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Using mobile monitoring to characterize roadway and aircraft contributions to ultrafine particle concentrations near a mid-sized airport

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HIGHLIGHTS

- We used mobile monitoring to estimate source contributions to UFP near an airport.
- Autoregressive integrated moving average models included aircraft and traffic terms.
- UFP was elevated near major roadways, near the airport, and during LTO activity.
- Our methods provide insight in settings where emissions vary in space and time.

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ABSTRACT

Ultrafine particles (UFP) have complex spatial and temporal patterns that can be difficult to characterize, especially in areas with multiple source types. In this study, we utilized mobile monitoring and statistical modeling techniques to determine the contributions of both roadways and aircraft to spatial and temporal patterns of UFP in the communities surrounding an airport. A mobile monitoring campaign was conducted in five residential areas surrounding T.F. Green International Airport (Warwick, RI, USA) for one week in both spring and summer of 2008. Monitoring equipment and geographical positioning system (GPS) instruments were carried following scripted walking routes created to provide broad spatial coverage while recognizing the complexities of simultaneous spatial and temporal heterogeneity. Autoregressive integrated moving average models (ARIMA) were used to predict UFP concentrations as a function of distance from roadway, landing and take-off (LTO) activity, and meteorology. We found that distance to the nearest Class 2 roadway (highways and connector roads) was inversely associated with UFP concentrations in all neighborhoods. Departures and arrivals on a major runway had a significant influence on UFP concentrations in a neighborhood proximate to the end of the runway, with a limited influence elsewhere. Spatial patterns of regression model residuals indicate that spatial heterogeneity was partially explained by traffic and LTO terms, but with evidence that other factors may be contributing to elevated UFP close to the airport grounds. Regression model estimates indicate that mean traffic contributions exceed mean LTO contributions, but LTO activity can dominate the contribution during some minutes. Our combination of monitoring and statistical modeling techniques demonstrated contributions from major surrounding runways and LTO activity to UFP concentrations near a mid-sized airport, providing a methodology for source attribution within a community with multiple distinct sources.

Abbreviations: ARIMA, autoregressive integrated moving average; GPS, global positioning systems; LTO, landing and take-off; PAH, polycyclic aromatic hydrocarbon; $PM_{2.5}$, fine particulate matter; PVD, T.F. Green International Airport; UFP, ultrafine particles; WCPC, water-based condensation particle counter.

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1. Introduction

In complex environments with multiple types of local air pollution sources, it can be challenging to characterize spatial patterns and disentangle source contributions. Source attribution is an important issue as it can inform effective control strategy or related policy. A variety of methods have been used to quantify the contribution from different suspected sources to ambient air pollutant levels, including chemistry-transport models (Arunachalam et al., 2011; Woody et al., 2011) and monitoring studies accompanied by chemical mass balance models (Schauer et al., 1996) or statistical modeling (Dodson et al., 2009; Hsu et al., 2012).

Any of these approaches is particularly challenging for ultrafine particles (UFP), because of its physical nature, rapid rates of formation, reaction and removal, and the lack of reliable emissions inventories, especially on short time scales. This is driven in part by the fact that UFP is not an officially regulated pollutant in most settings. Spatial gradients of UFP have been characterized in proximity to known sources such as roadways (Hagler et al., 2009) and airports (Zhu et al., 2011), but often focusing on distance-dependent gradients from a single source along a defined transect. This is in part because the cost and complexity of UFP monitors limit the number of sites that can be measured simultaneously.

A few monitoring studies have attempted to move beyond the limitations of fixed-site UFP monitoring, characterizing spatial patterns of UFP using mobile measurements. For example, Westerdahl et al. (2008b) used a mobile platform to measure UFP on multiple roadways in Los Angeles, but did not characterize spatial patterns across the monitoring domain. Other studies (Buonocore et al., 2009; Zwack et al., 2011) used mobile monitoring to characterize spatial and temporal patterns of UFP in urban settings in order to characterize contributions from traffic, but did not extend to other source types that may be important in some locations.

