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Chemical composition of size-resolved particulate matter at near-freeway and urban background sites in the greater Beirut area

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HIGHLIGHTS

- PM levels are dominated by $PM_{10-2.5}$ and $PM_{0.25}$ (36–43% of PM_{10}).
- PM levels are 1.3–2.6 times greater at the freeway than background location.
- PM at the background site is mainly influenced by secondary sources.
- PM at the freeway is dominated by vehicular emissions from road dust and tailpipe.
- EC and PAHs levels are 5 and 3.7 times greater at the roadside than I-710 in LA.

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ABSTRACT

To characterize road-traffic emissions in the greater Beirut area, size-resolved $PM_{10-2.5}$, $PM_{2.5-0.25}$ and $PM_{0.25}$ samples were concurrently collected at near-freeway and background sites. While particle mass levels were 1.3–2.6 times greater at the roadside than background location, $PM_{10-2.5}$ and $PM_{0.25}$ prevailed at both sites (36–43% of PM_{10}). A chemical mass closure showed that $PM_{10-2.5}$ was mostly composed of crustal material, contributing to 12–23% of its mass across sites. On the other hand, in $PM_{2.5-0.25}$ and $PM_{0.25}$, organic matter (46–56%) was dominant at the roadside location, while secondary ions (SI, 54–68%) were more abundant at the background site. In the vicinity of the freeway, organic carbon (OC) levels varied from 4 μg m^{-3} in $PM_{10-2.5}$ to 10.1 μg m^{-3} in $PM_{0.25}$, exceeding those at the background site by 4–7 times. In contrast, OC was largely water-soluble at the background location, with its water-soluble fraction displaying comparable $PM_{2.5-0.25}$- and $PM_{0.25}$-concentrations at both sites, corroborating its regional secondary origin. $PM_{0.25}$-elemental carbon (EC), which dominated overall EC mass, was 7-fold greater at the near-freeway than background location, indicating a contribution from diesel or also smoking vehicles to road-traffic emissions. $PM_{2.5}$-SI showed fairly uniform concentrations across sites, confirming their mainly regional source. Polycyclic aromatic hydrocarbons (PAHs) were undetected at the coastal background site, whereas their levels peaked at 11.5 ng m^{-3} in proximity to the freeway, with the majority confined to $PM_{0.25}$. Compared to other roadways, organic compounds at the freeway location exhibited high hopanes plus steranes-to-total carbon ratios (0.16–1.1 ng μg^{-1}), indicative of different engine configurations, fleet or also lubricating oil formulation. At both locations, $PM_{0.25}$-bound n-alkanes (C_{19}–C_{34}) showed a predominance of high molecular weight homologues and no carbon number preference, suggesting their likely road dust source. Findings of this work indicate that ambient particles at the urban background site in Beirut are mainly of secondary origin and exist in significantly lower levels relative to PM at the roadside location. Particle emissions at the near-freeway site markedly exceed those measured at roadways in similar areas in the U.S. with comparable meteorology and geomorphology. Compared to I-710—a diesel-impacted freeway in Southern California—levels of potentially toxic vehicular tracers are 5 (EC) and 3.7 (PAHs) times greater at the freeway in this study.

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1. Introduction

Mounting epidemiological evidence indicates significant associations between exposure to particulate matter (PM) and increased risk of adverse health outcomes (Peters et al., 2001; Pope et al., 2002). In urban areas, motor vehicles are the primary source of PM (Sternbeck et al., 2002; Westerdahl et al., 2005), with populations in close proximity to trafficked-roadways being most susceptible to particle-induced health effects (Tonne et al., 2007). PM vehicular emissions, derived from both exhaust and abrasion (Sternbeck et al., 2002), are composed of potentially toxic air pollutants, such as organic carbon (OC), polycyclic aromatic hydrocarbons (PAHs) and transition metals (Cho et al., 2005; See et al., 2007). Some of these components (OC, PAHs) also dominate the ultrafine particle-mode ($d_p < 0.1–0.2$ μm) because of its increased number and surface area relative to larger coarse ($PM_{10–2.5}$, 10 μm $< d_p <$ 2.5 μm) and fine ($PM_{2.5}$, $d_p <$ 2.5 μm) PM (Hughes et al., 1998; Morawska et al., 1998).

Lebanon, a country in the eastern Mediterranean basin, represents one case study of developing regions, where particle levels routinely exceed the World Health Organization (WHO) guidelines (Saliba et al., 2010). Lacking an effective mass transportation system (MoE/URC/GEF, 2012), road traffic emissions are a major cause for its elevated PM levels, particularly in urban areas. The rate of car ownership is estimated as 3 persons/car and is expected to further increase (MoE/URC/GEF, 2012). Accurate characterization of traffic-associated particle emissions in Lebanon is thus essential.

