Bull. Korean Fish. Soc. 17(6), 557～565, 1984　　韓水誌 17(6), 557～565, 1984

Year-to-Year Fluctuations of Seasonal Variation of Surface Temperature in the Korea Strait

Yong Q. KANG and Byung Don LEE
Department of Oceanography, National Fisheries University of Pusan,
Namgu, Pusan, 608 Korea

The year-to-year fluctuations of seasonal variation of sea surface temperatures (SST) in the Korea Strait are studied based on monthly SST data for more than 50 years at Mitsushima and Okinoshima in the strait. The frequency distribution of SST has two peaks at temperatures below and above the multi-year average, but that of SST anomalies has only one peak at the zero anomaly. More than 95% of the anomalies are in the range of ±2°C. The harmonic constansts of seasonal SST variation vary from year to year. The standard deviations of annual means, annual amplitudes, and semi-annual amplitudes are less than 1°C, and those of the annual and semi-annual phases are about 5° and less than 50°, respectively. The SST in the Korea Strait have a tendency to decrease their amplitudes as the annual means increase. Physical mechanisms responsible for the analyzed results are discussed in this paper.

Introduction

The seasonal variation of sea surface temperatures (SST) is usually represented, by means of the harmonic analysis, in terms of annual and semi-annual amplituudes and phases. The seasonal variation of SST in the East China Sea and in the North pacific Ocean were studied by Koizumi (1962) and Wyrtki (1965), respectively. The seasonal variations of SST in the seas adjacent to Korea were studied by means of harmonic analysis by Gong (1968), Hahn (1970a, b), Kano (1980), and Kang and Jin (1984). Harmonic analyses of SST in those studies were based on the monthly normals of SST.

The seasonal variation accounts for the most part of variance of SST. However, the seasonal variations themselves change from year to year. In this paper, the year-to-year fluctuations of the seasonal SST variation in the Korea Strait are investigated based on the monthly SST data continuously recorded for more than 50 years at two stations in the strait.

Data and Method of Analysis

This paper is based on the monthly SST data of 56 years (1914-1969) at Mitsushima (34°43′N, 129°27′E) and of 52 years(1914-1965) at Okinoshima (34°14′N, 130°07′E) in the Korea Strait, as shown in Fig. 1. The monthly SST at the two stations were published by Hahn (1970b). Some missing data at Okinoshima were interpolated by averaging the SST at the same months of the preceeding and the next years. The arithmatic means of SST for each of the 12 months over the record period of 56 and 52 years were taken as the monthly normals at Mitsushima and Okinoshima, respectively. The SST anomalies are the deviations of actual SST from the monthly normals.

The SST, T(t), of each year at each station is represented by a superposition of annual and semi-annual harmonics by

$$T(t)=\bar{T}+A\cos(\omega t-\phi)+A'\cos(2\omega t-\phi'), \quad (1)$$

where $\bar{T}$ is the annual mean of SST, ω the annual

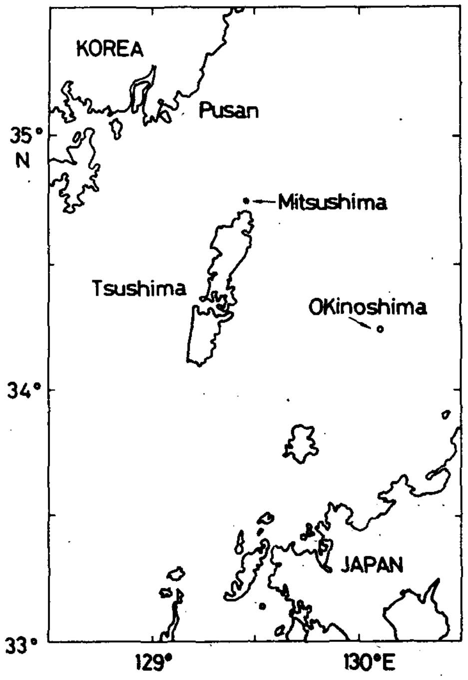

Fig . 1. Locations of Mitsushima and Okinoshima

angular speed, t the time from January 1, A and A' the amplitudes of annual and semi-annual variations, respectively, and ϕ and ϕ' the corresponding phases. The parameters, $\bar{T}$, A, A', ϕ, and ϕ', of each year were determined by the least squares fit of (1) to the data. Details of the least squares fit method were discussed by Kang and Jin (1984). Higher harmonics are neglected in (1), because their amplitudes are negligibly small. The correlations among the annual means, amplitudes, and phses are examined by means of the regression analysis. The correlation coefficient, r, between two sets of data x_i and y_i $(i=1,2,\cdots,N)$, with corresponding means of $\bar{x}$ and $\bar{y}$, is computed by

