CHANGES IN TRAFFIC PATTERNS AND AIR QUALITY ALONG MYSTIC AVENUE IN MEDFORD AND SOMERVILLE, MASSACHUSETTS, AFTER INSTALLATION OF AN INTERMITTENT BUS LANE

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August 10, 2022

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Executive Summary

In an effort to reduce traffic burden and improve air quality along Mystic Avenue (State Route 38) in Medford and Somerville, Massachusetts, a 1.9-mile-long bus lane was established on the western most of the two southbound (inbound) lanes of Mystic Avenue. The bus lane, which became operational on June 21, 2021, is restricted to Massachusetts Bay Transportation Authority buses during the hours of 6-9 AM on weekdays.

We were tasked with (1) making air quality measurements along the bus lane before and after it became operational, and (2) analyzing the measurements along with traffic data to determine whether changes in air quality were attributable to changes in traffic patterns.

To measure air quality, we set up a stationary monitoring site on the west side of the bus lane near the Mystic Activity Center in Somerville. There, we measured two pollutants that are useful markers of traffic exhaust – airborne particle number concentrations (dominated by ultrafine particles, i.e., particles less than 100 nanometers in diameter) and black carbon – between June and December 2021, i.e., from before the installation of bus lane to several months after installation. In addition, to better understand the spatial variation of air pollutants along the bus lane, we measured ultrafine particles and black carbon using a mobile laboratory – an electric vehicle equipped with rapid-response instruments. We drove the mobile laboratory along the bus lane as well as the northbound lanes on Mystic Avenue repeatedly between 6-9 AM on nine days, four before and five after the bus lane became operational.

Based on our analysis, we did not find evidence that changes in traffic patterns due to the installation of the bus lane caused a change (improvement or deterioration) in air quality. There were substantial spatial and temporal differences in pollutant concentrations. The highest air pollutant concentrations occurred on the section of Mystic Avenue closest to Interstate 93 (I-93) in Somerville. This section also had the highest traffic counts and was in an urban canyon, which likely caused localized pollutant trapping. The main factors that appeared to influence day-to-day differences in pollutant concentrations were season and wind direction: pollutant concentrations were generally higher during colder months than warmer months and during winds that placed Mystic Avenue downwind of I-93.

Based on our findings, we make the following recommendations for future studies involving intermittent bus lanes, and local-scale measurements of traffic and air quality during. First, traffic and air quality measurements should be collected simultaneously for at least five business days immediately before and immediately after the bus lane is first opened. This would increase the amount of data for before-and-after comparisons as well as control for expected day-of-the-week differences in traffic counts and weather patterns. Second, ideally, the bus lane should be first opened at a time when other changes in motorist driving behavior and bus ridership (e.g., around holidays and school vacations, and during planned traffic diversions and construction activities) are not anticipated. In addition, efforts should be made to increase bus ridership and to incentivize motorists to avoid using the bus lane during hours of intermittent prioritization. Although these recommendations derive from our study of the Mystic Avenue bus lane, they are broadly applicable to bus lane studies. Also, while we conducted this study during a period of intermittent prioritization of the bus lane, the same insights about study design would be relevant were the bus lane to become permanent and its impacts were analyzed.

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Introduction

The City of Medford, MA, (pop. 60,000) and the City of Somerville (pop. 76,000) immediately to the south are home to several major roadways including Interstate 93 and Massachusetts State Highways 28 and 38. These are among the busiest roadways in the Boston metropolitan area, together carrying over 240,000 vehicles per day through the two cities (Boston MPO, 2022). In an effort to increase bus efficiency, reduce traffic burden, and improve air quality in their communities, Medford and Somerville tested a bus lane with intermittent prioritization on Massachusetts Bay Transportation Authority (MBTA) bus route #95, which runs along Route 38 (Mystic Avenue) within the two cities. The test was performed in collaboration with the Massachusetts Department of Transportation (MassDOT) with support from the MassDOT Shared Streets and Spaces Grant program (MassDOT, 2022). First put into operation on June 21, 2021, the bus lane is 3-km long (1.9 miles) and runs down the right lane of the two southbound (inbound towards Boston) lanes of Mystic Avenue between Main Street in Medford and Wheatland Street in Somerville (Figure 1). The bus lane is intermittently available to MBTA buses between 6 AM and 9 AM Monday through Friday. Outside these hours the bus lane is open to all traffic.

To date, relatively few studies in the literature have directly measured the impacts of bus lanes on traffic patterns and air quality. Several previous studies have relied on traffic simulation and vehicle emissions models to predict the impacts of different bus lane scenarios on air quality. For example, Abbasi et al. (2020) modeled bus rapid transit (BRT) systems in Tehran and predicted that by converting shared bus lanes to dedicated lanes, emissions of carbon monoxide (CO) would decrease by 9%, particulate matter (PM) by 1%, and nitrogen oxides (NOx) by 3%. In addition, by replacing fixed traffic signals with actuated signals along bus routes, emissions of CO would decrease by 26%, PM by 3%, and NOx by 6%. Similarly, in a study of BRT systems with median bus lanes in Seoul, Kim et al. (2019) predicted that emissions of CO, CO_2, $PM_{2.5}$, PM_{10}, (particulate matter with aerodynamic diameter ≤2.5 and ≤10 microns, respectively) and NO_x could be lowered by 19–31% depending on the pollutant. Some studies have also evaluated BRT systems by analyzing pollutant measurements from monitoring stations distributed across cities. For example, Bel and Holst (2018) reported that in the two-year period after the start of a 19-km segment of a BRT in Mexico City in 2005, CO concentrations were reduced by 5.5-7.2%, NO_x by 4.7-6.5%, and PM_{10} by 7.3-9.2% relative to the two-year period before the start of the bus line. However, because of the length of the study period (4 years) and the size of the monitoring network (>500 km^2), the pollutant concentration reductions observed could not be unequivocally assigned to the BRT as distinct from other on-going air quality improvement efforts in the city.

The goal of our study was to determine whether the bus lane on Mystic Avenue caused short term (months) changes in traffic patterns and improved air quality along the length of the bus lane. To this end, we measured traffic-related air pollution (TRAP) in the months before and after the bus lane became operational. TRAP derives from the combustion of fossil fuels by motor vehicles including gasoline-powered passenger cars and diesel-powered trucks and buses. Other sources of TRAP include tire and brake wear and resuspended road dust. Because TRAP mixtures are composed of many different chemical components, it is not practical or feasible to measure all of them; therefore, surrogates of TRAP are typically used for assessing the contribution of traffic emissions to ambient air pollution. Common surrogates include carbon monoxide (CO), carbon dioxide (CO_2), nitric oxide (NO), nitrogen dioxide (NO_2), black carbon (BC), and ultrafine particles (UFP; particles with aerodynamic diameter <100 nanometers). UFP are generally good indicators of fresh combustion emissions (Baldauf et al. 2016); BC, a mixture of incompletely combusted semi-volatile and non-volatile organic chemicals (WHO, 2012), is used as an indicator of fresh diesel emissions (Liu et al, 2017). UFP are of concern for their possible role in disease causation (Knol et al., 2009). Due to their small size UFP are able to penetrate deep into the lungs, cross over into the bloodstream, and become widely distributed in the body where they have been shown to impact pulmonary and systemic inflammation, heart rate variability and blood pressure (Ohlwein et al., 2019).

In this report we focus on UFP, BC, and nitrogen oxides (NO_x; sum of NO and NO_2). The concentrations of these pollutants can be significantly elevated on major roadways compared to urban background (e.g., Karner et al., 2010), and as a result people residing in the vicinity of busy roadways or traveling on them can receive high exposures. The concentrations of UFP, BC, and NO_x depend on traffic conditions as well as meteorological factors including wind direction and speed, mixing height, temperature, and relative humidity (Baldauf et al., 2008). In our study we measured these pollutants under a range of traffic and meteorological conditions to control for factors other than bus lane use. Traffic was measured using counters placed at different locations along the bus lane; pollutant concentrations were measured using both mobile and stationary-site monitoring approaches. The two sets of measurements were then analyzed to determine if significant changes in traffic patterns had occurred due to the operation of the bus lane and whether air quality changes, if any, were attributable to changes in traffic.

