Satellite data analysis of the China Coastal Waters in the Seas surrounding Jeju Island, Korea

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ABSTRACT : China Coastal Water (CCW) usually appears in the seas surrounding Jeju Island annually (June–October) and is very pronounced in August. The power spectrum density (PSD), sea level anomalies (SLAs), and sea surface temperatures (SSTs) were found to peak annually and semiannually. The peaks at intervals of 80-, 60-, and 43-days are considered to be influenced by CCW and the Kuroshio Current. Generally, low-salinity water appears to the west of Jeju Island from June through October and gradually propagates to the east, where CCW meets the Tsushima Current. Empirical orthogonal function (EOF) analysis of SLAs and SSTs indicated that the variance in SLAs and SSTs was 55.70 and 98.09% in the first mode, respectively. The PSD for the first mode of EOF analysis of SLAs was stronger in the western than in the eastern waters because of the influence of CCW. The PSD for the EOF analysis of SSTs was similar in all areas (the Yangtze Estuary and the waters to the west and east of Jeju Island), with a period of approximately 260 days.

KEY WORDS: CCW, EOF, Harmonic analysis, PSD, Salinity, SLA, SST

1. INTRODUCTION

The seas surrounding Jeju Island are greatly affected by the Tsushima Current in the south (Rho, 1985) and by South Sea coastal waters in the north (Choi, 1989). The surface layers of the sea in this area are particularly influenced by China Coastal Water (CCW), with high temperatures and low salinity values in the summer (Kim and Rho, 1994). The goal of the present study was to characterize variations in sea level anomalies (SLAs), sea surface temperatures (SSTs), and salinity, and to monitor the presence of CCW and its flow pattern.

2. METHODS

The research area extended from the Yangtze Estuary to the seas south of Korea and surrounding Jeju Island (31–35° N, 120–129° E)(Fig. 1).

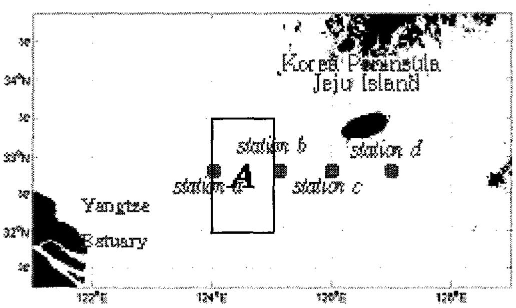

Fig. 1. Map shows the area studied.

To investigate aspects of, and the causes of, variation in SLAs and SSTs, the data were analyzed using empirical orthogonal functions (EOFs). The method of EOF analysis that is widely used in oceanographic and meteorological research is the same as principal components analysis (PCA).

This study was conducted from 1995 through 1999. During this time, a low-salinity core below 20.0 psu was observed in waters 30 nautical miles to the west of Jeju Island in summer 1996. Also, 700–900 mm precipitation was recorded from June through August 1998 because of China's heavy rainfall. More than 400 mm of rain fell in the Yangtze River area during June 1999.

Topex/Poseidon altimeter data obtained from CNES/AVISO for cycles 85 (January 4, 1995) through 268 (December 23, 1999) were used to determine variations in sea surface heights. Sea surface temperature (SST) data were from the NOAA/NASA Pathfinder Advanced Very High Resolution Radiometer (AVHRR). Salinity data were in situ measurements of surface salinity from lines 203–209 and 311–316 of the serial oceanographic observations of the National Fisheries Research and Development Institute (NFRDI).

3. RESULTS AND DISCUSSION

3.1 Sea level anomaly (SLA) variations

Figure 2 shows the mean seasonal variations in SLAs in 1996. SLAs were clearly distinguished by seasonal variation, and were greater during the summer and autumn of 1996 and 1999 than in other years, (1996: summer, 14.46 cm and autumn, 15.80 cm; 1999: summer, 14.44 cm and autumn, 15.99 cm). These results are attributable to the inflow of low-salinity CCW in 1996 and heavy rainfall in the Yangtze River watershed in 1999.

