Retrieval of Inherent Optical Properties in the Coastal Zone: An update of the Quai-Analytical Approach **(QAA)**

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Basic assumptions of QAA:

1. Remote sensing reflectance (r_{rs}) can be expressed as an algebraic function of absorption (a) and backscattering (b_b) coefficients;

2. A reference wavelength (λ_0) can be found where $a(\lambda_0)$ can be well estimated;

3. Particle backscattering coefficient (b_{bp}) has well established wavelength dependence.

Assumption 1:

$$r_{rs} = \mathrm{Fun}(a, b_{\mathrm{b}})$$ -- for optically deep waters.

$$r_{rs}(\lambda) \approx \left(g_0 + g_1\, u(\lambda)\right) u(\lambda)$$

- with:

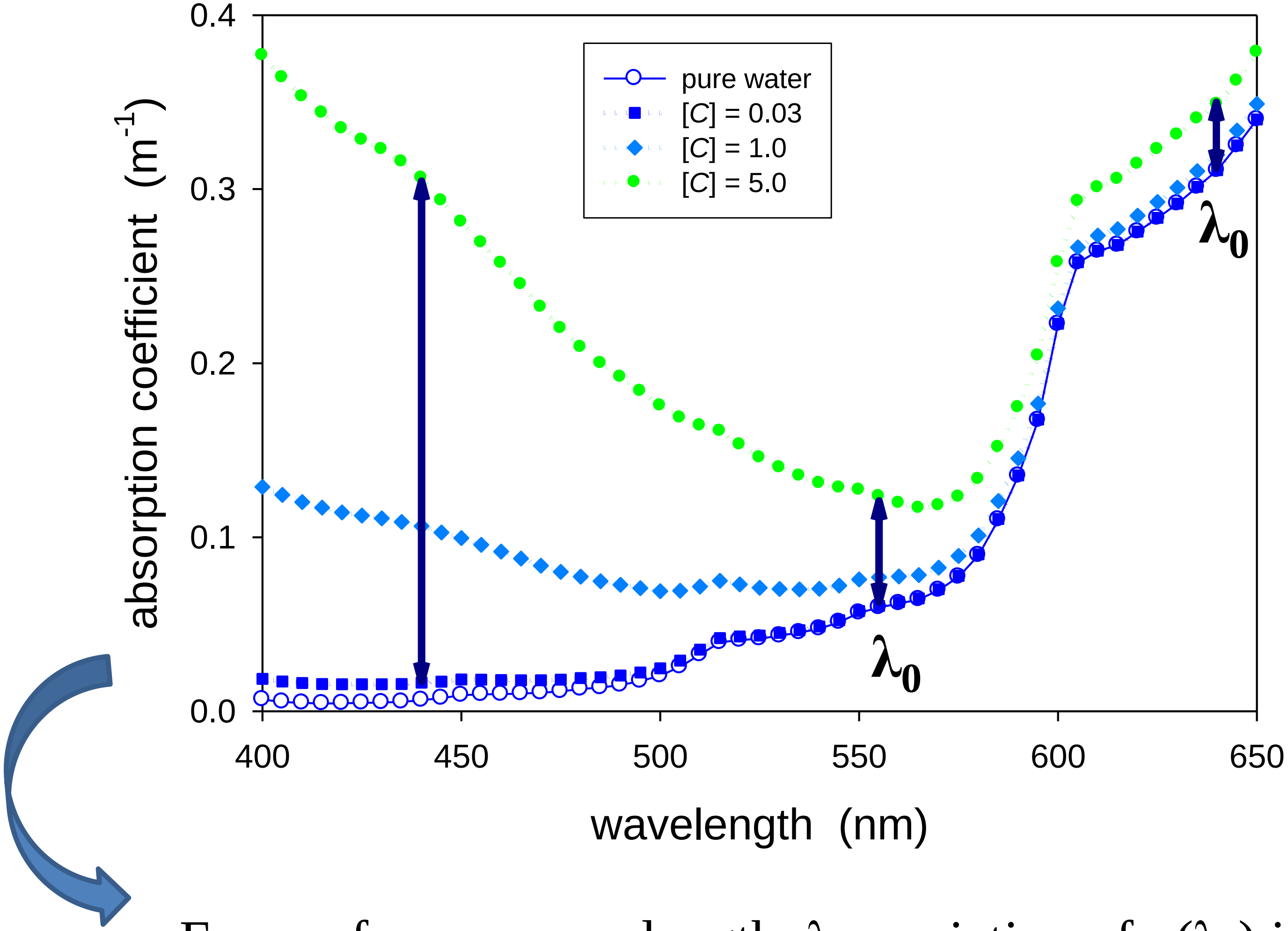
$$u(\lambda) = \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}$$

$$r_{rs}(\lambda) \Rightarrow u(\lambda)$$

When $a(\lambda)$ is known, $b_b(\lambda)$ can be calculated; or,
When $b_b(\lambda)$ is known, $a(\lambda)$ can be calculated.

(Lee et al. 2002, 2007)

Assumption 2:



For a reference wavelength, λ_0, variation of $a(\lambda_0)$ is limited.

Assumption 2:

$$a(\lambda_0) = a_w(\lambda_0) + \delta a(\lambda_0)$$

$$\chi = \log\left(\frac{r_{rs}(443) + r_{rs}(490)}{r_{rs}(\lambda_0) + 5\frac{r_{rs}(667)}{r_{rs}(490)} r_{rs}(667)}\right)$$

$$a(\lambda_0) = a_w(\lambda_0) + 10^{-1.146-1.366\chi-0.469\chi^2}$$

-- empirically developed with synthetical data

For λ_0 as 550, 555, or 560 nm.

Assumption 3:

$$b_b(\lambda) = b_{bw}(\lambda) + b_{bp}(\lambda)$$

$$b_{bp}(\lambda) = b_{bp}(\lambda_0)\left(\frac{\lambda_0}{\lambda}\right)^{\eta}$$

Estimation of η:

$$\eta = 2.0\left(1 - 1.2\ \exp\left(-0.9\frac{r_{rs}(443)}{r_{rs}(555)}\right)\right)$$

-- empirical, NOMAD

The data flow of QAA:

$$r_{rs}(\lambda)$$

$$\eta$$

$$a(\lambda_0) = a_w(\lambda_0) + \delta a(\lambda_0)$$

$$b_{bp}(\lambda_0) = F_2\left(r_{rs}(\lambda_0), a(\lambda_0), b_{bw}(\lambda_0)\right)$$

$$b_{bp}(\lambda) = b_{bp}(\lambda_0)\left(\frac{\lambda_0}{\lambda}\right)^{\eta}$$

$$a(\lambda) = F_3\left(r_{rs}(\lambda), b_{bp}(\lambda), b_{bw}(\lambda)\right)$$

$$\begin{cases} a(411) = a_w(411) + \zeta a_{ph}(443) + \xi a_{dg}(443) \\ a(443) = a_w(443) + a_{ph}(443) + a_{dg}(443) \end{cases}$$

$$\zeta = \frac{a_{ph}(411)}{a_{ph}(443)}$$

$$\xi = \frac{a_{dg}(411)}{a_{dg}(443)}$$

Decompose total absorption coefficient:

$$\begin{cases} a(410) = a_w(410) + \zeta\, a_{ph}(440) + \xi\, a_{dg}(440), \\ a(440) = a_w(440) + a_{ph}(440) + a_{dg}(440). \end{cases}$$

