February 2014

Environmental Technology Verification Report

Magee Scientific Model AE33 Aethalometer

Prepared by

Battelle
The Business of Innovation

Under a cooperative agreement with

EPA **U.S. Environmental Protection Agency**

Environmental Technology Verification Report

ETV Advanced Monitoring Systems Center

Magee Scientific Model AE33 Aethalometer

By

Kenneth Cowen
Thomas Kelly
Amy Dindal

Battelle
Columbus, Ohio 43201

Notice

The U.S. Environmental Protection Agency, through its Office of Research and Development, partially funded and collaborated in the research described herein. This report has been subjected to the Agency's peer and administrative review. Any opinions expressed in this report are those of the author(s) and do not necessarily reflect the views of the Agency, therefore, no official endorsement should be inferred. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Foreword

The EPA is charged by Congress with protecting the nation's air, water, and land resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, the EPA's Office of Research and Development provides data and science support that can be used to solve environmental problems and to build the scientific knowledge base needed to manage our ecological resources wisely, to understand how pollutants affect our health, and to prevent or reduce environmental risks.

The Environmental Technology Verification (ETV) Program has been established by the EPA to verify the performance characteristics of innovative environmental technology across all media and to report this objective information to permitters, buyers, and users of the technology, thus substantially accelerating the entrance of new environmental technologies into the marketplace. Verification organizations oversee and report verification activities based on testing and quality assurance protocols developed with input from major stakeholders and customer groups associated with the technology area. ETV consists of six environmental technology centers. Information about each of these centers can be found on the Internet at http://www.epa.gov/etv/.

Effective verifications of monitoring technologies are needed to assess environmental quality and to supply cost and performance data to select the most appropriate technology for that assessment. Under a cooperative agreement, Battelle has received EPA funding to plan, coordinate, and conduct such verification tests for "Advanced Monitoring Systems for Air, Water, and Soil" and report the results to the community at large. Information concerning this specific environmental technology area can be found on the Internet at http://www.epa.gov/etv/centers/center1.html.

Acknowledgments

The authors wish to acknowledge the support of all those who helped plan and conduct the verification test, analyze the data, and prepare this report. Specifically the authors thank Andrea Polidori of the South Coast Air Quality Management District, Joann Rice of EPA Office of Air Quality Planning and Standards, and Zachary Willenberg, Battelle Quality Assurance Officer, for their review of this verification report.

Contents

List of Figures

List of Tables

List of Abbreviations

AMS	Advanced Monitoring Systems Center
BC	black carbon
CH_4	methane
csv	comma separated variable
CV	coefficient of variation
DL	detection limit
DQO	data quality objective
DRI	Desert Research Institute
EC	elemental carbon
EPA	U.S. Environmental Protection Agency
ETV	Environmental Technology Verification
He	helium
IMPROVE	Interagency Monitoring of PROtected Visual Environments
KHP	potassium hydrogen phthalate
LAC	light absorbing carbon
LPM	liters per minute
$\mu g/m^3$	micrograms per cubic meter
NIST	National Institute of Science and Technology
OC	organic carbon
PE	performance evaluation
ppm	parts per million
QA	quality assurance
QC	quality control
QMP	quality management plan
r^2	coefficient of determination
RPD	relative percent difference
TOR	thermal optical reflectance
TOT	thermal optical transmittance
TSA	technical systems audit

Chapter 1
Background

The U.S. Environmental Protection Agency (EPA) supports the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized testing organizations; with stakeholder groups consisting of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance and quality control (QA/QC) protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The EPA's National Risk Management Research Laboratory and its verification organization partner, Battelle, operate the Advanced Monitoring Systems (AMS) Center under ETV. The AMS Center recently evaluated the performance of the Magee Scientific Model AE33 Aethalometer at an ambient air monitoring site in Columbus, Ohio. Black carbon (BC) monitors were identified as a priority technology category for verification through the AMS Center stakeholder process.

Chapter 2
Technology Description

The objective of the ETV AMS Center is to verify the performance characteristics of environmental monitoring technologies for air, water, and soil. This report provides results for the verification testing of the Magee Scientific Model AE33 Aethalometer. The following is a description of the Model AE33 Aethalometer, based on information provided by the vendor. The information provided below was not verified in this test. Details of the installation and operation of the Aethalometers during the test period are included in Section 3.2 of this report.

The Aethalometer™ is used for the real-time measurement of optically-absorbing 'Black' or 'Elemental' carbon aerosol particles. The name "Aethalometer" is derived from the classical Greek verb 'aethaloun' (αεθαλουν), meaning 'to blacken with soot'. It was conceptualized in 1979, commercialized in 1986, and has been under continuous development since that date. The Aethalometer Model AE31 was verified by the ETV Program in 2001. The Model AE33 Aethalometer was released in 2012, and incorporates many scientific and technical improvements relative to earlier models.

The Aethalometer uses a continuous filtration and optical measurement method to provide a continuous readout of real-time data for the concentration of 'BC', which is fundamentally defined by 'blackness', an optical measurement. The optical analysis for BC is designed to be consistent and reproducible, and may be validated by the use of Neutral Density optical standards.

Aethalometers provide fully automatic, unattended operation. The sample is collected and analyzed as a spot on a roll of filter tape: depending on location, one roll of tape may last for several months. No other consumables are required. The instrument requires no calibration other than periodic checks of the air flow sensor response.

The AE-33 performs optical analysis at seven discrete wavelengths from 370 nm to 950 nm. These data can be interpreted to provide an indication of source apportionment, due to the different spectral characteristics of diesel particulates versus biomass-burning smoke.[1]

In recent years, it became apparent that under certain conditions, at certain locations, filter-based optical measurement techniques can be influenced by a saturation effect (also known as the "loading effect") of variable magnitude. This effect, when present, can change the

reported data by up to a factor of 2 or more, depending on the nature of the aerosol and the settings of the instrument. At other locations, or at the same location under conditions of different aerosol climatology, the effect may be reduced or completely absent. The fact that the "loading effect" is variable and clearly dependent on some attribute of the aerosol indicates that it is a combination of some aspect of the instrumental method, together with an actual chemical or microphysical aspect of the aerosol. However, the "loading effect" is always found to be linear with respect to the light attenuation measured on the filter spot. The Model AE33 Aethalometer corrects for the "loading effect" by collecting two aerosol spots in parallel, but at rates of accumulation that differ by a factor of two. Mathematical combination of the data from the two parallel analyses permits reconstruction of the "ideal" result, together with a report of the "loading compensation parameter" which may be informative of aerosol properties in its own right.

Figure 2-1. Magee Scientific Aethalometer AE-33

Chapter 3
Test Design and Procedures

3.1 Introduction

The ETV Program's AMS Center conducts third-party performance testing of commercially available technologies that detect or monitor natural species or contaminants in air, water, and soil. Stakeholder committees of buyers and users of such technologies recommend technology categories, and technologies within those categories, as priorities for testing. Among the technology categories recommended for testing are "black carbon" monitors. Because of the nature of BC, this technology category includes monitors for both BC and EC. Two stakeholders were selected to serve as peer reviewers for the quality assurance project plan (QAPP)[2] and this verification report. The responsibilities of verification test stakeholders/peer reviewers included:

- Participate in technical panel discussions (when available) to provide input to the test design;
- Review and provide input to the QAPP; and
- Review and provide input to the verification report/verification statement.

The QAPP and this verification report were reviewed by experts in the fields related to black carbon monitors. The following experts provided peer review:

- Andrea Polidori, South Coast Air Quality Management District
- Joann Rice, EPA.

The purpose of this verification test was to generate performance data on BC monitors so organizations and users interested in installing and operating these systems can make informed decisions about their use. Black carbon is a term that is commonly used to describe strongly light absorbing carbon (LAC), which is thought to play a significant role in global climate change through direct absorption of light, interaction with clouds, and by reducing the reflectivity of snow and ice. BC is formed from the incomplete combustion of fossil fuels, biofuels, and biomass and can be emitted from both anthropogenic and natural sources. It is a primary component of soot and has been linked to adverse health effects and visibility reduction. Consequently, there is a great deal of interest in monitoring BC in the atmosphere. However, differences in measurement techniques result in measurements that are operationally defined and characterize the particulate matter based on either its light absorbing properties (leading to determination of BC) or its refractory properties (leading to

determination of EC), as illustrated in Figure 3-1. In this figure, the use of the subscript *a* denotes that the measurements are technique specific and result in estimations of BC or EC that are "apparent" based on the technique being used. The methods used to determine EC are termed thermal-optical in Figure 3-1 because they involve conversion of particulate carbon to gaseous form under varying temperatures and controlled atmospheres while the particulate sample is monitored by either transmission or reflection of light.

This verification test was conducted according to procedures specified in the peer-reviewed ETV *Quality Assurance Project Plan (QAPP) for Verification of Black Carbon Monitors.*[2] Deviations from this QAPP are described in Section 4.1 of this report.

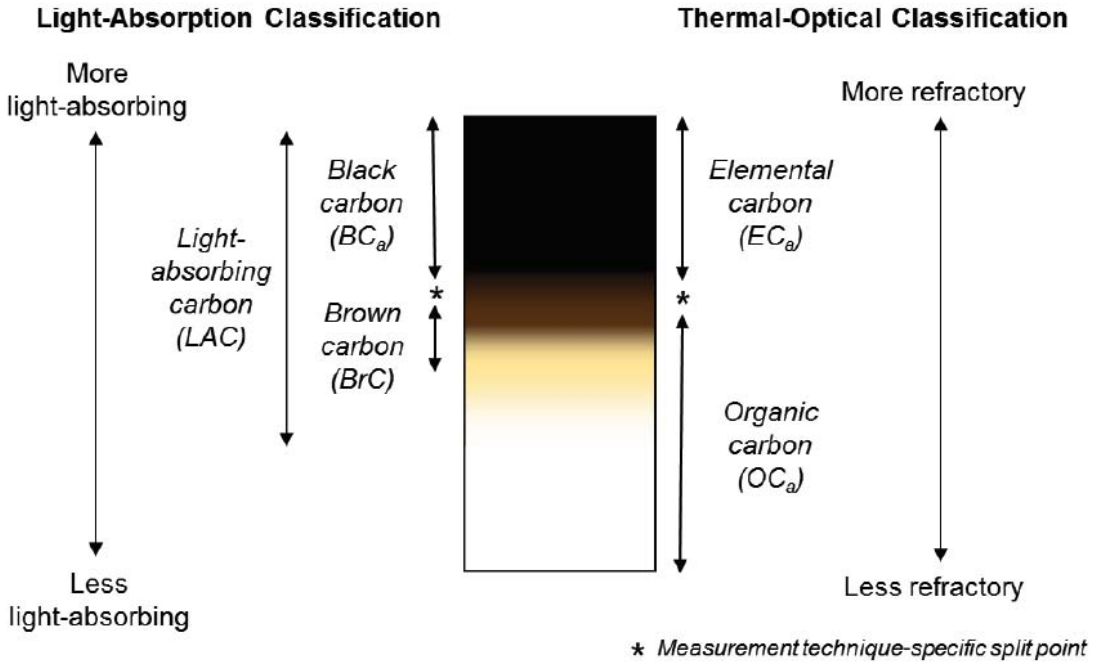

Figure 3-1. Illustration of measurements of carbonaceous particulate matter. (Source: U.S. EPA)[3]

The performance of the Model AE33 Aethalometer was verified by evaluating the following parameters:

- Comparability with collocated reference method results
- Precision between duplicate units
- Data completeness
- Reliability
- Operational factors such as ease of use, maintenance and data output needs, power and other consumables use, and operational costs.

3.2 Test Procedures

The test was conducted at the Battelle Columbus Operations Special Support Site (BCS3) located at 2555 International St., in Columbus, OH. For this test, duplicate AE33 Aethalometers continuously sampled ambient air for approximately 33 days, during which period filter samples were collected on thirty days to use as a basis of comparison for the analyzers being tested. Specifically, during each test period duplicate integrated filter samples were collected over successive 12-hour periods each day (except as noted below) using commercially available air sampling equipment. The duplicate reference samples were collected from 7:00 am to approximately 6:50 pm and from 7:00 pm to approximately 6:50 am daily. From April 5 through April 25, a single four-channel Anderson Model RAAS-400 speciation sampler was used to collect the duplicate reference filter samples using separate channels of the sampler. Samples were not collected during one of the planned 12-hour sampling periods (beginning on the evening of April 16) because of adverse weather conditions. On April 25, a failure in the electronics of the RAAS sampler rendered it inoperable and the lack of replacement parts resulted in the RAAS being inoperable for the remainder of the test period. Duplicate BGI Model PQ200 samplers were immediately available and were used in replacement of the RAAS for the collection of the reference samples from April 26 to May 7.

