COMBINING MASS MEASUREMENT WITH CARBON SPECIATION

UTILIZING THE ES-405 IN CONJUNCTION WITH THE BC 1060

ES-405 SIMULTANEOUS PARTICULATE PROFILER

BC 1060 PORTABLE CARBON MONITOR

Met One Instruments, Inc., Phone: 541.471.7111 Web: www.metone.com, Sales: sales@metone.com Service: service@metone.com

PM MEASUREMENT OF BLACK AND BROWN CARBON

The Met One Instruments, Inc. Model BC 1060 Portable Carbon Monitor simultaneously measures transmission of ultraviolet and infrared light across filter media upon which particulate matter "PM" containing black carbon "BC" and brown carbon "BrC" is being deposited. This allows determination of BC and BrC levels with sensitivity of less than 1 ng/m^3 in real time. For many air quality measurements, BC and BrC account for between 2% and 5% of total particulate matter. However, there are instances where BC and BrC can account for a much larger fraction of PM than this.

ROADSIDE MONITORING

Roadside monitoring provides a challenging PM monitoring environment for several practical reasons:

- External power is not always available.
- Shelters capable of housing equipment are not always available for such applications.
- Often it is necessary to periodically relocate the equipment favoring portable equipment.

In addition, there are measurement-specific challenges arising from roadside monitoring of gravimetric PM or BC:

- Rapidly changing PM and BC concentrations favor the use of instrumentation capable of reporting with high time resolution (1-minute or less).

- Rapidly changing BC concentrations can make source apportionment computations to determine the contribution from fossil fuel vs. biomass combustion challenging.

BC1060 & ES-405

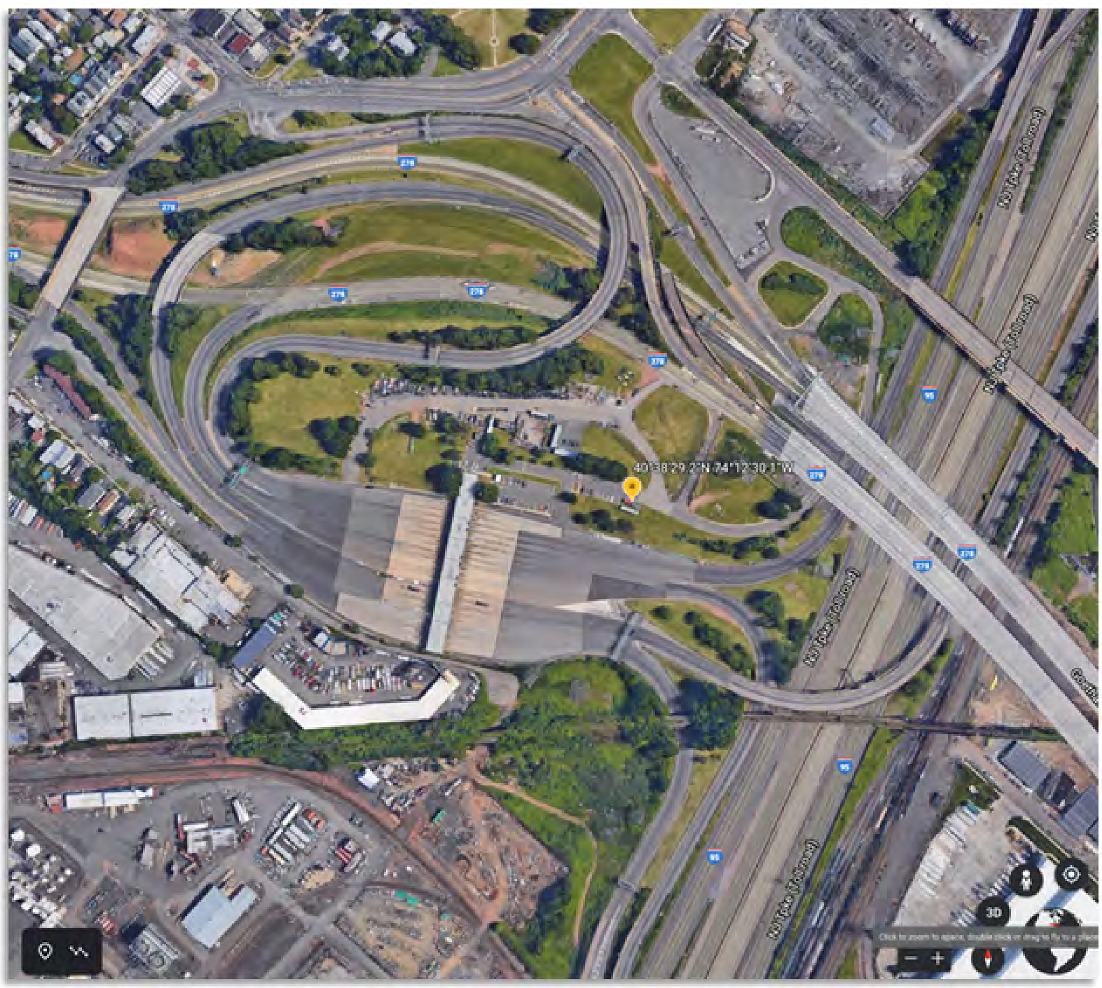
ELIZABETH, NJ
ROADSIDE MONITORING SITE

Met One Instruments has operated a monitoring site for many years in Elizabeth New Jersey, at a toll booth on the New Jersey Turnpike just south of Newark International Airport. Although the general region is highly industrialized, the proximity to the toll booth and the resulting number of large idling vehicles, including diesel powered trucks, can result in the production of locally high levels of soot.

