Improving Retrieval of IOPs from Ocean Color Remote Sensing Through Explicit Consideration of the Volume Scattering Function

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Summary of Project Objectives

✓ • VSF shape analysis

✓ • IOP-AOP closure analysis with *almost* fully parameterized, high quality data sets

• Performance assessment of radiative transfer approximations with explicit consideration of the VSF

3-Y project initiated Sep 2015

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Closure and uncertainty assessment for ocean color reflectance using measured volume scattering functions and reflective tube absorption coefficients with novel correction for scattering

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Table 2. Descriptions of Scattering Error Corrections Applied for WET Labs ac Device Absorption Measurements[a]

Label	Description	Formula for Scattering Error, $\varepsilon(\lambda)$
BL	Measured absorption at 715 nm reference wavelength assumed to be 100% scattering error (i.e., assumes no real absorption in the near-R). Error assumed spectrally constant.	$a_m(715)$
PROP	Measured absorption at 715 nm reference wavelength assumed to be 100% scattering error. Error is scaled spectrally by the ratio of measured total scattering ($c-a$) (i.e., assuming that the ratio of scattering error to total scattering is constant spectrally).	$a_m(715)\frac{c_m(\lambda)-a_m(\lambda)}{c_m(715)-a_m(715)}$
VSF98P	Scattering error is independently derived by convolving measured VSF β with angular weighting function W_ε of the scattering error for WET Labs ac device reflective tube modeled in McKee *et al.* [15]. Weighting function associated with 98% tube reflectivity is applied after Stockley *et al.* [13]. Error is scaled spectrally according to the PROP method.	$2\pi\int_0^\pi \sin(\theta)W_\varepsilon(\theta)\beta(\theta,658)\mathrm{d}\theta\frac{c_m(\lambda)-a_m(\lambda)}{c_m(650)-a_m(650)}$

[a]Scattering errors are subtracted from measured absorption a_m.

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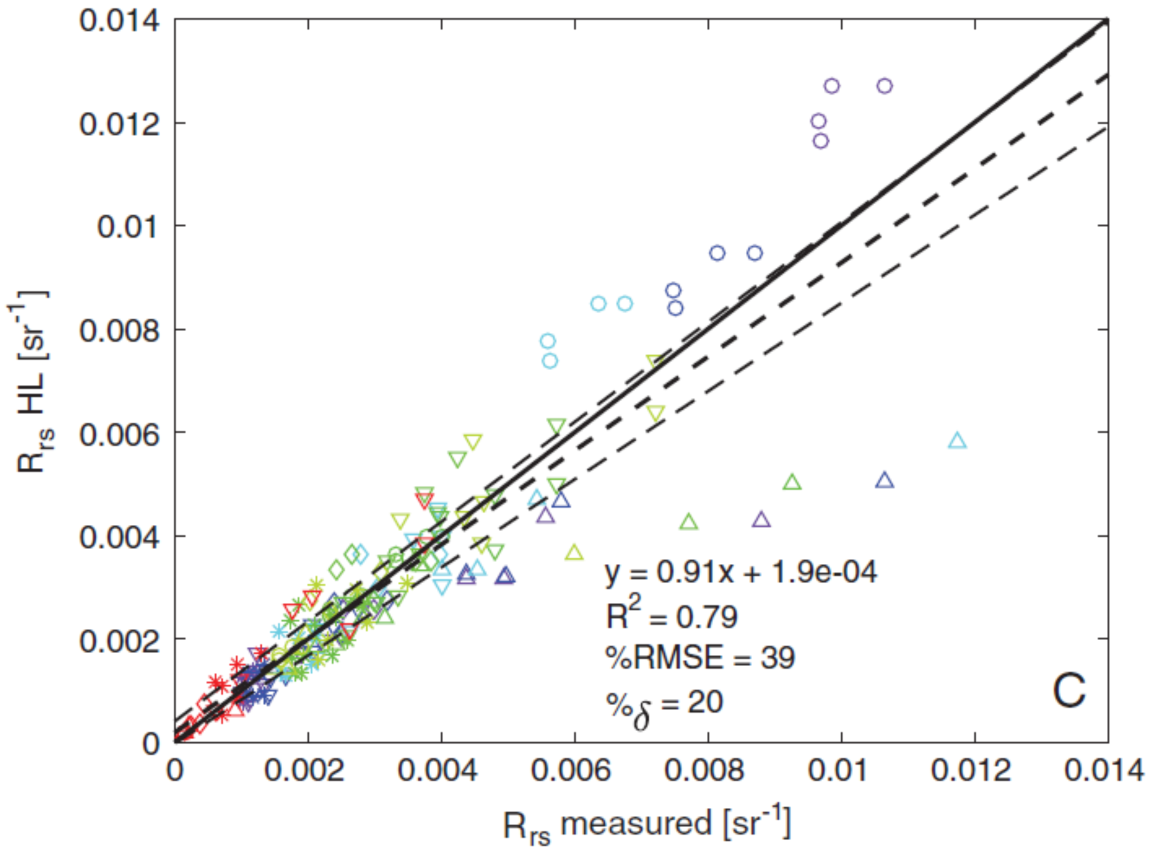
RRS match ups
24 stations, all wavelengths
measured VSFs