The reference samples were collected on pre-cleaned quartz fiber filters at a nominal flow rate of 16.7 LPM with both the RAAS and BGI samplers. The change in samplers was not expected to result in any differences in the measured EC concentrations since the samples were collected at the sample flow rate and with similar $PM_{2.5}$ size selective inlets. Actual differences that may have been observed are likely the result of differences in the calibrated flow rates of the samplers. Over the 33-day field period, a total of 118 filter samples were successfully collected (i.e., duplicate samples during 59 of the 60 12-hour sampling periods). The reference samples were analyzed for EC by Desert Research Institute (DRI) using the DRI Model 2001 EC-OC analyzers implementing the Interagency Monitoring of PROtected Visual Environments (IMPROVE) thermal/optical reflectance (TOR) method, which monitors the filter sample by means of optical reflectance.[4] DRI also reported EC results from the IMPROVE method with the filter monitored by thermal/optical transmission (TOT).[4] Results from the Aethalometers were compared to these filter sample results to assess the comparability of the Aethalometer results to the filter sample results. It should be noted that the Aethalometer measures BC using light absorption techniques whereas the TOR/TOT methods measure EC by thermal optical techniques in which CO_2 is generated from the oxidation of carbonaceous species which have been thermally liberated from the collected sample and the optical transmittance or reflectance of the filter is used to correct for residual carbon on the filter.

The precision of the Model AE33 Aethalometer was determined from comparisons of paired data from the duplicate units. Other performance parameters such as data completeness, maintenance requirements, ease of use, and operational costs were assessed from observations by the Battelle field testing staff. This test was not intended to simulate long-term (e.g., multi-year) performance of BC monitors. As such, performance and maintenance issues associated with long-term use of the Model AE33 Aethalometer are not addressed in this report.

Note that in this report the filter samples will be referred to as "reference samples." However, it should be noted that the IMPROVE method is not a true Reference Method in that it is not recognized as an absolute standard. Nonetheless, it is used within the IMPROVE network as the standard method for EC analysis. Thus the method was used in this test as an analytical technique used for comparison to the BC monitors. Other thermal/optical reference methods such as the NIOSH 5040 method may result in different results.

For the verification test, duplicate Model AE33 Aethalometers were installed inside an environmentally controlled instrument trailer at the monitoring site. The duplicate Model AE33 Aethalometers were installed by the vendor on March 27-28 and operated continuously at the site throughout the verification test, with the exception of several brief periods during which maintenance activities were performed.

Each Aethalometer drew sample air at 5 liters per minute (LPM) through approximately 3 meters of conductive (i.e., static-free) tubing connected to a $PM_{2.5}$ sharp cut cyclone inlet. Other than an initial flow rate check performed by the vendor, on March 27, no other quality control activities were performed on the Aethalometers for the duration of the verification test. The two inlet cyclones for the Aethalometers were positioned at one corner of the platform, at the same height as the reference sample inlet and at least one meter from each reference sampler. The RAAS-400 and the duplicate PQ200 samplers were installed on the platform such that each inlet was more than one meter from the other inlets. Battelle staff were trained on the operation of the analyzers and performed the maintenance on both units during the verification test. These activities were documented and are reported in Section 6.5 of this report.

3.3 Field Site

The test was conducted at the BCS3 facility located at 2555 International St., in Columbus, OH. Figure 3-2 shows an aerial photograph of the test site (red marker "A") and the surrounding area. The test site is located approximately ½ mile north of a rail yard and in the vicinity of multiple industrial and shipping facilities which result in frequent truck traffic past the site. The site also receives regionally transported air pollution due to its location on the western side of the Columbus metropolitan area. An environmentally controlled mobile laboratory was installed at the site to serve as a shelter for the Model AE33 Aethalometers and as work space for the testing staff. Figures 3-3 and 3-4 show the sampling trailer with RAAS sampler and BGI samplers, respectively, installed on a platform next to the trailer.

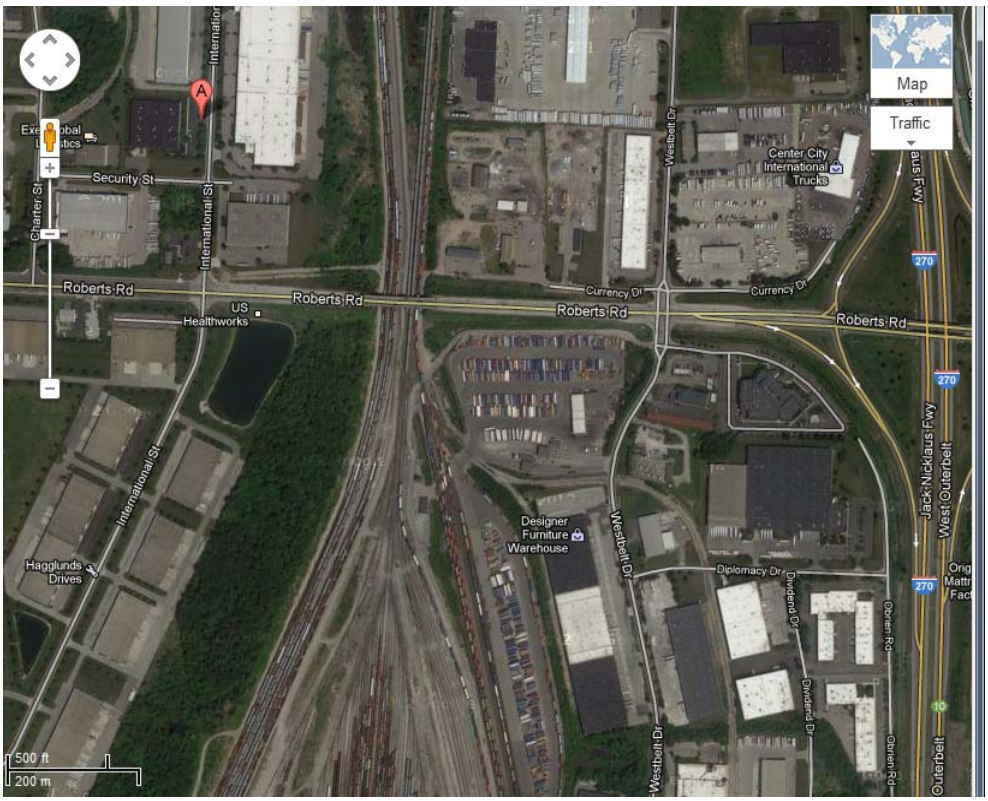

Figure 3-2. Aerial photograph of test site and surrounding area.

Figure 3-3. RAAS reference sampler installed at sampling site.

Figure 3-4. BGI PQ200 reference samplers installed at sampling site.

Chapter 4
Quality Assurance/Quality Control

QA/QC procedures and all verification testing were performed in accordance with test/QA plan for this verification test[1] and the quality management plan (QMP) for the AMS Center[6] except where noted below. QA/QC procedures and results for the reference method are described below. Other than an initial flow check during installation of the Aethalometers no additional QA/QC activities were performed on the Aethalometers. Maintenance activities performed on the Aethalometers are included in Section 6.5.1.

4.1 Amendments/Deviations

Two deviations to the test/QA plan were prepared, approved, and retained in the test documentation. The deviations established the following modification to the test/QA plan and the test procedures:

- The RAAS speciation sampler was replaced with duplicate BGI PQ200 samplers approximately half way through the sampling period because of a failure in the RAAS sampler. This change did not adversely affect the data quality since the new samplers functionally performed the same as the RAAS samplers. See Section 4.2.1 for a comparison of the results from the two sampler types.
- Routine flow checks were not performed as specified in the test plan for a portion of the test period. This deviation is not expected to adversely affect the results since subsequent leak checks met the acceptance criteria and no systemic bias was observed in the reference results.

4.2 Reference Method

The following sections describe the QA/QC procedures employed in the collection and analysis of reference samples. Only the results for the EC analyses are presented since OC results are not used to evaluate the performance of the Aethalometers.

4.2.1 Reference Method Sampling

This verification test included a comparison of Aethalometer results to those of the reference measurements described in Section 3.2. Figures 4-1 and 4-2, respectively, show the results of the TOR and TOT measurements of the duplicate reference samples collected during the testing period. In these figures, one of the two channels used in the RAAS for the collection of the reference samples was designated as the "primary sample" and the other channel was designated as the "collocated sample" to show potential biases between the two channels.

Similarly, one of the BGI samplers was designated as the "primary sample" and the other as the "collocated sample." Figures 4-3 and 4-4 show the corresponding differences between the primary and collocated reference sample measurements and indicate that there is no clear systematic bias observed in either the TOR or TOT results for either the RAAS sampler or the duplicate BGI samplers.

During the verification test the mean of the EC measurements for the duplicate reference samples ranged from <1.5 to 32.9 micrograms per filter (μg/filter) which corresponds to airborne concentrations ranging from <0.13 to 2.7 micrograms per cubic meter (μg/m^3) based on the sample volumes of ~12 m^3. According to DRI's documentation, at concentrations of greater than 10 times the method detection limit (10 x MDL ~1.5 μg/filter) the expected precision between duplicate samples is ~ 10%.[3] In general, the majority of the reference samples had EC concentrations that were below 10 times the MDL, consequently the percent difference between the duplicate samples was typically greater than 10%. Reference results that were reported as less than the MDL were assigned a value of ½ MDL for this report. Over all results with both reference sampler types, the calculated percent differences (i.e., the difference between the two duplicate results divided by their mean) ranged from -98% to 109%, with an average of 3%. The EC concentrations measured from the filters collected with the RAAS sampler ranged from <0.13 to 1.1 μg/m^3, with a mean concentration of 0.35 ± 0.28 μg/m^3. The average percent difference between the duplicate samples collected with the RAAS was 21% ± 71%. The EC concentrations measured from the filters collected with the BGI PQ200 samplers ranged from <0.13 to 2.7 μg/m^3, with a mean concentration of 0.64 ± 0.62 μg/m^3. The average percent difference between the duplicate samples collected with the BGI samplers was 1% ± 50%.

Figure 4-5 shows a scatter plot of the TOR results for the reference method samples indicating in which sampler type used to collect the filters (e.g., RAAS and BGI PQ200). Figure 4-6 presents a similar plot for the TOT analyses. These figures show that the TOT results exhibit a slope closer to 1.0, an intercept closer to zero, and a higher r^2 value, relative to the TOR results.

During testing a total of 12 reference method field blank samples were collected, representing 10% of the total reference method samples. The field blanks were installed in the filter cassettes and loaded into the reference method samplers without drawing air through the filters. Table 4-1 presents a summary of the field blank results including the results for the EC measurements for both the TOR and TOT analyses by the DRI Model 2001 analyzer. Table 4-1 shows that in nearly all cases no detectable EC was found on the reference method blank filters.

