Analysis of Short Term Ozone Measurements for Sensor Scale and Messages
U.S. Environmental Protection Agency
DRAFT
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Low-cost air quality sensors are becoming increasingly available to the public and there is a need to help people interpret air quality concentrations that are collected and reported in increments as short as one minute. However, health studies do not support linking 1-minute ozone exposures to adverse health effects. In addition, the relationship between 1-minute ambient ozone concentrations and ambient concentrations with longer averaging periods, for which health information is available, is variable. Consequently, the potential health implications of 1-minute ozone sensor readings are not clear.

Consistent with the available health evidence, the US Environmental Protection Agency's (EPA) existing air quality standards and tools to interpret air quality (i.e., the national ambient air quality standards (NAAQS) and the Air Quality Index (AQI), respectively) are based on longer averaging periods. It is not appropriate to directly compare a 1-minute ozone sensor reading to the level of the ozone NAAQS or to the ozone AQI breakpoints (both of which are based on 8-hour ozone concentrations). However, it is appropriate to set 1-minute sensor breakpoints such that, to the extent possible, ozone sensor messages received over a given time period are consistent with concurrent messaging based on 8-hour average ozone concentrations (e.g., messaging related to the AQI).

Given the above considerations, to inform the identification of ozone sensor breakpoints and messages, we investigate the relationship of 1-minute ozone readings to 8-hour averages in order to examine how sensor readings could relate to the ozone NAAQS and to the ozone AQI categories. The primary objective of this analysis is to inform the identification of breakpoints for sensor messaging that are based on probabilistic properties relating to the NAAQS and the AQI, and to the underlying human health considerations. Final breakpoints and the corresponding messages are outlined in "Interpretation and Communication of Short-term Air Sensor Data: A Pilot Project," available at http://bit.ly/SensorScalePilot.

Ozone Data

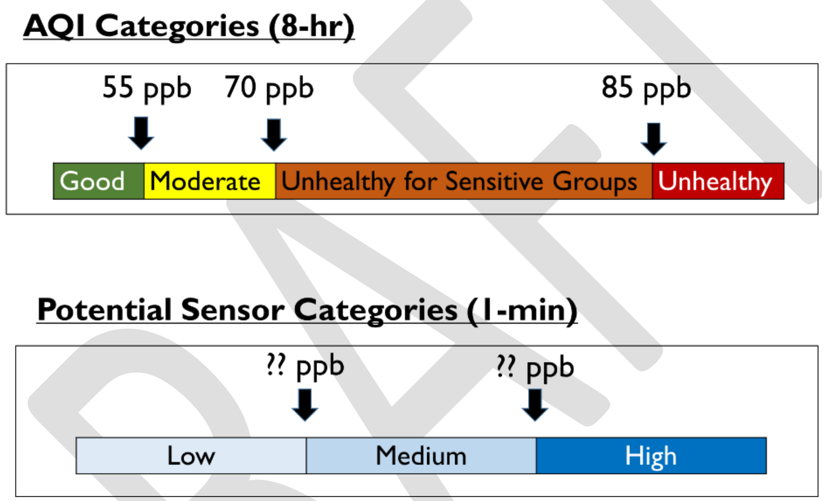
Ozone data utilized were from four Village Green Benches in DC, KS, PA, and NC for the period of March 31 to Sept 9, 2015. Federal Reference Monitor data from 14 sites was also utilized. This included sites in the Baltimore area: Aldino, Essex, Howard University, and Rockville; the Boston area: Lynn and Roxbury; the Denver area: Denver-Camp and Rocky Flats; New York: CCNY and Riverhead; near San Francisco: Livermore and Santa Rosa; and in North Carolina: Pittsboro and Rockwell. These sites were chosen because of the data quality and the representativeness of both high and low ozone areas and the data is quality assured. The ozone season of months April to September were evaluated for years 2011 to 2013, with the Denver sites also including 2014 data. For all locations, ozone observations that would be included in an averaged 8-hour block within Daytime hours were considered. Daytime hours correspond to 7am-11:59pm, as is consistent with ozone handling for the 2015 ozone National Ambient Air Quality Standards. There were just under 7.6 million observations across 823 total days, with approximately 3.3% missing. In order to best mimic real-time values corresponding to readings that the public might observe, no completeness criterion was implemented for calculation of averages. 1-minute values were compared with the maximum 8-hour block average in which that 1-minute observation occurred. This was done in order to mimic the instantaneous reading scenario in which a citizen might check a sensor in order to make a judgement about their current exposure. It is important to note that the Village Green data, while equipped with FEM grade monitors, is not maintained as an FEM site. Thus there may be additional uncertainty associated with the Village Green measurements.

