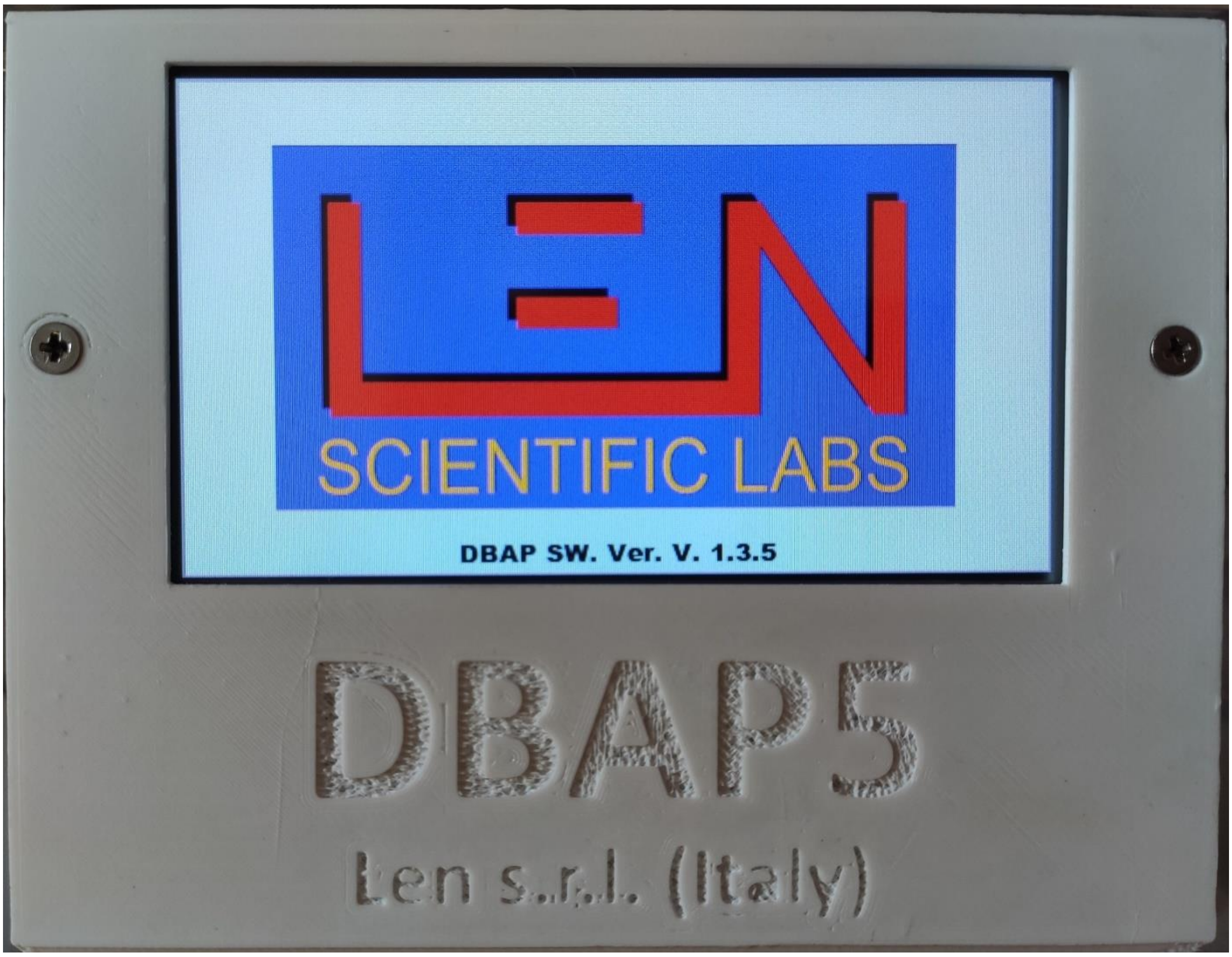
DBAP5

5 Wavelengths Dual Beam Absorption Photometer



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INDEX

Manual 1.10-EN – Firmware 1.3.8

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1 – Scientific reasons

Atmospheric aerosol, both of natural and anthropogenic origin, regulates the earth's global temperature by acting as a forcing on the radiative balance due to its optical properties, i.e., the ability to absorb and diffuse sunlight.
The absorption of solar radiation act as a regulator of the global terrestrial temperature, in fact the heating to the atmosphere and the cooling to the Earth surface caused by this absorption are hypothesized to have significant climate impacts [1], therefore reliable observations of the aerosol absorption coefficients (K_{ab}) are crucial for quantify the radiative forcing of the climate, and so aerosol absorption measurement are recommended for all station in GAW network.
From the absorption coefficients it is possible to retrieve the equivalent black carbon (EBC) concentration, using the adequate value of Mass Absorption Coefficient (MAC) in Eq. 1.1

Eq. 1.1 $$EBC = \frac{K_{ab}^{\lambda}}{MAC^{\lambda}}$$

EBC can have effect not only on air quality but also on human health, as highlighted by the WMO report [2].

