Technical report on WetLabs AC-S absorption and beam attenuation meter

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Abstract

The Ocean Optics 2013 class is a platform that introduces young and upcoming scientists to the field of ocean color. It provides the key tools in obtaining inherent and apparent optical properties of seawater useful in deriving radiometric quantities. Inherent optical properties IOPs are seawater characteristics that are independent of the ambient or solar light field but depend on the optically active seawater constituents. Routinely measured IOPs are absorption, beam attenuation, and scattering coefficients. Apparent optical properties AOPs are those that depend on IOPs and also the direction of the ambient or solar light field. IOPs can be measured in the laboratory or in-situ but AOPs depend on the ambient light hence need to be measured in-situ. The ocean color community has evolved over the years due to societal needs; and the AOP derived parameters, remote sensing reflectance R_{RS} , and water leaving radiance L_W have gained widespread interest. However, nature does haunt us with non-homogenous environmental conditions, optically active seawater constituents, cloud conditions and solar light. There is therefore a need to take stock of uncertainties in our ocean color observations. To mitigate uncertainties there are steps that are critical; instrument calibration, understanding raw data, data processing, and auxiliary information collection. In our project we aim to elucidate on how to prepare, acquire, analyze and present IOPs collected with a WETLabs AC-S absorption and beam attenuation instrument and mitigate some sources of uncertainties. The scope of this report is to provide a guideline to in-house calibration, instrument handling, data collection and possible ways to use information derived from the processed data.

Introduction

The Wetlabs AC-S, **Figure 1**, is a successor to the AC-9 meter (Leymarie et al., 2010; Zaneveld et al., 1992). It consists of flow-through tubes for simultaneous measurements of the absorption and beam attenuation coefficients of a sample fluid over a spectral range ~ (400 − 740) nm.

Figure 1 AC-S absorption and beam attenuation meter. The absorption and beam attenuation chambers both have flow inlet (A) and flow outlet (B). Note that these inlet and outlet can be reversed without changing measurement.

The absorption chamber has reflecting walls so that both forward scattered light and transmitted light reach the detector, so that only absorbed and backscattered light are removed from the beam. Hence the absorption coefficient of a sample fluid can be obtained (Zaneveld et al., 1992). For the purpose of this report we present inflow (A) and outflow (B) in Figure 1 but they can be interchanged, there is no prescribed inflow or outflow. **Figure 2** shows the light source which corresponds to the inflow side and detector end at the outflow side of the AC-S indicated in **Figure 1**. At the inflow side **Figure 2A** of both the absorption and beam attenuation chamber there is a

collimated light source which is filtered into discrete hyperspectral bandwidths using a rotating filter wheel with continuous interference filters. At the outflow side **Figure 2B** a diffuse detector (white looking surface) collects forward scattered and transmitted light in the reflective tube **Figure 2C. The transmission of this light is related to the absorption coefficient (equation 2)** assumed to be the absorption coefficient a [m^{-1}]. The non-reflective tube absorbs scattered light hence approximates the beam attenuation coefficient c [m^{-1}] collected into the field of view of the clear detector **Figure 2C** (Leymarie et al., 2010). To obtain an estimate of the scattering coefficient b [m^{-1}] we use **Equation (1)**,

$$b(\lambda) = c(\lambda) - a(\lambda)$$ **(1)**

In measuring a and c, the Beer-Lambert Law fundamentals are used to explain the relationship between the absorption coefficient and backscattering coefficient. Zaneveld et al. (1992) determine the light transmitted Tr from source to detector through the tubes of length L (e.g. images used here L = 0.16 m) **Figure 2** using **Equation (2)**,

