Ocean Optics 2007 Class Project: *in situ* optical and radiometric data accuracy assessment and optical closure

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Introduction

Agreement between water-leaving radiance and inherent optical properties (IOPs) is necessary for resolving ocean biogeochemical parameters from space. High error has been reported for *in situ* instruments retrieving upwelling radiance in scattering dominated waters. Sources contributing to this difference could be inaccuracies in radiometric measurements (*i.e.* sensor tilt and environmental conditions) and in IOP measurements and approximations. An evaluation of these and other possible sources of error are assessed through instrument inter-comparison and an appraisal of the assumptions and measurements included in modeling procedures.

Methods

A comprehensive suite of IOPs and apparent optical properties (AOPs) were measured with depth for two sampling locations in the Damariscotta River Estuary, Maine on July 13, 2007 (Figure, 1, Table 1). Measurements from upper (Station 1; 44.0320° N, 69.5353° W) and lower (Station 2; 43.9735° N, 69.5627° W) estuary stations were collected at 14:00 and 15:15 GMT, respectively.

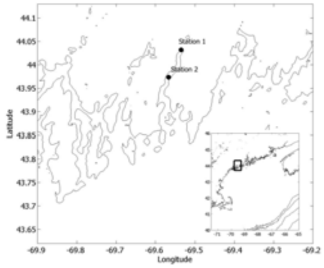

Figure 1: Stations 1 (upper estuary) and 2 (lower estuary) within the Damariscotta River Estuary, along the coast of Maine (see inset).

Measurement	Instrument	Wavelength(s) of measurement
Aborption (*a*) and attenuation (*c*)	ac-9 (WET Lab Inc.)	412, 440, 488, 532, 555, 650, 676, 715
Backcattering (b_b)	*ECO* VSF (WET Lab Inc.) BB9 (WET Lab Inc.)	660 400, 440, 488, 510, 532, 595, 660, 715, 880
$E_d(z, \lambda)$ and $L_u(z, \lambda)$	Hyperpro (Satlantic)	348nm to 802 nm, 137 wavelength total

Table 1: Summary of the measurements collected during the July 13, 2007 Damariscotta River Estuary cruise.

The light field was modeled using Hydrolight (Sequoia Scientific). Measured IOPs and a host of environmental conditions were included in the modeling procedure. The phase function was approximated using the Fournier-Forand approach, given measurements of the backscatter fraction ($B_p = b_{bp}/ b_p$). Particulate backscattering was obtained from an *ECO* VSF and BB9 and particulate scattering from an ac-9. Agreement between measured and modeled radiometric quantities is reported as percent difference (PD), where:

$$PD = \frac{(measured - modeled)}{measured} x100$$

Results and Discussion

The upper estuary station is shallow (7 m) and located near the river-estuary confluence. It is heavily freshwater influenced and experiences strong temperature and salinity driven stratification (Figure 2a). The lower estuary station is comparatively deep (25 m) and, though it maintains a freshwater signal at the surface, this location exhibited significantly lower temperature and higher salinity signals, indicative of heavy tidal influence (Figure 2b).

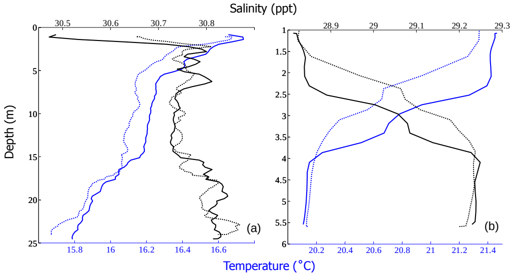

Figure 2: Temperature and salinity profiles from casts 1 (solid line) and 2 (dashed line) for (a) station 1 (upper estuary) and (b) station 2 (lower estuary).

Both stations were highly scattering dominated, where the single scattering albedo (ω_0 = b/c) measured 0.90 and 0.92, respectively. The lower estuary IOPs were homogenous with depth, aside from a particulate layer between 7.5 and 8 m depth, where CDOM and particulate absorption maximums were observed (a_{CDOM}(440)=0.263 m^{-1}; a_p(530)=0.162 m^{-1}). A similar particulate signal, evident in the backscattering and attenuation profiles, was observed at the freshwater-seawater interface of the upper estuary station (2-3 m depth).

Instrument Inter-comparison

Low instrument-specific variability was observed for the *ECO* VSF and BB9 (mean differences of 10% and 14% between successive casts), but significant disagreement in b_{bp} was found between the instruments (mean differences of 0.028 m^{-1} and 0.033 m^{-1} for upper and lower stations). The largest magnitude difference between the scattering meters occurred at the freshwater-seawater interface (the location of a particulate layer) for the upper estuary station and increased with depth for the lower estuary station (Figures 3a and b).

