→ 4th ESA ADVANCED TRAINING ON OCEAN REMOTE SENSING

Coastal Water Algorithms

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Outline

1. Definition and spectral signatures of Case-2 waters

Definition

Spectral signatures = (NAP / Chla / CDOM)

2. Atmospheric corrections

Methods / Algorithms

Validation

3. Level-2 products and inversion algorithms

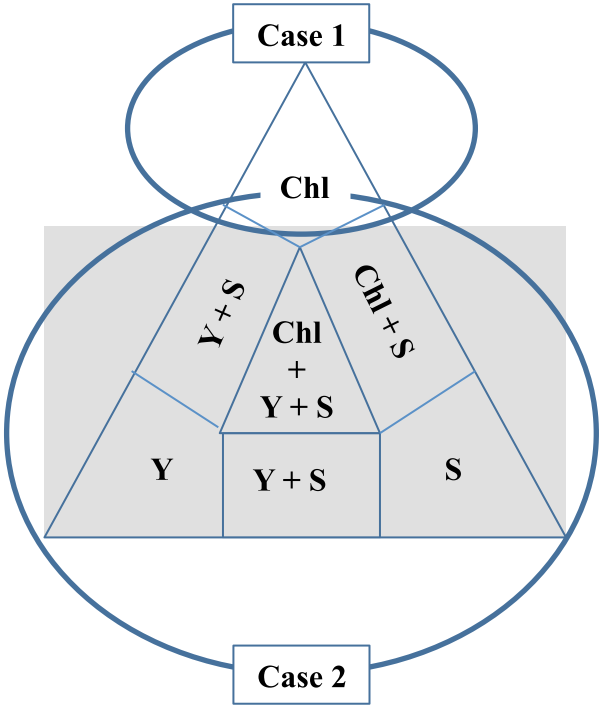
Bio-optical and biogeochemical products

Three main types of inversion algorithms

4. Application of the Ocean Colour methods in coastal seas: Experience at Ifremer Brest (F. Gohin)

5. Summary / Conclusions

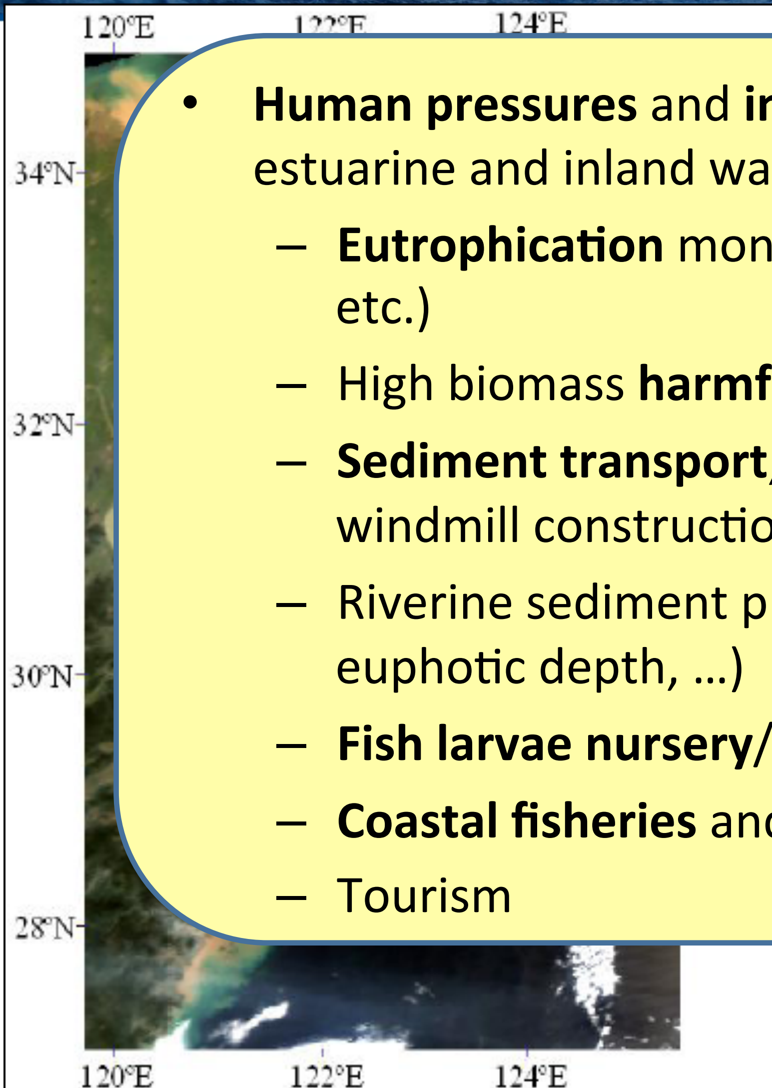
Classification of natural waters

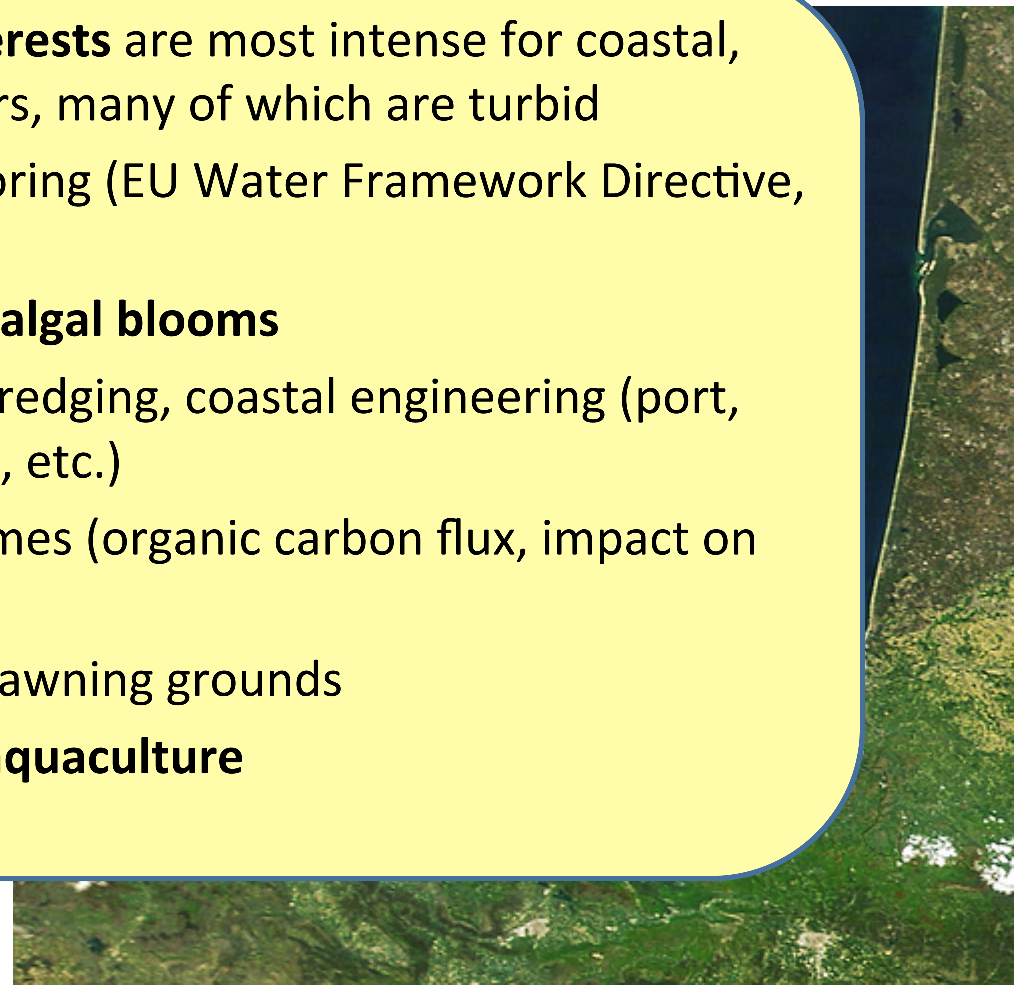


Morel / Antoine MERIS Case 1 water ATBD

- In Case 2 waters, terrestrial non-algal particles (S) and coloured dissolved organic matter (Y)
- Sources of S and Y: rivers, sediment resuspension, coastal erosion, wind
- Highly productive waters (high nutrient supply)

