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Variability in spectral backscatter estimated from satellites and its relation to *in situ* measurements in optically complex coastal waters

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Abstract. A large database of *in situ* bio-optical measurements was collected at the Long-term Ecosystem Observatory off the southern coast of New Jersey, USA. In part, the research effort focused on reconciling *in situ* estimates with satellite-derived estimates of the inherent optical properties (IOP). At 442 nm, *in situ* absorption values ranged from less than 0.2 to over 1.5 inverse metres. Satellite estimates of backscatter ranged from 0.002 to 0.03 inverse metres at 442 nm and showed significant variability in time and space during July 1999, reflecting the recurrent high frequency events that characterize the region—wind-mixing, storms and coastal upwelling. Despite this variability, there was good qualitative agreement between the satellite derived IOP estimates and *in situ* IOP measurements. Both absorption and backscatter values increased near-shore, reflecting enhanced concentrations of phytoplankton, sediments and dissolved organic matter.

1. Introduction 1

As part of the Hyperspectral Coastal Ocean Dynamics Experiments (HYCODE), this study had two main objectives: (1) to compare *in situ* spectral backscatter data with estimated backscatter derived from the Sea viewing Wide Field of view Sensor (SeaWiFS); and (2) to compare *in situ* spectral scattering data with that modelled from an *in situ* absorption/attenuation (WetLabs AC-9).

In situ measurements were collected at the Long-term Ecosystem Observatory (LEO-15) off the southern coast of New Jersey, USA using the Hobilabs HydroScat-6 spectral backscatterer. Four of the six wavelengths measured by the HydroScat-6 are used in this analysis; 442 nm, 488 nm, 589 nm and 620 nm, all measured at a 140° angle. For proper comparison of derived scattering and *in situ* scattering, a profiling Satlantic spectral radiometer was used to calculate the first

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optical depth. In addition, a WetLabs absorption/attenuation meter (AC-9) was used to quantify the spectral absorption and attenuation through the water column. AC-9 data were used to initialize the radiative transfer model Hydrolight v5.0 to model spectral backscatter. All of these instruments were on the same profiling cage within 20 cm of each other. Transect lines for three days highlighted in this study are given in figure 1.

2. Method 1

Spectral backscatter data from the HS-6 was first binned to 0.5 m depth 2
intervals to eliminate bias due to uneven depth profiling. For comparison to satellite-derived backscatter, the *in situ* backscatter data were averaged within the first optical depth, which contributes approximately 90% of the in-water reflectance. Depth-dependent AC-9 data were used for input in the Hydrolight v5.0 model and with backscatter as the output for every 0.5 m of the water column. The binned HS-6 data were compared to the Hydrolight backscatter at 0.5 m intervals.

SeaWiFS ocean colour imagery was processed into optical products of spectral absorption and backscattering at all wavelengths (Arnone and Gould 1998) using a modified version of the SeaWiFS Data Analysis System (SEADAS). SeaWiFS image processing was optimized for coastal water using the near-infrared (NIR) atmospheric correction (Arnone *et al.* 1998). This procedure uses an iterative procedure for coupled in-water and atmospheric models to determine the water-leaving radiance in coastal waters. Coastal waters can have significant reflectance in the 765 nm and 865 nm channels of SeaWiFS. The iterative procedure accounts for the water portion of these channels, which are used with atmospheric correction. Accurate reflectance measurements in coastal waters are required for accurate derived optical properties.

These SeaWIFS reflectance measurements are used with two semi-empirical

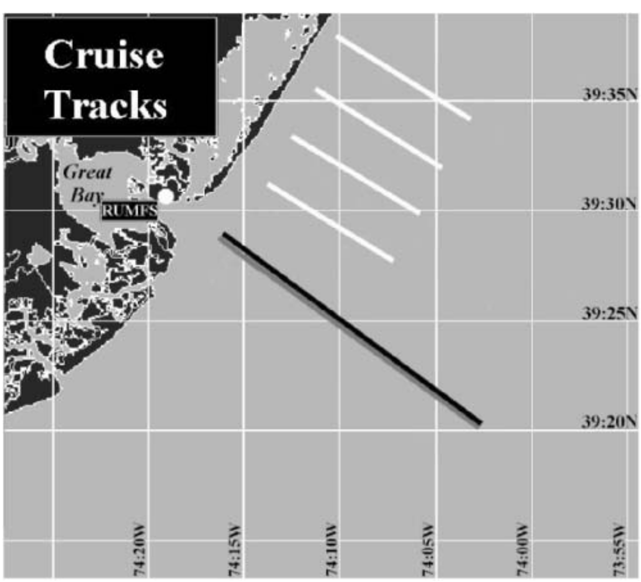

Figure 1. Cruise tracks for three days during July 1999, off the coast of New Jersey in relation to the Rutgers University Marine Field Station. Black line, July 7; white lines, July 16; grey line, July 30.

