Variability in measured and modelled remote sensing reflectance for coastal waters at LEO-15

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Abstract. A large database of *in situ* bio-optical measurements were collected at the LEO-15 (Long-term Ecosystem Observatory) off the southern coast of New Jersey, USA. The data were used to quantify the impact of coastal upwelling on near-shore bulk apparent (AOP) and inherent (IOP) optical properties. There was good qualitative agreement between the AOPs and IOPs in space and time. The measured IOPs were used as inputs to the Hydrolight radiative transfer model (RTE). Estimated spectral AOPs from the RTE were strongly correlated (generally $R^2 > 0.80$) to measured AOPs. If optical closure between in-water measurements was achieved then the RTE was used to construct the spectral remote sensing reflectance. The modelled remote sensing reflectances were compared to satellite-derived reflectance estimates from four different algorithms. Quantitative agreement between the satellite-measured and in-water modelled remote sensing reflectance was good but results were variable between the different models. The strength of the correlation and spectral consistency was variable with space and time. Correlations were strongest in clear offshore waters and lowest in the near-shore turbid waters. In the near-shore waters, the correlation was strongest for blue wavelengths (400–555 nm) but lower for the red wavelengths of light.

1. Introduction

Adaptive sampling approaches are critical for characterizing, quantifying and sampling episodic events since standard approaches do not resolve their frequency and the disproportionately large role they play on biological and chemical processes in coastal waters. Adaptive sampling depends on remote sensing imagery, but coastal waters are optically complex which can significantly compromise remote sensing-derived products. As part of ONR and Naval Research Laboratory (NRL) efforts at the Long-term Ecosystem Observatory (LEO-15) new algorithms are being developed and validated for the coastal waters. As part of those efforts, this paper validates satellite ocean colour reflectance data that are used as inputs to

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satellite models. Presented data were collected as part of the 1999 NOPP/ONR/NURP Coastal Predictive Skills Experiment.

2. Methods

Alongshore transects were conducted aboard the *R/V Walford* during the month-long experiment in July 1999. *In situ* measurements were collected by ship-board profiles at LEO-15 off the southern coast of New Jersey, USA. The profiling system

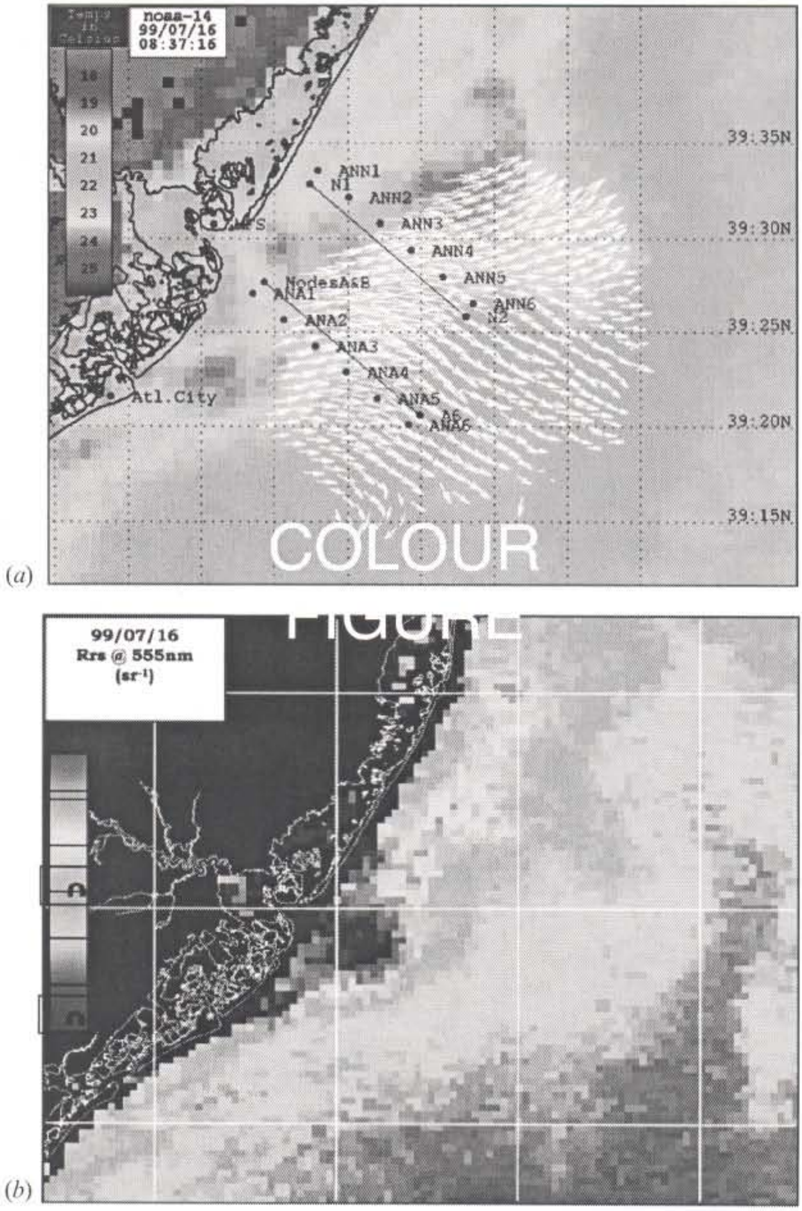

Figure 1. (*a*) AVHRR sea surface temperature (SST) and (*b*) SeaWiFS remote sensing reflectance (555 nm), both from July 16, 1999 off the coast of New Jersey. Imagery shows cold upwelled water and the associated optical fronts.

