OCEAN OBSERVATORIES INITIATIVE

DATA PRODUCT SPECIFICATION FOR OPTICAL BEAM ATTENUATION COEFFICIENT

Version 1-06
Document Control Number 1341-00690
2014-05-05

Consortium for Ocean Leadership
1201 New York Ave NW, 4th Floor, Washington DC 20005
www.OceanLeadership.org

in Cooperation with

University of California, San Diego
University of Washington
Woods Hole Oceanographic Institution
Oregon State University
Scripps Institution of Oceanography
Rutgers University

Document Control Sheet

Version	**Date**	**Description**	**Author**
0-01	2011-12-30	Initial Draft	S. Ackleson
0-02	2012-01-23	Revised based on focused review.	S. Ackleson
0-03	2012-02-22	Revised based on 5-day review.	S. Ackleson
1-00	2012-02-27	Initial Release	E. Chapman
1-01	2012-03-02	Formatting, copy edits	E. Griffin
1-02	2012-03-23	Administrative; text addition to App. B	E. Griffin
1-03	2013-02-21	Corrected statement regarding required instrument metadata	C. Wingard
1-04	2013-04-03	Revised section 4.2 with input from A. Plueddemann received for ECR 1300-00340; revised Variables and Symbols content; revised instrument wavelength output value in section 2.3; revised author contact information	M. Gibney
1-05	2013-06-25	Revised test data sets in tables 1a., 1b., and 1c.; revised equations in Section 3.2 Mathematical Theory	C. Wingard M. Gibney
1-06	2014-05-05	Revised test; noted testdata limitations	R. Desiderio

Signature Page

This document has been reviewed and approved for release to Configuration Management.

OOI Senior Systems Engineer: ______________________________

Date: 27 Feb 2012

This document has been reviewed and meets the needs of the OOI Cyberinfrastructure for the purpose of coding this algorithm.

OOI CI Signing Authority: William ______

Date: 27 Feb. 2012

Table of Contents

1 Abstract

The purpose of this document is to provide OOI programmers, product developers, reviewers and users with an overview of the theoretical and practical algorithm information (scientific, mathematical and computational) that is used by the Ocean Observatories Initiative (OOI) to derive the optical beam attenuation coefficient as a function of wavelength (OPTATTN) using data collected with a WET Labs ac-s absorption and attenuation meter. The procedures for reading raw data from the instrument, converting from raw data to inverse meters (m^{-1}), and correcting for environmental factors are covered in detail within the vendor-supplied user's manual (Revision J, February 9, 2009) as well as a companion document, *ac-s Protocol Document* (Revision P, December 2009). Example processing code is presented in the protocol document and reproduced in Appendix C.

OPTATTN is optical beam attenuation resulting from the combined effects of all water impurities; $c_{pd}(\lambda)$ [m^{-1}], where λ denotes wavelength in nanometers (nm) within the approximate spectral range from 400 to 750 nm. Impurities include all particulate and dissolved matter of optical importance. OPTATTN is the difference between total beam attenuation of the water mixture (c) and that of pure seawater (c_w): $c_{pd} = c - c_w$.

OPTATTN is a L2 product since it requires correction for the absorption of 'pure' seawater as a function of temperature, salinity, and wavelength. Corrected data therefore requires coincidental and co-located measurements of OOI data products water temperature (TEMPWAT) and practical salinity (PRACSAL).

The procedures described herein assume that the sensors are calibrated and free of confounding effects of instrument drift and biofouling.

2 Introduction

2.1 Author Contact Information

Please contact the Data Product Specification lead (DPS@lists.oceanobservatories.org) for more information concerning the algorithm and other items in this document.

2.2 Metadata Information

2.2.1 Data Product Name

The OOI Core Data Product Name for this data product is
- OPTATTN

The OOI Core Data Product Descriptive Name for this data product is
- Optical Beam Attenuation Coefficient (all water impurities only)

2.2.2 Data Product Abstract (for Metadata)

OPTATTN is an L2 product and is the spectral beam attenuation for the combination of all water impurities computed using data collected with a reflecting tube type ac-s absorption and attenuation meter and co-located and synchronized observations of water temperature and salinity.

2.2.3 Computation Name

Not required for data product algorithms.

