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Development of an approach to correcting MicroPEM baseline drift

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Abstract

Background—Fine particulate matter (PM_{2.5}) is associated with various adverse health outcomes. The MicroPEM (RTI, NC), a miniaturized real-time portable particulate sensor with an integrated filter for collecting particles, has been widely used for personal PM_{2.5} exposure assessment. Five-day deployments were targeted on a total of 142 deployments (personal or residential) to obtain real-time PM_{2.5} levels from children living in New York City and Baltimore. Among these 142 deployments, 79 applied high-efficiency particulate air (HEPA) filters in the field at the beginning and end of each deployment to adjust the zero level of the nephelometer. However, unacceptable baseline drift was observed in a large fraction (>40%) of acquisitions in this study even after HEPA correction. This drift issue has been observed in several other studies as well. The purpose of the present study is to develop an algorithm to correct the baseline drift in MicroPEM based on central site ambient data during inactive time periods.

Method—A running baseline & gravimetric correction (RBGC) method was developed based on the comparison of MicroPEM readings during inactive periods to ambient PM_{2.5} levels provided by fixed monitoring sites and the gravimetric weight of PM_{2.5} collected on the MicroPEM filters. The results after RBGC correction were compared with those using HEPA approach and gravimetric correction alone. Seven pairs of duplicate acquisitions were used to validate the RBGC method.

Results—The percentages of acquisitions with baseline drift problems were 42%, 53% and 10% for raw, HEPA corrected, and RBGC corrected data, respectively. Pearson correlation analysis of duplicates showed an increase in the coefficient of determination from 0.87 for raw data to 0.99 after RBGC correction. In addition, the slope of the regression line increased from 0.60 for raw data to 1.00 after RBGC correction.

Conclusions—The RBGC approach improved the baseline drift issue associated with MicroPEM data. The algorithm developed has the potential for use with data generated from other

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types of PM sensors that contain a filter for weighing as well. In addition, this approach can be applied in many other regions, given widely available ambient PM data from monitoring networks, especially in urban areas.

Keywords

PM_{2.5}; Personal exposure; MicroPEM; Baseline shift; Ambient level; HEPA correction

Introduction

Airborne particulate matter with an aerodynamic diameter below 2.5 μm (PM_{2.5}) have been shown to have health risks associated with their toxic components and their ability to lodge deeply in the lung (Laden et al., 2006; Chen et al., 2013; Hänninen et al., 2014). Personal exposure is believed to be the gold-standard method for characterizing exposure (Jantunen et al., 2002). Several real-time personal nephelometer sensors have been developed in recent years. Among them, the MicroPEM, a miniaturized PM_{2.5} personal exposure monitor (RTI International, Research Triangle Park, NC, USA), has been widely used (Jack et al., 2015; Vesper et al., 2015; Wang et al., 2017). The MicroPEM includes a two-stage impactor with a PM_{2.5} cut point, a light scattering nephelometer for real-time measurement, temperature and relative humidity sensors, a Teflon filter for integrative gravimetric measurement of PM_{2.5}, and a 3-axis accelerometer for the activity record (RTI, 2012).

Compared with some other personal sensors, the MicroPEM stands out due to its responsive range, portability, and agreement with standard units used by the US Environmental Protection Agency (EPA) (Steinle et al., 2013; EPA, 2014). In addition, PM collected on MicroPEM filters allows the nephelometer data for each deployment to be calibrated to the average optical properties of aerosol monitored, as well as being archived for later lab analyses such as black carbon, metals, polycyclic aromatic hydrocarbons, etc. However, the MicroPEM also has its limitations. According to a report from the EPA (EPA, 2014) as well as our on-going studies in New York and China, baseline drift of the real-time PM_{2.5} data has been observed in MicroPEM data on regular basis. Baseline drift (or, zero 3 offset) is a problem not only for MicroPEM nephelometers but is also an unresolved issue for other nephelometer sensors, all of which measure particle concentration based on the intensity of laser light reflected by particles (Wheeler et al., 2011; Ryswyk et al., 2013).

