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Temperature Variabilities at Upper Layer in the Korean Marine Waters Related to Climate Regime Shifts in the North Pacific

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한국주변해역 상층부의 수온 변동과 북태평양 기후체제와의 관계

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Abstract : *Temperature variability at the upper layer related to climate regime shifts in the Korean waters was illustrated using water temperature, climate index. Three major climate regime shifts (CRS) in 1976, 1988 and 1998 in north Pacific region had an significant influence on the major marine ecosystems structure pattern. Three marginal seas around Korean peninsula; East Sea, East China Sea and Yellow Sea also got important impact from this kind of decadal shift. We used 10m sea water temperatures in four regions of Korean waters since 1950 to detect major fluctuation patterns both seasonally and also decadal shift. 1988 CRS was occurred in all of the study areas in most seasons however, 1998 CRS was only detected in the Yellow Sea and in the southern part of the East Sea. 1976 CRS was detected in all of the study area mainly in winter. After 1998 CRS, the water temperature in the southern part of the East Sea, East China Sea and Yellow Sea were going into decreased pattern; however, in the northern part of the East Sea, it was further shifted to increasing pattern which was started from 1988 CRS period.*

Key Words : *Marginal sea, Climate regime shift, Sea water temperature, Seasonal Variability, Climate Index*

요 약 : 수온과 기후 지수 자료를 이용하여 한국주변해 상층부의 수온변동과 북태평양 기후체제와의 관계를 분석하였다. 1970, 1980 그리고 1990년대 후반에 발생한 기후체제전환은 해양생태계의 구조 변화에 중요한 영향을 끼쳤다. 북서태평양 대륙주변부에 위치한 우리나라 주변해역 또한, 10년 이상의 장주기적인 변화의 영향을 받지만, 해역별 반응은 다르다. 동해, 서해 , 남해 상층부(10 m)의 경우 1988년의 기후체제전환은 3개 해역의 상층부 수온변화에서 동시에 나타난다. 반면, 1998년은 동해남부해역과 서해, 1976년의 기후체제전환은 전 해역의 겨울철 수온변화에서만 그 영향이 나타난다. 1998년 기후체제전환 이후, 서해, 동중국해, 동해 남부의 수온은 점차 감소하지만, 동해 북부해역은 1988년 기후체제전환 이후 증가하는 형태이다.

핵심용어 : 대륙주변부해역, 기후체제전환, 수온, 계절변동, 기후지수

1. Introduction

Climate regime shifts in the Korean marginal sea waters have been studied for different physical oceanographic parameters and also for biological parameters (Kim et al., 2007; Zhang et al., 2000) since couple of decades before; seasonal temperature variability, regime shifts and their relation to large scale climate variability in the North Pacific, however very limitedly focused. Moreover, very few researches have been focused on the teleconnected pattern of the major climate variability and their coupled influence to the sea water temperature in these regions. Here, we focus the seasonal temperature fluctuation pattern and major regime shifts related to the coupled influence from the major climate variability in the North Pacific region.

East Sea, East China Sea and Yellow Sea are the major three contiguous marginal seas in the Northwest Pacific (Fig. 1). All these seas are laid between the dry continental air mass and high humid oceanic air mass. Seasonally, these waters are affected by

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the Yangtze River air mass, Okhotsk air mass, north Pacific air mass and Siberian air mass. Major climate variability in the north Pacific region (e.g PDO) has a greater influence to the sea water temperature fluctuation pattern in the Korean marginal seas. Higher anthropogenic activities and marked warming trend along with decadal climate mode in the sea water properties- all together make this region highly unstable.

Though these seas are interconnected each other, their topography, depths and major ocean current systems are quite unique. East Sea (ES) exhibits as a miniature of a big ocean as it has both wind driven and buoyancy driven boundary currents, a strong sub-polar front, mesoscale eddies, intense air-sea interaction, subduction and deep convection and topographic trapping (Mooers et al., 2006). It is situated between the subtropical and the subpolar zones. The Tsushima Warm Current (TWC) in the southern region and the Liman Cold Current (LCC) in the northern region are two major currents in the ES and divided by warm (southern) and cold (northern) regions respectively with the boundary (polar front) around 40°N (Fig. 1). Being divided by the strong polar front, the northern and the southern part of the ES are hydrographically and biologically distinct, southern region being more tropical/oligotrophic and the northern region being more boreal/eutrophic (Ashjian et al., 2005; Tian et al., 2008).

