Quality Assurance Project Plan

Project Number: 19-031

Detecting events and seasonal trends in biomass burning plumes using black and brown carbon: $(BC)^2$ El Paso

Prepared for
Texas Air Quality Research Program (AQRP)
The University of Texas at Austin

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Baylor University has prepared this QAPP following EPA guidelines for a Quality Assurance (QA) Category III Project: Measurement. It is submitted to the Texas Air Quality Research Program (AQRP) as required in the Work Plan requirements.

QAPP Requirements: Project Description and Objectives, Organization and Responsibilities, Scientific Approach, Sampling Procedures, Measurement Procedures, Quality Metrics, Data Analysis, Interpretation, and Management, Reporting, References, and Appendix

QA Requirements: Technical Systems Audits - Not Required for the Project
Audits of Data Quality – 10% Required
Report of Findings – Required in Final Report

TITLE AND APPROVAL SHEET

This document is a Level III Quality Assurance Project Plan for the Detecting events and seasonal trends in biomass burning plumes using black and brown carbon: $(BC)^2$ El Paso project. This project is managed by the staff at Baylor University and the University of Houston.

Approval Signatures:

Project Manager, Texas Air Quality Research Program

________________________________ Date: 10/24/2018__________
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Quality Assurance Project Plan Manager, Texas Air Quality Research Program

__Approved electronically_____________ Date: 10/16/2018__________
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Distribution List

Below is a list of individuals and their organizations that need copies of the approved Quality Assurance (QA) Project Plan and any subsequent revisions, including all persons responsible for implementation (e.g., project managers), the QA managers, and representatives of all groups involved. Paper copies need not be provided to individuals if equivalent electronic information systems can be used.

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1. PROJECT DESCRIPTION AND OBJECTIVES

1.1 ENVIRONMENTAL SYSTEM TO BE EVALUATED

This project seeks to improve the identification and quantification of biomass burning plumes impacting El Paso, TX through new long-term monitoring technologies for black carbon (BC, or elemental carbon) and brown carbon (BrC, or light absorbing organic carbon). This is a critical component of developing a strategy to meet National Ambient Air Quality Standards (NAAQS) in El Paso.

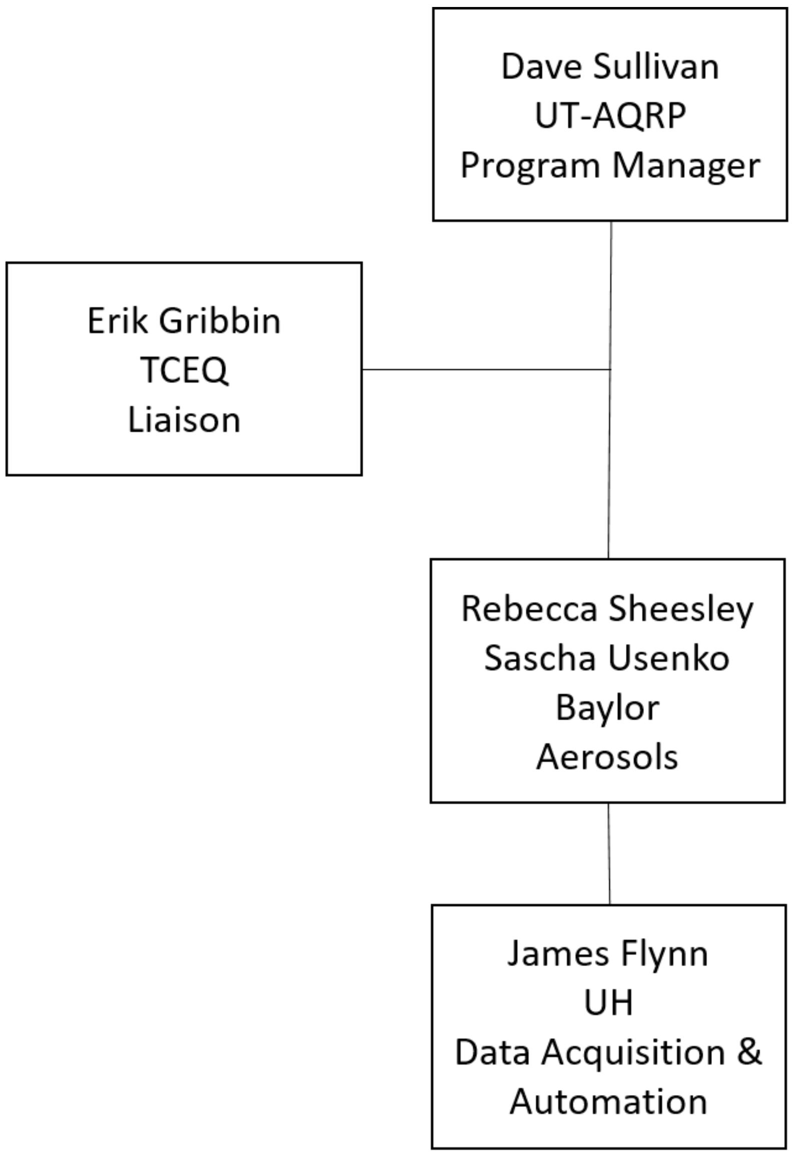
1.2 PROJECT SPECIFIC OBJECTIVES

This project will provide an in-depth evaluation of the Tricolor Absorption Photometer (TAP) and aethalometer and their abilities to continuously monitor and characterize BC and BrC from biomass burning. Field operations will be conducted by groups from Baylor University (BU) and the University of Houston (UH). We hypothesize that El Paso, TX will experience a range in Absorption Ångström Exponents (AAE) values which can be utilized to derive impact from biomass burning events. Changes in AAE can be driven by shifts in emission contribution between fossil fuel combustion and biomass burning. Thus, a field campaign, (BC)^2 El Paso, will be completed to identify and characterize biomass-burning events, utilizing AAE and co-located nephelometer and carbon monoxide (CO) instrumentations. In addition, the instrument evaluation of the TAP will help TCEQ determine the suitability of this instrument for future deployment in Texas for characterization of biomass burning impacts.

2. ORGANIZATION AND RESPONSIBILITIES

2.1 KEY PERSONNEL

The following flow chart identifies the key personnel at each organization that are responsible for the quality assurance (QA) and deliverables listed in this document.



2.2 PROJECT SCHEDULE

The schedule for this project and key milestones are listed in Table 1 below.

Deliverable	**Date**
Deliverable 1: AQRP approved Work Plan, Budget, Budget Justification, and Quality Assurance Project Plan	Submitted within 10 days of signing Master Subaward agreement
Deliverable 2: A Monthly Progress Report	The 8th of each month from the month after receiving Notice to Commence through August 2019
Deliverable : Monthly Financial Status Report	The 15th of each month from the month after receiving Notice to Commence through August 2019
Deliverable 3: Quarterly Report	Specific dates will be assigned after receiving Notice to Commence through August 2019 and will be blocked in three-month coverage periods
Deliverable 4.1: Draft Report **Deliverable 4.2:** Final Report	**4.1:** Thursday, August 1, 2019 **4.2:** Tuesday, September 3, 2019
Activities	
Purchase TAP and preparation of all instrumentation	Notice to Commence
Field deployment to El Paso area, (BC)^2 El Paso	8-10 weeks after Notice to Commence – June 30, 2019
Data reduction, QA/QC, and analysis	Field deployment – August 31, 2019

Table 1. Project Deliverables and Activities, with Due Dates

3. SCIENTIFIC APPROACH

3.1 SAMPLING DESIGN

We will conduct a multi-month field deployment of two tricolor absorption photometers (Bechtel, Inc. TAP), a seven-channel aethalometer (Magee Scientific AE42), and a three-wavelength nephelometer (TSI 3563) to characterize BC and BrC during $(BC)^2$ El Paso. We will use this BC and BrC optical properties as a proof-of-concept study to identify when biomass burning plays an important role in El Paso pollutant concentrations. The preferred sampling site will have additional aerosol measurements as well as CO and meteorological parameters either collocated or in close proximity.

3.2 GENERAL APPROACH AND MEASUREMENT PROCESSES

Biomass burning, which can include wildfires, agricultural burning and residential wood smoke, emits particulate matter (PM) and a wide range of gas phase pollutants. PM emissions from biomass burning are predominantly carbonaceous, with aerosol absorbance from both black carbon (BC, or elemental carbon) and brown carbon (BrC, or light absorbing organic carbon [1]. Biomass burning plumes can also impact ozone (O_3), particulate matter (PM) and secondary organic aerosol (SOA), through emission of NO_X (nitric oxide; NO and nitrogen dioxide; NO_2), sulfur dioxide, ammonia, and volatile organic compounds (VOCs). AQRP Project 16-008 (PI Wang) and AQRP Project 16-024 (PI Lonsdale) identify biomass burning plumes from out-of-state as a significant sources of regional background air pollution in Texas including O_3 and $PM_{2.5}$.

Meteorological conditions can drive regional biomass burning plumes into El Paso from across state and international boundaries [2]. The complexity of El Paso regional air pollution is heightened by its arid climate, topography, frequent temperature inversions and proximity to Juarez, Mexico; all of which have resulted in periodic increases in O_3, carbon monoxide (CO), and PM [3]. The Texas AQRP Priority Research Areas for 2018-2019 identified El Paso, Texas, as an area which needs additional O_3 and PM studies, including deployment of new monitoring technologies to identify episodes of biomass burning.

Biomass burning plumes can be identified utilizing absorption measurements of BC and BrC. Specifically, high AAE values (2-4.5) indicated the presence of BrC, which absorbs shorter ultraviolet wavelengths, while BC should exhibit AAE values closer to 1 (as it absorbs consistently across the visible spectrum). Biomass burning is a source of atmospheric BrC and BC, while motor vehicle exhaust will predominantly emit BC. AAE values are calculated for specific absorption coefficient pairs, i.e. a short and long wavelength pair. Most recently, Laing et al., outlines the use of TAP aerosol light absorption coefficient measurements (σ_{abs} at three wavelengths), nephelometer aerosol light scattering coefficient measurements (σ_{scat} at three wavelengths) and CO to identify both regional and long-range biomass burning events at MT Bachelor, Oregon [1]. Biomass burning events can also experience variability as the flaming condition (e.g. flaming, flames and smoldering, and smoldering) and long range transport of the fire emissions are capable of altering the relative contribution of BC and BrC to AAE.

4. SAMPLING PROCEDURES

4.1 SITE SPECIFIC FACTORS

While the sampling location is still to be determined, site infrastructure will primarily be supported under a separate award from the TCEQ. In general terms, Baylor University's atmospheric sampling trailer is planned for deployment to the El Paso area. This trailer has previously been used for both trace gas and aerosol sampling and has provisions for the installation of sampling equipment and inlets. Integration and trailer preparation will take place in Waco and/or Houston prior to deployment for (BC)^2 El Paso.

4.2 SAMPLING PROCEDURE

Because the particle instruments (TAPs, aethalometer and nephelometer) are semi-continuous (TAP) and continuous (nephelometer) techniques, special handling techniques/precautions for collected matrices are not necessary. A logbook will be kept for instrument operators to log information on the instruments on an as needed basis.

4.2.1 Tricolor Absorption Photometer

A 3λ tricolor absorption photometer (TAP; Model 2901, Brechtel Inc., Hayward, CA) measures aerosol light absorption at wavelengths 365 (UV), 528 (green), and 652 (red) nm. TAP uses 10 solenoid valves to cycle through 8 filter spots and 2 reference filter spots. The LED light source simultaneously shines through the sample and reference spots loaded with 47 mm glass-fiber filter (Brechtel TAP-FIL100). The reference spot allows a measurement by difference approach in the TAP so the increase in light attenuation due to deposited particles on the sample spot is directly compared to the light attenuation of a reference spot. This allows attenuation by collected aerosol to be distinguished from attenuation by the blank filter (see Appendix A: TAP Operations Reference Manual). The TAP is set to rotate to the next filter spot when a filter spot's transmission reaches user-set value and the reference channel gets altered whenever the sample spot is changed. Each of the 8 sample spots is separated from the other by O-rings that clamp the filter material to prevent any inter-spot leakage. The air flow passes through the filter and into a solenoid valve controlled by the TAP Reader software.

Filter changes are the primary TAP maintenance. These filter changes on the TAP require minimal tools and consumables and little time. Items required for a filter change include a torque driver, replacement filter, tweezers, and zip-lock plastic bag. The standard operating procedure for changing a TAP filter has been described (with photos) in the TAP Model 2901 UV system manual (Appendix A).

Filter area and wavelength corrections

Bond et al. presented correction for the Particle Soot Absorption Photometer (PSAP) to account the error in filter-based measurement of light absorbing aerosols [4]. As the TAP operates under the same principles, this correction will be applied to the TAP in the current project [5]. This correction uses a reference absorption determined as the difference between light extinction and light scattering by suspended particles. Bond et al. suggested that differences within instruments requires correction for true flow rates (Q_{true}) and filter spot area (A_{true}) and hence the adjusted absorption coefficient (σ_{adj}^*) for PSAP was derived as below:

$$\sigma_{adj}^* = (Q_{PSAP} / Q_{true}) (A_{true} / A_{ref}) \sigma_{PSAP} \quad (1)$$

where Q_{PSAP}, A_{true} and σ_{PSAP} are flow rate, filter spot area and reported absorption coefficient of PSAP.

Ogren (2010) further elaborated the correction and the alternative σ_{adj} was derived [6]. The filter spot area internally used by PSAP (A_{PSAP} = 17.83 mm^2) and the measured spot area of the manufacturer reference instrument (A_{ref} = 20.43 mm^2) was corrected as below:

$$\sigma_{adj} = (A_{PSAP} / A_{ref}) \sigma_{adj}^* = (17.83 / 20.43) \sigma_{adj}^* = 0.873 \sigma_{adj}^* \quad (2)$$

Equations (1) and (2) are based on equations (1 and 12) in Bond et al and equation (6) in Ogren (2010) which further yields the true aerosol absorption coefficient, calculated as:

$$\sigma_{ap} = 0.873 (Q_{PSAP} / Q_{true}) (A_{true} / A_{PSAP}) (\sigma_{PSAP} / K_2) – (K_1 / K_2) \sigma_{sp} \quad (3)$$

where σ_{ap} and σ_{sp} are aerosol absorption coefficient and aerosol scattering coefficients respectively and K_1 and K_2 are the calibration constants representing the response of the instrument to scattering and absorption respectively. Bond et al also reported the numerical values of K_1 and K_2 to be 0.02 ± 0.02 and 1.22 ± 0.20, respectively when the measurements were made at a wavelength of 550 nm [4].

