ITEM 2(a)

SANTA MONICA AIRPORT AIR QUALITY STUDY: CHANGES FROM THE SHORTENING OF THE RUNWAY

Prepared for:

The City of Santa Monica, CA

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Summary Report

Introduction

On August 28, 2017 the Airport Commission recommended that the City of Santa Monica conduct an air quality study at the Santa Monica Airport to measure air pollution before, during, and after the Runway Shortening Project ("Shortening"). The completion of the Shortening, which reduced the runway length from 5,000 feet (1,524 meters) to 3,500 feet (1,067 meters), restricted certain types of turbine aircraft (jets) from take-offs and landings. Completion of the Shortening also required a full closure of the runway, allowing an additional opportunity to conduct air quality monitoring during a period of no flight operations (shutdown) at the airport.

The City sought to learn from this study whether the change in the aircraft fleet mix (reduced jet activity) improved the air quality surrounding the airport by collecting data prior to the Shortening, during the full closure, immediately after the resumption of operations on the shortened runway and one year after the Shortening. We also compared our pre-shortening results to the study conducted by the South Coast Air Quality Management District (SCAQMD) in 2010 during runway repaving to determine whether there were changes in air quality around the airport in the period between the two studies.

We, the three authors of this report, were retained to conduct the air quality monitoring study. We are all air quality scientists with extensive experience in airport air quality measurement and analysis. While more detail is provided below and in the technical report that follows, it is clear that the Shortening resulted in important improvements in air quality in nearby residential neighborhoods.

Methods

Air pollutant concentrations were monitored at two sites: the eastern end of the runway 21 ("Runway Site") and at a nearby residence ("Residential Site") that were 276 and 362 meters, respectively, downwind from the centerline of the eastern end of the shortened runway. The two sites are shown in Figure A. During on-shore westerly ocean breezes (typical in Santa Monica), both of these locations are downwind of Runway 21, and are thus locations of maximum airport

air pollution impacts on average. We were able to separate times of these high impact, on-shore wind directions ("downwind") from other wind directions ("upwind"), such as reverse wind blowing in the direction of the ocean, which placed the two monitoring sites upwind of the airport.

Figure A: Satellite image of the area showing the enclosures for instruments at the two monitoring sites marked by red ovals.

Measurements were conducted before, during, and after the runway closure in Nov-Dec 2017 and about a year later in Dec 2017-Jan 2018. Measurements from a year after the shortening were obtained to quantify air quality improvements during a time when flight activity had returned to normal, although with far fewer jets.

The pollutants monitored included ultrafine particles (<100 nanometers; measured as particle number concentrations (PNC) which is a proxy for ultrafine particles)), black carbon (BC), and fine particulate matter mass ($PM_{2.5}$; <2.5 micrometers). $PM_{2.5}$ samples were collected on filters that were also analyzed for lead (Pb) concentrations. In short, PNC is a good marker of fuel combustion. In particular, aircraft-related impacts on PNC have been shown to be quite pronounced and concentrated under flight pathways. $PM_{2.5}$ is more of a regional pollutant in Los

Angeles area but is considered the driver of most major health effects due to air pollution. Lead typically makes up a small fraction of $PM_{2.5}$ mass but is known to have toxic effects deemed more dangerous than other $PM_{2.5}$ constituents. Lead is a concern around general aviation airports where propeller-driven aircraft use a leaded aviation gasoline called "Avgas." Lastly, BC is also a product of combustion, but more strongly reflects the incomplete combustion of diesel vehicles, thus allowing some indication of non-airport local and regional vehicular traffic emissions.

During all monitoring phases, winds blew from the west south-west (WSW; 224°±90°) and northeast (NE; 44°±90°) direction. When the winds are from WSW, they blow pollution generated within the airport downwind to the location of both monitoring sites, and therefore data from these conditions was termed '*downwind*' or '*impacted by the airport*' in this report. When winds were from the NE, they oriented the monitoring sites upwind of the airport, but downwind from the other dominant emission sources in the area (notably the freeways 1-10 and I-405 to the N and E of the monitoring sites). During this wind condition the monitoring locations were not impacted by the airport-related emissions and data from these conditions was termed '*upwind*' or '*not impacted by the airpor*t' in the report. The 'downwind' versus 'upwind' data provides a basis to compare the impact from the airport versus other sources, i.e., an additional contrast for comparison of the airport's impacts on air quality.

Results

We summarize the key findings of the study below, which are discussed in more detail in the body of the report.

1. Differences during Distinct Phases based on Flight Operations

a. **Pre-Shutdown.** Before the shutdown, when aircraft operations included jets, the average concentrations of PNC and BC were generally higher than the measurements made in the 2010 repaving study (we could not test if there were statistically significant differences because the raw data from SCAQMD wasn't available). See Figure B.

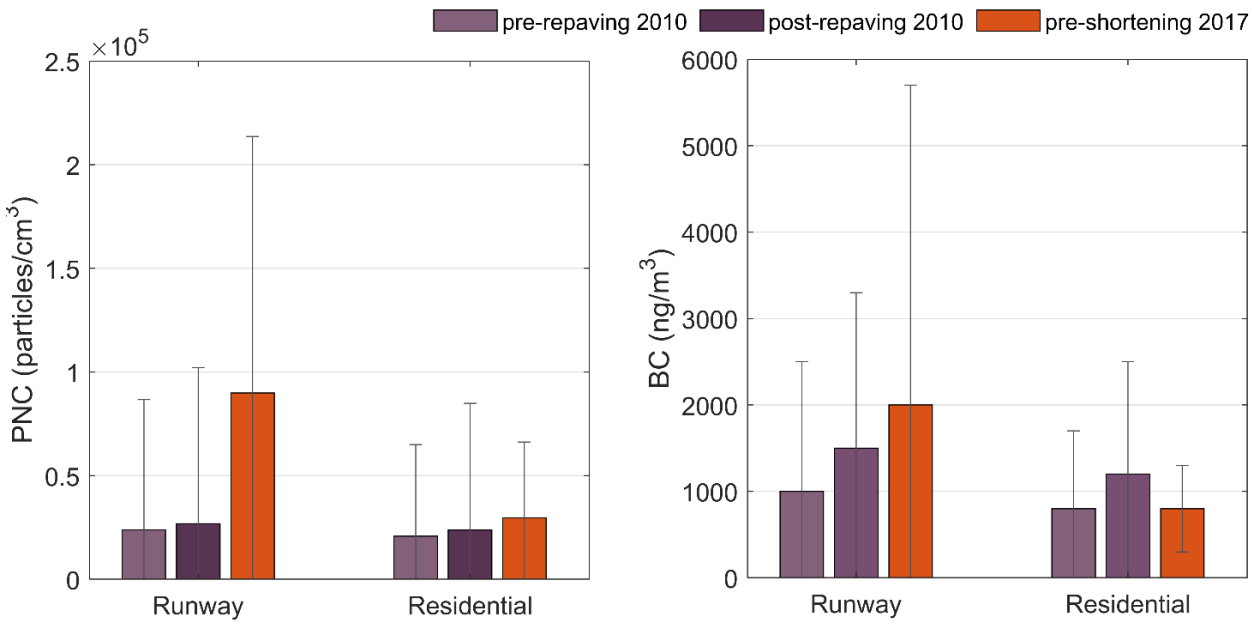

Figure B: Comparison of concentrations before runway shortening in December 2017 to those reported by SCAQMD for the 2010 repaving project.

i. *PNC*. When the runway monitoring location was impacted by airport emissions, we recorded an average of 90,000 particles/cm^3, which was higher than the averages of 24,000 and 27,000 particles/cm^3 reported by AQMD before and after the shutdown for repaving in 2010, respectively. Pre-shortening PNC at the residential site (30,000 particles/cm^3) was also higher than that reported by SCAQMD (21,000 and 24,000 particles/cm^3) in 2010 but the difference was less than that recorded at the runway site.

ii. *BC.* When the runway monitoring location was impacted by airport emissions, we recorded an average BC concentration of 2 µg/m^3, which was higher than the averages of 1 and 1.5 µg/m^3 reported by SCAQMD before and after the shutdown for repaving in 2010, respectively. Pre-shortening BC concentrations at the residential site (0.8 µg/m^3) was comparable to that reported by SCAQMD (0.8 and 1.2 µg/m^3) in 2010.

iii. *Lead.* Pre-shutdown mean lead concentration at the runway site was 24 ng/m^3, which was lower than the ~40 ng/m^3 mean lead concentration measured in 2006-2007 at both the runway and the residential site by SCAQMD in General Aviation Airport Study.

b. ***During the shutdown***. During the shutdown, the concentrations of all pollutants were substantially (and statistically significantly) lower than pre-shortening when the wind blew the pollution from the airport to the monitoring sites downwind. See Figure C1.

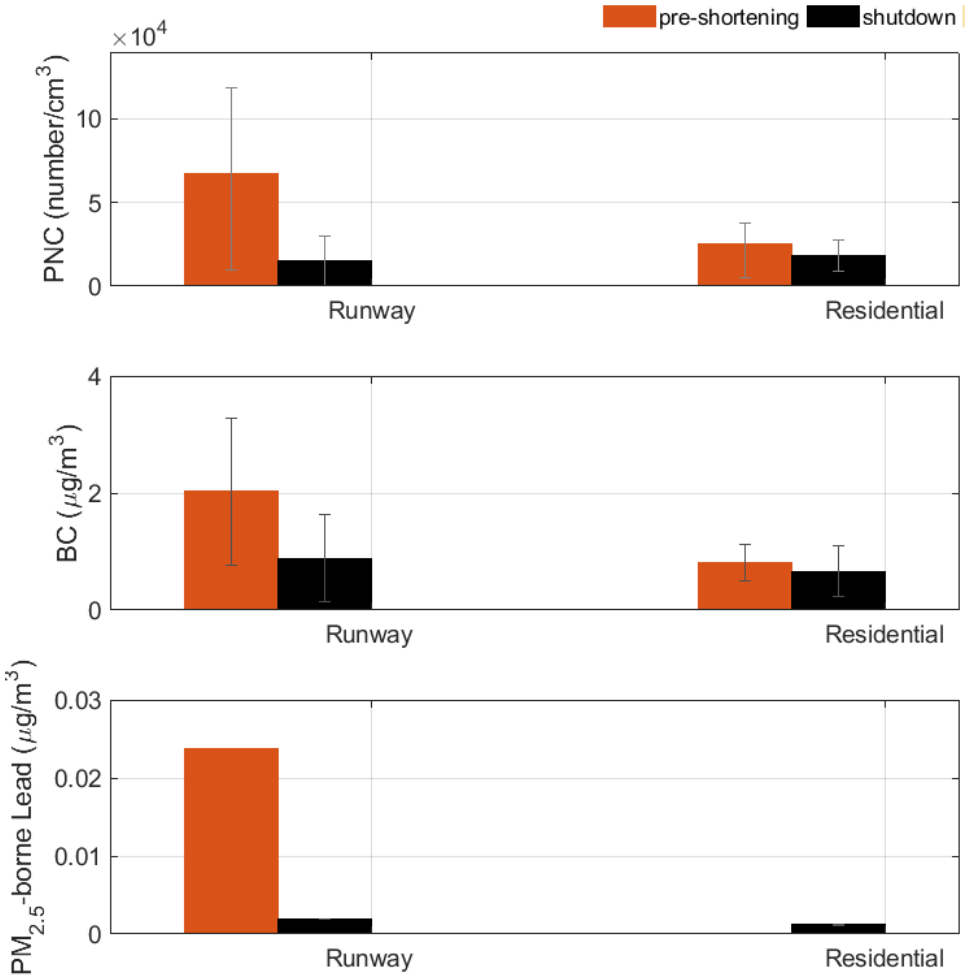

Figure C1: Average concentrations of ultrafine particles (PNC), BC and lead at the runway and residential sites during pre-shortening and shutdown phases of the study

i. <u>*PNC.*</u> During the shutdown, PNC were 75% and 50% lower than pre-shortening at the runway and residential sites, respectively.

ii. <u>*BC.*</u> During the shutdown, BC concentrations were 60% and 15% lower than pre-shortening conditions at the runway and residential sites, respectively.

iii. <u>*Lead.*</u> During the shutdown, mean lead concentration was 90% lower than pre-shortening at the runway site and the concentration at the residential site was similar to the runway site. These results reaffirm the observation reported earlier by

SCAQMD that aviation gas combustion (a leaded fuel still in use in U.S.) leads to particulate emissions that contain lead.

c. ***Post-shortening***. Just after shortening the concentrations of air pollutants were also substantially (and statistically significantly) lower than pre-shortening when the wind blew the pollution from the airport downwind to the monitoring sites. See Figure C2.

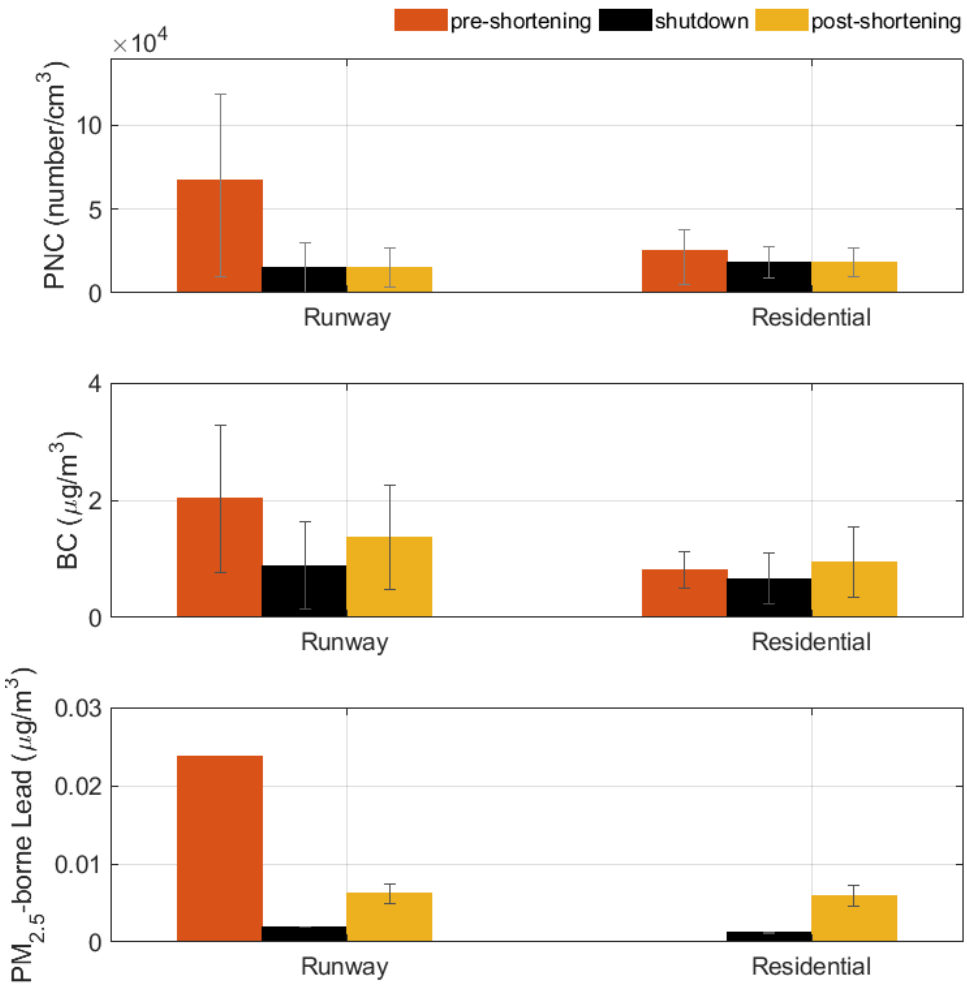

Figure C2: Average concentrations of ultrafine particles (PNC), BC and lead at the runway and residential sites during pre-shortening, shutdown and post-shortening phases of the study.

i. <u>*PNC.*</u> Post-shortening, PNC were 75% lower than pre-shortening at the runway site and 36% lower at the residential site.

ii. <u>*BC.*</u> Post-shortening, BC concentrations were 30% lower than pre-shortening at the runway site but they were 25% higher at the residential site. Note, the residential

location may also be impacted by emissions on Bundy Drive when the site is downwind of the airport which is a trafficked roadway.

iii. <u>*Lead.*</u> Post shortening, the mean lead concentration was still 75% lower than pre-shortening at the runway site and concentration was similar at the residential site.

d. ***One year later***. One year after the runway shortening was completed the concentrations of pollutants continued to be substantially (and statistically significantly) lower than pre-shortening in wind conditions that blew the pollution from the airport downwind to the monitoring sites. Also, one-year-later PNC and BC concentrations were comparable to the shutdown concentrations but one-year-later lead concentration was higher than the shutdown concentration. See Figure C3.

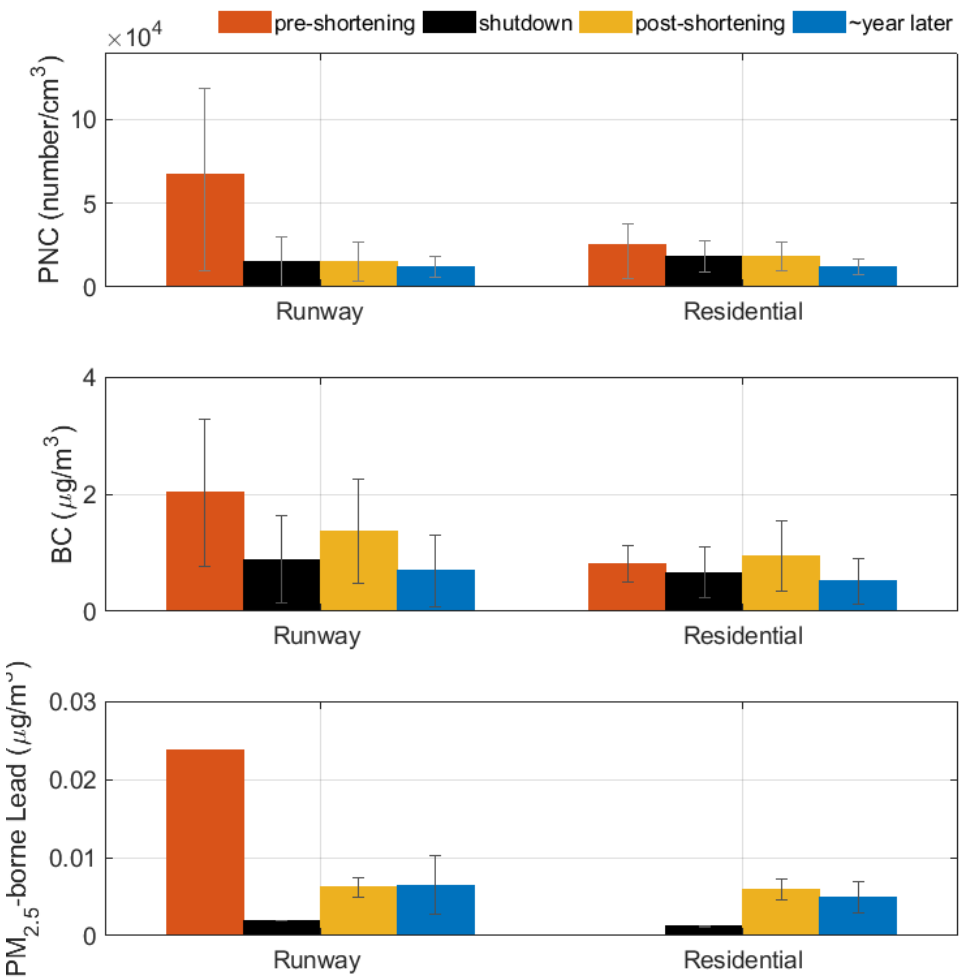

Figure C3: Average concentrations of ultrafine particles (PNC), BC and lead at the runway and residential sites during various phases of the study

i. *PNC.* One year later, PNC averages were 80% lower than pre-shortening at the runway site and 35% lower at the residential site. One year later, PNC averages were 25% lower than shutdown at the runway site but 35% higher at the residential site.

ii. *BC.* One year later, BC averages were 70% lower than pre-shortening at the runway site and 40% lower at the residential site. One year later, BC averages were 25% lower than shutdown at the runway site and 30% lower at the residential site.

iv. *Lead.* One year later, the mean lead concentration at the runway site was comparable to the post-shortening level, i.e., it continued to be 75% lower than pre-shortening. Similarly, the one-year-later mean lead concentration at the residential site was similar to post-shortening and it was also comparable to the one-year-later runway concentration. It is important to note that due to the Shortening there wasn't a similar decrease in piston engine operations (either post-shortening or one year later) which use the leaded aviation gas fuel.

