# RED TIDE DETECTION USING SeaWiFS STANDARD CHLOROPHYLL-a ALGORITHM IN SOUTHEAST KOREAN WATERS

**Gathot Winarso**
**National Institute of Aeronautics and Space (LAPAN), Jakarta**
**e-mail: gathot_winarso@lapan.go.id**

**Abstract.** *Cochlodinium polykrikoides* red tides have occurred in summer every year at coastal waters of the South Korea. Chlorophyll-a concentration data estimated from ocean color satellite SeaWiFS (Sea-viewing Wide Field-of-view Sensor) were used to detect the red tide in this study. The high value of chlorophyll-a concentration used to detect red tide was analyzed and compared with red tide map produced by National Fisheries Research and Development Institute of Korea (NFRDI). Based on SeaWiFS data and NFRDI red tide map, it was found that high chlorophyll-a concentration of ≥ 5 mg/m$^3$ in SeaWiFS images corresponded to the red-tide occurrence with some limitations.

**Keywords:** *Cochlodinium polykrikoides, Chlorophyll-a, SeaWiFS, Red tide*

## 1 INTRODUCTION

Red tide or Harmful Algal Bloom (HAB) appears to be increasingly common phenomena on a worldwide scale, resulting serious environmental problems on coastal area. Nutrient enrichment was caused by the increase of human activities for production of food and others and discharge of associated sewage and waste. One of the results of nutrient loading to inland and coastal waters is often increase of algal biomass, frequently dominated by one or more species. *Cochlodinium polykrikoides* red tides occurred almost every year in coastal waters of the South Korea (Lee, 2005). This red tide caused damages for fisheries worth of 76.4 billion won in 1995 and substantial annual economic losses since then (Kim *et al.*, 1997). The semi-enclosed nature of Korean south coastal bays often reaches extreme eutrophic condition by receiving terrestrial wastewater and pollutants. Generally, red tides developed in inland sea or inner bay with large and temporal influxes of freshwater and pollutants. Red tides caused by *C. polykrikoides* initially developed and tended to persist in the comparatively clean waters of outer bays and offshore areas (Lee *et al.*, 2006). To mitigate impacts of such red tide, it was necessary to monitor the bloom and to forecast their development and movement (Stumpf, 2001). Effective way to monitor red tide can be through remote sensing because of the synoptic and frequent coverage. Currently, remote sensing technology cannot specifically distinguish harmful algae; however, if the algae form red tide condition, ocean color remote sensing should be able to detect the specific spectral characteristics of the bloom as possibly high chlorophyll concentration (Ishizaka *et al.*, 2006). Gárate-Lizárraga *et al.* (2004) showed good correlation between *C. polykrikoides* cell number and chlorophyll-a concentration in west side of the Gulf of Mexico. Monitoring by remote sensing was becoming operational in China, Japan, Korea, Philippines and USA, and utilization of satellite data currently employing for other bloom-forming species were suggested to be adaptable to *Cochlodinium* events in some regions (Doucette and Lee, 2008).

Stumpf *et al.* (2003) developed a method to detect *Karenia brevis* bloom using anomaly of chlorophyll-a extracted from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) data in Gulf of Mexico, and this method was evaluated by Tomlinson *et al.* (2004). A massive dinoflagellate bloom near the mouth of Pearl River in November 1998 was examined using SeaWiFS-extracted chlorophyll-a data (Tang *et al.*, 2003). Tang *et al.* (2004) also observed harmful algal bloom off the coast of southern Vietnam by SeaWiFS-estimated chlorophyll-a data. Ishizaka *et al.* (2006), Azanza *et al.* (2006), Chang *et al.* (2008) used chlorophyll-a extracted from SeaWiFS/MODIS data by standard algorithm to study red tide.

Although SeaWiFS derived chlorophyll-a provided a means of delineating potential areas of red tide bloom with higher chlorophyll-a concentrations, it did not support the detection of dominant *C. polykrikoides* species in the bloom (Ahn *et al.*, 2006). In addition, SeaWiFS-derived chlorophyll-a often falsely identified *C. polykrikoides* bloom in areas abundant in dissolved organic and particulate inorganic matters around river mouths and estuaries (Ahn *et al*, 2006). High chlorophyll-a area appeared not to be a unique indicator for identifying bloom species (Stumpf *et al.*, 2003).

Feasibility of use of standard chlorophyll-a is still unclear, especially for relatively turbid coastal water, and it is important to analyze the ability of standard chlorophyll-a data to detect red tide. In this study, standard chlorophyll-a data was used to detect red tide in the south sea of Korea.

## 2 MATERIALS AND METHOD

### 2.1 Satellite Data

Ocean color satellite chlorophyll-a data obtained by SeaWiFS sensor were taken from National Aeronautics and Space Administration (NASA) ocean color homepage. The 2000-2004 standard level 2 employing OC4v4 algorithm data were downloaded and processed to daily chlorophyll-a data by merging more than 2 dataset in same day if any. In order to eliminate low quality pixels, flag data were removed. Cloud free chlorophyll-a data within red tide season during 2000-2004 were selected and analyzed.

