Detection of Phytoplankton Blooms in the Upper Gulf of Thailand Using Sentinel-3A OLCI Imagery

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ARTICLE INFO

Received: 22 Aug 2017
Received in revised:
6 Oct 2017
Accepted: 9 Oct 2017
Published online:
29 Oct 2017
DOI: 10.14456/ennrj.2018.2

Keywords:
Phytoplankton blooms/ Maximum chlorophyll index/ Sentinel-3A OLCI/ Upper Gulf of Thailand

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ABSTRACT

This study aims to use Sentinel-3A Ocean and Land Color Instrument (OLCI) imagery for detecting phytoplankton blooms in the Upper Gulf of Thailand by using the Maximum Chlorophyll Index (MCI). The results showed that the MCI was able to detect phytoplankton blooms in the study area. The areas with intense phytoplankton blooms showed high MCI values. The radiance spectrum (with a reflectance peak at wavelength 708.75 nm) and the difference between baseline wavelengths 708.75 nm and 681.25 nm were quite high. High MCI values corresponded well with locations of phytoplankton blooms seen on RGB False-Color Composite images. Thus, time series analysis of MCIs obtained from Sentinel-3A OLCI images could be used in detecting, tracking, and delineating phytoplankton blooms.

1. INTRODUCTION

The red tide phenomenon is a natural occurrence in marine and fresh waters caused by the rapid growth and multiplication of phytoplankton. Phytoplankton blooms can change the color of seawater from its normal color to red, brown, green or yellow depending on the type(s) of phytoplankton that form the phytoplankton bloom at a given time (Lerdwithayaprasith, 1991). Phytoplankton blooms have an impact on aquatic creatures and habitats. In particular, blooms can greatly reduce the oxygen content of the surrounding waters and can thus damage natural aquatic ecosystems and coastal aquaculture areas (Department of Marine and Coastal Resources, 2015).

The Upper Gulf of Thailand has become a buffer zone for waste water from residential communities, industries, and agricultural areas that are drained by the tributaries of major rivers such as the Bang Pakong, Chao Phraya, Tha Chin, and Mae Klong. Chumnantana (2006) described the color changes of marine waters adjacent to the mouths of four major rivers that discharge onto the Upper Gulf of Thailand from November 2003 to October 2004. The author's observations are consistent with those of Chuenniyom et al. (2016), who documented 12 phytoplankton blooms from November 2014 to September 2015 along the Samut Sakhon coastal area. Analysis of satellite imagery is the primary technique used to detect phytoplankton blooms, especially when they occur regularly in particular marine regions (Blondeau-Patissier et al., 2014a as cited in Srokosz and Quartly, 2013). The Maximum Chlorophyll Index (MCI) is an analytical product that highlights significant changes in the water-leaving reflectance spectra due to the presence of phytoplankton blooms (Blondeau-Patissier et al., 2014a).

MCI indicates the presence of high surface concentrations of chlorophyll *a* against a scattering background. The index is high in “red tide” conditions (intense, visible, surface, plankton blooms) (Gower and King, 2011). High MCI values are associated with high levels of chlorophyll *a* in oceanic, coastal, and lacustrine waters (Gower et al., 2005; Blondeau-Patissier et al., 2014b). MCI can detect plankton blooms (Gower et al., 2005) and floating *Sargassum* (Gower et al., 2006).

MCI values and composite maps can only be ideally obtained from imagery acquired by the

ENVISAT Medium Resolution Imaging Spectrometer (MERIS) because of its use of the 708.75 nm band. This band is very sensitive to strong reflectance in the NIR. The lack of similar bands in MODIS and VIIRS might hamper the detection of high-concentration bloom events (Blondeau-Patissier et al., 2014a). The Sentinel-3A OLCI instrument provides a continuation of the ENVISAT MERIS capability (European Space Agency, 2017).

This study aims to obtain an MCI product from recently available Sentinel-3A OLCI imagery and evaluate the usefulness of MCI as a tool for detecting phytoplankton blooms in the Upper Gulf of Thailand coastal ecosystem. Hopefully, the techniques used in this study will prove useful in increasing the capability for tracking phytoplankton blooms in marine coastal areas and will help provide timely and accurate advisories to local coastal aquaculture operators.

2. METHODOLOGY

2.1 Study area

The Upper Gulf of Thailand (Figure 1) is bounded by geographic coordinates of longitude 100° 00' to 101° 00' E and latitude 12° 30' to 13° 30' N. It covers an area of 10,000 km^2 and is surrounded by land to the north, east, and west. It opens into the South China Sea to the south and southeast. It has an average depth of about 20 m and average tidal heights of about 1 to 3 meters (Buranapratheprat, 2013).

The climate in the Gulf of Thailand is influenced by the northeast and southwest monsoons. The southwest monsoon originates from the Indian Ocean and brings moisture and rain to Thailand from May to August. Southwest monsoon winds can circulate either clockwise or counter-clockwise depending on various prevailing atmospheric conditions. The northeast monsoon, which lasts from November to January, brings high-pressure, counter-clockwise-rotating winds that cover the entire Upper Gulf of Thailand (Buranapratheprat, 2008). High-frequency radar measurements obtained in 2013 show that surface current patterns in the Upper Gulf of Thailand were consistent with the seasons of Thailand. The average current velocities were higher for the northeast monsoon than for the southwest monsoon (Kongprom et al., 2015).