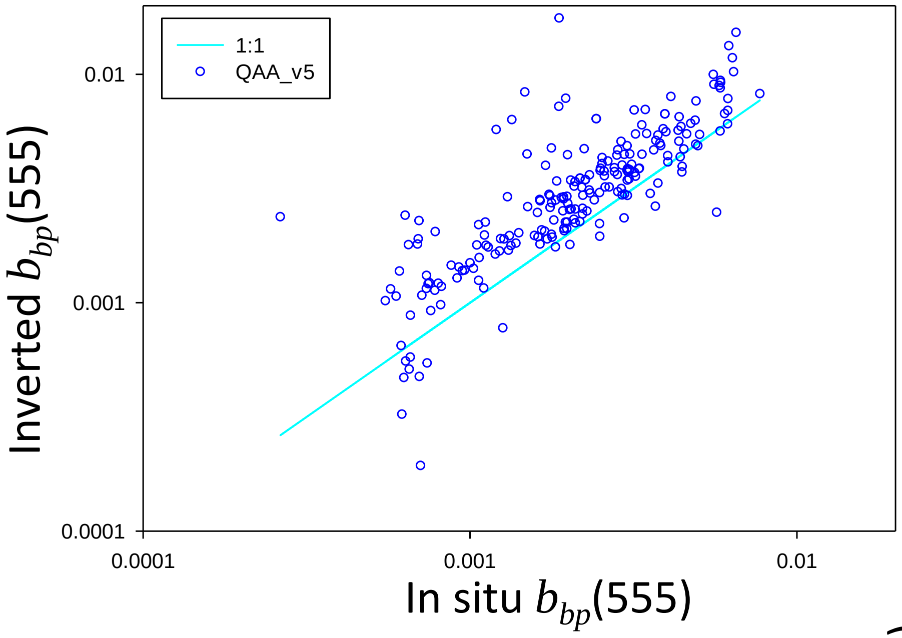
$$\begin{cases} a_g(440) = \dfrac{\left(a(410) - \zeta\, a(440)\right) - \left(a_w(410) - \zeta\, a_w(440)\right)}{\xi - \zeta}, \\ a_{ph}(440) = a(440) - a_w(440) - a_{dg}(440). \end{cases}$$

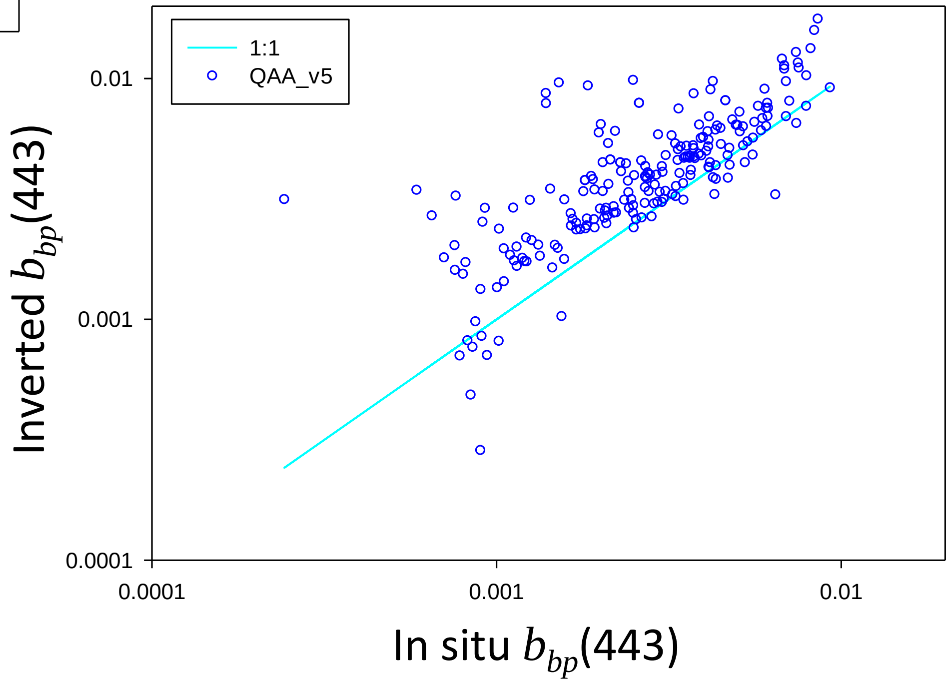
$$\zeta = 0.74 + \frac{0.2}{0.8 + r_{rs}(443)/r_{rs}(\lambda_0)}$$

$$\xi = e^{S(443-411)},$$

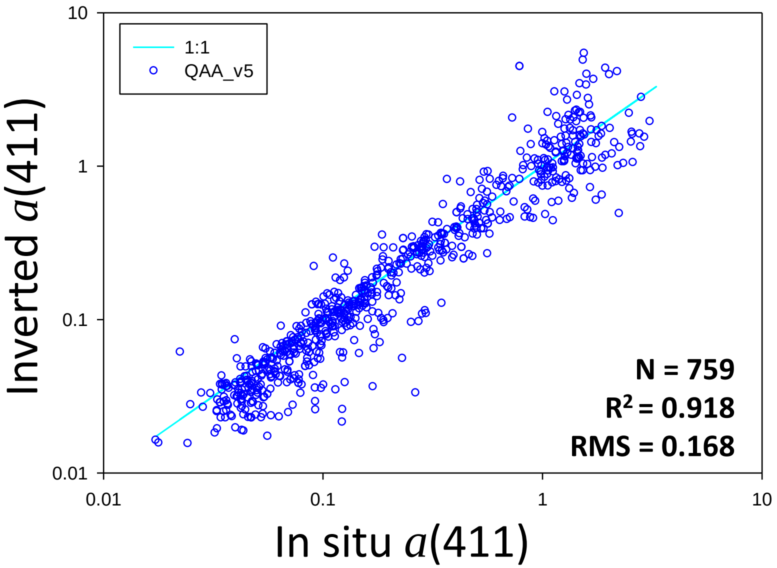
$$S = 0.015 + \frac{0.002}{0.6 + r_{rs}(443)/r_{rs}(\lambda_0)}$$

