Calibration and data processing for the WET Labs ACS meter for the 2014 field season

Instrument:	WET Labs ACS
Model/SN:	ACS/120
Purchase Date:	2012-12-13
Contact:	Colleen Mouw, cmouw@uri.edu
Authored:	Audrey Ciochetto, audreyciochetto@uri.edu
Document:	Version 1, 2017-01-17

I. Description

The WET Labs ACS concurrently measures *in situ* absorption (a, m^{-1}) and attenuation (c, m^{-1}) at 5Hz. The instrument uses a pump (Sea-Bird, SBE5T, 4500 RPM) to draw water through dual 25cm pathlength flow tubes, each with a light source, detector and filter wheel. Absorption and attenuation are resolved at 81 different wavelengths ranging from 400 to 756 nm. A more detailed description of specific instrument design and optics can be found in the user's guide (WET Labs 2011a).

The ACS was mounted on a package that also included a CTD (Sea-Bird, 37SI-100m), a BB9 (WET Labs, BB9) and a fluorometer (WET Labs, FL3). This allowed for concurrent measurements of temperature, salinity, depth, scattering coefficients, and chl, phycocyanin and CDOM fluorescence. Both temperature and salinity are necessary for ACS data processing. All instruments were connected through a data handling system (WET Labs, DH4) and controlled with the manufacturer's software (WET Labs, WL Logger Host, v7.09). Further information on set up and usage of data handling and software can be found in the user's guide (WET Labs 2011a). Collectively, this suite of instrumentation was called the Bio-Optical Package (BOP).

II. Calibration and Maintenance

The ACS comes with an instrument-specific device file (acs120.dev) that contains a temperature and pure-water offset calibration performed at the factory. The date on the factory calibration used for the 2013 field season was 2013-06-25.

In addition to factory calibrations, lab calibrations were carried out before and after each cruise following the procedure outlined in the NASA Ocean Optics Protocols, Revision 4, Volume IV, Chapter 3 (Pegau *et al.* 2002). Briefly, each ACS channel is first cleaned using isopropyl alcohol and Kimwipes (Kimberly Clark) until all surfaces are smudge and dust free. Purified, particle-free water is forced through the ACS channels under low pressure and data recorded for 30-45 s. Several replicates are taken to ensure consistency and a median value reported during processing. Water temperature is recorded and accounted for during data processing. Pure-water calibration values are provided for each cruise in separate text files.

III. Sample collection and processing

The ACS was deployed as part of the BOP for two successive casts at each station: unfiltered and filtered. This allowed for the determination of total, particulate and dissolved absorption and attenuation. For unfiltered casts, tubing, fit with coarse screens and covered with opaque electrical tape, was connected to the bottom intake flow tubes. The end of each tube was aligned such that BB9, fluorescence and ACS measurements were all drawn from the same vertical position. For filtered casts, a 0.2µm filter (PALL, Maxi Capsule Filter 12112) was modified by cutting off the barbed intake connector to provide uninhibited flow and attached to a barbed Y-connector such that water would be provided to both a and c channels simultaneously during the cast. Prior to deployment, the BOP was allowed to sit at 10 m for 5 min to get rid of any bubbles in the system. During deployment, the BOP was lowered at 0.2 m s^{-1} or as slow as possible to provide the maximum number of replicates for future binning (all other instruments besides the ACS take data at 1Hz). All casts were to ~50 m or to within 10-15 m of the bottom for shallower stations.

IV. Data Processing

ACS data were first extracted using the manufacturer's software (WET Labs, WAP) from binary data to raw text and then engineering units by applying the device file discussed in Section II. Detailed instructions on using WAP software can be found in the user's guide (WET Labs 2011b). All further data processing was carried out using a custom set of MATLAB scripts. Data were analyzed following the protocols of Pegau *et al.* 2002. Data processing steps follow. All steps are applied spectrally.

1) Retrieved a and c were corrected for temperature and salinity:

$$a_m^{TS} = a_m - [(T_m - T_r) \cdot \Psi_{Ta}] - [S_m - \Psi_{Sa}]$$
$$c_m^{TS} = c_m - [(T_m - T_r) \cdot \Psi_{Tc}] - [S_m - \Psi_{Sc}]$$

where a_m^{TS} and c_m^{TS} are corrected absorption and attenuation (m^{-1}), a_m and c_m are extracted values from the ACS (m^{-1}), T_m is the corresponding temperature from the CTD (°C), T_r is the reference temperature (15°C), Ψ_{Ta} and Ψ_{Tc} are the temperature correction coefficients (m^{-1} °C^{-1}) and Ψ_{Sa} and Ψ_{Sc} are the salinity correction coefficients (m^{-1} PSU^{-1}). Temperature and salinity correction coefficients were utilized from Sullivan *et al.* 2006 and linearly interpolated to wavelengths from our ACS. Since CTD measurements are made at 1Hz and ACS measurements at 5Hz, T_m was also linearly interpolated to match ACS measurement depths.

