HMM Imaging of the Aquatic ecosystem

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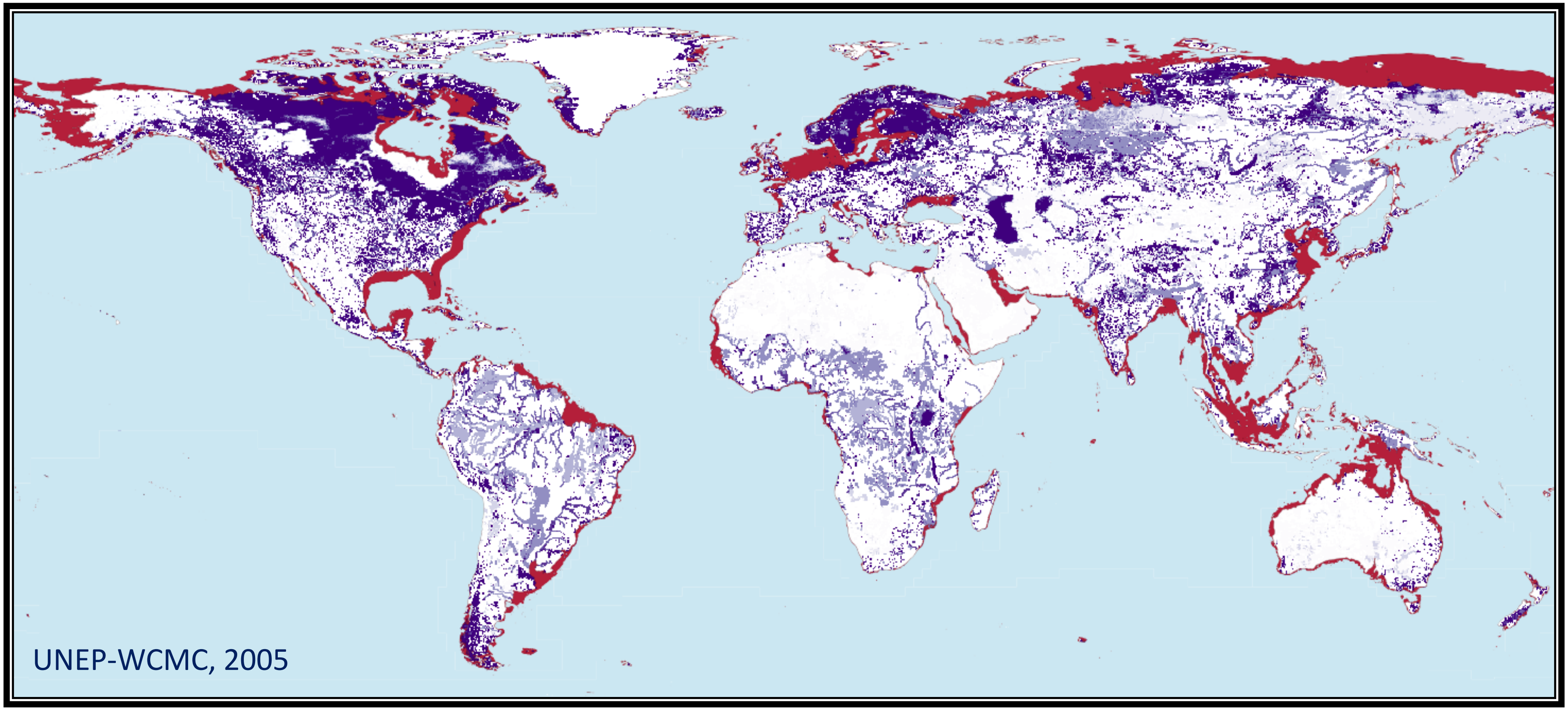
Outline

1. **The aquatic ecosystem**
2. **Spectral information and bio-optical models**
3. **Challenges**

