COMPARISON OF RED TIDE DETECTION BY A NEW RED TIDE INDEX METHOD AND STANDARD BIO-OPTICAL ALGORITHM APPLIED TO SEAWIFS IMAGERY IN OPTICALLY COMPLEX CASE-II WATERS

Palanisamy Shanmugam and Yu-Hwan Ahn

Ocean Satellite Research Group, Korea Ocean Research and Development Institute,
Ansan P.O. 29, Seoul 425-600, Korea
E-mail: pshanmugam@kord.re.kr

ABSTRACT:

Various methods to detect the phytoplankton/red tide blooms in the oceanic waters have been developed and tested on satellite ocean color imagery since the last two and half decades, but accurate detection of blooms with these methods remains challenging in optically complex turbid waters, mainly because of the eventual interference of absorbing and scattering properties of dissolved organic and particulate inorganic matters with these methods. The present study introduces a new method called Red tide Index (RI), providing indices which behave as a good measure of detecting red tide algal blooms in high scattering and absorbing waters of the Korean South Sea and Yellow Sea. The effectiveness of this method in identifying and locating red tides is compared with the standard Ocean Chlorophyll 4 (OC4) bio-optical algorithm applied to SeaWiFS ocean imagery, acquired during two bloom episodes on 27 March 2002 and 28 September 2003. The result revealed that OC4 bio-optical algorithm falsely identifies red tide blooms in areas abundance in colored dissolved organic and particulate inorganic matter constituents associated with coastal areas, estuaries and river mouths, whereas red tide index provides improved capability of detecting, predicting and monitoring of these blooms in both clear and turbid waters.

KEY WORDS: Red tide algal blooms, Red tide Index, OC4 bio-optical algorithm, SeaWiFS imagery

1. INTRODUCTION

Detecting and monitoring of red tide algal blooms is very important because these blooms cause massive mortalities of aquaculture fish and numerous ecological and health impacts in Korean waters and neighbouring coastal areas (Yuki and Yoshimatsu, 1989; Kim et al., 1998; Suh et al., 2004). The conventional way of monitoring red tide blooms with traditional field sampling at discrete locations is not feasible, therefore the only effective and possible of way of monitoring these blooms on a regular basis is through utilization of remote sensing technology.

Utilization of remote sensing technology because of its synoptic and repeat coverage has been explored in several ways for detecting harmful algal blooms, delineating their extent and addressing their impacts as well as describing the associated hydrographic conditions (Haddad, 1982; Tester and Stumpf, 1998; Schofield et al., 1999). Steidinger and Haddad (1981) were among the first to demonstrate the potential of satellite ocean color sensor with Coastal Zone Color Scanner (CZCS) for the detection of *Karenia brevis* bloom in western Florida waters. With the availability of daily imagery from the current SeaWiFS operational ocean color sensor, routine monitoring has been initiated by Stumpf (2001), who indicates that chlorophyll-*a* processed from these data provides a means for detection of red tide blooms in the coastal oceanic waters. Tomlinson et al. (2004) used chlorophyll anomalies obtained from SeaWiFS ocean color imagery for detecting *Karenia brevis* blooms in the eastern Gulf of Mexico, but frequent chlorophyll anomalies were falsely observed in the spring and early summer, prior to the beginning of the *Karenia brevis* bloom season. Since the chlorophyll-*a* does not provide sufficient information about various phytoplankton blooms, delineation of a particular phytoplankton species was accomplished by developing robust techniques based on unique optical properties of these algae (Brown and Yoder, 1994; Subramanian and Carpenter, 1994). Success of the above techniques are largely depending on absorbing and scattering properties of other water constituents; for instance, areas rich in colored dissolved and particulate inorganic matter are prone to the satellite-derived information that falsely identify red tides in these areas.

The objective of the present study is to develop a red tide index (RI) method to effectively detect and monitor red tide algal blooms that frequently occur in the Korean South Sea coastal areas. The result of this method is compared with the standard Ocean Chlorophyll 4 (OC4) bio-optical algorithm and field observations from these waters.

2. MATERIALS AND METHODS

2.1 Data

The SeaWiFS ocean color image data were acquired from using the High Resolution Picture Transmission (HRPT) antenna located at KORDI, during two bloom episodes on 27 March 2002 and 28 September 2003 in the Korean South Sea and Yellow Sea. The SeaWiFS ocean color instrument flown on Orbview-2, the SeaStar satellite in August 1997 by NASA, was specifically designed to provide near-global coverage every 2 days of upwelled radiance for eight narrow spectral channels (nm) in the visible and near-infrared spectral range (402-422, 433-453, 480-500, 500-520, 545-565, 660-680, 745-785, and 845-885) with the spatial resolution of ~1 km / pixel at nadir (Hooker et al., 1994). The near-infrared (NIR) bands (765 and 865 nm) are used to derive the atmospheric path radiance, which is then subtracted from the total signal to obtain water leaving radiance (L_w) in the visible. The spectral water-leaving radiance data are used to derive the ocean color parameters such as chlorophyll (Chl), *suspended sediments* (SS) and dissolved organic matter (DOM) concentrations (Table 1).

