Understanding Natural Variability of VSFs and Its Impact on Biogeochemical Retrieval from Ocean Color

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The main focus of this report is on the effect of the shapes of VSFs on remote sensing reflectance (Rrs)

Several ways to define a shape of a VSF

Backscattering ratio

$$\bar{b}_b = \frac{b_b}{b}$$

Normalized by b: the phase function

$$\bar{\beta}(\theta) = \frac{\beta(\theta)}{b}$$

$$b = 2\pi \int_0^{\pi} \beta(\theta) \sin\theta d\theta$$

Normalized by b_b: the χ factor

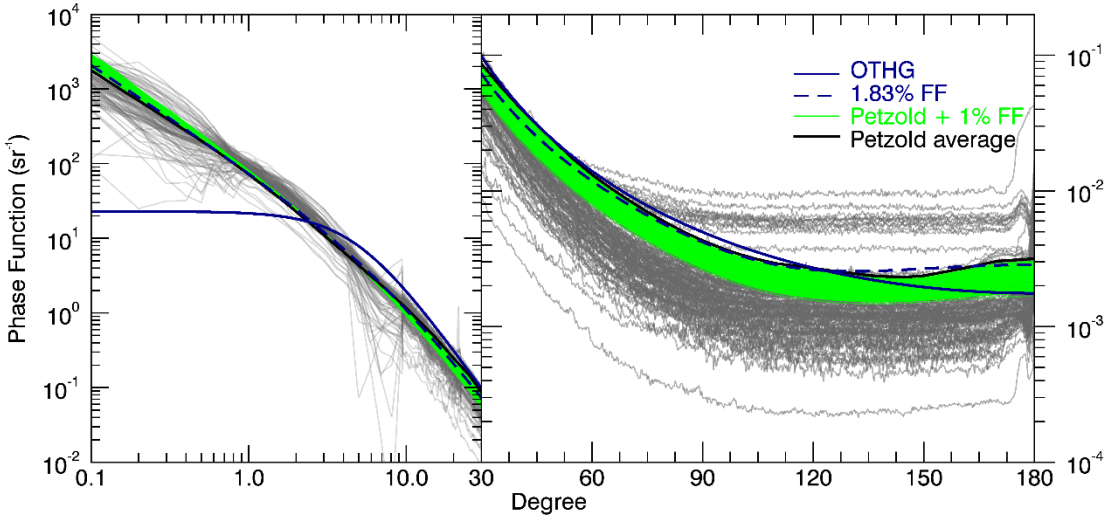
$$\alpha(\theta) = \frac{1}{\chi(\theta)} = \frac{2\pi\beta(\theta)}{b_b}$$

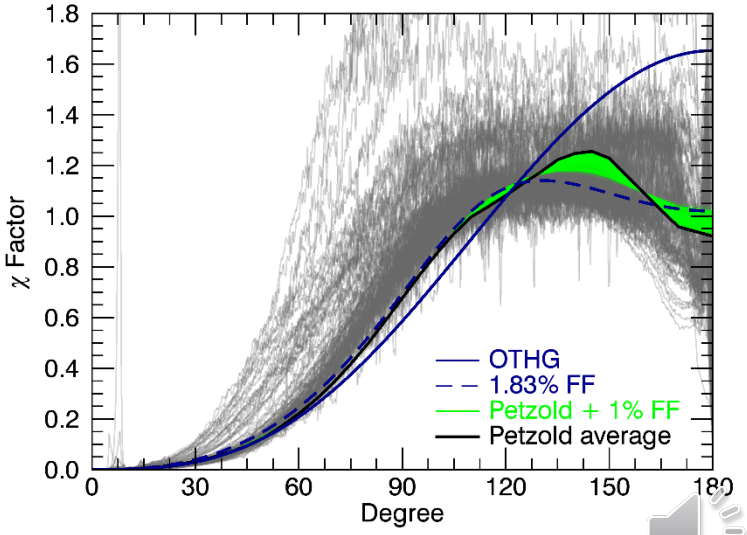
$$b_b = 2\pi \int_{\pi/2}^{\pi} \beta(\theta) \sin\theta d\theta$$

0.003 – 0.035 from measured VSFs

vs

0.011 – 0.018 from green lines in the figures.





Estimate uncertainty in Rrs due to VSF shapes

$$R_{rs} = \frac{f}{Q}\frac{b_b}{a + b_b}$$

We assume that any variations in Rrs observed for the same a and b_b and for the same viewing geometry, but for the different phase functions would be due to the shape effect.

Use HydroLight to simulate Rrs using 116 VSFs measured in Chesapeake Bay, Mobile Bay, Monterey Bay and North Atlantic Ocean.