was equipped with a Seabird CTD, 13-wavelength TBS-OCR Satlantic spectral radiometer, Wetlabs absorption/attenuation meter (AC-9), a HOBI Labs Hydroscat-6 backscatter sensor, beam-c transmissometer and a Sequoia laser *in situ* scattering and transmissometry (LISST). The data presented here are limited to July 16, 1999. Instruments were calibrated throughout the field season using manufacturer-recommended protocols. Data were processed and internal consistency between the optically derived parameters was tested by assessing optical closure between parameters using Hydrolight 4.0. AC-9 data binned to every 0.5 m was used to initialize the radiative transfer model Hydrolight v5.0 to model both the AOPs and remote sensing reflectance. Hydrolight-derived apparent optical properties (AOPs) and remote sensing reflectance were then compared to measured *in situ* AOPs and satellite-measured remote sensing reflectance as a function of wavelength.

Sea viewing Wide Field of view Sensor (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 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.

3. Results and discussion

The data collected on July 16, 1999 reflect a storm event which mixed cold water to the surface and was visible in Advanced Very High Resolution Radiometer

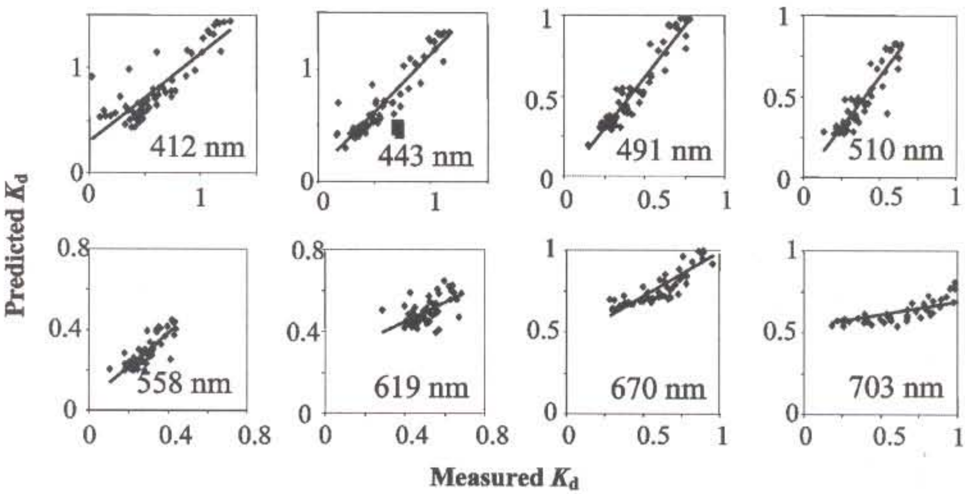

Figure 2. Comparison of spectral attenuation coefficients (K_d) measured by a profiling Satlantic radiometer versus that predicted using a radiative transfer model (Hydrolight) with input data from measured *in situ* absorption and attenuation using a Wetlabs AC-9. The relationships at eight wavelengths are shown from measurements made on July 16, 1999.

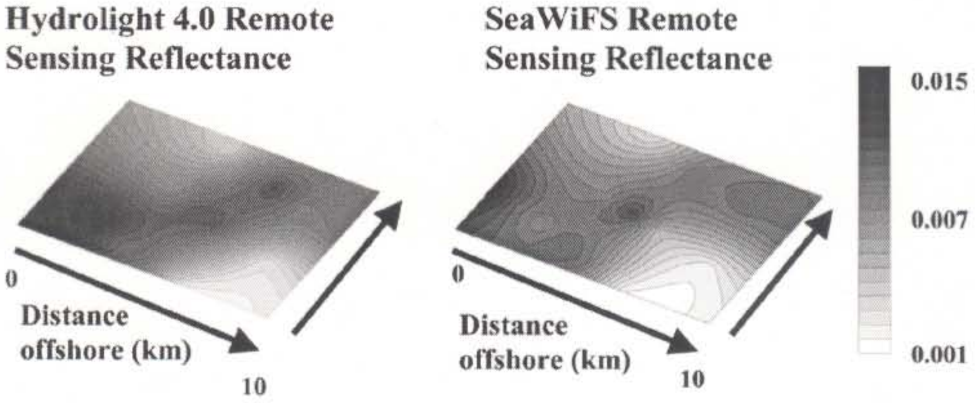

Figure 3. A spatial comparison of remote sensing reflectance (555 nm) modelled using a radiative transfer model (Hydrolight) with input data from measured *in situ* absorption and attenuation using a Wetlabs AC-9 versus measured by SeaWiFS. Data are from a spatial grid in the LEO-15 area off the coast of New Jersey on July 16, 1999.

(AVHRR) imagery (figure 1). Associated with the cold water were enhanced loads of particulate and dissolved matter and this increased material was evident in the remote sensing reflectance (data not shown). To test internal consistency of the *in situ* data, AC-9 data (using a default scattering phase function; Petzold 1972) were used by Hydrolight to calculate K_d. A total of 22 stations were occupied over four transect lines. Closure was most robust in the blue wavelengths of light. The closure between the inherent optical properties (IOPs) and AOPs was less robust in the red wavelength of light (figure 2).

The comparison between *in situ* derived remote sensing reflectance and SeaWiFS remote sensing reflectance shows that the measured *in situ* IOPs could provide reasonable measurements of the AOPs across significant optical gradients (figure 3). Despite good agreement across platforms, further work is needed to discern the spectral coherence between IOPs and AOPs in these optically complex coastal waters.

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