Project 018 Community Measurements of Aviation Emissions Contribution to Ambient Air Quality

Boston University School of Public Health

Project Lead Investigator

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University Participants

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- P.I.(s): Jonathan I. Levy, Professor and Associate Chair
- FAA Award Number: 13-C-AJFE-BU, Amendment 7
- Period of Performance: October 1, 2016 – September 30, 2017
- Task(s):
  1. Conduct ambient monitoring of UFP and other pollutants in communities underneath flight paths near Boston Logan International Airport, to determine the locations and atmospheric/flight activity conditions under which exposures could be elevated.
  2. Work with collaborators on ASCENT Projects 19 and 20 to quantify the health implications of modeled aviation-related air pollutant concentrations.

Project Funding Level

$200,000. Matching funds provided by non-federal donor to the Women's Health Initiative (WHI) cohort studies, provided as cost share support to Boston University through Project 3.

Investigation Team

Principal Investigator: Jonathan I. Levy, Sc.D. (Professor of Environmental Health, Department of Environmental Health, Boston University School of Public Health). Dr. Levy is the Boston University PI of ASCENT. He has primary responsibility for the execution of the project and contributes to manuscripts and reports produced.

Faculty member: Kevin J. Lane, Ph.D. (Assistant Professor of Environmental Health, Department of Environmental Health, Boston University School of Public Health). Dr. Lane joined the Project 18 team in July 2017. Dr. Lane has expertise in ultrafine particulate matter exposure assessment, geographic information systems, and statistical modeling of large datasets, along with cardiovascular health outcomes associated with air pollution exposures. He has contributed to study design and data analysis strategies, and as of 10/1/17, has primary responsibility for project execution.

Post-doctoral researcher: Matthew Simon, Ph.D. Dr. Simon joined the Project 18 team in September 2017, and is involved in data analyses, field study design and implementation, and scientific manuscript preparation.

Graduate Student: Chloe Kim, MPH. Ms. Kim is a doctoral student in the Department of Environmental Health at BUSPH. She has taken the lead on organizing and implementing the air pollution monitoring study and will be responsible for the design and execution of related statistical analyses.

Research Assistant: Claire Schollaert. Ms. Schollaert provides field support for the air pollution monitoring study, including design and implementation of monitoring platforms.

Project Overview

The primary goal was to conduct new air pollution monitoring underneath flight paths to and from Boston Logan International Airport, using a protocol specifically designed to answer the question of the magnitude and spatial distribution of ultrafine particulate matter (UFP) in the vicinity of arrival flight paths. Data was collected that would address the question of whether aircraft emissions, and in particular arrival emissions, can contribute significantly to UFP concentrations at appreciable distances from the airport. In addition, Task 2 had the goal of supporting the work of collaborators on Projects 19 and 20, regarding the appropriate concentration-response functions and other datasets to allow atmospheric modeling outputs to be used in health impact assessment calculations.