The time series of 1-minute ozone observations and corresponding maximum 8-hour block average for Village Green Bench and FRM monitoring station data can be seen in Figure S1 in the Supplementary Figures. Figure S2 shows the distribution of 1-minute ozone values for Village Green Bench and FRM monitoring station data for each of the 18 sites.

Methodology

We consider how the 1-minute observations and the distribution of their corresponding maximum 8-hour block averages relate to the breakpoints for the AQI categories for "Good", "Moderate", "Unhealthy for Sensitive Groups", and "Unhealthy". Sensor public messaging will be grouped into corresponding "Low", "Medium", and "High" categories.

Figure 1: AQI breakpoints and Sensor messaging categories



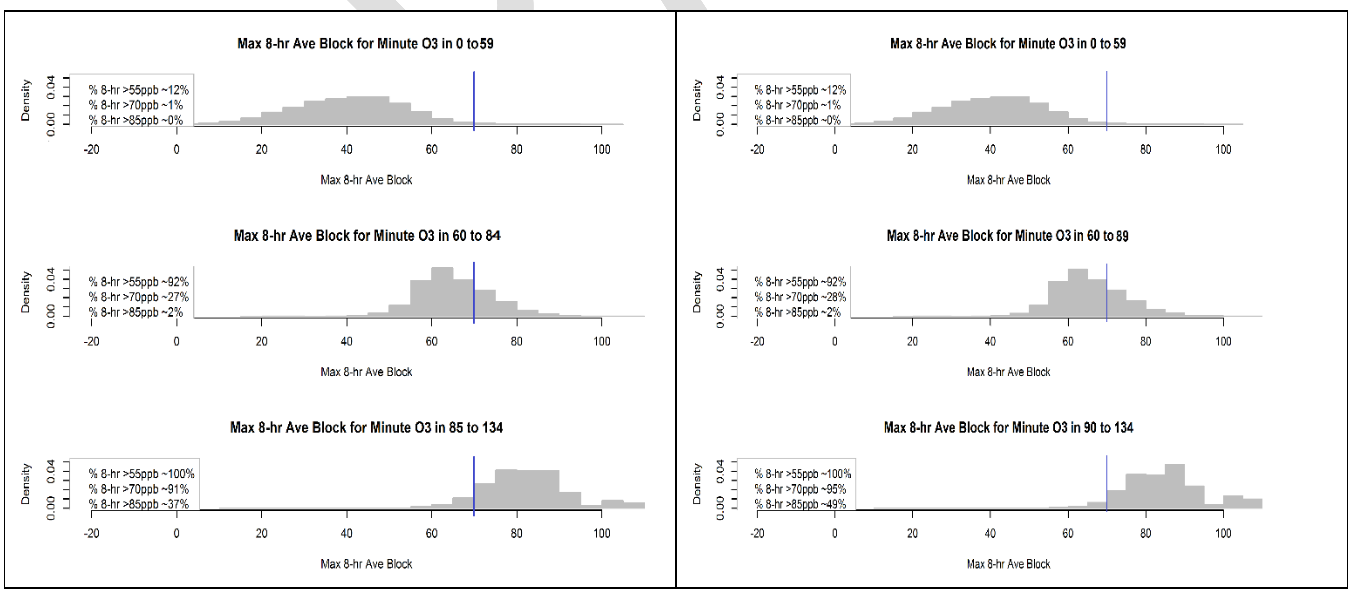
Breakpoint probabilities for the messaging categories represent the empirical probability of the maximum 8-hour block average exceeding specific AQI breakpoints given that the observed 1-minute value falls within a specified range. The specified ranges correspond to considerations for the possible Low, Medium, and High messaging categories. The distribution of corresponding maximum 8-hour block averages is examined to determine the probability that the maximum 8-hour block average exceeds the various AQI breakpoint ranges. These are conditional probabilities, conditioned on the observance of a given 1-minute value within a specified Low/Medium/High messaging category. No distributional or modeling assumptions are made about the underlying characteristics of the data and its corresponding behavior and/or distributional properties. This allows for a robust, empirical comparison of events that occur relatively infrequently, i.e., in the tails of the distribution, which is the area of interest for air quality exceedances and public health concerns. Final breakpoints and the corresponding messages are outlined in "Interpretation and Communication of Short-term Air Sensor Data: A Pilot Project," available at http://bit.ly/SensorScalePilot. The breakpoint for the "Very High" category while expected to be a very rare occurrence, would be represented by 1-minute readings which could indicate very high O_3 concentrations, or could also indicate a malfunctioning sensor.