Later Virkkula et al. (2005) reported that the correct wavelength of the instrument to be 574 nm instead of 550 nm used by Bond et al. [7]. After the wavelength adjustment Ogren reported the correction for measurements of scattering and absorption at wavelength λ becomes

$$\sigma_{ap} [\lambda] = 0.85 (Q_{PSAP} / Q_{meas}) (A_{meas} / A_{PSAP}) (\sigma_{PSAP} [\lambda] / K_2) – (K_1 /K_2) \sigma_{sp} [\lambda] \quad (4)$$

where Q_{meas} and A_{meas} are the measured flow rate and filter spot areas of the instrument. In TAP, $Q_{meas} = Q_{PSAP}$ and $A_{meas} = A_{PSAP}$, so equation (4) simplifies to

$$\sigma_{ap}[\lambda] = 0.85 (\sigma_{PSAP}[\lambda] / K_2) – (K_1 / K_2) \sigma_{sp}[\lambda] \quad (5)$$

Acquiring of real-time σ_{sp} data requires instrument like nephelometer run parallel to TAP. As notified in the TAP user manual (Photometer, n.d.), depending on the version of software, we have an option to define σ_{sp}. If we don’t have this option, then the program calculates

$$\sigma_{ap}[\lambda] = 0.85 (\sigma_{PSAP}[\lambda] / K_2) \quad (6)$$

Absorption Ångström Exponents Calculations

The Absorption Ångström Exponent (AAE) can be derived from the σ_{ap} (equation 6) for each wavelength pair (365, 528, 652 nm). Equation (7), serves as an example of this a calculation.

$$AAE = -\log(\sigma_{ap}[365]/ \sigma_{ap}[652])/\log(365/652) \quad (7)$$

Wavelength dependence of optical parameters

TAP and nephelometer do not have directly coinciding wavelengths for comparisons. TAP measures absorption coefficients at 467, 528, 652 nm (365 nm UV option) whereas TSI integrating nephelometer measures scattering coefficients at 450, 550 and 700 nm. Thus, the comparison parameters have to be extrapolated or interpolated to the same wavelengths.

Bond et al. reported absorption coefficient wavelength dependence exponent $\lambda^{-0.5}$ (ranging up to 1) and converted PSAP measurement from 550 to 574 nm using the equation as below [4]:

$$\sigma_{PSAP}[574] / \sigma_{PSAP}[550] = (574 / 550)^{-0.5} \quad (8)$$

However, applying equation (7) depends upon the particle size distribution. Cesnulyte et al. used a similar equation to extrapolate another aerosol optical property, aerosol optical depth (AOD) from 500 to 550 nm, where the exponent used is an Angstrom exponent calculated from the AOD data for the wavelength range 440-870 nm [8].

The linear and quadratic interpolation techniques have been used by Tripathi et al. to derive an AOD value at 550 from the available wavelength [9]. The R^2 values are then compared to choose between first and second-degree interpolation. This method will be assessed for use in the current project.

RH dependence of optical parameters

The scattering by fine mode aerosol fraction contributes largely to the total aerosol extinction (~88%) and the extinction coefficient ($\sigma_{ext}= \sigma_{sp} + \sigma_{ap}$) is enhanced at high ambient RH [10]. The effect of RH on the growth of the particles and subsequently on σ_{ext} was corrected by Dey and Tripathi [10] using the equation below:

For fine mode;

$$\sigma_{ext;RH} = \sigma_{ext;dry} (1 + a (RH/100)^{b}) \quad (9)$$

For coarse mode;

$$\sigma_{ext;RH} = \sigma_{ext;dry} (1 - (RH/100)^{-h}) \quad (10)$$

where,

$\sigma_{ext;RH} = \sigma_{ext}$ due to enhanced scattering by hygroscopic particles at higher RH as compared with dry-state extinction coefficient

‘‘a,’’ ‘‘b’’ and ‘‘h’’ are empirical fitting parameters and their values at each wavelength are include in Dey and Tripathi [11]. These corrections will be assessed for use in the current project with data collected during (BC)^2 El Paso.

4.2.2 Aethalometer

AE42 aethalometer (Magee Scientific, Berkeley, CA) measures light attenuation at seven different wavelengths (370, 470, 520, 590, 660, 880 and 950 nm). The aerosol stream is drawn through a spot on a filter at user-set flow rate. The detector measures the intensities of light transmitted through the sample spot versus the unexposed portion of the tape (reference spot) after being transmitted through aerosols which were continuously deposited on a quartz fiber filter. As the absorbing aerosols accumulate on the sample spot, the intensity of light transmission through the sample spot decreases. This decrease in light intensity is interpreted as an increase in the amount of collected aerosols which is divided by known air-flow volume to calculate the concentration. The aethalometer manufacturer (Magee Scientific) calibrated the instrument based on the assumption that the change in aerosol light attenuation coefficient (m^{-1}) is proportional to BC concentration ($g\ m^{-3}$) through a constant called specific absorption cross section ($m^2\ g^{-1}$). The aethalometer can also be operated to report aerosol absorption, similar to the TAP and has a similar set of reported corrections which will be assessed for application to the (BC)^2 El Paso campaign [12, 13].

Absorption Ångström Exponents Calculations

Similar to the AAE calculation for the TAP, AAE will be calculated using data from the aethalometer (see example equation 11).

$$AAE = -\log(\sigma_{ap}[370] / \sigma_{ap}[880])/\log(370/880) \quad (11)$$

4.2.3 Nephelometer

Light scattering (b_{sp}) will be measured using a TSI Model 3563 nephelometer (Appendix B: Nephelometer Operations Reference Manual). In most integrating nephelometers, a white light source is used to illuminate the air sample, and light scattered by particles (and gases) at a particular wavelength is measured using a photomultiplier tube. In this project, a three-wavelength instrument is used (450, 550, and 750 nm; blue, green, and red, respectively). Filters in front of the PMT’s (Photomultiplier tubes) are used for wavelength selection. In addition, the TSI instrument provides a separate measurement of particle back-scatter (b_{scat}). The instrument automatically calculates Rayleigh scattering from internally measured temperature and pressure and corrects the reported signal for those factors. Averaging time will be determined based on the performance of the aethalometer and TAP instruments.

5. MEASUREMENT PROCEDURE

Measurement and analytical methods are described in Section 4 SAMPLING PROCEDURES. Instrumental calibrations and blanks/zeros are described in Section 6 QUALITY METRICS.

6. QUALITY METRICS

6.1 QUALITY CONTROL CHECKS

6.1.1 GENERAL INFORMATION

Comparability is achieved when the results are reported in standard units to facilitate comparisons between the data from this project and other similar programs. In order to accomplish this objective, the reporting units for the ambient monitoring performed here will adhere to standard units for aerosols including µg m^{-3} and AAE.

The student or technician assigned to a specific monitoring instrument is responsible for operating samplers and providing minor corrective actions on equipment when required. Equipment problems are generally detected through a failed sample run or through performing routine quality control (QC) checks on a routine basis. The QC checks that are performed on the sampling equipment vary by instrument and are described in the citations referenced previously and the Appendices (A and B). When a major equipment problem is involved, the manufacturer is to be contacted, and their responsibility is to follow up on restoring the equipment to its proper operating status. This may be accomplished through telephone consultation with the student or technician, which may result in the removal of the equipment from the site for repair. Any equipment problems that can result in the loss of data are addressed with a high priority. All situations requiring corrective action will be documented in activity logs. Some specific QC protocols will be discussed following definitions for quality metrics that will be used. An attempt is made to provide adequate information from which to estimate and control the uncertainty and potential limitations of measurements generated by the monitoring. QC activities are generally applied to portions of a measurement process that are both critical to measurement quality and practically subject to evaluation and control. The portions of any given measurement process that are both critical and subject to evaluation and control vary with the measurement being made and the method used. The QC protocol used for any given measurement process may include some or all of the following:

a.) Sampling system contribution to the measurements;

b.) Measurement system contribution to the measurements;

c.) Qualitative performance of the method;

d.) Quantitative performance of the method;

e.) Precision of the measurements; and

f.) Accuracy (bias) of the measurements.

Prior to deployment, the equipment will be powered up, operating parameters will be checked, and the instruments will be tested. The purpose is to run operational checks to catch problems prior to field deployment, repair all malfunctioning equipment, and familiarize the staff with the equipment. Routine preventive maintenance procedures also are performed continuously during deployment. Routine preventive maintenance procedures and schedules for aerosol measurements are described in individual instrument service manuals or accepted operations reference manuals. Generally, students or technicians are responsible for all maintenance of monitoring systems. A backup student or technician may be called if the primary student or technician is not available. If problems are observed with particular instruments after being deployed, the manufacturer is to be contacted, and tests are performed to solve the problem. Corrective maintenance procedures also follow the manufacturer's recommendations in the instrument service manuals. To facilitate such procedures, some spare parts are maintained on hand to facilitate rapid repair of common maintenance needs, while others are acquired on an “as needed” basis. Spare parts are receipted, installed according to the manufacturer’s instructions, and tested to ensure correct instrument operation.

It should be stressed that data that do not meet acceptance criteria (for any of the instruments used) will have an associated flag attached in electronic files containing the data. In addition, laboratory notebooks will be used by personnel and will be used to specify data flags manually. In the interest of space, this is not included as a ‘corrective action’ in tables and discussions that follow.

6.1.2 DETECTION LIMIT

Detection limits will be expressed in units of concentration and reflect the smallest concentration of a compound that can be measured with a defined degree of certainty. The analytical instrument detection limit (IDL) for other parameters will be established with the application of available standards according to 40 *CFR* Part 136, Part B, where applicable.

6.1.3 BLANKS/ZEROS

The system contribution to the measurement results is determined by analysis of a blank or "zero air" (filtered air) level as part of each calibration and span check. The reference spot in the TAP and aethalometer serve as this blank or zero; since this is a continual comparison, the rest of this discussion pertains to the nephelometer. As part of the calibration, this zero level is used along with the upscale concentrations to establish the calibration curve. As part of the span check in the nephelometer, this level is used as a quality control check for monitor zero drift. If a method is found to have a system contribution for a target parameter at a concentration greater than three times the detection limit or greater than 10 percent of the median measured value for the parameter (whichever is larger), efforts must be taken to remove the contribution. Any system contribution for a target parameter (or for another constituent that interferes with analysis for a target parameter) that is above the detection limit must be thoroughly characterized such that the extent of influence on the target parameter measurement certainty is well understood. This may require an elevated frequency of blank analyses for an adequate period to characterize the contribution. A data flag will be used when values in the blank sample measurements indicate a contribution to the sample measurement result that is determined to be significant relative to the quality objectives specified for the measurement.

6.2 QUALITY ASSURANCE OBJECTIVES

The following sections describe the quality assurance objectives for this project. The findings of these activities will be included in the final reports.

6.2.1 PRECISION

Precision is a measure of the repeatability of the results. Estimates of precision are assessed in different ways for different measurement technologies.

- Precision for measurements from continuous monitors will be estimated by analysis of a test atmosphere containing the target compounds being monitored. Precision for trace gases is estimated from precision checks that are done as part of routine span checks of the monitors. This precision check consists of introducing a known concentration of the pollutant into the monitor in the concentration range required by 40 *CFR* Part 58. The resulting measured concentration is then compared to the known concentration.

- Analytical measurement precision for other species will be estimated by the comparison of replicate analyses of the test atmosphere containing the target compound or comparison to other data products, as appropriate. Precision can also be tested by direct comparison of the two TAP instruments operated simultaneously [5].

6.2.2 ACCURACY

Accuracy is the closeness of a measurement to a reference value and reflects elements of both bias and precision. Accuracy will be determined by evaluating measurement system responses for replicate analysis of samples containing the compounds of interest at concentrations representative of the ambient atmospheres typically being monitored during the study as outlined in 40 *CFR* 58. Note that technical system audits are not required for a Category III QAPP.

6.2.3 COMPLETENESS

Data completeness is calculated on the basis of the number of valid samples collected out of the total possible number of measurements. Data completeness is calculated as follows:

% Completeness = (Number of valid measurements x 100)/Total possible number of measurements

6.3 DATA AUDITING

Technical Systems Audits are not required for this project. Audits of data quality (minimum 10%) will be performed by visual inspection of the data, comparison of the data to the QA/QC criteria described in this document, and comparison with other measurements, as applicable. Data that passes these examinations will be deemed acceptable. Should data not pass examination on one or more of the checks, the data will be further examined by the researchers and as appropriate may be flagged as invalid, valid, or valid but having failed a check.

6.4 INSTRUMENT SPECIFICS

6.4.1 TAP (calibration QA/QC description)

During the (BC)^2 El Paso sampling campaign, factory calibrated brand-new TAPs will be used. The flow sensors, inlet flow temperature and case temperature of TAPs will be calibrated at the beginning of the sampling campaign. It requires no calibration other than periodic checks of the air flow meter response. The collocated TAP measurements will be performed for intra-instrument checks. Data corrections will be completed as described previously.

6.4.2 Aethalometer (calibration QA/QC description)

The Aethalometer is a self-contained, automatic instrument. A new filter tape will be installed at the start of the (BC)^2 El Paso campaign. It requires no gas cylinders, and little operator attention if operating well. It requires no calibration other than periodic checks of the air flow meter response. At the beginning of the sampling and during each filter spot advancement, AE-42 goes through all the regular checks for flow, leakages and lamp intensities. The aethalometer AE-42 data requires several corrections such as multiple light scattering effects within the filter, the “shadowing” effect due to filter loading and higher aerosol attenuation coefficient reported by AE-42 than actual air-borne aerosol absorption coefficients will be adjected as suggested by the previous studies [12, 14, 15].

