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Real time data acquisition and computation software package for Aethalometer

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Abstract
In this technical report we discuss about the design, development and implementation of the real time data acquisition, visualization and computation software package for the aethalometer. The graphical user interface (GUI) application software used for data acquisition, computation and visualization has been developed in-house using Microsoft Visual Basic 2010.NET rapid application development object oriented programming language. The software package has been designed and developed to work with all the existing aethalometers at Aerosol Monitoring Laboratory, PRL (Model no. AE31, AE33 and AE42). The software acquires the real time black carbon (BC) concentrations data from aethalometer using either interrupt (AE33 and AE42) or polling (AE33) mode of serial data communications. It computes the aerosol absorption coefficients (β_{abs}) at 370, 470, 520, 590, 660, 880, and 950 nm wavelengths using user configured algorithm. It also determines the $\AA$ngstr$\ddot{o}$m absorption exponent (AAE) and the percentage frequency distribution of AAE for the wavelength pairs; 370-950, 370-880, 370-590, 370-520, 450-700, 520-880, 520-950, 590-880 and 590-950 nm. It displays the black carbon concentrations data at 370, 470, 520, 590, 660, 880, and 950 nm, along with the real time diurnal plot of the averaged black carbon concentrations. The composite data (BC, β_{abs}, AAE) are logged into an ASCII file on daily basis. The software package also computes and saves the hourly and daily average along with standard deviation of the composite data, at the end of the day. The details about the aethalometer, aerosol absorption coefficients, $\AA$ngstr$\ddot{o}$m absorption exponent, data acquisition and visualization software are presented in this technical note.

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Contents

1. Introduction

Black Carbon (BC) is that fraction of aerosol particulate matter that is insoluble in polar and non-polar solvents. It is the most strongly light-absorbing component of particulate matter in the visible spectrum [3], and is primarily formed in the Earth's atmosphere by anthropogenic sources (incomplete combustion of fossil fuels, biofuels, and biomass). BC is the second leading cause of global warming, after carbon dioxide (CO_2) [5]. They adversely affect public health; contribute to local and global climate change; and reduce visibility. The study of black carbon aerosols is important because its own direct and indirect effects and also used as a tracer to indicate the transport of meteorological air masses. Aethalometer is an instrument that uses optical analysis to determine the mass concentration of BC particles in the ambient atmosphere. In the present work we will discuss about the in-house developed real time data acquisition, visualization and various aerosol properties (aerosol absorption coefficients and $\AA$ngstr$\ddot{o}$m absorption exponents) computation application software package for Aethalometer (AE31, AE33 and AE42).

2. Aethalometer

Aethalometer is a state-of-the-art instrument used to sample and measure the black carbon mass concentrations in the ambient air at seven different wavelengths from UV to IR regime (UV: 370 nm, Blue: 470 nm, Green: 520 nm, Yellow: 590 nm, Red: 660 nm, IR-1: 880 nm and IR-2: 950 nm). Different versions of aethalometer are developed and manufactured by Magee Scientific, USA viz; portable aethalometer for mobile operation (Model no. AE42), rack mount aethalometers for continuous operation (Model no. AE31 and AE33) and micro aethalometer for weather balloon and mobile operations (Model no. AE51). Aethalometer model no AE33 is the modified and upgraded version of aethalometer AE31. Table 1 shows the general specifications of different models of aethal-

