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Impact of local traffic exclusion on near-road air quality: Findings from the New York City "Summer Streets" campaign

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ABSTRACT

We monitored curbside airborne particulate matter (PM) concentrations and its proinflammatory capacity during 3 weekends when vehicle traffic was excluded from Park. Ave., New York City. Fine PM concentration peaked in the morning regardless of traffic while ultrafine PM was 58% lower during mornings without traffic. Ultrafine PM concentration varied linearly with traffic flow, while fine PM spiked sharply in response to random traffic events that were weakly correlated with the traffic signal cycle. Ultrafine PM concentrations decayed exponentially with distance from a cross street with unrestricted traffic flow, reaching background levels within 100 m of the source. IL-6 induction was typically highest on Friday afternoons but showed no clear relationship to the presence of traffic. The coarse fraction (>2.5 μm) had the greatest intrinsic inflammatory capacity, suggesting that coarse PM still warrants attention even as the research focus is shifting to nanoparticles.

1. Introduction

In recent years, numerous epidemiological studies have identified increased risks of adverse health effects in populations living, working or going to school near large roadways (Adar and Kaufman, 2007; Brugge et al., 2007; Samet, 2007; Salam et al., 2008). These include respiratory and cardiovascular diseases, premature mortality, birth and developmental defects, and cancer. The extent of elevated pollutant concentrations and the chemical and physical characteristics of pollutants near the road compared to the background depends on a variety of factors, including traffic activity, atmospheric conditions, topography, and structures near the road (Baldauf et al., 2008). Many studies have addressed the impact of traffic on ambient particulate concentrations near major roads and highways (Kaur et al., 2005b; Bowker et al., 2007; Zhang et al., 2004, 2005), during large-scale traffic exclusions associated with the Olympic Games (Friedman et al., 2001; Westerdahl et al., 2009; Wang et al., 2009) and speed limit reductions (Dijkema et al., 2008). The impact of local short-term traffic exclusion from city streets, however, is largely unknown despite its intuitive appeal as a mitigation measure for air pollution. This knowledge gap derives in part from the common belief that regional air quality is the dominant factor determining ambient PM2.5 (Kinney et al., 2000). However, regional data are typically collected from rooftop monitors with long time integrals to deliberately eliminate the impacts of short term, local events. We suspected that the high frequency "noise" contained in local traffic related events would be informative, especially for quantifying exposure risk to pedestrians.

In August 2008, New York City Mayor Bloomberg initiated the Summer Streets program during which Park Ave. was closed to vehicular traffic on three consecutive Saturday mornings to promote clean air and good health through exercise. The event was widely publicized as a way to enjoy physical exercise in clean air without having to leave the city. Bicycles were even available free of charge at different stations along Park Ave.. Summer Streets afforded a unique opportunity to study the impact of traffic on near-road particulate matter (PM) in a heavily congested and densely populated area in a major city. On all three Saturdays and preceding Fridays during Summer Streets, we monitored real time airborne PM concentrations and collected size fractionated PM samples for further analysis at strategic points along the closure route. This study quantifies the effects of short-term traffic exclusion on street level PM. It will inform the discussion of best management

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practices to mitigate the impact of transportation on local air quality as well as the broader discussion of sustainable urban development.

2. Methods

2.1. Setting

On 3 Saturday mornings (August 9, 16, and 23, 2008) Park Ave. was closed to vehicular traffic between 7.00am and 1.00pm for 6.9 miles between the Brooklyn Bridge and Central Park (Fig. 1). In order to accommodate traffic needing to cross Park Ave. several cross streets remained open, including 23rd St., providing an opportunity to study neighborhood scale effects on PM dispersion along the Park Ave. axis. The study area included 5 blocks along Park Ave., located in Community District 6 on the east side of Manhattan in New York City, USA. This is a mixed-use district that is zoned for manufacturing and high-density residential land uses with commercial space at street level. The buildings range up to 56 m in height with setbacks required for all stories above 38 m. Both Park Ave and 23rd St are approximately 30 m wide, including 2 lanes of traffic in both directions, parking lanes on both sides of the streets and sidewalks. Park Ave. has a 2.5 m median strip containing shrubs and small trees in raised planter boxes. There was $<$1 m difference in ground elevation among our sampling points.