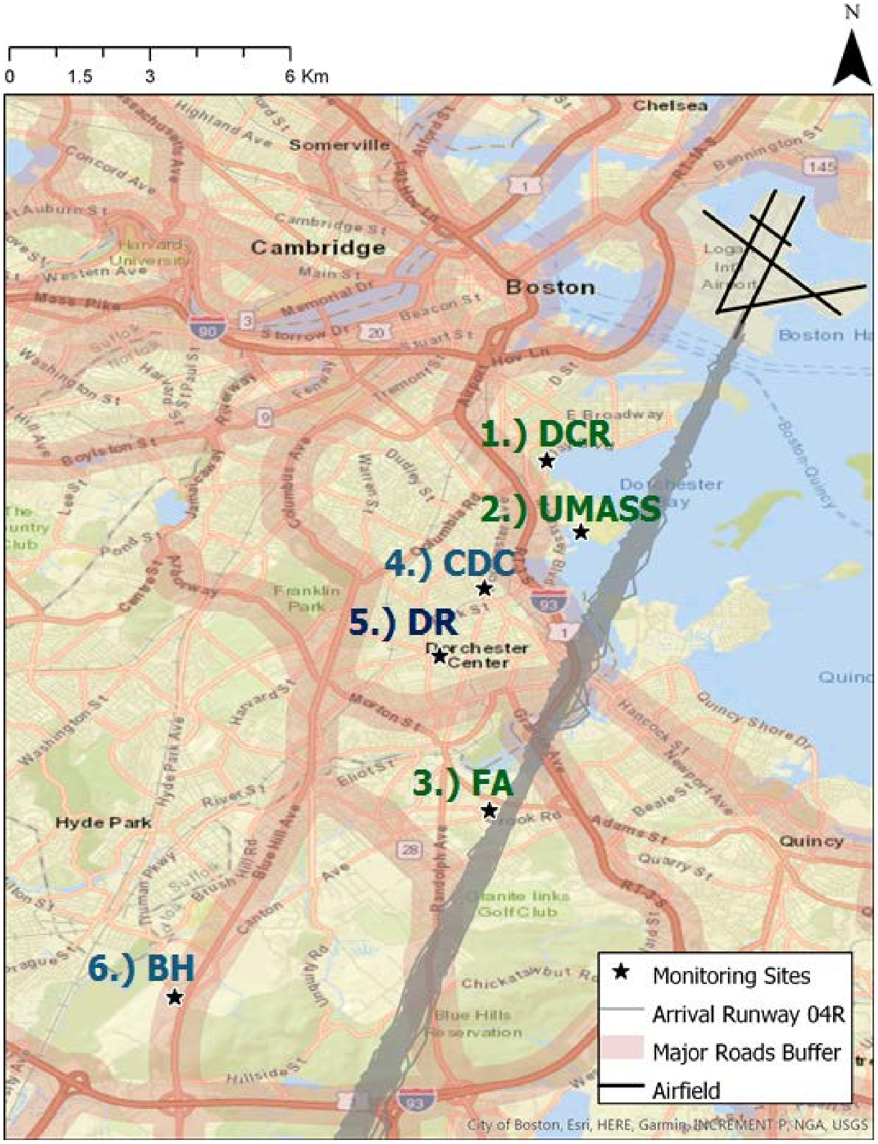

Figure 1. Monitoring sites and runway 4R flight path.

Task #1: Conduct ambient monitoring of UFP and other pollutants in communities underneath flight paths near Boston Logan International Airport, to determine the locations and atmospheric/flight activity conditions under which exposures could be elevated.

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Objective(s)

Project 18, Task 1 for the 2016-2017 funding cycle focused on designing and implementing an air pollution monitoring study that would allow us to determine contributions from arriving aircraft to ambient air pollution in a near-airport setting. The objective of this task was to address the question of whether aircraft emissions, and in particular arrival emissions, can contribute significantly to ultrafine particulate matter (UFP) concentrations at appreciable distances from the airport.

Research Approach

An air pollution monitoring campaign was conducted at six sites at varying distances from the airport and the arrival flight path to runway 4R (Figure 1). Sites were selected through a systematic process, considering varying distances from the airport and laterally from the 4R flight path, and excluding locations close to major roadways or other significant sources of combustion. These sites were chosen specifically to isolate the contributions of arrival aircraft on runway 4R, which is important for the flight activity source attribution task.

Three sets of particle number concentration (PNC, a proxy for UFP) monitoring instruments were rotated among monitoring sites in a pre-selected scheme to allow for multiple levels of comparison (e.g., sites underneath vs. not underneath flight paths given prevailing winds, sites at varying distances from the airport underneath the same flight path, sites at varying lateral distances underneath the same flight path). PNC was measured with TSI Condensation Particle Counters (Model 3783). In addition, black carbon was measured using AethLabs Microaethalometers (Model AE51), and meteorological data at each site were collected using Davis Vantage Pro2 weather stations. Over 28 million 1-second PNC measurements were collected from April – September of 2017, during one week sampling periods that averaged 63 days of sampling at each site (Table 1). Sites were monitored at each site multiple times under varying meteorological conditions during our campaign.

Milestone(s)

The core milestones articulated in the 2016-2017 Project 18 proposal included:

- Obtain all air pollution monitors and other materials necessary for a field campaign surrounding Logan Airport
- Select candidate monitoring sites and obtain permission to monitor at those sites
- Design field monitoring and site rotation protocols/schedules
- Implement air pollution monitoring protocols, including measurements of meteorological conditions and collection of PDARS data to be used in statistical analyses.
- Develop statistical techniques needed for source attribution given continuous air pollution and flight activity data.
- Complete primary statistical analyses and prepare scientific manuscripts

We obtained air pollution monitors and constructed sampling boxes and field protocols in Fall 2016, as planned. Selection of monitoring sites was successful, and we obtained permission to sample at six sites by Winter 2016-2017. We began collecting field data following our complete protocols in April 2017 with comprehensive data capture throughout the spring and summer, meeting our data collection milestone. As we did not obtain flight activity data until September 2017, given challenges with data access and changes from PDARS to NOP availability, the comprehensive set of statistical analyses were deferred until the subsequent funding year, but all core data collection milestones were easily met.

