VARIATIONS OF SEA LEVEL AND SEA SURFACE TEMPERATURE IN THE KOREAN SEAS IN THE LONG TERMS USING REMOTE SENSING

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KEY WORDS : MSLA, SST, Topex/Poseidon altimetry, Tide gauges, Interannual variations

ABSTRACT : Sea Level (SL) around the Korean peninsula was rising at the rate of 3.57 mm/yr on the average from 1993 to 2008, which is 1.2 times higher than the world ocean. The data provided from Korea Hydrographic Oceanographic Administration (KHOA). And satellite images (NOAA/AVHRR) were used during the period. In this study, we investigated SL and SST changes in regional sections of the East Sea, the Yellow Sea and the South Sea. SL and SST are high in the summer and fall, and it is low in spring and winter, at sea surface variation of satellite data (Mean Sea Level Anomaly) and in-situ data (Tide Gauge). The correlation coefficient shows 0.5729 at Mukho which is located on the coast, and Chujado and Heuksando are show 0.7160 and 0.6484, respectively. The correlation coefficient of SST is higher than sea surface variations which were 0.9499 in Mukho, 0.9611 in Chujado and 0.9442 in Heuksando. The comparison between SST and MSLA is 0.5584 at the East Sea, The Yellow Sea and The South Seas are 0.8442 and 0.7752, respectively. The correlation coefficient was lower in the East Sea. The reason is considered the effect of various currents. SST appears to be about 1 to 2 months faster than MSLA.

Ⅰ. INTRODUCTION

The ocean takes 71% of the earth surface and plays roles of storing the heats of the earth and adjusting the climate through circulation of ocean current and heat exchange between the ocean and the atmosphere. Recently, the interests in how change of the ocean and the overall climate system affect reciprocally are getting high as the earth warming emerges as a major issue globally.

According to the report of IPCC (Intergovernmental Panel on Climate Change) published in 2001, there was a statement that the sea level of the earth rose more than 10 cm in 20th century and the sea surface is expected to rise between minimum 10 cm and maximum 88cm. (IPCC,2001) Also, the rate of climb of global sea level was reported to record 3.10±4mm/yr^{-1}. (Cabanes *et al*.,2001)

The sea surface temperature is one of the factors which affect the change of the sea level. As for the long-term temperature changing trend around the Korean peninsula from 1968~2000, 0.72℃ rose in the East Sea with 0.022℃/yr^{-1},0.53℃ in the South Sea with 0.016℃$^{-1}$/yr and 0.99℃ in the West Sea with 0.03℃$^{-1}$/yr for 33 years. (Suh *et al*., 2003)

This study aims to understand the change of the sea surface temperature and the sea level and the interrelationship between them and examine the characteristics of the long-term climate change. Also this study aims to understand the timely and spacious change characteristics, the interrelationships and aspects of seasonal and annual changes through continuous monitoring on the change of the sea surface temperature and the sea level with long-term satellite data (SST, Altimeter) of North East Asia and forecast the change of the sea surface temperature and the sea level around the Korean Peninsula.

Ⅱ. DATA AND METHODS

NOAA/AVHRR (National Oceanic and Atmospheric Administration/Advanced Very High Resolution Radiometer) MCSST (Multi-Channel Sea Surface Temperature) data provided by PODAAC (Physical Oceanography Distributed Active Archive Center) of NOAA jet propulsion laboratory were used as the sea surface temperature data. Time scope of the data is 1993~2008 and each data is the average of 7 days. The shores and land where the data was not observed were masked, SLA (Sea Level Anomaly) by T/P (Topex/Poseidon) and Jason-1 satellites provided by AVISO (Archiving, Validation and Interpretation of Satellite Oceanographic data), were used the sea level during 16 years (Jan. 1993 to Dec. 2008). The correlation between sea level and sea surface temperature were analyzed and compared the characteristics of each waters.

Ⅲ. RESULTS AND DISCUSSIONS

1. ANALYSIS ON CORRELATION BETWEEN IN-SITU DATA AND SATELLITE DATA

(1) Altimeter Data

SLA data acquired by T/P and Jason-1 were extracted and averaged to understand the change of the sea level in long-term for each waters. According to the results, SLA in the East Sea recorded the slope of 4.23mm/yr and increase of 6.34 cm for the study scope. And the rise rate in each waters are the East Sea (4.23mm/yr) > the Yellow Sea (3.65mm/yr) > the South Sea (2.84mm/yr) in order, respectively (Table 1).

