



Recommendations
for the interpretation
of “black carbon”
measurements

A. Petzold et al.

This discussion paper is/has been under review for the journal Atmospheric Chemistry and Physics (ACP). Please refer to the corresponding final paper in ACP if available.

Recommendations for the interpretation of “black carbon” measurements

A. Petzold¹, J. A. Ogren², M. Fiebig³, P. Laj⁴, S.-M. Li⁵, U. Baltensperger⁶,
T. Holzer-Popp⁷, S. Kinne⁸, G. Pappalardo⁹, N. Sugimoto¹⁰, C. Wehrli¹¹,
A. Wiedensohler¹², and X.-Y. Zhang¹³

¹Forschungszentrum Jülich GmbH, Institut für Energie- und Klimaforschung IEK-8, 52425 Jülich, Germany

²NOAA/ESRL Global Monitoring Division, Boulder, CO 80305, USA

³Norwegian Institute for Air Research (NILU), 2027 Kjeller, Norway

⁴Laboratoire de Glaciologie et Géophysique de l'Environnement, Université de Grenoble I – CNRS, 38402 – Saint Martin d'Hères cedex, France

⁵Environment Canada, Processes Research Section, Toronto, ON M3H 5T4, Canada

⁶Laboratory of Atmospheric Chemistry, Paul Scherrer Institute, 5232 Villigen PSI, Switzerland

⁷Deutsches Fernerkundungsdatenzentrum, DLR, 82234 Oberpfaffenhofen, Germany

⁸Max Planck Institute for Meteorology, Bundesstrasse 53, 20146 Hamburg, Germany

⁹Istituto di Metodologie per l'Analisi Ambientale (CNR-IMAA), Potenza, 85050, Italy

¹⁰National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan

¹¹Physikalisch-Meteorologisches Observatorium Davos (PMOD/WRC), 7260 Davos, Switzerland

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



¹²Leibniz Institute for Tropospheric Research, Permoserstr. 15, 04318 Leipzig, Germany

¹³Chinese Academy of Meteorological Sciences, 46 Zhong-Guan-Cun S. Av., Beijing 100081, China

Received: 3 March 2013 – Accepted: 23 March 2013 – Published: 11 April 2013

Correspondence to: A. Petzold (a.petzold@fz-juelich.de)

Published by Copernicus Publications on behalf of the European Geosciences Union.

**Recommendations
for the interpretation
of “black carbon”
measurements**

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Abstract

Although black carbon (BC) is one of the key atmospheric particulate components driving climate change and air quality, there is no agreement on the terminology that considers all aspects of specific properties, definitions, measurement methods, and related uncertainties. As a result, there is much ambiguity in the scientific literature of measurements and numerical models that refer to BC with different names and based on different properties of the particles, with no clear definition of the terms. The authors present here a recommended terminology to clarify the terms used for BC in atmospheric research, with the goal of establishing unambiguous links between terms, targeted material properties and associated measurement techniques.

1 Introduction

Within the discussion of global climate change, the international community recognized the importance of establishing inventories for sources and sinks of particulate, light absorbing carbon (UNEP/WMO, 2011; Bond et al., 2013). One of the major contributors to the carbon cycle is combustion of fossil fuel and biomass, with carbonaceous particulate matter being one of the most important combustion by-products besides CO₂. One fraction of the carbonaceous aerosol, commonly called black carbon (BC), is characterized by its strong absorption of visible light and by its resistance to chemical transformation (Ogren and Charlson, 1983; Goldberg, 1985; Heintzenberg and Winkler, 1991). These distinct properties give it relevance in various fields related to climate change, air chemistry, ambient air quality, biogeochemistry, and paleoclimatology.

The BC fraction of the carbonaceous aerosol has been included in the Strategic Plan of the Global Atmosphere Watch program (GAW) of the World Meteorological Organization (WMO) (Müller et al., 2007). It has also become one of the key targets for current research on the aerosol impact on climate and also on mitigation strategies. Relative to the long-lived greenhouse gases (particularly CO₂ and CH₄), the light-absorbing

ACPD

13, 9485–9517, 2013

Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

carbonaceous aerosol is referred to as a short-lived climate forcer and its emission control policies are being contemplated as one near-term mitigation strategy for the climate impacts of anthropogenic emissions; see e.g. the integrated assessment of black carbon and tropospheric ozone by UNEP/WMO (2011).

Despite its high relevance for climate change research (Ramanathan and Carmichael, 2008; Bond et al., 2013), there is no agreed clear and unambiguous terminology available for quantifying carbonaceous matter in atmospheric aerosols. In the end, all definitions used in the scientific literature refer to a specific property of the respective carbonaceous fraction, or to the method that is used for the measurement. As there is no consensus within the community for using a specific definition for a particular measuring technique, there are numerous publications in the scientific literature that refer to the same property but with different terms and, vice-versa, with publications referring to different properties but with similar names. To a minor extent, the same is true also for modeling exercises where different terms are used, not always in relation to properties that can be derived from direct measurements.

While data on light-absorbing carbonaceous aerosols are collected globally by different measurement techniques, global emission inventories and modeling studies (e.g., Bond et al., 2007; Junker and Liousse, 2008; Vignati et al., 2010; Granier et al., 2011; Lee et al., 2012), as well as scientific assessments (Solomon et al., 2007; Bond et al., 2013), require data sets that are independent of the measurement method. It is difficult to clearly distinguish these terminologies in atmospheric chemistry and climate model applications.

In particular, BC emission inventories are to a large extent based on emission factors derived using thermal methods based on the detection of evolved carbon, while data from atmospheric monitoring stations are mostly derived from optical absorption methods. Consequently, Vignati et al. (2010) investigated the sources of uncertainties in modeling BC at the global scale and requested an increased understanding of observational data and associated uncertainties. However, the uncertainties are difficult to establish because the reasons for the large discrepancies between methods are often

Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

not fully understood and are to a large extent dependent upon season and location of sampling and type of aerosol.

This publication proposes a definition of terms and recommendations for interpreting measurements of “black carbon”, “elemental carbon”, “light absorption”, “refractory carbon” and other properties related to this distinct fraction of the carbonaceous aerosol. We start with a formal definition of black carbon and elemental carbon including the constituting properties of BC. An overview of available analytical methods will prepare the ground for a synopsis of historical and current operational definitions. Finally, the terminology recommended for future use is presented based on targeted particle properties. It will link considered properties to associated analytical methods in an unambiguous manner. These recommendations are a result of discussions carried out in the context of the Scientific Advisory Group for Aerosols of the WMO GAW program. However, the authors express their own views and do not act on behalf of, or commit, their institutions, ministries or WMO.

2 Definition of black carbon

From a formal standpoint and without referring to measurement methods or formation processes (Schwartz and Lewis, 2012), the technical term “black” describes ideally a completely light-absorbing object with reflectivity of zero, an absorptivity of unity and an emissivity of unity, although an object with an absorptivity of 0.95 would still be considered “black”. The term “carbon” refers to the sixth element of the periodic system while “elemental carbon” is used to denote carbon that is not bonded to other elements. Combining these formal views provides a strict definition of the terms “black carbon” and “elemental carbon”:

- Black carbon (BC) is carbon that is black. The formation process is excluded from this definition because of the variety of potential processes. While BC is mostly formed in incomplete combustion, it can be a product of pyrolysis of carbonaceous matter, i.e. the change of the chemical structure of carbonaceous

Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

compounds from loss of hydrogen and/or oxygen atoms at temperatures above approx. 250 °C (Chow et al., 2004), of dehydration of sugar, or of heating of wood under an oxygen-free atmosphere (Schwartz and Lewis, 2012). This fundamental definition of BC as carbon that is black agrees with the operationally-based definition by Moosmüller et al. (2009) who defined BC as “carbonaceous material with a deep black appearance, which is caused by a significant, non-zero imaginary part ... of the refractive index that is wavelength independent over the visible and near-visible spectral regions”.

- Elemental carbon (EC) is formally defined as a “substance containing only carbon, carbon that is not bound to other elements, but which may be present in one or more of multiple allotropic forms” (Schwartz and Lewis, 2012). Examples of elemental carbon are diamond, carbon nanotubes, graphite or fullerenes.

Hence, the formal terms “black carbon” and “elemental carbon” refer to a set of materials with different optical and physical properties instead of a given material with well-defined properties.

Unfortunately, these strict definitions are not particularly useful in practice, because carbonaceous matter appears in atmospheric aerosols under no circumstances as pure matter. Instead, it occurs as a highly variable mixture of different carbonaceous compounds with different material properties.

A more useful definition of BC takes into account the various properties of the particles that make them so relevant to climate change, air chemistry, ambient air quality, biogeochemistry, and paleoclimatology. These properties, compiled in Table 1, control the effects of the particles, as well as their atmospheric removal processes and hence spatial distributions. It is the combination of these properties that leads to the classification of BC as a unique substance, but unfortunately, none of the currently-available measurement methods quantifies all five of those properties simultaneously.

