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# Relationships between the Winter-Time Surface Water Temperature and the Summer-Time Bottom Water Temperature in the West Sea of Korea*

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# 서해의 겨울철 표면수온과 여름철 저층수온과의 관계

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***Abstract***

Based on the hydrographic data for 19 years (1968-1984) at 65 stations in the West Sea of Korea, we investigate the relationships between the sea surface temperature (SST) in winter and the bottom water temperature (BWT) in summer. The spatially-averaged anomalies of BWT are highly correlated with those of SST during the preceding winter. However, due to advection of heat by ocean currents, the spatial pattern of BWT anomaly in summer does not closely resemble that of SST anomaly in the preceding winter.

요약 : 한국 서해 65개 정점에 대한 19년간 (1968-1984)의 수산진흥원 해양관측 자료를 사용하여, 겨울철 표면수온과 여름철 저층수온과의 관계를 구명하였다. 여름철 저층수온 이상변동치의 공간적 평균과 6개월 전 겨울철 표면수온 이상변동치의 공간적 평균 사이에는 높은 상관관계가 있다. 하지만, 해류에 의한 열이송의 영향으로, 여름철 저층수온 이상변동치의 공간적 분포와 겨울철 표면수온 이상변동치의 공간적 분포 사이에는 유사성이 미약하다.

## INTRODUCTION

The West Sea of Korea (the Yellow Sea) is a semi-enclosed shallow sea with depths less than 100 m (Uda, 1966). During winter, the surface mixed layer extends down to the bottom and the water temperature is uniform throughout the whole water column. During summer, on the other hand, the West Sea water has a two-layer structure due to strong stratification associated with buoyancy flux across the sea surface. A typical thickness of surface mixed layer in summer is only about 20 *m* (Lie, 1984).

The waters that occupy the bottom layer in the central part of the Yellow Sea from spring to fall is called the Yellow Sea Bottom Cold Water (YSBCW). Since the YSBCW is formed and modified during the preceding winter, one expects that the bottom water temperature (BWT) in summer should be closely related with the sea surface temperature (SST) of the preceding winter. Yang *et al* (1984) showed that an abnormally cold YSBCW in summer of 1981 was associated with extensive cooling of the sea surface during the preceding winter.

A prediction of summer-time BWT has a

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practical application for an efficient management of fisheries. In the northern part of the North Sea, the winter-time SST is maintained in the lower layer in summer. Since the BWT determines the maturing process of herrings living in the lower layer, the beginning of the spawning migration in summer depends on the SST of the preceding winter. Thus, as early as in late winter, the duration of the summer herring season in the northern North Sea can be predicted on the basis of such relations (Dietrich *et al*, 1982).

In this paper, by means of statistical and time series analysis, we investigate the relationship between the summer-time BWT and the winter-time SST in the southeastern West Sea of Korea. Based on such relations, we seek a possibility for a prediction of summer-time BWT in the West Sea.

## DATA AND METHOD

Our study is based on the SST in February and the BWT in August for 17 years (1968~1984) at 65 stations in the West Sea of Korea. The temperature data we used are taken from the Annual Report of Oceanographic Observations published annually by the Fisheries Research and Development Agency (1968~1984). The locations of 65 stations are shown in Fig. 1. The bathymetry of our study area is shown in Fig. 2.

A typical pattern of temperature change in the West Sea is shown in Fig. 3. The change of water temperature for one year from February 1977 at the Station 310-07 shows the followings. In February, the whole water column has a uniform tempera-

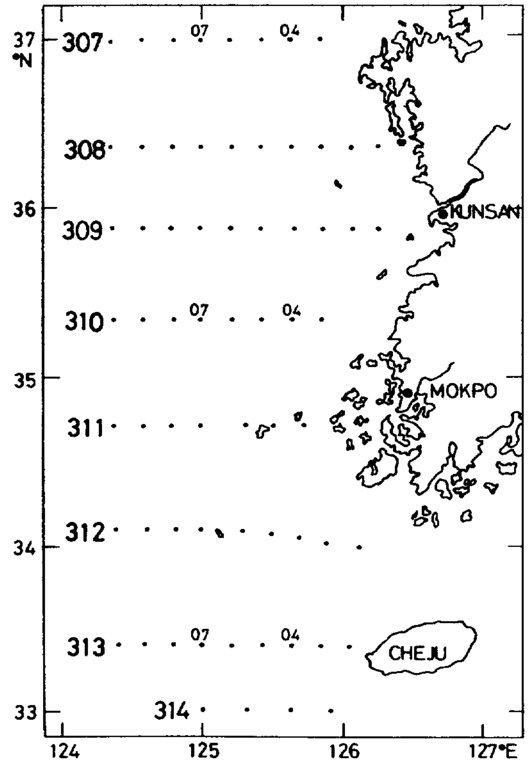

Fig. 1. Hydrographic stations of the Fisheries Research and Development Agency.