High-efficiency particulate air (HEPA) filter zeroing has been used for correcting baseline drift (Wallace et al., 2011; EPA, 2014; Sloan et al., 2016). Following the MicroPEM protocol, HEPA correction can be typically conducted at the beginning and/or in the end of deployment. Researchers have found that for a deployment of more than one day, this approach can be insufficient to correct the drift and a daily HEPA correction has been suggested (Wallace et al., 2011; EPA, 2014). However, it is impractical to have the daily correction in large epidemiological studies, given the demand of extra labor/travel time. To the best of our knowledge, no other efficient method for correcting baseline drift has been reported.

In this study, we aim to develop a reliable method to adjust the baseline while tying real-time data to the mass-weighted average optical properties of the particulate matter collected. We

used widely available PM data from established monitoring networks, e.g., EPA Airnow and World Air Quality Index (AQICN), to adjust the baseline during the periods of low activity when there are little to no local particle sources. The premise of this use is that the baseline of personal or indoor PM level generally followed a similar trend to that of ambient data during periods of low activity; typically this was the case as shown in Fig. S1. Thus we hypothesized that the baseline of a MicroPEM was proportional to the ambient level during periods of low activity. The gravimetric correction based on the PM mass collected onto MicroPEM filters was also included in this method. Given that baseline drift is a common issue for nephelometer PM sensors, the developed algorithm has the potential for use in correcting data from other types of nephelometers.

Materials and Methods

Data Acquisition and Sample Collection

Residential and personal PM_{2.5} levels were investigated in the Environmental Monitoring and Biological Airway Response Study (EMBARS) conducted in New York City (NYC), New York and Baltimore, Maryland (USA). The aim of this validation project is to determine the association between biological response of the airway gene-expression markers and continuous/integrated measures of second hand smoke (SHS) exposures for non-smoking adults and children, based in part on analysis of the Teflon filter by optical methods (Lawless et al, 2004; Yan et al. 2011). In this study, MicroPEMs were used to characterize PM_{2.5} exposure.

MicroPEMs were set to log data at 10-second intervals. Subsequently, the original data were reduced to one-minute or one-hour averages for different usages. To extend sampling run time and reduce noise, MicroPEMs ran at a flow rate of 0.4 L/min, with the internal flow measurements calibrated to a TSI Flowmeter 4140 (TSI Incorporated, MN, USA) at set up and then measured externally by the TSI flow meter in the field before and after each deployment. Each MicroPEM's baseline was set to zero under HEPA filtered air period (Pall Corporation, NY, USA) in the laboratory at set up. In a large fraction of deployments, a HEPA filter was attached to the MicroPEMs inlet in the field for 5 minutes at the beginning and the end of each deployment. Mettler Toledo UMX2 microbalance was used to pre- and post-weigh Teflon filters in a room-sized environmental chamber at RTI that was maintained at 35% RH and 21 °C. All filters are equilibrated in the chamber for a minimum of 24 hours before pre and post weighing. Filters were weighed twice in the same day and their difference between the two weighings must be less than 1 µg to be accepted as a valid measurement.

In both NYC and Baltimore, a total of 106 personal acquisitions, including one duplicate measurement, were collected over a sampling period of 4.01 ± 1.45 days. NYC residential sampling was performed in 24 homes, with 6 of these homes having valid duplicates. The average residential sampling period was 4.86 ± 0.49 days. Baltimore residential levels were not measured by MicroPEM and thus not included in this study.

