SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT

General Aviation Airport Air Monitoring Study

FINAL REPORT

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BACKGROUND

The Van Nuys and Santa Monica Municipal Airports (VNA and SMO, respectively) are among the most important general aviation airports (GA) in the South Coast Air Basin. In 2005, VNA was the world's busiest GA airport with around 450,000 takeoffs and landings annually, while SMO is the oldest operating GA airport in Los Angeles County. Both airports are surrounded by public areas and private residences, and odor and/or noise complaints by people living in nearby communities have raised concerns about possible health effects from exposure to gaseous and particle pollutants emitted from the airport areas.

OBJECTIVE

Conducted as part of a Community-Scale Air Toxics Ambient Monitoring Grant from the U.S. Environmental Protection Agency (U.S. EPA), the main goal of this study is to characterize the ambient levels of several important air toxics in communities adjacent to VNA and SMO. Since GA aircraft with piston-driven engines use leaded gasoline, lead monitoring was a major focus of this study. Also, because jet turbine engines emit substantial amounts of ultrafine particles (UFPs) and other combustion-related pollutants, attention was given to the monitoring of the particle number concentration (an indicator of UFPs). Recent studies conducted at the Los Angeles International Airport (LAX) and at SMO (Fanning et al., 2007; Westerdahl et al., 2008; Hu et al., 2009) have shown that UFP levels are higher in areas adjacent to and downwind of the airport runways. Volatile organic compounds (VOCs), carbonyl compounds, fine particulate matter ($PM_{2.5}$) and some of its organic and inorganic components (i.e. organic and elemental carbon, and trace elements) were also measured at VNA and SMO. Although the monitoring approach was designed to focus on long-term exposures, the potential for short-term exposures was examined by continuous measurements of UFP and carbon monoxide (CO).

METHODS

The monitoring strategy included deployment of sampling equipment near runways and at locations in the community under the flight path to detect and characterize pollution levels and exposure gradients caused by airport emissions. The sampling protocols were primarily based on previous AQMD air toxics studies such as the Multiple Air Toxics Exposure Study (MATES-III). Sites that were placed upwind and downwind of each airport included a full array of integrated samplers (for the collection of total suspended particles for lead analysis, selected VOCs, carbonyls, and metals) and continuous analyzers (for UFP and CO measurements). Other locations situated to the sides of the runways were monitored using lead samplers and CO sensors only. Sampling was conducted for two different periods at each airport to assess the seasonal variability of the measured pollutants. Each monitoring period lasted for a nominal three months. The first phase of sampling at VNA was from 11/22/2005 to 3/3/2006. This was followed

by a field campaign at SMO from 4/26/2006 to 7/19/2006. The second sampling campaign in Van Nuys was conducted from 7/28/2006 to 9/29/2006, followed by measurements in Santa Monica from 10/20/2006 to 3/1/2007. Integrated and continuous data from the analysis of all collected samples were analyzed to assess the levels of air toxics in the communities relative to other areas of Southern California. The data were also examined to determine, if possible, the contribution of airport-related emissions and those from other potential pollution sources (such as local traffic) on the measured ambient levels. Meteorological data at VNA and SMO were provided by the local airport authorities.

KEY FINDINGS

- The 24-hr average total suspended particulate (TSP) lead concentration gradient at the Van Nuys and Santa Monica Airports reflected the relative distance of the various monitoring sites from the runway areas. This indicates that piston-driven aircraft and the leaded fuel they use were sources of TSP lead at the monitored stations. Daily average TSP lead concentrations at VNA and SMO sites were substantially higher (up to two and nine times higher, respectively) than the corresponding South Coast Basin levels during the same time periods, and mostly below the new national ambient air quality standard (NAAQS) of 150 ng/m^3. However, 24-hr average concentrations close to, or above the current NAAQS for lead were recorded at SMO near the Tarmac in more than one occasion and during both phases of the study. In addition to direct aircraft exhaust contributions, decades of aircraft exhaust emissions may have caused lead accumulation in the soil on which the samplers were located. A recent study conducted by U.S. EPA regarding lead emissions from SMO included soil analysis for lead (U.S. EPA, 2010). However, results from the analysis of samples collected at SMO using the $PM_{2.5}$ speciation samplers indicates that the majority of particulate lead is present in the fine fraction, suggesting that a relatively high proportion of lead at this airport was not associated with re-suspended material.

- The atmospheric levels of VOCs at VNA and SMO stations were mostly influenced by their proximity to busy surface streets surrounding the airports' perimeters and nearby freeways. However, the contributions of these and other potential pollution sources (including airport-related emissions) to the measured VOC and carbonyl levels could not be assessed from the available data. The highest VOC concentrations measured at VNA and SMO were generally comparable to or lower than those observed at two companion urban monitoring sites (Burbank and Central Los Angeles, respectively), where motor-vehicles emissions dominate the atmospheric levels of most primary pollutants.

- The mass concentrations of $PM_{2.5}$, organic carbon (OC) and elemental carbon (EC) at all Van Nuys and Santa Monica stations were at or below the corresponding South Coast Basin averages. Comparisons among sampling sites did not show any significant spatial or temporal gradient that could be attributed to aircraft operations. It is likely that other local and regional sources (e.g. motor-

vehicle emissions from nearby traffic and atmospheric transport of aged pollutants, respectively) were mainly responsible for the observed atmospheric levels of $PM_{2.5}$ and its carbonaceous components.

- Aircraft idling near the runway before departure and during take-off were found to generate large numbers of UFPs over short time periods. Continuous (1-minute) particle number levels up to 600 times higher than those measured in background air were observed both in Van Nuys and in Santa Monica, including at a residential site located less than 100 m downwind of SMO. Emissions from major freeways and surface streets surrounding both airports are another source of UFPs, but the largest short term increases were often not consistent with motor-vehicle sources. Further work is needed to better define the contribution of aircraft to community UFP exposures with respect to specific aircraft and airport operations.

- The average diurnal profile of CO at the Van Nuys and Santa Monica stations followed a distinctively different pattern from that observed for other combustion-related pollutants such as UFP count and EC, with peak values during morning rush hour traffic and lower levels in the afternoon. This suggests that the concentration of this gaseous pollutant was dominated by contributions from motor-vehicle emissions from nearby roadways/freeway and surface streets, and that the influence from airport-related activities was not significant.

- Our results suggest that the majority of the trace elements detected in the $PM_{2.5}$ samples collected at both airports originated from re-suspension of crustal materials. The atmospheric concentrations of all measured metals are comparable to those reported in previous studies conducted in the South Coast Air Basin.

- An analysis of the VOC profile of two canister samples collected at SMO near the blast-fence when jet-propelled planes were idling close to the runway and when no airplane activity was occurring revealed that emissions from aircrafts idling before departure increased the concentration of all combustion-related VOCs substantially. The speciation profile of the idling sample closely resembles that of typical jet exhaust, indicating that short-term VOC levels near the runway were influenced by aircraft emissions when jets were idling before take-off. Conversely, the emission profile of the other sample is similar to that of diesel truck emissions; when no airplane activity was taking place, the ambient air was probably affected by diesel emissions from vehicles operating within or in close proximity of the airport's perimeter. Lastly, the VOC profiles of both these samples differ from that of gasoline vehicle exhaust, indicating that gasoline-powered vehicles did not influence the composition of the two canister samples at the time of sampling.

- Overall, the atmospheric concentrations of most of the measured air toxics were higher during the winter months than in the summer period. This seasonal pattern of air toxics levels is similar to that observed in previous studies in the South

Coast Air Basin. In the late fall and early winter, light winds result in reduced ventilation, and overnight inversions contribute to increasing surface-level concentrations of those pollutants that are emitted from ground-level sources. During the summer months, stronger on-shore breezes and atmospheric circulation due to increased solar insulation results in higher wind speeds, increased vertical atmospheric dispersion and, subsequently, reduced ambient concentrations at ground level.

CONCLUSIONS AND RECOMMENDATIONS

Overall, the most significant airport-related impacts on air quality were observed for lead and for UFPs. Airport impacts on other pollutant levels were difficult to determine, but appeared to be minor when considering long-term averages. This study focused on longer-term exposure as it was based on MATES-III sampling protocols. Shorter term impacts may be present, such as those observed for UFPs, instantaneous VOCs, and odors. Further investigation into short-term impacts would require a different study design with more continuous measurements, although continuous instruments for some air toxics are not commercially available. Future work may also include more detailed measurements of UFP levels correlated to aircraft type and aircraft operations.

INTRODUCTION

REGULATORY BACKGROUND

Questions regarding the impact of airport related pollution on local air quality arose in the 1960s. The first comprehensive studies on aircraft's emissions were conducted by the then Los Angeles County Air Pollution Conctrol District in 1960 and 1965 (Bastress 1973). Their results indicated that aircraft contributed to a small but significant fraction of the pollutants emitted in the Los Angeles County. However, the integrated and centralized assessment and gathering of data in a regulatory framework started after the Clean Air Act (CAA) of 1970 was passed by the United States Congress. CAA gave the Environmental Protection Agency (EPA) the right to establish air pollution standards, including those applicable to aircraft exhaust. Section 231(a)(2)(A) of the CAA directs the EPA administrator to "issue proposed emission standards applicable to the emission of any air pollutant from any class or classes of aircraft or aircraft engines which in his judgment causes, or contributes to, air pollution which may reasonably be anticipated to endanger public health or welfare". Under this authority EPA has conducted several rulemakings since 1973, establishing emission standards and related requirements for several classes of aircrafts and aircraft engines, including commercial and general aviation engines. Although airports don't meet the definition of "area" or "major" source under section 112 of the CAA, the EPA has taken a "combinations of sources" approach to tackle the issue of airport emissions and their impact on the surrounding communities. To this end, EPA released a report in April 1999 that assessed the potential impact of aircraft emissions on local air quality at ten selected airports (U.S. EPA, National Emission Trends, Average Annual Emissions, All Criteria Pollutants, 1970-2001, August 13, 2003).

The International Civil Aviation Organization (ICAO) was created by the United Nations in 1947 to "achieve maximum compatibility between the safe and orderly development of civil aviation and the quality of the human environment". The United States is one of more than 150 participating members or "Contracting States" of this organization. To achieve its objective, ICAO established exhausts emissions standards and test procedures for three pollutants: hydrocarbons (HCs), carbon monoxide (CO), and oxides of nitrogen (NOx), that are expected to be met by each of the Contracting States. Throughout the past few decades numerous and increasingly stringent standards have been set by ICAO to reduce aircraft emissions, and in 2005 EPA amended the existing emission standards for NOx for new commercial aircraft engines (EPA, 2005) to bring the United States aircraft standards into alignment with the international guidelines. These standards apply to new aircraft engines utilized on small regional jets, single-aisle airplanes, twin-aisle aircrafts, and other larger commercial units.

AIRCRAFT EMISSIONS

In addition to the carbon dioxide (CO_2) released by airplanes in flight through the burning of fuels [such as jet-A for turbine aircraft, or aviation gas (Avgas) for piston aircraft], other important pollutants are typically present in aircraft emissions. These include CO, nitrogen dioxide (NO_2) and nitrogen monoxide (NO), water vapor, sulfur

oxides (SOx), incompletely-burned HCs, transition metals (e.g. lead) and particulate matter (PM) of various sizes (http://epa.gov/oms/aviation.htm). Ultrafine particles [UFP; particle diameter (Dp) ≤ 0.10 μm] are the biggest contributor to the total particle number concentration and have the highest potential to penetrate deeply into the human lungs. In a recent study conducted by Ntziachristos et al. (2007a), size-fractionated ambient PM samples [i.e. UFP, accumulation (Dp ≤ 2.5μm), and coarse (2.5 μm ≤ Dp ≤ 10 μm) mode particles] were collected at four different locations in the Los Angeles Basin, and analyzed for their redox potential (an indicator of particle toxicity; Cho et al, 2005; Geller et al., 2006). The ultrafine fraction had the highest redox activity on a per-PM mass basis. No health-based standards are currently in place for this important PM fraction. Emissions from airports are associated with both direct emission (i.e. aircraft exhaust) and different airport activities including refueling, pre-flight safety procedures, and fuel venting (Federal Aviation Administration; http://www.faa.gov/regulations_policies/).

In the Los Angeles metropolitan area the combustion of gasoline and other hydrocarbon fuels in automobile, trucks, airplanes and marine vessels represent the main sources of PM (including UFP), transition metals, volatile organic compounds (VOCs), CO, NOx, and other primary emitted pollutants. In order to improve our understanding of the toxic risk associated with exposure to these particulate and gaseous species, it is important to characterize the contribution and spatial distribution of the most important mobile, point and areas sources, and their relative impact on nearby communities. Although most of the air toxic studies on combustion-related species have focused on motor-vehicles emissions, the contribution of aircraft emissions to air toxic exposure levels should be examined for individuals living in close proximity of an airport area.

The term “general aviation” (GA) refers to most of the aircraft used for recreational flying and personal transportation. Airplanes that support business travel, usually on an unscheduled basis, are also included in this category. General aviation flights range from gliders and powered parachutes to large, non-scheduled cargo jet flights. As a result, the majority of the world's air traffic falls into this category, and most of the world's airports serve GA exclusively. One of the fastest growing areas in the GA sector is that of small passenger aircraft and cargo for short distance. These airplanes, usually smaller than those operated by major carriers and often referred to as “air taxis”, provide scheduled services by carrying passengers, freight, or both. Air taxis have been playing an increasingly important role in the U.S. aviation system, and by 2015 such operations are forecast to represent 54% of total air traffic (http://www.apo.data.faa.gov/main/taf.asp; U.S. EPA Average Annual Emissions, All Criteria Pollutants Years Including 1980, 1985, 1989–2001, February 2003).

Most GA aircraft are powered by piston engines and are fueled by Avgas [one hundred octane low lead aviation gas (100LL Avgas) is the most commonly available type of aviation gasoline in the United States], which is characterized by a higher volatility and lead content than other gasoline fuels. Lead is added to the fuel as tetraethyl lead, an additive that boosts fuel octane and prevents valve seat recession, which can be a significant concern from a safety standpoint. Lead is not present in the jet fuel that is used in commercial, military, or other turbine-engine powered aircrafts.

RESULTS FROM PREVIOUS STUDIES

Unlike the present work, the vast majority of the studies that examined the impact of airport operations on local air quality focused on emissions from very large commercial aircraft. Spicer et al. (1984) first reported NOx, CO, PM, and speciated HC emission rates from jet aircraft turbine engines. Further studies by Spicer et al. (1992, 1994) provided additional information on the detailed organic composition of turbine engine exhausts, and revealed that during engine idle, emissions were dominated by products from fuel cracking, unburned fuel and products of incomplete combustion, with ethene, propene, acetylene and formaldehyde comprising 30–40% of the total HC emissions.

Between 1998 and 2001, the South Coast Air Quality Management District (AQMD) conducted a series of monitoring campaigns at several locations surrounding the Los Angeles International Airport (LAX) (AQMD 1998, 2000a, 2000b, 2001). PM_{10} ($Dp \leq 10$ μm), organic and elemental carbon (OC and EC, respectively), CO, and VOCs (e.g. benzene, 1,3 butadiene, and formaldehyde) concentrations were measured with time resolutions between 8 and 24 hours and were found to be higher than the corresponding ambient levels away from the airport. The relative contribution of LAX aircraft emissions to the total measured pollutant concentrations could not be estimated, mainly because more resolved (e.g. hourly) data were not available, and because vehicular emissions from heavily trafficked roads nearby (e.g. Aviation Boulevard and the 405 Freeway) may have influenced the atmospheric concentration of the targeted compounds.

In 2000, AQMD undertook a study at Felton Elementary School and Lloyde High School in response to community concerns about the impact of the pollutants emitted from the LAX and the 405 Freeway on local air quality (Air Monitoring Study at Felton and Lloyde Schools, September 2001, South Coast Air Quality Management District). The results indicated that concentrations of all monitored air contaminants (with the exception of carbonyl compounds) at these schools were at or below the average levels for the Los Angeles Basin. Increased concentrations of carbonyl species were probably related to emissions from both LAX and the heavily trafficked 405 Freeway. A proposed plan to conduct a more comprehensive air monitoring study with measurements within and outside the airport was delayed due to the September 11, 2001 incident. This monitoring campaign is currently planned to be conducted by Los Angeles World Airports, the operator of LAX, for 2011.

A more recent field study was conducted in 2003 by Westerdahl et al. (2008) to determine how emissions from LAX affect the ambient air of a nearby residential neighborhood located downwind of the airport. A mobile air monitoring platform was deployed to measure UFP number, black carbon (BC), NOx and particle-bound polycyclic aromatic hydrocarbons (p-PAHs) concentrations and the particle size distribution. Ultrafine particle counts at an upwind coastal site (580-3,800 #/cm^3) were substantially lower than those observed 500 m downwind of the airport (~50,000 #/cm^3) in a residential area. Black carbon, p-PAHs, and NOx levels were also elevated at locations further downwind, but to a lesser extent. Peaks of about 5×10^6 #/cm^3 were occasionally measured downwind of a runway used by jet aircrafts for take-off. The size distributions found at the upwind and downwind sites were dominated by particles with mode diameters of ~90 and ~10-15nm, respectively.

A similar study was conducted by the California Air Resource Board (CARB) and the University of California, Los Angeles (UCLA), in 2005-2006 (Fanning et al., 2007) to monitor UFP and BC levels at and in the vicinity of the LAX. Near real-time instruments were employed to measure the number concentrations and the size distribution of UFP from aircraft emissions, and to capture the corresponding temporal variability. Increased number concentrations of UFP with a mode diameter of around 14 nm were found downwind of an area where aircrafts were taking-off, and the total UFP counts exceeded 10^7 #/cm^3 in some occasions, consistent with the findings of Westerdahl et al., 2008. Number concentrations of UFP were lower at a residential community 2-3 km east of the LAX, but still higher than those at a background reference site located further away. Time averaged levels of $PM_{2.5}$ mass, formaldehyde, and acrolein were elevated at the airport sites relative to those at a background location. However, the concentrations of most VOCs were around or below the corresponding Los Angeles Basin average values. Despite the influence of airport emissions on the UFP count observed at this residential community, no increase in the exposure levels to any of the other measured pollutants were found.

During a monitoring study conducted in 2006 at the Teterboro Airport (TEB; one of the busiest GA airports in the United States located in Teterboro, New Jersey), ENVIRON Corp. measured the concentrations of selected air toxics at the airport fence-line, and evaluated the associated risks to human health (Teterboro Airport, New Jersey, Detailed Air Quality Evaluation, Final Report Prepared by ENVIRON Corp. in 2008). Four sampling stations were set-up to monitor $PM_{2.5}$, BC, and selected VOCs and carbonyls. The median, mean, and maximum concentrations of certain VOCs (formaldehyde and toluene in particular) were significantly higher than those measured further from TEB, where concentrations are typically dominated by mobile source emissions (such as in Elizabeth, New Jersey). The atmospheric concentrations of other VOCs detected around TEB (e.g., benzene, acetaldehyde) were comparable to those at other "representative" New Jersey locations. A conservative risk assessment was also conducted to estimate the health implications of these monitoring data. Between 75 and 87% of the cancer risk associated with the concentrations of VOCs detected at the 4 monitored locations was associated with formaldehyde exposure. Although the $PM_{2.5}$ and BC levels measured around the TEB area appeared to be higher than those at other New Jersey monitoring locations, the data were insufficient to quantify the contributions from airport activities, which are highly dependent on wind direction and wind speed.

Another relevant study was conducted in September 2004 at the Hartsfield-Jackson International Airport (one of the world's busiest airports both in terms of numbers of aircraft and numbers of passengers conveyed) in Atlanta, Georgia, to characterize commercial aircraft engine emissions of in-use aircrafts (Herndon et al., 2008). A mobile laboratory was set-up downwind of the active runway and taxiway, inside the airport fence-line. Emissions from in-use commercial aircraft engines were analyzed continuously for selected gaseous and particle species (e.g. CO, NOx and BC) and particle characteristics (e.g. particle number concentration and size distribution). The CO emission index (i.e. amount of CO emitted per Kg of fuel burnt) observed in ground idle plumes was up to 100% greater than that predicted by engine certification data provided by ICAO at 7% thrust conditions. Significant differences were also observed in the emissions of BC and particle number among different aircrafts and engine

models/technologies, suggesting that total emissions of gaseous and particle pollutants from aircraft exhausts might be misrepresented (or under estimated) in current inventories such as the ICAO databank (see Herndon et al. 2009 for more details). Therefore, this study concluded that there is a need to revise the current information about emissions of air contaminants from modern aircraft engines run under different operating conditions (e.g. idle, take-off and cruise).

Similar studies on air pollutant emissions from aircrafts and airport-related activities have also been conducted at several European cities. For example, during the AIRPUR project Lelievre et al. (2006) characterized the physical and chemical characteristics of various gaseous and particle pollutants at the Charles de Gaulle (CDG) Airports in Paris, France, using various real-time, integrated and remote sensing techniques, and investigated the influence of these emissions on local air quality. Measurements of PM, UFP number, soot, CO, NOx, and speciated VOCs were taken three days in late 2004 and seven days in early 2005 at aprons, beside taxiways and runways, at engine test areas, along roads, and at airport landscape areas. Sampling performed inside engine plumes for different power settings showed a maximum in UFP number on the order of 10^6 #/cm^3 at 7-10 nm in diameter, while the number concentration of the soot mode (20-40 nm) was a factor of 100 lower. The analysis of the collected filter samples revealed the presence of aggregated soot (20-40 nm) and aerosols containing some proportion of S, Si, Fe, Ca, Mg, and K. Volatile organic compound emissions indicated a maximum for ehtyne, propene, ethane, benzene, toluene, m/p-xylenes, nonane and 1,3-butadiene. Although contributions of particle and gaseous pollutants from the CDG Airports were found to be substantial, the airport maximums were lower than those observed in its vicinities and in the city of Paris during the same time period.

In a recent field campaign conducted in the spring/summer of 2008, Hu et al. (2009) measured real-time air pollutant concentrations downwind of Santa Monica Airport, a GA airport operated for private aircraft and corporate jets in Los Angeles County, California. Aircraft operations resulted in study average UFP levels that were elevated by factors of 10 and 2.5 at 100 and 660 m downwind of the runway, respectively, over background concentrations. These elevated UFP concentrations were mostly associated with jet departures, but also with jet taxi and idle, and operations of propeller aircrafts. Conversely, aircraft emissions did not appreciably elevate average levels of BC and p-PAHs, although spikes in the concentration of these pollutants were commonly associated with jet take-offs. Jet departures resulted in peak 1-min average concentrations of up to 2.2×10^6 #/cm^3, 440 ng/m^3, and 30 μg/m^3 for UFPs, p-PAH, and BC, respectively, 100 m downwind of the take-off area. These peak levels were elevated by factors of 440, 90, and 100 compared to the corresponding background concentrations.

CURRENT STUDY ON GENERAL AVATION

Between November 2005 and February 2007 AQMD conducted a series of field campaigns aimed to study the air quality in the communities around the Van Nuys Airport (VNA) and Santa Monica Municipal Airport (SMO). The concentrations of several gaseous and particle pollutants (i.e. PM, BC, OC, VOCs, lead and other trace elements, VOCs and carbonyls) and some of their physical and chemical characteristics

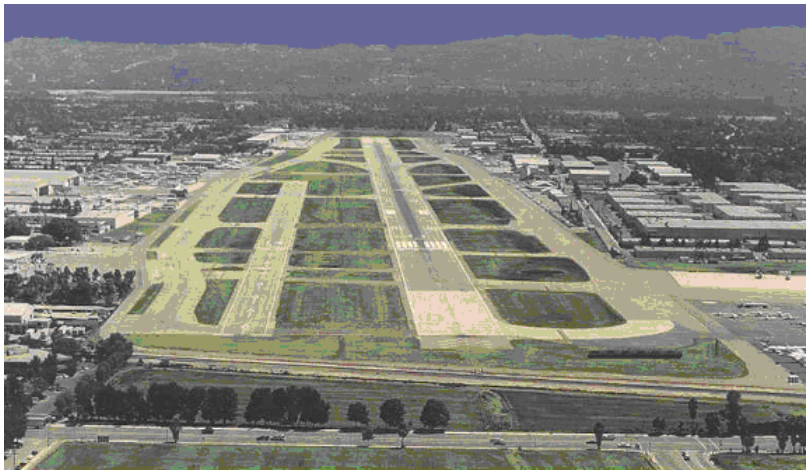
(e.g. number of UFPs) were measured using real-time and time-integrated instruments at multiple monitoring stations set-up inside and at different distances from the airports perimeters. The average concentrations of the measured chemical species were compared to the corresponding South Coast Air Basin averages and to values obtained at two additional concurrent monitoring sites located in Central Los Angeles and in Burbank, CA. The resulting data were analyzed to determine if one or both of the study areas showed ambient air toxic concentration gradients that can be attributed to aircraft emissions/airport activities and/or to other potential sources of air pollution such as roadway emissions.

Launched as part of the U.S. EPA Community Scale Air Toxics Grant, the main objectives of this study are a) to characterize the air toxics levels in the communities around SMO and VNA, b) to determine the potential impact of airport emissions on measured pollutant levels, c) to establish if airport-related emissions are distinguishable from those of other potential sources (e.g. nearby traffic), and d) to provide baseline data for future studies. Background information about the two airports studied during this field campaign is reported below.

The Van Nuys Airport (VNA)

Located in the San Fernando Valley area in the city of Los Angeles, California, VNA (Figure 1) is a public airport used by private, chartered, and small commercial aircraft (no commercial airlines fly into this airport). Owned and operated by Los Angeles World Airports (LAWA), VNA is one of the busiest GA airports in the world with around 450,000 takeoffs and landings annually (2005). With two parallel runways, this airport handled around 1,200 and 1,100 operations per day in 2005 and 2006, respectively. By comparison, LAX (with 4 runways and a large amount of commercial traffic) has about 1,700 operations/day. Most of the news helicopters used in the Los Angeles area are based at VNA. With 725 acres, this airport is surrounded by more open non-residential areas compared to SMO.

Figure 1 A current aerial view of the Van Nuys Airport



The Santa Monica Municipal Airport (SMO)

Located in the heart of the residential community of Santa Monica, California, the airport is around 9 miles north-west of LAX, and approximately 23 miles south-west of VNA. The Douglas Aircraft Company began to use SMO (Figure 2) to test and fly aircraft in 1922. By 1924, production was ramped up to 24/7 with the number of employees increasing into the thousands. A large number of employees working in aircraft manufacturing needed housing and, consequently, the City of Santa Monica and the Los Angeles County designated areas immediately adjacent to the airport for residential use. Santa Monica Airport handles an average of about 300 operations per day (2009 data) and annual jet air traffic has increased from about 1,000 in 1984 to almost 14,000 in 2009, mostly due to the ease of access and the increased fees associated with fewer access slots at LAX. Total aircraft operations in 2009 numbered 111,688 with 85% propeller, 13% jet, and 2% helicopters. In order to minimize the noise and pollution impact on the residential area nearby, the city of Santa Monica has strict ordinances that prohibit take-offs between the hours of 11pm and 7am on weekdays, and between 11pm and 8am on weekends. The lack of a buffer zone separating the airport from residences and odor and/or noise complaints by people living in nearby community have raised concerns about possible health effects from exposure to gaseous and particle pollutants emitted from the airport areas.

Figure 2 A current aerial view of the Santa Monica Airport

METHODS

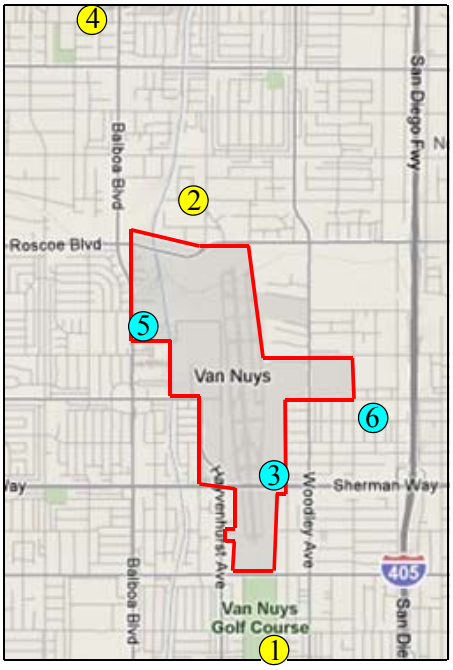
MONITORING SITES AT THE VAN NUYS AIRPORT

The airport air quality study work plan included a series of "fully" and "partially" instrumented sampling sites (Figure 3). The "fully" instrumented stations (i.e. VOR, Golf Course and Holmes School) were set-up at both ends of the runways and in nearby communities under the flight path, and were equipped with sequential VOC samplers (Xontec® 924 multi-canister VOC sampler), sequential carbonyl samplers (Xontec® 924 Sampler), total suspended particle (TSP) samplers for lead, speciated $PM_{2.5}$ samplers (Met One® SASS Sampler), continuous CO analyzers, and UFP counters (Condensation

Particle Counters, or CPCs; TSI® Model 3020 and Model 3781). The "partially" instrumented sampling sites (where only a TSP lead sampler and a CO sensor were operated) were located on both sides of the runways (i.e. Maintenance Yard and National Guard) and at a local elementary school (Cohasset School station). On July 2006, the Air National Guard station (Site 5 in Figure 3) was upgraded to a "fully" instrumented site.

The sampling campaign was divided into two intensive periods to study the seasonal variations of the studied air pollutants: from November 2005 to March 2006 (Phase 1) and from July 2006 to September 2006 (Phase 2). All sampling locations were chosen upon examination of historical wind patterns collected from the Federal Aviation Administration (FAA) meteorological network.

Figure 3 Map of the Van Nuys Airport sampling sites. Yellow and blue circles represent "fully" and "partially" instrumented sites, respectively (see text for details)



Site #	Location
1	Golf Course
2	VOR Site
3	Maintenance Yard
4	Holmes School
5	National Guard
6	Cohasset School

Van Nuys Airport Sampling Locations

Site 1: Golf Course (Executive Golf Course Service Yard site)
Address: 16235 Gilmore St., Van Nuys, California

This monitoring site was located at a Golf Course maintenance facility, about 700 m south of the airport and directly under the airport's fixed wing traffic paths. Carbon monoxide, TSP for lead, speciated $PM_{2.5}$, carbonyls, air toxics (in both the particle and the gaseous phases) and particle number concentration were collected/measured at this site.

