# Advanced measurement of black carbon

Because nothing in life is just black and white.


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# Aethalometer AE33 User's **TRAINING**

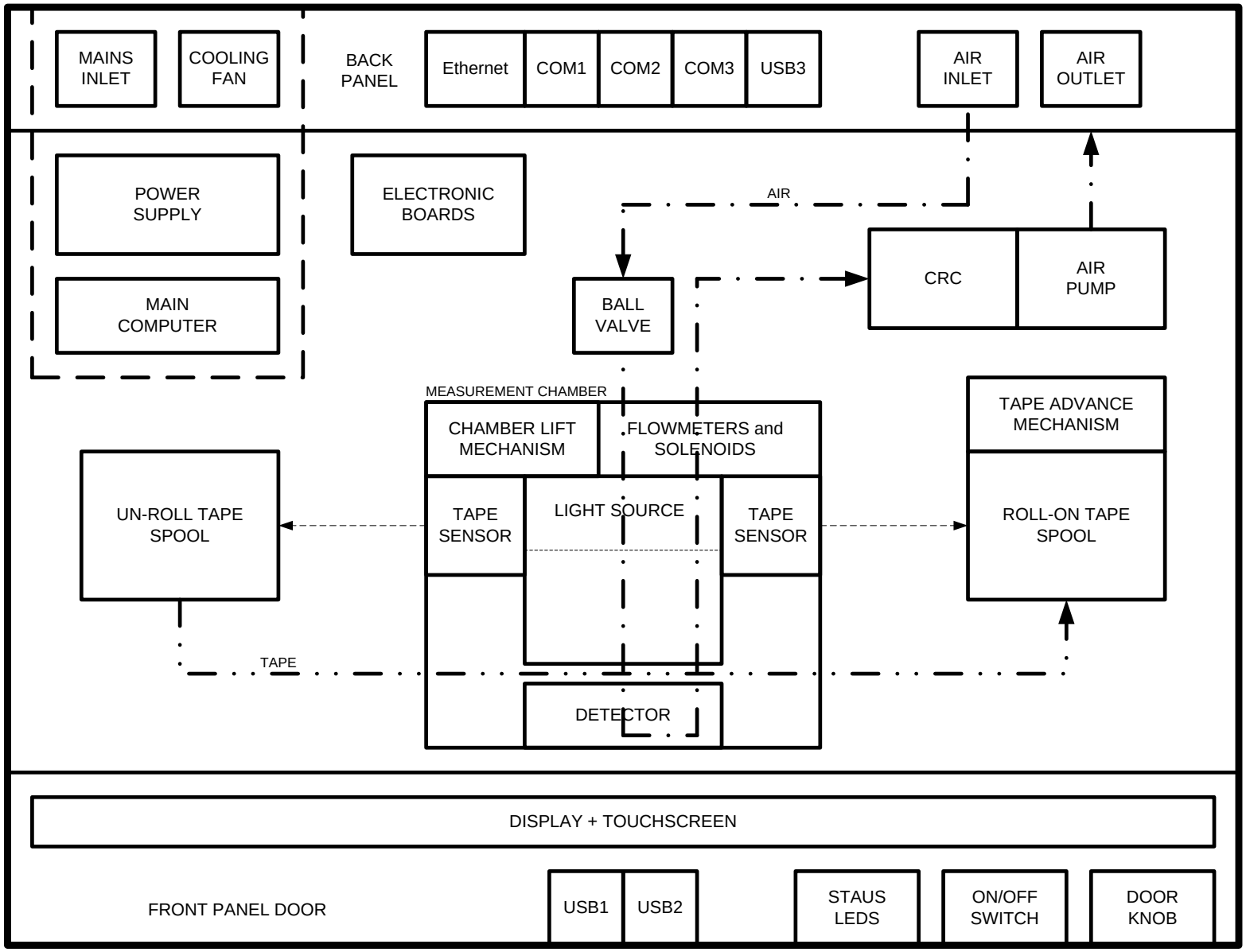
# Training outline

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
   - Home
   - Operation
   - Data
   - Setup file
   - Flow reporting standard
5. Quality control
   - Stability & Clean air test
   - Flow verification
   - Leakage test
   - ND test
6. Service & Maintenance
   - Startup procedure
   - Software compatibility
   - Troubleshooting
   - Mechanics
7. Installation
   - Tubing
   - Inlet
   - Air conditioning

