Final Report
to the Transportation Planning Organization
of Hillsborough County

on Agreement for Placement of Student Intern

Progress on the pilot low-cost air quality monitoring network

Project Period: September 2022 – August 2023

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Executive Summary

This final report documents progress on the establishment of a community air monitoring network near interstates in Hillsborough County using novel low-cost monitors. It describes work completed from September 2022–August 2023 through the placement of a doctoral student intern from the University of South Florida (USF) with the Transportation Planning Organization (TPO). The work described here supplements progress on the network achieved through a collaborative pilot project the previous year [Luo et al., 2023]. Collaborative partners include the Transportation Planning Organization (TPO), the Environmental Protection Commission (EPC), the University of South Florida (USF), and several community and civic organizations, public schools, and a library. The cooperation of the City of Tampa and Hillsborough County was also instrumental to successful siting of monitors. This report includes progress on novel monitor performance testing, community monitor installation, community air quality assessment, and education and outreach activities during this period.

Performance testing during this project period focused on evaluating the two novel lower-cost monitors that have been installed at community sites, the PurpleAir II-SD and the Clarity Node-S monitors. The accuracy and precision of these monitors were assessed for measuring levels of two common traffic related air pollutants, fine particles ($PM_{2.5}$) and nitrogen dioxide (NO_2). Both of these pollutants have had National Ambient Air Quality Standards (NAAQS) established to protect human health and welfare. The specifical pollutant measures of analysis were chosen for consistency with the short-term NAAQS and to allow comparison between pollutants; specifically, we assessed performance for daily mean (24-hr average) $PM_{2.5}$ and NO_2 and 1-hr average NO_2. To evaluate accuracy, we analyzed approximately one year of data from monitors installed at two EPC regulatory monitoring sites, the near-road site (Munro) and a multi-pollutant background site (Sydney). To evaluate precision, we analyzed data from sets of three replicate monitors of each type co-located together over a few-month period.

The performance of both types of monitors varied from month to month. For 24-hr $PM_{2.5}$ levels, which are measured by both monitors, accuracy performance (after calibration) was better for the Clarity Node-S for most performance measures, with all accuracy statistics except linearity meeting the target values. Although the performance of the PurpleAir II-SD was slightly worse for most measures, it performed better regarding bias. For the PurpleAir II-SD $PM_{2.5}$ sensor, both linearity and normalized error were outside the target ranges. 24-hr $PM_{2.5}$ measurements from replicate Node-S monitors were also more precise than those from the PurpleAir II-SD. Both devices performed reasonably for the purpose of providing supplemental information to the community on indicative daily $PM_{2.5}$ levels at the neighborhood scale, but work is needed to define appropriate ways to communicate uncertainty in this data and to designate appropriateness for different purposes. For NO_2, which is only measured by the Clarity Node-S, performance for measuring 1-hr average levels was weak, with a slight improvement seen for 24-hr average NO_2. Further work is needed to improve the quality of the NO_2 data (such as via novel emerging cross-network calibration approaches) or through testing of additional devices on the market. An ongoing quality assurance procedure to flag data for correction or devices for maintenance is also needed for network sustainability.

Progress on community monitoring during the reporting period included the installation of Clarity Node-S monitors at three city parks along the I-275 corridor (Robles, Perry Harvey, and Sulphur Springs). Trends and cycles in $PM_{2.5}$ levels measured at each site in the network were also analyzed. Specific peaks in the daily mean (24-hr average) levels observed at each community sites were not always captured at the reference sites, but the number of days with levels exceeding good air quality was represented reasonably by the reference data at the EPC Munro site. When comparing levels measured by the same monitor type (Clarity Node-S) for a consistent time period (3/1/2023–4/30/2023), the daily mean levels at the Sydney reference site were generally lower than those at the non-park community sites and Munro reference site. Average hourly $PM_{2.5}$ levels at the non-park community sites and at the on-road reference site (Munro) were higher than those observed at the background reference site (Sydney) and the park sites. The highest hourly levels each day were typically observed in the morning (from 4–11 am, depending on the location and monitoring device), with levels generally increasing from evening to early morning, and the lowest levels observed at mid-day. The highest daily levels each week were typically observed on Wednesday at all sites. These patterns are consistent with known patterns of atmospheric stability and somewhat aligned with expected traffic activity.

Several educational outreach activities, including online meetings, student engagement activities, and presentations, were also conducted during this reporting period with the purpose of involving and informing the community. Discussion and feedback from these activities indicates that many community stakeholders are interested in this project and its potential to supplement regulatory monitoring and inform community decision-making processes.

Overall, the successful collaboration among partners in this project demonstrates the effectiveness of a multi-stakeholder approach in addressing air quality and environmental inequality. The progress and findings during this reporting period provide a foundation for continuing efforts to establish a sustainable distributed community air monitoring network and promote informed decision making for improved air quality in Hillsborough County.

1 Introduction

Air pollution is a significant public health concern with detrimental effects on human well-being (WHO, 2023). Traffic-related air pollution (TRAP), in particular, has emerged as one of the major contributors to poor air quality in urban areas [Qiu et al., 2019]. It not only poses risks to human health but also contributes to environmental inequality, disproportionately affecting marginalized communities [Cushing et al., 2015; Gurram et al., 2019]. Studies examining both modeling and measurements in Hillsborough County have consistently revealed that African Americans and households living in poverty experience disproportionate exposure to traffic-related air pollution (TRAP) [Gurram et al., 2019; Stuart & Zeager, 2011; Yu & Stuart, 2013]. The 2021 State of the System Report published by the Hillsborough County Transportation Planning Organization (TPO) highlighted that over a quarter of the county's total population resides within 300 meters of high-volume roads. This percentage increased by nearly 7% between 2018 and 2021, with a corresponding 14% rise in the number of vulnerable individuals living within the same proximity. Compounding this issue is the fact that marginalized populations often feel disempowered and face challenges in participating in government decision-making processes that have direct implications for their air pollution exposure and health [Brickle & Evans-Agnew, 2017]. Therefore, addressing these issues requires effective monitoring strategies and interventions to reduce TRAP exposure inequality.

To address these needs, a collaborative partnership has formed to establish a community air monitoring network for TRAP in Hillsborough County using novel low-cost monitors. The network is expected to enable the characterization of air quality at high resolution in the county, with a focus on marginalized neighborhoods near the I-275 and I-4 highways, and to promote the involvement of community members in transportation decision-making processes. Collaborative partners include the Transportation Planning Organization (TPO), the Environmental Protection Commission, the University of South Florida (USF), other city and county offices, several community organizations, civic organizations, and public schools. This report describes work completed towards these aims between September 2022–August 2023 through the placement of a doctoral student intern from the University of South Florida (USF) with the Transportation Planning Organization (TPO). It supplements progress on the network achieved through a collaborative pilot project the previous year [Luo et al., 2023].

Goals during this reporting period included: 1) to evaluate the performance of the selected low-cost monitors based on one-year of collected data, 2) to expand the scope of the network developed during the pilot study and to provide up-to-date neighborhood air quality information, and 3) to foster community engagement and education about the project.

In this report, we describe updated findings on the performance of the PurpleAir II-SD and Clarity Node-S monitors based on approximately one year of collected data in section 2. Section 3 presents progress on the expansion of community air monitoring sites and analyses of data on air quality within the targeted communities. Section 4 describes community engagement activities during the reporting period and progress on the development of educational materials. Finally, we summarize the findings from the year's activities.

2 Novel monitor performance

This section reports on the performance of the two novel lower-cost air quality monitors that were previously chosen for the community network, the PurpleAir II-SD and Clarity Node-S. Specifically, we supplement the performance results described in Luo et al. [2023] with added analyses based on the additional record of collected data. This includes analyses of precision, using triplicate co-located monitors, and accuracy measured against a co-located reference monitor.

2.1 Performance of the PurpleAir II-SD $PM_{2.5}$ sensor

The PurpleAir II-SD monitor measures real-time (2-min frequency) levels of particles of different sizes present in the environment, along with measures for a few weather conditions. (Details are provided in Luo et al. [2023]). Here we describe methods and results on performance for measuring daily mean fine particle ($PM_{2.5}$) levels during a one-year testing period.

2.1.1 Methods

Analyses of performance were based on the USEPA performance testing guidance for $PM_{2.5}$ [Duvall et al., 2021]. The minimum recommended testing period for PM sensors is two months, spanning two different seasons. We analyzed performance each month of an approximately year-long testing period to gain a better understanding of variations in performance over time. Analyses were performed on data obtained from the PurpleAir II-SD monitors and the reference monitor installed at the Munro regulatory reference site of the Hillsborough County Environmental Protection Commission (EPC) for the period between 12/1/2021 to 11/25/2022. The analysis period was limited to slightly less than one year due to loss of power by the cellular node used for PurpleAir II-SD data collection.

We obtained reference $PM_{2.5}$ levels for the Munro site reference instrument (a Teledyne T640) directly from the EPC staff. Both minute frequency and 1-hour average concentrations were provided, with data removed for hours that were considered invalid. We calculated daily mean (24-hr) values from the valid hourly values for comparison to the novel monitor data. For values measured by the PurpleAir II-SD monitor, we retrieved both raw and calibrated daily (24-hr average) $PM_{2.5}$ concentrations from the PurpleAir data repository. We used data calibrated using the ALT method because it has been shown to improve accuracy [Wallace et al., 2021].

To assess performance, measures of both precision and accuracy were calculated from the daily values for each month of the testing period. Precision was evaluated by comparing calibrated pollutant levels from co-located PurpleAir II-SD monitors. Specifically, we calculated the standard deviation (SD) and coefficient of variation (CV) from replicate measurements. Accuracy was evaluated by comparing the calibrated pollutant levels from the novel monitor with those from the reference monitor. We calculated measures of bias (intercept and slope), linearity (R^2), and error (RMSE and NMSE) to evaluate accuracy. Distribution summary statistics and graphical visualizations of concurrent trend plots and side-by side box plots were also used to gain additional insights into performance.

2.1.2 Results

Precision. Figure 1 shows the trends in calibrated daily (24-hr mean) concentrations from the three collocated PurpleAir II-SD $PM_{2.5}$ monitors (PA1, PA2, and PA3). Table 1 provides descriptive statistics and precision performance statistics for each month of the testing period. We note that the third monitor (PA3) was not installed until 4/8/2022, so the precision statistics before that date are based on only two monitors. As seen in Figure 1, all co-located PurpleAir II-SD devices measured similar levels and had similar variations during the testing period. The period average levels measured by PA1 and PA2 were 6.2 and 5.9 µg/m^3, with monthly means ranging from 4.4 to 9.3 µg/m^3 and 4.2 to 8.9 µg/m^3, respectively. The period average from PA3 was 5.5 µg/m^3, with monthly means ranging from 4.6 – 6.5 µg/m^3. Calculated precision statistics (Table 1) indicate that the standard deviation (SD) between the device measurements met the USEPA testing guidance precision target (≤ 5 µg/m^3) for the full testing period and for all individual months, while the coefficient of variation (CV) values were slightly outside the target range (≤ 30%) for several individual months. As only one of these measures must be within the target, the PurpleAir II-SD meets the precision performance target.

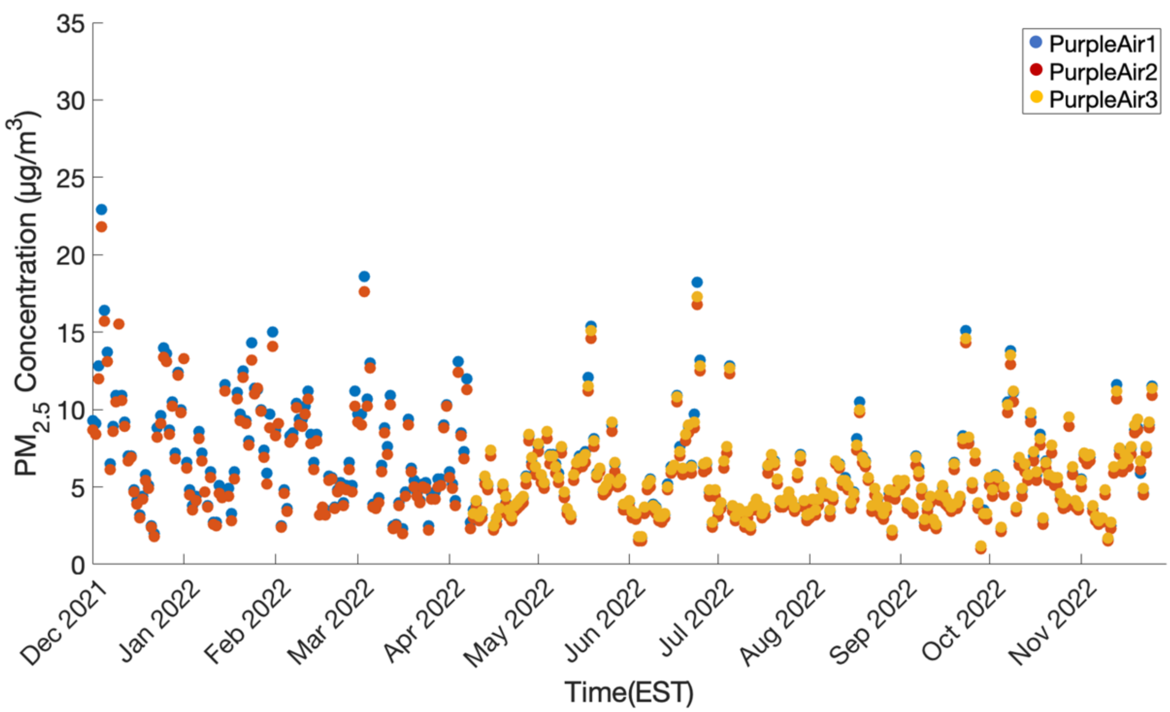

Figure 1. Trends in calibrated 24-hr average $PM_{2.5}$ concentrations measured by the replicate PurpleAir II-SD devices from precision testing.

Table 1. Descriptive statistics for calibrated 24-hr average $PM_{2.5}$ concentrations measured by the replicate PurpleAir II-SD monitors and precision performance statistics, by month and overall.

	Mean level [range] (µg/m^3)			Precision measures SD (µg/m^3)	CV (%)
	PA1	PA2	PA3[a]	Target value[b] ≤ 5	≤ 30
2021-Dec	9.3 [2.0, 22.9]	8.9 [1.8, 21.8]	/	3.1	34.6
2022-Jan	7.7 [2.7, 15.0]	7.3 [2.5, 14.1]	/	2.5	32.8
2022-Feb	6.7 [2.5, 11.2]	6.4 [2.4, 10.7]	/	1.8	27.9
2022-Mar	6.6 [2.3, 18.6]	6.3 [2.0, 17.6]	/	2.5	38.7
2022-Apr	4.4 [2.4, 8.3]	4.2 [2.2, 8.0]	4.6 [2.5, 8.4]	0.9	20.0
2022-May	6.5 [3.1, 15.4]	6.1 [2.9, 14.6]	6.5 [3.2, 15.1]	1.3	21.2
2022-Jun	5.9 [1.6, 18.2]	5.5 [1.5, 16.8]	5.9 [1.8, 17.3]	2.0	34.1
2022-Jul	4.7 [2.4, 12.8]	4.4 [2.2, 12.3]	4.7 [2.5, 12.7]	1.2	25.5
2022-Aug	4.9 [2.1, 10.5]	4.6 [1.9, 9.8]	4.9 [2.2, 10.0]	0.9	18.8
2022-Sep	4.9 [1.0, 15.1]	4.6 [1.0, 14.3]	4.9 [1.2, 14.6]	1.4	29.0
2022-Oct	6.2 [2.3, 13.8]	5.8 [2.1, 12.9]	6.3 [2.4, 13.5]	1.4	23.3
2022-Nov	6.2 [1.6, 11.6]	6.0 [1.5, 10.9]	6.4 [1.7, 11.4]	1.5	23.7
Apr–Nov[c]	5.5 [1.0, 18.2]	5.2 [1.0, 16.8]	5.5 [1.2, 17.3]	1.4	26.5
Overall	6.2 [1.0, 22.9]	5.9 [1.0, 21.8]	5.5 [1.2, 17.3]	1.6	27.3

[a]PA3 was installed on 4/8/2022, hence the overall period average is not comparable to that from PA1 or PA2. [b]From Duvall et al. [2021]. At least one of these targets should be met. Values in grey do not meet the individual target. PA stands for PurpleAir. [c]The period of time for which all three monitors were co-located.

