ON CHARACTERISTICS OF HARMFUL ALGAL BLOOMS IN THE SOUTHEAST COASTAL WATERS OF KOREA USING SATELLITE DATA

Do-hyun Hwang, Seung-Yeol Oh, Hong-Joo Yoon

Department of Spatial Information Engineering, Pukyong National University, 599-1, Daeyeon 3-Dong, Nam-Gu, Busan 608-737 Korea; Tel : +82-51-620-6114
E-mail: rupine725@hanmail.net

KEY WORDS: Harmful Algal Blooms (HABs), SeaWiFS, OC4, SST, Chlorophyll-*a*

ABSTRACT: Harmful Algal Blooms (HABs), caused by Cochlodinium species that appear from the middle of August until the end of September, affect economic loss and aquaculture in the southeast coastal waters of Korea. It was studied alongside the HABs with the environmental (meteorological and oceanic) and satellite data in September compared to the data in March, 2010.

Chlorophyll-*a* concentrations were calculated using Sea-viewing Wide Field-of-view Sensor (SeaWiFS) images by an Ocean Color 4 (OC4) algorithm. The cell concentrations of Chlorophyll-*a* in March was compared to the cell concentrations in September by using the SeaWiFS images. In meteorological data from March, the mean air temperature, the mean wind speed, and the sunshine were 5.87℃, 3.87m/s and 9.73h/day, respectively. The data from September, the mean air temperature, the mean wind speed, and the sunshine were 19.17℃, 1.4m/s and 9.03h/day, respectively. Sea Surface Temperature (SST) showed 10.85℃ in March and 22.05℃ in September. The HABs occurred when SST was 25.1～26.8℃ in September. The cell density of Gymnodinium and the cell density of C. polykrikoides were in a range of 40～3700cells/ml and 80～1300cells/ml. The mean air temperature in September was 13.3℃ higher than the mean air temperature in March. The sunshine duration in March was 0.7 hours longer than the sunshine duration in September. The mean wind speed in September was 2.47m/s faster than the mean wind speed in March.

As a result, the HABs was occurred when SST was higher and the wind speed was slower. The sunshine duration has not difference between March and September, but SST and the wind speed were considered to affect the occurrence of HABs.

1. INTRODUCTION

Harmful Algal Blooms (HABs), which mostly occurs in the South Sea of Korea because of the dominant causative species C. polykrikoides, are particularly found in summer and fall seasons (Ahn *et al*., 2006; Shanmugam *et al*., 2008). C. polykrikoides is one of the most frequently appearing harmful dinoflagellates which kill fish (Kim *et al*., 1999). Due to HABs, considerable economic losses were estimated at $95 million and $19 million USD in 1995 and 2003, respectively (NOWPAP, 2005). Therefore, HABs causes considerable damage to the fishing industry, especially the aquaculture in the South Sea of Korea. To minimize the damage of HABs and reduce the public health risks, it is a need to monitor the coastal area and predict the development of HABs.

Environmental factors such as water temperature, weather conditions (air temperature, cloud cover, sunshine, precipitation and wind) can greatly affect the initiation and subsequent development of HABs (Kim *et al*., 2009). Meteorological data for example, air temperature, precipitation, wind speed and direction, and sunshine duration is daily conducted by the Korea Meteorology Administration (KMA). Oceanic data such as Sea Surface Temperature (SST) and cell density are observed by the National Fisheries Research and Development Institute (NFRDI). There are previous studies that are demonstrated the physical condition of the water during the HABs outbreak (Han *et al*., 2008; Kim. *et al*., 2004). Satellite images provide the distribution of HABs with wide area, though it cannot be detected where it is covered with clouds. Therefore, by using the oceanic data, meteorology data and satellite data, this study gives the better understand about the characteristics of HABs.

