Quantifying the Spectral Absorption Coefficients of Phytoplankton and Non-Phytoplankton Components of Seawater from in Situ and Remote-Sensing Measurements

Dariusz Stramski (PI)

Rick A. Reynolds (Co-PI)

Scripps Institution of Oceanography
University of California San Diego

NASA PACE Science Team Meeting
Harbor Branch Oceanographic Institute, 16–18 January 2018

Main Accomplishments

- **Particulate absorption measurements**
  - Improved methodology (including the pathlength amplification correction) for measuring particulate absorption coefficient with a filter-pad technique.
- **IOP inversions**
  - Developed a model for partitioning the total absorption coefficient of seawater.
  - Developed an inverse model for retrieving IOPs from remote-sensing reflectance.
- **In situ determinations of water-leaving radiance**
  - Advanced an understanding and provided recommendations for extrapolation method to determine water-leaving radiance from near-surface radiometric measurements.

Particulate absorption measurements

Three filter-pad methods

Research Article Vol. 54, No. 22 / August 1 2015 / *Applied Optics* 6763

applied optics

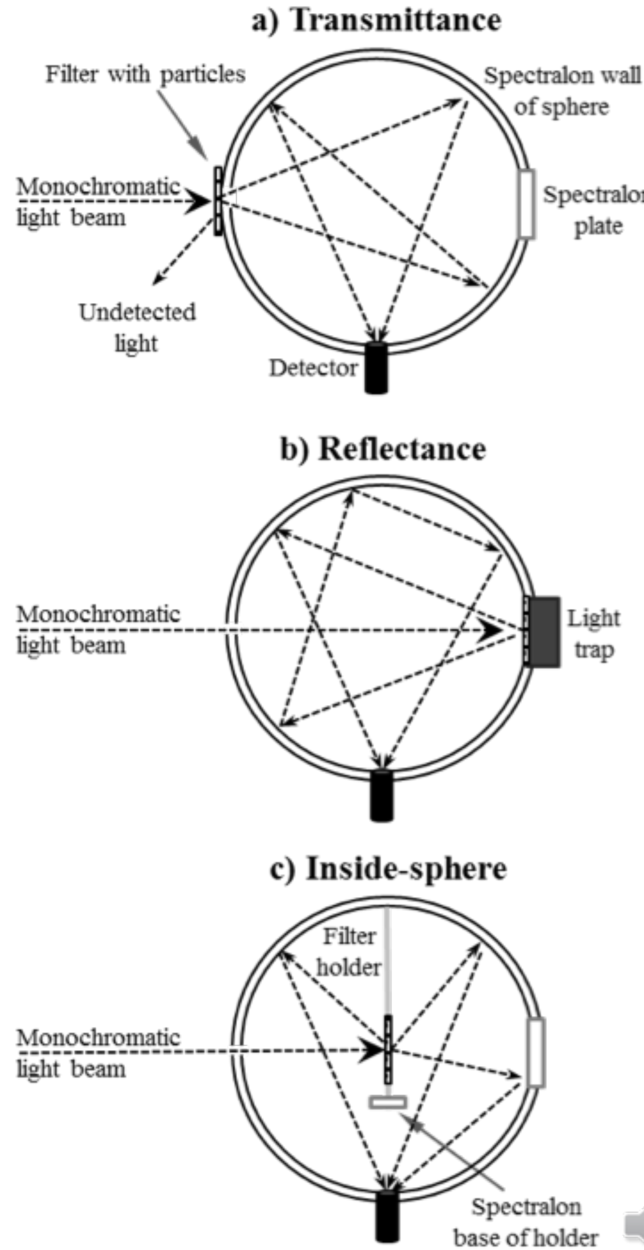
Correction of pathlength amplification in the filter-pad technique for measurements of particulate absorption coefficient in the visible spectral region

DARIUSZ STRAMSKI,[1,*] RICK A. REYNOLDS,[1] SŁAWOMIR KACZMAREK,[2] JULIA UITZ,[1,3] AND GUANGMING ZHENG[1,4,5]