### 2.2 In-situ data

Field based red tide information and maps were taken from NFRDI Harmful Algal Blooms Report in Korea Coastal Waters during 2000–2004 (Figure 1). The information in this report was collected from water sampling, visual observation by ship, from land and helicopter also from fisherman. Standard sampling method was used for calculating the number of cell of phytoplankton on general including eye microscopy and taxonomy key to phytoplankton species identification. Light Microscopy (LM) method and scanning electron microscope (SEM) method were used to get more accurate data. The data were used in this paper are only species target cell density and spatial distribution.

## 3 RESULT

### 3.1 Chlorophyll-a Concentration

On September 5, 2000 high satellite chlorophyll-a areas were observed around Geomo-do, Dolsan-do, Namhae-do, Saryang-do, Tomyeong and Geoje-do and confirmed by red tide area from NFRDI red tide map (red circle, Figure 2). Red tide was also reported around Naro-do with smaller concentration (Figure 2 red dotted circle), the satellite chlorophyll-a concentration was about 3.5 mg m$^{-3}$ and cell number of red tide was less than 2000 cell ml$^{-1}$. Gárate-Lizárraga *et al.* (2004) found that there was a positive correlation between cell numbers of *C. Polykrikoides* with chlorophyll-a concen-tration.

On October 3, 2003 (Figue 3), red tide map by NFRDI showed a warning region of red tide corresponded to a relatively high chlorophyll-a concentration from satellite. It could be noticed that a relatively high satellite chlorophyll-a extended to offshore from around Geomo-do and Namhae-do to near west of south Tsushima Island.

On August 23, 2002 large area of satellite chlorophyll-a near coastline, specifically near Geomo-do, Nampa-do and Saryang-do, was masked although red tide was reported by NFRDI (Figue 4c and d), high chlorophyll-a area still observed and confirmed by NFRDI red tide.

Satellite chlorophyll-a data was not available in near coast because the mask was performed to the region of west of Nampa-do, Saryang and Tomyeong. High chlorophyll-a concentration from satellite and from the field observation were observed on August 23, 2002 (Figure 4c and d).