Following the IOCCG Report No. 5 (2006, ed. Zhongping Lee):

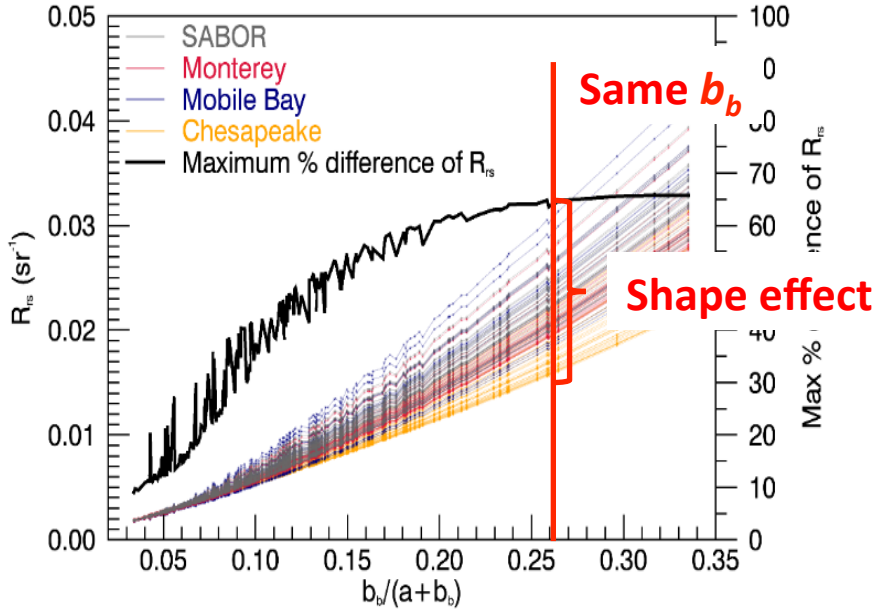
- 500 values of [C] (over 20 ranges, and 25 random values within each range)
- For each [C] value, spectral a and b_b are generated
- For each set of a and b_b, each of 116 measured phase functions was used for Hydrolight simulation
- The simulation was run for ϑ_s = 0:15:75, ϑ_v = 0:10:70, and φ = 0:15:180.
- Over 200 million simulated Rrs.

$$\Delta R_{rs} = \frac{|R_{rs}(i) - R_{rs}(j)|}{\frac{R_{rs}(i) + R_{rs}(j)}{2}}$$

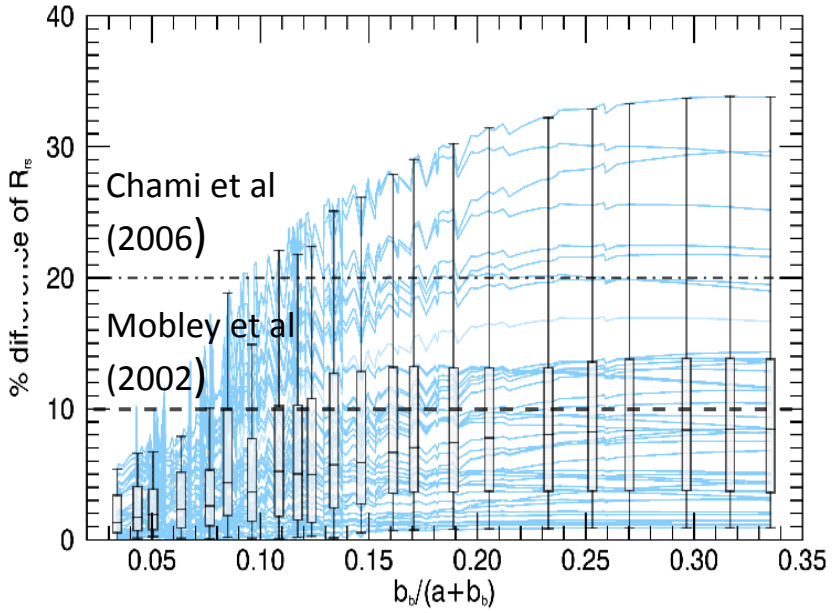
ΔRrs due to VSF shapes: θ_s = 30°, θ_v = 0°, λ = 532 nm