East China Sea has a wide continental shelf (average depth is about 272 m) with narrow continental slope. It is the most dynamic water body comparing to East Sea and Yellow Sea waters. Waters from several sources come to this area and make most unstable water properties (e.g. sea surface temperature). The warm and saline Kuroshio Branch Current from the west of Kyushu, Taiwan Warm Current (TC) from Taiwan Strait and cold, fresh water of Yangtze River Discharge from Chinese coastal region are mixing in this area and feed the East Sea southern part through Korea/Tsushima Strait. The Yellow Sea is the semi-enclosed shallow waterbody (average depth of about 44 m) with mud flat, and a low-saline, high-nutrient semi-enclosed shelf sea. While warm and saline water enters from the East China Sea into the Yellow Sea episodically in winter, cooler and fresher water originating from the rivers also enters into the Yellow Sea (Lee, 1998).

Teleconnected atmospheric circulation pattern influenced from the large scale climate variability in the North Pacific with complex ocean current dynamics in the northwest Pacific region make the Korean marginal sea water highly unstable, hence, study of long term seasonal pattern in the water properties have immense importance. Moreover, major fisheries in these seas are highly migratory species; most of them are spawning in the southern part of the East Sea and North East China Sea region, they migrate to the north East Sea region for feeding, also they come back to the North East China Sea for wintering. This typical migratory pattern of the fish species is established on the long term seasonal mode of the sea water temperature pattern in either in the spawning areas or feeding areas. Collapse of saury fishery and enhance of sardine fishery after 1976 CRS or enhance of common squid after 1988 CRS-all these phenomena were occurred in the Korean marine waters due to the mismatch (collapse) or well match (enhance) of that species' seasonal migration patterns with the optimum sea water temperatures. So, study of long term fluctuation pattern in the upper layer sea water temperatures with major regime shifts is important to identify the major commercial fish species assemblages pattern related to the climate variability in the North Pacific region.

The purpose of this study were to (i) explore long term seasonal sea water temperature fluctuation pattern in the Korean marginal seas, (ii) identify the major regime shifts in these seasonal sea water temperature patterns and (iii) investigate the relationship between the sea water temperature fluctuation pattern and regime shifts with the major large scale climate variability in the North Pacific.

2. Materials and Methods

Four different regions of the Korean marine waters have been selected for this study; north East Sea (NES, 40°- 42°, 133°-137°), south East Sea (SES, 35°- 38°N, 130°- 133°E), Northern East China Sea (ECS, 30°- 32°N, 125°- 127°E) and the Eastern Yellow Sea (YS, 35°- 37°, 125°- 126°E) (Fig. 1).

Upper layer water temperatures at the standard depths of 10 m for all study areas have been collected from the World Ocean Database (WOD 09), National Oceanographic data Center (NODC), NOAA, available at www.nodc.noaa.gov. These water temperature data were collected in seasonal basis; winter (Jan.-Mar.), spring (Apr.-Jun.), summer (Jul.-Sep.) and autumn (Oct.-Dec.).

For the NES region, winter data was available from 1961 to 2008, autumn data was from 1956 to 2008 and other seasons data were from 1950 to 2008. For SES region, all of the seasons data were available from 1950 to 2009. For the Northern East China Sea region, winter data was available from 1952 to 2009, spring data was from 1955 to 2009, summer data was from 1950 to 2009, autumn data form 1953 to 2009 and annual data we identified from 1955 to 2009. For the Eastern Yellow Sea region, all seasons data were available from 1964 to 2008.

Major climate-ocean variability in the northwest Pacific (NWP) region detected in several studies have been chosen; Pacific Decadal Oscillation (PDO) (Mantua et al., 1997), Aleutian Low Pressure (ALP) (Beamish et al., 1997), Arctic Oscillation (AO) (Thomson and Wallace, 1998), Siberian High Pressure (SHP) (Gong and Ho, 2002) and East Asian Winter Monsoon (EAWM) (Jhun and Lee, 2004).

