Spatial and temporal distribution of air pollutants in Everett, Massachusetts

A report from

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Submitted to

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Executive Summary

Our team, composed of the Mystic River Watershed Association (MyRWA) and Drs. Neelakshi Hudda and John Durant of Environmental Monitoring Partners, LLC, conducted an air quality study in the City of Everett from July 2023 to December 2024.

The goal of this work was to deliver information responsive to concerns voiced by Everett residents about air quality in the City with particular attention on the industrial area in southeast Everett. During this period, we worked with Everett Community Growers (ECG) and Everett municipal staff to understand community concerns about air quality, identify the target areas for monitoring, and share results.

We characterized the concentrations of combustion-generated air pollutants (specifically ultrafine particles, black carbon, carbon dioxide and nitrogen dioxide) using stationary monitoring as well as a state-of-the-art mobile monitoring lab. We captured (a) the variation caused by natural factors (meteorology, time of day and season, (b) the impacts from anthropogenic emissions in the study area, and (c) established the spatial extent of the impacts.

We met regularly with the ECG and the City of Everett to receive input on study design. Beginning in January 2024, the project team met with Everett residents at community workshops (co-hosted by ECG), tabled at events, conducted walking tours (co-hosted by MA Sierra Club) and listening sessions, and visited school classrooms. Residents largely agreed that air quality is an issue, identified concerns about major traffic routes, exposures at schools and the industrial section of Everett. Feedback from the community resulted in (a) modification of the mobile monitoring route to enable coverage of neighborhoods where vulnerable populations reside, and (b) requests to install stationary monitors at four sites in addition to the site at Everett City Hall (City Hall site funded separately by the US EPA as part of the CLEANAIR study) to more fully characterize spatial and temporal patterns in air pollution in residential areas.

Based on the mobile monitoring results, we see that there are three different zones within the City where ultrafine particle concentrations are relatively uniform (see Figure ES-1). The first zone includes the area south of and to within 200 m north of Route 16. This part of Everett is characterized by significant industrial and commercial activity. We observed a high fraction of diesel vehicles in this zone; diesel vehicles emit high amounts of ultrafine particles and other pollutants. North of the southern zone, we observed two other zones: a central zone and a northeastern zone. We show these in the map (Figure ES-1). On the right of the graphic, the color ramp indicates the concentration of ultrafine particles, a marker of fresh fuel combustion emissions. The three zones, northeastern, central and southern fall into categories of low, medium and high levels of ultrafine particle concentrations respectively. This general spatial classification was broadly applicable across many monitoring runs even though total concentrations changed with the prevailing winds. For example, on a given day during westerly winds, the concentrations were in a lower range across Everett but within that lower range the southern zone had higher concentrations than the central or northeaster zones.

Our other important findings include the following:

1. Because S-SW winds (this shorthand convention refers to winds emerging from between the South and Southwest) were prevalent during our summer monitoring campaign, we placed stationary monitoring sites in such a way as to fully capture the impacts of S-SW winds across the City. We observed that during S-SW winds Everett was downwind of its own industrial and highly trafficked areas (i.e., south of Route 16) as well as downwind of possible source areas south of the Mystic River. With the exception of SE winds (discussed in point 2 below), the highest concentrations across Everett were observed during SW winds. These winds are important to focus on given that their annual frequency is 15%. It is also interesting that stretching from the west part of Everett (Main St.) to centrally located City Hall to eastern Everett (Woodlawn St.), we see a very particular wind direction (SW) associated with higher impacts and although ground-level releases from local traffic on Broadway and Rt. 16 are contributing to it, the possibility of a large pollution source located in the 220-230 azimuth (North is 0 azimuth, South is 180, Southwest is 270) from the sites cannot be ruled out.

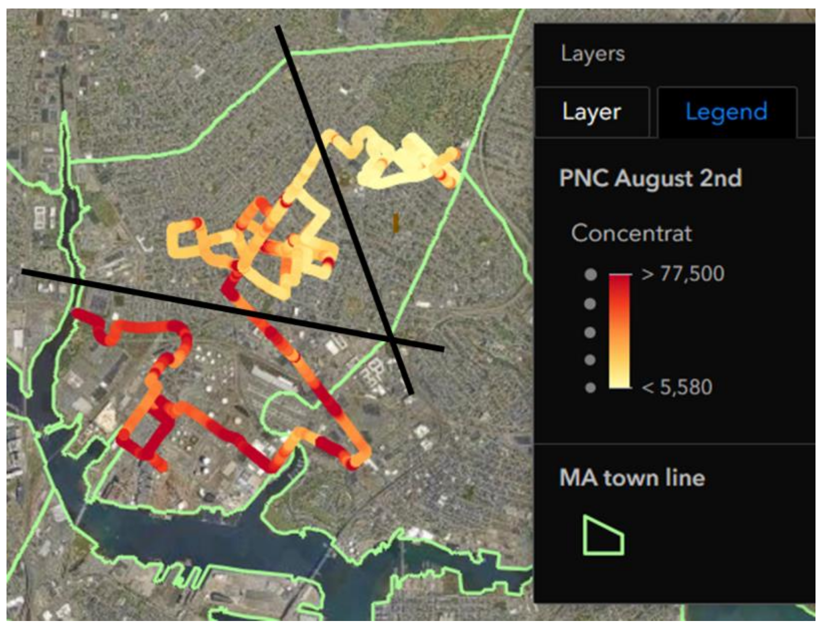


Figure ES 1: Ultrafine particle concentrations measured by mobile monitoring over a 2-hour period on a single day in Everett. The two black lines divide the city into three zones based on differences in particle concentrations.

2. The highest particle number concentrations - consistently across all sites - were associated with SE winds that orient Everett downwind of Boston Logan International Airport and underneath the trajectories of airplanes landing and taking off on runway 15R/33L; the annual frequency of SE winds is 4% (based on 2023 for the 135-165 degree

sector); thus, the overall impact of SE winds on pollutant concentrations in Everett is relatively moderate. Although Everett is >3 miles downwind of the airport, this impact is not unexpected given recent similar findings in Malden, Medford and Chelsea.

3. The lowest particle number concentrations - consistently across all sites - were associated with the W-NW-N winds. These winds orient Everett either upwind of its industrial sections and not downwind of other industrial or traffic areas, thus, resulting in relatively cleaner air in terms of particle number concentrations.
4. Overall, the daily average 'good practice' threshold of 10,000 particles/cm^3 (recommended in WHO guidelines) was commonly exceeded in Everett. This is not an unusually high concentration for an urban area, but there are parts of the Boston metropolitan areas, such as those to the west, where much lower concentrations are frequently observed. The hourly high threshold of 20,000 particles/cm^3 was also exceeded frequently during SE and S-SW winds, but we did not observe an exceedance of that threshold in W, NW or N winds. These winds are far more common during winter months when, due to limited dispersion, higher concentrations can be expected; thus, we expect the >10,000 particles/cm^3 threshold will likely be exceeded in winter during W, NW and N winds.
5. Patterns similar to ultrafine particles (but with fewer observations) were apparent in spatial trends for nitrogen dioxide (NO_2) and black carbon (BC).
6. It is important to note that our stationary measurements were limited to a few weeks in summer and that our campaign was aimed at developing a better understanding of spatial differences in pollutant concentrations across Everett and not aimed at delivering temporal insights. Therefore, our findings should not be used to estimate possible exposures, which should be based on longer-term estimates that capture temporal variation.

Conclusions: Everett is significantly impacted by local traffic emissions throughout the City. In the area including and south of Route 16 heavy-duty-truck-related emissions appear to be dominant, while in the more central part of Everett emissions from light-duty/car traffic is dominant. It is also evident that Everett is impacted by emissions from outside the city boundary, particularly from sources located south and southeast of the City. Concentrations of ultrafine particles frequently exceed the health-relevant thresholds set by the WHO, more so when influenced by emissions from the south and southeast.

Introduction

Background

Everett, Massachusetts, is a city of 49,000 residents located 3 miles northwest of Boston. The southern part of the city is currently zoned for industrial and commercial use with activities such as fuel storage, electricity generation, shipping, and scrap metal recycling representing important sectors of the Everett economy. Over the past decade this area of Everett has been undergoing a significant land use transition away from its historic base of activities and toward a more mixed economy that includes service sector activities such as restaurants, hotels, gaming and entertainment.

As this transition moves forward, changes in environmental quality will also occur, particularly in air quality. In some parts of the city, many polluting businesses will be shut down resulting in air quality improvement, but at the same time traffic patterns may change in other parts of the city leading to air quality detriment. It is useful to study and document these changes in air quality so that city planners in Everett can anticipate how changes to their economy will likely affect the environment.

We were tasked with designing and performing a study to systematically characterize air quality in Everett with a focus on combustion-generated air pollutants including ultrafine particles, black carbon, carbon dioxide, and nitrogen dioxide. These pollutants are commonly present in industrial and transportation emissions. The study was designed to measure both the spatial extent of air quality impacts, which may extend into the neighborhoods that surround the industrial area and transportation corridors, and temporal variation in pollutant concentrations caused by natural factors such as meteorology, time of day, and season.

Ultrafine Particles

In our study, we chose to focus on measurement of ultrafine particles (UFP; particles less than 100 nanometers in diameter) because they are an excellent marker of combustion emissions and because exposure to ultrafine particles has been shown to adversely impact human health. UFP are generated by a wide range of combustion sources (e.g., cars, buses, airplanes, heating of buildings with fossil fuels) and are thus ubiquitous in urban air and are strongly correlated with black carbon, carbon dioxide, and nitrogen dioxide concentrations. UFP enters the body via inhalation and can cause lung inflammation. In addition, because of their small size, UFP can enter the bloodstream and become widely distributed throughout the body. Increased concentrations of UFP in the air can exacerbate symptoms of respiratory and cardiovascular disease.

To date, no air quality regulations have been established for UFP in ambient air; however, the World Health Organization (WHO) has recently proposed air quality guidelines for UFP:

> "*Since then [2005], the body of epidemiological evidence [on UFP] has grown, and two systematic reviews have assessed scientific research papers published from 1997 to 2017 (HEI, 2013; Ohlwein et al., 2019), documenting the rising number of studies being conducted. The studies demonstrated short-term effects of exposure to UFP, including mortality, emergency department visits, hospital admissions, respiratory symptoms, and effects on pulmonary/systemic inflammation, heart rate variability and blood pressure; and long-term effects on mortality (all-cause, cardiovascular, IHD and pulmonary) and several types of morbidity. However, various UFP size ranges and exposure metrics were used, preventing a thorough comparison of results across studies (US EPA, 2019a). Therefore, there was a consensus in the GDG that the body of epidemiological evidence was not yet sufficient to formulate an AQG level.*
>
> *At the same time, however, there is a large body of evidence from exposure science that is sufficient to formulate good practice advice. The most significant process generating UFP is combustion and, therefore, the main sources of the UFP include vehicles and other forms of transportation (aviation and shipping), industrial and power plants, and residential heating. All of these utilize fossil and biofuels, as well as biomass. Since everyone is exposed to the emissions from these sources, exposure to UFP is of concern*."[1]

The WHO has issued four 'good practice' statements on UFP to guide decision-makers and researchers towards measures to reduce ambient UFP concentrations.

1. *Quantify ambient UFP in terms of particle number concentration (PNC) for a size range with a lower limit of ≤ 10 nm and no restriction on the upper limit.*
2. *Expand the common air quality monitoring strategy by integration of UFP monitoring into existing air quality monitoring. Include size-segregated real-time PNC measurements at selected air monitoring stations in addition to, and simultaneously with, other airborne pollutants and characteristics of PM.*
3. *Distinguish between low and high PNC to guide decisions on the priorities of UFP source emission control. Low PNC can be considered < 1,000 particles/cm³ (24-hour*

[1] WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide [Internet]. Show details Geneva: World Health Organization; 2021. URL: https://www.ncbi.nlm.nih.gov/books/NBK574595/

mean). High PNC can be considered >10,000 particles/cm^3 (24-hour mean) or 20,000 particles/cm^3 (1-hour mean).

4. *Utilize emerging science and technology to advance approaches to the assessment of exposure to UFP for application in epidemiological studies and UFP management."*[2]

In our report we compare our results to these guidelines.

