Closure of particle backscattering coefficient in oligotrophic waters

ZhongPing Lee [1], Yannick Huot [2]

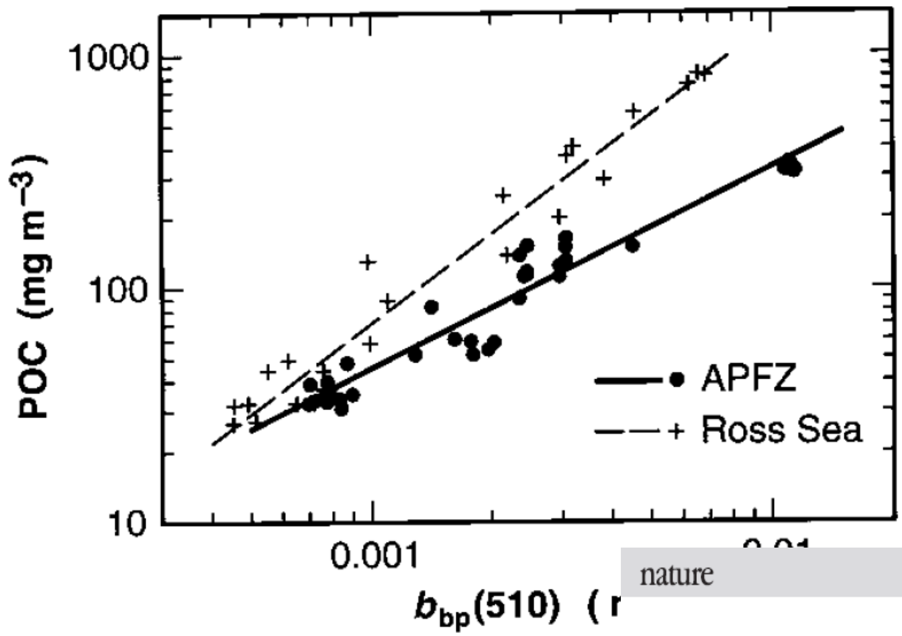
1. University of Massachusetts Boston
2. Université de Sherbrooke

Acknowledgements:

NASA, Jim Sullivan, Robert Brewin, Giorgio Dall'Olmo

particle backscattering coefficient: b_{bp}

Bulk optical property



$b_{bp} \rightarrow C_{cc}$

(Balch et al. 2005, 2010)

(Stramski et al, Science, 1999)

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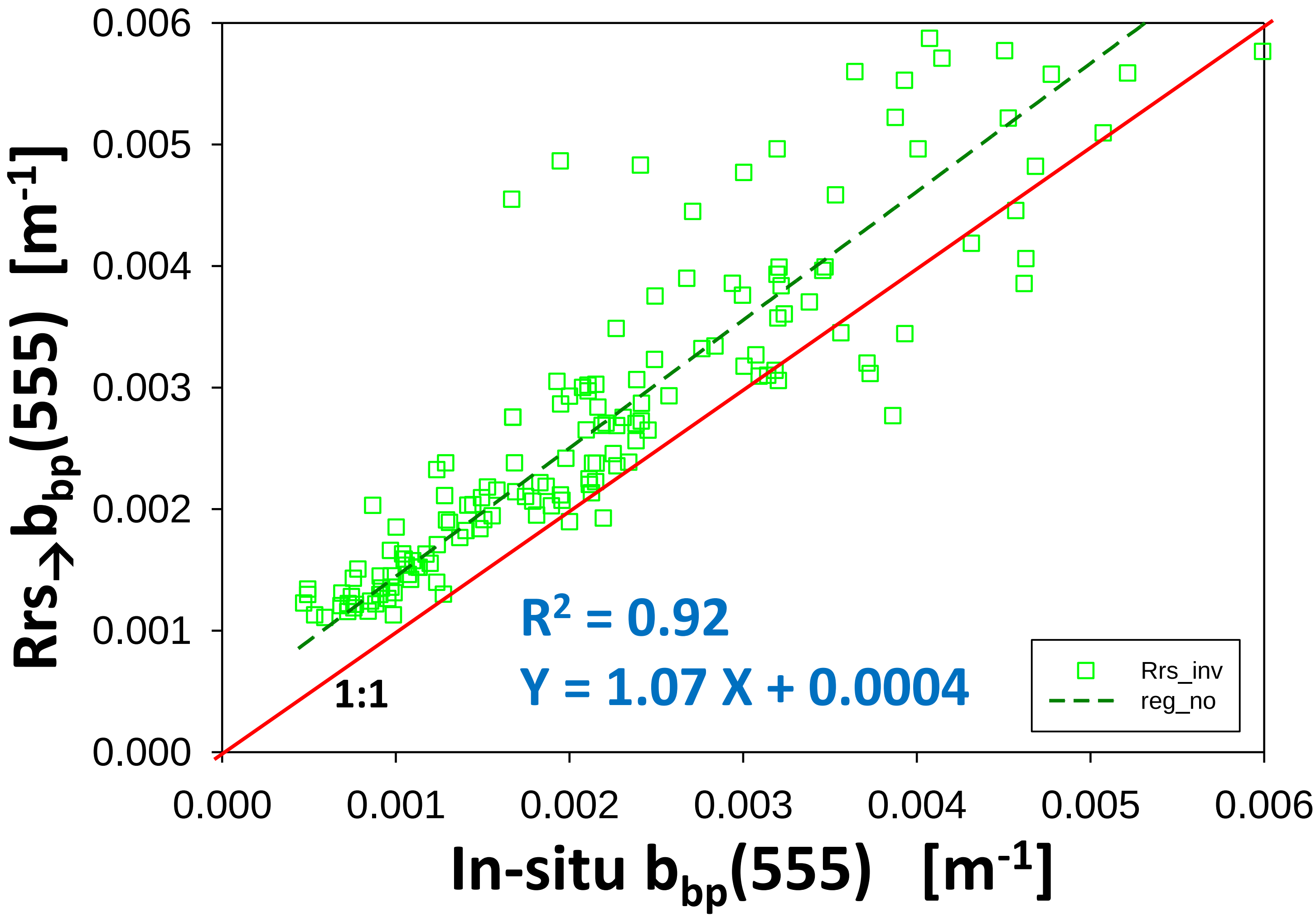
LETTERS

(Behenfeld et al, Nature, 2006)

Climate-driven trends in contemporary ocean productivity

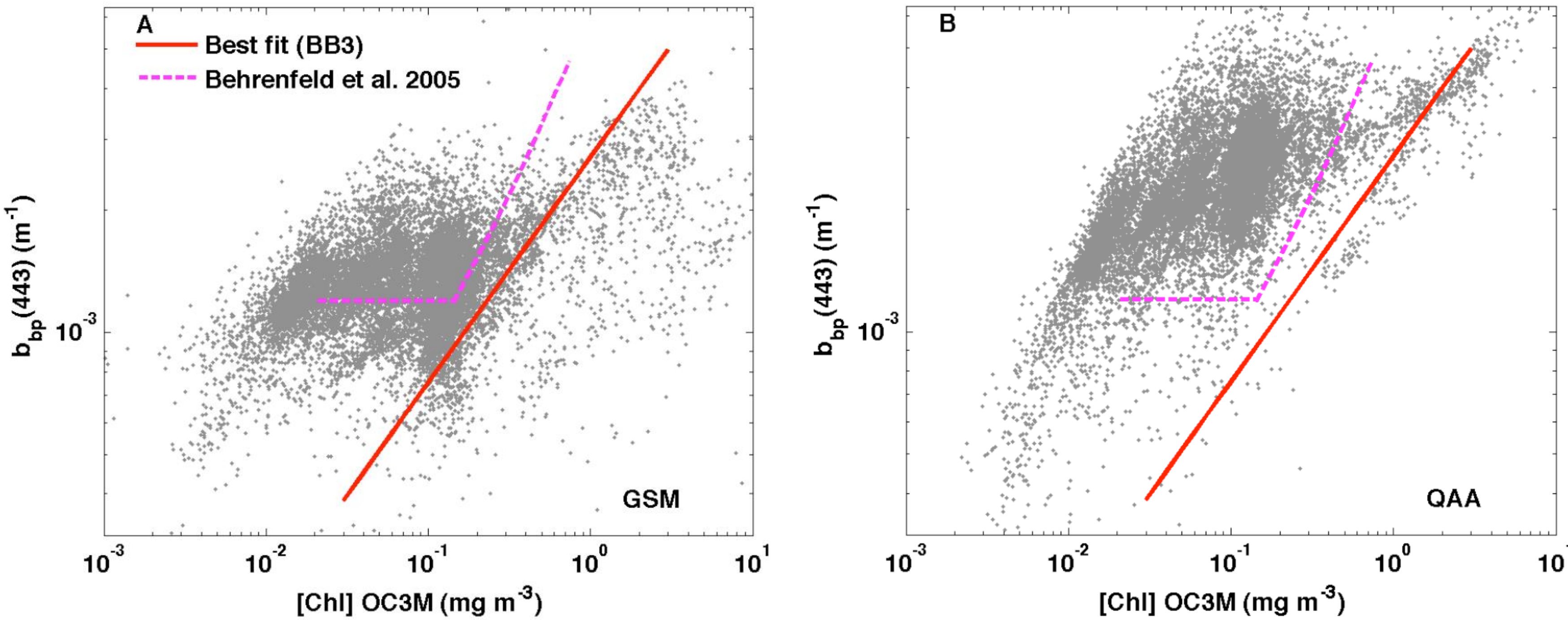
Michael J. Behrenfeld[1], Robert T. O'Malley[1], David A. Siegel[3], Charles R. McClain[4], Jorge L. Sarmiento[5], Gene C. Feldman[4], Allen J. Milligan[1], Paul G. Falkowski[6], Ricardo M. Letelier[2] & Emmanuel S. Boss[7]

