Introduction into Ocean Colour Remote Sensing using MERIS data

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Changes, Scenarios and Operational Assessment of the Coastal Environment

- Emergency preparation
- Routine forecasts
- Monitoring technology
- Synoptic analysis
- Environmental modelling
- Scenarios
- Assessment of present state
- Assessment of possible futures

Scientific knowledge

Basic principles of Water Color RS

- sensor
- sun
- air molecules
  - atmospheric scattering and absorption
- aerosols
- gases
- suspended particles
  - phytoplankton pigment
  - gelbstoff
- reflection and refraction
- scattering and absorption by water and its constituents
- bottom reflection
Absorption, scattering and beam attenuation

- Attenuation of a beam by absorption and scattering
- Consider a beam of photons which collide with particles

The beam is attenuated by photons, which are absorbed and photons, which are scattered into another direction and, thus, do not reach the detector.

\[ c = a + b \quad [\text{m}^{-1}] \]

Spectral Colour and wavelength in Nanometer (nm)

1 nm = 1 billion of a Meter = or million part of a millimeters
Phytoplankton

Photos by Marion Rademaker

Pigment absorption spectra - summer period
SIRTRAM case 5

attenuation 1 µg/l pig, 10 mg/l spm, 0.1 m-1 gelb at 440, sun 45, view 20

Downwelling irradiance attenuation coefficient

5 µg/l chl, 5 mg/l SPM,  agelb 0.4 m\(^{-1}\)
Signal depth $z_{90}$

$$z_{90} = \frac{1}{k}$$

- **coastal:**
  - TSM = 5 mg/l
  - Chlor. = 5 µg/l
  - Gelb = $a_{380} = 1$ m$^{-1}$

- **open ocean:**
  - Chlor. = 1 µg/l

**Reflexion of water**

$$R = \frac{\sqrt{1 + 2bb/a} - 1}{\sqrt{1 + 2bb/a} + 1}$$

Absorption $a$:

$$a = a_w + C_p a_a + C_s a_s + C_g a_g$$

Backscattering $bb$:

$$bb = bbw + C_p bb_p + C_s bb_s$$

- $a_w$: absorption of water
- $bw$: backscattering of water
- $C_p$, $C_s$, $C_g$: concentrations of pigment [µg/l], suspended matter [mg/l] and gelbstoff [$a_{440}$ m$^{-1}$]
- $a_a$, $a_s$, $a_g$: specific absorption coefficients of pigment, suspended matter and gelbstoff
- $bb_p$, $bb_s$: specific backscattering coefficients of pigment and suspended matter

$$R = 0.33 (bb/a)$$

$$k = \sqrt{a(a + 2bb)}$$

$$R = \frac{k - a}{k + a}$$
Case 1 Water
- Only 1 component modulates the radiance spectrum backscattered from the water: Phytoplankton Pigment + associated (correlated) substances
- Concentration range is 0.03 – 30 mg m⁻³
- Water in the near IR nearly black because of the high absorption of pure water and low concentration of particles (scattering)
- Atmospheric correction relatively simple
- MERIS product: algal_1

Case 2 Water
- Multiple independent components in water, which have an influence on the backscattered radiance spectrum
- Retrieval procedure has to deal with these multiple components, even if only one should be determined
- Optical properties are variable
- Often very high concentrations, where standard algorithms show saturation
- At high TSM concentrations problem with atmospheric correction
- MERIS products: algal_2, TSM, Gelbstoff
Empirical model

\[ C = A \left[ \frac{R(445)}{R(550)} \right]^B \]
Summary algal_1 pigment index algorithm

- Based on two colour ratios using a semianalytical model
- $R(445)/R(555)$ for chlorophyll concentration range $< 2 \mu g/l$
- $R(449)/R(555)$ for $> 2 \mu g/l$
- 3 orders of magnitude can be determined (0.03 – 30 $\mu g/l$)
- error $< 30\%$ on log scale
- Algal_1 index is determined by all material in case I water, including various algal pigments, bacteria, small detrital particles etc., but it is related to chlorophyll a and expressed as the concentration of chlorophyll a and also validated against chl. a
- F/Q ratio has to be determined iteratively using tabulated values because it requires the knowledge of chl. a
The Biosphere as seen by SeaWiFS

source: NASA GSFC and ORBIMAGE

Dissolved and suspended matter in coastal water

source: NASA GSFC and ORBIMAGE
Reflection

- $R(450)$
- $R(550)$

0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08

conc tmg/l

ENVISAT Instrumente
MERIS Medium Resolution Imaging Spectrometer

- FOV 68.5 deg, 1150 km
- IFOV 300 m, 1200 m
- revisit period 2-3 days
- 5 cameras, each 14 deg FOV
- Spectral range: 390 nm to 1040 nm
- Spectral resolution: 1.8 nm
- Band transmission: 15 spectral bands, programmable in position and width
- Band-to-band registration: Less than 0.1 pixel
- Band-centre knowledge accuracy: Less than 1 nm
- Polarisation sensitivity: Less than 0.3%
- Radiometric accuracy: Less than 2% of detected signal, relative to sun
- Band-to-band accuracy: Less than 0.1%
- Dynamic range: Up to albedo 1.0
- Radiometric resolution 12 bit