3 Analytical methods

The terms used to identify the various fractions of carbonaceous aerosol are primarily associated with the corresponding measurement methods (Andreae and Gelencsér, 2006; Bond and Bergstrom, 2006; Kondo et al., 2011; Buseck et al., 2012). Commonly, the terms “black carbon”, “soot”, “elemental carbon”, “equivalent black carbon” and “refractory black carbon” synonymously refer to the most refractory and light-absorbing component of carbonaceous combustion particles, even though the underlying definitions and measurement methods are different. Historical definitions and those used in the current literature will be summarized in Sect. 4, whereas this section introduces the families of available analytical methods.

3.1 Evolved carbon

Most common carbon-specific methods consist of combined thermal and gas-analytical approaches based on the analysis of gasification products evolving from a heated filter sample (Malissa et al., 1976; Puxbaum, 1979; Novakov, 1984). These methods make use of the thermal resistivity of the “elemental carbon” fraction of carbonaceous matter, which does not volatilize in an inert atmosphere at temperatures as high as 4000 K. It can only be gasified by oxidation starting at temperatures above 340 °C (Cachier et al., 1989; Jennings et al., 1994). The carbon contained in the analyzed aerosol sample is detected as CO₂ by non-dispersive infrared absorption or other CO₂ specific detection methods.

Currently, different analytical protocols are in use, e.g. IMPROVE (Chow et al., 1993), IMPROVE_A, NIOSH (Peterson and Richards, 2002; Chow et al., 2007a), and EUSAAR-2 (Cavalli et al., 2010). A recent review of evolved carbon methods is given by Chow et al. (2007b). The analytical protocol, however, is an essential part of the data and must be documented in metadata of the databases.

While evolved carbon methods agree within < 10 % (Schmid et al., 2001) or 0.22 (±0.12) μg m⁻³ (ten Brink et al., 2004), respectively, in determining the total mass

Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



concentration of particulate carbonaceous material, the selectivity of separating “elemental carbon” from the bulk of carbonaceous matter varies strongly with the analytical protocol (Schmid et al., 2001; Cavalli et al., 2010; Chow et al., 2011; Pio et al., 2011) and with impurities that may strongly modify the oxidation behavior of the carbonaceous fraction (Schmid et al., 2011). It has also to be mentioned that a correction for pyrolysis or charring, respectively, of carbonaceous matter, i.e. for the transformation of any carbonaceous matter into EC during the analytical process, is required depending on the analytical technique used (Huntzicker et al., 1982; Chow et al., 1993, 2004; Petzold and Niessner, 1995; Boparai et al., 2008).

3.2 Light absorption

The volumetric cross-section for light absorption, commonly called the light absorption coefficient (σ_{ap}), is the principal measure of any optical technique for measuring light-absorbing particles. It is typically reported with units of $m^2 m^{-3}$, i.e., m^{-1} , or Mm^{-1} , where $1 Mm^{-1} = 10^{-6} m^{-1}$. There is no overall agreed reference method for measurement of the aerosol light absorption coefficient, because all available methods suffer from cross-sensitivity to light-scattering particles and other potential measurement artifacts. However, photoacoustic spectroscopy is a candidate reference method for atmospheric observations and analytical applications (Arnott et al., 2003), while in the laboratory the measurement of light extinction minus light scattering may offer another possibility (Schnaiter et al., 2005b; Sheridan et al., 2005). An in-depth review of light absorption measurement methods is provided by Moosmüller et al. (2009).

The conversion of aerosol light absorption coefficient into light-absorbing carbon mass concentration [BC] is based on the relationship $[BC] = \sigma_{ap} \times MAC^{-1}$. It therefore requires precise knowledge of the mass-specific absorption coefficient (MAC) often reported in units of $m^2 g^{-1}$. This coefficient, however, varies significantly from time and space depending upon source emissions, transformation during transport, etc. (Bond and Bergstrom, 2006; Chan et al., 2011).

Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

As long as particles are fractal-like agglomerates with diameters D_{ps} of primary spherules falling into the Rayleigh regime, i.e., $D_{ps} \ll \lambda$, the MAC value of primary spheres is independent of D_{ps} , because for fractal-like aggregates particle absorption depends on the size of the primary spherules and not on the size of the aggregates (Berry and Percival, 1986; Petzold et al., 1997). If this condition is not met, then the MAC of the individual particles may depend on their sizes and the MAC of an aerosol composed of such particles will depend on the size distribution of those particles.

The application of this conversion also assumes that BC is the only light-absorbing particulate species present. Contributions to absorption from non-carbonaceous light-absorbing aerosol components like mineral dust (see e.g. Petzold et al. 2009, 2011), or by non-BC light absorbing carbonaceous matter (= brown carbon; see Andreae and Gelencsér (2006) and next section for a definition) must be excluded or corrected.

The most promising method for excluding measurement artifacts by non-BC light absorbing species is based on the spectral dependence of light absorption properties for different aerosol compounds, which is characterized by the absorption Ångström exponent $\hat{a}_{ap} = -\ln(\sigma_{ap}(\lambda_1)/\sigma_{ap}(\lambda_2))/\ln(\lambda_1/\lambda_2)$ for a certain wavelength interval $[\lambda_1, \lambda_2]$. While BC is characterized by a low value of \hat{a}_{ap} between 1.0 and approx. 1.5 (Kirchstetter et al., 2004; Schnaiter et al., 2006; Kim et al., 2012), organic carbon containing aerosol may show strong light absorption in the blue to ultraviolet spectral range (Kirchstetter et al., 2004; Graber and Rudich, 2006; Adler et al., 2010; Kim et al., 2012) associated with \hat{a}_{ap} values as high as 7 and beyond for the visible range (Chen and Bond, 2010). Mineral dust as another important light absorbing aerosol compound is characterized by strong absorption in the blue and green visible range and low absorption in the red spectral range which results in \hat{a}_{ap} values of 3 and larger at visible wavelengths (Petzold et al., 2009). Summarizing, over-determination of light absorption associated with BC by non-BC light-absorbing aerosol compounds can be minimized by choosing a wavelength in the red spectral region ($\lambda > 600$ nm) where cross-sensitivities to mineral dust and organic carbon compounds are lowest.

Furthermore, absorption enhancement by coated particles (Schnaiter et al., 2005a; Lack et al., 2009a; Lack and Cappa, 2010) and by relative humidity effects (Arnott et al., 2003; Lack et al., 2009b) has to be considered in the data analysis.

Another challenge for applying this conversion is the absence of an overall agreed reference material which links light absorption to BC mass concentration. Instead, different methods use different reference materials; see Baumgardner et al. (2012) for a state-of-the-art overview. From a large number of method intercomparison studies on chemical and optical methods in the past decade (e.g., Schmid et al., 2001; ten Brink et al., 2004; Hitzenberger et al., 2006; Park et al., 2006; Reisinger et al., 2008; Chow et al., 2009; Cavalli et al., 2010; Kondo et al., 2011), we know that mass concentrations of BC derived from chemical methods and those derived from optical methods may differ substantially, by up to a factor of 7, even though BC mass concentrations determined by both types of methods are usually correlated at a statistical significance level $P \leq 0.05$.

3.3 Laser incandescence

More recent methods for measuring the mass concentration of light-absorbing carbonaceous aerosol by means of laser heating of light-absorbing aerosol particles and subsequent analysis of emitted radiation (Melton, 1984) have developed from applications in flame diagnostics to atmospheric observation. These techniques are implemented as laser-induced incandescence method (LII) (Snelling et al., 2005; Chan et al., 2011) or as single-particle soot photometer method (SP2) (Stephens et al., 2003; Schwarz et al., 2006). Particularly the SP2 instrument was extensively compared in studies reported by Slowik et al. (2007), Cross et al. (2010), and Kondo et al. (2011). In a recent development the SP2 technology of laser vaporization was coupled to an aerosol mass spectrometer (SP-AMS) for analyzing charged clusters of vaporized carbon particles (Onasch et al., 2012); see further discussion in Sect. 3.5.

Incandescence methods detect carbon-containing particles by absorption of intense radiative energy which is transformed into heat and results in the re-emission of thermal

Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



**Recommendations
for the interpretation
of “black carbon”
measurements**A. Petzold et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

radiation (Melton, 1984; Stephens et al., 2003; Schwarz et al., 2006; Chan et al., 2011). While the primary signal is generated by absorption of radiation, i.e., by an optical process, the method response is due to the thermal emission from heated matter. Therefore, incandescence methods are mass-based, but, as for absorption methods, the instrument response depends on the type of carbonaceous particle (Gysel et al., 2012; Laborde et al., 2012) and the conversion of thermal radiation to carbon mass has to be established by proper calibration. Furthermore, the lower limit of detectable particle sizes has to be considered. This limitation is a serious constraint especially for the single-particle SP2 method (Schwarz et al., 2010), which only detects particles larger than 70–80 nm diameter. The calibration of incandescence instruments must be performed using reference carbon material such as fullerene or recommendations from Baumgartner et al. (2012).