1. Definition





- **Human pressures** and **interests** are most intense for coastal, estuarine and inland waters, many of which are turbid
  - **Eutrophication** monitoring (EU Water Framework Directive, etc.)
  - High biomass **harmful algal blooms**
  - **Sediment transport**, dredging, coastal engineering (port, windmill constructions, etc.)
  - Riverine sediment plumes (organic carbon flux, impact on euphotic depth, …)
  - **Fish larvae nursery**/spawning grounds
  - **Coastal fisheries** and **aquaculture**
  - Tourism

1. Spectral signatures

$$R_{rs} = f' \times b_b / (a + b_b)$$

➔ R_{rs} increases with increasing light scattering, decreases increasing with increasing light absorption

$$a = a_w + a_{Chla} + a_S + a_y$$

$$b_b = b_{bw} + b_{bChla} + b_{bS}$$

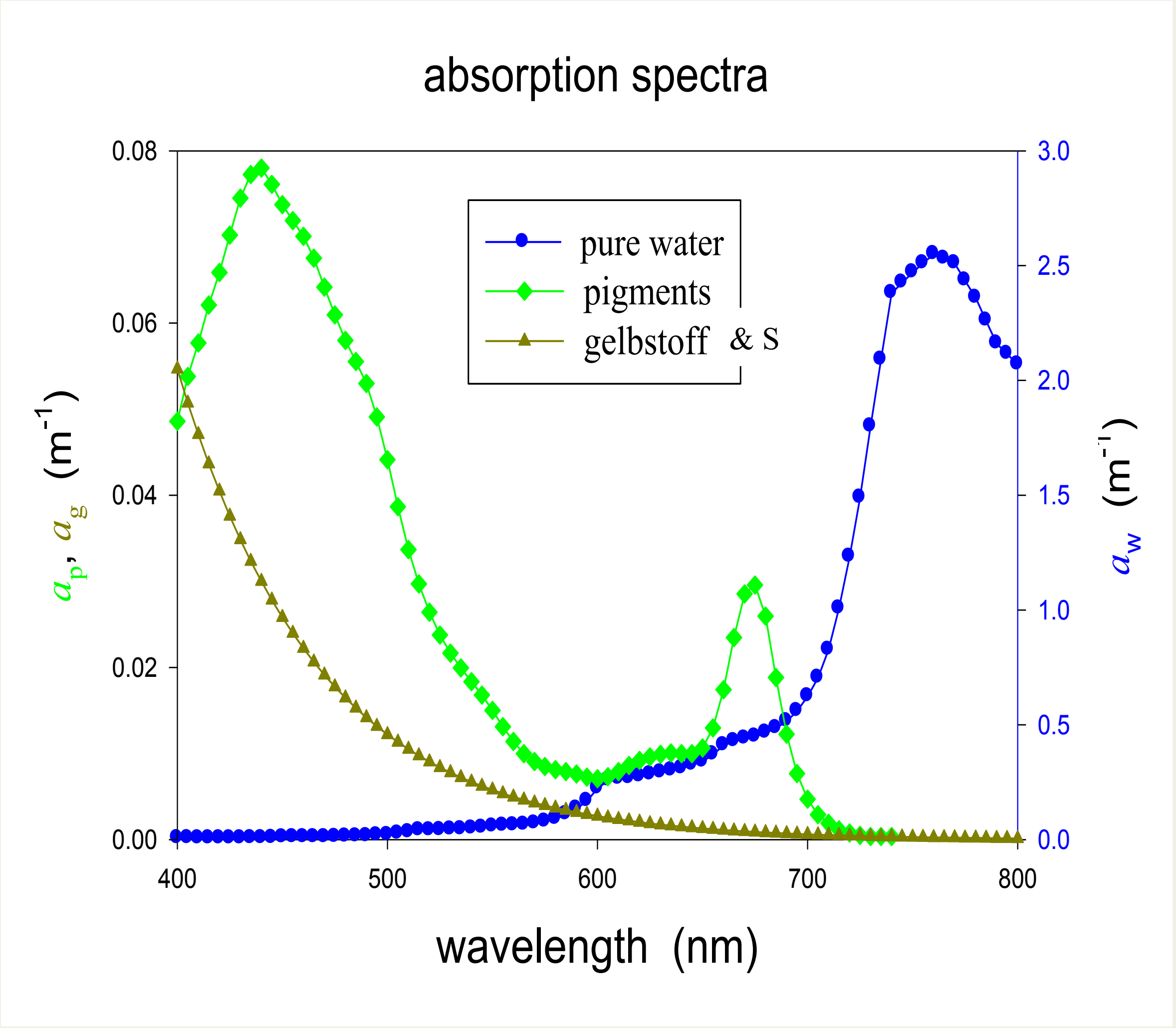
➔ The contributions of coloured water constituent are additive

$$a_{Chla} = Chla \times a^*_{Chla}$$

$$b_{bS} = S \times b^*_{bS}$$

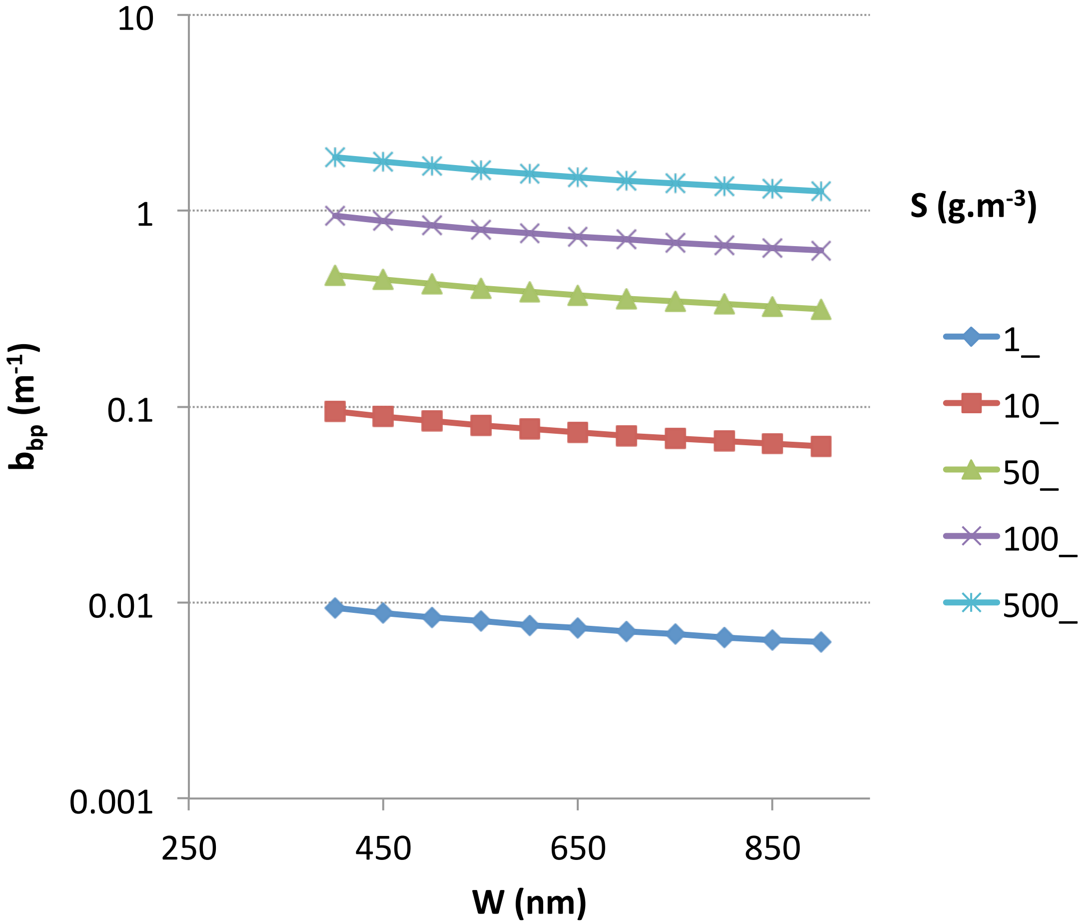
➔ Concentration × mass-specific absorption/backscattering coefficients

