Hyperspectral Remote Sensing of the Amazon River Plume

S. Bakken [1], J. Wei [2], Z. Lee [2], G. Johnsen [1], T.A. Johansen [1], J. Montoya [3] and A. Subramaniam [4]

[1] Norwegian University of Science and Technology, [2] University of Massachusetts, [3] School of Biological Sciences, Georgia Institute of Technology and [4] Columbia University, Lamont-Doherty Earth Observatory

Introduction

The Amazon River is the largest in the world and discharges more than 200,000 $m^3 s^{-1}$ into the Western Tropical North Atlantic Ocean. At its peak, the low salinity plume extends more than 2000 km from the mouth and covers an area greater than 1 million square kilometers. High concentrations of Colored Dissolved Organic Matter in the plume makes it challenging to accurately estimate phytoplankton biomass via multi-spectral remote sensing. Hyperspectral remote sensing measurements of downwelling irradiance and water-leaving radiance using the Sky Blocked Approach (SBA) [4] were made in the plume and surrounding oceanic waters during a field survey in June/July 2019. These measurements were quality controlled using a tilt filter to remove measurements that exceed a 5-degree tilt threshold from nadir and an outlier filter that removed artifacts. Over 4000 measurements were acquired at each station and the rigorous quality control resulted in about 1% of these measurements to be used for subsequent analysis, exploring if hyperspectral remote sensing can improve our understanding of the plume constituents. The spectral absorption properties of particulate and dissolved matter and HPLC diagnostic pigments were also measured at the same locations. The Quasi-Analytical Algorithm and OC4 with SeaWiFS coefficients were used to derive bio-optical parameters. Comparison with results derived from the SBA spectra and in-situ measurements of particulate absorption, colored dissolved organic matter and diagnostics phytoplankton pigments encourages use of hyperspectral measurements.

SBA Radiometer

The HyperPro II profiling system from Satlantic, Inc. was used as an SBA radiometer. It acquired hyperspectral remote sensing measurements of downwelling irradiance and water-leaving radiance in the range of 350 nm to 800 nm at 1.5 nm spectral resolution [4, 5].

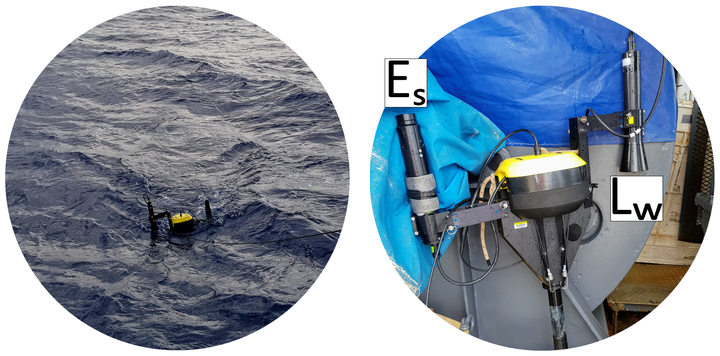


Fig. 1: SBA instrument

The SBA receives light emerging from the water and sky in a nadir direction. During ideal deployment of the SBA the base of the cone is beneath the water surface, while the fore optics of the radiometer is in the air. Reflected sea surface light is blocked by the cone, thus only the radiance emerging from beneath the water surface is measured. The radiometer position for downwelling irradiance accompanied the radiance sensor on a balanced float, recording L_w and E_s at the same location and time.

In-situ Measurements

In-situ measurements of particulate absorption, colored dissolved organic matter and diagnostics phytoplankton pigments were conducted for further comparison with hyperspectral measurements. Absorption was measured using a Shimadzu UV-2401PC.

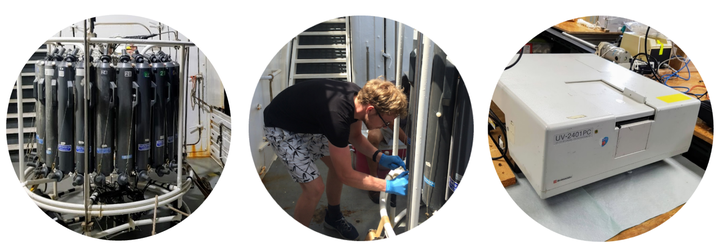


Fig. 2: In-situ sampling and measurements

Spectral Processing

To retrieve the most accurate L_w, E_S, and in turn above surface remote sensing reflectance R_{rs} the spectra was filtered in 3 stages.