Site 2: VOR (VHF Omnidirectional Range site)
Address: 8300 Hayvenhurst Place, Van Nuys, California

Set-up near the VHF Omnidirectional Range (VOR) navigation system, on the strip of land separating Hayvenhurst Ave. from Hayvenhurst Place, this station was situated just north of the airport, and sat directly under the airport's fixed wing traffic path. Here sampling consisted of CO, TSP for lead, speciated $PM_{2.5}$, carbonyls, air toxics (in both the particle and the gaseous phases) and particle number concentration.

Site 3: Maintenance Yard
Address: 7701 Sophia Ave., Van Nuys, California

This site was operated east of the runway and within the airport facilities maintenance complex adjacent to the Tarmac. Here sampling consisted of TSP for lead and CO.

Site 4: Holmes School (Holmes Middle School site)
Address: 9351 Paso Robles Ave., Los Angeles, California

This monitoring site was set-up in the teacher's parking lot on the south-east corner of the school complex, and near the intersection between Prairie Street and Paso Robles Ave. The school itself is approximately 2,400 m north-west of the airport and, although it was more than 1,000 m from the extended centerline of the runway, airplanes were observed directly over the school on several occasions. Here sampling consisted of CO, TSP for lead, speciated $PM_{2.5}$, carbonyls, air toxics (in both the particle and the gaseous phases) and particle number concentration. The first sampling session at the school was from December 2005 to February 2006. The second monitoring period started in July 2006 and it was stopped on 8/11/2006 because of a construction project at the school.

Site 5: National Guard (Air National Guard Site)
Address: Van Nuys Airport, Van Nuys, California

Located next to building No. 105 at the unused Air National Guard facility, this site was set-up within the north-west perimeter of the airport complex and perpendicular to the centerline of the runway. Here sampling consisted of TSP for lead, and CO (Dräger personal monitor) during Phase 1. This monitoring location was upgraded to a "fully" instrumented site upon closure of the Holmes Middle School station in August 2006, at which point sampling consisted of CO, TSP for lead, speciated $PM_{2.5}$, carbonyl, air toxics (in both the particle and the gaseous phases) and particle number concentration.

Site 6**:** Cohasset School (Cohasset Street Elementary School)
Address: 15810 Saticoy Street, Van Nuys, California

This monitoring station was operated on the roof of classroom 26, on the south-east perimeter of the school campus, and approximately 900 m east of the airport. Sampling at this site consisted of TSP for lead and CO.

MONITORING SITES AT THE SANTA MONICA AIRPORT

Similar to VNA, the airport air quality study work plan included a series of "fully" and "partially" instrumented sites (Figure 4). The stations were located close to the airport runway (West and East Tarmac sites), in the back yard of a private residence downwind of the airport (Ernst Residence site), at an elementary school further away from the SMO area (Richland School station), and at a park upwind of the airport (Marine Park site). These "fully" instrumented sites were equipped with sequential VOC samplers (Xontec® 924 multi-canister VOC sampler), carbonyl samplers (Xontec® 924 Sampler), TSP samplers for lead, speciated $PM_{2.5}$ samplers (Met One® SASS Sampler), continuous CO analyzers, and UFP counters (TSI® Model 3020 and Model 3781). The "partially" instrumented sampling stations (i.e. Maintenance Facility and Walgrove School), were set-up on opposite sides of the airport and the centerline of the runway. Only a TSP lead sampler and a CO sensor were run at these sites.

The sampling campaign was divided into two intensive periods to study the seasonal variations of the studied air pollutants: from April 2006 to July 2006 (Phase 1) and from October 2006 to February 2007 (Phase 2). All sampling locations were chosen upon examination of historical wind patterns collected from the FAA meteorological network.

Figure 4 Map of the Santa Monica Airport sampling sites. Yellow and blue circles represent "fully" and "partially" instrumented sites, respectively (see text for details)

Site #	Location
1	West Tarmac
2	East Tarmac
3	Ernst Residence
4	Richland School
5	Maintenance Facility
6	Walgrove School
7	Marine Park

Santa Monica Airport Sampling Locations

Site 1: West Tarmac
Address: Santa Monica Airport

This monitoring site was located in a field west of the runway, at the same elevation as the runway and within the south-west perimeter of the airport. Here sampling consisted of CO, TSP for lead, speciated $PM_{2.5}$, carbonyls, air toxics (both in the particle and in the gaseous phases) and particle number concentration.

Site 2: East Tarmac
Address: Santa Monica Airport

This station was set-up approximately 30 to 40 m west of the end of the runway, on the north-east perimeter of the airport and in very close proximity to the blast-fence. During Phase 1 sampling was limited due to lack of available power and consisted of TSP for lead (using battery operated samplers) and gaseous air toxics (collected once every six days). During the second phase of the study, SMO personnel provided power to the site and sample collection was upgraded to include continuous particle count measurements, three 8-hr VOC samples per day (i.e. 00:00 to 08:00, 08:00 to 16:00, and 16:00 to 00:00), and speciated $PM_{2.5}$.

Site 3: Ernst Residence
Address: 12130 Sardis Ave., Los Angeles, CA

Set-up in the back yard of a private residence, this site was directly under the fixed wing arrival/departure route. The residence (and the surrounding neighborhood) sits at a lower elevation than the airport and is approximately 100 m northeast of the end of the runway. Sampling consisted of CO, TSP for lead, speciated $PM_{2.5}$, carbonyls, air toxics (in both the particle and the gaseous phases) and particle count.

Site 4: Richland School (Richland Elementary School site)
Address: 11562 Richland Ave., Los Angeles, CA

This monitoring station was operated in the teacher's parking lot, close to the extended centerline of the runway. The school is less than 1,000 m northeast of the airport, and located at a lower elevation than SMO. At this location sampling consisted of CO, TSP for lead, speciated $PM_{2.5}$, carbonyls, air toxics (in both the particle and the gaseous phases) and particle number concentration.

Site 5: Maintenance Facility (Airport Maintenance Facility site)
Address: Santa Monica Airport

Set-up next to the airport facilities maintenance building, which is located on the Tarmac, this station was less than 150 m north of the runway. Sampling consisted of TSP for lead and CO.

Site 6: Walgrove School (Walgrove Elementary School site)
Address: 1630 Walgrove Ave., Los Angeles, CA

This monitoring site was located on the roof of one of the classrooms on the north perimeter of the campus and approximately 600 m south of SMO. Sampling consisted of TSP for lead and CO.

Site 7: Marine Park
Address: 1406 Marine Street; Santa Monica, CA

This station was set-up 1,000 m south-west of SMO, next to several tennis courts and directly under the fixed wing arrival/departure flight path. The park (and the surrounding neighborhood) is at a slightly lower elevation than the airport. Sampling at this site consisted of CO, TSP for lead, speciated $PM_{2.5}$, carbonyls, air toxics (in both the particle and the gaseous phases) and particle number concentration.

MEASURED POLLUTANTS

Table 1 lists the targeted air toxics measured at VNA and at SMO. Previous work has shown that these species are among the most significant contributors to health risks related to exposure to air toxics in the South Coast Air Basin (MATES III report). The air toxics data have been complemented by the additional measurements of OC, EC, $PM_{2.5}$ and ultrafine particle count. Information about wind speed and wind direction for the entire duration of the study has been obtained from the local airport authorities.

Table 1 List of the most relevant particle and gaseous species monitored during this study at both the Van Nuys and Santa Monica Airports

Target Pollutants		
$PM_{2.5}$ mass	1,3-Butadiene	Perchloroethylene
Organic Carbon (OC)	Methylene chloride	Formaldehyde
Elemental Carbon (EC)	Chloroform	Acetaldehyde
Trace Elements (e.g. Lead)	Benzene	Acetone
Ultrafine Particles (UFP) Count	Carbon Tetrachloride	Methyl Ethyl Ketone
Carbon Monoxide (CO)	Trichloroethene	
Vinyl Chloride	Toluene	

SAMPLING SCHEDULE

All 24-hr integrated $PM_{2.5}$ samples were collected on a one-in-three day basis. High volume total suspended particulate samples for lead analyses could not be collected at the East Tarmac site during Phase 1 because of a lack of electrical power, and a low volume sampler with a smaller power requirement (BGI® Model PQ100 Sampler; Waltham, Massachusetts) was used instead. Three 8-hr VOC samples (i.e. 00:00 to 08:00, 08:00 to 16:00, and 16:00 to 00:00) were collected every third day at the "fully" instrumented monitoring locations. This schedule is identical to that used by AQMD during the third Multiple Air Toxics Exposure Study (MATES III) and the typical U.S. EPA schedule for ambient PM sampling. One minute data from all continuous instruments (i.e. CO and ultrafine particle measurements) were recorded on a data logger and averaged to hourly concentrations to facilitate comparison among sites. The data files were periodically downloaded to a laptop computer and transferred to the AQMD's central database. A summary of the sampling schedule for VNA and for SMO is shown below (Table 2).

Table 2 Sampling schedule for the Van Nuys and Santa Monica Airports

Van Nuys Airport	Santa Monica Airport
November 2005 – Site set-up	March 2006 – Site set-up
December 2005 – Sampling start date (Phase 1)	April 2006 – Sampling start date (Phase 1)
March 2006 – Sampling end date	July 2006 – Sampling end date
July 2006 – Site set-up	November 2006 – Site set-up
August 2006 – Sampling start date (Phase 2)	December 2006 – Sampling start date (Phase 2)
November 2006 – End of the sampling campaign	March 2007 – End of the sampling campaign

LABORATORY ANALYSIS

Laboratory analysis of the collected samples was conducted by the AQMD laboratory. A variety of analytical methods were used to measure the concentrations of the targeted chemical compounds (Table 3).

Table 3 Sampling and analysis methods

Ambient Species	Sampling Method	Analysis Method
Volatile Organic Compounds	Silica-Lined Canisters	Gas Chromatography-Mass Spectrometry (GC-MS) with automated pre-concentration
Carbonyls	DNPH Cartridge	Solvent recovery and subsequent analysis via high pressure liquid chromatography (HPLC)
Carbon Monoxide	Continuous Analyzers	Infrared radiation absorption using gas filter correlation
Lead	TSP Samplers	Inductively Coupled Plasma Mass Spectrometry (ICP-MS)
Ultrafine Particles	CPC Particle Counter	Continuous particle counts via photo detection of light scattering from particles
$PM_{2.5}$ Mass	$PM_{2.5}$ Speciation Samplers	$PM_{2.5}$ Mass determined using analytical microbalance
$PM_{2.5}$ Metals	$PM_{2.5}$ Speciation Samplers	Metals determined by Energy Dispersive X-ray Fluorescence Spectrometry (EDXRF) & ICP-MS
Organic and Elemental Carbon	$PM_{2.5}$ Speciation Samplers	Sections of the PM filter were removed and analyzed using a thermal-optical carbon analyzer (IMPROVE method)

Volatile organic compounds were measured from air samples collected in silica-lined 6-liter canisters connected to Xontec® 910/912 multi-canister samplers. In addition to integrated 24-hr canister samples, VOCs were also collected at 8-hr intervals (i.e. 00:00 to 08:00, 08:00 to 16:00, and 16:00 to 00:00) to get some insight into the diurnal variation of this compound class. VOCs were identified and measured using a Gas Chromatograph-Mass Spectrometer (GC/MS). A modified EPA TO-15 method was used to collect and analyze all VOC samples.

Carbonyl compounds were sampled by drawing air through a DNPH (2, 4-Dinitrophenylhedrazine) cartridge attached to Xontec® 924 samplers; carbonyls undergo derivatization upon contact with DNPH. The derivatives were extracted using acetonitrile and analyzed using Waters® High Pressure Liquid Chromatography (HPLC) in accordance with U.S. EPA method TO-11. The HPLC system employed for the analysis of these samples consists of a Waters® 2690 separation module and a Waters® 996 Photodiode Array Detector.

At all "fully" instrumented sites, CO was continuously monitored in accordance with U.S. EPA equivalent methods criteria using CO Analyzers (Dasibi® 3008 model) that operate on the principle of infrared radiation absorption. Personal CO monitors, consisting of a CO detector tube attached to a small air pump (Dräger® Personal CO Monitors), were used at the "partially" instrumented stations. All sampling probes met U.S. EPA criteria for CO sampling. Data were stored on electronic data recorders, downloaded on a laptop computer, and transferred to AQMD's air quality database.

The concentrations of lead and beryllium were measured on total suspended particulate (TSP) samples collected on glass fiber filters using high volume samplers (Graseby/Anderson TSP Sampler). The glass fiber filters were extracted with acid and analyzed using Inductively Coupled Plasma Mass Spectrometer (ICP-MS; Leco® Renaissance Time of Flight).

The concentration of ultrafine particles at VNA (Phases 1 and 2) and at SMO (Phase 1 only) was measured continuously by mean of butanol-based condensation particle counters (CPCs; TSI® Model 3070). The CPC uses a laser photo diode to flash light on the particles that have been supersaturated and grown to detectable sizes with n-butyl alcohol. A photo detector is then used to count the particles in the sample stream. The sample inlet probe uses a $PM_{2.5}$ sharp cut cyclone to eliminate particles larger than 2.5 μm in diameter. Particle counts were recorded on the same electronic data recorders that also stored the CO data. Because the term of the loan for the butanol-based CPCs used during the first phase of the Santa Monica field campaign (April–July, 2006) expired at the end of September 2006, water-based CPCs (TSI® Model 3781) were purchased by AQMD and used instead during the second part of the campaign in Santa Monica (October 2006–February 2007). This newer model utilizes water instead of butanol to reach supersaturation conditions and grow particles, eliminating the characteristic strong odor associated with the Model 3070.

Integrated 24-hr $PM_{2.5}$ samples were collected on quartz or teflon filters using SASS $PM_{2.5}$ speciation samplers (Met One® SASS Speciation Sampler), and analyzed for: gravimetric mass (using an analytical micro-balance; Sartorus® MC-5), trace elemements, OC and EC. Metal analysis of particulate samples was performed using a methodology based on IO-3 (Compendium of Methods for Inorganic Air Pollutants)

implementing a combination of energy dispersive X-ray fluorescence (PANalytical Epsilon 5® Energy Dispersive X-Ray Fluorescence Spectrometer), and inductively coupled plasma mass spectrometry (Leco® ICP-MS).

Carbon analysis for the determination of OC and EC was performed on small circular disks taken from the loaded $PM_{2.5}$ quartz fiber filter samples. These disks were placed inside a heated furnace of a Thermal/Optical Carbon Analyzer (Desert Research Institute, Model 2001) one at the time and subjected to a programmed, step-wise temperature increase while helium gas (He) with varying amounts of oxygen was passed over the sample. This method (based on the IMPROVE protocol) uses a laser beam to monitor and correct, when necessary, the degree of oxidation or carbonization (pyrolysis) that occurs during the analysis.

RESULTS AND DISCUSSION

The data collected at VNA and at SMO were examined for upwind/downwind differences, concentration gradients, evaluated against measurements collected at companion AQMD sites (located in downtown Central Los Angeles and in Burbank, CA) and compared to the corresponding South Coast Air Basin averages (when available). Ultrafine particle count measurements were not taken elsewhere in the Basin and, thus, UFP number concentrations at the study sites were compared to one another to assess spatial and temporal variabilities.

METEOROLOGY

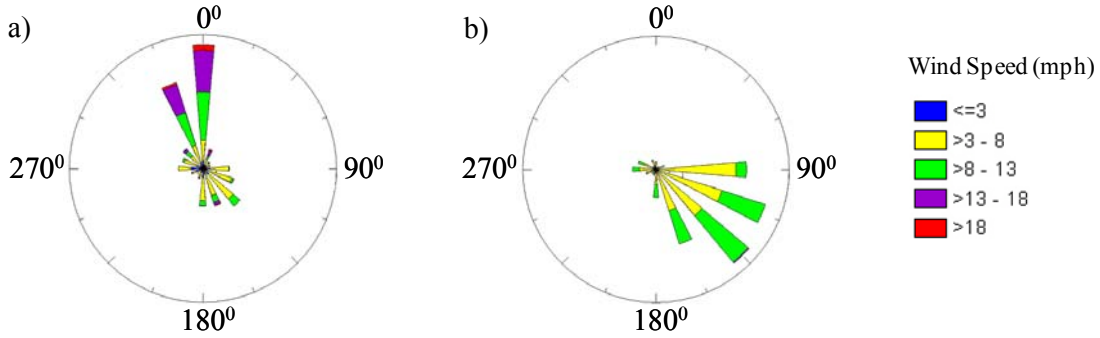
Van Nuys Airport

The wind patterns at the Van Nuys Airport are influenced by the orientation of the San Fernando Valley, the surrounding mountain ranges, and the synoptic weather systems which pass over Southern California. Wind conditions during Phase 1 (November 2005-March 2006) and Phase 2 (July-September 2006) of this study are typical for this location and the surrounding areas in the San Fernando Valley (e.g. Burbank) (Figure 5). In particular, winds around the Van Nuys Airport are influenced by a predominant on-shore flow during the day and a lighter off-shore flow at night. This land-sea breeze effect dominates the Basin for most of the year. During the winter months, north and north-northwest winds are more prevalent and stronger than at other times of the year (Figure 5a). Five to ten times a year, normally in the winter months, high pressure systems build over the desert plateaus of Nevada and Utah spreading southward into the Mojave Desert. The clockwise circulation around these high pressure systems can produce a warm, intense north-east wind known locally as Santa Ana winds. Santa Ana winds can last from a few hours to several days. The wintertime is the wettest season of the year in the Basin and the heaviest precipitation typically occur in February.

During Phase 2 of this study, the predominant wind flow at the Van Nuys Airport was from south-southeast (Figure 5b), although all wind directions are represented in varying amounts throughout the year. During summer, atmospheric conditions are more consistent when the dominant features influencing winds are strong temperature gradients caused by heating over the deserts and the cold waters along the coast. The July through

September wind rose has features that are representative of the San Fernando Valley during a transitional summer to fall climatology. At this time of year, predominant winds correspond more closely with south to south-east flows which dominate throughout the year.

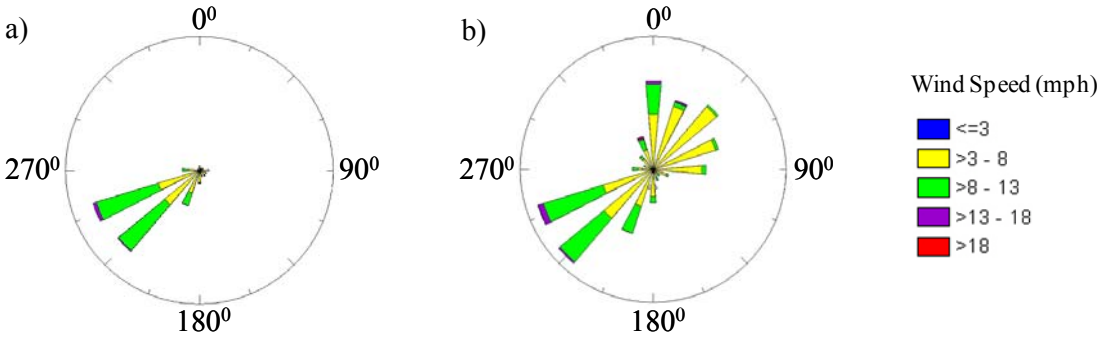
Figure 5 Average wind speed and direction at the Van Nuys Airport during a) Phase 1 (November 2005 - March 2006) and b) Phase 2 (July - September, 2006)



Santa Monica Airport

At this location winds were monitored from April through July 2006 (Phase 1) and between October 2006 and February 2007 (Phase 2). Wind rose charts for these time periods show the presence of a distinct daytime sea breeze, characteristic of beach communities in the South Coast Air Basin (Figure 6). During the spring and summer months, winds were predominantly from the west-southwest and southwest (Figure 6a). In addition to this strong onshore see breeze, the fall and winter periods were characterized by winds coming from all directions (Figure 6b). It is worth noting that strong north winds are probably indicating that Santa Ana offshore wind conditions were present occasionally.

Figure 6 Average wind speed and direction at the Santa Monica Airport during a) Phase 1 (April - July, 2006) and b) Phase 2 (October 2006 - February 2007)



LEAD

Van Nuys Airport

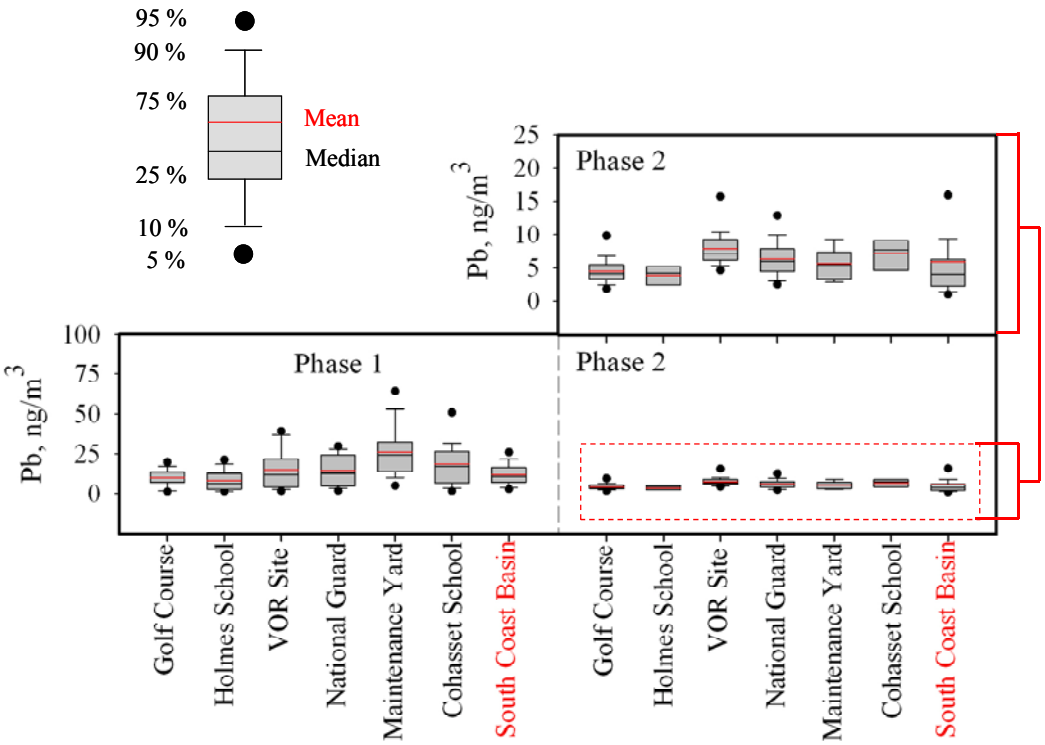
TSP lead concentrations collected at all six monitoring stations and during both phases of the study were examined for spatial and seasonal patterns, and the results have been summarized in Table 4 and Figure 7. The highest average and median lead levels (26.1 and 24.4 ng/m^3, respectively) during Phase 1 (November 2005-March 2006) were measured at the Maintenance Yard site, in close proximity to the east side of the runway and within the airport fence-line, and were approximately 3 times higher than the lowest average lead concentration (8.45 ng/m^3; measured at the Holmes School site) (Figure 7a). Higher increases over typical background concentrations are likely to occur on smaller time scales (1-min to 1-hr), especially during periods of intense traffic activity when piston driven aircraft are taking-off or landing. A non-parametric one-way Analysis of Variance (ANOVA) on ranks revealed that the median lead concentration at the Maintenance Yard site is significantly higher ($p<0.05$) than the corresponding median levels observed at all other airport sites and in the South Coast Basin (11.0 ng/m^3). The median lead concentrations at the Cohasset School (17.3 ng/m^3), at the VOR site (12.0 ng/m^3), and at the National Guard site (12.8 ng/m3) were also higher than the typical median value for the South Coast Basin.

Overall, our data suggest that the lead concentration gradient at VNA during Phase 1 reflect the distance of the six monitoring sites from the runway area, probably because of lead emissions from piston driven aircraft operations including idling, take-off, landing and re-fueling. As explained in a previous paragraph, most aircraft operation at GA airports are powered by piston engines and fueled by Avgas, which is characterized by a higher volatility and lead content than regular jet fuel. These results are in line with those obtained at the Buttonville Airport near Toronto in 2000 (Airborne Particulate Matter, Lead and Manganese at Buttonville Airport; prepared by Conor Pacific Environmental Technologies Inc. in 2000), where the average lead concentration in 24-hr PM_{10} air samples collected at four different sites near (15 to 50 m) the runway was 30 ng/m^3, a value four times higher than that measured at a background station. The Buttonville Airport averages about 22,000 aircraft movements per month, many of which are small aircraft using aviation gas containing lead, and it is fairly comparable to VNA in terms of size and traffic activity (VNA averages about 33,000 per month).

During the second part of the study (Phase 2; July-September 2006), the overall lead concentrations at all sites were substantially smaller than during Phase 1 (Figure 7b), with average values between 3.88 and 7.11 ng/m^3 (measured at the Holmes School and at the Cohasset School, respectively). A non-parametric one way ANOVA on ranks indicated that there is no statistically significant difference among the median lead concentrations across all monitored sites ($p > 0.05$). It is possible that these substantially lower concentrations observed in the warmer months are related to seasonal differences in airport practices and traffic volume or, most likely, in meteorological conditions. Generally, in the late fall and winter light winds result in reduced ventilation, and late night/early morning inversions contribute to increasing the surface-level concentrations of those pollutants that are emitted from ground-level sources. During the summertime months, stronger land breeze/sea breeze circulation and increased insulation results in

higher wind speeds, increased vertical atmospheric dispersion and, subsequently, reduced ambient concentrations.

Figure 7 Box plots showing the median and mean lead concentrations in total suspended particles (black and red lines within each box, respectively) (ng/m^3) measured at the Van Nuys Airport during Phase 1 (November 2005 - March 2006) and Phase 2 (July - September, 2006). Representative lead levels for the South Coast Basin are also reported for comparison. Data collected during Phase 2 have been magnified on the top right panel to facilitate a comparison among sites



Interestingly, a revised airport-specific lead inventory recently released by EPA in 2008 (Lead Emissions from the Use of Leaded Aviation Gasoline in the United States, prepared by the U.S. EPA) showed that in 2002 lead emissions from landing and take-off activities of piston-engine aircraft at the Van Nuys Airport amounted to 1,256 Kg (the highest recorded value in the U.S. for that year). It should be noted that the sum of lead emissions at the 3,413 airport facilities listed in this EPA document was estimated to be 282 tons, or about 45% of the total lead emitted nationwide from the use of leaded Avgas. The sources that are most likely to account for the remaining 55% include a) over 16,000 airport facilities where leaded Avgas is used but emissions are not accounted for in the national emission inventory, and b) lead emitted outside the landing and take-off cycle (airport-specific lead emissions estimates account only for the lead emitted during taxi/idle-out, takeoff, climb-out, approach, and taxi/idle-in and do not account for lead emitted during cruise).

Finally, as of October 2008 the U.S. Environmental Protection Agency strengthened the National Ambient Air Quality Standard (NAAQS) for lead, lowering it from 1500 ng/m^3 (quarterly average) to a more stringent 150 ng/m^3 (rolling 3-month average). In this respect, none of the concentrations measured at the Van Nuys Airport between November 2005 and September 2006 were close to or above the current NAAQS.

Table 4 Average and median lead concentrations in total suspended particles (ng/m^3) at the Van Nuys Airport during Phase 1 (November 2005 - March 2006) and Phase 2 (July - September, 2006). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid samples (Valid N) have also been reported along with representative lead data for the South Coast Basin (in red)

	Golf Course	VOR	Holmes School	National Guard	Cohasset School	Maintenance Yard	South Coast
				Phase 1			
Average	10.2	15.1	8.45	14.5	18.6	26.1	12.3
Median	10.1	12.0	6.52	12.8	17.3	24.4	11.0
SD	5.06	11.5	6.1	9.26	13.3	16.7	7.12
Min	1.45	1.51	1.55	1.68	0.95	0.10	0.93
Max	20.7	40.5	21.9	30.5	64.7	83.7	45.9
Valid N	30	31	33	33	29	33	180
				Phase 2			
Average	4.51	7.85	3.88	6.31	7.11	5.61	5.92
Median	4.13	7.06	4.19	5.96	7.64	5.49	4.02
SD	1.84	2.60	1.54	2.59	2.40	2.49	9.24
Min	1.81	4.66	2.09	2.49	4.07	2.51	0.75
Max	10.3	15.7	6.10	13.2	9.07	11.1	89.5
Valid N	22	19	5	21	4	18	131

Santa Monica Airport

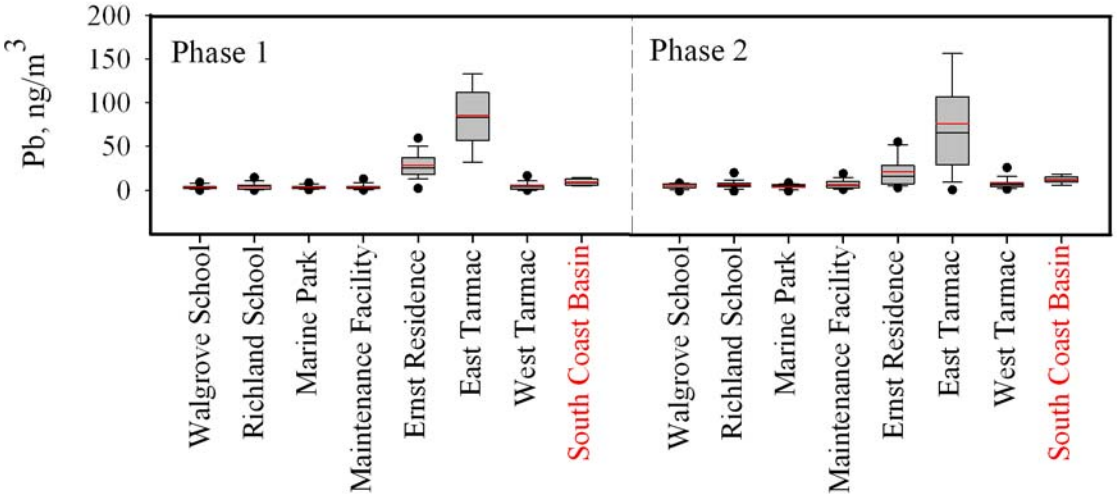
Figure 8 illustrates the spatial and seasonal variations in lead concentration (TSP) at all monitored SMO locations. As reported in Table 5, the highest average and median lead levels were measured at the East Tarmac and at the Ernst Residence sites, both located north (downwind) of the runway and under the fixed wing arrival route. The average and median lead concentrations at all other monitoring sites were always slightly lower than the correspondent values for the South Coast Basin. The results of a one-way ANOVA on ranks revealed that the median lead levels at the East Tarmac and Ernst Residence sites were significantly ($p<0.05$) higher than those at the other monitored locations throughout the entire duration of the study.

