Ifremer

esa

→ 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

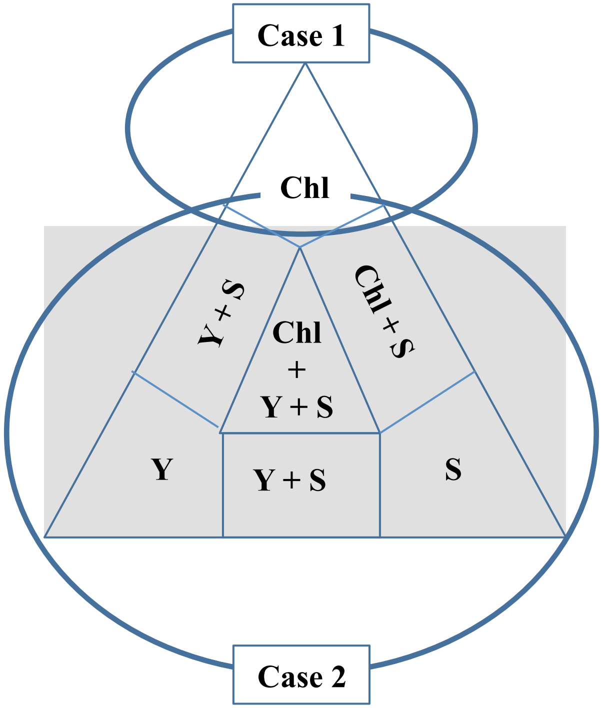
3. Level-2 products and inversion algorithms
Bio-optical and biogeochemical products
Three main types of inversion algorithms

