Atmospheric correction over turbid waters

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Rationale

- **15 years of continuous ocean satellite data:**
  - ~13 years for SeaWiFS
  - ~10 years for MERIS
  - ~10 years of MODIS-AQUA (and still counting)
  - VIIRS (2012-)
  - OLCI (2015-)
  - GOCI (2010-)

→ Possibility to study inter-annual and decennal variability of biogeochemical parameters in open but **also in coastal waters**

Rationale

Need for accurate atmospheric correction algorithms

→ Need to look at the existing algorithms

- Several AC developed for the past 12 years → no assessment of differences
- Future ocean color sensors: high spatial resolution, high radiometric resolution, other wavelengths

→ **Highest possibility to study coastal waters**

- ***Need for guidances on using the already developed AC*** (see number of requests on the forum of oceancolor.gsfc.nasa.gov)

Rationale

- Coastal waters more and more investigated in ocean color
- But more challenging than open ocean waters:
  - temporal & spatial variability
    - satellite sensor resolution
    - satellite repeat frequency
    - validity of ancillary data (SST, wind)
    - resolution requirements
  - Land contamination (adjacency effects)
  - non-maritime aerosols (dust, pollution)
    - region-specific models required?
    - absorbing aerosols
  - suspended sediments & CDOM
    - complicates estimation of R_{rs}(NIR)
    - complicates BRDF (f/Q) corrections
    - sensor saturation
  - shallow waters

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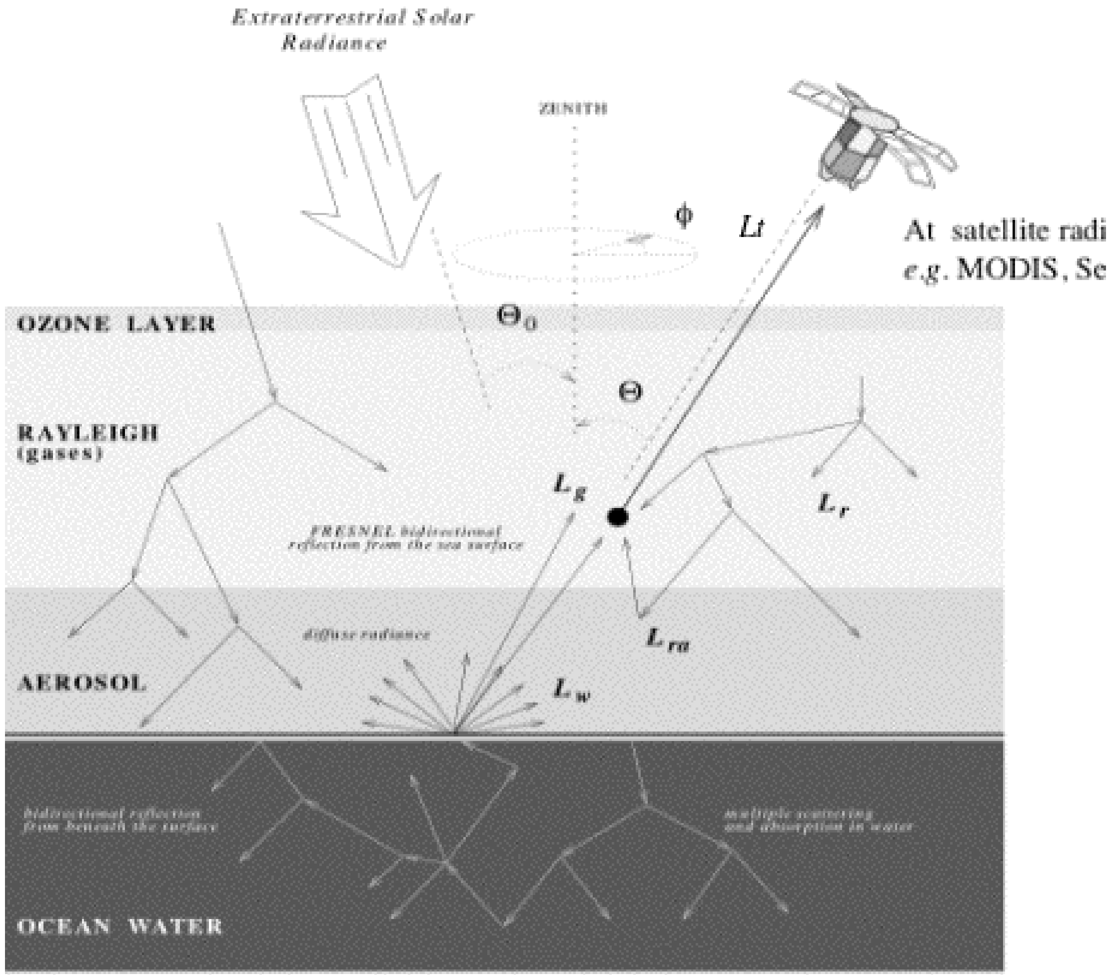
Rationale of atmospheric correction



ρ_t: total (measured)

ρ_r: Rayleigh (known)

ρ_a: aerosols (unknown)

ρ_{ra}: rayleigh-aerosols (unknown)

ρ_{wc}:whitecaps (modelled/wind)

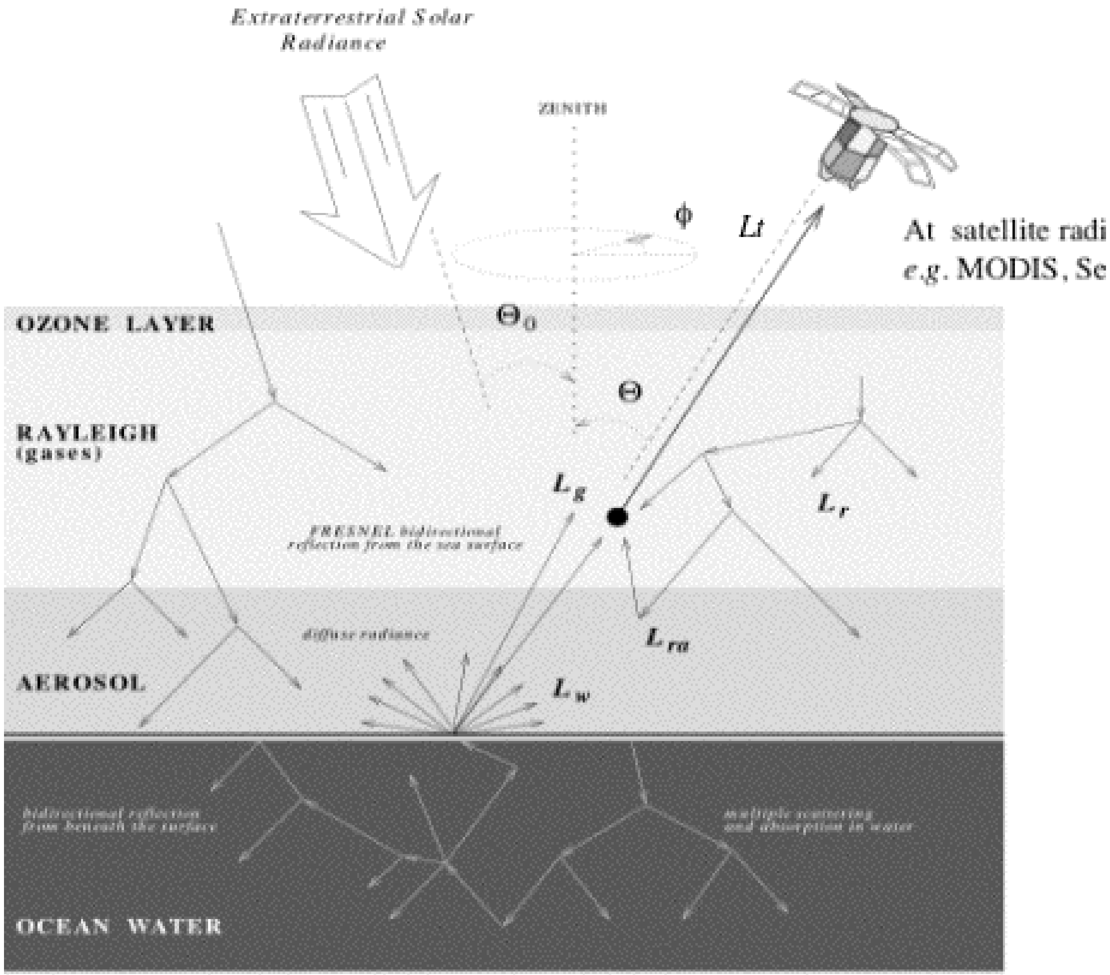
ρ_w: water (unknown, 10% of ρ_t)

$$\rho_t(\lambda) = \rho_r(\lambda) + \rho_a(\lambda) + \rho_{ra}(\lambda) + t(\lambda)\rho_{wc}(\lambda) + t(\lambda)\rho_w(\lambda) + t(\lambda)\rho_g$$

