

We thank the reviewer for their time reviewing our manuscript and their feedback. We have taken the time to make a number of significant improvements to the manuscript based on the reviewers' comments. We have included responses in blue below where the line numbers refer to the manuscript with track changes enabled.

Referee #2

GENERAL COMMENTS The authors present carefully-considered, practical guidance for performing quality assurance checks on PurpleAir data. The authors' model for correcting PurpleAir PM_{2.5} data benefits from a large training dataset that spans many months and locations (39 sites in 16 U.S. states). Together, the quality assurance guidelines and correction model presented here can help users improve the accuracy of PM_{2.5} data reported by PurpleAirs. There will likely be applications in which this U.S.-wide correction still does not produce sufficiently-accurate estimates of local ambient PM_{2.5} concentrations, but I am not here to argue for letting the perfect be the enemy of the good.

We thank the reviewer for their thoughtful review.

SPECIFIC COMMENTS

1. Lines 79–82: I found these two sentences confusing. Are the PurpleAirs that are part of the “larger project” counted as PurpleAirs sent out by EPA (group 1 on line 77) or PurpleAirs independently operated by air monitoring agencies (group 2 on line 77)? Can the authors clarify how these PurpleAirs fit in? Alternatively, can the authors remove these sentences and simply describe the study as involving PurpleAirs “sent out by EPA to capture a wide range of regions and meteorological conditions” and “other collocated sensors”?

We have clarified these lines as follows:

Lines 85-88: Data for this project came from 3 sources: 1) PurpleAir sensors sent out by EPA for collocation to capture a wide range of regions and meteorological conditions, 2) privately operated sensor data volunteered by state, local and tribal (SLT) air monitoring agencies independently operating collocated PurpleAir sensors, and 3) publicly available sensors located near monitoring stations and confirmed as true collocation by air monitoring agency staff.

2. Lines 91–92: The authors state here that their analysis included data from 50 PurpleAirs at 39 sites in 16 states. On lines 87–88, the authors state that their search identified 42 sites in 14 states. Does that mean the 50 PurpleAirs/39 sites/16 states includes both PurpleAirs sent out by EPA and PurpleAirs identified in the search?

Yes. This has been clarified in the text:

Lines 85-101: Data for this project came from 3 sources: 1) PurpleAir sensors sent out by EPA for collocation to capture a wide range of regions and meteorological conditions, 2) privately operated sensor data volunteered by state, local and tribal (SLT) air monitoring agencies independently operating collocated PurpleAir sensors, and 3)

publicly available sensors located near monitoring stations and confirmed as true collocation by air monitoring agency staff. In order to identify publicly available collocated sensors, in August of 2018, a survey of sites with potentially collocated PurpleAir sensors and regulatory PM_{2.5} monitors was performed by identifying publicly available PurpleAir sensor locations within 50 meters of an active EPA Air Quality System (AQS) site reporting PM_{2.5} data in 2017 or 2018. The 50-meter distance was selected because it is large enough to cover the footprint of most AQS sites and small enough to exclude most PurpleAir sensors in close proximity, but not collocated with, an AQS site. From a download of all active AQS PM_{2.5} sites and PurpleAir sensor locations on August 20, 2018, 42 unique sites were identified in 14 states. From this list of public PurpleAir sensors potentially collocated with regulatory PM_{2.5} monitors, we reached out to the appropriate SLT air monitoring agency to understand if these units were operated by the air monitoring agency and their interest in partnering in this research effort. If we could not identify the sensor operator of these 42 sensors, or if the sensor was not collocated at the air monitoring station, the sensor was not used in this analysis.

Lines 116-120: In total, 53 PurpleAir sensors at 39 unique sites across 16 states were ideal candidates and were initially included in this analysis with data included from September 2017 until January 2020. The supplement contains additional information about each AQS site (Table S1) and each individual sensor (Table S2).

3. Lines 121–127: Was the “within 5 µg m⁻³ or 61%” check performed on the 2- minute/80-second averages or on the 24-hour averages? Was this check performed on the cf_1 data or on the cf_atm data? Please clarify.

It was performed on the 24-hr averaged cf_1 data. This has been addressed in the text as follows:

Lines 283-392: Data cleaning procedures were developed using the typical 24-hr averaged agreement between the A and B channels expressed as percent error (Eq. 1).

$$\text{24-hr percent difference} = \frac{(A-B)*2}{(A+B)} \quad (1)$$

Where A and B are the 24-hr average PM_{2.5} cf_1 concentrations from the A and B channels. 24-hour averaged data points with percent differences larger than two standard deviations (2sd=61%) were flagged for removal.

Section 2: Can the authors include some information on the breakdown of regulatory monitors and reference PM_{2.5} measurements by type (FRM vs. FEM and type of FEM)? Maybe this information could be included in Tables S1–S2 and/or summarized in the text? FEM measurements do not always agree with FRM measurements and some FEMs might be more likely to deviate from FRMs than others. I downloaded the daily PM_{2.5} data from the sites listed in Table S1, over the date ranges listed in Table S2, from the AQS. It looks like there were 17 FRMs, 16 BAMs, 16 spectrometers (T640s), and 6 TEOMs across the 39 sites. It looks like the

breakdown of 24-hour measurements was approximately 10% FRM, 50% BAM, 30% spectrometer, and 10% TEOM.

Yes, we have included these details:

Lines 228-231: The dataset was comprised of data from 21 BAM 1020s or 1022s, 19 Teledyne T640 or T640xs, and 5 TEOM 1405s or 1400s. Sixteen sites had FRM measurements. After excluding part of the Iowa dataset BAM1020's provided the most 24-hr averaged points followed by the T640 and T640x, and the RP2025 (Figure S2). 1/5 of the data came from FRM measurements while the rest came from FEMs (Figure S3).

3. Lines 153–154: It looks like there were 13 sites with both FRM and FEM data. It looks like there were three sites (53-033-0057, 53-061-1007, and 55-087-0009) with two FEM monitors and one site (19-113-0040) with two FEMs plus an FRM. What did the authors do when multiple reference measurements (FRM or FEM) were available for a single 24-hour period at a single site? Were all 24-hour average measurements included as separate data points? Or was just one selected and, if so, which one?

Line 231-232: If daily measurements were collected using two methods both points were included in the analysis.

Lines 154–155 and 470–474: Did the authors look at the agreement between 24-hour average FRM and FEM measurements for the dates and sites where both were available? It might be useful for comparison to the agreement between PA and FM data. For the sites and dates listed in Tables S1–S2, it looks like the RMSE for 24-hour FEM measurements, compared to FRM measurements, was $1.7 \mu\text{g m}^{-3}$ for BAMs ($n = 4134$), $2.1 \mu\text{g m}^{-3}$ for spectrometers ($n = 4405$), and $1.1 \mu\text{g m}^{-3}$ for TEOMs ($n = 69$). Does a RMSE of $2.1 \mu\text{g m}^{-3}$ constitute “adequate accuracy”?

