Publishable Summary for 16ENV02 Black Carbon
Metrology for light absorption by atmospheric aerosols

Overview

The measurement of particles in the air characterised as black carbon is important both for their role in climate change and as a measure of combustion products associated with health effects. Measurements are made very widely, and compact, precise, real-time, relatively inexpensive instruments are available. Although it is conceptually a simple measure of the light absorbing properties of airborne particles, the metric does not currently have SI traceability, with consequences for the comparability and interpretation of data. The project will provide a workable solution to this major problem, with widespread benefits across climate change and air quality issues.

Need

The quantity of airborne particles loosely described as black carbon has been widely measured by various optical methods since the early 20th century, because instruments for this are relatively simple and reliable. The dominant sources have changed over the decades, from domestic and industrial coal burning to vehicle combustion emissions, with more recent contributions from wood-burning.

Black carbon has been identified as the second most important climate forcing agent behind CO_2, contributing an amount of radiative forcing nearly 30 % that of current CO_2 concentrations. Airborne particles have serious human health effects across Europe and worldwide. In 2011, about 430,000 premature deaths in the EU were attributed to fine particulate matter (PM). Studies suggest that black carbon is a better indicator of harmful particulate substances from combustion sources than PM mass concentration.

Although black carbon measurement is in principle a simple optical measurement of absorption, characterised by the aerosol light absorption coefficient, traceability is hampered by the fact that routine monitors determine the absorption of particulate matter collected on a fibrous filter. While the optical absorption measurement itself can be done accurately, the presence of the filter has a large effect, due to internal scattering within the filter, which can increase absorption by a factor of five, shadowing effects as the filter accumulates material. Empirical but non-traceable correction factors are then incorporated into the conversion from light absorption coefficient into the reported particle mass concentration; these correction factors need to be replaced with properly determined calibration factors in order to standardise the measurement results and ensure confidence and comparability in the field.

Objectives

The overriding objective of the project is, for the first time, to bring SI traceability to field of black carbon measurements, so that their accuracy and value is greatly increased. The specific objectives are:

1. To establish a set of well-defined physical parameters, such as aerosol light absorption coefficients and mass absorption coefficients, which together can be used to quantify black carbon mass concentrations with traceability to primary standards.
2. To develop and characterise black carbon standard reference materials (SRMs), representative of atmospheric aerosols, together with methods for using them to calibrate field black carbon monitors.
3. To develop a traceable, primary method for determining aerosol absorption coefficients at specific wavelengths that are to be defined for the benefit of users. The method should have defined uncertainties and a quantified lowest detection limit.
4. To develop a validated transfer standard for the traceable calibration of established absorption photometers such as multi angle absorption photometers, aethalometers and particle absorption photometers. The transfer standard should make use of the black carbon SRMs (developed in objective 2) and associated portable instrumentation characterised by the primary method (from objective 3).

5. To facilitate the take-up of the technology and measurement infrastructure developed in the project by standards developing organisations (CEN, ISO) and end users (e.g. Environmental Protection Agency (EPA), European Environment Agency (EEA), World Meteorological Organisation-Global Atmosphere Watch (WMO-GAW), the ACTRIS (Aerosols, Clouds, and Trace gases Research InfraStructure Network) Project).

Progress beyond the state of the art

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, aethalometers and particle absorption photometers. However, robust calibration techniques and traceability to the SI for these instruments are outstanding issues, such that results from different types of instrument can disagree by up to 30 %. This project will provide reference aerosols for the calibration of those filter-based techniques and will put traceability and calibration mechanisms in place for the first time, enabling the measurement of black carbon with a target uncertainty of ±10 % (95 % confidence level).

One important element of progress has been the realisation that the original strategy of developing a "near-black carbon source" would not be a viable approach. This is because filter-based instruments need corrections that depend on both particle size and the mixture of optical properties in the aerosol particles, neither of which are determined directly. Consequently, an instrument "corrected" to provide accurate measurements of the near-black calibration aerosol would be unlikely to give accurate measurements of ambient air, because the size and optical properties of the particles in ambient air would be different to the calibration particles. This problem will be avoided by developing two distinct categories of calibration aerosol, with similar size and optical properties to distinct types of ambient aerosol.

Results

1. Physical Parameters for traceable quantification of black carbon mass concentrations

The physical properties of aerosols (and the particles within them) that are relevant to black carbon measurements have been clearly defined, in a way that clarifies how traceability to the SI can be established. A key point in this context is that, because the presence of a filter affects the measured extinction in at least two distinct ways, it is necessary to calibrate filter-based instruments with at least two types of aerosol, with contrasting physical properties. This will prevent the calibration of an instrument in a way that is correct only for aerosol particles with a specific set of properties.