NOMAD

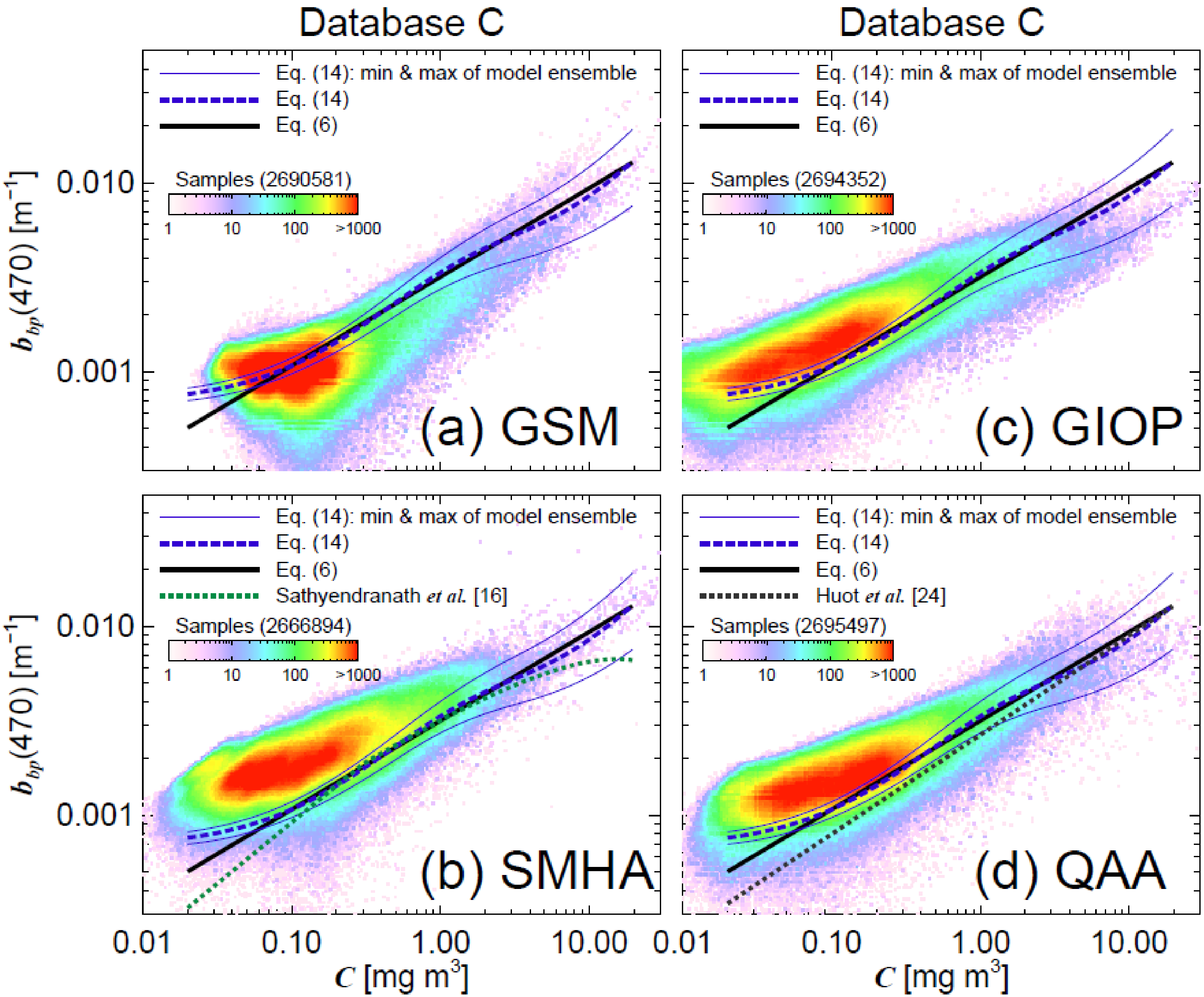


"Excellent" closure …

However:



(Huot et al 2008)



(Brewin et al 2012)

$Rrs_{\rightarrow} b_{bp}$ **much higher than** in-situ b_{bp}

for oligotrophic waters!

No closure **for such 'simple' waters !!**

Chl < 0.1 mg/m^3 makes ~50% of the global surface waters

Brief review of QAA:

$$R_{rs}(555) \rightarrow b_{bp}(555)$$

Based on:

$$R_{rs}(555) = G(555)\frac{b_b(555)}{a(555)+b_b(555)}$$

$$= \left(G_0 + G_1\frac{b_b(555)}{a(555)+b_b(555)}\right)\frac{b_b(555)}{a(555)+b_b(555)}$$

$$a(555) = a_w(555) + \Delta a(555) \qquad \approx a_w(555)$$

For oligotrophic waters

For Chl = 0.1 mg/m^3, $\Delta a(555)$ ~ 0.002 m^{-1}, 3% of $a_w(555)$.

Potential sources of error from Rrs inversion:

1. **Rrs–IOPs relationship**

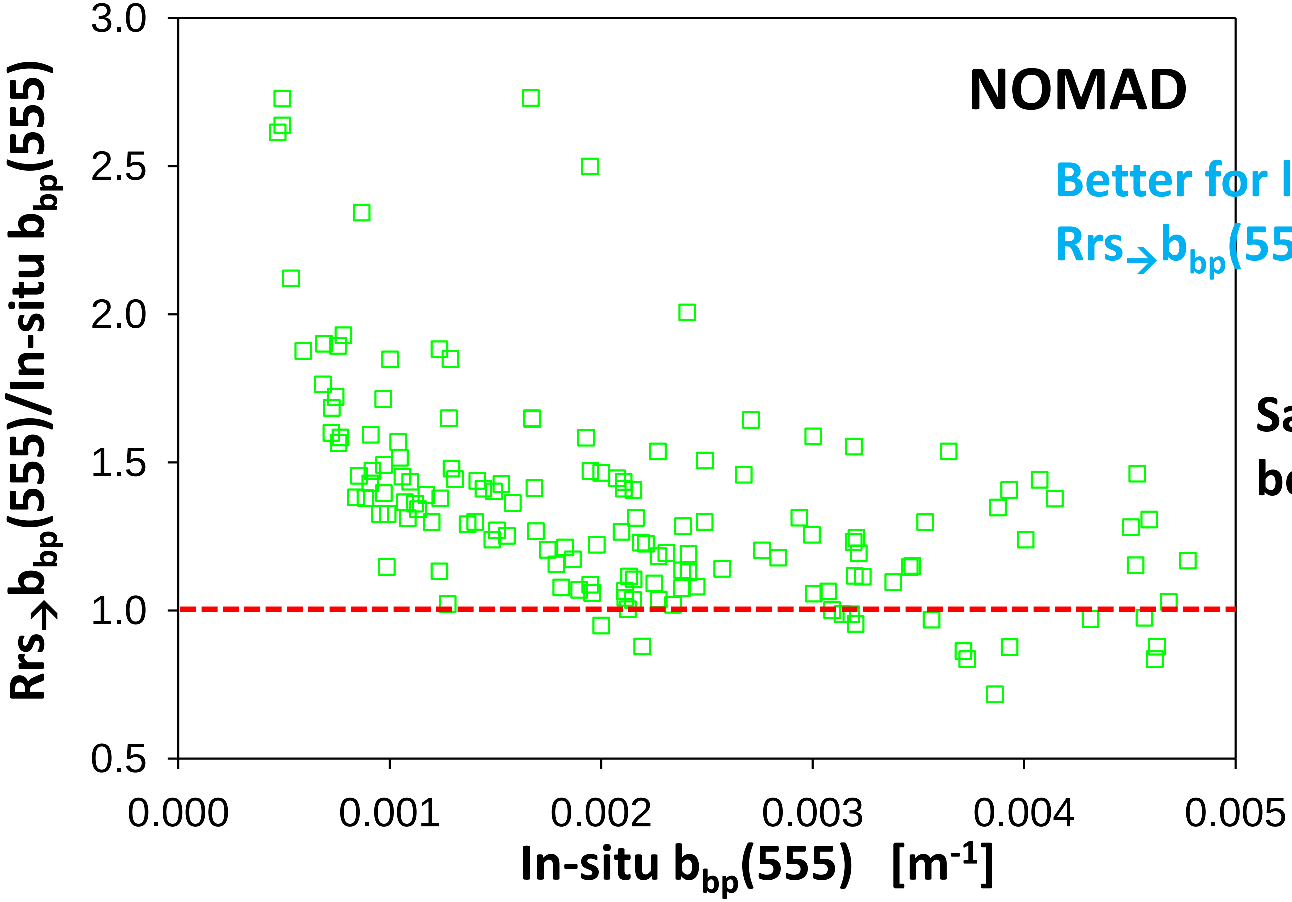
2. **Measured Rrs includes Raman scattering contribution**

3. **$a(555)$ or $a_w(555)$ value**

1. Rrs – IOPs relationship

$$R_{rs} = G\frac{b_b}{a+b_b} = \left(G_0 + G_1\frac{b_b}{a+b_b}\right)\frac{b_b}{a+b_b}$$

is supported by Radiative Transfer Theory (Zaneveld 1995)