We have included analysis based on EPA's tools to understand FEM and FRM performance. We focused on bias instead of RMSE. The T640s are typically biased high (which is likely what is driving the higher RMSE). We have added additional discussion and justification for using these devices.

Lines 235-255: 3.1 FRM and FEM Quality Assurance

The accuracy of the FRM and FEM measurements was considered. In total, Federal Reference Method (FRM) data was used from 13 organizations. The accuracy of these measurements was evaluated using the FRM performance assessments (U.S. EPA, 2020b). They were evaluated using the FRM/FRM precision and bias, the average field blank weight, and the monthly precision. The performance of the FEM monitors was evaluated using the PM_{2.5} continuous monitor comparability assessments (U.S. EPA, 2020a). FEM measurements are compared to simultaneous Federal Reference Method (FRM) measurements. Linear regression is used to calculate a slope, intercept (int), and correlation (R) and the FEM/FRM ratio is also computed. Based on data quality

objectives, the slope should be between 0.9 and 1.1, intercept between -2 and 2, correlation should be between 0.9 and 1, and the ratio should be within 0.9 and 1.1. The most recent 3 years of available data was used to evaluate each monitor.

Performance data was only available for 10 of the 13 collection agencies (77%, Table S3). All available agencies met the FRM/FRM precision goals. All but one state show negative FRM bias suggesting organization reported FRM PM_{2.5} is biased low by 1-22%. Four of the agencies (40%) only marginally fail the $\leq 10\%$ bias criteria with bias from -10.1% to -11%. The one organization with more significant bias (-22%) is driven by the difference in a single FRM measurement pair. All sites typically have acceptable field blank weights and monthly average precision within 30%. The performance of all FRM measurements are acceptable for use in developing the PurpleAir U.S.-wide correction.

Of the 46 unique FEM monitors, comparability assessments were only available for 24 monitors (51%, Tables S4,S5). All slopes were within the acceptable range. One intercept was slightly outside the acceptable range (2.35) and 3 correlations were slightly below the acceptable limit (0.86-0.89), however these values have been considered acceptable for this use. Of greater concern is that 10 FEMs had ratios greater than 1.1 up to 1.3 (41% of monitors) and these were all Teledyne T640 or T640x devices (Figure S4). The data from the T640 and T640x make up about 20% of the total dataset and excluding them would reduce the diversity of the dataset. Since these monitors are frequently used for regulatory applications, the performance of all FEM measurements has been considered acceptable for use in developing the PurpleAir U.S.-wide correction.

U.S. EPA PM_{2.5} Continuous Monitor Comparability Assessments:

<https://www.epa.gov/outdoor-air-quality-data/pm25-continuous-monitor-comparability-assessments>, 2020a.

U.S. EPA PM_{2.5} Data Quality Dashboard: https://sti-r-shiny.shinyapps.io/QVA_Dashboard/, 2020b.

4. Line 149: How come the PurpleAir data had to cover 90% of the 24-hour period to be considered “complete,” but the FEM data only had to cover 75% of the 24-hour period?

This was a somewhat arbitrary distinction however, we felt that a stricter criterion was warranted for the PurpleAir data since we assume it has a higher error. We have added additional discussion of this in the text:

Lines 264-265: A higher threshold of completeness was used for the PurpleAir data since there will likely be more error in these measurements than the FEM or FRM measurements.

5. Line 166: Why was dewpoint considered in addition to temperature and RH?

Some past work has found the dewpoint was able to explain error that temperature and RH were not able to explain. This has been added to the text.

Lines 392-393: Dew point was considered since past work has shown that dewpoint can, in some cases, explain error unexplained by temperature or RH (Mukherjee et al., 2019;Malings et al., 2020).

6. Lines 168–177: I agree that the model inputs should all be data from the Purple Air. I’m also glad the authors point out that temperature and RH data reported by PurpleAirs are biased high and low, respectively. I don’t agree with Reviewer 1 that temperature and RH values reported by PurpleAirs shouldn’t be used just because they’re inaccurate. Your model does not assume they’re accurate; it just assumes that they’re correlated with the actual temperature and RH (see Figure S6 in Magi et al., 2020 and Figures S12–S13 in Tryner et al., 2020). I’m not sure I agree that the temperature and RH reported by the BME280 reflect what the aerosol experiences during measurement. Inaccuracies in the PurpleAir temperature and RH data arise because there is no convective or forced airflow over the BME280 to dissipate heat from the breakout board or other electronic components inside the housing. The inlets to the PMS5003 sensors are at the bottom of the housing, and there is active airflow through the PMS5003 sensors.

We have removed the objected sentence and added the citations to Tryner and Magi in this location.

Lines 391-395: It is important to note that the meteorological sensor in the PurpleAir sensor is positioned above the particle sensors nestled under the PVC cap resulting in temperatures that are higher (2.7 to 5.3°C) and RH that is drier (9.7% to 24.3%) than ambient conditions (Holder et al., 2020;Malings et al., 2020)~~but which may be closer to what is experienced by the aerosol during measurement.~~ In addition, these internal measurements have been shown to be strongly correlated with reference temperature and RH measurements with high precision (Holder et al., 2020;Tryner et al., 2020a;Magi et al., 2019).

10. I agree with Reviewer 3 that correlation between input variables warrants further consideration. Can the authors add a correlogram to the supplement to indicate the extent to which different variables were correlated (lines 179–182)? Might the sensitivity of the model coefficients that the authors discuss on lines 347–349 be due to correlation between the independent variables? Are temperature and RH correlated? Could that be why temperature does not reduce error and bias in the nationwide dataset (line 362)—because it essentially provides the same information as RH?

We appreciate the reviewer’s suggestion and have added a correlogram to the SI and additional discussion to the text. We have also removed the consideration of models with moderately to strongly correlated additive terms throughout (see the response to reviewer 3’s comments)

Lines 357-367: In a multiple linear regression, all independent variables should be independent; however, much previous work has used models that incorporate additive temperature, RH, and dewpoint terms that are not independent (Magi et al., 2019;Malings

et al., 2020). We have not considered these models and have considered models with interaction terms (i.e. $RH * T * PM_{2.5}$) to account for inter-dependence between terms instead. Strong correlations ($r \geq \pm 0.7$) are shown between the 24-hr averaged FEM or FRM $PM_{2.5}$, PurpleAir estimated $PM_{2.5}$ (cf_1 and cf_atm), and each binned count (Figure S6). Since the binned counts include all particles greater than a certain size, we also consider the correlation between the delta of each bin (e.g. particles $>0.3 \mu m$ – particles $>0.5 \mu m$ = particles $0.3-0.5 \mu m$). The delta bin counts were still moderately to strongly correlated ($r=0.6-1$) with the weakest correlation seen between the smallest and largest bins (Figure S7). Moderate correlations ($r = \pm 0.4-0.6$) are seen between temperature, RH, and dewpoint. Weak correlations ($r \leq \pm 0.2$) are seen between the PM variables (i.e. $PM_{2.5}$ and bin variables) and environmental variables (i.e. temperature, RH, and Dewpoint). The correlation between variables was considered when considering model forms.