Accuracy. Because the replicate PurpleAir II-SD devices exhibited good consistency with each other, one device (PA1) was chosen for the analysis of performance for accuracy. Boxplots of the monthly distributions of calibrated daily (24-hr mean) concentrations measured by PA1 are shown in Figure 2, with detailed summary statistics for the measured data provided in Table 2. Daily average concentrations ranged from 1.0 µg/m^3 (in September) to 22.9 µg/m^3 (in December), with monthly mean values ranging from 4.7 µg/m^3 (in July) to 9.3 µg/m^3 (in December). Average and peak values in winter were generally highest and showed the largest spread (larger interquartile range) and were lowest in mid to late summer, with less spread.

Figure 3 shows trends in time of daily mean $PM_{2.5}$ concentrations (both the raw and calibrated values) that were measured by PA1 and the reference monitor, with detailed performance statistics for accuracy by month and overall provided in Table 3. Figure 4 shows a scatter plot comparison. Measurements from PA1 displayed similar levels and temporal variability as the reference monitor throughout the testing period (Figure 3). However, a broader range of values were measured for both the raw and calibrated data, showing both higher maximums and lower minimums than the reference data, especially for the raw data. Considering data from the entire testing period (Table 3, row labelled 'Overall') the calibrated 24-hr average measurements from the PurpleAir II-SD monitor met the USEPA testing guidance target for all performance measures except linearity (R^2) and normalized error (NRMSE). However, only RMSE consistently stayed within the performance target throughout the testing period. All other performance measures had at least one month with values outside the target. Linearity had the most months (8) outside the target range. No trends in increasing or decreasing performance over time are apparent in the data. Performance values observed here are lower than those reported for the Southern California environment; AQ-SPEC testing found PurpleAir measurements to correspond to FEM GRIMM and FEM BAM values with $R^2 > 0.94$ and $R^2 > 0.92$, but their testing period was only two-months (http://www.aqmd.gov/docs/default-source/aq-spec/field-evaluations/purple-air-pa-ii---field-evaluation.pdf?sfvrsn=11).

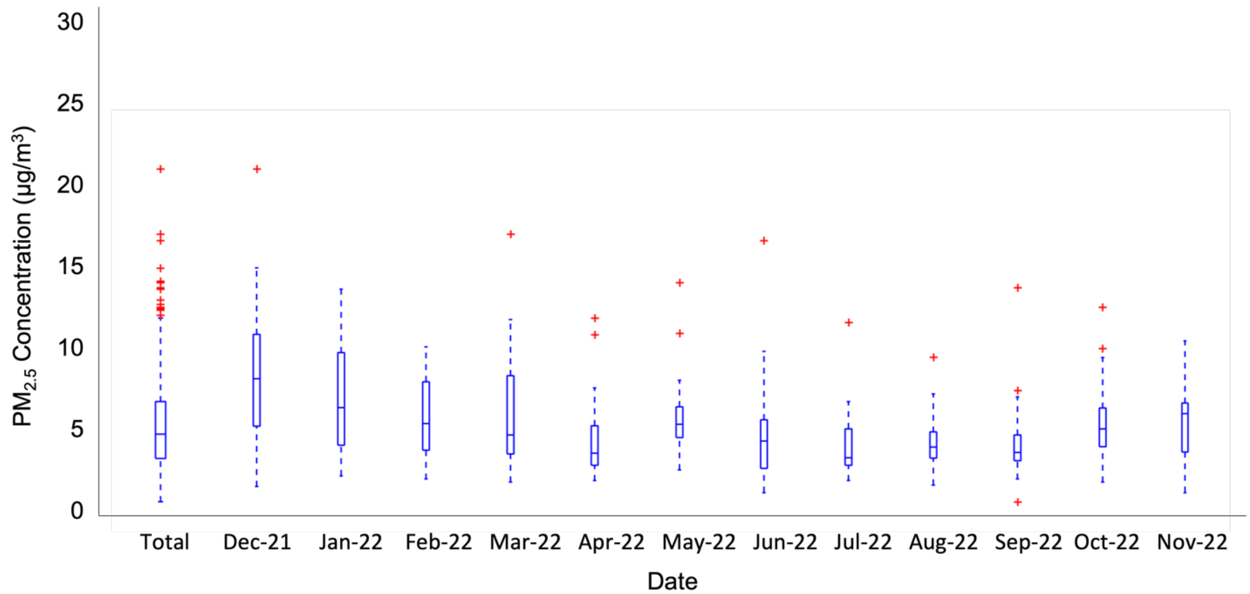

Figure 2. Boxplots of the monthly distributions of calibrated daily mean (24-hr) $PM_{2.5}$ concentrations measured by the PurpleAir II-SD monitor (PA1) during accuracy testing.

Table 2. Distribution summary statistics for calibrated 24-hr average $PM_{2.5}$ levels from the PurpleAir II-SD monitor (PA1), by month and overall, during the accuracy testing period.

	Descriptive statistics of $PM_{2.5}$ level ($\mu g/m^3$)					
	Mean	Min.	25^{th} %ile	50^{th} %ile (median)	75^{th} %ile	Max.
2021-Dec	9.3	2.0	6.0	9.1	12.0	22.9
2022-Jan	7.7	2.7	4.7	7.2	10.8	15.0
2022-Feb	6.7	2.5	4.4	6.2	8.9	11.2
2022-Mar	6.6	2.3	4.2	5.4	9.3	18.6
2022-Apr	5.2	2.4	3.4	4.2	6.0	13.1
2022-May	6.5	3.1	5.2	6.1	7.3	15.4
2022-Jun	5.6	1.6	3.2	5.0	6.4	18.2
2022-Jul	4.7	2.4	3.4	3.9	5.8	12.8
2022-Aug	5.0	2.1	3.9	4.6	5.6	10.5
2022-Sep	4.9	1.0	3.7	4.3	5.4	15.1
2022-Oct	6.3	2.3	4.6	5.8	7.2	13.8
2022-Nov	6.2	1.6	4.3	6.8	7.5	11.6
Overall	6.2	1.0	3.9	5.5	7.6	22.9

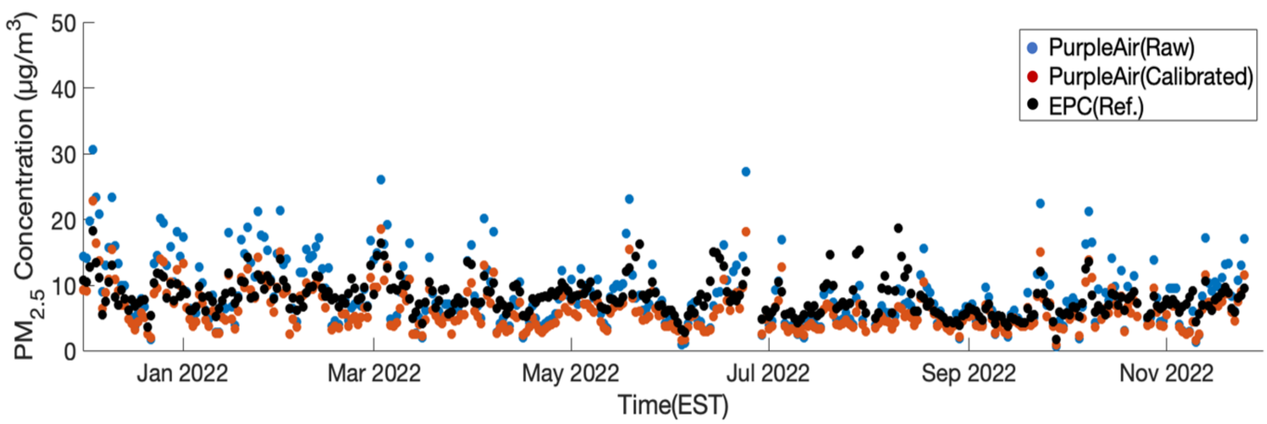

Figure 3. Trends over time in 24-hr $PM_{2.5}$ average concentrations from the PurpleAir II-SD monitor (PA1) versus the reference monitor within the 12-month accuracy testing period.

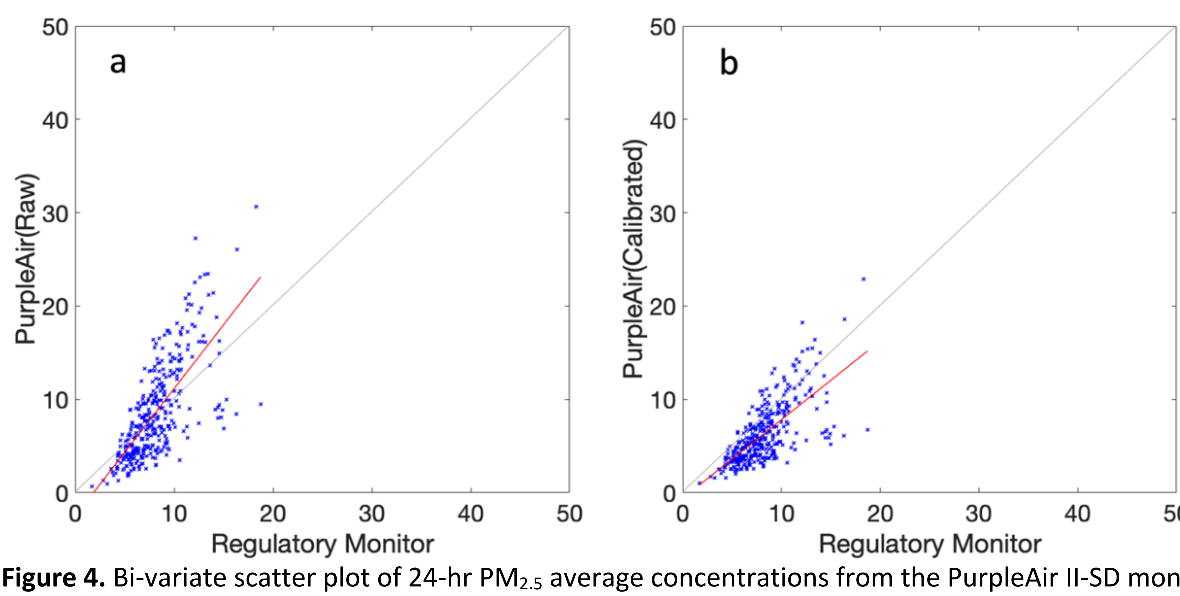

Figure 4. Bi-variate scatter plot of 24-hr $PM_{2.5}$ average concentrations from the PurpleAir II-SD monitor (PA1) versus the reference monitor during the 12-month accuracy testing period.

Table 3. Accuracy performance statistics for calibrated 24-hr averaged $PM_{2.5}$ levels measured by the PurpleAir II-SD monitor (PA1), by month and overall, during the testing period.

	Number[b]	Intercept (μg/m³)	slope	R^2	RMSE (μg/m³)	NRMSE (%)
Target value[a]	/	-5 ≤ b ≤ 5	1.0 ± 0.35	≥ 0.70	≤ 7	≤ 30
2021-Dec	31	-3.9	1.41	0.82	2.2	24
2022-Jan	31	-4.6	1.37	0.72	2.4	27
2022-Feb	28	-2.8	1.08	0.46	2.9	33
2022-Mar	31	-2.2	0.97	0.64	3.3	36
2022-Apr	30	-5.2	1.28	0.59	3.4	42
2022-May	31	1.6	0.55	0.29	3.2	37
2022-Jun	26	0.9	0.57	0.30	4.1	50
2022-Jul	31	1.3	0.44	0.38	3.8	49
2022-Aug	29	3.3	0.23	0.21	4.0	52
2022-Sep	30	-2.3	1.25	0.86	1.3	23
2022-Oct	29	-2.4	1.17	0.74	1.7	24
2022-Nov	25	-4.1	1.36	0.55	2.3	30
Overall	352	-0.60	0.84	0.48	3.0	37

[a]Target values are based on the USEPA performance testing guidance [Duvall et al., 2021]. Values in grey do not meet the target. [b]Although data were retrieved for every day of the testing period for the PurpleAir II-SD monitor (data completeness of 100%), some days were missing from the EPC datasets. These days were removed from the comparison datasets.

2.2 Performance of the Clarity Node-S multi-pollutant monitor

The Clarity Node-S measures 15-min frequency real-time levels of particles of different sizes present in the ambient environment, nitrogen dioxide (NO_2) gas, and a few ambient weather condition parameters. (Details are provided in Luo et al. [2023]). Here we describe methods and results on performance for measurement of daily mean $PM_{2.5}$ levels and daily mean and hourly mean NO_2 levels.

2.2.1 Methods

We analyzed the performance of the Clarity Node-S using data from instruments installed at regulatory reference monitoring sites in the county. Data used to assess accuracy were derived from novel and reference monitors located at the EPC monitoring site designated for near-road regulatory monitoring (the Munro site) for the period 4/8/2022–2/28/2023. Data were measured concurrently by a Clarity Node-S device installed on 4/8/2022 on the roof of the monitoring trailer and by the regulatory reference instruments at the site. For precision evaluation, data from three replicate devices co-located at the multi-pollutant EPC Sydney site from 11/9/2022 to 2/3/2023 were used.

As described in section 2.1.1, we obtained reference pollutant levels directly from the EPC staff for the Munro site reference instruments (a Teledyne T640 for $PM_{2.5}$ and a Teledyne-API Model 200EUP or T200UP for NO_2). 1-hour average concentrations of $PM_{2.5}$ were provided. Invalid hours were removed prior to longer-term averaging. Reference pollutant levels of hourly mean NO_2 were retrieved from the USEPA AirNow repository via the API. For comparison to the novel monitor data, we calculated daily mean (24-hr) values of $PM_{2.5}$ and NO_2 from the reported hourly mean data and used the reported hourly mean NO_2 levels directly. For the Clarity Node-S monitors, both raw and calibrated hourly $PM_{2.5}$ and NO_2 concentrations were retrieved via the Clarity API. A description of the calibration procedures conducted by the device manufacturer is provided in Luo et al. [2023].

Performance for measurement of $PM_{2.5}$ was based on the 24-hr average concentrations, consistent with the USEPA performance testing guidance for fine particles [Duvall et al., 2021], and the averaging time for the short-term National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$. For NO_2, performance for both 24-hr average and 1-hr average concentrations was assessed. The former allows comparison between the two pollutants, while the latter aligns with the short-term averaging time used in the National Ambient Air Quality Standards (NAAQS) for NO_2. Note that there is currently no established performance testing guidance available for NO_2.

The same analyses and performance measures were used here as described in Section 2.1.1. This included both graphical analysis of distribution plots and calculation of performance statistics. Precision was evaluated using SD and CV between raw data from the replicate co-located Clarity Node-S monitors. Accuracy for both raw and calibrated data was evaluated using measures of bias (intercept and slope), linearity (R^2), and error (RMSE and NMSE) in comparison with the reference data. To enable assessment of changes in performance over time, statistics were calculated both for the entire testing periods and by month.

2.2.2 Results

2.2.2.1 Performance of the Clarity Node-S $PM_{2.5}$ sensor

<u>Precision.</u> Figure 5 shows the trends in raw daily (24-hr average) $PM_{2.5}$ concentrations measured by three co-located Clarity Node-S devices (CN1, CN2, and CN3) located at the Munro regulatory site between November 9, 2022 to February 3, 2023. Table 4 lists the descriptive statistics and calculated performance statistics overall and by month. The devices measured similar values and showed similar variations in time, with means over the testing period ranging between devices from 9.8 to 11.0 $\mu g/m^3$. Both precision performance statistics (SD and CV) were within the target values from the USEPA testing guidance. Measures were slightly better than those observed for Clarity devices by the USEPA for 1-hr average $PM_{2.5}$ data over a one-month testing period [Frederick et al., 2020], which showed SD and CV values among 9 Clarity devices were 3.15$\mu g/m^3$ and 26.5%, respectively.