Spatial Resolution	Spectral Resolution		
1.1 kilometers at nadir	Band	wavelength	color
Estimates of biogeochemical variables (e.g. <chl> and <SS>)	1	402-422nm	Violet
	[illegible]	[illegible]	[illegible]
	3	480-500nm	Blue
	4	500-520nm	Green
	5	545-565nm	Green
	6	660-680nm	Red
Atmospheric correction	7	745-785nm	NIR
	8	845-885nm	NIR

Table 1. Characteristics of SeaWiFS data

2.2 Application of standard atmospheric correction and bio-optical algorithms for SeaWiFS

The Level 1A SeaWiFS ocean color radiance counts collected on 27 March 2002 and 28 September 2003 were atmospherically corrected and processed to level 2 using NASA SeaDAS version 4.4 (Tomlinson et al., 2004). The surface Chl-*a* concentrations were then derived by using NASA Ocean Chlorophyll 4 (OC-4) bio-optical algorithm within SeaDAS software (Yoder et al., 2002). The SeaWiFS OC-4 algorithm is a maximum band-ratio algorithm employing 4 spectral bands: band 2, 3, 4 and 5. Band 5 (555 nm) is taken as the reference wavelength band and three band ratios are computed for each measurement of the radiance or reflectance spectrum O'Reilly et al. (1998) as follows:

$$<Chl>= 10^{0.366-3.067R+1.930R^2+0.649R^3-1.532R^4}$$

and

$$where R = \log_{10}\left\{\frac{R_{rs}(443) > R_{rs}(490) > R_{rs}(510)}{R_{rs}(555)}\right\}$$

R_{rs} is the remote sensing reflectance.

2.3 Red tide Index (RI) method

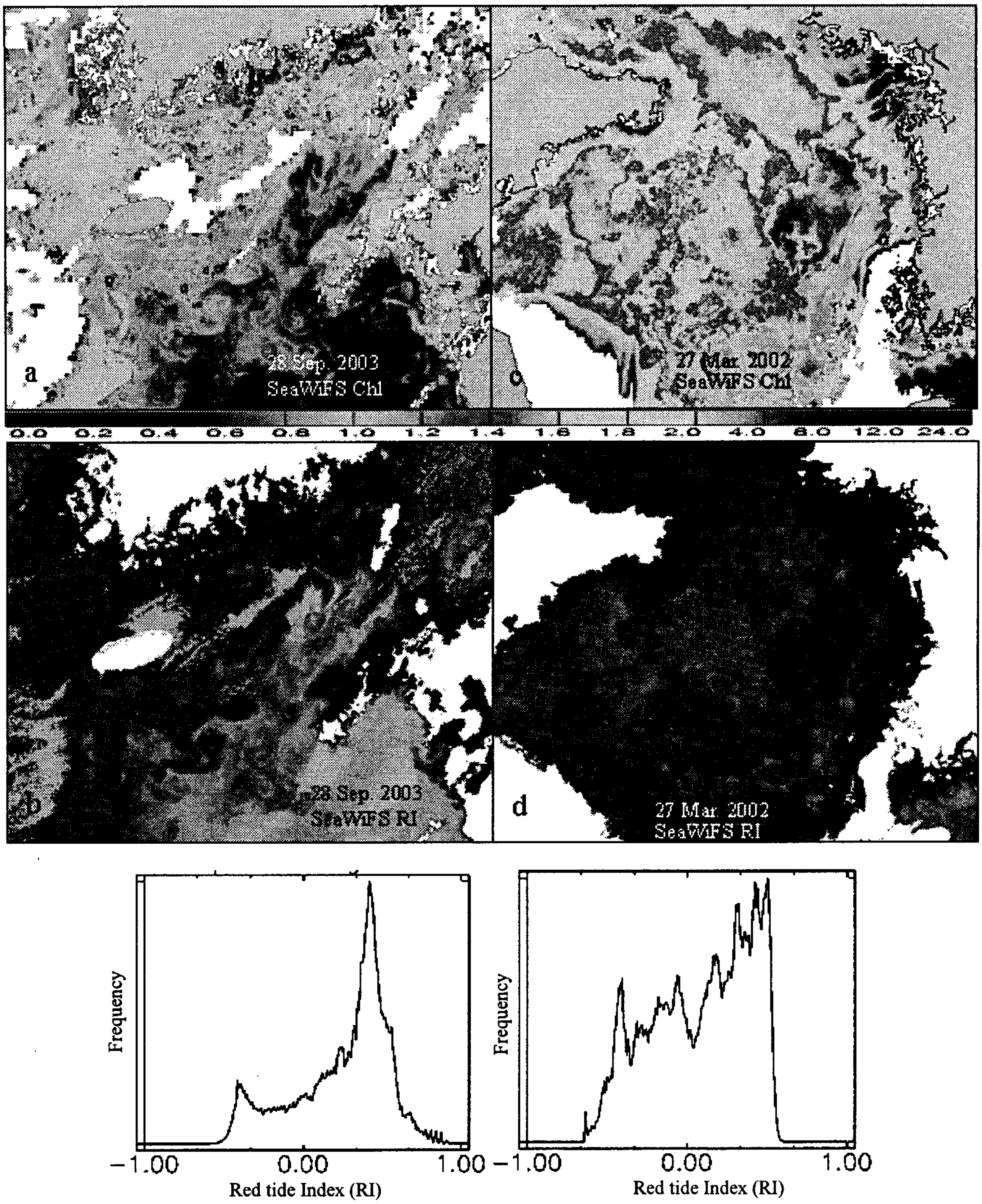
This study leads to the development of a new method aiming to improve red tide detection over large areas, mainly through the use of spectral indices, hereafter referred to as red tide index (RI). The RI calculations are based on the principle that rapid growth of red tide algal blooms absorbs radiation in the blue region of the spectrum while strongly reflecting radiation in the green region. Therefore, red tide index is built on three spectral bands in the blue-green part of the spectrum, affected by both pigment absorption and the scattering. RI provides a number which quantifies the "redness" of this bloom. A red tide index (RI) value of zero means non-red tides (or non-bloom waters) and close to +1 (>0.3) indicates the highest possible "redness" of harmful algal blooms. Two extreme conditions (for example, areas with higher dissolved organic and particulate inorganic matter concentrations and deep blue waters) may yield indices from −1 to 0.

