PUGET SOUND
Clean Air Agency

Community-Directed Air Monitoring

with the Trailer for Researching Environmental Equity (TREE)

January 2026

pscleanair.gov


THE NORTH FACE

Our Vision

Healthy air, climate, and environmental justice for the benefit of all people in the Puget Sound region.

Our Mission

We preserve, protect, and enhance air quality and public health, enforce the Clean Air Act, support policies that reduce climate change, and partner with communities to do this work equitably.

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Acronyms and Glossary

Agency	Puget Sound Clean Air Agency
AQI	Air Quality Index
BC	Black Carbon
CAPS	Cavity Attenuated Phase Shift. A specific measurement method used in one of our instruments to measure nitrogen dioxide.
CAT	Community Air Tool, a map developed by the Agency, using geographic and demographic data, to identify communities with greater risks from air pollution.
CBPF	Conditional Bivariate Probability Function (CBPF) analysis which uses meteorological parameters to help identify source contributions.
CID	Chinatown- International District. A National Historical neighborhood about one mile south of downtown Seattle.
CO_2	Carbon Dioxide
DRCC	Duwamish River Cleanup Coalition
DVYC	Duwamish Valley Youth Corps
EPA	United States Environmental Protection Agency
FEM	Federal-Equivalent-Method
NFRM	Near Federal Reference Method
NO_2	Nitrogen Dioxide
PCBs	Polychlorinated biphenyls
PM_{10}	Coarse particulate matter; smaller than 10 microns in diameter.
$PM_{2.5}$	Fine particulate matter; smaller than 2.5 microns in diameter.
PMF	Positive Matrix Factorization. A mathematical analysis tool that finds groups or mixtures of pollutants that make up the total amount of pollution that was measured.
TREE	Trailer to Research Environmental Equity
UFP	Ultrafine Particles
WBBA	Washington Build Back Black Alliance
WiLD	Interim Community Development Association's (CDA's) Wilderness Inner-City Leadership Development (WILD) youth group

Executive Summary

Overview

The Trailer for Researching Environmental Equity (TREE) project designed and implemented an innovative, community-driven, air monitoring approach that empowered residents of disproportionately impacted communities to help them better understand their local air quality. Through this effort, the project aimed to advance environmental equity, improve transparency, and build capacity for sustainable, community-led air quality action.

The TREE project is funded by the U.S. Environmental Protection Agency (EPA) through the Enhanced Air Quality Monitoring for Communities grant program. The three-year award (May 2023 through April 2026) provided $499,408 in federal funding to support community-driven air monitoring, data interpretation, and public engagement in partnership with local organizations. The grant aims to expand access to neighborhood-level air quality information, especially in communities with environmental justice concerns, and to help inform future mitigation and policy actions.

In the Puget Sound region, communities with the highest exposure to air pollution have also faced systemic socioeconomic challenges. Lower-income neighborhoods and communities of color disproportionately experience traffic-related air pollution, industrial emissions, and associated health burdens. Consistent with the Agency's Strategic Plan and environmental justice commitments, this project prioritized communities that have historically faced barriers to participation in environmental decision-making and experienced disproportionate exposure to harmful air pollutants.

The TREE Steering Committee, composed of community partners who helped shape the project from its inception, identified four areas where air quality, health, and socioeconomic burdens overlap: Lakewood (just south of Tacoma), and three neighborhoods in Seattle-the Chinatown-International District (CID), the Duwamish Valley, and the Central District. These areas were selected with support of the Agency's Community Air Tool[1], which integrates air quality, health, and socioeconomic data. This collaborative approach supported a more equitable project design and more meaningful engagement.

Community-Centered Engagement Approach

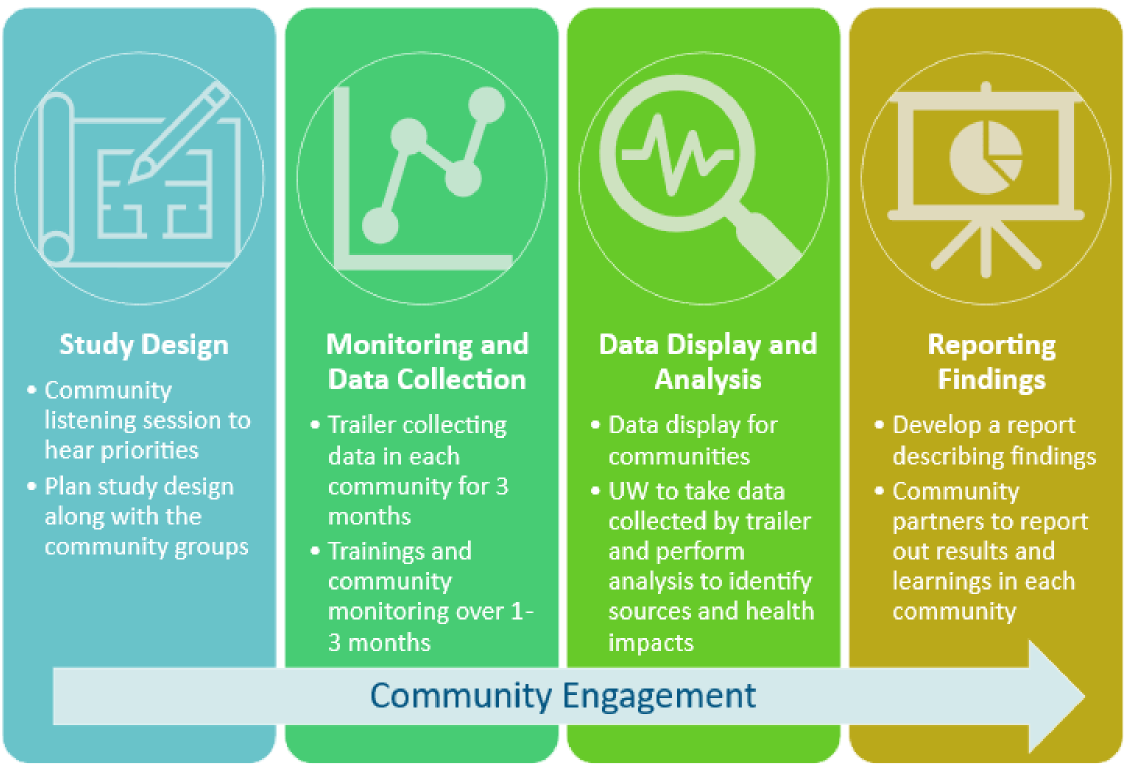
By design, the TREE project used a community-centered engagement model to ensure collaboration, transparency, and shared ownership. The approach included four key phases which are illustrated in **Figure 1**. As a first step, the Puget Sound Clean Air Agency (PSCAA) staff engaged audiences to develop each study starting with an interactive listening session for each area. Each listening session identified local air quality concerns and guided decisions about monitoring locations and pollutants. PSCAA staff built local capacity and strengthened engagement with co-designed workshops and monitoring activities for each community. During community-led monitoring, residents and youth received training and collected data using handheld sensors alongside the TREE trailer. Data was shared throughout the project on a public website and in ongoing discussions with community partners, ensuring results were accessible and easy to interpret. Finally, results and lessons learned will be shared through workshops and tailored summary materials for each neighborhood, supporting community reflection and next steps for improving local air quality.

[1] Community Air Tool, PSCAA

During the upcoming results workshops, we will also be seeking feedback on how communities plan to use the information we shared, such as informing local environmental priorities, identifying locations for further monitoring, and supporting conversations within the community to raise awareness. We will also gather reflections on their overall experience with the project, including what worked well, what could have been improved, and how they would like to be engaged in future efforts. This input will help shape the final phase of the report and guide recommendations for continued collaboration.

Overall, community reactions to the engagement process have been strongly positive. Participants consistently expressed appreciation for the transparency of the monitoring process, the opportunity to see real-time data collected in their own neighborhoods, and the chance to meaningfully influence the study design. Youth participants especially valued hands-on learning and described feeling more empowered to understand and speak about local environmental issues.

Figure 1. Four phases of community-centered engagement approach



Trailer Monitoring Overview

TREE trailer measurements highlighted strong seasonal differences across the four communities. Lakewood's spring monitoring showed generally low pollution levels, aside from a sharp July 4th fireworks spike. The CID experienced moderate summer wildfire impacts and higher near-road air pollution levels, while the Duwamish Valley's fall monitoring reflected ongoing freight and industrial activity. The Central District's winter monitoring reflected the combined influence of seasonal stagnant weather (inversions) and adjacent roadway traffic. After adjusting for seasonal weather patterns to equivalent annual averages, the Lakewood monitoring location showed the highest estimated annual $PM_{2.5}$, followed by the CID, Central District and Duwamish Valley. However, the differences among sites were small and not statistically significant, and all estimated annual averages were well below the state and federal $PM_{2.5}$ annual standards. Across all sites, weekday pollution levels were slightly higher than weekend levels, reflecting daily traffic patterns.

The air sampling results from the trailer were shared with the University of Washington for a source-analysis study, which is included in this report.

Community-Led Spatial Monitoring Overview

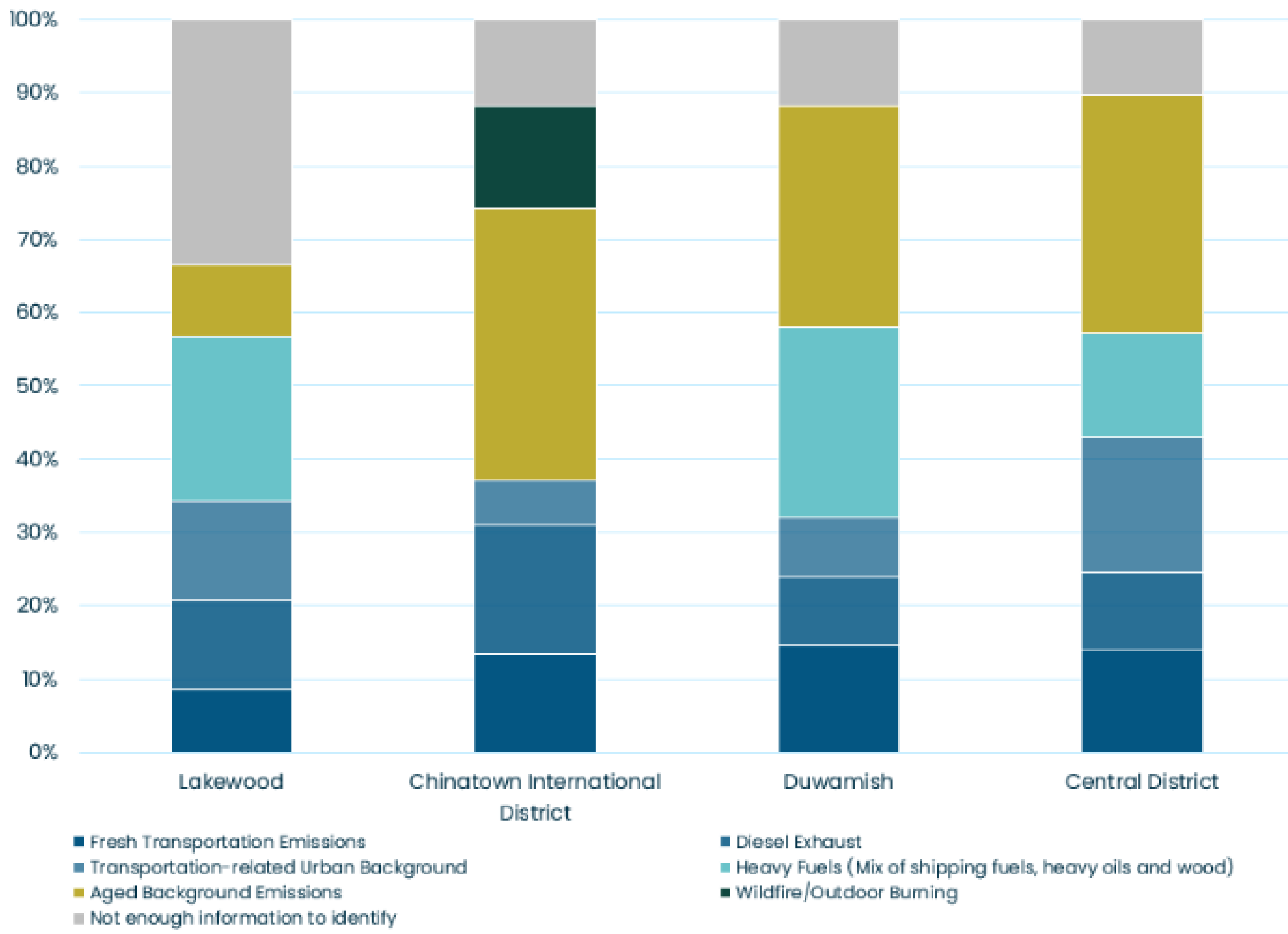
Community walking-tour data showed spatial variation in pollutant levels across all neighborhoods. Higher concentrations consistently appeared near major roadways, busy intersections, and in commercially and industrially zoned areas that have more freight volumes, while lower levels were found in residential areas farther from traffic and in open spaces. In the CID, additional summer wildfire smoke contributed to elevated $PM_{2.5}$, while the Duwamish Valley showed a stronger influence from heavy duty trucks and freight movement. The smoothed neighborhood maps from spatial interpolation made patterns visible for youth, showing how pollution varies block by block depending on adjacent sources. The walking tours also highlighted how weather conditions can influence measured concentrations, as well as the sensitivity of the instruments to hyperlocal, short-duration pollution events, reinforcing youth awareness of how air quality can change in real time.

Sources of Air Pollution

For the TREE study, we partnered with the University of Washington to identify major air pollution sources using a short-term dataset collected from the TREE monitoring trailer, rather than the multi-year chemical speciation data typically used in source apportionment studies. This approach allowed us to identify several important source categories; however, the limited monitoring period and absence of detailed chemical speciation data meant that some sources could not be fully separated and were associated with greater uncertainty. Source apportionment showed that transportation-related emissions (fresh transportation emissions, diesel exhaust, and transportation-related urban background emissions) were the dominant contributor to fine particles ($PM_{2.5}$) across all four communities, representing 32-43% of total $PM_{2.5}$ mass (**Figure 2**). Specifically, transportation-related contributions were estimated at 34% in Lakewood, 37% in the Chinatown–International District (CID), 32% in the Duwamish Valley, and 43% in the Central District. Fresh transportation emissions and diesel truck emissions were highest in locations closest to major roadways.

The source conducted by UW could not clearly distinguish all sources given the limited timeframe and data points used, instead statistically grouping many into a factor we refer to as 'aged background emissions'. This factor represents aged emissions from various sources in the community. These sources could include more transportation emissions or biomass (wood-related) burning. Any remaining $PM_{2.5}$ not accounted for in the analysis has been classified as "Not enough information to identify".

Figure 2. Sources and categories of air pollution from the four neighborhoods using Positive Matrix Factorization.



The sites generally exhibited similar source profiles in the analysis. Among the differences, heavy fuel combustion (a mix of shipping fuels, heavy oils, and wood) was higher in the Duwamish Valley, likely due to its proximity to the port and industrial areas. In contrast, wildfire/outdoor burning emissions were uniquely elevated in the CID, primarily driven by summertime wildfires and outdoor burning.

Overall, multiple source types contributed to community exposures, but transportation-related emissions were the most consistent and substantial contributor across all four neighborhoods.

Health Risks

Our findings demonstrate that **communities with higher proportions of older adults experience the greatest impacts**. This is because older people are more vulnerable to the adverse health impacts of air pollution. Additionally, our region has higher proportions of lower income and persons of color at adjacent major roadways , reinforcing the importance of targeted pollution reduction and health-equity interventions.

Across all four neighborhoods, **$PM_{2.5}$ exposure contributed to measurable health risks**. All-cause mortality risks ranged from 59-84 per 100,000 cases for adults over 18 years old across all neighborhoods. Projected impacts on elderly residents were higher, ranging from 139 to 182 cases per 100,000 across all neighborhoods.

Additionally, we estimated respiratory and cardiac impacts, as well as work loss and restricted activity days, for each of the four communities based on their population age distributions. We include a summary table of the results in the Health Risk Analysis Section of this report.

Overall Conclusions

This project demonstrated the value of combining high-quality stationary monitoring with community-led data collection to improve understanding of air pollution patterns in overburdened communities. The results show that:

- A **mobile air sampling platform, coupled with handheld sensor workshops, helped community members self-educate** on air quality concerns.
- **Transportation emissions remain a major contributor** to pollution exposure across all sites.
- Communities face **measurable health burdens** from $PM_{2.5}$, with the highest impacts occurring where pollution sources intersect with older populations and in overburdened communities.
- **Seasonal weather and events**, including wildfire smoke and winter stagnation, continue to influence pollution levels.

These findings support continued investment in clean transportation strategies, electrification, community engagement and education, and accessible public communication tools to reduce exposure and advance environmental equity across the region.

[2] Schulte, Jill, prepared for King County Equity and Social Justice Initiative, "Traffic Density, Census Demographics and Environmental Equity in Housing", November 2012.

Introduction

Agency Background and Mission

The Puget Sound Clean Air Agency is a special-purpose regional government agency working to protect public health, improve air quality, and reduce our region's contribution to climate change while integrating environmental justice and equity principles. The Agency serves the residents of King, Kitsap, Pierce, and Snohomish counties, with a mission to preserve, protect, and enhance air quality and public health, enforce the Clean Air Act, support policies that reduce climate change, and partner with communities to achieve these goals equitably.

Project Background and Purpose

In 2023, the United States Environmental Protection Agency (EPA) awarded the Puget Sound Clean Air Agency (Agency) an Enhanced Air Quality Monitoring for Communities grant to conduct the project "Community-directed air monitoring with the TREE trailer (Trailer for Researching Environmental Equity) as a central hub with branching sensors to characterize air quality in disproportionately impacted and underserved communities."

This project aimed to design and implement an innovative, community-driven air monitoring approach that empowers disproportionately impacted communities to better understand their local air quality. Through this effort, we sought to advance environmental equity, improve transparency, and build capacity for long-term, community-led air quality action.

For our air sampling, we used the TREE trailer, which is a mobile monitoring trailer equipped with high-quality, stationary reference instruments. The trailer measured a comprehensive suite of pollutants, including fine particles ($PM_{2.5}$), black carbon, nitrogen oxides, carbon dioxide, ultrafine particle number concentrations, and lead samples. The trailer also included meteorological sensors to measure wind speed, wind direction, ambient temperature, and barometric pressure. We deployed the trailer at locations selected in collaboration with community partners. From this central hub, community members conducted additional air monitoring activities using portable handheld sensors during walking tours and other events. We cross-referenced data collected from these portable sensors with the research-grade instruments in the TREE trailer to enhance both data accuracy and community engagement.

We partnered with the University of Washington's Department of Environmental & Occupational Health Sciences team to analyze the data and identify dominant pollution sources and potential health risks. Throughout the project, we shared data through enhanced web-based tools, providing near real-time access for communities and partners. We also communicated results regularly with community organizations to ensure findings were understandable, actionable, and supportive of local goals and initiatives.

To help guide our work, we also partnered with the Washington Build Back Black Alliance, Duwamish Valley Community Coalition, Eco Infinity, and prominent community leaders near King County International Airport. These groups connected us with four youth organizations to provide sampling and study design: Duwamish Valley Youth Corps, Interim CDA, Rainier Scholars, and Wa-Ya Outdoor Institute.

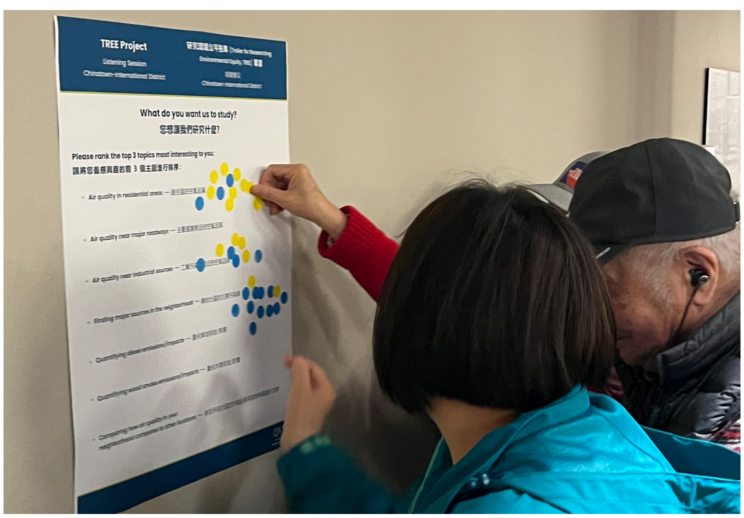
Regional and Historical Context

In the Puget Sound region, the communities that experience the highest impacts of air pollution also tend to face greater socioeconomic challenges. According to the U.S. Environmental Protection Agency's 2020 Environmental Justice report, low-income, minority, Tribal, and Indigenous communities were more likely to be affected by environmental hazards and to live near contaminated lands[3].

The COVID-19 pandemic further highlighted these inequities, with increasing evidence of racial disparities in infection and mortality rates. In King County, communities experiencing high rates of COVID-19 also faced a disproportionate cumulative burden of environmental and social inequities.[4,5] A recent study showed that 80 percent of census tracts in King County with high COVID-19 rates also had the county's highest concentrations of fine particulate matter ($PM_{2.5}$).

This project aims to enhance air quality monitoring in environmentally burdened communities across the Puget Sound region while providing air quality education and engagement opportunities for community members. The four communities we focused on during this project were identified as being within the top five percent of the most impacted areas in our jurisdiction, based on the Agency's environmental justice screening tool, the Community Air Tool (CAT). The CAT scores each Census block group according to air pollution levels, health impacts, and demographic indicators

We built upon our existing relationships with communities in the Seattle Duwamish Valley, Chinatown-International District, and Lakewood, collaborating to reduce air pollution exposure and advance environmental equity. In addition, we expanded our monitoring efforts to new areas, including part of Seattle's Central District, which also ranks within the top five percent of disproportionately impacted areas in the region.



Chinatown-International District TREE Listening Session

The Trailer for Researching Environmental Equity

[3] EPA Annual Environmental Justice Progress Report FY20 https://www.epa.gov/sites/default/files/2021-01/documents/2020_ej_report-final-web-v4.pdf

[4] Ingram, C., Min, E., Seto, E. et al. Cumulative Impacts and COVID-19: Implications for Low-Income, Minoritized, and Health-Compromised Communities in King County, WA. J. Racial and Ethnic Health Disparities (2021). https://doi.org/10.1007/s40615-021-01063-y

[5] Seto E, Min E, Ingram C, Cummings B, Farquhar SA. Community-Level Factors Associated with COVID-19 Cases and Testing Equity in King County, Washington. International Journal of Environmental Research and Public Health. 2020; 17(24):9516. https://doi.org/10.3390/ijerph17249516

Communities of Focus and Community Partners

Communities of Focus

In the Puget Sound region, the communities that bear the highest impacts of air pollution also experience greater socioeconomic challenges. Lower-income communities and communities of color have faced higher exposure to pollutants such as diesel exhaust. The Agency's Strategic Plan prioritizes reducing air pollution and exposure in communities that have historically faced barriers to economic opportunity and participation in decision-making, to champion clean and healthy air for all.

The Agency's environmental justice mapping tool, the **Community Air Tool (CAT)**, helped identify where air quality, health, and socioeconomic burdens overlap. Using the CAT, along with input from community partners, we identified four communities for enhanced engagement and air quality monitoring. Three of these were existing Agency focus communities (Seattle Duwamish, Chinatown International District and Lakewood), and one was a new addition for this project (the Central District).

Duwamish Valley — This area includes the neighborhoods of Tukwila-Allentown, Seattle Georgetown, and Seattle South Park. It is an industrial corridor surrounded by railyards, Boeing Field, major roadways, and industrial sources. The area also includes a Superfund site along the Duwamish Waterway. The Agency has a long history of partnership and collaboration with Duwamish Valley community groups and has been monitoring air pollution there since the early 1970s.

Chinatown–International District (CID) — The CID is a vibrant and historic center of Seattle's Asian American community, home to Chinese, Japanese, Vietnamese, Filipino, and other ethnic groups. Bounded by Interstate 90 and divided by Interstate 5, the neighborhood experiences some of the highest traffic volumes in the Pacific Northwest. The Agency has previously characterized air quality in the CID through EPA air toxics monitoring grants.

Lakewood — Lakewood has a rich history, commercial districts, parks, and diverse population. It lies within the Tacoma–Pierce County w maintenance area for the 2006 daily standard, is intersected by Interstate 5, and contains several state highways, industrial areas, and a major military base. The Agency has characterized air pollution in this area through multiple studies.

Central District — The Seattle Central District is considered by many to be the historic heart of the city's African American community. It has a diverse and engaged population but has also experienced significant redevelopment, gentrification, and rising cost of living. While not an existing Agency focus community, the Central District was selected for this project due to its disproportionate socio-economic burdens and the opportunity to build long-term relationships and trust with community partners.

[6] Where you live could influence your COVID-19 risk, DEOHS School of Public Health, University of Washington, https://deohs.washington.edu/edge/blog/where-you-live-could-influence-your-covid-19-risk

Community Partners

From the beginning of the project, the Agency worked closely with community groups to guide the community engagement structure and identify youth organizations for monitoring activities (see **Table 1** below). Additionally, community leaders near King County International Airport provided guidance through Community Partner Steering Committee Meetings.

Table 1. Community partners for the project

Community Organization	Role in the Project
Duwamish Valley Community Coalition	Participated in the planning committee and linked to the Duwamish Valley Youth Corps
Eco Infinity Nation LLC	Participated in the planning committee and helped identify youth groups in three Seattle neighborhoods
Washington Build Back Black Alliance (WBBA)	Participated on the planning committee and helped identify youth groups in the Lakewood area

Community Youth Groups

We worked closely with our community partners to establish the structure for community engagement. With the support of our community partners, we identified and partnered with four community-based youth organizations, each representing one of the four focus neighborhoods, to lead the community monitoring activities of the project. These groups included:

- **Duwamish River Cleanup Coalition (DRCC) / Duwamish Valley Youth Corps (DVYC)** (Duwamish)
- **InterIm Community Development Association's (CDA) Wilderness Inner-City Leadership Development (WILD) youth program** (Chinatown–International District)
- **Rainier Scholars** (Central District)
- **Wa-Ya Outdoor Institute** (Lakewood)

Each organization played a central role in the listening sessions, community-led monitoring, participating in trainings, conducting walking air quality tours, and helping interpret and share results with their communities.

Model of Engagement

The project followed a community-centered engagement model designed to ensure collaboration, transparency, and shared ownership throughout all stages of the study. This model emphasized early involvement of community partners, capacity building through participatory monitoring, and the return of results in accessible, meaningful formats. The engagement approach was structured around four interconnected phases, described briefly below, that guided the project from planning to completion. This model of engagement allowed deep knowledge and advocacy to occur. Students interacted with Air Quality Scientists, became familiar with scientific monitoring equipment, and developed their own community engagement strategies to advocate for better air quality in their communities amongst their families and peers.

Grant Application

The project partners approached the Agency to collaborate on an EPA funding opportunity to conduct community monitoring. These partners included the Washington Build Back Black Alliance, Eco Infinity, the University of Washington, and community leaders near King County International Airport. The Agency hosted meetings to discuss project goals, overall design, compensation methods, and neighborhoods of interest. A draft application was shared with the partners, and the Agency received letters of support and commitments from them for the submission.

Listening Sessions and Study Design

The project began with community listening sessions to identify local priorities, air quality concerns, and community goals. These sessions included custom presentations and reviewing a known air quality context specific to their communities. Following the presentation, we received participation through polls, map-dot exercises, and facilitated discussions that helped residents articulate where they experience pollution and what outcomes mattered most to them. Participants were compensated for their time, expertise, and input, ensuring equitable involvement from community members.

Community input directly informed the study design, including the selection of monitoring sites, pollutants to measure, and communication and outreach needs. These insights shaped the tailored monitoring plans for each neighborhood and ensured that the data collection reflected community perspectives. More detailed results from the listening sessions, including participation summaries and example outputs, are provided in the next section "Community Listening Sessions and Collaborative Study Design".

Community-Led Monitoring

During the data collection phase, youth and community organizations played an active role in local air monitoring. Participants received training on air quality concepts, how to operate handheld monitoring instruments, how to record geolocated data, and how to interpret basic pollution patterns. For each community, the youth participated in multiple walking tours to investigate air quality in areas the community identified as priorities from the listening sessions. This hands-on approach built local capacity by strengthening participants' skills in environmental data collection, increasing their understanding of pollution sources and health impacts, and empowering them to communicate findings within their communities. It also provided valuable context for interpreting monitoring results.

Data Sharing with Communities

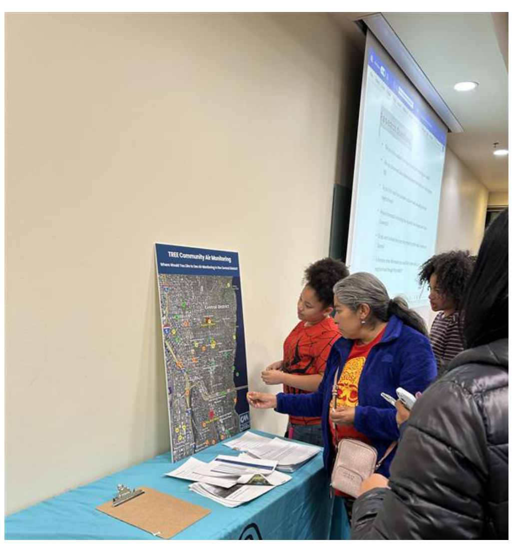
We shared all monitoring results through a project website designed to make data accessible and understandable for community members. Throughout the study, project staff and youth partners reviewed and discussed results together, incorporating community feedback into how information was displayed. This collaborative approach reflected the project's broader goal of two-way communication and community empowerment. The screenshots from the website are presented in the sub-section, "Data Display for the Community Groups".

Sharing Results and Lessons Learned

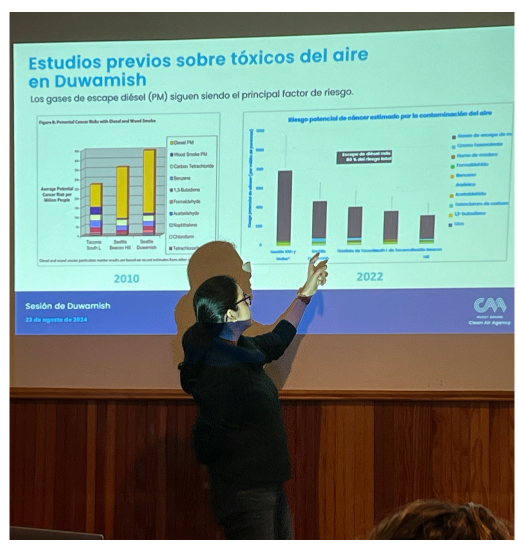
In each community, we shared findings with communities through workshops, presentations, and short summary reports tailored for each neighborhood. These activities emphasized two-way communication providing opportunities for community members to reflect on results, discuss potential actions, and inform next steps for ongoing air quality improvement efforts.

This model of engagement strengthened partnerships between the Agency, community organizations, and research collaborators, ensuring that the study outcomes supported both scientific understanding and community-driven goals. The following sections describe each phase of engagement in greater detail.

Air Monitoring Specialist, Adam Petrusky, giving a TREE Trailer tour to youth.



Central District listening session participants marking locations of interest for the study.



Air Quality Scientist, Isha Khanna presenting Duwamish Valley data to participants.

Study Design: Community Listening Sessions and Collaborative Monitoring

The project focused on deep, direct community engagement through a series of listening sessions designed to raise awareness about local air quality and gather input on pollutants, emission sources, and monitoring locations of concern. These sessions were essential to ensuring that the study design reflected community priorities, neighborhood-specific environmental conditions, and lived experiences. They also strengthened transparency and trust, creating space for residents to shape decisions throughout the project.

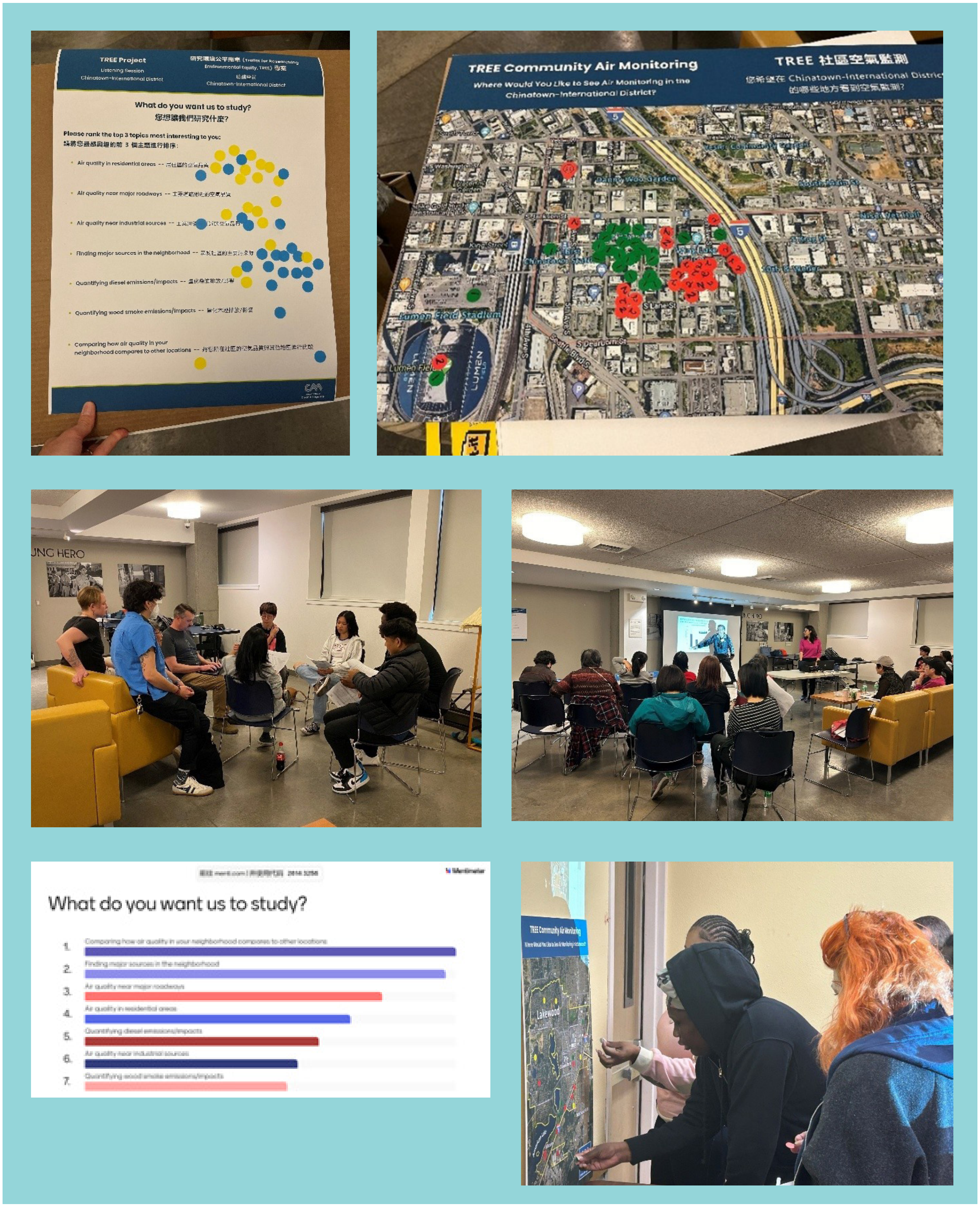
The project team successfully hosted four listening sessions across the participating communities, each drawing strong and enthusiastic participation. Attendees engaged in substantive discussions about local air quality challenges, research questions, desired outcomes, and preferences for monitoring locations. To support equitable participation, all attendees were compensated at a rate of $30 per hour for two hours of engagement. Interpretation services and translated materials were provided when needed to ensure full and inclusive participation.