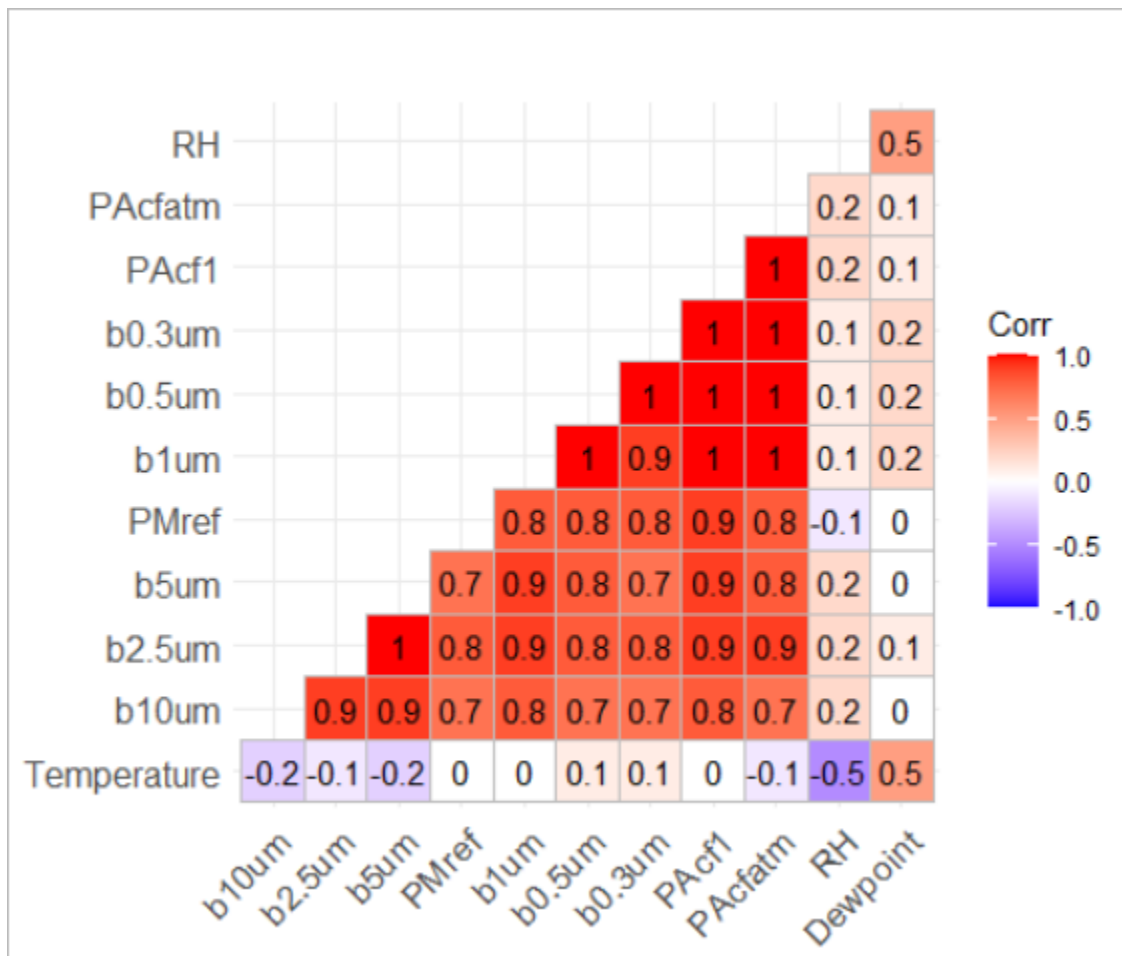


Figure S6. Correlogram showing the pearson correlation (Corr) between considered correction input variables.

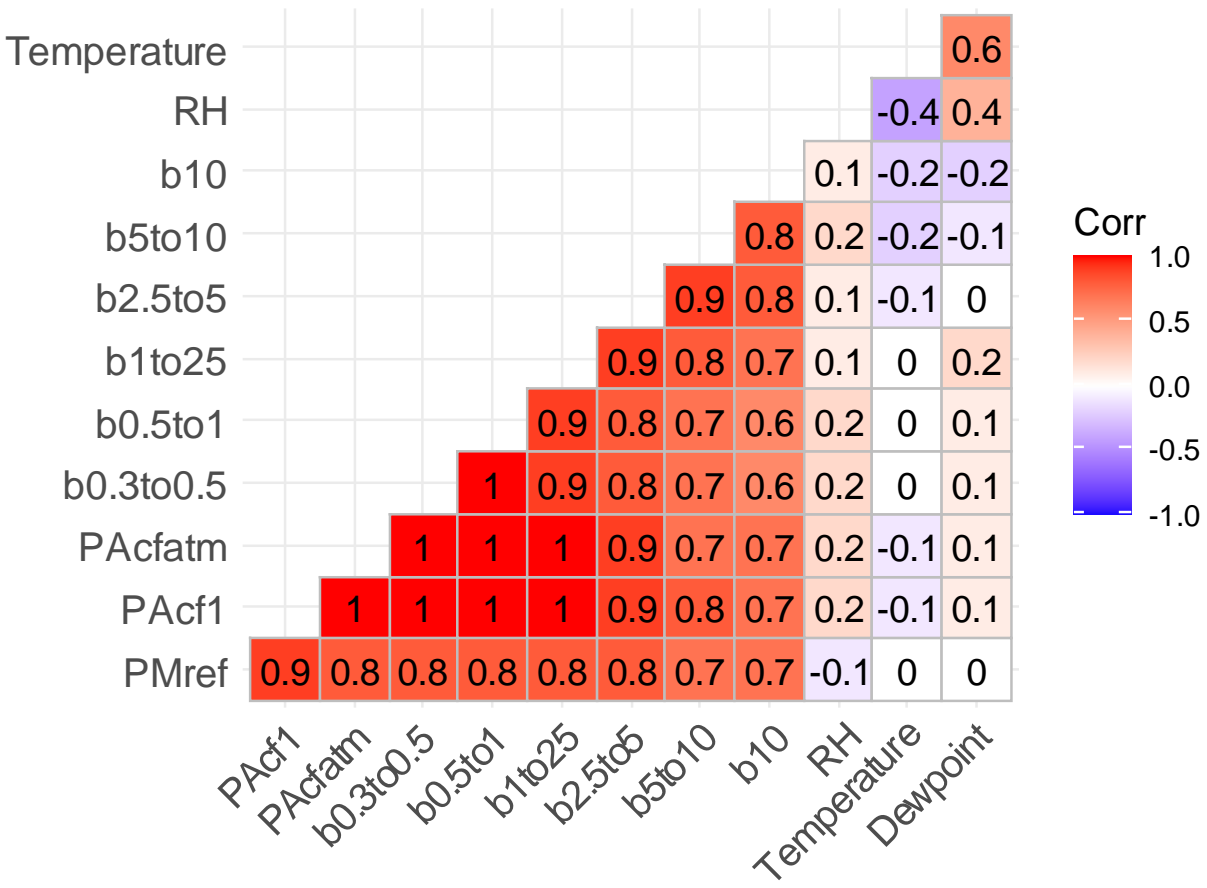


Figure S7. Correlogram showing the pearson correlation (Corr) between considered correction input variables including the difference between bins (e.g. b0.3to0.5 = bin<0.3 - bin<0.5).