MERIS Spectral Band Setting

<table>
<thead>
<tr>
<th>No.</th>
<th>Band centre (nm)</th>
<th>Band width (nm)</th>
<th>Potential Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>412.5</td>
<td>10</td>
<td>Yellow substance and turbidity</td>
</tr>
<tr>
<td>2</td>
<td>442.5</td>
<td>10</td>
<td>Chlorophyll absorption (maximum)</td>
</tr>
<tr>
<td>3</td>
<td>490</td>
<td>10</td>
<td>Chlorophyll and other pigment concentrations</td>
</tr>
<tr>
<td>4</td>
<td>510</td>
<td>10</td>
<td>Suspended sediment, red tides</td>
</tr>
<tr>
<td>5</td>
<td>560</td>
<td>10</td>
<td>Chlorophyll baseline (absorption minimum)</td>
</tr>
<tr>
<td>6</td>
<td>620</td>
<td>10</td>
<td>Suspended sediments, scattering, cyanobacteria</td>
</tr>
<tr>
<td>7</td>
<td>665</td>
<td>10</td>
<td>Chlorophyll absorption (maximum)</td>
</tr>
<tr>
<td>8</td>
<td>681.25</td>
<td>7.5</td>
<td>Chlorophyll fluorescence, red edge</td>
</tr>
<tr>
<td>9</td>
<td>708.75</td>
<td>10</td>
<td>Aerosol type, (Red/NIR boundary), atmos corr.</td>
</tr>
<tr>
<td>10</td>
<td>753.75</td>
<td>7.5</td>
<td>Oxygen absorption reference band, Vegetation</td>
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<tr>
<td>11</td>
<td>761.875</td>
<td>2.5</td>
<td>Oxygen absorption R-branch</td>
</tr>
<tr>
<td>12</td>
<td>778.75</td>
<td>15</td>
<td>Aerosols over ocean (thicka-.type), Vegetation</td>
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<tr>
<td>13</td>
<td>865</td>
<td>20</td>
<td>Aerosols opt. thicka-.type, Vegetation</td>
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<tr>
<td>14</td>
<td>885</td>
<td>10</td>
<td>Water Vapour over land</td>
</tr>
<tr>
<td>15</td>
<td>900</td>
<td>10</td>
<td>Water Vapour, Vegetation</td>
</tr>
</tbody>
</table>
MERIS swath covered by 5 cameras

MERIS spectrometer
Imaging Spectroscopy using MERIS

clouds:
- Albedo
- optical thickness
- top height

Aerosols

Water vapour

Phytoplankton
- primary production

Suspended matter
- Gelbstoff

Vegetation / Land use
Globale Wasserdampfverteilung 2003

ESA Training Course Oceanography from Space, Hamburg 25. – 29.7.2006

MERIS: Aufnahme der Helgoländer Bucht

MERIS FR
16.4.2003
Helgoland Bight

Section
160 km
Test: area of Skagerrak seen by MERIS during a bloom of E. huxleyi June 2003

Mouths of the Ganges
India - Bangladesh
Nov. 2003
Multivariate Relationship

reflectance spectrum

pure water

phytoplankton

dsuspended matter

dissolved org. matter

sun zenith

view zenith

azimuth diff

inverse model

forward model

Simplified scheme of NN Algorithm

Input layer: reflectances and angles

Hidden layer

Output layer: concentrations

Chlorophyll

Susp. Matter

Geilstoff

\[ y_l = \sum_{i=1}^{L} w_{l,i} \cdot x_i \cdot \left( y_c - \sum_{i=1}^{L} v_{c,i} \cdot \left( y_c - \sum_{i=1}^{L} w_i \cdot x_i \right) \right) \]
Case 2 Water Algorithm

Bio-optical measurements
\(a(\lambda), b(\lambda), \text{Pig}, \text{TSM}, C, Y\)
\(Lu/Ed(\lambda,z), \text{RLw}\)

Bio-optical Model
Incl. variability

Set up radiance transfer model
Monte Carlo, Hydrolight

Simulation of RLw(\(\lambda, \theta_s, \phi_s\))
> 20000 Spectra

Training and Test of aNN

faNN, baNN
MERIS Processor

3 angles 8 RLw

TSM Pig Gelb Conf. Flag

MERIS Product

Radiative transfer simulations for NN training

direct radiance \(F_s = 1.0\)

Fixed vertical profile of:
Ozone rayleigh aerosols

rough sea surface, fixed wind 7 m/s
Cox-Munk isotropic slope distribution

homogenous water of infinite depth
Water characterized by:
\(a_w, a_g, b_w, b_g, P_w, P_s\)
a=absorption, b=scattering, P=phase function
w=water, c=chlorophyll, s=suspended matter, g=gelbstoff

Detector:
\(Ed(Lu,0,\phi)\)