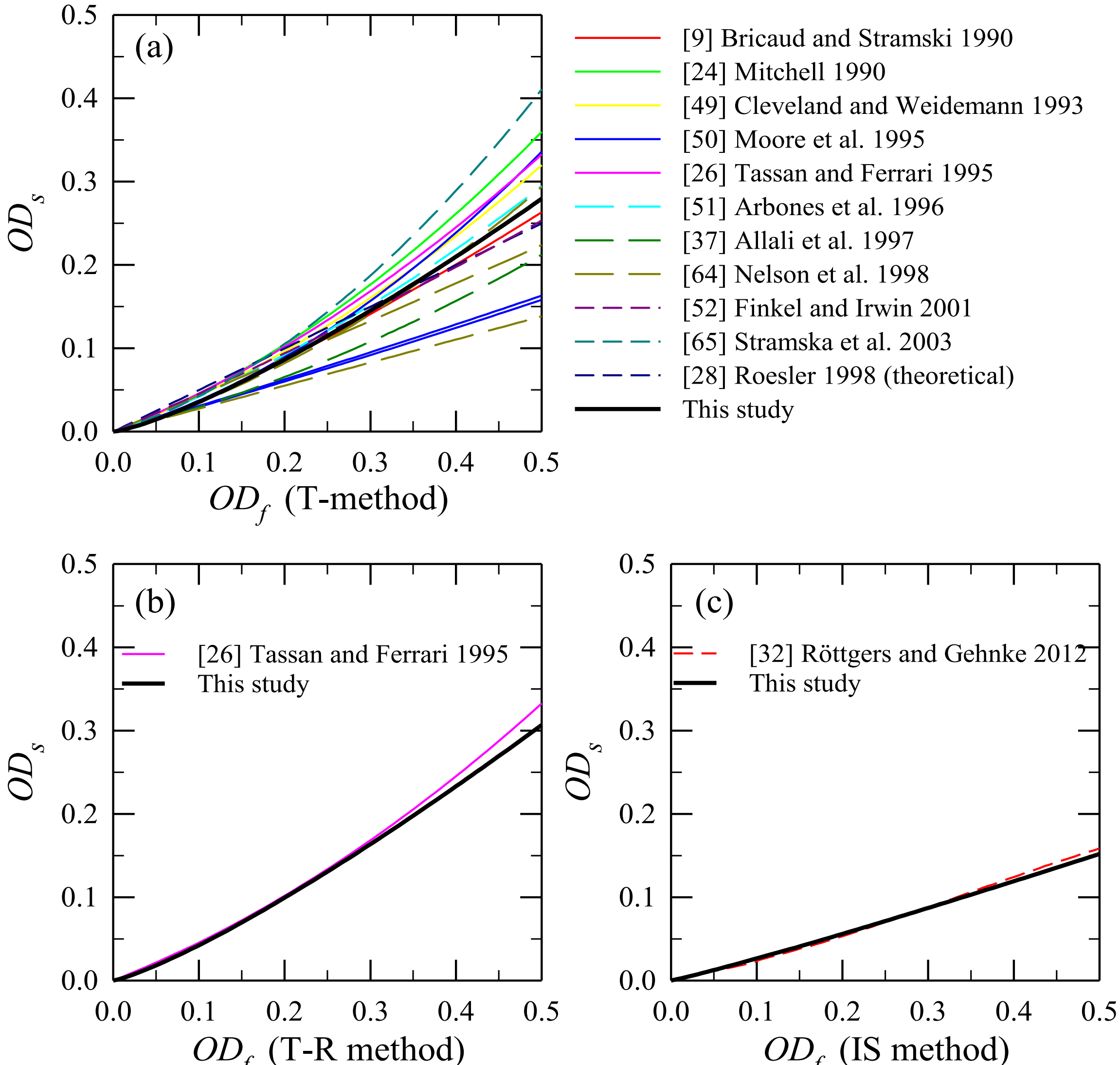
[1]Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, La Jolla, California 92093-0238, USA
[2]Institute of Oceanology, Polish Academy of Sciences, Powstancow Warszawy 55, 81-712 Sopot, Poland
[3]Currently at Sorbonne Universités, UPMC Université Paris 06, CNRS, Observatoire Océanologique de Villefranche (OOV), Laboratoire d'Océanographie de Villefranche (LOV), 181 Chemin du Lazaret, 06 230, Villefranche-sur-Mer, France
[4]Currently at NOAA/NESDIS/Center for Satellite Application and Research, 5830 University Research Court, College Park, Maryland 20740, USA
[5]Currently at Global Science & Technology, Inc., 7855 Walker Drive, Suite 200, Greenbelt, Maryland 20770, USA
*Corresponding author: dstramski@ucsd.edu

Received 2 April 2015; revised 26 June 2015; accepted 1 July 2015; posted 1 July 2015 (Doc. ID 237332); published 27 July 2015

