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
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>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Formula for Scattering Error, $\varepsilon(\lambda)$</th>
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</thead>
<tbody>
<tr>
<td>BL</td>
<td>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.</td>
<td>$a_m(715)$</td>
</tr>
<tr>
<td>PROP</td>
<td>Measured absorption at 715 nm reference wavelength assumed to be 100% scattering error. Error is scaled spectrally by the ratio of measured total scattering ($\epsilon - a$) (i.e., assuming that the ratio of scattering error to total scattering is constant spectrally).</td>
<td>$a_m(715) \frac{c_m(\lambda) - a_m(\lambda)}{c_m(715) - a_m(715)}$</td>
</tr>
<tr>
<td>VSF98P</td>
<td>Scattering error is independently derived by convolving measured VSF $\beta$ with angular weighting function $\mathcal{W}_\epsilon$ 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.</td>
<td>$2\pi \int_0^\pi \sin(\theta) \mathcal{W}_\epsilon(\theta) \beta(\theta, 658) d\theta \frac{c_m(\lambda) - a_m(\lambda)}{c_m(650) - a_m(650)}$</td>
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*Scattering errors are subtracted from measured absorption $a_m$. 
RRS match ups
24 stations, all wavelengths measured VSFs

• 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

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

- 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 $b_b/a$
- $4^{th}$ 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

24 stations total (same as Tonizzo et al. 2017)
Uses constant empirical $\beta(\theta) / b_b$ relationship derived in Sullivan and Twardowski [2009]
Match up results, Zaneveld algorithm

<table>
<thead>
<tr>
<th>vs. $R_{RS}$ measured</th>
<th>%RMSE</th>
<th>%BIAS$_{abs}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Meas $\beta$</td>
<td>single $\beta/b_b$</td>
</tr>
<tr>
<td>Hydrolight</td>
<td>32</td>
<td>34</td>
</tr>
<tr>
<td>RT approx.</td>
<td>31</td>
<td>32</td>
</tr>
</tbody>
</table>

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

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