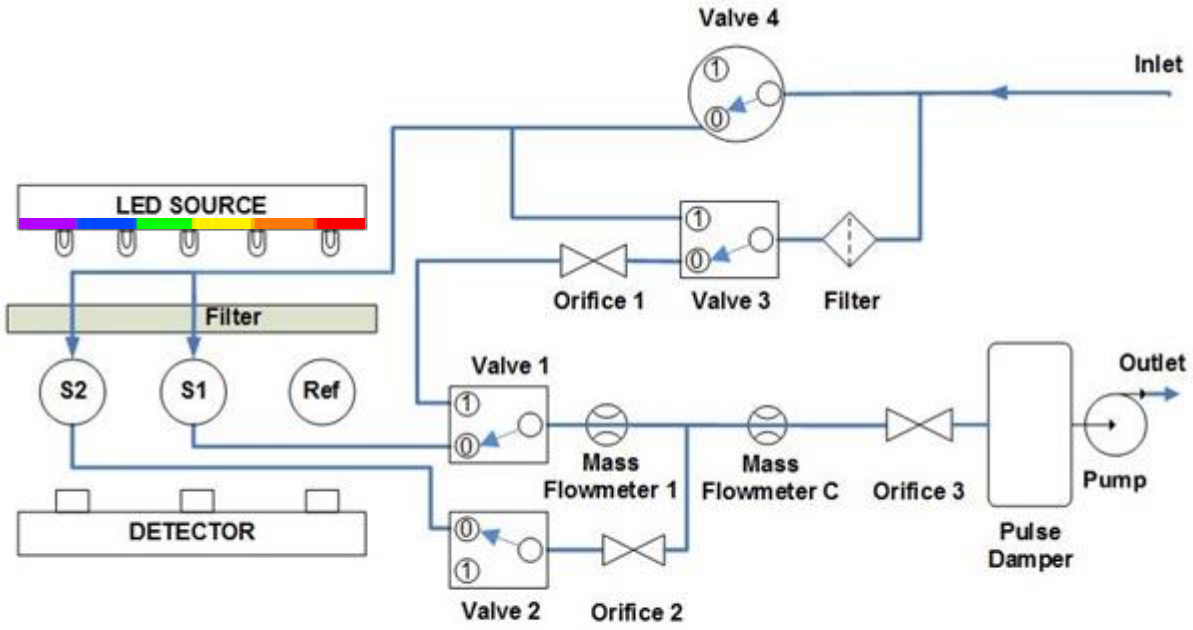
# 1. Introduction

- **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



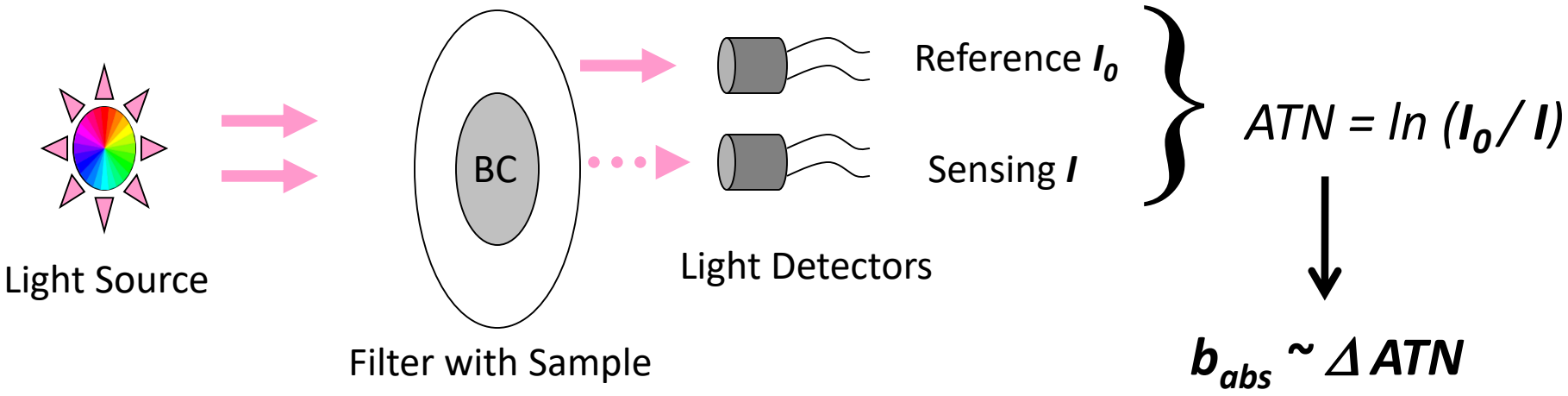
# 1. Introduction – flow diagram




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*** ~ change in ATN.

Measure optical absorption continuously : λ = 370 to 950 nm.

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

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

Real-time data: **1 s -1 min**

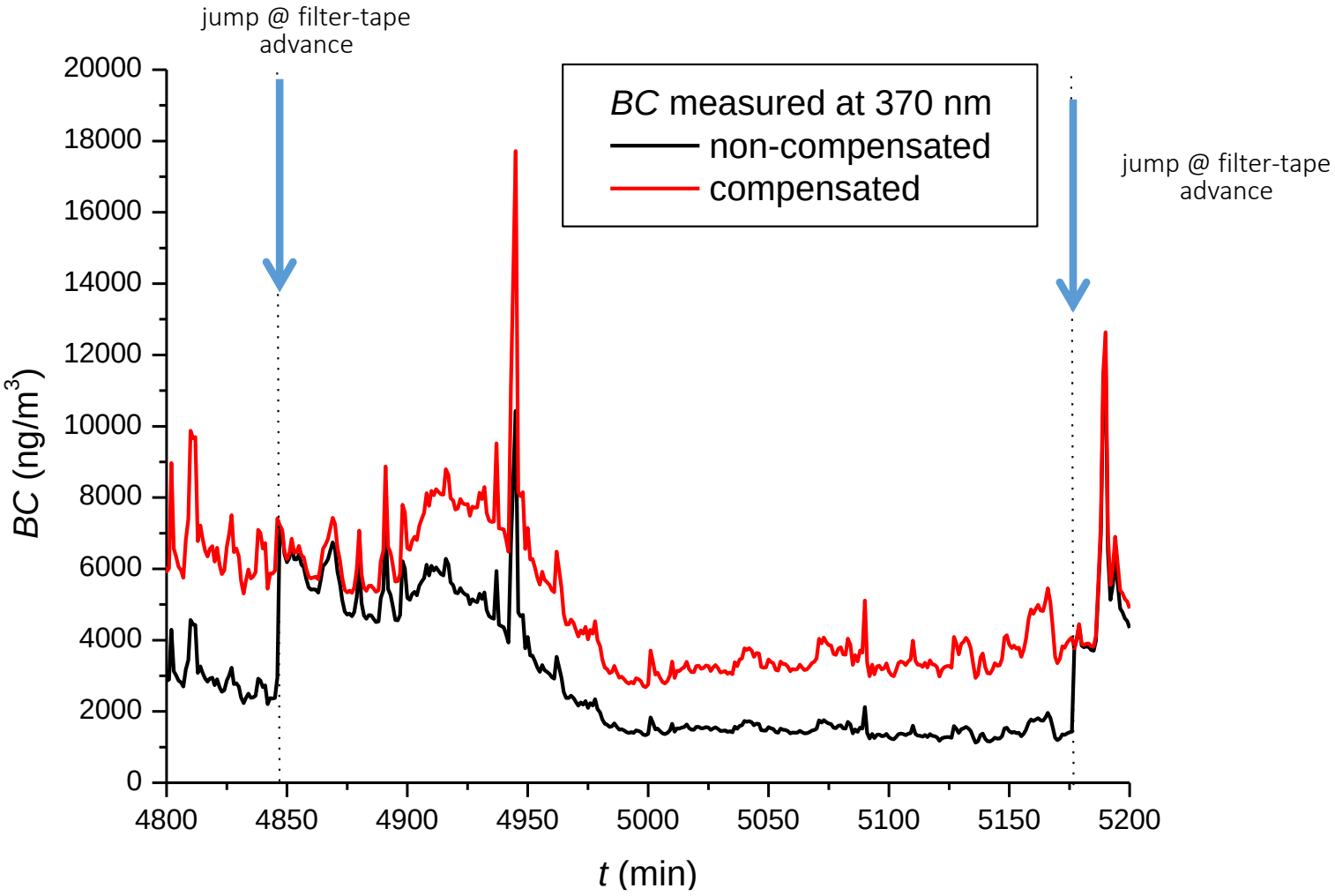
# 2.1 Basic calculations

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

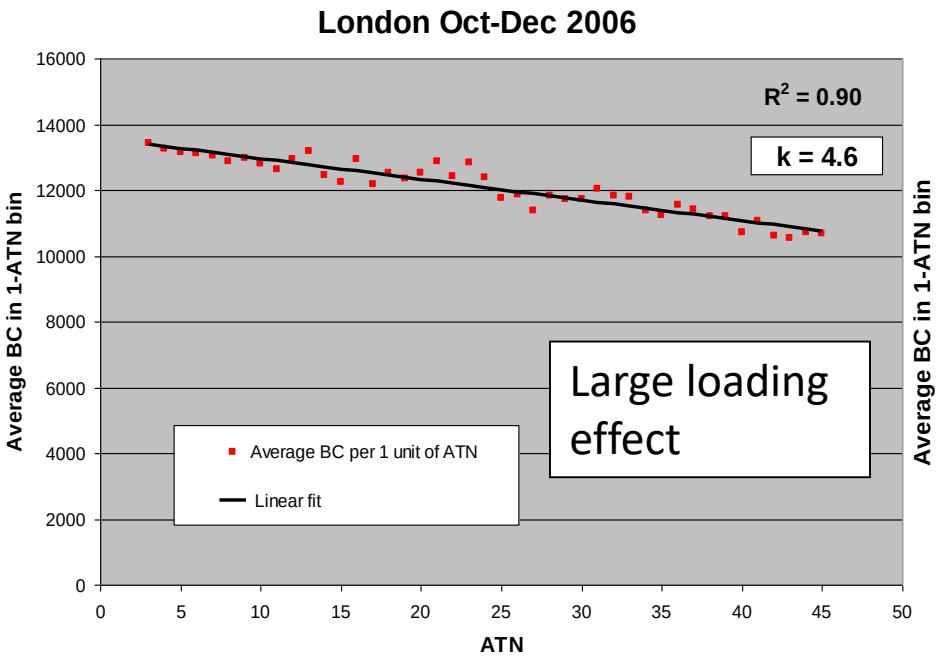
  $\sigma_{filter} = \sigma_{air} * C$ (Weingartner et al. 2003)