Investigation of PM in Lebanon has been generally restricted to urban areas and has focused on determining the ionic and elemental content of coarse or fine PM (Kouyoumdjian and Saliba, 2005; Massoud et al., 2011; Saliba et al., 2010). Very few studies examined PM-organic matter (Shaka and Saliba, 2004), smaller particle-size modes or PM composition at roadways. To determine chemically-speciated and size-resolved properties of traffic-related particle emissions in Lebanon, coarse, accumulation ($PM_{2.5–0.25}$, 2.5 μm $< d_p <$ 0.25 μm) and quasi-ultrafine ($PM_{0.25}$, $d_p <$ 0.25 μm) PM samples were collected at two contrasting locations in the greater Beirut area. Sampling sites included near-freeway and background locations. To the best of the authors' knowledge, this is the first study to provide a comparative and comprehensive analysis of size-fractionated ambient PM in Lebanon. Results are also evaluated in the context of metropolitans and roadways worldwide. Findings of this work provide the much-needed information on road-traffic emissions in Lebanon and could ultimately aid in establishing air pollution control strategies, currently very limited, in this region.

2. Methodology

2.1. Sampling sites

The sampling campaign was conducted in the greater Beirut area at two contrasting sites, including urban background and near-freeway locations, as shown in Fig. 1. The background site was situated at the American University of Beirut (AUB), in a location overlooking AUB campus from the south/east and the Mediterranean coast from the north/west. It is surrounded by a dense vegetation cover and mostly pedestrian roads, with the nearest street located about 150 m west of the site. This coastal roadway separates the site from the Mediterranean Sea and experiences fairly high traffic activity throughout the day, particularly during rush hours (7–9 a.m. and 4–7 p.m.). The sampling site is also within 1.5 and 2.5 km of a leisure yacht club and the commercial port of Beirut, respectively. Particle levels at this coastal site are commonly

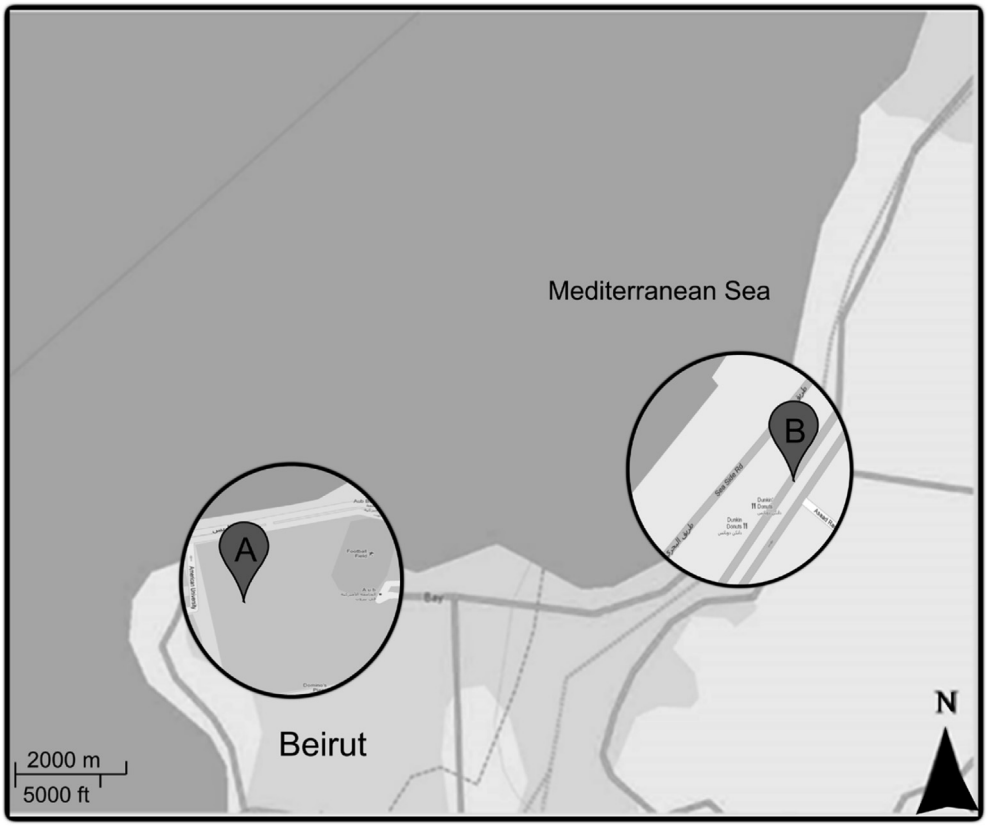

Fig. 1. Map of the urban background (A) and near-freeway sites (B).