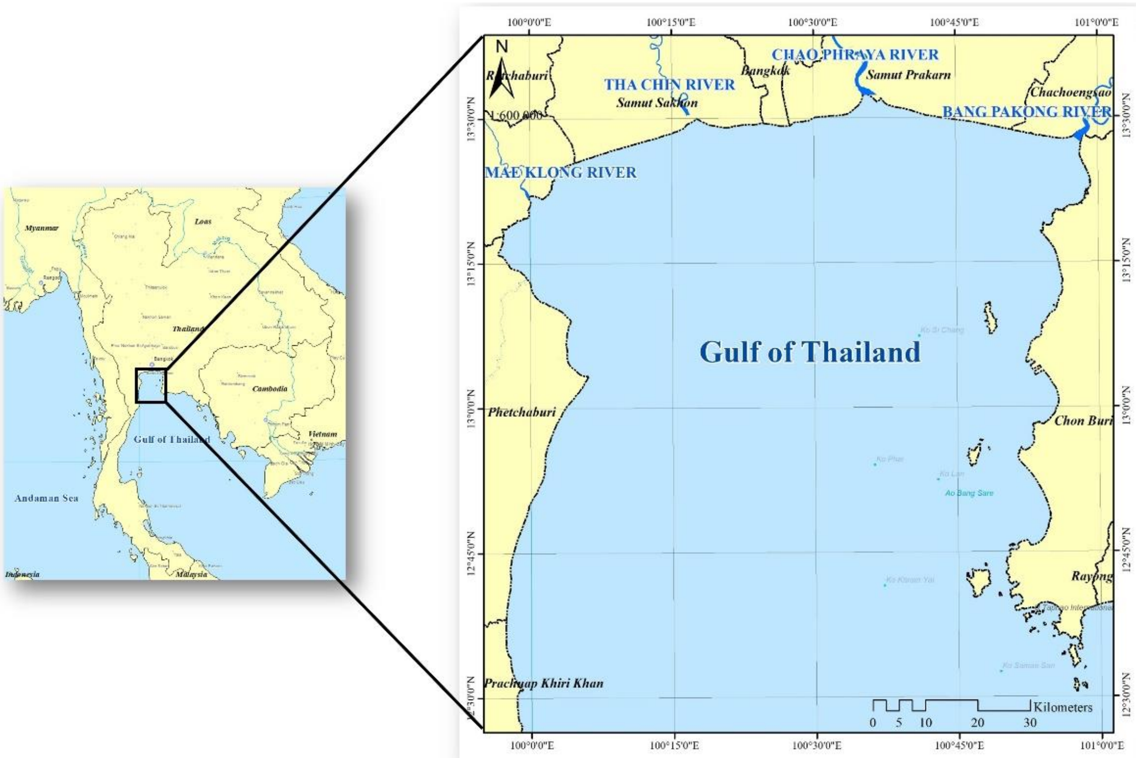

Figure 1. Maps showing the location of the Upper Gulf of Thailand

2.2 Data description

This study used Sentinel-3A OLCI satellite images to obtain Level-1B chlorophyll-related imagery products including Top of atmosphere (TOA) reflectance data radiometrically corrected, calibrated, and spectrally characterized by the Copernicus Open Access Hub. The OLCI is based on MERIS. It has 21 bands with a spectral range extending from 400 nm to 1,040 nm compared to MERIS's 15 bands. The OLCI design is optimized to minimize sun-glint and to obtain a full resolution of 300 m over all surfaces (European Space Agency, 2017). The details are shown on Table 1.

Table 1. OLCI specification bands (European Space Agency, 2017)

Band #	λ center (nm)	Width (nm)	Lmin W/(m^2.sr. µm)	Lref W/(m^2.sr. µm)	Lsat W/(m^2.sr. µm)	SNR@Lref
Oa1	400	15	21.60	62.95	413.5	2188
Oa2	412.5	10	25.93	74.14	501.3	2061
Oa3	442.5	10	23.96	65.61	466.1	1811
Oa4	490	10	19.78	51.21	483.3	1541
Oa5	510	10	17.45	44.39	449.6	1488
Oa6	560	10	12.73	31.49	524.5	1280
Oa7	620	10	8.86	21.14	397.9	997
Oa8	665	10	7.12	16.38	364.9	883
Oa9	673.75	7.5	6.87	15.70	443.1	707
Oa10	681.25	7.5	6.65	15.11	350.3	745
Oa11	708.75	10	5.66	12.73	332.4	785
Oa12	753.75	7.5	4.70	10.33	377.7	605
Oa13	761.25	2.5	2.53	6.09	369.5	232
Oa14	764.375	3.75	3.00	7.13	373.4	305
Oa15	767.5	2.5	3.27	7.58	250.0	330
Oa16	778.75	15	4.22	9.18	277.5	812
Oa17	865	20	2.88	6.17	229.5	666
Oa18	885	10	2.80	6.00	281.0	395
Oa19	900	10	2.05	4.73	237.6	308
Oa20	940	20	0.94	2.39	171.7	203
Oa21	1020	40	1.81	3.86	163.7	152

Note: Dark grey indicates MERIS heritage bands, light gray indicates additional bands available with OLCI.

2.3 Methods

The methods of this study were composed of systematic processes and steps as shown on Figure 2.

2.3.1 Image pre-processing

The pre-processing procedures made on the Sentinel-3A OLCI satellite images were performed using the Sentinel Application Platform (SNAP) data visualization software and consists of the following steps:

1) Pixel identification and classification (IdePix)

The IdePix Processor provides a pixel classification of element properties such as clear/ cloudy, land/water, etc. The information obtained from this stage was used as the input data for masking clouds and land surfaces.

2) Re-projection

Sentinel-3A OLCI Level-1B images were re-projected on a WGS 84 geographic coordinate reference system (CRS).

2.3.2 Image processing

1) Maximum chlorophyll index (MCI)

Data processing of Sentinel-3A OLCI Level-1B images for obtaining the MCI was performed using bands 10, 11, and 12 corresponding to wavelengths of 681.25 nm, 708.75 nm, and 753.75 nm, respectively. The MCI is computed as radiance at 709 nm above a linear baseline defined by radiances at 681 and 753 nm as shown on Equation 1 (Gower et al., 2005; Gower et al., 2008).

$$MCI = L_{709} - L_{681} - 0.389\,(L_{753} - L_{681}) \quad (1)$$

where L_{681}, L_{709}, L_{753} represent Level 1 TOA radiances (as measured by the satellite sensors) at wavelengths of 681 nm, 709 nm, and 753 nm, respectively. The factor 0.389 represents the wavelength baseline ratio (709–681)/(753–681). The MCI therefore indicates an excess radiance at 709 nm above the baseline, which often indicates a water-leaving radiance spectrum with a peak at 709 nm. Models indicate that this particular spectrum is characteristic of the reflected light coming from intense surface plankton blooms in which high concentrations of phytoplankton are distributed in near-surface waters (Gower and King, 2014).

2) Cloud and land masking

Cloud- and land-masking data derived from MCI analysis was implemented.

3) Mapping of phytoplankton blooms

The analysis data from MCI was mapped into the locations of phytoplankton blooms in the study area.

2.3.3 Accuracy Assessment

Validating MCI's for detecting phytoplankton blooms was accomplished by comparing the mapped locations and extents of phytoplankton blooms delineated by the MCI values on particular days with Sentinel-3A RGB False-Color Composite images together with other relevant data.

