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Atmospheric Measurement Techniques Discussions

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Interactive comment on "Combining low-cost, surface-based aerosol monitors with size-resolved satellite data for air quality applications" *by* Priyanka deSouza et al.

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Response to Reviews

We are grateful for the constructive reviews we received for our paper. We have modified the manuscript to address the reviewers' comments, and herein resubmit the updated paper and detailed responses to the reviewers.

General comments It is not clear the general scope of the manuscript. it seems that an older draft has been readapted for new purposes. From the title I would expect that the performances of new low-cost sensors in monitoring aerosols are assessed and

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Discussion paper

supported by satellite measurements. Rather, the satellite observations are needed to improve low-cost sensor performances and extend its measurement range. This is pretty unusual. Usually it is the other way round. Satellite observations are at much coarser resolution.

We appreciate that the reviewer grasps the novelty of our method. The purpose of the manuscript is to develop a novel technology to use the size distribution from the low-cost OPC-N2s to constrain the measurements from MISR (which provides stable and consistent size resolved information over time) for the aerosol size range which is visible to both instruments. As the OPC-N2s cannot detect particles of sizes smaller than 0.38 μm, we use the constrained MISR size-resolve information to improve the OPC estimates.

The low-cost OPCs have well known limitations, and we present an approach that uses MISR-retrieved particle properties to address some of those limitations. For this application, the MISR Research Algorithm aerosol data offer sufficiently high spatial resolution (1.1 km pixels). They can provide meaningful information over any large urban area, as has been demonstrated previously in papers; for example, Patadia et al. (2012) applied the MISR RA results over Mexico City.

The authors are however aware that considering the monthly effective fraction doesn't make so much sense. In-situ measurements can catch a variability that is order of magnitude higher.

Right. However (1) the only in situ data available for the Nairobi experiment are from the OPCs, which we use to the extent possible, and (2) the Nairobi experiment itself has many issues, which we enumerate. In particular, the low-latitude location of the city, and the generally low AOD during the study period, limit the number of available, good-quality MISR observations.

This is the best we can do with the current data, and is one reason why the experiment is relegated to Supplemental Material: to make a clear distinction between the presentation of the method in the main text, appropriate for the AMT journal, and the Nairobi experiment, which represents a loose demonstration of the method and not a validation. This is also why we enumerate the limitations of that experiment, and why we call for a future experiment that addresses these limitations.

With the planned deployment of MAIA, which can provide retrievals at higher temporal resolution, this limitation can be addressed in future experiments. We note this in the Conclusions of the main document. Specifically, we say:
"We hope with the increasing focus on air quality (e.g., the expansion of the SPARTAN network, Weagle et al., 2018), broader application of low-cost monitoring can occur. Further, the planned MAIA instrument (expected launch year: 2022), like MISR, will be able to provide size-resolved information about aerosols from space for a subset of cities at higher temporal resolution (Diner et al., 2018). As such, it should better capture the variability in aerosol type, and the data can be incorporated into our methodology."

Moreover, OPC can't detect aerosols with a diameter smaller than 0.38 micrometers. Exhaust and combustion aerosol size is much lower that that value.

We are of course aware of that too, and we say so in Section 2.1 of the paper. The key here is that the aerosol in Nairobi has a size distribution that is sampled by MISR, and the large-end tail of which is sampled by the OPCs. We use the region of size-overlap to perform the particle-size scaling, and the result is given in Figure 1 of the paper. Despite the limitations, the results are quite reasonable, which indicates that the two instruments are in fact sampling parts of the same particle size distribution.

In the paper some statements are not state-of-the-art and should be corrected. Technology made progress in the last years and cheaper reliable instruments are available nowadays. This reminds the observations stated in the first comment.

Thank you. We have altered our estimates of how much a reference monitor costs: "This is because air quality monitoring equipment tends to be costly to purchase (capital costs are in the range of several thousand of US dollars) and maintenance, and data processing and analysis requires additional expertise and resources (Kumar et al., 2015; Mead et al., 2013)."

The presented methodology might be interesting, but the same experiment should be repeated where lidar and sun-photometer measurements are available. Why developing a technique in a place where it cannot be properly validated ? There is an agreement between MISR-MAIAC and in-situ sensor, but this tells us nothing if the retrievals are accurate I would perform the same analysis at NASA Goddard to prove true those claims.

The MISR AOD and Research Algorithm particle properties have been validated extensively in previous papers cited in the current paper in section 2.2.1. There would be no point in repeating that work here.

When the Nairobi experiment was designed and performed, its effectiveness and its limitations were not known. The current paper represents an effort to develop a technique that makes use of low-cost sensors for meaningful air quality monitoring. In the process of developing this technique and applying it to the Nairobi data, we identified the limitations of the Nairobi experiment very specifically in Section 4.3. This puts us in a position to at least propose an experiment that addresses the limitations, can be used to formally validate the technique, and we hope, be applied more widely, especially where air quality monitoring is very limited or entirely absent due to the high cost of reference monitors.