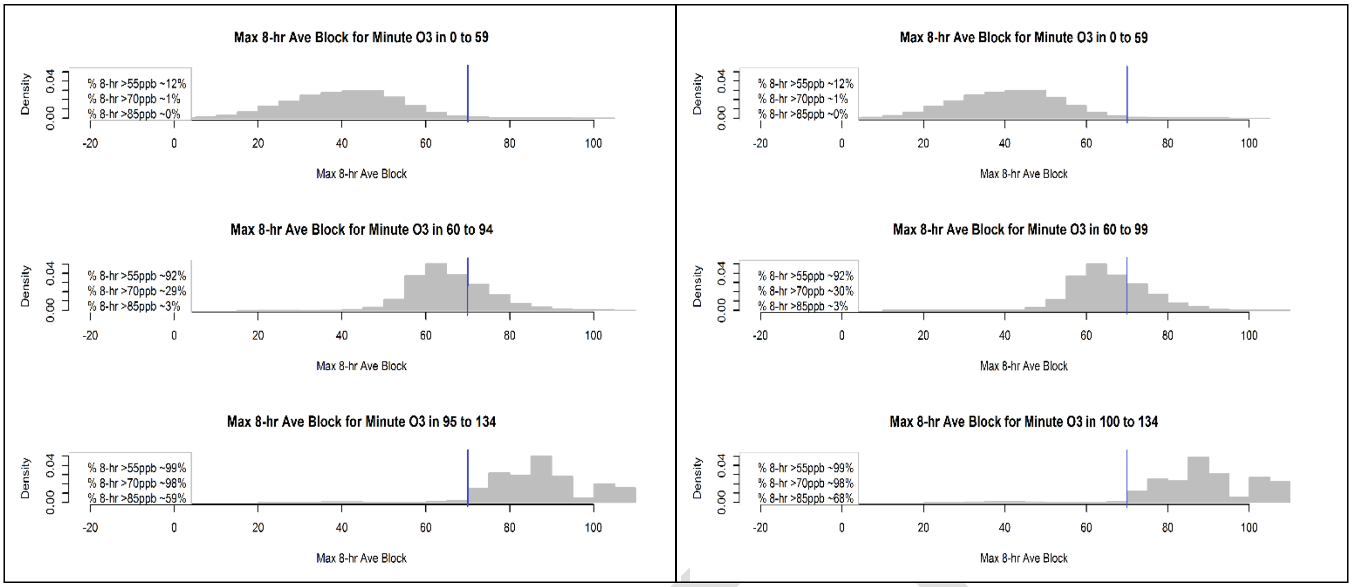
Breakpoint Considerations: Conditional Distributions

“Low” to “Medium” category lower breakpoints 55, 60, 65, and 70ppb were considered along with “Medium” to “High” category breakpoints of 85, 90, 95, and 100ppb. Thus sixteen sets of possible breakpoint messaging ranges were explored. The example detailed in the figures and tables is for the possible “Low” range of 0-59ppb with corresponding “Medium” options 60-84, 60-89, 60-94, and 60-99ppb.

