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Spatial and temporal analysis of black carbon aerosols in Istanbul megacity

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HIGHLIGHTS

- We present the measured BC aerosol concentrations in Istanbul for the first time.
- Diurnal variations of BC concentrations and the traffic density have significant correlation.
- BC and $PM_{2.5}$ concentrations are strongly influenced by the local traffic volumes.
- High BC contribution to $PM_{2.5}$ mass concentration has been found.
- BC and $PM_{2.5}$ concentrations are not affected from the seasonal variations.

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ABSTRACT

Black carbon (BC) is an important component of particulate matter due to its effects on human health and climate. In this study, we present the first BC concentrations measured in the Istanbul megacity (~15 million inhabitants). Two measurement campaigns have been conducted to measure BC and fine particulate matter ($PM_{2.5}$) concentrations at four locations, characterized by different traffic densities. In the first campaign, BC daily mean concentrations have been found to be between 4 μg/m^3 and 10 μg/m^3. In the second campaign, BC and $PM_{2.5}$ have been measured at the site with the highest traffic density for an entire year. Annually averaged BC contributes by 38 ± 14% to the $PM_{2.5}$ levels (annual average BC: 13 μg/m^3 and $PM_{2.5}$: 36 μg/m^3). Diurnal variations of BC concentrations followed those of traffic density (correlation coefficient of 0.87). These measurements are essential to identify the sources of BC and $PM_{2.5}$ concentrations in Istanbul and develop mitigation measures.

1. Introduction

Capsule: Black carbon aerosols at different locations of the Istanbul megacity have been investigated in conjunction with traffic data.

Sources of air pollution in urban areas are both anthropogenic (e.g., traffic, house heating) and natural (volcanoes, desert dust, etc.). Anthropogenic emissions have been increasing significantly during the last century, and are responsible for the majority of pollutants released into the atmosphere. Among these pollutants, due to their direct impacts on human health, ground-level ozone and fine particulate matter are the most critical ones. Particulate matter (PM) content might change significantly due to its sources. Carbonaceous (organic carbon [OC] and black carbon [BC]) aerosols represent a significant fraction of PM concentrations in urban atmosphere (Jacobson et al., 2000; Hidy, 2009).

The total carbon mass (TC) in PM can be divided into three fractions: organic carbon (OC), which is the volatile fraction; inorganic carbonates, and black carbon (BC) or elemental carbon (EC) in the non-volatile fraction (WMO/GAW, World Meteorological Organization Global Atmosphere Watch, 2003). The distinction between BC and EC is made by the measurement method used. Whereas EC is measured through thermal methods, BC is measured through optical techniques (Hitzenberger et al., 2006). Because most of this study is based on the optical method, BC term will be used throughout the text.

BC aerosols absorb sunlight and heat from the atmosphere, thus affecting regional atmospheric stability and vertical air motions. As a consequence BC affects the large-scale atmospheric circulation and

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hydrologic cycle (Menon et al., 2002). Panicker et al. (2010) found for an urban sire in India that although BC can be a small contributor to the total fine PM mass, BC contribution to the total lower atmospheric aerosol forcing is proportionally much higher (55%) due to its strong radiative absorption. BC also warms the Earth by reducing albedo when deposited on snow and ice, and this exacerbates melting in the Arctic, the Himalayas and other glaciated and snow-covered regions (e.g. Qian et al., 2011; Kopacz et al., 2011). Ramanathan and Carmichael (2008) estimated that emissions of BC represent the second strongest contribution to current global warming, as a result of BC's high radiative forcing and regional distribution. Public health studies reveal that components of the atmospheric aerosols have different impacts on human health. BC leads to adverse impacts on human health leading to premature deaths worldwide (UNEP, United Nations Environment Programme, 2011). Smith et al. (2009) stated that, on the basis of the 1 $\mu g/m^3$ contrast, the percentage increase in all-cause mortality for $PM_{2.5}$ was 0.58; sulfate effects were about twice those of $PM_{2.5}$, and effects of elemental carbon (EC, an indicator of black carbon mass) about ten times greater. EC and BC have all been associated with cardiovascular health effects (Jansen et al., 2005). Long-term exposure to traffic-related air pollution, especially to diesel exhaust, has been associated with increase in cardiopulmonary mortality (Brook et al., 2010; Hoek et al., 2002). Tertre et al. (2002) showed that cardiac admissions to hospitals for all ages were increased by about 1.1% per 10 $\mu g/m^3$ increase in black smoke, suggesting a significant role for diesel exhaust.