Nitrogen dioxide (NO_2) and black carbon (BC)

In addition to UFP, we also measured NO_2 and BC with our mobile monitoring platform. NO_2 and BC are both combustion biproducts and are ubiquitous in urban air due to emissions from fossil-fuel-burning transportation sources (e.g., cars, trucks, buses, airplanes, trains, ships, etc.), industry, and power generation. NO_2 is formed by the reaction between oxygen and nitrogen in air at high temperatures in internal combustion engines. People who are exposed to high concentrations of NO_2 can experience irritation of the respiratory system leading to symptoms such as coughing, wheezing or difficulty breathing. Short term exposures can aggravate respiratory diseases, particularly asthma, and lead to increased rates of hospital admissions and emergency rooms visits. Long-term exposures may contribute to the development of asthma and potentially increase susceptibility to respiratory infections. As a result, NO_2 is a regulated pollutant under the Clean Air Act. BC is produced by the incomplete combustion of fossil fuels and lubricating fluids in engines. Visible plumes of BC can often be seen as black clouds of fine particles in the emissions from buses and trucks. Exposure to BC is associated with cardiopulmonary health effects and cancer. To date, there are no regulatory standards in the U.S. for BC.

Methods

Monitoring at Stationary Sites

We monitored UFP at five sites in Everett: at a site in the commercial area south of Route 16 (S-Charlton St.), a central site (C-Everett City Hall), a site in the north (N-Henry St.), a site in the east (E-Woodlawn St.), and a site in the west (W-Main St.) (Figure 1). All but the central site were located at ground level; the central site was located on the roof of City Hall, a four-story building. We implemented a group-wise monitoring design with up to three sites grouped together and monitored simultaneously. This allowed us to look across sites for spatial patterns while controlling for temporal variation (i.e., temporally varying effects were common to all sites in the trio). Everett City Hall and the Woodlawn Street site to the east

[2] https://www.ncbi.nlm.nih.gov/books/NBK574595/box/ch4.box15/?report=objectonly

were held in common in all trios. The rationale being to provide a contrast between other sites and the central site and contrast between other sites and the Woodlawn Street site, which we expected to have relatively cleaner air and is also the easternmost downwind site for southwestern winds that are prevalent in the Boston area during summer. The groupings and monitoring periods are indicated in Table 1. Ambient PNC was monitored using three identical water-based condensation particle counters (CPC; TSI Inc. Model 3783, lower size limit of 7 nm). The monitors were housed at each site in weather-resistant, temperature-controlled shelters. PNC measurements were recorded every second.

Mobile Monitoring

Mobile monitoring was performed using the EMP Air Pollution Monitoring Laboratory (EMPL). EMPL is an all-electric vehicle equipped with marine deep-cycle batteries and an inverter that provides 120v AC to the instruments. EMPL contains an air sampling manifold mounted between the two rear windows to which the instrument inlets are plumbed. Ambient air is conveyed through the manifold by two fans mounted on either end. Instrument inlet lines are connected to the manifold upstream of the inlet fan. For this study, EMPL was equipped with a TSI Model 3783 condensation particle counter (dp_{50} = 7 nm), an aethalometer (Model AE33, Magee Scientific, Berkeley, CA) for measuring black carbon, a LiCOR Model 830 carbon dioxide/water vapor analyzer (Lincoln, NE), and a Cavity Attenuated Phase Shift (CAPS) nitrogen dioxide monitor (Aerodyne Research, Billerica, MA). PNC, CO_2, and NO_2 measurements were collected at 1-second resolution while black carbon (BC) measurements were collected every minute. Individual measurements were mapped to location by 1-second GPS readings (Model GPSMAP 64sx, Garmin Ltd., Olathe, KS).

Mobile monitoring was generally conducted along the route shown in Figure ES-1 but was adapted to include community requests or construction detours. The route was designed to allow measurement of traffic-related air pollution along both busy urban streets and in quiet residential areas. We conducted 16 mobile monitoring runs in summer 2023, fall 2023, and summer 2024 during morning and evening traffic rush hours and daytime non-rush hours. Mobile monitoring was performed on both weekdays and weekends, and at different times of the day. The majority of monitoring was performed between 05:00 and 24:00.

Quality Assurance and Data Processing

The CPCs were manufacturer-calibrated prior to the start of the study, and based on side-by-side comparisons, the CPCs had <10 % difference in their measurements, which was within instrument specifications. During weekly visits to the stationary sites, data were downloaded, instrument times were corrected for time drift as necessary based on NIST time at time.gov, the CPCs were checked for pulse height, nozzle pressure, and temperature, and other errors (which were corrected upon discovery), and the FMPS electrometers were zeroed. Instrument-reported flow rates were regularly checked for accuracy (TSI 4100 flow meter), and a polyethersulfone membrane filter (rated at 99.97% removal efficiency for 0.3 μm particles) was placed on the inlet to check that the PNC dropped to <10 particles/cm^3 on the CPCs and FMPSs. The inlet tubing on the CPCs and BC analyzer were made of conductive silicon material, and the lengths of the tubing were minimized to reduce particle losses. The inlet tubing for the NO_2 and CO_2 analyzers was made of Tygon. During mobile monitoring, effort was made to drive the EMPL at or below posted speed limits (30-50 kmph depending on the road segment), and to keep several vehicle lengths (>3-5) behind other vehicles to minimize potential monitoring bias caused by close proximity to plumes of fresh tailpipe emissions. This was especially important when mobile lab was behind heavy duty diesel-powered vehicles (e.g., trucks and buses), which are significant sources of UFP (as well as nitrogen oxides (NOx) and black carbon (BC) and other pollutants).

Datasets were reviewed for measurements automatically flagged by the CPCs (e.g., due to nozzle clogs, temperature faults, and low pulse heights) as well as unusually low concentrations. Data marked with fatal errors (as opposed to warnings) and/or concentrations <100 particles/cm^3 were removed (<4% of data were removed for these reasons). We did not correct for particle losses in the sampling lines (<50 cm in length); losses have been observed to be small for particles >20 nm in diameter (especially for short sampling lines). Pollutant spikes due to other vehicles near the mobile lab were not removed from the dataset.

Processed data were aggregated to minutely and hourly resolution; details in figure and table captions state the time basis for the statistics reported. Meteorological data was obtained from the Automated Surface Observing System (operated by National Weather Service) for Boston Logan Airport and was processed using EPA's AERMET program.

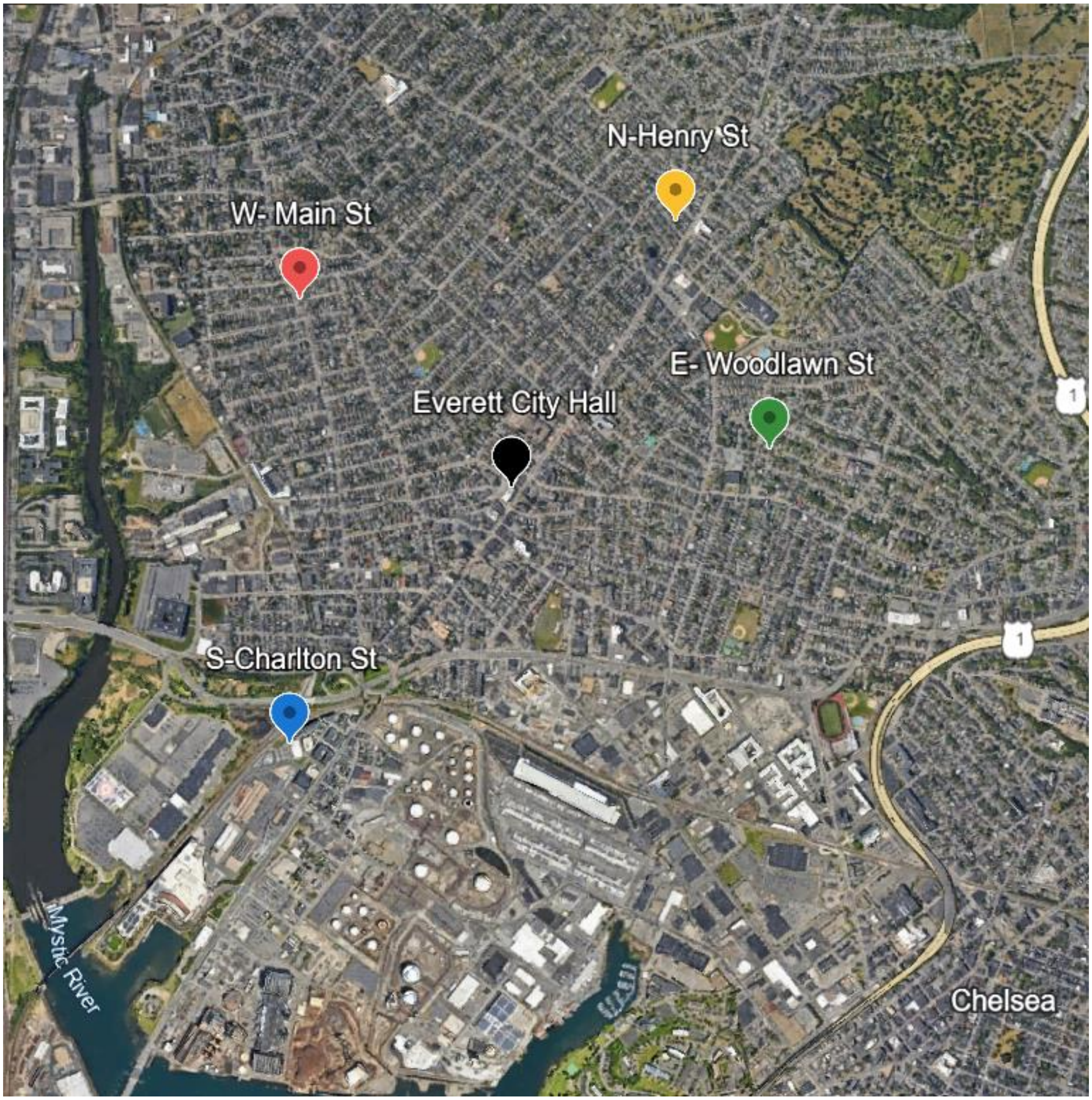


Figure 1. Monitoring sites in Everett.

Meteorology

During the study period winds were predominantly out of the southwest, which was consistent with expected summertime wind patterns in the Boston area. Southwest winds broadly oriented the industrial part of Everett upwind of the residential parts and was a rationale for conducting monitoring in summer months. During the study, the mean wind direction was 210°, which occurred at 64% frequency, and the mean speed was 4.62 m/s; calm winds, defined as <0.5 m/s, occurred 2.7% of the time. A wind rose for the study is shown in Figure 2 and relevant statistics for the study periods corresponding to site groupings are summarized in Table 1.