Due to the closer proximity of the runway monitoring site to the runway compared to the residential site, both pollutant concentrations and the relative reduction in concentrations due to the Shortening were greater at the runway site than at the residential site. A greater reduction was observed in PNC than in BC concentrations, expectedly, because jets are a stronger source of ultrafine particles due to higher exhaust temperatures and fuel consumption rates during all phases of the landing and takeoff cycle. Jets also contribute to BC, particularly takeoff events, but vehicular-traffic related contribution to BC is also significant in the area (as was also indicated in the 2010 SCAQMD study). Lastly, the spatial gradient in lead concentration (i.e., difference between runway and residential site) seems to be far less than that observed in PNC and BC.

2. Effect of Shortening on Short-Term Concentration Spikes

A key difference between pre- and post-shortening on air quality was the lack of short-term pollutant-concentration spikes caused by individual jet plumes. The time-series for PNC and BC concentrations for pre-shortening, shutdown and post-shortening phases of the study are shown in Figure D and Figure E, respectively. Spikes frequently observed in the pre-shortening phase were not only less frequent, rare or absent in the post-shortening phase, but they were also of lower magnitude.

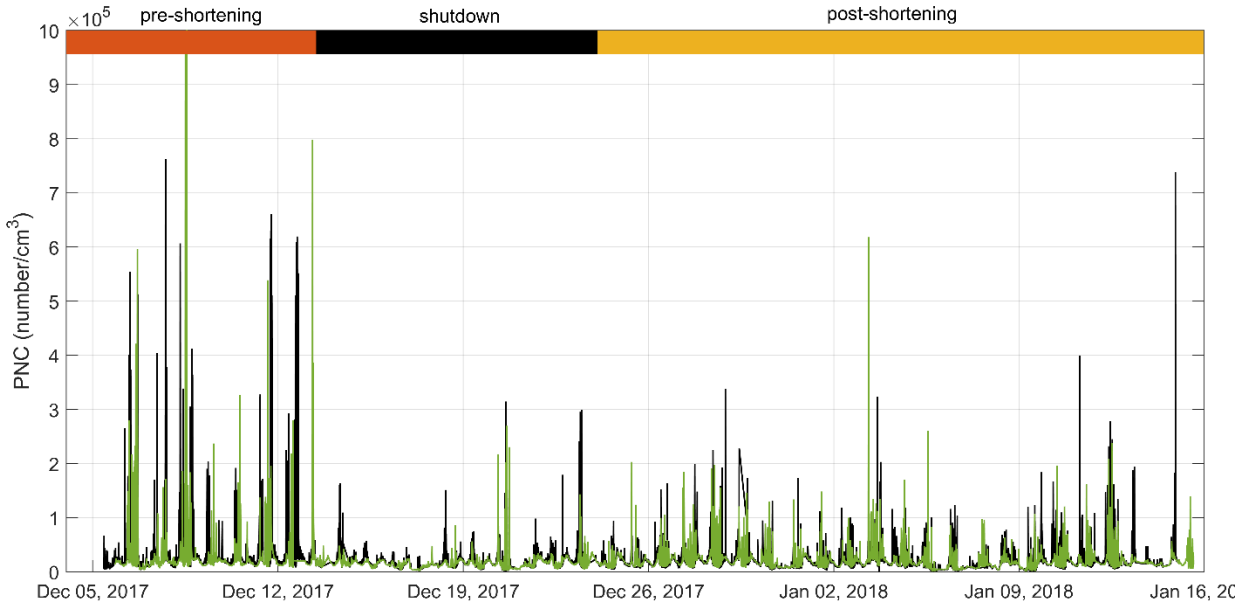

Figure D: Time-series for particle number concentration (PNC) measured at the Runway Site and Residential site (green) during pre- shortening, during shutdown and post-shortening.

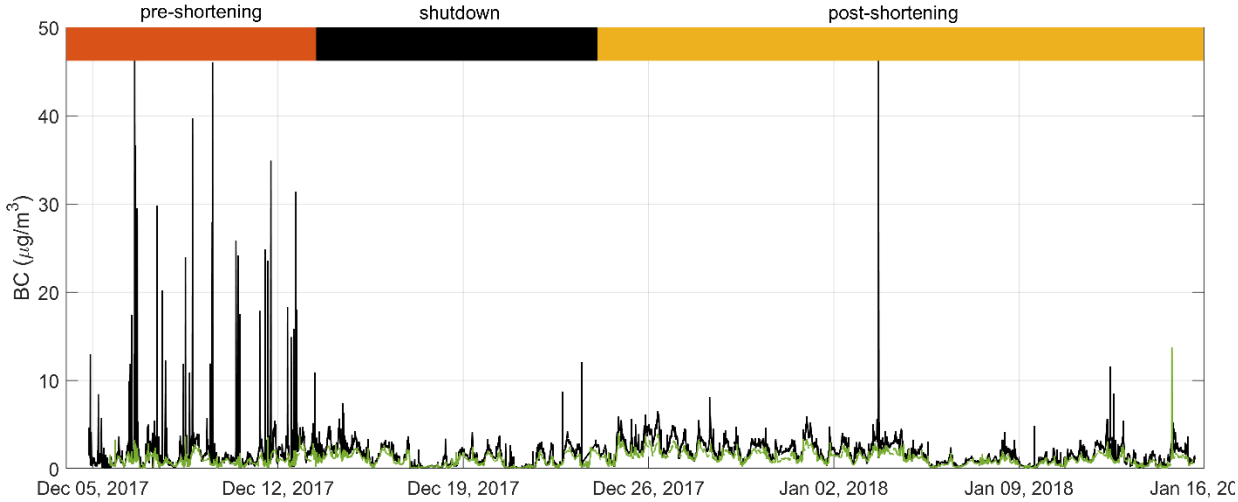

Figure E: Time-series for BC concentration measured at the Runway Site (runway) and Residential site (green) during pre- shortening, during shutdown and post-shortening.

3. Impact of Airport Emissions versus Other Sources

Because we monitored under wind conditions during which the sites were both impacted (i.e., they were downwind) and not impacted (i.e., they were upwind and impacted by the nearby freeways) by airport emissions, we were able to compare the impact of the airport to other large sources of air pollution in the area. Comparison of the data from these two conditions suggests that post-shortening PNC and BC concentrations were comparable or lower when sites were impacted by the airport versus when they were not. In other words, the Shortening reduced the air quality impacts to a level where they were comparable or even lower than those of other larger sources in the area (e.g., the freeways situated to the north and east of the monitoring locations).

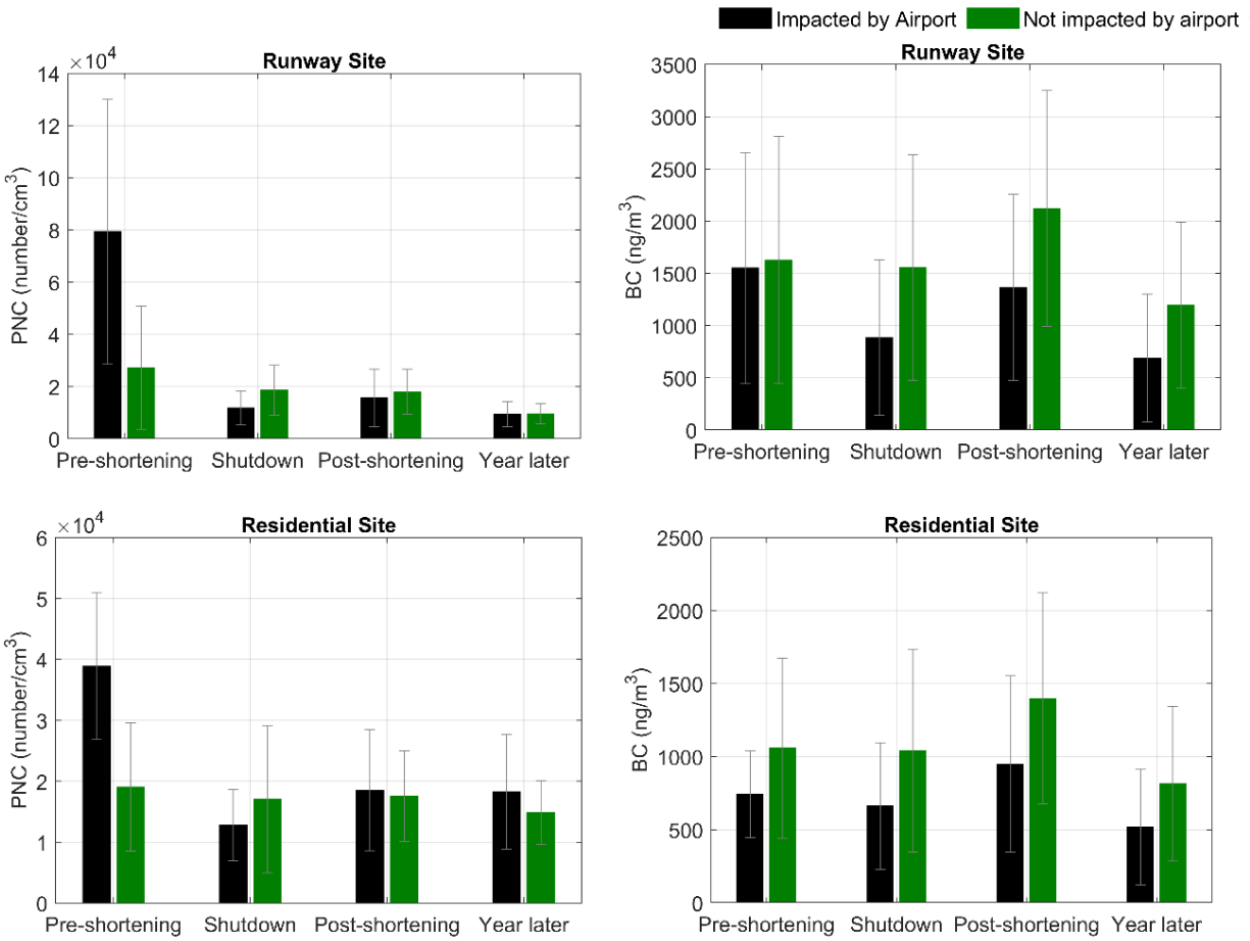

Figure F: Comparison of concentrations when monitoring sited were impacted by airport-related emissions versus they were not impacted by the airport.

This trend was observed immediately after the runway shortening and it has persisted as reflected in the data collected ~year after the shortening. One important caveat is that we could not determine if this is true for lead; likely it is not the case for lead because there are not known to be other sources of lead in the area that is upwind of the sites during northeasterly wind flow conditions.

In addition, it is notable that sources other than airport contribute substantially to the BC concentrations at the monitoring sites. As shown in Figure F, BC concentrations were higher (green bars) when sites were not impacted by the airport compared to when they were impacted by the airport (black bars). We believe this is due to diesel vehicle traffic on nearby roadways because diesel engines are a relatively strong source of BC.

Conclusions

Shortening resulted in a sharp drop in jet traffic. The results from air monitoring study indicate that, in turn, this resulted in sharply reduced concentrations of BC and PNC at the two monitoring sites in December 2017. The concentrations remained low one year later and were similar to those during times of shutdown of flight activity. The reductions were greater for PNC than BC likely due to contributions of local vehicular diesel emissions to BC. Lead concentrations were also reduced, but less so than PNC, likely due to the continued use of Avgas (which contains lead) at the airport.

Overall, with the exception of lead, which does not have known local sources other than the airport, the runway shortening has improved air quality near the airport to the extent that airport impacts are now comparable to or lower than air quality impacts from other sources in the area such as vehicular traffic.

Technical Report

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1. Introduction

The City of Santa Monica hired us, a team of investigators from Tufts University and the University of Southern California, to perform an assessment of the air quality near Santa Monica Airport (SMO), a the general aviation airport, before, during and after the shortening of its main runway. We were tasked to investigate whether the change in the jet aircraft fleet mix following runway shortening (from 5,000 to 3,500 feet; henceforth referred to as 'Shortening') improved the air quality surrounding the airport by measuring air pollutant concentrations prior to the runway shortening, during the full closure, immediately after the resumption of operations on the shortened runway and one year after the runway shortening. The purpose of the shortening was to restrict certain types of turbine aircraft (jets) from take-offs and landings at the airport.

Our objectives were:

1. Conduct measurements of particle number concentrations (PNC), black carbon (BC) concentration and lead (Pb) in the fine size fraction of particulate matter ($PM_{2.5}$) before, during, and after the scheduled closure for Shortening, and a year after Shortening near the runway and in the residential neighborhood;
2. Compare concentrations of these pollutants for each distinct phase of the study based on flight activity restrictions to investigate and quantify if Shortening has improved air quality;

and

3. Compare these measurements to previously-reported measurements by SCAQMD in 2010 at the same locations. [1,2]

This technical report describes the methods and results in greater detail. The key findings and conclusions are presented in the Summary Report.

2. Methods

2.1 Monitoring Schedule and Locations

Monitoring was conducted in two phases as summarized in Table 1. Phase 1 was conducted in the winter of 2017-2018 and lasted 40 days. It covered 9 days before runway modification, 10 days during the runway modification, and 14 days post runway modification. For 3 days (Dec 7-Dec 9, 2017) emissions from wildfires (Sylmar Fires) that were burning in the region could have impacted the study area and air quality data. Therefore, for those days the results were analyzed separately where possible, i.e., in the continuous measurements of PNC and BC. Phase 2 lasted 30 days in the fall-winter of 2018 nearly a year after the Shortening in order to ensure that airport operations had reached long-term, steady-state levels.

Table 1: Monitoring periods

Phase 1	**Conditions**
12/04/2017-12/12/2017	Pre-shutdown for runway shortening, i.e., *pre-shortening*
12/13/2017-12/22/2017	Airport shutdown during runway shortening related construction work, i.e., *shutdown*
12/23/2018-01/15/2018	Post-shutdown and operations on a shortened runways, , i.e., *post-shortening*
Phase 2	**Conditions**
11/23/2018-12/23/2018	Post-shutdown and operations on a shortened runways, i.e., *~year later*

Monitoring was conducted at two locations downwind (northeast) of Runway 21. One location was a site 276 meters downwind from the centerline of the eastern edge of the shortened runway 21 (along azimuth 217.1°), henceforth referred to as *runway* site. The second location was at a private residence 362 meters downwind from the centerline of the eastern edge of the shortened runway 21 (along azimuth 223.3°) henceforth referred to as *residential* site. Sites were 92 meters apart (300 ft.) with the residential site at a lower elevation than the runway site. During typical sea-breeze conditions, this elevation change over 300 feet was not observed to result in emissions missing the sampling location. Note that SCAQMD also conducted measurements at these sites during their 2010 repaving study and the 2006-2007 General Aviation Airport Study.

Both locations were downwind of the airport during westerly winds and upwind of the airport during easterly winds, allowing a distinction to be made between “Downwind” impacts from the airport and “Upwind” impacts from other sources of pollution such as the I-405 Freeway approximately 1200 meters to the east and the I-10 Freeway approximately 800 meters to the north. The residential site was also located in close proximity to Bundy Drive, so during Downwind conditions, it is believed that vehicle emissions from Bundy Drive may have contributed to the Residential measurements. However, as will be presented, these contributions were generally small compared to airport contributions before the Shortening and the differences observed between the various sampling phases was large compared to the Bundy contributions.

Figures 1 and 2 show the airport, the monitoring locations and the surrounding area. Satellite imagery from google maps (in Figure 3) shows the enclosures in which the monitoring equipment was housed.

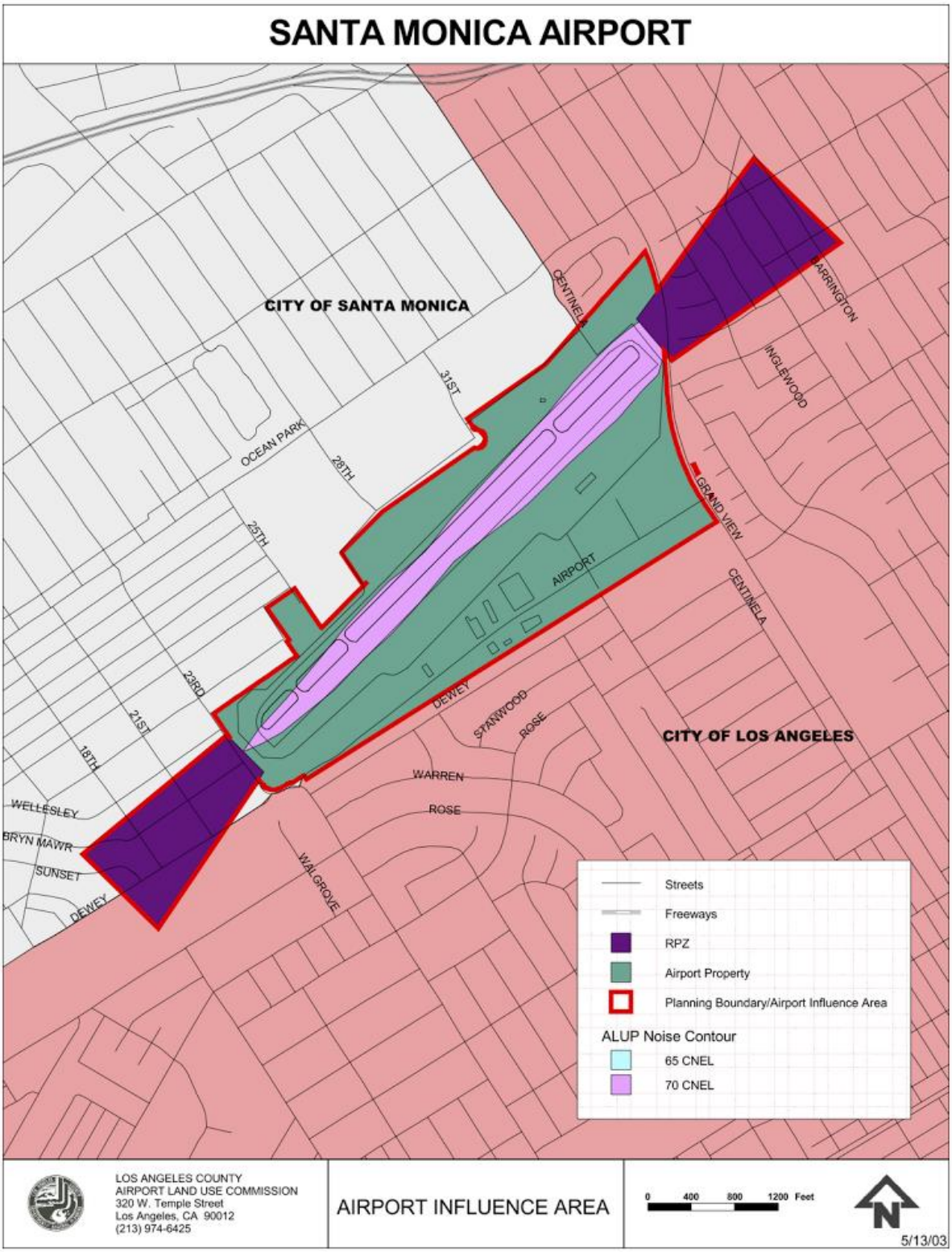

Figure 1: Map showing the airport property and noise contours.

Figure 2: Satellite image derived from google maps showing the runway 3-21 at the airport. Red arrows indicated the shortened length.

Figure 3: Satellite image of the area showing the enclosures for instruments at the two monitoring sites marked by red ovals.