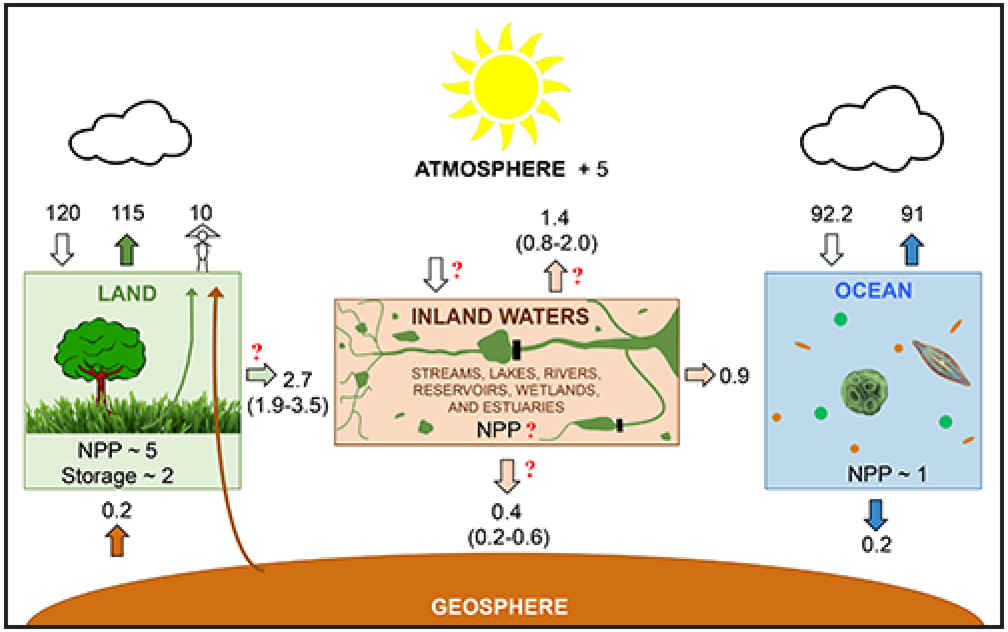
Global distribution of coastal and inland waters



Red: water depth is less than 50 m and land elevation is less than 50 m.
Light to dark violet: concentration of inland wetlands, lakes, rivers and other aquatic systems. Increased darkness means greater percentage of areal coverage for inland aquatic ecosystems.

Inland waters cover less than 4% of Earth’s surface. Most of them were never sampled.

The global carbon cycle



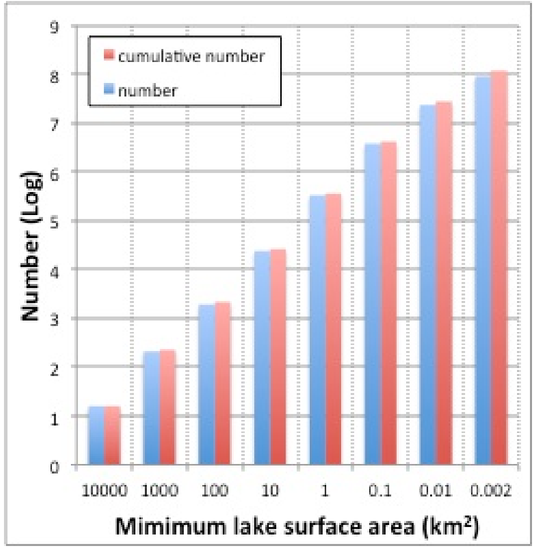
Global carbon cycle. All units are in 10^9 tons of C per year (Gt/y).
https://eos.org/opinions/global-significance-of-the-changing-freshwater-carbon-cycle

- **Human activities** emit 10 Gt/y of carbon. Half is removed by land and ocean, half remains in the atmosphere.
- **Land** absorbs 120 Gt/y and emits 115 Gt/y. The difference (5 Gt/y), called net primary production (NPP), is removed from the atmosphere. From these 5 Gt/y, 2.7 Gt/y are transported to inland waters and 2 Gt/y are stored in soils.
- **Ocean** NPP is 1 Gt/y. They store 0.2 Gt/y in sediments.
- **Inland waters** receive 2.7 Gt/y from land, from which they emit 1.4 Gt/y to the atmosphere, transport 0.9 Gt/y to oceans and store 0.4 Gt/y in sediments.

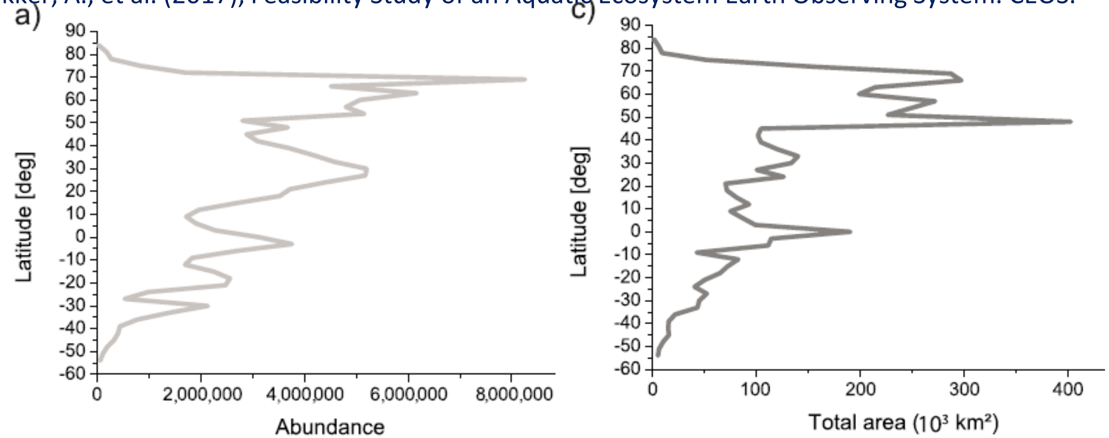
➢ **The figures have great uncertainty.** 20% of the absorbed carbon is not covered by the models; there is an unknown sink. In particular data and models of inland waters are lacking.