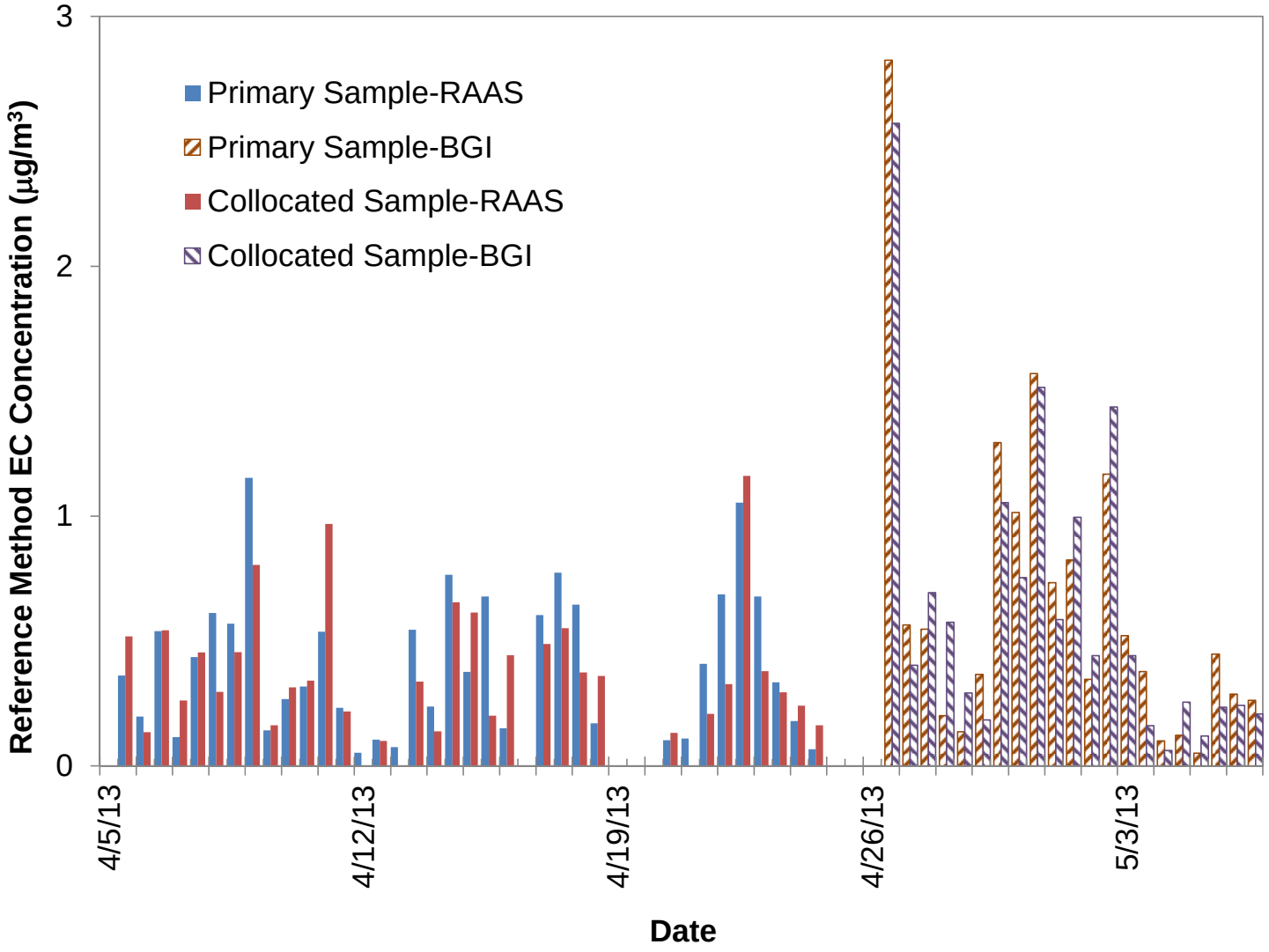

Figure 4-1. Duplicate Reference Method EC results from TOR analysis.

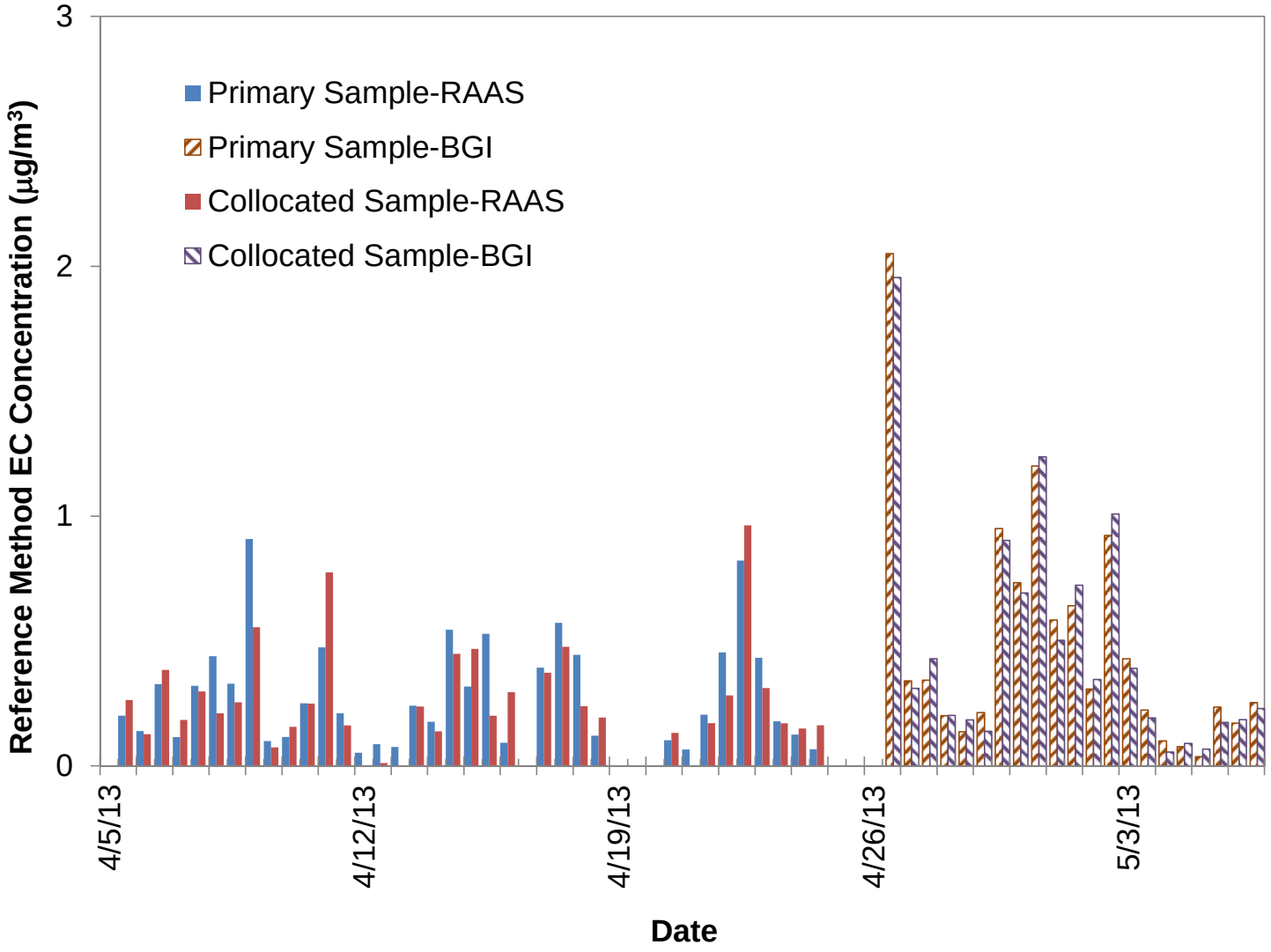

Figure 4-2. Duplicate Reference Method EC results from TOT analysis.

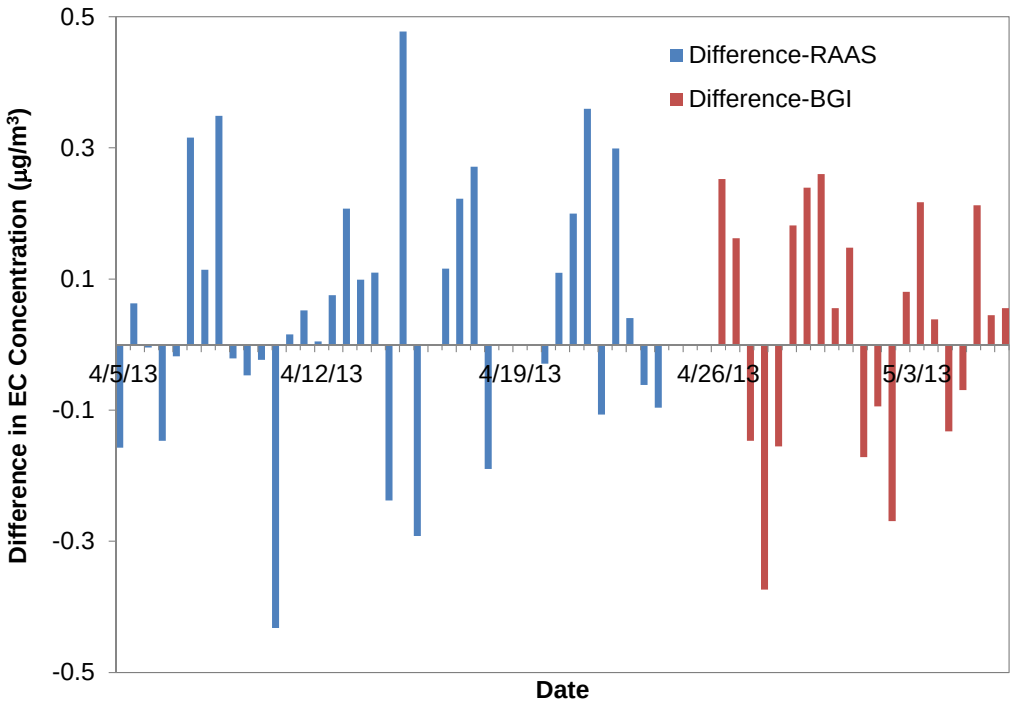

Figure 4-3. Differences between the duplicate reference method EC results from TOR analysis.

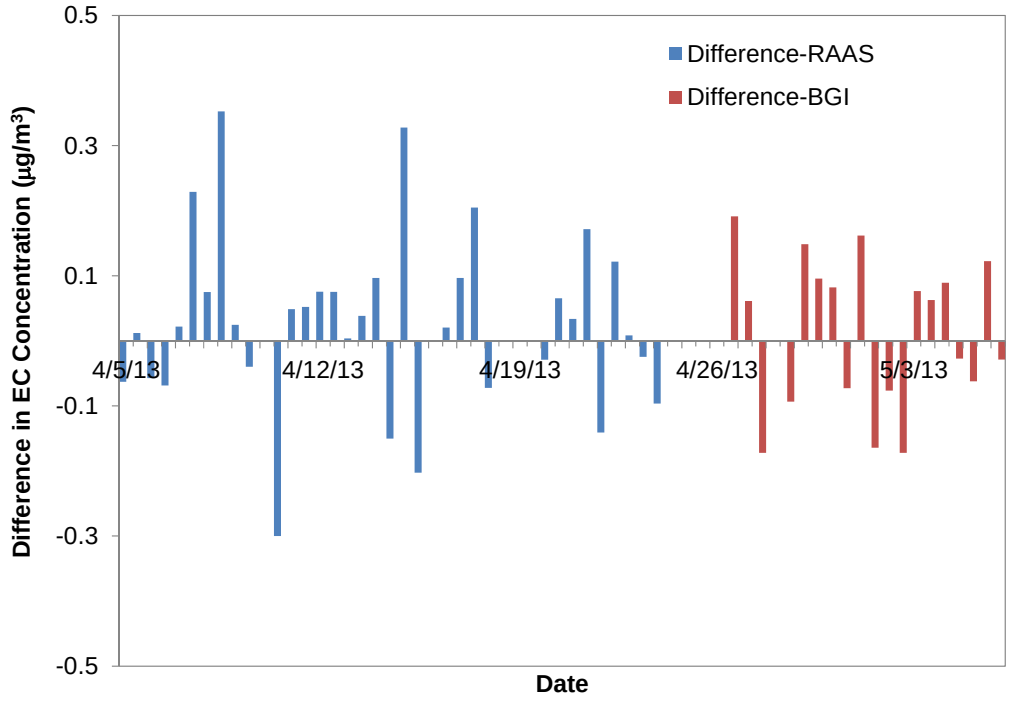

Figure 4-4. Differences between the duplicate reference method EC results from TOT analysis.

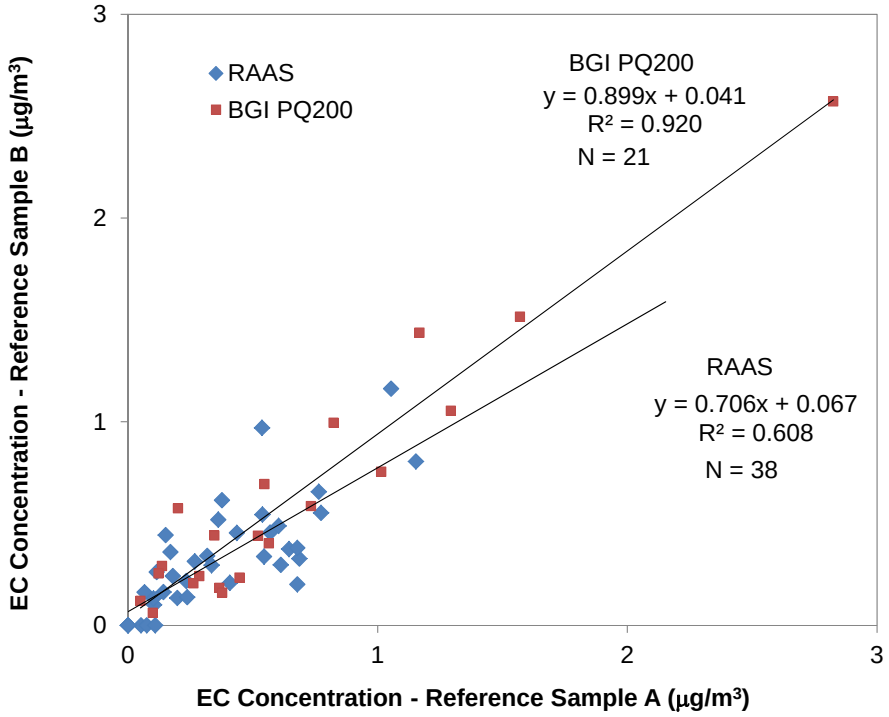

Figure 4-5. Regression of reference method results from TOR analysis by sampler type.