Major Accomplishments

As described above, the 2017 air pollution field monitoring campaign was conducted from April – September at six sites at varying distances from the airport and the arrival flight path to runway 4R (Figure 1). This met all targets for sample size and data capture, providing a strong foundation for forthcoming statistical analyses.

Table 1. Distribution of PNC at the six monitoring sites

-	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Sample Size (days)	67	71	57	61	57	62
Sample Size (seconds)	5,262,301	5,301,907	4,126,007	4,363,564	4,233,284	4,661,517
0.1st percentile	800	1,100	1,600	2,500	2,000	1,800
1st percentile	1,000	2,900	2,500	5,100	2,900	2,500
5th percentile	4,300	5,800	4,300	8,200	5,700	4,300
50th percentile	14,100	16, 600	11,600	20,600	17,100	12,000
95th percentile	55,600	63,000	28,000	67,900	47,100	31,400
99th percentile	116,800	119,200	47,400	103,200	70,700	50,500
99.9th percentile	180,200	206,600	87,500	150,800	96,500	95,800

The summary statistics presented in Table 1 cannot provide definitive insight about aviation contributions to measured PNC, but are helpful for hypothesis generation. For example, note that Site 4 has the highest concentrations of all sites through the 95th percentile of the distribution, consistent with its location in an urban neighborhood with traffic sources in relatively close proximity. However, Site 2 has the highest concentrations at the 99th percentile and above. Site 2 does not have nearby traffic (located on a college campus) and is relatively close to the 4R arrival flight path, so the elevated concentrations above the 99th percentile would be consistent with an intermittent contribution from aviation emissions. Similarly, Site 1 also is elevated at the 99th percentile or above and is located closer to the airport and 4R arrival path. However, no formal conclusions can be drawn without statistical analyses that include flight activity and meteorology, and the full set of National Offload Program (NOP) data that were made available on September 22, 2017. Ongoing Project 18 efforts are now focused on linking the NOP data with our PNC second-by-second data and conducting regression analysis.

Prior to conducting statistical analyses, it is important to determine the degree of error in our measurements, to determine whether concentration spikes can be reasonably interpreted. PNC monitoring instruments were tested for agreement during lab and field based co-location. Co-location testing of the three CPCs showed extremely high correlations (R^2=0.98; Figure 2) and similar ability to detect short-term concentration increases. This reinforces that our large sample size will have the statistical power to detect a variety of associations and to construct models with subsets of data if informative (i.e., restricting to specific times of day or meteorological conditions).