1. Spectral signatures



- **Pure water** absorbs light in the near-unfrared
- **Chla** has two peaks of absorption (443 and 675 nm)
- **Non-algal particles** (S) and **gelbstoff** (Y) both absorb at short (blue) wavelengths)

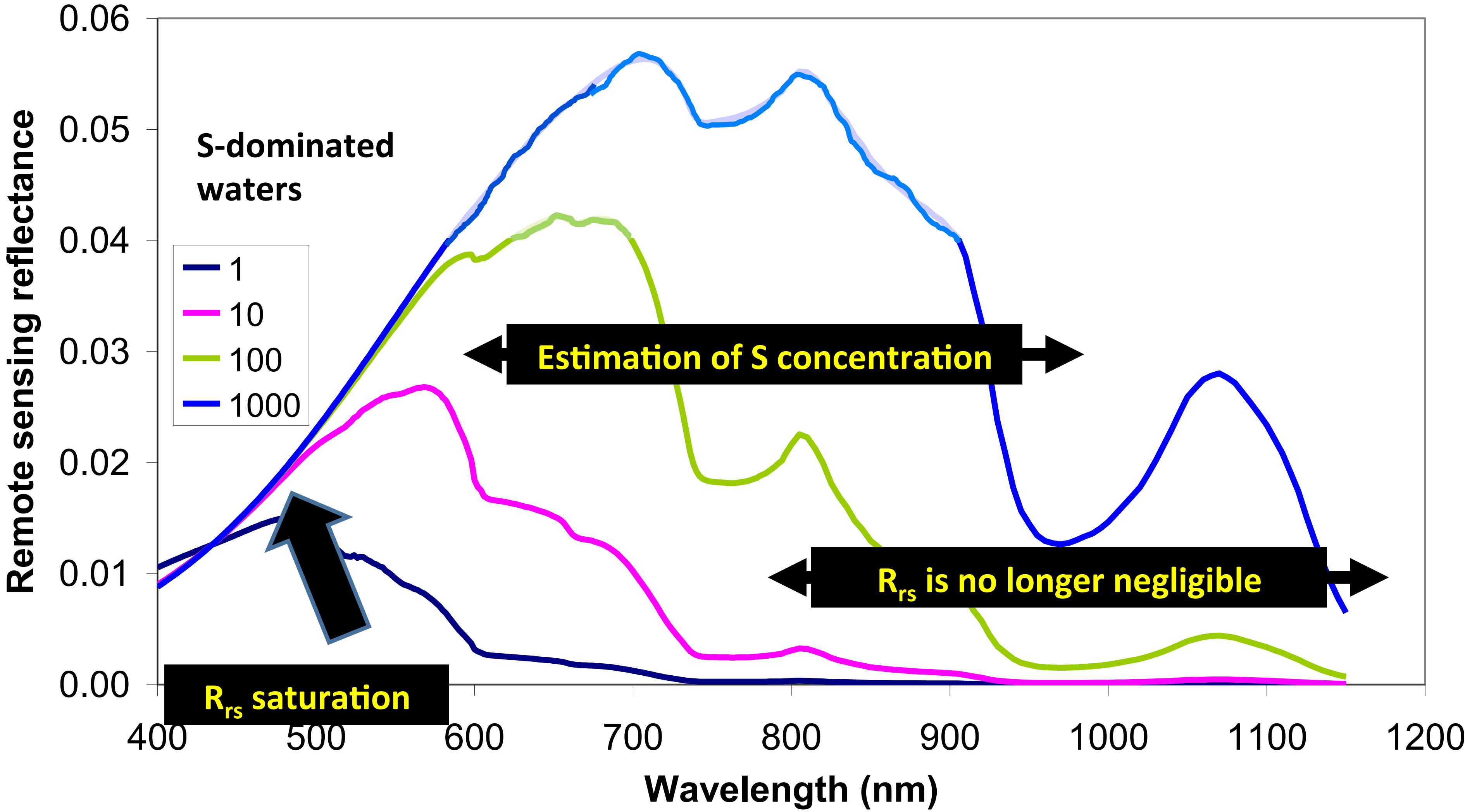
1. Spectral signatures



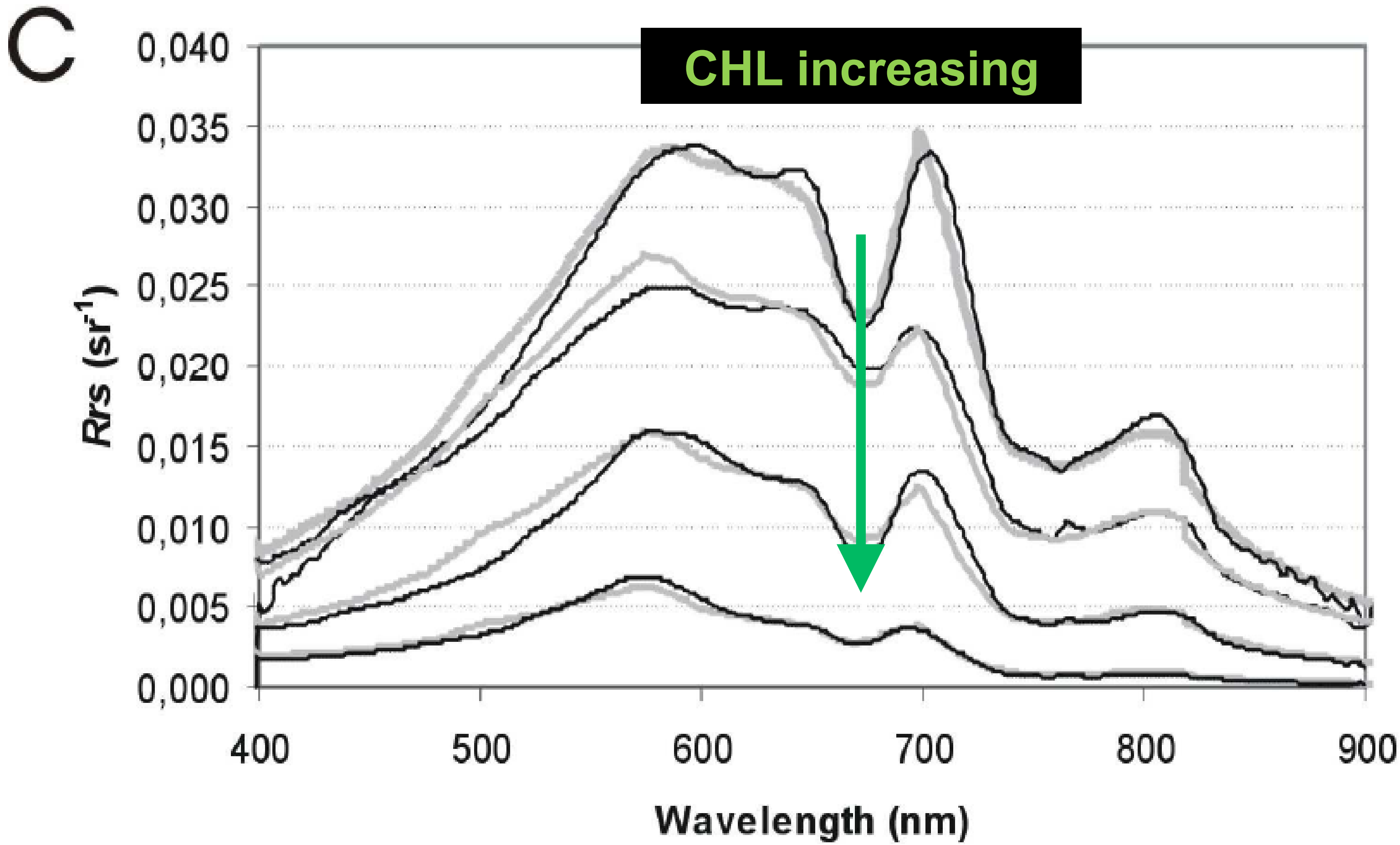
- **Particles, mainly non-algal** (S), backscatter light
- b_{bp} is a **proxy of particles concentration**
- **Smooth (power-law) spectral variations** (slope depends on size distribution)