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

5. Summary / Conclusions

1. Definition

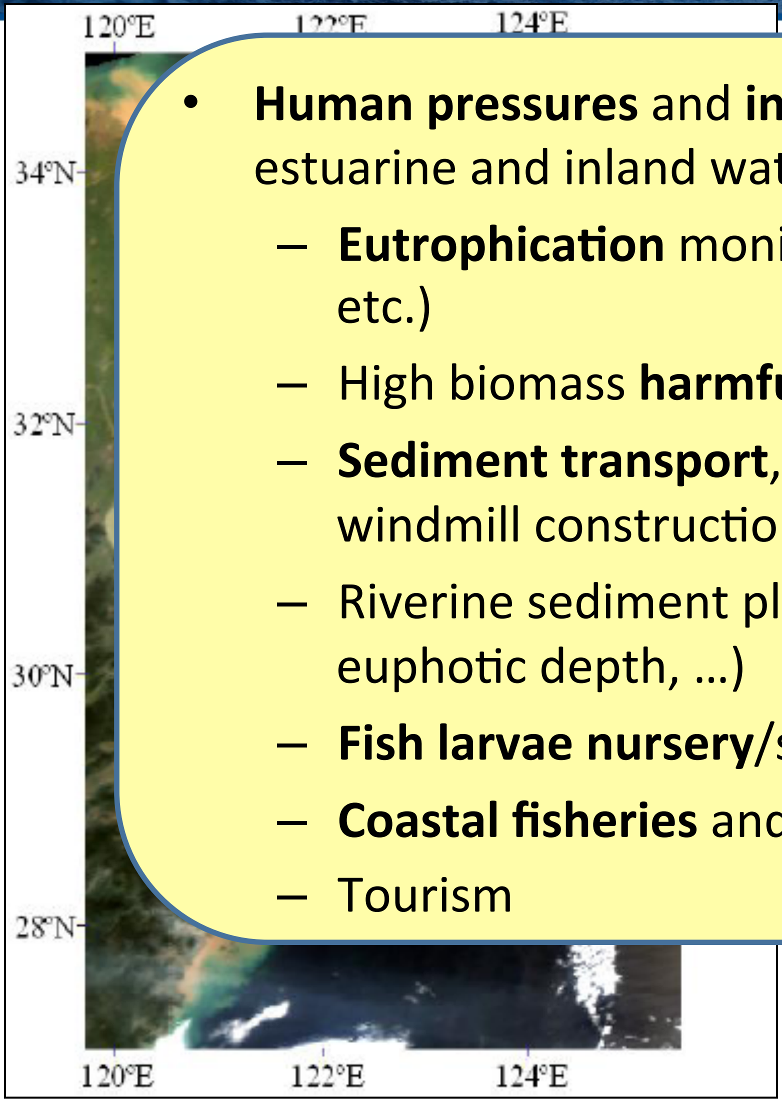
Classification of natural waters

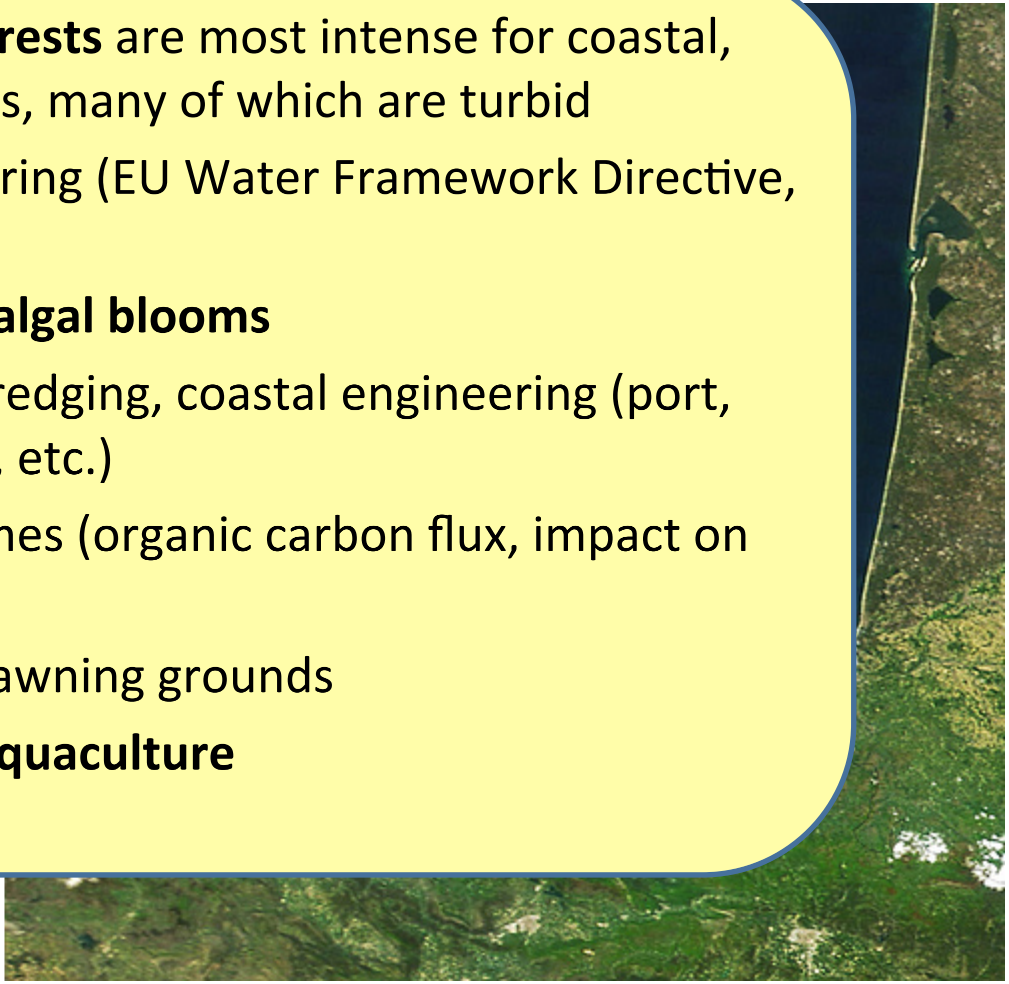


Morel / Antoine MERIS Case 1 water ATBD

- **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

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

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

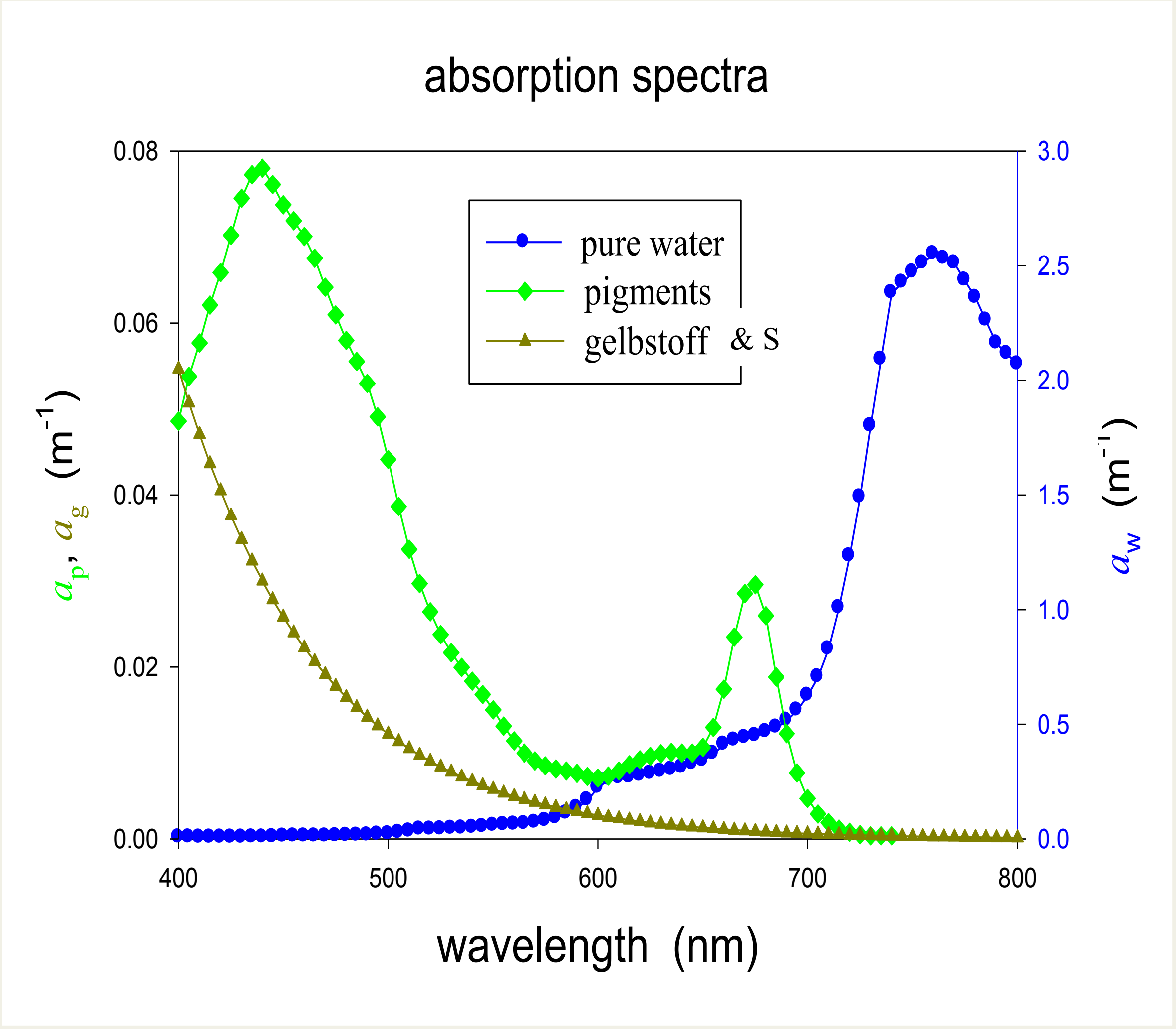
$$a_{Chla} = Chla \times a^{*}{}_{Chla}$$

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

➔ The contributions of coloured water constituent are additive

➔ Concentration × mass-specific absorption/backscattering coefficients

1. Spectral signatures

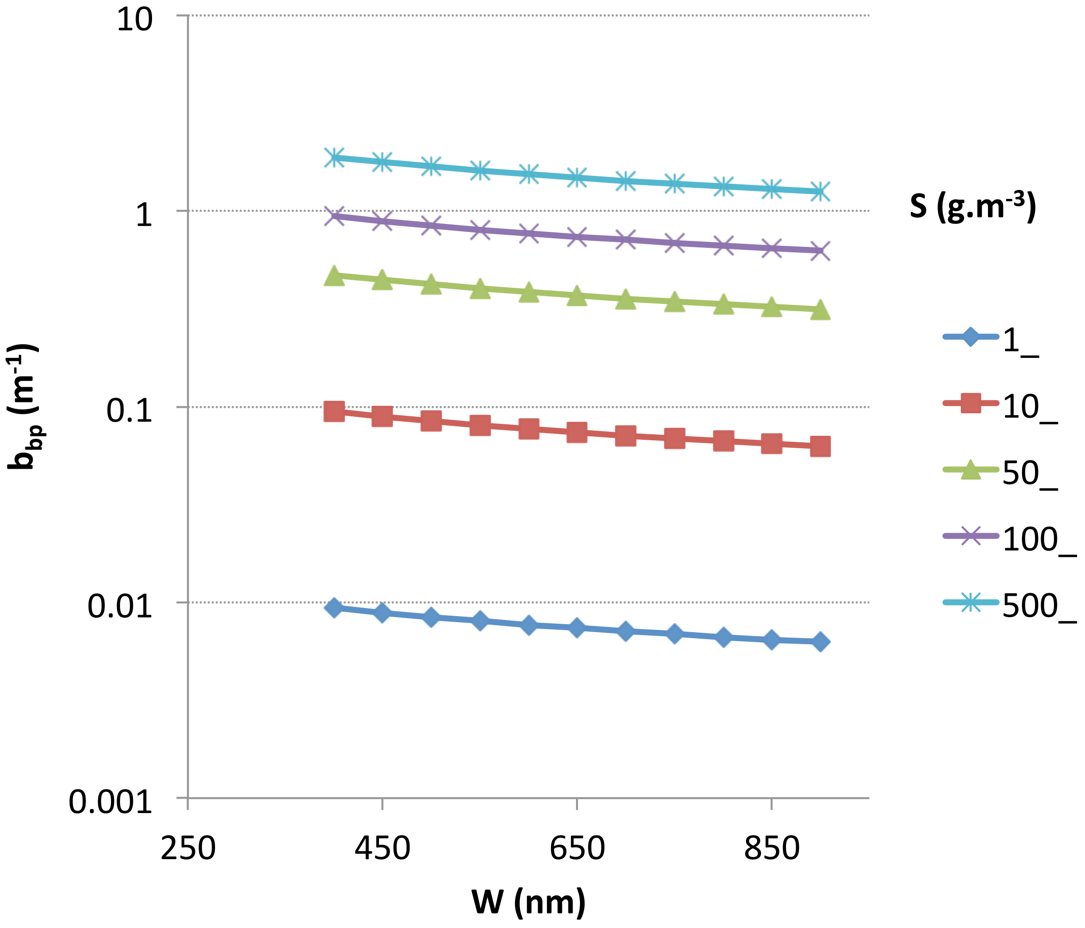


- **Pure water** absorbs light in the near-unfrared

- **Chla** has two peaks of absorption (443 and 675 nm)

