Project 018 Modeling Airport-Related Air Pollutant Concentrations and Health Impacts

Boston University School of Public Health

Project Lead Investigator

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University Participants

Boston University School of Public Health

- P.I.(s): Jonathan I. Levy, Professor and Associate Chair
- FAA Award Number: 13-C-AJFE-BU, Amendment 5
- Period of Performance: October 1, 2015 – September 30, 2016
- Task(s):
    1. Apply the health damage functions (all airports) and spatial pollutant concentration surfaces (directly modeled airports) to evaluate hypothetical policy scenarios.
    2. Compare aviation-related health impacts as well as damage functions with those from other important source sectors.
    3. Identify UFP concentration datasets that could be used to determine the magnitude and spatial extent of contributions from arriving aircraft in a near-airport setting.
    4. Apply multivariable regression modeling techniques to quantify the contribution of aircraft arrivals and other source activity with measured UFP concentrations.

Project Funding Level

$150,000. Matching funds provided by carry forward from funding from the North American Insulation Manufacturers Association, with 75:25 cost share waiver.

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.

Post-doctoral researcher: Stefani Penn, MS, PhD. Dr. Penn led the analytical efforts to develop the individual airport health damage function model, as part of her dissertation work, including the effort to design individual airport atmospheric modeling runs and to estimate health damage functions.

Graduate Student: Lindsay Underhill, MS. Ms. Underhill leads the analytical efforts involving application of the health damage function models (Tasks 1 and 2).

Graduate Student: Chloe Kim, MPH. Ms. Kim leads the analytical efforts involving identification of UFP monitoring datasets and statistical analyses of those data (Tasks 3 and 4).

Research Assistant: May Woo. Ms. Woo supported data management and other analytical efforts across the project.

Project Overview

The overall objective of this research is to develop tools that will enable quantification of airport-specific health impacts from aircraft emissions at selected airports, working collaboratively with air quality modeling efforts under other ASCENT projects. Our primary objective within this funding year was to apply previously-developed health damage function models for policy and comparative analyses. In addition, there has been increasing interest in 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. Our objective within the current funding year was to identify and work with an existing near-airport dataset and apply advanced regression modeling techniques to isolate the contribution of aircraft emissions, specifically examining the magnitude associated with arrival flight paths. This work will enhance the interpretability of the dispersion model-based work and will provide additional insight about individual airport contributions to exposures and health risks.

Task 1 - Apply the health damage functions (all airports) and spatial pollutant concentration surfaces (directly modeled airports) to evaluate hypothetical policy scenarios.

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Objective(s)

To demonstrate the utility of our individual airport health damage function modeling approach, we proposed to apply our previously-generated estimates of health risks per unit emissions to a series of hypothetical policy scenarios. We proposed to work closely with FAA and other stakeholders to determine realistic scenarios, including some that have been evaluated using other modeling approaches, which would allow us to do model intercomparisons and general quality assurance checks. Along with the defined scenarios, we proposed to conduct a series of “what if” analyses meant to determine the importance of the individual airport insights. Because of the importance and sensitivity of this work, we proposed to present both our hypothetical policy scenarios and set of “what if” analyses to FAA and the ASCENT advisory board, gathering feedback before conducting the analyses.

Research Approach

Given regression models developed previously as part of Project 18, explaining variability in health risks per unit emissions across airports and pollutants, we developed statistical code to calculate health damage functions for all airports in the US (both directly modeled by Project 18 and others), and to rapidly estimate the national health impacts of alternative emissions scenarios. In December 2015, we were given four emissions scenarios to model by FAA: 1. Use of ultra-low sulfur fuel: sulfur emissions reduced by 97.5% nationally; 2. Use of 50% blended fuel: 50% primary elemental carbon emissions, 50% sulfur emissions; 3. Implementation of ULS fuel along the East Coast (~50% reduction in sulfur emissions for airports in the eastern seaboard states); 4. Implementation of ULS fuel along the West Coast (~50% reduction in sulfur emissions for airports in CA, OR, WA). Those analyses were completed and presented at the spring 2016 ASCENT meeting, but we were subsequently told by FAA to discontinue this task, given a lack of consensus at FAA on the most appropriate scenarios to model.

Milestone(s)

We proposed to identify defined policy scenarios by 12/31/15 (Task 1.1), to apply the health damage functions to evaluate policy scenarios by 4/30/16 (Task 1.2), and to complete the policy analysis manuscript by 9/30/16 (Task 1.3). Tasks 1.1 and 1.2 were completed by the due dates, but Task 1.3 was not completed per FAA guidance to discontinue the work.

Major Accomplishments

As this task was discontinued per FAA request, no major accomplishments are provided.

Publications

None

Outreach Efforts

None

Awards

None

Student Involvement

Individual airport health damage function modeling was led by Stefani Penn as a doctoral student (graduated 9/15), and the policy scenario modeling work was led by Lindsay Underhill as a doctoral student.