BC 1060 & ES-405

ELIZABETH, NJ
ROADSIDE MONITORING SITE

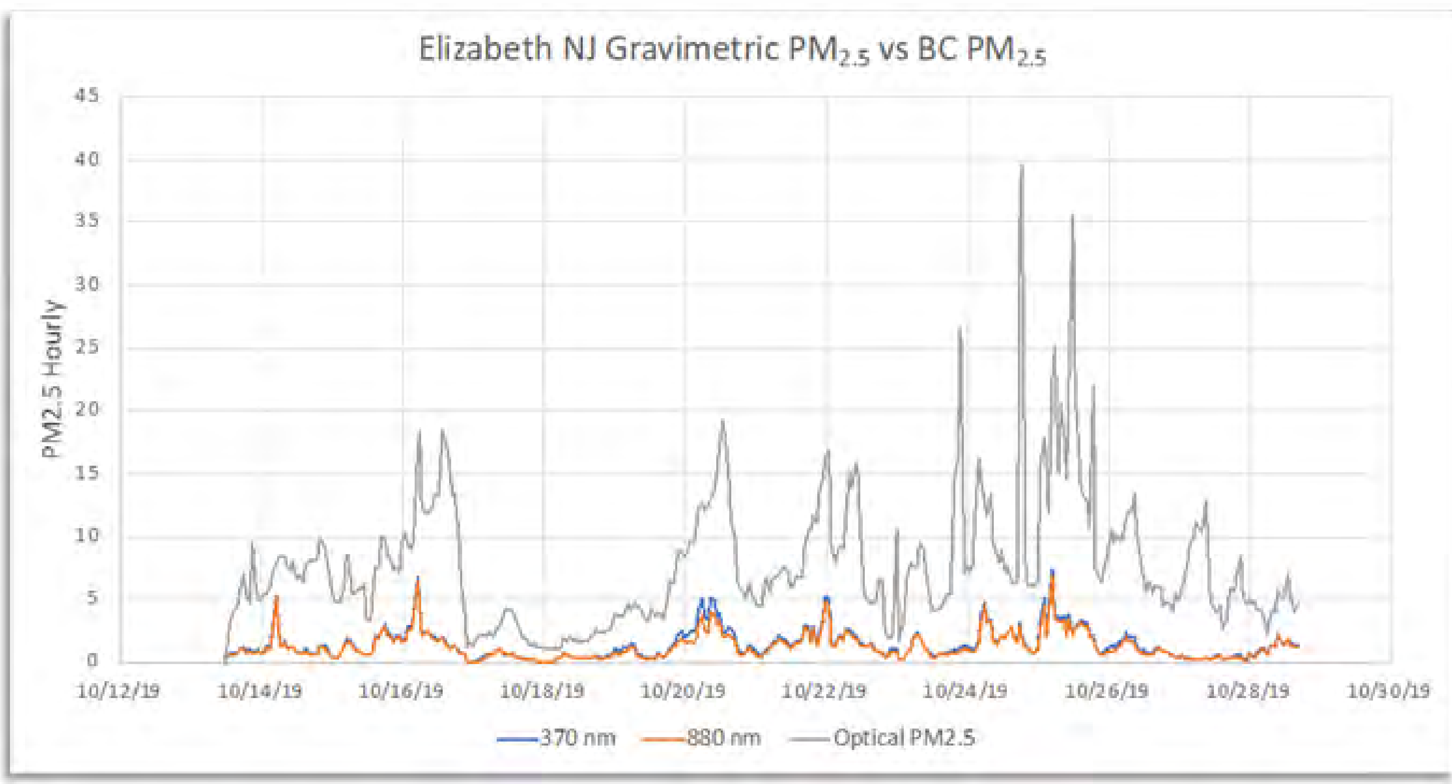
As is shown in this satellite image, the monitoring station is approximately 120 meters from the toll booth and approximately 20 meters from the roadway approaching the toll booth. Vehicles approaching the toll booth from either direction can become backed up. When this happens the idling vehicles can generate significant levels of PM in the form of BC. During events such as these, the percentage of PM in the form of BC can significantly exceed 5%, especially if there are no other nearby sources of PM being generated. The toll booth exists as a large, geographically fixed source of PM emissions.