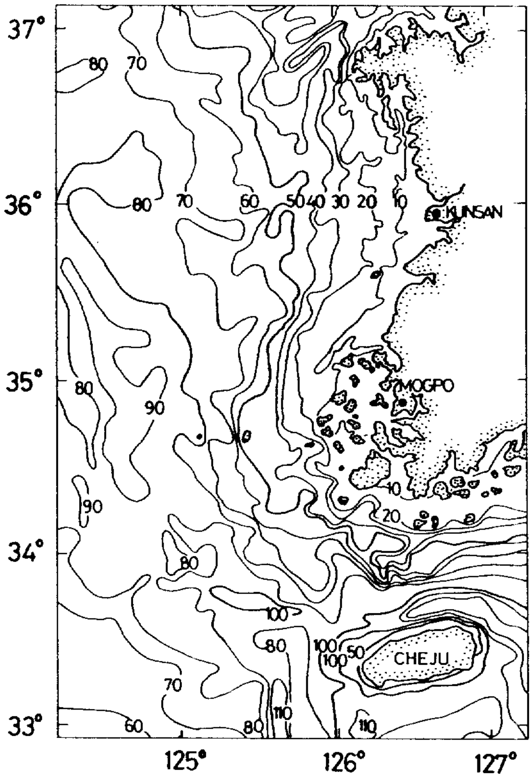

Fig. 2. Bathymetry of the West Sea of Korea. Contour interval is 10 m.

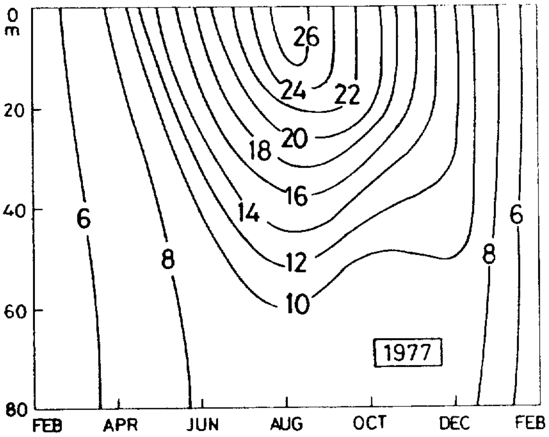

Fig. 3. Isopleths of water temperature at the Station 310-07 for one year from February 1977.

ture of 6℃. From spring to fall, a strong stratification is formed. In August, the SST is 26℃ and the BWT is less than 10℃. An annual march of SST is characterized with a temperature change up to 20℃: the SST is 6℃ in February and 26℃ in August. The BWT, on the other hand, undergoes only a slight change during a year cycle. The BWT is 6℃ in February and 8℃ in August, and the annual range of BWT is only 2℃.

We study the relationships between the SST in winter and the BWT in the following summer as follows. The normals of SST and BWT are obtained by an arithmetic averaging of the temperature data of the same calendar months for 17 years at each station. The anomalies of SST and BWT are obtained by substracting the normal from the observed actual temperature. The degree of fluctuations of the anomalies are estimated by computing root-mean-square (rms) amplitudes of anomalies of the same calendar months for 17 years at each station. The frequency distribution of anomalies are computed by counting the numbers of temperature data lying within each interval of 0.5℃ units.