11. Lines 202–206: Were these analyses performed using the model fit to the full dataset (Equation 8)? Or were they performed using the cross-validation methods described on lines 187–195? If the model fit to the full dataset was used, how do the authors justify that choice? Wouldn't the model be expected to almost always predict the AQI correctly for the dataset it was fit to?

The reviewer brings up a good point. We have instead plotted the data generated from LOSO withholding.

Lines 736-739: Lastly, we summarize the performance of the sensors across the U.S. using the U.S. daily AQI categories (Federal Register, 1999). For this analysis we use the data corrected using the LOSO withholding where a final correction is built for all but one state and then applied to the withheld state.

This allows us to better understand how the correction will perform in locations not included in our analysis.

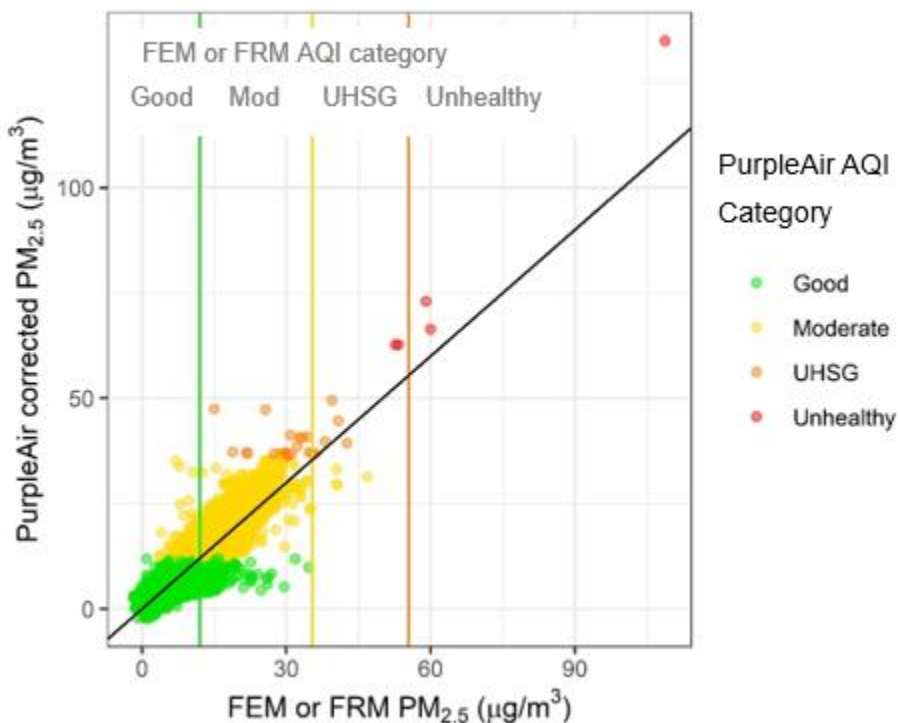


Figure 7. 24-hr AQI categories as measured by the corrected PurpleAir and the FEM or FRM for the full dataset generated with the models built using LOSO withholding.

12. Lines 220–231: It’s great to see this thorough discussion of quality assurance criteria!

Thank you!

13. Line 239: Were these summary statistics calculated before reducing the size of the Iowa dataset and, if so, did any of these values change after?

Line 350-352: These summary statistics were calculated after selecting a random subset of the Iowa data. The median of the Iowa dataset increased from 7 to 10 µg m⁻³ after subsetting since more of the high concentration data was conserved.

14. Line 242: By “10,907 days,” do the authors mean 10,907 pairs of PA/FM 24-hour PM_{2.5} concentrations? Were multiple data points from a single site on a single day (either multiple PurpleAirs or multiple regulatory monitors) treated as one day or as multiple days? Please clarify. This comment also applies to Table 1. There certainly weren’t 3762 days between 11/29/2017 and 12/29/2019.

Line 122: Initially, there were 10,907 pairs of 24-hr averaged collocated data from Iowa

Line 231-232: If daily measurements were collected using two methods both points were included in the analysis.

Table 1: # of Days points

15. Lines 310–312: I agree that it's more appropriate to use the cf_1 data in your model instead of the cf_atm data displayed on the PurpleAir website. The cf_1 data explained more variance than cf_atm data and cf_atm data are known to be nonlinear at concentrations above $25 \mu\text{g m}^{-3}$.

Thank you.

16. Line 335: Does the “linear correction” refer to Equation 3?

Yes, this has been updated in the text

Line 665-666: when applying a linear correction (Eq. 4).

17. Lines 335–337: Is there a typo here? The text says that MBE drops from 3.3 to $0 \mu\text{g m}^{-3}$ for LOBD and from 4.2 to $0 \mu\text{g m}^{-3}$ for LOSO, but in Figure 4 it looks like the opposite: MBE drops from 4.2 to $0 \mu\text{g m}^{-3}$ for LOBD and from 3.3 to $0 \mu\text{g m}^{-3}$ for LOSO.

Yes, thank you for catching this typo we have updated in the text.

Lines 666-667: Using LOBD, the MBE across withholding runs drops significantly from 4.2 to $0 \mu\text{g m}^{-3}$ with a similar significant drop, from 2.8 to $0 \mu\text{g m}^{-3}$

18. Sections 3.4 and 3.5: Did the authors look at whether/how their results varied if only FRM measurements were used as the reference or if only measurements from a single type of FEM (BAM, spectrometer, TEOM) were used as the reference? It seems like the authors' large dataset could be used to investigate this question, which might inform others who try to correct PM sensors by collocating them with regulatory monitors. Groups conducting smaller collocation studies that span a small geographic area might only have access to a single type of FEM, so it would be good to know how that might affect their results.

We have added a brief discussion of this in the text.

Lines 695-710: 5.3.1 The influence of FEM and FRM type

We briefly considered whether the use of both FEM and FRM measurements influenced these results. When sub-setting the data to develop models using the 24-hr averaged $\text{PM}_{2.5}$ data from only the FEM versus only the FRM, only the coefficient for the PA slope term changed. The coefficient was slightly larger for FEM measurement (0.537) and smaller for FRM measurements (0.492). Although the coefficients are significantly different ($p < 0.05$) they are within 10% leading to little difference in the interpretation of PurpleAir $\text{PM}_{2.5}$ measurements. We briefly considered whether the FEM coefficient was driven by the T640s and found that if we build this model excluding all T640 and T640x data, it is not significantly different (0.53). Concerns about error between different types of FEM measurements cannot be explored using this dataset. Further, FEM instruments are not randomly distributed across the U.S. but rather clustered at sites operated by the same air agency. Future work and a more concerted effort may be needed to explore this issue. Overall, the accuracy of all these FEM and FRM methods have been determined accurate enough for regulatory purposes and so we have used all to determine our U.S.-

wide correction. Although FRM measurements are the gold standard, using only FRM measurements would have severely limited our dataset. In addition, the use of FEM measurements will be important in future work to explore the performance of this model correction at higher time resolutions. At higher time resolutions, the noise and precision between different FEMs may impact perceived performance and future work should further explore this.