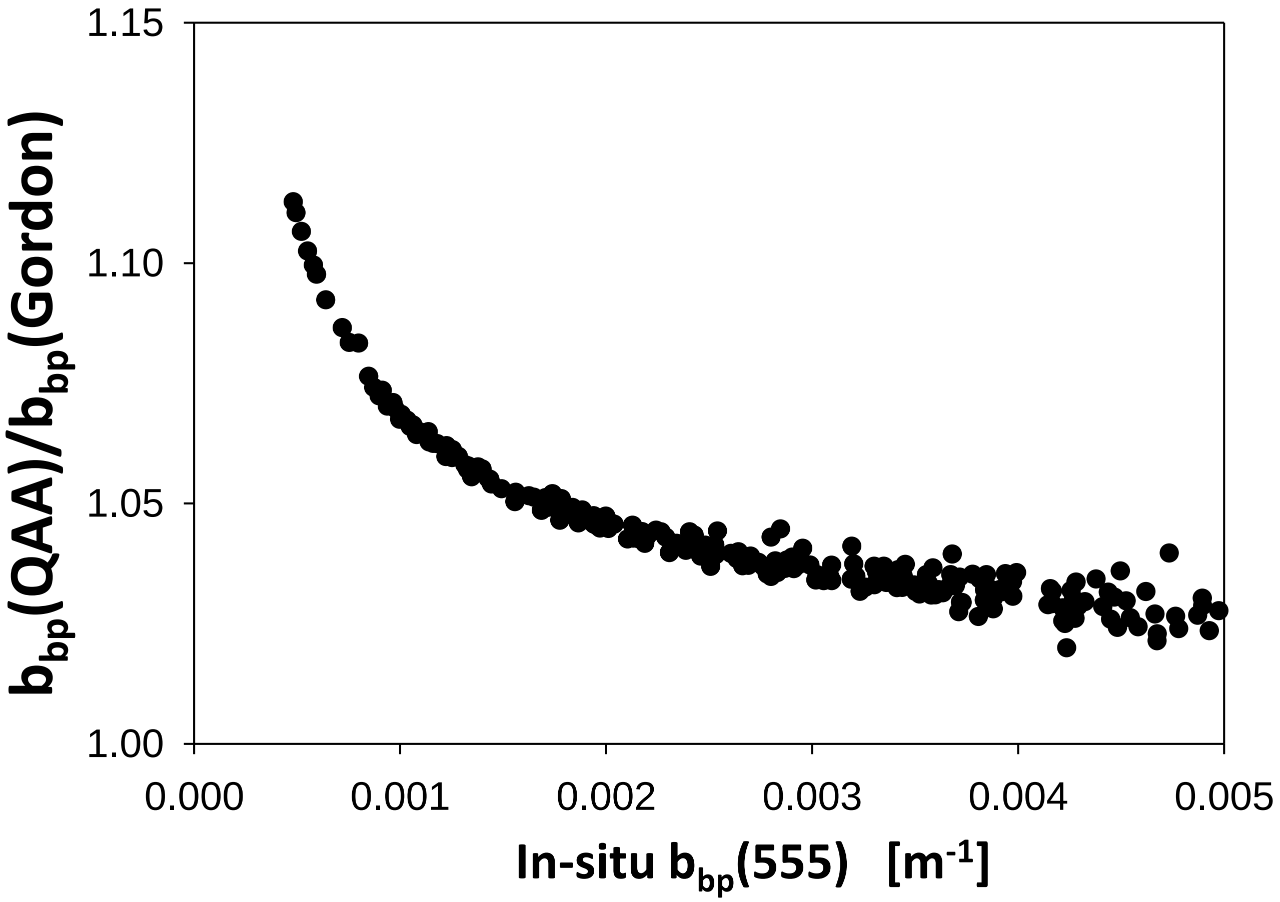


Better for larger $b_{bp}(555)$, but Rrs→$b_{bp}(555)$ is higher

Same $b_{bw}(555)$ used for both determinations.

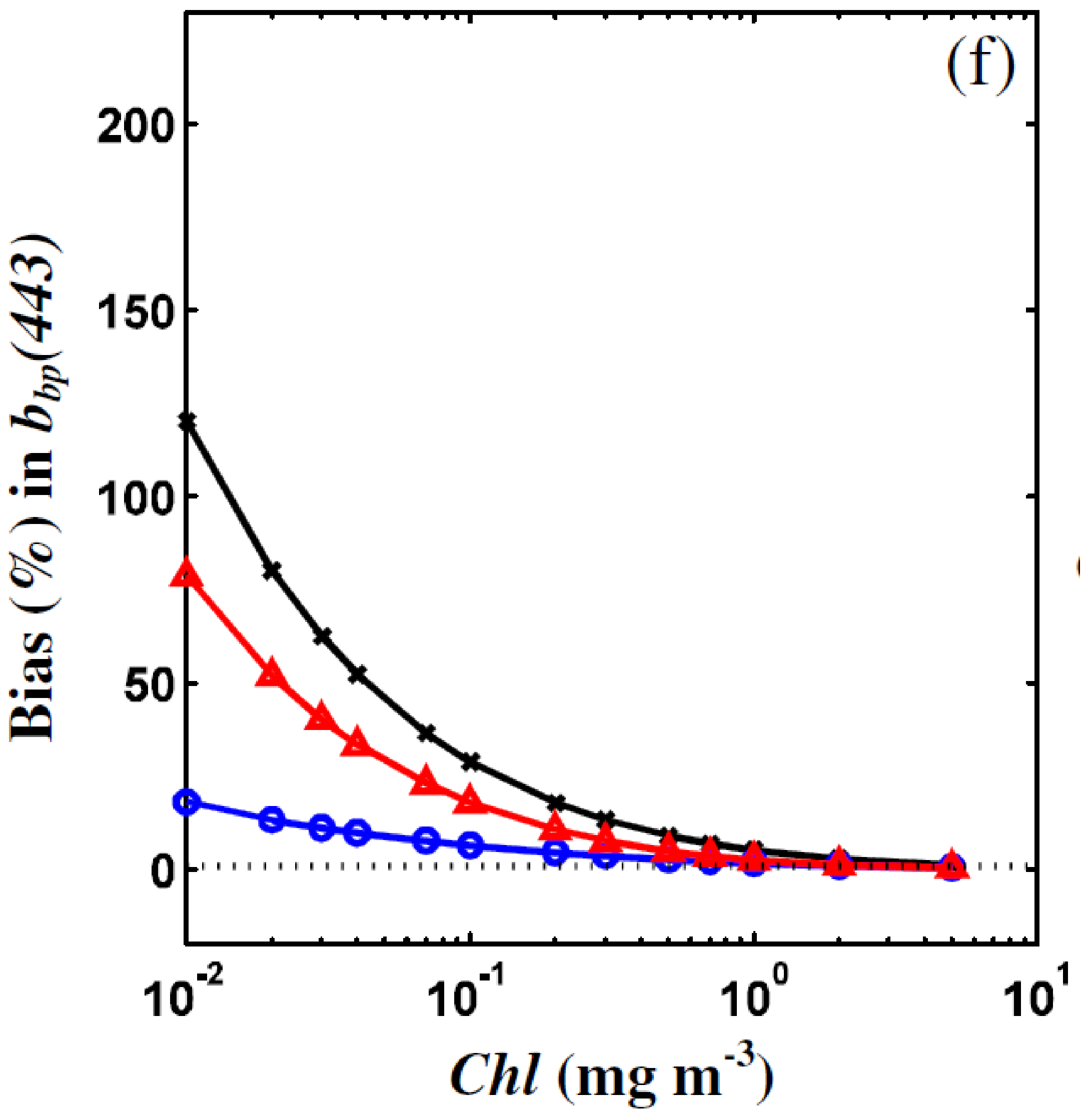
Impact of Rrs-model parameters

Gordon (0.0949;0.0794) vs QAA (0.09;0.125)



Not enough to have a factor of 2 impact.

2. Measured Rrs includes Raman scattering contribution



(Westberry et al 2013)

Empirical Raman correction (Lee et al 2013):

