Heated Inlet Calibration of PM Sensors

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Abstract

Air pollution is a public health emergency in the U.S. and around the world. Small particles made of dust and waste comprise much of what is referred to as air pollution. These particles, known as particulate matter (PM), can negatively affect the health of humans and other animals. When these minuscule particles enter the lungs, various respiratory issues can arise. For this reason, the measurements of PM in an area is very important and must be recorded accurately.

Under conditions of high relative humidity, particulate matter can increase in size due to water uptake; a process known as hygroscopic growth. Low-cost light-scattering sensors do not take this into account and subsequently produce inaccurate PM measurements. In this study, two methods of correcting for PM data affected by hygroscopic growth were compared. The hypothesis was that both the correction equation and the heated inlet would produce equally reliable results. This would suggest that the heated inlet was an accurate correction device.

This project was selected due to the availability of various PM measurement devices at the Howard University Beltsville Campus (HUBC) in Beltsville, MD. The BAM1020 owned by the Maryland Department of the Environment (MDE) at HUBC was used as a reference measurement. Final results and conclusions demonstrate the reliability of inexpensive PM measurement devices and heated inlets. If citizen scientists are able to gain accurate data from low-cost instruments, a large and useful network of PM measurements can be developed.

Method

To Collect the First Set of Data

1. Gathered two PMS3003 devices and inserted each into radiation shields.
2. Collocated the instruments with the reference BAM1020 at the MDE trailer at HUBC.
3. Plugged-in devices and collected measurements for three weeks.
4. Downloaded data from each PMS3003 as text files. Obtained BAM1020 data over the same time range from MDE.

To Collect the Second Set of Data

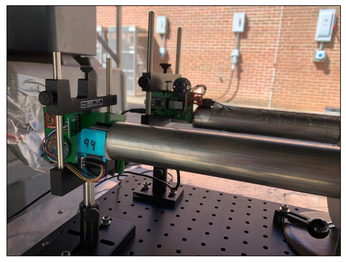
1. Created an inexpensive heated inlet using heated cable, stainless steel tubing, and aluminum tape.
2. Gathered the two PMS3003 devices. Fitted one with the heated inlet modification and one with a control stainless steel tube to maintain uniform air flow.
3. Set the instruments up outside the main building at HUBC.
4. Plugged-in devices and collected measurements for one week.
5. Downloaded data from each PMS3003 as text files.

To Analyze Data

1. Imported all data to the Wolfram Mathematica program.
2. Created a correction equation derived from the linear regression of BAM vs. the more accurate PMS3003 from the first dataset.
3. Applied correction equation to data from unmodified PMS3003 from the second dataset.
4. Calculated Root-Mean-Square-Error (RMSE) of raw, unmodified PM data vs. corrected data from previous step.
5. Calculated RMSE of raw, unmodified PM data vs. modified PM data from the second dataset.

Set-Up

The setup for the first set of data.



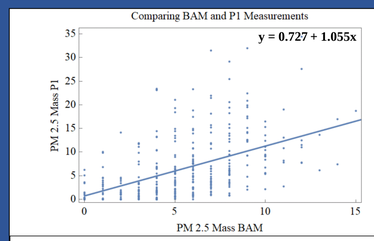
The setup for the second set of data.

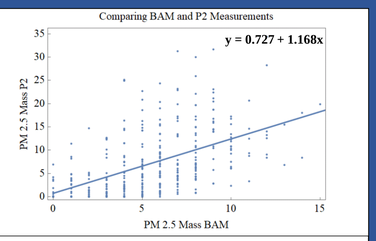
Heated Inlet

A heated inlet made of stainless steel tubing and heated cable was created as an inexpensive correction device that would dry air before entering the PMS3003. Grade 316 stainless steel was chosen for its resistance to corrosion in the presence of gases in the Earth's atmosphere. Heated cable was chosen for its availability as well as versatility.

The tube was lined with the cable to prevent overheating and subsequently successfully heated the inlet while not generating excessive temperatures thus conserving volatile components of PM.