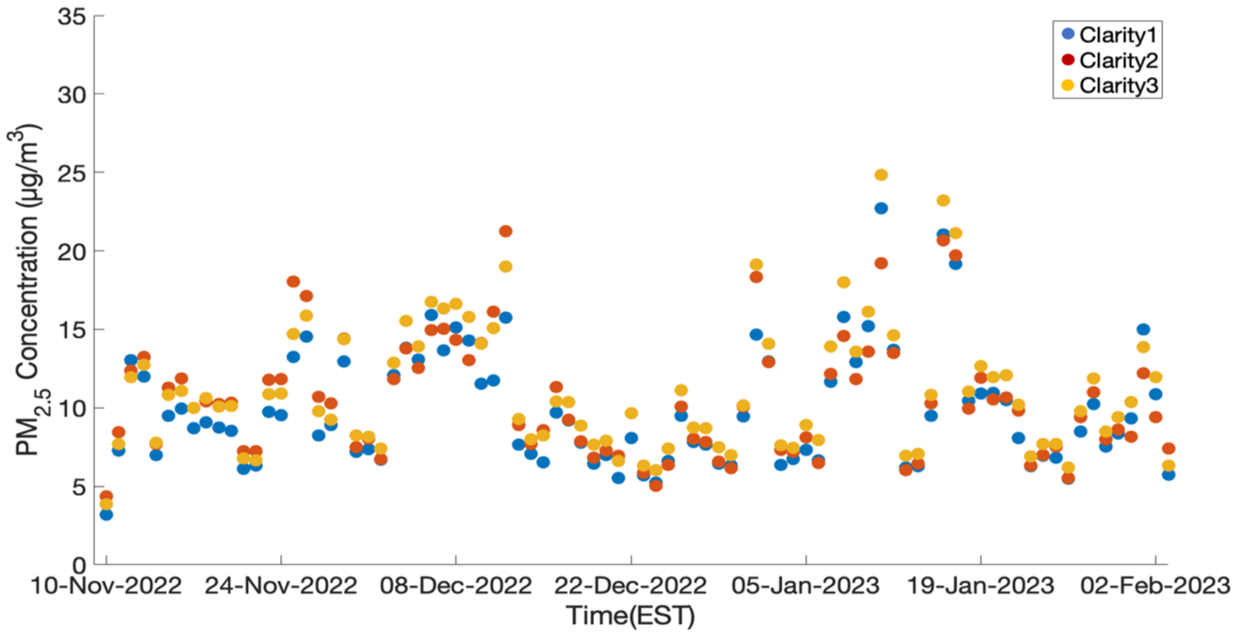

Figure 5. Trends in 24-hr average $PM_{2.5}$ concentration (µg/m^3) from co-located replicate Clarity Node-S devices during precision testing.

Table 4. Descriptive statistics for calibrated 24-hr average $PM_{2.5}$ concentrations measured by the replicate Clarity Node-S devices and precision performance statistics, by month and overall.

	Mean level [range] (µg/m^3)			Precision measures SD (µg/m^3)	CV (%)
				Target value[a]	
	CN1	CN2	CN3	≤ 5	≤ 30
2022-Nov (Start 9th)	9.2 [3.2, 14.5]	10.8 [4.4, 18.0]	10.2 [3.9, 15.9]	1.7	16.6
2022-Dec	9.4 [5.3, 15.9]	10.1 [5.0, 21.3]	10.7 [6.0, 19.0]	2.1	20.6
2023-Jan to Feb 3rd	10.6 [5.5, 22.7]	10.7 [5.5, 20.7]	12.0 [6.2, 24.8]	2.6	23.4
Overall	9.8 [3.2, 22.7]	10.5 [4.4, 21.3]	11.0 [3.9, 24.8]	2.2	21.2

[a]At least one of these precision targets should be met [Duvall et al., 2021]. CN stands for Clarity Node-S.

Accuracy. Cumulative distribution boxplots of the 24-hr average calibrated concentrations measured by the Clarity Node-S (CN1) for each month during the 11-month accuracy testing period and overall are presented in Figure 6, with descriptive statistics listed in Table 5. Values ranged from 1.70 μg/m^3 in June 2022 to 20.4 μg/m^3 in January 2023, with an overall period mean of 7.60 μg/m^3. The mean values remained similar from April 2022 to July 2022, then increased from August 2022 to January 2023, and decreased again slightly in February 2023.

Figure 7 provides the trends in time of both the raw and calibrated 24-hr average $PM_{2.5}$ concentrations collected by the CN1 Clarity Node-S device for the period 4/8/2022–2/28/2023 at the Munro monitoring site. A scatter plot of the Clarity Node-S values against the reference values is shown in Figure 8. The plot shows that the raw Clarity Node-S data overestimated the higher values. It is clear from the figures that the calibrated values are in better agreement with the data from the regulatory monitor. Table 6 provides the accuracy performance statistics for the calibrated Clarity Node-S data for $PM_{2.5}$. For the entire testing period, the intercept and slope of the calibrated 24-hr average values were 1.5 μg/m^3 and 0.75, respectively, which meets the target range in the USEPA testing guidance. The intercept met the performance target range for all months, but the slope was outside the range (biased low) from May through August 2022. The overall linearity performance (R^2 = 0.52) was lower than the target value (≥ 0.70), but data from all but two months (August and November) were within the target range. Both the RMSE and NRMSE were within the target range overall, but NMRSE was outside the range in the initial months from April through August. The performance for 24-hr average $PM_{2.5}$ levels over the full testing period of the Clarity Node-S was similar to, but slightly better for most measures, than that of the PurpleAir II-SD (Table 3). Additionally, fewer months had values outside the target performance ranges.

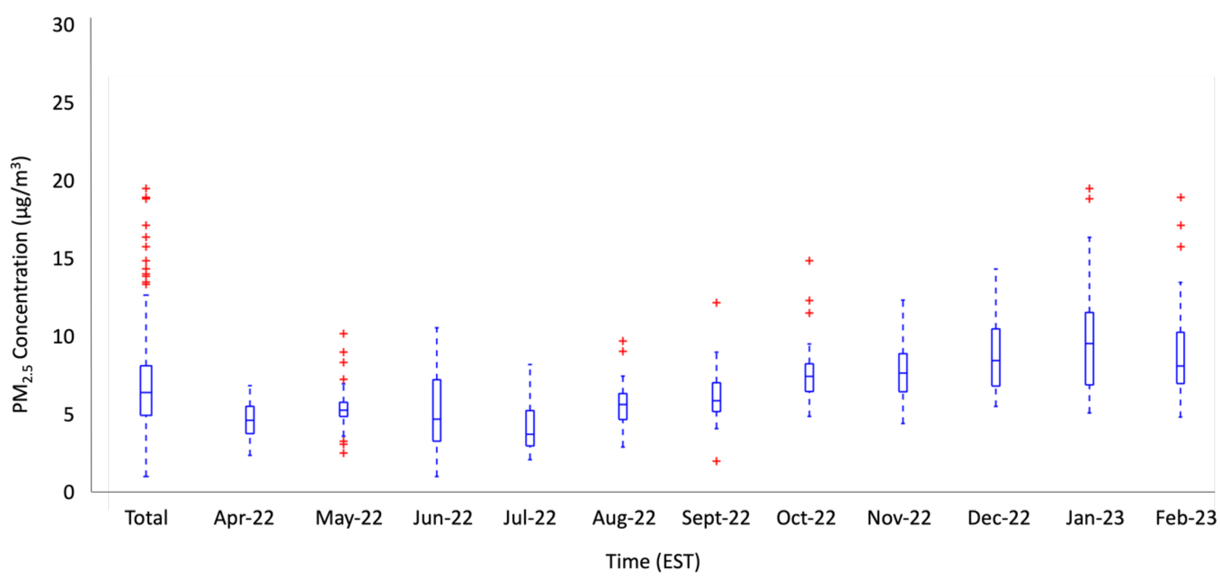

Figure 6. Boxplots of the monthly distributions of daily calibrated mean (24-hr) $PM_{2.5}$ concentrations measured by Clarity Node-S during accuracy testing.

Table 5. Descriptive statistics of the calibrated 24-hr average $PM_{2.5}$ levels measured by the Clarity Node-S during the testing period, by month and overall, for the period 4/8/2022–2/28/2023.

	Mean	Minimum	25th percentile	Median	75th percentile	Maximum
22-Apr	5.36	3.07	4.48	5.33	6.24	7.57
22-May	6.23	3.24	5.59	5.99	6.50	10.9
22-Jun	5.84	1.70	3.99	5.41	7.96	11.3
22-Jul	4.99	2.79	3.69	4.44	5.97	8.95
22-Aug	6.35	3.60	5.39	6.36	7.07	10.4
22-Sep	6.92	2.71	5.90	6.60	7.77	12.9
22-Oct	8.55	5.59	7.20	8.17	8.99	15.7
22-Nov	8.73	5.13	7.18	8.39	9.65	13.1
22-Dec	9.51	6.23	7.55	9.20	11.2	15.1
23-Jan	10.5	5.81	7.63	10.3	12.3	20.4
23-Feb	9.93	5.55	7.71	8.85	11.0	19.8
Overall	7.60	1.70	5.65	7.13	8.86	20.4

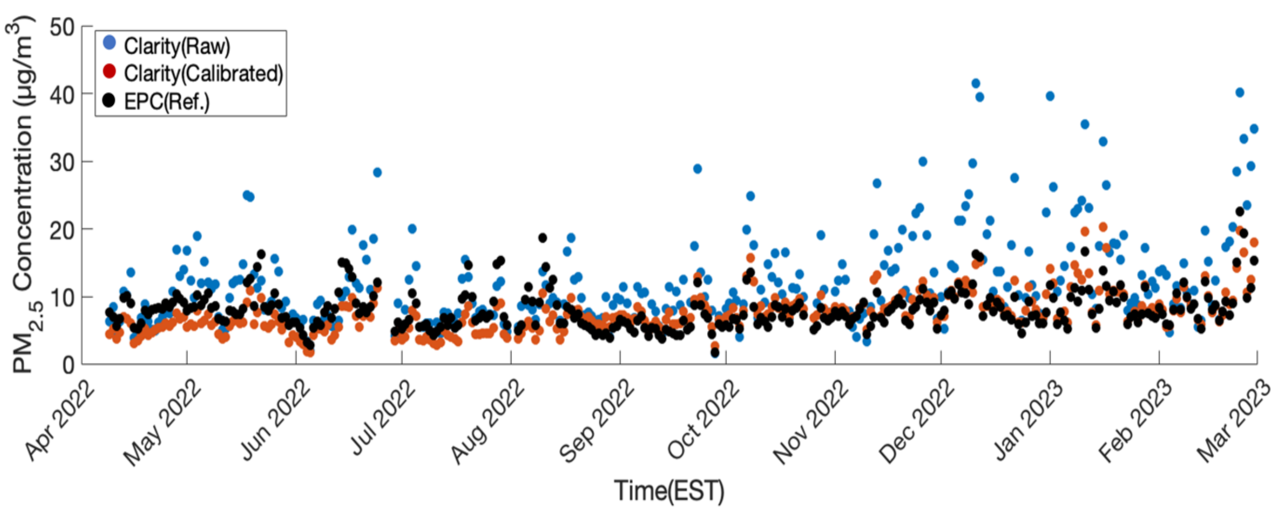

Figure 7. Trends over time of raw and calibrated 24-hr average $PM_{2.5}$ concentrations measured by the Clarity Node-S against the reference monitor at the Munro site for an 11-month accuracy testing period.

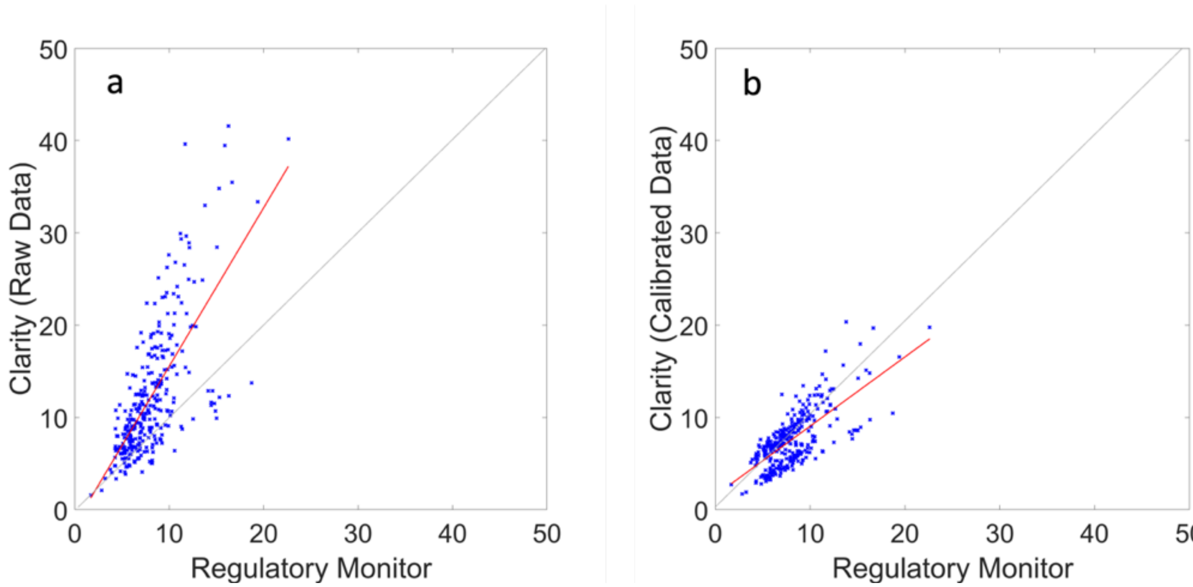

Figure 8. Bi-variate scatter plots of the (a) raw and (b) calibrated 24-hr average $PM_{2.5}$ concentration from the Clarity Node-S versus the reference measurements at the Munro site during accuracy testing.

Table 6. Accuracy performance statistics for the calibrated Clarity Node-S 24-hr average $PM_{2.5}$ levels against reference measurements for each month and overall, during the testing period

	Number[b]	Intercept (µg/m^3)	slope	R^2	RMSE (µg/m^3)	NRMSE (%)
Target value[a]	/	-5 ≤ b ≤ 5	1.0 ± 0.35	≥ 0.70	≤ 7	≤ 30
2022-Apr	22	-0.73	0.76	0.90	2.7	34
2022-May	31	0.88	0.61	0.77	2.9	32
2022-Jun	26	0.67	0.63	0.74	2.9	36
2022-Jul	31	0.62	0.57	0.92	2.9	39
2022-Aug	29	4.5	0.24	0.26	3.2	42
2022-Sep	30	1.6	0.93	0.92	1.3	22
2022-Oct	29	1.1	1.0	0.87	1.4	19
2022-Nov	30	1.1	0.98	0.68	1.4	19
2022-Dec	31	2.5	0.80	0.81	1.3	15
2023-Jan	31	-1.6	1.3	0.86	2.2	25
2023-Feb	28	1.3	0.87	0.92	1.1	11
Overall	318	1.5	0.75	0.52	2.2	28

[a]Target values are based on the USEPA performance testing guidance [Duvall et al., 2021]. Values in grey do not meet the target. [b]Only 22 days of data in April are included because data collection began on 4/9/2022. Although data were available for every day of the testing period for the Clarity Node-S monitor, days missing from the EPC datasets were also removed from the comparison datasets.

2.2.2.2 Performance of the Clarity Node-S NO_2 sensor

Precision. Figures 9 and 10 show the concurrent calibrated 1-hr and 24-hr mean NO_2 levels measured by the co-located Clarity Node-S devices (CN1, CN2, and CN3) during the period 11/9/2022 to 2/3/2023 at the Sydney regulatory site. Table 7 provides the mean and range of values observed for each month and overall, along with the calculated precision performance measures. While there is greater variability in the 1-hr values, the 24-hr values from all devices clearly follow similar trends. As expected, precision performance is better for the 24-hr values than the 1-hr values. The CV is good at 18% for the 24-hr values and somewhat higher at 34% for the 1-hr values.

