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A study of ambient fine particles at Tianjin International Airport, China

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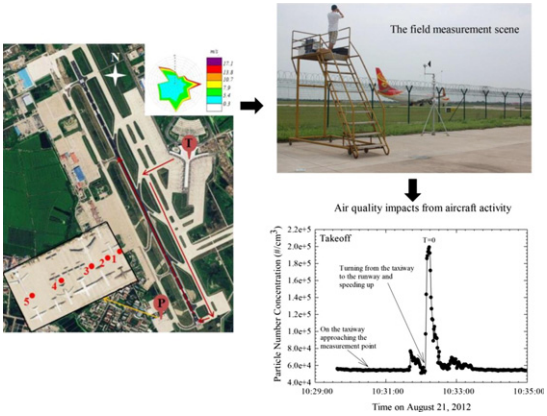
HIGHLIGHTS

- The first paper that researched aircraft-emitted UFPs in China.
- Experimental research on the effects of wind on particle number concentration
- Investigation on particle emissions during a cycle of aircraft takeoff and landing
- Particle size distributions at increasing distances downwind from the runway

GRAPHICAL ABSTRACT



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ABSTRACT

The total count number concentration of particles from 10 to 1000 nm, particle size distribution, and $PM_{2.5}$ (aerodynamic diameter ≤ 2.5 μm) mass concentration were measured on a parking apron next to the runway at Tianjin International Airport in China. The data were collected 250, 270, 300, 350, and 400 m from the runway. Wind direction and wind speed played important roles in determining the characteristics of the atmospheric particles. An inverted U-shaped relationship was observed between the measured particle number concentration and wind speed, with an average peak concentration of 2.2×10^5 particles/cm^3 at wind speeds of approximately 4–5 m/s. The atmospheric particle number concentration was affected mainly by aircraft takeoffs and landings, and the $PM_{2.5}$ mass concentration was affected mainly by the relative humidity (RH) of the atmosphere. Ultrafine particles (UFPs, diameter < 100 nm), with the highest number concentration at a particle size of approximately 16 nm, dominated the measured particle size distributions. The calculated particle emission index values for aircraft takeoff and landing were nearly the same, with mean values of 7.5×10^{15} particles/(kg fuel) and 7.6×10^{15} particles/(kg fuel), respectively. The particle emission rate for one aircraft during takeoff is two orders of magnitude higher than for all gasoline-powered passenger vehicles in Tianjin combined. The particle number concentrations remained much higher than the background concentrations even beyond 400 m from the runway.

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1. Introduction

Airports are important sources of particulate matter (PM) in urban areas (Zhu et al., 2011; Westerdahl et al., 2008; Hu et al., 2009). Numerous epidemiological studies have shown consistent associations between exposure to airborne micro and nano particles and exacerbation of various respiratory and cardiovascular diseases (Lin et al., 2002; Jerrett et al., 2005). For example, an increased risk of hospital admissions around the Rochester and LaGuardia airports has been observed (Lin et al., 2008).

In response to increasing concern regarding exposure to airport-related particulate pollutants, many studies have been conducted to examine the characteristics of these pollutants at airports. Early studies of airport-related particulate pollutants have focused on the mass concentrations and chemical compositions of particulate pollutants (Childers et al., 2000; Woody et al., 2011; Yu et al., 2004; Unal et al., 2005; Fang et al., 2007). Recent studies have examined UFPs, which are more toxic than larger particles at the same mass concentration (Donaldson et al., 2001; Brown et al., 2000). Previous UFP studies have found that traffic-related emissions were the most significant contributors to UFP levels in urban areas (Hitchins et al., 2000; Zhu et al., 2002b). However, a study of aircraft emissions at the Santa Monica Airport showed that UFP emissions from aircraft per kg of fuel consumed were 16–100 times higher than those from light-duty vehicles and 5–8 times higher than those from heavy-duty vehicles (Hu et al., 2009). A recent study found that particle number concentrations near a regional airport were attributable mainly to aircraft activities (Klapmeyer and Marr, 2012). Data collected downwind of aircraft takeoffs at Los Angeles International Airport showed very high number concentrations of UFPs. During some monitored takeoffs, the total particle number concentration exceeded 10^7 particles/cm^3 (Zhu et al., 2011). Hsu and colleagues found significant higher increases in UFPs at Los Angeles International airport due to landing and takeoff activity: a 2×10^6–7×10^6 particles/cm^3 increase at a monitor at the end of the departure runway, and a 8×10^4–1.4×10^5 particles/cm^3 increase at a site 250 m downwind from the runway (Hsu et al., 2013). Mazaheri and colleagues examined particle emissions from commercial aircraft at each stage of the takeoff and landing cycle. They found that particles were predominantly within the size range of 4–100 nm in diameter in all cases and that particles larger than 118 nm originated from background aerosols rather than the aircraft plume (Mazaheri et al., 2009). Herndon and colleagues observed two modes, one at an aerodynamic diameter of 90 nm and a second at or below the instrument cutoff (<30 nm) (Herndon et al., 2005). In another study carried out at the Oakland International Airport, the particle size distributions from aircraft emissions were typically found to be bimodal, with a nucleation mode consisting of freshly nucleated PM and an accumulation mode consisting mostly of PM soot with some condensed volatile material (Lobo et al., 2012). The modal diameters at takeoff and idle were found to be 13.2 nm and 13.1 nm, respectively (Lobo et al., 2012). Hu and colleagues reported that even 660 m downwind of a runway, the average UFP concentrations were still an order of magnitude above background levels at the Santa Monica Airport (Hu et al., 2009). Similarly, a study carried out at the Los Angeles International Airport indicated that UFPs could persist for nearly 1 km from the end of the runway (Westerdahl et al., 2008).