It is worth noting that the average lead concentrations at the East Tarmac station (85.2 and 77.0 ng/m^3, for Phases 1 and 2, respectively) were 14 to 26 times higher than the corresponding average background levels at the Marine Park site, and around one half

the current, more stringent, NAAQS for lead (150 ng/m^3; rolling 3-month average) (Table 5). Twenty four hour average values close to, or above the current NAAQS for lead were recorded at the East Tarmac site in more than one occasion and during both phases of the study. The highest recorded 24-hr lead concentration value was 299 ng/m^3 and refers to a TSP sample collected at the East Tarmac in Phase 2. These increased values are probably related to the close proximity (30-40 m) of this last site to the blast-fence, where planes sometimes idle before clearance for take-off, and to the fact that the predominant winds (from southwest) are aligned to the runways of the airport and blowing towards the East Tarmac station.

Located around 100 m northeast of the runway and directly under the fixed wing arrival route, the Ernst Residence site (where average lead levels were 28.6 and 22.2 ng/m^3 during Phases 1 and 2, respectively) was also characterized by increased lead concentrations with respect to background conditions (average lead values at the Marine Park station were 4 to 9 times lower). Unlike what was observed at VNA, the magnitude of the lead concentrations measured in Santa Monica was not substantially different between Phase 1 and Phase 2 (Figures 8).

Figure 8 Box plots showing the median and mean lead concentrations in total suspended particles (black and red lines within each box, respectively) (ng/m^3) measured at the Santa Monica Airport during Phase 1 (April - July, 2006) and Phase 2 (October 2006 - February 2007). The correspondent lead levels for the South Coast Basin have also been reported for comparison



It is worth mentioning that a revised airport-specific lead inventory released by EPA in 2008 (Lead Emissions from the Use of Leaded Aviation Gasoline in the United States, prepared by the U.S. EPA) showed that in 2002 lead emissions from landing and take-off activities of piston-engine aircraft at SMO were 369 Kg, a value 3.4 times lower than that recorded at VNA during the same year, but within the top 2% among the 3,413 airport facilities considered in this EPA document.

Overall, our results show that the measured lead concentration at the Santa Monica sites increased with decreasing distance from areas where airplanes were idling, taking-off and landing. These outcomes are in line with those obtained at the Buttonville Airport near Toronto in 2000 (discussed in the previous chapter) and with those from a study conducted at the O'Hare International Airport (Chicago, Illinois) in 2000, where airport emissions were found to have an impact in the areas adjacent to the airport for several key target compounds including lead (Chicago O'Hare Airport Air Toxic Monitoring Program; prepared by the Illinois Environmental Protection Agency, Bureau of Air, in 2002).

Table 5 Average and median lead concentrations in total suspended particles (ng/m^3) at the Santa Monica Airport during Phase 1 (April - July, 2006) and Phase 2 (October 2006 - February 2007). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid samples (Valid N) have also been reported along with representative lead data for the South Coast Basin (in red)

	Walgrove School	Richland School	Marine Park	Maintenance Facility	Ernst Residence	East Tarmac	West Tarmac	South Coast
				Phase 1				
Average	3.38	4.50	3.30	3.66	28.6	85.2	4.58	9.47
Median	2.66	4.00	2.76	2.69	25.3	83.5	4.07	8.86
SD	2.35	3.57	2.17	3.20	14.1	33.0	4.18	3.55
Min	0.10	0.10	0.10	0.10	1.59	27.0	0.10	5.19
Max	9.58	14.7	8.72	13.5	60.1	135.0	17.7	15.0
Valid N	29	37	30	32	20	12	31	13
				Phase 2				
Average	5.79	7.59	5.50	7.68	22.2	77.0	9.05	13.1
Median	5.97	6.92	5.95	6.52	17.1	67.0	7.14	12.7
SD	2.66	5.32	2.48	4.92	16.6	68.6	6.84	4.05
Min	ND	ND	0.10	1.78	3.99	0.10	2.01	4.88
Max	9.22	30.1	9.86	21.3	70.1	299	37.7	19.3
Valid N	25	32	35	25	38	33	32	16

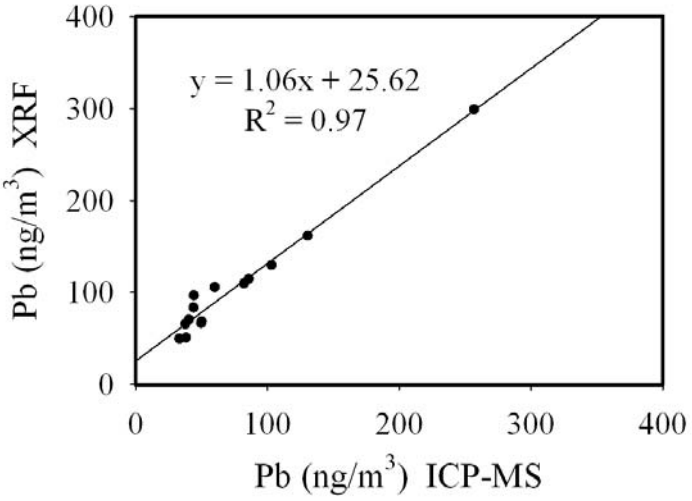
ND = non detected

EAST TARMAC SITE (METHOD COMPARISON)

During Phase 1 electrical power was not available at the East Tarmac site to operate the hi-volume TSP samplers. Therefore, a smaller battery powered low volume sampler (BGI® Model PQ100 Sampler; Waltham, Massachusetts) configured to collect TSP was deployed instead. In this case, all filter samples were collected on teflon substrates at 12 lpm and analyzed for lead using X-Ray Fluorescence (XRF) rather than Inductively Coupled Plasma Mass Spectrometry (ICP-MS). $PM_{2.5}$ speciated samples were also collected at the Ernst Residence, Marine Park and Richland School stations during the entire duration of the study and analyzed for lead using XRF. Small quantities of all

loaded teflon filters were also digested with acid, and the extracts analyzed by ICP-MS to compare the two methods. Although the lead concentrations obtained by XRF may be biased about 25 ng/m^3 high compared to those from ICP-MS analyses, an excellent agreement ($R^2 = 0.97$) was found between the results of these two analytical methods (Figure 9). It is possible that the teflon filter matrix may require a more rigorous digestion step than the glass fiber filter typically used for ICP-MS, since teflon is well known for its resistance to aqueous wetting.

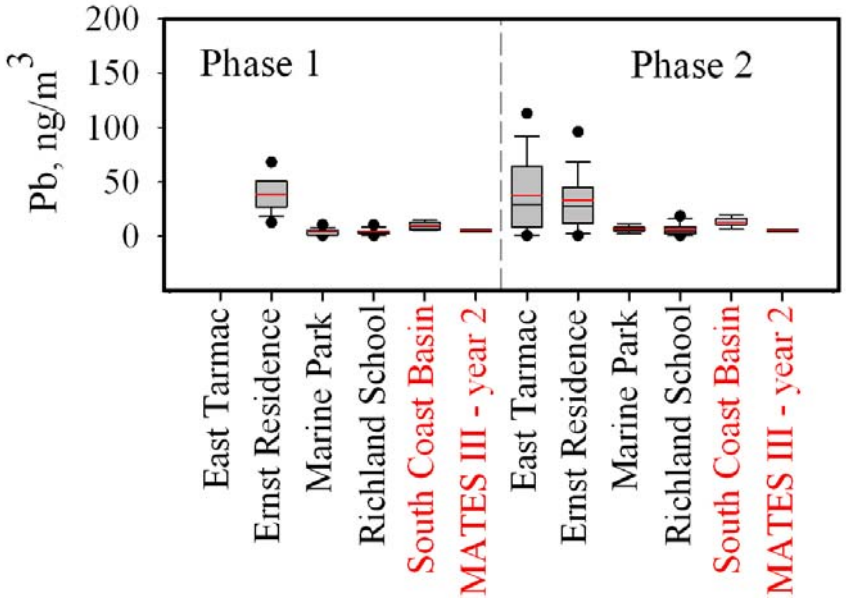
Figure 9 Comparison between lead concentrations obtained from XRF and ICP-MS analyses of selected TSP samples collected at the East Tarmac site (Santa Monica Airport) during Phase 1



Lead data from the analysis of samples collected using the $PM_{2.5}$ speciation samplers show a spatial pattern across the four monitored locations (i.e. East Tarmac, Ernst Residence, Marine Park and Richland School stations) (Figure 10) similar to that observed from the TSP lead data (Figure 8). The average and median lead concentrations in fine particles were elevated above the typical South Coast Basin levels at both the Ernst Residence site (during both phases) and at the East Tarmac station (during Phase 2 only; $PM_{2.5}$ samples for lead analysis were not collected at this location during Phase 1). This suggests that a relatively high proportion of lead at these two stations was not associated with re-suspended material (which would consist of coarser particles primarily above 2-5µm in diameter), and may have originated from fresh emissions from aircraft idling, landing, or taking-offs, or from other airport-related activities such as re-fueling. At all sites Pb($PM_{2.5}$) / Pb(TSP) ratios were between 0.83 and 1.48. Values higher than one may be due to differences in measurement methods. The average and median lead levels measured in $PM_{2.5}$ particles during the second year of the MATES III study (from April 2005 to March 2006) were comparable to the corresponding average concentrations observed at the Marine Park station (background site) during both Phases 1 and 2 of this

study. Overall, our results suggest that aviation gas combustion leads to the formation and emission of small primary $PM_{2.5}$ particles containing lead.

Figure 10 Box plots showing the median and mean lead concentrations (ng/m^3) in fine particulate matter ($PM_{2.5}$) measured at four monitoring sites of the Santa Monica Airport (black and red lines within each box, respectively) during Phase 1 (April - July, 2006) and Phase 2 (October 2006 - February 2007). Lead levels for the South Coast Basin (same time periods) and at MATES III sites (from April 2005 to March 2006 only) are shown for comparison



VOLATILE ORGANIC COMPOUNDS (VOC)

The following volatile organic compounds (VOCs) were selected for discussion because of their potential importance relative to toxic cancer risk in the South Coast Air Basin: 1,3-butadiene, methylene chloride, chloroform, benzene, carbon tetrachloride, toluene, and perchloroethylene. Nearly all samples collected at all sites showed vinyl chloride and trichloroethene levels at or below their corresponding detection limits. Thus, the concentrations of these two volatile species are not discussed in the following paragraphs. Averaged 24-hr VOC concentrations were then compared to the corresponding daily-averaged levels at two AQMD companion monitoring stations, one in Burbank, CA (about 14 mi south-east of VNA) and the other in Central Los Angeles (around 14 mi east of SMO). In an effort to get some insight into the daily variations of the measured VOCs three 8-hr samples (i.e. 00:00 to 08:00, 08:00 to 16:00, and 16:00 to 00:00) were collected daily at four sites for VNA [i.e. Golf Course, Holmes School, National Guard (Phase 2 only) and VOR] and at five sites for SMO (i.e. Richland School, Marine Park, Ernst Residence, East Tarmac and West Tarmac). A detailed discussion of important VOC results follows.

Van Nuys Airport

With the exception of chloroform, the average and median concentrations of 1,3-butadiene, methylene chloride, benzene, carbon tetrachloride, toluene, and perchloroethylene were generally higher during the first phase of the study (November 2005 – March 2006) (Figures 11a, 11b, and 11c) as compared to the second phase. Typically, in the fall/winter months light winds result in reduced ventilation, and late night/early morning inversions contribute to increased surface-level concentrations of pollutants emitted from ground-level sources. During the summer months, stronger land/sea breeze circulation and increased insulation results in higher wind, increased vertical atmospheric dispersion and, subsequently, reduced ambient concentrations. A similar seasonal variability in the concentration of benzene, 1,3 butadiene, methylene chloride and perchloroethylene, with wintertime maximums and summertime minimums, was also observed in the South Coast Basin during the MATES II and MATES III studies (prepared by AQMD in 2000 and 2008, respectively).

The spatial distribution of most VOCs did not vary substantially across the two sampling periods and, in most cases, the highest concentrations across all Van Nuys stations were observed at sites that were closer to busy surface streets and, to a lesser extent, to the airport area. For example, the Golf Course station, characterized by relatively high VOC levels, was less than 100 m north of Victory Blvd. (a major east-west arterial road traversing the entire length of the San Fernando Valley) and about 700 m from the south perimeter of the airport, directly under the airport's fixed wing traffic path. Because the concentration of vehicle-related pollutants decreases exponentially with distance from roadways and returns to background levels after only 300 to 2,500 m (depending on the type of the pollutant, traffic conditions, time of the day, and local meteorology) (Zhu et al., 2002a and 2002b; Hu et al., 2009), it is possible that motor-vehicle emissions played a significant role in increasing the measured atmospheric concentrations of most VOCs at the Golf Course site. Conversely, the Holmes School station, where lower gaseous concentrations were generally observed, was around 2,400 m north-west of the Van Nuys Airport and at least 300 m away from any major surface street. The levels of most volatile species at the VOR and National Guard sites (set-up in close proximity and within the airport fence-line, respectively) were mostly between those recorded at the Golf Course and at Holmes School monitoring stations.

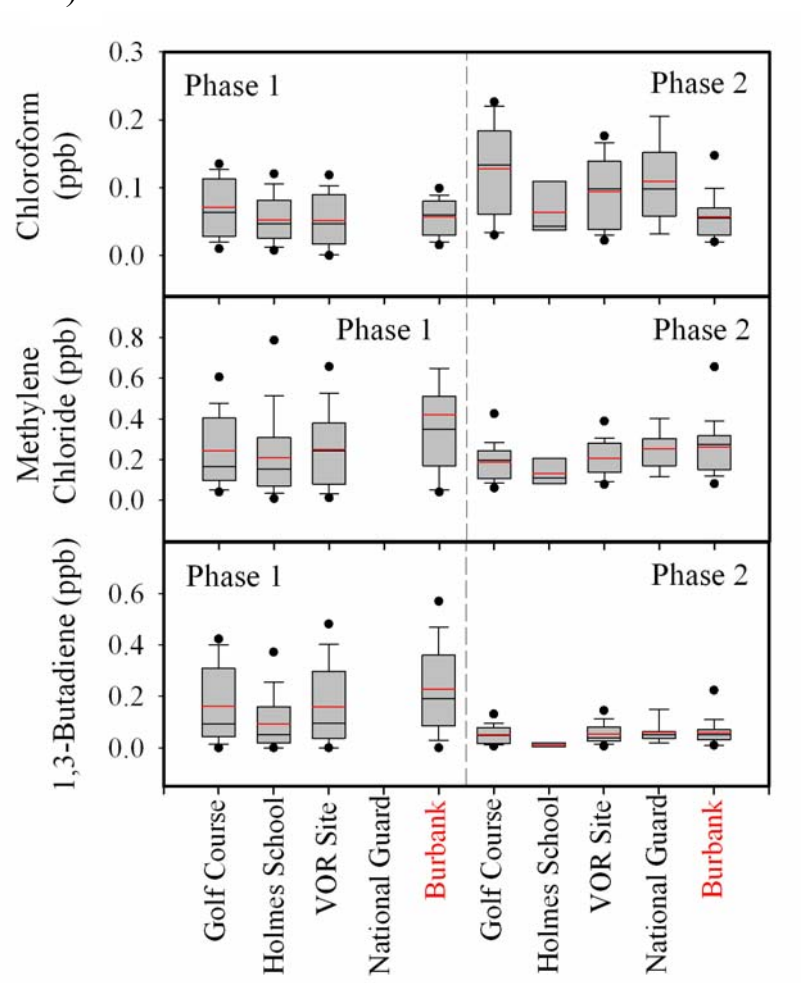
The highest VOC concentrations measured at VNA were comparable to those observed at an urban site in Burbank (especially during Phase 1; Figure 11), located in close proximity to the Ventura Freeway (Route 134), the Golden State Freeway (I-5), and several other major and local roads. Overall, our results seem to suggest the concentration gradient of most VOCs measured in the VNA area is mostly influenced by proximity to mobile sources surrounding the airport's perimeter. The extent of the contributions of this and other pollution sources including aircraft emissions and other airport activities to the measured VOC levels cannot be assessed from the available data.

These outcomes are in line with those obtained from similar studies in other parts of the United States. For example, the results from a recent field campaign conducted by ENVIRON Corp. at the Teterboro Airport in New Jersey (one of the busiest GA airports in the United States) revealed that the concentrations of most VOCs were comparable to or lower than those measured in the urban area of Elizabeth (NJ), where the atmospheric levels of these volatile pollutants are typically dominated by mobile source emissions

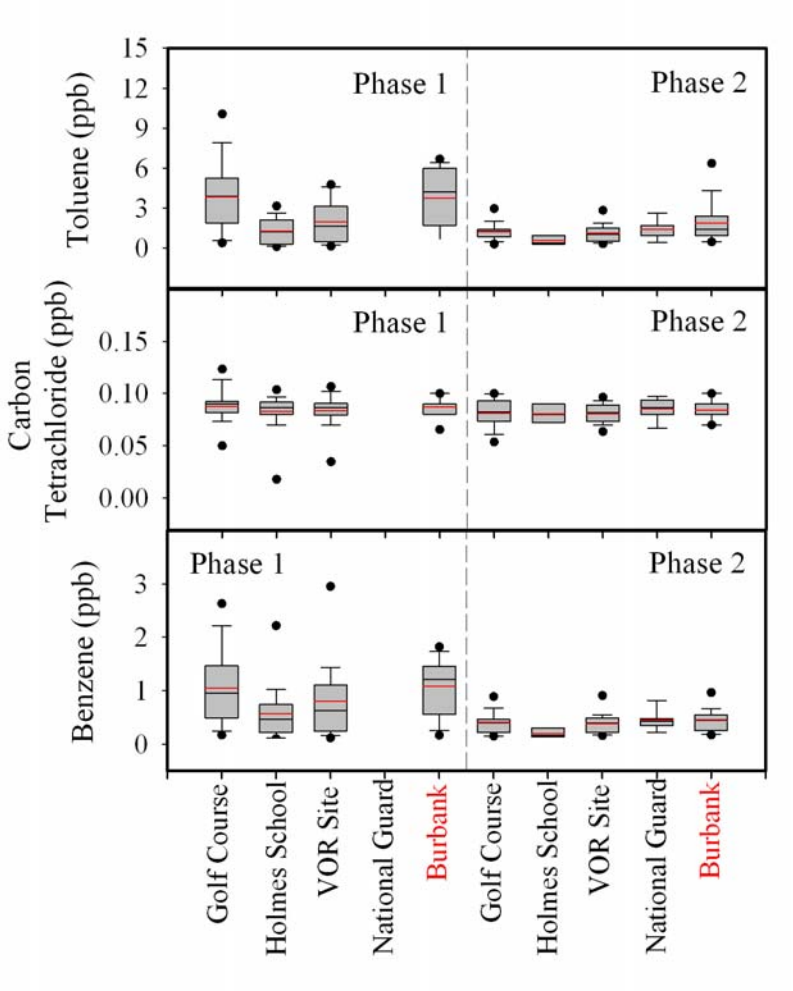
(Teterboro Airport, New Jersey, Detailed Air Quality Evaluation, Final Report Prepared by ENVIRON Corp. in 2008). A comparison between ambient VOC data at the O'Hare International Airport (one of the world's busiest airports) and those representing "typical urban" concentrations in the Chicago, Atlanta, Detroit, Houston and Milwaukee metropolitan areas led to similar conclusions (Chicago O'Hare Airport Air Toxic Monitoring Program; prepared by the Illinois Environmental Protection Agency, Bureau of Air, in 2002). A summary of all 1,3-butadiene, methylene chloride, chloroform, benzene, carbon tetrachloride, toluene, and perchloroethylene data collected at VNA can be found in Appendix A.

Figure 11 Spatial distributions of a) 1,3-butadiene, methylene chloride, and chloroform, b) benzene, carbon tetrachloride, and toluene, and c) percholoethylene at 5 monitoring sites of the Van Nuys Airport (i.e. Golf Course, Holmes School, VOR, and National Guard sites) during Phase 1 (November 2005 - March 2006) and Phase 2 (July - September, 2006). Data collected concurrently at a monitoring station in Burbank are also included for comparison

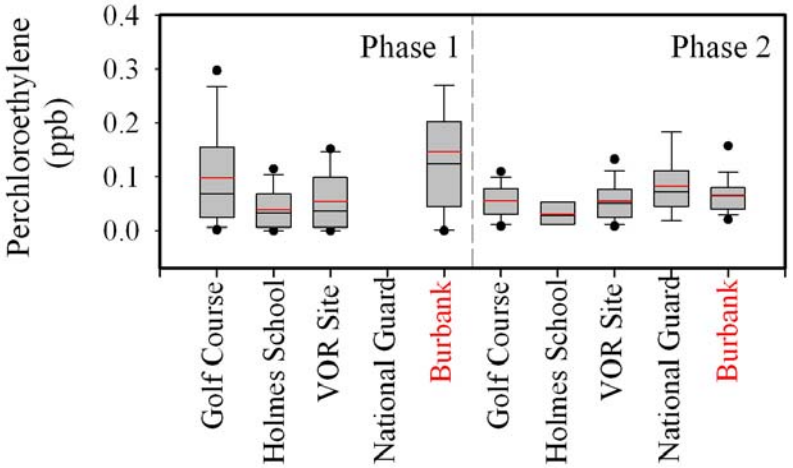
a)



b)


Toluene (ppb)
Carbon Tetrachloride (ppb)
Benzene (ppb)
Phase 1
Phase 2
Golf Course
Holmes School
VOR Site
National Guard
Burbank

c)


Perchloroethylene (ppb)
Phase 1
Phase 2
Golf Course
Holmes School
VOR Site
National Guard
Burbank

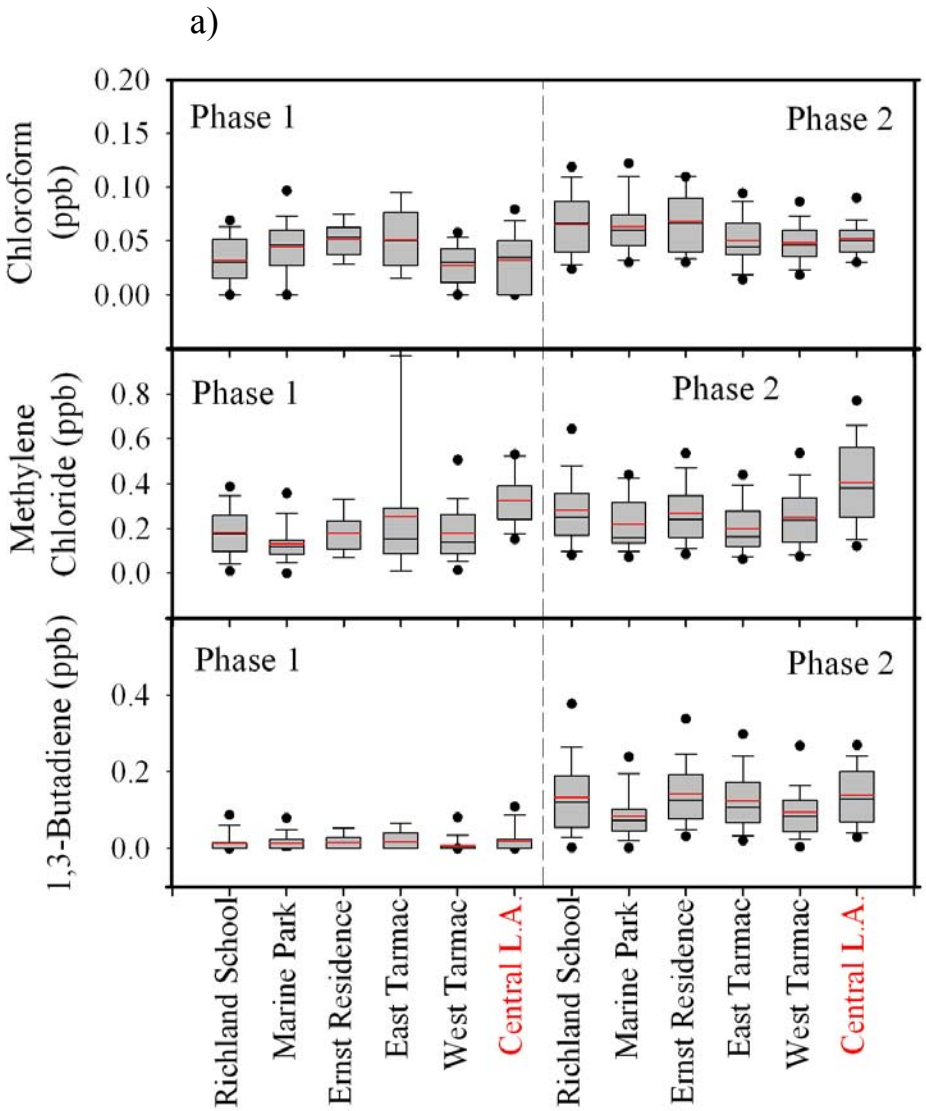
Santa Monica Airport

With the exception of carbon tetrachloride, the average and median concentrations of all VOCs present in substantial amounts in the canister samples collected at SMO (namely, 1,3-butadiene, methylene chloride, chloroform, benzene, carbon tetrachloride, toluene, perchloroethylene and trichloroethene) were generally higher during the fall/winter months (from October 2006 to February 2007; Phase 2) than in the spring/summer period (between April 2006 and July 2006; Phase 1). This is consistent with typical seasonal changes in local meteorological conditions, and with what was observed at the Van Nuys Airport.

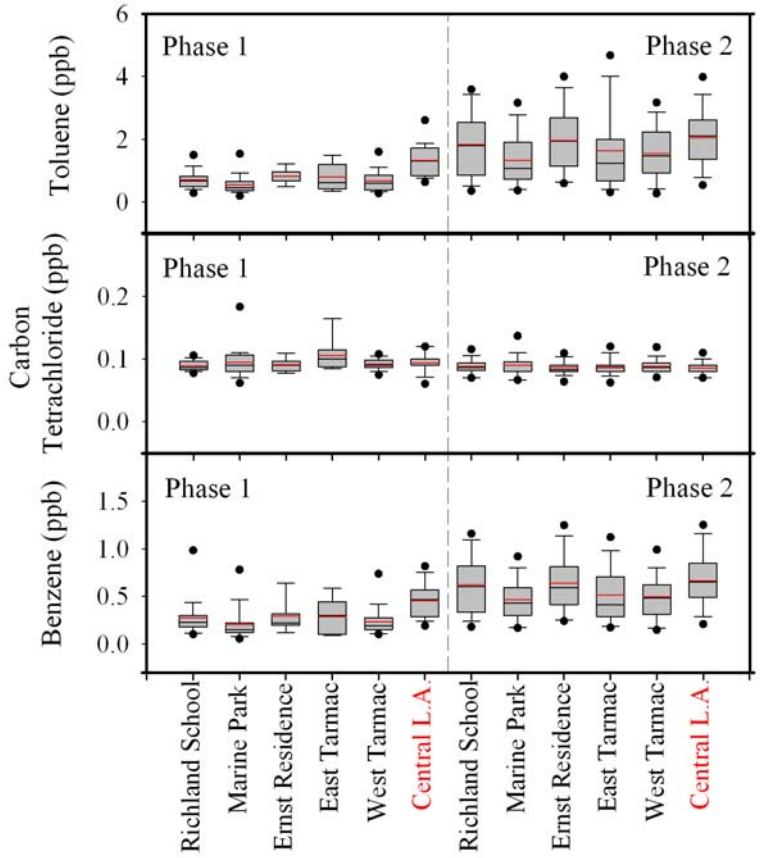
Although the spatial distribution of most volatile species did not vary substantially across the 2 sampling periods, it is difficult to discern a consistent concentration gradient across the sampling sites (Figures 12a, 12b, and 12c). However, in most occasions slightly higher VOC levels were observed at the Richland School, East Tarmac, Ernst Residence, and West Tarmac stations, probably because of their relative proximity to the Santa Monica freeway (I-10), to several congested surfaces streets and, possibly, to the airport area. In particular, the Richland School site (the furthest from SMO) was less than 300 m south of the I-10 (a major east-west interstate highway that runs east from Santa Monica through Los Angeles), about 600 m west of interstate 405 (I-405; a heavily traveled north-south thoroughfare known to be one of the busiest freeways in the United States), and close to several trafficked surface streets. The East Tarmac and Ernst Residence sampling locations were within 100 m from the inner and outer edge of the airport fence-line, respectively, in very close proximity to Bundy Dr. and National Blvd (two highly trafficked streets adjacent to the north-east side of the airport), and about 600-800 m south of the I-10. The West Tarmac site was within the southwest perimeter of the airport, less than 100 m from the southern end of the runway, but approximately 1,700 m away from the I-10. Lastly, the Marine Park station, where the lowest VOC levels were generally measured, was the farthest from the I-10 (more than 2,100 m) and possibly too far from the airport perimeter to be influenced by VOCs emitted from aircraft operations and other related-activities.

As observed at VNA, the VOC levels in Santa Monica were generally comparable to or lower than those at the companion urban monitoring station (Central Los Angeles, in this case) where motor-vehicles emissions dominate the atmospheric levels of most primary pollutants. Overall, our results seem to suggest that the VOC levels measured at the Santa Monica stations were mostly influenced by their proximity to nearby freeways (e.g. the I-10) or local surface streets and, possibly to a lesser degree by their relative distance to the airport. However, the contributions of these and other pollution sources to the measured VOC levels cannot be assessed from the available data. A summary of all 1,3-butadiene, methylene chloride, chloroform, benzene, carbon tetrachloride, toluene, perchloroethylene and trichloroethene data collected at SMO can be found in Appendix A.