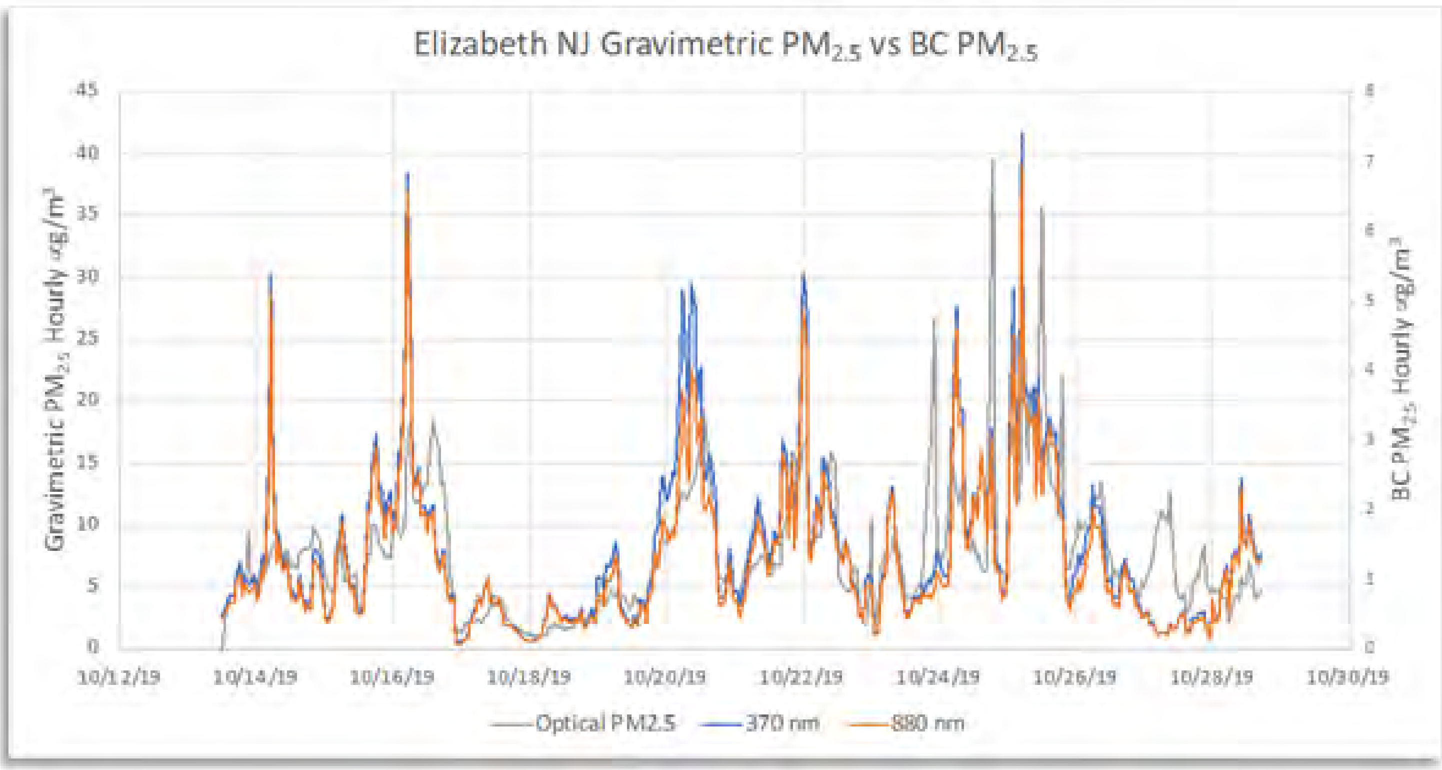
BC 1060 & ES-405

COMBINING MASS SPECIATION & MASS MEASUREMENT

The BC 1060 portable carbon monitor, configured to monitor BC and BrC in the form of $PM_{2.5}$, was collocated with an ES-405 aerosol monitor configured to simultaneously monitor and report PM_1, $PM_{2.5}$, PM_4 and PM_{10}. This chart shows the gravimetric $PM_{2.5}$ PM hourly concentration as measured by the ES-405 compared to the BC signals at both 370 nm and 880 nm illumination. All analyzers have the capacity to collect and report data with 1-minute time resolution. Data presented here is with 1-hour time resolution. The first thing to notice is that the 370 nm and 880 nm outputs are almost identical. This is a strong indication that at this monitoring site for the period monitored, BC comes almost exclusively from the combustion of fossil fuels. If there was BC originating from biomass combustion present, the 370 nm signal would be substantially greater than the 880 nm signal. Given the location of the monitoring station this should not come as a surprise.



The second observation made is that the contribution of PM coming from BC is significantly higher than the 2-5% levels that are typically measured at air quality monitoring sites. At this site BC accounts for typically 10-25% of total gravimetric PM. When the BC concentrations are plotted on the secondary axis it is apparent that the correlation between gravimetric $PM_{2.5}$ and BC $PM_{2.5}$ is quite high. Again, this should come as no surprise given the location of this monitoring station. In the figure below, the BC concentrations are plotted along the secondary y-axis to allow one to see the high degree of correlation between gravimetric mass and BC.



BC 1060 & ES-405

COMBINING MASS SPECIATION & MASS MEASUREMENT

Finally, this chart shows the gravimetric mass concentrations for the ES-405 for PM_1, $PM_{2.5}$ and PM_{10}. In this chart one can see the general agreement between the Met One Instruments, Inc. BAM 1020, an EPA equivalent method for PM_{10}, $PM_{2.5}$ and $PM_{10-2.5}$, and the ES-405. One can also see the fraction of PM_{10}, which typically includes wind-blown dust, and $PM_{2.5}$ which comes mainly from combustion.

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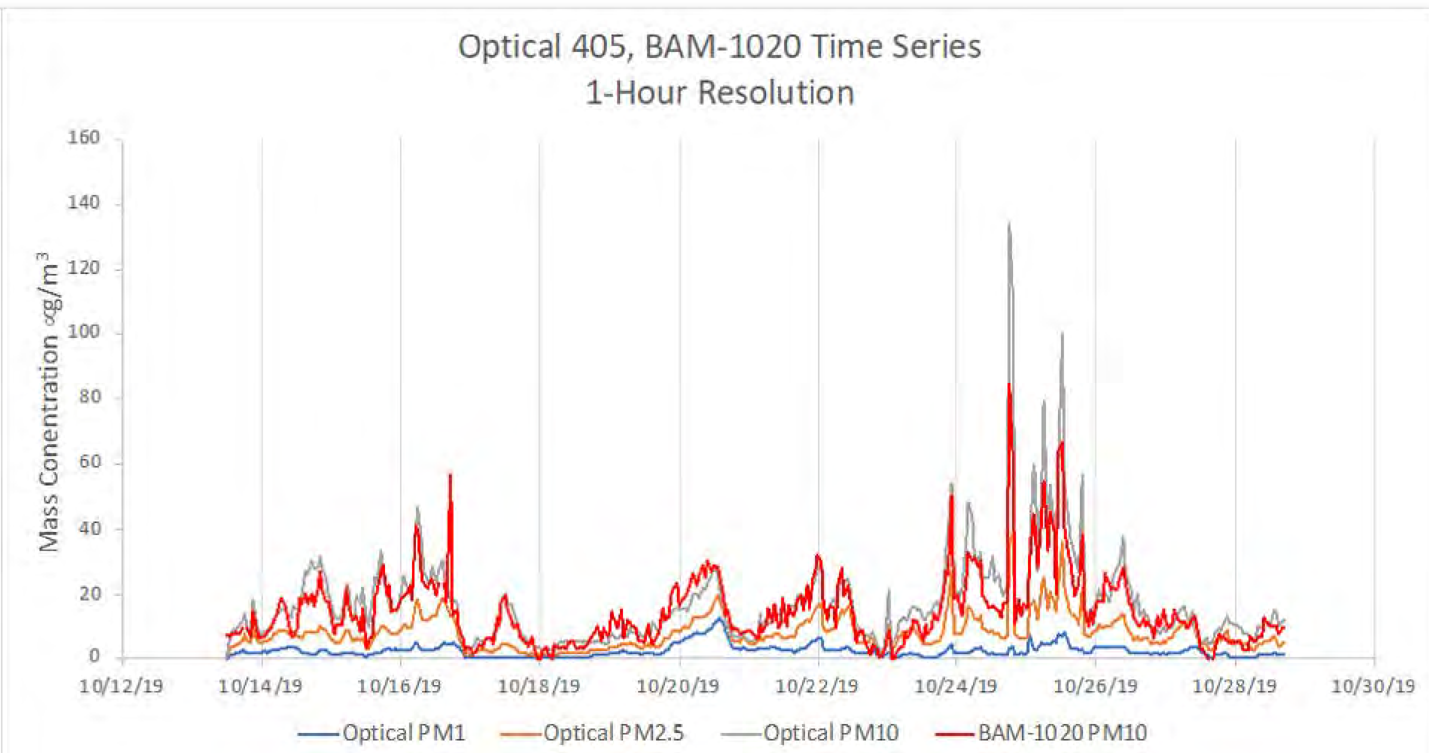

