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

Overview

The measurement of particles in 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 the worlds of both climate change and air quality.

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, and to 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 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).

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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 different types of instrument can give results differing 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 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, because filter-based instruments need corrections that depend on both particle size and the mixture of optical properties in the aerosol particles, so that an instrument corrected to give accurate measurements of the near-black aerosol would be unlikely to give accurate measurements of ambient air. 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 two distinct ways, it is necessary to calibrate filter-based instruments with at least two types of aerosol, with contrasting physical properties.

*2. Black carbon Standard Reference Material*s

Standard Reference Materials, together with a method for their controlled introduction to black carbon instruments 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 explored. A combination of a new type of premixed flame combustion generator, which provides soot particle with stable EC/OC content independent from the soot particle size to make “fresh” aerosol, combined with a micro-smog chamber to coat soot particles with organic material and thus generate an “aged” aerosol, appears to be a promising approach. A peer-reviewed paper is available.

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

A preferred lab-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. 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, or, if not, a procedure for calibrating field instruments in the laboratory using these sources rather than more expensive primary methods. This will be tested in a series of European field trials across a range of ambient concentrations, typically up to 50 Mm^{-1}, to assess the impact of field conditions on instrument accuracy.

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 and the International Aerosol Conference; training to 6 groups of people provided at TROPOS; and a peer-reviewed paper (see below), with several more in preparation.

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 will be 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 than is currently the case 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 output is 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 output 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

Project start date and duration:		01 July 2017, 36 months
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