Many of the spatial patterns of UFP generally anticipated in near-roadway settings may not be present in proximity to an airport, which includes sources that operate on varied spatiotemporal scales. Aircraft have intermittent source contributions that differ in magnitude and spatial scale for arrivals, departures, and taxiing, leading to complex spatiotemporal patterns. Other airport sources (e.g., ground support equipment) may correlate over time with flight activity but with a differing dispersion profile, and roadways have more temporally consistent contributions, with different diurnal and wind-dependent patterns than those anticipated for aircraft. Mobile monitoring has been conducted in the vicinity of a major airport to characterize the effects of airport operations (Westerdahl et al., 2008a,b), but data were reported at a series of fixed locations rather than characterizing a spatial surface, and relative source contributions were not considered. To our knowledge, no studies have tried to formally determine the relative contributions of traffic, flight activity, and other airport-related sources to UFP concentrations in neighborhoods surrounding an airport, considering how those contributions vary over time and space. More generally, a near-airport setting allows for investigation of methods for characterizing source contributions, because of the multiple source types and their varying spatial and temporal patterns.

Within this study, we conducted mobile UFP monitoring in neighborhoods surrounding T.F. Green International Airport (PVD) in Warwick, RI, collecting UFP concentration data along with a location variable (using global positioning systems (GPS)) and source activity data. The goal of this study is to develop a method using mobile monitoring techniques to better understand how an ambient pollutant with complicated sources behaves over time and space near a complex environment such as an airport. In this study, we determine the contribution of flight activity and roadway traffic to UFP levels in five neighborhoods surrounding PVD, accounting for meteorological factors.

2. Materials and methods

2.1. Monitoring time and locations

A mobile monitoring campaign around PVD was designed to characterize the spatial patterns of air pollution in the communities surrounding the airport. The monitoring campaign was conducted in five residential areas for one week in both spring and summer of 2008 (March 24–27, June 2–6). The study area is pictured in Fig. 1. The target monitoring areas were selected to represent the closest residential areas to PVD, capturing a variety of wind directions and local sources. The five residential areas include the Fieldview community (southwest of the airport), Fire Station community (west to northwest of the airport), Lydick community (north to northeast of the airport), Pembroke community (east and northeast of the airport), and Strawberry Field community (southeast of the airport). These residential areas also complement stationary monitoring sites that were analyzed previously (Hsu et al., 2012), and all four stationary monitoring sites collecting continuous data were close to or on the mobile monitoring routes.

2.2. Monitoring study design

Before each monitoring session, we characterized the prevailing wind and dispatched one monitoring team to a residential community upwind of the airport and a second monitoring team to a downwind residential community. Two sets of backpacks were outfitted with the monitoring equipment and given to teams along with a scripted walking route to follow. These routes were created during the design phase of the study to provide broad spatial coverage while recognizing the complexities of simultaneous spatial and temporal heterogeneity, following the concept that the monitoring backpack will hit the same location multiple times at different times of the day. Each individual monitoring session lasted for 1.5–3 h, depending on the length of the route, with two to three of these sessions occurring per day. The first monitoring session started at approximately 8:30 AM, followed by the second session starting around 1 PM, and the last session starting at 5:00 PM or 7:00 PM. These times were chosen primarily to cover different times of the day reflecting local activities, as well as airport activities. Additionally, each mobile monitoring team carried monitoring log sheets and recorded the status of the equipment as a QA/QC measure.

2.3. Instrumentation

Field staff were outfitted with backpacks containing instrumentation that could measure 1-min averaged concentrations of UFP as well as fine particulate matter ($PM_{2.5}$) and particle-bound PAHs, although we only consider UFP in this analysis. Ultrafine particles were measured using Model 3781 Water-based Condensation Particle Counters (WCPC), connected to external batteries to facilitate mobile implementation. As these WCPCs are sensitive to movement and need to be maintained in a vertical position while sampling, field staff were trained on how to best carry the instruments, and there were some data losses associated with these measurements. In addition to the pollution-monitoring instruments, each backpack was outfitted with a GPS (Garmin GPSMAP 60CSx/GeoTX2) device to continuously record the spatial location of the backpack. The GPS device coded the spatial location