Each session followed a consistent format that included:

- **A short presentatio**n introducing the project goals, pollutants to be measured, and how monitoring data would be used.
- **Small-group discussions** facilitated by project staff and community partners to explore air quality challenges, daily exposure concerns, and desired project outcomes.
- **Interactive map-dot exercises** where participants placed stickers on neighborhood maps to identify key areas of interest—such as schools, parks, major roadways, industrial areas, or residential blocks that experience noticeable pollution.
- **"What do you want us to study?"** exercises that invited participants to propose topics or questions they felt were most important for their community through dot exercises or interactive polls.
- **Feedback boards and surveys** that allowed participants to share written comments, rank concerns, and propose additional monitoring ideas.

This structured and participatory approach helped build transparency and trust while ensuring residents had a meaningful role in shaping the study. Input from the listening sessions informed the final selection of monitoring locations, the design of community-led sampling activities, and outreach materials**. Figure 3** below shows examples of the various activities used during the listening sessions, including mapping exercises, surveys, and discussion activities.

Figure 3. Activities from the community listening sessions, including priority-setting exercises (dot voting and interactive polls), mapping of locations of interest, group discussions, and participant engagement with project materials..



Listening Sessions: Community Priorities and Input

Lakewood (March 1, 2024 – Tillicum Community Center)

Ten people attended the event and expressed concerns about near-road air pollution, particularly emissions from the I-5 corridor and their potential health impacts on nearby residents. Discussions focused on understanding how traffic emissions affect day-to-day exposure and identifying monitoring locations that capture community exposure patterns.

Chinatown–International District (May 3, 2024 – Hirabayashi Place)

Twenty-six Cantonese-speaking residents participated, supported by interpretation services and translated materials. Community members raised concerns about restaurant emissions, diesel exhaust, and indoor air quality challenges in multifamily buildings. Participants also explored ideas about possible mitigation strategies, including the use of vegetative or sound barriers to reduce roadway impacts.

Seattle Duwamish (August 23, 2024 – Duwamish River Community Hub)

Ten people attended the event and roughly half were primarily Spanish-speaking. With interpreter support, participants discussed air quality challenges associated with proximity to the port, industrial operations, and freight corridors. Community members identified priority pollutants and emphasized the need for monitoring that captures both daily exposures and episodic events.

Central District (December 2, 2024 – 2100 Building)

Twenty-nine community members attended and provided detailed insights on preferred monitoring locations, including the neighborhood high school, several elementary schools, and adjacent residential areas. Discussions highlighted ongoing concerns about traffic emissions from major roadways and their impact on children and older adults.

Pictures and maps summarizing site-selection discussions from all listening sessions are provided in **Appendix A**.

Integration of Community Input into Study Design

Insights gathered from these listening sessions directly informed the community-led monitoring phase. Based on this input, the project team collaborated with community organizations in each neighborhood to co-design a monitoring approach that reflected local priorities. Partnerships included Wa-Ya Outdoor Institute in Lakewood, InterIm Community Development Association's (CDA's) Wilderness Inner-City Leadership Development (WILD) youth group in the Chinatown–International District, the Duwamish Valley Youth Corps in the Seattle Duwamish area, and Rainier Scholars in the Central District.

These organizations played an active role in shaping the monitoring plan, selecting locations, identifying pollutants of concern, and preparing for community-based sampling activities. This collaborative design process ensured that the study addressed concerns identified by those most impacted by air quality issues in their neighborhoods and strengthened local capacity for ongoing air quality stewardship.

Monitoring Details

Map and Description of Monitoring Sites

The TREE trailer was deployed sequentially across the four project neighborhoods, with each location selected in collaboration with community partners to ensure that the monitoring site was safe, representative of local conditions, and logistically feasible for long-term operation during the study. Each deployment lasted approximately three months to ensure equal monitoring period at each site within a year and meet the scope of the grant.

The map below (**Figure 4**) shows the monitoring locations used for the study using aerial images. Each aerial image presents the trailer location (colored dot) and its surrounding neighborhoods (Lakewood – Fire Station, South Seattle College Georgetown and Central District – Coyote Central). The upper left image presents the location (dark blue dot) of the Ecology site at 10th and Weller in the CID. For Lakewood, Duwamish, and the Central District, the TREE trailer was installed directly at the selected community sites. In the Chinatown–International District, a secure and representative placement for the trailer could not be identified; therefore, we added monitors at the Washington State Department of Ecology's regulatory station at 10th Avenue S and Weller Street. This ensured access to high-quality, continuous measurements during the CID monitoring period. **Table 2** summarizes the coordinates, deployment dates, and map links for each monitoring site.

Figure 4. Locations of the trailer in each of the four neighborhoods using aerial imagery taken from Google Earth Engine.

Table 2. TREE trailer monitoring locations with start and end time.

Name	Latitude	Longitude	Start date	End Date	GoogleMap Link
Lakewood – West Pierce Fire & Rescue, Station 23	47.126708°	-122.550245°	2024/04/24	2024/07/23	https://maps.app.goo.gl/6kT2XV5S5doaTCxY7
Seattle Chinatown International District - 10th and Weller *	47.597360°	-122.319813°	2024/06/01	2024/09/03	https://maps.app.goo.gl/emCBHIcGF9J7eTdZA
South Seattle College – Georgetown campus	47.541572°	-122.325098°	2024/09/03	2024/10/31	https://maps.app.goo.gl/fRqiNskdi1nctGxWA
Seattle Central District – Coyote Central	47.608172°	-122.302323°	2024/12/02	2025/03/04	https://maps.app.goo.gl/usXQtn9L4NB7HJnr9

**For the CID – 10th and Weller site, the TREE trailer was not used, instead, the data were collected mainly from the existing instrumentation at Ecology's 10th and Weller monitoring station (only the CO2 instrument was borrowed from the trailer). Therefore, the data from several instruments at this location are available beyond the scheduled period indicated here.*

TREE Trailer Configuration and Instrumentation

The TREE trailer served as the central monitoring platform for this study, providing continuous, research-grade measurements of key air pollutants at each community site. The unit is an 8' × 10' cargo trailer retrofitted to house multiple instruments in a temperature-controlled environment, with external probes mounted on a central mast that also supported an ultrasonic wind anemometer. The trailer was connected to a fixed power outlet at each location and operated for approximately three months before rotating to the next site.

Inside the trailer, the monitoring suite included a Federal Equivalent Method (FEM) $PM_{2.5}$ analyzer, a $PM_{2.5}$ nephelometer, a black carbon aethalometer, a Cavity Attenuated Phase Shift (CAPS) NO_2 monitor, a carbon dioxide sensor, an ultrafine particle counter, and standard meteorological instrumentation. Outside the trailer, a Near-Federal Reference Method (NFRM) PM_{10} sampler collected filter-based samples for metals analysis. Because community members identified lead as a pollutant of concern, collected PM_{10} filters were sent to an accredited laboratory, Eastern Research Group (ERG), for lead analysis.

A data logger running Envidas Ultimate software was used to acquire $PM_{2.5}$, black carbon, CO_2, and meteorological data, which were transmitted hourly to a central server. The NO_2 CAPS instrument used the manufacturer's software for data capture, while both the ultrafine particle counter and the NFRM sampler stored data on internal memory. Data from these instruments were manually downloaded and transferred to Agency servers on a weekly basis.

A summary of all monitoring parameters and associated equipment used in the TREE trailer is provided in **Table 3**. All measurements were recorded in Pacific Standard Time (PST), with no daylight savings adjustment.
All parameters listed in Table 3 were used by University of Washington in modeling sources of air pollution. We primarily report on $PM_{2.5}$ because it is the key driver of the health risk. Nitrogen dioxide is not reported separately, as the measured concentrations were far below the National Ambient Air Quality Standard (NAAQS).

For many of the other parameters measured, there are no established health-based reference points or regulatory standards for comparison, including carbon dioxide, total particle number concentration (for ultrafine particles), and black carbon (which serves as a marker for diesel exhaust).

Table 3. Instruments deployed in the TREE trailer.

Instrument name & model	Manufacturer	Variable Name	Unit	Notes
BAM 1020	Met One	$PM_{2.5}$ concentration	µg/m³	
BAM 1020	Met One	Total flow volume (Q_{TOT})	m³	
BAM 1020 –BX-596	Met One	Ambient temperature	∘F	
BAM 1020 –BX-596	Met One	Barometric pressure	mb	
NanoScan SMPS Model 3910	TSI	Total particle concentration	particles/cm³	
Aethalometer AE-33	Magee Scientific	Black carbon	µg/m³	Measured at 880 nm, BC, Ch6
Aethalometer AE-33	Magee Scientific	Ultraviolet	µg/m³	Measured at 370 nm, UV, Ch1
Nephelometer Aurora 1000	American Ecotech	Scattering coefficient (σ_{sp}) or BSCAT	Mm^{-1} (inverse megameters)	Measured at 525 nm
Nephelometer Aurora 1000	American Ecotech	Estimated $PM_{2.5}$ concentration	µg/m³	Calculated from BSCAT: NPM25 = (24.5 * BSCAT) + 1.6
Nephelometer Aurora 1000	American Ecotech	Estimated visibility	miles	Calculated from BSCAT: VIS = (3.9/ ((BSCAT/10) + 0.0133))/1.609
LI-850	LI-COR	CO_2	ppb	
CAPS NO2	Aerodyne Research, Inc.	CAPS NO_2	ppb	
Ultrasonic Anemometer 86004	R. M. Young Company	Scalar wind speed	mph	
Ultrasonic Anemometer 86004	R. M. Young Company	Unit vector wind direction	degrees	
Ultrasonic Anemometer 86004	R. M. Young Company	Vector wind speed	mph	
Ultrasonic Anemometer 86004	R. M. Young Company	Vector wind direction	degrees	
Universal Temperature Probe EI-1034	Electronic Innovations Corp	Temperature inside the trailer	∘F	

Chinatown–International District Monitoring Approach

In the Chinatown–International District, the TREE trailer could not be deployed due to the lack of a suitable location with reliable power access and adequate site security. To ensure high-quality data collection in this neighborhood, the project instead leveraged the Washington State Department of Ecology's regulatory monitoring site located at 10th Avenue S and Weller Street.

This fixed-site regulatory station provided continuous measurements of key pollutants using research-grade instruments. The specific monitoring parameters and instruments available at this site are listed in **Table 4**. While the instrumentation differed slightly from the full TREE Trailer suite, the regulatory site offered a secure, powered, and representative location for capturing community-scale air quality conditions in the CID.

Table 4. Instruments deployed at the 10th and Weller – Seattle Chinatown International District monitoring site.

Instrument name & model	Manufacturer	Variable Name	Unit reported in spreadsheet	Notes
BAM 1020	Met One	$PM_{2.5}$ concentration	µg/m³	
41342VF Temperature Probe	RM Young	Ambient temperature	°F	Located about 2 m from surface
SMPS 3938 W	TSI Incorporated	Total particle concentration	particles/cm³	
Aethalometer AE-33	Magee Scientific	Black carbon	µg/m³	Measured at 880 nm, BC, Ch6
Aethalometer AE-33	Magee Scientific	Ultraviolet	µg/m³	Measured at 370 nm, UV, Ch1
LI-850	LI-COR	CO_2	ppb	
M200EU	Teledyne API	NO_2	ppb	
M200EU	Teledyne API	NO	ppb	
M200EU	Teledyne API	NO_x	ppb	
Ultrasonic Anemometer	American Ecotech	Trace CO	ppb	
Ultrasonic Anemometer	Vaisala	Scalar wind speed	mph	
Ultrasonic Anemometer	Vaisala	Unit vector wind direction	degrees	
Ultrasonic Anemometer	Vaisala	Vector wind speed	mph	
Ultrasonic Anemometer	Vaisala	Vector wind direction	degrees	
Universal Temperature Probe EI-1034	Electronic Innovations Corp	Temperature inside the shelter	°F	

Siting Criteria and Limitations

We typically follow EPA neighborhood-scale monitoring siting criteria when establishing new monitoring stations, as outlined in our Standard Operating Procedures and detailed in the project Quality Assurance Project Plan. For this grant, however, several community-selected locations did not fully meet these criteria. This is a common challenge for trailer-based deployments, as the areas of highest community interest are often space-constrained or lack the infrastructure needed for compliant siting. In addition, the TREE trailer requires a reliable electrical connection, which further restricts viable placement options.

These constraints introduced certain tradeoffs in siting decisions, and in some cases may have influenced data representativeness or data quality. **Table 5** below summarizes key siting limitations and considerations for each monitoring location.

Table 5. List of potential limitations with siting criteria.

Name	Limitations with Siting Criteria	Potential Limitations on Data	Web map location
Lakewood – West Pierce Fire & Rescue, Station 23	Located close to tree dripline.	Notable CO_2 diurnal cycle possibly from tree respiration, and shielded winds resulting in lower wind speeds overall.	https://maps.app.goo.gl/6kT2XV5S5doaTCxY7
Seattle Chinatown International District - 10th and Weller *	Meets criteria for EPA Near Road Monitoring Station.	Will show mostly highway emissions.	https://maps.app.goo.gl/emCBH1cGF9J7eTdZA
South Seattle College – Georgetown campus	Located near a two-story building, within 30 meters of an urban arterial road (E Marginal Way).	Winds could be affected by the building, may see higher fractions of vehicle emissions.	https://maps.app.goo.gl/fRqiNskdi1nctGxWA
Seattle Central District – Coyote Central	Located near a one-story building, within 30 meters of an urban arterial road (Cherry St).	Winds could be affected by the building, may see higher fractions of vehicle emissions.	https://maps.app.goo.gl/usXQtn9L4NB7HJnr9

Community Monitoring Details

In addition to the TREE trailer measurements, each community participated in a series of hands-on monitoring activities using portable handheld sensors. These activities were conducted in partnership with youth groups and community organizations, who received training on air quality concepts, sensor operation, and data collection methods from a PSCAA Air Quality Scientist. Walking monitoring tours were conducted in all four neighborhoods, allowing participants to measure street-level variations in pollutant concentrations and identify different types of pollution in real-time.

The handheld sensors measured a range of pollutants, including particulate matter, black carbon, and ultrafine particles. These data provided a complementary, high-resolution view of local air quality patterns and helped community members directly observe how pollution varied block-by-block, near busy roads, and around areas where residents had expressed concern. All handheld measurements were cross-referenced with the TREE trailer instruments to support data interpretation and increase confidence in the results. **Table 6** summarizes the hand-held sensors used during the community monitoring phase, and **Figure 5** provides photographs of each device.

Table 6. Handheld sensors used during community monitoring.

Instrument name & model	Manufacturer	Variable	Unit	Notes
Airbeam 3	Habitat Map	PM_1	µg/m³	See HabitatMap - AirBeam3 for details
Airbeam 3	Habitat Map	$PM_{2.5}$	µg/m³	
Airbeam 3	Habitat Map	PM_{10}	µg/m³	
microAeth AE-51	AethLabs	Black carbon	µg/m³	Measurement done at 880 nm
Dylos DC1700-PM	Dylos Corporation	$PM_{2.5}$	µg/m³	See Dylos - DC1700-PM for details
Partector 2	Naneos CH	Ultrafine particle number	pt/cm³	
Partector 2	Naneos CH	Ultrafine particle mass	µg/m³	

Figure 5. Handheld sensors deployed during community monitoring. From left to right: Airbeam 3 for PM_1, $PM_{2.5}$, PM_{10}; MicroAeth (AE-51) for black carbon; Dylos DC1700-PM for $PM_{2.5}$ and; Partector 2 for ultrafine particle number and mass.

Youth workshops varied based on the age group, interests, and available time, but we followed a consistent overall structure and a common curriculum for using handheld air-quality monitors. With the younger students, such as the Wa-Ya group, we dedicated more time to hands-on data collection. While with older students, sessions typically began with a short presentation on different air-quality topics and/or quizzes reviewing air-quality concepts, followed by monitoring walks.

The youth group leaders selected the monitoring routes for the community monitoring, with our team providing recommendations as needed. Before heading out, we reviewed the plan for the day and highlighted what students should pay attention to—such as pollution sources, weather, and nearby activities. In addition to the handheld monitors displayed in **Figure 5** and detailed in **Table 6**, we provided them with a phone able to record geolocation (GPS) and log the Airbeam 3 data (via the associated app). Groups of 4-5 students were also provided with a clipboard and an observation sheet to record environmental conditions, possible sources, weather, and readings from the monitors ($PM_{2.5}$, PM_{10} & UFP).

Monitoring walks typically lasted 1-2 hours for each session, depending on the group and how the sessions were structured. During and immediately after each monitoring session, students were asked to report back their findings to their peers, based on their observations. We encouraged discussions by asking them questions such as which locations were the cleanest or most polluted, what surprised them, and how the weather conditions may have influenced the air quality readings.

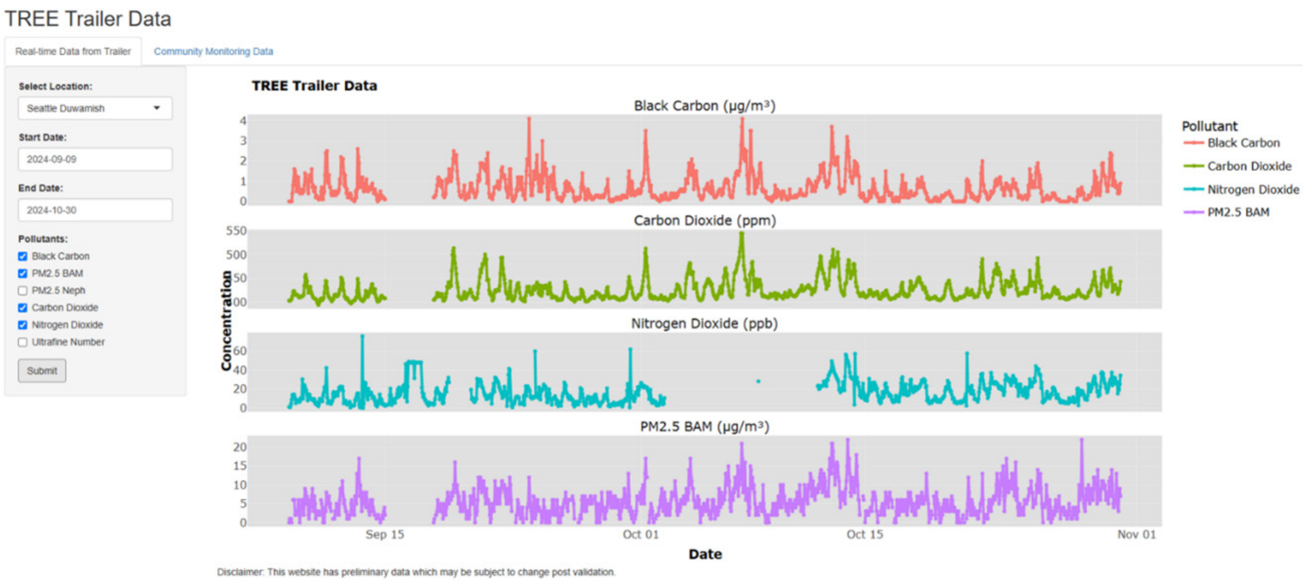
Data Display for the Community Groups

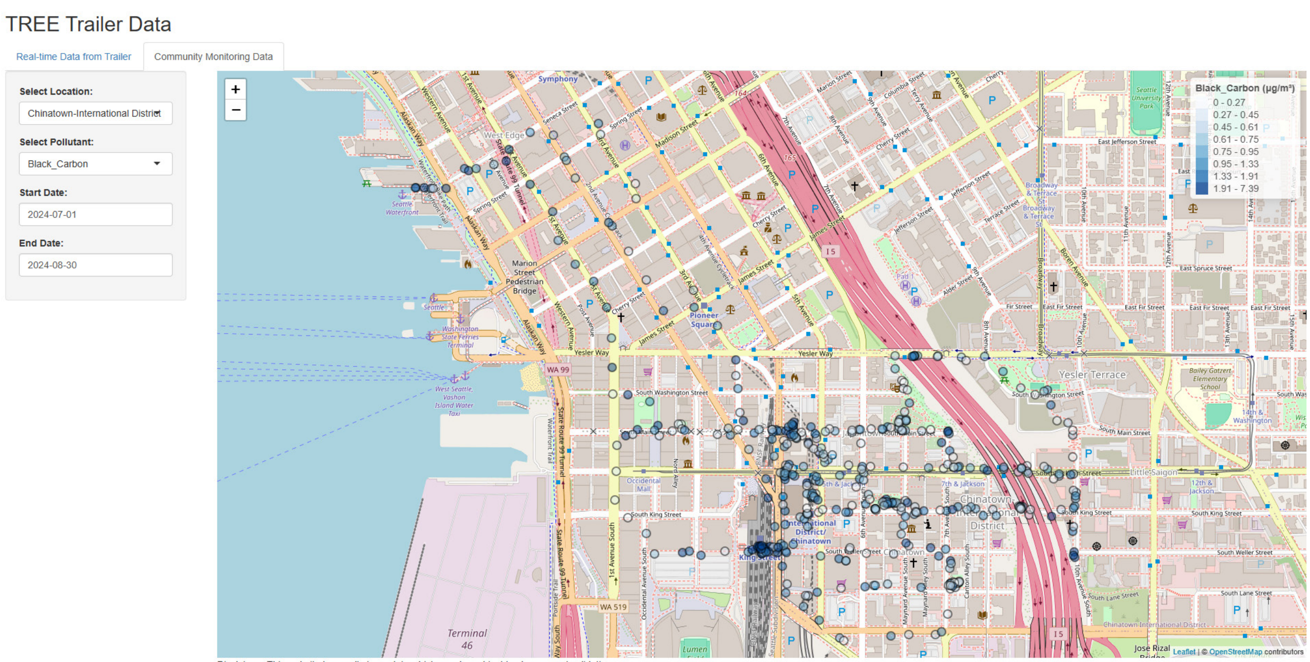
To ensure transparency, accessibility, and long-term usefulness, all air monitoring results were shared through an interactive data website developed specifically for this project. The platform presents both real-time and summarized visualizations and allows users to explore trailer-based measurements and community-led walking monitoring results in a single location. Residents can view pollutant trends over time, compare multiple pollutants, and examine neighborhood-specific data. The website can be accessed at: http://apps.pscleanair.gov/TREE/. **Figure 6** below shows example screenshots from the site.

Throughout the study, project staff and partners regularly engaged youth groups and other community members to explore the data together. These sessions focused on understanding how to read the graphs, identifying local patterns, and discussing what the results meant for daily life in their neighborhoods. Youth participants also provided feedback on the website's display, which directly benefited how information was displayed. Their input helped ensure that the site was not only scientifically accurate, but also approachable and easy to navigate for people with different levels of technical background.

This collaborative process strengthened community ownership of the results and improved the clarity of the data tools. All monitoring results remain publicly accessible through the website, allowing residents, organizations, and partners to continue exploring the data, sharing findings, and using the information to support local discussions and decision-making long after the project period.

Figure 6. Example screenshots from the TREE interactive data website





Monitoring Results and Observations

Trailer Monitoring

This section summarizes results from the mobile TREE trailer monitoring conducted in each neighborhood. The trailer measured multiple pollutants continuously, providing insight into day-to-day patterns, short-term peaks, and the influence of local emission sources. Because the trailer was deployed during different seasons, the findings also reflect seasonal conditions unique to each monitoring period. The short summaries that follow aim to describe pollutant levels, notable events, and weekday–weekend patterns to help characterize air quality in each neighborhood.

Lakewood

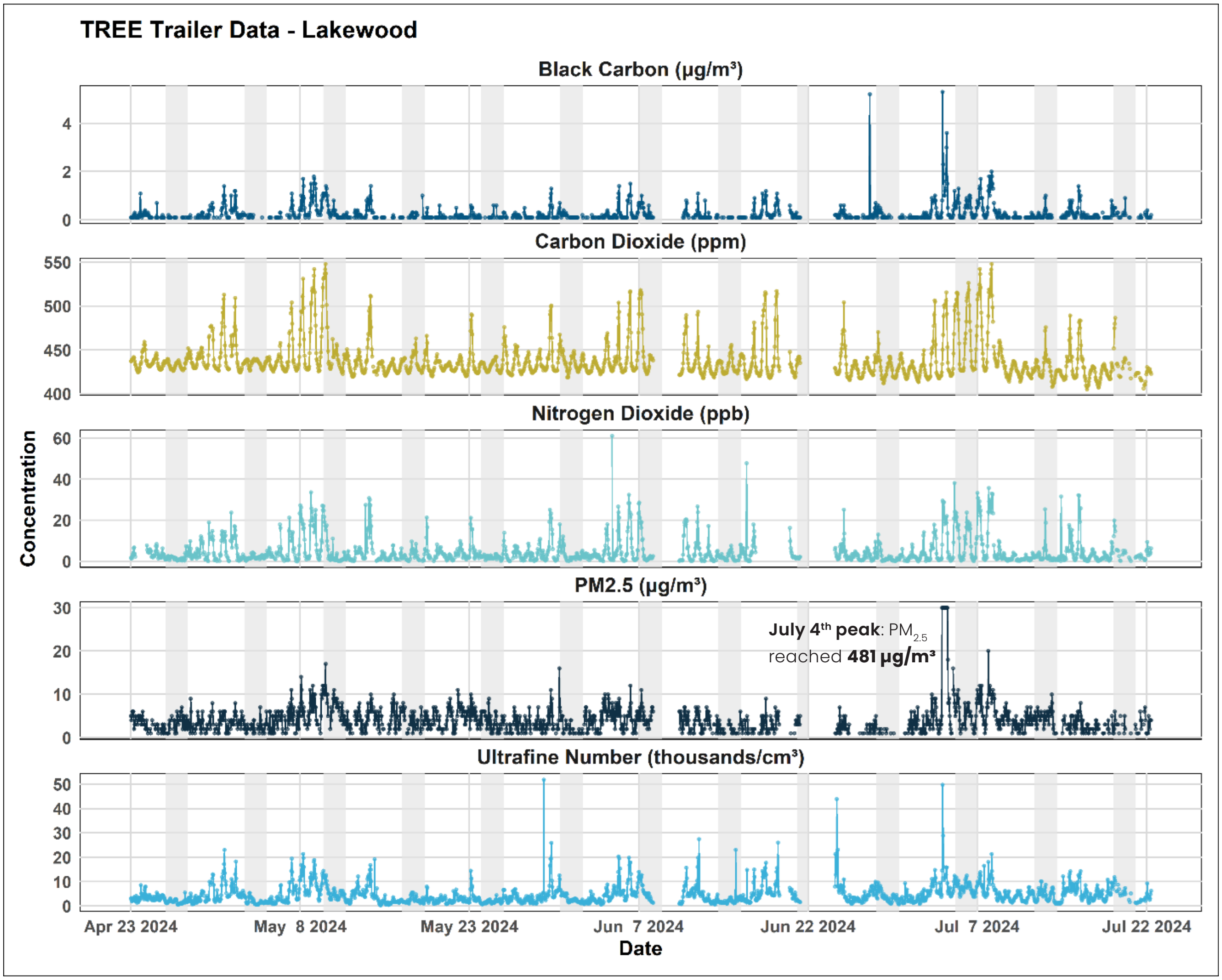
Lakewood was monitored from mid-April through mid-July 2024. Under typical conditions (excluding the July 4–5 fireworks period), average concentrations of $PM_{2.5}$, black carbon, NO_2, CO_2, and ultrafine particles were low (**Table 7**). A single extreme spike in $PM_{2.5}$ and black carbon occurred on July 4 due to fireworks, with $PM_{2.5}$ briefly reaching 481 µg/m³ and black carbon 5.3 µg/m³ (1-hr average values). Otherwise, concentrations were generally higher near local traffic sources and lower on windy or rainy days, reflecting enhanced dispersion. Weekday–weekend differences were small, with slightly higher NO_2 and ultrafine particle levels on weekdays consistent with higher commuter traffic volumes.

Table 7. Summary of hourly pollutant concentrations at the Lakewood trailer site.

Pollutant	Mean	Standard Deviation	Hourly Min	Hourly Max	Units
$PM_{2.5}$	4.0	1.7	1.0	20	µg/m³
Black carbon	0.2	0.3	0.10	5.2	µg/m³
Carbon dioxide	438	22	405	548	ppm
Nitrogen dioxide	4.5	6.3	0.01	61	ppb
Ultrafine number	4.57	3.9	0.33	51.8	thousands/cm³
Note: These values exclude the July 4th peak caused by fireworks as it is not representative of typical conditions.					

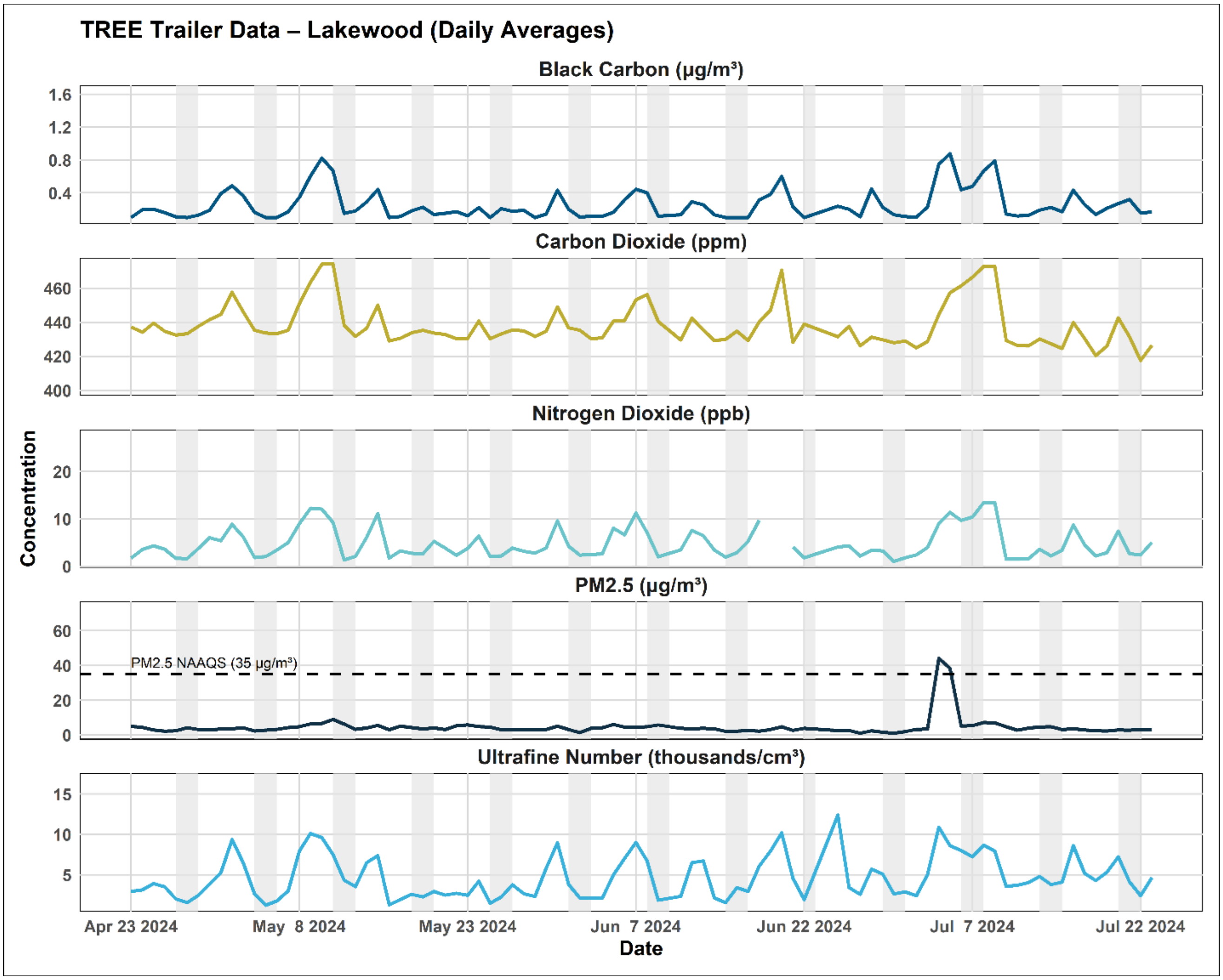
Figure 7 and **Figure 8** present continuous time series for all pollutants measured by the TREE trailer as hourly and daily averages respectively. Most pollutants showed relatively low and stable concentrations, with short-term variability driven by local traffic, weather conditions, and day-to-day community activity. For $PM_{2.5}$, however, July 4th produced an extreme spike (481 µg/m³, 1-hr average) associated with fireworks. Including this full value would compress the remaining data and obscure typical trends. To preserve readability, the $PM_{2.5}$ panel limits the y-axis to the range of normal conditions, while still retaining the full dataset. The July 4th peak is indicated separately in the figure for transparency.

Figure 7. Hourly-average time-series of air pollutant measurements from the TREE trailer monitoring in Lakewood. Grey areas denote weekends.



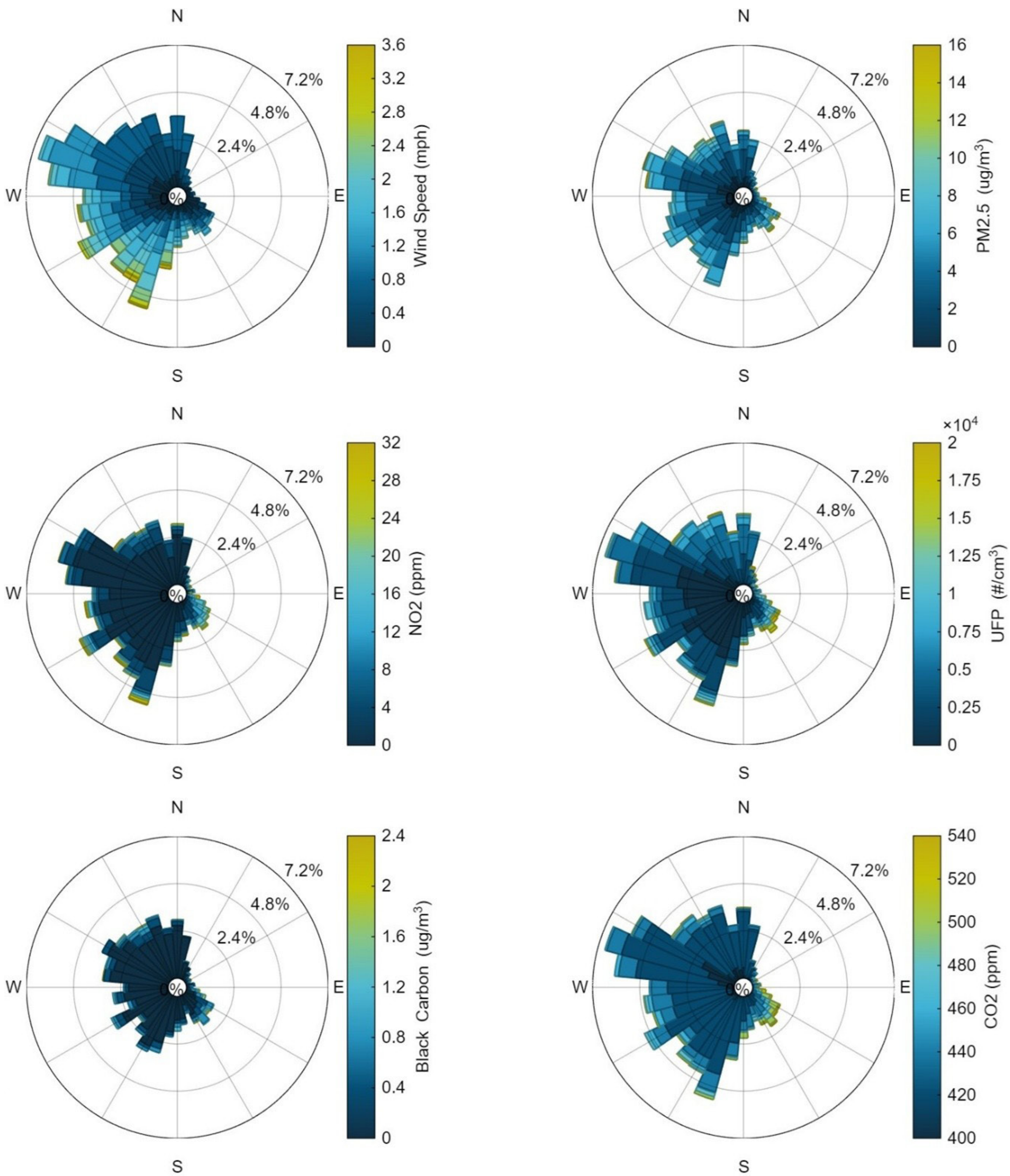
(Note: The $PM_{2.5}$ panel excludes the July 4th peak (481 µg/m³) from the y-axis range to improve readability; the peak value is shown in the plot annotation.)