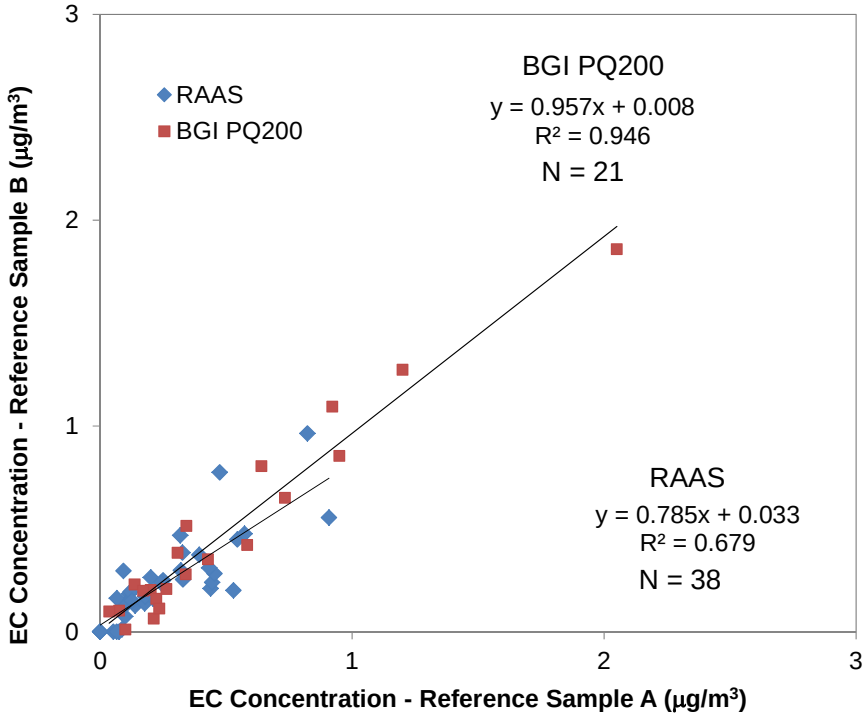

Figure 4-6. Scatter plot of reference method results from TOT analysis by sampler type.

Additionally, flow rate checks of the reference samplers were performed at least every three days during the sampling period to ensure that the reference samplers were operating within 5% of their nominal flow rate.

Table 4-1. Summary of Reference Method Field Blank Results

Filter ID	EC (μg/filter)	
	TOR	TOT
BTOQ001	0.00	0.00
BTOQ002	0.00	0.00
BTOQ011	0.05	0.00
BTOQ055	0.00	0.00
BTOQ072	0.00	0.00
BTOQ073	0.00	0.00
BTOQ074	0.00	0.00
BTOQ075	0.00	0.00
BTOQ090	0.00	0.00
BTOQ097	0.00	0.00
BTOQ109	0.00	0.00
BTOQ110	0.10	0.00

4.2.2 Reference Method Analysis

Routine calibrations of the DRI Model 2001 carbon analyzers used to analyze the reference samples were performed at the beginning and end of each day by injecting known volumes of either CH_4 or CO_2 with nominally the same amount of carbon (approximately 21.4 μg) and comparing the resulting OC3 and EC1 measurements[4]. The acceptable level is ±5% difference between peaks injected during the OC3 and EC1 temperature step. Table 4-2 presents a summary of these routine calibrations for each of the carbon analyzers (identified as uniquely numbered CA units below) and the calculated percent differences between carbon measurements from the OC3 and EC1 measurements for each calibration. Exceedences of the acceptance criterion require recalibration of the analyzer.

.

Table 4-2. Auto-Calibration Results of DRI EC/OC Analyzer.

	OC3 (μg)								
Date	**CA#6**	**CA#7**	**CA#8**	**CA#9**	**CA#10**	**CA#11**	**CA#12**	**CA#13**	**CA#16**
4/23/2013	21.80	20.90	22.35	20.22	21.67	21.08	21.06	22.59	17.67
5/17/2013			20.10	22.33		21.89	21.10		22.50
5/18/2013		22.75	20.31	22.37		21.87	21.17		22.37
5/20/2013			20.27	22.29			21.01		22.39
5/21/2013	19.46			22.24	21.15	21.85	21.00		22.41
	EC1 (μg)								
	CA#6	**CA#7**	**CA#8**	**CA#9**	**CA#10**	**CA#11**	**CA#12**	**CA#13**	**CA#16**
4/23/2013	21.11	20.53	22.02	20.78	21.29	20.91	20.94	21.40	19.48
5/17/2013			20.26	22.04		21.27	21.00		21.43
5/18/2013		22.31	20.09	22.00		21.17	20.82		21.40
5/20/2013			20.25	21.95			20.94		21.46
5/21/2013	20.10			22.00	21.70	21.24	20.92		21.52
	%Diff								
	CA#6	**CA#7**	**CA#8**	**CA#9**	**CA#10**	**CA#11**	**CA#12**	**CA#13**	**CA#16**
4/23/2013	3.3%	1.8%	1.5%	-2.7%	1.8%	0.8%	0.6%	5.6%	-9.3%
5/17/2013			-0.8%	1.3%		2.9%	0.5%		5.0%
5/18/2013		2.0%	1.1%	1.7%		3.3%	1.7%		4.6%
5/20/2013			0.1%	1.5%			0.3%		4.3%
5/21/2013	-3.2%			1.1%	-2.5%	2.9%	0.4%		4.1%

*CA#16 was taken offline on 4/23/2013 for FID and laser issues.

†Missing values indicate the instruments were offline during the day.

Full instrument calibrations are performed semiannually or after major maintenance or repairs and are used to establish the calibration slope used in converting CO_2 detector counts to μg of carbon. Four types of standards are used for full instrument calibration: 5% nominal methane (CH_4) in helium (He), 5% nominal CO_2 in He, potassium hydrogen phthalate (KHP), and sucrose. Instrument calibration involves spiking pre-fired quartz punches at four different levels with 5.0 to 20.0 microliters (μl) of the 1,800 parts per million (ppm) KHP and sucrose solutions and injecting CH_4 and CO_2 gases at four levels from 200 to 1,000 μL of the. The calibration slopes derived from the two gases and the KHP- and sucrose-spiked filter punches are averaged together to yield a single calibration slope for a given analyzer. This slope represents the response of the entire analyzer to generic carbon compounds and includes the efficiencies of the oxidation and methanator zones and the sensitivity of the FID. Table 4-3 presents a summary of the recent full calibrations of the analyzers used to analyze the reference samples. Note that the treatment of the calibration data ensures that the data passes through the origin, so no intercept is presented. The calculated slopes are compared to previous calibration results and should be with 10% of previous calibrations if no major changes to the instrument have been made. If the differences in the slope exceed 10%, the calibration must be repeated to verify the results.

Table 4-3. Full Calibration Results used for DRI Analyzers

Analyzer	Date	Slope	r^2
CA#6	4/3/2013	21.482	0.991
CA#7	5/7/2013	19.436	0.976
CA#7	4/26/2013	22.000	0.996
CA#7	10/11/2012	20.513	0.986
CA#8	5/13/2013	20.094	0.981
CA#8	12/7/2012	20.483	0.987
CA#9	4/18/2013	22.040	0.988
CA#10	5/21/2013	21.457	0.982
CA#10	5/4/2013	23.228	0.996
CA#10	3/29/2013	20.502	0.991
CA#11	3/14/2013	21.320	0.987
CA#12	4/1/2013	20.904	0.989
CA#13	11/19/2012	20.818	0.985
CA#16	3/10/2013	22.685	0.987

The instrument calibration was verified several times a week using sucrose and KHP standards near the midpoint of the calibration curve (18 μgC). Table 4-4 presents a summary of the calibration checks performed. In all cases the agreement between the measured and standard concentration was within the ±1 μgC acceptance criterion.

Table 4-4. Results of Periodic Calibration Checks

Date	CA#6	CA#8	CA#9	CA#10	CA#11	CA#12	CA#13	CA#16
4/23/2013	18.718	17.729	18.441	17.450	18.119	17.876	18.071	17.761
5/17/2013		17.433	17.783		18.149	17.688	17.749	18.104
5/20/2013		17.505	17.447		18.439	17.692		18.595
5/21/2013		17.739	17.523	17.223	17.332	17.402		18.147

†Missing values indicate the instruments were offline during the day.

Temperature calibrations are performed at least semiannually on all instruments to verify that the sample temperature is as accurate as possible. Quick-drying temperature-indicating liquids of different melting points, TempilaqºG (Tempil, Inc., South Plainfield, NJ, USA), were used as temperature indicators. Temperature indicators of 121, 184, 253, 510, 704, and 816 ºC were chosen for the IMPROVE_A protocol temperature calibration. The accuracy of TempilaqºG is certified within 1% of its designated temperature and is traceable to the National Institute of Standards and Technology (NIST). Table 4-5 shows the results of the most recent temperature calibrations of the analyzers used to analyze the reference samples. In all cases the linear relationship between the thermocouple and standard TempilaqºG values met the $r^2 > 0.99$ acceptance criterion.

Table 4-5. Temperature Calibration Results

	Date	Slope	Intercept	r^2
CA#6	11/26/2012	1.016	8.3	0.999
CA#6	5/16/2013	1.027	19.0	0.999
CA#7	4/29/2013	1.041	8.9	0.991
CA#7	6/3/2013	1.01	3.0	1.000
CA#8	12/7/2012	1.018	5.8	1.000
CA#8	5/13/2013	1.037	7.6	0.997
CA#9	4/5/2013	1.012	8.7	0.999
CA#9	4/22/2013	1.026	1.8	0.999
CA#10	2/19/2013	1.015	8.0	0.999
CA#11	3/15/2013	1.019	11.7	0.999
CA#12	2/25/2013	1.02	7.1	1.000
CA#13	11/19/2012	1.012	9.7	0.999
CA#13	5/21/2013	0.995	12.7	0.999
CA#16	3/11/2013	1.012	11.2	1.000

System blanks were performed once a week without filter punches in the analyzer to determine the instrument baseline. Calculated carbon concentrations from the system blank should not be more than 0.2 μg carbon. Table 4-6 presents a summary of the EC system blank results for the analyzers used to analyze the reference samples. Table 4-6 shows that the great majority of the EC system blanks showed no detectable carbon, and all EC blanks easily met the 0.2 μgC acceptance criterion.

Table 4-6. System Blank Results

	EC (μg)							
	CA#6	**CA#8**	**CA#9**	**CA#10**	**CA#11**	**CA#12**	**CA#13**	**CA#16**
4/28/2013	0.000	0.000	0.003		0.000	0.000	0.000	
5/5/2013	0.000	0.000	0.000		0.000		0.000	0.000
5/12/2013	0.002			0.068	0.000	0.000	0.000	0.000
5/19/2013		0.000	0.000		0.000	0.000		0.000
5/26/2013	0.004	0.000	0.000	0.000	0.000	0.000		

*System blanks on 5/12/2013 were high due to instruments being idle for the weekend and subsequent laboratory blank checks indicated normal conditions.

Laboratory blanks were performed daily to check for system contamination and evaluate laser response. If total carbon exceeded 0.2 μgC, values were voided and additional laboratory blanks were run after performing the oven bake procedure until the system is clean (i.e., OC < 0.2 μg C/cm^2 and no EC). Analyzers exceeding the limit for laser drift, reflectance, transmittance, total carbon, and calibration peak area after three laboratory blank

runs must be taken offline for maintenance. Table 4-7 presents the results of the laboratory blanks for the analyzers used to analyze the reference samples. One of the analyzers (CA#7) repeatedly failed the blank check and was taken offline on 5/18/2013 for maintenance.

Table 4-7. Laboratory Blank Results

	EC (μg)								
	CA#6	**CA#7**	**CA#8**	**CA#9**	**CA#10**	**CA#11**	**CA#12**	**CA#13**	**CA#16**
4/23/13	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000
5/17/13			0.000	0.000	0.000	0.000	0.000	0.000	0.000
5/18/13		0.017	0.000	0.000			0.000		0.000
5/20/13	0.063	0.005	0.000	0.000	0.000	0.000	0.003		0.000
5/21/13	0.000	0.000	0.011	0.000	0.012	0.000	0.021		0.005

CA#7 was taken offline for 5/18/2013.