2.2.4 Computation Abstract (for Metadata)

OPTATTN is the spectral beam attenuation for the combination of all water impurities, computed using vendor-supplied algorithms that transform instrument voltage to scientific units, corrected for internal instrument temperature and ambient water temperature and practical salinity based on community-accepted procedures.

2.2.5 Instrument-Specific Metadata

Instrument specific factory calibration data, passed to CI and stored as part of an instrument's metadata, are required to convert the raw absorption reference and signal counts (OPTCREF and OPTCSIG) to attenuation (c).

2.2.6 Synonyms

Synonyms for this data product are

- Spectral Attenuation
- Spectral Beam Attenuation
- Beam-c

2.2.7 Similar Data Products

Similar products that with which OPTATTN may be confused:

- Diffuse attenuation (the attenuation of downwelling solar irradiance)
- *k*

2.3 Instruments

The primary instrument (OPTAA) is the WET Labs ac-s spectral absorption and attenuation meter . The instrument provides a 75 wavelength output from approximately 400–750 nm with approximately 4 nm steps. Individual filter steps have a full-width half maximum response that range between about 10 to 18 nm. There are a total of 35 OPTAA instruments deployed throughout the initial OOI construction and integrated into the Pioneer, Endurance, Regional and Global arrays. They are deployed at fixed depths (near-surface, mid-water column and sea floor) and installed on moored profilers.

The ac-s performs concurrent measurements of the water attenuation and absorption by incorporating a dual optical path configuration in a single instrument. Each optical path contains separate optics and detectors appropriate to the given measurement. Attenuation is a measure of light transmitted through a non-reflecting tube while absorption requires a measurement of light transmission through a highly polished, reflecting tube. This data product specification only addresses the computation of OPTATTN and, therefore, references only the attenuation measurement.

OPTATTN is an L2 product in that computation requires the raw signals emanating from a properly calibrated and configured instrument as well as water temperature (TEMPWAT) and salinity (PRACSAL) derived from a co-located and synchronized CTD. While small corrections for salinity are available at visible wavelengths ($\lambda < 700$ nm), temperature and salinity corrections are more significant at infrared wavelengths ($\lambda > 700$ nm) and must be performed in order to use OPTATTN to correct optical absorption (OPTABSN) values for scattering artifacts. Detailed procedures for correcting ac-s data for temperature and salinity are outlined within a separate protocols document available through the vendor (WET Labs Inc., 2009b).

2.4 Literature and Reference Documents

Ackleson, S. G. and J. O'Donnell. 2011. Small-scale variability in suspended matter associated with the Connecticut River plume front. J. Geophys. Res., 116(C10013), doi: 10.1029/2011JC007053.

WET Labs, Inc. 2009a. Spectral Absorption and Attenuation Meter ac-s User's Guide, Revision J.

WET Labs, Inc. 2009b. ac Meter Protocol Document, Revision P.

Boss, E. et al. 2001. Spectral particulate attenuation and particle size distribution in the bottom boundary layer of a continental shelf, J. Geophys. Res., 106(C5), 9509–9516, doi:10.1029/2000JC900077.

W. Scott Pegau, Deric Gray, and J. Ronald V. Zaneveld. 1997. Absorption and attenuation of visible and near-infrared light in water: dependence on temperature and salinity. Appl. Opt. 36: 6035-6046.

Kitchen, J. C., J.R.V. Zaneveld and H. Pak. 1982. Effects of particle size distribution and chlorophyll content on beam attenuation spectra. Appl. Opt., 21:3913-3918.

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

Mueller, J. L., G. S. Fargion, C. R. McClain, S. Pegau, J. R. V. Zaneveld, B. G. Mitchell, M. Kahru, J. Wieland and M. Stramska. 2003. 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, Volume IV, Issue May 2002.

2.5 Terminology

2.5.1 Definitions

The following terms are defined here for use throughout this document. Definitions of general OOI terminology are contained in the Level 2 Reference Module in the OOI requirements database maintained on a Dynamic Object Oriented Requirements System tool (DOORS).