2. STUDY AREA, DATA AND METHODS

2.1 Study Area

The study areas were Tongyeong and Geojae which are located in the South Sea of Korea to the east side (Fig. 1). These regions were affected by Sacheon River which most supply freshwater to Tongyeong coastal area (Denny *et*

al., 2009).

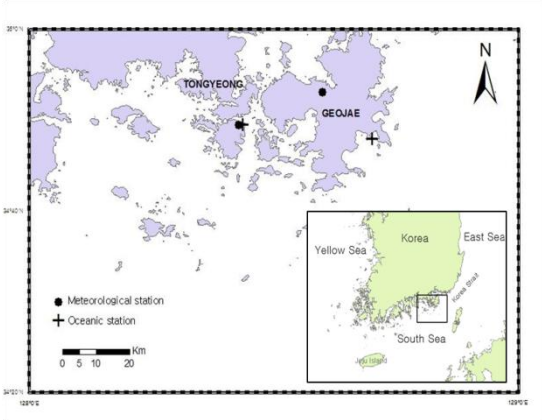


Figure 1. South Sea of Korea to the east side.

2.2 Data and Methods

Meteorological data such as air temperature, precipitation, wind speed and direction, and sunshine duration for March and September 2010 were detected from KMA. The wind speed and direction were recorded every hour and the others were recorded every day. Oceanic data such as water temperature and the cell density for March and September 2010 were obtained from NFRDI. Satellite data from Sea-viewing Wide Field-of-view Sensor (SeaWiFS) L2 images and SST images were provided by the website of NASA(http://seadas.gsfc.nasa.gov/seadas) for March and September 2010. The SeaWiFS data were processed using the SeaWiFS Data Analysis System (SeaDAS) software and the SST data were processed using the MATLAB software.

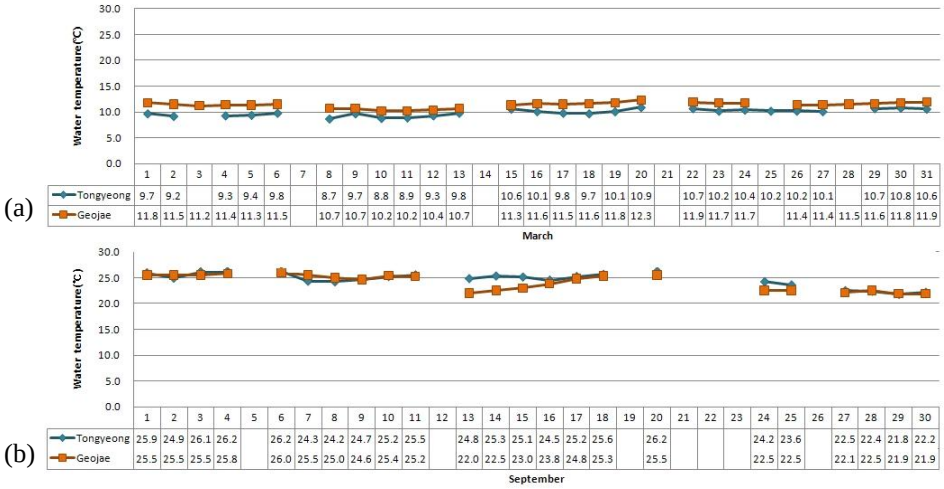
3. RESULTS

3.1 Oceanic Data

The distribution of HABs were recorded the cell density and water temperature by NFRDI. Table 1 shows that it occurred in Tongyeong from 13 September ~ 19 September 2010. There were two species cause the HABs, which were Gymnodiniump sp. and C. Polykrikoides. Gymnodinium ranged 40 to 3700 cell/ml and C. Polykrikoides ranged 80 to 1300 cell/ml. It issues the HABs watch when the cell density of Gymnodinium sp. is more than 500 cell/ml and alerts the density of Gymnodinium sp. is more than 2000 cell/ml. Also, it issues the HABs watch when the cell density of C. Polykrikoides is more than 300 cell/ml and alerts the density of C. Polykrikoides is more than 1000 cell/ml. Water temperature ranged 25.1 to 26.77℃. As Fig. 2b, the mean water temperature detected in Geojae and Tongyeong were 24.6 and 24.1℃, respectively. Fig. 2b on 13 September ~ 18 September (There were no data on 19 September) 2010, the range of water temperature were 22.3 to 25.3℃ in Geojae, and 24.5 to 25.6℃ in Tongyeong. The time of HABs outbreak, water temperature (Table 1) is more than the mean temperature that indicates warm water temperature. It is considered to cause the occurrence of the HABs.