- **Non-algal particles** (S) and **gelbstoff** (Y) both absorb at short (blue) wavelengths)

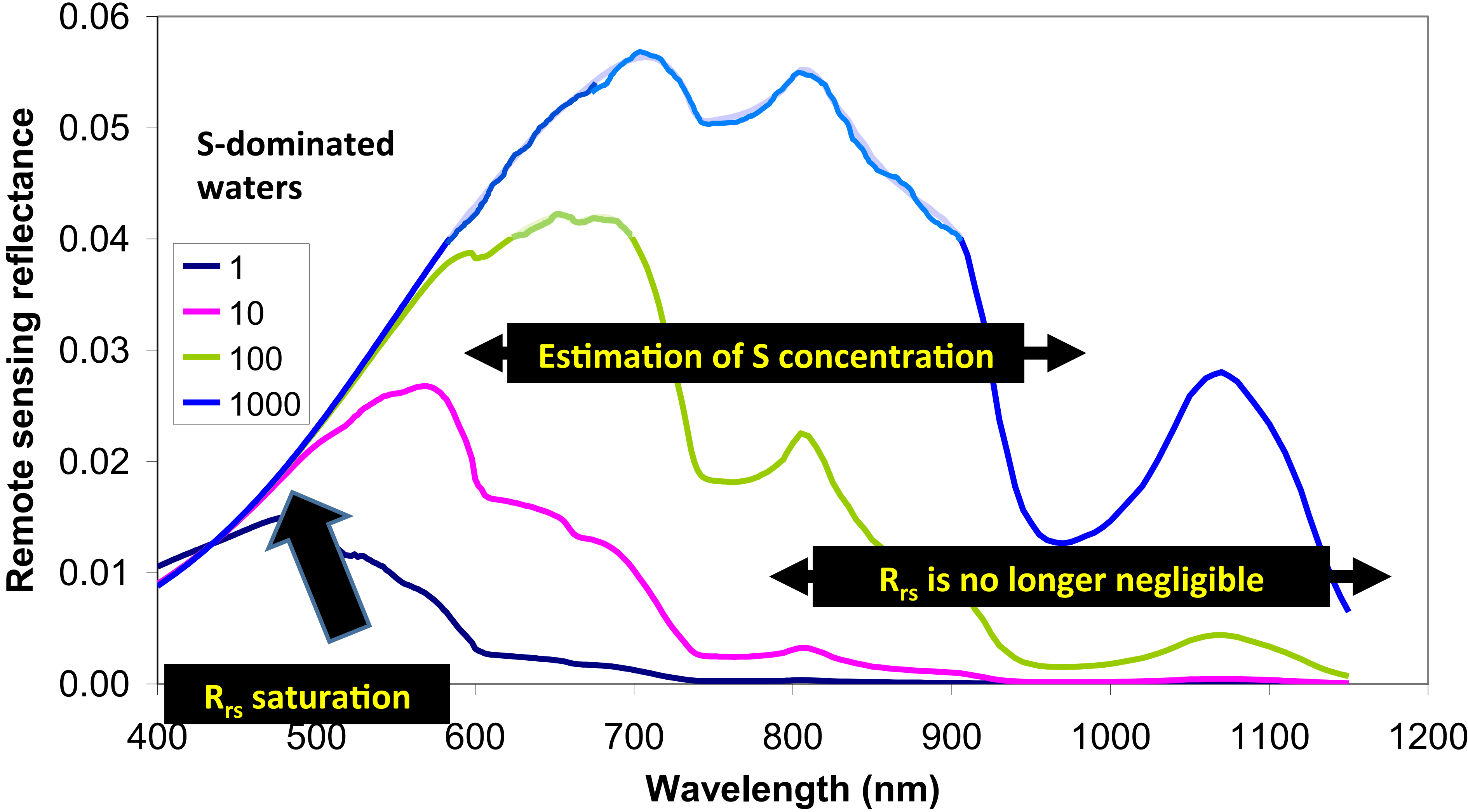
1. Spectral signatures



- **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)



