

Advanced measurement of black carbon

Because nothing in life is just black and white.



Aethalometer AE33 TECHNICAL TRAINING

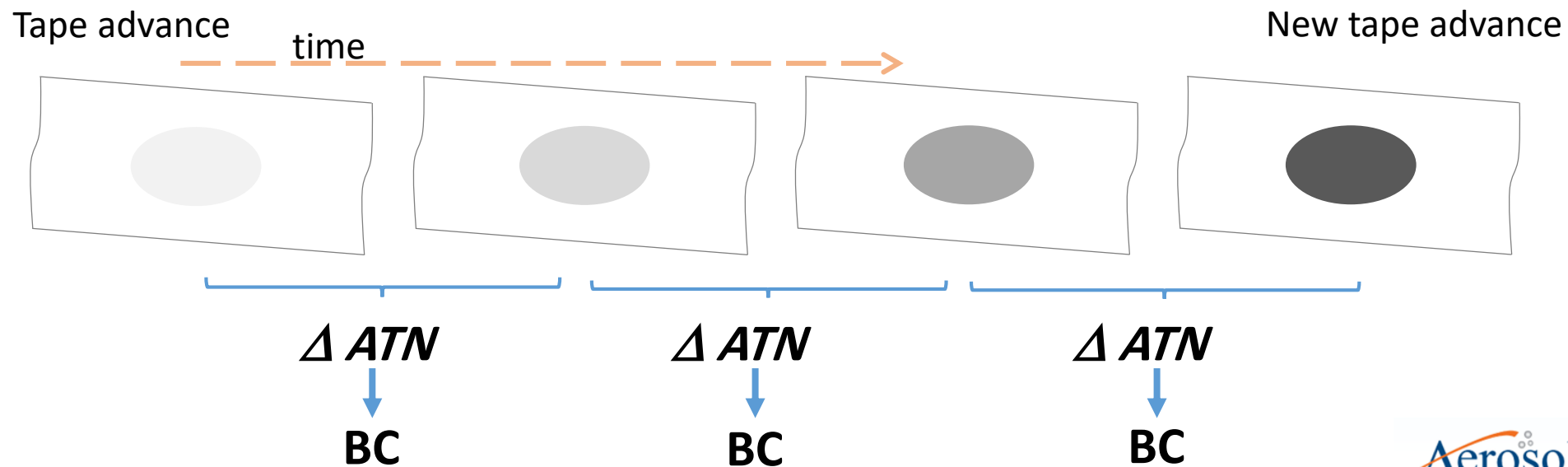
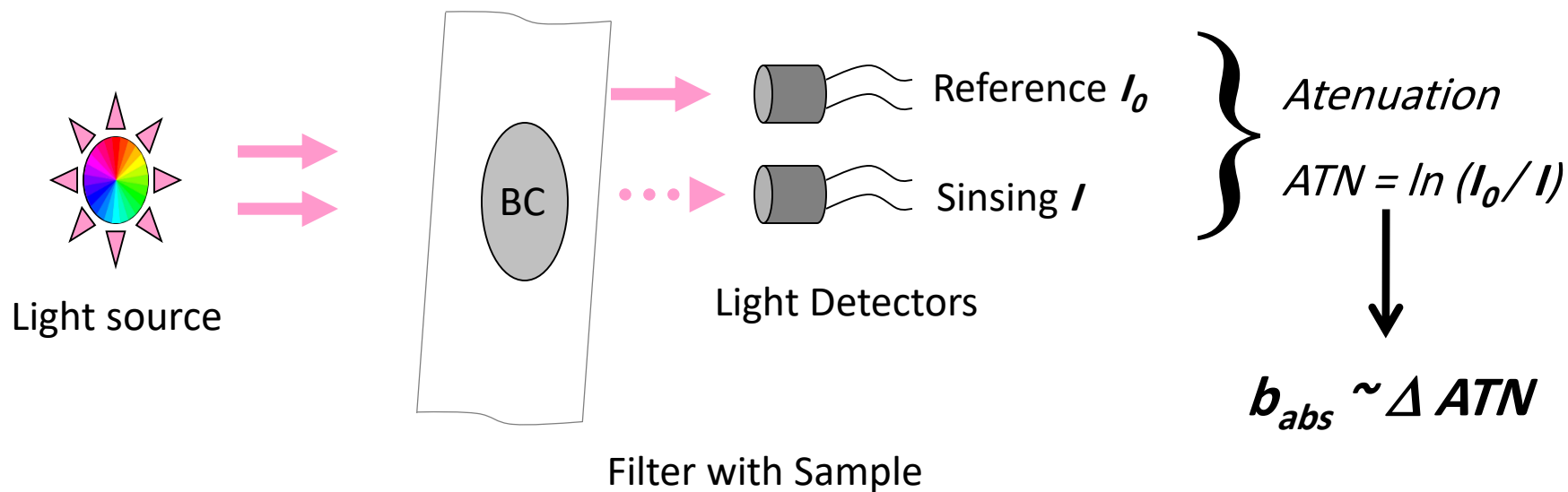
Introduction



- Multiple wavelengths: absorption: UV-IR, quantitative source apportionment: fossil fuel vs. wood-smoke – BC and CM.
- Dynamic loading compensation dual spot compensation algorithm eliminates filter loading artifacts.
- Additional info from compensating coefficient (aerosol age)
- Automated QA/QC with zero, optical span checks and flow calibration.
- Improved performance: low noise, fast time resolution.
- Easily integrates into networks with AethNET or via data loggers: ease of communication and maintenance.

!! FREE DEMO AethNET TRIAL !!

The principle – general



Basic calculations



- Basic equation

- $BC = \frac{S \cdot \Delta atn}{F \cdot \Delta t \cdot \sigma}$

- Sigma & multiple scattering parameter

- $\sigma_{filter} = \sigma_{air} * C$ (Weingartner et al. 2003)

- $C=1.57$

- Loading effect compensation

- $BC_{comp} = BC / (1 - k * ATN)$

- Measured leakage

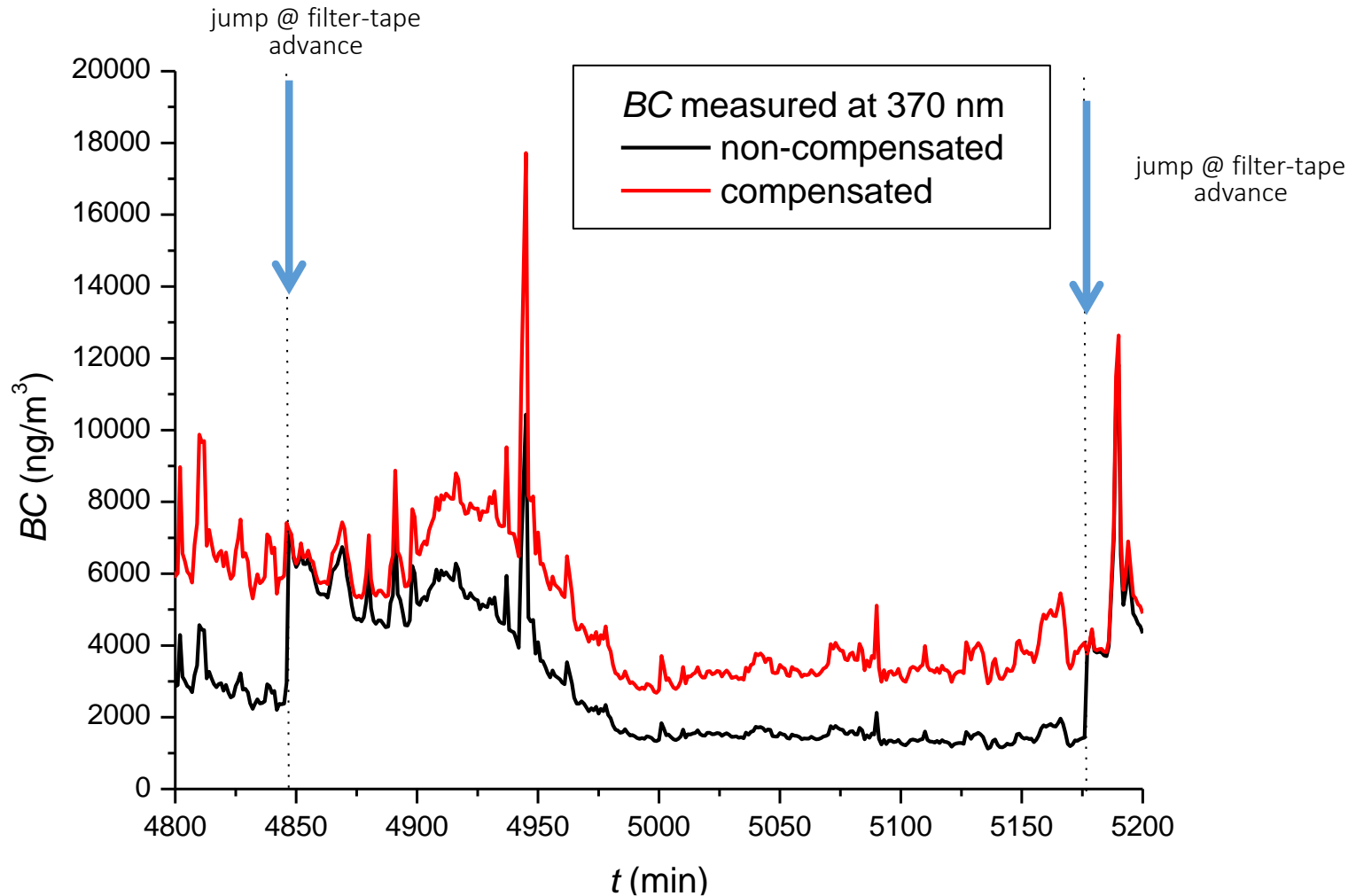
- $F_{in} = F_{out} * (1 - \zeta)$

- Leakage factor $\zeta = 0.025$

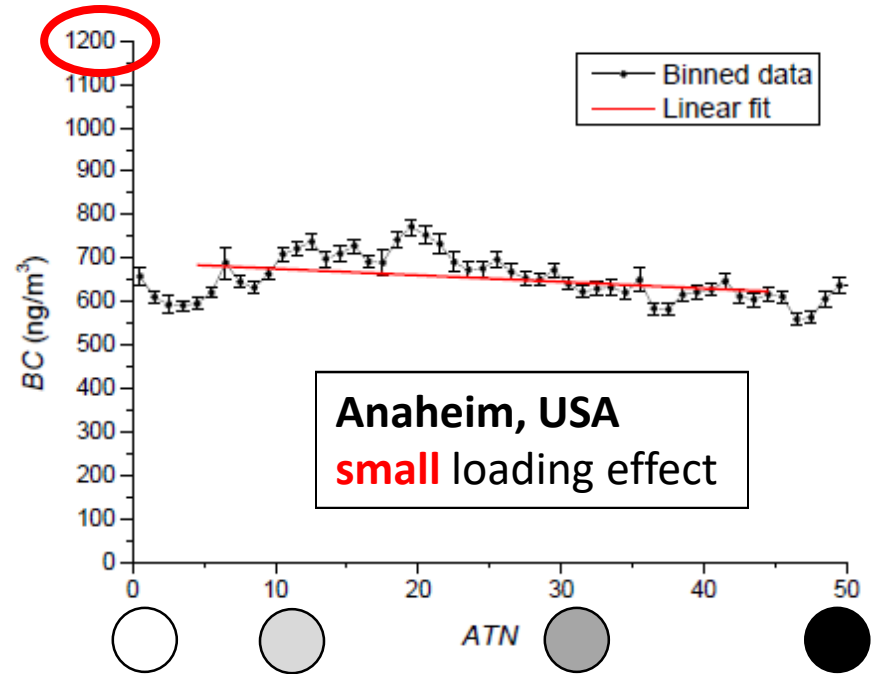
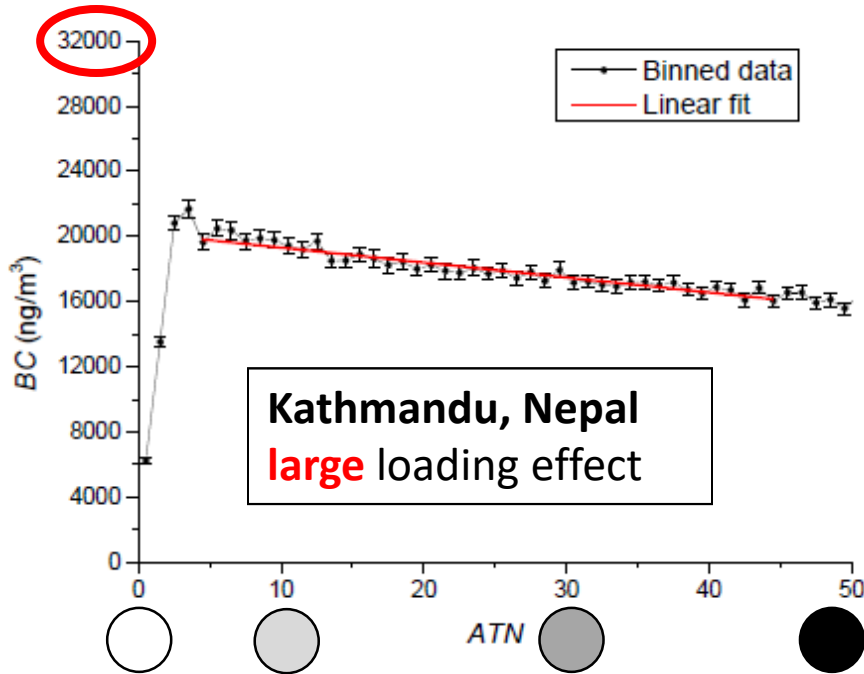
- Final equation

- $BC = \frac{S \cdot \Delta atn_1}{F_1(1-\zeta) \cdot \sigma_{air} \cdot C_{teflon} \cdot (1-k \cdot ATN_1) \cdot \Delta t}$

Loading effect compensation



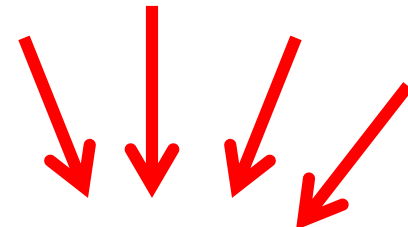
Loading effect compensation



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

Reduction of the instrumental response due to loading of the filter. Jump at the tape advance.

- ambient data – no dependence of BC on ATN
- slope k variable: site; source; aerosol age, composition
- need to determine it dynamically – do not assume, rather **measure**



Loading effect compensation

the DualSpot™ method

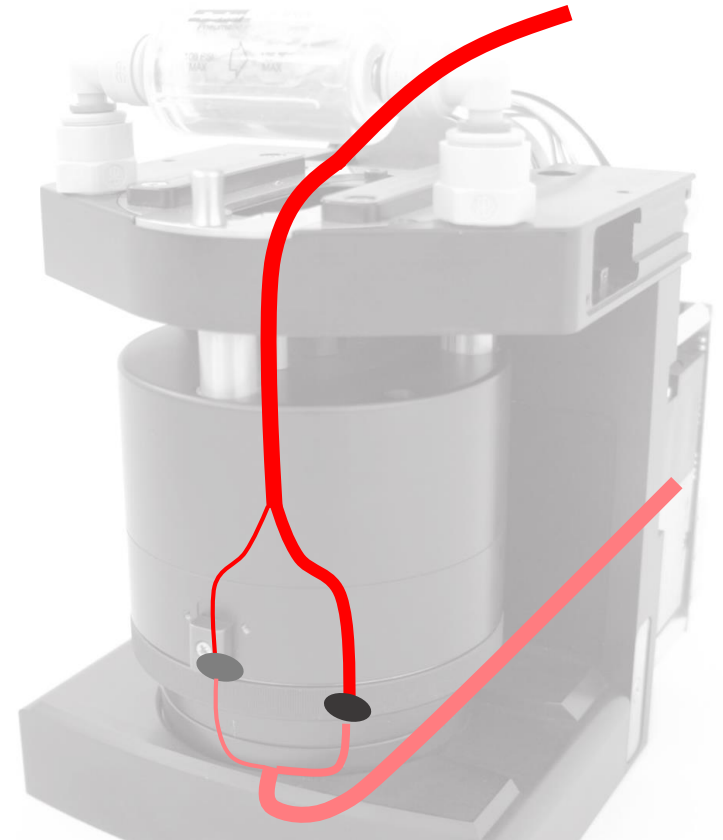
The **ONLY** analyzer on the market that eliminates the „loading effect“.

Origin

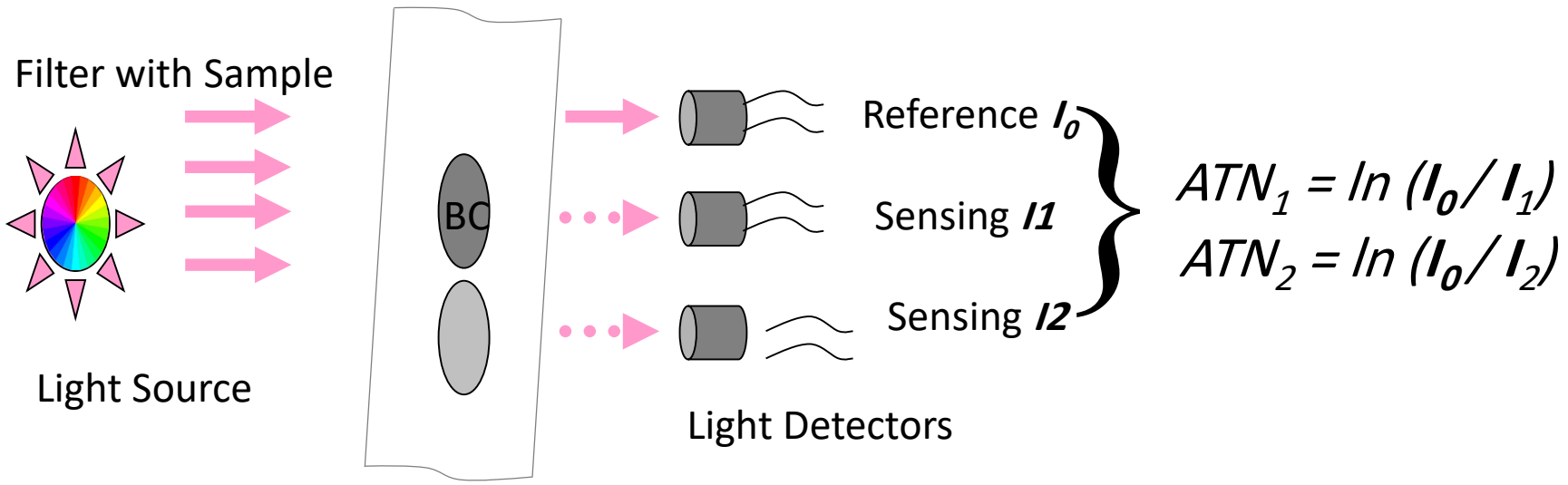
- As the loading of particles on the filter increases, the existing particles may “*shadow*” the freshly-collected ones. The new particles are not exposed to the same intensity distribution of light, and do not make the same contribution to ATN per unit mass.

Result

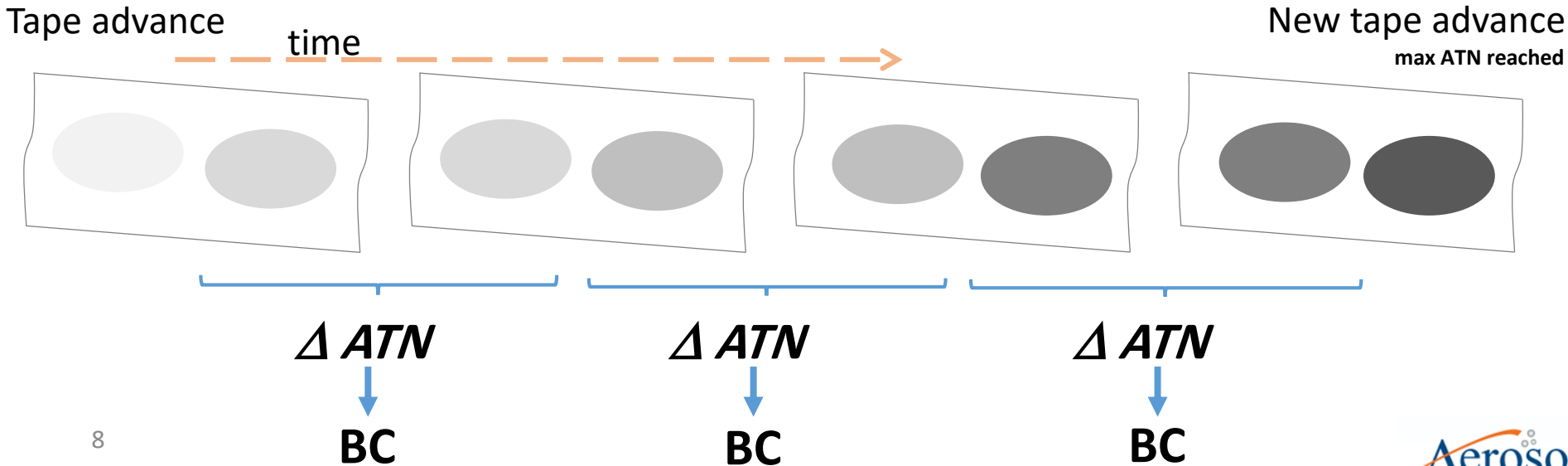
- The relationship of ATN / BC becomes non-linear.



Loading effect compensation

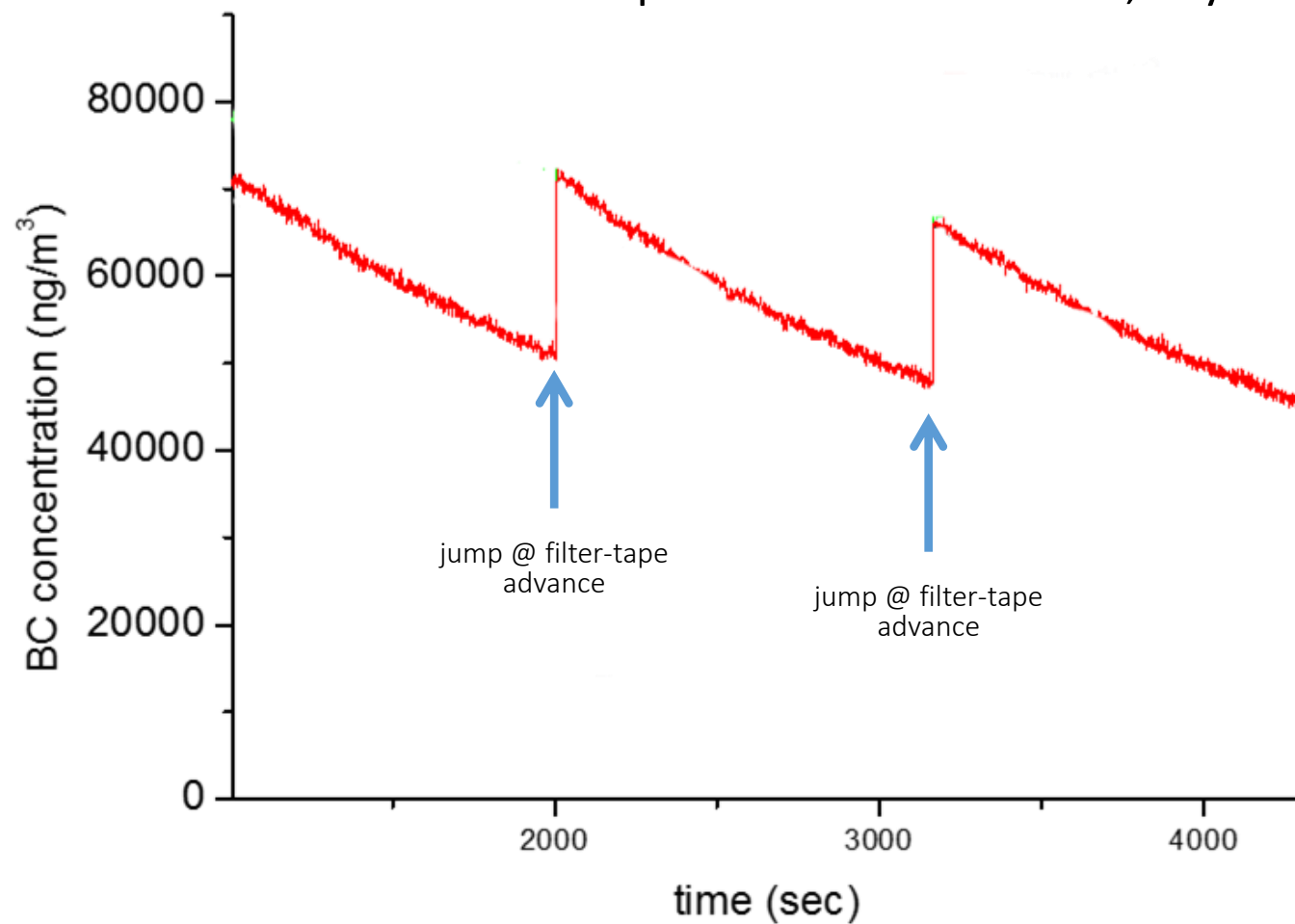


Two parallel spots with different flow, therefore -> different loading and attenuation.

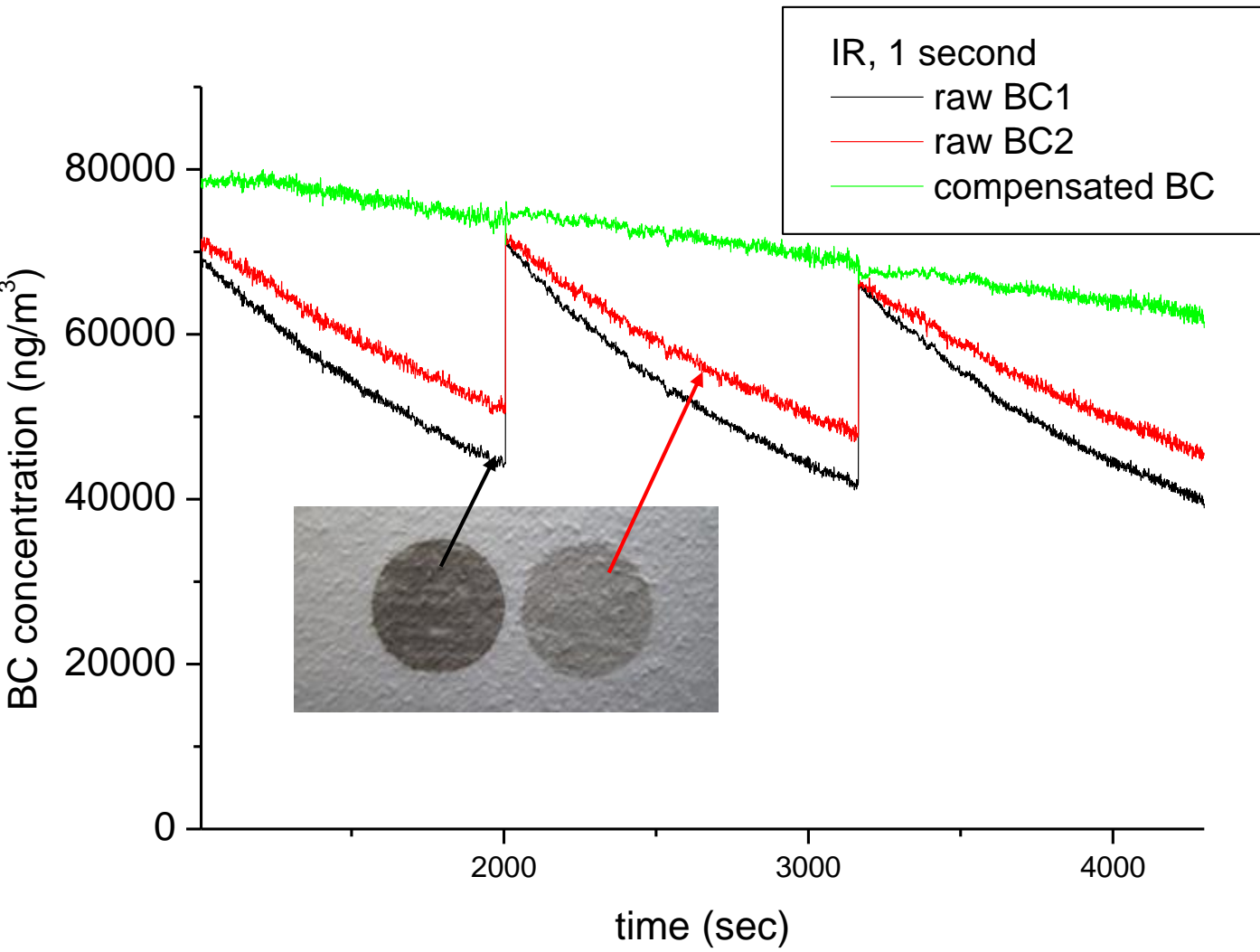


Loading effect compensation

BC response of old AE models, any other mode on the market.



Loading effect compensation



Two parallel spots with different flow, therefore different loading and attenuation.

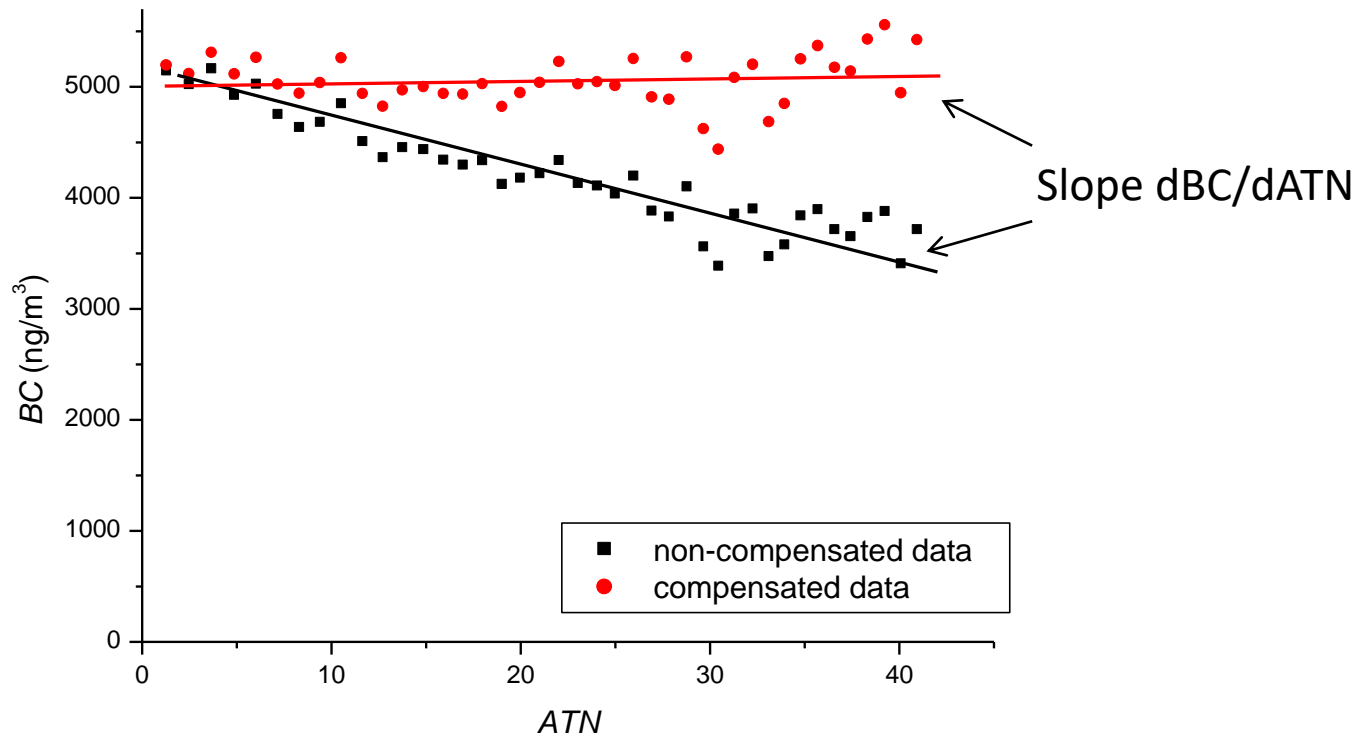
Calculate loading compensated BC and $k!$

Loading effect compensation validation

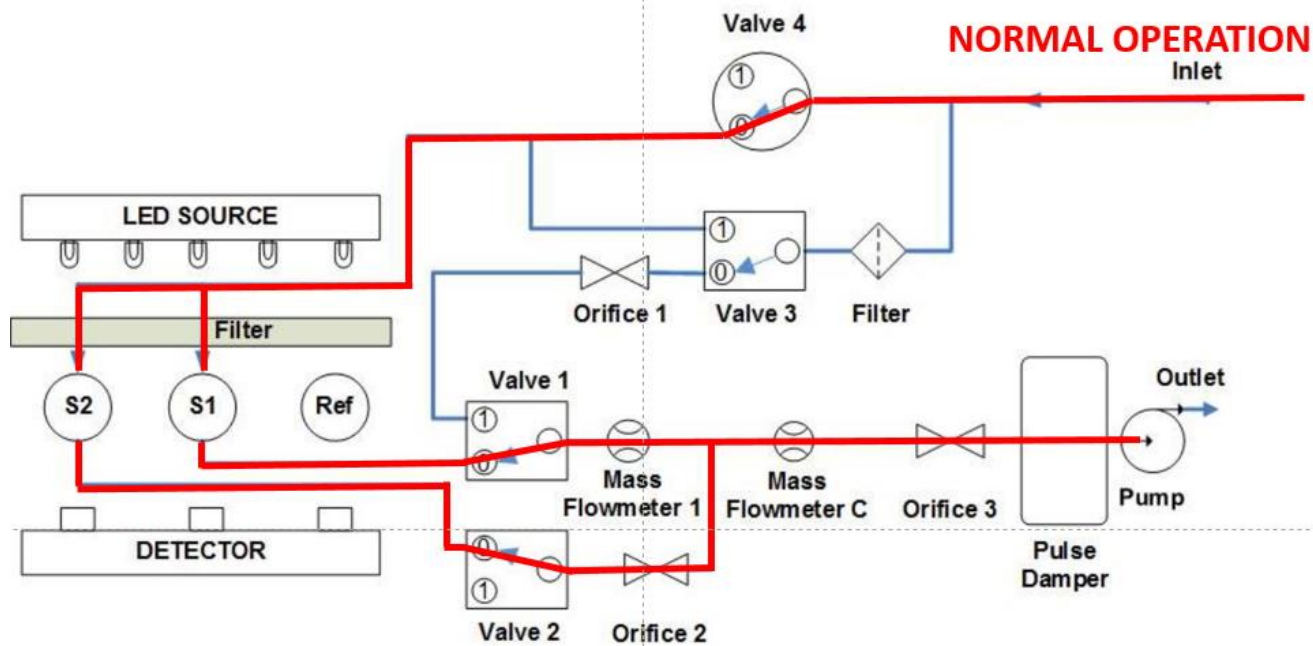


1. Determination of compensation parameter $k(\lambda)$
2. Calculation of compensated BC :

$$BC = BC_1 / (1 - k * ATN_1)$$



Flow diagram/Measurement



The code representing the Valve Status is formed from a series of binary values.

From highest to lowest binary values these are:

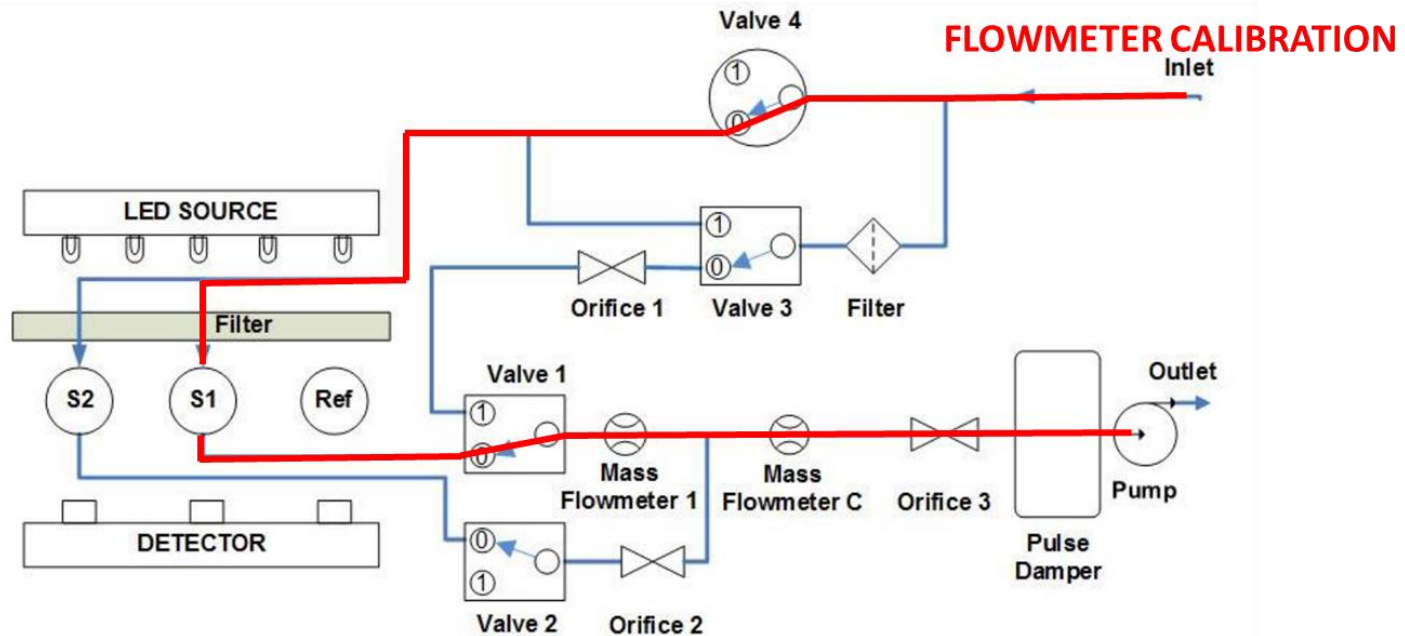
Valve 4-moving (1=YES / 0=NO), Valve 4 position (1=ON / 0=OFF),

Valve 3 position (1=ON / 0=OFF), Valve 2 position (1=ON / 0=OFF),

Valve 1 position (1=ON / 0=OFF)

Mode	Valve4	Valve3	Valve2	Valve1	Valve status
Bypass	1	0	1	1	01011
Warm-up/clean air	1	1	0	0	01100
Measurement	0	0	0	0	00000
Flowmeter calibration	0	0	1	0	00010

Flow diagram/Flow calibration



The code representing the Valve Status is formed from a series of binary values.

From highest to lowest binary values these are:

Valve 4-moving (1=YES / 0=NO), Valve 4 position (1=ON / 0=OFF),

Valve 3 position (1=ON / 0=OFF), Valve 2 position (1=ON / 0=OFF),

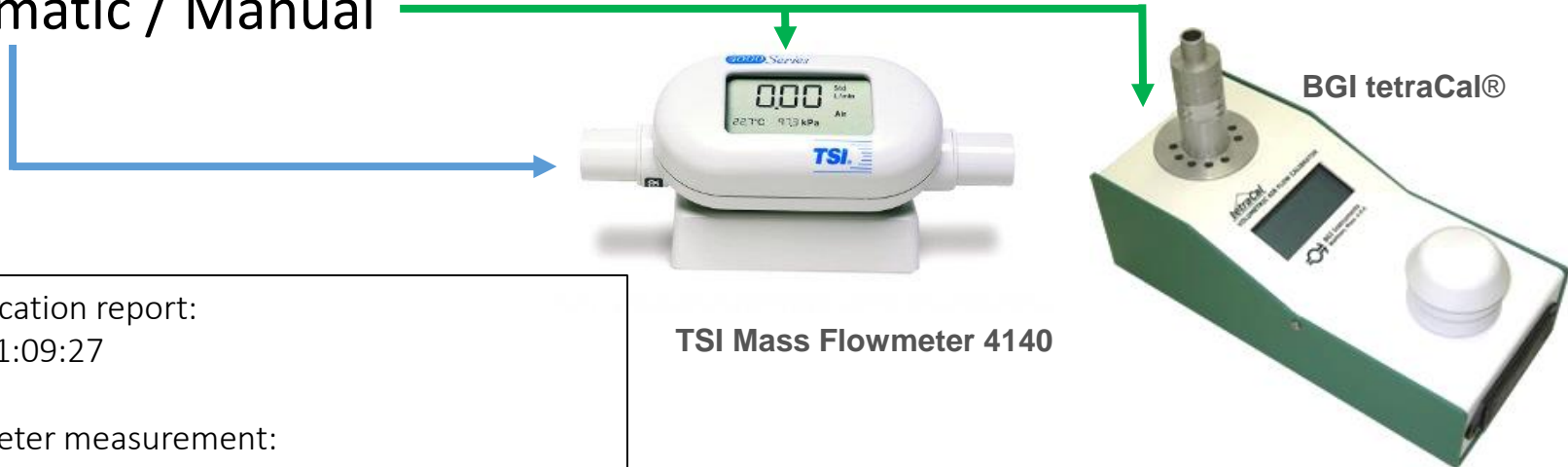
Valve 1 position (1=ON / 0=OFF)

Mode	Valve4	Valve3	Valve2	Valve1	Valve status
Bypass	1	0	1	1	01011
Warm-up/clean air	1	1	0	0	01100
Measurement	0	0	0	0	00000
Flowmeter calibration	0	0	1	0	00010

Quality control/flow verification



- Automatic / Manual



Auto flow verification report:
25 May 2013 21:09:27

External flowmeter measurement:

P	T	Fin
101325	21.11	919
101325	21.11	2946
101325	21.11	4912

Flow verification results:

Flow reporting standard: AMCA 101325 Pa 21.11 °C

Fin	F1	(%)	Fc	(%)
919	921	(100)	913	(100)
2946	2946	(100)	2946	(100)
4912	4908	(100)	4907	(100)

TSI Mass Flowmeter 4140

BGI Tetracal flow calibrator is recommended

During flow check a calibration pad is used.

Flow calibration is needed if difference > 10 %

Quality control/leakage test



- **Leakage test**

Leakage (ζ) is measured during instrument operation:

$$\zeta = 1 - (F_{in}/F_{out})$$

Average leakage is 7% at 5 LPM. It can differ slightly from spot to spot and during the spot loading. After performing leakage test a report is being generated:

Manual leakage test report
Serial number: AE33-S02-00232
Date and time: 01 Dec 2014 11:21:21
Selected flow: 5000 mlpm
Flow through tape: 4700
Flow through calibration pad: 5000
Instrument leakage is: 6 %

Leakage should be measured using a low pressure drop calibrator: BIOS is not OK

Leakage should be < 10 %

Quality control/stability test



Stability test (without flow):

- Average BC ~ 30 ng/m³
- Point to point variation of BC (PPBC61) at 1 s timebase:

$$PPBC = \frac{1}{n} \sum_{i=0}^n \text{abs}(BC(t_{i+1}) - BC(t_i))$$

- PPBC61 < 450 ng/m³

After performing stability test a report is being generated:

Stability test report.

Serial number: AE33-S02-00232

Date and time: 02 Dec 2014 11:46:03

Duration: 00:20:00, Timebase: 1 sec, Flow: 0 mlpm

	AverageBC PPBC		(ng/m ³)	
	Spot1	Spot2	Spot1	Spot2
Ch1	-13	-4	261	645
Ch2	-5	-3	357	934
Ch3	-3	8	365	899
Ch4	0	16	348	956
Ch5	-2	11	369	1023
Ch6	-23	-29	402	1118
Ch7	-16	-24	473	1230

Result of stability test is acceptable.

Quality control/clean air test



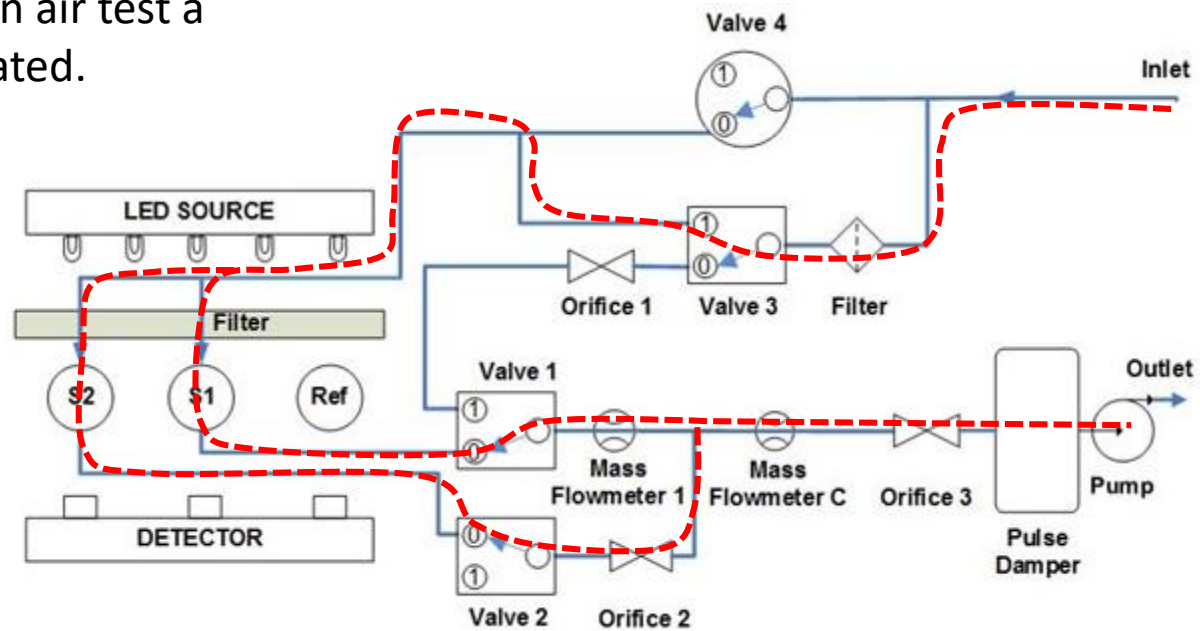
Clean air test (flow trough built-in filter):

- Average BC < 30
- Point to point variation of BC (PPBC) at 1 s timebase, 5 lpm: PPBC61 < 550 ng/m³

Automatic clean air test

- Performed weekly or monthly
- Average BC and PPBC for each channel and spot are displayed in the log file

After performing clean air test a report is being generated.



Quality control/ND test



- ND test – determination of optical sensitivity

Files used to compare: NDtest_AE33-S01-00074_20130509_161427.dat
NDtest_AE33-S01-00074_20130510_080954.dat

Filterset AE33-ND-0002

Old filterset AE33-ND-0002

Optical test slope result:

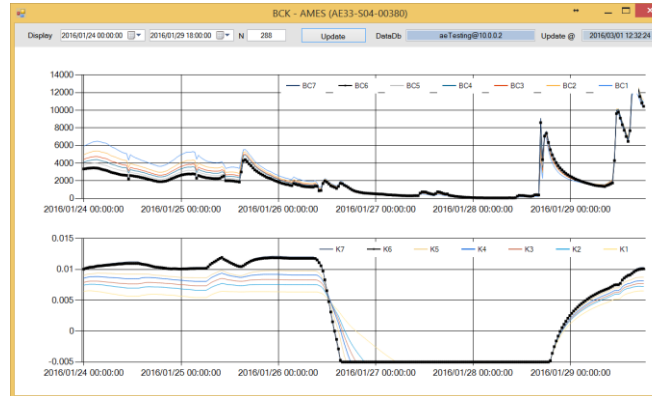
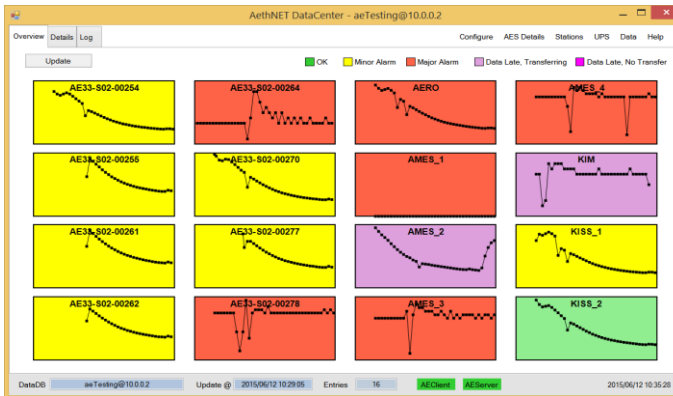
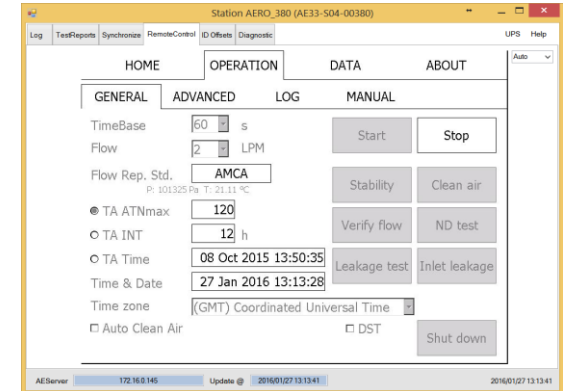
Ch1	s1 0.995	s2 0.993
Ch2	s1 0.983	s2 0.980
Ch3	s1 0.984	s2 0.980
Ch4	s1 0.981	s2 0.978
Ch5	s1 0.979	s2 0.976
Ch6	s1 0.974	s2 0.972
Ch7	s1 0.977	s2 0.975



Slope should not differ for more than 10 % from unity

AethNET is a complete solution for Aethalometer measurements

- ❑ All instrument data is available at the data center including diagnostics.
- ❑ Email notifications.
- ❑ Automatic data validation including complex algorithms.
- ❑ Data visualization.
- ❑ Instrument remote control.
- ❑ Full access to authorized users.
- ❑ No need to worry about data acquisition and storage.
- ❑ Support by experts from Aerosol.



MAGEE
SCIENTIFIC
AETH
ALERTS

TEST: Instrument stopped!

- ❑ **Operation status**
Instrument stopped due to an error! The error needs to be fixed, before the instrument can be started.
- ❑ **Filter tape status**
Tape not moving or end of tape. Schedule filter tape replacement.
- ❑ **Flow status**
- ❑ **LED status**
- ❑ **Chamber status**
- ❑ **Tests status**
- ❑ **Settings status**
- ❑ **External device status**
- ❑ **CF card status**
Instrument database is reaching the size limit. Please remove older data.

Data is automatically validated

The following parameters are checked:

- Are BC and K values inside averages: drop in K values can be caused by inlet blockage.
- Spot1 / Spot2 ratio: debris in the chamber, signal noise.
- Reference stability, signal levels: LED source problems.
- Temperature variation: relocate the instrument.
- Loading compensation: manually compensate data.
- ATN0 variation: spot overlap, increased filter humidity.
- FVRF: flow calibration required, degraded chamber sealing.
- Flow changes: can be caused by non BC particles.

Instrument diagnostics

- Detailed instrument diagnostics can be run on demand.
- Generates a list of possible issues.

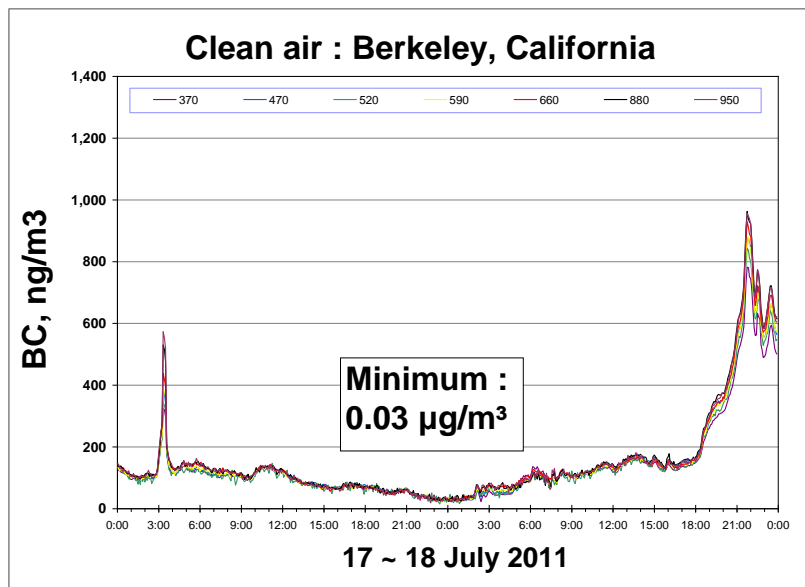
mBC	aBC	MBC	mK	MK	mBB	aBB	MBB
-1368	84.0	3309	-3.3e-3	1.3e-2	0.0	31.0	100.0
appBC	MappBC	MppBC	appBC2	MappBC2	MppBC2	appK	MppK
134	902	10951	305	2479	7645	3.6e-6	1.4e-4
mRef	MRef	appRef	MppRef	mSens1	MSens1	mSens2	MSens2
748517	955609	77	559	531148	956836	638383	1007249
mFC	MFC	ppF1	mFR	MFR	MBCL	mBCR	MBCR
3939	4006	0.03	0.34	0.36	1.5	0.07	1.72
mATN0	MATN0	MppATN0	MBCS	mFVRF	MFVRF	appBB	MappBB
-23	33	9.1	0.0	0.93	4.88	28.90	79.05
ppTemp	mAlarms	MAlarms	IAlarms	ABC	CAP		
9	56	1	0	100.0	100.0		

Possible issues detected:

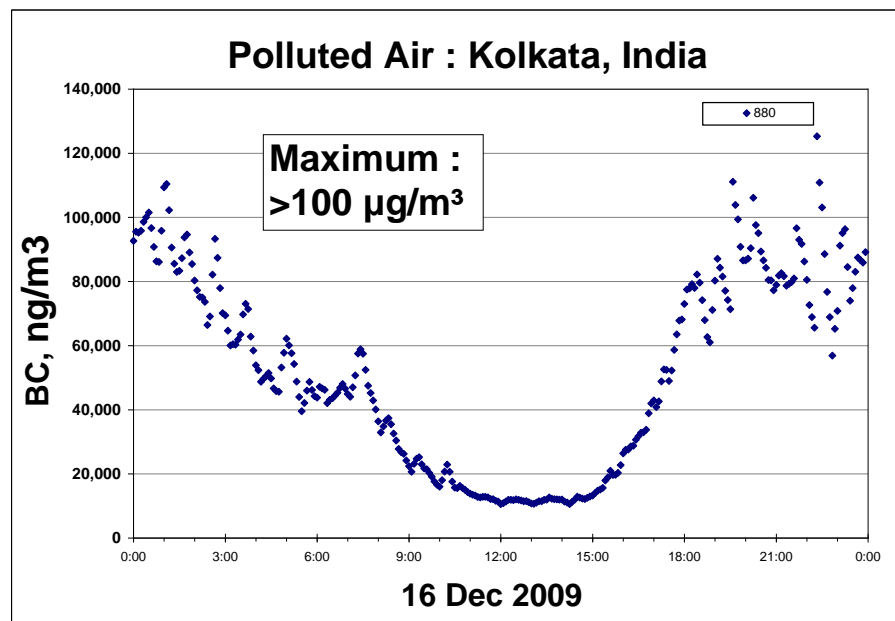
- Minimum BC value is out of range: check loading compensation and clean the chamber.
- Large BC noise (15 min interval): check that the instrument is not located close to air condition.
- Large maximum reference noise: spikes in the reference signal can be observed as artificial peaks in BC.
- Low spot1 to spot2 ratio: low ratio may indicate debris in the chamber or noise on spot2.
- High FVRF: perform flow calibration if last FVRF not between 0.9 and 1.1.
- Large BB noise.
- Large number of warning messages: check log.

Wide Dynamic Range of actual measurements

Clean air from ocean: $BC < 50 \text{ ng/m}^3$



Highly Polluted Air : $BC > 100 \mu\text{g/m}^3$

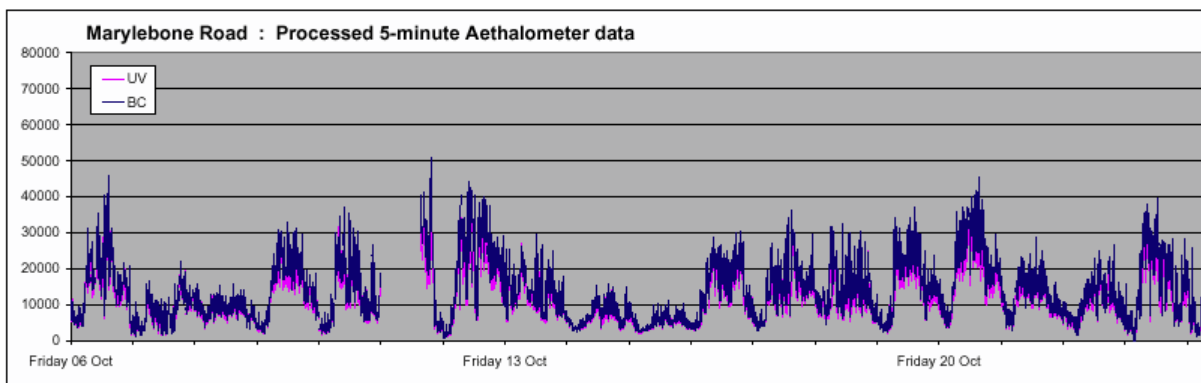


Can study diurnal patterns

Urban roadside emissions study London

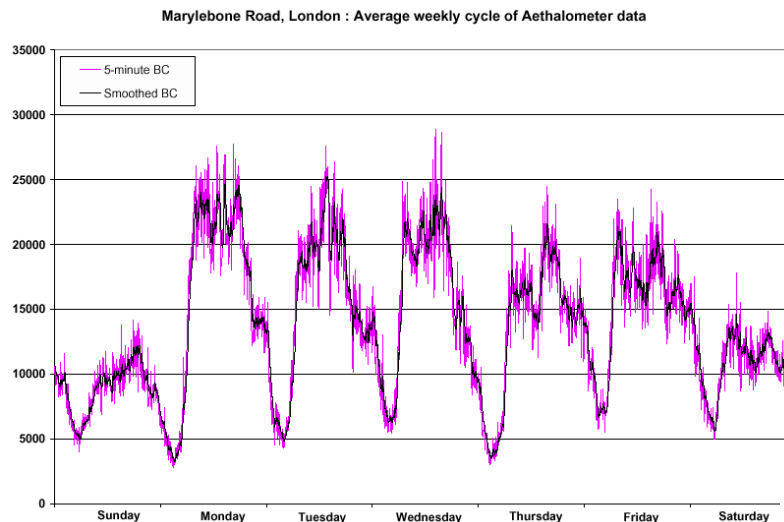
Time series from roadside location in London : 3 months of data on 5-minute time-base

Problem: Derive **meaningful** conclusion from 19,125 data points.



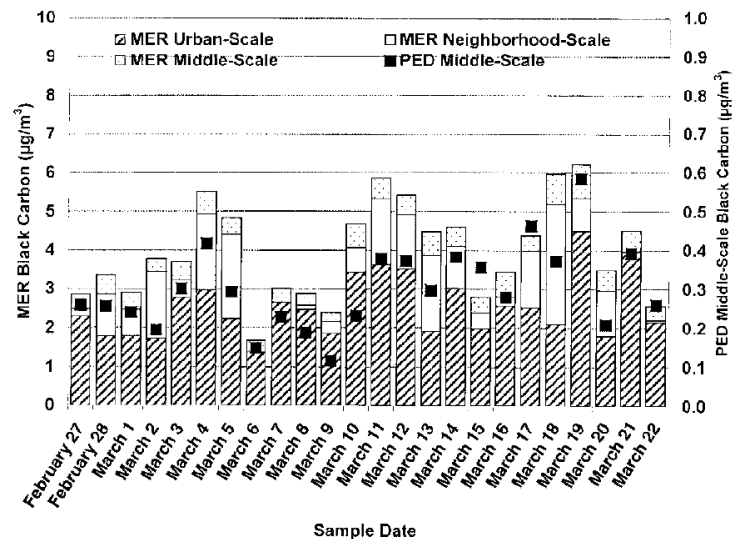
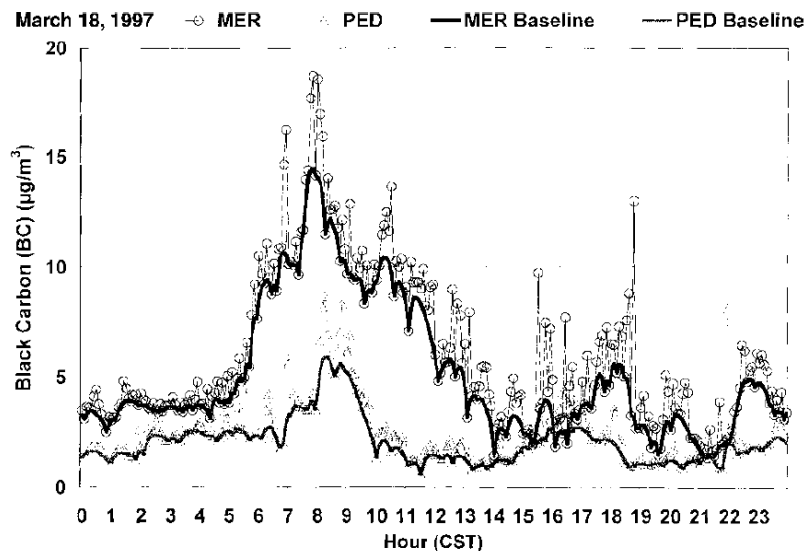
Data courtesy of P. Quincey, NPL, UK

Gather into overlays : 12 weekly cycles of 5-minute data



Can study local vs distant contributions

- Short-duration pulses (5-min averages) are attributed to middle-scale contributors, while longer durations (hourly averages) are attributed to neighborhood-scale or urban-scale emitters.
- Wind direction and speed is measured to determine where distant contributions are coming from.



Source apportionment

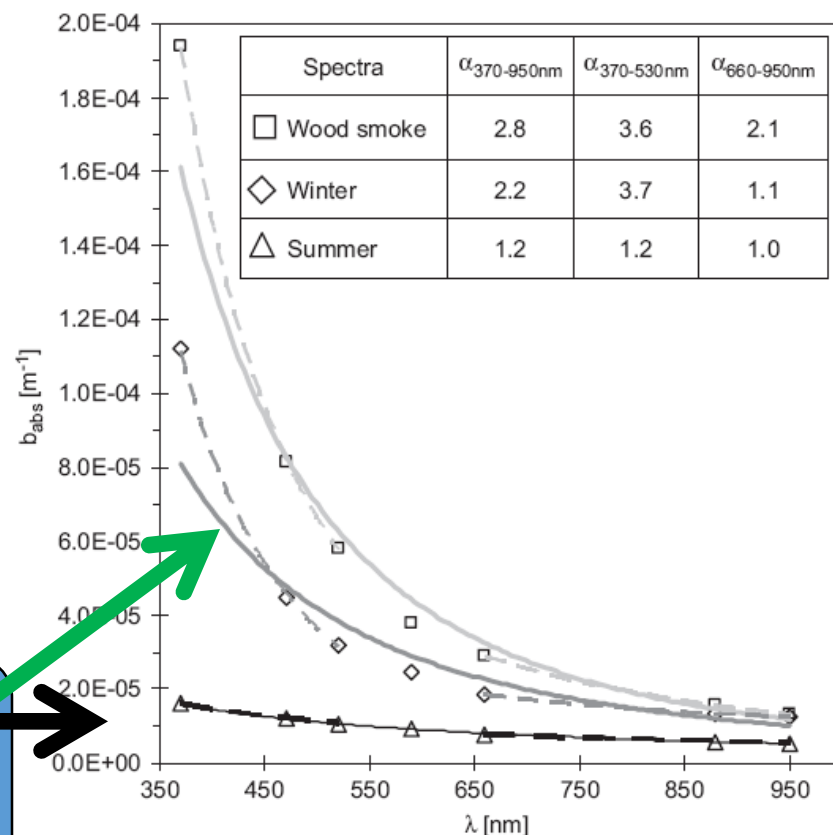
Biomass-smoke vs. diesel - 7λ

- measure attenuation with the Aethalometer
- absorption coefficient - b_{abs}
- for pure black carbon: $b_{abs} \sim 1/\lambda$
- generalize **Angstrom exponent**:

$$b_{abs} \sim 1/\lambda^\alpha$$

diesel: $\alpha \approx 1$

biomass-smoke: $\alpha \approx 2$ and higher



J. Sandradewi et al., A study of wood burning and traffic aerosols in an Alpine valley using a multi-wavelength Aethalometer, Atmospheric Environment (2008) 101–112

Quantification

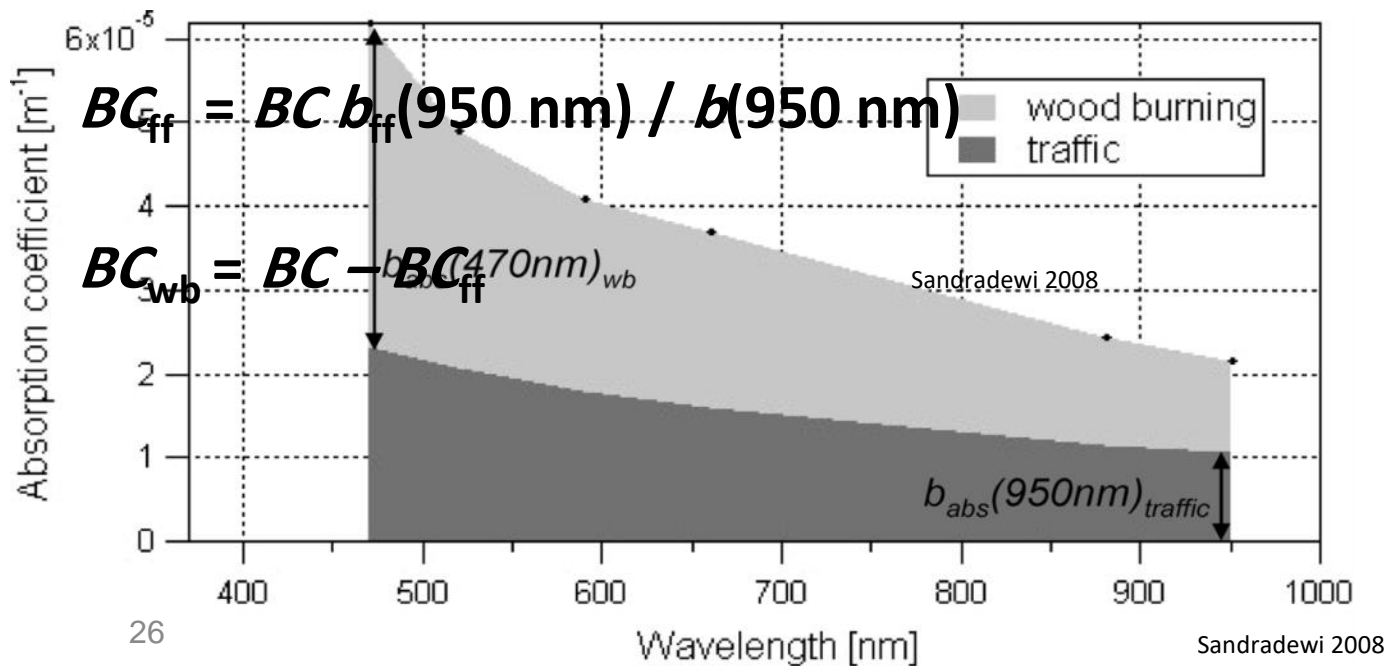
$$b(\lambda) = b_{wb}(\lambda, \text{wood}) + b_{ff}(\lambda, \text{fossil}) \quad \lambda = 470 \text{ nm}, 950 \text{ nm}$$

$$b_i(470 \text{ nm}) / b_i(950 \text{ nm}) = (470 \text{ nm} / 950 \text{ nm})^{-\alpha}$$

$$\alpha = 1,0 \pm 0,1 \text{ (fossil)} \quad \text{Bond \& Bergstrom 2004}$$

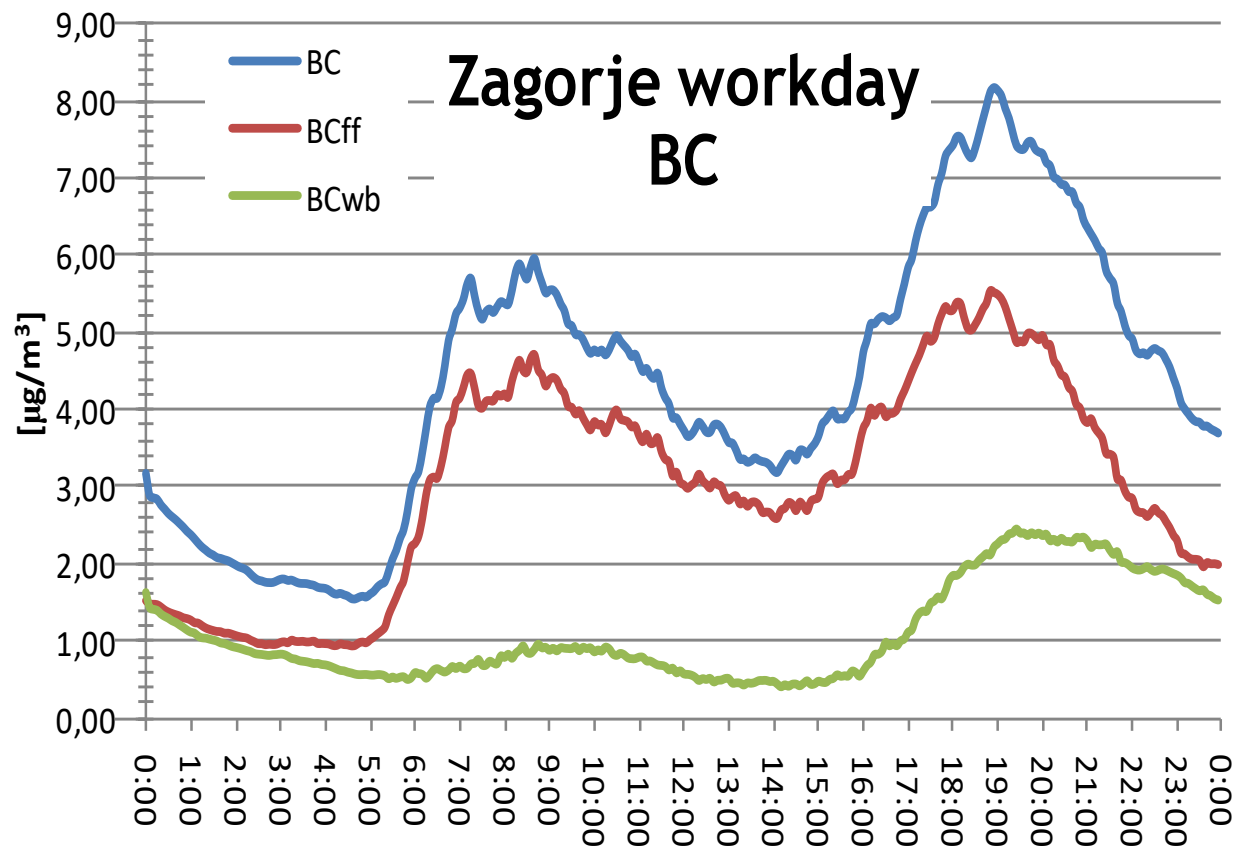
$$\alpha = 2,0 - 0,5 / +1,0 \text{ (wood)} \quad \text{Kirchstetter 2004,}$$

Day 2006,
Lewis 2008



Source apportionment

which sources to regulate?



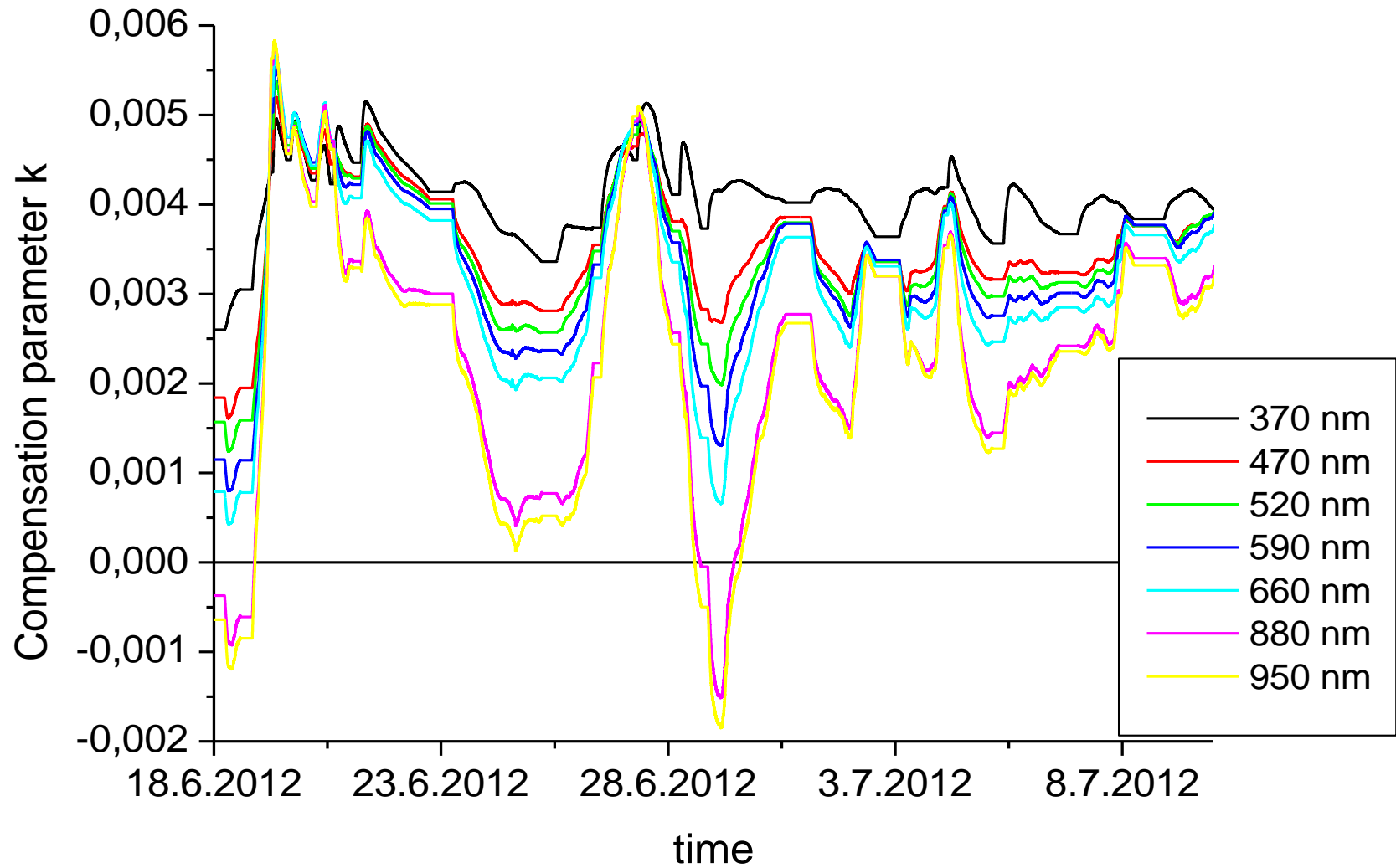
Traffic

73% ± 8%

27% ± 8%

Wood smoke

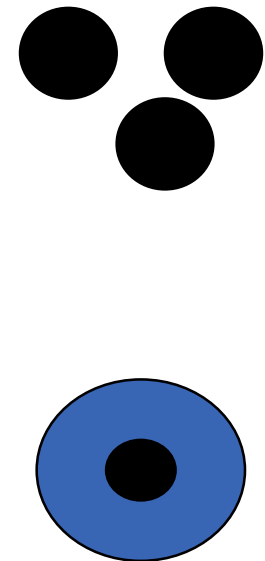
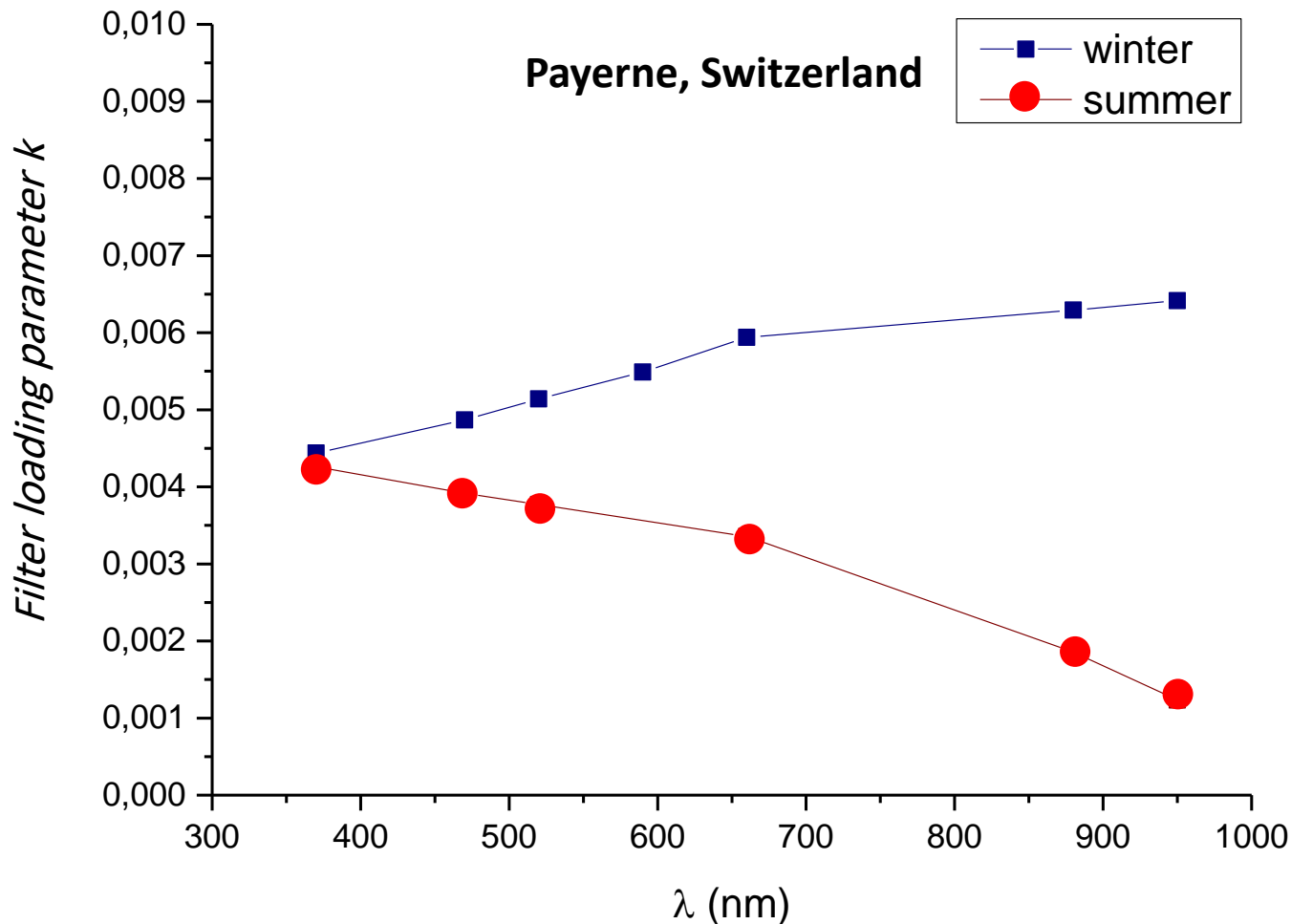
k factors provide additional information



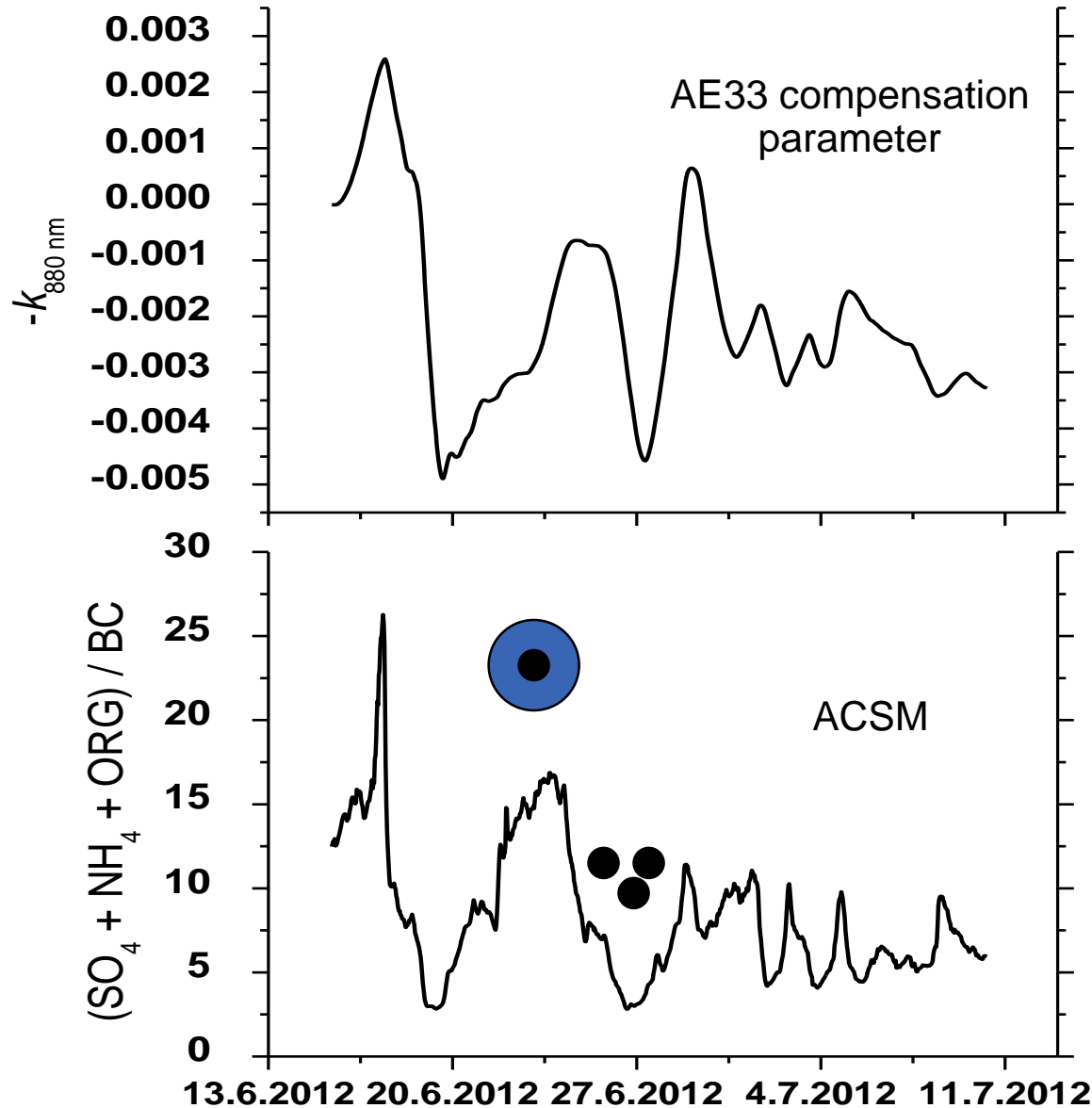
k factors depend on aerosol age



Dual spot Aethalometer AE33 measures filter loading effect
Filter loading effect is related to the particle coating



Compensation depends on the aerosol type: effect of particle coating



Paris summer
campaign 2012

We can **discriminate**
between fresh & old:
local & regional.

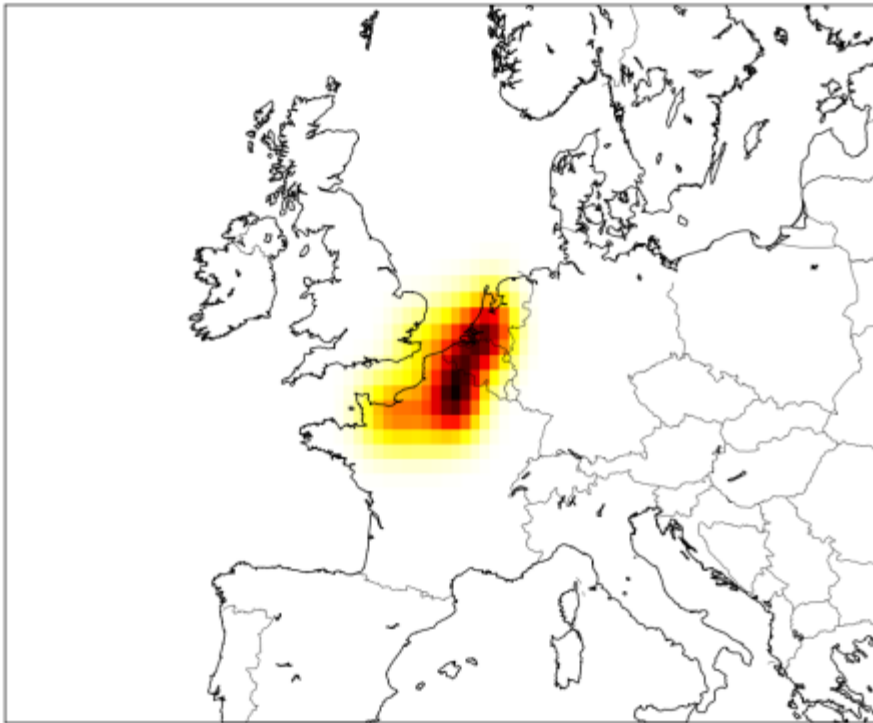
Compensation
parameter and sum of
anorganic secondary
aerosol + organic
aerosol correlate well.

Differentiation of fresh and aged aerosols

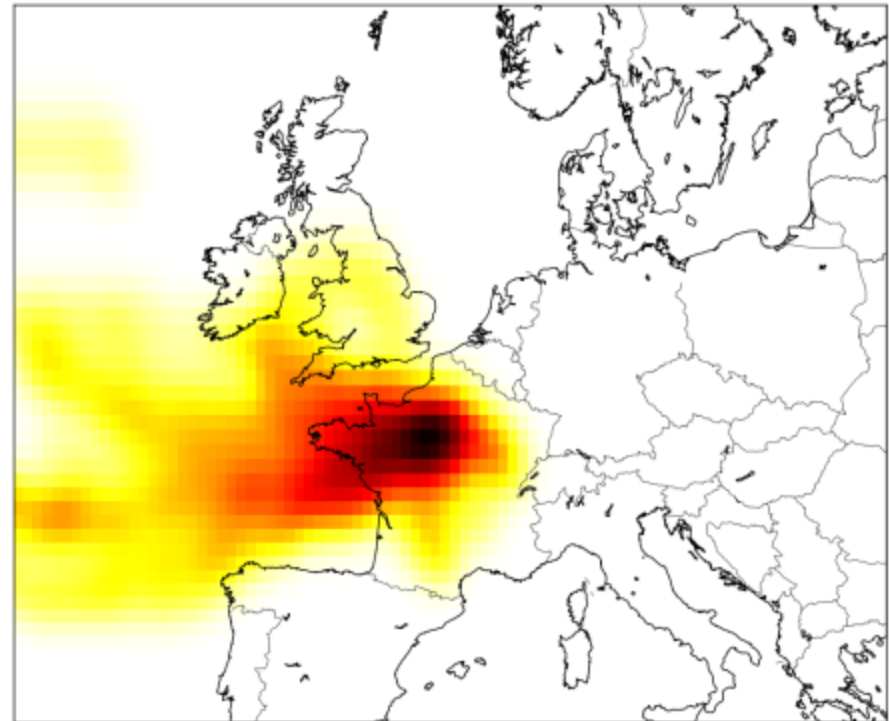
- Compensation parameter $k_{880\text{nm}}$ obtained from AE33
- PSCF (Back trajectory analysis using Potential Source Contribution Function)

Paris – **summer** campaign 2012

$k_{880\text{nm}} > 0.002$ **fresh** aerosols




$k_{880\text{nm}} < 0.002$ **aged** aerosols



Variety of applications


Evaluating transport air quality measures




Motivation

Atmospheric pollution represents a risk factor for respiratory health. Traffic emissions are of particular concern in urban areas. Many large cities all over the world have recognized the need for an encouragement of public transportation usage, traffic flow improvement, speed limit reduction, traffic restrictions are an unpopular tool to mitigate air quality. Traffic restrictions are an unpopular tool to mitigate air quality in urban areas. Many large cities all over the world have recognized the need for an encouragement of public transportation usage, traffic flow improvement, speed limit reduction, traffic restrictions are an unpopular tool to mitigate air quality in urban areas.

Among traffic-related pollutants, black carbon (BC) has been found to be a particularly important pollutant. BC concentrations vary proportionally with those of CO, NO₂ and NO. BC can therefore be considered a surrogate marker for other traffic-related pollutants. It is an emissions because it is primarily and directly emitted by diesel engines.




Evaluating Residential wood burning abatement




Motivation

Residential wood burning contributes significantly to the total particulate matter (PM) in urban areas. In cold climates, residential wood combustion was found to be a significant source of aerosol mass at various rural and urban sites throughout the world. It is particularly important on cold winter days when lower atmospheric trapping hinders dispersion of pollutants. Smoke from wood stoves is generated primarily by incomplete combustion of wood. A number of different factors related to the wood stove's design and operation can affect its efficiency. Measures include replacing old stoves with the most modern heating methods or better building isolations. All these measures aim to improve air quality in urban areas.




Mine ventilation optimization



Motivation

Mines use large ventilation systems to maintain a safe and healthy working environment. Diesel particulate matter (DPM) is often a key factor for air quality. DPM emissions and exposure levels are high in mines. Due to existing technology to continuously clean air, it becomes more difficult to supply air to the mine. As mines go deeper it becomes more difficult to supply air. Cleaning and reuse of available air is a good way to improve air quality. Understanding the range and timing of dust concentrations may enable new ventilation on demand fan and filtration systems to be developed.



Regional vs. Black Carbon pollution



Motivation

Once emitted into the atmosphere, the BC aerosol can be transported over long distances. The particles are ultimately removed from the atmosphere by dry deposition to the Earth's surface. The lifetime of BC particles is about one (1) week. Globally, the largest BC sources are the open burning of biomass, the largest fossil fuel and biomass burning. Air pollution is a global problem. When considering the region burning of biomass, it is a regional problem.



Fossil fuel vs. Biomass burning Black Carbon



Motivation

Atmospheric pollution represents a risk factor for respiratory health. The two major contributors come from traffic and off-road diesel engines account for 70% of BC emissions whereas the burning of residential solid fuels, especially of Asian and African BC emissions. Wood combustion in residential areas is commonly used for heating. Abatement measures include better stoves and can be reduced by encouragement of public transport, road utilization, traffic flow improvement, speed limit reduction. Since all retrofits are an unpopular and costly regulation and how efficient the regulations are.



Global Black Carbon pollution



Motivation

Black carbon (BC) has a unique and important role in the solar radiation, influences cloud processes, and affects the second largest climate warmer, after carbon dioxide. A large concentration is due to anthropogenic activities. Concentrated emissions because black carbon is rapidly removed from the carbon emission reduction represents a potential mitigation forcing from anthropogenic activities in the short term and long term. Comparison with remote sensing observations indicate that the black carbon is too low in many global aerosol models. It is done on a global scale.




Spacial scale contributions to Black Carbon pollution

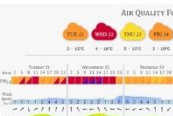


Motivation

Fixed-site air quality monitors used for compliance monitoring and to declare air quality alerts are intended to represent outdoor population exposures of people living in an approximately 5- to 20-km radius around the monitoring sites. Mass differences of 20-100% or more have been found between 24-hour averages taken at nearby locations. These differences occur because mass is a superposition of source emissions with provable contributions at most 1-200, 1000, 100, neighborhood (1-5 km), urban (5-50 km) and distant (>50 km) spatial scales. A method that resolves contributions from different spatial scales allows particle measurements from all monitoring sites to be better interpreted. Black carbon is an especially useful observable for this purpose, because its origin is exclusively from primary emitters.




Black Carbon Pollution Alert



Motivation

Exposure to air pollution, especially at high concentrations, is associated with respiratory problems, heart disease, cancer, and adverse other health problems. Personal exposure to ambient air quality by staying indoors, reducing outdoor air infiltration, and limiting physical exertion, especially outdoors and during high pollution alerts and offering forecasts can reduce actions. In addition forecasts can help authorities plan mitigation measures.



Black Carbon car emission



Motivation

One of the main sources of air pollution is traffic. To assess air pollution the emissions are calculated from the vehicle factors. Since the emission factors depend on vehicle performance, driving environment (city, highway, rural) and limiting physical exertion, especially outdoors and during high pollution alerts and offering forecasts can reduce actions. In addition forecasts can help authorities plan mitigation measures.



Vertical profile Black Carbon Pollution

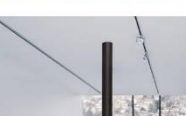


Motivation

Detailed vertical profiles of aerosol parameters are needed to assess the impact of aerosols on climate and human health. Recent studies have demonstrated the inability to compute measurements, vertical profiles of aerosol optical properties and/or relative effects throughout the vertical column, such as above or below the cloud of forcing. BC profiles are globally scarce compared to ground level data. Knowledge about aerosol vertical profiles over Europe, this is a major challenge.




Stove characterization Based on Black Carbon




Motivation

Smoke from wood burning stoves and fireplaces can be a significant source of air pollution. People can reduce their exposure by choosing low-emission stoves, operating them properly to improve combustion efficiency, reduce emissions, and use fuel wisely. The U.S. Environmental Protection Agency (EPA) set standards for the U.S. unless they meet certain criteria. The EPA Emission Certification Label. Certified stoves are more efficient than non-certified stoves, and are more efficient than the Aethalometer to measure smoke.




Fenceline Monitoring of Black Carbon



Motivation

In industrial fence line communities the environmental and pollution concentrations are below the regulation limit. Operations include undetected leaks (called fugitive emissions) and can come from industry, refineries, energy production, construction and nearby communities and reduce air quality. It is important to know how much effect these special operations have on the industry as assurance for the affected communities. The detectors can be positioned permanently inside the fence or outside the fence. The data can be sent to the data center.



Marine vessel Black Carbon Pollution



Motivation

The duration of use is usually significantly longer for marine vessels. Therefore, these vessels are often powered by relatively old engines. Also, the quality of fuel used for marine vessels is usually not as good as that used for automotive engines. port areas may exhibit the multi-scale of studies that addressed outdoor air pollution. Ship emissions contribute also to global warming. It is estimated that around 13% to global greenhouse gas emissions.



Urban Black Carbon Monitoring



Motivation

Aerosols affect the climate due to their ability to scatter and absorb sunlight, and to act as cloud condensation nuclei, thus modifying the lifetime of clouds, droplet size and precipitation rate. The absorbing species (i.e. black carbon, dust) absorb atmospheric sunlight thus "masking" (land cooling) the surface and warming the atmosphere in the process. This can affect atmospheric thermal structure and regional circulation systems such as monsoons. Measurements of the vertical distribution of aerosol properties provide essential information for generating more accurate model estimates of radiative forcing and atmospheric heating rates compared with employing remotely sensed column averaged properties.



Conclusions



- AE33 measures BC concentrations on 1 min time scale (even 1s).
- BC values are compensated for filter loading effect on-line.
- Automatic and manual QA/QC procedures.
- In addition to BC AE33 provides also:
 - Biomass burning ratio.
 - Absorption Angstrom exponent.
 - Compensation factors k (fresh vs aged aerosols).
 - Diurnal patterns.
 - Local vs distant contribution to pollution.