Using the Met One Instruments BAM 1020 to Compute AQI & NowCast Indices

INTRODUCTION

The Met One Instruments BAM 1020 is used extensively in government air quality monitoring networks worldwide to measure $PM_{2.5}$ and PM_{10}. The data collected from these instruments is often reported to the public as measured $PM_{2.5}$ or PM_{10} in micrograms per cubic meter (mg/m3). It is also frequently used to compute an Air Quality Index "AQI" or a "NowCast" index either instead of or in addition to the direct $PM_{2.5}$ or PM_{10} readings.

The AQI or NowCast indices are usually reported along with a color code that indicates the air quality with respect to the pollutant being reported. Green shows good air quality, yellow shows moderate air quality, orange shows unhealthy for sensitive groups, etc.

In this application note we will present a case study of how to compute these indices from raw data produced by the BAM 1020. We will then discuss the advantages and the disadvantages of using the raw data compared to the AQI or NowCast indices.

BACKGROUND

In the summer of 2018 huge forest fires burned for several months in southern Oregon and in northern California. These fires burned thousands of square miles of forest and were not completely extinguished until seasonal rains arrived in the fall.

Met One Instruments, Inc. is headquartered in Grants Pass, Oregon and was close to the epicenter of the summer 2018 fires. We operate BAM 1020 monitors at our corporate headquarters continuously and recorded the events by tracking $PM_{2.5}$, a criteria pollutant associated with combustion for the duration of these events.

$PM_{2.5}$ is particulate matter whose diameter is less than 2.5 microns in diameter. For comparison purposes a human hair is approximately 75 microns in diameter, therefore about 30 times the width of $PM_{2.5}$ particulate matter. Individual 2.5-micron particles cannot be seen by the human eye. However, when present

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in large concentrations they have the effect of reducing visibility. At high concentration levels over extended periods of time $PM_{2.5}$ is a serious health risk. The US-EPA has designated $PM_{2.5}$ as a criteria pollutant and has mandated its extensive monitoring nation-wide. Therefore, there is great interest in accurately monitoring and reporting it.

The BAM 1020 Beta Attenuation Mass Monitor is US-EPA designated for continuous $PM_{2.5}$ monitoring and is used extensively in air quality monitoring networks worldwide. In its standard configuration, the BAM 1020 will measure and then report PM levels with high accuracy on an hourly basis.

Beta gauges are insensitive to the chemical composition, particle size distribution, color, index of refraction, or other optical properties of PM. This is especially important when it comes to monitoring PM during fires as woodsmoke causes erroneous, inaccurate measurements on commonly used PM monitors employing optical methods.

Direct $PM_{2.5}$ Measurement

The US-EPA has established standards for $PM_{2.5}$. The current annual concentration standard for $PM_{2.5}$ is 12 mg/m^3. The current daily concentration standard for $PM_{2.5}$ is 35 mg/m^3. There is currently no US-EPA hourly standard for $PM_{2.5}$. Most of the time in southern Oregon, where Met One Instruments' headquarters is located, $PM_{2.5}$ are levels are quite low as the population is low (about 35,000 for Grants Pass city and 83,000 for Josephine County). We have operated a BAM 1020 beta attenuation mass monitor configured for $PM_{2.5}$ measurement for

US EPA AIR QUALITY INDEX CHART

Air Quality Index		
AQI Category and Color	**Index Value**	**Description of Air Quality**
Good Green	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Moderate Yellow	51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups Orange	101 to 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Unhealthy Red	151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy Purple	201 to 300	Health alert: The risk of health effects is increased for everyone.
Hazardous Maroon	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected.

many years at this location. The BAM 1020 reports $PM_{2.5}$ with 1-hour time resolution on a continuous basis. This data may be used directly for air quality assessment. However, it is most often converted into the color-coded AQI or NowCast index values for public reporting purposes.

Air Quality Index "AQI"

The $PM_{2.5}$ AQI is an index developed by various governmental agencies such as the US-EPA, or China's CNEMC, to convey how polluted the air is with respect to $PM_{2.5}$. The computational formulae used for AQI computation varies depending on the regulatory jurisdiction. For the purpose of our discussion we will use the computations used by the US-EPA.