Methods

Traffic Data

Monitoring was performed on 11 days between November 5, 2020 and December 18, 2021, three days before the bus lane went into effect and eight days afterward (Table 1). Eight different sites were monitored: five sites in Medford and three in Somerville (Figure 1). On each day of monitoring, between one and six sites were monitored continuously for 24 hours. Traffic data included total vehicles counted in 15-minute intervals in both the southbound and northbound lanes (all vehicles, all lanes, each direction) and average vehicle speed in each direction for each hour of monitoring. In addition, on some days, lane-specific counts and fleet composition data were collected. Because monitoring was not performed at the Main Street site before the bus lane became operational or at the Harvard Avenue site after the bus lane became operational, we did not use data from these two traffic sites in our analysis. Removing these sites reduced the number of different days of data from 11 to seven for our analysis. Specifically, we compared traffic data from November 5, 2020 (before) with data from August 5, August 11, August 21, September 21, December 8, and December 9, 2021 (after) (Table 1). On all days of traffic monitoring, data were collected using radar-based traffic recorders (Black Cat II Plus, Jamar Technologies) operated by Precision Data Industries, LLC (Hudson, Massachusetts).

Prior to the start of the bus lane, the Cities of Medford and Somerville performed public outreach in the form of a public meeting, emails to residents, a website, and several electronic message boards along Mystic Avenue to inform motorists and bus riders about the new bus lane program; however, the cities did not perform any enforcement of the bus lane – e.g., state and local police did not make traffic stops to issue warnings or tickets to drivers not observing the bus lane restrictions.

Air Quality Monitoring

We used both mobile monitoring and stationary monitoring to measure air quality on Mystic Avenue: mobile monitoring was used to measure on-road air quality under actual driving conditions experienced by motorists; stationary monitoring was used to measure temporal variation in air quality. Mobile monitoring was performed with an all-electric vehicle equipped with rapid-response instruments for measuring UFP, BC, and NOx (see Table 2). We performed mobile monitoring on four days before and five days after the bus lane became operational (Table 3). On each day of monitoring, we drove north and south along Mystic Avenue repeatedly between 6 AM and 9 AM. The entire monitoring route, which extended beyond the length of the bus lane (Figure 1), 4.5 km long (2.8 miles), and at typical driving speeds of 48 km h^{-1} (30 miles h^{-1}) it took ~10 minutes (including time spent at intersections) to drive the southbound part of the route and about the same amount of time to drive the northbound part of the route. Instrument clocks were set to the National Institute of Standards and Time (NIST) clock before the start of monitoring on each day of monitoring. Measurements were collected at a frequency of every second to every minute depending on the instrument (see Table 2). Individual pollutant measurements were matched to location by 1-second-interval GPS readings. There was only one day of simultaneous traffic and mobile monitoring, December 8, 2021.

The stationary monitors included a BC analyzer and a size mobility particle scanner (SMPS), both of which were housed in a weather-proof box equipped with a heater/AC unit for temperature control (see Table 2). The SMPS counts particles by size, thus providing information about the size distribution of particles as well as the total number concentration of particles in all size bins. In this report we will focus on the total number concentration of particles. The box was located just outside the Mystic Activity Center, ~7 meters from the western edge of the bus lane (see Figure 1). Measurements were made at this site between June 2021 and December 2021.

Air Quality Data Analysis

Mobile monitoring data were processed in the following manner. First, following each day of monitoring, data were downloaded from the instruments and compiled in an MS Excel spreadsheet. Second, data for individual pollutants went through quality assurance checks where data flagged automatically by instruments were excluded. Third, time-series plots were generated and visually examined to ensure that values reported were both within the minimum and maximum measurable concentrations for each instrument and consistent with concentration ranges expected based on previous studies in Somerville (Padró-Martínez et al., 2012) as well as other urban areas (Karner et al., 2010). Fourth, data from all instruments were pooled and matched to location by 1 second GPS readings. Fifth, we adjusted for known time lags (i.e., time between when air arrives in the inlet line and a response is observed on the monitor) and checked that pollutant concentration spikes were lining-up across instruments. After these steps were performed, the processed and lag-adjusted data were converted into a database and imported into MATLAB (2019b) for statistical analysis. Over 90% of the air quality data collected during the mobile monitoring campaign satisfied our quality assurance metrics and were used in the analysis. To visualize spatial trends, the data were mapped using ArcGIS Software and datalayers obtained from MassGIS. Stationary-site data were similarly processed and adjusted. Gaps in the stationary-site dataset were caused by power failures and instrument malfunction.

Results and Discussion

Traffic Data

The results in Figure 2 indicate that the bus lane did not appear to have a short-term (months) impact on traffic volume on Mystic Avenue. In Medford the counts at the three southbound sites were substantially higher (40-240%) *after* the bus lane became operational; however, this increase was not due to the bus lane, but rather to a traffic diversion near Medford Square that prevented southbound traffic on Main Street from turning onto the Route 16/I-93 on-ramp. This traffic was instead diverted to Harvard Street and the I-93 interchange near Moreland Street. In Somerville southbound traffic counts were somewhat higher at two sites (Moreland Street (20%) and Shore Drive (10%)) after the bus lane became operational compared to before. Northbound traffic counts at the three sites in Medford increased modestly after the bus lane became operational (10-40%) whereas at the three sites in Somerville, traffic counts decreased (by 8-40%) after the bus lane became operational. It is unclear whether these differences are contributed to by the bus lane or whether other factors are more important such as differences in the number of days of traffic monitoring used for the comparison: in Medford there were only two days of traffic measurements, one day before and one day after the bus lane became operational, while in Somerville there were five days of traffic counts, one before and four after the bus lane became operational. Also, there were differences in the number of sites monitored per day of monitoring: in Medford, all three sites were monitored on both days whereas in Somerville different sites were monitored on different days (Table 1). These methodological differences in how traffic data was collected likely contributes to the spatial and temporal patterns observed in Figure 2. In general, the northbound counts were much higher at the three sites in Somerville compared to the three sites in Medford. This is consistent with sharp decreases in traffic due to northbound vehicles in Somerville turning onto I-93 north at the interchange near Moreland Street.

More finely time-resolved trends shown in Figure 3 from four days of traffic monitoring at Moreland Street indicate that there was little difference in combined volume on Mystic Avenue in the two southbound lanes after the installation of the bus lane compared to before the installation of the bus lane. Further, on August 5, 2021, measurements collected separately for the two southbound lanes indicate that counts were lower in the bus lane than in the adjacent southbound lane between 6-9 AM, but the counts suggest that bus lane compliance was low (~30%).

Air Quality Monitoring

Mobile Monitoring

As indicated in Figure 4, which shows particle number concentrations (PNC), BC concentrations, and NOx concentrations along Mystic Avenue for all nine southbound and 11 northbound traverses of the bus lane between 6 AM and 9 AM on a single day (December 8, 2021, ~6 months after the implementation of the bus lane), there was little difference in spatial patterns between the lanes, which is evidence that the three pollutants were well mixed laterally – i.e., from one side of Mystic Avenue to the other – along the length of the monitoring route. For this reason, we created summary figures based on combined southbound and northbound measurements as opposed to southbound-only or northbound-only measurements. In contrast, along the length of the bus lane there was spatial variation in PN, BC, and NOx concentrations (Figure 4). In general, pollutant concentrations were higher in Somerville relative to Medford consistent with traffic patterns. In addition, the concentrations of all three pollutants were elevated between Moreland Street and Grant Street, both southbound and northbound (even the lowest concentrations between these two streets were elevated relative to elsewhere on the route). The measurements in Figure 5, which derive from a single southbound traverse of the monitoring route between 6:19 AM and 6:27 AM on December 8, 2021, graphically illustrate the spatial differences in pollutant concentrations along the length of the monitoring route. The high-concentration spike of each pollutant at ~06:25 AM, which occurred when the mobile lab was near the intersections with Shore Drive and Temple Street, are likely attributable to three factors: traffic volume (which was highest along this part of the route), the traffic lights at Shore Drive and Temple Street (stop and go driving produces higher emissions rates relative to constant speed conditions (Goel and Kumar, 2015)), and pollutant trapping within the urban canyon formed by I-93, which is elevated 30-40 feet above grade on the east side of Mystic Avenue, and a row of apartment buildings on the west side. TRAP generated by vehicles in urban canyons is sometimes prevented from mixing vertically due to cross winds that move over the tops of canyons (i.e., in the case of Mystic Avenue, winds with strong southwesterly or northeasterly components). Previous studies have shown TRAP concentrations to be much higher on city streets during cross winds compared to the same streets during winds parallel to the canyons (e.g., Boddy et al., 2005). In addition, the urban-canyon effects we observed were likely exacerbated by seasonal factors: for example, lower average air temperatures and boundary layer (mixing) height in winter cause pollutant concentrations to be as much as twice as high on average relative to warmer months (Padró-Martínez et al., 2012); thus, canyon effects in winter could cause greater TRAP concentration increases than during the summer.