Replicates of analyzed samples were performed at the rate of one per group of ten samples. The replicate was selected randomly and run immediately after each group of ten was completed. The random analyzer for the replicate was identified using a chart created in Microsoft Excel using the random number generator, which results in replicate analysis on the same and different analyzers. The $\mu g/cm^2$ values for EC were compared with the original run for both the TOR and TOT analysis. Precision was determined from replicate measurements as the average fractional difference between original and replicate analysis concentrations. Concentration uncertainty is the fractional precision times sample concentration. If sample concentration times fractional precision is zero, then the detection limit is used as concentration uncertainty. Table 4-8 shows the results of the replicate analyses. The results of the replicate analyses ranged from 0% to 52% for the TOR analysis and from 0% to 36% for the TOT analysis. In general, the percent difference exceeded the goal of 15% for the majority of the duplicate analyses indicating a lower degree of data quality than desired.

4.3 Audits

Three types of audits were performed during the verification test: a performance evaluation (PE) audit of the reference method sampling, a technical systems audit (TSA) of the verification test performance, and a data quality audit. Audit procedures are described further below.

4.3.1 Performance Evaluation Audit

A PE audit of the RAAS reference method sampler was performed by measuring the sample flow rate through the two channels used for collection of the reference samples. The flow rate through each channel was measured using a NIST-traceable flow transfer standard (BIOS DryCal, Serial No. 103777). After installation of the BGI PQ200 samplers, the flow rates of those samplers were audited using a BGI DeltaCal calibrator (Serial No. 001255). The results of those checks are summarized in Table 4-9, and indicate that the sampler flow rates were well within the target ±5% tolerance of the nominal 16.7 L/min flow rate.

Table 4-8. Replicate EC Analysis Results

Run 1		
Filter ID	**TOR**	**TOT**
BTOQ037	6.97	4.55
BTOQ041	7.77	6.06
BTOQ107	2.55	1.89
BTOQ114	3.81	3.00
BTOQ133	4.37	2.43
BTOQ086	4.33	2.52
BTOQ055	0.00	0.00
BTOQ057	5.22	4.17
BTOQ081	8.21	6.09
BTOQ009	3.44	1.99
BTOQ078	4.76	3.30
BTOQ095	8.68	6.91
Run 2		
BTOQ037	5.85	3.76
BTOQ041	6.40	5.21
BTOQ107	1.50	1.46
BTOQ114	4.38	3.93
BTOQ133	3.89	2.50
BTOQ086	3.47	1.76
BTOQ055	0.00	0.00
BTOQ057	3.96	3.23
BTOQ081	6.96	4.43
BTOQ009	3.27	2.03
BTOQ078	6.16	3.81
BTOQ095	7.50	6.08
Percentage Diff.		
BTOQ037	17.5%	19.0%
BTOQ041	19.3%	15.1%
BTOQ107	52.1%	25.8%
BTOQ114	14.0%	26.9%
BTOQ133	11.8%	3.1%
BTOQ086	22.1%	35.5%
BTOQ055	0.0%	0.0%
BTOQ057	27.3%	25.3%
BTOQ081	16.5%	31.6%
BTOQ009	5.2%	2.1%
BTOQ078	25.6%	14.2%
BTOQ095	14.7%	12.7%

Table 4-9. Summary of Flow Rate PE Audit

Date	Reference Sampler	Measured Flow (L/min)	Difference from Nominal
4/5/13	RAAS – Channel 1	16.63	-0.6%
	RAAS – Channel 4	16.67	0.0%
4/26/13	BGI – Sampler 1	16.82	0.9%
	BGI – Sampler 2	16.83	1.0%

Additionally, the temperature and pressure sensors of the reference samplers were audited using NIST-traceable transfer standards. A summary of those audit results are shown in Table 4-10 and indicate that both the temperature and pressure sensors in the reference samplers were within the acceptance criteria for the verification test (i.e., ± 2ºC for temperature, and ± 5 mmHg for pressure).

Table 4-10. Summary of Temperature and Pressure PE Audit

Date	Reference Sampler	Sampler Temp. (ºC)	Audit Temp. (ºC)	Sampler Pressure (mmHg)	Audit Pressure (mmHg)
4/5/13	RAAS	15.3	15.6	--	--
4/8/13	RAAS	--	--	736	736
4/26/13	BGI – Sampler 1	12.6	12.1	749	749
	BGI – Sampler 2	13.0	12.8	748	749

4.3.2 Technical Systems Audit

A Battelle QA Officer performed one TSA as part of this verification test. The TSA was performed at the BCS3 site in Columbus, OH. The TSA focused on observation of the reference method sampling and field QA/QC procedures in preparation for the field test. The purpose of the audit was to ensure that the verification test was being performed in accordance with the AMS Center QMP, and the test/QA plan for this verification test. In the audit, the Battelle QA Officer observed the reference method sampling and sample recovery, compared the actual test procedures being performed to those specified or referenced the test/QA plan, reviewed data acquisition and handling procedures, inspected documentation of reference sample chain of custody, performance of flow, pressure, and temperature PE audits, and reviewed test record books. One finding and five observations were noted requiring two deviations. The first deviation pertained to leak checks not occurring at the recommended frequency after each flow check. The VTC started performing leak checks after each flow check. It is not expected that the failure to conduct the leak checks had a substantial impact on the results since subsequent leak checks passed the acceptance criteria and there were no systemic biases between the reference results prior to conducting regular leak checks. The second deviation was to address the change from the Anderson RAAS to the two BGI PQ 200 samplers. While not a finding, this deviation was necessary to document the change in

samplers and did not impact the quality of results. The remaining observations noted were minor and did not impact the quality of results.

4.3.3 Data Quality Audit

At least 10% of the data acquired during the verification test were audited. Battelle's Quality Manager traced the data from the acquisition, through reduction and statistical analysis, to final reporting, to ensure the integrity of the reported results. All calculations performed on the data undergoing the audit were checked and QC results verified. Corrections from the other vendor report were made to the Magee data prior to QA review, resulting in minor comments. A few data issues were noted in the data quality audit, with minimal to no effect on the overall quality of the verification results. A few data issues were noted in the data quality audit, with minimal to no effect on the overall quality of the verification results.

4.4 QA/QC Reporting

Each audit was documented in accordance with Sections 3.3.4 and 3.3.5 of the QMP for the ETV AMS Center.[6] The results of the audits were submitted to the EPA.

4.5 Data Review

All data received from DRI for the reference measurements underwent 100% review and validation by Battelle technical staff before being used for any statistical calculations. This review included a review of the data files containing the measured EC values from the individual thermal steps for each filter and tracing of the calculated total EC measurements for both the TOR and TOT methods. The Aethalometer data were reviewed to ensure that the minute by minute data were appropriately averaged into hourly and 24-hour values. Based on review of Aethalometer data files and operator logs, a small number of 2 hour measurements were missing because of instrument maintenance activities. Those data are detailed in Section 6.5.1. All reference data were found to be valid and were included in the data analysis.

Records generated in the verification test received a one-over-one review (e.g., review by staff not involved in the generation of the record, but with at least the same technical expertise as the person generating the record) before these records were used to calculate, evaluate, or report verification results. Data were reviewed by a Battelle technical staff member involved in the verification test. The person performing the review added his/her initials and the date to a hard copy of the record being reviewed.

Chapter 5
Statistical Methods

The statistical methods used to evaluate the quantitative performance factors listed in Section 3.1 are presented in this chapter.

5.1 Comparability

The Aethalometers were evaluated for comparability in two ways. Firstly, comparability was determined from a linear least squares regression analysis of the measured BC concentrations from the Aethalometers against the corresponding EC results from the reference method. For comparison to the reference results, average concentrations from each of the Aethalometers were determined separately for each of the 12-hour sampling periods, by averaging the monitor's individual 1-minute readings into hourly averages and then averaging the hourly results into 12-hour averages over the corresponding reference method sampling period. The 12-hour averages from the two Aethalometers were plotted against the mean of the corresponding duplicate reference method measurements. The slope and intercept of these plots was determined from a linear regression analysis and reported independently for each of the monitors.

Additionally, comparability was determined in terms of the relative percent difference (RPD) between the mean value of the reference measurements and the results from each Aethalometer tested. The RPD was calculated using Equation 1:

$$RPD = \frac{1}{n}\sum_{i=1}^{n}\frac{C_i - \overline{C(ref)_i}}{C(ref)_i}\cdot 100 \qquad (1)$$

where: C_i is the average BC concentration measured by the BC monitor during the i^{th} reference sampling period, and

$\overline{C(ref)_i}$ is the mean of the duplicate reference method BC concentrations for the i^{th} reference sampling period.

Both measures of comparability were determined relative to the mean results from the duplicate reference results.

5.2 Correlation

The degree of correlation of the results from each Aethalometer to the reference method results were determined based on the coefficient of determination (r^2) value of the linear regression performed to assess comparability (Section 5.1). Correlation was determined separately for each unit of each BC monitor undergoing testing, and relative to the results from the reference method.

5.3 Precision

Precision (P) was determined based on a comparison of paired measurements from the duplicate BC monitors being tested. For this assessment of precision, the P between the paired measurements from the duplicate BC monitors was calculated using Equation 2:

$$P = \frac{1}{n}\sum_{i=1}^{n} \frac{\left|C(1)_i - C(2)_i\right|}{[C(1)_i + C(2)_i]/2} \qquad (2)$$

where $C(1)_i$ and $C(2)_i$ are the BC concentrations measured by the first and second of the two duplicate Aethalometers. Precision was calculated for each set of duplicate BC monitors for each reference sampling period, and the overall mean precision is also reported. For this calculation, measurement data below the vendor's stated instrumental detection limit was excluded from the analysis.

5.4 Data Completeness

Data completeness was assessed in two ways, based on the overall data return achieved by each Model AE33 Aethalometer during the testing period. First, for each of the BC monitors data completeness was calculated as the total hours of apparently valid data reported by the monitor divided by the maximum total possible hours of monitoring data in the entire field period. Also, for each Model AE33 Aethalometer data completeness was calculated as the percentage of 12-hour reference method sampling periods in which the monitor provided at least 9 hours of valid data (75%). The causes of any substantial incompleteness of data return was established from operator observations or vendor records, and noted in the discussion of data completeness results.

5.5 Operational Factors

Operational factors such as maintenance needs, data output, consumables used, ease of use, repair requirements, etc., were evaluated based on observations recorded by Battelle staff, and explained by the vendor as needed. A laboratory record book was maintained at the test site, and was used to enter daily observations on these factors. Examples of information recorded in the record book include the daily status of units, maintenance performed, and observations recorded during the installation and removal of the units.

Chapter 6
Test Results

Figure 6-1 shows the hourly average data from the duplicate Aethalometers during the verification testing period. These data are corrected to standard temperature and pressure conditions (1 atmosphere, 25 ºC). The two units are identified by their serial numbers (089 and 090, respectively). To facilitate comparisons to the reference method results the concentrations are reported in µg/m^3 rather than ng/m^3 as reported in the raw Aethalometer data files. The calculated differences (expressed in terms of SN089 – SN090) are presented in Figure 6-2, and show a general tendency for SN 089 to read lower than SN 090.

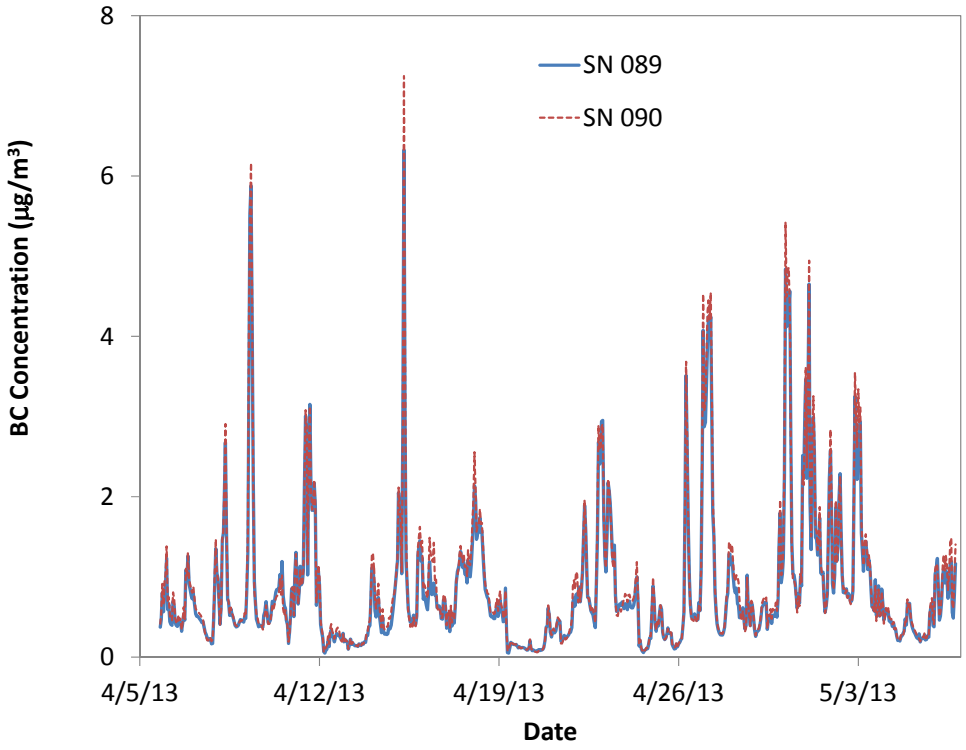

Figure 6-1. Measured hourly average BC concentration from the duplicate Model AE33 Aethalometers during testing.