Various cross correlations between the winter-time SST anomalies and the summer-time BWT anomalies are defined as follows. Let $x_{ij}$ and $y_{ij}$ be the SST anomaly in Feburary and the BWT anomaly in August, respectively, at the $i$-th station of the $j$-the year. The spatially-averaged anomalies of SST, $X_j$, and of BWT, $Y_j$ of the $j$-th year are computed by

$$X_j = \sum_{i=1}^{M} x_{ij}/M, \qquad Y_j = \sum_{i=1}^{M} y_{ij}/M, \qquad (1)$$

where M is the total number of stations (M = 65). The cross correlation coefficient, R, between the spatially averaged anomalies is computed by

$$R = \sum_{j=1}^{N} X_j Y_j / \left( \sum_{j}^{N} X_j^2 \sum_{j}^{N} Y_j^2 \right)^{1/2}, \qquad (2)$$

where N is the total number of years (N = 17). The local cross correlation coefficient, $r(i)$, between the winter-time SST anomalies and the summer-time BWT anomalies at i-th station is computed by

$$r(i) = \sum_{j=1}^{N} x_{ij} y_{ij} / \left( \sum_{j}^{N} x_{ij}^2 \sum_{j}^{N} y_{ij}^2 \right)^{1/2}. \qquad (3)$$

The resemblance between the spatial patterns of the winter-time SST anomalies and the summer-time BWT anomalies of the j-th year is estimated by a "map correlation" coefficient, $r_{map}(j)$, computed by

$$r_{map}(j) = \sum_{i=1}^{M} x_{ij} y_{ij} / \left( \sum_{i}^{M} x_{ij}^2 \sum_{i}^{M} y_{ij}^2 \right)^{1/2}. \qquad (4)$$

We display the time series of spatially averaged SST and BWT and determine a linear regression curve between them by the least squares method. We display the fluctuations of map correlation coefficients for the years from 1968 to 1984. We map spatial distributions of the local cross correlation coefficients between the winter-time SST anomaly and summer-time BWT anomaly at each station during 1968 to 1984.

## MEAN FIFLD AND ANOMALIES

The distributions of mean water temperatures in the adjacent seas of Korea, including our area of study, can be found in a recent oceanographic charts published by the Fisheries Research and Development Agency (1986). In this paper, we briefly describe the mean field of SST in February and of BWT in August for the years 1968 to 1984 in the West Sea of Korea.

In February, the surface mixed layer reaches down to the bottom, and the differences between the SST and BWT are less than 0.5°C at almost all stations (58 stations among 65 stations). The average difference between SST and BWT in February is only 0.1°C, and the standard deviation of difference is 0.28°C. That is, the water temperatures in the West Sea of Korea in winter are vertically homogeneous throughout the whole water column.

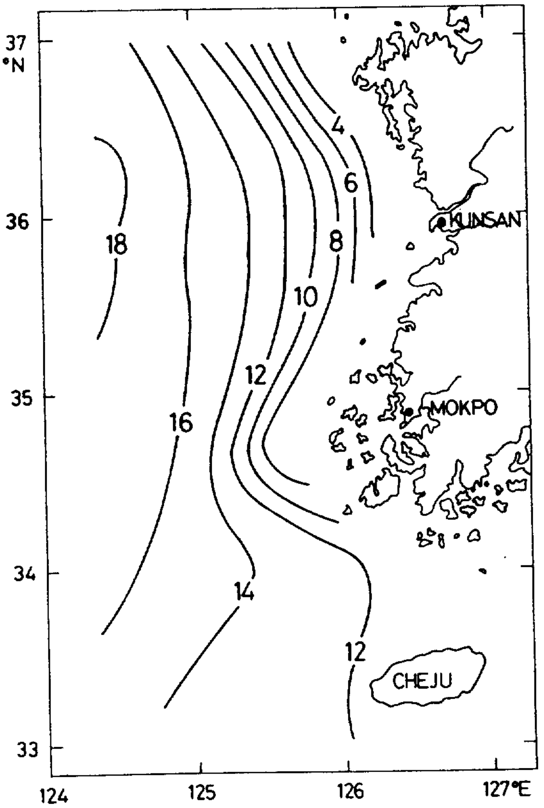

Fig. 4. Distribution of the average difference between SST and BWT in August of 1968 to 1984.

In August, on the other hand, the ocean has a two-layer structure, and the BWT is much cooler than the SST. Fig. 4 shows the distributions of the difference between SST and BWT in August. In the coastal region within 50 miles from the coast, the difference is less than 10°C mainly due to the shallowness of the ocean and the tide-associated mixing of waters. In the offshore regions at distances greater than 50 miles from the coast, the differences between SST and BWT are greater than 10°C.