1. Removed all missing values and bad sensor readouts. With an erroneous readout every associated value was removed.
2. Removed all values associated with an absolute viewing angle exceeding $5.0°$ from nadir. This also corrected for erroneous effects due to light entering the SBA cone.
3. Removed spectra outside 20% and 80% of the computed quantiles of each wavelength of L_w and E_S.

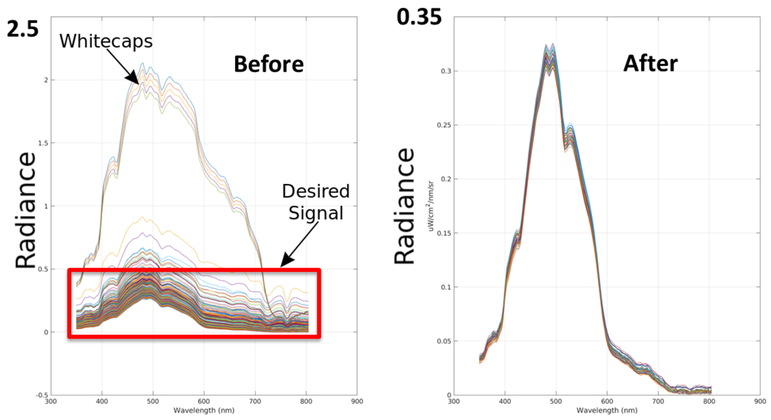
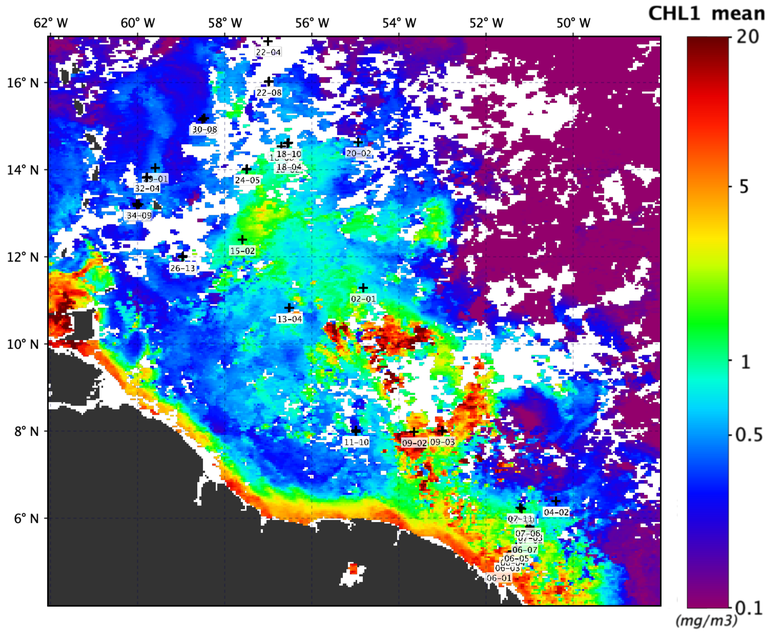


Fig. 3: Processing results from stage 3 of the radiance at station 09-02, filtering out undesired signals.

The stages were performed in succession. The resulting R_{rs} is assumed to be free from undesired artifacts e.g. stray light, measurements of whitecaps, or unrepresentative outliers. The resulting median reflectance was used to derive bio-geophysical parameters through the e Quasi-Analytical Algorithm (QAA_V6) [3, 1] and OC4 [2] using SeaWiFS coefficients. For QAA, the absorption coefficients of pure seawater at 410 and 440 nm were set to 0.0162m^{-1} and 0.0145m^{-1} respectively, and the slope of the absorption coefficient for phytoplankton pigments was estimated by QAA.
We did not make corrections for shadowing due to the SBA cone in our processing. The processing performed differs from what has been done previously [5].

