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Research Paper
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High Frequency Variation of Low Water Temperature due to Arctic Oscillation Around the Western and Southern Coast of Korea During Winter 2017/2018

In-Seong Han*† · Joon-Soo Lee** · Ju-Yeon Kim** · Ji-Yeon Hong**

*, ** Ocean Climate and Ecology Research Division, National Institute of Fisheries Science, 216 Gijanghaean-Ro, Gijang-Eup, Gijamg-Gun,
Busan 46083, Korea

Abstract : *During the winter of 2017/2018, significantly low water temperatures were detected around the western and southern coasts of Korea (WSCK). In this period, sea surface temperature (SST) in the Korea Waters was about 2℃ lower than mean temperature. Using the real-time observation system, we analyzed the temporal variation of SST during this period around the western and southern coasts. Low water temperature usually manifested over a period of about 10~20 days. The daily Arctic oscillation index was also similarly detectable with the variation of SST. From the cross-correlation function, we compared two periodic variations, which were SST around the WSCK and the Arctic oscillation index. The cross correlation coefficients between both variations were approximately 0.3~0.4. The time lag of the two time series was about 6 to 7 days. Therefore, significanlyt low water temperatures during winter in the Korean coastal areas usually became detectable 6 to 7 days after the negative peak of Arctic oscillation.*

Key Words : *Arctic Oscillation, Climate change, Low water temperature, Cold surge, Cross correlation*

1. Introduction

During early January and early March of 2018, mass mortalities in aquaculture farms occurred around the WSCK. These mass mortalities were caused by low water temperatures related to cold surges, with economic damage exceeding 10 billion KRW (Related Ministries, 2019). Similar fisheries saw damages, which had been caused by low water temperature due to cold surges, during the winters from 2011 to 2013 (Shin and Yoon, 2017). Responding to aquaculture damage caused by repeated abnormal water temperature, the MOF (Ministry of Oceans and Fisheries) of Korea issued guideline for abnormal water temperature warning since 2017. According to this guideline, low water temperature warnings to be issued when water temperature was detected as lower than 4℃.

Recently, extreme cold surges manifested at several mid-latitude areas, affected North America, Europe, and East Asia. These extreme weather events might be caused by a weakening polar vortex, which is expected to be related with extreme Arctic warming. As we know well, a weak and strong polar vortex is represented by the Arctic Oscillation. The impact of Arctic oscillation is very important to the climates of mid-latitude areas (He et al., 2017; Hu et al., 2018; Kolstad et al., 2010; Wallace, 2006; Wu and Wang, 2002; Zhang et al., 2016). Generally, jet streams move to high latitudes and are particularly strong when the Arctic oscillation is positive. In this phase, cold blasts of Arctic air cannot escape to mid-latitudes, and warm weather conditions appear there. On the other hand, negative Arctic oscillation makes the same jet stream move southward, while it also weakens. As a result, cold blasts from the Arctic move to the mid-latitude regions. Therefore, cold surges at the mid-latitude are usually induced by the negative Arctic oscillation (Jeong and Ho, 2005; Park et al., 2017a).

Around East Asia, cold surges were frequently detected by the negative polar vortex in connection with Arctic warming (Shin et al., 2005; Heo and Lee, 2006; Park et al., 2017b). During wintertime, Arctic oscillation is a major factor for the control of weather conditions over East Asia (Park et al., 2010). Lim et al. (2003) reported that Arctic oscillation has a meaningful relationship with temperature anomalies during Korean wintertime. Strong cold surges in Korea induced by negative Arctic oscillation should be cause for disasters such as cold waves which can cause death due to hypothermia (Park et al., 2016).

Abnormal water temperatures related to climate change appeared around the Korean Peninsula recently (Kim and Han, 2017; Suh et al., 2001). Min and Kim (2006) reported that a distinctive rising trend of SST in winter around the coastal areas of Korea are clearly related to the weakening of the Siberian High, using 36

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† Corresponding Author : hisjamstec@korea.kr, 051-720-2230

years (1969 to 2004) of ocean and atmospheric data. However, a distinctive rising trend of winter SST has not been apparent in the Korean Waters since 2010. Such a phenomenon should be closely related with increases in winter cold surges brought on by significant Arctic warming.