(2) SST Data

SST data acquired by NOAA/AVHRR were extracted and averaged to understand the change of the sea surface temperature in long-term for each waters. According to the results, SST in the East Sea recorded the slope of 0.059℃/yr and the increase of 0.89℃. And the rise rate in each waters are the East Sea (0.059℃/yr) > the South Sea (0.058℃/yr) > the Yellow Sea (0.04℃/yr) in order. The East Sea and the South Sea showed similar rise rates, which is a little different from the trend of satellite altimeter data (Table 1).

Table 1. Rising of SL and SST in each waters using satellite data

Area	SL		SST	
	Slope (mm/yr)	**Increase (cm)**	**Slope (℃/yr)**	**Increase (℃)**
East Sea	4.23	6.34	0.059	0.89
Yellow Sea	3.65	5.47	0.04	0.6
South Sea	2.84	4.26	0.058	0.87

(3) T/G and T/P

Table 1 is the result of time series analysis between T/G around the Korean Peninsula and the nearest Pixel T/P data and shows high correlation with 0.7160, 0.7694 and 0.6961 in Geomundo, Jeju and Gunsan respectively where are relatively located in outer seas.

Table 2. Correlation coefficient of T/P and T/G

Area		Correlation coefficient
East Coast	Mukho	0.5729
	Ulleungdo	0.4080
	Pohang	0.4028
South Coast	Geomundo	0.6388
	Chujado	0.7160
	Jeju	0.7694
Yellow Coast	Mokpo	0.6787
	Heuksando	0.6484
	Gunsan	0.6961

(4) In-situ SST NOAA SST

Table 2 shows the comparison of in-situ SST and NOAA SST. The sea surface temperatures of all research sites showed high correlation value unlike the sea levels and it must be due to low accuracy of T/P as is known to in around the shores.

Table 3. Correlation coefficient of NOAA and in-situ data

Area		Correlation coefficient
East Coast	Mukho	0.9499
	Ulleungdo	0.9639
	Pohang	0.9270
South Coast	Geomundo	0.9606
	Chujado	0.9661
	Jeju	0.9482
Yellow Coast	Mokpo	0.9195
	Heuksando	0.9442
	Gunsan	0.9189

2. COMPARISON OF SST AND SL IN EACH WATERS

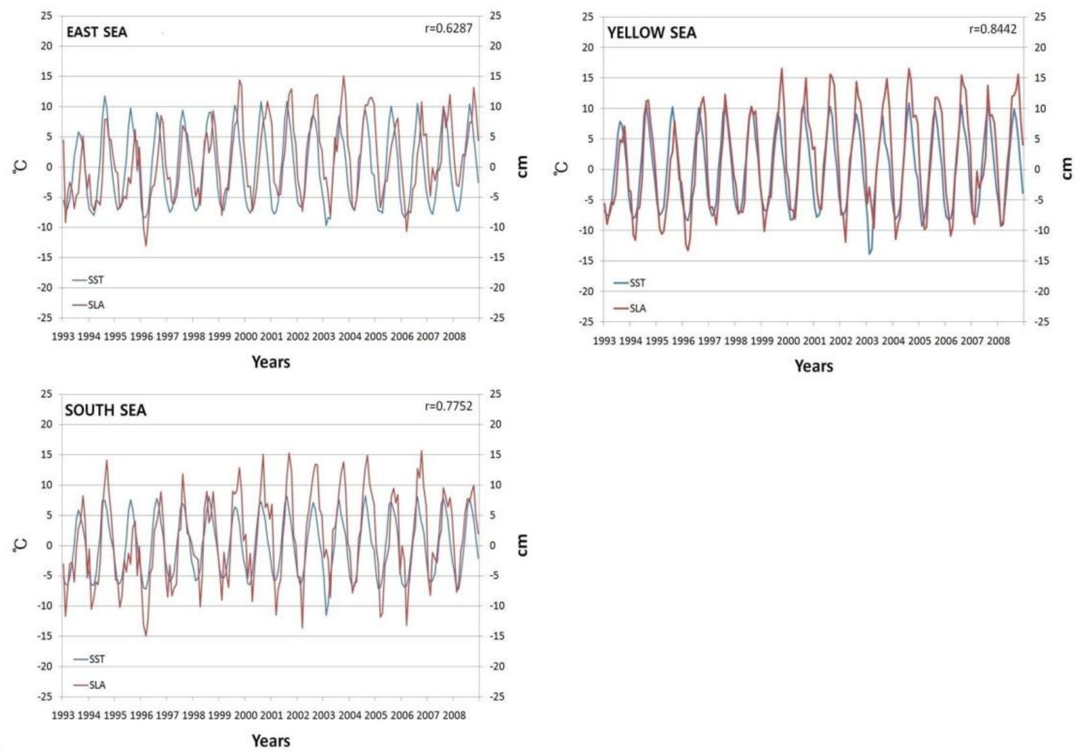

Figure 1. Comparison of time series between SL and SST in each waters.