6.4.3 Nephelometer

Calibration of the integrating nephelometer will be performed at least twice during the project using the detailed procedures in the Model 3563 Integration Nephelometer Operation Service Manual. A calibration will be performed at the beginning of the project and at the end of the project. Additional calibrations will be performed only when a span gas check has shifted. Span checks will be performed biweekly with filtered air as the low span level and carbon dioxide (CO_2) as the high span level. The zero-background will be checked every hour for 5 minutes. These performance checks are based on the recommendation of the TSI service manual and the TSI Model 3563 Integrating Nephelometer Reference Manual (1 July 2014) written by Patrick J. Sheridan and John A. Ogren for use by the World Meteorological Organization (WMP) and Global Atmosphere Watch (GAW) program.

7. DATA ANALYSIS, INTERPRETATION, AND MANAGEMENT

The data will be provided in time-stamped delimited text format, likely in 5- or 10-minute averages, suitable for use in a database to the TCEQ. Data will include the time series of all parameters discussed above.

The general statistics to be used are considered standard so little detail is provided here. Metrics to be used include averages, medians, standard deviations, diurnal profiles, and similar values. Time series will be inspected to identify commonalities, and regression analysis will be used to determine relationships between specific variables. These will be applied to both the output data generated from the measurements as well as to parameters derived from these measurements.

8. REPORTING

8.1 DELIVERABLES

Deliverables for this project will include:

- Monthly reports including accomplishments, problems encountered and corrective actions, goals for the next reporting period, and a description of the project's progress as described above.

- Quarterly reports written to be understandable by a reasonably well informed lay person and without excessive technical language. These reports will discuss general activities, preliminary findings (if any), and progress towards project goals.

- Draft final and final reports describing all activities and summarizing all findings, including the 10% Audits of Data Quality required by this category level of QAPP.

8.2 FINAL PRODUCT

The final report will include descriptions of the (BC)^2 El Paso field campaign including site and instrumental information, time series of all collected data, and preliminary statistical analysis of the data, and an evaluation of the technical feasibility of one or more of these instruments to be utilized in a monitoring network in El Paso as well as other regions for the quantification of the relative contribution of biomass burning to the overall aerosol loading. The final report may also include recommendations for future work (depending on the outcome of this project).

Drafts of journal manuscripts based on the work performed as part of this project will be presented to the TCEQ upon submission to the journal. Manuscripts are likely to include attempts to analyze these data in manners that will elucidate the relative contribution of biomass burning as well as the suitability one or more of these instruments to be utilized in a monitoring network to identify relative contributions of biomass burning.

9. REFERENCES

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APPENDIX A: TAP OPERATIONS REFERENCE MANUAL

BRECHTEL

TAP

TRICOLOR ABSORPTION PHOTOMETER

MODEL 2901 SYSTEM MANUAL

BMI PN 003100024 Rev 10

Contents

List of Figures

1 Unpacking

Each TAP receives thorough testing and inspection at the factory to ensure your instrument is ready for operation when you receive it. Inspect the packaging before opening. If the packaging is damaged and/or the shock watch has been tripped, contact and notify the shipping company immediately.

If the packaging does not show signs of damage, after carefully opening, inspect the instrument for broken parts, scratches, dents or other signs of damage incurred during shipping. **Notify BMI within 2 days of receiving package if ShockWatch has been tripped.**

Verify the contents of the shipment with the unpacking instructions, which are included both with the instrument and as a separate .pdf. **Retain all shipping packaging, foam inserts and cushions to ensure a safe delivery should the instrument need to be returned.**

Figure 1: Shock Watch

2 TAP Overview

The TAP has been designed in a small and light form factor with an easy to change filter. The flow rate is displayed via the front mounted display and can be adjusted with the flow needle valve as required. The TAP differs from the single spot absorption photometers in that it utilizes 10 solenoid valves to cycle through 8 sample filter spots and 2 reference filter spots. As shown in the flow schematic, the sample enters the barbed fitting in the rear of the unit and passes first through the sample spot of the 47 mm filter. The same LED light source simultaneously shines light through the current sample and reference spots. Each of the 8 sample spots is separated from the other by O-rings that clamp the filter material to prevent any inter-spot leakage. The air flow passes through the filter and into a solenoid valve controlled by the TAP Reader software. The flow exits the sample solenoid valve and is routed to one of two reference spots in the same 47 mm filter used for the sample spots. Since no particles remain in the flow at this point, the reference spots allow changes in light transmission due to filter, flow or other changes to be monitored in real time. More importantly, the reference spot allows a differential measurement approach in the TAP so the increase in light attenuation due to deposited particles on the sample spot can be largely separated from filter effects. Each time the sample spot is changed the reference channel is also changed. The flow passes through the reference spot and into another solenoid valve, exiting the valve the flow enters the internal flow meter. The needle valve is located downstream of the flow meter, with the vacuum connection on the rear panel directly connected internally to the outlet of the needle valve.

The TAP uses 47-mm diameter, glass-fiber filters (Brechtel TAP-FIL100). These filters are made of two fibrous layers, borosilicate glass fibers overlaying a cellulose fiber backing material (for strength and stability). The cellulose fiber layer is thought to take up water under conditions of high humidity, which is one reason the TAP has an internal heater to decrease the risk of condensation within the instrument.

The red indicator lamp on the front of the TAP is off during normal sampling and on during a filter change. A blinking lamp indicates an error condition that must be corrected before continuing.

The TAP requires an external computer for data logging and instrument control. The internal software in the TAP provides the minimum functionality for measuring signals (light intensity reaching the ten detectors, flow rate, case temperature, and sample temperature) and controlling the hardware (light source, case heater, and solenoid valves). The internal software detects when the pushbutton on the front panel is depressed and controls whether the red indicator lamp is lit or not.

IMPORTANT NOTE*:* Beginning in March 2016, Pall Corporation discontinued production of the glass fiber filters used in the TAP. After this date the only valid filter material selection in the TAP Reader software is 'Azumi M371'. A preliminary filter loading correction is implemented in the TAP Reader software (version 2.6 and higher). A final version of the correction will be implemented as soon as possible.

When combined with the TAP Graphical User Interface Software, the TAP reports the change in light transmission through the filter. The TAP provides 8 automatically changing filter sample spots to provide the user with increased sample time between filter changes. All data collected is saved and displayed in real time for analysis. Software communication

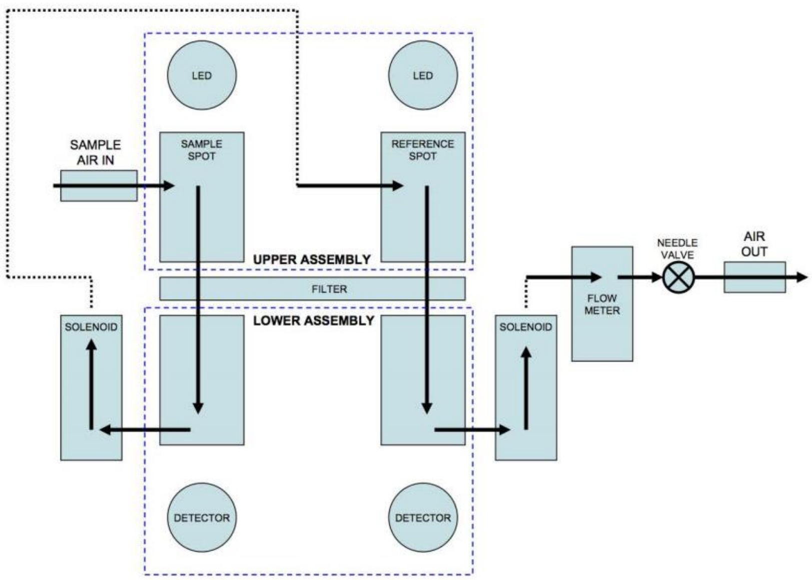

Figure 2: Schematic of the sample air flow within the TAP.

to the TAP is established through the COMM Out port on the back of the instrument using the RS-232 protocol.

3 Theory of Operation

3.1 Introduction

Light absorption in a medium can be quantitatively described using the Beer-Lambert Law

$$I = I_0 e^{-\sigma[\lambda]l}, \tag{1}$$

where I and I_0 are the output and input intensity of light in Watts per square meter passing through an absorbing medium, σ is the medium's attenuation coefficient in inverse meters at wavelength λ in meters, and l is the path length in meters through the medium. This is demonstrated qualitatively in figure 3[1] by the attenuation of a green laser through a solution of Rhodamine 6B.

Figure 3: Beer–Lambert law in solution

In order to apply this to a light absorption photometer the critical assumption is made that absorption through a length of air at a given time is equivalent to filtering out the absorbing species from the air on a filter and passing the light through this instead. If this is true, then in a given time period Δt this can be expressed as

$$I(t) = I(t-\Delta t)e^{-\sigma_{PSAP}[\lambda]\frac{Q_{PSAP}\Delta t}{A_{PSAP}}}, \tag{2}$$

where $I(t)$ is the intensity of the light reaching the detector at any given time, $\sigma_{PSAP}[\lambda]$ is the average, wavelength-dependent absorption coefficient of the air parcel that passed through the filter in Δt, A_{PSAP} is the filter area, and Q_{PSAP} is the flow through the filter area. A_{PSAP}, Q_{PSAP}, and Δt define the length of the air parcel passing through the filter

[1]by Amirber - Own work. Licensed under CC BY-SA 3.0 via Commons

area.[2] Unfortunately, this assumption does not take into account the filter material or the properties of the bulk developed in depositing the particles both on and in the filter, but we can define a filter-loading correction factor, $f(\tau)$, determined empirically, to correct for this, resulting in

$$I(t) = I(t-\Delta t)e^{-\sigma_{PSAP}[\lambda]\frac{Q_{PSAP}\Delta t}{A_{PSAP}}\frac{1}{f(\tau)}}. \quad (3)$$

With some minor rearrangement this becomes

$$\sigma_{PSAP}[\lambda] = f(\tau)\frac{A_{PSAP}}{Q_{PSAP}\Delta t}\ln\left(\frac{I(t-\Delta t)}{I(t)}\right), \quad (4)$$

the most basic description of an absorption photometer's operation.

3.2 Absorption Coefficient Correction

The analysis below follows "Comment on 'Calibration and Intercomparison of Filter-Based Measurements of Visible Light Absorption by Aerosols'" by John A. Ogren 2010.

Eqn. 12 in the above work is

$$\sigma_{ap}[\lambda] = 0.85\left(\frac{Q_{PSAP}}{Q_{meas}}\right)\left(\frac{A_{meas}}{A_{PSAP}}\right)\frac{\sigma_{PSAP}[\lambda]}{K_2} - \frac{K_1}{K_2}\sigma_{sp}[\lambda]. \quad (5)$$

Here σ_{ap} is the aerosol absorption coefficient, σ_{sp} is the aerosol scattering coefficient, $K_1 = 0.02 \pm 0.02$ and $K_2 = 1.22 \pm 0.20$ are empirical coefficients defined by the equation

$$0.85\sigma_{PSAP} = K_1\sigma_{sp} + K_2\sigma_{ap}, \quad (6)$$

and Q is the flow[3] through both the experimental and reference channel, and A is the area of each sensor spot. Here $f(\tau) = (1.0796\tau + 0.71)^{-1}$ is the experimentally determined correction function for filter loading, $I(t) = \frac{\langle color-dark\rangle_t}{\langle colorref-darkref\rangle_t}$ is the ratio of the average intensity of one color at the experimental spot to the reference spot over time period Δt, and $\tau = \frac{I(t)}{I_{wf}}$ is the filter transmission[4], and I_{wf} is the intensity ratio measured while doing the white filter check. In our instrument $Q_{PSAP} = Q_{meas}$ and $A_{PSAP} = A_{meas}$, so Eqn. 12 simplifies to

$$\sigma_{ap}[\lambda] = 0.85\frac{\sigma_{PSAP}[\lambda]}{K_2} - \frac{K_1}{K_2}\sigma_{sp}[\lambda]. \quad (7)$$

Depending on the version of software you have, you may have an option to define σ_{sp}. If you don't have this option, then the program actually calculates

$$\sigma_{ap}[\lambda] = 0.85\frac{\sigma_{PSAP}[\lambda]}{K_2} \quad (8)$$

instead.

[2]The PSAP label is used here to match the equations described below for further corrections of the absorption coefficient. This analysis is not unique to the PSAP.

[3]The flow data is corrected for temperature and pressure before being used in the calculation.

[4]To calculate the transmission we use the color ratio from the most recent $\triangle t$, e.g. if you're doing 5 sec averaging make sure to use the color ratio from the current 5 second interval, not the previous 5 second interval, or the full 10 seconds used for each measurement.

3.3 Data Filter

The TAP software allows the user to implement a four stage, single-pole, low pass filter in its Advanced options tab. The filter's arguments are 2.17872e-1, 1.26719, -6.02159e-1, 1.27174e-1, -1.00721e-2, and it has an effective first-order time constant of 2.6 seconds. All raw data recorded by the TAP software does NOT have the filter applied.[5]

3.4 Data Averaging

The TAP software allows the user to set a running, boxcar average. The running average will be composed from the data currently available, until the data series reaches the desired length. For example, if the average is set to 60 seconds, and there are currently 3 seconds of data, the displayed value will be a 3 second average.

[5]The TAPs have a legacy option in their firmware to implement an adjustable low pass filter. This firmware filter was applied to the "raw" data and is disabled in the current software.

4 Installation

4.1 Mounting

The TAP is shipped with 4 rubber feet so that it can be installed on a table top. The feet can also be removed and the TAP can be bolted down with 6-32 screws for non-movable installation (figure 4). Bolts should not extend further than a quarter inch into the cover.

