**FINAL REPORT**

***Assessing Impacts to Air Quality from Vehicle Emissions in Teton County, WY***


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**Jackson, WY**

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- Environmental Health Trust
- Willie Neal Environmental Awareness Fund
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- Wyoming Controls

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# Executive Summary

To assess impacts from vehicle emissions in Teton County, WY, air quality measurements were completed during two measurement campaigns. Winter measurements spanned January – March, 2018, with measurement of ozone ($O_3$) and particulate matter ($PM_{2.5}$ / $PM_{10}$) at 1-minute intervals for 2-hour periods at four sites. Summer measurements spanned June – August, 2018, with measurements at 5-minute intervals for 2-week periods at four sites.

All measurements were made with Aeroqual S500 portable air quality monitors. The Aeroqual factory-calibrated data was corrected using offset and gain values derived from co-location periods with WYDEQ Federal Equivalent Method (FEM) instrumentation. Attempts at measuring $NO_2$ were unsuccessful due to poor co-location results for the Aeroqual S500 $NO_2$ sensor.

Winter results show mostly "clean" air quality at all measurement sites, with 5-minute ozone and $PM_{2.5}$ concentrations remaining mostly in the "low" EPA 1-minute pilot category, and $PM_{10}$ concentrations remaining well below the EPA 24-hr standard. Occasional measured spikes of higher PM concentration (into "medium" and "high" EPA 1-minute $PM_{2.5}$ pilot categories) are restricted to sampling in close proximity to emission sources (within meters). Examples of these high-emission scenarios include direct vehicle tail pipe emissions and accelerating snowmobiles.

Summer results also show mostly "clean" air quality at all sites. With nearly continuous measurement at 5-minute intervals throughout the summer, ozone measurements remained predominantly in the "low" EPA 1-minute pilot category, only occasionally reaching "medium" levels. The measured ozone 8-hr average never exceeded the EPA 8-hr standard of 70 ppb.

PM measurements also show mostly "clean" conditions at all summer sites, with exception to impacts from regional wildfire smoke which increased from late July into August. Occasional 5-minute PM spikes to unhealthy levels likely result from vehicle emissions (particularly diesel vehicles) and/or commercial cooking emissions, depending on location. For $PM_{2.5}$, these spikes can reach "medium" and "high" EPA 1-minute pilot categories. There is no evidence for significant impacts to air quality from brake emissions at the base of Teton Pass in Wilson, WY.

In terms of overall air quality and public health, regional wildfire smoke presents the greatest measured impact. The highest levels of 24-hr average $PM_{2.5}$ and $PM_{10}$ were measured during multi-day periods of heavy smoke conditions during mid to late August. $PM_{2.5}$ 24-hr averages during this period reached near or above the EPA 24-hr standard on several days (depending on data source).

These results show that despite vehicle traffic volumes that are overwhelming road capacity in Teton County during summer months, the overall volume of vehicles is insufficient to significantly impact ozone and particulate matter concentrations at roadside locations. Although short-term exposure within close proximity of emission sources can present unhealthy conditions, vehicle emissions in Teton County currently has limited impact to ambient air quality.

# 1. Introduction

## 1.1 Project Overview and Motivation

Congested traffic in the Jackson, Wyoming area has been identified in recent years as a major problem facing Teton County. Traffic volumes on WY 22, US 26, and the Moose-Wilson Road (WY 390) can range from 13,000 to greater than 22,000 vehicles per day (Jackson/Teton County Comprehensive Plan, 2018 Annual Indicator Report), making these roads some of the busiest in the state. Local advocacy and conservation groups have cited that 62% of greenhouse gas emissions in Teton County are from ground transportation (Heede, 2009). In response to these concerns, local government and nonprofit organizations are promoting comprehensive programs to reduce emissions through alternative transportation plans and the use of electric vehicles.

However, there has been limited assessment of the impact of vehicle emissions to air quality as related to public health in Teton County. As stated in the “Air Quality Feasibility Report” (Teton Conservation District, 2017), air sampling in Teton County over past decades has been “very limited”. In addition, “site selection for where sampling takes place has not been done with regard to where pollution may be occurring or where humans might be most impacted...”.

The goal of this project is to characterize ambient air quality with measurements of select criteria air pollutants at roadside locations. The monitoring campaign targeted high-volume traffic areas that also see high pedestrian/bicycle or store-front use by the public. In addition, we leveraged new air quality sensor technology allowing measurement at high temporal resolution (1-minute to 5-minute intervals), with small, lightweight monitors that were mounted directed adjacent to roadways.

This report summarizes the results from measurements made in two phases. Phase I (January – March 2018) focused on ambient air quality in cold-weather conditions for 1-2 hour periods at select locations. These locations included:

- Jackson Elementary School
- Snow King Events Center
- Base of Teton Pass (Wilson, WY)
- Snowmobile Hill Climb at Snow King Mountain

Phase II was the primary focus of the study (June – August 2018), and included two-week installations at four sites. These locations included:

- Jackson Town Square
- Base of Teton Pass (Wilson, WY)
- Intersection of WY 22 and US 89
- Intersection of Virginian Lane and Snow King Ave

Site photos and maps are provided in the “Results and Discussion” for each site (section 3). All results figures are at high resolution (zoom in for detailed view).

## 1.2 Criteria Air Pollutants

The Clean Air Act requires the U.S. Environmental Protection Agency (EPA) to establish national air quality standards for six common air pollutants that are found throughout the United States. The EPA refers to these pollutants as “criteria” pollutants because they are regulated using human health-based and/or environmentally-based criteria to set permissible levels. The levels set by the EPA are known as National Ambient Air Quality Standards (NAAQS). In this study, we completed measurements of three criteria pollutants: ozone, particular matter, and nitrogen dioxide.

### 1.2.1 Ozone

Ozone ($O_3$) is a powerful oxidant due to its unstable triatomic form and exists in two separate regions of the atmosphere. Approximately 90% of ozone exists in the upper atmosphere (Seinfeld and Pandis, 2016) and is known as stratospheric ozone. This upper atmosphere ozone layer plays an important role by blocking UV radiation to the earth, and is well-known for the ozone depletion problem related to CFC emissions that came to public attention in the 1980s.

Ground-level ozone (or tropospheric ozone) is the form regulated by the EPA as a criteria pollutant and is the focus of measurement in this study. Near the earth’s surface, ozone forms through a complex photochemical reaction (driven by sunlight) involving volatile organic compounds (VOCs) and nitrogen oxides ($NO_x$). Ground-level ozone has naturally varying background levels (typically 10 - 50 ppb, depending on location, elevation, and extent of regional anthropogenic influence) that are not harmful to human health. However, elevated ozone can result from increased levels of VOCs and $NO_x$ as a result of fuel combustion and other industrial processes. Exposure to elevated ozone has harmful health effects, primarily to the respiratory system.

### 1.2.2 Particulate Matter

Particulate matter is regulated in two size classes:

- **$PM_{2.5}$ :** Particles with a diameter smaller than 2.5 micrometers (μm, or microns). Also called fine particles.
- **$PM_{10}$ :** Particles with a diameter between 2.5 μm and 10 μm. Also called inhalable coarse particles.
- Particles larger than 10 μm (e.g., sand and large dust) are not regulated by the EPA.

Common sources of PM include dust, wildfire smoke, fuel combustion, and agricultural / industrial processes. Exposure to both fine ($PM_{2.5}$) and coarse ($PM_{10}$) particles is associated with harmful health effects, particularly those involving the heart and lungs. In general, the size of the particles is directly linked to their potential for causing health problems. Fine particles are most dangerous as they can penetrate deeper into the lungs where they can enter the circulatory system.

### 1.2.3 Nitrogen Dioxide

Nitrogen dioxide ($NO_2$) is one of a group of highly reactive nitrogen oxide gasses. $NO_2$ is commonly associated with vehicle fuel combustion, and can be identified as the light brown "haze" visible in major cities during peak traffic periods.

Although $NO_2$ was measured throughout this study, co-location results with WYDEQ (section 2.2.1) were in poor agreement. In general, the $NO_2$ data collected was not reliable, consistent, or representative of ambient levels. Therefore, $NO_2$ results have not been included in this report. Further details on the $NO_2$ sensor used in this study are included in section 2.1.

### 1.2.4 EPA standards and non-regulatory 1-minute categories

The EPA NAAQS referred to in this study (ozone and particulate matter) are shown below in Table 1.1. Primary standards provide public health protection, including protecting the health of sensitive populations such as asthmatics, children, and the elderly. Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings. Units of measure for the standards are parts per million (ppm) by volume, parts per billion (ppb) by volume, and micrograms per cubic meter of air ($\mu g/m^3$). The full list of EPA NAAQS can be found at https://www.epa.gov/criteria-air-pollutants/naaqs-table.

| Pollutant | Primary / Secondary | Averaging Time | Level | Form |
|---|---|---|---|---|
| Ozone ($O_3$) * | primary and secondary | 8 hours | 0.070 ppm (70 ppb) | Annual 4th-highest daily max. 8-hr concentration, averaged over 3 yrs. |
| $PM_{2.5}$ | primary | 1 year | 12.0 $\mu g/m^3$ | Annual mean, averaged over 3 yrs. |
| $PM_{2.5}$ | secondary | 1 year | 15.0 $\mu g/m^3$ | Annual mean, averaged over 3 yrs. |
| $PM_{2.5}$ * | primary and secondary | 24 hours | 35 $\mu g/m^3$ | 98th percentile, averaged over 3 yrs. |
| $PM_{10}$ * | primary and secondary | 24 hours | 150 $\mu g/m^3$ | Not to be exceeded more than once per year on average over 3 yrs. |

***Table 1.1:*** *EPA National Ambient Air Quality Standards (NAAQS). Asterisk (*) indicates standards that are shown in the results figures of this report (section 3).*

For the results presented in this report, EPA standards for 8-hr ozone, 24-hr $PM_{2.5}$ and 24-hr $PM_{10}$ are shown for reference in all figures. Corresponding 8-hr or 24-hr averages for the measured species are calculated from 1-minute or 5-minute data and shown for comparison with EPA standards.

In addition to reporting the EPA NAAQS, we also show color-coded **EPA 1-minute non-regulatory categories** in all figures for ozone and $PM_{2.5}$. In a report "Interpretation and Communication of Short-term Air Sensor Data: A Pilot Project" (EPA, 2016), guidance is provided to help interpret 1-minute sensor data. This high resolution data has become available with an emerging market of low-cost portable air quality sensors over the last decade. The 1-minute pilot categories are provided as part of the EPA "Air Sensor Toolbox" (https://www.epa.gov/air-sensor-toolbox).

| **1-Minute $O_3$ Readings<br>Pilot Version (not for regulatory purposes)** | |
|---|---|
| **Low<br>0 – 59 ppb** | Enjoy your outdoor activities. |
| **Medium<br>60 – 89 ppb** | If medium readings continue, use the Air Quality Index to plan outdoor activities. |
| **High<br>90 – 149 ppb** | If high readings continue, consider adjusting outdoor activities, especially if you are sensitive to ozone. Check the Air Quality Index to find out. |
| **Very High<br>>150 ppb** | If high reading continue, consider adjusting outdoor activities. Check the Air Quality Index to find out. Very high readings may mean the sensor is not working properly. |

***Table 1.2:*** *Ozone 1-minute EPA categories (pilot version). Colors correspond to the shaded areas used in results figures (section 3).*

| **1-Minute $PM_{2.5}$ Readings<br>Pilot Version (not for regulatory purposes)** | |
|---|---|
| **Low<br>0 – 29 μg/m$^3$** | Enjoy your outdoor activities. |
| **Medium<br>30 – 69 μg/m$^3$** | If medium readings continue, use the Air Quality Index to plan outdoor activities. |
| **High<br>70 – 499 μg/m$^3$** | If high readings continue, consider adjusting outdoor activities, especially if you are sensitive to ozone. Check the Air Quality Index to find out. |
| **Very High<br>>500 μg/m$^3$** | If high reading continue, consider adjusting outdoor activities. Check the Air Quality Index to find out. Very high readings may mean the sensor is not working properly. |

***Table 1.3:*** *$PM_{2.5}$ 1-minute EPA categories (pilot version). Colors correspond to the shaded areas used in results figures (section 3).*

These 1-minute categories are similar to the standardized **EPA Air Quality Index (AQI)**, which rates air quality using "Good", "Moderate", "Unhealthy for Sensitive Groups", "Unhealthy", "Very Unhealthy", and "Hazardous". The AQI ratings correspond to a generalized scale ranging 0 – 500, where 100 corresponds to the EPA primary standard for a particular species, defining the boundary between "Moderate" and "Unhealthy for Sensitive Groups".

Because this study is focused on short-term exposure and uses high-resolution data with measurement duration at single sites no longer than two weeks, we have chosen to present results in relation to the 1-minute pilot categories instead of the standard AQI categories. **The shaded areas on all results figures (section 3) correspond to the 1-minute categories in Tables 1.2 and 1.3.**

# 2. Methods

## 2.1 Instrumentation

All measurements were made with Aeroqual Series 500 portable air quality monitors (https://www.aeroqual.com/product/series-500-portable-air-pollution-monitor). These monitors were chosen based on previous work demonstrating accurate sensor performance (e.g. Williams et al., 2013; MacDonald et al., 2014; Lin et al., 2015), proven cold-temperature performance for the ozone sensor (Aeroqual, 2006), and recommendation by air quality experts (B. Lefer, personal communication, 2017). Table 2.1 lists specifications for each Aeroqual sensor used in this study.