Approach for HEPA Baseline Correction and Gravimetric Correction

The HEPA baseline correction method was applied to those deployments having both valid start and end HEPA data. Real-time $PM_{2.5}$ data were corrected by the following equation:

$$c[PM_{2.5}]_i^{HEPA} = c[PM_{2.5}]_i - HEPA_{Start} + \frac{HEPA_{Start} - HEPA_{End}}{K - 1} * (i - 1) \quad (1)$$

Here $c[PM_{2.5}]_i$ and $c[PM_{2.5}]_i^{HEPA}$ are the real-time $PM_{2.5}$ concentrations of minute i before and after HEPA correction; $HEPA_{Start}$ and $HEPA_{End}$ are the HEPA correction values for start and end HEPA corrections; K is total sampling time in minutes.

After the HEPA correction, $PM_{2.5}$ concentrations are then gravimetrically corrected (GC). The GC ratio (r_{GC}) is the ratio of gravimetric mass to the accumulated weight calculated based on HEPA corrected nephelometer data. The following equation is used to calculate r_{GC} :

$$r_{GC} = \frac{m_{post} - m_{pre} - m_{field\ blank}}{\sum (c[PM_{2.5}]_i^{HEPA} * mv)} \quad (2)$$

Where mv (acronym for minute volume) is the average of the volume (in m^3) of air per minute passing through a microPEM, and m_{pre} and m_{post} are filter mass weighed before and after the deployment (in μg). The $m_{field\ blank}$ is the average weight change of field blank filters (FBF), which had been installed in MicroPEMs and brought to and from the field but not used for active sampling. The weight change of each FBF was calculated as the difference of the FBF weights measured before and after deployment. The median FBF was used to correct the possible filter weight changes positive or negative due to transport, storage, and handling. Adjusted $PM_{2.5}$ concentrations after HEPA correction would be corrected using r_{GC} :

$$c[PM_{2.5}]_i^* = c[PM_{2.5}]_i^{HEPA} * r_{GC} \quad (3)$$

Running Baseline & Gravimetric Correction (RBGC)

In our study, we found that MicroPEM deployments after HEPA correction could still have a large portion of the nephelometer data (>40%) with large negative $PM_{2.5}$ levels, indicating that the baseline was not stable and thus making the simple subtraction of interpolated HEPA values inadequate. In order to correct this issue, we developed another protocol combining both running baseline and gravimetric corrections, as shown in equation 4. Figure S2 conceptually shows how the correction was made: 1) the original data with issues (typically negative drifts) were adjusted to presumed baseline based on fixed site data (explained in detail in the next paragraph) and 2) the total mass on the filter calculated from adjusted real-time data (step 1) was set equal to gravimetric mass of particles on the filters.

$$\sum_1^N ((BL + r_c * (c[PM_{2.5}]_i - c[PM_{2.5}]_{LowPM}) * mv) = GM \quad (4)$$

where $c[PM_{2.5}]_i$ is the raw $PM_{2.5}$ concentration at minute i as measured by the MicroPEM; N is the total sampling time (in minutes); BL is the baseline $PM_{2.5}$ concentration (using equations 5, 6, and 7); mv is the minute volume; GM is the gravimetric mass of particles collected on the MicroPEM filter during the total deployment; $c[PM_{2.5}]_{LowPM}$ is the $PM_{2.5}$ concentration from MicroPEM in a selected two-hour period when BL was chosen; and r_c is the correction ratio used to adjust the concentrations (see equation 8 below). The approach for the selection of the period for baseline adjustment is described below. .

The baseline (BL) $PM_{2.5}$ was calculated through equations 5–7 for each sampling day. The major assumption was that the baseline level was proportional to ambient $PM_{2.5}$ concentration during inactive personal time periods (e.g., sleeping or resting at home) when local sources of particles (e.g., cooking, cleaning, incense) was minimal, resulting in the majority of particles being from penetration of ambient air. In order to calculate the proportion z , which is the ratio of correct baseline of the MicroPEM to ambient level as reported by a fixed-site monitor using a reference method, two scenarios were considered, dependent on R_{GMOA} values in equation 6, where R_{GMOA} is the ratio of the GM (gravimetric mass of particles collected on the MicroPEM filter) to the calculated mass assuming MicroPEM sampled ambient air during the whole deployment. The calculated mass was the sum (over the whole deployment) of the product of the nearby fixed monitoring site hourly $PM_{2.5}$ concentration (C_{fs}) multiplied by the total volume of air the MicroPEM sampled in that hour. In other words, R_{GMOA} was the ratio of $PM_{2.5}$ at locations of the MicroPEM to that at the fixed site. This ratio was independent of real-time $PM_{2.5}$ data measured by the MicroPEM.