$$r=\sum(x_i-\bar{x})(y_i-\bar{y})/[\sum(x_i-\bar{x})^2\sum(y_i-\bar{y})^2]^{1/2}, \tag{2}$$

where $\sum$ stands for the summation over i from $i=1$ to N. The constants a and b of the linear regression curve $y=ax+b$ are determined by the least squares fit which minizes the function $\mathcal{E}$ defined by

$$\mathcal{E}=\sum(y_i-a-bx_i)^2. \tag{3}$$

Also, the fluctuations of SST and SST anomalies at Mitsushima and Okinoshima are compared by the regression analysis.

Results

1. Normals and Anomalies

Fig. 2 shows the monthly normals and standard deviations of SST at Mitsushima and Okinoshima over 56 and 52 years, respectively. Fig. 2 shows that the SST varies more rapidly in summer than in winter. The standard deviations of monthly SST of about 1.3°C in winter are larger than those of about 0.9°C in summer.

Fig. 3 shows the frequency distribution of SST at the two stations. Note that the maximum frequencies are found not at the mean SST but at temperatures about 5°C higher or lower than the mean

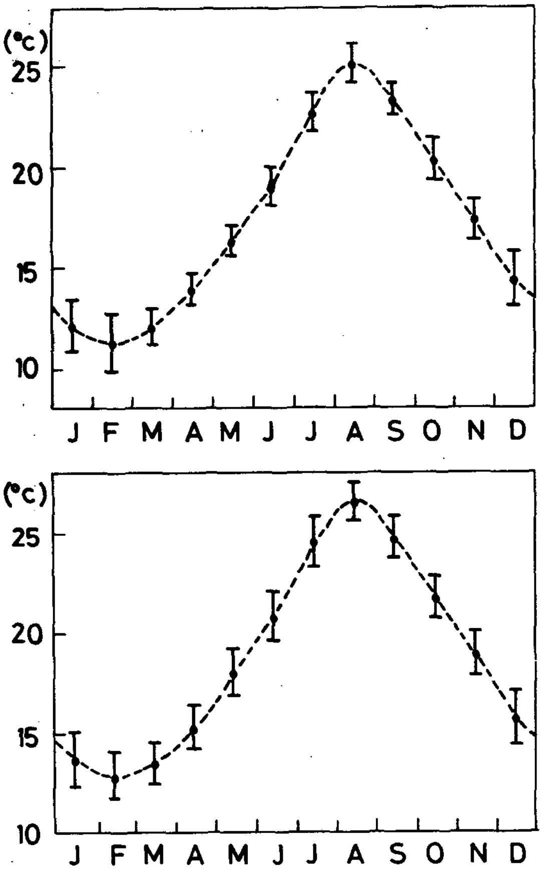

Fig. 2. Monthly normals of SST, with standard deviations, at Mitsushima and Okinoshima. The mean temperature at each station is shown by an arrow