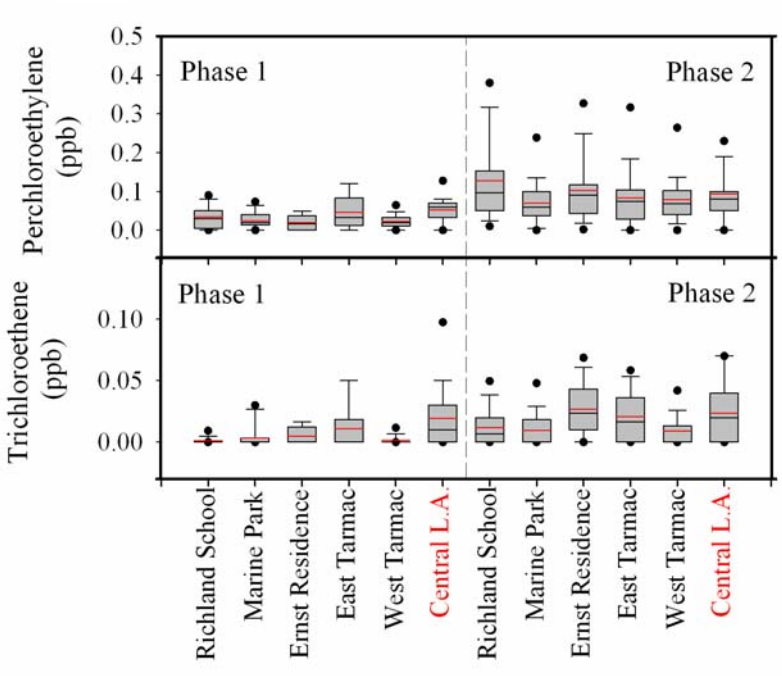
Figure 12 Spatial distributions of a) 1,3-butadiene, methylene chloride, and chloroform, b) benzene, carbon tetrachloride, and toluene, and c) trichloroethane and perchloroethylene at selected monitoring sites of the Santa Monica Airport (i.e. Richland School, Marine Park, Ernst Residence, East Tarmac, West Tarmac sites) during Phase 1 (April - July, 2006) and Phase 2 (October 2006 - February 2007). Data collected concurrently at a monitoring site in Central Los Angeles are also included for comparison



b)


Toluene (ppb)
Carbon Tetrachloride (ppb)
Benzene (ppb)
Phase 1
Phase 2
Richland School
Marine Park
Ernst Residence
East Tarmac
West Tarmac
Central L.A.

c)

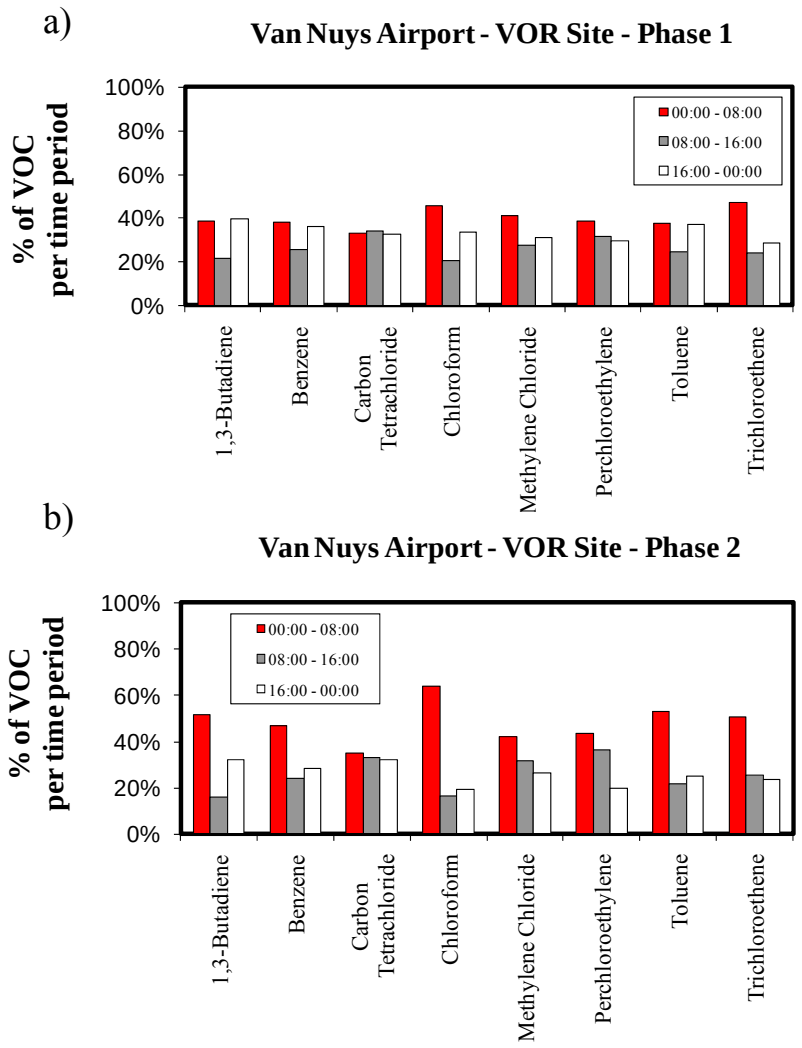

Perchloroethylene (ppb)
Trichloroethene (ppb)
Phase 1
Phase 2
Richland School
Marine Park
Ernst Residence
East Tarmac
West Tarmac
Central L.A.

EIGHT-HOUR VOC

Van Nuys Airport

In addition to integrated 24-hr canister samples, VOCs were also collected daily at 8-hr intervals (i.e. 00:00 to 08:00, 08:00 to 16:00, and 16:00 to 00:00) to examine the diurnal variability of this important compound class. Typically, the concentrations of most VOCs were higher between 00:00 and 08:00 and, to a lesser extent, from 16:00 and 00:00, probably because of a decreased mixing height and increased atmospheric stability early in the morning and late at night. Interestingly, the percentage contribution of most VOCs collected between 00:00 and 08:00 to their corresponding 24-hr average concentrations was higher during the summer months (the average for all VOCs and at all sites during Phase 2 is 45%) than in the fall/winter period (the corresponding average contribution during Phase 1 is 37%). This situation (shown for the VOR site in Figures 13a and 13b and representative of all other stations at VNA) may be due to more persisting inversions throughout the winter days and, perhaps, to seasonal variations in airport activities such as increased air traffic in the early mornings of most summer months (July – September, 2006). All available 8-hr VOC concentrations and the corresponding percentage contributions to their total daily levels have been summarized in Appendix A.

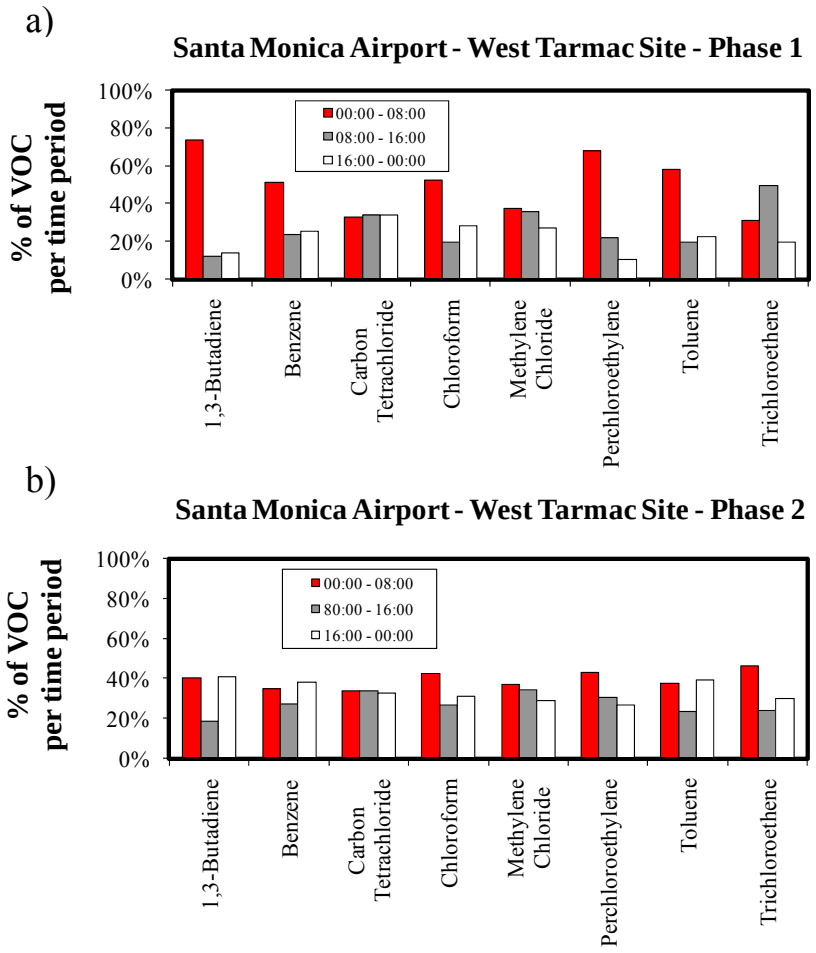
Figure 13 Percentage contribution of volatile organic compounds (VOCs) measured at the VOR site during three 8-hr intervals (i.e. 00:00 to 08:00, 08:00 to 16:00, and 16:00 to 00:00) to the corresponding 24-hr average concentrations. The two panels refer to a) Phase 1 (November 2005 - March 2006) and b) Phase 2 (July - September, 2006) data



Santa Monica Airport

As at VNA, three integrated 8-hr canister samples (i.e. 00:00 to 08:00, 08:00 to 16:00, and 16:00 to 00:00) were collected daily at all Santa Monica sites and analyzed for VOCs. Also in this case, the concentrations of most volatile species were higher between 00:00 and 08:00, and the percentage contribution of most VOCs collected in this time frame to their corresponding 24-hr average concentrations was higher during the spring/summer months (the average for all VOCs and at all sites during Phase 1 is 49%) than in the fall/winter period (the corresponding average contribution during Phase 2 is 42%). This situation is illustrated for the West Tarmac site in Figures 14a and 14b, and it is representative of all other Santa Monica stations. All available 8-hr VOC levels and the corresponding percentage contributions to their total daily concentrations have been summarized in Appendix A.

Figure 14 Percentage contribution of volatile organic compounds (VOCs) measured at the West Tarmac site during three 8-hr intervals (i.e. 00:00 to 08:00, 08:00 to 16:00, and 16:00 to 00:00) to the corresponding 24-hr average concentrations. The two panels refer to a) Phase 1 (April - July, 2006) and b) Phase 2 (October 2006 - February 2007) data

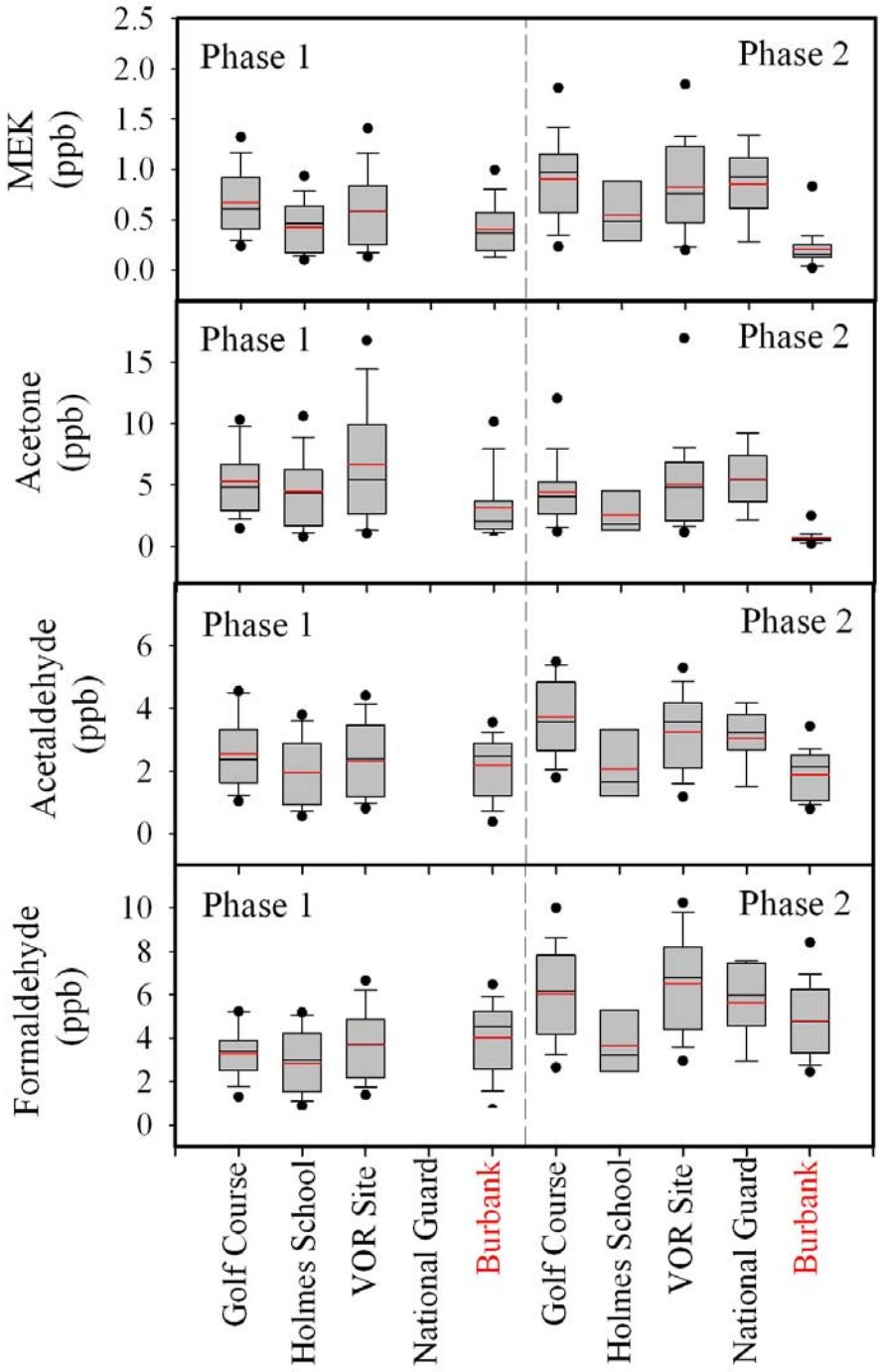


CARBONYLS

Van Nuys Airport

The most abundant carbonyl species present in all canister samples collected at VNA were formaldehyde, acetaldehyde, acetone and methyl ethyl ketone (MEK). Previous studies conducted on commercial aircraft engines have found formaldehyde and acetaldehyde to be the dominant carbonyls in aircraft exhaust emissions (Agrawal et al., 2008). As for most VOCs, our results seem to suggest that the concentration gradient of the majority of carbonyl compounds measured across all Van Nuys sites is influenced by proximity to local streets and, to a lesser extent, to the airport area (Figure 15). In particular, while the lowest carbonyl levels were observed at the Holmes School station (~ 2,400 m from the north-west perimeter of the airport and more than 300 m away from any major surface street), higher concentrations of MEK, acetone, acetaldehyde and formaldehyde were always detected at the Golf Course, VOR, and National Guard sites (closer to more heavily traveled roads and near or within the airport fence-line). However, unlike what was observed for most volatile species, the concentrations of all carbonyl compounds measured at the urban site in Burbank were generally lower than those recorded at the Van Nuys Airport stations (Figure 15). The difference was more evident in Phase 2 during the warmer months. More specifically, a non-parametric one-way ANOVA on ranks showed that the median ambient levels of acetone (during Phases 1 and 2) and those of MEK (during Phase 1 only) in Burbank were significantly lower ($p < 0.05$) than the corresponding concentrations at all other monitoring sites. Although it is possible that emissions of certain carbonyls from aircraft and airport operations might have increased the ambient concentrations of these air toxics with respect to typical urban levels, the extent of the contribution of this and other airport-related sources to the carbonyl levels measured at the Van Nuys Airport cannot be assessed from the available data. A summary of all formaldehyde, acetaldehyde, acetone and MEK data collected at VNA during this study can be found in Appendix A.

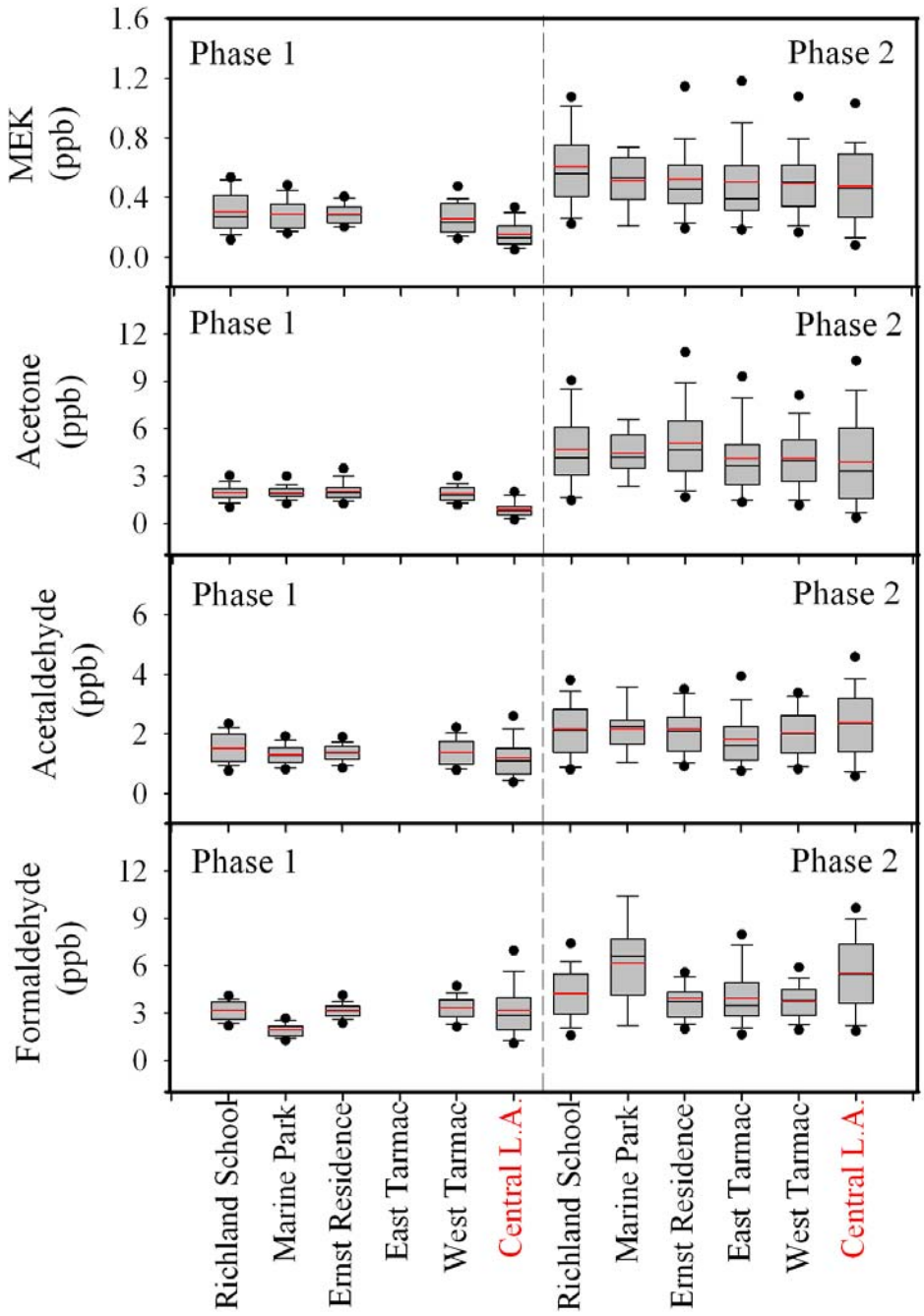
Figure 15 Spatial distributions of formaldehyde, acetaldehyde, acetone, and methyl ethyl ketone (MEK) at selected monitoring sites of the Van Nuys Airport (i.e. Golf Course, Holmes School, VOR, and National Guard sites) during Phases 1 and 2. Data collected at an AQMD monitoring station in Burbank are also included for comparison



Santa Monica Airport

The average and median concentrations of the most abundant carbonyl compounds measured at SMO (formaldehyde, acetaldehyde, acetone and MEK) were higher during the fall/winter period (from October 2006 to February 2007; Phase 2) than during the spring/summer months (from April 2006 to July 2006; Phase 1) (Figure 16), which is consistent with the expected seasonal variations in local meteorological conditions. The ambient concentrations of the carbonyls measured at an urban site in Central Los Angeles were generally comparable to those recorded at the Santa Monica stations. The exception is lower MEK and acetone at the Central Los Angeles site during Phase 1, but there is no obvious explanation for this observed difference. Although the spatial distribution of most carbonyl species did not vary substantially across the two sampling periods, it is difficult to discern a definite concentration gradient across the monitoring sites. However, it is worth mentioning that the average and median formaldehyde concentration at the Marine Park site (away from the I-10 freeway and relatively far from the airport perimeter) were the lowest across all stations monitored during Phase 1, and the highest during Phase 2. The reasons for this unexpected seasonal difference are not clear, but might be related to one or more localized sources of carbonyls around the park area. We cannot exclude that emissions of formaldehyde and other carbonyl compounds from aircraft and airport activities might have also contributed to increase the concentrations of these pollutants at SMO sites. However, the extent of the contribution of this and other potential important sources (e.g. motor-vehicle emissions from the I-10 freeway and from other local roadways) to the carbonyl levels measured around SMO cannot be assessed from the available data. A summary of all formaldehyde, acetaldehyde, acetone and MEK data collected at SMO throughout this study can be found in Appendix A.

Figure 16 Spatial distributions of formaldehyde, acetaldehyde, acetone, and methyl ethyl ketone (MEK) at selected monitoring sites of the Santa Monica Airport (i.e. Richland School, Marine Park, Ernst Residence, East Tarmac, and West Tarmac sites) during Phases 1 and 2. Data collected at an AQMD monitoring station in Central Los Angeles are also included for comparison

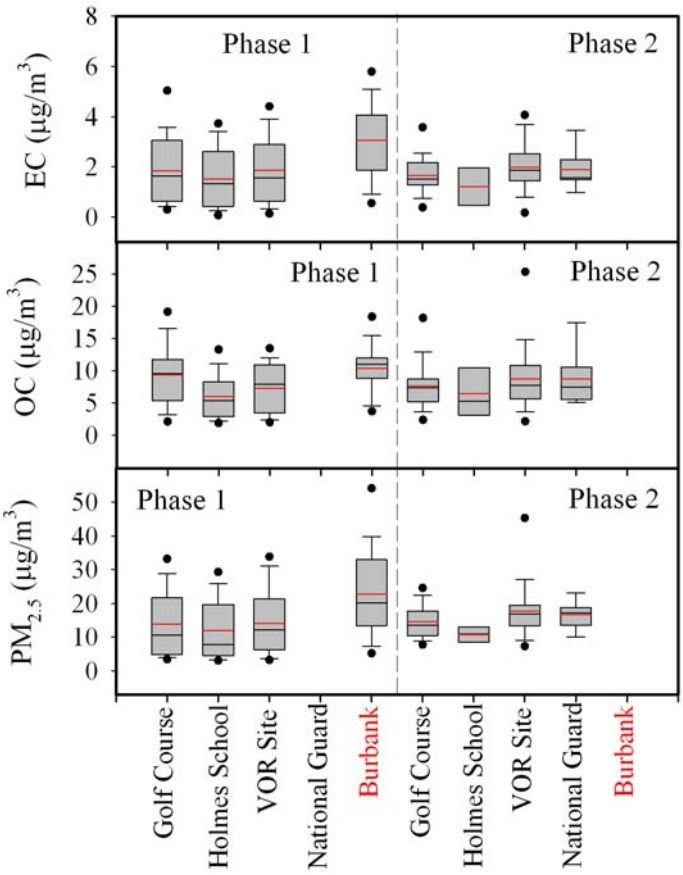


$PM_{2.5}$ MASS, ELEMENTAL AND ORGANIC CARBON

Van Nuys Airport

Although the average and median levels of $PM_{2.5}$, OC and EC measured at VNA sites were not substantially different across the two phases of the study, a higher variability in the atmospheric concentrations of these three particulate pollutants was observed during Phase 1 (November 2005 – March 2006), as shown in Figure 17 and in Table 6. The spatial distribution of $PM_{2.5}$ and that of its carbonaceous components did not vary substantially across the two sampling periods and, in most cases, it was similar to that observed for most VOCs and carbonyl compounds. In particular, the highest average concentrations of $PM_{2.5}$, OC and EC across all Van Nuys stations were measured at locations that were closer to the airport (i.e. VOR and National Guard stations) and to heavily trafficked surface streets (i.e. Golf Course site), while the lowest levels were recorded at the Holmes School site (background), further away from these pollution sources.

Figure 17 Spatial distributions of fine particulate matter ($PM_{2.5}$), organic and elemental carbon (OC and EC, respectively) at selected monitoring sites of the Van Nuys Airport (i.e. Golf Course, Holmes School, VOR, and National Guard sites) during Phases 1 and 2. Data collected at an AQMD monitoring station in Burbank are also included for comparison



The average and median concentrations of $PM_{2.5}$, OC and EC at the Golf Course, VOR and National Guard stations were elevated by a factor of less than two with respect to "background levels". At Holmes School this is probably due to the fact that these measurements refer to integrated 24-hr average samples. More substantial increases in the concentrations of EC may occur on shorter time-scales (e.g. minutes to hours) and closer to the runway area, especially while airplanes are taking-off. A previous study that focused on the chemical and physical analysis of the exhaust from various in-use commercial aircraft at two different airports indicated that take-off plumes are characterized by substantial increases in black carbon (BC; another indicator, along with EC, of combustion particles similar to those emitted from diesel engines) content (Herndon et al., 2005).

A non-parametric one way ANOVA on ranks indicated that during Phase 1 the median concentrations of $PM_{2.5}$ and EC at an urban site in Burbank (20.2 and 3.05 $\mu g/m^3$, respectively) were significantly higher ($p<0.05$) than the corresponding levels measured at all Van Nuys stations. Similarly, a statistically significant difference ($p<0.05$) in median OC levels was also observed between the Burbank station and the Holmes School and VOR sites. Overall, our data do not point to airport operations as the main source of the particulate pollutants measured at VNA sites. It is more likely that other local and regional sources (e.g. motor-vehicle emissions from nearby traffic and atmospheric transport of aged pollutants, respectively) contributed to the observed atmospheric levels of fine PM and those of its carbonaceous components. This is consistent with the previous observations of the concentration gradients of the gaseous pollutants measured at the same locations. None of the seasonal average (or median) $PM_{2.5}$ values measured at VNA sites were higher than the corresponding 2006 annual average in the South Coast Basin (20.6 $\mu g/m^3$), or the U.S. EPA NAAQS for fine PM (35 $\mu g/m^3$, expressed as the 3-year average of the 98^{th} percentile of 24-hr concentrations).

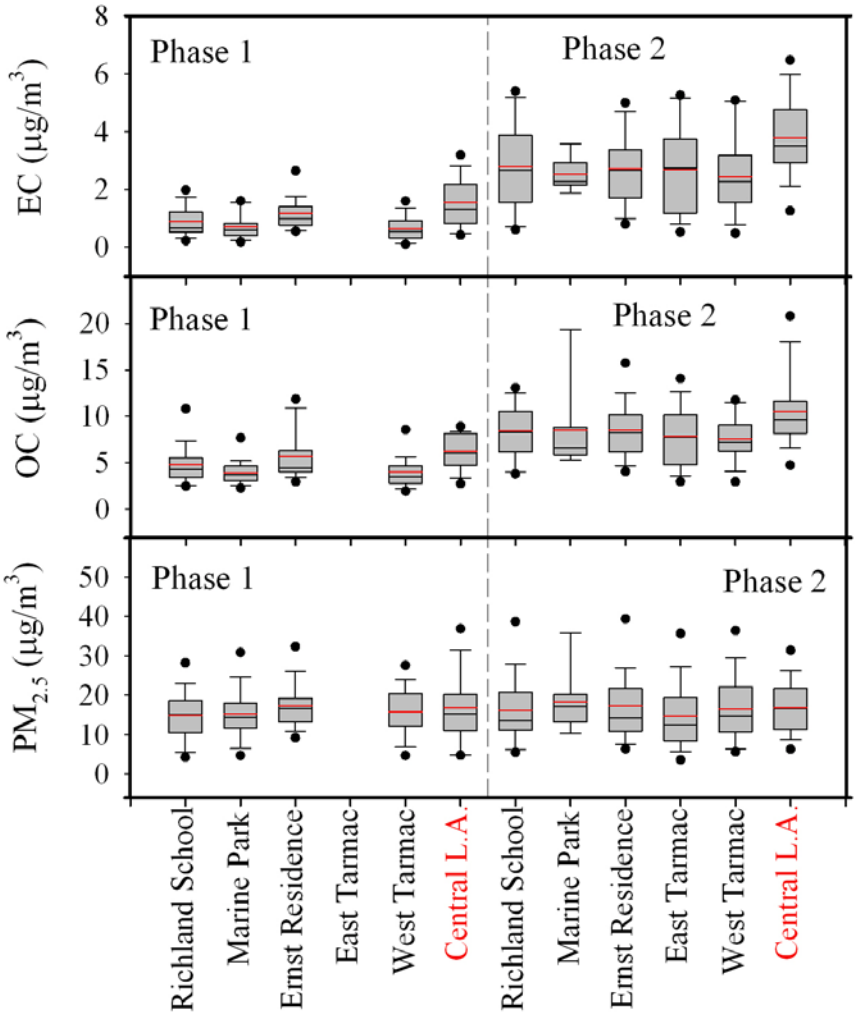
Table 6 Average and median fine particulate matter ($PM_{2.5}$), organic and elemental carbon (OC and EC, respectively) concentrations ($\mu g/m^3$) at the Van Nuys Airport stations and at an urban site in Burbank (CA) during Phase 1 (November 2005 - March 2006) and Phase 2 (July - September, 2006). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid samples (Valid N) have also been included

	Golf Course	Holmes School	VOR	National Guard	Burbank
			$PM_{2.5}$* - *Phase 1		
Average	13.9	12.0	14.2	N/A	22.8
Median	10.6	7.84	12.2	N/A	20.2
SD	9.87	8.69	9.75	N/A	13.0
Min	3.51	2.89	2.99	N/A	4.03
Max	37.4	31.7	34.8	N/A	58.7
Valid N	32	33	33	N/A	39
			$PM_{2.5}$* - *Phase 2		
Average	14.7	10.8	17.7	16.7	N/A
Median	13.6	10.9	16.8	17.3	N/A
SD	4.69	2.70	8.45	4.23	N/A
Min	7.72	6.48	7.13	10.1	N/A
Max	24.8	13.6	48.2	26.3	N/A
Valid N	22	5	22	14	N/A
			OC* - *Phase 1		
Average	9.35	6.03	7.28	N/A	10.4
Median	9.79	5.00	7.89	N/A	11.0
SD	4.74	3.38	3.88	N/A	3.75
Min	1.97	1.72	1.60	N/A	2.89
Max	19.4	13.4	13.8	N/A	19.6
Valid N	31	33	33	N/A	39
			OC* - *Phase 2		
Average	7.63	6.49	8.76	8.74	N/A
Median	7.32	5.30	7.69	7.49	N/A
SD	3.75	4.72	5.19	4.12	N/A
Min	2.18	2.11	1.94	4.98	N/A
Max	19.1	14.4	27.0	17.8	N/A
Valid N	22	5	22	14	N/A
			EC* - *Phase 1		
Average	1.85	1.51	1.86	N/A	3.07
Median	1.62	1.33	1.56	N/A	3.05
SD	1.36	1.18	1.33	N/A	1.48
Min	0.25	0.03	0.11	N/A	0.43
Max	5.51	3.93	4.67	N/A	6.18
Valid N	31	33	33	N/A	39
			EC* - *Phase 2		
Average	1.65	1.21	1.99	1.89	N/A
Median	1.52	1.20	1.86	1.57	N/A
SD	0.72	0.88	0.94	0.81	N/A
Min	0.33	0.44	0.10	0.77	N/A
Max	3.75	2.62	4.08	4.02	N/A
Valid N	22	5	22	14	N/A

Santa Monica Airport

The average and median $PM_{2.5}$ mass concentrations at SMO stations showed rather low spatial and seasonal variability (from 14.9 to 17.4 µg/m^3 during Phase 1, and from 14.7 to 17.3 µg/m^3 during Phase 2), and were comparable (or lower) to those measured at an urban station in Central Los Angeles (Figure 18 and Table 7). As observed in the previous section, this is probably related to the fact that regional transport was driving the $PM_{2.5}$ levels in this area at the time of sampling. None of the 24-hr seasonal average (or median) $PM_{2.5}$ values measured at SMO sites were higher than the corresponding 2006 annual average in the South Coast Basin (20.6 µg/m^3).