Equation 6 shows the method of using R_{GMOA} to assign the z value, our estimate of the ratio of the baseline of the MicroPEM real-time data to the fixed site, which is similar to the penetration factor or indoor to outdoor ratios (I/O) during inactive periods. We chose 0.6 for a z threshold value since it is the median z values during low activity times among our acquisitions without baseline drift issues (Table S1). The range of z values was similar to the I/O for naturally ventilated buildings in the absence of indoor sources and human activity (Morawska et al., 2013). As such, if $R_{GMOA} < 0.6$, it indicated the $PM_{2.5}$ concentration in the participant's microenvironment is lower than ambient level, likely due to removal from air filtration or low air exchange rate (Hänninen et al., 2005). In this case z is set to R_{GMOA} . On the other hand, if R_{GMOA} was more than 0.6 (i.e., $PM_{2.5}$ was similar to or higher than the fixed site ambient level after accounting for particle penetration), it indicates that $PM_{2.5}$ were then impacted by personal activities and/or indoor $PM_{2.5}$ sources, leading to the existence of peaks; consequently, z was then set to 0.6. In this last case we chose a z value of 0.6 rather than the exact R_{GMOA} value of each entire deployment, since the use of R_{GMOA} can overestimate the baseline $PM_{2.5}$ level. Assuming R_{GMOA} , the overall personal to ambient ratio for the whole deployment period of 4–5 days, was 1.7. This ratio integrated the whole sampling period when there were strong local active sources such as cooking,

cleaning, smoking etc and when there were no or weak local sources. When local sources were strong, personal $PM_{2.5}$ level was much higher than the ambient level and thus the personal to ambient ratio at this period will be higher than 1.7, e.g., > 4 . During the baseline time, personal sampler measured $PM_{2.5}$ levels were similar to or lower than the ambient level. Therefore R_{GMOA} cannot be used for baseline correction since it was higher than the ratio of personal exposure to ambient during the quiescent periods.

$$R_{GMOA} = GM / \left[\text{flow} * \sum_1^N c[PM_{2.5}]_{ifs} \right] \quad (5)$$

$$z = \begin{cases} 0.6, & (R_{GMOA} \geq 0.6) \\ R_{GMOA} & (R_{GMOA} < 0.6) \end{cases} \quad (6)$$

$$BL = z * C_{fs} \quad (7)$$

Here, $c[PM_{2.5}]_{ifs}$ is the $PM_{2.5}$ concentration at minute i from the fixed monitoring site.

Finally, the z value was used to calculate a corrected baseline, as shown in equation 7 by multiplying z by the C_{fs}

Selection of the period for baseline adjustment

Ambient data varied temporally; thus it was critical to choose appropriate time intervals for baseline correction. In this study, we chose two consecutive hours with the lowest $PM_{2.5}$ level and no-/low-activity (defined as 15% of the hour showing activity in the accelerometer data of the MicroPEM), often from midnight to early morning, denoted here by T_{lowPM} , to avoid impact on MicroPEM values by personal activities such as resuspension (Morawska et al., 2013) and/or other local sources of particles. T_{lowPM} can be viewed as a period with no or limited obvious local sources (such as second-hand smoke and cooking, etc.) when regional background $PM_{2.5}$ is the main contributor to personal exposure. Since the baseline was not stable throughout sampling, T_{lowPM} was determined for each sampling day, and the product of fixed site $PM_{2.5}$ during T_{lowPM} and z was set as the baseline (BL) of that day. Accordingly, baseline levels differed from day to day, thus the term “running baseline correction” was used to describe this method.