Figure 4: Removable feet

4.2 Connecting plumbing

The 1/8 inch barb fitting on the back of the TAP (figure 5), labeled VAC IN, needs to be connected to a vacuum pump capable of pulling 2 LPM at 9"Hg. **Oscillations and disruptions in the vacuum source may cause the filter to oscillate and affect the measurements.** A suitable pump may have been optionally purchased with the instrument. The sample line should be connected to the SAMPLE IN port. A $\frac{1}{4}$-inch barb is included pre-installed on the instrument, or the underlying 10-32 threads may be used to adapt to other fittings.

4.3 Connecting the power

The included AC adapter has an input voltage of 100-240 Volts ~1 AMP, 50-60 Hertz and an output of 24 Volts at 3 AMP. Replacement AC power cords are available for various wall plug styles. Insert the connector from the AC adapter into the TAP (figure 5) and connect to power source. **Ensure the barrel plug is fully seated in the connector before connecting the instrument to a computer.**

4.4 Connecting to a computer

The TAP may be furnished with an optional tablet, or you may use your own Windows computer to connect to the TAP. The Brechtel control software records, saves, and analyzes data from the instrument. Raw serial communication is also supported. An RS-232 to USB adapter cable is included with the instrument.

1. Plug the serial-to-USB connector into the instrument and the computer (figure 5). **Failure to tighten the thumb screws on the COM cable may result in loss of communication with PC.**
2. Start the TAP control software (see instructions below).

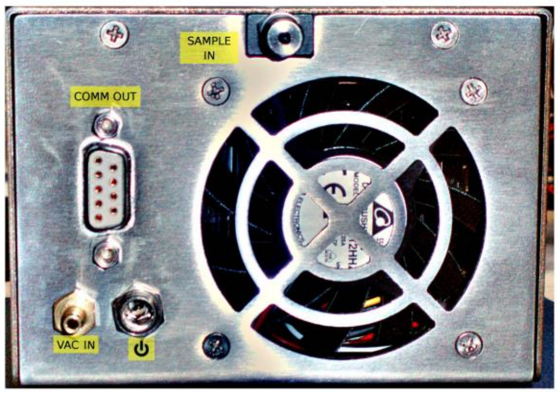

Figure 5: Back of TAP

4.5 Filter Material and Spot Area

As of this writing, only Azumi M371 and Pall E70 and Emfab filters have been characterized to work with the TAP. These options are available in the provided TAP software, which will perform all necessary corrections based on the selected option.

The TAP filter spot area is a function of the filter material in use. It is 2.5281E-5 sq. m for the Azumi filter and 3.0721E-5 sq. m for the available Pall filters.

4.6 Installing a filter

1. Press the red filter change button (figure 6).

Figure 6: Red filter change button

2. Remove the 4 thumb screws from the top of the instrument (figure 7).

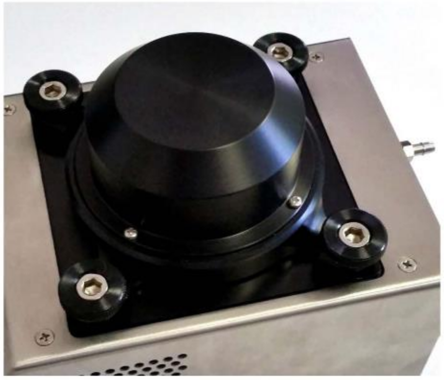

Figure 7: TAP thumb screws

3. Gently remove the upper "top hat" from the instrument body by pulling upwards (figure 8).

Figure 8: TAP top hat removal

10

4. Remove the old filter. It may be discarded if desired.

5. Clean any filter residue or debris from mating surfaces using a clean ethanol-soaked wipe (figure 9), taking care to prevent debris from falling into the instrument flow path. This is most easily accomplished by holding the unit or top hat such that any debris that falls, falls away from the optical path. If any debris gets into the instrument, gently blow it out with dry filtered air.

Figure 9: Filter debris

6. Verify that all 11 O-rings on the instrument body (figure 10) and all 12 o-rings on the top hat assembly are present (figure 11). Your o-ring color may vary. The numeration on figure 10 and figure 11 refer to the o-rings. They are in no way connected to the experimental or reference spot number as displayed in the GUI or recorded in the data file.

Figure 10: Body o-rings

7. Every 20 filter changes, lightly lubricate the side o-rings, 11 and 12, on the top hat assembly (figure 11).

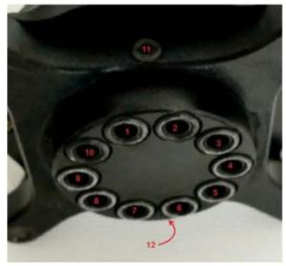

Figure 11: Top hat o-rings

8. Using a set of tweezers, place a new filter into the TAP cavity (figure 13) with the rough white perforated side facing up (figure 12). Make sure only one filter is installed; sometimes two filters stick together.

(a) Face down filter (b) Face up filter

Figure 12: TAP filter orientation

Figure 13: New filter installed

9. Below, figure 14 shows the experimental and reference channels for the TAP instrument, as well as the direction of channel progression. Channel 9 is the reference for all odd spots, and channel 10 is the reference for all even spots.

10. Verify the correct orientation of the top hat before placing it onto the instrument body (figure 15). The two side connectors should line up.

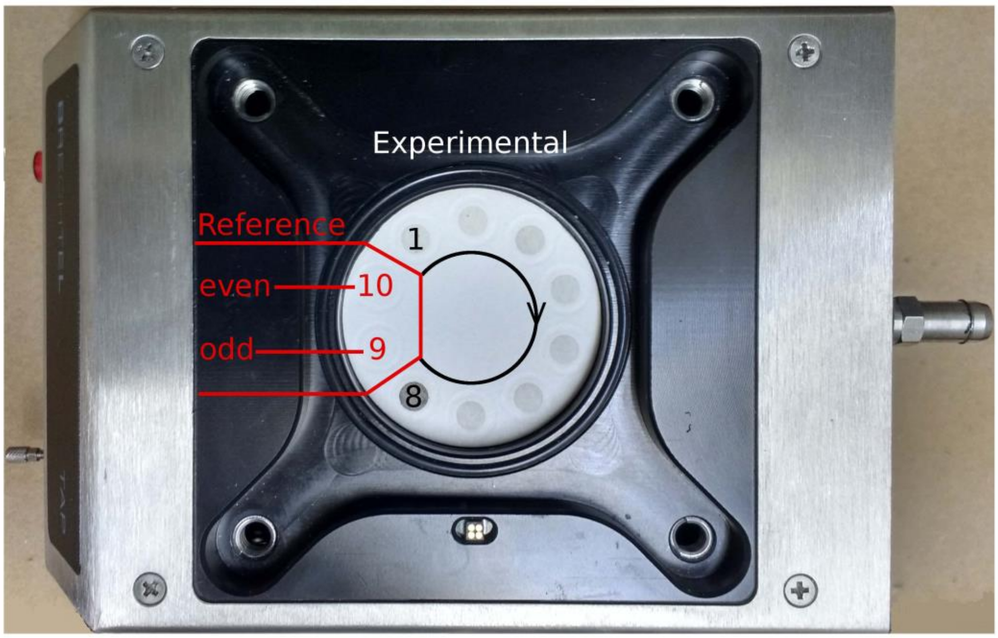

Figure 14: Experimental and reference channels

Figure 15: Top hat orientation

11. Gently seat the top hat in the cavity. Do not force it in. **It is impossible to fully seat the top hat in the cavity if it is in the wrong orientation, and attempting to do so may damage the instrument.** If you encounter difficulty, check the orientation and try again.
12. Once seated, secure the top hat with the 4 thumb screws from figure 7. Tighten them in a star pattern. You should be able to fully engage the threads without tools, but if necessary the thumb screws have sockets for hex keys.
13. Press the red button to signal that the filter change is complete. The red lamp should turn off. **The TAP will not begin sampling automatically after a filter change. The TAP Graphical User Interface Software must issue commands to the TAP to begin sampling.**
14. Once the TAP begins sampling after the filter change, compare the flow rate with the value before the filter change. If the flow rate is significantly different, the top hat may not be fully seated, or you may have accidentally inserted multiple filters.

4.7 White filter check

The white filter check is a baseline measurement of the intensity measured on all ten detectors with a new filter using particle-free air. It is important to establish a baseline range for the instrument.

The TAP must be warmed up for at least 10 minutes before performing a white filter test and before acquiring data. First, ensure that a filter is installed on the input flow. Brechtel has supplied a canister filter for this purpose. Put a new filter in the TAP (see Installing a Filter), start the Brechtel TAP control software, and select START. The TAP GUI will ask if you have a new or old filter. Select "Yes" to automatically begin a white filter check.

The instrument will notify the user when the white filter check is complete, so that the user can remove the filter from the inlet and begin normal sampling. The check normally requires 30-40 minutes.

5 Operation with TAP Graphical User Interface Software

Warning: The TAP GUI turns off the firmware low pass filter and automatically sets the LED power.

1. Launch the BMI TAP Reader software.
2. Correctly set the COM Port on the Main tab.
3. (Optional) Select the Advanced tab and change the configuration as necessary.
4. (Optional) Press "Save current settings" to save the current setting on all tabs as startup settings.
5. Press "START" on the Main tab to run.

5.1 Advanced Tab

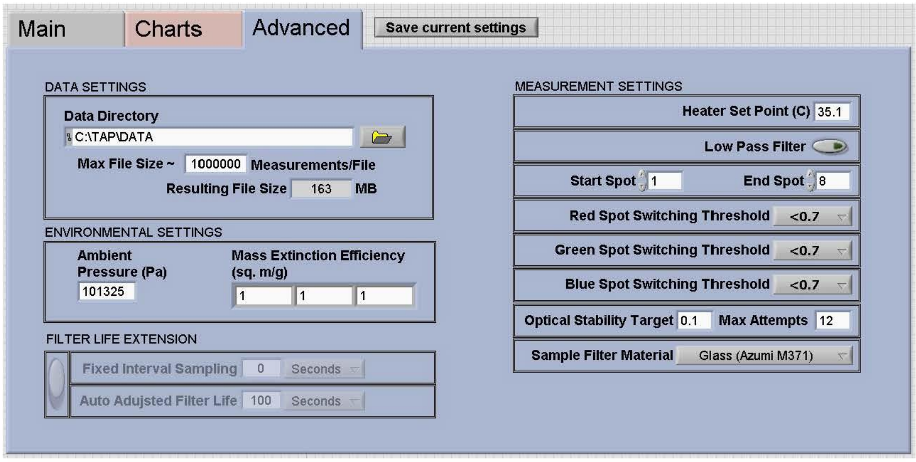

Figure 16: TAP GUI Advanced Configuration Tab

5.1.1 Data Settings

Data Directory	This is the directory where the TAP data will be saved as a .dat file
File Size	The size of the .dat file can be set to an approximate number of measurements with an associated file size. Once the size has been met a new file will be created and saved in the same directory.

5.1.2 Environmental Settings

Mass Extinction Efficiency	Please enter the conversion factor between absorption and extinction efficiency for your soot.
Pressure (Pa)	Set this value according to the atmospheric pressure for which the TAP is installed. This must be manually measured.

5.1.3 Filter Life Extension

Fixed Interval Sampling (disabled)	Set the amount of time that the user wishes to have the unit sit idle between measurements to extend filter life.
Auto Adjusted Filter Life (disabled)	Set the amount of time that the user wishes the filter to last. When this feature is used, the wait between averages will auto adjust to preserve the filter life accordingly.

5.1.4 Measurement Settings

Heater Set Point (C)	Changes the heater set point in the firmware. Changing this setting WILL interrupt data taking.
Low Pass Fillter	This low pass filter is a software-based, 4 stage, single pole filter with effective first-order time constant of 2.6 seconds. Arguments are 2.17872e-1, 1.26719, -6.02159e-1, 1.27174e-1, -1.00721e-2. The firmware low pass filter is turned off.
Start Spot	The first filter spot used by the unit to take measurements.
End Spot	The last filter spot used by the unit to take measurements.
Red/Green/Blue Spot Switching Threshold	The transmission threshold to initiate a channel switch command. The sample channel will be changed as soon as any threshold is crossed.
Optical Stability Target	The maximum relative standard deviation in the reference intensity acceptable for taking data.
Max Counter	The number of tries (of 45 seconds each) that the unit will give the reference channel to see if it stabilizes below the maximum relative standard deviation described above.
Filter Material	Which filter material are you sampling with?