1. Spectral signatures

Varying Total Suspended matter concentration (mg/m3)



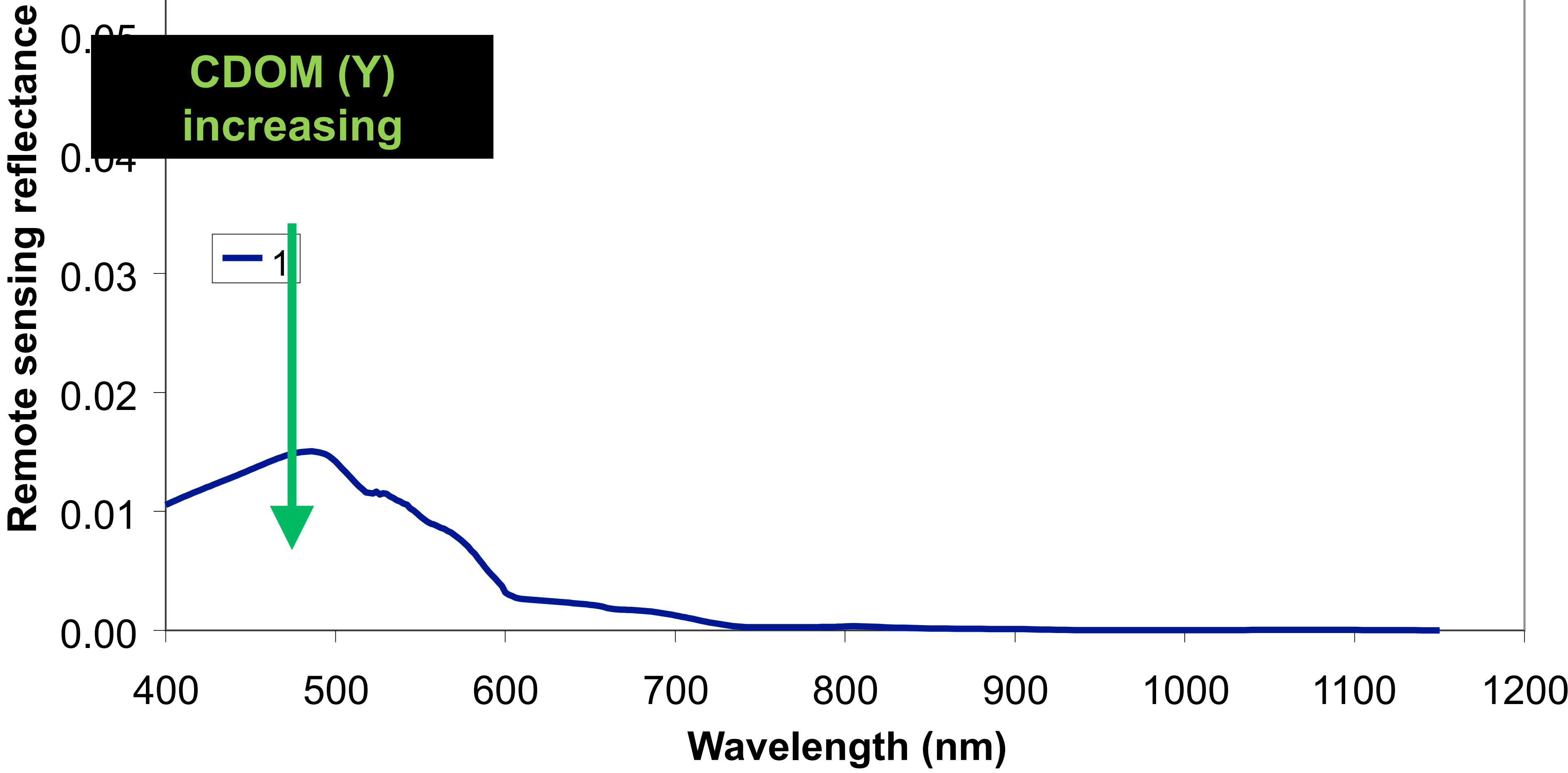
1. Spectral signatures



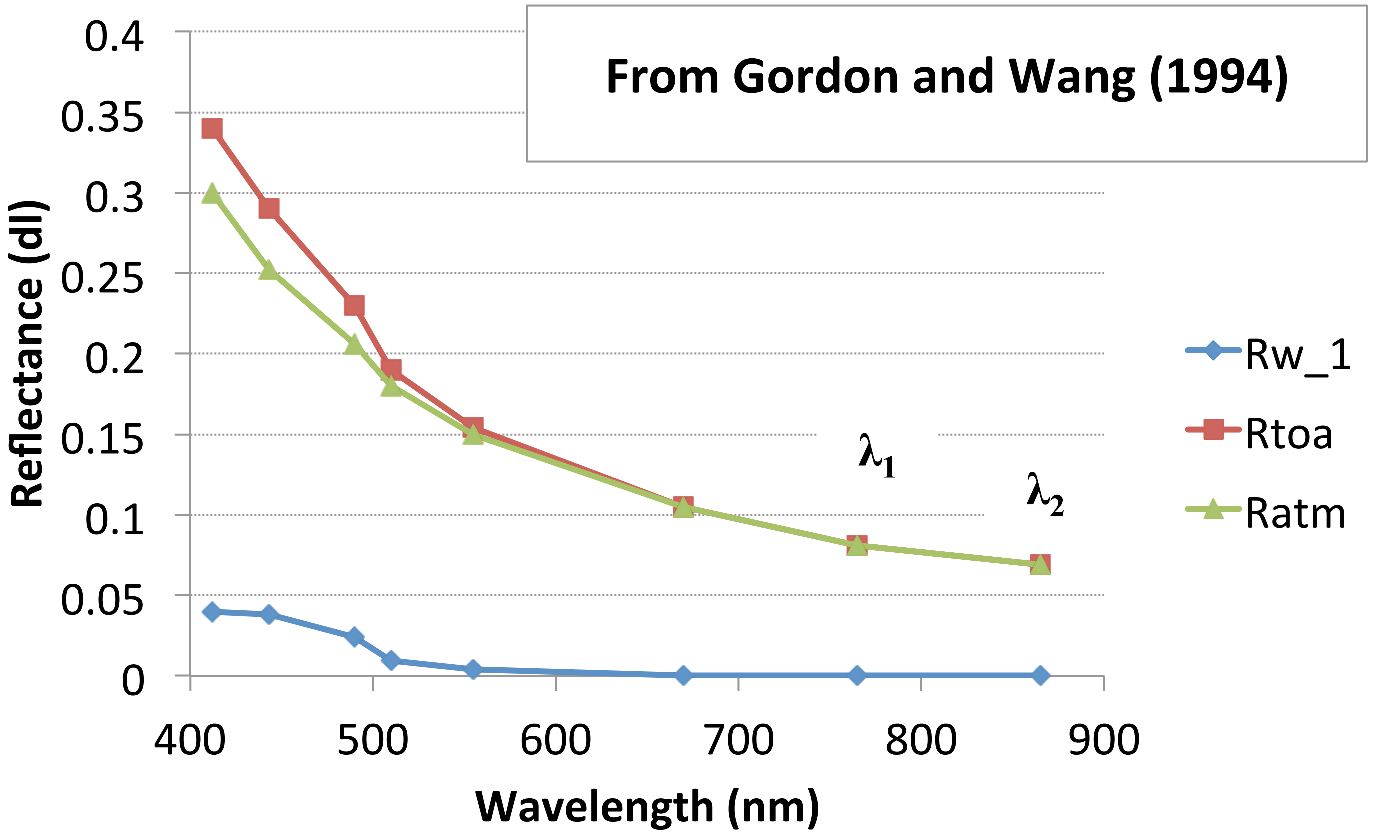
➔ **In turbid (absorbing and scattering) waters, light absorption by Chla at 443 nm disappears but light absorption by Chla is is clearly detecetd**