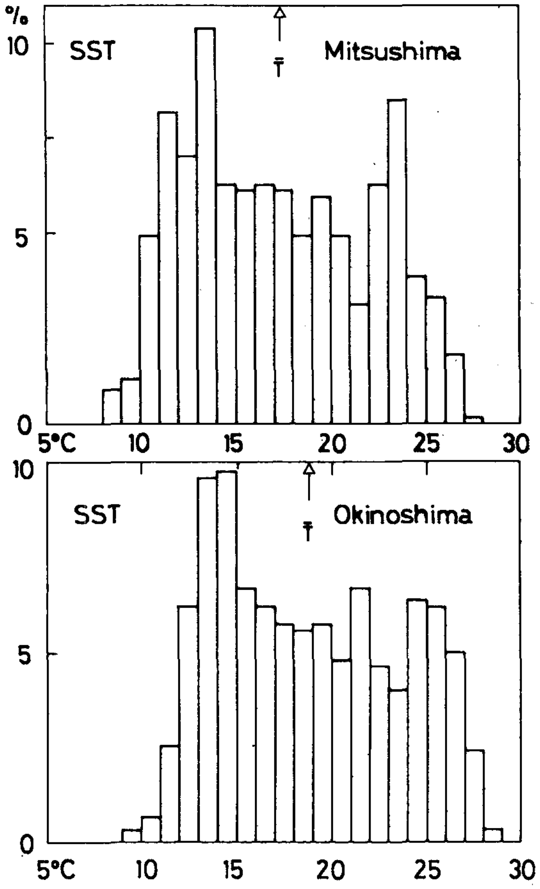

Fig. 3. Frequency distributions of SST at Mitsushima and Okinoshima

SST. On the other hand, the frequency distribution of SST anomalies, shown in Fig. 4, are almost symmetric with respect to the zero anomaly. More than 95% of the SST anomalies are within the range of ±2°C.

The SST at Mitsushima and Okinoshima are strongly correlated, as shown by the scatter diagram between them for 52 years (624 months) in Fig. 5. The linear regression curve between them determined by the least squares fit is $T_M = -0.51 + 0.95\ T_0$, where T_M and T_0 are the SST at Mitsushima and Okinoshima, respectively. This suggests that an increase of SST by 1°C at Okinoshima is associated with that of 0.95°C at Mitsushima.

The correlation between the SST anomalies at Mitsushima and Okinoshima is shown in Fig. 6. The correlation coefficient between them is 0.33. Since the probability of the correlation coefficient between 624 pairs of uncorrelated parent population to

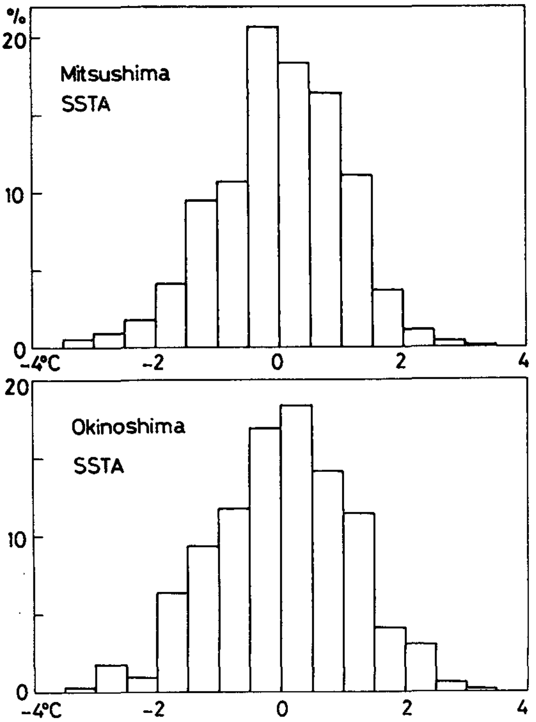

Fig. 4. Frequency distributions of SST anomalies at Mitsushima and Okinoshima

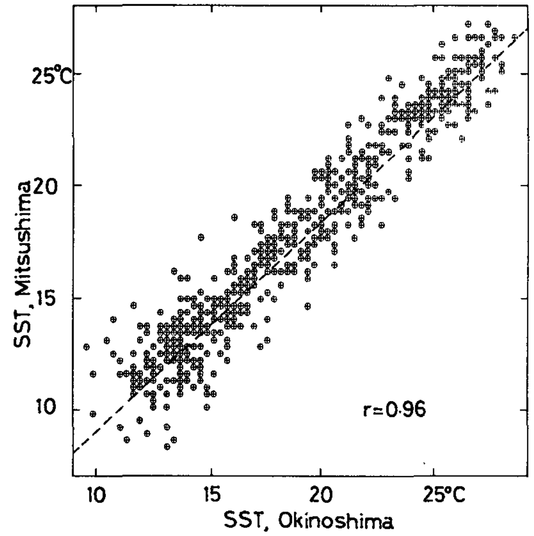

Fig. 5. Scatter diagram between SST at Okinoshima (x-axis) and at Mitsushima (y-axis)

