The Spectral Discrimination of Surface Harmful Algal Bloom in Complicated Coastal Water Conditions

2009-10-27

Young Baek Son¹, Joji Ishizaka¹, & Young Sang Suh²
¹: HyARC, Nagoya University, Japan, ²: NFRDI, Korea
1. Introduction

Before 1995

Diatom Blooms

1982

1984

1994

After 1995: *C. polykrikoides* Blooms

<table>
<thead>
<tr>
<th>Year</th>
<th>First Occur.</th>
<th>Terminated</th>
<th>Duration</th>
<th>First Occur</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>Aug. 29</td>
<td>Oct. 22</td>
<td>55 days</td>
<td>A</td>
</tr>
<tr>
<td>1996</td>
<td>Sep. 4</td>
<td>Oct. 2</td>
<td>28 days</td>
<td>A</td>
</tr>
<tr>
<td>1997</td>
<td>Aug. 24</td>
<td>Sep. 20</td>
<td>27 days</td>
<td>A</td>
</tr>
<tr>
<td>1998</td>
<td>Aug. 11</td>
<td>Oct. 4</td>
<td>34 days</td>
<td>A</td>
</tr>
<tr>
<td>1999</td>
<td>Aug. 22</td>
<td>Sep. 22</td>
<td>29 days</td>
<td>B</td>
</tr>
<tr>
<td>2000</td>
<td>Aug. 20</td>
<td>Sep. 10</td>
<td>19 days</td>
<td>C</td>
</tr>
<tr>
<td>2001</td>
<td>Aug. 14</td>
<td>Sep. 24</td>
<td>41 days</td>
<td>B</td>
</tr>
<tr>
<td>2002</td>
<td>Aug. 2</td>
<td>Sep. 27</td>
<td>57 days</td>
<td>C</td>
</tr>
<tr>
<td>2003</td>
<td>Aug. 13</td>
<td>Oct. 14</td>
<td>62 days</td>
<td>C</td>
</tr>
<tr>
<td>2004</td>
<td>Aug. 5</td>
<td>Sep. 4</td>
<td>30 days</td>
<td>D</td>
</tr>
<tr>
<td>2005</td>
<td>Jul. 19</td>
<td>Sep. 16</td>
<td>58 days</td>
<td>C</td>
</tr>
</tbody>
</table>

After 1995:

C. polykrikoides Blooms

First occur. : Aug. 29
Terminated : Oct. 22
Duration : 55 days
First Occur : A

First occur. : Sep. 4
Terminated : Oct. 2
Duration : 28 days
First Occur : A

First occur. : Aug. 24
Terminated : Sep. 20
Duration : 27 days
First Occur : A

First occur. : Aug. 11
Terminated : Oct. 4
Duration : 34 days
First Occur : A

First occur. : Aug. 22
Terminated : Sep. 22
Duration : 29 days
First Occur : B

First occur. : Aug. 20
Terminated : Sep. 10
Duration : 19 days
First Occur : C

First occur. : Aug. 14
Terminated : Sep. 24
Duration : 41 days
First Occur : B

First occur. : Aug. 2
Terminated : Sep. 27
Duration : 57 days
First Occur : C

First occur. : Aug. 13
Terminated : Oct. 14
Duration : 62 days
First Occur : C

First occur. : Aug. 5
Terminated : Sep. 4
Duration : 30 days
First Occur : D

First occur. : Jul. 19
Terminated : Sep. 16
Duration : 58 days
First Occur : C

1982

1984

1994
2. Methods and Data: To detect the huge blooms from space

1) Five MODIS satellite data were matched with in-situ red tide information (NFRDI).
2) MODIS satellite products:
   - the spectral normalized water-leaving radiance ($nLw$),
   - satellite chlorophyll concentration ($\text{Chlor-a}$),
   - fluorescence line height (FLH),
   - phytoplankton absorption ($a_{ph}$) and detritus/gebstoff absorption ($a_{dg}$),
   - particle backscattering coefficients ($b_p$).
3) ~ 300 satellite sub-sample data collected from red tide areas:
   - the spectral response of red tide signals
   - the red and non-red tide waters -> spectral classification and band ratio.
4) Demonstrates how the improved discrimination in mapping HAB distributions.