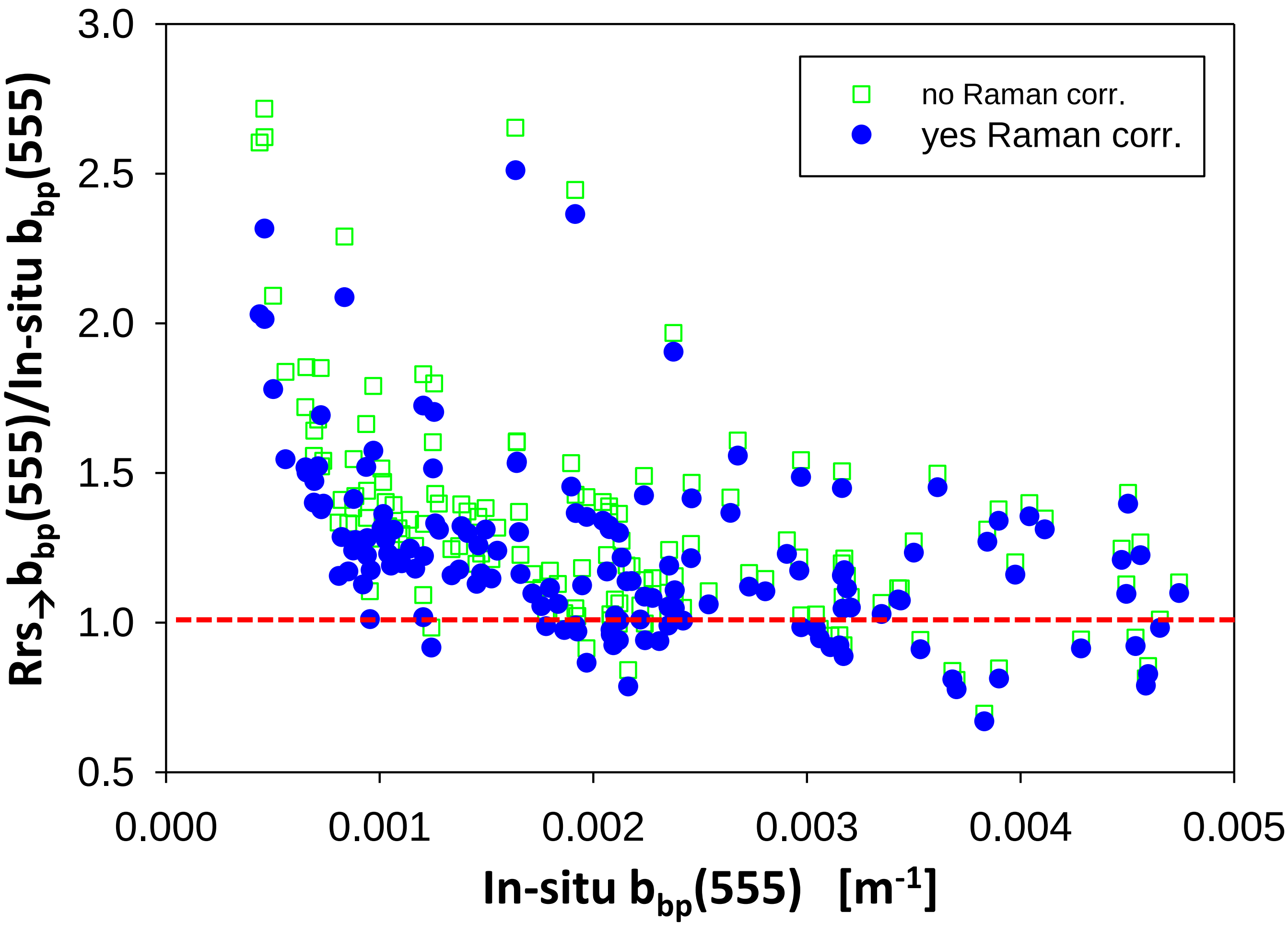
$$R_{rs} = \frac{R_{rs}^{T}}{1 + RF}$$

R_{rs}^{T} : Rrs from measurements

RF: Raman Factor

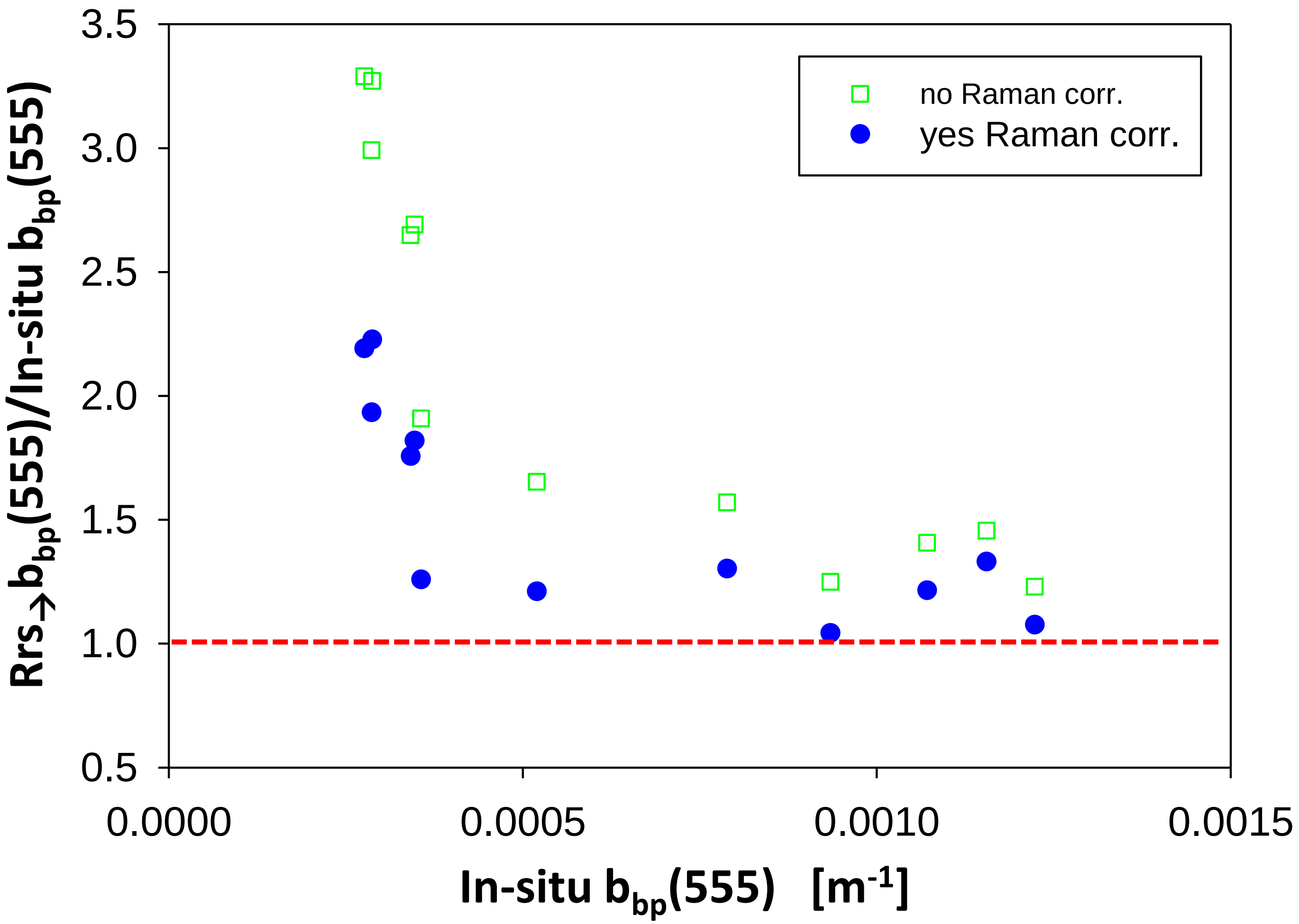
$$RF(\lambda) = \alpha(\lambda)\left(\frac{R_{rs}^{T}(440)}{R_{rs}^{T}(550)}\right) + \beta_1(\lambda)\left(R_{rs}^{T}(550)\right)^{\beta_2(\lambda)}$$

NOMAD



Yes, remove Raman effect reduces b_{bp} from Rrs

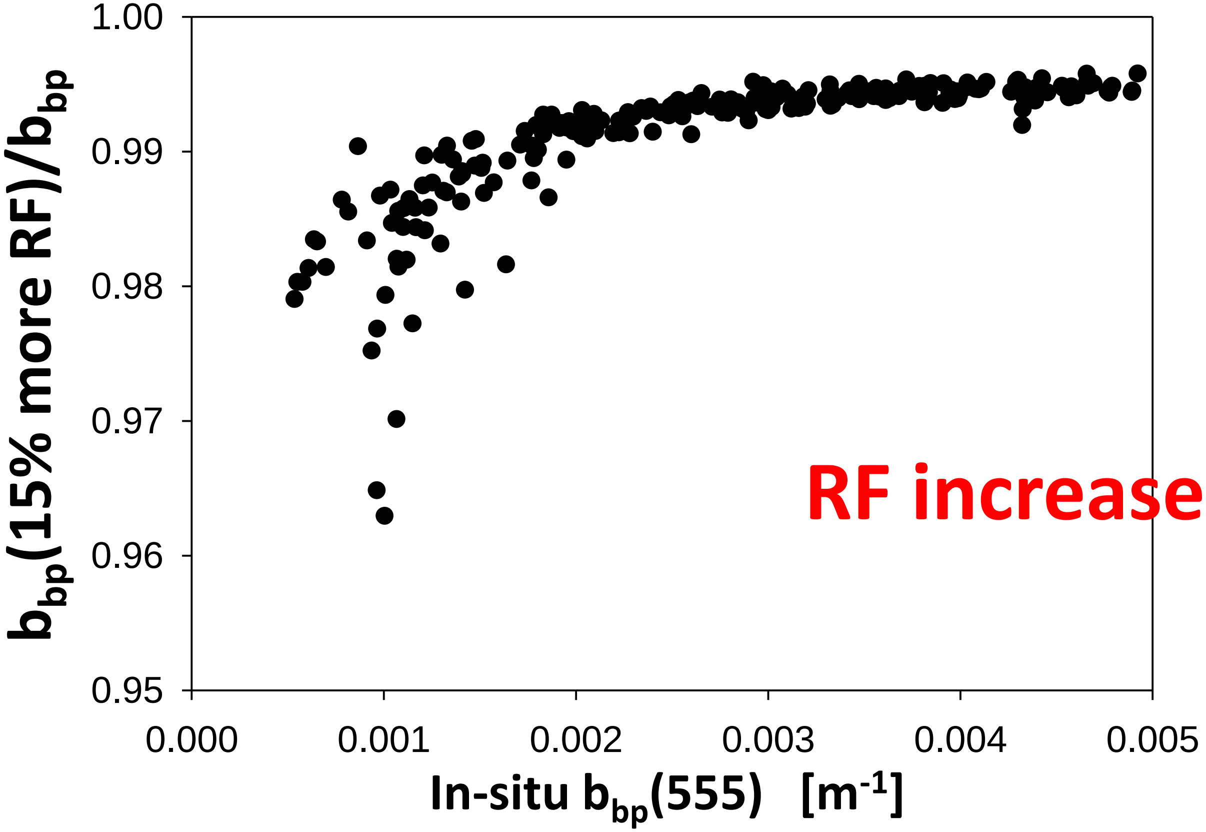
BIOSOPE data



$Rrs_{\rightarrow}b_{bp}(555)$ is still generally much higher than in-situ $b_{bp}(555)$, especially for waters with very sparse in particles.

Imperfect Raman correction?

$$RF(\lambda) = \alpha(\lambda)\left(\frac{R_{rs}^{T}(440)}{R_{rs}^{T}(550)}\right) + \beta_1(\lambda)\left(R_{rs}^{T}(550)\right)^{\beta_2(\lambda)}$$



RF increased by 15%

3. $a(555)$ or $a_w(555)$ value

↓ $a_w(555)$ → ↓ $b_{bp}(555)$

Reference	$a_w(555)$
Pope and Fry (1997)	**0.0596**
Smith and Baker (1981)	~0.0673
Tom and Patel (1979)	~0.063
Sogandares and Fry (1997)	~0.072
Buiteveld et al (1994)	0.064

The smallest value for $a_w(555)$ was used.

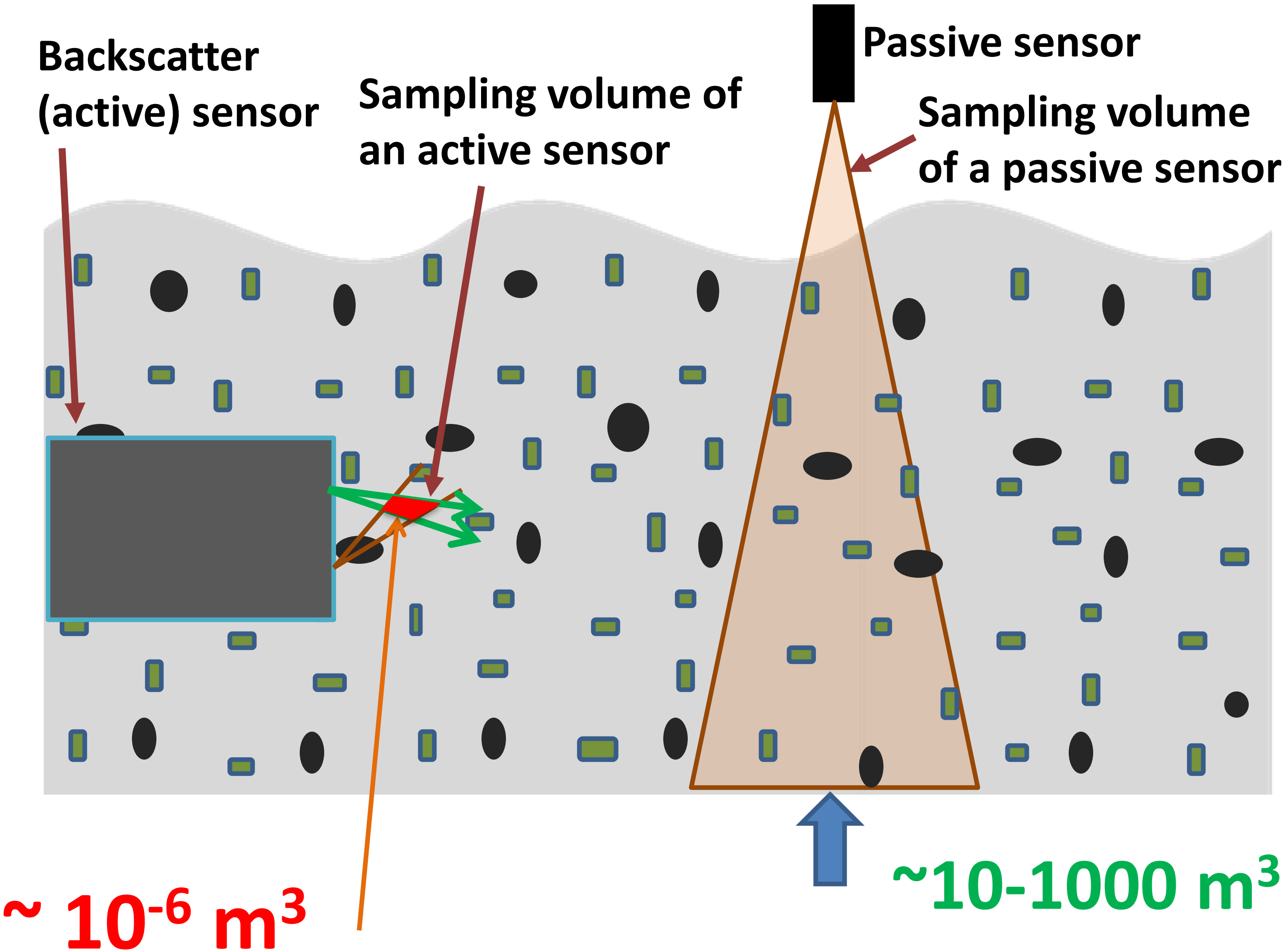
Potential sources of errors from in situ b_{bp}:

