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Atmospheric Measurement Techniques Discussions

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Interactive comment on "Using Low Cost Sensors to Measure Ambient Particulate Matter Concentrations and On-Road Emissions Factors" *by* K. K. Johnson et al.

K. K. Johnson et al.

karoline.johnson@duke.edu

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Please see attached responses to reviewer #3 followed by responses to other reviewers.

Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2015-331, 2016.

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Discussion paper

1

Final Responses: Responses are bolded under each reviewer comment

Referee #3:

General comments: The subject area of this study, low cost sensors for air quality measurements, is a very hot topic. It is therefore important papers in this area are written with great care to understand what new sensors can or cannot do, and a detailed analysis of the measurement data to check for cross-correlation and challenges. Unfortunately this paper has not realized this. The stated goal of the work was: "to evaluate a variety of lower cost alternatives for generating continuous pollutant measurements". However deploying the home-made box of sensors for between a few days up to a few weeks without replicates or complete data analysis of all the parameters is not particularly useful.

We agree with the reviewer that this is an emerging research area of significant interest, and that careful evaluation of low cost sensors is important. While the field study testing period was constrained to a short period of time, we would argue that the unique testing environment – both urban United States and high concentration India environments – provide important evidence on sensor performance. These results will add to the growing body of work testing these and other sensors in a variety of environmental conditions.

I would suggest the authors re-analysis all the data which they have recorded and undertake some studies, e.g. if you used 50% of the measurement period to calibrate the PM sensor, how well does it do against the other 50% of the dataset etc.

We agree that this would be a useful evaluation, and was also mentioned by several of the reviewers. We have conducted additional analyses for the Hyderabad data using a few days of data to calibrate the data and then applying the calibration to the rest of the time period. The results are available in sections 3.1.3, Table 4, and Figure 6.

Some further quality control experiments in the laboratory should also be done before re-submitting to peer review. The authors need to focus less on correlation plots and spend more time on the actual data, and the physical reasons for them, then more may be learned about how to do low cost measurements well.

We agree that tests under controlled laboratory conditions provide some useful information on what drives the signal for low cost optical particle sensors, and we cite recent studies that have conducted that work (e.g., Austin et al., 2015; Wang et al., 2015). There are limitations in the ability to generate aerosol mixtures that match the variability of chemical and physical composition of particles in urban environments. This research study emphasizes the performance of sensors in real-world settings that represent areas that are likely to be of great interest for the deployment of sensors (e.g., urban areas near roads, high concentration areas in India). This work is meant to complement ongoing laboratory evaluations of optical particle sensors.

Specific comments: Abstract The abstract almost wholly misrepresents the results of the study. Rather than reporting poor correlation of the sensors against the reference instrument, that area is almost completely ignored with a focus on emission factors. That part of the paper used less than two hours of data (with a correlation of 0.18 to a reference instrument) to conclude that emission factors could be measured with ~30% error. The conclusion that the paper's results has showed the potential usefulness

Fig. 1. Reviewer responses

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Discussion paper

Performance of Low Cost Sensors Measuring Ambient Particulate Matter in High and Low Concentration Urban Environments

Karoline K. Johnson[1], Michael H. Bergin[1], Armistead G. Russell[2], Gayle S. W. Hagler[3]

[1]School of Civil and Environmental Engineering, Duke University, Durham, NC, 27708, USA
[2] School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA, 30332, USA
[3] U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC, 27711, USA

Correspondence to: Karoline K. Johnson (Karoline.johnson@duke.edu)

Abstract. Air quality is a growing public concern in many countries, as is the public interest in having information on air pollutant concentrations within their communities. Quantifying the spatial and temporal variability of ambient fine particulate matter ($PM_{2.5}$) is of particular importance due to the potential health impacts associated with $PM_{2.5}$. This work evaluates three models of PM sensors (Shinyei: models PPD42NS, PPD20V, PPD60PV) in three locations: urban background (average $PM_{2.5}$: 8 µg m^{-3}) and roadside sites in Atlanta, Georgia, USA (average $PM_{2.5}$: 21 µg m^{-3}), as well as a location with substantially higher ambient concentrations in Hyderabad, India (average $PM_{2.5}$: 72 µg m^{-3}). Additionally, a low cost carbon dioxide (CO_2) sensor (COZIR GC-0010) and a mid-cost black carbon sensor (microAeth AE51) were tested at the roadside in Atlanta. Low cost sensor measurements were compared against reference monitors at all locations. The PPD20V sensors had the highest correlation with the reference environmental beta attenuation monitor (E-BAM) with R^2 values above 0.80 at the India site while at the urban background site in Atlanta, the PPD60PV had the highest correlation with the tapered element oscillating microbalance (TEOM) with an R^2 value of 0.30. At the roadside site, only the PPD20V was used, with an R^2 value against the TEOM of 0.18. Although the results of this work show poor performance under lower USA concentrations, the results indicate the potential usefulness of these low cost sensors, including the PPD20V, for high concentration applications up to approximately 250 µg m^{-3}. The CO_2 sensor had an R^2 value of 0.68 with the reference analyzer while the BC sensor correlated strongly to a multiangle absorption photometer (MAAP), with an R^2 of 0.99, at the Atlanta roadside site. These field testing results, although limited in nature, provide important insights into the varying performance of low cost particulate sensors used in highly contrasting atmospheric conditions and underlines the need to evaluate these emerging technologies, not only in the laboratory, but in their planned environment of application, prior to widespread use.