$$Tr = e^{-(a(\lambda)+b(\lambda))L}$$ **(2)**

A comprehensive introduction to the absorption and beam attenuation measurements along with instrument design is available in several works (Leymarie et al., 2010; Roesler and Boss, 2008; Slade et al., 2010; Zaneveld et al., 1992).
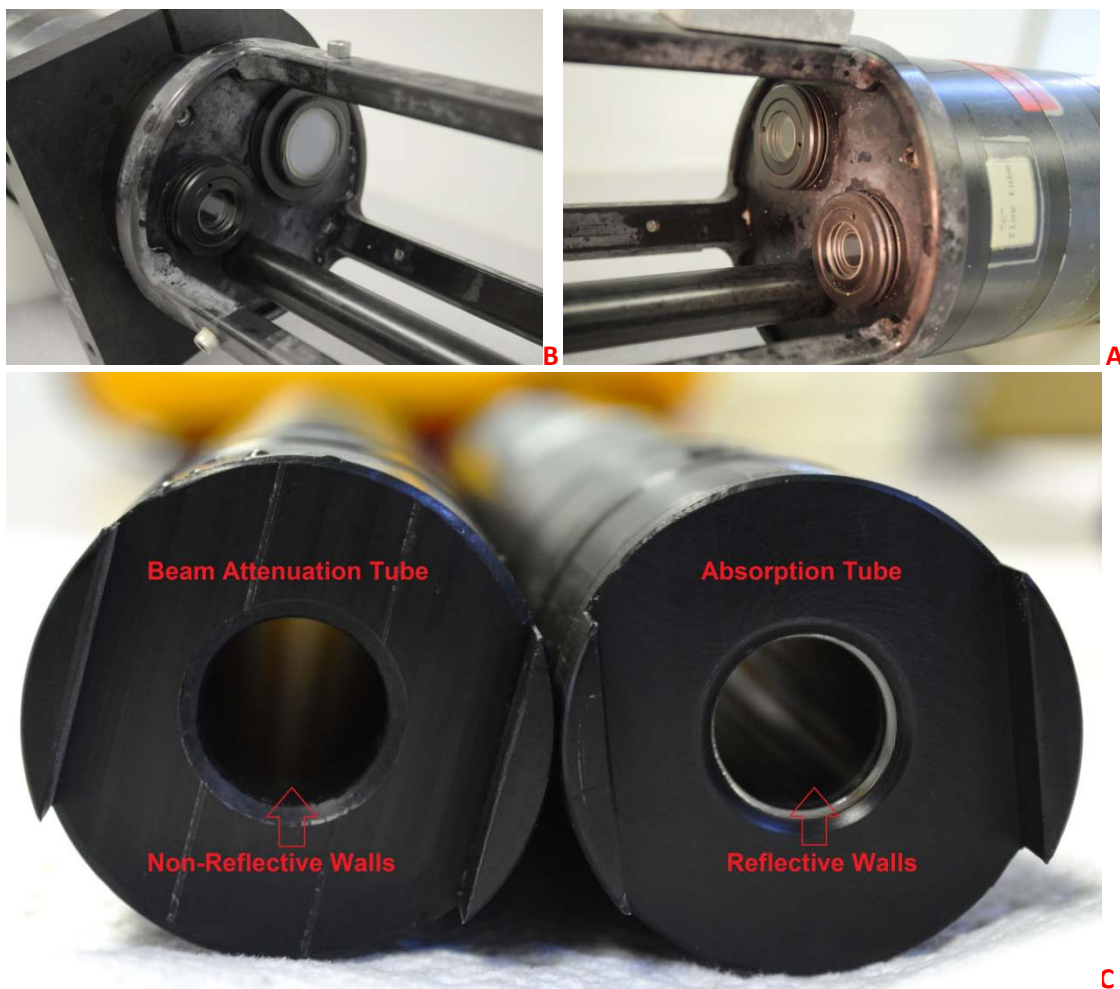

Figure 2 Light source windows at the inflow **A** and detector windows at the outflow **B** end of the AC-S. At the absorption detector end **B** a diffuser is used hence the white looking surface. The sample

flows through the absorption (reflecting walls) and beam attenuation (black/absorbing walls) tubes **C**.

