Advanced measurement of black carbon

Because nothing in life is just black and white.

ASA
آزمون صنعت آروین

Aerosol

MAGEE
SCIENTIFIC

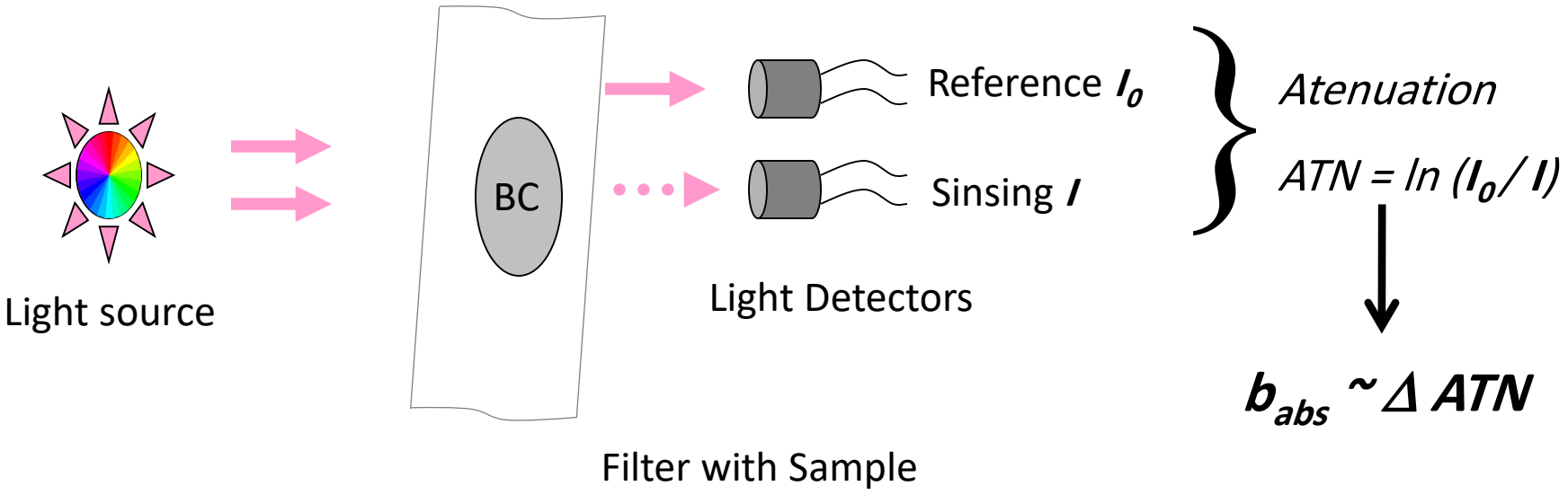
Aethalometer AE33 TECHNICAL TRAINING

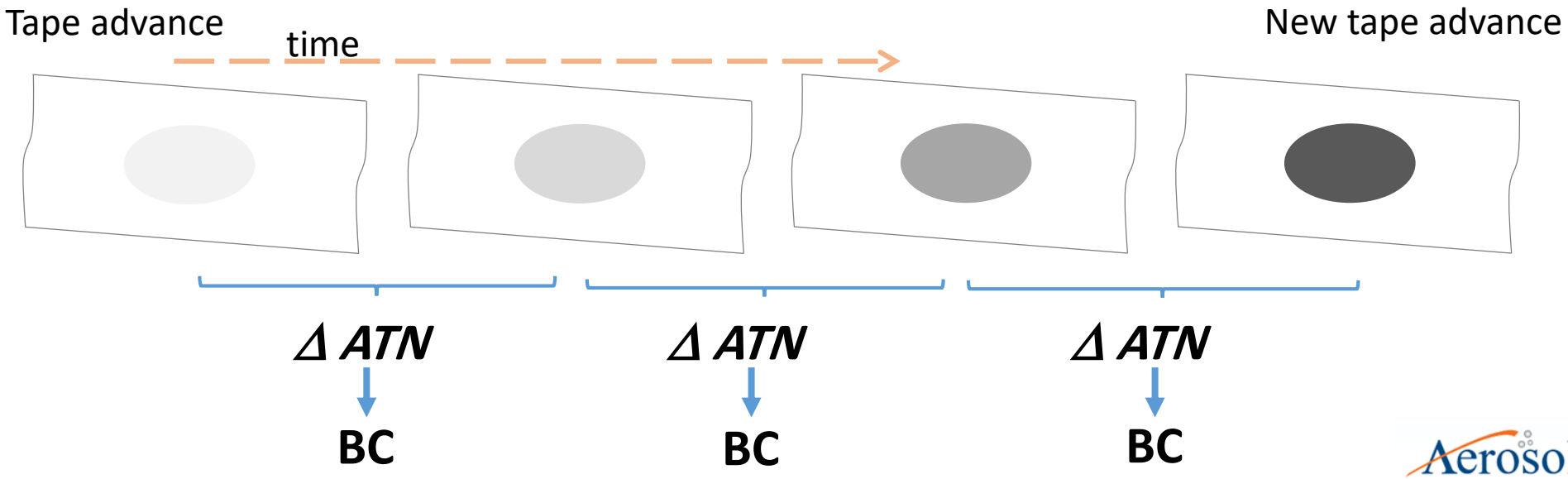
Introduction

- **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 coeficient (**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





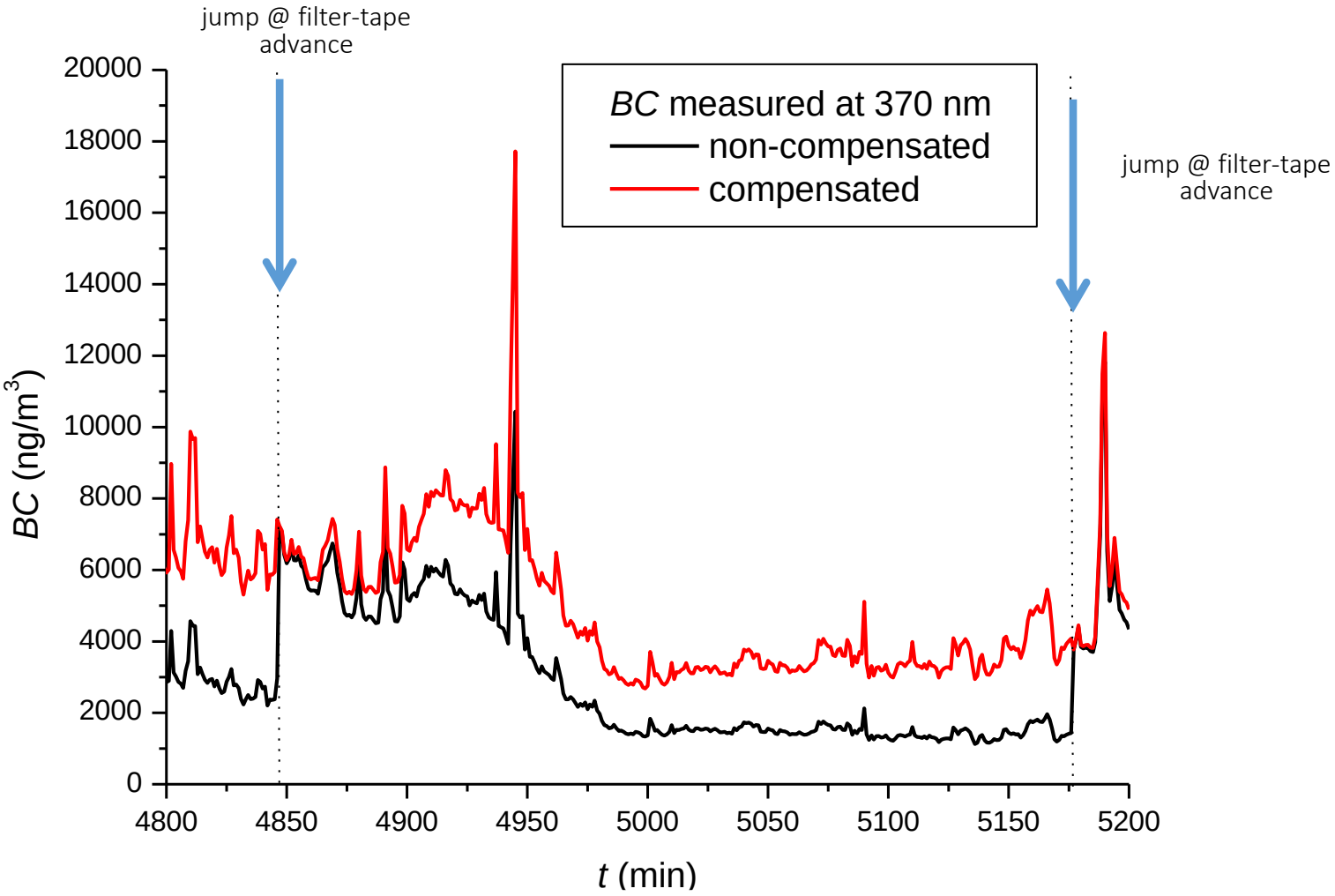
Basic calculations

- Basic equation
  - $BC = \frac{S*\Delta atn}{F*\Delta t*\sigma}$
- Sigma & multiple scattering parameter

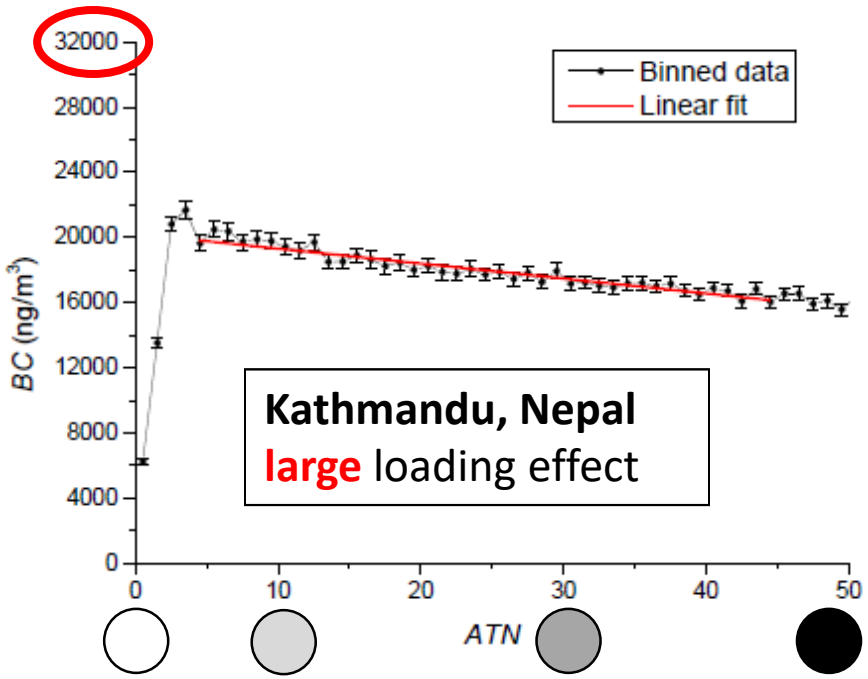
  $\sigma_{filter} = \sigma_{air} * C$ (Weingartner et al. 2003)