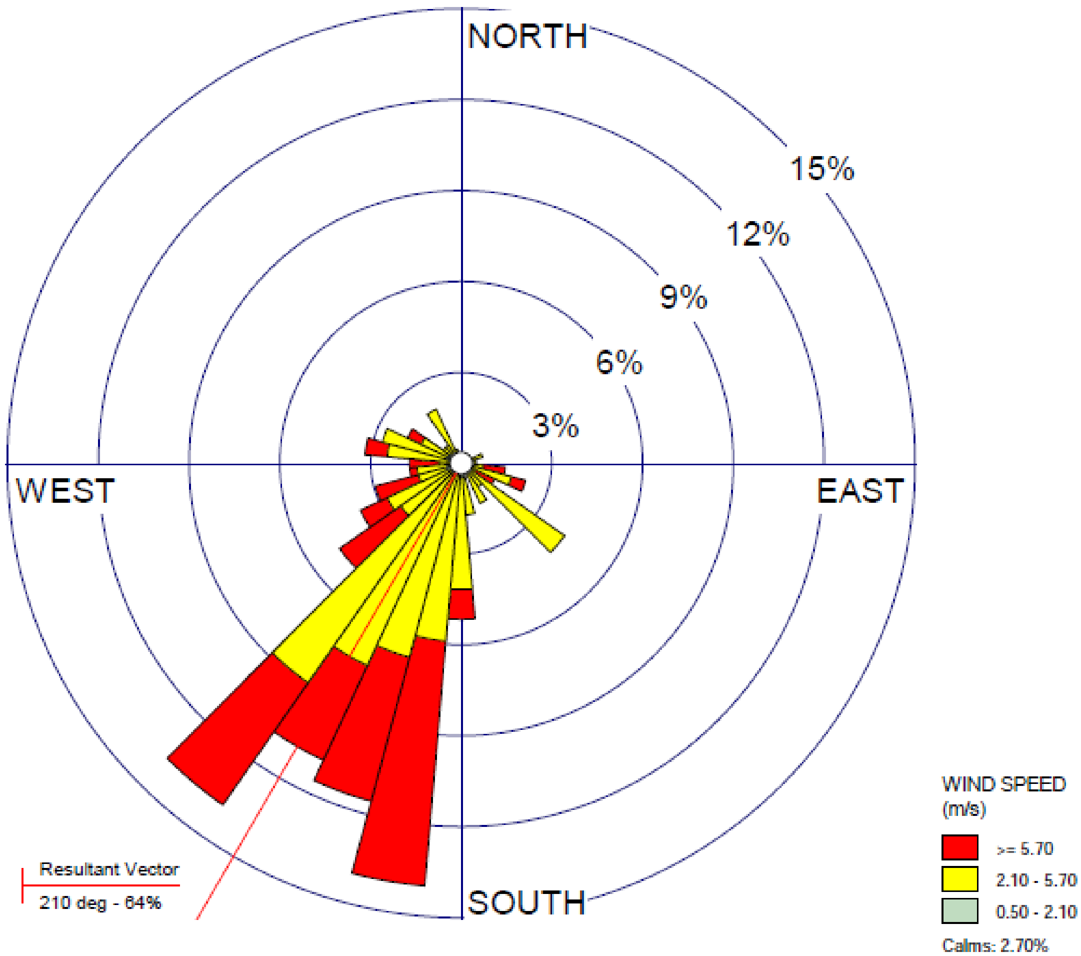


Figure 2: Windrose during the study period (July 3-19) based on data collected at Boston Logan International Airport by the National Weather Service.

Table 1: Groupings of stationary monitoring sites and monitoring periods.

Grouping	Locations	Overlap with rotational site in the grouping	Average Particle Number Concentrations[1]	Dates	Mean Wind Direction and Speed
North-Central-East	**Henry St**		11000 ± 91%	July 3-8	198 (54% of measurements were from this direction), 4.01 m/s; 5.56% calms; 144 hours of measurements
	City Hall	n/a	n/a		
	Woodlawn St	99%	11000 ± 109%		
West-Central-East	**Main St**		14000 ± 100%	July 9-15	206 (82%), 4.90 m/s; with 1.79% calms; 168 hours of measurements
	City Hall	81%	17000 ± 129%		
	Woodlawn St	100%	13000 ± 77%		
South-Central-East	**Charlton St**		14000 ± 86%	July 15-19	237 (62%), 4.96 m/s; 0.83% calms; 120 hours of measurements
	City Hall	100%	11000 ± 100%		
	Woodlawn St	93%	9000 ± 100%		

[1]Average for the duration of the monitoring is based on minutely concentrations ± standard deviation expressed as percentage of the average.

Results

Table 1 summarizes the average PNC measured at the five monitoring sites. Note, for the two sites that were part of all groupings, Tables 1 shows averages corresponding to the time periods that match the site grouping

Trends with respect to wind direction

We present two main findings with respect to wind direction – one expected and one unexpected – before describing more nuanced results. Table 3 shows minutely-average particle number concentrations at all sites by 10-degree-wide wind direction bins. Note, the sites were monitored at different times over the course of the study.

1. Most of the highest UFP concentrations that were measured across all five sites occurred during southeasterly winds. This finding was not unexpected by the research team, but it is not commonly known. These winds orient Everett downwind of Boston Logan International Airport, a significant source of UFP. Previous studies have shown the remarkable impact of aviation emissions on UFP in many parts of the Boston area including neighborhoods such as Chelsea and Winthrop. Figures 3 (a) - 3 (c) show time series plots of PNC at hourly resolution, and the highest concentration events occur during southeasterly winds. It is worth noting that UFP concentrations observed during southeasterly winds were high at all sites, and that at the City Hall site, which was on the fourth floor, PNC was higher than measured at ground level at the other sites.

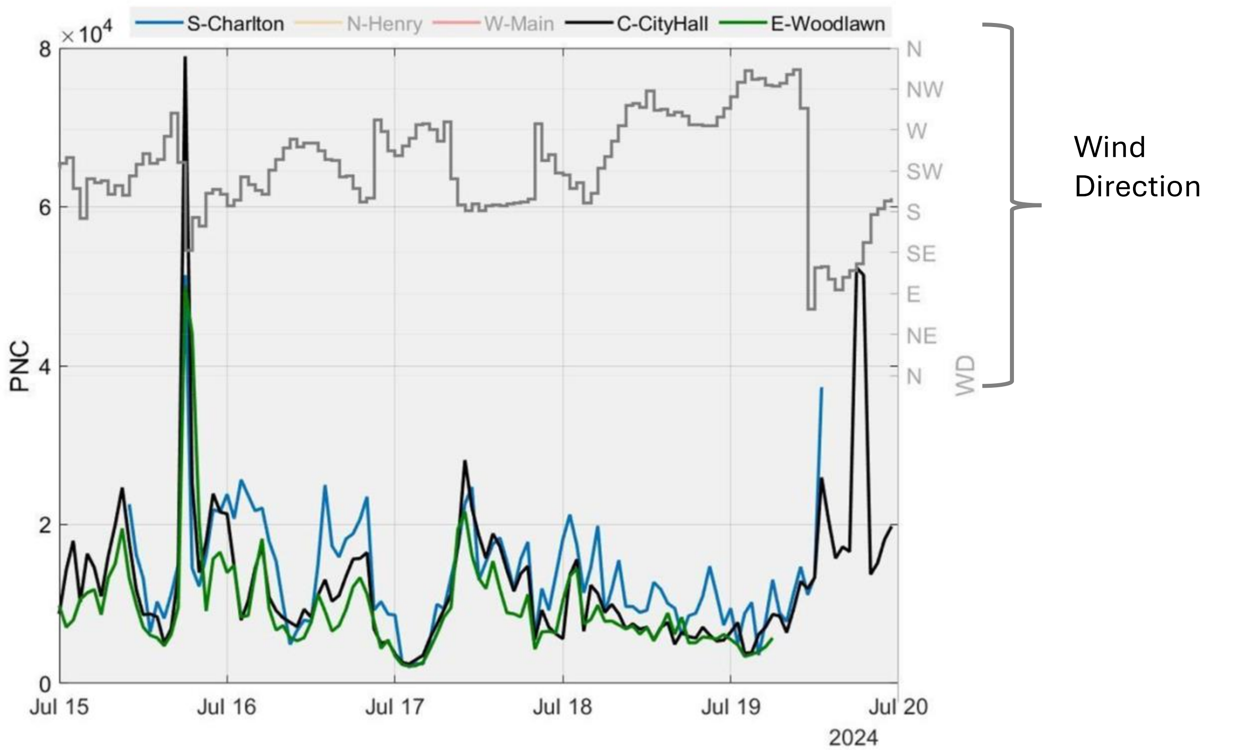
   Although southeasterly winds are clearly associated with many-fold higher UFP concentrations, they occur infrequently. As shown in the windrose in Figure 2, southeasterly winds occurred only ~4% of the time during the study period and their annual frequency is also on the order of 4%. Nonetheless, our results are consistent with other studies that have demonstrated large impacts on particle number concentrations from aviation activity in neighborhoods that are distant from the airport. Despite their infrequency, the magnitude and prevalence of these impacts over large, populated areas merits further investigation.

2. The lowest particle number concentrations were measured during westerly and northwesterly winds (Table 3). At the Charlton Street site, the lower concentrations during these winds were not as low as at other sites because during westerly-northwesterly-northerly winds this site is downwind of Route 16, another source of UFP.

Table 3: Average of minutely-averaged particle number concentrations at all sites by 10-degree-wide wind direction bins.

WD	S-Charlton	W-Main	C-City Hall	N-Henry	E-Woodlawn
355 - 5				11100	10200
5-15				8500	8000
15-25					
25-35					
35-45					
45-55				13100	15400
55-65				15400	15500
65-75	11200	13300	11900	19500	13000
75-85		15400			11700
85-95		11400	11000		20600
95-105				11500	10600
105-115		10800	13000	14800	8400
115-125	24600	26800	28500	21400	23800
125-135		30000	27400	28100	31000
135-145	51400		78900	13300	25100
145-155			51400		
155-165	12200		14000	10700	21000
165-175	14500	7000	17800	10000	16800
175-185	17800	15200	19200	16800	15200
185-195	17700	14100	16000	9800	12000
195-205	20200	13700	18300	11300	11000
205-215	20300	13300	17500	9300	10900
215-225	18000	12300	16400	7200	10200
225-235	15100	8100	11800	8000	8500
235-245	13300	9600	9300	10700	7100
245-255	8600	8800	6900	12800	6900
255-265	7500	7200	7000		6100
265-275	10200		5600	3700	4800
275-285	8400		6100	4500	5400
285-295	10400	6600	7000	5800	6100
295-305	9400		7100	8900	7700
305-315	9300	7900	6500		5900
315-325	8700		8000	10700	6100
325-335	7200		5500		3800
335-345	10100		6600		3400
345-355					

Higher concentrations in highlighted in red and lower concentrations in blue.


S-Charlton
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C-CityHall
E-Woodlawn
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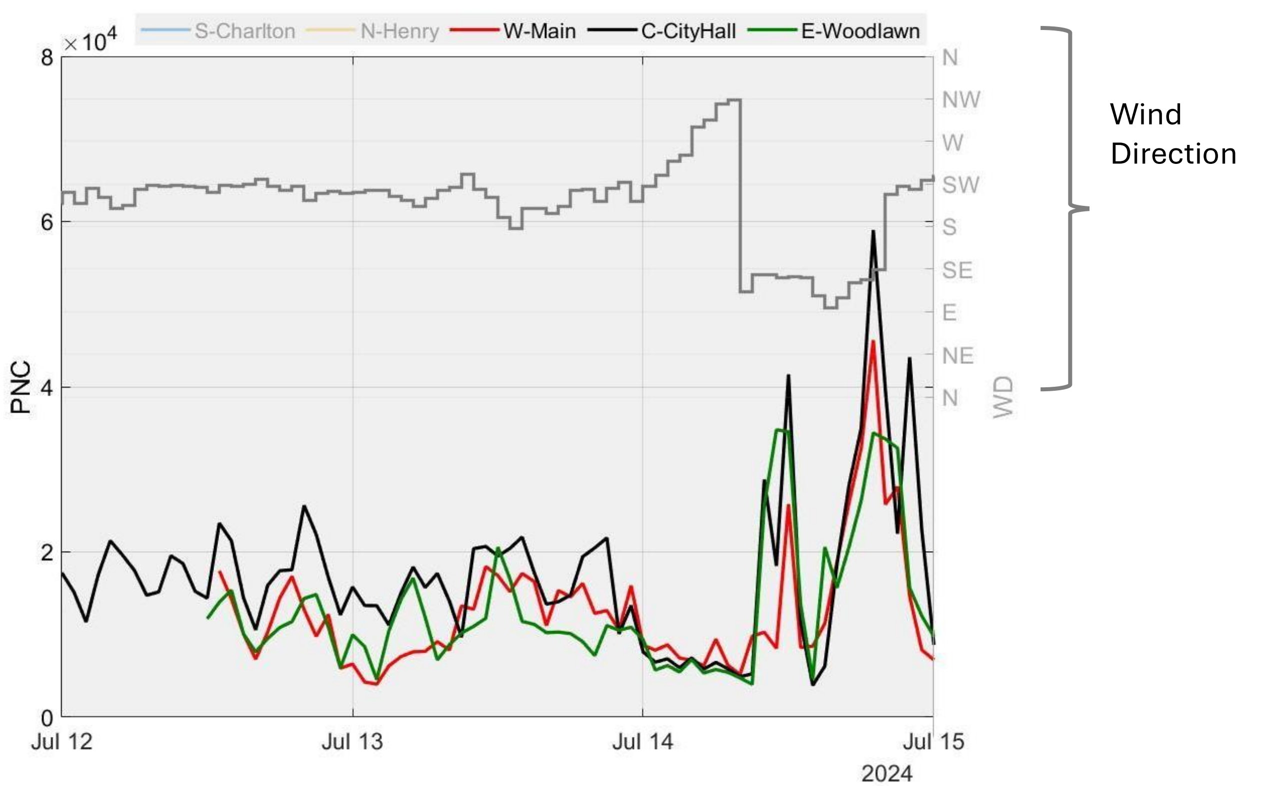
Wind Direction


