AEROSOL
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Aethalometer® – AE36

Smartest way to monitor Black Carbon: Traffic and Biomass Burning pollution

White paper

Ljubljana, February 2024

Aethalometer® - AE36

Contents

1. Summary

The Aethalometer is the most widely used filter photometer capable of measuring the light-absorbing properties of aerosol particles. Its robust design, ease of use, and quality data allow it to be used in different environments and numerous applications. The new AE36 is built upon the existing well-proven and rugged design. We improved the performance of the Aethalometer, making it insensitive to Relative Humidity (RH) changes, lowering the Limit of detection (LOD), and making the Instrument's operation even smoother with the new point-of-load electronics design. It is made to run unattended for a very long time thanks to the new self-cleaning procedure, 2-times longer filter tape, and the new RAS (Remote Access System) module in the updated CAAT software for a seamless network connection wherever you are. To add ease of use, we redesigned the graphical user interface, including real-time data visualization, providing a quick check of the data on-site. Data handling is now faster with automatic data validation, and the implemented BC Index makes communicating pollution levels to the public easier. The AE36 is thus the first Instrument in the World that helps authorities follow WHO 2021 recommendations in developing standards or targets for ambient Black Carbon (BC) concentrations.

The most important new features of the AE36 are:

- The new filter compartment design eliminates the Instrument's sensitivity to the changes in RH.
- Real-time BC Index.
- Graphical presentation of data in time series or wind-rose.
- Even longer autonomy with a 20m filter tape option
- Simplified maintenance with the self-cleaning procedure.
- Automatic data validation with new status control.
- Straightforward network connection for remote management and data transfer with Remote Access Software (RAS).
- The time interval of data acquisition is adapted to the Air Quality measurement networks (1 min and 5 min).
- Hermetic seals prevent the ingress of dust and moisture.

The AE36 keeps the most essential features of its predecessor:

- Patented 'Dual Spot' technology eliminates the data artifact due to filter loading.
- Integrates with TCA08 for OC/EC analysis.
- Analysis at multiple wavelengths allows real-time BC source apportionment to fossil fuel and biomass burning.
- Automatic flow calibration procedure using external standards ensures accuracy.
- Built-in 'zero' test from internal clean-air source checks leakage and noise.
- 'Span' test of optical detectors using external standards validates performance.
- Front-panel USB ports provide local download without interruption of data.
- Low power consumption (30 W) permits off-grid use.
- Completely automatic operation upon power-up provides continuity.
- Direct coupling to CO_2 sensor (optional accessory) integrates BC and CO_2 data.
- Direct coupling to meteorology sensor (optional accessory) reports P, T, and RH permits calculation of BC concentration data under 'local' conditions.
- AE36 data can be transferred to the Carbonaceous Aerosol Analysis Tool (CAAT), a desktop software for advanced analysis (averaging, diurnal profiles, calculating Brown Carbon (BrC), etc.).

2. DualSpot™ technology

The AE36 Aethalometer uses the patented Dual Sport™ method to compensate for the 'spot loading effect' and also to provide a real-time output of the 'loading compensation' parameter, which may provide additional information about the physical and chemical properties of the aerosol (Drinovec et al., 2015).

The 'spot loading effect' is a variable phenomenon that gradually reduces instrumental response as the aerosol deposit density of the filter tape increases from zero to the predetermined Limit of 'Maximum Attenuation.' When the filter tape advances to a fresh spot, the data undergoes a discontinuous jump from its previous lower value, calculated when the spot was heavily loaded, to a higher value, calculated from collection on a fresh spot at zero loading. In the Aethalometer, the reduction of data at increasing loadings is well described by a linear function of attenuation, but its magnitude cannot be predicted: some aerosols in some locations in some seasons may show a small or zero 'loading effect,' while under other conditions, the effect may be more significant and noticeable. Empirically, it is found that fresher aerosols closer to their combustion sources will show a more substantial spot loading effect'. In contrast, well-aged aerosols with high chemical activity and oxidative processing may show almost zero effect under atmospheric conditions. The effect is revealed statistically by processing data collected over many tape advances, representing many data points collected at loadings, i.e., attenuation (ATN) values ranging from zero to the preset maximum. The data is collected into bins according to loading. Suppose the calculated result is systematically reduced as a loading function. The data will show a clear negative slope, with the intercept representing the 'zero loading' value.

An instrument based on firmware with a fixed 'loading non-linearity' parameter will not operate correctly at all locations. The 'loading non-linearity' parameter must be measured.

Thus, the loading effect phenomenon can be represented as

$$\text{BC (reported)} = \text{BC (zero loading)} * \{ 1 - k \cdot \text{ATN} \}$$

BC (zero loading) is the desired ambient BC value obtained without any loading effect, and k is the 'loading compensation parameter'.

The analysis of many datasets from various locations shows that this relationship is linear in all cases studied; but with different values of k. It is, therefore, possible to eliminate the 'loading effect' of k by making two simultaneous identical measurements, BC1 and BC2, at different degrees of loading ATN_1 and ATN_2.

$$BC_1 = BC * \{ 1 - k \cdot ATN_1 \}$$
$$BC_2 = BC * \{ 1 - k \cdot ATN_2 \}$$

We may calculate the 'loading compensation parameter' k and the desired value of BC compensated back to zero loading from these two linear equations.

The AE36 Aethalometer analyzes the Black Carbon component of aerosols on two parallel spots drawn from the same input stream but collected at different accumulation rates, i.e. at different values of ATN. Combining the data according to the above equations, the AE36 yields the value of BC extrapolated back to 'zero loading' and real-time output of the 'loading compensation parameter' k, providing insights into the aerosol nature and composition. This process is performed in real-time for all wavelengths: examining the k values as a function of wavelength provides further information about the aerosol composition. An example of the real-time loading compensation process is shown in Fig. 1 for extreme concentrations of black carbon.