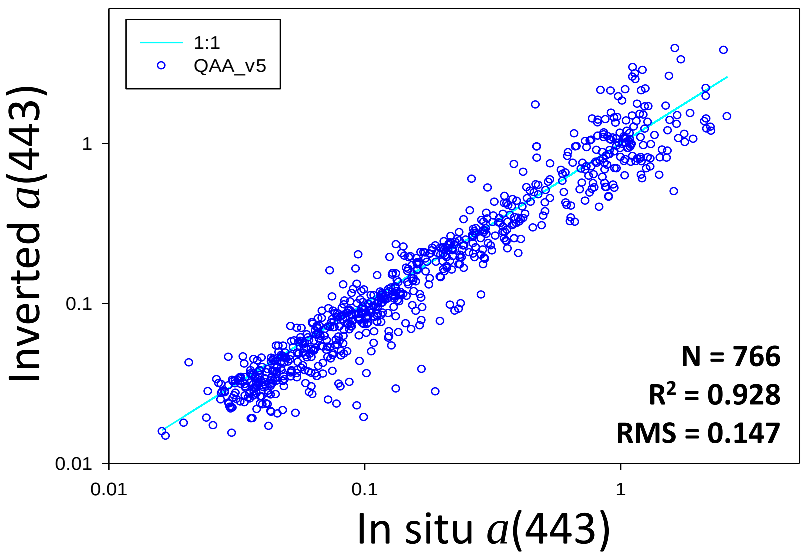
Application with NOMAD

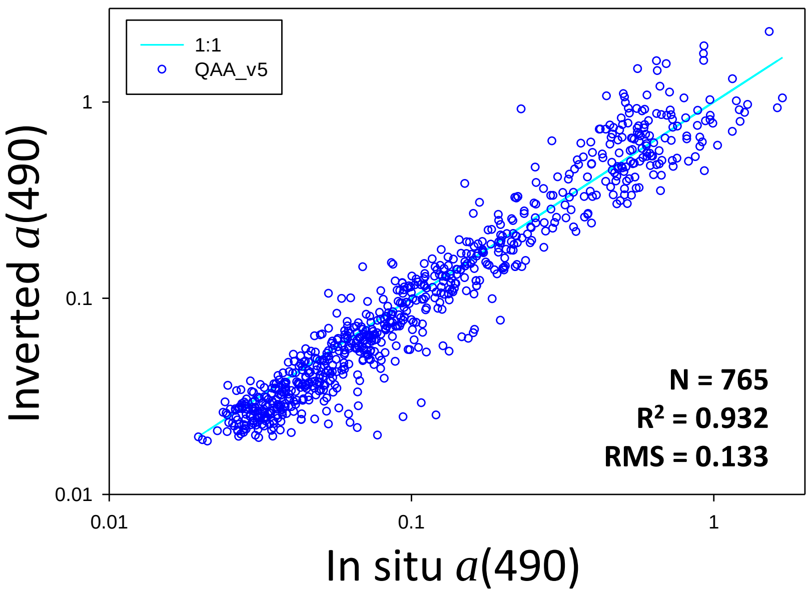




Application with NOMAD

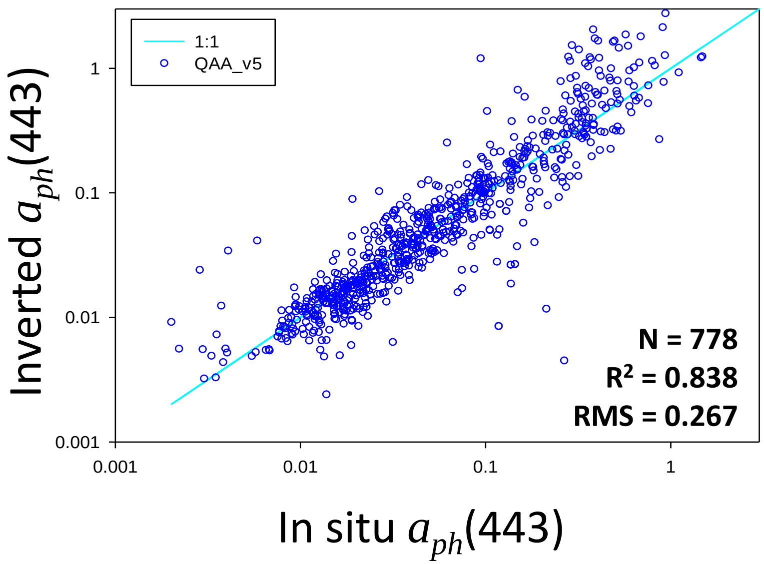


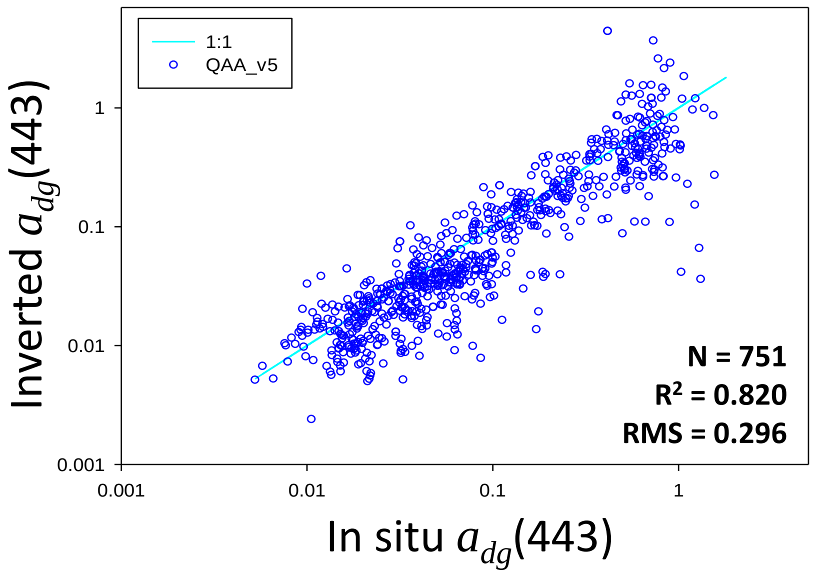




$$a(\lambda) = \frac{(1-u(\lambda))b_b(\lambda)}{u(\lambda)}$$

Application with NOMAD





Uncertainty quantification:

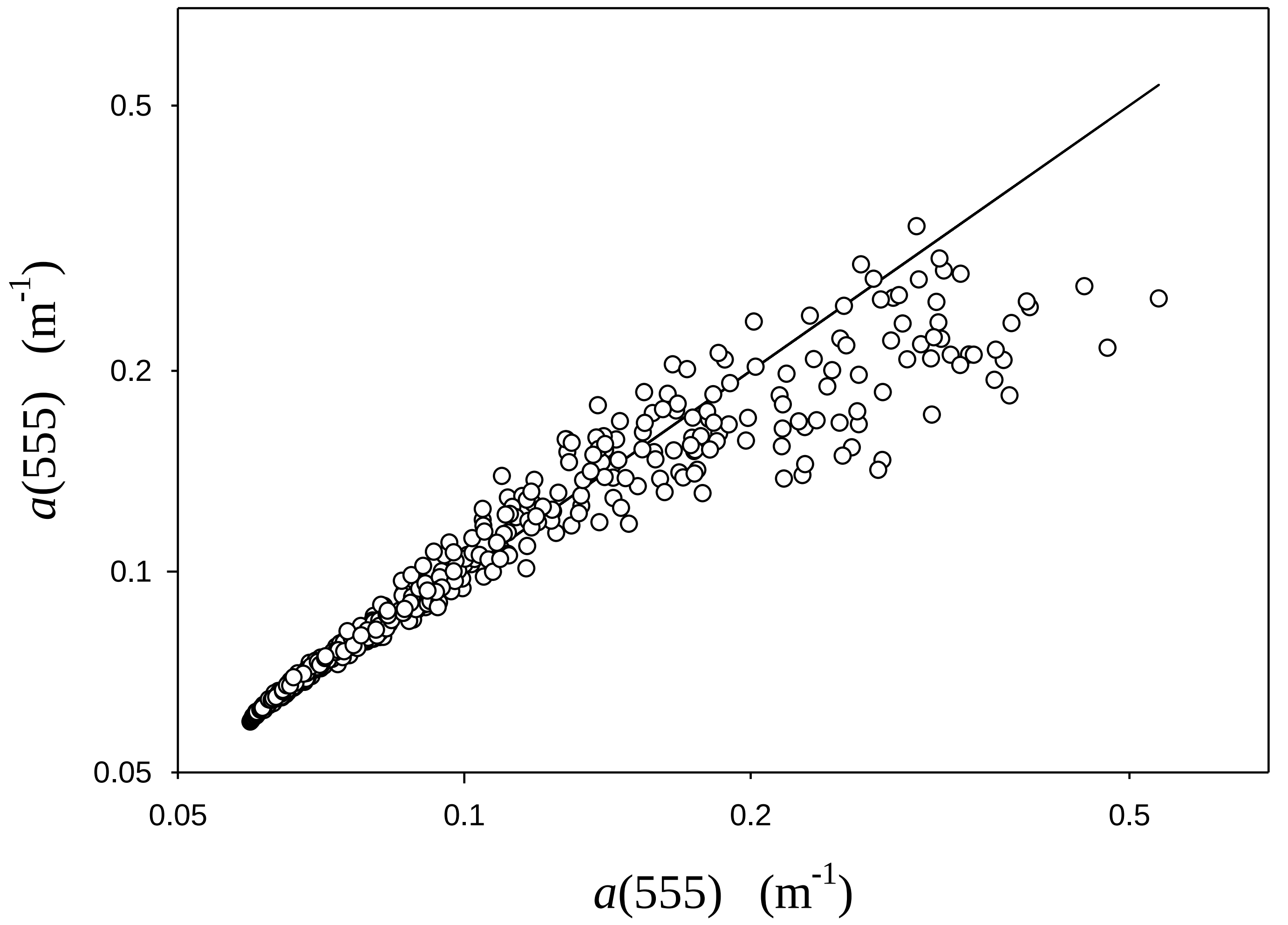
The QAA scheme is applicable to all waters. The only difference is, for different waters, the error bar.

Two error sources solely from the **algorithm**: **$\Delta a(\lambda_0)$ and $\Delta\eta$**.