Overall, we did not find evidence that operation of the bus lane led to significant changes (improvement or deterioration) in air quality along Mystic Avenue in Medford and Somerville. Figure 6 shows all of the PN and BC measurements collected on all nine days of mobile monitoring. Each pair of box plots in the figure was created by placing all of the data from north of Moreland Street in one bin and all of the data from south of Moreland Street in another. Moreland Street serves as an important geographic benchmark in terms of both traffic and air quality: because Moreland Street is very near the I-93 interchange, traffic is much heavier and air quality is generally poorer to the south. As shown in the figure, PN and BC concentrations were not consistently different along Mystic Avenue in the months after the start of bus lane operations compared to before the start of operations. On the contrary, the figures show that meteorology and (possibly) pollutant contributions from I-93 played more of a role in influencing air quality along Mystic Avenue than did the bus lane. The clearest example of this is seen by comparing pollutant concentrations on December 6, 7, and 8, 2021. On December 7 pollutant concentrations on Mystic Avenue were generally low when westerly winds (ranging from 251-263° at 5.4 m/s) caused Mystic Avenue to be upwind of I-93. In contrast, on the previous day (December 6) and on the following day (December 8) pollutant concentrations were considerably higher (2-3-fold) on Mystic Avenue when southeasterly winds (ranging from 98-138° at 3.3 m/s on December 6) and northerly winds (ranging from 355-8° at 2.6 m/s on December 8) caused Mystic Avenue to be downwind of I-93.

Stationary Monitoring Results

As shown in Figure 7, pollutant concentrations measured at the stationary site before and after the bus lane started operating were not significantly different. Comparison of BC data gathered at the stationary site before and after the installation of the bus lane, i.e., a winter month before the implementation of the bus lane (December 2020) versus the same winter month after the implementation of the bus lane (December 2021), did not indicate statistically significant differences in concentrations (Wilcoxon test p-value = 0.13). The cumulative frequency of occurrence is shown in Figure 7a; the median BC concentration was 270 ng/m^3 in December 2020 (n = 316 hours of data) and 290 ng/m^3 in December 2021 (n = 733 hours of data). The pattern of dependence of concentrations on wind direction was consistent between the two years: generally higher concentrations were observed during winds that oriented the site downwind of I-93 as opposed to winds from other directions (Figure 7b).

Figure 7c compares hourly data at the Mystic Avenue site and an urban background site ~4 miles (7 km) south in Roxbury operated by the Massachusetts Department of Environmental Protection (DEP Site# 250250042). Except for the days when there was active construction adjacent to the Mystic Avenue (which caused data loss due to instrument vibration), the BC concentrations were lower or comparable to the background site. Furthermore, a remarkably coincident temporal pattern was observed (after June 2021 in Figure 7c), again highlighting the influence of meteorology, which applies at a regional scale and drives the relatively large temporal changes in concentrations observed at the Mystic Avenue site and elsewhere. Figure 7d shows time series of monthly-average BC data collected at the Mystic Avenue site, the Roxbury site, and a site near I-93 north in South Boston (the Von Hillern site, MA DEP Site# 250250044). Monthly average BC concentrations monitored at Mystic Avenue were lower than those measured at these regulatory sites, but the temporal patterns were generally consistent.

Further, we show data for several week and weekend days (between October 18 and November 14, 2021) in Figures 8 and 9 for BC and PN, respectively. These figures underscore the observations made earlier in the report: (1) day-to-day variations in BC and PN concentrations are large and often exceed the change in concentrations observed due to increase in traffic during morning rush hours; and (2) we did not observe a sharp change (increase or decrease) in air pollutant concentrations coincident with bus lane hours - the trend during these hours was consistent with expected gradual increase and decrease in concentrations due to rush hour traffic patterns.

Implications

There were several methodological challenges encountered during this project that have bearing on our findings and the conclusions that can be drawn from them. First, there are no traffic measurements from the hours immediately after operation of the bus lane began on June 21, 2021 and the days thereafter (the earliest date for traffic measurements following the opening of the bus lane was August 5, 2021); thus, we do not know if and to what extent traffic patterns may have changed during the time when motorists were most fully aware of the existence and operation of the bus lane. Second, the start of the bus lane operation was near the date that public schools in Medford and Somerville recessed for the summer, which also would have caused changes in traffic patterns and bus ridership as students and parents transitioned to non-school-year activities. Third, motorists who continued to use the bus lane between 6 and 9 AM on weekdays were not ticketed by local and state police and were thus not fully incentivized to use the bus lane. These limitations present opportunities for future investigations of this bus lane (as well as other bus lanes more generally): (1) traffic data should be collected for at least five business days at all sites immediately before and immediately after the bus lane is first opened (this would increase the amount of data allowing for more robust before-and-after comparisons as well as controlling for expected day-of-the-week differences in traffic counts (Padró-Martínez et al., 2012) and changes in weather patterns); (2) the bus lane should be first opened at a time when other large-scale changes in motorist driving behavior and bus ridership are not anticipated (e.g., around holidays, school vacations, large storm events, etc.); and (3) motorists who violate the bus lane restrictions should be pulled over and warned for the first offense and ticketed and fined for subsequent offenses.

Two unanticipated challenges during our study period were caused by a traffic diversion along the bus lane and jack hammering near our stationary monitoring site. The increase in southbound traffic along the bus lane in Medford after the bus lane became operational was not due to the bus lane itself but rather to a diversion near the north end of the bus lane. Such diversions are not uncommon and difficult to avoid; however, by altering the study design to anticipate the timing of diversions (assuming they are planned), the robustness of the resulting traffic and air quality datasets would be enhanced. Likewise, jack hammering (as part of a utility project) on Mystic Avenue occurred between June 11 and 20, 2021 - right at the start of bus lane operations - near our stationary site. Because the BC analyzer is sensitive to vibration, our BC measurements during the jack hammering events were compromised. To avoid such data losses, future investigations with study protocols that call for use of stationary monitoring equipment would benefit from better coordination between municipal transportation planners (bus lane proponents) and managers and contractors charged with road repair and other projects during the time of data collection.

In addition to these methodological issues, the proximity of I-93 (a significant source of TRAP) to the bus lane (~15 m at its closest point) represents another challenge. As shown in Figures 4-6, when winds had a northerly or easterly component, PN, BC, and NOx concentrations were generally elevated compared to when winds were out of the south or the west, strongly suggesting contributions from I-93. This is consistent with the results of a previous study of the I-93/Mystic Avenue corridor in Somerville, which also showed TRAP concentrations on Mystic Avenue are elevated when winds are out of the north and east (Padró-Martínez et al., 2012). The challenge of measuring air quality changes along the bus lane without interference from I-93 TRAP inputs could be addressed by coordinating traffic and air quality monitoring activities immediately before and after the opening of the bus lane and closely observing weather forecasts. For example, if traffic and air quality monitoring were performed continuously for at least one week prior to and one week following the opening of the bus lane, this would allow for data collection during a variety of wind conditions including southwesterly winds (~40% of winds in the Boston area (Hudda et al., 2018)), which would place Mystic Avenue upwind of I-93 and thereby enable the effects of the bus lane on air quality to be evaluated independently of TRAP contributions from I-93.