Beam Attenuation coefficient (*c*): The fraction of a light beam transmitted upon traversal of a pathlength r which is attenuated by absorption and scattering processes is given by exp(-cr) where c is the beam attenuation coefficient . Since attenuation is a function of λ, the descriptor is typically appended to the term only when spectral dependency is referenced, e.g., $c(\lambda)$. Subscripts identify the component of the water mixture that beam attenuation refers to, such as pure water (c_w) or water particulate and dissolved impurities (c_{pd}). This specification describes the derivation and computation of beam attenuation pertaining to all water impurities corrected for water temperature and salinity effects.

2.5.2 Acronyms, Abbreviations and Notations

General OOI acronyms, abbreviations and notations are contained in the Level 2 Reference Module in the OOI requirements database (DOORS). The following acronyms and abbreviations are defined here for use throughout this document.

ITS-90	International Temperature Scale of 1990

2.5.3 Variables and Symbols

The following variables and symbols are defined here for use throughout this document.

a	Absorption coefficient of water and associated impurities (m^{-1})

b	Scattering coefficient of water and associated impurities (m^{-1})
c	Beam attenuation of water and associated impurities (m^{-1})
c_{pd}	Beam attenuation for all particulate and dissolved water impurities (m^{-1})
$c_{pd;ts}$	Beam attenuation for water impurities corrected for temperature and salinity effects (m^{-1})
c_{off}	Clean water offset value determined during pre-deployment calibration (m^{-1})
C_{ref}	Raw beam attenuation reference data (wavelength-specific, uncalibrated) (counts)
C_{sig}	Raw beam attenuation signal data; measured amount of light that reached the c detector (wavelength-specific, uncalibrated) (counts)
I_o	Initial light intensity
I_r	Light intensity after having propagated a distance r
r	Path length (m)
s	Water salinity (psu)
t	Water temperature (°C)
t_r	Reference water temperature recorded during pre-deployment calibration (°C)
T	Internal instrument temperature (°C)
λ	Wavelength (nm)
Δ_T	Correction for internal instrument temperature from vendor-supplied table (m^{-1})
Ψ_T	Correction constant for water temperature
Ψ_{sc}	Attenuation correction constant for water salinity

3 Theory

3.1 Description

Beam attenuation, $c(\lambda)$, is a fundamental inherent optical property of water and defined as the rate that the intensity of a beam of light will decrease in response to the combined effects of absorption and scatter as a function of propagation distance (Fig. 1). Light scatter within ocean waters resulting from suspended living and inanimate particulate matter tends to dominate *c*, particularly in portions of the spectrum outside of chlorophyll absorption regions. The magnitude of *c* has been used as a local proxy for suspended sediment concentration (Kitchen et al, 1982) while, recently, the spectral response of *c* has been used to investigate relative changes in the particle size distribution (Boss et al., 2001; Ackleson and O'Donnell, 2011).

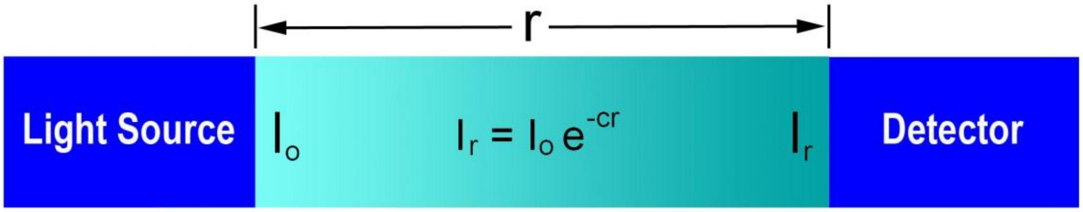

Figure 1. Diagram showing a common transmissometer or c-meter design. The c-meter portion of the OPTAA instrument is identical.

3.2 Mathematical Theory

Beam attenuation expresses the rate of decrease in the intensity of a light beam as it propagates through a volume of water and is the combined effects of absorption [$a(\lambda)$] and light scatter [$b(\lambda)$]; $c = a+b$. The rate of intensity decrease is a function of the optical properties of pure water and the properties and concentration of particulate and dissolved matter. The units of *a, b*, and *c* are inverse meters (m^{-1});

$$I_r = I_o e^{-(a+b)r}$$

$$I_r = I_o e^{-(c)r}$$

Rearrangement of this equation yields a simple expression for beam attenuation:

$$c = -\ln\left[{}^{I_r}/_{I_o}\right]/r$$

where I_o is the reference beam intensity, and I_r is the beam intensity after having propagated through a water path of length r. The optical path length within the ac-s instrument is 0.25 m. The ac-s meter measures $I_r(\lambda)$ and $I_o(\lambda)$ and r is constant (r = 0.25 m).