Figure 8. Daily-average time-series of air pollutant measurements from the TREE trailer monitoring in Lakewood. Grey areas denote weekends.



As shown in **Figure 9**, winds during the Lakewood monitoring period primarily came from the south and southwest, with generally low wind speeds. The overall low wind speeds may be due to the nearby trees surrounding the anemometer, acting as a wind damper. Pollution roses for $PM_{2.5}$, NO_2, black carbon, and ultrafine particles show slightly higher concentrations under southwesterly winds which is consistent with influences from nearby local roadways and residential activity. Southeasterly and easterly winds occurred substantially less often during the monitoring period but presented some higher levels of $PM_{2.5}$, NO_2 and UFP, which could indicate a contribution from car and truck emissions from I-5. Overall, the wind and pollution roses indicate that pollutant levels in Lakewood were relatively low and were mainly caused by diffuse local sources rather than any dominant single source.

Figure 9. Wind and pollution roses for Lakewood.



Chinatown International District

The Chinatown–International District (CID) was monitored from early June through the end of August, 2024 for most variables except CO_2. The CO_2 instrument was still deployed in the TREE trailer at Lakewood in early June and only got moved to the CID station in late July when the Lakewood monitoring ended. Average concentrations of $PM_{2.5}$, black carbon, NO_2, CO_2, and ultrafine particles were moderate for an urban neighborhood and reflected the site's proximity to I-5 and dense local traffic (**Table 8**). Short-term peaks occurred across several pollutants, particularly ultrafine particles and NO_2, consistent with fresh vehicle emissions and nearby roadway activity. One brief $PM_{2.5}$ spike (101 µg/m³) was observed during the monitoring period and was likely associated with a short-duration, localized combustion event; this spike was not representative of typical conditions at the site. Overall patterns were influenced by typical summer conditions, including periods of warm, stagnant weather that reduced dispersion. Weekday–weekend differences were modest, with slightly higher weekday levels for NO_2, black carbon, and ultrafine particles, aligning with commuter traffic patterns.

Table 8. Summary of hourly pollutant concentrations measured at the CID monitoring site.

Pollutant	Mean	Standard Deviation	Hourly Min	Hourly Max	Units
$PM_{2.5}$	7.1	5.2	1.0	101	µg/m³
Black carbon	1.0	0.8	0.10	0.8	µg/m³
Carbon dioxide	441	18	405	524	ppm
Nitrogen dioxide	14.0	8.3	1.9	49	ppb
Ultrafine number	14.8	8.5	1.0	53.8	thousands/ cm³
Note: Carbon dioxide was monitored only for a month.					

Figure 10 and **Figure 11** present continuous time series for all pollutants measured by the TREE trailer as hourly and daily averages respectively. The figures highlight day-to-day variability driven by traffic patterns, wind shifts, and summer meteorology. Compared with the Lakewood site, CID shows more frequent short-duration pollution spikes, particularly for ultrafine particles, black carbon, and nitrogen dioxide which is consistent with its dense urban setting and proximity to major roadways like I-5. Seasonal patterns typical of summer, such as elevated afternoon mixing heights and occasional wildfire-related haze, contributed to broader fluctuations over the monitoring period.

Figure 10. Hourly-average time-series of air pollutant measurements from the TREE trailer monitoring in the Chinatown International District. Grey areas denote weekends.

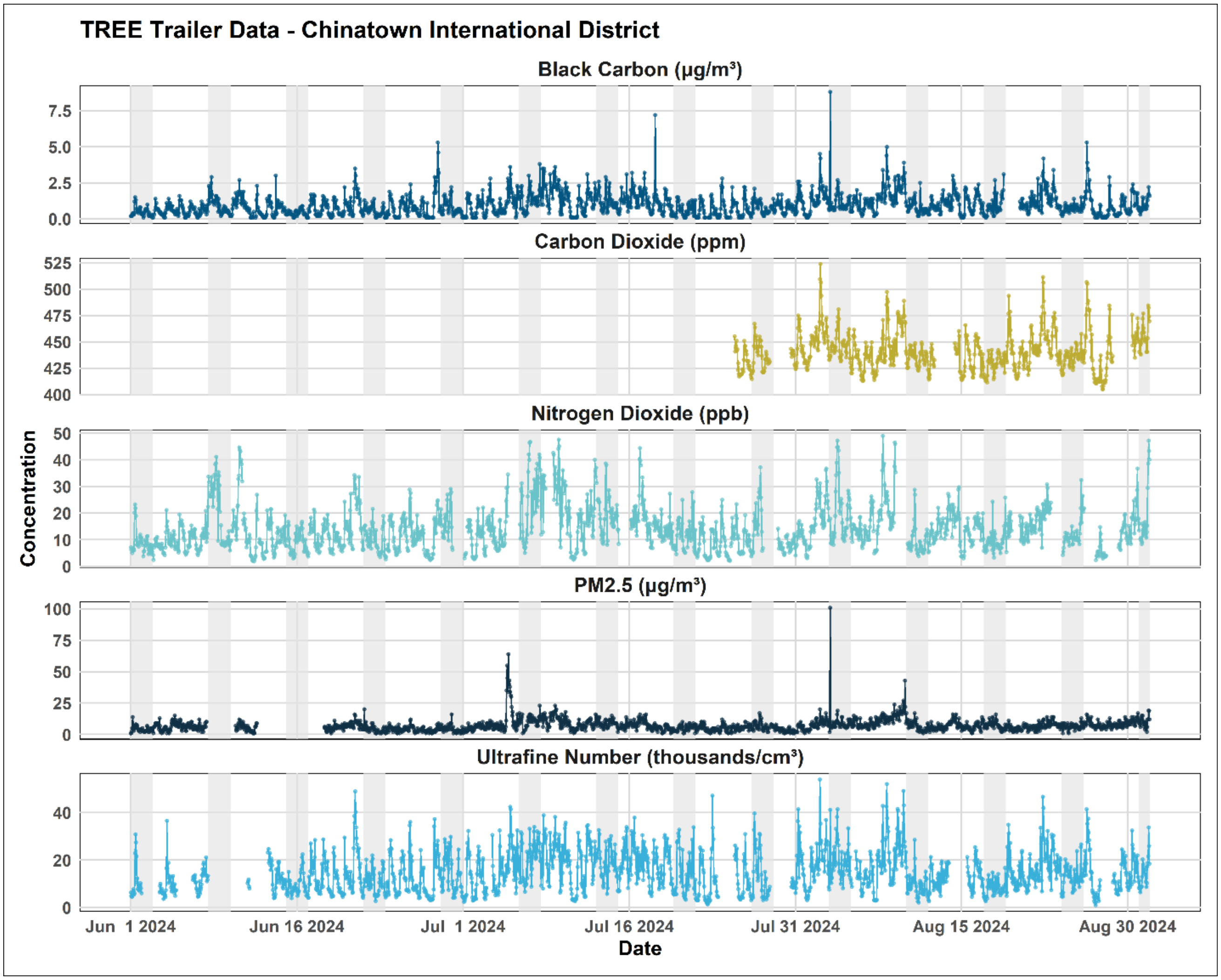
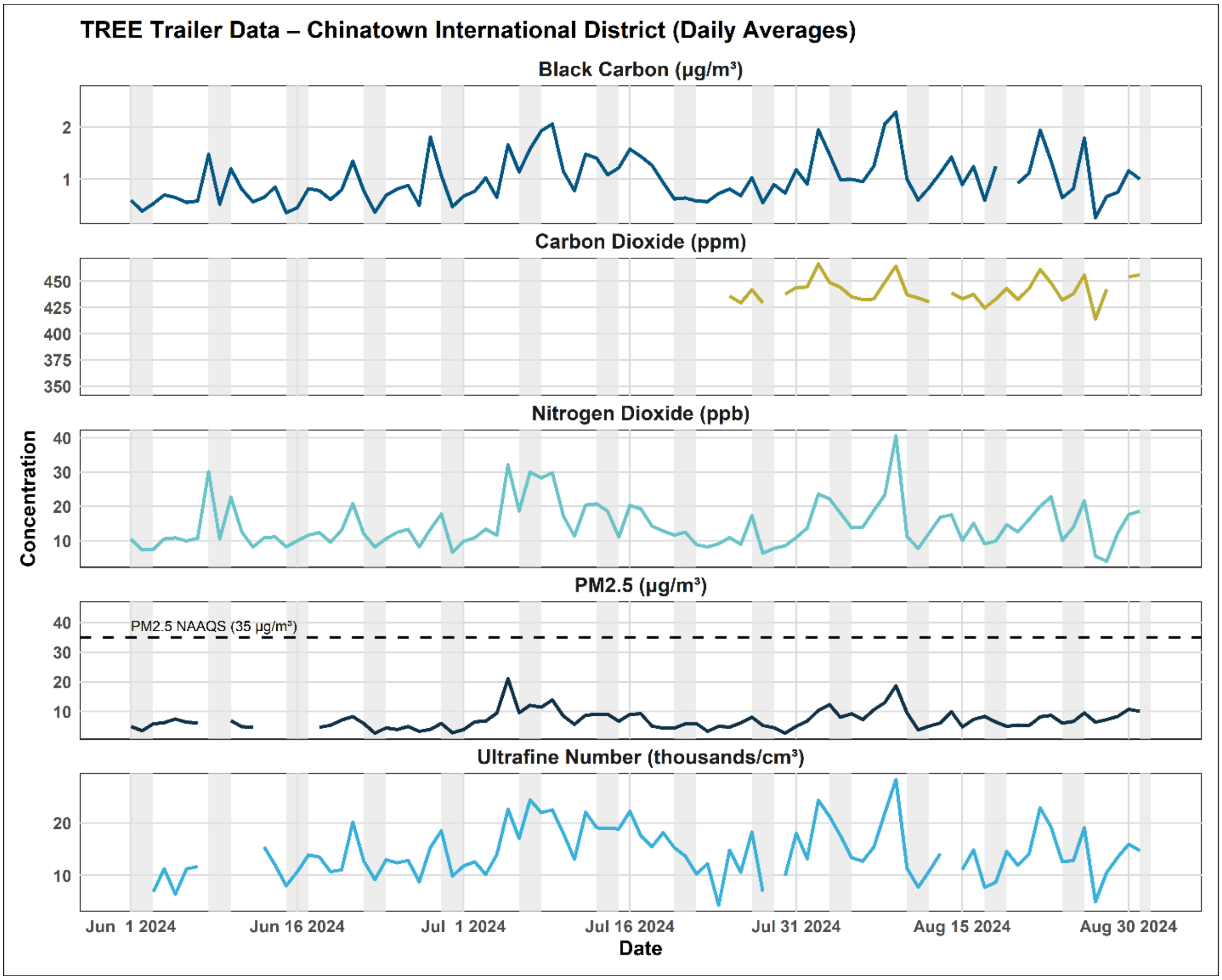
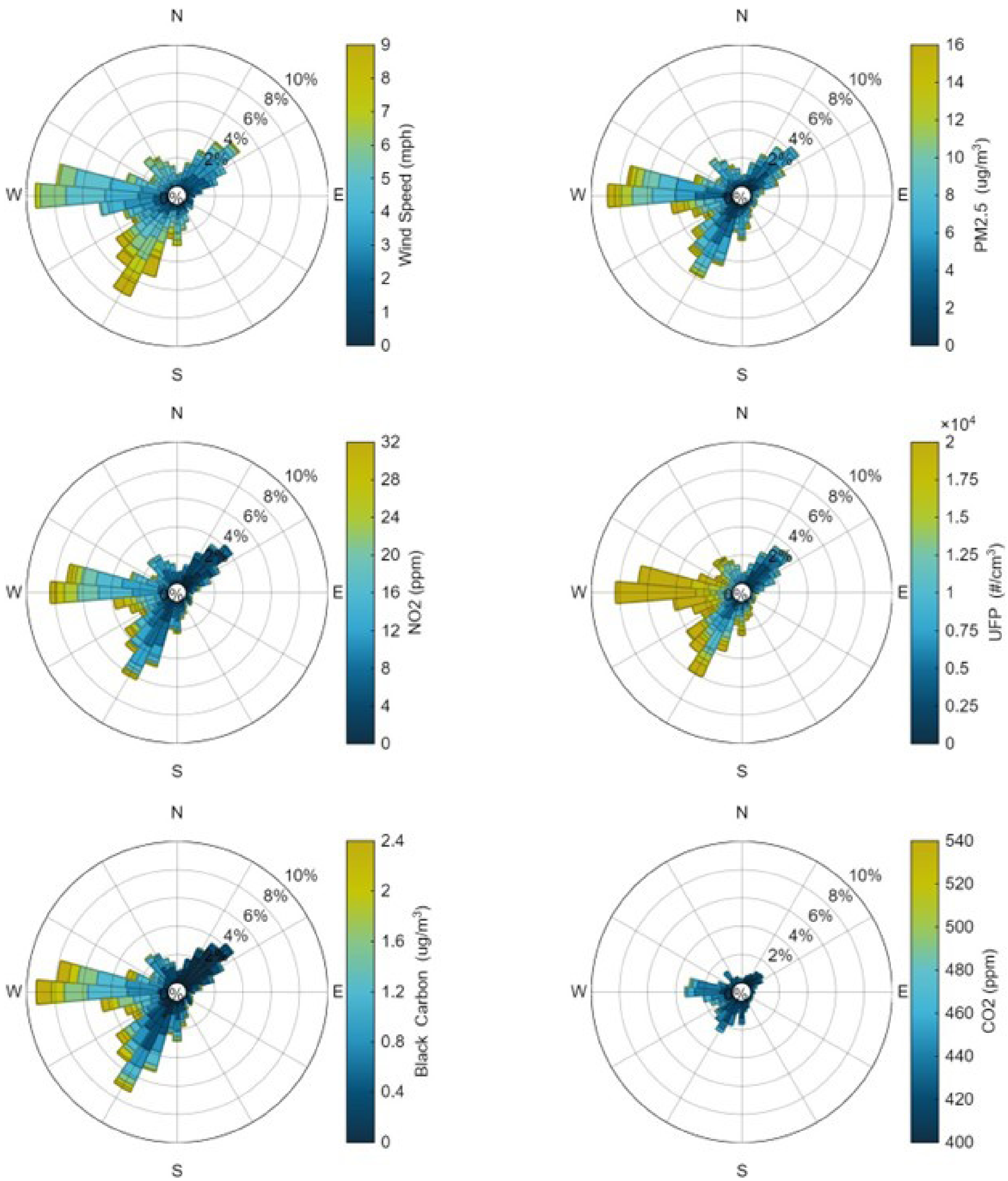


Figure 11. Daily-average time-series of air pollutant measurements from the TREE trailer monitoring in CID. Grey areas denote weekends.



Wind and pollution roses for the CID (**Figure 12**) show that winds were predominantly from the west and southwest, directing air from I-5 toward the monitoring site (located less than 10 meters east of I-5). Higher concentrations of $PM_{2.5}$, NO_2, and ultrafine particles were most frequently observed under these wind directions, indicating the strong influence of vehicle emissions and dense roadway activity surrounding the neighborhood. Pollution levels were generally lower when winds arrived from the east or northeast, where there are fewer major traffic sources. Overall, the patterns reinforce the role of transportation as a key contributor to air quality conditions in the CID.

Figure 12. Wind and pollution roses for Chinatown International District.



(Note: The lower-right CO2 pollution rose is smaller overall as it includes fewer data points since the instrument was only installed in late July as it was still deployed in Lakewood.

Duwamish Valley

The Duwamish neighborhood was monitored from early September through late October 2024. Unfortunately, the sampling at this site had to be cut short due to trailer break-ins , resulting in approximately two months of monitoring rather than the three months completed at the other sites. Average concentrations of $PM_{2.5}$, black carbon, NO_2, CO_2, and ultrafine particles are shown below (**Table 9**). Short-term peaks were frequent, especially for NO_2, ultrafine particles, and black carbon—indicating strong influences from truck traffic and nearby industrial sources. Seasonal early fall conditions, including calmer mornings and occasional stagnation, also contributed to elevated pollutant levels and reduced dispersion. Weekday–weekend differences were modest but consistent, with slightly higher weekday concentrations of NO_2, black carbon, and ultrafine particles, aligning with work-week freight activity and industrial operations.

Table 9. Summary of pollutant concentrations measured at the Duwamish monitoring site.

Pollutant	Mean	Standard Deviation	Hourly Min	Hourly Max	Units
$PM_{2.5}$	5.5	4.1	1.0	22	µg/m^3
Black carbon	0.72	0.7	0.10	4.7	µg/m^3
Carbon dioxide	427	24	394	724	ppm
Nitrogen dioxide	22	12.6	4.9	77	ppb
Ultrafine number	10.3	6.0	0.727	40.3	thousands/cm^3

Figure 13 and **Figure 14** present continuous time series for all pollutants measured by the TREE trailer as hourly and daily averages respectively. The data display recurring weekday peaks in NO_2, black carbon, and ultrafine particles linked to truck traffic and nearby industrial activity, while PM2.5 exhibited smoother, more regional patterns with fewer sharp spikes. Periods of low wind and stable atmospheric conditions coincided with higher pollutant concentrations, highlighting the combined role of local sources and meteorology in shaping day-to-day variability during the monitoring period.

Figure 13. Hourly-average time-series of air pollutant measurements from the TREE trailer monitoring in the Duwamish Valley. Grey areas denote weekends.

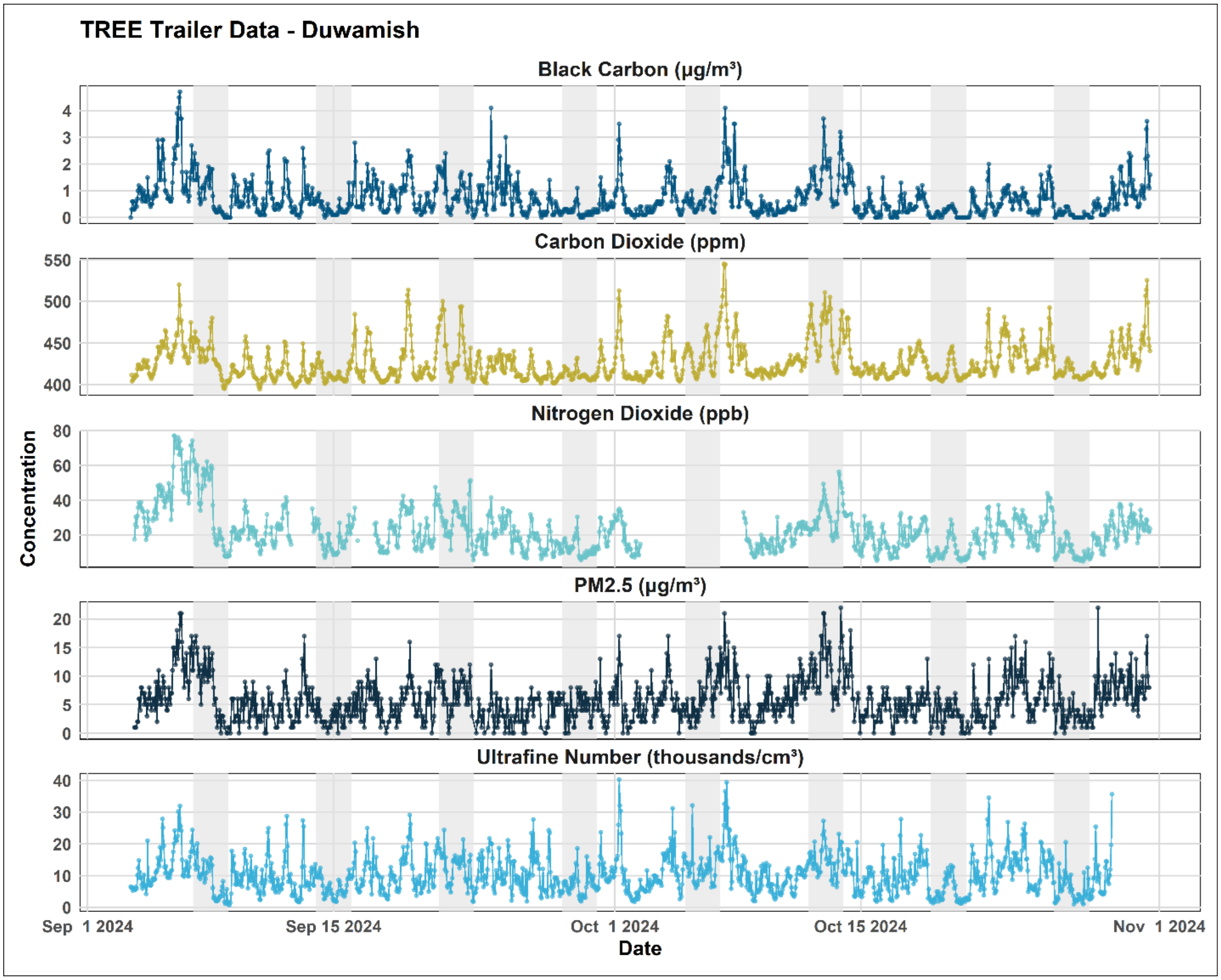
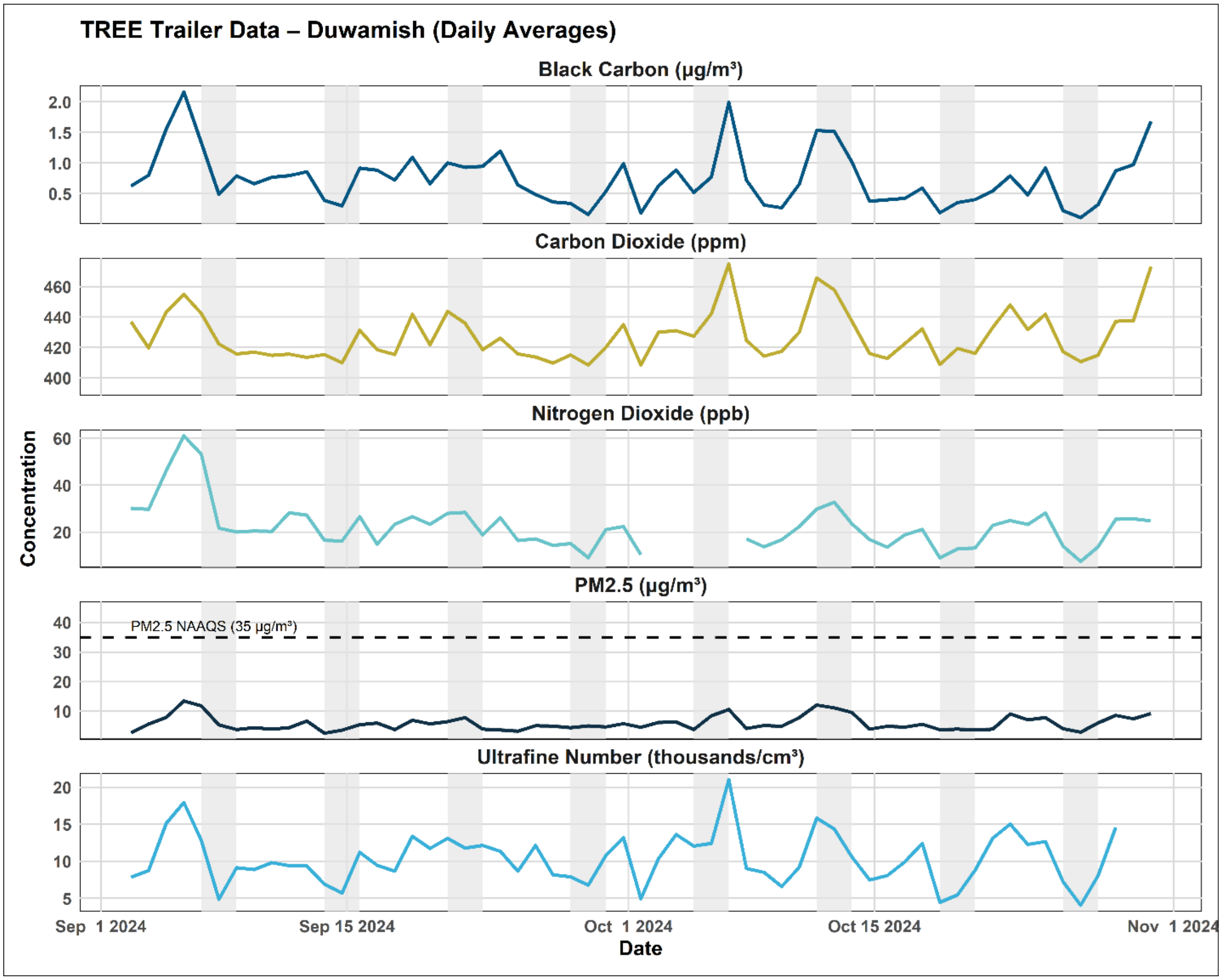
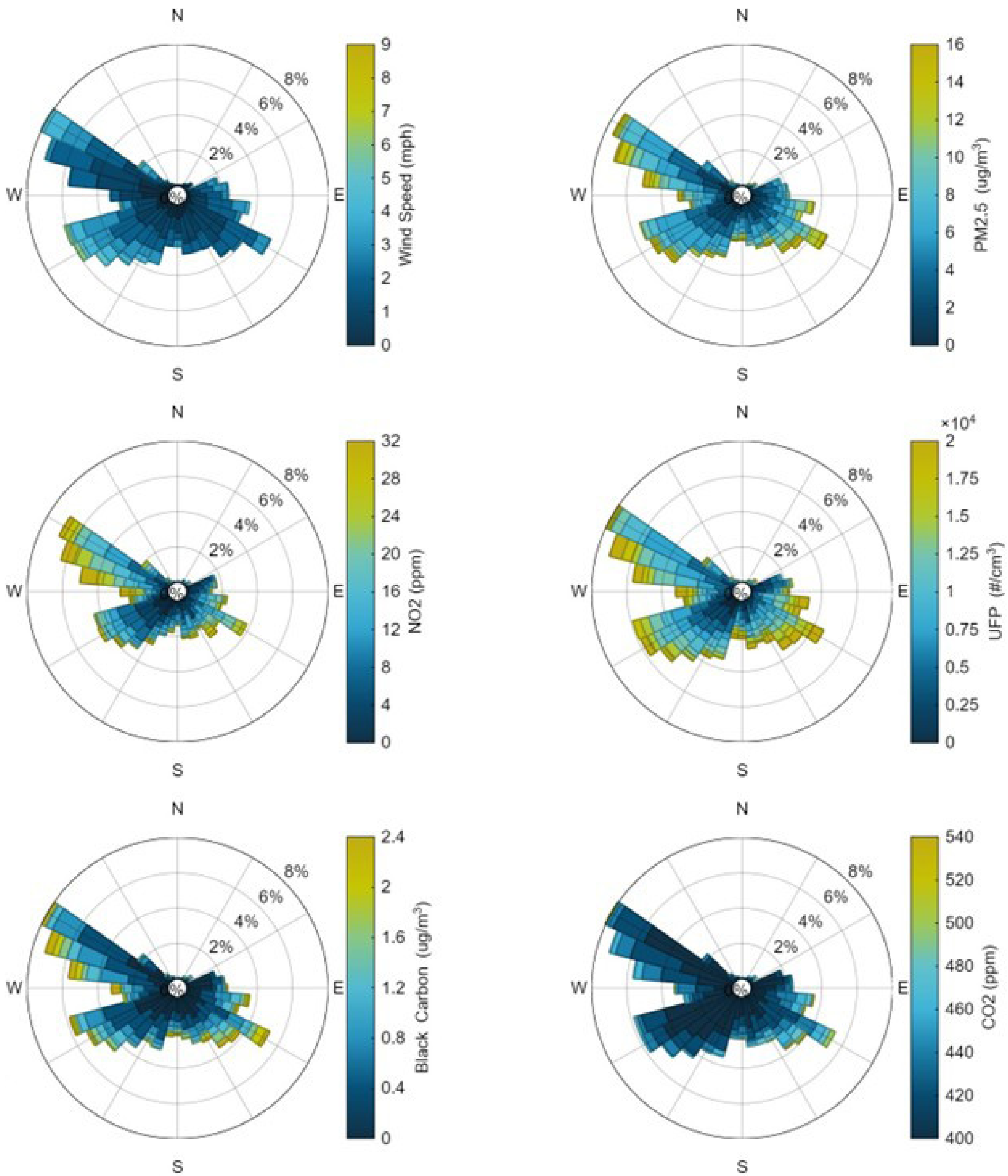


Figure 14. Daily-average time-series of air pollutant measurements from the TREE trailer monitoring in the Duwamish Valley. Grey areas denote weekends.



As shown in **Figure 15** winds during the monitoring period were primarily from the northwest, the southwest, and, to a lesser extent the southeast. Pollution roses indicate that higher concentrations of NO_2 and ultrafine particles were most often associated with winds coming from the southwest, pointing toward port activity and major roadways as key influencing sources. $PM_{2.5}$ and black carbon also showed elevated values under these same wind directions, suggesting contributions from both diesel freight activity and local traffic near the Georgetown industrial area. Overall, the wind and pollution roses illustrate that source impacts were directionally consistent, with higher pollutant levels occurring when winds transported air from transportation-dense areas toward the monitoring trailer. At this site, the TREE trailer was located directly south of a building which was acting as a wind break, potentially contributing to the lack of recorded winds coming from the north.

Figure 15. Wind and pollution roses for the Duwamish Valley



Central District

The Central District was monitored from early December through early March 2025, covering the winter season when colder temperatures and stagnant air can limit dispersion and elevate local pollution levels. Average concentrations of $PM_{2.5}$, black carbon, NO_2, CO_2, and ultrafine particles were highest among all neighborhoods, due to the winter season monitoring (**Table 10**). Short-term peaks were observed across several pollutants, particularly NO_2 and ultrafine particles, which aligned with nearby traffic corridors and fresh emissions during morning and evening activity periods. Winter meteorology contributed to reduced atmospheric mixing, occasionally enhancing pollutant buildup during calm or inversion conditions.

Weekday–weekend differences were modest. Weekdays showed slightly higher levels of PM2.5, black carbon, NO_2, and ultrafine particles, reflecting commuter patterns and increased diesel and gasoline traffic along major arterials. CO_2 varied little between day types. Overall, pollutant levels in the Central District reflected a combination of seasonal winter effects and the influence of local transportation activity.

Table 10. Summary of pollutant concentrations measured at the Central District monitoring site.

Pollutant	Mean	Standard Deviation	Hourly Min	Hourly Max	Units
$PM_{2.5}$	6.0	4.5	1.0	34	µg/m³
Black carbon	0.55	0.5	0.03	4.4	µg/m³
Carbon dioxide	443	31	407	604	ppm
Nitrogen dioxide	12.4	8.0	0.1	40	ppb
Ultrafine number	5.9	4.7	0.3	29.3	thousands/cm³

Figure 16 and **Figure 17** present continuous time series for all pollutants measured by the TREE trailer as hourly and daily averages respectively. Patterns show a mix of daily variability and short-lived peaks associated with traffic and winter stagnation events. $PM_{2.5}$, black carbon, and NO_2 exhibited clear morning and evening increases on many days, while ultrafine particles showed sharp intermittent spikes characteristic of near-source vehicle emissions. Please note that the large data gaps found in the UFP time series are due to the NanoScan SMPS instrument not working (inlet and charge flow errors) and taken out of the TREE trailer for repair.

Figure 16. Hourly-average time-series of air pollutant measurements from the TREE trailer monitoring in the Central District. Grey areas denote weekends.

