

Estimation of temperature, salinity and scattering corrections of inherent optical properties using the AC-S in-situ spectrophotometer

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Abstract

Absorption and attenuation data were collected in the North Aegean Sea during the Perseus and AegeanMarTech cruises using the spectral absorption and attenuation meter AC-S (WETLabs, Inc). Instrument drift, temperature, salinity and scattering corrections were applied to obtain accurate results. Negative absorption and attenuation coefficient values were observed at longer wavelengths. A range of methods were used to estimate absorption: the proportional scattering method appears to overestimate, while the flat method to underestimate absorption. The Kirk scattering method was found to provide the most reasonable results. However, further pure water calibrations are necessary to obtain more precise data.

Keywords: absorption, attenuation, AC-S scattering corrections methods, ocean optics.

1. Introduction

Inherent optical properties (IOPs) are those properties that are independent of the ambient light field within a medium. The IOPs of natural waters are the most significant factors affecting light propagation within the water column, and are thus used in estimating aquatic biomass, primary production and carbon pools (Linhai et al., 2013). Various instruments have been developed for the measurement of IOPs (Bricaud et al., 1983; Maffione et al., 1993; Smith & Baker, 1981). The spectral absorption and attenuation AC-S meter (WETLabs, 2011) is a spectrophotometer widely used to measure dissolved, particulate and pure water optical properties. Three analysis steps are necessary to obtain accurate absorption and attenuation coefficients from AC-S measurements: (1) pure water calibration of the AC-S, (2) temperature and salinity corrections and (3) scattering corrections. The AC-S instrument drift is described by pure water calibration results. Temperature and salinity effects are large in the near-infrared and reduce to undetectable in the visible (Pegau et al., 1997). Scattering corrections in the absorption tube are necessary to estimate the portion of lost light scattered at angles greater than 41 degrees (Zaneveld et al., 1994) and thus to avoid the overestimation of the absorption coefficient.

The main objective of this work was to study and present some preliminary results of the IOPs measured with a WETLabs AC-S absorption and attenuation instrument in the Aegean Sea. Calibration and data analysis methods for the AC-S are described and evaluation of the pure, temperature, salinity and scattering corrections are presented.

2. Materials and methods

2.1 AC-S description

The AC-S consists of dual 25-cm path-length flow tubes for the measurement of absorption and attenuation coefficients. The absorption side has a reflecting tube and a large area detector, whereas the attenuation side has a non-reflective tube and a collimated detector. The instrument covers the 400–730 nm wavelength spectrum in approximately 4 nm steps. Uncorrected attenuation (c_{raw}) and absorption (a_{raw}) coefficients (in m^{-1}) are estimated from: (a) the signal and reference measurements of light, (b) the light path-length, (c) the pure water offset values (in m^{-1}) and (d) an internal

temperature compensation correction value derived from the factory temperature calibration (WETLabs, 2011).

2.2 Instrument drift, temperature and salinity corrections

Processing started by merging AC-S raw data with Conductivity-Temperature-Depth (CTD) data, as a function of time. The time lag was derived through estimating lagged cross correlation between CTD temperature and the external temperature of AC-S. In the laboratory, calibration values for pure water were obtained by averaging absorption and attenuation coefficients of optically pure water, generated by a Milli-Q water purification system (Millipore). The water calibration and all AC-S data measurements were normalized to a constant temperature 23.2 °C to account for the temperature dependence of the absorption coefficient of pure water. All AC-S measurements were unfiltered hence the measured values correspond to the total absorption and attenuation coefficients minus water.

2.3 Reflective tube scattering corrections

Three different scattering correction methods have been applied to the temperature, salinity and instrument drift corrected AC-S data. The first method, called flat scattering method (Eq. 1), subtracts the absorption measurement at a reference wavelength from all corrected data, where the absorption is assumed to be zero. As reference wavelength we used 715nm.

$$a_{\text{flat}} = a_{\text{mts}} - a_{\text{mts}}(\lambda_{\text{ref}}) \quad (1)$$

where, a_{mts} is the absorption coefficient corrected for temperature, salinity and instrument drift, and λ_{ref} is the reference wavelength.

The second scattering correction method proposed by Kirk (1992) and is described by Eq. 2

$$a_{\text{kirk}} = a_{\text{mts}} - \text{CFS} * b_{\text{mts}} \quad (2)$$

where, CFS is the constant fraction of scattering proposed by Kirk (1992) and b_{mts} is obtained from $(c_{\text{mts}} - a_{\text{mts}})$, where c_{mts} is the attenuation coefficient corrected for temperature, salinity and instrument drift. As CFS we used 0.14 as recommended by the manufacturer (WETLabs, 2011) for open ocean.

The third scattering correction method called proportional method (Zaneveld et al., 1994) and is described by Eq. 3

$$a_{\text{proportional}} = a_{\text{mts}} - [a_{\text{mts}}(\lambda_{\text{ref}}) * (b_{\text{mts}} / b_{\text{mts}}(\lambda_{\text{ref}}))] \quad (3)$$

3. Results

3.1 Calibration pure water offsets

Two water calibrations have been carried out in the laboratory on 13 November 2014 and the final pure water offset values were obtained by taking the mean of the two repetitions. The minimum and maximum values of attenuation water offsets were -0.3643 and 0.3386 m⁻¹ respectively and the range of absorption water offsets was 0.1719 - 0.2797 m⁻¹.