Spectrophotometric measurement of particulate matter retained on filters is the most common and practical method for routine determination of the spectral light absorption coefficient of aquatic particles, $a_p(\lambda)$, at high spectral resolution over a broad spectral range. The use of differing geometrical measurement configurations and large variations in the reported correction for pathlength amplification induced by the particle/filter matrix have hindered adoption of an established measurement protocol. We describe results of dedicated laboratory experiments with a diversity of particulate sample types to examine variation in the pathlength amplification factor for three filter measurement geometries; the filter in the transmittance configuration (T), the filter in the transmittance-reflectance configuration (T-R), and the filter placed inside an integrating sphere (IS). Relationships between optical density measured on suspensions (OD_s) and filters (OD_f) within the visible portion of the spectrum were evaluated for the formulation of pathlength amplification correction, with power functions providing the best functional representation of the relationship for all three geometries. Whereas the largest uncertainties occur in the T method, the IS method provided the least sample-to-sample variability and the smallest uncertainties in the relationship between OD_s and OD_f. For six different samples measured with 1 nm resolution within the light wavelength range from 400 to 700 nm, a median error of 7.1% is observed for predicted values of OD_s using the IS method. The relationships established for the three filter-pad methods are applicable to historical and ongoing measurements; for future work, the use of the IS method is recommended whenever feasible.



β-relationships for T, T-R, and IS methods (black solid lines) proposed as a community standard for pathlength amplification correction in NASA Measurement Protocols (literature data are shown for comparison).



Absorption partitioning model

$$\text{Total } a(\lambda) = a_w(\lambda) + a_{ph}(\lambda) + a_d(\lambda) + a_g(\lambda)$$

Pure seawater	Phyto-plankton	Non-algal particles	CDOM

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Oceans

RESEARCH ARTICLE

10.1002/2014JC010604

Key Points:

- A partitioning model for light absorption coefficient of natural waters
- Nonalgal particulate and CDOM components are separated
- No restrictive assumptions about absorption coefficients are required

Supporting Information:

- Supporting Information S1

Correspondence to:
G. Zheng,
guangming.zheng@noaa.gov

Citation:
Zheng, G., D. Stramski, and P. M. DiGiacomo (2015), A model for partitioning the light absorption coefficient of natural waters into phytoplankton, nonalgal particulate, and colored dissolved organic components: A case study for the Chesapeake Bay, *J. Geophys. Res. Oceans*, *120*, 2601–2621, doi:10.1002/2014JC010604.

Received 19 NOV 2014
Accepted 22 JAN 2015
Accepted article online 27 JAN 2015
Published online 3 APR 2015

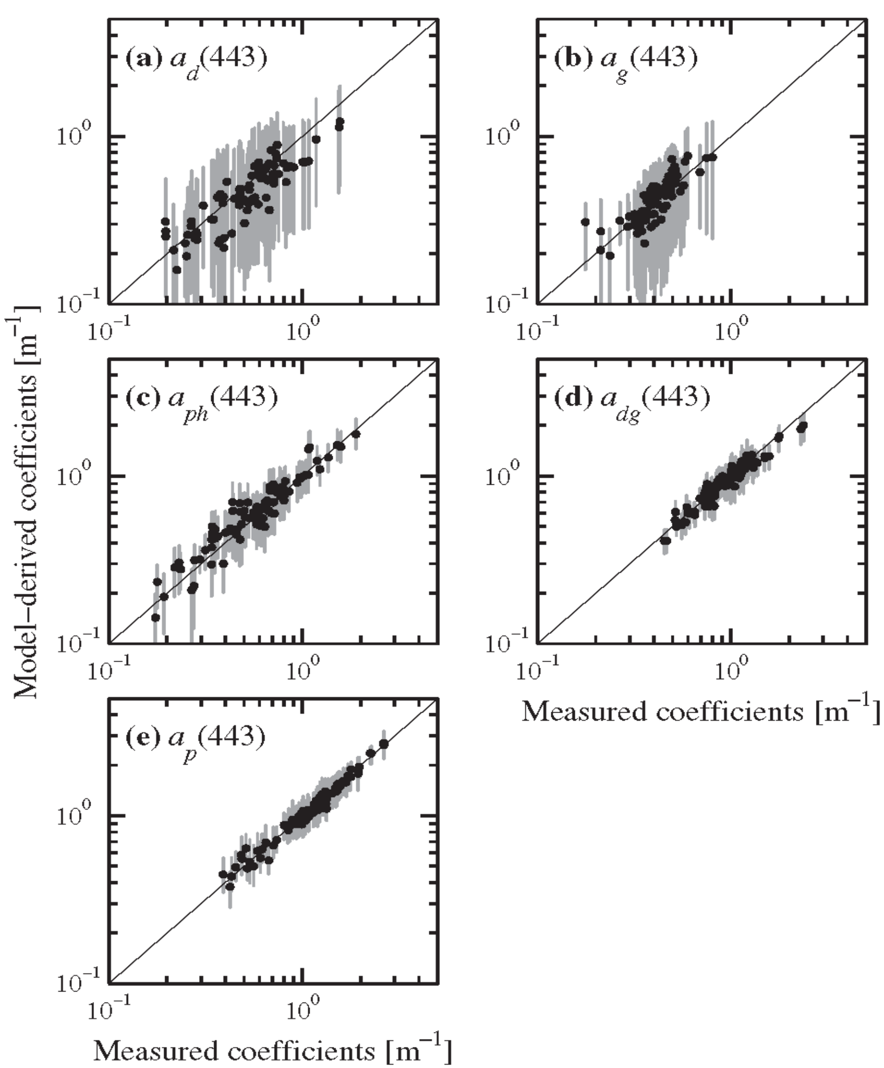
A model for partitioning the light absorption coefficient of natural waters into phytoplankton, nonalgal particulate, and colored dissolved organic components: A case study for the Chesapeake Bay