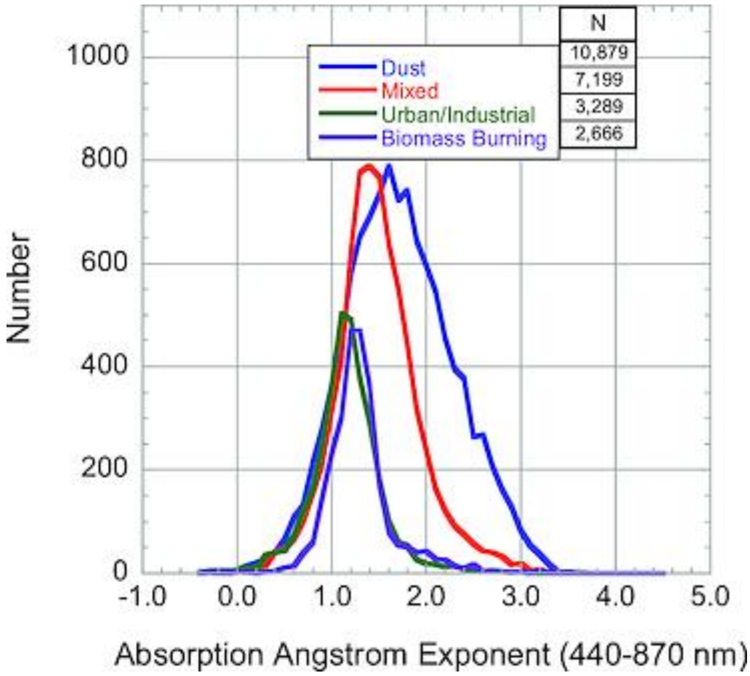
A key factor in better understand the aerosol composition is the spectral dependency of absorption coefficient, given by the Angstrom Absorption Exponent (AAE) defined as

Eq. 1.2 $$K_{ab}^{\lambda} \propto \lambda^{-AAE}$$

The values of AAE between 870 nm and 420 nm, calculated from Eq. 2 as

Eq. 1.3 $$AAE_{420-870} = \left(\frac{\ln\left(K_{ab}^{870}/K_{ab}^{420}\right)}{\ln(870/420)}\right)$$

is widely used to characterize the particle composition, as reported in [3] where AERONET AOD dataset has been investigated. From this work, Figure shows that different AAE values are related to different aerosol composition.



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[1] Particulate absorption of solar radiation: anthropogenic vs. dust. C. Wang et al 2009 Atmos. Chem. Phys.

[2] Health effects of black carbon 2012 World Health Organization

[3] An analysis of AERONET aerosol absorption properties and classifications representative of aerosol source regions. D. M. Gilles et al. 2012 J. Geophys. Res.

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2 - Instrument description

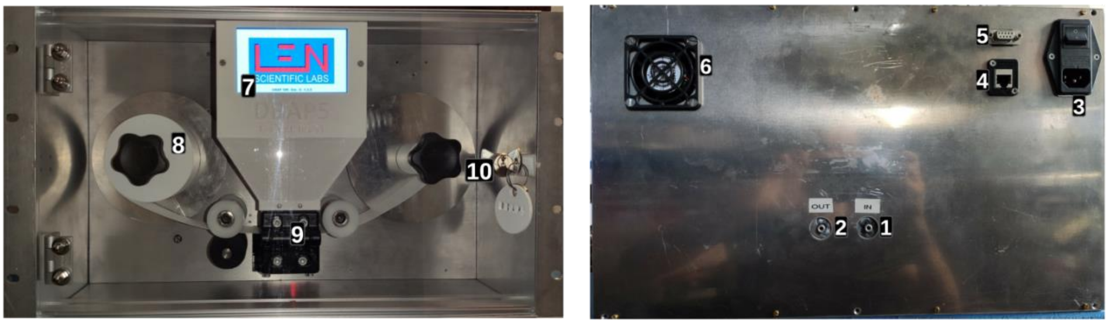

Fig.1 - left: Front view; right: back view

1. Air inlet
2. Air outlet
3. Power plug and switch
4. Ethernet plug RJ45
5. RS232 port db9 female
6. Cooling fan
7. Touch screen
8. Filter tape
9. Measurement chamber
10. Plexiglas cover lock

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2.1 - Pneumatic circuit

Figure 2.2 shows the DBAP5 pneumatic circuit. Air flow entering the measuring chamber (1) through the proper inlet is continuously measured by a Venturi tube (2). Any eventual flow fluctuation due to the pump (4) is attenuated by an expansion lung (3). Air flow is then evacuated through the instrument outlet.