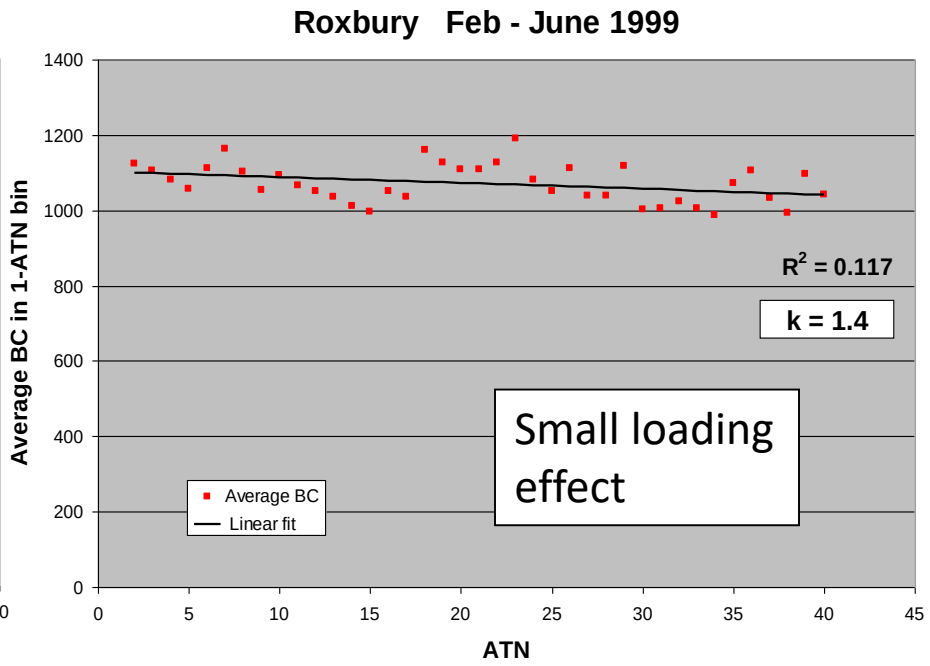
  $C$=1.57
- Loading effect compensation
  - $BC_{comp} = BC/(1 - k * ATN)$
- Measured leakage
  - $F_{in} = F_{out} * (1 - \zeta)$
  - Leakage factor $\zeta$ = 0.07
- Final equation
  - $BC = \frac{S*\Delta atn_1}{F_1(1-\zeta)*\sigma_{air}*C_{teflon}*(1-k*ATN_1)*\Delta t}$

# 3.1 Loading effect compensation



# 3.1 Loading effect compensation



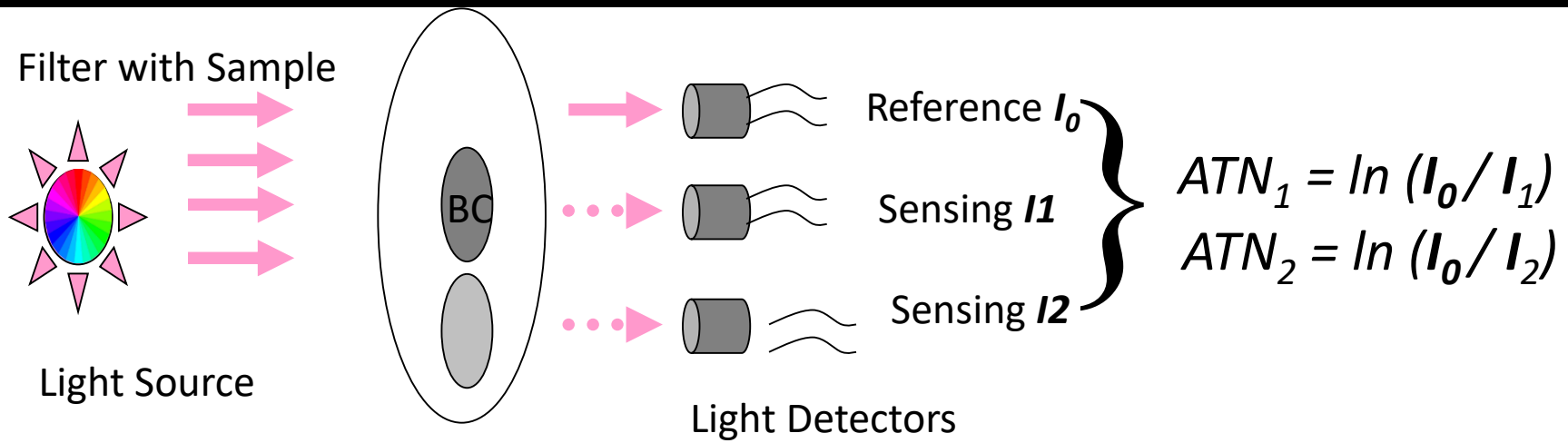




**BC** (reported) = **BC** (zero loading) · { 1 - ***k*** · **ATN** }

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

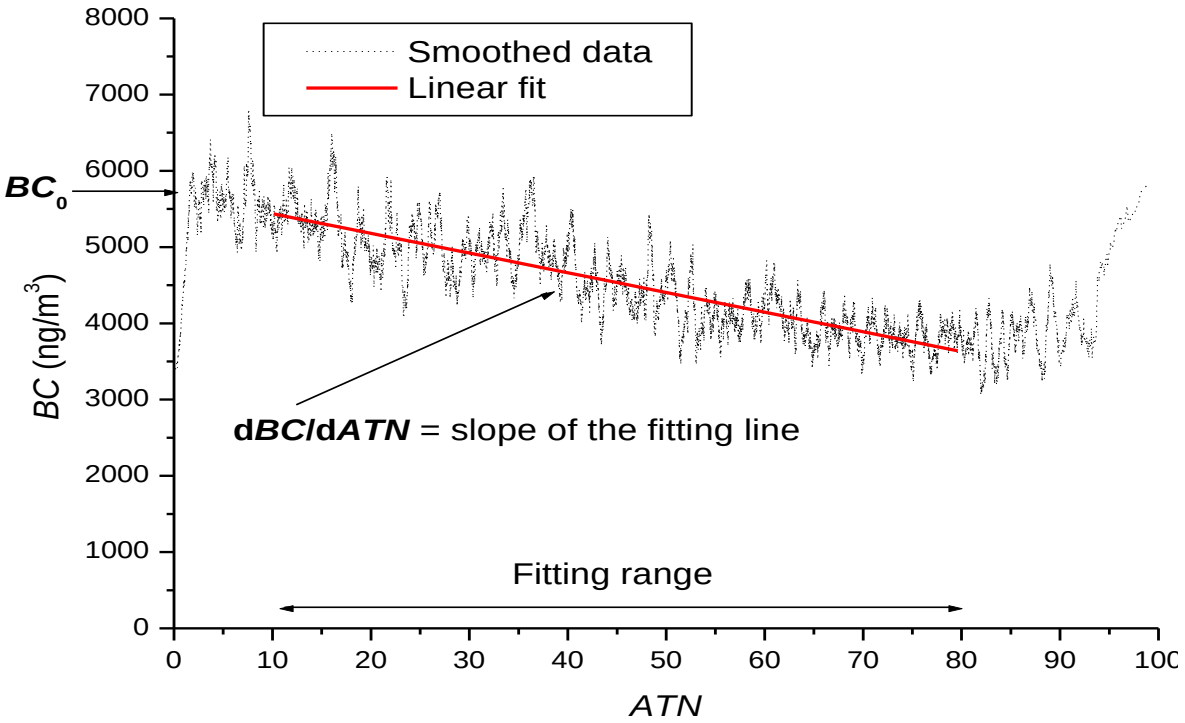



**Two parallel spots** with different flow, therefore ->

**different loading and attenuation**.

Calculate loading compensated ***BC***:

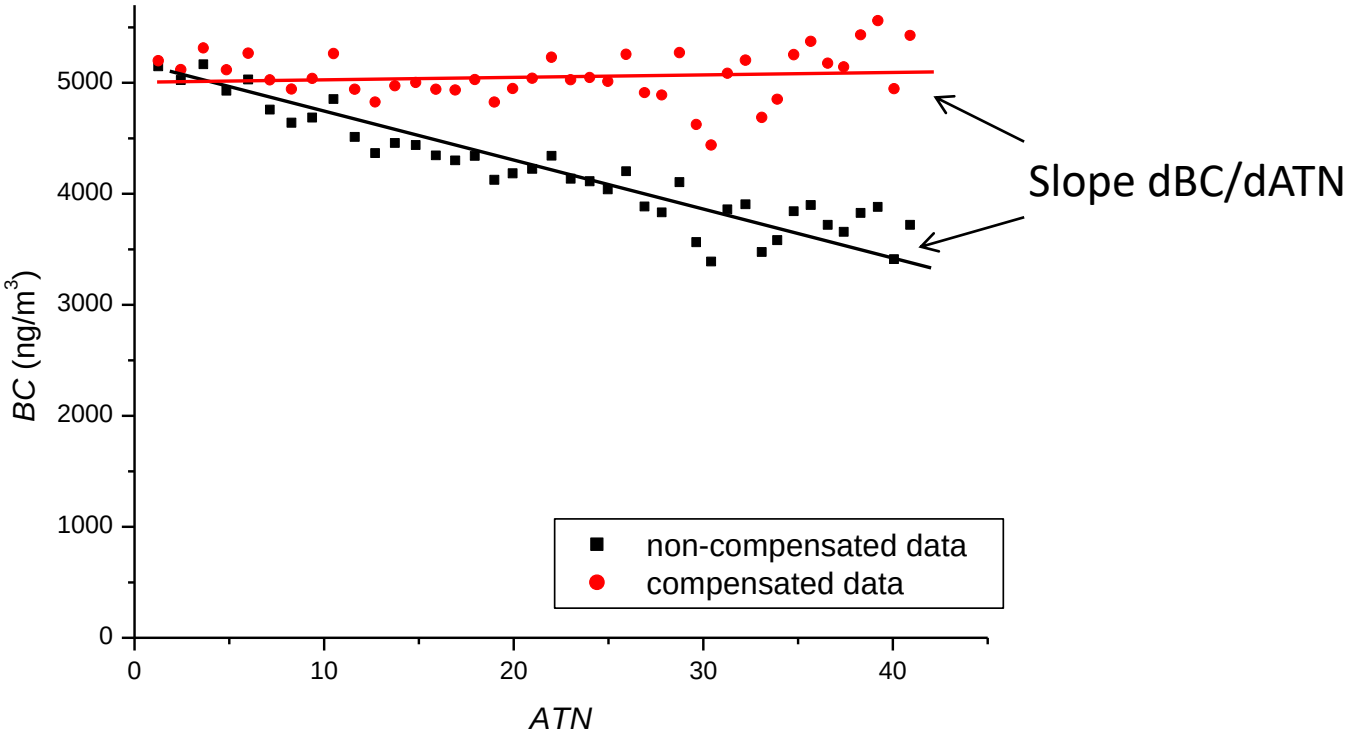
$BC=BC_1/(1-k*ATN_1)$



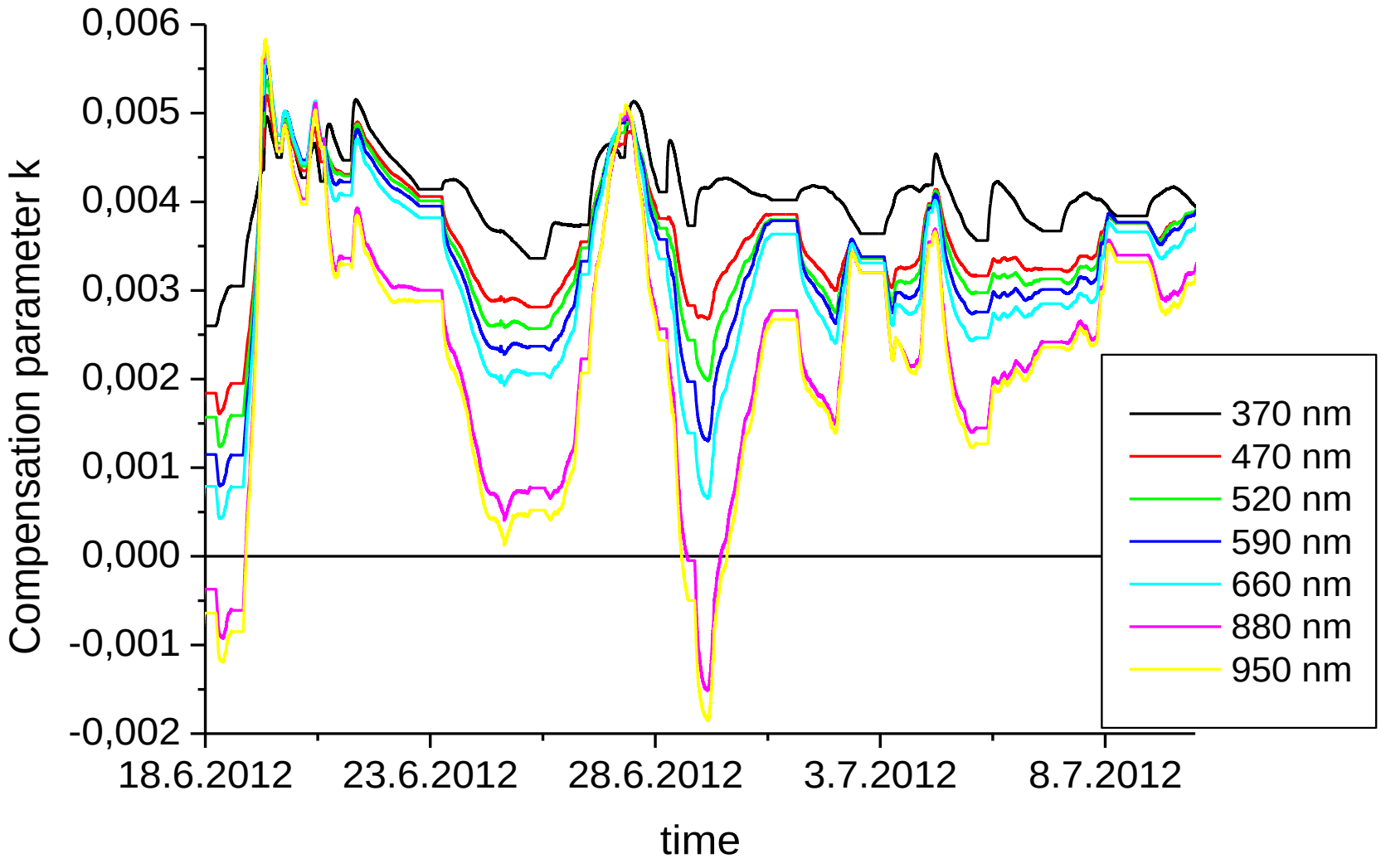
# 3.1 Loading effect compensation

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

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

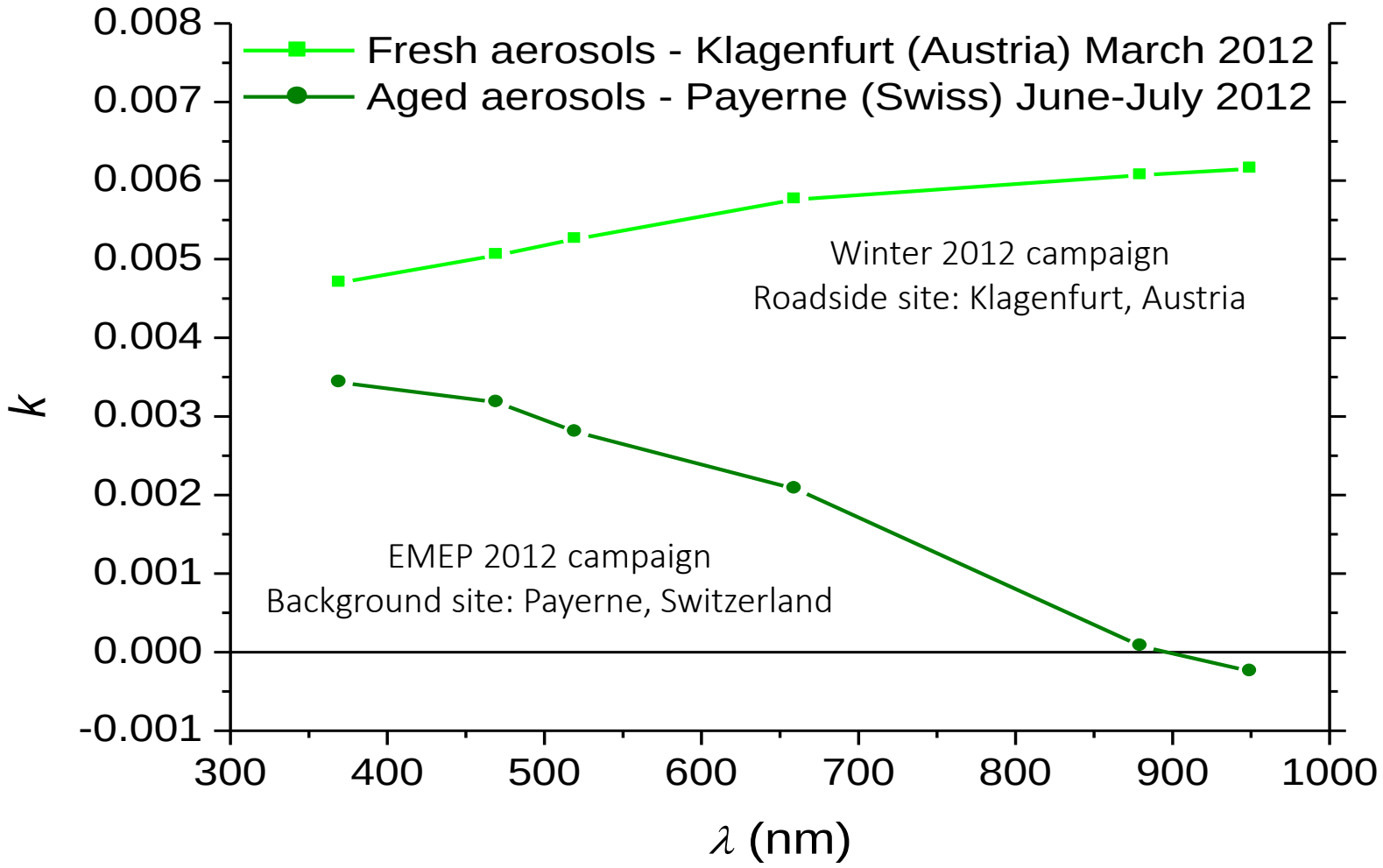