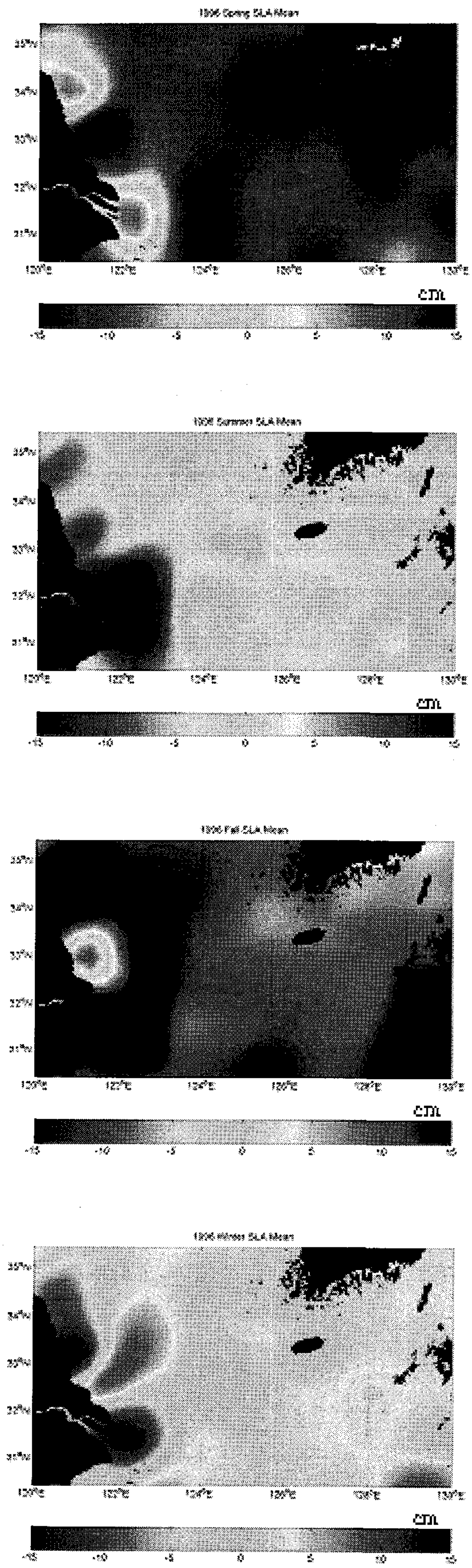

Fig. 2. Seasonal variation in SLAs in 1996.

In PSD for between Jeju Island and the Yangtze Estuary (Station B). The results indicate that the annual amplitude had a period of about 365 days and the semiannual amplitude had a period of about 153 days. Here, 100- and 60-day periods were considered involved with CCW and the Kuroshio Current, respectively.

3.2. Sea surface temperature (SST) variations

SSTs showed the same tendencies each season. Temperatures were low in the upper layer of the Yellow Sea and high in the lower layer of the East China Sea, along the dotted line shown in Fig. 3. The high temperatures along the southern section of the dotted line are attributable to the influence of the Kuroshio Current. Fig. 4 clearly shows the distribution of SSTs and the boundary between the Yellow Sea and the East China Sea. This boundary formed by CCW is thought to act as a barrier to the flow of CCW. This barrier along the dotted line forms in slightly different locations each year, but the difference is not great. Therefore, the location of these barriers was considered to indicate the flow of CCW.

In the PSD for SSTs at Station A in the central area between Jeju Island and the Yangtze Estuary. It was similar to the PSD of SLAs. The results indicate that the annual amplitude had an approximately 365-day period and the semiannual amplitude had an approximately 180-day period. Each period was considered to involve the Kuroshio Current, and the 43-day period to also involve CCW.

3.3. Harmonic analysis of SLAs and SSTs

To estimate seasonal variance in SLAs and SSTs in the waters near Jeju Island, the annual amplitude and annual phase derived from harmonic analysis of SLAs and SSTs were calculated (Fig. 4). The annual amplitude of SLAs at Je_E was 8–9.5 cm and the annual phase was 267° (end of August). The annual amplitude of SLAs at Je_W was 13 cm with an annual phase of 275° (early September). Je_E was about 8 days earlier than Je_W. The annual amplitude of SSTs at Je_E was 7–8.5°C. when the annual phase was usually 242° (early August). The annual amplitude of SSTs at Je_W was 5.5~6°C when the annual phase was 236° (the end of June). Therefore, SSTs at Je_E were about 6 days earlier than at Je_W, possibly because of the high temperature of the Kuroshio Current.

Table 1 shows the annual amplitude and annual phase of SLAs and SSTs at Je_E and Je_W. Here, SLAs of Je_E and Je_W appeared about one month later than SSTs. Fig. 5 shows the spatial mean SLA and SST for area A (32~33°30' N, 124~125°E). There was typical annual variance and a time lag of about one to three months between SLAs and SSTs, except in 1997. The correlation coefficient between SLAs and SSTs was highest (0.72) in area A.