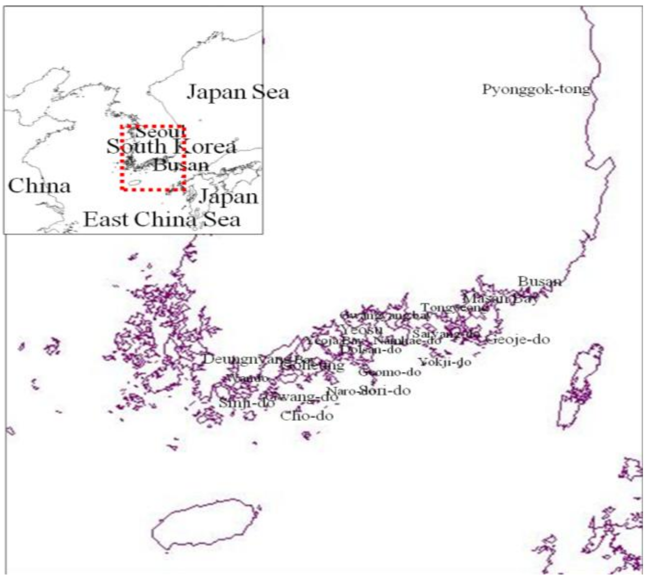


Figure 1. Map of study area

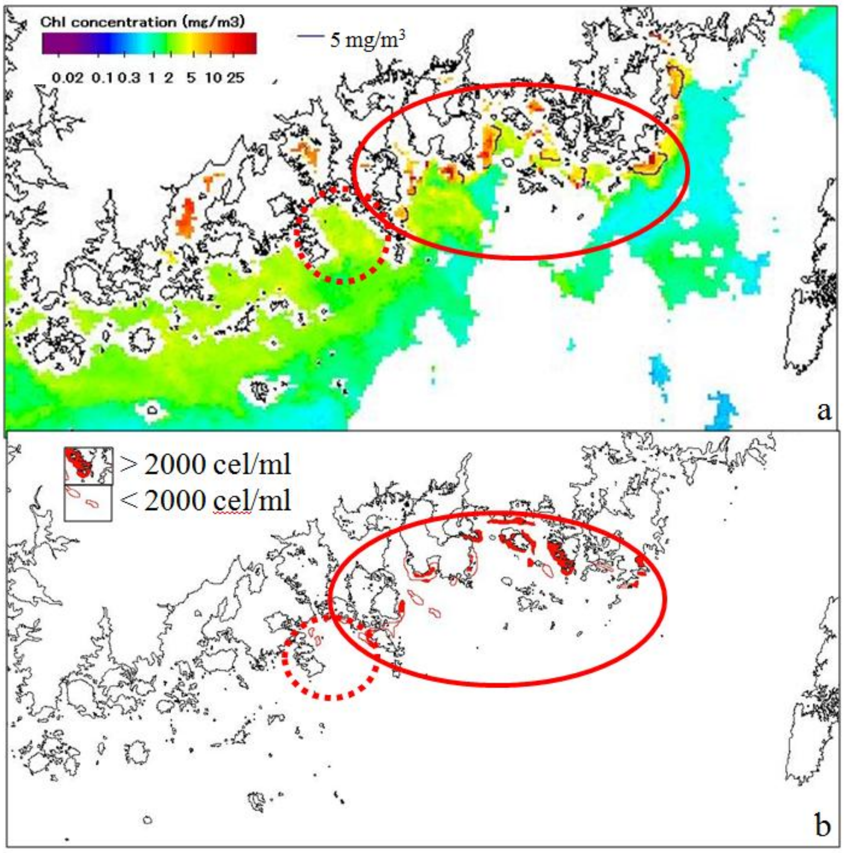


Figure 2. Satellite chlorophyll-a (a) and red tide map by NFRDI (b) on September 5, 2000. Red circles with solid and dotted lines indicate high chlorophyll-a area corresponded and not corresponded to red tide area, respectively

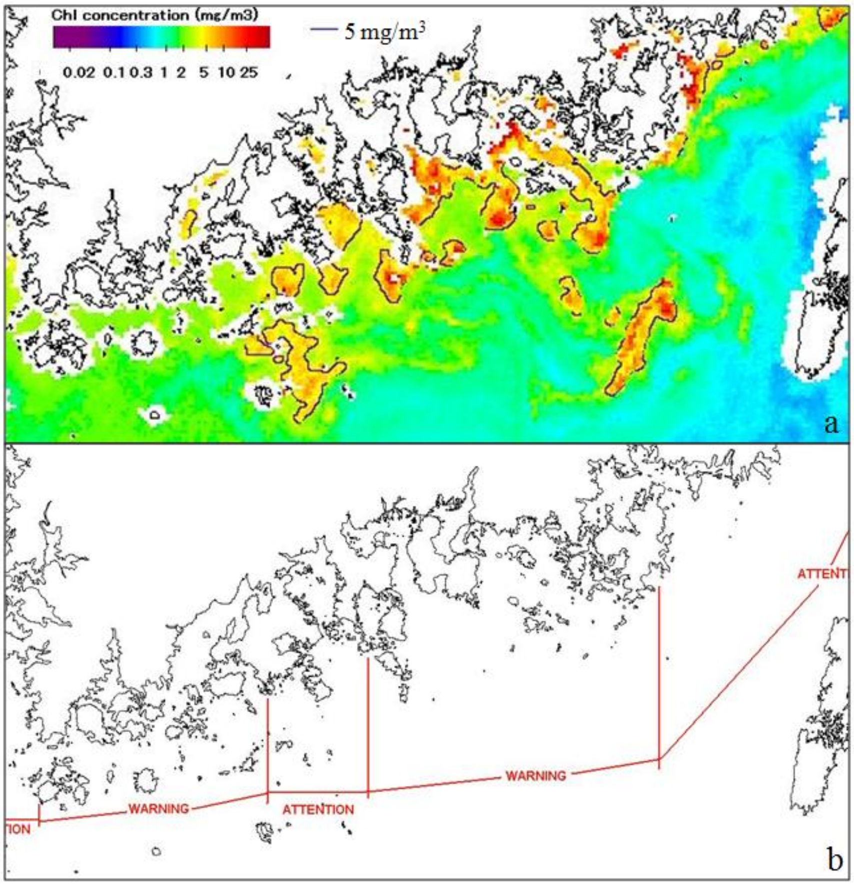


Figure 3. Satellite chlorophyll (a) and red tide map by NFRDI (b) on October 3, 2003