The rms amplitudes of SST anomalies in February and of BWT anomalies in August during 1968 to 1984 are shown in Fig. 5. The rms amplitudes of SST anomalies in February are 1 to 2°C, and those of BWT anomalies in August are 1 to 4°C. Fluctuations of the SST anomalies in February are large in the southern part and small in the northern part. Fluctuations of BWT anomalies, on the other hand, are large in the northern part and small in the southern part.

Frequency distributions of SST anomalies in February and those of BWT anomalies in August for 17 years monthly data at 65 stations are shown in Fig. 6. This figure shows that the fluctuations of BWT anomalies in August are more widely scattered than those of SST anomalies in February.

## RELATIONS BETWEEN WINTER AND SUMMER-TIME ANOMALIES

### *a. Spatially-Averaged Anomalies*

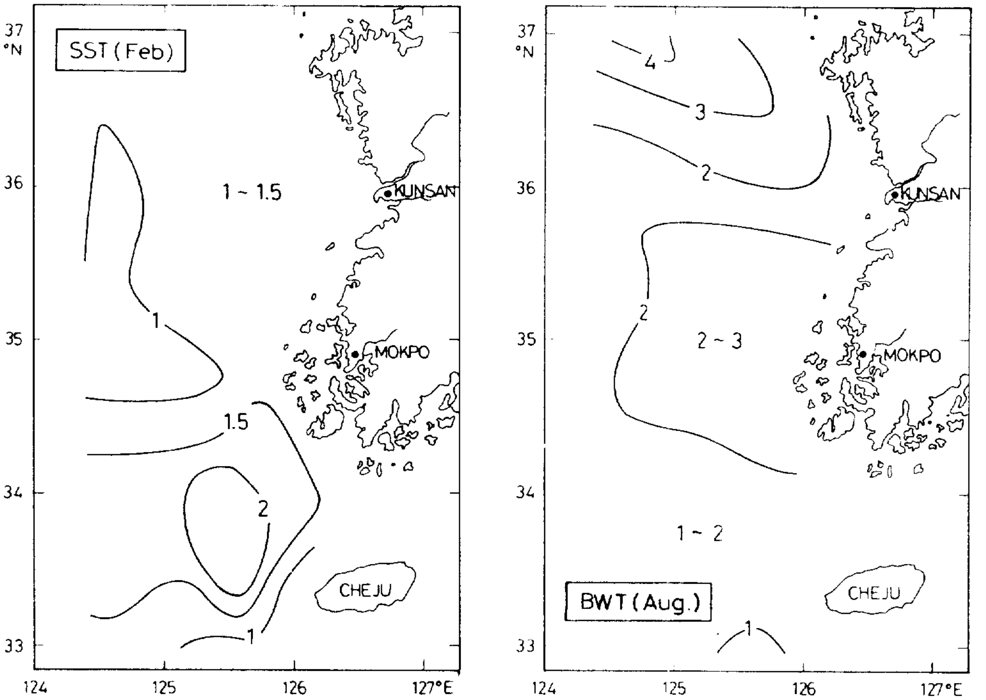

Fig. 5. The rms amplitudes (℃) of SST anomalies in Februaries and BWT anomalies in Augusts for 17 years, 1968–1984.

The spatially-averaged anomalies of SST in winter and those of BWT in summer are obtained by an arithmetic average of anomalies at 65 stations. The time series of spatially-averaged SST anomalies in February and of BWT anomaly in August during 1968 to 1984 are shown in Fig. 7. This figure shows that the spatially-averaged BWT anomalies in summer are highly correlated with the spatially-averaged SST anomalies of the preceding winter. The cross-correlation coefficient between them, computed by (2), is 0.84.

Fig. 7 shows that the SST in February of 1977 was abnormally cold and the BWT in August of the same year was also abnormally cold. In 1979, both the SST in winter and the BWT in summer were abnormally warm. Exceptionally low correlation between SST and BWT was found in 1974. The SST in February of 1974 was only 0.5℃ higher than the normal year, but the