➢ **Inland waters bury more carbon than the oceans.**

Latitudal and size distribution of inland waters



Verpoorter, C., et al. (2014), A global inventory of lakes based on high-resolution satellite imagery. *Geophys. Res. Lett.*, *41*, 6396–6402
Dekker, A., et al. (2017), Feasibility Study of an Aquatic Ecosystem Earth Observing System. CEOS.



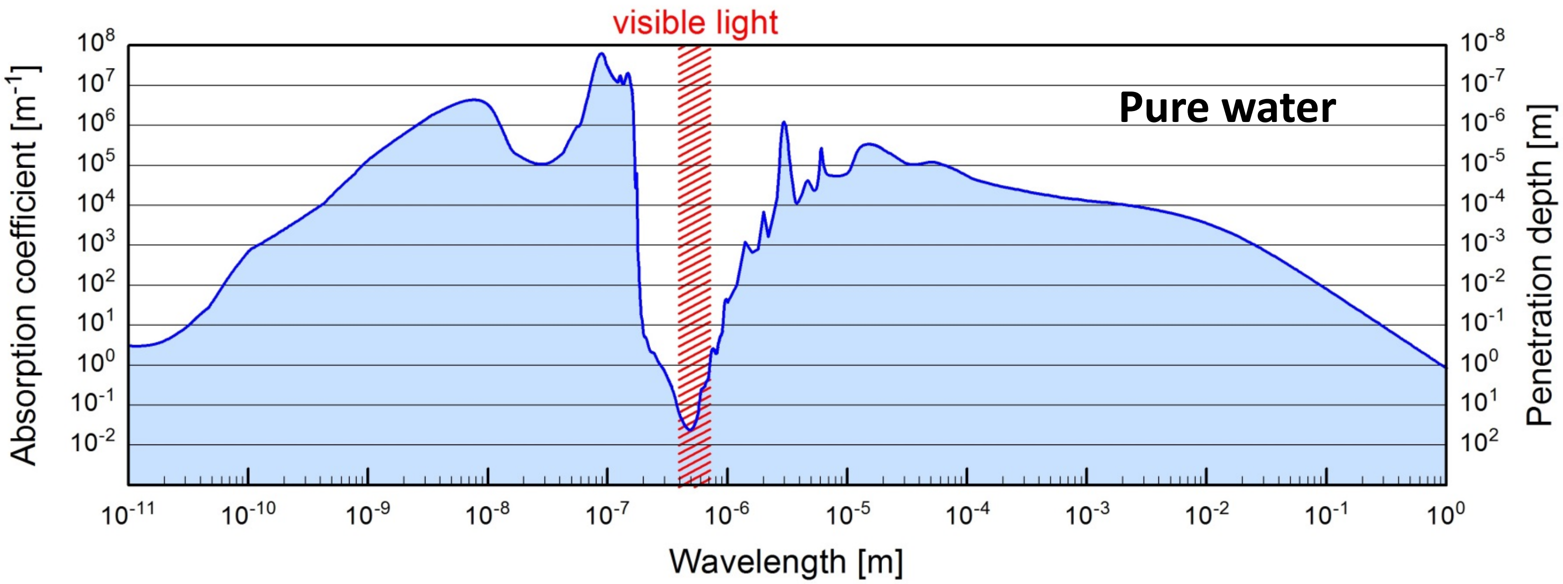
Size distribution (left) and latitudal distribution (top) of inland waters.

Size Class	Required GSD*	% Total Area	Total number
≥ 10 km²	1054 m	44	25,976
≥ 1 km²	333 m	60	353,552
≥ 0.1 km²	105 m	80	4,123,552
≥ 0.01 km²	33 m	90	27,523,552
≥ 0.002 km²	15 m	100	117,423,552
*Calculated using a box of 3 x 3 pixels sufficient to resolve the specified lake size			

Ground sampling distance requirements for remote sensing.

The majority of inland waters is small and far North. There is concern that northern lakes and streams are emitting more carbon in response to thawing permafrost and changing hydrology.

