Publishable Summary for 22NRM02 STANBC
Standardisation of Black Carbon aerosol metrics for air quality and climate modelling

Overview

Black carbon (BC) is an air pollutant that contributes to climate forcing, reduced crop yields and impacts on our health. Produced by incomplete combustion of transport and other fossil fuels, air quality networks have been set-up to monitor its mass concentration and legally binding procedures are in place to identify and treat emission sources. Networks measure equivalent Black Carbon (eBC) mass concentrations in real time with light absorption photometers, but traceability is incomplete, uncertainties are poorly understood, and robust documentary standards are lacking. This project will address these needs and via input into normative standards aims to generate greater reliability for measurements of this important air pollutant.

Need

Carbonaceous particles continue to receive high levels of attention from the scientific community and policy makers, because of their role in both climate change and health effects. The dominant sources of Black Carbon have changed over the decades, with modern emissions arising from vehicle combustion emissions, forest fires, wood and biomass burning. Black Carbon has been identified as an important climate-forcing agent, contributing to atmospheric warming due to its much shorter atmospheric lifetime than CO_2. Mitigation strategies for BC could rapidly slow the rate of climate change. Without a reliable measurement infrastructure from the NMI level to field-based measurements supported by underpinning CEN standards upon which legislation can rely, the European vision for a toxic-free environment and climate neutrality will not be put into practice. This project will contribute to the developments of such standards (Objective 4).

The mass concentration of airborne particles loosely described as black carbon has been widely measured by various optical methods since the early 20th century, with hundreds of filter-based optical absorption photometers now installed at European aerosol-monitoring sites due to their portable and robust design. However, these are notorious for their high measurement uncertainties, estimated to be up to 400 % for eBC mass concentration. These uncertainties depend on the aerosol properties at the measurement location. As a result, field measurements at different monitoring sites are often not comparable and it is difficult to extract meaningful long-term data. To overcome these limitations, there is need to determine methods for calibrating filter-based light absorption photometers (Objective 3) using the in-situ reference methods developed in Objective 1 and the parameters for conversion of the optical measurements into mass (Objective 2).

Objectives

The overall objective of the project is to establish a sound measurement framework for both aerosol light absorption coefficient and its conversion to eBC mass concentration, bringing traceability and consistency to both, and consequently making measurements across different air quality monitoring networks in Europe (and worldwide) more accurate and comparable.

The specific objectives of the project are:

1. To develop traceable in situ reference methods for aerosol light absorption coefficient (extinction minus scattering and photo-thermal interferometry) with a robust uncertainty budget estimation as a function of the light wavelength and ambient aerosol properties (e.g, single scattering albedo SSA) suitable for

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The project has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

European Partnership Co-funded by the European Union

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use in generating a calibration chain to instruments used to monitor environmental levels of BC. Target measurement uncertainties for the reference methods are ≤ 10 %. In addition, to provide clear guidelines to end users about the specifications, limitations and application range of each reference method.

2. To determine traceable methods for the measurement of the aerosol mass absorption cross-section with a robust uncertainty budget estimation at various wavelengths based on traceable measurements of light absorption and EC mass. In addition, to establish the relationship between eBC mass, rBC mass and EC mass (EN 16909:2017) via inter-comparisons.
3. To determine methods for calibrating filter-based light absorption photometers using the *in situ* reference methods developed in Objective 1 and a series of well-defined synthetic aerosols generated in the laboratory. The SSA of the synthetic aerosols will span the whole range (from < 0.5 to almost 1) to determine SSA-dependent calibration factors, including multiple scattering factors with the associated measurement uncertainties (target uncertainties are < 15 % for 95 % confidence level).
4. To contribute to the development of a new CEN standard on i) traceable reference methods for determining aerosol light absorption coefficients (i.e. at multiple wavelengths) and ii) materials and methods for calibrating filter-based photometers against the reference method(s). This should include close collaboration with CEN/TC 264, CEN/TC 264/WG 35 and ISO/TC 146/SC 3.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (e.g. accredited laboratories), standards developing organisations (e.g. CEN/TC 264, CEN/TC 264/WG 35 and ISO/TC 146/SC 3) and end users (e.g. national and international climate and air quality monitoring networks, instrument manufacturers), and to disseminate to the wider stakeholder community via the European Metrology Network (EMN) for Climate and Ocean Observation, EMN Pollution Monitoring and national and European air quality monitoring networks (e.g. ACTRIS, EMEP, GUAN, NABEL, UK Black Carbon Network, Atmo-France, FMIODATA) and instrument manufacturers.