We consider the empirical distribution of the maximum 8-hour block averages given the corresponding 1-minute observations used in the calculation of the maximum 8-hour block averages. The 8-hour block averages are considered for 1-minute observations that fall within a specified range under consideration for messaging breakpoints. Figure 2 shows the distribution of maximum 8-hour block averages for the 1-minute in the ranges 60-84, 60-89, 60-94, and 60-99ppb. The general trend shows that lower 8-hour block averages are associated with lower 1-minute values. For example it is shown in the top left plot in Figure 2 that for 1-minute observations in the range 0-59ppb, only 12% of the corresponding 8-hour block averages are above 55ppb and only 1% are above 70ppb. Analogously, the trend among the higher values is that higher 8-hour block averages are associated with higher 1-minute values. The bottom right plot in Figure 2 indicates that for 1-minute observations above 100ppb, 99% of the corresponding 8-hour averages are above 55ppb and 98% are above 70ppb. Each set of histograms considers a full implementation of possible “Low,” “Medium,” and “High” breakpoints, where the “Low” range is 0-59ppb.

Figure 2: Conditional distribution of maximum 8-hour block averages for the possible sensor messaging categories and the corresponding AQI breakpoints. 0-59ppb is the range considered for the “Low” category. 60-84, 60-89, 60-94, and 60-99ppb are consideration for “Medium”, and greater than or equal to 85ppb, 90ppb, 95ppb, and 100ppb are considered for “High”. The vertical blue line indicates 70ppb. Note: While the analysis includes the full range of data, for display purposes only the x-axis is truncated to 100ppb.





Breakpoint Considerations: Messaging Frequencies

The empirical frequencies (%) for the messaging categories Low, Medium, and High were also considered. Messaging frequencies are not conditional probabilities - they simply represent the frequency with which the range of values corresponding to a given message (i.e., "High") is observed at the corresponding breakpoint range. Note that these frequencies are based on 1-minute readings, which are highly correlated – i.e., high values of ozone likely occur near other high values. Final breakpoints and the corresponding messages are outlined in in "Interpretation and Communication of Short-term Air Sensor Data: A Pilot Project," available at http://bit.ly/SensorScalePilot, with selected messaging ranges indicated by shading in the following tables.

1-minute observations in the range 0-59ppb occurred with relative frequency 91.1%. Therefore a "Low" message would be observed approximately 91.1% of the time if the "Low" range was 0-59ppb. Given a "Low" range of 0-59ppb, Table 1 shows the messaging frequencies for a variety of "Medium" to "High" breakpoints.

Table 1: Messaging Frequencies for the "Medium" and "High" categories

Medium	%	High	%
60-84	8.4	85-150	0.5
60-89	**8.6**	**90-150**	**0.3**
60-94	8.7	95-150	0.2
60-99	8.8	100-150	0.1

For example, given a "Medium" range of 60-89ppb, the "Medium" message would be seen with a relative frequency of 8.6%. Table 1 indicates that "High" would occur 0.5% to 0.1% across the increasing options for the Medium ranges. The empirical frequency for >150ppb was 0%.

Breakpoint Considerations: AQI breakpoint ranges and corresponding possible messaging categories

Tables 2-4 display the empirical probabilities of maximum 8-hour block averages falling in the corresponding AQI breakpoint ranges for the possible sensor messaging categories. Interpretation examples follow each table.

Table 2: Max 8-hr Block Average for Minute Ozone Observations in **Low** Category

	1-minute ozone concentrations categorized as Low			
AQI breakpoints (Category)	0 to 54	0 to 59	0 to 64	0 to 69
% 8 hr > 55 (Above Good)	8	**12**	14	16
% 8 hr 55 to 70 (Moderate)	8	**11**	13	14
% 8 hr > 70 (Above Moderate)	0	**1**	1	2
% 8 hr 70 to 85 (Unhealthy Sensitive)	0	**1**	1	2
% 8 hr > 85 (Unhealthy)	0	**0**	0	0

If Low was set at 0-59ppb for 1-minute readings, the maximum 8-hr block average would be above 59ppb in the Moderate and above AQI categories with 12% relative frequency, with 0% frequency in "Unhealthy" (>85ppb) and 1% frequency "Unhealthy for Sensitive Groups". If Low was set at 0-69ppb, a maximum 8-hr block average would exceed "Good" (55ppb) 16% of the time, with 2% chance of falling in the range for "Unhealthy for Sensitive Groups".