1. Satellite Data Processing

MODIS high-resolution Level 0 data (http://oceancolor.gsfc.nasa.gov/)

Process from Level 0 to Level 1A / Level 1B

True color image at 250 m resolution using (645, 555, 469 nm)

Process from Level 1B to Level 2 at 1 km resolution
Products = CHL, FLH, $a_{ph}$, $a_{dg}$, $b_p$, $nLw$(412, 443, 488, 531, 551, 667, 678, 748, 869)
1. The potential spectral characteristic of red tide: averaged MODIS chlorophyll-a concentration.
2. Radiance spectra: two dominant peaks at 531/551 (green bands) and 678 (red band) nm.
3. Low value at blue wavelengths (> 10 mg m\(^{-3}\): red line): high phytoplankton and detritus/gelbstoff absorptions and small difference between blue and red bands.
4. High value at blue bands (< 10 mg m\(^{-3}\): blue line): low phytoplankton and detritus/gelbstoff absorptions and high difference between blue and red bands.
3. Results

1. Red Tide Classification

Step 1
Highest value in $nLw_{(531)}$ and $nLw_{(551)}$ with fluorescence peak

Step 2

\[
\frac{nLw_{(412)}}{nLw_{(551)}} \geq \frac{nLw_{(551)} - nLw_{(488)}}{nLw_{(551)}}
\]

Step 3: Low Detritus/Gelbstoff

\[
\frac{nLw_{(433)}}{nLw_{(531)}} \geq \frac{nLw_{(488)}}{nLw_{(551)}}
\]

Yes

Step 4: High Detritus/Gelbstoff

\[
\frac{nLw_{(531)}}{nLw_{(488)} + nLw_{(443)}} \geq \frac{nLw_{(488)}}{nLw_{(551)} - nLw_{(488)}}
\]

Yes

Red Tide

No

Non-Red Tide

1. *C. polykrikoides* blooms:
   - Onshore (high influence of CDOM or organic/inorganic material, *increasing absorption in blue bands*)
   - Offshore (less influence of CDOM or organic/inorganic material, *decreasing absorption and increasing water backscattering in blue bands*).

2. Step 2: Relatively high and low contribution of detritus/gelbstoff to chlorophyll

3. Step 3: Lower contribution of CDOM to chlorophyll

4. Step 4: Higher contribution of CDOM to chlorophyll
1. Blue bands: Increasing pigment absorption at 443 nm caused lower slope between blue and green bands.
2. Different radiance value at blue bands: the relative effect of CDOM per chlorophyll
3. Red tide waters are related to enhanced phytoplankton absorption and FLH with varying chlorophyll
Inshore showed the low salinity due to heavy rain, so HAB moved to offshore.

- Visual appearance of *C. polykrikoides* bloom:
  
  the discolored water from *blue* to *dark red brown*.

- Increasing absorption of chlorophyll and non-living particles induced the decreasing radiance at blue wavelengths with no scattering the light that visually appeared in water discolored as *dark* or *black*. 
4. Discussions : Case Study

**Step 1 & 2**

Blue : low gelbstoff/detritus
Red : high gelbstoff/detritus

**Step 3: Low Detritus/Gelbstoff**
- \( n_{443} < n_{555} \)
- \( n_{443} < n_{555} < n_{555} \)

**Step 4: High Detritus/Gelbstoff**
- \( n_{443} > n_{488} \)
- \( n_{488} > n_{443} \)

**Red Tide Classification**

- Alert : > 1000 cells ml\(^{-1}\)
- Attention : > 300 cells ml\(^{-1}\)

**Red Tide Area**

Blue : step 3
Red : step 4
2002-09-08(251) – After Rusa

Typhoon Rusa: Aug. 22 – Sep. 1, 2002

[Map showing Typhoon Rusa's path and affected areas]
4. Discussions: Case Study

True Color Image

MODIS Chlorophyll

Red Tide Area

Blue: low gelbstoff/detritus
Red: high gelbstoff/detritus

2002-09-08(251) – After Rusa

Red Tide Classification

Step 1 & 2

Blue: step 3
Red: step 4
4. Discussions : Case Study
4. Discussions: Case Study
4. Discussions : Case Study

True Color Image

2007-08-21(233)
MODIS Chlorophyll

Red Tide Area

Blue : low gelbstoff/detritus
Red : high gelbstoff/detritus

Step 1 & 2

Blue : step 3
Red : step 4

Red Tide Area
5. Conclusions

1. For understanding of algal blooms at the South Sea of Korea, we developed a systematic method for classifying complicated coastal waters included red tide using MODIS remote sensing data.

2. We developed a spectral classification to discriminate the red and non-red tide conditions, which guided by different four criteria.

3. *C. polykrikoides* blooms in SSK observed that radiance is higher at green bands and lower at blue bands due to the influence of strong pigment backscattering and high chlorophyll absorptions.