Winter measurements (Jan – March 2018) were completed using the monitors in handheld mode, measuring at 1-minute intervals for 1-2 hour periods. Summer measurements (June – Sept 2018) were completed with the monitors housed in enclosures mounted at roadside locations, measuring at 5-minute intervals for 2-week periods. Specific details for each measurement site are provided in the results section for each location (section 3).

Outdoor enclosures manufactured by Aeroqual were used for the ozone and $NO_2$ monitors. These enclosures were custom wired for a single power source and mounted together on Unistrut rail (Figure 2.1). For the $PM_{2.5}$/$PM_{10}$ monitor, a custom enclosure was manufactured by Inversion Labs. This enclosure allowed sampling of ambient air through the enclosure wall with a 1.5 cm length of PTFE non-reactive tubing (Figure 2.2). For additional details on enclosure design see the following link: http://inversionlabs.com/2018/04/11/custom-enclosures-for-air-quality-monitoring.html

| Sensor | Sensor Type | Range | Min. Detection Limit | Accuracy of Factory Calibration | Resolution | Response Time | Temp Range | RH Range |
|---|---|---|---|---|---|---|---|---|
| $PM_{2.5}$/ $PM_{10}$ | LPC | 0.001 - 1.000 (mg/m$^3$) | 0.001 (mg/m$^3$) | ± 0.005 (mg/m$^3$) + 15% | 0.001 (mg/m$^3$) | 5 s | 0 – 40 °C | 0 – 90% |
| $O_3$ | GSS | 0 – 0.15 ppm | 0.001 ppm | < ± 0.005 ppm | 0.001 ppm | 60 s | 0 – 40 °C | 10 – 90% |
| $NO_2$ | GSE | 0 – 1 ppm | 0.005 ppm | < ± 0.02 ppm (0-0.2 ppm) < ± 10% (0.2-1 ppm) | 0.001 ppm | 30 s | 0 – 40 °C | 15 – 90% |

***Table 2.1:*** *Aeroqual S500 sensor specifications. LPC: Laser Particle Counter; GSS: Gas-Sensitive Semiconductor; GSE: Gas-Sensitive Electrochemical.*

*Figure 2.1:* Aeroqual enclosures used for the Aeroqual S500 ozone and $NO_2$ monitors.*


***Figure 2.2:** Custom enclosure used for the Aeroqual S500 $PM_{2.5}$/$PM_{10}$ monitor.*

In addition to the Aeroqual monitors, a time-lapse camera was installed at the base of Teton Pass, at the intersection of Virginian Lane and Snow King Ave., and at the intersection of WY 22 / US 89. This camera was used to capture general traffic conditions during peak emission scenarios.

## 2.2 Calibration

The Aeroqual S500 sensor heads are delivered factory-calibrated, with each sensor receiving a 3-point calibration against reference standards. The PM sensor is calibrated against a Met One Instruments Optical Particle Counter using 0.54 µm latex microspheres. The ozone sensor is calibrated against a NATA certified ozone UV photometer, and the $NO_2$ sensor is calibrated against a chemiluminescence NOx analyzer.

Although it is possible to field-calibrate the ozone and $NO_2$ sensors using calibration gases, all field calibrations were completed using co-location techniques following the methods of Lin et al. (2015). The Aeroqual monitors were co-located with Federal Equivalent Method (FEM) instruments operated by the Wyoming Department of Environmental Quality Air Quality Division (WYDEQ AQD) for multi-day periods. At the end of the study, the co-location data is then analyzed to derive linear correction values (offset and gain) which are applied to the field data.

### 2.2.1 WYDEQ Jackson Mobile Co-location

The WYDEQ Jackson Mobile site was installed August 2, 2018 approximately 0.6 km (0.4 miles) north of the Town of Jackson in the National Elk Refuge. Inversion Labs planned to co-locate with the WYDEQ Jackson Mobile in the spring prior to summer measurements, once mid-summer, and again after measurements were complete. However, delays in siting the Jackson Mobile allowed co-location only near the end of the study in late August / early September 2018. Co-location data was collected Aug 7 – Aug 15 and again Sep 1 – Sep 9. Persistent power outages at the site prevented collection of gaseous data after Sep 4.

Jackson Mobile co-location data consisted of 265 hourly measurements for ozone, 266 hours for $NO_2$, and 336 hours for PM. Air temperature ranged -1.1 °C to 32.4 °C, and RH ranged 8.6% to 97.6%   Co-location results are shown in Figures 2.4, 2.5, 2.6, and 2.7.


***Figure 2.3:*** *Aeroqual monitors (mounted on black crank-up tower) co-located with the WYDEQ Jackson Mobile in September, 2018.*

Co-location data for the Aeroqual $NO_2$ sensor showed poor agreement with the WYDEQ Thermo Scientific Model 42i NO-$NO_2$-$NO_x$ Analyzer ($R^2$=0.01, Figure 2.5). In addition, analysis of field measurements throughout the duration of the study showed unreasonable levels of $NO_2$. Inaccurate $NO_2$ data was first observed with initial use of the sensor during cold-weather measurements in Dec 2017. Due to possible cold temperature effects on the electrochemical sensor, measurements of $NO_2$ were discontinued for the 2017-18 winter. A new $NO_2$ sensor was ordered from Aeroqual with a factory calibration date of Feb 23, 2018, and was not used until air temperatures were above freezing.

During data collection at a “Clean Air” site in June, 2018, a field zero-calibration was attempted with the new $NO_2$ sensor, following procedures provided by Aeroqual technicians. Although near-zero $NO_2$ values were expected at this site (no nearby combustion sources), baseline values before the zero-calibration ranged ~70 – 100 ppb. The zero-calibration provided some improvement of the data, with values ranging ~0 – 40 ppb after the calibration. In addition, due to a known sensitivity to ozone, Aeroqual recommended correcting the $NO_2$ data as:

$$[NO_2]_{corrected} = [NO_2]_{measured} - (0.5 * [O_3]_{measured})$$

Lin et al. (2015) also found poor accuracy during an extensive co-location experiment with the Aeroqual $NO_2$ sensor, and identified a significant correlation between $NO_2$ error and the magnitude of ozone measurements. Using data from a reference $NO_2$ analyzer, the authors were able to derive a correction equation using the relationship of $NO_2$ error vs. $O_3$ concentration. We attempted these same techniques using WYDEQ co-location data, but were unable to derive a significantly correlated relationship. In summary, attempts at a zero-calibration, application of the Aeroqual-recommended correction, and application of the Lin et al. (2015) correction all failed to provide accurate $NO_2$ data. Unfortunately, we were unable to provide any usable $NO_2$ data for this study.

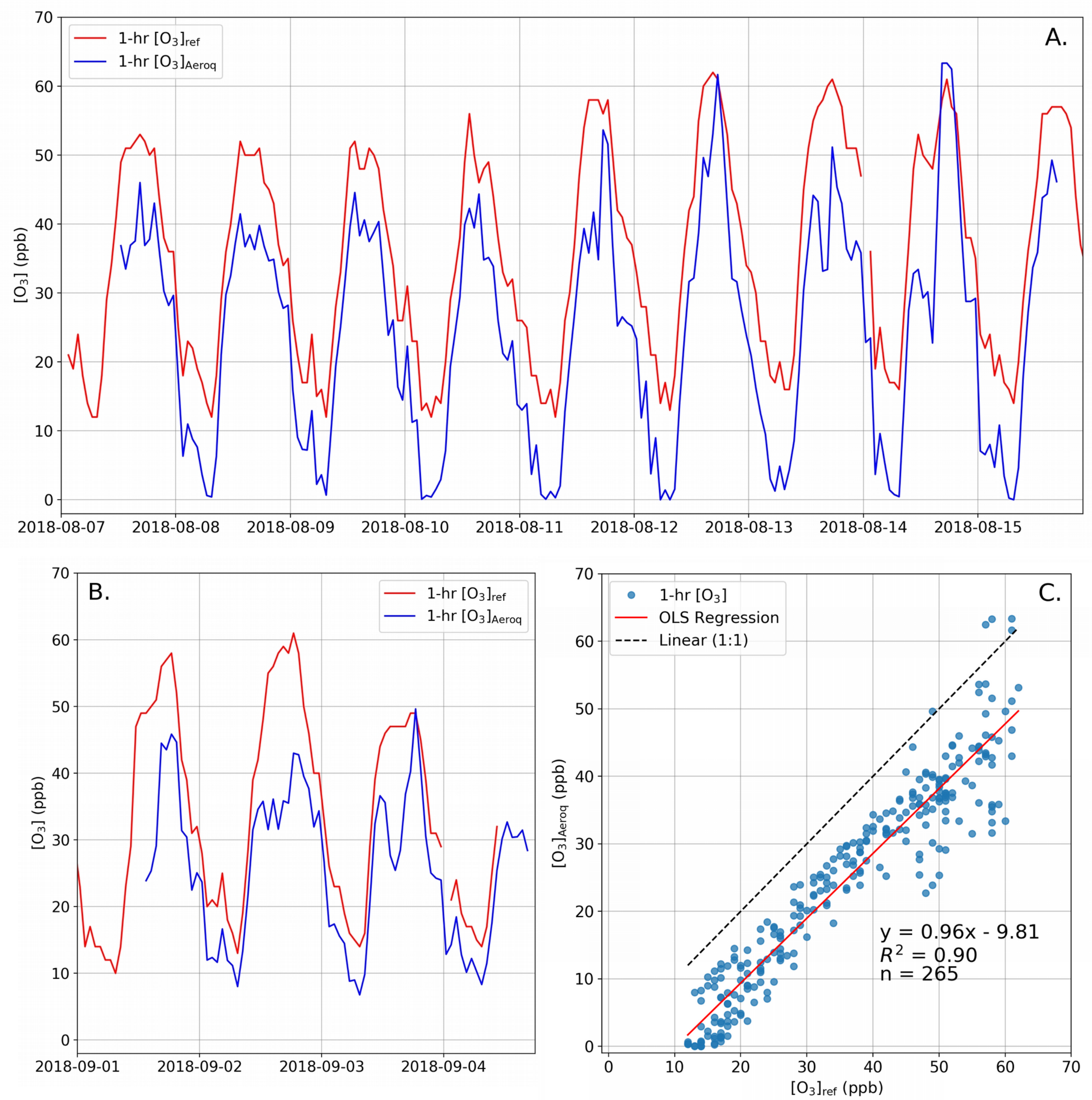



***Figure 2.4:*** *Ozone co-location data (hourly) at the WYDEQ Jackson Mobile site for Aug 7-15 and Sep 1-4, 2018. Time series for WYDEQ reference data (red) and Aeroqual data (blue) are shown in Panels A. and B. The linear equation for the ordinary least squares (OLS) regression used to correct ozone field data is shown in Panel C.*

However, co-location data for ozone and $PM_{2.5}$/$PM_{10}$ showed overall good agreement with reference data. The Aeroqual ozone sensor was referenced against a WYDEQ Teledyne Photometric $O_3$

Analyzer (Model 400E), showing strong correlation ($R^2$=0.90, Figure 2.4). The Aeroqual $PM_{2.5}/PM_{10}$ sensor was referenced against WYDEQ Met One Instruments BAM 1020 Particulate Monitors, showing moderately strong correlation for both $PM_{2.5}$ ($R^2$=0.64, Figure 2.6) and $PM_{10}$ ($R^2$=0.65, Figure 2.7). Offset and gain correction values derived using the intercept and slope values shown in Figures 2.4, 2.6, and 2.7 were applied to all Aeroqual-measured field data in the study.

