Ocean Colour Remote Sensing in Turbid Waters

Lecture 2:
Introduction to computer exercise #1
“The Colour of Water”

by Kevin Ruddick
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

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

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

  \[ b_b <<< a \quad \Rightarrow \quad R_{rs} \lambda = \gamma' \frac{b_b \lambda}{a \lambda} \]

- For most reflective water, relation is asymptotic:

  \[ b_b >>> a \quad \Rightarrow \quad R_{rs} \lambda \approx \gamma' \]

  - And reflectance is limited by a maximal value, which no longer depends on values of IOPs
  - BUT this doesn’t happen often and model shouldn’t be used there
Decomposition of IOPs: absorption

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

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

- (total) yellow substance \( a_Y(\lambda) \)

- Pure water
- Non-algae particles
- Phytoplankton
- Coloured Dissolved Organic Matter
Decomposition of IOPS: backscatter

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

\[
b_b \lambda = b_{bw} \lambda + b_{\phi} \lambda + b_{NAP} \lambda
\]

\(b_{bw}\) - Pure water
\(b_{\phi}\) - Non-algae particles
\(b_{NAP}\) - Phytoplankton

(total) particulate \(b_{bp}\)
Optical properties of pure sea water (1/3)

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

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

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

- Absorption of pure sea water:
  - Dominant absorber for red and especially near infrared

![Pure water absorption graph](image.png)

[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

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

[Morel and Maritorena, 2001]

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

\( C = \text{Chl a} \)
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
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 (m$^{-1}$) vs. wavelength (nm) for different NAP concentrations (1 g/m$^3$, 10 g/m$^3$, 100 g/m$^3$).](image)
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 | IOPs | Reflectance

- **Chl a**
- **CDOM**
- **NAP**

**Water absorption**

**Phyto absorption**

**Total Yellow substance absorption**

**Total backscatter**

**Inverse Model (Remote Sensing)**

\[ Rrs = \gamma \frac{b_b}{a} \]

**Forward Model (Marine Optics)**
Example reflectance spectra

- Water-leaving reflectance
- Wavelength (nm)

Increasing blue absorption
Increasing backscattering (particles)
Exceptions

- Assumptions:
  - 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 …