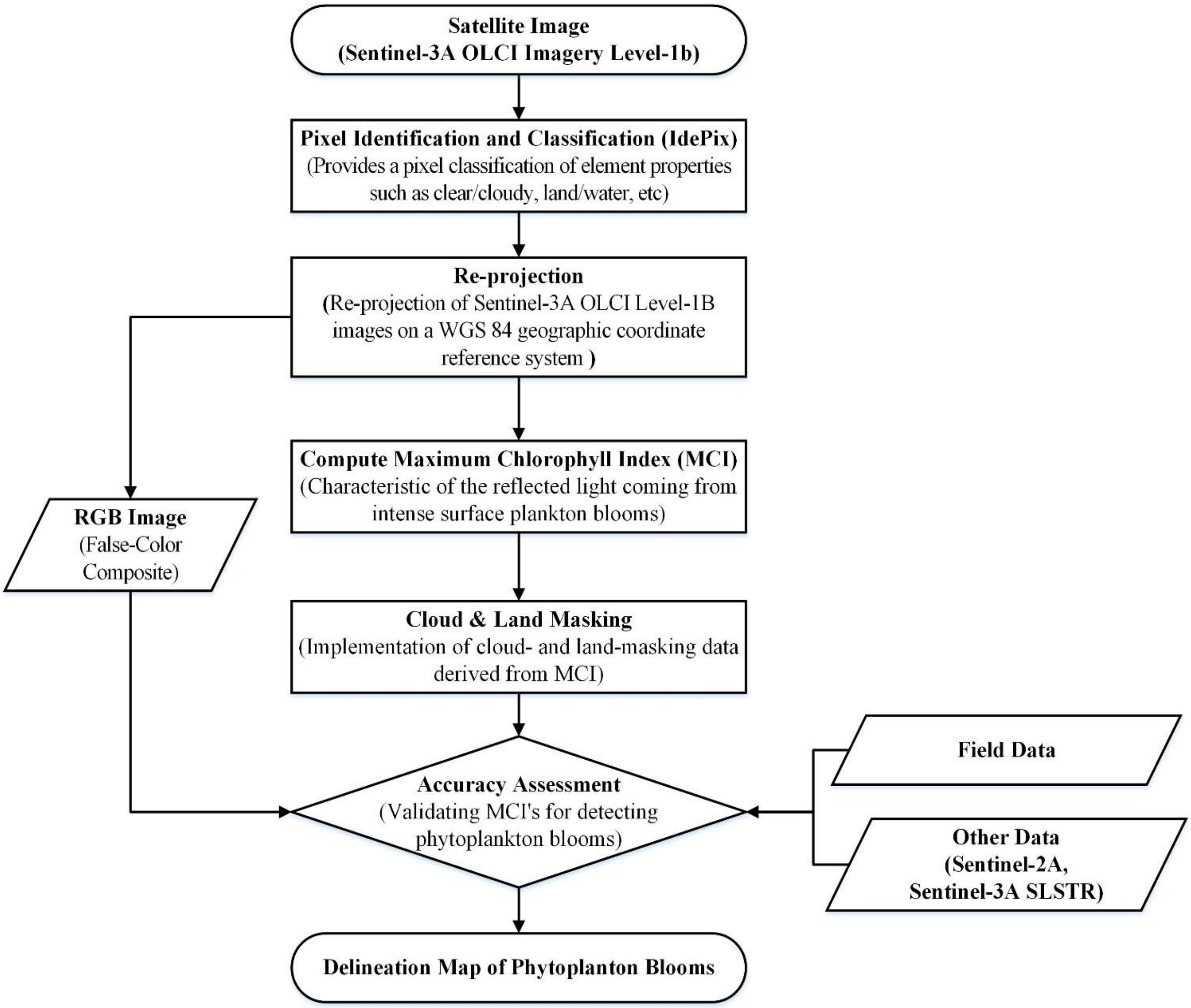

Figure 2. Flowchart of study methodology

3. RESULTS AND DISCUSSION

3.1 Detection of phytoplankton blooms

Detection of phytoplankton blooms by MCI values obtained from Sentinel-3A OLCI imagery at bands 10, 11, 12 taken from the Upper Gulf of Thailand on 19 March 2017, 27 April 2017, and 16 June 2017 was performed with the following details.

1) Detection of phytoplankton blooms on 19 March 2017

The intense phytoplankton bloom points found in the area were near the coast as shown on Figure 3. Differences in scales of radiance spectra for all wavelengths in the phytoplankton blooms areas indicated high values in point (a) compared to the reference point in clear-water point (b) as shown on Figure 4. For the wavelength 708.75 nm, the difference in radiance at (a) and (b) was 14.54 mW/m^2/sr/nm, while the MCI was 12.83 at point (a).

