Dear Editor,

Thank you for agreeing to consider a revision of our manuscript, "Evaluation and Calibration of Clarity Node S Low-Cost Sensors in Lubbock, Texas". We modified and revised the manuscript to address the reviewers' comments as well as to clarify points that they found confusing or unclear.

We would like to thank the two reviewers, Dr. Brayden Nilson and the anonymous reviewer for their helpful comments and suggestions, and many thanks to you for your time and efforts with this revision. In line with the comments and suggestions, we revised the manuscript and made the requested additions and changes. Below are all the comments (in bold) followed by the replies. The parts that are in italics are corrections that are included in the revised version of the paper:

Sincerely,
Karin Ardon-Dryer

Response to Reviewer 2

RC2: 'Comment on egusphere-2025-4300', Anonymous Referee #2, 20 Nov 2025 reply

The manuscript titled "*Evaluation and Calibration of Clarity Node S Low-Cost Sensors in Lubbock, Texas*" presents a rigorous and well-executed evaluation of four low-cost particulate matter (PM) sensors. The study addresses the critical need for affordable and dense air quality monitoring networks, particularly in regions lacking comprehensive regulatory coverage. Given the increasing relevance of low-cost sensors (LCS) in environmental and public health research, this work is timely and valuable. The methodology is robust, involving long-term collocation with reference instruments, regression-based calibration, and comparative assessments across multiple sites and time periods. The detailed description of experimental setup, calibration approaches, and statistical metrics (e.g., LR, MLR, RMSE, MAE, R^2) enhances transparency and reproducibility. The introduction of PM_{10} as a predictor variable is a noteworthy contribution, and the manuscript provides one of the first formal PM_1 calibrations for Clarity Node S sensors. Overall, the study offers important insights for deploying sensor networks in challenging environmental conditions and provides broadly applicable methodological lessons despite localized calibration results. The discussion of limitations is balanced and useful.

Limitations:

- **The calibration results are highly site-specific to the semi-arid, dust-influenced environment of Lubbock. While acknowledged, the generalization to other climates or aerosol regimes is not demonstrated.**

Thank you for this comment. We agree that the calibration results presented in this study are site-specific to the semi-arid, dust-influenced environment of Lubbock, and we do not intend to suggest that the same correction can be directly applied in other climates or aerosol regimes.

Our position, which is now more clearly stated in the revised manuscript, is that low-cost sensor corrections should be developed and evaluated within the context of local meteorology, dominant particle sources, and aerosol characteristics. To illustrate this point, we added additional analyses showing that corrections or parameterizations developed for Clarity sensors in other regions do not perform adequately when applied to this dust-dominated environment. These results reinforce the need for region-specific calibration rather than universal transferability.

The broader contribution of this work is therefore not a universally applicable correction, but a demonstration of an approach for improving low-cost sensor performance in environments dominated by coarse-mode dust, which remains underrepresented in the literature. We explicitly acknowledge the limitations of this approach and its reduced applicability outside similar semi-arid regions in a newly added limitations section. We believe these revisions clarify the intended scope of the study and appropriately constrain the generalization of the results.

This information was added to the revised manuscript:

4 Limitation

There are several limitations that arise from this work that should be mentioned. This correction may be only effective in locations impacted by dust events or storms (or pollution with large particles) and may not be effective or useful for other pollution types. The correction depended on having measurements of PM_{10}. To develop this correction in other locations, the reference unit should contain both $PM_{2.5}$ and PM_{10} measurements. This means that locations without a reference unit that contain both $PM_{2.5}$ and PM_{10} measurements would not be able to follow this correction. And across the USA, the number of locations that contain both PM sizes is very limited (Ardon-Dryer et al. 2023). After the correction is developed, it is recommended to use the LCS unit PM_{10} values. Unfortunately, in the case of the Clarity Node S sensors, that was not an option, as Clarity Node S sensors were unable to detect these particle size concentrations accurately. Ideally, if the LCS cannot allow the usage of its PM_{10} values to correct the $PM_{2.5}$, correction should be made to the closest reference unit with PM_{10} values. If only one reference unit with PM_{10} available, the correction might be effective only during synoptic dust events that have an impact on a large area, meaning only small differences will be found between neighborhoods (Sandhu et al., 2024; Robinson and Ardon-Dryer, 2024). But it may not be effective during convective dust events when the impact might be localized at a neighborhood level, as shown in Ardon-Dryer (2025). To overcome this issue, as in the case of Phoenix, Arizona, which has multiple PM_{10} sensors, the LCS should be corrected based on the nearest reference sensor. Another limitation is the fact that since the correction depends on the reference unit PM_{10} measurements, times when the reference unit is not active cannot be used, and no calibration will be produced. This could be the case when the reference sensors are down for calibration or maintenance.