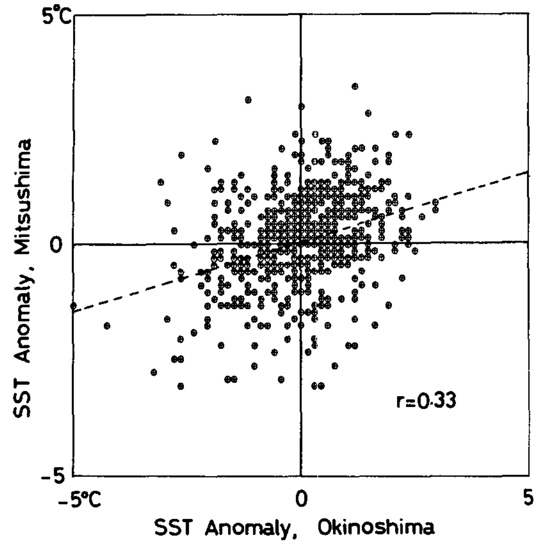

Fig. 6. Scatter diagram between SST anomalies at Okinoshima (x-axis) and at Mitsushima (y-axis)

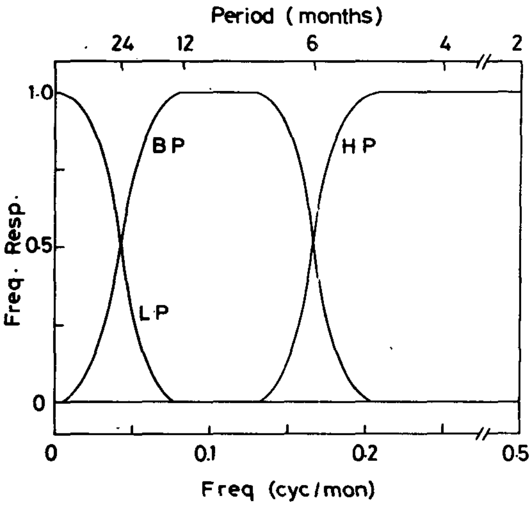

Fig. 7. Frequency response of low-, band-, and high-pass filters applied to the SST anomaly series

exceed 0.33 is less than 0.1%, the SST anomalies at Mitsushima and Okinoshima are statistically correlated at 0.1% level (Bevington, 1965). However, the "degree" of correlation for SST anomalies between two station is much lower than the corresponding one for actual SST which includes seasonal variations.

The frequency dependency of correlation between SST anomalies at Mitsushima and Okinoshima is studied by computing the correlation coefficients of low-, band-, and high-passed anomaly series separately. The symmetric convolution filter applied to the SST anomaly series has 24 weights on both sides, and Hamming window is applied to reduce Gibb's phenomena (Kim and Kang, 1984). The frequency response of the filters used are shown in Fig. 7. The correlation coefficient beween long period anomalies (periods longer than 2 years) at Mitsushima and Okinoshima is only 0.18. On the other hand, the correlation coefficients of intermediate periods (periods between 6 months to 2 years) and of short periods (periods shorter than 6 months) are 0.37 and 0.35, respectively. These indicate that the short period anomalies with periods less than 2 years are more correlated than the long period anomalies with periods longer than 2 years.

2. Harmonic Constants

The SST of each year for 56 years at Mitsushima are harmonically fitted by Eq. (1), and the year-to-year fluctuations of harmonic constants are shown in Fig. 8. The means and standard deviations of harmonic constants of SST at Mitsushima are:

$\overline{T}=17.37\pm0.57$ (°C)
$A=6.47\pm0.60$ (°C)
$\phi=229.4^\circ\pm5.0^\circ$
$A'=0.78\pm0.33$ (°C)
$\phi'=104.5^\circ\pm35.1^\circ$.

Similarly, the year-to-year fluctuations of harmonic constants at Okinoshima are shown in Fig. 9. The corresponding values at Okinoshima are:

$\overline{T}=18.86\pm0.71$ (°C)
$A=6.47\pm0.55$ (°C)
$\phi=228.3^\circ\pm5.2^\circ$
$A'=0.81\pm0.39$ (°C)
$\phi'=100.6^\circ\pm45.5^\circ$

These show that the seasonal variations of SST vary from year to year. The standard deviations of annual means, annual amplitudes, and semi-annual amplitudes are less than 1°C, and those of annual and semi-annual phases are about 5° and less than