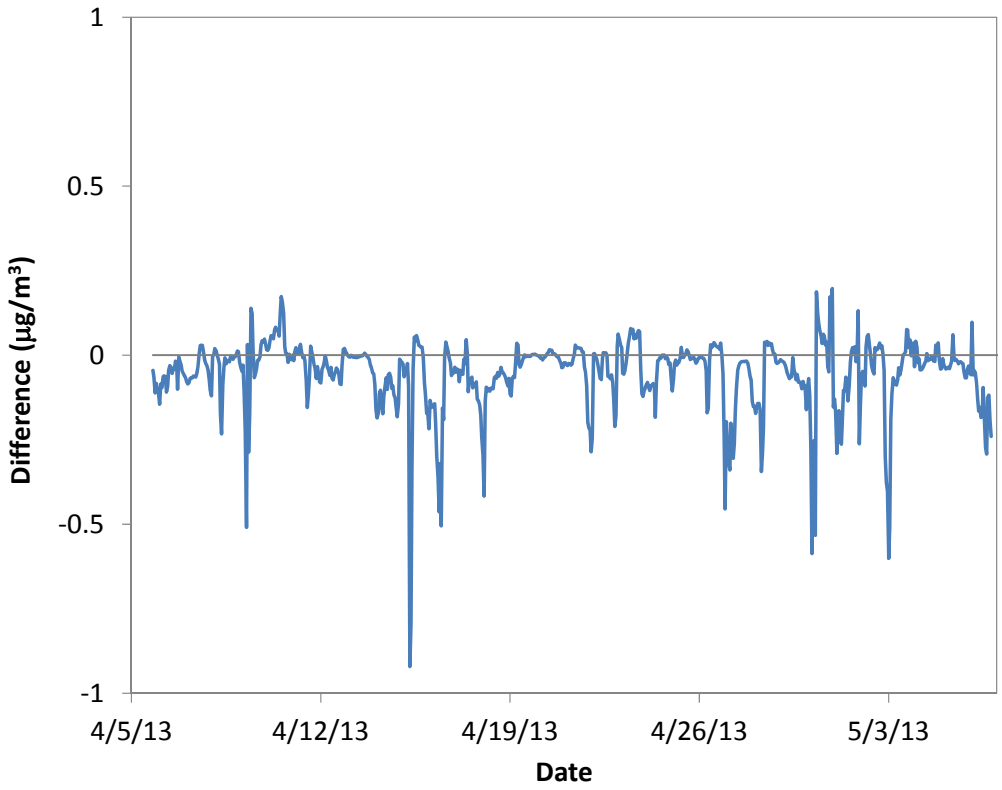

Figure 6-2. Calculated differences between the hourly average BC concentration from the duplicate Model AE33 Aethalometers during testing (Difference = SN 89 - SN 90).

6.1 Comparability

The comparability of the Model AE33 Aethalometers with the reference method was determined in two ways. Firstly, comparability was determined from a linear least squares regression analysis of the BC concentrations measured by the Model AE33 Aethalometers and the EC concentrations measured by the reference methods as described in Section 5.1.1. Also, comparability was determined from the RPD of the 12-hour Aethalometer averages and the mean of the reference method data for each sampling period, as described in Section 5.1.2. For these calculations, the 12-hour results for the Model AE33 Aethalometers were calculated as the averages of the hourly Aethalometer averages from the respective reference method periods. Comparability was determined independently for each of the Model AE33 Aethalometers, and comparability was calculated with respect to both the TOR and TOT reference method results. The results of these analyses are presented below.

Figures 6-3 and 6-4 show time series plots of the 12-hour average Aethalometer results and the corresponding mean TOR and TOT reference method results, respectively. The dates shown correspond to the start of the respective sampling periods, with the first sampling period beginning on April 5 at 7:00 pm and ending on April 6 at 6:50 am.

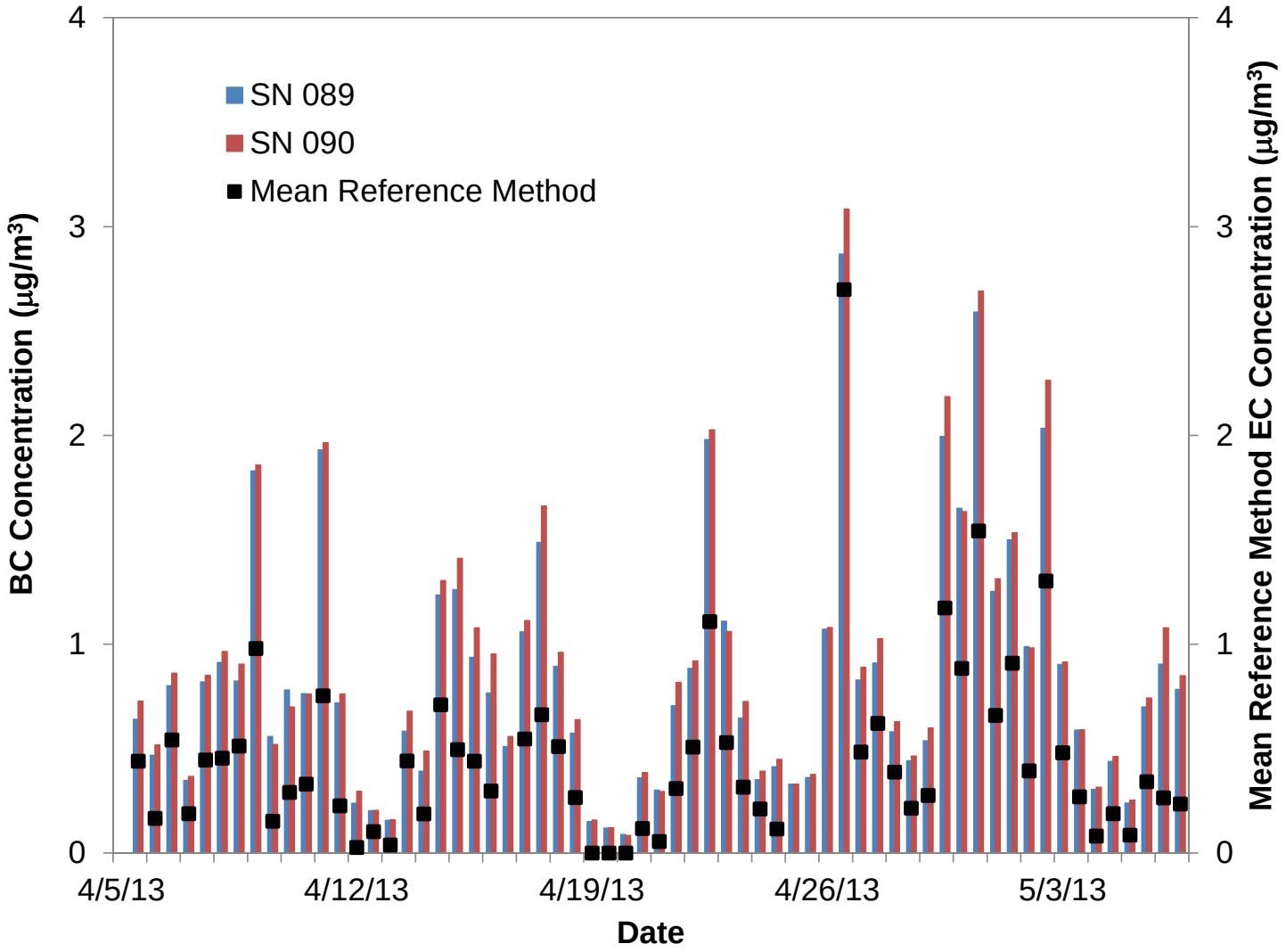

Figure 6-3. Comparison of the 12-hour BC averages from the Model AE33 Aethalometers and the mean reference method TOR EC concentrations.

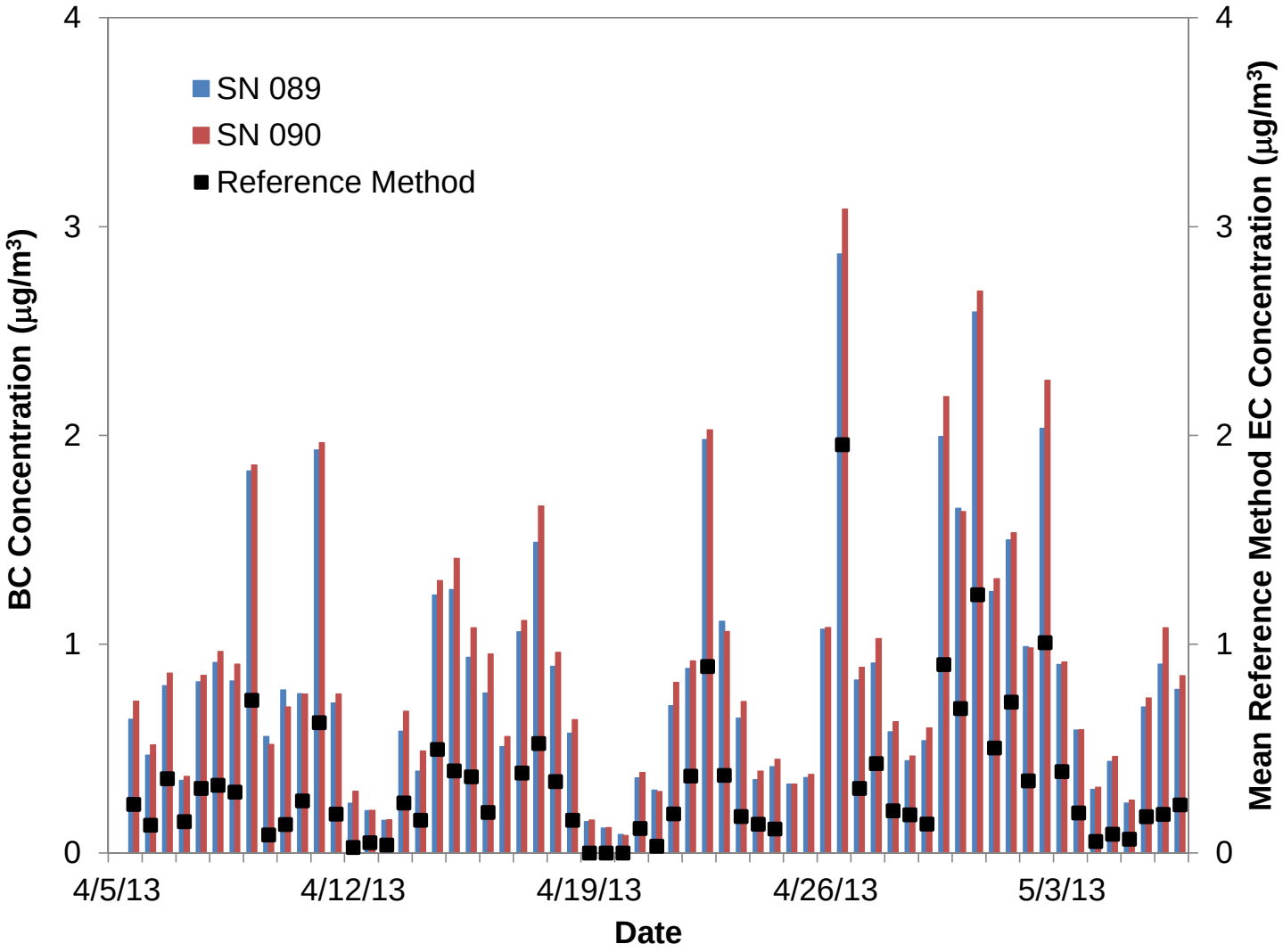

Figure 6-4. Comparison of the 12-hour BC averages from the Model AE33 Aethalometers and the mean reference method TOT EC.

