). The effective mixed layer in the West Sea is 20 to 50m and they are comparable to the depth of the sea. The effective mixed layer in the South Sea is from 30 to 60m. The effective mixed layer of 30 to 60m in the East Sea is similar to that in the South Sea, except a particularly large value up to 80m is found near Ullung Island (upper-right corner of the figure). Fig. 6 suggests that the magnitude of seasonal storage of heat in the West Sea is not small compared to that in the South or East Seas of Korea.

DISCUSSION AND CONCLUSIONS

The seasonal storage of heat in the neighbouring seas of Korea is analyzed by harmonic method. The amplitude of annual variation of heat content in the neighbouring seas of Korea is 20 to 40Kcal/cm^2. In regions close to the coast the annual amplitude is limited by the shallowness of water column. The annual amplitude in the West Sea are about the same as that in the East or South Seas. So far as seasonal storage of heat is concerned, the West Sea is not a shallow sea. Annual amplitude of heat content and effective mixed layer depth in the West Sea are comparable to those in the East Sea.

The annual variation of heat content in the regions within 50miles from the east coast of Korea has a peculiar feature. The amplitudes are relatively small and the phases are considerably delayed compared to other parts of the East Sea. A particularly large amplitude is found in a region around Ullung Island in the East Sea. The spatio-temporal inhomogeneity of seasonal heat storage in the East Sea seems to be related with heat advections of which details are not well posed yet.

For a seasonal variation of heat content given by (3), the heat storage rate or the change rate of heat content is given by

$$dQ/dt = -\omega Q_1 \sin(\omega t - \phi_1) - 2\omega Q_2 \sin(2\omega t - \phi_2). \quad (5)$$

For an annual amplitude of heat content change of 30Kcal/cm^2 (see Fig. 2), the annual amplitude of heat storage rate ωQ_1 is 15kcalcm^{-2} month^{-1}, This figure is much larger than the annual variation of incoming solar radiation. The average annual amplitude of incoming radiation reaching onto the Japan Sea is about 4Kcal cm^{-2} month^{-1} (Maizuru Mar. Obs., 1972). If there were no advection of heat by ocean current or winds, the amplitude of heat storage rate in the ocean cannot exceed that of incoming radiation (Kang, 1984a). The heat storage rates in the neighbouring seas of Korea are a few times larger than that of incoming radiation, and this fact suggests that heat advection plays a significant role on the annual variation of heat content in the neighbouring seas of Korea.

The seasonal variation of heat in the neighbouring seas of Korea can be summarized as follows. The seasonal storage of heat occurs basically in the top 100m in the East Sea and in almost the whole water column in the West Sea of Korea. The magnitude of seasonal storage and release of heat in the West Sea are about the same as those in the East Sea. The heat content in the West and South Sea are maximal in September and that in the East Sea is maximal in September, October, or November. The phase difference between the variations of sea surface temperature and heat content is less than one month in the West and South Seas and up to 3 months in the East Sea. The seasonal variation of heat content in the East Sea shows a pronounced spatial inhomogeniety. Although the West Sea is a shallow sea, the seasonal storage of heat in the West sea is about the same as that in the East Sea and the effective thickness of mixed layer in both seas are almost the same. The rate of change of heat content in the neighbouring seas of Korea is much larger than the annual variation of incoming radiation, and this fact suggests that the heat advections are important for the variations of heat content in the neighbouring seas of Korea.

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