S-Charlton
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Wind Direction

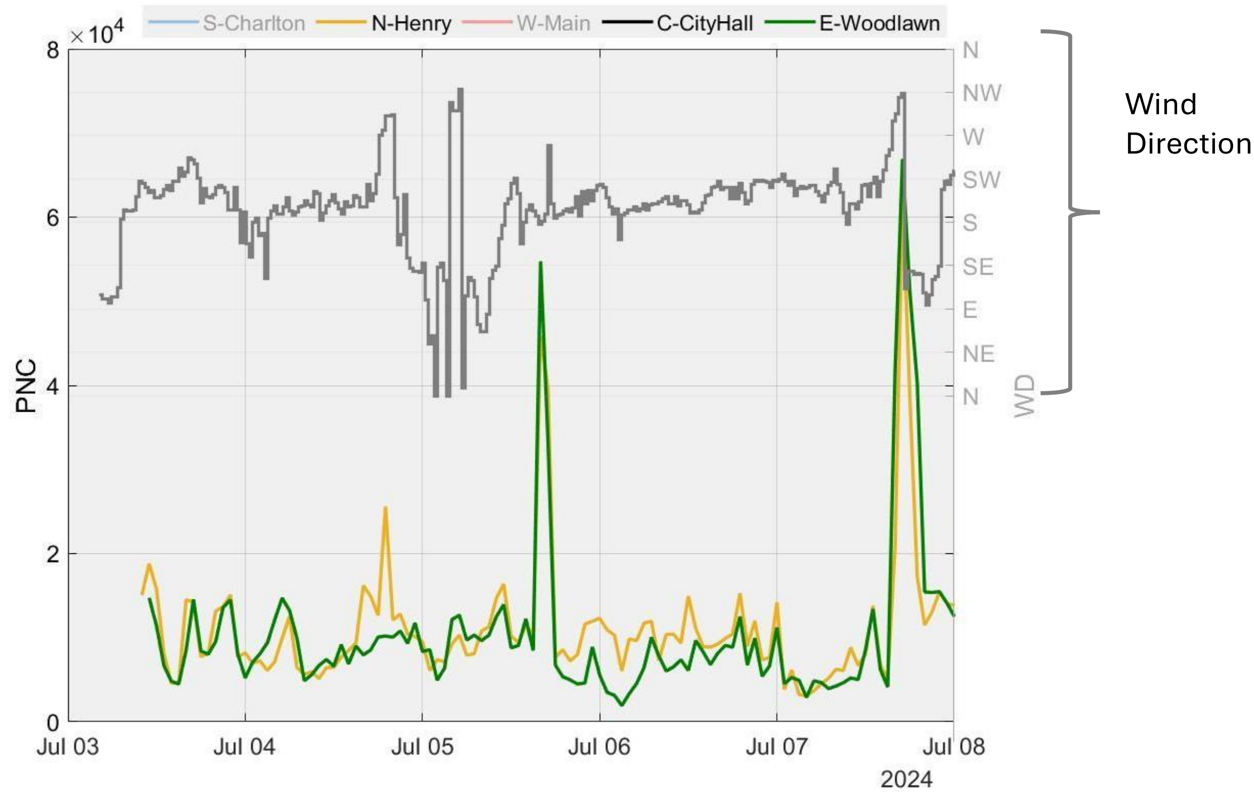

Figure 3: Time-series of particle number concentrations monitored simultaneously at S-Charlton St., C-City Hall, and E-Woodlawn sites (upper panel). at W-Main St., C-City Hall, and E-Woodlawn sites (middle panel), and at C-City Hall and E-Woodlawn sites (lower panel). Wind direction (gray line) is plotted on the secondary vertical (right) axis.

Comparison of sites within a grouping

This section describes differences observed across groups of sites. Analysis across multiple sites at once yields insights into spatial trends across Everett - specifically, which parts of the city experience higher concentrations for a given hour and day under the same meteorological conditions.[3] This section also describes the impacts of winds from the south and southwest, which orient residential sections of Everett downwind of more industrial and heavily trafficked parts of the city.

<u>South-Central-East Grouping:</u>

In this grouping, ultrafine particle number concentrations (PNC) were highest at the S-Charlton St. site, followed by the centrally located City Hall site, and lowest at the E-Woodlawn St. site. The daily average PNC at the S-Charlton St. site was 55% higher than at E-Woodlawn St. and 35% higher than at C-City Hall. see bottom right panel of Figure 4. These

[3]Note, here we are not discussing temporal trends, such as when are the concentrations higher or lower during a day or a week or a longer period of time? That analysis requires a larger dataset for which long-term monitoring is being conducted at the City Hall.

measurements were made between July 16 and 18 (counting only the full 24-hour 100% data recovery days in making this comparison).

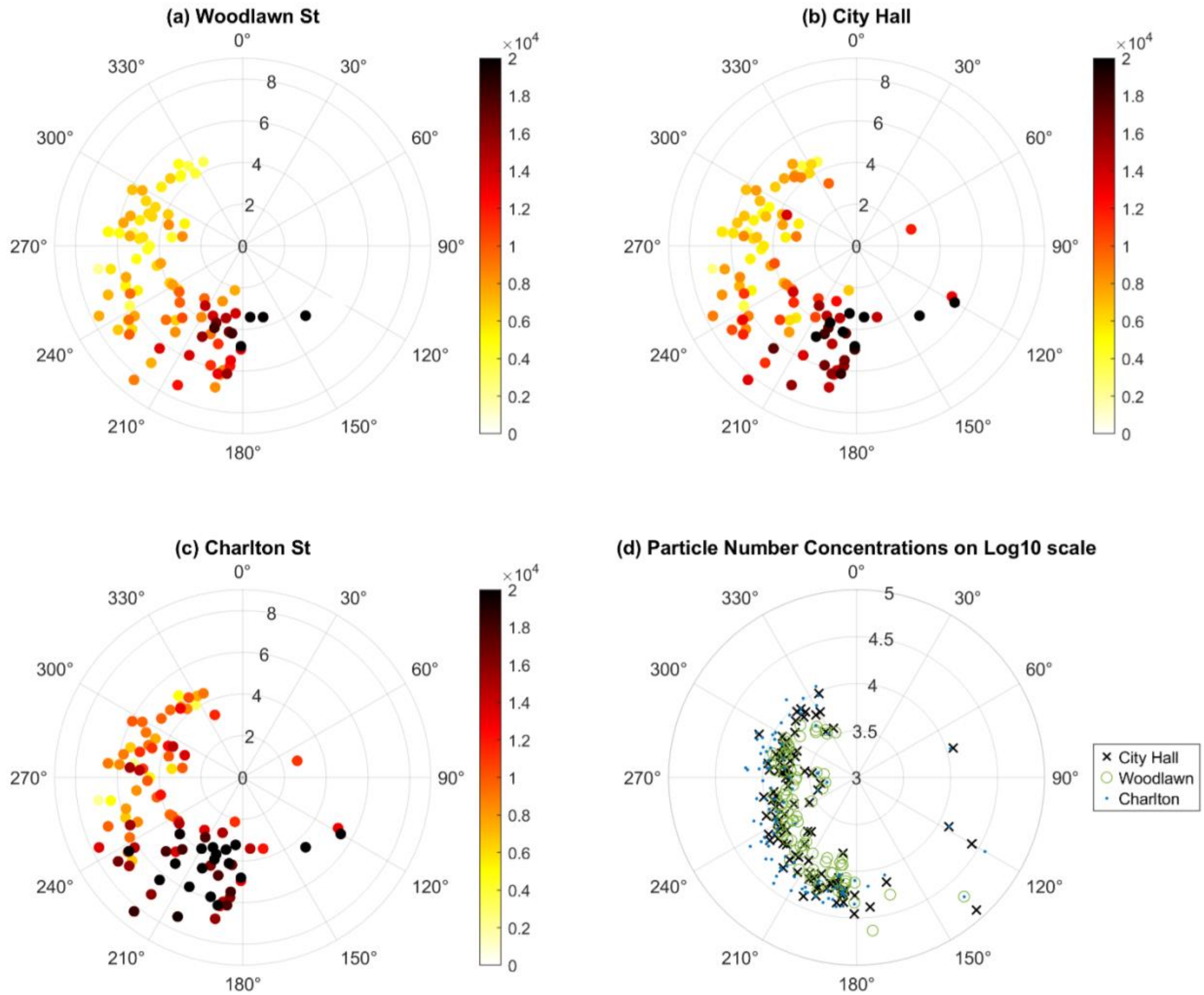

Figure 4: Polar plots (pollutant roses) of hourly average ultrafine particle number concentrations at the south-central-east sites measured simultaneously in July 2024. The radial axis in the roses (a)-(c) shows the wind speed and the polar axis shows the direction from which the wind is blowing. Colors represent concentrations (see color ramp on the side of the plots), ranging from 0 to 20,000 particles/cm^3, which is the high hourly threshold per WHO guidelines. Figure (d) shows all the concentration data for each on a log10 scale (so that it is easier to visualize the data); note that unlike the roses in (a)-(c), the radial axis in (d) is concentration and not wind speed.

During this period, on all days the daily average PNC at the E-Woodlawn St. site was below the WHO high threshold of 10,000 particles/cm^3 for the daily average, but it always exceeded this threshold at the S-Charlton St. site. Furthermore, the short-term (hourly average) threshold of 20,000 particles/cm^3 was exceeded only 4% of the time (and that too due to S-SE winds) at the E-Woodlawn St. site. But it was exceeded during 17% of the monitoring hours at S-Charlton St. site and a vast majority of those hours occurred during S-SW winds that orient the site not downwind of the industrial section of Everett, but downwind of the

MBTA bus-fleet yards and Encore Casino, as well as several big-box stores. This threshold was never crossed during westerly or northerly or easterly winds. The centrally located City Hall site was in between the S-Charlton and E-Woodlawn sites in terms of air quality: the hourly threshold of 20,000 particles/cm^3 was exceeded 8% of the time during simultaneous monitoring for this grouping. These hourly average values are shown in Figure 4 plotted against hourly wind direction and speed, and the color ramp maximum (black color) is set to the 20,000 particles/cm^3 threshold. Note that there is a preponderance of black points in S-SW winds at S-Charlton St. sites with decreasing concentrations in these winds at the C-City Hall and the E-Woodlawn St. sites.

