Bio-optical Algorithms for European Seas: Performance and Applicability of Neural-Net Inversion Schemes

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Outline

• This study uses bio-optical algorithms (MLPs) to assess MERIS ocean color products in the Northern Adriatic Sea, the Baltic Sea and the Western Black Sea

• Research objectives included:
  – Dataset selection and quality assurance
  – Assessment of the MLP performance and applicability
  – Comparisons with MERIS products
Dataset selection

• Reference field measurements are the BiOMaP and CoASTS data, produced by the JRC and accessible within the framework of specific collaborations between JRC and FCT/UNL for MERIS products validation.

• Complementary benchmark analyses were also undertaken on the basis of the NASA Bio-Optical Marine Data Set (NOMAD).
Dataset selection (cont.)

• The selection of BiOMaP and CoASTS data was supported by:
  
  – Novel methods for the quality assurance of in-situ measurements of absorption, attenuation and back-scattering
  
  – MC simulations of the radiative transfer process in the water medium to investigate uncertainties induced by sea-surface wave focusing on radiometric data products derived from free-fall optical systems
  
  – Use of AERONET-OC measurements to assess the quality of MERIS radiometric products
MLP bio-optical algorithms

• Operational MLPs were implemented to derive Chl-a, $a_{ys}(412)$ and TSM from $L_{WN}$ on the basis of BiOMaP and CoASTS data

• MLP performance was assessed through:

$$\varepsilon = 100 \frac{1}{N} \sum_{i=1}^{N} \left| \hat{t}_i - t_i \right|$$

$$\delta = 100 \frac{1}{N} \sum_{i=1}^{N} \frac{\hat{t}_i - t_i}{t_i}$$

• MLP parameter tables have been produced to permit user implementations of the bio-algorithms, and their application to MERIS images
MLP parameter tables

% Pre-processing
l = \log_{10}(RRS);
ndata = size(l, 1);
tmp = l - repmat(mu_l, ndata, 1);
x = tmp ./ repmat(s_l, ndata, 1);

% MLP mapping
z = \tanh(x*net.w1 + ones(ndata, 1)*net.b1);
y = z*net.w2 + ones(ndata, 1)*net.b2;

% Post-processing
tmp = y.*repmat(s_c, ndata, 1);
c = 10^((tmp+repmat(mu_c, ndata, 1));
Northern Adriatic Sea

- North Adriatic Sea and AAOT
- Chl-a [mg m⁻³]
- aₚₜ (412 nm) [m⁻¹]
- TSM [g m⁻³]

Graphs showing comparisons between computed and measured values for Chl-a, aₚₜ, and TSM, with statistical metrics provided.
Eastern Mediterranean Sea
Western Black Sea

**Graphs:**
- **Chl-a [mg m^{-3}]:**
  - \( N = 206 \)
  - \( \varepsilon = 25\% \)
  - \( \delta = 5\% \)
  - \( r^2 = 0.82 \)

- **\( a_{ys}(412 \text{ nm}) \) [m^{-1}]:**
  - \( N = 206 \)
  - \( \varepsilon = 17\% \)
  - \( \delta = 2\% \)
  - \( r^2 = 0.83 \)

- **TSM [g m^{-3}]:**
  - \( N = 206 \)
  - \( \varepsilon = 14\% \)
  - \( \delta = 1\% \)
  - \( r^2 = 0.83 \)
Performance analysis

• Cross-validation results at individual basins and for the BiOMaP data ensemble
• Results for Chl-a, $a_{ys}(412)$ and TSM are in green, yellow and gray, respectively

![Graph showing baseline and confidence intervals for performance analysis results across different basins.]
Cross-basin applicability analysis

**Chl-a [mg m⁻³] North Adriatic Sea and AAOT**
- GLOB [N=1137, ε=47 %]
- EMED [N=118, ε=32 %]
- LIGS [N=82, ε=26 %]
- NADR [N=107, ε=32 %]
- AAOT [N=1028, ε=31 %]
- VADR [N=1135, ε=31 %]
- BLKS [N=185, ε=41 %]
- ECHN [N=47, ε=49 %]
- BLTS [N=317, ε=54 %]