5.2 Charts Tab

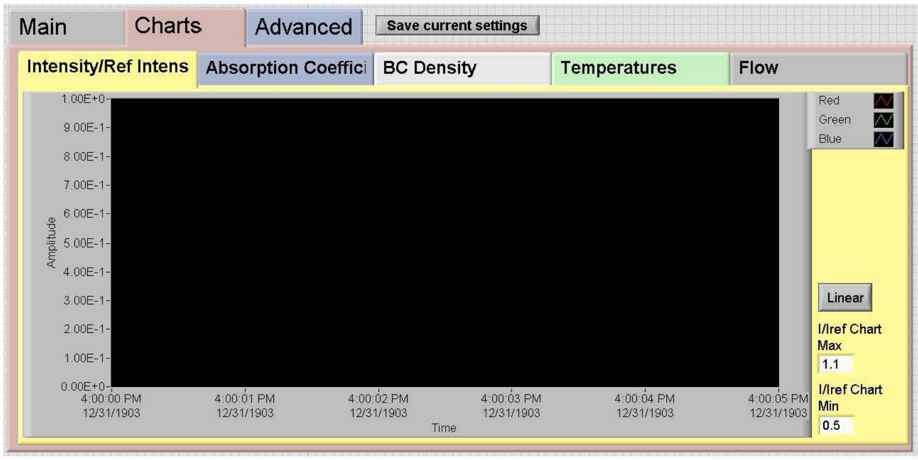

Figure 17: TAP GUI Charts Tab: Intensity/RefIntensity

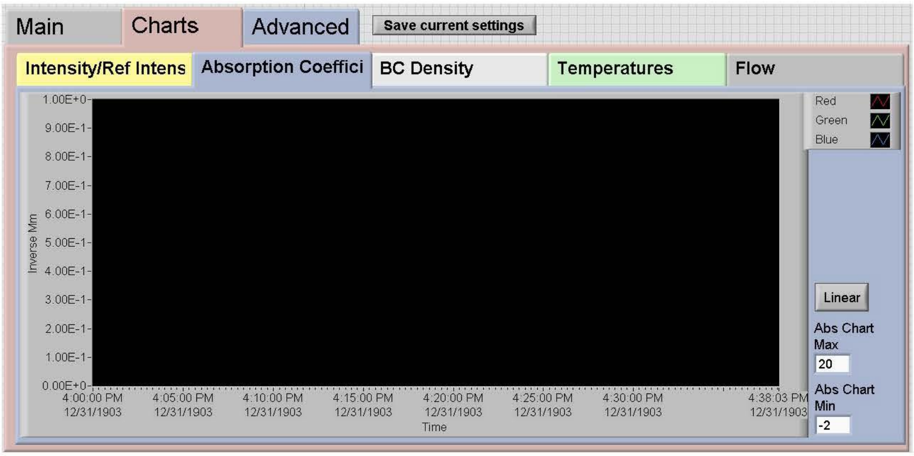

Figure 18: TAP GUI Charts Tab: Absorption Coefficients

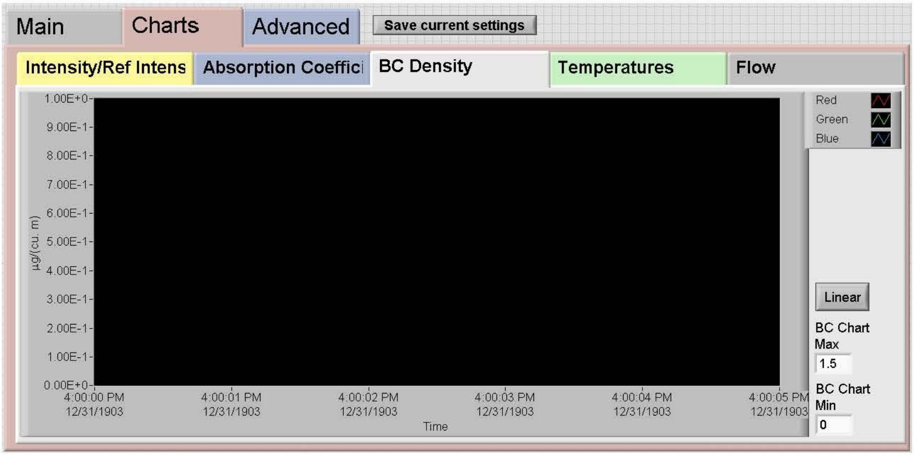

Figure 19: TAP GUI Charts Tab: Black Carbon Density

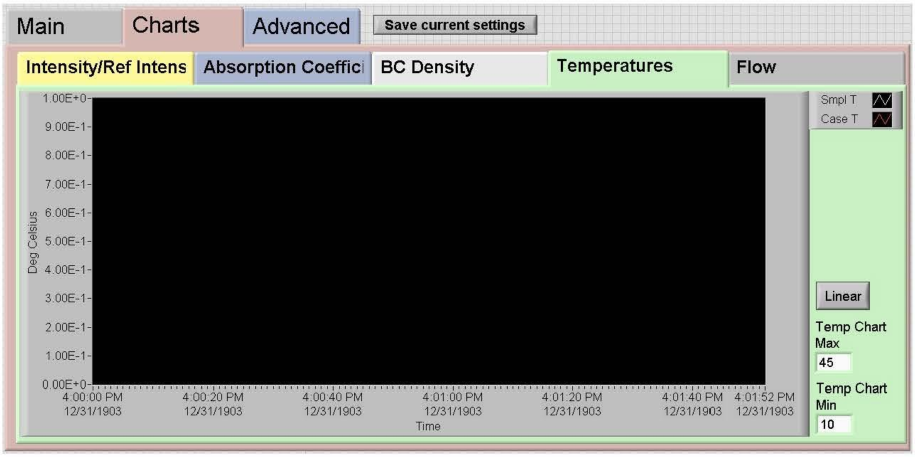

Figure 20: TAP GUI Charts Tab: Temperatures

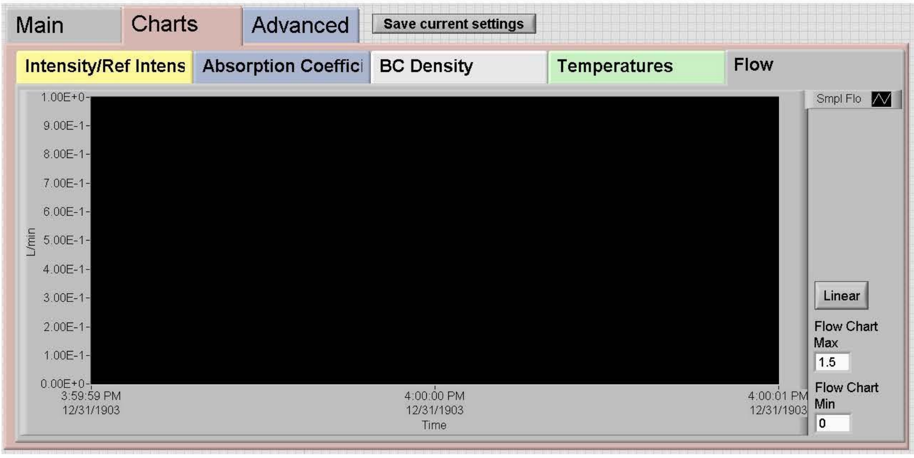

Figure 21: TAP GUI Charts Tab: Flow

All charts are accesible by clicking the corresponding tab. The x-axis is always time. The upper right corner of each subtab has a legend detailing the traces shown. All charts contain three controls:

Linear/Log	Changes the scaling of the y-axis.
Chart Max	Sets maximum y-value.
Chart Min	Sets minimum y-value.

5.3 Main Tab

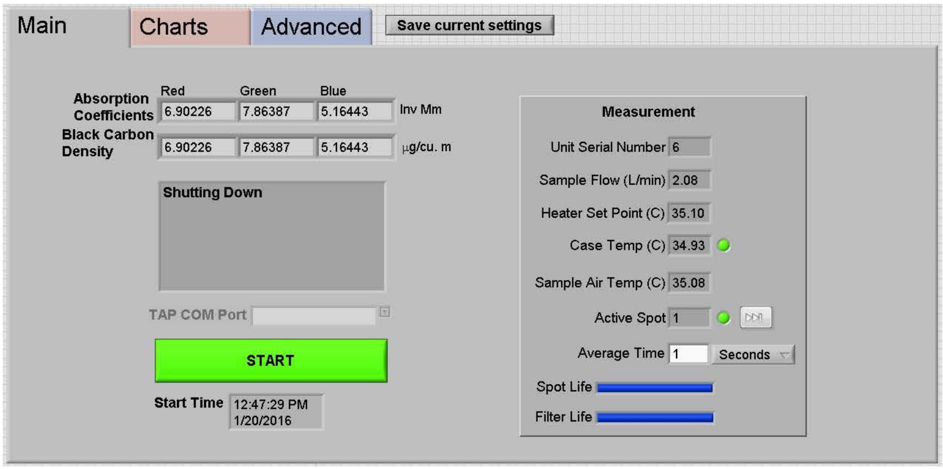

Figure 22: TAP GUI Main Tab

Absorption Coefficients	Displays calculated absorption coefficients in three wavelengths in inverse Mm.
Black Carbon Density	Displays absorption coefficients scaled by the Mass Extinction Efficiency from the Advanced tab. Has units of $\mu g/m^3$.
User Message Block	Gives the user updates about the current status of the TAP and GUI.
TAP COM Port	Select the COM port the TAP is connected to.
START/SHUTDOWN	Begins data collection/stops data collection when pressed.
Start Time	Displays the time that data taking begins.
Unit Serial Number	Displays serial number read in firmware.
Sample Flow	Displays current measurement of flow in L/min.
Heater Set Point	Displays current value from Advanced tab and firmware.
Case Temp	Displays current measurement of temperature of metal block under internal filter in C.
Sample Air Temp	Displays current measurement of air inlet temperature in C.
Active Spot	Displays current experimental spot drawing flow. Clicking the skip button will cause the unit to skip to the next spot immediately.
Average Time	The number of seconds to average the recorded light intensities. It is a running, boxcar average.
Spot Life	Displays the remaining life of the active spot.
Filter Life	Displays the remaining life of the current filter.

5.4 Output Data Format

The control software saves collected data in the "Data Directory" folder specified in the Advanced tab. A sample data set is included below. These .dat files contain both raw data directly from the instrument (in red below), as well as data with processing applied by the control software (see Theory of Operation). The file may be opened with any text editor.

5.4.1 Example File Header

Raw data at the end of the line has the Dark or Dark Ref value subtracted from it.
The absorption coefficient is calculated using the analysis in "Comment on 'Calibration and Intercomparison of Filter-Based Measurements of Visible Light Absorption by Aerosols'" by John A. Ogren 2010.
Sigma(abs)=f(Tr)*Sigma(0)-s*Sigma(scat): s = 0.02+/-0.02

Unit Serial Number: 22

Hardware Parameters:
Filter Material: Glass (Azumi M371)

Spot Area = 2.5281E-5 sq. m
Pall E70 correction from paper divided by 1.25 for rough equivalence.

Firmware Parameters:
firmware vers = 10.108
output interval = 1
stbl = 1.0
Tcase = 1.039004e-03, 2.376432e-04, 0.000000e+00, 1.616100e-07
Tair = 1.039004e-03, 2.376432e-04, 0.000000e+00, 1.616100e-07
Flow = -1.166108e-01, 4.338535e-02, 3.336363e-02, 3.287070e-02
pid = 250, 5, 1
lpf = 1, 0, 0, 0, 0

Software Parameters:
Software Version = 4.4.0
Port = COM4
White Filter Check Results[6] = 0.941648, 0.966884, 0.968108, 0.976536, 0.974668, 0.940121, 1.01651, 1.02871, 1.05487, 1.09712, 1.13925, 1.07085, 0.989169, 0.961492, 1.00110, 1.02287, 1.07244, 1.03554, 1.02547, 0.990426, 1.00892, 0.928665, 0.955096, 0.943986, 1.00000
LED Mode = 0
Red LEDs Percentage Power = 67, 70, 67, 68, 61, 70, 66, 68, 67, 70
Green LEDs Percentage Power = 100, 100, 100, 100, 100, 100, 100, 100, 100, 100
Blue LEDs Percentage Power = 89, 94, 89, 89, 83, 94, 86, 93, 89, 94
Software low pass filter is a 4 stage, single pole filter with effective first-order time constant of 2.6 seconds. Arguments are 2.17872e-1, 1.26719, -6.02159e-1, 1.27174e-1, -1.00721e-2.

5.4.2 Data Output

Date (yymmdd)	Time (24hr)	Active Spot	Ref Spot
150616	13:38:22	0	0
150616	13:39:08	1	1
150616	13:39:09	1	1

LPF	AvgTime	Red Abs Coef	Green Abs Coef	Blue Abs Coef
0	1	0	0	0
0	1	2.801488	1.749561	2.065082
1	60	1.413076	-0.706978	2.315388

Sample Flow (L/min)	Heater Set Point	Sample Air Temp (C)	Case Temp (C)
0	35.1	35.09	35.10
2.059	35.1	35.07	35.09
2.061	35.1	35.12	35.08

[6] White filter check values, I_{wf}, as described in Theory of Operation, are listed from left to right as follows: ch1_Red, ch1_Green, ch1_Blue, ... , ch8_Red, ch8_Green, ch8_Blue.

Red Ratio	Green Ratio	Blue Ratio	Dark
0.997581	0.997394	0.997485	-149.103897
0.943785	0.987831	0.982759	-147.742401
0.943781	0.987833	0.982752	-147.753006
Red	**Green**	**Blue**	**Dark Ref**
167783.0313	91418.8828	181310.578	2210413522
175655.8281	103790.117	191074.484	-138.529495
175645.9844	103784.82	191071.094	-138.667725
Red Ref	**Green Ref**	**Blue Ref**	
167783	91418.88	181310.5781	
186118.5	105068.7	194426.6406	
186108.8	105063.1	194424.5	

5.5 TAP.config File Settings

These settings are found in the TAP.config file in the C:TAP directory. They are the startup defaults for the GUI. If the file is missing or damaged a new, default file is generated. If this occurs, a white filter check needs to be run.

File Paths	Value
Data File Path	The full path to the directory where data (and raw data, if Raw Data Dump = TRUE) is to be saved, e.g. "/C/TAP/DATA".
Communication	**Value**
COM Port	The serial port address, e.g. "COM3".
Data Settings	**Values**
Average Time	Number of second to collect data to calculate the mean of the absorption coefficient.
Average Time Unit	1, 60, or 3600 for seconds, minutes, or hours respectively as the time unit for Average Time.
File Size	Approximate number of measurements for 1 data file to hold before a new one is created.
Start Spot	The experimental spot that the program will begin on. Normally 1.
End Spot	The experimental spot that the program will end on. Normally 8.
Red Spot Switching Threshold	Threshold for spot change. Either settable as 0.5 or 0.7 transmission. This is recorded here as 5 or 7.
Green Spot Switching Threshold	Threshold for spot change. Either settable as 0.5 or 0.7 transmission. This is recorded here as 5 or 7.
Blue Spot Switching Threshold	Threshold for spot change. Either settable as 0.5 or 0.7 transmission. This is recorded here as 5 or 7.
Cal Temp	Temperature in Kelvin that the unit was calibrated at. Used for flow correction.