3.4 Raman spectroscopy

Methods sensitive to the structural order of carbon atoms in aerosol particles, such as Raman spectroscopy (Sze et al., 2001; Sadezky et al., 2005; Ivleva et al., 2007), are well suited for unambiguously identifying carbonaceous particles with an inherent graphite-like structure. They have shown the direct link between graphite-like carbon structure and strong light absorption properties (Rosen and Novakov, 1977). Combined with suitable calibration methods, this relationship can be used for the measurement of graphite-like carbon in atmospheric particle samples (Mertes et al., 2004). Whereas this method has its strengths in identifying characteristics of the carbon structure, its applicability for a quantitative measurement of carbon mass is limited for today's technology.

3.5 Aerosol mass spectroscopy

Aerosol mass spectrometry methods utilize single particle laser ablation systems based on laser induced plasma or multi-photon ionization, or laser vaporization

Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

5 methods under incandescent conditions combined with heated filaments, and subsequent mass-spectrometry techniques for analyzing the chemical composition of individual aerosol particles. The actual measurements are ions of carbon clusters (e.g., C+, C2+, C3+, etc.) in the mass spectra. These methods thus target the elemental chemical composition of the particles. Soot particle aerosol mass spectrometry (SP-AMS) (Cross et al., 2010; Onasch et al., 2012) and aerosol time-of-flight mass spectrometry (ATOFMS) (Noble and Prather, 1996; Spencer and Prather, 2006; Spencer et al., 2007) are the most advanced representatives of this family of methods.

10 As a distinct feature, the SP-AMS technique represents a hybrid of laser incandescence and mass spectrometry methods. It combines a laser incandescence approach for heating and vaporizing the sampled particles with mass spectrometry techniques for the detection of resulting charged carbon clusters. With respect to the detected property, SP-AMS measurements are more similar to the single particle mass spectrometers (i.e., carbon cluster ion detection) than the incandescence signal (intensity of thermal radiation) measured by the SP2. In contrast, the carbon ions measured by an SP-AMS are related to the carbon that is evaporating under incandescent conditions (i.e., refractory), and not a product of a laser induced plasma or multi-photon ionization events which may control the ions observed by single particle laser ablation systems. Thus, it is a not yet fully answered question whether the SP-AMS measurements should be classified with SP2 measurements or single particle laser ablation measurements.

3.6 Electron microscopy

25 Particle morphology and microstructure are commonly addressed by means of electron microscopy, either in its transmission (TEM) or scanning (SEM) mode (Fruhstorfer and Niessner, 1994; Posfai et al., 2003, 2004; Adachi et al., 2007; Tumolva et al., 2010). In particular, electron tomography (van Poppel et al., 2005) is a promising technique for identifying three-dimensional structures of nanoparticles. Although microscopy techniques are the only available methods that directly target particle morphology, their

application for routine monitoring purposes is strongly limited due to labor-intensive sample preparation and data analysis.

4 Historic and current terminology

As stated in the WMO/GAW Report 153 on Aerosol Measurement Procedures (Bal-
tensperger et al., 2003), carbonaceous species are the least understood and most dif-
ficult to characterize of all aerosol chemical components. As a first step, total aerosol
carbon mass (TC) can be divided into three fractions: inorganic carbonates (IC), or-
ganic carbon (OC), and a third fraction called variously elemental carbon, black carbon,
soot, or refractory carbon. In climate change and air quality research, the latter fraction
of the carbonaceous aerosol is commonly addressed as black carbon (BC), but is often
assumed to be elemental carbon (EC). It is also loosely termed soot even though soot
denotes the ensemble of the particles emitted during incomplete combustion, i.e., the
sum of black carbon and organic carbon (see below).

4.1 Historic definitions

Starting from the pioneering work of Novakov (1984), Goldberg (1985) and Shah and
Rau (1990) the following analytically-based definitions have been introduced:

- Total carbon (TC): total particulate carbonaceous material (Novakov, 1984); com-
monly assumed as $TC = EC + OC$ (Shah and Rau, 1990), often neglecting inor-
ganic carbon.
- Organic carbon (OC): any of the vast number of compounds where carbon is
chemically combined with hydrogen and other elements like O, S, N, P, Cl, etc.
(Shah and Rau, 1990).

Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

- Elemental carbon (EC): a form of carbon that is essentially pure carbon rather than being chemically combined with hydrogen and/or oxygen. It can exist either in an amorphous or crystalline structure (Shah and Rau, 1990).
- Carbonate carbon (CC) or inorganic carbon (IC): inorganic carbonate salts (Shah and Rau, 1990).
- Black carbon (BC): combustion-produced black particulate carbon having a graphitic-like microstructure (Novakov, 1984), or “... an impure form of the element [carbon] produced by the incomplete combustion of fossil fuels and biomass. It contains over 60 % carbon with the major accessory elements hydrogen, oxygen, nitrogen, and sulfur” (Goldberg, 1985).

From a source-based approach the following definitions were made:

- Primary carbon: particulate carbon produced in sources, rather than in the atmosphere, being the sum of primary organic species and black carbon (Novakov, 1984).
- Secondary carbon: organic particulate carbon formed by atmospheric reactions from gaseous precursors (Novakov, 1984). In current literature this fraction is referred to as secondary organic aerosol (SOA).
- Soot: synonymous with primary carbon derived from combustion (Novakov, 1984), or a common name for elemental carbon (Shah and Rau, 1990).

From these historic definitions it is evident that there is no unambiguous separation line between the definitions for elemental carbon, black carbon and soot. Rather, these terms are commonly, but incorrectly, used synonymously.

4.2 Current terminology

More precise and operational definitions have been developed with progressing understanding and measurement capabilities. An in-depth discussion of these issues can

be found in the papers by Bond and co-authors (2006, 2013), Andreae and Gelencsér (2006), and in interactive comments to Buseck et al. (2012); see Schwartz and Lewis (2012), Prather (2012), Gysel (2012) and published reviews:

- “Soot carbon” or “Soot” (C_{soot}): particles containing carbon with the morphological and chemical properties typical of soot particles from fossil fuel combustion. Soot carbon particles are formed from agglomerates of spherules composed of graphitic-like micro-crystallites. They consist almost exclusively of carbon, with minor amounts of hydrogen and oxygen (Ogren and Charlson, 1983; Andreae and Gelencsér, 2006) and are characterized by a specific surface area $\geq 100 \text{ m}^2 \text{ g}^{-1}$ (Gilot et al., 1993; Kandas et al., 2005). Note that this definition excludes any organic species that might be present as a coating on the spherules.
- Graphitic carbon: particulate carbon having a graphitic-like microstructure characterized by sp^2 – bonded carbon atoms (Ogren and Charlson, 1983). Graphitic carbon is often used as another term for EC (Shah and Rau, 1990).
- ns-soot: from the standpoint of particle morphology, Buseck et al. (2012) introduced the term “ns-soot”, which refers to the carbon nanospheres as the constituting element of typical combustion particle aggregates. This definition is linked to the various methods of electron microscopy.
- Elemental carbon (EC): carbonaceous fraction of particulate matter that is thermally stable in an inert atmosphere to high temperatures near 4000 K and can only be gasified by oxidation starting at temperatures above 340°C . It is assumed to be inert and non-volatile under atmospheric conditions and insoluble in any solvent (Ogren and Charlson, 1983).
- Black carbon (BC): Following Bond et al. (2013), who deserve credit for synthesizing BC definitions for the first time, BC is characterized by the following distinct properties: (1) it strongly absorbs visible light with a mass absorption cross section (MAC) at a wavelength $\lambda = 550 \text{ nm}$ above $5 \text{ m}^2 \text{ g}^{-1}$ for freshly produced

Recommendations
for the interpretation
of “black carbon”
measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

particles; (2) it is refractory with a volatilization temperature near 4000 K; (3) it is insoluble in water, in organic solvents including methanol and acetone, and in the other components of the atmospheric aerosol; and (4) it consists of aggregates of small carbon spherules of < 10 to approx. 50 nm in diameter. In order to include a distinct microstructural feature, we add a fifth property saying that (5) it contains a high fraction of graphite-like sp^2 – bonded carbon atoms; see Table 1 for a compilation of properties.

With respect to its light-absorbing properties the following definitions have been introduced:

- Light-absorbing carbon (LAC): carbon fraction of the atmospheric aerosol that strongly absorbs light in the visible spectral region (Andreae and Gelencsér, 2006; Bond and Bergstrom, 2006).
- Brown carbon (C_{brown}): light-absorbing organic matter in atmospheric aerosols of various origins, e.g., soil humic substances, humic-like substances (HULIS) (Graber and Rudich, 2006), tarry materials from combustion, bioaerosols, etc. (Posfai et al., 2004; Andreae and Gelencsér, 2006), which tend to appear brown rather than black. The brownish appearance is associated with a non-uniform absorption over the entire visible wavelength range, i.e., increasing absorption with decreasing wavelength in the visible range of the solar spectrum.