ρ_g: glitter (masked or modelled

Objectives: **5% for absolute radiances and 2% for relative reflectances**

Rationale of atmospheric correction



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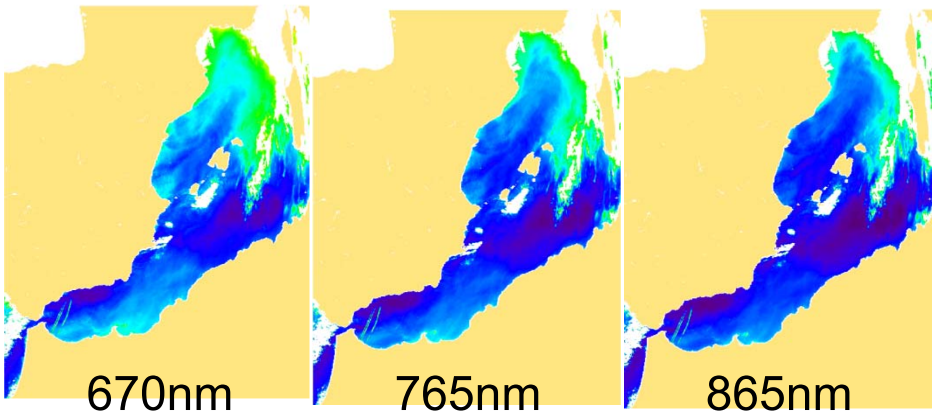
Objectives: 5% for absolute radiances and 2% for relative reflectances

Classic Black Pixel Assumption (1/2)

NIR bands

$\rho_t(\lambda)-\rho_r(\lambda)= \rho_{ra}(\lambda)+ \rho_a(\lambda) = \rho_A(\lambda)$



Hypothesis: absorbing ocean

→ $\rho_w(\lambda)$ negligeable

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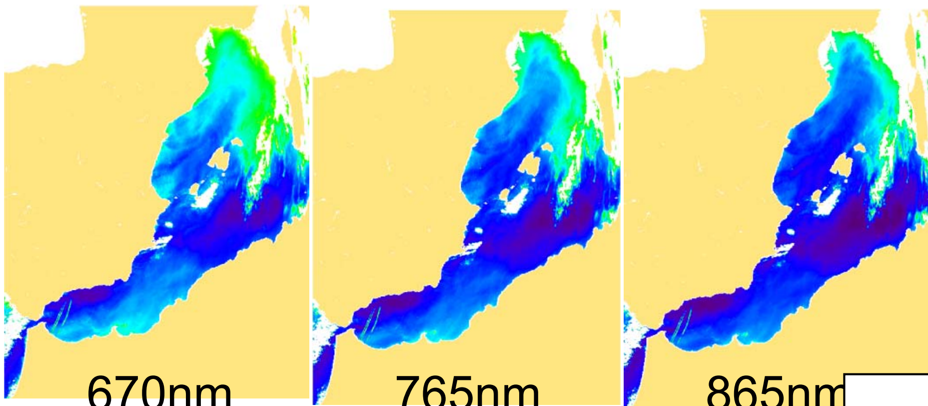

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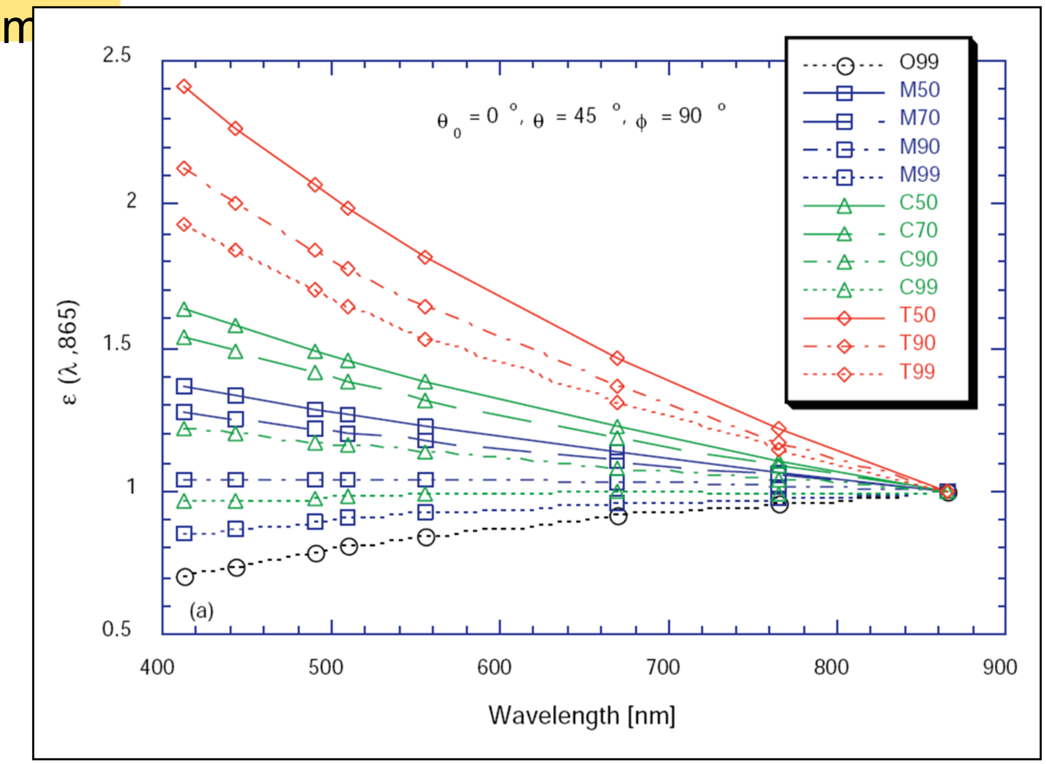
calculate aerosol ratios, ε :

$$\varepsilon(748,869) \sim \frac{\rho_a(748)}{\rho_a(869)}$$

$$\varepsilon(\lambda,869) \sim \frac{\rho_a(\lambda)}{\rho_a(869)}$$



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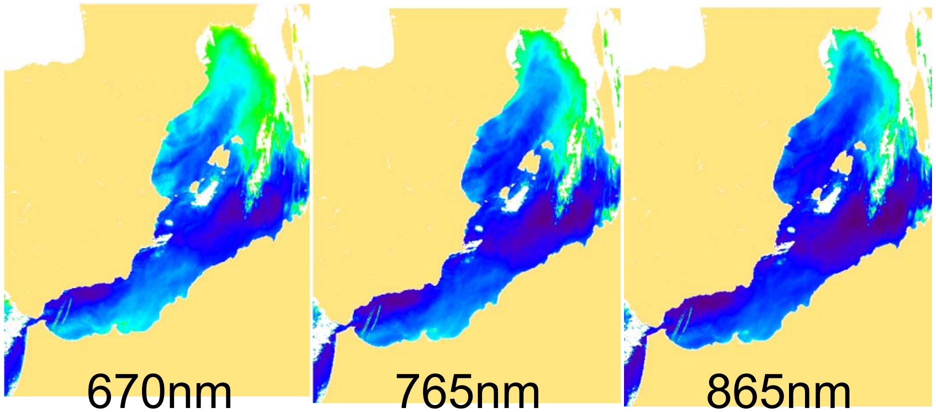