Studies about low water temperatures during wintertime with aquaculture mass mortality in Korea have been rarely carried out. However, some studies about low water temperature affecting fisheries have been carried out as follows. Choi et al. (2008) studied winter mass mortality of red sea bream, *Pagrus major*, in the South Sea of Korea. They reported that the reason for such mortality was low water temperatures around the aqua farms in question. Park et al. (2012) also studied the mass mortality of the finless porpoise, *Neophocaena asiaeorientalis*, at a dike of the Saemangeum Sea. They presented some evidence for the reasons about the mass mortality of finless porpoises being unusually low temperatures. Through laboratory experiments, Shin et al. (2018) looked into the survival and physiological responses of red sea bream, *Pagrus major*, in conjunction with decreasing sea water temperatures. Their study is quite useful in determining the appropriate area for the aquaculture of red sea bream.

Though several climate, oceanography, and fishery studies related to cold surges and extreme low water temperatures has been carried out, we could not clearly understand the variation and changes in extremely low water temperatures in the coastal areas of Korea. In this study, we examine the variations of sea water temperature and Arctic oscillation during the winter of 2017/2018, and present a high frequency relationship between water temperatures and Arctic oscillation.

2. Data and Methods

To examine the long-term trend of sea water temperatures in the Korean Waters, we used NSO (NIFS Serial oceanographic Observations) data for February. NSO measured temperature and biogeochemical factors 6 times a year, deployed at 207 stations since 1968. NIFS (National Institute of Fisheries Science) also also operated RISA (Real-time Information System for Aquaculture) since 2003. RISA consists of 54 stations along the Korean coastal area and measure the surface temperature at 30 minute intervals. In this study, we used data from 6 stations which had detected significantly low water temperatures, and which had issued low water temperature warnings during the winter of 2017/2018, in the southern and western coastal areas (Fig. 1).

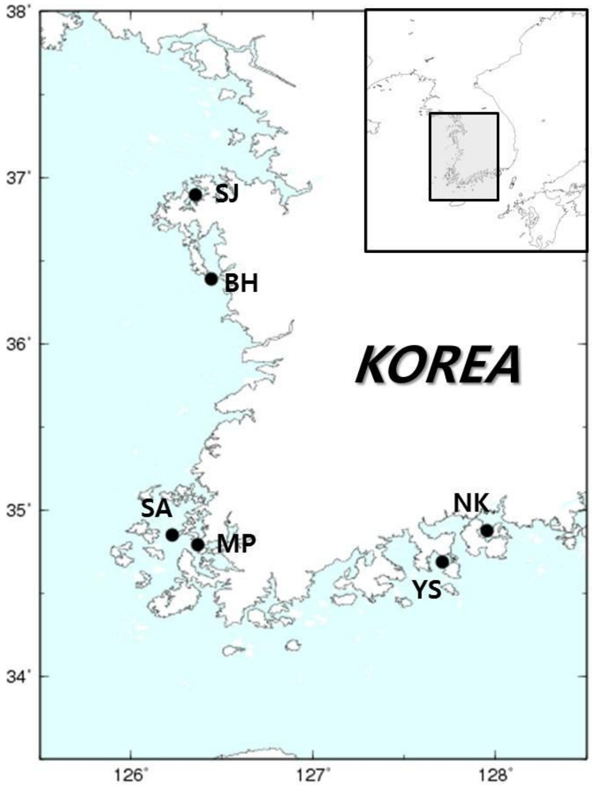

Fig. 1. Location of 6 the RISA stations.

Detailed explanations of stations are shown in Table 1. Sampling the depths of surface water temperature at each stations are range in 2 to 7 m. To eliminate fluctuations of less than 24 hours, 30 minute interval data were converted to a daily mean water temperature.

Table 1. Detailed explanations of RISA stations

Code name	Districts	Latitude	Longitude	Depth (m)	Sampling depth (m)
SJ	Seosan Jigok	36° 53’38”N	126°21’09”E	12	5
BH	Boryung Hyojado	34° 24’57”N	126°26’00”E	8	5
SA	Shinan Aphae	34° 50’53”N	126°13’29”E	10	5
MP	Mokpo	34° 47’21”N	126°21’55”E	7	5
YS	Yeosu Sinweol	34° 41’15”N	127°42’29”E	7	2
NK	Namhae Kangjin	34° 52’28”N	127°57’08”E	13	6

Daily Arctic oscillation index data was obtained by the NCEP (National Centers for Environmental Prediction) / NOAA (National Oceanic and Atmosphere Administration). NCEP explained that the daily Arctic oscillation index is constructed by projecting the daily 100mb height anomalies pole-ward of 20°N on to the loading pattern of the Arctic oscillation. The loading pattern of the Arctic oscillation is defined as the leading mode of EOF (Empirical Orthogonal Function) analysis of the monthly mean 100mb height during the 1979 to 2000 period.