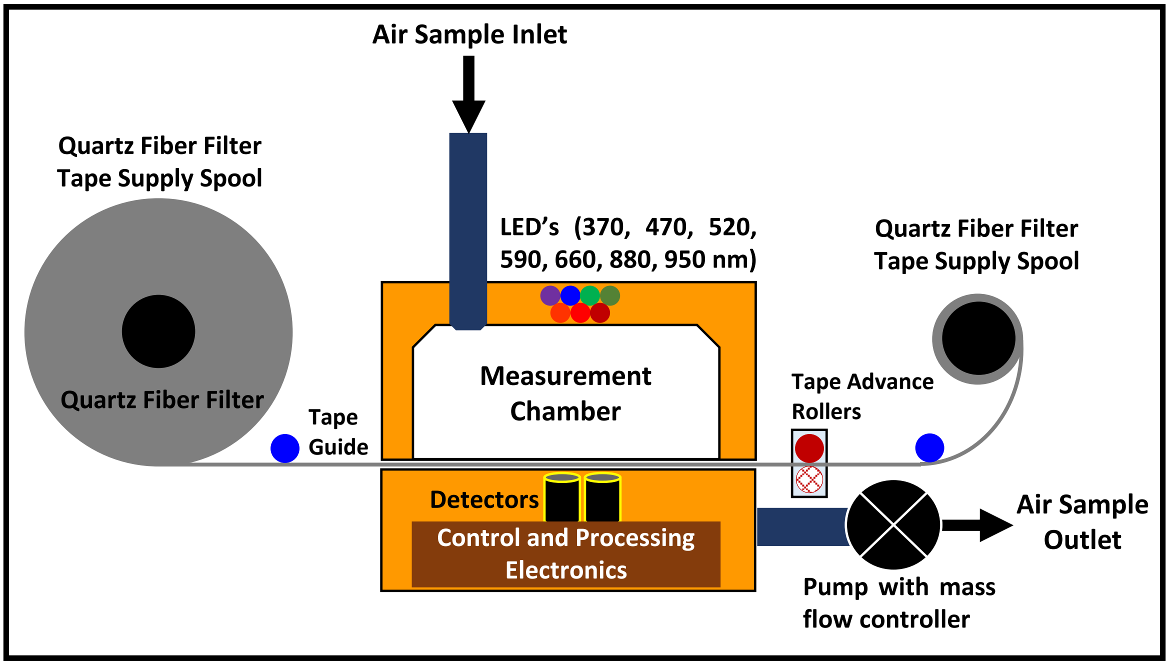

Figure 1. Schematic of aethalometer

Figure 2. Aethalometer AE42-portable type (left), AE31-rack mount (center), AE33-rack mount (right)

Table 1. Specifications of Aethalometer

Sr. No.	Parameter	Specifications
1	Wavelengths	370, 470, 520, 590, 660, 880, and 950 nm
2	Optical Source	LED
3	Sample Collection Media	Quartz fiber filter tape (AE42 and AE31) Teflon-coated glass fiber filter tape (AE33)
4	Resolution	1 ng/m^3
5	Measurement Time Base	2 – 15 min (user selectable – AE42 and AE31) 1 second or 1 min (user selectable – AE33)
6	Air flow rate	User programmable 2-5 LPM
7	Internal Vacuum Pump	Dual diaphragm, brushless motor
8	Communication	RS-232 (AE42 and AE31) RS-232, Ethernet, and USB ports (AE33)

ometer (available and in continuous operation at Aerosol Monitoring Laboratory) (Figure 2). It measures black carbon mass concentrations from the attenuation of light beam transmitted through the sample accumulated on a 1.67 sq. cm quartz fibre filter, which is proportional to the amount of black carbon mass loading in the filter [4]. It uses an optical source assembly that incorporates seven different solid-state light sources at 370, 470, 520, 590, 660, 880 and 950 nm wavelength and each source has emission spectra with a typical half-width of 20 nm. These sources are activated sequentially to illuminate the aerosol sample at seven discrete wavelengths each time base cycle. A quartz fibre filter tape is pulled between the optical sources and detectors as shown in Figure 1. The principle of the aethalometer is to measure the attenuation of a beam of light transmitted through a filter, while the filter is continuously collecting an aerosol sample. Attenuation is measured through a ”Sensing” spot of the filter, on which the aerosol is collected, and a ”Reference” spot of the filter, as a check of the stability of the optical source. The basic algorithm used to calculate the aerosol black carbon concentrations in the sampled air stream is based on the following measurements: (a) measurements of the Reference and Sensing beam detector outputs with the lamps OFF, to determine their zero offsets (b) measurements of the Reference and Sensing beam detector outputs with the lamps ON, to determine the transmitted light intensities (c) measurement of the air flow through the system (d) knowledge of the active collecting area of the spot on the filter, and of the specific attenuation of the particular combination of light source, detector, optical components and the filter medium in use. Black carbon mass concentration ($M_{blackcarbon}(\lambda)$) is computed from the attenuation of light as $M_{blackcarbon}(\lambda)$ = (Atn(t + $\triangle$t) / σ) * (A / V), where t is the sampling time interval, V (= flow rate * sampling time) is the volume of the air sampled between t + $\triangle$t and t, A is the aerosol collecting spot area of filter (1.67 sq. cm) and σ is the wavelength dependent specific attenuation cross section (m^2g^{-1}). σ at different wavelengths for Magee Scientific Aethalometer are given as 14625/λ. Table 2 shows the σ values at different wavelengths for aethalometer AE31, AE33 and AR42. It is operated continuously at a pre-defined flow rate and time resolution in an automated mode, under which the filter tape advances when the attenuation at 370 nm reaches 75. We are periodically cleaning the optical chamber, calibrating the flow meter and replacing the quartz fiber tape and bypass filter cartridge.

