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Analysis of major air pollutants and submicron particles in New York City and Long Island

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HIGHLIGHTS

- One-year air quality data measured hourly at 2 urban sites in NYC and Long Island.
- Particle number resolved over 6 bins, gases, PM2.5 mass, EC/OC and sulfate measured.
- Primary and secondary organic carbon are estimated using the EC tracer method.
- Seasonal, weekly, diurnal cycles and relationships with weather are investigated.
- Location of the potential sources and role of regional transport are discussed.

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ABSTRACT

A year-long sampling campaign of major air pollutants and submicron particle number size distributions was conducted at two sites taken as representative of city-wide air quality in New York City and Long Island, respectively. A number of species were quantified with hourly time resolution, including particle number concentrations in 6 size ranges (20–30 nm, 30–50 nm, 50–70 nm, 70–100 nm, 100–200 nm, and >200 nm), nitrogen oxides, sulfur dioxide, ozone, carbon monoxide, methane, non-methane hydrocarbons, $PM_{2.5}$ mass concentration and some PM major components (sulfate, organic and elemental carbon). Hourly concentrations of primary and secondary organic carbon were estimated using the EC tracer method. Data were matched with weather parameters and air parcel back-trajectories. A series of tools were thus applied to: (i) study the seasonal, weekly, diurnal cycles of pollutants; (ii) investigate the relationships amongst pollutants through correlation and lagged correlation analyses; (iii) depict the role of atmospheric photochemical processes; (iv) examine the location of the potential sources by mean of conditional bivariate probability function analysis and (v) investigate the role of regional transport of air masses to the concentrations of analyzed species. Results indicate that concentrations of NO_x, SO_2, CO, non-methane hydrocarbons, primary OC and EC are predominantly determined by local sources, but are also affected by regional transports of polluted air masses. On the contrary, the transport of continental polluted air masses has a main effect in raising the concentrations of secondary $PM_{2.5}$ (sulfate and secondary organic carbon). By providing direct information on the concentrations and trends of key pollutants and submicron particle number concentrations, this study finally enables some general considerations about air quality status and atmospheric processes over the New York City metropolitan area.

1. Introduction

Over the last several decades, an increasing number of epidemiologic studies have concluded that ambient air pollution and particularly airborne particulate matter (PM) are causal risk factors for many adverse human health effects, including respiratory illnesses (Götschi et al., 2008; Laumbach and Kipen, 2012; Adam et al., 2015), cardiovascular diseases (Anderson et al., 2012; Shah et al., 2013; Franklin et al., 2015) and carcinogenic effects (Turner et al., 2011; Pope et al., 2011; Loomis et al., 2013). Given the

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biological evidence, outdoor air pollution and airborne particulate matter (PM) have been categorized in class 1 by the International Agency for Research on Cancer in 2013, i.e. known carcinogenic to human beings (Straif et al., 2013).

A significant drop in the ambient concentrations of many air pollutants has been measured in many developed countries (including U.S.) as a result of implementation of legislation and regulations through the application of successful abatement technologies and other mitigation measures (Parrish et al., 2011; Colette et al., 2011). Current United States air quality is regulated through the National Ambient Air Quality Standards (NAAQS) that set limit values to be attained across U.S. for pollutants considered harmful to public health and the environment, i.e. nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), carbon monoxide (CO), PM with aerodynamic diameters less than 10 and 2.5 μm (PM_{10} and $PM_{2.5}$, respectively) and particle-bound lead.

New York City (NYC) is the most populous city in the U.S. with ~8.5 million inhabitants in 2014. However, the population reaches almost 20 million inhabitants when considering the whole New York–New Jersey–Pennsylvania metropolitan area. Air quality has generally improved since 1970s across NYC (NYC Department of Health and Mental Hygiene, 2013a). For example, Parrish et al. (2011) have reported slow improvements for both ozone and $PM_{2.5}$ between 2000 and 2010, while Duncan et al. (2016) have observed a strong decrease (−45.5%) in NO_2 from 2005 to 2014. Downward trends in air pollutants across New York were observed by Buckley and Mitchell (2011), while substantial decreases in $PM_{2.5}$ mass and major components across New York since the early 2000s were reported by Rattigan et al. (2016). Currently, NAAQS are generally not exceeded in NYC (NY State Dep. Environmental Conservation, 2016), except for ozone (marginal to moderate non-attainment). However, air pollution still remains a serious concern for policy-makers and the scientific community in NYC as well as in the whole metropolitan area. Even with attainment of the NAAQS, it has been estimated that ambient concentrations of $PM_{2.5}$ in NYC still contribute to more than 3000 deaths every year, 2000 hospital admissions for lung and heart conditions, and approximately 6000 emergency department visits for asthma in children and adults (NYC Department of Health and Mental Hygiene, 2013a; b).