The following governing equation applies to raw data emanating from the ac-s (see discussion of equation 8 in user's manual):

$$c_{pd} = \left(c_{off} - r^{-1}\left[\ln\left(\frac{C_{sig}}{C_{ref}}\right)\right]\right) - \Delta_T$$

where c_{pd} is the wavelength-specific beam attenuation coefficient (m^{-1}) for water impurities (particulate and dissolved), c_{off} is the wavelength-specific water offset provided by the vendor for each instrument, r is the instrument path length (0.25 m) and C_{sig} and C_{ref} are wavelength-specific signal and reference light intensity, respectively. The final term on the right side, Δ_T, is a correction for internal instrument temperature based on a vendor-supplied, instrument-specific calibration table (see discussion regarding equation 7 in user's manual);

$$\Delta_T = \Delta_{T1} + \frac{(T - T_1)}{(T_2 - T_1)} \times (\Delta_{T2} - \Delta_{T1})$$

where T is the internal instrument temperature at the time of data collection, T_1 and T_2 are the two bracketing temperature bins within the calibration table or devise file (*.dev) and Δ_{T1} and Δ_{T2} are the respective correction values.

After correcting for internal instrument temperature, c_{pd} must next be corrected for effects of water temperature and salinity. The temperature and salinity corrections discussed here are different than the instrument temperature correction. These corrections relate to physical changes in the attenuation coefficients of clear water, c_w, due to changing dissolved salt content and temperature. These corrections are quite small in the visible portion of the spectrum (λ between 400 nm and 700 nm) but can be significant within the near infrared portion of the spectrum ($\lambda >$ 700 nm). The temperature and salinity corrected beam attenuation, $c_{pd;ts}$, is computed as:

$$c_{pd:ts} = c_{pd} - (\Psi_t * (t - t_r) + \Psi_{sc} * s)$$

where Ψ_t and Ψ_{sc} are corrections constants for water temperature (t) and salinity (s), respectively, and t_r is the reference water temperature recorded at the time of pre-deployment instrument calibration. Values for Ψ_t and Ψ_{sc} are presented in Appendix A. Intermediate values must be interpolated:

$$\Psi_t = \Psi_{t1} + \frac{(\lambda - \lambda_1)}{(\lambda_2 - \lambda_1)} \times (\Psi_{t2} - \Psi_{t1})$$

$$\Psi_{sc} = \Psi_{sc1} + \frac{(\lambda - \lambda_1)}{(\lambda_2 - \lambda_1)} \times (\Psi_{sc2} - \Psi_{sc1})$$

where subscripts 1 and 2 refer to the two bracketing wavelengths and associated temperature and salinity correction factors.

3.3 Known Theoretical Limitations

Attenuation is a bulk optical measure and, therefore, is the result of the combined effects of a water volume and associated impurities. Therefore, the accuracy of *c* is dependent upon assumptions regarding the homogeneity and distribution of impurities within the sample volume. These effects are neglected and it is assumed that the sample volume is well-mixed.

3.4 Revision History

Revisions to test data as a result of correcting mathematical equations.

4 Implementation

4.1 Overview

The beam attenuation algorithm is a multi-step process: 1) read raw, uncorrected signal and reference light levels delivered from the ac-s instrument, 2) compute initial attenuation corrected for changes in internal instrument temperature, 3) applies a pre-deployment instrument calibration referenced to clean water, and 4) correct the initial attenuation values for ambient water temperature and salinity (see processing flow presented in Figure 2, Section 4.3). While the vendor does supply stand-alone software for processing ac-s data, the procedures within this document assume that each step will be coded into the cyberinfrastructure and that vendor-supplied applications will not be used. Example code is provided in WET Labs *ac-s Protocol Document* (Revision P, December 2009) and reproduced in Appendix C.