Plans for Next Period

None, as the work was discontinued per FAA request.

Task 2 - Compare aviation-related health impacts as well as damage functions with those from other important source sectors.

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Objective(s)

For any analyses of the health effects of aviation emissions, it is important to be able to place the output in context. Aviation is a relatively small contributor to ambient air pollution in most locations, so it is valuable to consider how other source sectors contribute. However, while multiple previous studies have done these comparisons, no studies to date have compared health damage functions (health impacts normalized by emission rate) across source sectors using comparable modeling techniques. This type of comparison will provide multiple useful insights, including whether aviation sources are more like ground-level sources (e.g., residential combustion, road traffic) or sources with elevated stack heights (e.g., power plants) from a public health perspective, and the extent to which the geographic patterns of where airports are located influence the damage functions relative to other source sectors.

Research Approach

For each of the three source sectors (power plants, residential combustion sources, and aviation), health damage functions were derived using identical versions of CMAQ-DDM using the same meteorological year and other basic assumptions. Briefly, we used CMAQ v 4.7.1 instrumented with DDM in three dimensions. We modeled power plants as state aggregates, allocating each power plant to a 36 x 36 km grid cell. Residential combustion sources were modeled as low-level area sources, aggregated to county level for apportionment to grid cells by state. Airports were modeled individually, for the subset of 66 airports included in the modeling platform, using chorded aircraft LTO emissions derived from AEDT. Because modeling the full year was computationally intensive, we selected two months (January and July) to provide bi-seasonal representation, using all-source emissions and meteorology from 2005. To provide initial background conditions, a spin-up period of 11 days prior to each month was simulated. Whole-month sensitivity values from January and July were averaged to represent annual estimated contributions to ambient $PM_{2.5}$ and O_3 concentrations. Values are reported as 24-hour averages for $PM_{2.5}$ constituents and 8-hour maximum values for O_3 for consistency with current regulatory policies.

Due to the computationally intensive nature of CMAQ-DDM, it was not practical to construct separate runs for each source sector and source-state. To maximize efficiency, we incorporated 1-3 states or airports into a single DDM run, and we developed algorithms to separate the concentration impacts from each state or airport. Briefly, we applied image separation techniques using MATLAB 8.1.0, R2013a (MathWorks, Natick, MA). We developed a region-growing algorithm to determine regions of concentrations attributable to each source-state for each emitted precursor / ambient pollutant relationship within each model run and season. This algorithm allowed for both positive and negative sensitivities to be included within regions, and ensured that within a run, a smaller state's region could capture the extent of its health impacts. Quality assurance (QA) analyses were performed, including analysis of total health impact and health damage function distributions for resultant health values, as well as visual inspection of concentration surfaces. For runs that did not meet QA criteria, we re-ran CMAQ-DDM for individual states in isolation. This process allowed determination of emissions impacts from individual source-states within a CMAQ-run group. The image segmentation algorithm is described in detail in Penn et al. 2016.

The resultant ambient pollutant concentrations (for $PM_{2.5}$ and O_3) were then linked with population and mortality rate data from the Centers for Disease Control and Prevention (CDC). Concentration-response functions associating ambient pollutant concentrations with health effects were derived from the epidemiological literature. To associate premature mortalities with $PM_{2.5}$ concentrations, we applied a central estimate concentration-response function of a 1% increase in mortality associated with every 1 $\mu g/m^3$ increase in annual average $PM_{2.5}$ concentration. To associate premature mortalities with O_3 concentrations, we applied a central estimate concentration-response function of a 0.4% increase in daily mortality per 10 ppb increase in daily 8-hour maximum O_3 concentrations, based on major multi-city and meta-analysis studies that evaluated health impacts across the year.

Health damage functions (HDFs) were calculated as mortality risk per thousand tons of emitted pollutants. HDFs were developed by source sector and source state for several precursor pollutants, including primary elemental carbon (PEC), primary organic carbon (POC), and primary sulfate (PSO4) as primary $PM_{2.5}$ precursors; nitrogen oxides (NOx), sulfur dioxide (SO_2), and volatile organic compounds (VOCs) as secondary $PM_{2.5}$ precursors; and NOx and VOCs as O_3 precursors. To compare HDFs across source sectors, we focused on a subset of states with sufficiently robust values. Exclusion criteria included states with very low emissions for at least one of the source sectors or states where a majority of total aviation emissions was not modeled directly, to ensure robust health damage functions that are representative of the state as a whole. For the remaining 21 states, we first visually compared HDFs across pollutants, sources, states, and seasons to examine potential drivers of variability. We then formalized the comparisons by developing explanatory variables related to downwind population patterns and meteorology. While developing formal regression models to explain variability was beyond the scope of the work and not needed given the applications, we examined explanatory variables individually and in combination.

Milestone(s)

We proposed to complete the manuscript comparing health damage functions across source sectors by 6/30/16 (Task 2). This task was not completed by the projected date, in part because of the multiple redirections of effort related to Task 1, which was ultimately discontinued per FAA request. The core datasets have been compiled and the final comparative analyses are in progress, and we anticipate the manuscript being completed in the first quarter of 2017.