This study quantifies the spatio-temporal effects of this traffic exclusion on the concentrations of fine particulate matter (FPM), ultrafine particulate matter (UFP), and their proinflammatory capacity. To monitor these effects, in real time, we used two different kinds of particle counters and a video traffic counter. In addition we used multistage cascade impactors to collect particles onto filters for subsequent lab analyses to determine the inflammatory capacity of different size particles. Specifics are described below.

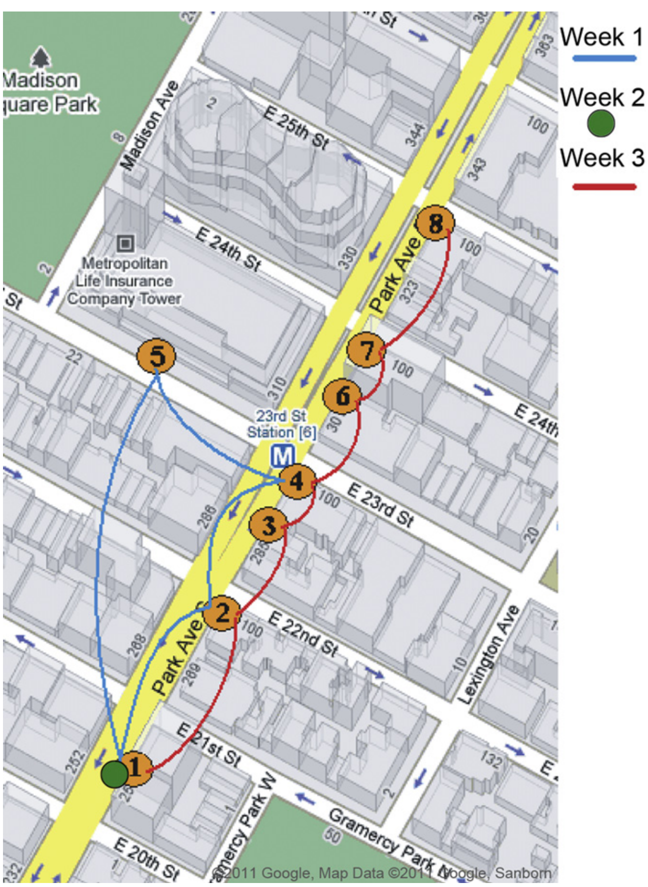

Fig. 1. Monitoring Route Map for "Summer Streets" Campaign. The circled numbers represent the monitoring stations. FPM was monitored at Stations 1 and 5 throughout the study while UFP was measured at both these and the other stations in different weeks depending on the objective for each week. Note that in Week 2 both FPM and UFP were monitored at the same station on Park Ave. (green dot). Map courtesy of Google.

2.2. Instrumentation and sampling

We positioned one fixed curbside monitor at mid-block on the east side of Park Ave. between 20th and 21st Streets. A second monitor at mid-block on the south side of 23rd St. logged simultaneous measurements on this cross street with uninterrupted traffic. Each station included a portable aerosol spectrometer (PAS; Grimm Model 1.187) to monitor PM counts in 14 size classes (i.e., 0.3–0.4; 0.4–0.5; 0.5–0.65; 0.65–0.8; 0.80–1.0; 1.0–2.0; 2.0–3.0; 3.0–4.0; 4.0–5.0; 5.0–7.5; 7.5–10.0; 10.0–15.0; 15.0–20.0; $>$20.0 μm) between 0.3 and 20 μm every 6 s, two Sioutas 5 stage cascade impactor (SKC) and pumps (SKC, Leland Legacy) to collect size fractionated particles for subsequent immunoassays for proinflammatory cytokine induction, and a hot wire anemometer (AirFlow) for periodic hand checking of wind speed and direction. A 6 s sampling frequency was used on the PAS to approximate the human inhalation rate and thus estimate exposure risk. Laptop computers connected to the PAS units allowed us to note dynamic changes in particle counts (number/m^3) and record traffic conditions associated with these events. The PAS instruments were cross calibrated by running them synchronously at the Park Ave. sampling location for 1 h with the inlets of the isokinetic probes positioned immediately adjacent to one another. The average of the 2 instruments was calculated for each size class every 6 s, readings from both instruments were regressed against the mean for each interval, and the resulting linear equations were used to make a post hoc corrections for intrinsic differences between the instruments.