2.2 Pollutants Monitored

Portable water-proof enclosures were set-up at ground level at both sites for housing the air quality equipment to measure the concentrations of BC, PNC and $PM_{2.5}$. BC and PNC were monitored continuously at fine time resolution (minutes) and time-integrated $PM_{2.5}$ samples were collected to attain enough mass for to analyze for elemental composition to assess the concentration of lead (Pb). Table 2 provides the instrument types and time resolutions used.

Table 2: Instruments used to conduct air quality monitoring

Pollutant	Runway Site	Residential Site
BC	Magee Scientific Aethalometer AE33, 1-minute resolution	Magee Scientific Aethalometer AE-16, 5 minute resolution
PNC	TSI Incorporated Environmental Particle Counter (CPC 3783), 1 second resolution	TSI Incorporated Environmental Particle Counter (CPC 3783), 1 second resolution
$PM_{2.5}$	Harvard Personal Exposure Monitor (H-PEM), 7 to 15 day intervals	Harvard Personal Exposure Monitor (H-PEM), 7 to 15 day intervals

Sites were serviced every 7-10 days and regular site service included air flow measurements, filter changes, and condensing fluid refills and wick change if required, clock-adjustments if necessary, and data downloads.

Particle number concentrations (PNC) are a close and commonly-measured proxy for ultrafine particles (UFP), particles smaller than 0.1 microns. For comparison, a human hair diameter is about 70 microns, so these particles are invisible and do not scatter light by themselves. Concentrations are measured after condensing a fluid onto them and growing the particles to light scattering size in a “Condensation Particle Counter” or CPC. Ultrafine particles are good indicators of fresh combustion emissions and particularly good markers of aircraft under high fuel consumption conditions such as take offs, or jets due their high fuel consumption to produce high power.

PNC was measured at both locations using identical CPCs (TSI EPC Model 3783). This model uses water as a condensing medium and can measure PNCs in the 0 to one million particles per cm^3. A cubic centimeter of air is similar in volume to a cube of sugar.

The CPC was operated at a time-resolution of 1 second (one measurement per second) and its accuracy is ±10% at one million particles/cm^3. The minimum detectable particle size is 0.07 um, which covers all but the very smallest ultrafine particles that tend to increase in size over short distances or times when colliding with other particles. We operated it at high-flow mode (3±0.3 liters/minute) at which it has a response time of <3 seconds to a 95% concentration step change. Thus, it was able to capture rapid spikes in PNC concentrations, described later.

The following except from the manufacturer's website describes the internal workings of the CPC: [3]:

> *"The EPC™ monitor utilizes a patented laminar-flow, water-based condensation growth technique. Particles which are too small (nanometer scale) to scatter enough light to be detected by conventional optics are grown to a larger size by condensing water on them. In this instrument, an air sample is continuously drawn through the inlet via an external pump and a portion of the flow is sent to the exhaust as bypass flow. The aerosol sample is pulled through a cool region saturated with water vapor and its temperature is equilibrated. The sample then passes to a growth section where wetted walls are heated to produce an elevated vapor pressure resulting in a thermodynamic 'supersaturation' condition. The small cool particles in the flow stream act as nuclei for condensation, and grow into micron sized droplets. The droplets are passed through a laser beam and create a large light pulse. Every particle pulse event is detected and counted. In this technique particle concentration is measured by counting every single particle in the air stream."*

Both CPCs were calibrated at TSI, the manufacturer, immediately before deployment in Phase 1. To ensure the results were comparable across the two instruments, the instruments were run side-by-side before and after each Phase 2 of the campaign to check agreement. Agreement was always within the manufacturer specified agreement of ±20%. See Figures A1-A2 in the Appendix A for the 24-hours side-by-side test results. The side-by-side comparison at the start of the campaign was conducted at the runway site and the side-by-side at the end of the campaign was conducted in the laboratory.

As part of our analyses, readings from the lowest reading CPC were later adjusted to match the higher reading CPC by statistical matching (least squares linear regression). The first two weeks of the data used an adjustment factor of ~15% based on the side-by-side at the beginning of the Phase 2 and last two weeks of data was adjusted by the factor of ~18% based on the side-by-side comparison at the end of the Phase 2.

Black Carbon (BC) was also monitored as a product of combustion but reflects the incomplete combustion portion. It is also more sensitive to sources such as diesel engines, which have less complete combustion due to less-than-complete fuel air mixing in two-stroke engines. BC was measured with light absorption techniques using Magee Scientific Aethalometers.[4] Real-time (minute by minute) measurement BC aerosol concentration is made by measuring the rate of increase in darkness particle deposits collected on a spot on a quartz filter. This change in darkness, or "transmittance," the attenuation of light through the filter is directly proportional to BC concentration. The latest model, AE33, uses a dual-spot technology to directly compensate for filter tape light absorption.[5] The total optical absorption is measured simultaneously at seven wavelengths (370, 470, 520, 590, 660, 880, 950 nm) which varies by type of carbon compound. The data obtained from the sixth channel (measurement at 880 nm) is the defining standard used for reporting BC, considered to be composed of mostly elemental carbon or soot. This model AE33 was deployed at the runway site. The other channels show increased sensitivity of BC with additional organic material, which is present in wildfire smoke, for example, which was known to be a potential occurrence in Los Angeles during the winter season.

A single-wavelength (880nm) Model AE16 was used at the residential site. [4] Before deployment ambient side-by-side tests between AE33 and AE16 were conducted and for the 880 nm wavelength channel the agreement was within 10% ($r^2 = 0.9$). Similar to the CPCs, AE16 values were adjusted to be in agreement with AE33 based on the least-squares, linear regression fit of data from the side-by-side tests (see Figure A3 in Appendix A).

Fine Particulate Matter ($PM_{2.5}$) was collected in time-integrated samples (with two duplicates per sub-phase of the study in Phase 1 and two duplicate samples in Phase 2) using H-PEM (Harvard School of Public Health Personal Exposure Monitor) model HP2518 which is a single stage impactor operating on the principle that when *"an aerosol distribution is accelerated in a nozzle and the jet is pointed at a solid surface a proportion of the distribution will be captured by that surface*."[6,7] $PM_{2.5}$ was collected on PTFE (Teflon) Membrane 37 millimeter filters (2 micron pore size). Filters were weighed before and after the sampling event under matching laboratory temperature and humidity conditions. Later they were analyzed for elemental composition to obtain **lead (Pb) concentration in $PM_{2.5}$** using Energy Dispersive X-ray Fluorescence Spectrometry

(EDXRF) similar to the methods used in SCAQMD General Aviation Airport Study.[1] This method energizes individual particle component atoms with X-rays, that later give off element-specific photons when stabilizing that can be collected to identify the amount of a particular element such as lead. For both total $PM_{2.5}$ mass and lead, blank filters (lab blanks) and filters handled like samples (travel blanks) were analyzed and the average of these small values (to account for impurities added to the $PM_{2.5}$ filters inadvertently during lab and field activities) was subtracted from all results in order to only report what was collected from the air.

2.3 Data Analysis

The basic steps of data processing involved first importing data into Microsoft Excel spreadsheets and performing quality assurance checks. Graphs of the concentrations versus time (time-series graphs) then allowed visual inspection for data gaps or unreasonable values (e.g., negative values). All times and dates reported are based on local time.

Next, a database was generated where files were collated and data for all pollutants were aligned based on time stamps. Data were then imported into MATLAB2018, a software analysis package. All further analysis (aggregation to hourly level), statistical analysis and graphics were generated in MATLAB2018. Non-parametric statistics (which do not assume any underlying data distribution characteristics, hence are more conservative) were used because the pollutant data was non-normally distributed (e.g., large numbers of high values, common for air pollution data); differences were tested using the Wilcoxon rank sum test using a statistical significance threshold of 0.05.

2.4 Other Data Acquisition and Analysis

2.4.1 Meteorological data

Meteorological data collected at the airport (KSMO) and nearly Los Angeles International Airport (KLAX) via Automated Surface Observing Stations (ASOS) were obtained from the National Centers for Environmental Information.[8] The 1-minute ASOS wind data consists of running 2-minute average speeds and directions, reported every minute. AERMINUTE (Version 15272) [9] was used to processes 1-minute ASOS wind data to generate hourly average speeds and directions.

Wind roses (360 degree wind direction distributions) were generated using WRPLOT View (Lakes Environmental Software, Ontario, Canada).[10]

2.4.2 Flight data

Flight activity data were obtained or recorded in the following ways:

1. Flight activity records for the months overlapping with air quality monitoring (i.e., Dec 2017, Jan 2018, Nov 2018 and Dec 2018) were provided by SMO. This included time-stamped information on jet and helicopter arrivals and departures, namely, aircraft type, registration, arrival/departure, date and time of arrival/departure, and runway used. It did not include data on taxi and hold times.
2. Flight activity statistics were also downloaded from Federal Aviation Authority's Operations & Performance Database (https://aspm.faa.gov/) to look at longer term trends at SMO. These included daily or monthly aggregates of flight activity.

2.4.3 Comparison to earlier studies

Where possible, comparisons were made to an earlier study conducted by SCAQMD in 2010 which used a similar water-based CPC (TSI Model 3785 [discontinued in 2010]) that detects particles in the 0.05 to > 3 µm size at concentrations up to 10^7 particles/cm^3. These data were reported at 1-minute resolution. BC measurements were made using Magee Scientific portable Aethoalometer AE-42 at 5-min resolution. Instruments used in the previous SCAQMD study and the current study have the same manufacturer and the same operating principles but were not an exact match because we used more current models. As a result, data from these different models are highly comparable but may have small differences due to the lack of exact instrument match. [11]

To briefly summarize the SCAQMD study, the SCAQMD conducted a detailed side-by-side comparison of CPC Models 3785 and 3783[12] (separate from the SMO repaving study of 2010). They found that correlations improved with increasing averaging time (r^2 = from 0.15 at 1-min averaging time to r^2 = 0.96 at 15-min averaging time) and Model 3783 (also used in current study) recorded the highest number concentrations, especially under conditions where it sampled fresh

emissions and that this model which (designed for long-term monitoring) provided relatively consistent data over one-month. We report here data ranging from 1-min to 1-hour averaging time but statistics in the SAQMD report were based on 1-min averaging time at which the correlation between two models were only modest. The statistics indicating central tendencies (mean and median) are comparable but extreme values such as maximum or minimum concentrations are averaging time dependent and not directly comparable.

3. Results and Discussion

3.1 Meteorology

Typically, the daytime winds at SMO are southwesterly which puts the two monitoring sites consistently downwind of the airport. However, a greater frequency than expected of non-typical wind directions occurred during our study. The annual wind rose (e.g., the distribution of wind directions in a 360 degree plot) (Dec 2017-Nov 2018) is shown in Figure 4 and the wind roses for the two phases of the monitoring and sub-phases of Phase 1 are shown in Figure 5. Also, see Appendix A for the wind roses for Santa Monica airport during the monitoring phases. Appendix A indicates that there was a higher incidence of the NE flow pattern in the region (Figures A4-A5). Due to a differing fractions of non-typical winds over our sampling intervals, we stratified the data into two categories based on the wind directions that orient he monitoring sites downwind or upwind of the runway, in order to maximize comparability across study phases. The runways at SMO are oriented along the 44° and 224° from true north. We classified 44°±90° winds as “upwind” winds. The other 180° wide sector, i.e., 134°-314° we classified as “downwind” winds. The frequency of these wind categories is summarized in Table 2.

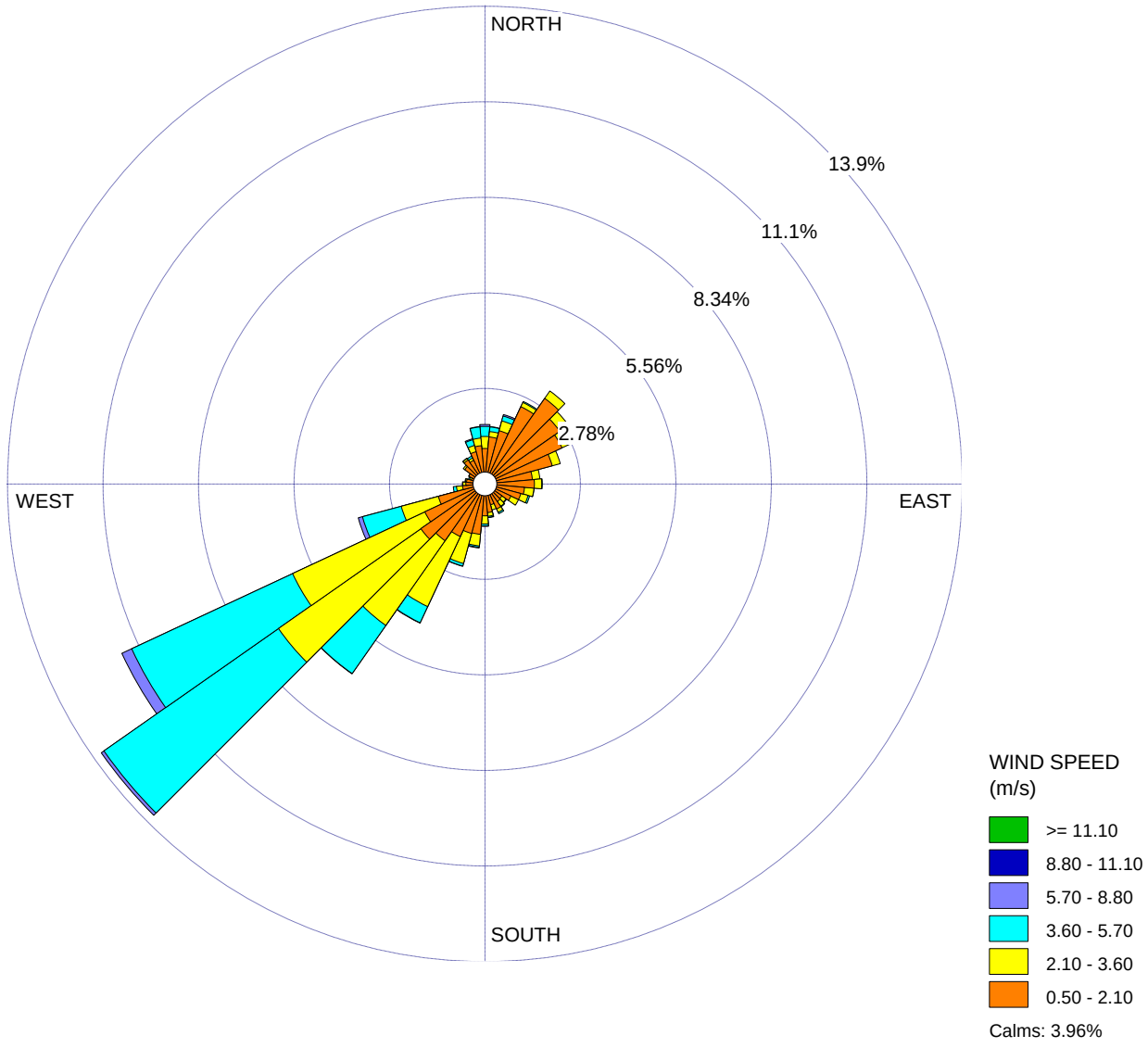

Figure 4: Annual wind rose (December 2017-November 2018) based on measurements conducted by NWS at Santa Monica Airport. Each spoke indicates the direction from which the wind is blowing from.

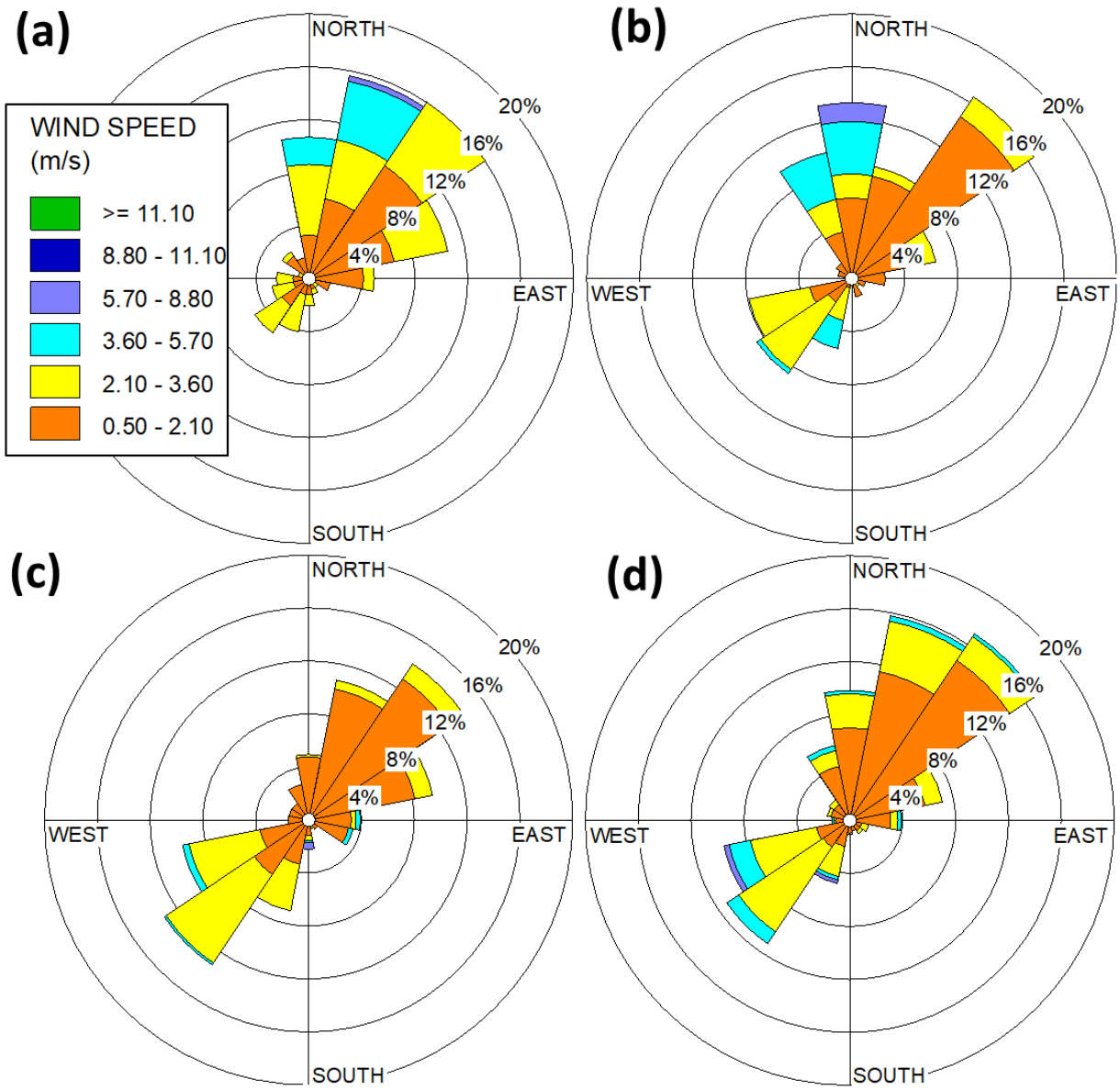

Figure 5: Wind roses for the sub-phases of Phase 1 [(a): pre-runway-shortening, (b) airport shutdown during runway shortening, and (c) post-runway-shortening] and Phase 2 [(d: entire period] of the monitoring. Each spoke indicates the direction from which the wind is blowing from.

Table 3: Summary of meteorological parameters during monitoring

Phase 1	**Temp (°F)**	**RH (%)**	**WS (m/s)**	**Upwind (h)**	**Downwind (h)**
2017/12/04-2017/12/12	64.2 ± 8.2	17.5 ± 12.0	2.3 ± 1.0	142	39
2017/12/13-2017/12/22	57.7 ± 7.2	32.2 ± 12.4	2.3 ± 1.2	167	73
2018/12/23-2018/01/15	58.0 ± 6.7	48.2 ± 8.5	1.7 ± 0.9	349	223
Phase 2					
2018/11/23-2018/12/23	61.8 ± 5.5	45.7 ± 8.9	2.0 ± 1.0	480	240

3.2 Flight Activity

3.2.1 Flight Activity during Air Quality Monitoring

Jet Activity. The biggest change in activity level due to runway shortening was a large drop in jet traffic. See Figure 6. Immediately after runway shortening, i.e., during the first two weeks of the airport reopening after the construction, daily average jet flight operations (both arrivals and departures) was only a quarter of the operations before the shortening construction shutdown as shown in Figure 6. That was also the rationale for conducting Phase 2 of the study when the operations were back to a new, steady level, i.e., approximately one year later. During this latter phase, operations were slightly higher than immediately after reopening but still very much lower than the daily averages for operations before runway shortening; daily average jet activity (for both arrivals and departures) were a third of the average before shutdown for shortening.