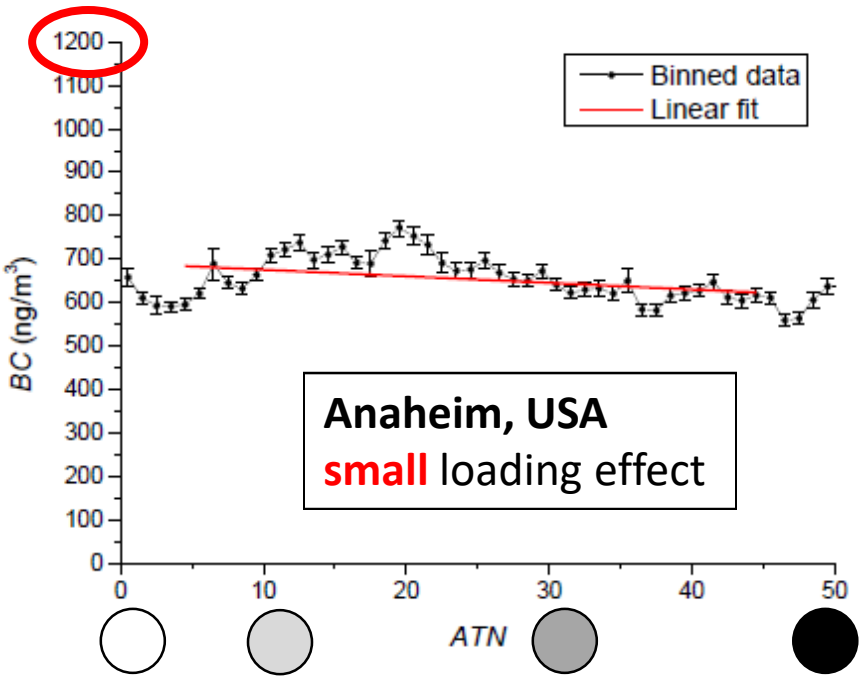
  C=1.57
- Loading effect compensation
  - $BC_{comp} = BC/(1 - k * ATN)$
- Measured leakage
  - $F_{in} = F_{out} * (1 - \zeta)$
  - Leakage factor ζ= 0.025
- Final equation
  - $BC = \frac{S*\Delta atn_1}{F_1(1-\zeta)*\sigma_{air}*C_{teflon}*(1-k*ATN_1)*\Delta t}$

Loading effect compensation



Loading effect compensation





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

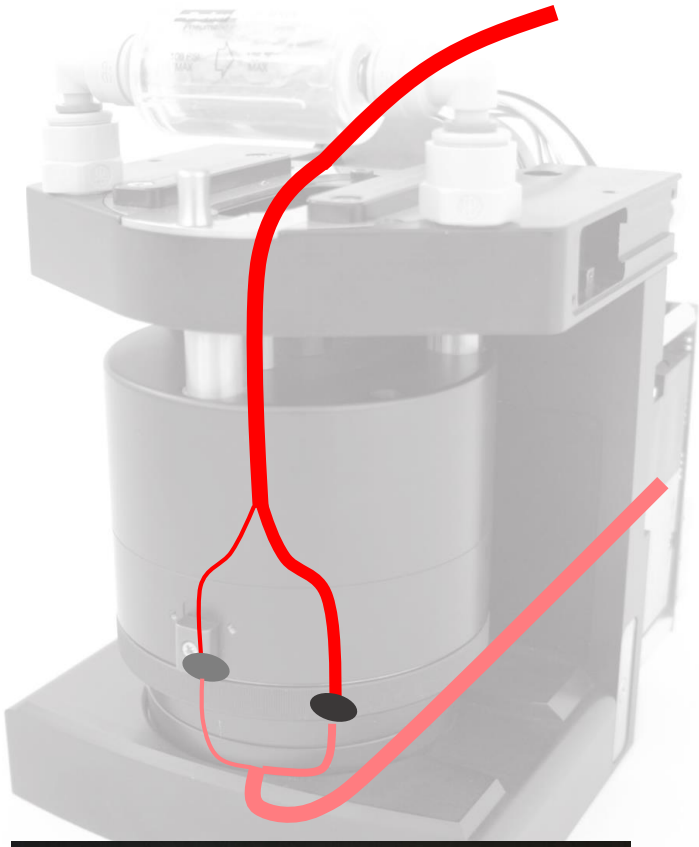
Reduction of the instrumental response due to loading of the filter. Jump at the tape advance.

- 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“.

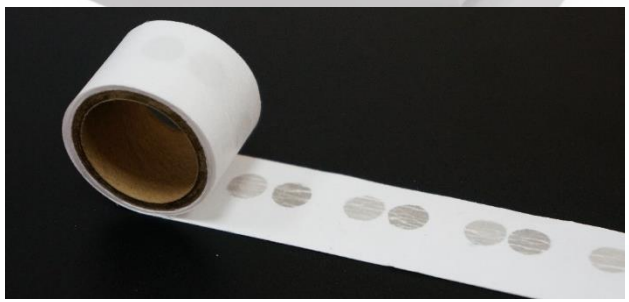


<u>Origin</u>

- As the loading of particles on the filter increases, **the <u>existing</u> 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.

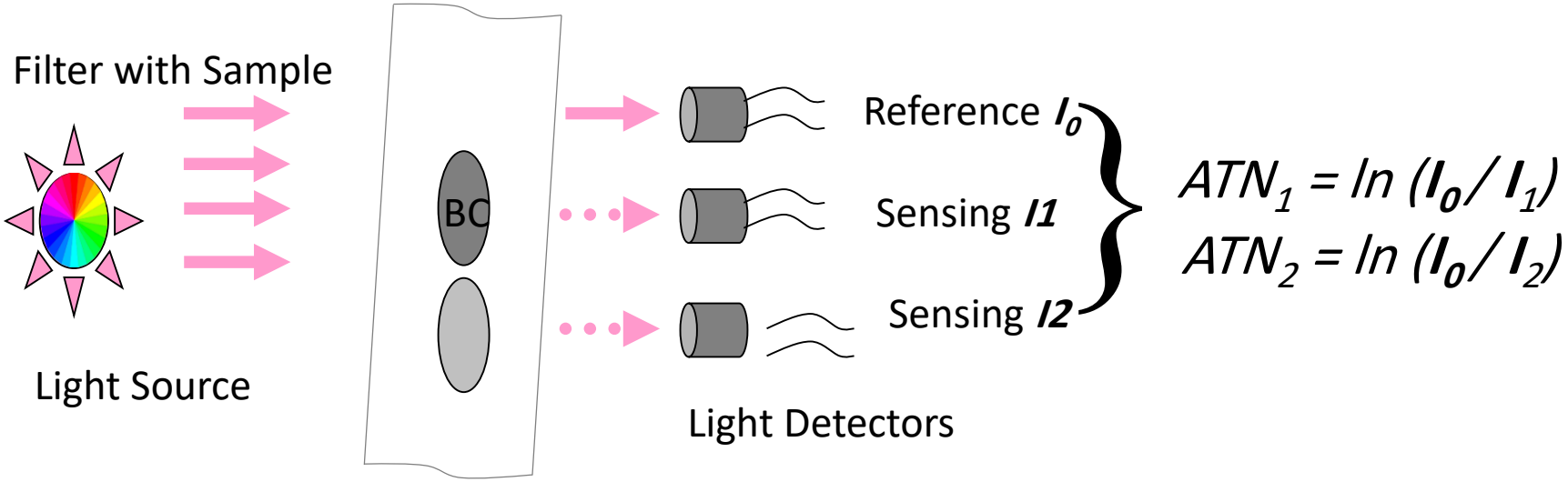
<u>Result</u>

- The relationship of ATN / BC becomes <u>non-linear.</u>

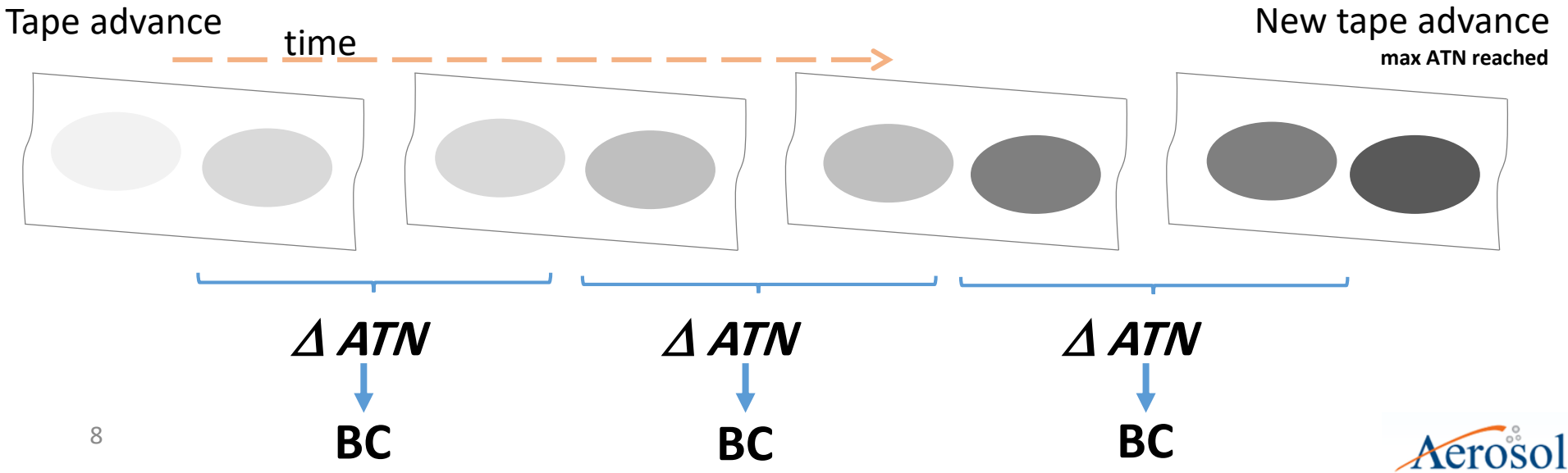


Aerosol

Loading effect compensation

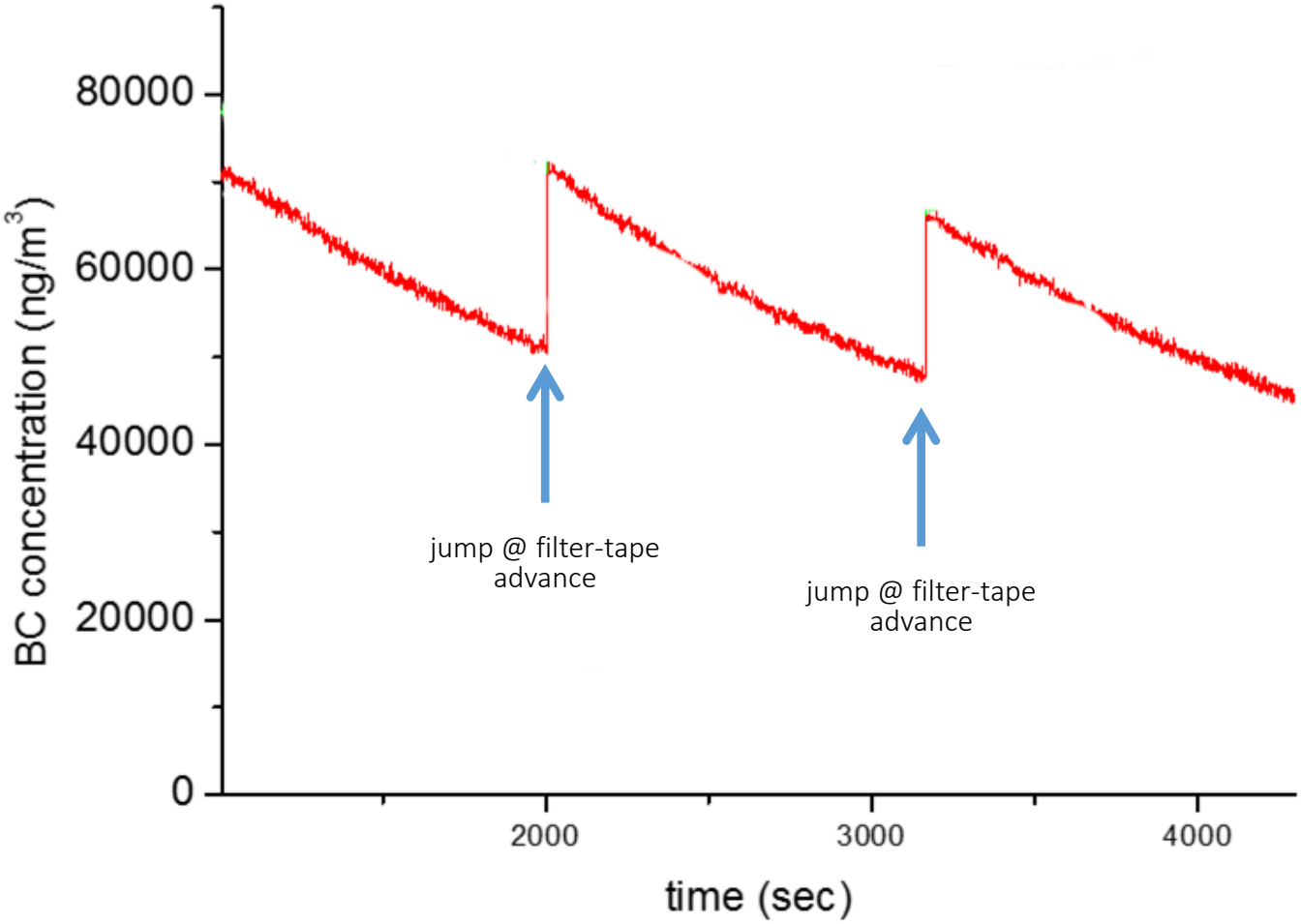


Two parallel spots with different flow, therefore -> **different loading and attenuation**.

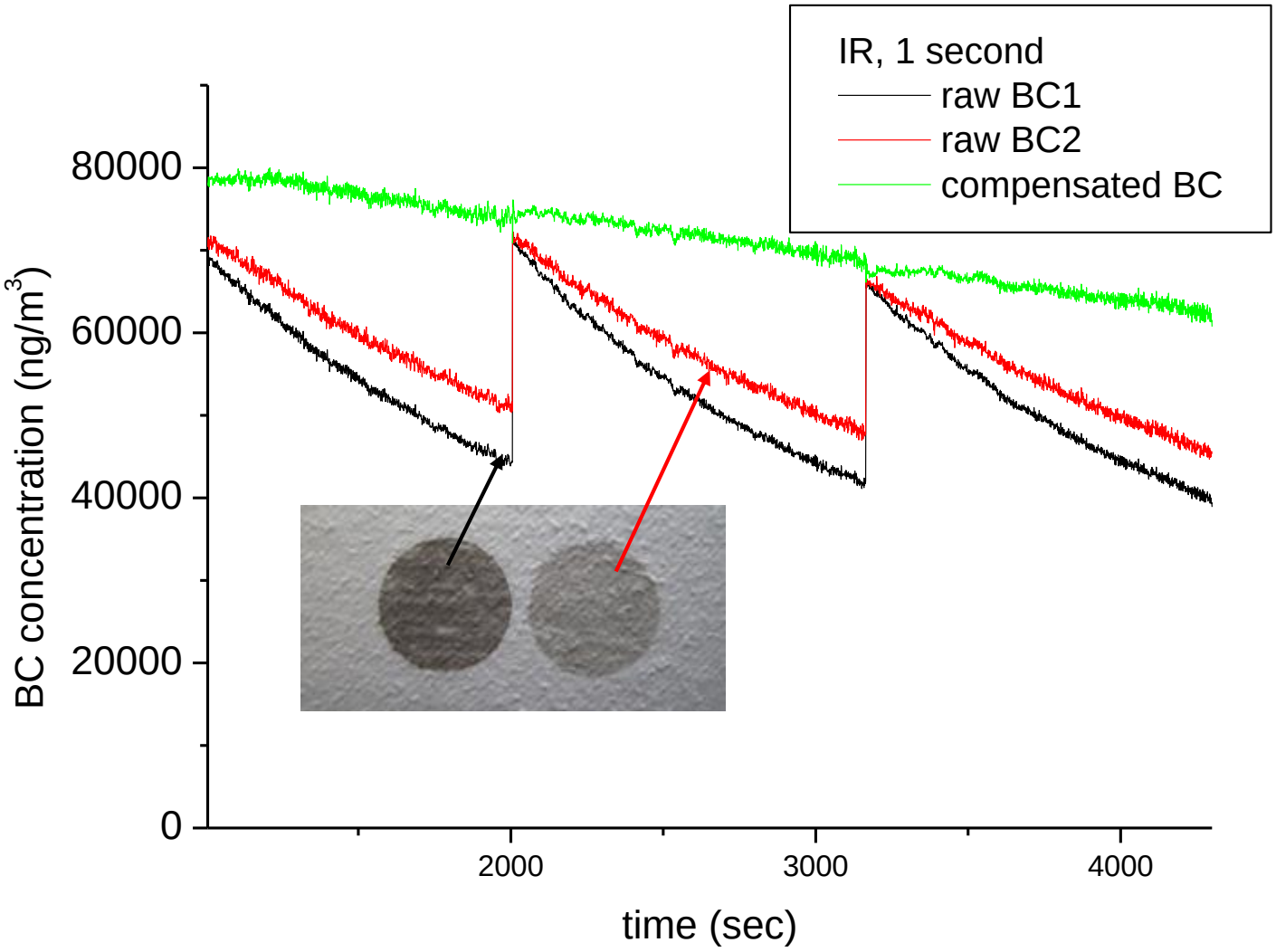


Loading effect compensation

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



Loading effect compensation



Two parallel spots with different flow, therefore

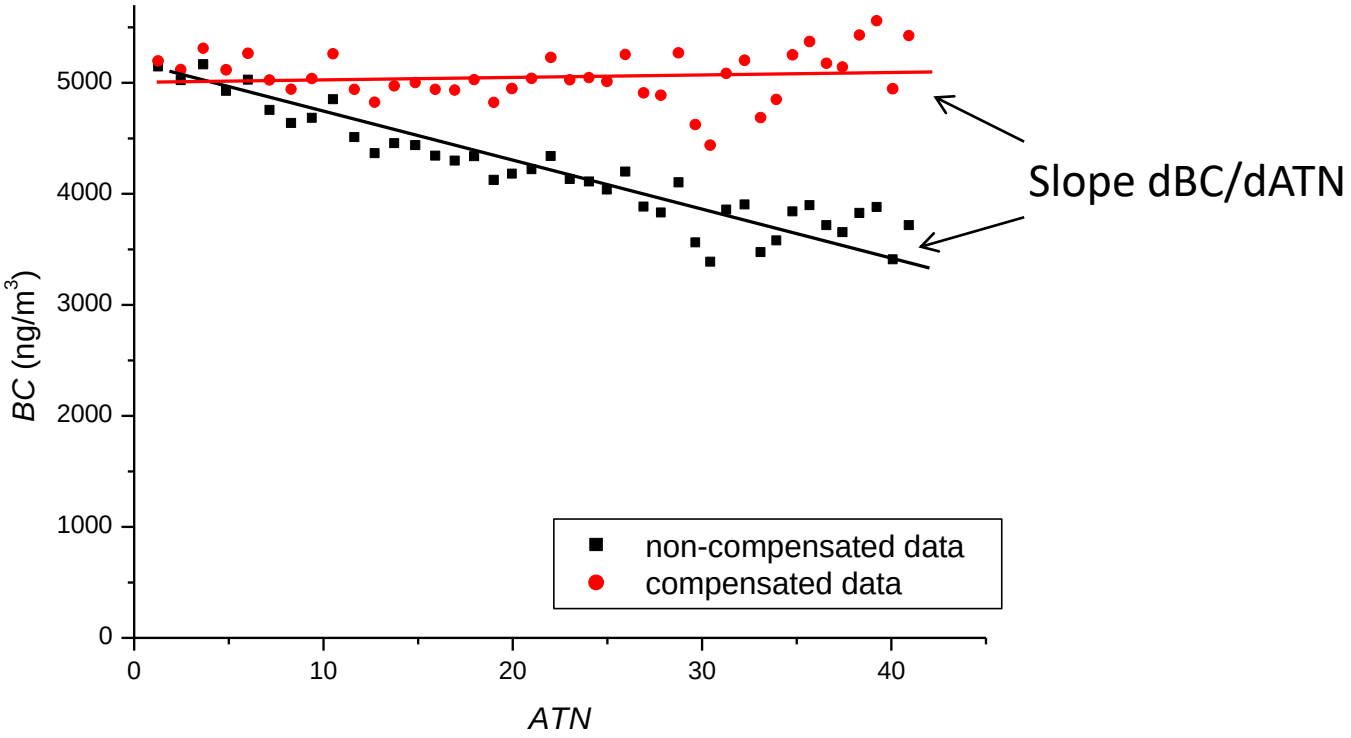
different loading and attenuation.

Calculate loading compensated **BC** and ***k***!

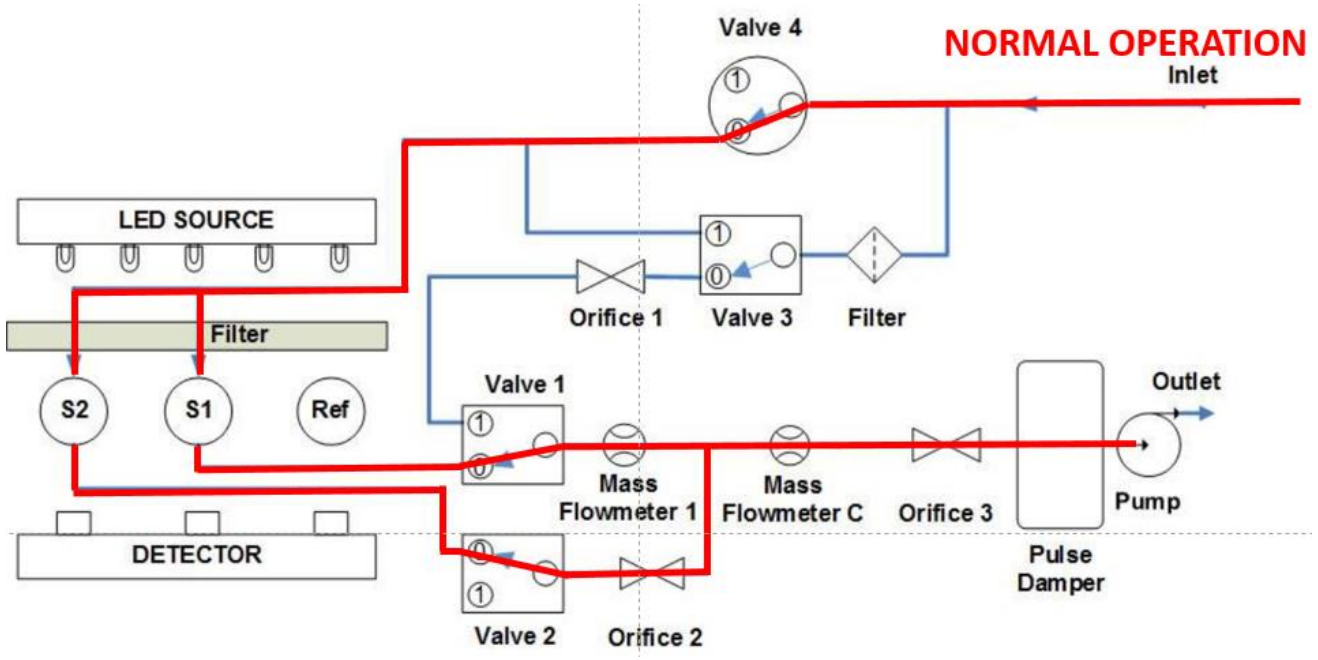
Loading effect compensation validation

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:

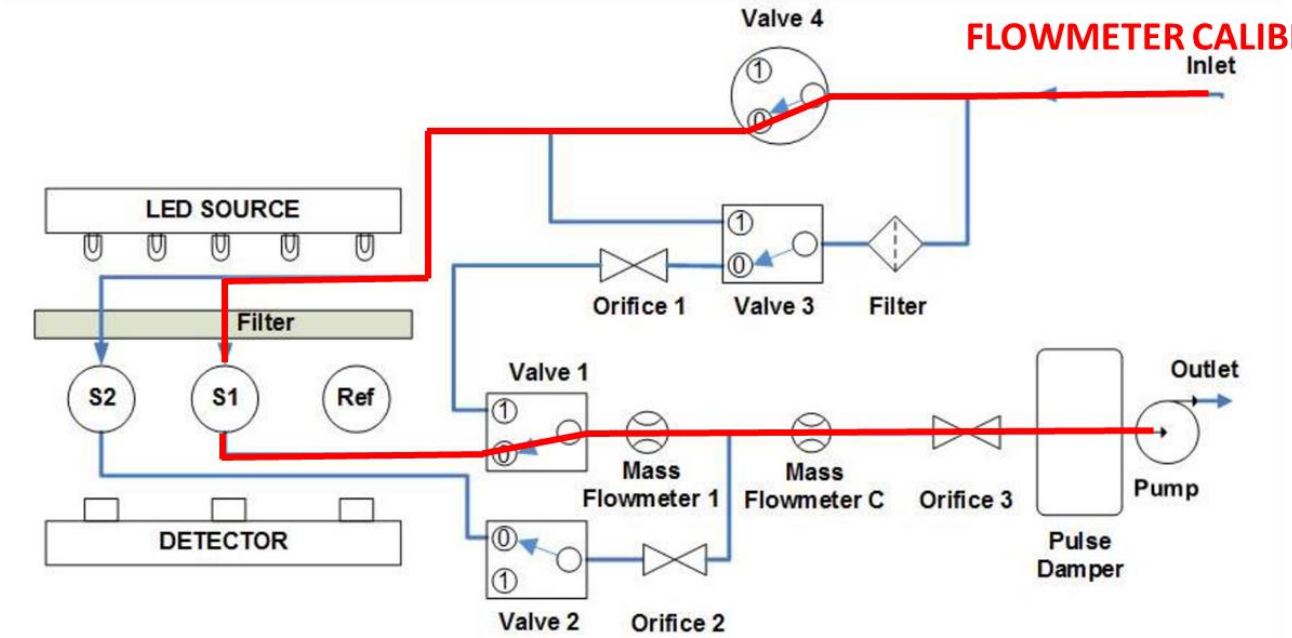
Valve 4-moving (1=YES / 0=NO), Valve 4 position (1=ON / 0=OFF),

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



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Measurement	0	0	0	0	00000
Flowmeter calibration	0	0	1	0	00010

Quality control/flow verification

- Automatic / Manual

TSI Mass Flowmeter 4140

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)

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:

ζ=1-(Fin/Fout)

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:

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

- 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/m3)	
	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

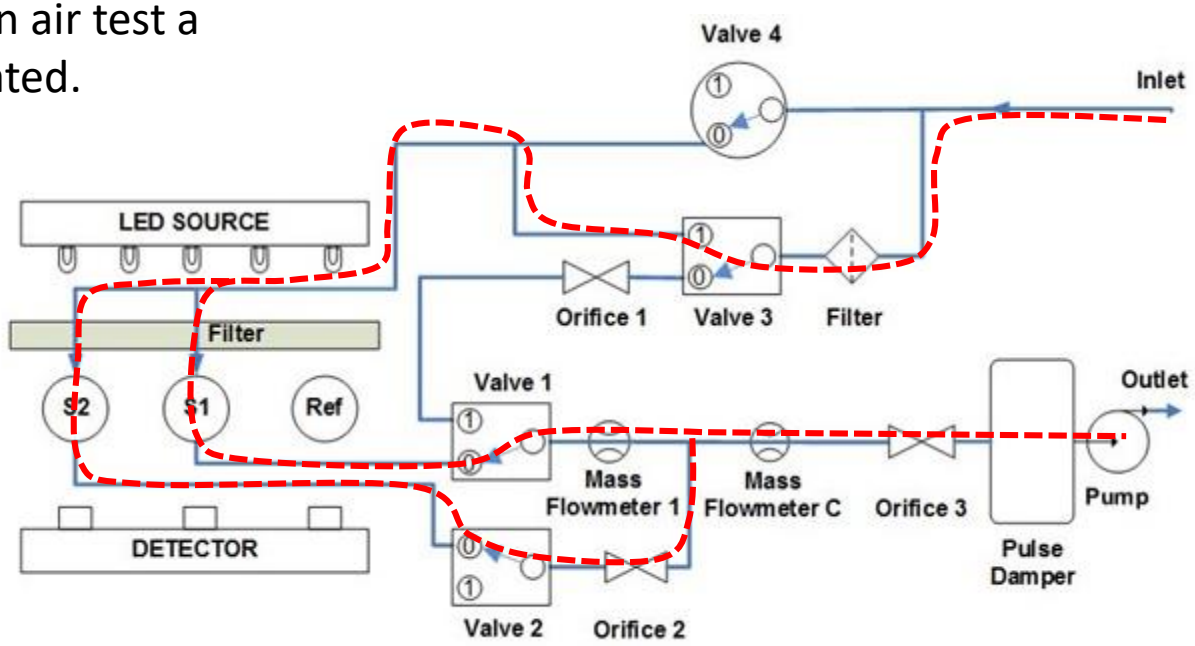
Clean air test (flow trough built-in filter):

- 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 chanel 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

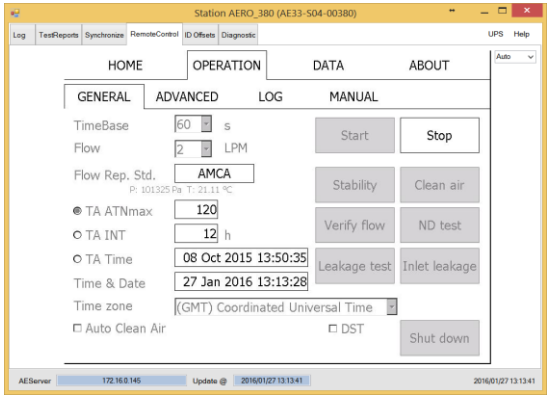
Optical test slope result:

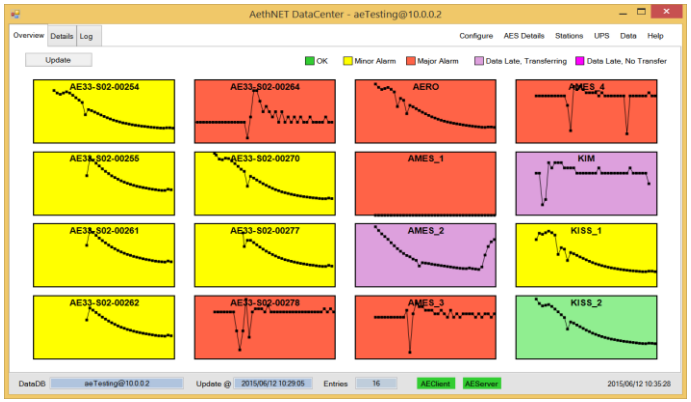
Ch1	s1 0.995	s2 0.993
Ch2	s1 0.983	s2 0.980
Ch3	s1 0.984	s2 0.980
Ch4	s1 0.981	s2 0.978
Ch5	s1 0.979	s2 0.976
Ch6	s1 0.974	s2 0.972
Ch7	s1 0.977	s2 0.975

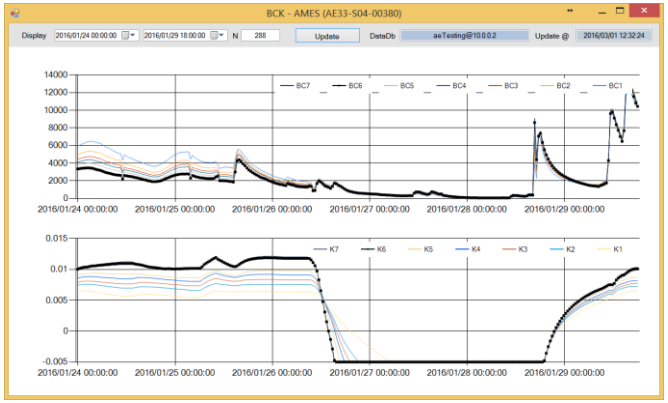
Slope should not differ for more than 10 % from unity

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.







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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.

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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**	**lAlarms**	**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.

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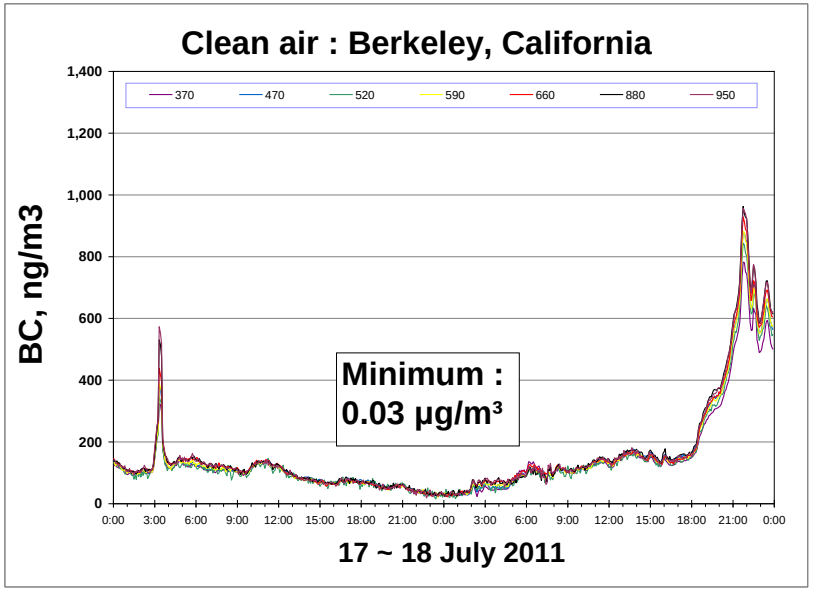
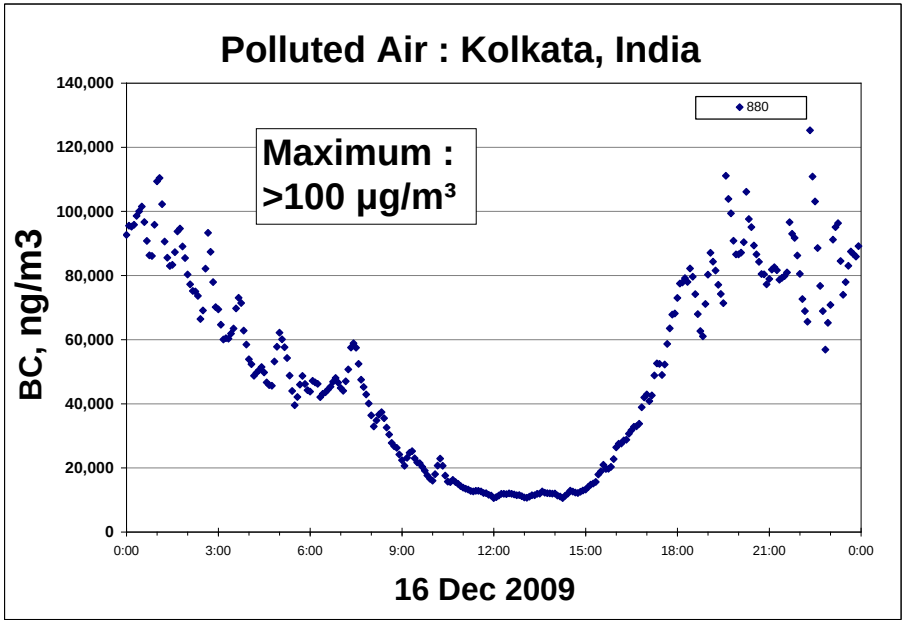
Wide Dynamic Range of actual measurements

Clean air from ocean: BC < 50 ng/m³



Highly Polluted Air : BC >100 µg/m³

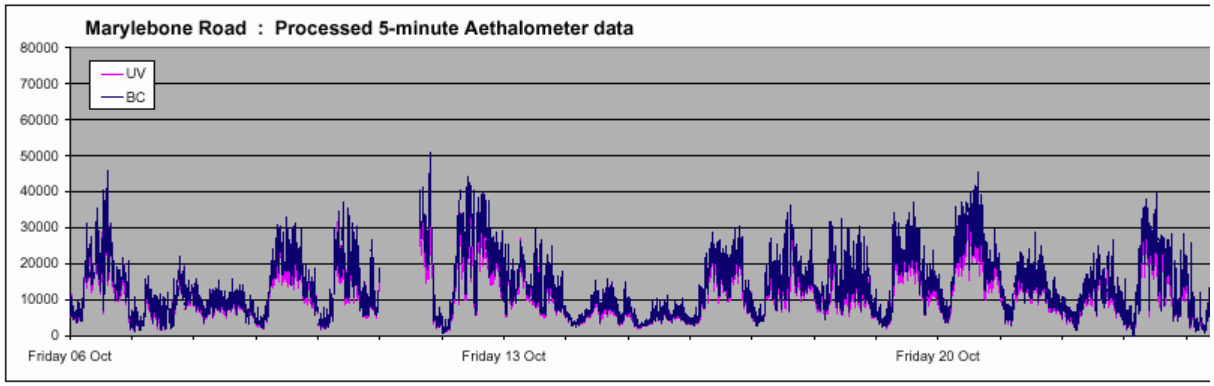


Can study diurnal patterns

Urban roadside emissions study …… London

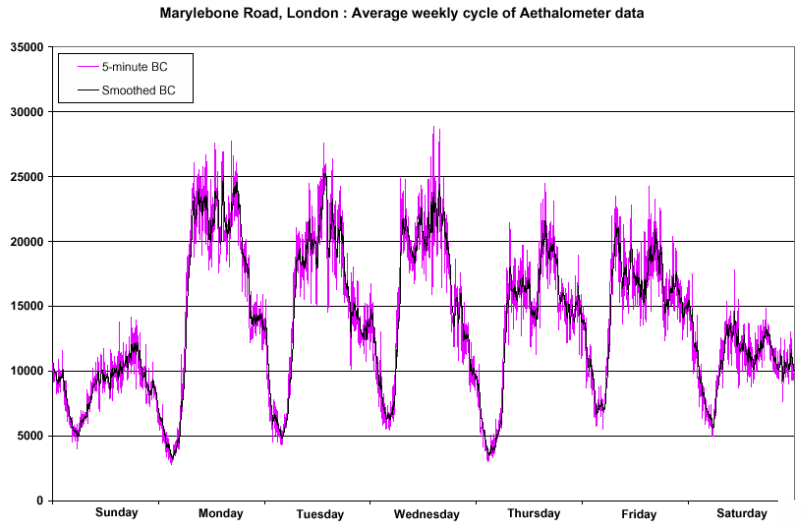
Time series from roadside location in London : 3 months of data on 5-minute time-base

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



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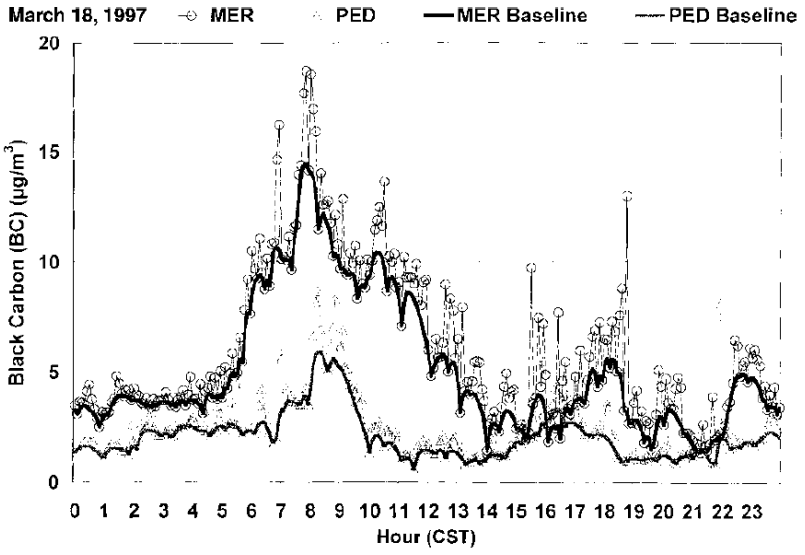
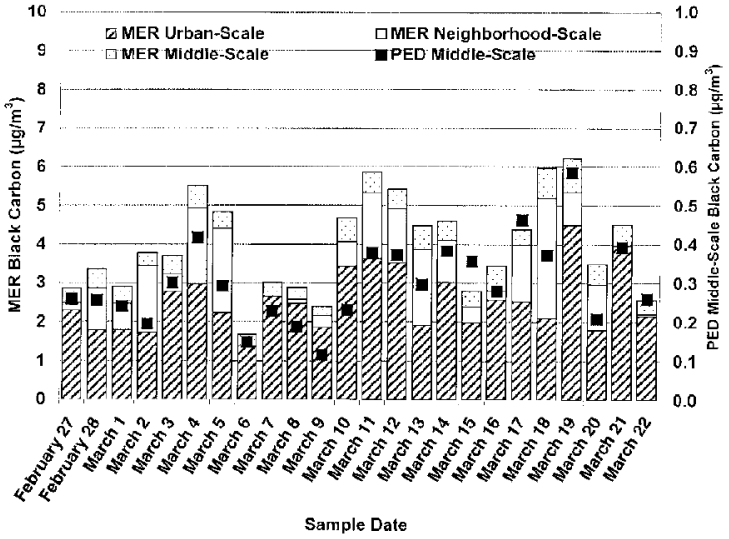
Can study local vs distant contributions

- 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 comming from.





Source apportionment

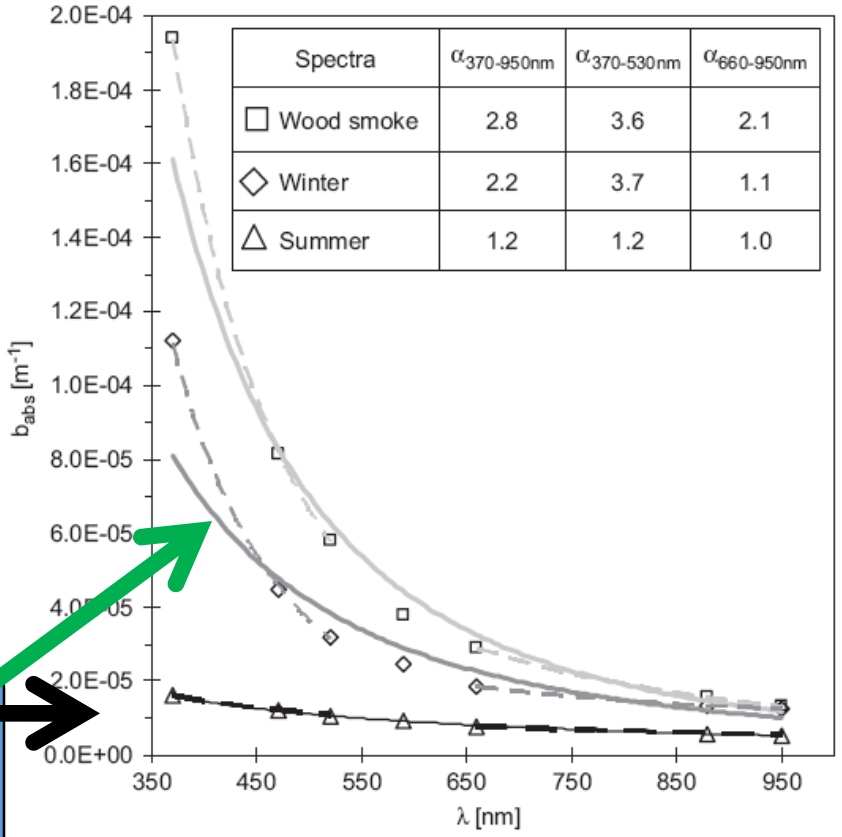
Biomass-smoke vs. diesel - 7λ

- 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

Aerosol

Quantification

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

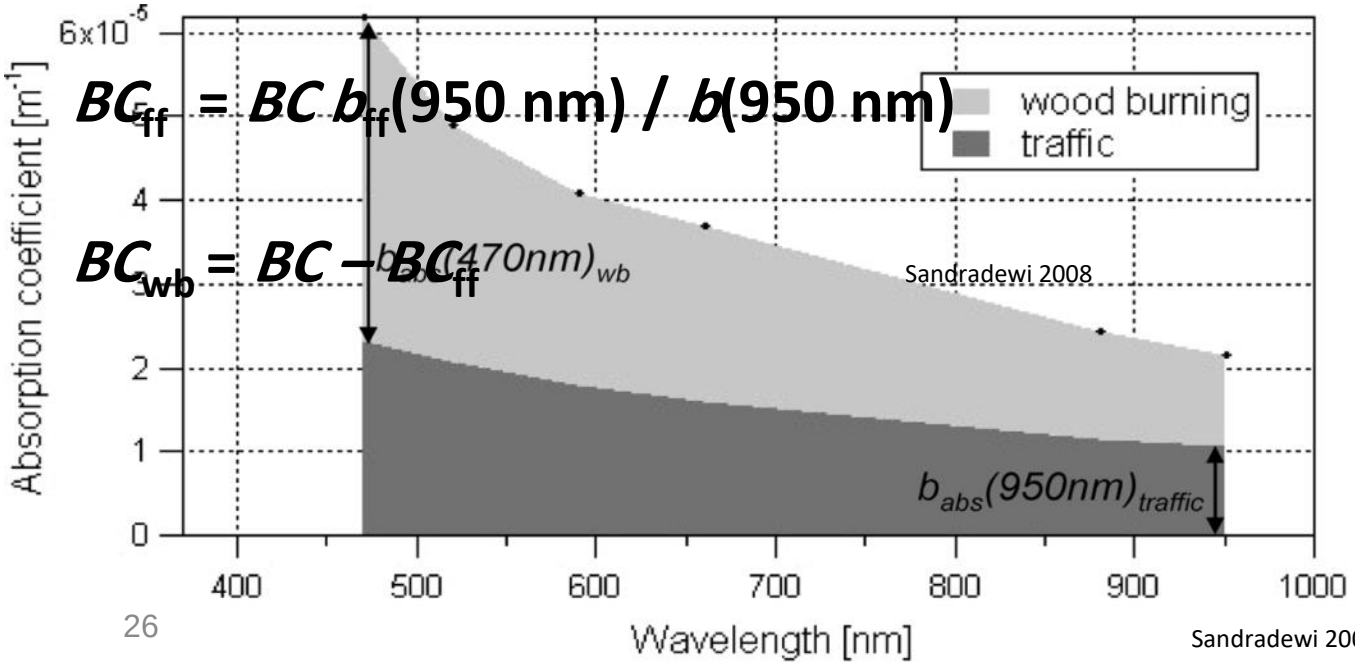
$b_i(470\text{ nm}) / b_i(950\text{ nm}) = (470\text{ nm} / 950\text{ nm})^{-\alpha}$

$\alpha = 1,0 \pm 0,1$ (fossil) Bond & Bergstrom 2004 .

$\alpha = 2,0$ -0,5/+1,0 (wood) Kirchstetter 2004, Day 2006, Lewis 2008

$BC_{ff} = BC\ b_{ff}(950\text{ nm}) / b(950\text{ nm})$

$BC_{wb} = BC - BC_{ff}$

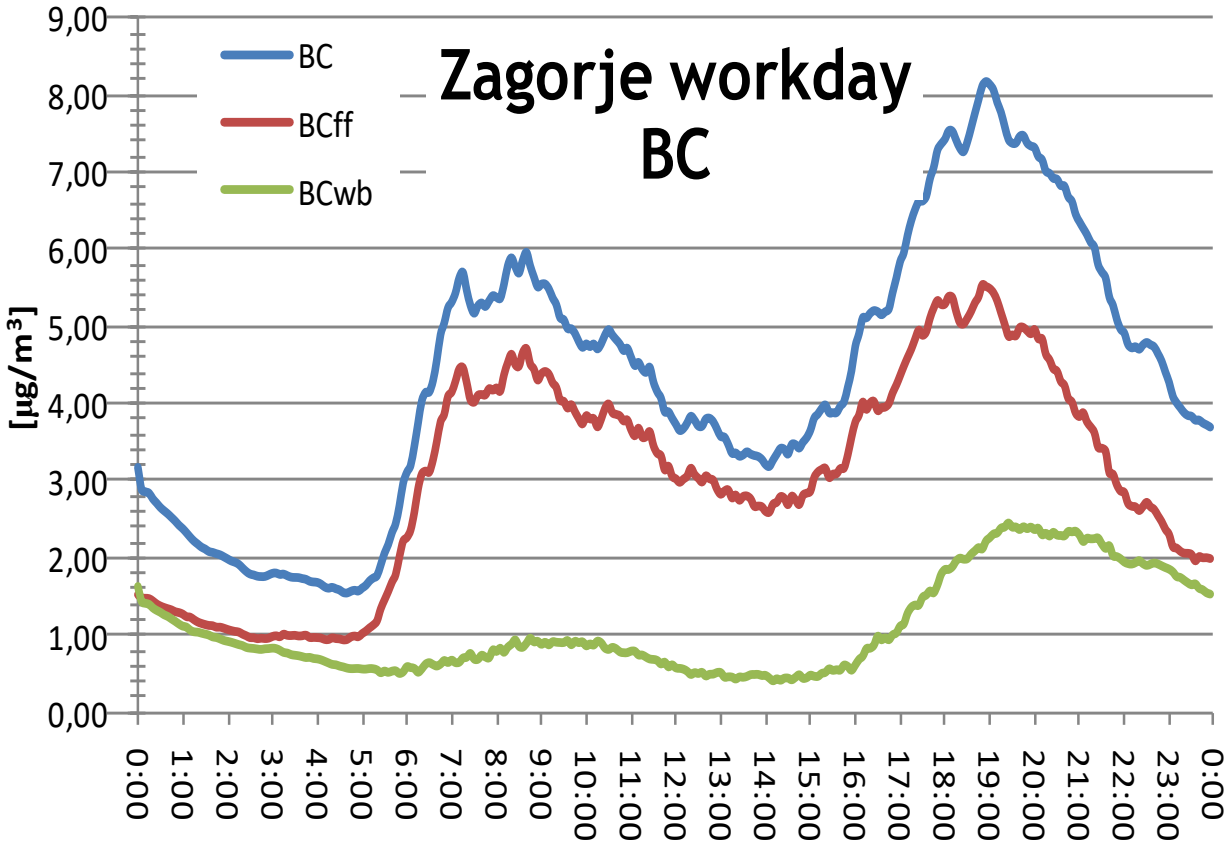


Sandradewi 2008

Sandradewi 2008

Source apportionment

which sources to regulate?



Traffic

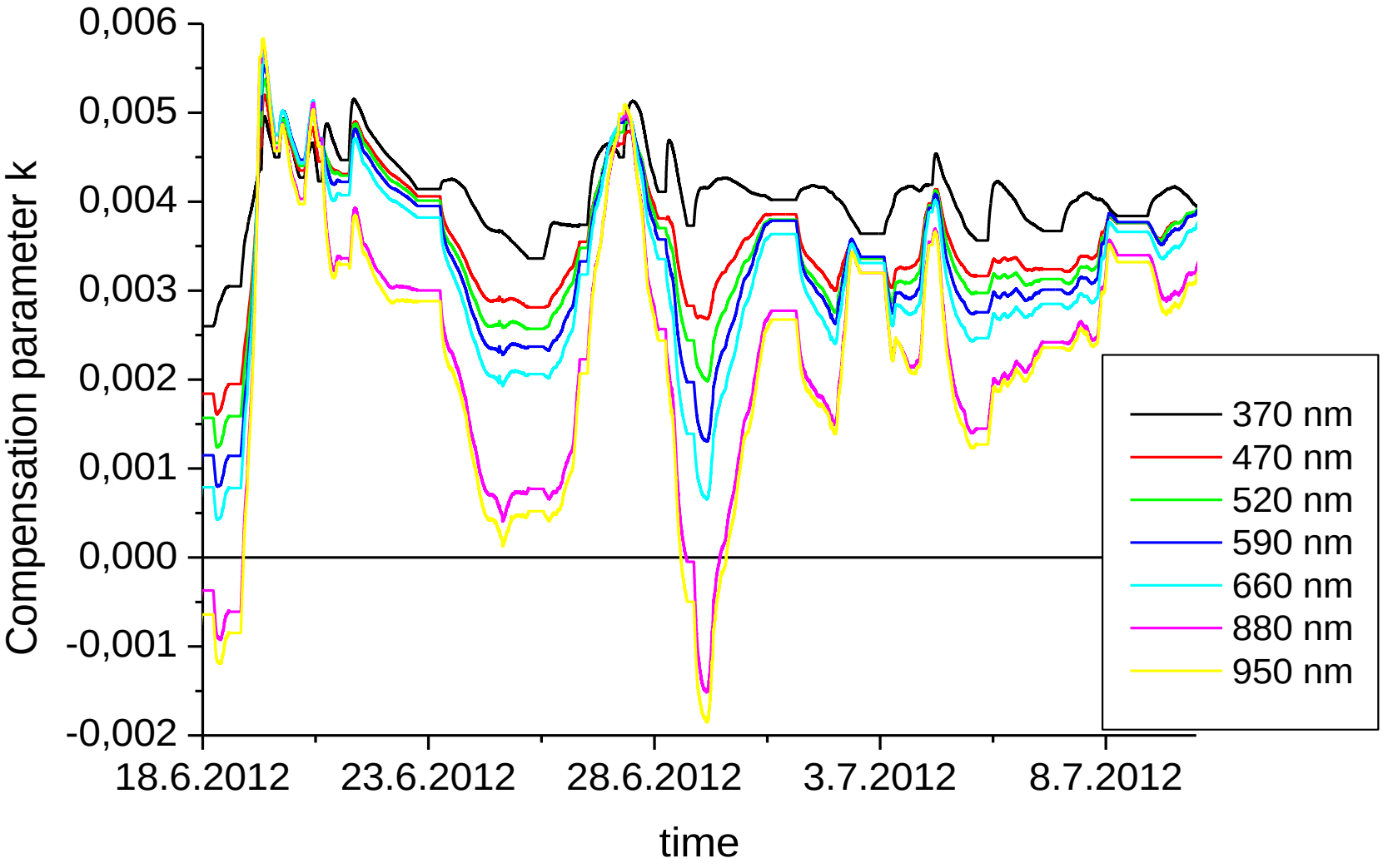
73% ± 8%

27% ± 8%

Wood smoke

Aerosol

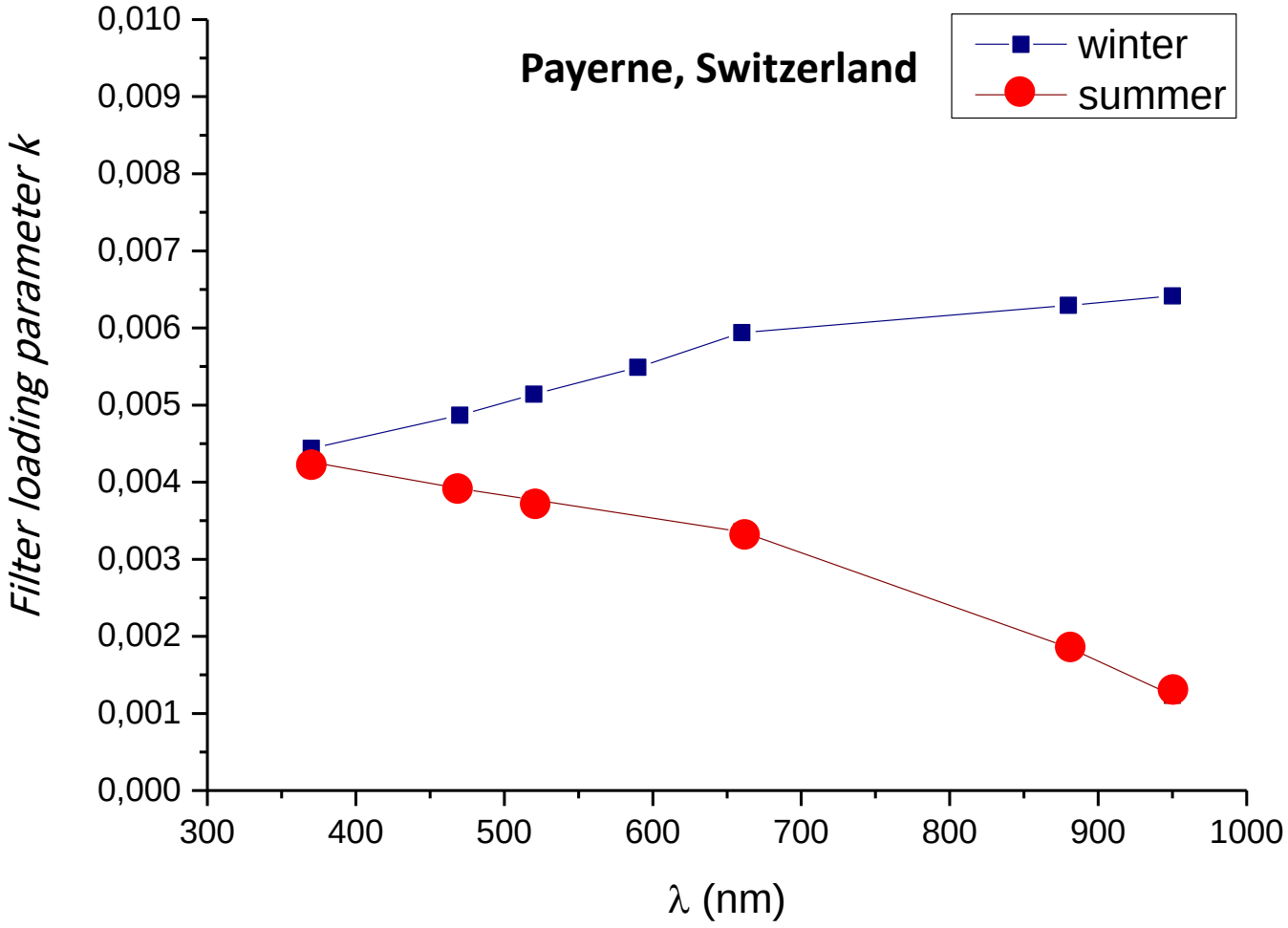
k factors provide additional information

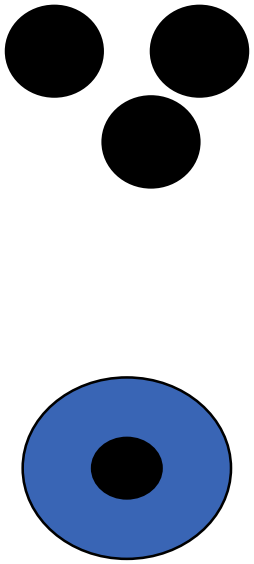


k factors depend on aerosol age

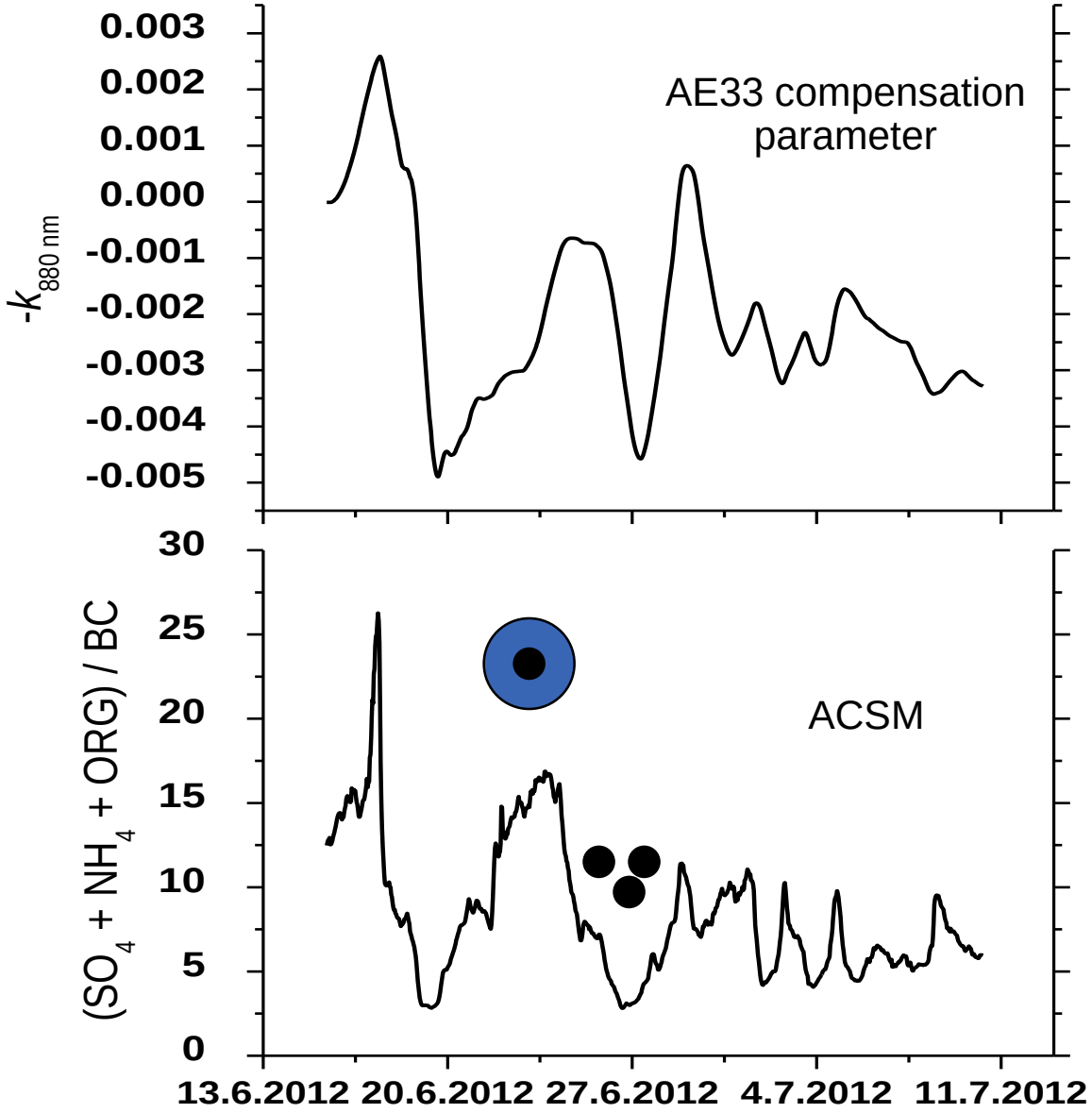
Dual spot Aethalometer AE33 measures filter loading effect

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.

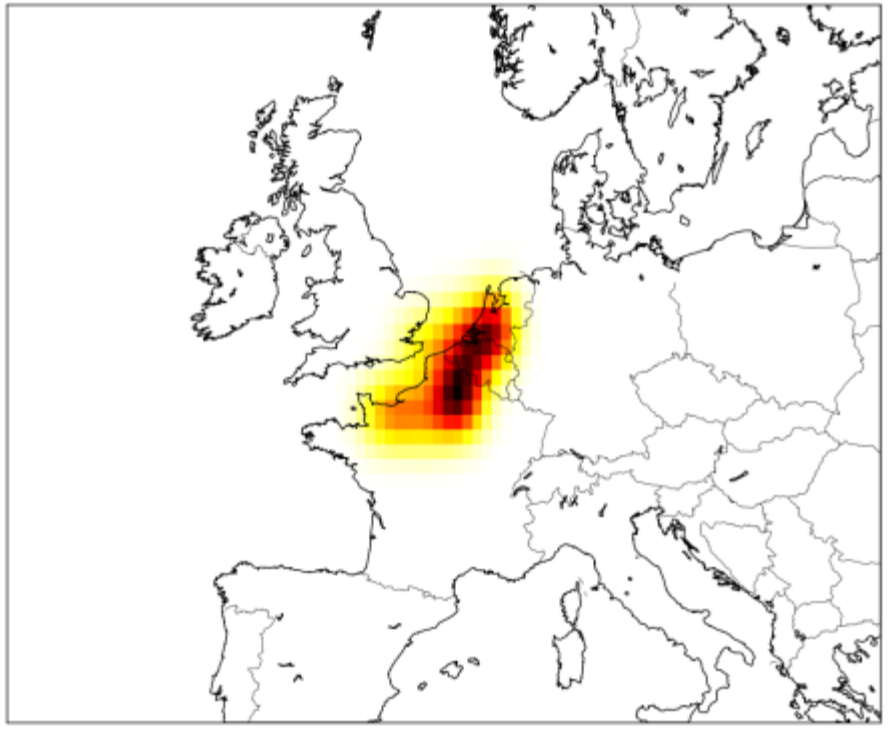
Compensation parameter and sum of anorganic secondary aerosol + organic aerosol correlate well.

Differentiation of fresh and aged aerosols

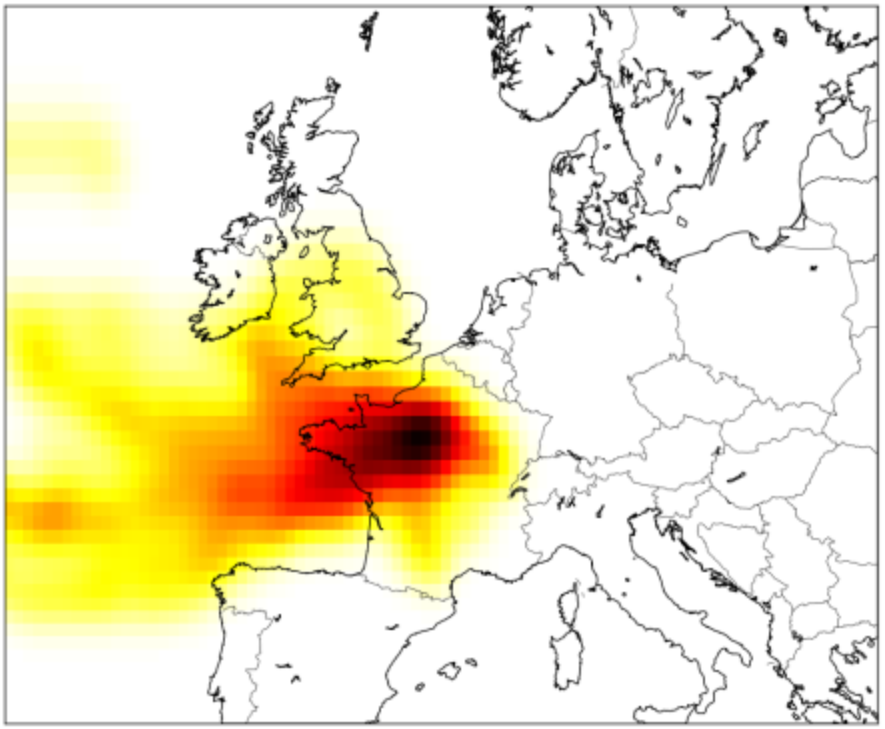
- Compensation parameter k_{880nm} obtained from AE33
- PSCF (Back trajectory analysis using Potential Source Contribution Function)

Paris – **summer** campaign 2012

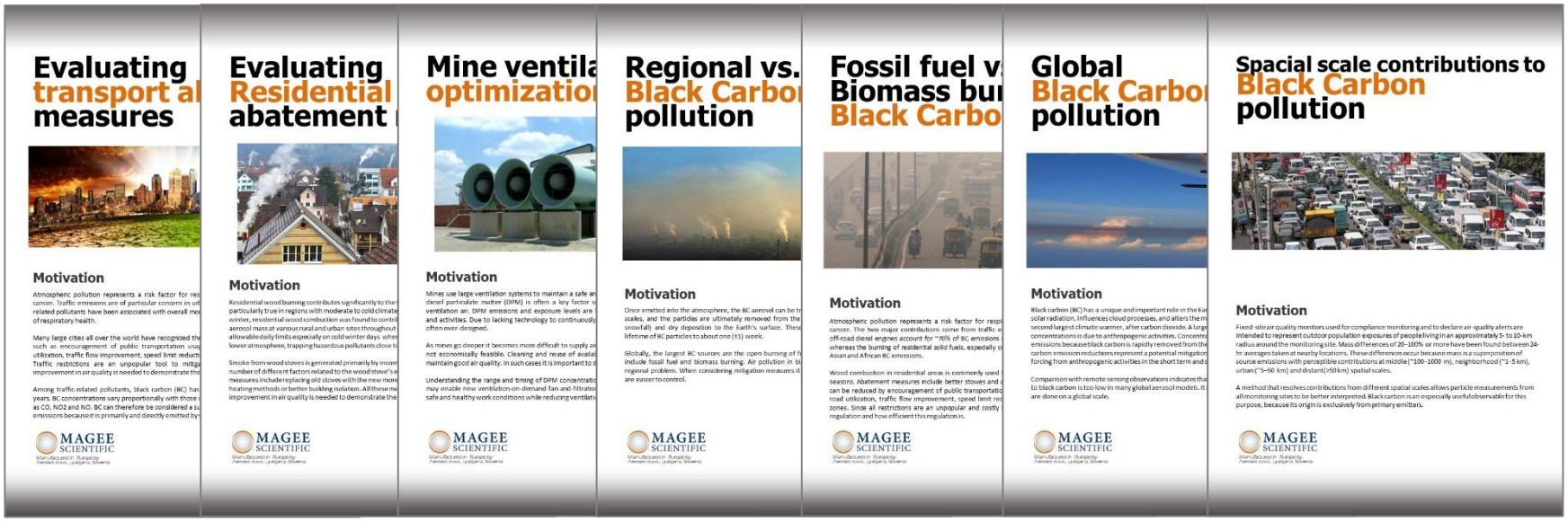
k_{880nm}>0.002 **fresh** aerosols



k_{880nm}<0.002 **aged** aerosols



Variety of applications



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.