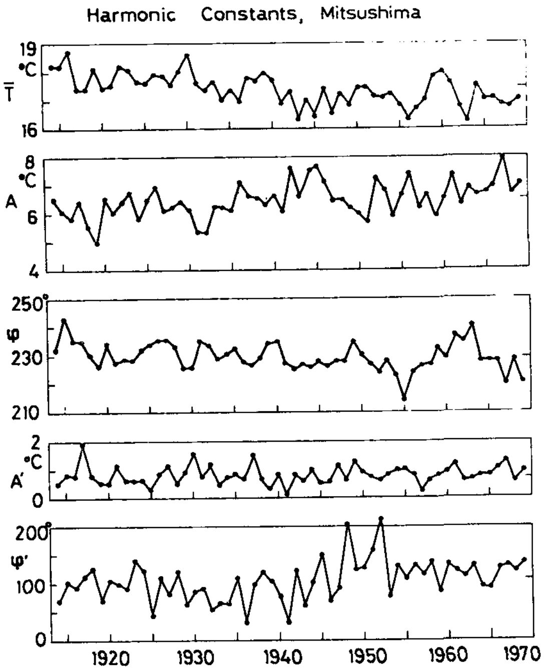

Fig. 8. Year-to-year fluctuations of harmonic constants of SST at Mitsushima for 56 years (1914~1969). $\bar{T}$ is the anual mean, A the annual amplitude, ϕ the annual phase, A′ the semi-annual amplitude, and ϕ' the semiannual phase. The averages of each constants are shown by tickmarks on the right hand side of each figure

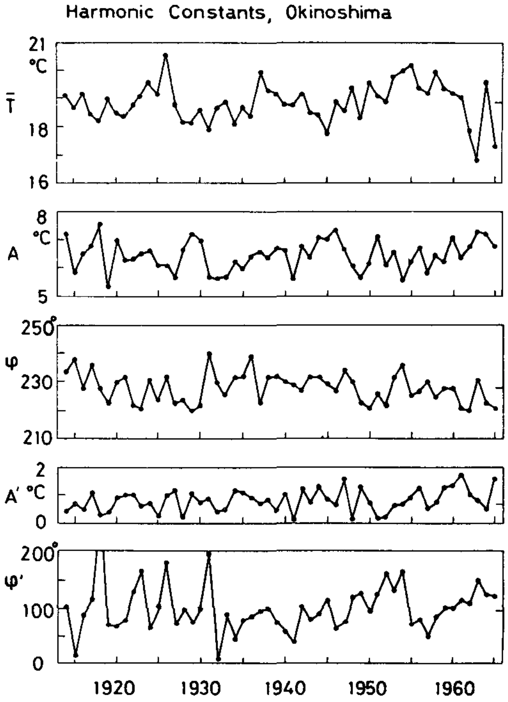

Fig. 9. Year-to-year fluctuations of harmonic constants of SST at Okinoshima for 52 years (1914~1965). Symbols are the same as in Fig. 8

50°, respectively.

Fig. 10 shows the scatter diagram between annual means and amplitudes of SST at Mitsushima. It shows that the annual amplitudes have a tendency to decrease with an increase of mean SST. The same tendency is also found at Okinoshima. The correlation coefficient between annual means and annual amplitudes of SST at Mitsushima for 56 years is −0.41, and that at Okinoshima for 52 years is −0.27. The probabilities of having those correlation coefficient from uncorrelated parent population at Mitsushima and Okinoshima are less than 0.2% and 5%, respectively (Bevington, 1969). The linear regression curve between them shows that an increase of mean SST by 1°C yields a decrease of annual amplitude by 0.43°C at Mitsushima and 0.21°C at Okinoshima.

The annual phases have a tendency to be delayed

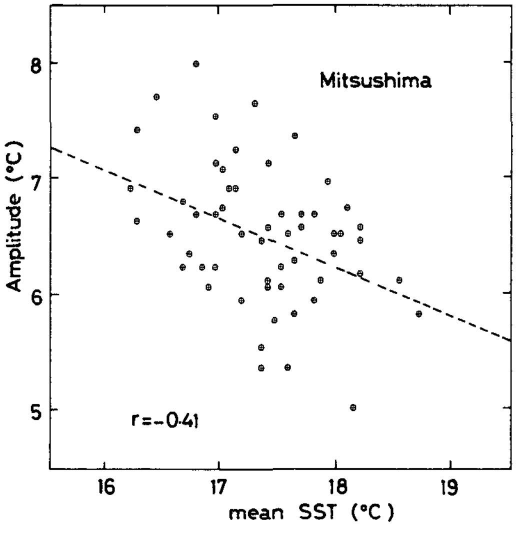

Fig. 10. Scatter diagram between annual means and annual phases of SSS at Mitsushima for 56 years (1914~1969)