Based on a large number of studies conducted in developed countries, Europe and the U.S. are taking measures to improve the air quality at airports. European airports, e.g., in Switzerland, Sweden and the UK, have already applied airport emission charging schemes, and EU air quality directives may result in the introduction of more local air quality management schemes and emissions-related charging regimes in the future (EASA, 2010). To reduce all sources of airport ground emissions, especially PM, the U.S. Federal Aviation Administration (FAA) created the Voluntary Airport Low Emissions Program (VALE) in 2004 (FAA, 2007). China is an important aviation market, and nearly a quarter of the growth in the global aviation industry is expected to be associated with China (IATA, 2012). In view of the growing public concern regarding airport pollution, and the rapid growth of aviation travel in China, the objective of this study was to systematically evaluate PM levels, especially $PM_{2.5}$ and UFPs, and analyze the physical characteristics, transport behavior and the influencing factors of particulates in the area around Tianjin Airport.

2. Experimental method

2.1. Measurement locations

Tianjin International Airport is located east of Tianjin, at 39°07′ N, 117°20′ E, and has a passenger throughput of more than 7 million passengers per year. Five sampling sites were located on an abandoned parking apron without any active aircrafts or ground vehicles on the southwest side of the airport. The sites were oriented along a line perpendicular to the runway at distances of 250, 270, 300, 350, and 400 m (Fig. 1). In many prior studies, the sampling sites were located approximately in line with the runway because the runways were designed to be oriented with the direction of the prevailing wind (Hu et al., 2009; Zhu et al., 2011; Lobo et al., 2012). In this study, because of the limitations of the experimental geographical conditions, the sampling sites were located perpendicular to the runway. But in many cases, the sampling sites were also located downwind of the runway due to the variable wind direction during sampling days. It should be noticed that the distances to the runway are not typically the particle transport distances between the runway and the sites, as the wind direction was rarely perpendicular to the runway. The measurements were taken during the daytime on August 20–28, 2012, from 7:00 AM to 19:00 PM. When an aircraft took off, it started from the front of the terminal and traveled along the taxiway until it arrived at either the southern or northern end of the taxiway, after which it turned approximately 180°, accelerated and took off. When an aircraft approached, it landed on either the southern or northern end of the runway and taxied to the parking apron. During the morning of August 20 and the 12 h of daytime on August 23 and 24, aircraft took off from and landed on the northern end of the runway. During the remainder of the week, aircraft took off from and landed on the southern end of the runway. The aircraft takeoff and landing orientations were changed due to the changes of prevailing wind direction. On average, 63 aircraft took off and 67 landed on each sampling day. The flight activity number was almost the same during each test hour.

2.2. Sampling and instrumentation

Two condensation particle counters (CPC 3007, TSI, Inc., St. Paul., MN) were used to measure the particle number concentration of particles ranging in size from 10 to 1000 nm, with a maximum concentration detection limit of 10^5 particles/cm^3, and a 50% size detection threshold of 10 nm. According to the instrument specification, the accuracy of the concentration readings up to 10^5 particles/cm^3 is $\pm$20%. Hämeri et al. (2002) reported that when particle concentration was up to 4×10^5 particles/cm^3, the coincidence of the CPC 3007 would be serious, and measurements should be corrected. The two counters had been calibrated by the manufacturer and an inter-comparison was made between the instruments in order to ensure the comparability of the results. To measure the $PM_{2.5}$ mass concentration, an optical instrument (DustTrak 8530, TSI, Inc., St. Paul., MN) (Wang et al., 2009) was used. It was calibrated by the manufacturer and was also calibrated to the local aerosols via the gravimetric method. A calibration factor of 1.1 was obtained. These instruments were set to record particle concentration data every second. An aerosol monitoring system (AGM 1500, MSP, Inc., Shoreview, MN) was used to measure particle sizes from 15 to 600 nm. Twenty-four channels were adjusted, with each channel tested for 1 s to capture the temporal variability in the particle number