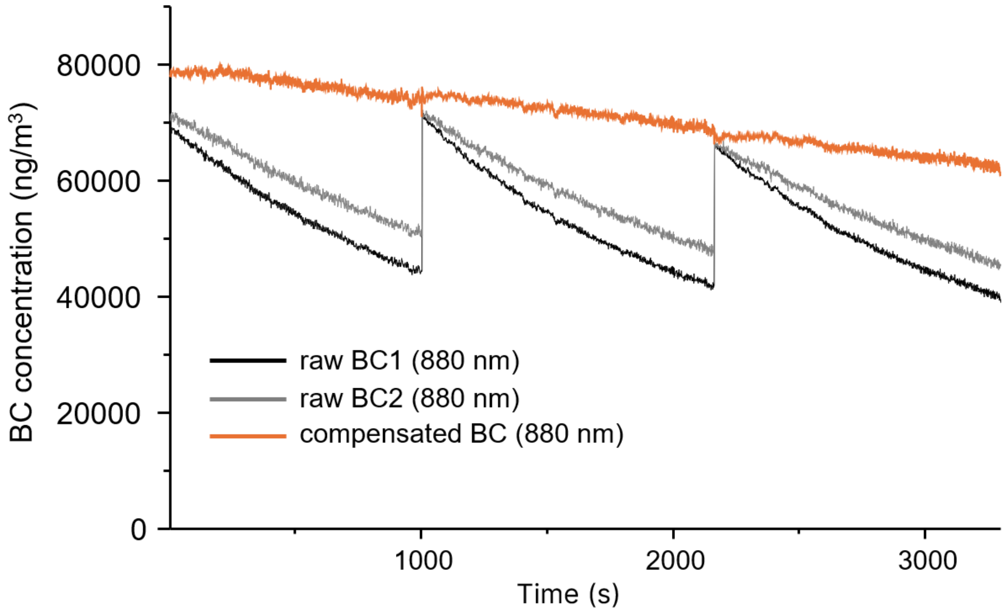

Figure 1 The time-series of Aethalometer raw and compensated BC concentrations with 1 second time base – note the extreme concentrations and loading effects.

Real-time loading compensation is essential for real-time source apportionment (see Chapter 3), as it is based on absorption data at 470 and 950 nm. Without loading compensation, the uncertainty in the source apportionment calculation increases significantly.

Note that 'spot loading effects' are also exhibited by other filter-based BC-measuring instruments (Kanaya et al., 2008; Virkkula, 2010; Hyvärinen et al., 2013). Published results show that the effect is not linear and consequently not readily amenable to mathematical compensation without making assumptions about the nature of the aerosol. However, with patented DualSpot™ technology the properties of aerosol connected to loading effect are not assumed, but measured in real-time.

References:

Drinovec, L., Močnik, G., Zotter, P., Prévôt, A.S.H., Ruckstuhl, C., Coz, E., Rupakheti, M., Sciare, J., Müller, T., Wiedensohler, A., Hansen, A.D.A., 2015. The "dual-spot" Aethalometer: an improved measurement of aerosol black carbon with real-time loading compensation. Atmospheric Meas. Tech. 8, 1965–1979.

Virkkula A., 2010, Correction of the Calibration of the 3-wavelength Particle Soot Absorption Photometer (3λ PSAP), Aerosol Sci. Tech., 44, 706-712.

Hyvärinen et al., 2013, Correction for a measurement artifact of the Multi-Angle Absorption Photometer (MAAP) at high black carbon mass concentration levels, Atmos. Meas. Tech., 6, 81-90.

Kanaya et al., 2008, Mass concentrations of black carbon measured by four instruments in the middle of Central East China in June 2006, Atmos. Chem. Phys., 8, 7637–7649.

3. Source Apportionment

Source apportionment of black carbon concentration is based on the Sandradewi et al. (2008) model, also called the "Aethalometer model", with optical absorption coefficient being a sum of biomass burning and fossil fuel burning fractions. New terminology guidelines for the two fractions of black carbon, i.e. solid fuel and liquid fuel fractions, are also being introduced in some measurement networks. Model is based on the difference in absorption coefficient wavelength dependency assuming that absorption due to the fossil fuel and biomass emissions follow $\lambda^{-\alpha_{ff}}$ and $\lambda^{-\alpha_{bb}}$ spectral dependencies, respectively. The exponents which describe the spectral dependence are called absorption Ångström exponents (AAE). Default values used in the Aethalometer are $\alpha_{ff} = 1$ for fossil fuel and $\alpha_{bb} = 2$ for biomass. The following equations can be used to describe the absorption coefficient from both sources based on 470 nm and 950 nm absorption measurement:

$$\frac{b_{abs}(470\ nm)_{ff}}{b_{abs}(950\ nm)_{ff}} = \left(\frac{470}{950}\right)^{-\alpha_{ff}}$$
$$\frac{b_{abs}(470\ nm)_{bb}}{b_{abs}(950\ nm)_{bb}} = \left(\frac{470}{950}\right)^{-\alpha_{bb}}$$

$$b_{abs}(470\ nm) = b_{abs}(470\ nm)_{ff} + b_{abs}(470\ nm)_{bb}$$
$$b_{abs}(950\ nm) = b_{abs}(950\ nm)_{ff} + b_{abs}(950\ nm)_{bb}$$

where $b_{abs}(\lambda)$ is the absorption coefficient at specified wavelength, λ is wavelength, $b_{abs}(\lambda)_{ff}$ is a fossil fuel fraction and $b_{abs}(\lambda)_{bb}$ a biomass burning fraction of absorption coefficient. Fraction of biomass burning BB(%) of black carbon (BC880) is:

$$BB(\%) = \frac{b_{abs}(950\ nm)_{bb}}{b_{abs}(950\ nm)}$$

Biomass burning and traffic related BC fractions are then calculated as:

$$BC_{bb} = BB/100 \times BC$$
$$BC_{ff} = (1 - BB/100) \times BC$$

An example of the result of such source apportionment measurements in the intensive Comparative Study of Black Carbon and Other Carbonaceous Aerosols in Four South-Eastern European (SEE) Hotspots is depicted in Figure 3.