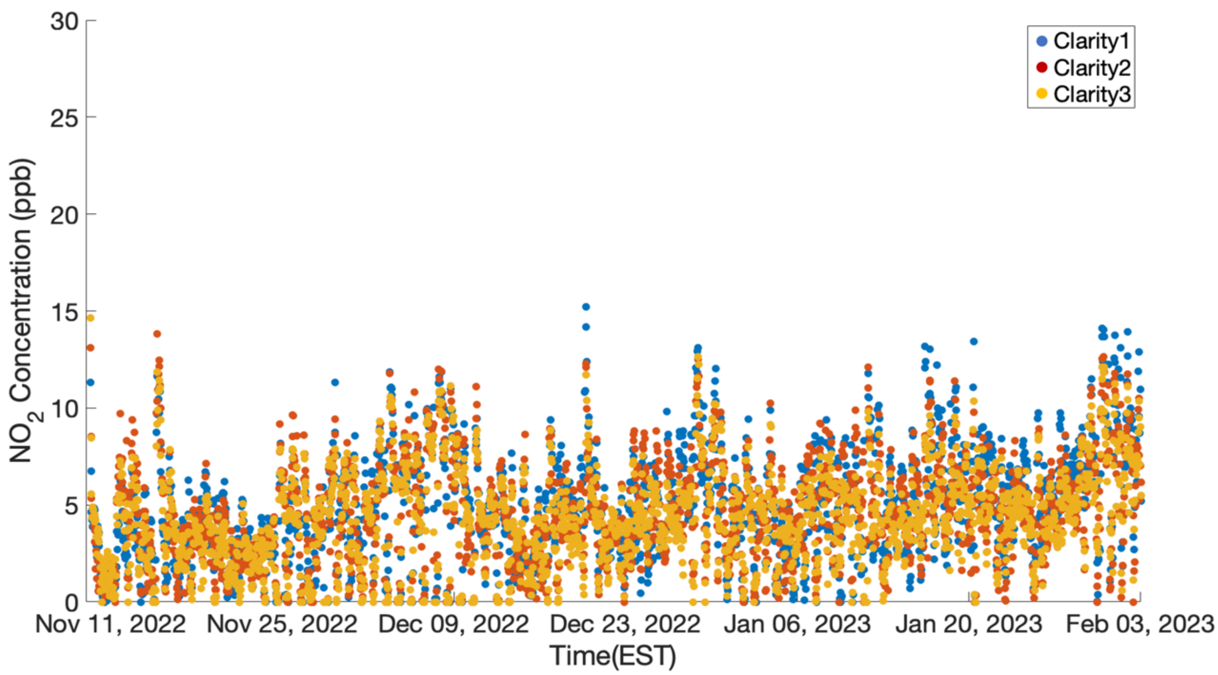

Figure 9. Trends of calibrated 1-hr averaged NO_2 concentrations from three replicate Clarity Node-S devices during precision testing.

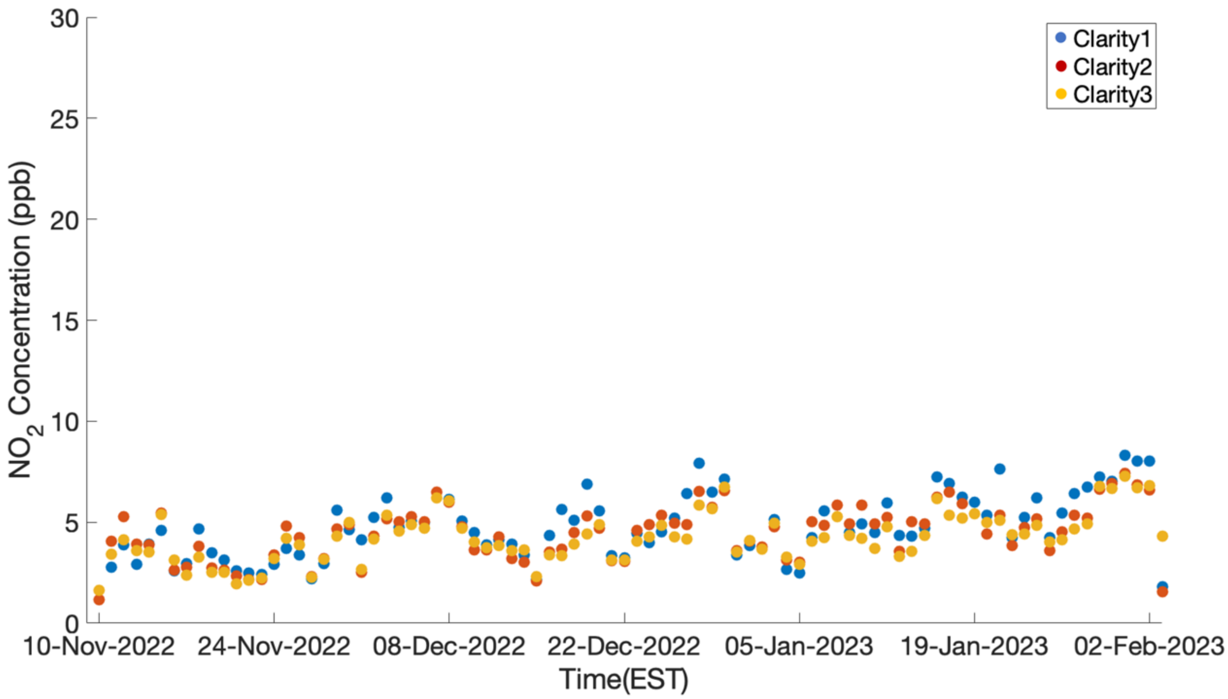

Figure 10. Trends of calibrated 24-hr averaged NO_2 concentrations from three replicate Clarity Node-S devices during precision testing.

Table 7. Descriptive statistics for calibrated 1-hr and 24-hr NO_2 concentrations measured by the replicate Clarity devices and precision performance statistics, by month and overall.

	Mean level [range] (ppbv)			Precision measures	
	CN1	CN2	CN3	SD (ppbv)	CV (%)
Calibrated data (1-hr)					
2022-Nov (Start 9th)	3.3 [0, 11.7]	3.5 [0, 13.8]	3.3 [0, 14.6]	1.3	40
2022-Dec	5.0 [0, 15.2]	4.5 [0, 12.5]	4.3 [0, 12.6]	1.6	34
2023-Jan to Feb 3rd	5.4 [0, 14.1]	5.0 [0, 12.7]	4.7 [0, 12.1]	1.4	28
Overall	4.7 [0, 15.2]	4.5 [0, 13.8]	4.2 [0, 14.6]	1.5	34
Calibrated data (24-hr)					
2022-Nov (Start 9th)	3.3 [1.2, 5.6]	3.5 [1.2, 5.4]	3.2 [1.6, 5.4]	0.60	18
2022-Dec	5.0 [2.2, 7.9]	4.5 [2.1, 6.6]	4.3 [2.3, 6.7]	0.67	15
2023-Jan to Feb 3rd	5.4 [2.5, 8.3]	5.0 [3.0, 7.4]	4.7 [2.9, 7.3]	0.68	13
Overall	4.7 [1.2, 8.3]	4.5 [1.2, 7.4]	4.2 [1.6, 7.3]	0.81	18

Accuracy Performance for 1-hr NO_2. Table 8 shows the descriptive statistics of the calibrated NO_2 1-hr concentrations from the Clarity Node-S device (CN1). Values ranged from 0 ppbv in April and May 2022 to 58.9 ppbv in December 2022, with an overall mean of 15.1 ppbv for the accuracy testing period. The median value of 14.8 ppbv was slightly lower than mean value. The monthly mean value increased substantially from May to the highest monthly average (21.2 ppbv) in January 2023.

Figure 11 shows raw and calibrated 1-hr average NO_2 concentrations over time during the testing period from 4/9/2022 to 2/28/2023, from both the Clarity Node-S device (CN1) and the regulatory monitor at the EPC Munro site. Figure 12 shows raw and calibrated bi-variate scatter plots against reference measurements. The raw data show a large number of negative values, that are substantially corrected by the calibration. Table 9 provides accuracy performance statistics from comparison of the 1-hr Clarity Node-S values against reference measurements. Performance results indicate monthly average error ranging from 4.4 to 14 ppbv (or 54–126% when normalized), with a period average error of 8.7 ppbv (95% of the mean measured reference value). Error was smallest in the early months of the evaluation period, and largest in December and January. The 1-hr Clarity Node-S measurements also showed substantial bias, with a period-average intercept of 10.2 ppbv and a period-average slope of 0.53. A clear relationship is not present in the scatter plot (Figure 11) and the linearity statistic was also weak. R^2 values ranged from 0.01 in December, to 0.47 in May, with a period average of only 0.25.

Table 8. Descriptive statistics for calibrated 1-hr average NO_2 concentrations (ppbv) from the Clarity Node-S monitor, by month and overall, during the testing period.

	Mean	Minimum	25^{th} percentile	Median	75^{th} percentile	Maximum
2022-Apr	8.8	0	5.9	8.8	12.0	19.5
2022-May	8.6	0	5.3	8.4	11.8	22.4
2022-Jun	11.0	0.6	8.4	11.2	13.4	22.2
2022-Jul	12.1	2.0	9.7	11.9	14.6	27.0
2022-Aug	14.1	2.4	11.6	14.4	16.6	32.4
2022-Sep	15.0	4.2	12.9	15.2	17.3	29.6
2022-Oct	16.9	7.3	14.7	16.9	19.0	30.2
2022-Nov	17.0	7.6	14.7	17.0	19.2	29.8
2022-Dec	21.0	8.4	15.7	18.6	22.6	58.9
2023-Jan	21.2	8.1	15.7	19.5	24.7	53.6
2023-Feb	17.7	6.6	14.6	17.3	20.1	41.7
Overall	15.1	0	11.2	14.8	18.1	58.9

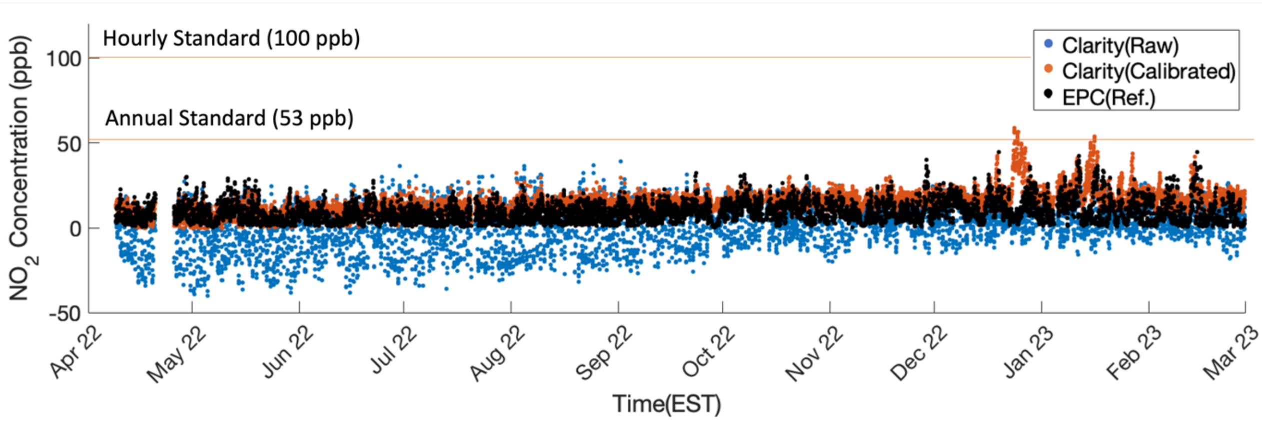

Figure 11. Trends over time of 1-hr average NO_2 concentrations from the Clarity Node-S and reference monitor over the 11-month accuracy testing period.

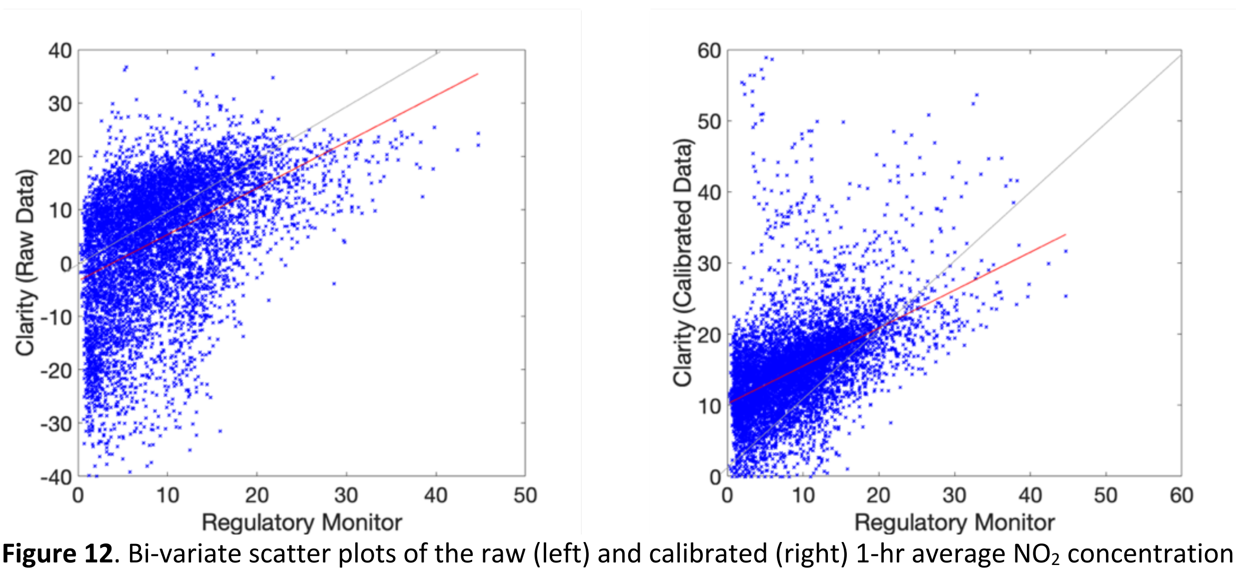

Figure 12. Bi-variate scatter plots of the raw (left) and calibrated (right) 1-hr average NO_2 concentration from the Clarity Node-S versus the reference measurements.

Table 9. Accuracy statistics for 1-hr average NO_2 concentrations from the Clarity Node-S versus the reference data, by month and overall, during the testing period

	Number[b]	Intercept (ppbv)	slope	R^2	RMSE (ppbv)	NRMSE (%)
Ideal values[a]	/	0	1	1	0	0
2022-Apr	401	5.0	0.47	0.29	4.5	56
2022-May	736	4.3	0.53	0.47	4.4	54
2022-Jun	704	8.1	0.40	0.24	5.7	78
2022-Jul	713	9.5	0.41	0.25	7.0	108
2022-Aug	738	10.4	0.48	0.33	7.5	98
2022-Sep	714	11.7	0.38	0.31	7.4	84
2022-Oct	710	12.4	0.40	0.40	7.0	61
2022-Nov	696	13.4	0.38	0.40	8.7	91
2022-Dec	733	19.7	0.10	0.01	14	110
2023-Jan	711	14.8	0.54	0.31	12	102
2023-Feb	654	14.5	0.36	0.32	11	126
Overall	7510	10.2	0.53	0.25	8.7	95

[a]There is no evaluation guidance for realistic performance statistics for NO_2 measurement with novel monitors, hence only ideal values are listed. [b]7824 hourly data were retrieved from Clarity (data completeness: 100%). Some hourly data were missing from EPC datasets; these data were removed from both datasets for comparison (see Table 10).

Table 10. Completeness of the hourly NO_2 data from the Clarity Node-S and the reference data

	Total possible hours[a]	Reference data[b]		Clarity Node-S data	
		No. of hours	%	No. of hours	%
2022-Apr	528	401	76	528	100
2022-May	744	736	99	744	100
2022-Jun	720	704	98	720	100
2022-Jul	744	713	96	744	100
2022-Aug	744	738	99	744	100
2022-Sep	720	714	99	720	100
2022-Oct	744	710	95	744	100
2022-Nov	720	696	97	720	100
2022-Dec	744	733	99	744	100
2023-Jan	744	711	96	744	100
2023-Feb	672	654	97	672	100
Overall	7824	7510	96	7824	100

[a]The number of hours in the month. For example, May has 31 days, and each day has 24 hours. Therefore, the total hours possible for May is 31 days * 24 hours/day = 744 hours data. [b]Retrieved from the AirNow data repository.

Accuracy Performance for 24-hr NO_2. Table 11 shows descriptive statistics for calibrated 24-hr average NO_2 concentrations for the accuracy testing period, April 2022 to February 2023. The mean for the entire testing period was 15.0 ppbv, which is the same as the median value. The monthly mean remained the same (8.6 ppbv) in April and May 2022. Then it increased from June 2022 to January 2023, and slightly decreased from 21.0 ppbv to 17.7 ppbv. The minimum value was 5.0 ppbv observed in May 2022, while the maximum value (43.7 ppbv) occurred in December 2022.