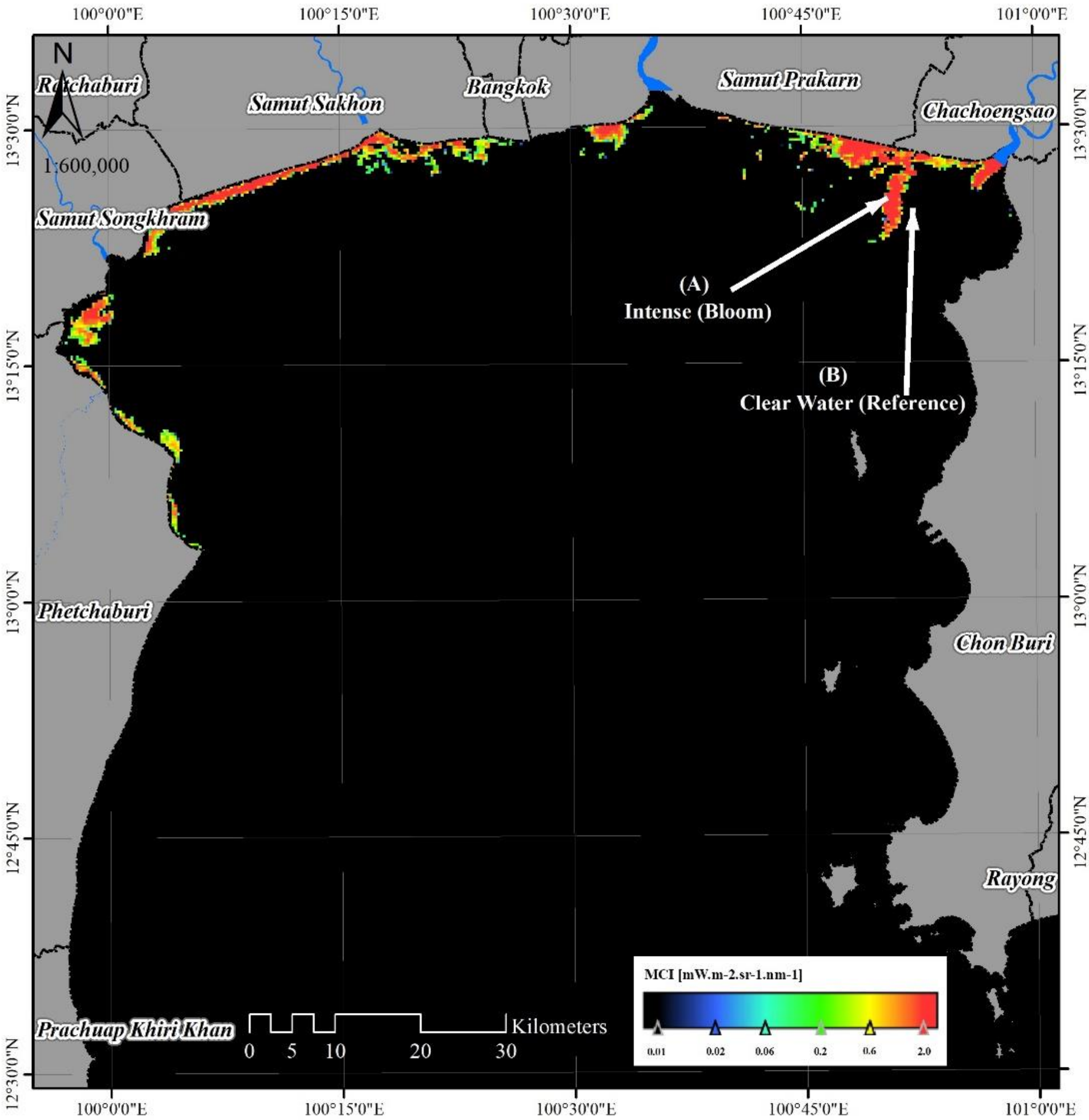

Figure 3. MCI on 19 March 2017

2) Detection of phytoplankton blooms on 27 April 2017

The area of phytoplankton blooms was near the coast and in the middle of the sea as shown on Figure 5. This is based on the radiance spectra in all wavelengths by comparisons in areas of intense phytoplankton concentrations in high-bloom area (a) with a clear-water area reference point (b) as shown on Figure 6. In addition, the wavelength 708.75 nm at point (a) and (b) presented radiance difference of 11.28 mW/m^2/sr/nm and at point (a) the MCI was 5.01.

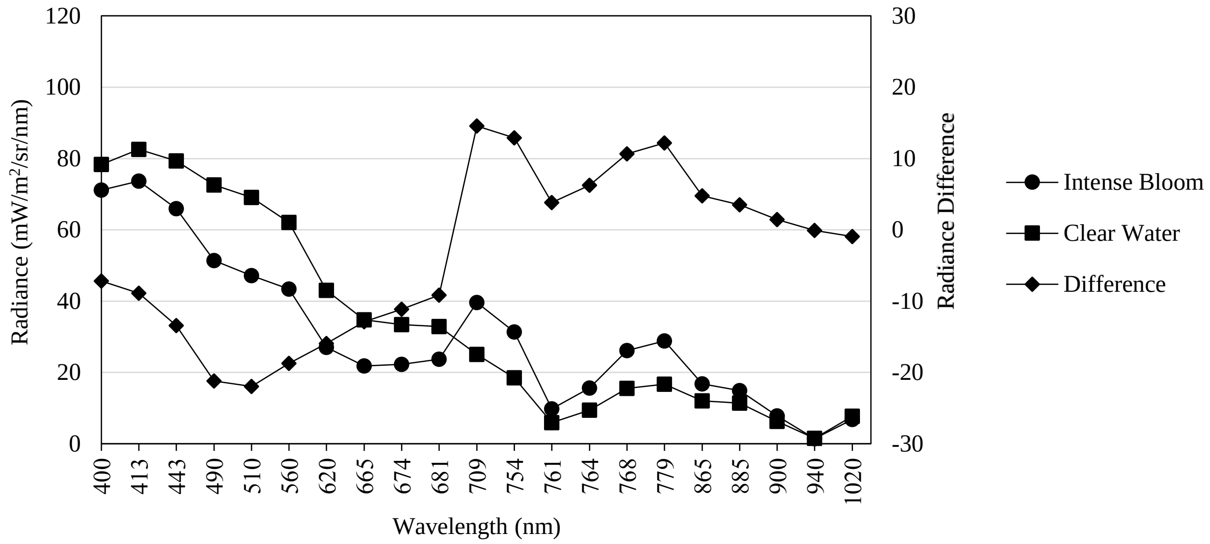

Figure 4. Radiance spectra at intense bloom (a) and clear water (b) on 19 March 2017