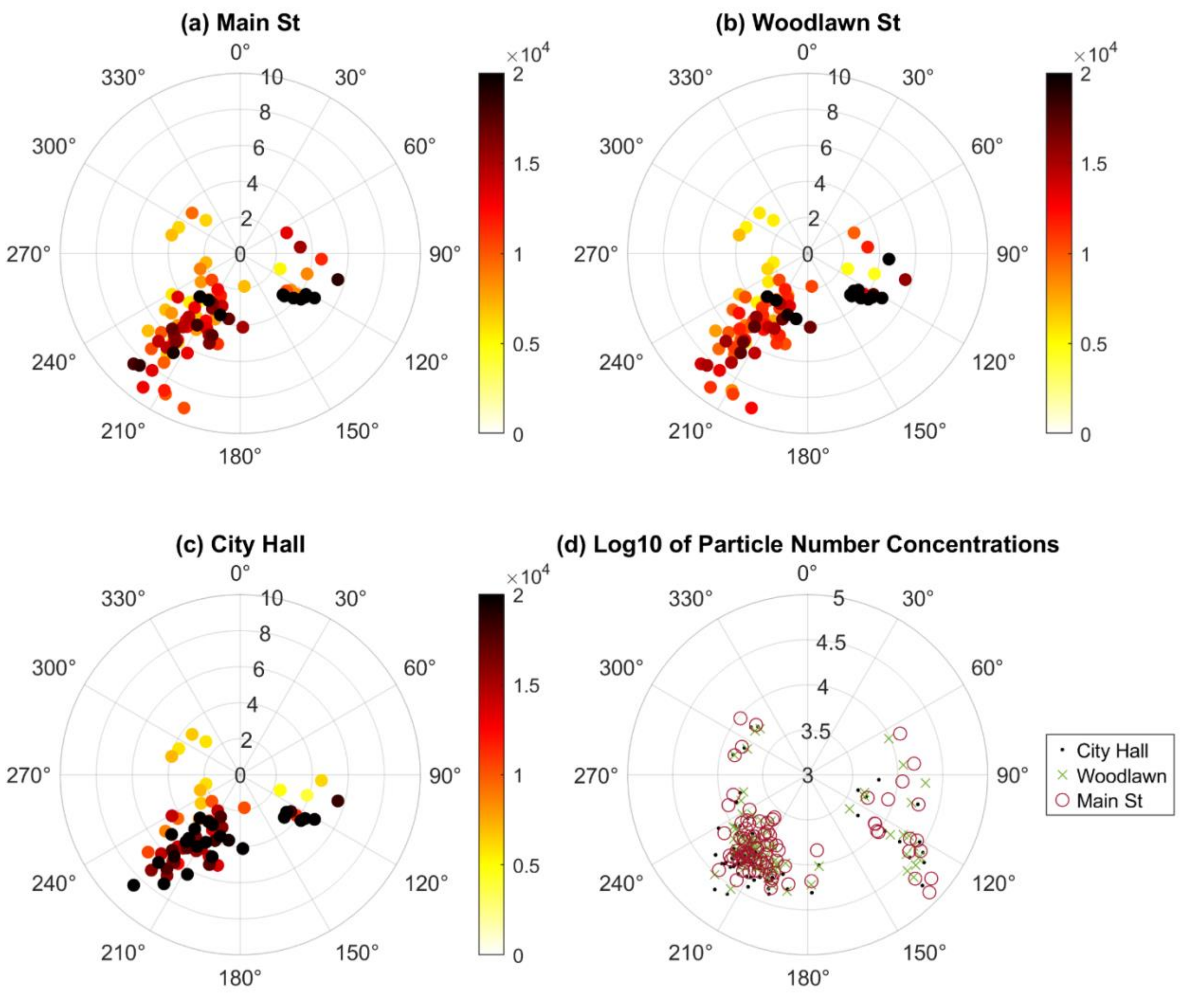

Figure 5: Polar plots (pollutant roses) of hourly average ultrafine particle number concentrations at the west-central-east sites measured simultaneously in July 2024. The radial axis in the roses (a)-(c) shows the wind speed and the polar axis shows the direction from which the wind is blowing. Colors represent concentrations (see color ramp on the side of the plots), ranging from 0 to 20,000 particles/cm^3, which is the high hourly threshold per WHO guidelines. Figure (d) shows all the concentration data for each on a log10 scale (so that it is easier to visualize the data); note that unlike the roses in (a)-(c), the radial axis in (d) is concentration and not wind speed.

West-Central-East Grouping:

In this grouping, the concentrations were highest at the C-City Hall site and comparable at the W-Main St. and E-Woodlawn St. sites. On a daily average basis, between July 13 and 14 (counting only the full 24-hour 100% data recovery days in making this comparison) the concentrations were ~30% higher at City Hall; see Figure 5 (d). During this period, the daily average was above the "high" WHO threshold of 10,000 particles/cm^3 at all three sites.

Furthermore, the short-term (hourly average) threshold of 20,000 particles/cm^3 was exceeded 14% and 11% of the time (again mostly during S-SE winds) at the East-Woodlawn and West-Main St. sites. But it was exceeded during 29% of the monitoring hours at City Hall site and the majority of those hours occurred during SW winds that oriented the site almost parallel to Broadway St. and the traffic emissions from vehicles on Broadway. Again, this threshold was never crossed during westerly, northerly, or easterly winds but they occurred very infrequently during monitoring. These hourly average values are shown in Figure 5 plotted against hourly wind direction and speed, and the color ramp maximum (black color) is set to the 20,000 particles/cm^3 threshold. Note that there is a preponderance of black points in SW winds at the City Hall site with relatively lower concentrations during SW winds at the other two sites. The pattern of similarity with City Hall -SW winds is striking and raises the possibility that there may be a large source of UFP to the SW in or near Everett that contributes to all sites and in addition to that baseline, the local emission from Broadway impact the City Hall site.

North-Central-East Grouping

The concentration observed at N-Henry St and E-Woodlawn St. sites were remarkably similar – the average of hour-to-hour difference was <1000 particles/cm^3 and concentrations were highly correlated (r^2 =0.78) (although North-Henry St. was marginally higher than East-Woodlawn St (11,400 vs. 10,700 particles/cm^3)). There were differences, such as during SE winds when the E-Woodlawn St. site was closer to Boston Logan airport, it had higher concentrations than at the Henry Street site. During W or NW there was almost no difference between the sites (note the overlap of pints in the sub-figure on the bottom right of Figure 6). Overall, our conclusion is that both these sites represent northern Everett well in terms of air quality, and further those neighborhoods of Everett exhibit lower spatial variability and lower concentrations. Nonetheless, during the simultaneous monitoring period, the WHO guidelines for the daily high threshold (10,000 particles/cm^3) was exceeded on three out of four days at the N-Henry St. site and two out of four days at the E-Woodlawn St. site, and further, the hourly high threshold of 20,000 particles/cm^3 was exceeded 6% of the monitoring hours at both sites (again mostly during SE winds).

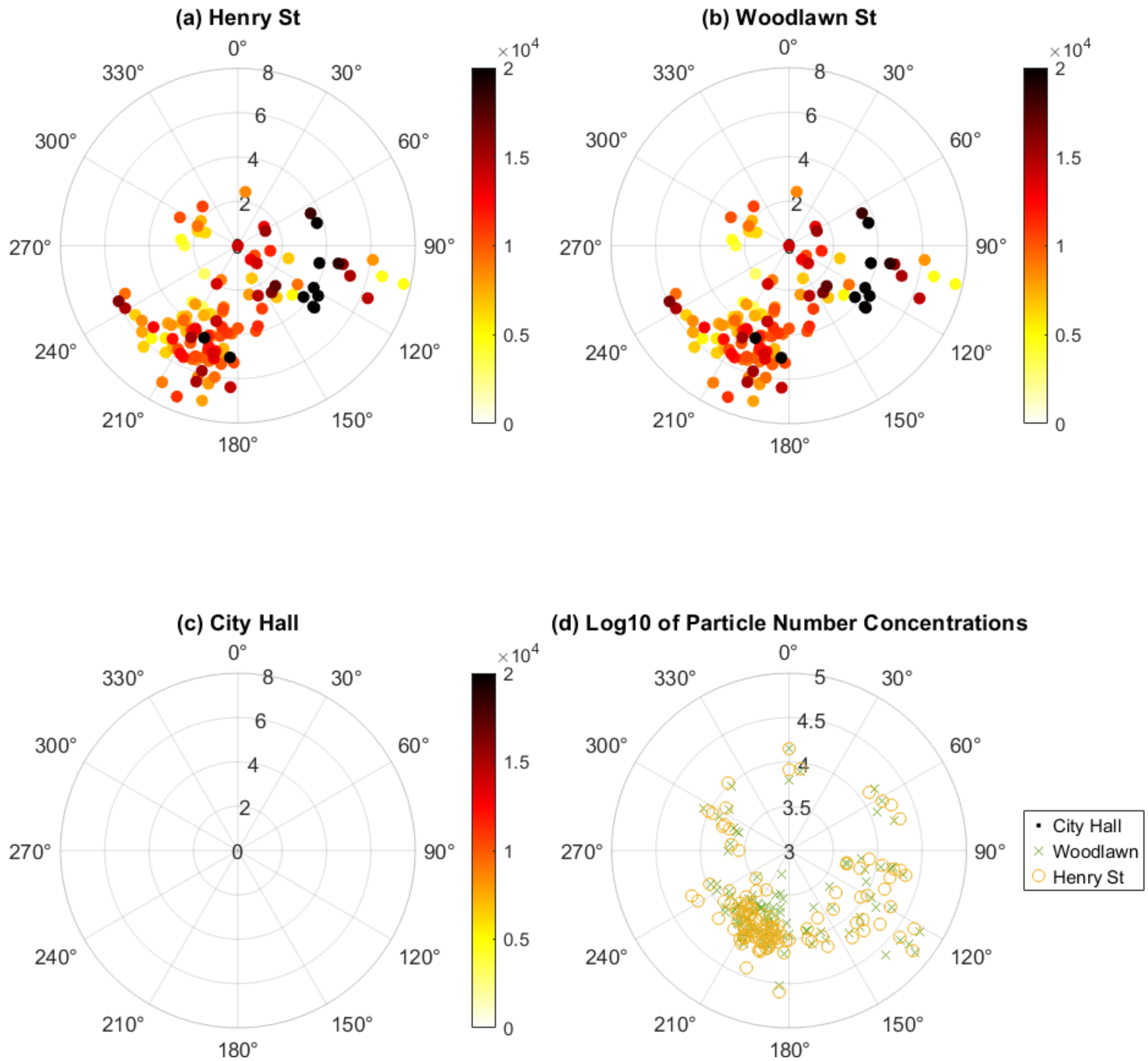

Figure 6: Polar plots (pollutant roses) of hourly average ultrafine particle number concentrations at the north-east sites measured simultaneously in July 2024. The radial axis in the roses (a)-(c) shows the wind speed and the polar axis shows the direction from which the wind is blowing. Colors represent concentrations (see color ramp on the side of the plots), ranging from 0 to 20,000 particles/cm^3, which is the high hourly threshold per WHO guidelines. Figure (d) shows all the concentration data for each on a log10 scale (so that it is easier to visualize the data); note that unlike the roses in (a)-(c), the radial axis in (d) is concentration and not wind speed. Note: No data has been plotted in Figure 6 (c) because the City Hall site was down during those days.

Spatial Trends

We have interpreted the mobile monitoring results in two ways. First, because we can traverse much of the city in a span of 1-2 hours with the mobile monitoring vehicle, we can interpret the spatial patterns across the city under similar meteorological conditions. Second, because we conducted mobile monitoring on different days and during various times of the day, it lets us compare the spatial pattern when meteorological or traffic conditions differ. For example, we can compare patterns during southerly versus northeasterly winds and during rush-hour versus non-rush-hour traffic. To that end, we are not discussing each mobile monitoring run in isolation, but rather we are providing salient examples that support the finding from examination of the data from all sixteen (16) runs.

Figures 7 and 8 show that during SE and S winds ultrafine particle concentrations follow a gradient with the highest concentrations in southern parts of Everett – within 200 m south of route 16 – are , followed by lower concentrations in the central part of Everett (along Main Street in particular) and the lowest concentrations in northeast Everett Day-to-day or hour-to-hour the differences observed and present zone to zone can differ but broadly the pattern of spatial variation remains the same. Figures 7 and 8 show the pattern but also support some aforementioned findings. Note that on August 2 and September 21 - data shown in Figures 7 and 8 across Everett we observe higher concentrations of ultrafine particles, which show the contribution and role of sources outside Everett on air quality across Everett. Furthermore, the contributions from sources within Everett are evident in higher concentrations in southern and central Everett. Note the contrast during later morning (non-rush-hour traffic) versus evening (rush-hour traffic) hours in central Everett in Figure 7 versus Figure 8; expectedly, we saw higher contributions during hours of congested traffic in central Everett.

Figure 9 shows the pattern during westerly winds – typically, associated with a relative lower background across Everett (see higher presence of lighter colored points in Figure 9 versus 7 and 8) – where the contributions from local sources such as traffic on roads and intersections can be easily seen against a cleaner background. Figures 10-11 are superior examples (both figures are based on data collected on August 1 but Figure 9 shows data during rush hour traffic and Figure 10 during midday non-rush hour traffic) that show the distinctly show contributions from local traffic on Rt 16, busier roads, intersections but also the relatively homogenous cleaner background in northeast Everett, higher concentration on eastern parts of central Everett that are downwind during westerly winds and generally higher concentrations in southern part of Everett.

The broad observation that northeastern parts of Everett have relatively lower concentrations than central Everett which has lower concentrations that southern Everett is reenforced consistently in the spatial patterns show for Nitrogen dioxide (NO2) in Figures 12-15 and in BC in Figure 16-17. However, these patterns are starker than in ultrafine particles. NO2 and BC are primarily emitted by diesel engines in urban traffic areas and the patterns observed in Everett are consistent with presence of diesel or heavy duty truck traffic in the City.