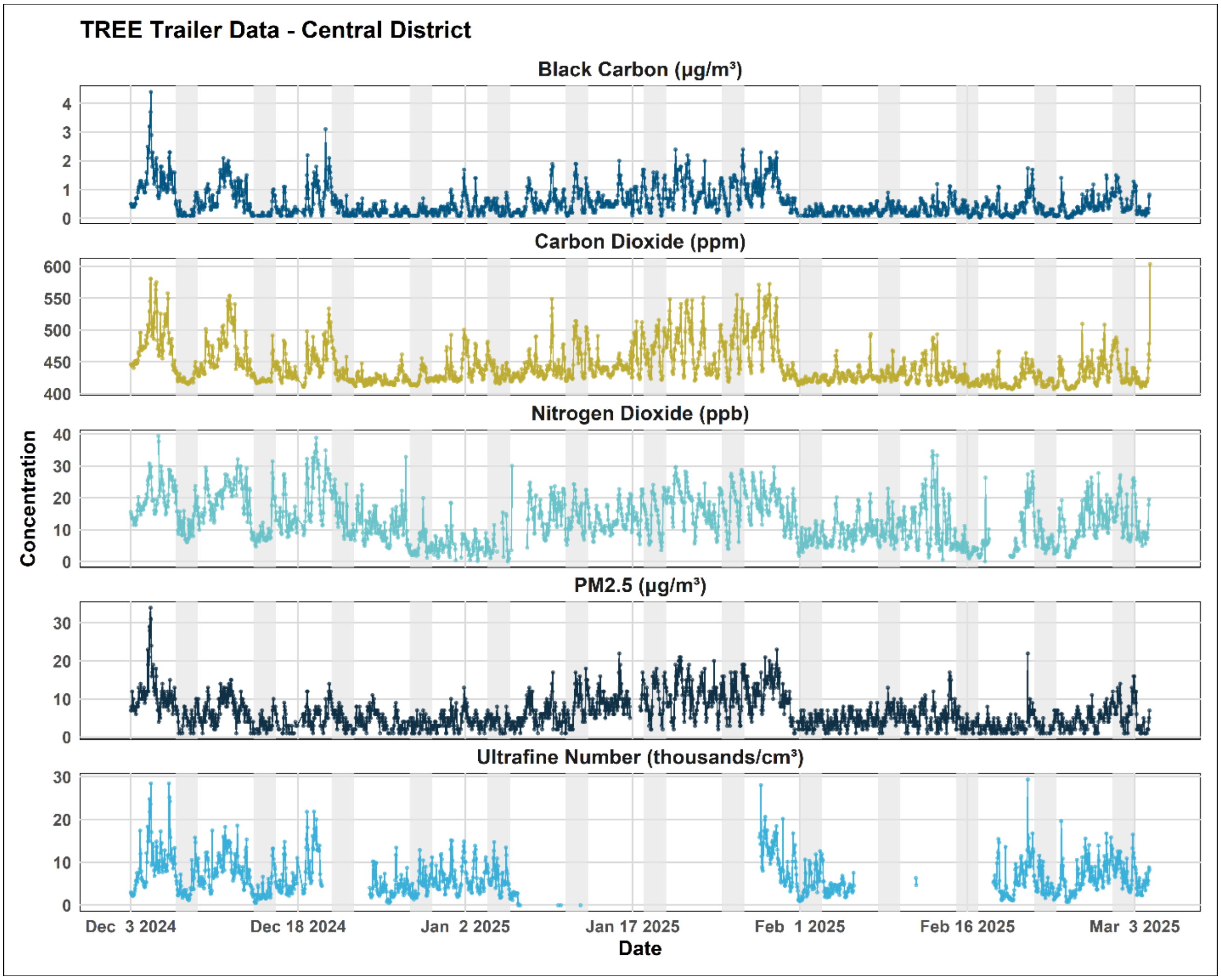
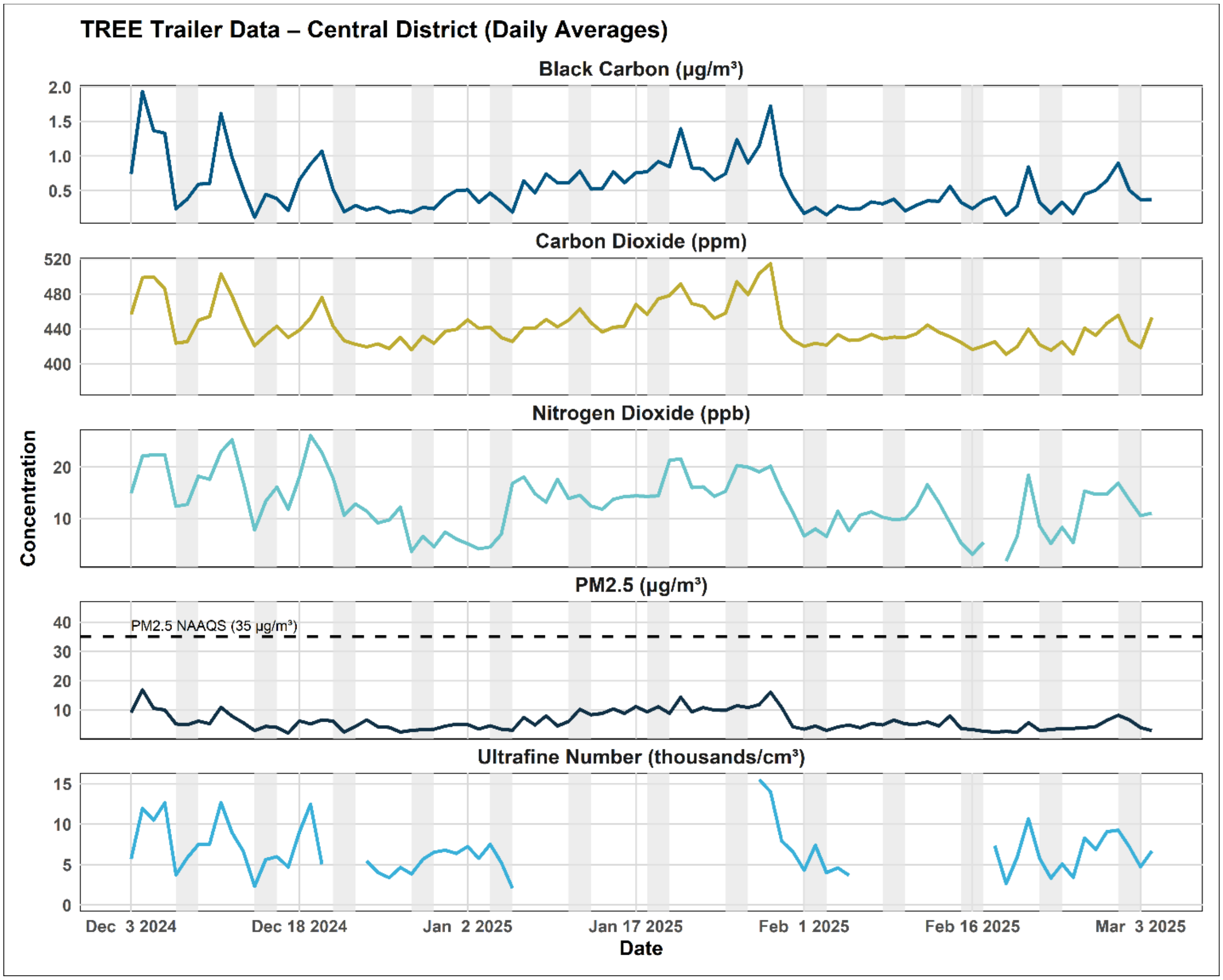
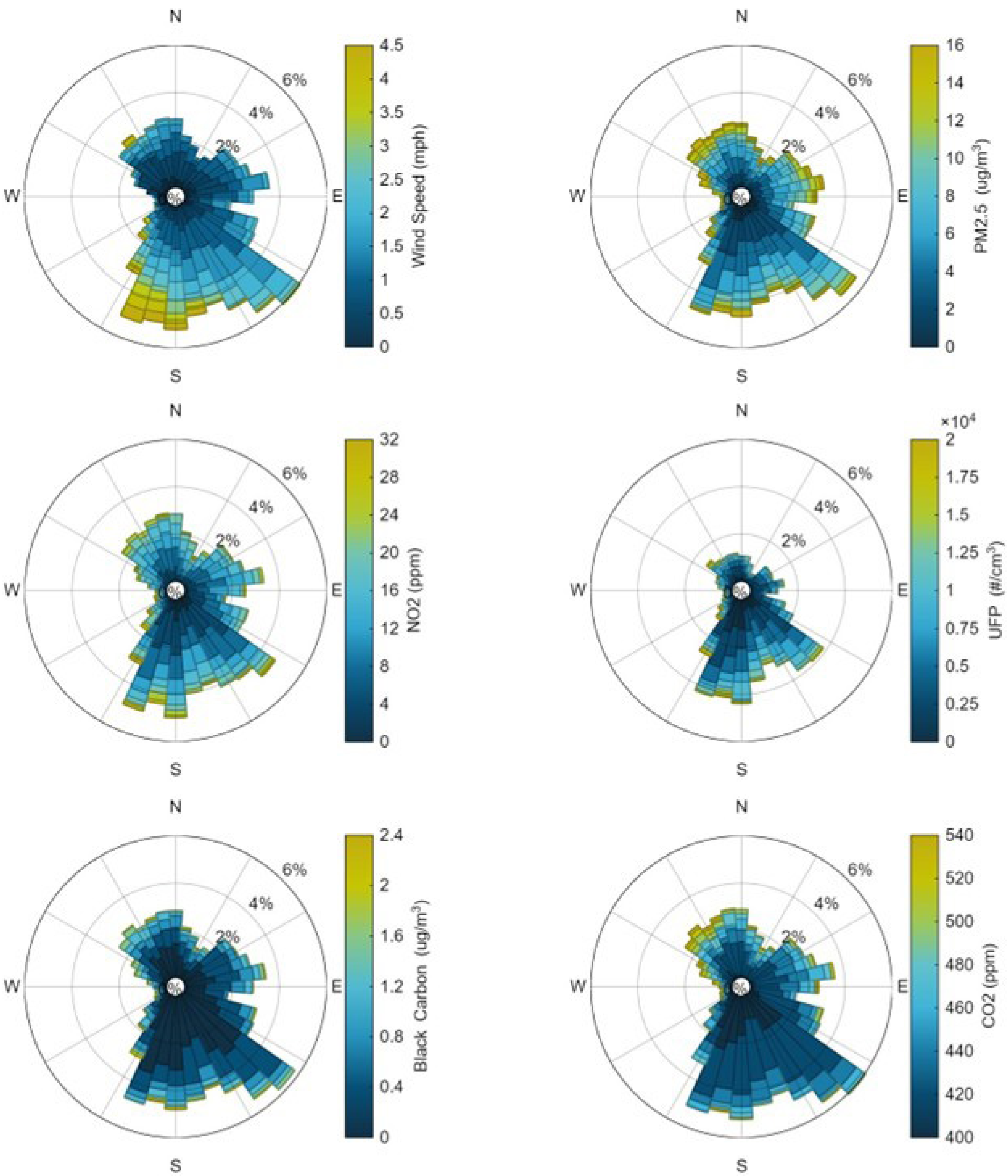


Figure 17. Daily-average time-series of air pollutant measurements from the TREE trailer monitoring in the Central District. Grey areas denote weekends.



As shown in **Figure 18**, winds during the Central District winter monitoring period were generally light, except during some stormy conditions with higher wind speeds from the south. Wind directions were most frequent from the south and southeast overall. Pollution roses show that elevated concentrations of $PM_{2.5}$, NO_2, black carbon, and ultrafine particles were most associated with winds from these same directions, indicating that nearby traffic corridors and roadway intersections to the south and southeast likely influenced measured levels locally. Under calm or low-wind conditions, which were frequent in the winter, pollutant buildup was more pronounced—consistent with reduced dispersion. Overall, the wind and pollution roses reinforce the role of local traffic, wood smoke, and winter stagnation conditions in shaping day-to-day air quality patterns in the Central District.

Figure 18. Wind and pollution roses for the Central District.



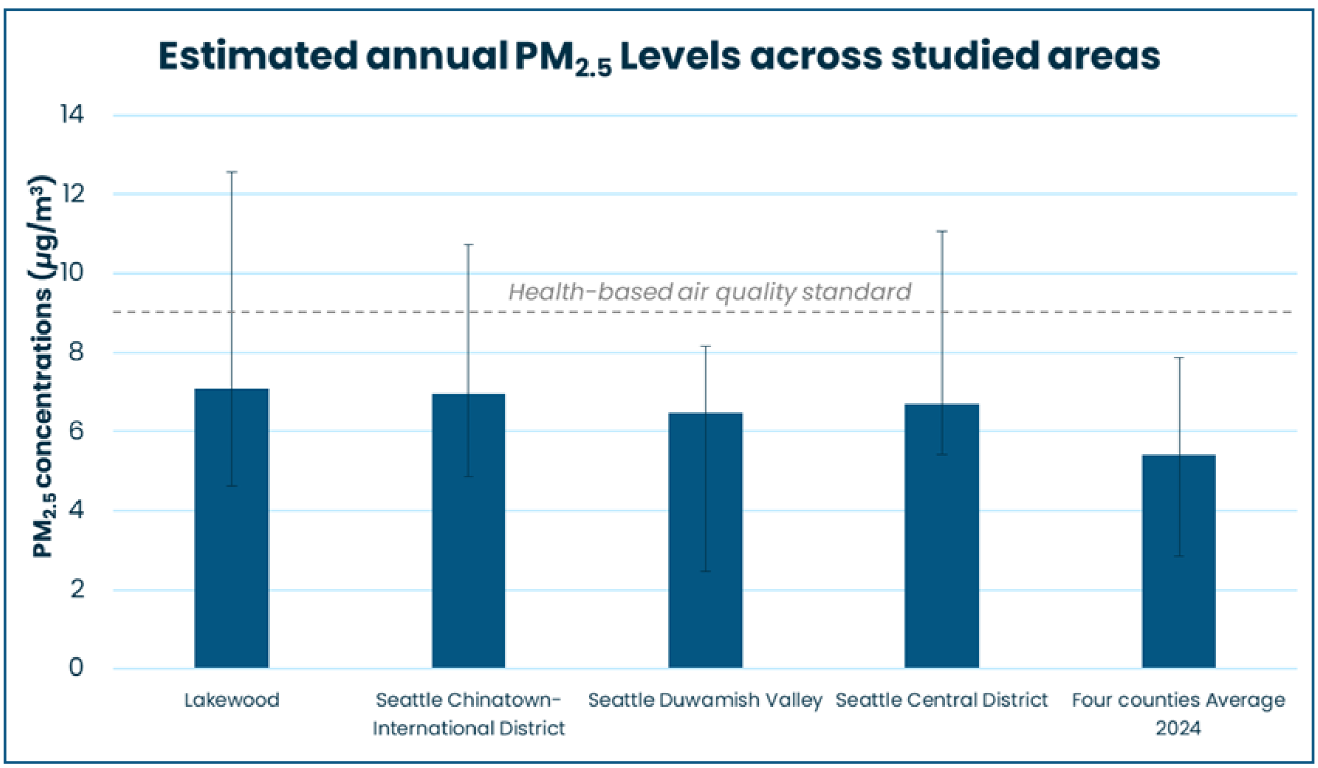
(Note: The middle-right UFP pollution rose is smaller overall as it includes fewer data points since the instrument was not working for a substantial part of the study period.)

Summary for all neighborhoods

Because monitoring occurred during different months and seasons in each neighborhood, direct comparison of raw $PM_{2.5}$ concentrations would not accurately reflect long-term differences in exposure. To support a more meaningful comparison, the neighborhood-specific $PM_{2.5}$ averages were converted into equivalent annual average concentrations. This was done by applying seasonal adjustment factors derived from nearby PSCAA and Ecology regulatory monitoring stations from 2015-2024. For each neighborhood and each year, we calculated the ratio between the station's average during the same monitoring period and its full-year average. A statistical sampling method (bootstrapping) was used to obtain the best ratio for each site and estimate overall uncertainty. Details of estimation are provided in **Appendix F**.

After applying these adjustment factors, the equivalent annual average $PM_{2.5}$ concentrations (and 95% uncertainty interval) were estimated as 7.1 (4.6-12.6) µg/m³ in Lakewood, 7.0 (4.9-10.8) µg/m³ in the Chinatown–International District, 6.5 (2.5-8.2) µg/m³ in the Duwamish area, and 6.7 (5.4-11.1) µg/m³ in the Central District (Figure 19). These adjusted values show that, after accounting for seasonal scaling, all the sites had similar equivalent annual averages. The estimates are consistent with $PM_{2.5}$ levels observed across the regional fixed-site monitoring network and sensor network, suggesting that differences in the raw seasonal measurements may not reflect meaningful long-term differences in ambient $PM_{2.5}$ concentrations.

Figure 19. Estimated Annual Average $PM_{2.5}$ Levels at all four sites, with 95% confidence intervals and the US EPA National Ambient Air Quality Standard.



[7] PSCAA 2024 Data Summary. https://pscleanair.gov/DocumentCenter/View/6035/2024-Data-Summary

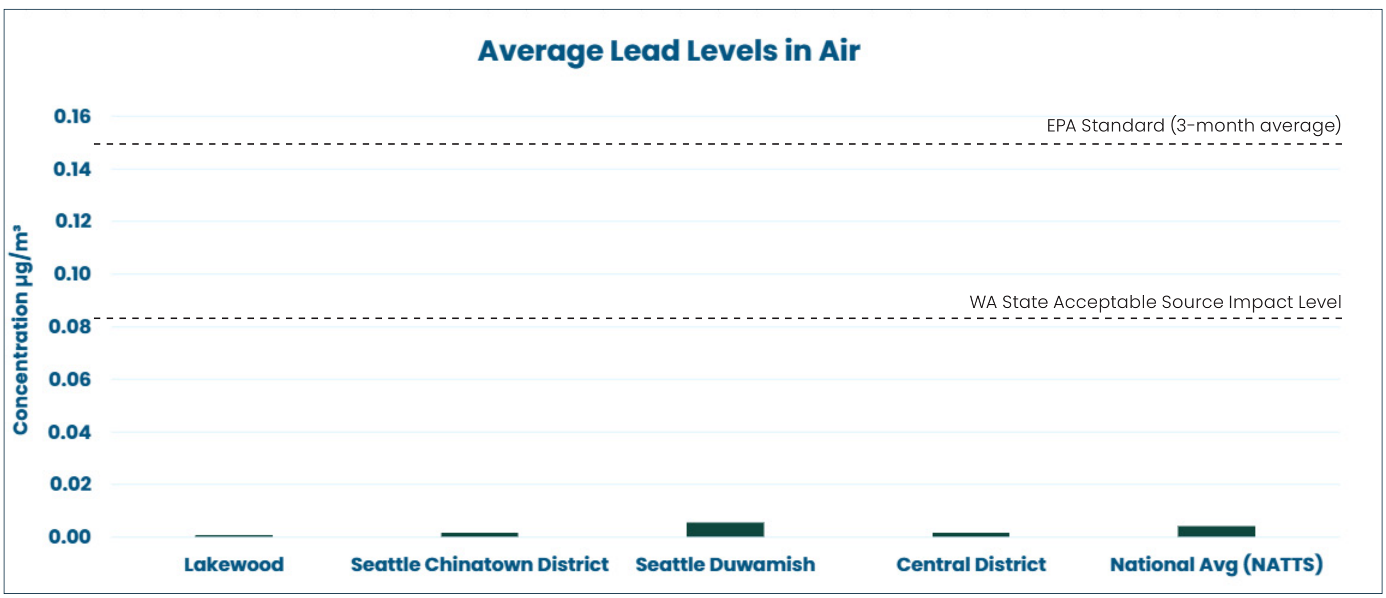
Lead Monitoring Results

Lead was measured as part of the PM_{10} metals analysis in response to community interest. As shown in Figure 20, average lead concentrations across all four monitoring locations were very low and well below state and federal health-based benchmarks. The highest site-level average was observed in the Duwamish neighborhood (0.0054 µg/m³), followed by the Seattle Chinatown–International District (0.0015 µg/m³), the Central District (0.0015 µg/m³), and Lakewood (0.00066 µg/m³). For comparison, the national average lead concentration from the NATTS network for 2021-2023 for 3-month average is 0.004 µg/m³, placing Duwamish slightly above the national average and the other three sites below it. This result is consistent with our lead monitoring in a recent [PSCAA air toxics study](#).

Seasonal conditions likely played a role in the observed differences. Duwamish was monitored in the fall, when cooler temperatures, and reduced atmospheric mixing can lead to slightly higher particulate concentrations. Lakewood, monitored in the spring, showed the lowest levels, and both CID and the Central District were monitored during summer and winter periods when background particulate levels can vary. These seasonal influences, combined with differences in local traffic and industrial activity, help explain the variation across neighborhoods.

Even with these differences, the measured lead concentrations remained far below the EPA 3-month lead standard (0.15 µg/m³) and the Washington State Acceptable Source Impact Level (0.083 µg/m³) . Overall, lead levels in ambient air across all four neighborhoods were low and do not indicate a significant health concern.

Figure 20. Average lead concentrations by neighborhood compared with NATTS and regulatory standards.



[8] US EPA, 2024. Overview of Lead (Pb) Air Quality in the United States. Updated: August 9, 2024. https://www.epa.gov/system/files/documents/2024-08/pb_2023.pdf

[9] US EPA, NAAQS for Lead, https://www.epa.gov/lead-air-pollution/national-ambient-air-quality-standards-naaqs-lead-pb

[10] WA State Acceptable Source Impact Level, WAC 173-460-150, https://app.leg.wa.gov/wac/default.aspx?cite=173-460-150

Community Monitoring

As part of the community-led monitoring activities in this project, youth groups conducted air-quality walking tours using handheld sensors to collect real-time pollutant measurements. These sessions were designed to help residents observe how air pollution varies within their neighborhoods, understand how nearby emission sources influence local conditions, and build skills in interpreting air-quality data. Across all neighborhoods, the walking tours revealed clear spatial variation in pollutant levels, with consistently higher concentrations near major roadways, busy intersections, and commercially or industrially zoned areas with greater freight activity. Lower levels were typically found in residential areas farther away from traffic and in parks or open spaces.

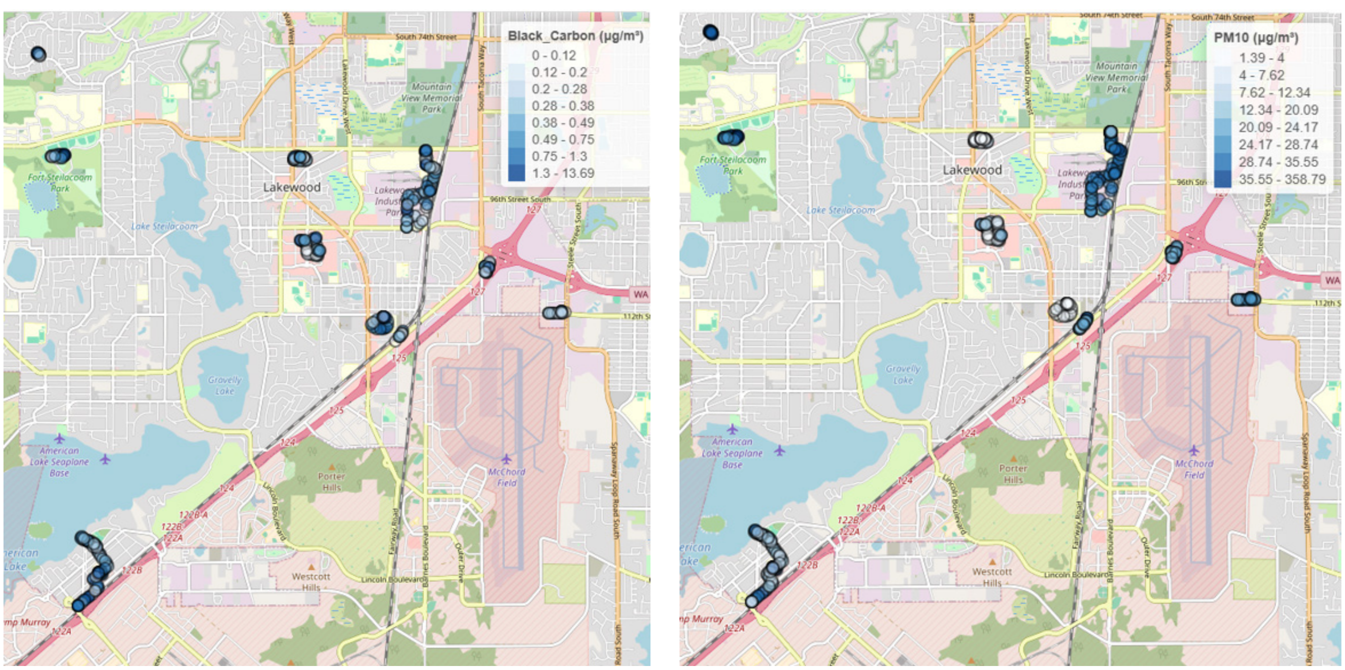
The walking tours also highlighted how environmental conditions—such as wind, temperature, and rain—can shift pollutant patterns throughout the day. Youth noted that wildfire smoke in the summer contributed to elevated $PM_{2.5}$ levels in the Chinatown–International District and that freight movement played a more prominent role in the Duwamish Valley. In addition, the handheld monitors proved sensitive to hyperlocal, short-duration pollution events, such as emissions from idling locomotives, outdoor grilling, cigarette smoke, or smoke exhaust at some commercial cooking locations (restaurants, food trucks). These real-time observations reinforced for the youth how even small, localized activities can affect the air they breathe on a block-by-block scale.

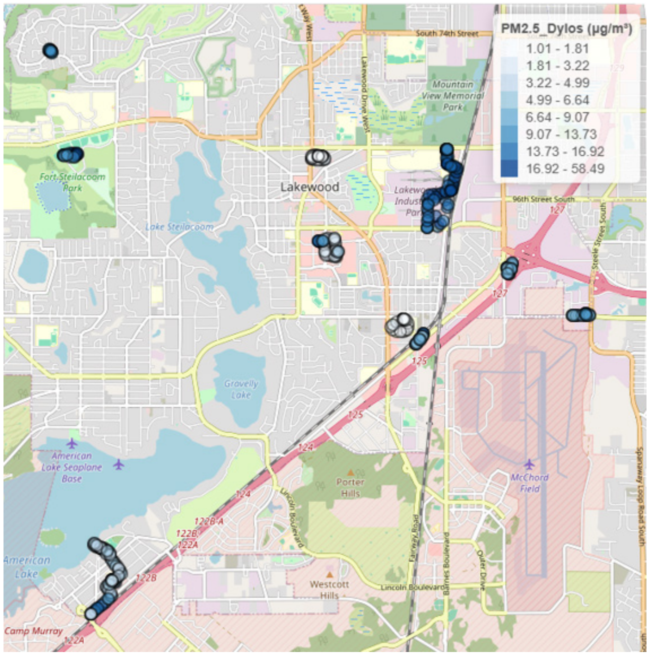
The following sections describe findings from each neighborhood in more detail.

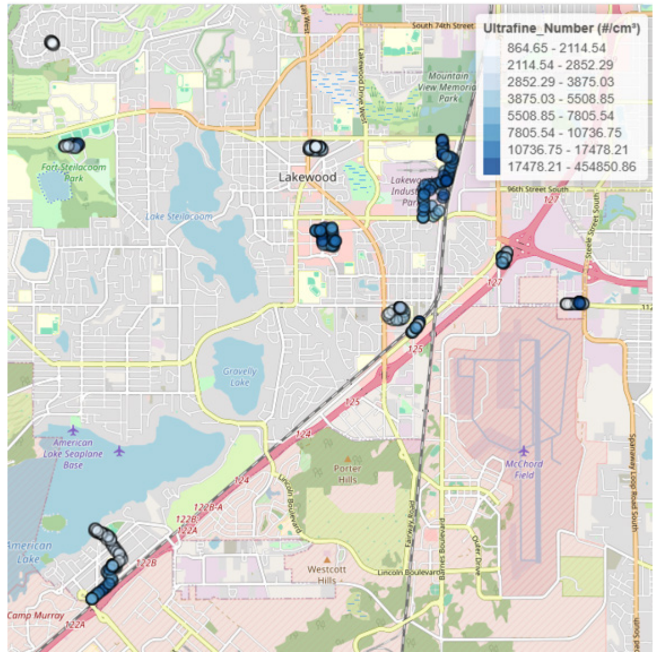
Lakewood

Community-based monitoring in Lakewood took place during the spring, a period with frequent rainfall and generally clean background air. Even under these conditions, and recognizing that there was limited monitoring, the maps show broad spatial patterns that help illustrate how pollution can vary across the neighborhood (**Figure 21**).

Figure 21. Lakewood Community monitoring data for black carbon, PM_{10}, $PM_{2.5}$ and ultrafine particles.







Across pollutants ($PM_{2.5}$, PM_{10}, black carbon, and ultrafine particles), higher readings generally appeared near major roadways, particularly Interstate 5, Highway 512, and the I-5/Bridgeport Way SW interchange. Several localized higher values also appeared along Bridgeport Way SW, an area with consistent vehicle activity. In contrast, interior residential areas and locations farther west tended to show lower concentrations across most pollutants, reflecting greater distance from major traffic corridors.

While $PM_{2.5}$ and PM_{10} showed moderate variation, ultrafine particles and black carbon displayed the clearest roadway-related gradients, with higher concentrations closer to busy intersections and freeway ramps. These patterns align with expectations for pollutants strongly influenced by vehicle emissions associated with traffic corridors, demonstrating the continuing impact of roadway emissions on community air quality.

Because the walks represent limited monitoring conducted at a given time and under specific weather and seasonal conditions, these maps should therefore be viewed as illustrative tools rather than definitive measurements. Overall, they provided a useful hands-on demonstration for participating youth; showing how air pollution can vary from block to block and how local pollution sources influence can neighborhood-scale air quality.

Chinatown International District

Community-based monitoring in the Chinatown–International District took place during the summer, when regional wildfire smoke and outdoor burning activities can raise background particulate levels. With those seasonal conditions in mind, the maps provide an illustrative snapshot of how pollution varied across the neighborhood during the walks, rather than a precise measurement of typical conditions (Figure 22).

Across the CID, the highest readings for $PM_{2.5}$, PM_{10}, black carbon, and ultrafine particles generally appeared near major transportation corridors—particularly the I-5/I-90 interchange, Alaskan Way, and other busy arterials that carry substantial diesel and freight traffic. Elevated values were also observed around the train station, train tunnel, and bus stops there. Elevated levels were detected near the waterfront. While ship emissions may have contributed somewhat, handheld sensors can be affected by humidity in waterfront environments, sometimes leading to artificially high readings.

Figure 22. CID Community monitoring data for black carbon, PM_{10}, $PM_{2.5}$ and ultrafine particles.

Concentrations tended to decrease within the interior blocks of the CID and in residential sections farther from the freeways and waterfront, reflecting reduced direct exposure to those dense transportation sources. Ultrafine particle levels showed the clearest roadway influence, dropping quickly with distance from major arterials and ramps.

Because the walks represent limited monitoring conducted under specific weather and seasonal conditions, these maps should be viewed as illustrative tools rather than definitive measurements. Overall, they were highly useful in helping community participants visualize how pollution can vary from block to block and how local traffic and freight movement influence neighborhood-scale air quality.

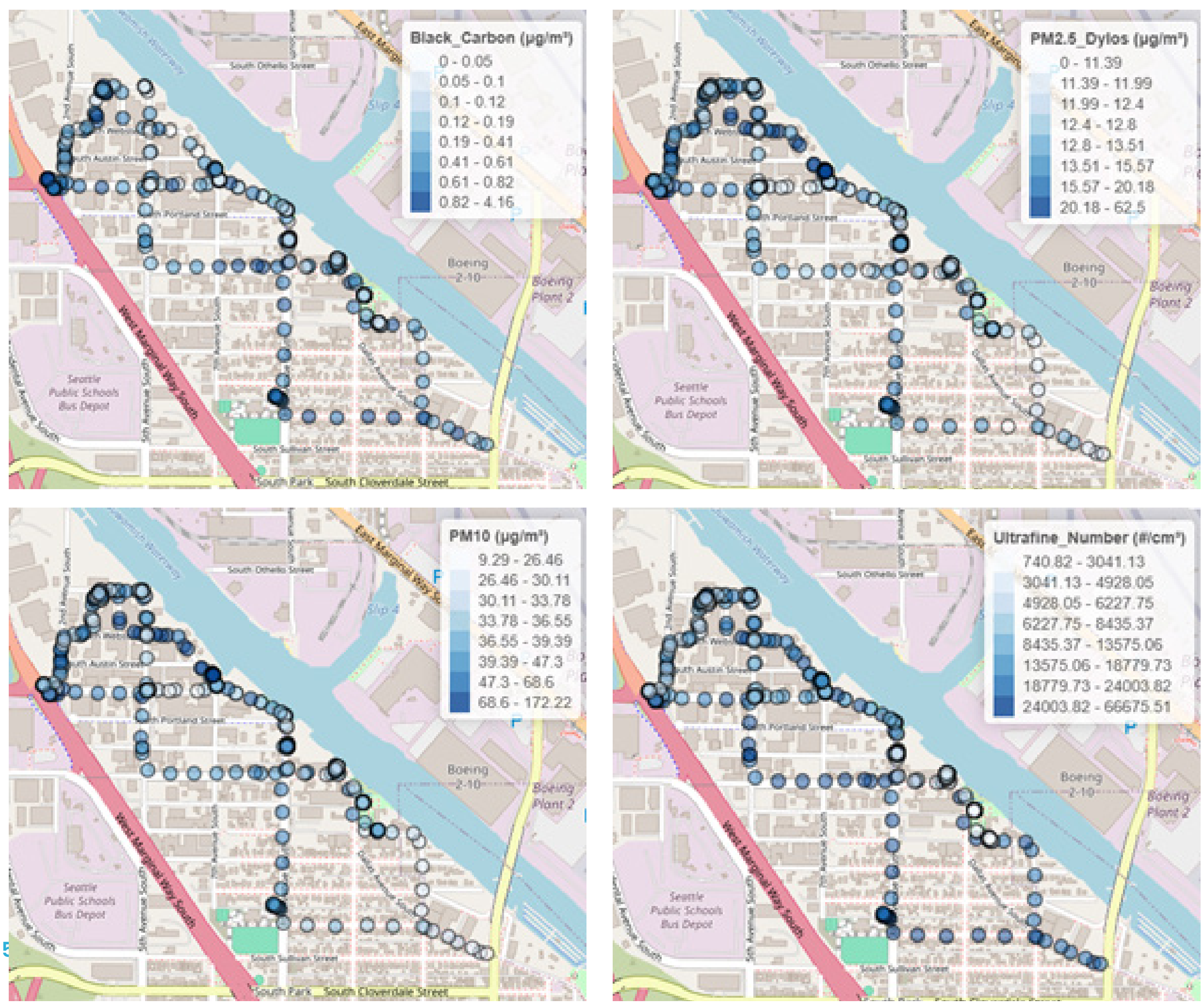
Duwamish Valley

Community-based monitoring in the Duwamish Valley was conducted during the fall, a season when cooler temperatures and more stable atmospheric conditions can limit pollutant dispersion. These conditions, combined with the neighborhood's proximity to major truck corridors, the Duwamish Waterway, and businesses, shaped the general patterns observed in the community monitoring (**Figure 23**).

Across the monitored area, black carbon and ultrafine particles were highest near West Marginal Way S, consistent with expected emission from a major roadway. Levels along the river also appeared higher. As in the CID sampling, ship emissions or other emissions may have contributed to the elevated concentrations. In addition, businesses located along the waterway could also be influencing pollutant levels in this area. Additionally, handheld sensors can be influenced by humidity near water, sometimes producing artificially high readings. Another possible factor is upwind or downwind transport of air pollution along the river. These community walks were limited in number. With repeated routes over multiple days, more distinct patterns could emerge, such as showing stronger gradients near major roads.

These patterns should be understood as illustrative rather than definitive. The walks represent limited monitoring under specific weather conditions. Overall, the results provided community youth group participants with a clear, hands-on demonstration of how local emissions from trucks and river-adjacent activity may influence air quality at the neighborhood scale.

Figure 23. Duwamish Community monitoring data for black carbon, PM_{10}, $PM_{2.5}$ and ultrafine particles.