4. Analysis of MODIS ocean color imagery revealed that pixel-based classification projected into distinct clusters in space domain, suggesting that this approach is promising for mapping phytoplankton blooms from various water conditions regionally based on remote sensing data.
Thank you
3. Results and Discussions

「だいち」がとらえた赤潮のシートウルース

2007年
8月21日

2000固体/mL

株式会社 環境シミュレーション研究所

Environment Simulation Laboratory Co, Ltd.
3. Results

Blue circle:

\[ \frac{nLw(412)}{nLw(551)} \geq \frac{nLw(551) - nLw(488)}{nLw(551)} \]

Red circle:

\[ \frac{nLw(412)}{nLw(551)} < \frac{nLw(551) - nLw(488)}{nLw(551)} \]
3. Results

**Phytoplankton Absorption Coefficient**

Blue Line: \[
\frac{nLw(412)}{nLw(551)} > \frac{nLw(551) - nLw(488)}{nLw(551)}
\]

Low effect of Detritus/gelbstoff

Red Line: \[
\frac{nLw(412)}{nLw(551)} < \frac{nLw(551) - nLw(488)}{nLw(551)}
\]

High effect of Detritus/gelbstoff

**Detritus/gelbstoff Absorption Coefficient**

**Particle Backscattering Coefficient**
3. Results: Low effect of Detritus/gelbstoff

1. Red tide: relative high FLH and phytoplankton absorption values.
3. Results: High effect of Detritus/gelbstoff

Red Color:
\[
\frac{1}{nLw(488) - nLw(443)} \geq \frac{1}{nLw(531) - nLw(488)}
\]

Green Color:
\[
\frac{1}{nLw(443) - nLw(488)} < \frac{1}{nLw(531) - nLw(488)}
\]

1. Potential Red tide: relative high FLH, satellite chlorophyll and phytoplankton absorption values.
3. Results: High effect of Detritus/gelbstoff

1. Red tide: relative high FLH, satellite chlorophyll and phytoplankton absorption values.
3. Results and Discussions: Water type classification

Werdell and Bailey (2005)

Fig. 9. The NOMAD $R_{\text{m}}(\lambda)$ spectra displayed for geometrically increasing chlorophyll a concentration ranges, as indicated by the title of each plot. Solid black lines indicate the median spectrum for each chlorophyll a range. Dashed black lines display a theoretical clear-water spectrum for the median chlorophyll a concentration for each range. The latter spectra were derived using the Case-1 approximations described in Morel and Maritorena (2001).
4. Discussions : Case Study

2003-08-22(234)
MODIS Chlorophyll

Red Tide Classification
Step 1 & 2

Blue : low gelbstoff/detritus
Red : high gelbstoff/detritus

Red Tide Area

Step 1 & 2
Blue : low gelbstoff/detritus
Red : high gelbstoff/detritus

Red Tide Area
4. Discussions: Case Study

True Color Image

2004-08-28 (241)
MODIS Chlorophyll

Red Tide Classification
Step 1 & 2

Blue: low gelbstoff/detritus
Red: high gelbstoff/detritus

Red Tide Area
3. Results: Water Type Classification

2. Water Type Classification

Step 2-1

Highest value in $nLw(531)$ and $nLw(551)$

Step 2-2

Yes

$nLw(667) > nLw(678)$

No

Step 2-3

Highest value in $nLw(412)$ and $nLw(443)$ with zero value in $nLw(748)$ and $nLw(869)$

Yes

Turbid Water

High Chl. Water

No

Clear Water

Intermediate Water

Bright color (B1, B2): Radiance peaks at green band. Higher radiance and particulate backscattering but phytoplankton absorption is minimal.

High chlorophyll and red tide (H, R): Radiance peaks at green band. Higher absorption of the phytoplankton and gelbstoff/detritus. Particulate backscattering values are ~3-4 times lower than in bright color samples.
3. Results: Water Type Classification

2. Water Type Classification

<table>
<thead>
<tr>
<th>Step 2-1</th>
<th>Step 2-2</th>
<th>Step 2-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest value in $nLw(531)$ and $nLw(551)$</td>
<td>$nLw(667) &gt; nLw(678)$</td>
<td>Highest value in $nLw(412)$ and $nLw(443)$ with zero value in $nLw(748)$ and $nLw(869)$</td>
</tr>
<tr>
<td>Turbid Water</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>High Chl. Water</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Clear Water</td>
<td>Intermediate Water</td>
<td></td>
</tr>
</tbody>
</table>

Weak fluorescence signals disappeared through surface turbid water column due to complex interactions with suspended particulate materials (Ahn and Shanmugam, 2006; Babin et al., 1996)
3. Results: Water Type Classification

Low and moderate chlorophyll (L, M): Radiance peaks from 412 nm to 531 nm (blue to green bands) absorption and backscattering of the phytoplankton, gelbstoff, and detritus in all visual wavelengths