Settings and presentation

- display of BB % on the Home screen.
- The percentage of BC emitted by biomass burning sources is stored in the Data table, column name BB.

- The algorithm can be fine-tuned by changing the value of absorption Ångström exponents α_{ff} and α_{bb} on the 'Settings' |' Advanced' screen (Aff and Abb settings)
- The calculated values are limited to the 0-100% range.

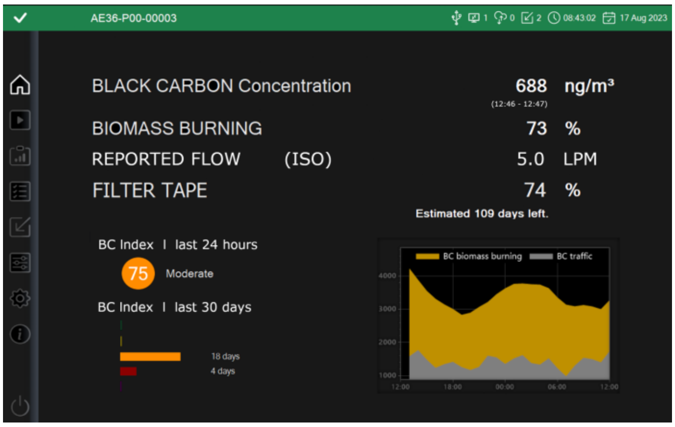

Figure 2 The home screen of the Aethalometer AE36.

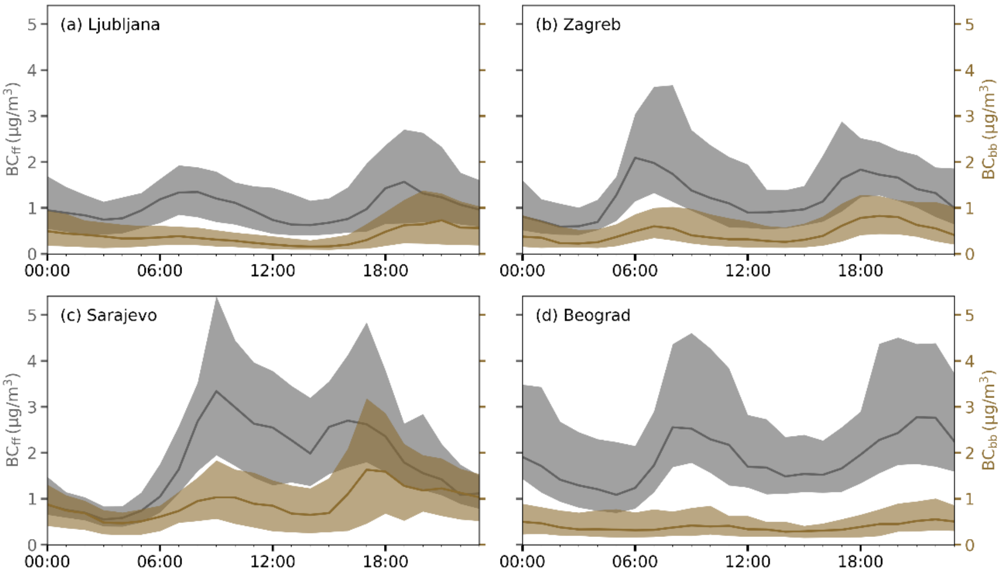

Figure 3 Display of diurnal profiles for BC_{ff} and BC_{bb} for four capital cities in the SEE region: (a) Ljubljana (Slovenia), (b) Zagreb (Croatia), Belgrade (Serbia), and Sarajevo (Bosnia and Herzegovina).

For real-time source apportionment, real-time filter loading compensation with Dual Spot algorithm is needed. The source apportionment algorithm uses compensated data at wavelengths 950 and 470 nm. Using uncompensated measurements introduces a significant uncertainty in the source apportionment calculation since it compares two measurements with different loading effects (loading effect vary with different wavelengths - different k values). Therefore, no filter photometer manufacturer, except AE36 and AE36s, can claim that their Instrument is capable of real-time source apportionment, as they do not have real-time filter loading compensation. The same applies to the real-time BrC model.

Reference

Sandradewi, J. et al. (2008), Using Aerosol Light Absorption Measurements for the Quantitative Determination of Wood Burning and Traffic Emission Contributions to Particulate Matter, Environ. Sci. Technol. 42, 3316–3323.

4. Advanced apportionment of Carbonaceous Aerosol (connectivity to TCA08)

AE36 can be used in the CASS system (Carbonaceous Aerosol Speciation System; AE36 + TCA08) for the advanced TC-BC method (Rigler et al., 2020; Ivančič et al., 2022).

Carbonaceous aerosols (CA) represent extreme diversity and make up a large fraction of ambient fine particulate matter ($PM_{2.5}$), acting as an atmospheric pollutant with critical local, regional, and global importance. The composition of CA provides a characteristic "fingerprint" and indicates the sources of airborne particulate matter.

Carbonaceous aerosol (CA) includes an organic fraction, organic aerosol (OA), and a refractory, strongly light-absorbing fraction referred to as black carbon (BC, optical measurement). The mass of carbon atoms in CA and OA is called total carbon (TC) and organic carbon (OC), respectively. The BC is chemically inert and has a well-defined chemical structure. It is exclusively emitted from incomplete combustion, thus having only a primary origin. OA is directly emitted to the atmosphere in particulate form as primary organic aerosols (POA) by combustion and from biogenic sources, or it can have a secondary origin, named secondary organic aerosols (SOA), formed by the oxidation of volatile organic compounds (VOC) in the atmosphere. Organic aerosol can be further divided into light-absorbing OA, also known as brown carbon (BrC) (Andreae and Gelencsér, 2006; Liu et al., 2020), and non-light-absorbing OA ($OA_{non\text{-}abs}$), both with possible primary and secondary origin (POA_{BrC}, SOA_{BrC}, $POA_{non\text{-}abs}$, $SOA_{non\text{-}abs}$, respectively). While the $OA_{non\text{-}abs}$ have a cooling effect due to the scattering of the sunlight, BrC absorbs solar radiation mainly in the ultraviolet region (Laskin et al., 2015; Moise et al., 2015).