Figure 18 Spatial distributions of fine particulate matter ($PM_{2.5}$), organic and elemental carbon (OC and EC, respectively) at selected monitoring sites of the Santa Monica Airport (i.e. Richland School, Marine Park, Ernst Residence, East Tarmac, and West Tarmac sites) during Phases 1 and 2. Data collected at an AQMD monitoring station in Central Los Angeles are also included for comparison



The spatial distribution of OC and EC did not vary substantially across the two sampling periods and, for the most part, it was similar to that observed for VOC and carbonyl compounds. In particular, the atmospheric levels of these two carbonaceous components seemed to be more variable at sites that were closer to the airport area of operation (e.g. East Tarmac and Ernst Residence), and slightly lower average and median OC and EC values were generally measured at the Marine Park site (background), away from the influence of airport emissions. A non-parametric ANOVA on ranks revealed that, with the exception of the median OC level at the Ernst Residence site during Phase 1, the median ambient levels of OC and EC at the Santa Monica stations were significantly lower ($p<0.05$) than those in Central Los Angeles, both during Phase 1 and Phase 2. This might be due to a relatively higher contribution of carbonaceous material from motor-vehicles at this urban site in Central Los Angeles. Higher average and median concentrations were measured in the colder months (October 2006–February 2007), which is consistent with more persistent inversions during the fall/winter period.

As noted in previous sections, the effect of airport activities on EC may be observed on a shorter time-scale (e.g. minutes to hours), and previous studies have shown sharp increases in EC (or BC) levels during take-off and landing (Herndon et al., 2008; Westerdahl et al., 2008; Dodson et al., 2009; Hu et al., 2009). In particular, in the summer/spring of 2008 Hu et al. (2009) conducted a four-day field campaign using an electric vehicle equipped with fast response instruments to measure real time air pollutant concentrations downwind of SMO. They found that aircraft did not appreciably elevate the average levels of BC (which supports this study's results), although spikes in the concentration of this and other combustion-related pollutants (i.e. polycyclic aromatic hydrocarbons and UFP) were generally observed during jet take-offs and, possibly, aircraft arrivals. Specifically, jet departures resulted in 1-min average BC concentrations of up to 30 $\mu g/m^3$ at a site located 100 m downwind of the takeoff area (in a similar geographical location as our Ernst Residence station), a value 100 higher than the corresponding summer background level.

Table 7 Average and median fine particulate matter ($PM_{2.5}$), organic and elemental carbon (OC and EC, respectively) concentrations ($\mu g/m^3$) at the Santa Monica Airport stations and at an urban site in Central Los Angeles (CA) during Phase 1 (April - July, 2006) and Phase 2 (October 2006 - March 2007). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid samples (Valid N) have also been included

	Richland School	Marine Park	Ernst Residence	East Tarmac	West Tarmac	Central Los Angeles
				$PM_{2.5}$ *- Phase 1*		
Average	14.9	15.2	17.4	N/A	15.8	16.9
Median	15.2	14.4	16.7	N/A	15.8	15.3
SD	6.76	6.70	5.75	N/A	6.28	9.14
Min	4.13	4.64	9.18	N/A	4.74	4.71
Max	35.8	34.8	34.6	N/A	32.5	40.7
Valid N	35	30	25	N/A	34	28
				$PM_{2.5}$ *- Phase 2*		
Average	16.2	18.5	17.3	14.7	16.6	16.8
Median	13.6	17.1	14.3	12.5	14.8	16.6
SD	9.20	8.90	9.36	8.81	9.28	6.79
Min	4.95	9.81	5.07	1.86	3.10	5.63
Max	49.8	45.4	51.2	41.4	49.6	33.5
Valid N	43	13	40	29	39	27
				OC *- Phase 1*		
Average	4.78	3.96	5.69	N/A	4.05	6.26
Median	4.32	3.70	4.48	N/A	3.52	6.07
SD	2.13	1.60	2.65	N/A	2.49	1.92
Min	2.09	1.92	2.83	N/A	1.78	2.38
Max	11.9	11.3	12.3	N/A	16.7	9.52
Valid N	37	31	26	N/A	35	34
				OC *- Phase 2*		
Average	8.43	8.49	8.49	7.84	7.60	10.5
Median	8.28	6.63	8.24	7.77	7.22	9.62
SD	2.97	4.90	3.16	3.30	2.44	4.15
Min	2.88	5.32	3.66	2.58	2.30	4.31
Max	15.7	22.7	17.2	14.9	13.2	22.3
Valid N	43	13	40	29	39	30
				EC *- Phase 1*		
Average	0.89	0.70	1.17	N/A	0.64	1.54
Median	0.66	0.60	0.98	N/A	0.54	1.31
SD	0.52	0.43	0.59	N/A	0.44	0.87
Min	0.07	0.09	0.54	N/A	0.02	0.25
Max	1.99	1.94	2.90	N/A	1.65	3.70
Valid N	69	60	50	N/A	66	66
				EC *- Phase 2*		
Average	2.78	2.52	2.70	2.69	2.43	3.79
Median	2.67	2.28	2.66	2.74	2.27	3.50
SD	1.53	0.57	1.20	1.53	1.34	1.35
Min	0.48	1.74	0.63	0.53	0.21	0.57
Max	5.92	3.74	5.02	5.32	5.79	6.64
Valid N	43	13	40	29	39	30

ULTRAFINE PARTICLES

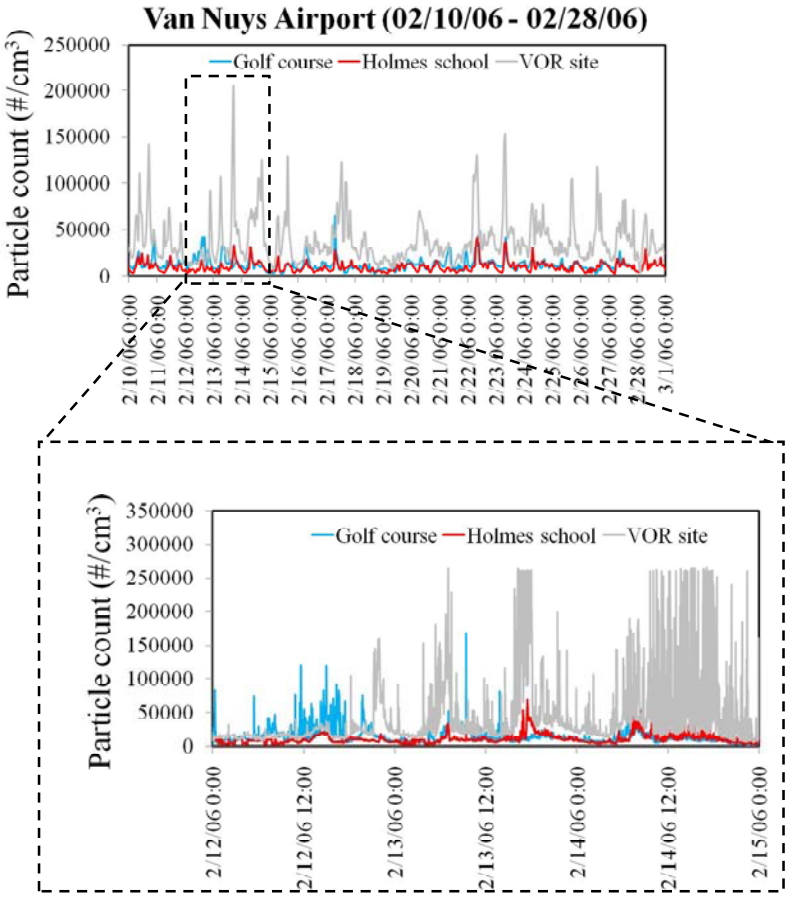
Van Nuys Airport

Ultrafine particle (UFP) number concentration measurements (#/cm^3) were taken between November 2005 and March 2006 (Phase 1) and again from July to September of 2006 (Phase 2) at four selected sites of the Van Nuys Airport: the Golf Course, VOR, Holmes School (only during Phase 1), and National Guard (only during Phase 2) stations. Butanol-based condensation particle counters (CPC) were used at all sites throughout the two monitoring campaigns. The highly resolved (1-min) data were averaged over 1-hr periods to facilitate comparison among these sites, and average diurnal variation plots were obtained to gain some insight into how UFP levels changed throughout the day. Overall, the data collected at the Van Nuys stations were found to be dynamic in range, with significant variability over very short temporal and spatial scales. A more in-depth analysis of these data is described below for each of the two monitoring periods.

Phase 1(November 2005 - March 2006)

Figure 19 (main panel) illustrates the representative time evolution of the 1-hr UFP count measured at all monitored locations between 02/10/06 and 02/28/06, and shows that during the winter months the highest particle number concentrations were observed at the VOR site, close (about 150 m) to the north side of the airport and under the fixed wing arrival/departure route. On 2/13/06 at 17:00 the 1-hr UFP count level at this station peaked at a maximum value of about 203,000 #/cm^3, a concentration 19 and six times higher than that measured at the Golf Course and at the Holmes School sites, respectively, during the same time frame and further away from the airport fence-line. The latter station was set-up about 2,400 m north-west of the airport and, although airplanes were observed directly over the school on several occasions, it can be considered to be typical of background conditions in the study area.

Figure 19 Representative hourly average ultrafine particle (UFP) number concentrations (#/cm^3) at the Van Nuys Airport measured from 02/10/06 to 02/28/06. Hourly data were averaged from 1-min values to facilitate comparison among sites (top panel). An example of more resolved 1-min data is shown in the magnified portion of the graph within broken lines



When averaged across the entire duration of Phase 1, the particle count at the VOR site (~32,100 #/cm^3) was 1.4 times higher than that at the Golf Course station (~23,400 #/cm^3), and 3.6 times more elevated than that at the Holmes School site (8,900 #/cm3) (Table 8). These results are in line with those obtained at the Santa Monica Airport during this and previous studies (e.g. Hu et al., 2009), where measured UFP concentrations decreased with increasing distance from the runway.

Table 8 Average and median ultrafine particle (UFP) number concentrations (µg/m^3) at the Van Nuys Airport stations during Phase 1 (November 2005 - March 2006). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid samples (Valid N) have also been included

	Van Nuys Airport			
	Golf Course	**Holmes School**	**VOR**	**National Guard**
	***UFP number (#/cm^3)** - Phase 1*			
Average	23365	8892	32084	N/A
Median	18914	7124	26265	N/A
SD	19600	6423	23307	N/A
Min	1691	1389	1949	N/A
Max	182581	136558	202621	N/A
Valid N	2065	1634	2157	N/A

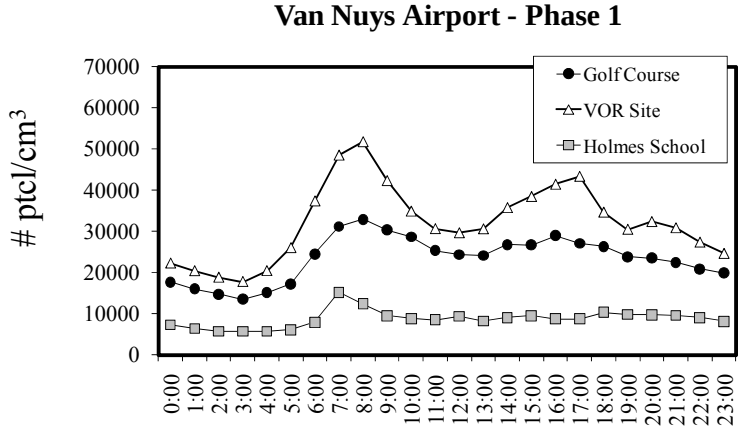
A closer look at the more resolved 1-min data revealed the presence of sharp particle count peaks at both the VOR and, less frequently, the Golf Course sites (see magnified portion of Figure 19), probably caused by aircraft takeoffs/landings. A few occasional spikes in UFP count were also observed at the Holmes School station (not shown), and were likely attributable to landing aircraft passing overhead, or nearby vehicular traffic. Between peak events the counts generally returned to levels closer to those in background air. Because of limitations with the data-logging system connected to the butanol-based CPCs, particle counts higher than 260,000 #/cm^3 could not be measured at VNA sites during Phase 1. It is likely that the actual maximum UFP peaks corresponding to periods of aircraft operations were higher than the instrument threshold, but less than 0.45, 0.15 and 0.05% of all 1-min measurements at the VOR, Golf Course, and Holmes School sites, respectively, were equal to and likely higher than 260,000 #/cm^3. The effect of underestimating these extreme data-points on comparisons of 1-hr average particle levels across sites is minimal. This limitation of the data-logging systems was corrected before the beginning of Phase 2.

Unfortunately, detailed information about the aircraft operating at VNA (e.g. model and engine type) and their takeoff/landing schedule was not available at the time of the study, and the effect of aircraft movements on the magnitude of the measured UFP peaks could not be assessed at VNA sites. However, while working at the VOR station AQMD staff members reported that observations of particle count peaks corresponded with visual sightings of aircrafts preparing from departure, taking off, or landing, with a short delay between the sighting and the peak count recorded on the instrument. It is

interesting to note that a few recent field campaigns conducted both in the United States and in Europe (i.e. APEX, EXCAVATE and AIRPUR) have indicated that while the PM mass in the exhaust of turbine engines is essentially a conserved quantity as the plume dilutes downwind, the particle number is probably a consequence of post emission condensation (Wey et al., 2006; Lelievre et al., 2006; Herndon et al., 2008). In particular, formation of UFPs by nucleation seems to occur up to a distance of 25 m from the exit of the engine (Lelievre et al., 2006).

Figure 20 shows the average diurnal profile of hourly particle number concentrations at VNA monitoring sites. Whether the "bimodal" appearance of the particle count distribution (with peaks between 7:00 and 10:00 am, and from 3:00 to 8:00pm) can be attributed to airport activities or to rush hour traffic from the highly trafficked surface streets surrounding the airport (e.g. Roscoe Blvd. and Balboa Blvd.) cannot be assessed from the available data. Ultrafine particle levels at night and early in the morning (i.e. from 22:00 to 03:00) suggest a substantial decrease in particle count as the airport activities and the vehicular traffic subsided in the evening hours.

Figure 20 Average diurnal profiles of the ultrafine particle (UFP) number concentration (#/cm^3) measured at three sites of the Van Nuys Airport (i.e. Golf Course, VOR, and Holmes School stations) during Phase 1 (November 2005 - March 2006)

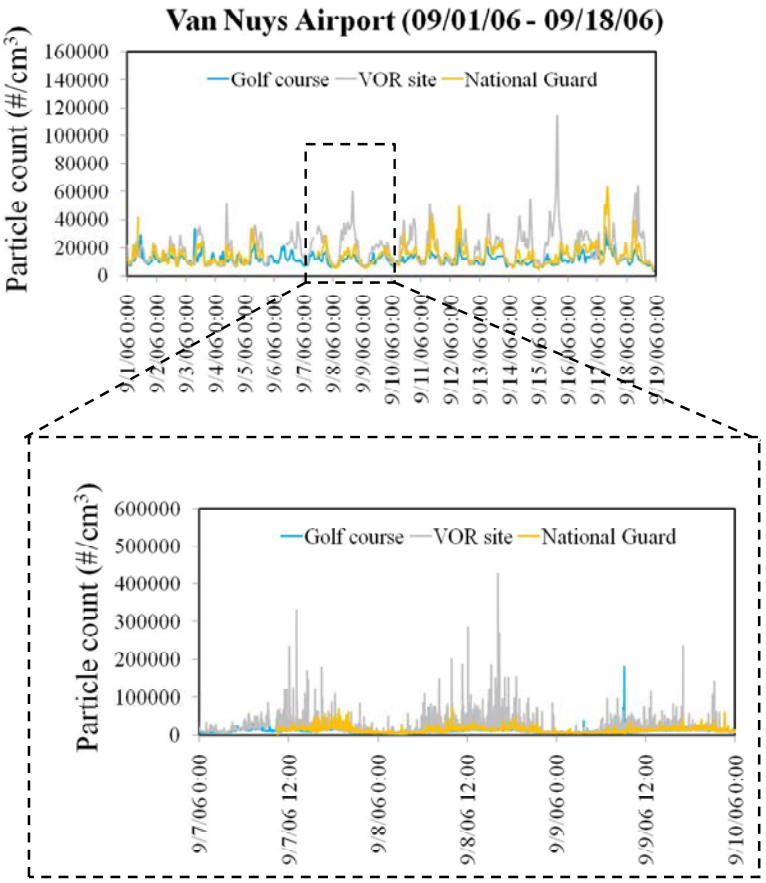


Phase 2 (July - September, 2006)

The UFP levels measured at VNA in the summer/fall period were significantly lower than those observed during Phase 1, but followed a similar concentration gradient across all available sampling locations (see the main panel of Figure 21 for a representative time series from 09/01/06 to 09/18/06). Particle count data at the Holmes School (background) station were not available during this part of the study since the site was no longer available. Ultrafine particle measurements were carried out at the National Guard station instead, within the north-west perimeter of the airport complex and away from the fixed wing arrival/departure routes or traffic paths. Also in this case, the highest 1-hr particle count peaks (between 70,000 and 115,000 #/cm^3) were measured at the VOR site, and were about half of the highest number concentrations observed at the same location during Phase 1. On 9/15/06 at 15:00 the particle number concentration at the

VOR station increased to a maximum value of about 115,000 #/cm^3, about ten and 13 times the corresponding count levels measured at National Guard and at the Golf Course sites, respectively.

Figure 21 Representative hourly average ultrafine particle (UFP) number concentrations (#/cm^3) at the Van Nuys Airport measured between 09/01/06 and 09/18/06. Hourly data were averaged from 1-min measurements to facilitate comparison among sites (top panel). An example of more resolved 1-min data showing elevated UFP levels from 09/07/06 to 09/09/06 is illustrated in the magnified portion of the graph within broken lines



When averaged across the entire duration of Phase 2, the UFP concentration at the VOR site (~19,200 #/cm^3) was only slightly more elevated than that measured at the National Guard (16,400 #/cm^3) and at the Golf Course (11,700 #/cm^3) stations (Table 9) Lower concentrations during the summertime period are expected for most air pollutants, mostly because of a decreased atmospheric stability and less frequent inversions, which favor atmospheric dispersion.

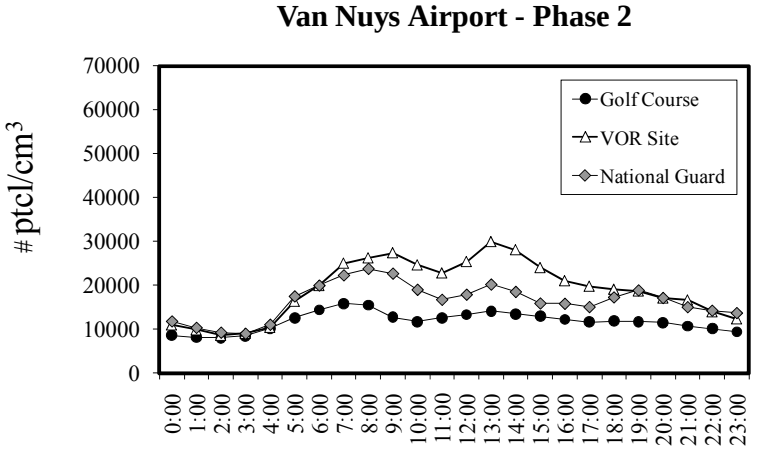
Table 9 Average and median ultrafine particle (UFP) number concentrations (μg/m^3) at the Van Nuys Airport stations during Phase 2 (July - September, 2006). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid samples (Valid N) have also been included

	Van Nuys Airport			
	Golf Course	**Holmes School**	**VOR**	**National Guard**
	UFP number (#/cm^3) *- Phase 2*			
Average	11740	9115	19154	16404
Median	11116	8340	17181	15197
SD	4093	3868	10878	7719
Min	3171	1327	3652	3519
Max	42494	34182	114296	62955
Valid N	1055	290	1005	726

A more in depth analysis of the highly resolved 1-min data confirmed that, although sharp peaks as high as 300,000-400,000 #/cm^3 (probably associated with aircraft takeoffs or landings) were observed on different occasions at the VOR site, the overall UFP levels measured during the second part of the sampling campaign were significantly lower than those seen during Phase 1 (magnified portion of Figure 21). However, on 09/08/06 at 16:09 the 1-min ultrafine particle concentration at the VOR station reached a maximum of 427,000 #/cm^3, a value 32 and 36 times more elevated than those at the Golf Course and National Guard sites during the same time period. No information about the operations schedule at VNA or local roadway traffic is available to specifically identify the cause of that high particulate count value.

Figure 22 shows the average diurnal profile of hourly particle number concentrations observed at VNA sites during Phase 2. As during the fall/winter period, the highest particle number counts throughout the warmer months occurred from late morning to late afternoon. Ultrafine particle concentrations at night and early in the morning (i.e. from 22:00 to 03:00) were typically comparable at all stations, suggesting a substantial decrease in UFPs in and around the VNA area as the airport activities and the vehicular traffic subsided in the evening hours.

Figure 22 Average diurnal profiles of the ultrafine particle (UFP) number concentration (#/cm^3) measured at three sites of the Van Nuys Airport (i.e. Golf Course, VOR, and National Guard stations) during Phase 2 (July - September, 2006)



Santa Monica Airport

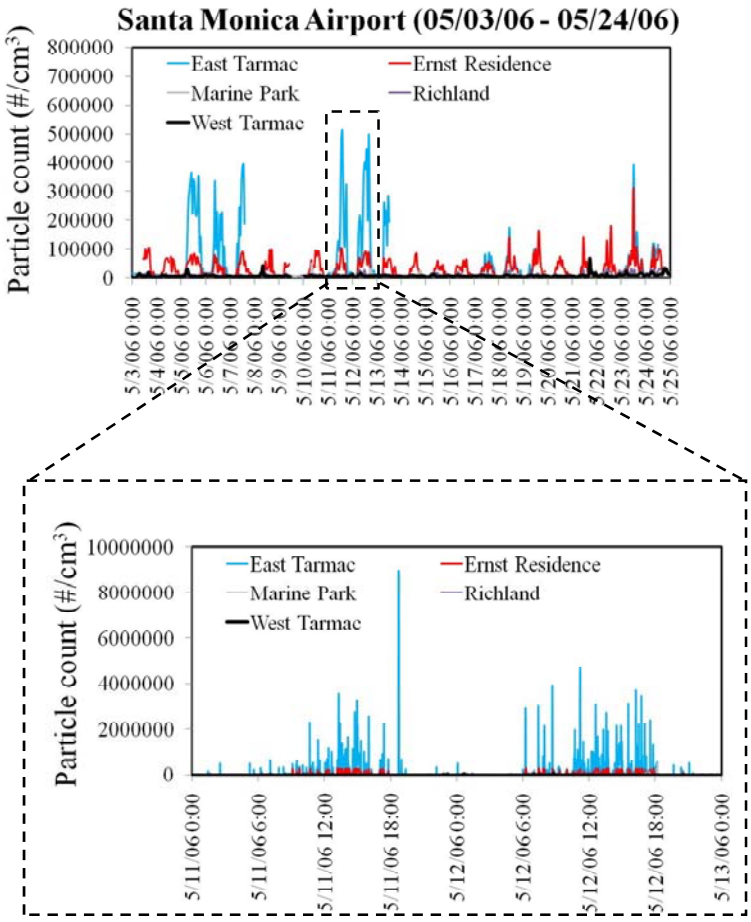
Ultrafine particle number concentrations (#/cm^3) were measured between April and July 2006 (Phase 1) and from October 2006 to February 2007 (Phase 2) at five selected sites of the Santa Monica Airport, namely East Tarmac, Ernst Residence, West Tarmac, Richland School, and Marine Park (only during Phase 2). The highly resolved (1-min) data were averaged over 1-hr periods to facilitate comparison among these sites. Average diurnal variation plots were also obtained for all stations to gain some insight into how UFP levels changed throughout the day. As at VNA, the data collected at SMO were found to be very dynamic in range, with even higher spatial and temporal variabilities. Because the terms of the loan for the butanol-based CPCs used during the first phase of the Santa Monica field campaign expired at the end of September 2006, water-based CPCs were purchased by AQMD and used during Phase 2.

Phase 1(April - July, 2006)

The time series plot in Figure 23 (main panel) summarizes observations made from 05/03/06 to 05/24/06 and illustrates how during the first phase of the study the UFP number concentration gradient was affected primarily by proximity to the take-off location on the airport's runway. The highest 1-hr average particle count peaks were measured at the East Tarmac site, approximately 35 m west from the end of the runway and near the blast-fence. In particular, on 05/11/06 at 14:00 the 1-hr ultrafine particle count level at this station increased to about 510,000 #/cm^3, a concentration five times higher than that recorded at the Ernst Residence site (about 100 m downwind of the runway but outside the airport's fence-line) during the same time period. The corresponding ultrafine levels measured at the West Tarmac (around 100 m west from the southern end of the runway), Richland School (the furthest site from SMO), and Marine Park (background) stations were 7,500, 7,000, and 6,500 #/cm^3, respectively, or 70 to 80 times lower than those at East Tarmac. These findings are consistent with an aircraft

source given the stations relative proximity to the area where aircraft were idling and taking off, and the predominant wind flow (from the south-southeast direction).

Figure 23 Representative hourly average ultrafine particle (UFP) number concentrations (#/cm^3) at the Santa Monica Municipal Airport measured from 05/03/06 to 05/24/06. Hourly data were averaged from 1-min measurements to facilitate comparison among sites (top panel). An example of more resolved 1-min data showing elevated UFP levels from 05/11/06 to 05/12/06 is illustrated in the magnified portion of the graph within broken lines



When averaged across the entire duration of Phase 1, the UFP level at the East Tarmac site (~52,200 #/cm^3) was two times higher than that at the Ernst Residence station (~26,300 #/cm^3), and seven times more elevated than that at the background site (Marine Park; 8,000 #/cm^3) (Table 10). Our results are lower than those obtained by Hu et al. (2009) during a four day campaign conducted in the spring/summer of 2008, when the study-average UFP concentrations at two sites 80 and 100 m downwind of the airport were 106,000 and 97,000 #/cm^3, respectively, or about 10 times the corresponding background levels for all measurement days combined. One explanation for this

discrepancy is that while our CPCs were operated 24-hours, Hu et al. measured only daytime UFP number concentrations and within a much shorter time frame (i.e. 4 to 6 hours for four sampling days) when the airport was in operation.