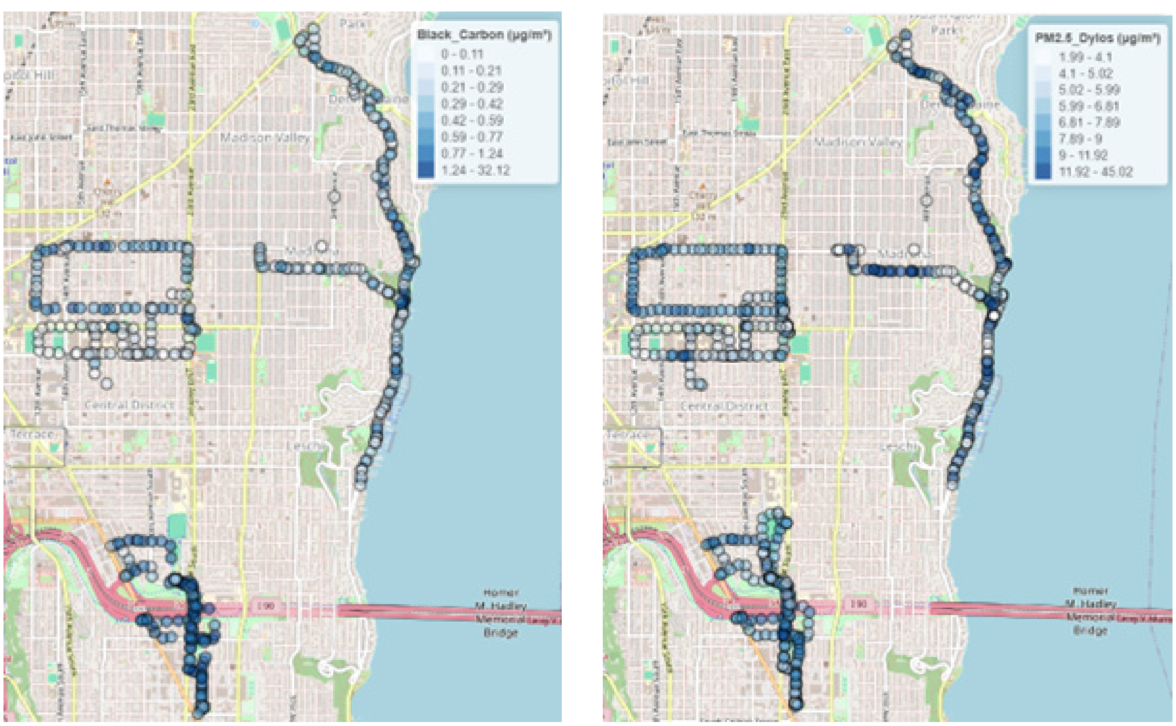
Central District

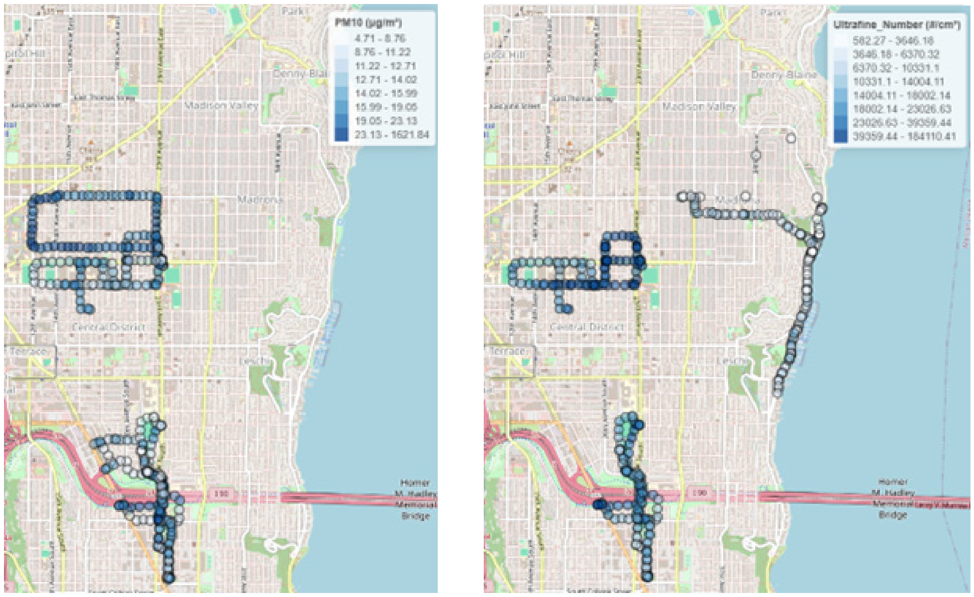
Community-based monitoring in the Central District took place during the winter, a season when colder temperatures and periods of air stagnation can trap pollutants close to the ground. These weather conditions, combined with the neighborhood's mix of residential blocks and busy arterials, shaped the general patterns visible in the maps (**Figure 24**).

Across the monitoring routes, higher readings for $PM_{2.5}$, PM_{10}, black carbon, and ultrafine particles tended to appear near major traffic corridors, including arterials that connect downtown and the I-90 corridor. Lower values were generally observed within interior residential areas farther from heavy traffic, besides a few locations where values were slightly higher due to wood smoke. Some portions of the eastern route along Lake Washington showed higher concentrations, particularly for black carbon and ultrafine particles, which may reflect traffic influence along lakeside arterials and limited wintertime dispersion. Adjacent to Lake Washington, humidity may also influence sensor readings, as noted above in the waterfront (CID) and river (Duwamish Valley) examples, sometimes causing artificially high measurements.

Because a limited number of measurements were collected during one season, the maps illustrate study-specific spatial patterns rather than average pollution levels. Overall, they provided a useful hands-on demonstration for participating youth, showing how winter conditions and nearby traffic influence air quality at the neighborhood scale.

Figure 24. Central District Community monitoring data for black carbon, PM_{10}, $PM_{2.5}$ and ultrafine particles.





Source Identification

Positive Matrix Factorization

Positive Matrix Factorization (PMF) is a model that is widely used for source apportionment of air pollution, and the Agency has previously applied it to estimate sources of $PM_{2.5}$ pollution. A brief description of how it resolves contributing sources is below.

For the TREE study, we partnered with the University of Washington who used the PMF model using a novel and limited dataset from the TREE trailer. Unlike previous studies that relied on years of $PM_{2.5}$ speciation data – including metals, ions and carbon fractions- the TREE dataset included much shorter timeframes and did not include chemical speciation measurements. To address these constraints, UW utilized ultrafine particle fractions and other additional parameters listed in **Table 3** in the PMF model. While this approach allowed identification of several source categories, the limited temporal coverage and reduced number of input variables affected the resolution of the results. As a result, some sources could not be fully resolved, and certain factors were not well understood.

PMF resolves the observed data matrix (X) into a factor profile matrix (F) and a factor contribution matrix (G) . The model can be expressed as:

$$x_{ij} = \sum_{k=1}^{K} g_{ik} f_{kj} + e_{ij}$$

where x_{ij} is the concentration of species j in sample i; f_{kj} is the concentration of species j in factor k; g_{ik} is the contribution of factor k in sample i; e_{ij} is the residual; and K is the number of factors. The factor contribution and profile matrices are obtained by minimizing the sum of squared, uncertainty-weighted residuals, with the f and g matrices constrained to be non-negative. All PMF analyses were conducted using the EPA PMF 5.0 software. In

[11] U.S. Environmental Protection Agency EPA Positive Matrix Factorization (PMF) 5.0 Fundamentals and User Guide; 2014.

this study, PMF was applied separately for each of the four monitoring sites. A total of 17 species were input into the PMF model, including background-subtracted CO_2, BC, ultraviolet particulate matter (UVPM), NO_2, $PM_{2.5}$, total particle number concentration (PNC; 10–420 nm), and PNC within 11 size bins, following a similar approach used in a previous study in the greater Seattle area. Background subtraction was applied to CO_2 to remove regional and ambient baseline concentrations, allowing the model to better capture local emission influences and improve separation of source-related variability. The concentration x_{ij} and the corresponding uncertainty σ_{ij}, which were input into the PMF model, were estimated by the equations below:

$$\overline{x_{ij}} = \begin{cases} \frac{1}{2} MDL_j, x_{ij} < MDL_j \\ x_{ij}, x_{ij} \geq MDL_j \end{cases}$$

$$\sigma_{ij} = \begin{cases} \frac{5}{6} MDL_j, x_{ij} < MDL_j \\ \sqrt{\left(ErrF_j \times x_{ij}\right)^2 + \left(0.5 MDL_j\right)^2}, x_{ij} \geq MDL_j \end{cases}$$

where MDL_j is the method detection limit for species j; and $ErrF_j$ is the error fraction of concentrations of species j, which was determined by the median of absolute relative deviation between the primary and the collocated back-up instrument measurements.

Missing concentration data were substituted weekday-and hour-specific median values, with corresponding uncertainties set to four times the substituted concentrations. In the EPA PMF 5.0 software, each pollutant was categorized as “strong,” “weak,” or “bad” based on its signal-to-noise ratio (S/N), following criteria used in previous studies . In this study, total PNC (10–420 nm) was also set as additional variable for total ultrafine particles (UFP) and was automatically classified as “weak due to its low S/N ratio” Models with 3–8 factors were tested, and the optimal solution was selected based on the maximum individual column mean (IM) and standard deviation (IS) of the scaled residuals[14, 15]. Poorly fitted “strong” species were reclassified as “weak” to improve factor interpretability. Based on these criteria, a five-factor solution was selected for all four sites. Finally, the factor profile (f_{kj}) and factor contribution (g_{ik}) were obtained from the PMF analysis. The brown carbon (BrC) mass concentration was further estimated by Delta-C approach, which subtracted BC from UVPM mass concentration from each factor profile[16].

[12] Liu, N. R.; Oshan, R.; Blanco, M.; Sheppard, L.; Seto, E.; Larson, T.; Austin, E., Mapping Source-Specific Air Pollution Exposures Using Positive Matrix Factorization Applied to Multipollutant Mobile Monitoring in Seattle, WA. *Environ Sci Technol* **2025**, 59, (7), 3443-3458.

[13] Liu, N. R.; Oshan, R.; Blanco, M.; Sheppard, L.; Seto, E.; Larson, T.; Austin, E., Mapping Source-Specific Air Pollution Exposures Using Positive Matrix Factorization Applied to Multipollutant Mobile Monitoring in Seattle, WA. Environ Sci Technol **2025**, 59, (7), 3443-3458.

[14] Lee, E.; Chan, C. K.; Paatero, P., Application of positive matrix factorization in source apportionment of particulate pollutants in Hong Kong. Atmos Environ **1999**, 33, (19), 3201-3212

[15] Wang, M.; Wang, Q. Y.; Ho, S. S. H.; Li, H.; Zhang, R. J.; Ran, W. K.; Qu, L. L.; Lee, S. C.; Cao, J. J., Chemical characteristics and sources of nitrogen-containing organic compounds at a regional site in the North China Plain during the transition period of autumn and winter. Sci Total Environ **2022**, 812.

[16] Wang, Y. G.; Hopke, P. K.; Rattigan, O. V.; Chalupa, D. C.; Utell, M. J., Multiple-year black carbon measurements and source apportionment using Delta-C in Rochester, New York. J Air Waste Manage 2012, 62, (8), 880-887.

Factor Interpretation

Several complementary analytical approaches were used to interpret the emission sources represented by each PMF factor.

Comparison with Previous Studies

Factor profiles and particle size distributions were compared with results from an earlier mobile monitoring campaign in the greater Seattle area that measured the same pollutants across a broader regional network. Because that study relied on land-use regression for source interpretation, its results provided an external reference that helped address the spatial limitations of relying on four fixed monitoring sites in this study.

Pollutant Ratio Analysis

Ratios of key markers within each factor (e.g., BC/CO_2, BrC/CO_2, NO_2/CO_2, PNC/CO_2, $PM_{2.5}$/BC) were examined to support source identification. These ratios were also used to estimate fuel-based emission factors for BC, NO_2, and PNC for traffic-related factors, which were compared with published values to validate the interpretations.

Wind-Based Analysis (CBPF)

A Conditional Bivariate Probability Function (CBPF) analysis was conducted using measured wind speed and direction. This approach identifies wind sectors associated with elevated factor contributions (above the 75th percentile), helping to pinpoint likely source areas and distinguish between local and regional influences.

Temporal Pattern Evaluation

Diurnal and day-to-day variations in factor contributions were assessed as additional evidence supporting source interpretation. These patterns were interpreted with caution, as they can be affected by boundary layer dynamics and other atmospheric processes that influence short-term pollutant variability.

Source Contribution Modeling

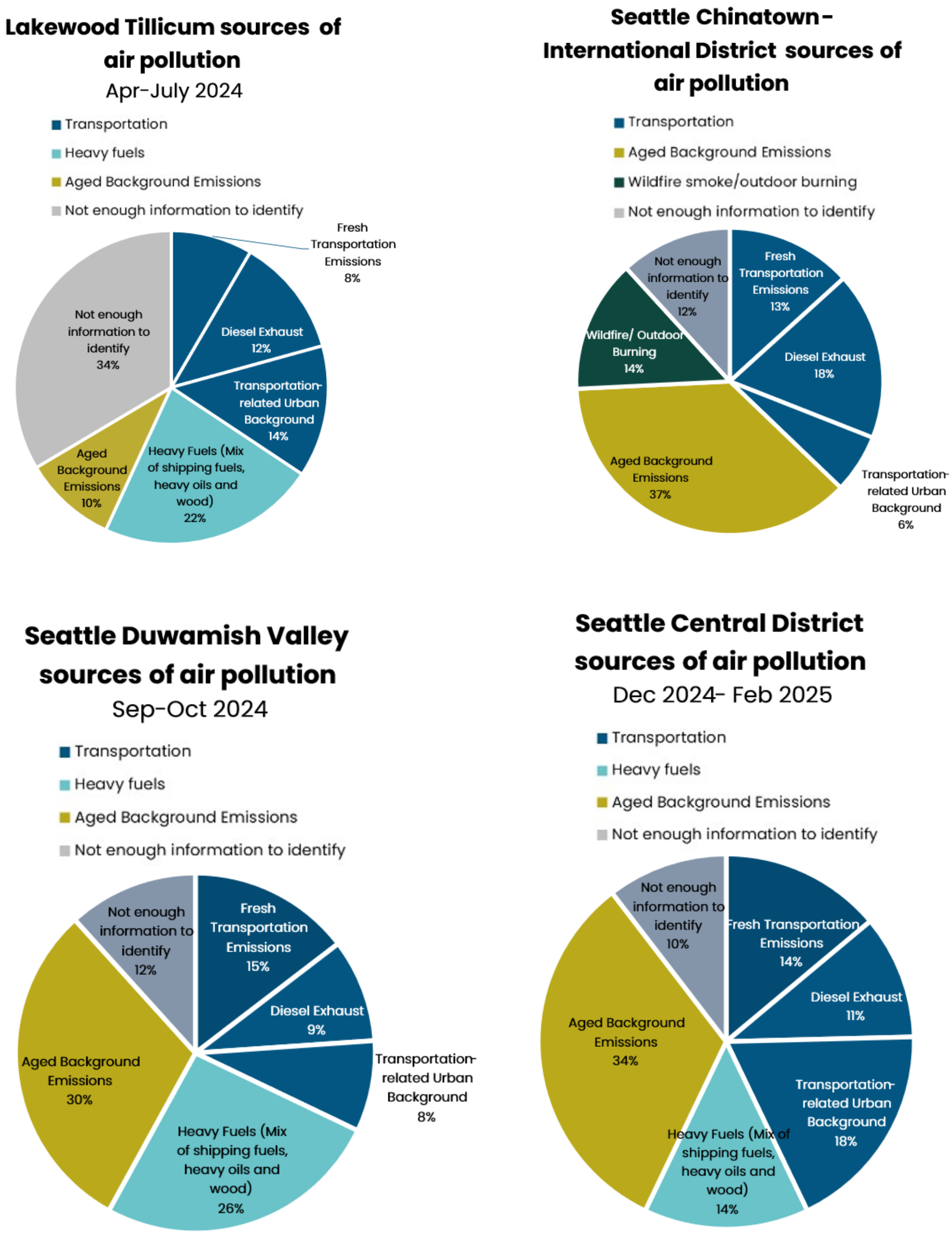
To estimate the overall contribution of road traffic and other sources to air pollution, additional statistical modeling was conducted. One PMF-derived factor represented accumulation-mode aerosols, likely reflecting aged particles originating from traffic emissions. To quantify this link, we calculated cross-correlation functions (CCFs) between the accumulation-mode factor and traffic-related factors (gasoline and diesel). Significant positive correlations at specific lags indicated delayed relationships, which were further evaluated using a Distributed Lag Nonlinear Model (DLNM).

The DLNM assumed a linear exposure-response relationship, a natural spline (three degrees of freedom) for the lag effect, and an AR(1) residual structure. The optimal lag order was selected using the Akaike Information Criterion (AIC). The attributable fraction of road traffic to the accumulation-mode factor was then estimated through counterfactual analysis, by setting gasoline or diesel contributions to zero in the fitted model. The resulting road traffic contributions were combined with the original PMF outputs to derive total source contributions to each pollutant. These were further compared with reported $PM_{2.5}$ source apportionment results from Agency's previous Air Toxics study for consistency validation.

Source Apportionment Results

A total of five factors were identified through the PMF analysis at each neighborhood monitoring site. These factors roughly correspond to transportation-related emissions (fresh transportation emissions, diesel exhaust, urban background pollution), heavy fuels (mix of shipping fuels, heavy oils and wood), and an aged background emissions , with some site-specific variations described in the following sections. For easier interpretation, the relative contributions of the five factors to $PM_{2.5}$ at all four sites are summarized in the pie charts in **Figure 25**.

Figure 25. Relative contributions of the five identified source factors to $PM_{2.5}$ at each monitoring site.



Fresh Transportation Emissions

Factor 1 represents fresh transportation emissions from the on-road vehicular exhaust and at some sites, minor contributions from the aircraft emissions, characterized by a strong ultrafine particle signature. As shown in the factor profiles (**Appendix E, Figure E1**), this factor contributes more than half of all particles in the 10–20 nm range, reflecting newly formed exhaust from gasoline and diesel vehicles. The profiles also show a secondary mode at larger particle sizes, suggesting a small contribution from regional aircraft activity, although roadway sources remain the dominant driver across all sites.

The pie charts (**Figure 25**) illustrate how fresh transportation emissions contribute to $PM_{2.5}$ mass at each site. While transportation emissions dominate the ultrafine range, their share of $PM_{2.5}$ is more modest, accounting for 8% in Lakewood, 13% in the Chinatown–International District, 15% in Duwamish, and 14% in the Central District. Directional patterns from the CBPF analysis further support this interpretation (**Appendix E, Figure E2**). Each site shows elevated contributions from directions aligned with major roadways: southeasterly winds toward I-5 in Lakewood, influences from both I-5 and I-90 in the CID, strong signals from the freight corridor near E Marginal Way S in Duwamish, and contributions aligned with nearby arterials and I-5 in the Central District.

It was also observed that weekday concentrations were higher than weekend levels, reflecting increased commuter and business traffic. This pattern contrasts with aircraft activity, which typically increases during weekends and holidays.

Diesel Emissions

Factor 2 represents diesel emissions as illustrated in the factor profiles (**Appendix E, Figure E1**). At the Lakewood, Duwamish Valley, and Central District sites, this factor exhibited particle sizes between 13 and 100 nm, with a pronounced peak in the 24–32 nm range, consistent with characteristic diesel exhaust, which typically produces abundant particles below 30 nm. The observed size pattern closely resembles diesel-related factors identified in previous University of Washington mobile monitoring studies across the Seattle region[17].

At the CID site, the particle size distribution for Factor 2 was broader, with its peak shifted toward larger diameters (approximately 32–56 nm). After comparing with all factor profiles, it suggests that the factor at CID represents a mixed source of diesel and heavy fuels combustion.

The pie charts (**Figure 25**) show that diesel emissions contribute a moderate share of $PM_{2.5}$ mass at each site: 12% in Lakewood, 18% in the CID, 9% in Duwamish, and 11% in the Central District. These contributions are smaller than those observed for ultrafine particles but are consistent with diesel exhaust being a number-dominated, rather than mass-dominated, source.

Spatial patterns from the CBPF analysis (**Appendix E, Figure E2**) further support this interpretation. All four sites showed alignment with major roadways and freight corridors where heavy-duty diesel trucks are most active. We also observed higher diesel emission contributions on weekdays than weekends, reflecting increased truck traffic related to goods movement, deliveries, and business operations during the workweek.

[17] Liu, N. R.; Oshan, R.; Blanco, M.; Sheppard, L.; Seto, E.; Larson, T.; Austin, E., Mapping Source-Specific Air Pollution Exposures Using Positive Matrix Factorization Applied to Multipollutant Mobile Monitoring in Seattle, WA. *Environ Sci Technol* **2025**, 59, (7), 3443-3458.

Transportation-related Urban Background

Factor 3 represents a transportation-related urban background factor, largely shaped by aged road traffic emissions as shown in the factor profiles (**Appendix E, Figure E1**). It accounted for more than 90 percent of the background-subtracted CO2 across all four monitoring sites, indicating that it reflects no specific adjacent source of emissions, but rather a regionally mixed pollution source. The strong CO2 signal could suggest that this factor represents widespread combustion-related activity common in urban areas. However, this factor could also serve as a statistical balancing factor to account for all the species used in the analysis.

The factor profiles showed that particle size distributions differed among sites. At Lakewood, Factor 3 was dominated by particles smaller than 24 nm, consistent with nucleation-mode aerosols in areas with limited nearby traffic. While nucleation-mode particles can originate from nearby traffic, they can also form through secondary processes such as photochemical reactions in cleaner air masses. The relative absence of larger particles at this site suggests that the air mass was moving and well-ventilated, allowing freshly formed ultrafine particles to remain small rather than coagulating into larger size fractions. This combination points to a mixture of local formation and regional background influences rather than strong, persistent traffic emissions. At the CID and Duwamish sites, which are closer to major highways, the size distribution spanned a much broader range, from about 10 to 178 nm. This may indicate that these sites are also influenced by particles that have undergone atmospheric aging, such as growth, mixing, or condensation. The Central District displayed an intermediate pattern, suggesting influence from both nearby roadways and more regional air masses.

The pie charts (**Figure 25**) show that Factor 3 contributed modest amounts to $PM_{2.5}$ mass, with site-specific contributions of about 14 percent in Lakewood, 6 percent in the CID, 8 percent in Duwamish, and 18 percent in the Central District.

The CBPF plots (**Appendix E, Figure E2**) show diffuse spatial patterns that support this interpretation. At Lakewood, a weak signal appeared to the east, consistent with the direction of I-5 and nearby rail activity. At the CID site, there was a modest relationship from the west and southwest at higher wind speeds, influenced by the I-5 corridor and the I-5/I-90 interchange. At the Duwamish and Central District sites, the CBPF plots showed little directional structure, indicating contributions from a broadly mixed urban air mass rather than a specific local source.

We observed slightly higher contributions on weekdays, reflecting increased commuter activity and overall traffic volume. Contributions also tended to increase during warmer days, likely due to enhanced photochemical processing that can produce additional secondary particles.

Heavy Fuels (Mix of Shipping Fuels, Heavy Oils, and Wood)

Factor 4 represents heavy fuels combustion, with a mix of shipping fuels, heavy oils, and wood, for the Lakewood, Duwamish, and Central District sites as shown in the factor profiles (**Appendix E, Figure E1**). This factor was characterized by particles primarily between 24 and 133 nm, with a peak in the 42–75 nm range. These size characteristics are consistent with emissions from heavy fuel combustion sources. Factor 4 also exhibited relatively high BrC/CO_2 ratios, indicating a possible contribution from biomass or other carbonaceous fuel burning.

As shown in the pie charts in **Figure 25**, heavy fuel combustion contributed substantially to $PM_{2.5}$ at the Lakewood, Duwamish, and Central District sites, accounting for 33%, 43%, and 27% of $PM_{2.5}$, respectively. At the CID site, this factor did not emerge as a distinct source in the PMF analysis, indicating that heavy fuels emission signatures were instead mixed into other factors, most likely the diesel-related factor (Factor 2).

The overall particle size and composition profile of Factor 4 closely resembled that of the oil combustion factor identified in previous analyses for the greater Seattle area, where such emissions were linked to residential heating and maritime activities. At the Duwamish site, the conditional bivariate probability function (CBPF) plot (**Appendix E, Figure E2**) showed a signal from the north at low wind speeds, which aligns with the direction of nearby industrial and port areas. This pattern suggests that Factor 4 at Duwamish likely reflects a mixture of heavy fuels combustion from port operations and industrial activities. At the Lakewood and Central District sites, the spatial patterns were less pronounced, indicating more contribution from wood combustion due to the cold weather.

Aged Background Emissions

Factor 5 represents aged background emissions from multiple sources at all four monitoring sites as shown in the factor profile (Appendix E, Figure E1). This factor was enriched in two particle size ranges: a smaller portion near 32 nm and a dominant portion above 56 nm, with the highest contributions occurring for particles larger than 100 nm. This size distribution indicates the presence of aged or secondary aerosols that have grown through coagulation or condensation. Factor 5 also displayed elevated BrC to CO2 ratios and contributed substantially to $PM_{2.5}$ mass, with a relatively high $PM_{2.5}$ to BC ratio, indicating influence from biomass combustion and aged particulate matter.

Comparison with factor profiles from previous studies suggests that Factor 5 represents a mixture of aged accumulation-mode particles from various sources. The particle size characteristics align with distributions typically associated with aged regional aerosols, which often show peaks near both 60 nm and 180 to 200 nm. These similarities indicate that this factor reflects a combination of aged traffic emissions, transported urban particles, and biomass-burning sources.

The CBPF plots (Appendix E, Figure E2) show spatial patterns consistent with these interpretations. At the Lakewood and CID sites, the strongest contributions were aligned with the I-5 corridor, reflecting dense traffic activity. In Duwamish, contributions were highest toward the Highway 99 corridor. At the Central District site, elevated contributions appeared toward both the downtown core and nearby residential neighborhoods, indicating influence from regional traffic as well as local biomass (or wood-related) burning activity. At both Duwamish and the Central District, the overlap of contributions with nearby residential areas further supports the role of household wood combustion.

Temporal patterns show that at the CID site, higher contributions coincided with days affected by moderate wildfire smoke, demonstrating sensitivity to regional biomass burning. In Lakewood, increased contributions occurred between May 10–11 and July 5–9, periods associated with warmer temperatures and potential influences from Independence Day fireworks. Elevated temperatures likely enhanced the aging of traffic emissions, while fireworks may have contributed to short-term increases in particulate matter.

Factor 5 includes contributions from aged road traffic particles, indicating that fresh transportation emissions can influence the formation and growth of accumulation-mode particles. Using Akaike Information Criterion (AIC) minimization, the maximum lag hours for Factor 3 (urban background) were estimated as 7 hours in Lakewood, 0 hours in the CID, 0 hours in Duwamish, and 4 hours in the Central District. No lag was applied for Factor 2 (diesel truck emissions). Results from the DLNM fitting and counterfactual analysis showed that Factor 3 contributed 51%, 4%, 21%, and 22% to accumulation-mode aerosols at the Lakewood, CID, Duwamish, and Central District sites, respectively, while Factor 2 contributed 14%, 23%, 2%, and 2%. The pie charts in **Figure 25** reflect these finalized contributions to accumulation-mode aerosols.

Wildfire/Outdoor Burning Emissions

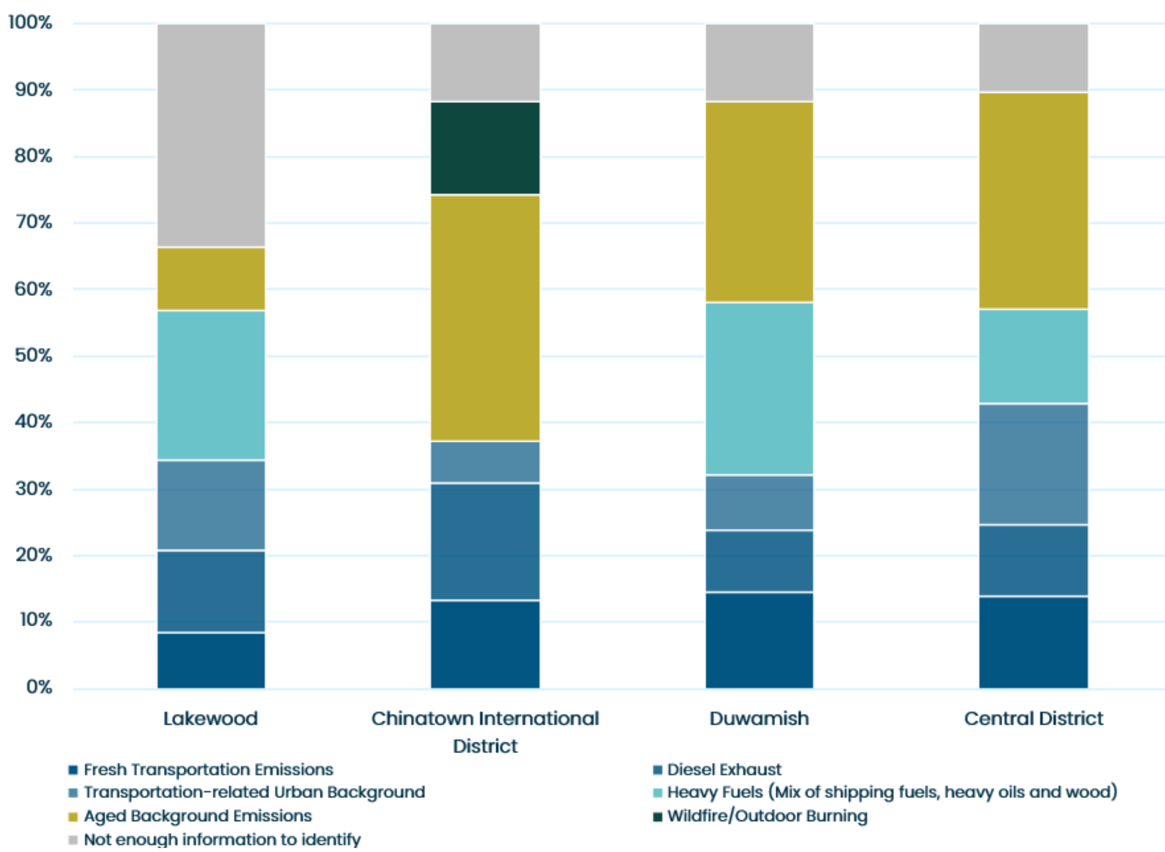
At the CID site, a distinct factor was identified and interpreted as wildfire and outdoor burning emissions. This factor displayed a bimodal particle size distribution characteristic of biomass-burning aerosols, and its contributions aligned closely with days affected by regional wildfire smoke (**Figure 25**). A comparable wildfire smoke factor was not observed at the other three monitoring locations.

As the CID sampling occurred during mid-summer, the most likely source is wildfire smoke transported into the area, with possible smaller contributions from outdoor burning or emissions from nearby restaurants. The particle size features and temporal correlation with wildfire smoke events support this interpretation.

Source Apportionment Summary

Source apportionment results showed that **transportation-related emissions**—including fresh transportation emissions, diesel exhaust, and transportation-related urban background emissions—were the **most consistent and substantial contributor** to $PM_{2.5}$ across all four neighborhoods (**Figure 26**). Transportation-related $PM_{2.5}$ accounted for **32-43%** of total fine particle mass, with the highest contributions observed in neighborhoods closest to major roadways. These same sources also strongly influenced ultrafine particle counts and background-subtracted CO_2 levels.

Figure 26. Sources and categories of air pollution from the four neighborhoods using PMF.



Heavy fuel combustion, a mix of shipping fuels, heavy oils, and wood, was found to be higher in Duwamish due possibly to seaport, outdoor burning, and industrial fuel use, and in Lakewood due to wood burning due to the cold weather season.

In addition to transportation, the analysis identified an aged background emissions factor, which captured a large share of the remaining $PM_{2.5}$. These categories represent mixtures of **aged and regionally transported emissions**, including transformed traffic pollution and potential contributions from biomass (wood-related) burning—that could not be distinctly separated into individual sources. Any remaining $PM_{2.5}$ not clearly assigned to a factor was classified as **"Not enough information to identify."** Biomass burning emissions were uniquely elevated in the Chinatown–International District, strongly influenced by summer wildfire smoke episodes and likely other outdoor burning.

Size-resolved particle data provided additional insight into these source categories. The smallest particles (10–13 nm) were associated with fresh transportation emissions from on-road vehicles and aircraft emissions, while diesel emissions were most prominent in the 24-32 nm range. Heavy fuel (a mix of shipping fuels, heavy oils and wood) emissions contributed mainly to mid-sized particles (around 42–56 nm), and wildfire/outdoor burning emissions as well as aged background emissions dominated particles larger than 100 nm, reflecting aged traffic emissions and biomass burning.

Transportation sources were the strongest drivers of particle number concentrations and background-subtracted CO_2, while BC, UVPM, and NO_2 levels reflected varying influences from local traffic, industrial activity, and combustion sources depending on location.

Overall, the four neighborhoods experienced contributions from several source types, but **transportation-related emissions remained the dominant and most widespread influence**. Differences across neighborhoods aligned with local conditions, including **freeway proximity in the CID, heavy fuel use in the Duwamish Valley**, and **combined regional and local residential influences in Lakewood and the Central District**. These findings highlight the need for coordinated strategies that reduce **transportation emissions**, mitigate **wildfire smoke impacts**, and address **heavy fuel use (shipping, wood, and heavy oils)** to lower community exposure over time.

Health Risk Assessment

While much of the engagement aspect of the TREE trailer and community monitoring focused on real-time short-term measurements, it is long-term exposures to air particle pollution that drives public health impacts. Hence, our health risk assessment focused on long-term exposure to $PM_{2.5}$, which drives the health risk. We used EPA's Co-benefits Risk Assessment (COBRA) Screening Model framework to assess risk, following the steps below.

1. **Annualization of $PM_{2.5}$ concentrations**: Average $PM_{2.5}$ concentrations measured during the monitoring period were converted to annual average concentrations. The conversion ratio was calculated as the statistically sampled ratio between the monitoring-period and annual $PM_{2.5}$ concentrations from nearby EPA regulatory stations (2015–2024).
2. **Estimation of health risks**: Health risks (mortality, incidence, hospitalizations) attributable to $PM_{2.5}$ were calculated using log-linear or logistic exposure-response functions:

$$\text{Log-linear: } \Delta Cases = \frac{y_{baseline}}{100000} \times population \times \left(1 - \frac{1}{\exp(\beta \cdot \Delta x)}\right)$$

$$\text{Logistic: } \Delta Cases = \frac{y_{baseline}}{100000} \times population \times \left(1 - \frac{1}{(1 - y_{baseline})\exp(\beta \cdot \Delta x) + y_{baseline}}\right)$$

where ΔCases is the attributable cases due to $PM_{2.5}$ exposure; $y_{baseline}$ is the baseline mortality, incidence, or hospitalization rate per 100,000; *population* is the population in the census tract where the trailer monitoring site was located; β is the coefficient in the exposure-response function; and Δx is the $PM_{2.5}$ exposure concentration. To allow comparison across sites, attributable risks were expressed per 100,000 population.

3. **Source-specific health risks**: The proportional population attributable fraction (PAF) approach was used to estimate health risks for $PM_{2.5}$ from individual sources:

$$\Delta Cases_k = \Delta Cases \times \frac{\Delta x_k}{\Delta x}$$

Where ΔCasesk is the $PM_{2.5}$-attributable cases due to the kth source; and Δxk is the $PM_{2.5}$ exposure concentration from the kth source. All spatial analyses and statistical analyses described in this section were performed with R statistical software.

Risk Analysis Results

Using the estimated annual $PM_{2.5}$ concentrations for each neighborhood, we applied exposure–response functions from the literature to estimate a range of potential health impacts (**Table 11**). The exposure response functions used in the study are in Appendix G. The values represent annual excess cases per year in each neighborhood, with 95% uncertainty intervals shown in parentheses.

Table 11. Median (95% uncertainty interval) of health risks attributable to annual average $PM_{2.5}$ exposures (per 100,000).