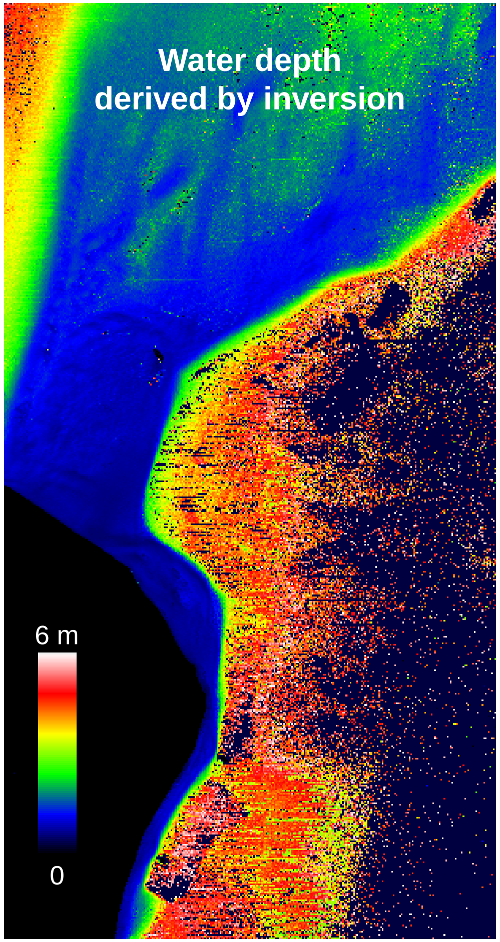
Potential of remote sensing



- Visible light bears information about the upper water layer (order of 10 m) and (in shallow waters) the bottom
- The other wavelengths can be used to derive information about the surface (skin temperature, waves) and the reflected light (useful for atmosphere correction)

Wavelength dependent penetration depth

Penetration depth of electromagnetic radiation into water is strongly wavelength dependent



Airborne image from the Baltic Sea acquired with hyperspectral sensor HySpex VNIR-1600

Inherent optical properties of water and its constituents

Inherent optical properties (IOPs) depend only on the material, not on the light field.

Relevant IOPs for remote sensing:

- $\boldsymbol{a(\lambda)}$ Absorption coefficient
- $\boldsymbol{b_b(\lambda)}$ Backscattering coefficient

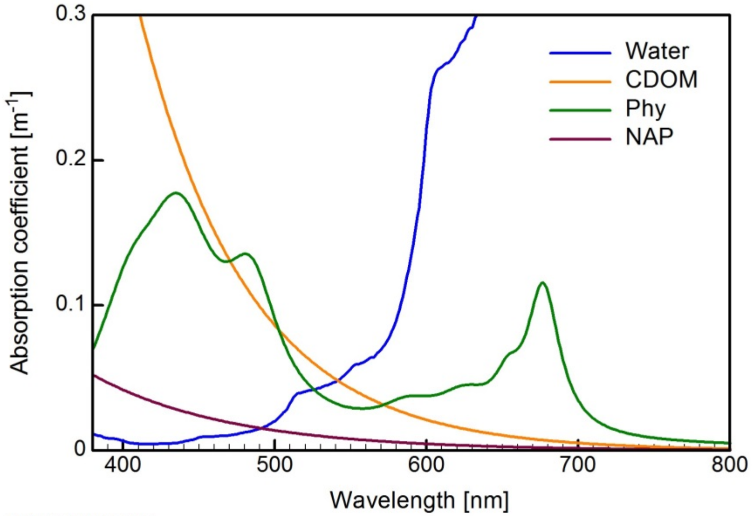
Optically relevant components:

w	water
CDOM	colored dissolved organic matter
phy	phytoplankton
NAP	non-algal particles

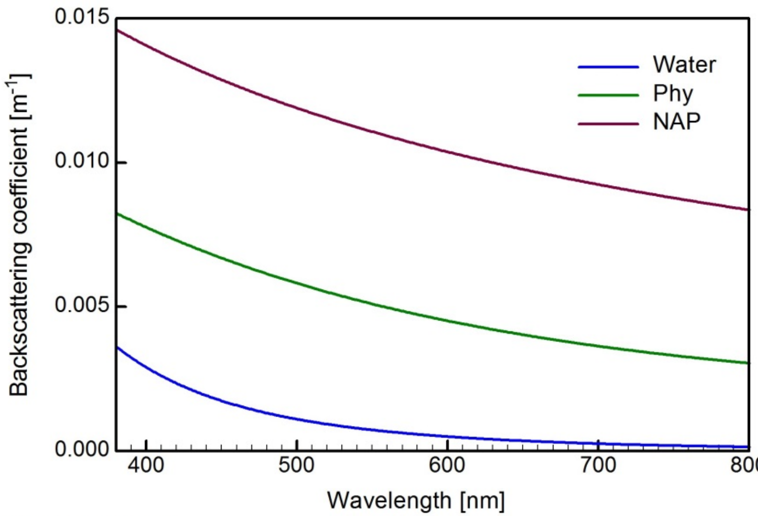
$$a(\lambda) = a_w(\lambda) + C_{CDOM} \cdot a^*_{CDOM}(\lambda) + C_{phy} \cdot a^*_{phy}(\lambda) + C_{NAP} \cdot a^*_{NAP}(\lambda)$$

$$b_b(\lambda) = b_{b,w}(\lambda) + C_{phy} \cdot b^*_{b,phy}(\lambda) + C_{NAP} \cdot b^*_{b,NAP}(\lambda)$$

