We would like to thank anonymous reviewers 2 for the helpful comments and suggestions. In line with the reviewer comments and suggestions, and in line with new publications that were published while this paper was under review, we modify and revised the manuscript. Below are all the comments (in bold) followed by the replies. The parts that are in italic are corrections that are included in the revised version of the paper.

Sincerely,
Karin Ardon-Dryer

Response to Reviewer 2

This is an informative manuscript that evaluates the performance of networks of the PurpleAir PA-II low-cost aerosol sensor in real-world use. These sensors are commonly purchased by private citizens and installed, sometimes haphazardly, in residential and commercial neighborhoods. They are quite low-cost (<$300/unit) and data from these sensors could be used to increase understanding of the spatial distribution of PM2.5 and supplement more comprehensive, but much more costly and less ubiquitous, air quality monitoring stations (AQMS). The real question is whether these sensors provide data of adequate quality to be useful. The paper is generally clear and well-written, and it makes a strong case that the sensors have value and can provide scientifically useful information, at least under the conditions evaluated. It is also nice to see a high school student involved in the study. That said, there are some changes that need to be made to improve the manuscript. In particular, the evaluation of the sensitivity of the sensors to relative humidity (RH) and temperature (T) needs to be reworked, and some of the information in the tables could be presented more effectively with graphics. Below are major concerns, followed by a couple of minor issues. I have not checked the references for completeness.

1) In section 3.3.1, the effect of RH and T on unit performance are evaluated by regressing these values against the PM2.5 values from the PA-II units. Unsurprisingly, there was no significant correlation against either of these parameters. Instead, what needs to be compared is RH and T against the *difference* between the PA-II units and the nearest AQMS values. Biases associated with T and RH are minimized in the AQMS sensors but

would show up in the PA-II sensors, which do not control sample RH or T (although T is higher inside the sensing elements; thus we would expect RH to be reduced significantly below ambient). Any large bias associated with RH or ambient T should show up in this comparison (except see minor comment (b) below).

We took into consideration the reviewer comments, therefore we made extensive changes in our manuscript. First, we added an evaluation of the PA-II sensitivity to RH and T, for co-located PA-II units with AQMS (Fig S4). We also added an entire paragraph that discusses the impact of RH and T on the PA-II. Also, based on the reviewer's comments and suggestions as well as new publications that were published while the original manuscript was under review, we added an entirely new analysis to the paper. We performed a multivariate linear regression (MLR) on the co-located units (PA-II and AQMS, that were at a distance up to 1.1 km) and used the coefficient from the MLR to correct that additional PA-II unit measurements taken in the same region. This correction of the PA-II PM2.5 values improve the comparison between the PA-II units and the AQMS as well as between the PA-II to other PA-II units, as showed by improving the slop and reduction of the root mean square error (RMSE) and mean absolute error (MAE) values.

The following information was added to the manuscript
The overestimating raises questions about the accuracy of the PA-II units. According to PurpleAir (PurpleAir, personal communication, 2019) the company does not calibrate the PA-II units; instead, before each PA-II unit is sent out to a customer, the company performs a comparison test with a dozen PA-II units to find and remove outliers from the shipment (PurpleAir, personal communication, 2019). Previous studies suggested that part of the problem with the PA-II unit results from the optical particle counter being impacted by changes of RH (Crilley et al., 2018; Malings et al., 2020; Magi et al., 2020). Water vapor can condense on aerosol particles, making them grow hygroscopically under high RH conditions (Lundgren and Cooper, 1969). The PA-II units do not have any heater or dryer at their inlets to remove water from the sample before measuring the particles; therefore, deliquescent or hygroscopic growth of particles, mainly under high RH conditions, can lead to higher reported PM concentrations (Di Antonio, 2018; Jayaratne et al., 2018; Bi et al., 2020), which ends as an overestimate of the PM compared to the reference units. Weather conditions can impact the values reported by low-cost sensors (Morawska et al.,

