Evaluation of Hyperspectral Ocean Color Algorithm Performance in Optically Complex Coastal Waters

Steven E. Lohrenz, Ruiping Ma, and Sumit Chakraborty*

UMass Dartmouth

School for Marine Science and Technology, University of Massachusetts, Dartmouth, New Bedford, MA 02744

slohrenz@umassd.edu

**Current affiliation: Woods Hole Group, 81 Technology Park Drive, East Falmouth, MA 02536*

SMAST

ABSTRACT

Optically complex coastal waters present a challenge for ocean color remote sensing because of the high degree of spatial heterogeneity and limitations in the performance of algorithms. Ship-based underway hyperspectral observations of remote sensing reflectance provide a means for improved spatial resolution and greater degrees of freedom for semi-analytical algorithms. Here, we describe a series of complementary observations of surface hyperspectral radiance and irradiance and in situ measurements of apparent and inherent optical properties and key constituents in coastal waters of the northern Gulf of Mexico. The Satlantic HyerSAS-UV system was used to provide above-water measurements of radiance and irradiance, as well as extended spectral range into the UV-B, thereby yielding broad spatial and temporal coverage and higher frequency sampling. In addition to radiometry measurements, discrete profiles of spectral absorption and backscattering were determined using a WETLabs, Inc. ac-s absorption/attenuation meter and bb9 backscattering meter, respectively. Spectrophotometric measurements of particulate and dissolved absorption were also made using conventional methods. These in situ measurements were compared to inherent optical properties estimated by inversion of the HyperSAS reflectance using the quasi-analytical algorithm (QAA v6). Results illustrate the utility of remote sensing reflectance as means of characterizing distributions of biogeochemical properties in an optically complex coastal regime, the Mississippi River outflow region.

METHODS

Data were acquired in April 2009 in the outflow region of the Mississippi River from aboard the R/V Cape Hatteras using the HyperSAS-UV optical remote sensing system (Figure 1), manufactured by Satlantic. The instrument is comprised of two 166-channel MiniSpec radiance sensors for measurement of total above-water (Lt) and sky radiance (Ls), and 166-channel MiniSpec irradiance sensors for measurement of downwelling spectral irradiance (Ed) in both UV (350-400 nm) and visible (400-800 nm) wavelengths. Additionally integrated into the optical system were discrete sensors at selected UV wavelengths (305, 325, 340, 380 nm) and one red wavelength (671 nm). The HyperSAS-UV was mounted at an above water height of approximately 8 m. Zenith and nadir viewing angles of the radiance sensors were 45°. Relative solar azimuthal angles of 90°-135° are considered preferable (Hooker et al., 2004) and data were discarded in situations where conditions were unsuitable for collection.

Figure 1. HyperSAS hyperspectral radiometry system (left), manufactured by Satlantic, Inc. and optical profiling package (right) as deployed aboard the R/V Cape Hatteras in April 2009.

Remote sensing reflectance (Rrs, sr^{-1}) was estimated from the HyperSAS-UV according to Mobley (1999). Data were filtered to remove effects of episodic and sky glint (Hooker, et al., 2002; Hooker and Morel, 2003) and sea foam from the ship's wake by eliminating all spectra with the exception of those having the lowest 5% of values in the near infrared (~670 nm). Baseline corrections were applied for the offshore station (see Figure 3) by adjusting Rrs spectra such that the minimum values in the near infrared were zero. HyperPro estimates of Rrs were determined according to procedures given in Zibordi et al. (2012).

Discrete profiles of spectral absorption and backscattering were determined using a WETLabs, Inc. ac-s absorption/attenuation meter and bb9 backscattering meter, respectively. Comparisons were made to inherent optical properties estimated by inversion of the HyperSAS reflectance using the Lee et al. (2002) quasi-analytical algorithm (QAA v6) as well as spectrophotometric measurements of particulate and dissolved absorption using conventional methods (Mueller et al., 2003).

MODIS Aqua satellite imagery was acquired from the NASA Ocean Color website (http://oceancolor.gsfc.nasa.gov). Same day satellite matchups to the in situ observations were extracted from the processed images as the average of a 3x3 pixel window centered on the location of the in situ observation.