Concentration of:
total suspended matter mg/l chlorophyll µg/l
\(a(440) m^{-1}\)
The MERIS case II water NN algorithm

\[ r, r' - \text{log of reflectances} \]
\[ c - \text{log of concentrations} \]
\[ g - \text{geometry information} \]
\[ q - \text{quality indicator} \]

If \( RLw < 0.0009 \), \( RLw = 0.0009 \) (\( \rho \approx 0.003 \))

flag PCD1_16,17

q true if

\[ \text{sum} \left( \frac{r(i)}{r'(i)} \right) > 4.0 \]

C:

\[ \log(b_{tot}) \]
\[ \log(a_{ys} + a_{btsm}) \]
\[ \log(a_{pig}) \]

All at 443 nm

Scheme of a bio-optical model: optical components for MERIS

Water sample

Particle total absorption

Absorption of bleached fraction = spm absorption

Gelbstoff absorption spectrum

Absorption of bleached Fraction + Gelbstoff = total gelbstoff

Absorption of Total - bleached fraction = phytoplankton absorption

Particle scattering backscattering

Tsm

Algal_2

a_ys
How to compute total scattering and absorption from case 2 products

• Algal_2
  – Conversion from a_pig_443 (NN output) to chlorophyll concentration
  – algal_2=21*a_pig_443^1.04

  – Inverse to compute absorption again:
  – a_pig_443=exp(log(algal_2/21)/1.04)

• TSM
  – Total_susp = 1.73*b_tot_443
  – Inverse to compute total scattering again:
  – b_tot_443=total_susp/1.73

• Total absorption:
  – a_tot_443= a_pig_443 + yellow_subs

Pigment absorption spectra H187, Norway different locations
COLORS Helgoland Gelbstoff absorption all stations

Pigment absorption – Chl. a, H187

Conversions:
Chl. a [mg m-3] = 21 * a_pig_442 ^1.04
Conversions:

\[ \text{TSM (g m}^{-3}\text{)} = 1.72 \times b_{\text{tsm}_442} \]

Bio-optical model

- Based on: MAVT North Sea / German Bight ( GKSS), Norwegian waters (NIVA, Uni Oslo, NERSC), Baltic Sea (IOW), recommendations by M. Babin
- Gelbstoff absorption exponent: 0.014 ± 0.002
- Bleached particle absorption exponent: 0.008 ± 0.005
- Particle scattering exponent: 0.4 ± 0.2
- White particles scattering exponent: 0.0
- Phytoplankton pigment absorption: > 221 spectra different areas and seasons
- Gelbstoff absorption @ 443 nm: 0.005 – 5.0 m\(^{-1}\)
- Particle scattering @ 443 nm: 0.005 – 30.0 m\(^{-1}\)
- White particle scattering: 0.005 – 30.0 m\(^{-1}\)
- Phytoplankton pigment absorption: 0.001 – 2.0 m\(^{-1}\)
- Minimum particle scattering: 0.25*a_pig(443)
- Bleached particle absorption: 0.1*b_p(443)*ran_gauss*0.03*b_p(443)
comparison transect  Cuxhaven -> Helgoland
c.a. 60 km from highly turbid waters to average North-Sea water
comparison concentrations Meris <-> in-situ along track Cuxhaven-Helgoland

2003-09-06 [d00]
TSB level product

match-up

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comparison concentrations Meris <-> in-situ along track Cuxhaven-Helgoland

2003-09-06 [d00]
CN level2-product

match-up

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Chlorophyll Distribution North Sea March 2003 (MERIS)

L3-Product:
Monthly Median MERIS-Algal2
March 2003, 37 scenes,
GKSS-ESA-Algorithm

Mean Chlorophyll
North Sea
March 2003

Project: REVAMP
Maximum Chlorophyll
North Sea
March 2003

Maximum Chlorophyll
North Sea
May 2003
Maximum Chlorophyll
North Sea
June 2003

NN sensitivity test, all cases

Case 2 water chlorophyll retrieval with NN
NN sensitivity, typical North Sea water

Pigment in North Sea Water (gelb < 0.2 m-1, MSM < 5 mg/l)

Overall retrieval accuracy

Conc_b p 
0.05 - 0.5 -5 -45
Conc_plg 
0.005 - 0.03 - 0.15 - 1.0
Conc_gelb 
0.005 - 0.035 - 0.2 -0.15
Summary Case 2 water algorithm

- Based on inverse modelling: optimization, neural network
- depending on bio-optical model 3 or more classes of substances can be derived
- most robust is to derive first the inherent optical properties (a,b, bb)
- beside concentrations also other properties can be determined, such as signal depth, penetration depth etc.
- error depends on bio-optical model and possible masking by a dominant optical component, confidence range or error must be provided pixel by pixel
- depending on the radiative transfer model, the bi-directional effects of radiances can be simulated and used in the inverse model
- be aware of ambiguities

Comparison Case 1 / Case 2 Water Algorithm for Pigment

Adriatic Sea, May 3, 2002

Algal_1

Algal_2
Radiances at Top of Atmosphere (TOA)

![Graph showing radiances at TOA](image)

Thank You for Listening