Finally, while we did not observe that the new bus lane on Mystic Avenue resulted in significant changes (improvements or deterioration) in vicinal air quality, our study provides insights into the main factors that influence air quality near urban roadways (i.e., at the micro-scale, <100 m). These insights may be beneficial for the design of future bus lane evaluation projects.

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TABLE 1 DATES OF TRAFFIC MONITORING.

	Traffic monitoring sites on Mystic Avenue[1,2]							
Date	South of Main St.[3]	South of Reardon Rd.	South of Billings Ave.	South of Harvard St.[3]	South of Bonner Ave.	South of Moreland St.	South of Shore Dr.	North of Grant St.
11/5/20		X	X		X	X	X	X
4/27/21				X				
4/28/21				X				
6/21/21	Bus lane became operational							
8/5/21						X[4]	X	X[5]
8/11/21						X[5]		
8/21/21								X[4]
9/21/21		X	X		X			
12/8/21						X	X	X
12/9/21						X	X	X
12/15/21	X							
12/16/21	X							
12/18/21	X							

[1]Blue indicates Medford monitoring sites, green indicates Somerville.
[2]See Figure 1.
[3]Data from this site was not used for the before and after comparison.
[4]Southbound counts only.
[5]Northbound counts only.

TABLE 2. MOBILE MONITORING DATES AND TIMES

Date	Start Time	End Time	Hourly Wind Direction	Ave. Wind Speed (m/s)
December 9, 2020	6:44 AM	8:43 AM	270-283º	3.7
December 10, 2020	7:31 AM	9:02 AM	279-285º	4.8
March 17, 2021	7:52 AM	10:07 AM	243-245º	4.0
March 19, 2021	7:10 AM	10:47 AM	357-8º	9.6
September 15, 2021	5:44 AM	9:30 AM	156-190º	3.5
September 16, 2021	7:58 AM	9:21 AM	19-26º	5.3
December 6, 2021	6:09 AM	9:31 AM	98-138º	3.3
December 7, 2021	5:40 AM	9:42 AM	251-263º	5.4
December 8, 2021	5:42 AM	9:45 AM	355-11º	2.6

Hourly wind direction for each hour of monitoring and wind speed averaged over the monitoring period were collected at Logan Airport (KBOS) and obtained from the National Centers for Environmental Information (NOAA NCEI).

TABLE 3. AIR POLLUTION MONITORING EQUIPMENT IN THE TAPL AND THE STATIONARY SITE AT THE MYSTIC ACTIVITY CENTER.

Parameter	**Equipment; manufacturer/model**	**Detection Limit**	**Instrument reporting interval (sec)**	**Averaging time (sec)**
Instruments used in the mobile monitoring lab				
Particle number concentration (PNC), a proxy for ultrafine particles (UFP)	Condensation Particle Counter (CPC) ; TSI 3783	1 particle/cm^3 in the 7-3,000 nm size range	1	1
Nitrogen oxides (NOx)	Chemiluminescence analyzer; Thermo Scientific 42i	0.40 ppb	1	20
Black carbon (BC)[1]	Aethalometer; Magee Scientific AE-33	10 ng/m^3	1	1
Latitude/ Longitude	GPS receiver; Garmin GPS V	NA	1	1
Instruments used at the stationary monitoring site				
Particle number concentration (PNC) and size distribution	Scanning Mobility Particle Sizer; TSI 3034	1 particle/cm^3 in the 7-3,000 nm size range	180	180
Black carbon (BC)	Aethalometer; Magee Scientific AE-16	10 ng/m^3	60	60

[1]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) has been reported.

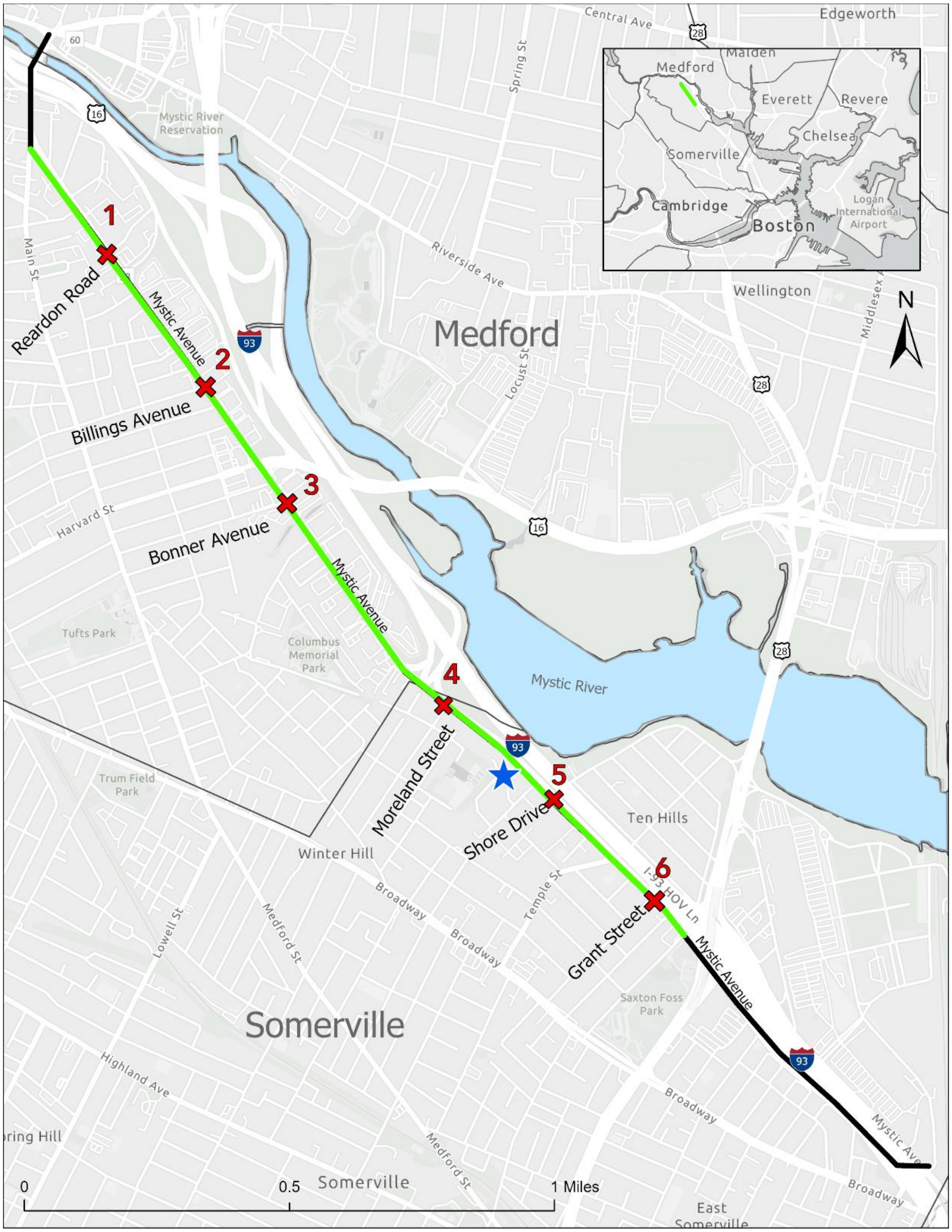

FIGURE 1. THE BUS LANE (GREEN LINE) EXTENDS FROM THE INTERSECTION OF MAIN STREET AND MYSTIC AVENUE IN MEDFORD TO THE INTERSECTION WHEATLAND STREET AND MYSTIC AVENUE IN SOMERVILLE. TRAFFIC MONITORING WAS PERFORMED NEAR THE FOLLOWING INTERSECTIONS: 1. REARDON ROAD, 2. BILLINGS AVENUE, 3. BONNER AVENUE, 4. MORELAND STREET, 5. SHORE DRIVE, AND 6. GRANT STREET. MOBILE MONITORING WAS PERFORMED ALONG THE ENTIRE LENGTH OF THE BUS LANE (BOTH DIRECTIONS) AS WELL AS ON THE ROAD SEGMENTS (BLACK LINES) EXTENDING FROM EACH END. THE STATIONARY MONITORING SITE IS MARKED BY THE BLUE STAR. THE FIGURE WAS CREATED IN ARCGIS SOFTWARE USING DATALAYERS ACQUIRED FROM MASSGIS.