Carbonaceous aerosols, especially the BC, have been receiving increased attention due to their rapidly rising emissions in emerging countries, such as China and India. Recent estimates of global BC emissions range from 8 to 24 Tg per year (Chow et al., 2010; Lamarque et al., 2010). Average daily BC levels of 1–5 $\mu g/m^3$ were measured in megacities of developed countries (e.g., New York, Paris, Barcelona, Athens), where emission control strategies are applied (Grivas et al., 2012; Lambe et al., 2009; Perez et al., 2010). In developing countries, where emissions of air pollutants are increasing dramatically (e.g., Mexico City, Beijing, Karachi, Hyderabad, Mumbai) BC concentrations as high as 100 $\mu g/m^3$ have been measured in the megacities (Badarinath et al., 2009; Dutkiewicz et al., 2009; Hidy, 2009). Only few studies have investigated the carbonaceous aerosols over Turkey. Theodosi et al. (2010) measured the chemical composition of PM_{10} aerosols (PM of diameter smaller than 10 μm) over Istanbul from July 2008 to June 2009 and found an annual mean EC concentration of 2.9 $\mu g/m^3$. Ahmed et al. (2009) compared with the thermal and optical measurement methods of BC, and as a part of that study, they measured the BC concentrations (0.1–1.0 $\mu g/m^3$) in the outskirts of Antalya (Mediterranean coast of Turkey) from September to December 1993. Air pollution from vehicles has important impacts on urban environment, especially in the city center of megacities, like Istanbul, where the traffic congestion generally occurs. Traffic congestions in Istanbul are expected to worsen in the future, with projected increasing population, 3 millions of vehicles on-road and ca. 1000 new vehicles entering the traffic every day (Kanakidou et al., 2011; TUIK, 2012). These vehicles are mainly using fossil fuels in Istanbul, and more than half of them diesel (TUIK, 2012). These facts lead to prolonged exposure of humans to high concentrations of BC in Istanbul. Therefore, the availability of BC observations and their source attribution is important for the mitigation strategies.

The present study aims to quantify BC levels and their variability in the megacity of Istanbul. For this purpose, BC concentrations in Istanbul have been measured using an aethalometer between 2009 and 2011. First measurement campaign has been conducted at 4 different locations throughout the city in spring 2009 and spring 2010. These monitoring sites have been selected on the basis of their differences in traffic densities as provided by the Istanbul Metropolitan Municipality Traffic Department. During the second campaign, continuous measurements have been conducted at a high traffic site for an entire year (from August 2010 to July 2011). In addition to the BC measurements, $PM_{2.5}$ (PM with diameter smaller than 2.5 μm) has been simultaneously collected by an air sampler. A description of the measuring sites, the sampling and analysis methods, and the traffic density data are provided in the Methods section. The data are analysed in order to understand the spatial as well as temporal distributions of BC and BC relation to traffic density over the megacity of Istanbul.

2. Material and methods

2.1. Measuring sites

Istanbul is a megacity with over 15 million inhabitants (making approximately 20% of Turkey's total population) (OECD, 2008) and it is responsible for the 40% of Turkey's industrial activities. The megacity

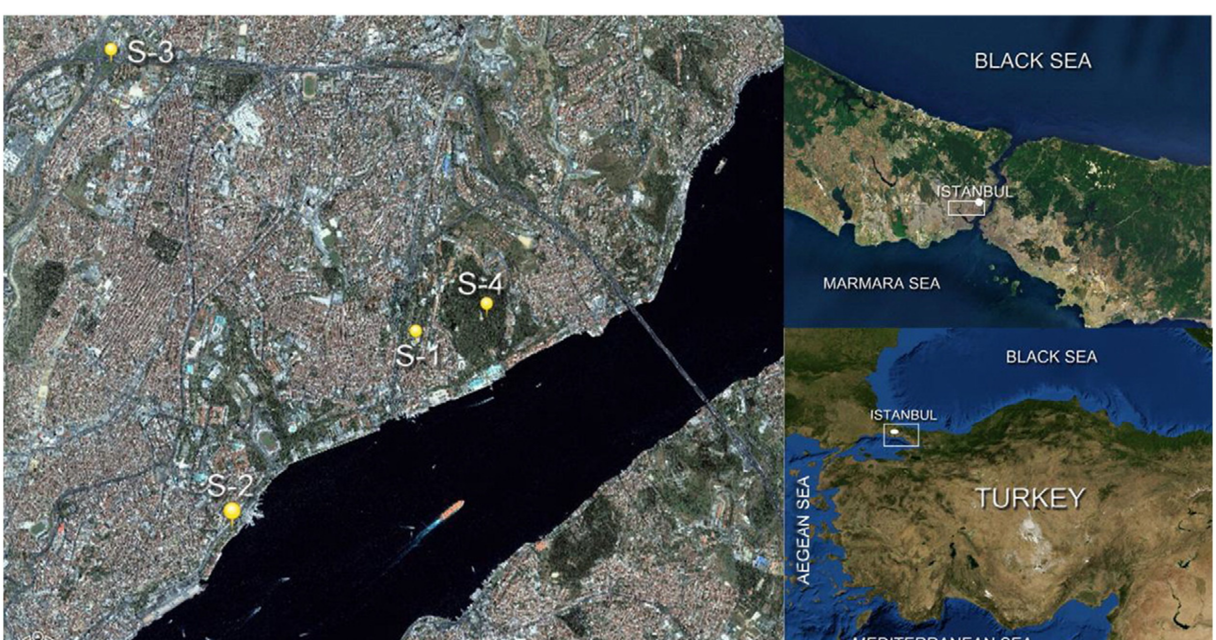

Fig. 1. Locations of the sampling sites: S1, Barbaros Blvd.; S2, Kabatas; S3, Okmeydani; and S4, Yildiz Park.