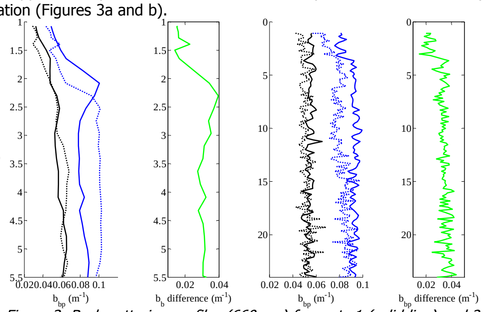

Figure 3: Backscattering profiles (660 nm) for casts 1 (solid line) and 2 (dashed line) with a BB9 (blue line) and ECO VSF (black line) for (a) upper and (b) lower estuary locations and the corresponding instrument difference in b_{bp}.

Modeled Radiance Reflectance

Incorporation of BB9 measurements in the modeling scheme produced an overestimation of R ($R = L_u(z, \lambda)/E_d(z, \lambda)$) (Tables 2 & 3, Figure 4). The shape of modeled *R* was accurate, where *R* normalized to 560 nm produced mean and maximum differences of 5% and 10% for the upper estuary. *ECO* VSF backscattering profiles produced magnitude and shape errors (Figure 4). Strong closure was achieved by employing the mean *ECO* VSF and ac-9 measured B_p of 0.0187 and 0.020 for the upper and lower estuary stations, respectively for use in the Fournier-Forand model (Tables 1 & 2, Figure 4).

Wavelength	412	440	488	532	555	591	683
BB9	19	12	12	11	18	6	10
ECO VSF-z	3	16	39	23	36	6	4
ECO VSF mean B_p=0.0187	6	10	8	2	6	1	3
Petzold	10	13	9	1	8	1	6

Table 2: Difference (%) between measured and modeled R (sr^{-1}) in the upper estuary using B_p from the BB9, the ECO VSF profile (ECOVSF-z), the mean of the ECO VSF profile, where B_p = 0.0187, and Petzold Average Particle Phase Function.

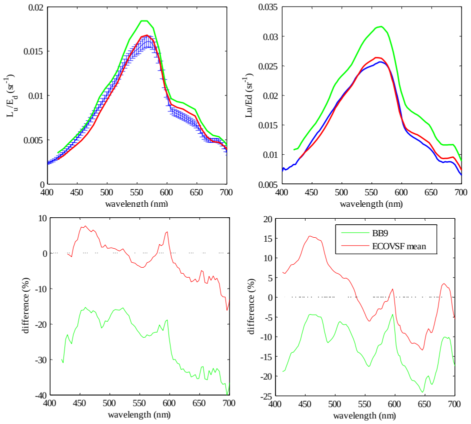

Figure 4: Measured and modeled R (sr^{-1}) using the BB9 profile of B_p (green line) and ECO VSF mean B_p (red line) for the (a) upper and (b) lower estuary stations and the corresponding PD.

Wavelength	440	488	532	555	591	683
BB9	23	21	18	24	22	33
ECO VSF mean B_p = 0.020	2	2	1	4	2	8

Table 3: Difference (%) between measured and modeled R (sr^{-1}) for the lower estuary station, using B_p from the BB9 profile and the mean of the ECO VSF profile, where B_p = 0.020.

Maximum PD and high variability in measured and modeled diffuse attenuation coefficients, $K_d(z)$ and $K_{Lu}(z)$, occurred in the surface layer (0-2 m), likely the result of wave focusing and/or sensor tilt. Tilt was greatest at the surface and decreased with depth until stabilizing at 3 m. Variability in measurements and disagreement between measured and modeled $K_d(z)$ and $K_{Lu}(z)$ were also observed for the deep layer (6-8 m), where the signal-to-noise ratio is low due to low light levels.

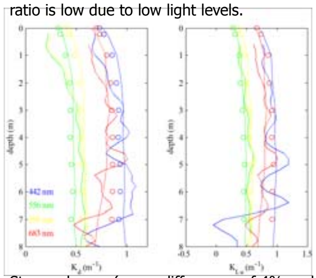

Figure 5: Measured (solid line) and Hydrolight predicted K_d (m^{-1}) and K_{Lu} (m^{-1}), where B_p was determined using BB9 (dashed line) and the mean B_p from the ECO VSF profile (circles).

Strong closure (mean differences of 4% and 1%) was achieved for the upper and lower estuary stations when the mean backscattering ratio obtained using an *ECO* VSF and ac-9 was employed. Herein instrument duplication and measurement verification was necessary to resolve disagreements between measured and modeled quantities.

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