Hypothesis: absorbing ocean

→ $\rho_w(\lambda)$ negligeable

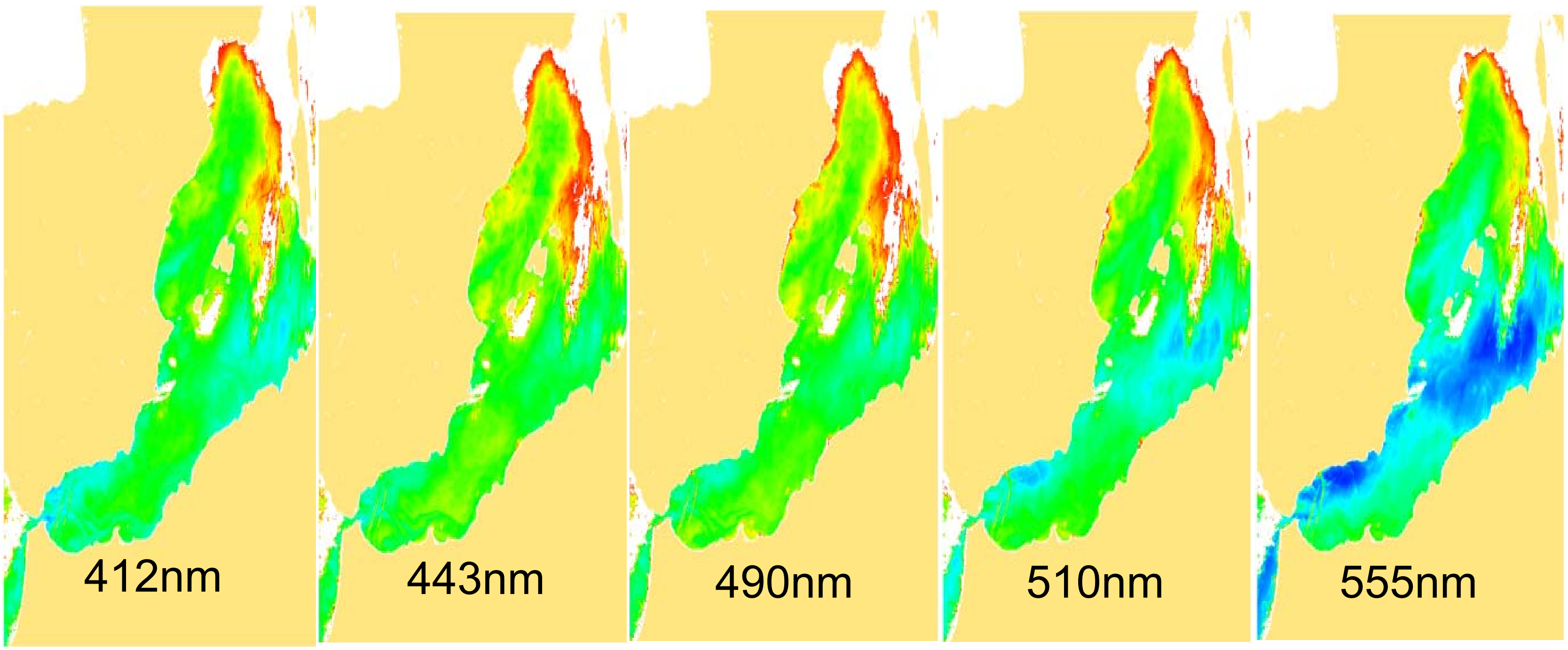
Determination of aerosols models

τ, α

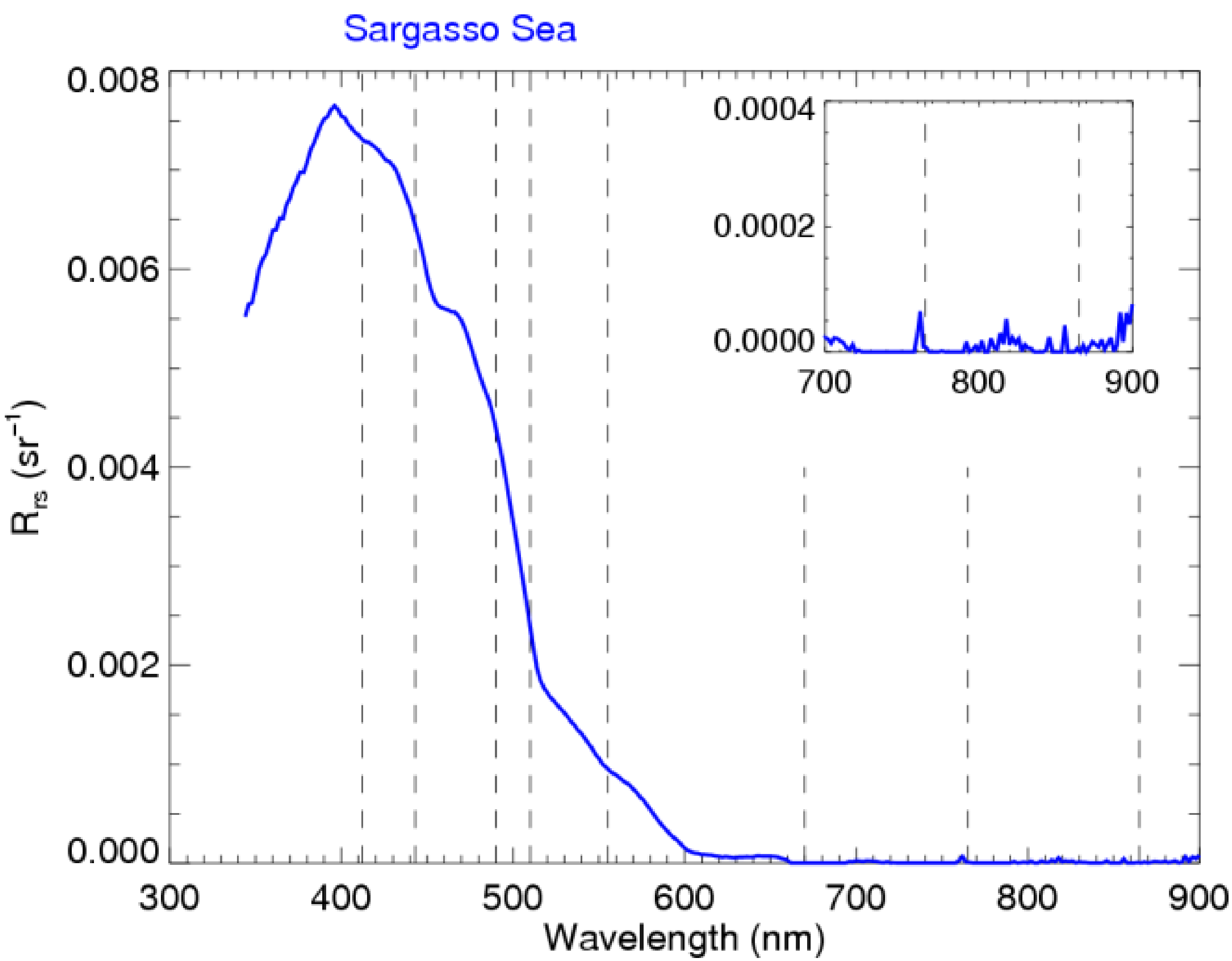
→ Calculation of ρ_A and t

Classic Black Pixel Assumption (2/2)

Visible bands, $(\rho_t(\lambda)-\rho_r(\lambda)-\rho_A(\lambda))/t(\lambda)= \rho_w(\lambda)$



no one uses the “black pixel assumption” anymore



Courtesy of PJ Werdell

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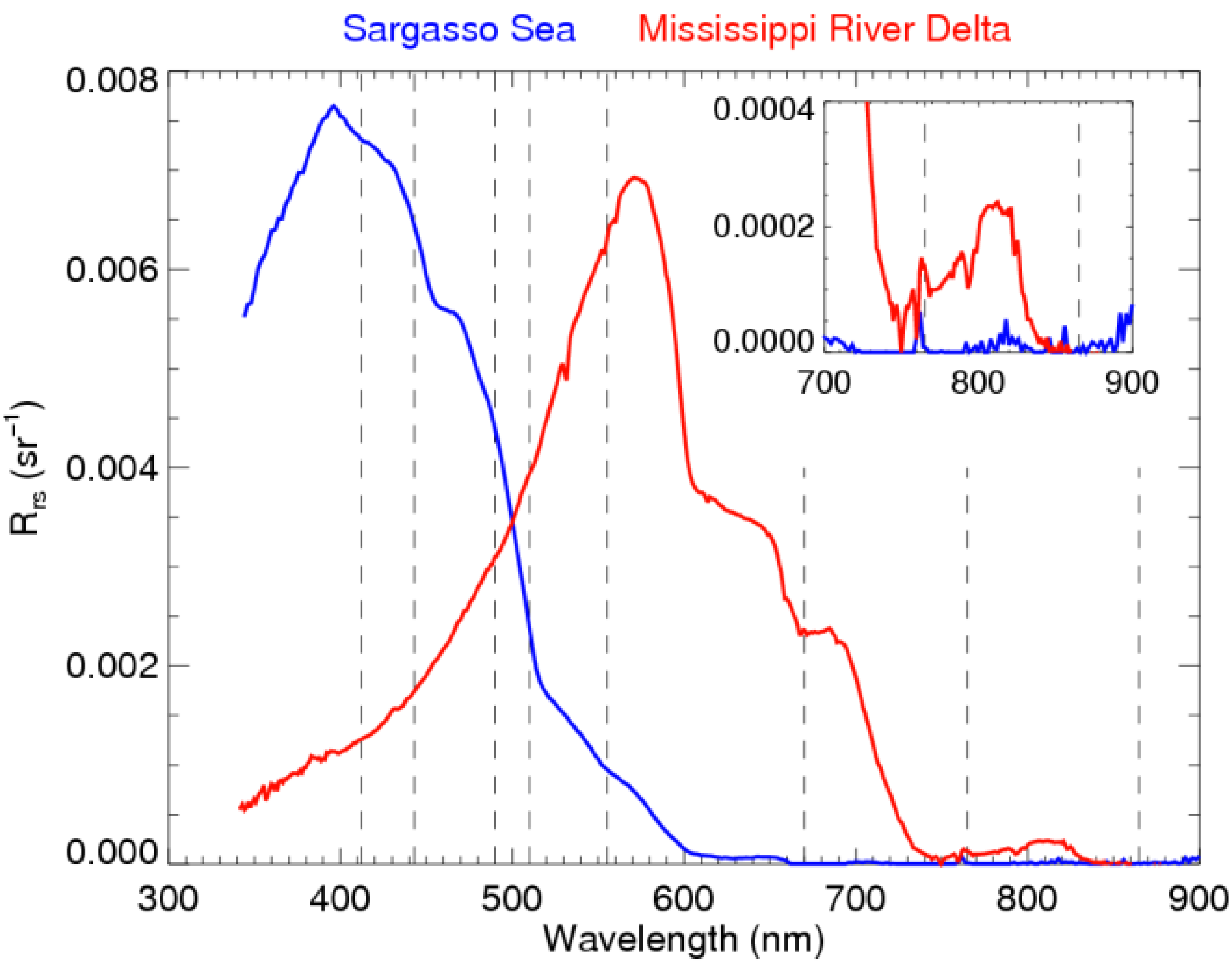

Courtesy of PJ Werdell

Approaches to account for R_{rs}(NIR) > 0 sr^{-1} overlap

many approaches exist, here are a few examples:

- assign aerosols (ε) and/or water contributions (Rrs(NIR))

  e.g., Hu et al. 2000, Ruddick et al. 2000

- use shortwave infrared bands

  e.g., Wang & Shi 2007

- use of UV bands

  He et al., 2012

- correct/model the non-negligible R_{rs}(NIR)

Lavender et al.	2005	MERIS
Bailey et al.	2010	used in SeaWiFS Reprocessing 2010
Moore et al.	1999	MERIS/OLCI
Wang et al.	2012	GOCI

- use a coupled ocean-atmosphere optimization/inversion

  e.g., Chomko & Gordon 2001; Stamnes et al. 2003; Jamet et al., 2005; Ahn and Shanmugam, 2007; Doerffer & Schiller, 2008; Kuchinke et al. 2009; Schroeder et al., 2007; Steinmetz et al., 2010; Brajard et al., 2012

Courtesy of Jeremy Werdell

Evaluation

- Evaluation of AC already exists in journals:
  - SeaWiFS: Zibordi et al. (2006, 2009); Banzon et al., 2009; Jamet et al. (2011);
  - MODIS-AQUA: Zibordi et al. (2006, 2009); Wang et al. (2009), ;Werdell et al., 2010; Goyens et al. (2013)
  - MERIS: Zibordi et al. (2006, 2009); Cui et al. (2010); Kratzer et al. (2010); Melin et al. (2011)