Major Accomplishments

As seen in Figure 18.1, HDFs were successfully derived and were shown to vary by pollutant precursor, source sector, state, and season. Overall, the range of HDFs for primary $PM_{2.5}$ from aviation is lower than those from power plants and residential combustion in January, but the distributions are similar in July. However, aviation HDFs are not consistently lower than the other sectors, and in a few cases, they are higher than HDFs from other sectors. For example, in January, the HDF for California is higher for aviation compared to residential combustion, but lower for aviation compared to power plants. This is likely attributable to a complex combination of source locations relative to population patterns and emissions/plume characteristics.

We examined the variability of pollutant-, sector-, and season-specific HDF values between states to potentially identify factors contributing to regional differences. In line with our expectation that population would be a key driver of HDF variability for primary $PM_{2.5}$ precursors, we found that the highest HDF values tend to be from states with a relatively greater potential for population exposure to source emissions (i.e. high population density downwind). To develop a more refined sense of the influence of population patterns, we developed metrics that reflected the emissions-weighted average population within various distances from sources, taking account of meteorological trends.

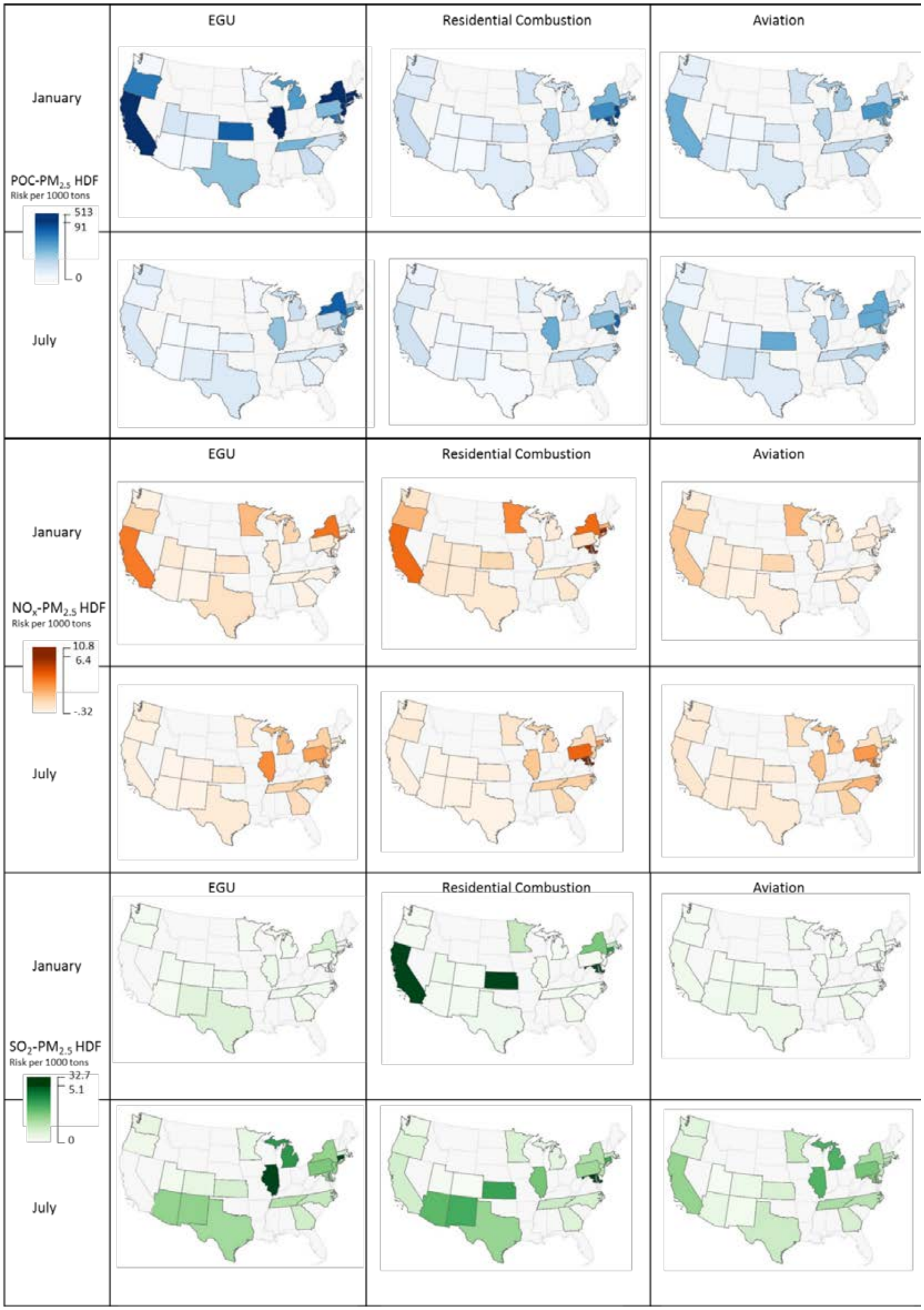

Figure 18.1. HDF variability by source sector, season, and $PM_{2.5}$ precursor pollutant, including POC in blue (top), NO_x in orange (middle), and SO_2 in green (bottom). The comparative analysis is focused on states with sufficient emissions from each sector and excluded states are represented in gray.