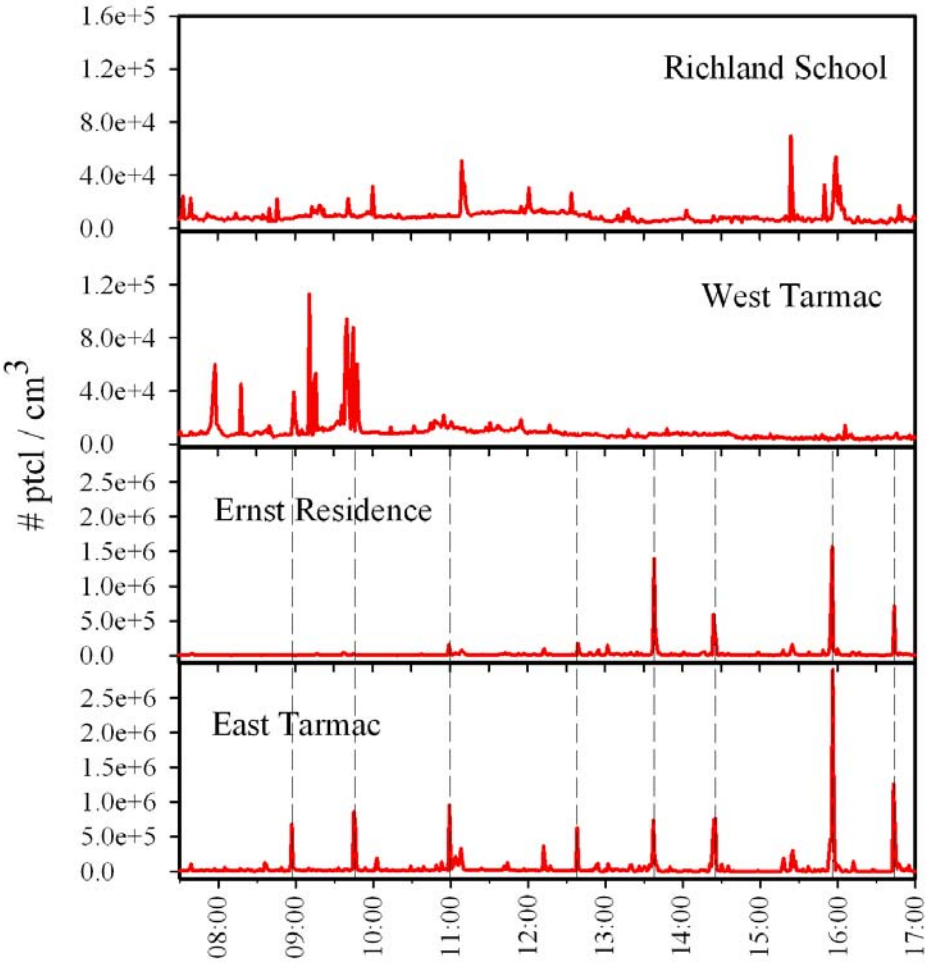
Table 10 Average and median ultrafine particle (UFP) number concentrations (#/cm^3) at the Santa Monica Airport stations during Phase 1 (April - July, 2006). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid samples (Valid N) have also been included

Santa Monica Municipal Airport					
	Richland School	**Marine Park**	**Ernst Residence**	**East Tarmac**	**West Tarmac**
	UFP number (#/cm^3) *- Phase 1*				
Average	13273	8037	26284	52240	8406
Median	10011	7216	14963	31097	7316
SD	9135	4505	28147	67741	5310
Min	ND	1684	1221	1345	1444
Max	80548	53010	312524	513135	96942
Valid N	2804	1753	1846	930	2469

An analysis of the more resolved 1-min data revealed the presence of spikes in particle number concentrations as high as 9,000,000 #/cm^3, as measured on 05/11/06 at 18:45 at the East Tarmac (magnified portion of Figure 23). These exceptionally elevated levels were rare, but 1-min maxima between 4,000,000 and 4,500,000 #/cm^3 were relatively more common at the East Tarmac and, occasionally, at the Ernst Residence site. The 1-min concentration measured at the Marine Park (background) site was as much as 2,100 times lower than the corresponding value at the East Tarmac. However, a relative decrease in 1-min background particle counts between 100 and 600 times was more common during Phase 1. For comparison, Hu et al. (2009) observed that the maximum 1-min UFP measured in Clarkson Rd. (100 m north from the runway of SMO) was 2,200,000 #/cm^3, or about 440 times the corresponding summer background level (~5,000 #/cm^3), which is consistent with our observations at the Ernst Residence site (set-up in close proximity to Clarkson Rd.) during the same season. Increased peak concentrations in UFP counts were also measured near the Los Angeles International Airport (LAX) during a study carried out between September 2005 and March 2006 by Fanning et al. (2007). Here, the highest peaks in UFP number levels were clearly correlated with aircraft take-off events, and 2% of the measured data points (recorded at 1-sec intervals) exceeded 10,000,000 #/cm^3, the upper limit of the CPCs used for that study. In earlier work conducted by Westerdahl et al. (2008) at the same international airport (LAX), data collected about 100 m downwind of one of the south runways revealed that particle counts (measured at 10-sec intervals) reached approximately 4,800,000 #/cm^3 during some of the observed take-offs.

The effect of aircraft movements on the magnitude of the UFP number peaks measured at SMO sites is illustrated in Figure 24, which shows the particle number concentration time series at the East Tarmac, West Tarmac, Ernst Residence and Richland School stations on 07/07/06. As expected, measurements at the East Tarmac and Ernst Residence sites peaked when aircraft where either taxing or taking-off.

Figure 24 Ultrafine particle (UFP) number concentrations data showing the impact of aircraft movements at the East Tarmac, Ernst Residence, West Tarmac, Richland Elementary School sites on 07/07/06



These time periods (corresponding to the broken lines in Figure 24) have been highlighted in red in Table 11, which also includes detailed information about the model and identification number of the aircraft associated with these increases in particle number concentration. AQMD staff members operating at the East Tarmac site reported that observations of particle count peaks during takeoffs corresponded with visual sightings of aircraft preparing from departure, with a short delay between the sighting and the peak count recorded on the instrument (often accompanied by an odor of jet-fuel).

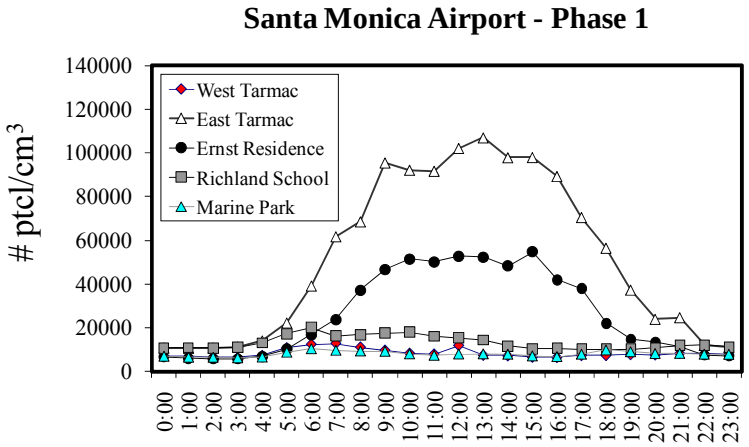
Jets and piston driven planes taxi a few hundred meters from the take-off area to the north of the runway near the East Tarmac site. As summarized in Table 11, the taxi time for most aircraft is between two and five minutes (for comparison, the acceleration time on the runway during takeoff is only of 20-30 seconds). Also, because the jet flight path from SMO intersects LAX flight paths less than 20 Km after takeoff, aircraft departing from SMO must wait for permission from LAX, resulting in an additional waiting time of up to 5 minutes or more. Therefore, the typical total taxi-waiting time observed for an average airplane ("Grand Total" in Table 11) during our field campaign was between 4 and 10 minutes. It is likely that these relatively long standby periods contribute to increased the concentrations of UFPs and other combustion products (e.g. BC) in the vicinity of the takeoff area.

Table 11 Santa Monica Airport take-off observation data on 7/17/2006. Time periods associated with the particle number concentration peaks in Figure 24 are highlighted in red

Observation No.	Aircraft No.	Aircraft Type	Taxi Begins (a)	Hold Begins (b)	Departure Time (c)	Total Taxi (b-a)	Total Hold (c-b)	Grand Total (c-a)
1	480DG	Cessna 560	7:34:19	7:37:22	7:39:01	03:03	01:39	04:42
2	374QS	Cessna 560	7:39:57	7:43:25	7:46:41	03:28	03:16	06:44
3	25FS	Cessna 550	8:13:27	8:16:16	8:17:27	02:49	01:11	04:00
4	555LG	CL-600-2B16	8:47:50	8:53:06	8:57:25	05:16	04:19	09:35
5	834QS	Cessna 560	9:12:26	9:16:14	9:22:16	03:48	06:02	09:50
6	238SM	Cessna 560XL	9:31:11	9:35:09	9:37:40	03:58	02:31	06:29
7	268QS	Falcon 2000	9:38:00	9:41:23	9:45:51	03:23	04:28	07:51
8	647QS	Cessna 560XL	9:58:00	10:01:16	10:03:12	03:16	01:56	05:12
9	827RM	Beech B100	10:04:04	10:06:17	10:12:40	02:13	06:23	08:36
10	25LZ	Cessna 525A	10:22:20	10:26:50	10:29:26	04:30	02:36	07:06
11	884QS	Hawker 800XP	10:48:00	10:50:28	10:53:40	02:28	03:12	05:40
12	426CH	Cessna 560XL	10:55:24	10:57:41	10:59:40	02:17	01:59	04:16
13	324MM	Beech 400	10:58:41	11:01:14	11:09:15	02:33	08:01	10:34
14	169TA	CL-600-2A12	12:35:11	12:38:20	12:39:12	03:09	00:52	04:01
15	281QS	Falcon 2000	13:31:41	13:33:45	13:37:51	02:04	04:06	06:10
16	268QS	Falcon 2000	14:18:03	14:20:45	14:24:22	02:42	03:37	06:19
17	227WS	Cessna 560	14:18:03	14:21:42	14:25:30	03:39	03:48	07:27
18	105AX	Beech 400A	15:20:21	15:23:38	15:27:07	03:17	03:29	06:46
19	51HF	Cessna 525A	15:48:11	15:50:20	15:53:37	02:09	03:17	05:26
20	777DY	Cessna 525A	15:50:08	15:53:47	15:54:48	03:39	01:01	04:40
21	411QS	G-IV	15:51:52	15:54:29	15:56:20	02:37	01:51	04:28
22	931QS	Cessna 750	16:38:21	16:41:19	16:43:45	02:58	02:26	05:24

As suggested by the average diurnal profile of hourly particle number concentrations measured at SMO sites (Figure 25), the highest traffic activity during Phase 1 occurred between 09:00 and 17:00. Ultrafine particle levels at night and early in the morning (i.e. from 22:00 to 03:00) were typically comparable at all stations, suggesting a substantial decrease in particle count as the numbers of take-offs and landings subsided in the evening hours and ceased overnight. Hu et al. (2009) analyzed airport count information from traffic logs provided by SMO, and reported that in the spring/summer of 2008 the great majority of aircraft operations (diurnal hourly arrivals and departures) took place from 09:00 and 20:00, consistent with our results. The Santa Monica Airport allows operations of nonemergency aircraft only from 07:00-23:00 on weekdays and 08:00-23:00 on weekends due to noise ordinances.

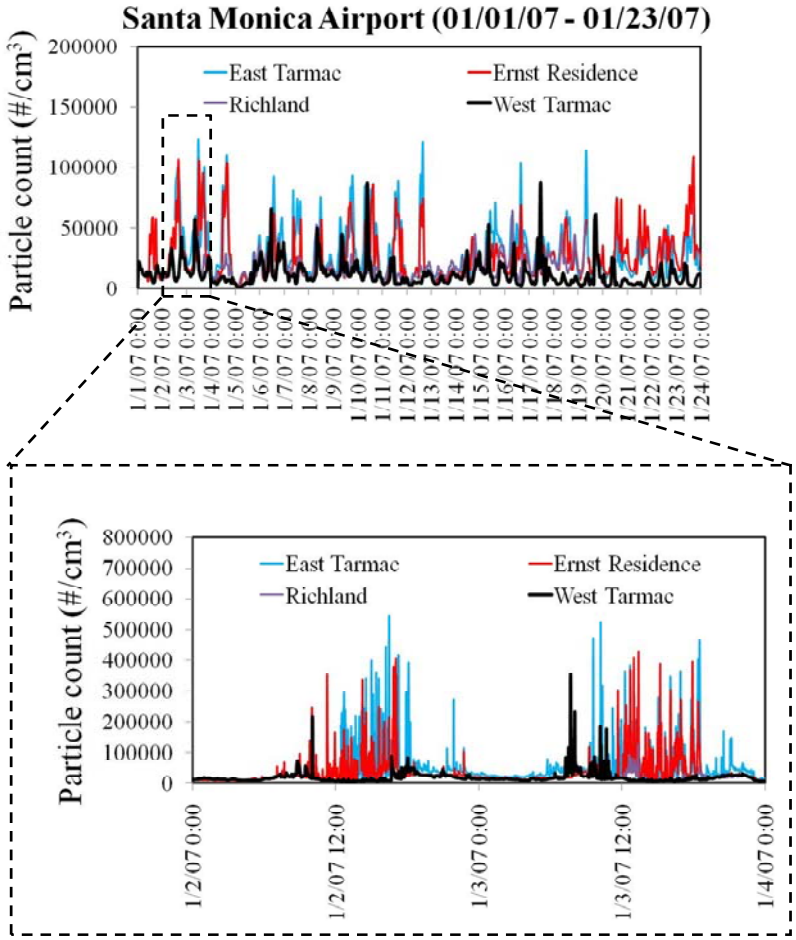
Figure 25 Average diurnal profiles of the ultrafine particle (UFP) number concentration (#/cm^3) measured at five sites of the Santa Monica Airport (i.e. East Tarmac, West Tarmac, Ernst Residence, Richland School, and Marine Park) during Phase 1 (April - July, 2006)



Phase 2 (October 2006 - February 2007)

During the second field campaign at SMO, the UFP concentrations (measured using water-based CPCs) were substantially lower than those observed during Phase 1, and more homogeneous across sampling sites (main portion of Figure 26). The magnitude of the highest 1-hr peaks at the East Tarmac and Ernst Residence stations (124,000 and 155,000 #/cm^3, respectively) were comparable to the maximum 1-hr ultrafine levels measured at the West Tarmac site (122,000 #/cm^3) and 2-2.5 times higher than that the Richland School station (64,000 #/cm^3; 900 m north-east of SMO). Because of an instrument malfunction no particle count data were obtained at the Marine Park (background) station, which makes it difficult to estimate the relative increase in UFP concentration downwind of the runway with respect to background conditions.

Figure 26 Representative hourly average ultrafine particle (UFP) number concentrations (#/cm^3) at the Santa Monica Municipal Airport measured from 01/01/07 to 01/23/07. Hourly data were averaged from 1-min measurements to facilitate comparison among sites (top panel). An example of highly resolved 1-min data showing elevated UFP levels from 01/02/07 to 01/03/07 is illustrated in the magnified portion of the graph within broken lines



When averaged across the entire duration of Phase 2, the UFP level at the East Tarmac and Ernst Residence sites (~27,900 and 25,000 #/cm^3, respectively) were still about 2.5 times higher than those at the other two sites (Table 12).

Table 12 Average and median ultrafine particle (UFP) number concentrations (#/cm^3) at the Santa Monica Airport stations during Phase 2 (October 2006 - March 2007). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid samples (Valid N) have also been included

Santa Monica Municipal Airport					
	Richland School	**Marine Park**	**Ernst Residence**	**East Tarmac**	**West Tarmac**
	UFP number (#/cm^3) *- Phase 2*				
Average	11503	N/A	24987	27907	11404
Median	9454	N/A	18468	22002	9053
SD	9398	N/A	20650	21023	9724
Min	167	N/A	1135	1200	1167
Max	63722	N/A	155498	124213	121802
Valid N	1048	N/A	1956	1312	1908

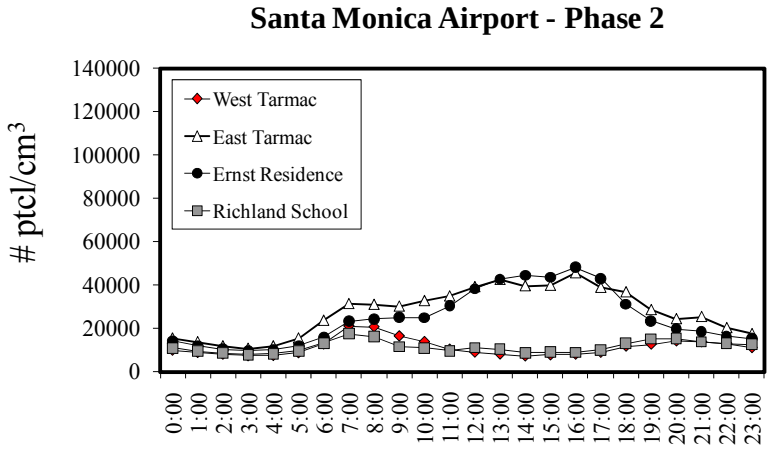
The fact that most of the 1-min peak concentrations measured at the East Tarmac and Ernst Residence sites (see the magnified portion of Figure 26 for data collected between 01/02/07 and 01/03/07) were never above 500,000 #/cm^3 (more than one order of magnitude less than the highest levels recorded during the spring/summer campaign) is likely related to limitations of the water-based CPCs (i.e. their detectable particle range is between 0 and ~500,000 #/cm^3). Also, it is possible that the counting efficiency of water-based CPCs for particles smaller than 20 nm in diameter (which comprise a substantial fraction of the total number of particles in aircraft emissions) is significantly lower than that of their butanol-based counterparts (Herman et al., 2007; Mordas et al., 2008). Although these measurement uncertainties limit our ability to provide a more quantitative assessment of the effect of aircraft takeoffs/landings at sites upwind and downwind of the SMO runway during Phase 2, 1-min particle counts at the East Tarmac and Ernst Residence sites were still up to 70 times higher than those observed at the other two stations further away from the airport (i.e. Richland School and West Tarmac).

Recent studies conducted at the Santa Monica Airport (Hu et al., 2009) and at LAX (Fanning et al., 2007; Westerdahl et al., 2008) have shown that UFPs downwind of these two airports were dominated by freshly generated particles with peak modes between 10 and 15 nm, while the upwind aerosol was comprised by larger aged particles with a diameter of about 90 nm. There is now a growing body of work concerning the potential for adverse health effects from exposure to UFPs emitted from different combustion processes (Xia et al., 2004; Delfino et al., 2005; Sioutas et al. 2005; Nel et al., 2006; Pope and Dockery, 2006), and the presence of highly elevated ultrafine particle

levels downwind of general aviation and international airports may have potential health implications for persons living in adjacent areas.

Figure 27 shows the average diurnal profile of hourly particle number concentrations observed at SMO sites during Phase 2. As during the first phase of the study, the highest traffic activity occurred between 09:00 and 18:00. Average UFP levels at night and early in the morning (i.e. from 22:00 to 03:00) were comparable at all stations, suggesting a substantial decrease in particle count as airport activities subsided at night.

Figure 27 Average diurnal profiles of the ultrafine particle (UFP) number concentration (#/cm^3) measured at four sites of the Santa Monica Airport (i.e. East Tarmac, West Tarmac, Ernst Residence, and Richland School) during Phase 2 (October 2006 - February 2007)



DAILY CARBON MONOXIDE (CO) VARIATIONS

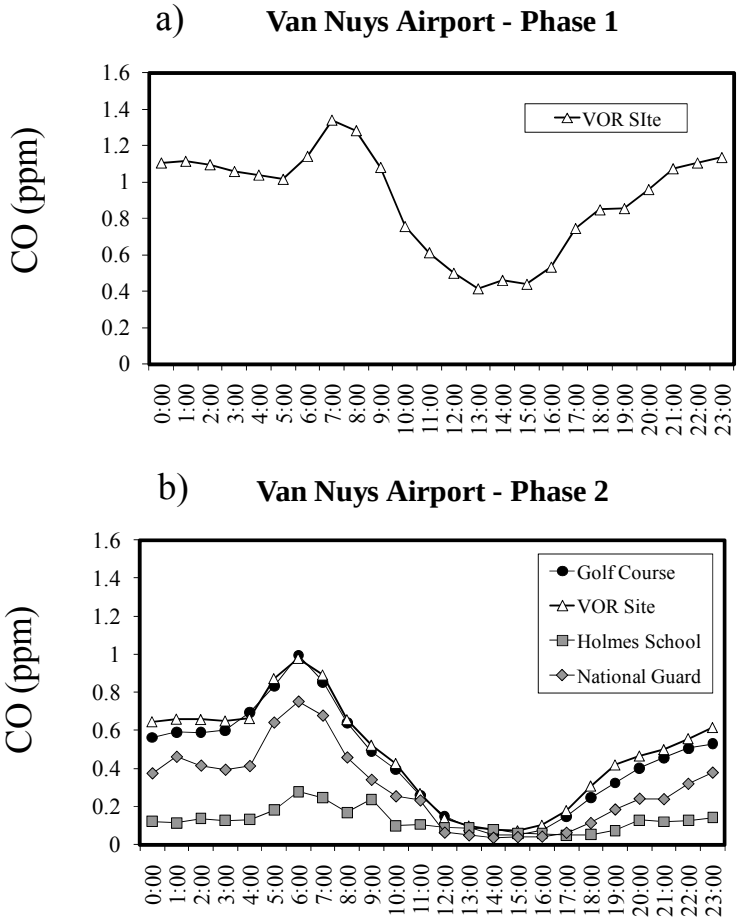
Carbon monoxide (CO) was measured at all "fully" instrumented sites by mean of Dasibi® 3008 CO Analyzers. Attempts were made to use personal monitors at the "partially" instrumented stations, but the resulting data are not reliable and will not be discussed in the following paragraphs. Because of the malfunctioning of several monitors deployed at VNA and some data recovery problems, CO concentrations for Phase 1 are only available at the VOR site. None of the 1-hr average CO concentrations measured at both VNA and SMO was above the current U.S. EPA NAAQS for CO (35 ppm, not to be exceeded more than once per year).

The average diurnal profile of CO at VNA during Phases 1 and 2 (Figures 28a and 28b, respectively) followed a distinctively different pattern from that observed for other combustion-related pollutants such as UFP count and BC, with peak values during morning rush hour traffic (average peak concentrations were between 1 and 1.4 ppm) and lower levels (typically below 0.2 ppm) in the afternoon. This indicates that the concentration of this gaseous pollutant was probably dominated by contributions from motor-vehicle emissions from nearby roadways and freeways, and surface streets, and that the influence from airport-related activities was not significant. This seems to be

particularly true at the VOR and Golf Course sites (outside the airport fence-line and where the highest CO levels were generally measured) and at the National Guard station.

Similar results were obtained from previous work conducted in close proximity to international airports. For example, using nonparametric regression of hourly pollutant concentrations on wind speed and direction, Yu et al. (2004) studied the impact of two major urban airports, LAX and the Hong Kong International Airport (HKG), on local air quality. At both locations CO was dominated by emissions from ground vehicles going in and out of the airport. However, near HKG Airport operations were occasionally found to be a significant contributor to CO and respirable suspended particles. Emissions from the parking lots surrounding an airport area have also been associated with increased CO concentrations (Schurmann et al. 2006).

Figure 28 Average diurnal variations of carbon monoxide (CO; ppm) at four sites of the Van Nuys Airport (i.e. Golf Course, VOR, Holmes School and National Guard). Measurements were taken from a) November 2005 to March 2006 (Phase 1) and b) between July and September 2006 (Phase 2). Because of a malfunctioning of several monitors deployed at VNA and issues related to data recovery, CO concentrations for Phase 1 are only available at the VOR site

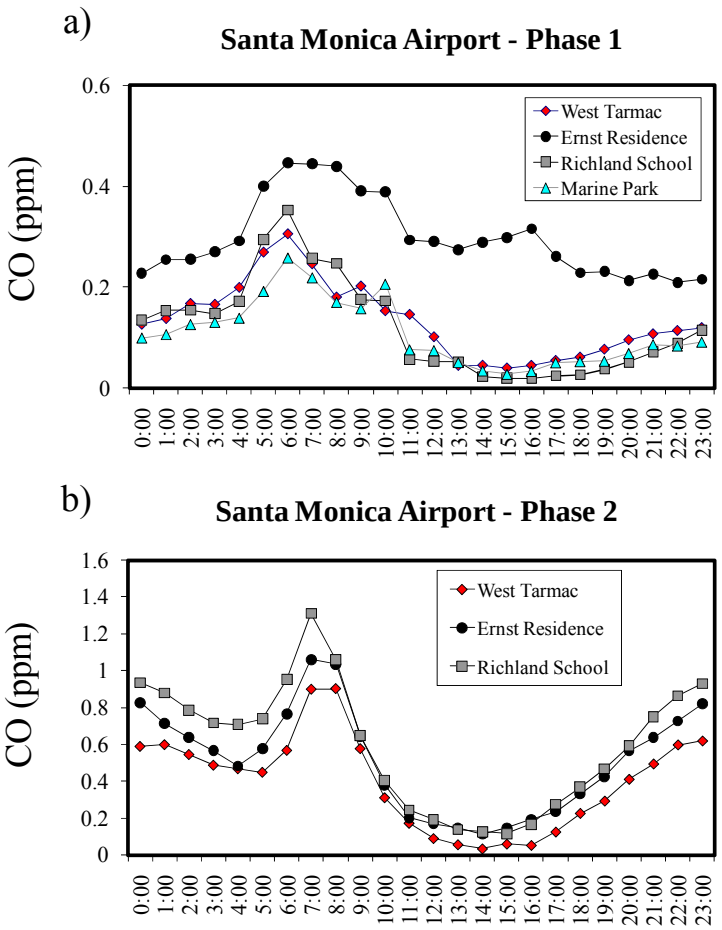


As observed at VNA, the average diurnal profile of CO at SMO followed a distinctively different pattern from that observed for UFP count and BC (Figures 29). Also in this case, increased CO values during morning rush hour (not higher, on average, than 1.4 ppm) and minimum values in the afternoon (generally below 0.2 ppm) suggest that the concentration of this gaseous pollutant was mostly influenced by motor-vehicle emissions from roadways or freeways in the SMO area. The slightly higher CO levels measured at the Ernst Residence site during Phase 1 (Figure 29a) are probably due to the close proximity of this station to Bundy Dr. and National Blvd, two highly trafficked streets adjacent to the north-east side of the airport. The same relative increase in CO at the Ernst Residence station was not observed during the second part of the study (Figure 29b), when the average CO levels at all monitored sites were almost three times higher than during Phase 1.

It is important to note that short term increases in CO concentrations from aircraft emissions have been typically observed when measurements are taken within a short distance from the plume of an engine. During a sampling campaign conducted at the Zurich Airport (Switzerland) Schurmann et al. (2007) collected real-time CO data in an area where four aircraft were generally parked and simultaneously handled. Here each aircraft movement on the taxiway led to short-term (3-min) CO peaks as high as 3,900 ppm at a distance between 50 and 100 m behind the aircraft, a concentration about 40 times higher than the corresponding background level. At low power setting such as when idling or taxiing, jet and piston engines emit high amounts of CO (and incompletely oxidized hydrocarbons), due to incomplete combustion.

A summary of all CO concentration data collected at VNA and SMO during this study can be found in Appendix A.

Figure 29 Average diurnal variations of carbon monoxide (CO; ppm) at different four sites of the Santa Monica Municipal Airport, namely West Tarmac, Ernst Residence, Richland School, and Marine Park. Measurements were taken a) from April to July 2006 (Phase 1) and b) between October 2006 and March 2007 (Phase 2)



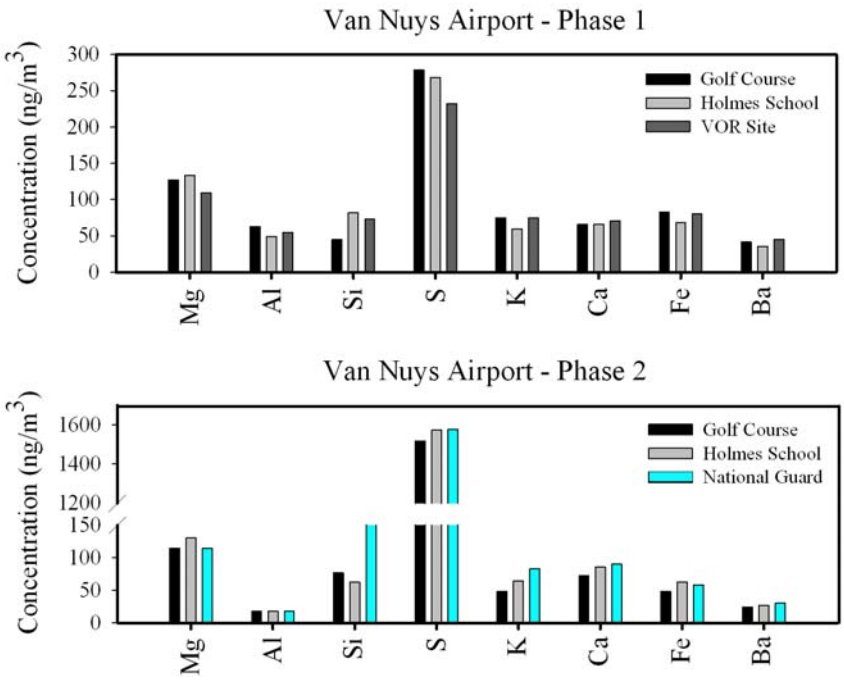
TRACE ELEMENTS

As discussed in the previous sections, particle and gaseous pollutants in and around an airport area can be emitted from a multitude of airport-related sources such as re-fueling, ground support vehicles, passenger cars coming in and out the airport, but also from nearby traffic. Therefore, estimating the relative contributions of these and other point and area sources to the measured atmospheric concentrations of the targeted air pollutants can be challenging. The elemental composition of the collected aerosols can be used to provide an important fingerprint to help distinguish among emission sources from different environments including, roadways (Ntziachristos et al., 2007b), harbor/ports (Arhami et al., 2009), and airports (Groma et al., 2008). Although more than 40 trace elements were analyzed on the $PM_{2.5}$ samples collected at the Van Nuys and Santa Monica Airports, only the concentrations of those species that were present in significant amounts (i.e. Mg, Al, Si, S, K, Ca, Fe, and Ba) will be discussed in the following

paragraphs. The temporal and spatial distribution of lead has already been characterized in a previous section.

The spatial distribution of each trace element measured at VNA was quite uniform across all sampling stations (i.e. Golf Course, VOR, Holmes School, and National Guard, all set-up outside the airport fence-line), regardless of their relative distance from the airport and runway (Figure 30). Typically, S was the most abundant element in the collected PM samples, followed by Mg, Ca, K, Fe, Si, Ba and Al. Sulfur is typically generated from combustion sources such as gasoline and diesel-powered motor-vehicles and aircraft, and it is a component of both Avgas and jet fuel. Previous studies conducted in the Los Angeles area (Ntziacristos et al., 2007b; Arhami et al., 2009) have indicated that S is present in all three fractions of the atmospheric PM (ultra-fine, accumulation and coarse), with high values found in both ultra-fine and accumulation mode particles. During a recent campaign conducted between February and April 2006 and in close proximity to and downwind of the I-710 freeway (the primary route for heavy-duty diesel truck traffic between the ports complex of Long Beach/San Pedro and the shipping yards in East Los Angeles) Ntziachristos et al. (2007b) reported that the study average S concentration in $PM_{2.5}$ particles was about 300 ng/m^3. This level is comparable to that observed at the Van Nuys sites during Phase 1 (240 to 280 ng/m^3) (Figure 30a), but is more than five times lower than the range of values measured during Phase 2 (1,520 to 1,580 ng/m^3) (Figure 30b). This substantial difference can probably be attributed to increased presence of secondary sulfate particles during the summer campaign (Phase 2). The remaining trace elements detected in VNA samples mainly originate from mechanical processes such as vehicle brake abrasion (Ba and Fe; Sanders et al., 2003) or from re-suspension of crustal materials (i.e. Mg, Ca, K, Fe, Si, and Al), and their concentrations are well within those reported in previous road-side, tunnel, and port studies conducted in the Los Angeles Basin (Singh et al., 2002; Ntziachristos et al., 2007b; Arhami et al., 2009) and other urban areas (Birmili et al., 2006). Calcium (used as anti-wear, detergent, and stabilizing additive in oils) has also been proposed as marker for lube-oil combustion.