1. Calibration

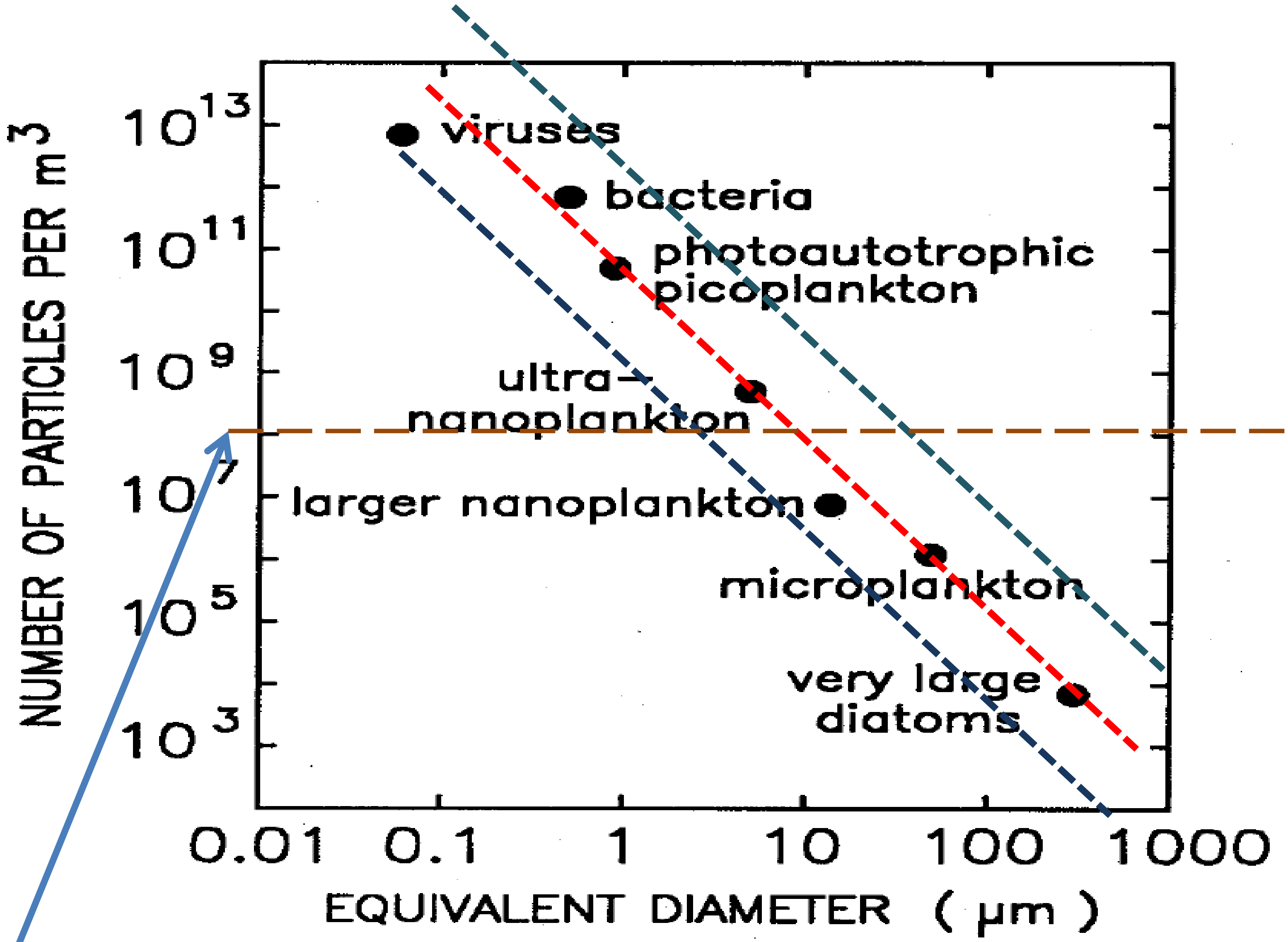
2. Sampling volume?

3. Measurement uncertainty?

2. Sampling volume?

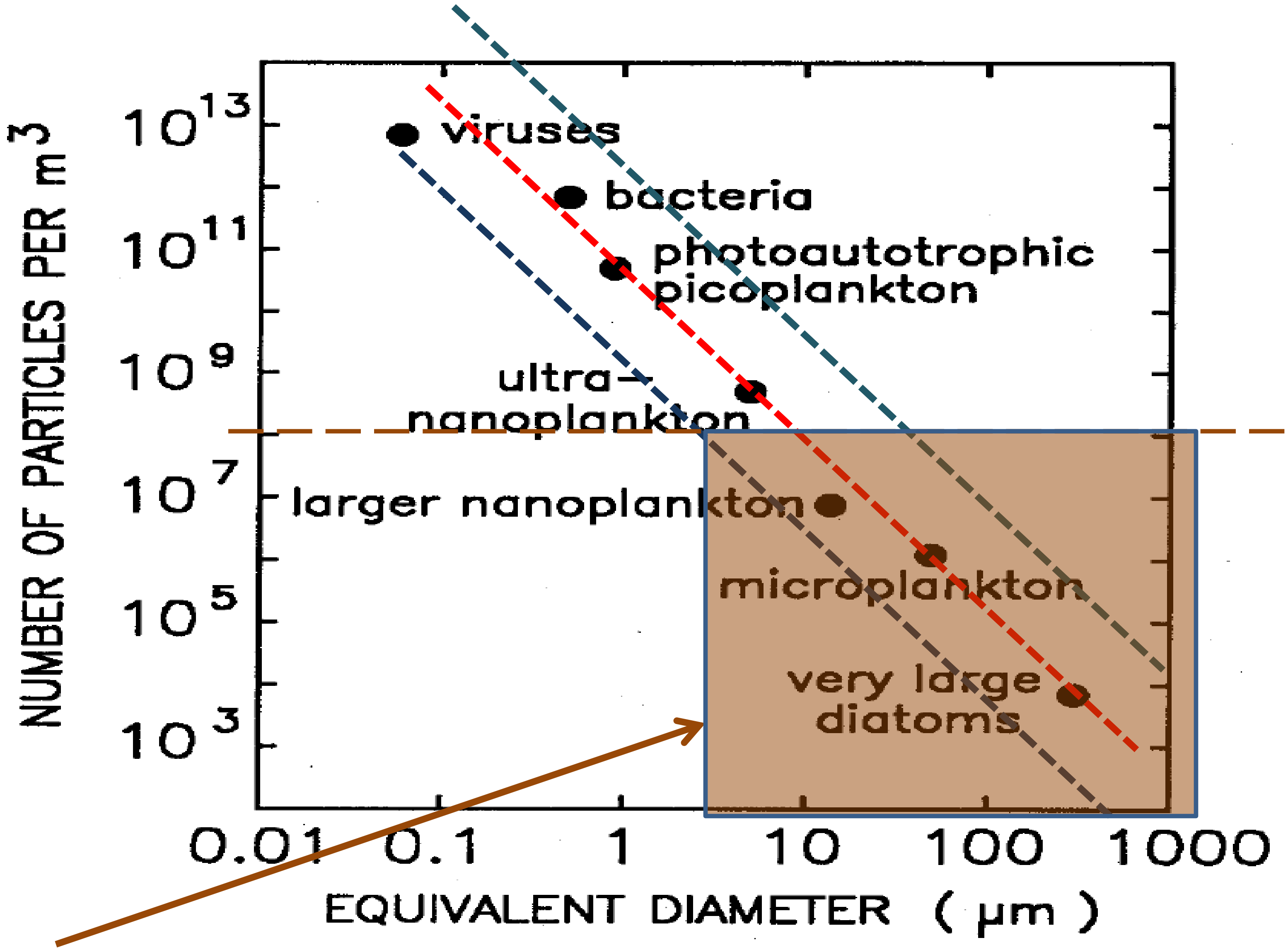


"bulk" property?