Figure 13 shows the raw and calibrated 24-hr average NO_2 concentrations measured by the Clarity Node-S along with the reference measurements over the accuracy testing period. Data from the Clarity Node-S initially had many negative values in the first few months. However, these negative values improved over time. Calibration substantially reduced the number of negative values, but the calibrated values consistently overestimated the higher levels. Bi-variate scatter plots are shown in Figure 14. They demonstrate that the raw 24-hr average NO_2 concentrations had very little correspondence with regulatory measurements. After calibration, the points clustered together, with some apparent correlation observed. Table 12 provides accuracy performance statistics against the reference measurements. Performance results indicate monthly average error ranging from 2.8 to 12 ppbv (or 35–108% when normalized), with a period average error of 7.5 ppbv (82% of the mean measured reference value). Error was smallest in the early months of the testing period, and largest in December and January, similar to the 1-hr analysis. The 24-hr Clarity1 measurements also showed some bias, with a period-average intercept of 8.9 ppbv, and a period-average slope of 0.67. The linearity statistic was also weak; R^2 values ranged from 0.01 in December, to 0.58 in February, with a period average of 0.24. Performance for 24-hr average NO_2 levels was substantially worse than that for 24-hr average $PM_{2.5}$ levels.

Table 11. Descriptive statistics for calibrated 24-hr average NO_2 concentrations (ppbv) from the Clarity1, by month and overall, during the testing period.

	Mean	Minimum	25th percentile	Median	75th percentile	Maximum
2022-Apr	8.6	5.5	6.7	8.2	10.0	13.3
2022-May	8.6	5.0	6.1	9.0	10.4	12.6
2022-Jun	11.1	7.4	10.0	10.6	12.3	14.7
2022-Jul	12.1	8.8	11.6	12.3	13.0	15.6
2022-Aug	14.1	9.8	13.2	14.2	15.1	17.5
2022-Sep	15.0	11.0	14.2	15.1	15.8	18.9
2022-Oct	16.9	14.1	15.6	16.8	18.2	21.3
2022-Nov	17.0	12.1	16.1	17.1	18.2	19.7
2022-Dec	20.9	14.2	16.7	18.8	21.0	43.7
2023-Jan	21.0	13.7	17.7	20.2	22.3	33.9
2023-Feb	17.7	14.5	15.5	17.1	18.5	27.1
Overall	15.0	5.0	11.8	15.0	17.4	43.7

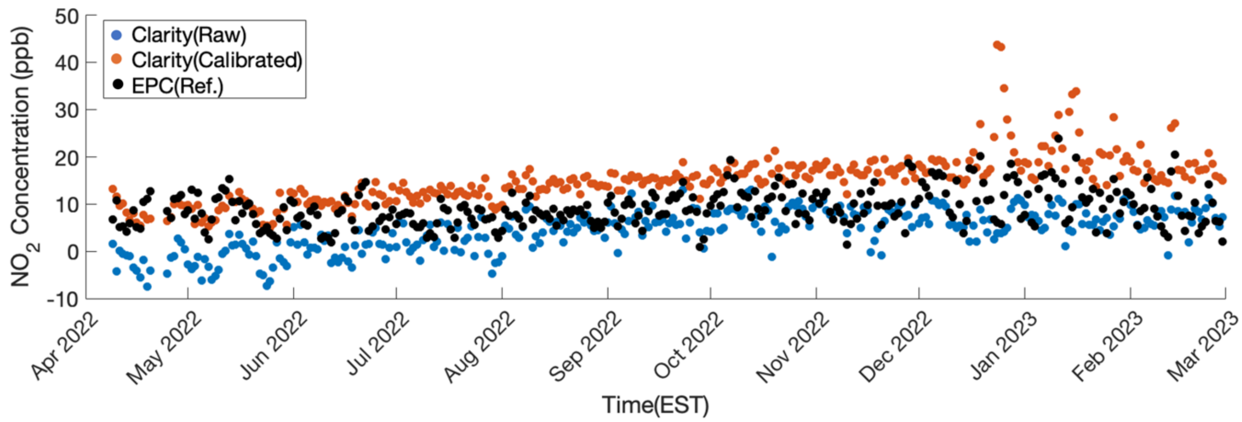

Figure 13. Trends over time of raw and calibrated 24-hr NO_2 average concentration measured by the Clarity Node-S device against reference data.

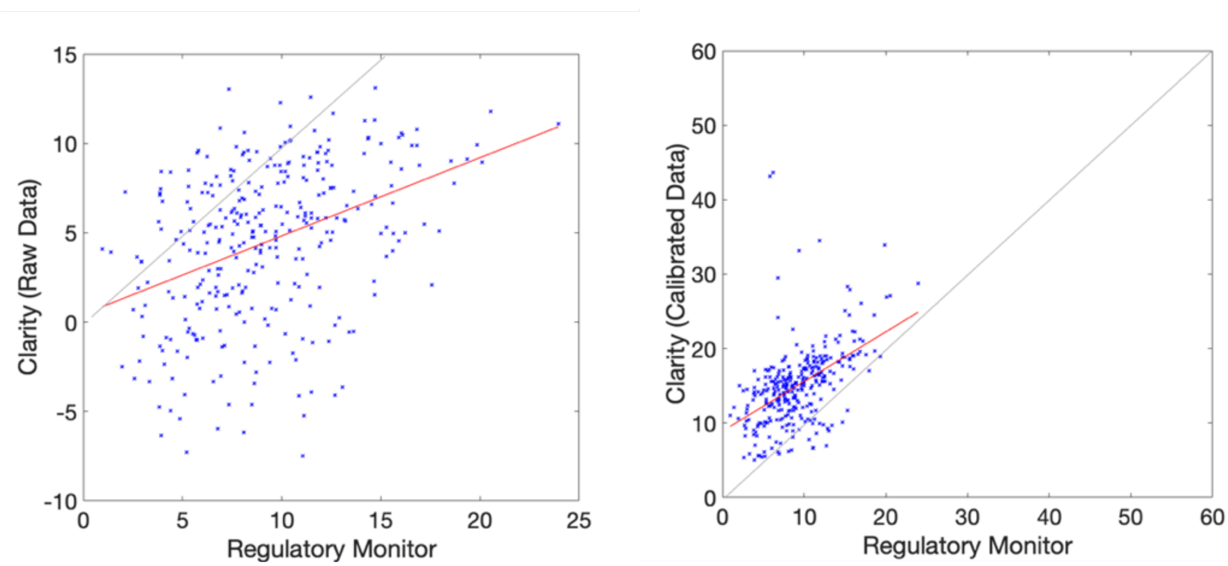

Figure 14. Bi-variate scatter plots of the raw (left) and calibrated (right) 24-hr average NO_2 concentration from the Clarity Node-S versus the reference measurements.

Table 12. Accuracy statistics for 24-hr average NO_2 concentrations from the Clarity Node-S versus the reference data, by month and overall, during the testing period

	Number[b]	Intercept (ppbv)	slope	R^2	RMSE (ppbv)	NRMSE (%)
Ideal values[a]	/	0	1	1	0	0
2022-Apr	18	7.5	0.13	0.03	3.1	38
2022-May	31	5.3	0.40	0.37	2.8	35
2022-Jun	30	9.4	0.23	0.19	4.7	64
2022-Jul	31	10.5	0.26	0.14	6.0	91
2022-Aug	31	10.7	0.44	0.30	6.6	85
2022-Sep	30	12.1	0.33	0.49	6.5	74
2022-Oct	31	13.4	0.31	0.33	6.2	55
2022-Nov	30	13.8	0.34	0.54	7.8	81
2022-Dec	31	23.0	-0.16	0.01	12	99
2023-Jan	31	13.1	0.67	0.35	10	88
2023-Feb	28	12.9	0.54	0.58	9.4	108
Overall	322	8.9	0.67	0.24	7.5	82

[a]There is no evaluation guidance for realistic performance statistics for NO_2 measurement with novel monitors, hence only the ideal values are listed here. [b]326 daily data were retrieved from Clarity (data completeness: 100%). 4 days of data (4/21/2022 – 4/24/2022) were missing from the retrieved EPC dataset. EPC data completeness in April and for the entire testing period was 82% and 99%, respectively.

2.3 Summary of Performance Findings for PurpleAir II-SD and Clarity Node-S

Tables 13 and 14 provide summaries of the performance statistics found here. For 24-hr average $PM_{2.5}$ levels, we found the performance of the Clarity Node-S, after calibration, to be generally reasonable, meeting most of the accuracy and precision performance targets in the USEPA testing guidance. However, the linearity (R^2) is somewhat low at only 0.52, and outside the target range. The PurpleAir II-SD had slightly worse performance than the Clarity Node-S for most measures. Both linearity (R^2) and normalized error (NMRSE) were outside the target ranges, however overall bias (intercept and slope) was better than for the Clarity Node-S. Additionally, based and 11 months of data, we found the accuracy of PurpleAir II-SD to vary substantially over time. Only the root-mean-squared error (RMSE) consistently met the performance target, with a period average error of 3.0 $\mu g/m^3$. The performance of the Clarity Node-S also varied from month to month, but fewer months had performance statistics outside the target range. No trends in increasing or decreasing performance over time are apparent in the data.

For NO_2, which is only measured by the Clarity Node-S, performance testing indicated low accuracy. For example, linearity with the reference measurement overall was only about 0.25 for both 24-hr and 1-hr average NO_2. Bias and normalized error were also high. Precision for measuring 24-hr average NO_2 was good at 18%, but that for 1-hr average NO_2 was 34%. Performance was better for most measures for 24-hr average NO_2 than for 1-hr average NO_2.

Table 13. Summary of performance statistics for 24-hr average $PM_{2.5}$ from the novel monitors.

	Accuracy					Precision	
	Intercept[b]	slope	R^2	RMSE[b]	NRMSE (%)	SD[b]	CV (%)
Target values[a]	-5 ≤ b ≤ 5	1.0 ± 0.35	≥ 0.70	≤ 7	≤ 30	≤ 5	≤ 30
PurpleAir II-SD	-0.60	0.84	0.48	3.0	37	1.6	27
Clarity Node-S[c]	1.5	0.75	0.52	2.2	28	2.2	21

[a]Target values are based on the USEPA performance testing guidance for 24-hr $PM_{2.5}$ [Duvall et al., 2021)]. Values in grey do not meet the target. [b]Units are μg/m³. [c]After calibration.

Table 14. Summary of NO_2 performance statistics for the Clarity Node-S monitor.

	Accuracy					Precision	
	Intercept[b]	slope	R^2	RMSE[b]	NRMSE (%)	SD[b]	CV (%)
Ideal values[a]	0	1	1	0	0	0	0
1-hr NO_2	10.2	0.53	0.25	8.7	95	1.5	34
24-hr NO_2	8.9	0.67	0.24	7.5	82	0.8	18

[a]There is no evaluation guidance for realistic performance statistics for NO_2 measurement with novel monitors, hence only the ideal values (perfect accuracy and precision) are listed here. [b]Unit is ppbv. [c]After calibration.

3 Community air quality monitoring

3.1 Monitoring network expansion

During this project year, three community air monitoring sites added to the network. They are Sulfur Spring Park, Perry Harvey Sr. Park, and Robles Park. In total, low-cost monitors have been installed at seven community locations near the I-275 and I-4 highways (and at two regulatory reference monitoring sites). Figure 15 shows a map of the existing sites, along with the monitors installed at each. Table 15 provides descriptive information about each site.

3.2 Community air quality assessment

More data on neighborhood air quality were collected and analyzed during the internship period. Here we describe results from analysis of the 24-hr $PM_{2.5}$ levels based on the Clarity and PurpleAir device data.

Figure 16 (a, b, and c) provides 24-hr $PM_{2.5}$ levels measured at both the community sites and the EPC regulatory sites, with descriptive statistics for the full testing period provided in Table 16a. As community data for each site and device were collected over different timeframes, the record of observed 24-hr average $PM_{2.5}$ concentrations varied. Hence, Table 16b shows descriptive statistics for a concurrent testing period (3/1/2023 – 4/30/2023) and monitor type (Clarity Node-S devices) to allow comparisons between sites. Based on the calibrated data from the Clarity Node-S devices over the concurrent testing period, the lowest mean concentration (7.2 $\mu g/m^3$) of 24-hr average $PM_{2.5}$ was observed at Perry Harvey Park. The concentrations at the park sites were generally lower than those at the non-park community sites. For the reference sites, the mean daily $PM_{2.5}$ level measured at the Sydney background site was lower than that at the non-park sites, but higher than that at the park sites. The mean level measured at the Munro near-road reference site was intermediate.

Several of the raw measured concentration seen in Figure 16 at all sites were higher than the primary daily National Ambient Air Quality Standard (NAAQS) threshold level for 24-hr $PM_{2.5}$ of 35 $\mu g/m^3$. However, once calibrated, all values were below the standard level as shown in Table 17 (a and b). Much of the calibrated data values were also below the more stringent Air Quality Index (AQI) category threshold for good air quality of 12 $\mu g/m^3$, although a few to many days with average levels above 12 $\mu g/m^3$ can be seen in the calibrated data for most sites. At community sites, the number of days with average levels above the good AQI threshold was highest at Seminole Elementary School according to the Clarity Node-S data, with 40 days with moderate AQI (Table 17a). Additionally, we see many days that the average concentration exceeds typical background levels of about 5 $\mu g/m^3$, with some spikes that reach over 20 $\mu g/m^3$. Further analysis is necessary to gain a better understanding of the causes for the variations in community air quality. Overall, result suggest the need for continued monitoring to ensure the protection of health for all people.

Figure 15. A map of the locations of monitoring sites. The red pins indicate the community air monitoring sites, while the yellow pins indicate the reference sites. Type(s) of monitor(s) installed at each site are provided in parentheses. PA indicates a PurpleAir device. See Table 15 for the meaning of the site name abbreviations.

Table 15. Descriptive information on the low-cost monitors at the community sites

Site abbreviation	Site full name	Address	Installed Monitor	Distance to Road (m)	Direction to Interstate*
THJCA	Tampa Heights Junior Civic Assoc.	2005 N Lamar Ave, Tampa, FL 33602	PurpleAir II-SD, Clarity Node-S	15 4	East (I-275) East (I-275)
SES	Seminole Elementary School	6201 N Central Ave, Tampa, FL 33604	PurpleAir II-SD, Clarity Node-S	118 106	East (I-275) East (I-275)
NMZ	New Mount Zion Baptist Church	2511 E Columbus Dr, Tampa, FL 33605	PurpleAir II-SD	105	South (I-4)
Saunders	Robert W. Saunders Sr. Public Library	1505 N Nebraska Ave, Tampa, FL 33605	Clarity Node-S	415	NW (I-275)
Sulfur Springs	Sulfur Springs Park	701 E Bird St, Tampa, FL 33604	Clarity Node-S	220	West (I-275)
Perry Harvey	Perry Harvey Park	1000 E Harrison St, Tampa, FL 33602	Clarity Node-S	100	NW (I-275)
Robles	Robles Park	3305 N Avon Ave #5906, Tampa, FL 33603	Clarity Node-S	220	East (I-275)

Direction of the road in relation to the monitor.

