MODIS Validation for Water Quality Parameters in Mayagüez Bay

Fernando Gilbes¹, William Hernández, Natlee Hernández, José Martínez, and Vilmaliz Rodriguez

Geological and Environmental Remote Sensing Lab
Department of Geology
University of Puerto Rico at Mayagüez
¹gilbes@cacique.uprm.edu
MOTIVATION FOR THIS WORK

- MODIS (Moderate Resolution Imaging Spectroradiometer) is considered an improved generation of ocean color sensors.
- However, its validation in coastal waters is still underway.
- There is a great expectation toward MODIS due to its temporal, spatial, and spectral resolutions.
- Therefore, the testing and validation of MODIS in coastal waters of Puerto Rico is necessary for an implementation of continuous monitoring of water quality parameters using remote sensing.
MODIS TEMPORAL RESOLUTION

EOS AM
~10:30 AM
LOCAL TIME

EOS PM
~1:30 PM
LOCAL TIME
MODIS SPATIAL RESOLUTION

Bands 1-2 = 250 m
Bands 3-7 = 500 m
Bands 8-36 = 1000 m
<table>
<thead>
<tr>
<th>Primary Use</th>
<th>Band</th>
<th>Bandwidth</th>
<th>Primary Use</th>
<th>Band</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land/Cloud/Aerosols Boundaries</td>
<td>1</td>
<td>620 - 670</td>
<td>Surface/Cloud Temperature</td>
<td>20</td>
<td>3.660 - 3.840</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>841 - 876</td>
<td>Chl-a</td>
<td>21</td>
<td>3.929 - 3.989</td>
</tr>
<tr>
<td>Land/Cloud/Aerosols Properties</td>
<td>3</td>
<td>459 - 479</td>
<td></td>
<td>22</td>
<td>3.929 - 3.989</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>545 - 565</td>
<td></td>
<td>23</td>
<td>4.020 - 4.080</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1230 - 1250</td>
<td>Chl-a</td>
<td>24</td>
<td>4.433 - 4.498</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>1628 - 1652</td>
<td></td>
<td>25</td>
<td>4.482 - 4.549</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>2105 - 2155</td>
<td>Atmospheric Temperature</td>
<td>26</td>
<td>1.360 - 1.390</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>405 - 420</td>
<td>Atmospheric Water Vapor</td>
<td>27</td>
<td>6.535 - 6.895</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>438 - 448</td>
<td></td>
<td>28</td>
<td>7.175 - 7.475</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>483 - 493</td>
<td>Cloud Properties</td>
<td>29</td>
<td>8.400 - 8.700</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>526 - 536</td>
<td>Chl-a</td>
<td>30</td>
<td>9.580 - 9.880</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>546 - 556</td>
<td>Ozone</td>
<td>31</td>
<td>10.780 - 11.280</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>662 - 672</td>
<td>Surface/Cloud Temperature</td>
<td>32</td>
<td>11.770 - 12.270</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>673 - 683</td>
<td>Cloud Top Altitude</td>
<td>33</td>
<td>13.185 - 13.485</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>743 - 753</td>
<td></td>
<td>34</td>
<td>13.485 - 13.785</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>862 - 877</td>
<td></td>
<td>35</td>
<td>13.785 - 14.085</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>890 - 920</td>
<td></td>
<td>36</td>
<td>14.085 - 14.385</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>931 - 941</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>915 - 965</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**MODIS SPECTRAL RESOLUTION**
MAYAGUEZ BAY

Deep and Clear Waters

Sewage Outfall

Shallow and Clear Waters with Coral Reefs

Añasco River

Yaguez River

Guanajibo River

Climatology of Añasco River Discharge

(Dry Season)

(Rainy Season)

Month
To validate the accuracy of the MODIS sensor for measuring
- phytoplankton Chlorophyll-a (Chl-a)
- suspended sediments (SS)
in Mayagüez Bay, Puerto Rico.
TECHNICAL APPROACH

Chl-a

- Testing of NASA OC3 algorithm using the 1 km bands
- Develop local algorithm using 500 m bands

SS

- Testing the Miller & Mckee algorithm using 250 m bands
- Develop local algorithm using 250 m bands
20 SAMPLING DATES