2. Black carbon Standard Reference Materials

Standard Reference Materials, together with a method for their controlled introduction to black carbon instruments in the lab and in the field, are being developed and tested. The required properties of these two Materials have been defined, specifically (1) "fresh combustion particles" with size 50 – 100 nm and Single Scattering Albedo (SSA) 0.05 – 0.2 at 550 nm, and (2) "aged combustion particles" with size 200 – 400 nm and SSA 0.7 – 0.9 at 550 nm. Several methods for generating them have been characterised at TROPOS and at METAS. A new type of premixed flame combustion generator, which provides soot particle with stable EC/OC content independent from the soot particle size, has been found suitable for producing "fresh" aerosol, along with other variations and techniques. The new soot generator combined with a micro-smog chamber to coat soot particles with organic material has been found suitable for generating an "aged" aerosol. A peer-reviewed paper is published.

3. A traceable, primary method for determining aerosol absorption coefficients

A preferred laboratory-based, SI-traceable, well-characterised method for determining aerosol absorption coefficients at specific wavelengths will be designed and published. This is being selected from options including established techniques such as extinction minus scattering and more novel techniques such as photothermal interferometry. Several refinements to the methods have been made, for example to the baseline correction for extinction measurements and to the design of photothermal interferometry instruments, with several publications in progress. The chosen method will be suitable both for calibrating instruments in the laboratory, and for certifying the properties of the Standard Reference Materials of Objective 2. Improved uncertainty budgets are being prepared for the primary methods.

4. A validated transfer standard for calibration of field absorption photometers

A practical and validated protocol for calibrating field black carbon instruments will be developed, incorporating portable Standard Reference Material sources, if possible, otherwise, a procedure for calibrating field instruments in the laboratory using these sources rather than more expensive primary methods. A substantial field comparison of black carbon instruments was carried out in Palls, Finland in June/July 2019, at low concentrations. A second field trial is taking place in Athens, Greece in November 2019 – January 2020, to investigate higher concentrations.

Impact

Impact activities to date include establishing a Stakeholder Committee; presentations to relevant standardisation and metrological committees, and scientific conferences, including the ETH Conference on combustion generated nanoparticles, the European Aerosol Conference and the International Aerosol Conference; training to 15 groups of people provided at TROPOS; and a peer-reviewed paper (see below), with several more in preparation.

The results so far achieved in the project are adequately and appropriately communicated to the stakeholders and end-user community of EC Directives and European standardisation activities such as CEN and BIPM (CIPM). Input and feedback is ongoing from this community to improve the project impact and its outcomes.

During the course of the project the consortium have run a regular series of intercomparison and training workshops. Further to this, an Integrating nephelometer intercomparison workshop has been held which also included training.

Impact on industrial and other user communities

In commercial terms the project will give a direct advantage to European black carbon instrument manufacturers, who will have early access to traceable calibration facilities for their current instruments, and who will also make use of the facilities to develop innovative designs much more quickly than would otherwise be the case. It will also offer a great advantage to European manufacturers of aerosol generators of the type that will be developed within the project. End users would include government, environmental and citizen monitoring groups, who all employ black carbon measurement devices.

Impact on the metrology and scientific communities

The simplest direct impact of the research will be that measurements of black carbon become more accurate and more comparable in the aerosol monitoring networks across Europe, through the development of reference materials for black carbon, primary national facilities and traceable calibration mechanisms.

Impact on relevant standards

The project outputs are expected to provide the basis for new documentary standards for monitoring black carbon by European and International standards-developing organisations like CEN and ISO. No such standards currently exist.

Longer-term economic, social and environmental impacts

In terms of socio-economic benefits, the project outputs will potentially lead to revised air quality legislation, based on black carbon, for which reliable measurement methods would be available.

Indirectly, the impact will be very widespread. In terms of scientific benefits, the improved measurements will be used directly within EU atmospheric aerosol projects, refining climate change models and mitigation proposals, and improving the quality of conclusions from cohort health studies looking at the effects of air pollution. Air quality measures to reduce black carbon emissions such as emission reduction and low emission zones have already been taken. However, traceable black carbon metrics to reliably quantify the success of these measures are not yet available, and will be addressed by this project.

List of publications

Michaela N. Ess & Konstantina Vasilatou (2019) Characterization of a new miniCAST with diffusion flame and premixed flame options: Generation of particles with high EC content in the size range 30 nm to 200 nm, Aerosol Science and Technology, 53:1, 29-44, DOI:10.1080/02786826.2018.1536818 https://www.tandfonline.com/doi/full/10.1080/02786826.2018.1536818

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Project start date and duration:	01 July 2017, 36 months	
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Internal Funded Partners: 1 NPL, United Kingdom 2 IL, Finland 3 LNE, France 4 PTB, Germany	External Funded Partners: 5 NCSR Demokritos, Greece 6 TROPOS, Germany	Unfunded Partners: 7 FHNW, Switzerland 8 METAS, Switzerland 9 PSI, Switzerland