Increasing constraint on the shape of VSFs

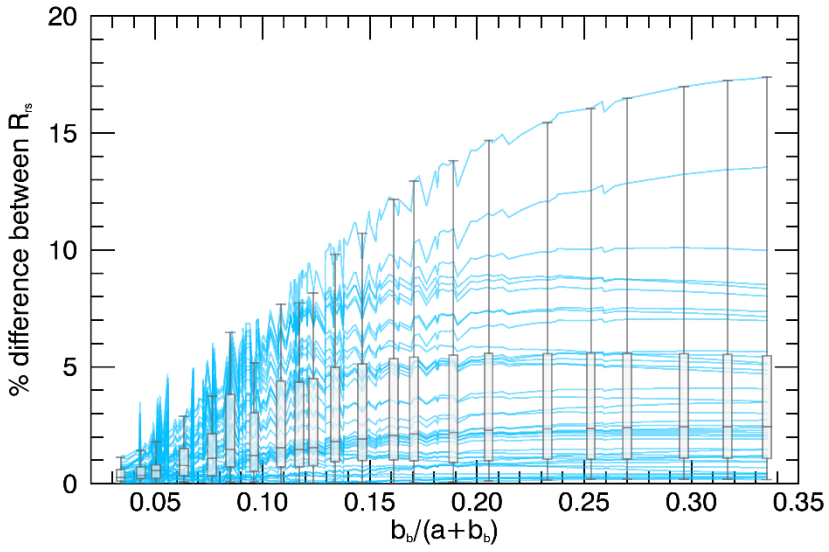
Same b_b



Same b_b + same b_b ratio

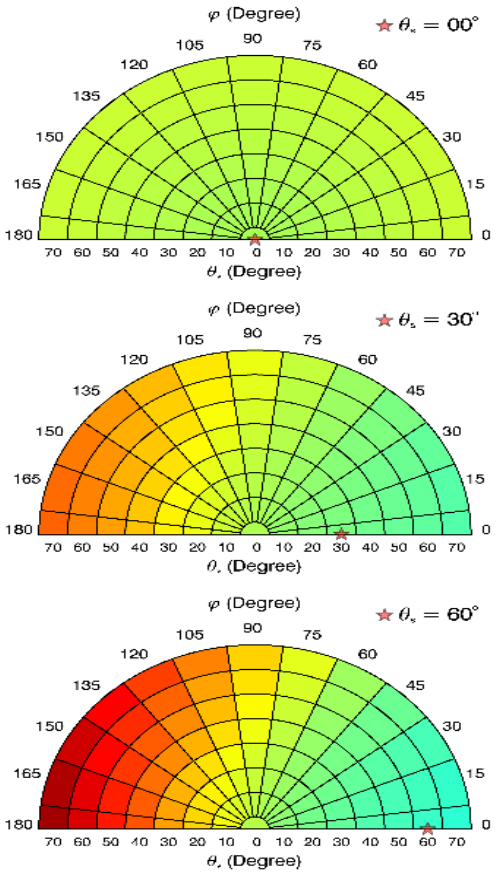


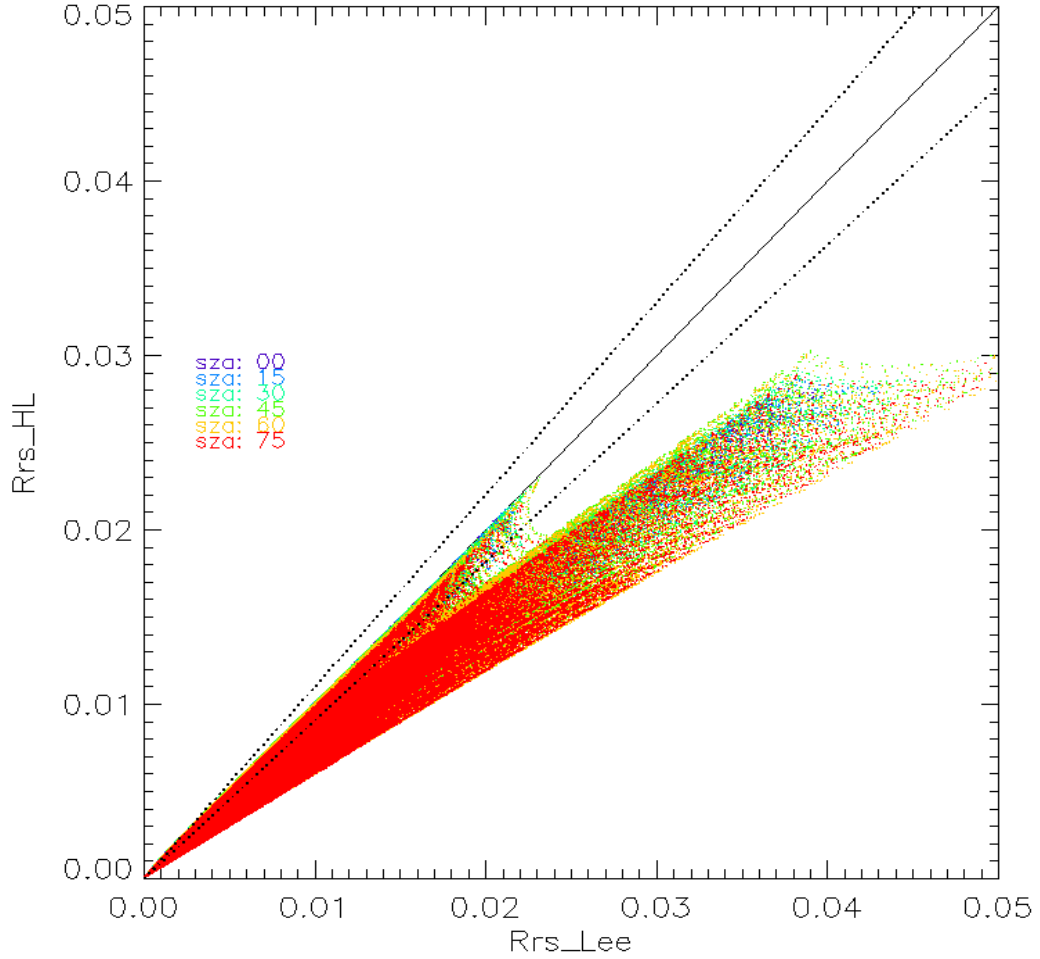
Same b_b + same χ



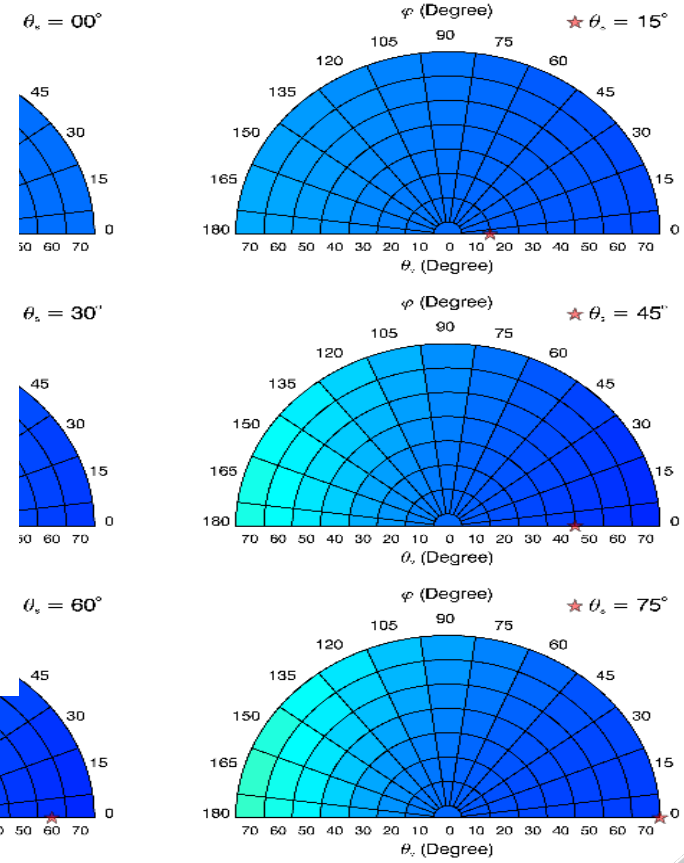
Maximum ΔRrs due to VSF shapes: BRDF

Same b_b





ame b_b + same χ



Comparison of Lee et al. (2011) BRDF model with HydroLight simulation using a phase function that has a shape different from those used in the model development.