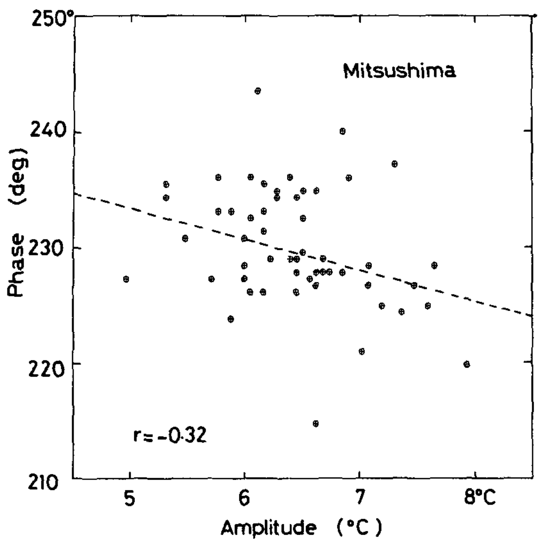

Fig. 11. Scatter diagram between annual amplitudes and annual phases of SST at Mitsushima for 56 years

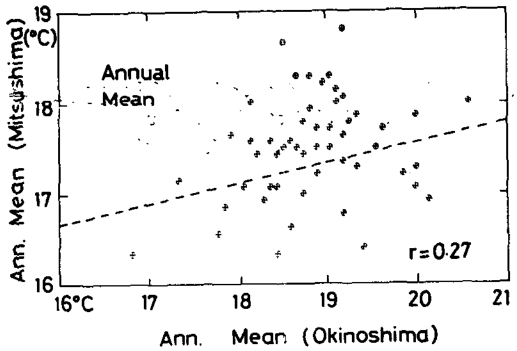

Fig. 12. Scatter diagram between annual averages of SST at Okinoshima (x-axis) and at Mitsushima (y-axis) for 52 years (1914~1965)

as the annual amplitudes increase, as shown by the scatter diagram between them at Mitsushima (Fig. 11). The correlation coefficient of -0.32 between annual amplitude and annual phase at Mitsushima is significant at 2% level, but that of -0.12 at Okinoshima is significant only at 20% level.

Harmonic constants of SST at Mitsushima are positivly correlated with those at Okinoshima. The scatter diagram between annual means of SST at Okinoshima and Mitsushima for 52 years is shown in Fig. 12. Similar diagrams for annual amplitudes, annual phases, semi-annual amplitudes, and semi-annual phases show that all of them between two stations are positively correlated. Fig. 12 shows, among others, the scatter diagram between annual amplitudes at Okinoshima and at Mitsushima. The correlation coefficients of 0.42 for annual amplitudes, 0.46 for semi-annual amplitudes, and 0.41 for semi-annual phases are significant at 0.2% level, and those of 0.27 for annual means and 0.23 for annual phases are significant at 10% level.

Discussion and Conclusions

The SST at Okinoshima approximately represents the SST in the Eastern Channel of the Korea Strait, and the SST at Mitsushima can be a useful indicator for the SST in the Western Channel (Fig. 1). The monthly normals and anomalies of SST at those two stations are analyzed in this paper. Besides, the year-to-year fluctuations of seasonal SST variations are also studied.

The monthly normals of SST at both stations vary rapidly in summer and slowly in winter (Fig. 2). This non-sinusoidal variation arises mainly due to non-uniformity of the depth of surface mixed layer in time. Since the surface mixed layer in summer is shallower than in winter, the effective heat capacity of the ocean in summer is smaller than that in winter and, therefore, the SST vary more rapidly in summer than in winter. The standard deviations of SST from monthly normals are of an order of 1°C.

The frequency distribution of SST has two peaks at temperatures other than the mean SST (Fig. 3). Those two peaks are intrinsically associated with the annual variation of SST. Suppose the SST variations consist of persistent annual variation only, that is, $T(t)=\bar{T}+A\cos(\omega t-\phi)$, where $\bar{T}$, A and ϕ are constant. Since this equation can be written as $\omega t-\phi=\cos^{-1}[(T-\bar{T})/A]$, the time interval δt associated with the temperture difference $\delta T=[T, T+\delta T]$ is

$$\omega\,\delta t=\cos^{-1}[(T+\delta T-\bar{T}/A]-\cos^{-1}[(T-\bar{T})/A]. \tag{4}$$