2 Methods
2.1 Cleaning
The AC-S shown in **Figure 1**. In this section we will provide some basic steps of disassembling the components that require cleaning, i.e. the tubes and sensor windows shown in **Figure 2**. The first step is to remove the inflow and outflow sleeves, you need to loosen the screw **Figure 3A**. These screws should never be tight. Take care that you do not remove it completely; the idea of loosening the screw is to allow free movement of the sleeve and align the flow tube to the tube openings **Figure 3B**. The screw just needs to be loose and out of the groove **Figure 3C**. To remove the sleeve avoid pulling on the reflecting tube as over time it might damage the attaching points of the sleeve and reflecting tubing and Figure 3C indicates where you can put finger tips at the sleeve end X **Figure 3C** and carefully pull it. After you have pulled the sleeves on both ends, carefully remove the tube avoid scratching the sensor windows, you can use the tube inflow and outflow to guide you in avoiding this. This is a challenge!
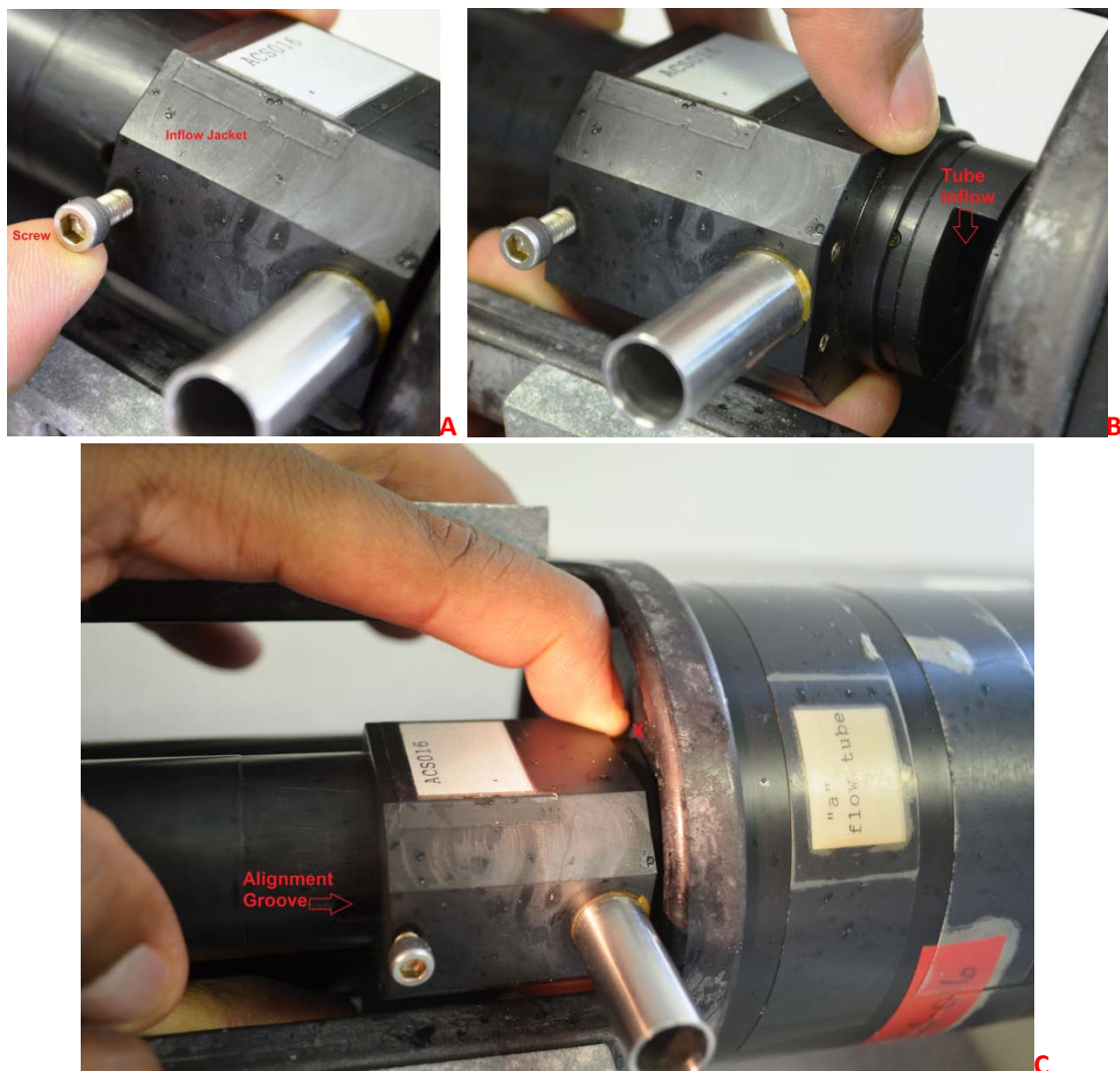
Figure 3 The inflow sleeve and the alignment screw **A**, tube inflow point **B** and the recommended point of sleeve top **X** removal after loosening the screw **C**.

To avoid misplacing or wrong replacement of components after cleaning, we suggest you use a clean table or surface and have kitchen paper towel on which to place the components. **Figure 4** shows how you can arrange the components. In any case labeling the tubes and sleeves can be helpful, for instance when in future you wish to do error source tracing and instrument use consistency, sample labels can be seen in **Figure 3C**. It makes it easy to remember where each component belongs.

Figure 4 The AC-S 16 tubes and tube sleeves disassembled for cleaning using lens paper.

To clean the sensor windows and the tubes use wet lens paper, e.g. Fisherbrand Lens Paper, wetted with isopropyl alcohol to dissolve certain materials and mild soapy water to dissolve fat **Figure 5A**. It is possible to use Kim wipes but take extra care to avoid scratching the wall and sensor window. Avoid contaminating the lens paper by holding it by a corner or you can wear gloves although it is not necessary. Wipe each sensor window gently towards you as shown by the arrow in **Figure 5B**. To avoid scratching the window it is recommended to tap-tap without wiping. **Figure 5C** shows how to clean inside the tubes, it is recommended to use a clean small tube and put the wet lens paper at the top opening. Gently push it whilst rotating the small tube to carefully clean the inside walls of the tube. We suggest visual inspection of the sensor windows and tubes to eliminate any further visible dust, microparticles or grease. Replace all components carefully.

**Figure 5** Steps in applying the isopropyl alcohol **A,** cleaning the sensor windows **B,** and tubes **C**.

2.2 Calibration Setup

Once all the components are replaced, set up the AC-S in the upright position or the position you will use it in. Secure the AC-S to avoid it dropping and also place it in a sink to allow easy bubble and water flow and drainage. At the inflow and outflow ends connect dark tube extensions to mitigate stray light **Figure 6**. The calibration is done with optically pure water e.g. Milli-Q water. Use a glass container and tubing that has been pre-rinsed at least three times with the Milli-Q water. Leave the Milli-Q water for at least an hour or two to allow for degassing or debubbling but take care that you do not leave it for too long. Also take care that your container is clean and closed, you can use Parafilm to mitigate contamination. Avoid using plastic, as it is more chemically reactive and can then contaminate your Milli-Q water. Place your container at a higher position than the inflow point. Open the valve **Figure 6** and slowly allow water to flow through the optical tube.

It is recommended to start the setup on the absorption side because it is more sensitive to bubble effects. Connect the power and data cables to the computer but only turn on the power supply of the AC-S when everything is connected **Figure 7**. Turn on the power supply.