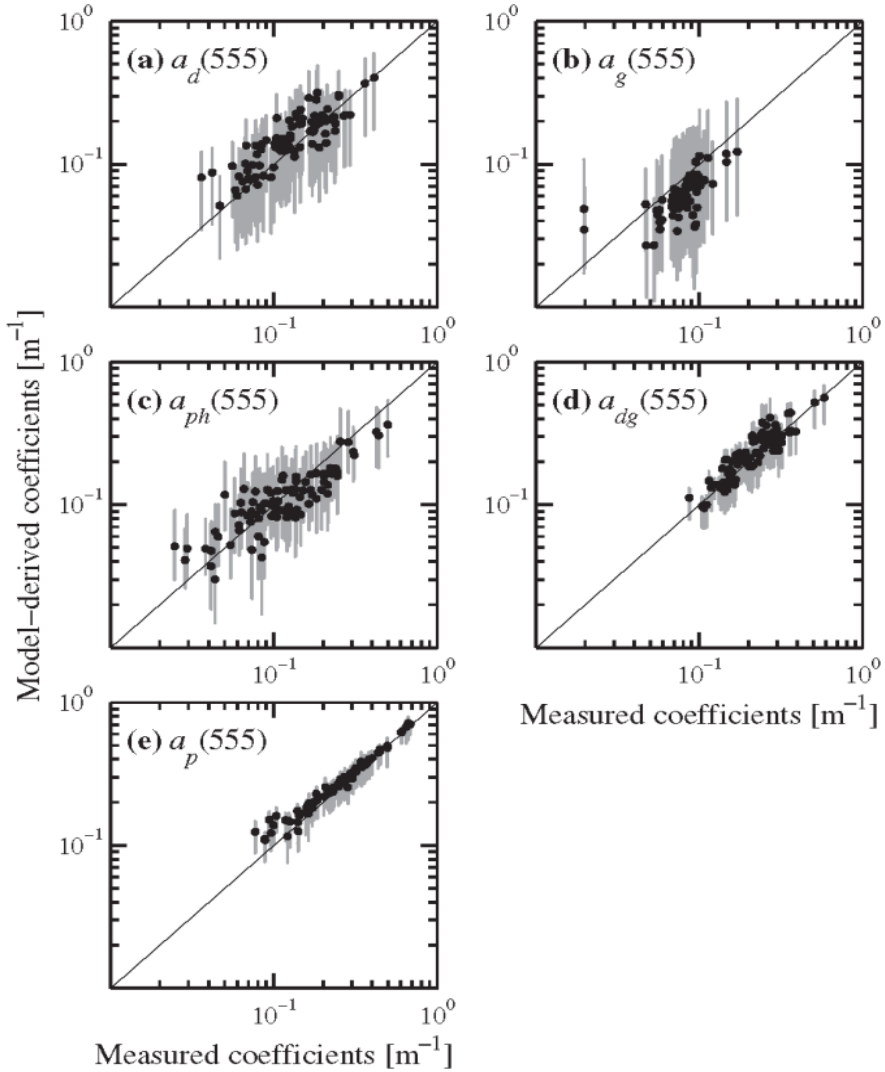
Guangming Zheng[1,2,3], Dariusz Stramski[4], and Paul M. DiGiacomo[1]