C: concentration, *: normalized to concentration



ABSORPTION | 5.5.2017



BACKSCATTERING | 5.5.2017

Reflectance of deep water

Apparent optical properties (AOPs) depend on the material and on light field geometry.
IOPs are additive, but not AOPs.

Bio-optical models are the equations relating AOPs to the concentrations and IOPs of water constituents.

Reflectance is an AOP, yet in good approximation proportional to the IOP („Gordon factor")

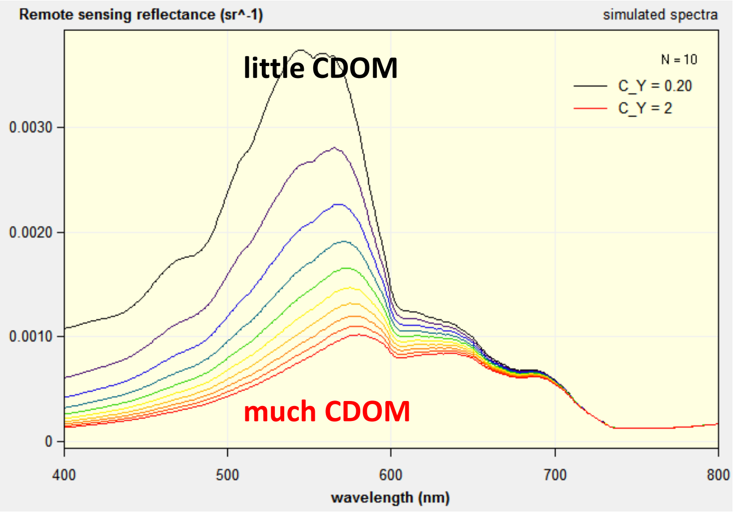
$$u(\lambda) = \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}$$

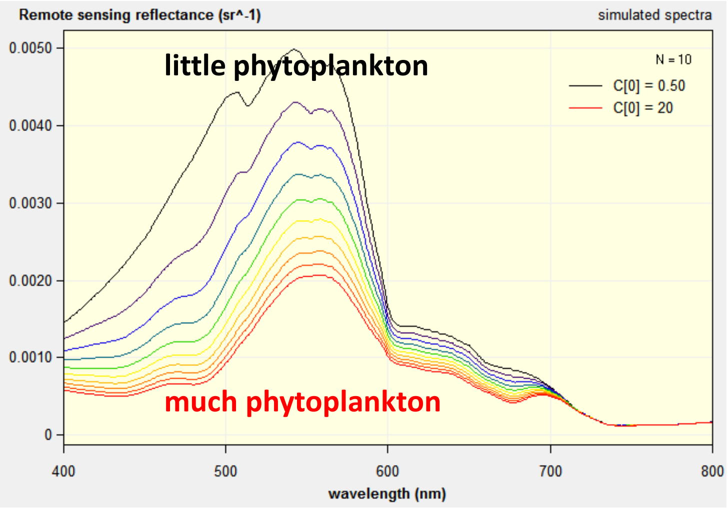
The factor of proportionality depends on light field geometry, viewing geometry, and on *u*.
It is in the order of 1/3 for irradiance reflectance.

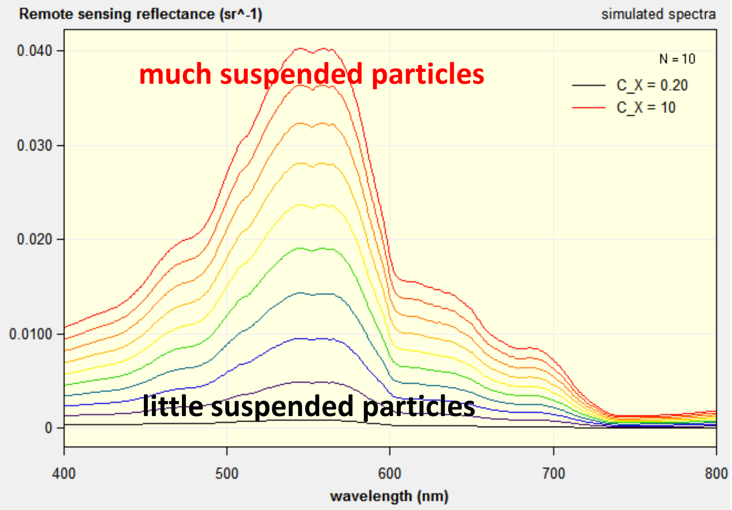
***u* is highly nonlinear with concentration, thence reflectance**. Linearisation is not possible.