RESULTS

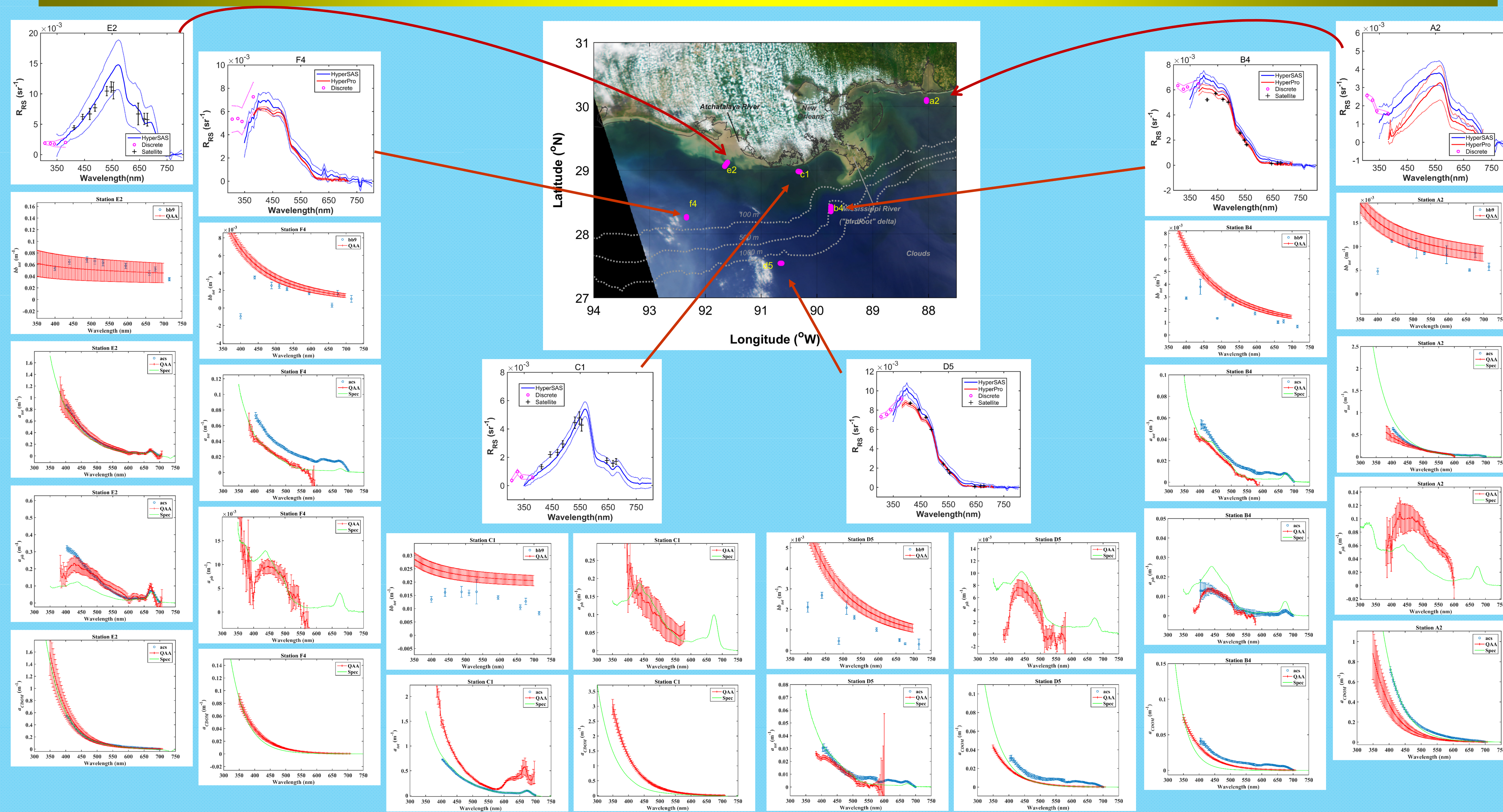

Figure 2. Remote sensing reflectance (Rrs) was determined at various locations in the outflow region of the Mississippi River. The solid blue lines represent measurements with the HyperSAS, while the black circles illustrate satellite observations. For some stations, the HyperSAS Rrs estimates were compared to estimates derived with the HyperPro profiling radiometer. The QAA algorithm (Lee et al., 2002) (version 6) was used to retrieve absorption and backscattering properties. The retrieved absorption products were compared to independent measurements using in situ instrumentation and analyses of discrete samples by spectrophotometry)(see also Figure 3).

Optical conditions in the outflow region of the Mississippi River are highly complex and dynamic. This is illustrated in the true color MODIS Aqua image for 24 April 2009 (Figure 2). An examination of the magnitude and shape of reflectance spectra revealed distinct patterns for different water masses. Rrs spectra acquired at an inner shelf estuarine station west of the "birdfoot" delta were characterized by maxima around 550 nm and above with complex spectral features, an apparent indication of high pigment and dissolved organic matter concentrations at this location. It was also evident that there was non-zero water-leaving radiance, and no attempt was made to baseline correct spectra at these stations. Rrs at an offshore station exhibited a maximum shifted to the blue region of the spectrum.