[1]NOAA/NESDIS/Center for Satellite Application and Research, College Park, Maryland, USA, [2]Earth System Science Interdisciplinary Center, University of Maryland, College Park, Maryland, USA, [3]Now at Global Science and Technology Inc., Greenbelt, Maryland, USA, [4]Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, La Jolla, California, USA

Abstract We present a model, referred to as Generalized Stacked-Constraints Model (GSCM), for partitioning the total light absorption coefficient of natural water (with pure-water contribution subtracted), $a_{nw}(\lambda)$, into phytoplankton, $a_{ph}(\lambda)$, nonalgal particulate, $a_d(\lambda)$, and CDOM, $a_g(\lambda)$, components. The formulation of the model is based on the so-called stacked-constraints approach, which utilizes a number of inequality constraints that must be satisfied simultaneously by the model outputs of component absorption coefficients. A major advancement is that GSCM provides a capability to separate the $a_d(\lambda)$ and $a_g(\lambda)$ coefficients from each other using only weakly restrictive assumptions about the component absorption coefficients. In contrast to the common assumption of exponential spectral shape of $a_d(\lambda)$ and $a_g(\lambda)$ in previous models, in our model these two coefficients are parameterized in terms of several distinct spectral shapes. These shapes are determined from field data collected in the Chesapeake Bay with an ultimate goal to adequately account for the actual variability in spectral shapes of $a_d(\lambda)$ and $a_g(\lambda)$ in the study area. Another advancement of this model lies in its capability to account for potentially nonnegligible magnitude of $a_d(\lambda)$ in the near-infrared spectral region. Evaluation of model performance demonstrates good agreement with measurements in the Chesapeake Bay. For example, the median ratio of the model-derived to measured $a_d(\lambda)$, $a_g(\lambda)$, and $a_{ph}(\lambda)$ at 443 nm is 0.913, 1.064, and 1.056, respectively. Whereas our model in its present form can be a powerful tool for regional studies in the Chesapeake Bay, the overall approach is readily adaptable to other regions or bio-optical water types.

Comparison of model-derived and measured absorption coefficients for 443 and 555 nm for the data set from the Chesapeake Bay





The model performs generally well, for example in the blue the median ratio of model-derived to measured values is less than 10% and the median absolute percent difference less than 20%

- Evaluation of the prototype absorption partitioning model (based on the Chesapeake Bay case study) with different data sets shows inconsistent performance, for example good for Puget Sound data but not consistently good enough for the global data set.

- A new partitioning model has been developed. The model exhibits satisfactory performance when tested with a globally-distributed dataset encompassing various oceanic and coastal marine environments.

  The paper in preparation:

  Li, L., D. Stramski, and R.A. Reynolds. A model for partitioning the light absorption coefficient of seawater into phytoplankton, non-algal particulate, and CDOM components for applications over a broad range of oceanic and coastal marine environments.