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Using the Met One Instruments BAM 1020 to Compute AQI & NowCast Indices

As we shall see, the AQI is not always a good predictor for future air quality. AQI, unlike direct PM measurements, is a unitless number that varies from 0 to more than 500. $PM_{2.5}$ AQI is a midnight-to-midnight 24-hour value based on 1-hour measured values. The $PM_{2.5}$ AQI is computed from the following formula:

$$AQI = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}} \left(C_p - BP_{Lo} \right) + I_{Lo}$$

24 1-hour measured PM values from midnight to midnight are needed to compute the Air Quality Index "AQI". In this computation it is necessary to know the breakpoints between the AQI categories. These are given below in Table 1.

In Table 1 the first column shows the 24-hour $PM_{2.5}$ range (low breakpoint to high breakpoint) for "Good" air quality. This corresponds to an AQI ranging from 0 to 50. Therefore, if the 24-hour integrated $PM_{2.5}$ concentration was 6.0 mg/m^3 (C_p), BP_{Hi} would be 12.0 mg/m^3, BP_{Lo} would be 0 mg/m^3, circumstances I_{Hi} would be 50, and I_{Lo} would be 0. The $PM_{2.5}$ range 0 mg/m^3 to 12 mg/m^3 correspond to the AQI range ($I_{Hi} - I_{Lo}$). Therefore, for a daily $PM_{2.5}$ average concentration of 6.0 mg/m^3, the AQI would be calculated in the following manner:

$$AQI = \frac{(50 - 0)}{(12.0 - 0.0)} \left(6 - 0\right) + 0 = 25$$

Table 1: $PM_{2.5}$ Air Quality Breakpoints

24-Hour $PM_{2.5}$ Range (mg/m^3) $(BP_{Hi} - BP_{Lo})$	AQI Range $(I_{Hi} - I_{Lo})$	Category
0.0-12.0	0-50	Good
12.1-35.4	51-100	Moderate
35.5-55.4	101-150	Unhealthy for Sensitive Groups
55.5-150.4	151-200	Unhealthy
150.5-250.4	201-300	Very Unhealthy
250.5-350.4	301-400	Hazardous
350.5-500.4	401-500	Hazardous

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Using the Met One Instruments BAM 1020 to Compute AQI & NowCast Indices

A $PM_{2.5}$ AQI of 25 denotes good air quality and would be in the "green" zone. We will determine the AQI for actual PM data collected from our Grants Pass, Oregon corporate headquarters during a fire event during the summer of 2018. Table 2 shows AQI being calculated from actual hourly $PM_{2.5}$ data collected during July and August 2018 at the beginning of a smoke episode.

As can be seen from Table 2 the maximum hourly $PM_{2.5}$ concentrations often substantially exceed the daily $PM_{2.5}$ average. The AQI is only available for the previous, complete 24-hour period meaning that this index is not useful for reporting current conditions because current $PM_{2.5}$ measurements will not be incorporated into the AQI until the following day.

NowCast AQI

Consequently, the US-EPA developed an alternate air quality index known as NowCast AQI that uses the most currently available hourly $PM_{2.5}$ air quality data to compute the NowCast index. NowCast relies on the most recent 12-hour period of air quality data to compute the index. However, because of weighting factors in the NowCast computational algorithm, during periods of rapidly changing $PM_{2.5}$ concentrations (either up or down), NowCast closely tracks a 3-hour average converted into an AQI. During periods where the $PM_{2.5}$ concentration is not rapidly changing, it does not. NowCast therefore has the advantage of being based on the most recent air quality data.

Table 2: BAM-1020 Hourly PM Concentrations mg/m^3

Hour Beginning	7/26/18	7/27/18	7/28/18	7/29/18	7/30/18	7/31/18	8/1/18
12:00 AM	13.8	9.9	7.3	132.5	86.0	8.1	20.2
1:00 AM	32.3	11.6	5.9	131.6	131.4	8.8	43.4
2:00 AM	54.1	10.0	11.8	105.0	125.2	10.1	53.8
3:00 AM	43.1	9.6	9.2	97.9	115.5	10.9	55.6
4:00 AM	39.2	7.8	8.2	77.0	121.1	12.1	51.7
5:00 AM	40.5	9.6	7.7	88.1	113.2	17.7	59.1
6:00 AM	39.8	9.0	12.7	81.9	105.7	20.9	61.5
7:00 AM	44.6	9.4	16.5	97.2	111.9	33.8	70.5
8:00 AM	50.6	8.7	17.7	97.6	116.0	45.7	68.4
9:00 AM	44.0	10.0	15.5	96.3	159.9	103.3	79.6
10:00 AM	50.0	11.7	18.7	74.4	257.2	67.0	64.4
11:00 AM	46.0	15.3	18.9	73.8	205.9	60.4	43.9
12:00 PM	39.1	9.0	18.4	74.8	133.8	23.2	37.6
1:00 PM	51.7	11.0	23.1	66.0	161.8	20.3	27.3
2:00 PM	72.4	9.9	22.8	58.3	66.4	31.8	22.3
3:00 PM	28.1	7.1	20.6	46.0	47.4	19.4	12.8
4:00 PM	8.7	17.8	36.1	38.7	23.6	27.1	29.7
5:00 PM	6.3	31.7	25.5	43.0	38.5	11.9	166.6
6:00 PM	4.0	15.7	38.5	81.4	89.8	11.9	249.2
7:00 PM	3.8	3.0	90.9	102.5	9.7	7.8	109.9
8:00 PM	4.5	5.1	122.4	135.1	10.4	7.8	10.0
9:00 PM	4.9	4.8	121.4	116.6	6.9	5.4	8.8
10:00 PM	7.1	5.3	131.3	86.2	8.7	7.1	7.7
11:00 PM	6.3	7.2	132.3	90.8	7.3	8.0	11.6
C_p	30.6	10.4	38.8	87.1	93.8	24.1	56.9
BP_{Lo}	12.1	0	35.5	55.5	55.5	12.1	55.5
BP_{Hi}	35.4	12	55.4	150.4	150.4	35.4	150.4
I_{Hi}	100	50	150	200	200	100	200
I_{Lo}	51	0	101	151	151	51	151
AQI	90	43	109	167	171	76	152