1 Introduction

Exposure to particulate matter (PM), particularly particles less than or equal to 2.5 micrometers in size ($PM_{2.5}$), is associated with a variety of adverse health impacts, including lung cancer (Laden et al., 2006), cardiovascular disease (Laden et al., 2006;Miller et al., 2007;Puett et al., 2009), and premature mortality (Puett et al., 2009). Although some cities in the US have PM values above the National Ambient Air Quality Standard (NAAQS) (EPA, 2013) annual $PM_{2.5}$ concentration value of 12

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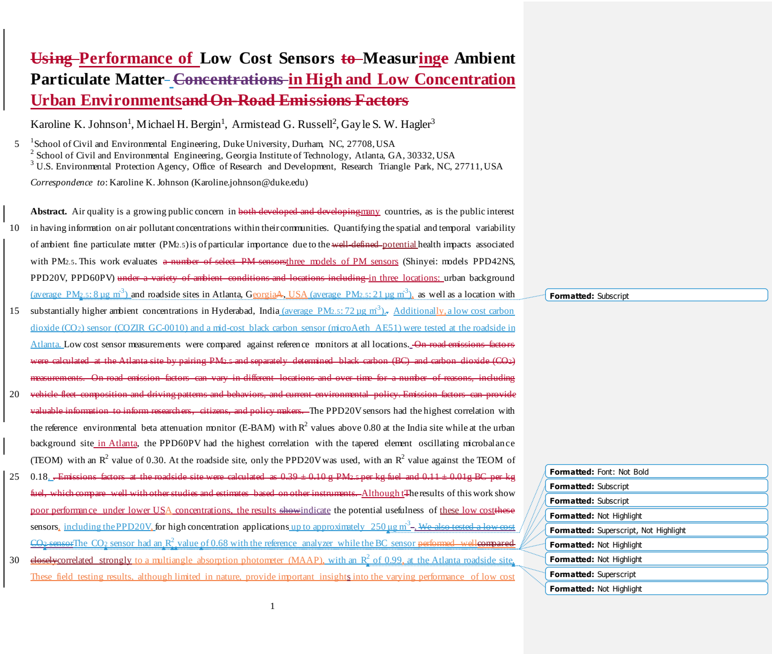
Fig. 2. Revised paper



~~Using~~ Performance of Low Cost Sensors ~~to~~ Measuring~~e~~ Ambient Particulate Matter ~~Concentrations~~ in High and Low Concentration Urban Environments~~and On-Road Emissions Factors~~

Karoline K. Johnson[1], Michael H. Bergin[1], Armistead G. Russell[2], Gayle S. W. Hagler[3]

[1]School of Civil and Environmental Engineering, Duke University, Durham, NC, 27708, USA
[2] School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA, 30332, USA
[3] U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC, 27711, USA

Correspondence to: Karoline K. Johnson (Karoline.johnson@duke.edu)

Abstract. Air quality is a growing public concern in ~~both developed and developing~~many countries, as is the public interest in having information on air pollutant concentrations within their communities. Quantifying the spatial and temporal variability of ambient fine particulate matter ($PM_{2.5}$) is of particular importance due to the ~~well-defined~~ potential health impacts associated with $PM_{2.5}$. This work evaluates ~~a number of select PM sensors~~three models of PM sensors (Shinyei: models PPD42NS, PPD20V, PPD60PV) ~~under a variety of ambient conditions and locations including~~ in three locations: urban background (average $PM_{2.5}$: 8 μg m^{-3}) and roadside sites in Atlanta, Georgia~~A~~, USA (average $PM_{2.5}$: 21 μg m^{-3}), as well as a location with substantially higher ambient concentrations in Hyderabad, India (average $PM_{2.5}$: 72 μg m^{-3}). Additionally, a low cost carbon dioxide (CO_2) sensor (COZIR GC-0010) and a mid-cost black carbon sensor (microAeth AE51) were tested at the roadside in Atlanta. Low cost sensor measurements were compared against reference monitors at all locations. ~~On road emissions factors were calculated at the Atlanta site by pairing $PM_{2.5}$ and separately determined black carbon (BC) and carbon dioxide (CO_2) measurements. On road emission factors can vary in different locations and over time for a number of reasons, including vehicle fleet composition and driving patterns and behaviors, and current environmental policy. Emission factors can provide valuable information to inform researchers, citizens, and policy makers.~~ The PPD20V sensors had the highest correlation with the reference environmental beta attenuation monitor (E-BAM) with R^2 values above 0.80 at the India site while at the urban background site in Atlanta, the PPD60PV had the highest correlation with the tapered element oscillating microbalance (TEOM) with an R^2 value of 0.30. At the roadside site, only the PPD20V was used, with an R^2 value against the TEOM of 0.18. ~~Emissions factors at the roadside site were calculated as 0.39 ± 0.10 g $PM_{2.5}$ per kg fuel and 0.11 ± 0.01g BC per kg fuel, which compare well with other studies and estimates based on other instruments.~~ Although t~~T~~he results of this work show poor performance under lower USA concentrations, the results ~~show~~indicate the potential usefulness of these low cost~~these~~ sensors, including the PPD20V, for high concentration applications up to approximately 250 μg m^{-3}. ~~We also tested a low cost CO_2 sensor~~The CO_2 sensor had an R^2 value of 0.68 with the reference analyzer while the BC sensor ~~performed well~~compared ~~closely~~correlated strongly to a multiangle absorption photometer (MAAP), with an R^2 of 0.99, at the Atlanta roadside site. These field testing results, although limited in nature, provide important insights into the varying performance of low cost

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Fig. 3. Revised paper with track changes

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