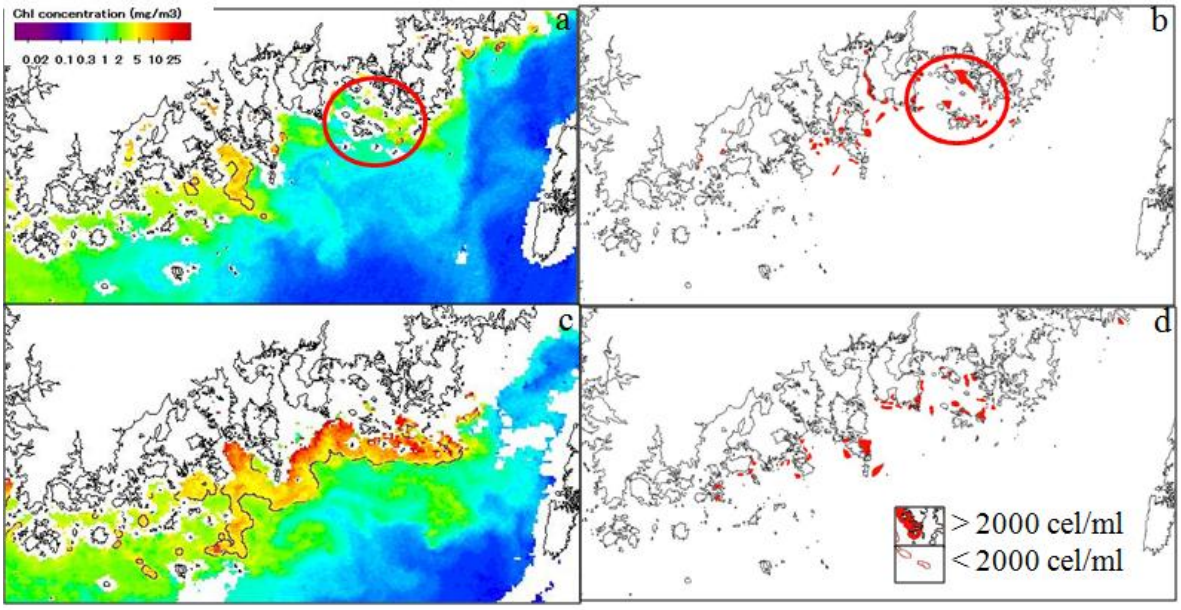


Figure 4. Satellite chlorophyll (a, c) and red tide map by NFRDI (b, d) on August 22 (a, b) and 23 (c, d), 2002. Red thick line circle indicated red tide area with low satellite chlorophyll-a

On August 26, 2001 high chlorophyll-a was observed between Naro-do and Gwang-do and between Goheung and Cho-do (Figure 5). Red tide occurrence was not reported by NFRDI map, nLw 555 data showed that nLw 555 was relatively high (more than 2 mW $cm^{-2}$ $str^{-1}$ $um^{-1}$) in the high chlorophyll-a area. The high turbidity in coastal area indicated by high nLw 555 might caused the overestimation of satellite chlorophyll-a. False red-tide occurrences with high chlorophyll-a seems due to turbid water.

### 3.2 Time series analyses

In 2001 cloud free daily data were presented between August 20 and 24 (Figure 6). On August 20, high chlorophyll-a area was observed between Naro-do and Geomo-do, chlorophyll-a concentration was still relatively low and high chlorophyll-a area was found only at small spot area. It seemed that red tide was in the initial stages. On August 21, the high chlorophyll-a area was detected in the almost same place, and the concentration as well as increase of cell density in NFRDI report. On August 22, high chlorophyll-a area spread out offshore until open sea at around Naro-do (red circle on Figure 6), and it showed the extension stage of red tide. The high chlorophyll-a areas were located in reported red tide locations (Figure 7). On August 24, at the Naro-do area, high chlorophyll-a was spread out from the same area one day before. However, chlorophyll-a concentration decreased until 5.56 $mg.m^{-3}$, and this area was reported as red tide area with low-density cell number showing the termination stage of red tide. In this case the lifetime of red tide was 5 days.

In 2003, several cloud free data were obtained from September 21 until October 3 (Figure 8). On September 21, high chlorophyll-a concentration was observed at narrow area of west of Dolsan-do as an initial stage of red tide. The area of high chlorophyll-a increased on September 25 as a growing stage around Dolsan-do and the area reached to near west of Yokji-do on September 26. On September 28, chlorophyll-a concentration in the same area was still high, although spatial extension slightly decreased. On September 30, high chlorophyll area was observed around seawater between Naro-do and Geomo-do and widely spread southward to offshore area.

Chlorophyll-a concentration at around Sori-do southern Geomo-do and southern Namhae-do increased on October 2, and became higher than September 30. Small patches of high chlorophyll-a were found in the western Tsushima Strait, and it seems that extension of high chlorophyll-a was the one extended from Sori-do on September 30. The extension stage of this red tide persisted for more than 4 days. Red tide was reported by NFRDI during same period; however, it was only limited just near coast, and the wide spread of red tide was not described.

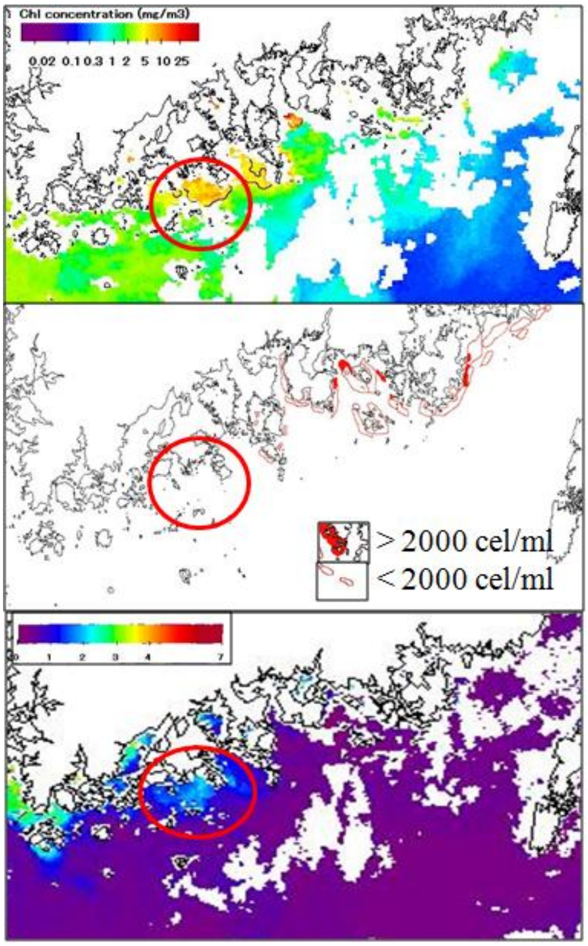


Figure 5. Satellite chlorophyll-a (a), red tide map by NFRDI map (b) and nLw 555 (c) on August 26, 2001. Red thin circle indicates area where overestimation was expected by high suspended sediment