- **Spectral unmixing methods, as known from land applications, do not work.**

Typical reflectance spectra of deep water







The examples represent water types with relatively low concentrations of water constituents (oligotrophic to mesotrophic conditions).

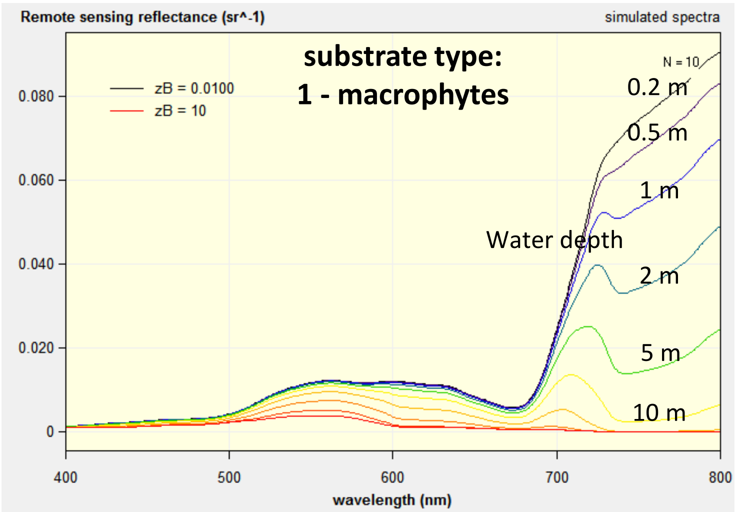
Non-iterated parameters:

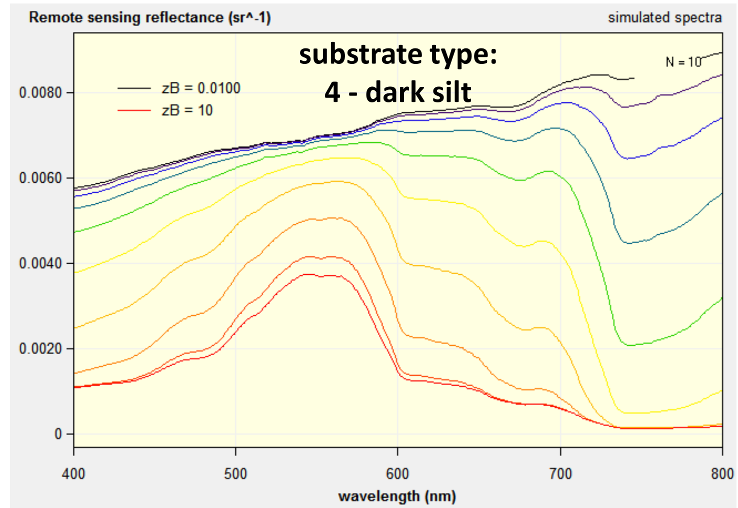
C_{NAP} = 1 g m^{-3}

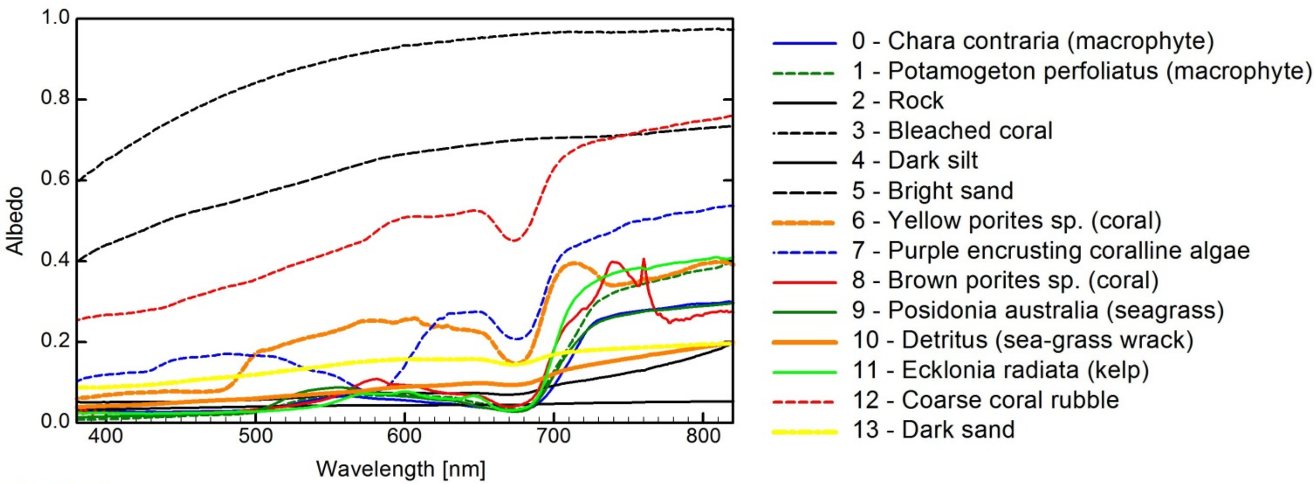
C_{CDOM} = 1 g m^{-3} [a_{CDOM}(440) = 0.2 m^{-1}]