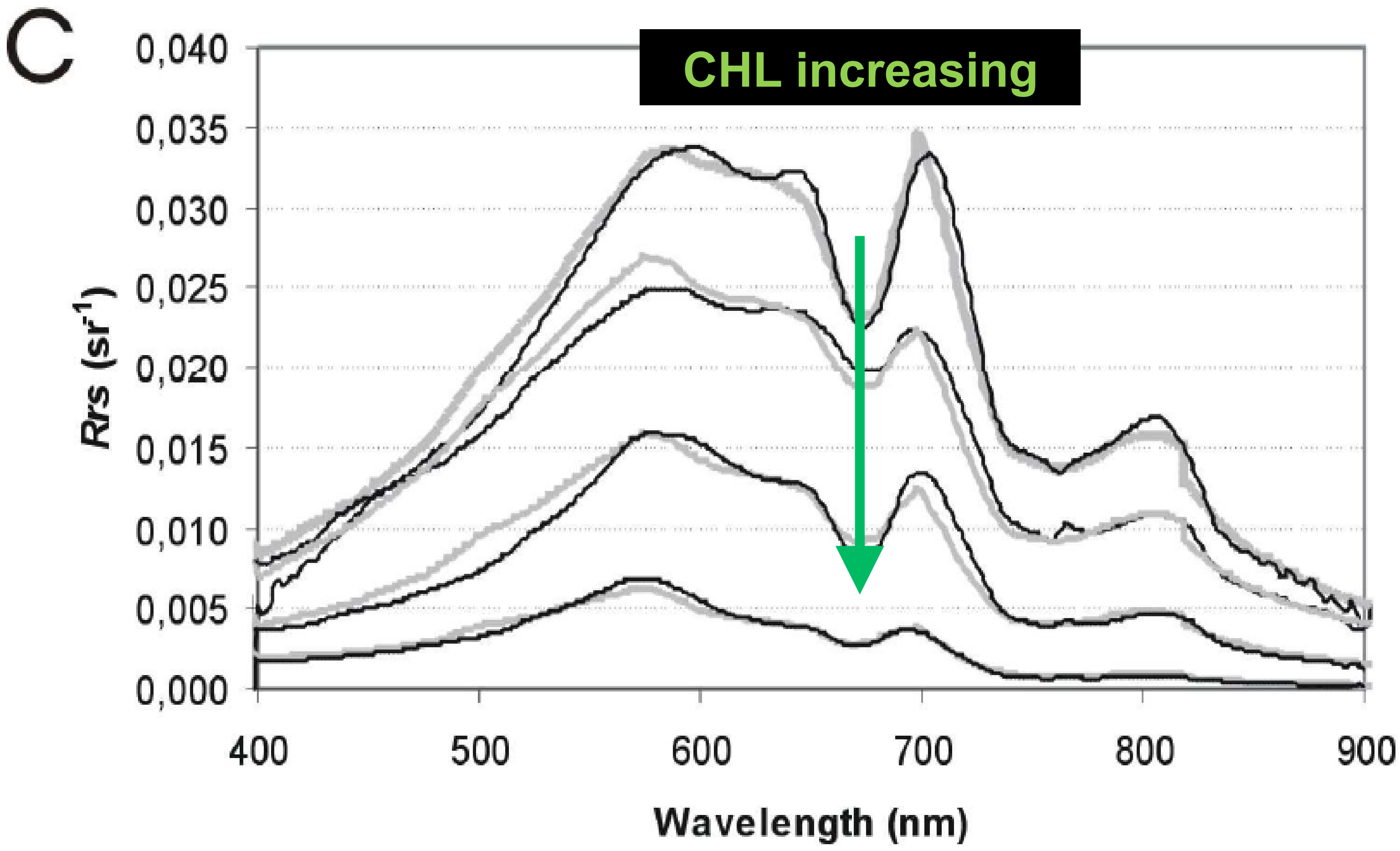
S-dominated waters

Estimation of S concentration

R_{rs} is no longer negligible

R_{rs} saturation

1. Spectral signatures

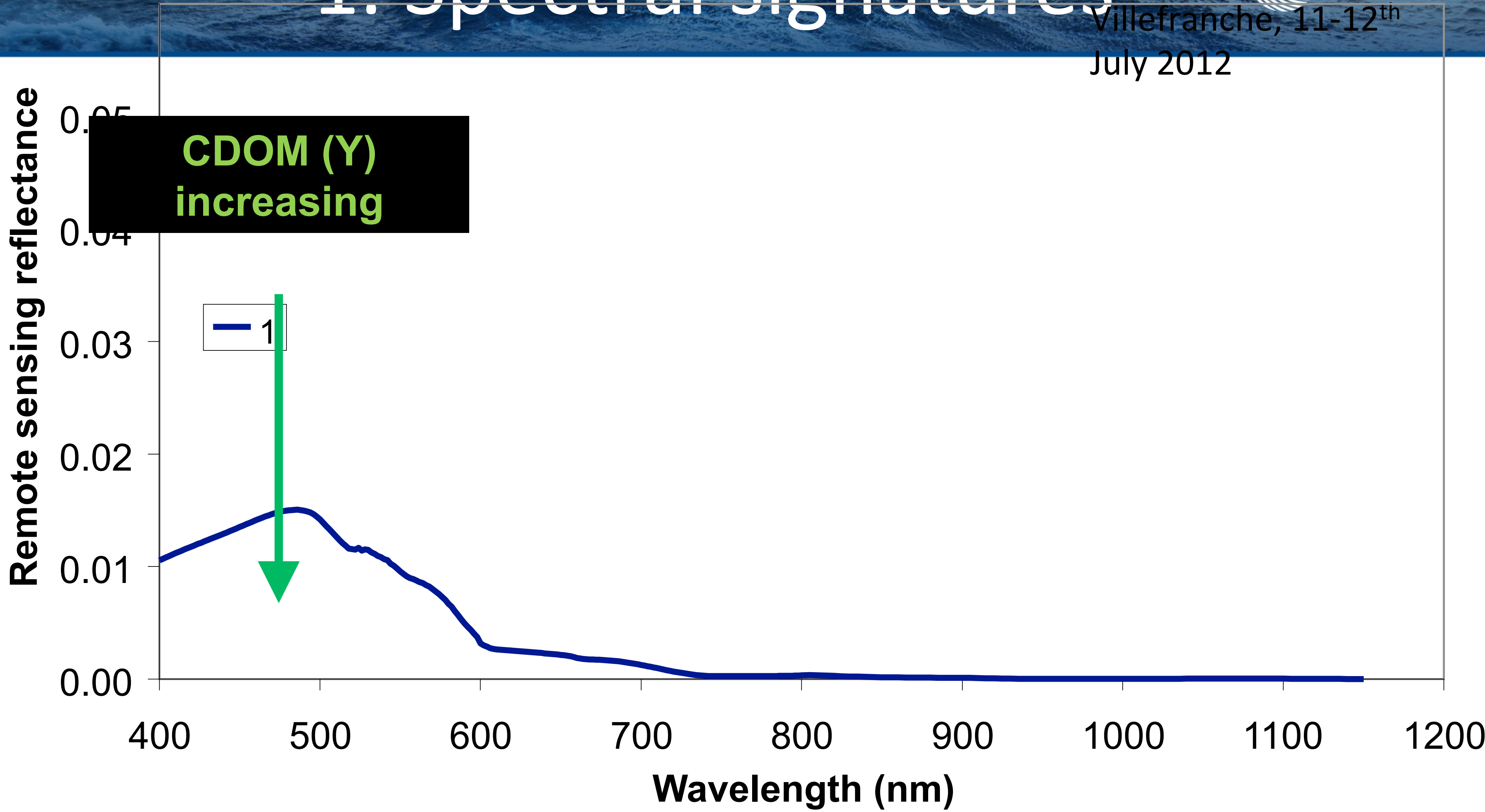


CHL increasing

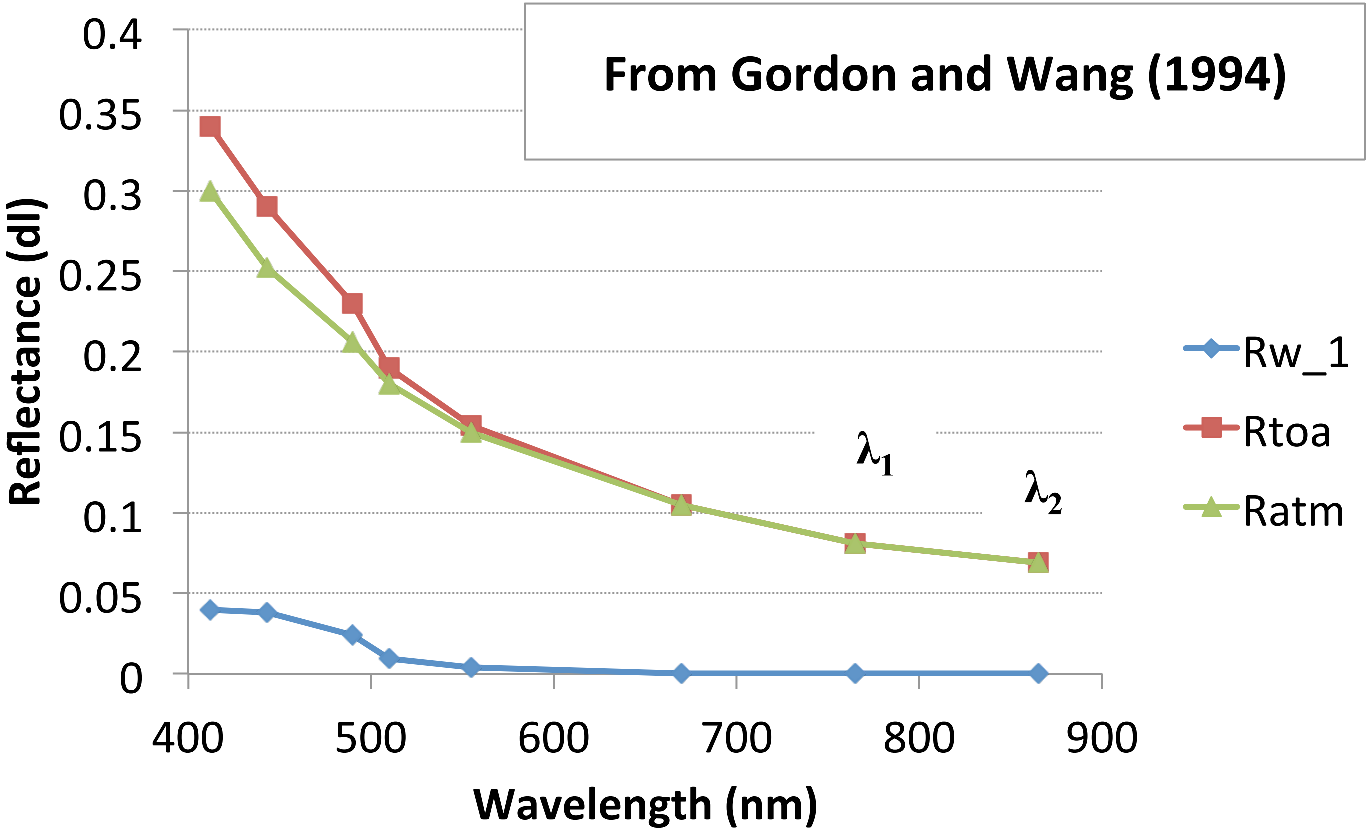
➔ **In turbid (absorbing and scattering) waters, light absorption by Chla at 443 nm disappears but light absorption by Chla is is clearly detecetd**