# 3.1 Loading effect compensation



# 3.1 Loading effect compensation

Spectral fingerprint of parameter ***k***



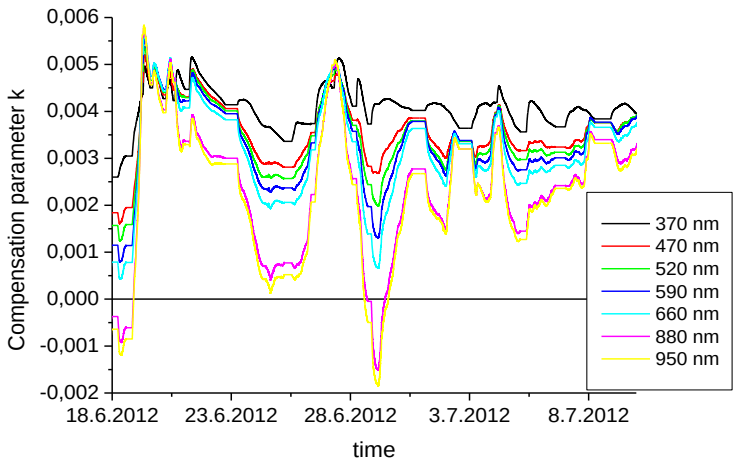
# 3.1 Loading effect compensation

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:

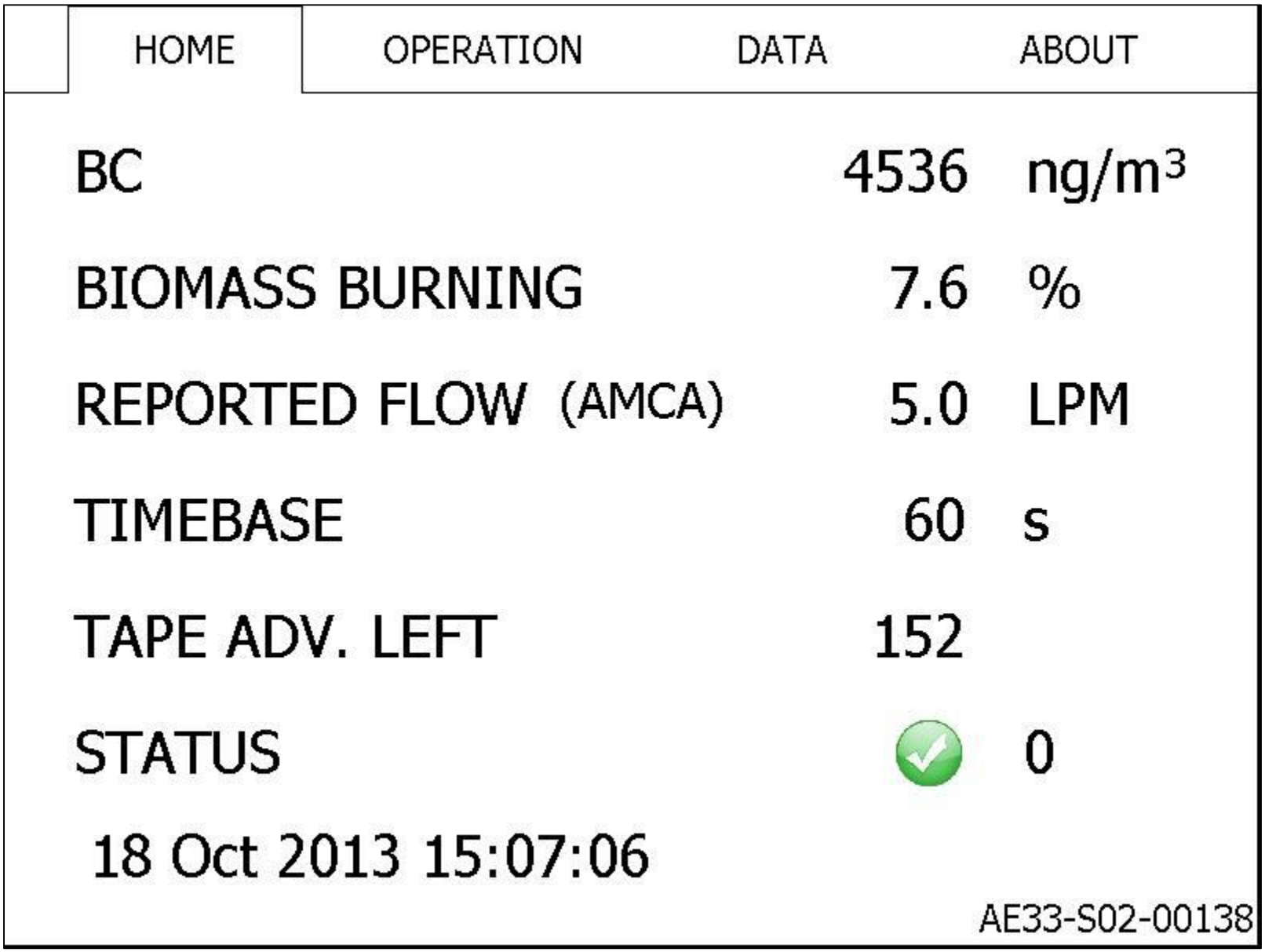
- Default setting: -0.005 < k < 0.015
- Expected values: 0 < k < 0.01