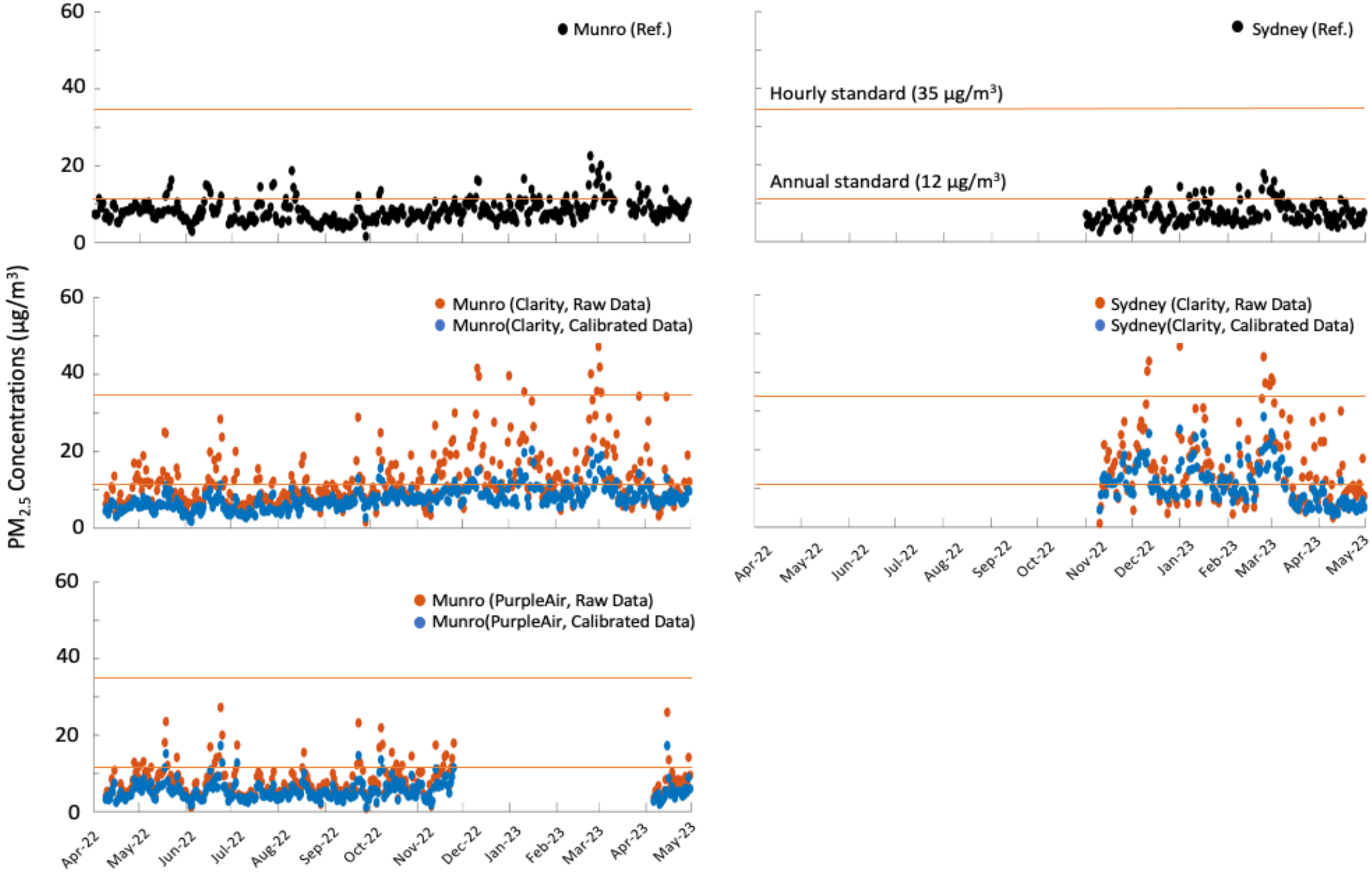

Figure 16a. Trends over time in 24-hr average $PM_{2.5}$ concentrations measured at the EPC reference sites (Munro and Sydney) by the reference monitors and co-located novel monitors. Note that calibrated data (blue dots) were used for assessing performance. Time periods of measurement are as follows: Munro ref. (4/9/2022 – 2/28/2023), Munro Clarity (4/9/2022 – 4/30/2023), Munro PurpleAir (4/9/2022 – 11/25/2022 and 4/6/2023 – 4/30/2023), Sydney ref. (11/9/2022 – 2/28/2023), Sydney Clarity (11/9/2022 – 4/30/2023).

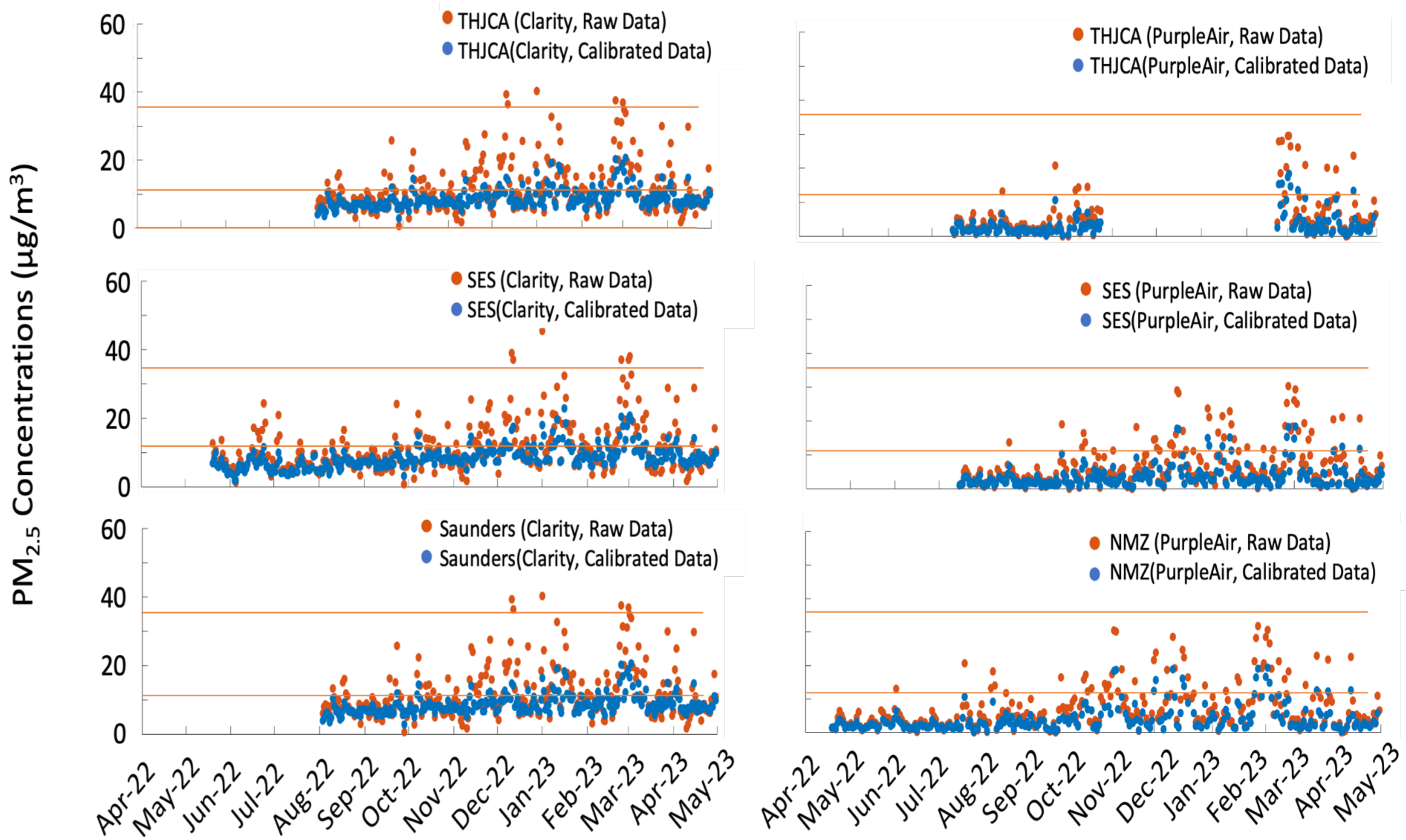

Figure 16b. Trends over time in 24-hr average $PM_{2.5}$ concentrations measured at the neighborhood sites. Note that calibrated data (blue dots) were used for assessing performance. Time periods of measurement are as follows: THJCA (7/22/2022 – 4/30/2023), SES (5/20/2022 – 4/30/2023), Saunders (8/3/2022 – 4/30/2023), and NMZ (4/15/2022 – 4/30/2023). Community site names for the codes are provided in the Table 15.

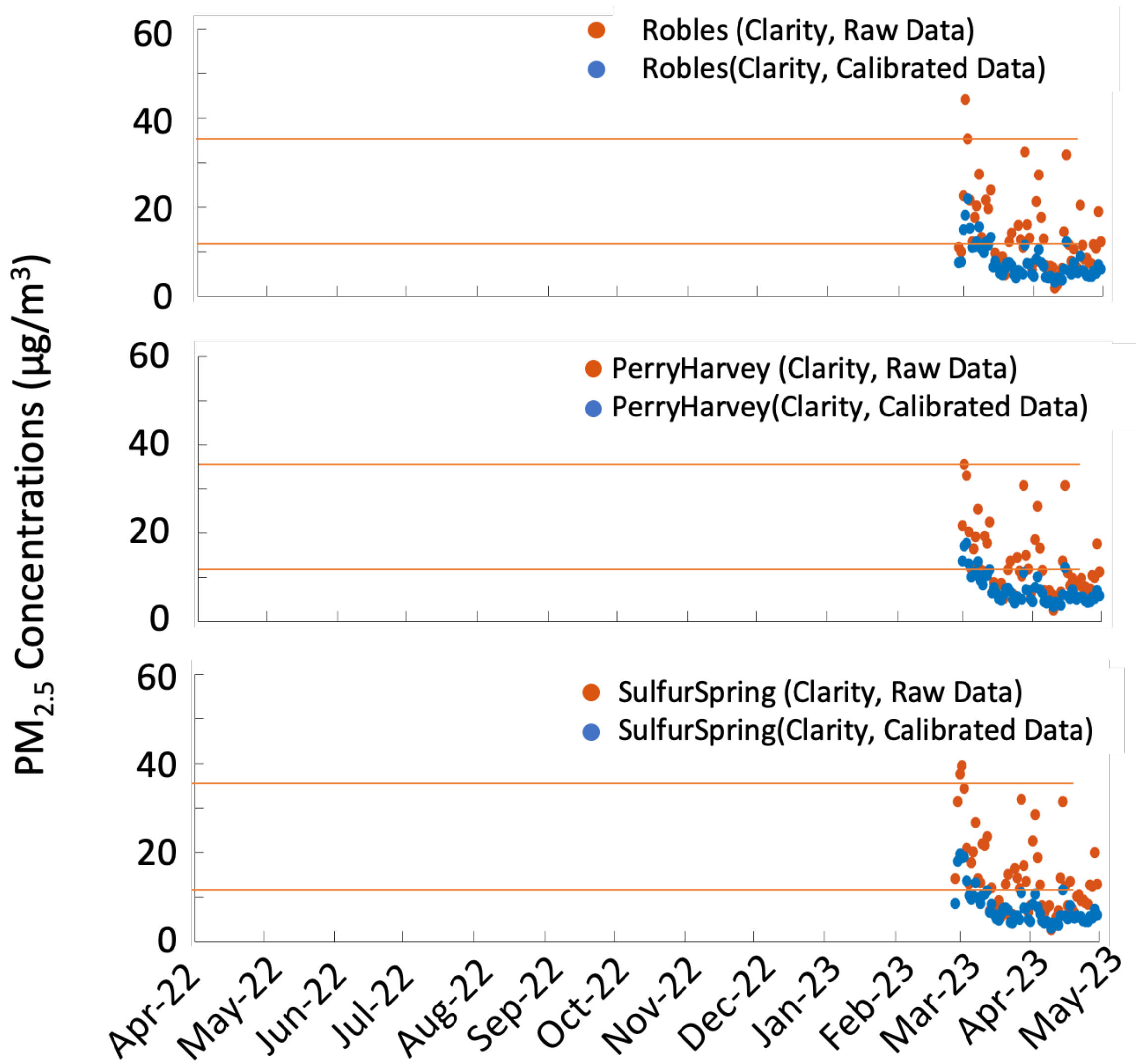

Figure 16c. Trends over time in 24-hr average $PM_{2.5}$ concentrations measured at the park sites. Community site names for the codes are provided in the Figure 14 caption. Note that calibrated data (blue dots) were used for assessing performance. Time periods of measurement are as follows: Perry Harry Park (3/1/2023 – 4/30/2023), Robles Park, (3/1/2023 – 4/30/2023), Sulfur Springs (2/27/2023 – 4/30/2023). Community site names for the codes are provided in the Table 15.

Table 16a. Descriptive statistics of the data shown in Figure 16 (a, b, and c).

	Numbers of observations	Mean	Minimum	25th percentile	Median	75th percentile	Maximum
EPC (Sydney, ref.)	181	7.5	2.6	5.5	6.8	9.1	17.7
EPC (Sydney, CN)	172	11.2	3.2	7.3	10.0	14.5	28.6
EPC (Munro, ref.)	370	8.4	1.7	6.3	7.9	9.6	22.6
EPC (Munro, CN)	387	7.8	1.7	5.9	7.3	9.1	20.4
EPC (Munro, PA)	256	5.5	1.2	3.8	5.1	6.6	17.3
SES (CN)	346	8.6	1.8	6.7	8.2	10.0	22.9
SES (PA)	290	3.6	0.3	1.5	2.7	4.3	18.4
NMZ (PA)	290	4.0	0.2	1.6	2.7	5.1	19.3
THJCA (CN)	283	8.2	2.4	6.6	7.8	9.3	19.8
THJCA (PA)	159	3.4	0.4	1.5	2.3	3.8	18.4
Saunders (CN)	271	8.8	2.9	6.8	8.2	10.1	20.6
Perry Harvey (CN)	61	7.2	3.3	4.9	6.1	8.6	17.7
Robles (CN)	63	7.7	3.2	5.0	6.5	9.6	21.9
Sulfur Spring (CN)	63	7.6	3.1	5.0	6.2	9.2	19.6

ref. indicates data from regulatory measurements, while CN indicates calibrated data from Clarity devices. PA indicates calibrated data from PurpleAir devices. Data from each site are for different time periods.

Table 16b. Descriptive statistics of calibrated 24-hr average $PM_{2.5}$ concentrations measured by the Clarity Node-S devices at the reference sites and community sites during a consistent period (3/1/2023 – 4/30/2023).[a]

	Numbers of observations	Mean[a]	Minimum	25th percentile	Median	75th percentile	Maximum
SES	61	9.7	5.9	7.6	8.7	10.6	20.8
Saunders	61	9.6	5.7	7.6	8.7	10.5	20.6
EPC (Munro)	61	9.2	5.6	7.2	8.3	10.2	18.9
THJCA	61	8.8	5.2	6.8	8.0	9.6	19.8
EPC (Sydney)	61	8.2	3.2	4.9	6.2	10.2	24.3
Robles	61	7.7	3.2	4.9	6.2	10.0	21.9
Sulfur Spring	61	7.4	3.1	4.9	6.0	8.8	19.6
Perry Harvey	61	7.2	3.3	4.9	6.1	8.6	17.7

[a]Data are only reported for devices with a full record of data for the period. [b]Rows are in descending order by mean concentration.

Table 17a. Number and percentage (%) of 24-hr average $PM_{2.5}$ concentrations exceeding the thresholds over the full testing period.

	Numbers of observations			Days above 24-hr NAAQS level (35 μg/m^3), # (%)	Days with AQI above 'good': 24-hr level > 12 μg/m^3 # (%)		
	ref.	CN	PA	all	ref.	CN	PA
EPC (Munro)	370	387	256	0 (0)	40 (6.9)	35 (9.0)	7 (2.7)
EPC (Sydney)	181	172		0 (0)	16 (13.3)	64 (37.2)	
SES	-	346	290	0 (0)	-	40 (11.6)	11 (3.8)
Saunders Library	-	271	-	0 (0)	-	33 (12.2)	-
THJCA	-	283	159	0 (0)	-	25 (8.8)	7 (4.4)
NMZ	-	-	290	0 (0)	-	-	15 (5.2)
Robles Park	-	63	-	0 (0)	-	9 (14.3)	-
Perry Harvey Park	-	61	-	0 (0)	-	6 (9.8)	-
Sulfur Spring Park	-	63	-	0 (0)	-	6 (9.5)	-

ref. indicates data from regulatory measurements, CN indicates calibrated data from Clarity Node-S devices, and PA indicates data from the PurpleAir II-SD devices. Data from each site are for different time periods.

Table 17b. Number and percentage (%) of 24-hr average $PM_{2.5}$ concentrations exceeding the thresholds during a consistent period (3/1/2023 – 4/30/2023).