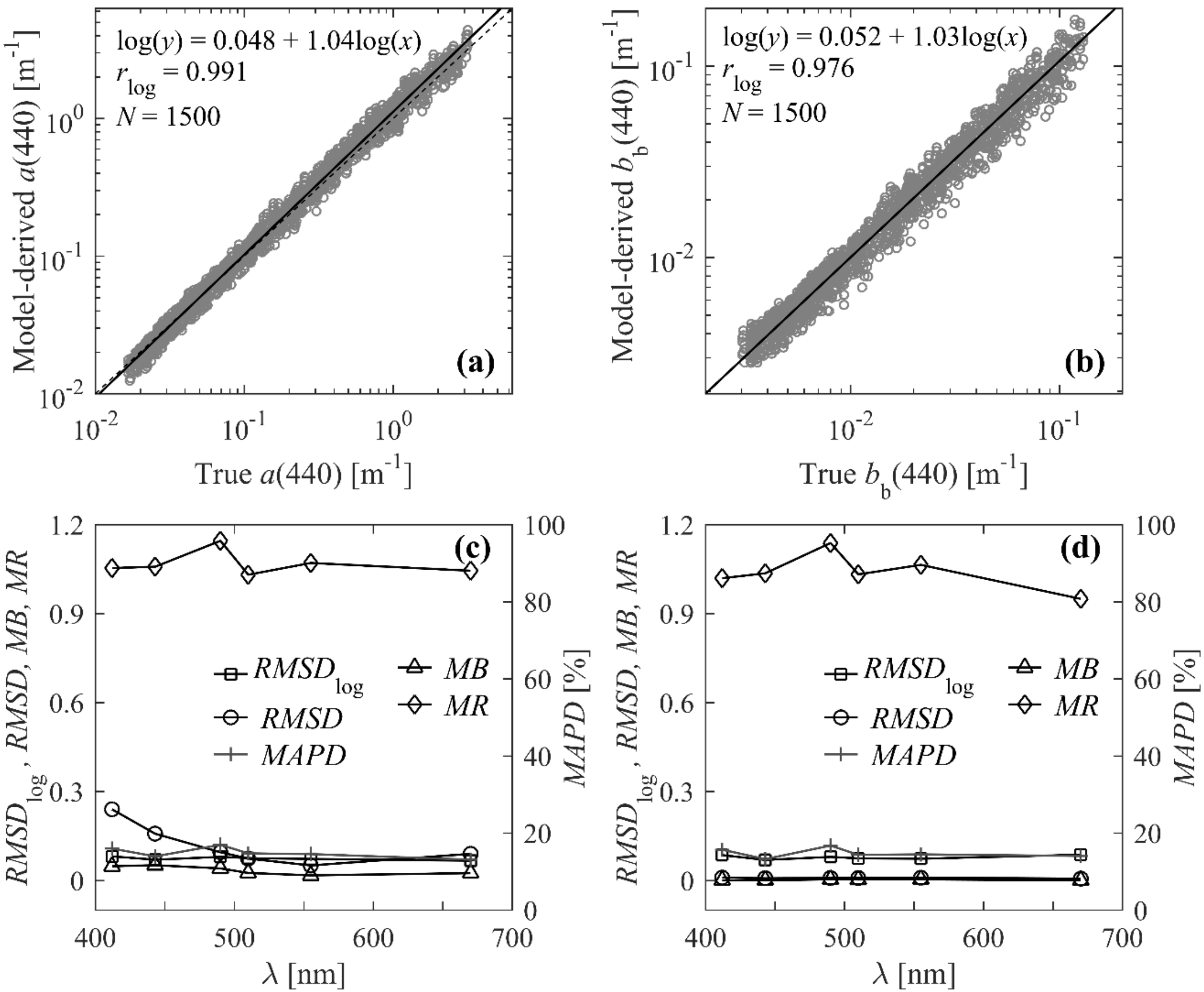
Inverse reflectance model: LS2

Modified & improved version of Loisel and Stramski (2000) to derive $a(\lambda)$ and $b_b(\lambda)$ from $R_{rs}(\lambda)$ was developed

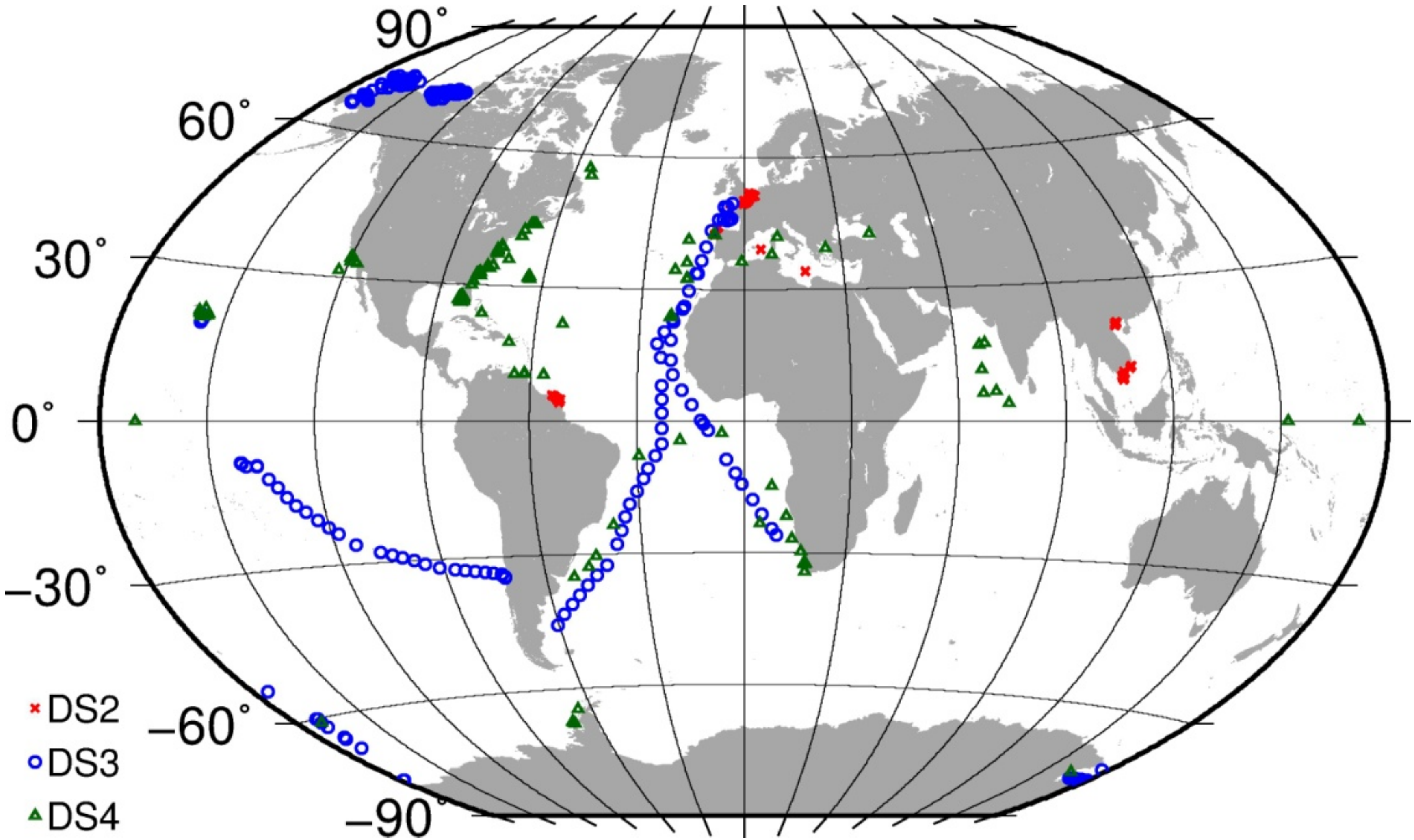
- Model development based on radiative transfer simulations
- Model evaluation with a synthetic dataset
- Model validation with in situ and satellite-in-situ match-up datasets
- **The paper completed and accepted for publication**:

Loisel, H. Stramski, D., Dessaily, D., Jamet, C., Li, L., and Reynolds, R.A., An inverse model for estimating the optical absorption and backscattering coefficients of seawater from remote-sensing reflectance over a broad range of oceanic and coastal marine environments. *Journal of Geophysical Research Oceans, in press.*

Model evaluation with a synthetic dataset



Model validation with in situ datasets (DS2 and DS3) and satellite-in situ match-up dataset (DS4)



Water-leaving radiance from in situ measurements

7050 Vol. 55, No. 25 / September 1 2016 / *Applied Optics* **Research Article**

applied optics

Effects of inelastic radiative processes on the determination of water-leaving spectral radiance from extrapolation of underwater near-surface measurements

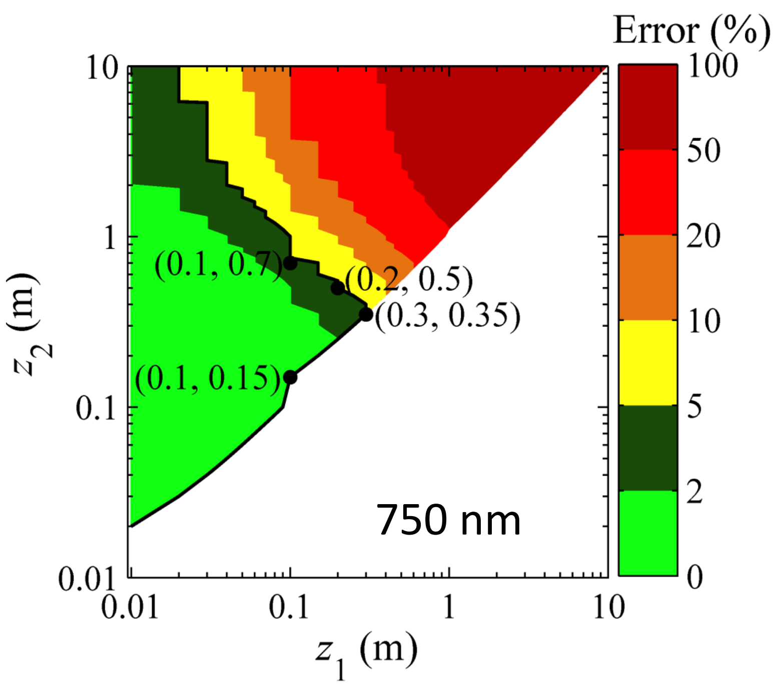
LINHAI LI,* DARIUSZ STRAMSKI, AND RICK A. REYNOLDS

Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, La Jolla, California 92093-0238, USA
**Corresponding author: lil032@ucsd.edu*