After the daily baseline is determined, r_c in equation 4 can be computed and the $PM_{2.5}$ value at minute i is calculated using the following equation:

$$c[PM_{2.5}]_i^* = BL + r_c * (c[PM_{2.5}]_i - c[PM_{2.5}]_{LowPM}) \quad (8)$$

Evaluation of Correction Methods

In order to evaluate the correction methods, we classified corrected PM_{2.5} data into three groups, “Good”, “Fair”, and “Unacceptable” based on percentage of negative PM_{2.5} data (Table. 1). A cutoff value of $-5 \mu\text{g}/\text{m}^3$ was chosen since MicroPEM can detect a change of $5 \mu\text{g}/\text{m}^3$ (RTI, 2012), in which case a true zero of PM_{2.5} can have a reading of $-5 \mu\text{g}/\text{m}^3$. A positive r_c is also required since a negative r_c would result in negative concentrations. In addition, the impact on seven pairs of duplicates was used to validate the approach. After correction, results of side-by-side duplicates were compared to examine the consistence of PM_{2.5} levels between duplicates.

Ambient fixed site PM_{2.5} data are from the U.S. EPA official website (EPA, Air Data). The R program was used to process, analyze and report data.

Results

HEPA and RBGC Corrections

In total, we acquired real-time data for 142 MicroPEM deployments, among which 63 were collected from Baltimore and 79 from NYC. About 41.5% of acquisitions had the baseline drift issue (fair and unacceptable), as shown in Table 2. The incidence of baseline issues was highest (60%) when average PM_{2.5} was below $10 \mu\text{g}/\text{m}^3$, and was between 30 to 40% when average PM_{2.5} was above $10 \mu\text{g}/\text{m}^3$ (Fig. S3).

Among these 142 acquisitions, 79 had both start and end HEPA measurements, and the remaining 63 had either only one or no HEPA correction (Table. 2). Even in the 79 data files with both start and end field HEPA measurements, the HEPA correction regularly appeared to be insufficient to solve the baseline issues. Out of 43 NYC personal acquisitions, 37 had both start and end HEPA corrections. Of these 37 personal acquisitions, 16 had good results, 3 fair, and 18 unacceptable before HEPA correction (Table 2). After HEPA correction, 12 had good results, 2 fair, and 23 unacceptable.

In sharp contrast, the RBGC approach substantially increased the percentage of good results, from 58.5% to 90.1%, after correction. As for the 59 raw data files with baseline drift, 48 (81.4%) of them meet our validation criteria after RBGC. Among 35 data files with negative baseline drift in raw data, 31 (88.6%) of them meet the good criteria after RBGC. The percentage of acquisitions in both fair and unacceptable groups decreased, with 5 acquisitions being fair and 9 being unacceptable. The 9 acquisitions were not used in further data analysis.

Comparison between Duplicates

Duplicate acquisitions were used to compare the different baseline correction methods and validate the RBGC correction approach. Fig. 1 shows a comparison of one pair of duplicates before and after correction via the HEPA and RBGC methods. MicroPEM unit PM066N produced quite a large percentage (77.5%) of negative raw data below $-5 \mu\text{g}/\text{m}^3$. Though improved after HEPA correction, there was still a considerable fraction (9.2%) of negative data from this unit. After RBGC correction, all PM066N data were above zero with

consistent baseline, and similar temporal patterns were observed between it and its duplicate (Fig 1c).

Fig. 2 showed scatter plots of the average $PM_{2.5}$ concentrations (across whole sampling periods) among the 7 pairs of duplicates before and after corrections. The coefficient of determination increased from 0.75 for the raw data (Fig. 2a), to 0.97 for both running baseline correction (Fig. 2b) using the equation S1 in Supporting Information (RB only without GC correction), and RBGC correction (Fig. 2c). Although coefficients of determination after RB and RBGC corrections were comparable, the slopes and intercepts were quite different, changing from 0.71 and 3.72 after RB to 1.00 and $-1.02 \mu\text{g}/\text{m}^3$ after RBGC (Fig. 2).