- **The Clarity Node S PM_{10} measurements show poor agreement with reference data, with regression failing to substantially improve accuracy. This limits the practical utility of the PM_{10} channel in this context.**

Thank you for this comment. We agree that the Clarity Node S PM_{10} measurements show limited agreement with the reference data and that the regression approach did not substantially improve PM_{10} accuracy in this context. In response, we have added additional analyses comparing the Clarity PM_{10} measurements with an FRM reference instrument to more clearly document the extent and nature of this limitation. These results are now included to provide transparency regarding the performance of the PM_{10} channel and to clarify its restricted practical utility under the conditions examined. We also expanded the discussion to explicitly acknowledge this limitation and to distinguish between the role of PM_{10} as an input to support dust-event correction versus its suitability as a standalone measurement. This clarification has been incorporated into the revised manuscript.

The following information was added to the revised manuscript to address this comment:

Since there were daily filter measurements from the Harvard impactor for PM_{10}, a comparison of daily PM_{10} values was made between the HI, EDM-180, and raw LEAPS units that were active on AEROS during July 3-14, 2024. It should be noted that since only one PM_{10} filter was collected each day, no SD values could be calculated. Results of this comparison are presented in Fig. S3. HI and EDM-180 had a good agreement with each other (for these 12 days), with an average difference of ~0.7μg m^{-3}. Comparison between the two had an R^2 value of 0.91, an RMSE of 2.24

$\mu g\ m^{-3}$, an MAE of 1.75 $\mu g\ m^{-3}$, and a slope of 1.08. Next, a comparison was made between the HI and EDM-180 to the three LEAPS units (LEAPS01, LEAPS41, and LEAPS42). Overall, the LEAPS unit measured much lower PM_{10} daily values than those measured by the HI and EDM-180 (on average, lower by 2.2 and 2.4 times, respectively). Comparison of these 12 days between the three LEAPS units to the two reference units resulted in a very low R^2 value (average R^2 value of 0.32 for HI and 0.27 for EDM-180). Highlighting the inability of the Clarity sensor to detect the PM_{10} concentrations. This comes as no surprise, as previous studies have found that the Clarity sensor or the PMS5003 did not respond to variations in PM_{10} concentrations, regardless of high or low PM_{10} concentrations, producing very high uncertainties, with a combination of bias and noise (Demanega et al., 2021; Molina Rueda et al., 2023).