4.2 Inputs

- Inputs to the Algorithm are L0 data packets from OPTAA sensor containing reference (OPTCREF) and signal (OPTCSIG) beam attenuation and internal instrument temperature measurements.
- Co-located, synchronized measurements of water temperature (TEMPWAT) and practical salinity (PRACSAL).

4.3 Processing Flow

The processing flow for the OPTATTN is comprised of four steps (Figure 2); 1) unpack the binary data records according to procedures prescribed within the ac-s user's manual (Revision J, February 9, 2009), 2) compute the internal instrument temperature correction factor, 3) convert raw beam intensities to scientific values with instrument temperature correction applied, and 4) determine and apply corrections for water temperature and salinity.

4.4 Outputs

The output of the OPTATTN algorithm is Optical Beam Attenuation for the combined effects of all water impurities. The units are inverse meter, expressed as a double precision floating point number. To obtain total beam attenuation of the water mixture, the user would need to add the constant value for pure seawater at the wavelengths of interest (e.g, see Mueller et al., 2003). This calculation is not a part of the product computation. OPTATTN only refers to the component of attenuation pertaining to water impurities.

4.5 Code Verification and Test Data Sets

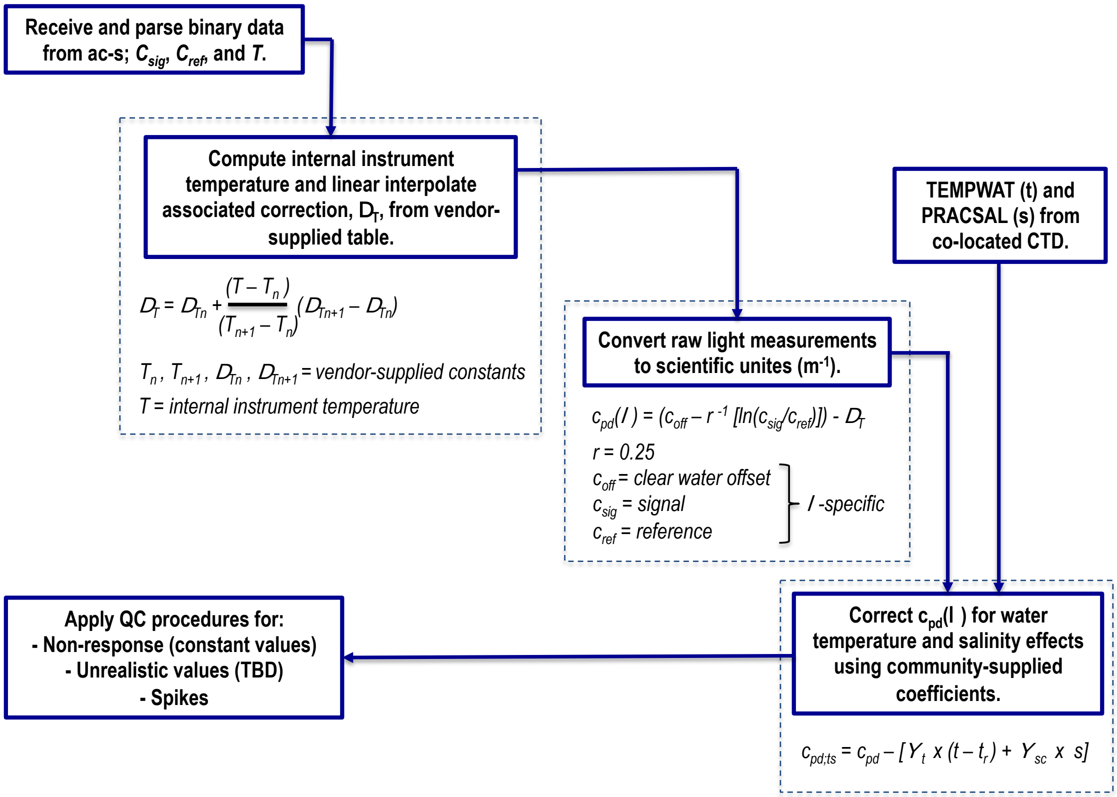

Figure 2. Algorithm computation flow.