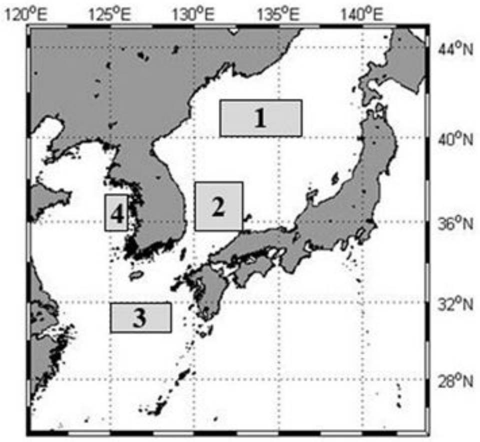

Fig. 1. Study areas in the different Korean marine waters; (1) north East Sea (NES), (2) south East Sea (SES), (3) Northern East China Sea (ECS), (4) Eastern Yellow Sea (YS).

3. Results and Discussion

3.1 Temperature variability in the northern part of the East Sea

Annual and seasonal fluctuation patterns in the 10 m sea water temperatures of northern part of the East Sea have been identified since 1950s (Fig. 2). The annual pattern reveals that since mid of 1970s to early 1990s, the temperature was lower than average whereas from mid of the 1990s, the temperatures was in increasing pattern mode (Fig. 2a). Winter and autumn (Fig. 2b and 2e) have almost similar fluctuation patterns for long term basis. Both have lower temperature values than average in the late 1970s and a sharp shift to the higher temperature than average in the late 1980s. CRS has been demonstrated in the table 1. In this region, 1976 CRS was limited to winter and autumn season only. 1988 CRS was detected in all of the seasons without spring. Most recent 1998 CRS has been detected in the spring and summer time. In this region, 1988 CRS was the most evident phenomena.

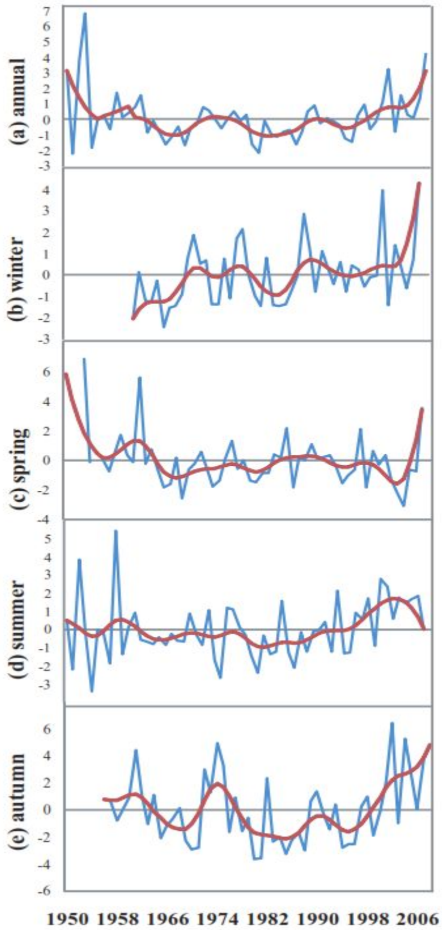

Fig. 2. Time series of annual and seasonal sea water temperature (10 m) anomaly of northern East Sea (NES) (Smoothed by a low-pass Butterworth filter with 10-yr cut-off period).

Table 1. Regime shifts (dark circle) in the north East Sea water temperatures in relation to North Pacific Climate Regime Shifts since 1950 (data smoothed by a low-pass butterworth filter with 10-yr cut-off period)

North East Sea	1976 CRS	1988 CRS	1998 CRS
Annual	●	●	
Winter	●	●	
Spring			●
Summer		●	●
Autumn	●	●	

3.1.1 Temperature variability in the southern part of the East Sea

Annual and seasonal fluctuation patterns in the 10 m sea water temperatures of southern part of the East Sea have been illustrated in the figure 3. The annual sea water fluctuation pattern reveals that since mid of 1970s to early 1990s, the temperature was lower than average whereas from mid of the 1990s, the temperatures was in increasing pattern (Fig. 3a). From the late of 1990s, the temperature was also started to decrease in the annual pattern. So, all the 1976, 1988 and 1998 CRS have been occurred in annual pattern of the sea water temperatures in this region (Table 2). In winter season (Fig. 3b), also all of the CRS was highly evident. In spring season (Fig. 3c), however, the slight shifts were detected in all that CRS period. In summer season, the CRS was limited to 1988 and 1998 and in autumn season, the CRS was limited only in 1998. In this region, recent 1998 CRS was most evident among all other CRS.