4.3 Limitations of current terminology

Currently used terminology exhibits distinct ambiguities and limitations. The term “black carbon” implies optical properties and composition similar to soot carbon or light-absorbing carbon (LAC, which includes C_{soot} and C_{brown}), and particle morphology similar to ns-soot. The word “black” has also come to be associated with measurements by filter-based optical methods, which frequently assume a particular wavelength dependence and absorption per unit mass (Liousse et al., 1993; Petzold et al., 1997; Jeong et

al., 2004). Moreover, the term “black” is associated with the almost uniform absorption of light over the entire visible wavelength range, with the imaginary part of the refractive index being almost wavelength-independent over the visible and near-infrared spectral range. However, in the climate-science community, BC is the most commonly used term, without consideration of its unclear definition.

The term “elemental carbon” is rated as not necessarily provided by the measurements (Andreae and Gelencsér, 2006; Bond and Bergstrom, 2006) because the name implies a near-elemental composition of the carbon. Instead, EC determined by evolved carbon methods from atmospheric aerosol samples still contains some carbon with functional groups (e.g., C-O) and the molar H/C ratio determined for black carbon in ash is about 0.20 (Kuhlbusch, 1995). Following this concern, Andreae and Gelencsér (2006) proposed the use of “Apparent Elemental Carbon” (EC_a) as the proper terminology for the fraction of carbon that is oxidized above a certain temperature threshold in the presence of an oxygen containing atmosphere. However, the term “elemental carbon” is well established in a wide range of literature focusing on combustion methods and emission inventories. In addition, it is widely used within official bodies as CEN, ISO, as well as NIOSH and operationally defined in all the thermal protocols included in respective standards. Finally, the term “elemental carbon” is used in legislation related to ambient air quality and workplace safety.

5 Recommended terminology and related measurement methods

In consideration of the inadequate definitions available in the literature, and in order to overcome this unsatisfying situation, the authors propose the following consistent terminology which is built along the line of targeted material properties. Table 2 summarizes the recommended terminology and includes related measurement methods and specific instruments. Reporting procedures for the World Data Centre for Aerosols are found at <http://www.gaw-wdca.org/>.

Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Total carbon (TC) mass is used to characterize the mass of all carbonaceous matter in airborne particles.

Total carbon mass is a well-defined property that can be measured with precision better than 10 % by evolved carbon methods.

Black carbon (BC) is a useful qualitative description when referring to light-absorbing carbonaceous substances in atmospheric aerosol; however, for quantitative applications the term requires clarification of the underlying determination.

In the absence of a method for uniquely determining the mass of BC, the authors recommend that the term “BC” should be used as a qualitative and descriptive term when referring generally to material that shares some of the characteristics of BC (see Table 1), in particular its carbonaceous composition combined with its light-absorbing properties. In this manner, BC is already used in atmospheric modeling and assessment studies. For quantitative applications like reporting data from observations or building inventories, the authors suggest using more specific terminology that refers to the particular measurement method as defined in the following. One strong recommendation, however, is to avoid using the term “BC” for evolved carbon methods.

Equivalent black carbon (EBC) should be used instead of black carbon for data derived from optical absorption methods, together with a suitable MAC for the conversion of light absorption coefficient into mass concentration.

In the absence of a standard reference material, it is recommended to report such measurements as aerosol light absorption coefficient, thus avoiding the additional uncertainty introduced by assuming a specific MAC value. When reporting EBC, i.e. mass concentration, it is crucial to identify the MAC value used for the conversion and to specify the approach used for separating potential contributions of BrC or mineral dust to the aerosol light absorption coefficient.

Elemental carbon (EC) should be used instead of black carbon for data derived from methods that are specific to the carbon content of carbonaceous matter.

It is recommended to report data from evolved carbon methods and aerosol mass spectrometry methods as EC. Additionally, data from Raman spectroscopy, which

Recommendations
for the interpretation
of “black carbon”
measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

addresses the graphite-like structure of carbon atoms, should be reported as EC. Data from any future methods that address the amount of carbon atoms contained in the analyzed sample of particulate matter should also be reported as EC.

Refractory black carbon (rBC) should be used instead of black carbon for measurements derived from incandescence methods.

For incandescence-based methods like LII, SP2 and SP-AMS it is recommended to report data as refractory black carbon, rBC, since these methods mainly address the thermal stability of the carbonaceous matter and require light-absorbing efficiency, i.e., some “blackness” of the analyzed particulate matter. Terminology used so far (e.g. refractory BC, rBC, equivalent refractory BC, erBC, and similar terms containing EC or refractory carbon, RC) should be replaced by the term rBC.

Soot is a useful qualitative description when referring to carbonaceous particles formed from incomplete combustion.

The term soot generally refers to the source mechanism of incomplete combustion (Glassman and Yetter, 2008) rather than to a material property. It is widely used in research on the formation of carbonaceous particles in combustion processes and on the emission of particulate matter from combustion sources. Since atmospheric research usually addresses mixed and aged particles that can no longer be associated with a combustion source process, the recommendation is to avoid using this term for atmospheric aerosol.

With the above recommendations almost all currently known needs for unambiguous terminology of black carbon related research should be covered. As a consequence we recommend terminating the use of other terms that have been applied in the past. In order to support the efforts towards consistent reporting of BC-related measurements the authors of future research papers are requested to clearly state means of calibration and conversion as metadata with any published values.

Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page	
Abstract	Introduction
Conclusions	References
Tables	Figures
⏪	⏩
◀	▶
Back	Close
Full Screen / Esc	
Printer-friendly Version	
Interactive Discussion	

Discussion Paper | Discussion Paper | Discussion Paper | Discussion Paper | Discussion Paper



6 Conclusions

Despite the huge efforts undertaken in the research field of carbonaceous particles in the atmosphere, the research community is still not and may never be in a position to offer unambiguous conversion relationships between BC data originating from different methods and different aerosol types. Methods are associated with distinct particle properties, which may depend not only on particle chemical composition but also on physical properties like particle size or mixing state. These complex interdependencies very likely inhibit universal quantitative one-to-one conversion relationships between properties.

After having critically reviewed the currently used terminology and after having considered the use of terms not only in the research area of atmospheric composition, air quality and climate change but also in legislation on air quality control and work place safety we propose a terminology that reflects the widespread origin of BC data and permits a consistent reporting of data in the scientific literature that were generated by similar methods.

Acknowledgements. The authors gratefully acknowledge valuable contributions from R. Hitzengerger (Univ. Vienna, Austria), T. Kuhlbusch (Univ. Duisburg, Germany), E. Lewis (Brookhaven National Laboratory, USA), T. Onasch (Aerodyne Research, USA), and M. Schultz (Forschungszentrum Jülich) during the preparation of the manuscript.

The service charges for this open access publication have been covered by a Research Centre of the Helmholtz Association.

References

Adachi, K., Chung, S. H., Friedrich, H., and Buseck, P. R.: Fractal parameters of individual soot particles determined using electron tomography: Implications for optical properties, *J. Geophys. Res.*, 112, D14202, doi:10.1029/2006jd008296, 2007.

Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Adler, G., Riziq, A. A., Erlick, C., and Rudich, Y.: Effect of intrinsic organic carbon on the optical properties of fresh diesel soot, *P. Natl. Acad. Sci.*, 107, 6699–6704, doi:10.1073/pnas.0903311106, 2010.

Andreae, M. O. and Gelencsér, A.: Black carbon or brown carbon? The nature of light-absorbing carbonaceous aerosols, *Atmos. Chem. Phys.*, 6, 3131–3148, doi:10.5194/acp-6-3131-2006, 2006.

Arnott, W. P., Moosmüller, H., Sheridan, P. J., Ogren, J. A., Raspet, R., Slaton, W. V., Hand, J. L., Kreidenweis, S. M., and Collett, J. L. J.: Photoacoustic and filter-based ambient aerosol light absorption measurements: Instrument comparisons and the role of relative humidity, *J. Geophys. Res.*, 108, 4034, doi:10.1029/2002JD002165, 2003.

Baltensperger, U., Barrie, L., Fröhlich, C., Gras, J., Jäger, H., Jennings, S. G., Li, S.-M., Ogren, J. A., Wiedensohler, A., Wehrli, C., and Wilson, J.: WMO/GAW Aerosol Measurement Procedures, Guidelines and Recommendations, WMO/GAW No. 153, 67 pp., 2003.