C_{phy} = 5 mg m^{-3}

Typical reflectance spectra of shallow waters



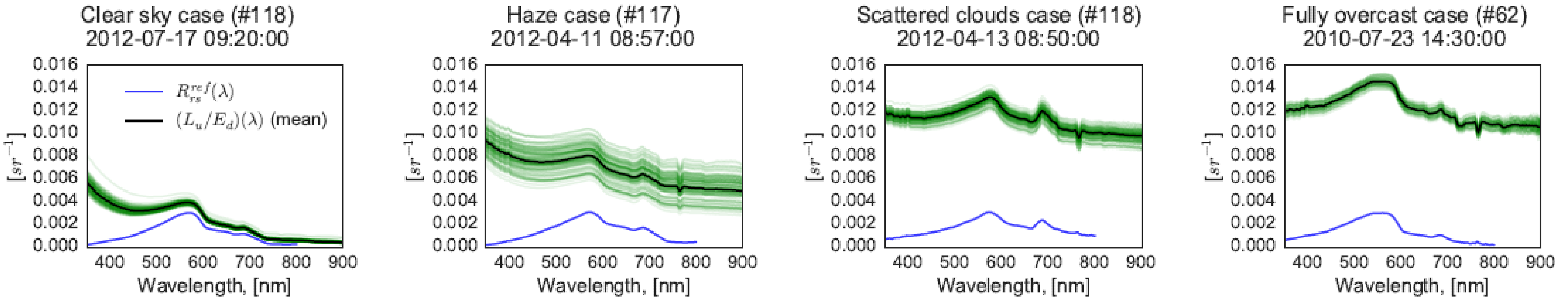




BOTTOM | 5.5.2017

DLR

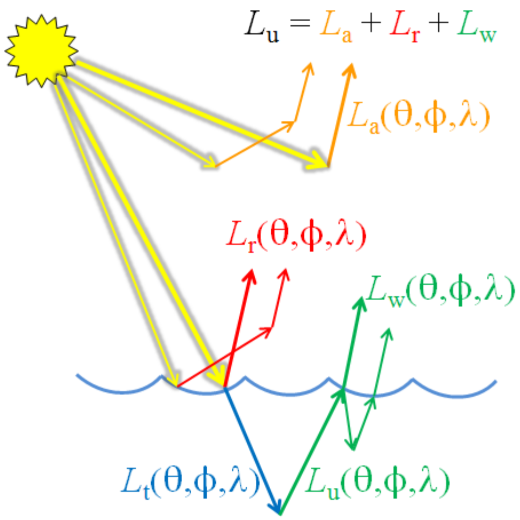
Specular reflections at the water surface



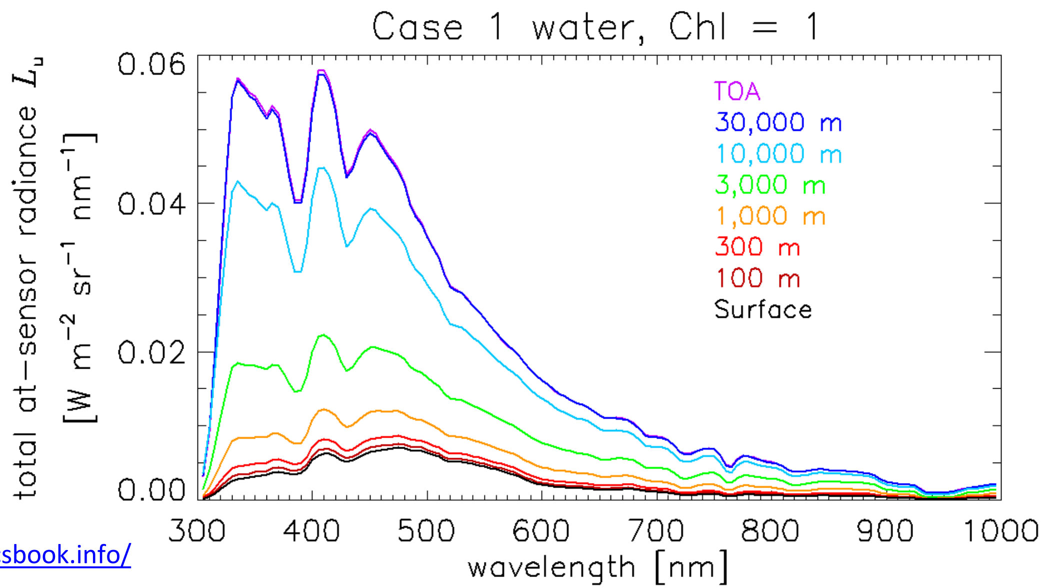
P.M.M. Grötsch, P. Gege, S.G.H. Simis, M.A.Eleveld, S.W.M. Peters (2017): Validation of a spectral correction procedure for sun and sky reflections in above-water reflectance measurements. Optics Express 25, A742-A761.