The discrete UV Rrs measurements extended measurements into the UV beyond the range possible with the HyperSAS alone. The 380 nm wavelength provided overlap with the HyperSAS data. Results in the region of overlap showed good agreement between the HyperSAS and discrete measurements.

Rrs spectra derived from the HyperSAS-UV and HyperPro were in reasonable agreement with one another and with MODIS Aqua satellite-derived Rrs , although coastal waters were more variable and exhibited some differences.

Comparisons of absorption and backscattering as determined from WETLabs, Inc. ac-s and bb-9 instruments with retrieved values using the QAA algorithm applied to HyperSAS-UV data revealed reasonable agreement for absorption at mid-shelf and offshore stations, spanning a wide dynamic range of conditions (Figure 3).

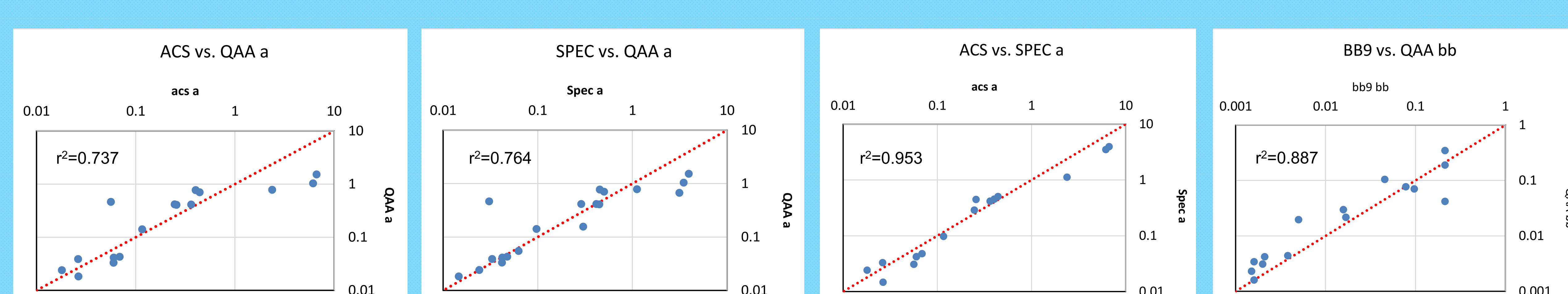

Figure 3. Relationships among absorption at 443 nm (a, m^{-1}) determined using the WETLabs, Inc. ac-s and spectrophotometer and backscattering at 532 nm (bb, m^{-1}) determined using the WETLabs, Inc. bb9 as compared to absorption and backscattering retrieved from Rrs by the QAA algorithm (Lee et al., 2002) (version 6). Red dashed line represents 1:1 relationship. The results were consistent over a wide dynamic range.

CONCLUSIONS

These preliminary results demonstrate the utility of underway shipboard hyperspectral and UV measurements of Rrs. Continuous underway measurements provide more extensive spatial and temporal coverage. Contamination of the data due to sun glint, as well as suboptimal conditions for sample collection, present challenges for post-processing and data quality. However, filtering of the data has been shown to be effective for reducing these problems. Future studies will extend these measurements to a wider range of water mass conditions, and further evaluate the performance of inversion algorithms for retrieval of optical properties and concentrations of key constituents.

Funding for this project was provided by ONR (Award Number: N000140310896) , by the National Science Foundation (OCE-0752254) , and the National Aeronautics and Space Administration (NNX10AU06G, NNX12AP84G and NNX14AR71G). We are grateful to Kevin Martin and the captain and crew of the R/V Cape Hatteras.

REFERENCES

Hooker, S. B., G. Zibordi, J. F. Berthon, and J. W. Brown (2004), Applied Optics, 43, 4254-4268.

Hooker, S. B. and A. Morel (2003), Journal of Atmospheric and Oceanic Technology 20(1): 187-205.

Hooker, S. B., G. Lazin, G. Zibordi and S. McLean (2002), Journal of Atmospheric and Oceanic Technology 19(4): 486-515.

Lee, Z. P., K. L. Carder and R. A. Arnone (2002), Applied Optics 41(27): 5755-5772.

Mobley, C. D. (1999), Applied Optics 38(36): 7442-7455.

Mueller, J. L. and others (2003), in Ocean Optics Protocols For Satellite Ocean Color Sensor Validation, Revision 5, Volume V, NASA.