Baumgardner, D., Popovicheva, O., Allan, J., Bernardoni, V., Cao, J., Cavalli, F., Cozic, J., Diapouli, E., Eleftheriadis, K., Genberg, P. J., Gonzalez, C., Gysel, M., John, A., Kirchstetter, T. W., Kuhlbusch, T. A. J., Laborde, M., Lack, D., Müller, T., Niessner, R., Petzold, A., Piazzalunga, A., Putaud, J. P., Schwarz, J., Sheridan, P., Subramanian, R., Swietlicki, E., Valli, G., Vecchi, R., and Viana, M.: Soot reference materials for instrument calibration and intercomparisons: a workshop summary with recommendations, *Atmos. Meas. Tech.*, 5, 1869–1887, doi:10.5194/amt-5-1869-2012, 2012.

Berry, M. V. and Percival, I. C.: Optics of fractal clusters such as smoke, *Opt. Act.*, 33, 577–591, 1986.

Bond, T. C. and Bergstrom, R. W.: Light absorption by carbonaceous particles: An investigative review, *Aerosol Sci. Technol.*, 40, 27–67, 2006.

Bond, T. C., Anderson, T. L., and Campbell, D.: Calibration and intercomparison of filter-based measurements of visible light absorption by aerosols, *Aerosol Sci. Technol.*, 30, 582–600, 1999.

Bond, T. C., Bhardwaj, E., Dong, R., Jogani, R., Jung, S. K., Roden, C., Streets, D. G., and Trautmann, N. M.: Historical emissions of black and organic carbon aerosol from energy-related combustion, 1850–2000, *Global Biogeochem. Cy.*, 21, Gb2018, doi:10.1029/2006gb002840, 2007.

Bond, T. C., Doherty, S. J., Fahey, D. W., Forster, P. M., Berntsen, T., DeAngelo, B. J., Flanner, M. G., Ghan, S., Kärcher, B., Koch, D., Kinne, S., Kondo, Y., Quinn, P. K., Sarofim, M. C., Schultz,

Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

M. G., Schulz, M., Venkataraman, C., Zhang, H., Zhang, S., Bellouin, N., Guttikunda, S. K., Hopke, P. K., Jacobson, M. Z., Kaiser, J. W., Klimont, Z., Lohmann, U., Schwarz, J. P., Shindell, D., Storelvmo, T., Warren, S. G., and Zender, C. S.: Bounding the role of black carbon in the climate system: A scientific assessment, *J. Geophys. Res.*, doi:10.1002/jgrd.50171, 2013.

Boparai, P., Lee, J. M., and Bond, T. C.: Revisiting thermal-optical analyses of carbonaceous aerosol using a physical model, *Aerosol Sci. Technol.*, 42, 930–948, doi:10.1080/02786820802360690, 2008.

Buseck, P. R., Adachi, K., Gelencsér, A., Tompa, ě., and Pósfai, M.: Are black carbon and soot the same?, *Atmos. Chem. Phys. Discuss.*, 12, 24821–24846, doi:10.5194/acpd-12-24821-2012, 2012.

Cachier, H., Bremond, M. P., and Buat-Menard, P.: Thermal separation of soot carbon, *Aerosol Sci. Technol.*, 10, 358–364, 1989.

Cavalli, F., Viana, M., Yttri, K. E., Genberg, J., and Putaud, J.-P.: Toward a standardised thermal-optical protocol for measuring atmospheric organic and elemental carbon: the EUSAAR protocol, *Atmos. Meas. Tech.*, 3, 79–89, doi:10.5194/amt-3-79-2010, 2010.

Chan, T. W., Brook, J. R., Smallwood, G. J., and Lu, G.: Time-resolved measurements of black carbon light absorption enhancement in urban and near-urban locations of southern Ontario, Canada, *Atmos. Chem. Phys.*, 11, 10407–10432, doi:10.5194/acp-11-10407-2011, 2011.

Chen, Y. and Bond, T. C.: Light absorption by organic carbon from wood combustion, *Atmos. Chem. Phys.*, 10, 1773–1787, doi:10.5194/acp-10-1773-2010, 2010.

Chow, J. C., Watson, J. G., Prithett, L. C., Pierson, W. R., Frazier, C. A., and Purcell, R. G.: The DRI Thermal/Optical Reflectance carbon analysis system: Description, evaluation, and applications in U.S. air quality studies, *Atmos. Environ.*, 27A, 1185–1201, 1993.

Chow, J. C., Watson, J. G., Chen, L. W. A., Arnott, W. P., Moosmüller, H., and Fung, K.: Equivalence of elemental carbon by thermal/optical reflectance and transmittance with different temperature protocols, *Environ. Sci. Technol.*, 38, 4414–4422, 2004.

Chow, J. C., Watson, J. G., Chen, L. W. A., Chang, M. C. O., Robinson, N. F., Trimble, D., and Kohl, S.: The IMPROVE-A temperature protocol for thermal/optical carbon analysis: Maintaining consistency with a long-term database, *J. Air Waste Manage. Assoc.*, 57, 1014–1023, doi:10.3155/1047-3289.57.9.1014, 2007a.

Chow, J. C., Yu, J. Z., Watson, J. G., Ho, S. S. H., Bohannan, T. L., Hays, M. D., and Fung, K. K.: The application of thermal methods for determining chemical composition of carbonaceous

Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

aerosols: A review, *J. Environ. Sci. Health A Tox. Hazard Subst. Environ. Eng.*, 42, 1521–1541, doi:10.1080/10934520701513365, 2007b.

Chow, J. C., Watson, J. G., Doraiswamy, P., Chen, L. W. A., Sodeman, D. A., Lowenthal, D. H., Park, K., Arnott, W. P., and Motallebi, N.: Aerosol light absorption, black carbon, and elemental carbon at the Fresno Supersite, California, *Atmos. Res.*, 93, 874–887, doi:10.1016/j.atmosres.2009.04.010, 2009.

Chow, J. C., Watson, J. G., Robles, J., Wang, X. L., Chen, L. W. A., Trimble, D. L., Kohl, S. D., Tropp, R. J., and Fung, K. K.: Quality assurance and quality control for thermal/optical analysis of aerosol samples for organic and elemental carbon, *Anal. Bioanal. Chem.*, 401, 3141–3152, doi:10.1007/s00216-011-5103-3, 2011.

Cross, E. S., Onasch, T. B., Ahern, A., Wrobel, W., Slowik, J. G., Olfert, J., Lack, D. A., Massoli, P., Cappa, C. D., Schwarz, J. P., Spackman, J. R., Fahey, D. W., Sedlacek, A., Trimborn, A., Jayne, J. T., Freedman, A., Williams, L. R., Ng, N. L., Mazzoleni, C., Dubey, M., Brem, B., Kok, G., Subramanian, R., Freitag, S., Clarke, A., Thornhill, D., Marr, L. C., Kolb, C. E., Worsnop, D. R., and Davidovits, P.: Soot Particle Studies-Instrument Inter-Comparison-Project Overview, *Aerosol Sci. Technol.*, 44, 592–611, 2010.

Fruhstorfer, P. and Niessner, R.: Identification and classification of airborne soot particles using an automated SEM EDX, *Mikrochim. Acta*, 113, 239–250, doi:10.1007/bf01243614, 1994.

Gilot, P., Bonnefoy, F., Marcuccilli, F., and Prado, G.: Determination of kinetic data for soot oxidation – Modelling of competition between oxygen diffusion and reaction during thermogravimetric analysis, *Combust. Flame*, 95, 87–100, doi:10.1016/0010-2180(93)90054-7, 1993.

Glassman, I. and Yetter, R. A.: *Combustion*, Academic Press, Burlington, MA, USA, 2008.

Goldberg, E. D.: *Black Carbon in the Environment – Properties and Distribution*, John Wiley & Sons Inc., New York, 216 pp., 1985.

Graber, E. R. and Rudich, Y.: Atmospheric HULIS: How humic-like are they? A comprehensive and critical review, *Atmos. Chem. Phys.*, 6, 729–753, doi:10.5194/acp-6-729-2006, 2006.

Granier, C., Bessagnet, B., Bond, T., D’Angiola, A., van der Gon, H. D., Frost, G. J., Heil, A., Kaiser, J. W., Kinne, S., Klimont, Z., Kloster, S., Lamarque, J. F., Liousse, C., Masui, T., Meleux, F., Mieville, A., Ohara, T., Raut, J. C., Riahi, K., Schultz, M. G., Smith, S. J., Thompson, A., van Aardenne, J., van der Werf, G. R., and van Vuuren, D. P.: Evolution of anthropogenic and biomass burning emissions of air pollutants at global and regional scales during the 1980–2010 period, *Climatic Change*, 109, 163–190, doi:10.1007/s10584-011-0154-1, 2011.

