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The Los Angeles International Airport as a source of ultrafine particles and other pollutants to nearby communities

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Abstract

Air monitoring was performed in the vicinity of the Los Angeles International Airport (LAX) during the spring of 2003. The purpose of this monitoring was to determine the extent of airport emissions on downwind ambient air in a mixed use neighborhood that includes residences. A mobile air monitoring platform was developed and deployed to measure ultrafine particle numbers (UFP), size distributions, particle length, black carbon (BC), oxides of nitrogen (NO_x), and particle-phase polycyclic aromatic hydrocarbons (PM-PAH).

Pollutant levels were low at a coastal site upwind of the airport, with UFP ranging between 580 and 3800 counts cm^{-3}, oxides of nitrogen (NO_x) from 4 to 22 ppb, black carbon from 0.2 to 0.6 $\mu g\,m^{-3}$, and PM-PAH ranged from 18 to 36 $ng\,m^{-3}$. Markedly higher UFP counts, with average counts of approximately 50,000 cm^{-3}, were observed at a site 500 m downwind of the airport, which was strongly influenced by aircraft landings and where the community interfaced with airport facilities. Black carbon, PM-PAH, and NO_x levels were elevated to a lesser extent at downwind locations. Transient peaks in UFP corresponding to aircraft landings and takeoffs were evident. A maximum UFP count reached 4.8 million particles cm^{-3} downwind of a runway used by jet aircraft for takeoffs. Particle size distributions differed substantially between upwind and downwind locations. The particle numbers at the upwind site were dominated by particles of approximately 90 nm diameter while downwind sites were dominated by particles peaking at approximately 10–15 nm. Additional data obtained from a study of UFP levels conducted subsequently by a co-author indicates that aircraft-generated UFP persist up to 900 m from an LAX runway [Biswas, S., Fine, P.M., Geller, M.D., Hering, S.V., Sioutas, C., 2005. Performance evaluation of a recently developed water-based condensation particle counter. Aerosol Science and Technology 39, 419–427]. Considered together, these observations suggest that airport operations are associated with elevated levels of UFP much further downwind in the neighboring community than would have been predicted by prior studies of UFP from roadway-traffic.

Keywords: Jet; Particle size; Coastal air; Los Angeles; Black carbon

1. Introduction

Particles in urban air are of concern because of numerous reports that they can harm human health. Health impacts include aggravation of asthma,

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increased hospitalization rates, and even associations with increased death rates, especially among people with chronic cardiovascular or respiratory diseases (Brunekreef and Holgate, 2002; Dockery, 2001; Jerrett et al., 2005; Pope et al., 1991, 2002).

Recent research has implicated a new size-class of ambient PM, ultrafine particles (UFP), as especially harmful (Nemmar et al., 2001; Oberdorster, 2001; Utell and Frampton, 2000). Several studies have performed air monitoring to assess UFP levels in urban air, and it appears that vehicular traffic is a dominant source of these particles (Aalto et al., 2005; Hasegawa et al., 2004; Singh et al., 2006; Wehner et al., 2002). These particles have diameters of less than 100 nm (0.10 μm), and while they account for only a small fraction of the total mass of PM, UFP contribute the vast majority of particle numbers in air. They are emitted by combustion processes and also formed in outdoor and indoor air as a result of chemical reactions, photochemical processes, and nucleation. These particles have a large surface-area-to-mass ratio and may contain elemental carbon, sulfates, organic compounds, and metals.

Studies have been performed to assess the levels and nature of UFP on or near highways, with special emphasis on measuring the emissions from diesel trucks and buses (Bukowiecki et al., 2003; Kittelson et al., 2004; Molnar et al., 2002; Pirjola et al., 2004; Westerdahl et al., 2005; Zhu et al., 2002). On-roadway studies indicate that UFP levels can be as much as 15–20 times that seen in community air not influenced by heavy traffic, and that there tend to be two peaks in particle counts, one in the 10–20 nm size range and the other in the 80–90 nm size range (Kittelson et al., 2004; Westerdahl et al., 2005). On- and near-roadway measurements of BC, which is one component of UFP, indicate that BC is also elevated when diesel powered vehicles are present, especially when operated at highway speeds (Hitchins et al., 2000; Kittelson et al., 2004; Westerdahl et al., 2005). There may be many other sources of UFP that impact community air, such as ships, but few published studies have been performed to evaluate them (Lu et al., 2006; Saxe and Larsen, 2004).

The movement of UFP from roadways into community air and buildings was described by (Zhu et al., 2005). In studies performed near two Los Angeles freeways, measured levels of UFP, BC, and CO were observed to decline very quickly to near background levels by 300 m away from the roadway edge (Zhu et al., 2002).

During the winter and spring of 2003 we performed mobile air monitoring in various locations in the Los Angeles Basin to assess the nature of UFP and associated pollutants on roadways (Westerdahl et al., 2005). While measuring these pollutants on arterial roads near the Los Angeles International Airport (LAX) we found surprisingly high UFP levels. Numerous studies have been performed to measure (under controlled conditions) or model emissions from jet aircraft both on the ground and at altitude (Arnold et al., 1998; Brown et al., 1996; Herndon et al., 2005; Johnson et al., 2003; Karcher et al., 2000; Petzold et al., 2005; Spicer et al., 1994; Yu and Turco, 1998). Jet engines combust considerable amounts of fuel while on the ground, during takeoffs, and landings. This combustion releases many pollutants including UFP, carbon, CO, sulfuric acid, volatile organic compounds (VOCs), and NO_x.