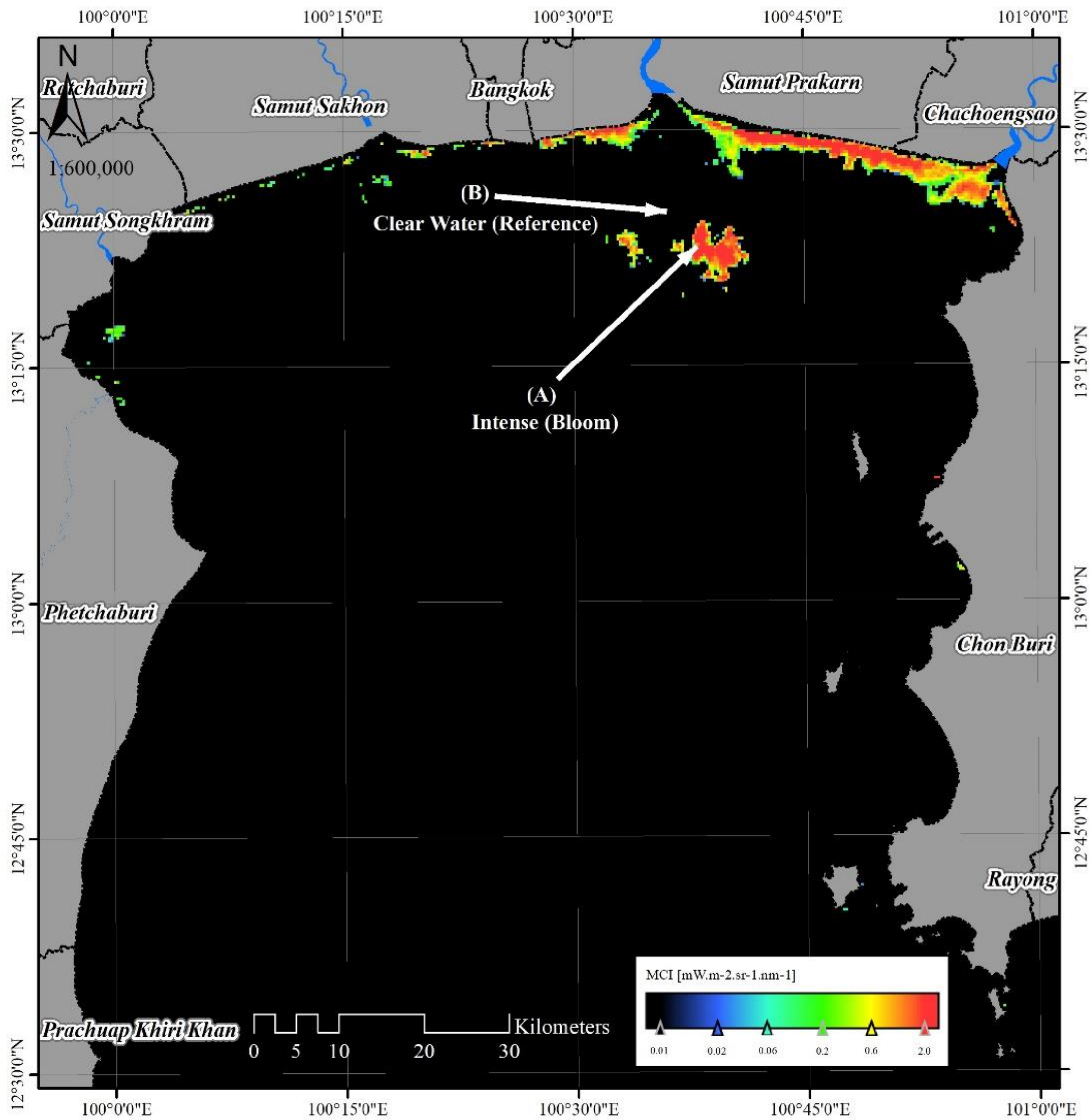

Figure 5. MCI on 27 April 2017

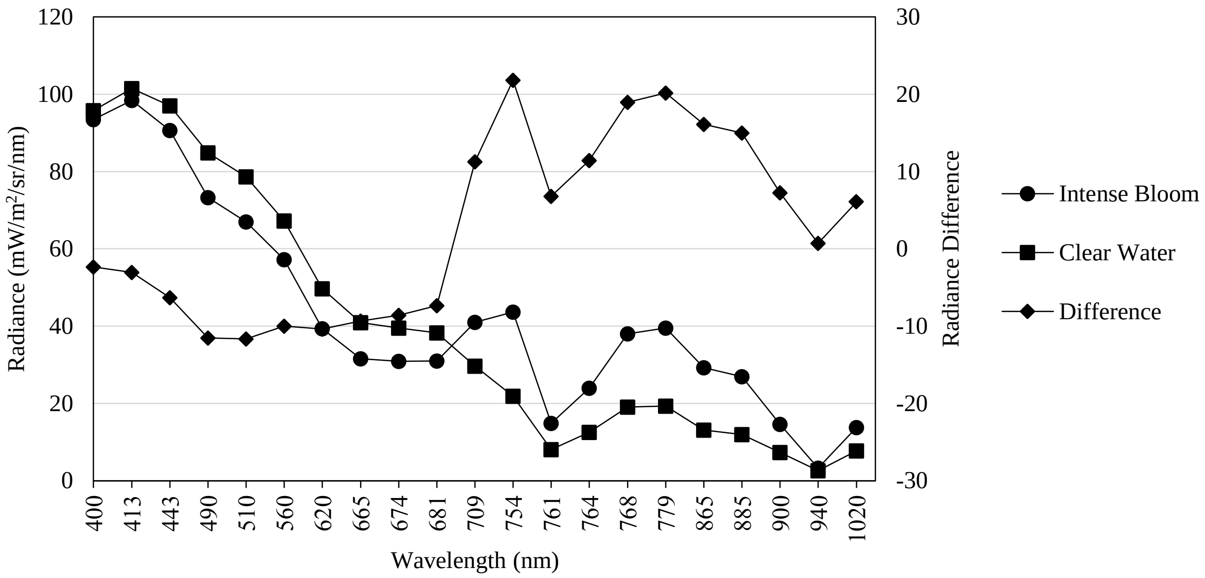

Figure 6. Radiance spectra at intense bloom (a) and clear water (b) on 27 April 2017

3) Detection of phytoplankton blooms on 16 June 2017

Phytoplankton bloomed in the areas near the coast and in the middle of the sea, as shown on Figure 7. Based on the radiance spectra at all wavelengths, comparisons were made on the intensities of the phytoplankton concentrations in high-bloom area at point (a) and with clear-water reference area at point (b) as shown on Figure 8. It was found that with wavelength 708.75 nm at points (a) and (b), there was a difference in radiance of 18.39 mW/m^2/sr/nm; and that at point (a), the MCI was 5.96.

In summary, the detection of phytoplankton blooms on 19 March 2017, 27 April 2017, and 16 June 2017 based on the radiance spectra at all wavelengths, significant differences in area extents of high intensity (a) at 708.75 nm and at 681.25 nm were found. Also, at point (a) where phytoplankton concentrations produced blooms with higher radiance values than at point (b), the radiance peak was at 708.75 nm.

3.2 Evaluation accuracy of phytoplankton bloom detection with MCI

Validation of the detection of phytoplankton blooms from the MCI product was accomplished by comparing the results of an analysis of MCI with Sentinel-3A RGB False-Color Composite images in Band 11 (red), Band 6 (green), and Band 4 (blue) and with other related information. The details are as follows:

1) A comparison of the 19 March 2017 results obtained by matching the MCI maps with the Sentinel-3A RGB False-Color Composite images and with Sea Surface Temperature (SST) data from the Sentinel-3A Sea and Land Surface Temperature Radiometer (SLSTR) is shown on Figure 9. High MCI values corresponded well with locations of phytoplankton blooms seen on RGB False-Color Composite images.

2) A comparison of the results of the analysis on 27 April 2017 was performed between the MCI maps, the Sentinel-3A RGB False-Color Composite images, the Sentinel-2A RGB False-Color Composite images -- band 5 (red), band 3 (green), and band 2 (blue), SST data from Sentinel-3A SLSTR instrument, and field data on phytoplankton bloom events is shown on Figure 10. The field data indicated that the bloom on 28 April 2017 was caused by *Noctiluca scintillans* which imparted a dark-green color on the water as shown on Figure 11.