Field Measurements

The SBA measurements were made as part of the EN640 cruise onboard the RV ENDEAVOR. In total there were 16 stations where water samples and SBA measurements were collected simultaneously over 20 days. The cruise followed the Amazon river plume based off of salinity readings and gradients ranging from 15.8-34.7 g/kg. At each station, water samples were collected using Niskin bottles on a CTD rosette and between 1050 and 3200 mL of water was filtered on to a 25mm GF/F filter for particulate absorption and phytoplankton pigment concentrations. About 50 mL of water was also filtered through a 0.2 micrometer filter and the filtrate was used to measure absorption due to dissolved material. See stations below.



Comparison

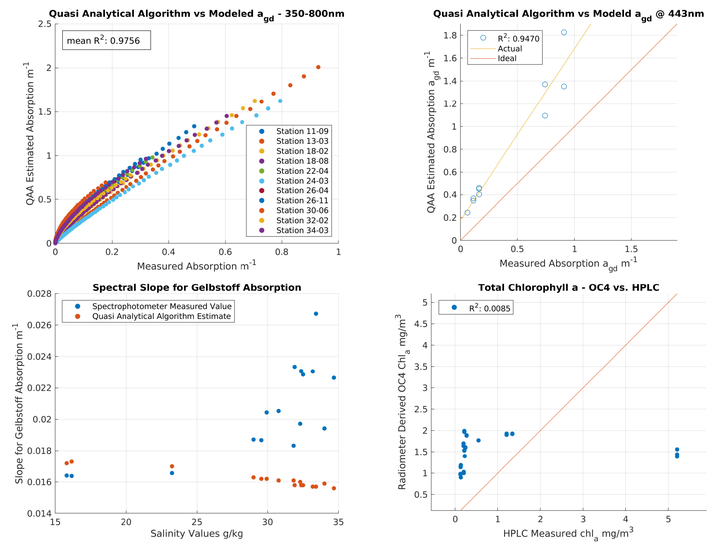


Fig. 5: Scatter plots for comparison

Conclusion & Future Work

The QAA, originally developed for optically deep waters, can model absorption coefficients of interest in the 350 to 800 nm of spectral region in the amazon river plume. The QAA provides precise measurements for absorption in areas dominated by dissolved organic matter. The total chlorophyll a concentration computed by OC4 does not match well with the measured HPLC values, i.e. the approach does not fit well with the optical complexity found in the amazon river plume. This encourages a hyperspectral approach.
Future work aims to investigate, how well the QAA derived absorption coefficients can be used to estimate the chlorophyll concentration, differentiating between phytoplankton functional types using SBA radiometer retrieved reflectance values, and comparing the Quasi-Analytical Algorithm with the Generalized Inherent Optical Properties Algorithm.

Acknowledgements

This work was supported by the US National Science Foundation grant OCE 1737128, the Norwegian Research Council through the Centre of Autonomous Marine Operations and Systems (NTNU AMOS) (grant no. 223254), and the MASSIVE project (grant no. 270959). Thanks to the crew of RV ENDEAVOR for help during deployment of the SBA Radiometer. Thanks to Kelly Luis for help processing the SBA Radiometer data.

References

[1] https://www.ioccg.org/groups/Software_OCA/QAA_v6_2014209.pdf. (Accessed on 01/17/2020).

[2] Chuanmin Hu, Zhongping Lee, and Bryan Franz. “Chlorophyll aalgorithms for oligotrophic oceans: A novel approach based on three-band reflectance difference”. In: *Journal of Geophysical Research: Oceans* 117.C1 (2012).

[3] ZhongPing Lee, Kendall L Carder, and Robert A Arnone. “Deriving inherent optical properties from water color: a multiband quasi-analytical algorithm for optically deep waters”. In: *Applied optics* 41.27 (2002), pp. 5755–5772.

[4] ZhongPing Lee et al. “Robust approach to directly measuring water-leaving radiance in the field”. In: *Applied Optics* 52.8 (2013), pp. 1693–1701.

[5] Zhongping Lee et al. “On-Water Radiometry Measurements: Skylight-Blocked Approach and Data Processing”. In: (2019).

NTNU
Norwegian University of Science and Technology
University of Massachusetts Boston
Georgia Tech School of Biological Sciences
Lamont-Doherty Earth Observatory
Columbia University | Earth Institute