3.2 Instrument drift, temperature, salinity and scattering corrections

A vertical profile of raw AC-S data was collected on 10 October 2013, at an offshore pelagic station at 40.332°N, 25.458°E in the North Aegean Sea. The illustration of all different corrections applied to raw absorption and attenuation data are shown in Fig. 1.

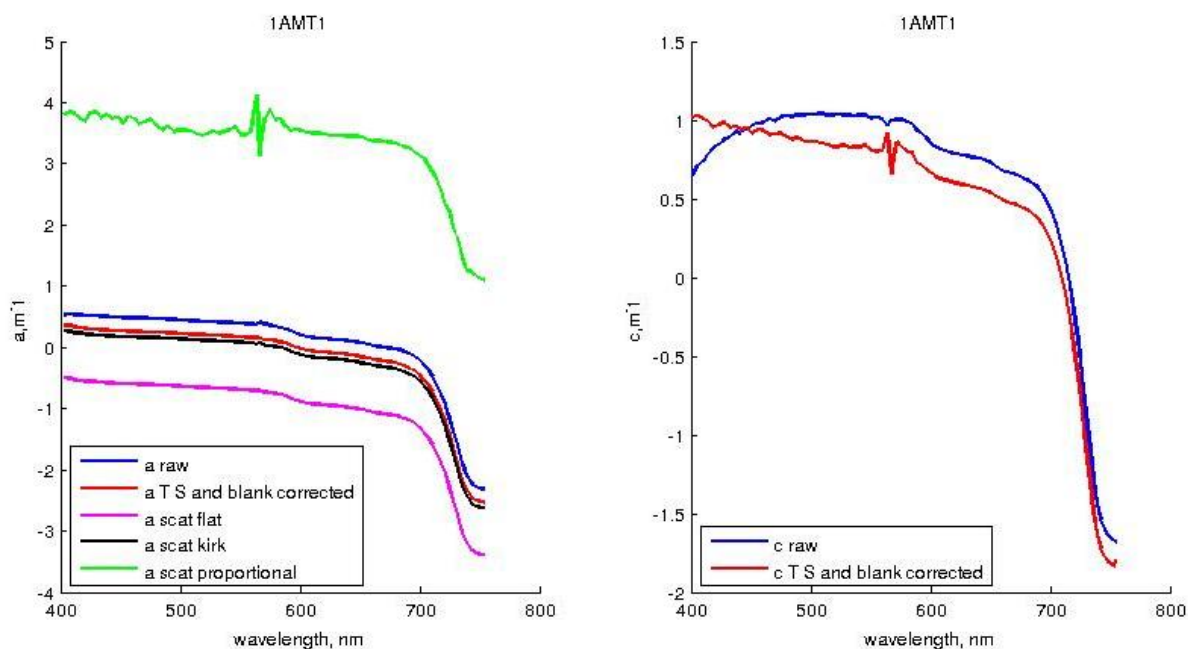


Fig. 1. Temperature, salinity, blank and scattering corrections for absorption (a , m^{-1}) and attenuation (c , m^{-1}) coefficients, as a function of wavelength (nm), at 30 meter depth of a pelagic N. Aegean station.

In a_{raw} and a_{mts} negative absorption values occurred at wavelengths greater than 600 and 674 nm, respectively. The a_{flat} scattering correction method results in negative absorption values throughout the entire spectral range, whereas the proportional scattering method overestimates the absorption coefficient. In contrast, a_{kirk} values appear to be more reasonable. In short wavelengths (< 446 nm) temperature, salinity and blank corrections overestimate the attenuation coefficient. Negative raw and corrected attenuation values appear in the near-infrared region.

4. Conclusions/Discussion

Absorption and attenuation measurements using the AC-S meter always exhibit scattering errors. The relative errors on the measured absorption coefficients are lower than 25% but reach up to 100% in highly scattering waters, while errors on attenuation coefficients are more stable, with an underestimation mainly driven by the volume scattering function, VSF (Leymarie et al., 2010). According to the AC-S protocol document (WETLabs, 2011) the application of flat and proportional scattering methods requires the assumption of negligible absorption in a reference wavelength and the wavelength independence of VSF. These assumptions are not valid in our study because of the under and overestimation of absorption coefficient in flat and proportional scattering correction methods, respectively. The appearance of high absorption values in the proportional method is due to the measurements of some spectral characteristics of scattering in the two different flow tubes. Underestimation of absorption values using the flat scattering method has also been reported by Röttgers et al., in coastal waters. The Kirk scattering method has been found to perform better in turbid inland floodplain lakes (Carvalho et al., 2014). In this study, the Kirk scattering method is found

to give the most reasonable correction results in the specific open ocean station in the North Aegean Sea.

In situ measurements of IOPs in clear open ocean waters are difficult when the signal is within the resolution limit of the instrument. Drift in instrument electronics or optics and fouling of optical windows at this resolution can provide further issues affecting precise absorption measurements. Pure water calibrations are used to correct these issues. In our oligotrophic study station, very high absorption values have been recorded comparable to those obtained from the Baltic Sea (Berthon et al., 2008) hence the examination of the rate of the instrumental drift is critical. New pure water calibrations are scheduled in order to obtain the most accurate data possible.

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