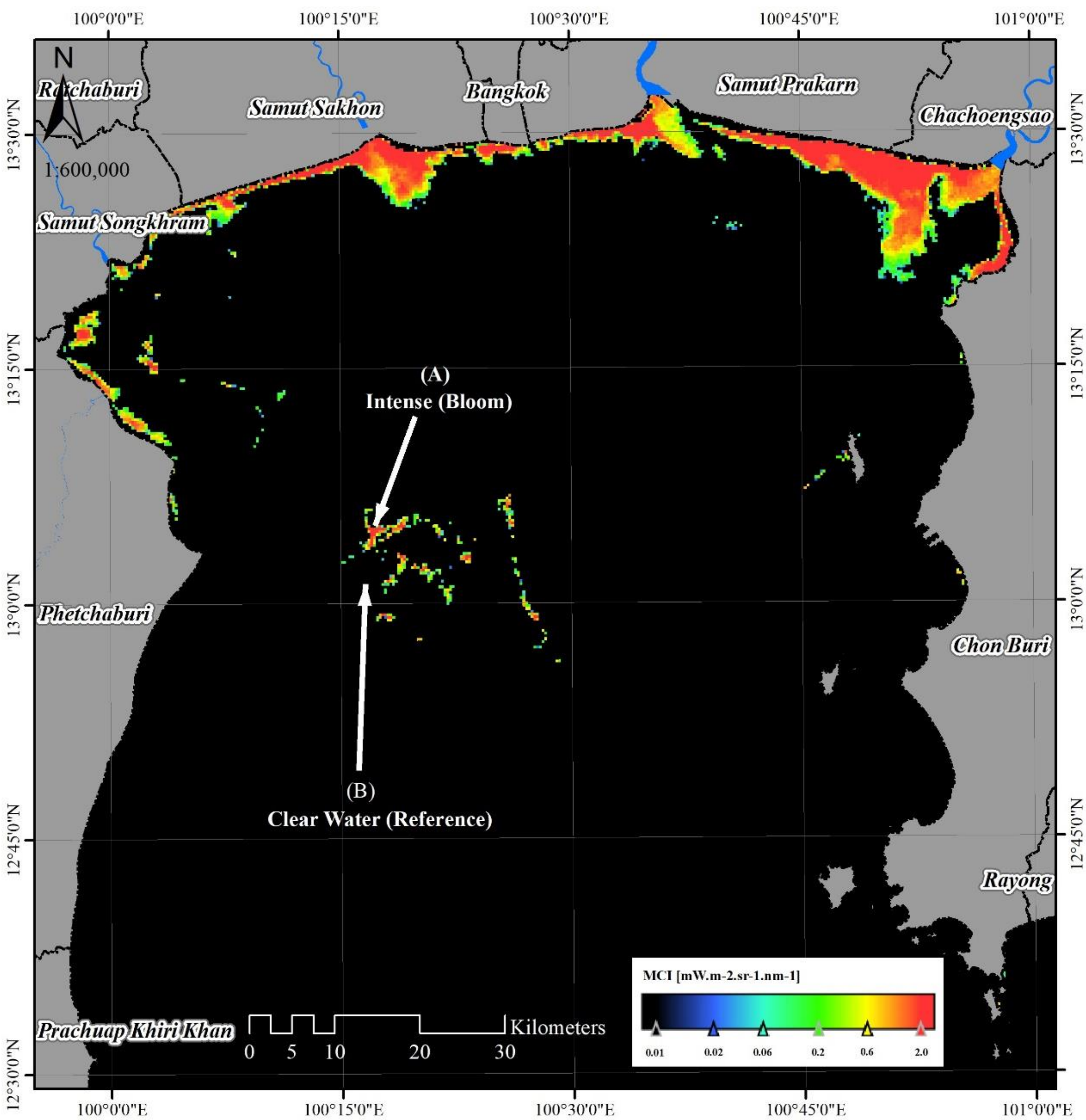

Figure 7. MCI on 16 June 2017

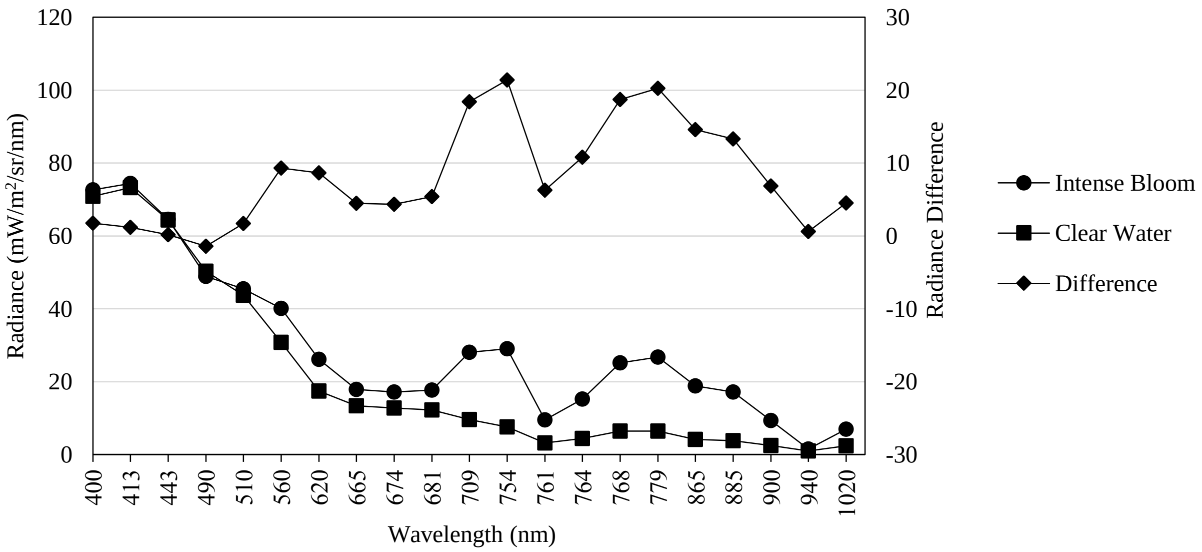

Figure 8. Radiance spectral at intense bloom (a) and clear water (b) on 16 June 2017

3) Similarly, a comparison of the 16 June 2017 results was performed by matching the MCI maps, the Sentinel-3A RGB False-Color Composite images, and the SST data is shown on Figure 12. High MCI values corresponded well with locations of phytoplankton blooms seen on RGB False-Color Composite images.

In general, evaluating the accuracy of the MCI product in detecting phytoplankton blooms in the coastal area revealed that the locations and extents of the intense phytoplankton blooms as delineated by the MCI values were spatially accurate when the positions of the blooms acquired from the RGB False-Color Composite images were used as reference. In the near-shore or estuarine areas, no obvious color anomalies were visible on the RGB satellite images because the phytoplankton blooms were being incorporated into freshwater sediment. These results were consistent with those of He et al. (2008), MCI were used to detect a red tide event in June 2005 in the East China Sea. MCI can be used as an effective tool for red tides detection. However, the MCI product was measurable because the MCI was designed primarily for detecting high concentrations of phytoplankton blooms on the water surface (Blondeau-Patissier et al., 2014a). Moreover, the phytoplankton bloom areas showed slightly higher SSTs compared to the surrounding environment.