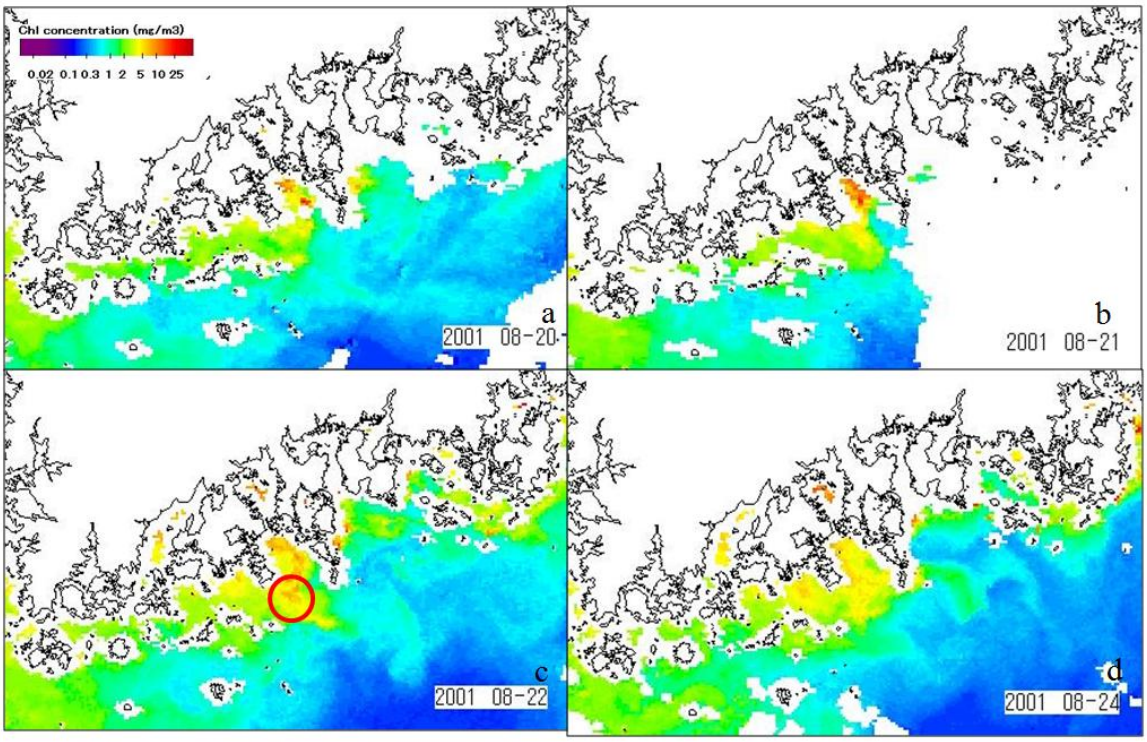


Figure 6. Time series of satellite chlorophyll-a on August 20 (a), 21 (b), 22 (c), and 24 (d). 2001 circle in (c) indicates area where high chlorophyll-a due to overestimation by sediment