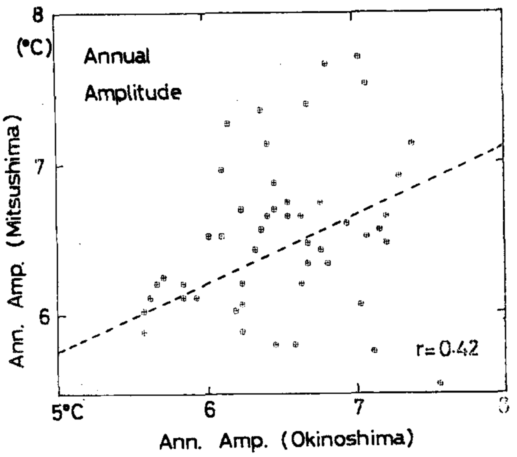

Fig. 13. Scatter diagram between annual amplitudes of SST at Okinoshima (x-axis) and at Mitsushima (y-axis) for 52 years

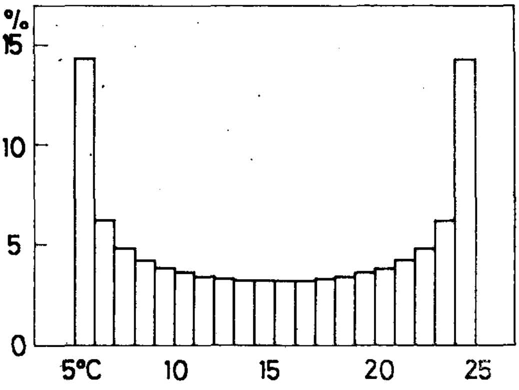

Fig. 14. Frequency distributions of sinusoidally varying SST described by $T(^\circ C)=15+10\cos(\omega t+\phi)$ where ω is the annual angular speed and ϕ an arbitrary constant

Fig. 14 shows the frequency distribution associated with the SST variation in °C specified by $T(t)=15+10\cos(\omega t-\phi)$, where ϕ is an arbitrary constant. The frequency distributions of SST at Mitsushima and Okinoshima, shown in Fig. 3, are not exactly the same as the hypothetical distribution curve of Fig. 14, because the SST variations are slower in winter than in summer, and also because the harmonic constants vary from year to year. In Fig. 3 the peak distribution at temperature below the mean SST is larger than that above the mean, because the SST in winter vary more slowly than in summer and the duration with the SST close to the minimum is longer than that close to the maximum (see Fig. 2). The frequency distribution of SST anomalies, on the other hand, has only one peak at the zero anomaly (Fig. 4). More than 95% of the anomalies are in the range of ±2°C.

The SST variation at Mitsushima and Okinoshima are very closely correlated ($r=0.96$) as shown in Fig. 5, because the seasonal variations of SST are caused mainly by the seasonal variation of incoming radiation which depends primarily on latitudes. However, the correlation coefficient of 0.33 between SST anomalies at two stations indicates that the SST anomalies are spatially less coherent than the SST themselves (Fig. 6). It is noteworthy that the high frequency anomalies with time scales less than 2 years are more highly correlated than the low frequency anomalies with time scales longer than 2 years. The reason why the low frequency anomalies are spatially less correlated than the high frequency ones is not known. The relatively low correlation coefficient of 0.18 for low frequency anomalies implies that the long-term fluctuations of thermal structure in the Eastern and Western Channels are quite different each other.

The annual amplitudes of SST are found to be negatively correlated with the annual means of SST at both stations (Fig. 10). The negative correlation may be associated with the year-to-year changes of the thickness of the upper layer of the ocean. If the thickness of the upper layer were increased, then the effective heat capacity of the ocean would increase and the annual range of SST would decrease (Kang, 1984a). On the other hand, the warm water advection in a relatively thicker upper layer would yields a relative decrease of the mean SST. Kang's (1984a) theoretical model showed that a deepening of the upper layer reduces the annual amplitude and delays the annual phase of SST. In fact, the annual amplitude and annual phase of SST at Mitsushima are negativety correlated (Fig. 11). In principle, the year-to-year changes of the upper layer can explain the relations among the annual means, amplitudes, and phases of SST at Mitsushima. But, unfortunately, this conceptual hypothesis cannot be verified in this paper due to the lack of appropriate temperature data in the interior of the ocen.