Airports have not previously been evaluated as a source of UFP to community air. However, in response to community concern regarding potential exposures to airport-related harmful pollutants and complaints that soot was settling onto exposed surfaces, in 1998 and 1999 the South Coast Air Quality Management District conducted a series of studies near the LAX to evaluate the impacts of airport operations on levels of particles with aerodynamic diameters less than or equal to 10 μm (PM10), VOCs, CO, and carbon soot in community air (Barbosa et al., 1999). The studies did not detect any specific pollutant markers that could be ascribed to aircraft operations. The results did suggest that ground traffic in the vicinity of the airport contributed to somewhat elevated pollutant levels.

This paper reports on results from measurements we made in the spring of 2003 to evaluate the nature and extent of the impact of airport operations on community air downwind of LAX.

2. Methods

2.1. Study site description

LAX has two main runways that are aligned with the prevailing west to east winds (Fig. 1). It is located at the western side of the Los Angeles Basin at 33°56′35″N latitude and 118°24′28″W longitude. The Santa Monica Bay and the Pacific Ocean are

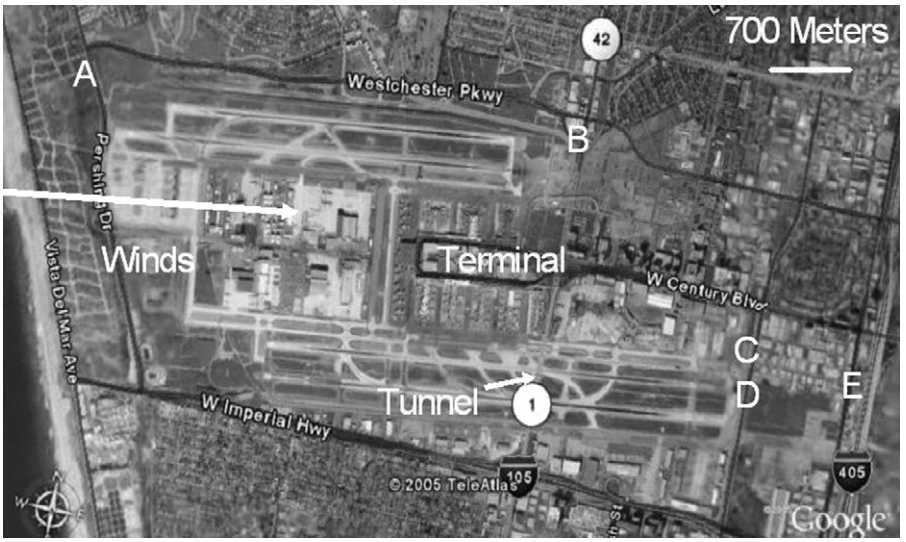

Fig. 1. LAX study area. Site A (upwind), site B (500 m downwind of landing activity, site C (Taxiway area), site D (takeoff site), site E (900 m downwind of takeoff site).

located approximately 800 m to the west of the western fence line of the airport. The airport sits approximately 35 m above the level of the Bay. There are no residences or businesses and only very light vehicular traffic between the western perimeter of the airport and the Bay. Observations were made during the mid afternoon periods on 19, 21, 23, and 24 of April 2003. Winds came from the Bay during sampling operations as determined by a review of Air Flow Charts assembled by the Meteorology Section of the California Air Resources Board and confirmed by evaluation of records collected by LAX. Takeoffs and landings proceeded from the east to the west into the prevailing winds. Pollutant data were collected at various sites in and around the airport as noted in Fig. 1. Air coming from the Bay was assessed approximately 500 m upwind of the north runway (site A in Fig. 1). Monitoring sites were also located downwind of the airport. Downwind site B was approximately 500 m north and east of the centerline of the north runway at the interface between the airport and community commercial activities. Downwind site C was in a parking lot approximately 100 m downwind of the taxiway supporting the south runway. Downwind site D was just south of site C at the edge of a roadway approximately 100 m downwind of the south runway. Data were also collected while driving on roadways near the sites described above, while driving through the terminal area of the airport and through a tunnel under the south runway on Sepulveda Boulevard. Observations of particle counts were made on 5 August 2004 by the Aerosol Group at the University of Southern approximately 900 m downwind of the south runway (site E) (Biswas et al., 2005).

2.2. Experimental approach

Our protocols are reported in detail in a prior publication (Westerdahl et al., 2005). In summary, we employed an electrically powered Toyota RAV 4 compact sport utility vehicle (SUV) as a mobile platform to conduct measurements of particles and related air pollutants while in motion or as a fixed site. We collected time resolved measures of particle counts with two types of TSI, Inc. (Shoreview, MN, USA) condensation particle counters (CPCs) (Agarwal and Sem, 1980), and particle size distributions with two synchronized TSI Scanning Mobility Particle Sizing Spectrometers (SMPS) (Wang and Flagan, 1990). In order to cover a wide size range of particle sizes from approximately 5 to 600 nm diameter, one SMPS system was equipped with a nano-differential mobility analyzer (DMA), while the other was equipped with a long DMA. A measure related to particle length was assessed with a TSI electrical aerosol detector (EAD), a device that is based on diffusion charging of particles followed by charge detection with an electrometer (Woo et al., 2001). Black carbon was determined