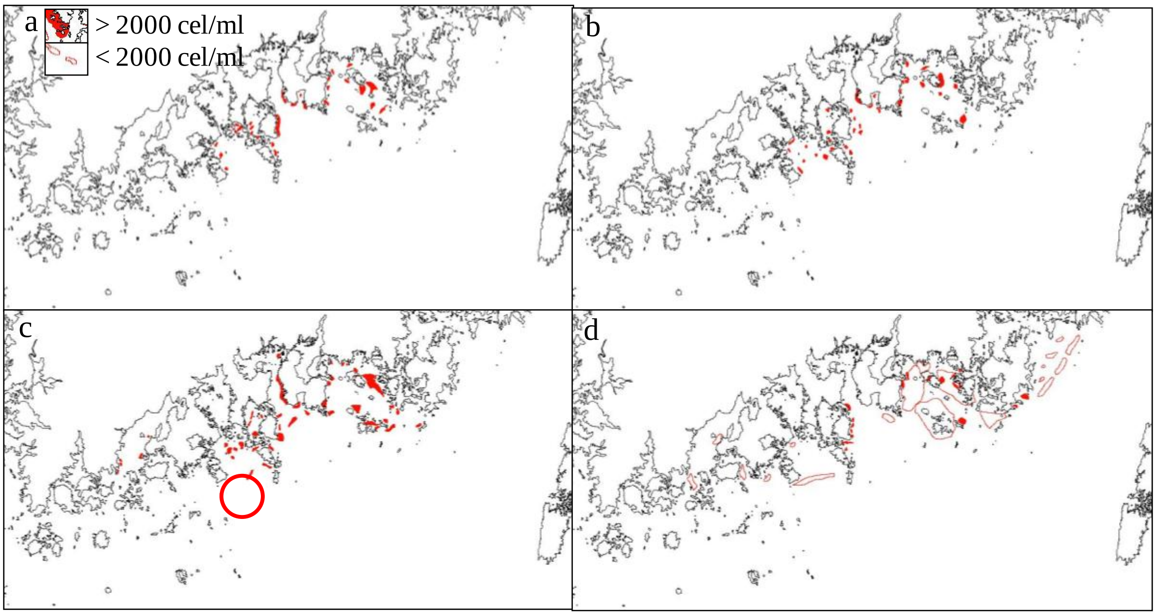


Figure 7. NFRDI red tide map on August 20(a), 21(b), 22(c) and 24(d), 2001. Circle in (c) indicates area where high chlorophyll-a spread out as shown in Figure 6 (August 22)

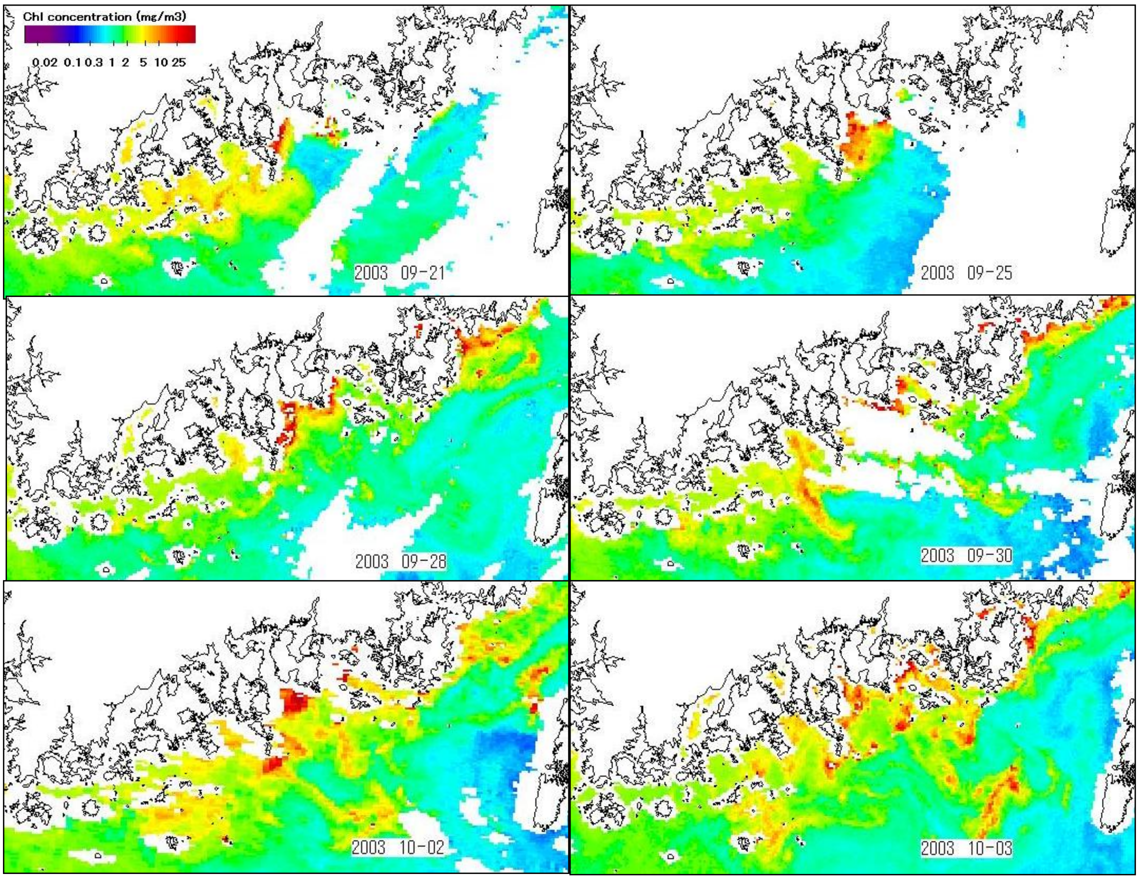


Figure 8. Satellite chlorophyll-a on September 21(a), 25(b) and 30(c), October 02(d) and 3 (e), 2003

# 4 DISCUSSION

## 4.1 Feasibility of Red Tide Detection by Satellite Chlorophyll-a

Red tide on August 20-24, 2001 and September 21 – October 3, 2003 were identified by high chlorophyll-a and confirmed by NFRDI red tide map. This was different from the result of Suh *et al.* (2004) who could not notice any special red tide features from August to September 2000 and 2001 while the red tide blooms occurred frequently. They used average chlorophyll-a value of 18 x 18 km area, and it might be the cause of failure of detection of red tide.