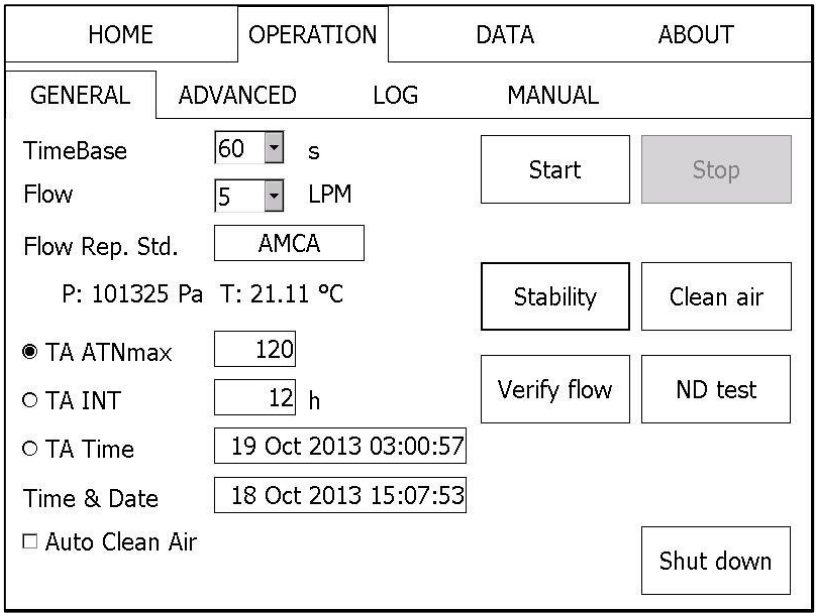
# 4. User interface

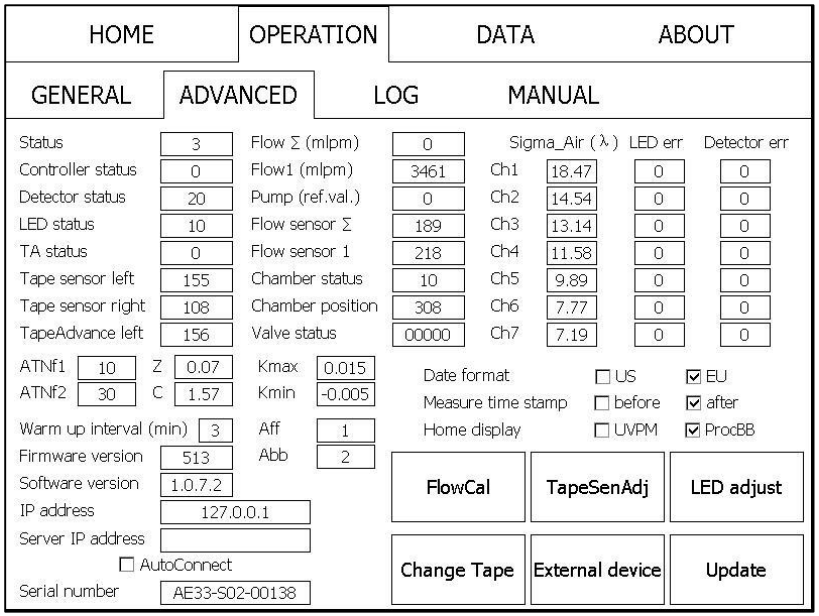
- 8.4'' color touch-screen with status indicator LED's
- Status de-convolution on home screen
- live data access on data screen
- Access to log records from last start of the instrument.....