From error propagation theory:

$$\Delta b_{bp}(\lambda) = \sqrt{\left(B(\lambda_0)\left(\frac{\lambda_0}{\lambda}\right)^{\eta}\Delta a(\lambda_0)\right)^2 + \left(\left[B(\lambda_0)\,a(\lambda_0) - b_{bw}(\lambda_0)\right]\left(\frac{\lambda_0}{\lambda}\right)^{\eta}\ln\left(\frac{\lambda_0}{\lambda}\right)\Delta\eta\right)^2}$$

$$\Delta a(\lambda) = \sqrt{\left(A(\lambda)\,B(\lambda_0)\left(\frac{\lambda_0}{\lambda}\right)^{\eta}\Delta a(\lambda_0)\right)^2 + \left(A(\lambda)\left[B(\lambda_0)\,a(\lambda_0) - b_{bw}(\lambda_0)\right]\left(\frac{\lambda_0}{\lambda}\right)^{\eta}\ln\left(\frac{\lambda_0}{\lambda}\right)\Delta\eta\right)^2}$$



IOCCG synthetical data

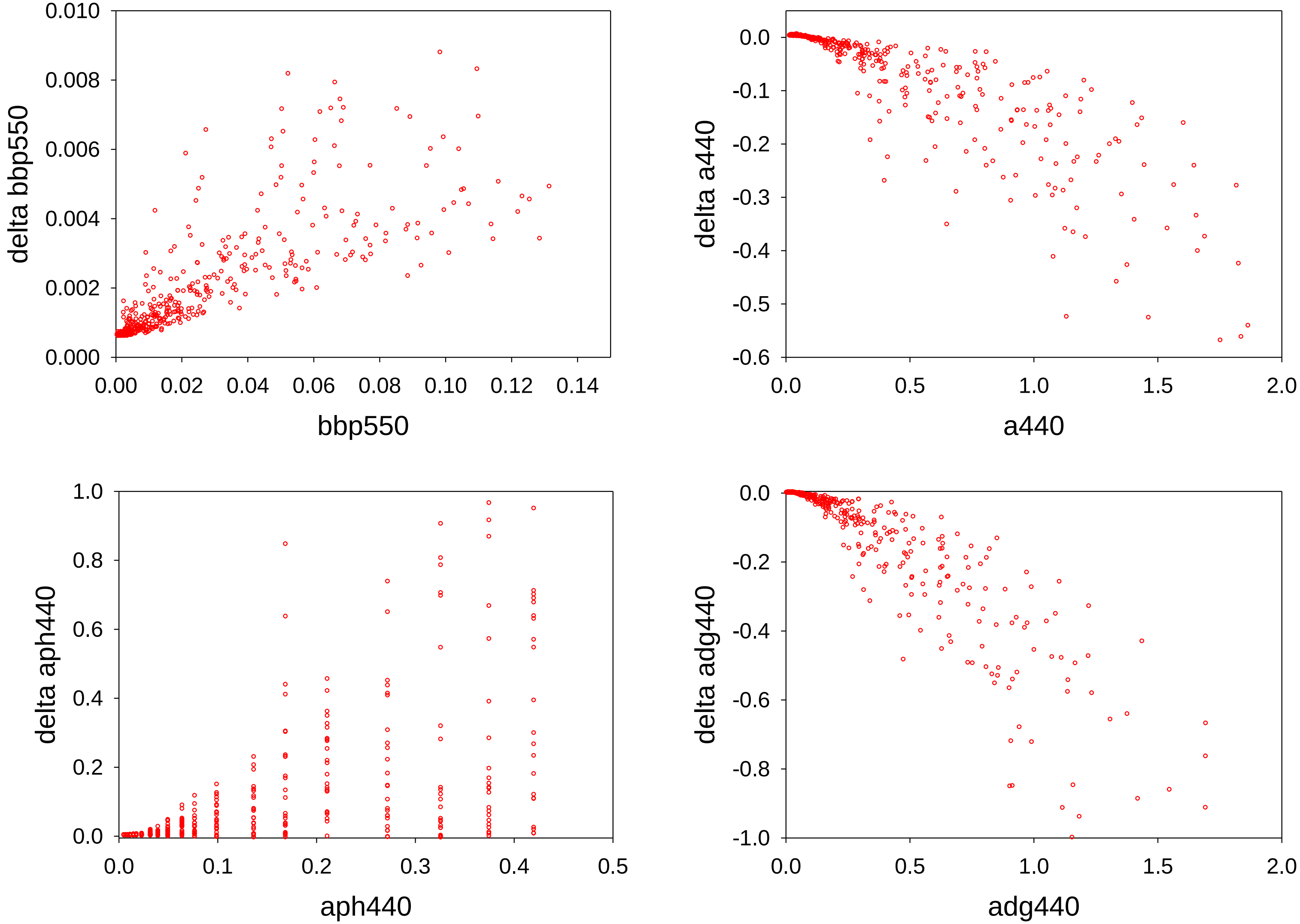
Uncertainty resulted from Rrs:

$$\Delta u(\lambda) = \frac{1}{\sqrt{(g_0)^2 + 4\, g_1\, r_{rs}(\lambda)}} \Delta r_{rs}(\lambda)$$

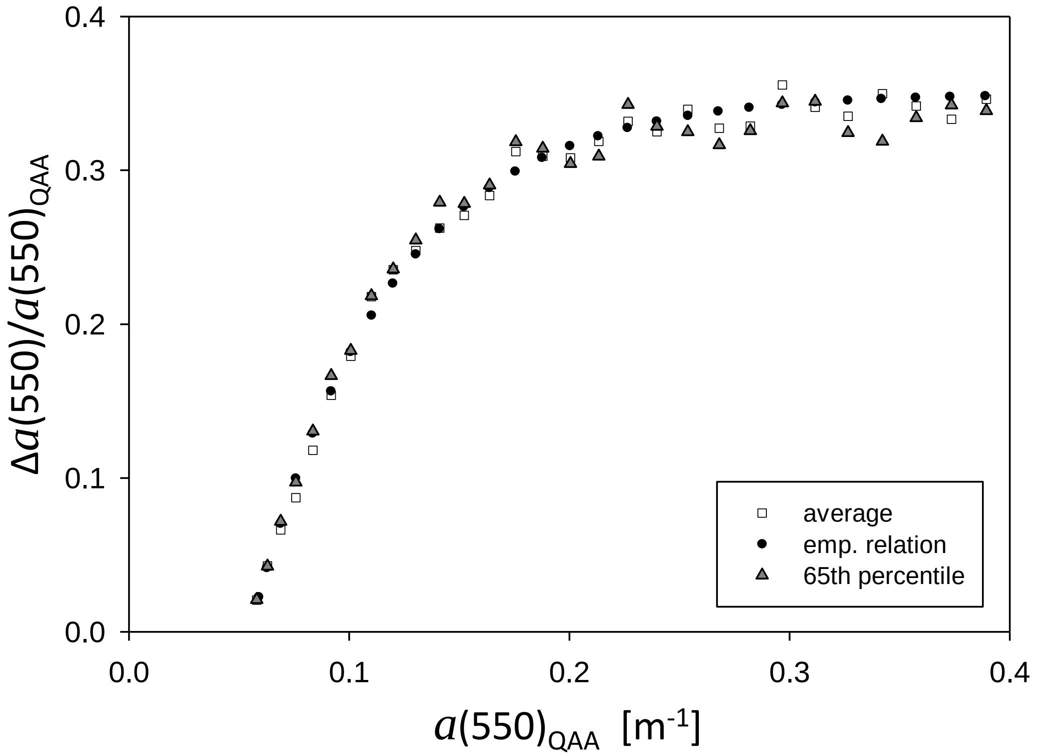
$$\Delta b_{bp}(\lambda_0) = \frac{a(\lambda_0)}{1 - u(\lambda_0)} \Delta u(\lambda_0) + \frac{u(\lambda_0)\, a(\lambda_0)}{(1 - u(\lambda_0))^2} \Delta u(\lambda_0)$$

$$\Delta a(\lambda) = \frac{1 - u(\lambda)}{u(\lambda)} \Delta b_b(\lambda) - \left(\frac{1 - u(\lambda)}{(u(\lambda))^2} + \frac{1}{u(\lambda)} \right) b_b(\lambda)\, \Delta u(\lambda)$$

Impact of a spectrally flat bias of 0.0005 sr^{-1}.