Ref Rel St Dev	The standard deviation must be below this value for a spot's data to be considered stable and begin recording data at that spot after each spot change.
Max Counter	Maximum number of times to retry Ref Rel St Dev criteria.
Last White Filter	The results of the last white filter check - 1 separated by <tab>, described in Theory of Operation as I_{wf}. White filter values are listed from left to right as follows: ch1_Red, ch1_Green, ch1_Blue, ... , ch8_Red, ch8_Green, ch8_Blue.
Pressure	Current pressure in Pascals.
Cal Pressure	Pressure in Pascals that the unit was calibrated at. Used for flow correction.
Mass Extinction Efficiency	The factors to convert absorption coefficients to $\mu g/m^3$ of black carbon for each color, e.g. "7 <tab> 8 <tab> 9".
Filter Material	Selects the fiber filter type, spot size, and correction to use.
Raw Data Dump	If FALSE, does nothing. If TRUE creates a RAW_TAP_SN#_date_time.dat file with the raw output from the TAP.
Spot Change Timer?	If FALSE, the program will remain on a given spot until a color's switching threshold is reached. If TRUE, the program will remain on a given spot until Spot Change Time (s) is reached or the threshold is reached, whichever comes first.
Spot Change Time (s)	Amount of time in seconds to remain on each experimental spot.
Heater Set Point	The set point for the internal heater. Cannot be set above 50C.
Stop before White Filter?	If FALSE, the program will skip the initial dialog box asking if the filter is new and immediately begin taking data. If TRUE, the program puts up a dialog box asking the user if the filter is new. If the user responds yes, then a white filter check will begin.
Stop after White Filter?	If FALSE, the program will immediately begin taking data after the white filter check is complete with the filter installed on the inlet. If TRUE, the program puts up a dialog box telling the user to remove the filter and then hit okay before normal data operation starts.

Auto Start	If FALSE, allows user to check communication and start settings on the Advanced tab before beginning a run when the user pushes start of the Main tab. If TRUE, immediately starts run.
Low Pass Filter	If FALSE, software low pass filter is off. If TRUE, software low pass filter is on. Software low pass filter is a 4 stage, single pole filter with effective first-order time constant of 2.6 seconds. Arguments are 2.17872e-1, 1.26719, -6.02159e-1, 1.27174e-1, -1.00721e-2.

Display Settings	**Values**
I/Iref Log	Startup value. If FALSE, scale is linear. If TRUE, scale is logarithmic.
I/Iref Min	Startup minimum value.
I/Iref Max	Startup maximum value.
Flow Log	Startup value. If FALSE, scale is linear. If TRUE, scale is logarithmic.
Flow Min	Startup minimum value.
Flow Max	Startup maximum value.
Abs Log	Startup value. If FALSE, scale is linear. If TRUE, scale is logarithmic.
Abs Min	Startup minimum value.
Abs Max	Startup maximum value.
Temp Log	Startup value. If FALSE, scale is linear. If TRUE, scale is logarithmic.
Temp Min	Startup minimum value.
Temp Max	Startup maximum value.
BC Log	Startup value. If FALSE, scale is linear. If TRUE, scale is logarithmic.
BC Min	Startup minimum value.
BC Max	Startup maximum value.

6 TAP Specifications

Category	Value
Centroid wavelengths and (FWHM), nm	640 (25); 520 (35); 465 (22) or 365 (15)
Filter Media	Glass fiber, 47 mm diameter
Volumetric flow rate	2 LPM
Vacuum requirement	9 inHg
Noise (σ of 60-sec averages on filtered air), Mm	~0.2, RGB ~0.5, UV
Number of Sample Spots	8
Number of Reference Spots	2
Dimensions (L × W × H)	160mm × 110mm × 115mm (6.25in × 4.25in × 4.5in)
Weight	1.6 kg (3.5 lbs)
Power Consumption	70 W @ 90-264 VAC, using supplied adapter 3.0 A @ 24 VDC
Power Adapter Dimensions (L × W × H)	132mm × 58mm × 30.5mm (5.2 in × 2.3 in × 1.2 in)
Mounting	4 removable rubber feet in rectangular pattern, 85.73mm × 111.13mm (3.375 in × 4.375)
Serial communications	RS232, 57600 baud, no parity, 8 data bits, 1 stop bit.

7 RS-232 Commands

RS-232 communications may be used to control the unit directly, bypassing the Brechtel control software. Brechtel does not recommend using direct RS-232 control for collection of raw, unprocessed instrument data, as these values are included in the Brechtel TAP control software data records (See Output Data Format in Section 4).

The TAP serial communications have been specially-formatted to maintain compatibility with legacy software. The port should be configured to 57600 baud transmission with 8 data bits, no parity bits, and 1 stop bit. When initially powered on, the TAP idles, leaving all valves closed (and thus preventing flow through the instrument). It will, however, immediately begin broadcasting its state over the serial connection (See State Transmission Record Format below).

The instrument stores total accumulated spot airflow in non-volatile memory, so if power to the instrument is interrupted during manual operation, measurements can be resumed by simply enabling flow through the desired spot. However, Brechtel recommends always starting a new spot after loss of instrument power. Both the total spot airflow and intensity measurements are reset during manual operation filter changes.

Commands are issued over-the-wire by transmitting the command as ASCII text, followed by a carriage return and line feed. In most serial communications software, this can be accomplished by simply typing the command and pressing the <Enter> key.

7.1 Universal Commands

At any time, the following four commands are available.

main Returns to the main menu

? Queries the current menu

hide Disables unpolled data transmission

show Enables unpolled data transmission

7.2 Main Menu Commands

This is the default state upon power up.

cfg Requests the configuration menu

cal Requests the calibration menu

stop Stops current filter, beginning a filter change.

go Starts new filter, completing a filter change. When preceded by the stop command, increments <Filter ID>.

spot Requests active spot.

spot=0 Stop sampling and flow.

spot=n Switches <Active spot> to n and begins sampling. spot=+ Switches <Active spot> to next spot and begins sampling.

Warning: main, cfg, and cal commands may pause unpolled data reports for approximately 15 seconds.

7.3 Configuration Menu Commands

sn Requests the serial number.

fw Requests the firmware version.

rst Performs a full software reset, clearing all stored information and calibration. Not recommended by Brechtel.

oint Requests output interval in seconds

oint=s Sets output interval to s seconds

lpf Shows digital filter settings.

lpf=args Sets digital filter settings. Default filter is a 4-stage single-pole low-pass filter, with effective first-order time constant of 2.6 seconds. args should be formatted as B0,B1,B2 ,B3,B4 with default lpf=2.17872e-1, 1.26719, -6.02159e-1, 1.27174e-1, -1.00721e-2. When off, lpf =1,0,0,0,0. If using GUI, will be turned off.

hsp Requests case heater setpoint in degrees C

hsp=T Sets the case heater setpoint to t degrees C. Temperature should be formatted as ##.#

stbl Requests the case temperature window for stable operation. Exceeding this window will raise a status flag.

stbl=t Sets the case temperature window. The temperature window will be defined by T +/- t. Format as ##.#

7.4 Calibration Menu Commands

Tc Requests the case temperature calibration.

Tc=args Sets the case temperature calibration. args corresponds to a third degree polynomial, with constant first, and should be formatted as c0,c1,c2,c3. Default setting is Tc=1.039004e-3, 2.376432e-4, 0, 1.6161e-7.

Ta Requests the inlet flow temperature calibration.

Ta=args Sets the case temperature calibration. args corresponds to a third degree polynomial, with constant first, and should be formatted as d0,d1,d2,d3. Default setting is Ta=1.039004e-3, 2.376432e-4, 0, 1.6161e-7.

flow Requests the flow calibration.

flow=args Sets the flow calibration. args corresponds to a third degree polynomial, with constant first, and should be formatted as f0,f1,f2,f3. Internally clips to 0.0 SLPM min, 3.0 SLPM max. Default values are -8.03700e-01,1.20400e+00,-4.99400e-01,9.74000e-02

pid Requests the instrument PID gain settings.

pid=args Sets the PID gain settings. Format args as p,i,d led Requests the LED mode and intensity settings. led=args Sets the LED mode and intensity settings. Format args as m,r,g,b with defaults 1,100,100,100.

7.5 Changing a filter command sequence

1. hide
2. spot=0
3. stop
4. Physically change the filter (See Installing a Filter in Section 3)
5. go
6. spot=1
7. show

8 Instrument Record Format

8.1 Instrument Record Fields

Instrument state, including data and status, is transmitted in 458-byte records of comma-separated ASCII text. Records are terminated by an additional carriage return and line feed. There are 49 fields in total:

1. <Record type>
2. <Status flags>
3. <Elapsed time>
4. <Filter ID>
5. <Active spot>
6. <Flow rate>
7. *<Sample volume for active spot>*
8. *<Case temperature>*
9. *<Sample air temperature>*

10. - 49. *<Channel component intensities>*

An example record, for reference, with line feeds added for readability:
03, 0002, 00003ef7, 0018, 01, 1.996, *0.00142*, *37.00*, *34.22*, *c343ef6c, 48b09b55, 4834423c, 486dc150, c3423a45, 48758f3c, 48011951, 4827deac, c2bd6321, 487189bf, 47fc6640, 48213bd4, c2ab3f0d, 48756a90, 480020b0, 48250060, c2c627a3, 486fdf58, 480007a6, 4828f8c7, c2f23422, 48702856, 47f488a6, 481fa9d0, c38221db, 4883722d, 480480a7, 4830920e, c3893305, 4881ff54, 47ff16d0, 48289c3b, c3301adc, 48880fb4, 4806eb88, 4833d955, c358a903, 48a4f341, 48246cf4, 4857f0f1*

Record type	Currently recorded as 03. Has no effect on instrument operation.
Status flags	TAP status is recorded as a packed 4-digit hex integer. Note that bits are additive: for example, a value of 0x0300 would indicate that both a temperature error (0x0200) and a lamp/filter error (0x0100) were detected. Enumerated in table 2.
Elapsed time	Elapsed time is recorded in seconds since instrument power-up. It is formatted as an 8-digit hex integer and unused by the Brechtel TAP control software. For example: 0x00003ef7 = 16119 seconds.
Filter ID	The filter ID increments on every stop+go command sequence and can only be reset with an rst command (see Configuration Menu below). It is stored in non-volatile memory, formatted as a 4-digit hex integer, and unused by the Brechtel TAP control software. For example: 0x0018 = 24
Active spot	The active spot field indicates which sample channel is currently active. It is formatted as a 2-digit decimal integer. An active spot of 00 indicates that no spot is active. Example: 01 = Sample channel 1
Flow rate	Flow rate is given in SLPM. It is formatted as a 4-digit fixed-point decimal. For example: 1.996 = 1.996 SLPM.
Sample volume for active spot	This field describes the total aggregate flow through the sample channel for this filter. It is formatted as a 6-digit fixed-point decimal with units of cubic meter. For example: 0.00142 = 0.00142 m^3
Case temperature	This field indicates the temperature of the instrument body, given in degrees Celsius. It is formatted as a 4-digit fixed-point decimal. For example: 35.00 = 35.00 ÂºC
Sample air temperature	This field indicates the temperature of the sample inlet airflow, given in degrees Celsius. It is formatted as a 4-digit fixed-point decimal. For example: 34.22 = 34.22 ÂºC
Channel component intensities	Readings are given as tuples of (dark, red, green, blue) component intensities for each channel. These are then concatenated into a single list: <CH0 DARK>, <CH0 RED>, <CH0 GRN>, <CH0 BLU>, <CH1 DARK>, <CH1 RED>, <CH1 GRN>, <CH1 BLU>, <CH2 DARK>, <CH2 RED>, <CH2 GRN>, <CH2 BLU>... Channel 0 is used as reference for sample <Active spot> = [2, 4, 6, 8]. Channel 9 is used as reference for sample <Active spot> = [1, 3, 5, 7]. Please see Channel Component Conversion for conversion details.

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8.2 Flag Bit Description

0x0400 (0000 0100 0000 0000)	Case temperature unstable (above or below case temperature window)
0x0200 (0000 0010 0000 0000)	Temperature error
0x0100 (0000 0001 0000 0000)	Lamp or filter error
0x0002 (0000 0100 0000 0010)	Flow error
0x0001 (0000 0000 0000 0001)	Filter changing

Table 2: TAP Status Flags

8.3 Channel Component Conversion

Individual intensities are represented using a multi-step conversion:

1. The IEEE754 single precision (32-bit) floating point intensity reading from the detector is converted to raw bits.
2. These bits are reinterpreted as a 32-bit decimal integer.
3. That integer is converted to hexadecimal base.
4. The hexadecimal integer is added to the record (like the rest of the record, it is encoded as an ASCII string on the wire).

For example, reversing this process using a value from the example record above yields:

1. $0xc343ef6c = (3276009324)_{10}$
2. $(3276009324)_{10} = (11000011010000111110111101101100)_2$
3. $(11000011010000111110111101101100)_2 = -1.9593524e2$

9 USB Connection for Optional BMI Tablet

9.1 Lenovo/Dell Tablets

When purchased with the optional BMI tablet, the instrument will be shipped with a Plus Port, a tablet power supply, and a serial/USB converter.

The Plus Port allows the tablet to charge (in USB slave mode) while simultaneously reading data from the serial/USB converter (in USB host mode). To operate the instrument with the BMI-supplied tablet, connect the tablet power supply to the Plus Port, the serial converter to the Plus Port, and the Plus Port to the tablet (see figure 23).

Figure 23: BMI Tablet/Plus Port Connection

9.2 Toshiba Tablets

When purchased with the optional BMI tablet, the instrument will be shipped with a color-coded Y-USB cable, a gender changer, a tablet power supply, and a serial/USB converter.

The Y-USB cable allows the tablet to run off AC power (keeping the battery at its current charge) while simultaneously reading data from the serial/USB converter (in USB host mode). To operate the instrument with the BMI-supplied tablet, connect the tablet power supply to the red end of the Y-USB cable, the micro USB end of the Y-USB cable to the tablet, and the final end of the Y-USB cable to the gender changer and then the serial converter.