Outcome	Age	Lakewood	CID	Duwamish	Central District
All-cause mortality	18+	83.8 (54.8-157.7)	62.5 (40.9-110.3)	59.3 (19.8-79.3)	64.8 (40.4-115.2)
All-cause mortality	65+	181.6 (120.3-323.3)	147.2 (99.7-238.4)	137.6 (54.2-174.6)	148.4 (110.6-234.1)
Infant mortality	0	18.6 (0.0-58.0)	14.5 (0.0-41.9)	12.3 (0.0-33.7)	14.8 (0.0-42.2)
Emergency room visits, CVD	0+	10.0 (0.0-27.7)	10.5 (0.0-20.2)	8.0 (0.0-19.2)	9.3 (0.0-22.2)
Emergency room visits, Respiratory diseases	0+	12.4(0.1-32.7)	13.5 (0.1-28.4)	11.6 (0.0-21.6)	12.7 (0.1-31.8)
Hospitalization, CVD	65+	17.4 (9.4-32.2)	13.2 (8.4-22.8)	12.1 (4.6-16.0)	13.1 (8.5-23.7)
Hospitalization, Alzheimer'sdisease	65+	28.0 (19.7-37.6)	22.6 (17.3-28.5)	21.3 (10.2-25.7)	22.4(16.7-28.7)

Outcome	Age	Lakewood	CID	Duwamish	Central District
Hospitalization, Parkinson's disease	65+	11.8 (7.2-18.3)	11.2 (6.5-15.7)	10.0 (3.9-15.1)	10.9 (7.0-17.3)
Hospitalization, Respiratory disease	65+	1.4 (0.0-3.5)	1.4 (0.0-3.0)	1.1 (0.0-2.6)	1.4 (0.0-3.1)
Hospitalization, Respiratory disease	0~18	2.9 (1.5-6.8)	3.5 (1.6-7.0)	3.0 (1.0-5.6)	3.6 (1.7-6.1)
Nonfatal acute myocardial infarction	65+	2.4 (1.3-4.6)	2.0 (1.0-3.3)	1.7 (0.5-2.5)	1.9 (1.2-3.1)
Incidence, stroke	65+	11.4 (2.9-26.2)	11.6 (2.5-23.6)	9.9 (2.4-17.4)	11.5 (2.5-23.7)
Incidence, out of hospital cardiac arrest (High)	0+	3.0 (0.0-7.9)	2.9 (0.0-7.1)	2.2 (0.0-5.5)	2.9 (0.0-7.1)
Incidence, out of hospital cardiac arrest (Low)	0+	0.9 (0.0-9.5)	0.9 (0.0-0.8)	0.6 (0.0-6.7)	0.9 (0.0-7.0)
Incidence, out of hospital cardiac arrest	18+	6.7 (2.1-15.4)	6.3 (2.5-12.7)	4.8 (1.5-10.6)	6.4 (2.6-12.7)
Incidence, lung cancer	30+	22.2 (6.0-43.8)	22.6 (7.5-39.6)	19.5 (5.4-33.2)	22.3 (7.5-41.0)
Incidence, Hay fever/Rhinitis	3~17	2719 (837.9-5879.7)	2462.4 (736.2-4858.1)	2243.5 (431.5-4426.7)	2630.3 (833.8-4738.2)
Incidence, Asthma	0~17	612.6 (423.1-988.3)	610.1 (438.6-867.4)	567.5 (240.0-698.2)	587.8 (484.1-882.4)
Asthma symptoms: Albuterol use	6~17	0.7 (0.0-2.3)	0.7(0.0-2.3)	0.5 (0.0-1.5)	0.7 (0.0-2.2)
Minor restricted activity days	18~64	41317.1 (25044.6-71337.2)	40370.1 (25772.5-63458.6)	36298.1 (14468.7-47253.9)	39648.1 (28616.0-63230.7)
Work loss days	18~64	7025.8 (4584.6-12691.3)	6680.8 (4653.5-10891.6)	6251.1 (2443.5-7955.0)	6650.9(4946.2-11161.5)

Overall, the four areas have similar values. Of the study areas, Lakewood showed the highest $PM_{2.5}$-attributable all-cause mortality rates for adults (83.8 (54.8–157.7) per 100,000) and highest older adult mortality rate (181.6 (120.3–323.3) per 100,000). It had a slightly higher annual average concentration, Pierce County had a higher baseline mortality, and older adults account for a higher percentage of the population.

Results Workshops and Polls

In early 2026 we plan to return to each community serviced during the TREE project with monitoring results and key findings. During the workshops, we will seek feedback on how communities plan to use the shared information such as informing local environmental priorities, identifying locations for further monitoring, and supporting conversations within the community to raise awareness. We will also gather reflections on their overall experience with the project, including what worked well, what could have been improved, and how they would like to be engaged in future efforts. This input will help shape the final phase of the report and guide recommendations for continued collaboration and future engagement efforts conducted by the Agency.

Details of results workshops to be conducted

This is a placeholder for the section on the results workshops.

Conclusions

Overall conclusions

This study applied an integrated approach that combined trailer monitoring with source apportionment to quantify contributions from major pollution sources and evaluate associated health risks across four overburdened Puget Sound communities: Lakewood, the Chinatown–International District (CID), the Duwamish Valley, and the Central District. Five key source categories were identified—fresh transportation emissions, diesel exhaust, transportation-related urban background, heavy fuels, and aged background emissions, influenced by both aged traffic emissions and wood combustion.

Attributable transportation-related sources contributed roughly one-third of $PM_{2.5}$ and dominated particle number concentrations, whereas heavy fuel and wildfire smoke were more strongly associated with larger particles. Health risk assessments indicated that $PM_{2.5}$ exposure continues to impose a meaningful health burden, with the highest risks occurring in communities experiencing elevated $PM_{2.5}$ levels, higher baseline disease rates, or older populations. Our region has higher proportions of lower income and persons of color adjacent to major roadways, reinforcing the importance of targeted pollution reduction and health-equity interventions. These findings emphasize the need for targeted strategies to reduce emissions from both transportation and combustion-related sources to improve air quality and public health in disproportionately impacted communities.

In addition to the technical monitoring, the study's community-led data collection—particularly the youth walking tours and handheld sensor measurements—played an important role in increasing local understanding and awareness of air-quality issues. These activities allowed residents to directly observe how pollution varies block by block, how weather and localized sources influence concentrations, and how neighborhood-specific conditions shape exposure. The community monitoring efforts strengthened environmental health literacy, built capacity for future local assessment work, and provided lived-experience context that complemented the trailer-based measurements and source-apportionment analyses. Together, these components demonstrate the value of integrating community-engaged monitoring with technical approaches to support more equitable and actionable air-quality decision-making.

Lessons learned

Monitoring period and temporal coverage

a. Short-term monitoring at each site (three months) does not capture seasonal variability, potentially biasing estimates of annual average exposure and source contributions.

b. Non-overlapping monitoring periods between sites limit direct comparisons.

Power supply and infrastructure

a. Finding an appropriate power connection was a recurring challenge during trailer deployments. In some locations, power availability was sufficient, but others experienced outages due to storms or temporary circuit overloads.

b. Reliable and consistent power access is critical for maintaining uninterrupted sampling and data integrity in future deployments.

Site security

a. Security of the monitoring trailer emerged as a key operational concern. At one location, temporary fencing was installed, but two break-in attempts within a week forced an early end to sampling.

b. Future deployments should prioritize site selection with secure access and implement robust protective measures such as enhanced fencing, lighting, and camera surveillance.

Instrument operation and data quality

a. Limited operational experience with the NanoScan instrument led to delays in troubleshooting diagnostic errors and resulted in some invalidated data.

b. Standard operating procedures (SOPs) for maintenance and error resolution should be strengthened, and additional hands-on training provided before deployment to ensure consistent data quality.

Source apportionment approach:

a. Reliance on particle size distributions of ultrafine particles (UFPs) was a substantial limitation to reflect $PM_{2.5}$ mass contributions – some portions were unresolved.

b. Incorporating $PM_{2.5}$ speciation or other additional parameters (e.g., metals, polycyclic aromatic hydrocarbons) could improve the results of source apportionment.

Health risk assessment scope:

a. The assessment does not focus on potential cancer risk, which was not modeled in this study.

b. Additional epidemiological studies are needed for size-resolved particles and multi-pollutant exposures to better understand source-specific health impacts.

Public Outreach

a. Community engagement was central to project success, but expanded outreach tools, multilingual materials, and ongoing communication strategies could further strengthen participation and ensure long-term community access to results.

Despite these challenges, the study successfully demonstrated a robust, community-centered approach to air quality monitoring. The results highlight the dominant influence of transportation and heavy fuels combustion sources on $PM_{2.5}$ exposure and health risks in overburdened communities. Importantly, this work expanded community-led monitoring in the region.

Appendices

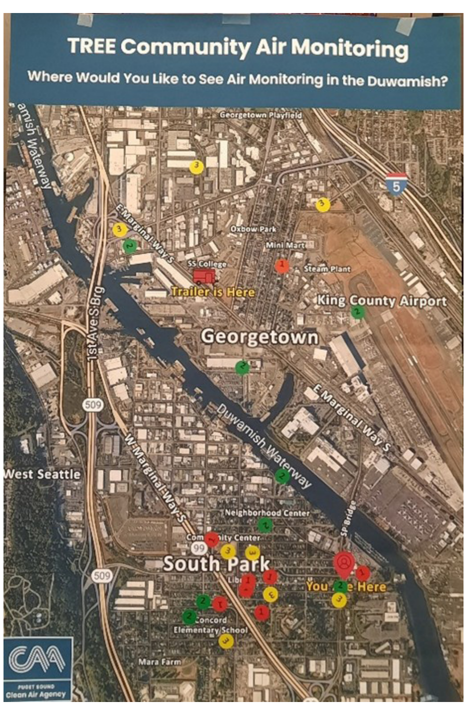
Appendix A. Listening Session Notes and Maps

Areas of Interest

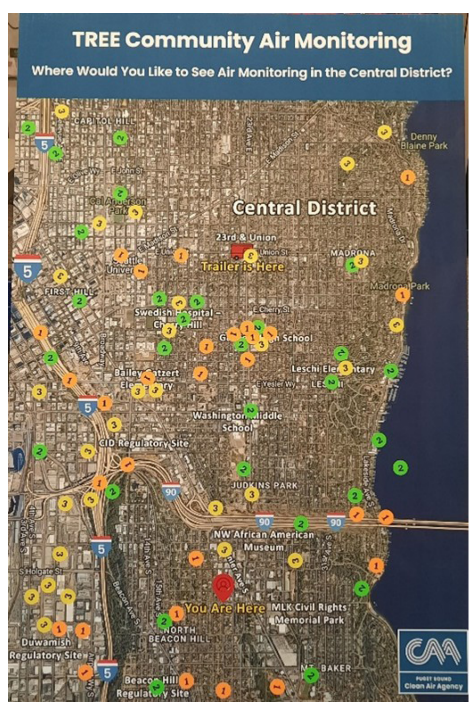
Figure A1. Maps from listening sessions where participants marked their areas of interest for (a) Lakewood, (b) Chinatown International District, (c) Duwamish, and (d) Central District.

(a) Lakewood

(b) Chinatown International District



(c) Duwamish



(d) Central District

Appendix B. Community-monitoring Reports From Youth Groups

After the youth groups completed their community-led monitoring, they presented reports describing their experiences, which are copied below.

Wa-Ya Outdoor Institute
Lakewood monitoring with PSCAA

What went well:

- Scheduling
  - Have an agenda for all of the locations before the monitoring starts.
  - Setting 4-hour days over the span of 5 weeks. We monitored multiple locations with a snack break in a single session.
- Transportation for all the students.
- Having a binder with everyone invoice
- "Opening circle"
  - A space where we can all get to know each other
  - Go over the plan for that session
- Engagement

What could have been better:

- Having an attendance sheet in my invoice binder with the dates and names of the attendees
- We struggled with keeping the kids in a tight group; some walked fast. Others walked slowly. It was easy for our group to get spread out. I would recommend having a leader in the front and a leader in back.
- We could have established a way to get everyone's attention immediately if we needed to ("1 2 3 eyes on me" or the clapping method)
- More engagement! Kids have a shorter attention span, the more engagement, the better.

DVYC x TREE Cohort

A partnership between PSCAA and DRCC

DRCC
7400 3rd Ave S.
Seattle, WA 98108

TREE: Trailer for Researching Environmental Equity

PSCAA: Puget Sound Clean Air Agency

DVYC: Duwamish Valley Youth Corps

DRCC: Duwamish River Community Coalition

Report for Duwamish Valley Air Monitoring

September - November, 2024

On Thursday September 12th, 2024, the Duwamish Valley Youth Corps began their fall program with orientation at the South Park Neighborhood Center and 49 students in attendance. Of these 49 youth, 10 were selected to participate in what was known as the "TREE Cohort". Youth in this group ranged in age from 14-17. This group met twice a week for the following 11 weeks, on Thursdays and Saturdays. Thursday sessions were shorter and had a classroom setting, while Saturday sessions were longer and featured more hands-on activities and walking tours.

Several partners collaborated on the educational materials and workshops planned for the TREE Cohort and included: the Just Health Action Watershed Model, Seattle Public Utilities South Park Water Quality Facility planning in partnership with Mithun Landscape Architects, and Puget Sound Clean Air Agency's TREE trailer & mobile air monitoring. Due to the collaborative nature of the fall cohort's partnerships and the limited number of dates for engagement, the schedule was busy with activities, field trips and walking tours. The weather was also a significant factor in determining some days in which the youth were unable to take air quality samples.

Over the course of the 11 week program, several folks from the PSCAA team came to South Park to educate and work with the TREE Cohort, presenting slide shows to cover a range of topics related to air quality and facilitating walking tours to gather air quality information. DRCC staff assisted in the facilitation and discussion of these topics, as well as driving vans to transport youth to and from air monitoring sites. Youth had access to a range of advanced handheld air monitoring equipment, and were also given a private tour of the TREE trailer in Georgetown. The majority of air quality walking tours took place in the industrial South Park area.

Unfortunately, on October 30th the TREE trailer was broken into and vandalized in its original location and had to be moved, interrupting air monitoring efforts in the Duwamish Valley for approximately one month.

Attendance was consistent throughout the program, and each youth worked for a total of 15 hours on the TREE project. At the end of the fall program, on Saturday November 23rd, the TREE Cohort presented at the annual DVYC Environmental Justice Youth Forum. Over 150 community members joined us for the event, and attendees learned from our youth about the air monitoring efforts that they had conducted in partnership with PSCAA, how to make a difference in the air quality in their lives, and how to protect themselves and their community when the air quality is low.

Overall the program was successful. Youth learned about the importance of air monitoring in their community, and how such information is gathered and used towards environmental justice efforts. We are grateful for the opportunity to work with PSCAA to empower and educate our youth to advocate for equitable air quality standards across our city.

DUWAMISH RIVER COMMUNITY COALITION

PUGET SOUND Clean Air Agency

DUWAMISH VALLEY YOUTH CORPS DVYC

Appendix C. Surface Maps Using Community Monitoring DataMaps

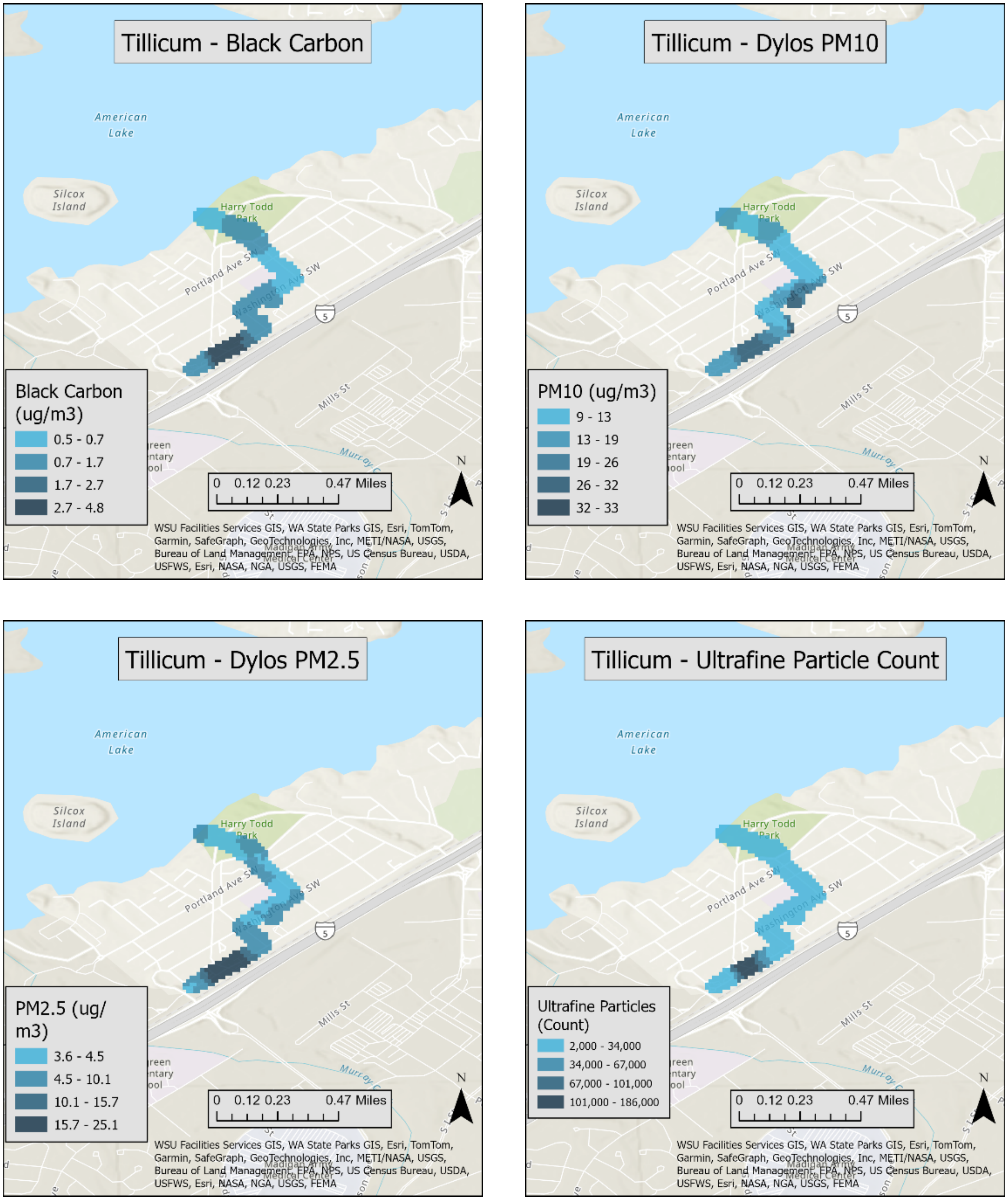
Data collected during the community monitoring walks were compiled and analyzed to produce neighborhood-scale pollutant surface maps. Using a geostatistical interpolation method (kriging), we developed continuous surfaces for black carbon (BC), $PM_{2.5}$, PM_{10}, and ultrafine particle number concentrations using a 50 meter buffer. These maps highlight how pollution varied across each neighborhood and help illustrate where concentrations tended to be higher; often near major roadways, freight corridors, and other local sources.

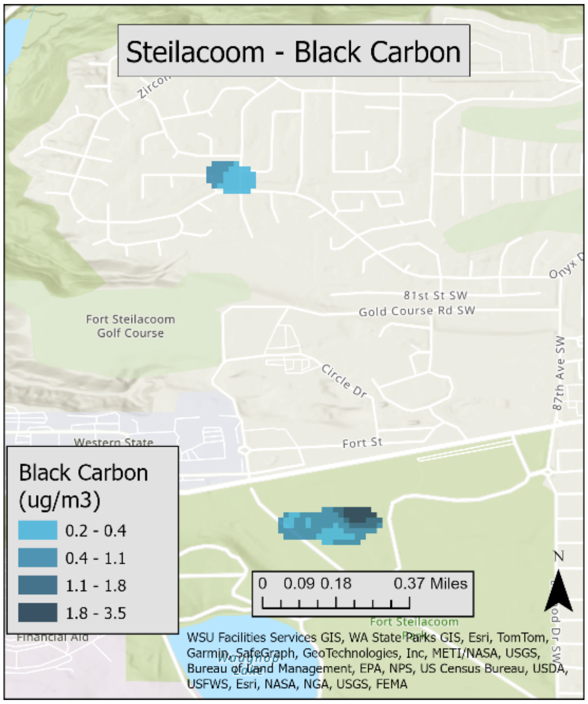
Several constraints are important when interpreting these maps. In many cases, areas were sampled only once; under different weather conditions, seasons, and times of day; and without repeated measurements or diurnal adjustments. Wind, temperature, and atmospheric stability during each walk strongly influence local pollution levels, and some routes had limited measurement points. As a result, the surface maps should be viewed as **illustrative patterns**, not precise or comprehensive representations of average pollution conditions.

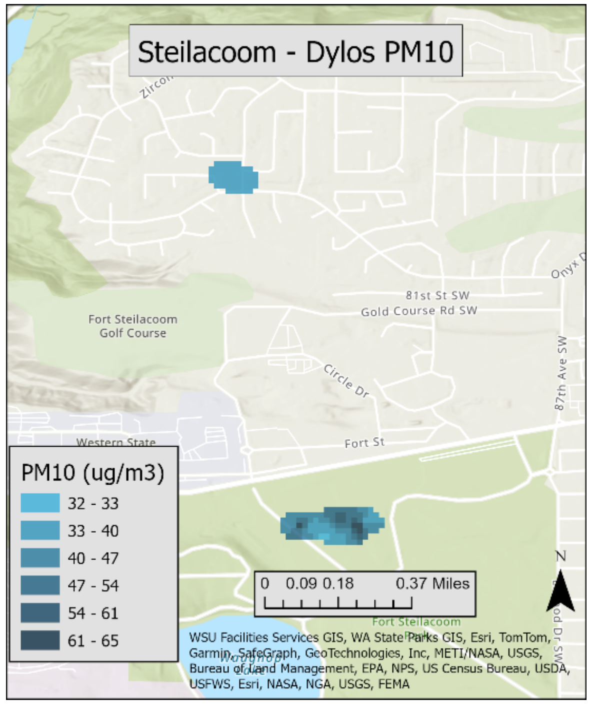
Despite these limitations, the maps were a valuable hands-on tool for youth and community partners. They provided a clear visualization of how air pollution can vary block-by-block and generally showed higher readings near major roads and industrial activity, with lower readings in interior residential areas and parks. These insights supported community learning and helped build understanding of how local sources and meteorology shape neighborhood air quality.

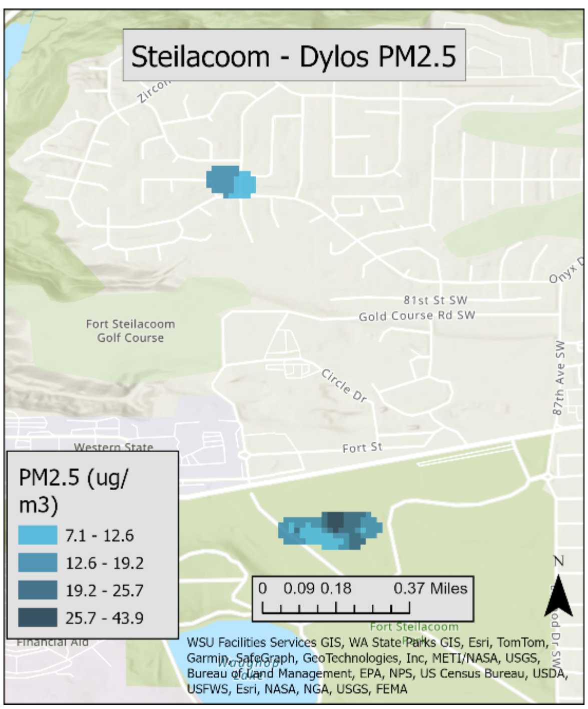
The surface maps for each pollutant and each neighborhood are shown below for reference.

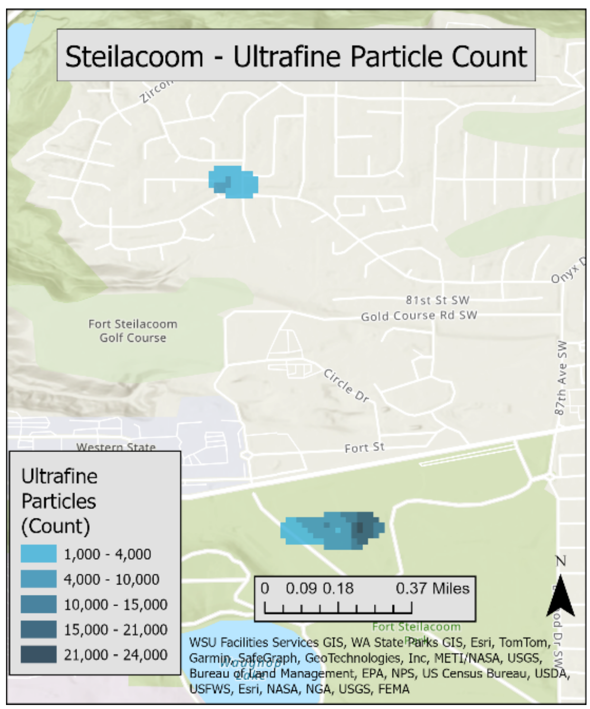
Figure C1. Lakewood surface maps for black carbon, PM_{10}, $PM_{2.5}$, and ultrafine particle number concentrations. Note: The Lakewood community monitoring data are split into three maps – Tillicum, Steilacoom, and Lakewood – due to their large geographic coverage..

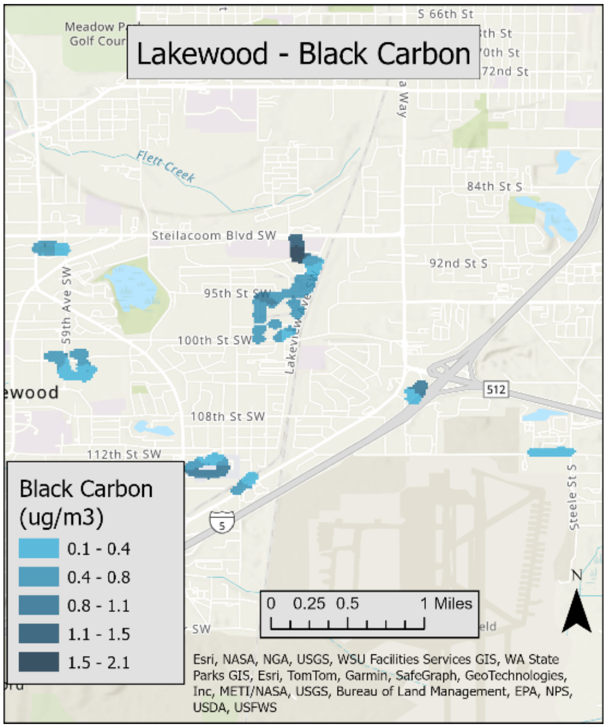


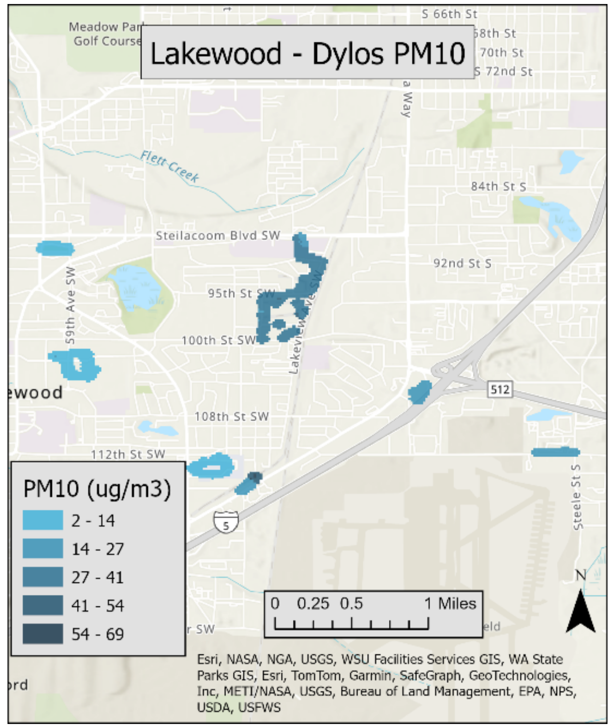

Steilacoom - Black Carbon
Fort Steilacoom Golf Course
81st St SW
Gold Course Rd SW
Circle Dr
Fort St
87th Ave SW
Black Carbon (ug/m3)
0.2 - 0.4
0.4 - 1.1
1.1 - 1.8
1.8 - 3.5
0 0.09 0.18 0.37 Miles
N
WSU Facilities Services GIS, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA, USFWS, Esri, NASA, NGA, USGS, FEMA

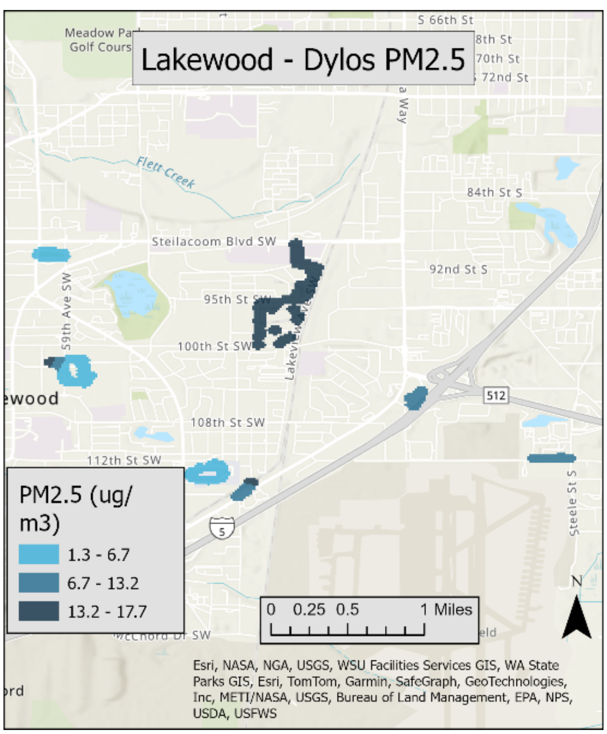

Steilacoom - Dylos PM10
Fort Steilacoom Golf Course
81st St SW
Gold Course Rd SW
Circle Dr
Fort St
87th Ave SW
PM10 (ug/m3)
32 - 33
33 - 40
40 - 47
47 - 54
54 - 61
61 - 65
0 0.09 0.18 0.37 Miles
N
WSU Facilities Services GIS, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA, USFWS, Esri, NASA, NGA, USGS, FEMA


Steilacoom - Dylos PM2.5
Fort Steilacoom Golf Course
81st St SW
Gold Course Rd SW
Circle Dr
Fort St
87th Ave SW
PM2.5 (ug/m3)
7.1 - 12.6
12.6 - 19.2
19.2 - 25.7
25.7 - 43.9
0 0.09 0.18 0.37 Miles
N
WSU Facilities Services GIS, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA, USFWS, Esri, NASA, NGA, USGS, FEMA


Steilacoom - Ultrafine Particle Count
Fort Steilacoom Golf Course
81st St SW
Gold Course Rd SW
Circle Dr
Fort St
87th Ave SW
Ultrafine Particles (Count)
1,000 - 4,000
4,000 - 10,000
10,000 - 15,000
15,000 - 21,000
21,000 - 24,000
0 0.09 0.18 0.37 Miles
N
WSU Facilities Services GIS, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA, USFWS, Esri, NASA, NGA, USGS, FEMA


Lakewood - Black Carbon
Black Carbon (ug/m3)
0.1 - 0.4
0.4 - 0.8
0.8 - 1.1
1.1 - 1.5
1.5 - 2.1
0 0.25 0.5 1 Miles
N
Steilacoom Blvd SW
95th St SW
100th St SW
108th St SW
112th St SW
59th Ave SW
84th St S
92nd St S
S 66th St
Flett Creek
512
5
Esri, NASA, NGA, USGS, WSU Facilities Services GIS, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS


Lakewood - Dylos PM10
PM10 (ug/m3)
2 - 14
14 - 27
27 - 41
41 - 54
54 - 69
0 0.25 0.5 1 Miles
N
Steilacoom Blvd SW
95th St SW
100th St SW
108th St SW
112th St SW
59th Ave SW
84th St S
92nd St S
S 66th St
Flett Creek
512
5
Esri, NASA, NGA, USGS, WSU Facilities Services GIS, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS


Lakewood - Dylos PM2.5
PM2.5 (ug/m3)
1.3 - 6.7
6.7 - 13.2
13.2 - 17.7
0 0.25 0.5 1 Miles
N
Steilacoom Blvd SW
95th St SW
100th St SW
108th St SW
112th St SW
59th Ave SW
84th St S
92nd St S
S 66th St
Flett Creek
512
5
Esri, NASA, NGA, USGS, WSU Facilities Services GIS, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

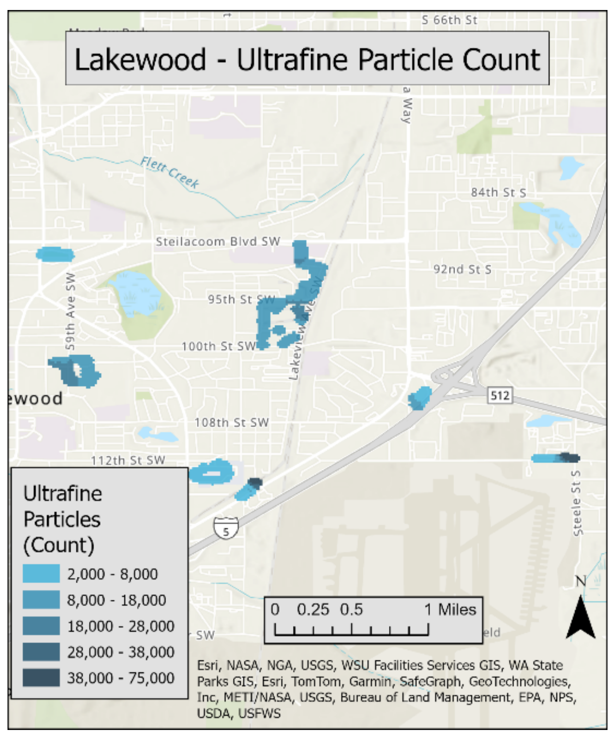

Lakewood - Ultrafine Particle Count
Ultrafine Particles (Count)
2,000 - 8,000
8,000 - 18,000
18,000 - 28,000
28,000 - 38,000
38,000 - 75,000
0 0.25 0.5 1 Miles
N
Steilacoom Blvd SW
95th St SW
100th St SW
108th St SW
112th St SW
59th Ave SW
84th St S
92nd St S
S 66th St
Flett Creek
512
5
Esri, NASA, NGA, USGS, WSU Facilities Services GIS, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

Figure C2. CID surface maps for black carbon, PM_{10}, $PM_{2.5}$, and ultrafine particle number concentrations..