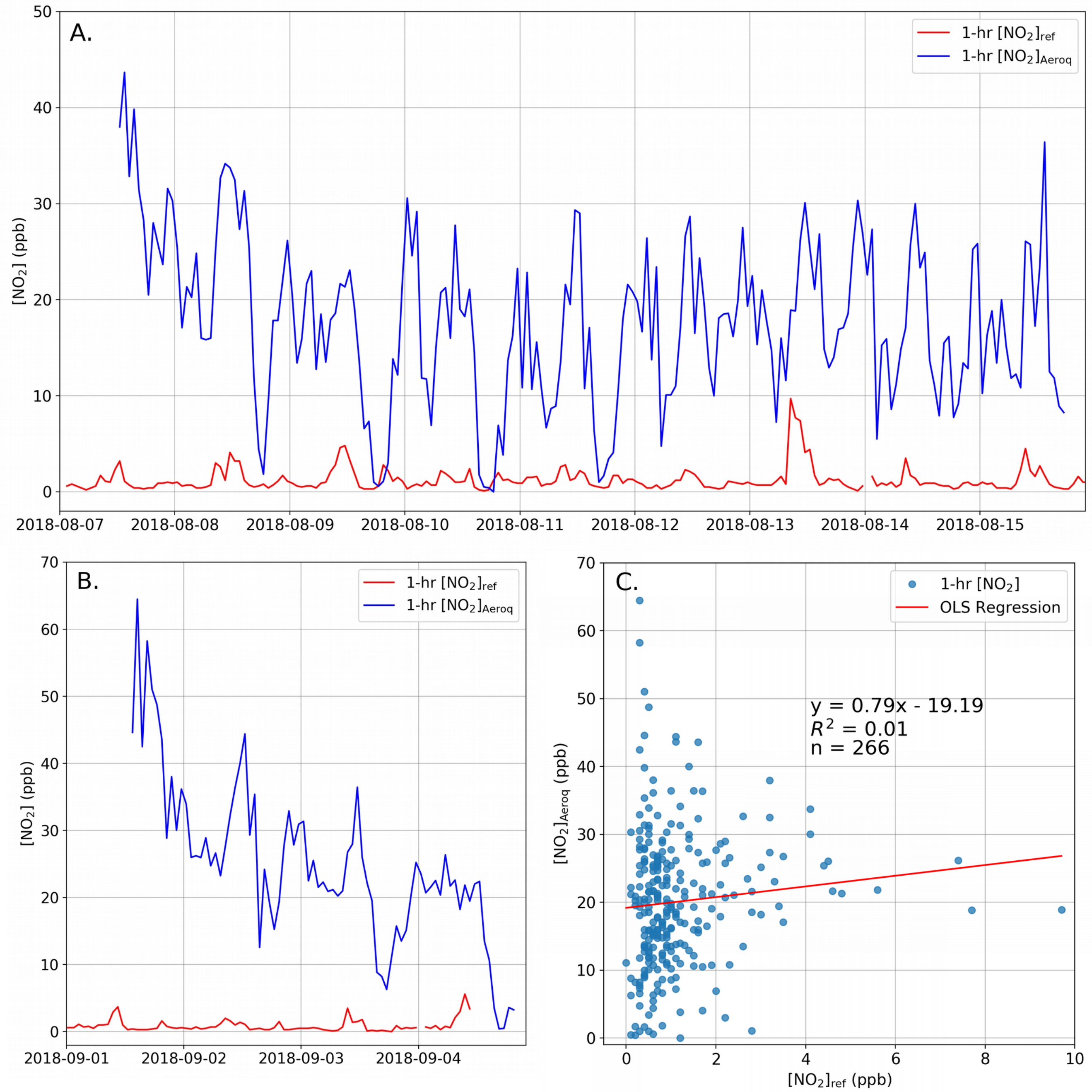



***Figure 2.5:*** *$NO_2$ co-location data (hourly) at the WYDEQ Jackson Mobile site for Aug 7-15 and Sep 1-4, 2018. Time series for WYDEQ reference data (red) and Aeroqual data (blue) are shown in Panels A. and B. Due to poor agreement with reference data (Panel C.), Aeroqual $NO_2$ data was not included in the results of this study.*

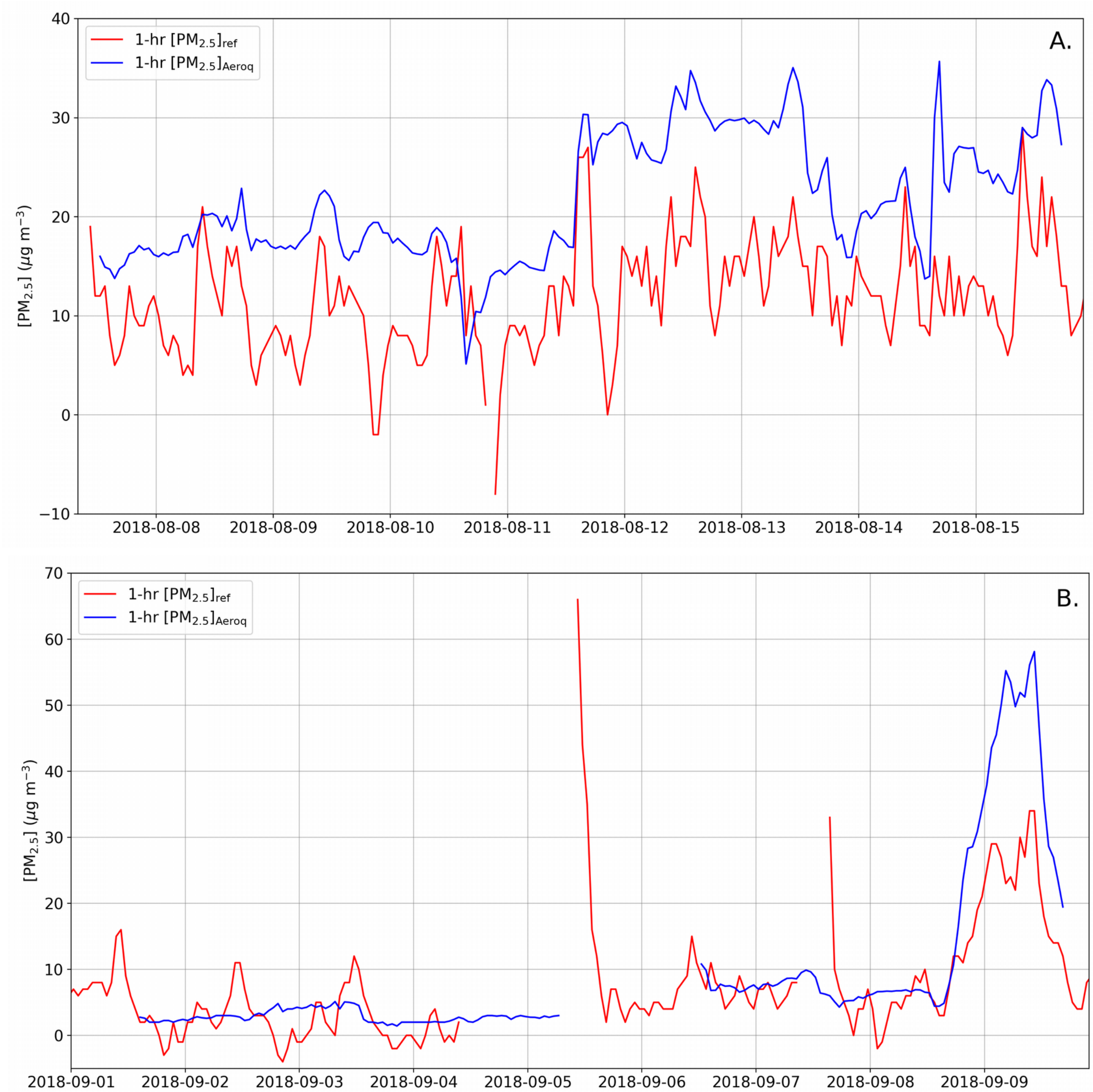
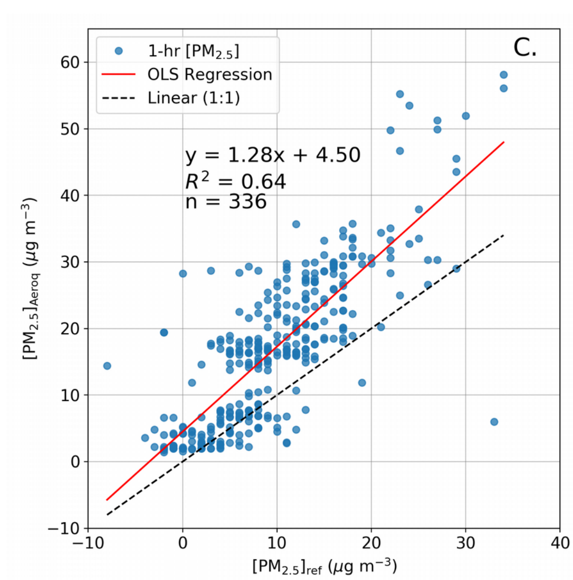
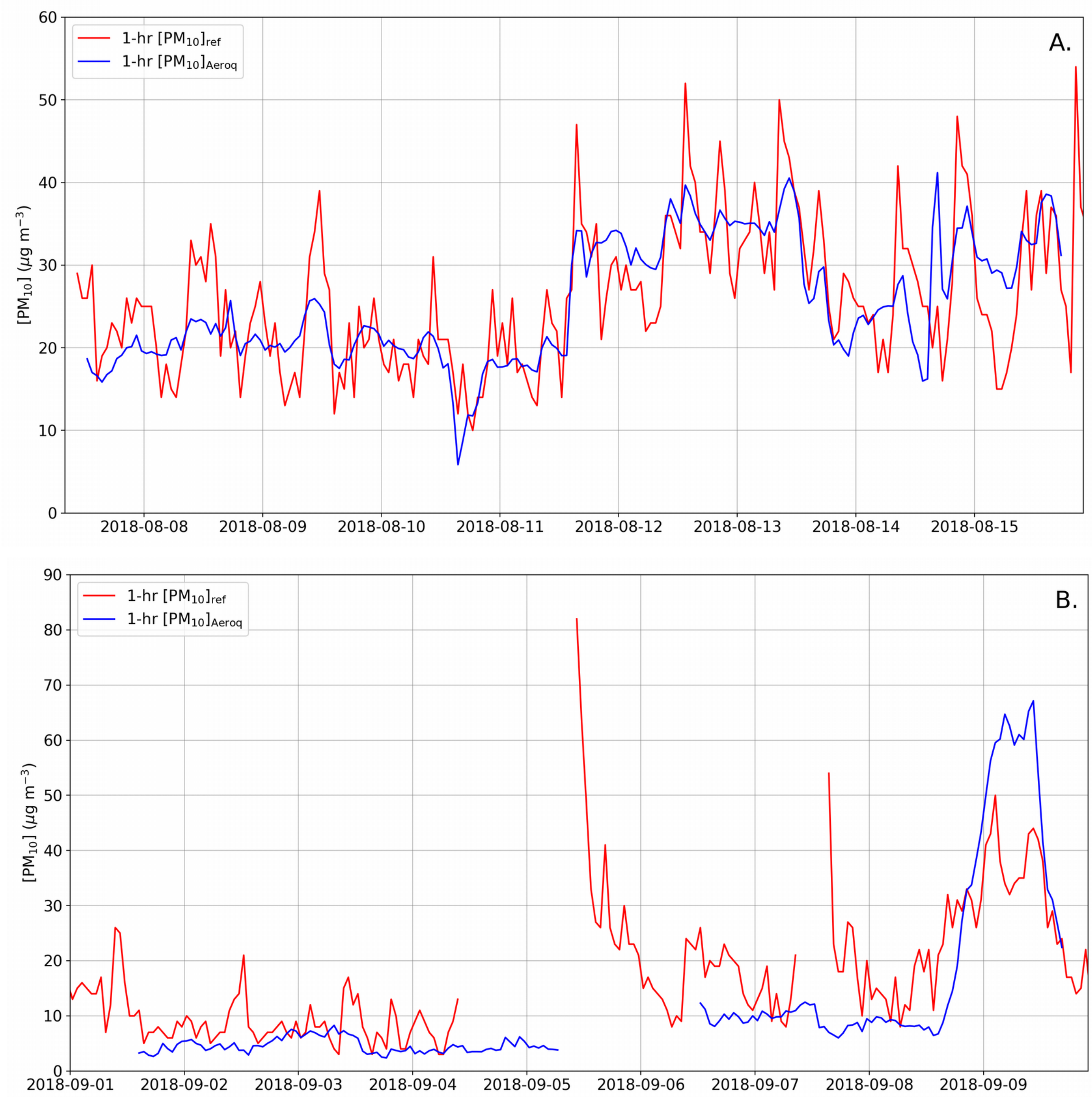



***Figure 2.6:*** *$PM_{2.5}$ co-location data (hourly) at the WYDEQ Jackson Mobile site for Aug 7-15 and Sep 1-9, 2018. Time series for WYDEQ reference data (red) and Aeroqual data (blue) are shown in Panels A. and B. The linear equation for the ordinary least squares (OLS) regression used to correct $PM_{2.5}$ field data is shown in Panel C.*