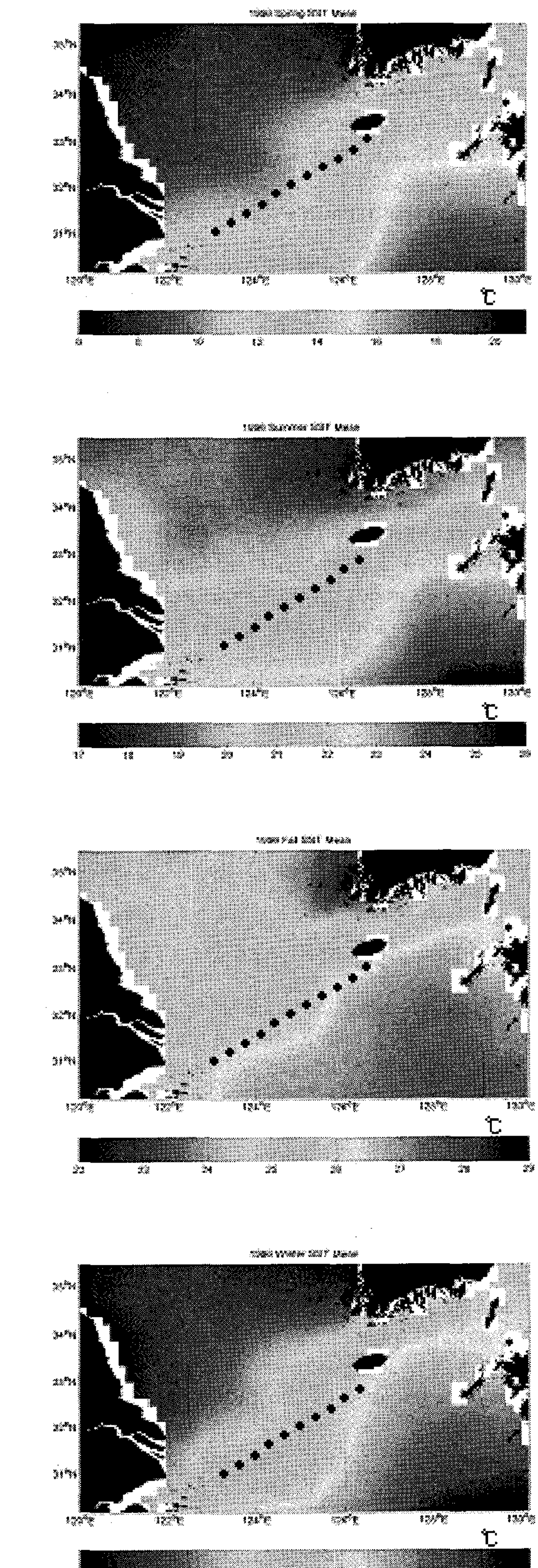

Fig. 3. Seasonal variations in SSTs in 1996.

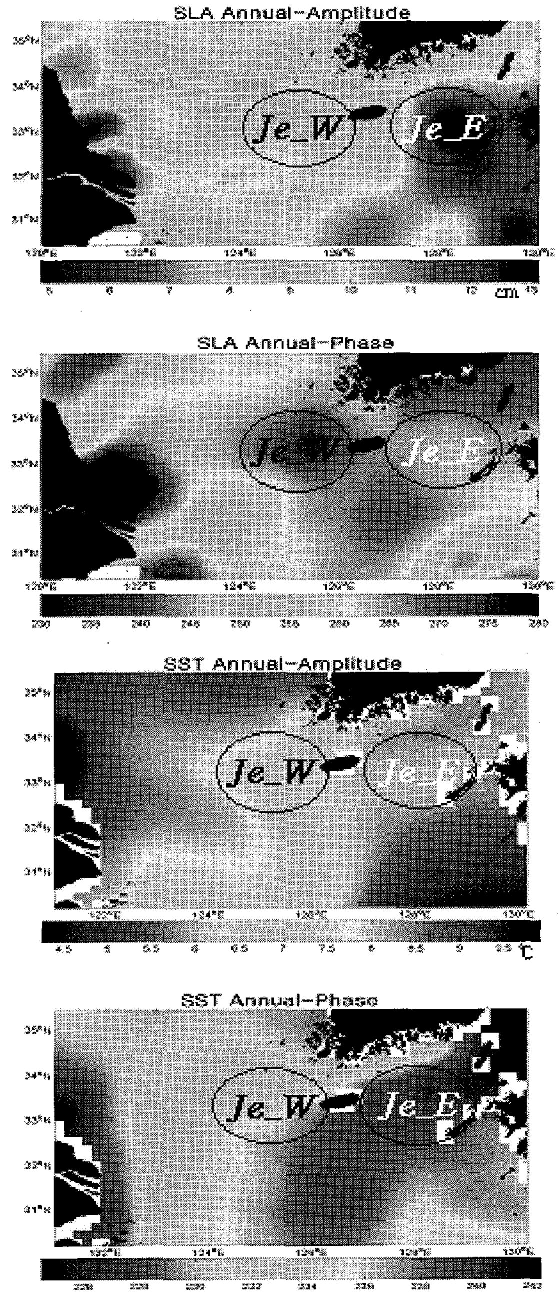

Fig. 4. Harmonic analysis of SLAs and SSTs.