Table 1
Monitoring instruments employed in the mobile monitoring platform

Instrument	Parameter measured	Units reported	Time resolution
TSI Portable CPC, Model 3007	Particle count, 10 nm–1 μm	Particle counts cm^{-3}	10 s
TSI CPC, Model 3022A	Particle count, 7 nm–1 μm	Particle counts cm^{-3}	10 s
TSI Electrical Aerosol Detector, Model 3070A	Particle length	mm cm^{-3}	10 s
Magee Scientific Portable Aethalometer	Black carbon	ng m^{-3}	1 min
TSI Scanning Mobility Particle		Particle number/size	1 min scan rate
Scanning spectrometer			
Model 3080 classifier			
Nano-DMA, 3025cpc	5–153 nm		
Long DMA, 3025cpc	16–600 nm		
Ecochem PAH Analyzer, Model PAS2000	Particulate matter-phase	PAH (ng m^{-3})	2 s
Teledyne-API NO_x Analyzer, Model 200e	NO, NO_x, NO_2	ppb	20 s

with a Magee Scientific Aethalometer (Berkeley, CA, USA) (Hansen et al., 1984). Particle-bound polycyclic aromatic hydrocarbons were measured with an Ecochem photoelectric aerosol sensor (Echochem Analytics, League City, TX, USA) (Burtscher and Schmidtott, 1986). Oxides of nitrogen (nitric oxide (NO), NO_x, and nitrogen dioxide (NO_2) were assessed with a Teledyne API chemiluminesce analyzer (San Diego, CA, USA). All instruments reported data with one minute or shorter time resolution (see Table 1).

Data for BC and NO_x components were recorded on a data logger, while SMPS and CPC data were captured on a portable computer. Care was taken to ensure that the time settings of video and data recordings were in agreement (typically within 5 s). The records from the CPC and EAD were the most temporally resolved providing data every 10 s. The time series data from these instruments served to identify short-term emission events, such as from aircraft landings or takeoffs, not evident with data from less temporally resolved instruments such as the SMPS, the Aethalometer, and the NO_x analyzer. The SMPS data were evaluated using TSI Aerosol Instrument Manager (AIM) software, and exported to Microsoft Excel where they were merged to allow construction of particle size distribution data. The size of particles included in the current paper range from 7 to 350 nm. Data from multiple SMPS scans collected at the coastal site were combined to improve count statistics because UFP concentrations at this site were low. SMPS data collected during landing activities were combined to capture the impacts of multiple operations on community air quality. Observations were also made while driving on the 105, and 710 freeways (on 24 April 2003) to compare the nature of emissions from vehicular traffic with airport operations. At site D, a single takeoff event was observed. This event was somewhat shorter than the 60 s period required for an SMPS scan. Our approach to capture size distribution data during this event was to use data from the two SMPS units (one with the nano-DMA and one with the long DMA) to generate a single file. The CPC data identified the time periods of elevated and fairly constant UFP during the event. Data from the start and end of the SMPS instrument records were edited to reflect this elevated period. The files were then merged to produce a single-size distribution.

Observations of individual aircraft operations, including takeoffs and landings were recorded by a video tape recorder that operated during the sampling. These tapes included verbal reports of concurrent events, sound, and odors and also documented the nature of traffic on roadways during mobile operation.

3. Results

3.1. Pollutant concentration findings

Data collected while driving in the vicinity of LAX was found to be very dynamic with significant variability over very short temporal and spatial scales. Time series plots of observations made on 23 April (see Figs. 2a and b) illustrate how the pollutant concentrations related to the different locations in (in front of terminal) and around (sites B–D) the airport. From upwind to downwind locations the dynamic range in concentration was in excess of three orders of magnitude for UFP and