Using the Met One Instruments BAM 1020 to Compute AQI & NowCast Indices

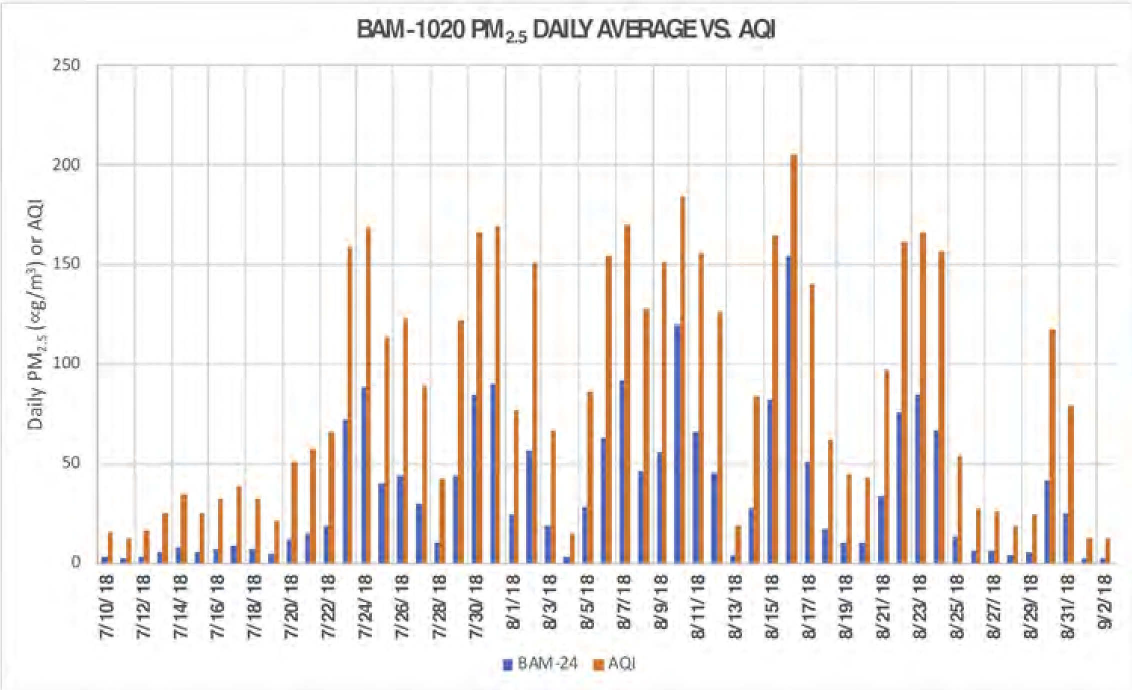
The NowCast computation for $PM_{2.5}$ is taken directly from the US-EPA airnow.gov Website:

Use the past 12 hours of PM measurements in micrograms per cubic meter (µg/m³):

1. Select the minimum and maximum PM measurements.
2. Subtract the minimum measurement from the maximum measurement to get the range.
3. Divide the range by the maximum measurement in the 12-hour period to get the scaled rate of change.
4. Subtract the scaled rate of change from 1 to get the weight factor. The weight factor must be between .5 and 1. The minimum limit approximates a 3-hour average.
5. If the weight factor is less than 0.5, then set it equal to 0.5.
6. Multiply each hourly measurement by the weight factor raised to the power of the number of hours ago the value was measured (for the current hour, the factor is raised to the zero power).
7. Compute the NowCast by summing the products from Step 6 and dividing by the sum of the weight factor raised to the power of the number of hours ago each value was measured.
8. Convert this value to an AQI.

Figure 1 shows the daily $PM_{2.5}$ average computed from the BAM-1020 configured as a US-EPA designated federal equivalent method “FEM” compared to the $PM_{2.5}$ AQI. Both are shown on the same y-axis.