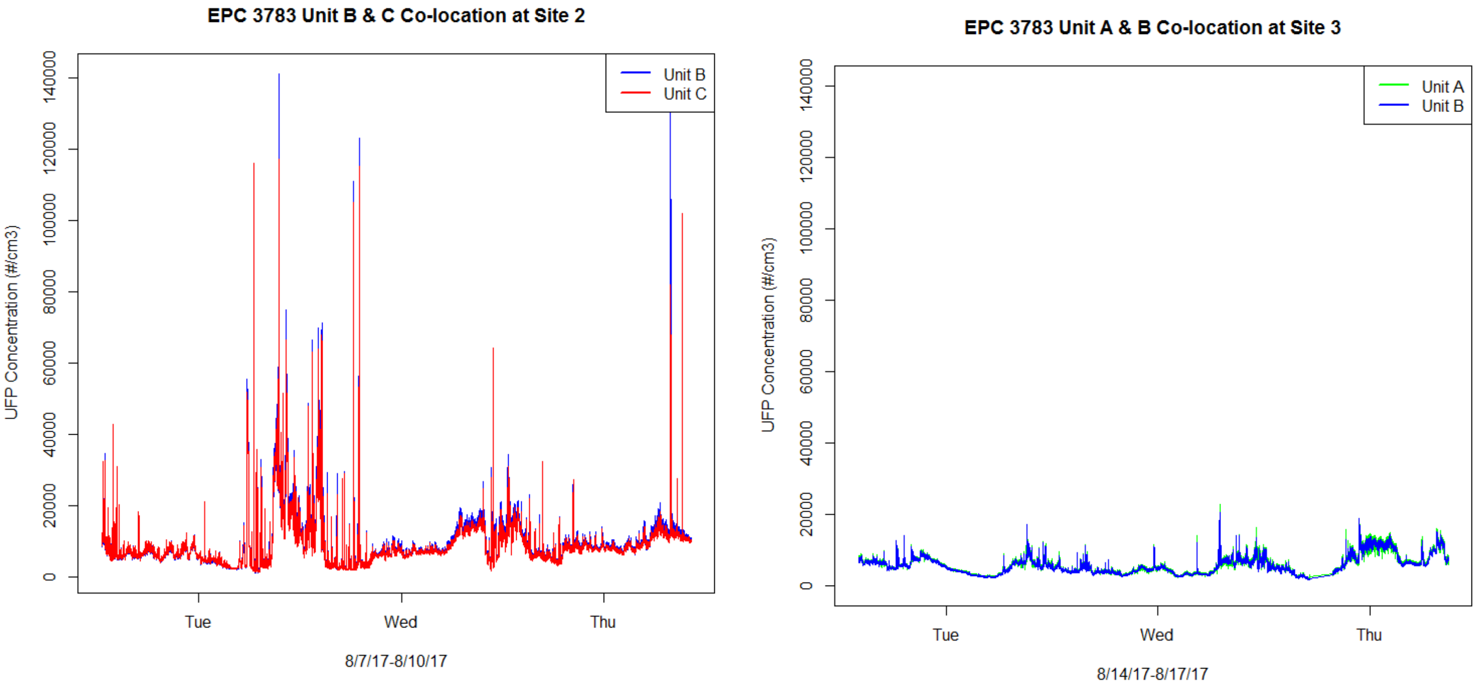

Figure 2. Results from PNC co-location experiments.