2018). Changes in T or RH have been found to affect the performance of the PA-II units, especially under atmospheric conditions, as they cannot be controlled (Bi et al., 2020). Therefore, MLR between a PA-II, and an AQMS, which also considers changes of T and RH, can help correct the reported $PM_{2.5}$ *values of the co-located PA-II units. Similar corrections have been suggested and implemented in other locations with PA-II units (Bi et al., 2020; Magi et al., 2020) and other low-cost sensors (Malings et al., 2020). Most of these studies focus on co-located units or on units that were up to 1 km from the reference unit.*

Calculations of the ratio between the measured $PM_{2.5}$ *from the PA-II to the AQMS as a function of T and RH, known as a hunidogram, were performed (Fig S4). Some of the PA-II units seem to be impacted by T and RH more than others; these units also had relatively low* R^2 *values with the AQMS unit, as in the case of DE-PA-6 in Denver (Fig. S4A).*

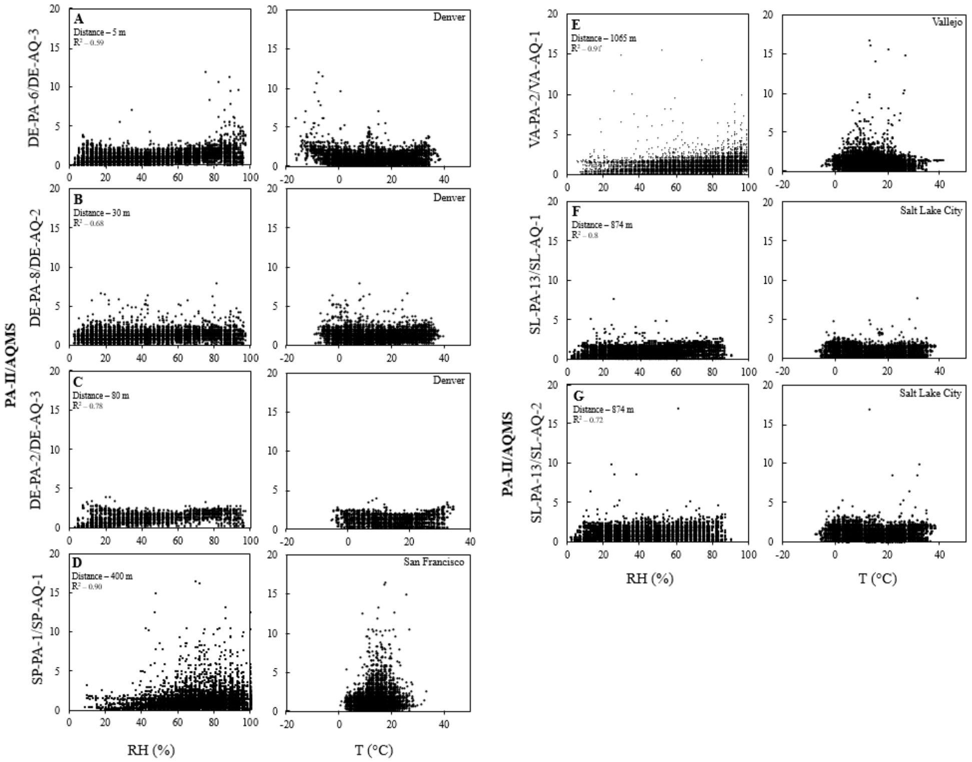

Figure S4: *Ratio between measured* $PM_{2.5}$ *from PA-II to the AQMS, as a function of temperature and relative humidity (hunidogram) for all collocated PA-II and AQMS pairs. Information on the distance and* R^2 *values between the two presented in each plot.*

2) There are a lot of values in tables in this manuscript, many of which really belong in the supplemental information. I would much prefer to see a new figure with scatterplots of each sensor against the AQMS values in the main text, and move Figs. S1 amd S3 there as well. The detail in the tables should be moved to the SI.