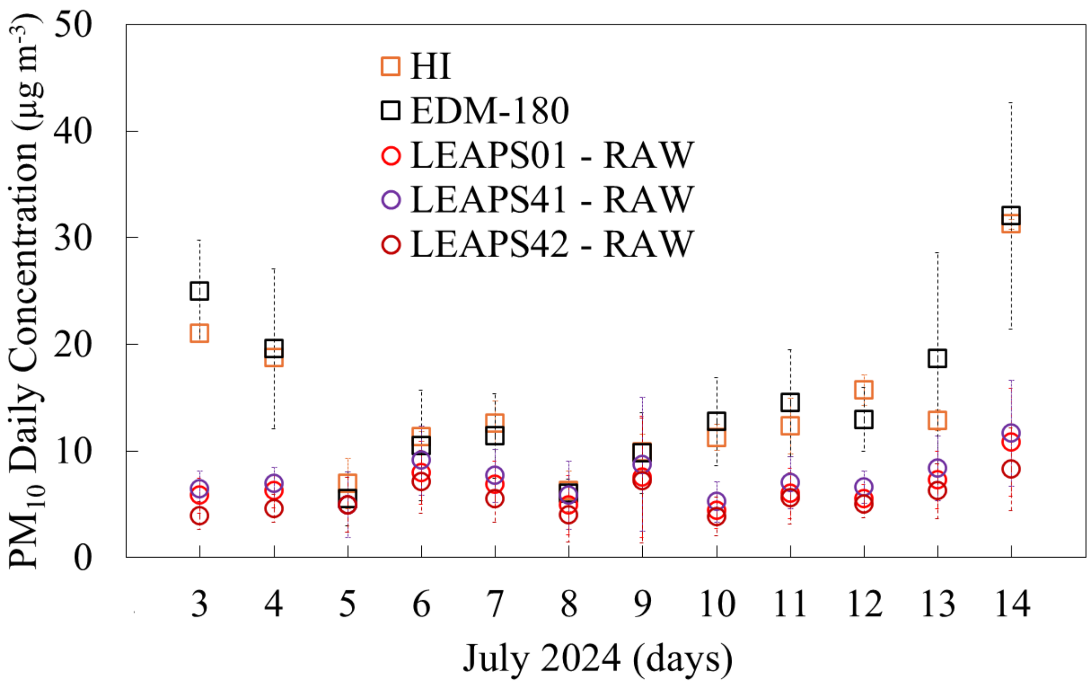

Figure S3: Comparison of daily PM_{10} concentrations between Harvard impactor (orange square), EDM-180 (black square), and the three raw LEAPS units (different colored circles) for July 2024.

One of the reference instruments (BAM-1022) produced negative $PM_{2.5}$ values in more than half the dataset. This complicates inter-comparisons and may introduce biases in calibration and evaluation.

Thank you for raising this important concern. We agree that the presence of negative $PM_{2.5}$ values in the BAM-1022 dataset complicates inter-comparisons and can affect calibration and evaluation. In the revised manuscript, we have clarified that the BAM-1022 was operated independently and that we did not control its configuration or post-processing. To avoid introducing bias, the primary calibration development and evaluation were therefore based on our collocated FEM reference instrument. In response to this and related comments, we conducted additional analyses to explicitly document the frequency and impact of negative BAM values and to assess how they influence comparative performance metrics.

We have expanded the discussion to describe how these negative values were handled in the analysis and to highlight their implications for interpreting BAM-based comparisons. This additional information is now included in the revised manuscript to improve transparency and to ensure that readers can appropriately contextualize the BAM results.

The following information was added to the revised manuscript to address this comment:
According to Jiang et al. (2023), there is very limited documentation on handling negative $PM_{2.5}$ data in the literature. Ambient air always contains certain amounts of particles, and negative $PM_{2.5}$ concentrations should never occur, yet some instruments, like BAM-1022, can record negative $PM_{2.5}$ values.

Some studies converted the negative values to 0 µg m^{-3}, while others used a lower limit of detection threshold for the $PM_{2.5}$ concentrations (Magi et al., 2020; Khreis et al., 2022). Multiple attempts were made, including removal of all the reported negative values, converting the negative values to 0 µg m^{-3} as suggested by Khreis et al. (2022), as well as using a limit of detection threshold (2.4 µg m^{-3}; based on Magi et al., 2019). Yet none of these attempts improved the regression between LEAPS02 (TTU-calibration) to the TCEQ BAM-1022 unit; R^2 values remained below 0.4. To examine the BAM-1022 negative values in depth, all the minimum daily values reported by TCEQ since the site became operational (on August 13, 2016) were observed. From August 13, 2016, to July 11, 2018, the site hosted a TEOM unit, and on July 11, 2018, the unit was replaced with the BAM-1022. None of the 667 days operated by the TEOM had negative hourly $PM_{2.5}$ concentrations. Out of the 2278 days examined since the BAM-1022 became operational (July 11, 2018, to December 31, 2024), more than half (53.2%) had negative $PM_{2.5}$ concentrations daily minimum. It is known that some negative readings are caused by instrument faults or procedural errors, meaning they can be invalid and excluded from air quality reporting towards the public domain (Jiang et al., 2023). But in the case of the unit in Lubbock, they are reported. Perhaps since the air quality system database for the USA (USEPA, 2014) treats negative data from $PM_{2.5}$ continuous monitors as valid, and only values below a threshold of -10 µg m^{-3} are removed. Yet, the USEPA. (2016) indicated that it is generally agreed that negative data should be excluded from public reporting.