Level 1A SeaWiFS products were processed separately with the Spectral Shape Matching Method (SSMM) (for correcting the atmospheric effects) (Ahn and Shanmugam, 2004) and red tide index method. The SeaWiFS data processing took place in the following steps; SeaWiFS image was georeferenced to a standard datum and projection, pixel digital counts were then converted to radiance using SeaWiFS calibration coefficients given in Hooker et al. (1994), followed by application of SSMM to obtain the desired water-leaving radiance from the SeaWiFS TOA radiance. Finally, red tide index method was applied to the SeaWiFS image to derive indices for red tide detection.

3. RESULTS AND DICUSSION

Figs. 1a and c are the chlorophyll images of 28 Sep. 2003 and 27 March 2002 processed from SeaWiFS ocean color data using OC4 bio-optical algorithm, showing patterns of chlorophyll variability in the Korean South Sea (SS) and Yellow Sea (YS) respectively. Higher chlorophyll concentration results from occurrence of red tide algal blooms, exclusive of coastal areas where high suspended sediments (SS) and dissolved organic matters (DOM) concentrations overstate the satellite-derived chlorophyll falsely identifying the red tide blooms in these areas. This implies that OC4 algorithm, which uses three band ratios, is highly susceptible to other water constituents such as SS and DOM, not fully supporting the identification of red tide algal blooms in the coastally-influenced turbid waters. On the other hand, the standard atmospheric correction algorithm developed for SeaWiFS by Gordon and Wang (1994) fails in extremely turbid and shallow coastal waters (see a mask over these areas in Figs. 1a and c).