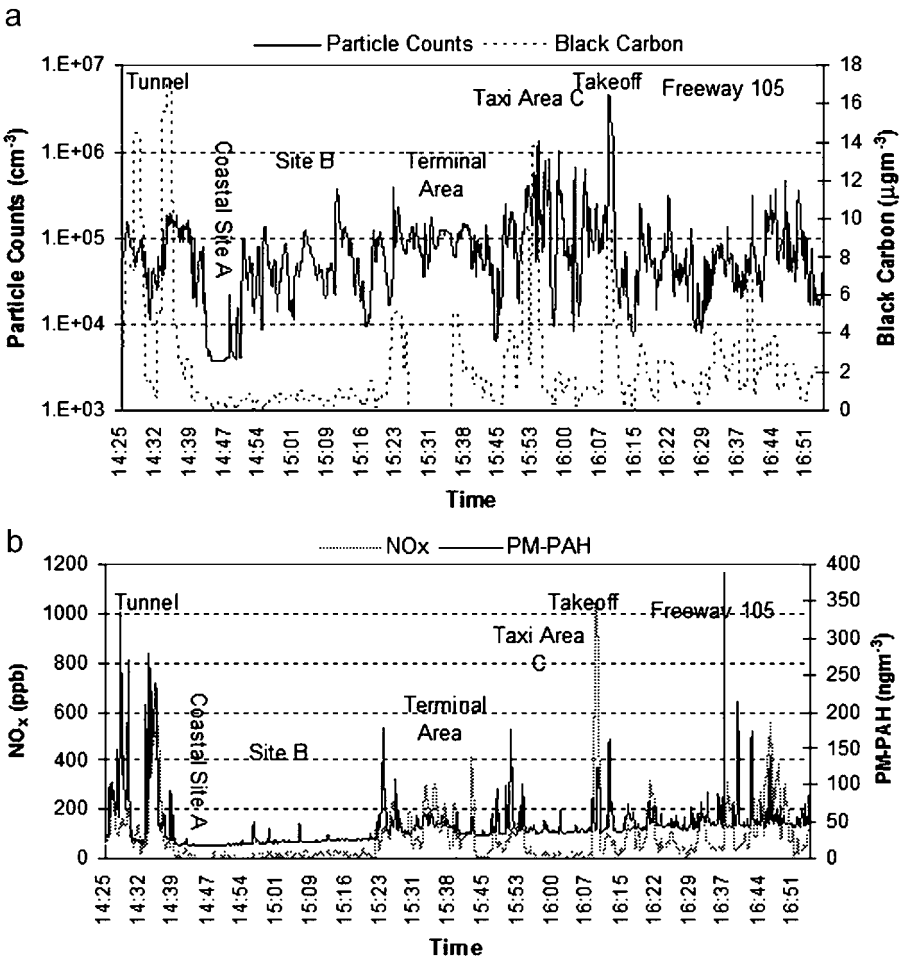

Fig. 2. Time series display of observations in and around LAX: (a) displays data for particle counts and BC, while (b) displays PM-PAH and NO_x. Note that particle counts are displayed on a log scale.

within two orders of magnitude for BC, PM-PAH, and for NO_x.

All pollutant measures were lowest at the coastal location, site A. At downwind site B, near the end of the north runway, most pollutant levels remained low, with the exception of particle counts which showed repeated excursions that corresponded to individual aircraft as they passed overhead prior to landing. Measurements made while driving on surface streets and within the terminal area show much higher levels of NO_x and BC (some BC data are missing from the terminal area data series) than at the community interface (site B). Elevated particle counts observed during on-road measurements (made while in-motion) correlated with overall traffic intensity and proportion of heavy-duty vehicles. Data collected at site C, downwind of the taxiway for the south runway, show a pattern of repeated high excursions of particle counts and elevated BC, with only modest NO_x values. These data reflect the contributions of airport ground traffic, cargo handling vehicles, and aircraft taxiing. Measurements directly downwind of the south runway at site D show the impact of a single takeoff of a large multi-engine jet aircraft. Very high particle counts, with a 10 s peak at 4.8 million counts cm^{-3}, along with elevated NO_x (mostly as NO) and BC, were observed during this takeoff. PM-PAH readings at all sites where vehicular traffic was present are elevated, especially in the tunnel, in the terminal and on the freeways. Aircraft dominated areas appear to show lower PM-PAH levels. In general, BC, particle counts, and NO_x levels vary together indicating they are associated with similar sources.

Fig. 3 illustrates the patterns of particle counts observed at each study site. Particle counts observed

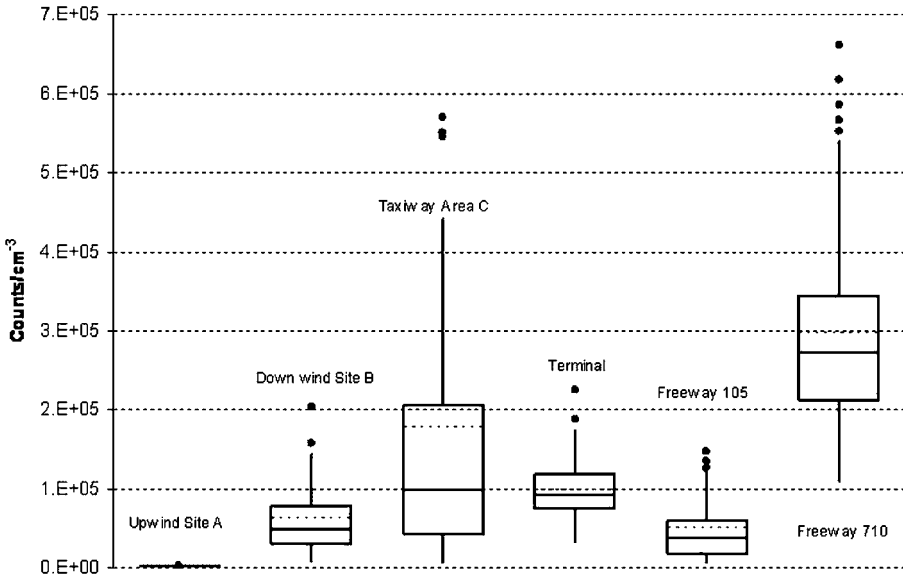

Fig. 3. Comparison of particle counts at various locations near LAX and on Freeway 710, a roadway with a large proportion of diesel trucks.

while driving on Interstate 105 near the airport illustrate typical contributions of freeway traffic to particle counts. Data from the 710 freeway, approximately 20 km inland from LAX, are also included for the purpose of further comparison. This freeway regularly carries high numbers of diesel trucks (Westerdahl et al., 2005).

Black carbon concentrations varied across the study sites, with a mean of 0.3 $\mu g\,m^{-3}$ at site A, 0.7 $\mu g\,m^{-3}$ at site B, 1.8 $\mu g\,m^{-3}$ at site C, 3.8 $\mu g\,m^{-3}$ in the terminal region, and 22.7 $\mu g\,m^{-3}$ on Freeway 710. The mean level of BC on Freeway 105, which has a low volume of truck traffic, was 1.5 $\mu g\,m^{-3}$. The mean NO_x levels at sites A–C and the terminal were 1.6, 18.7, 76.9 and 144.2 ppm, respectively. Mean NO_x levels on the 105 freeway were 57.4 ppm and on the 710 freeway 520.7 ppm. The mean PM-PAH levels were 18.2, 24.6, 50.1 and 60.1 $ng\,m^{-3}$ at sites A, B, C, and the terminal, respectively. PM-PAH mean levels were 47.0 $ng\,m^{-3}$ on the 105 Freeway and 169.4 $ng\,m^{-3}$ on the 710 Freeway.