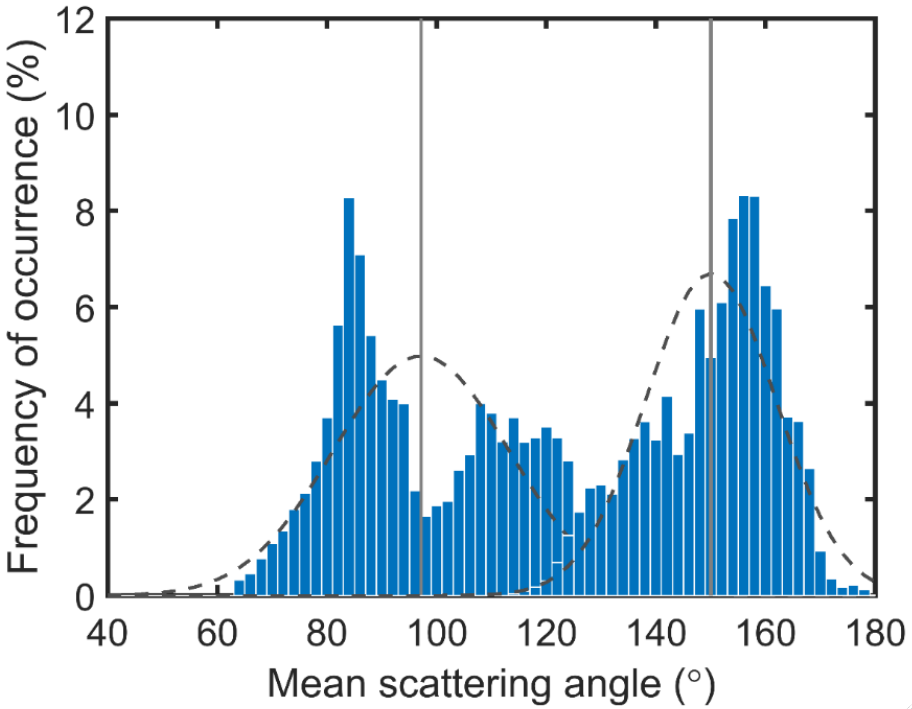
Rrs is directly proportional to χ factor

From RTE, Zaneveld (1982; 1995) derived:

$$r_{rs}(\theta,\phi) = \frac{1}{2\pi\chi(\gamma_m)} \frac{b_b}{g(a,\beta,\theta,\varphi)}$$

$$g(a,\beta,\theta,\phi) = \mu_d \left[K_{Lu}(\theta,\phi)\left|\cos\theta\right| + a + b_b - (f_L(\theta,\phi)-1)b_f \right]$$

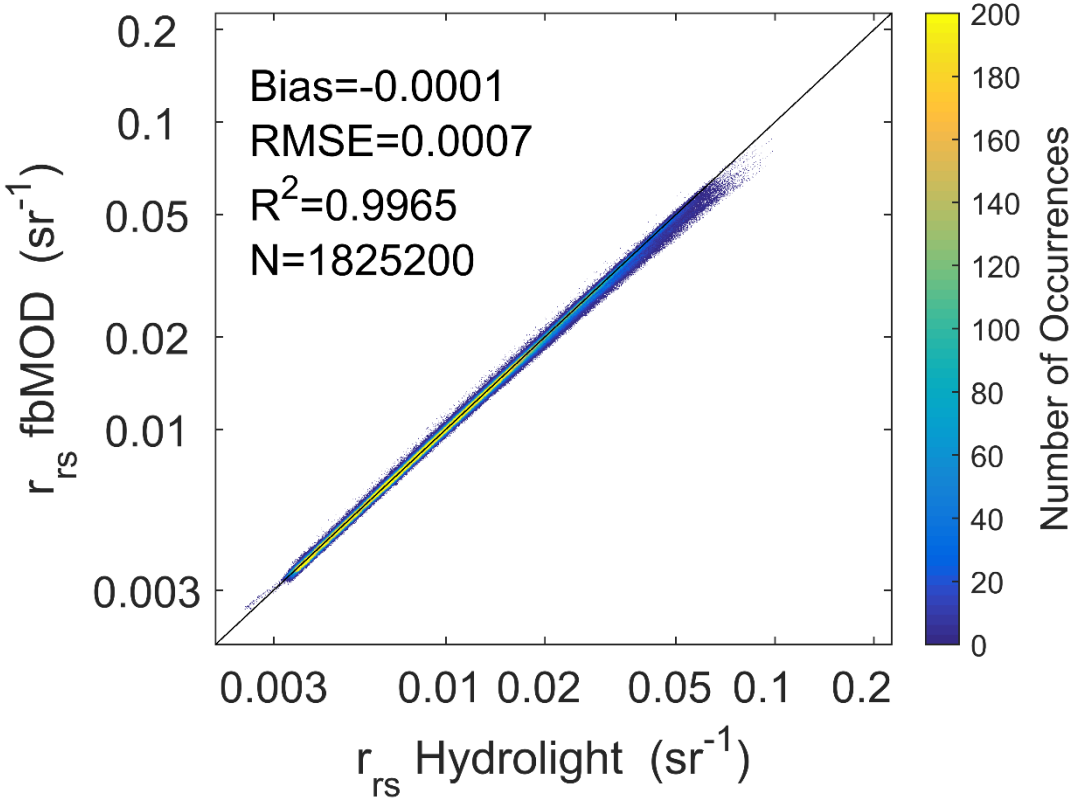
HydroLight-simulated mean scattering angles