Figure 6 Illustration of setting up calibration components. Use dark tape covered inflow and outflow tubes, a valve to control water flow and elevated location for the glass container with Milli-Q water.
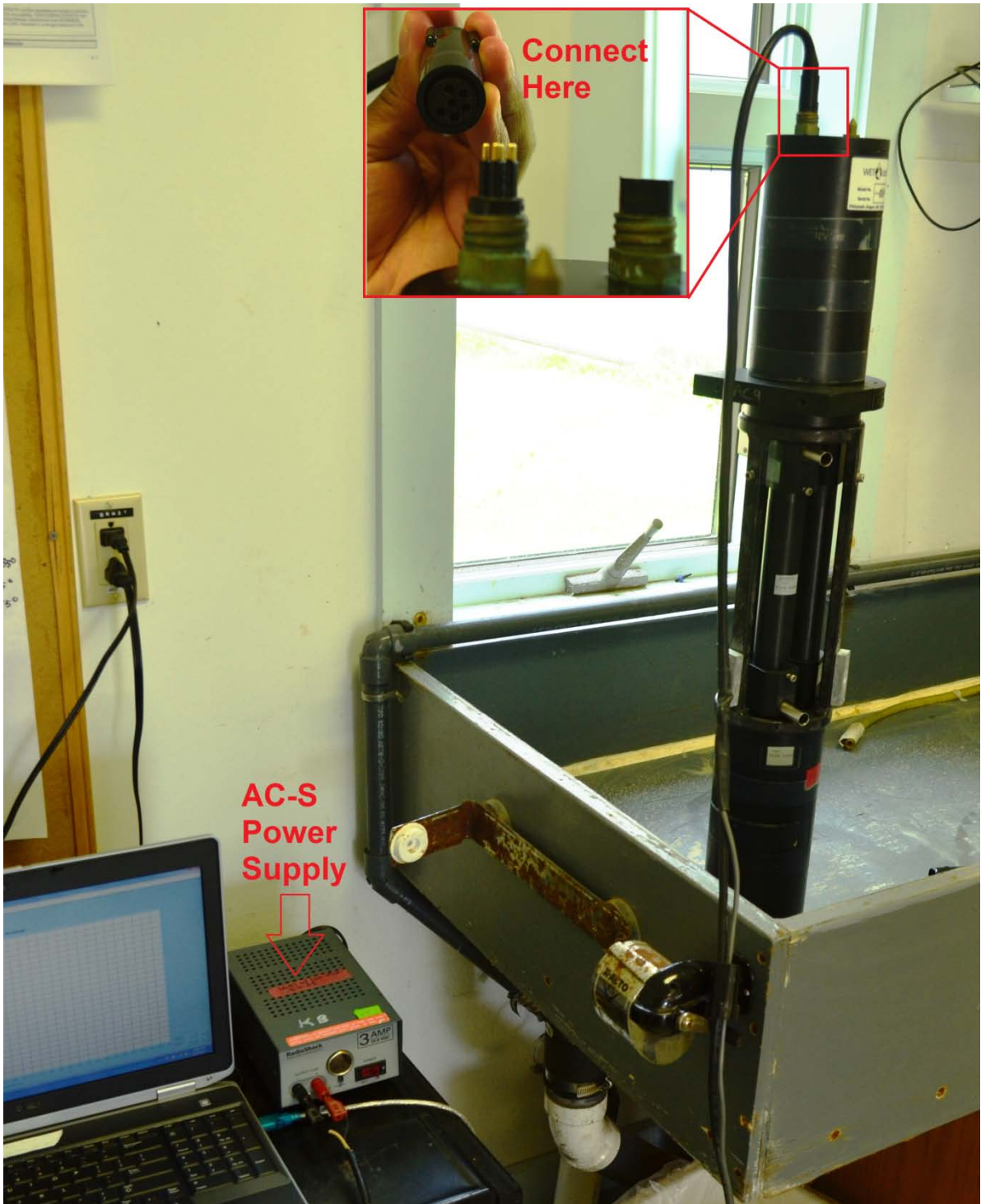
Figure 7 An overview of the clean AC-S connected to the computer, with the power supply indicated. The inset shows the connector from the power supply and data cable.