1. Spectral signatures

Villefranche, 11-12th July 2012



2. Atmospheric corrections



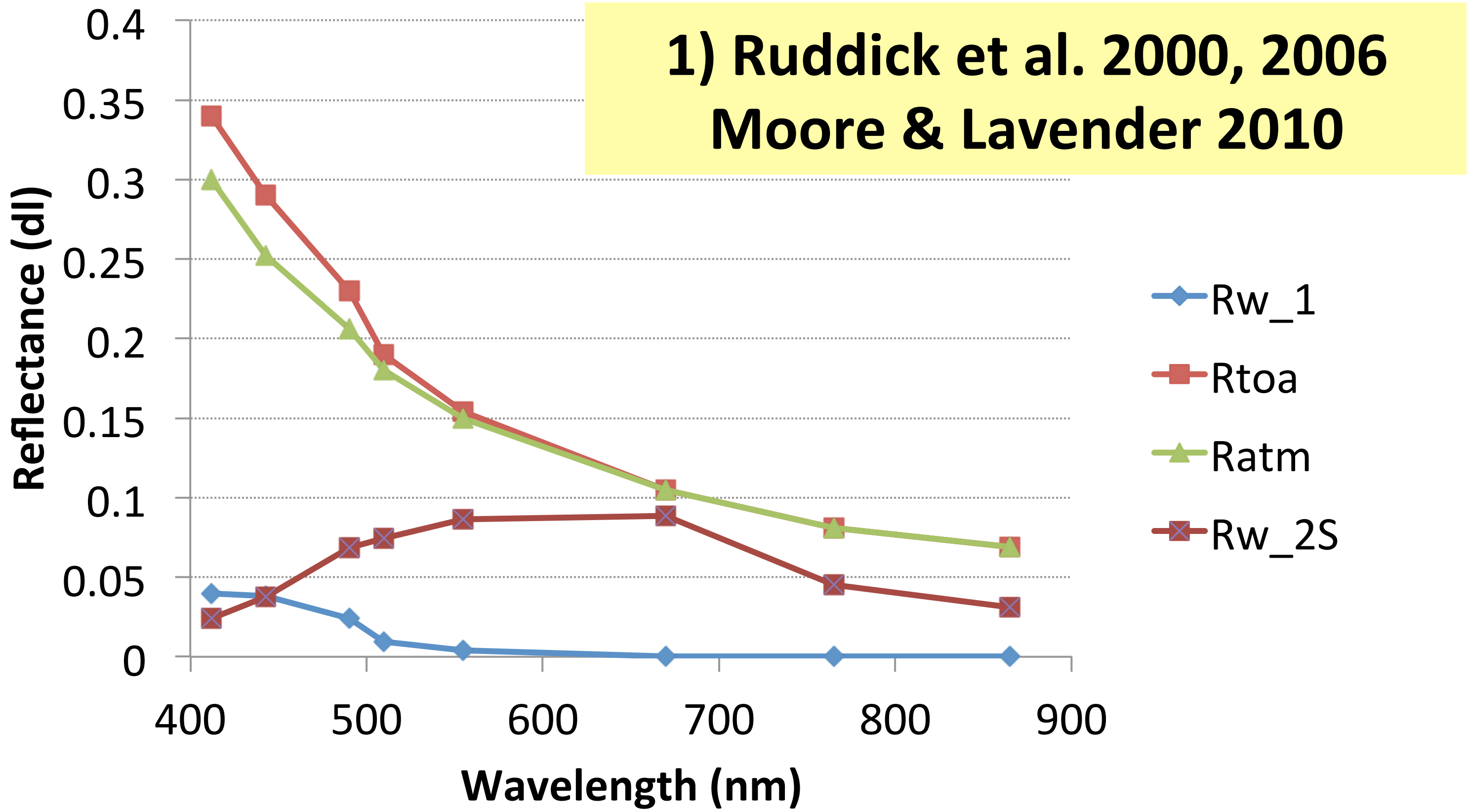
$$Rtoa(\lambda) = Rr(\lambda) + Rra(\lambda) + t \times Rw(\lambda), \qquad \varepsilon(\lambda_1,\lambda_2) = Rra(\lambda_1) / Rra(\lambda_2) = (\lambda_1 / \lambda_2)^n$$

Light absorption and scattering by air molecules (Rayleigh) (LUT)

Light scattering by aerosols is computed in the NIR and extrapolated to the visible

2. Atmospheric corrections

Ifremer | esa



$$Rtoa(\lambda) = Rr(\lambda) + Rra(\lambda) + t \times Rw(\lambda), \quad \varepsilon_w(\lambda_1,\lambda_2) = \text{constant (pure water)}$$

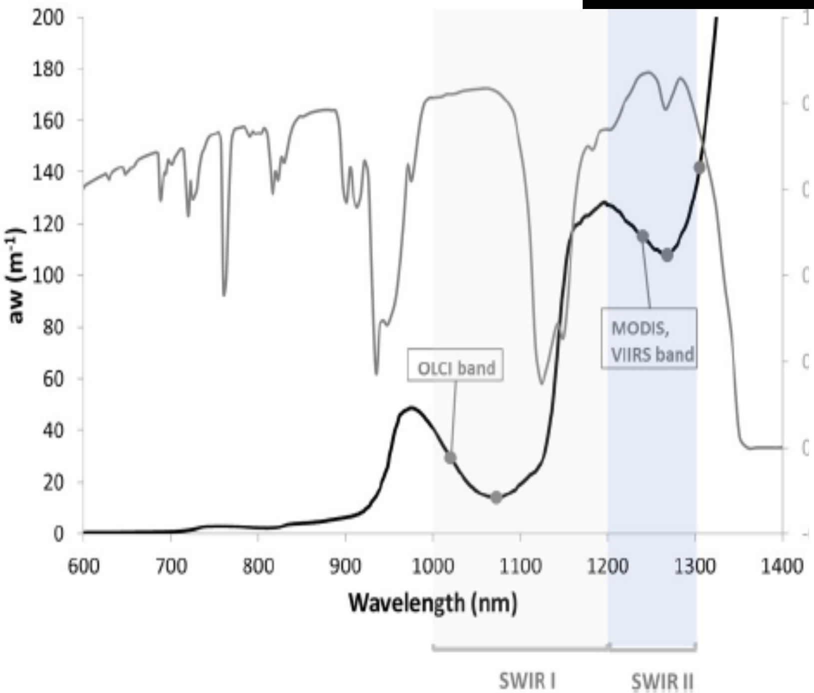
Light absorption and scattering by air molecules (Rayleigh) (LUT)

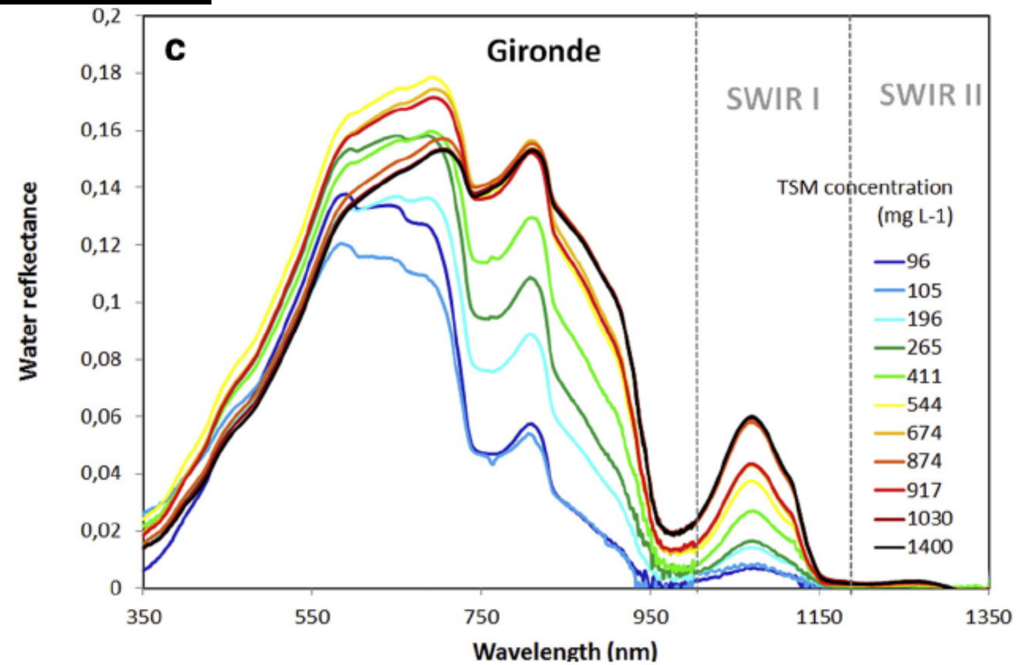
Pixel-by-pixel iterations to fit Ratm(λ_1,λ_2)