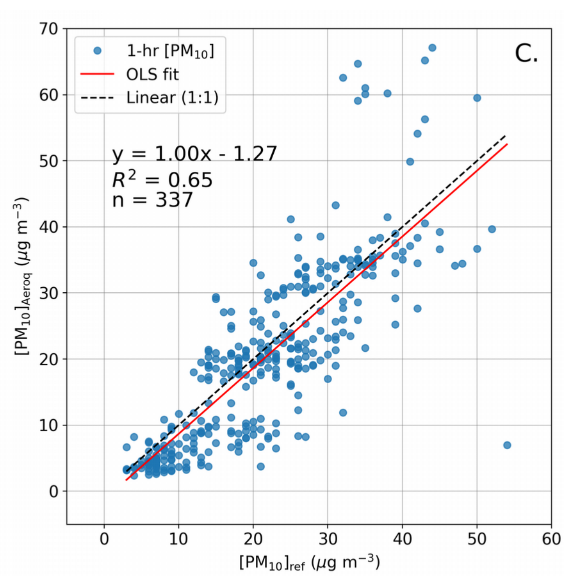
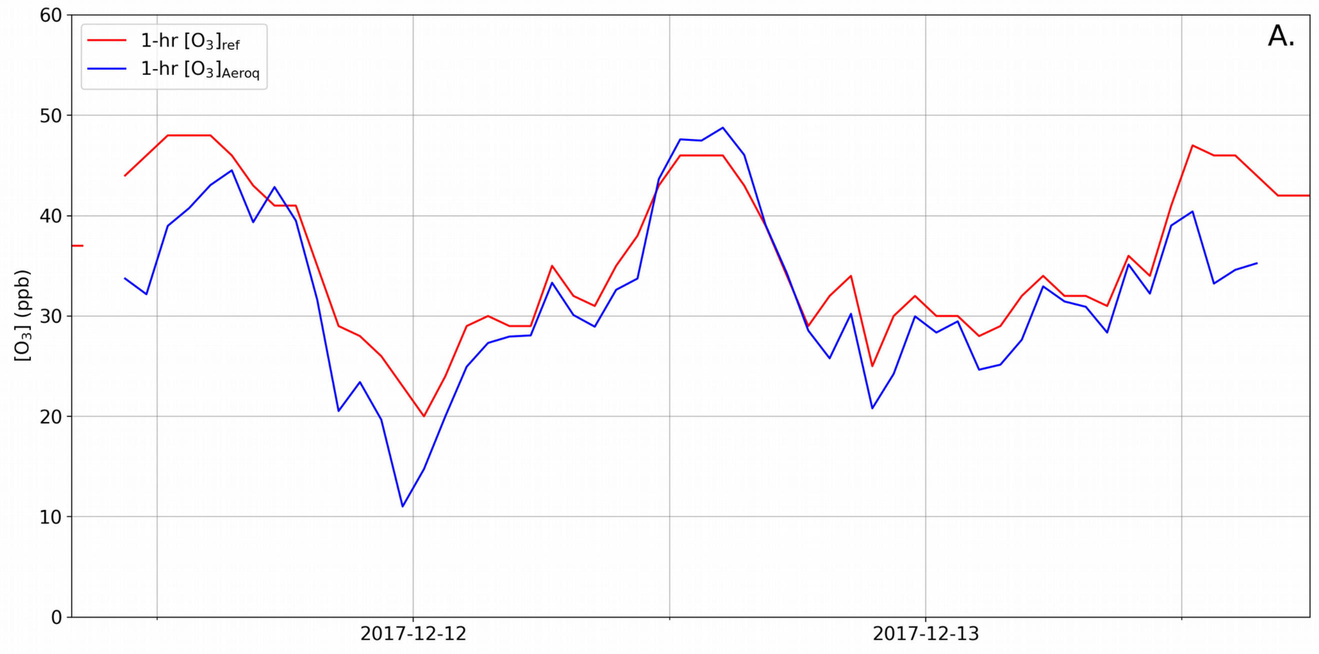




***Figure 2.7:*** *$PM_{10}$ co-location data (hourly) at the WYDEQ Jackson Mobile site for Aug 7-15 and Sep 1-9, 2018. Time series for WYDEQ reference data (red) and Aeroqual data (blue) are shown in Panels A. and B. The linear equation for the ordinary least squares (OLS) regression used to correct $PM_{10}$ field data is shown in Panel C.*

### 2.2.2 WYDEQ Pinedale Co-location

To analyze cold temperature performance of the Aeroqual S500 sensors, a co-location experiment was conducted at the WYDEQ Pinedale monitoring site during December 11 – 13, 2018. Air temperatures ranged -7.3 °C to 11.8 °C, with RH ranging 10.3% to 94.9%. Overall good agreement was found for measurements of ozone and $PM_{2.5}$ (Figures 2.8 and 2.9). $PM_{10}$ is not measured at the WYDEQ Pinedale site.



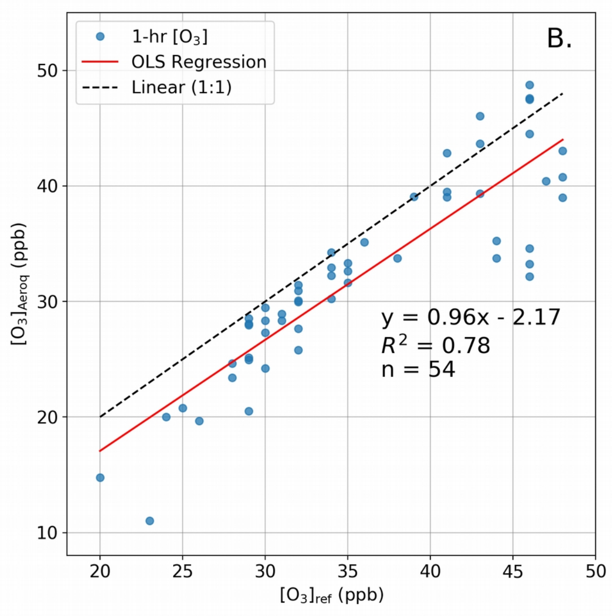




***Figure 2.8:*** *Ozone co-location data (hourly) at the WYDEQ Pinedale monitoring station for Dec 11-13, 2017. Time series for WYDEQ reference data (red) and Aeroqual data (blue) are shown in Panel A. The linear equation for the ordinary least squares (OLS) regression is shown in Panel B. This equation was not used to correct field data.*

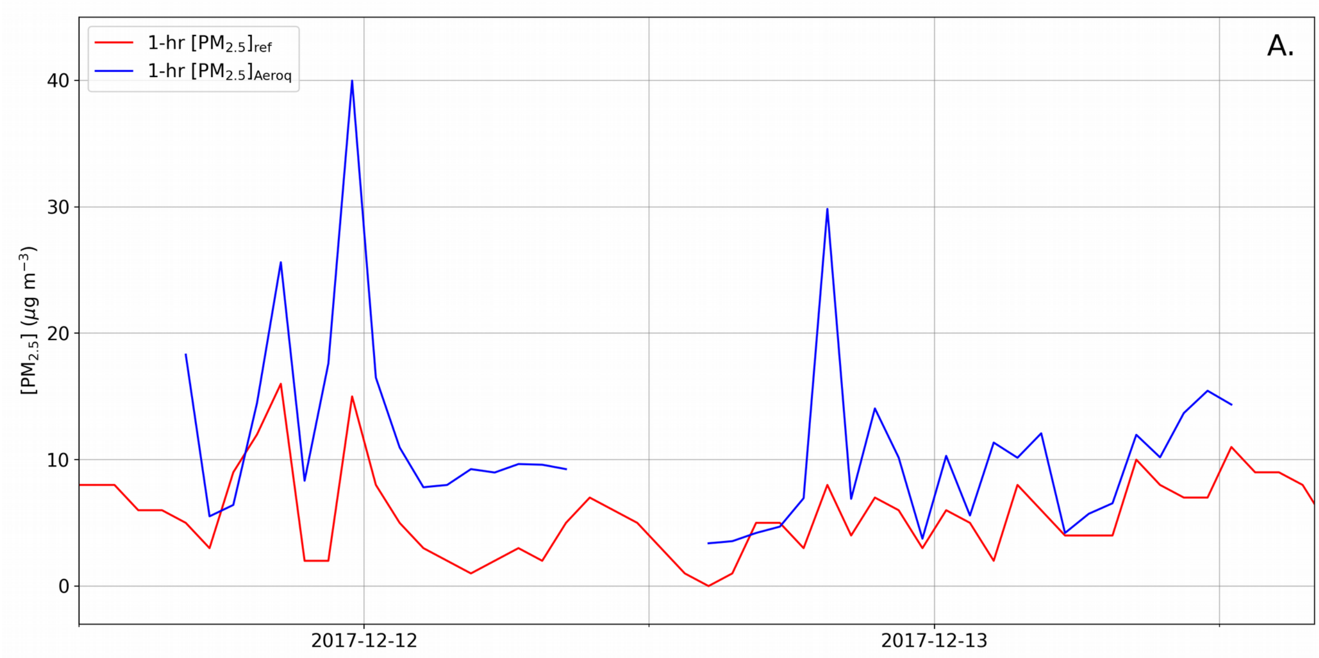
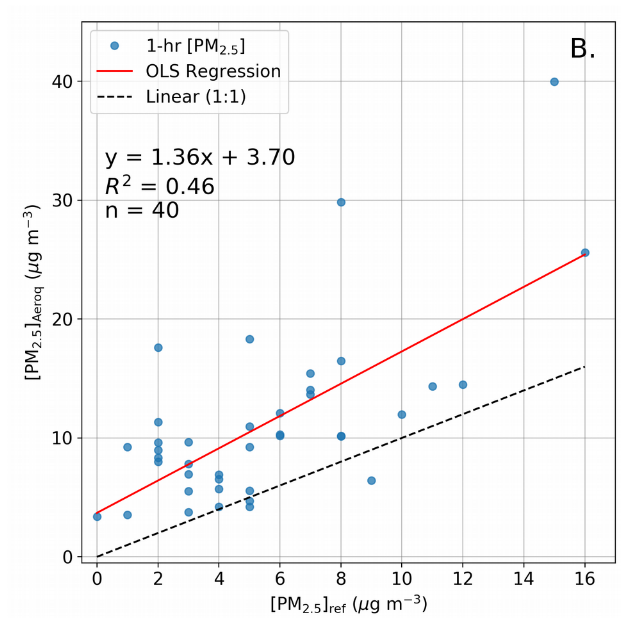



***Figure 2.9:*** *PM$_{2.5}$ co-location data (hourly) at the WYDEQ Pinedale monitoring station for Dec 11-13, 2017. Time series for WYDEQ reference data (red) and Aeroqual data (blue) are shown in Panel A. The linear equation for the ordinary least squares (OLS) regression is shown in Panel B. This equation was not used to correct field data.*




Results for ozone and PM$_{2.5}$ from the WYDEQ Pinedale co-location showed similar offset and gain values to the Jackson Mobile co-location. Because the number of measurements in the Jackson Mobile co-location were much greater (e.g. n=265 vs. n=40), we opted to use the correction equations from the Jackson Mobile co-location for all Aeroqual field data in the study (applied to both winter and summer data).

An additional third co-location was conducted at the Grand Teton National Park (GTNP) air quality site located at the Teton Science Schools Kelly campus, during February 10 – 14, 2018. Measured data was limited to ozone, with air temperature ranging -19.0 °C to -0.6 °C, and RH ranging

42% to 91%. Analysis of hourly Aeroqual S500 ozone data and reference ozone data (Thermo Model 49i $O_3$ Analyzer) showed weak correlation ($R^2$=0.38, n=97), particularly at the lowest range of temperatures, where Aeroqual data was typically offset 10 – 15 ppb lower than reference data (results not shown). This is possibly due to lower fan speeds in the Aeroqual ozone sensor head at low temperatures. However, this co-location was limited in duration and did not provide results reliable enough to use for correction of winter field data.

Although the Pinedale co-location period had relatively warmer temperatures (low of -7.3 °C), the Aeroqual and reference ozone data agreed much better for this site than at the GTNP Kelly site. In addition, previous work (Aeroqual, 2006) shows strong correlation between Aeroqual and reference ozone data collected in Antarctica over 3 months at air temperatures averaging -30 °C (using a secondary fan to draw air through an inlet). Due to the limited cold-temperature co-location data collected in this study, for interpretation of winter results (section 3.1), we recommend doubling the Aeroqual-specified accuracy (± 0.005 ppm) to ± 0.010 ppm.

Finally, we note that due to limited co-location analysis, we were unable to assess or quantify possible sensor drift over the period of measurement. The “Antarctic Test Results” (Aeroqual, 2006) show no drift over 3 months of continuous operation for the Aeroqual ozone sensor. Lin et al. (2015) also showed no drift for Aeroqual ozone and $NO_2$ sensors over 2 months of continuous operation. However, we are unable to extend these results with confidence to our study, and we are unable to assess possible drift of the Aeroqual $PM_{2.5}$/$PM_{10}$ measurements.

# 3. Results and Discussion

## 3.1 Winter Air Quality

Winter air quality measurements were completed January – March, 2018. The goal of this study period was to characterize short-term exposure to vehicle-related emissions, particularly during periods of stable atmospheric inversion where pollutants can be concentrated in the near-surface boundary layer. Due to reasons cited in section 2, measurements were limited to ozone and $PM_{2.5}$/$PM_{10}$ during this period.