Note, the 'pre-shortening' daily averages shown here are for the days when air-quality monitoring was performed, and therefore the values are not necessarily representative of the general flight activity levels for other times preceding the runway shortening; those trends are discussed in the next section.

Turboprop Activity. The turboprop activity was reduced immediately after runway shortening, i.e., during the first two weeks of the airport reopening after the construction; daily average flight operations (both arrivals and departures) were approximately half of the operations before the shortening construction shutdown as shown in Figure 7. Since turboprops can operate on the shortened runway, the decrease was likely due to timing of the reopening (late Dec) rather than the shortening itself. During Phase 2, operations were comparable to the averages observed before shortening.

Propeller Activity. There wasn't a considerable change in average activity levels for propeller planes (given the range of variation in daily levels) between pre-shortening, post-shortening and Phase II periods. Also, propeller plane activity comprised the largest fraction of total flight operations at the airport. See Figure 8.

A majority of flight activity occurred on runway 21, i.e., flights arrived from the east and landed on runway 21 and flights departed towards the ocean/west. See Table 4.

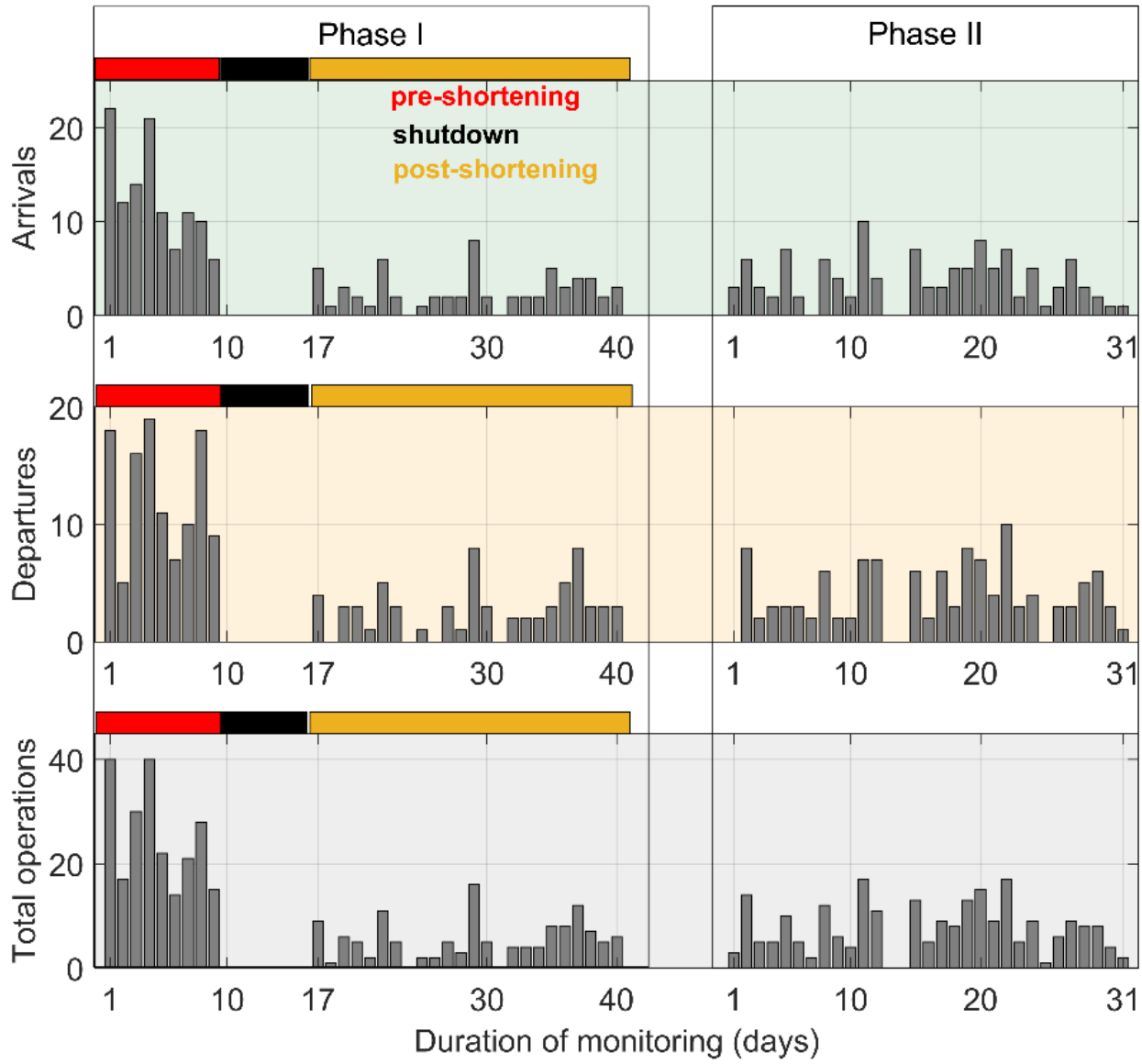

Figure 6: Daily average jet activity during the air quality monitoring.

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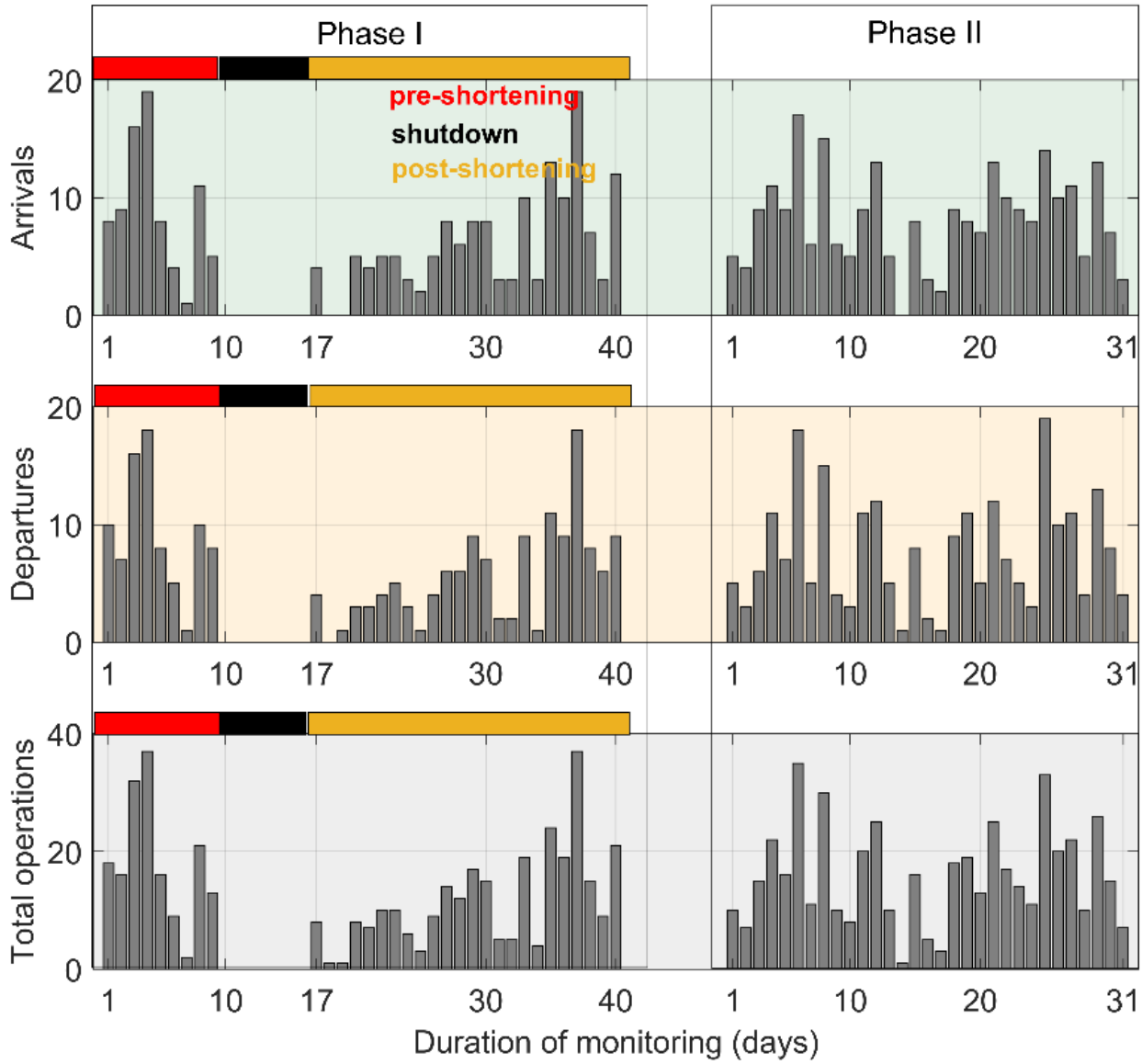

Figure 7: Daily average turboprop activity during the air quality monitoring. Touch-n-go operations are included in total operations.

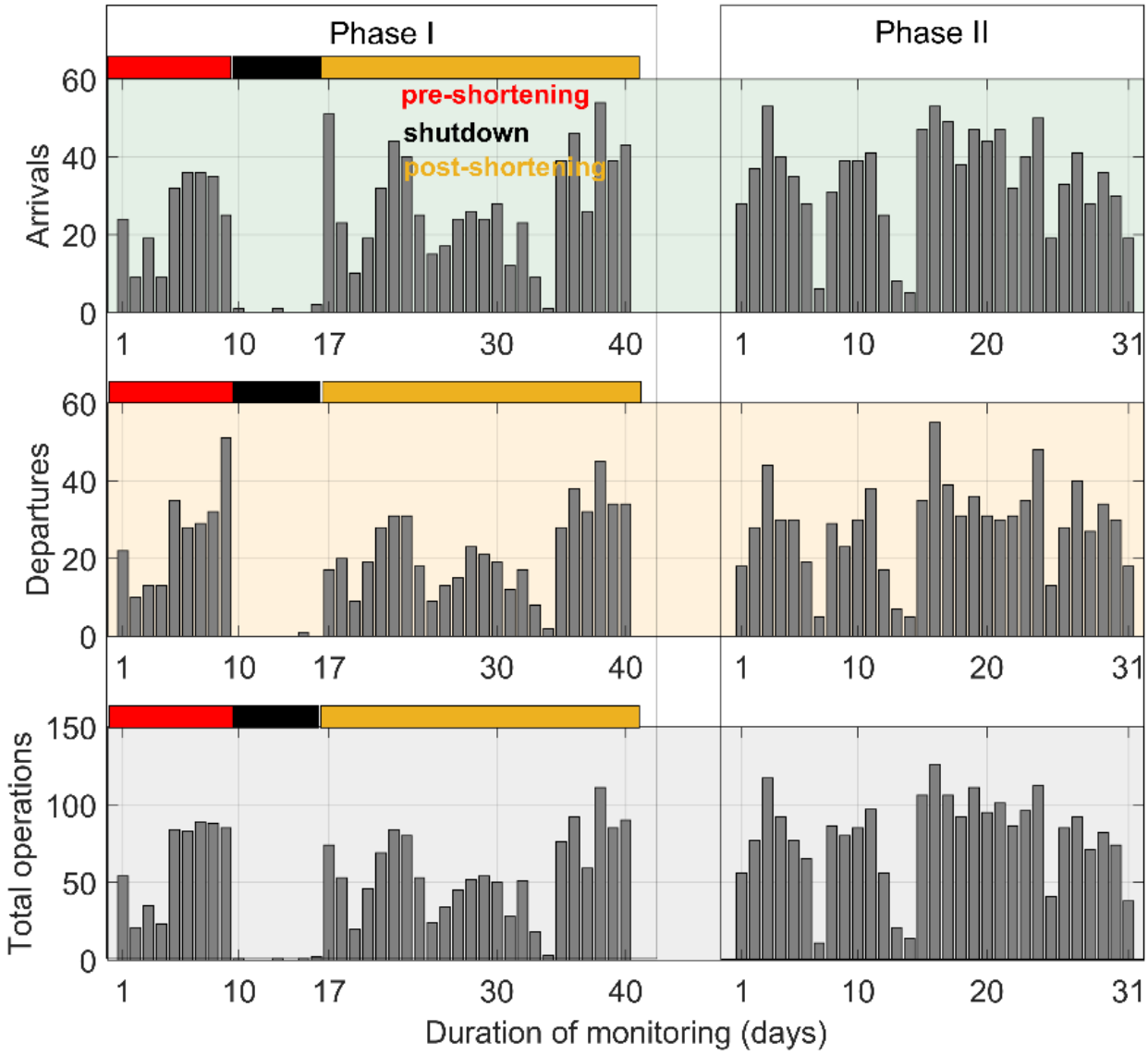

Figure 8: Daily average propeller activity during the air quality monitoring. Touch-n-go operations are included in total operations.

Table 4: Fraction of flight activity of runway 21 based on the flights for which runway assignment was available.

	Jets		Turboprop		Propeller	
Phase 1	Arrivals	Departures	Arrivals	Departures	Arrivals	Departures
2017/12/04-2017/12/12	75%	94%	70%	82%	86%	89%
2017/12/13-2017/12/22	shutdown					
2018/12/23-2018/01/15	92%	80%	98%	100%	99%	97%
Phase 2						
2018/11/23-2018/12/23	93%	97%	92%	94%	92%	93%

3.2.2 Longer-term Flight Activity Trends

We also analyzed the longer-term flight activity trends at the airport to assess if approximately one year after the Shortening, the flight activity had return to a steady, normal level.

The analysis of flight records from FAA suggest that flight activity was lower in 2017 but was comparable to pre-2017 levels (See Figure 9). However, the FAA and SMO have a different methodology for automating activity assessments and therefore the activity numbers aren't directly comparable. For example, the FAA database counts every loop of local operations that are mostly by small prop aircraft that stay in the local pattern while SMO operations logs it as a singular operation. However, since the counting methodology remains consistent year-to-year for each organization, the conclusions regarding trends can be drawn despite the different methodologies. Of particular interest to us was the flight activity during the months of air quality monitoring. The monthly operations for 2009-2019 are shown in Figure 10. In Nov-Dec, 2017, i.e., during the period of runway shortening and Phase 1 of the study flight activity was depressed to about half of the average for the same time period for 2009-2016. However, it did recover to comparable levels to the longer-term average in Nov-Dec 2018 when Phase 2 of the study was conducted.

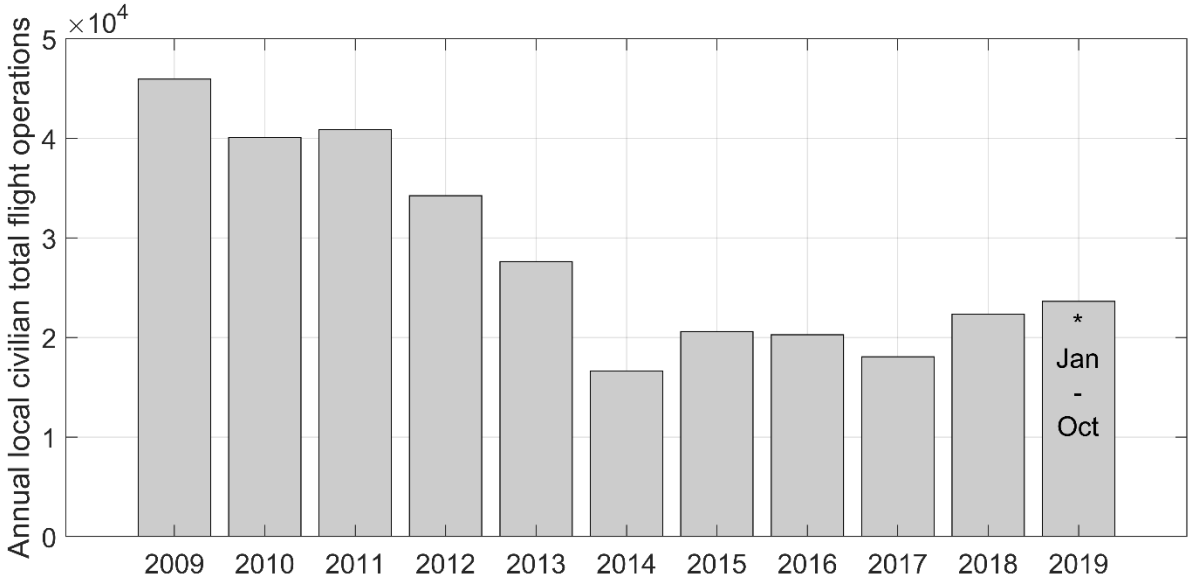

Figure 9: Annual local, civilain total operations at SMO during 2009-2019 as reported in the FAA AQMS database.

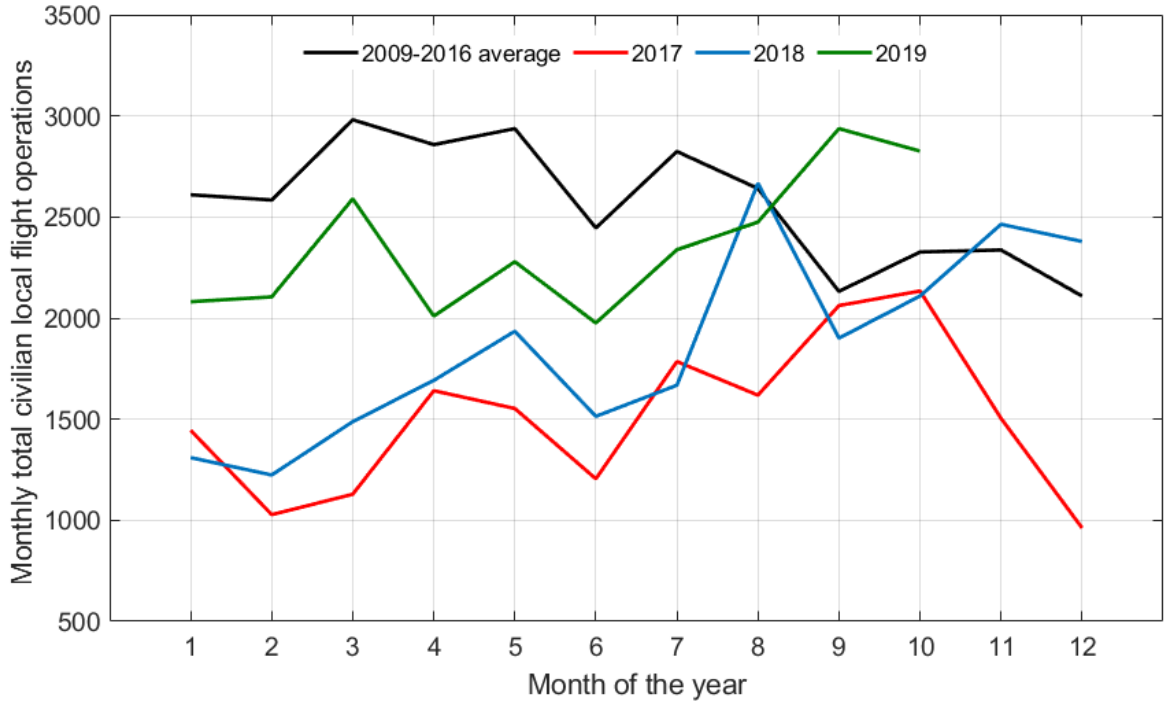

Figure 10: Monthly local, civilain total operations at SMO during 2009-2019 as reported in the FAA AQMS database.