Figure 1: Daily $PM_{2.5}$ vs. $PM_{2.5}$ AQI



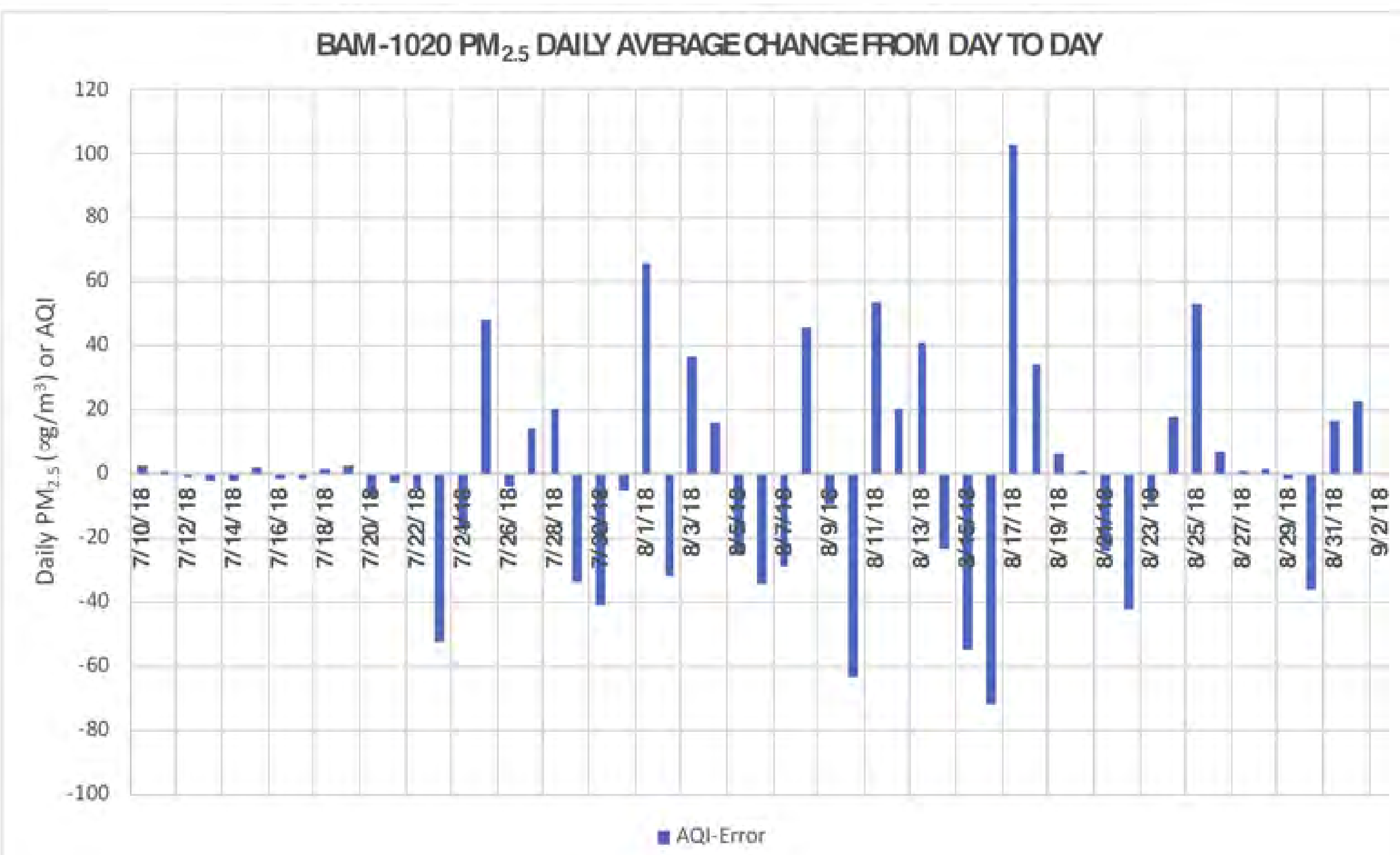
Using the Met One Instruments BAM 1020 to Compute AQI & NowCast Indices

The daily $PM_{2.5}$ average can change substantially from day to day. Therefore, the usefulness of the previous day's AQI value as the sole predictor of the current air quality is limited, especially when the local air quality is severely impacted by forest fires and can change rapidly. This is shown in Figure 2, the previous day's $PM_{2.5}$ average is used to predict the current day's $PM_{2.5}$ average.

Generally, local $PM_{2.5}$ measurements are combined with additional information including meteorological data in order to come up with a forecast for the coming day. As can be seen from Figure 2, the prediction error for the current data set could be ± 100 µg/m³ from day to day. We computed the RMS error to be 24.9 AQI units based on 102 days of data.

With NowCast AQI, the effective time resolution shifts from 24-hours to the most recent 3-hours, when $PM_{2.5}$ concentrations are rapidly changing. Figure 3 shows the relationship between the NowCast AQI computation and the running 3-hour gravimetric BAM 1020 output for $PM_{2.5}$. The running 3-hour $PM_{2.5}$ value and the NowCast AQI value track one another reasonably well.