Figure 18,2 provides an illustration of the importance of more spatially refined analyses to facilitate interpretation of values. We present the relative proximity of POC emissions from aviation to high population areas within northwestern and northeastern states in the US. In general, the HDF values for the selected northwestern states are lower than those from the northeastern states. In both regions, emissions are clustered around areas with high population density; however, the northeast tends to have more densely populated areas surrounding and downdwind of areas of high emissions.

Figure 18,2. Relationship between population density and (2a) primary organic carbon (POC) emissions in January from aviation in the northwestern US and (2b) POC emissions in January from the aviation sector in the northeastern US. Total emissions per 36 x 36 km grid cell is represented by red graduated symbols, with larger symbols indicating higher emissions. Population density is represented by grayscale shading, with darker shading indicating higher population density.

As anticipated, HDF patterns for secondarily formed pollutants are less easily explained by population patterns, given the influence of meteorology and background concentrations on $PM_{2.5}$ and O_3 formation. In ongoing analyses, we are developing refined estimates of downwind populations at various distances and of background concentrations of key pollutants, to inform future comparative analyses.

Publications

Penn SL, Arunachalam S, Woody M, Heiger-Bernays W, Tripodis Y, Levy JI. Estimating state-specific contributions to PM2.5- and O3-related health burden from residential combustion and electricity generating unit emissions in the United States. Environ Health Perspect, in press.

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. Under review.

Underhill LJ, Penn SL, Boone S, Arunachalam S, Woo M, Levy JI. A comparative analysis of health damage functions across pollutants, source sectors, and geographic locations. Presented at the International Society for Exposure Science Annual Meeting, October 2016.

Outreach Efforts

Presentation at ASCENT meetings and academic conferences.

Awards

None

Student Involvement

Individual airport health damage function modeling was led by Stefani Penn as a doctoral student (graduated 9/15), and the comparative analysis work was led by Lindsay Underhill as a doctoral student.

Plans for Next Period

We plan to complete the formal comparative analyses and the corresponding manuscript in the first quarter of 2017.

Task 3 - Identify UFP concentration datasets that could be used to determine the magnitude and spatial extent of contributions from arriving aircraft in a near-airport setting.

Boston University School of Public Health

Objective(s)

As an initial step in constructing models of the contribution of aircraft arrivals to UFP concentrations, we needed to identify a candidate dataset for secondary analysis. While fully addressing all relevant research questions is challenging using field data not collected with the primary objective of aviation source apportionment, multiple pre-existing datasets would allow us to gain important insights and better determine the appropriate scope and scale of future efforts. Our objective was therefore to contact investigators, conduct sufficient preliminary analyses, and execute data use agreements to allow for statistical analyses to be conducted by our research team.

Research Approach

Not applicable – see Task 4 for analytical approaches for these data.

Milestone(s)

We proposed to identify the UFP concentration dataset and execute a data use agreement by 12/31/15 (Task 3), and this was completed in a timely fashion, with slight delays related to maternity leave for the doctoral student working on the project.

Major Accomplishments

We reviewed recent publications and available data and determined that the most appropriate candidate for secondary data analysis would be the CAFEH study conducted in the Boston area (http://sites.tufts.edu/cafeh/). The study had extensive fixed-site and mobile monitoring data including UFP across multiple neighborhoods that are both along flight paths and further away from flight paths. After meeting with lead investigators from CAFEH, we determined that real-time UFP monitoring data from a single fixed site at the Boston Globe would be ideal for our initial analysis (Figure 18.3). The site is directly underneath arrival flight paths and is generally upwind from major highways and other sources of UFP, so it would provide the cleanest natural experiment, without the analytical challenges related to mobile monitoring data collected in close proximity to traffic sources.