Per the reviewer's suggestions all tables were moved to the supplement (Now Tables S1-S3) and scatterplot of the PA-II compared to the AQMS were added to the manuscript (Fig. 4 and Fig.5). We compared the co-located units before and after we performed the MLR (Fig 4,) and observed the difference before and after we applied the coefficients from the MLR to the rest of the PA-II units (Fig 5.)

As suggested by the reviewer the figure with the map (originally Fig S1) was moved to the main manuscript, and it is now Fig. 2. Figure S3 was also moved to the main manuscript, it is now Fig. 7. We made changes in the figure, we evaluated the impact of the distance on the R^2, RMSE, MAE, and the slope values. This was performed both between the PA-II to the nearest AQMS as well as between the PA-II units.

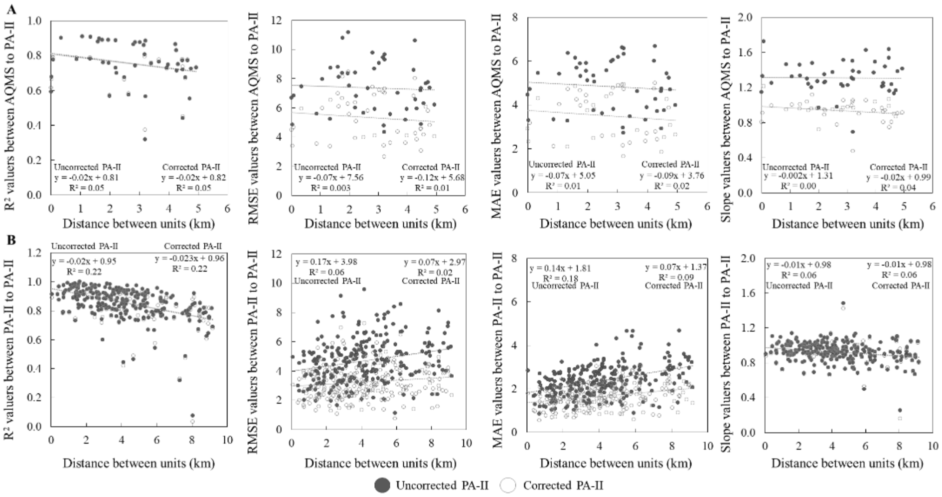

***Figure 7**: Comparison of distance (km) between PA-II to its nearest AQMS in all regions (A) and between each PA-II unit to all other PA-II units per region (B) to R^2, RMSE, MAE and slope values received from the $PM_{2.5}$ hourly measurements comparison.*

3) The linear regressions should be performed with "2-sided" regressions because there is uncertainty in both the x and y values of the scatterplots. Standard linear regression assumes

uncertainty only in the y values. I also suggest you remove obvious outliers (for example, the July 4th fireworks smoke) before performing regressions; these outliers can severely torque the slopes and r2 values.

We apologize but we were unsure about the reviewer meaning for 2-sided regression and why he considers the AQMS measurements as uncertain. Our study, like others treats the AQMS as an absolute and does not question the validity or accuracy of its measurements.

As suggested by the reviewer we removed all the outlier's events before the statistical tests, we also performed an analysis that allows us to remove outlier PA-II units. A new section was added to the manuscripts about describing both.