2. Atmospheric corrections

2) The NIR-SWIR atmospheric correction (Wang & Shi 2007)*

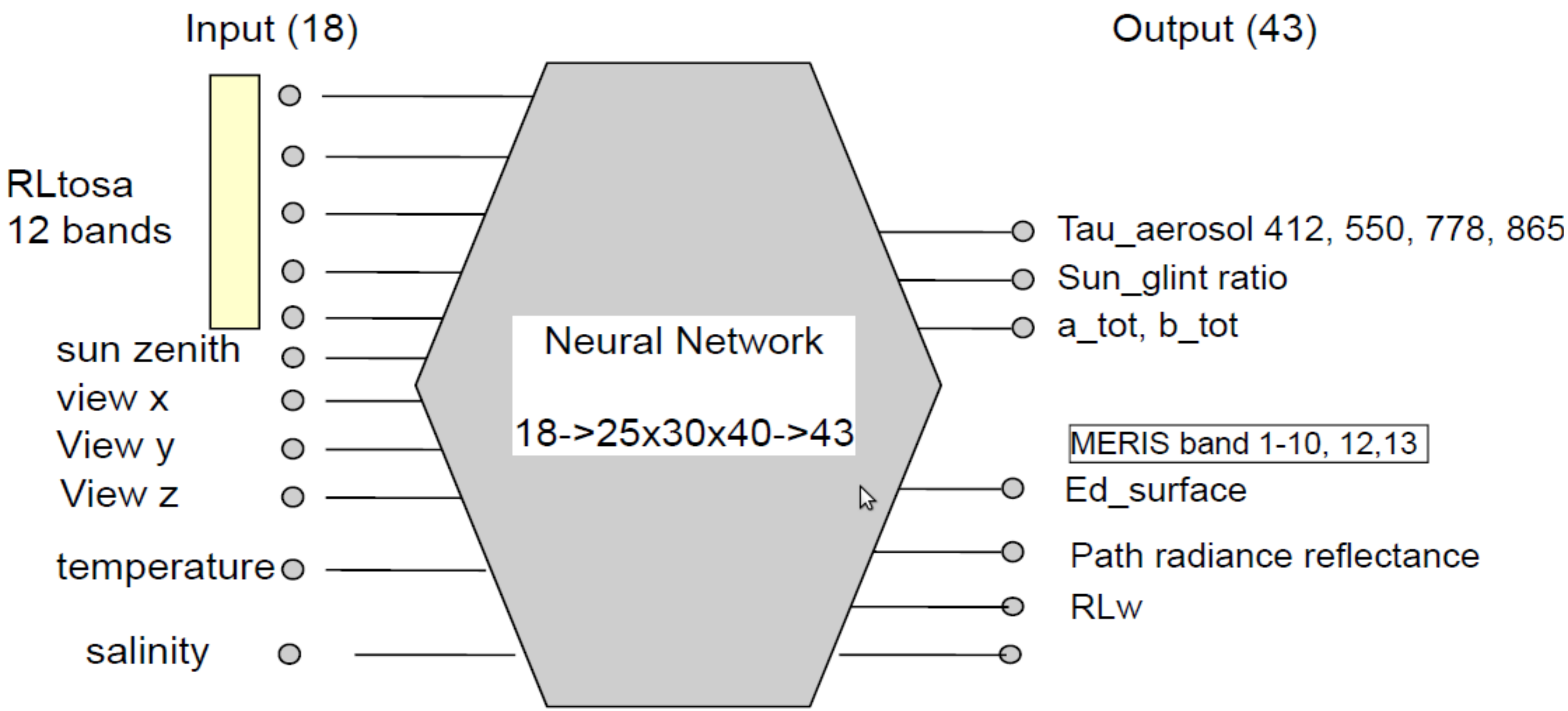
Knaeps et al. 2015





(*) ➔Use of 1240, 1640 and 2130 nm spectral bands (**MODIS, VIIRS**) to determine aerosol contribution and extrrapolate to visible

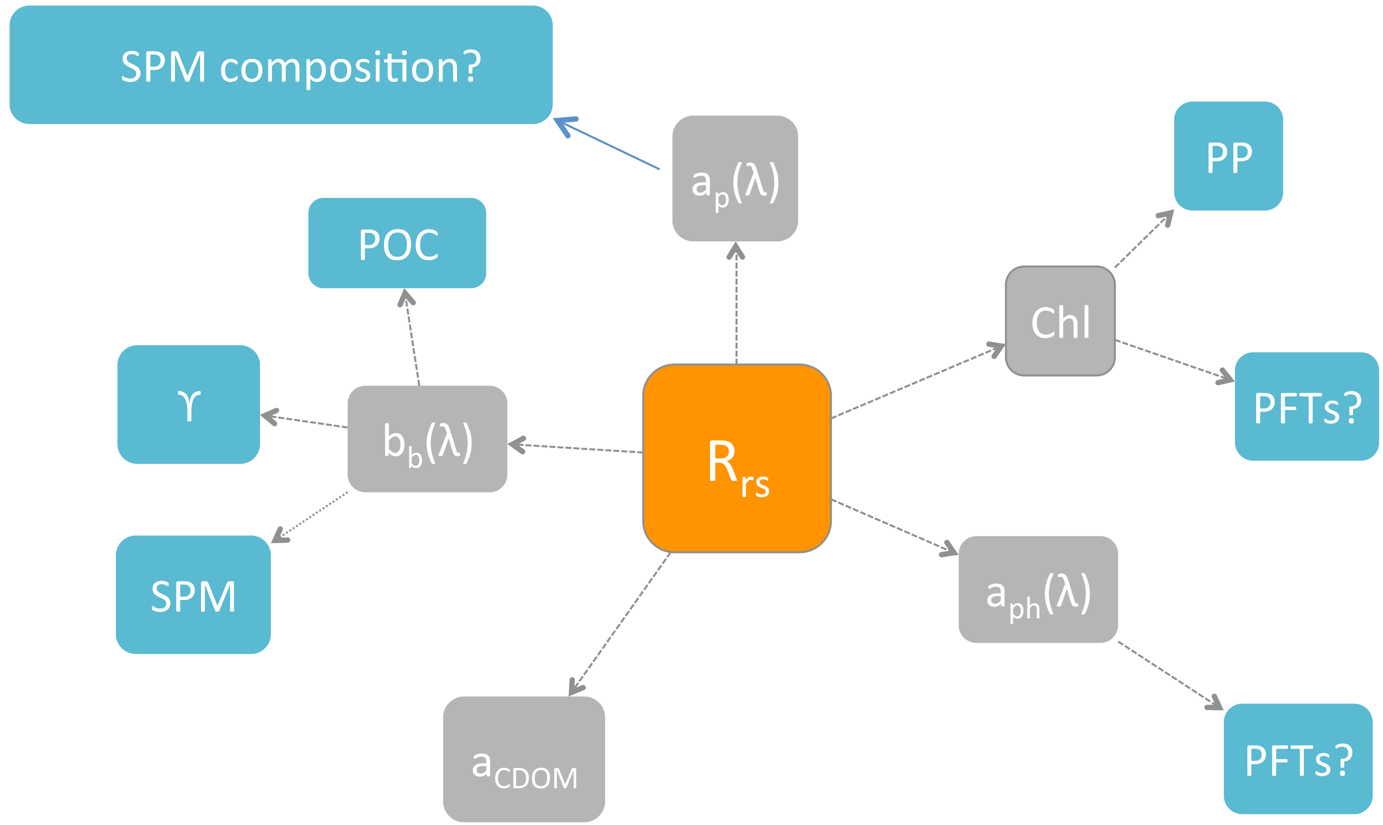
3) The Neural Network (NN) approach (Doerffer 1997)



$$RLw(\theta,\phi) = Lw(\theta,\phi) / Ed$$

For each water type

3. Products and inversion algorithms



(SPM = S + Chl)