6.1.1 Regression Analysis

Figures 6-4 and 6-5 show linear regressions of the 12-hour BC averages from the Aethalometers with the corresponding TOR and TOT reference method results, respectively. These figures show that there is a positive bias (i.e., slope > 1) of the Aethalometer results relative to the reference method results, as well as a positive intercept of ~0.3 μg/m^3 for each of the regression lines.

Note that a single data point at the highest observed BC concentration appears to be an outlier and significantly impacts the calculated slopes and intercepts for the regression lines. A linear relationship appears to exist below 1.5 μg/m^3 and that additional measurements at higher concentrations are needed to confirm a linear relationship at higher concentrations. It is not apparent whether this point is an outlier or is indicative of a non-linear correlation between the IMProVE method results and the Aethalometer at high concentrations. This data point is clearly apparent in each of the regression plots and consistently falls below the regression lines in each plot.

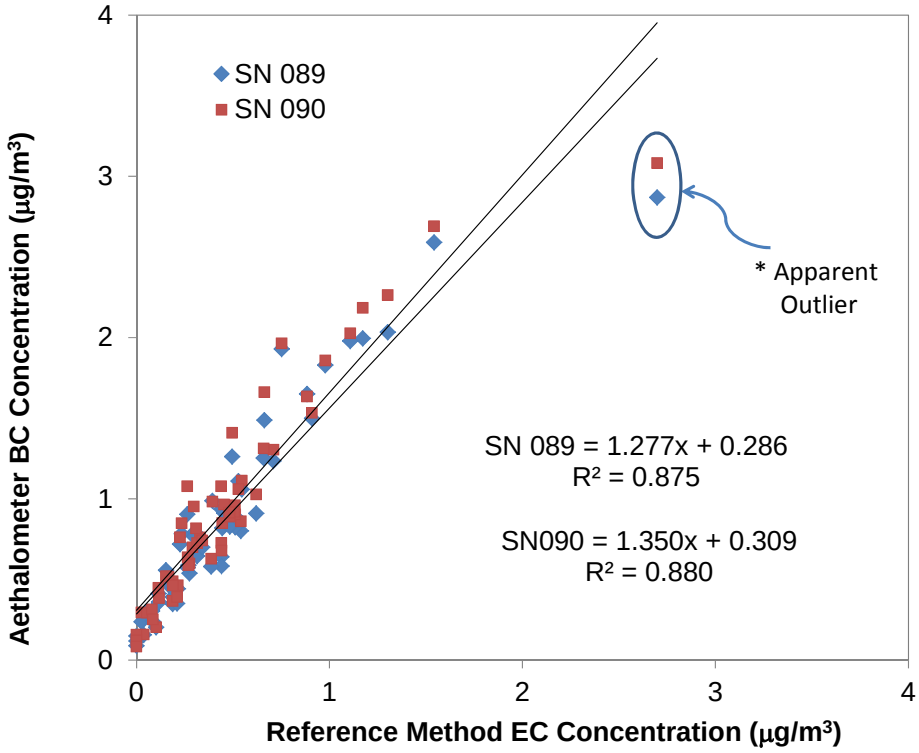

Figure 6-4. Linear regression of 12-hour Aethalometer BC averages against mean reference method TOR EC results.

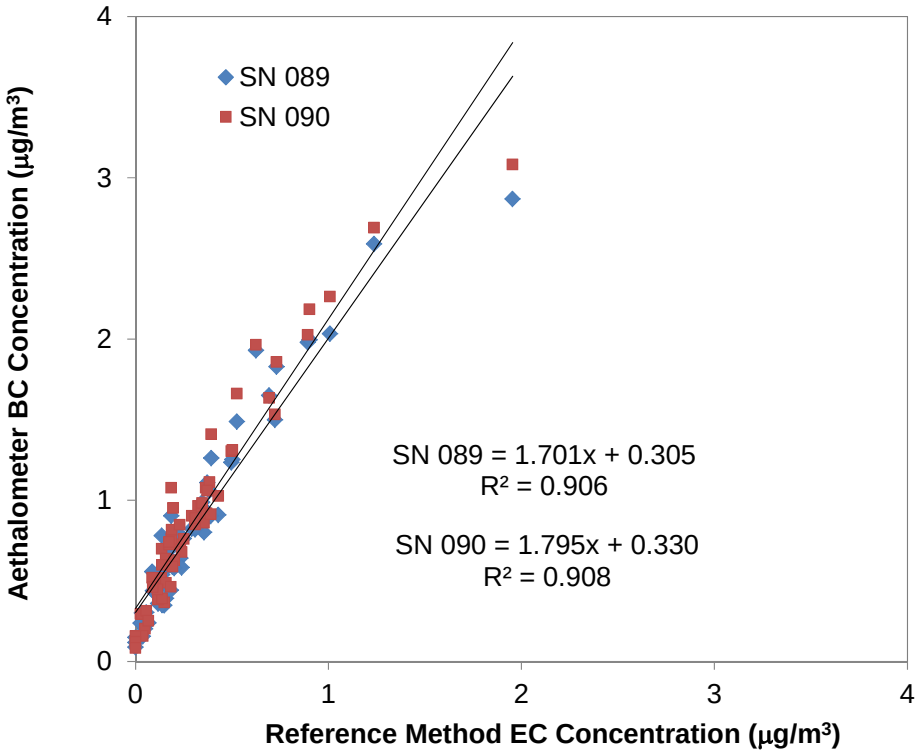

Figure 6-5. Linear regression of 12-hour Aethalometer BC averages against mean reference method TOT EC results.

Table 6-1 presents a summary of the regression results from the Aethalometers relative to both the TOR and the TOT reference method results. The uncertainties (one standard deviation) of the calculated slopes and intercepts are included parenthetically. These results show a positive bias (slope > 1, positive intercept) for the Aethalometers relative to the reference method for both the TOR and TOT analyses. All of the regression slopes in Table 6-1 are significantly different from 1.0 at the 95 percent confidence level, and all of the intercept values are similarly significantly different from zero at that confidence level. These regression results include the apparent outlier data point at the highest observed concentration.

Table 6-1. Summary Regression Results of the Aethalometers and the Reference Method

	TOR		TOT	
	Slope	**Intercept (µg/m^3)**	**Slope**	**Intercept (µg/m^3)**
SN 089	1.277 (0.064)	0.286 (0.041)	1.701 (0.072)	0.305 (0.034)
SN 090	1.350 (0.066)	0.309 (0.042)	1.795 (0.076)	0.330 (0.036)

Table 6-2 presents revised regression results excluding that data point. In general, the exclusion of the apparent outlier data point resulted in an increase in the slopes of the regression results and a decrease in the intercepts. All of the regression slopes in Table 6-2 are significantly different from 1.0 at the 95 percent confidence level, and all of the intercept values are similarly significantly different from zero at that confidence level.

Table 6-2. Summary of Regression Results of the Aethalometers and the Reference Method Excluding Apparent Outlier Data Point

	TOR		TOT	
	Slope	**Intercept ($\mu g/m^3$)**	**Slope**	**Intercept ($\mu g/m^3$)**
SN 089	1.585 (0.061)	0.172 (0.032)	2.013 (0.067)	0.224 (0.027)
SN 090	1.661 (0.064)	0.194 (0.034)	2.105 (0.074)	0.249 (0.030)

6.1.2 Relative Percent Difference Analysis

Table 6-3 presents a summary of the calculated RPD between the 12-hour averages for the the Aethalometers relative to the TOR and the TOT reference method results. For these calculations, reference method results below twice the method detection limit were excluded. For perfect agreement between the Aethalometers and the reference method results, the RPD would be zero. In general, the measured concentrations from the Aethalometers were approximately twice as high as those from the reference method resulting in positive RPD values. It should be noted that only about two thirds of the TOR reference method results and fewer than half the TOT reference method results were above twice the detection limit.

Table 6-3. Summary of Relative Percent Difference between the Aethalometers and the TOR Reference Method Results

	RPD[a]	
	TOR	**TOT**
SN 089	95.6% (N=39)	149.7% (N=26)
SN 089 – RAAS	100.9% (N=23)	168.0% (N=15)
SN 089 - BGI	88.1% (N=16)	124.7% (N=11)
SN 090	109.5% (N=39)	163.7% (N=26)
SN 090 – RAAS	115.3% (N=23)	183.9% (N=15)
SN 090 - BGI	101.0% (N=16)	136.1% (N=11)

a: Includes only reference data that exceeded twice the method detection limit.

6.2 Correlation

Table 6-4 presents a summary of the coefficient of determination (r^2) for the results from the Aethalometers relative to both the TOR and the TOT reference method results (see Figures 6-2 and 6-3). The correlation results were calculated including all of the data and also with the apparent outlier shown in Figure 6-4 removed. In all cases, exclusion of the apparent outlier increased the calculated r^2 value, with a larger increase in r^2 for the TOR results than in r^2 for the TOT results. With both data sets the correlation of Aethalometer results with TOT results was higher than with TOR results.

Table 6-4. Summary of Correlation Results of the Aethalometers and the Reference Method

	r^2 (All data)		r^2 (Outlier removed)	
	TOR	**TOT**	**TOR**	**TOT**
SN 089	0.875	0.906	0.924	0.941
SN 090	0.880	0.908	0.922	0.936

6.3 Precision

Table 6-5 presents a summary of the calculated unit-to-unit precision for the duplicate Aethalometers for the calculated hourly and 12-hour averages. The total number of paired measurements in which the readings from both analyzers exceeded the detection limit of 0.005 $\mu g/m^3$ is included parenthetically for each calculation.

Table 6-5. Summary of Calculated Unit-to-Unit Precision Results of the Aethalometers

	RPD
1-hour	8.5% (N=756)
12-hour	7.1% (N=63)

Figures 6-6 and 6-7 show linear regressions of the hourly averages from the duplicate Aethalometers on a linear and logarithmic scale, respectively. Figures 6-8 and 6-9 show similar plots for the 12-hour averages. Table 6-6 summarizes the results of the unit-to-unit linear regressions of the Aethalometer data.

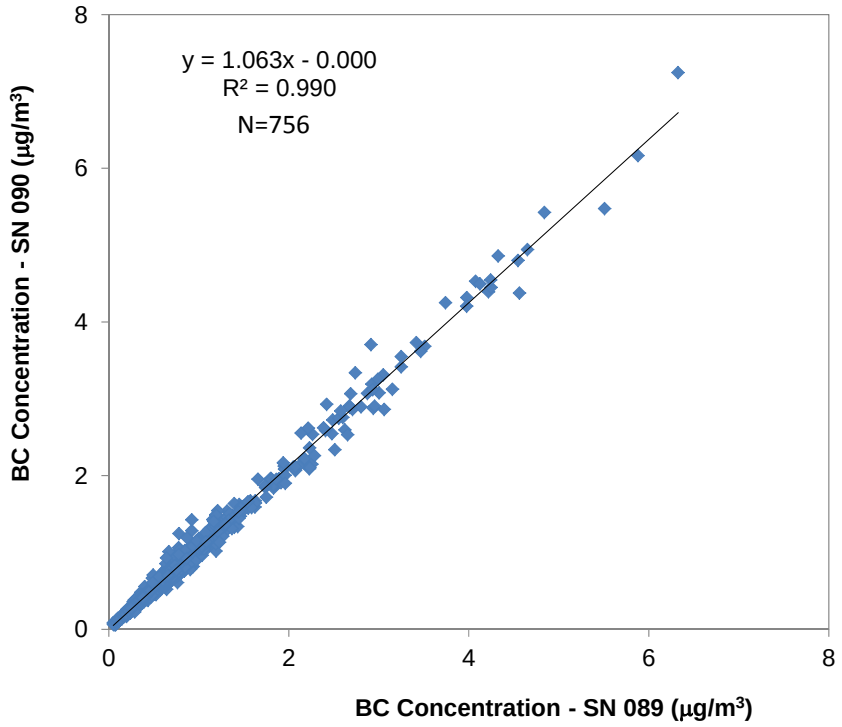

Figure 6-6. Linear regression of Aethalometer 1-hour averages (linear scale).