1. Spectral signatures

Villefranche, 11-12th July 2012



2. Atmospheric corrections

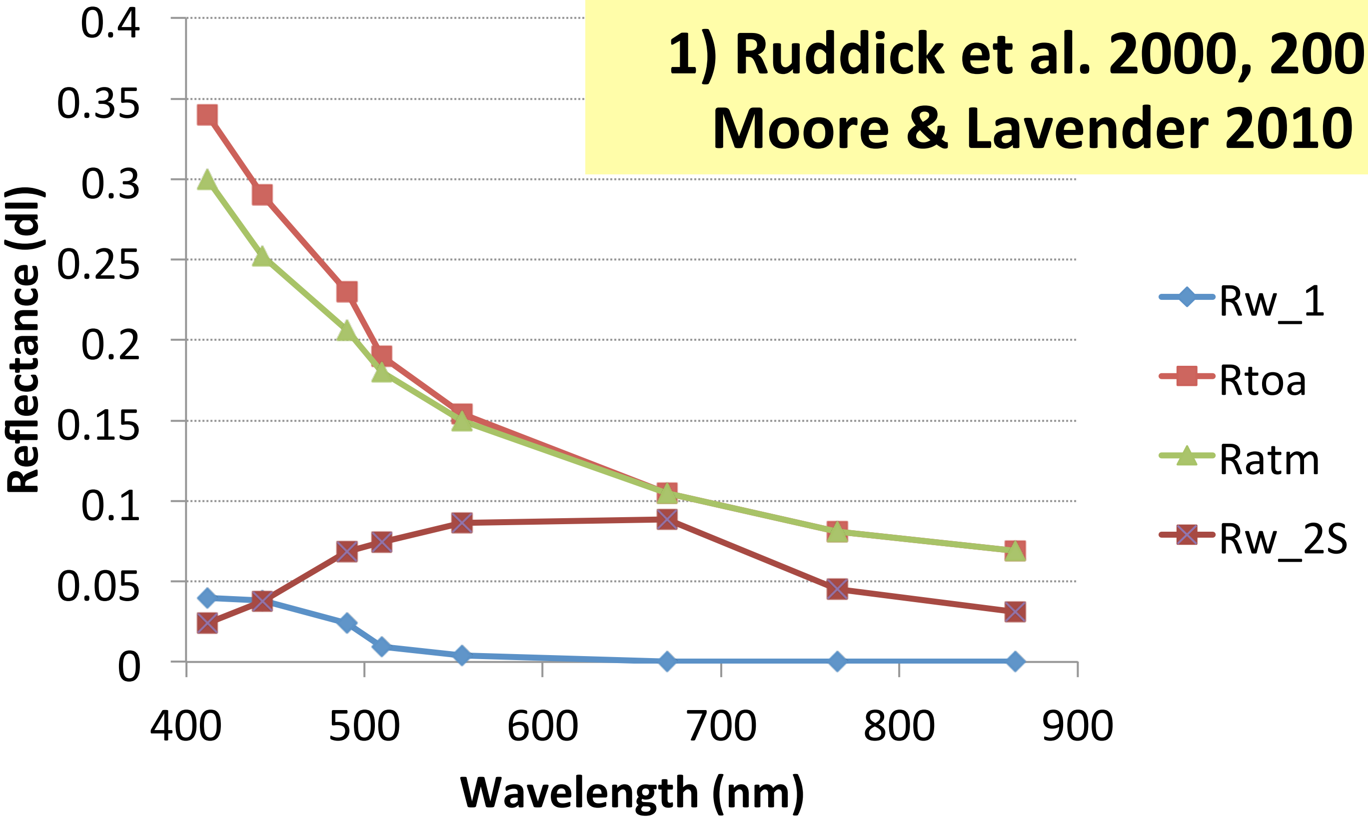


$$Rtoa(\lambda) = \boxed{Rr(\lambda)} + Rra(\lambda) + t \times Rw(\lambda), \qquad \varepsilon(\lambda_1,\lambda_2) = Rra(\lambda_1) / Rra(\lambda_2) = (\lambda_1 / \lambda_2)^n$$

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



1) Ruddick et al. 2000, 2006
Moore & Lavender 2010

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

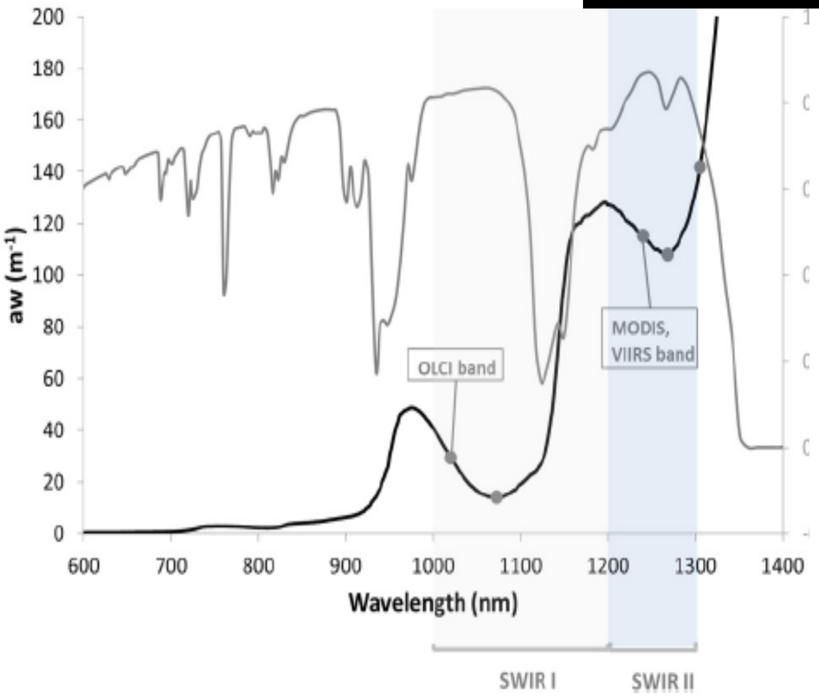
Light absorption and scattering by air molecules (Rayleigh) (LUT)