The following information was added to the manuscript

2.5. Remove of outlier PA-II units and irregular hours

The first step was to identify outliers among the PA-II units, per region, meaning PA-II units that behave differently from the other PA-II units in their region. By comparing R^2 *between the* $PM_{2.5}$ *values measured by each pair of PA-II units, using a linear regression, we identified the outlier units. A PA-II unit that did not have an* $R^2 \geq 0.75$ *with at least 75% of the other PA-II units in its region was considered an outlier unit, and therefore was removed from future analysis (Fig. S1 shows a comparison for each of the four regions). Only one unit from SF (SF-PA-9, see Fig. S1B) had very low* R^2 *when compared to all other PA-II units. Most PA-II units had high* R^2 *values (>0.9) with the other units. Irregular* $PM_{2.5}$ *hourly measurements were removed from all units (PA-II and AQMS). These irregular hourly measurements were identified as a large single hourly increase of* $PM_{2.5}$ *values (>70 µg* m^{-3}*) that was not measured by any other unit in the region. Such a large increase was caused most likely by a local source near a specific unit, such as a small-scale fire, lawn mower, barbecue, cigarette smoke, or fireworks (Zheng et al., 2018), and attributed to the location of many of the PA-II units in a residential area. Firework events were removed, as they were very localized events and were measured by a single unit. Overall, less than 0.03% of the hourly* $PM_{2.5}$ *measurements identified as irregular hours were removed from different PA-II and AQMS units.*

4) There is lack of specificity in the abstract and throughout the text about "co-located" and "same location". I was quite confused when first reading the abstract, because it says that this manuscript reports analysis of PA-II units that are not "co-located" with AQMS sites, but then in the next sentence that "we selected eight different locations, where each location contains multiple PA-II units (minimum of seven per location, a total of 86 units) and at least one AQMS (total of 14)." This sounds to me like "colocated" because you have not specified the criteria used for selecting PA-II units. I suggest you use "nearby" or "regional" rather than "location" throughout the text to avoid confusion. And please define the distance criteria for which PA-II units were selected for comparison with AQMS instruments.

We apologize that our lack of clarity about the location aspect of the units. As the reviewer suggested we added more clarification to the manuscript. Co-located units are PA-II and AQMS units that are up to 1.1 km between each other, this is similar range to what was done by Bi et al. (2020) . We also changed the use of the word location to region as suggested by the reviewer. In addition, we provide the extract criteria for a distance that was used in our analysis to define each region.

This information was added to the abstract:
For this study, we selected four different regions, each containing multiple PA-II units (minimum of seven per region). In addition, each region needed to have at least one AQMS unit that was co-located with at least one PA-II unit, all units needed to be at a distance of up to 5 km from an AQMS unit and have up to 10 km between each other.

5) You may want to explore the seasonality of differences between the PA-II units and the AQMS values. For example, in winter in Utah, I would expect big gradients between airport sensors on the flat plains and residential sensors on the slopes. This may become evident in the analysis I suggest in comment (1) above.

Per the reviewer comments we analyzed the seasonality differences between the PA-II units and the AQMS values in all four regions, we attempted to identify the impact of T and RH as suggested by the reviewer. All regions had lower R^2, RMSE and MAE values in the spring compared to the other seasons, however, this difference was not statistically significant for all cases. Next, we calculated the average RH and T for each season, and we compared it to the R^2, RMSE and MAE values. To our surprise there was no seasonal impact of RH or T on these values. We found that the lower R^2, RMSE and MAE values in the spring result from the overall lower PM2.5 values measured in that season for all four regions (as can be seen in Fig.3 in the manuscript). The PM concentrations had a stronger impact on the PA-II and AQMS comparisons than the T and RH had, therefore, we decided not to include this analysis in the manuscript.

As for the reviewer's example, we explored the spatial changes between the PA-II units, mainly in Salt Lack City, Utah as suggested by the reviewer. All the units that we used in the study were in residential area and not next to the airport. Overall, most sensors behaved in a similar way, as shown by the figure below. A similar range (bins of 5 µg m-3) of $PM_{2.5}$ concentration were measured by all the units. However, in the very few cases in which we observed some spatial differences (mainly in August 2018, as shown in the Figure below), we could determine the causes of these differences.