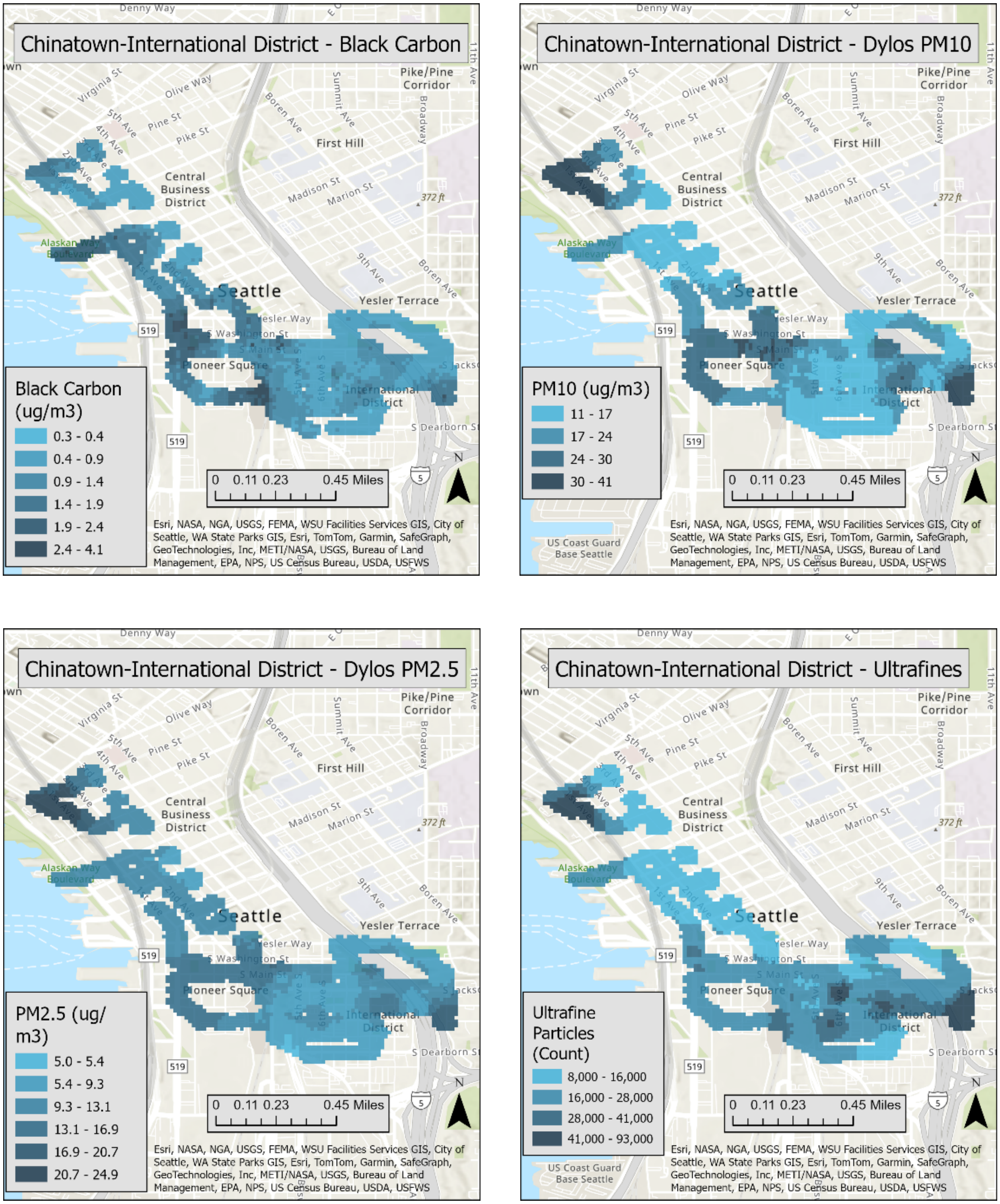


Figure C3. Duwamish surface maps for black carbon, PM_{10}, $PM_{2.5}$, and ultrafine particle number concentrations.

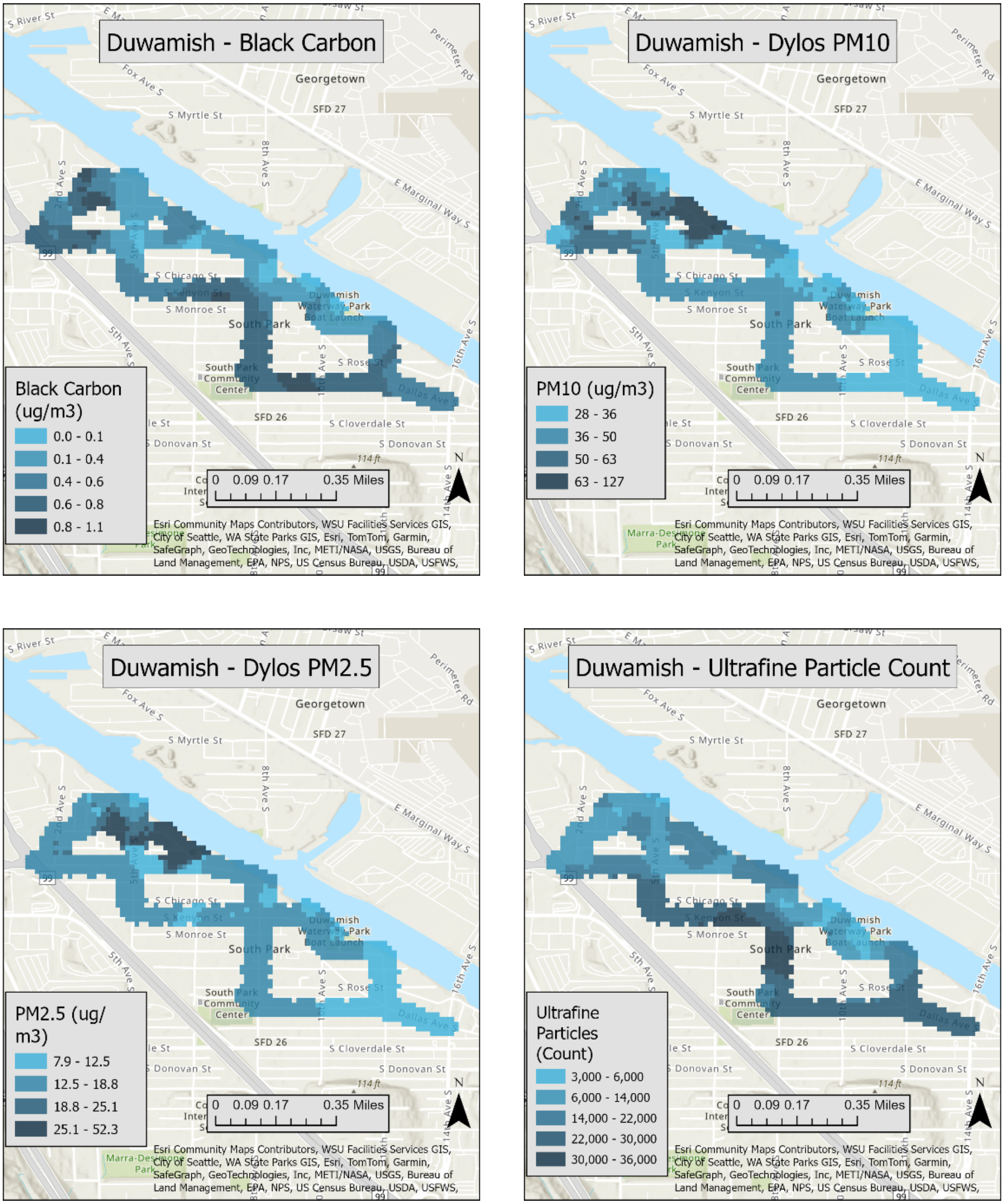
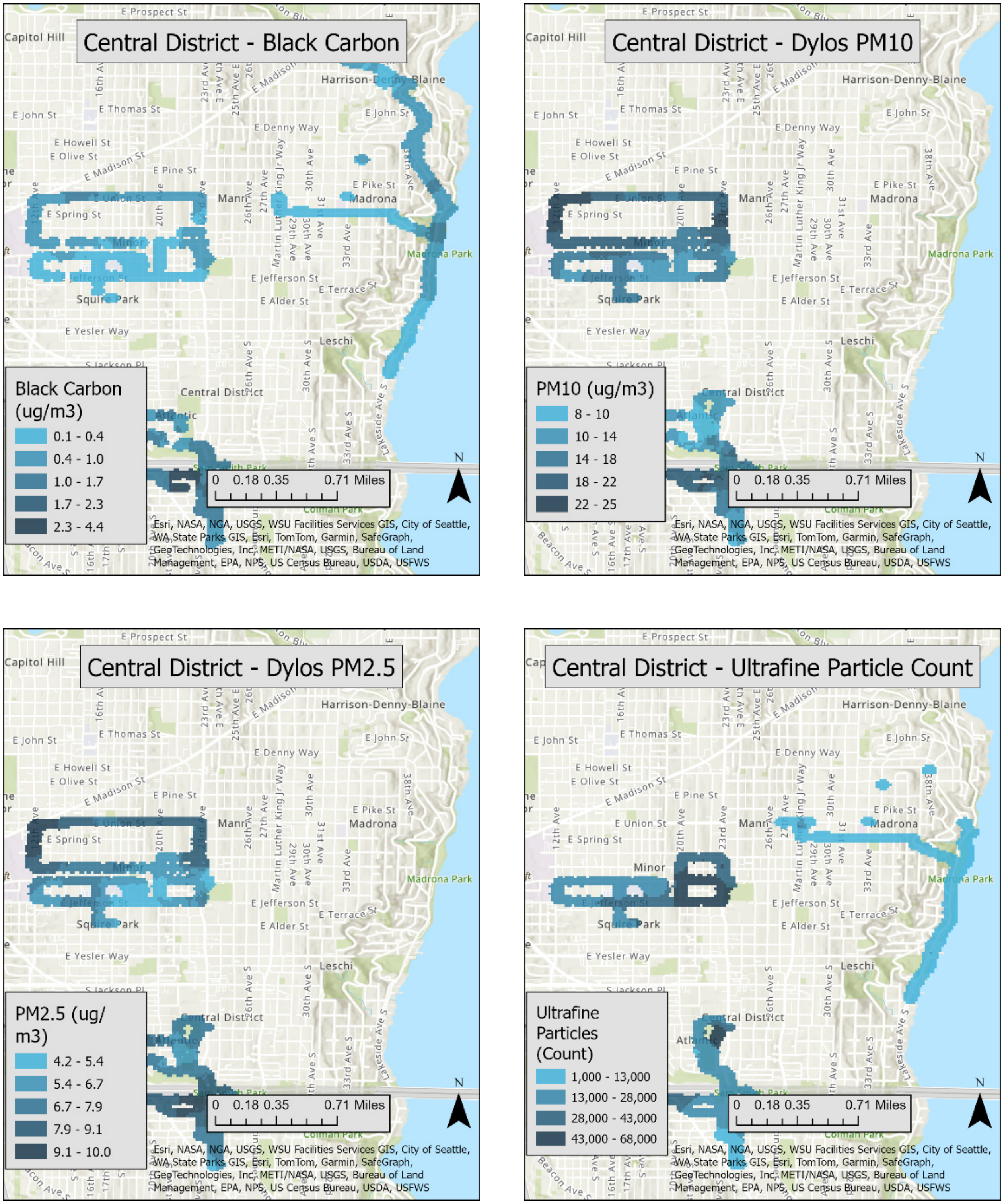


Figure C4. Central District surface maps for black carbon, PM1$_{0}$, PM$_{2.5}$, and ultrafine particle number concentrations.



Appendix D. Ultrafine Measurements Using the TREE Trailer

Ultrafine Particle Size Distribution Plots

Figure D1. Ultrafine particle size distribution (dN/dlogDp) and hourly averaged geometric means (black dots) are on the top plot, and total concentration (#/cm3) is on the bottom plot. Data presented here were collected with a TSI NanoScan at the Lakewood site.

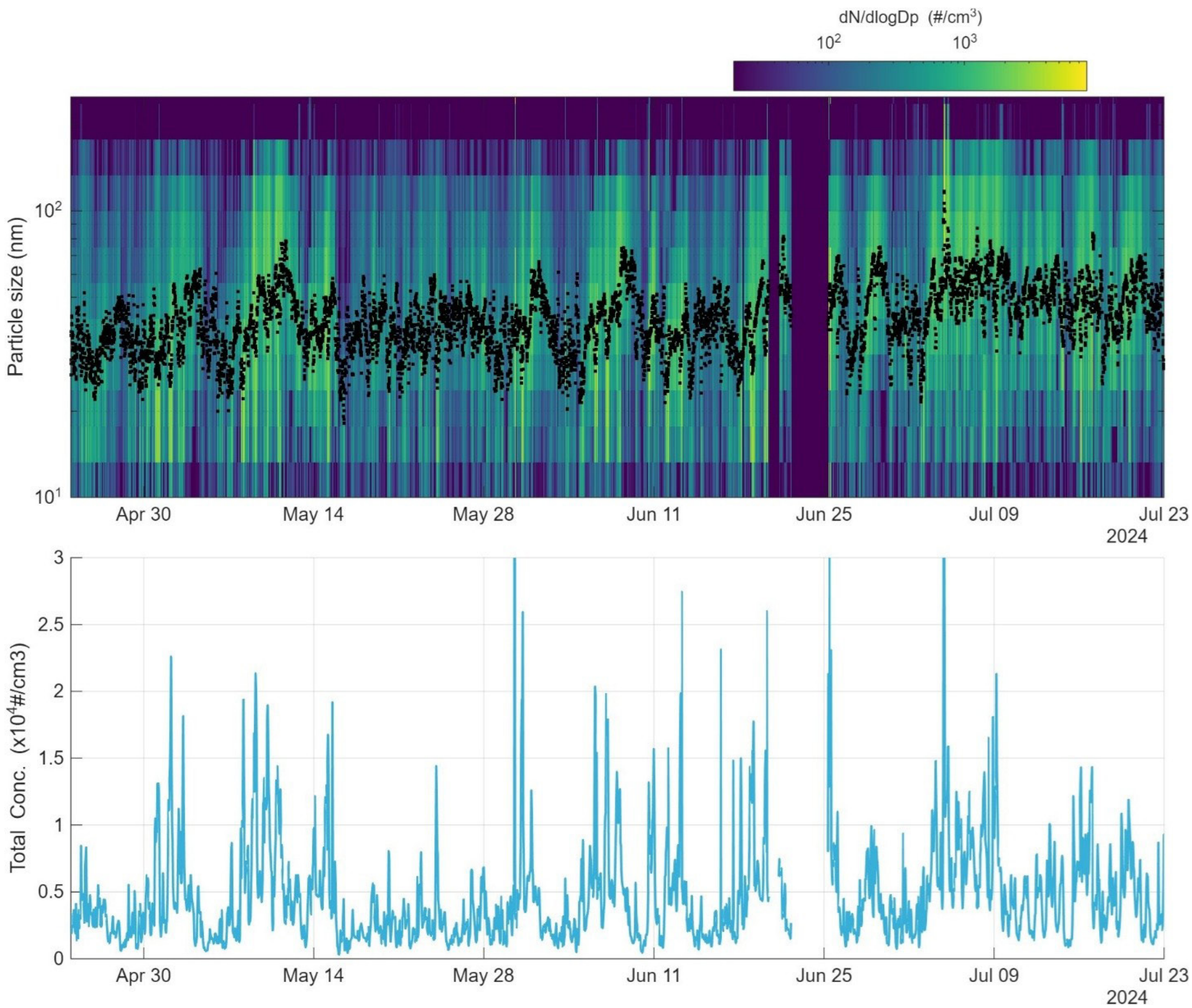


Figure D2. Ultrafine particle size distribution (dN/dlogDp) and hourly averaged geometric means (black dots) are on the top plot, and total concentration (#/cm3) is on the bottom plot. Data presented here were collected with a TSI SMPS at the Chinatown International District station.

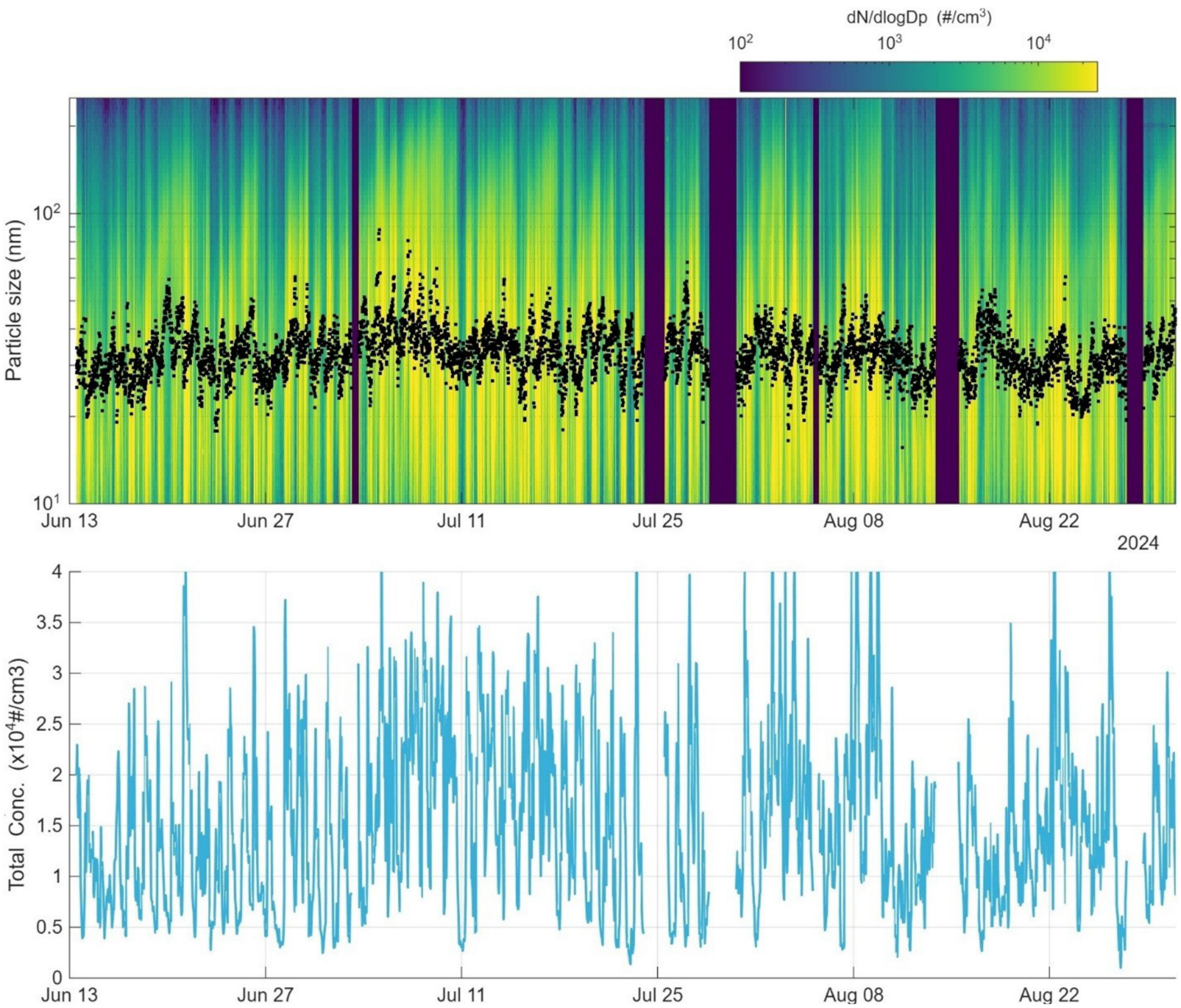


Figure D3. Ultrafine particle size distribution (dN/dlogDp) and hourly averaged geometric means (black dots) are on the top plot, and total concentration (#/cm3) is on the bottom plot. Data presented here were collected with a TSI NanoScan at the South Seattle College - Georgetown site.

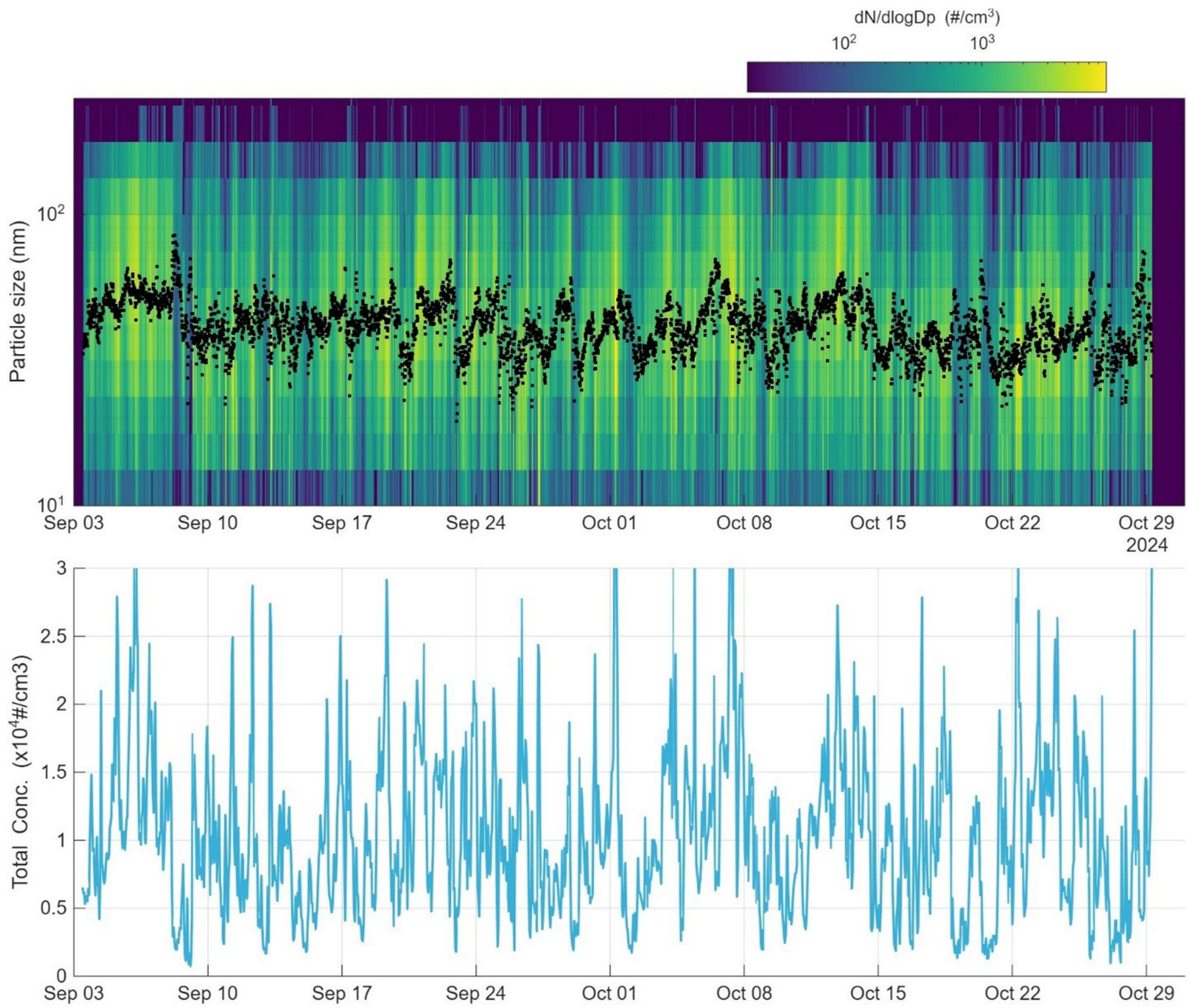
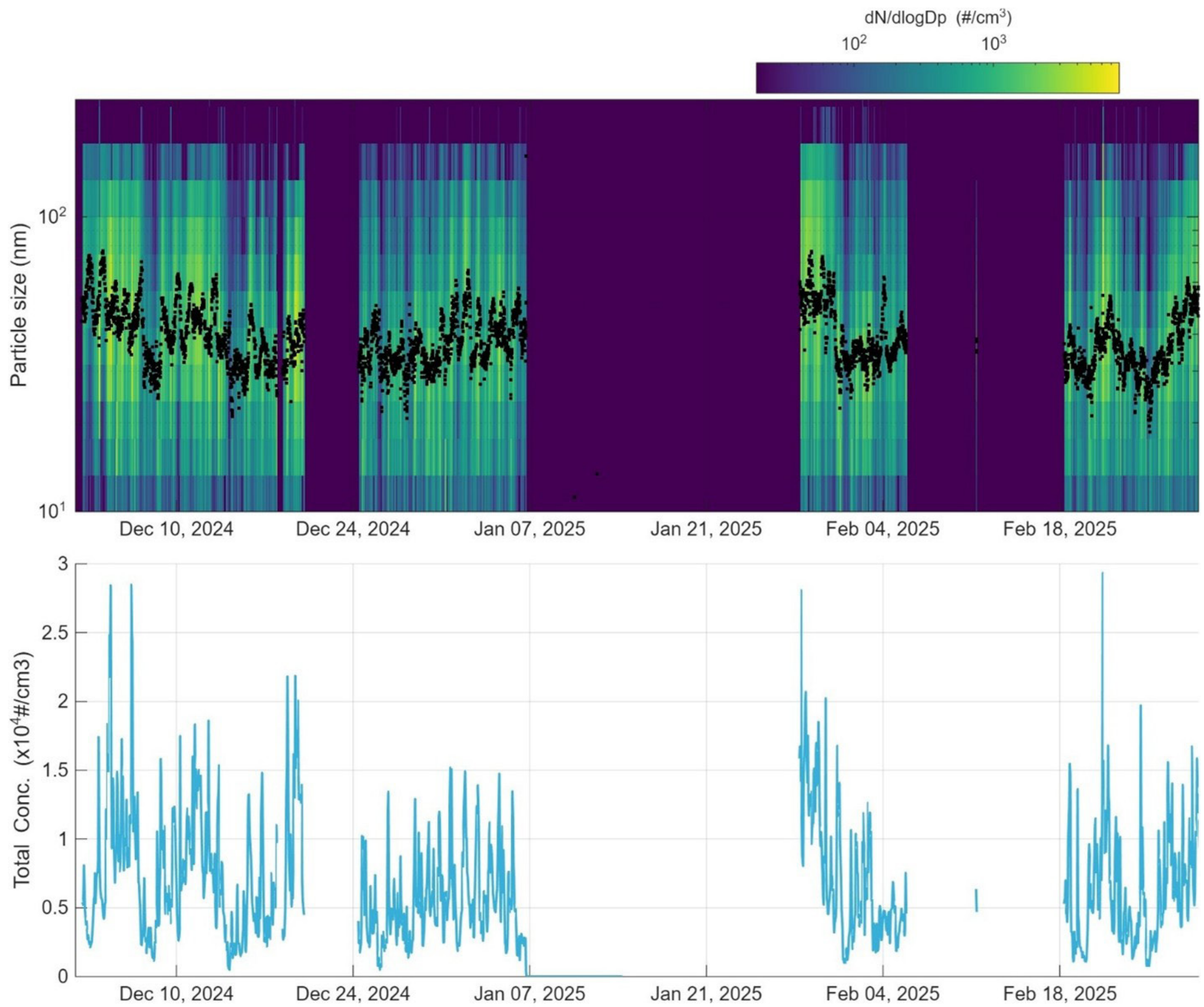


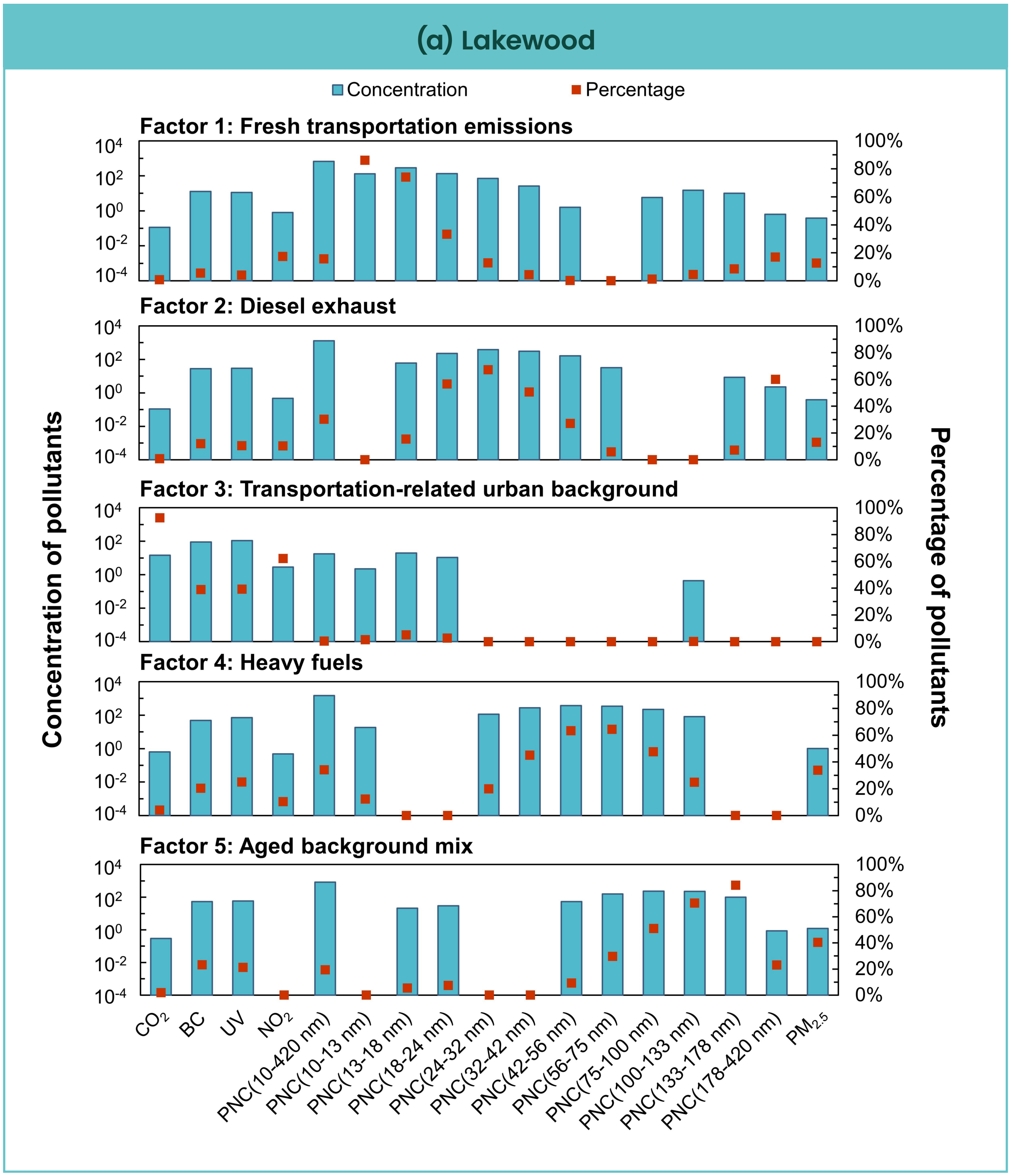
Figure D4. Ultrafine particle size distribution (dN/dlogDp) and hourly averaged geometric means (black dots) are on the top plot, and total concentration (#/cm3) is on the bottom plot. Data presented here were collected with a TSI NanoScan at the Central District site. Dark blue indicates dates when the NanoScan was taken out of the site for fixing as it was not operating properly.



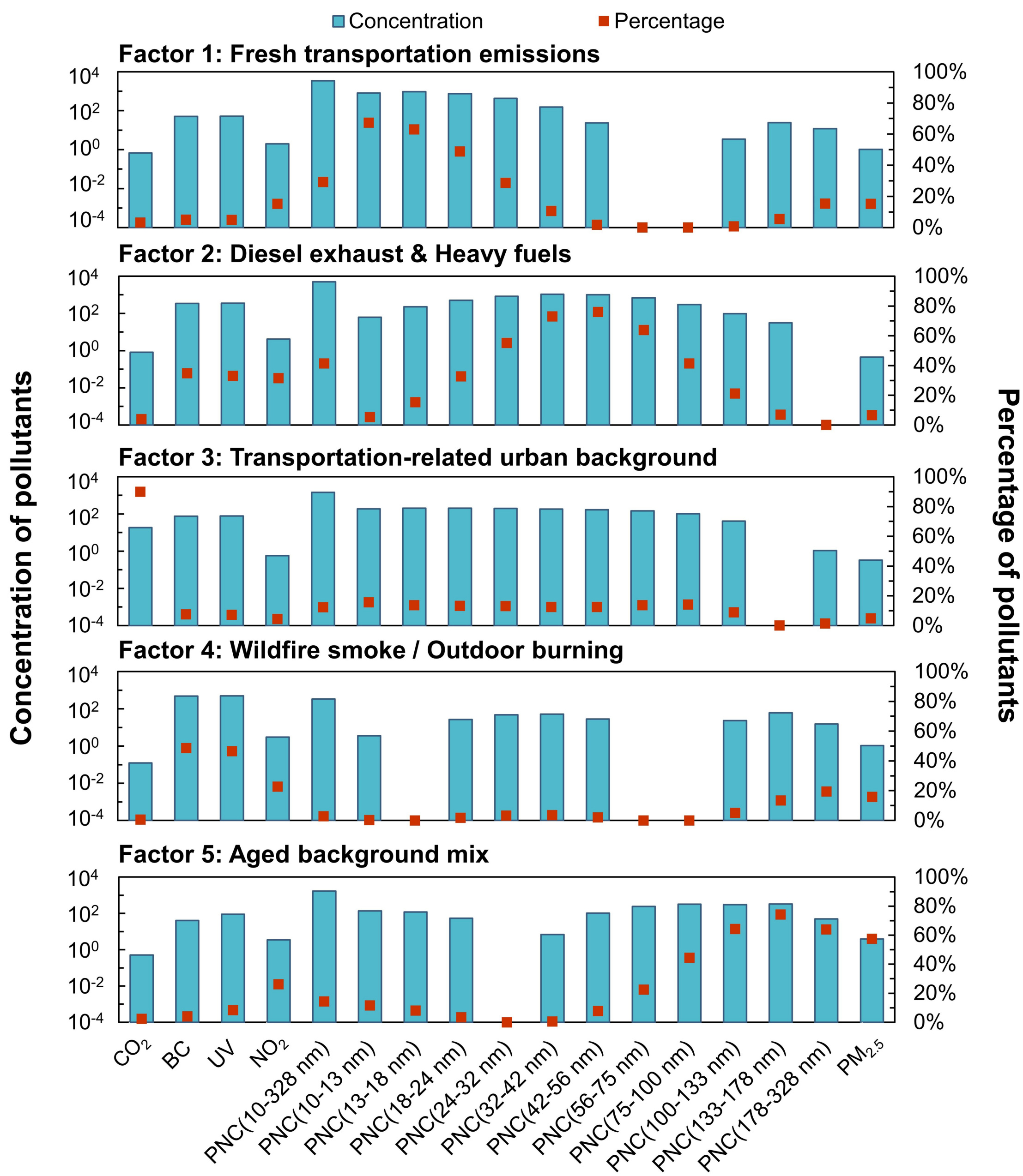
Appendix E. Source Apportionment

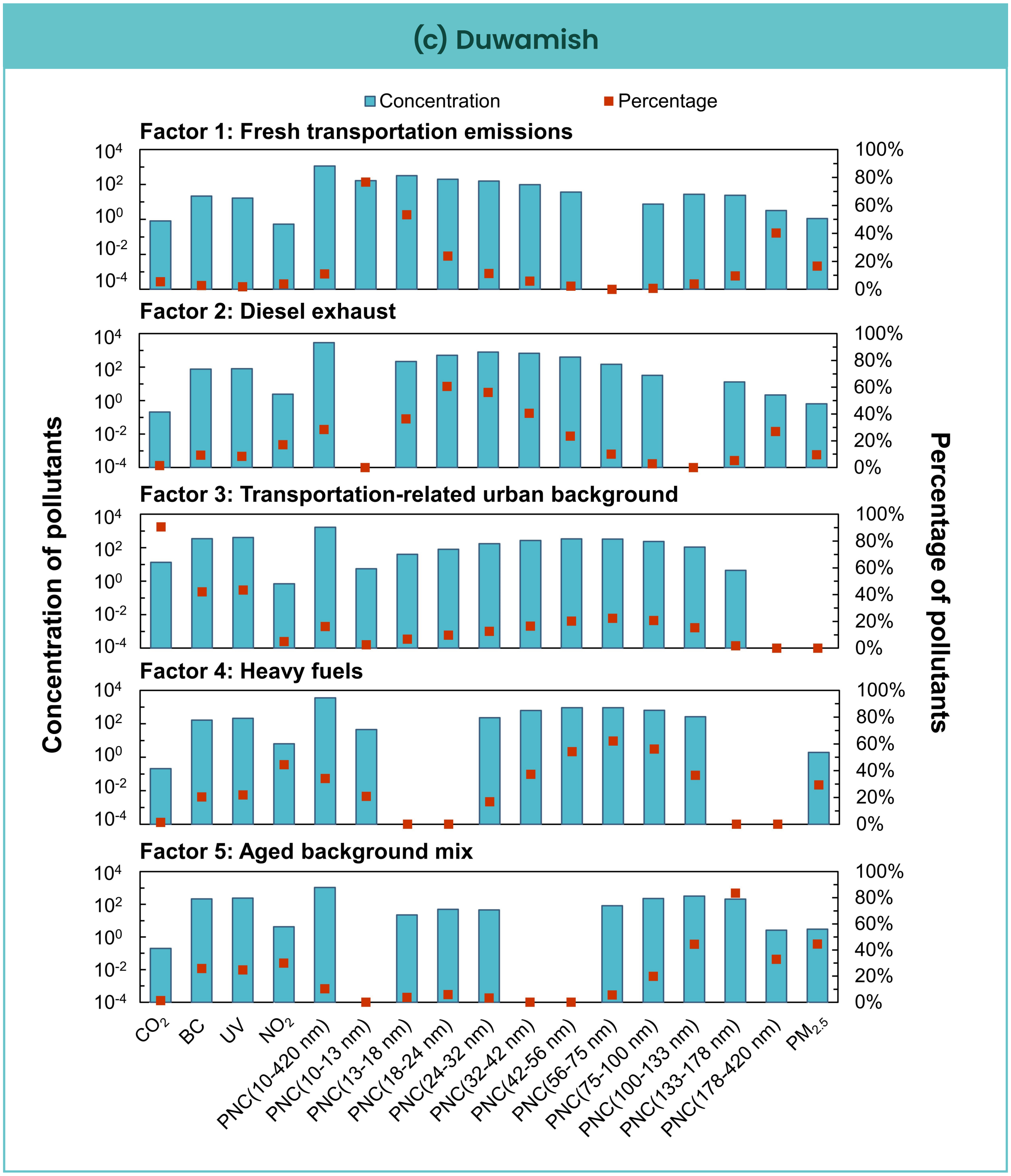
Factor Profiles

Figure E1. The factor profiles of PMF analysis at the (a) Lakewood, (b) Chinatown International District, (c) Duwamish, and (d) Central District sites.