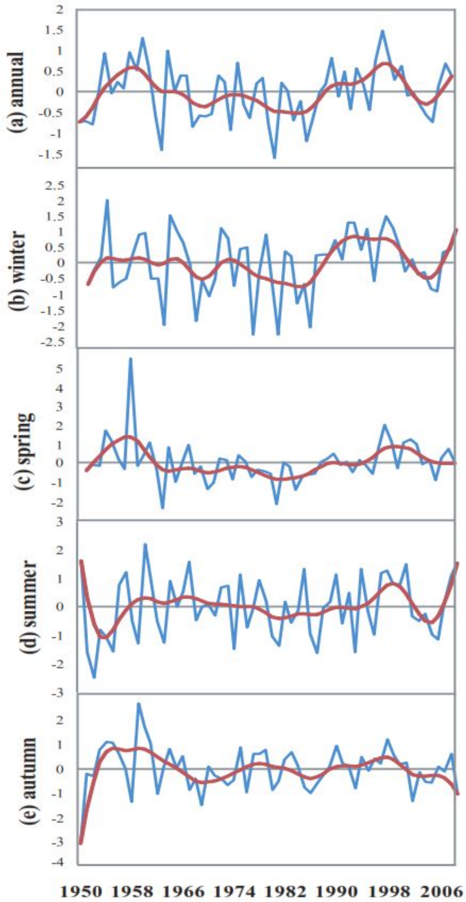

Fig. 3. Time series of annual and seasonal sea water temperature (10 m) anomaly of southern East Sea (SES) (Smoothed by a low-pass Butterworth filter with 10-yr cut-off period).

Table 2. Regime shifts (dark circle) in the South East Sea water temperatures in relation to North Pacific Climate Regime Shifts since 1950 (data smoothed by a low-pass Butterworth filter with 10-yr cut-off period)

South East Sea	1976 CRS	1988 CRS	1998 CRS
Annual	●	●	●
Winter	●	●	●
Spring	●	●	●
Summer		●	●
Autumn			●

3.2 Temperature variability in the East China Sea

Annual and seasonal fluctuation patterns in the 10 m sea water temperatures of East China Sea have been illustrated figure 4. There were three regimes can be detected in annual fluctuation

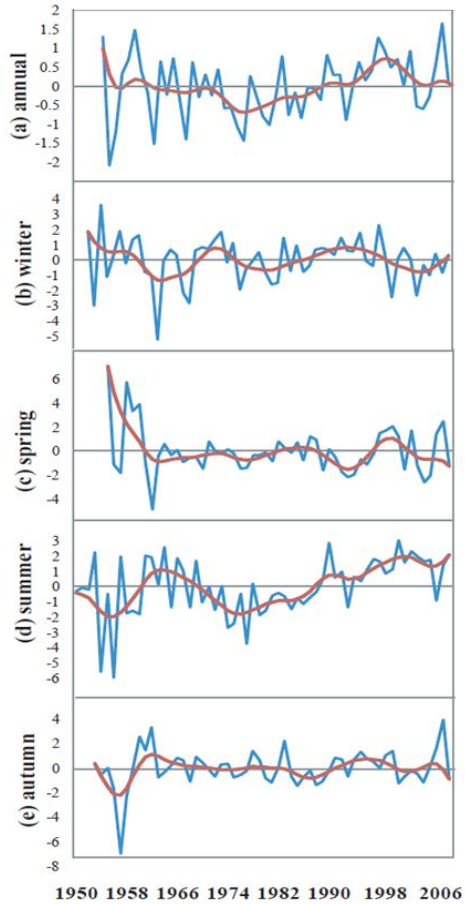

Fig. 4. Time series of annual and seasonal sea water temperature (10 m) anomaly of East China Sea (ECS) (Smoothed by a low-pass Butterworth filter with 10-yr cut-off period).

pattern; a warm regime- from 1950s to early 1970s, a colder one- from early 1970s to early 1990s and a warmer regime- from early 1990s to the late 1990s; after 1998 CRS, it was in a decreasing pattern (Fig. 4a). In winter season (Fig. 4b), all the three CRS were evident clearly. In spring season (Fig. 4c), 1988 CRS and 1998 CRS were detected. In summer season (Fig. 4d); there was clear increasing trend in temperature since mid of 1970s. 1988 CRS has been identified in most of the seasons except autumn (Table 3).