Concurrently collected data on particle counts, particle size distributions, and on co-pollutants, obtained at coastal site A, provide a unique perspective on the characteristics of the air mass coming into the basin. The lowest instantaneous measure of particle counts was 580 counts cm^{-3} with values of 1200–3800 observed on the four days of monitoring at this site. These values are similar to the 1500–5000 particles cm^{-3} measured by Biswas et al. (2005) at a location near this site.

Particle counts made at 900 m downwind of the South Runway (site E) which was being used for takeoffs, and at 500 m downwind of the North Runway (site B) which was used for landings show very clear repeated and substantial impacts of aircraft operations. Figs. 4a and b present data from these locations as time series plots (4 August 2004 for Fig. 4a and 24 April 2003 for Fig. 4b). Observations of particle count peaks during landings corresponded with visual sightings of aircraft as they passed overhead (with an approximate 20 s delay between the sighting and the peak count), and often were coincident with an odor of jet fuel. Between peak events the counts returned to levels quite similar to coastal air. Peaks are higher at site E, despite its greater distance from the runway. The data from these two days cannot be formally compared, but do illustrate that elevated levels of UFP can be detected far from the active runways. Meteorological factors were similar, but not identical on the two days. During the periods of sampling, the hourly average winds were from the west at both sites. At site E wind speeds of 5.1 $m\,s^{-1}$, temperature of 22.8 °C, and relative humidity of 60% were observed. At site B, wind speed, temperature, and relative humidity were 7.2 $m\,s^{-1}$, 16.7 °C, and 53%, respectively.

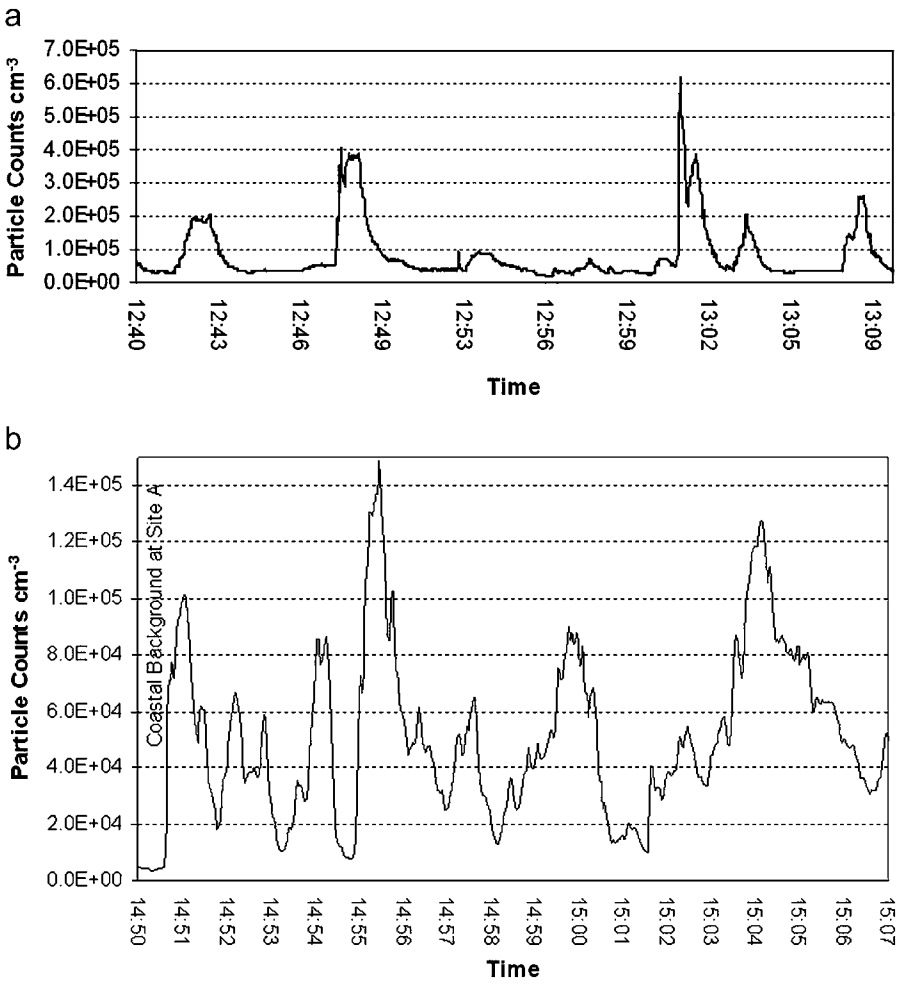

Fig. 4. Time series displays of particle counts observed downwind of takeoff on 24 October 2004 at site E (4a) and of landings on 23 April 2003 (4b) at interface with community at site B.

During the observed takeoff event at site D, particle counts began at approximately 50,000 and reached 4.8 million particles cm^{-3} as shown in Fig. 5. The clarity of this event is somewhat complicated by a preceding takeoff event, nonetheless a two orders of magnitude range in the particle counts is evident. Other pollutants measured during the takeoff event show substantial elevations as seen in Fig. 6. NO_x levels before the event were approximately 8 ppb and rose to 1045 ppb, mostly due to NO. Black carbon rose from approximately 800 to 9550 ng m^{-3}, and PM-PAH values rose from 37 to 124 ng m^{-3}.