Discussion

Baseline drift may be caused by variations in sampling conditions, such as vibration or temperature change, which potentially can affect the alignment of optics in the nephelometer, or the amount of stray light entering the system, or other issues; however, the exact reasons are not clear. The 41.5% baseline drift rate in all acquisitions demonstrates the necessity to develop a robust approach to fix the issue. Devices with nephelometers for real-time measurement often have baseline issues. For example, a weekly drift of up to $40 \mu\text{g}/\text{m}^3$ was observed in pDR measurements (Quintana et al., 2000) while more than half of DustTrak instruments encountered drift in monitoring periods exceeding five days (Wallace et al., 2011). Other optical devices can also have baseline issues. For example, in the microAeth (AethLab, CA), which measured black carbon, baseline drift was mainly due to rapid change in relative humidity. However, this issue can be ameliorated through use of a Nafion inlet before optical measurement if the unit is being worn on the body (Cai et al., 2013). An analysis of our MicroPEM data revealed no temporal association between baseline drift and RH changes. Based on the manual provided by RTI (RTI, 2012), variations due to RH change are accounted for during data processing by device software.

In our study, based on relatively low $PM_{2.5}$ concentrations found in NYC and Baltimore, we found that HEPA correction could not always solve the baseline issue, regardless of sampling duration. As shown in Fig. 1a, baseline drift can occur within the first 24 hours, rendering the HEPA correction unable to correct the issue (Fig. 1b). Sampling durations in the EMBARS project, typically lasting for five days or more, were comparable to other weekly long studies (Quintana et al., 2000; Wallace et al., 2011). On the other hand, we have had much greater success with the HEPA correction approach in biomass studies in Africa where both ambient and personal exposures are appreciably higher and the daily temperature swings are much lower (Chillrud, unpublished data).

RBGC Effects and Validation by Duplicates

Baseline drift can lead to a substantial loss of data (Howard-Reed et al., 2000), thus it is important to develop an approach for correcting these data for drift. Ideally, the MicroPEM can be compared to another “certified” monitor placed side-by-side at least one time each day so that baseline can be adjusted. However, this comparison requires substantial additional labor and devices, which most research projects cannot afford.

In this study, we took advantage of widely available ambient PM_{2.5} data reported from nearby fixed sites in government monitoring networks. Many cities in countries such as the US and China have monitoring networks that are already established or are in the process of being established.

After RBGC, about 90% of data files meet our validation criteria, demonstrating that the RBGC method works in adjusting baseline drift in most cases. However, meeting the criteria based on percentage of negative data does not necessarily mean the data are correct and close to the true PM level; the baseline adjustment merely adjusts the daily real-time PM_{2.5} data as a whole (Fig. 1) by adding the daily difference between fixed site data and PM_{2.5} data at T_{lowPM} to all MicroPEM PM_{2.5} data points. Fortunately, the total mass of PM_{2.5} collected onto MicroPEM filters (i.e., the net filter weight after deployment), can be used to adjust the slope of the response, thus bringing RBGC corrected data back to the average concentration during the deployment. Figure 2 illustrates the necessity of the combination of both RB and GC corrections. Without gravimetric correction (GC), the PM_{2.5} data that are above baseline cannot be adjusted, leading to inaccuracy of peak data and average PM_{2.5} levels (Fig. 2b). The necessity of GC has also been emphasized in other studies (Soneja et al., 2014; Zhang et al., 2017). If applying GC correction (no RB correction) only, both baseline and peak data are drifted even though the average PM_{2.5} level is correct. The 10% data files (9 samples) cannot be corrected by this method, mainly due to that the selection of z value and the period for baseline adjustment were not ideal for these samples. If the z value was set as 0.9, only 3 samples failed. In our previous studies, the median NYC I/O of PM_{2.5} was about 1.1 for a 2-week integration period (Jung et al., 2010); However, in this application T_{lowPM} chosen were those periods without many indoor activities. As such, we conservatively used 0.6, which was the median of z value of samples without the baseline drift issue (Table S1).