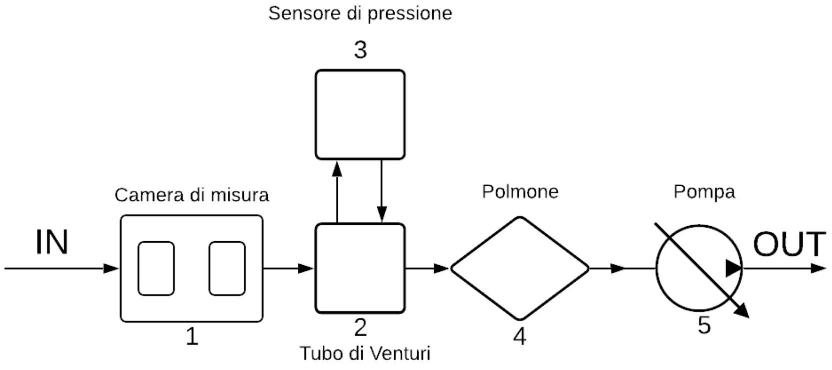


Figura 2.2: Pneumatic Circuit

Air flow in the Venturi tube is measured using equation 2.1

Eq. 2.1 $$Q = a + b\sqrt{dP}$$

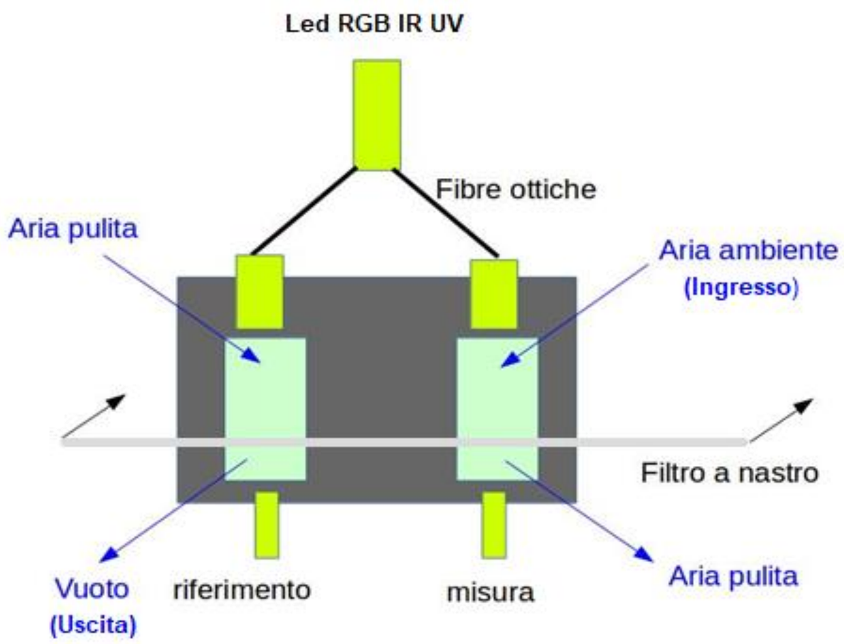
where Q is the air flow in l/min and *dP* is the differential pressure measured in the Venturi tube.
Coefficients *a* and *b* mainly depend on the geometric characteristics of the tube. In DBAP5 they are set following a factory calibration, however they can be changed following a further calibration performed by user [1].

2.2 - Measurement chamber

The measuring chamber (figure 2.3), designed according to dual beam technology, has two distinct cells (reference and measurement) in which the light generated by the LED is conveyed using an optical fiber. This technique, ensuring a continuous comparison with the uncontaminated filter during the measurement, cuts any errors due to possible changes in the optical properties of the filter due, for example, to changes in humidity and temperature. The light intensity is in fact measured downstream of the filter in both cells, supplying the transmittance (t) at each instant of time and for each wavelength, the variation of which over time supplies the absorption coefficient (paragraph 3).

1 - *see paragraph 5.3 for parameters setting*

figure 2.3: measurement chamber



Ambient air enters the upper part of the measuring cell, passes through the filter, depositing the particulate load on it, and exits the lower part of the cell.
After passing through the filter, the air is free of aerosols and enters the reference cell from above.
The developed measuring chamber ensures that the filter is subjected to the same pressures to minimize the possible difference in the optical path of the light inside the filter due to different deformations of the filter itself.

2.3 - LED

Light sources are at the following wavelength:

IR: 870 nm
RED: 634 nm
GREEN: 522 nm
BLUE: 465 nm
UV: 420 nm

2.4 - Touch screen

The instrument display is a touch screen that allow the user to perform basic operation on the instrument and control the measured data. The use of touch screen is described in chapter 4.

2.5 - Tape Filter

The tape filter used for the measurement is made of fiberglass (GF 10 width 40 mm, retention degree 99.98%).
To keep measure efficiency filter must be advanced when particles load became too intensive, thus the advancement is driven by transmittance value, as described in paragraph 3.2, that can be set by the user
For the filter replacement procedure, refer to paragraph 6.

3 – Measurement principle

The method for finding the absorption coefficient for each wavelength, and then the equivalent black carbon, is based on the measurement of the change in filter transmittance as particulate matter accumulates on it.
Using the 'dual-beam' technology (par. 2) the transmittance (I) is defined for each wavelength as the ratio between the light intensity measured in the measuring cell (I_m) and in the reference cell (IR), transmittance which is normalized to 1 in the first measurement cycle (t = 0).

Eq. 3.1 $$\tau^{\lambda}(t) = \frac{\tau_m^{\lambda}(t)/\tau_r^{\lambda}(t)}{\tau_m^{\lambda}(t=0)/\tau_r^{\lambda}(t=0)}$$

the attenuation coefficient for each wavelength (K_{att}) in unit of in m-1 is calculated from the filter transmittance variation over a time interval following Eq.3.2

Eq. 3.2 $$K_{att}^{\lambda}(t) = \frac{A}{Qdt}\ln\left(\frac{\tau^{\lambda}(t-dt)}{\tau^{\lambda}(t)}\right) \quad [m^{-1}]$$

where A is the area of the filter where particles are collected (spot area) in m^3, Q is the air flow passing through the filter in m^3/s and dt the time interval in seconds between the two measurements, which is set to 60 s.
The absorption coefficients are then calculated from the attenuation coefficients taking in account of two effects on the aerosol optical properties due to the filter media, using the correction factor

Eq. 3.3 $$F(\tau) = \frac{1}{C(a+b\tau)}$$

where the coefficient C depends mainly on the type of filter and considers the increase in absorption due to multiple scattering within the filter fiber.
F(t) depends linearly on the transmittance and describe the shadow effect the leads to an underestimation of absorption due to the growth of the particulate load on the filter itself.
In equation 3.3 C, a and b can be set by the user, and by default they are set as:

$$a = 0.531$$
$$b = 0.610$$
$$C = 23. + 0.0006\lambda$$

the absorption coefficients (K_{ab}^{λ}) are therefore calculated as:

Eq. 3.4 $$K_{ab}^{\lambda} = K_{att}^{\lambda}F(\tau)$$

The Equivalent Black Carbon (EBC) is derived from the absorption coefficients using equation 1.1.
DBAP5 gives the value of EBC calculated at 870 nm (IR), using a MAC of 8.8e-6, value that can be set by the user following the scientific upgrade. DBAP5 also allows the user the possibility to set a MAC value for each wavelength to get EBC for all the 5 colours.

Eq. 3.5 $$BC = \frac{K_{ab}^{\lambda=870}}{MAC^{\lambda=870}} \quad [\mu g/m^3]$$

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To minimize measurement noise especially in clean environment, the user can decide to receive the absorption coefficient as simple moving average (SMA) over a time (P) of a maximum of 10 minutes.