A test data set below (Table 1a, 1b, and 1c) provide a few data points over the expected range of attenuation values; $c_{pd;ts} = .01 – 10$ assuming a 0.25 m path length instrument. The offset for pre-deployment, clear-water calibration is constant and the correction based on internal instrument temperature is allowed to vary over a reasonable range. These data are only presented as an example for testing the coded algorithms. Each instrument will have a separate device file containing clear water offsets and internal instrument temperature correction coefficients. However, corrections for ambient temperature and salinity (Appendix A) apply to all data streams after correcting for internal temperature and clear water offset.

Note that these Tables are useful for checking simplified OPTAA data product calculations but that in reality there will be on the order of 80 ‘c’ wavelengths and on the order 35 internal temperature bin values for each of these wavelengths. Also, there will be one internal temperature measurement for each OPTAA data packet (suite of wavelengths and counts for each wavelength channel). In addition, there will be one temperature and one salinity value used for each data packet suite of measurements to correct the beam attenuation values for the variation of the absorption of seawater as a function of temperature and salinity.

For realistic OPTAA datasets see the file OPTAA_unit_test.xlsx in the data artifact section for OPTATTN on alfresco: Company Home>>OOI>REFERENCE>> Product Specification Artifacts >>1341-00690.

Table 1a. Test computations of internal instrument temperature correction.

λ	T_i(counts)	T_i(°C)	T_1	T_2	ΔT_1	ΔT_2	ΔT
500	48750	15.00	14.5036	15.5200	-0.004929	-0.004611	-0.0048
550	48355	16.00	15.5200	16.4706	-0.004611	-0.004418	-0.0045
600	47950	17.00	16.4706	17.4833	-0.004418	-0.004355	-0.0044
650	47535	18.00	17.4833	18.4831	-0.004355	-0.004131	-0.0042
700	47115	19.00	18.4831	19.5196	-0.004131	-0.003422	-0.0038
715	46684	20.00	19.5196	20.5565	-0.003422	-0.002442	-0.0030

Table 1b. Test computations of unit conversion.

λ	C_{sig}	C_{ref}	r	c_{off}	ΔT	$c_{pd}(\lambda)$
500	50	500	0.25	0.01	-0.0048	9.2251
550	150	500	0.25	0.01	-0.0045	4.8304
600	250	500	0.25	0.01	-0.0044	2.7870
650	350	500	0.25	0.01	-0.0042	1.4409
700	450	500	0.25	0.01	-0.0038	0.4352
715	495	500	0.25	0.01	-0.0030	0.0532

Table 1c. Test computations of water temperature and salinity correction.

λ	$c_{pd}(\lambda)$	t	t_{ref}	Ψ_t	s	Ψ_{sc}	$c_{pd;ts}(\lambda)$
500	9.2251	4	20	0.00003	10	-0.000043	9.2260
550	4.8304	8	20	0.00002	15	-0.000040	4.8312
600	2.7870	12	20	0.00098	20	-0.000034	2.7955
650	1.4409	16	20	0.00001	25	-0.000009	1.4412
700	0.4352	20	20	0.00070	30	-0.000181	0.4406
715	0.0532	24	20	0.00416	35	-0.000232	0.0447