3. Inversion algorithms

1) Empirical

based on field (and satellite) data

2) Semi-analytical

$$Rrs = f' \times b_b / (a + b_b)$$

$$a = a_w + a_{Chla} + a_{NAP} + a_y$$

$$b_b = b_{bw} + b_{bChla} + b_{bNAP}$$

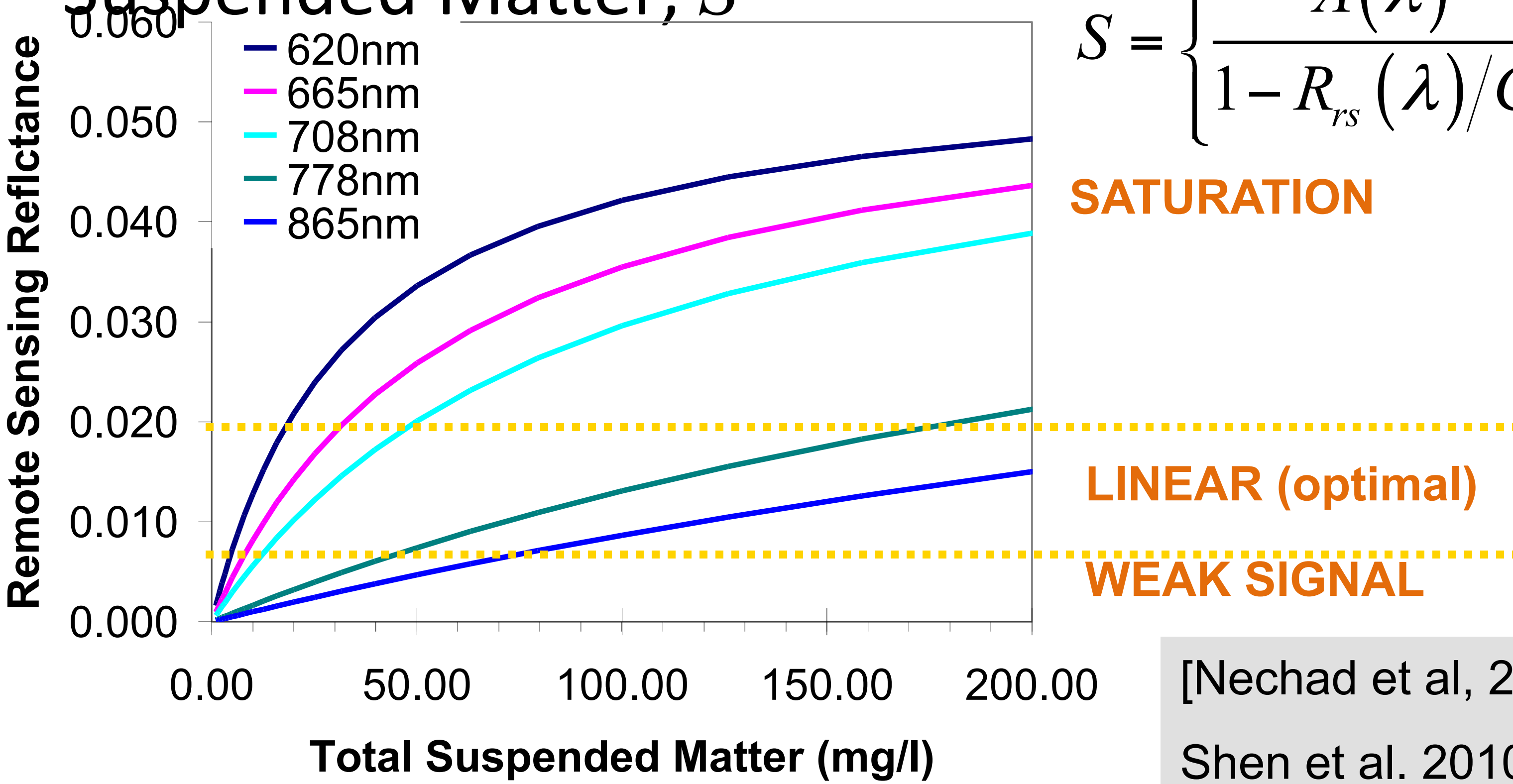
3) Neural Network

Trained using field data and/or RT simulations

3. SPM inversion algorithms

- Remote-sensing reflectance, R_{rs}, at any single wavelength, λ, is almost linearly related to Total Suspended Matter, S

$$S = \left\{ \frac{A(\lambda)}{1 - R_{rs}(\lambda)/C} \right\} R_{rs}(\lambda)$$

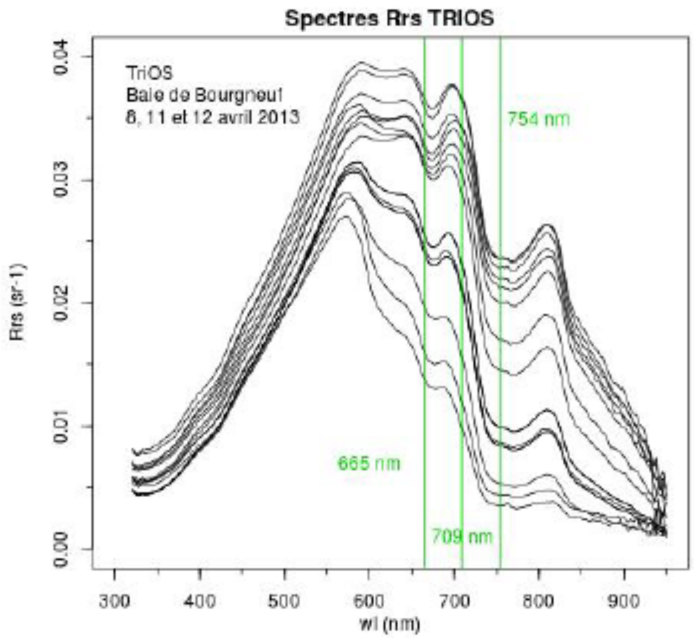


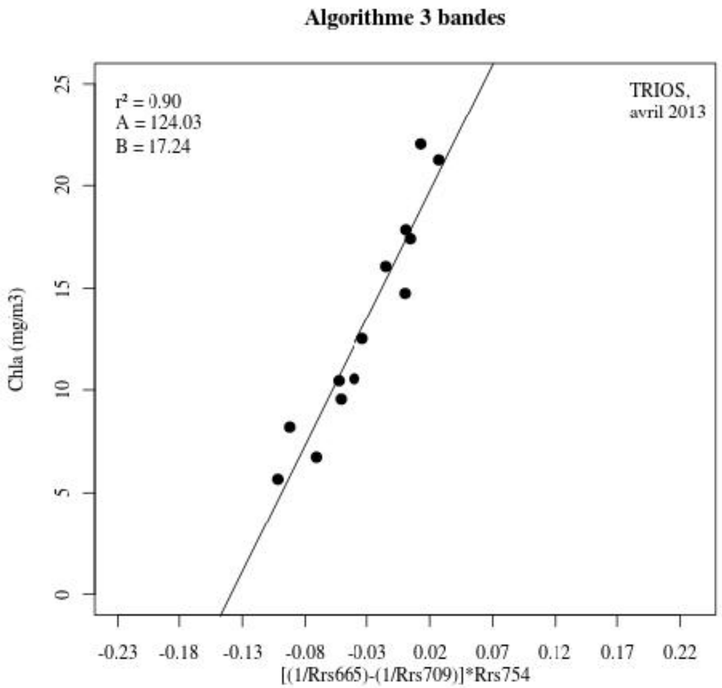
[Nechad et al, 2010]