Eq. 3.6 $$K_{ab}^{\lambda} = \sum_{i=-P}^{i=0} K_{ab}^{\lambda}(i)$$

where i=0 represent the last received data

3.1 - Measurement cycle

After closing the measurement chamber, the pump is turned on and the dark current noise is measured with LED off. The background noise thus obtained will be subtracted from the next light intensity measurements.

Subsequently all five transmittances are normalized to 1. This phase has a total duration of 5 seconds since 1 second is used per colour for normalization.

After these first two phases, the real measurement cycle begins: transmittance (Eq. 3.1) is measured every second for each wavelength and integrated over a minute to perform the calculation of the absorption coefficient in m^{-1} (Eq. 3.4) and of the equivalent black carbon in $\mu g/m^3$ (Eq. 3.5).

After P minutes (chosen SMA interval) the first value of the absorption coefficients and EBC is supplied for each of the 5 wavelengths, values that are updated every minute.

3.2 - Filter tape advancement

As the amount of absorbing matter collect on the filter reach a critical value the light intensity variation became very weak leading big uncertainty in the measure. Thus, the filter tape is advanced when the transmittance in the green value reaches the value of 0.6.

When this transmittance threshold is reached the measure is stopped, pump turned off and the measurement chamber lift the upper part to let the filter tape pass inside. After the filter is in the new position the measurement chamber is closed and the measure start again.

The user can in any case change the default value of green transmittance and extend the limit to other wavelength. In case of limits set on more than one colour, the first reached threshold will move the filter.

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4 – Local control (touch screen)

After the instrument has been turned on, it is able to receive remote command (RS22, telnet), and after touching the screen the instrument can receive local command, following the menu shown in figure 4.1.
Choosing the maintenance icon on the bottom-right of the screen it is possible to change language (Italian, English or Franch) used on the touch screen

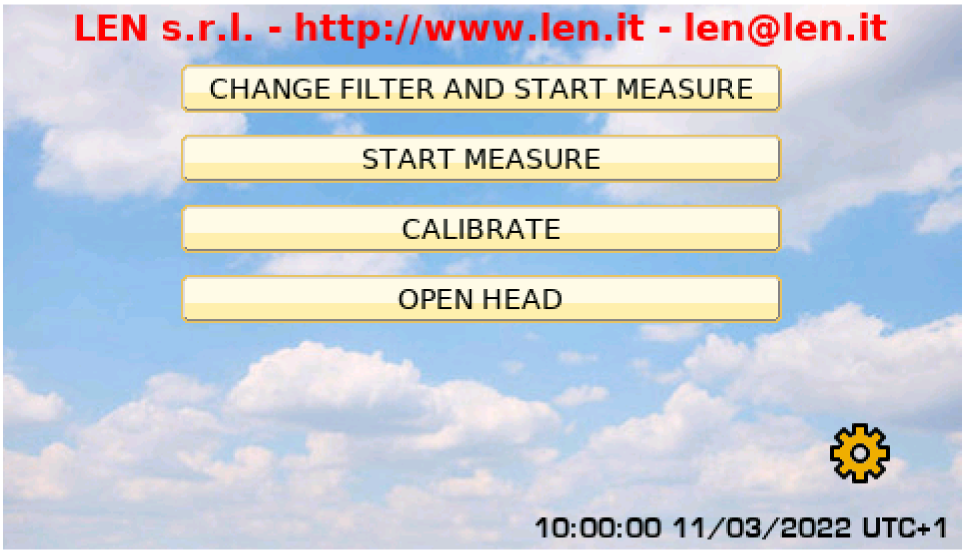

Figura 4.1: main menu

4.1- Measurement options

In the main menu the top first two button (change filter and start measures and start measures) start the measure, choosing the first choice the filter tape advance and the measurement cycle start, choosing the second choice the measurement cycle will start without changing the filter position.
During measurement operations, the display will show the time series of the absorption coefficients measured for all wavelengths during the time interval showed above (Range display time). The vertical grid shows 2-hour intervals. The last measured values of absorption coefficient (in m^{-1}) and transmittance are shown, for each wavelength, in the boxes at the bottom of the screen. By acting on the buttons that show the name of the colours, you can choose whether to display the absorption coefficient measured at the relative wavelength. 1 to 5 curves can be displayed on the same time. However, at least one time series is always displayed.
Exit button can be used for stopping the measurement and zoom button is for show on screen the last 2 hour of measure instead of the last 24

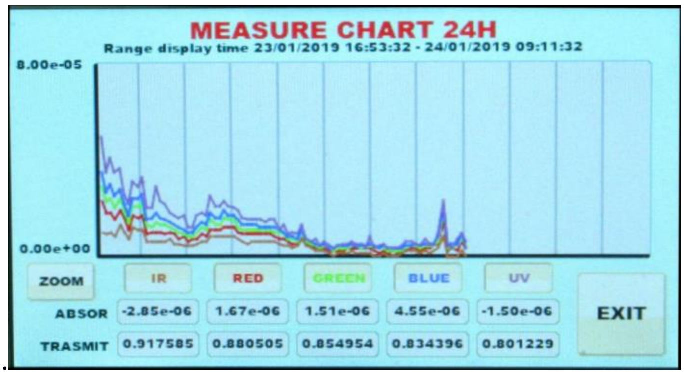

Figure 4.2: measurement screen 24 hours

Compared to the earlier screen, the navigation buttons are displayed to the right of the ordinate of the graph. Pressing the button at the top moves the time window of the zoom one hour back, while the one at the bottom produces the opposite effect. As seen for the screen of figure 4.2, the colours to be displayed can be selected with the relative buttons, to exit the zoom press the ZOOM button again.