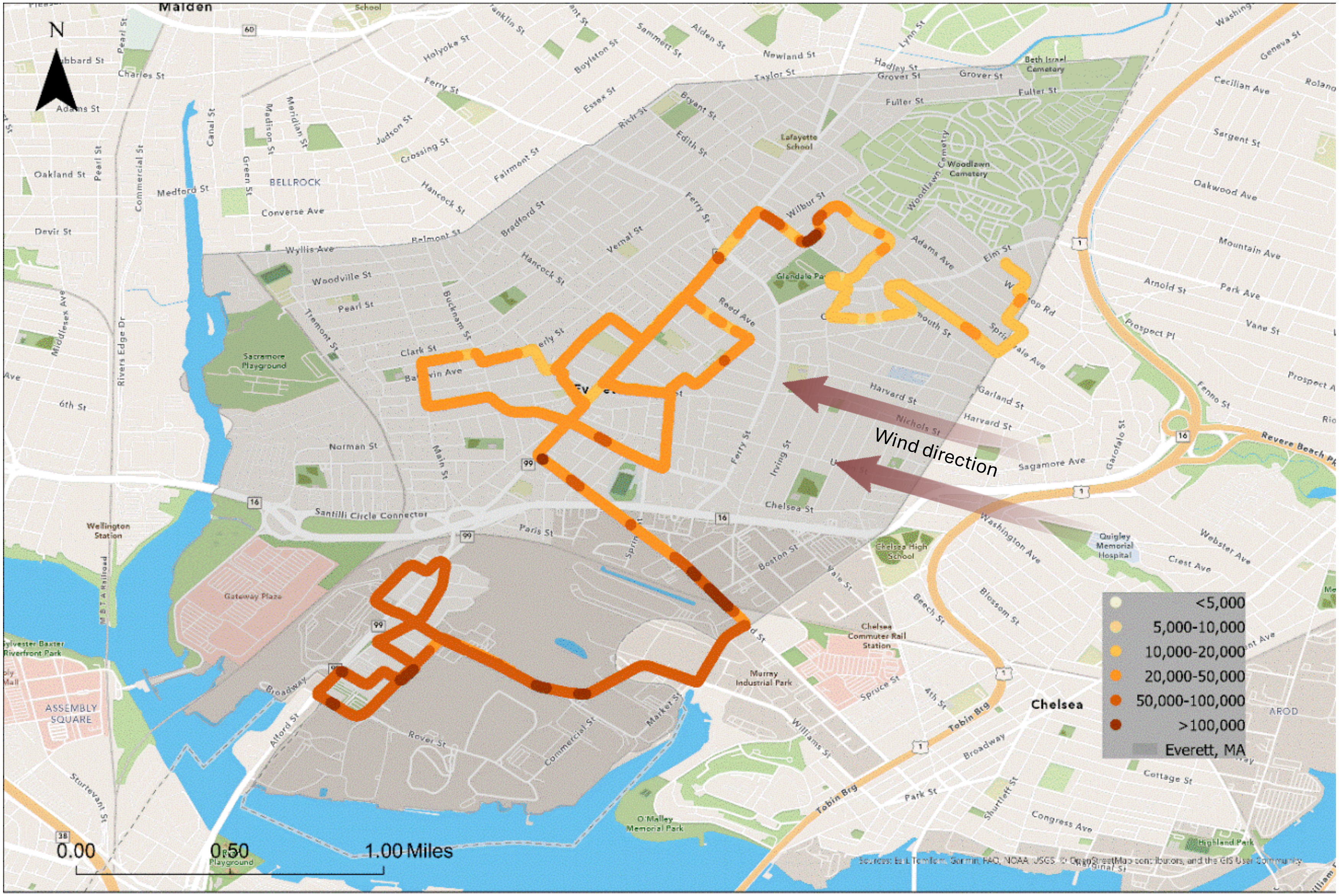

Figure 7: Ultrafine particle number concentrations in Everett based on mobile monitoring from 11:38 am to 12:32 pm on August 2, 2024 during southeasterly winds. Concentrations shown in the legend have units of particles/cm^3.

Figure 8: Ultrafine particle number concentrations in Everett based on mobile monitoring from 07:20 pm to 08:30 pm on September 21, 2023 during southerly winds. Concentrations shown in the legend have units of particles/cm^3.

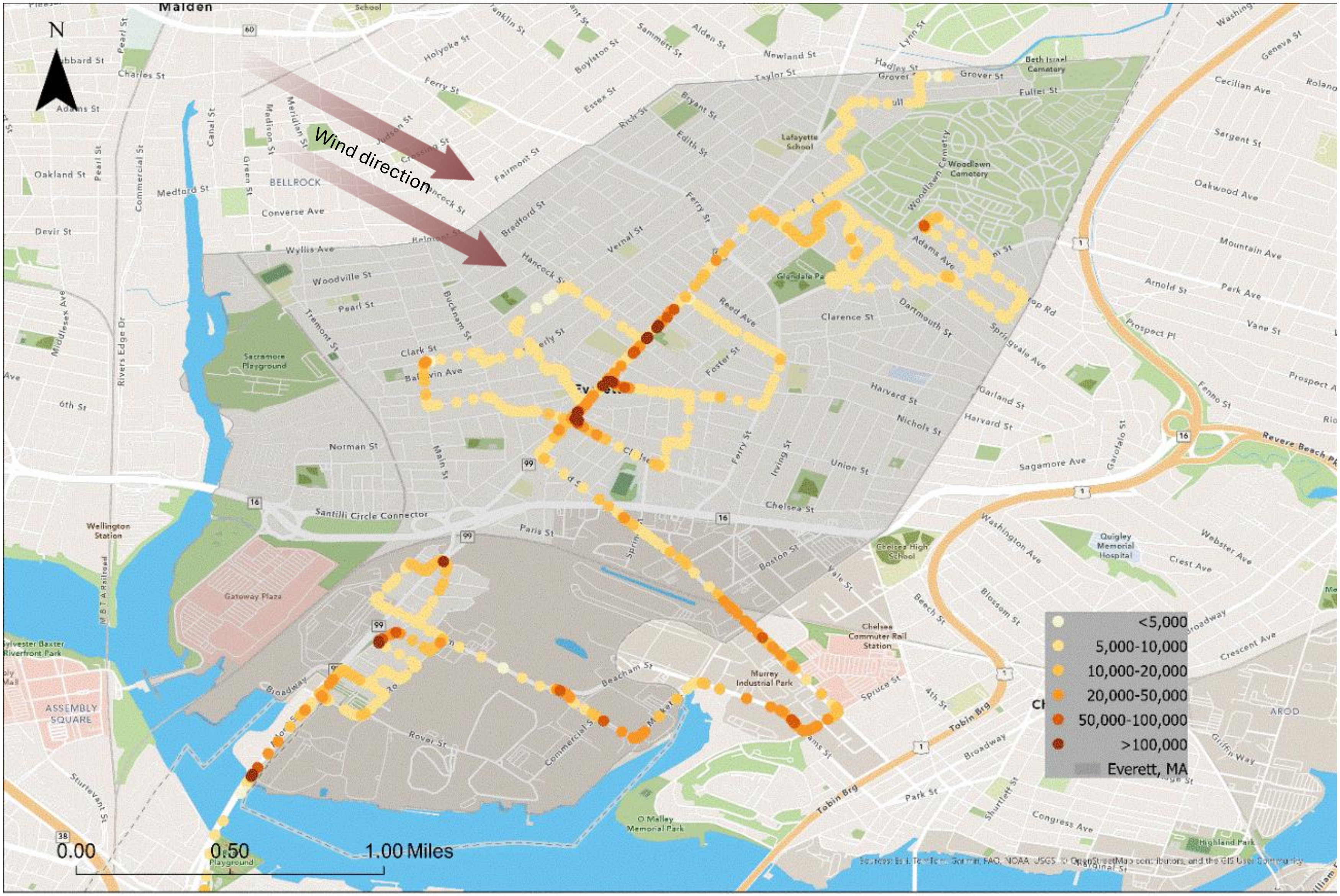

Figure 9: Ultrafine particle number concentrations in Everett based on mobile monitoring from 1:45 pm to 3:30 pm on November 08, 2024 during *__northwesterly__* *winds. Concentrations shown in the legend have units of particles/cm*^{3}.

Figure 10: Ultrafine particle number concentrations in Everett based on mobile monitoring from 9:35 am to 11:25 am on August 01, 2024 during ***westerly*** *winds. Concentrations shown in the legend have units of particles/cm³.*

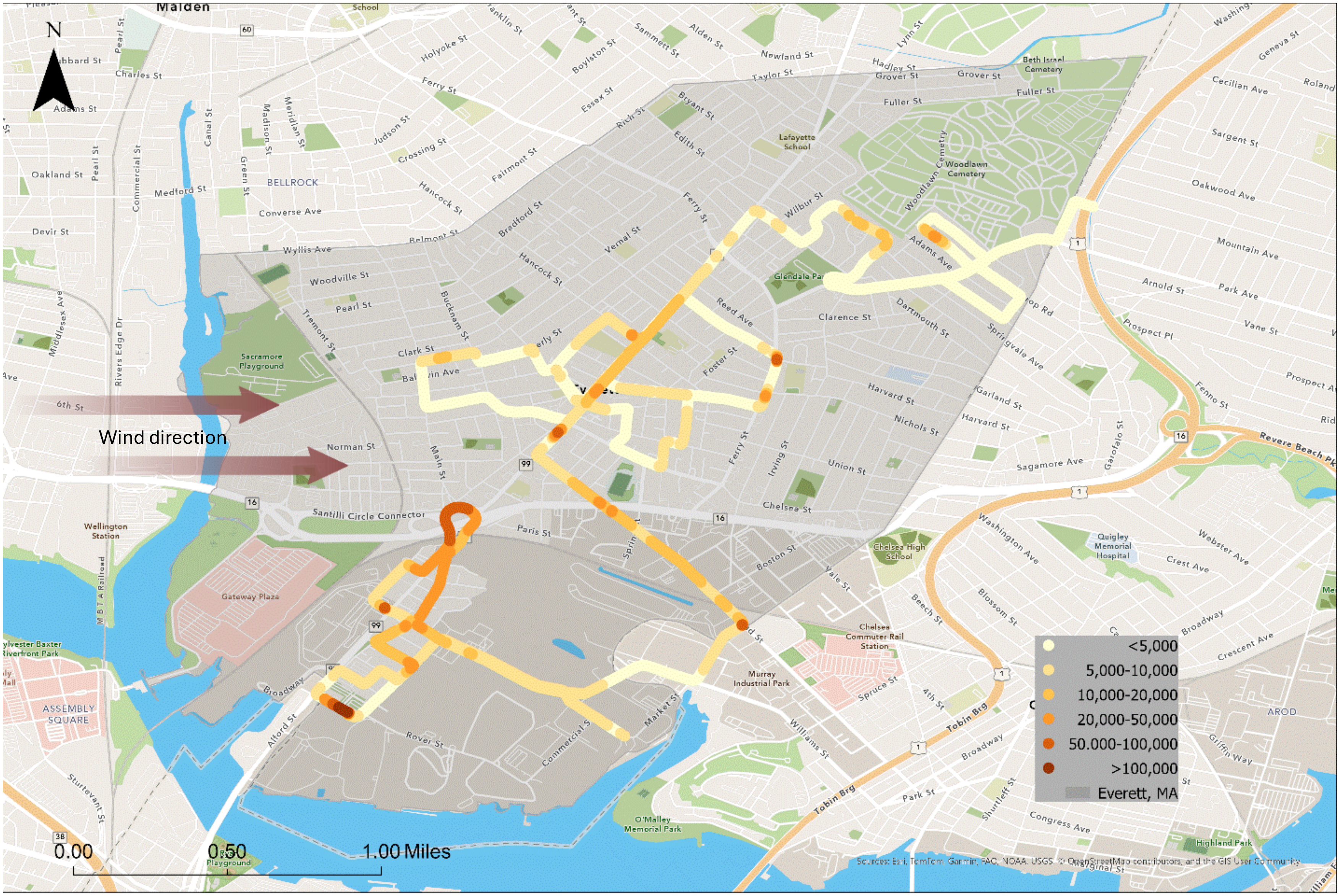

Figure 11: Ultrafine particle number concentrations in Everett based on mobile monitoring from 2:24 pm to 3:25 pm on August 01, 2024, during westerly winds. Concentrations shown in the legend have units of particles/cm³.