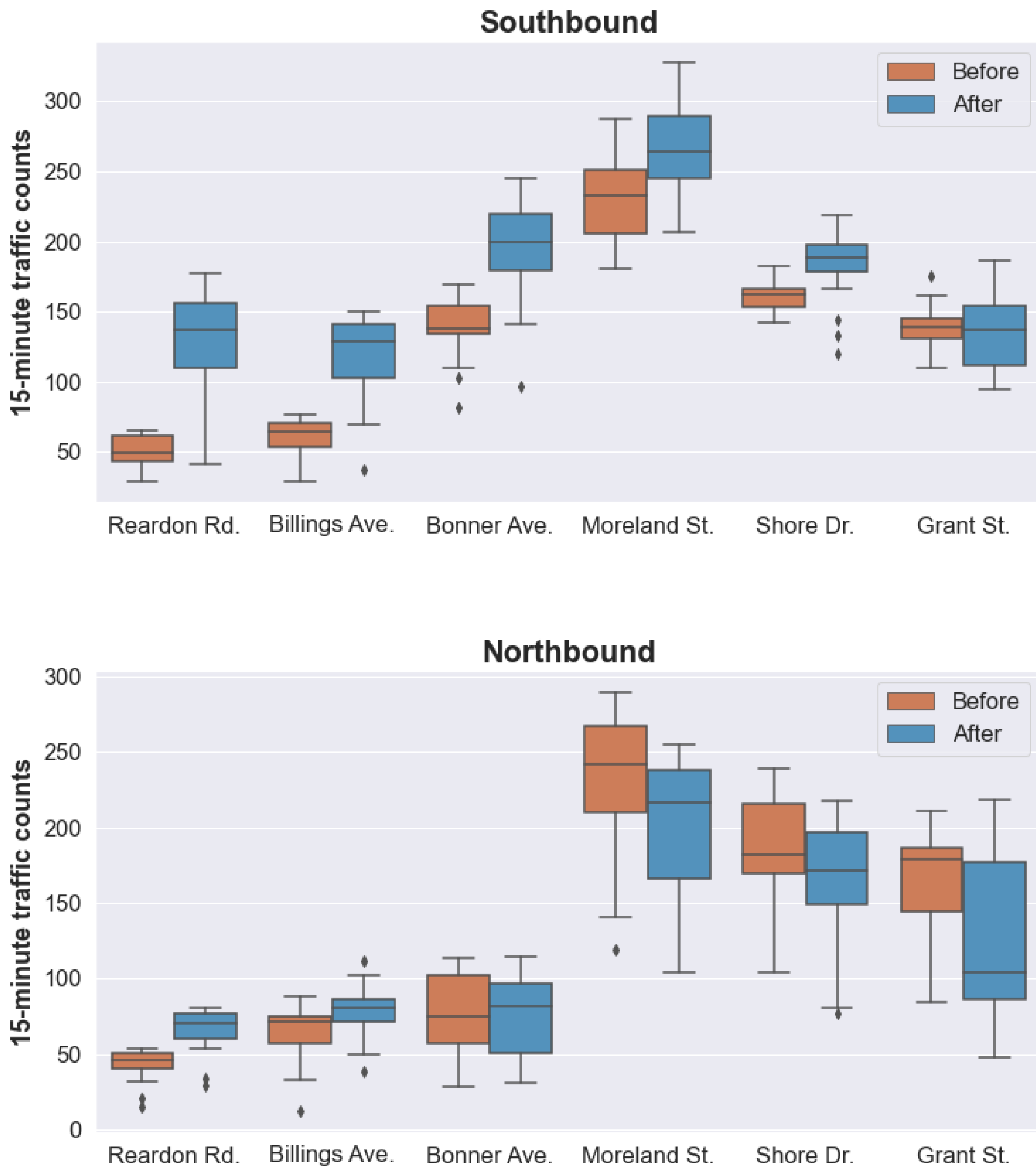

Figure 2. Box plots of traffic counts at 15-minute intervals at six sites along Mystic Avenue in Medford and Somerville between 6 and 9 AM before and after the bus lane became operational. The upper panel shows the southbound counts (total counts in both southbound lanes); the lower panel shows the northbound counts (total counts in both northbound lanes). The dark horizontal line in each box represents the median. The 'before' data was collected on 11/5/2020 at all six sites; the 'after' data was collected on 9/21/2021 (Medford) and on 8/5/2021, 8/11/2021, 8/21/2021, 12/8/2021 and 12/9/2021 (Somerville)(see Table 1). Traffic monitoring locations are shown in Figure 1.

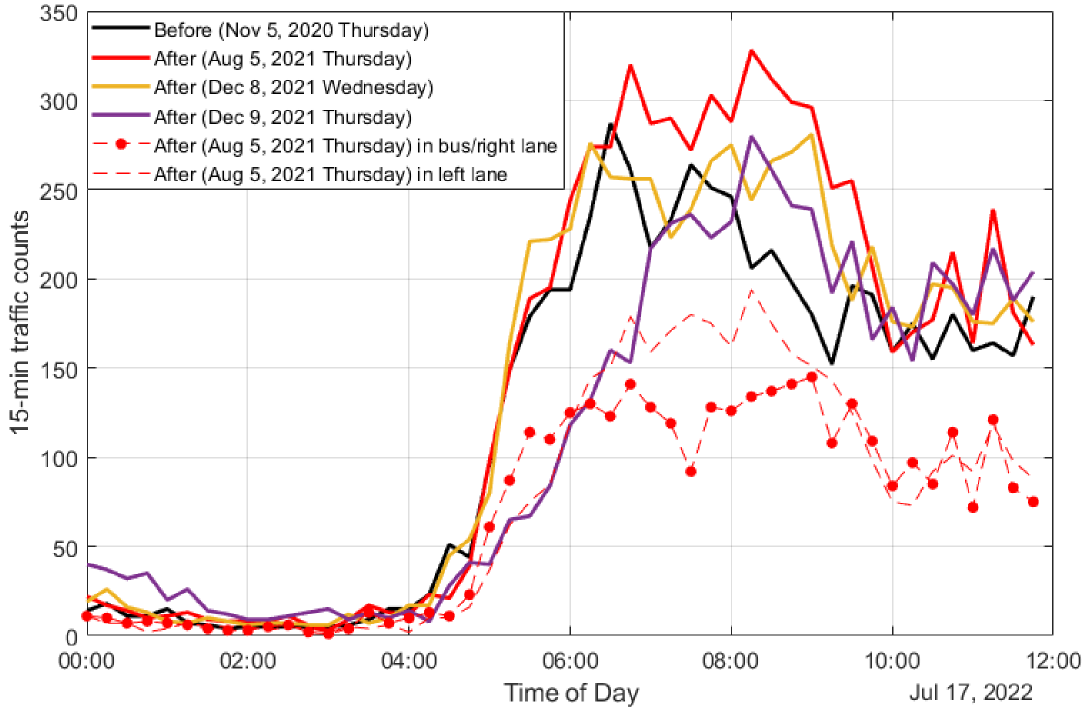

FIGURE 3. SOUTHBOUND TRAFFIC COUNTS COLLECTED AT MORELAND STREET ON ONE DAY BEFORE AND THREE DAYS AFTER THE INSTALLATION OF THE BUS LANE. ON AUGUST 5, DATA WAS COLLECTED SEPARATELY FOR THE LEFT LANE AND THE RIGHT OR THE BUS LANE.

