Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2016-131-RC3, 2016

Atmospheric Measurement Techniques Discussions

Interactive comment on "Community Air Sensor Network (CAIRSENSE) project: Evaluation of low-cost sensor performance in a suburban environment in the southeastern United States" *by* Wan Jiao et al.

Anonymous Referee #3

Received and published: 25 August 2016

General comments This an important topic with a great deal of significance to the air monitoring community involved either research or community air monitoring projects. And it represents a good start at addressing the many issues one faces when doing such studies with low cost sensors. An overarching concern with this paper is that it too briefly describes sensor systems being tested beyond a define low cost. Several seem unsuitable or not designed for such outdoor use. Further, it would seem that the process for selection of the sensors may not have included important and readily available units (for example there is are Aeroqual sensors for gases beyond those selected and AQ mesh also may offer a PM sensor option). A final point is that many

readers would like guidance on how to select and use these and other sensors. This topic is not included.

Specific comments

Abstract-issues of data quality are raised as being important for low cost sensors. However, this is a weak point in paper. What is acceptable or sufficient data quality? For PM the authors appears to be a defined level of acceptable quality-when agreement between reference monitors and the sensor shows a "moderate to strong" agreement of r=0.5. This reviewer finds that such a level of agreement is arbitrary and perhaps unacceptable for many uses. While text on page 8, line 12 seems to acknowledge that there is no good means to classify agreement, the arbitrary use of terms like weak, moderate, good and fairly strong are still used in the findings section. Reading page 8 one would expect only r or r2 values to be presented in the abstract, results and summary sections and not the qualitative terminology.

"Overall, this study demonstrates a straightforward methodology for establishing low-cost air quality sensor performance in a real-world setting and demonstrates the feasibility of deploying a local sensor network to measure ambient air quality trends." This closing statement of the abstract seems only generally based on the paper and does not include a clear summary of data quality findings of the study. The paper does not provide detailed protocol/procedures needed for testing of sensors and characterization that users should carry out before they deploy monitors-rather it seems to simply be based on partial success of a small scale deployment of wireless network. This summary of the study should be modified to better reflect the specific findings of the study that includes the findings of sensors used in the field tests (which seem quite negative) not just the protocol. A key issue needs some consideration– whether these sensors/systems are actually suitable as they come from the seller for use as outdoor air monitors in community monitoring. Does the research point out useful things regarding how users should select, evaluate and employ low cost sensors? A cautionary statement such is as found on page 13, line 22 should be pulled into the abstract.

Page 2, line 27-in defining low cost it is unclear whether it is proper to set a 2K USD per sensor limit for consideration. Sensor are only useful if part of a complete system so it is important to define what a "sensor device" consists of. The paper should include data on the complete system costs and if web/server based systems such as the AQmesh the system costs should include service costs. Further, this tight cost definition could cut out other sensors that cost a bit more but might produce better data.

Page 3, line 11-there is mention of two PM sensors and how they perform. However, the text only mentions performance acceptability in very general terms in undefined moderate, high or very high concentration situations. However, these concentration and performance characteristics are not defined or described. This issue is important and should be expanded with details added beyond the simple reference in the text.

The "ad-hoc" testing of the candidate sensor systems does not appear to include comparisons to reference monitors. This would have increased the value of observations. Why was this not done? Page 4, line22-sensor devices are not adequately described and details regarding their suitability for measurement of outside air is not included. One clear example is the MetOne 831. It is not a sensor, rather it is a complete monitor and there are several others that could have been included. It is not designed for the application in continuous outdoor air monitoring, instead it might be more properly be considered a hand held PM survey instrument. The air egg devices also don't seem to be designed for use in outdoor air. The authors should expand discussions of the selection process and suitability of the sensors selected.

Page 4, line 27–There is an enumeration of 'sensor types' for the various pollutants-especially for gases. However, it is likely to be unclear to many readers what is meant by sensor types. Are any of the actual sensors the same in any of the units since only Aeroqual, and perhaps Caripol appear to make some of their own gas sensors (this reviewer understands that they also may use sensors made by others-especially Alfasense. Perhaps the table and text would be improved by a more clear definition of sensors in each system tested. The list of pollutants assessed is not complete-the AQ

mesh appears to have reported NO and CO2 in addition to those on the list. Aeroqual 50 sensors and sensor testing could have included CO and SO2. Why were these not included in tests? A final point on sensor descriptions is that the sensors used in the Air Quality Egg units are described as being electrochemical-It would appear they are not. Rather they may be metal oxide units. The authors should clarify this and include any corrections in Table 1.