3. Aerosol absorption coefficients

The fraction of incident radiant energy removed by absorption per length of travel of radiation through the atmosphere is defined as absorption coefficient ($\beta_{abs-raw}$). It is also defined as the absorption component of aerosol extinction coefficient and computed as $\beta_{abs-raw}$ = BC * σ. A correction is required to provide the real aerosol absorption coefficient (β_{abs}) because of (1) the multiple scattering of the light beam within the filter fibers when the filter is relatively unloaded with aerosols and (2) the shadowing effect of the particles which occurs as the filter gets more highly loaded. The corrections are performed using the procedure described by Weingartner et. al. (2003)[9] and is given as β_{abs} = $\beta_{abs-raw}$ / (C * R), where C

Table 2. Specific attenuation cross sections for Aethalometer

Sr. No.	Wavelength (nm)	$\sigma(\mathbf{m}^2 g^{-1})$
1	370	39.5
2	470	31.1
3	520	28.1
4	590	24.8
5	660	22.2
6	880	16.6
7	950	15.4

Figure 3. GUI application software for Aethalometer

factor is used to correct the multiple scattering within a relatively clean filter and the R factor corrects for the shadowing effect. The value of C was empirically determined and given by Bodhaine (1995) [2], Weingartner et. al. (2003) [9], Arnot et. al. (2005) [1], Schmid et. al. (2006) [7] for seven different wavelengths (Table 3). The correction for shadowing effect (R) which is a function of attenuation is given as R = [(f^{-1} -1)*[ln(Atn)-ln(10%)]*[ln(50%)-ln(10%)]$^{-1}$] + 1 [9]. f is the free parameter which relates to the slope of this linear function and Weingartner et. al. (2003) suggest two methods for its estimation; (1) using two identical collocated aethalometer and (2) collocated simultaneous measurement of scattering coefficients. In order to compute the real time spectral absorption coefficients both the above methods were not applicable and in the present work we have used R=1 typically observed for an urban location. Sandradewi et. al. (2008) has statistically estimated the f values over an urban location as 1.148, 1.134, 1.127, 1.118, 1.078 and 1.068 at 370, 470, 520, 590, 660, 880 and 950 nm respectively, which shows $< \pm 4\%$ change in the f values [6]. β_{abs} values at 450, 550 and 700 nm are interpolated using the measured β_{abs} values at 370, 470, 520, 590, 660, 880 and 950 nm, as the β_{abs} values at 450, 550 and 700 nm are required further to study along with collocated aerosol scattering coefficients (β_{scat}) at 450, 550 and 700 nm.