3.2. Particle size distributions

An illustration of aircraft influence on particle size distribution was obtained at site D as a commercial jet ramped up its engines prior to takeoff, the event shown in the CPC data in Fig. 5. The solid vertical lines show when the SMPS scans began and ended while the dashed vertical lines show which portion of the SMPS scans were used to generate the merged distribution data for this event as described in the methods section. Fig. 7 displays the particle number and calculated mass size distribution for the takeoff event. Both indices show a clear bimodal distribution with particle numbers showing peaks at approximately 12 nm mobility diameter and at 80–90 nm, while calculated mass peaks occur at approximately 20 nm with a second peak estimated at approximately 150 nm. No measurements of particle density were available for the aircraft emissions; however, a density of 1.2 g cm^{-3} is applied; this is a midrange value from the Los Angeles area (Geller et al., 2006). Under this

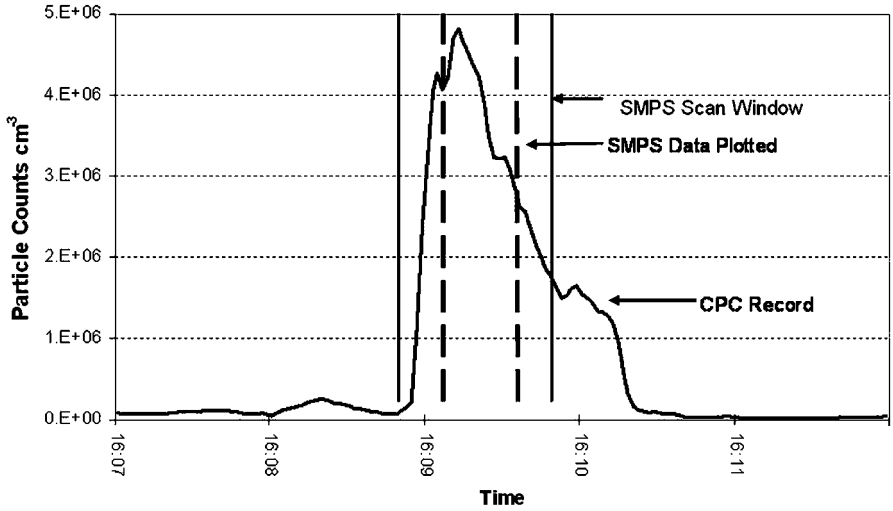

Fig. 5. Particle counts recorded by TSI Model 3022a while an aircraft prepared for takeoff at site D. SMPS scan performed during period enclosed by solid vertical lines, data displayed in Fig. 7 obtained from constrained file assembled from time period between dashed lines.

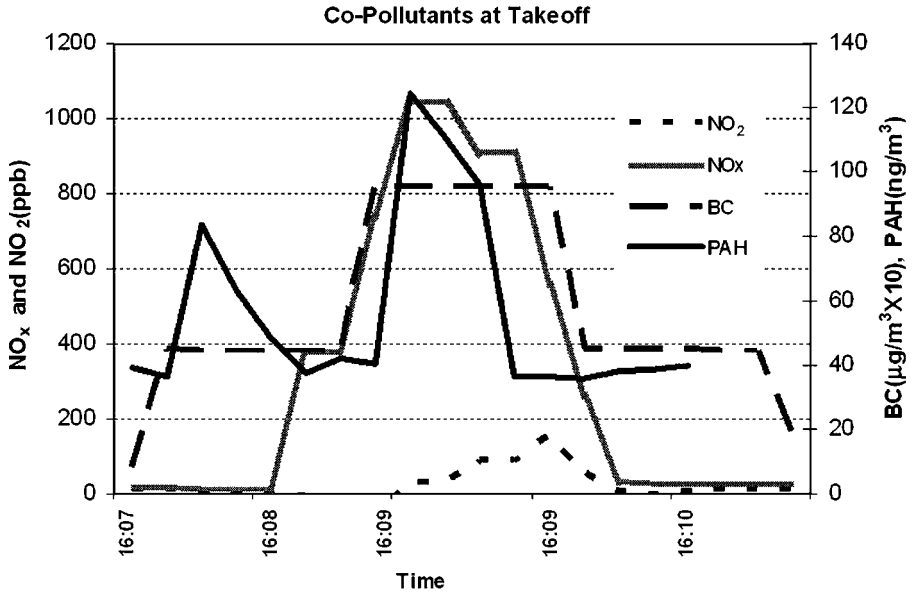

Fig. 6. Pollutant levels observed during takeoff event at site D. Note dominance of NO_x which is primarily contributed by freshly emitted NO.

assumption, the mass of particles in the 7–40 nm peak is estimated to be 7.6 $\mu g\,m^{-3}$, and for the entire UFP range of 7–100 nm the mass is estimated to be 10.7 $\mu g\,m^{-3}$. The mass of particles at the coast was estimated from the SMPS to be approximately 5 $\mu g\,m^{-3}$ with a density of 1.1 $g\,cm^{-3}$ (Geller et al., 2006). The calculated mass at takeoff was 32.3 $\mu g\,m^{-3}$, based on the merged SMPS data. Overall, it is estimated that this takeoff contributed approximately 27.3 $\mu g\,m^{-3}$ of particulate matter above background levels measured at site D.