### 3.1.1 Jackson Elementary School (JES)


***Figure 3.1:*** *Air quality measurements were completed at the JES drop-off and bus staging areas on January 3 and 16, 2018. In addition to fixed positions such as shown (left), a technician walked with the monitors on the sidewalk near vehicles and buses.*

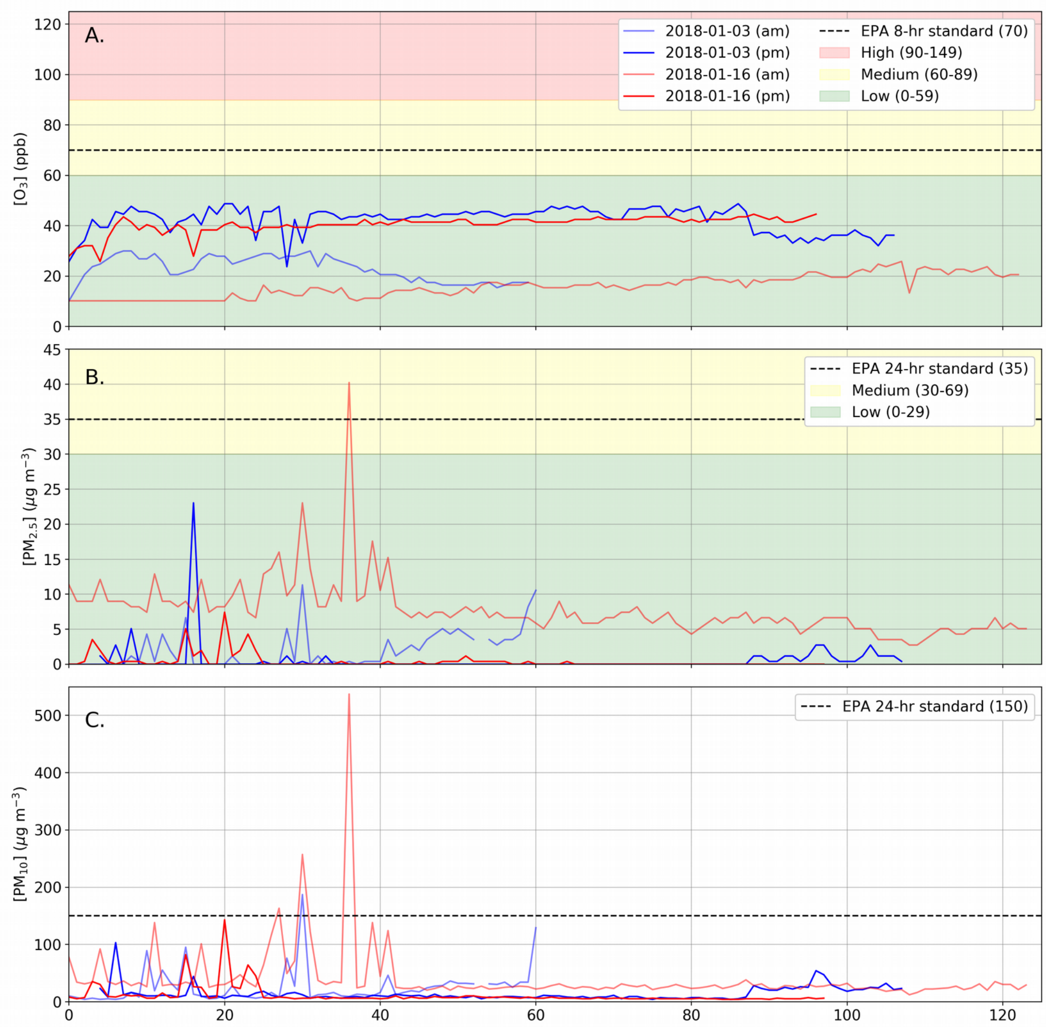



***Figure 3.2:*** *1-minute data for ozone (panel A.), $PM_{2.5}$ (panel B.), and $PM_{10}$ (panel C.) at JES on Jan 3 (blue) and Jan 16, 2018 (red). Light lines are morning drop-off and dark lines are afternoon pick-up. Colored bands for ozone and $PM_{2.5}$ show EPA 1-minute pilot categories.*

***Discussion: Jackson Elementary School***

The JES site is characterized by vehicle and bus traffic during morning and afternoon drop-off hours. Vehicle traffic is typically 5 – 20 idling cars and/or trucks, and bus traffic consists of 4-6 diesel school buses assembling and idling in a nearby drop-off area. The heavy traffic periods persist for approximately 45 minutes.

All measurements at JES were made during periods of atmospheric inversion with clear weather, high pressure, no wind, and cold air temperatures. Morning air temperatures ranged -20 – -13 °C (-4 – 9 °F), and afternoon air temperatures ranged -5 – -3 °C (23 – 27 °F).

Ozone results show normal background levels, with slightly elevated levels (30-40 ppb) in the afternoon due to photochemical production. There is no indication of additional ozone production due to vehicle emissions, with ozone concentrations remaining at low levels for all measured periods.

$PM_{2.5}$ and $PM_{10}$ also show mostly low levels with short spikes to higher concentrations. In general, these spikes occur during the drop-off periods during the first 40-60 minutes of measurement. The monitors were then left running after traffic had cleared, such that the second half of the measurement periods represent air quality conditions without traffic.

These short PM spikes occur when walking directly through an exhaust plume from a vehicle tail pipe, or from standing directly next to idling or moving diesel buses. For $PM_{2.5}$ these spikes reached the “medium” EPA 1-minute category for a single measurement. These short-term spikes are expected for sampling air directly in an emission plume, and correspond to very brief periods of unhealthy conditions for the public who may be standing in or passing directly through tail pipe emissions. However, moving the monitors only 3 meters (10 ft.) away resulted in mostly clean air measurements.

We also note that the PM monitor is sensitive to water vapor, which constitutes some portion of tail pipe emissions. The overall slightly elevated PM levels on the morning of January 16 was most likely due to suspended ice crystals in the air, which were obviously visible.

Overall, normal levels of ozone and low levels of $PM_{2.5}$ and $PM_{10}$ were measured at this site, with only very brief elevated PM spikes due to direct measurement in close proximity to emission sources.

### 3.1.2 Snow King Events Center

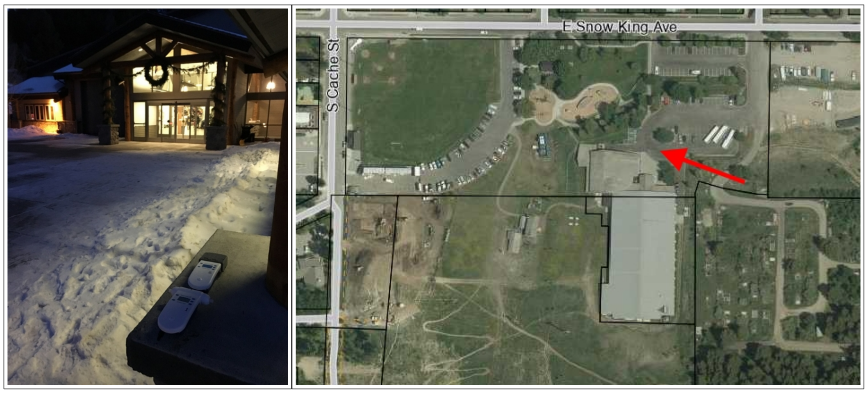



***Figure 3.3:*** *Air quality measurements were completed at the Snow King Events Center drop-off area on January 2, 2018. In addition to fixed positions such as shown (left), a technician walked with the monitors on the sidewalk near idling vehicles.*

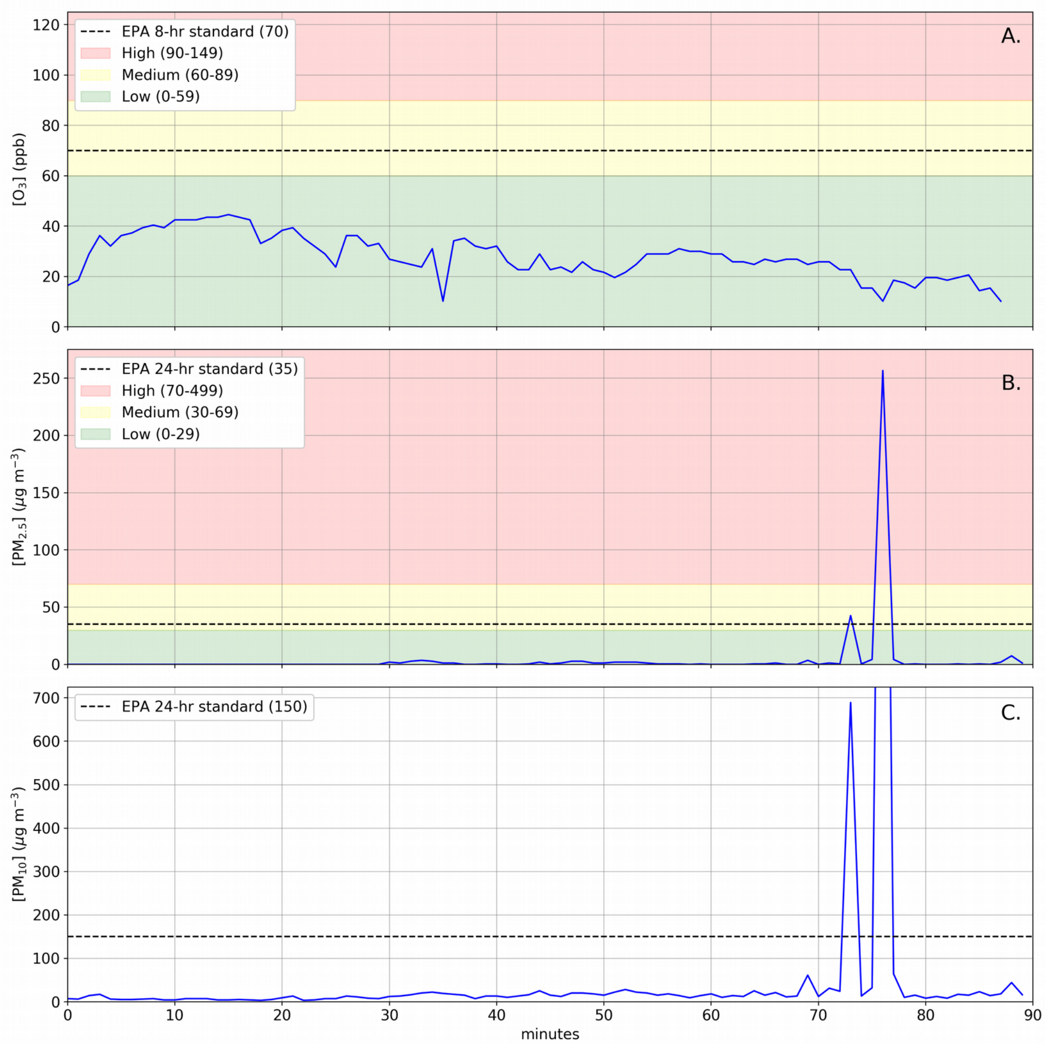



***Figure 3.4:*** *1-minute data for Ozone (panel A.), $PM_{2.5}$ (panel B.), and $PM_{10}$ (panel C.) at Snow King Events Center on Jan 2, 2018 (5:20 – 6:50 pm). Colored bands for ozone and $PM_{2.5}$ show EPA 1-minute pilot categories.*

***Discussion: Snow King Events Center***

The Snow King Events Center site is characterized by vehicle traffic during evening hours corresponding with hockey activities. Vehicle traffic is typically 3-5 idling cars and/or trucks.

Air temperatures during the measurement period ranged -13 – -7 °C (9 – 19 °F) with stable atmospheric inversion conditions.

Ozone measurements show normal background levels, with a slight declining trend corresponding with the end of diurnal photochemical production. There is no indication of additional ozone production due to vehicle emissions, with ozone concentrations remaining at low levels throughout the period of measurement.

$PM_{2.5}$ and $PM_{10}$ levels are overall very low at this site, likely due to the relatively low volume of traffic. Although most cars idle at the curb for hockey pick-up and drop-off, there are usually not more than 3-5 vehicles at any given time.

The large spike in PM levels recorded at approximately 75 minutes resulted from moving into the emission plume of an idling F-350 diesel truck (~1.5 meters directly downwind). The second spike in $PM_{10}$ (above the y-axis scale in Panel C.) peaks at 2,376 µg/m$^3$. We note that this represents measurements directly in a diesel emission plume, and is not representative of ambient conditions.

Overall, normal levels of ozone and low levels of $PM_{2.5}$ and $PM_{10}$ were measured at this site, with only a single elevated PM spike due to direct measurement in close proximity to a diesel emission source.

### 3.1.3 Base of Teton Pass (Wilson, WY)

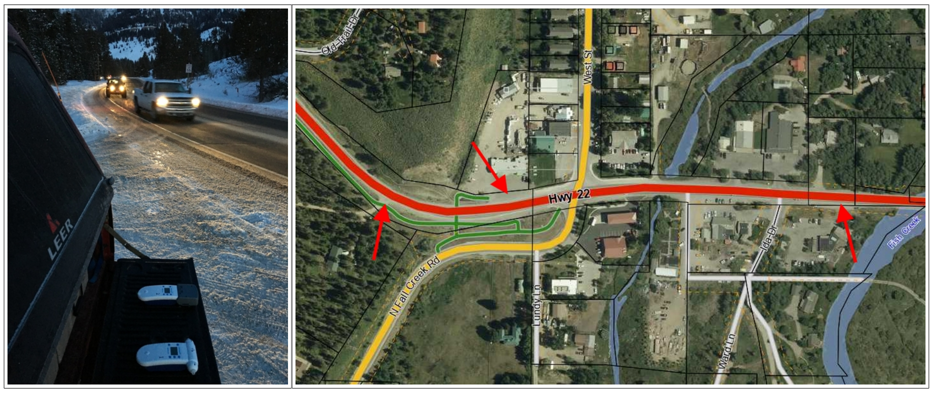



***Figure 3.5:*** *Air quality measurements were completed at the base of Teton Pass in Wilson, WY on Jan 24, Jan 29, and Mar 7, 2018. Locations included a driveway on the south side of Hwy 22 (pictured, left), the Stagecoach Bar, and in a pullout near Pearl St. Bagels.*