Despite the number of stations measuring air quality and the large number of scientific studies available in literature, limited data are still available for some air pollutants, including submicron particles (SMPs, <1 μm) and ultrafine particles (UFPs, less than 100 nm in diameter), which have been widely associated with severe adverse effects upon human health (e.g., Knibbs et al., 2011; Strak et al., 2012; Ostro et al., 2015; Lanzinger et al., 2016). Moreover, limited studies have focused on air pollution climate, i.e. on the relationships amongst air pollution and weather.

This study investigates air pollutions in NYC and Long Island through the analysis of hourly-resolved concentrations of common gaseous air pollutants, $PM_{2.5}$ mass and $PM_{2.5}$-bound major species, submicron particle number concentrations and their size distributions, with special emphasis for UFPs. Intensive sampling campaigns were simultaneously conducted at two sites: Queens (NYC) and Eisenhower Park (Long Island). A large set of air pollutants was measured over 1 year (2009–2010) at 1 h intervals. Datasets include: (i) key gaseous air pollutants, i.e. nitrogen oxides ($NO + NO_2 \equiv NO_x$), sulfur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), methane (CH_4), non-methane hydrocarbons (NMHCs), total hydrocarbons (THCs); (ii) $PM_{2.5}$ mass and $PM_{2.5}$-bound species, such as sulfate (SO_4^{2-}), organic (OC), elemental (EC) and total (TC) carbon; (iii) particle number concentrations (PNC) over 6 size ranges (20–30 nm, 30–50 nm, 50-70 nm–70–100 nm, 100–200 nm, and 200–~1000 nm). The concentrations of primary and secondary organic carbon were estimated using an EC tracer method (Section 3.1). The seasonal, weekly, and diurnal cycles of the air pollutants were investigated in detail along with several derived variables (Sections 4.1 and 4.2). Data were matched with micro-meteorological parameters and analyzed to explore the possible effects of weather upon the air quality and to locate the probable local emission sources (Section 4.4). A back-trajectory-based hybrid model was applied for assessing the potential role of regional and long-range transports upon air quality (Section 4.5). These results give important insights into pollutant sources, influences upon concentrations and key inter-relationships in pollutant behaviors and presents a synthesized description of pollution climate regimes for typical urban sites in NYC or even for large cities across northeastern U.S. having similar anthropogenic activities and weather conditions.

2. Materials and methods

2.1. Site description

Measurements were made from June 2009 to July 2010 at two sites categorized as urban, i.e. representative of city-wide background pollution concentrations. Queens College (QC: 40° 44.225′N; 73° 49.295′W; 24 m a.s.l.) is located in a high population density section of Queens County (Fig. 1) and it is representative of the New York City metropolitan area. QC is also affected by emissions from two traffic highways, i.e. the Long Island Expressway (I-495) and the Van Wyck Expressway (I-678). Eisenhower Park (EP: 40° 44.586′N 73° 35.132′W; 25 m a.s.l.) is situated on the border of a 3.8 km^2-wide public park located in Nassau County. The park is devoted to many entertainment and sport activities and is backed by unoccupied parklands. However, EP is also affected by: (i) heavy road traffic as it is adjacent to a 4 lane roadway that runs parallel to the site in a NNW direction, within 22 m of a roadway in a W-WSW direction, and within 53 m of the roadway in a S direction; and (ii) emissions from a waste-to-energy conversion plant and from several restaurants close to the site (Fig. 1).

2.2. Experimental

Instruments were operated continuously over the sampling period to quantify ambient air pollutant concentrations with 1 h resolution time. A more extensive range of pollutants were monitored at QC (NO, NO_2, NO_x, SO_2, O_3, CO, CH_4, NMHCs, THC, $PM_{2.5}$, SO_4^{2-}, OC, EC, TC and SMP) than at EP (NO, NO_2, NO_x, SO_2, $PM_{2.5}$ and SMP).

Two ultrafine particle monitors (TSI Model 3031) were deployed at both sites to measure particle size distributions from 20 nm (electrical mobility diameter) to approximately $PM_{2.5}$ μm in six channels: 20–30 nm (ch1), 30–50 nm (ch2), 50–70 nm (ch3), 70–100 nm (ch4), 100–200 nm (ch5) and >200 nm (ch6). The instruments operated with $PM_{2.5}$ cyclones, i.e. the upper size was set to particles with an aerodynamic diameter less than 2.5 μm. The operating principle of the UFP monitor is based on diffusion charging of particles using a "Corona-Jet" charger (Medved et al., 2000), followed by size segregation in a differential mobility analyzer and detection via a sensitive electrometer.

U.S. EPA equivalent or reference methods were used for the gas measurements (Thermo Electron Corporation model 42C NO-NO_2-NO_x; model 43C SO_2; model 49C O_3; model 48C CO). Methane, Non-Methane Hydrocarbons (NMHCs), and total hydrocarbons (THC) were analyzed using flame ionization detector method (model APHA-360, HORIBA Ltd., Japan).

$PM_{2.5}$ mass concentrations were measured with tapered element oscillating microbalances (Thermo-Fisher Scientific TEOM