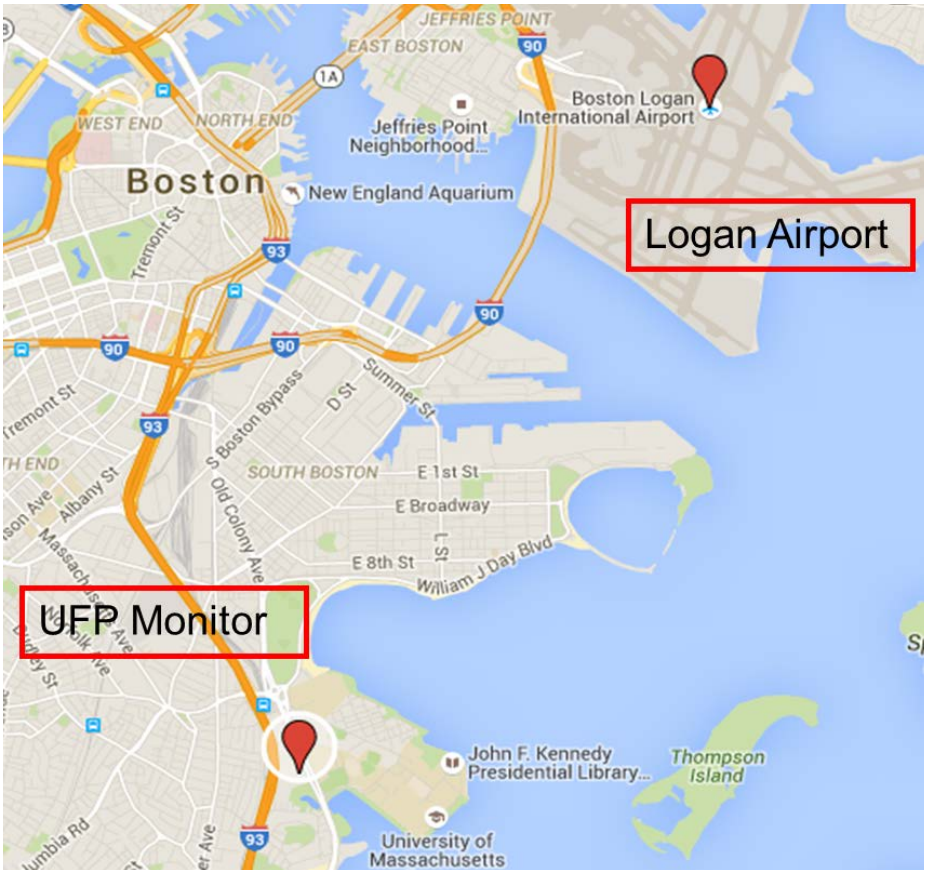

Figure 18,3. Location of UFP monitor relative to Logan Airport and major highways.

Publications

Not applicable – see Task 4.

Outreach Efforts

Not applicable – see Task 4.

Awards

Not applicable – see Task 4.

Student Involvement

The effort to identify an appropriate dataset was led by Chloe Kim, a doctoral student at BUSPH.

Plans for Next Period

None, as the task was completed and all analyses of the data are described under Task 4.

Task 4 - Apply multivariable regression modeling techniques to quantify the contribution of aircraft arrivals and other source activity with measured UFP concentrations.

Boston University School of Public Health

Objective(s)

With the dataset identified in Task 3, our objective was to conduct a series of statistical analyses aimed at quantifying the contribution of aircraft arrivals to UFP concentrations at the identified monitoring site underneath an arrival flight path. This involved using regression models to predict measured UFP concentrations as a function of real-time flight activity, meteorology, and other related variables. The objective was to use a regression modeling structure that accounted for the anticipated lag between when the flight was overhead and when the plume would reach the monitoring site, while also capturing autocorrelation in the real-time measurements. In addition, we proposed to conduct a series of data visualizations and exploratory analyses to identify the prevailing meteorological conditions that led to elevated concentrations.

Research Approach

Four different datasets – flight activity data, UFP concentration data, wind data, and temperature data – were collected and merged by their date-time stamp. PDARS/ASDE-X data (flight activity data) were provided by the FAA at 1-second resolution capturing all non-military arrival aircrafts to runway 4L and 4R at Boston Logan International Airport. Real-time UFP concentrations were collected from CAFEH investigators using a TSI 3775 Condensation Particle Counter between March 9, 2011 and May 31, 2011 at 1-second resolution at the Boston Globe building, which is located ~7 km south of the airport and underneath the flight arrival path to 4L/4R. Meteorological data were collected at 1-minute resolution at Boston Logan International Airport by the National Climatic Data Center.

We determined aircraft position at each observed second by its latitude and longitude in relation to the UFP monitor location. We then constructed multiple dummy variables to indicate the presence of aircraft at each time point within defined grid cells; by incorporating all of these spatial variables into the regression model, we were able to capture potential time lags between emissions and exposure. Multivariable regression models were developed using log-transformed UFP concentrations as the outcome variable and aircraft presence/absence at defined locations as the predictors, adjusting for wind speed, temperature, time of day, and day of week for each given wind direction (by 30° sections).

Milestone(s)

We proposed to complete statistical analyses of UFP concentrations and aircraft arrivals (Task 4.1) by 6/30/16 and to complete the related manuscript (Task 4.2) by 9/30/16. The tasks were delayed slightly because of the maternity leave of the doctoral student leading the analysis, as well as because of the statistical complexity and interpretability challenges inherent in real-time air pollution and flight activity data. The core regression models have been constructed and a manuscript is in progress, and we anticipate the manuscript being completed in the first quarter of 2017.