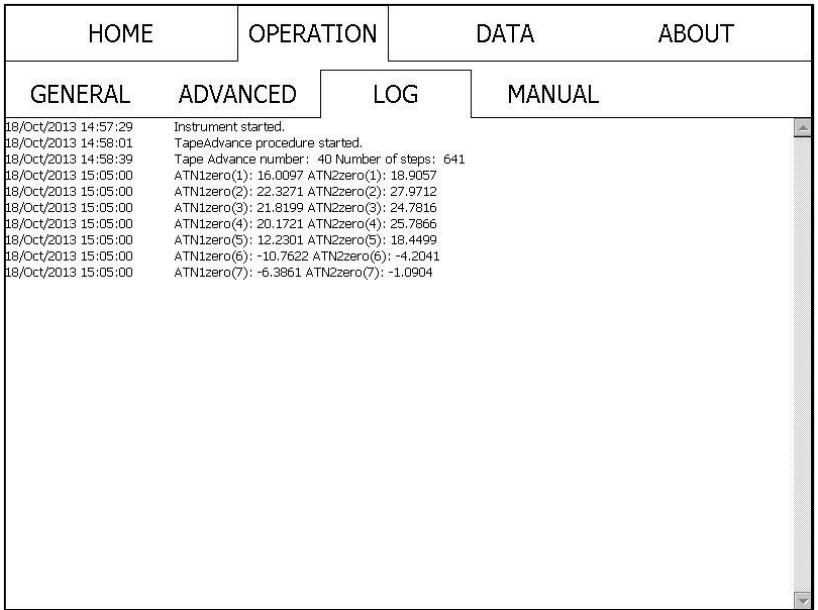
# 4. User interface/home screen

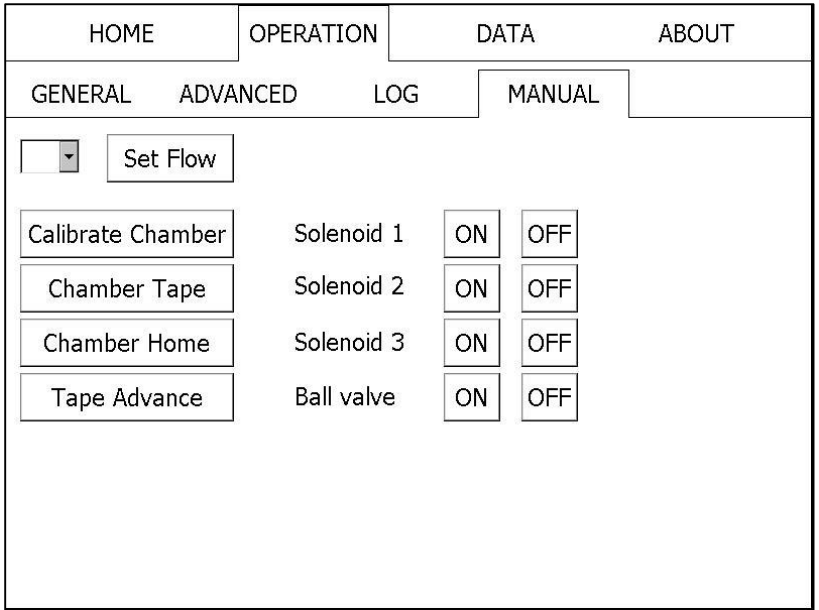


# 4. User interface/operation screen

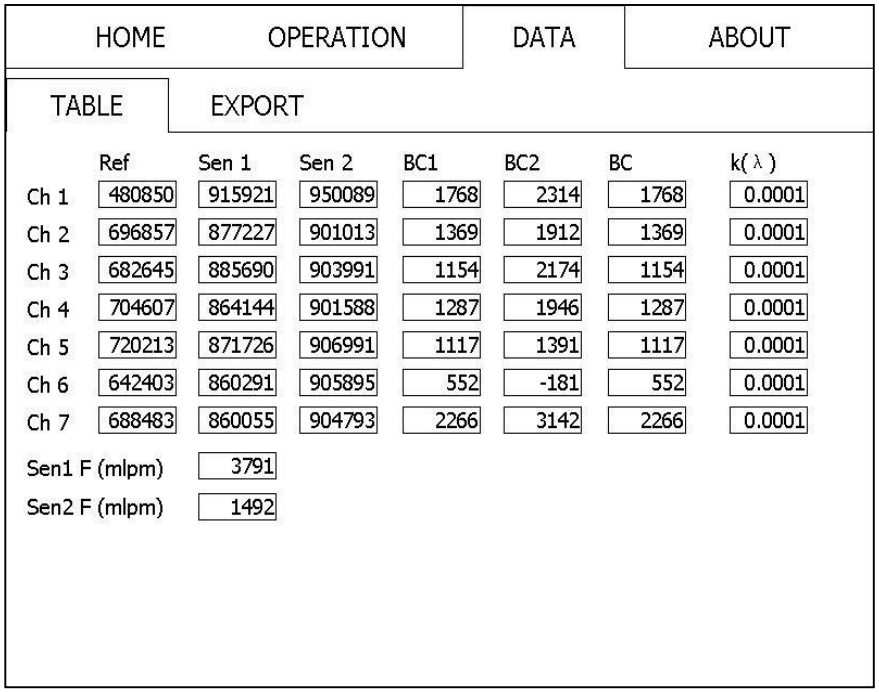


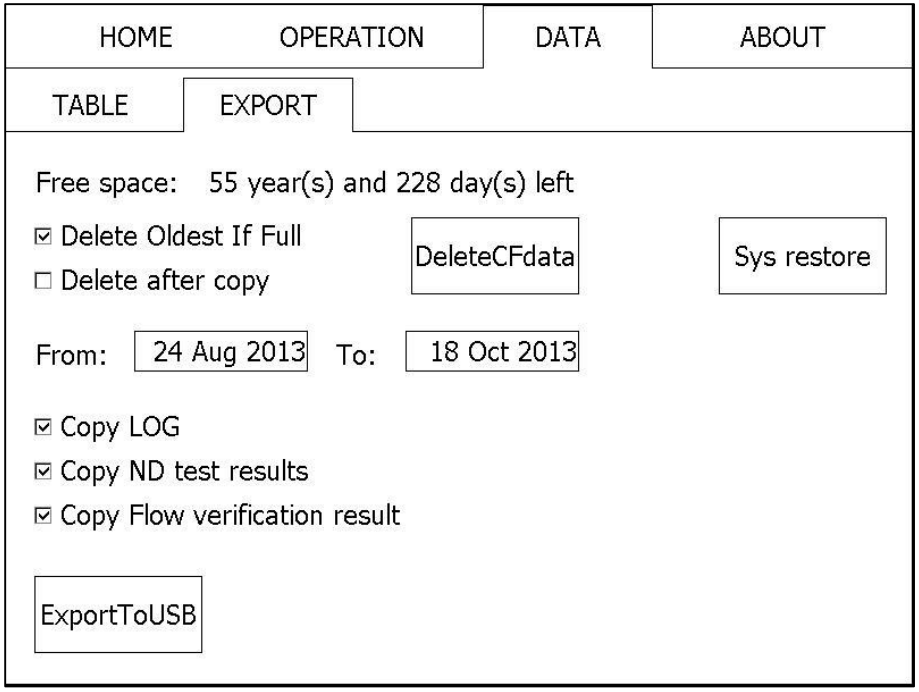



# 4. User interface/data screen



# 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**:

$$V = nR\boldsymbol{T}/\boldsymbol{p}$$

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

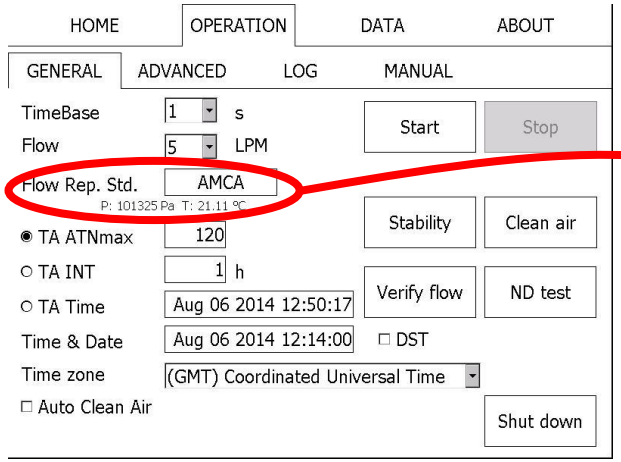
It is always possible to recalculate to other flow reporting standard:

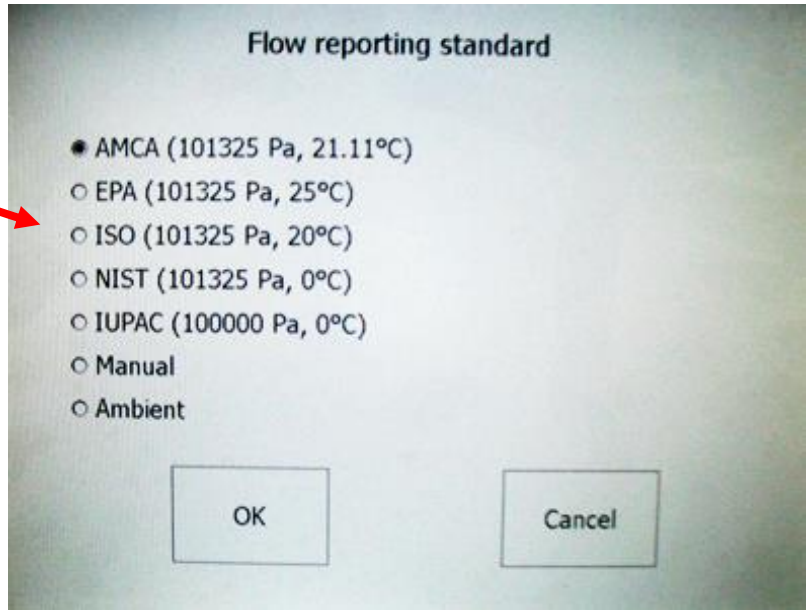
$$F_2 = F_1 \frac{T_2}{T_1}\frac{p_1}{p_2}$$

(Temperature must be reported in degrees kelvin)

# 4. User interface/settings

## Flow reporting standard



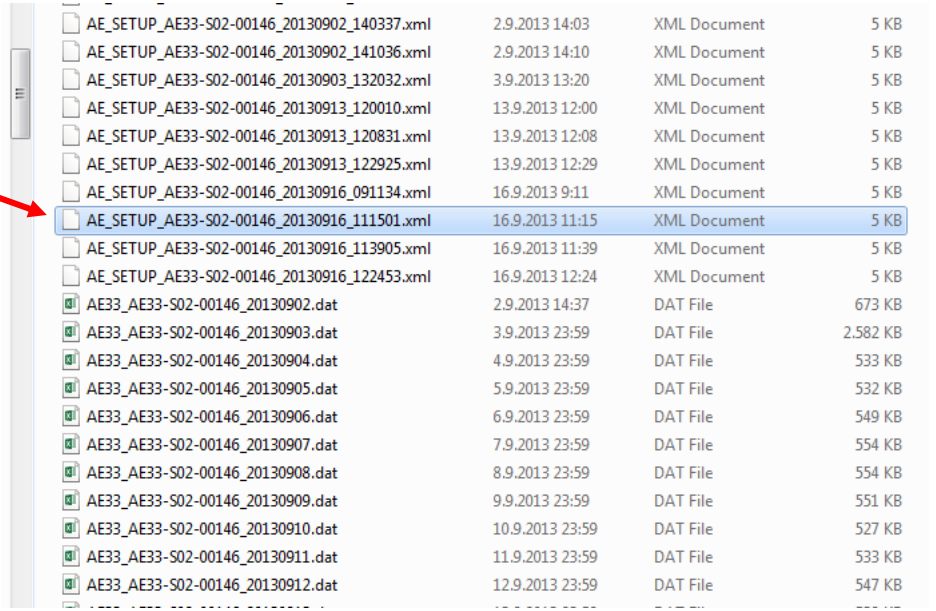

Volumetric flow recalculation:

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

# 4. User interface/setup file

**Setup file**

- Changes, saving
- Export
- Setup file restore




**Most important parameters:**

- Sigma values
- Leakage parameter ζ
- 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


TSI Mass Flowmeter 4140


BGI Tetracal flow calibrator is recommended

During flow check a calibration pad is used.