19. Lines 443–449: Do the authors think the lack of an RH term in the AQ&U model is the reason it overestimates PM_{2.5} concentrations for the authors' dataset? RH is typically low in Salt Lake City, while the authors of this study have data from several sites in more humid locations.

We have added an additional sentence to address this

Line 809-811: Since RH is typically low in Salt Lake City this may lead to some of the overestimate in using this equation in more humid parts of the country.

20. Lines 489–490: Is the BME280 sensor inside the PurpleAir expected to fail before the PMS5003 sensors? Is there evidence (in the literature or from the authors' experience) that this has occurred in the past? If not, why is this concern emphasized?

It may fail independently of the PMS5003. We saw this occasionally in our dataset and have added additional discussion

Lines 267-280: 3.2.2 PurpleAir Temperature and RH errors

For correction model development, it was important to start with the most robust dataset possible. In the 2-minute or 80-second data, occasionally, an extremely high temperature (i.e. 2147483447) or an extremely low temperature (i.e. -224 or -223) was reported, likely due to electrical noise or a communication error between the temperature sensor and the PurpleAir microcontroller. The high error occurred in 24 of 53 sensors but occurred infrequently (34 instances in $\sim 10^7$ points total) while the low error impacted only 2 sensors (1% of the full dataset). Temperature values above 540°C (1000°F) were excluded before calculating daily averages since temperature errors were extreme and easily detected above this level. Similarly, the RH sensor occasionally read 255%; this problem was experienced by each sensor at least once but still occurred infrequently (1083 points out of $\sim 10^7$ total). No other values were found outside 0-100% in the 2-minute or 80-second data before averaging. These points were removed from the analysis before 24-hr averaging.

Missing temperature or RH impacted only 2% of the dataset (184 points) with 8 sensors having one to four 24-hr averages with missing temperature or RH. One sensor, WI4, had 167 days (90%) without temperature data. Most of the available temperature data was recorded in the first few weeks of operation. It is unclear what caused the temperature data to be missing. All 184 points were missing temperature but only 17 were also missing RH (0.2% of full dataset).

21. Lines 512–515: Did the authors provide guidance to the air monitoring agencies on how to appropriately site the PurpleAirs? If so, can the authors relay that guidance in Section 2.1? It might be helpful to PurpleAir users. If not, would the authors like to comment on what they would consider ideal siting and/or provide examples of siting pitfalls? I feel like this might be appropriate given the emphasis on quality assurance elsewhere in the manuscript.

Siting guidance was not explicitly outlined for the agencies, but additional discussion has been added to the text.

Lines 111-115: When EPA provided PurpleAir sensors to air monitoring agencies, EPA suggested that they be deployed with similar siting criteria as regulatory monitors. Some sites had space and power limitations to consider but trained technicians cited sensors allowing adequate unobstructed airflow. In many cases, sensors were attached to the top rung of the railings at the monitoring shelters where they were within a meter or so of other inlet heights and within 3 meters or so of the other instrument inlets.

22. Line 530: On lines 150–151, the authors note that they included exceptional event days in their analysis. Did/can the authors identify specific events like dust storms wildfires with the help of site operators? Have the authors considered looking at the performance of their model specifically during extreme events? I think the results would be of interest to readers.

We agree that this would be of interest. We are in the process of collecting a more detailed dataset of exceptional events and plan to publish more detail on smoke and dust impacted times in future publications.

23. Table 2: Do these metrics describe the performance of Equation 8? Equation 8 was fit to the data described by the “AB, completeness, problem sensors” criteria, correct? If so, I’m not sure it’s appropriate to evaluate a model using the same data used to fit the model and then compare that performance to other datasets that the model was not fit to (rows 1–6).

We acknowledge the concerns of the reviewer. This is a question that could be explored in much greater detail in future work. We don’t want to complicate the message of the paper, so we have made this discussion more general and moved the discussion to the SI (section 3, Table S7) with an acknowledgement of the limitations of our methods. We have removed the table that was in the text and have only left the detailed table that was in the SI (Table S7).

Lines 323-330: 3.2.4 Importance of PurpleAir Quality Control procedures

This work did not seek to optimize data cleaning procedures to balance data retention with data quality, instead it focused on generating a best-case dataset from which to build a model. However, the removal of outlier points based on the difference between the A and B channels appears to reduce the errors most strongly (Supplement section 3, Table S7) when compared to removing incomplete daily averages or removing problematic sensors. Since both channels are needed for comparison, it makes sense to average the A and B channels to improve the certainty on the measurement. The data completeness

control provides less benefit and may not be needed for all future applications of these correction methods. In addition, sensors with systematic offsets were uncommon and did not largely impact the overall accuracy, so the A and B channel comparison on the 24-hour averaged data points (e.g. $5 \mu\text{g m}^{-3}$ and 61%) may be sufficient.

24. Figure 4: I'm not sure that the ALL column adds useful information to this figure (for the reason given on lines 341–342).

We have removed this column from the figure.