2.3 Measurements

Start up the AC-S software, WetView, and load the current device file for the AC-S to be calibrated. The screen should look as in **Figure 8** a. Use the zoom options to optimally observe the signal.
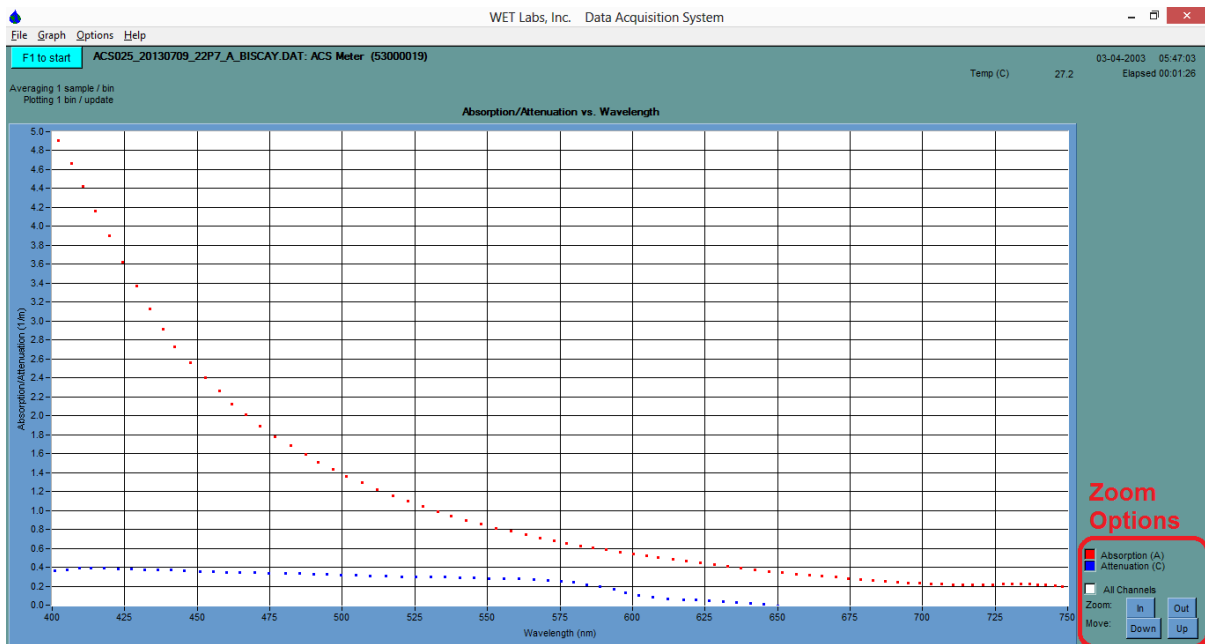
Figure 8 A screenshot of the AC-S WetView software, highlighted are the zoom options and legend of the plot. Red is the absorption and blue is the beam attenuation raw measurement. Note the present values are not of optically pure water.

As a reference we present pure water (Pope and Fry, 1997) absorption and beam attenuation coefficients in **Figure 9**. In the presence of bubbles in the optical path your observable real time spectra will not be stable. To debubble squeeze the inflow and outflow tubes close to the flow through tubes or by tilting or rocking the AC-S. After repeated debubbling and rocking, a stable spectrum should be with a reading range ± 0.01 m^{-1}. Carefully follow the same procedure on the beam attenuation side.
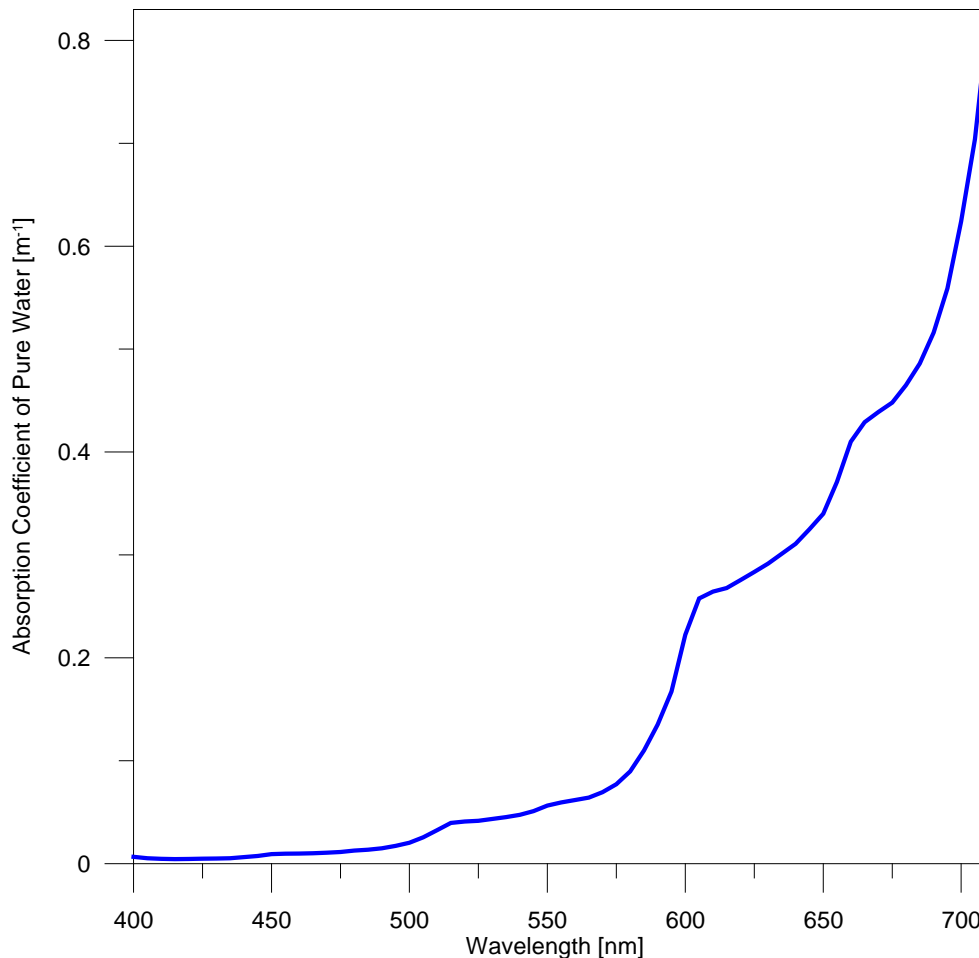
Figure 9 The absorption coefficient of pure water (Pope and Fry, 1997).