**Recommendations
for the interpretation
of “black carbon”
measurements**

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

- Gysel, M.: Interactive comment on “Are black carbon and soot the same?” by P. R. Buseck et al., *Atmos. Chem. Phys. Discuss.*, 12, C9448–C9448, 2012.
- Gysel, M., Laborde, M., Mensah, A. A., Corbin, J. C., Keller, A., Kim, J., Petzold, A., and Sierau, B.: Technical Note: The single particle soot photometer fails to reliably detect PALAS soot nanoparticles, *Atmos. Meas. Tech.*, 5, 3099–3107, doi:10.5194/amt-5-3099-2012, 2012.
- Hansen, A. D. A., Rosen, H., and Novakov, T.: The aethalometer – an instrument for the real-time measurement of optical absorption by aerosol particles, *Sci. Total Environ.*, 36, 191–196, 1984.
- Heintzenberg, J. and Winkler, P.: Elemental carbon in the atmosphere – Challenges for the trace analyst, *Fresenius J. Anal. Chem.*, 340, 540–543, doi:10.1007/bf00322425, 1991.
- Hitzenberger, R., Petzold, A., Bauer, H., Ctyroky, P., Pouresmaeil, P., Laskus, L., and Puxbaum, H.: Intercomparison of thermal and optical measurement methods for elemental carbon and black carbon at an urban location, *Environ. Sci. Technol.*, 40, 6377–6383, doi:10.1021/es051228v, 2006.
- Huntzicker, J. J., Johnson, R. L., Shah, J. J., and Cray, R. A.: Analysis of Organic and Elemental Carbon in Ambient Aerosols by a Thermal-Optical Method in: *Particulate Carbon: Atmospheric Life Cycle*, edited by: Wolff, G. T., and Klimisch, R. L., Plenum Press, New York, 1982.
- Ivleva, N. P., McKeon, U., Niessner, R., and Pöschl, U.: Raman microspectroscopic analysis of size-resolved atmospheric aerosol particle samples collected with an ELPI: Soot, humic-like substances, and inorganic compounds, *Aerosol Sci. Technol.*, 41, 655–671, doi:10.1080/02786820701376391, 2007.
- Jennings, S. G., O’Dowd, C. D., Cooke, W. F., Sheridan, P. J., and Cachier, H.: Volatility of elemental carbon, *Geophys. Res. Lett.*, 21, 1719–1722, doi:10.1029/94gl01423, 1994.
- Jeong, C. H., Hopke, P. K., Kim, E., and Lee, D. W.: The comparison between thermal-optical transmittance elemental carbon and Aethalometer black carbon measured at multiple monitoring sites, *Atmos. Environ.*, 38, 5193–5204, doi:10.1016/j.atmosenv.2004.02.065, 2004.
- Junker, C. and Lioussé, C.: A global emission inventory of carbonaceous aerosol from historic records of fossil fuel and biofuel consumption for the period 1860–1997, *Atmos. Chem. Phys.*, 8, 1195–1207, doi:10.5194/acp-8-1195-2008, 2008.
- Kandas, A. W., Gokhan Senel, I., Levendis, Y., and Sarofim, A. F.: Soot surface area evolution during air oxidation as evaluated by small angle X-ray scattering and CO₂ adsorption, *Carbon*, 43, 241–251, doi:10.1016/j.carbon.2004.08.028, 2005.

Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Kim, J., Bauer, H., Dobovicnik, T., Hitzengerger, R., Lottin, D., Ferry, D., and Petzold, A.: Constraining optical properties and refractive index of soot through combined experimental and modelling studies, European Aerosol Conference (EAC), Granada, Spain, 2–7 September 2012, Paper A-WG01S1P04, 2012.

5 Kirchstetter, T. W., Novakov, T., and Hobbs, P. V.: Evidence that the spectral dependence of light absorption by aerosols is affected by organic carbon, *J. Geophys. Res.*, 109, D21208, doi:10.1029/2004JD004999, 2004.

Kondo, Y., Sahu, L., Moteki, N., Khan, F., Takegawa, N., Liu, X., Koike, M., and Miyakawa, T.: Consistency and traceability of black carbon measurements made by laser-induced incandescence, thermal-optical transmittance, and filter-based photo-absorption techniques, *Aerosol Sci. Technol.*, 45, 295–312, doi:10.1080/02786826.2010.533215, 2011.

10 Kuhlbusch, T. A. J.: Method for determining black carbon in residues of vegetation fires, *Environ. Sci. Technol.*, 29, 2695–2702, doi:10.1021/es00010a034, 1995.

Laborde, M., Mertes, P., Zieger, P., Dommen, J., Baltensperger, U., and Gysel, M.: Sensitivity of the Single Particle Soot Photometer to different black carbon types, *Atmos. Meas. Tech.*, 5, 1031–1043, doi:10.5194/amt-5-1031-2012, 2012.

Lack, D. A., Cappa, C. D., Cross, E. S., Massoli, P., Ahern, A. T., Davidovits, P., and Onasch, T. B.: Absorption enhancement of coated absorbing aerosols: Validation of the photoacoustic technique for measuring the enhancement, *Aerosol Sci. Technol.*, 43, 1006–1012, doi:10.1080/02786820903117932, 2009a.

Lack, D. A., Quinn, P. K., Massoli, P., Bates, T. S., Coffman, D., Covert, D. S., Sierau, B., Tucker, S., Baynard, T., Lovejoy, E., Murphy, D. M., and Ravishankara, A. R.: Relative humidity dependence of light absorption by mineral dust after long-range atmospheric transport from the Sahara, *Geophys. Res. Lett.*, 36, L24805, doi:10.1029/2009gl041002, 2009b.

25 Lack, D. A. and Cappa, C. D.: Impact of brown and clear carbon on light absorption enhancement, single scatter albedo and absorption wavelength dependence of black carbon, *Atmos. Chem. Phys.*, 10, 4207–4220, doi:10.5194/acp-10-4207-2010, 2010.

Lee, Y. H., Lamarque, J.-F., Flanner, M. G., Jiao, C., Shindell, D. T., Berntsen, T., Bisiaux, M. M., Cao, J., Collins, W. J., Curran, M., Edwards, R., Faluvegi, G., Ghan, S., Horowitz, L. W., McConnell, J. R., Ming, J., Myhre, G., Nagashima, T., Naik, V., Rumbold, S. T., Skeie, R. B., Sudo, K., Takemura, T., Thevenon, F., Xu, B., and Yoon, J.-H.: Evaluation of preindustrial to present-day black carbon and its albedo forcing from Atmospheric Chemistry and

Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

[Title Page](#)
[Abstract](#)
[Introduction](#)
[Conclusions](#)
[References](#)
[Tables](#)
[Figures](#)




[Back](#)
[Close](#)
[Full Screen / Esc](#)
[Printer-friendly Version](#)
[Interactive Discussion](#)

- Climate Model Intercomparison Project (ACCMIP), *Atmos. Chem. Phys.*, 13, 2607–2634, doi:10.5194/acp-13-2607-2013, 2013.
- Lioussé, C., Cachier, H., and Jennings, S. G.: Optical and thermal measurements of black carbon aerosol content in different environments: Variation of the specific attenuation cross-section, σ (σ), *Atmos. Environ. A*, 27, 1203–1211, doi:10.1016/0960-1686(93)90246-u, 1993.
- Malissa, H., Puxbaum, H., and Pell, E.: Simultaneous relative conductometric determination of carbon and sulfur in dusts, *Fresenius Z. Anal. Chem.*, 282, 109–113, doi:10.1007/bf00663313, 1976.
- Melton, L. A.: Soot diagnostics based on laser heating, *Appl. Opt.*, 23, 2201–2208, 1984.
- Mertes, S., Dippel, B., and Schwarzenbock, A.: Quantification of graphitic carbon in atmospheric aerosol particles by Raman spectroscopy and first application for the determination of mass absorption efficiencies, *J. Aerosol Sci.*, 35, 347–361, doi:10.1016/j.jaerosci.2003.10.002, 2004.
- Miyazaki, Y., Kondo, Y., Sahu, L. K., Imaru, J., Fukushima, N., and Kano, M.: Performance of a newly designed continuous soot monitoring system (COSMOS), *J. Environ. Monit.*, 10, 1195–1201, doi:10.1039/b806957c, 2008.
- Moosmüller, H., Chakrabarty, R. K., and Arnott, W. P.: Aerosol light absorption and its measurement: A review, *J. Quant. Spectrosc. Radiat. Transfer*, 110, 844–878, 2009.
- Müller, G., Artz, R., Baltensperger, U., Carmichael, G., Dlugokencky, E., Penkett, S., Stähelin, J., Webb, A., Hov, Ø., Klausen, J., Sturges, B., Barrie, L., Braathen, G., Jalkanen, L., and Nickovic, S.: WMO global atmosphere watch (GAW) strategic plan: 2008–2015, World Meteorological Organization, Geneva, GAW Report No. 172, 104 pp., 2007.
- Noble, C. A. and Prather, K. A.: Real-time measurement of correlated size and composition profiles of individual atmospheric aerosol particles, *Environ. Sci. Technol.*, 30, 2667–2680, doi:10.1021/es950669j, 1996.
- Novakov, T.: The role of soot and primary oxidants in atmospheric chemistry, *Sci. Total Environ.*, 36, 1–10, doi:10.1016/0048-9697(84)90241-9, 1984.
- Ogren, J. A. and Charlson, R. J.: Elemental carbon in the atmosphere – cycle and lifetime, *Tellus*, 35B, 241–254, 1983.
- Onasch, T. B., Trimborn, A., Fortner, E. C., Jayne, J. T., Kok, G. L., Williams, L. R., Davidovits, P., and Worsnop, D. R.: Soot particle aerosol mass spectrometer: Development, validation, and

Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

initial application, *Aerosol Sci. Technol.*, 46, 804–817, doi:10.1080/02786826.2012.663948, 2012.