- **BUT** most of the time only about one specific AC (with eventually comparisons with the official AC)

- Only few papers on round-robin

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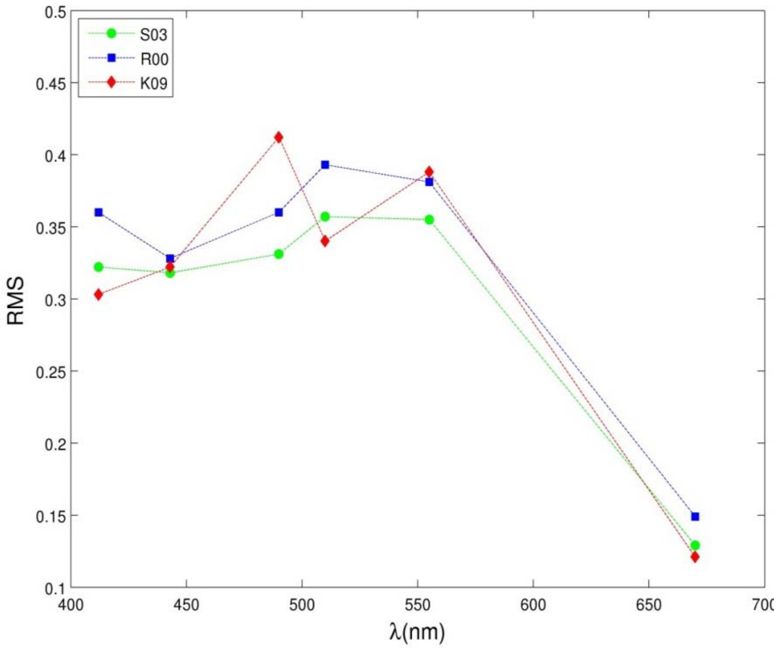
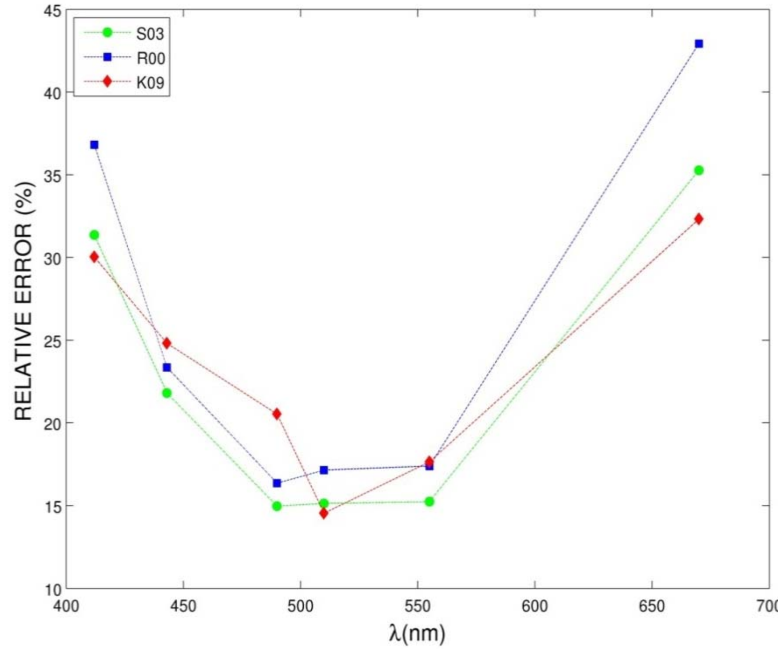
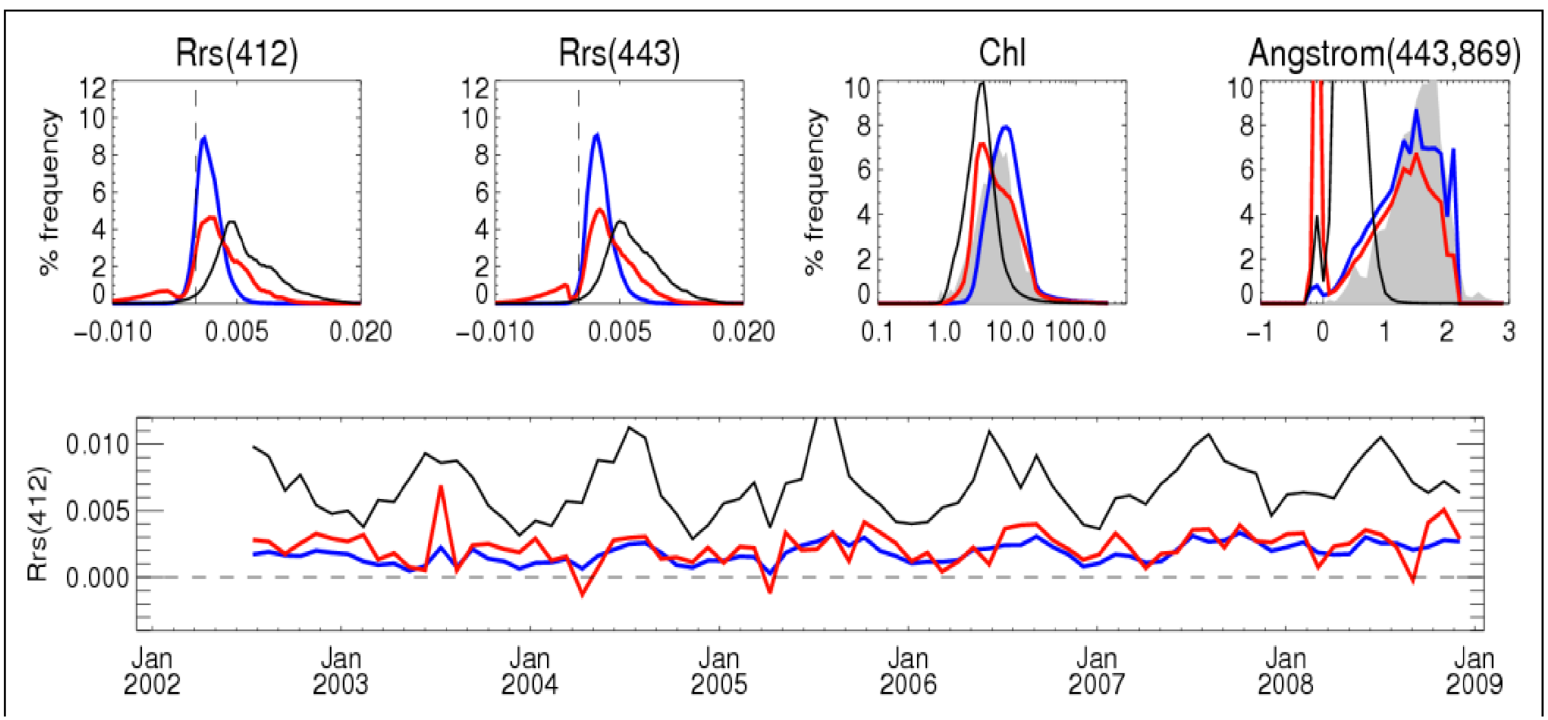