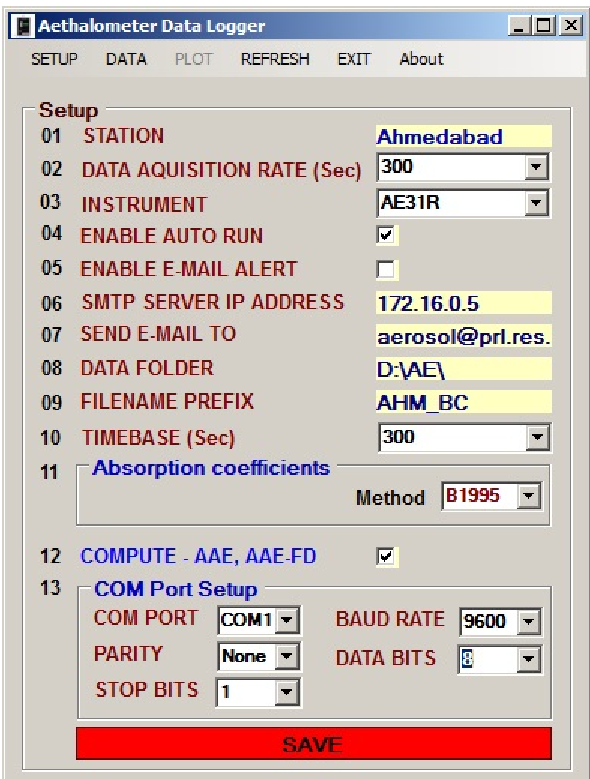

Figure 4. Setup configuration for Aethalometer data logger

4. *Å*ngstr*ö*m absorption exponents

The *Å*ngstr*ö*m absorption exponent (AAE) gives the change in light absorption as a function of wavelength and is calculated as: AAE = $-\ln(\beta_{abs_{\lambda 1}}/\beta_{abs_{\lambda 2}})/\ln(\lambda_1/\lambda_2)$. Typically, graphitic carbon has an AAE of $\tilde{1}$, biomass burning has been reported AAE's of about 2 and AAE's of up to 6 have been reported for pure HULIS (humic-like substances). Higher values of AAE signifies the dominance of smaller size particles and viceversa. In the present work, we have computed AAE for the following wavelength pairs; 370-950, 370-880, 370-590, 370-520, 450-700, 520-880, 520-950, 590-880 and 590-950 nm.

Table 3. C values from Bodhaine, 1995 (B1995), Weingartner et. al., 2003 (W2003), Arnott et. a., 2005 (A2005), Schmid et. al., 2006 (S2006) at 370, 470, 520, 590, 660, 880 and 950 nm

Wavelength (nm)	B1995	W2003	A2005	S2006
370	1.2299	3.78	1.813	2.355
470	1.5877	3.78	2.073	2.656
520	1.7666	3.78	2.076	2.677
590	2.0170	3.64	2.104	2.733
660	2.2675	3.64	2.182	2.827
880	3.0546	3.50	2.226	2.933
950	3.3051	3.50	2.199	2.925

5. Aethalometer data logger

The aethalometer does not have any real time data acquisition and visualization software for black carbon concentrations. We have designed, developed and implemented real time data acquisition, visualization and computational software package "Aethalometer Data Logger, Ver: AE.2014.3.B" for aethalometer (Model AE31, AE33 and AE42). It can acquire and display the real time black carbon concentrations at 370, 470, 520, 590, 660, 880 and 950 nm. It also computes the aerosol absorption coefficients at seven different wavelengths, *Å*ngstr*ö*m absorption exponent at 370-950, 370-880, 370-590, 370-520, 450-700, 520-880, 520-950, 590-880 and 590-950 nm wavelengths pair, and *Å*ngstr*ö*m absorption exponent percentage frequency distribution for the AAE ranges 0-1, 1.0-1.5, 1.5-2.0, 2.0-2.5, and 2.5-3.0.

Graphical user interface software package is made compatible to Microsoft Windows 7/8.x operating system with .NET framework. Aethalometer uses an ASCII-based communication protocol in the form of strings through its RS232 serial port. The computer is interfaced with aethalometer via serial crossover cable (standard serial cable with null modem adapter). The software has been developed to work with these ASCII-based communication protocols. The instrument AE31 and AE42 can be operated in Interrupt mode while AE33 can be operated in polling mode of serial data communications (factory default settings). The instrument AE31 and AE42 dumps the black carbon concentrations data once per timebase period and the software is programmed to read the data using interrupt mode of serial data communication. Table 4 shows the serial commands for the instrument AE33, where the instrument time is first synchronized with the data acquisition computer and then the black carbon concentrations data is requested for every measurement.

Figure 5. Aethalometer data screen during data acquisition operation

Table 4. Data request serial commands for aethalometer AE33

Serial Command	Remarks
$AE33:TyyyyMMddHHmmss[CR] where, yyyy – year MM – month dd – day HH – hour (24 Hr format) mm – minute ss – second	Synchronize time with the computer
$AE33:D1[CR]	Request last measurement data

6. Software Design and Implementation

The in-house developed real time data acquisition, visualization and computation program has been written in Microsoft Visual Basic 2010.NET an object-oriented programming language. It is a multi-paradigm, high level programming language, implemented on the .NET Framework which enables the rapid application development of graphical user interface (GUI) application software [8]. The asynchronous serial data acquisition is established through 'SerialPort' class in VB.NET using 'System.IO.Ports' namespace [10]. The ASCII file read and write operation have been implemented using System.IO namespace with 'FileStream' class [11]. The instantaneous dynamic plot has been implemented using ZedGraphControl class which provides a user control interface to the 'ZedGraph' class library [12]. The graphpane (plot) can be zoomed or panned by the user, either via a mouse drag operation or by the context menu commands. The timer control has been used to trigger the real-time serial data acquisition subroutine and it plays an important role in the GUI based application programming. Aethalometer can be interfaced with a computer using RS232 DB9 serial port or laptop through USB port (USB to RS232 serial converter). The aethalometer and computer has been configured for asynchronous serial communication with the following serial port settings; baud rate: 9600 (AE31 and AE42) and 115200 (AE33), parity: none, data bits: 8, stop bit: 1 and flow control: none. The real time black carbon concentrations at 370, 470, 520, 590, 660, 880 and 950 nm are measured and then computed aerosol absorption coefficients (β_{abs}) and Ångström absorption exponent (AAE) data are written into the daily generated data file in ASCII format. The setup and deployment packages was developed using the in-built deployment tool in VB 2010.NET. The GUI application works in Microsoft Windows 7/8.x operating system with .NET framework.