In this paper, based on the SST data for more than 50 years, it was shown that the seasonal variation of SST in the Korea Strait vary from year to year. The standard deviation of annual means, annual and semi-annual amplitudes are less than 1°C, and those of the annual and semi-annual phases are about 5° and less than 50°, respectively. These standard deviations give a probable 'error bars' for the harmonic constants of SST variation which are determined based on the multi-year normals of SST. Various factors, such as heat advection by ocean currents, atmospheric forcings to change the thermal structure of the upper layer of the ocean, etc. are expected to contribute to the year-to-year fluctuations of SST (Kang, 1984b). Detailed mechanisms responsible for the year-to-year fluctuations of SST in the Korea Strait, however, are not well understrstood yet.

Acknowledgements

We wish to thank Heung-Jae Lie, Korea Ocean Res. Dev. Inst., Hee-Joon Kim and Jae Chul Lee, Nat. Fish. Univ. Pusan, for helpful comments on the manuscript, Myoung-Shin Jin and Young-Sang Suh, Nat. Fish. Univ. Pusan, for punching the data and drafting figures. Research support by the Korea Science and Engineering Foundation is gratefully acknowledged.

References

Bevington, P.R. 1969. Data reduction and error analysis for the physical sciences. McGraw-Hill, Inc., New York 336 pp.

Gong, Y. 1968. On the seasonal variation of coastal surface water temperature. Bull. Fish. Res. Dev. Agency, Korea, 3, 57-79.

Hahn, S.D. 1970a. Periodic variations of water temperature in the seas around Korea (I). Annual and secular variations of surface water temperature, Kumun-do region, southern sea of Korea. J. Oceanol. Soc. Korea 5, 6-13.

Hahn, S.D. 1970b. Periodic variations of water temperature in the seas around Korea (II). Annual and long-term variations of surface water temperature in the regions of Mishima and Okinoshima. J. Oceanol. Soc. Korea 5, 41-40.

Kang, Y.Q. 1984a. One-dimensional model of the oceanic and continental seasons. J. Korea Meteorol. Soc. 20(1), 60-66.

Kang, Y.Q. 1984b. Atmospheric and oceanic factors affecting the air-sea thermal interaction in the East Sea (Japan Sea). J. Oceanol. Soc. Korea 19(2)(in press).

Kang, Y.Q. and M.S. Jin. 1984. Seasonal variation of surface temperatures in the neighbouring seas of Korea. J. Oceanol. Soc. Korea 19, 31-35.

Kano, Y. 1980. The annual variation of the temperature, salinity and oxygen content in the Japan Sea. Oceanogr. Mag. 31, 15-26.

Kim, H.J. and Y.Q. Kang 1984. A note on oceanographic applications of digital filters. J. Oceanol. Soc. Korea 19(2)(in press).

Koizumi, M. 1962. Seasonal vatiation of surface temperature of the East China Sea. Oceanogr. Soc. Japan, 20th anniv. vol. 321~329.

Wyrtki, K. 1965. The annual and semiannual variation of sea surface temperature in the North Pacific Ocean. Limnol. Oceanogr. 10, 307-313.

Year-to-Year Fluctuations of Seasonal Variation of Sea Surface Temperature in the Korea Strait

대한해협 표면수온의 계절변화와 연별변동

강용균 · 이병돈
부산수산대학

대한해협의 Mitsushima와 Okinoshima에서 50년 이상 연속적으로 관측된 표면수온 자료의 분석을 통하여, 이 해협표면수온의 계절적 변화의 연별변동을 조사하고, 또한 누년간의 계절적 평균을 제거한 이상 수온(temperature anomalies)의 변동에 대하여 분석하였다. 표면수온의 빈도 분포는 누년 평균치에서 최대치를 나타내지 않고, 평균치보다 높은 수온과 낮은 수온 두 곳에서 최대빈도를 나타낸다. 계절적 변화를 제거한 이상수온은 0°C 에서 최대 빈도를 나타내며, 95% 이상의 이상수온의 범위는 ±2°C 이내이다. 표면수온 계절변화의 조화상수는 해에 따라서 바뀌는 바, 연평균과 연주기 및 반년주기의 진폭의 표준편차는 1°C 미만이고, 연주기 및 반년주기 위상의 표준편차는 각각 5° 정도 및 50° 미만이다. 대한해협에서 표면수온의 연평균이 증가함에 따라 연주기 진폭은 감소하는 경향이 나타난다. 본 논문에서는 자료 분석을 통하여 나타난 수온 변화에 대한 물리적인 설명을 제시하고 있다.