SeaWIFS

Jamet et al., 2011



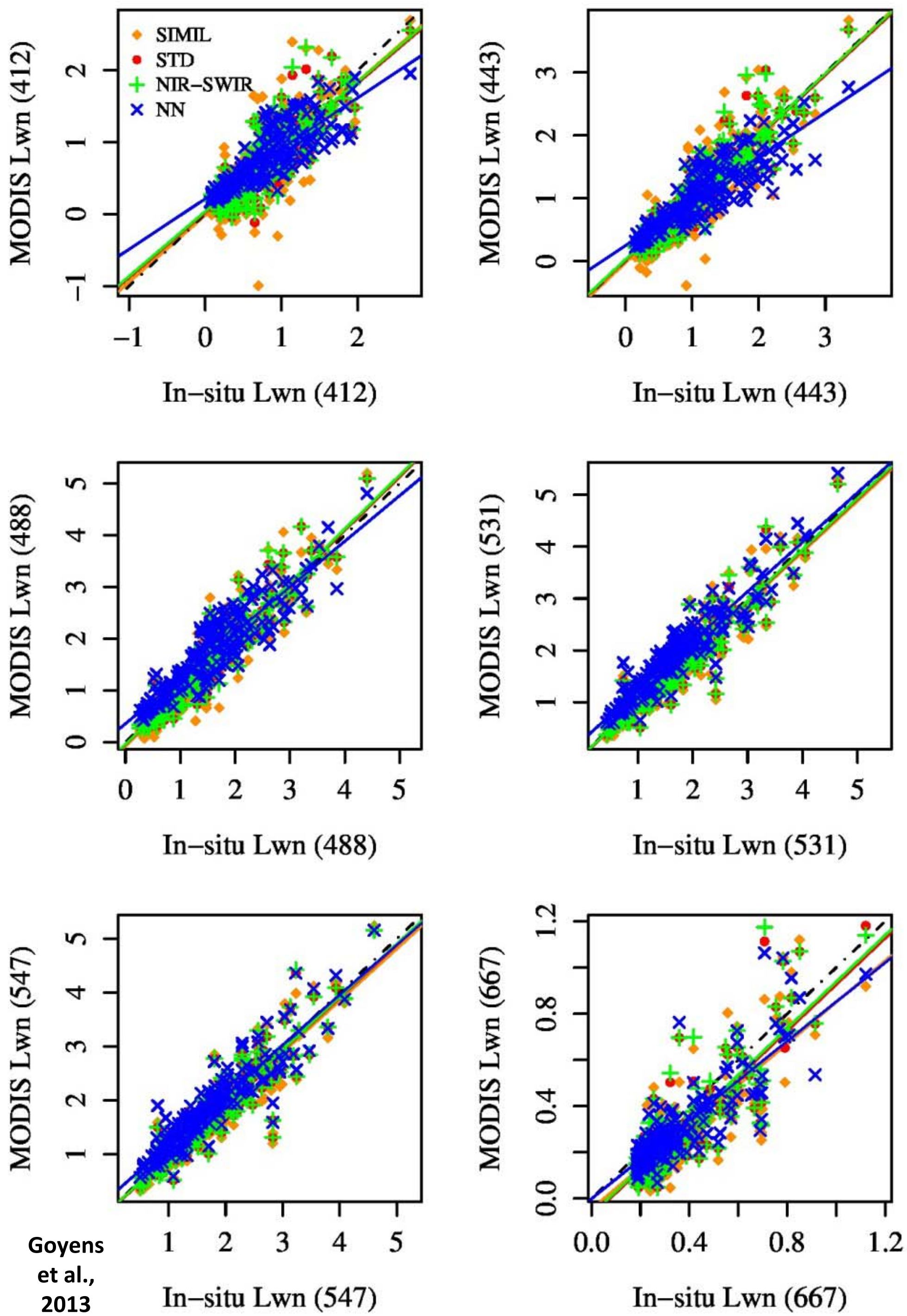
MODIS-AQUA

NIR

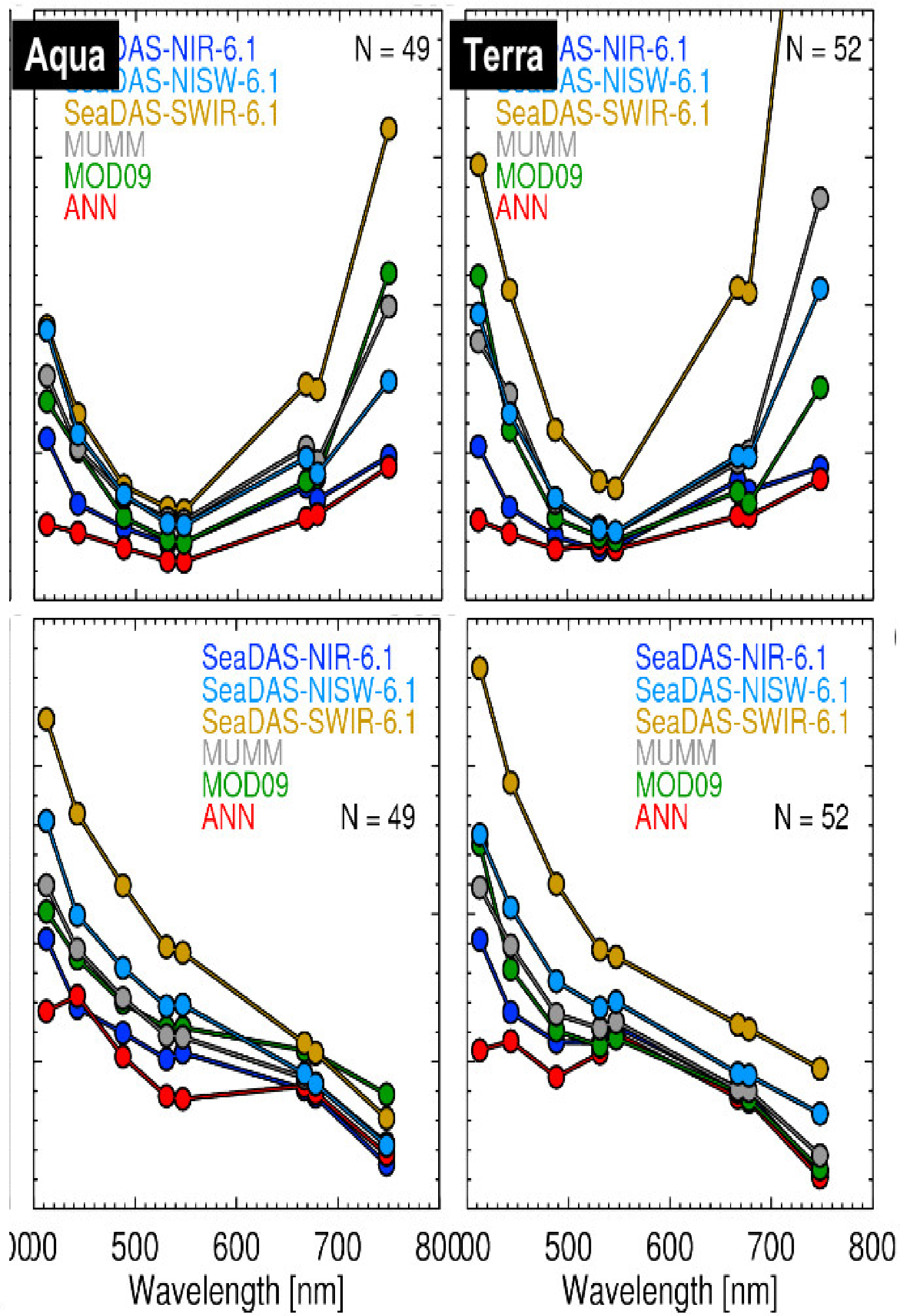
NIR-SWIR 2009

MUMM

Courtesy of Jeremy Werdell



Goyens et al., 2013



Courtesy of Thomas Schroeder

	R	Intercept	Slope	RE	RMSE	Bias	$L_{wn}<0$
nLw(412)							
SIMIL	0.75	**−0.015**	**0.93**	45	0.381	−11	15
STD	**0.86**	0.021	0.90	35	0.262	−2	2
NIR-SWIR	0.84	0.036	0.90	36	0.271	**1**	1
NN	0.81	0.214	0.70	**31**	**0.270**	11	**0**
nLw(443)							
SIMIL	0.86	−0.025	**1.00**	30	0.357	−4	4
STD	**0.93**	**0.009**	0.98	**21**	**0.241**	**1**	0
NIR-SWIR	0.92	0.023	0.99	21	0.254	3	0
NN	0.86	0.246	0.71	24	0.323	3	0
nLw(488)							
SIMIL	0.92	−0.075	**1.04**	20	0.351	−3	0
STD	**0.95**	−0.052	**1.04**	**13**	**0.263**	**−0.2**	0
NIR-SWIR	0.95	**−0.04**	**1.04**	13	0.274	1	0
NN	0.91	0.357	0.88	27	0.385	20	0
nLw(531)							
SIMIL	0.92	−0.022	0.98	14	0.32	−4	0
STD	**0.95**	−0.024	**0.99**	**11**	**0.269**	−3	0
NIR-SWIR	0.94	**−0.015**	**0.99**	**11**	0.273	**−2**	0
NN	0.94	0.273	0.954	19	0.338	16	0
nLw(547)							
SIMIL	0.91	**−0.003**	0.96	14	0.329	−4	0
STD	**0.93**	−0.02	0.98	**11**	**0.286**	−3	0
NIR-SWIR	**0.93**	−0.011	**0.98**	**11**	0.288	**−2**	0
NN	0.92	0.232	0.93	15	0.315	10	0
nLw(667)							
SIMIL	0.81	−0.046	0.90	33	0.136	−26	0
STD	**0.87**	−0.075	**1.00**	30	0.12	−25	0
NIR-SWIR	0.86	−0.07	**1.00**	30	0.121	−23	0
NN	0.85	**−0.001**	0.85	**22**	**0.107**	**−15**	0

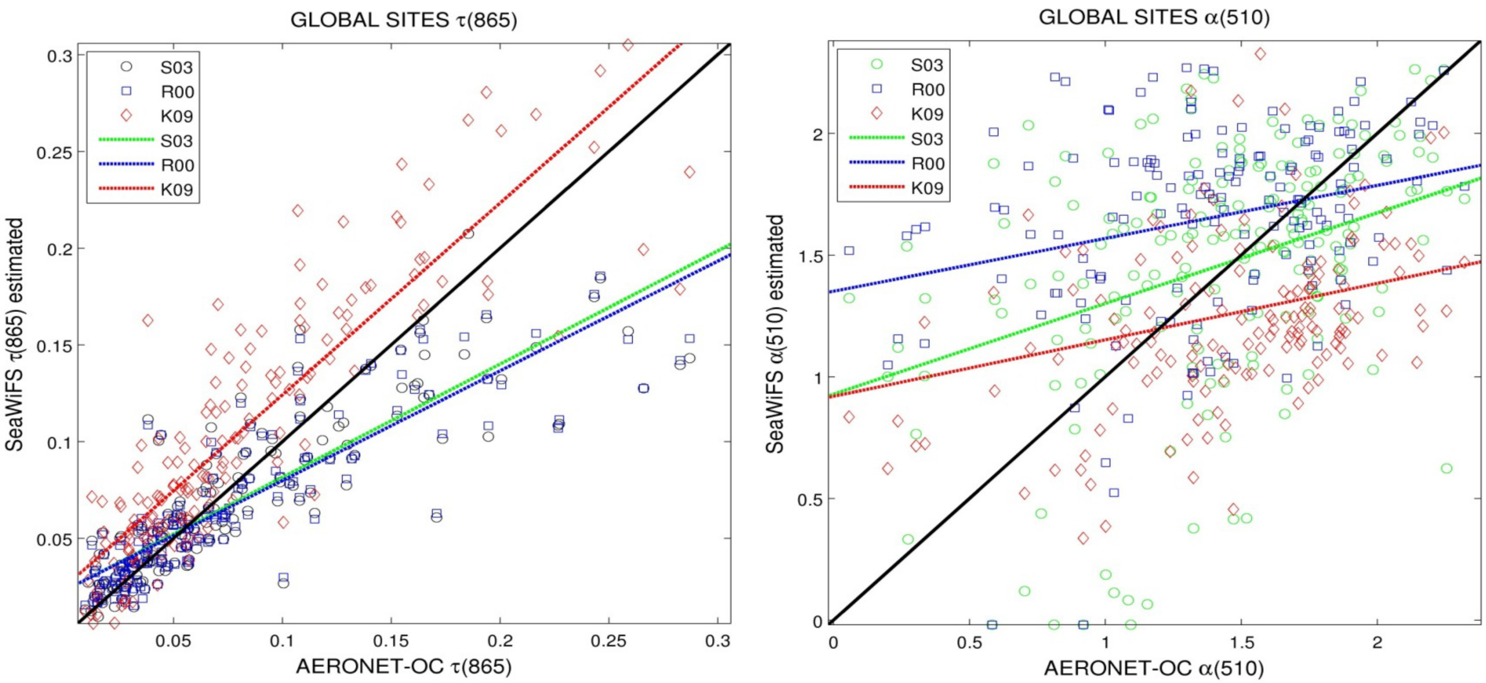
Goyens et al., 2013

Table 3
Statistical results for the retrieved values of $nL_w(\lambda)$ obtained with S03, R00 and K09.