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) |

Flow calibration is needed if difference > 10 %

# 5. 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 %

# 5. Quality control/stability test

<u>Stability test (without flow):</u>

- Average BC ~ 30 ng/m3
- 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/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.

# 5. Quality control/clean air test

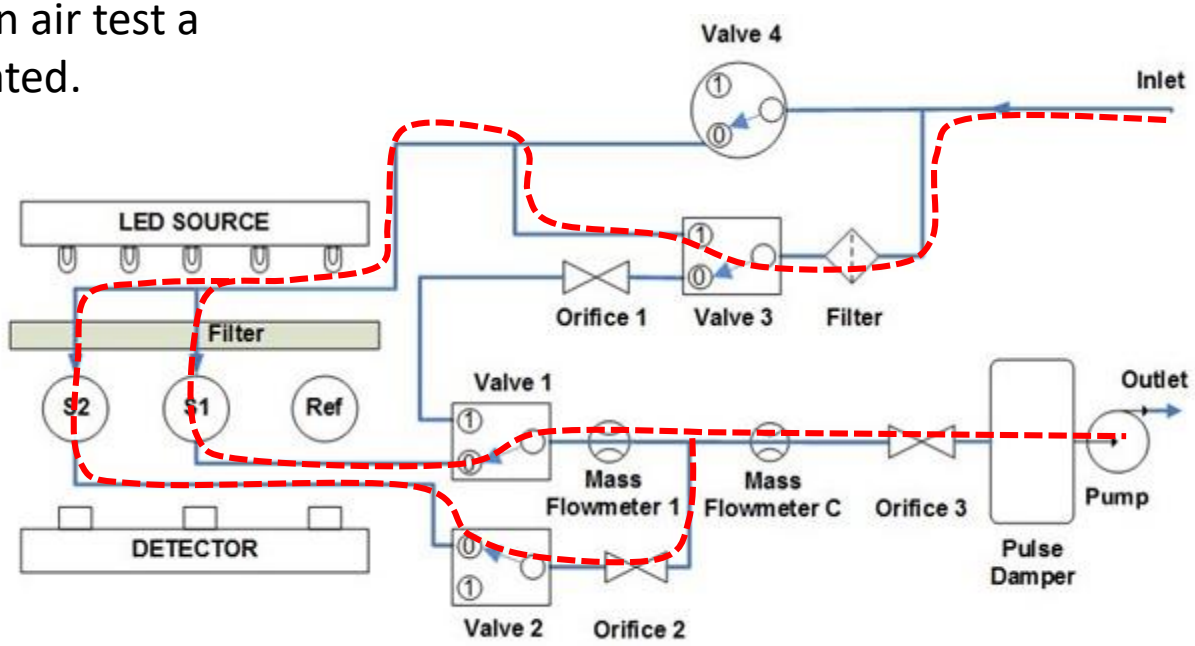
Clean air test (flow trough built-in filter):

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



# 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 & Maintainance/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

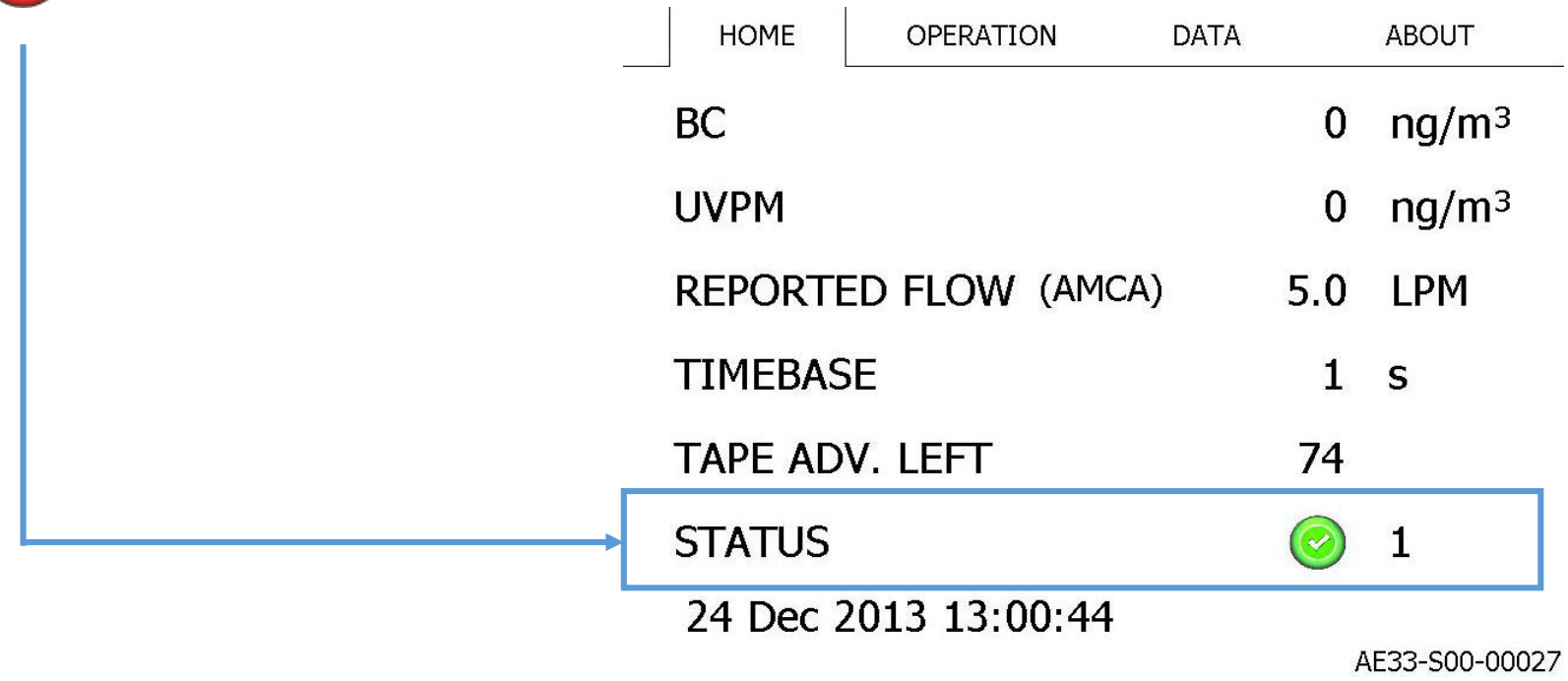
# 6. Service & Maintainance/status

- 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.



# 6. Service & Maintainance/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 channe 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 |

# 6. Service & Maintainance/tests

- 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 mm < TA length <40)
  -> if wrong perform tape sensor calibration

# 6. Service & Maintainance

- **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 & Maintainance/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 disconected
- Negative data values
- Noisy data – insect screen?

# 7. Installation

- Connection to the manifold – influence of other instrumentas
- 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
support@aerosol.si

**Please include:**

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