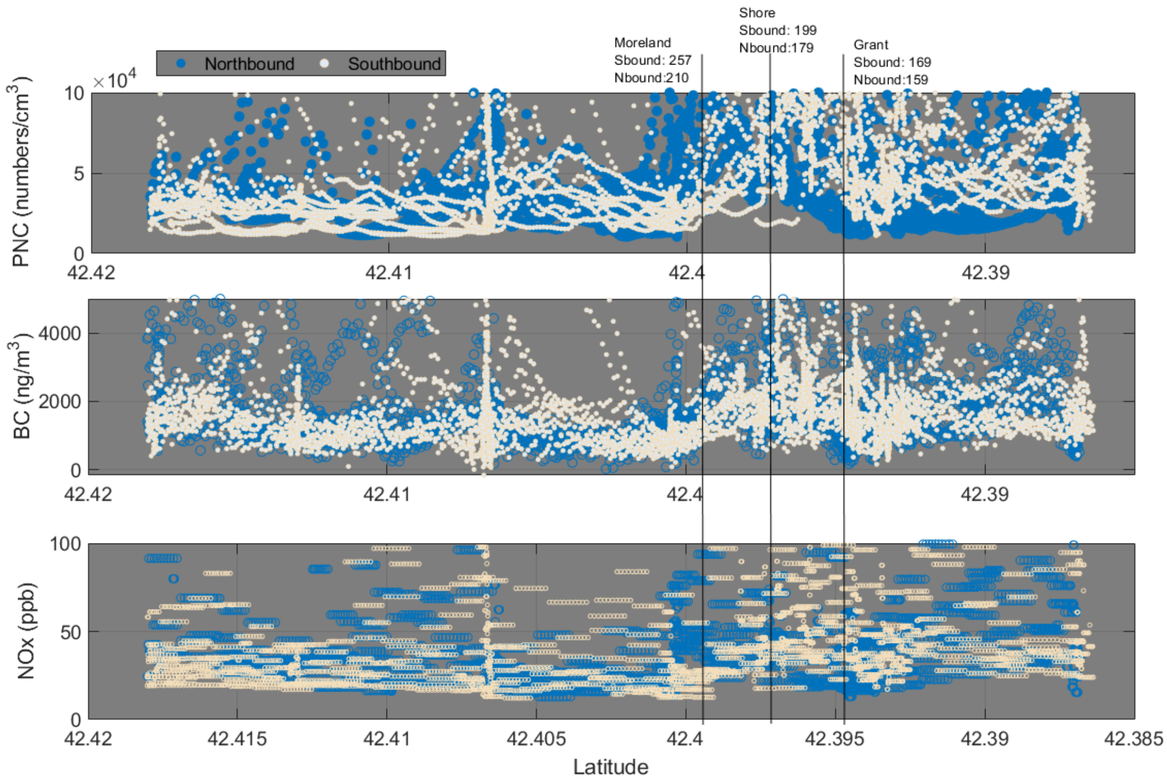

FIGURE 4. PNC, BC, AND NOX MEASUREMENTS COLLECTED DURING 9 RUNS ALONG THE SOUTHBOUND AND 11 RUNS ALONG NORTHBOUND LANES OF MYSTIC AVENUE BETWEEN 6:00 AND 9:00 AM ON DECEMBER 8, 2021. THE X-AXIS IS SHOWN AS LATITUDE WITH NORTH AT LEFT (MAIN ST. END OF ROUTE) AND SOUTH AT RIGHT (ROUTE 28 END OF ROUTE). BLACK VERTICAL LINES INDICATE TRAFFIC MONITORING SITES ALONG MYSTIC AVENUE: SOUTH OF MORELAND STREET (I-93 ON/OFF RAMP), SOUTH OF SHORE DRIVE (SHORE) AND NORTH OF GRANT STREET (GRANT). THE NUMBERS AT THE TOP OF EACH VERTICAL LINE INDICATE THE 15-MINUTE-AVERAGE TRAFFIC VOLUMES IN EACH DIRECTION AT THE THREE SITES BETWEEN 6 AND 9 AM.

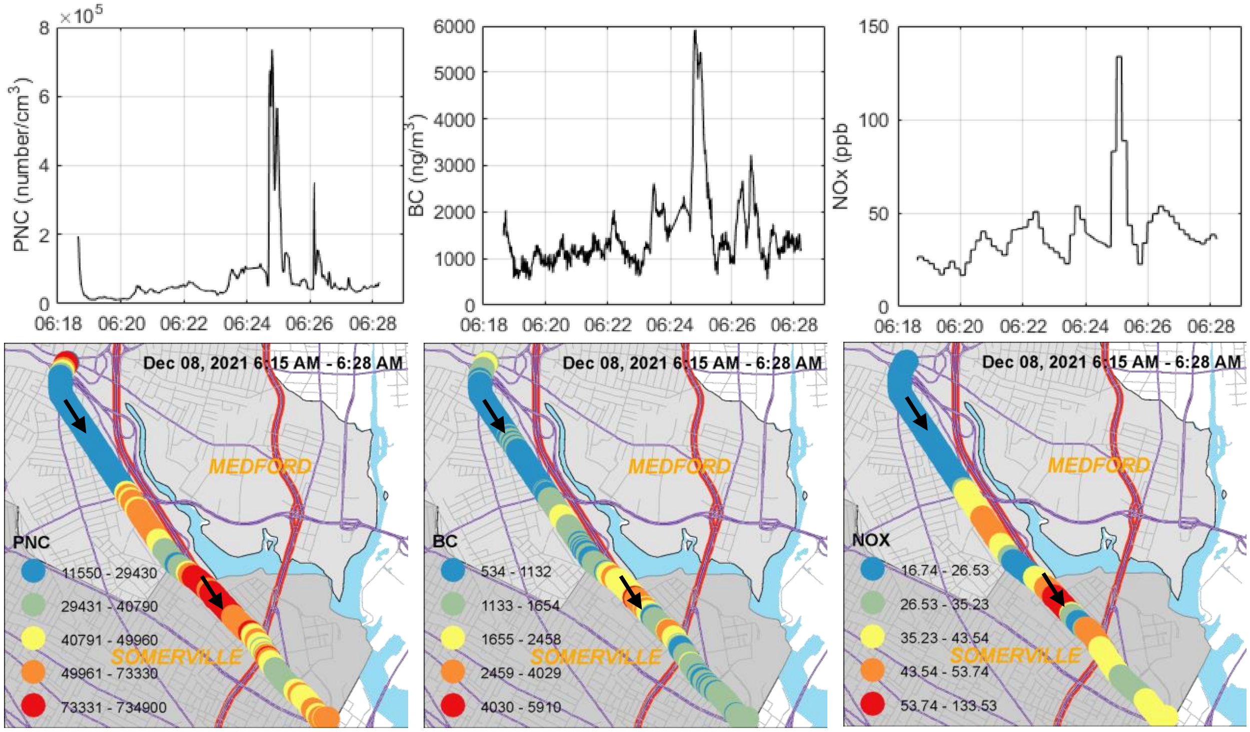

FIGURE 5. PNC, BC, AND NOX MEASUREMENTS COLLECTED ALONG THE SOUTHBOUND LANES OF MYSTIC AVENUE BETWEEN 6:15 AND 6:28 AM ON DECEMBER 8, 2021. UPPER PANELS SHOW POLLUTANT TIME-SERIES PLOTS; THE PANELS BELOW SHOW THE SAME DATA ON MAPS. THE HIGH CONCENTRATION SPIKE OF EACH POLLUTANT AT ~06:25 AM OCCURRED WHEN THE MOBILE LAB PASSED THE I-93 ON/OFF RAMP. THE BLACK ARROWS ON THE MAPS SHOW THE DIRECTION THE MOBILE LAB WAS HEADING WHEN THE MEASUREMENTS WERE MADE.

