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Nice model and useful evaluation of the PurpleAir sensor for a unique, more direct application

R Subramanian (Referee)

Referee comment on "Evaluating the PurpleAir monitor as an aerosol light scattering instrument" by James R. Ouimette et al., Atmos. Meas. Tech. Discuss.,
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The PurpleAir (and similar low-cost PM) sensors have received a lot of attention recently, due to their popularity and wide deployments worldwide. Many publications have shown the utility of these sensors for air quality applications, including (at the risk of tooting my own horn) several of my own papers (e.g. Rose Eilenberg et al. <https://doi.org/10.1038/s41370-020-0255-x>). A number of laboratory and field evaluations have shown the limitations of these sensors, especially the fact that the size distribution reported by the Plantower sensor is unrealistic (e.g. Kuula et al., Tryner et al., Zou et al.) and that the Plantower sensor is a nephelometer, not a particle counter despite manufacturer claims (He, Kuerbanjiang, & Dhaniyala). Bernd Laquai (2017) had shown the lack of response of a similar low-cost PM sensor to coarse aerosols https://www.researchgate.net/publication/320707986_Particle_mass_distribution_dependent_inaccuracy_of_low_cost_sensors_Bjhike_HK-A5 ; I have seen similar results in our testing in Doha, Qatar (hopefully, to be published soon!)

Hagan and Kroll have also published an optical model for various low-cost OPCs
<https://amt.copernicus.org/articles/13/6343/2020/amt-13-6343-2020.html>

However, this paper makes a unique contribution in that they measure the insides of the sensor, develop a nice model specific to the PurpleAir PMS5003 that predicts the nephelometric response compared to a perfect nephelometer, and use that to show that the Plantower effectively cannot detect supermicron particles due to the optical

configuration, with a smaller contribution from the flow path (which was my default assumption). These results likely also explain the laboratory test results across a range of PM sensors (Plantower, Nova, Sensirion, etc.) by Kuula et al. (though the Omron remains a mystery - it uses a thermal heater for convective flow with a relatively straight path, and was responsive to coarse mode aerosol). The long-term evaluation at Mauna Loa and Boulder further enhance the value of this paper. Hence, I recommend publication after minor revisions.

Specific comments:

1. Please use $PM_{2.5}$ throughout, not the eyesore that is "PM2.5".

2. Line 178: Is the 9.4 cm^3 volume for one half of the sensor or both halves?

3. Lines 201-204: This seems a noteworthy finding - that even at low wind speeds, particles larger than $2 \mu\text{m}$ may not even make it inside the sensor - with losses of $\sim 90\%$ for $5 \mu\text{m}$ particles. These losses, combined with the inefficient scattering due to the optical configuration, likely explain Kuula's results. On the other hand, the Omron sensor in Kuula's testing detected coarse particles, and that flow path is more straightforward (uses convective heating for aspiration).

4. Line 223 - it would appear (given the aspiration efficiency above) that this statement "most particles larger than $10 \mu\text{m}$ are lost" could be made for particles larger than $2 \mu\text{m}$?

5. Sec 3.3 - it is not clear how (or if) the model accounts for the non-ideal response of the photodiode - SI suggests it does not. Please explain how this may affect your results.

6. Fig 7 - this figure might be better shown (or additionally shown) without the normalization to 0.1 μm particle. It will be interesting to know the absolute effect of polarization and PA geometry on scattering at a given diameter without this normalization.

7. Sec 4.3 - PurpleAir monitors come in a plastic housing and are not heated (except for some internal heating by the electronics board). Since Mauna Loa and Boulder are both low-RH environments usually, the effect of the heater modification introduced by the authors is unclear. Can you provide a comparison of the RH in the heated and unheated PurpleAir with ambient RH? Does heating affect the plastic housing of the PurpleAir e.g. offgassing/melting?

8. Can you compare the NRMSE values with uncertainties reported in previous PurpleAir evaluations? e.g. in Malings et al. (2020), we report a mean absolute error of $\sim 4 \mu\text{g}/\text{m}^3$ for hourly average $\text{PM}_{2.5}$ (average $\text{PM}_{2.5}$ in Pittsburgh is $\sim 10 \mu\text{g}/\text{m}^3$). Others have published similar values as well.

9. It would be good to place the results in Sec 5.2.5 PA-PMS size distribution in the context of previous results by Kuula et al., Tryner/Volckens, Zou/May, and He/Dhaniyala.
<https://amt.copernicus.org/articles/13/2413/2020/>
<https://doi.org/10.1016/j.jaerosci.2020.105654>
<https://doi.org/10.1080/02786826.2021.1905148>
<https://doi.org/10.1080/02786826.2019.1696015>

10. Lines 859-860: It has been shown (e.g. Malings et al.) that the as-reported $PM_{2.5}$ mass concentrations (effectively CH1) are ~double the reference $PM_{2.5}$ values. However, the authors here speculate that the unmodified PurpleAir may underestimate high-RH, low visibility aerosol scattering coefficients. (Is there an unheated nephelometer, given the heat of the halogen lamp?) If I understand correctly, the authors are comparing PA response to scattering coefficient at ambient high RH. It might help to make this more explicit, e.g. state that "previous studies have reported overestimated $PM_{2.5}$ mass concentrations by the PurpleAir at high RH, but that is when the PA is compared to a reference monitor reporting dry aerosol concentrations - which is quite different than our application of the PA as an aerosol light scattering instrument".