Constituent retrieval in lakes and other deep and optically complex waters from satellite imagery

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Outline

- **Challenge**
  - Where to apply which algorithms

- **Introduction**
  - Optical water classes and recent criticism

- **Methods**
  - Validation studies review approach

- **Results**
  - Quantitative literature analysis
  - Choice of algorithms derived for diversity 2

- **Conclusions**
Introduction

Forel-Ule scale (1889)

Photos by Janet Vail (Arnone et al., 2004)
Introduction

Jerlov water types

- Coastal ocean
- Open ocean

Dietrich et al. (1975) based on Jerlov (1951)
Introduction

Relative absorption

440 nm

TSM

CHL-a

CDOM

J  Jerlov types 1B-9

× ×  size ≈ bulk absorption

**Introduction**

Case 1, case 2

**Case 1**: Optical properties are determined primarily by phytoplankton and related CDOM and detritus.

**Case 2**: Everything else.

*Sathyendranath in IOCCG (2000), definitions by Morel (1988)*
Introduction

**Strengths**
- Guided the development of early bio-optical models
- Conduced to the success of the first ocean colour sensors
- Helps to prevent the inappropriate use of algorithms

**Weaknesses**
- Is a simplification for a past stage of knowledge
- “May bring ambiguity, confusion, misuse, or an excuse for poor performance of algorithms”

Mobley et al. (2004)
To which optically complex waters do recent “Case 2” algorithms apply?

The literature review includes:

- **Matchup** validation studies
- Constituent retrieval from satellite imagery
- Optically **deep and complex** waters
- Explicit **concentration** ranges and $R^2$
- Published in **ISI listed** journals
- Between Jan 2006 and May 2011

These criteria apply to a total of 52 papers.
The literature review aims to:

- Quantify the use of recent algorithms and sensors
- Derive algorithm applicability ranges within “case 2”
- Clarify the ambiguous use of attributes like “turbid” and “clear”

<table>
<thead>
<tr>
<th>Authors</th>
<th>Oligotrophic</th>
<th>Mesotrophic</th>
<th>Eutrophic</th>
<th>Hypereutr.</th>
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<td>Chapra &amp; Dobson (1981)</td>
<td>0-2.9</td>
<td>2.9-5.6</td>
<td>&gt;5.6</td>
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<td>Wetzel (1983)</td>
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<td>3-78</td>
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<td>Bukata et al. (1995)</td>
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<td>2.5-6</td>
<td>6-18</td>
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<td>3.5-9</td>
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<td>This study</td>
<td>0-3</td>
<td>3-10</td>
<td>&gt;10</td>
<td>?</td>
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</table>

Odermatt et al. (2012)
Results

**CHL band ratios**

- **OC2** (490, 555 nm)
  - Witter et al., 2009 (R² = 0.5)
  - D’Sa et al., 2006 (R² = 0.8)
- **OC3** (443, 490, 555 nm)
  - Mélin et al., 2007 (R² = 0.7)
  - Horion et al., 2010 (R² = 0.7)
  - Witter et al., 2009 (R² = 0.5)
- **OC4** (443, 490, 510, 555 nm)
  - Dupouy et al., 2010 (R² = 0.8)
  - Mélin et al., 2007 (R² = 0.7)