Progress beyond the state of the art and results

The current state-of-the-art is that black carbon measurements are being widely made based on a principle that has been used for many decades, with one of several designs of filter-based instrument, such as multi angle absorption photometers (MAAP), aethalometers and other particle absorption photometers. These instruments do not measure BC mass concentration directly; they determine light attenuation as it passes through the filter with the sample, convert it to the absorption coefficient based on several assumptions, and calculate the so-called equivalent BC (eBC) mass concentration with the use of a fixed MAC value.

Due to recent developments within the EMPIR 16ENV02 Black Carbon (2017-2020) and other EU projects, there are now traceable techniques that measure aerosol light absorption while the particles are airborne, and these of course are not complicated by the effects of filter-based measurements. Studies are clarifying the corrections needed to obtain accurate aerosol absorption coefficients and eBC mass concentration from filter-based instruments by inter-comparisons with reference methods, but further work is needed. The corrections can be made more valuable by including more detailed information on the particles (e.g. light scattering properties, particle size etc.).

The technical results that are expected from this project are as follows:

<u>Objective 1. Standardisation of traceable, primary methods for determining aerosol light absorption coefficients at multiple wavelengths of the light source</u>

Traceable calibration procedures based on absorbing gas NO_2 and nigrosin particles were developed. NO_2 calibration uses a mobile permeation source to produce NO_2 with the precise amount fraction in the carrier gas traceably to primary standards. Gas absorption is calculated from the overlap of high resolution NO_2 absorption spectrum with the emission spectrum of light used for the measurement. Calibration with nigrosin particles is based on known refractive index and the selected size of monodisperse particles. Particle size selection using centrifugal particle mass analyser and electrostatic classifier in series is proposed. Mie calculation is then performed using mass equivalent diameter and measured particle number concentration to produce absorption coefficient at the desired wavelength. Nigrosin enables calibration in the whole visible and near infrared spectrum while NO_2 calibration is limited to the visible part. Both calibration methods agree better than 10%.

Transfer of calibration from primary to secondary standard is performed using nebulized CAB-O-JET200 because of its monotone spectral dependence of absorption.

Objective 2. Standardisation of methods for the determination of the aerosol mass absorption cross-section (MAC)

MAC is not a constant but depends on various BC aerosol properties. The dependency of MAC on particle size and aerosol mixing state was systematically investigated in the laboratory using different core sizes of miniCAST generated soot particles coated with organics. Various methods for measuring the light absorption coefficient (extinction minus scattering, filter-based light absorption, photothermal interferometry, photoacoustic method) and various methods for determining the carbon mass (thermography method, incandescent light method) were applied. For coated soot particles, the total mass and the organic mass were measured in addition to the coating thickness from SP2. The dependency of MAC values on aerosol characteristics was compared with the Mie-model successfully. The results will provide a unique set of MAC values that can be used to convert aerosol light absorption reported by filter-based absorption photometers into eBC mass concentration – an important step for using BC mass concentrations in the context of air quality.

Objective 3. Protocol for the lab-based calibration of filter-based absorption photometers

Calibration of filter-based absorption photometers has only been performed for a small subset of relevant aerosols (i.e. aerosols with low SSA) and is not yet standardised. The calibration procedure will be extended to include more environmentally relevant reference aerosols, covering the whole aerosol SSA range (i.e. from almost 0 up to about 1). This step is important to enable traceable measurements at monitoring stations in completely different environments, spanning from highways in urban agglomerations to the remote Antarctic. The consortium has been working on the preparation of a measurement campaign to take place at METAS in May-June 2024, where different test aerosol mixtures will be used, including bare soot particles and three different aged aerosols, prepared by mixing soot particles with secondary organic and inorganic aerosols.

Objective 4. New CEN TC 264 standard

Currently, no normative standard exists on BC-related metrics. The consortium will initiate a new Working Group (or Subgroup of WG 35) within CEN TC 264 dedicated to the standardisation of aerosol light absorption and eBC mass concentration. The results of this project will feed directly into the new standard, so completing the required measurement infrastructure to support the (NEC) Directive (2016/2284/EU) and the revision of the Air Quality Directive from 2008. A project survey has been done to identify potential stakeholders. A stakeholder questionnaire about metrology needs for black carbon determination is being prepared and will be circulated among the stakeholder community.