Duplicates provide an opportunity for objectively validating this approach. The coefficient of determination increased from 86.8% before correction to 98.6% after correction (Fig. 2), indicating only 1.4% of variation that cannot be explained by their duplicates after correction.

Limitations

Limitations of this study include the difficulty in distinguishing positive baseline drift from real PM_{2.5} measurements. In addition, using a fixed threshold value 0.6 to adjust the baseline oversimplifies the complexity of living environments in cities with different air exchange rates or variable rates. Besides, the use of advanced air-handling units (e.g., an air purifier) in some homes can lead to a much lower indoor PM_{2.5} concentrations than the ambient, complicating the baseline correction. One way to deal with this issue is to include the air handling method in questionnaire. Furthermore, the impact of organic carbon (OC) level on microPEM readings has not been considered and this study was not designed to address this issue as well. Indoor OC is typically higher than outdoor and the optical response of PM_{2.5} might be affected by the higher indoor OC levels. To estimate this impact, we would have needed to simultaneously collect indoor and ambient samples in different devices, and then compare the ratio of the sum of real-time readings to PM weight on filters

between the two samples. However, this study can indirectly answer this question. Some subjects had both residential only and personal MicroPEMs (the latter with both indoor and outdoor data) samples and if real-time data were significantly impacted by indoor OC (e.g., leading to a bias), we can observe a difference in the aforementioned ratio between these two types of samples. Such a difference was not observed (i.e., the slope is close to one), suggesting the impact of OC on indoor PM_{2.5} measurement, in our samples, was not very obvious.

Implications

As discussed earlier, baseline drift is not only an issue for the MicroPEM but also for other units measuring particle concentration based on optical characteristics of PM. The proposed method has the potential to be used for other real-time data as long as there are nearby fixed monitoring sites, usually owned by governmental environment protection agencies, e.g., USEPA or Chinese EPA. The instruments selected in these sites have passed rigorous validation tests and are regularly inspected. It is noteworthy to mention that due to differences in sampling methods, a side-by-side testing of the MicroPEM and the instrument used at the fixed site are necessary to determine whether there are systematic variations between the two methods (Zhang et al., 2017). However, it must be pointed out that compared to most other nephelometers, the MicroPEM has a distinct advantage by including a gravimetric filter allowing each deployment to be calibrated to the filter weight. One exception is the large E-Sampler by Met-One, which is designed for fixed site ambient monitoring, and not only has the ability to collect a filter for GC, but also the ability to automatically carry out HEPA corrections on a fixed time schedule (user defined rate from every few hours, or daily) (Met One Instruments, Inc., 2011). Further, it has a heated inlet to avoid condensation issues when the ambient temperature is below the dew point.

Conclusions

The combined running baseline and gravimetric correction (RBGC) was successfully applied to rectify baseline drift issues that often occurred in our use of the MicroPEM. The results after RBGC were also compared to those after HEPA correction. RBGC effectively corrects about 81.4% of the measurements with baseline drift, leaving 9 data files uncorrectable. In our NYC data, HEPA correction was not sufficient for correcting baseline issues in 46.8% of the 79 deployments with HEPA data. This study also demonstrates that gravimetric correction is a necessary approach to adjust the slope of response. Duplicates validated the RBGC method developed in this study, showing consistent results between duplicates after RBGC correction. Given the widely available PM monitoring network, this approach can be used in many other regions. This approach also provides a useful method to correct data from relatively inexpensive, miniaturized instruments, such as MicroPEM, using data from federal reference methods adopted in regional monitoring networks.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Highlights

- Unacceptable baseline drift of real-time PM_{2.5} data measured by microPEM can lead to exposure miscalculation.
- A reliable method was developed to adjust the baseline based on ambient PM_{2.5} levels provided by fixed monitoring sites.
- It is also critical to tie the real-time data with mass-weighted average optical properties of PM_{2.5} collected.
- This method can efficiently correct ~ 81% of the measurements with the baseline drift issue.

