Ocean Colour Remote Sensing in Turbid Waters

Lecture 2:
Introduction to computer exercise
“The Colour of Water”

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Overview of this lecture

• Objective: introduce the HYPERTEACH ocean colour model as basis for exercise session

• NB. This is an approximate model for educational purposes only
• NOT for ocean colour data processing
• NOT for research grade publications
• JUST for understanding first order variability of marine reflectance

• CONDITIONS of USE:
  – I will not hold anyone responsible for mis-use, etc.
  – I will not use this for ocean colour data processing or research grade publications - for that I will use accurate radiative transfer models such as HYDROLIGHT (water) or 6SV (atmosphere)
  – I will use this model for quickly understanding ocean colour variability
  – I will not cheat and go straight to the answers
  – I will think of ways this could be improved for educational purposes and help by providing suggestions

We Accept
Variation of reflectance with IOPs

• Gordon-Morel type approximate reflectance model

\[ R_{rs} (\lambda) = \gamma' \frac{b_b (\lambda)}{a(\lambda) + b_b (\lambda)} \]

• For all but most reflective water, relation is linear:

\[ b_b \ll a \implies R_{rs} (\lambda) = \gamma' \frac{b_b (\lambda)}{a(\lambda)} \]

• (NB This model is not appropriate for high reflectance)
Decomposition of IOPs: absorption

- The total absorption can be decomposed into a linear sum of (mutually exclusive) components:

\[
a(\lambda) = a_w(\lambda) + a_\phi(\lambda) + a_{CDOM}(\lambda) + a_{NAP}(\lambda)
\]

(totol) yellow substance \( a_Y(\lambda) \)

- Pure water
- Phytoplankton
- Coloured Dissolved Organic Matter
- Non-algae particles
The total backscatter can be decomposed into a linear sum of (mutually exclusive) components:

\[ b_b(\lambda) = b_{bw}(\lambda) + b_{b\phi}(\lambda) + b_{bNAP}(\lambda) \]

- Pure water
- Non-algae particles
- Phytoplankton
Optical properties of pure sea water (1/3)

- Backscatter of pure sea water (includes bubbles?):
  - Generally low, especially for green-red

\[ b_{bw} = 0.5 \times 0.00288 \times \left( \frac{\lambda}{500\,nm} \right)^{-4.32} \]  

[Morel, 1974]
Optical properties of pure sea water (2/3)

- Absorption of pure sea water:
  - Dominant absorber (except in very turbid waters) for red and especially near infrared

[Buiteveld et al, 1994]
Optical properties of pure water (3/3)

• If water contains no other constituents (no phytoplankton or other particles, no coloured dissolved organic matter) then:

\[ R_{rs}(\lambda) = \gamma' \frac{b_b(\lambda)}{a(\lambda)} \approx 0.069 \frac{b_{bw}(\lambda)}{a_w(\lambda)} \]

• Not a realistic case, but useful extreme case (blue/violet water)
Optical properties of phytoplankton (1/2)

- Backscatter of phytoplankton:
  - Main backscatterer in open ocean, relatively flat spectrum

\[
b_{b\phi} = \left\{ 0.002 + 0.01 \times \left[ 0.50 - 0.25 \log_{10} C \right] \left( \frac{\lambda}{550 \text{nm}} \right)^{0.766} \right\} \times 0.416 \times C^{0.766}
\]

\[\nu \in (-0.65, 0)\]

[Morel and Maritorena, 2001]
Optical properties of phytoplankton (2/2)

- Absorption of phytoplankton:
  - Main absorber in open ocean, spectral features in blue and red
  - Phyto absorption proportional to Chl $a$ (first approximation)
  - Tabulated spectra given as function of Chl $a$ [Bricaud et al, 1995]
Coloured Dissolved Organic Matter (CDOM)

- CDOM = humic/fulvic acids from degradation of terrestrial or marine vegetation (correlated with salinity or phytoplankton)
  - neg. backscatter, absorbs strongly in blue: « yellow » substance
  - can be main absorber in coastal waters with high river input but low suspended matter e.g. parts of Baltic Sea, Black Sea

Coloured Dissolved Organic Matter (CDOM) absorption

Absorption coefficient (/m)

\[ a_{\text{CDOM}}(443\text{nm}) = 0.1 /m \]
\[ a_{\text{CDOM}}(443\text{nm}) = 1.0 /m \]

Wavelength (nm)
Optical properties of non-algal particles (1/2)

- Non-algal particles (NAP) may have diverse nature and origin: e.g. mineral particles (coastal/bottom erosion, river outflow), detrital particles (decayed phytoplankton)
- Backscatter relatively flat spectrally, $\alpha$ NAP concentration, can be main backscatterer in coastal and estuarine waters

Non-algae particle backscatter

![Graph showing backscatter coefficient vs. wavelength for different NAP concentrations](image_url)
Optical properties of non-algal particles (2/2)

- Absorption of non-algal particles is strong in blue (like CDOM) with exponential decrease to higher wavelengths: « particulate » yellow substance
- Proportional to conc. of non-algae particles
From water constituents to reflectance via IOPs

Constituents: Chl a, CDOM, NAP

IOPs:
- Water absorption
- Phyto absorption
- Total Yellow substance absorption
- Total backscatter, $b_b$

Reflectance:

Inverse Model (Remote Sensing):

Forward Model (Marine Optics):

$Rrs = \gamma b_b / a$
Example reflectance spectra

- Increasing water-leaving reflectance
- Increasing blue absorption
- Increasing backscattering (particles)
Exceptions

• Assumes:
  - No bottom reflectance
  - No inelastic scattering (fluorescence, Raman, bioluminescence)
  - Vertically homogeneous (no stratification, no deep CHL max, etc.)
Make your own reflectance spectra

- Now follow the exercises and make your own reflectance spectra …