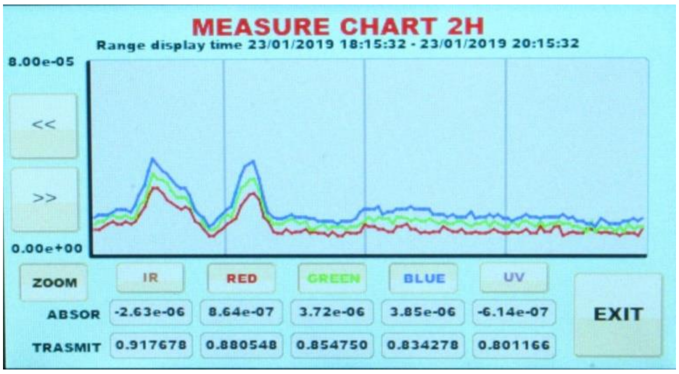

Figure 4.3: measurement screen 2 hours

4.1- Calibrate options

The CALIBRATE button put the instrument in the calibration mode, mode that is principally used by the manufacturer. In this mode the screen will display the signal received by the two detectors of the measurement chamber to check the signal stability (Fig 4.3)
The screen shows the result of the signal in the selected wavelength, choosing DARK the LED will be turned off and the dark current measurement is performed.

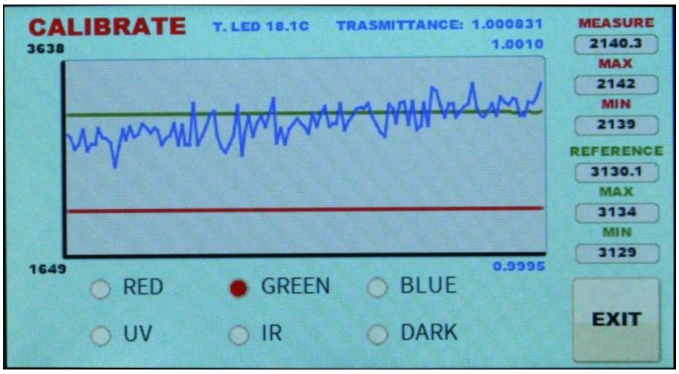

Figura 4.4: calibration

$.2 - Open head option

The OPEN HEAD button forces the measurement chamber to open, and the screen of figure 4.5 appear on the display. From this new menu it is possible to advance the filter (by choosing FRWARD REEL), open more the chamber (OPEN HEAD) or close the measurement chamber (CLOSE HEAD).

Figura 4.5 menu after OPEN HEAD command

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5 – Remote control

Using the communication protocol via RS232 or telnet allow the user to gain a greater control of the instrument.
Serial port settings: 57600, 8, N, 1.
Network settings: must be provided by the user exclusively via the serial link (command: change_ip and change_gateway, paragraph 5.3),
To visualize on a computer terminal all possible command type “?”

DBAP_TELNET Help menu:

ADMIN
CHANGE_FILTER
CHANGE_GATEWAY
CHANGE_IP CHANGE_PORT
CHANGE_SNTP_SERVER
CLOSE_HEAD
CLOSE_REMOTE_SESSION
DATE
DELETE_ALL_MEASURES
DELETE_DATE_MEASURES
DELETE_LOGS
DISABLE_FLUXMETER
DISABLE_PUMP
DISABLE_REMOTE_CONSOLE
ENABLE_FLUXMETER
ENABLE_PUMP
ENABLE_REMOTE_CONSOLE
FORWARD_REEL
GET_DATE_MEASURES
GET_LAST_MEASURES
LED_BLUE
LED_GREEN
LED_IR
LED_NONE
LED_RED
LED_UV
OPEN_HEAD
READ_ENVIRO_PRESSURE
READ_FLUX_L_MINUTE
READ_FLUX_PRESSURE
READ_FLUX_TEMP
READ_INT_TEMP
READ_LED_TEMP
SET_BC_CONSTANT
SET_DATE
SET_DEFAULT_FLUX
SET_FACTORY_CONFIG
SET_FILTER_CORRECTION_CONST
SET_FILTER_CORRECTION_CONST
SET_FLOW_CONST_A
SET_FLOW_CONST_B
SET_LEVELS_FILTER_CHANGE
SET_SMA_STEPS
SET_SPOT_AREA
SET_TIME_ZONE
SHOW_CONFIG
SHOW_DATE_MEASURES
SHOW_LOG
SHOW_STATUS
SHOW_VER
SPD
START_CALIBRATION
START_MEASURE
PUMP
START_PUMP
START_STREAMING
STOP_CALIBRATION
STOP_MEASURE
STOP_PUMP
STOP_STREAMING

Commands are not case sensitive, and they must be followed by the \n\r character.
DBAP5 commands can be divided in Action, Write and Read commands. Action commands are used for activating some operation, Write commands for parameters set and Read commands to receive information and data for the instrument.

5.1 -Read Command

?

Show Help Menu.

DATE

show instrument date and time

GET_DATE_MEASURES

show data of the given day starting from the give time (time is optional), data format is reported in appendix A

Usage: *get_date_measure 29/01/2019* 07:30 (if time is missing all the daily data are given)

GET_LAST_MEASURES

Show last measurement data, it can be given with an integer (n) less then 1440 as argument to get last n measurement data. Data format is reported in appendix A

Usage: *get_last_measures ; get_last_measures n*

READ_ENVIRO_PRESSURE

Show air pressure.

READ_FLUX_TEMP

Show the temperature (Celsius degree) inside the Venturi tube.

READ_INT_TEMP

Show the internal temperature (Celsius degree).

READ_LED_TEMP

Show led temperature (Celsius degree).

READ_FLUX_L_MINUTE

Show flow in litre/minute.

READ_FLUX_PRESSURE

Show the differential pressure (mbar) in the Venturi tube.

SHOW_CONFIG

Show the parameter setting on the instrument.

SHOW_DATE_MEASURES

show the date of the measured saved in the instrument memory, if used with argument it will show the date starting from the given date

Usage: *show_date_measures, show_date_measures 29/01/2019*

SHOW_LOG

shows the instruments logs (maximum last 1000 events).