Comments and Suggested Revisions:
(i) Some sentences are overly long or repetitive; tightening the prose would improve readability.

Thank you for this comment. We carefully reviewed the entire manuscript and revised the text to improve clarity and conciseness, including shortening overly long sentences and removing repetitive phrasing. We believe these edits have improved the overall readability of the manuscript.

(ii) For several anomalies (e.g., July-August drift), the manuscript notes possible explanations but leaves them unresolved. More definitive interpretation or clearer acknowledgement of uncertainty would be helpful.

Thank you for this comment. We revisited the data and conducted a more detailed examination of the July–August anomalies. During this period, two distinct populations of $PM_{2.5}$ concentrations were observed, particularly in July, which appear to correspond to 21 days (480 hours) and 10 days

(161 hours), respectively. When analyzed separately, each group shows strong agreement between the EDM-180 and corrected LEAPS01 PM2.5 values ($R^2 = 0.91$ and 0.84, respectively), suggesting that the anomalies are associated with underlying differences in the measured conditions.

Examination of meteorological data from both local sensors and the ASOS station indicates significant differences between these two groups in wind speed, temperature, relative humidity, dew point, and pressure, but not in wind direction. These differences may have contributed to the formation of distinct particle populations and could explain the deviations in sensor response during this period. However, we do not have additional chemical or gas measurements in the area to fully verify these hypotheses. As such, the explanation remains provisional, and we have updated the manuscript to clearly acknowledge this uncertainty. This provides context for the observed anomalies while highlighting the limitations of the available dataset.

The following information was added to the revised manuscript to address this comment:

This observation was unclear and there was no explanation for what caused the July and August deviations. It was speculated that since the HI was used in early July, perhaps the walk near the sensors to install and remove the filter holder might have impacted the LEAPS and EDM-180 measurements. However, even after the removal of these days, the R^2 values for July remain low (R^2 of 0.52). Perhaps changes in the internal sensor T and RH during each month could explain the differences. Observation of T and RH throughout the entire examined period (Shown in Fig. S6) did not show any significant differences for July and August. Even observations of meteorological conditions during these months measured by the ASOS unit, including T and RH, dew point temperature, wind speed, and visibility (Fig. S6), did not seem to indicate that July and August had different conditions compared to the other months. Other observations of the monthly scatterplot (in Fig. S5) for July and August highlight that maybe there were two population groups for $PM_{2.5}$ concentrations. An examination was made for July since it seems to have a significantly higher number of observations than August. Two distinct groups were observed in July, one based on 21 days (480 hours), and the other on 10 days (161 hours). When each group was examined separately (Fig. S7), very high R^2 values were found between the EDM-180 and the corrected LEAPS01 $PM_{2.5}$ values (R^2 values of 0.91 for the first group with 21 days and R^2 values of 0.84 for the second group with 10 days). Observations of the meteorological conditions during each group highlight a significant difference in wind speed, dew point temperature, temperature, relative humidity, and pressure, but not in the wind direction or the wind rose (shown in Fig. S7). It seems as if the meteorological conditions could have led to a different chemical reaction, which could have an impact on the particle type and concentration. Unfortunately, there is not a single sensor in the area that measures gases or other pollution types. Therefore, this suggestion will remain as an assumption until additional measurements are added to the area. The different measurements of August times were a continuation of those from July.