It will be important to record the temperature but you do not need to measure salinity for Milli-Q water. Save your calibration file - a simple format example is,

([sensor name a for absorption c for attenuation]_ddmmyyyy_T[digits before comma]p[decimal digits].[file extension])
e.g.

a_31072013_T23p3.dat – for an absorption measurement collected on 31.07.2013 at 23.3 °C

In some cases you might have a stable spectrum with negative values. Negative values can be a result of a. bubbles which means that you must redo the calibration process and cleaning, and/or b. sensor bias or offset of which you need to be conscious.

Data Processing
The data file can be processed using a spreadsheet e.g. Microsoft Excel. Please note that the row numbers in this report might differ with each instrument. The first 95 rows contain the device metadata and manufacturer instrument calibration information. It will also contain the manufacturer's absorption and beam attenuation temperature correction information along with default software date and time information which might not match the time of your measurement. In row 96 columns 2 to 165 you will find spectral beam attenuation c and beam absortion a headers. In column 1 row 97 you will find the ascending time stamp from start 0 to end time when you stopped measuring. The goal now is to obtain a median of this dataset for a and c. Take care that you only deal with data matching the file sensor name. The measurement interval is at least half a

second and therefore to obtain a stable spectrum it is recommended you collect measurements over a minute. It is recommended to take the median absorption and beam attenuation spectrum of the calibration dataset. Avoid taking the average value as it may have a bias. We present sample calibration spectra using the extracted median absorption and beam attenuation spectra, in **Figure 10**. For reference print out a copy of the calibration plots for use during field measurements.
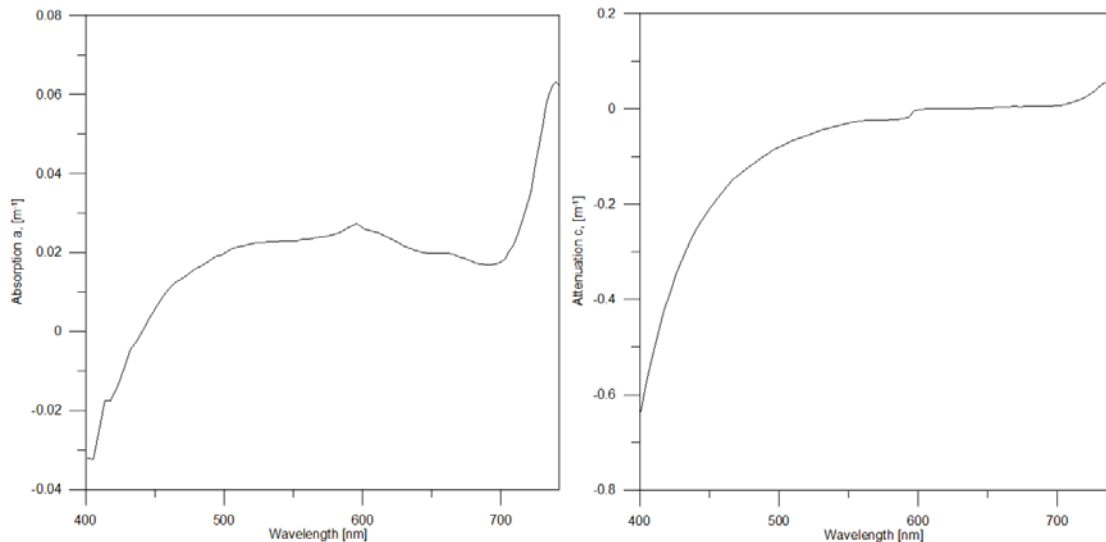

Figure 10 Sample calibration (blank) plot of absorption on the left and beam attenuation on the right.

It is important to handle the instrument with care at all times during deployment of your AC-S. Clean the instrument and redo calibration until you get to withing ± 0.01 m^{-1} from each other. A post field work calibration might be necessary to check the bias or offset of the sensors. An ideal setup is presented in **Figure 2** in Sullivan et al. (2006).