	Numbers of observations			Days above 24-hr NAAQS level (35 μg/m^3), # (%)	Days with AQI above 'good': 24-hr level > 12 μg/m^3 # (%)		
	ref.	CN	PA	all	ref.	CN	PA
EPC (Munro)	52	61	25	0 (0)	12 (23.1)	9 (14.8)	1 (4.0)
EPC (Sydney)	61	61	-	0 (0)	4 (6.6)	11 (18.0)	
SES	-	61	61	0 (0)	-	10 (16.4)	3 (4.9)
Saunders Library	-	61	-	0 (0)	-	10 (16.4)	-
THJCA	-	61	61	0 (0)	-	8 (13.1)	5 (8.2)
NMZ	-	-	61	0 (0)	-	-	6 (9.8)
Robles Park	-	61	-	0 (0)	-	9 (14.8)	-
Perry Harvey Park	-	61	-	0 (0)	-	6 (9.8)	-
Sulfur Spring Park	-	61	-	0 (0)	-	5 (8.2)	-

ref. indicates data from regulatory measurements, CN indicates calibrated data from Clarity Node-S devices, and PA indicates data from the PurpleAir II-SD devices.

Figures 17 and 18 (provide graphs of the diurnal cycles and weekly cycles, respectively, of the $PM_{2.5}$ level at each monitoring site, based on data from the EPC regulatory measurements and Clarity devices (after calibration). Table 18 provides details on the peak hours and days with their mean values. Regarding the average values found for each hour of the day (Figure 17 a and b), concentrations at the urban sites (all sites except the Sydney background site) appear to increase and show more spread from evening to early morning, with mean levels peaking in the morning (4–11 am). Concentrations at the background site show more pronounced variability. In urban areas, the $PM_{2.5}$ peaks are likely influenced by the combination of morning rush hour traffic and the lower atmospheric mixing heights commonly experienced during early hours of the day. Levels during mid-day (about 10 am to 4 pm) were observed to generally be lowest and have the least spread. The means and peaks of $PM_{2.5}$ levels at the community and regulatory sites look higher than those at the parks. This supports the idea that urban planning may play an important role in community air quality. Average $PM_{2.5}$ levels measured each day of the week at each community and reference site (Figure 18 a and b), were fairly consistent throughout the week. The day with the highest mean concentrations was consistently Wednesday across sites.

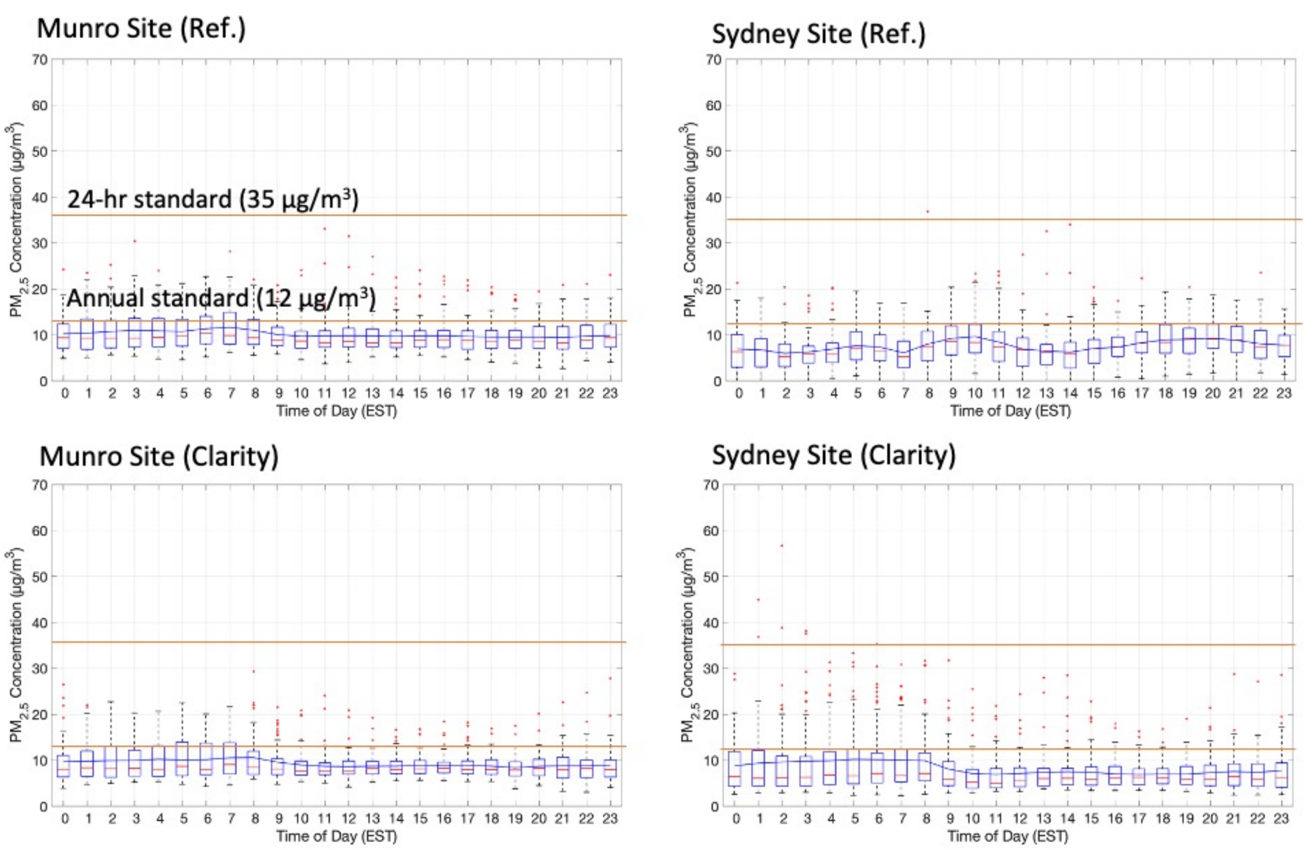

Figure 17a. Diurnal cycle boxplots of the cumulative distribution of $PM_{2.5}$ levels by hour of day at each of the reference sites for the period 3/1/2023 – 4/30/2023.

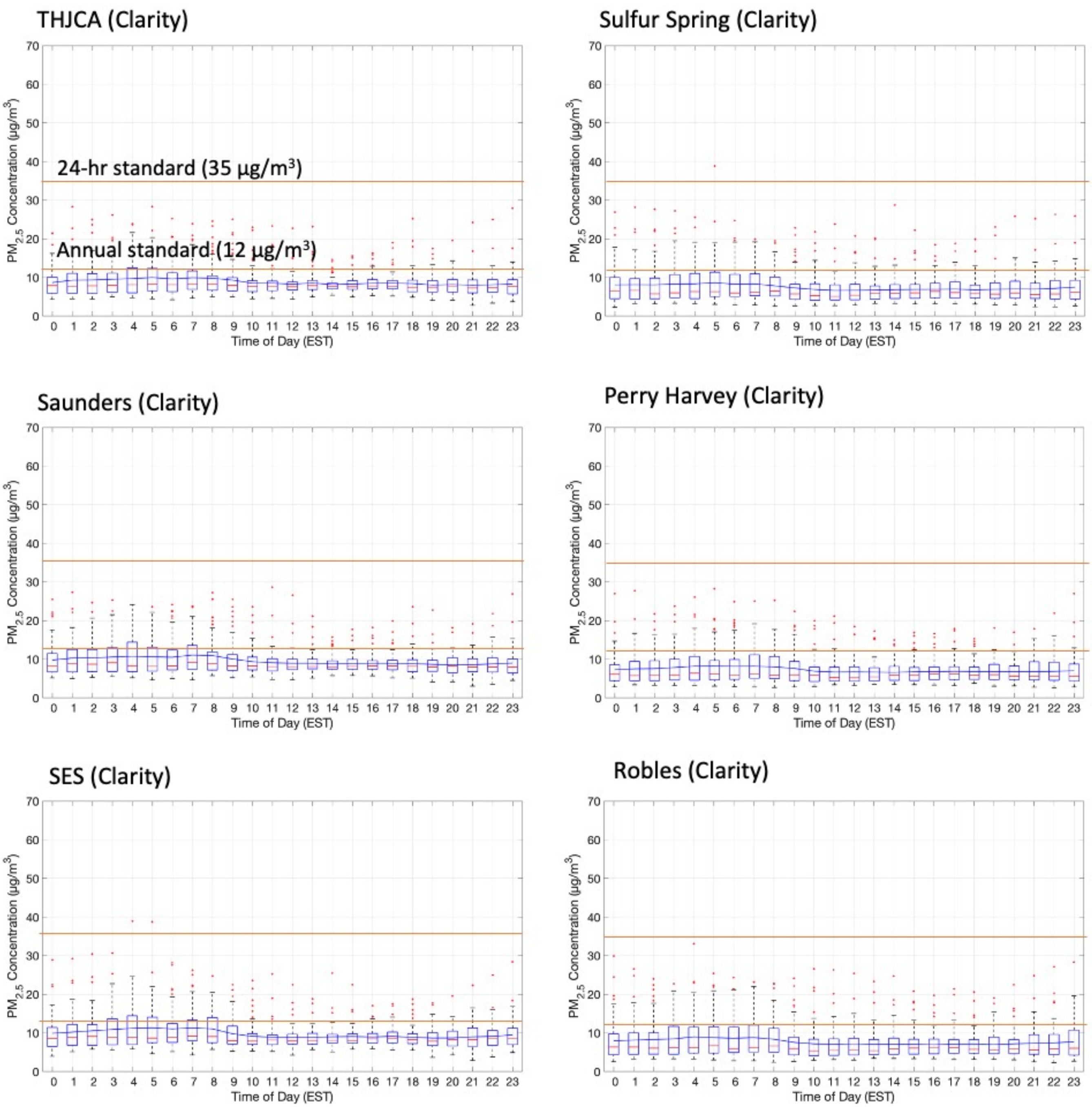

Figure 17b. Diurnal cycle boxplots of the cumulative distribution of $PM_{2.5}$ levels by hour of day at each of the community sites for the period 3/1/2023 – 4/30/2023. Community site names for the codes are provided in the Table 15.

Table 18. Peak hours and peak days of mean $PM_{2.5}$ concentrations at each site (3/1/2023 – 4/30/2023)

	Peak hour (Time, Value [$\mu g/m^3$])		Peak day (Day, Value [$\mu g/m^3$])	
	ref.	CN	ref.	CN
EPC (Munro, CN)	7-8 AM, 11.7	8-9 AM, 10.6	Wednesday, 11.4	Wednesday, 10.3
EPC (Sydney, CN)	10-11 AM, 9.7	5-6 AM, 10.3	Wednesday, 8.9	Wednesday, 9.8
SES (CN)	-	5-6 AM, 11.4	-	Wednesday, 10.7
Saunders Library (CN)	-	7-8 AM, 11.1	-	Wednesday, 10.5
THJCA (CN)	-	5-6 AM, 10.0	-	Wednesday, 9.9
Robles Park (CN)	-	4-5 AM, 9.0	-	Wednesday, 8.2
Perry Harvey Park (CN)	-	5-6 AM, 8.2	-	Wednesday, 7.8
Sulfur Spring Park (CN)	-	5-6 AM, 8.7	-	Wednesday, 8.5

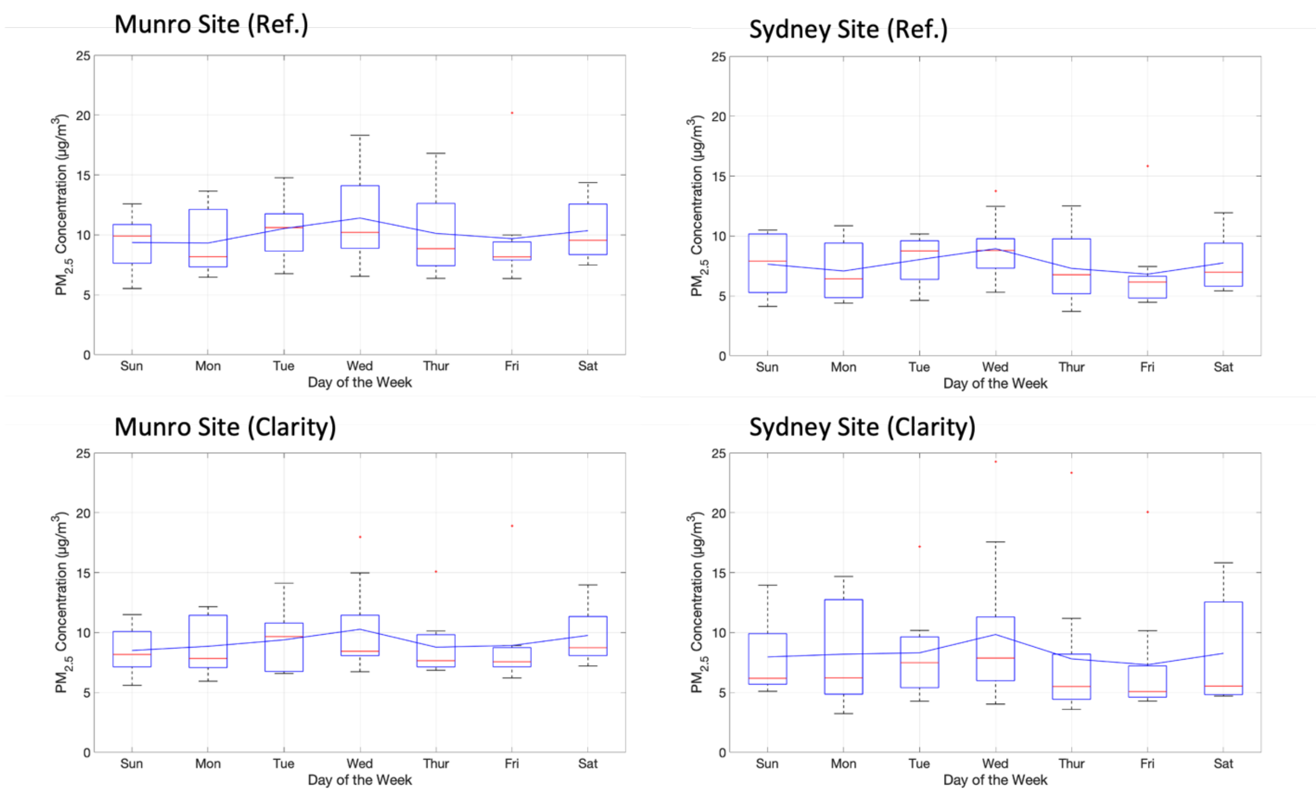

Figure 18a. Weekly cycle boxplots of the cumulative distributions of $PM_{2.5}$ levels by day of the week at each of the reference sites for the periods 3/1/2023 – 4/30/2023. Community site names for the codes are provided in the Table 15.