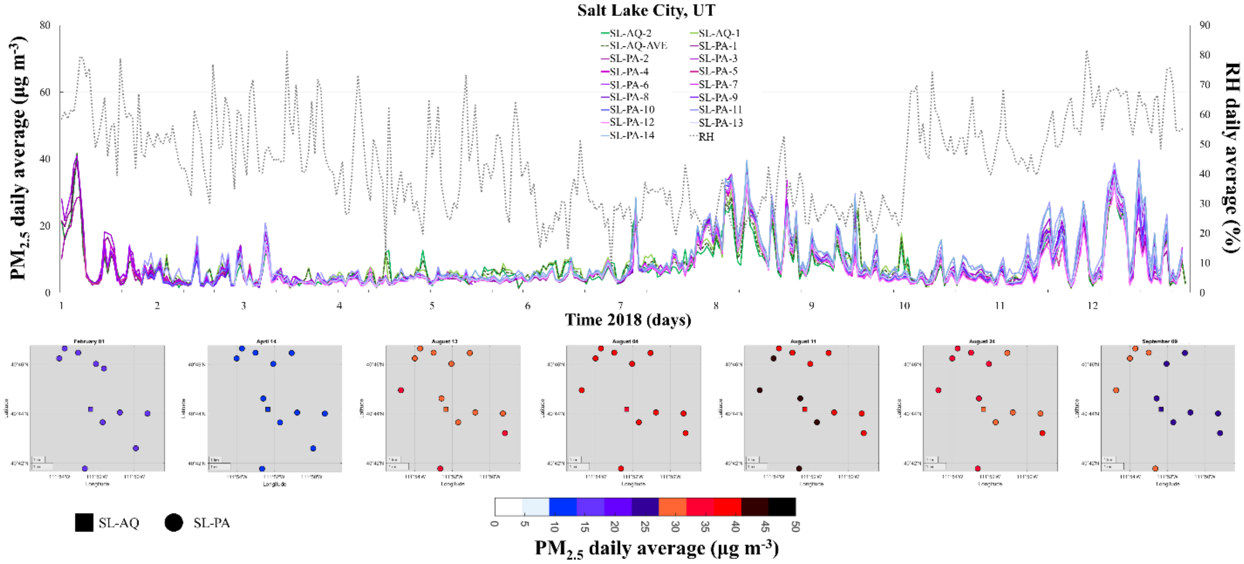

Fig 2. Time series of daily $PM_{2.5}$ measurements from the AQMS and PA-II units in Salt Lake City during 2018 (top). Measurements from AQMS are represented by the green lines and the PA-II units are indicated by purple lines, RH values represented by the gray dotted line. Maps of different days during 2018 with the spatial distribution of the daily $PM_{2.5}$ measurements (lower panel).

AQMS represented by the square and PA-II by round shape. Each color represents $PM_{2.5}$ values in bins of 5 μg m^{-3}.

Minor comments:

a) Lines 151-164. These are not needed; this information is already in the tables.

This entire paragraph was removed from the manuscript

b) In Sect. 3.2.2., these differences between the AQMS values and the PA-II data in Utah in winter may be associated with the volatility of ammonium nitrate, which dominates the aerosol composition there (Womack et al., https://doi.org/10.1029/2019GL082028). The PA-II instrument would be less likely to volatilize ammonium nitrate, while the NAAQS FRM does volatilize it (Grover et al., https://doi.org/10.1029/2004JD004995).

We would like to thank the reviewer for bringing up this point. The reviewer comments regarding the volatility of ammonium nitrate helped us to understand one of the causes for the increase of $PM_{2.5}$ in Salt Lake City during the winter months. We added this information to the manuscript

The following information was added to the manuscript

On average the PA-II values were higher by 2.1 ± 2.6 μg m^{-3} from those measured by the AQMS. The still higher $PM_{2.5}$ values could be due to the volatility of ammonium nitrate, which is a dominant aerosol composition at the region of Salt Lake City during the winter times (Moravek et al., 2019; Womack et al., 2019). It has been shown that sensors similar to the ones used in the PA-II units would be less likely to volatilize ammonium nitrate, unlike the one used in the AQMS units (Grover et al., 2005).

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