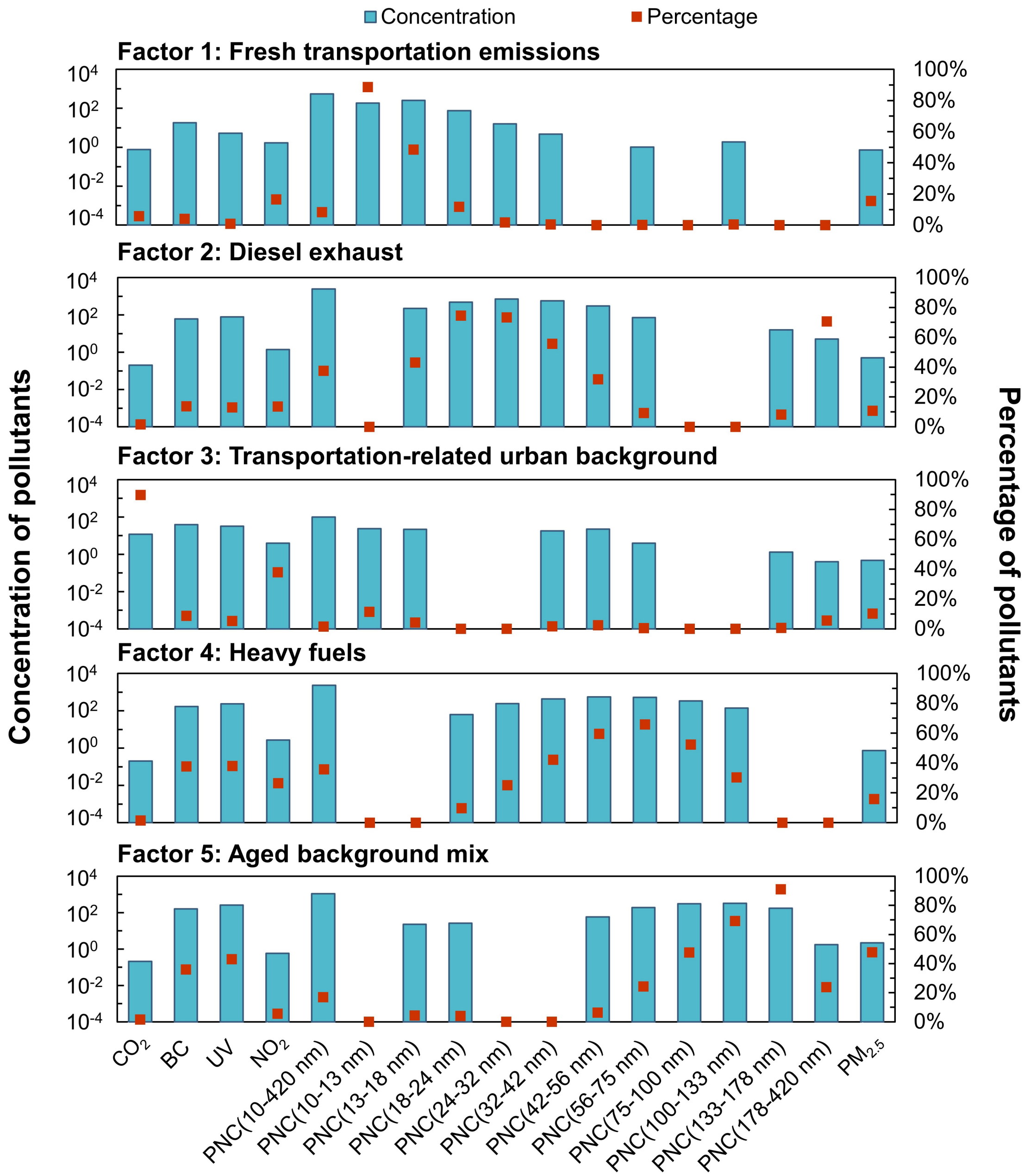
(b) Chinatown International District





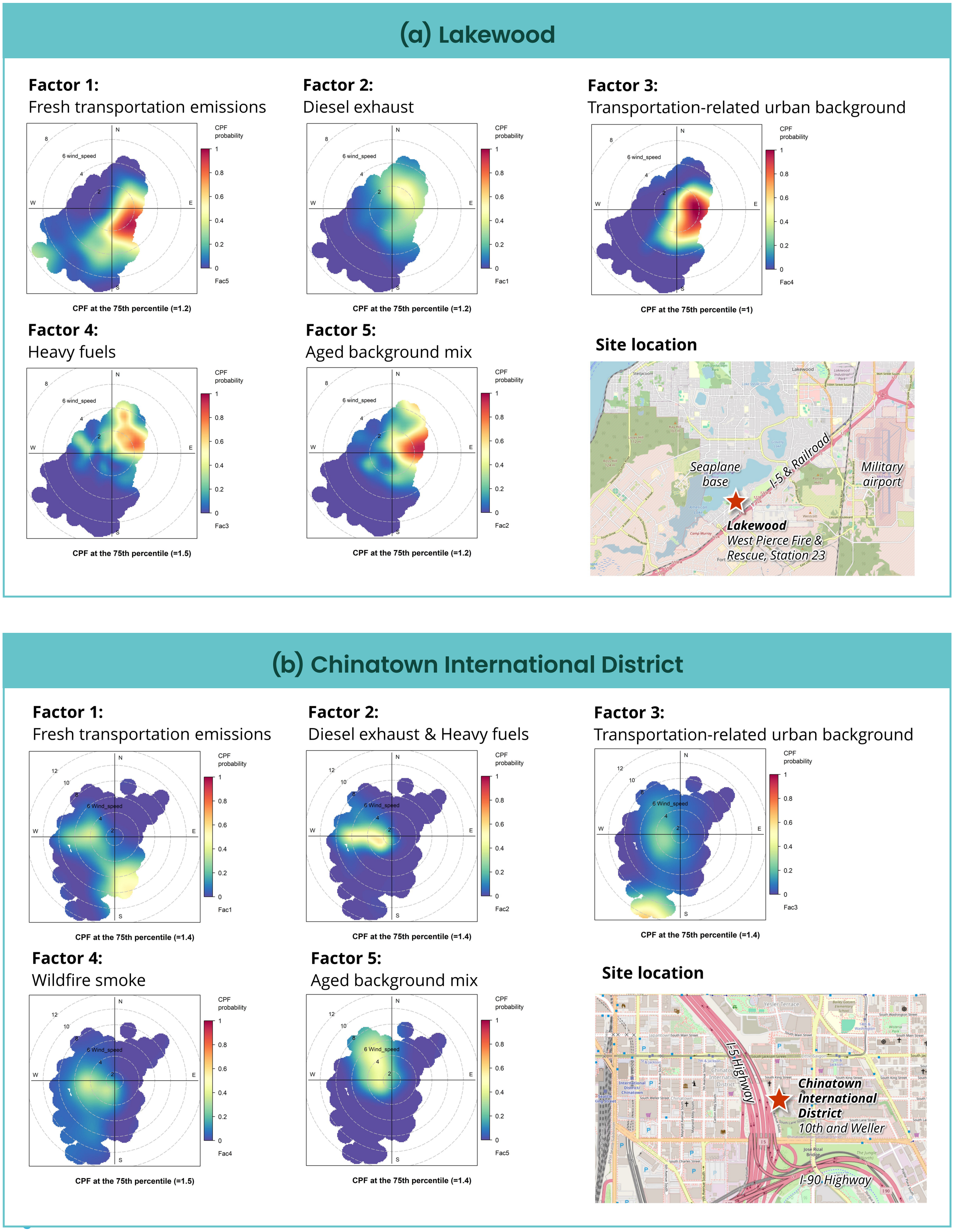
(c) Duwamish
Concentration
Percentage
Factor 1: Fresh transportation emissions
Factor 2: Diesel exhaust
Factor 3: Transportation-related urban background
Factor 4: Heavy fuels
Factor 5: Aged background mix
Concentration of pollutants
Percentage of pollutants
10^4
10^2
10^0
10^-2
10^-4
100%
80%
60%
40%
20%
0%
CO2
BC
UV
NO2
PNC(10-420 nm)
PNC(10-13 nm)
PNC(13-18 nm)
PNC(18-24 nm)
PNC(24-32 nm)
PNC(32-42 nm)
PNC(42-56 nm)
PNC(56-75 nm)
PNC(75-100 nm)
PNC(100-133 nm)
PNC(133-178 nm)
PNC(178-420 nm)
PM2.5

(d) Central District



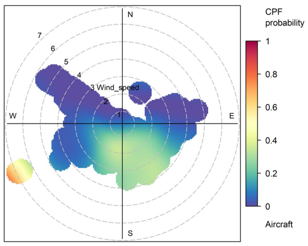
CBPF Plots

Figure E2. The CBPF plots for the (a) Lakewood, (b) Chinatown International District, (c) Duwamish, and (d) Central District sites.



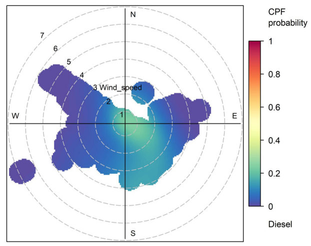
(c) Duwamish

Factor 1:
Fresh transportation emissions



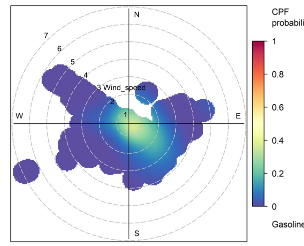
CPF at the 75th percentile (=1.3)

Factor 2:
Diesel exhaust



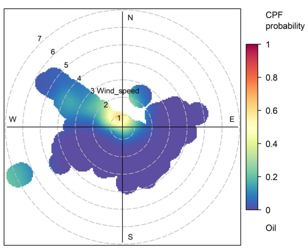
CPF at the 75th percentile (=1.4)

Factor 3:
Transportation-related urban background



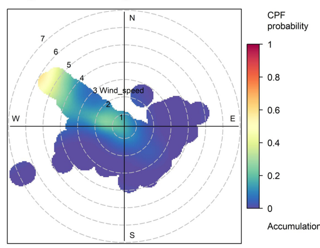
CPF at the 75th percentile (=1.4)

Factor 4:
Heavy fuels



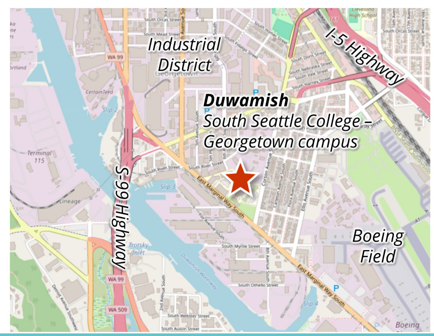
CPF at the 75th percentile (=1.5)

Factor 5:
Aged background mix



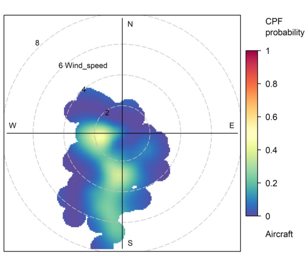
CPF at the 75th percentile (=1.4)

Site location



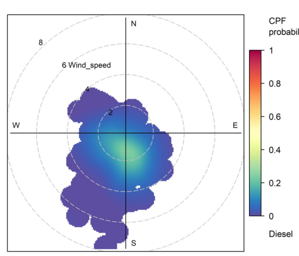
(d) Central District

Factor 1:
Fresh transportation emissions



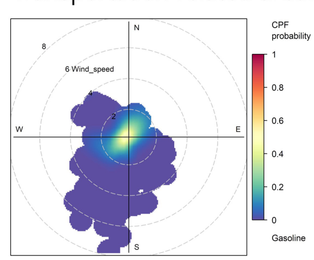
CPF at the 75th percentile (=1.3)

Factor 2:
Diesel exhaust



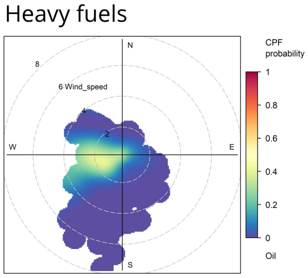
CPF at the 75th percentile (=1.4)

Factor 3:
Transportation-related urban background



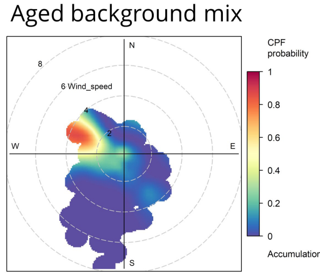
CPF at the 75th percentile (=1.5)

Factor 4:
Heavy fuels



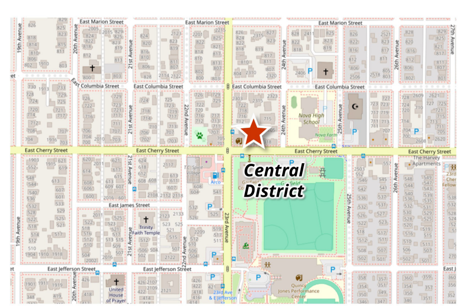
CPF at the 75th percentile (=1.4)

Factor 5:
Aged background mix



CPF at the 75th percentile (=1.1)

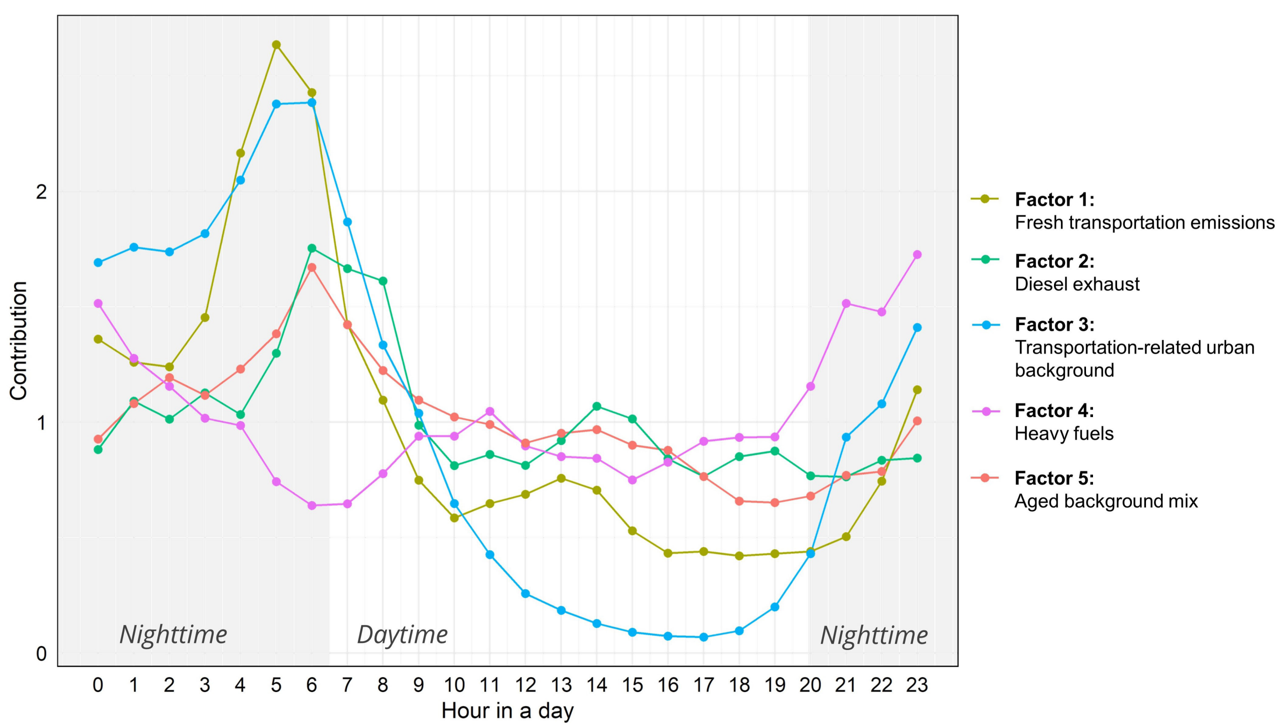
Site location



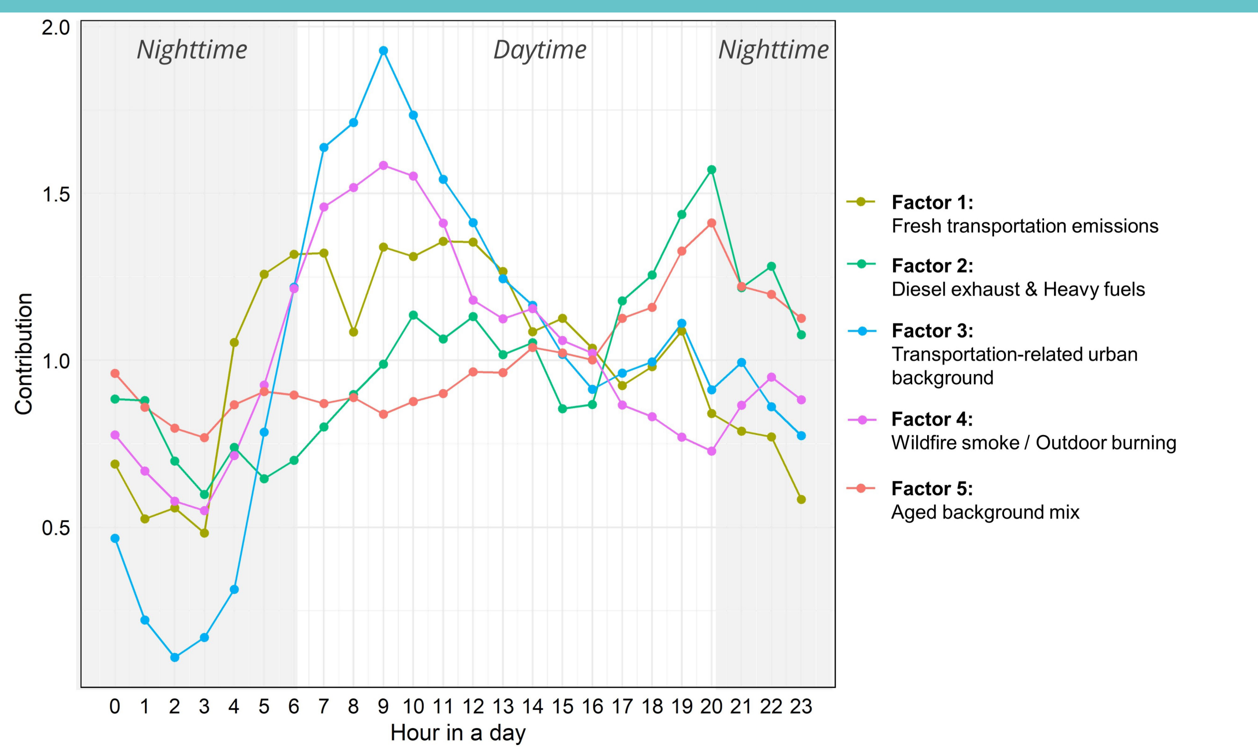
Diurnal Pattern Plots

Figure E3. Diurnal variation of factor contributions at the (a) Lakewood, (b) Chinatown International District, (c) Duwamish, and (d) Central District sites.

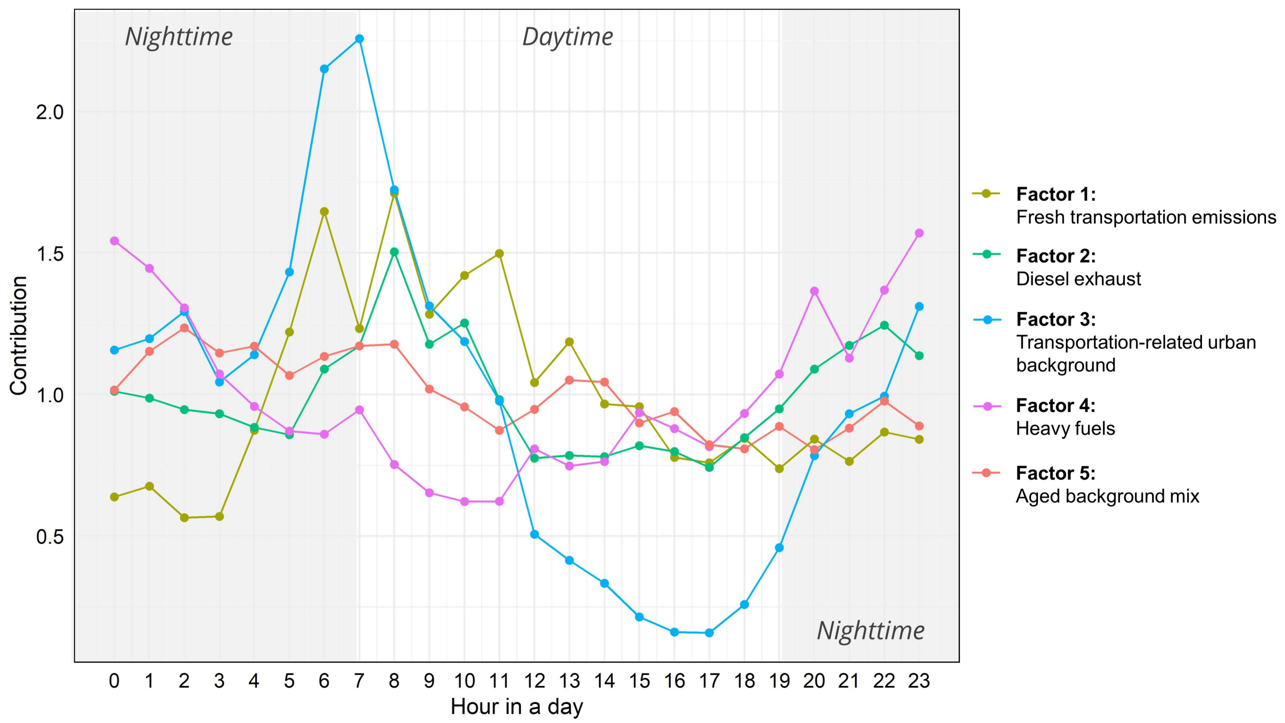
(a) Lakewood



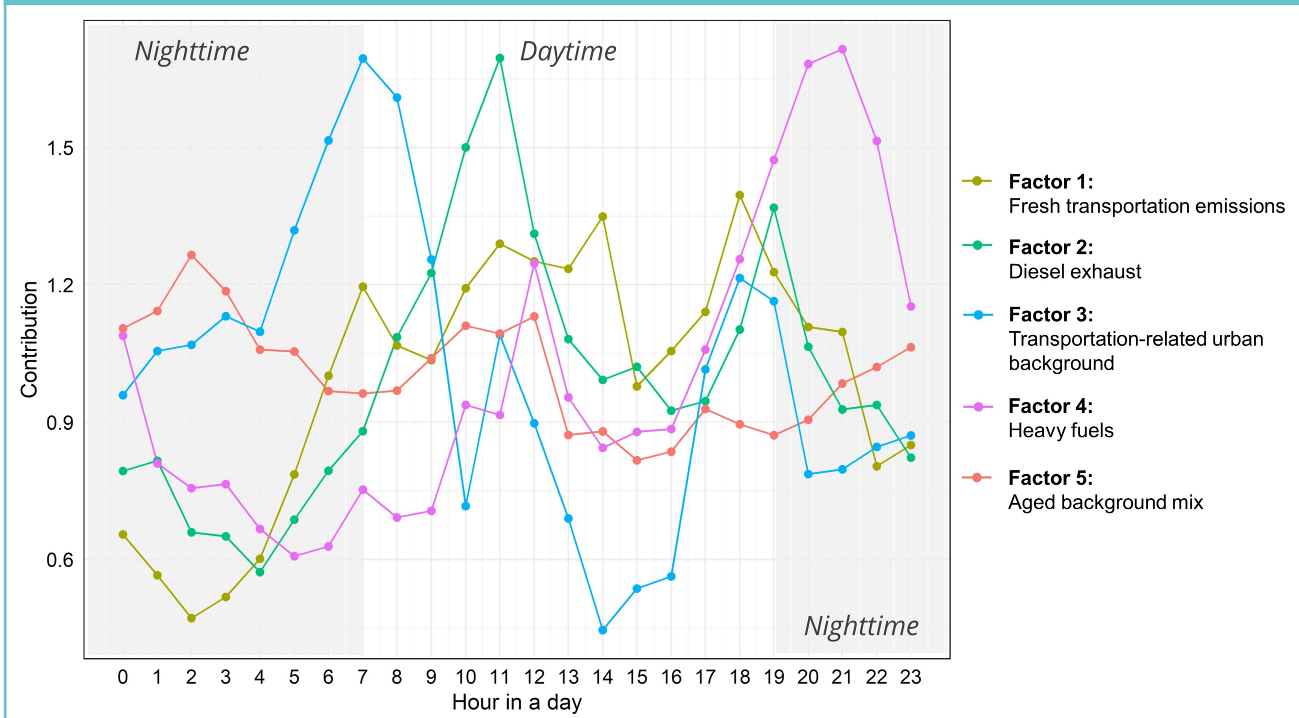
(b) Chinatown International District



(c) Duwamish



(d) Central District



Appendix F. Estimation of annual averages

Conversion of $PM_{2.5}$ exposure data

Because the health risk assessment focuses on the impacts of **long-term exposure to $PM_{2.5}$**, we first converted the average $PM_{2.5}$ concentrations measured during the monitoring period into **equivalent annual average concentrations**.

For each community-based monitoring site and year, we calculated a **conversion ratio** defined as the ratio of (1) the average $PM_{2.5}$ concentration at the nearest U.S. EPA regulatory monitoring station during the community monitoring period to (2) the annual average $PM_{2.5}$ concentration at the same regulatory monitoring station. The equivalent annual average $PM_{2.5}$ concentration at each community-based site was then estimated by dividing the observed average $PM_{2.5}$ concentration during the monitoring period by this conversion ratio.

As an example, the Lakewood site conducted air quality monitoring from April 24 to July 23, 2024, with the nearest U.S. EPA regulatory monitor located at the Tacoma L St station. To estimate the conversion ratio for the Lakewood site in 2024, we divided the average $PM_{2.5}$ concentration at the Tacoma L St station during the monitoring period (3.85 µg/m³) by the annual average $PM_{2.5}$ concentration at the same station in 2024 (5.16 µg/m³), resulting in a conversion ratio of **0.749**.

Table F1. Annual average $PM_{2.5}$ concentration from EPA stations (µg/m3).

Year	Lakewood	CID	Duwamish	Central District
EPA Station	Tacoma L. St.	Seattle 10th and Weller	Duwamish	Beacon Hill
2015	7.98	9.34	9.81	6.55
2016	6.55	7.63	6.58	5.50
2017	7.22	8.11	9.78	7.14
2018	7.87	9.39	8.91	6.67
2019	8.07	7.40	8.30	5.25
2020	9.41	9.35	10.21	6.31
2021	6.19	6.58	6.70	4.38
2022	8.65	9.01	8.98	7.20
2023	7.25	7.92	7.93	6.08
2024	5.16	6.56	6.50	4.19
Mean	7.44	8.13	8.37	5.93
Standard Deviation	1.24	1.11	1.41	1.01

Table F2. Conversion ratios between average $PM_{2.5}$ concentration during the monitoring period and the annual average $PM_{2.5}$ concentration.

Year	Lakewood	CID	Duwamish	Central District
2015	0.879	0.793	0.947	0.905
2016	0.694	1.006	0.838	1.053
2017	0.577	1.235	1.109	1.049
2018	0.488	1.429	1.005	0.577
2019	0.620	0.848	0.983	1.094
2020	0.428	0.659	2.648	0.602
2021	0.737	1.162	0.980	0.854
2022	0.392	0.768	2.008	0.739
2023	0.895	1.108	1.021	0.786
2024	0.749	1.080	0.958	0.930
Mean	0.646	1.009	1.250	0.859
Standard Deviation	0.176	0.240	0.592	0.183

The equivalent annual average $PM_{2.5}$ concentration was calculated by dividing the observed mean concentration measured by the monitoring trailer during the sampling period by the corresponding conversion ratio. To quantify uncertainty in the estimated equivalent annual average concentration for each site, we implemented a two-component bootstrap approach.

First, uncertainty in the conversion ratio was characterized using 100 bootstrap samples drawn with replacement from the ten available annual conversion ratios (2015–2024). This procedure generated a site-specific distribution of conversion ratios that captures variability arising from interannual differences in the ratio derivation process. Second, uncertainty in the observed mean $PM_{2.5}$ concentration during the monitoring period was assessed using a block bootstrap with a block size of one day. Entire days of hourly observations were resampled with replacement to preserve within-day temporal dependence. For each site, 100 block-bootstrap replicates of the monitoring-period mean concentration were generated.

Finally, the uncertainty distributions from these two components were propagated through the conversion calculation to obtain an overall uncertainty distribution for the equivalent annual average $PM_{2.5}$ concentration at each site, resulting in 100 simulated estimates per site. Summary statistics for the $PM_{2.5}$ exposure concentrations before and after conversion are presented in the table below.

Table F3. Median (95% uncertainty interval) of the average $PM_{2.5}$ concentration at four selected sites (µg/m3).

Community	Average during the monitoring period from the trailer	Equivalent annual average
Lakewood	4.50 (3.94-5.26)	7.08 (4.64-12.56)
Chinatown International District	7.11 (6.51-7.97)	6.96 (4.86-10.73)
Duwamish	6.54 (5.89-7.97)	6.48 (2.47-8.16)
Central District	6.06 (5.51-6.57)	6.70 (5.42-11.08)

Appendix G. Health Risk Analysis

Table G1. Exposure-response functions of $PM_{2.5}$ used in COBRA.

Pollutant	Metric	Outcome	Age	Beta(SE)	Note	Form
$PM_{2.5}$	Annual	All-cause mortality	18+	0.01133 (0.00160)	High	Log-linear
$PM_{2.5}$	Annual	All-cause mortality	65+	0.00639 (0.00038)	Low	Log-linear
$PM_{2.5}$	Annual	Infant mortality	0	0.005603 (0.004539)		Logistic
$PM_{2.5}$	Daily	Emergency room visits, CVD	0+	0.000611 (0.000422)		Logistic
$PM_{2.5}$	Daily	Emergency room visits, Respiratory diseases	0+	0.000545 (0.000267)		Log-linear
$PM_{2.5}$	Daily	Hospitalization, CVD	65+	0.000648 (0.000089)		Log-linear
$PM_{2.5}$	Annual	Hospitalization, Alzheimer's disease	65+	0.139762 (0.017753)		Log-linear
$PM_{2.5}$	Annual	Hospitalization, Parkinson's disease	65+	0.076961 (0.018905)		Log-linear
$PM_{2.5}$	Daily	Hospitalization, Respiratory disease	65+	0.00025 (0.000120)		Log-linear
$PM_{2.5}$	Daily	Hospitalization, Respiratory disease	0~18	0.002752 (0.000772)		Log-linear
$PM_{2.5}$	Daily	Nonfatal acute myocardial infarction	65+	0.0011 (0.0002)		Logistic
$PM_{2.5}$	Annual	Incidence, stroke	65+	0.00343 (0.001265)		Log-linear
$PM_{2.5}$	Daily	Incidence, out of hospital cardiac arrest	0+	0.003922 (0.00222		Logistic
$PM_{2.5}$	Daily	Incidence, out of hospital cardiac arrest	0+	0.00198 (0.005018)		Logistic
$PM_{2.5}$	Daily	Incidence, out of hospital cardiac arrest	18+	0.006376 (0.002823)		Logistic

$PM_{2.5}$	Daily	Incidence, lung cancer	30+	0.037844 (0.013121)		Log-linear
$PM_{2.5}$	Annual	Incidence, Hay fever/Rhinitis	3~17	0.025464 (0.009618)		Logistic
$PM_{2.5}$	Annual	Incidence, Asthma	0~17	0.043672 (0.000885)		Log-linear
$PM_{2.5}$	Daily	Asthma symptoms: Albuterol use	6~17	0.001996 (0.001477)		Log-linear
$PM_{2.5}$	Daily	Minor restricted activity days	18~64	0.00741 (0.00070)		Log-linear
$PM_{2.5}$	Daily	Work loss days	18~64	0.0046 (0.00036)		Log-linear

PLEASE CONTACT US

for questions, concerns, and suggestions.

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