Field Data Processing
The data collection of field measurements is the same procedure as the laboratory calibration measurements. Instead of the glass container with Milli-Q water, in–situ measurements will be obtained by sucking water through the AC-S using a pump e.g. SeaBird as shown in **Figure 11**. The water flow through the AC-S into the pump and then through the salinity meter whilst temperature is measured outside. Therefore there is a time delay that results as we measure salinity as well as AC-S data. When you want to measure in-situ, first lower the AC-S to 10 m so as to collapse bubbles. Once bubbles clear the AC-S software output **Figure 8** will have stable spectra.
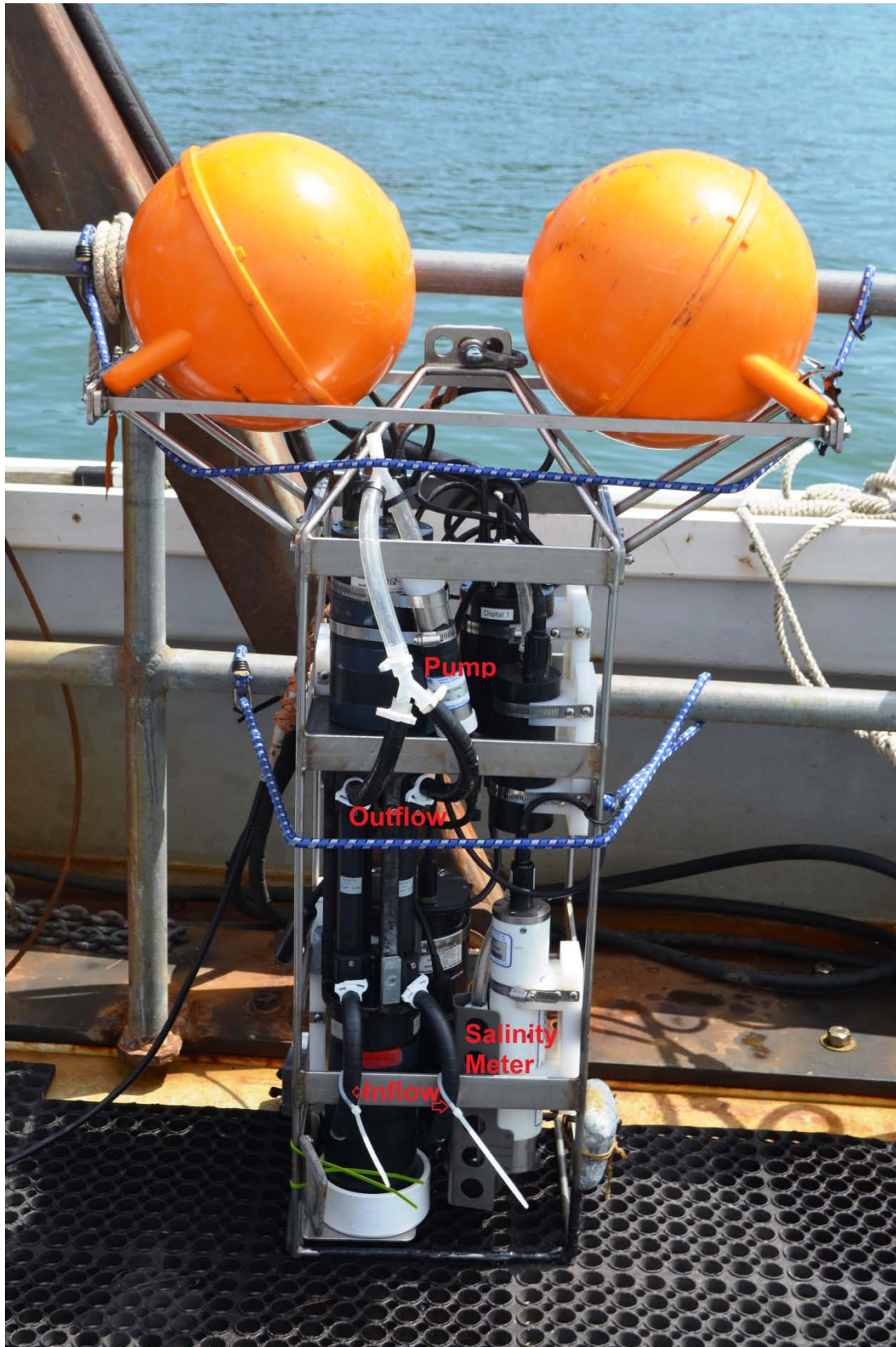
Figure 11 AC-S meter on a frame with the CTD suite. Seawater will pass flow thought the inflow point into the AC-S and is sucked into the salinity meter by the pump.

The median Milli-Q calibration absorption and beam attenuation spectra will henceforth be termed the **blanks**. After your field data collection you will need to get spectra corrected for the calibration in section 2, **Equation (3)** and **Equation (4),**

$$a_{corrected}^{blank}(\lambda) = a_{measured}(\lambda) - a_{blank}(\lambda) \tag{3}$$

$$c_{corrected}^{blank}(\lambda) = c_{measured}(\lambda) - c_{blank}(\lambda) \tag{4}$$

Experiments have shown that water absorption and beam attenuation coefficient measurements are significantly influenced by temperature and salinity changes (Leymarie et al., 2010; Pegau et al., 1997; Sullivan et al., 2006). Sullivan et al. (2006) have shown how these changes are common at wavelengths λ > 550 nm. The blank corrected spectra from **Equation (3)** and **Equation (4)** should therefore be temperature and salinity corrected, to standard temperature and salinity values.

$$a_{corrected}^{T-S}(\lambda) = a_{corrected}^{blank}(\lambda) - \Psi_T(\lambda) * (T_i - T_{norm}) - \Psi_S(\lambda) * (S_i - S_{norm}) \tag{5}$$

$$c_{corrected}^{T-S}(\lambda) = c_{corrected}^{blank}(\lambda) - \Psi_T(\lambda) * (T_i - T_{norm}) - \Psi_S(\lambda) * (S_i - S_{norm}) \tag{6}$$

where T_i and S_i are temperature and salinity of sample *i* collected by CTD attached to the same frame with the AC-S meters and T_{norm} and S_{norm} are the reference or calibration blank temperature and salinity respectively. We use Milli-Q water which is optically pure water, hence $S_{norm} \approx 0$. Ψ_T and Ψ_S are the spectral temperature and salinity dependency constants available in Table 2 in Sullivan et al (2006). We present an example of how raw absorption and beam attenuation measurements will look like upon temperature and salinity correction in **Figure 12**.