Fig. 1.

Raw, HEPA corrected and RBGC corrected $PM_{2.5}$ of a group of side-by-side residential acquisitions. PM066N and PM444N are MicroPEM unit IDs. The Y-axis for $PM_{2.5}$ are zoomed in close to zero so that the effects of correction can be readily identified.

Fig. 2. Correlation between average PM_{2.5} of residential/personal deployments and duplicates for raw data, RB corrected, and RB plus GC corrected results.

Table 1

PM_{2.5} evaluation criteria. The percentile is the count of minutes when PM_{2.5} values are less than 0, −5 or −20 µg/m³, respectively, out of the total sampling minutes.

	PM _{2.5} < 0 µg/m ³	PM _{2.5} < −5 µg/m ³	PM _{2.5} < −20 µg/m ³
Good	< 10%	< 5%	< 1%
Fair	< 20%	< 10%	< 5%

Note: The PM_{2.5} file dataset needs to meet all three listed criteria to be “Good” or “Fair”. If it does not meet any criteria for “Good ” or “Fair”, it is “Unacceptable”. If r_C is negative, then PM_{2.5} file is detected as “Unacceptable”, regardless what the percent of negative PM_{2.5} values is.

Summary of PM_{2.5} data file assessment before correction, after HEPA correction and after RBGC correction.

Table 2

	Count		Raw.2		Raw.1		Raw.0		HEPA.2		HEPA.1		HEAP.0		RBGC.2		RBGC.1		RBGC.0	
	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Baltimore Personal (N)																				
Start & end HEPA	63	6	1	1	2	2	5	1	3	9	0	0	0	0	0	0	0	0	0	0
One/No HEPA		34	4	4	16	NA	NA	NA	NA	47	3	4	NA	NA	47	3	4	NA	NA	4
NYC Personal (N)	43	16	3	3	18	12	12	2	23	31	2	4	23	31	2	2	4	23	31	4
Start & end HEPA		3	2	2	1	NA	NA	NA	NA	5	0	1	NA	NA	5	0	1	NA	NA	1
One/No HEPA		22	2	2	9	20	20	6	7	33	0	0	7	33	0	0	0	7	33	0
Start & end HEPA	36	2	0	0	1	NA	NA	NA	NA	3	0	0	NA	NA	3	0	0	NA	NA	0
One/No HEPA		2	0	0	1	NA	NA	NA	NA	3	0	0	NA	NA	3	0	0	NA	NA	0
NYC Home (N)																				
Start & end HEPA		83	12	12	47	37	37	9	33	128	5	9	33	128	5	5	9	33	128	9
One/No HEPA		63%	8%	8%	29%	56%	56%	11%	33%	89%	5%	6%	33%	89%	5%	5%	6%	33%	89%	6%
Total Count: Baltimore & NYC	142	44%	12%	12%	44%	32%	32%	5%	62%	84%	5%	12%	62%	84%	5%	5%	12%	62%	84%	12%
Baltimore Personal		67%	6%	6%	28%	61%	61%	18%	21%	100%	0%	0%	21%	100%	0%	0%	0%	21%	100%	0%
NYC Personal		58%	8%	8%	33%	47%	47%	11%	42%	90%	4%	6%	42%	90%	4%	4%	6%	42%	90%	6%
NYC Home																				
All																				

Note 2 represents "Good", 1 is "Fair" while 0 is "Unacceptable"; Raw.2 and Raw.1 mean that the original raw data meet all three criteria for the "Good" or "Fair" standards. And Raw.0 means that the raw data does not meet any criteria for the "Good", "Fair" or "Unacceptable" standard. RBGC represent the running baseline and gravimetric correction. NA means that data are not available.