	RMS	Relative error (%)	R	Slope	Intercept
$nL_w(412)$					
S03	0.322	31.36	*0.72*	*1.02*	*−0.08*
R00	0.360	36.81	0.68	0.85	−0.08
K09	*0.303*	*30.02*	0.68	0.86	0.004
nLw(443)					
S03	*0.318*	*21.81*	0.81	*1.00*	*−0.02*
R00	0.328	23.35	0.79	0.89	−0.02
K09	0.322	24.81	*0.85*	0.76	0.01
nLw(490)					
S03	*0.331*	*14.97*	*0.87*	*0.94*	*0.02*
R00	0.360	16.36	0.85	0.86	0.04
K09	0.412	20.53	0.85	1.07	0.08
nLw(510)					
S03	0.357	15.13	*0.85*	*0.90*	*0.03*
R00	0.393	17.15	0.83	0.81	0.09
K09	*0.340*	*14.54*	0.82	0.89	0.14
nLw(555)					
S03	*0.355*	*15.24*	*0.80*	*0.93*	*0.01*
R00	0.381	17.39	0.75	0.81	0.11
K09	0.388	17.64	0.73	0.94	0.07
nLw(670)					
S03	0.129	35.27	0.68	0.85	−0.03
R00	0.149	42.92	0.60	0.58	0.01
K09	*0.121*	32.32	*0.68*	0.61	0.03

The numbers in italic represent the best statistical results.

Jamet et al., 2011



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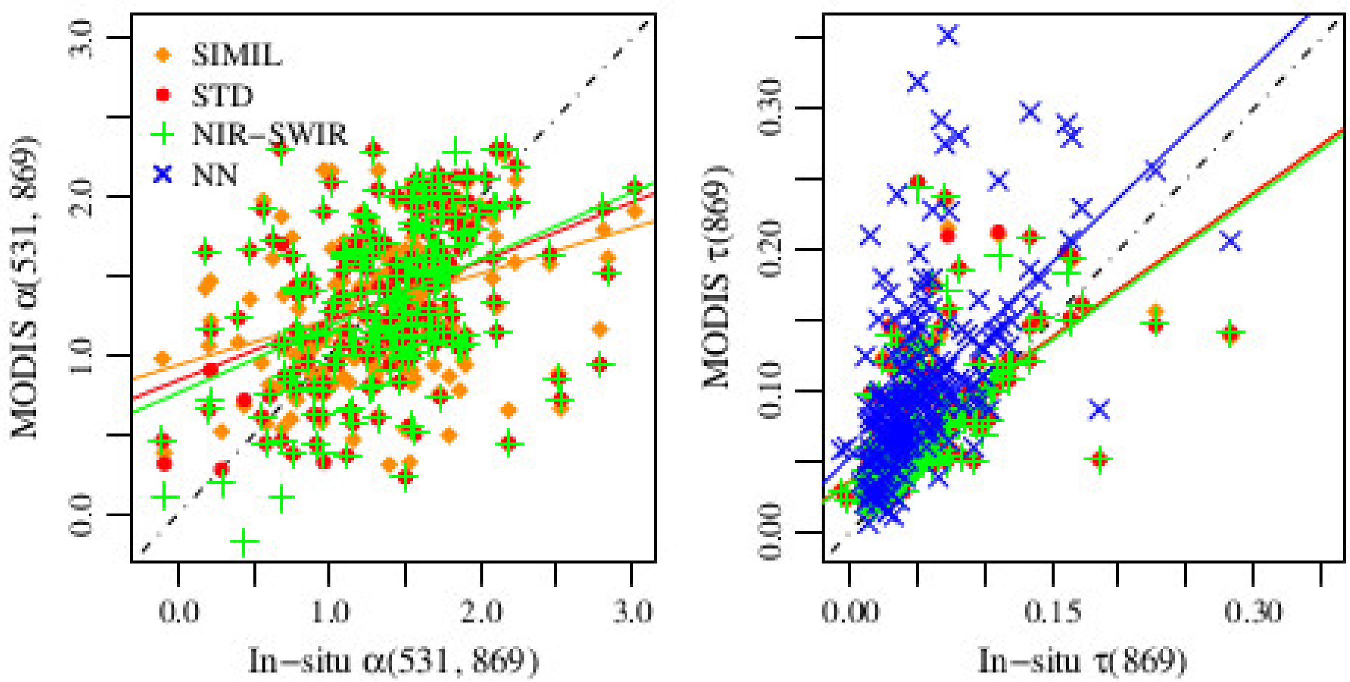
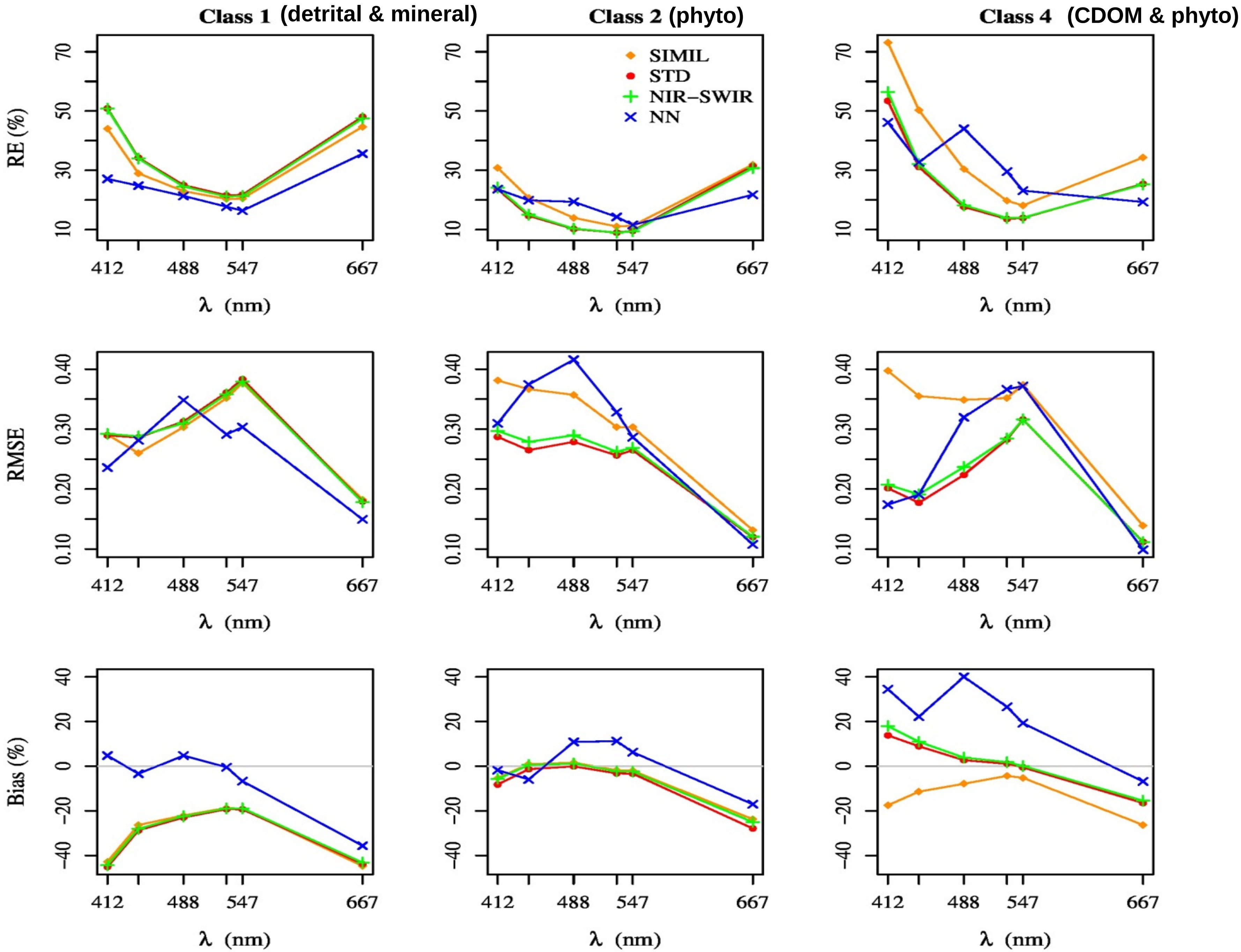