SHOW_STATUS

shows instrument status and errors.

SHOW_VER

shows the firmware version.

START_STREAMING

start data streaming over RS232 or telnet

Data format is reported in appendix A

STOP_STREAMING

stop data streaming

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5.2 - Write command (parameter setting)

CHANGE_IP ***only over*** **RS232**

set ip and netmask for TCP/IP communication

usage: *change_ip xxx.xxx.xxx.xxx yyy.yyy.yyy.yyy (x is ip, y is netmask)*

CHANGE_GATEWAY ***only over*** **RS232**

set the gateway for TCP/IP communication

usage: change_gateway zzz.zzz.zzz.zzz

CHANGE_SNTP_SERVER

set the NTP server for time synchronization

used without parameter will disable the time synchronization

SET_BC_CONSTANT

set the color and the related MAE of Eq. 3.4 to calculate the EBC

Usage: *set_bc_constant color value (default is E8.83-6 for IR 1 for other colours)*

SET_DATE

set instrument date and time

usage: *set_date 23:59:59 31/12/2019*

SET_FACTORY_CONFIG

set instrument factory configuration (app B)

SET_FILTER_CORRECTION_CONST

set the coefficient for the filter correction function (Eq. 3.3)

usage: *set_filter_correction_const colour a b*

setting a=1 and b=0 the absorption and attenuation coefficients will be the same

SET_FLOW_CONST_A

set coefficients for the air flow calibration (Eq. 2.1).

usage: *set_flow_const_a value.*

SET_FLOW_CONST_B

set coefficients b for the air flow calibration (Eq. 2.1).

usage: set_flow_const_b value.

SET_LEVELS_FILTER_CHANGE

set the transmittance threshold for advancing the filter tape (Par 3.2)

usage: *set_level_filter_change red_value green_value blu_value uv_value e ir_value*

setting the value to 0 will disable the tape movement for the related colour

SET_SMA_STEPS

set the number of measures to use for the SMA calculation (Eq. 3.6)

usage: *set_sma_steps num*

num must be in the range 1-10

SET_SPOT_AREA

set the filter spot area (Eq. 3.2) in m^2.

Usage: *set_spot_area 0.0001368*

SET_TIME_ZONE

set time zone

usage: *set_time_zone -1*

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5.3 - Action command

CHANGE_FILTER

Action: open the measuring chamber, filter advancement and close the measuring chamber. Command can only be run when the measurement is not active, after this action measure does not start automatically.

CLOSE_HEAD

Action: close measurement chamber

DELETE_LOGS

Action: remove all system logs

DISABLE_PUMP

This command allows to perform measures without flow (pump off). Data are then given with a fictitious flow of 1.3 l/min. Used mainly for electronic noise check.

Command can only be run when the measurement is not active, after this action measure does not start automatically.

ENABLE_PUMP

Action: Enable pump, to use after the disabled pump command to return in normal operation mode

Command can only be run when the measurement is not active, after this action measure does not start automatically.

FORWARD_REEL

Action: Advancing the filter.

The command can be executed only when the measurement chamber is open.

LED_BLUE

Action: activate only blue led.

To be used in calibration mode.

LED_GREEN

Action: activate only green led.

To be used in calibration mode.

LED_IR

Action: activate only IR led.

To be used in calibration mode.

LED_NONE

Action: none of the led is active.

To be used in calibration mode for dark current

LED_RED

Action: activate only red led.

To be used in calibration mode.

LED_UV

Action: activate only UV led.

To be used in calibration mode.

OPEN_HEAD

Action: Open the measurement chamber.

Command can only be run when the measurement is not active.

START_CALIBRATION

Action: put the instrument in calibration mode.

Command can only be run when the measurement is not active.

START_MEASURE

Action: start measures

START_PUMP

Action: activate the pump

STOP_CALIBRATION

Action: stop the calibration mode.

STOP_MEASURE

Action: stop the measures.

STOP_PUMP

Action: stop the pump

5.4- Other commands

ADMIN

enable the administration mode

reserved for the producer – need a password

DELETE_ALL_MEASURES

delete all the stored measure

DELETE_DATE_MEASURES

remove the measured related to the specified day

usage: *delete_date_measure 31/12/2019*

EXIT ***only over TCP/IP***

turn off telnet connection

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6- Changing the tape filter

1. stop measures
2. Open head
3. open the Plexiglas cover
4. Advance the remaining filter by manually running the right knob (1)
5. when the filter is totally removed unscrew the right knob and remove the used tape filter from the support
6. Place back right knob on the support
7. unscrew the left knob (2) and insert the new tape filter on the support
8. block the filter screwing back the knob
   insert the tape filter from the left side of the control camera and pass it through, then stop it. use the adhesive tape on the right support
9. close the Plexiglas cover
10. close head
11. advance the filter (forward_reel) to check if the operation was successful