- April 24-26, 2001
- October 2-4, 2001
- February 26-28, 2002
- August 20-22, 2002
- October 7-9, 2003
- January 12-14, 2004
- February 12, 2004
- August 19, 2004
- March 10, 2005
- July 19, 2005
- August 17, 2005
- September 20, 2005
- October 19, 2005
- December 6, 2005
- March 8, 2006
- April 21, 2006
- September 26, 2006
- October 26, 2006
- May 1-2, 2007
GRID OF SAMPLING STATIONS
The SeaWiFS Data Analysis System (Sea DAS) was used to process the raw 1km images and generate Chl-a images using the standard OC3 algorithm.
STANDARD MODIS OC3 ALGORITHM

\[ C = 10^{(0.2830 - 2.753 R_{3M}^3 + 1.457 R_{3M}^2 + 0.659 R_{3M}^3 - 1.403 R_{3M}^4)} \]

where \( R_{3M} = \log_{10} (\frac{R}{550} > \frac{R}{550}) \)
EXAMPLE OF MODIS CHL-A
### 1st Challenge - Get Good Images

<table>
<thead>
<tr>
<th>Date</th>
<th>Satellite</th>
<th>Percent of Missing Data</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 24-26, 2001</td>
<td>Aqua &amp; Terra</td>
<td>100%</td>
<td>Satellite not available</td>
</tr>
<tr>
<td>October 2-4, 2001</td>
<td>Aqua &amp; Terra</td>
<td>100%</td>
<td>Satellite not available</td>
</tr>
<tr>
<td>February 26-28, 2002</td>
<td>Aqua &amp; Terra</td>
<td>100%</td>
<td>Satellite not available</td>
</tr>
<tr>
<td>August 20, 21, 22, 2002</td>
<td>Aqua &amp; Terra</td>
<td>100%</td>
<td>Clouds</td>
</tr>
<tr>
<td>February 25, 26, 27, 2003</td>
<td>Aqua</td>
<td>92%</td>
<td>Clouds</td>
</tr>
<tr>
<td>February 25, 26, 27, 2003</td>
<td>Terra</td>
<td>33%</td>
<td>Clouds</td>
</tr>
<tr>
<td>October 7, 8, 9, 2003</td>
<td>Aqua</td>
<td>100%</td>
<td>Not image available for PR</td>
</tr>
<tr>
<td>October 7, 8, 9, 2003</td>
<td>Terra</td>
<td>33%</td>
<td>Clouds</td>
</tr>
<tr>
<td>January 12, 13, 14, 2004</td>
<td>Aqua</td>
<td>56%</td>
<td>Clouds</td>
</tr>
<tr>
<td>January 12, 13, 14, 2004</td>
<td>Terra</td>
<td>33%</td>
<td>Clouds</td>
</tr>
<tr>
<td>12-Feb-04</td>
<td>Aqua</td>
<td>100%</td>
<td>Clouds</td>
</tr>
<tr>
<td>12-Feb-04</td>
<td>Terra</td>
<td>30%</td>
<td>Clouds</td>
</tr>
<tr>
<td>19-Aug-04</td>
<td>Aqua &amp; Terra</td>
<td>100%</td>
<td>Clouds</td>
</tr>
<tr>
<td>10-Mar-05</td>
<td>Aqua</td>
<td>0%</td>
<td>Good Image</td>
</tr>
<tr>
<td>10-Mar-05</td>
<td>Terra</td>
<td>67%</td>
<td>Clouds</td>
</tr>
<tr>
<td>19-Jul-05</td>
<td>Aqua &amp; Terra</td>
<td>100%</td>
<td>Clouds</td>
</tr>
<tr>
<td>17-Aug-05</td>
<td>Aqua</td>
<td>100%</td>
<td>Clouds</td>
</tr>
<tr>
<td>17-Aug-05</td>
<td>Terra</td>
<td>83%</td>
<td>Clouds</td>
</tr>
<tr>
<td>20-Sep-05</td>
<td>Aqua &amp; Terra</td>
<td>100%</td>
<td>Clouds</td>
</tr>
<tr>
<td>19-Oct-05</td>
<td>Aqua</td>
<td>100%</td>
<td>Clouds</td>
</tr>
<tr>
<td>19-Oct-05</td>
<td>Terra</td>
<td>17%</td>
<td>Clouds</td>
</tr>
<tr>
<td>6-Dec-05</td>
<td>Aqua</td>
<td>100%</td>
<td>Clouds</td>
</tr>
<tr>
<td>6-Dec-05</td>
<td>Terra</td>
<td>33%</td>
<td>Clouds</td>
</tr>
<tr>
<td>8-Mar-06</td>
<td>Aqua</td>
<td>100%</td>
<td>Clouds</td>
</tr>
<tr>
<td>8-Mar-06</td>
<td>Terra</td>
<td>33%</td>
<td>Clouds</td>
</tr>
<tr>
<td>21-Apr-06</td>
<td>Aqua &amp; Terra</td>
<td>100%</td>
<td>Not image available for PR</td>
</tr>
<tr>
<td>26-Sep-06</td>
<td>Aqua &amp; Terra</td>
<td>100%</td>
<td>Clouds</td>
</tr>
<tr>
<td>26-Oct-06</td>
<td>Aqua</td>
<td>100%</td>
<td>Clouds</td>
</tr>
<tr>
<td>28-Oct-06</td>
<td>Terra</td>
<td>50%</td>
<td>Clouds</td>
</tr>
</tbody>
</table>
FIELD VERSUS MODIS CHL-A