Goyens et al., 2013



Goyens et al., 2013; Vantrepotte et al., 2012

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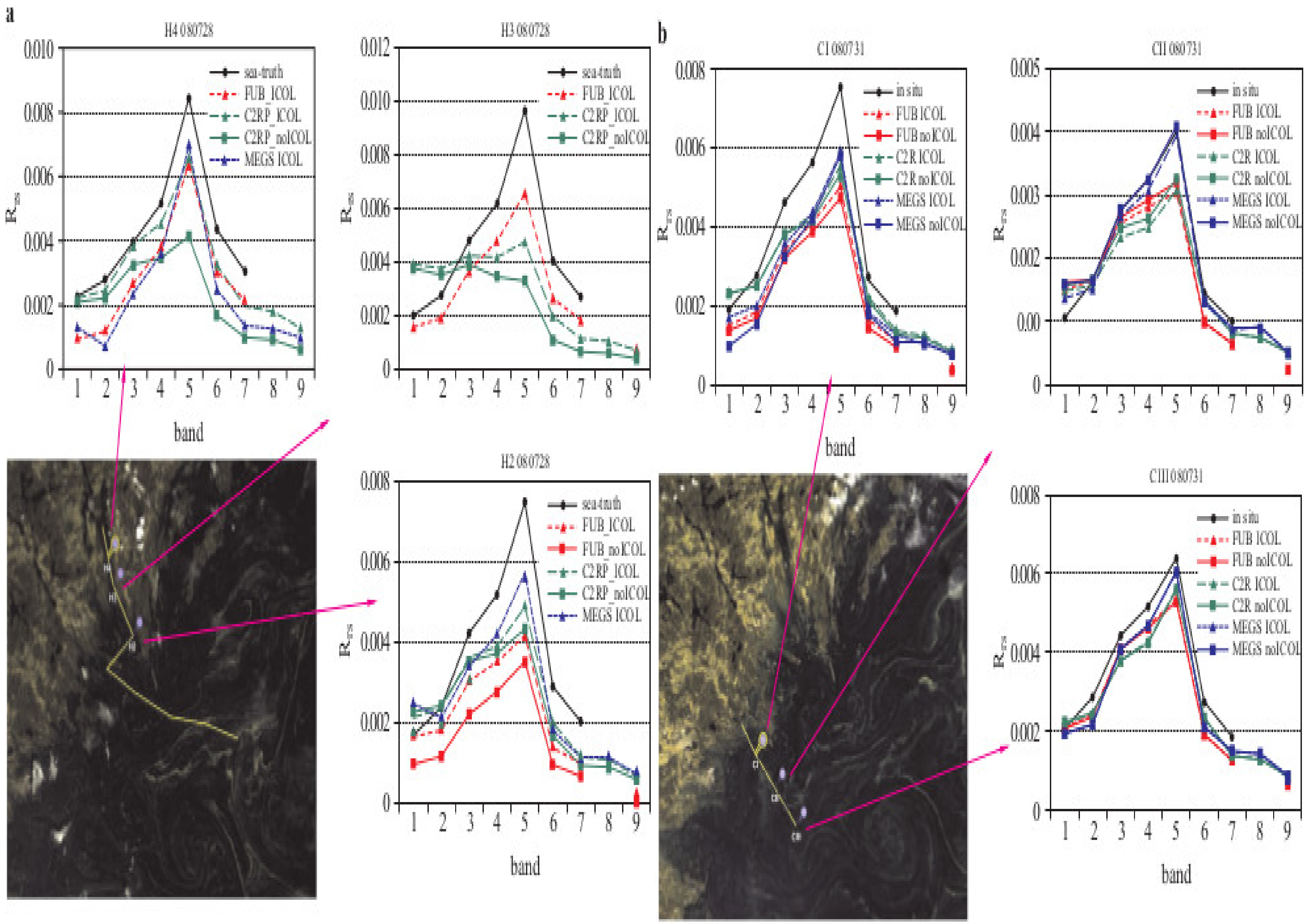


Kratzer et al., 2010

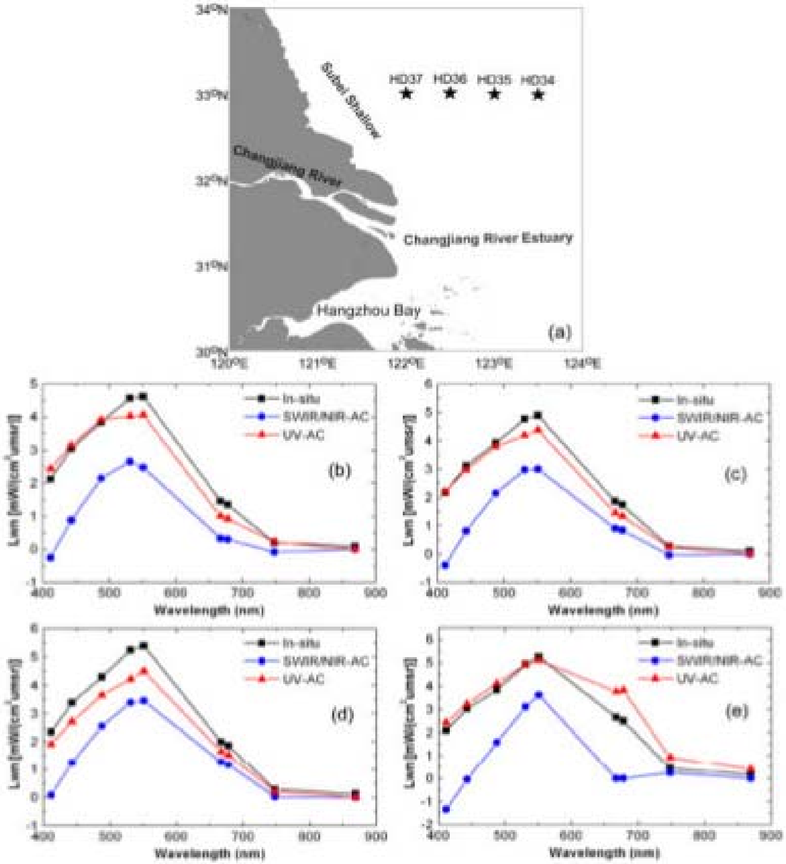


Fig. 6. Comparisons between satellite retrieved and in situ measured normalized water-leaving radiances. (a) Locations of the in situ measurement of normalized water-leaving radiances on 5 April 2003 (marked as stars); (b) comparison at station HD34; (c) comparison at station HD35; (d) comparison at station HD36; (e) comparison at station HD37.

USE OF UV BANDS

He et al., 2012

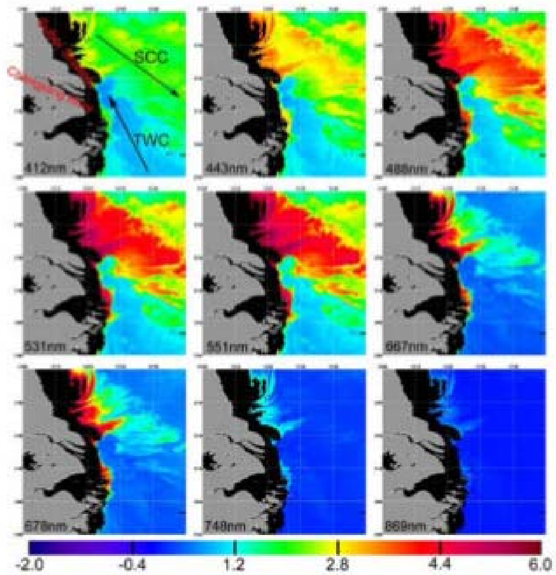


Fig. 4. The L_{wn} retrieved by Aqua/MODIS on 5 April 2003 using the UV-AC(412nm) algorithm (unit: mW/(cm^2·μm·sr)). Arrows in the sub-image of 412nm indicate the Subei Coastal Current (SCC) and the Taiwan Warm Current (TWC).

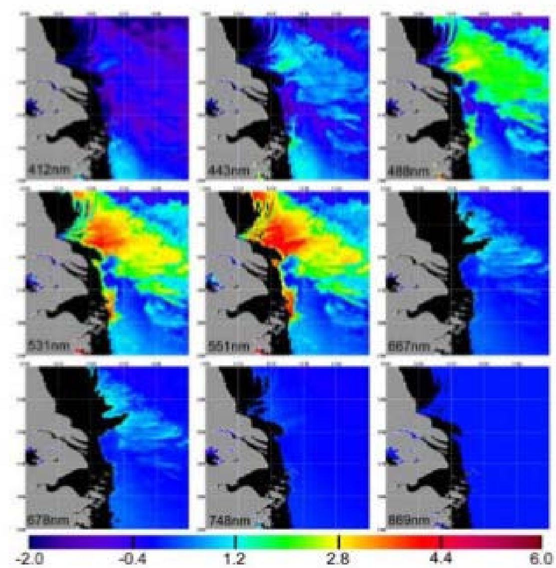


Fig. 5. The L_{wn} retrieved by Aqua/MODIS on 5 April 2003 using the SeaDAS 6.3 based on the SWIR/NIR-AC algorithm (unit: mW/(cm^2·μm·sr)).

Conclusions

- Several methods exist today → **Difficult to estimate which one is the best**
- All methods have advantages and limitations
- Not sure accuracy is reached for short visible wavelengths
- Still work to do or the actual accuracy is enough for bio-optical applications???

Why a new IOCCG WG?