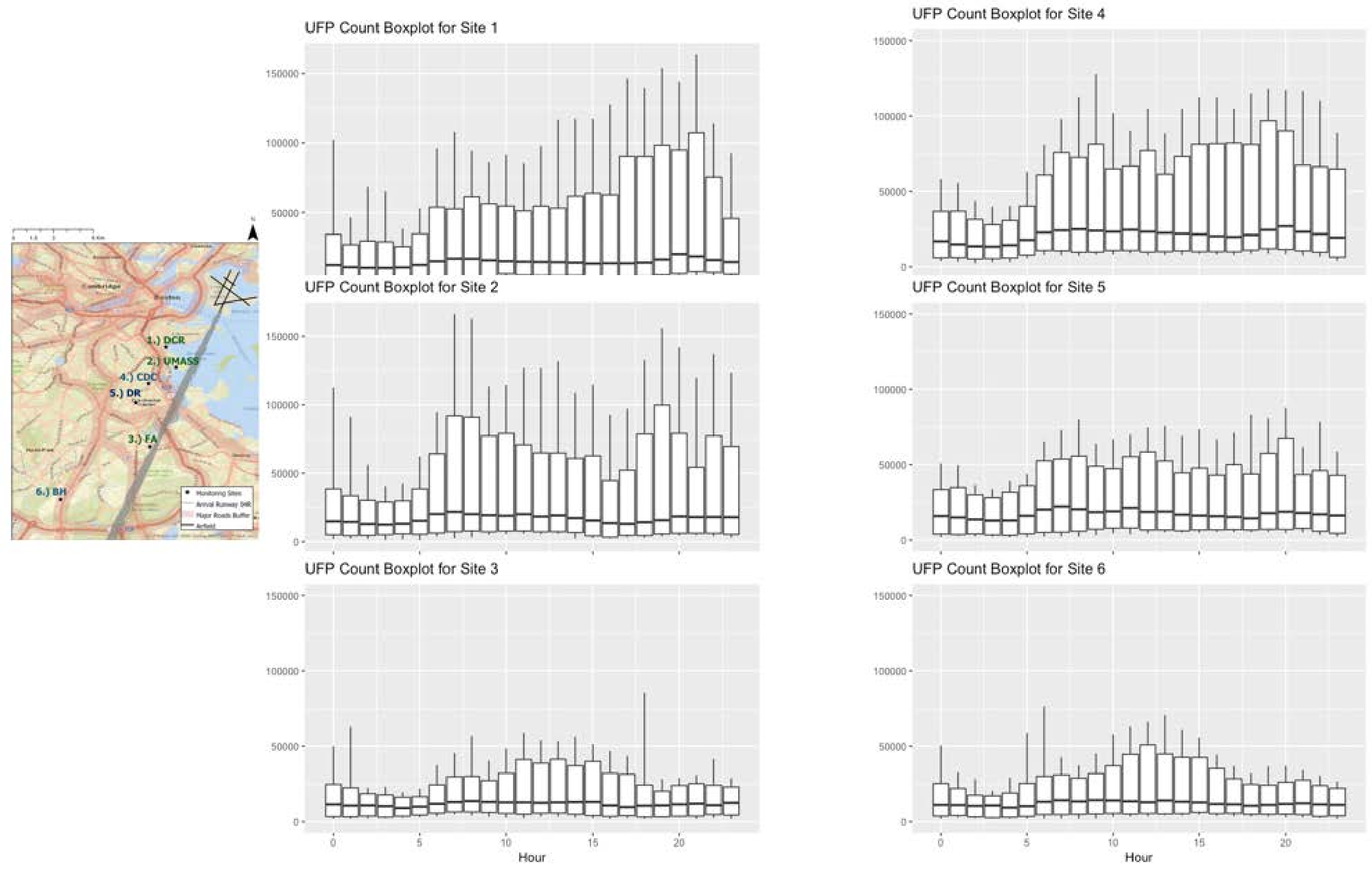

Figure 3. Diurnal boxplots for each monitoring site

Another approach for developing preliminary insights from our monitoring data is to examine diurnal concentration patterns. The diurnal variation of PNC (Figure 3) at each monitoring site allow for continued hypothesis generation. For example, all sites have a similar pattern of increasing concentrations in the early morning hours, which would be consistent with a growing traffic contribution or aviation contributions. Variations in diurnal patterns across sites, coupled with attributes of the sites themselves (i.e., proximity to runways and major roadways), may yield interesting hypotheses for future analyses. For example, elevated concentrations within an hour above the 95th percentile (but not at the median) would be consistent with an intermittent contribution from aviation emissions, versus consistently elevated concentrations at all percentiles. Examining the diurnal patterns, Sites 1 and 2 appear to have greater differences between the median and 95th percentile patterns, which could indicate aviation contributions. In contrast, Sites 4 and 5 have more local traffic and higher altitude flights, and display similar patterns at the median and the 95th percentile. After the NOP data have been linked with the PNC data it will allow for a more robust comparison of the PNC measures to flight path information and inform additional hypotheses with regard to aviation source contributions.

Table 2. PNC distribution by runway 4R being operational or non-operational and wind direction at Sites 2 and 3.

	S2-4R Operational	S2-4R Non-Operational	S2-4R Non-Operational	S3-4R Operational	S3-4R Non-Operational	S3-4R Non-Operational
Date	April 18	July 4	July 10	April 18	July 4	July 21
Sample Size	50,551	59,215	84,097	43,861	35,535	86,400
Wind	NW, N, NE	NE, ENE	SE, SSE	E, NE, NNE	ENE, NE	SW, SSE
0.1st percentile	2,958	8,076	6,913	3,008	11,842	8,504
1st percentile	3,174	10,857	8,267	3,350	12,065	9,039
5th percentile	4,890	13,841	9,335	3,940	12,289	9,460
50th percentile	20,818	20,462	13,923	10,318	14,422	12,519
95th percentile	75,715	41,335	23,362	22,480	21,150	19,094
99th percentile	120,463	54,703	26,008	34,611	25,758	25,768
99.9th percentile	198,934	61,582	37,077	58,117	30,223	30,995

Hypotheses can also be informed by considering concentration patterns by wind direction and by degree of flight activity. During our monitoring campaign, Runway 4R was fully operational for a portion of the period, non-operational for a portion of the period due to runway construction, and partially operational for a portion of the period immediately subsequent to the construction. This provides a natural experiment in which we can examine concentration patterns with varying amounts of flight activity as well as varying meteorology. As shown in Table 2, at Site 2 when 4R was operational and wind direction was from the N/NW/NW (optimal for runway utilization and for dispersion to the monitoring site), concentrations were elevated at the 95th percentile and above, when compared with a day with similar wind conditions when the runway was not operational. Additionally, when 4R was not operational and the winds were from the SE/SSE, the PNC distribution at Site 2 was higher at the lowest percentiles but significantly lower for most of the distribution. At Site 3, located at a greater distance from the airport but along the 4R arrival flight path, concentrations were similarly elevated during an operational day with favorable winds, albeit only at the 99th percentile and above and with a lower magnitude difference with a comparable non-operational day. This is consistent with a small and intermittant but measurable influence of aircraft arrivals at this monitoring site.