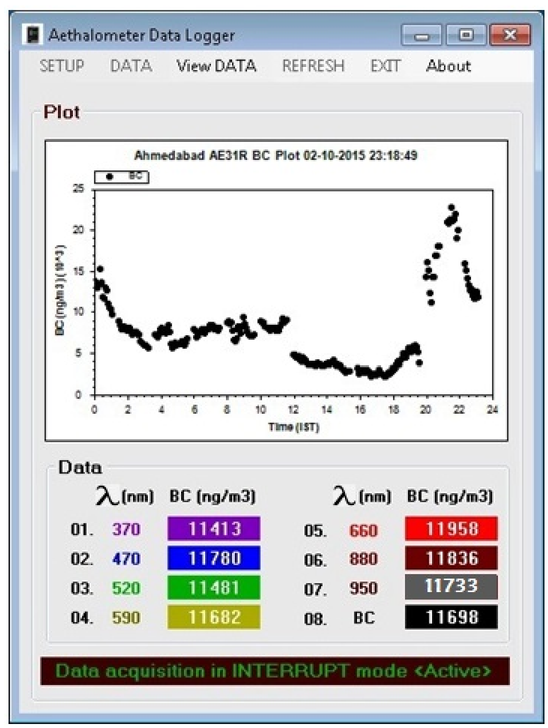

Figure 6. Real time averaged BC diurnal plot in the Aethalometer Data Logger software

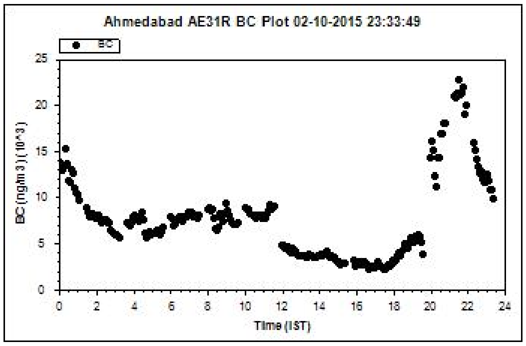

Figure 7. Averaged BC diurnal plot for October 02, 2015 at Ahmedabad

7. Software functions and processes

The ”Aethalometer Data Logger” (version: AE.2014.3.B) GUI application package consists of six operational menu strip items; (i) SETUP (ii) DATA (iii) PLOT (iv) REFRESH (v) EXIT and (vi) ABOUT as shown in Figure 3. The software can be configured through ’SETUP’ menu strip item (Figure 4) and the various user editable parameters in the Setup frame are (a) Station name, (b) Data Acquisition rate (in seconds), (c) Instrument type (AE31R for rack mount aethalometer model AE31, AE33R for latest rack mount aethalometer model AE33 and AE42P for portable aethalometer model AE42), (d) Auto Run (auto enable the program once the GUI application is loaded in the computer startup program after 10 sec), (e) Email Alert (transmits system generated alert to the configured email ID), (f) SMTP server IP address (172.16.0.5), (g) Send Email To, (h) Data folder, (j) Filename prefix, (k) Instrument Time Base (in seconds), (l) Aerosol absorption coefficients computation methods, (m) Compute *Å*ngstr*ö*m absorption exponent (AAE) and *Å*ngstr*ö*m absorption exponent frequency distribution (AAE-FD), and (n) Serial port setup (Com port ID, data baud rate (9600 for AE31 and AE42, 115200 for AE33), parity (none), Data bits (8), Stop bit(1)). The ’DATA’ menu strip item is used to view the real-time black carbon concentrations data at seven wavelengths (370, 470, 520, 590, 660, 880 and 950 nm) along with the configured setup parameters. The ’REFRESH’ button reloads and initialize the system variables and ’EXIT’ command closes the ASCII setup file, ASCII data file and serial port (if exists in open state), and quits the application software. ABOUT button shows the software user guide and contact information. When the GUI application software is executed for the first time in a computer, it will prompt to configure the application setup and the setup parameters are saved in AE_Setup.txt file in the configured folder. The software is programmed to detect the available serial port (physical or logical) and enumerate the com ports in the com port setup frame. The software reads the system setup and configures the computer serial port and the system variables. Depending upon the user instrument configuration the software chooses the corresponding mode of serial data communication. The data acquisition operation can be initiated using ”START” command button. It starts acquiring the data and displays the instantaneously measured black carbon concentrations at 370, 470, 520, 590, 660, 880 and 950 nm wavelengths (Figure 5). When the data acquisition program is active except ’PLOT’ menu strip item and ”STOP” command button all other items are disabled (Figure 5). The data acquisition can be stopped using the ”STOP” command button. The ’PLOT’ menu strip is used to display the real time plot of the averaged black carbon concentrations along with BC concentration data in the tabular format at all the wavelengths (Figure 6). It logs the instantaneous acquired data into ASCII file on daily basis. The software can also be configured to upload the daily data file and system alert (if any) to the configured email address through SMTP server. At the end of the day the application package auto saves the averaged black carbon concentration diurnal plot in JPG format (Figure 7) for the user ready references.