The cost limit for sensor devices was stated as $2000 per sensor. What is the cost/sensor for this device, including data processing that a user would encounter if they used this sensor system for the period they were used? The AQMesh unit cost should include the support/data fee for the user since its data are not available to the user without this fee.

One further point regarding selection and use of sensors is that PM sensors rely on photometry. Some report particle counts while others convert and report data as mass. Conversions to mass are not straightforward and should be more completely described. Also, it is not clear that the PM sensors are equipped with size selective mechanisms to assure they measure only PM 2.5 for comparisons with reference monitors. Humidity is known to strongly impact photometer based results and this issue should be discussed. Together these factors make it quite complicated to understand and compare the performance of the various PM sensors and especially why one should expect agreement with regulatory grade PM 2.5 monitors. Finally, of the sensor systems included, only the AQMesh has a commercial system for measurement of the target gaseous pollutants. There have been several versions of the AQMesh and version 3 was used here. What is the current version (as Aug 2016) and how does it differ?

Page 5, Line 4- This text states that the investigators followed manufacturers' recommendations for operation. Do the various sensors provide operational directions for use in measuring outdoor air and where there any considerations made for humidity corrections performed or recommended by manufacturers?

Page 5, line 11- It is appears that the researchers were provided adjusted processed sensor data for the units from AQ mesh. If the data were processed in any way by the vendor this process should be completely described. Such adjustments could influence the values reported in this paper. This is an important issue since the readers need to know they do not have access to sensor data from this system instead they only receive processed data so they can't independently perform comprehensive tests of this system.

What were the actual dates of performance of the two protocols? Further information is needed to describe attempts to consider response by season or temperature regimes Page 8, line 30 and following-it is unclear how the decision to perform FEM comparisons with 12 hour time resolution was based on performance of the BAM. Perhaps this decision impacted the comparisons with the other sensors, since they too must have undergone data averaging. It seems that one hour data is of great value in this comparison study. Data should be explored to consider hourly comparability and observations. This is because users are not going to restrict their use to 12 hour averages; rather they are likely to want hourly or even sub hourly data. The choice seems to be based on imprecision of the BAM. This is illogical. Regulatory monitoring programs all over the world report hourly data from BAMs. Data for hourly agreement between the BAM and various monitors REALLY MUST BE PRESENTED!

Page 9, line 9 and following-comparisons of the raw (or internally processed data) from the various instruments is too simply reviewed. One should expect the various instruments to report quite different values that may or may not be related to PM 2.5 mass. None are mass (gravimetric) monitors and none appear to have physical size cuts to assure PM 2.5 is being reported. Carefully conducted calibration vs. reference studies have been performed on some of these units and should have been considered as a useful output of this study as well.

What were the overall summary findings for the PM sensors? Are they suitable for use and under what constraints? It would appear that after reviewing the data pre-

sented on tables 3 and 5 that none of the PM sensors tested under the rather careful protocol employed represent good choices for application in community/citizen based air monitoring. If the authors agree with this summary they need to clearly say so. If they do not agree they should clearly present a rationale for their use. It appears that the Cariclip values for ozone and NO2 are presented after adjustment by AQ monitor data. This may improve the data, but it should be clearly pointed out in the discussion of results and evaluations of the data. The community/citizen user of this sensor is not likely to have the luxury of operations next to a FEM site. The unadjusted data should be reported-perhaps as "oxidant" and the utility of this sensor should be made clear. It appears it does not report ozone and it may not report NO2. However, this is somewhat complicated by the summary of NO2 sensors on page 10, line 10, where it is mentioned that NO2 data from the Cariclip was evaluated. Was there a separate NO2 sensor for the Cariclip? Please clarify cariclip sensor and data handling.

Page 11, line 7- it appears that Aeroqual sm50 units could have included this gas as well as CO. Why were these not included for the sm50-an additional base unit would have been needed, but it is a missed opportunity for a logical comparison.

Page 13, line 22- "These results underscore the importance of individual sensor performance testing prior to field use, and the corresponding higher uncertainty in sensor datasets that do not incorporate field testing in their application." While such work seems not to be the focus of this study this reviewer agrees strongly with this assessment and finds that users need to know that this paper actually finds that many of the sensors tested would produce quite poor data without special care and even after lab and field testing the data are at times capable of only weak agreement with what regulatory grade ambient air monitors report. I guess what I am trying to say is that it is essential for the user to understand the performance of their sensor systems and this really requires quite complicated testing. THIS STATEMENT FROM LINE 22 SHOULD BE ADDED TO THE ABSTRACT!

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