3.3 Air Quality

3.3.1 Black Carbon (BC)

3.3.1.1 Fine temporal resolution time-series

There were strong similarities in temporal patterns of BC concentrations between the runway and residential site. For example, the time-series of measurements at fine time-resolutions (1-min and 5-min at the runway and residential sites, respectively) in Figures 11 and 12 show that:

(1) Rapid short-term changes (e.g., hours) and shorter-term spikes in concentrations (minutes) in BC concentration occur simultaneously at both sites. The SCAQMD report discusses the spikes in great detail and established that they originate from aircraft-activity, particularly takeoffs. When a fresh aircraft plume hits the monitoring site, a spike is recorded. During our measurements, it was clear that the spikes frequently observed in the pre-shortening phase were not only less frequent, rare or absent in the post-shortening phase, but they were also of lower magnitude.

(2) The runway site (black line) BC concentrations were consistently higher than the residential site (green line) concentrations, reflecting differences in dilution. Emissions are further diluted by the time they are measured at the residential site which is further downwind of the runway thus creating a spatial gradient.

(3) BC concentrations were typically lower during nighttime hours when there was no flight activity and higher during the daytime hours when flight activity was occurring.

Data from three days, one from each distinct phase of monitoring in Phase 1, i.e., pre-shortening, shutdown, and post-shortening, are highlighted and enlarged in Figure 11 (lower panels) to demonstrate that the difference in concentrations at the two sites was variable over the short term but typically much lower during nighttime hours and higher during the daytime hours.

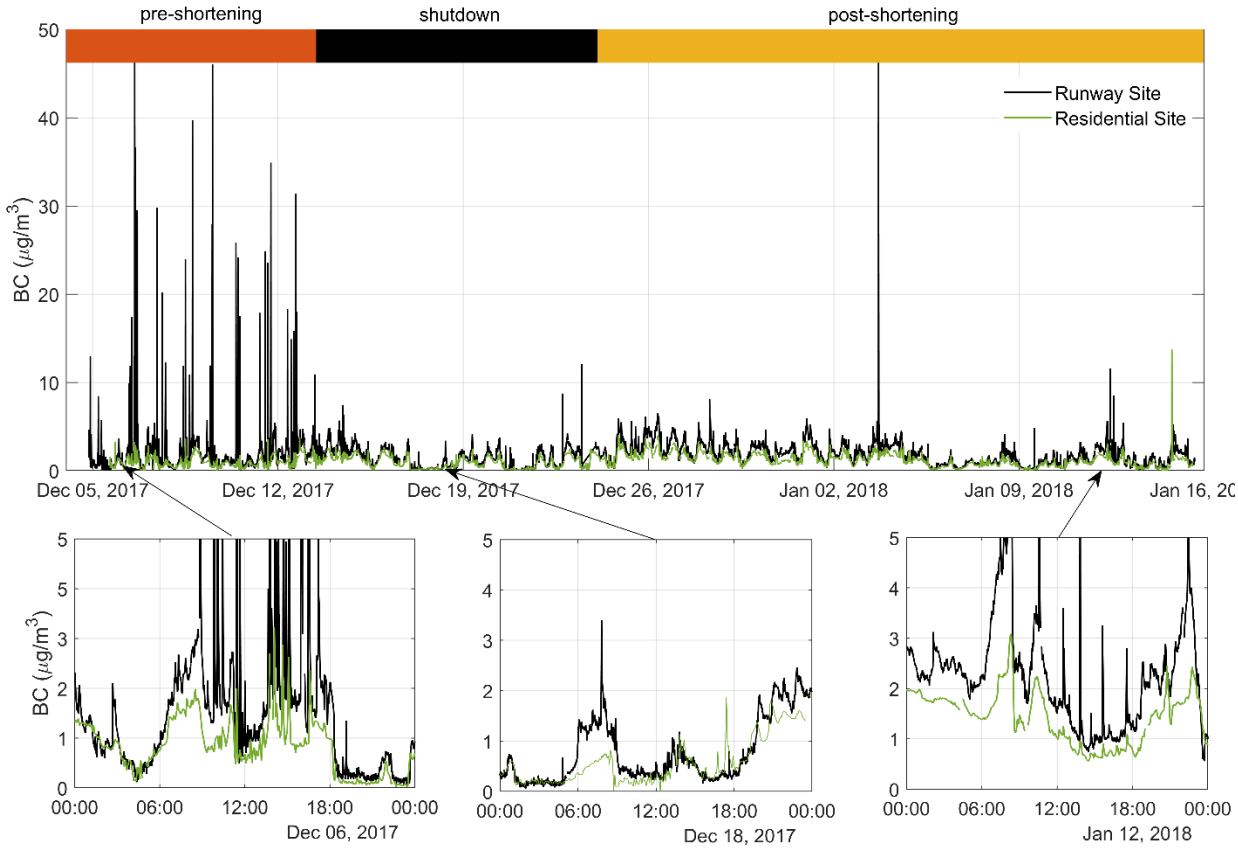

Figure 11: Time-series for BC concentration measured at the runway and residential site during Phase I (i.e., pre- shortening, during shutdown and post-shortening). Note the ten-fold difference in y-axis scale between the phase-wide times series versus the individual days.

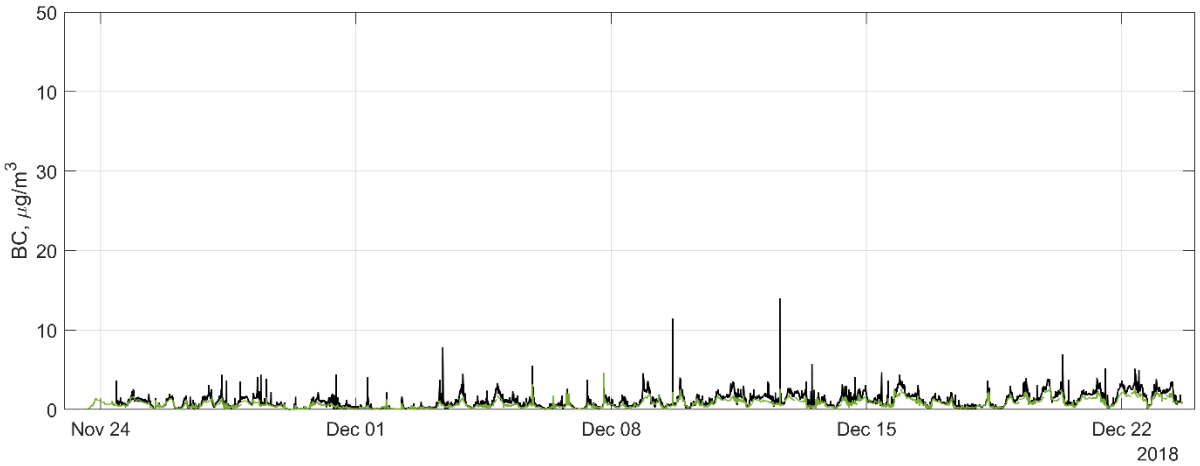

Figure 12: Time-series for BC concentration measured at the runway and residential site during Phase II of the study (i.e., ~year after shortening).

3.3.1.2 Cumulative frequency distributions

Cumulative frequency distributions are a way to visualize the frequency of occurrence of concentration above a certain threshold. They allow for compact comparison of multiple data distributions (e.g., data from each sampling phase) and the differences between them. A leftward and upward shift in one distribution compared to another indicates lower concentrations.

The frequency distributions of the BC concentrations are shown in Figure 14. One distinct finding shown here is that the BC concentrations measured one year after the Shortening are lower than even the shutdown concentrations except for the lowest third of measurements, where concentrations are very low. It is important to note that the compressed logarithmic concentration scale means that small differences between the curves from left to right represent large differences in concentrations.

At the other extreme, the top 10% of the observations have been enlarged and highlighted in the Figure 13 insets. The Insets show that unusually high magnitude concentration spikes that were observed about 2% of the time at the runway site pre-shortening downwind of the runway were not present at the residential location nor were they observed at later times.

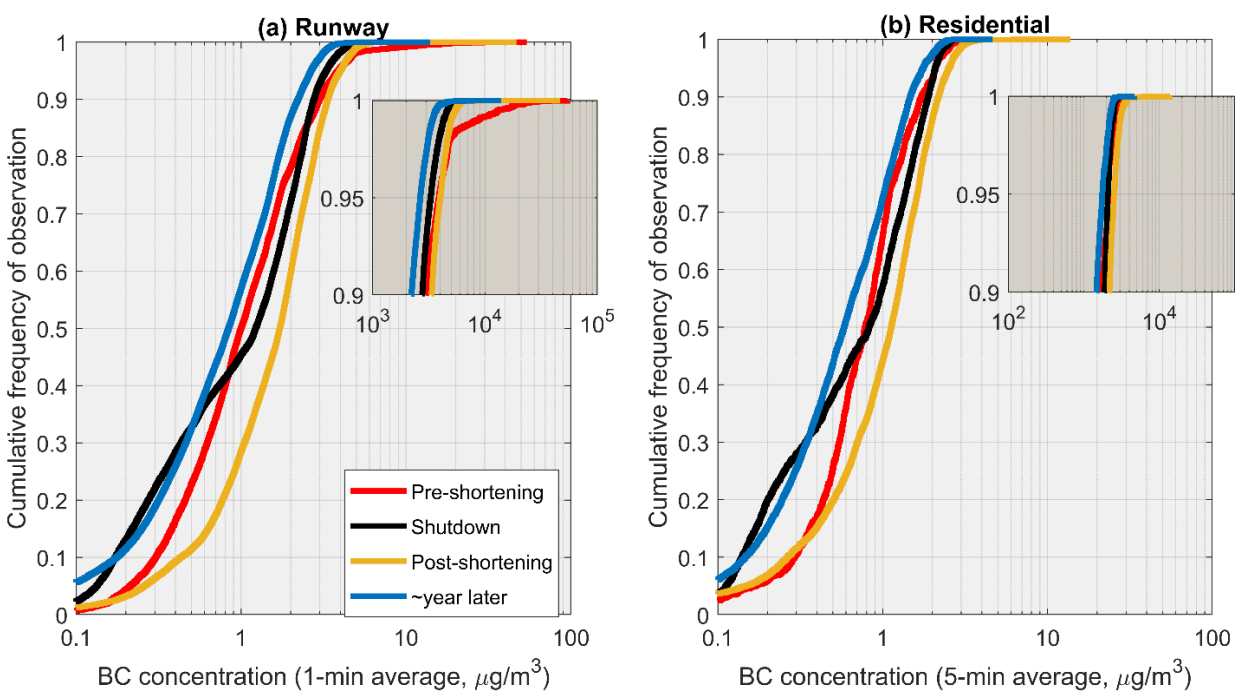

Figure 13: Cumulative frequency of observation for BC concentrations measured at (a) the runway site and (b) the residential during the different phases of the study. The data shown in Figures 14 are for all wind conditions and see Figure 15 for data stratified by wind direction.

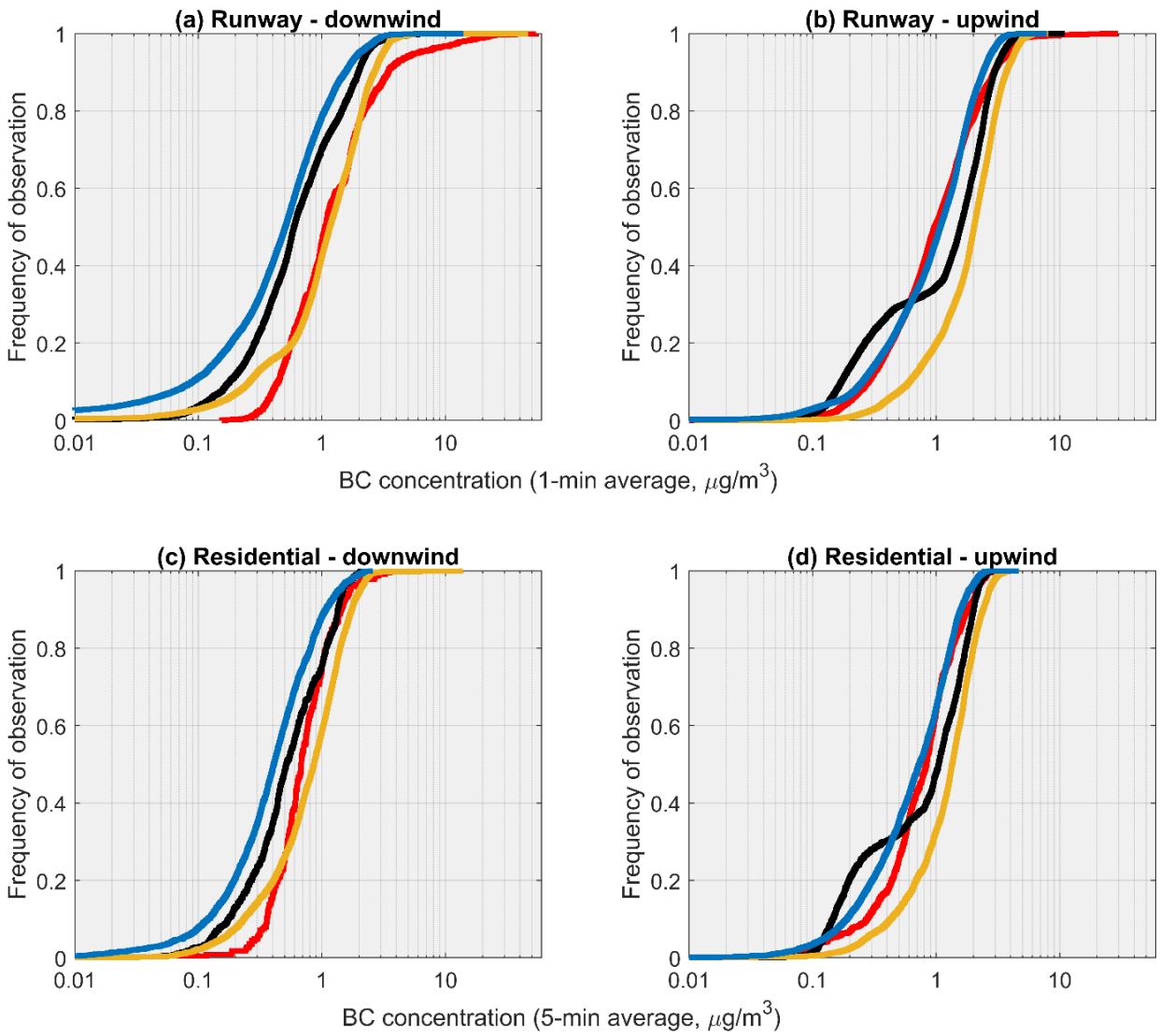

Figure 14: Cumulative frequency of observation for BC concentrations (measured at 1-min and 5-min resolution) during the different phases/sub-phases of the air quality monitoring study separated by wind conditions that orient the sites downwind or upwind of the airport.

3.3.1.3 Comparison of upwind vs downwind conditions

When the results are stratified by wind direction, the BC concentration differences before and after runway shortening are present at all concentrations. For downwind conditions, the BC concentrations were always lower than those measured previously including shutdown. In contrast, during upwind conditions, the BC concentration distributions before and one year after the shutdown are very similar (red and blue lines), indicating a consistent contribution from non-airport sources of air pollution to the northeast.

An additional visualization of differences is provided by the boxplots of Figure 15. In box plots the middle 50% of the data is contained in the range of the boxes and most of the rest of the data falls within the range of the solid line extending from the box. When sites are upwind of the airport they are downwind of two freeways I-10 and I-405 and the runway site is also downwind of Bundy Drive. BC concentrations were generally higher when sites were upwind of the airport compared to when they were downwind of the airport**.** This result underscores the contribution of traffic emissions to the BC concentrations in the area.

Statistics for fine-time resolution data from different phases and sub-phases of the study are summarized in Table 5.

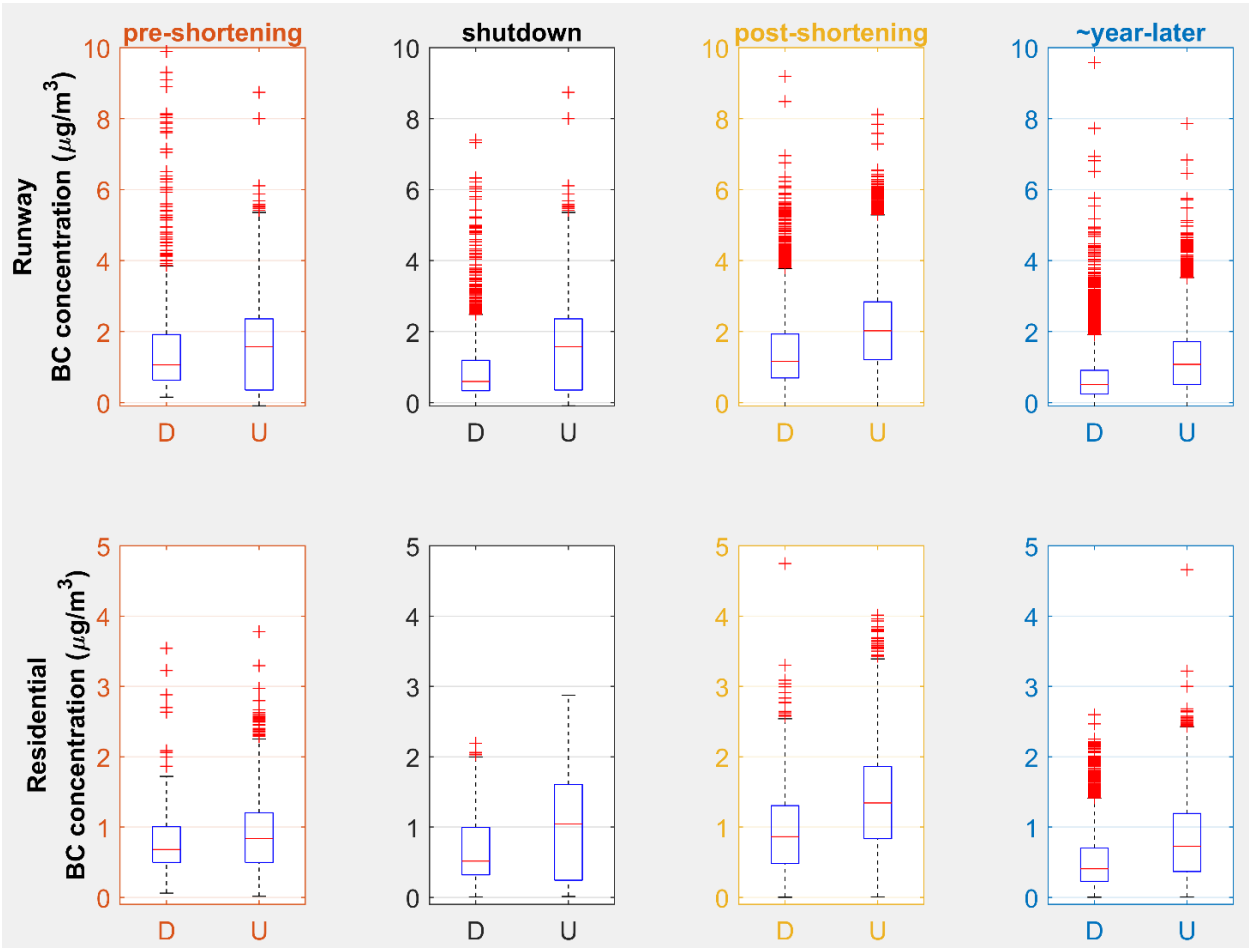

Figure 15: Tukey's boxplots comparing BC concentrations during downwind (D) vs. upwind (U) conditions at the two sites during different phases of the study. Note the two-fold difference in y-axis scale between the runway and the residential site.

Table 5: Phase-wide summary statistics based on one/five-minute average black carbon concentrations at the two monitoring sites during the conditions when sites were downwind and upwind of the airport. Lowest values are shaded blue and highest values are shaded red.