$a(\lambda_{0:}$ 550) uncertainty:

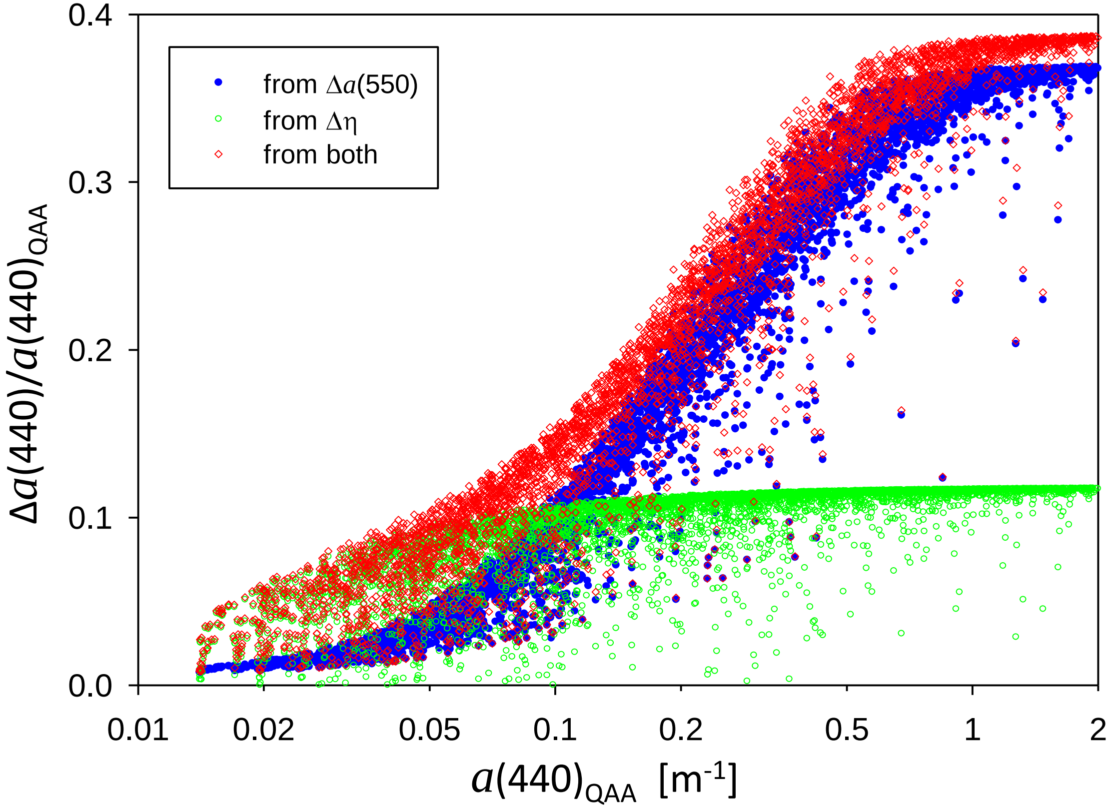


$$\Delta a(550) \approx 0.35\left(1 - 2.4\,\mathrm{Exp}(-16.0\,a(550)_{QAA})\right)a(550)_{QAA}$$

Higher uncertainty for more turbid waters (higher a(550)).

(Lee et al 2010)

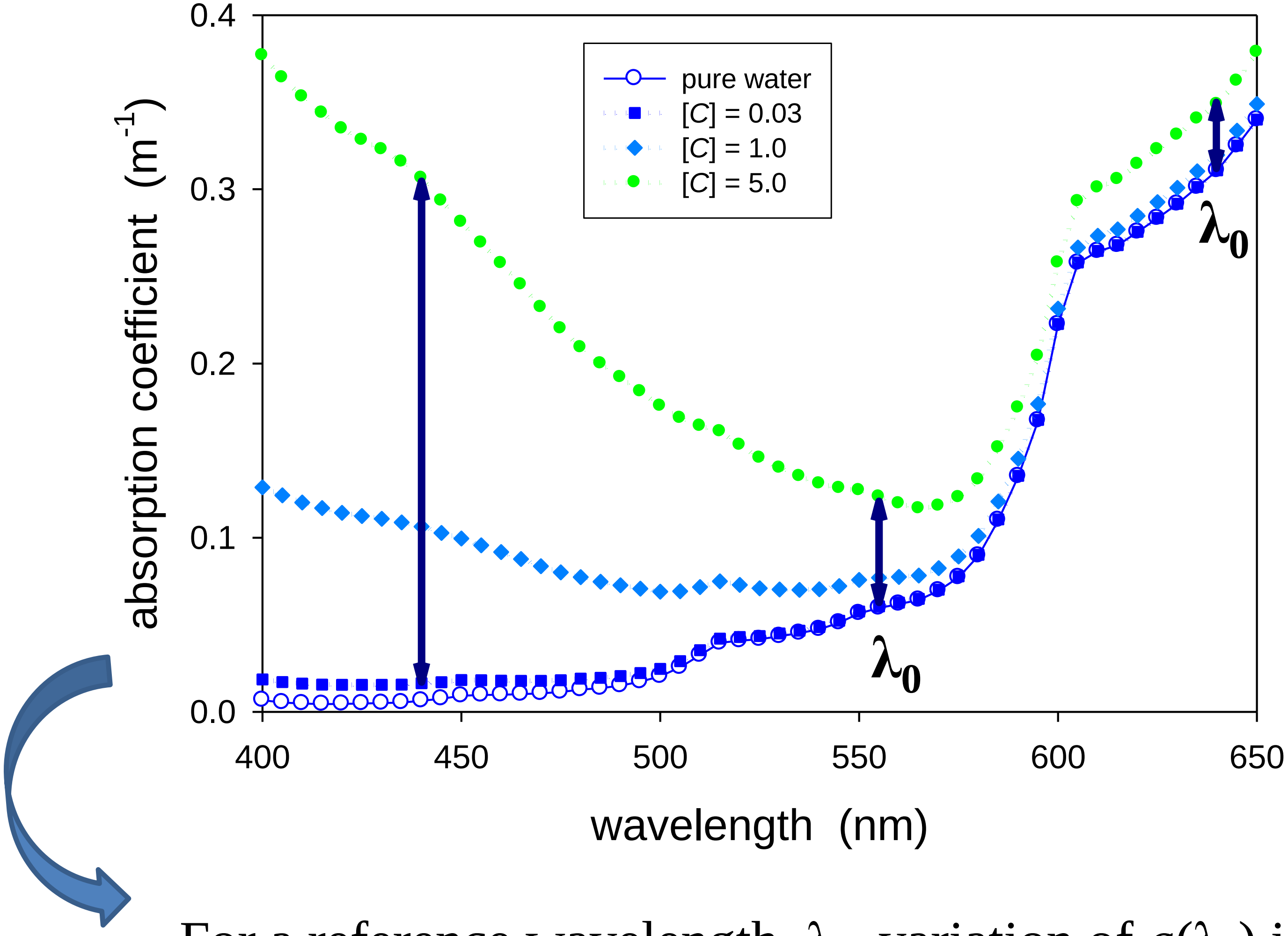
Uncertainty of *a*(440):



Larger uncertainties for coastal waters …

Reduce IOP uncertainties for Turbid waters

Assumption 2:



For a reference wavelength, λ_0, variation of $a(\lambda_0)$ is limited.

Assumption 2:

$$a(\lambda_0) = a_w(\lambda_0) + \delta a(\lambda_0)$$

λ_0 set as 670 nm, instead of 55x nm

$$a(670) = a_w(670) + 0.07\left(\frac{R_{rs}(670)}{R_{rs}(440)}\right)^{1.1}$$

(Lee et al 2002)

R_{rs}(670) for most of the ocean waters are too small, then high uncertainty for b_{bp}.

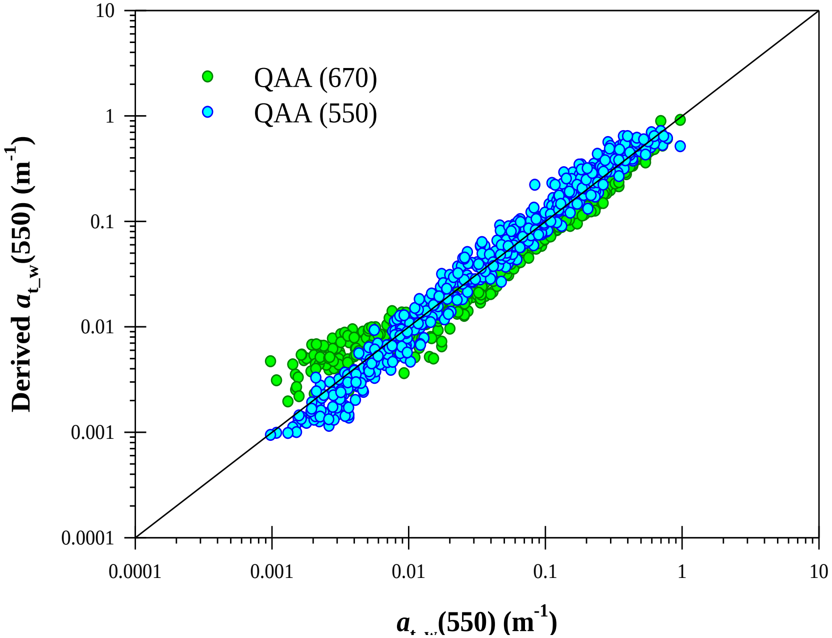
What would be the "proper" situation for a switch of λ_0?