**Chl-a [mg m⁻³] Black Sea**
- GLOB [N=1137, ε=91 %]
- EMED [N=118, ε=191 %]
- LIGS [N=82, ε=38 %]
- NADR [N=107, ε=50 %]
- AAOT [N=1028, ε=37 %]
- VADR [N=1135, ε=38 %]
- BLKS [N=185, ε=22 %]
- ECHN [N=47, ε=55 %]
- BLTS [N=317, ε=61 %]

**Chl-a [mg m⁻³] Baltic Sea**
- GLOB [N=1137, ε=233 %]
- EMED [N=118, ε=937 %]
- LIGS [N=82, ε=317 %]
- NADR [N=107, ε=99 %]
- AAOT [N=1028, ε=245 %]
- VADR [N=1135, ε=231 %]
- BLKS [N=185, ε=317 %]
- ECHN [N=47, ε=103 %]
- BLTS [N=317, ε=26 %]

**Chl-a [mg m⁻³] BiOMaP**
- GLOB [N=1137, ε=50 %]
- EMED [N=118, ε=14 %]
- LIGS [N=82, ε=27 %]
- NADR [N=107, ε=35 %]
- AAOT [N=1028, ε=35 %]
- VADR [N=1135, ε=35 %]
- BLKS [N=185, ε=29 %]
- ECHN [N=47, ε=45 %]
- BLTS [N=317, ε=40 %]
Cross-basin applicability analysis (cont.)
Comparisons with MERIS products

• Assessment of MERIS Chl-a estimates in the Northern Adriatic Sea, Baltic Sea and Western Black Sea on the basis of MERIS level 2 data products (3rd reprocessing)

• Compared with reference Chl-a concentration derived from MLP_{BMP} regional algorithms trained with in-situ measurements collected in the BiOMaP and CoASTS programs
MERIS image processing

• Methods
  – Retrieval of algal-1 and algal-2 Chl-a maps from MERIS L2 products
  – Application of \( \text{MLP}_{\text{BMP}} \) regional algorithms to \( R_{\text{RS}} \) images taken from the same MERIS L2 products

• Software tools
  – BEAM/Java code for data retrieval and MLP application
  – BEAM graph-processing tool (gpt) for reprojection
  – MATLAB code for data analysis and visualization
Assessment

• The scattering and the bias of MERIS Chl-a estimates \( \hat{t}_i \) with respect to the corresponding \( \text{MLP}_{\text{BMP}} \) results \( t_i \) are assessed by absolute and signed percent differences \( \varepsilon \) and \( \delta \), respectively:

\[
\varepsilon = 100 \frac{1}{N} \sum_{i=1}^{N} \left| \frac{\hat{t}_i - t_i}{t_i} \right| \quad \delta = 100 \frac{1}{N} \sum_{i=1}^{N} \frac{\hat{t}_i - t_i}{t_i}
\]

where \( N \) is the total number of samples

• Only pixels in ROI(s) are considered
  – ROIs with a reduced number of noisy pixels were defined by visually inspecting product maps
Northern Adriatic Sea

(a) BiOMaP nadr
(b) MERIS algal-1
(c) MERIS algal-2
(d) ROI
(e) BiOMaP vs. algal-1
(f) BiOMaP vs. algal-2
Northern Adriatic Sea (cont.)

<table>
<thead>
<tr>
<th>ROI</th>
<th>N</th>
<th>$\varepsilon$ [%]</th>
<th>$\delta$ [%]</th>
<th>$r^2$</th>
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<tr>
<td>Total</td>
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<table>
<thead>
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<th>ROI</th>
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Source: MER_RR_2PRACR20100824_092645_000026292092_00208_44350_0000.N1
Baltic Sea

(a) BiOMaP blts
(b) MERIS algal-1
(c) MERIS algal-2

(d) ROI
(e) BiOMaP vs. algal-1
(f) BiOMaP vs. algal-2
### Baltic Sea (cont.)

#### MERIS algal-1 vs. MLP\textsubscript{BMP}

<table>
<thead>
<tr>
<th>ROI</th>
<th>N</th>
<th>ε [%]</th>
<th>δ [%]</th>
<th>r²</th>
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<tr>
<td>#4</td>
<td>0</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>#5</td>
<td>55</td>
<td>279.0</td>
<td>279.0</td>
<td>0.39</td>
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<tr>
<td>#6</td>
<td>0</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>#7</td>
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<td>175.7</td>
<td>175.7</td>
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<td>#8</td>
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<td>Total</td>
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#### MERIS algal-2 vs. MLP\textsubscript{BMP}

<table>
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<th>ROI</th>
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<th>ε [%]</th>
<th>δ [%]</th>
<th>r²</th>
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<tr>
<td>#1</td>
<td>1045</td>
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<tr>
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Source: MER\_RR\_2PRACR20080731\_092147\_000026342070\_00437\_33557\_0000.N1
Western Black Sea

(a) BiOMaP blks

(b) MERIS algal-1

(c) MERIS algal-2

(d) ROI

(e) BiOMaP vs. algal-1

(f) BiOMaP vs. algal-2
### Western Black Sea (cont.)