Specific comments identified by the reviewer in the Supplemental Information:

Line 33: In the Abstract we say: "We thus identify factors that will reduce the uncertainty in this approach for future experiments." The reviewer notes: "There is not ground truth observations to assess the uncertainty"

We agree with you, that in the future we need to repeat our experiment with better ground-truth observations. We spell out what these improvements should be in Section

4.2, where we stress the importance of repeating the experiment with co-location with a reference monitor, and with a surface lidar instrument.

Line 45-48: The reviewer notes that we overestimate the price of a reference monitor Thank you. We have modified the text, see our previous answer.

Line 55: One of the major drawbacks of using the lower-cost sensors is that no standards or certification criteria exist for these instruments yet, and consequently, the quality of the data they produce is of special concern

The reviewer notes re the term special concern: still, this statement is strong. Low-cost instruments also assure quality measurements. Carotenuto, F.; Brilli, L.; Gioli, B.; Gualtieri, G.; Vagnoli, C.; Mazzola, M.; Viola, A.P.; Vitale, V.; Severi, M.; Traversi, R.; Zaldei, A. Long-Term Performance Assessment of Low-Cost Atmospheric Sensors in the Arctic Environment. Sensors 2020, 20, 1919.

Cavaliere, A.; Carotenuto, F.; Di Gennaro, F.; Gioli, B.; Gualtieri, G.; Martelli, F.; Matese, A.; Toscano, P.; Vagnoli, C.; Zaldei, A. Development of Low-Cost Air Quality Stations for Next Generation Monitoring Networks: Calibration and Validation of PM2.5 and PM10 Sensors. Sensors 2018, 18, 2843.

Thank you, we have modified the sentence to read: "One of the major drawbacks of using the lower-cost sensors is that no standards or certification criteria exist for these instruments yet, and consequently, the quality of the data they produce is of concern, although the performance of such instruments has been improving (Carotenuto et al., 2020; Cavaliere et al., 2018; EPA, 2016; Lewis and Edwards, 2016)"

Line 73: The reviewer says "I doubt that low cost instruments can be effective in aerosol speciation"

Thank you. In this line we were referring to challenges of using satellite-derived AOD information and were speaking of MISR's ability to discriminate between the different aerosol components. We do not believe that low-cost sensors can discriminate between aerosol types. We only use the ability of the OPC-N2s to report particle number concentrations in different size bins in detailing this method.

We copy the entire paragraph here for context:

"Among the main challenges in using satellite-derived AOD for this application are:

- The low temporal frequency of measurements from polar-orbiting instruments (i.e., at most, about once daily for MODIS, and between two and nine days for MISR, depending on latitude) compared to diurnally varying pollution levels in many settings
- Inaccuracies introduced in satellite aerosol retrieval algorithms by uncertain aerosol and surface optical properties
- The relatively coarse retrieval-product spatial resolution and aerosol species discrimination
- Inability to retrieve aerosol in the presence of cloud cover, and possible sub-pixel cloud
- The relationship between satellite-derived AOD and PM2.5 is not straightforward. AOD is the integral of atmospheric optical extinction from the surface to the top of the atmosphere under ambient temperature and humidity conditions, whereas PM2.5 is the near-surface aerosol mass concentration of dry particles with diameters < 2.5 μm. The relationship depends upon the aerosol vertical distribution, hygroscopic growth factor, mass extinction efficiency, and ambient atmospheric relative humidity profile (Gupta et al., 2006). The relationship is also time dependent and can vary across typical satellite grid-cells (Engel-Cox et al., 2004; Hu, 2009; Lee et al., 2011)."

Line 98: The reviewer notes to detail the full acronym SPARTAN
Thank you, we have reported the full name:
"To respond to this challenge, the Surface PARTiculate mAtter Network (SPARTAN) network"

Line 99: The reviewer notes: "also 7-SEAS NASA mission aims to setup permanent and mobile stations in wild and difficult accessible regions to monitor aerosols as shown in https://www.atmos-chem-phys.net/16/14057/2016/"
Thank you for this information! We see that the measurements for this mission are made by a cruise ship. Although we think such maritime measurements are exceedingly important, we see the most important use of our methodology for measuring PM2.5 concentrations over land, where people live.

Line 140: The reviewer notes that our characterizing of the OPC-N2 as unique is not fully true because many other sensors exist. Thank you for this note. Although many other low-cost sensors exist, the OPC-N2 is the only low-cost sensor (< USD 500) that has been shown to provide size resolved information- within a specific diameter range with any kind of accuracy. We note this in the text.

Line 261: The reviewer notes that our use of monthly effective fraction of each MISR component AOD to scale the more frequent MAIAC AODs is wrong. The reviewer again points this out for line 285
Please see our previous response

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