Full resolution SeaWiFS data with 1 km is required to detect and describe red tide of *C. polykrikoides* in this area.

Chlorophyll-a estimation from SeaWiFS data appeared to be useful in demarcating the locality, spatial extension and distribution of these blooms (Ahn *et al.*, 2006). Figure 8 for example of the complete time series of bloom process.

The widespread of red tide could be observed and useful when lack of coverage field observation. This method can be used for red tide monitoring when the transformation of red tide may affect to other location. The red tide occurrence at Hyogo and Tottori Prefecture Japan was indicated due to red tide contamination downstream waters of Tsushima Current (Miyahara *et al.*, 2009). Miyahara *et al.* (2009) used Aqua/MODIS to observe high chlorophyll-a and Lagrangian model to simulate spatial and temporal variations of the blooms in 2003 and 2007. The red tide observation using satellite chlorophyll-a could be use as warning red tide in Japan coastal.

### 4.2 Limitation of Satellite Detection of Red Tide with Standard Chlorophyll-a

Relatively low density of red tide cell often resulted low satellite chlorophyll-a concentration was one of cause discrepancy between NFRDI red tide map and satellite chlorophyll-a detection. Gárate-Lizárraga *et al* (2004) found good correlation between cell numbers of *C. Polykrikoides* with chlorophyll-a concentration. Although mask caused failure of detection, high chlorophyll-a area can be observed specifically when red tide widespread to offshore area. For example, on August 21, 2002 high chlorophyll-a area was observed along the coastal area and confirmed by NFRDI red tide map. Tang *et al.* (2003) found some pixels at the bloom area in Pearls River Hong Kong were masked out and unable to establish a relationship between the bloom and feature in ocean color image. However, The SeaWiFS image has shown high Chl-a area coinciding with the bloom area. SeaWiFS imagery currently cannot discriminate between different algal classes and that the elevated Chl-a concentrations seen in the river plume are most likely contaminated by high concentration of colored dissolved organic matter. However, satellite images could help to detect the location and to estimate the spatial extend of the bloom within situ measurements (Tang *et al.*, 2003).

False detection found on August 26, 2001 was confirmed due to chlorophyll-a overestimation by relatively turbid waters. NLw 555 image shown in the area was high. Although SeaWiFS data processing recognizes that the chlorophyll-a concentration algorithms might be incorrect in areas where turbid water is present (http://daac.gsfc.nasa.gov/oceancolor/scifocus/oceanColor/turbid_1.shtml). Tan *et al.* (2006) found over-estimating chlorophyll at the areas of high-normalized water leaving radiance at 555nm value (nLw 555). Strong relationship between the nLw 555 and total suspended sediment concentration suggested that high turbidity could contribute to the over-estimation of SeaWiFS chlorophyll-a.

SeaWiFS derived chlorophyll-a provided a means of delineating potential areas of red tide bloom with higher chlorophyll-a concentrations, it did not support the detection of dominant *C. polykrikoides* species in the bloom (Ahn *et al*, 2006). In addition, SeaWiFS-derived chlorophyll-a often falsely identified *C. polykrikoides* bloom in areas abundant in dissolved organic and particulate inorganic matters around river mouths and estuaries (Ahn *et al.*, 2006). Consequently, high chlorophyll-a area appears not to be a unique indicator for identifying bloom species (Stumpf *et al.*, 2003).

Standard satellite chlorophyll-a area was enough for delineating potential areas of red tide bloom with higher chlorophyll-a concentrations, but should be mentioned about the limitation of standard chlorophyll-a in coastal water. In situ measurement and checking by nLw 555 was necessary. The false of high chlorophyll area can be judged by comparing chlorophyll image with nLw 555. Red tides caused by *C. polykrikoides* initially develop and tend to persist in the comparatively clean waters of outer bays and offshore areas (Lee, 2006). The problem of overestimation due to high turbidity may be less.

*C polykrikoides* red tide mostly occurred at southern coast, and in some years it also spreaded to eastern coast. At the western coast, red tide occurred mostly bloom of non-*C polykrikoides* species (Lee, 2005). However, high satellite chlorophyll-a was observed almost every year in both average and maximum composite images. It was expected that the high satellite chlorophyll-a area found at the western coast was caused by high turbidity and/or shallow area. Bloom of other species might have also lead satellite chlorophyll-a increase. High satellite chlorophyll-a area in the eastern coast in 2000 was caused by upwelling and not *C polykrikoides* red tide.

## 5. CONCLUSION

In general, the occurence of red tide was corresponded to a relatively high concentration of chlorophyll-a from satellite. Red tide detection from satellite may be inaccurate due to the fact that red tide mostly bloom near the coast where normally found high suspended materials causing satellite failure to detect chloropyll-a concentration.

## 6 ACKNOWLEDGEMENT

We would like to deliver great gratitude to Prof Ishizaka and his lab members for his supervision and advising during this research. Also we want to thank the SeaWiFS Project and the Distributed Active Archive Center at the Goddard Space Flight Center, NASA , for the production and distribution of SeaWiFS. Besides, we would also like to express our gratitude to NFRDI South Korea for providing the red tide data.