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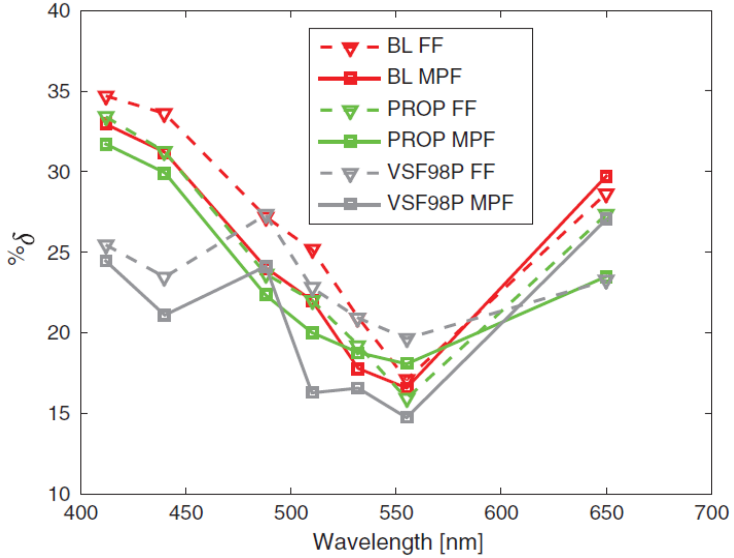
Conclusions

- About half of error coming from reflectance measurements in match ups, other half from IOP measurement uncertainties, RT modeling
- Closure uncertainties associated with IOPs roughly consistent with aggregate uncertainties of measurement inputs
- Uncertainties for specific cases, particularly Ligurian Sea data set, was larger than could be explained by aggregate uncertainties on measurements
- Up to 25% bias uncertainty in the blue observed in very clear waters, even with current state-of-the-art methods
- Using Fournier-Forand analytical phase functions only increased absolute bias by 3% relative to using measured phase functions
- Lack of polarization in Hydrolight RT modeling may account for unexplained uncertainties

Absolute bias

$$\%\delta = 100 * \frac{\delta}{\bar{y}}, \qquad \delta = \frac{\sum_{i=1}^{n} |y_i - \hat{y}_i|}{n}$$

24 stations, Case I+II



For entire data set (all λ):

%δ = 17%

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Backscattering and absorption effects on asymptotic light fields in seawater