Major Accomplishments

First examining the distribution of UFP concentrations by wind direction (Figure 18.4), we see elevated concentrations with winds from the west (210-300 degrees), consistent with the proximity of the monitor to I-93, a major north-south highway located < 50 meters due west of the monitor. There also appears to be a secondary peak between 0 and 60 degrees, consistent with an aircraft influence related to 4L/4R.

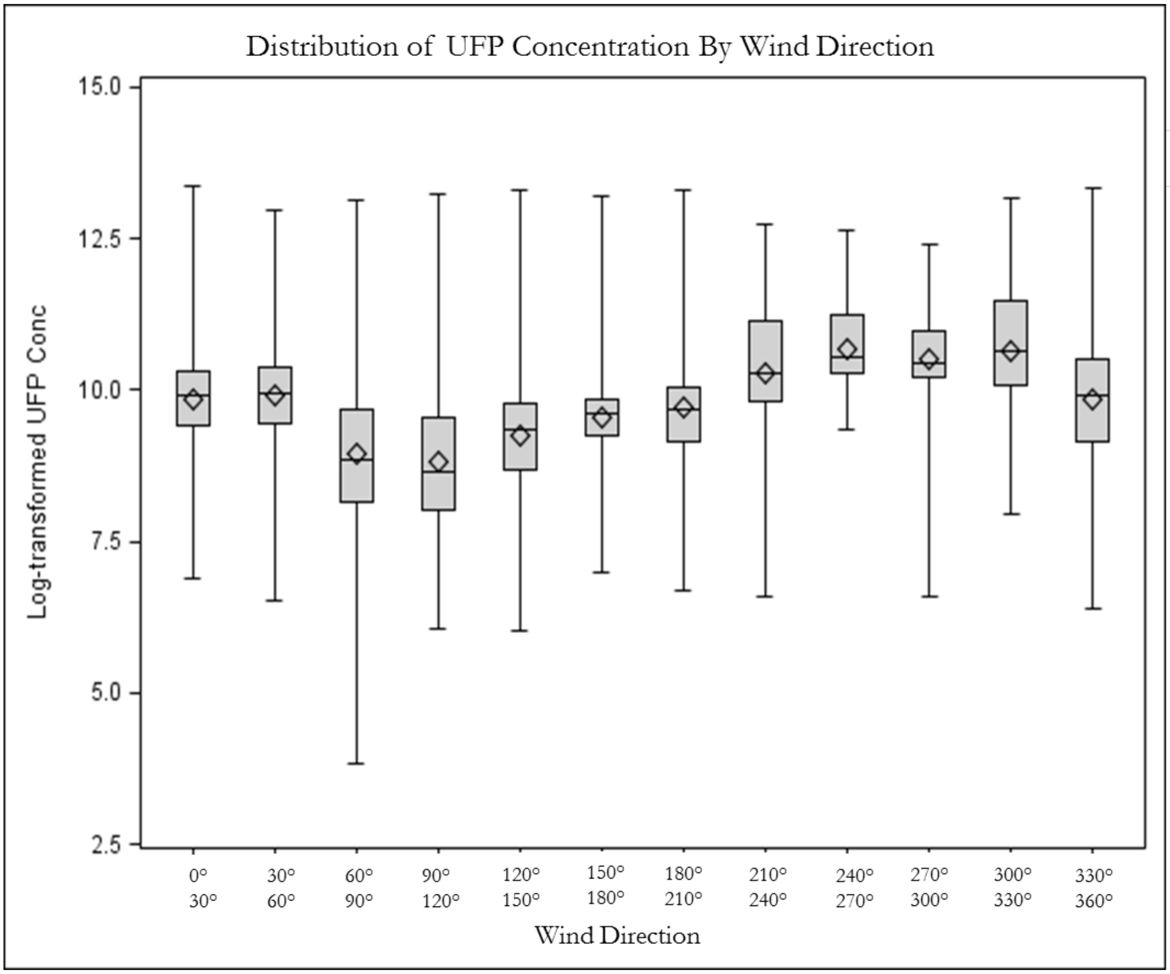

Figure 18,4. UFP concentrations at the Boston Globe site as a function of wind direction.

Our analyses also suggested that the impact of aircraft arrivals on ambient UFP concentrations may not be limited to areas directly underneath the flight path, given that plumes of descending aircraft travel in a highly complex manner that is not yet well understood. As an illustration, we mapped UFP concentrations of two example flights. Within Figure 18.5, the spatial patterns of UFP measurements reflect the geographic locations of aircraft during the second in which fixed-site UFP concentrations were measured at the Boston Globe site. In other words, the concentrations represented at a given point in space do not reflect concentrations measured in that location, but rather concentrations at the fixed site when the aircraft was at the designated location. For both flights, there were two segments of elevated UFP concentrations. One happens close to the monitor, when the aircraft are relatively lower, suggesting a relatively short lag between emissions and increased concentrations. A second elevation happens further away from the monitor when the aircraft are relatively higher, with the influence of wind speed and direction suggesting an influence earlier in the flight trajectory. When wind speed is slower (left of Figure 18.5), there is a lingering effect of the aircraft for some time (~3 min) over a larger area, while when wind speed is faster (right of Figure 18.5), the longer-distance effect of the aircraft is higher but disappears more quickly (~1 min).