The radiance reflected at the surface can be much higher than the water leaving radiance.

Influence of the atmosphere

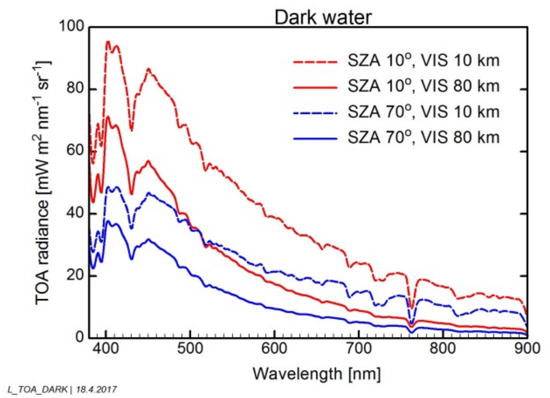


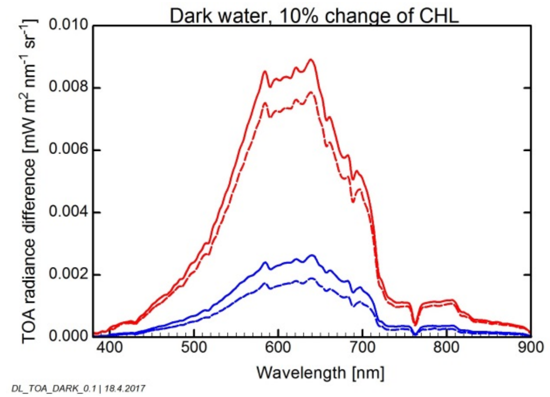
http://www.oceanopticsbook.info/



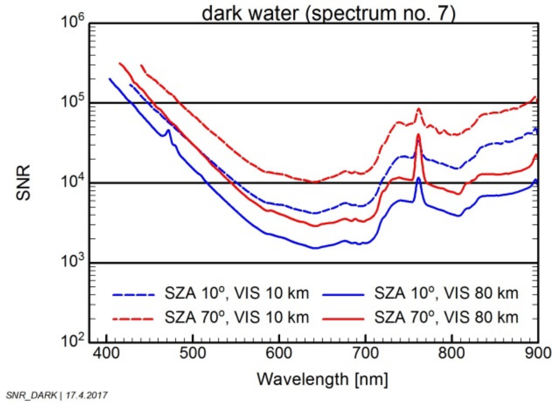
From satellite, the radiance of the atmosphere is an order of magnitude higher than the water leaving radiance.

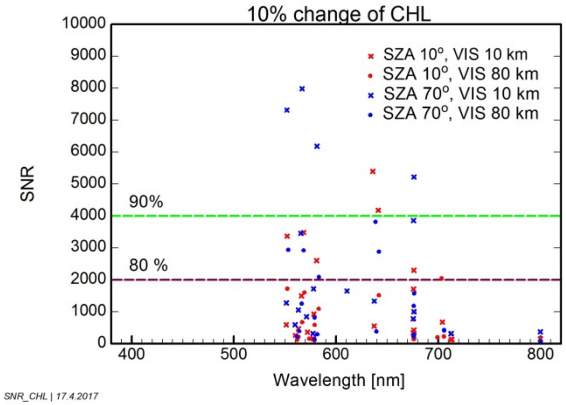
Wanted signal much lower than background signal





Left: Top of atmosphere (TOA) radiances of dark water for different sun zenith angles and visibilities. **Right:** TOA radiance differences induced by changing chlorophyll by 10%.





SNR required to detect 10% changes of chlorophyll-a concentration for different water types.

Challenges

Environment

- many spectrally different components
- IOPs of components not constant
- reflections at the water surface
- atmosphere

Models and software

- simulation
- data analysis
- spectral ambiguities

Sensor

- sensitivity
- calibration
- availability
- observation geometry

Services

- data provider
- data products