Outcomes and impact

The project's outputs have been presented in different conferences including the following:

- European Aerosol Conference 2023.
- 13th ICCPA International Conference on Carbonaceous Particles in the Atmosphere

Consortium members have participated in standardisation committee meetings including the following:

- ISO TC24 SC4 Particle characterisation
- Slovenian Institute for Standardization meeting

The issues of climate change and air pollution are truly international. Per unit of mass, black carbon has a warming impact on climate that is 460-1500 times stronger than that of CO_2, which makes its monitoring and mitigation important for early reductions in current global warming predictions. The breadth and depth of the challenges that need to be overcome to provide traceability for BC-related optical and mass concentration measurements require an extensive range of expertise. The scope of this project is therefore beyond the capabilities of a single NMI and a pan-European approach is essential in order to deliver the work.

Normative projects tackling global challenges, such as pollution and its detrimental effects on public health, must achieve wide consensus in order to harmonise procedures in Europe (and worldwide). They rely therefore by nature on the close collaboration between countries and the will to align national regulations. The EPM programme, bringing together NMIs, research institutes, instruments manufacturers and experts from air quality monitoring networks across Europe, is the ideal platform for the work described in this project.

Outcomes for industrial and other user communities

The EMPIR 16ENV02 Black Carbon and 18HLT02 AeroTox projects have greatly contributed to the development and characterisation of novel aerosol instruments (including a soot generator, the oxidation flow reactor known as OCU, and the photo-thermal interferometer PTAAM-2λ). All these are manufactured in Europe and will be employed in the calibration procedure for filter-based absorption photometers either as reference aerosol sources or as reference measurement methods. Moreover, several manufacturers of filter-based absorption photometers are based in the EU. This project will enhance the end users' confidence in these instruments through standardisation, promote sales and help European manufacturers assume a leading role in the global market.

Outcomes for the metrology and scientific communities

The direct impact of the proposed research will be more accurate and more comparable measurements of aerosol light-absorption coefficient and better estimates of eBC mass concentration than in the current status of the widespread aerosol monitoring networks in Europe, through the standardisation of traceable methods for calibrating filter-based absorption photometers.

Indirectly, the impact would be very widespread. In terms of scientific benefits, the improved measurements would fit into EU atmospheric aerosol projects, refining climate change models, and improving the quality of conclusions from cohort health studies looking at the health effects of air pollution. Air quality measures to reduce human exposure to BC such as emission reduction and low emission zones have already been taken.

However, traceable BC-related metrics to reliably quantify the success of these measures are not yet available. The results of this project will feed directly into national air quality monitoring networks across Europe. The improved measurement accuracy will also help set up reliable black carbon emission inventories.

Outcomes for relevant standards

Currently, there are no legislated limits for BC for outdoor air concentrations, only the total mass of fine particles is regulated. This is partly due to the fact that there is no well-defined metric for BC mass concentration in ambient air. Ultimately, the project will provide a CEN standard on BC-related metrics and form the basis for future European legislation.

Longer-term economic, social and environmental impacts

According to WHO "…air pollution imposes a large economic cost on the countries of the WHO European Region. As at 2010, the annual cost of premature deaths from air pollution across the countries of the WHO European Region stood at EUR 1.4 trillion, and the overall annual cost of health impacts from air pollution stood at EUR 1.6 trillion". Thus, even a small decrease in health effects from air pollution would lead to substantial economic benefits.

Moreover, the effects of climate change can be expected to reduce the global economic output by 2050 for 11 % to 14 % compared with growth levels without climate change. That amounts to as much as EUR 23 trillion in reduced annual global economic output worldwide as a result of global warming. Though long-term warming is dominated by CO_2, the reduction of short-lived climate forcers, such as black carbon, can contribute significantly to limiting warming to 1.5 °C above pre-industrial levels. Unlike CO2, which can stay in the atmosphere for hundreds of years, black carbon only remains there for up to two weeks. This means that efforts to reduce it would bring "immediate benefits" for the climate (and human health), according to the Climate & Clean Air Coalition, a United Nations initiative. Mitigating the results of climate change through BC reduction could lead to economic benefits in the order of billions of Euros.

List of publications

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This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

Project start date and duration:		1 June 2023, 36 months
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Chief Stakeholder Organisation: JRC		Chief Stakeholder Contact: Jean-Philippe Putaud
Internal Beneficiaries: 1. PTB, Germany 2. FMI, Finland 3. JSI, Slovenia 4. LNE, France	External Beneficiaries: 5. Haze, Slovenia 6. NCSR Demokritos, Greece 7. TROPOS, Germany	Unfunded Beneficiaries: -
Associated Partners: 8. FHNW, Switzerland 9. METAS, Switzerland 10. NPL, UK 11. NRC, Canada		