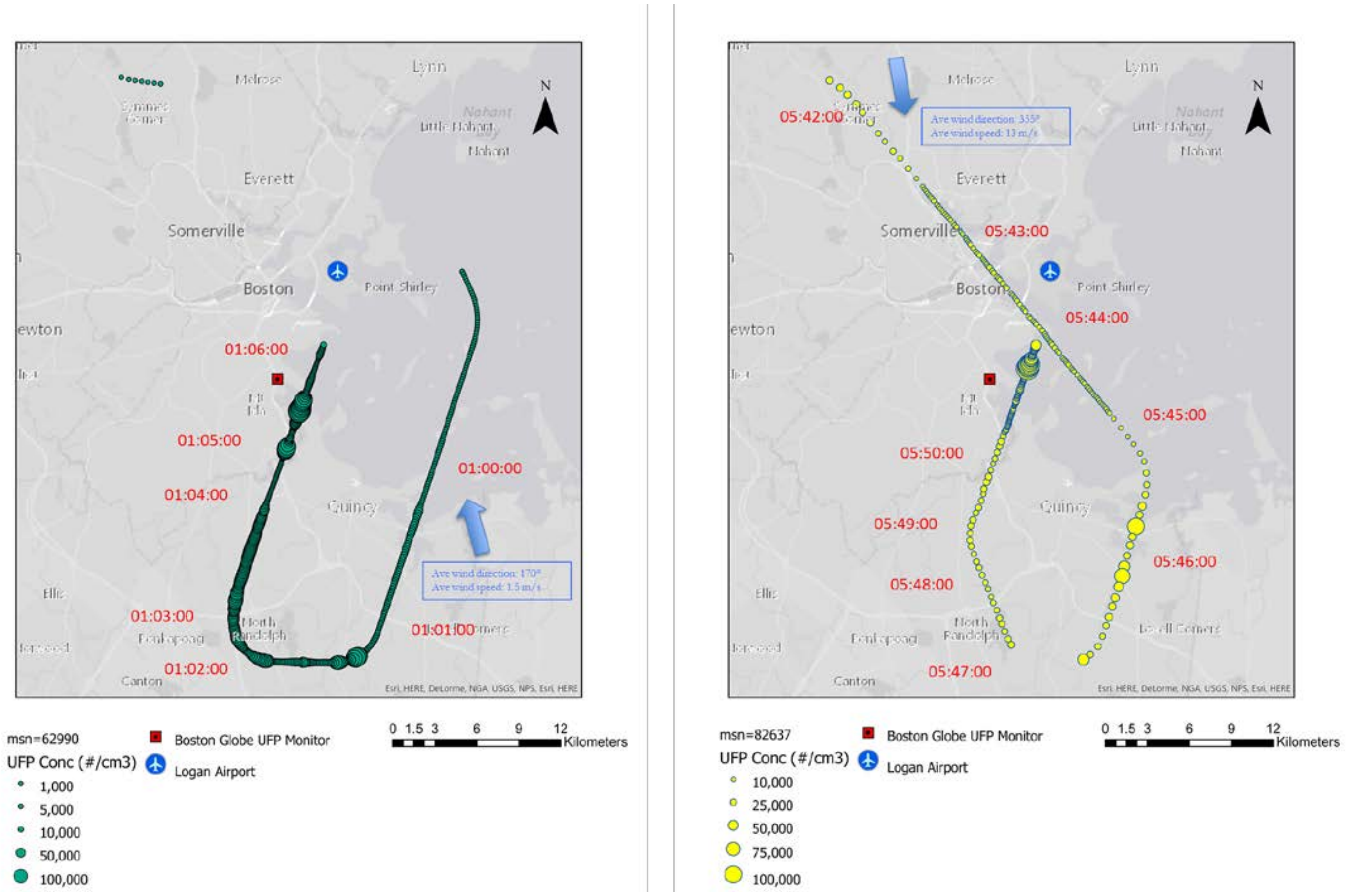

Figure 18,5. UFP concentrations at the Boston Globe site for two sample flight trajectories. Measurements in space represent concentrations measured at the fixed site during the second in which the aircraft was in a given location.

Within our regression models, we identified geographic hot spots under specific wind conditions (Figure 18.6). Since the models did not include time lags and the spatial covariates were intended to capture lags between emissions and ground-level impact, the hot spots likely reflect the effects of aircraft arrivals at earlier locations in their trajectories. As anticipated, the locations of hotspots vary widely depending on the wind direction. However, the consistent pattern is that the greatest increases in UFP concentrations were observed when aircraft were farther from the monitor. Given distance, elevation, and prevailing winds, this likely reflects times earlier in the flight trajectory when the monitor would be downwind of the plume (i.e., Figure 18.5). These results suggest that the impacts of aircraft arrivals on ambient UFP concentrations may not be limited to areas directly underneath the flight path. Given the elevation of the aircraft above the monitoring site, the point of average maximal impact appears to be a considerable distance from the flight path.