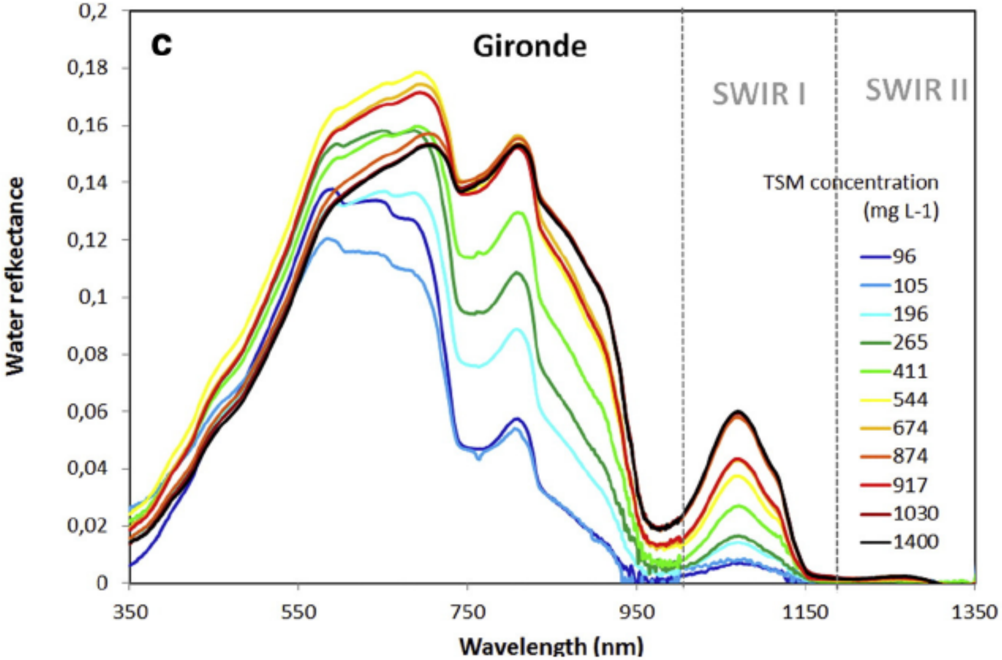
Pixel-by-pixel iterations to fit Ratm(λ_1,λ_2)

2. Atmospheric corrections

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

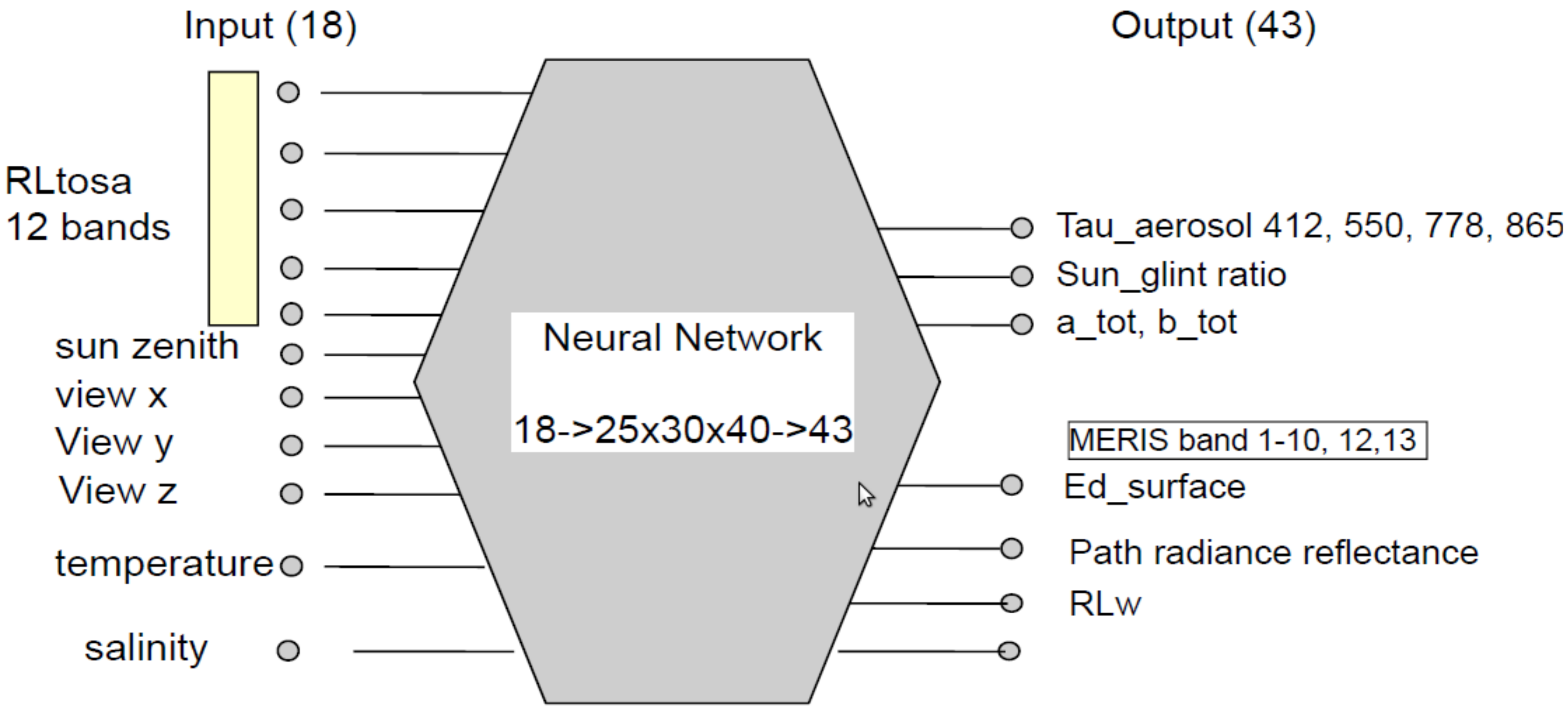
Knaeps et al. 2015





(*) ➔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)



Input (18)

RLtosa
12 bands

sun zenith
view x
View y
View z
temperature
salinity

Neural Network

18->25x30x40->43

Output (43)