To clarify the high frequency, which is about a 5 to 20 days period, we used a cross correlation function between daily sea water temperature with 6 RISA stations, and the daily Arctic oscillation index from December 2017 to February 2018.

3. Results

3.1 Feature of water temperatures during the winter of 2017/2018 around the Korean peninsula

To understand the long-term change to SST in the Korean Waters, we examine the NSO SST anomaly data, which was calculated using the 1970 to 2000 mean SST, in February from 1968 to 2018. During the 1970's and 1980's, significantly low water temperatures frequently occurred in the Korean Waters in winter. However, positive SST anomalies in February were dominant from the late 1980's to the late 2000's. Since 2010, SST anomalies were change to negative values, as in Fig. 2.

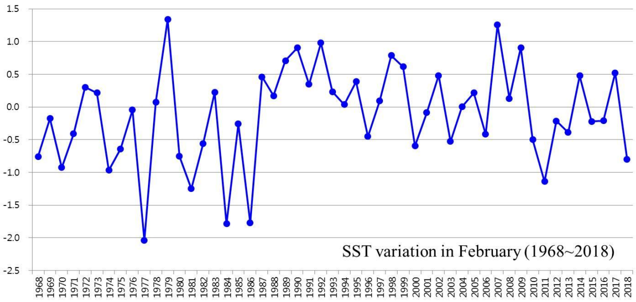

Fig. 2. Temporal variation of SST anomalies in the Korean Waters from 1968 to 2018, by NSO.

After 2010, negative SST anomalies in February appeared during 7 of the 9 years. From 1968 to 2009, SST in February clearly manifested, increasing in trend by about 0.0246℃/year. However, this trend reversed at a rate of about -0.0165℃/year from 2009 to 2018. From these results, the SST in winter usually resulted in lower water temperatures around the Korean Peninsula, particularly during the 2010's.

During the winter of 2017/2018, the mid-latitudes have been experiencing significant cold surges. Of note, February 2018 was the sixth warmest February in the past 138 years of modern record-keeping, according to a monthly analysis of global temperatures by NASA (National Aeronautics and Space Administration) / GISS (Goddard Institute for Space Studies) (NASA, 2018) (Fig. 3).

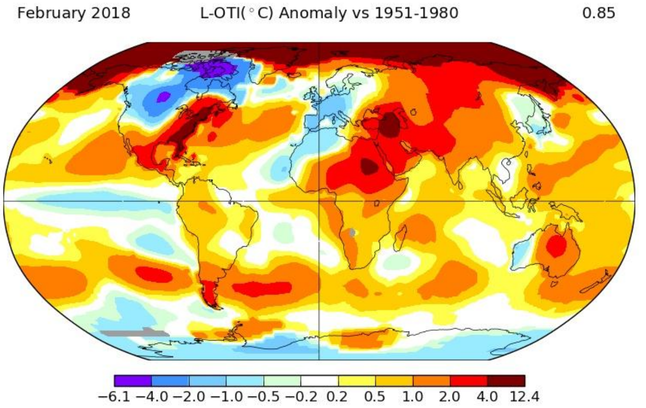

Fig. 3. Global monthly temperature anomalies in February 2018 by NASA/GISS (source: data/giss.nasa.gov/gistemp/maps/).

Globally, the mean temperature anomaly was about 0.82℃. From the global temperature anomalies in February 2018, however, distinctive negative anomalies of surface temperature appeared around the Northern parts of North America, Western Europe, and East Asia. On the other hand, significant positive anomalies of surface temperature appeared in the Arctic area. We can conjecture that a distinctive weakening polar vortex occurred in this period.