**Terra Data**

![Graph showing the relationship between field chlorophyll (ug/l) and MODIS Chlorophyll (ug/l) with $R^2 = 0.028$.]

**Aqua Data**

![Graph showing the relationship between field chlorophyll (ug/l) and MODIS Chlorophyll (ug/l) with $R^2 = 0.026$.]
Georeferenced B3/B4 Ratio (500 m)
MODIS Terra image - February 12, 2004
[Chl-a] vs B3/B4 MODIS Terra
(8 outliers eliminated)

\[ y = -0.6829x + 1.4605 \]
\[ R^2 = 0.616 \]

\[ y = -0.5231\ln(x) + 0.665 \]
\[ R^2 = 0.618 \]
NEW ALGORITHM VERSUS OC3

[Chlorophyll-a] = Empirical algorithm
500 m resolution
[Chl-a] = -42.12*(B3/B4)+1.8219

[Chlorophyll-a] = OC3 MODIS algorithm
1 km resolution
SUSPENDED SEDIMENTS

- Miller and McKee (2004)
  - Study of northern Gulf of Mexico-Mississippi Delta
  - Linear relationship: *in situ* Suspended Matter vs. MODIS Terra Band 1 (620 – 670 nm)
  - Provided evidence of sediment transport

Calibrated images of Mississippi River delta derived from MODIS Terra Band 1 (Miller & McKee, 2004)
Miller and McKee (2004) Algorithm

\[ TSM = -1.91 \times 1140.25 \text{(MODIS Band 1)} \]
RESULTS IN MAYAGUEZ BAY

![Graph showing measured suspended sediment concentration against MODIS Band 1 suspended sediment concentration with an R² value of 0.0845]
2ND APPROACH-A NEW ALGORITHM

- Image preprocessing with ENVI (Environment for Visualization of Images)
  - Geo-referencing: UTM 19 (Datum NAD 83)
  - 17 GPS points corroborated
  - Atmospheric correction:
    - Dark Subtract

GPS points used in geo-reference validation
FIELD SS AND MODIS-B1 %REFLECTANCE

All Stations: (2001 – 2006)

y = 105.19x + 2.6373
R² = 0.1443
FIELD SS AND MODIS‐B1 %REFLECTANCE

Dry Season (2001 – 2006)

- \[ y = 80.703x + 3.614 \]
- \[ R^2 = 0.0695 \]


- \[ y = 136.58x + 0.8668 \]
- \[ R^2 = 0.2788 \]
FIELD SS AND MODIS-B1 %REFLECTANCE

**In-shore Stations (2001 – 2006)**

\[ y = 63.781x + 5.962 \]

\[ R^2 = 0.0473 \]


\[ y = 55.796x + 3.2736 \]

\[ R^2 = 0.0468 \]
REFLECTANCE VS. SEDIMENTS

- Reflectance
  - Previous findings
    - Increase in SS = Increase in reflectance
    - Red & Near IR wavelengths show lower slopes in high SS
  - Mayagüez Bay
    - Concentration too low to provide strong response

From Witte et al. (1982)
A NOVEL APPROACH FOR SS
VILMALIZ RODRIGUEZ POSTER

SS = 337.26 *(Band 1) + 854.12 *(Band 2)

\[ y = 0.4033 \times \text{band 1} - 0.0006 \]

\[ \text{SS (mg/l)} = 452.41 \times y + 2.9603 \]
SS WITH NEW ALGORITHM

October 7, 2003

January 14, 2004
CONCLUSIONS

- Image processing and analyses clearly demonstrated that MODIS is not the most appropriate ocean color sensor for Mayagüez Bay.
- Another sensor with better temporal, spatial, and spectral resolutions is still needed for the estimation of Chl-a and SS in tropical coastal waters.
- However, MODIS Band 1 gives good qualitative results of SS when a site-specific algorithm is applied in Mayagüez Bay.
- Future work with MODIS in this region must include (but not limited):
  - Improve the atmospheric correction
  - Consider other sources of error like bottom and land signal
  - Contamination by CDOM (Patrick Reyes Presentation-Tomorrow)