Apportionment of different components of carbonaceous aerosol relies on specific information available in the measured dataset. Simultaneous measurements of BC and TC result in a high-time-resolution organic carbon dataset. Spectrally resolved optical absorption measurements allow further differentiation to BrC and BC, which are closely linked to emission sources. Further information on the primary and secondary components takes advantage of highly time-resolved measurements, which provide important insight into temporal behavior of different components. By applying different apportionment and numerical models from published studies, the CA was finally apportioned into six components (Figure 4):

$$\mathrm{CA(t)} = \mathrm{BC_{ff}(t)} + \mathrm{BC_{bb}(t)} + \mathrm{POA_{non-abs}(t)} + \mathrm{POA_{BrC}(t)} + \mathrm{SOA_{non-abs}(t)} + \mathrm{SOA_{BrC}(t)}$$

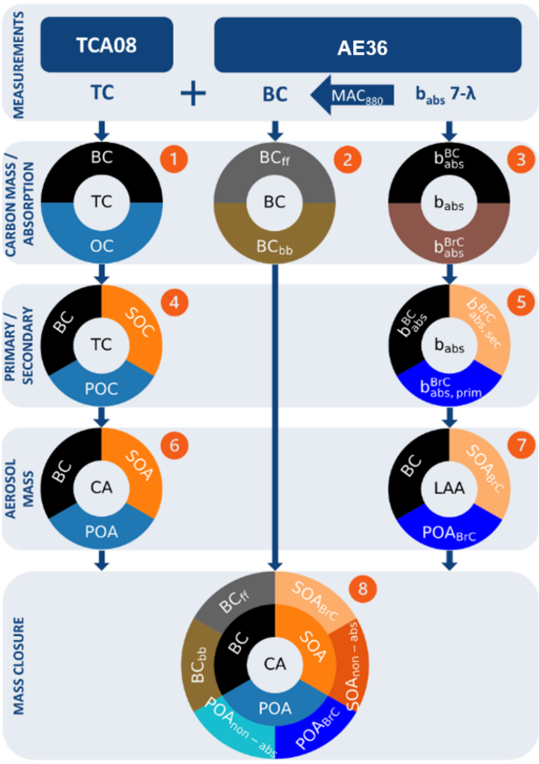

Figure 4: Flowchart for CA apportionment to six components using the following steps: 1. CASS measurements, 2. Aethalometer model, 3. BrC model, 4. BC tracer, 5. BC tracer for BrC, 6. Carbon content OA/OC, POA/POC, SOA/SOC, 7. Conversion of absorption to mass concentration using specific mass absorption cross-sections, 8. Non-light-absorbing OA determination.

References

Rigler, M., Drinovec, L., Lavrič, G., Vlachou, A., Prévôt, A.S.H., Jaffrezo, J.L., Stavroulas, I., Sciare, J., Burger, J., Kranjc, I., Turšič, J., Hansen, A.D.A., Močnik, G., 2020. The new Instrument using a TC–BC (total carbon–black carbon) method for the online measurement of carbonaceous aerosols. Atmospheric Meas. Tech. 13, 4333–4351. https://doi.org/10.5194/amt-13-4333-2020

Ivančič M., Gregorič A., Lavrič G., Alföldy B., Ježek I., Hasheminassab S., Pakbin P., Ahangar F., Sowlat M., Boddeker S., et al. Two-Year-Long High-Time-Resolution Apportionment of Primary and Secondary Carbonaceous Aerosols in the Los Angeles Basin Using an Advanced Total Carbon–Black Carbon (TC-BC(λ)) Method. Sci. Total Environ. 2022;848:157606. doi: 10.1016/j.scitotenv.2022.157606.

Laskin, A., Laskin, J., Nizkorodov, S.A., 2015. Chemistry of Atmospheric Brown Carbon. Chem. Rev. 115, 4335–4382. https://doi.org/10.1021/cr5006167

Moise, T., Flores, J.M., Rudich, Y., 2015. Optical Properties of Secondary Organic Aerosols and Their Changes by Chemical Processes. Chem. Rev. 115, 4400–4439. https://doi.org/10.1021/cr5005259

5. Relative humidity robustness

Filter photometers are sensitive to changes in relative humidity (dRH/dt). Aerosol samples contain water vapor, which can be adsorbed to the fibers or to the binding material of the filter tape used in filter photometers, thus introducing noise in the data (Düsing et al., 2019). Water vapor can reach the filter through the sample inlet or enter through openings in the filter tape compartment, especially in environments where relative humidity changes rapidly (air-conditioned (AC) containers, mobile stations, etc.). The effects on BC measurements due to rapid changes in relative humidity as a result of AC operation in the vicinity of the predecessor of AE36, Aethalometer AE33, are seen in Figure 5.

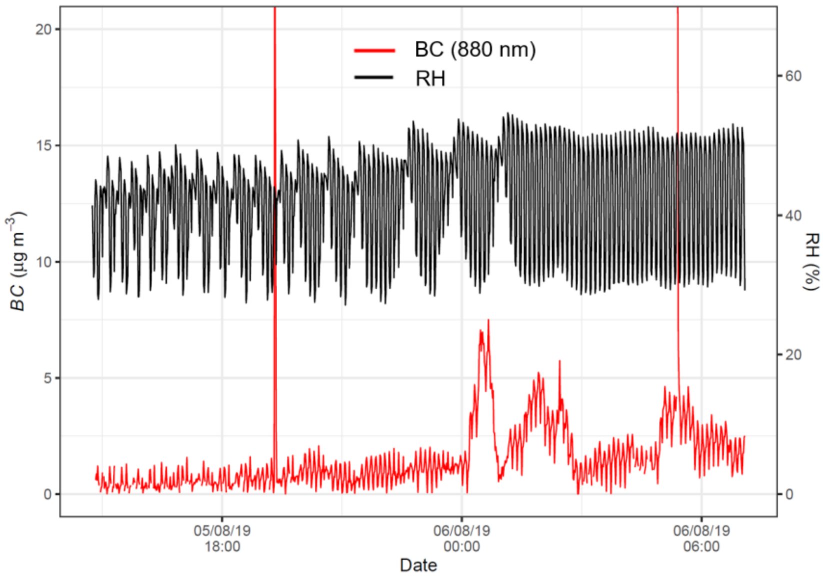

Figure 5 The effects on BC measurements due to rapid changes in relative humidity as a result of AC operation in the vicinity of the predecessor of AE36, Aethalometer AE33

The changes of RH in the sample inlet can be reduced using an Aerosol Inlet Dryer. The influence on the measurements due to rapid RH changes in the vicinity of the filter tape is reduced in the new Aethalometer AE36 with air sealing the filter tape compartment (Figure 5).