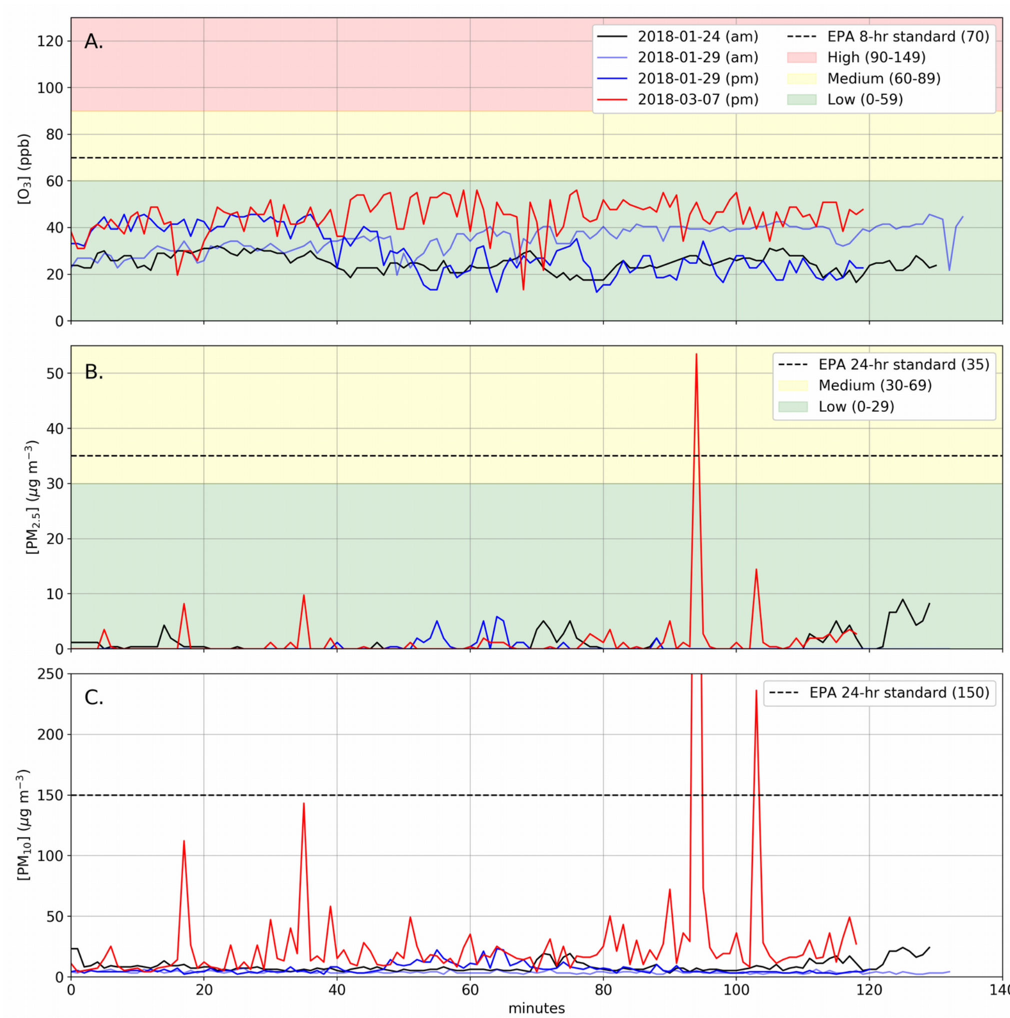



***Figure 3.6:*** *1-minute data for ozone (panel A.), $PM_{2.5}$ (panel B.), and $PM_{10}$ (panel C.) at the base of Teton Pass measured on Jan 24 (black), Jan 29 (lt blue / dk blue), and Mar 7 (red). Colored bands for ozone and $PM_{2.5}$ show EPA 1-minute pilot categories.*

***Discussion: Base of Teton Pass (Wilson, WY)***

The Teton Pass site is characterized by vehicle traffic (car / truck / heavy truck) on 2-lanes (Hwy 22) through Wilson, WY. This area tends to have heavy “rush-hour” periods associated with eastbound (morning) and westbound (afternoon) commuter traffic. The speed limit is 25 mph, increasing to 45 mph on either side of the town of Wilson. There is also concern in this area for potential brake emissions associated with eastbound traffic descending Teton Pass.

Air temperatures during the measurement periods ranged -8 – 3 °C (17 – 38 °F) with weather conditions ranging from clear and calm to overcast with calm south wind.

Ozone measurements show normal background levels. There is no indication of additional ozone production due to vehicle emissions, with ozone concentrations remaining at low levels for all periods of measurement.

$PM_{2.5}$ and $PM_{10}$ levels are mostly very low for all periods and locations of measurement, with exception to March 7 (4:15 – 6:00 pm), located at a pullout on the south side of Hwy 22 outside Pearl St. Bagels. This measurement period shows various spikes to higher concentrations with a single $PM_{2.5}$ spike to the “medium” EPA 1-minute pilot category (corresponding $PM_{10}$ concentration of 776 $\mu g/m^3$). This spike is likely due to a single passing vehicle with high-particulate exhaust, or could also be from another vehicle idling in the same pullout close to the sensors. It is unclear why this day showed higher PM concentrations than other days, as all periods of measurement involved some amount of heavy “rush-hour” traffic. The influence of additional vehicles pulling in and out of the pullout likely created the additional PM spikes on this day.

Even considering the slightly elevated levels on March 7, overall PM concentrations were surprisingly clean at all locations. A factor that partially helps support cleaner PM conditions during winter is the snow-covered roads which prevent excessive dust production compared to summer road conditions.

There is no also no strong evidence for elevated PM concentrations due to brake emissions from eastbound traffic descending Teton Pass in winter. The elevated levels on March 7 are likely not due to brake emissions since the majority of traffic was westbound.

Overall, normal levels of ozone and low levels of $PM_{2.5}$ and $PM_{10}$ were measured for all locations at the base of Teton Pass, with several slightly elevated PM spikes on March 7.

### 3.1.4 Snowmobile Hill Climb


***Figure 3.7:*** *Air quality measurements were completed at the Snowmobile Hill Climb (base of Snow King) on Mar 25, 2018. Measurements were taken throughout the public vendor area, and next to the snowmobile staging area and starting gate.*

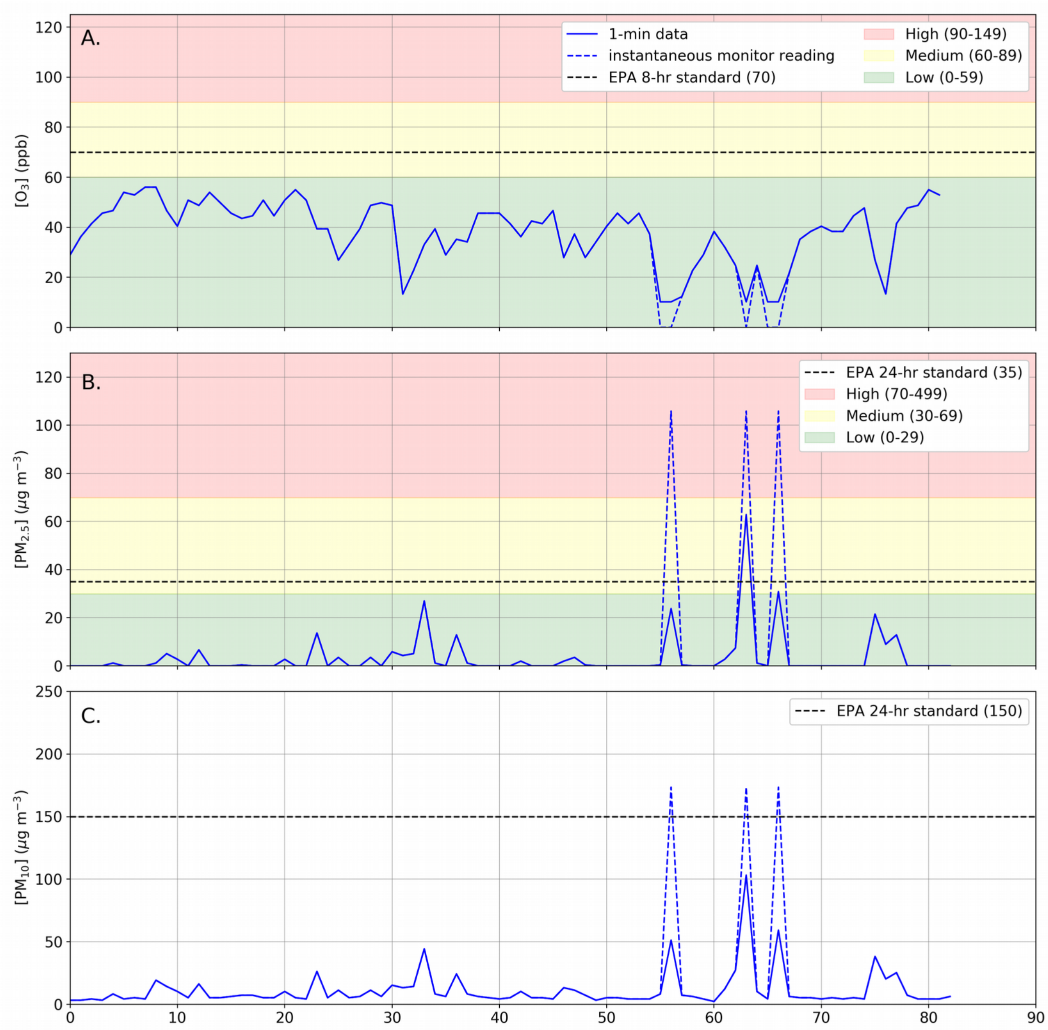



***Figure 3.8:*** *1-minute data for ozone (panel A.), $PM_{2.5}$ (panel B.), and $PM_{10}$ (panel C.) measured at the Snowmobile Hill Climb on Mar 25, 2018. Dashed lines are instantaneous monitor readings that were not recorded in the 1-minute data. Colored bands for ozone and $PM_{2.5}$ show EPA 1-minute pilot categories.*

***Discussion: Snowmobile Hill Climb***

The Snowmobile Hill Climb event features snowmobiles racing up Snow King Mountain with a starting gate located at the base area. Many hundreds of spectators are at the site with a vendor area for food and merchandise. Air quality measurements at the base of Snow King spanned ~1.5 hrs from 11:45 am to 1:10 pm on March 25, 2018. Air temperature was -0.5 °C (31°F) with calm wind, and overcast to broken sky conditions.

Ozone measurements show normal background levels. There is no indication of significant additional ozone production due to human sources (vehicle, snowmobile, or vendor cooking), with ozone concentrations remaining at relatively low levels during the period of measurement.

$PM_{2.5}$ and $PM_{10}$ levels remain at relatively low levels except for spikes to higher concentrations during the period spanning 50 – 70 minutes. The dashed lines in figure 3.8 show the min. / max. instantaneous concentrations displayed on the monitor, but not recorded in the 1-minute data. These high-concentration spikes were measured at two locations: 1. At the fence separating the crowd from the starting ramp/jump (~7-8 meters from snowmobiles); 2. At the fence separating the crowd from the snowmobile staging area (~9-10 meters from snowmobiles). At the starting ramp, PM levels would spike as single snowmobiles accelerated through the start. At the staging area, PM levels spiked as racers warmed up their engines with prolonged engine revving. These measurements were taken among the general public standing along fences, in relatively close proximity to the emission sources.

When PM levels spike to high concentrations, ozone concentrations consistently drop to zero. This is likely due to high concentration of volatile organic compounds (VOCs) in the snowmobile emissions. The Aeroqual manual for the GSS ozone sensor states that the sensor background compensation may become overwhelmed at high VOC concentrations, causing low ozone readings. Measurement of ozone in the presence of high concentrations of VOCs, particularly alkenes, may also be lower due to gas phase ozone reaction with VOCs. Although direct measurement of VOCs is necessary to demonstrate high VOC concentrations, the drop to zero ozone likely indicates high VOC levels in the snowmobile emissions.

Although ozone and PM levels remain relatively low throughout the general Snowmobile Hill Climb event area, these measurements indicate spikes in PM (and likely VOCs) to unhealthy levels when standing along fences directly adjacent to the start ramp and staging areas.

## 3.2 Summer Air Quality

Summer air quality measurements were completed during June – September, 2018 at four roadside locations and a “clean air” site. The goal of the summer measurement campaign was to characterize the range of pollutant concentrations at roadside locations with high vehicle traffic density. The summer campaign allowed for extended monitor deployment at air temperatures within the rated temperature range for the Aeroqual sensors. Due to reasons cited in section 2, measurements were limited to ozone and $PM_{2.5}$/$PM_{10}$ during this period.