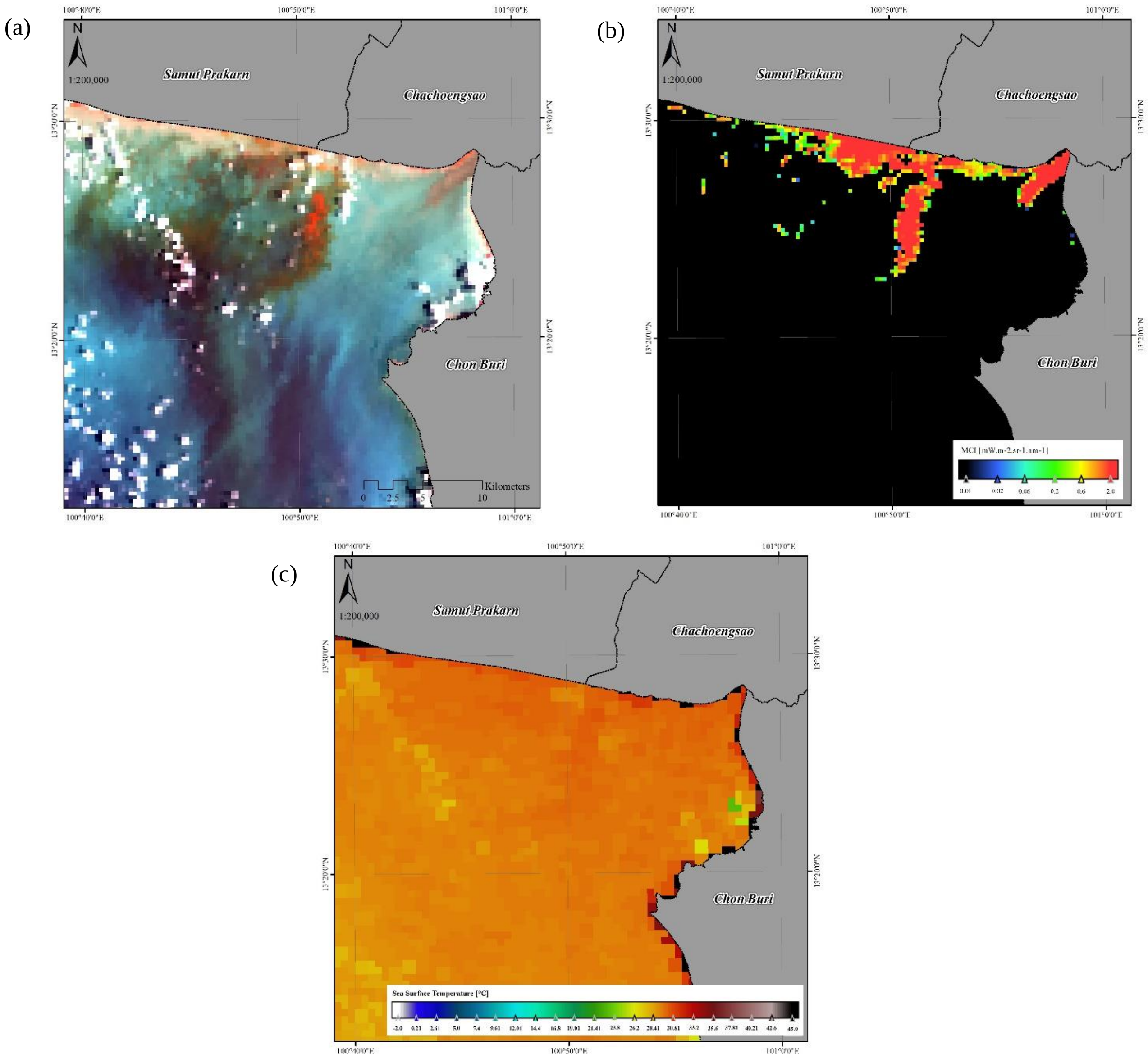

Figure 9. Comparison of the result of Sentinel-3A OLCI on 19 March 2017 between (a) Sentinel-3A OLCI RGB (False-Color Composite), (b) Sentinel-3A (MCI), and (c) Sentinel-3A SLSTR (SST)