In contrast, red tide index (RI) method applied to the atmospherically corrected SeaWiFS images by SSMM provided indices from −1 to 1, highly sensitive to red tide algal matters variability. In RI images shown in Figs. 1b and d, red tide algal blooms (in red color) are shown to have higher indices (>0.3), non-red tide algal matters (in



Figures 1a-d. Detection of red tide algal blooms by the red tide index (RI) method and the standard OC4 bio-optical algorithm applied to the SeaWiFS ocean color imagery acquired on 28 September 2003 and 27 March 2002 over the Korean South Sea (SS) and Yellow Sea (YS). The SeaWiFS-derived Chl does not appear to support accurate detection of red tide algal blooms from coastally-induced turbid waters dominated by suspended sediments and colored dissolved organic matters (a and c), whereas red tide index shows apparent patterns of red tide bloom in the East China Sea, South Sea and Yellow Sea (b and d).

greenish and brownish red color) have the indices of 0.0-0.3, and extremely turbid and clear waters (in dark blue and green, and cyan respectively) have the least indices (-1 to -0.5 and -0.5 to 0 respectively) (also see the bottom panels). To corroborate the red tide detection with RI method, we used data of Cochlodinium polykrikoides cell concentrations from National Fisheries Research and Development Institute (NFRDI), measured in the South Sea Coastal Areas (SSCA) and East Sea Coastal Area (ESCA) during Sep. 2003. The Cochlodinium polykrikoides cell concentrations often exceeded 30000 cells/ml in the SSCA and 10000 cells/ml in the ESCA as shown in Table 1.

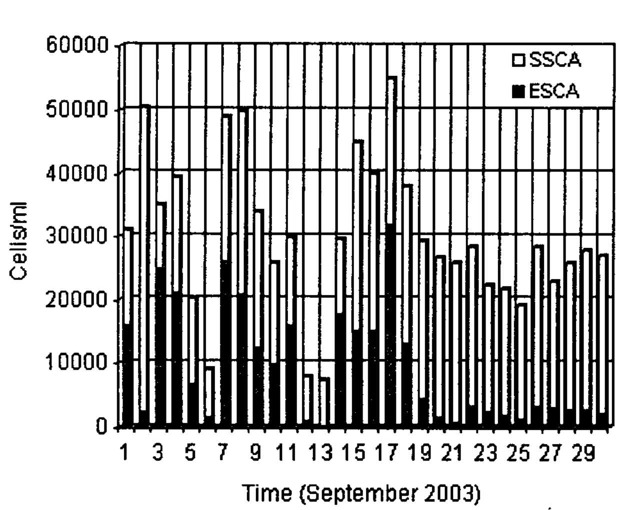


Figure 2. Cochlodinium polykrikoides cell concentrations observed on 28 September 2003 in the South Sea Coastal Areas (SSCA) and East Sea Coastal Areas (ESCA).

We believe that the bloom initiated on 28 Sep. 2003 in the ECS and SS might have been caused by Cochlodinium polykrikoides species, supported by enhanced nutrient levels as a result of upwelling and fronts, however, the type of algal bloom in the YS is not clearly known due to absence of field data.

From these results, we believe that accurate detection of red tides is not feasible with algorithms (e.g., OC-4) based on spectral ratios of water-leaving radiance (L_w) or remote sensing reflectance (R_{rs}) in the visible spectral bands, usually $L_w(443)/L_w(555)$ and/or $L_w(443)/L_w(520)$ for CZCS, and $R_{rs}(443)$/Rrs(555), $R_{rs}(490)$/Rrs(555), and/or, $R_{rs}(510)/R_{rs}(555)$ for SeaWiFS, because these ratios can significantly vary in response to other water parameters besides chlorophyll concentration. Even in waters dominated solely by phytoplankton, application of these color ratios algorithms can lead to overestimates or underestimates of pigment concentrations due to differences in the spectrum of water-leaving radiance per unit of pigment biomass. This can result from pigmentation differences such as the presence of high surface concentrations of phycobilipigments in a bloom area of cyanobacteria or from physiological and ecological effects such as chronic low light acclimation in high latitude environments (Tomlinson et al., 2004).

4. CONCLUSION

There have been significant number of studies that evaluated feasibility of red tide detection with different techniques /methods based on optical properties, spectral ratioing and discrimination, chlorophyll anomaly and climatological data analysis. However, these approaches were not found to fully support the accurate identification, monitoring and forecasting of future locations of red tide algal blooms resulting from clear oceanic waters and high scattering and absorbing waters around coastal areas. In most of the cases, areas with abundance of colored dissolved organic matter and suspended sediment concentrations are observed to be prone to the results of the above methods that falsely identify these harmful algal blooms. False information gained from these methods will not allow state managers to better anticipate red tides blooms and focus their sampling efforts on threatened aquaculture fish-harvesting areas in complex oceanic ecosystems. Our analysis clearly indicated that accurate identification of potential areas of red tide algal blooms in coastal turbid waters is not feasible with OC-4 bio-optical algorithm, mainly due to eventual interference of SS and DOM, but feasible with RI method which provides indices behaving as good measure of detecting red tide algal blooms in both clear and turbid waters. We will plan to extend this method for detecting red tide blooms of other regions and will continue in the future for validation and refinement.

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