>100 particles will be sampled by the 10^{-6} m^3 sample volume

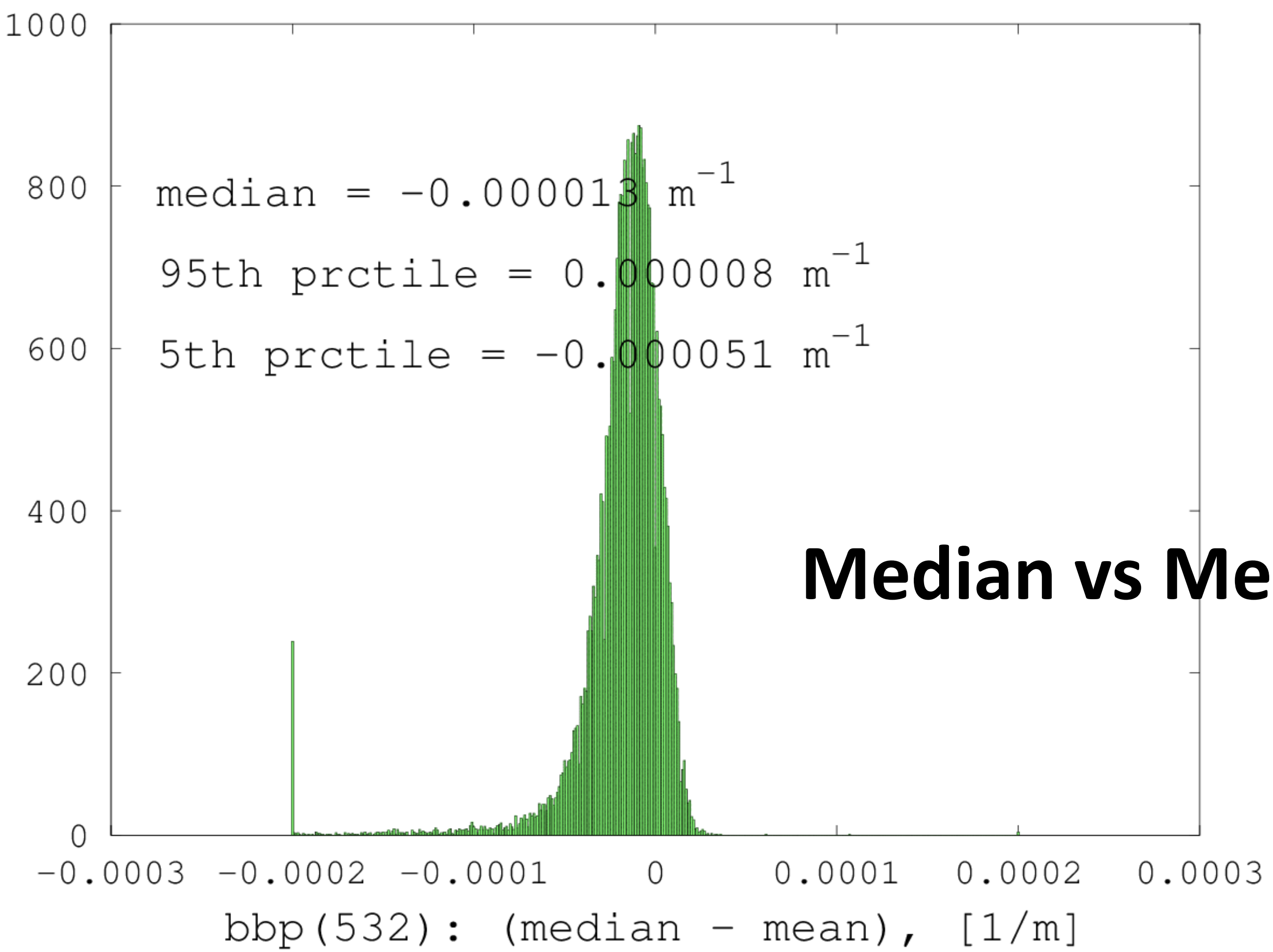
(Stramki and Kiefer 1991)



Particles could be under-represented (or missed) by 10^{-6} m^3 volume

(Stramki and Kiefer 1991)

Treat 1 min of measurements as "bulk"

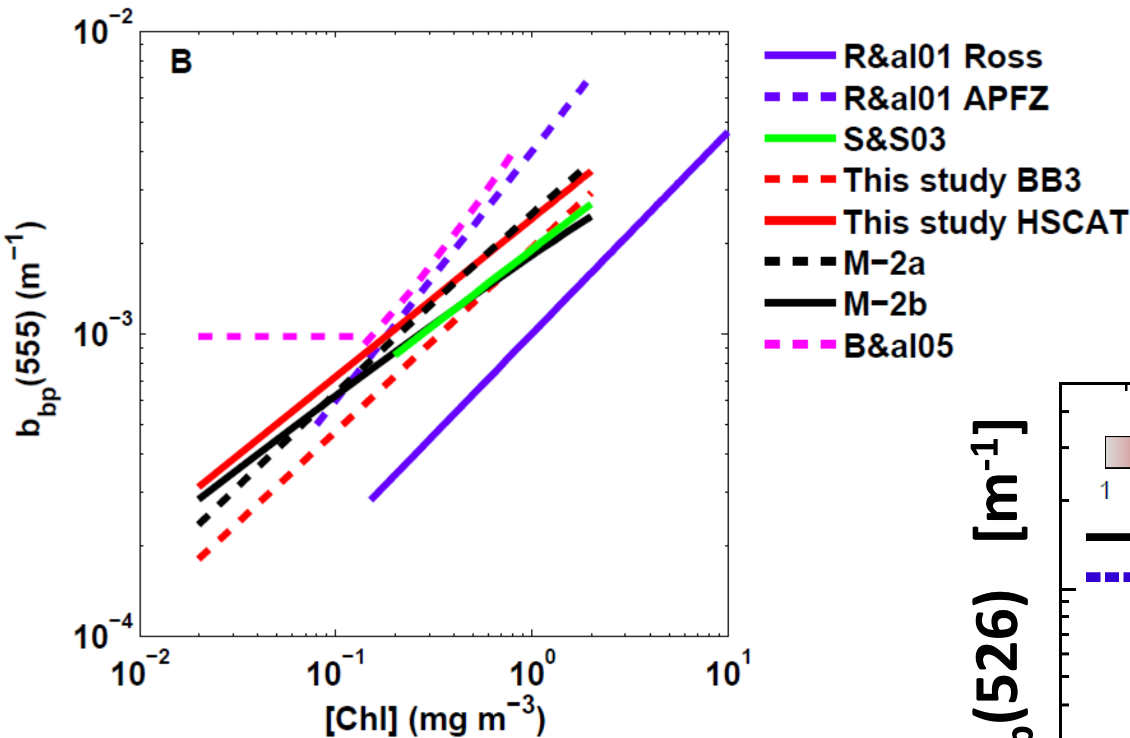


Median vs Mean

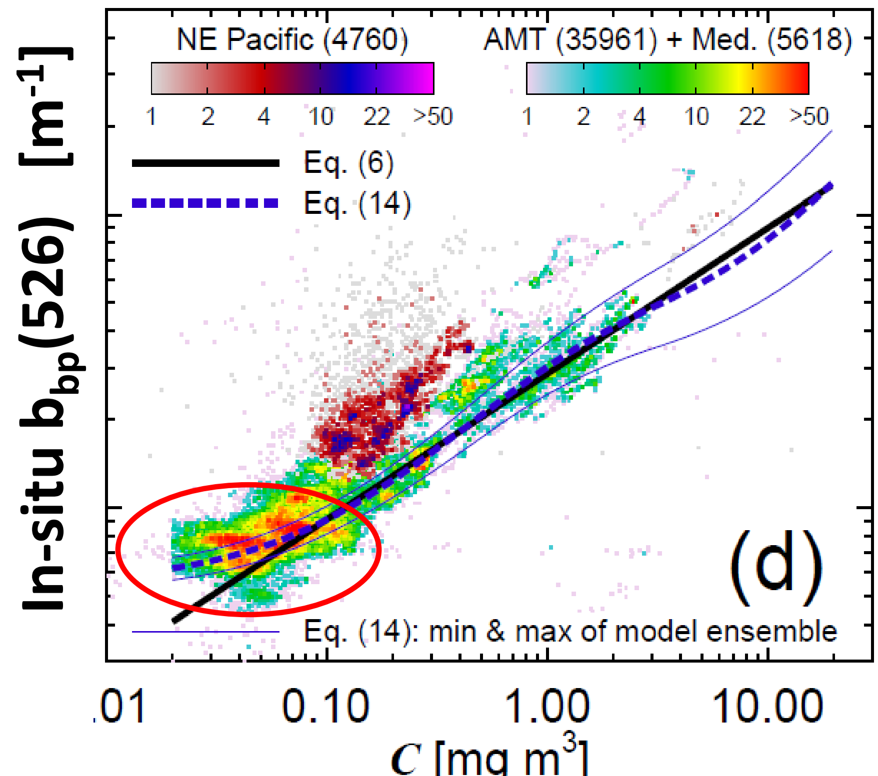
(Dall'Olmo and Brewin)

Sample volume seems not a big issue, *if* averaged/handled properly.

3. Measurement uncertainty?



(Huot et al 2008)



(Brewin et al 2012)

For Chl = 0.1 mg/m³

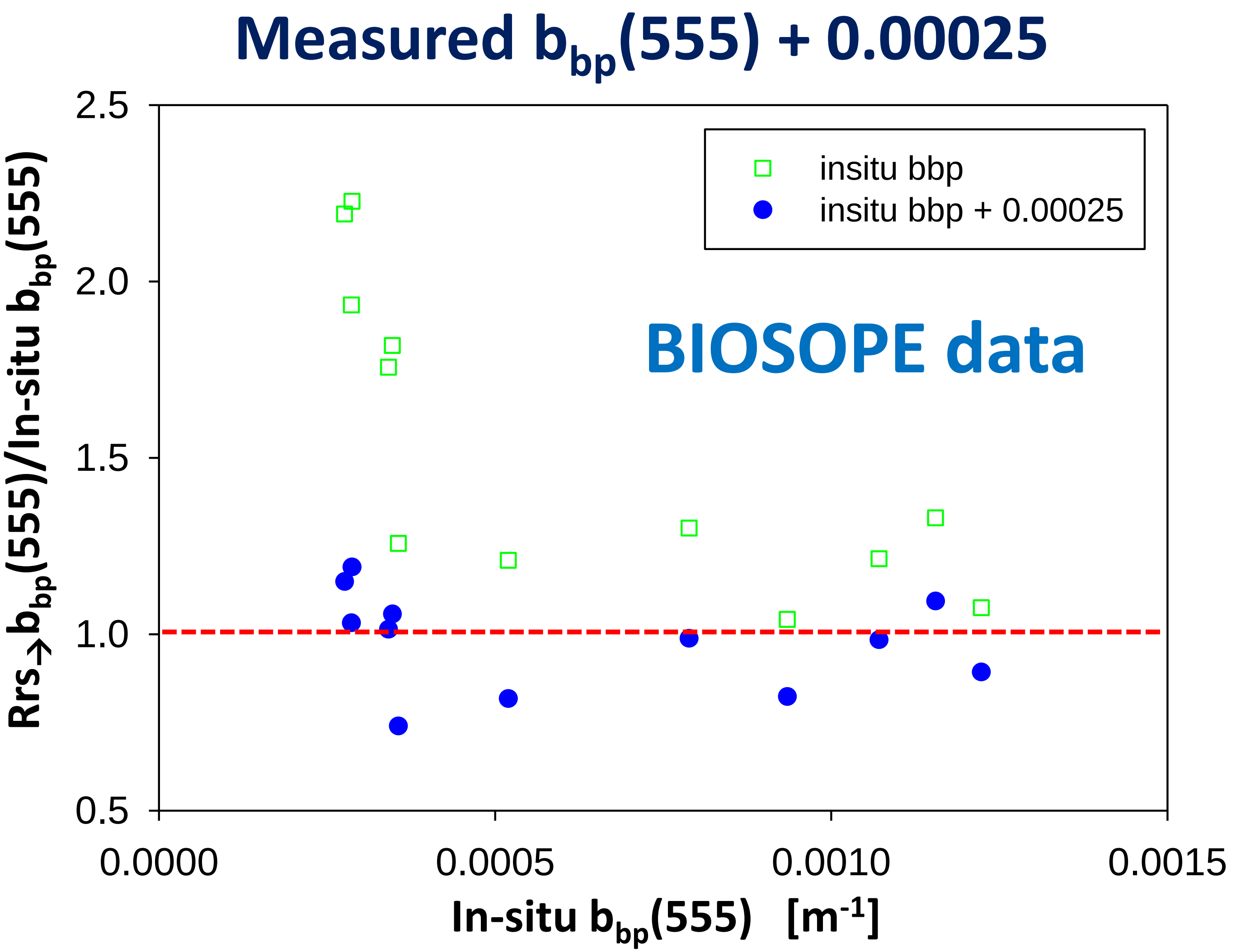
$b_{bp}(555)$:

BB3: ~0.0004 m^{-1}

HSCAT: ~0.0007 m^{-1}

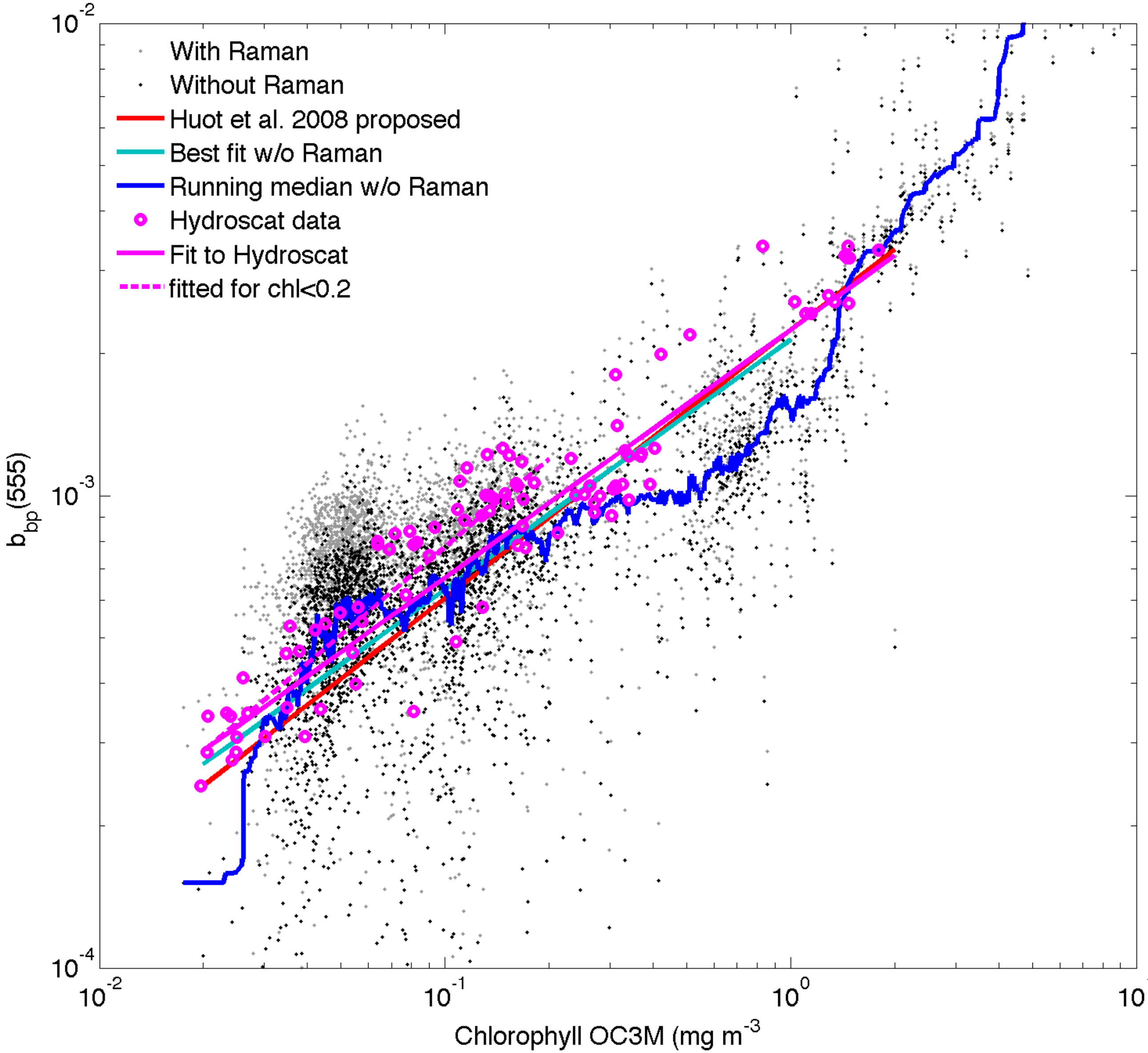
~0.0007 m^{-1}

If indeed insitu sensor missed (under-measured) b_{bp}



Much better closure for oligotrophic waters!

Updated comparison



Summary:

1. For oligotrophic ocean, b_{bp}(55x) can be retrieved very well from Rrs. Important to correct Raman effect.

2. We still have a (small) gap between inversion and insitu, though.

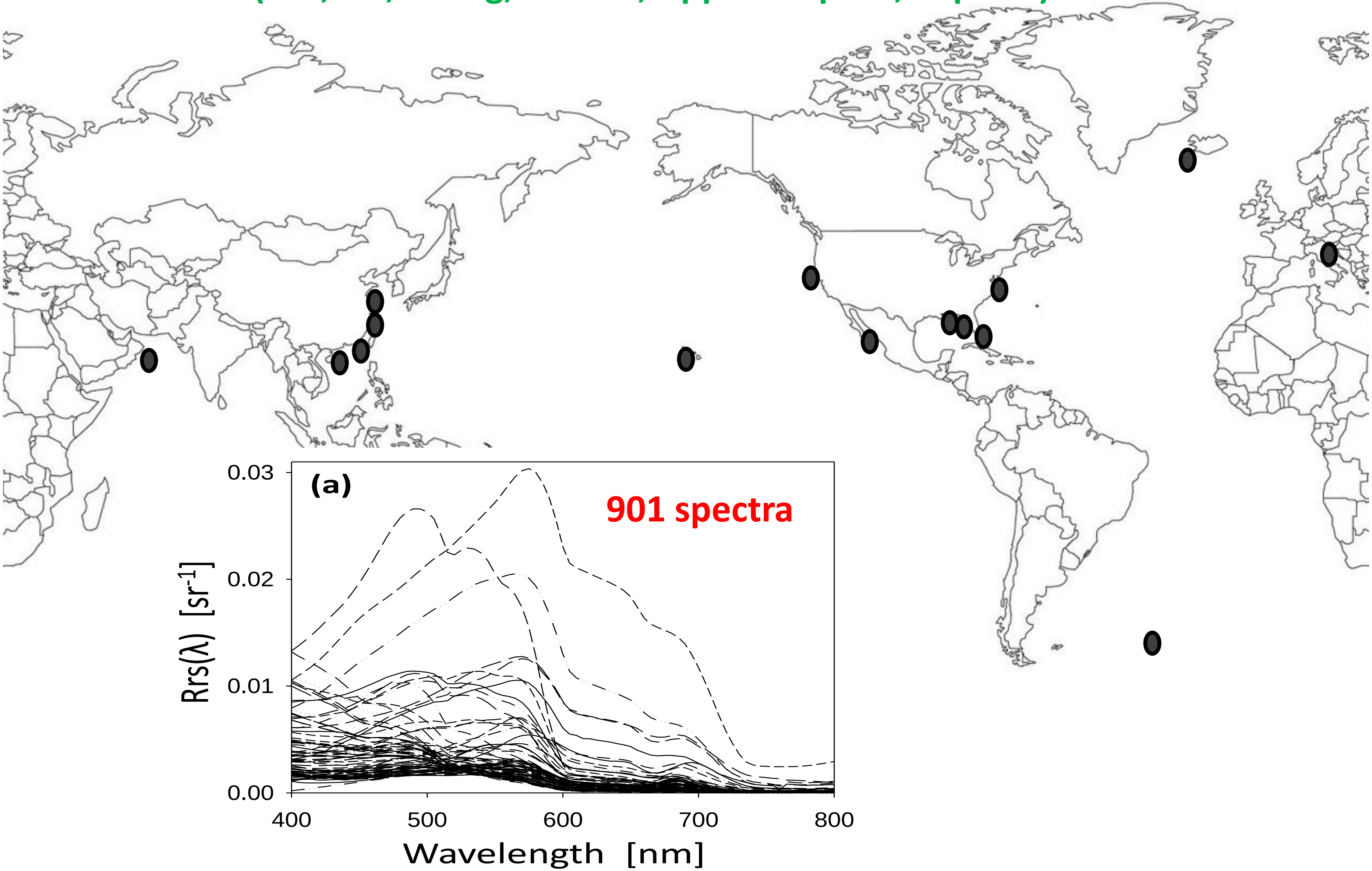
- Representation of "bulk" product
- Extremely low signal