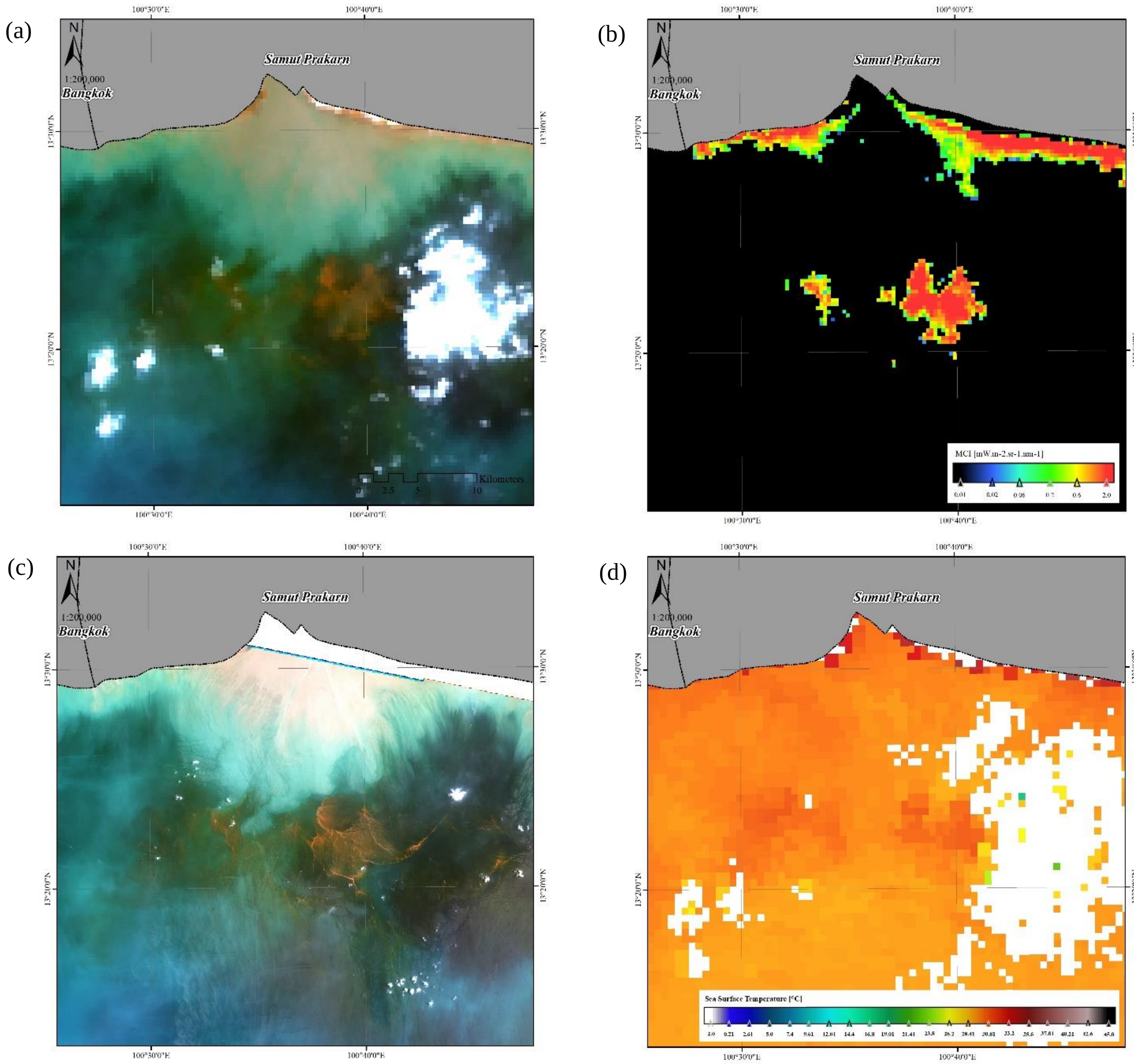

Figure 10. Comparison of the result of Sentinel-3A OLCI on 27 April 2017 with (a) Sentinel-3A OLCI RGB (False-Color Composite), (b) Sentinel-3A (MCI), (c) Sentinel-2A RGB (False-Color Composite), and (d) Sentinel-3A SLSTR (SST)

Figure 11. Photo showing seawater color(s) in the study area where a phytoplankton bloom was found on 28 April 2017

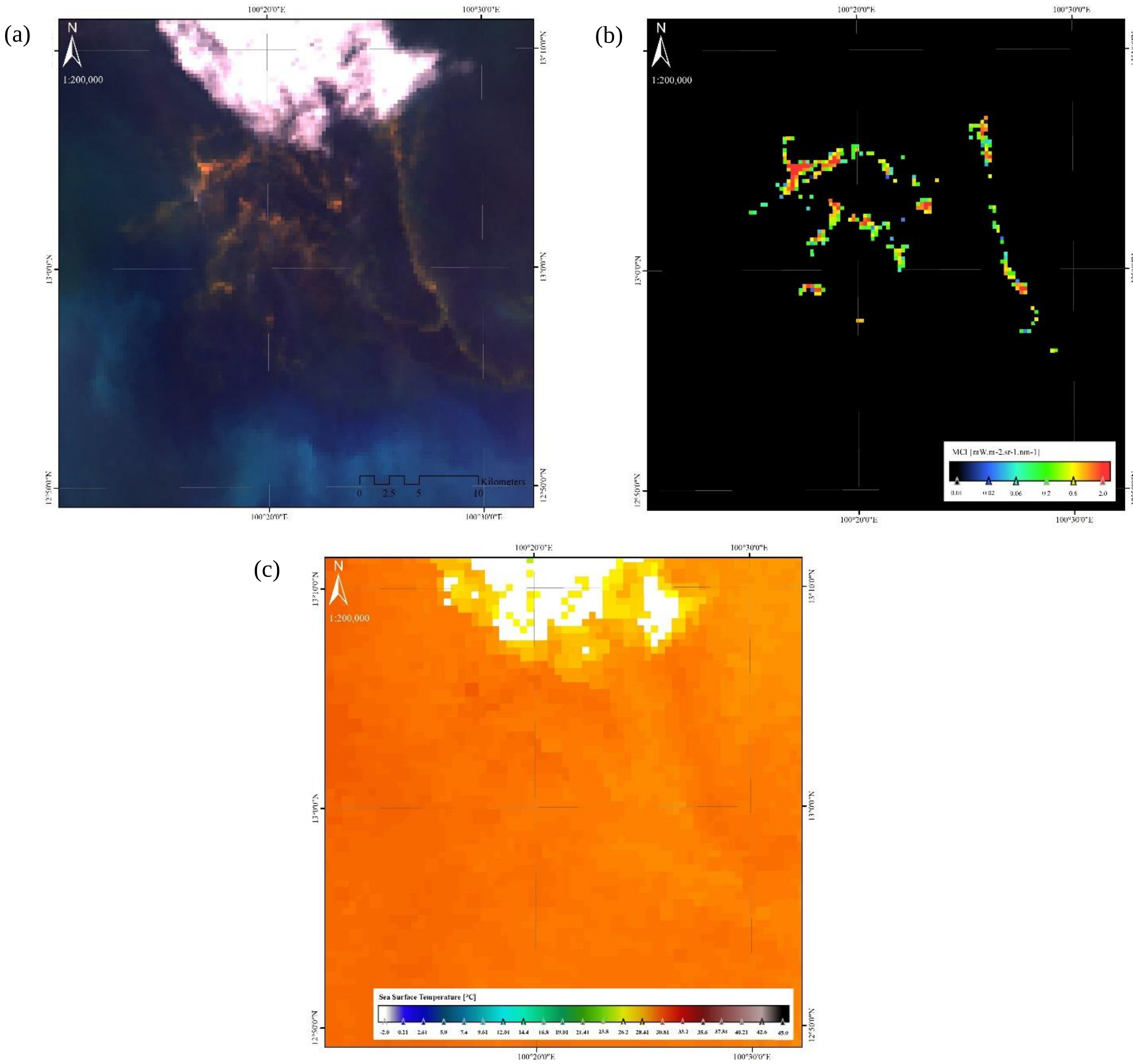

Figure 12. Comparison of the result of Sentinel-3A OLCI on 16 June 2017 with (a) Sentinel-3A OLCI RGB (False-Color Composite), (b) Sentinel-3A (MCI), and (c) Sentinel-3A SLSTR (SST)

4. CONCLUSIONS

The Maximum Chlorophyll Index (MCI) product obtained from Sentinel-3A OLCI imagery of the Upper Gulf of Thailand showed positive results in detecting phytoplankton blooms in the area, specifically during the periods 19 March 2017, 27 April 2017 and 16 June 2017. The areas that had intense phytoplankton blooms registered high MCI values. A radiance spectra with a peak at 708.75 nm and baseline difference of 681.25 nm was also high.

MCI values showed good correlation with RGB False-Color Composite images of the phytoplankton blooms obtained for the same area at the same time period. MCI shows a high potential as a tool for measuring and monitoring the marine environment.

ACKNOWLEDGEMENTS

This study was accomplished with the cooperation of the researchers, the team, and the relevant agencies. We also thank GISTDA for the financial support and for the use of their facilities

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