Figure 2: AQI Prediction Error



Using the Met One Instruments BAM 1020 to Compute AQI & NowCast Indices

Figure 3: $PM_{2.5}$ NowCast vs. $PM_{2.5}$ 3-Hour Running Average

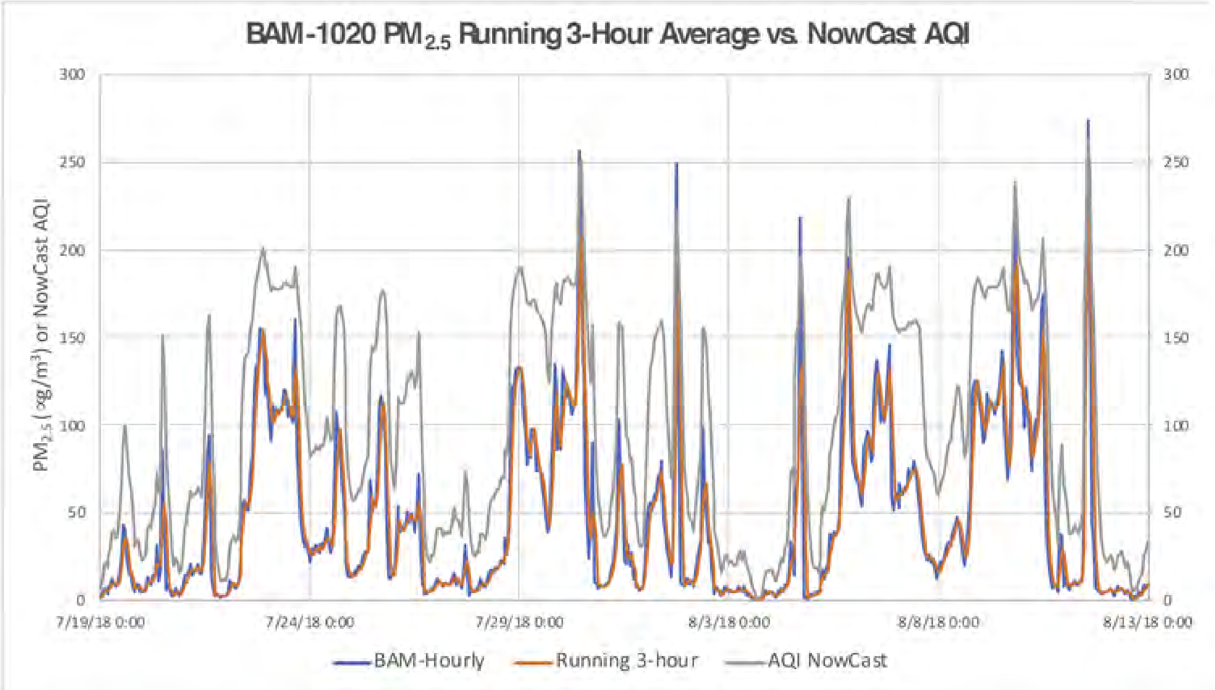


Figure 4: NowCast Prediction Error

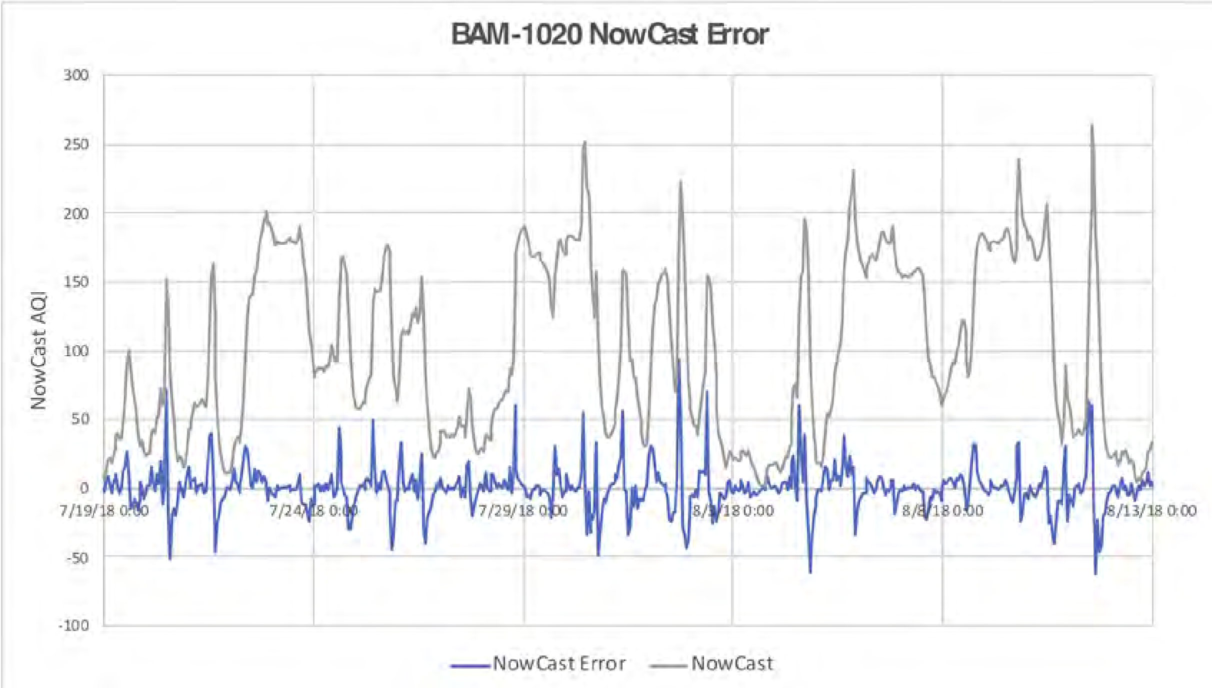


Figure 4 shows the NowCast computation from the hourly BAM 1020 data and the error in using the current hour's NowCast value to predict what the next hour's NowCast value is going to be. As can be seen, the error is much smaller for the NowCast AQI than the corresponding error is for the standard AQI computation. We computed the RMS error for the NowCast AQI to be 13.1 NowCast AQI units, around 50% lower than the RMS error for the AQI computation. This result should not be a surprise as the NowCast AQI is updated hourly, whereas the standard AQI is updated only once per day. However, NowCast AQI uses the most recent 12 hours of data to compute the NowCast AQI index for rapidly changing concentrations, as might be seen during a special event such as a fire.

DISCUSSION & CONCLUSION

Met One Instruments, Inc. beta gauges such as the BAM 1020 beta attenuation mass monitor are ideal for computing AQI and NowCast AQI values because of their inherent accuracy and their ability to produce data with a minimum of one-hour time resolution. AQI computations are based on the most recent midnight-to-midnight data collection period, whereas NowCast AQI is based on the most recent 12-hours of PM data.

Furthermore, if the PM levels are rapidly changing up or down, then the NowCast AQI may be approximated from the most recent 3-hours of PM data, meaning that NowCast AQI uses PM measurements up to and including the most recent hour to perform its computations. Because the BAM 1020 generates updates once per hour and other Met One Instruments, Inc. beta gauges, such as the BAM 1022, E-BAM, and E-BAM PLUS all can produce highly accurate PM updates on time scales shorter than one hour, all devices are suitable for computation of both AQI and NowCast indices. Reference samplers can collect only 24-hour integrated samples and therefore cannot be used for NowCast AQI computations. In addition, filter media collected from reference samplers must be sent to a lab for equilibration and reweighing. This process often takes several weeks meaning that AQI computations arising from reference sampler data will be of no use in predicting air quality.

Based on the data that we collected at our facility in Grants Pass, Oregon, during the fire events in the summer and fall of 2018, we have shown that the AQI was of minimal use by itself in predicting the subsequent AQI value during the next 24-hour midnight-to-midnight period as frequently there were massive changes up or down in the reported AQI from one day to the next. We showed that during the same events, the NowCast AQI was generally a better predictive tool in anticipating future NowCast values.