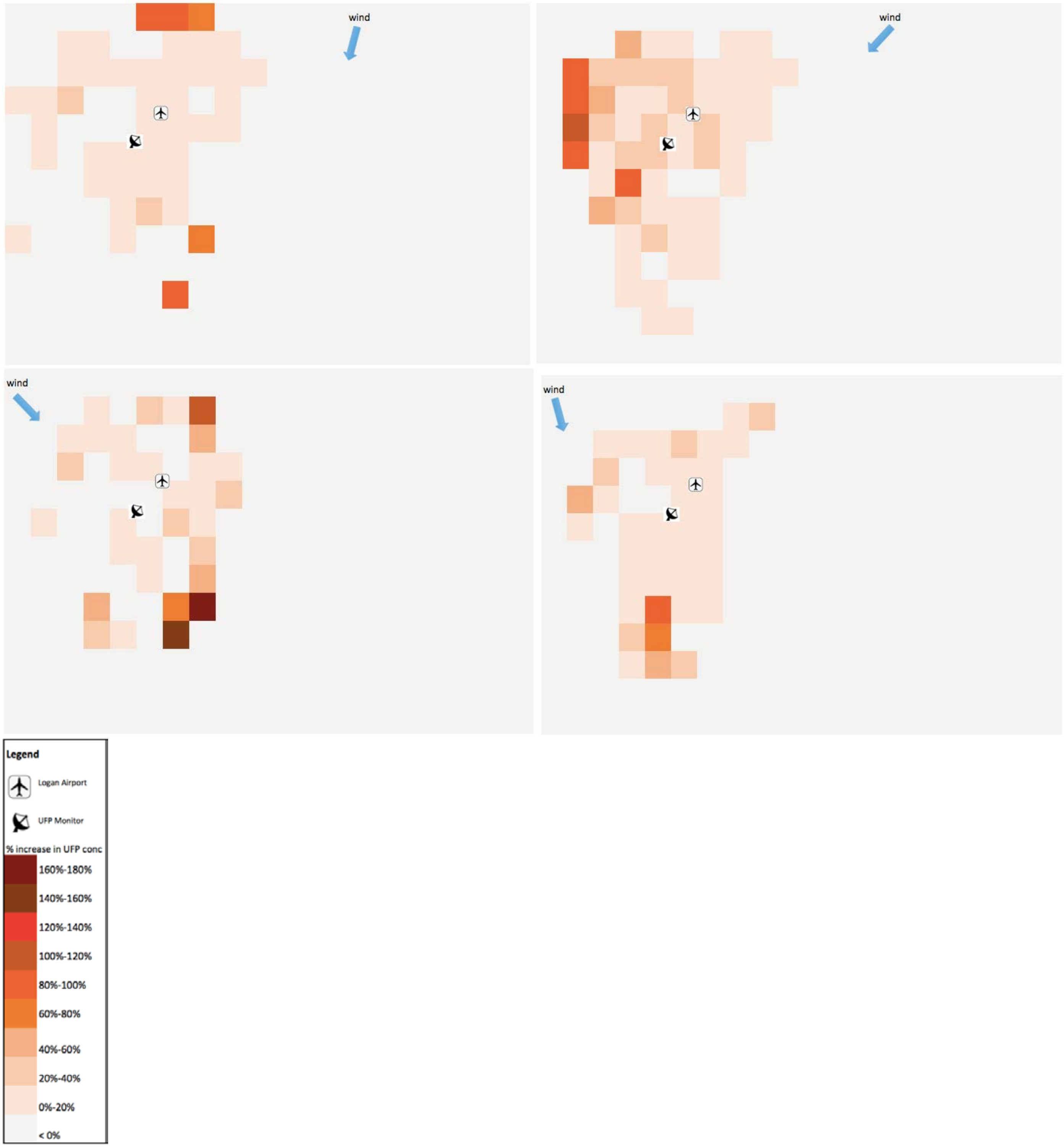

Figure 18,6. Heat-map displaying aircraft locations associated with increased UFP concentrations under four different wind directions, derived from multivariable regression models.

Publications

Kim CS, Tripodis Y, Levy JI. Magnitude and spatial patterns of ultrafine particulate matter associated with aircraft arrivals near Boston Logan Airport. Presented at the International Society for Exposure Science Annual Meeting, October 2016.

Outreach Efforts

Presentation at ASCENT meetings and academic conferences.

Awards

None

Student Involvement

The work was led by Chloe Kim as a doctoral student.

Plans for Next Period

We plan to complete the final statistical analyses and the corresponding manuscript in the first quarter of 2017. We also plan to use the modeling results to support site selection for our forthcoming UFP monitoring campaign.