Table 1. The cell density of the phytoplankton species and the water temperature during the HABs outbreak

Date of outbreak	Species	Cell density (cell/ml)		Water temperature (℃)	
		Min.	Max.	Min.	Max.
2010.09.13	Gymnodinium sp.	40	240	26.00	26.00
2010.09.14	Gymnodinium sp.	850	1720	25.10	25.50
2010.09.14	Gymnodinium sp.	750	3700	25.50	25.50
2010.09.15	Gymnodinium sp.	650	2850	26.32	26.32
2010.09.15	Gymnodinium sp.	540	2500	25.94	25.94
2010.09.16	Gymnodinium sp.	550	890	25.41	25.94
2010.09.17	Cochlodinium polykrikoides	505	1030	25.63	25.70
2010.09.18	Cochlodinium polykrikoides	200	1300	25.70	26.30
2010.09.19	Cochlodinium polykrikoides	80	720	25.93	26.77



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Tongyeong	9.7	9.2		9.3	9.4	9.8		8.7	9.7	8.8	8.9	9.3	9.8		10.6	10.1	9.8	9.7	10.1	10.9		10.7	10.2	10.4	10.2	10.2	10.1		10.7	10.8	10.6
Geojae	11.8	11.5	11.2	11.4	11.3	11.5		10.7	10.7	10.2	10.2	10.4	10.7		11.3	11.6	11.5	11.6	11.8	12.3		11.9	11.7	11.7		11.4	11.4	11.5	11.6	11.8	11.9

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Tongyeong	25.9	24.9	26.1	26.2		26.2	24.3	24.2	24.7	25.2	25.5		24.8	25.3	25.1	24.5	25.2	25.6		26.2				24.2	23.6		22.5	22.4	21.8	22.2
Geojae	25.5	25.5	25.5	25.8		26.0	25.5	25.0	24.6	25.4	25.2		22.0	22.5	23.0	23.8	24.8	25.3		25.5				22.5	22.5		22.1	22.5	21.9	21.9

Figure 2. Daily mean water temperature in (a) March and (b) September 2010, in Geojae and Tongyeong.

3.2 Meteorological Data

The meteorological data were air temperature, precipitation, sunshine duration, wind speed, wind direction from the KMA in March and September 2010. Fig. 3 represents the data in Geojae in March 2010. Fig. 4 represents the data in Tongyeong in March 2010. As Fig. 3a, the air temperature ranged from -0.2℃ to 14.8℃ and the mean air temperature was 7.61℃. It was steadily decreased to -0.2℃ and there were upward and downward trends. The highest precipitation was 54.5mm/day which was considered that it was not the rainy season. The sunshine duration ranged from 0 to 11.3 hours and the mean sunshine duration was 3.77 hours. The air temperature in Tongyeong that shows Fig. 4a, ranged from -0.1 to 14.4℃ and it is a similar result as did Fig. 3a. The mean air temperature was 7.32℃. The highest precipitation was 48.5mm/day. The sunshine duration ranged from 0 to 11 hours and the average sunshine duration was 4.02 hours. Fig. 5 shows the data in Geojae in September 2010. The air temperature ranged 17.7 to 28.1℃ and it was a steady drop. The mean air temperature in September is 15.8℃ higher than the mean air temperature in March. The highest precipitation was 112.5mm/day. The sunshine duration ranged 0 to 11.2 hours and the mean sunshine duration was 5.41 hours. It is 1.64 hours longer than the mean sunshine duration in March. The number of sunshine duration days is more than Fig. 3b, although the range of sunshine duration in March and the range of sunshine duration in September are similar. The data in Tongyeong in September 2010 is shown Fig. 6. The range of the air temperature is 18.2 to 27.6℃ and the mean air temperature is 23.1℃. It is 15.8℃ higher than the mean air temperature compared with the mean air temperature in March. The highest precipitation was 99mm/day and it is doubled compared with the Fig. 4a. The sunshine duration ranged 0 to 11 hours. The mean sunshine duration was 6.15 and it is 2.13 hours longer than the mean sunshine duration in March. Fresh water from the Sacheon River flows to Tongyeong which provides the good nutrition to live some species that cause the HABs. When the precipitation increases, the duration of HABs and the density of C. polykrikoides also increase (Lee, 2006).