**SeaWiFS**
- 5

**MODIS**
- 2

**MERIS**
- 1

**GLI**
- 1

**HICO**
- 2

**TM/ETM+**
- 1

**Meristem**
- 8

**Red-NIR 2 band**
- 2

**Red-NIR 3 band**
- 1

**HICO red-NIR**
- 684, 700, 720 nm

**HISCO red-NIR**
- 665, 748 nm

**MCI**
- 681, 708, 753 nm

**FLH**
- 665, 681, 708 nm

**MOSES**
- 2009b (R² = 0.6)

**Gitelson et al.**
- 2011 (R² = 0.9)

**Koponen et al.**
- 2007 (R² = 0.8)

**Moses et al.**
- 2009a, 2009b (R² = 0.9)
- 2010 (R² = 0.9)

**Matthews et al.**
- 2010 (R² = 0.9)

**Yang et al.**
- 2011 (R² = 0.8)

**Binding et al.**
- 2011 (R² = 0.6)

**Gonzalez-Vilas et al.**
- 2011 (R² = 0.9)

**Kabbara et al.**
- 2008 (R² = 0.7)

**Mahasandana et al.**
- 2009 (R² = 0.7)

**empirical**
- 2

*Odermatt et al. (2012)*
Results

TSM band ratios

Odermatt et al. (2012)
Results

CDOM band ratios

Odermatt et al. (2012)
## Results

### spectral inversion

<table>
<thead>
<tr>
<th>Authors</th>
<th>Algorithm</th>
<th>CHL [mg/m(^3)]</th>
<th>TSM [g/m(^3)]</th>
<th>CDOM [m(^{-1})]</th>
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<tr>
<td></td>
<td></td>
<td>max</td>
<td>min</td>
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<td>Odermatt et al. (2012)</td>
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<td>70.5</td>
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<td>70.5</td>
<td>1.9</td>
<td>19.6</td>
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<tr>
<td>- Numerous and independent</td>
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<td>74.5</td>
<td>11.7</td>
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<tr>
<td>- Adequate for low to medium concentrations</td>
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<td>247.0</td>
<td>69.2</td>
<td>60.7</td>
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<tr>
<td>- Inadequate for high concentrations</td>
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<td>9.0</td>
<td>0.0</td>
<td>-</td>
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<tr>
<td></td>
<td></td>
<td>12.6</td>
<td>0.1</td>
<td>14.3</td>
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<td>2.5</td>
<td>0.1</td>
<td>2.7</td>
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<tr>
<td>- Limited in number and independence</td>
<td></td>
<td>2.2</td>
<td>1.3</td>
<td>2.1</td>
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<tr>
<td>- Often restricted to “domestic” use</td>
<td></td>
<td>4.0</td>
<td>0.6</td>
<td>-</td>
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<tr>
<td></td>
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<td>5.0</td>
<td>1.8</td>
<td>13.0</td>
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<tr>
<td></td>
<td></td>
<td>20.0</td>
<td>0.0</td>
<td>30.0</td>
</tr>
</tbody>
</table>

*Odermatt et al. (2012)* validated | falsified | threshold $R^2=0.6$
**Results**

**variability scheme**

**Retrieved constituent**

**concentration level**

**type**

**contravariance**

Reading example: D’Sa et al. (2006) retrieve low CDOM with 510, 565 nm bands at 0.3-13.0 mg/m³ CHL and 0.5-5.5 g/m³ TSM

Odermatt et al. (2012)
**Results**

Validation ranges for red-NIR band ratios for very turbid TSM and for eutrophic CHL. NN for intermediate concentrations. OC band ratios for oligotrophic CHL. Representing coastal waters of mostly co-varying constituents. Odermatt et al. (2012)
**Results**

**Algorithm-specific classes**

**wc retrieval:**
- FLH, MCI
- Gitelson 2/3-band

**atm. correction:**
- none
- SCAPE-M

**wc retrieval:**
- FUB
- blue-green bands

**atm. correction:**
- C2R (+ICOL!)
- FUB (+ICOL?)

**wc retrieval & atm. correction:**
- C2R
- FUB
Conclusions from the validation review:

- Band ratio validation studies allow a good estimate of validity ranges
- MERIS neural networks are the only spectral inversion algorithms with sufficient validation from several independent studies
- MERIS’ 708 nm band provides unparalleled accuracy for eutrophic waters
- A justified, water-type specific choice of algorithms can be derived

Open issues for use of the findings in diversity 2:

- How is the required preclassification applied?
  - Based on previous knowledge or on-the-flight?
  - Spatio-temporally static or dynamic? – based on previous knowledge or iterative processing?
  - Should algorithm blending be applied?
Conclusions

- **Optical lake water preclassification**
  - varies temporally and across classes (fuzziness)
  - may require multiple or blended algorithms

- **Validity range classes**
  - are currently defined by concentrations
  - require extensive *in situ* data
  - or iterations with constituent retrieval
  - or transformation to corresponding reflectance classes
Fuzzy c-means (FCM) clusters for *in situ* reflectance
Outlook

optical classification

FCM (SST, PAR, CHL derived) ecological provinces in July 2000:

Dowell et al. in IOCCG (2009)
Seasonality of „hardened“ ecological provinces:

Jan 2000

Apr 2000

Jul 2000

Oct 2000

Dowell et al. In IOCCG (2009)
Annex partition by SeaWiFS

Lee & Hu (2006)
Outroduction

This work:

See also: