

# Advanced measurement of black carbon

Because nothing in life is just black and white.



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# Aethalometer AE33 User's TRAINING

# Training outline



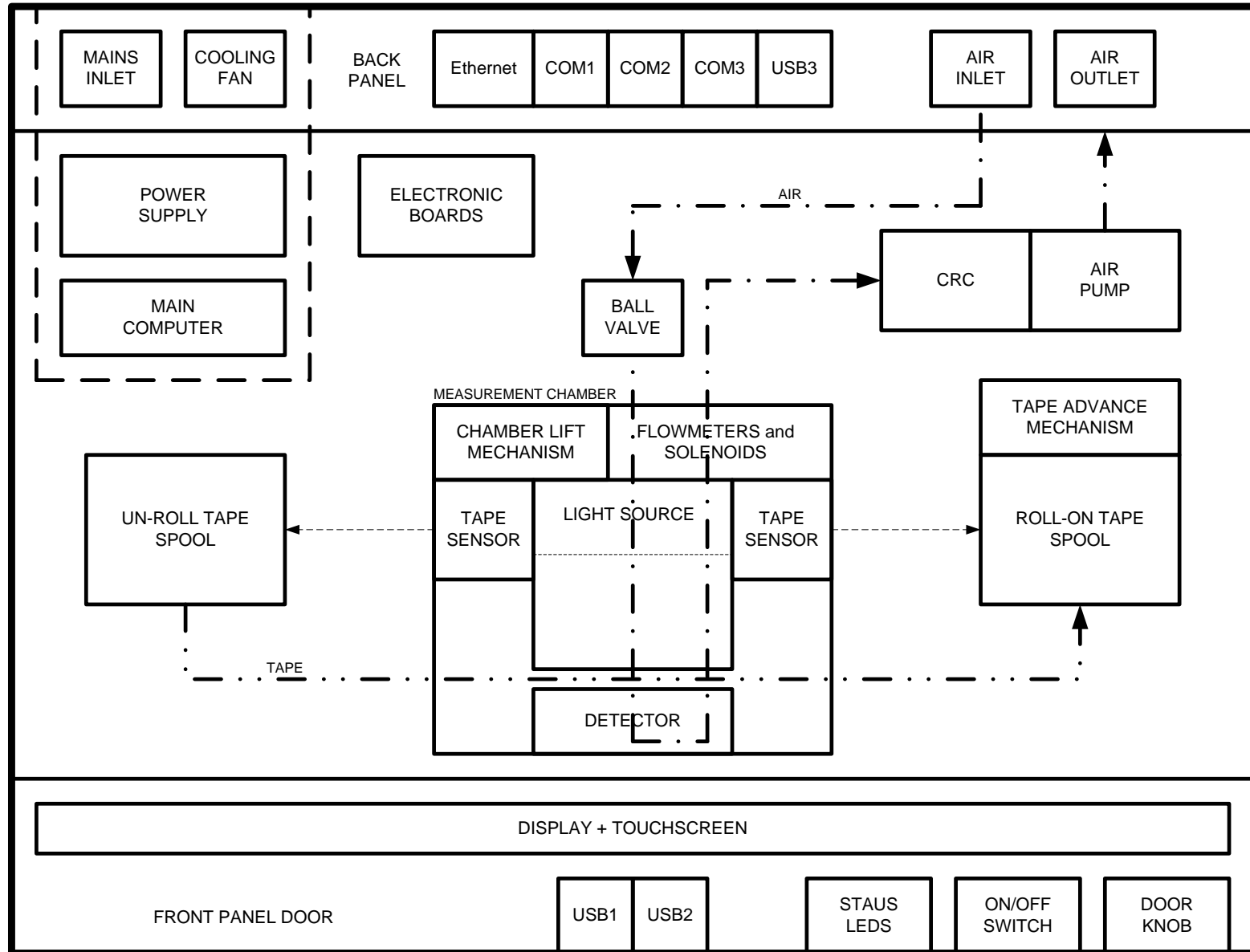
- 1. Introduction to BC**
- 2. Basic calculations**
  - Loading effect compensation
  - Sigma & multiple scattering parameter
  - Leakage
- 3. Loading effect compensation**
  - Introduction to loading effect
  - Algorithm sensitivity
- 4. User interface**
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  - Operation
  - Data
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  - Flow reporting standard
- 5. Quality control**
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- 6. Service & Maintenance**
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  - Software compatibility
  - Troubleshooting
  - Mechanics
- 7. Installation**
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  - Inlet
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# 1. Introduction

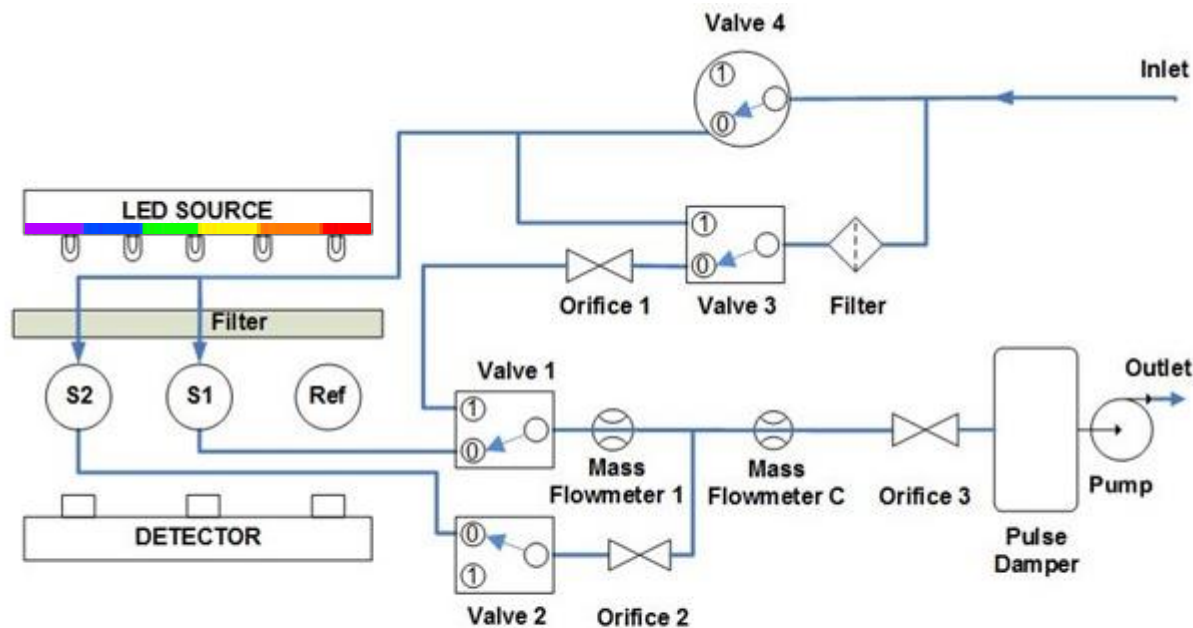


- Multiple wavelengths: absorption: UV-IR, quantitative source apportionment: fossil fuel vs. wood-smoke – BC and CM.
- Dynamic loading compensation dual spot compensation algorithm eliminates *filter loading* artifacts.
- Automated QA/QC with zero, optical span checks and flow calibration.
- Improved performance: low noise, fast time resolution.
- Easily integrates into networks: ease of communication and maintenance.

# 1. Introduction – functional diagram



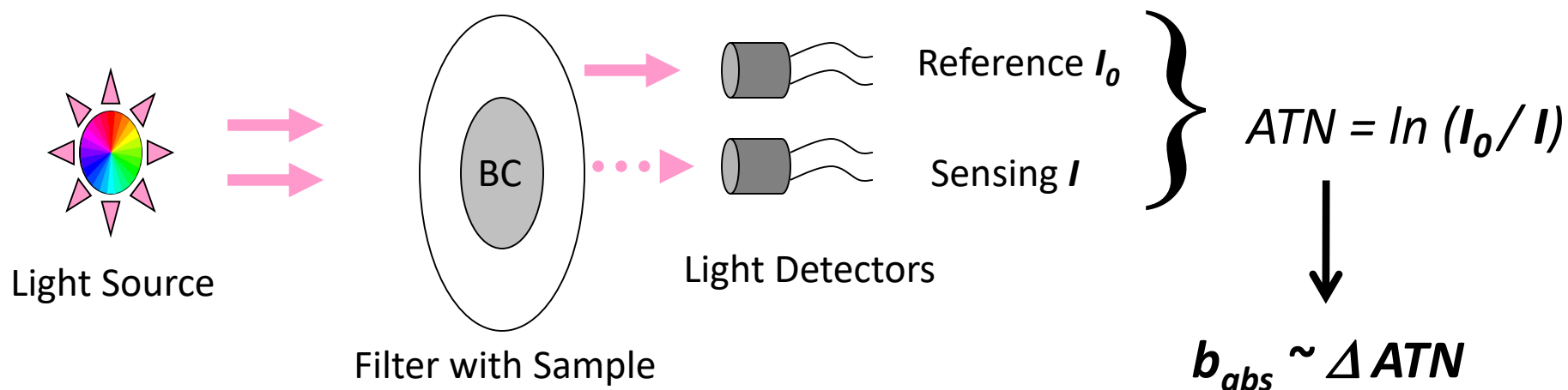
# 1. Introduction – flow diagram



Valve status contains a series of binary values: Valve 4-moving (1=YES/0=NO), Valve 4 (1=ON/0=OFF), Valve 3 (1=ON/0=OFF), Valve 2 (1=ON/0=OFF), Valve 1 (1=ON/0=OFF).

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

## 2. Basic calculations



Collect sample continuously.

*Optical absorption*  $\sim$  change in ATN.

Measure optical absorption continuously :  $\lambda = 370$  to  $950$  nm.

Convert *optical absorption* to *concentration of BC*:

$$BC(t) = b(t) / \sigma$$

Real-time data: 1 s -1 min

# 2.1 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

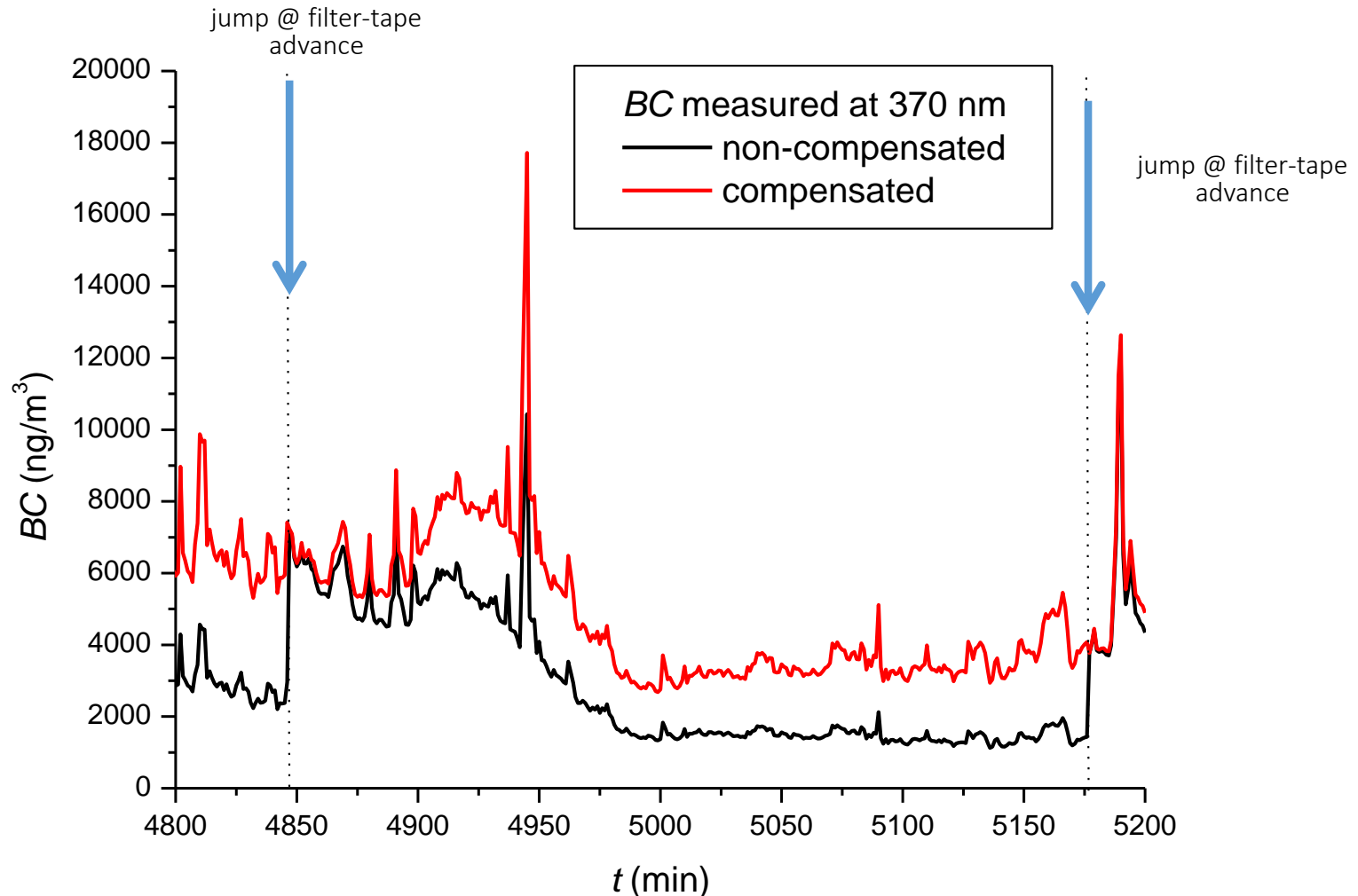
- $F_{in} = F_{out} * (1 - \zeta)$

- Leakage factor  $\zeta = 0.07$

- Final equation

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

# 3.1 Loading effect compensation

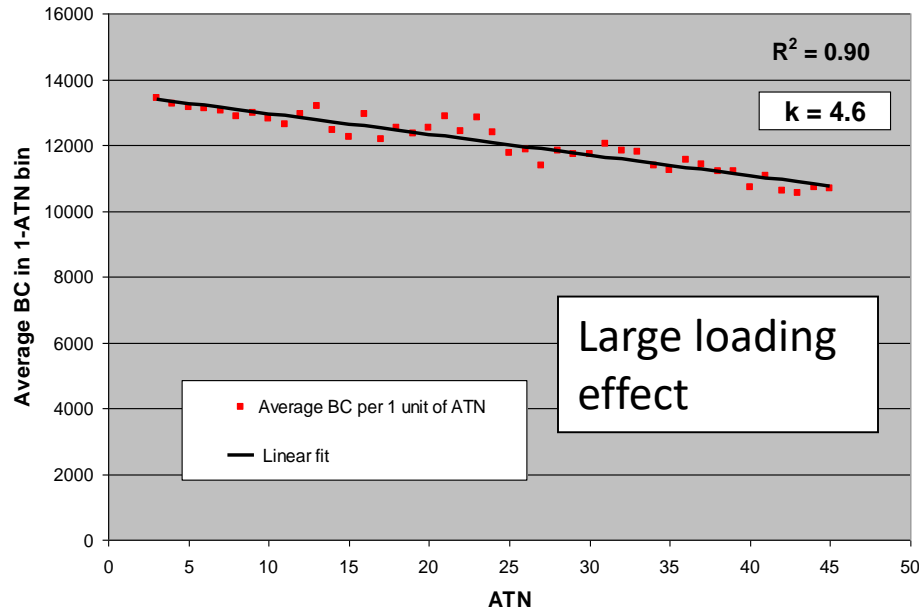




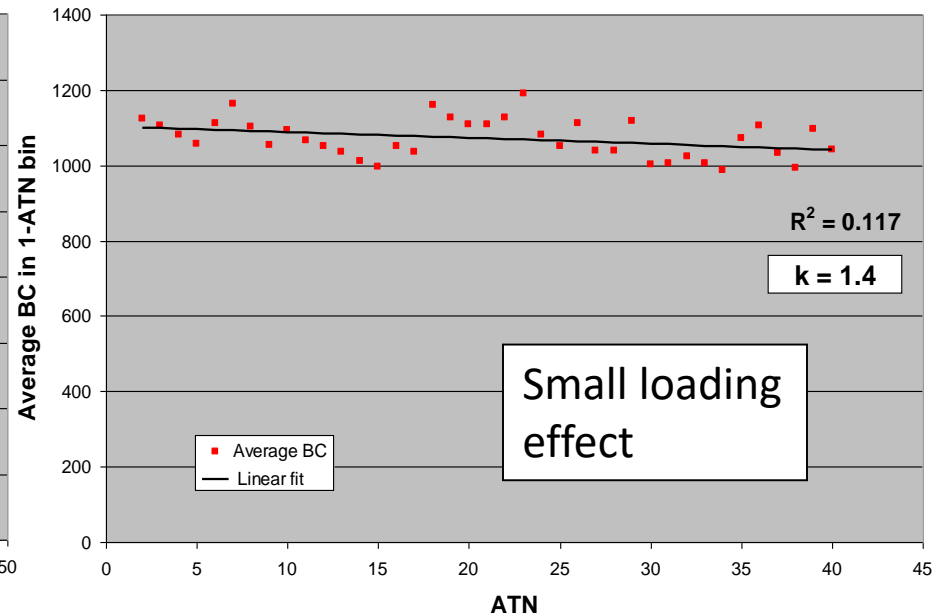
# 3.1 Loading effect compensation



London Oct-Dec 2006



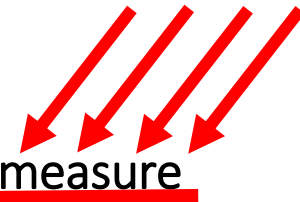
Roxbury Feb - June 1999



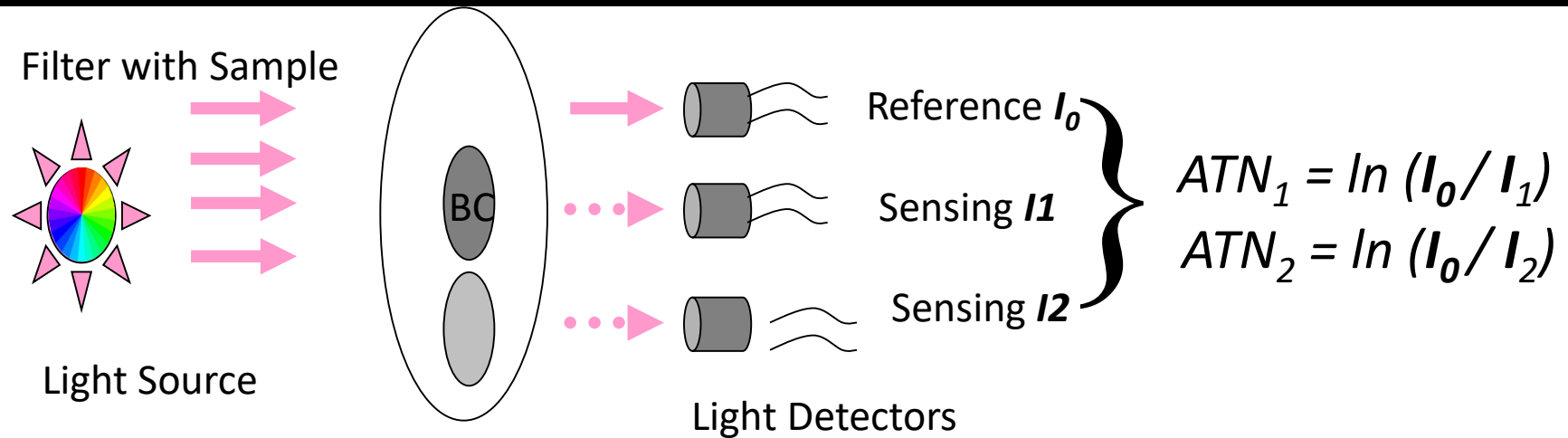
$$\text{BC (reported)} = \text{BC (zero loading)} \cdot \{ 1 - k \cdot \text{ATN} \}$$

Linear reduction of the instrumental response due to loading of the filter fiber.  
Jump at the tape advance (Virkkula 2007).

- 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



# 3.1 Loading effect compensation

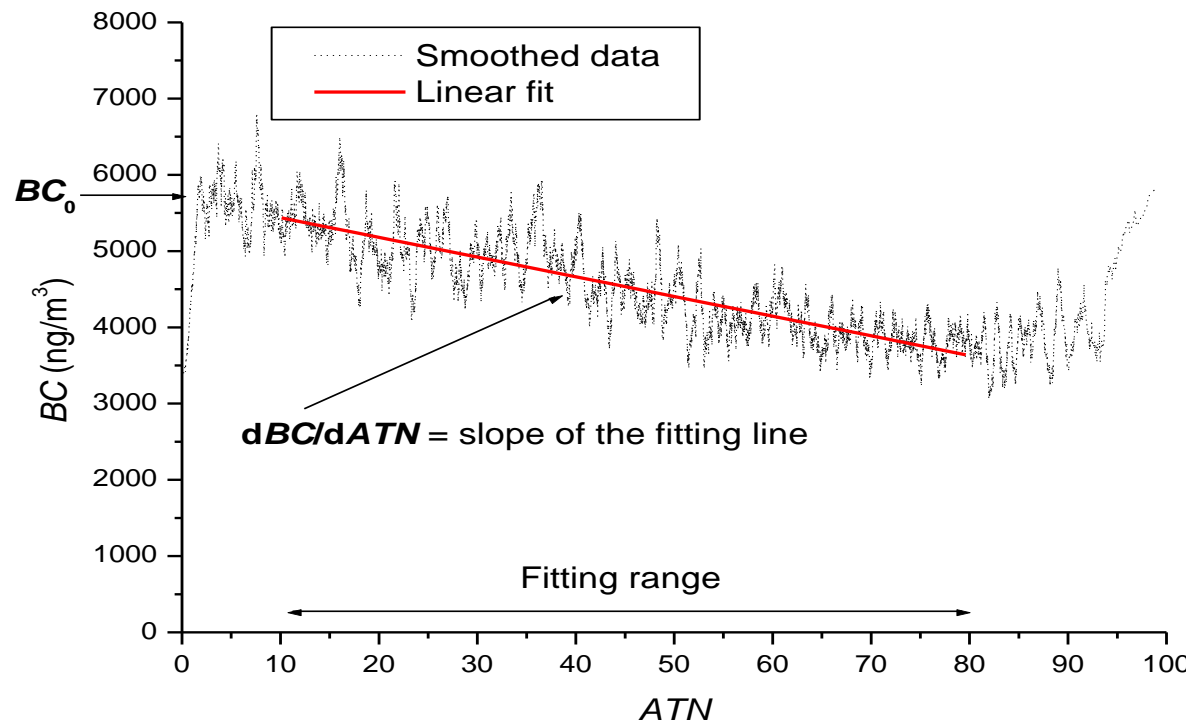


Two parallel spots  
with different flow,  
therefore ->

different loading  
and attenuation.

Calculate loading  
compensated  $BC$ :

$$BC = BC_1 / (1 - k \cdot ATN_1)$$

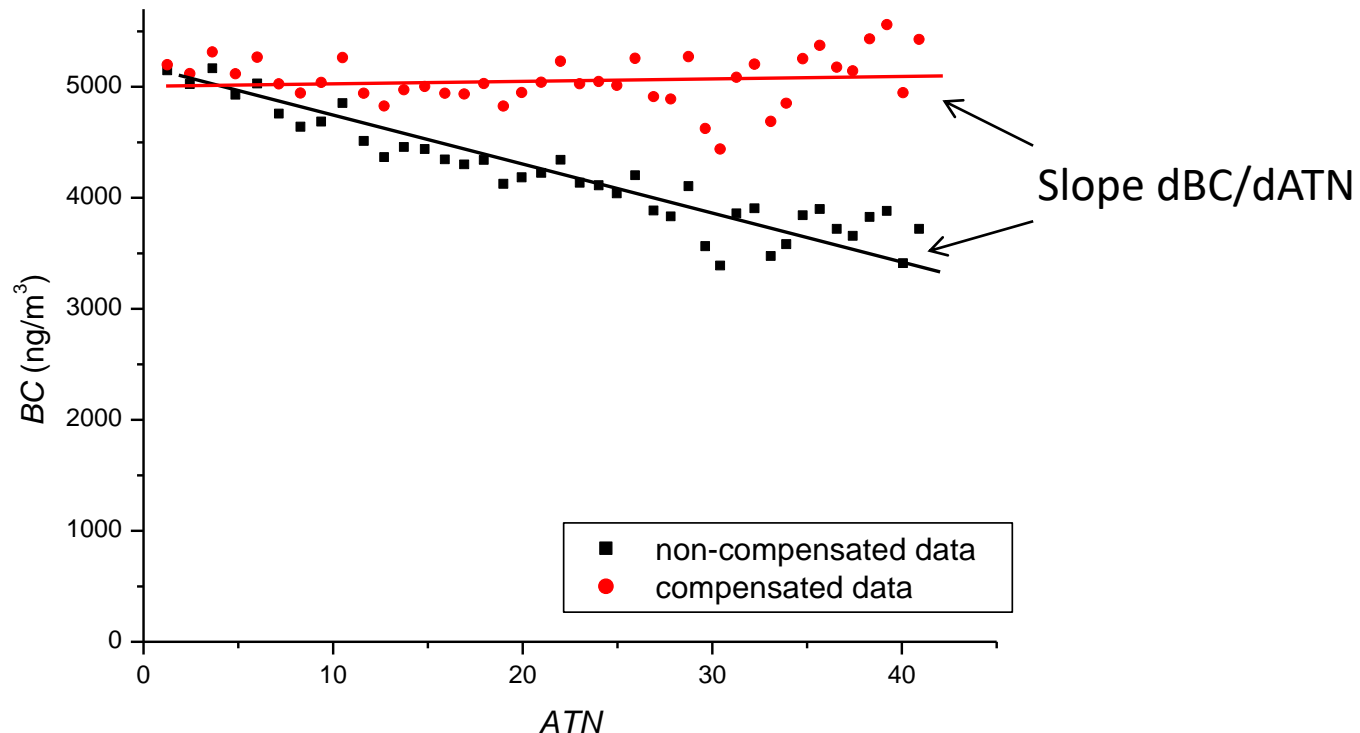


# 3.1 Loading effect compensation

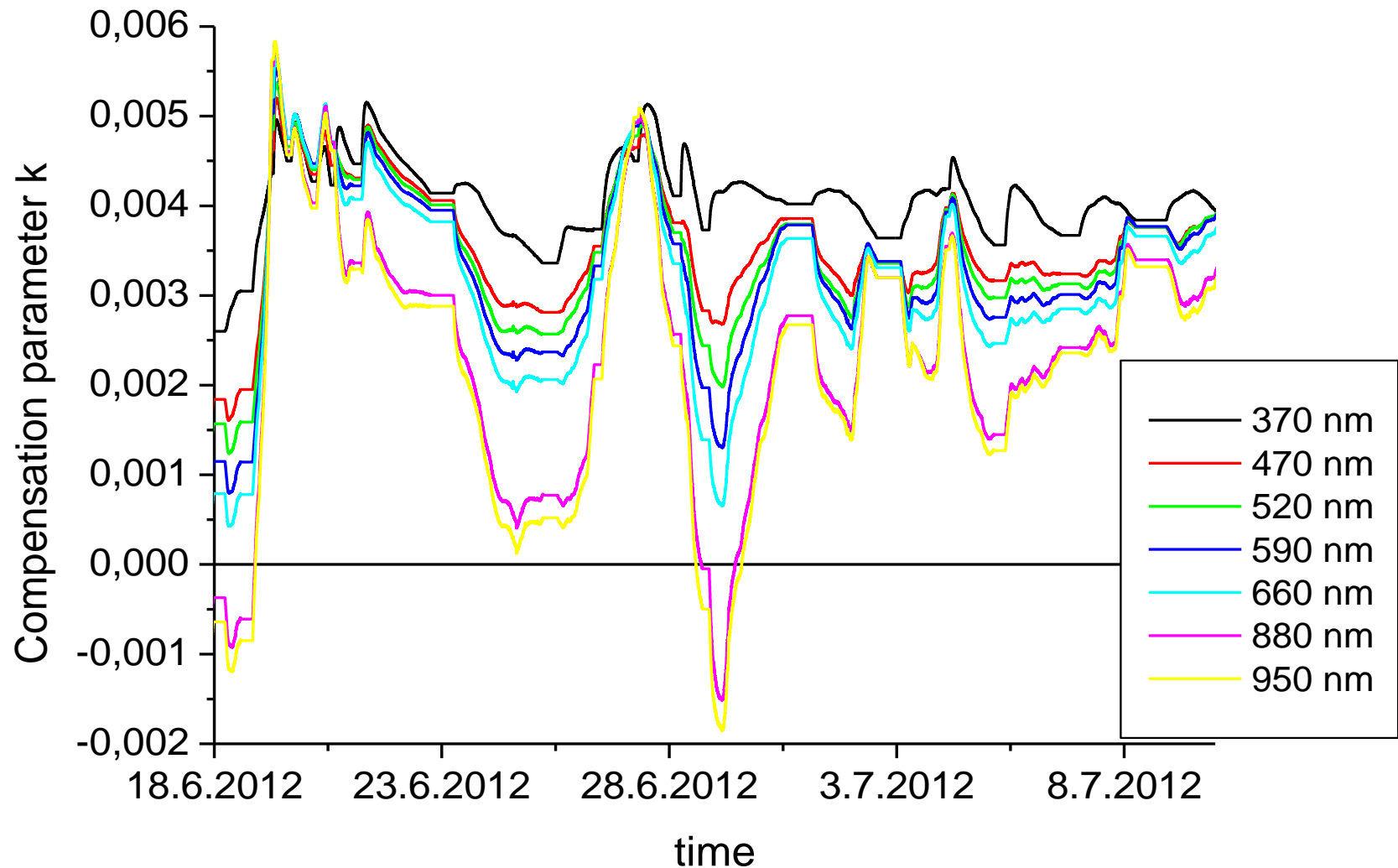


1. Determination of compensation parameter  $k(\lambda)$
2. Calculation of compensated  $BC$ :

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



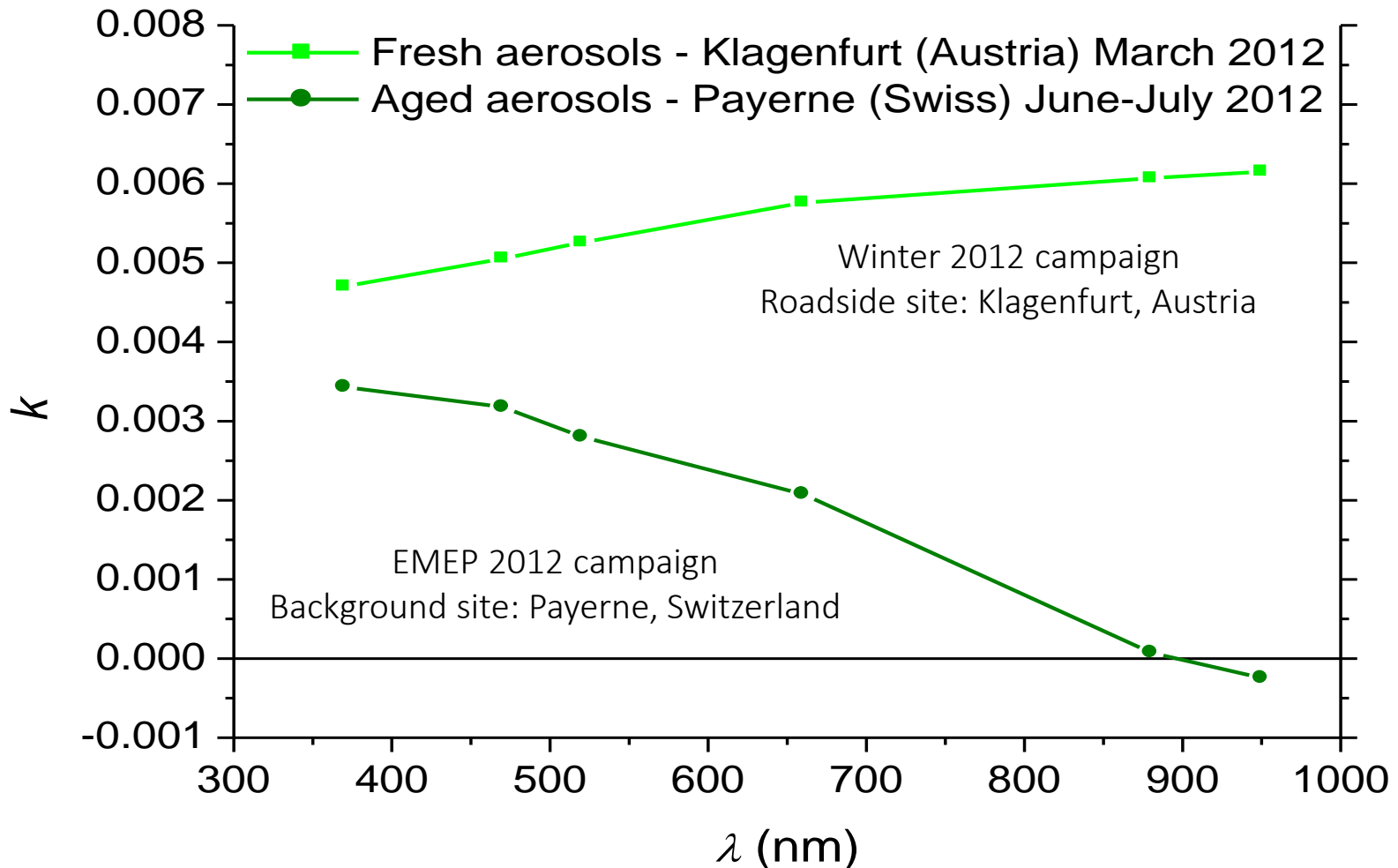
# 3.1 Loading effect compensation



# 3.1 Loading effect compensation



## Spectral fingerprint of parameter $k$



# 3.1 Loading effect compensation

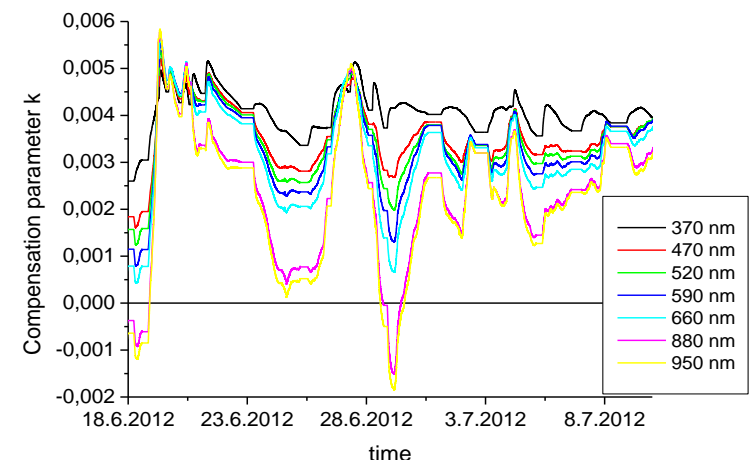


Algorithm sensitivity:

- Temperature -> warming up instrument to room temp.
- Humidity -> no fast humidity & T changes
- Input pressure -> constant pressure

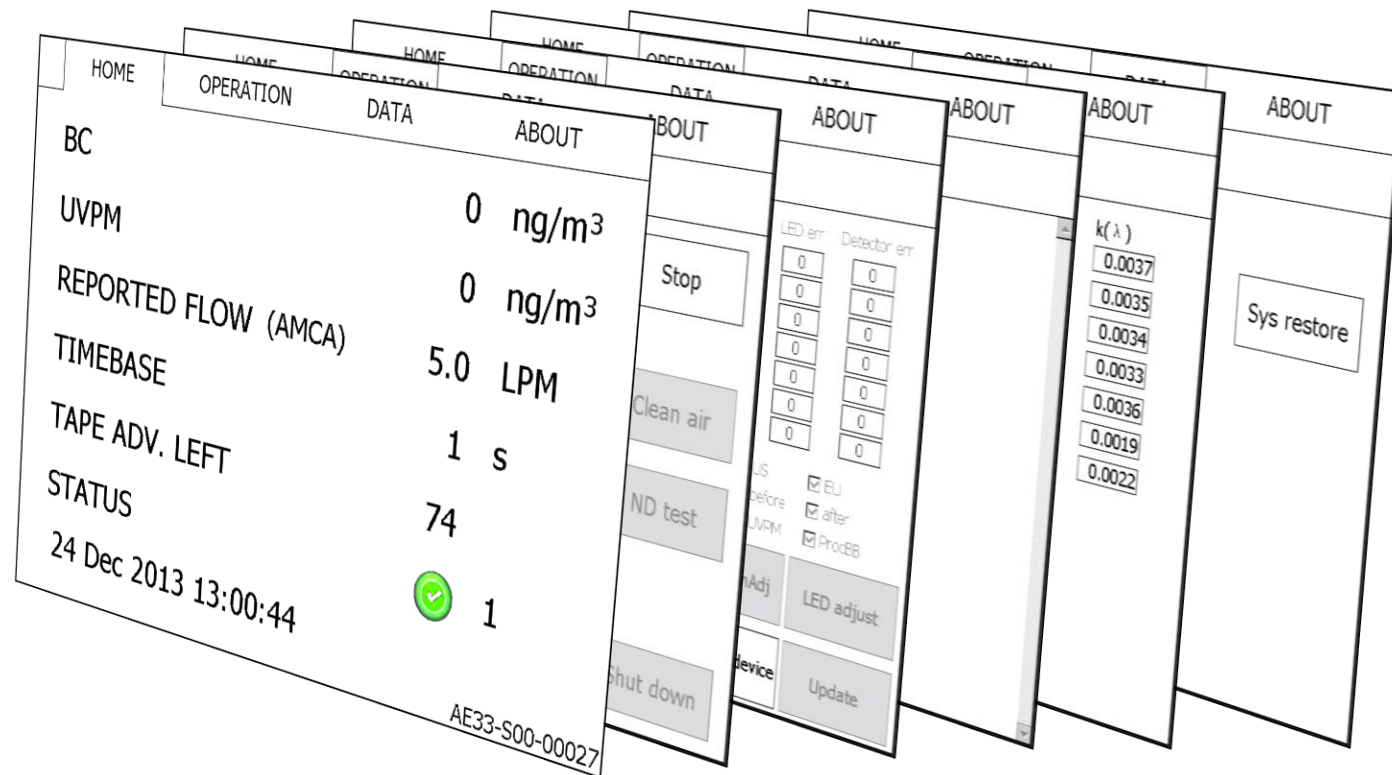
Setting  $k_{\min}$  &  $k_{\max}$  values:

- Default setting:  $-0.005 < k < 0.015$
- Expected values:  $0 < k < 0.01$




# 4. User interface

- 8.4" color touch-screen with status indicator LED's
- Status de-convolution on home screen
- live data access on data screen
- Access to log records from last start of the instrument.....



# 4. User interface/home screen



	HOME	OPERATION	DATA	ABOUT
BC			4536	ng/m <sup>3</sup>
BIOMASS BURNING			7.6	%
REPORTED FLOW (AMCA)			5.0	LPM
TIMEBASE			60	s
TAPE ADV. LEFT			152	
STATUS				0
18 Oct 2013 15:07:06				
AE33-S02-00138				



# 4. User interface/operation screen



HOME		OPERATION		DATA		ABOUT	
GENERAL		ADVANCED		LOG		MANUAL	
TimeBase	60 s			Start		Stop	
Flow	5 LPM						
Flow Rep. Std.	AMCA						
P: 101325 Pa T: 21.11 °C				Stability		Clean air	
● TA ATNmax	120			Verify flow		ND test	
○ TA INT	12 h						
○ TA Time	19 Oct 2013 03:00:57						
Time & Date	18 Oct 2013 15:07:53						
<input type="checkbox"/> Auto Clean Air						Shut down	

HOME		OPERATION		DATA		ABOUT	
GENERAL		ADVANCED		LOG		MANUAL	
Status	3	Flow $\Sigma$ (mlpm)	0	Sigma_Air ( $\lambda$ )	LED err	Detector err	
Controller status	0	Flow1 (mlpm)	3461	Ch1	18.47	0	0
Detector status	20	Pump (ref.val.)	0	Ch2	14.54	0	0
LED status	10	Flow sensor $\Sigma$	189	Ch3	13.14	0	0
TA status	0	Flow sensor 1	218	Ch4	11.58	0	0
Tape sensor left	155	Chamber status	10	Ch5	9.89	0	0
Tape sensor right	108	Chamber position	308	Ch6	7.77	0	0
TapeAdvance left	156	Valve status	00000	Ch7	7.19	0	0
ATNf1	10	Z	0.07	Kmax	0.015	Date format: <input type="checkbox"/> US <input checked="" type="checkbox"/> EU	
ATNf2	30	C	1.57	Kmin	-0.005	Measure time stamp <input type="checkbox"/> before <input checked="" type="checkbox"/> after	
Warm up interval (min)	3	Aff	1	Home display		<input type="checkbox"/> UVPM <input checked="" type="checkbox"/> ProcBB	
Firmware version	513	Abb	2	FlowCal		TapeSenAdj	
Software version	1.0.7.2			LED adjust			
IP address	127.0.0.1			Change Tape		External device	
Server IP address				Update			
<input type="checkbox"/> AutoConnect							
Serial number	AE33-S02-00138						

HOME		OPERATION		DATA		ABOUT	
GENERAL		ADVANCED		LOG		MANUAL	
<div> <div>18/Oct/2013 14:57:29 Instrument started.</div> <div>18/Oct/2013 14:58:01 TapeAdvance procedure started.</div> <div>18/Oct/2013 14:58:39 Tape Advance number: 40 Number of steps: 641</div> <div>18/Oct/2013 15:05:00 ATN1zero(1): 16.0097 ATN2zero(1): 18.9057</div> <div>18/Oct/2013 15:05:00 ATN1zero(2): 22.3271 ATN2zero(2): 27.9712</div> <div>18/Oct/2013 15:05:00 ATN1zero(3): 21.8199 ATN2zero(3): 24.7816</div> <div>18/Oct/2013 15:05:00 ATN1zero(4): 20.1721 ATN2zero(4): 25.7866</div> <div>18/Oct/2013 15:05:00 ATN1zero(5): 12.2301 ATN2zero(5): 18.4499</div> <div>18/Oct/2013 15:05:00 ATN1zero(6): -10.7622 ATN2zero(6): -4.2041</div> <div>18/Oct/2013 15:05:00 ATN1zero(7): -6.3861 ATN2zero(7): -1.0904</div> </div>							

HOME		OPERATION		DATA		ABOUT	
GENERAL		ADVANCED		LOG		MANUAL	
<div> <div>Set Flow</div> </div>							
Calibrate Chamber		Solenoid 1	ON	OFF			
Chamber Tape		Solenoid 2	ON	OFF			
Chamber Home		Solenoid 3	ON	OFF			
Tape Advance		Ball valve	ON	OFF			

# 4. User interface/data screen



HOME		OPERATION		DATA		ABOUT	
TABLE		EXPORT					
	Ref	Sen 1	Sen 2	BC1	BC2	BC	k( λ )
Ch 1	480850	915921	950089	1768	2314	1768	0.0001
Ch 2	696857	877227	901013	1369	1912	1369	0.0001
Ch 3	682645	885690	903991	1154	2174	1154	0.0001
Ch 4	704607	864144	901588	1287	1946	1287	0.0001
Ch 5	720213	871726	906991	1117	1391	1117	0.0001
Ch 6	642403	860291	905895	552	-181	552	0.0001
Ch 7	688483	860055	904793	2266	3142	2266	0.0001
Sen1 F (mlpm)		3791					
Sen2 F (mlpm)		1492					

HOME		OPERATION		DATA	ABOUT		
TABLE		EXPORT					
Free space: 55 year(s) and 228 day(s) left							
<input checked="" type="checkbox"/> Delete Oldest If Full		<input type="checkbox"/> Delete after copy		<input type="button" value="DeleteCFdata"/>	<input type="button" value="Sys restore"/>		
From:	<input type="text" value="24 Aug 2013"/>	To:	<input type="text" value="18 Oct 2013"/>				
<input checked="" type="checkbox"/> Copy LOG							
<input checked="" type="checkbox"/> Copy ND test results							
<input checked="" type="checkbox"/> Copy Flow verification result							
<input type="button" value="ExportToUSB"/>							

# 4. User interface/settings



## Flow reporting standard

Sample flow is measured by a mass flow sensor.

The mass flow is transformed to volumetric flow at certain pressure  $p$  and temperature  $T$ :

$$V = nRT/p$$

**Volumetric flow depends on the reporting pressure & temperature.  
Different flowmeters and instruments use different flow reporting standards.**

It is always possible to recalculate to other flow reporting standard:

$$F_2 = F_1 \frac{T_2}{T_1} \frac{p_1}{p_2} \quad (\text{Temperature must be reported in degrees kelvin})$$

# 4. User interface/settings

## Flow reporting standard

HOME OPERATION DATA ABOUT

GENERAL ADVANCED LOG MANUAL

TimeBase 1 s

Flow 5 LPM

Flow Rep. Std. **AMCA**

P: 101325 Pa T: 21.11 °C

• TA ATNmax 120

○ TA INT 1 h

○ TA Time Aug 06 2014 12:50:17

Time & Date Aug 06 2014 12:14:00

Time zone (GMT) Coordinated Universal Time

□ Auto Clean Air

Start Stop

Stability Clean air

Verify flow ND test

Shut down

Flow reporting standard

- AMCA (101325 Pa, 21.11°C)
- EPA (101325 Pa, 25°C)
- ISO (101325 Pa, 20°C)
- NIST (101325 Pa, 0°C)
- IUPAC (100000 Pa, 0°C)
- Manual
- Ambient

OK Cancel

Volumetric flow recalculation:

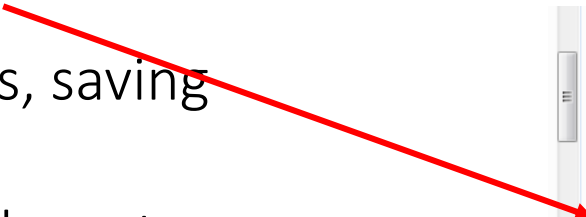
$$F_2 = F_1 \frac{T_2 p_1}{T_1 p_2}$$

# 4. User interface/setup file



## Setup file

- Changes, saving
- Export
- Setup file restore



AE_SETUP_AE33-S02-00146_20130902_140337.xml	2.9.2013 14:03	XML Document	5 KB
AE_SETUP_AE33-S02-00146_20130902_141036.xml	2.9.2013 14:10	XML Document	5 KB
AE_SETUP_AE33-S02-00146_20130903_132032.xml	3.9.2013 13:20	XML Document	5 KB
AE_SETUP_AE33-S02-00146_20130913_120010.xml	13.9.2013 12:00	XML Document	5 KB
AE_SETUP_AE33-S02-00146_20130913_120831.xml	13.9.2013 12:08	XML Document	5 KB
AE_SETUP_AE33-S02-00146_20130913_122925.xml	13.9.2013 12:29	XML Document	5 KB
AE_SETUP_AE33-S02-00146_20130916_091134.xml	16.9.2013 9:11	XML Document	5 KB
AE_SETUP_AE33-S02-00146_20130916_111501.xml	16.9.2013 11:15	XML Document	5 KB
AE_SETUP_AE33-S02-00146_20130916_113905.xml	16.9.2013 11:39	XML Document	5 KB
AE_SETUP_AE33-S02-00146_20130916_122453.xml	16.9.2013 12:24	XML Document	5 KB
AE33_AE33-S02-00146_20130902.dat	2.9.2013 14:37	DAT File	673 KB
AE33_AE33-S02-00146_20130903.dat	3.9.2013 23:59	DAT File	2,582 KB
AE33_AE33-S02-00146_20130904.dat	4.9.2013 23:59	DAT File	533 KB
AE33_AE33-S02-00146_20130905.dat	5.9.2013 23:59	DAT File	532 KB
AE33_AE33-S02-00146_20130906.dat	6.9.2013 23:59	DAT File	549 KB
AE33_AE33-S02-00146_20130907.dat	7.9.2013 23:59	DAT File	554 KB
AE33_AE33-S02-00146_20130908.dat	8.9.2013 23:59	DAT File	554 KB
AE33_AE33-S02-00146_20130909.dat	9.9.2013 23:59	DAT File	551 KB
AE33_AE33-S02-00146_20130910.dat	10.9.2013 23:59	DAT File	527 KB
AE33_AE33-S02-00146_20130911.dat	11.9.2013 23:59	DAT File	533 KB
AE33_AE33-S02-00146_20130912.dat	12.9.2013 23:59	DAT File	547 KB

## Most important parameters:

- Sigma values
- Leakage parameter  $\zeta$
- Max, min k
- Flowmeter calibration values
- Tape sensor calibration values
- Selected flow reporting standard
- Auto Clean air test settings

# 4. User interface/data file



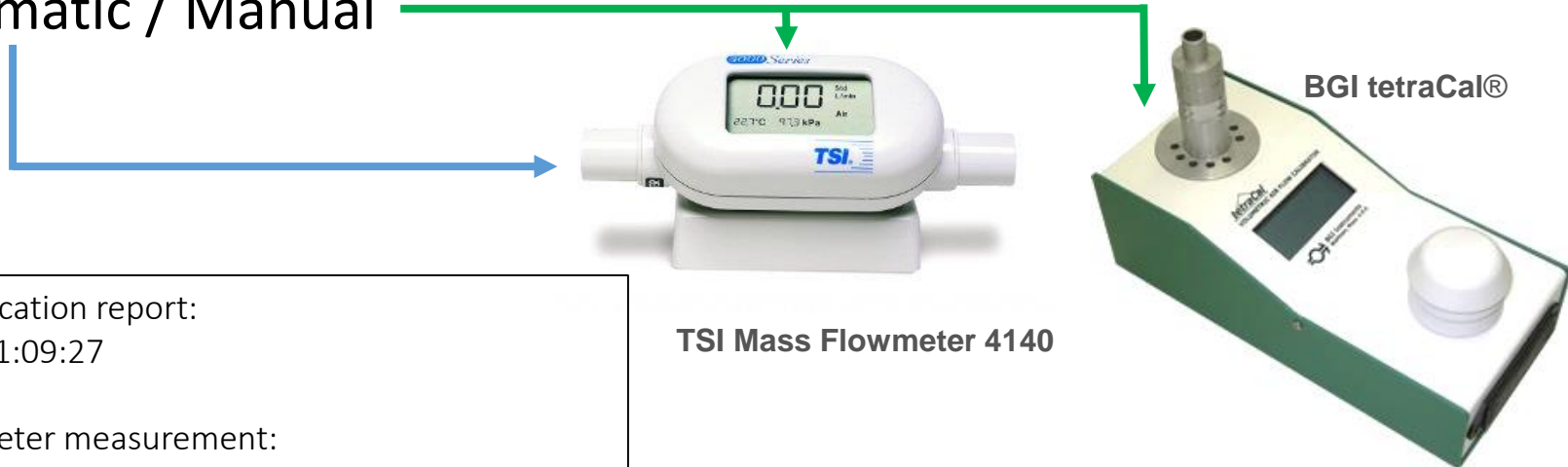
## Data file structure:

- Date(yyyy/MM/dd); Time(hh:mm:ss); Timebase;
- RefCh1; Sen1Ch1; Sen2Ch1; RefCh2; Sen1Ch2; Sen2Ch2; RefCh3; Sen1Ch3;  
Sen2Ch3; RefCh4; Sen1Ch4; Sen2Ch4; RefCh5; Sen1Ch5; Sen2Ch5; RefCh6;  
Sen1Ch6; Sen2Ch6; RefCh7; Sen1Ch7; Sen2Ch7;
- Flow1; Flow2; FlowC; Pressure(Pa); Temperature(°C); RH(%);
- ContTemp; SupplyTemp; Status; ContStatus; DetectStatus; LedStatus; ValveStatus;  
LedTemp;
- BC11; BC12; BC1; BC21; BC22; BC2; BC31; BC32; BC3; BC41; BC42; BC4; BC51;  
BC52; BC5; BC61; BC62; BC6; BC71; BC72; BC7;
- K1; K2; K3; K4; K5; K6; K7;
- TapeAdvCount;
- External devices

# 5. 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 %**

# 5. Quality control/leakage test



- **Leakage test**

Leakage ( $\zeta$ ) 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 %**



# 5. Quality control/stability test



## Stability test (without flow):

- Average BC  $\sim 30$  ng/m<sup>3</sup>
- Point to point variation of BC (PPBC) at 1 s timebase:  $PPBC = \frac{1}{n} \sum_{i=0}^n abs(BC(t_{i+1}) - BC(t_i))$
- PPBC61 < 450 ng/m<sup>3</sup>

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 <sup>3</sup> )	
	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.

# 5. Quality control/clean air test



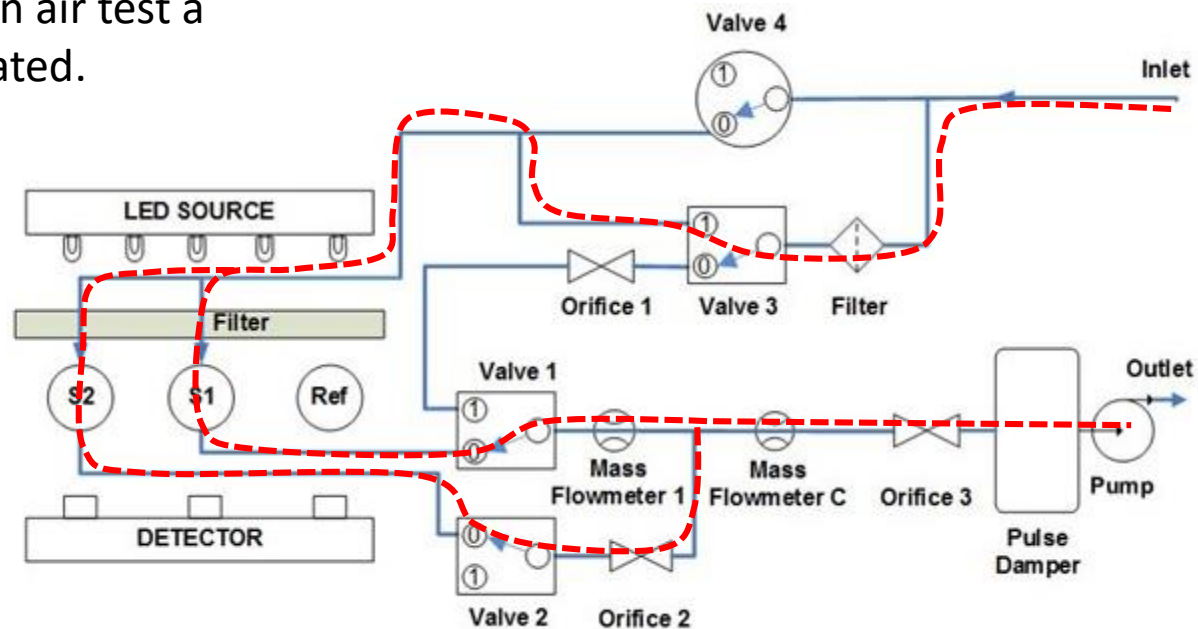
## Clean air test (flow trough built-in filter):

- Average BC < 30
- Point to point variation of BC (PPBC) at 1 s timebase, 5 lpm: PPBC61 < 550 ng/m<sup>3</sup>

## 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.



# 5. 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**

# 5. Quality control/startup



- **Startup procedure:**
  - stability, clean air, indoor air
  - Leakage
  - Tape sensor
  - Flow verification, Flow ratio
  - Neutral density filter test
  - -> Fill in „Final inspection record“

# 6. Service & Maintenance/startup



## • Start-up screen statuses

**Communication** -> communication with controller

- erased firmware because of forced shutdown (with bootloader 200 & 210 only) -> use a programmer to upload newer bootloader
- hardware problem -> check cables and controller board

**Instrument data** -> Obtain data (serial number) from the controller

**Storage** -> check CF card

- CF card error -> get new CF card

**Configuration settings** -> read setting from the setup file

- restore from one of the older setup files

**Valves** -> check operation of the ball valve

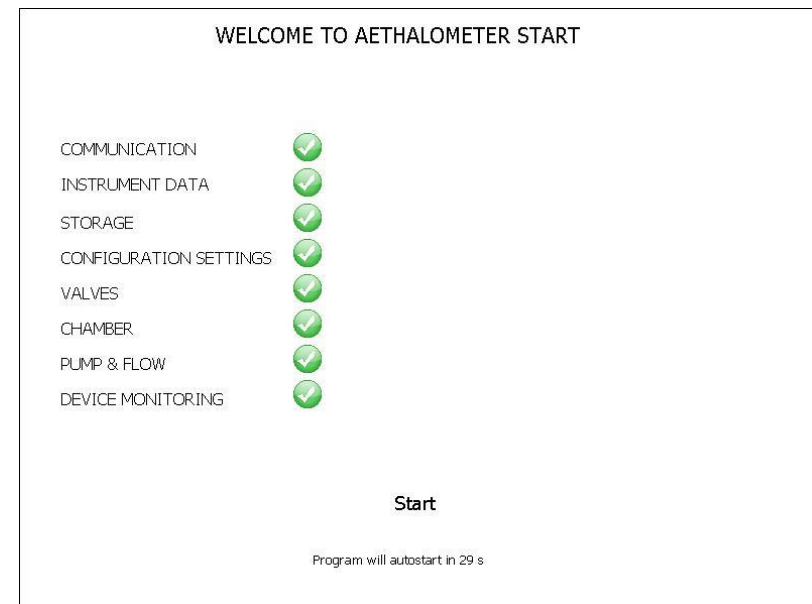
- ball valve timeout

**Chamber** -> chamber movement test

- locked chamber
- hardware error

**Pump & Flow** -> test if pump is working

**Device monitoring** -> Win CE operating system test



# 6. Service & Maintenance/status



- Instrument status




Normal operation



Warning ; Instrument is still performing measurements, but there is/was an issue, that needs to be checked



Instrument stopped. Immediate response needed.

	HOME	OPERATION	DATA	ABOUT
BC			0	ng/m <sup>3</sup>
UVPM			0	ng/m <sup>3</sup>
REPORTED FLOW (AMCA)			5.0	LPM
TIMEBASE			1	s
TAPE ADV. LEFT			74	
STATUS				1
24 Dec 2013 13:00:44				

# 6. Service & Maintenance/status list

Status relates to:	bit position	binary	decimal	
Operation	1 and 0	00	0	Measurement
		01	1	Tape advance (tape advance, fast calibration, warm-up)
		10	2	First measurement – obtaining ATN0
		11	3	Stopped
Flow	3 and 2	00		Flow OK
		01	4	Flow low/high by more than 0.25 LPM
		10	8	Check flow status history
		11	12	Flow low/high & check flow status history
LED	5 and 4	00		LEDs OK
		01	16	Calibrating LED
		10	32	Calibration error (at l OK)
		11	48	LED error (all channel COM error)
Chamber	6	0		Chamber OK
		1		Chamber error

Filter tape	8 and 7	00		Filter tape OK
		01	128	Tape warning (less than 30 spots left)
		10	256	Tape last warning (less than 5 spots left)
		11	384	Tape error (tape not moving, end of tape)
Tests & procedures	12, 11, 10	000		No test
		001	1024	Stability test
		010	2048	Clean air test
		011	3072	Change tape procedure
		100	4096	Optical test
External device	13	0	0	Connection OK
		1	8192	Connection Error

- QA/QC test results

- **ND test** (checks optical system) – slope close to 1, insect screen...
- **flow verification** (checks if flowmeters need to be calibrated);
  - use good flow calibrator
  - be sure which flow reporting standard is used
- **stability test**
  - 1 s measurement interval, 20 min duration
  - test is automatically performed with flow=0. Fixed flows values are used to calculate BC.
  - if there is increased noise
    - > upgrade firmware to 421 & 513
    - > electronics problem
- **clean air test**
  - 1 s measurement interval, 20 min duration
  - if there is increased noise
    - > clean optical chamber
    - > check for air-conditioning effects
- **filter tape** – tape advance length ( $30\text{ mm} < \text{TA length} < 40$ )
  - > if wrong perform tape sensor calibration



# 6. Service & Maintenance



- **Problem solving guide**

1. Check instrument **status**
2. Check configuration (**software version, firmware version**)
3. Check **log file** (are there any »no communication. Data missing« lines. Are the ATN0 values similar for different tape advances, are there any flow calibrations)
4. Check **setup file** (check the parameters – compare with the standard values)
5. Check **data file**
  - detector values: check range; is there any noise, is it the same for all spots & channels
  - flow: is it stable? (should not deviate for more than 10 mlpm), check F2/F1 ratio
  - Status history
  - BC – is there any noise in the BC measurements? Is this a noise or true measurement?  
Are BCX1 and BCX2 values similar? Draw all the channels BCX1 – check if they are parallel
  - k values: are they in the range expected for the measured air?

# 6. Service & Maintenance/FAQs



- **FAQs**

- flow calibration problem -> repeat the calibration. Be sure to use calibration pad and understand the flow reporting standard.
- Status 387 – Tape error ( slipping filter roll) -> tighten the nut on the right filter spool
- Status 8192 Ext device disconnected
- Negative data values
- Noisy data – insect screen?

# 7. Installation

- Connection to the manifold – influence of other instruments
- Instrument's own connection – protect inlet from rain

## Tubing

- Use conductive tubing
- Round bends, short

## Inlet

- PM 2.5, PM10
- Bug screen

## Air conditioning effects

- Influence all aerosol instruments
- Condensation of water vapour in tubes
  - Damage to the instrument
  - Loss of particles
  - Increased measurement noise
- Solution
  - > **Nafion dryer**



# 6. Service & Support



For support please contact:

**Aerosol d.o.o.**

[www.aerosol.si](http://www.aerosol.si)

support@aerosol.si

**Please include:**

- **serial number of the instrument**
- **software version**
- **sample of recent data (always send raw files)**
- **setup file**
- **log file**