Figure 6.1 shows the correct position of the tape filter inside the instrument

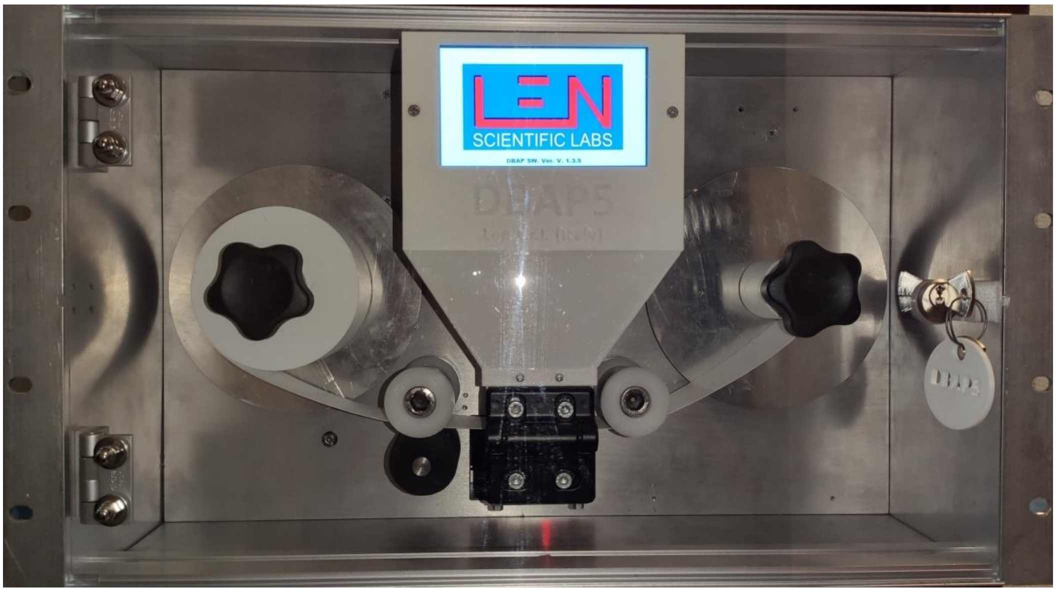

Figure 6.1

APPENDICE A: data format

in the following table is reported the data format obtained in streaming or by using get_last_measures / get_data_measures command.

Parameter	*Unit*	*Parameter*	*Unit*
Date	yyyy-mm-dd	BLUE transmittance	
Time	HH:MM:SS	UV transmittance	
Decimal day (0 = 1st January	days	IR absorption coefficient	m^{-1}
Venturi tub differential pressure	mbar	RED absorption coefficient	m^{-1}
Flow	l/min	GREEN absorption coefficient	m^{-1}
LED temperature	°C	BLUE absorption coefficient	m^{-1}
Air temperature (in Venturi tube)	°C	UV absorption coefficient	m^{-1}
Main-Board temperature	°C	Equivalent Black carbon IR	$\mu g/m^3$
IR transmittance		Ambient pressure	hPa
RED transmittance		Flags	hexadecimal
GREEN transmittance			

APPENDIX C: Electrical and mechanical specification

Electrical

Power supply	220 Vac	Max 0.5A
Power consumption		36 Watt
Mains filter	Arctronics AR3 series	
Protection	2 x fuse (5x20)	2A
Power plug	IEC	
Ethernet	RJ45	10-100 Mbit
RS232	DB9 (3 pin)	57,600 Kbaud

Mechanical

Dimension	19” x 6 Unit	Max 460 x 300 x 270 mm
weight	11 Kg	
Tape filter	width40 mm	type GF10
Air Inlet	D= 6 mm	
Air outlet	D= 6 mm	
Air flow (adjustable)	1 - 5 l/min	
Working temperature	10-30 C°	

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APPENDIX D: Normative

The instrument is harmonized with the following standards

- CE, UL60950-1, EN60950-1
- CEI EN 61010-1
- 2006/95/EC
- 2004/108/CE
- 1990-03-05/4690 /art 3 22012008/37

Intended use: Laboratory equipment for environmental monitoring

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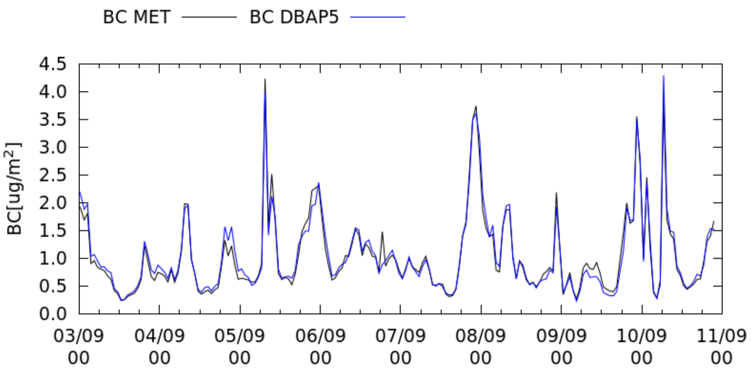
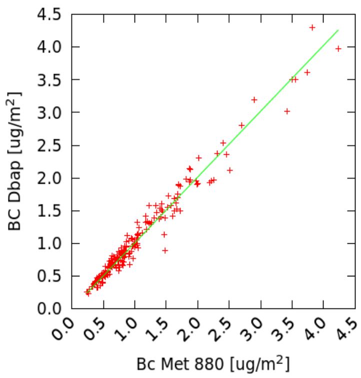
APPENDIX E: Comparison with other instrumentation

The commercial instrument used for the comparison is ARPAE's Metone BC-1054.
The measurements object of the comparison was carried out in the ARPAE supersite at the CNR research area of Bologna in the period from 3/9/2019 to 10/9/2019 inclusive and the data used are the hourly averages of the measurements per minute by the two instruments.
DBAP5 gives K_{ab} at wavelengths of 430, 465, 522, 634, 870 in m-1 and the BC at wavelength of 870 nm in ug / m3; Metone gives the BC value in ug / m3 at wavelengths of 370, 430, 470, 525, 565, 590, 660, 700, 880, 950 nm.

Equivalent Black Carbon

The BC provided by DBAP5 and the BC at 880 nm provided by Metone were compared.
he results obtained are shown in the following graphs, where the linear relationship has a coefficient of 1.006 with an r2 equal to 0.99.