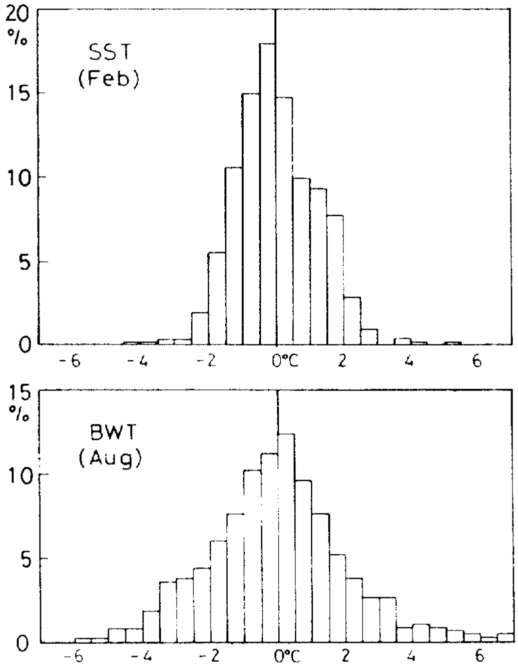

Fig. 6. Frequency distribution of SST anomalies in February and BWT anomalies in August from 1968 to 1984.

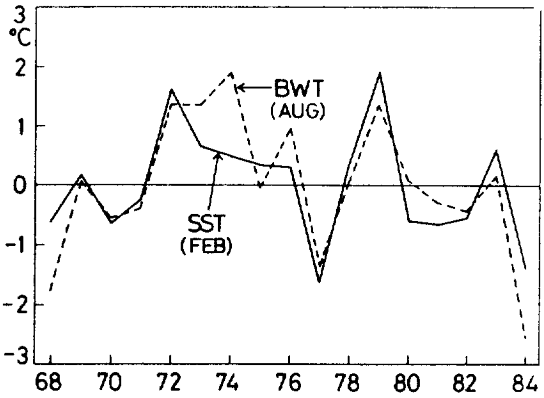

Fig. 7. Time series of spatially-averaged SST anomalies in February and BWT anomalies in August during 1968 to 1984 in the West Sea of Korea.

BWT in August of 1974 was 2.0℃ higher than the normal year.

Fig. 8 shows the scatter diagram between the spatially-averaged SST anomalies in February and the BWT anomalies in August for 17 years (1968~1984). A linear regression curve determined by the least squares fit between them is

$$BWT = 1.05\ SST - 0.07. \qquad (5)$$

This linear regression suggests that an increase of BWT in summer by 1℃ is associated with an increase of SST by about 1℃ in the preceding winter.

### b. Map Correlation

Resemblance between the spatial patterns of the winter-time SST anomalies and the summer-time BWT anomalies is estimated by computing map correlation coefficient given by (4). Fig. 9 shows the year-to-year fluctuations of the map correlation coefficients between the spatial patterns of SST anomaly in February and of BWT anomaly in the following August. The map correlation coefficients are between -0.08 (in 1969) and 0.74 (in 1977), and it differs greatly from year to year. The average value of map correlation for 17 years is only 0.23, and this figure shows that the spatial pattern of summer-time BWT anomalies is quite different from that of winter-time SST anomalies.

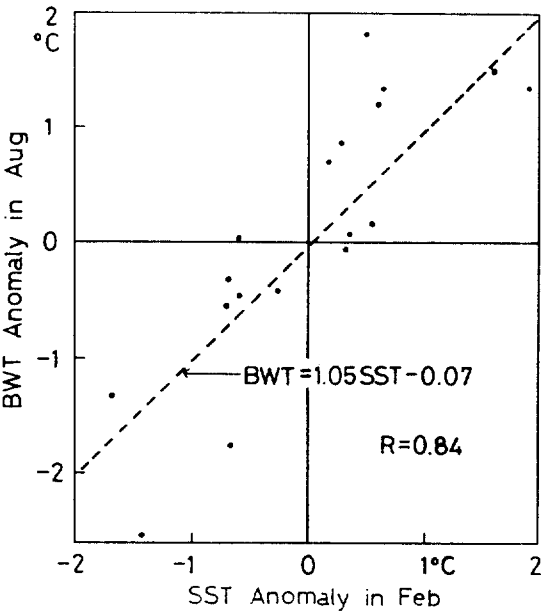

Fig. 8. Scatter diagram between spatially-averaged SST anomaly in February and BWT anomaly in August during 1968 to 1984. The linear regression curve is shown by a dashed line.