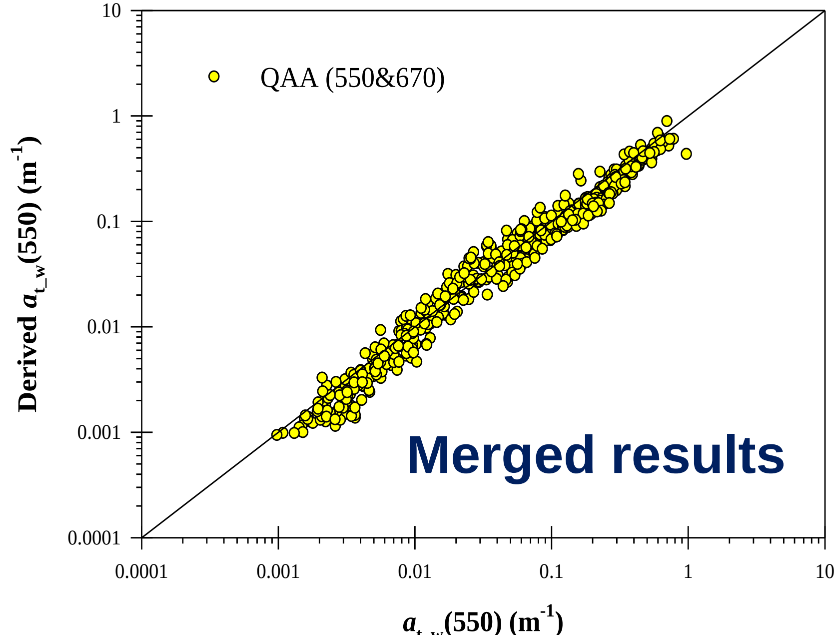
If $R_{rs}(670) \geq 0.0015$ sr^{-1}, $\lambda_0 = 670$;
Else, $\lambda_0 = 55x$.

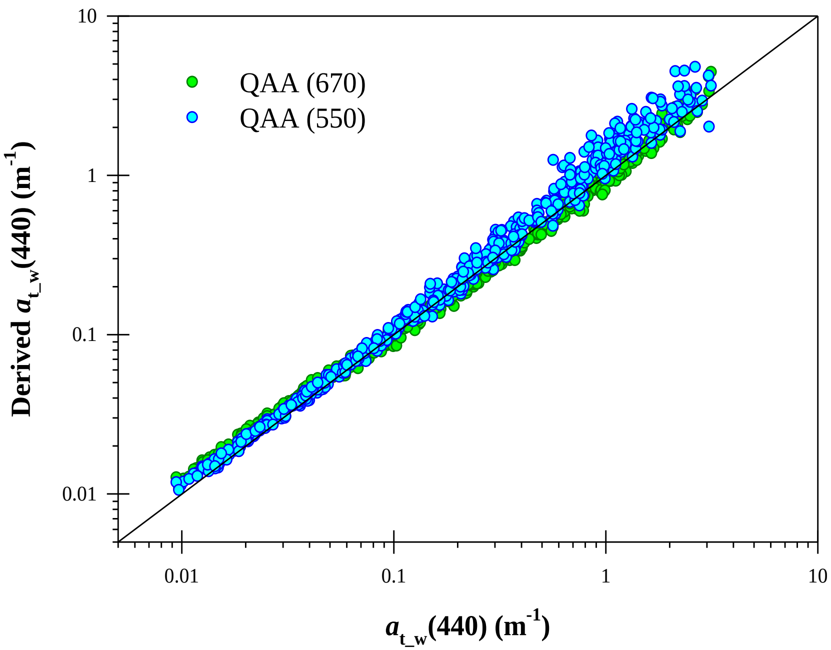
When $R_{rs}(670) = 0.0015$ sr^{-1}, the noise-equivalent Rrs (MODIS) ~5%.

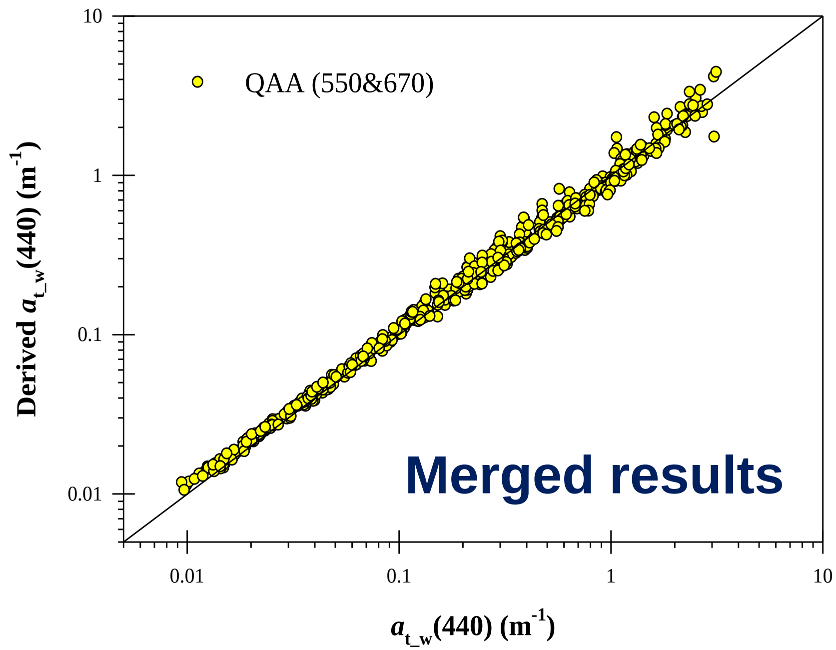
0.0015 sr^{-1} is also the value of $R_{rs}(555)$ of oligotrophic oceans.