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in-water algorithms to uncouple the surface water backscatter and absorption properties. These algorithms are based on a reflectance value of ca 0.33 multiplied by the ratio of backscatter to absorption at a specific wavelength. The modified algorithm determines backscatter at 670 nm using the reflectance relationship at 670 nm by assuming a known absorption at 670 nm. Then, using Gould and Arnone 3
(1999), the backscatter is estimated at all wavelengths.

The Carder *et al.* (1999a, b) algorithm was also used to estimate spectral backscatter. Here the 550 nm channel is used. This algorithm portioned the total spectral absorption into the absorption from chlorophyll and absorption from dissolved organics and particles. These components were combined with water absorption to estimate the total absorption at each wavelength (Arnone and Gould 1998). The reflectance ratio is then used to convert to spectral backscatter.

SeaWiFS optical properties were compared with *in situ* optical properties measured using an absorption scattering instrument. The spectral backscatter estimated from SeaWiFS was converted to total scattering using a Petzold volume scattering function (Petzold 1972, Gould *et al.* 1999). There are limitations with the Petzold conversion, but this study is data limited in coastal waters.

3. Results 1

There was generally good agreement between wavelength-specific measured *in situ* backscatter and the SeaWiFS derived estimates for both algorithms (table 1). This relationship was robust across several days and stations (figure 2). The SeaWiFS algorithms, however, tended to cluster offshore and inshore waters separately (data not shown), suggesting additional complexity across optical fronts, which characterize the study region. Modelled *in situ* backscatter derived from the AC-9 also correlated well with measured values at depth; however, this coherence generally broke down in surface waters, illustrating the importance of collecting good surface measurements with the AC-9 in remote sensing applications.

Table 1. Correlation coefficients (R^2) for measured *in situ* backscatter and those derived from SeaWiFS.

		SeaWiFS algorithm (Arnone *et al.* 1998)				SeaWiFS algorithm (Carder *et al.* 1999a, b)			
	(nm)	443	490	555	670	443	490	555	670
Measured July 7 ($n=6$)	442	0.63	–	–	–	0.90	–	–	–
	488	–	0.55	–	–	–	0.85	–	–
	589	–	–	0.68	–	–	–	0.96	–
	602	–	–	–	0.70	–	–	–	0.96
Measured July 16 ($n=12$)	442	0.57	–	–	–	0.57	–	–	–
	488	–	0.64	–	–	–	0.63	–	–
	589	–	–	0.67	–	–	–	0.69	–
	602	–	–	–	0.69	–	–	–	0.74
Measured July 30 ($n=8$)	442	0.65	–	–	–	0.65	–	–	–
	488	–	0.62	–	–	–	0.72	–	–
	589	–	–	0.35	–	–	–	0.46	–
	602	–	–	–	0.69	–	–	–	0.76

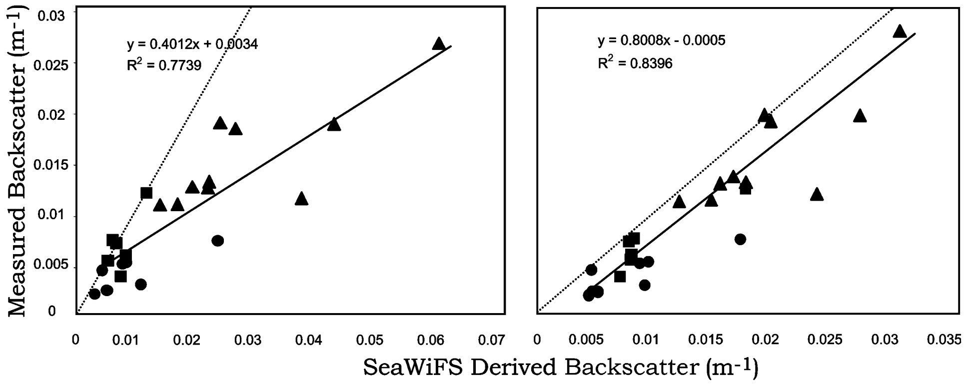

Figure 2. Comparison of optical backscatter derived from SeaWiFS (490 nm) with that measured *in situ* (448 nm). Dotted line shows the 1 : 1 relationship. Squares, July 7; triangles, July 16; circles, July 30.

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