Tau_aerosol 412, 550, 778, 865
Sun_glint ratio
a_tot, b_tot

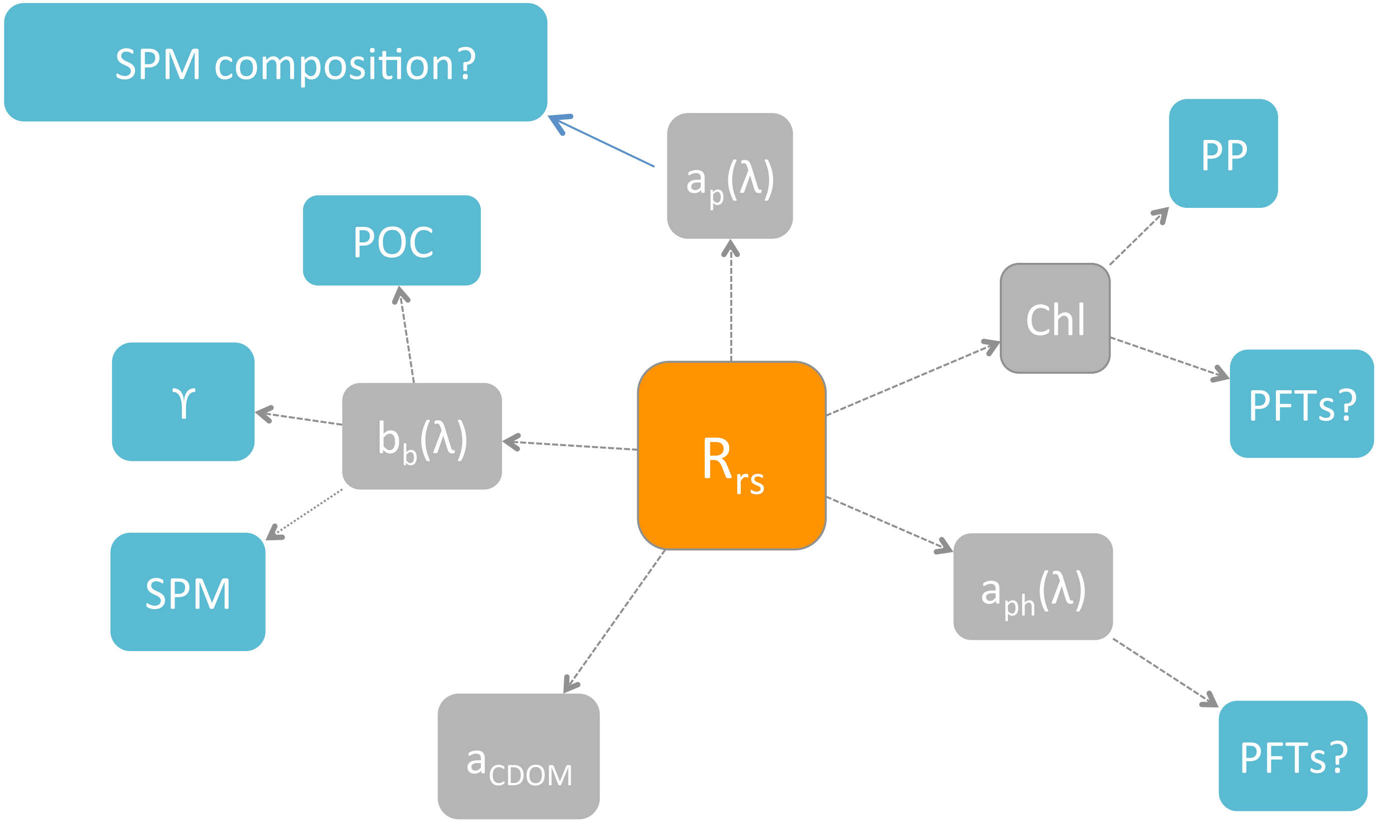
MERIS band 1-10, 12,13

Ed_surface
Path radiance reflectance
RLw

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

For each water type

3. Products and inversion algorithms



SPM composition?

$a_p(\lambda)$

PP

POC

Chl

ϒ

$b_b(\lambda)$

R_{rs}

PFTs?

SPM

$a_{ph}(\lambda)$

a_{CDOM}

PFTs?

(SPM = S + Chl)

3. Inversion algorithms

1) Empirical

based on field (and satellite) data

2) Semi-analytical

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

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

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

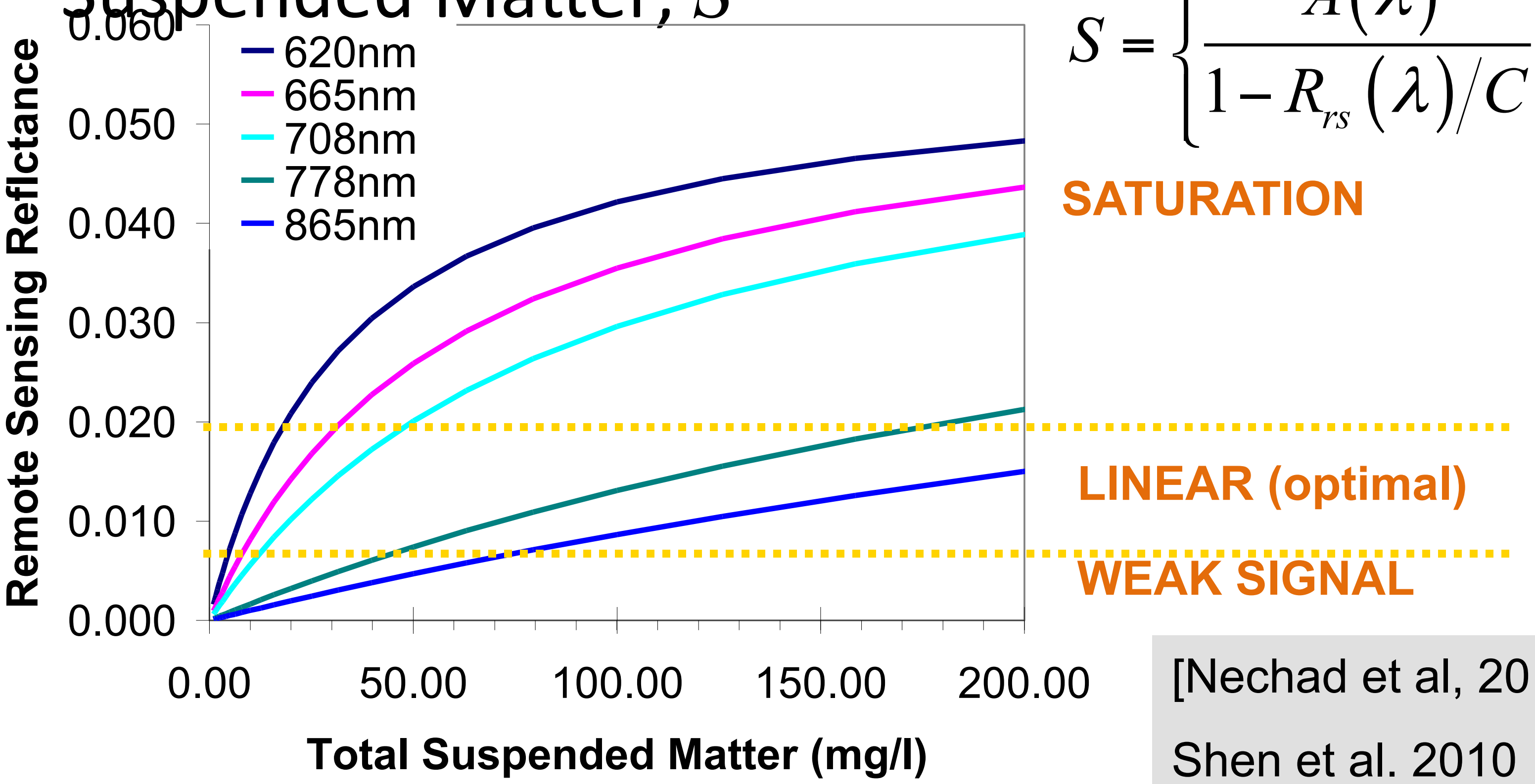
3) Neural Network

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

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



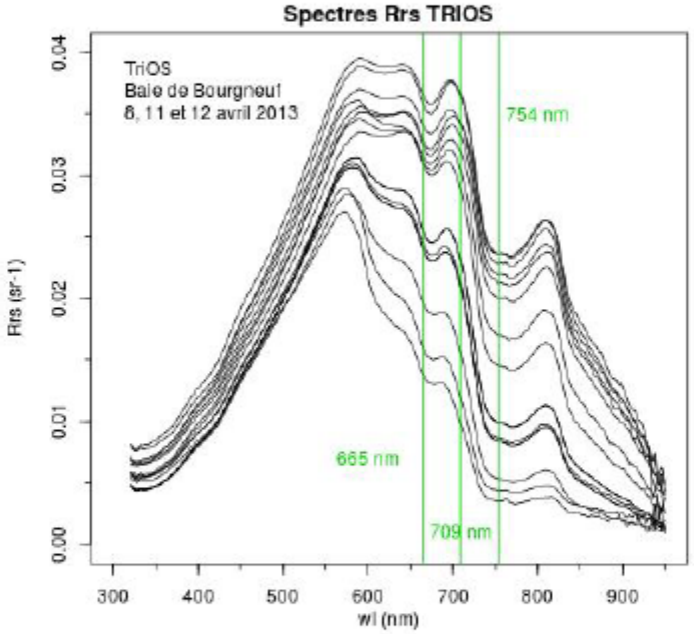
[Nechad et al, 2010]