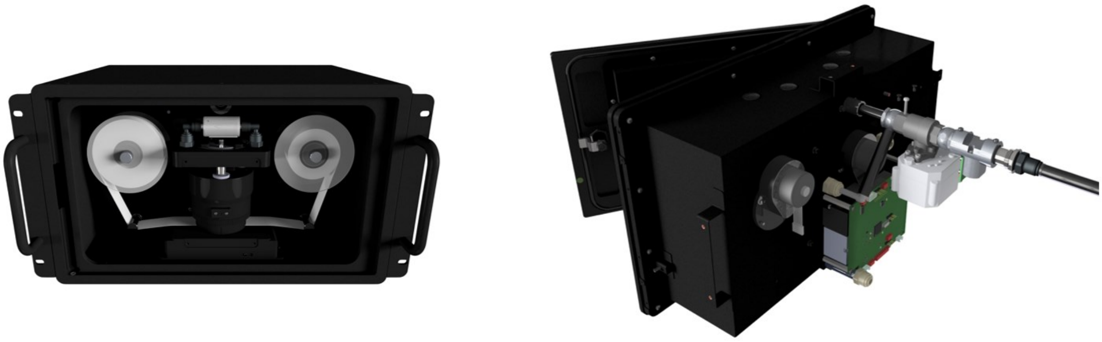

Figure 5 Filter compartment of AE36 from the front and backside. Hermetic seals prevent dust and moisture ingress in the vicinity of filter tape.

In our simulation chamber, we replicated a situation where the humidity in the surroundings of the Instrument changed rapidly, simulating the fluctuation of RH introduced by AC. We controlled the temperature changes (T) and RH inside the simulation chamber while sampling clean air with stable RH. Our results showed that the AE36/AE36s were unaffected by the changes in RH (Figure).

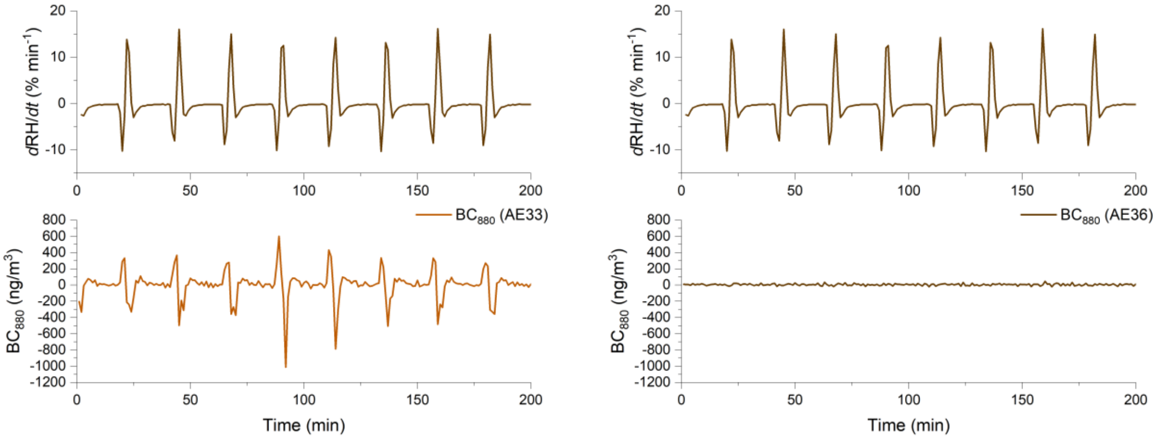

Figure 6. Simulation chamber with AE33(left) and AE36 (right) sampling clean air with stable RH. The humidity in the surroundings of the Instrument changed rapidly, simulating the fluctuation of RH introduced by AC. The AE36s was unaffected by the changes in RH.

To monitor the influence of RH and prevent damage caused by condensing water, we added two RH sensors in AE36 (Figure). One is installed at the beginning of the inlet and monitors the humidity of the sampled air. If the air sample humidity exceeds the user-defined limit value, the Instrument will stop sampling and thus prevent water intrusion and probable damage to the flowmeters.

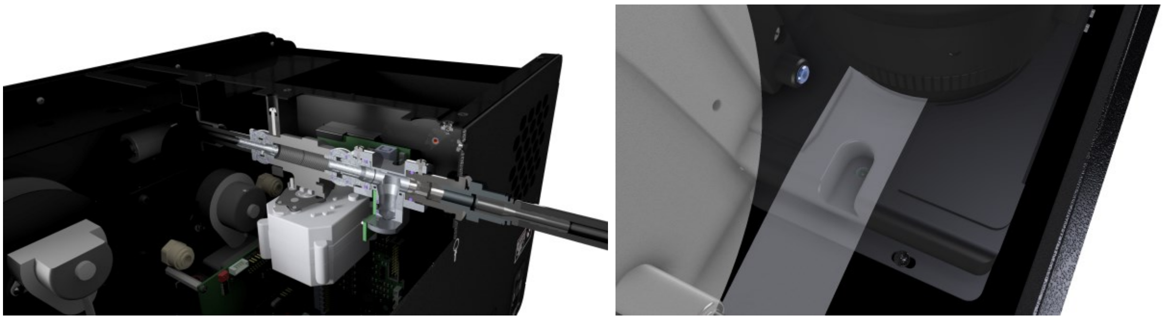

Figure 7. Two RH sensors were installed in AE36. The left position of the RH sensor is in the inlet line, and the right RH sensor is in the filter tape compartment.

The second sensor is installed in the filter chamber, monitoring changes of RH there-in. The Instrument will prompt a warning if the changes between two consecutive measurements are too high. Using both sensors, the user can meet the guidelines in the WMO/GAW Aerosol Measurement Procedures, Guidelines and Recommendations document.

References

GAW Report No. 227: WMO/GAW Aerosol Measurement Procedures, Guidelines and Recommendations, 2nd Edition, World Meteorological Organization, 2016

Düsing, S., Wehner, B., Müller, T., Stöcker, A., and Wiedensohler, A.: The effect of rapid relative humidity changes on fast filter-based aerosol-particle light-absorption measurements: uncertainties and correction schemes, Atmos. Meas. Tech., 12, 5879–5895, https://doi.org/10.5194/amt-12-5879-2019, 2019.

6. AE36 performance

The AE36's enhanced performance characteristics, compared to its predecessor and other filter photometers on the market, are primarily attributed to several key technical improvements:

1. Relative Humidity (RH) Robustness: The influence on the measurements due to rapid RH changes in the vicinity of the filter tape is reduced in the new Aethalometer AE36 with air sealing the filter tape compartment.
2. Power Supply Design: The power supply circuitry has been significantly improved using the point of load design to provide stable and efficient power delivery, reducing the risk of performance degradation due to power fluctuations.
3. Firmware Signal Processing: Advanced signal processing algorithms implemented in the firmware enable more accurate and reliable data interpretation, contributing to the overall performance enhancement.
4. Air-Sealed Filter Compartment: The filter compartment is air-sealed, preventing the ingress of dust and other contaminants, thereby maintaining the integrity of the filter and the accuracy of measurements.

The Table below provides a detailed specification of the AE36 key performance metrics, including Resolution, Limit of Detection (LoD), Precision, Measurement uncertainty, and measuring range. These metrics provide a comprehensive overview of the AE36 capabilities and performance characteristics. Please note that these values are subject to change based on operating conditions and calibration.

Parameter	AE33	AE43	AE36
Resolution (1s timebase, 3.8 LPM)	<1 ng/m³ @ $ATN = 0$ 50 ng/m³ @ $\|ATN\| = 30$	<1 ng/m³ @ $ATN = 0$ 50 ng/m³ @ $\|ATN\| = 30$	<1 ng/m³ @ $ATN = 0$ 50 ng/m³ @ $\|ATN\| = 30$
Sensitivity / Limit of detection (mean + 2σ)	700 ng/m³ @ 3.8 LPM, 1s 40 ng/m³ @3.8 LPM, 1 min	400 ng/m³ @ 3.8 LPM, 1s 25 ng/m³ @3.8 LPM, 1 min	260 ng/m³ @3.8 LPM, 1 s 15 ng/m³ @3.8 LPM, 1 min
Precision	<10%	<10%	<10%
Measurement uncertainty	BC: 27% Source apportionment: 30%	BC: 27% Source apportionment: 30%	BC: 27% Source apportionment: 30%
Measuring range (measuring interval, working interval)	0 – 100 μg/m³	0 – 100 μg/m³	0 – 100 μg/m³

7. New GUI design

The new GUI can be navigated by pressing the icons in the vertical menu bar on the left side of the screen. The settings are divided into eight groups (Home, General, Data, QA/QC, External device and protocols, Settings, System and Info). Easy to use, the redesigned layout includes helpful additions, including a graphical data display on the "Data/Graph" screen and a wind regression analysis on the "Data/Pollution rose" panel (Figure 8). The graphical data display can plot a time series of compensated absorption coefficient values, or BC concentration, in real-time or for the selected period. The Pollution can be used to identify the air pollution source location. Note that the wind sensor must be connected to an external device for this analysis.

Figure 8. Graphical data presentation on AE36- timeseries of absorption coefficient at 7 wavelengths left, and Pollution rose right.

8. Black Carbon Index

AE36 includes BC Index™, a proprietary measure of air quality based on Black Carbon concentrations (Fig. 9). It helps organizations monitor and communicate the level of air polluted with BC. BC Index™ provides a convenient way to track air quality levels in real time and can help make decisions to protect human health. AE36, the first in the World, allows authorities to follow WHO global air quality guidelines (WHO, 2021) in developing standards or targets for ambient Black Carbon concentrations.

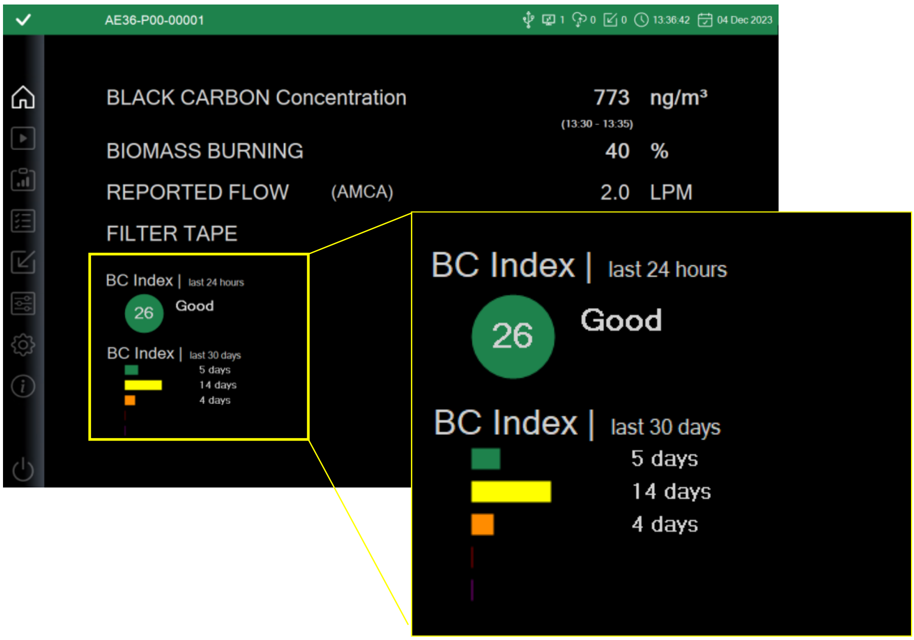

Figure 9. AE36 includes BC Index™, a proprietary air quality measure based on BC concentrations.

BC index follows the principle of Air Quality Index (AQI) determination. It relies on the linear interpolation method of BC concentration, which is applied between preset boundaries of BC Index categories (Fung et al., 2022). The following equation calculates the BC Index:

$$\textbf{BC Index} = \frac{I_{high}-I_{low}}{BC_{24\_high}-BC_{24\_low}}\left(BC_{24} - BC_{24\_low}\right) + I_{low},$$

Where BC_{24} is the 24-hour running mean of hourly averaged BC concentration, BC_{24_low} and BC_{24_high} are the lower and upper Limits of the index category, and I_{low} I_{high} are the corresponding index values. BC Index is displayed if there is 75% data availability for the previous 24 hours. Default BC limits are presented in the Table below and can be set by the user on the 'SYSTEM' | 'Display' screen (see Section Error! Reference source not f ound.).

Index category	Category limits	BC limits (ng/m³)
Good	< 50	< 1000

Satisfactory	51 - 75	1000 - 3000
Fair	76 - 100	3000 - 7000
Poor	101 - 150	7000 - 12000
Very poor	151 - 500	60000

Reference:
Fung, P. et al. (2022), Improving the current air quality index with new particulate indicators using a robust statistical approach, Sci. of the Total Environ. 844, 157099.

WHO global air quality guidelines. Particulate matter (PM 2.5 and PM 10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Geneva: World Health Organization; 2021. License: CC BY-NC-SA 3.0 IGO

9. Data Auto validation and new STATUS logic

Validating data is a crucial component of quality control and assurance (QA/QC). The new status control allows for a quick overview of the Instrument's status and easy filtering of valid data.

The Instrument's General Status is indicated by The color of the top line of the screen, the status description on the "Home" screen, and the LED indicator next to the screen. The colors indicate:

- Green = Instrument is measuring without warning.
- Green and blinking = The Instrument is running in QA/QC mode with no warnings, or the Instrument is conducting tape advance.
- Orange = Instrument is running with warnings; check status.
- Red = Instrument is stopped or in error.

Pressing the Status icon on the left side of the status line will display the detailed status code and short sub-status description (
Figure).

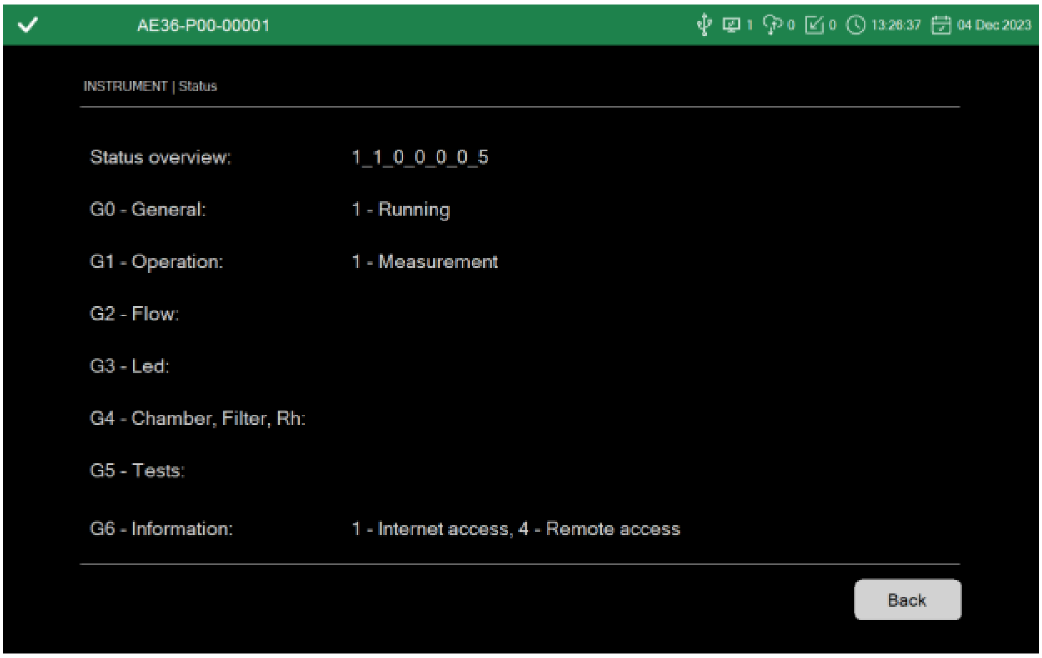

Figure 10. Instrument Status screen shows the Instrument's status overview and the deconvolution of the instrument status.

The status code of the Instrument consists of seven sub-status values, which are eight-bit sets. The Instrument's general state is displayed in the first set, "G0".
The second set, "G1" will show the operation the Instrument is performing. "G2", "G3" and "G4" will show information on mechanical components, "G5" denotes QA/QC tests and "G6" Information on connectivity, storage, etc.
With this status code the data can be processed more quickly by filtering out only valid measurement data – data lines with the Status code G1=1, thus excluding data lines with

errors, warnings, calibration values and QA/QC tests. This filter can be applied on the Export Data screen, where the user can download measurement data using the "validated" option.

10. Optimized maintenance

An extended period of unsupervised operation was envisioned for AE36. Several safety and diagnostic features ensure the Instrument is running optimally while having complete control over the Instrument and data quality.

The AE36 can operate unattended for extended periods thanks to its robust construction, automatic zero testing, 2-times longer filter tape (20 m instead of standard 10 m), and smooth connectivity wherever you are, thanks to the RAS module in the new CAAT software. Thus reducing the site visits and the operator's workload.

The Self-cleaning procedure was also developed to clean the optical chamber and internal tubing. This procedure uses valves and the pump to create alternating high and low pressure in the system, which removes the dirt deposited with time. The dirt is collected on the filter tape. After the procedure, a clean air test is recommended to ensure the analytical area is free of particles or dirt. The Self-cleaning procedure reduces the buildup of dirt and other contaminants that may affect the data quality and, therefore, significantly reduces maintenance and ensures accurate readings over an extended period.

11. Automatic Zero and Span

Zero

The AE36 Aethalometer can automatically check the 'zero-air' response of the Instrument under dynamic operating conditions. This test is implemented by back-flushing the inlet connection with an excess flow of internally filtered air and circulating the filtered air in the Instrument.

The result of the clean air test is presented for all wavelengths and both spots in terms of:

- average BC concentration (AverageBC),
- point-to-point variation of BC concentration (PPBC),

The test result is acceptable if the values of

$$\mathbf{PPBC} = \frac{1}{n}\sum_{i=0}^{n}\left|BC_{t_{i+1}} - BC_{t_i}\right|$$

are below the limits presented in the Table below:

Wavelength (nm)	PPBC Spot 1 (ng/m^3)	PPBC Spot 2 (ng/m^3)
370	220	750
470	180	590
520	200	660
590	220	740
630	230	790
880	330	1100
950	360	1200

If one of the reported values of PPBC on Spot 1 is larger than this limit value, inspect and clean the optical chamber. The average BC values should be close to zero if the Aethalometer is warmed up and stabilized for at least one hour. A short transient may be seen at first due to a filter compression artifact.

Span

The Aethalometer AE36's optical detectors' response may be verified using a kit of Neutral Density optical filters, as shown in Figure 11 below. These are glass elements with a range of known and stable optical absorptions, from light to dark, which are traceable from manufacturing records to primary standards. When inserted into the AE36 Aethalometer, the photodetectors give a particular output signal. The stability and reproducibility of the relationship between the optical signal and ND Filter density from one validation test to another, and the comparison with the original factory values, is a measure of the consistency of performance of the Instrument's optics.

Figure 11. The optical Validation Kit consists of traceable standard Neutral Density Optical Filters inserted into the AE36 optical path to determine the reproducibility of the relationship between LED optical source intensity and detector response.

12. Remote Access System (RAS)

The RAS application (Figure 12) is a software tool running on Windows (7, 10, or 11) operating system for remote control and downloading the AE36 and AE36s Aethalometers' data.

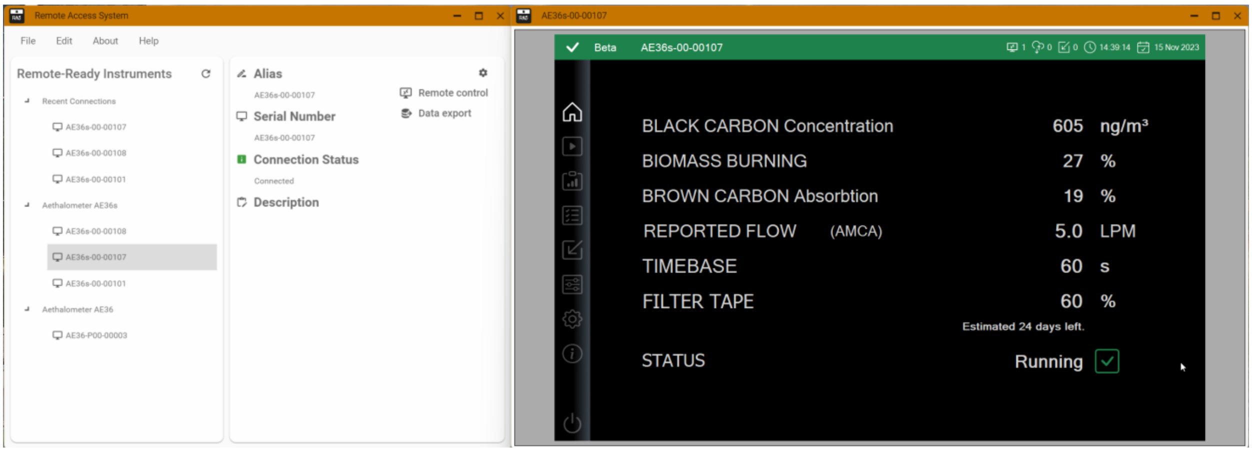

Figure 1. The left window shows a list of remote-ready instruments in the Remote Access System window, and on the right, the Instrument remote window displays the selected Instrument's Home screen.

RAS allows the user to remotely control and download data from any AE36s/AE36 instrument connected to the same network as the computer they are currently remotely connecting to or from any instrument within that subnet available for remote connection.

Following the setup of the connection, an additional instrument window will appear next to the instrument remote window on the RAS Main Home screen. On this screen, operators can navigate, investigate, and alter the Instrument's operation as if the actual Instrument's graphical user interface were in front of them.

13. User and Communications Interfaces

The AE36 Aethalometer incorporates the following user, data and communications features:

- Large color graphics touch-screen for data display and local user interface;
- USB ports for insertion of a memory stick for local data download;
- USB ports for connection of a keyboard, if necessary for initial setup of parameters, such as station identification;
- RS-232 COM port for data transmission to digital datalogger;
- Ethernet port for full network access and control, including
    i. Remote data acquisition, either batch or streaming
    ii. Remote retrieval of instrument status and state-of-health
    iii. Remote control of instrument operating parameters

14. Modular Construction

The AE36 Aethalometer is constructed with a modular design so that sub-units may be easily serviced. The only item requiring attention in routine use is cleaning the optical insert to remove accumulated dust or other contamination that may be brought in with the sample air stream. The optical chamber is attached with a bayonet fitting for quick removal; easy cleaning; and reliable re-assembly. The entire Instrument is hermetically sealed to reduce the entry of dust and moisture.

15. Contact

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Ljubljana, February 2024