9.3 Laptop

When purchased with the optional BMI laptop, the instrument will be shipped with a laptop power supply and a serial/USB converter. To operate the instrument with the laptop, connect the power supply and the serial/USB converter to the laptop. Use a USB port on the laptop to connect the converter. Determine the correct COM port number assigned by the computer to the converter. Connect the serial port end (DB9) of the converter to the rear panel of the TAP. In the TAP Reader software, enter the correct COM port under the Advanced tab.

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APPENDIX B: NEPHELOMETER OPERATIONS REFERENCE MANUAL

TSI Model 3563 Integrating Nephelometer Operations Reference Manual

Written for use by the World Meteorological Organization (WMO) Global Atmosphere Watch (GAW) Program

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measurement (i.e., the difference from the CO_2 target value), calculated from each of the six nephelometer channels (three wavelengths each with a total and hemispheric backscatter measurement) should be within a few percent, with no individual channel's error being larger than 10%. If observed errors are larger than this, it suggests an instrument problem and/or a poor calibration. A span check algorithm is provided in Appendix A so that users can perform these calculations. As discussed below, span gas checks should occur at regular intervals (e.g., weekly to monthly) so that instrument performance can be tracked over time.

Span checks that show large negative values are often caused by CO_2 either not entering the nephelometer as expected or not staying inside the instrument. If the CO_2 is delivered under elevated pressure, hoses can be blown off fittings inside the nephelometer cover. Check to make sure no tubes have been disconnected or ruptured and that CO_2 is in fact flowing through the nephelometer. Since the CO_2 measurement is made relative to the measurement of filtered air, large negative errors will also be encountered if the filtered air measurement is compromised. This can happen if the zero filter ball valve is not completely sealing off the inlet and directing all air through the heap filter. If this turns out to be the case, either adjust the ball valve so that it completely seals off the inlet, or else replace it if necessary.

The second performance check is an instrument noise check. For this check, a second HEPA filter is required and should be mounted on the instrument inlet. Nephelometer data should be recorded using the Logging feature in the Data Collection module of the TSI Nephelometer software, or with any terminal emulation software. The nephelometer should be configured using the following commands (these are described in the Nephelometer Instruction Manual):

UE
STA60
STB30 (sufficient for a high flow rate like 30 lpm, should be longer for lower flow rates)
STP3600
STZ300
SMZ1
SP75
UD1
UZ1
UB

In this configuration, the nephelometer measures the scattering coefficient of filtered air for 54 minutes of each hour. There is a 5 minute zero period and two 30-second blanking periods. The noise check should be run for 12-24 hours to determine variability in the background values.

A program can then be run on this log file that calculates means and standard deviations for the 1-minute filtered air and zero background measurements. A Perl version of this program is included in Appendix B. As with the span gas checks, a noise check should be done periodically (at least once a year) to check that instrument background values remain low and consistent. Typical ranges of the nephelometer performance statistics for the TSI 3563 nephelometers operated by the Global Monitoring Division of NOAA/ESRL (13 instruments) are shown below. Units for all values are Mm^{-1}.

	Mean	St. Dev.
Filtered Air, Total Scatter (all wavelengths):	0.01-0.10	0.10-0.40
Filtered Air, Backward Scatter (all wavelengths):	0.01-0.05	0.07-0.30
Neph. Background, Total Scatter (all wavelengths):	2-8	0.02-0.12
Neph. Background, Backward Scatter (all wavelengths):	1-9	0.01-0.12

Values observed that are far beyond the upper end of these ranges suggest an instrument problem; additional inspection of nephelometer is suggested.

Arrival of Working Instrument

Same initial inspection and performance checks as for new instrument arrival, except that some additional maintenance and recalibration may be required. Refer to the Instruction Manual for calibration instructions. For possible maintenance required, see Routine Maintenance and Special Maintenance sections.

Shipping

Most users ship their TSI model 3563 nephelometers in the original wooden crate, although as the crates age it may be necessary to build a new crate or purchase an appropriate shipping container. With use the blown-in foam becomes broken, so some additional cushioning may also be required. The major criteria for fabricating a replacement shipping box for the nephelometer are:

- Protection. This is the most important criterion. The nephelometer is a rather heavy instrument with hard metal edges that can break through a flimsy shipping container. The shipping box should be made of a sturdy material; for example, wood, metal, or heavy plastic have all been used successfully. The box should have form-fitting or blown-in foam so that the instrument does not shift position in the box during transport or lifting. Cardboard and light plastic boxes should not be used because they provide a lesser degree of protection, they are easily damaged, and they require frequent replacement. Pieces of foam, newspaper, styrofoam peanuts, and other types of loose packing material should be avoided because they can allow the instrument to shift position inside the box.

- Weight and Dimensions. The wooden crates that the nephelometers are shipped from TSI in weigh approximately 61 kg (134 lbs.) when loaded with the nephelometer and accessory kit. If new shipping containers are constructed, keep in mind that several international delivery services (e.g., FedEx) have limits of 150 lbs. (68 kg) for standard air freight service. Larger packages are considerably more expensive to ship.

Finally, when shipping a TSI nephelometer make sure that the inlet and outlet are tightly sealed. This will eliminate the possibility of dust, packing debris, insects, etc., getting into the nephelometer and minimize the need for taking apart the instrument for cleaning. Also, it is wise to make sure the top and bottom covers and the PMT cover are tightly secured to protect sensitive and fragile instrument components.

Calibrations

Detailed instructions on how to calibrate the nephelometer are given in Chapter Four of the Model 3550/3560 Series Integrating Nephelometer Instruction Manual. Calibration should be performed only when a span gas check or instrument comparison suggests that a nephelometer's calibration has shifted. Routine re-calibration is not recommended as long as regular span checks are performed. The TSI nephelometer software displays the K2 and K4 constants determined in each calibration. The K2 constant is a measure of how much light is being detected by each PMT during the calibration portion of each chopper cycle. This value can vary over a fairly wide range depending on the thickness or on the presence of scratches in the finish of the reflective coating on the chopper shutter. Typical values for K2 for all three wavelengths in a properly functioning nephelometer are 2E-3 to 8E-3, although it is possible that values for a particular nephelometer could lie slightly outside this range. The K4 constant is related to the fraction of the scattering volume illuminated during the backscatter measurement. Typically, the value of this constant is near 0.5.

After a calibration has been performed, it is always a good idea to perform a span gas check to see how well the nephelometer measures quantity with a known scattering value. If the span check errors are large, a repeat of the calibration may be necessary. Alternatively, the full calibration procedure can be repeated until reproducible values of the K2 and K4 constants are achieved.

Diagnostic Measurements

In order to track the performance of a nephelometer, records should be kept of diagnostic measurements over time. This is the best way to determine if the performance of your nephelometer has changed. Measurements and checks that should be recorded and monitored over time include:

- Span gas checks (weekly to monthly)
- Overnight noise checks (at least yearly)
- Zero Background checks (hourly)
- Lamp current and voltage (continuous)
- Nephelometer temperature, pressure, and relative humidity (continuous)

The rationale for doing span gas and overnight noise checks has already been discussed. Zero background checks show when the instrument background changes, and are especially useful in showing when the inside of a nephelometer is getting dirty. The monitoring of lamp current and voltage is necessary because lamps that are aging begin to draw more current. If the lamp draws too much current, the analog circuit board could be damaged. We recommend replacing the lamp when the lamp current rises over 7 amps. Temperature, pressure and relative humidity measurements are required for interpretation of nephelometer measurements, and are also useful in diagnosing many potential instrument problems.

Routine Maintenance

Maintenance procedures for the nephelometer are described in Chapter Eight of the TSI Nephelometer Instruction Manual. Most of these procedures are recommended to be done "as needed" or "periodically". Some need to be performed when the diagnostic measurements suggest it is time for maintenance. Routine maintenance procedures are relatively simple to perform and include:

- Replacement of particulate filters (yearly, more frequently at very dusty or polluted sites)
- Replacement of the fan filter (inspect yearly)
- Replacement of lamp (as needed, generally 2-3 times per year)
- Checking for instrument leaks (yearly)
- Cleaning the main cavity of the nephelometer (as needed, if instrument background goes above ~ 10 Mm^{-1})
- Cleaning or changing the flocked paper (when main cavity is cleaned)
- Cleaning the light pipe lens (when main cavity is cleaned)
- Calibration or replacement of the T, P, and RH sensors (check annually)

Special Maintenance

Special maintenance procedures should be performed on an "as needed" basis. These procedures are often on sensitive components of the nephelometer, so extra care should be exercised when working on these procedures. Special maintenance procedures include:

- Cleaning or replacement of aged bandpass filters
- Adjustment or replacement of PMTs
- Replacement of old/scratched chopper shutter
- Replacement of EPROM chip
- Replacement of motor control microprocessor
- Replacement of chopper and backscatter shutter motors
- Adjustment/replacement of IR reflective diodes
- Cleaning of the backscatter shutter
- Replacement or realignment of the zero filter ball valve

We recommend replacement of an old chopper shutter, rather than cleaning. We have found through experience that it is very difficult to clean one of these shutters without leaving a dull deposit or imparting additional scratches on the reflective surface. The TSI Nephelometer Instruction Manual recommends cleaning a dirty chopper shutter with isopropyl alcohol and cotton swabs. Feel free to try this, but don't be surprised if you end up needing a new chopper shutter anyway.

The two IR reflective diodes are used to detect when the zero valve and the chopper shutter are in the appropriate positions. The lenses for these diodes can get dirty and may need to be cleaned periodically. These diodes have been found to fail over time, so when cleaning or adjustment does not make these perform better, it is time for a new diode.

The backscatter shutter should be cleaned so that dirt or dust on the shutter does not lead to additional scattering of light from the lamp. Care should be taken not to change the orientation of the backscatter shutter (i.e., the angle at which it rotates). If this orientation is changed, the K4 constant will change and a new calibration will be required.

Over time, the ball valve assembly can cause problems either by developing a misalignment or by becoming more difficult to turn. These problems can cause background measurements that are off by varying degrees, or in the extreme case of a ball valve that will not turn a nephelometer unable to calculate its own backgrounds. A misaligned ball valve lets ambient air into the instrument during the zero air background measurement, which obviously compromises the background measurement. This can be observed by shining a flashlight into the nephelometer inlet when the valve is supposed to be in the zero air position. Seeing a gap where air can get directly into the nephelometer confirms the problem.

A misalignment of the ball is usually caused by one or more of the four set screws that hold the couplers in place becoming loose. This permits the shaft to rotate relative to the aluminum flange that is used a positioning device. They way to correct this problem is to loosen all of the set screws so that the ball can be turned by hand. Position the ball so that it is as far open as possible; i.e., that it allows air to enter the nephelometer as efficiently as possible. Then position the flange so that its edge is directly over the IR reflective diode sensor that determines flange (and valve) position. The metal should be 1-3 mm away from the sensor. If the distance is greater than that, adjust the position of the IR reflective diode closer to the aluminum flange. After aligning the ball and getting the flange in the correct position, tighten the set screws to lock the assembly in place. Make sure when the ball valve changes position during background checks that the ball is also in the proper (sealed) position at that time.

In the extreme case, an aged ball valve can become locked in position and the shaft will either break or the motor or coupling will be damaged. Replacement of the ball valve is discussed in the next section.

<u>Repairs</u>

Nephelometer repairs can be tricky and in general are best left to the factory. Repairs of this type include electronic repairs, circuit board repairs, motor repairs, etc. There are a few repairs that can usually be made by a competent end user. These include:

- Replacement of broken zero filter motor, ball valve, or coupler

- Repair or replacement of ribbon cables and connectors
- Replacement of white rectangular plastic AMP connectors and attached cables

If the ball valve is not turning easily, it probably needs to be replaced. This ball valve can be ordered from TSI, but can also be ordered directly from the manufacturer. The manufacturer is Georg Fischer Piping Systems. The valve is a "Ball Valve Type 346" with a 1-inch bore. See the web page at

http://www.us.piping.georgefischer.com/index.cfm?6330B9B99D5F474C87D47549DE959C77

This valve is now out of production, but the manufacturer states that it will be supported with parts for 10 years (starting Dec. 2004). If you have a broken ball and/or stem, you can simply order another ball set. The part number you will need is 161.482.877. If you need a new ball valve (including the valve body), you will need part number 161.483.943.

To replace the broken valve, loosen the 4 large hex-head bolts that secure the valve and inlet housing to the nephelometer body. Remove the broken valve, inlet housing, and hepa filter. Remove the coupling and flange from the shaft of the broken valve and install it on the shaft of the new valve. Make sure to align the set screws with the groove in the shaft so that the ball position will be correct. Place the new ball valve in position, making sure that the couplers fit together and that the flange is close to the IR reflective diode sensor. Tighten the four hex-head bolts down to secure the ball valve. CAUTION: The ball valve body has o-ring seals at each end, so the bolts do not have to be tightened really tight. The o-rings have to be compressed, but over-tightening the bolts can impede the turning of the ball in the valve.

Replacement of the zero filter motor assembly should be straightforward – just a one-for-one replacement. Again, make sure that the couplers fit together and that the ball is aligned after the replacement.

<u>NOAA Modifications</u>

We make several modifications to the standard TSI nephelometer. These include:

- installing plastic clips to hold the circuit boards together
- replacing fan covers with a large speaker grill, and removing the metal strip down the middle of the cutout so the lamp can be changed without removing nephelometer cover
- installation of a small solenoid valve on the ¼-inch port fitting next to the lamp shield
- installation of a second BNC-style connector on the communications power/communications panel so that the solenoid valve can be controlled remotely for automated span gas checks
- cutting the nephelometer top cover lengthwise so that it can be removed without having to remove inlet and outlet plumbing

References

Anderson, T.L., Covert, D.S., Marshall, S.F., Laucks, M.L., Charlson, R.J., Waggoner, A.P., Ogren, J.A., Caldow, R., Holm, R.L., Quant, F.R., Sem, G.J., Wiedensohler, A., Ahlquist, N.A., and Bates, T.S. (1996) Performance characteristics of a high-sensitivity, three-wavelength, total scatter/backscatter nephelometer. **J. Atmos. Oceanic Technol. 13**, 967-986.