#### MERIS algal-1 vs. MLP$_{BMP}$

<table>
<thead>
<tr>
<th>ROI</th>
<th>N</th>
<th>$\epsilon$ [%]</th>
<th>$\delta$ [%]</th>
<th>$r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>1135</td>
<td>51.5</td>
<td>49.3</td>
<td>0.95</td>
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<td>#2</td>
<td>3033</td>
<td>213.6</td>
<td>213.6</td>
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<td>#3</td>
<td>489</td>
<td>357.7</td>
<td>357.7</td>
<td>0.60</td>
</tr>
<tr>
<td>Total</td>
<td>4657</td>
<td>189.2</td>
<td>188.7</td>
<td>0.96</td>
</tr>
</tbody>
</table>

#### MERIS algal-2 vs. MLP$_{BMP}$

<table>
<thead>
<tr>
<th>ROI</th>
<th>N</th>
<th>$\epsilon$ [%]</th>
<th>$\delta$ [%]</th>
<th>$r^2$</th>
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<td>115.5</td>
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<td>#3</td>
<td>6700</td>
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<td>141.5</td>
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<tr>
<td>Total</td>
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<td>118.5</td>
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<td>0.86</td>
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Source: MER_RR__2PRACR20080708_081104_000021512070_00107_33227_0000.N1
Summary and conclusions

• MLPs were developed from quality assured BiOMaP and CoASTS data fulfilling the need of in-situ measurements collected in different basins with consistent instrument sets and measurement protocols

• The selected basins show a wide range of optically complex water conditions

• MERIS algal-2 Chl-a estimates exhibit a better agreement with MLP_BMP results than algal-1 in the considered optically complex waters
Summary and conclusions (cont.)

- Northern Adriatic Sea
  - Algal-1 overestimates MLP_{BMP} by more than 100%
  - Algal-2 and MLP_{BMP} show a substantial agreement

- Baltic Sea
  - Both algal-1 and algal-2 overestimate MLP_{BMP}
  - Algal-1 displays a clear saturation pattern
  - Specific trends at a sub-regional level

- Western Black Sea
  - A correlation between MERIS and MLP_{BMP} somehow in between to what observed in the other two basins
  - Specific trends at a sub-regional level
Foreseen studies

• Unified framework where bio-optical algorithms are developed and applied accounting for geographical distribution and optical properties to improve ocean color products retrieval
• Automated ROI selection and data processing (time series)
• Extension of the analysis to the absorption of the yellow substance (\(a_{ys}\)) and concentration of the total suspended matter (TSM)
• Extension of the analysis to additional European Seas (e.g., Atlantic off Portugal)
E.g.: Atlantic off Portugal

(a) BiOMaP allb
(b) MERIS algal-1
(c) MERIS algal-2
(d) ROI
(e) BiOMaP vs. algal-1
(f) BiOMaP vs. algal-2

Source: MER_RR__2PRACR20100825_103551_000026292092_00223_44365_0000.N1
E.g.: Atlantic off Portugal (cont.)

(a) BiOMaP emed

(b) MERIS algal-1

(c) MERIS algal-2

(d) ROI

(e) BiOMaP vs. algal-1

(f) BiOMaP vs. algal-2
E.g.: Atlantic off Portugal (cont.)

(a) BiOMaP nadr

(b) MERIS algal-1

(c) MERIS algal-2

(d) ROI

(e) BiOMaP vs. algal-1

(f) BiOMaP vs. algal-2
Acknowledgments

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Selected publications


Monte Carlo simulations

Results have shown coefficients of variation of subsurface radiometric values in the range of 0.5%–3.5% for Ed(0-), below 0.4% for Eu(0-), and up to 1.2% for Lu(0-)
Dataset selection and QA

Binned data computed applying the standard moving average scheme and the optimized filtering scheme (left and right panel, respectively)