- Complement of the IOCCG report #10: « *Atmospheric Correction for Remotely-Sensed Ocean-Colour Products* » (Wang, 2010)
  →Update (could also be an update of IOCCG report #3)

- This WG focused mainly on open ocean waters
- **And in coastal waters??**
- ***Need for guidances on using the already developed AC***

→ Purpose of this new WG

Summary

- **Goal: Inter-comparison and evaluation of existing AC algorithms over turbid/coastal waters**

  → **Understanding retrievals differences between algorithms**
- **Challenge:** to understand the advantages and limitations of each algorithm and their performance under certain atmospheric and oceanic conditions
- Only focus on AC algorithms that deal with a non-zero NIR water-leaving radiances.
- High demand for AC guidelines
- **Outputs timely**

  → **Guidances on the use of AC over turbid waters**

  → **Recommendations for improving and selecting the optimal AC**
- Not a sensor-oriented exercise

Questions

- How well do the aerosols need to be retrieved?
- Does the technique matter?
- How good is the extrapolation from SWIR to NIR to VIS?
- How to improve AC with the historic wavelengths?
  - Better bio-optical models
  - New contrains (such as relationships between Rrs, cf Poster of Goyens et al.)
  - Regional AC?
- Do we really need extra wavelengths in NIR/SWIR? What info can offer the future satellite sensors?

Evaluation of AC

- Can round robin lead to improvements?
  - What can we learn?
    - Range of validity and advantages
    - Limitations
  - Sensitivity studies
    - Fixed aerosols→ Variation/change of the bio-optical model
    - Fixed bio-optical model → Variation/change of the aerosol models
  - Uncertainties propagation and budget on the hypothesis
    - Ruddick et al. (2000)
    - Bayseian statistics for NN (Aires et al., 2004a, 2004b, 2004c)
      - Uncertainties on the NN parameters (weights)
      - Uncertainties on the outputs
    - Others ?

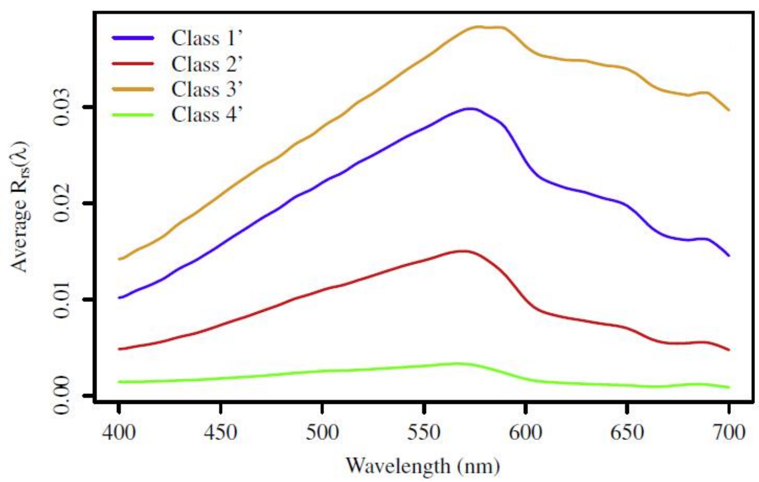
Evaluation of AC

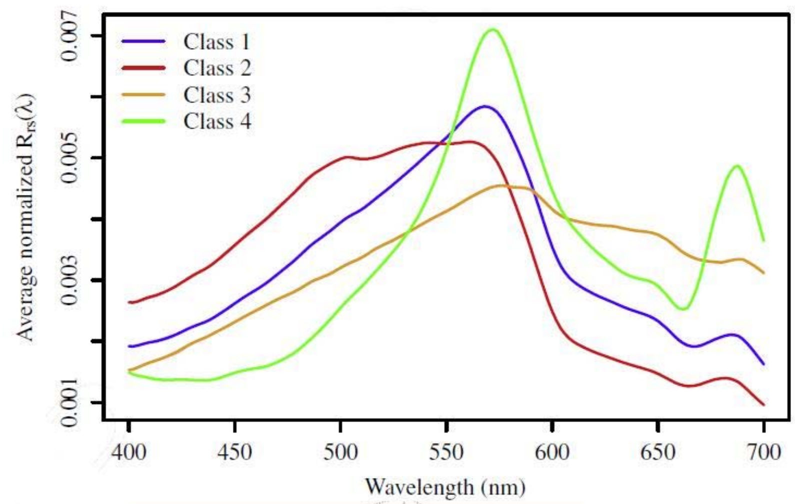
- Can round robin lead to improvements?
  - What can we learn?
    - Drawbacks and advantages
    - Limitations
  - Sensitivity studies
    - Fixed aerosols→ Variation/change of the bio-optical model
    - Fixed bio-optical model → Variation/change of the aerosol models
  - Uncertainties propagation and budget on the hypothesis
    - Ruddick et al. (2000)
    - Neukermans et al., (2012)
    - Bayseian statistics for NN (Aires et al., 2004a, 2004b, 2004c)
      - Uncertainties on the NN parameters (weights)
      - Uncertainties on the outputs

Classification of Lw spectra per water type

- 4 water type classes defined by Vantrepotte et al. (2012)

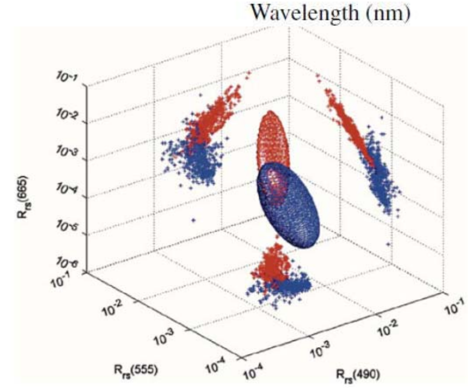
Focus on turbid waters only ! → *Distinguish classes based on normalized reflectance spectra*





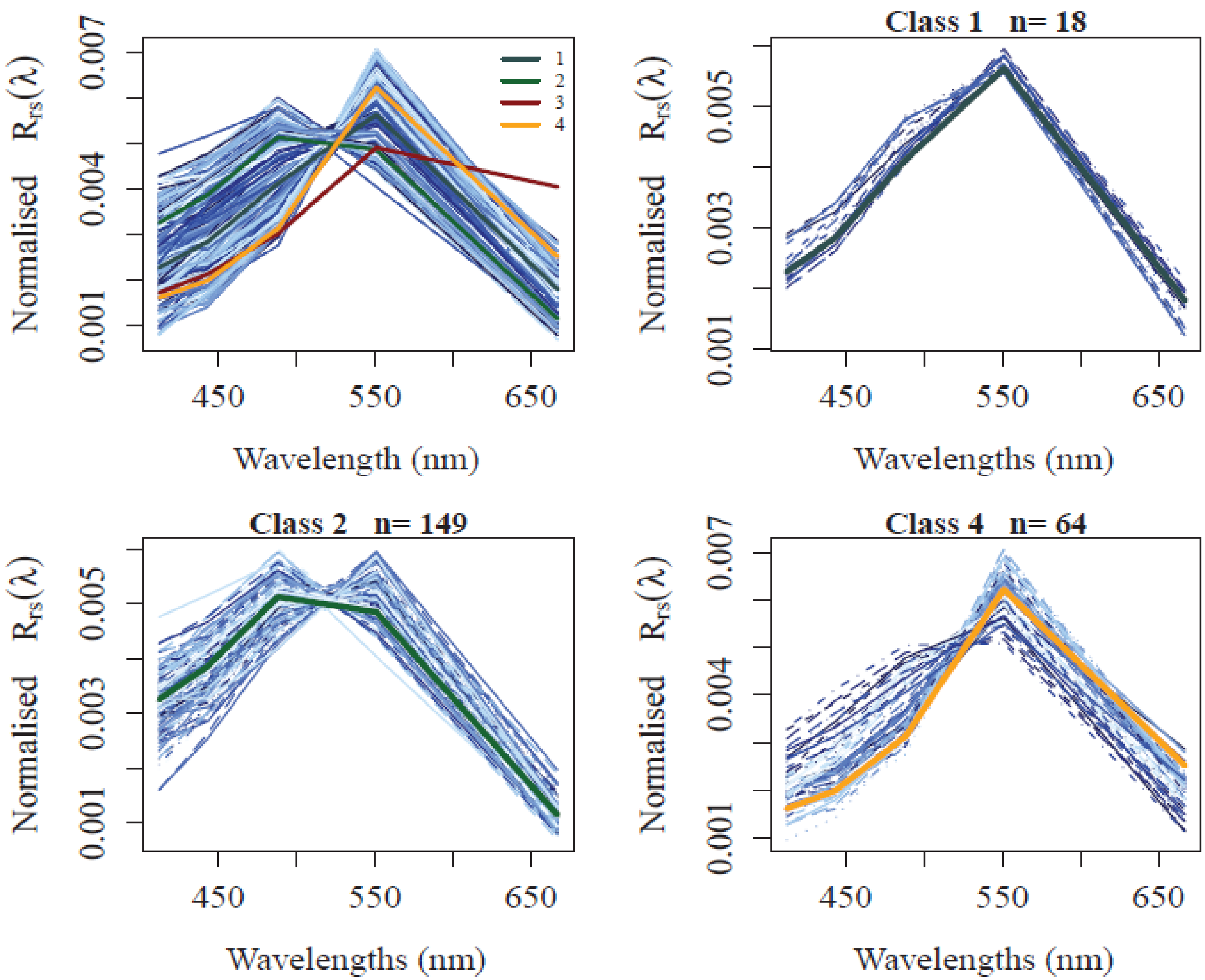
- Novelty detection technique:

Assigns each spectra to one of the 4 water type classes using the Mahalanobis distance



D'Alimonte et al. (2003)

Evaluation of the algorithms as a function of the water type



We don't have any mathup for Class 3 (very turbid water masses)!

Goyens et al., 2013