Calibration and data processing for the WET Labs BB9 for the 2013 field season

Instrument:	WET Labs BB9
Model/SN:	BB9/1018
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Contact:	Colleen Mouw, cmouw@uri.edu
Author:	Audrey Ciochetto, audreyciochetto@uri.edu
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I. Description

The WET Labs BB9 resolves the volume scattering coefficient (β, m^{-1} sr^{-1}) at nine wavelengths: 412, 440, 488, 510, 532, 595, 650, 676, and 715 nm. The instrument illuminates a volume of water using modulated LEDs and detects scattered light at an acceptance angle of 124° from the source beam. Data are measured at 1 Hz. A more detailed description of specific instrument design and optics can be found in the user's guide (WET Labs 2011a).

The BB9 was mounted on a package that also included a CTD (Sea-Bird, 37SI-100m), an ACS (WET Labs, ACS) and a fluorometer (WET Labs, FL3). This allowed for concurrent measurements of temperature, salinity, depth, absorption/attenuation, and chl, phycocyanin and CDOM fluorescence. Temperature, salinity and absorption are necessary for BB9 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 BB9 comes with an instrument-specific device file (BB9-1018) that contains a dark count and scaling factor ([m^{-1} sr^{-1}] $count^{-1}$) at each wavelength. The date on the factory calibration was 2012-11-27.

In addition to this factory calibration, two calibrations were performed at WET Labs in Narragansett, RI using 0.1µm NIST-traceable beads (Thermo-Scientific, 3100A) following the procedure of Sullivan *et al.* 2013. The first was on 2013-07-10 at a water temperature of 25°C, (bead lot number 41784) and the second was on 2015-02-11 at 9°C (bead lot number 43585). The latter is shown in Table 1. Most of our field data were measured in waters colder than 10°C and most often at ~4°C. Our BB9 instrument demonstrated a significant temperature sensitivity (J. Sullivan *pers. comm*. 2015-03-03) and calibration choice impacted the magnitude of retrieved values and the spectral shape of scattering coefficients. Therefore, we elected to apply the 2015 calibration to the 2013 dataset as it more closely matched field measurement temperature.

Table 1. BB9 calibration on 2015-02-11 at 9°C

Wavelength (nm)	Scaling factor ([m^{-1} sr^{-1}] $count^{-1}$)	Dark count
412	1.616E-05	45.0
440	1.320E-05	49.2
488	1.073E-05	40.3
510	8.200E-06	49.9
532	6.780E-06	47.8
595	3.664E-06	38.9
650	2.931E-06	44.5
676	3.204E-06	49.7
715	2.710E-06	50.0

Dark offsets measured in the field during the 2013 season were not different from factory and/or Rhode Island calibrations. Dark counts shown in Table 1 were applied.

III. Sample collection and processing

The BB9 was mounted at the base of the BOP package such that the cage and other instrumentation would not interfere with the sensor. The ACS and fluorometer were also mounted such that all measurements were at the same depth. The package was lowered at 0.2 m s^{-1} or as slow as possible to provide the maximum number of replicates for future binning. All casts were to ~50 m or to within 10-15 m of the bottom for shallower stations.

IV. Data Processing

BB9 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. Only raw text files were used during data processing as the calibration in Table 1 was applied. 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 Zaneveld *et al.* 2002. Data processing steps follow. All steps are applied spectrally.

1) The calibration from Table 1 was applied to raw counts to retrieve the total volume scattering function β_t (m^{-1} sr^{-1}):

$$\beta_t = S(C_m - C_d)$$

where S is the scaling factor, C_m is the measured instrument count and C_d is the dark offset.

2) Data from the ACS were analyzed (see WetlabsACS_Mouw_2013.pdf) to retrieve total absorption (a_t, m^{-1}). ACS data were interpolated to BB9 wavelengths using a Piecewise Cubic Hermite Interpolating Polynomial.

3) β_t was corrected for absorption:

$$\beta = \beta_t \cdot e^{(l \cdot a_t)}$$

where *l* is the pathlength of the BB9 (0.0391 m). As noted in WetlabsACS_Mouw_2013.pdf, the pump on the ACS was not strong enough to pull water through the system and absorption was only measured at the surface. Thus, BB9 data are also only provided at the surface where absorption data is available.

4) The volume scattering function (β_w) and total scattering (b_w, m^{-1}) of water was retrieved using the model of Zhang and Hu 2009 using CTD temperature and salinity as inputs. Since the CTD and BB9 record data at the same rate, no interpolation was needed. Backscattering of water (b_{bw}, m^{-1}) was considered half of total scattering ($b_{bw} = b_w/2$).

5) Volume scattering of the particulate fraction was retrieved: $\beta_p = \beta - \beta_w$

6) Particulate backscattering was retrieved utilizing the χ factor of Sullivan *et al.* 2013:

$$b_{bp} = 2\pi \cdot \chi \cdot \beta_p$$

where $\chi = 1.076$ for 124°.

7) Total backscattering was calculated: $b_b = b_{pb} + b_{bw}$.

8) Data were binned to 1m. The median value for each bin is reported.

V. References

Zaneveld, J.R.V, S. Pegau and J.L. Mueller (2002) Volume scattering function and backscattering coefficients: instruments, characterization, filed 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 5, pp 65-76.

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WET Labs (2011a) *Scattering Meter ECO BB-9 User's Guide*.

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