2) The pure-water laboratory calibration was applied:

$$a = a_m^{TS} - a_{wcal}$$
$$c = c_m^{TS} - c_{wcal}$$

where a_{wcal} and c_{wcal} are the median of pure water calibrations carried out before and after each cruise. Pure water calibrations are temperature corrected as in step 1 prior to subtraction. For unfiltered casts, a and c retrieved in this step represent all non-water components (a_{gp} and c_{gp}, m^{-1}). For filtered casts, a and c represent dissolved components (a_g and c_g, m^{-1}).

3) Data were quality controlled:
ACS data from 2013 showed evidence of bubbles, especially in filtered casts. Objective quality control was applied to remove these values. First, values ≥90% of instrument range were

excluded. Next, any negative values were set to zero. Finally, values falling outside the median ± 3 standard deviations of each 1-m depth bin were excluded. Despite these measures, data from the c-channel of the filtered cast were determined completely unreliable. Since these casts are theoretically particle free, c_g should be equivalent to a_g. We utilized this assumption in all further data processing.

4) At the end of the season, it was discovered that the pump was not strong enough to pull water through the system. Therefore, each measured "cast" is only representative of the surface where the instrument was allowed to passively fill with water. Data from all casts were combined into a single spectrum and assigned to the surface layer.

5) Scattering corrections were applied to a_{gp} using the variable scattering error method as recommended by Pegau *et al*. 2003 and Zaneveld *et al*. 1994:

$$a_{gp} = a_{gp} - \varepsilon\left(c_{gp} - a_{gp}\right)$$

where ε is retrieved as:

$$\varepsilon = \frac{a_{gp}(\lambda_r)}{c_{gp}(\lambda_r) - a_{gp}(\lambda_r)}$$

where λ_r is the reference wavelength (720 nm).

6) Particulate absorption and attenuation were retrieved:

$$a_p = a_{gp} - a_g$$

$$c_p = c_{gp} - a_g$$

where a_g was assumed equivalent to c_g as described in step 3 above.

7) Pure water absorption (a_w) and attenuation (c_w) from Pope and Fry 1997 were linearly interpolated to ACS wavelengths and added to a_{gp} and c_{gp} to retrieve total a and c (a_t and c_t).

V. Cautionary Notes

As previously indicated in step 3 of data processing, ACS data showed evidence of bubbles, especially in filtered casts. Objective quality control measures were applied to the data to exclude these cases. Also, as noted in step 4, the pump was not strong enough to pull water through the system and collected data is assigned to the surface layer, where the ACS was allowed to passively fill with water.

VI. References

Pegau, S., J.R.V. Zaneveld and J.L. Mueller (2002) Volume Absorption Coefficients: Instruments, Characterization, Field Measurements and Data Analysis Protocols. In: Mueller, J.L., G.S. Fargion, and C.R. McClain [Eds.] *Ocean Optics Protocols for Satellite Ocean Color Sensor Validation, Revision 4, Volume IV: Inherent Optical Properties: Instruments,* *Characterizations, Field Measurements and Data Analysis Protocols.* NASA/TM-2003-211621, NASA Goddard Space Flight Center, Greenbelt, MD, Chapter 3, pp 27-38.

Pope, R.M. and E.S. Fry (1997) Absorption spectrum (380-700nm) of pure water. II. Integrating cavity measurements. Applied Optics: 18, 8710-8723.

Sullivan, J.M., M.S. Twardowski, J.R.V. Zaneveld, C.M. Moore, A.H. Barnard, P.L. Donaghay and B. Rhoades (2006) Hyperspectral temperature and salt dependencies of absorption by water and heavy water in the 400-750 nm spectral range. Applied Optics 45(21): 5294-5309.

WET Labs (2011a) *AC Meter Protocol Document*.

WET Labs (2011b) *WET Labs Archive File Processing (WAP) User's Guide*.

Zaneveld, J.R.V., J.C. Kitchen and C. Moore (1994) The scattering error correction of reflecting-tube absorption meters. Ocean Optics XII, Proc. SPIE, 2258: 44-55.