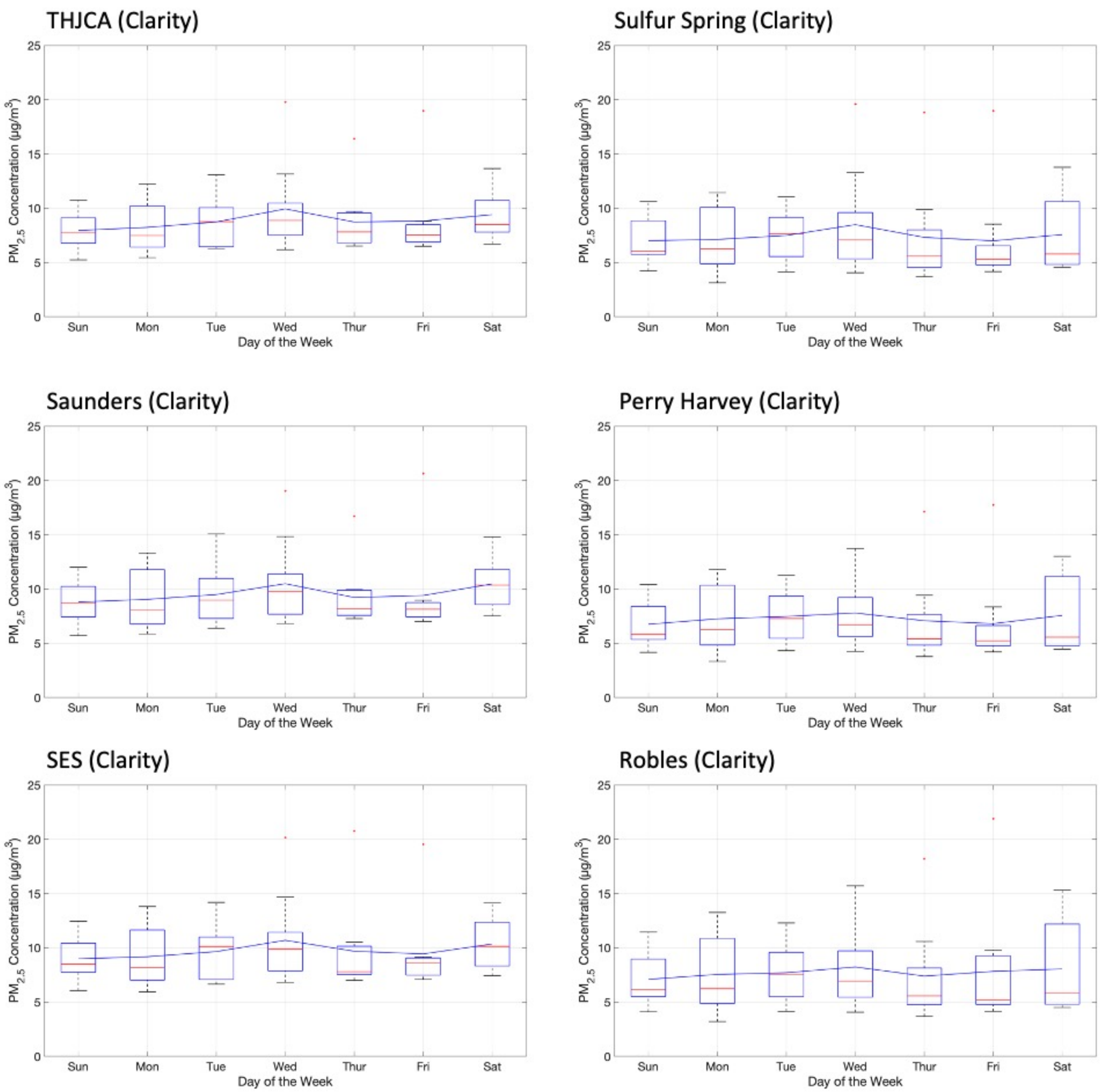

Figure 18b. Weekly cycle boxplots of the cumulative distributions of $PM_{2.5}$ levels by day of the week at each of the community sites for the period 3/1/2023 – 4/30/2023. Community site names for the codes are provided in the Table 15.

3.3 Discussion of community air quality

This year, we expanded our air monitoring efforts to three additional sites located in city parks. We also collected and analyzed data from all sites over the year. However, due to the different time periods of installation and calibration procedures, periods of data collected between sites and devices differed. Hence, comparisons between sites and cycle analysis results here are primarily based on two months (3/1/2023–4/30/2023) of concurrently available 24-hr average $PM_{2.5}$ data from the Clarity Node-S devices. Collection and analysis of a longer period of concurrent measurement remains a priority for continuing work. Furthermore, analysis of NO_2 at the community air quality sites are not included because calibrations to ensure consistent quality of the data are still ongoing.

Overall, our results indicate that 24-hr average $PM_{2.5}$ concentrations remained below the U.S EPA NAAQS threshold for all data studied, irrespective of measurement device or site. However, there were several days at all sites for which measured levels by at least one monitor exceeded the AQI good air quality level (12 $\mu g/m^3$). This suggests that ongoing monitoring of neighborhood levels is important for protection of community health.

Comparing between sites for the two-month period of concurrent data (3/1/2023–4/30/2023), mean levels of $PM_{2.5}$ at the non-park community sites (SES, Saunders, and THJCA) were higher than those observed at the park sites (Robles Park, Sulfur Springs Park, and Perry Harvey Park). This is consistent with research indicating the presence of green space can improve air quality. Further, these observations support the notion that urban planning can play an important role in influencing community air quality. Mean levels of 24-hr average $PM_{2.5}$ measured by the Clarity Node-S at the on-road reference site (Munro) were in the range of those measured at the non-park community sites, though both SES and Saunders had higher mean levels. Levels measured at the background reference site (Sydney) were lower than levels measured at the non-park community sites, but higher than those at the park sites.

Mean hourly-average levels of $PM_{2.5}$ were observed to peak in the early morning (4–9 am) by the Clarity Node-S devices at all sites, a window consistent with the reference monitor at the Munro EPC site. However, the reference monitor at the background site (Sydney) indicated a peak later in the morning (10–11 am). The patterns observed are expected to vary based on specific location, season, and local activities. During the early morning hours, there is typically an increase in traffic emissions. In addition, meteorological factors, such as temperature inversions and low wind speeds, tend to occur during the early morning hours. These conditions can trap pollutants close to the ground, leading to higher concentrations of $PM_{2.5}$. The background site (Sydney) experiences a different pattern; it might be influenced by the wind or fewer local sources of pollution. Placement of meteorological instruments at community monitoring sites could help to explore potential sources affecting pollutant levels. Although little variability by day of the week was observed at most sites, Wednesday had peak mean levels for all monitoring sites. One possible reason is the mid-week increase in traffic activities. However, a more detailed analysis is needed to confirm the specific reasons.

4 Community education and engagement

The community education and engagement initiative aimed to foster awareness and involvement among community members regarding TRAP and its impacts. The summary highlights the key aspects of this program, including the development of educational materials and community engagement activities performed during the internship period.

4.1 Development of educational materials

Educational materials play a crucial role in enhancing community knowledge and capacity, as well as promoting engagement and empowerment in decision-making processes related to urban planning, community environment, and health. It is essential to develop these materials based on the instruments utilized in the communities and information obtained from the community air monitoring network. Therefore, these materials were designed to enhance community members' understanding of TRAP, its sources, health effects, and strategies for mitigating exposure. The development process involved careful consideration of the target audience's needs and preferences to ensure the materials were engaging and informative.

During this year, we focused on developing introductory videos for the project and illustrative videos for the PurpleAir map and Clarity map. These videos serve as valuable resources for community members, helping them better understand the projects and gain insights into community air quality. By utilizing these educational materials, we hope to equip the community with the necessary information and tools to actively participate in shaping their environment and make informed decisions.

4.2 Community engagement activities

Throughout the year, we actively engaged with the community through various events and presentations to raise awareness about air quality issues and promote environmental justice. The community engagement activities performed during this project period are listed and described below. These events and presentations contributed to community education, empowerment, and the promotion of environmental justice.

- 11/5/2022, The YES! Of America Fair, which took place at All People's Park, provided a valuable platform to interact with the community and raise awareness about the community monitoring network. We established an informative booth that covered topics such as air quality concerns, the health implications involved, and the significance of this project in tackling environmental inequity. Additionally, we presented various air monitoring equipment and conducted engaging hands-on demonstrations for individuals who showed interest.
- 11/17/2022, Tampa Heights Civic Association Air Quality Presentation. This activity provided a valuable opportunity to engage with community leaders and raise their awareness about air quality issues that impact their neighborhood. Our team developed an extensive presentation on air quality, encompassing information about common air pollutants, their sources, and the associated health effects. We also shared the air

quality data collected from the community monitors already deployed. Following the presentation, a question-and-answer session took place, during which attendees expressed their keen interest in understanding the air quality levels and the potential health impacts within their neighborhood.

- 12/2/2022, Tampa Heights Community Garden Holiday Event. We arranged an informational booth to exhibit the objectives of the project, as well as the data and findings pertaining to air quality in the Tampa Heights area. Community members expressed significant concerns regarding their living environment in close proximity to the nearby highway interstate, which serves as a significant source of traffic-related air pollution (TRAP). We actively engaged in conversations with community members to comprehend their concerns and discuss potential solutions. Furthermore, we conducted analyses and discussions on the factors contributing to the inequality in TRAP exposure, including urban planning and historical structural issues.
- 12/16/2022, The Tampa Heights Gala, a prestigious event that gathered leaders from diverse sectors such as government officials, business leaders, community organizers, and environmental advocates, presented a valuable opportunity to interact with influential decision-makers and stakeholders. We seized the occasion to communicate this project's objectives, data, and findings concerning air quality in the Tampa Heights area. Additionally, we advocated for the implementation of sustainable and equitable environmental policies, fostering a dialogue towards a healthier and more balanced environment.
- 4/14/2023, we delivered a presentation about the air quality project to the Tampa Climate Alliance, starting with an introduction to the project's objectives and methodology. We proceeded by providing a concise summary of the collected and analyzed air quality data. During the presentation, we highlighted the disparities in exposure to TRAP across different communities, including low-income neighborhoods and communities of color. This prompted a dynamic discussion among attendees regarding potential solutions, such as policy changes and community empowerment initiatives. The audience expressed a keen interest in collaborating with our project team to advance environmental justice and enhance air quality in the Tampa area. The event played a pivotal role in further engaging and empowering the community in their commitment to environmental justice.
- 4/30/2023, At the NMZ Ministry Fair, we organized an air quality information booth, similar to the Tampa Heights Gala, which gave us another opportunity to engage with community members. During the event, we successfully obtained email addresses from six individuals who expressed a keen interest in staying informed about the progress of the community air quality monitoring project. This enabled us to establish a direct line of communication, keeping community members updated about future developments and events related to community air quality.
- 5/4/2023, we actively participated in the EPC's Clean Air Fair, which provided an outstanding opportunity to connect with a wide range of individuals and organizations. By collaborating with other like-minded entities, we worked together towards our common objectives of enhancing air quality in the Tampa Bay Area.

5 Conclusions

To achieve the goals of the project, we enhanced the evaluation of performance of the two low-cost monitors used in the network, expanded the monitoring network with additional sites, analyzed neighborhood air quality, and promoted community engagement and education. Findings and conclusions are summarized here.

Regarding performance, we found the Clarity Node-S, after internal calibration using manufacturer models, to match reference measurements somewhat more accurately for 24-hr average $PM_{2.5}$ levels than the PurpleAir II-SD. Replicate measures from the Clarity Node-S were also more precise. Neither monitor's values met all the USEPA performance guideline targets overall or for every month of the testing period. Additionally, the performance varied substantially by month, especially for the PurpleAir data, but no trends in increasing or decreasing performance over time were apparent. Based on these results, both devices appear to perform reasonably for community engagement on indicative supplemental neighborhood levels of daily $PM_{2.5}$. We are currently in the process of developing a quality assurance plan that defines categories of data quality and the appropriate interpretation of data from each category for different purposes. Performance of the Clarity Node-S for measuring 1-hr and 24-hr average NO_2 levels was weak. Further work is needed to either improve the quality of the data (such as via novel emerging cross-network calibration approaches) or through testing of additional devices on the market. An ongoing quality assurance procedure to flag data for correction or devices for maintenance is also needed for network sustainability.

Three additional neighborhood air monitoring sites were installed this year to expand the network. They are Sulfur Spring Park, Perry Harvey Sr. Park, and Robles Park along the I-275 and I-4 highways and intersection area. More data were collected for analysis of trends, the diurnal cycle, and weekly cycle. 24-hr averaged $PM_{2.5}$ levels measured by the regulatory monitor at the background site (Sydney) were consistently lower than those measured at the Munro site and most community sites, though levels measured by the Clarity device at the Sydney site were higher. More studies are needed to explore the potential reasons. Typically, the highest diurnal hourly values were observed between 4 - 11 am at all sites, which can be attributed to a combination of factors such as morning rush hour traffic and the lower atmospheric mixing heights typically seen during the early hours of the day. Some peak values at each of the community sites were not seen at the reference sites. During the night hours (12 to 8:00 am), the $PM_{2.5}$ levels were higher than during mid-day at all sites expect the background site. The average and peak hourly levels of $PM_{2.5}$ at the community and reference sites appear to be higher than those observed at the parks. This observation suggests that urban planning, such as including green areas, may have an important impact on neighborhood air quality. Weekly cycles indicated that the day of the week with the highest $PM_{2.5}$ levels was Wednesday at all monitoring sites.

The community education and engagement initiative aimed to increase awareness and participation among community members regarding the impacts of traffic related air pollution (TRAP). The program included the development of educational materials tailored to community needs and preferences, covering topics such as TRAP sources, health effects, and mitigation strategies. Additionally, various community engagement activities were conducted to raise awareness about air quality issues and promote environmental justice. These activities included participation in fairs, presentations to community leaders, and events at community sites. The initiative fostered education, empowerment, and collaboration, providing valuable insights for decision-making processes and interventions related to air quality and community well-being.

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In addition to the funding received through the intern agreement, the work described here was supported by the USF College of Public Health. This support included an internal grant titled "Pilot study and methods development on the use of low-cost sensors and citizen science to reduce air pollution exposure inequality and empower vulnerable communities." The grant provided funding for an undergraduate student assistant, as well as additional project equipment and supplies. The COPH also provided supplemental support for doctoral student and faculty time. Furthermore, the acquisition of low-cost monitoring equipment was made possible by funds from the Federal Highway Administration through a State Transportation Innovation Council (STIC) grant.

References

Brickle, M. B., & Evans-Agnew, R. (2017). Photovoice and youth empowerment in environmental justice research: A pilot study examining woodsmoke pollution in a pacific northwest community. *Journal of Community Health Nursing*, *34*(2), 89-101. https://doi.org/10.1080/07370016.2017.1304148

Cushing, L., Faust, J., August, L. M., Cendak, R., Wieland, W., & Alexeeff, G. (2015). Racial/ethnic disparities in cumulative environmental health impacts in California: evidence from a statewide environmental justice screening tool (CalEnviroScreen 1.1). *American Journal of Public Health*, *105*(11), 2341-2348. https://doi.org/10.2105/AJPH.2015.302643

Duvall, R., Clements, A., Hagler, G., Kamal, A., Kilaru, V., Goodman, L., Frederick, S., Barkjohn, K., VonWald, I., & Greene, D. (2021). Performance testing protocols, metrics, and target values for fine particulate matter air sensors: Use in ambient, outdoor, fixed sites, non-regulatory supplemental and informational monitoring applications. *US EPA Office of Research and Development*.https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=350785&Lab=CEMM

Frederick, S., K. Johnson, C. Johnson, R. Yaga, and A. Clements. (2020). Performance Evaluations of PM2.5 sensors in Research Triangle Park, NC: PurpleAir PA-II-SD, Aeroqual AQY, Applied Particle Technology Maxima, Vaisala AQT420, Sens-it RAMP, and Clarity Node-S. Presented at EPA Air Sensors Brownbag, Research Triangle Park, NC, February 12. https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=CEMM&dirEntryId=348487

Gurram, S., Stuart, A. L., & Pinjari, A. R. (2019). Agent-based modeling to estimate exposures to urban air pollution from transportation: Exposure disparities and impacts of high-resolution data. *Computers Environment and Urban Systems, 75*, 22-34. https://doi.org/10.1016/j.compenvurbsys.2019.01.002

Luo, Y., Nice, S., Saliceto, G., Stuart, A.L. (2023). Low-cost monitoring to reduce traffic-related air pollution exposure and inequality, a pilot study. Final Report to the Transportation Planning Organization of Hillsborough County on Research Agreement for Project Period: September 2021–August 2022. https://planhillsborough.org/wp-content/uploads/2023/04/Low-Cost-Air-Quality-Monitoring-Pilot-Study-USF-Final-Report-04062023.pdf

Qiu, G., Song, R., & He, S. (2019). The aggravation of urban air quality deterioration due to urbanization, transportation and economic development–Panel models with marginal effect analyses across China. *Science of The Total Environment, 651*, 1114-1125. https://doi.org/10.1016/j.scitotenv.2018.09.219

Stuart, A. L., & Zeager, M. (2011). An inequality study of ambient nitrogen dioxide and traffic levels near elementary schools in the Tampa area. *Journal of Environmental Management, 92*(8), 1923-1930. https://doi.org/10.1016/j.jenvman.2011.03.003

Wallace, L., Bi, J., Ott, W. R., Sarnat, J., & Liu, Y. (2021). Calibration of low-cost PurpleAir outdoor monitors using an improved method of calculating PM2.5. *Atmospheric Environment*, *256*, 118432. https://doi.org/10.1016/j.atmosenv.2021.118432

Yu, H., & Stuart, A. L. (2013). Spatiotemporal distributions of ambient oxides of nitrogen, with implications for exposure inequality and urban design. *Journal of the Air & Waste Management Association, 63*(8), 943-955. https://doi.org/10.1080/10962247.2013.800168