Appendix A Temperature and Salinity Correction Factors

λ (nm)	Ψ_t (m^{-1} °C^{-1})	Ψ_{sc} (m^{-1} PSU^{-1})
400	0.0001	-0.00001
402	0.0001	-0.00002
404	0.0001	-0.00002
406	0.0001	-0.00002
408	0.0000	-0.00002
410	0.0000	-0.00002
412	0.0000	-0.00002
414	0.0001	-0.00002
416	0.0000	-0.00002
418	0.0000	-0.00003
420	0.0000	-0.00003
422	0.0000	-0.00003
424	0.0000	-0.00003
426	0.0000	-0.00003
428	0.0000	-0.00003
430	0.0000	-0.00003
432	0.0000	-0.00003
434	0.0000	-0.00003
436	0.0000	-0.00003
438	0.0000	-0.00004
440	0.0000	-0.00004
442	0.0000	-0.00004
444	0.0000	-0.00004
446	0.0000	-0.00004
448	0.0000	-0.00004
450	0.0000	-0.00004
452	0.0000	-0.00004
454	0.0000	-0.00004
456	0.0000	-0.00004
458	0.0000	-0.00004
460	0.0000	-0.00004
462	0.0000	-0.00004
464	0.0000	-0.00004
466	0.0000	-0.00004
468	0.0000	-0.00004
470	0.0000	-0.00004
472	0.0000	-0.00004
474	0.0000	-0.00004
476	0.0000	-0.00004
478	0.0000	-0.00004
480	0.0000	-0.00004
482	0.0000	-0.00004
484	0.0000	-0.00004
486	0.0000	-0.00004
488	0.0000	-0.00004
490	0.0000	-0.00004
492	0.0000	-0.00004
494	0.0000	-0.00004
496	0.0000	-0.00004
498	0.0000	-0.00004
500	0.0000	-0.00004
502	0.0000	-0.00004
504	0.0000	-0.00004
506	0.0000	-0.00004
508	0.0001	-0.00004
510	0.0001	-0.00004
512	0.0001	-0.00004
514	0.0001	-0.00004
516	0.0001	-0.00004
518	0.0001	-0.00004
520	0.0001	-0.00004
522	0.0001	-0.00004
524	0.0001	-0.00004
526	0.0001	-0.00004
528	0.0000	-0.00004
530	0.0000	-0.00004
532	0.0000	-0.00004
534	0.0000	-0.00004
536	0.0000	-0.00004
538	0.0000	-0.00004
540	0.0000	-0.00004
542	0.0000	-0.00004
544	0.0000	-0.00004
546	0.0000	-0.00004
548	0.0000	-0.00004
550	0.0000	-0.00004
552	0.0000	-0.00004
554	0.0000	-0.00004
556	0.0000	-0.00004
558	0.0000	-0.00004
560	0.0000	-0.00004
562	0.0000	-0.00004
564	0.0000	-0.00004
566	0.0000	-0.00004
568	0.0000	-0.00004
570	0.0000	-0.00004
572	0.0000	-0.00005
574	0.0001	-0.00005
576	0.0001	-0.00005
578	0.0001	-0.00005
580	0.0002	-0.00005
582	0.0003	-0.00005
584	0.0003	-0.00005
586	0.0004	-0.00005
588	0.0005	-0.00005
590	0.0006	-0.00005
592	0.0006	-0.00005
594	0.0007	-0.00005
596	0.0008	-0.00005
598	0.0009	-0.00004
600	0.0010	-0.00003
602	0.0010	-0.00003
604	0.0010	-0.00002
606	0.0010	-0.00001
608	0.0010	0.00000
610	0.0009	0.00001
612	0.0009	0.00001
614	0.0008	0.00002
616	0.0007	0.00002
618	0.0006	0.00002
620	0.0006	0.00002
622	0.0005	0.00002
624	0.0004	0.00002
626	0.0003	0.00002
628	0.0003	0.00002
630	0.0002	0.00002
632	0.0001	0.00002
634	0.0001	0.00001
636	0.0000	0.00001
638	0.0000	0.00001
640	0.0000	0.00001
642	0.0000	0.00000
644	0.0000	0.00000
646	0.0000	0.00000
648	0.0000	-0.00001
650	0.0000	-0.00001
652	0.0000	-0.00001
654	0.0001	-0.00001
656	0.0001	-0.00002
658	0.0001	-0.00002
660	0.0002	-0.00002
662	0.0002	-0.00002
664	0.0002	-0.00002
666	0.0001	-0.00002
668	0.0001	-0.00002
670	0.0001	-0.00002
672	0.0000	-0.00002
674	0.0000	-0.00003
676	-0.0001	-0.00004
678	-0.0001	-0.00005
680	-0.0001	-0.00006
682	-0.0001	-0.00006
684	-0.0001	-0.00008
686	-0.0001	-0.00009
688	0.0000	-0.00010
690	0.0000	-0.00011
692	0.0001	-0.00013
694	0.0002	-0.00014
696	0.0003	-0.00016
698	0.0005	-0.00017
700	0.0007	-0.00018
702	0.0009	-0.00019
704	0.0013	-0.00020
706	0.0017	-0.00021
708	0.0021	-0.00022
710	0.0026	-0.00022
712	0.0032	-0.00023
714	0.0038	-0.00023
716	0.0045	-0.00023
718	0.0054	-0.00024
720	0.0063	-0.00024
722	0.0073	-0.00024
724	0.0083	-0.00024
726	0.0094	-0.00022
728	0.0104	-0.00021
730	0.0113	-0.00017
732	0.0121	-0.00012
734	0.0128	-0.00006
736	0.0133	0.00002
738	0.0136	0.00012
740	0.0136	0.00022
742	0.0133	0.00031
744	0.0129	0.00041
746	0.0124	0.00049
748	0.0116	0.00056
750	0.0107	0.00062