In order to determine the effects of time of day and presence/absence of traffic, separate sets of samples were collected during the morning (7.00am –1.00pm) and afternoon (1.00pm-6.00pm) periods at both static sampling locations, yielding a total of 4 sets of filters each day. The impactor pumps were operated at 9 l/min ± 10 ml according to the manufacturer's specifications. All 4 pumps were calibrated prior to each day's collection using a field standard (DriCal DC-Lite Primary Flow Meter) with in-line cascade impactors loaded with a solid 37 mm PTFE filter to provide appropriate back pressure. During field measurements, sample inlets for the particle counters and the impactors were positioned 1.6 m above the pavement to approximate human height.

In addition to the 2 fixed locations for fine PM, we measured ultrafine particles (UFP) using a roving electrical mobility spectrometer (TSI 3039 Fast Mobility Particle Sizer^{TM}, FMPS) operated at a flow rate of 10 l min^{-1}. Particles in 32 size ranges from 5 nm to 560 nm were sampled every second. We moved FMPS among multiple locations to obtain information about the spatio-temporal variation in UFP (Fig. 1). 23rd St. remained open to traffic while Park Ave. was closed. To quantify pollution gradients away from the 23rd St. source, Stations 1–4 were located south of the 23rd St. intersection with Park Ave. while Stations 6–8 were north of the intersection. Station 5 was located at mid-block on 23rd St.. The FMPS was mounted on a cart equipped with deep draw batteries and AC/DC inverters to provide electrical power for prolonged operation. The sampling was conducted only while the FMPS was stationary. The FMPS was calibrated and certified by the manufacturer prior to our field campaign to give total number concentration within ±20% of actual value. We also calibrated the FMPS each day using the manufacturer-supplied equipment and procedure to maintain acceptable noise levels in electrometers. The FMPS has been widely used in mobile platform measurements, and vibration does not affect the instrument performance (Hu et al., 2009; Wang et al., in press).

We could not monitor UFP in 2 locations simultaneously with only one FMPS, so instead of co-locating the instrument at the Park Ave. station throughout the campaign, we moved it among multiple locations to obtain information about the spatio-temporal variation in UPM. Each week had several broad objectives: During Week I (August 8–9, 2008), the FMPS was positioned at Station 1 for 1 h and then was moved among stations 2, 4, and 5 for 15 min periods throughout the day. Our goal was to determine the time required for UFP concentrations to reach steady state after traffic was re-introduced. During Week II (August 15–16, 2008), we co-located the FMPS with the fine PM counter on Park Ave. (Station 1) to permit direct comparison of the responses of fine and ultrafine PM to traffic. During Week 3 (August 22–23, 2008), we moved the instrument for 15 min monitoring periods among three locations both north and south from the 23rd St. intersection to detect dispersion gradients along Park Ave.

We monitored traffic continuously on both streets using a video detection system (Autoscope Solo^{TM} Terra traffic imaging system) positioned on the 18th floor of 257 Park Ave in the Environmental Defense Fund office. The video and air pollutant measurements were synchronized each day before the sampling started and we observed minimal drift during any sampling period.

2.3. Biomarkers

2.3.1. Particle collection and extraction

We collected size fractioned particles to test their ability to induce the proinflammatory cytokine Interleukin (IL)-6 in murine macrophage cultures as a biomarker of proinflammatory responses known to be induced by urban PM (Hetland et al., 2005; Qu et al., 2010). Murine and human macrophages have been shown to respond similarly to PM (Obot et al., 2004). In order to determine the effects of time of day and presence/absence of traffic, separate sets of samples were collected during the morning (700–1300 h) and afternoon (1300–1700 h) periods