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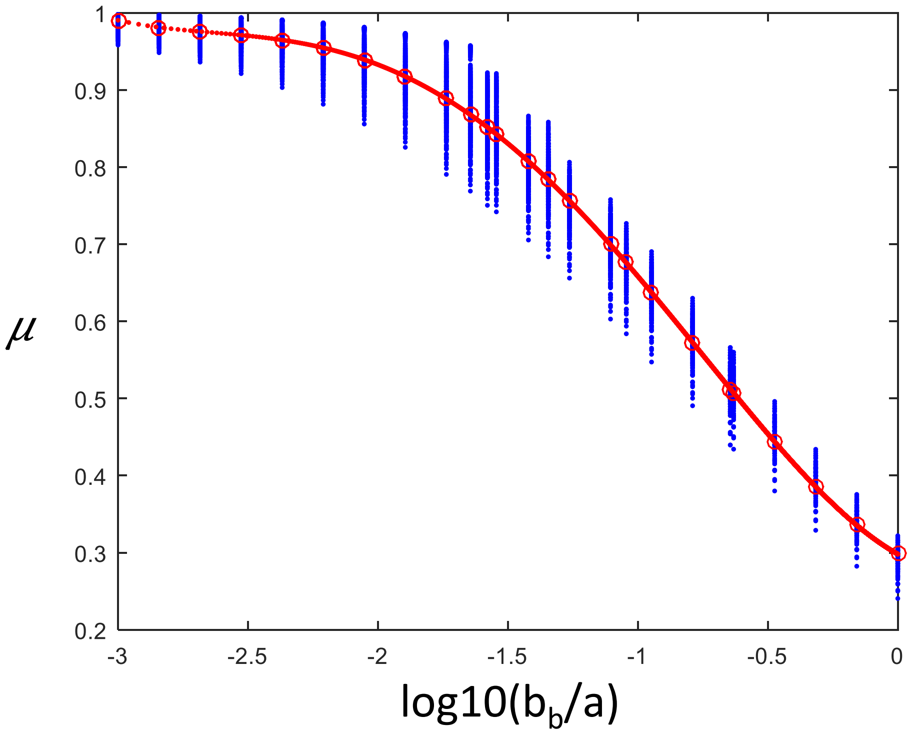
In prep, Optics Express

- Light field in asymptotic regime not dependent on incident light field, i.e., described only by IOPs
- Relationships between asymptotic light field structure and IOPs may be used to develop new ocean color algorithms