The size distributions of particle numbers at several sites are displayed in Fig. 8. Coastal air coming into the region has a low level of particles in 7–60 nm size range relative to levels at other study sites. There is considerable qualitative similarity of particle number distributions at other combustion-dominated downwind sites impacted by the airport,

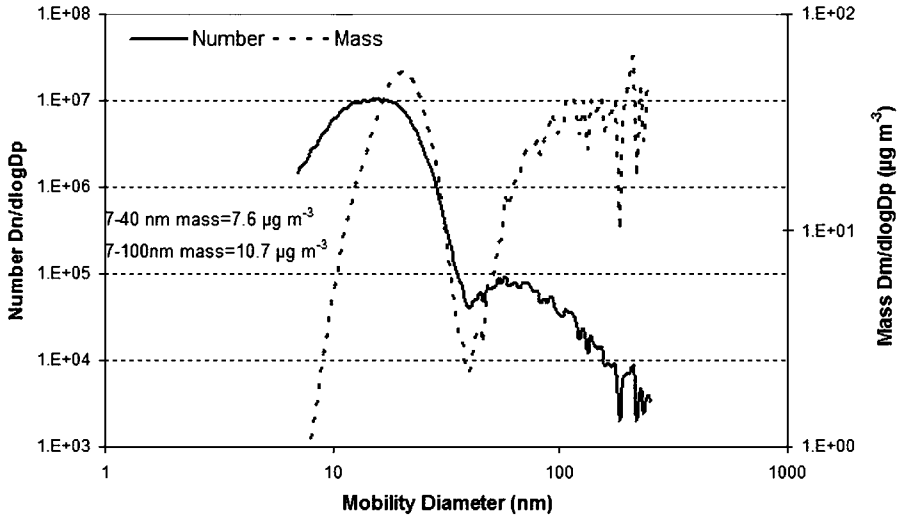

Fig. 7. Particle number and mass distribution observation made during the takeoff of a jet aircraft at site D. Mass estimates are shown for first peak (7–40 nm) and for UFP size range (7–100 nm) with estimated particle density of 1.2 g cm^{-3}.

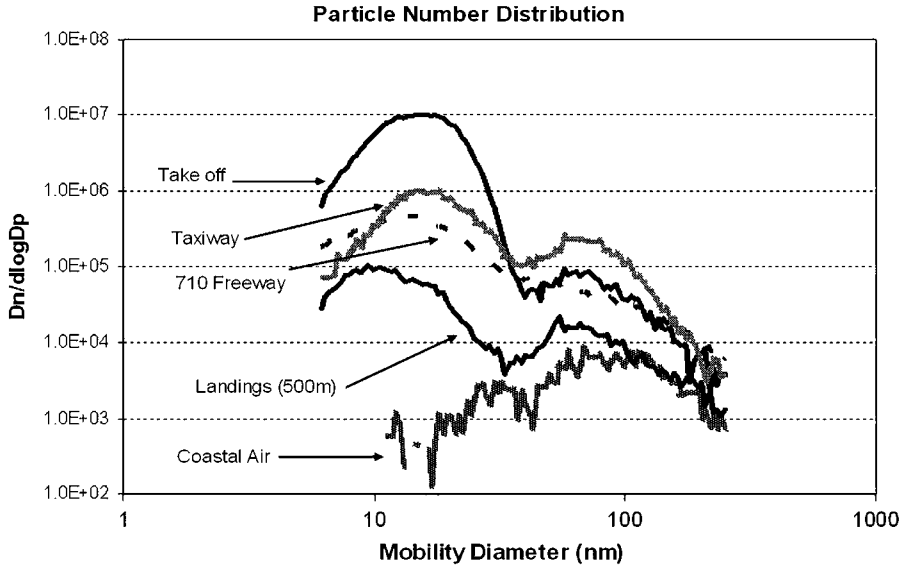

Fig. 8. Display of particle size distribution of clean coastal air, at various locations near LAX, on a segment of the 710 Freeway. Bimodal distributions are apparent in areas with combustion particles.

as well as the 710 Freeway. Each distribution shows a mixture of fresh and aged particles. The most evident differences are in the levels of the finest fraction (7–40 nm) of particles found in each location.

4. Discussion

This study reports the findings of air monitoring in and near the LAX airport. The most novel aspect of the study is the assessment of UFP and associated pollutants produced by airport operations at the interface between the airport perimeter and the community. The results demonstrate that aircraft operations, including those taking place on the ground, and aircraft landing and takeoffs influence air quality near the airport. Also unique are findings of low levels of UFP at the coast and at a site just upwind of the airport and upwind of the major urban area of Los Angeles, with counts as low as 580 particles cm^{-3}. Particle numbers increase as the air mass moves across the airport

with periodic peaks, observed in downwind community locations, in the range of 20,000–400,000 particles cm^{-3} that appeared to reflect emissions of individual aircraft takeoffs and landings. A maximum peak of 4.8 million particles cm^{-3} was measured on a city street downwind of a takeoff from the south runway.

The higher numbers of particles seen at downwind sites represent the contribution of the overall airport activities, including takeoffs, landings, and complex ground operations. These ground operations include aircraft taxiing, diesel-powered ground support vehicles, and a mixture of gasoline, compressed natural gas, and diesel-powered vehicles on the terminal roadway and surface streets near the airport. Takeoffs, landings, and ground operations add UFP and other pollutants to ambient air as it moves from the coast across the airport facility. Simple examinations of differences in pollutant levels between the monitoring locations at the coast and those immediately downwind of the airport show that there is about a 100-fold increase in particle counts, a 134-fold increase in NO_x, and a 12-fold increase in BC.