Park, K., Chow, J. C., Watson, J. G., Trimble, D. L., Doraiswamy, P., Arnott, W. P., Stroud, K. R., Bowers, K., Bode, R., Petzold, A., and Hansen, A. D. A.: Comparison of continuous and filter-based carbon measurements at the Fresno Supersite, *J. Air Waste Manage. Assoc.*, 56, 474–491, 2006.

Peterson, M. R. and Richards, M. H.: Thermal-optical transmittance analysis for organic, elemental, carbonate, total carbon, and OCX2 in PM_{2.5} by the EPA/NIOSH method, in: *Proceedings, Symposium on Air Quality Measurement Methods and Technology – 2002*, Pittsburgh, PA, 2002, 83-81-83-19, 2002.

Petzold, A. and Niessner, R.: Method comparison study on soot-selective techniques, *Mikrochim. Acta* 117, 215–237, 1995.

Petzold, A. and Schönlinner, M.: Multi-angle absorption photometry – A new method for the measurement of aerosol light absorption and atmospheric black carbon, *J. Aerosol Sci.*, 35, 421–441, 2004.

Petzold, A., Kopp, C., and Niessner, R.: The dependence of the specific attenuation cross-section on black carbon mass fraction and particle size, *Atmos. Environ.*, 31, 661–672, 1997.

Petzold, A., Schlösser, H., Sheridan, P. J., Arnott, W. P., Ogren, J. A., and Virkkula, A.: Evaluation of multiangle absorption photometry for measuring aerosol light absorption, *Aerosol Sci. Technol.*, 39, 40–51, 2005.

Petzold, A., Rasp, K., Weinzierl, B., Esselborn, M., Hamburger, T., Dörnbrack, A., Kandler, K., Schütz, L., Knippertz, P., Fiebig, M., and Virkkula, A.: Saharan dust refractive index and optical properties from aircraft-based observations during SAMUM 2006, *Tellus*, 61B, 118–130, 2009.

Petzold, A., Veira, A., Mund, S., Esselborn, M., Kiemle, C., Weinzierl, B., Hamburger, T., Ehret, G., Lieke, K., and Kandler, K.: Mixing of mineral dust with urban pollution aerosol over Dakar (Senegal): impact on dust physico-chemical and radiative properties, *Tellus B*, 63, 619–634, doi:10.1111/j.1600-0889.2011.00547.x, 2011.

Pio, C., Cerqueira, M., Harrison, R. M., Nunes, T., Mirante, F., Alves, C., Oliveira, C., Sanchez de la Campa, A., Artinano, B., and Matos, M.: OC/EC ratio observations in Europe: Rethinking the approach for apportionment between primary and secondary organic carbon, *Atmos. Environ.*, 45, 6121–6132, 2011.

**Recommendations
for the interpretation
of “black carbon”
measurements**

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Posfai, M., Simonics, R., Li, J., Hobbs, P. V., and Buseck, P. R.: Individual aerosol particles from biomass burning in southern Africa: 1. Compositions and size distributions of carbonaceous particles, *J. Geophys. Res.*, 108, 8483, doi:10.1029/2002jd002291, 2003.

Posfai, M., Gelencser, A., Simonics, R., Arato, K., Li, J., Hobbs, P. V., and Buseck, P. R.: Atmospheric tar balls: Particles from biomass and biofuel burning, *J. Geophys. Res.*, 109, D06213, doi:10.1029/2003jd004169, 2004.

Prather, K.: Interactive comment on “Are black carbon and soot the same?” by P. R. Buseck et al., *Atmos. Chem. Phys. Discuss.*, 12, C7311–C7312, 2012.

Puxbaum, H.: Characterization of carbon, sulfur and nitrogen-compounds in atmospheric particles by combined thermal and gas-analytical methods, *Fresenius Z. Anal. Chem.*, 299, 33–41, doi:10.1007/bf00552578, 1979.

Ramanathan, V. and Carmichael, G.: Global and regional climate changes due to black carbon, *Nature Geosci.*, 1, 221–227, doi:10.1038/ngeo156, 2008.

Reisinger, P., Wonaschutz, A., Hitzengerger, R., Petzold, A., Bauer, H., Jankowski, N., Puxbaum, H., Chi, X., and Maenhaut, W.: Intercomparison of measurement techniques for black or elemental carbon under urban background conditions in wintertime: Influence of biomass combustion, *Environ. Sci. Technol.*, 42, 884–889, doi:10.1021/es0715041, 2008.

Rosen, H. and Novakov, T.: Raman-scattering and characterization of atmospheric aerosol particles, *Nature*, 266, 708–710, doi:10.1038/266708a0, 1977.

Sadezky, A., Muckenhuber, H., Grothe, H., Niessner, R., and Poschl, U.: Raman microspectroscopy of soot and related carbonaceous materials: Spectral analysis and structural information, *Carbon*, 43, 1731–1742, doi:10.1016/j.carbon.2005.02.018, 2005.

Schmid, H., Laskus, L., Abraham, H. J., Baltensperger, U., Lavanchy, V., Bizjak, M., Burba, P., Cachier, H., Crow, D., Chow, J., Gnauk, T., Even, A., ten Brink, H. M., Giesen, K.-P. H., Regina, Hueglin, C., Maenhaut, W., Pio, C., Carvalho, A., Putaud, J.-P., Toom-Sauntry, D., and Puxbaum, H.: Results of the carbon conference international aerosol carbon round robin test stage I, *Atmos. Environ.*, 35, 2111–2121, 2001.

Schmid, J., Grob, B., Niessner, R., and Ivleva, N. P.: Multiwavelength Raman microspectroscopy for rapid prediction of soot oxidation reactivity, *Anal. Chem.*, 83, 1173–1179, doi:10.1021/ac102939w, 2011.

Schnaiter, M., Linke, C., Mohler, O., Naumann, K. H., Saathoff, H., Wagner, R., Schurath, U., and Wehner, B.: Absorption amplification of black carbon internally mixed with secondary organic aerosol, *J. Geophys. Res.*, 110, D19204, doi:10.1029/2005jd006046, 2005a.

Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Schnaiter, M., Schmid, O., Petzold, A., Fritzsche, L., Klein, K. F., Andreae, M. O., Helas, G., Thielmann, A., Gimmler, M., Mohler, O., Linke, C., and Schurath, U.: Measurement of wavelength-resolved light absorption by aerosols utilizing a UV-VIS extinction cell, *Aerosol Sci. Technol.*, 39, 249–260, 2005b.

5 Schnaiter, M., Gimmler, M., Llamas, I., Linke, C., Jäger, C., and Mutschke, H.: Strong spectral dependence of light absorption by organic carbon particles formed by propane combustion, *Atmos. Chem. Phys.*, 6, 2981–2990, doi:10.5194/acp-6-2981-2006, 2006.

Schwartz, S. E., and Lewis, E. R.: Interactive comment on “Are black carbon and soot the same?” by P. R. Buseck et al.: Disagreement on proposed nomenclature, *Atmos. Chem. Phys. Discuss.*, 12, C9099–C9109, 2012.

10 Schwarz, J. P., Gao, R. S., Fahey, D. W., Thomson, D. S., Watts, L. A., Wilson, J. C., Reeves, J. M., Darbeheshti, M., Baumgardner, D. G., Kok, G. L., Chung, S. H., Schulz, M., Hendricks, J., Lauer, A., Karcher, B., Slowik, J. G., Rosenlof, K. H., Thompson, T. L., Langford, A. O., Loewenstein, M., and Aikin, K. C.: Single-particle measurements of midlatitude black carbon and light-scattering aerosols from the boundary layer to the lower stratosphere, *J. Geophys. Res.*, 111, D16207, doi:10.1029/2006jd007076, 2006.

15 Schwarz, J. P., Spackman, J. R., Gao, R. S., Perring, A. E., Cross, E., Onasch, T. B., Ahern, A., Wrobel, W., Davidovits, P., Olfert, J., Dubey, M. K., Mazzoleni, C., and Fahey, D. W.: The detection efficiency of the single particle soot photometer, *Aerosol Sci. Technol.*, 44, 612–628, 2010.

Shah, J. J. and Rau, J. A.: Carbonaceous Species Methods Comparison Study: Interlaboratory Round Robin Interpretation of Results, Final Report to Research Division California Air Resources Board, Project A832-154, Sacramento, CA 95812, 77 pp., 1990.