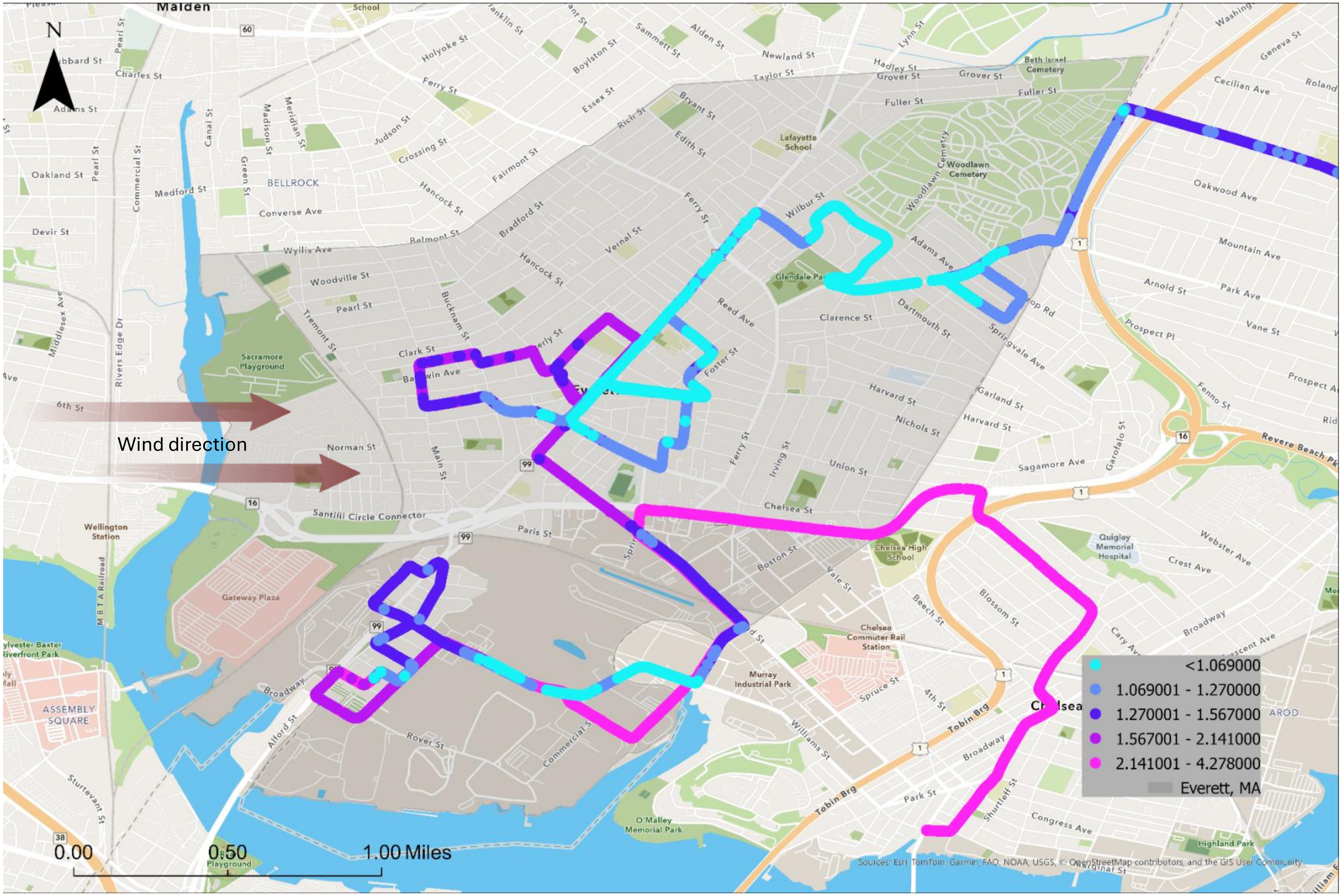

Figure 12: Nitrogen dioxide concentrations in Everett based on mobile monitoring from 9:35 am to 11:25 am on August 01, 2024 during westerly winds. Concentrations shown in the legend have units of parts per billion (ppb). These concentrations are all well below the regulatory limits for NO_2 (the 1-hour standard is 100 ppb).

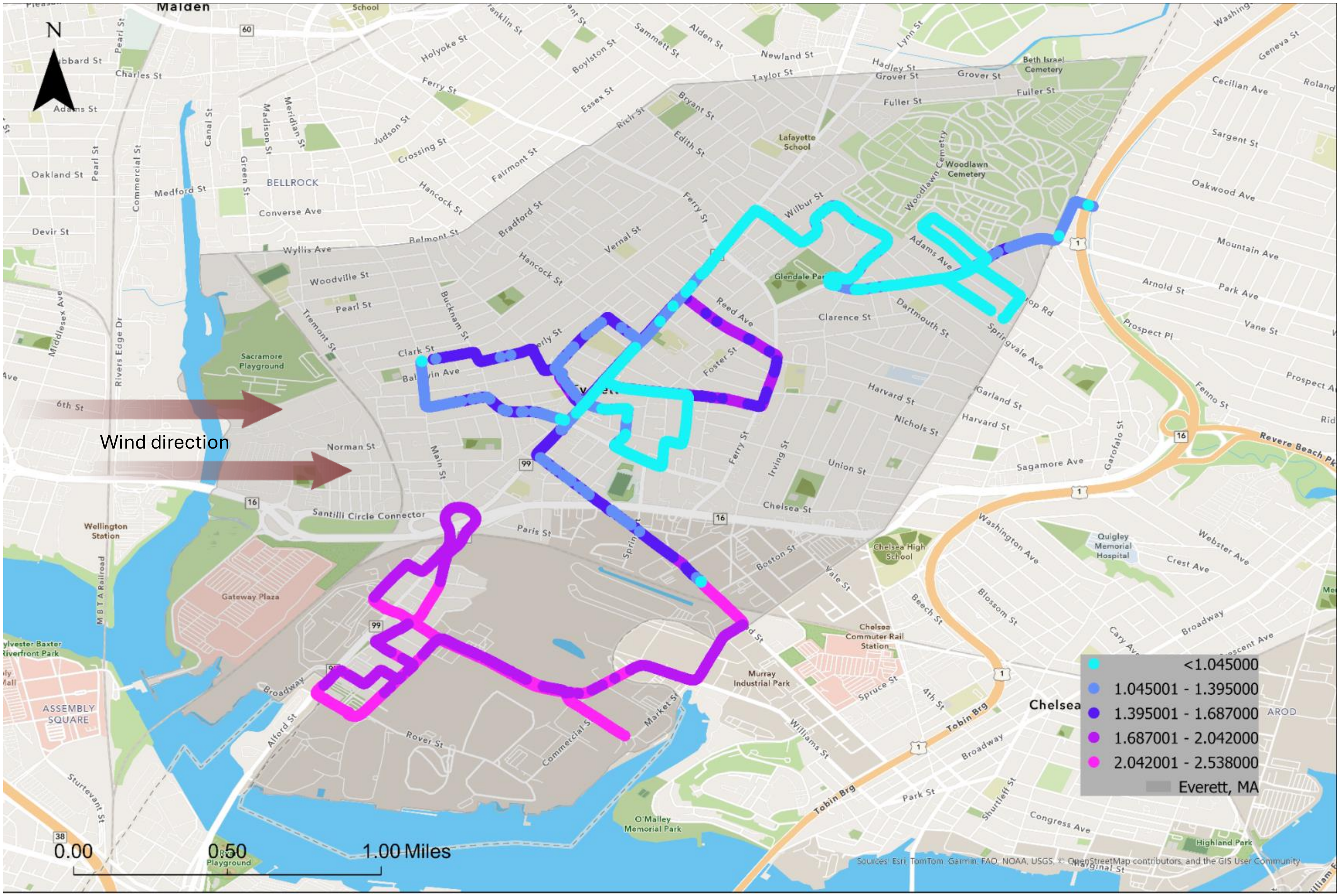

Figure 13: Nitrogen dioxide concentrations in Everett based on mobile monitoring from 2:24 pm to 3:25 pm on August 01, 2024, during westerly winds. Concentrations shown in the legend have units of parts per billion (ppb). These concentrations are all well below the regulatory limits for NO_2 (the 1-hour standard is 100 ppb).

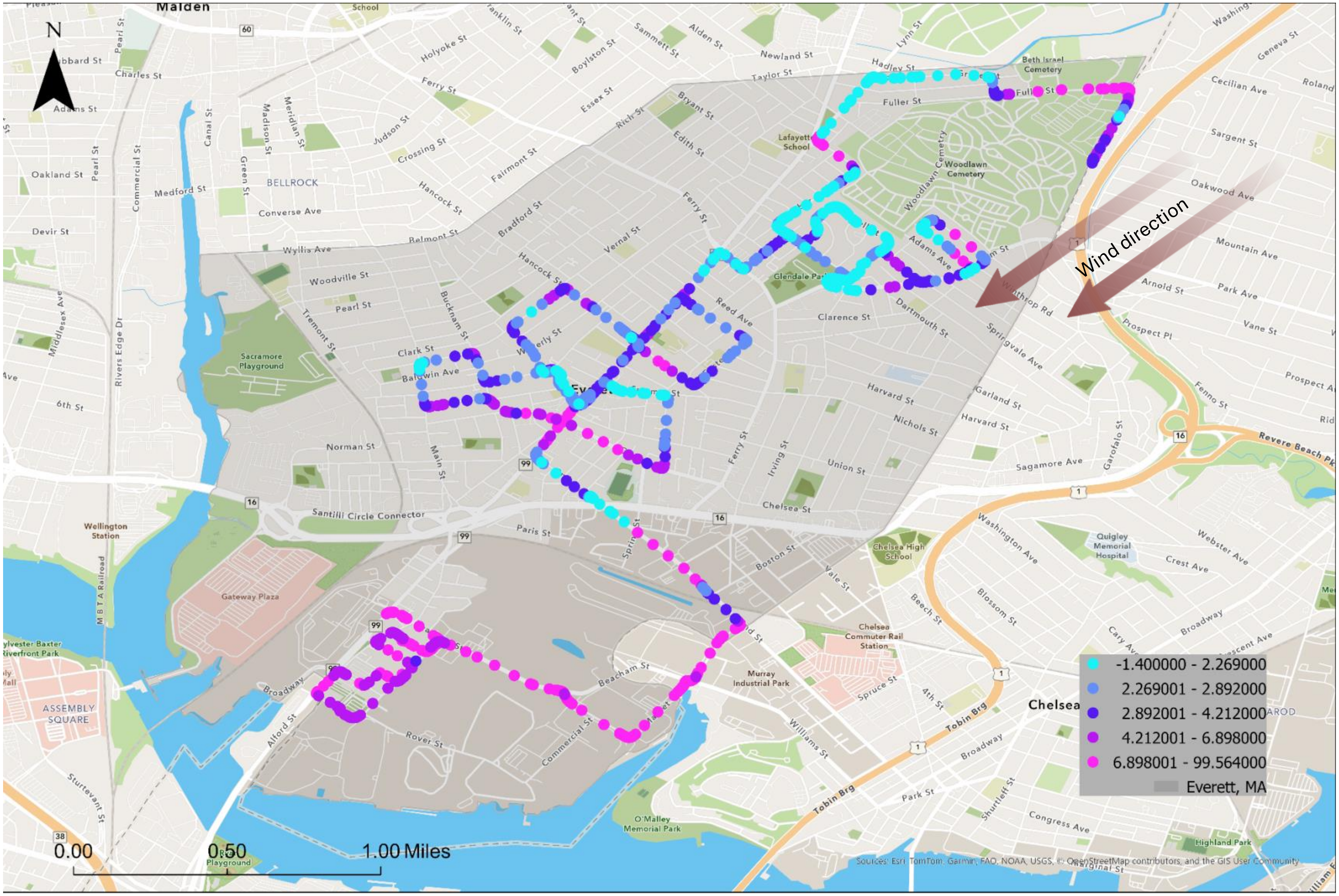

Figure 14: Nitrogen dioxide concentrations in Everett based on mobile monitoring from 3:30 pm to 4:30 pm on August 29, 2023, during northeasterly winds. Concentrations shown in the legend have units of parts per billion (ppb). These concentrations are all well below the regulatory limits for NO_2 (the 1-hour standard is 100 ppb).