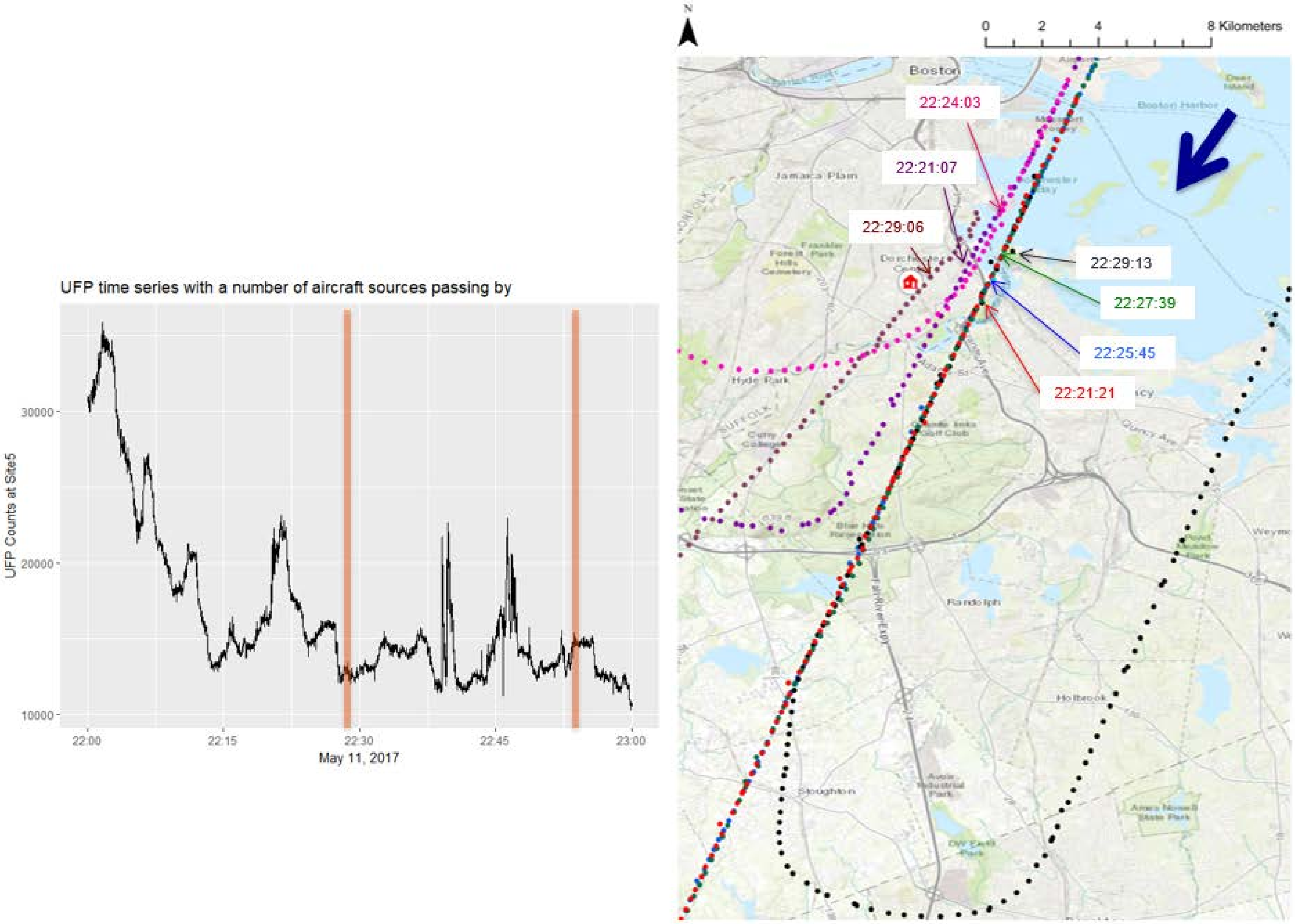

Figure 3. Example of flight activity data and runway PNC temporally linked.

Our regression models will ultimately leverage real-time flight activity data linked with one-second PNC measurements. Illustrating the complexity of these patterns, Figure 3 presents a time-series plot of data from a single hour of measurements at Site 2, with an overlay of flight activity. On a day with winds from the NNE, concentration peaks did occur on or around the times when aircraft were arriving, but peaks also occurred at other time points and the lags between flights and concentration increases were not consistent. This emphasizes the importance of regression modeling that accounts for lags between flight activity and concentrations as well as meteorological conditions, which can appropriately evaluate the incremental contribution of aviation activities.

Publications

None

Outreach Efforts

Dr. Jonathan Levy presented an update of the Project 18 field monitoring and descriptive data analysis at the ASCENT Fall 2017 meeting, along with a poster at the Spring 2017 meeting.

Doctoral student Chloe Seyoung Kim presented an oral presentation on a portion of the major accomplishments of Project 18 at the International Society for Exposure Science annual meeting in October 2017.

Awards

None

Student Involvement

Chloe Seyoung Kim, a doctoral student at BUSPH, was involved with the monitoring of PNC during the field campaign, data compilation and merging as well as statistical analysis.