### c. Local Cross Correlation

In order to study the dependency of summer-time BWT anomaly on the winter-time

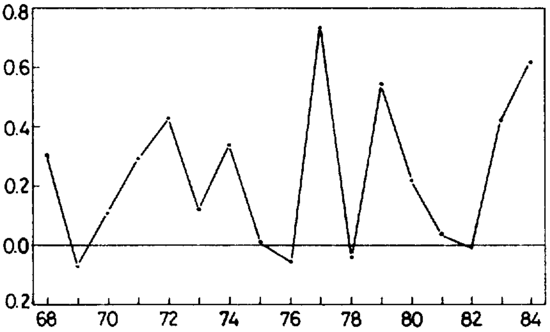

Fig. 9. Year-to-year fluctuations of the map correlation coefficients between the spatially-averaged patterns of SST anomalies in February and BWT anomalies in August during 1968 to 1984. Average value over 17 years is 0.23.

SST anomaly of the preceding winter at the same station, we computed local cross-correlation coefficient between the SST anomalies in Febuary and the BWT anomalies in August for 17 years at each station by (3). The distribution of the local cross correlation coefficients is shown in Fig. 10. The local cross correlation at individual station differ from station to station. The local cross correlation coefficients at 65 stations have a mean of 0.35 and a standard deviation of 0.23. The local cross correlation coefficients between the winter-time SST and the summer-time BWT anomalies at individual station are much lower than that between the spatially-averaged winter-time SST anomalies and summer-time BWT anomalies.

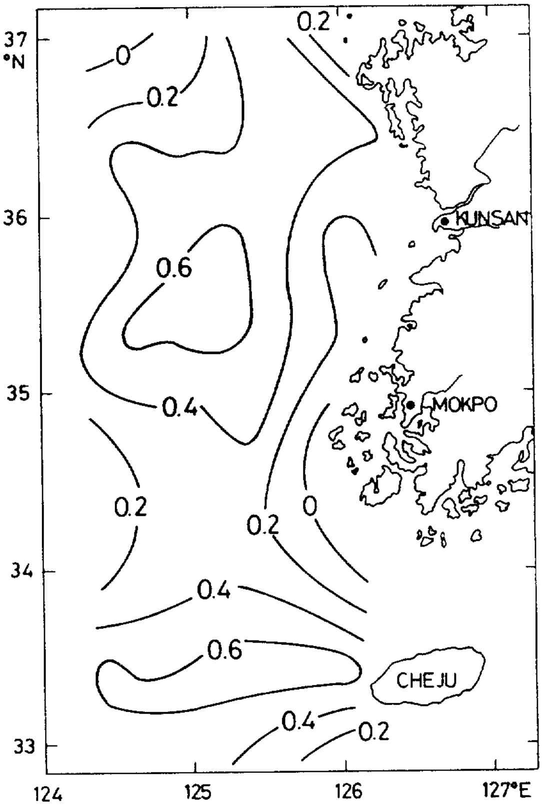

Fig. 10. Distribution of local correlation coefficients between SST anomalies in February and BWT anomalies in August during 1968 to 1984.

## DISCUSSION AND CONCLUSIONS

In this paper, through analysis of hydrographic data for 17 years at 65 stations in the West Sea of Korea, we showed that the spatially-averaged BWT anomalies in summer are highly correlated with the spatially-averaged SST anomalies of the preceding winter. A linear regression curve between them, (5), shows that an increase of SST in February by 1°C. is associated with an increase of BWT in the following August by 1°C Hence, the spatially-averaged BWT anomaly in summer can be predicted from the observation of SST during the preceding winter. The BWT in summer is related with the SST of the preceding winter, because the waters that occupy the bottom layer in summer had been vertically mixed and were in contact with the atmosphere during the preceding winter when the surface mixed layer extended down to the bottom.

However, due to advection of heat by ocean currents, the water formed in the winter does not remain at the same location until the next summer. The migration of water body by ocean currents is one of the possible mechanisms that can explain the reason why the local cross correlations between the winter-time SST anomalies and the summer-time BWT anomalies at individual station are quite low. The local cross correlation coefficient between winter-time SST and summer-time BWT anomalies averaged over 65 stations is only 0.35, whereas the cross correlation between the spatially-averaged winter-time SST and summer-time BWT anomalies is as high as 0.84.

A resemblance between spatial patterns of the winter-time SST and the summer-time BWT anomalies is estimated by map correlation coefficients. The map correlation is low (average value is 0.23 only), and it varied significantly from year to year. As mentioned above, the smallness of the map correlation can be explained by the fact the the water body migrates with ocean currents. Year-to-year fluctuations of map correlation coefficient can be explained by considering the fact that the advection pattern of heat by ocean currents may differ from year to year.

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