	BC (µg/m³)							
	Runway or East-tarmac site				Residential or Ernst residence site			
	Phase 1		Phase 2		Phase 1		Phase 2	
	Upwind	Downwind	Upwind	Downwind	Upwind	Downwind	Upwind	Downwind
Average	1.8	1.3	1.2	0.7	1.2	0.9	0.8	0.5
Median	1.7	1.0	1.1	0.5	1.2	0.8	0.7	0.4
Stdev	1.4	1.3	0.8	0.7	0.7	0.6	0.6	0.4
Valid N	40000	19000	28000	14000	7000	4000	6000	3000

3.3.1.4 Longer-term averages

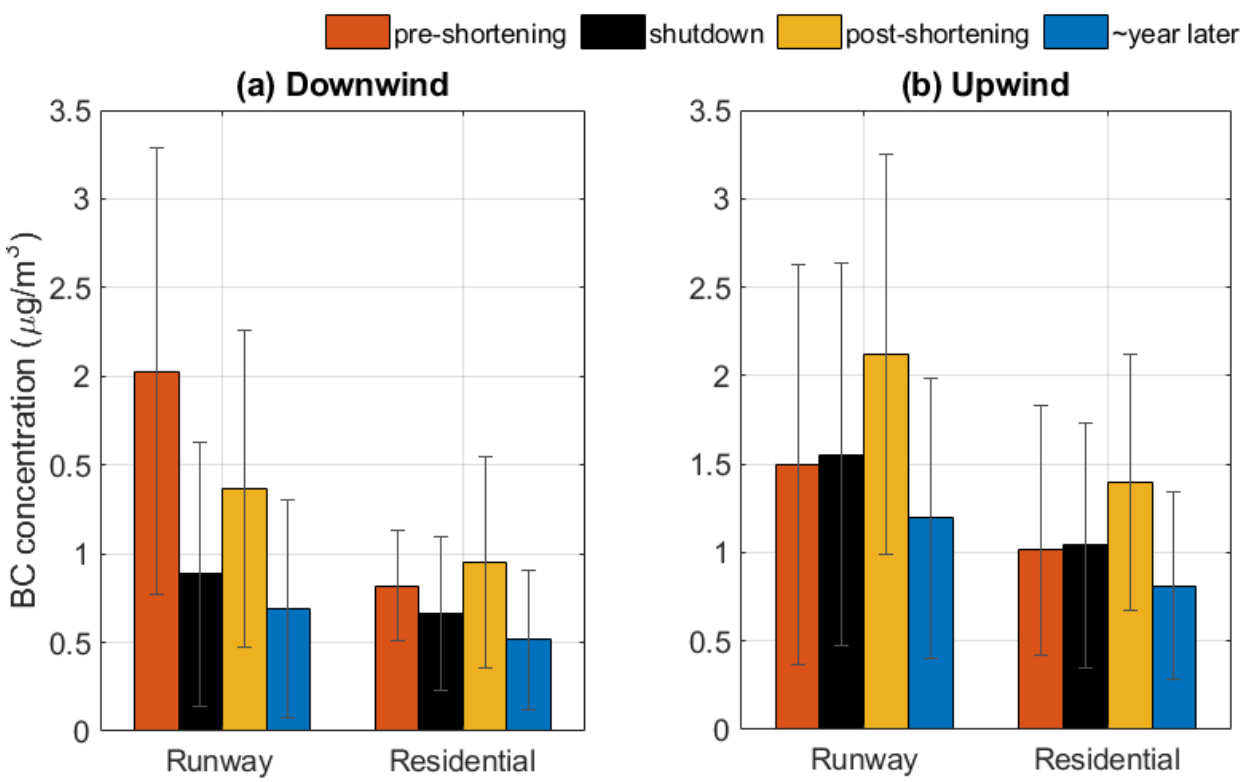

Figure 16: BC concentrations during different phases of the study.

The averages for different phases and sub-phases of the study are summarized in Table 6 and plotted in Figure 16. During the shutdown, BC concentrations were 60% and 20% lower than pre-shortening at the runway and residential site, respectively, when the sites were downwind of the airport. Post-shortening phase-average BC concentrations were 30% lower than pre-shortening

at the runway site but were 20% higher at the residential site. The higher concentrations at the runway site are likely due BC contributions from local traffic on Bundy Dr. that is highly trafficked. During westerly winds, this roads is only upwind of, and therefore emission on it impact, the residential site and not the runway site. Phase 2, i.e., ~year-later, averages were 70% lower than pre-shortening at the runway site and 40% lower at the residential site**.** It is interesting to note, that phase-average BC concentrations were consistently higher at the residential site when it was upwind of the airport and downwind of I-10 and I-405. The same was true for the runway site except during the pre-shortening sub-phase.

Lastly, BC concentrations at the runway site were 50-70% higher when the site was upwind of the airport compared to when it was downwind of the airport in all but the pre-shortening phase of the study. Pre-shortening BC were 25% higher when the site was downwind compared to when it was upwind of the airport. BC concentrations at the residential site were higher (25-70% depending on the phase) during conditions that oriented the site upwind of the airport and downwind of the freeways compared to the when the site was downwind of the airport.

Table 6: Phase/sub-phase summary statistics based on hourly averaged black cabon concentrations (µg/m^3) at the two monitoring sites during the conditions when sites were downwind and upwind of the airport.

	Runway Site			Residential Site		
	Upwind	**Downwind**	**Ratio upwind to downwind**	**Upwind**	**Downwind**	**Ratio upwind to downwind**
Phase I						
Pre-shortening	1.5 ± 1.1	2.0 ± 1.3	0.74	1.0 ± 0.6	0.8± 0.3	1.25
Sylmar fire	*1.9 ± 1.3*	*1.0 ± 0.6*	*1.79*	*1.1 ± 0.6*	*0.7 ± 0.3*	*1.71*
Shutdown	1.6 ± 1.1	0.9 ± 0.7	1.76	1.0 ± 0.7	0.7 ± 0.4	1.57
Post-shortening	2.1 ± 1.1	1.4 ± 0.9	1.55	1.4 ± 0.7	1.0 ± 0.6	1.47
Phase 2						
~Year later	1.2 ± 0.8	0.7 ± 0.6	1.74	0.8 ± 0.5	0.5 ± 0.4	1.57

3.3.1.5 Statistical Comparison

Phases-to-phase differences. The distributions shown in Figure 14 were tested for statistically-significant differences in central tendency of the fine-resolution averages. Compared to the median when the runway site was downwind of the airport during the pre-shortening sub-phase,

significantly lower median concentrations were observed during shutdown (p-value <0.001) and ~year later (p-value <0.001), but not post-shortening (p-value = 0.18). Further, the ~year later median was also significantly lower than that during the shutdown period (p-value <0.001). Similarly, when the residential site was downwind of the airport, significantly lower median concentrations were observed during shutdown (p-value <0.001) and ~year later (p-value <0.001) compared to pre-shortening, but not post-shortening (p-value = 0.995), and the ~year later median was also lower than that during the shutdown period (p-value <0.001).

Comparison of the distributions of the hourly averages yielded results similar to phase-wide averages and fine-time resolution measurements. When the runway site was downwind of the airport, the median of the distribution of hourly averages during shutdown (p-value < 0.001), post-shortening (p-value <0.05) and ~year later (p-value <0.001) were all significantly lower than pre-shortening. When residential site was downwind of the airport, medians of the distribution of hourly averages during shutdown (p-value < 0.05) and ~year later (p-value <0.001) were statistically significantly lower than pre-shortening but not post-shortening (p-value = 0.77).

Upwind vs Downwind differences. Compared to the distribution of the fine-resolution measurements when the runway site was upwind of the airport, the medians were higher when the sites were upwind of the airport in both phases of the study (p-value < 0.001).

3.3.2 Ultrafine Particle Number Concentrations

3.3.2.1 Fine temporal resolution time-series

There were strong similarities in temporal patterns of PNC between the runway and residential site. For example, the time-series of measurements at fine time-resolutions (1-min for both the runway and residential sites) in Figures 17 and 18 show that:

(1) Rapid short-term changes (e.g., hours) and shorter-term spikes in concentrations (minutes) in PNC occur simultaneously at both sites. The SCAQMD report discusses the spikes in great detail and established that they originate from aircraft-activity, particularly takeoffs. When a fresh aircraft plume hits the monitoring site, a spike is recorded. During our measurements, it was clear that the spikes frequently observed in the pre-shortening phase were less frequent in the post-

shortening phase, and they were also of lower magnitude. Also, the spikes in PNC were far more frequently observed than spikes in BC concentrations suggesting that a lot more events at the airport create PNC spikes than BC spikes.

(2) The runway site (black line) PNC were generally higher than the residential site (green line) concentrations, reflecting differences in dilution. Emissions are further diluted by the time they are measured at the residential site which is further downwind of the runway thus creating a spatial gradient.

(3) PNC were typically lower during nighttime hours when there was no flight activity and higher during the daytime hours when flight activity was occurring.

Data from three days, one from each distinct phase of monitoring in Phase 1, i.e., pre-shortening, shutdown, and post-shortening, are highlighted and enlarged in Figure 11 (lower panels) to demonstrate that the difference in concentrations at the two sites was variable over the short term but typically much lower during nighttime hours and higher during the daytime hours.

Data from three days, one from each distinct phase of monitoring in Phase 1, i.e., pre-shortening, shutdown, and post-shortening, have been highlighted in Figure 17 (lower panels). These panels demonstrate that the baseline PNC at the two sites were quite comparable in all sub-phases of the study but the frequency and the magnitude of the spikes differed significantly between the sub-phases.

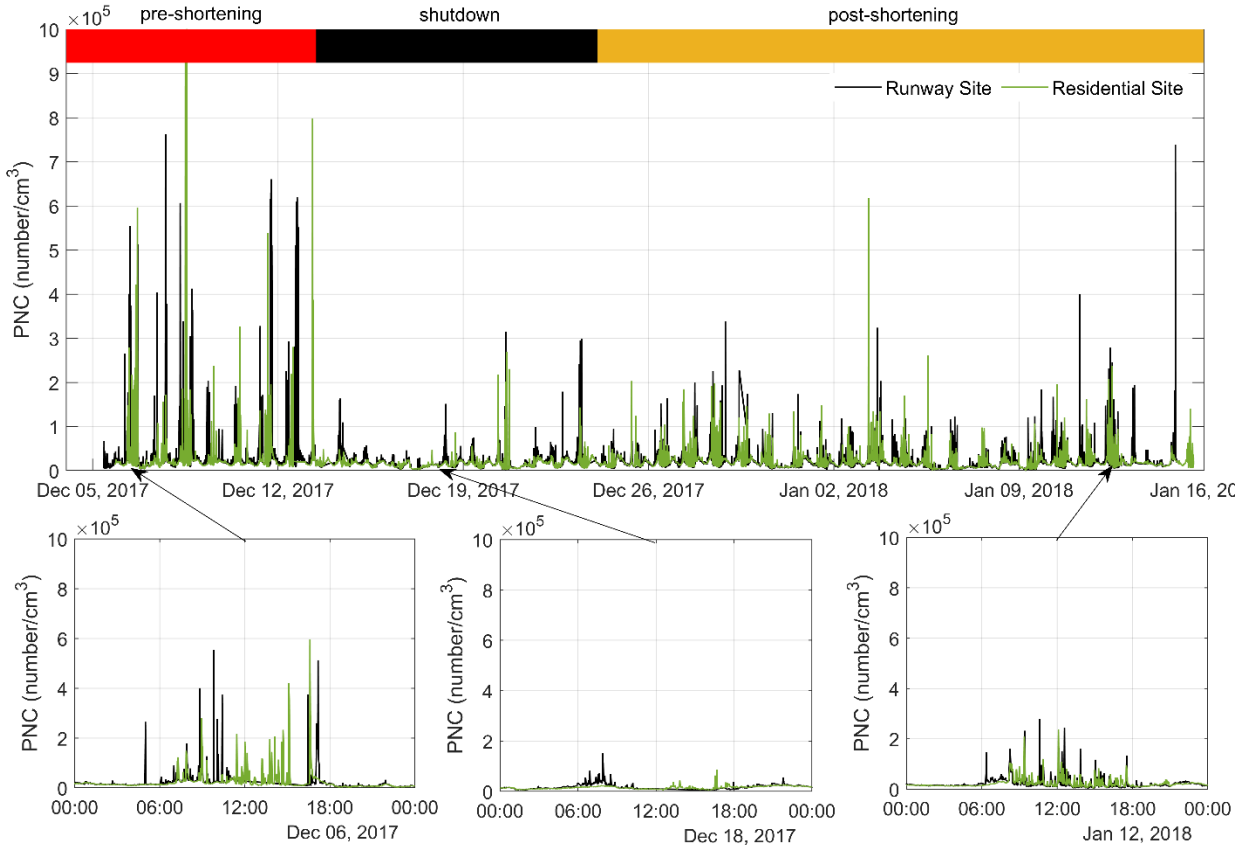

Figure 17: Time-series for particle number concentration (PNC) measured at the runway and residential site during Phase I (i.e., pre- shortening, during shutdown and post-shortening).

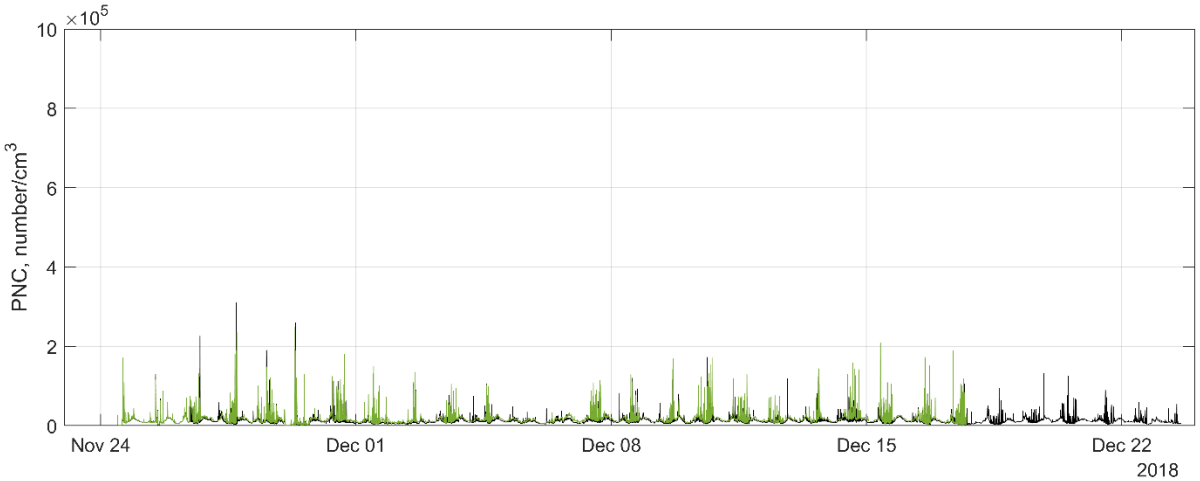

Figure 18: Time-series for particle number concentration (PNC) measured at the runway and residential site during Phase II of the study (i.e., ~year after shortening).

3.3.3.2 Cumulative Frequency Distributions

The cumulative frequency of observation of PNC are shown in Figure 19. These are further stratified by conditions that orient the sites downwind/upwind of the airport in Figure 20. When the results are stratified by wind direction, the leftward shift in the curves after the shortening (i.e., red curve for pre-shortening vs. all other sub-phases) is dramatically evident for the runway site and even at the residential site (Figure 20 a and c) during downwind conditions.

The differences in distributions for other sub-phases were rather limited compared to this reduction. Nonetheless, it is important to note that the compressed logarithmic concentration scale (PNC on the horizontal x-axis) means that small differences between the curves from left to right represent large differences in concentrations. Summarily, shutdown, post-shortening and ~year-later distributions were comparable at the runway site when it was downwind of the airport. At the residential site, the distribution showed lowest concentration during shutdown phase and post-shortening and ~year later were comparable and somewhat higher than shutdown.

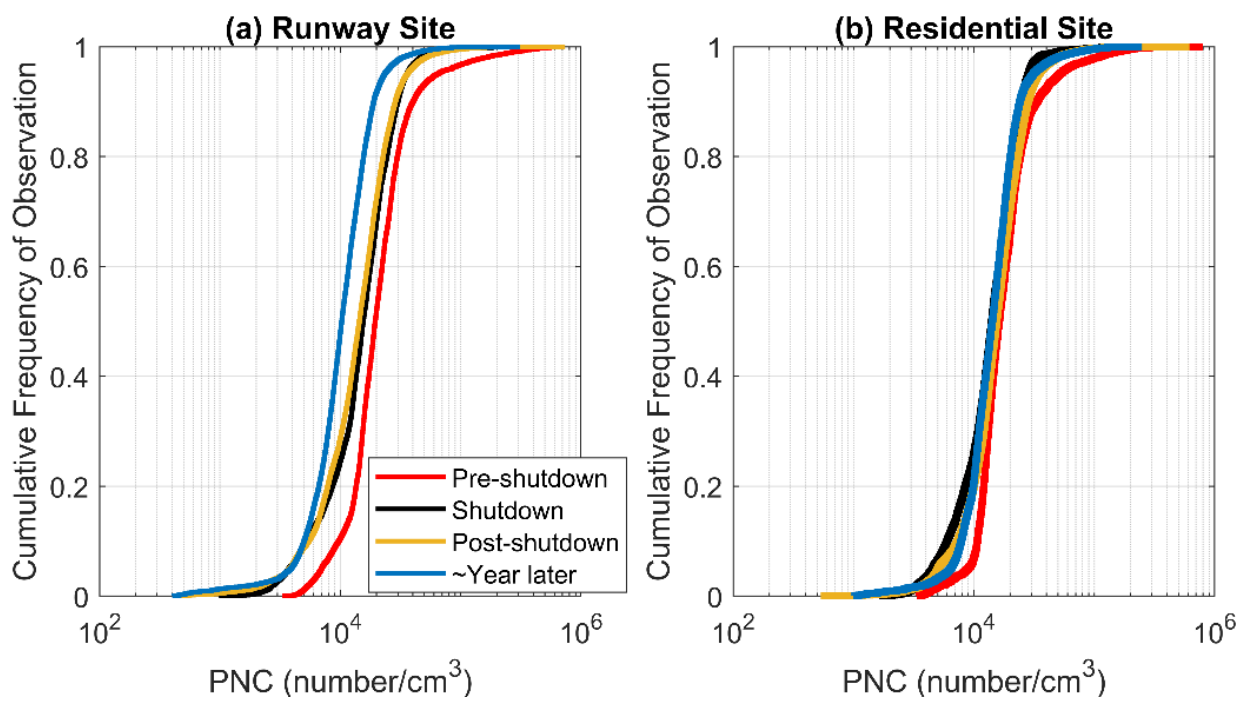

Figure 19: Cumulative frequency of observation for particle number concentration (PNC) measured at (a) the runway site and (b) the residential during the different phases of the study.

3.3.2.3 Comparison of unwind vs downwind conditions

PNC were generally higher or comparable when sites were upwind of the airport compared to when they were downwind of the airport except during pre-shortening at both sites as indicated by the boxplots in Figure 21. When sites are upwind of the airport they are downwind of two freeways I-10 and I-405 that are highly trafficked and the runway site is additionally downwind of Bundy Dr. that is also highly trafficked.