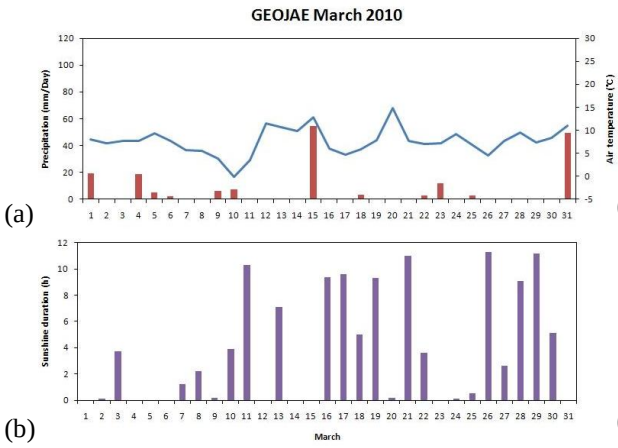


Figure 3. (a) Daily accumulation of precipitation (bar-graph) and daily mean air temperature (line graph), (b) Daily sunshine duration in March 2010, Geojae.

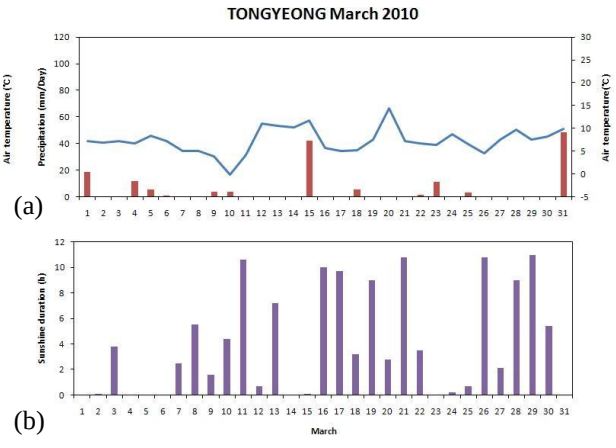


Figure 4. (a) Daily accumulation of precipitation (bar-graph) and daily mean air temperature (line graph), (b) Daily sunshine duration in March 2010, Tongyeong.

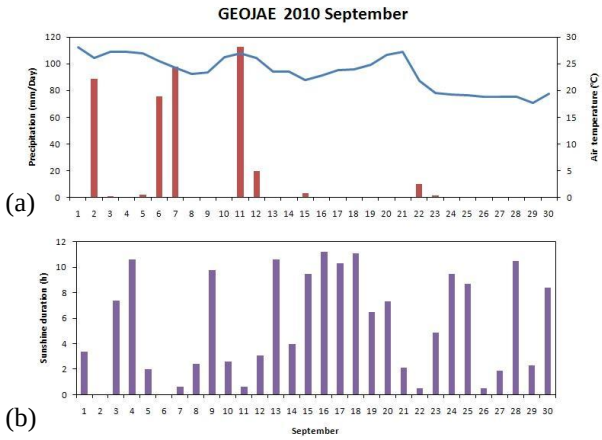


Figure 5. (a) Daily accumulation of precipitation (bar-graph) and daily mean air temperature (line graph), (b) Daily sunshine duration in Sept. 2010, Geojae.