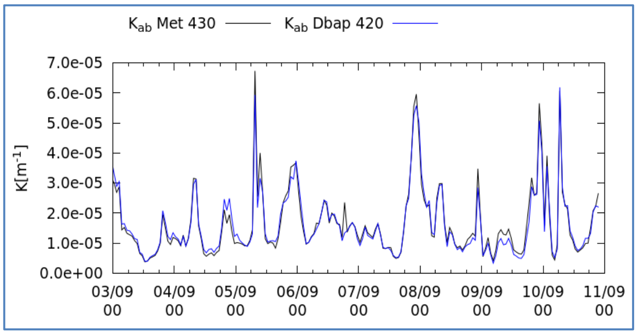
<u>Absorption coefficients (K_{ab})</u>

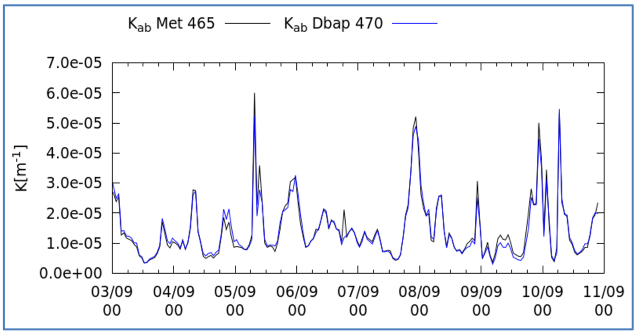
The comparison between the absorption coefficients provided by the two instruments was performed for the following pairs of wavelengths close to each other:

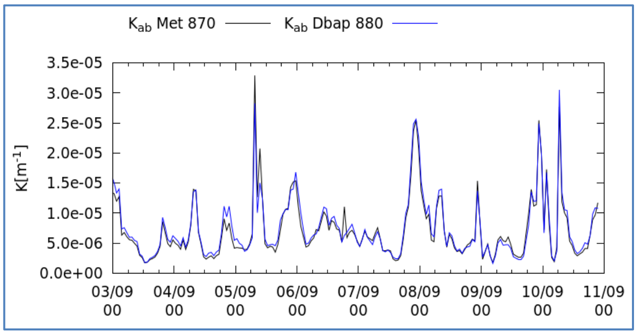
(DBAP, Metone): (420-430); (465-470); (522-525); (870-880).

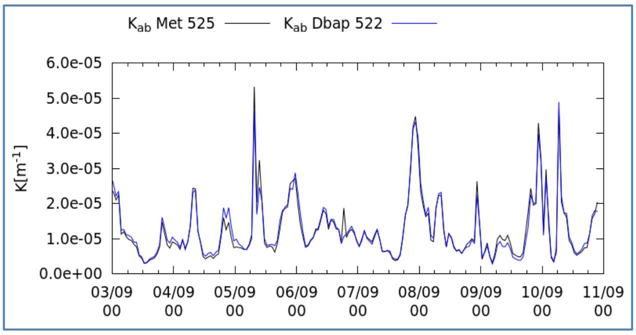
In the following page time series, scatter plot and statistical parameter of the comparison are reported.

K_{ab} Time series

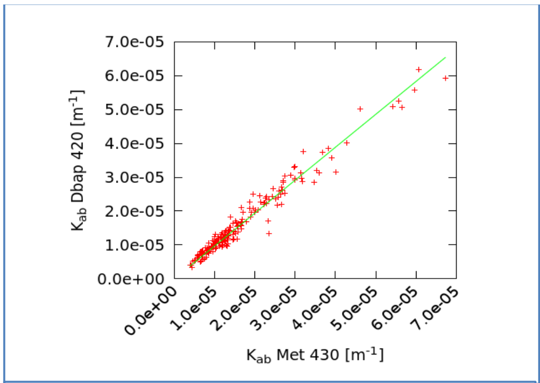


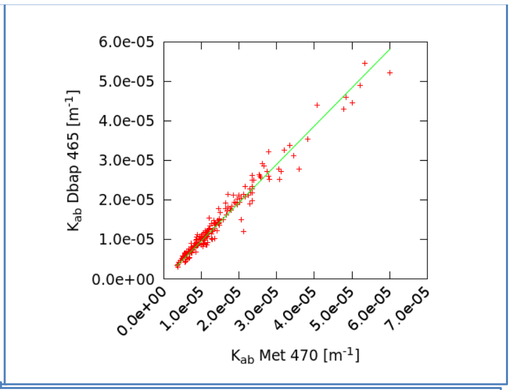


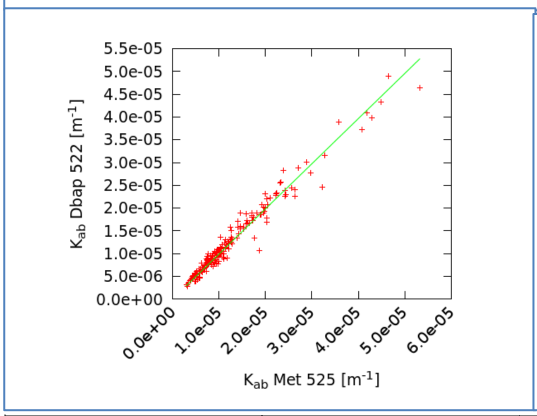


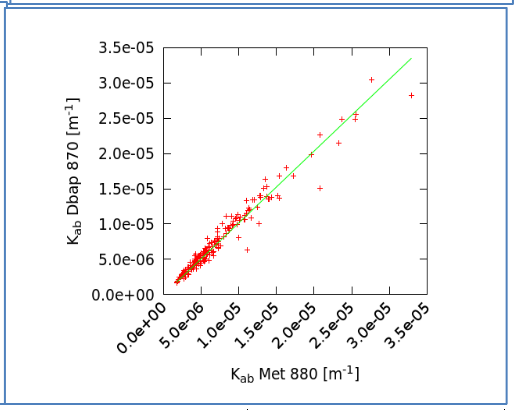


K_{ab} Scatter plot









λ	*420-430*	*465-470*	*522-525*	*870-880*
slope	0.97	0.97	0.99	1.01
r^2	0.99	0.99	0.99	0.99

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