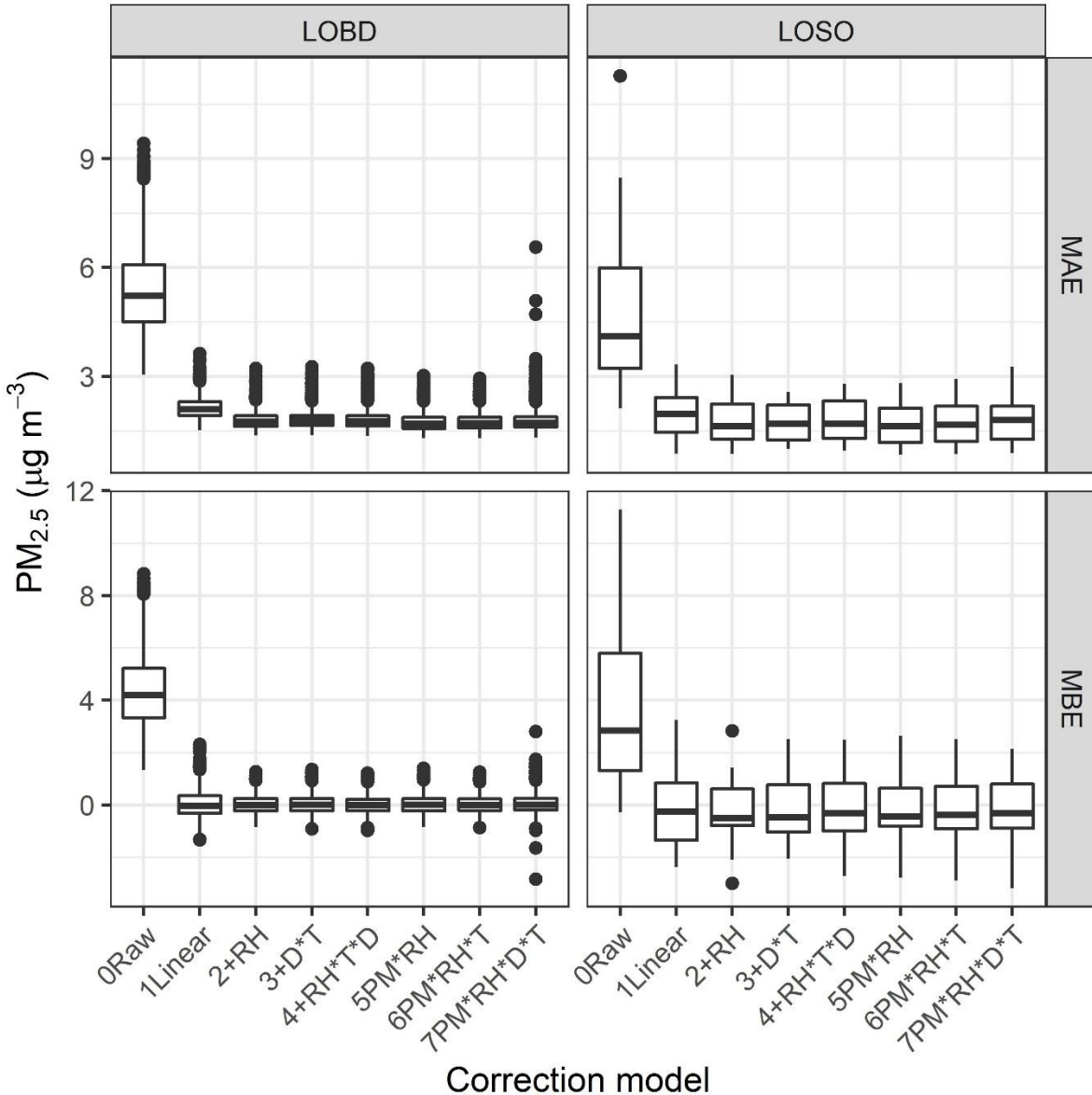


Figure 1. Performance statistics including mean bias error (MBE) and mean absolute error (MAE) are shown by correction method (0-5), where each point in the boxplot is the performance for either a 12-week period excluded from correction building (“LOBD”), or a single state excluded from correction building (“LOSO”).

ORGANIZATION

A lot of material is presented in a way that seems disjointed. One way to remedy this issue would be to consistently describe methods in the methods section and results in the results section. Another option is to organize the sections after the introduction as Data Collection, Quality Assurance, Model Development, and Model Evaluation instead of using conventional Methods and Results sections.

We thank the reviewer for their detailed feedback, and we have reorganized the paper into 2) Data Collection, 3) Quality Assurance, 4) Model Development, 5) Model Evaluation

1. Lines 102–109: It's great that the authors (i) point out the need to look for erroneous temperature and relative humidity values during the quality assurance process and (ii) describe the erroneous values that they observed! This information will help PurpleAir users look for erroneous temperature and relative humidity data to exclude from their own analyses. However, I think it would be more appropriate for the information on the nature and frequency of the erroneous temperature and RH values to appear along with the information on how many data points were excluded due to disagreement between the channel A and B PM_{2.5} concentrations (Section 3.1).

We have moved this discussion to section 3.2.2 PurpleAir Temperature and RH errors (under section 3.2 PurpleAir Quality Assurance & Data Cleaning)

2. Lines 116–120: The results shown in Figure 1 are discussed here and in Section 3.1. I would prefer to see this discussion all in one place.

We have combined this discussion in section 3.2.3

3. Lines 121–127: If the “within 5 $\mu\text{g m}^{-3}$ or 61%” check was performed on the 2- minute/80-second averages, I think it would make more sense for this text to appear before the paragraph describing the completeness threshold. If the “within 5 $\mu\text{g m}^{-3}$ or 61%” check was performed on 24-hour averages, I think this text should remain here.

This occurred on the 24-hr averaged data. It has been clarified in the text and appears in section 3.2.3

3. Lines 128–134: I think this text should appear before the paragraph on lines 102– 109. The authors should describe how they downloaded the data before describing how they cleaned and averaged the data.

We have moved this paragraph as suggested.

Now section 2.2.1 lines 150-156: When a PurpleAir sensor is connected to the internet, data is sent to PurpleAir's data repository on ThingSpeak. Users can choose to make their data publicly viewable (public) or control data sharing (private). Agencies with privately

reporting sensors provided application programming interface (API) keys so that data could be downloaded. PurpleAir PA-II-SD models can also record data offline on a microSD card; however, these offline data appeared to have time stamp errors from internal clocks that drift without access to the frequent time syncs available with access to WiFi so they were excluded from this project. Data were downloaded from the ThingSpeak API using Microsoft PowerShell at the native 2-minute or 80-second time resolution and were saved as csv files that were processed and analysed in R (R Development Core Team, 2019).

4. Lines 135–142: This material should appear after the first paragraph in Section 2.2.1 so that the authors' description of how they compared channel A and B data for quality assurance will make sense to readers who are not already familiar with Plantower sensors or PurpleAirs.

We have moved this information to section 2.2.1

5. Lines 219–220: I think this sentence should be moved to Section 2.2.1. Can the authors also provide additional information on this collocation? Where did it take place? How many PurpleAirs were collocated? I assume this was only monitors sent out by EPA and not monitors already being operated by air monitoring agencies. How long did the collocation last?

This was not a thorough evaluation so this sentence has been removed from the paper.

What duration were data averaged over before calculating Pearson and Spearman correlations?
What duration were data averaged over before comparing the channel A and B PM_{2.5} concentrations?

This was all done at 24-hr averages

Lines 283-291: The two Plantower sensors within the PurpleAir sensor (channels A and B) can be used to check the consistency of the data reported. All comparisons in this work have occurred at 24-hour averages. Anecdotal evidence from PurpleAir suggests some disagreements may be caused by spiders, insects, or other minor blockages that may resolve on their own. Data cleaning procedures were developed using the typical 24-hr averaged agreement between the A and B channels expressed as percent error (Eq. 1).

$$24\text{-hr percent difference} = \frac{(A-B) * 2}{(A+B)} \quad (1)$$

Where A and B are the 24-hr average PM_{2.5} cf_1 concentrations from the A and B channels. 24-hour averaged data points with percent differences larger than two standard deviations (2sd=61%) were flagged for removal.

Lines 315-317: Six of these 10 sensors had ≤4% of the data removed by data cleaning steps and their Pearson correlation, on 24-hour averages, improved to ≥0.98 (from r < 0.7) suggesting that the low correlation was driven by a few outlier points.

