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A filter-based light-absorption measurement with polar photometer: Effects of sampling artefacts from organic carbon

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ABSTRACT

In this work, light-absorption measurements were carried out on quartz-fibre and PTFE (i.e. Teflon®) filters using a home-made polar photometer in order to assess the role of organic sampling artefacts on optical measurements. Filter-based light-absorption instruments are generally operated with quartz/glass-fibre filter tapes and – as far as we know – currently there are no systematic studies on the sampling artefacts affecting the light absorption coefficient measurements. In this work, particulate matter (PM) samples were collected in Milan (Italy) during different sampling campaigns with the aim of (1) validating the polar photometer; (2) comparing the absorption properties measured on PM collected on different filter media; (3) investigating the causes of the observed differences.

The polar photometer was demonstrated to give aerosol light absorption coefficients (σ_{ap} in Mm^{-1}) fully comparable to those obtained by a Multi-Angle Absorption Photometer (MAAP) when using quartz-fibre filters to collect atmospheric particles. The aerosol light absorption coefficients determined on samples collected in parallel on quartz-fibre and PTFE filters showed significant differences (about 40%). These differences were much lower (i.e. 8%) when the quartz-fibre filter sampling line was equipped with a denuder to remove organic gases from the incoming air stream evidencing a relevant role of organic sampling artefacts in light absorption measurements by filter-based systems.

1. Introduction

Atmospheric aerosols affect the Earth's radiation balance directly absorbing and scattering solar radiation and indirectly acting as cloud condensation nuclei (Foster et al., 2007). It is noteworthy that uncertainties related to aerosol radiative forcing are still large and a detailed aerosol characterisation (i.e. chemical composition, size distribution, and optical properties) is needed to improve the level of confidence on this topic (Jacobson, 2001).

Atmospheric aerosol mainly consists of components like sulphates, nitrates, and organics which scatter solar radiation (Seinfeld & Pandis, 1998; Watson, 2002). Black carbon (BC) is a minor component in terms of aerosol mass but it is the most efficient light-absorbing aerosol species in the visible spectral range. This makes BC a driver for global warming and this is the reason why BC gained the attention of the scientific community in recent years, after having recognised it as an important air pollutant especially in areas affected by emissions due to combustion processes like urban areas (Andreae & Gelencsér, 2006).

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For sake of completeness, mineral dust (e.g. haematite) should be also mentioned among the aerosol light-absorbing aerosol components (Moosmüller et al., 2009); however, its contribution to light absorption is generally small, becoming important only during desert dust events (Collaud Coen et al., 2004). Moreover, organic compounds such as humic like substances (HULIS) in atmospheric aerosol may also contribute to light absorption mainly at UV wavelengths (Andreae & Gelencsér, 2006; Kirchstetter & Thatcher, 2012).

In spite of the important role of aerosol absorption properties, their measurement is still challenging as light absorption represents a small fraction of light extinction compared to light scattering. Many measurement methods have been developed so far and a lot of inter-comparisons among different methods have been conducted (see for example Bond et al., 1999; Chow et al., 2009; Kanaya et al., 2008; Müller et al., 2011; and references therein). The relevance of such measurements is due to the importance of black carbon in climate studies as well as in air quality assessments. Nevertheless, at the state of the art, a reference methodology and a clear definition of black carbon do not exist (Bond & Bergstrom, 2006). Recently, Petzold et al. (2013) have proposed a terminology to clarify the terms used for black carbon. In that paper, the term equivalent black carbon (EBC) is suggested when the absorption properties have been measured by optical techniques and a suitable MAC value (i.e. the mass-specific absorption coefficient reported in m^2/g) is used to convert light absorption into mass concentration. Very often the MAC value is derived from the sample absorption measurement and TOT/TOR analysis of elemental carbon (EC), which is not standardised yet. Depending on the aerosol size distribution and refractive index, the MAC value can range between 2 and 25 m^2/g (Bond & Bergstrom, 2006) and the absorption properties due to the internally mixed BC particles can be enhanced as compared to those in the externally mixed BC particles (Naoe et al., 2009). In summary, the MAC value depends on the type of aerosol, the ageing, and the size of BC particles; thus it has to be determined for each site (Cozic et al., 2008). Moreover, the MAC value shows a significant variability according to the thermal protocol used for its determination with TOT/TOR analysis (Vecchi et al., 2012); the most widespread thermal protocols used in Europe are summarised in CEN/TR 16243 (2011).

Filter-based light absorption/extinction measurement systems are widespread in monitoring networks and often used for continuous in-situ measurements. In the US-IMPROVE network measurements by the Hybrid Integrating Plate/Sphere Analysis method (HIPS) are carried out off-line on PM2.5 loaded PTFE filters (http://vista.cira.colostate.edu/improve/Publications/SOPs/ucdavis_sops/SOP276_Optical_Absorption_2013.pdf). Examples of continuous light-absorption/extinction monitoring systems are the Aethalometer (Magee Scientific), the Particle Soot Absorption Photometer (PSAP, Radiance Research), the Multi-Angle Absorption Photometer (MAAP, Thermo Scientific), the Continuous Soot Monitoring System with the heated inlet line (COSMOS, Kanomax), among others. They all rely on the collection of atmospheric particles on a filter matrix (usually a glass or quartz-fibre filter tape) and the on-line determination of the light absorption or extinction coefficient, from which BC concentrations are then derived. It is well known that there are drawbacks in filter-based optical instruments due to the particle loading, multiple scatterings or relative humidity effects and correction algorithms are needed to account for the differences recorded in inter-comparison exercises with non filter-based instrumentation (Bond et al., 1999; Collaud Coen et al., 2010; Hyvärinen et al., 2013; among others). Moreover, Cappa et al. (2008) and Lack et al. (2008) evidenced biases in filter-based absorption measurements specifically due to organic aerosol loading with laboratory and ambient measurements. At the state of the art, a number of studies have assessed sampling artefacts due to organics (e.g. Turpin et al., 2000; Vecchi et al., 2009a; Viana et al., 2007) in different filter media but – as far as we know – none has studied the role of different filter matrices in measuring the aerosol light absorption optical properties as reported in this paper.

The aim of this work was to study the role of organic sampling artefacts in filter-based light absorption measurements; thus, field campaigns were designed to measure optical absorption in aerosol samples collected on different filter media. The optical measurements were carried out on quartz-fibre and PTFE filters (i.e. filter types widely used by the aerosol community) using a home-made polar photometer suitably set up to measure light absorption of atmospheric particles collected on 47 mm diameter filters (or, more generally, on single filters of any size). Indeed, samples collected on filters are often available in aerosol monitoring campaigns and generally an optical characterisation of these samples is not performed. The non-destructive methodology described here also complements the routine chemical–physical characterisation typically performed on daily particulate matter samples, giving additional information on light-absorption properties of the aerosol samples collected on any filter type.

It is noteworthy that a better comprehension of the biases affecting filter-based measurements will also lead to a more accurate determination of the aerosol light absorption coefficient and therefore of equivalent black carbon, although the uncertainty due to the application of a MAC value still remains.

2. Material and methods

2.1. Field campaigns

The sampling site is located in the campus of the University of Milan (Northern Italy), which is approximately 2 km far from the city centre. The sampling platform is placed on the roof of our Department (at a height of about 10 m a.g.l.) and it is representative of an urban background station as not directly influenced by local pollution sources (Marcazzan et al., 2001, 2004).