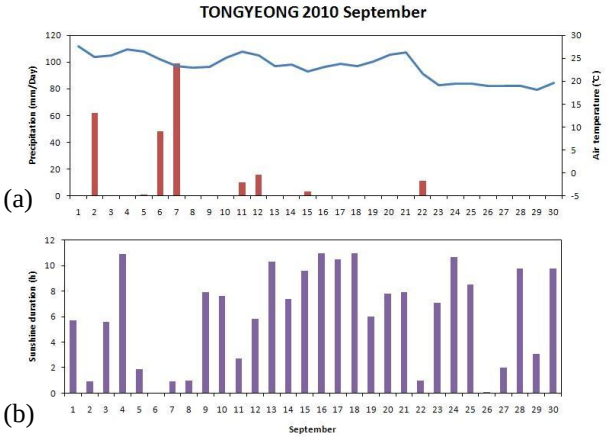


Figure 6. (a) Daily accumulation of precipitation (bar-graph) and daily mean air temperature (line graph), (b) Daily sunshine duration in Sept. 2010, Tongyeong.

The histogram of Fig. 7 shows that the wind direction and speed in Geojae, March 2010. It blew from southeasterly wind and northwesterly wind. The frequent wind speed is 39.1% that ranged 0.5 to 2.1m/s. Fig. 8 shows the wind direction and wind speed in Tongyeong March 2010. It is a dominant northeasterly wind. The most frequent percent of wind speed is 33.9% that ranged 2.1m/s to 3.6m/s. Fig. 9 represents the wind direction and speed in Geojae, September 2010. The wind direction is southeasterly wind and northwesterly wind. Most percent of wind speed is between 0.5m/s and 2.1m/s. The histogram of Fig. 10 represents that the wind direction and the wind speed in Tongyeong September 2010. There is a predominant northeasterly wind. The percent of wind speed which are 33.1 and 31.3% ranged 0.5 to 2.1m/s and 2.1 to 3.6m/s, respectively. It shows that there is a calm and light wind. The good condition of HABs occurrence is light winds which ranged 2 to 4.6m/s, and blows to southwesterly winds (Yoon and Kim, 2003).

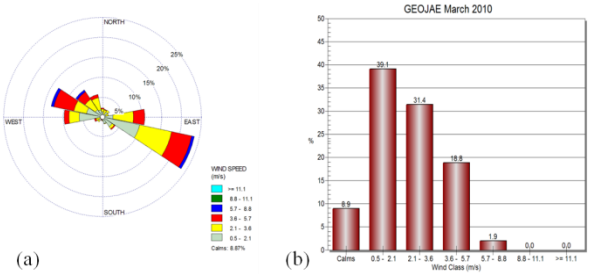


Figure 7. Histogram of (a) the wind direction and (b) the wind speed on March 2010 in Geojae.

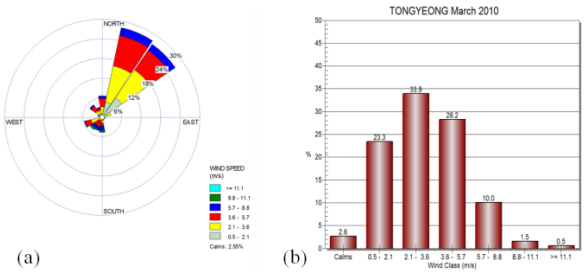


Figure 8. Histogram of (a) wind direction and (b) the wind speed on March 2010 in Tongyeong.