7. Lines 242–251: I think it would be more appropriate for this paragraph to appear along with the material discussed in Section 2.2.

This was moved to section 2.1.1 (lines 122-132)

7. Line 255: I would prefer to see Table S4 in the main manuscript. In Table S4, why is the RH model just called “RH” but the temperature and dew point models are called “+T” and “+D,” respectively? Can the models be labeled RH, T, and D or +RH, +T, and +D? Also, why not group Nonlinear RH with RH, +T, and +D? Why not group +RH+T+D with +RH+T, +RH+D, and +D+T?

We have moved this to the main text and have considered different models to address reviewer 3’s comments. We group nonlinear RH with the *PM models since it is multiplied by PM.

Table 2. Correction equation forms considered and the root mean squared error (RMSE). The best performing model from each increasing complexity (as indicated with *) was validated using withholding in the next sections (Section 5).

Name	Eqn	RMSE ($\mu\text{g m}^{-3}$) (cf_1)	RMSE ($\mu\text{g m}^{-3}$) (cf_atm)
linear	$PA = PM_{2.5} * s_1 + b$	2.88*	3.01
+RH	$PA = s_1 * PM_{2.5} + s_2 * RH + i$	2.52*	2.59
+T	$PA = s_1 * PM_{2.5} + s_2 * T + i$	2.84	2.96
+D	$PA = s_1 * PM_{2.5} + s_2 * D + i$	2.86	2.99
PM* Nonlinear RH	$PA = s_1 * PM_{2.5} + s_2 * \frac{RH^2}{(1-RH)} * PM_{2.5} + s_3 * \frac{RH^2}{(1-RH)} + i$	2.86	2.99
+RH*T	$PA = s_1 * PM_{2.5} + s_2 * RH + s_3 * T + s_4 * RH * T + i$	2.52	2.60
+RH*D	$PA = s_1 * PM_{2.5} + s_2 * RH + s_3 * D + s_4 * RH * D + i$	2.52	2.60
+D*T	$PA = s_1 * PM_{2.5} + s_2 * D + s_3 * T + s_4 * D * T + i$	2.51*	2.61
+RH*T*D	$PA = s_1 * PM_{2.5} + s_2 * RH + s_3 * T + s_4 * D + s_5 * RH * T + s_6 * RH * D + s_7 * T * D + s_8 * RH * T * D + i$	2.48*	2.57
PM*RH	$PA = s_1 * PM_{2.5} + s_2 * RH + s_3 * RH * PM_{2.5} + i$	2.48*	2.53
PM*T	$PA = s_1 * PM_{2.5} + s_2 * T + s_3 * T * PM_{2.5} + i$	2.84	2.96
PM*D	$PA = s_1 * PM_{2.5} + s_2 * D + s_3 * D * PM_{2.5} + i$	2.86	3.00
PM*RH*T	$PA = s_1 * PM_{2.5} + s_2 * RH + s_3 * T + s_4 * PM_{2.5} * RH + s_5 * PM_{2.5} * T + s_6 * RH * T + s_7 * PM_{2.5} * RH * T + i$	2.46*	2.53
PM*RH*D	$PA = s_1 * PM_{2.5} + s_2 * RH + s_3 * D + s_4 * PM_{2.5} * RH + s_5 * PM_{2.5} * D + s_6 * RH * D + s_7 * PM_{2.5} * RH * D + i$	2.54	2.57
PM*T*D	$PA = s_1 * PM_{2.5} + s_2 * T + s_3 * D + s_4 * PM_{2.5} * T + s_5 * PM_{2.5} * D + s_6 * T * D + s_7 * PM_{2.5} * T * D + i$	2.52	2.63
PM*RH*T*D	$PA = s_1 * PM_{2.5} + s_2 * RH + s_3 * T + s_4 * D + s_5 * PM_{2.5} * RH + s_6 * PM_{2.5} * T + s_7 * T * RH + s_8 * PM_{2.5} * D + s_9 * D * RH + s_{10} * D * T + s_{11} * PM_{2.5} * RH * T + s_{12} * PM_{2.5} * RH * D + s_{13} * PM_{2.5} * D * T + s_{14} * D * RH * T + s_{15} * PM_{2.5} * RH * T * D + i$	2.42*	2.51

8. Lines 262–264: I think this sentence should appear with the description of Plantower

This has been moved alongside the description of the Plantower.

Lines 139 to 140: The Plantower sensor reports estimated mass of particles with aerodynamic diameters <1 μm (PM₁), <2.5 μm PM_{2.5}, and <10 μm (PM₁₀).

9. If the authors want to stick with the conventional “methods” and “results” organization, the text on lines 255–256, 262–272, 276–277, 288–293, 299–300, 306, and 310–329 is technically methods. The models considered should be described in the methods section and then the amount of variance explained/comparison to prior studies should appear in the results section. If the authors wish to use some alternative organization, I think it would make sense to merge Section 2.3 with Section 3.3. (Model input consideration & Determining parameters and equations to use)

We have heavily reorganized the paper so that it fits more consistently into the proposed alternate sections 2) Data Collection, 3) Quality Assurance, 4) Model Development, 5) Model Evaluation

TECHNICAL CORRECTIONS

Line 12: Please insert a comma after “sensors” and another after “(PM)”.

Line 12-13: PurpleAir sensors, which measure particulate matter (PM), are widely used by individuals, community groups, and other organizations including state and local air monitoring agencies.

Lines 45–50: This sentence contains five instances of “and” and zero commas, which made it difficult to follow. Please consider rephrasing or splitting it into multiple sentences.

We have clarified this sentence:

Lines 45-50: For optical particulate matter (PM) sensors, correction procedures are often needed due to both the changing optical properties of aerosols associated with both their physical and chemical characteristics (Levy Zamora et al., 2019; Tryner et al., 2019), and the influence of meteorological conditions including temperature and relative humidity (RH) (Jayaratne et al., 2018; Zheng et al., 2018). In addition, some air sensors have out of the box differences and low precision between sensors of the same model (Feenstra et al., 2019; Feinberg et al., 2018).

Line 53: Insert “(Plantower PMS5003)” after “particle sensors”.

Inserted Line 53: PurpleAir sensors are a PM sensor package consisting of two laser scattering particle sensors (Plantower PMS 5003),

Line 54: Specify “(Bosch BME280)” instead of “(BME280)”.

Inserted

Line 54: pressure-temperature-humidity sensor (Bosch BME280),

Line 68: “location specific” should be “location-specific”.

Updated Line 74: location-specific

Line 71 and elsewhere: “U.S. wide” should be “U.S.-wide”.

We have updated this throughout.

Line 98: Please insert a comma after “sensors” and another after “B”.

Updated line 140: The PurpleAir sensor contains two Plantower PMS5003 sensors, labeled as channel A and B,

8. Lines 113–114: I suggest rewriting this sentence in past tense to be consistent with the rest of the paragraph (change “ensures” to “ensured” and “are” to “were”).

This sentence has been rewritten.