IOCCG (2006) data set

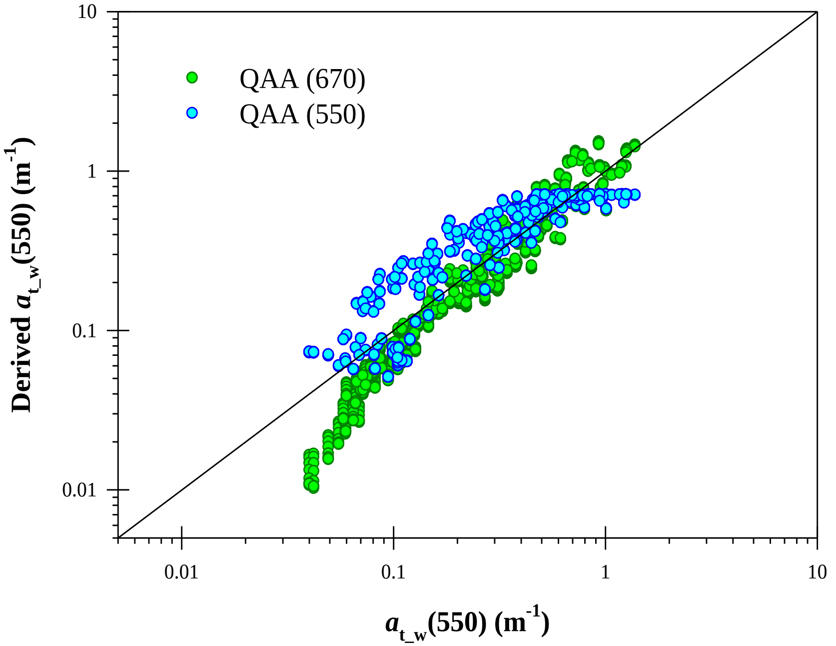


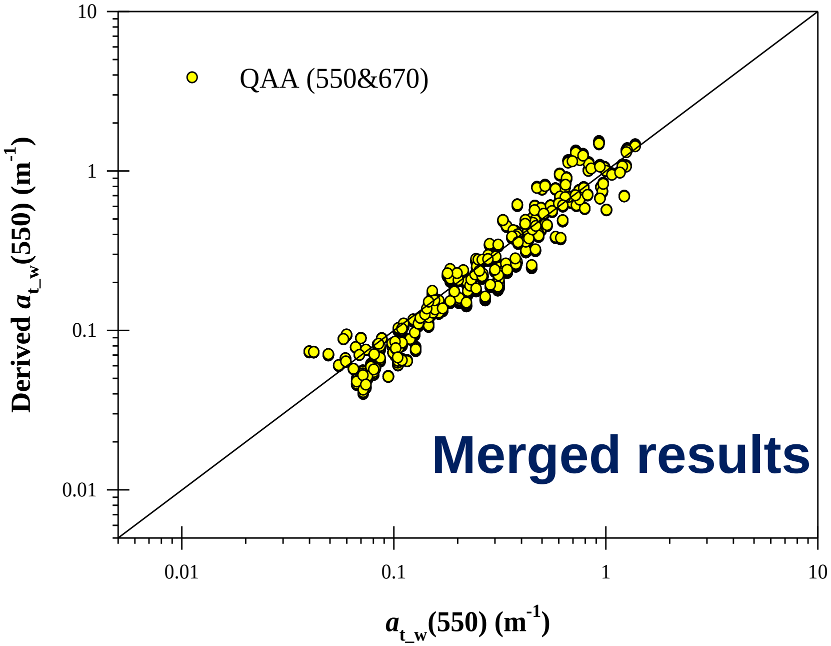


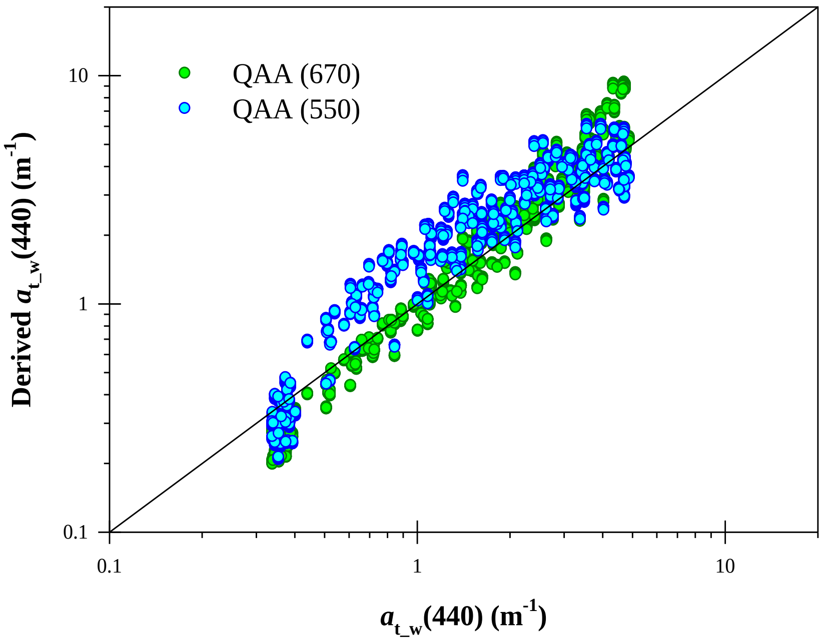


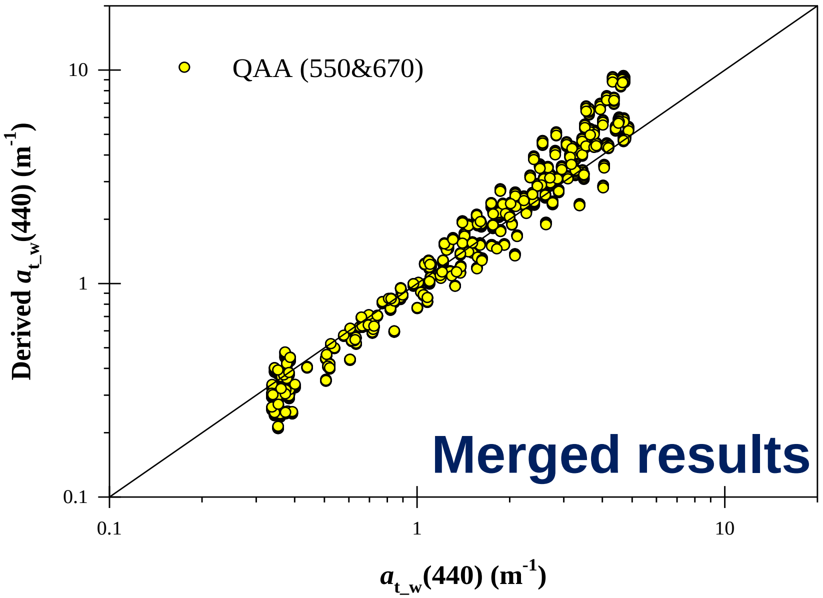


Extended Hydrolight simulation for highly turbid water:



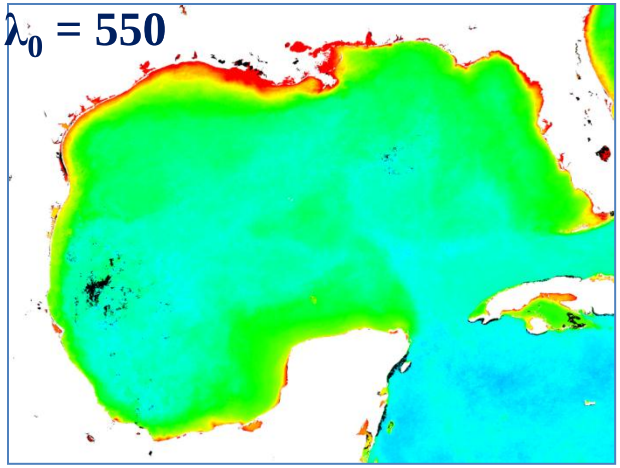


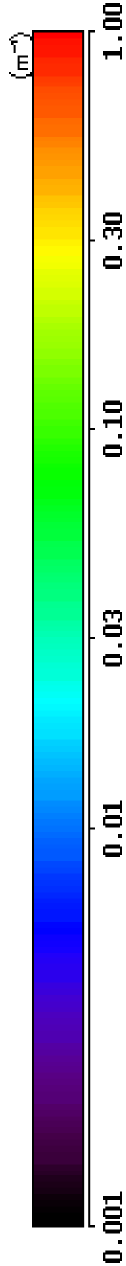




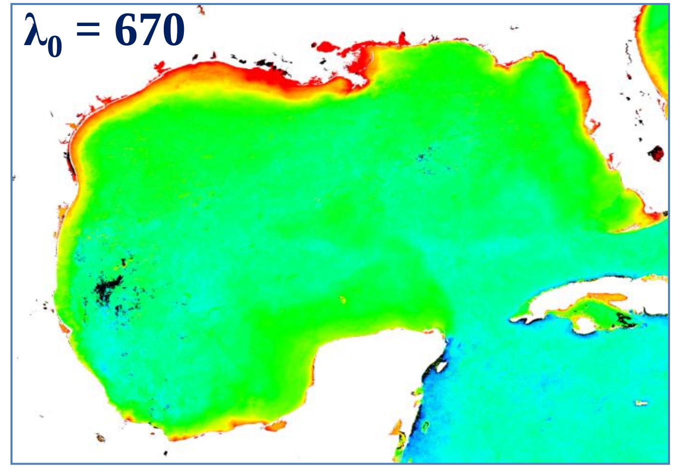
Apply to MODIS images

$\lambda_0 = 550$

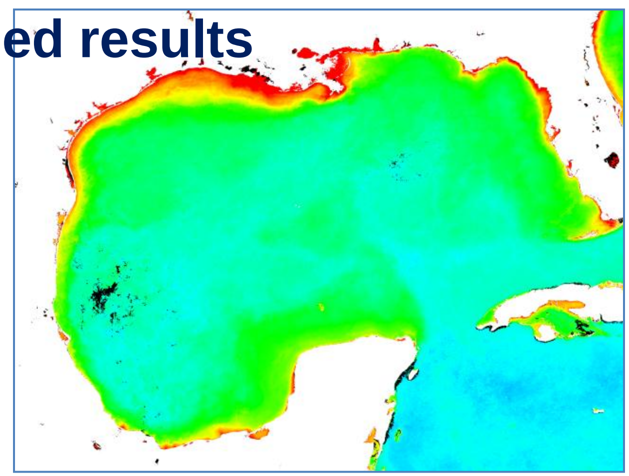


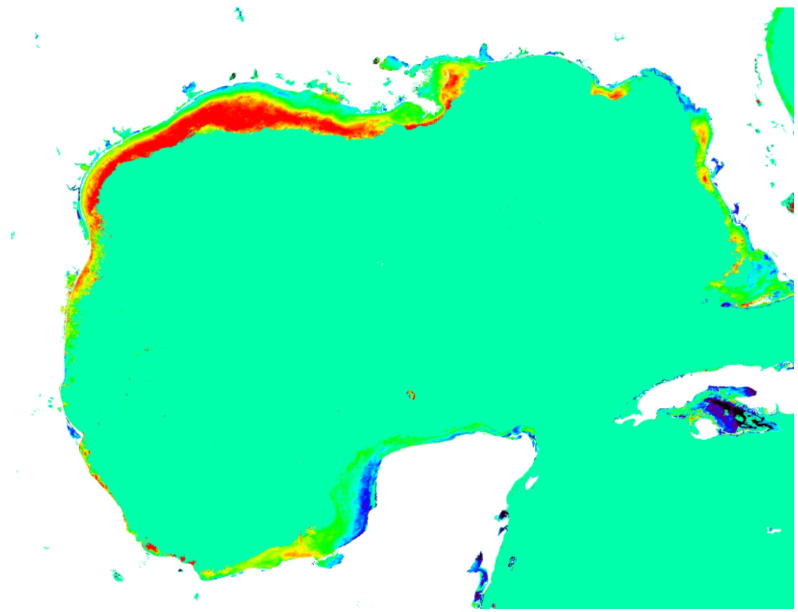


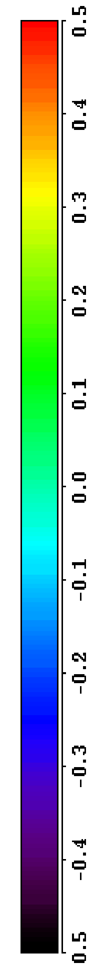
$\lambda_0 = 670$



Merged results



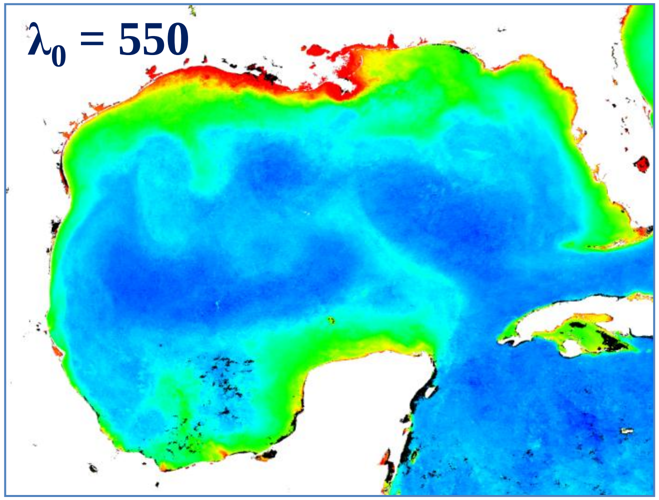


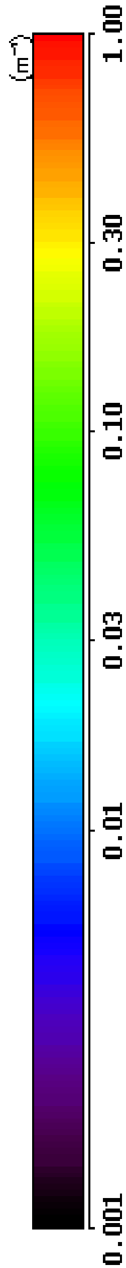


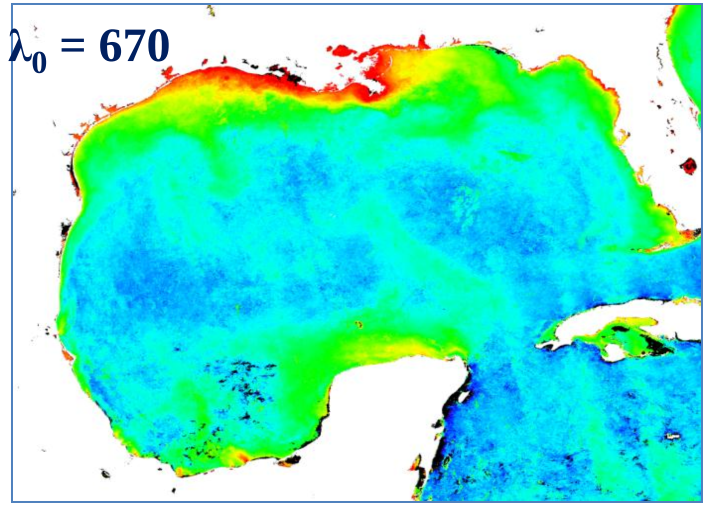
Difference between merged and $\lambda_0 = 550$

MODIS, January 2008

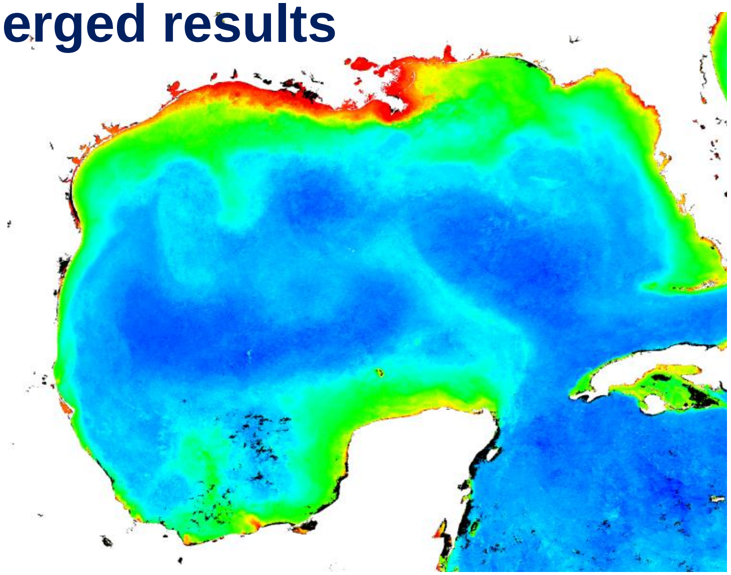
Apply to MODIS images

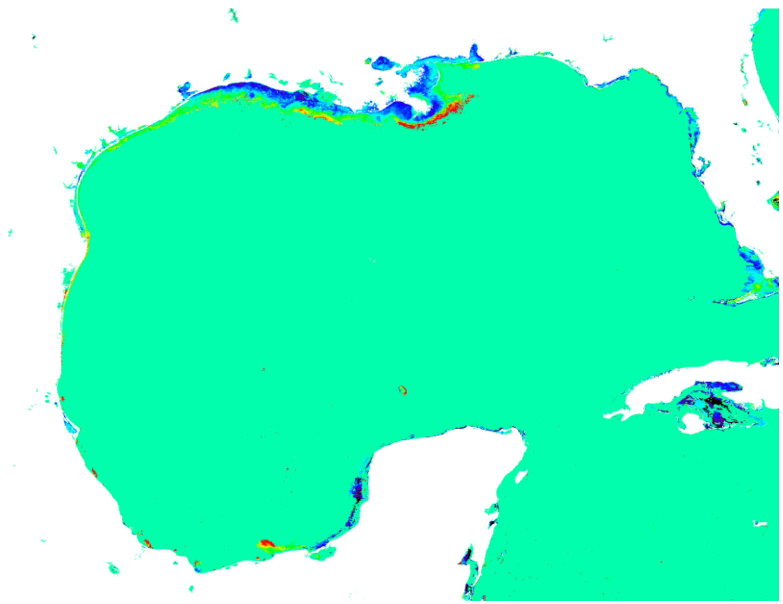


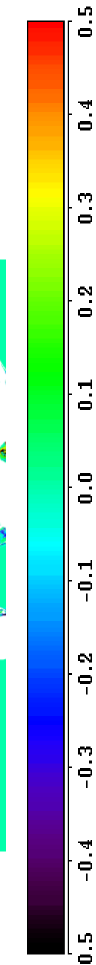




Merged results







Difference between merged and $\lambda_0 = 550$

MODIS, June 2008

Main points of QAA:

1. A model-based semi-analytical algorithm.
2. Applicable to all OCR sensors (after small adjustments).
3. **Applicable to both oceanic and coastal waters.**
4. Available in SeaDAS and BEAM.
5. Uncertainties of IOP products can be quantified pixel-wise.