### 3.2.1 “Clean Air” Site


***Figure 3.9:*** *Air quality measurements were completed at a “clean air” site during June 21 – 24, 2018, located in an agricultural field south of Wilson, WY. The site is intended to characterize regional ambient air quality away from emission sources.*

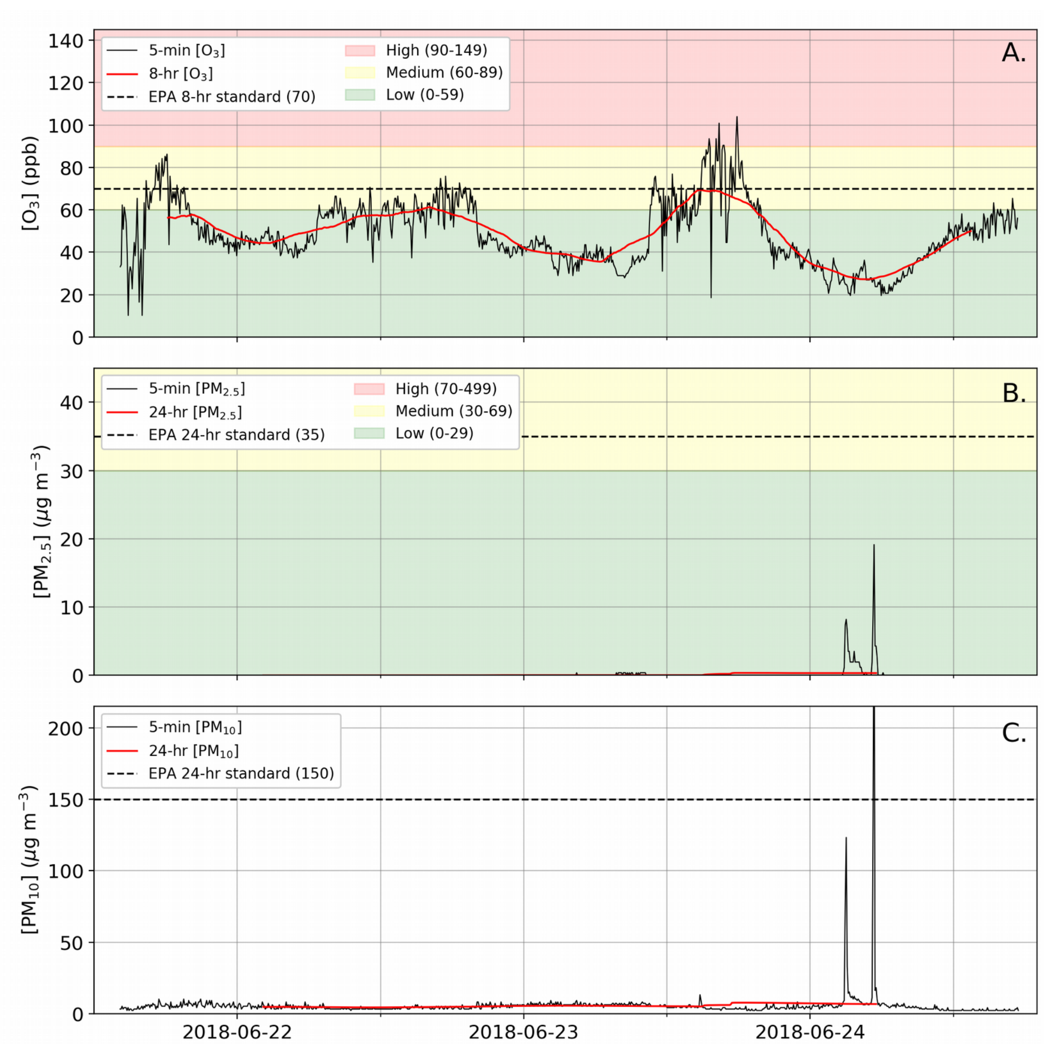



***Figure 3.10:*** *5-minute data for ozone (panel A.), $PM_{2.5}$ (panel B.), and $PM_{10}$ (panel C.) measured at a “Clean Air” site. 8-hr and 24-hr averages (red lines) are calculated as a rolling mean from the 5-minute data. Colored bands for ozone and $PM_{2.5}$ show EPA 1-minute pilot categories.*

***Discussion: "Clean Air" Site***

The "Clean Air" site was intended to provide a baseline for regional air quality conditions away from emission sources. The nearest road is ~320 meters to the east with light rural traffic. Dominant wind flow is from the southwest with air masses originating in non-populated mountainous terrain.

Air temperatures during June 21 – 24, 2018 ranged ~ 1.5 – 13 °C (35 – 55 °F). Weather conditions were mostly clear and dry with calm wind, except for a heavy afternoon rain storm with lower air temperatures on June 23.

Although ozone measurements mostly show normal background levels with diurnal cycles corresponding to photochemical production, the highest ozone concentrations of the campaign were measured at this site. 8-hr average concentrations never exceeded the 8-hr EPA standard, but 5-minute measurements reach "medium" and "high" levels using the EPA 1-minute pilot categories. The increased levels measured on the afternoon of June 23 could be due to an intense rain and thunderstorm during these hours. Ozone produced as a result of electrical activity in a thunderstorm can be brought down from higher levels in the troposphere to the surface. In addition, high relative humidity (likely close to 100%) could have affected the ozone sensor readings. Otherwise, the higher ozone concentrations at this site are likely related to peaks in background ozone that typically occur during the month of May in the Northern Hemisphere (Vingarzan, 2004).

PM levels show very clean regional background air, with concentrations remaining near zero for the measurement period. The two spikes on June 24 occurred early in the morning hours and could have resulted from gusty wind that brought a plume of dust, tree pollen, or hay pollen across the measurement site.

### 3.2.2 Jackson Town Square

***Figure 3.11:*** *Air quality measurements were completed at the Jackson Town Square during June 25 – July 9, 2018. The monitors were installed on a light post on the west side of the Square.*

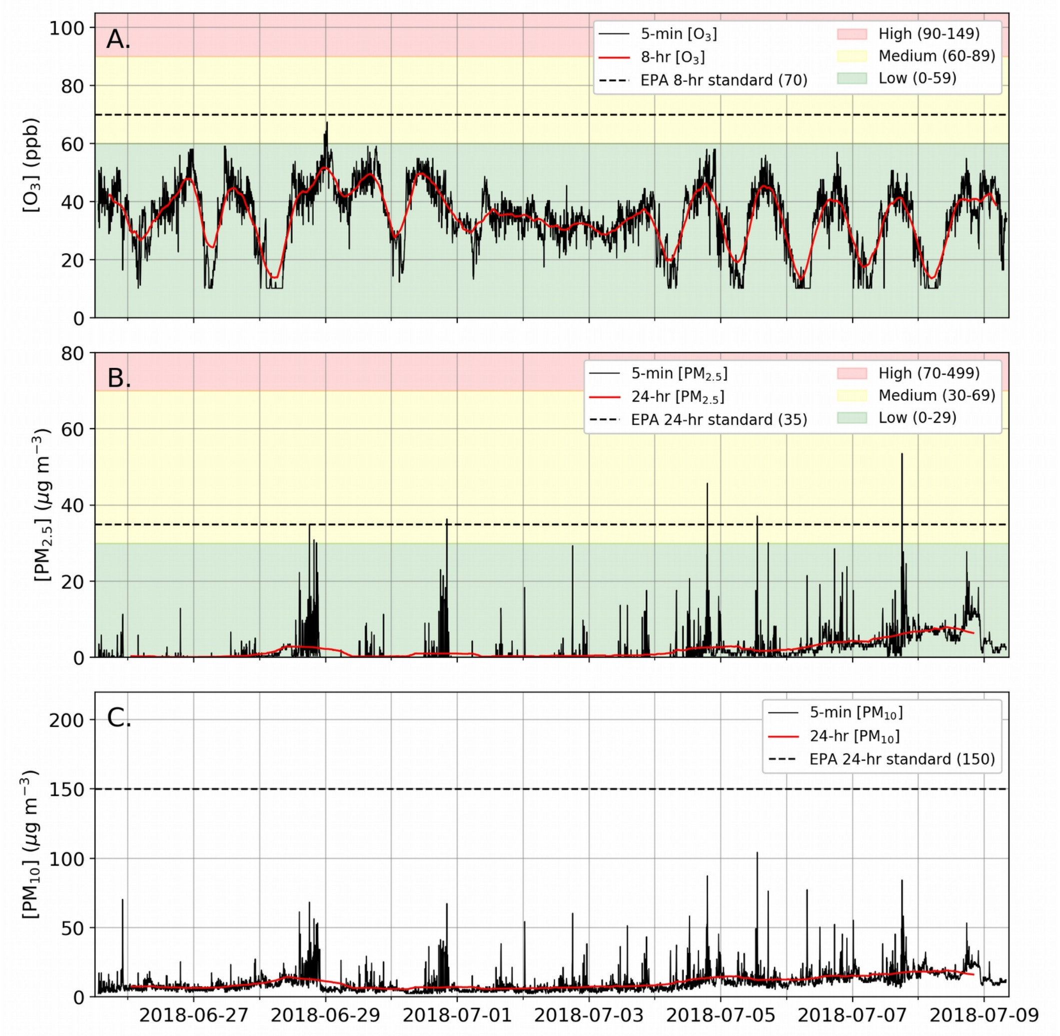



***Figure 3.12:*** *5-minute data for ozone (panel A.), $PM_{2.5}$ (panel B.), and $PM_{10}$ (panel C.) measured at the Jackson Town Square. 8-hr and 24-hr averages (red lines) are calculated as a rolling mean from the 5-minute data. Colored bands for ozone and $PM_{2.5}$ show EPA 1-minute pilot categories.*

***Discussion: Jackson Town Square***

The Town Square site is characterized by vehicle traffic (car / truck / heavy truck) on 2-lanes (Cache St.) along the west side of the Town Square. Although there is some increase in traffic during "rush-hour" periods, this area has fairly consistent traffic patterns during the summer tourist season. In addition, there are emissions from commercial kitchen exhaust at multiple locations surrounding the square. Public exposure includes a high density of pedestrian foot traffic.

Ozone measurements show normal background levels. There is no indication of significant additional ozone production due to human sources (vehicle or kitchen emissions), with ozone concentrations remaining at relatively low levels during the period of measurement.

$PM_{2.5}$ and $PM_{10}$ measurements show mostly low levels, with occasional spikes to higher levels ($PM_{2.5}$ spikes reach "medium" EPA 1-minute levels on four days). These spikes are likely related to both vehicle and commercial cooking emissions, with the blocks of higher PM emissions in the afternoon/evening (e.g. June 28 and 30) likely related to cooking emissions. The Cowboy Bar and restaurant is located directly across the street and generally upwind from the monitoring site. The slight increase in 24-hr average PM levels after July 6 is due to slight increases in regional wildfire smoke, corresponding to the start of the Martin Fire in northern Nevada along with additional fires in northern California.

Overall, normal levels of ozone and low levels of $PM_{2.5}$ and $PM_{10}$ were measured at the Town Square site, with spikes to slightly elevated PM concentrations usually occurring in the afternoon/evening hours.

### 3.2.3 Base of Teton Pass (Wilson, WY)

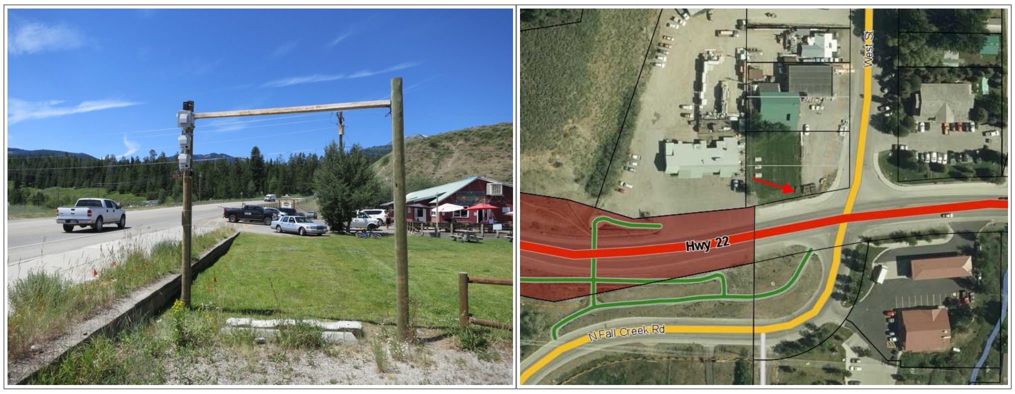



***Figure 3.13:*** *Air quality measurements were completed at the base of Teton Pass during July 10 – 24, 2018. The monitors were installed on a sign post on the north side of Hwy 22, on the east edge of the Stagecoach Bar lawn area.*