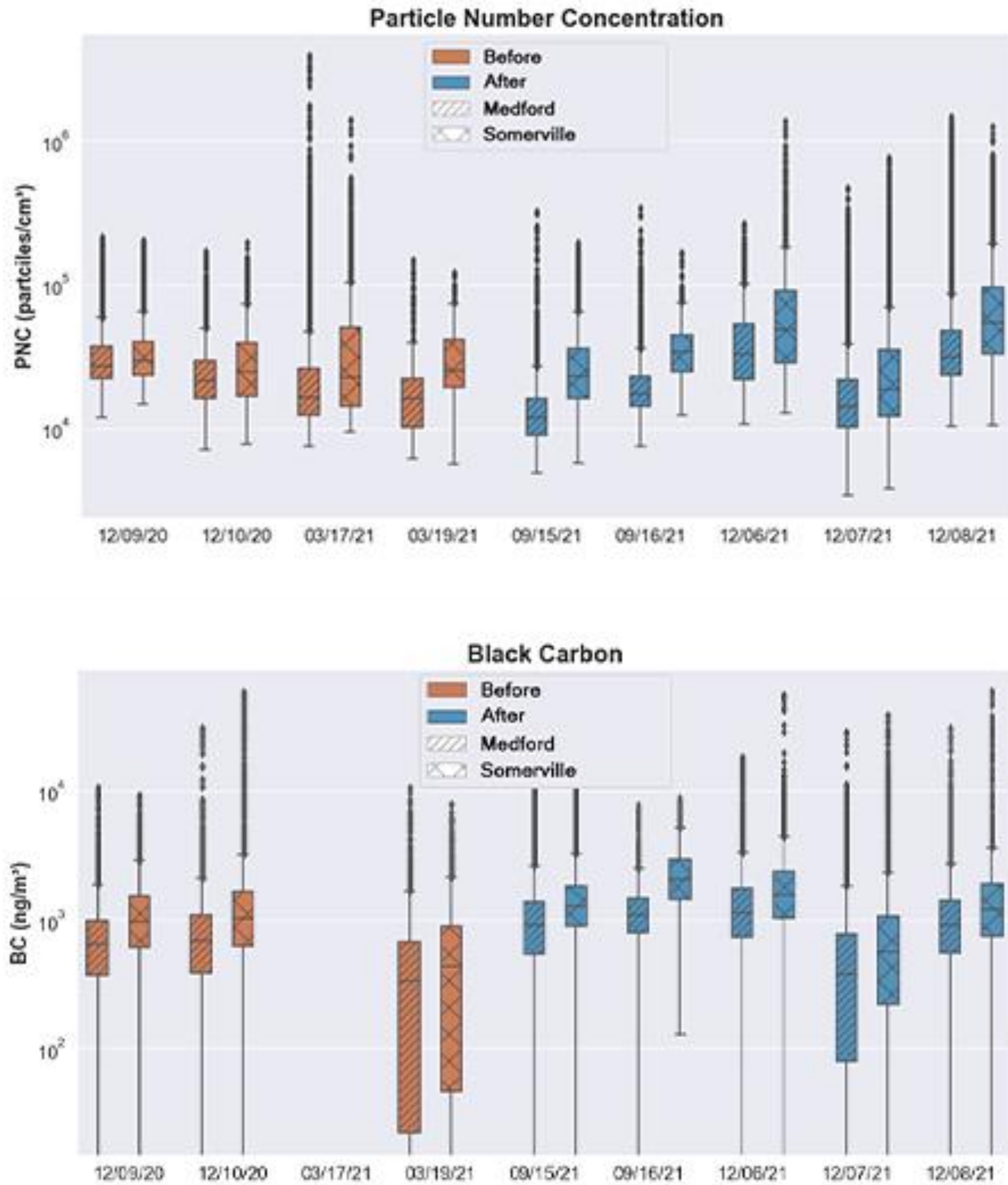

FIGURE 6. BOXPLOTS OF PARTICLE NUMBER CONCENTRATION (PNC) AND BLACK CARBON (BC) CONCENTRATION MEASURED DURING MOBILE MONITORING ON MYSTIC AVENUE BEFORE AND AFTER THE BUS LANE WAS IMPLEMENTED.

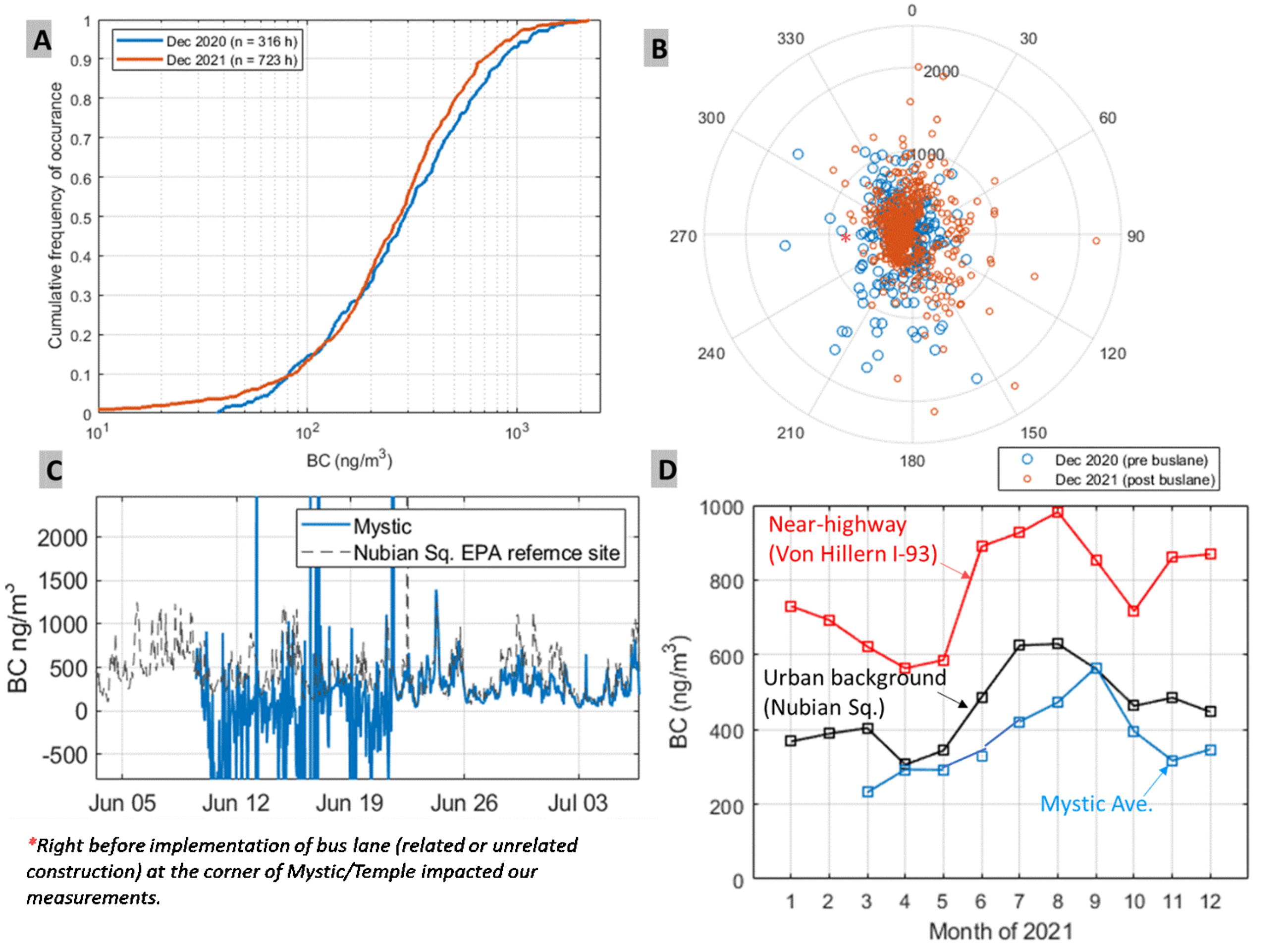

FIGURE 7. COMPARISON OF A MONTH OF BC MEASUREMENTS BEFORE AND AFTER THE INSTALLATION OF THE BUS LANE (DECEMBER 2020 VS 2021) IN THE FORM OF FREQUENCY DISTRIBUTION (A) AND A POLAR PLOT (B), WHICH SHOWS WIND DIRECTION AROUND THE CIRCUMFERENCE AND BC CONCENTRATION ALONG THE RADIAL AXIS. (C) FINE TEMPORAL RESOLUTION COMPARISON OF MYSTIC AVE. MEASUREMENTS TO THE REGULATORY SITE THAT IS CONSIDERED TO REPRESENT THE URBAN BACKGROUND IN THE REGION. (D) BC CONCENTRATION MONITORED AT THE STATIONARY SITE COMPARED TO TWO REGULATORY SITES IN THE BOSTON AREA.