Appendix B Output Accuracy and Quality Control

Assuming that impurities are evenly distributed within the sample volume and that attenuation has been appropriately corrected for ambient water temperature and salinity, WET Labs Inc. estimates an instrument error of +/- 0.01 m^{-1}.

Quality control procedure should be applied after the computation of OPTATTN and should include:

- Global Range (GLBRNG): minimum = 0, maximum = 100
- Stuck Value Test (STUCKVL)
- Spike Test (SPKETST): > 2x the adjacent product values

The following requirements in the DOORS database describe optical attenuation accuracy requirements:

- The instrument shall measure spectral attenuation with an accuracy within ±0.01 c(λ)/m of the true value. <L2-SR-RQ-3536, L4-CG-IP-RQ-399, L4-RSN-IP-RQ-353>
- The instrument shall measure spectral attenuation with a precision of 0.005 c(λ)/m. <L2-SR-RQ-3748, L4-CG-IP-RQ-520, L4-RSN-IP-RQ-573>
- ATTE-005 The instrument should measure spectral attenuation with a precision of 10-3 c(λ)/m. This is an objective. <L2-SR-RQ-3749, L4-CG-IP-RQ-521, L4-RSN-IP-RQ-574>

Appendix C Example Code

The following code corrects ac-s attenuation and absorption data for ambient temperature and salinity (see WET Labs *ac-s Protocol Document,* Revision P, December 2009).

```
function  [corrected_data] = acscor(data)

% Corrects ac9 for effects of temperature and salinity.

load TS.cor ;
% Temperature and salinity coefficients file.

Tref = 12.0;
% Reference temperature (temperature at time of calibration).

acs_cal = load('acs010_051006.cor' );
% This is an instrument-specific file supplied by the vendor.

c_wl = acs_cal(:,1)';
a_wl = acs_cal(:,3)';

acs_Wcal = [acs_cal(:,2)'; acs_cal(:,4)'];
% Transform calibration file to 2x84 (varies with acs) matrix; first
% row is a, second row is c.

% Find temperature and salinity coefficients at wavelengths matching
% acs.
t = zeros(2,length(a_wl);
for  k = 1:length(a_wl)
[near_c, t(1,k)] = find_nearest(c_wl(k),TS(:,1));
[near_a, t(2,k)] = find_nearest(a_wl(k),TS(:,1));
end
acs_c_tempcor = TS(t(:,1),2);
acs_a_tempcor = TS(t(:,2),2);
acs_c_salcor = TS(t(:,1),3);
acs_a_salcor = TS(t(:,2),4);

% Column assignments must be corrected for each dataset
 temp = data(:,3); % CTD temperature
 sal = data(:,5); % CTD salinity column
% In this case, “data” is a merged CTD and ac-s data file

acs_c = data(:,12:95); % c (in ascending wavelengths)
acs_a = data(:,96:179); % a (in ascending wavelengths)

% Correct data to reference temp., 0 PSU, subtract Pure Water Offset.
for  z = 1:length(a_wl);
acs_a_cor(:,z) = acs_a(:,z) - ((temp - Tref) * acs_a_tempcor(z))...
 - (sal * acs_a_salcor(z)) - repmat(acs_Wcal(1,z),r,1);
acs_c_cor(:,z) = acs_c(:,z) - ((temp - Tref) * acs_c_tempcor(z))...
 - (sal * acs_c_salcor(z)) - repmat(acs_Wcal(2,z),r,1);
end

[corrected_data] = [acs_a_cor acs_c_cor];
```