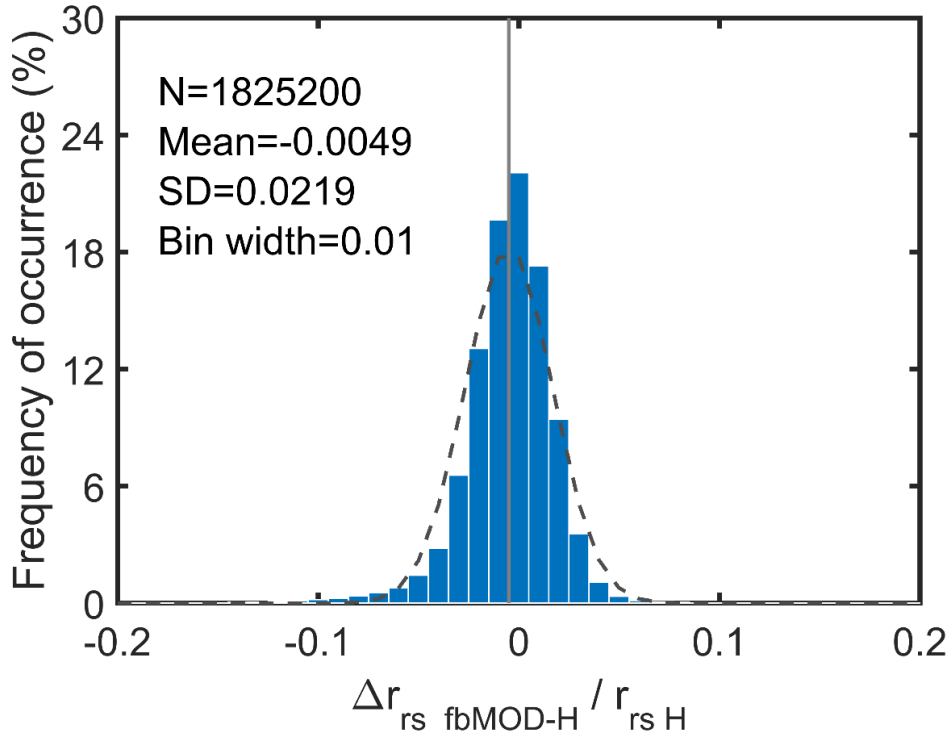


A Zaneveld Rrs model explicitly accounting for the shape of the VSFs (MS under preparation)

$$r_{rs}(\theta,\phi) = \frac{1}{2\pi\chi(\gamma_m)} \frac{b_b}{g(a,\beta,\theta,\varphi)} \qquad \frac{1}{\chi(\gamma_m)} \equiv \alpha(\gamma_m) = \frac{b_{bw}}{b_b}\alpha_w(\gamma_m) + \frac{b_{bp}}{b_b}\alpha_p(\gamma_m)$$

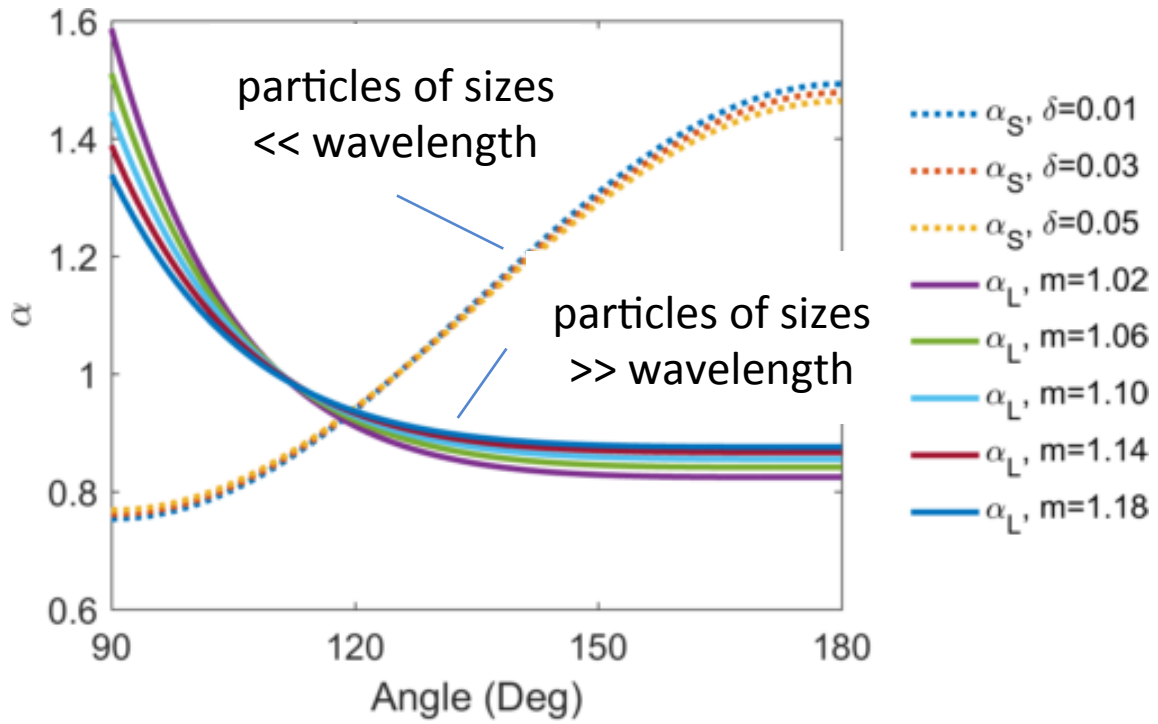
$$\alpha_w(\gamma_m) = c_{w,1}\alpha_w(\gamma_s) + c_{w,0} \qquad \alpha_p(\gamma_m) = c_{p,1}\alpha_p(\gamma_s) + c_{p,0}$$