## 7 REFERENCES

Ahn, Y.H., P. Shanmugam, J.H. Ryu, and J.C. Jeong, 2006, Satellite detection of harmful algal bloom occurrences in Korean waters, *Harmful Algae*, 5:213–231.

Azanza, R.V., L.T. David, R.T. Borja, I.U. Baula, and Y. Fukuyo, 2006, An extensive Cochlodinium bloom along the western coast of Palawan, Philippines, *Harmful Algae*, 7:324–330.

Chang, F.H., M.J. Uddstrom, M.H. Pinkerton, and K.M. Richardson, 2008, Characterising the 2002 toxic *Karenia concordia* (Dinophyceae) outbreak and its development using satellite imagery on the north-eastern coast of New Zealand, *Harmful Algae*, 7:532–544.

Doucette, G.J. and C.K. Lee, 2008, Preface to the Harmful Algae Special Issue: Recent progress on the research and management of *Cochlodinium blooms*, *Harmful Algae*, 7:259–260.

Gárate-Lizárraga , D.J. López-Cortes , J.J. Bustillos-Guzmán and F. Hernández-Sandoval, 2004, Blooms of *Cochlodinium polykrikoides* (Gymnodiniaceae) in the Gulf of California, Mexico. *Revista de biología tropical*, 52: 51-58.

Ishizaka, J., Y. Kitaura, Y. Touke, H. Sasaki, A. Tanaka, and H. Murakami, 2006, Satellite detection of red tide in Ariake Sound, 1998–2001, *Journal Oceanogr*, 62:37−45.

Kim, H.G., Choi, W.J., Jung, Y.G., Jung, C.S., Park, J.S., An, K.H., Baek, C.I., 1999, Initiation of Cochlodinium polykrikoides blooms and its environmental characteristics around the Narodo Island in the Western part of South Sea of Korea, *Bull. Nat. Fish. Res. Dev. Inst. Korea*, 54:119–129.

Kim, H.G., S.G. Lee, K.H. An, 1997, *In:* An, K.H. (Ed.), Recent Red Tides in Korean Waters, *Kudeok Publishing*, Pusan, p. 280.

Lee, C.K., 2005, National Report on HABs in Korea. *NOWPAP-CEARAC*, Toyama City Toyama Japan.

Lee, Y.S. and S.Y. Lee, 2006, Factors affecting outbreaks of *Cochlodinium polykrikoides* blooms in coastal areas of Korea, *Marine Pollution Buletin* 52: 626–634.

Lee, Y.S., 2006, Factor affecting outbreaks of high-density *Cochlodinium polykrikoides* red tides in the coastal seawaters around Yeosu and Tongyeong, Korea, *Mar. Poll. Bull.*, 52:1,249–1,259.

Miyahara, K., G. Onitsuka, and S. Watanabe, 2009, Blooms and monitoring of *Cochlordinium polykrikoides* Margalef in the Sea of Japan. *Bull. Plankton Soc. Japan*, 56:56-59 (in Japanese with English abstract).

Stumpf, R. P., M.E. Culver, P.A. Tester, M. Tomlinson, G.J. Kirkpatrick, B.A. Pederson,E. Truby, V. Ransibrahmanakul, and M. Soracco, 2003, Monitoring Karenia brevis blooms in the Gulf of Mexico using satellite ocean color imagery and other data, *Harmful Algae News*, 2:147−160.

Stumpf, R.P., 2001, Applications of satellite ocean color sensors for monitoring and predicting harmful algal blooms, *J. Human Ecol. Risk Assess*, 7:1363–1368.

Suh, Y. S., L. H. Jang, N. K. Lee, and J. Ishizaka, 2004. Feasibility of red tide detection around Korean waters using satellite remote sensing, *J. Fish. Sci. Tech.*, 7:148-162.

Tan, C.K., J. Ishizaka, S. Matsumura, F.M. Yusoff, and M.I. Mohamed, 2006, Seasonal variability of SeaWiFS chlorophyll a in the Malacca Straits in relation to Asian monsoon, *Cont. Shelf Res.*, 26:168–178.

Tang D.L., D.R. Kester, I.H. Ni, Y.Z. Qi, and H. Kawamura, 2003, In situ and satellite observations of a harmful algal bloom and water condition at the Pearl River estuary in late autumn 1998, *Harmful Algae*, 2:89–99.

Tang, D.L., H. Kawamura, Hai Doan-Nhu, and W. Takahashi, 2004, Remote sensing oceanography of a harmful algal bloom off the coast of southeastern Vietnam, *J. Geophysic. Res.*, 109, C03014.

Tomlinson, M.C., R.P. Stumpf, V. Ransibrahmanakul, E.W. Truby, G. J. Kirkpatrick, B.A. Pederson, G.A. Vargo, and C.A. Heil, 2004, Evaluation of the use of SeaWiFS imagery for detecting Karenia brevis harmful algal blooms in the eastern Gulf of Mexico, *Remote Sens. Env*, 91:293–303.