Table 3. Regime shifts (dark circle) in the East China Sea water temperatures in relation to North Pacific Climate Regime Shifts since 1950 (data smoothed by a low-pass Butterworth filter with 10-yr cut-off period)

East China Sea	1976 CRS	1988 CRS	1998 CRS
Annual	●	●	●
Winter	●	●	●
Spring		●	●
Summer		●	
Autumn			

3.3 Temperature variability in the Yellow Sea

Annual and seasonal fluctuation patterns in the 10m sea water temperatures of Yellow Sea have been illustrated in the figure 5. There were three prominent regimes in the annual temperatures pattern; from mid of 1960s to mid of 1970s, a warmer regime, from mid of 1970s to late 1980s, a colder regime and from late 1980s to present, a warmer one (Fig. 5a). In winter season (Fig. 5b), a slight shift was detected in the time of 1976 and for this region 1998 CRS has been identified in all the seasons in this area (Table 4). 1988 CRS also has been identified in most of the seasons without autumn.

3.4 Temperature variability in the sea water and its relation to climate indices

The correlation coefficients between upper layer sea water temperatures in all of the study areas and climate indices are illustrated in the table 5. In the north East Sea region, AO, SHP and EAWM have a significant correlation with the annual, winter and autumn sea water temperatures. However, there are no significant correlation between sea water temperatures with PDO and ALP. In the south East Sea region, there are significant correlations between annual, winter and spring sea water temperatures

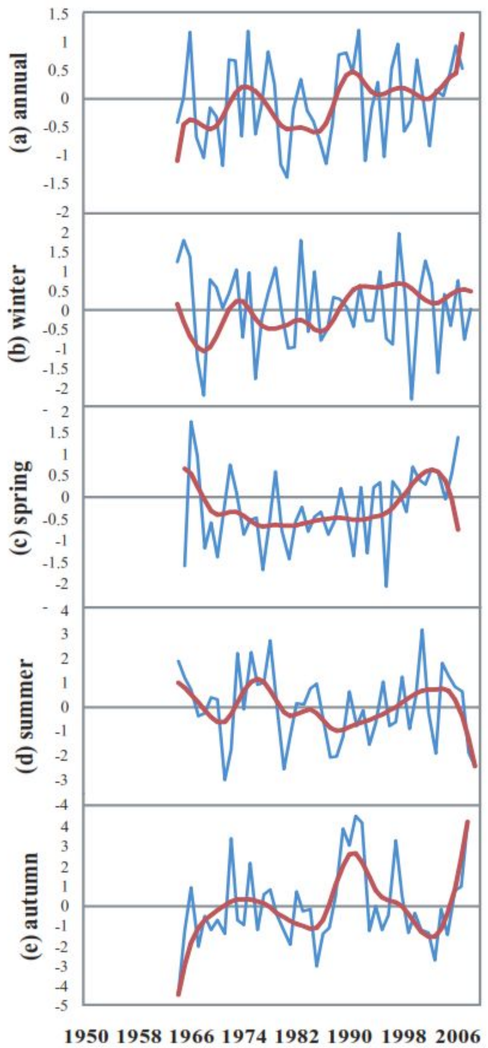

Fig. 5. Time series of annual and seasonal sea water temperature (10 m) anomaly of Yellow Sea (YS) (Smoothed by a low-pass Butterworth filter with 10-yr cut-off period).

Table 4. Regime shifts (dark circle) in the Yellow Sea water temperatures in relation to North Pacific Climate Regime Shifts since 1950 (data smoothed by a low-pass Butterworth filter with 10-yr cut-off period)

Yellow Sea	1976 CRS	1988 CRS	1998 CRS
Annual	●	●	●
Winter	●	●	●
Spring		●	●
Summer		●	●
Autumn			●

with all climate indices. There is no significant correlation in the autumn sea water temperature with any climate indices. In the Northern East China Sea region, only annual and winter temperatures have significant correlation with the AO, SHP and EAWM, however, there are no significant correlations between PDO and ALP with the sea water temperatures. In the Eastern Yellow Sea region, annually, the sea water temperature is significantly correlated with all the climate indices. In winter, the significant correlation is limited to the AO, SHP and EAWM. Also in autumn, there are significant correlations from the climate indices except SHP. In the north East Sea region, however, there are early influences (in autumn) from the AO and SHP which are normally active in the winter season. Also in the Eastern Yellow Sea region, early influences (in autumn) from AO, EAWM, PDO and ALP are detected except SHP.