Prior studies performed downwind of freeways suggest that air quality impacts of UFP from traffic and potentially other sources might be localized, with UFP diminishing to urban background levels within 300 m of the source (Zhu et al., 2002). However, this study demonstrates that plumes from aircraft operations extend far beyond this distance, with aircraft-related elevated levels observed at the "fence line" boundary of the LAX airport (approximately 500 m from a runway used for landings) and at a site 900 m downwind of a runway used for takeoffs. At this second site there was a 10-fold increase above local background UFP levels, with one peak approaching a 20-fold increase. Somewhat smaller increases were found 500 m downwind of the runway employed for landings.

There are a number of possible explanations for the observed high levels of aircraft-related UFP at monitoring locations greater than 300 m downwind of the airport. Among these is that the measurements reflect emissions from aircraft on approach that passed overhead—hence although the monitoring site was at 500 m downwind of the airport, the source (i.e., aircraft) was in fact much closer. Federal Aviation Administration guidelines indicate that a normal landing approach slope is 3 (Federal Aviation Administration, 2006). Thus aircraft may be only 100 m overhead at 1.6 km from the end of the runway. Plumes emitted aloft spread in both horizontal and vertical directions. The vertical component of the plume could reach the ground and contribute to the high values observed at distances from the airport.

Another explanation for the observed high levels of aircraft-related UFP at locations distant from the airport relates to the nature of the aircraft emissions. In the case of the site 900 m downwind of the airport, planes taking off emitted very large numbers of UFP. Physical and chemical processes reduce UFP counts as plumes move away from aircraft, and contribute to rapidly decreasing UFP levels as one moves away from the airport. Among these processes are dispersion, coagulation and volatilization of organic constituents. However, it is plausible that the very large number of UFP emitted from aircraft cannot be sufficiently dissipated through these processes to reduce the concentration of particles to background levels even over relatively long distances.

The physical properties of the UFP are also found to differ as one moves from the coastal upwind site, to the area near an aircraft takeoff, and ultimately into community air. Particles near the coast have a number maximum at approximately 80–100 nm. Directly downwind of a takeoff, the number maximum occurs in the 10–15 nm size range with a much smaller peak at approximately 80–90 nm. Particles present in plumes somewhat distant from the airport exhibit a similar bimodal nature but with a larger contribution of 80–90 nm particles.

In the current study, highly time-resolved measurements of UFP, from which PM mass could be estimated, indicate that airport operations contribute to PM mass. Prior studies which collected 24-h integrated measures of PM10 in and around LAX, failed to detect any impacts of airport operations on PM mass at the airport or the neighboring community (Barbosa et al., 1999). The different results suggest that time resolved measurements are needed to detect PM mass associated with aircraft operations. Further, site selection for such monitoring is very important.

Results indicate that aircraft-related UFP at LAX are associated with the two chemical constituents of the particles measured: BC and PM-PAH. Other constituents were present, but not measured. They do not show the same level of increase as the particle counts. A comparison of the average concentrations of BC, PM-PAH, and UFP observed at the coastal site with the average concentrations observed

during landings 500 m downwind of a runway, revealed an enrichment of slightly less than 2-fold for BC and PM-PAH, but UFP counts increased 12-fold. PM-PAH levels seen at takeoff are only approximately three times that of upwind background, with one peak observed of $125\,ng\,m^{-3}$, which is approximately six times that of background. PM-PAH values observed at the site 500 m downwind of landings are only slightly elevated above the coastal background. When PM-PAH observations are viewed in areas were vehicular traffic is present, such as on the 710 Freeway (Westerdahl et al., 2005) or in the Sepulveda tunnel it appears that traffic may be a more important contributor to PM-PAH levels than aircraft operations. The observations on the 710 were seen to be above $100\,ng\,m^{-3}$ on 24 April, reaching levels in excess of $200\,ng\,m^{-3}$ for brief periods. These observations are supported by a study of potential human exposures to PM-PAHs from various airport-related activities (Childers et al., 2000). PM-PAH levels in that study were highest when measured near diesel-powered ground generators.

5. Conclusions

This study demonstrates the utility of the mobile monitoring approach. The flexibility of a mobile platform allowed quick relocation as needed to be in or near plumes from operations of interest. The real-time displays of the various pollutants allow confirmation that meaningful data are being collected and the impacts of individual aircraft operations can be assessed. The dynamic nature of air quality observed in and near this airport serves to demonstrate the difficulty of applying conventional air monitoring protocols to determine the scope, nature, and spatial impacts of aircraft and airport ground operations on air quality.

Monitoring was conducted for brief periods and does not fully represent the impacts of routine airport operations. More comprehensive studies are needed to characterize the nature of emission from airports, their impacts on community air, and on exposures to residents of the nearby communities. However, the data from this study strongly suggest large jet aircraft taking off from an urban airport, such as LAX, are an important source of UFP. UFP emitted by aircraft pass into populated areas of communities downwind of LAX and persist to nearly 1 km from the end of a runway. It is likely, but not yet shown, that the degradation in air quality continues beyond this distance.

There is a fair degree of agreement among health researchers that UFP may harm health, but it is unclear whether exposures specific to aircraft or airport operations pose a potential risk to the health of people who live and work in areas proximate to airports. Ambient air quality standards do not exist for UFP, thus air quality regulators and land use planners are not compelled to consider this PM metric as airport operations and expansions are reviewed. However, future airport-related planning and development should address UFP exposures in communities downwind of an airport.

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