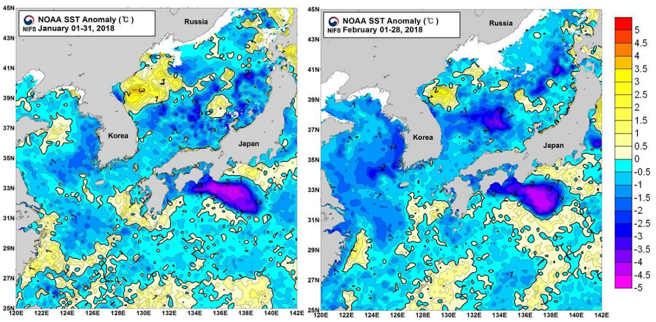

Fig. 4. Distribution of monthly mean SST anomalies in January (left) and February (right) 2018. Blue colors indicate the negative anomaly.

As for the general status of water temperature in the Korean waters, we examined the distributions of monthly mean SST anomalies, which were calculated from 1990 to 2010, in January and February 2018 from NOAA/AVHRR (Advanced Very High Resolution Radiometer) satellite data (Fig. 4). We found there to be significant negative SST around the Korean Peninsula during these periods. In particular, significant low water temperatures 2℃ below the mean value were discerned in the western and southern coastal areas of Korea.

3.2 Temporal variation of SST and Arctic oscillation

SST anomalies, which were calculated using mean values from 2012 to 2017, manifesting at each 6 RISA stations from December 2017 to February 2018 are shown in figure 5. Shaded marks in this figure indicate the period of spring tide. We find that the periodic variation is about 10 to 20 days at each station. Significantly low water temperatures around the WSCK appeared on the 10 December 2017, 28 December 2017, 12 January 2018, 26 January 2018, 7 February 2018, and 14 February 2018.

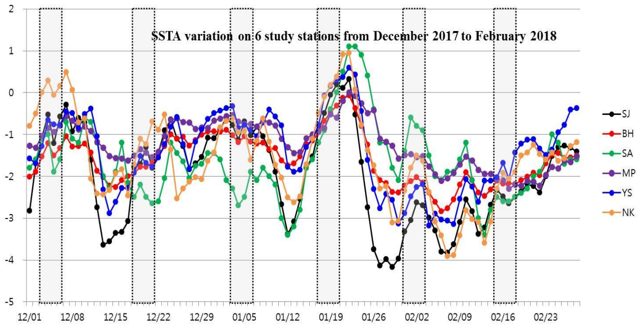

Fig. 5. Temporal variation of SST anomalies as observed by 6 RISA stations from December 2017 to February 2018. The period shaded indicates periods of spring tide.

In particular, distinctive low water temperatures were recorded as 3℃ lower than the mean value, occurring 5 times during the defined period. We also discovered that temporal variations of SST anomalies at each station were not clearly related to the spring tide period. Therefore, this temporal variation should be considered related to the weather conditions, pointing to the occurrence of cold surges.

Figure 6 shows the temporal variation of the Arctic oscillation index from December 2017 to February 2018. The range of this index was from 2.6 to -3.6. In this figure, we can observe several negative peaks around 5 December 2017, 25 December 2017, 5 January 2018, 20 January 2018, 1 February 2018, and 28 February 2018. These negative peaks may be part of a periodic variation of about 10 to 20 days, similar to SST around the WSCK in Fig. 5.

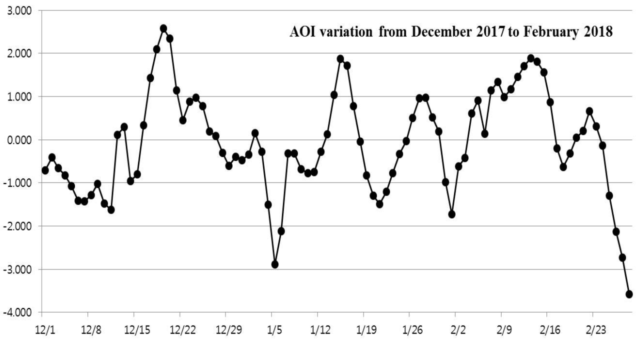

Fig. 6. Temporal variation of Arctic oscillation index from December 2017 to February 2018.

3.3 Relationship between SST and Arctic oscillation

We examined the periodic variation of SST anomalies at RISA stations and Arctic oscillation index previously. To clarify the relationship of both variations, we analyzed the cross correlation function of both variations as presented in Fig. 7. The maximum cross correlation coefficients between SST at the 6 RISA stations and the Arctic oscillation index were in the range of 0.3 to 0.4. The time lags between both variations were about 6 to 7 days.