Table 1. Harmonic analysis of SLAs and SSTs.

		SLA	SST
Je_E	amplitude	8~9.5 cm	7 ~ 8.5℃
	phase	267° (end of August)	242° (early August)
Je_W	amplitude	over 13 cm	5.5 ~ 6℃
	phase	275° (early September)	236° (end of July)

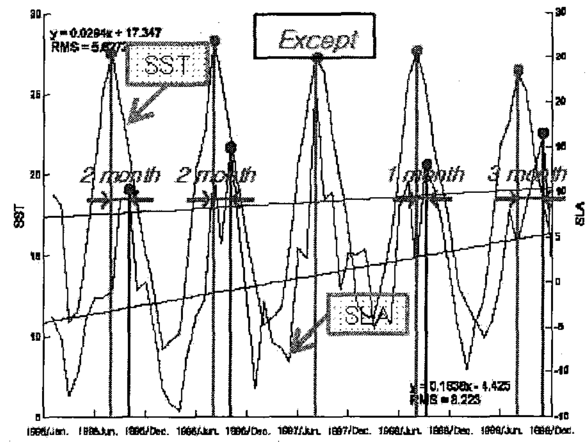

Fig. 5. Time series of SLAs and SSTs in Area A.

3.4. Salinity

The salinity west of Jeju Island in August was 9 psu lower than that east of Jeju Island (Fig. 6). Although the location with the lowest salinity was not consistent every year, it was usually first evident to the southwest of Jeju Island, suggesting that CCW approaches from the west of Jeju Island

The salinity of the western waters was usually 1–3 psu lower than that of the eastern waters. Therefore, we postulate that CCW influences the western waters, and that the Kuroshio Current influences the eastern waters.

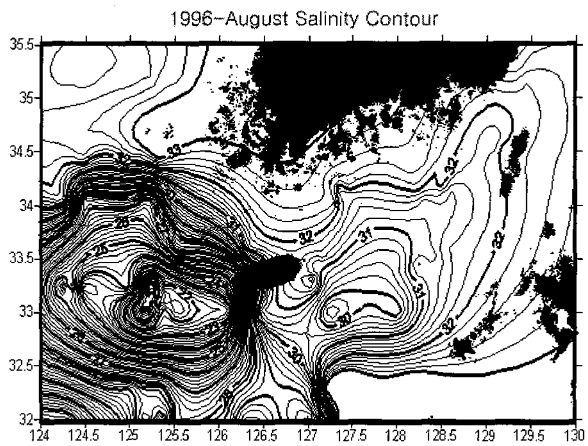

Fig. 6. Distribution of salinity in 1996.

3.5. Empirical orthogonal functions for SLAs and SSTs

3.5.1. Sea level anomalies (SLAs)

The first, second, and third modes accounted for 55.70, 26.22, and 13.13% of the variation, respectively. In total, they explained 95.04% of the variance, indicating that sea surface variations in the study area can be explained by the three modes.

3.5.2. Sea surface temperatures (SSTs)

In the first mode of EOF for SSTs. The first mode explained 98.70% of the total variance.

4. CONCLUSIONS

For PSD, SLAs and SSTs peaked with annual and semiannual amplitudes. The 80-, 60-, and 43-day period peaks were considered influenced by CCW and the Kuroshio Current.

Salinity during the periods investigated in 1996 was lowest to the southwest of Jeju Island. Salinity usually began decreasing in June (ca. 32 psu), and was lowest in August, rising to over 31 psu in October. These results indicate that CCW usually appears in June, is strongest in August, and gradually diminishes in October.

To investigate aspects and causes of variation in SLAs and SSTs, the data were analyzed using EOF methods. The first, second, and third modes accounted for 55.70, 26.22, and 13.13%, respectively, of the variance in SLAs, i.e., 95.04% of the total variance combined, indicating that sea surface variations in the study area could be explained by just three modes. For SSTs, the first mode represented 98.70% of the total variance.

Acknowledgements

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