It was revealed that above rise rates of SL and rise rates of SST in each waters have different patterns. So the correlation between the two data was compared by each waters. According to the result, the Yellow Sea and the South Sea showed significantly high correlation with 0.8442 and 0.7752, respectively. Regular patterns could be seen as in Fig. 1. as time series analysis of total research waters. A peak of sea surface temperature appeared and a peak of sea level appeared in 1~3 months. The sea water can be said to react more sensitively to the temperature.

3. SEASONAL ANALYSIS OF SL IN EACH WATERS

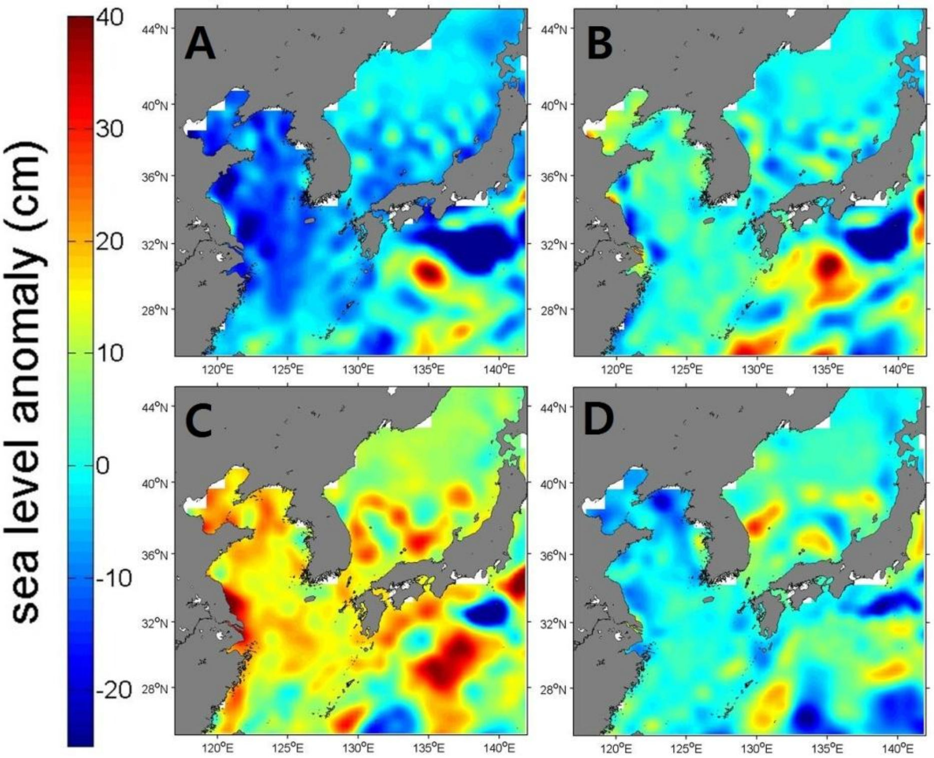

Figure 2. Seasonal average of MSLA, for (A) spring, (B)summer, (C)fall and (D) winter.

Data acquired by satellite altimeters were investigated to examine the seasonal changes of sea level by each waters. Low rise rates of sea level were recorded in spring in total areas and the Yellow Sea showed a down trend with -1.13mm/yr. In case of the Yellow Sea, summer (5.34mm/yr) and fall (5.79mm/yr) showed high rise rates and the South Sea showed very high rise rate, 7.52mm/yr in summer. The East Sea also recorded a very high rise rate of 5.78mm/yr.

Table 4. Seasonal variations of sea level in each waters

Area		Yellow Sea	South Sea	East Sea
Spring	Slope(mm/yr)	-1.13	0.12	0.96
	Increase(cm)	-1.69	0.17	1.43
Summer	Slope(mm/yr)	5.34	7.52	5.78
	Increase(cm)	8.00	11.28	8.67
Fall	Slope(mm/yr)	5.79	2.99	4.42
	Increase(cm)	8.68	4.49	6.63
Winter	Slope(mm/yr)	4.85	4.87	5.30
	Increase(cm)	7.27	7.30	7.95