We assume that the scattering coefficient is the difference between the beam attenuation coefficient and the absorption coefficient of a sample as given as **Equation (1)**. The challenge is in collecting accurate absorption coefficients because optically active seawater constituents contribute back and forward scattered light in all directions. These components cannot be directly measured and quantified with available technology (Piskozub et al., 2004). To mitigate the scattering effect a hybrid residual scattering correction is applied to **Equation (5)**, note this is just one of the many available scattering correction approaches,

$$a_{corrected}^{scatter}(\lambda) = a_{corrected}^{T-S}(\lambda) - a_{corrected}^{T-S}(\lambda_r) * \frac{b_{corrected}^{T-S}(\lambda)}{b_{corrected}^{T-S}(\lambda_r)} \tag{7}$$

where $b_{corrected}^{T-S}(\lambda)$ is derived by replacing the left hand side solutions of **Equation (5)** and **Equation (6)** into **Equation (1)** and λ_r is a reference in the near infrared (Leymarie et al., 2010) e.g. in our example we use 730 nm . This wavelength is used because it is assumed that there is no absorption at the reference wavelength, so that the signal there is only due to scattered light.
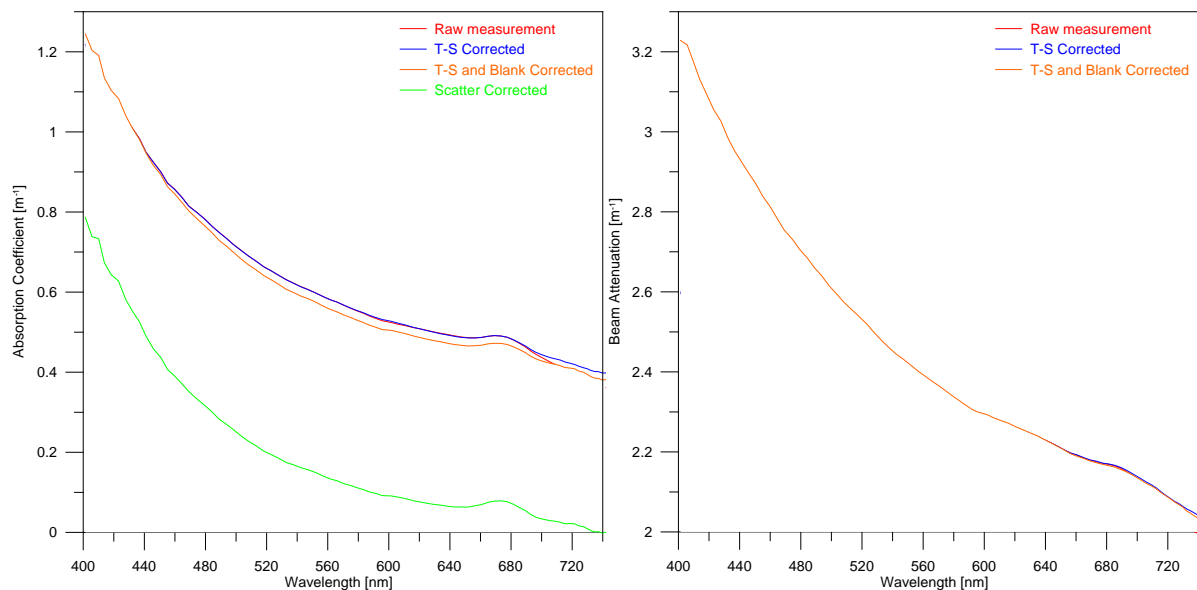
Figure 12 Illustration of how the temperature, salinity, scattering and blank correction steps will affect raw absorption and beam attenuation measurements.

Auxiliary measurements such as temperature using a CTD need to be matched to AC-S measurements. This is because time lag or time delays are likely due to different sensor position-Approximately the same water parcel needs to be measured by the different sensors. When filtering for colored dissolved organic material CDOM we will have a larger time delay that must be accounted for. There are two approaches of collecting temperature i.e. using a temperature sensor on a CTD or deriving it from the absorption in the infrared.

To obtain more stable profiles it is useful to bin the data to a depth interval such as 25cm. Some researchers also use a spike removal algorithm. The total absorption and beam attenuation components are determined without a filter and using filter water through a 0.2 µm for CDOM and process these measurements as explained. Particulate absorption and attenuation data can be obtained by using a 0.2 µm filter at the AC-S water intake. When this data is subtracted from the unfiltered data, the particulate spectra are obtained. This approach results in very accurate spectra as any fouling or time drift is subtracted.

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