  Insitu sensor calibration and data handling

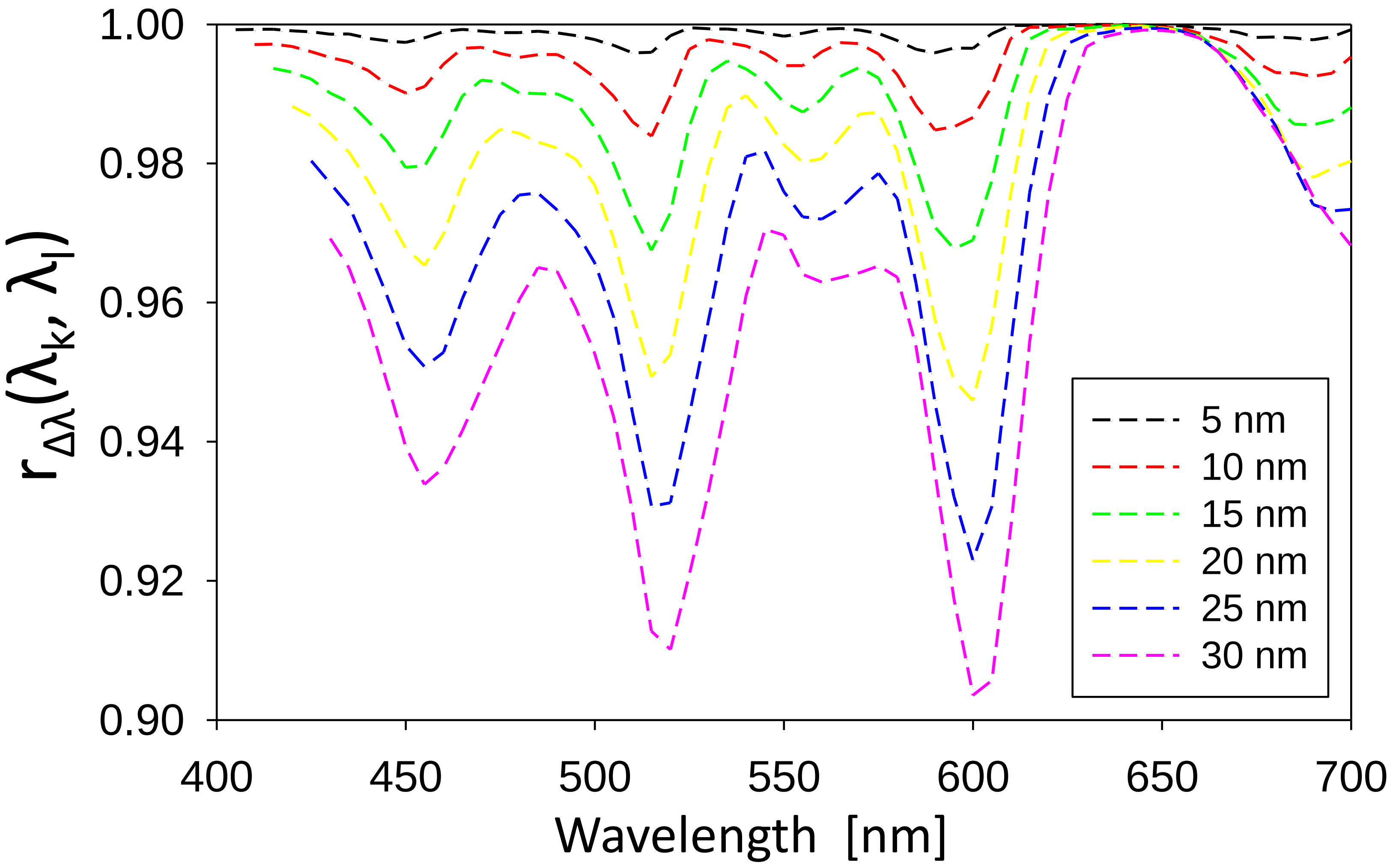
3. If ignoring the ~0.0003 m^{-1} bias, "excellent" closure is indeed achieved between inverted and insitu b_{bp}(55x).

Something about spectral resolution

(Lee, Hu, Shang, Zibordi, Applied Optics, in press)

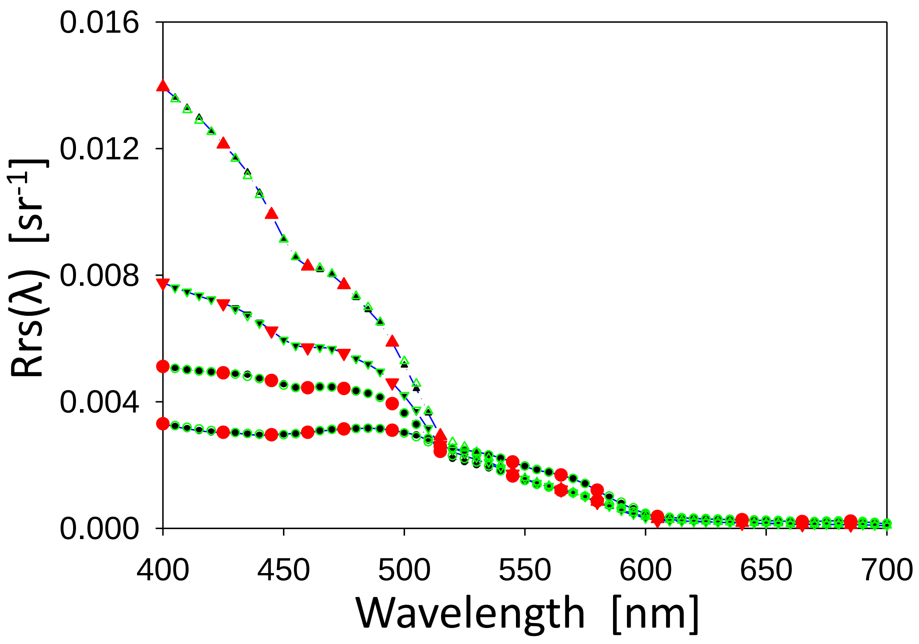


Correlation coefficient between neighboring bands, for 6 different gaps

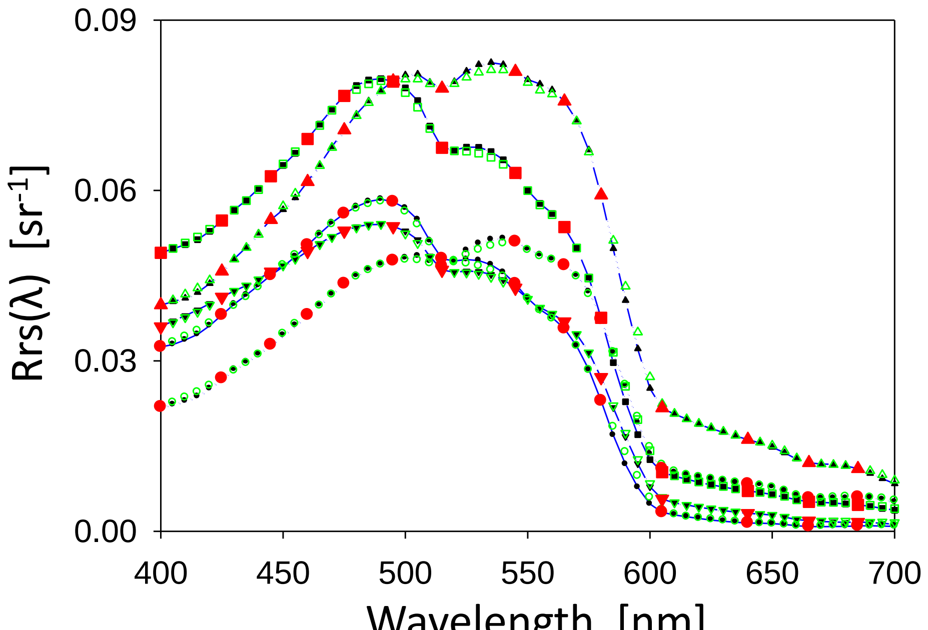


Rrs is highly correlated between neighboring bands

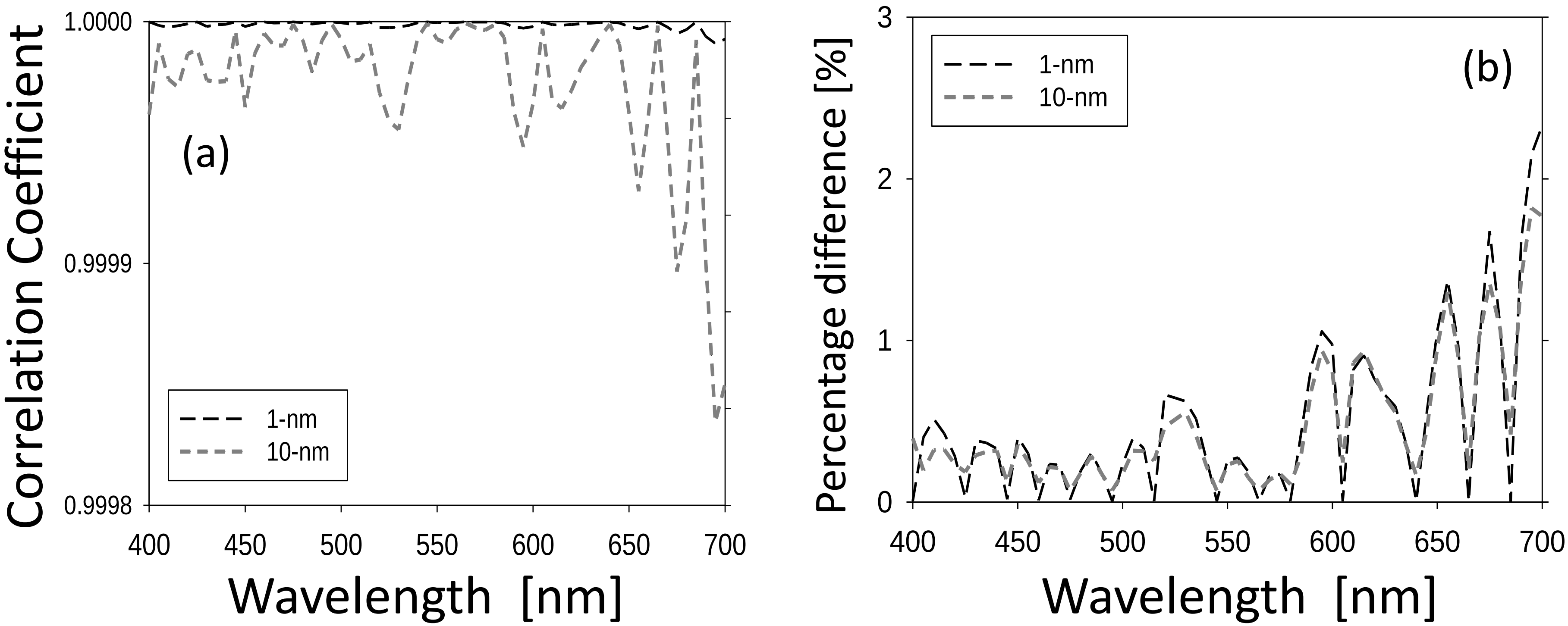
Re-constructed vs measured spectral Rrs



$$R_{rs}^{rc}(\lambda_j) = \sum_{i=1}^{15} K_{ij} R_{rs}(\lambda_i)$$



Characteristics between measured and re-constructed spectral Rrs



Hyperspectral (contiguous , 5-nm resolution) Rrs can be reconstructed from 15-band Rrs with negligible error.

Thank you!