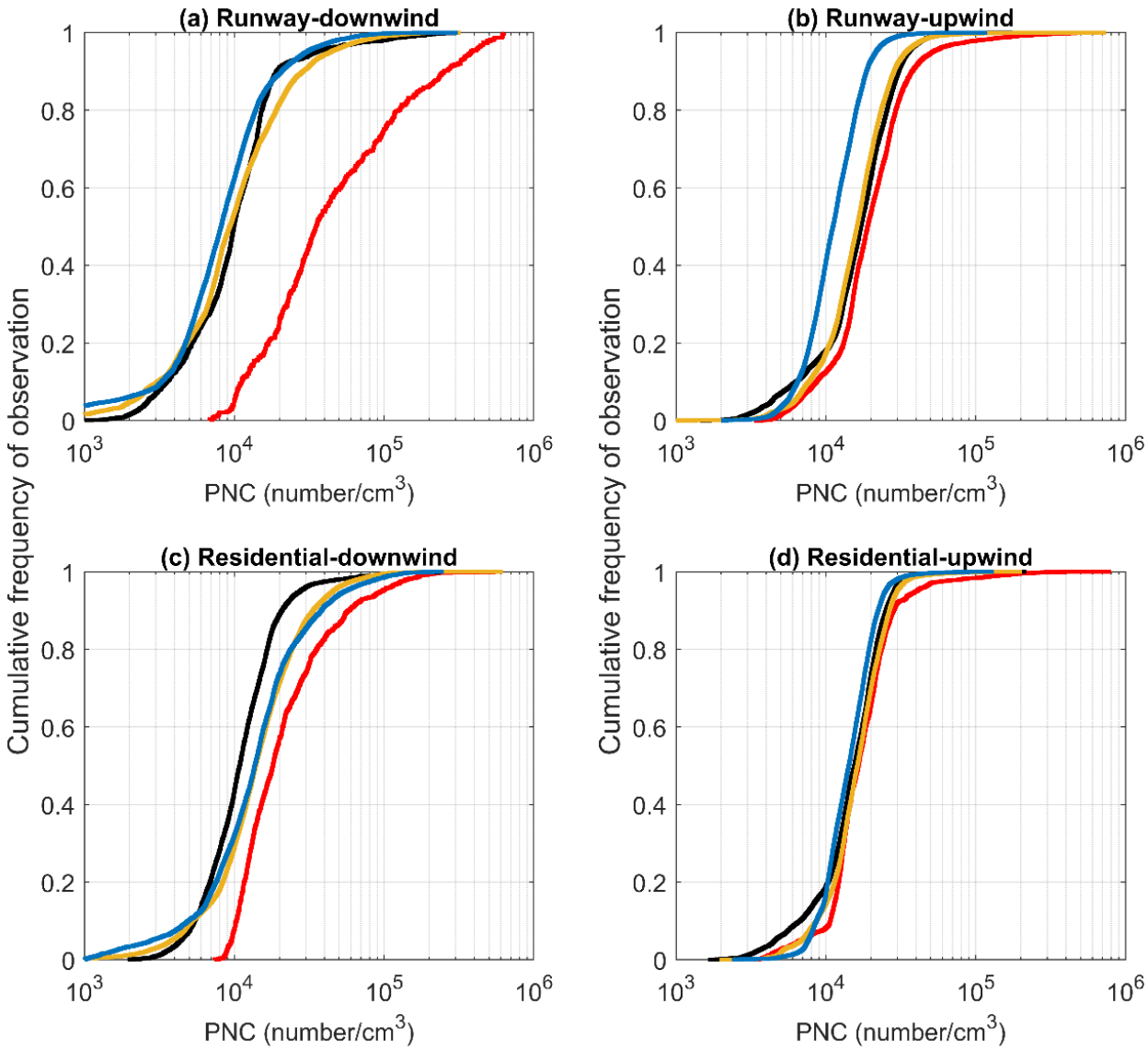

Figure 20: Cumulative frequency of observation for particle number concentration (PNC) (measured at 1-sec resolution and averaged to 1-min) during the different phases/sub-phases of the air quality monitoring study separated by wind conditions that orient the sites downwind or upwind of the airport.

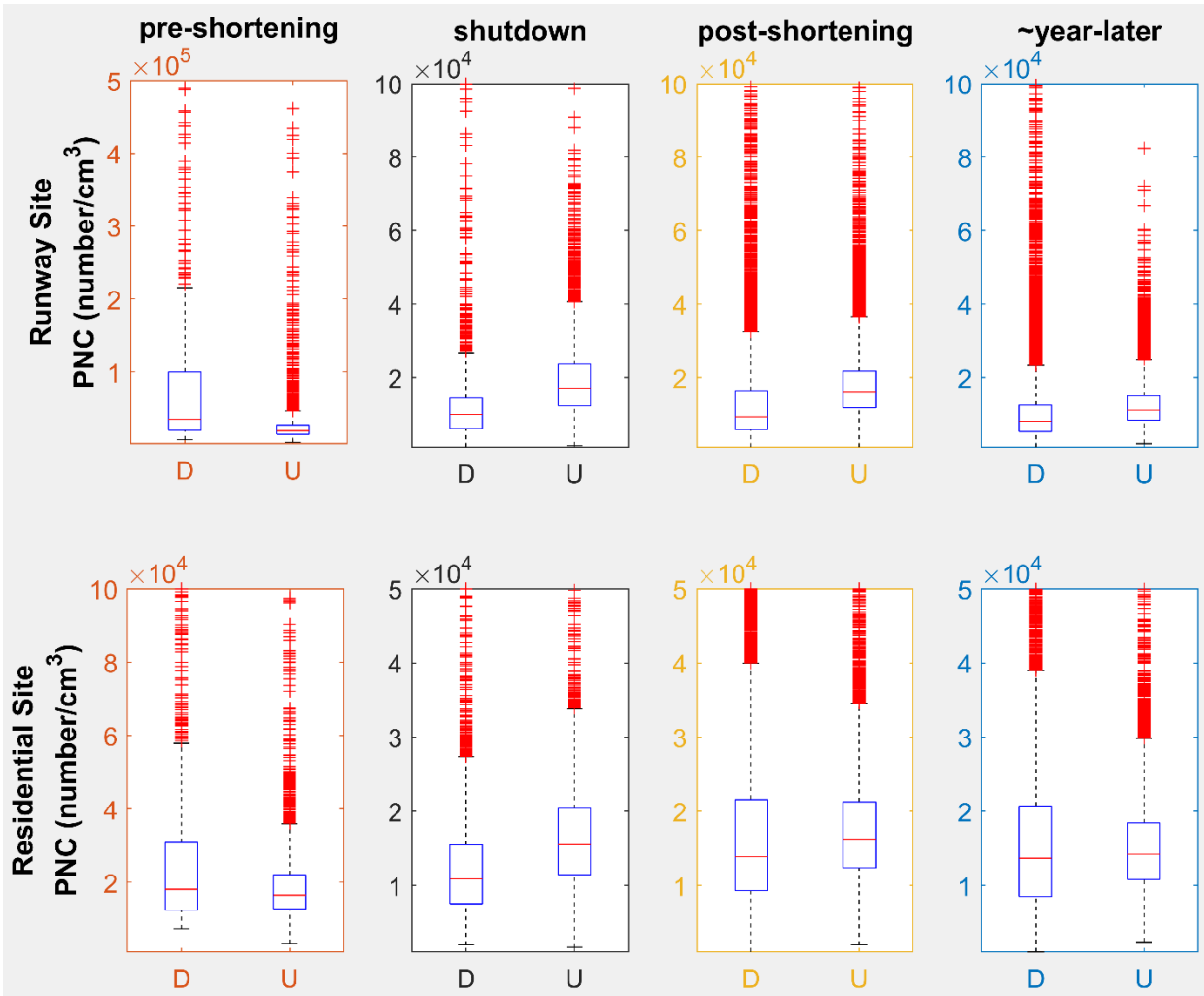

Figure 21: Tukey's boxplots comparing particle number concentrations during downwind vs. upwind conditions at the two sites during different phases of the study.

Summary statistics for fine-resolution measurements for the two phases of the study are summarized in Table 7 below.

Table 7: Phase-wide summary statistics based on one-minute average particle number concentrations at the two monitoring sites during the conditions when sites were downwind and upwind of the airport. Lowest values are shaded blue and highest values are shaded red.

	PNC (number/cm^3)							
	Runway or East-tarmac site				Residential or Ernst residence site			
	Phase 1		Phase 2		Phase 1		Phase 2	
	Upwind	Downwind	Upwind	Downwind	Upwind	Downwind	Upwind	Downwind
Average	19000	17000	12000	11000	16000	15000	17000	18000
Median	17000	10000	11000	8000	14000	9000	15000	14000
Stdev	18000	33000	5000	13000	15000	27000	11000	20000
Valid N	33000	11000	27000	13000	62000	25000	59000	28000

3.3.2.4 Longer-term averages

The averages for different phases and sub-phases of the study are summarized in Table 8 and plotted in Figure 22. During the shutdown, PNC were 75% and 50% lower than pre-shortening at the runway and residential site, respectively, when the sites were downwind of the airport. Post-shortening PNC were 75% lower than pre-shortening at the runway site and 35% lower at the residential site. Phase 2, i.e., ~year-later, averages were 80% lower than pre-shortening at the runway site and 35% lower at the residential site. It is interesting to note, that PNC were at the residential and runway site were comparable (ratio of upwind to downwind ranged from 0.84-1.19) in all but the pre-shortening phase of the study.

Table 8: Phase/sub-phase summary statistics based on hourly average particle number concentrations at the two monitoring sites during the conditions when sites were downwind and upwind of the airport.

	Runway Site			Residential Site		
	upwind	**downwind**	**Ratio upwind to downwind**	**upwind**	**downwind**	**Ratio upwind to downwind**
Phase I						
Pre-shortening	26,000±21,000	68,000±58,000	0.38	21,000±17,000	30,000±15,000	0.70
Sylmar fire	24,000±11,000	49,000±41,000	0.49	19,000±6,000	27,000±11,000	0.70
Shutdown	19,000±10,000	16,000±16,000	1.19	17,000±8,000	14,000±9,000	1.21
Post-shortening	18,000±9,000	16,000±12,000	1.13	18,000±8,000	19,000±10,000	0.95
Phase II						
~Year later	13,000±5,000	12,000±6,000	1.08	16,000±6,000	19,000±11,000	0.84

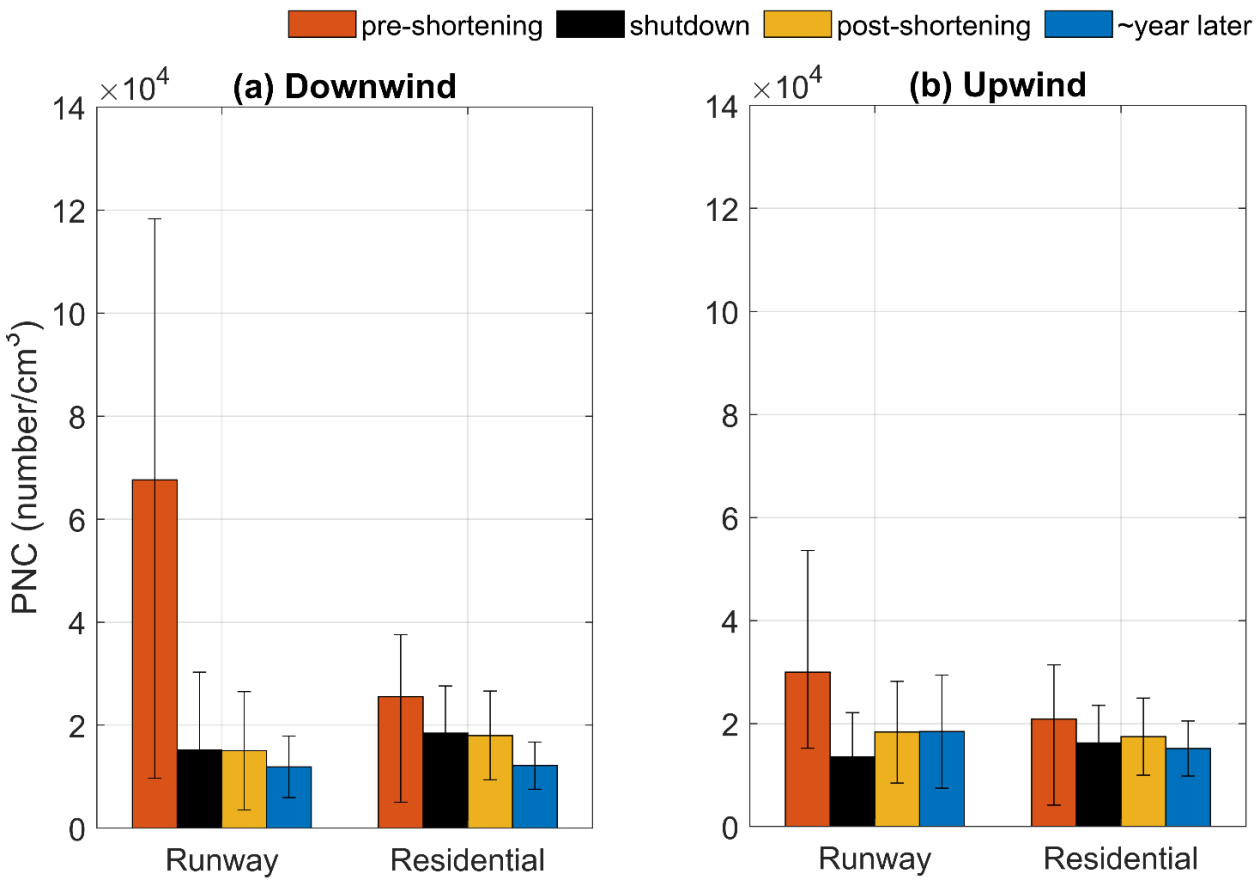

Figure 22: Particle number concentrations (PNC) during different phases of the study.

3.3.2.5 Statistical Comparison

Phases-to-phase differences. Compared to the distribution of the fine-resolution measurements when the runway site was downwind of the airport during the pre-shortening sub-phase, statistically significantly lower median concentrations were observed during shutdown (p-value <0.001), and ~year later (p-value <0.001) and post-shortening (p-value <0.001); and ~year later median was also lower than that during shutdown period (p-value <0.001). And similar to the runway site, when the residential site was downwind of the airport, compared to pre-shortening statistically significantly lower median concentrations were observed during shutdown (p-value <0.001), and ~year later (p-value <0.001) and post-shortening (p-value <0.001); and ~year later median was higher than that during shutdown period (p-value <0.001). Comparison of the distributions of the hourly averages yielded results that were similar to the phase-wide averages and the fine-time resolution comparisons. When runway site was downwind of the airport,

median of the distribution of hourly averages during shutdown (p-value < 0.001), post-shortening (p-value < 0.001) and ~year later (p-value < 0.001) were all statistically significantly lower than pre-shortening); and ~year later median was neither lower (p-value = 0.08) nor higher (p-value = 0.92) than that during shutdown period. When residential site was downwind of the airport, median of the distribution of hourly averages during shutdown (p-value < 0.001), post-shortening (p-value < 0.001) and ~year later (p-value < 0.001) were all statistically significantly lower than pre-shortening; and ~year later median was higher than that during shutdown period (p-value <0.001).

Upwind vs Downwind differences. Compared to the distribution of the fine-resolution measurements when the runway site was downwind of the airport, the medians were higher when the sites were upwind of the airport in both phases of the study (p-value < 0.001). Only for the sub-phase pre-shortening was the median during downwind conditions higher than that during upwind conditions at both the runway and the residential site.

3.3.3 Lead in Fine Particulate Matter

Pre-shutdown mean lead concentration at the runway site was 0.024 µg/m^3, lower than the ~0.04 µg/m^3 mean lead concentration reported by SCAQMD for measurements conducted in 2006-2007 at the runway and the residential site for the General Aviation Airport Study. During the shutdown, mean lead concentration was 90% lower (0.0016 µg/m^3) than pre-shortening at the runway site and the mean concentration was similar at the residential site (0.0009 µg/m^3). Results reaffirm the observation reported earlier by SCAQMD that aviation gas combustion (a leaded fuel still in use in US) leads to particulate emissions that contain lead. However, post shortening, the mean lead concentration was still 75% lower (0.0062 µg/m^3) than pre-shortening at the runway site and concentration was similar at the residential site (0.0056 µg/m^3), but higher than shutdown levels. One year later, the mean lead concentration at the runway site was comparable to the levels right after shortening and still 75% lower (0.0062 µg/m^3) than pre-shortening, while the mean lead concentration at the residential site (0.0047 µg/m^3) was similar to right after shortening.

One possible explanation for the large difference in lead between pre-shortening and post-shortening or a year later is that jet induced resuspension of fine particulate lead (if not direct primary emissions by burning leaded fuel) contribute significantly to the airborne lead concentrations in the area, therefore, a decrease in jet activity could have also caused a decrease in fine particulate lead concentration. The values are summarized in Table 9 and plotted on Figure 23.

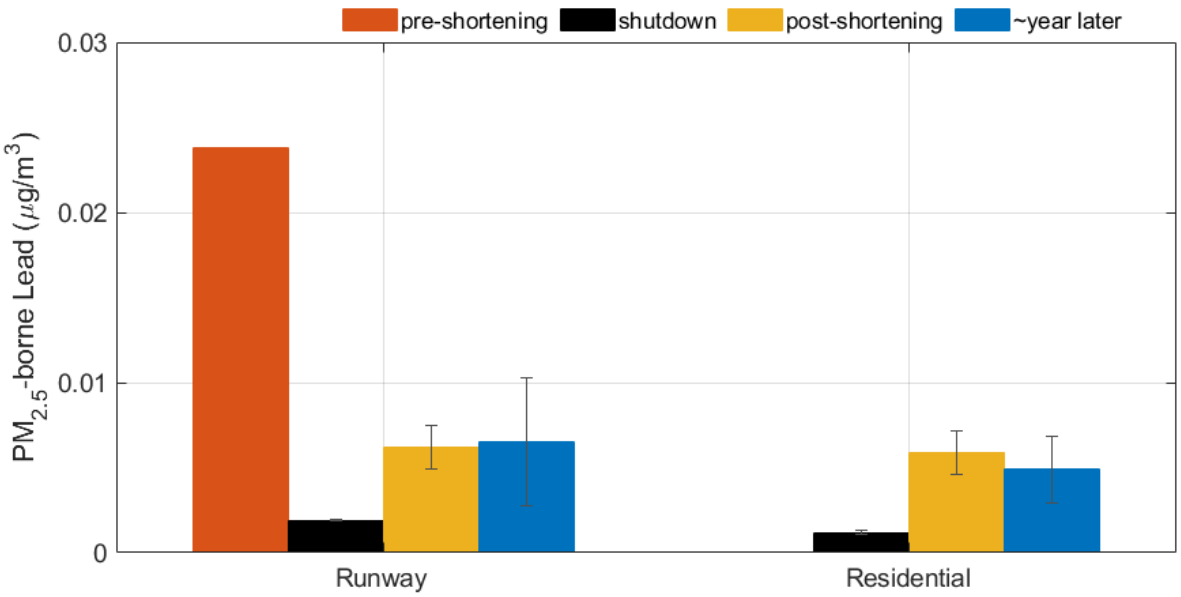

Figure 23: Concentrations of lead in fine particulate matter during various phases of the study.

Table 9: Average concentration of lead in fine particulate mater

	Runway Site (µg/m³)	Residential Site (µg/m³)
Phase 1		
pre-shutdown	0.0236 (n = 1)	QA/QC fail
shutdown	0.0016±0.00004 (n = 2)	0.0009±0.00012 (n = 2)
post-shutdown	0.0059±0.00130 (n = 3)	0.0056±0.00129 (n = 3)
Phase 2		
year-later	0.0062±0.00376 (n = 4)	0.0047±0.00197 (n = 3)
Lab blank	0.0000 (n = 1)	
Field blank	0.0003±0.00054 (n = 3)	

It is also notable that the post-shortening and year later values are also lower than those summarized by US EPA for 17 airport facilities in 2013 (see Figure 24 which is a taken from the EPA report EPA-420-F-15-003).[13] For reference, the National Ambient Air Quality Standard

(NAAQS) for lead 0.15 µg/m^3 for a 3-month average concentration of lead in total suspended particles.

Concentrations of Lead at Airports

Airport, State	Lead Design Value,* µg/m^3
Auburn Municipal Airport, WA	0.06
Brookhaven Airport, NY	0.03
Centennial Airport, CO	0.02
Deer Valley Airport, AZ	0.04
Gillespie Field, CA	0.07
Harvey Field, WA	0.02
McClellan-Palomar Airport, CA	0.17
Merrill Field, AK	0.07
Nantucket Memorial Airport, MA	0.01
Oakland County International Airport, MI	0.02
Palo Alto Airport, CA	0.12
Pryor Field Regional Airport, AL	0.01
Reid-Hillview Airport, CA	0.10
Republic Airport, NY	0.01
San Carlos Airport, CA	0.33
Stinson Municipal, TX	0.03
Van Nuys Airport, CA	0.06

* Maximum three-month average concentration in the monitoring dataset

Figure 24: Summary table of lead concentrations from report EPA-420-F-15-003.