4. SEASONAL COMPARISON OF SST IN EACH WATERS

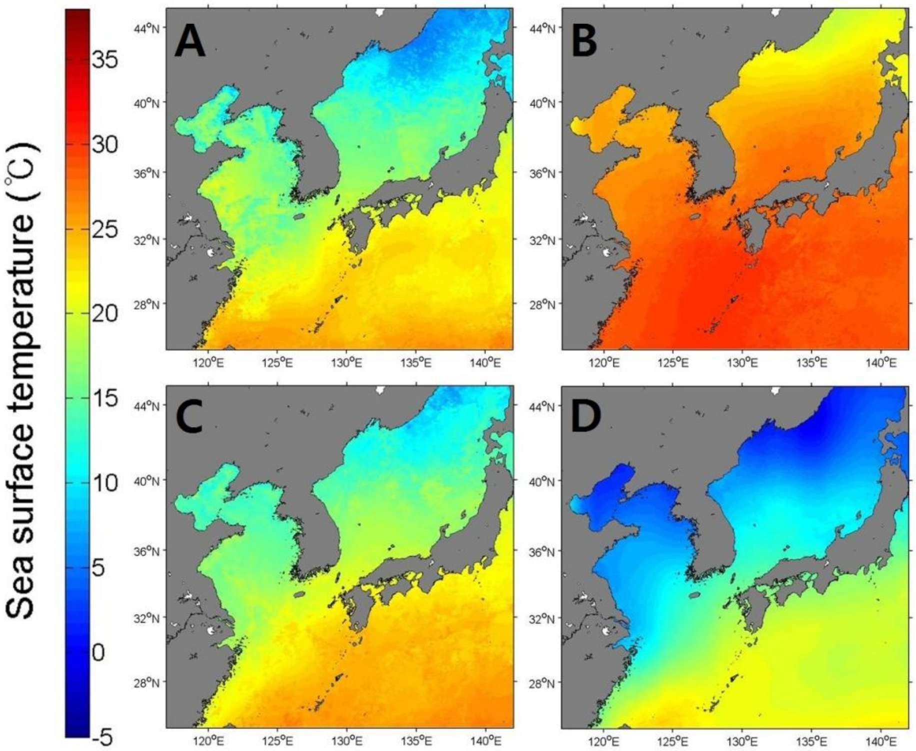

Figure 3. Seasonal average of SST, for (A) spring, (B) summer, (C) fall and (D) winter.

Table 5. Seasonal variations of sea surface temperature in each waters

Area		Yellow Sea	South Sea	East Sea
Spring	**Slope(℃/yr)**	0.05	0.05	0.04
	Increase(℃)	0.72	0.81	0.53
Summer	**Slope(℃/yr)**	0.14	0.15	0.31
	Increase(℃)	2.14	2.31	4.63
Fall	**Slope(℃/yr)**	-0.03	0.01	0.13
	Increase(℃)	-0.48	0.18	1.96
Winter	**Slope(℃/yr)**	-0.08	-0.05	0.02
	Increase(℃)	-1.06	-0.68	0.27

The seasonal changes of sea surface temperature in each waters were investigated. Then, the slope of sea surface temperature was different from that the sea level. The change of sea level was decrease in spring, but the change of sea surface temperature was decrease in winter. In case of the Yellow Sea, the sea surface temperatures of fall (-0.03℃/yr) and winter (-0.08℃/yr) showed a decreasing trend slightly. In case of the Yellow Sea and South Sea, while the temperature change trends were very similar, and the East Sea recorded high rise rate with summer (0.31℃/yr) and fall (0.13℃/yr). This should be considered that the average sea surface temperature rose as the fronts, which were formed in the East Sea, moved to north due to the rise of sea surface temperature.

Ⅳ. CONCLUSIONS

In this study, the in-situ data and satellite data were used to investigate the trends of sea surface temperatures and sea level around Korean waters. As the results, peaks of sea surface temperature appeared faster about 1 to 3 months than those of sea levels. Therefore, it should be suggested the change of sea surface temperature acts fastly to the change of sea levels.

In the case of sea level, rise rates of sea level showed low value on spring in total water areas, and rise rates of the sea level showed a trend with -1.13mm/yr in the Yellow Sea. In case of the Yellow Sea, sea level showed a high rise rates of summer (5.34mm/yr) and fall (5.79mm/yr). The case of the South Sea showed very high rise rates, as 7.52mm/yr in summer. The case of the East Sea recorded very high rise rates of 5.78mm/yr.

The seasonal changes of sea surface temperature in each waters were investigated. Then, the slope of sea surface temperature was different from that of the sea level. The change of sea level was decreased in spring, and the change of sea surface temperature was decreased in winter. In the case of the Yellow Sea, the sea surface temperatures showed slightly a decreasing trend in fall (-0.03℃/yr) and winter (-0.08℃/yr).

The slope of sea surface temperature in the Yellow Sea and South Sea were very a similar, and the East Sea recorded very a high value in summer (0.31℃/yr) and fall (0.13℃/yr). This should be considered that the average sea surface temperature rose near the polar-front in the East Sea, which moved to north due to the rise of sea surface temperature with the influence of global warming.

ACKNOWLEDGEMENTS

This work was researched by the supporting project to BK21 and educate GIS experts.

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