Methods in Oceanography 7 (2013) 52–62

Contents lists available at ScienceDirect

Methods in Oceanography

journal homepage: www.elsevier.com/locate/mio

Full length article

The characteristics of particulate absorption, scattering and attenuation coefficients in the surface ocean; Contribution of the Tara Oceans expedition

Emmanuel Boss [a,*], Marc Picheral [b,e], Thomas Leeuw [a], Alison Chase [a], Eric Karsenti [c], Gabriel Gorsky [b,e], Lisa Taylor [a], Wayne Slade [d], Josephine Ras [b,e], Herve Claustre [b,e]

[a] School of Marine Sciences, University of Maine, 458 Aubert Hall, Orono, ME 04401, USA
[b] CNRS, UMR 7093, LOV, Observatoire océanologique, 06230 Villefranche/mer, France
[c] EMBL Heidelberg, Meyerhofstraße 1, 69117 Heidelberg, Germany
[d] Sequoia Scientific, Inc., 2700 Richards Road, Suite 107, Bellevue, WA 98005, USA
[e] UPMC Univ Paris 06, UMR 7093, LOV, Observatoire océanologique, 06230 Villefranche/mer, France

ARTICLE INFO

Article history:
Available online 15 December 2013

Keywords:
Bio-optics
Particle absorption coefficient
Particle scattering coefficient
Particle attenuation coefficient

ABSTRACT

A dataset consisting of AC-S measurements of (hyper-) spectral particulate absorption, scattering and attenuation coefficients were obtained from measurements performed on the flow-through system of the R/V Tara during its 2.5-year long expedition.

The AC-S instruments were robust, working continuously with weekly maintenance for about 3 months at a time, and provided absorption (attenuation) data for 454 (375) days, or 90% (75%) of total possible days during the expedition.

This dataset has been mapped to 1 km × 1 km bins to avoid over emphasizing redundant data, and to match the spatial scale of typical ocean color satellite sensors. It consists of nearly 70,000 particulate absorption spectra and about 60,000 particulate scattering and attenuation spectra. These data are found to be consistent with chlorophyll extraction and with the published average shapes of particulate absorption and scattering spectra and bio-optical relationships. This dataset is richer than previous ones

* Corresponding author. Tel.: +1 207 745 3061; fax: +1 207 581 4388.
E-mail address: Emmanuel.boss@maine.edu (E. Boss).

http://dx.doi.org/10.1016/j.mio.2013.11.002

in the data from open-ocean (oligotrophic) environments making it more representative of global distributions and of utility for global algorithm development.

1. Introduction

The Tara Oceans expedition, a 2.5-year long and 57,000 mile long course (Fig. 1), was conceived to provide a snapshot of the distribution of planktonic organisms in the world ocean, providing "A global-scale study of morphological, genetic, and functional biodiversity of plankton organisms in relation to the changing physico-chemical parameters of the oceans" (Karsenti et al., 2011).

As part of this expedition, we installed an AC-S hyper-spectral spectrophotometer (WET Labs, Inc., Philomath, OR) on R/V Tara's flow-through seawater system, measuring both absorption and attenuation coefficients. The flow-through seawater was supplied by a diaphragm pump plumbed to the bow intake. By alternating sampling with water passing through a 0.2-μm membrane filter cartridge, we obtained the particulate attenuation and absorption coefficients. While this method has been evaluated previously (e.g., Dall'Olmo et al., 2009; Slade et al., 2010; Westberry et al., 2010), it has never been used to this extent.

In this manuscript we analyze the robustness of the AC-S, present the salient features of the absorption and attenuation data set obtained, and highlight some of the biogeochemical parameters that can be derived from it. In particular, we compare our hyper-spectral data with the multi-spectral data (measured with WET Labs AC-9 instruments) presented in Barnard et al. (1998) and Babin et al. (2003), the most extensive datasets of particulate IOPs published to date.

2. Methods

The in-line sampling system (including a photo) and the data processing methodology have been described in detail in Slade et al. (2010). In short, water from the ship's flow-through system (pumped from $\sim$2 m below surface) was passed through a debubbler and then through a WET Labs AC-S. The AC-S sensor was operated constantly (lamps on) except when in port or once per week for weekly instrument cleaning and filter cartridge replacement. Periodic switching of a custom valve passed 0.2 μm filtered seawater through the sensor for 10 min of every hour, or 5 min of every half-hour in coastal waters (the automated valve system has been recently commercialized by Sequoia Scientific, Inc., Bellevue, WA). Interpolating between the readings of filtered water to the time when measurements of the unfiltered water are made (and their subtraction from the measurements without filter) provided the particulate absorption and attenuation values. Absorption data are then corrected for scattering and residual temperature (Slade et al., 2010). The only exception to the protocol in Slade et al. (2010) was for cases when we had absorption data but no attenuation measurements (due to the failure of the c-side of the AC-S ($\sim$10% of the sampling days)). In that case we processed the data in two ways: (1) assume scattering to be spectrally flat when scatter-correcting the data, as typically done with bench-top spectrophotometers; (2) use the bio-optical relations derived in this paper to obtain a chlorophyll-based attenuation spectra, and use these attenuation spectra to scatter correct the absorption (see below).

In series with the AC-S, a SBE45 MicroTSG (Sea-Bird Electronics, Inc., Bellevue, WA) unit was installed in the flow-through system. Note that due to the subtraction of the dissolved spectra and the residual temperature correction, the SBE45 temperature and salinity measurements were not necessary for the processing of the flow-through AC-S measurements.

Data were first averaged to 1-min time bins (to average high frequency system noise, e.g. due to particles which are observed differently by the a- and c-sides of the instrument). These 1 min data were submitted to databases (SeaBASS and PANGAEA) as merged files (using time as the common