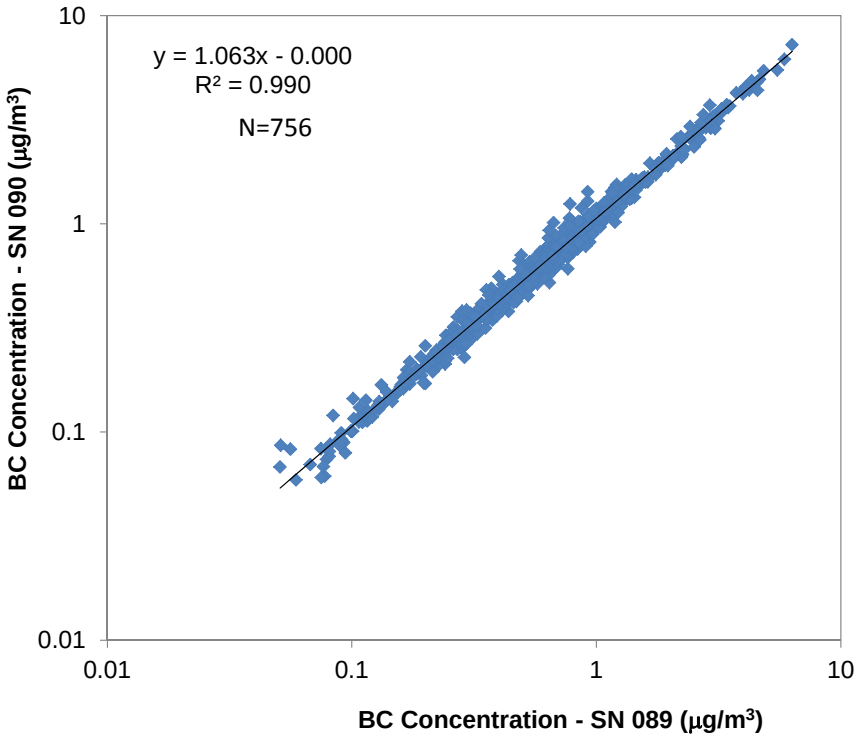

Figure 6-7. Linear regression of Aethalometer 1-hour averages (logarithmic scale).

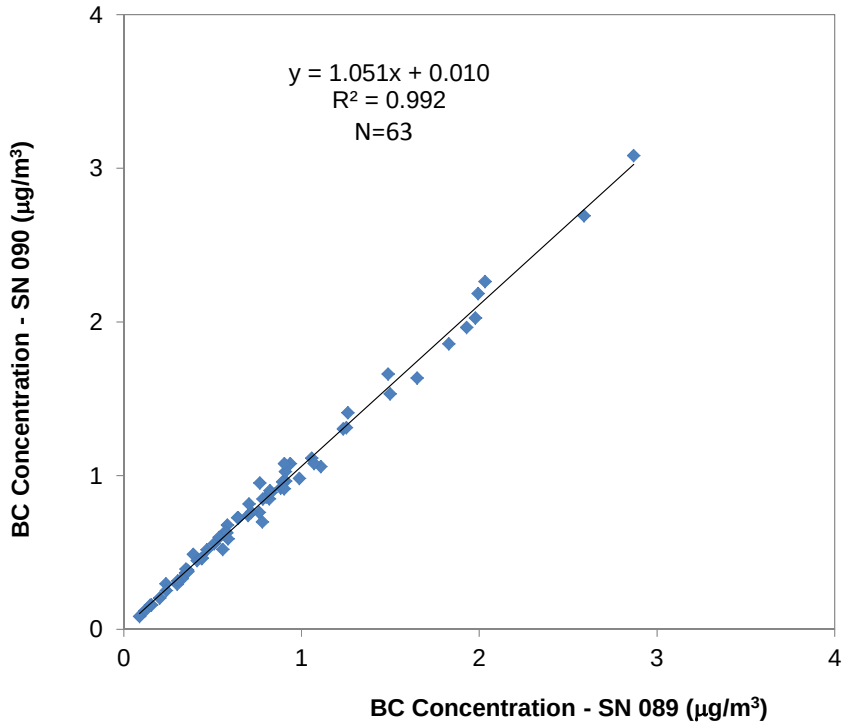

Figure 6-8. Linear regression of the Aethalometer 12-hour averages (linear scale).

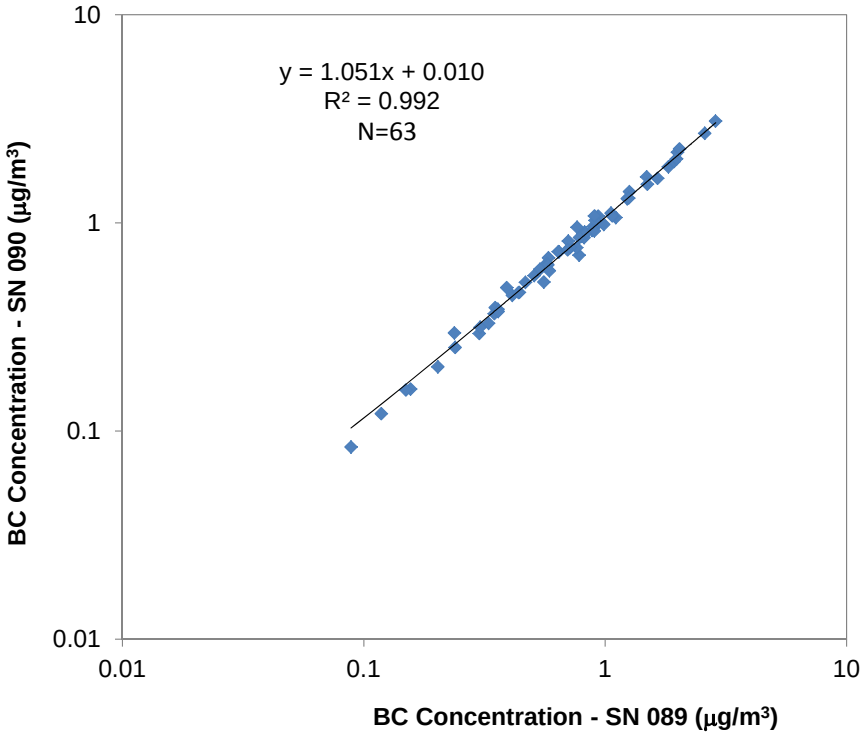

Figure 6-9. Linear regression of the Aethalometer 12-hour averages (logarithmic scale).

Table 6-6. Summary of Unit-to-Unit Regression Results of the Aethalometers

	Slope	Intercept ($\mu g/m^3$)	r^2
1-hour	1.063 (0.004)	-0.000 (0.005)	0.990
12-hour	1.051 (0.012)	0.010 (0.012)	0.992

Fort both the 1-hour and 12-hour averages, the regression slopes in Table 6-6 are significantly different from 1.0 at the 95 percent confidence level, whereas the intercept values are not significantly different from zero at that confidence level.

6.4 Data Completeness

Table 6-7 presents a summary of the data completeness for the duplicate Aethalometers during the testing period. These results are based on the total number of 1-minute measurements recorded during the testing period and the total number of valid 12-hour averages that were calculated to correspond to the reference method sampling periods. Each of the analyzers recorded valid data for at least 99.5% of the total 1-minute periods during the verification test and valid 12-hour averages were calculated for 100% of the reference method sampling periods. Other than the maintenance activities noted in Section 6.5.1, the data loss observed in the 1-minute readings is attributed to periods during which the filter tape in the Aethalometers was advanced.

Table 6-7. Summary of data completeness for the Aethalometers

Analyzer	1-minute			12-hour		
	Total Periods	Valid Measurements	% Complete	Total Periods	Valid Measurements	% Complete
SN 089	45,360	45,157	99.6%	63	63	100%
SN 090	45,360	45,149	99.5%	63	63	100%

6.5 Operational Factors

This section addresses the maintenance, consumables, waste generation, ease of use, and other factors relevant to operation of the Model AE33 Aethalometer.

6.5.1 Maintenance

Table 6-8 shows the maintenance activities that were performed on the two Model AE33 Aethalometers during the verification test.

Table 6-8. Summary of Maintenance Performed on Aethalometers

Date	Maintenance	Approximate time	Data loss
3/29/13	Restore instrument defaults from memory card for each analyzer	~10 minutes	~15 minutes
4/17/13	Restore instrument defaults from memory card for SN90	~5 minutes	~10 minutes

6.5.2 Consumables/Waste Generation

The Aethalometer uses rolls of filter tape to sample the ambient air. The tape was not exchanged during the verification testing period and only a small fraction (estimated at less than 10%) of the total amount of tape on the rolls in the two Aethalometers was used between the time of installation and the end of the verification test (~43 days).

6.5.3 Ease of Use

Installation of the Aethalometers was straightforward and involved removal of the analyzers from their respective shipping containers, placing the analyzers on a bench in the mobile laboratory, and supplying power to the analyzers. Electrically-conductive ("static dissipative") flexible tubing was used as sampling inlets for the Aethalometers and was installed using a "push-in" fitting. Installation of the two units including the sample inlets was completed in approximately 5 minutes. Installation of the sampling lines and inlet cyclones for the two Aethalometers required approximately 10 minutes. After installation, the units were allowed to operate overnight and the flow rates were checked the following morning using a NIST traceable flow device. That flow calibration required less than half an hour to complete. Routine operation required no effort other than brief daily instrument checks and approximately weekly data downloads. The downloaded data files were in comma separated variable (csv) format and were processed in Microsoft Excel.

Chapter 7
Performance Summary

Table 7-1 presents a summary of the results of the verification of the Model AE33 Aethalometer during this verification test.

Table 7-1. Summary of Verification Test Results for the Model AE33 Aethalometer

Comparability- Regression analysis comparison to reference samples	**Analyzer**	**TOR**		**TOT**	
		Slope	**Intercept**	**Slope**	**Intercept**
	SN089	1.277 (0.064)	0.286 (0.041)	1.701 (0.072)	0.305 (0.034)
	SN090	1.350 (0.066)	0.309 (0.042)	1.795 (0.076)	0.330 (0.036)

Comparability- Calculation of RPD between Aethalometer results and reference method results	**Analyzer**	**RPD**	
		TOR	**TOT**
	SN089	95.6% (N=39)	149.7% (N=26)
	SN090	105.9% (N=39)	163.7% (N=26)

Correlation - Regression analysis comparison to reference samples	**Analyzer**	**r^2**	
		TOR	**TOT**
	SN089	0.875	0.906
	SN090	0.880	0.908

Precision - Comparison of results from duplicate monitoring systems		**RPD (# of Observations)**
	1-hour	8.5% (N=756)
	12-hour	7.1% (N=63)

Precision – Regression analysis of results from duplicate monitoring systems	**Period**	**Slope**	**Intercept ($\mu g/m^3$)**	**r^2**
	1-hour	1.063 (0.004)	-0.000 (0.005)	0.990
	12-hour	1.051 (0.012)	0.010 (0.012)	0.992

Data Completeness	**Analyzer**	**Period**	**Total Periods**	**Valid Measurements**	**% Complete**
	SN089	1-minute	45,360	45,157	99.6%
		12-hour	63	63	100%
	SN090	1-minute	45,360	45,149	99.5%
		12-hour	63	63	100%

Table 7-1 (continued). Summary of Verification Test Results for the Model AE33 Aethalometer

Maintenance	• Default instrument settings restored from internal memory card twice during testing. • No routine maintenance performed during testing.
Consumables/waste generated	• Filter tape required.
Ease of use	• Installation of two units without inlets completed in ~5 minutes. • Installation of inlets and sampling lines completed in ~10 minutes • Calibration of flow rates completed in less than30 minutes, after allowing the units to operate overnight. • Routine operation required no effort other than brief daily instrument checks and approximately weekly data downloads. • Data exported as csv files and processed using Microsoft Excel.

Chapter 8
References

1. Allen, G.A., Babich, P., and Poirot, R.L., "Evaluation of a New Approach for Real Time Assessment of Wood Smoke PM." Found at: http://www.ct.gov/deep/lib/deep/air/regulations/proposed_and_reports/pm25/appendix_2c.pdf

2. Battelle, *Quality Assurance Project Plan for Verification of Black Carbon Monitors: Version 1*, Battelle, Columbus, Ohio, April 12, 2013.

3. Report to Congress on Black Carbon, EPA-450/R-12-001, U.S. Environmental Protection Agency, March 2012. Available at http://www.epa.gov/blackcarbon/.

4. Desert Research Institute, DRI Model 2001 Thermal/Optical Carbon Analysis (TOR/TOT) of Aerosol Filter Samples - Method IMPROVE_A, DRI SOP#2-216r3, prepared by DRI, Reno, NV, October 22, 2012.

5. U.S. EPA, Environmental Technology Verification Program Quality Management Plan, EPA Report No: EPA 600/R-08/009, U.S. Environmental Protection Agency, Cincinnati, Ohio, January 2008.

6. Battelle, Quality Management Plan for the ETV Advanced Monitoring Systems Center, Version 8.0, U.S. EPA Environmental Technology Verification Program, prepared by Battelle, Columbus, Ohio, April 5, 2011.