Lines 271-272: This methodology ensured that the averages used were truly representative of daily averages reported by regulatory monitors.

9. Lines 135–136: This sentence was difficult to follow. Maybe rephrase as: “The Plantower sensor reports estimated mass of particles with aerodynamic diameters $< 1 \mu\text{m}$ (PM_{1}), $< 2.5 \mu\text{m}$ ($\text{PM}_{2.5}$), and $< 10 \mu\text{m}$ (PM_{10}).”

10. Lines 145–146: I think “earliest data” should be “date”.

corrected

11. Line 148: “local time” should be “local standard time,” correct?

corrected

12. Lines 284–285: I assume “30 and 80%” refers to RH? Can you write “30% and 80% RH” to ensure this is clear?

updated

13. Line 305: Insert a comma after “Lastly”.

corrected

14. Line 311: “corrections” should be “correction”.

corrected

15. Line 314: There are two periods at the end of this sentence.

corrected

16. Line 406: The authors alternate between “quality assurance,” “cleaning,” and “quality control” throughout the manuscript. More consistent terminology would be preferable.

We have simplified throughout to only use “quality assurance” when discussing exploring the quality of the data and “data cleaning” when discussing removing specific problematic data.

17. Line 420–421: Should this sentence read, “In this work, we also excluded three PurpleAir sensors because there was overall poor agreement between the A and B channels even after excluding individual data points.”? If not, then maybe I do not understand what the authors are trying to say.

Yes, thank you for catching this mistake. This sentence does not appear in the final manuscript.

18. Line 562: Should there be an “and” between “correction methods” and “quality assurance methodology”?

Yes, thank you for pointing out this typo

Lines 950-951: Developing correction methods and data cleaning methodology for additional sensor types could further increase the amount of data available to communities, epidemiologists, decision makers, and others.

19. Line 559–561: Can the authors please revise this sentence? It’s quite long and contains some redundant statements.

Lines 946-949: Most other sensor types do not contain duplicate PM_{2.5} measurements which will make ensuring their data quality more challenging and more complex methods of data cleaning may be required, or similar data quality may not be possible.

20. Figure 1: I like how the authors use this figure to illustrate possible data quality issues, but it’s really hard to see the data here. Can the authors make the whole figure larger, use smaller strip text so that the plot panels are larger, and use open circles as markers? Can the authors also either reorder the facets so that the PurpleAirs in CA, for example, appear in the order CA1, CA2, CA3, CA4, CA5, CA6, CA7, CA10, CA11, CA12, CA13, CA15, CA16, CA17, CA18, CA19? This could be accomplished by labeling “CA1” as “CA01” or by reordering the factor associated with these labels.

We have updated the figure also taking into account the other reviewer’s suggestion to include correlation

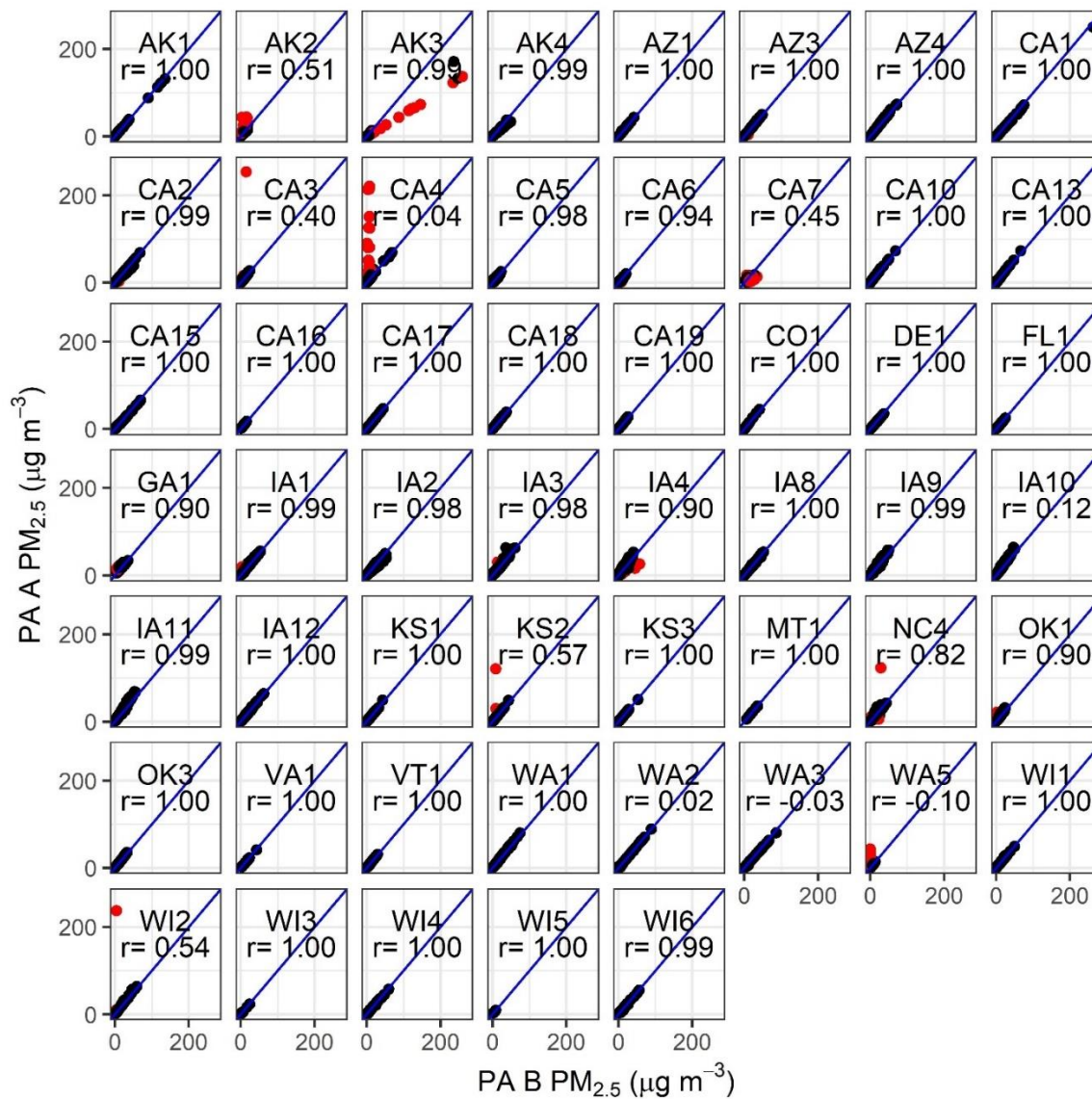


Figure 2. Comparison of 24-hour averaged $PM_{2.5}$ data from the PurpleAir A and B channels. Excluded data (2.1%) are shown in red and represent data points where channels differed by more than $5 \mu g m^{-3}$ and 61%. AK3, CA7, WA5 were excluded from further analysis. Pearson correlation (r) is shown on each plot.

21. Table S7: There is a broken reference at the end of the caption.

Updated.