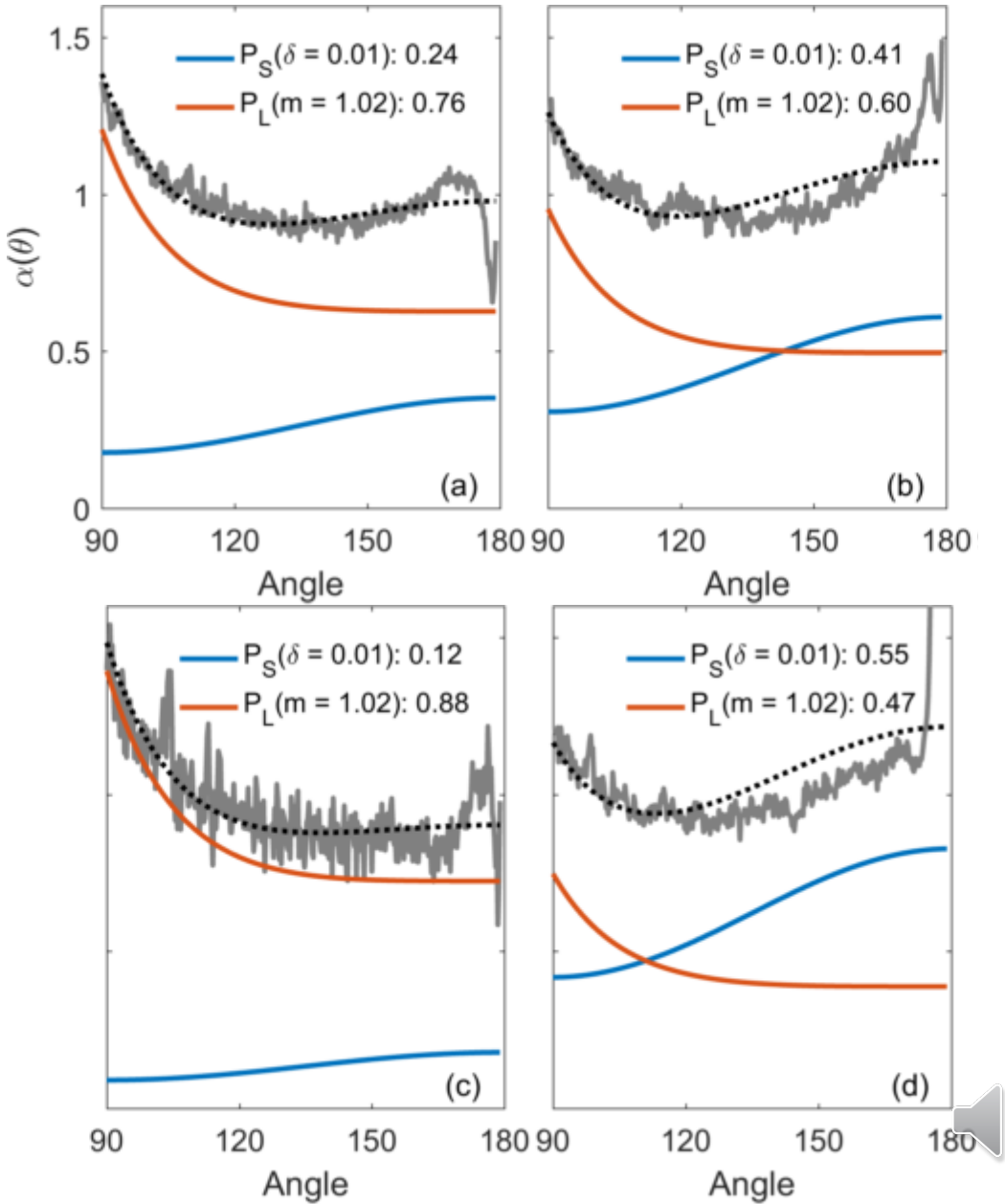




To estimate the χ factor (Zhang et al. in review)

