Sentinel-2 Red-Edge Bands Capabilities for Retrieving Chlorophyll-a: Lake Burullus, Egypt

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The TIGER initiative

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Why Sentinel-2 for water quality?

The aquatic biosphere is uniquely monitored by EO sensors as they provide synoptic information on key water quality variables at high temporal frequency.

The Multi-Spectral Instrument (MSI) payload of SENTINEL-2 mission will sample 13 spectral bands: four bands at 10 m, six bands at 20 m and three bands at 60 m spatial resolution.

The twin satellites of SENTINEL-2 mission offer data at frequency of 5 days at the Equator.
Challenges

Part of the reality

What you see is not what you get!

UNIVERSITY TWENTE.
Requirements and objective

Consistent EO-estimates of water quality parameters in inland and coastal waters requires three components:

– (i) a reliable atmospheric correction method;
– (ii) an accurate retrieval algorithm and
– (iii) an objective method for calibration and validation.

The objective:

– Investigate the capabilities of red-bands of the Sentinel-2 MSI sensor in detecting Chl-a in inland waters;
– Calibrate and validate such a model.
Study area

The Lake Burullus is located on the coastal shore of the north Nile Delta (30° 35 to 31° 8 E, 31° 22 to 31° 37 N);

The Lake surface area is about 65X14 km² with an average depth of 1 m;

The gradient between the brackish (southern) part of the lake and marine waters provides a unique ecotonal zone where many marine and fresh water organisms flourish.
Field and EO data

- MERIS images and Rapid Eye acquired in 2011 and 2013 concurrent with the field measurements.
- In situ Data (Chl-a), 22 in situ measuring locations (2 campaign in Jan and July 2011) matching MERIS images.
- 11 in situ measuring locations, for Rapid Eye (12 May 2013)

<table>
<thead>
<tr>
<th>MSI</th>
<th>$\lambda$ nm</th>
<th>$\Delta\lambda$ nm</th>
<th>Rapid Eye</th>
<th>$\lambda$ nm</th>
<th>$\Delta\lambda$ nm</th>
<th>MERIS</th>
<th>$\lambda$ nm</th>
<th>$\Delta\lambda$ nm</th>
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<td>65</td>
<td>1</td>
<td>475</td>
<td>70</td>
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<td>560</td>
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<td>5 m</td>
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<tr>
<td>4</td>
<td>665</td>
<td>30</td>
<td>3</td>
<td>655.5</td>
<td>55</td>
<td>7</td>
<td>665</td>
<td>10</td>
<td>300 m</td>
</tr>
<tr>
<td>5</td>
<td>705</td>
<td>15</td>
<td>4</td>
<td>710</td>
<td>40</td>
<td>9</td>
<td>709</td>
<td>10</td>
<td>20 m</td>
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# Field and EO data

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<tr>
<th>WQV</th>
<th>min</th>
<th>max</th>
<th>mean</th>
<th>Stdev</th>
<th>nr</th>
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<tr>
<td>MERIS [mg.m(^{-3})]</td>
<td>12.28</td>
<td>121.00</td>
<td>57.33</td>
<td>28.97</td>
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<tr>
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<tr>
<td>RapidEye</td>
<td>28.73</td>
<td>88.27</td>
<td>51.92</td>
<td>19.72</td>
<td>11</td>
</tr>
</tbody>
</table>
Why Red-bands models?

The model establishes a linear relationship between Chl-a concentration and the:

1. Normalized Difference Chlorophyll Index (NDCI): \( NDCI = \frac{R(708) - R(665)}{R(708) + R(665)} \)
   
   Mishra and Mishra (2012)

   Basically based on the Gitelson et al., (2006) model

2. RedEdg2/(RedEdge1-Red)

These models did work for MERIS, Rapid Eye, SPOT, but how about the Sentinel-2?
There is a similarity between the results of the two data sets. NDCI is positive at about >75 mg.m\textsuperscript{-3}

Ideally, the validity of any model is tested against an independent data set. But how to subdivide? Many combinations of matchups can be used!
Calibration and validation

- We use the GeoCalVal model of Salama et al., 2012

- GeoCalVal derives the probability distributions (PDs) of calibration coefficients and validation errors

  - Data set $n$
  - split
  - Cal set $= k$
  - regression
  - model coefficients
  - apply the model
  - store
  - Val set $= n-k$
  - errors
  - store
  - randomly picks $j$
  - $j=j+1$
  - form new cal set $[k,j]$
  - $K=k+j$
  - finish
  - $N$
  - $Y$
Calibration and validation, MERIS

Slope for NDCI, [mg.m\(^{-3}\)]

Intercept for NDCI ratio, [mg.m\(^{-3}\)]

MAE of derived Chla, [mg.m\(^{-3}\)]

R\(^2\) of derived Chla
Calibration and validation, Rapid Eye

- **Slope for NDCI, [mg.m⁻³]**
- **Intercept for NDCI ratio, [mg.m⁻³]**
- **MAE of derived Chla, [mg.m⁻³]**
- **R² of derived Chla**
Rapid Eye products of Chl-a

Chl-a mg m$^{-3}$

RapidEye 06-06-2013

31°32'N 31°28'N

30°44'E 30°48'E 30°52'E 30°56'E
Noise model:

\[
\frac{S}{N} = \frac{S}{\sqrt{\alpha S + \beta}}
\]

Which can be converted into:

\[
N = \sqrt{\alpha S + \beta}
\]

First \(\alpha\) and \(\beta\) were estimated for all bands, with a correction for the spatial (20x20 m) and spectral (15 nm) resolutions.
Sentinel-2 expected accuracy

Improvement in SNR of Sentinel-2 MSI over the Rapid Eye

Sentinel-2 has about 28-70% more SNR w.r.t Rapid Eye

The expected accuracy from Chl-a models would be the same or greater
Expected noise over water

The Noise model is used to simulate the noise level above water for four Sentinel-2/MSI bands:

1. Estimate the reflectance:
   \[ \rho = \frac{\pi L}{E_s \cos \theta_s} \]

2. and the noise of it
   \[ N = \sqrt{\alpha \rho + \beta} \]

In comparison to field measured values, where Chl-a varies between 12-120 mg.m\(^{-3}\), the noise level may cancel out to be 13% of error!
Demonstration with SPOT time series

![Chl-a mg.m⁻³](SPOT 10-03-2013)
Preliminary conclusions

• NDCI is consistent between MERIS and Rapid Eye matchup data.
• The increased SNR of Sentinel-2 over Rapid Eye is about 28-70% and is therefore expected to improve on the results of Chl-a (<12 mg.m\(^{-3}\)).
• The noise level of Sentinel-2 can adequately be modeled and adjusted to nominal radiometric and spatial resolutions:
  – The SNR of the Red-band (665) is better than that of the 705 nm by ~40% (due to the course radiometric resolution 30 nm).
  – It is because of this wide band the reflectance at the Red band will be larger than that at the Red Edge band 705 nm for low Chl-a. i.e. the NDCI will positive for Chl-a>75 mg.m\(^{-3}\)
• We’ve demonstrated the potential of Sentinel-2 in deriving Chl-a in productive inland waters.
Acknowledgment

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