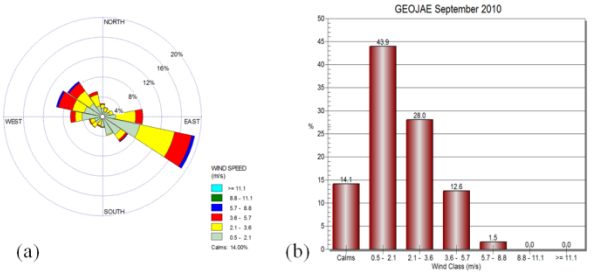


Figure 9. Histogram of (a) the wind direction and (b) the wind speed on September 2010 in Geojae.

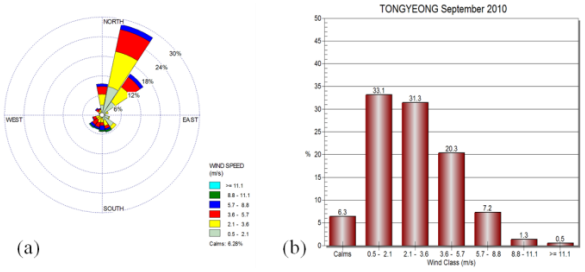


Figure 10. Histogram of (a) wind direction and (b) the wind speed on September 2010 in Tongyeong.

3.3 Satellite Data

Fig. 11 shows that the concentration of chlorophyll-*a* and SST which were detected by satellites on 16 March 2010. As Fig. 2a, Fig. 3b and Fig. 4b, the water temperature were 11.6 and 10.1℃ in Geojae and Tongyeong, the sunshine duration was 9.4 and 10 hours in Geojae and Tongyeong. The wind speeds (Fig. 7b and Fig. 8b) were 3.7 and 4.1 m/s in Geojae and Tongyeong. Those are a quite fast speed compared with the light winds in Fig. 9b and Fig. 10b. The concentration of chlorophyll-*a* were between 6 and 12 mg/㎥ which indicates that there was not detected the HABs. There was no difference of SST approximately 15℃. Fig. 12 shows that the concentration of

chlorophyll-*a* images and SST images detected on 30 September 2010. According to Fig. 2b, Fig. 5b and Fig. 6b, the water temperature were 21.9 and 22.2℃ in Geojae and Tongyeong and the sunshine duration was 8.4 and 9.8 hours in Geojae and Tongyeong. The wind speeds (Fig. 9b and Fig. 10b) were 0.9 and 1.7 m/s in Geojae and Tongyeong that are light winds. Fig. 12a represents that the HABs was detected. The high concentration of chlorophyll-*a*, ranged 8 to 20 mg/㎥, is distributed along the southeast coastal area. Also, Fig. 12b is shown that SST was approximately 25℃ and it is 10℃ higher than March (Fig. 11b). When the HABs occurred as Table 1, the water temperature was between 25.1 and 26.77℃ that indicates the HABs occurred on 30 September 2010. According to the NFRDI, they gave the information about the occurrence of the HABs by C. polykrikoides on 1 October 2010.