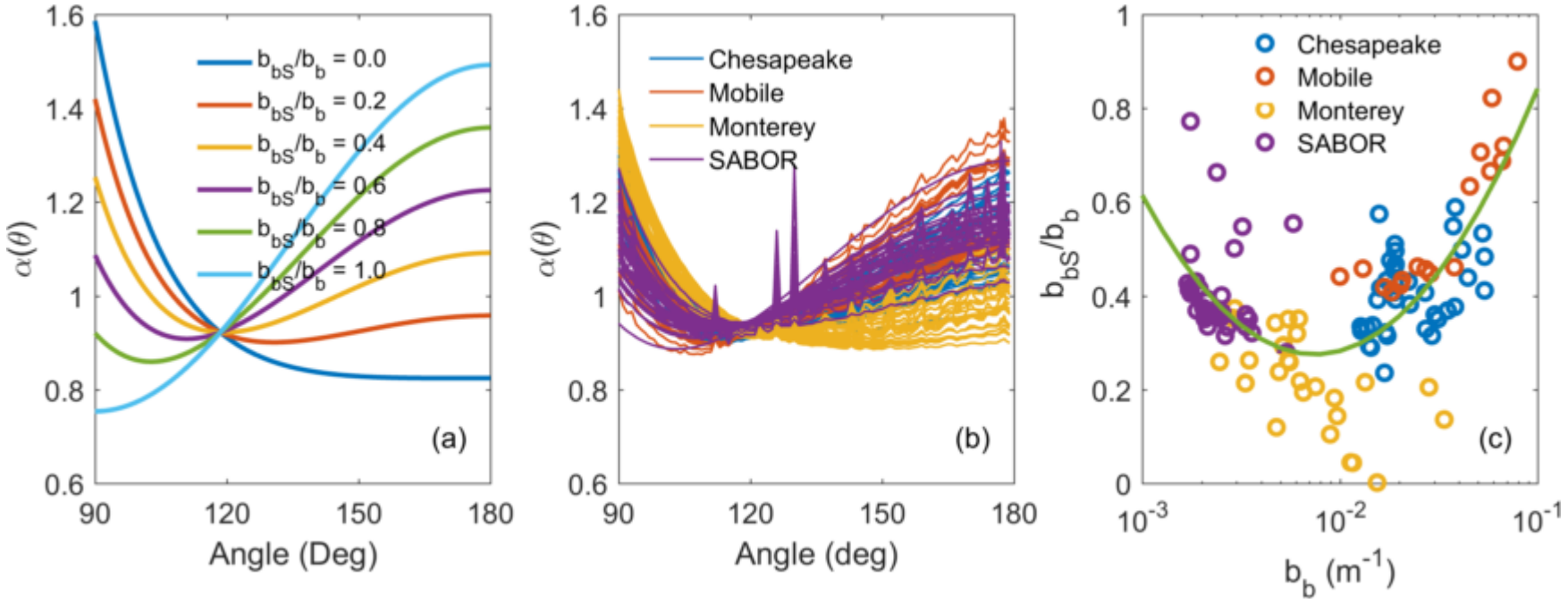
$\alpha = 1/\chi$





Conclusion: the χ factor can be represented by a linear mixing of two end members: one for extremely small particles and the other for large particles as compared to the wavelength.

To estimate the χ factor



$$\alpha(\theta) = \frac{b_{bS}}{b_b}\alpha_S(\theta) + (1 - \frac{b_{bS}}{b_b})\alpha_L(\theta).$$

$$\frac{b_{bS}}{b_b} = 0.45(\pm 0.05)(\log b_b)^2 + 1.90(\pm 0.21)\log b_b + 2.29(\pm 0.21).$$

Conclusions

- The natural variability of the shape of particle VSFs has been underestimated due to limited measurements.
- Therefore, the impact of the VSF shapes on Rrs has been underestimated as well.
- The variability of Rrs due to VSF shapes generally increases with backscattering and with both viewing and sun angles
  - For nadir view, the maximum and median uncertainties are 70% and 10%
- Knowledge of the VSF shapes in the backward angles (i.e., the Chi factor) can significantly reduce the uncertainty
  - Rrs can be predicted within 2%
- Currently, we're incorporating our latest results of predicting the Chi factor from b_b into the Zaneveld-type Rrs model.