Plans for Next Period

Four tasks are proposed over the next study period (10/1/17-9/30/18):

Task 1: Construct regression models to determine the contributions of aircraft arrivals to UFP and BC concentrations measured during the 2017 monitoring campaign.
Task 2: Conduct site selection for the 2018 monitoring campaign by analyzing the 2017 measurements and by considering optimal sites to determine multiple types of aviation source contributions.
Task 3: Measure UFP and other air pollutants at sites near Boston Logan International Airport selected under Task 2.
Task 4: Develop platforms that would allow for comparisons between atmospheric dispersion models implemented by collaborators on ASCENT Project 19 and monitored pollutant concentrations from Project 18.

Task 1: Construct regression models to determine the contributions of aircraft arrivals to UFP and BC concentrations measured during the 2017 monitoring campaign.

Utilizing the air pollution data collected during the 2017 monitoring campaign has allowed for an examination of average UFP concentrations on the days when the 4R runway was operational and not operational under all wind conditions, to examine the overall impact of arrival aircraft on ambient UFP concentrations at the study sites. Additionally, an examination of the correlations of simultaneously measured UFPs from multiple study sites to examine the similarities and variations of aircraft impact at different monitoring sites is already underway. The contributions of aircraft to ambient UFP and BC concentrations will be examined by comparing them to the background concentrations as well as by how well UFP and BC measurements correlate.

A few different analytical approaches are being explored to interpret the data collected during the field campaign prior to constructing regression models. Examination of space-time plots of the PNC data will inform if there are distinct patterns of plume movement and potential time lag differences between the sites under specific meteorological conditions. Results from these descriptive analyses will subsequently inform the regression model development process.

For the regression models, the goal is development of multivariate generalized additive models to examine the association between UFP and BC concentrations and real-time flight activity, accounting for aircraft locations in space relative to the monitor including terms for wind speed/direction and temperature. Each study site will be modeled individually to look at location-specific impact of aircraft arrivals along with meteorological and other local environmental conditions, and then combined models will be explored. Each of these regression models will be able to estimate on a short-term and long-term basis the amount of the measured UFP attributable to flight activity, by zeroing out the flight activity terms and determining the predicted concentrations. This would answer the question regarding the spatiotemporal patterns of aviation-related UFP contributions, as well as the relative influence of flight arrivals (and departures where relevant) in different locations.

Task 2: Conduct site selection for the 2018 monitoring campaign by analyzing the 2017 measurements and by considering optimal sites to determine multiple types of aviation source contributions.

The 2017 air pollution monitoring campaign was designed specifically to isolate the contributions of arrival aircraft on runway 4R, which is important for the initial source attribution task, but may not be the optimal sites to determine multiple types of aviation source contributions. A crucial first step in planning the 2018 monitoring campaign will be to evaluate the data obtained during the 2017 monitoring campaign and evaluate the attributes of current and new sites that would allow for additional levels of analysis. For example, new site selection might want to isolate departure contributions as well as arrivals, at varying distances and directions from the airport.

Construction of geospatial layers reflecting key inclusion/exclusion criteria will be used to facilitate site selection. For example, retaining the exclusion criteria that includes proximity to a major roadway or other major local sources of air pollution will help isolate the effects of aircraft within statistical analyses. Mapping key flight paths to determine geographic areas that meet the selection criteria will include both arrivals and departures. A subset of sites from the 2017 monitoring campaign will be selected, to allow for continuity, but choosing a number of new sites to extend the scope of the regression analyses. The length of deployment and the ancillary data collection strategies will also be reassessed to maximize expansion of Task 1 regression model development and future investigations of aviation source contributions. Additionally sites will be prioritized where previously established relationships with individuals or businesses can ensure security and access, to simplify the process of monitor deployment. Also, the new sampling campaign will incorporate additional monitoring equipment to enhance the air pollution analysis to include UFP size distribution and NO/NO_2, which is described in greater detail under Task 3.

Task 3: Measure UFP and other air pollutants at sites near Boston Logan International Airport selected under Task 2.

Given the sites chosen under Task 2, a monitoring campaign in 2018 will be conducted to inform an aviation source attribution analysis to expand upon Task 1 regression model development. Instrumentation and protocol will be similar to the ongoing 2017 monitoring campaign, but with some key enhancements to improve insights regarding aviation source contributions.

Monitoring instruments will include the TSI Model 3783 water-based CPC for UFP, our primary measure of interest, which was used in the 2017 monitoring campaign. The 3783 is intended for long-term deployment and can record 1-second average concentrations, valuable time resolution for capturing short-term concentration spikes. Of note, as the Model 3783 CPC is temperature-sensitive, it needs to be deployed in a conditioned space to protect against extreme heat or cold, allowing for long-term deployment.