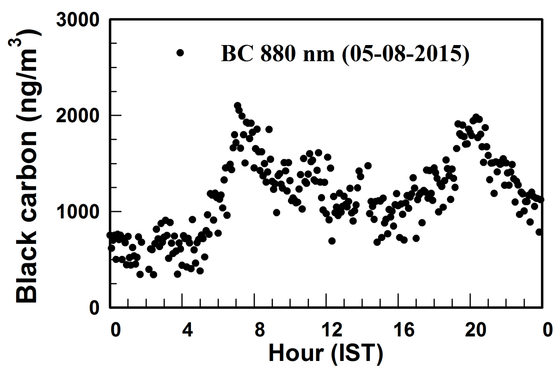

Figure 8. Diurnal variation of black carbon at 880 nm over Ahmedabad observed on August 08, 2015

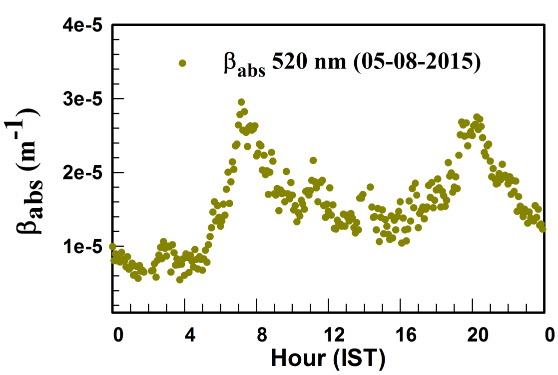

Figure 9. Diurnal variation of aerosol absorption coefficients (β_{abs}) at 520 nm over Ahmedabad on August 08, 2015

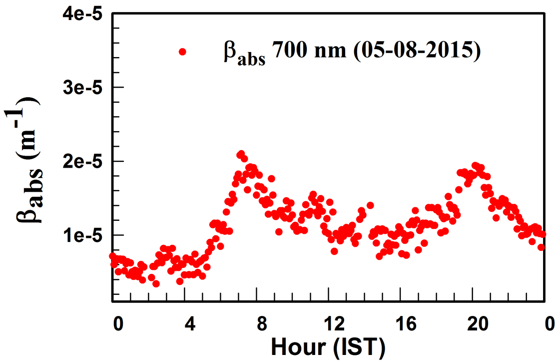

Figure 10. Diurnal variation of aerosol absorption coefficients (β_{abs}) at 700 nm over Ahmedabad on August 08, 2015

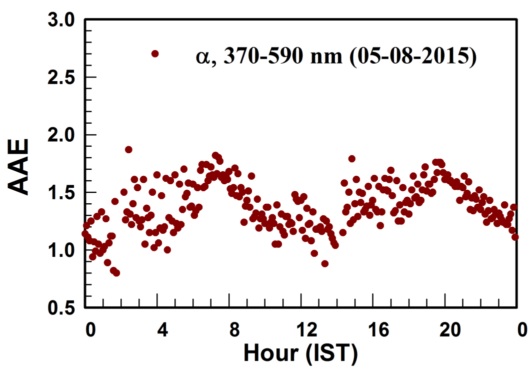

Figure 11. Diurnal variation of Ångstr$\ddot{o}$m absorption exponent (AAE) for the wavelength pair 370-590 nm over Ahmedabad on August 08, 2015