Anderson, T.L., and Ogren, J.A. (1998) Determining aerosol radiative properties using the TSI 3563 nephelometer. **Aerosol Sci. Technol. 29**, 57-69.

Appendix A: Span check algorithm for TSI 3563 Nephelometer

A. Configuration commands.

UE
STA60
STB30 (sufficient for a high flow rate like 30 lpm, should be longer for lower flow rates)
STP3600
STZ300
SMZ1
SP75
UD1
UZ1
UY1
UT1
UP3
VZ
UB

B. Procedure

Flush with air for 3-5 minutes at ~ 30 lpm
Turn off blower, close off output, restrict input if possible.
Flush with CO_2 for 10 minutes at ~ 5 lpm
Measure with CO_2 for 5 minutes at ~ 5 lpm
Record average values during CO_2 measurement
Open input and output fully, turn on blower
Flush with air for 3-5 minutes at ~30 lpm
Measure with air for 10 minutes at ~ 30 lpm
Record average values during air measurement
Perform a zero

C. Data logging

Average values of the following nephelometer parameters should be recorded for the CO_2 and AIR measurements. Separate values are recorded for the blue, green, and red channels [λ] in most cases.

Photon Count Records (B, G, R):

- NTCAL[λ]: photon counts from calibrator (total scatter)
- NTMEAS[λ]: photon counts from measure (total scatter)
- NTDARK[λ]: photon counts from dark (total scatter)
- REVT: revolutions of chopper for total scatter measurement
- NBCAL[λ]: photon counts from calibrator (back scatter)
- NBMEAS[λ]: photon counts from measure (back scatter)
- NBDARK[λ]: photon counts from dark (back scatter)
- REVB: revolutions of chopper for backscatter measurement

Data Records (D):
- BSP[λ]: total scattering coefficient (m^{-1})
- BBSP[λ]: back scattering coefficient (m^{-1})

Auxiliary Status Records (Y):
- PRES: barometric pressure (hPa)
- TEMP: sample temperature (K)
- T-IN: inlet temperature (K)
- RH: relative humidity (percent)
- VLAMP: lamp voltage (V)
- ALAMP: lamp current (A)

C. Data reduction

The calculations use the following constants:
Standard temperature and pressure:
T_STP = 273.15 K
P_STP = 1013.25 hPa
Rayleigh scattering coefficient of air at STP:
BSGAIR[λ] = (27.89, 12.26, 4.605) Mm^{-1} for (450, 550, 700) nm wavelength
BBSGAIR[λ] = BSGAIR[λ] / 2
Rayleigh scattering coefficient of CO2, relative to air:
RAYCO2 = 2.61
Rayleigh scattering coefficient of CO2 at STP:
BSGCO2TRUE[λ] = BSGAIR[λ] * RAYCO2
BBSGCO2TRUE[λ] = BSGCO2TRUE[λ] / 2
chopper rotation rate = 22.994 revolutions per second
chopper gate widths = (40, 60, 140) degrees for (calibrate, dark, signal) sections

Calculate average gas density and lamp power:
DENAIR = PRES[AIR] / TEMP[AIR] *273.15 / 1013.25
DENCO2 = PRES[CO2] / TEMP[CO2] *273.15 / 1013.25
POWER = VLAMP * ALAMP

Convert photon counts to count rates in Hz (eq. 7-15 in TSI manual), for CO2 and AIR measurements separately:
HZTCAL[λ] = NTCAL[λ] * (360/40) * 22.994 / REVT
HZTMEAS[λ] = NTMEAS[λ] * (360/140) * 22.994 / REVT
HZTDARK[λ] = NTDARK[λ] * (360/60) * 22.994 / REVT
HZBCAL[λ] = NBCAL[λ] * (360/40) * 22.994 / REVB
HZBMEAS[λ] = NBMEAS[λ] * (360/140) * 22.994 / REVB
HZBDARK[λ] = NBDARK[λ] * (360/60) * 22.994 / REVB

Don't bother with dead time correction (eq. 7-16 in TSI manual), because count rates on CO2 and air are too low for dead time to matter.

Calculate CO2 Rayleigh scattering at STP, as measured by nephelometer:
BSGCO2[λ] = BSPCO2[λ] / DENCO2 - BSPAIR[λ] / DENAIR + BSGAIR[λ]
BBSGCO2[λ] = BBSPCO2[λ] / DENCO2 - BBSPAIR[λ] / DENAIR + BSGAIR[λ]/2

Calculate percentage error in measured CO2 Rayleigh scattering:
ERRTS[λ] = (BSGCO2[λ] / BSGCO2TRUE[λ] - 1) * 100
ERRBS[λ] = (BBSGCO2[λ] / BBSGCO2TRUE[λ] - 1) * 100

Calculate nephelometer sensitivity factor, defined as the photon count rate (Hz) attributable to Rayleigh scattering by air at STP:
SENSTS[λ] = ((HZTMEASCO2[λ] - HZTDARKCO2[λ]) / DENCO2
- (HZTMEASAIR[λ] - HZTDARKAIR[λ]) / DENAIR)
/ (RAYCO2 - 1)
SENSBS[λ] = ((HZBMEASCO2[λ] - HZBDARKCO2[λ]) / DENCO2
- (HZBMEASAIR[λ] - HZBDARKAIR[λ]) / DENAIR)
/ (RAYCO2 - 1)

Absolute values of ERRTS[λ] and ERRBS[λ] larger than a few percent indicate a potential problem with the nephelometer or with the calibration parameters stored within the nephelometer. If larger errors are encountered, the span check should be repeated. If the errors persist, the full calibration procedure recommended by TSI should be performed.

Long-term trends in SENSTS[λ] and SENSBS[λ] should be monitored for degradation of phototube sensitivity.

Appendix B: Evaluation of nephelometer noise levels from overnight zero-air runs

Program to calculate nephelometer statistics (mean and standard deviation of the filtered air and zero background measurements for all six channels).

(start of program)

```
#!/usr/bin/perl
# Name: nephstat
# Desc: calculate performance statistics from a raw neph data file
# Call: nephstat infile [ > outfile ]
# Uses: data file written by TSI neph software
#  OUT: standard output
#  Rev: 970529 JAO translate awk version to perl

eval '$'.$1.'$F[1];' while $ARGV[0] =~ /^([A-Za-z_0-9]+=)(.*)/ && shift;
                  # process any FOO=bar switches

  $xBtsBair = 0;  $xxBtsBair = 0;
  $xBtsGair = 0;  $xxBtsGair = 0;
  $xBtsRair = 0;  $xxBtsRair = 0;
  $xBbsBair = 0;  $xxBbsBair = 0;
  $xBbsGair = 0;  $xxBbsGair = 0;
  $xBbsRair = 0;  $xxBbsRair = 0;
  $xBtsBbkg = 0;  $xxBtsBbkg = 0;
  $xBtsGbkg = 0;  $xxBtsGbkg = 0;
  $xBtsRbkg = 0;  $xxBtsRbkg = 0;
  $xBbsBbkg = 0;  $xxBbsBbkg = 0;
  $xBbsGbkg = 0;  $xxBbsGbkg = 0;
  $xBbsRbkg = 0;  $xxBbsRbkg = 0;
  $nAir = 0;      $nBkg = 0;

 while (<>) {
    tr/\n\r//d;               # strip record separator
    @F = split(",");          # split input line on commas

    if (/^D,N/) {       # normal data records
      $xBtsBair += $F[3];  $xxBtsBair += $F[3] * $F[3];
      $xBtsGair += $F[4];  $xxBtsGair += $F[4] * $F[4];
      $xBtsRair += $F[5];  $xxBtsRair += $F[5] * $F[5];
      $xBbsBair += $F[6];  $xxBbsBair += $F[6] * $F[6];
      $xBbsGair += $F[7];  $xxBbsGair += $F[7] * $F[7];
      $xBbsRair += $F[8];  $xxBbsRair += $F[8] * $F[8];
      $nAir += 1;
    }
    if (/^Z/) {               # zero records
      $x = $F[1] - $F[7];     $xBtsBbkg += $x;  $xxBtsBbkg += $x * $x;
      $x = $F[2] - $F[8];     $xBtsGbkg += $x;  $xxBtsGbkg += $x * $x;
      $x = $F[3] - $F[9];     $xBtsRbkg += $x;  $xxBtsRbkg += $x * $x;
      $x = $F[4] - $F[7]/2;   $xBbsBbkg += $x;  $xxBbsBbkg += $x * $x;
      $x = $F[5] - $F[8]/2;   $xBbsGbkg += $x;  $xxBbsGbkg += $x * $x;
      $x = $F[6] - $F[9]/2;   $xBbsRbkg += $x;  $xxBbsRbkg += $x * $x;
      $nBkg += 1;
    }
  }   # end while
```

```
# print out statistics

  $aBtsBair = $xBtsBair / $nAir; $sBtsBair = sqrt( $xxBtsBair / $nAir - $aBtsBair**2 );
  $aBtsGair = $xBtsGair / $nAir; $sBtsGair = sqrt( $xxBtsGair / $nAir - $aBtsGair**2 );
  $aBtsRair = $xBtsRair / $nAir; $sBtsRair = sqrt( $xxBtsRair / $nAir - $aBtsRair**2 );
  $aBbsBair = $xBbsBair / $nAir; $sBbsBair = sqrt( $xxBbsBair / $nAir - $aBbsBair**2 );
  $aBbsGair = $xBbsGair / $nAir; $sBbsGair = sqrt( $xxBbsGair / $nAir - $aBbsGair**2 );
  $aBbsRair = $xBbsRair / $nAir; $sBbsRair = sqrt( $xxBbsRair / $nAir - $aBbsRair**2 );
  $aBtsBbkg = $xBtsBbkg / $nBkg; $sBtsBbkg = sqrt( $xxBtsBbkg / $nBkg - $aBtsBbkg**2 );
  $aBtsGbkg = $xBtsGbkg / $nBkg; $sBtsGbkg = sqrt( $xxBtsGbkg / $nBkg - $aBtsGbkg**2 );
  $aBtsRbkg = $xBtsRbkg / $nBkg; $sBtsRbkg = sqrt( $xxBtsRbkg / $nBkg - $aBtsRbkg**2 );
  $aBbsBbkg = $xBbsBbkg / $nBkg; $sBbsBbkg = sqrt( $xxBbsBbkg / $nBkg - $aBbsBbkg**2 );
  $aBbsGbkg = $xBbsGbkg / $nBkg; $sBbsGbkg = sqrt( $xxBbsGbkg / $nBkg - $aBbsGbkg**2 );
  $aBbsRbkg = $xBbsRbkg / $nBkg; $sBbsRbkg = sqrt( $xxBbsRbkg / $nBkg - $aBbsRbkg**2 );

  printf "Total\tFiltered Air\tMean\tBlue\t%8.3f\t1/Mm\n",  $aBtsBair*1E6;
  printf "Total\tFiltered Air\tMean\tGreen\t%8.3f\t1/Mm\n", $aBtsGair*1E6;
  printf "Total\tFiltered Air\tMean\tRed\t%8.3f\t1/Mm\n",   $aBtsRair*1E6;
  printf "Back\tFiltered Air\tMean\tBlue\t%8.3f\t1/Mm\n",   $aBbsBair*1E6;
  printf "Back\tFiltered Air\tMean\tGreen\t%8.3f\t1/Mm\n",  $aBbsGair*1E6;
  printf "Back\tFiltered Air\tMean\tRed\t%8.3f\t1/Mm\n",    $aBbsRair*1E6;
  printf "Total\tFiltered Air\tStdDev\tBlue\t%8.3f\t1/Mm\n",      $sBtsBair*1E6;
  printf "Total\tFiltered Air\tStdDev\tGreen\t%8.3f\t1/Mm\n",     $sBtsGair*1E6;
  printf "Total\tFiltered Air\tStdDev\tRed\t%8.3f\t1/Mm\n", $sBtsRair*1E6;
  printf "Back\tFiltered Air\tStdDev\tBlue\t%8.3f\t1/Mm\n", $sBbsBair*1E6;
  printf "Back\tFiltered Air\tStdDev\tGreen\t%8.3f\t1/Mm\n",      $sBbsGair*1E6;
  printf "Back\tFiltered Air\tStdDev\tRed\t%8.3f\t1/Mm\n",  $sBbsRair*1E6;
  printf "Total\tBackground\tMean\tBlue\t%8.3f\t1/Mm\n",    $aBtsBbkg*1E6;
  printf "Total\tBackground\tMean\tGreen\t%8.3f\t1/Mm\n",   $aBtsGbkg*1E6;
  printf "Total\tBackground\tMean\tRed\t%8.3f\t1/Mm\n",           $aBtsRbkg*1E6;
  printf "Back\tBackground\tMean\tBlue\t%8.3f\t1/Mm\n",           $aBbsBbkg*1E6;
  printf "Back\tBackground\tMean\tGreen\t%8.3f\t1/Mm\n",    $aBbsGbkg*1E6;
  printf "Back\tBackground\tMean\tRed\t%8.3f\t1/Mm\n",            $aBbsRbkg*1E6;
  printf "Total\tBackground\tStdDev\tBlue\t%8.3f\t1/Mm\n",  $sBtsBbkg*1E6;
  printf "Total\tBackground\tStdDev\tGreen\t%8.3f\t1/Mm\n", $sBtsGbkg*1E6;
  printf "Total\tBackground\tStdDev\tRed\t%8.3f\t1/Mm\n",   $sBtsRbkg*1E6;
  printf "Back\tBackground\tStdDev\tBlue\t%8.3f\t1/Mm\n",   $sBbsBbkg*1E6;
  printf "Back\tBackground\tStdDev\tGreen\t%8.3f\t1/Mm\n",  $sBbsGbkg*1E6;
  printf "Back\tBackground\tStdDev\tRed\t%8.3f\t1/Mm\n",    $sBbsRbkg*1E6;

exit 0;
```

(end of program)