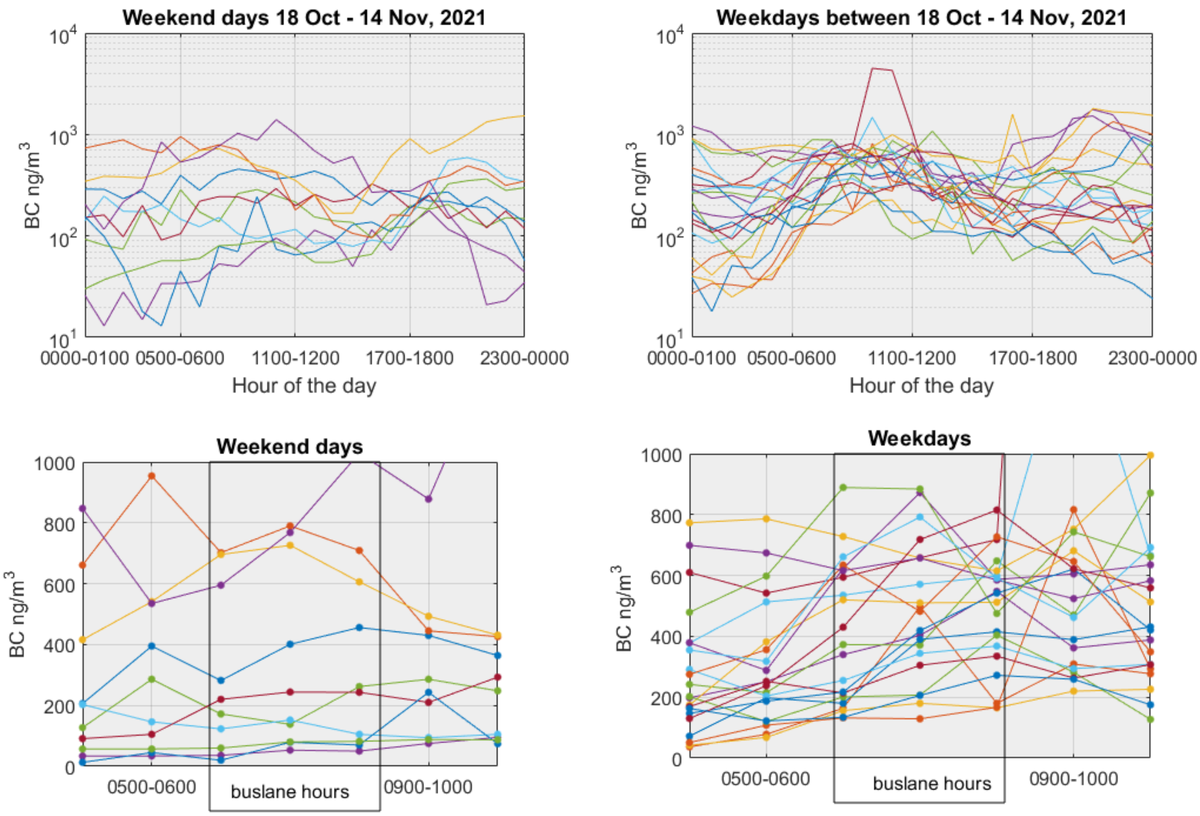

FIGURE 8. HOURLY AVERAGE BLACK CARBON (BC) CONCENTRATIONS MEASURED AT STATIONARY SITE ON DIFFERENT DAYS BETWEEN OCTOBER 18 AND NOVEMBER 14, 2021, AFTER THE INSTALLATION OF THE BUS LANE SEPARATED BY WEEKDAYS AND WEEKEND DAYS. EACH COLOR REPRESENTS A DIFFERENT DAY. TOP PANELS SHOW ALL 24 HOURS OF DATA AND THE BOTTOM PANELS SHOW DATA FOR THE BUS LANE HOURS (0600-0900) AND TWO MORE HOURS BEFORE AND AFTER THE BUS LANE HOURS TO SHOW THE TEMPORAL TREND DURING THE MORNING HOURS.

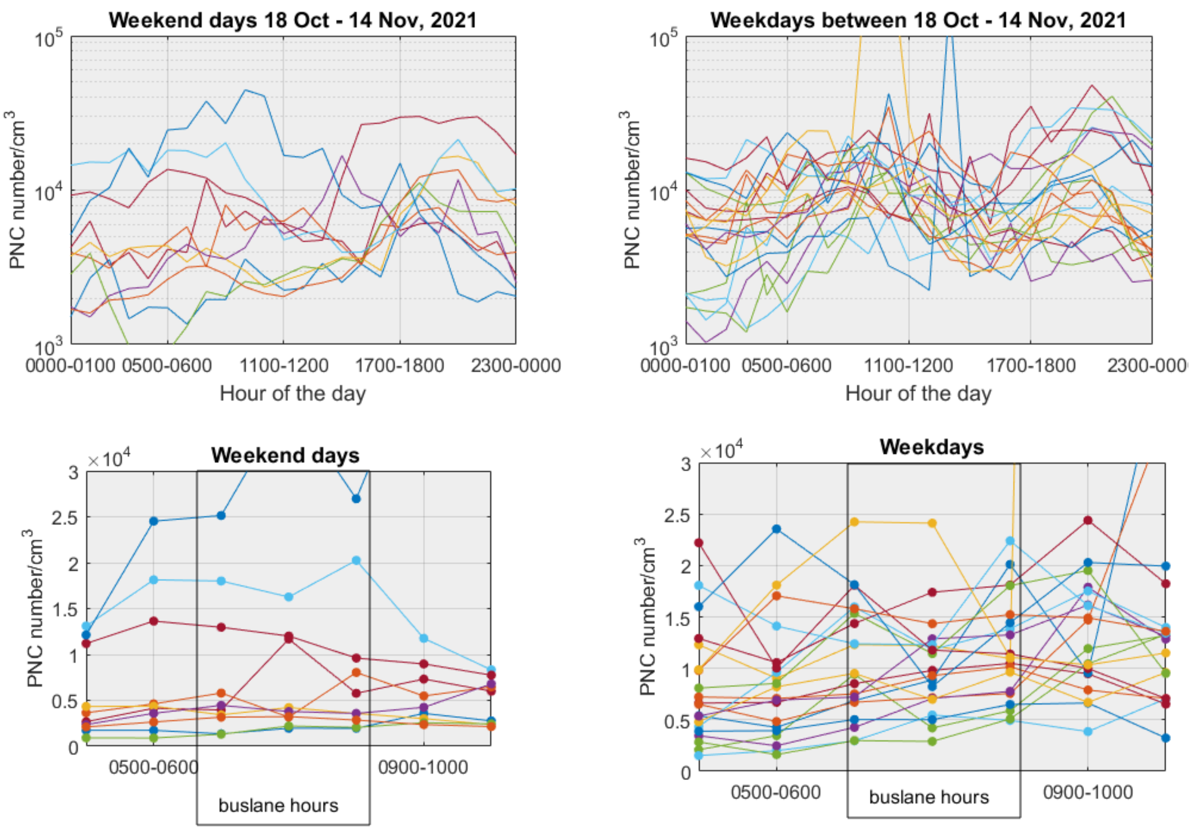

FIGURE 9. HOURLY AVERAGE PARTICLE NUMBER CONCENTRATION (PNC) CONCENTRATIONS MEASURED AT STATIONARY SITE BETWEEN OCTOBER 18 AND NOVEMBER 14, 2021, AFTER THE INSTALLATION OF THE BUS LANE SEPARATED BY WEEKDAYS AND WEEKEND DAYS. EACH COLOR REPRESENTS A DIFFERENT DAY. TOP PANELS SHOW ALL 24 HOURS OF DATA AND THE BOTTOM PANELS SHOW DATA FOR THE BUS LANE HOURS (0600-0900) AND TWO MORE HOURS BEFORE AND AFTER THE BUS LANE HOURS TO SHOW THE TEMPORAL TREND DURING THE MORNING HOURS.