20 Sheridan, P. J., Arnott, W. P., Ogren, J. A., Andrews, E., Atkinson, D. B., Covert, D. S., Moosmüller, H., Petzold, A., Schmid, B., Strawa, A. W., Varma, R., and Virkkula, A.: The Reno Aerosol Optics Study: An evaluation of aerosol absorption measurement methods, *Aerosol Sci. Technol.*, 39, 1–16, 2005.

30 Slowik, J. G., Cross, E. S., Han, J. H., Davidovits, P., Onasch, T. B., Jayne, J. T., Williams, L. R., Canagaratna, M. R., Worsnop, D. R., Chakrabarty, R. K., Moosmüller, H., Arnott, W. P., Schwarz, J. P., Gao, R. S., Fahey, D. W., Kok, G. L., and Petzold, A.: An inter-comparison of instruments measuring black carbon content of soot particles, *Aerosol Sci. Technol.*, 41, 295–314, doi:10.1080/02786820701197078, 2007.

Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

[Title Page](#)
[Abstract](#)
[Introduction](#)
[Conclusions](#)
[References](#)
[Tables](#)
[Figures](#)




[Back](#)
[Close](#)
[Full Screen / Esc](#)
[Printer-friendly Version](#)
[Interactive Discussion](#)

Snelling, D. R., Smallwood, G. J., Liu, F., Gülder, Ö. L., and Bachalo, W. D.: A calibration-independent LII technique for soot measurement by detecting absolute light intensity, *Appl. Opt.*, 44, 6773–6785, 2005.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., and Miller, H. L.: IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of IPCC, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp., 2007.

Spencer, M. T. and Prather, K. A.: Using ATOFMS to determine OC/EC mass fractions in particles, *Aerosol Sci. Technol.*, 40, 585–594, doi:10.1080/02786820600729138, 2006.

Spencer, M. T., Shields, L. G., and Prather, K. A.: Simultaneous measurement of the effective density and chemical composition of ambient aerosol particles, *Environ. Sci. Technol.*, 41, 1303–1309, doi:10.1021/es061425+, 2007.

Stephens, M., Turner, N., and Sandberg, J.: Particle identification by laser-induced incandescence in a solid-state laser cavity, *Appl. Opt.*, 42, 3726–3736, doi:10.1364/ao.42.003726, 2003.

Sze, S. K., Siddique, N., Sloan, J. J., and Escribano, R.: Raman spectroscopic characterization of carbonaceous aerosols, *Atmos. Environ.*, 35, 561–568, doi:10.1016/s1352-2310(00)00325-3, 2001.

ten Brink, H., Maenhaut, W., Hitzengerger, R., Gnauk, T., Spindler, G., Even, A., Chi, X. G., Bauer, H., Puxbaum, H., Putaud, J. P., Tursic, J., and Berner, A.: INTERCOMP2000: the comparability of methods in use in Europe for measuring the carbon content of aerosol, *Atmos. Environ.*, 38, 6507–6519, doi:10.1016/j.atmosenv.2004.08.027, 2004.

Tumolva, L., Park, J. Y., Kim, J. S., Miller, A. L., Chow, J. C., Watson, J. G., and Park, K.: Morphological and elemental classification of freshly emitted soot particles and atmospheric ultrafine particles using the TEM/EDS, *Aerosol Sci. Technol.*, 44, 202–215, doi:10.1080/02786820903518907, 2010.

UNEP/WMO: Integrated Assessment of Black Carbon and Tropospheric Ozone, Summary for Decision Makers, WMO, Geneva, Switzerland, 30 pp., 2011.

van Poppel, L. H., Friedrich, H., Spinsby, J., Chung, S. H., Seinfeld, J. H., and Buseck, P. R.: Electron tomography of nanoparticle clusters: Implications for atmospheric lifetimes and radiative forcing of soot, *Geophys. Res. Lett.*, 32, L24811, doi:10.1029/2005gl024461, 2005.

Vignati, E., Karl, M., Krol, M., Wilson, J., Stier, P., and Cavalli, F.: Sources of uncertainties in modelling black carbon at the global scale, *Atmos. Chem. Phys.*, 10, 2595–2611, doi:10.5194/acp-10-2595-2010, 2010.

Virkkula, A., Ahlquist, N. C., Covert, D. S., Arnott, W. P., Sheridan, P. J., Quinn, P. K., and

5 Coffman, D. J.: Modification, calibration and a field test of an instrument for measuring light absorption by particles, *Aerosol Sci. Technol.*, 39, 68–83, 2005.

**Recommendations
for the interpretation
of “black carbon”
measurements**

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Table 1. Properties defining Black Carbon and their consequences for effects and removal.

Property	Characteristics	Consequences
Microstructure	graphitic-like structure containing a large fraction of sp^2 -bonded carbon atoms	Low chemical reactivity in the atmosphere; slow removal by chemical processes; strong optical absorption
Morphology	aggregates consisting of small carbon spherules of < 10 to approx. 50 nm in diameter; specific surface area typically greater than $100 \text{ m}^2 \text{ g}^{-1}$	High capacity for sorption of other species
Thermal stability	refractory material with a volatilization temperature near 4000 K; gasification is possible only by oxidation, which starts at temperatures above 340°C	High stability in the atmosphere; longer atmospheric residence time
Solubility	insoluble in organic solvents including methanol and acetone, in water, and in the other components of the atmospheric aerosol	Slow removal by clouds and precipitation, unless coated with water-soluble compounds; longer atmospheric residence time
Light absorption	strong light absorption in the spectral range of visible light with mass-specific absorption coefficient typically greater than $5 \text{ m}^2 \text{ g}^{-1}$ (at $\lambda = 550 \text{ nm}$) for freshly-produced particles; weak wavelength dependence of light absorption with absorption Ångström exponent typically 1.0–1.5; characterized by a significant, non-zero and almost wavelength-independent imaginary part of the refractive index over the visible and near-visible spectral regions	Reduction of the albedo of clouds, snow, and ice; atmospheric heating; surface cooling – all of which lead to effects on solar radiation and climate

**Recommendations
for the interpretation
of “black carbon”
measurements**

A. Petzold et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Recommendations for the interpretation of “black carbon” measurements

A. Petzold et al.

Table 2. Recommended terminology and related measurement techniques and instruments.

Property	Technique	Instrument	Reference	Reported value	Recommendation
Light absorption	Light absorption measurement	various in-situ and filter-based methods	(Sheridan et al., 2005; Moosmüller et al., 2009)	Light absorption coefficient σ_{ap} ; mass concentration computed from σ_{ap} by applying a specific mass absorption cross-section MAC	report as σ_{ap} ; if reported as EBC, specify MAC value used for the conversion from light absorption into mass concentration
		Photoacoustic Spec. Aethalometer MAAP	(Arnott et al., 2003) (Hansen et al., 1984) (Petzold and Schönlinner, 2004; Petzold et al., 2005)		
		PSAP	(Bond et al., 1999; Virkkula et al., 2005)		
		COSMOS	(Miyazaki et al., 2008)		
Refractory	Measurement of thermal radiation	SP2	(Stephens et al., 2003; Schwarz et al., 2006; Kondo et al., 2011)	Mass concentration	report as rBC specify means of calibration, conversion factor from thermal radiation to carbon mass, and the size-cut of rBC particles report as rBC
		LII	(Snelling et al., 2005; Chan et al., 2011)		
	Soot Particle Aerosol Mass Spectrometry	SP-AMS	(Onasch et al., 2012)	Mass concentration OC/rBC mass fraction	
Chemical composition, carbon content	Evolved carbon methods, thermal evolution of carbon, with optical correction for pyrolysis	various temperature protocols	IMPROVE (Chow et al., 1993), IMPROVE_A, NIOSH (Peterson and Richards, 2002; Chow et al., 2007a), EUSAAR-2 (Cavalli et al., 2010)	Mass concentration OC/EC mass fraction	report as EC; specify temperature protocol used for the sample analysis
	Aerosol Time-of Flight Mass Spectrometry Soot Particle Aerosol Mass Spectrometry	ATOFMS SP-AMS	(Onasch et al., 2012)	Mass concentration OC/rBC mass fraction	report as rBC, because technique detects carbon that is evaporating under incandescent conditions
Graphite-like microstructure	Raman spectroscopy		(Sze et al., 2001; Mertes et al., 2004; Sadezky et al., 2005; Iľveva et al., 2007)	Mass concentration	report as EC, specify means of calibration
Particle morphology	Electron microscopy	TEM	(van Poppel et al., 2005; Tumolva et al., 2010)	Structural information	not applicable

[Title Page](#)
[Abstract](#)
[Introduction](#)
[Conclusions](#)
[References](#)
[Tables](#)
[Figures](#)
[Back](#)
[Close](#)
[Full Screen / Esc](#)
[Printer-friendly Version](#)
[Interactive Discussion](#)