3.3.4 Comparison to 2010 SCAQMD Study

We contrast the measurements from our study with the most comparable measurements from the SCAQMD 2010[2] study undertaken in 2010 in Tables 10-13. As discussed in the methods, the central tendency measures such as mean and median are comparable between the two studies while other statistical measures are not. Tables 10-13 show that both BC and PNC concentrations at the runway site during the pre-shortening interval were distinctly and consistently higher than those measured at the runway in the repaving study in 2010, while concentrations were roughly equal at the Residential site. One year after the shortening, both BC and PNC concentrations were distinctly lower than SCAQMD results for both locations.

It is worth noting that a distinguishing feature of our study is that we stratified data for the wind conditions that orient the site downwind and unwind of the airport; the timing and meteorology that prevailed during our study allowed for that stratification. The winds during the SCAQMD study were predominantly from the southwest and therefore statistics were drawn on the entire dataset in that study. We report data from the downwind conditions in the following Tables 10-13.

Table 10: Comparison of runway site BC concentration data from AQMD study of repaving project in 2010 to the current runway-shortening study in 2017-2019.[1] Lowest values are shaded blue and highest values are shaded red.

	BC (ug/m^3)						
	Runway site						
	Repaving 2010			Phase I			Phase 2
	Before	During	After	pre-shortening	shutdown	post-shortening	~year later
Average	1.0	1.1	1.5	2.0	0.9	1.4	0.7
Median	0.6	0.7	1.0	1.1	0.6	1.2	0.5
Stdev	1.5	1.1	1.8	3.7	0.8	1.0	0.7
Valid N	2,933	1,242	3,092	1,131	4,327	12,589	13,546

Table 11: Comparison of residential site BC concentration data from AQMD study of repaving project in 2010 to the current runway-shortening study in 2017-2019.[2] Lowest values are shaded blue and highest values are shaded red.

	BC (ug/m^3)						
	Residential site						
	Repaving 2010			Phase I			Phase 2
	Before	During	After	pre-shortening	shutdown	post-shortening	~year later
Average	0.8	0.9	1.2	0.8	0.7	0.9	0.5
Median	0.5	0.6	0.9	0.7	0.5	0.9	0.4
Stdev	0.9	0.9	1.3	0.5	0.5	0.7	0.4
Valid N	2,233	1,248	3,077	225	860	2,534	2,628

[1] The statistics for the current study were generated based on 1-minute averages compared to 5-min averages in SCAQMD study.
[2] Both studies report statistics based on 5-minute averages

Table 12: Comparison of runway site particle number concentration (PNC) data from AQMD study of repaving project in 2010 to the current runway-shortening study in 2017-2019.[3] Lowest values are shaded blue and highest values are shaded red.

	PNC (number/cm^3)						
	Runway site						
	Repaving 2010			Phase I			Phase 2
	Before	During	After	pre-shortening	shutdown	post-shortening	~year later
Average	24,000	13,000	27,000	90,000	15,000	15,000	11,000
Median	9,000	10,000	12,000	35,000	10,000	9,000	8,000
Stdev	63,000	11,000	75,000	124,000	25,000	19,000	13,000
Valid N	13,360	6,360	11,700	376	2,365	8,494	13,383

Table 13: Comparison of residential site particle number concentration (PNC) data from AQMD study of repaving project in 2010 to the current runway-shortening study in 2017-2019.[4] Lowest values are shaded blue and highest values are shaded red.

	PNC (number/cm^3)						
	Residential site						
	Repaving 2010			Phase I			Phase 2
	Before	During	After	pre-shortening	shutdown	post-shortening	~year later
Average	21,000	11,000	24,000	30,000	14,000	18,000	18,000
Median	10,000	10,000	13,000	18,000	11,000	14,000	13,000
Stdev	44,126	8,954	61,138	36,527	14,919	17,593	18,665
Valid N	13,429	6,360	11,511	1,396	4,220	11,673	9,658

[3] Both studies report statistics based on 1-minute averages
[4] Both studies report statistics based on 1-minute averages

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(1) Fine, P.; Chavez, P.; Hom, S.; Koch, M.; Low, J.; Parent, R.; Wilson, S. General Aviation Airport Air Monitoring Study. **2010**, No. August.

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(12) Lee, E. S.; Polidori, A.; Koch, M.; Fine, P. M.; Mehadi, A.; Hammond, D.; Wright, J. N.; Miguel, A. H.; Ayala, A.; Zhu, Y. Water-Based Condensation Particle Counters Comparison near a Major Freeway with Significant Heavy-Duty Diesel Traffic. *Atmos. Environ.* **2013**, *68*, 151–161.

(13) USEPA. *Airport Lead Monitoring (EPA-420-F-15-003, January 2015)*; **2015**.

Appendix A: Air Quality and Meteorological Data

Air Quality Instruments Side-By-Side Comparison

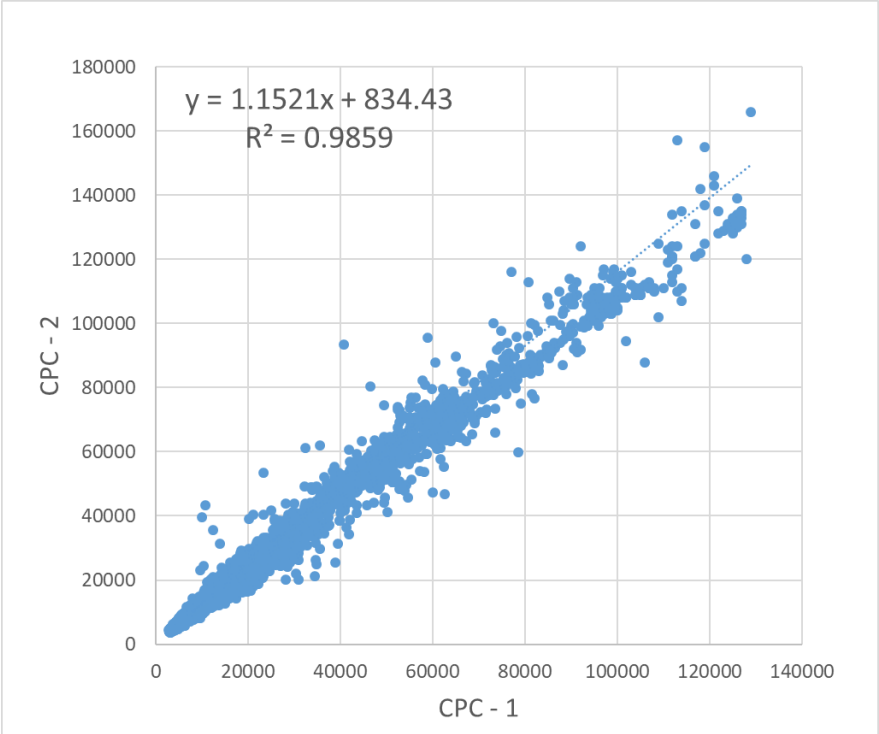

Figure A1: Side-by-side comparison of the two CPC used in this study before the beginning of Phase II

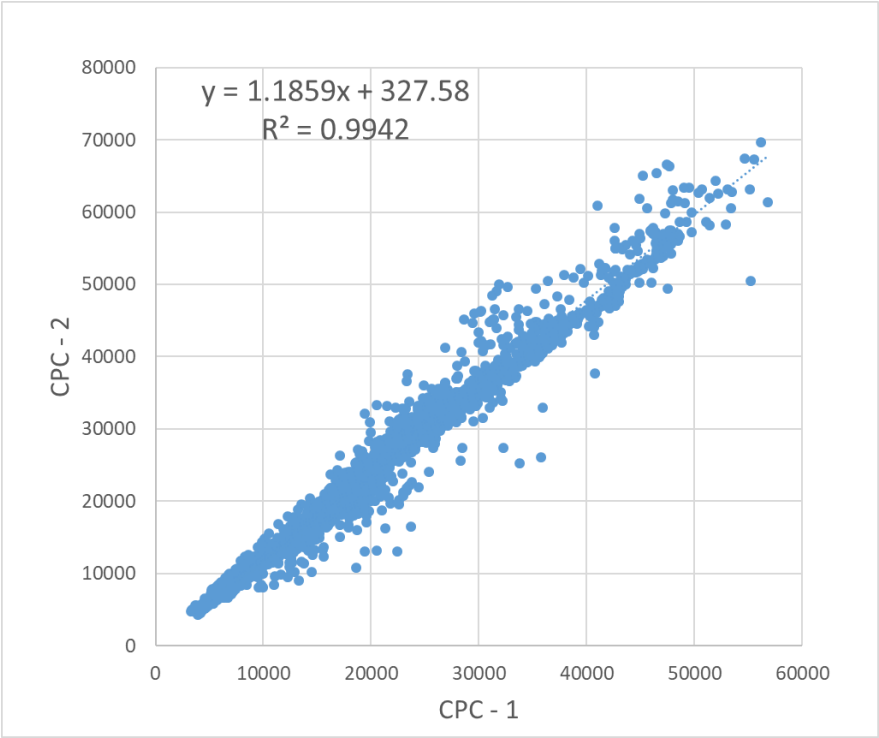

Figure A2: Side-by-side comparison of the two CPC used in this study at the end of Phase II

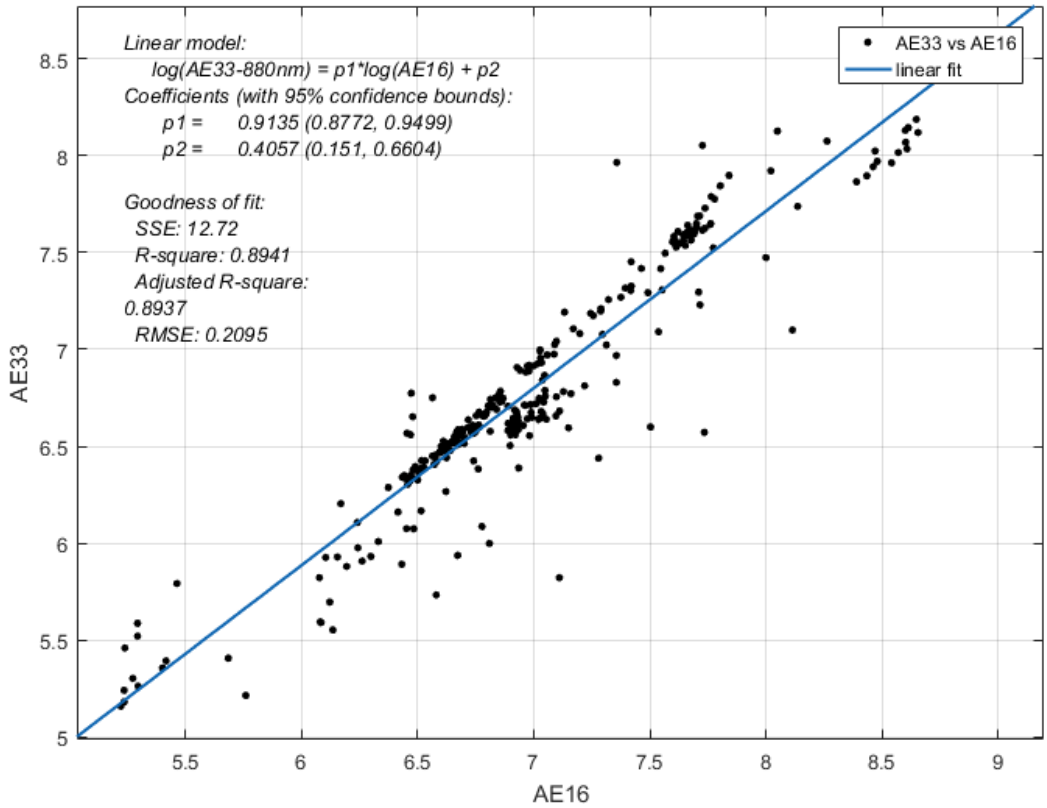

Figure A3: Side-by-side comparison of the two Aethalometers used in this study

Meteorological data

AERMINUTE summary of KSMO data quality

		TOTAL	VALID	INVALID	CALM	MISSING
YEAR	MONTH	HOURS	HOURS	HOURS	HOURS	HOURS

2017	December	744	677	0	30	37
2018	January	744	710	0	32	2
2018	November	720	697	0	12	11
2018	December	744	699	2	18	25

AERMINUTE summary of KLAX data quality

		TOTAL	VALID	INVALID	CALM	MISSING
YEAR	MONTH	HOURS	HOURS	HOURS	HOURS	HOURS

2017	December	744	701	3	10	30
2018	January	744	705	1	10	28
2018	November	720	708	0	1	11
2018	December	744	722	0	7	15

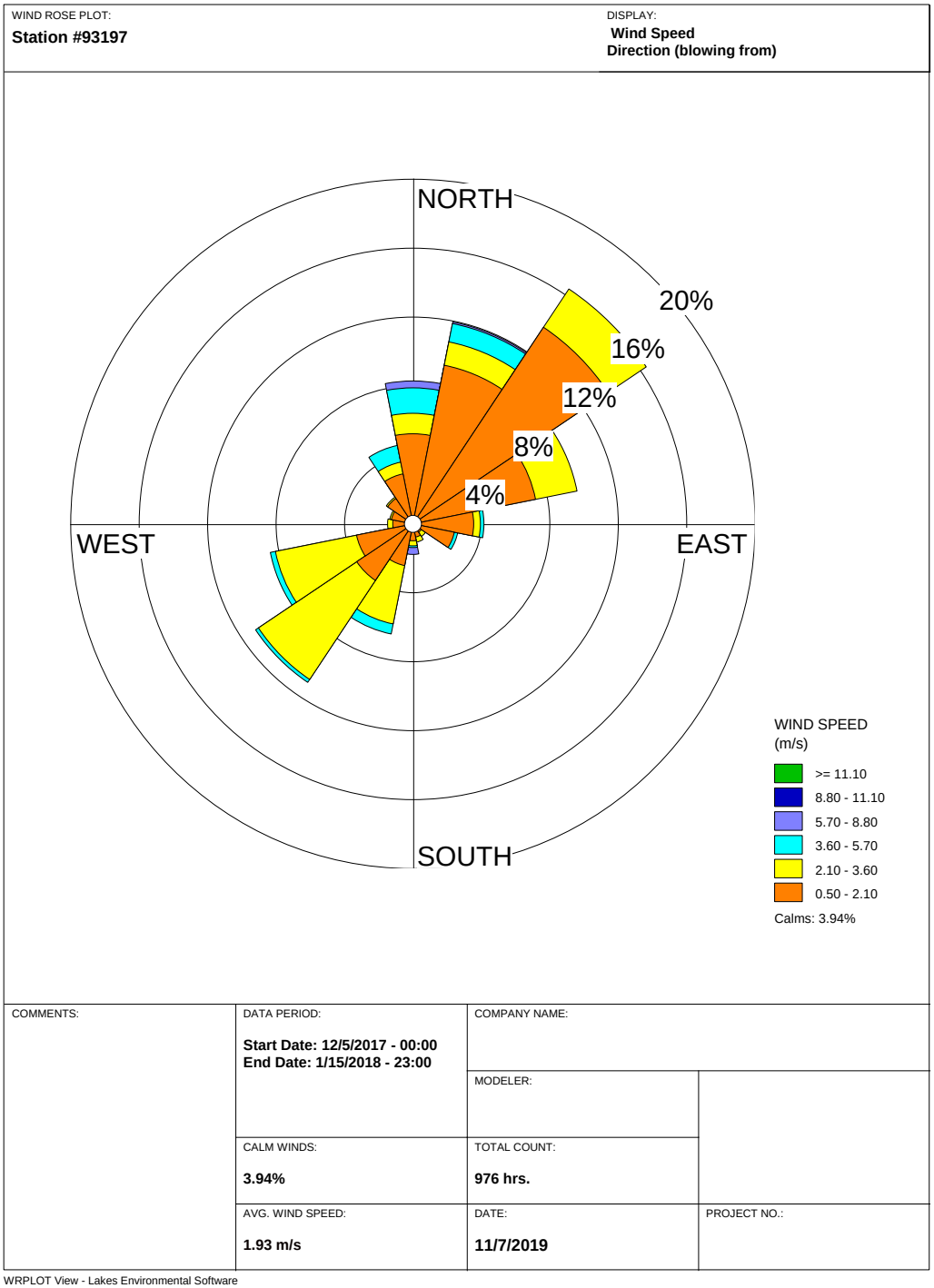

Figure A4: Wind rose for the duration of Phase I of the study based on data from the NWS weather station at the Santa Monica Airport.

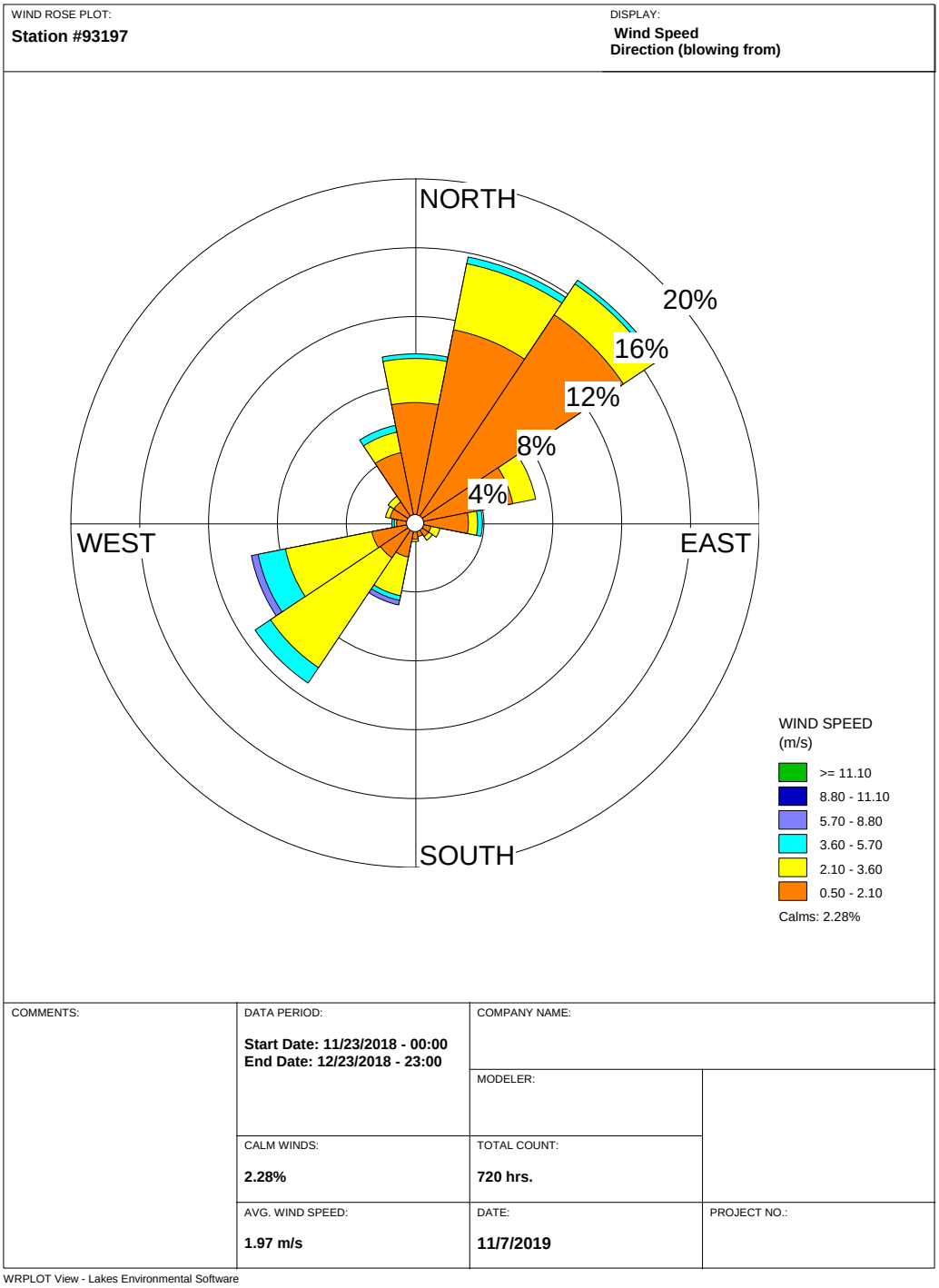

Figure A5: Wind rose for the duration of Phase II of the study based on data from the NWS weather station at the Santa Monica Airport.