Table 3: Max 8-hr Average Block for Minute Ozone Observations in **Medium** Category for Lower Range 0-59ppb

AQI breakpoints (Category)	60-84	60-89	60-94	60-99
% 8 hr > 55 (Above Good)	92	**92**	92	92
% 8 hr 55 to 70 (Moderate)	65	**64**	63	62
% 8 hr > 70 (Above Moderate)	27	**28**	29	30
% 8 hr 70 to 85 (Unhealthy Sensitive)	25	**26**	26	28
% 8 hr > 85 (Unhealthy)	2	**2**	3	2

If Medium was set at 60ppb-89ppb, 92% would be above the "Good" category, with 64% in the "Moderate" AQI category, 26% in "Unhealthy for Sensitive Groups", and 2% "Unhealthy". If Medium was 60ppb-99ppb, 92% would be above "Good", with 62% in "Moderate", 28% in "Unhealthy for Sensitive Groups", and 2% "Unhealthy".

Table 4: Max 8-hr Block Average for Minute Ozone Observations in **High** Category

AQI breakpoints (Category)	85-150	90-150	95-150	100-150
% 8 hr > 55 (Above Good)	100	**100**	99	99
% 8 hr 55 to 70 (Moderate)	9	**5**	2	0
% 8 hr > 70 (Above Moderate)	91	**95**	98	99
% 8 hr 70 to 85 (Unhealthy Sensitive)	54	**43**	39	31
% 8 hr > 85 (Unhealthy)	37	**49**	59	98

If High was set at 90-150ppb, approximately 100% of the corresponding maximum 8-hour block averages would be above the "Good" AQI category (≥55ppb) and 95% above "Moderate" (≥70ppb), with 43% in "Unhealthy for Sensitive Groups" and 49% in "Unhealthy". At 100-150ppb, 99% would be above the "Good" range with 98% in "Unhealthy" (The slight difference between 100% at 85ppb and 99% at 100ppb are due to rounding and to reaching the limits of number of exceedances within this data set.)

Supplementary Figures

Figure S1: Time Series of ozone values and corresponding maximum 8-hour block average for Village Green Bench and FRM monitoring station data for the 18 sites. The horizontal blue line indicates 70ppb.