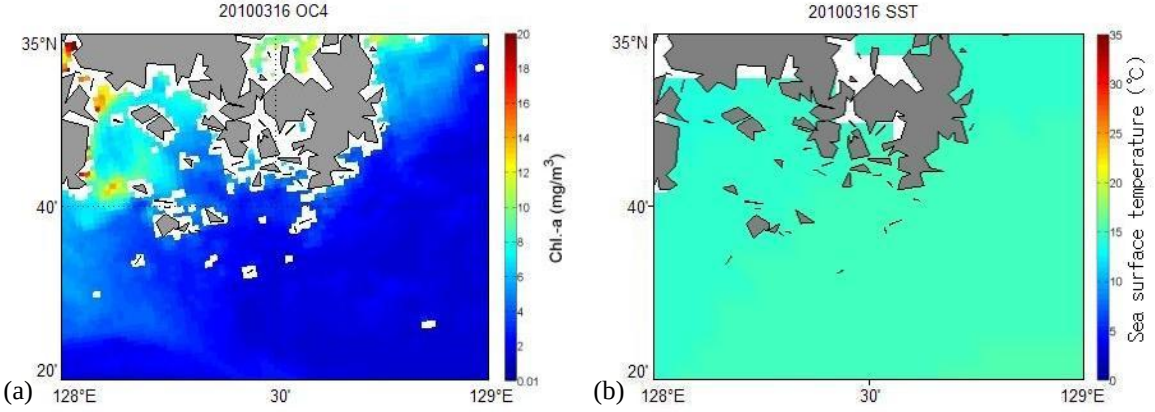


Figure 11. (a) Concentration of chlorophyll-*a* and (b) SST on 16 March 2010.

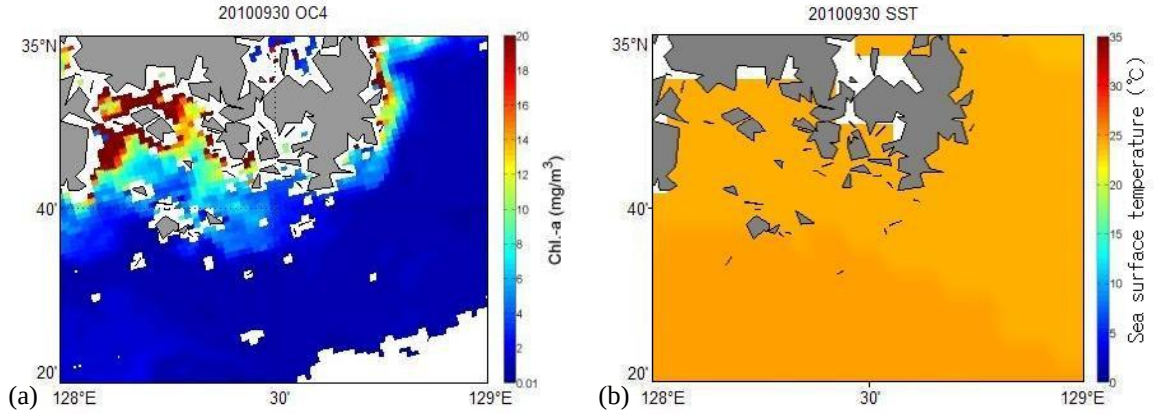


Figure 12. (a) Concentration of chlorophyll-*a* and (b) SST on 30 September 2010.

4. CONCLUSION

In this study, the oceanic data, meteorological data and satellite data for March and September 2010 were used to study the characteristics of the HABs occurrence in southeast coastal area. In the oceanic data, the density of Gymnodinium sp. and C. Polykrikoides were 40 ~ 3700 cell/ml and 80 ~ 1300 cell/ml, respectively. The mean water temperature were 24.6 and 24.1℃ in Geojae and Tongyeong. Where the HABs occurred, the water temperature were ranged 25.1 to 26.77℃. As the meteorological data, the mean air temperature, precipitation, sunshine duration, wind speed and direction for March were 7.47℃, 11.39mm/day, 3.90hours, 2.8m/s and northwesterly, and for September were 23.3℃, 30.2mm/day, 5.78 hours, 2m/s and northwesterly, respectively. Warm water temperature and light winds are considered to occurrence the HABs.

Using the satellite images, they shows that the clean coastal area on 16 March 2010, the outbreak of the HABs on 30 September 2010 and SST as the same days. On 16 March 2010 images, the concentration of chlorophyll-*a* within the coastal area were 6 ~ 12mg/㎥ and the images on 30 September 2010, the concentration of chlorophyll-*a* were 8 to 20 mg/㎥. The day after the detection, the NFRDI announced the occurrence of the HABs. The SST images were shown approximately 15℃ on 16 March 2010 and approximately 25℃ on 30 September 2010. Warm water temperatures supply the increase of Gymnodinium sp. and C. polykrikoides. Therefore, to monitor and

predict using the satellite images provide useful information about the HABs.

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