To enhance the UFP monitoring campaign a TSI Scanning Mobility Particle Sizer Spectrometer (SMPS) 3938, which is widely used as the standard for measuring airborne particle size distributions, will be integrated into the sampling campaign. The SMPS 3938 connects with the 3783 to provide particle size distribution of short-term concentration spikes. Insight on particle size distributions is crucial information for validating aviation source contributions and connecting with outputs from atmospheric dispersion models for UFP being developed within Project 19. Although obtaining and deploying three SMPS 3938 instruments is beyond the scope of this project, an instrument will be borrowed from collaborators at Tufts University. This instrument will be rotated through the sampling locations.

In addition, the AethLabs model AE51 microaethalometer will be used to measure BC. A number of low-cost NO/NO_2 sensors have recently been developed, and a sensor that gives high-fidelity outputs could allow for future studies with simultaneous real-time measurements at numerous sites. This also provides an additional pollutant for any future comparisons with atmospheric dispersion model outputs, which could help isolate factors that influence predictions of particulate matter vs. gas-phase pollutants.

The local Davis Vantage Pro2 weather stations will be used to capture real-time wind speed/direction and other meteorological conditions. Obtaining flight activity data from FAA for the time periods of sampling will be essential for regression model development, which will include location of each flight as well as basic aircraft characteristics, which could be linked with AEDT to determine aircraft-specific attributes that may be predictive of emissions and corresponding concentrations.

Task 4: Develop platforms that would allow for comparisons between atmospheric dispersion models implemented by collaborators on ASCENT Project 19 and monitored pollutant concentrations from Project 18.

While the primary objective of Tasks 1-3 is to inform aviation source attribution using ambient pollution measurements, the insights from these models could be connected with atmospheric dispersion models applied at the same location and dates. Within Project 19, UNC researchers are implementing CMAQ and other dispersion models to examine the air quality implications of emissions of various air pollutants from aviation, with a current focus on modeling UFP. If in the future Project 19 applies atmospheric dispersion modeling tools focused on locations near Boston Logan International Airport, this would allow for future comparative analyses. The purpose of this Task is to develop data processing systems that would allow for these comparative analyses to be conducted.

To aid these efforts, development of two types of output files under Task 4 will occur. First, the UFP measurements collected during the 2017 monitoring campaign will be processed and provided in a format requested by Project 19. These measurements reflect the contributions from both aviation and other sources, and can be directly compared with all-source dispersion models such as CMAQ. The BU research team will complete QA/QC of the 2017 monitoring data, post-process the data in a form that would be aligned with atmospheric dispersion modeling outputs from Project 19, and make the data available to UNC collaborators. In the second phase, subsequent to the completion of all regression models (Task 2), development of an analogous database with the aviation-attributable UFP concentrations will be processed. This will be calculated by comparing the regression model predictions with the predictions given no aviation sources (i.e., all aviation terms set to zero). This would allow for comparisons with aviation source contribution estimates from atmospheric dispersion models.

Task #2: Work with collaborators on ASCENT Projects 19 and 20 to quantify the health implications of modeled aviation-related air pollutant concentrations.

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Objective(s)

Multiple tasks within ASCENT Projects 19 and 20 involve estimation of the public health impacts of air pollution exposures associated with aviation sources or potential control strategies. For example, MIT researchers are in the process of developing global adjoint models for ozone, which require globally appropriate concentration-response functions and population datasets. Similarly, UNC researchers are continuing implementation of CMAQ-DDM to examine the air quality implications of changing emissions of various air pollutants from aviation, with corresponding health risk implications. The objective of this task was to support MIT and UNC collaborators on an as-needed basis, conducting new literature review or synthesis as needed.

Research Approach

Other than limited ad hoc consultations, no formal collaboration or input was requested, so there were no defined efforts underneath this task

Milestone(s)

Not applicable

Major Accomplishments

Not applicable

Publications

Penn SL, Boone ST, Harvey BC, Heiger-Bernays W, Tripodis Y, Arunachalam S, Levy JI. Modeling variability in air pollution-related health damages from individual airport emissions. Environ Res 156: 791-800 (2017).

Outreach Efforts

During this funding period, the health damage function work was presented at the Fall 2016 ASCENT meeting and the October 2016 FAA Tools/Analysis Coordination Meeting.

Awards

None

Student Involvement

Stefani Penn and Lindsay Underhill, both doctoral students at BUSPH, were involved in various aspects of developing the health impact assessment modeling platform.

Plans for Next Period

There are no plans to continue any formal consultative engagement on this topic, though we will continue to be available for ad hoc discussions on relevant topics, and collaborative work with Project 19 on health impacts of air pollution will be conducted if appropriate.