Shen et al. 2010

Doxaran et al. 2002-2009

➔ Blue/green R_{rs} ratio usually fail in coastal waters





D"après Gitelson et al, 2008

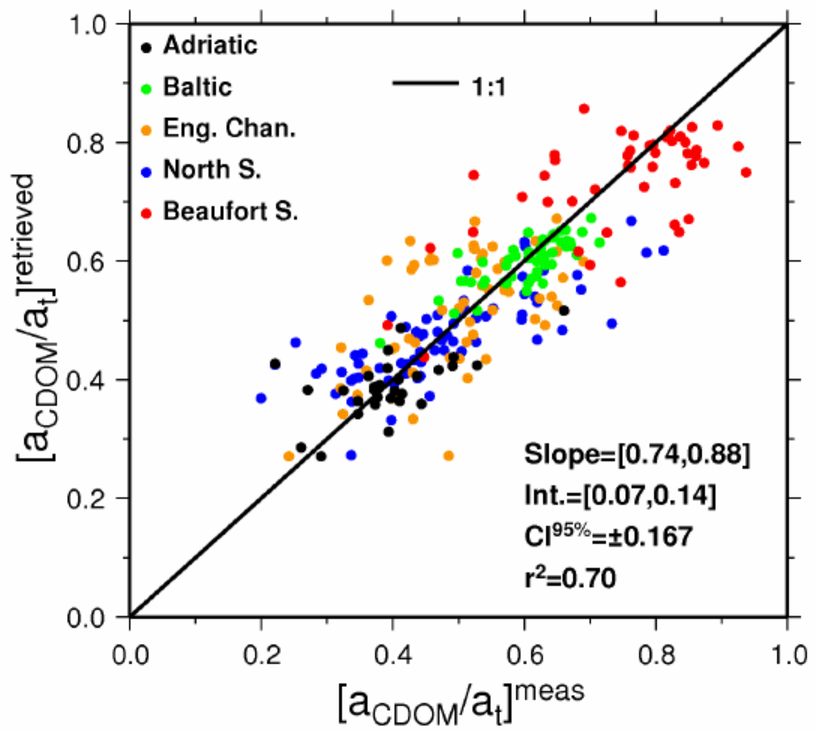
➔ Use of the second absorption peak of Chla (675 nm)

3. CDOM inversion algorithms

Taking into account the contributions of S and Chla:

$$\left[\frac{a_{CDOM}}{a_t}\right](412) = \alpha + \beta \cdot \log_{10}\left(\frac{R_{rs}(412)}{R_{rs}(555)}\right) + \chi \cdot \log_{10}\left(\frac{R_{rs}(490)}{R_{rs}(555)}\right) + \delta \cdot \log_{10}\left(R_{rs}(555)\right)$$

General retrieval of Light absorption (or concentration) of CDOM or Y (Bélanger 2006), with regional adaptations (Bélanger et al. 2008; Matsuoka et al. 2012)



3. Semi-analytical algorithms

Semi-analytical (SA) ocean color models allow retrieving multiple ocean properties from a single water-leaving radiance spectrum.

$$\hat{L}_{wN}(\lambda) = \frac{tF_0(\lambda)}{n_w^2} \sum_{i=1}^{2} g_i \left\{ \frac{b_{bw}(\lambda) + b_{bp}(\lambda_0)(\lambda/\lambda_0)^{-\eta}}{b_{bw}(\lambda) + b_{bp}(\lambda_0)(\lambda/\lambda_0)^{-\eta} + a_w(\lambda) + \mathrm{Chl}\, a_{\mathrm{ph}}^*(\lambda) + a_{\mathrm{cdm}}(\lambda_0)\exp[-S(\lambda - \lambda_0)]} \right\}^i$$

Rrs ➔ IOPs ➔ coloured constituents

3. Semi-analytical algorithms

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Rrs ➔ IOPs ➔ coloured constituents

The **GSM** (Maritorena et al. 2002), the **QAA** (Lee et al. 2002-2013) and **C2R-NN** (Doerffer and Schiller 2007) algorithms are well-known SA models implemented into SeaDAS and Beam-Visat softwares.

These algorithms may fail in specific coastal environments where regional algorithms will perform better.

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Application of the Ocean Colour methods in coastal seas: Experience at Ifremer Brest

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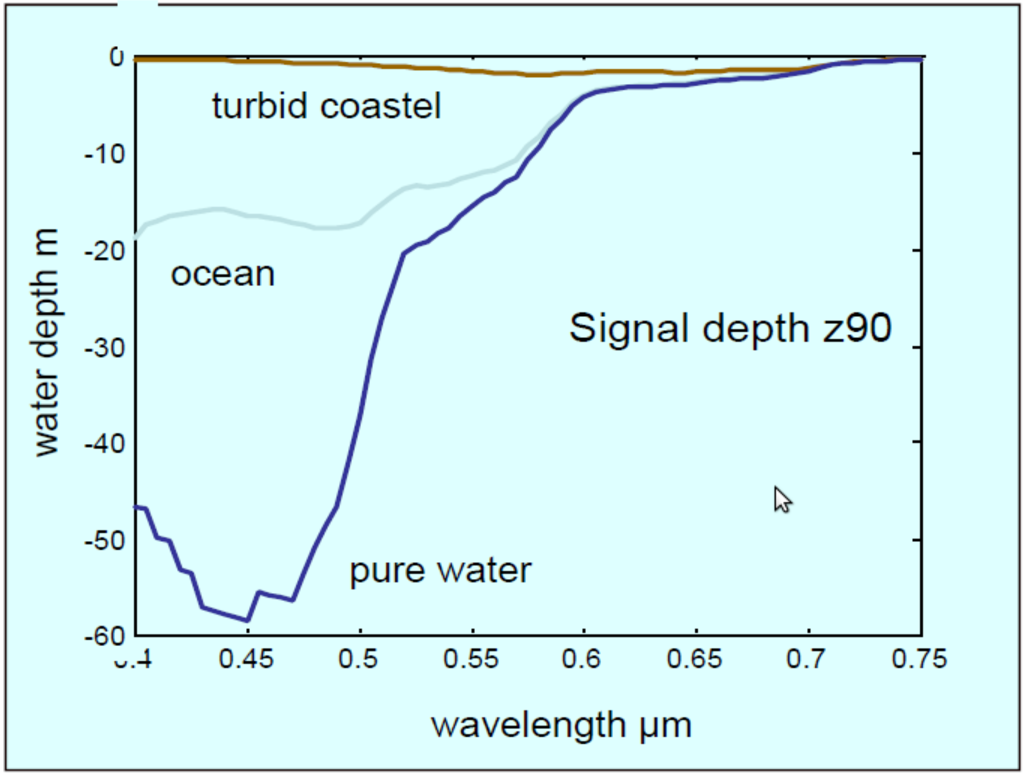
But optical depth is a limit of ocean colour satellite observations

Signal depth at different spectral bands

Multiband algorithms: the information for each band may come from a different water layer



$z_{90}=1/k$

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

open ocean:
Chlor.=1µg/l

Summary

- **Complex Coastal Water Algorithms (SA, NN) and often regional**

- **Two steps:**
  - Atmospheric corrections (TOA >> Rrs)
  - Inversion (Rrs >> IOPs, coloured water constituents)

- **Ocean colour satellite products are (potentially) very useful in coastal waters:**
  - Water quality monitoring
  - Biogeochemistry, Sediment transport
  - Fluxes / exchanges at the land-ocean interface

Useful references / Links

International Ocean Colour Coordinating Group
http://www.ioccg.org/

European Space Agency MERIS Handbook
https://earth.esa.int/handbooks/meris/

NASA Ocean Color homepage
http://oceancolor.gsfc.nasa.gov/cms/

LOV Remote Sensing Group publications as pdf files
http://omtab.obs-vlfr.fr/

Thank you for attention!

RBINS Remote Sensing and Ecosystem Modelling team website
http://odnature.naturalsciences.be/remsem/