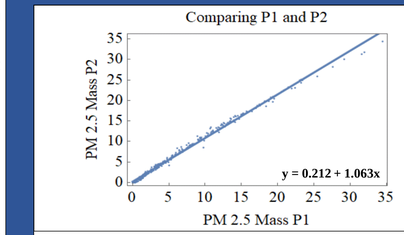
Correction Equation

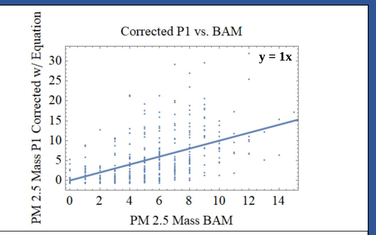




After collecting data for the first dataset, linear regressions of measurements from each PMS3003 sensor versus the BAM1020 were created. The correction equation used in this experiment was derived from the linear regression between the BAM1020 and the more accurate PMS3003 device. By comparing the slopes of each graph it was determined that the first PMS3003 sensor was more accurate. Its linear equation y=0.727 + 1.055x was used to create the correction equation.

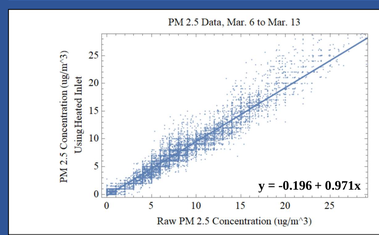
Testing Sensors & Equation

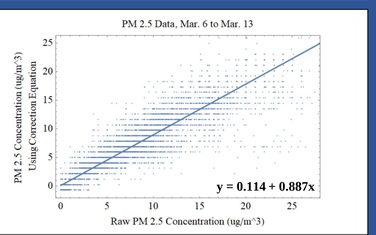




The measurements from both Plantower sensors were compared to determine the relationship between the two. The corrected P1 data was also compared to the reference BAM measurements. If they were found to positively agree with each other, then the values obtained by one sensor could be used as the raw, unmodified values of the other and the equation correction could be used as a reliable calibration method.

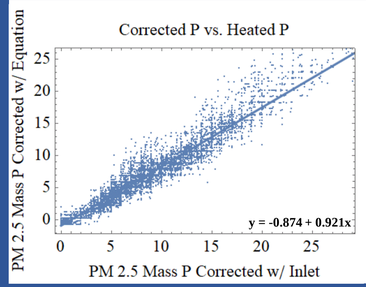
Using Heated Inlet & Correction Equation





In the second dataset, one sensor was equipped with the heated inlet while the other was not and instead acted as a source of raw, unmodified PM 2.5 data. This raw data was used to discover the effects of the heated inlet on PM data. The raw data was also calibrated using the correction equation.

Comparing Calibration Methods



The calibration methods were compared and the root-mean-square-error (RMSE) of each calibration method was calculated. While the RMSE is generally calculated using reference data of some kind, the second dataset of this experiment did not feature a reference sensor. Therefore, all corrected data was compared to the raw PM measurements.

The use of the correction equation yielded an RMSE value of 3.030. The use of the heated inlet yielded an RMSE value of 1.560.

Summary & Discussion

The calibration methods produced unequal RMSE values, therefore, rejecting the hypothesis. It can be concluded that the inexpensive heated inlet created was an inaccurate and unreliable calibration device.

The BAM1020 device featured an integrated heated inlet that modified the RH of all incoming air. This ensured that all PM measurements were taken at the same RH and were, therefore, comparable. The inexpensive heated inlet used in this study modified the temperature of all ambient air, not the RH. All measurements were taken at a temperature higher than the ambient air, but this value was not constant.

The second dataset was only one week long as opposed to the first dataset that was three weeks long. One week worth of monitoring is insufficient for producing trustworthy conclusions. A span of approximately three weeks or longer would have allowed for more accurate results and implications.

Future Research

Future research on this project should focus on discovering the most inexpensive yet accurate method of low-cost light-scattering PM sensor calibration. Once determined, low-cost PM sensors can be used by various people and groups in large networks. This would allow applications of PM measurements to occur globally, therefore, assisting atmospheric scientists and citizens in research studies.

Methods of calibration could include:

- Deriving and utilizing correction equations on raw data
- Constructing heated inlets that regulate the temperature and/or RH of incoming air
- The use of Teflon tubing to remove excess water vapor

References

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