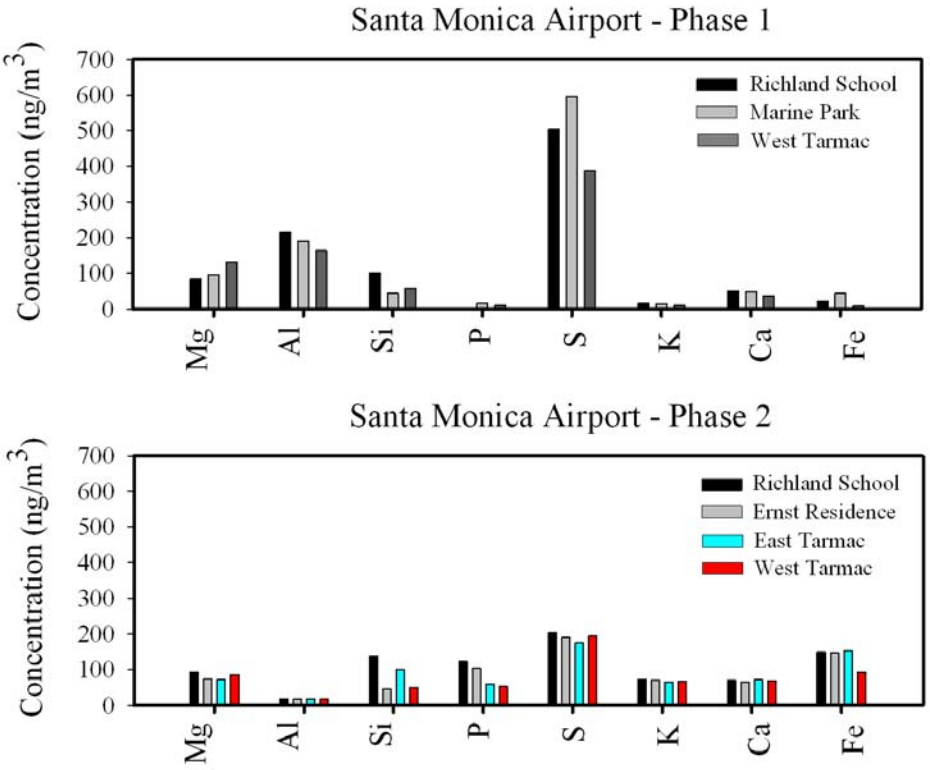
Figure 30 Ambient concentrations of selected metals in fine particulate matter ($PM_{2.5}$) at different sampling locations of the Van Nuys Airport during a) Phases 1 (from November 2005 to March 2006) and b) Phase 2 (from July to September 2006)



Similarly, the concentrations of most trace elements measured at SMO were comparable at all stations (i.e. Richland School, Marine Park, East Tarmac, West Tarmac, and Ernst Residence), regardless of their relative distance from the airport area (Figure 31). Average S concentrations were substantially lower throughout the second part of the study (October 2006–February 2007), with values ranging from 175 ng/m^3 at the East Tarmac site (in very close proximity to an area where aircraft were idling and taking-off) to 200 ng/m^3 at the Richland School site (background station) (Figure 31b). Overall, the temporal profile of the trace elements measured at SMO throughout the entire duration of this study is variable, with higher Al and S levels in the warmer months and increased P, K, Ca and Fe concentrations during the colder period. This is also consistent with increased amounts of of secondary sulfate in late spring and early summer.

Overall, the majority of the trace elements detected in the $PM_{2.5}$ samples collected in Santa Monica probably originated from re-suspension of crustal materials, and their concentrations are comparable to those reported in previous studies conducted in the Los Angeles Basin (Singh et al., 2002; Ntziachristos et al., 2007b; Arhami et al., 2009) and other urban areas (Birmili et al., 2006). A summary of all trace element data collected at VNA and SMO during this study can be found in Appendix A.

Figure 31 Ambient concentrations of selected metals in fine particulate matter ($PM_{2.5}$) at different sampling locations of the Santa Monica Airport during a) Phase 1 (from April to July 2006) and b) Phase 2 (from October 2006 to March 2007)



JET SIGNATURES

To better characterize the influence of aircraft emissions on the air pollution levels at SMO, two canister samples were collected on 05/12/06 at the East Tarmac site, one when jet-propelled planes were idling near the runway (sample #1) and one when no airplane activity was ongoing (sample #2). On the same day, a third canister sample was taken behind the blast-fence when jets were taking-off (sample #3). These air samples were then analyzed to determine the concentrations of several relevant VOCs and gaseous air toxics. The results of this analysis are reported below in Table 13 and suggest that emissions from aircraft idling near the Tarmac (sample #1) increased the concentration of many measured pollutants substantially. Of the overall speciated mixture, some compounds such as 1,3-butadiene, benzene and toluene are considered to be hazardous air pollutants (HAPs), while others (e.g. acetone) may be significant contributors to the overall level of VOC emissions but data indicating toxicity are lacking.

It is worth noting that at cruise speed, most aircraft engines convert significantly more than 99% of the fuel through complete combustion to CO_2 and H_2O. However, at idle conditions (those most commonly found near the East Tarmac station) less fuel is consumed and, in order to maintain a stable combustion at lower power settings, a small loss in combustion efficiency occurs. This leads to higher emissions of incompletely

burned hydrocarbons (Aircraft Engine Speciated Organic Gases: Speciation of Unburned Organic Gases in Aircraft Exhaust, prepared by EPA in 2009).

Interestingly, the concentrations of all gaseous species observed at the East Tarmac site while no aircraft activity was ongoing (sample #2) were comparable to those measured from the analysis of the canister sample collected behind the blast-fence when jets were taking-off (sample #3; see Table 13 for details). This agrees well with the results from a previous study conducted at the Logan Airport in Boston, where the aircraft exhaust from engine idle and taxiway acceleration was found to contain substantially greater concentrations of hydrocarbons (including formaldehyde, acetaldehyde, benzene, and toluene) than the exhaust during landing and takeoff (Herndon et al., 2005). This observation is also qualitatively consistent with the ICAO databank values for hydrocarbon emissions at idle relative to takeoff (ICAO, 2006)

Table 13 Ambient concentrations (ppb) of several important gaseous pollutants present in canister samples collected at the East Tarmac site (samples #1 and #2) and behind the blast-fence (sample #3) at SMO

	Sample #1 East Tarmac (Airplanes idling) (ppb)	**Sample #2** East Tarmac (No airplane activity) (ppb)	**Sample #3** Blast-Fence (Airplanes take-off)
(m+p)-Xylenes	1.32	0.20	0.33
1,2-Dibromoethane	ND	ND	ND
1,2-Dichloroethane	ND	ND	ND
1,2-Dichloropropane	ND	ND	ND
1,3-Butadiene	7.39	ND	0.38
Acetone	6.13	4.20	4.01
Benzene	4.83	0.34	0.44
Carbon Tetrachloride	0.09	0.09	0.09
Chloroethene	ND	ND	ND
Chloroform	ND	0.03	0.04
Ethylbenzene	0.45	0.08	0.12
MEK	ND	ND	0.45
Methylene chloride	0.22	0.20	0.25
MTBE	0.03	ND	ND
o-Dichlorobenzene	ND	0.02	0.03
o-Xylene	0.39	0.26	0.21
p-Dichlorobenzene	ND	0.02	0.05
Perchloroethylene	0.04	0.03	0.06
Styrene	0.67	0.08	0.15
Toluene	2.37	1.08	0.74
Trichloroethene	ND	ND	ND

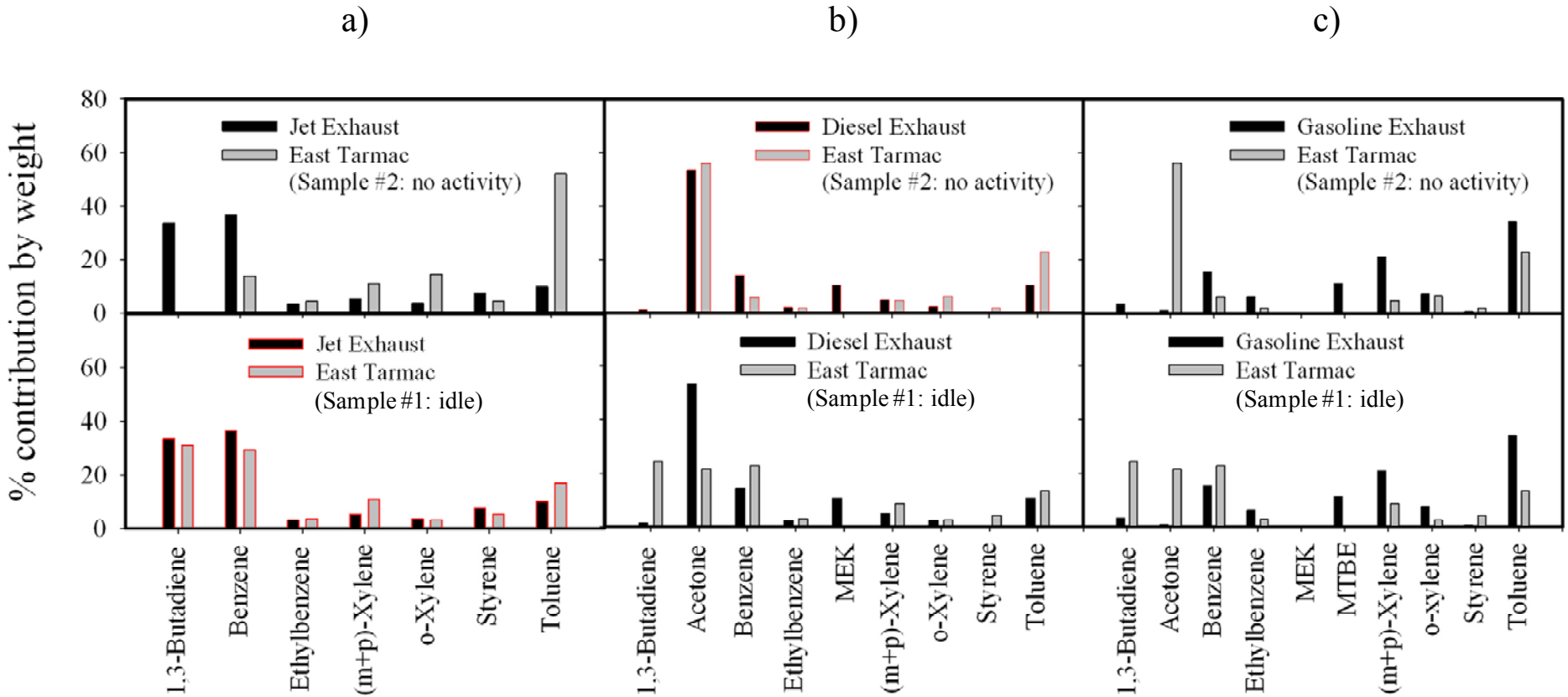
ND = non detected

The emission profiles of the two canister samples collected at the East Tarmac station were then compared to those of jet fuel exhaust (aircraft exhaust-jet fuel), typical gasoline vehicle emissions (gasoline - catalyst - stabilized exhaust - ARB summer 2003), and diesel exhaust (farm equipment - diesel - light & heavy), all downloaded from the California Air Resource Board (CARB) speciation database for organic compounds (ORGPROF; http://www.arb.ca.gov/ei/speciate/speciate.htm). This database provides estimates of the chemical composition of emissions for a variety of emission source categories, and data are reported as the fraction of the total organic gases (TOG) that are reactive organic gases (ROGs). Hence, the concentrations of each species detected in the two canister samples collected at the East Tarmac (samples #1 and #2) were converted to the corresponding percentage contribution to the total measured gaseous levels to facilitate a comparison with the ARB data.

Formaldehyde and ethylene were not quantified in samples #1, #2, and #3 since GC/MS analysis of canister samples is not accurate for formaldehyde detection, and ethylene is not considered an air toxic. However, data obtained from the chemical analysis of emissions from a commercial aircraft gas turbine engine (a CFM56 high bypass turbofan) indicate that the sum of these two compounds alone represent about 55% of the total speciated non-methane hydrocarbon (NMHC) emissions on a concentration basis (Spicer, 1994). The same work also reported that around 40% of the organic gas mass was accounted for by the compounds, ethene, formaldehyde, propene, ethyne and methane. While different data sets provide detailed information on the emission indexes of several air pollutants from various jet-engines types, the exact amount of individual organic gases emitted from jet propelled aircraft is difficult to quantify because it depends on the type of the engine/airframe being tested, the sampling conditions (e.g. engine tests vs ambient sampling near airports), which species are included in the total mix, and which measurement technique has been employed for their analysis. Recent studies conducted both in the United States and in Europe (Herndon et al., 2006; Schürmann et al., 2007) have shown that refueling activities can also alter the profile of most hydrocarbons considerably. These factors should be kept in mind while comparing the results of the various emission profiles presented below.

As shown in Figure 32a, sample #1 closely resembles the emission profile of typical jet exhaust, which suggests that the ambient air at the East Tarmac site was influenced by jet aircraft emissions when idling before take-off. Conversely, the emission profile of sample #2 is similar to that of diesel emission (Figure 32b), probably because when no airplane activity was taking place near the East Tarmac site the ambient air was affected by diesel emissions from vehicles operating within or in close proximity of the airport's perimeter. Lastly, the emission profiles of samples #1 and #2 seem to differ from that of gasoline exhaust (Figure 32c), indicating that gasoline-powered vehicles did not influence the composition of the two canister samples at the time of sampling. A more extensive study and data analysis is needed to confirm these results and to better evaluate the contributions of jet exhaust and diesel emissions to the composition of ambient air at the East Tarmac site and, in general, in the SMO area.

Figure 32 Comparison between the emission profiles of the two canister samples collected at the East Tarmac site and those of a) jet fuel, b) diesel exhausts, and c) gasoline vehicle emissions. Data are expressed as the percentage weight contribution of each species to the total measured organic gas concentration. The emission profiles of jet fuel exhaust (aircraft exhaust - jet fuel), typical gasoline vehicle emissions (gasoline - catalyst - stabilized exhaust - ARB summer 2003), and diesel exhaust (farm equipment - diesel - light & heavy) were downloaded from the California Air Resource Board (CARB) speciation database for organic compounds (ORGPROF; http://www.arb.ca.gov/ei/speciate/speciate.htm)

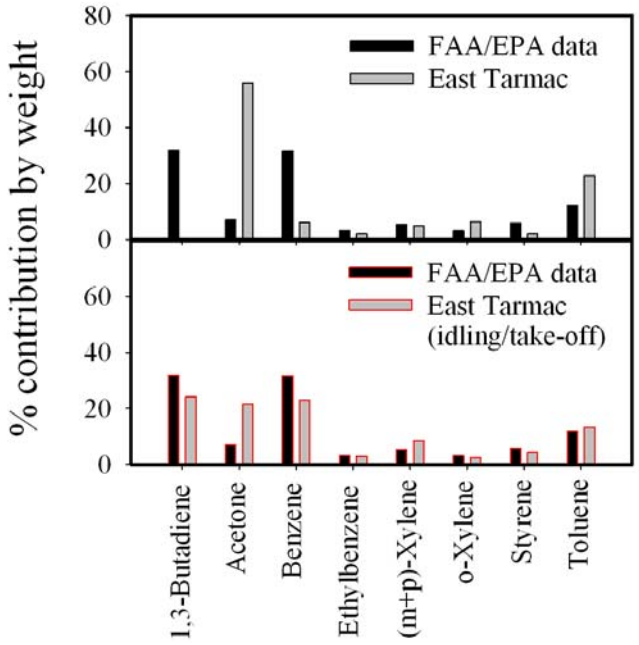


It is worth noting that the benzene/toluene ratio of sample #1 (canister sample affected by emissions from airplanes idling at the East Tarmac) was equal to 2, while the corresponding ratio for sample #2 (characteristic of "airport background" conditions) was about 0.3. After complete ignition, when the engine temperature of an aircraft is constant and relatively high (during taxiing, for example), aromatics tend to crack leading to the production of increasing amounts of benzene. Thus for idling conditions, a benzene/toluene ratio of about 1.6 is expected (Schurmann et al., 2007). Conversely, the characteristic benzene/toluene ratio for kerosene fuel evaporation is about 0.27. Therefore, sample #2 might be indicative of fuel evaporation (Schurmann et al., 2007).

In an attempt to better characterize the hazardous air pollutants (HAPs) speciation profile for commercial aircraft engines, the Federal Aviation Administration (FAA) and the U.S. EPA have recently reviewed the available HAPs emission data from commercial aircrafts (Aircraft Engine Speciated Organic Gases: Speciation of Unburned Organic Gases in Aircraft Exhaust, prepared by EPA in 2009). Consolidated HAPs information from measurements conducted during the past 35 year using various sampling and analysis methods were investigated and combined to provide a single, accurate, and more reliable profile. The resulting FAA/EPA document includes results from the work of Spicer et al. (1994) on military engines, and from the more recent Aircraft Particle Emissions eXperiment (APEX) campaign on commercial aircrafts (see Wey, 2004; Onasch et al., 2006; Wey et al., 2006; Lobo et al., 2007, for details). In addition to dedicated engine tests, sampling from airports during routing operation (most noticeably from the works of Herndon et al., 2006 and Schürmann et al., 2007) have also provided useful data for HAPs emissions that have been included in the above mentioned FAA/EPA work.

The speciated data included in this FAA/EPA document were also compared to the emission profile of sample #1 at the East Tarmac. No correlation was observed between the HAPs emission profile from the EPA/FAA document and that from the analysis of sample #2 (top panel in Figure 33). Overall, although our data are based on limited measurements, they seem to confirm that emissions from jets idling near the East Tarmac before take-off may increase the short term concentrations of several HAPs at this location.

Figure 33 Comparison between the hazardous air pollutants (HAPs) speciation profile for commercial aircraft engines emission profiles provided by EPA (Aircraft Engine Speciated Organic Gases: Speciation of Unburned Organic Gases in Aircraft Exhaust, prepared by EPA in 2009) and those of the two canister sample collected at the East Tarmac site when jets were either idling or taking-off (sample #1; bottom panel) and when no aircraft activity was ongoing (sample #2; top panel)



CONCLUSIONS AND RECOMMENDATIONS

Long-term average concentrations of CO, $PM_{2.5}$, OC, EC, VOCs, carbonyls and trace elements in communities near VNA and SMO were generally similar to, and often lower than, those measured elsewhere in the South Coast Air Basin. For these pollutants, there were generally no distinguishable concentrations gradients within the studied communities which would suggest the airport as a major source. Therefore, emissions from aircraft and other airport-related sources are not likely to significantly increase the long-term risk associated with exposure to these pollutants. The exception to this general finding is TSP lead. Study-average concentrations near VNA and SMO were found to be significantly higher than the corresponding levels present in background air or elsewhere in the Basin, and the concentration gradient pointed to the runway take-off area as a source. Lead is likely emitted from piston-driven engines using leaded general aviation fuel. However, the highest lead levels found in this study, which occurred on airport property, are still below the recently tightened U.S. EPA National Ambient Air Quality Standard for lead.

Near-continuous measurements obtained during this and other field campaigns have shown that sharp and rapid increases (e.g. 1-min) in the concentrations of UFPs occur when jet aircraft are idling, taking off, and sometimes landing. At VNA the highest particle counts were generally measured about 150 m from the north side of the airport, at a site located under the fixed wing arrival/departure route. Here, the average UFP number concentration measured in the colder months (fall 2005 - winter 2006) were 3.6 times higher than those observed at a background site set-up about 2,400 m northwest of the airport. At SMO the spring/summer 2005 average UFP levels recorded 35 m west from the end of the runway and near the blast-fence were two times higher than those 100 m north (and downwind) of the runway and seven times higher than those in background air. Overall, our results are in line with those obtained by Hu et al. (2009) during a four day campaign conducted at SMO during the spring/summer of 2008, when the study-average UFP concentrations at two sites 80 and 100 m downwind of the airport were about 10 times the corresponding background levels for all measurement days combined. Our analysis of aircraft activity data at SMO confirmed that peaks in UFP concentration at the downwind sites were associated with jet aircraft take-off operations. These short-lived spikes in UFP levels were up to 2,000 times higher than background levels, and often extended into residential areas. Further work is needed to better understand the emission rates, atmospheric behavior, physical and chemical properties, and health consequences of both short-term and long-term exposure to UFP emitted from jet aircraft.

The majority of previous studies focusing on the characterization of engine exhaust and the effect of emissions on local air quality have been conducted on large commercial jets. Although there are likely differences in the chemical and physical characteristics of emissions from piston-driven airplanes, small private jets, and larger commercial aircraft, the results of our study are consistent with previous works at LAX and other large international airports in the US and in Europe.

The monitoring plan developed for this study was based largely on the Multiple Air Toxics Exposure Study III (MATES III), a monitoring and evaluation study conducted by AQMD between April 2004 and March 2006 to characterize the long-term carcinogenic risk from exposure to air toxics in the South Coast Air Basin. Time-integrated (24-hr) measurements were taken for most of the pollutants measured, and

therefore a limitation of this study was that short-term exposures could not be assessed. The only near-continuous measurements available were UFP and CO, as well as some limited instantaneous VOC samples. The short-term VOC samples collected near the blast-fence area did show evidence of jet exhaust. Community members as well as AQMD staff have experienced short-term odors during nearby aircraft operations. As more advanced continuous instrumentation for measuring air toxics becomes available, future work could include an assessment of these short-term impacts and acute exposures. Future work may also include measurements of UFP levels and particle size distributions correlated to aircraft type and aircraft operations.

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APPENDIX A

Table A1 Average and median 1,3-butadiene, methylene chloride, and chloroform concentrations (ppb) at the Van Nuys Airport during Phase 1 (November 2005 - March 2006) and Phase 2 (July - September, 2006). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid samples (Valid N) have also been reported for each species along with the corresponding values from a companion monitoring station in Burbank (in red). Concentrations reported as 0.00 ppb represent non detected (ND) values.

	Van Nuys Airport				
	Golf Course	**Holmes School**	**VOR**	**National Guard**	**Burbank**
	1,3-Butadiene (ppb) *- Phase 1*				
Average	0.16	0.09	0.16	N/A	0.23
Median	0.09	0.05	0.10	N/A	0.19
SD	0.14	0.10	0.15	N/A	0.17
Min	0.00	0.00	0.00	N/A	0.00
Max	0.44	0.41	0.52	N/A	0.62
Valid N	29	25	30	N/A	30
	1,3-Butadiene (ppb) *- Phase 2*				
Average	0.05	0.01	0.05	0.06	0.06
Median	0.05	0.01	0.04	0.05	0.05
SD	0.03	0.01	0.04	0.04	0.05
Min	0.01	0.00	0.01	0.01	0.01
Max	0.13	0.02	0.15	0.18	0.23
Valid N	20	4	20	14	20
	Methylene Chloride (ppb) *- Phase 1*				
Average	0.25	0.21	0.25	N/A	0.42
Median	0.17	0.16	0.24	N/A	0.35
SD	0.18	0.20	0.20	N/A	0.49
Min	0.04	0.00	0.00	N/A	0.03
Max	0.67	0.87	0.70	N/A	2.81
Valid N	29	25	30	N/A	30
	Methylene Chloride (ppb) *- Phase 2*				
Average	0.19	0.13	0.21	0.25	0.26
Median	0.20	0.11	0.21	0.25	0.28
SD	0.09	0.07	0.09	0.09	0.13
Min	0.06	0.08	0.08	0.12	0.08
Max	0.43	0.24	0.39	0.46	0.67
Valid N	20	4	20	14	20
	Chloroform (ppb) *- Phase 1*				
Average	0.07	0.05	0.05	N/A	0.06
Median	0.06	0.05	0.05	N/A	0.06
SD	0.04	0.03	0.04	N/A	0.03
Min	0.00	0.01	0.00	N/A	0.01
Max	0.14	0.12	0.13	N/A	0.11
Valid N	29	25	30	N/A	30
	Chloroform (ppb) *- Phase 2*				
Average	0.13	0.06	0.09	0.11	0.06
Median	0.13	0.04	0.10	0.10	0.06
SD	0.07	0.04	0.05	0.06	0.03
Min	0.03	0.04	0.02	0.03	0.02
Max	0.23	0.13	0.18	0.22	0.15
Valid N	20	4	20	14	20

Table A2 Average and median benzene, carbon tetrachloride, and toluene concentrations (ppb) at the Van Nuys Airport during Phase 1 (November 2005 - March 2006) and Phase 2 (July - September, 2006). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid samples (Valid N) have also been reported for each species along with the corresponding values from a companion monitoring station in Burbank (in red). Concentrations reported as 0.00 ppb represent non detected (ND) values.

	Van Nuys Airport				
	Golf Course	**Holmes School**	**VOR**	**National Guard**	**Burbank**
	Benzene (ppb) *- Phase 1*				
Average	1.05	0.57	0.80	N/A	1.08
Median	0.95	0.46	0.63	N/A	1.21
SD	0.69	0.53	0.86	N/A	0.52
Min	0.15	0.10	0.11	N/A	0.11
Max	3.03	2.71	4.66	N/A	1.85
Valid N	29	25	30	N/A	30
	Benzene (ppb) *- Phase 2*				
Average	0.39	0.20	0.38	0.45	0.43
Median	0.40	0.16	0.39	0.43	0.46
SD	0.19	0.09	0.18	0.20	0.20
Min	0.15	0.13	0.16	0.20	0.17
Max	0.90	0.34	0.93	1.07	0.98
Valid N	20	4	20	14	20
	Carbon Tetrachloride (ppb) *- Phase 1*				
Average	0.09	0.08	0.08	N/A	0.09
Median	0.09	0.09	0.09	N/A	0.09
SD	0.02	0.02	0.02	N/A	0.01
Min	0.03	0.00	0.00	N/A	0.06
Max	0.13	0.11	0.11	N/A	0.10
Valid N	29	25	30	N/A	30
	Carbon Tetrachloride (ppb) *- Phase 2*				
Average	0.08	0.08	0.08	0.09	0.08
Median	0.08	0.08	0.08	0.09	0.08
SD	0.01	0.01	0.01	0.01	0.01
Min	0.05	0.07	0.06	0.06	0.07
Max	0.10	0.09	0.10	0.10	0.10
Valid N	20	4	20	14	20
	Toluene (ppb) *- Phase 1*				
Average	3.85	1.28	1.98	N/A	3.76
Median	3.88	1.26	1.67	N/A	4.20
SD	2.58	0.98	1.60	N/A	2.10
Min	0.31	0.12	0.14	N/A	0.17
Max	10.2	3.27	4.85	N/A	6.83
Valid N	29	25	30	N/A	30
	Toluene (ppb) *- Phase 2*				
Average	1.22	0.56	1.15	1.43	1.87
Median	1.28	0.38	1.04	1.43	1.43
SD	0.61	0.40	0.66	0.72	1.50
Min	0.31	0.30	0.34	0.43	0.48
Max	3.03	1.15	2.89	3.36	6.46
Valid N	20	4	20	14	20

Table A3 Average and median perchloroethylene concentrations (ppb) at the Van Nuys Airport during Phase 1 (November 2005 - March 2006) and Phase 2 (July - September, 2006). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid samples (Valid N) have also been reported for each species along with the corresponding values from a companion monitoring station in Burbank (in red). Concentrations reported as 0.00 ppb represent non detected (ND) values.

	Van Nuys Airport				
	Golf Course	**Holmes School**	**VOR**	**National Guard**	**Burbank**
	***Perchloroethylene (ppb)** - Phase 1*				
Average	0.10	0.04	0.05	N/A	0.15
Median	0.07	0.03	0.04	N/A	0.13
SD	0.09	0.04	0.05	N/A	0.15
Min	0.00	0.00	0.00	N/A	0.00
Max	0.32	0.12	0.15	N/A	0.79
Valid N	29	25	30	N/A	30
	***Perchloroethylene (ppb)** - Phase 2*				
Average	0.05	0.03	0.05	0.08	0.07
Median	0.06	0.03	0.05	0.07	0.07
SD	0.03	0.02	0.03	0.05	0.03
Min	0.01	0.01	0.01	0.01	0.02
Max	0.11	0.06	0.13	0.21	0.16
Valid N	20	4	20	14	20

Table A4 Average and median 1,3-butadiene, methylene chloride, and chloroform concentrations (ppb) at the Santa Monica Airport during Phase 1 (April - July, 2006) and Phase 2 (October 2006 - February 2007). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid samples (Valid N) have also been reported for each species along with the corresponding values from a companion monitoring station in Central Los Angeles (in red). Concentrations reported as 0.00 ppb represent non detected (ND) values.

	Santa Monica Municipal Airport					
	Richland School	**Marine Park**	**Ernst Residence**	**East Tarmac**	**West Tarmac**	**Central Los Angeles**
	1,3-Butadiene (ppb) *- Phase 1*					
Average	0.01	0.01	0.02	0.02	0.01	0.02
Median	0.00	0.00	0.00	0.00	0.00	0.00
SD	0.03	0.02	0.02	0.03	0.02	0.03
Min	0.00	0.00	0.00	0.00	0.00	0.00
Max	0.09	0.08	0.06	0.07	0.10	0.11
Valid N	24	19	16	9	24	20
	1,3-Butadiene (ppb) *- Phase 2*					
Average	0.13	0.08	0.14	0.12	0.09	0.14
Median	0.12	0.07	0.13	0.11	0.08	0.13
SD	0.09	0.06	0.08	0.08	0.06	0.08
Min	0.00	0.00	0.00	0.02	0.00	0.00
Max	0.42	0.24	0.35	0.32	0.31	0.31
Valid N	41	21	43	24	44	39
	Methylene Chloride (ppb) *– Phase 1*					
Average	0.18	0.13	0.18	0.25	0.18	0.33
Median	0.18	0.12	0.18	0.15	0.14	0.33
SD	0.11	0.08	0.09	0.29	0.12	0.11
Min	0.00	0.00	0.05	0.01	0.00	0.15
Max	0.39	0.36	0.37	0.97	0.55	0.53
Valid N	24	19	16	9	24	20
	Methylene Chloride (ppb) *- Phase 2*					
Average	0.28	0.22	0.27	0.20	0.25	0.41
Median	0.25	0.16	0.24	0.16	0.24	0.38
SD	0.16	0.12	0.15	0.11	0.15	0.19
Min	0.07	0.07	0.07	0.06	0.07	0.10
Max	0.85	0.44	0.84	0.44	0.82	0.84
Valid N	41	21	43	24	44	39
	Chloroform (ppb) *- Phase 1*					
Average	0.03	0.04	0.05	0.05	0.03	0.03
Median	0.03	0.05	0.05	0.05	0.03	0.04
SD	0.02	0.02	0.02	0.03	0.02	0.03
Min	0.00	0.00	0.02	0.02	0.00	0.00
Max	0.07	0.10	0.09	0.10	0.06	0.08
Valid N	24	19	16	9	24	20
	Chloroform (ppb) *- Phase 2*					
Average	0.07	0.06	0.07	0.05	0.05	0.05
Median	0.07	0.06	0.07	0.04	0.05	0.05
SD	0.03	0.02	0.03	0.02	0.02	0.02
Min	0.01	0.03	0.03	0.01	0.01	0.03
Max	0.14	0.12	0.13	0.10	0.10	0.12
Valid N	41	21	43	24	44	39

Table A5 Average and median benzene, carbon tetrachloride, and toluene concentrations (ppb) at the Santa Monica Airport during Phase 1 (April - July, 2006) and Phase 2 (October 2006 - February 2007). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid samples (Valid N) have also been reported for each species along with the corresponding values from a companion monitoring station in Central Los Angeles (in red).