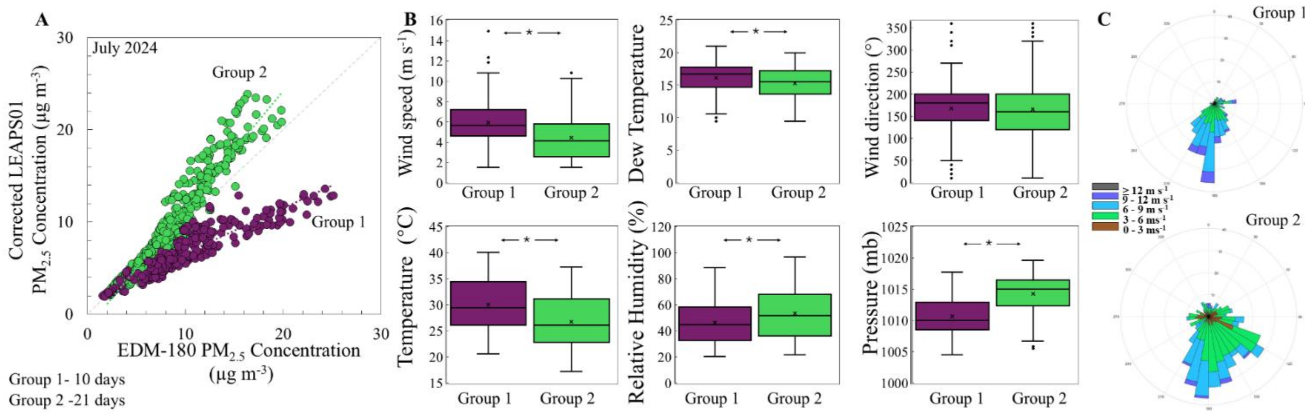

Figure S7: Comparison of $PM_{2.5}$ concentrations of the EDM-180 and corrected LEAPS01 for July 2024 (A), highlighting two different groups based on different days of the month. Comparison of meteorological conditions (B), including wind speed, dew point temperature, wind direction, temperature, relative humidity, and pressure, as well as wind rose for each group (C). An asterisk in B indicates a significant difference between the two groups ($P<0.001$) based on one-way ANOVA.

(iii) Lines 473, 561: Replace conversational phrasing ("We wonder…") with objective academic language (e.g., "It was hypothesized that…").

Per the reviewer's comment, we checked the entire manuscript and changed as many sentences as possible to make sure none have conversational phrasing.

(iv) Throughout the manuscript, substitute informal expressions ("We were hoping…", "We wonder…") with impersonal scientific style.

Changes made to the revised manuscript based on this comment and the one mentioned before, see example of changes made in the revised manuscript in comment iii

(v) Define all abbreviations upon first use; terms such as "LT" and "TTU" are sometimes introduced without initial clarification.

We thank the reviewer for pointing these out. We made sure to add the definition for these abbreviations in the text the first time they appear in the text

(vi) Equations and variable formatting need greater consistency and clarity.

Per the reviewer's comment, we checked all the equations. We thank the reviewer for this comment, as we were able to find a typo. Per the reviewer's comment, we modified the question and the text that describes the variable and simplified the equation as much as possible.

These are some examples of changes that were made in the revised manuscript:

The final correction (named TTU-calibration) was selected to correct the LEAPS $PM_{2.5}$ values units:

$$LEAPS_{PM2.5-TTUc} = (LEAPS_{PM2.5} + 5.77 - (0.0988 * LEAP_T) + (0.00042 * LEAPS_{RH}) + (0.289 * EDM_{PM10}))/2.117 \quad (1)$$

Where $LEAPS_{PM2.5}$ represents the uncorrected (raw) LEAPS $PM_{2.5}$ hourly values, $LEAPS_T$ and $LEAPS_{RH}$ are LEAPS hourly T (°C) and RH (%) values. EDM_{PM10} is the PM_{10} hourly value measured by the EDM-180.

The CC calibration utilized this equation:

$$LEAPS_{PM2.5-CC} = (LEAPS_{PM2.5} + 0.18 - (0.047 * LEAPS_{RH}) - (1.7 * LEAPS_{PM10}))/-1.67 \quad (2)$$

Where $LEAPS_{PM2.5}$, $LEAPS_{PM10}$, and $LEAPS_{RH}$ represent the average LEAPS $PM_{2.5}$, PM_{10}, and RH hourly values.

The final correction of PM_1 is utilized in this equation:

$$LEAPS_{PM1-TTUc} = (LEAPS_{PM1} + 5.77 - (0.12 * LEAP_T) - (0.015 * LEAPS_{RH}) + (0.016 * EDM_{PM10}))/1.51 \quad (3)$$

Where $LEAPS_{PM1}$ represents the uncorrected LEAPS PM_1 hourly values, $LEAPS_T$ and $LEAPS_{RH}$ are hourly T and RH values. EDM_{PM10} is the PM_{10} hourly value measured by the EDM-180.