As a sample case study, we have plotted certain parameters from the daily logged data file. Figure 8 shows the measured black carbon (BC) concentrations at 880 nm over Ahmedabad on August 05, 2015. BC shows strong diurnal variation with maxima and minima. The diurnal variation of BC is mainly influenced by the diurnal evolution of atmospheric boundary layer, which depends on the Earth's surface temperature and remains low during early morning hours and gradually increases with decreasing solar zenith angle and reaches a maximum height at noontime and then starts decreasing in the evening with increasing solar zenith angle. Aerosol absorption coefficients (β_{abs}) also shows strong diurnal variation and β_{abs} at 520 and 700 nm over Ahmedabad is shown in Figure 9 and 10 respectively. The β_{abs} at 700 nm has interpolated using the β_{abs} data at 370, 470, 520, 590, 660, 880 and 950 nm. Figure 11 and 12 shows the Ångstr$\ddot{o}$m absorption exponent (AAE) for the wavelength pairs 370-590 and 450-700 nm for August 05, 2015 over Ahmedabad. The percentage frequency distribution of the Ångstr$\ddot{o}$m absorption exponent for the wavelength pair 370-590 nm is shown in Figure 13, which reveals the dominance of AAE in the range 1-1.5. The higher values of AAE during the diurnal maxima reveals the dominance of smaller size particles (fine mode). In addition, the software package also computes the hourly and daily average data along with its standard deviation for black carbon concentrations at 370, 470, 520, 590, 660, 880 and 950 nm, Aerosol absorption coefficients and Ångstr$\ddot{o}$m absorption exponent for the wavelength pairs; 370-950, 370-880, 370-590, 370-520, 450-700, 520-880, 520-950, 590-880 and 590-950 nm. It logs the real time measured BC along with the computed β_{abs} and AAE as *.DAT file (Figure 14). The hourly averaged composite data (BC, β_{abs} and AAE) is saved as *.HAV data file (Figure 15). In addition, it also generates the *.AFD for the percentage frequency distribution of the AAE in the different pre designated bins. The package generates the monthly data file with daily averaged composite data.

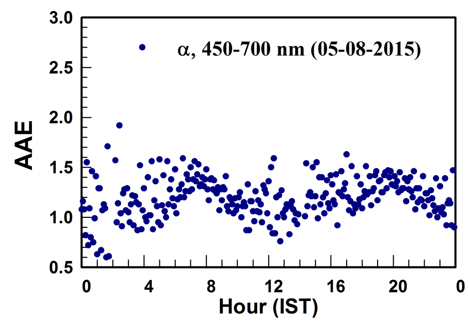

Figure 12. Diurnal variation of Ångstr$\ddot{o}$m absorption exponent (AAE) for the wavelength pair 450-700 nm over Ahmedabad on August 08, 2015

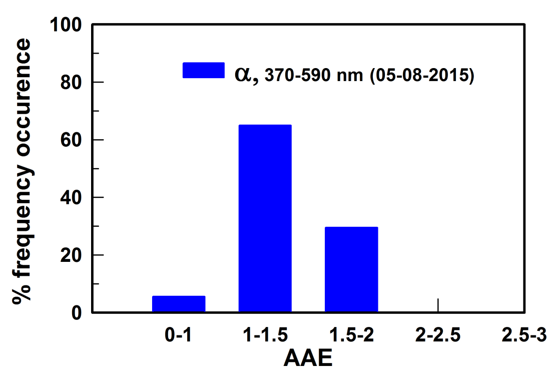

Figure 13. Percentage frequency distribution of Ångstr$\ddot{o}$m absorption exponent (AAE) for the wavelength pair 370-950 nm observed over Ahmedabad on August 08, 2015

8. Summary

The real time data acquisition, visualization and aerosol properties computation software has been designed, developed and successfully implemented for aethalometer (Magee Scientific AE31, AE33 and AE42) at Aerosol Monitoring Laboratory (AML), Space and Atmospheric Sciences Division, Physical Research Laboratory, Ahmedabad. The "Aethalometer