	Santa Monica Municipal Airport					
	Richland School	**Marine Park**	**Ernst Residence**	**East Tarmac**	**West Tarmac**	**Central Los Angeles**
	Benzene (ppb) *- Phase 1*					
Average	0.27	0.21	0.30	0.29	0.23	0.46
Median	0.23	0.15	0.22	0.30	0.19	0.47
SD	0.21	0.17	0.25	0.18	0.15	0.18
Min	0.10	0.06	0.10	0.09	0.10	0.19
Max	1.15	0.78	1.17	0.59	0.82	0.82
Valid N	24	19	16	9	24	20
	Benzene (ppb) *- Phase 2*					
Average	0.62	0.46	0.64	0.52	0.50	0.66
Median	0.60	0.43	0.60	0.41	0.49	0.65
SD	0.31	0.21	0.31	0.28	0.25	0.28
Min	0.16	0.17	0.19	0.17	0.14	0.20
Max	1.52	0.93	1.58	1.16	1.38	1.31
Valid N	41	21	43	24	44	39
	Carbon Tetrachloride (ppb) *- Phase 1*					
Average	0.09	0.09	0.09	0.11	0.09	0.09
Median	0.09	0.09	0.09	0.10	0.09	0.09
SD	0.01	0.03	0.01	0.03	0.01	0.02
Min	0.08	0.06	0.07	0.09	0.07	0.06
Max	0.11	0.18	0.12	0.17	0.11	0.12
Valid N	24	19	16	9	24	20
	Carbon Tetrachloride (ppb) *- Phase 2*					
Average	0.09	0.09	0.09	0.09	0.09	0.09
Median	0.09	0.09	0.08	0.09	0.09	0.09
SD	0.02	0.02	0.01	0.01	0.01	0.01
Min	0.06	0.07	0.06	0.06	0.06	0.06
Max	0.16	0.14	0.14	0.12	0.15	0.11
Valid N	41	21	43	24	44	39
	Toluene (ppb) *- Phase 1*					
Average	0.71	0.55	0.81	0.80	0.66	1.33
Median	0.67	0.45	0.82	0.62	0.60	1.31
SD	0.30	0.30	0.24	0.42	0.35	0.52
Min	0.25	0.19	0.43	0.33	0.26	0.62
Max	1.59	1.53	1.36	1.48	1.75	2.64
Valid N	24	19	16	9	24	20
	Toluene (ppb) *- Phase 2*					
Average	1.82	1.31	1.96	1.63	1.53	2.05
Median	1.80	1.06	1.94	1.23	1.46	2.09
SD	1.07	0.81	1.07	1.24	0.90	0.95
Min	0.26	0.36	0.36	0.29	0.21	0.49
Max	4.82	3.19	4.67	4.70	3.88	4.33
Valid N	41	21	43	24	44	39

Table A6 Average and median trichloroethene and perchloroethylene concentrations (ppb) at the Santa Monica Airport during Phase 1 (April - July, 2006) and Phase 2 (October 2006 - February 2007). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid samples (Valid N) have also been reported for each species along with the corresponding values from a companion monitoring station in Central Los Angeles (in red). Concentrations reported as 0.00 ppb represent non detected (ND) values.

	Santa Monica Municipal Airport					
	Richland School	**Marine Park**	**Ernst Residence**	**East Tarmac**	**West Tarmac**	**Central Los Angeles**
	Trichloroethene (ppb) *- Phase 1*					
Average	0.00	0.00	0.01	0.01	0.00	0.02
Median	0.00	0.00	0.00	0.00	0.00	0.01
SD	0.00	0.01	0.01	0.02	0.00	0.03
Min	0.00	0.00	0.00	0.00	0.00	0.00
Max	0.01	0.03	0.02	0.05	0.01	0.10
Valid N	24	19	16	9	24	20
	Trichloroethene (ppb) *- Phase 2*					
Average	0.01	0.01	0.03	0.02	0.01	0.02
Median	0.01	0.00	0.02	0.02	0.00	0.02
SD	0.02	0.01	0.02	0.02	0.01	0.02
Min	0.00	0.00	0.00	0.00	0.00	0.00
Max	0.07	0.05	0.08	0.06	0.06	0.09
Valid N	40	21	43	24	43	39
	Perchloroethylene (ppb) *- Phase 1*					
Average	0.03	0.02	0.02	0.05	0.02	0.05
Median	0.03	0.02	0.02	0.03	0.02	0.06
SD	0.03	0.02	0.02	0.04	0.02	0.03
Min	0.00	0.00	0.00	0.00	0.00	0.00
Max	0.09	0.07	0.05	0.12	0.07	0.13
Valid N	24	19	16	9	24	20
	Perchloroethylene (ppb) *- Phase 2*					
Average	0.13	0.07	0.10	0.08	0.08	0.09
Median	0.10	0.06	0.09	0.08	0.07	0.08
SD	0.13	0.06	0.08	0.08	0.06	0.09
Min	0.00	0.00	0.00	0.00	0.00	0.00
Max	0.72	0.25	0.34	0.36	0.32	0.53
Valid N	41	21	43	24	44	39

Table A7 Average 8-hr VOC concentrations (ppb) at the Van Nuys Airport during Phase 1 (November 2005 - March 2006). The corresponding percentage contributions to their total daily levels have also been included

		Van Nuys Airport - *Phase 1*					
		Concentration (ppb)			**Percentage Contribution**		
		00:00 08:00	**08:00 16:00**	**16:00 00:00**	**00:00 08:00**	**08:00 16:00**	**16:00 00:00**
1,3-Butadiene	**GOLF COURSE**	0.22	0.11	0.15	45.4%	23.0%	31.6%
Benzene		1.28	0.86	1.03	40.3%	27.2%	32.5%
Carbon Tetrachloride		0.09	0.09	0.09	34.2%	32.6%	33.2%
Chloroform		0.11	0.05	0.06	48.7%	22.0%	29.3%
Methylene Chloride		0.34	0.20	0.20	46.3%	26.7%	27.1%
Perchloroethylene		0.12	0.07	0.10	41.8%	24.4%	33.8%
Toluene		5.11	2.82	3.72	43.8%	24.2%	32.0%
Trichloroethene		0.02	0.06	0.07	15.1%	39.0%	45.8%
1,3-Butadiene	**HOLMES SCHOOL**	0.10	0.06	0.12	37.1%	20.5%	42.3%
Benzene		0.63	0.49	0.60	36.7%	28.4%	34.9%
Carbon Tetrachloride		0.08	0.08	0.09	32.7%	33.0%	34.4%
Chloroform		0.07	0.03	0.06	45.7%	19.0%	35.3%
Methylene Chloride		0.20	0.21	0.22	30.8%	33.7%	35.5%
Perchloroethylene		0.04	0.04	0.04	33.7%	34.7%	31.6%
Toluene		1.37	1.04	1.45	35.4%	27.0%	37.6%
Trichloroethene		0.00	0.04	0.04	4.5%	51.1%	44.4%
1,3-Butadiene	**VOR**	0.19	0.10	0.19	38.8%	21.7%	39.5%
Benzene		0.92	0.63	0.88	38.1%	25.8%	36.1%
Carbon Tetrachloride		0.08	0.09	0.08	33.3%	33.9%	32.7%
Chloroform		0.07	0.03	0.05	45.8%	20.4%	33.8%
Methylene Chloride		0.31	0.21	0.24	41.2%	27.5%	31.2%
Perchloroethylene		0.06	0.05	0.05	38.6%	31.8%	29.6%
Toluene		2.28	1.49	2.25	37.9%	24.7%	37.4%
Trichloroethene		0.10	0.05	0.06	47.2%	24.0%	28.8%

Table A8 Average 8-hr VOC concentrations (ppb) at the Van Nuys Airport during Phase 2 (July - September 2006). The corresponding percentage contributions to their total daily levels have also been included

		Van Nuys Airport - *Phase 2*					
		Concentration (ppb)			**Percentage Contribution**		
		00:00 08:00	**08:00 16:00**	**16:00 00:00**	**00:00 08:00**	**08:00 16:00**	**16:00 00:00**
1,3-Butadiene	**GOLF COURSE**	0.08	0.02	0.04	56.3%	16.2%	27.5%
Benzene		0.54	0.33	0.28	46.9%	29.0%	24.2%
Carbon Tetrachloride		0.09	0.09	0.07	34.7%	35.1%	30.1%
Chloroform		0.24	0.06	0.07	65.3%	15.1%	19.6%
Methylene Chloride		0.24	0.18	0.13	44.3%	32.3%	23.4%
Perchloroethylene		0.06	0.06	0.04	39.4%	37.9%	22.7%
Toluene		1.89	0.97	0.71	52.9%	27.2%	19.9%
Trichloroethene		0.00	0.01	0.00	32.0%	48.0%	20.0%
1,3-Butadiene	**HOLMES SCHOOL**	0.01	0.01	0.01	37.5%	37.5%	25.0%
Benzene		0.24	0.16	0.16	42.4%	28.4%	29.1%
Carbon Tetrachloride		0.08	0.08	0.08	33.1%	34.7%	32.2%
Chloroform		0.10	0.03	0.04	56.3%	19.5%	24.1%
Methylene Chloride		0.15	0.12	0.10	40.4%	32.2%	27.3%
Perchloroethylene		0.03	0.03	0.02	40.0%	37.5%	22.5%
Toluene		0.74	0.39	0.40	48.4%	25.6%	26.0%
Trichloroethene		0.00	0.01	0.00	25.0%	75.0%	0.0%
1,3-Butadiene	**NATIONAL GUARD**	0.09	0.04	0.04	49.8%	25.7%	24.5%
Benzene		0.58	0.39	0.30	45.4%	30.8%	23.7%
Carbon Tetrachloride		0.09	0.08	0.09	33.9%	32.3%	33.8%
Chloroform		0.19	0.08	0.04	60.9%	24.7%	14.4%
Methylene Chloride		0.33	0.22	0.18	45.4%	30.3%	24.3%
Perchloroethylene		0.09	0.09	0.06	36.4%	38.1%	25.5%
Toluene		2.11	1.11	0.86	51.8%	27.2%	21.0%
Trichloroethene		0.01	0.01	0.01	48.5%	29.0%	22.5%
1,3-Butadiene	**VOR**	0.08	0.03	0.05	51.7%	16.1%	32.2%
Benzene		0.52	0.27	0.32	47.0%	24.4%	28.6%
Carbon Tetrachloride		0.08	0.08	0.08	34.9%	33.0%	32.1%
Chloroform		0.17	0.04	0.05	63.9%	16.5%	19.6%
Methylene Chloride		0.25	0.19	0.16	42.0%	31.6%	26.4%
Perchloroethylene		0.07	0.06	0.03	43.4%	36.6%	20.0%
Toluene		1.74	0.72	0.82	52.9%	21.9%	25.1%
Trichloroethene		0.01	0.00	0.00	50.8%	25.4%	23.7%

Table A9 Average 8-hr VOC concentrations (ppb) at the Santa Monica Airport during Phase 1 (April - July, 2006). The corresponding percentage contributions to their total daily levels have also been included

		Santa Monica Municipal Airport - *Phase 1*					
		Concentration (ppb)			**Percentage Contribution**		
		00:00 08:00	**08:00 16:00**	**16:00 00:00**	**00:00 08:00**	**08:00 16:00**	**16:00 00:00**
1,3-Butadiene	**EAST TARMAC**	0.01	0.02	0.04	21.1%	26.3%	52.6%
Benzene		0.39	0.27	0.16	47.7%	32.8%	19.4%
Carbon Tetrachloride		0.11	0.10	0.10	37.1%	31.2%	31.7%
Chloroform		0.09	0.04	0.03	58.9%	23.9%	17.3%
Methylene Chloride		0.26	0.25	0.06	45.6%	43.6%	10.9%
Perchloroethylene		0.06	0.03	0.01	57.2%	30.7%	12.1%
Toluene		0.96	0.81	0.44	43.2%	36.8%	20.0%
Trichloroethene		0.02	0.01	0.01	56.0%	23.3%	20.7%
1,3-Butadiene	**WEST TARMAC**	0.02	0.00	0.00	73.8%	12.3%	13.8%
Benzene		0.36	0.17	0.18	51.0%	23.6%	25.4%
Carbon Tetrachloride		0.09	0.09	0.09	32.6%	33.7%	33.7%
Chloroform		0.04	0.02	0.02	52.5%	19.4%	28.1%
Methylene Chloride		0.20	0.19	0.14	37.2%	35.7%	27.0%
Perchloroethylene		0.05	0.01	0.01	68.0%	21.6%	10.4%
Toluene		1.18	0.39	0.46	58.0%	19.4%	22.5%
Trichloroethene		0.00	0.00	0.00	30.9%	49.4%	19.7%
1,3-Butadiene	**ERNST RESIDENCE**	0.01	0.02	0.02	22.8%	40.6%	36.5%
Benzene		0.42	0.28	0.19	46.9%	31.3%	21.9%
Carbon Tetrachloride		0.09	0.09	0.09	33.3%	32.5%	34.2%
Chloroform		0.07	0.04	0.05	45.5%	23.6%	30.9%
Methylene Chloride		0.20	0.27	0.08	36.1%	49.9%	14.0%
Perchloroethylene		0.02	0.02	0.01	38.0%	40.6%	21.4%
Toluene		1.04	0.80	0.59	42.8%	32.8%	24.4%
Trichloroethene		0.01	0.00	0.00	78.1%	17.5%	4.4%
1,3-Butadiene	**MARINE PARK**	0.03	0.01	0.00	72.7%	15.3%	12.0%
Benzene		0.34	0.15	0.12	55.3%	24.5%	20.1%
Carbon Tetrachloride		0.09	0.11	0.08	32.5%	38.7%	28.8%
Chloroform		0.07	0.03	0.03	52.4%	21.7%	26.0%
Methylene Chloride		0.21	0.12	0.07	52.8%	29.6%	17.6%
Perchloroethylene		0.05	0.02	0.01	62.4%	22.0%	15.6%
Toluene		0.98	0.36	0.30	59.8%	22.0%	18.2%
Trichloroethene		0.00	0.01	0.00	25.0%	70.0%	5.0%
1,3-Butadiene	**RICHLAND SCHOOL**	0.03	0.01	0.01	63.4%	16.4%	20.2%
Benzene		0.44	0.21	0.18	53.2%	25.1%	21.7%
Carbon Tetrachloride		0.09	0.09	0.09	34.4%	32.4%	33.2%
Chloroform		0.06	0.02	0.02	59.1%	19.2%	21.7%
Methylene Chloride		0.21	0.22	0.10	39.0%	41.5%	19.5%
Perchloroethylene		0.06	0.03	0.02	54.7%	28.2%	17.1%
Toluene		1.13	0.55	0.47	52.8%	25.5%	21.7%
Trichloroethene		0.00	0.00	0.00	58.2%	41.8%	0.0%

Table A10 Average 8-hr VOC concentrations (ppb) at the Santa Monica Airport during Phase 2 (October 2006 - February 2007). The corresponding percentage contributions to their total daily levels have also been included

		Santa Monica Municipal Airport - *Phase 2*					
		Concentration (ppb)			**Percentage Contribution**		
		00:00 08:00	**08:00 16:00**	**16:00 00:00**	**00:00 08:00**	**08:00 16:00**	**16:00 00:00**
1,3-Butadiene	**EAST TARMAC**	0.12	0.11	0.14	33.5%	29.2%	37.3%
Benzene		0.56	0.46	0.52	36.5%	29.9%	33.6%
Carbon Tetrachloride		0.09	0.09	0.08	34.0%	33.7%	32.2%
Chloroform		0.07	0.04	0.04	44.3%	27.4%	28.3%
Methylene Chloride		0.24	0.22	0.15	39.2%	35.8%	25.0%
Perchloroethylene		0.11	0.09	0.05	44.7%	35.5%	19.8%
Toluene		1.66	1.40	1.68	35.0%	29.5%	35.5%
Trichloroethene		0.04	0.01	0.01	57.9%	20.8%	21.3%
1,3-Butadiene	**WEST TARMAC**	0.12	0.05	0.12	40.4%	18.7%	40.9%
Benzene		0.52	0.40	0.57	34.8%	26.9%	38.3%
Carbon Tetrachloride		0.09	0.09	0.09	33.8%	33.6%	32.6%
Chloroform		0.06	0.04	0.04	42.5%	26.6%	30.9%
Methylene Chloride		0.28	0.26	0.22	37.1%	34.1%	28.8%
Perchloroethylene		0.10	0.07	0.06	42.9%	30.5%	26.6%
Toluene		1.73	1.09	1.80	37.5%	23.6%	38.9%
Trichloroethene		0.01	0.01	0.01	46.0%	24.1%	29.9%
1,3-Butadiene	**ERNST RESIDENCE**	0.18	0.10	0.16	40.5%	22.3%	37.2%
Benzene		0.77	0.49	0.70	39.3%	24.9%	35.8%
Carbon Tetrachloride		0.09	0.09	0.09	33.4%	33.3%	33.3%
Chloroform		0.10	0.04	0.06	48.3%	21.3%	30.4%
Methylene Chloride		0.34	0.26	0.23	41.0%	31.6%	27.4%
Perchloroethylene		0.15	0.10	0.07	46.7%	30.2%	23.1%
Toluene		2.41	1.47	2.14	40.1%	24.4%	35.5%
Trichloroethene		0.05	0.01	0.02	58.8%	14.4%	26.8%
1,3-Butadiene	**MARINE PARK**	0.11	0.05	0.12	40.2%	17.5%	42.3%
Benzene		0.55	0.38	0.55	37.1%	25.5%	37.4%
Carbon Tetrachloride		0.09	0.09	0.09	34.0%	33.4%	32.6%
Chloroform		0.09	0.05	0.06	44.8%	23.0%	32.1%
Methylene Chloride		0.28	0.19	0.22	40.3%	27.0%	32.7%
Perchloroethylene		0.11	0.06	0.05	49.1%	26.9%	23.9%
Toluene		1.69	0.97	1.57	39.9%	23.0%	37.2%
Trichloroethene		0.01	0.01	0.01	50.1%	20.6%	29.3%
1,3-Butadiene	**RICHLAND SCHOOL**	0.19	0.06	0.14	48.0%	16.1%	36.0%
Benzene		0.80	0.43	0.65	42.8%	22.7%	34.5%
Carbon Tetrachloride		0.09	0.09	0.09	33.7%	33.4%	32.9%
Chloroform		0.10	0.04	0.06	49.3%	20.1%	30.6%
Methylene Chloride		0.36	0.23	0.24	43.1%	27.7%	29.2%
Perchloroethylene		0.22	0.10	0.07	56.6%	25.0%	18.4%
Toluene		2.46	1.17	1.84	45.0%	21.4%	33.6%
Trichloroethene		0.02	0.01	0.01	56.9%	19.4%	23.6%

Table A11 Average and median formaldehyde and acetaldehyde concentrations (ppb) at the Van Nuys Airport during Phase 1 (November 2005 - March 2006) and Phase 2 (July - September, 2006). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid samples (Valid N) have also been reported for each species along with the corresponding values from a companion monitoring station in Burbank (in red).

	Van Nuys Airport				
	Golf Course	**Holmes School**	**VOR**	**National Guard**	**Burbank**
	Formaldehyde (ppb) *- Phase 1*				
Average	3.30	2.85	3.70	N/A	4.04
Median	3.40	2.96	3.72	N/A	4.52
SD	1.12	1.46	1.67	N/A	1.67
Min	1.19	0.77	1.15	N/A	0.54
Max	5.23	5.23	6.89	N/A	6.87
Valid N	27	26	27	N/A	28
	Formaldehyde (ppb) *- Phase 2*				
Average	6.05	3.66	6.52	5.64	4.80
Median	6.18	3.23	6.77	5.98	4.76
SD	2.10	1.60	2.22	1.68	1.72
Min	2.54	2.24	2.87	2.54	2.44
Max	10.2	5.95	10.3	7.56	8.41
Valid N	22	4	22	15	19
	Acetaldehyde (ppb) *- Phase 1*				
Average	2.55	1.96	2.31	N/A	2.17
Median	2.37	1.96	2.39	N/A	2.48
SD	1.07	1.05	1.22	N/A	0.97
Min	0.97	0.53	0.72	N/A	0.31
Max	4.56	3.80	4.53	N/A	3.81
Valid N	27	26	27	N/A	28
	Acetaldehyde (ppb) *- Phase 2*				
Average	3.72	2.05	3.25	3.04	1.88
Median	3.57	1.65	3.58	3.24	2.14
SD	1.22	1.23	1.23	0.89	0.80
Min	1.75	1.06	1.11	1.26	0.79
Max	5.49	3.85	5.36	4.22	3.43
Valid N	22	4	22	15	19

Table A12 Average and median acetone and methyl ethyl ketone (MEK) concentrations (ppb) at the Van Nuys Airport during Phase 1 (November 2005 - March 2006) and Phase 2 (July - September, 2006). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid samples (Valid N) have also been reported for each species along with the corresponding values from a companion monitoring station in Burbank (in red).

	Van Nuys Airport				
	Golf Course	**Holmes School**	**VOR**	**National Guard**	**Burbank**
	***Acetone (ppb)** - Phase 1*				
Average	5.28	4.47	6.66	N/A	3.15
Median	4.81	4.35	5.43	N/A	2.00
SD	2.72	2.96	4.91	N/A	2.71
Min	1.03	0.66	0.93	N/A	0.35
Max	10.6	11.1	17.7	N/A	11.22
Valid N	27	26	27	N/A	28
	***Acetone (ppb)** - Phase 2*				
Average	4.42	2.56	5.09	5.51	0.66
Median	4.06	1.81	4.81	5.42	0.60
SD	2.57	1.89	3.69	2.38	0.49
Min	1.19	1.28	1.10	2.00	0.20
Max	12.7	5.3	18.5	11.4	2.49
Valid N	22	4	22	15	19
	***MEK (ppb)** - Phase 1*				
Average	0.67	0.43	0.58	N/A	0.41
Median	0.61	0.46	0.59	N/A	0.37
SD	0.31	0.26	0.39	N/A	0.26
Min	0.23	0.10	0.13	N/A	0.05
Max	1.40	0.94	1.51	N/A	1.05
Valid N	27	26	27	N/A	28
	***MEK (ppb)** - Phase 2*				
Average	0.90	0.55	0.82	0.85	0.21
Median	0.97	0.48	0.76	0.93	0.16
SD	0.41	0.32	0.44	0.36	0.17
Min	0.21	0.27	0.20	0.15	0.02
Max	1.87	0.98	1.93	1.53	0.83
Valid N	22	4	22	15	19

Table A13 Average and median formaldehyde and acetaldehyde concentrations (ppb) at the Santa Monica Airport during Phase 1 (April - July, 2006) and Phase 2 (October 2006 - February 2007). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid samples (Valid N) have also been reported for each species along with the corresponding values from a companion monitoring station in Central Los Angeles (in red). Concentrations reported as 0.00 ppb represent non detected (ND) values.

	Santa Monica Municipal Airport					
	Richland School	**Marine Park**	**Ernst Residence**	**East Tarmac**	**West Tarmac**	**Central Los Angeles**
	Formaldehyde (ppb) *- Phase 1*					
Average	3.16	1.91	3.14	0.00	3.32	3.14
Median	3.14	1.92	3.11	0.00	3.32	2.84
SD	0.59	0.40	0.44	0.00	0.71	1.61
Min	2.13	1.19	2.28	0.00	2.12	0.97
Max	4.41	2.74	4.26	0.00	4.92	7.41
Valid N	37	32	25	4	34	34
	Formaldehyde (ppb) *- Phase 2*					
Average	4.20	6.18	3.89	3.93	3.75	5.50
Median	4.22	6.61	3.72	3.46	3.77	5.45
SD	1.67	2.59	2.21	1.72	1.06	2.38
Min	1.25	2.08	1.66	1.56	1.84	1.17
Max	8.30	11.4	16.4	8.50	6.08	9.91
Valid N	44	12	42	29	41	44
	Acetaldehyde (ppb) *- Phase 1*					
Average	1.53	1.31	1.36	0.00	1.39	1.18
Median	1.51	1.29	1.39	0.00	1.38	1.10
SD	0.50	0.32	0.30	0.00	0.43	0.62
Min	0.77	0.78	0.84	0.00	0.71	0.36
Max	2.65	1.97	1.97	0.00	2.31	2.76
Valid N	37	32	25	5	34	34
	Acetaldehyde (ppb) *- Phase 2*					
Average	2.17	2.18	2.17	1.82	2.03	2.37
Median	2.13	2.25	2.11	1.62	2.01	2.35
SD	0.92	0.76	1.19	0.89	0.81	1.15
Min	0.80	0.81	0.91	0.74	0.75	0.38
Max	4.11	3.81	8.16	4.23	3.89	4.90
Valid N	44	12	42	29	41	44

Table A14 Average and median acetone and methyl ethyl ketone (MEK) concentrations (ppb) at the Santa Monica Airport during Phase 1 (April - July, 2006) and Phase 2 (October 2006 - February 2007). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid samples (Valid N) have also been reported for each species along with the corresponding values from a companion monitoring station in Central Los Angeles (in red). Concentrations reported as 0.00 ppb represent non detected (ND) values.

	Santa Monica Municipal Airport					
	Richland School	**Marine Park**	**Ernst Residence**	**East Tarmac**	**West Tarmac**	**Central Los Angeles**
	***Acetone (ppb)** - Phase 1*					
Average	1.95	1.97	2.04	0.00	1.90	0.88
Median	1.94	1.90	1.97	0.00	1.78	0.79
SD	0.55	0.46	0.57	0.00	0.52	0.53
Min	0.77	0.97	1.20	0.00	1.09	0.25
Max	3.63	3.42	3.56	0.00	3.55	2.50
Valid N	37	32	25	3	34	34
	***Acetone (ppb)** - Phase 2*					
Average	4.68	4.45	5.07	4.09	4.14	3.89
Median	4.15	4.21	4.65	3.67	4.00	3.30
SD	2.35	1.35	2.48	2.24	2.00	2.84
Min	1.23	1.99	1.39	1.30	1.08	0.12
Max	11.7	7.00	11.3	10.6	9.51	10.72
Valid N	44	12	42	29	41	44
	***MEK (ppb)** - Phase 1*					
Average	0.30	0.29	0.29	0.00	0.26	0.15
Median	0.27	0.29	0.28	0.00	0.23	0.13
SD	0.13	0.10	0.07	0.00	0.11	0.09
Min	0.12	0.15	0.20	0.00	0.12	0.05
Max	0.57	0.49	0.41	0.00	0.60	0.38
Valid N	37	32	25	5	34	34
	***MEK (ppb)** - Phase 2*					
Average	0.61	0.52	0.52	0.50	0.50	0.47
Median	0.56	0.53	0.46	0.39	0.51	0.46
SD	0.26	0.17	0.29	0.27	0.23	0.27
Min	0.20	0.16	0.18	0.18	0.17	0.07
Max	1.26	0.75	1.87	1.30	1.18	1.21
Valid N	44	12	42	29	41	44

Table A15 Average and median carbon monoxide (CO) concentrations (ppm) at the Van Nuys Airport during Phase 1 (November 2005 - March 2006) and Phase 2 (July - September, 2006). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid data (Valid N) have also been reported. Concentrations reported as 0.0 ppm represent non detected (ND) values.

	Van Nuys Airport			
	Golf Course	**Holmes School**	**VOR**	**National Guard**
	***CO (ppm)** - Phase 1*			
Average	2.3	0.6	1.1	N/A
Median	0.7	0.2	0.7	N/A
SD	7.7	1.0	1.1	N/A
Min	0.0	0.0	0.0	N/A
Max	13.6	11.8	4.0	N/A
Valid N	1530	1973	2099	N/A
	***CO (ppm)** - Phase 2*			
Average	0.4	0.1	0.5	0.3
Median	0.3	0.1	0.3	0.2
SD	0.4	0.2	0.5	0.4
Min	0.0	0.0	0.0	0.0
Max	2.3	1.6	2.7	3.6
Valid N	1328	377	1331	1044

Table A16 Average and median carbon monoxide (CO) concentrations (ppm) at the Santa Monica Airport during Phase 1 (April - July, 2006) and Phase 2 (October 2006 - February 2007). Minimum (Min) and maximum (Max) values, standard deviations (SD), and the total number of valid data (Valid N) have also been reported. Concentrations reported as 0.0 ppm represent non detected (ND) values.

	Santa Monica Municipal Airport				
	Richland School	**Marine Park**	**Ernst Residence**	**East Tarmac**	**West Tarmac**
	***CO (ppm)** - Phase 1*				
Average	0.1	0.1	0.3	N/A	0.1
Median	0.0	0.0	0.3	N/A	0.1
SD	0.3	0.2	0.2	N/A	0.2
Min	0.0	0.0	0.0	N/A	0.0
Max	7.2	2.2	2.4	N/A	3.1
Valid N	2804	1734	1848	N/A	2671
	***CO (ppm)** - Phase 2*				
Average	0.6	N/A	0.5	N/A	0.4
Median	0.3	N/A	0.2	N/A	0.2
SD	0.7	N/A	0.7	N/A	0.5
Min	0.0	N/A	0.0	N/A	0.0
Max	4.2	N/A	3.7	N/A	3.1
Valid N	3061	N/A	1805	N/A	1317