Table 5. Correlation coefficients between upper layer temperatures and climate indices

SWT	AO	SHP	EAWM	PDO	ALP
North East Sea					
annual	.263*	-.319*	-.232	-.223	-.087
winter	.416**	-.320*	-.364**	-.070	-.023
spring	.116	-.011	-.058	-.190	-.031
summer	.019	-.322*	-.053	.115	.126
autumn	.337**	-.408**	-.164	-.205	-.099
South East Sea					
annual	.292*	-.400**	-.518*	-.276*	-.257*
winter	.437*	-.455**	-.672**	-.200	-.294*
spring	.258*	-.403**	-.403**	-.178	-.150
summer	.143	-.261*	-.236	-.216	-.225
autumn	-.058	-.025	-.127	-.023	-.054
East China Sea					
annual	.309*	-.500**	-.446**	-.074	-.048
winter	.344**	-.434**	-.540**	-.239	-.233
Spring	.249	-.431**	-.240	-.035	.004
Summer	.103	-.164	-.098	.029	.125
autumn	.048	-.300*	-.141	.161	.047
Yellow Sea					
annual	.304*	-.256	-.620**	-.369**	-.350*
winter	.389**	-.510**	-.567**	-.193	-.008
spring	.312*	-.293*	-.437**	-.249	-.142
summer	-.077	.113	-.131	-.122	-.209
autumn	.299*	-.143	-.319*	-.374**	-.329*

SWT: Sea Water Temperature. AO: Arctic Oscillation; SHP: Siberian High Pressure; EAWM: East Asian Winter Monsoon; PDO: Pacific Decadal Oscillation; ALP: Aleutian Low Pressure. Single and double asterisks represent significance at $P < 0.05$ and $P < 0.01$, respectively.

Large scale climate variability in the North Pacific region are interconnected through teleconnected pattern. PDO and ALP in the central North Pacific, AO in the North pole region, SHP in the middle to high latitude Eurasia and EAWM in the East Asian region, all are either directly or indirectly interconnected. EAWM has the significant influence on most of the regions sea water temperatures through vertical mixing process. However, EAWM is influenced by all of the climate variability in the North Pacific region. Pressure gradient between the SHP in the Eurasia and ALP in the Alaska, North Pacific region significantly influence the EAWM and consequently influence the sea water upper layer temperature. AO, however, influence the sea water temperature in these region through the SHP system. AO and SHP system has a significant negative correlation (Gong and Ho, 2002); when AO was in positive phase after 1988 climate regime shift, SHP was abruptly changed to negative phase. SHP control the surface air temperature in the Eurasia region and consequently control the upper layer sea water temperatures in all of the study areas. PDO-the decadal sea water temperature anomaly in the central North Pacific, however, influence the northwest Pacific marginal sea water temperatures through Rossby waves surfacing from the northeast Pacific to northwest Pacific. Also North Pacific subtropical gyre oscillation which might have influenced from the PDO decadal variability, control the Kuroshio Current volume transport to the northwest Pacific region. Decadal pattern of Kuroshio Current volume transport, however, control the Tsushima Warm Current volume transport to the North East China Sea and East Sea region.

4. Conclusion

Long term seasonal fluctuation pattern of upper layer (10 m) water temperatures in the northern and southern part of East Sea, East China Sea and Yellow Sea have been analyzed. From the regime shifts analysis, 1988 CRS has been the most dominant features in most of the seasons in all of the study areas than other two 1976 CRS and 1998 CRS. 1998 CRS was strongly detected in the Yellow Sea and the southern part of the East Sea region. However, in winter, all the three major CRS were detected in all of the seasons and in all the study areas. Annually and in winter season, significant influences have been detected in all the study area; however, influences from PDO and ALP are limited to south East Sea and Yellow Sea region. Both of AO and SHP are active quite early from winter in the north East Sea region. Also in the Yellow Sea region, AO is also early activated and have greater influences on the sea water temperature.

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