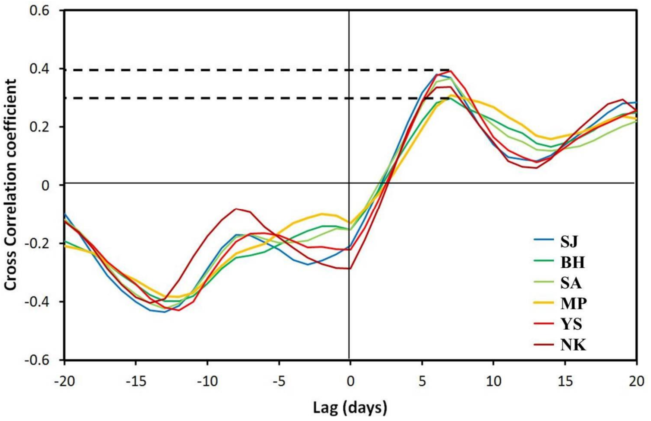

Fig. 7. Cross correlation coefficients and time lags between SST at 6 the RISA stations and Arctic oscillation index from December 2017 to February 2018.

If we examine each station, the maximum correlation coefficients are 0.38 in SJ, 0.30 in BH, 0.37 in SA, 0.31 in MP, 0.34 in YS and 0.34 in NK, respectively. The time lags when the maximum cross correlation appeared are 6 days at SJ and 7 days at the other stations. This indicates that significantly low water temperatures around the WSCK usually appeared 6 to 7 day after the negative peaks of the Arctic oscillation index.

These results indicate that the surface water temperature in the WSCK region is directly influenced by the Arctic oscillation, which is believed to be caused by distinctive Arctic warming of late. It also helps to consider the future view and to respond to the low water temperature warning in the Korean coastal area during the winter.

4. Summary and Discussion

In the course of this study, we examined the feature of water temperatures during recent winters, as well as the relationship between the SST around the WSCK region and Arctic oscillation from December 2017 to February 2018.

Since the 2010's, SST during the winter usually manifested negative anomalies in the Korean Waters. This declining SST trend during recent winters is clearly the opposite of results shown by previous bodies of researches such as Min and Kim (2006), Seong et al. (2010) and Suh et al. (2012). These research reports exhibited a dominant increasing trend of SST during winter in the Korean Waters. This means that the long-term trend of SST in the Korean Waters during winter was clearly changed from an increasing to a decreasing trend since the 2010's. This change is likely be closely related to climate change, and specifically Arctic warming.

Since the 2010's, significantly low water temperature during winter were frequently detected in the Korean Waters. In particular, SST around the WSCK region during winter was directly related to changing weather conditions, including a weakening of polar vortex. During the winter of 2017/2018, distinctive cold surges frequently appeared on the Korean Peninsula. In this period, the SST in the Korean Waters was 2℃ below than the mean value.

From the RISA results, we identified that significantly low water temperature frequently manifested within a period of about 10 to 20 days. These periodic variations were not related to tidal period. We also examined the temporal variation of the Arctic oscillation index from December 2017 to February 2018. This variation was also shown a periodic variation of about 10 to 20 days.

Using the cross correlation function, we examined the relationship between SST around the WSCK and Arctic oscillation. The cross correlation coefficients recorded at the 6 RISA stations with Arctic oscillation index are about 0.3 to 0.4. The time lag of both time series is about 6 to 7 days. This indicates that significantly low water temperatures manifested around the WSCK region 6 to 7 days after the negative peak of Arctic oscillation. Moreover, SST around the Korean coastal area is closely related to the weakening of the polar vortex, which is caused by extreme Arctic warming.

This result is very useful in terms of responding to the disasters of fisheries affected by abnormal water temperatures, which usually indicate mass mortalities at aqua-farms. NIFS has issued abnormal water temperature warnings since 2017. During the issuance of a warning, the NIFS also puts out a newsflash which includes a forecast of abnormal water temperature. The relationship between SST and Arctic oscillation during the winter is expected to increase the confidence of such forecasts.

In this study, we examined the high frequency relationship, which is the period of about 10 to 20 days, between SST and Arctic oscillation. The Arctic oscillation is one of the most important global climate phenomena. In future studies, we will examine the long-term relationship between both of these phenomena. Then, we will also look into the relationship between various climate indices such as the Siberian High pressure and Aleutian Low pressure with wind speed and air temperatures as well as and long-term changes in winter SST in the Korean Waters.

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