Average cosine of asymptotic light field

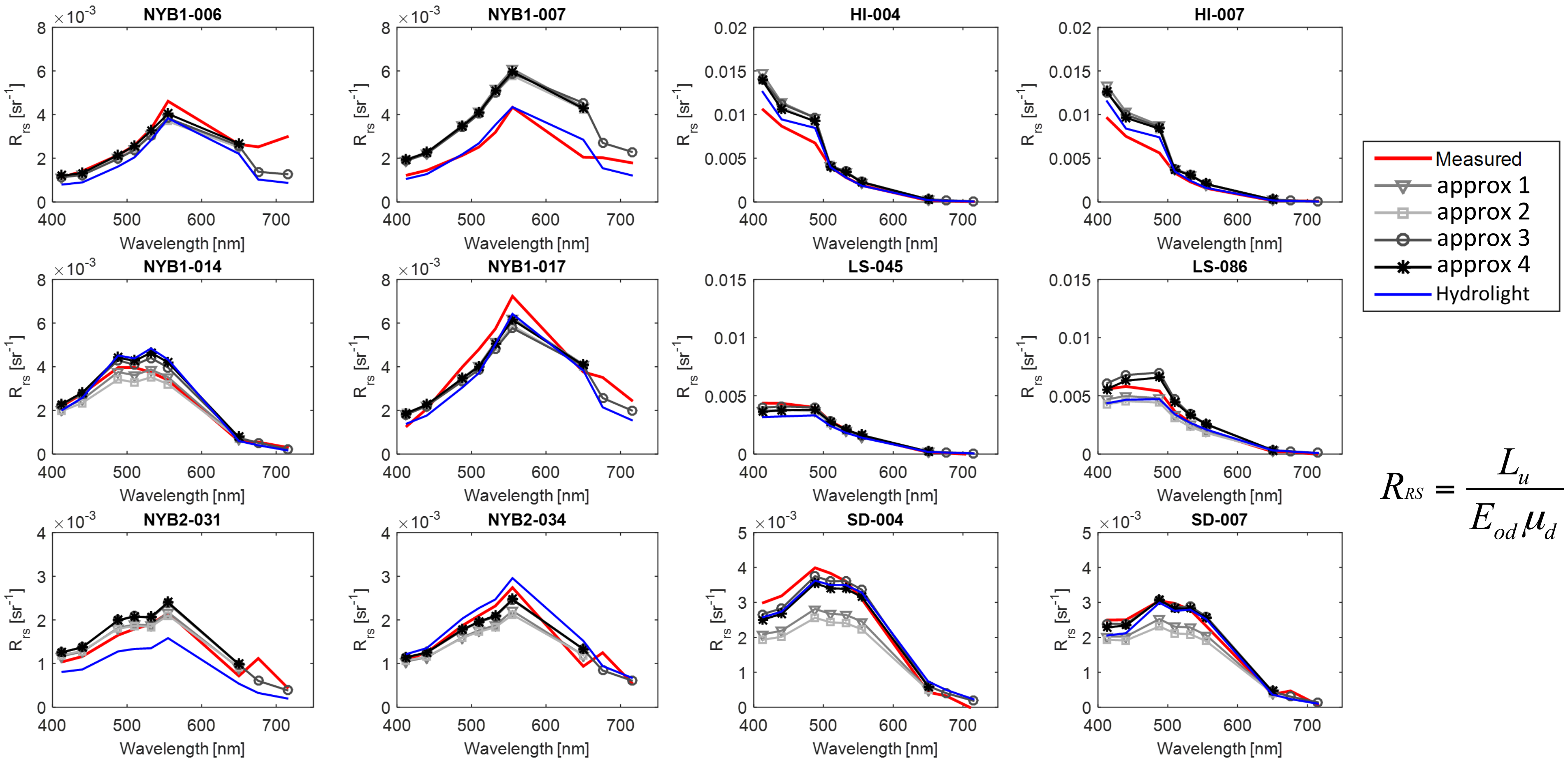


$$\bar{\mu}(z) = \frac{\int_0^{2\pi}\int_0^{\pi} L(\theta, \phi, z)\cos\theta \sin\theta \, d\theta \, d\phi}{\int_0^{2\pi}\int_0^{\pi} L(\theta, \phi, z)\sin\theta \, d\theta \, d\phi}$$

- Modeled with Hydrolight
- Full range of Fournier-Forand phase functions ($1.02 \leq n \leq 1.24$; $3.2 \leq \gamma \leq 4.0$) and b_b/a
- 4th order polynomial fit has 2.6% absolute error
- Consistent with Berwald et al. (1995)

Tonizzo and Twardowski, in prep

Performance assessment of Zaneveld (1995) algorithm



$$R_{RS} = \frac{L_u}{E_{od}\mu_d} = \frac{f_b \frac{b_b}{2\pi}}{k + c - f_L b_f}$$

24 stations total (same as Tonizzo et al. 2017)

Uses constant empirical β(θ) / b_b relationship derived in Sullivan and Twardowski [2009]

Match up results, Zaneveld algorithm

		%RMSE		$\%BIAS_{abs}$	
		Meas β	single β/b_b	Meas β	single β/b_b
vs. R_{RS} measured	Hydrolight	32	34	17	19
	RT approx.	31	32	17	18

Performance of Zaneveld analytical approximation was equivalent to full RT simulations for a broad range in water types, even with single shape for β_p / b_{bp}

Remarkable!

Next steps…

- Submit asymptotic light field manuscript
- Continue work on PACE IOP manuscript
- Continue performance assessment of RT approximations with explicit consideration of the VSF

Thank you