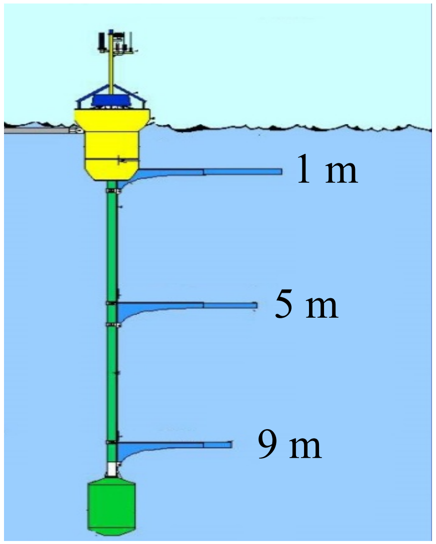
Received 20 May 2016; revised 14 July 2016; accepted 24 July 2016; posted 28 July 2016 (Doc. ID 266597); published 29 August 2016

Extrapolation of near-surface underwater measurements is the most common method to estimate the water-leaving spectral radiance, $L_w(\lambda)$ (where λ is the light wavelength in vacuum), and remote-sensing reflectance, $R_{rs}(\lambda)$, for validation and vicarious calibration of satellite sensors, as well as for ocean color algorithm development. However, uncertainties in $L_w(\lambda)$ arising from the extrapolation process have not been investigated in detail with regards to the potential influence of inelastic radiative processes, such as Raman scattering by water molecules and fluorescence by colored dissolved organic matter and chlorophyll-*a*. Using radiative transfer simulations, we examine high-depth resolution vertical profiles of the upwelling radiance, $L_u(\lambda)$, and its diffuse attenuation coefficient, $K_{L_u}(\lambda)$, within the top 10 m of the ocean surface layer and assess the uncertainties in extrapolated values of $L_w(\lambda)$. The inelastic processes generally increase L_u and decrease K_{L_u} in the red and near-infrared (NIR) portion of the spectrum. Unlike K_{L_u} in the blue and green spectral bands, K_{L_u} in the red and NIR is strongly variable within the near-surface layer even in a perfectly homogeneous water column. The assumption of a constant K_{L_u} with depth that is typically employed in the extrapolation method can lead to significant errors in the estimate of L_w. These errors approach ~100% at 900 nm, and the desired threshold of 5% accuracy or less cannot be achieved at wavelengths greater than 650 nm for underwater radiometric systems that typically take measurements at depths below 1 m. These errors can be reduced by measuring L_u within a much shallower surface layer of tens of centimeters thick or even less at near-infrared wavelengths longer than 800 nm, which suggests a requirement for developing appropriate radiometric instrumentation and deployment strategies.

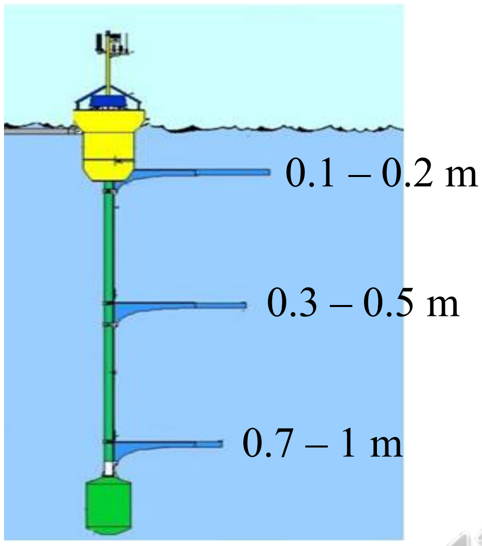
- Because of inelastic radiative processes the diffuse attenuation coefficient of upwelling radiance in the red and near-IR varies strongly with depth in the near-surface layer.
- In the red and near-IR the errors in water-leaving radiance determined from extrapolation of near-surface underwater measurements taken at depths ≥ 1 m can be very large (tens of percent).
- Measurements must be made within the top ~0.5 – 1 m of the water column to ensure errors less than 5%, for example at 0.2 and 0.5 m to ensure that the error at 750 nm is less than 5%.



Unacceptable configuration



Required configuration



Contributions to PACE Science Team collaborative efforts

- Werdell et al. 2018. An overview of approaches and challenges for retrieving marine inherent optical properties from ocean color remote sensing. *Progress in Oceanography*, in press.

- Casey et al. A global hyperspectral database of in situ ocean inherent and apparent optical properties. In preparation.

- Multi-investigator experiment in coastal waters of Florida to compare various absorption measurement techniques.

  Measurements of particulate absorption completed in our lab.

  Data analysis underway.

  Collaboration on joint papers expected in the near-future.