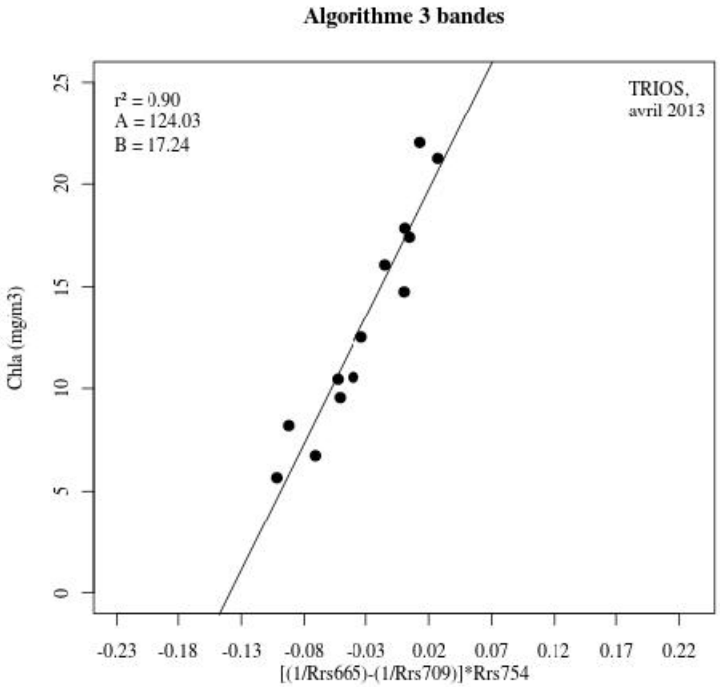
Shen et al. 2010

Doxaran et al. 2002-2009

3. Chl inversion algorithms

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





D"après Gitelson et al, 2008

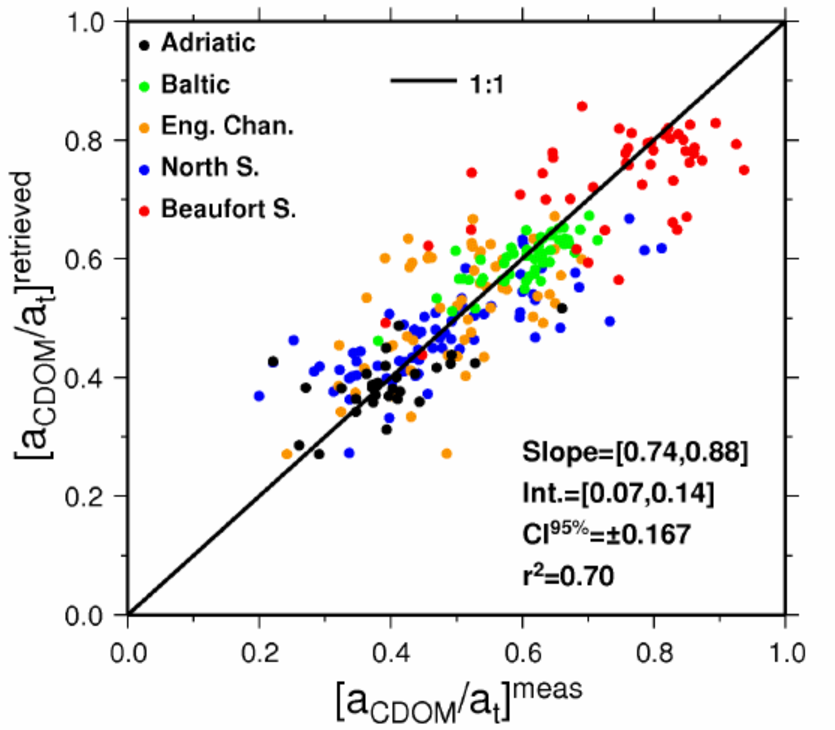
➔ Use of the second absorption peak of Chla (675 nm)

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.

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

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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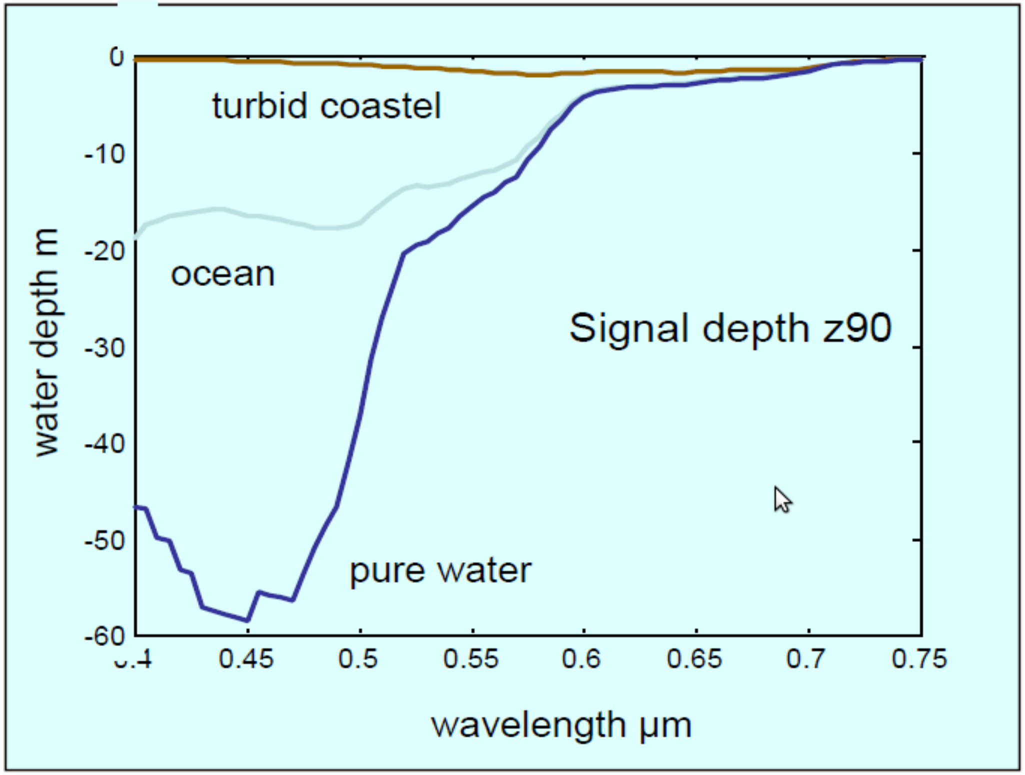
But optical depth is a limit of ocean colour satellite observations

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/