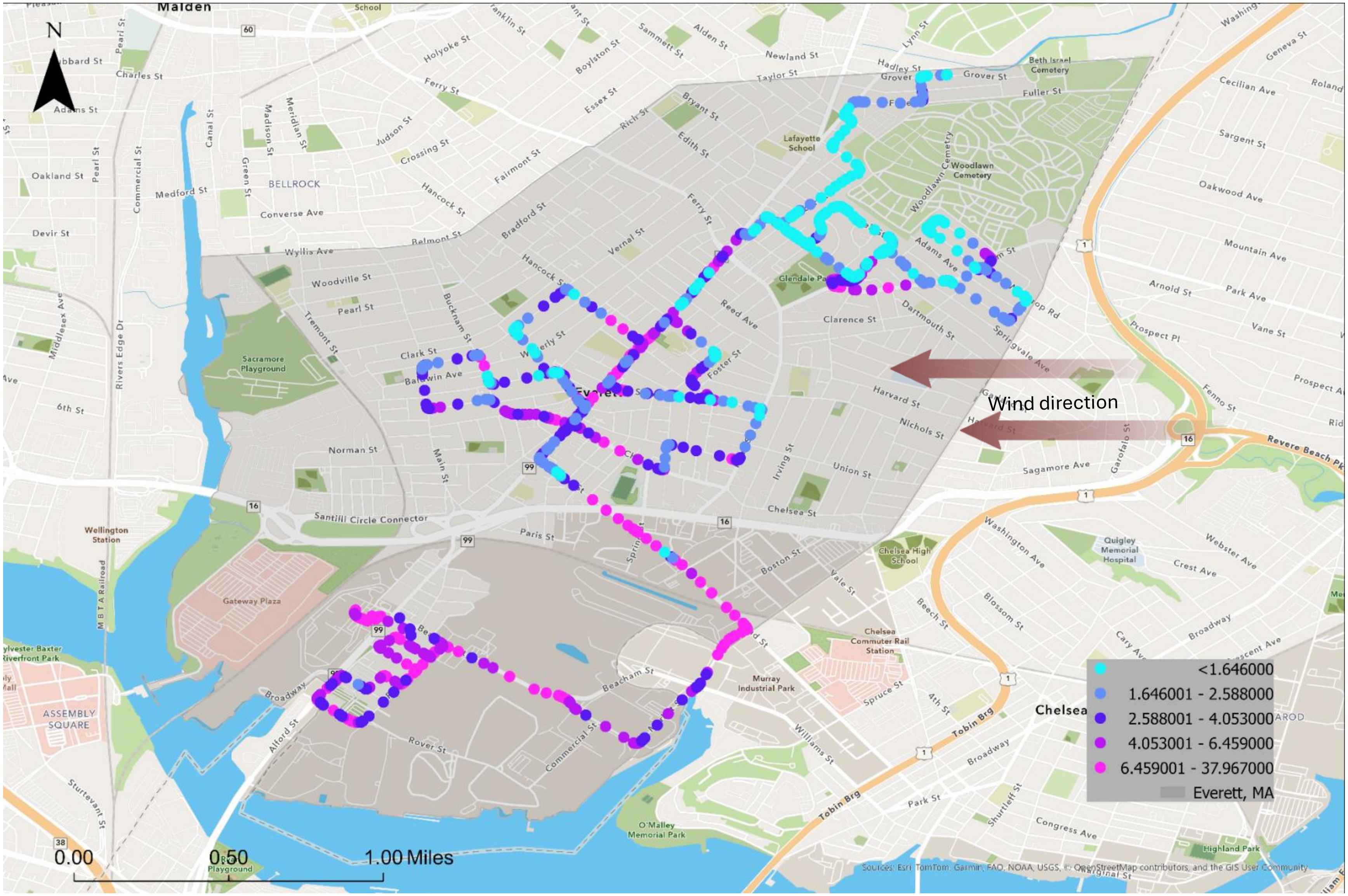

Figure 15: Nitrogen dioxide concentrations in Everett based on mobile monitoring from 3:20 pm to 4:30 pm on August 27, 2023, during easterly winds. Concentrations shown in the legend have units of parts per billion (ppb). These concentrations are all well below the regulatory limits for NO_2 (the 1-hour standard is 100 ppb).

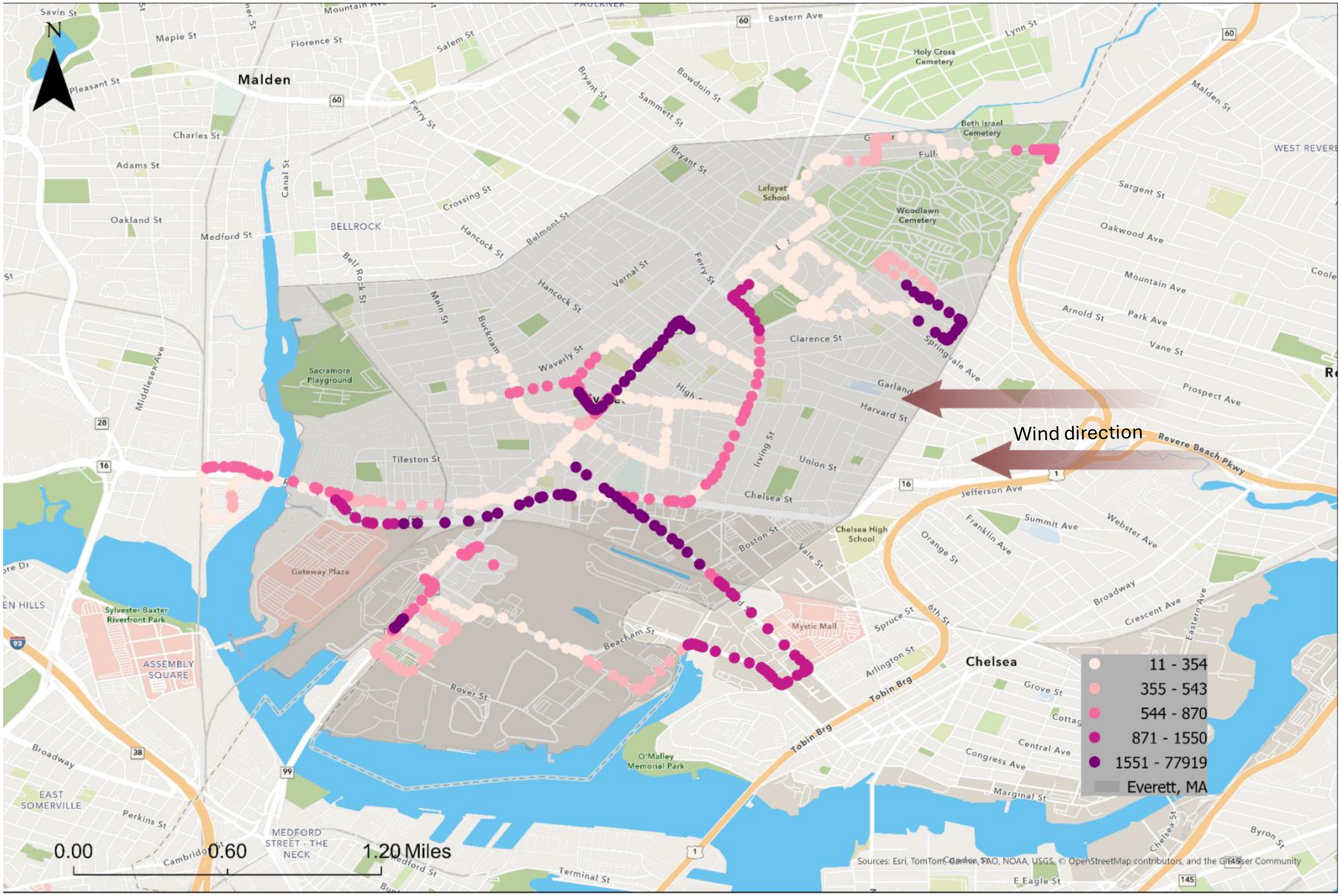

Figure 16: Black carbon concentrations in Everett based on mobile monitoring from 1:30 pm to 3:00 pm on August 22, 2023, during easterly winds. Concentrations shown in the legend have units of nanograms per cubic meter.

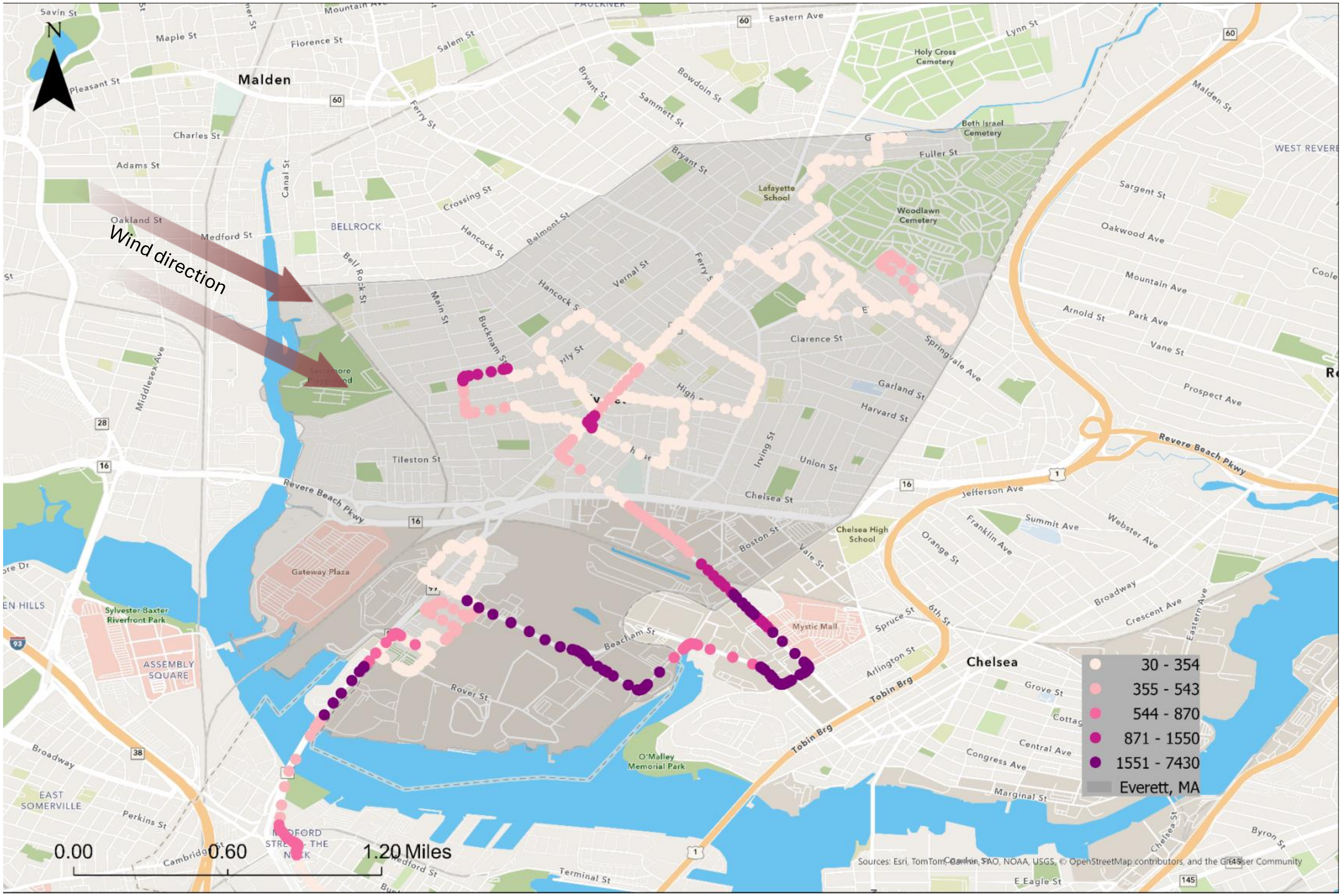

Figure 17: Black carbon concentrations in Everett based on mobile monitoring from 1:45 pm to 4:00 pm on November 08, 2023, during northwesterly winds. Concentrations shown in the legend have units of nanograms per cubic meter.

Acknowledgements

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