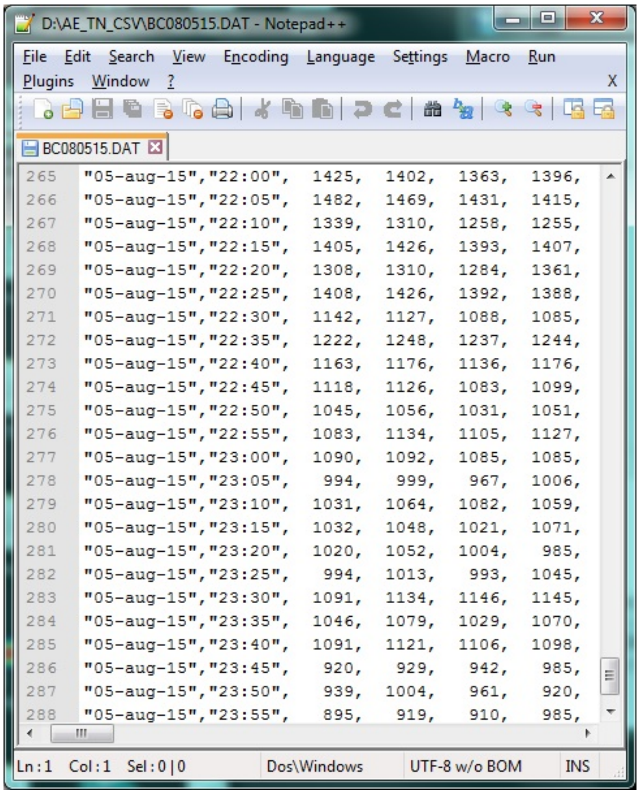

Figure 14. Composite data file for August 08, 2015 over Ahmedabad

Data Logger is a state-of-the-art software which acquires the data from the different models of Aethalometer through serial RS232 communication using interrupt (AE31 and AE42) or polling (AE33) mode of data communication. It computes in real time the aerosol absorption coefficients (β_{abs}) using the user configured computation method at 370, 470, 520, 590, 660, 880 nm and 950 nm wavelengths. It also determines the *Å*ngstr*ö*m absorption exponent (AAE) for the wavelength pairs; 370-950, 370-880, 370-590, 370-520, 450-700, 520-880, 520-950, 590-880 and 590-950 nm along with its percentage frequency distributions. The instantaneously measured black carbon concentrations and computed aerosol absorption coefficients and AAE are logged into files in ASCII format. The software displays the data and the averaged black carbon concentrations diurnal plot. At the end of the day, the software computes and saves the hourly and daily average of the BC, β_{abs} and AAE. The software package is made compatible to Microsoft Windows 7/8.x operating system with .NET framework. The software is made available in the installer setup and deployment format.

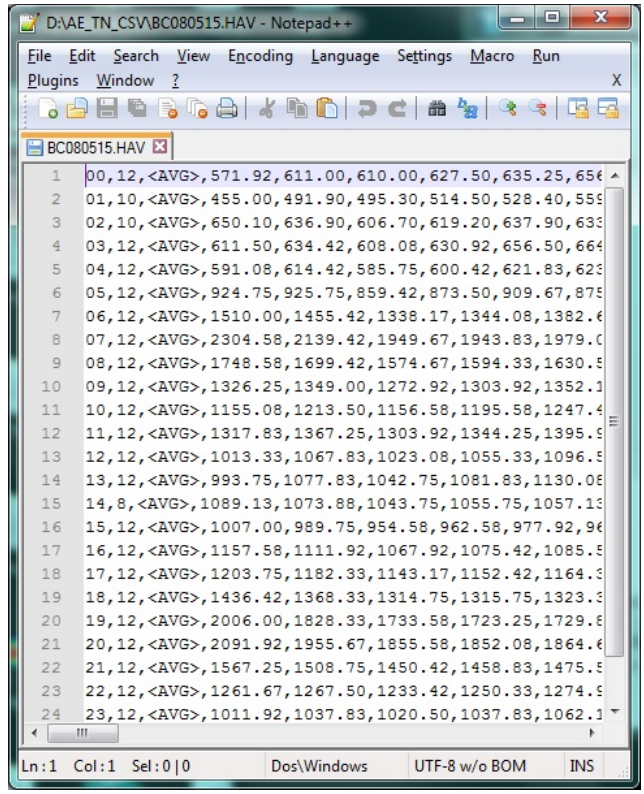

Figure 15. Hourly averaged composite data file for August 08, 2015 over Ahmedabad

9. Acknowledgements

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