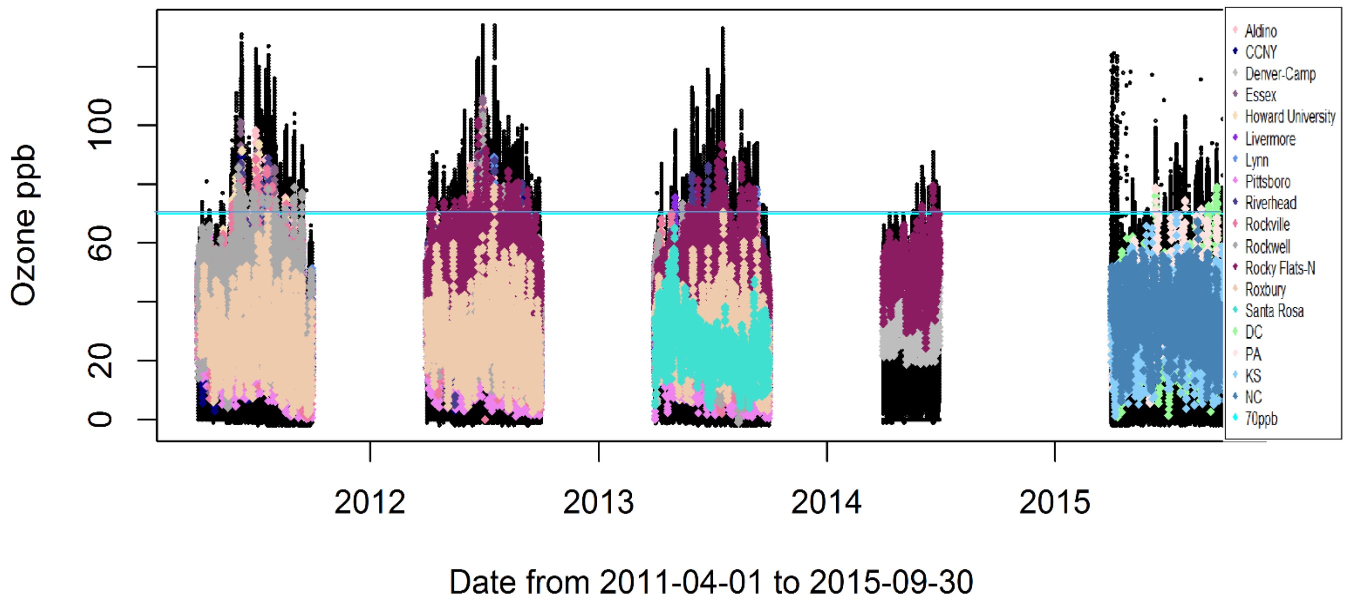


Figure S2: Box plots of 1-minute ozone values for Village Green Bench and FRM monitoring station data across the 18 sites.

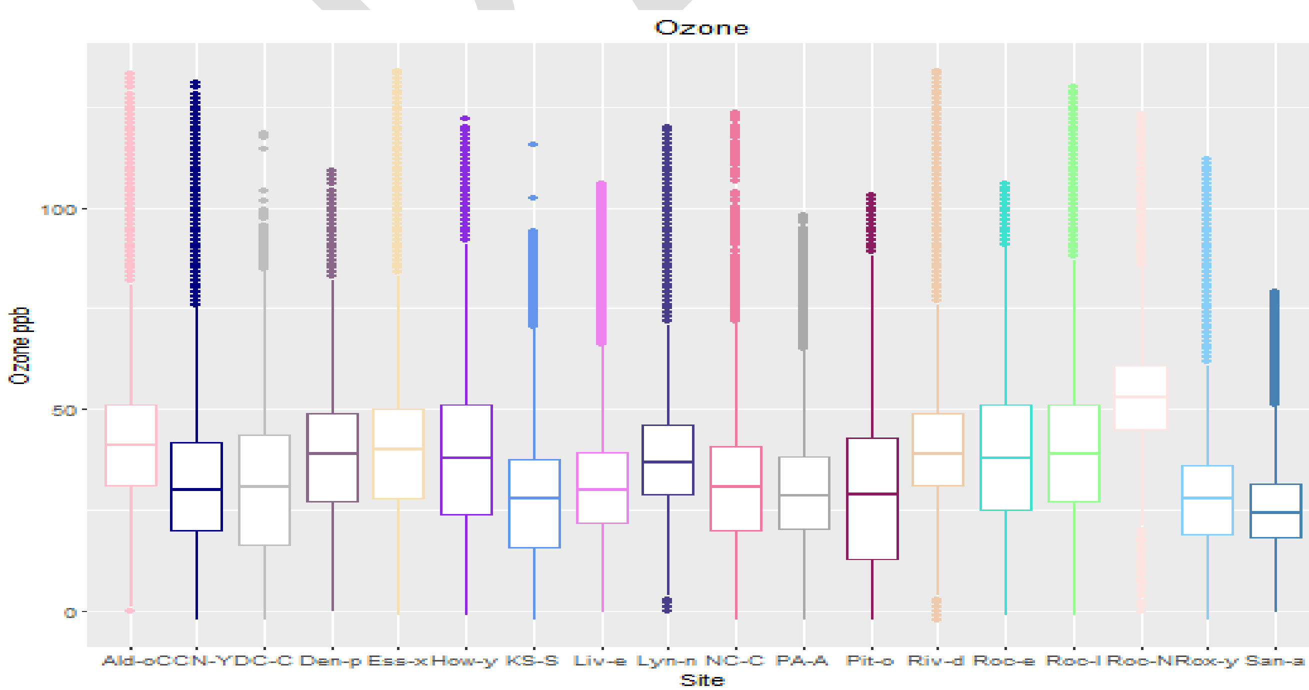


Figure S3: Density of 1-minute ozone observations and corresponding maximum 8-hour block average for Village Green Bench and FRM monitoring station data. The horizontal blue line indicates 70ppb.