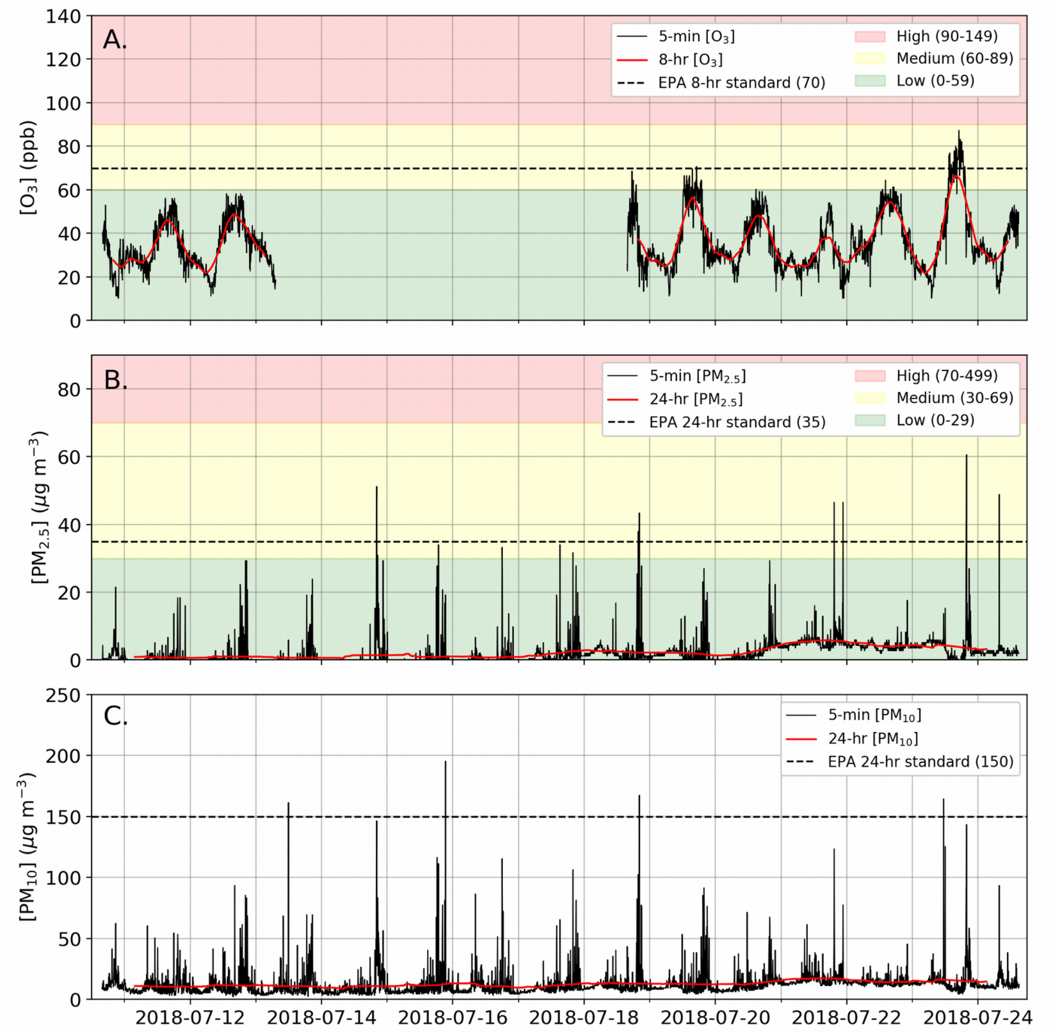



***Figure 3.14:*** *5-minute data for ozone (panel A.), $PM_{2.5}$ (panel B.), and $PM_{10}$ (panel C.) measured at the the base of Teton Pass. 8-hr and 24-hr averages (red lines) are calculated as a rolling mean from the 5-minute data. Colored bands for ozone and $PM_{2.5}$ show EPA 1-minute pilot categories.*

***Discussion: Base of Teton Pass (Wilson, WY)***

The Teton Pass site is characterized by vehicle traffic (car / truck / heavy truck) on 2-lanes (Hwy 22) through Wilson, WY. This area tends to have heavy “rush-hour” periods associated with eastbound (morning) and westbound (afternoon) commuter traffic. The speed limit is 25 mph, increasing to 45 mph on either side of the town of Wilson. There is concern in this area for potential brake emissions associated with eastbound traffic descending Teton Pass. This site is also in relatively close proximity to cooking emissions from the Streetfood Restaurant, located approximately 40 meters to the northwest.

Ozone measurements show mostly normal background levels. Highest ozone levels were reached the afternoon of July 23 with the peak 8-hr average (66 ppb) nearing the EPA 8-hr standard of 70 ppb. 5-minute data during the peak period ranges 60 – 87 ppb, in the “medium” EPA 1-minute category. This peak is likely due to increased photochemical production, with no clear evidence for increased emission of ozone precursors from vehicle-related sources. No ozone data exists during July 14 – 18 due to power issues at the site.

$PM_{2.5}$ and $PM_{10}$ measurements show overall low levels, with the largest spikes to higher concentrations occurring in the afternoon and evening hours. Due to the timing of these spikes (usually ~5:00 – 10:00 pm), the most likely source is cooking exhaust from the Streetfood restaurant, with minor additions from traffic on the highway and entering / exiting the Stagecoach parking lot. Conversation with cooks at Streetfood indicates that the kitchen grill is cleaned and shutdown by 10 pm each night. In addition, the terrain around the Stagecoach Bar prevents consistent wind direction, where rotors and eddies could disperse cooking emissions over the PM sensor. Figure 3.15 shows these evening spikes, along with small increases that are present during morning commuter traffic.

Another relatively smaller but significant source of PM is likely diesel truck emissions during acceleration onto Hwy 22 from West St. or Fall Cr. Rd. (e.g. Figure 3.16), or during acceleration westbound up Teton Pass. In addition, road dust re-suspended by vehicle traffic likely adds to measurable PM.

The slight increase in 24-hr average PM levels after July 20 is due to a slight increase in regional wildfire smoke, causing reduction in regional visibility.

There is no clear evidence for significant impacts from brake emissions at this site. 5-minute $PM_{2.5}$ levels mostly remain in the “low” EPA 1-minute category, with the 24-hr $PM_{2.5}$ and $PM_{10}$ averages well below the EPA 24-hr standards. In addition, the timing of the PM spikes does not correspond to heaviest commuter traffic, and in the case of brake emissions, we would expect to see more significant impacts during the morning commuter hours. Additional analysis related to brake emissions at this site are described in an accompanying white paper (“Brake Emissions at the Base of Teton Pass, WY”).

Overall, mostly normal levels of ozone and low levels of $PM_{2.5}$ and $PM_{10}$ were measured at this site.

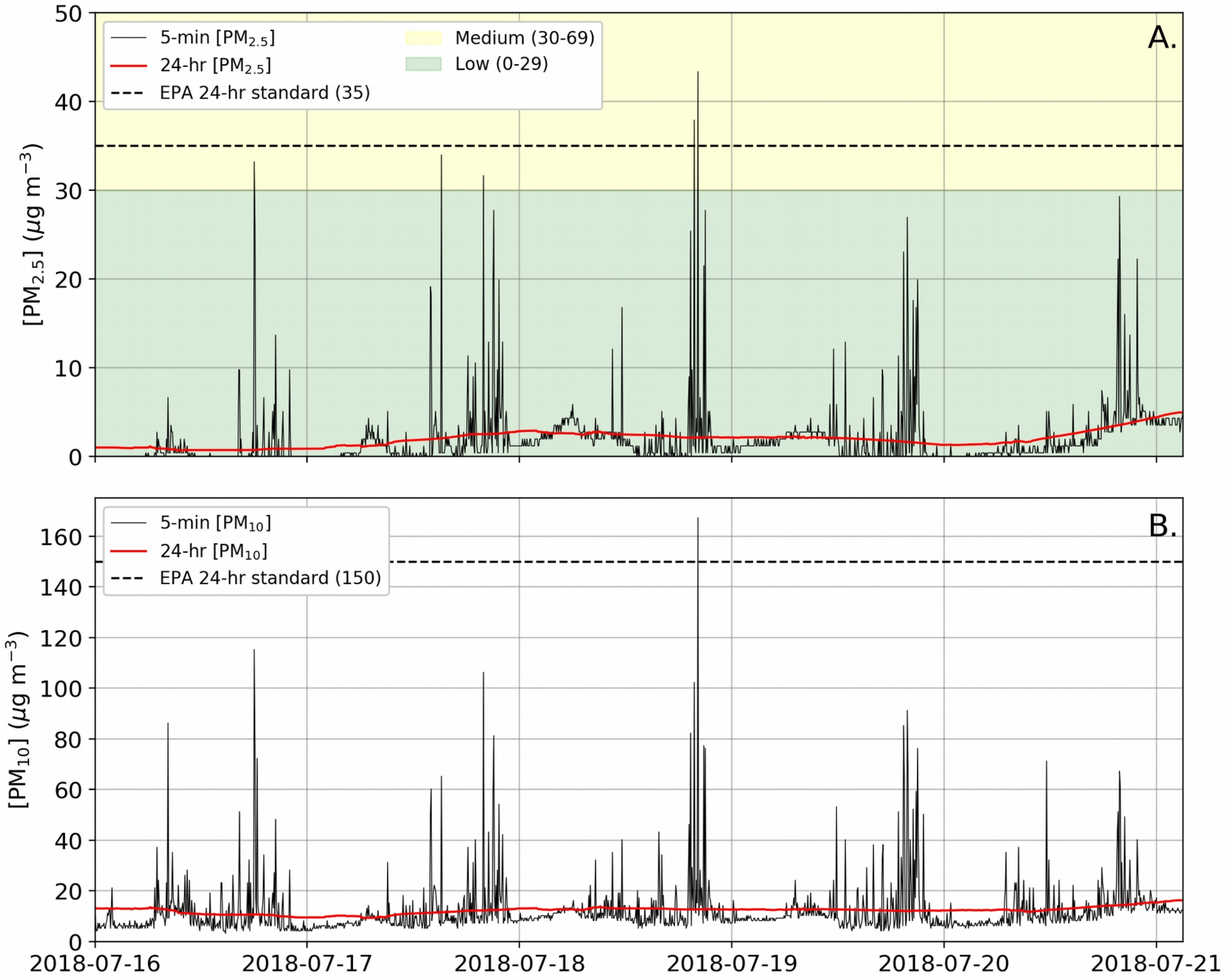



***Figure 3.15:*** *5-minute data for $PM_{2.5}$ (panel A.), and $PM_{10}$ (panel B.) measured at the base of Teton Pass (zoomed-in view from Figure 3.14). Slight increases in $PM_{2.5}$ from morning commuter traffic are visible, with spikes to higher concentrations dominating in the late afternoon and evening hours.*

***Figure 3.16:*** *Time-lapse camera image of diesel truck emissions on July 14, 2018.*

### 3.2.4 Intersection of WY 22 / US 89

***Figure 3.17:*** *Air quality measurements were completed at the intersection of WY 22 / US 89 during July 25 – August 6, 2018. The monitors were installed on a light post on the southeast corner of the intersection.*

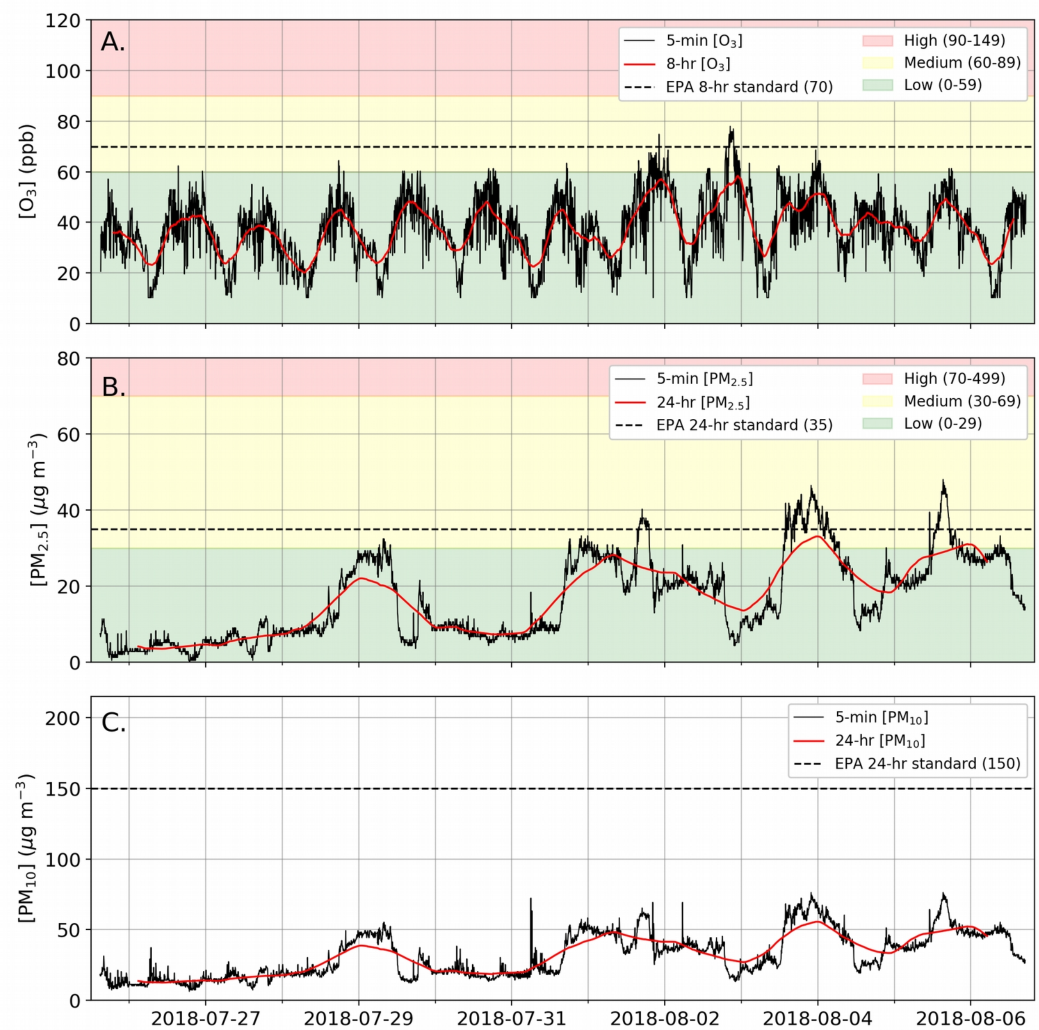



***Figure 3.18:*** *5-minute data for ozone (panel A.), $PM_{2.5}$ (panel B.), and $PM_{10}$ (panel C.) measured at the the intersection of WY 22 / US 89. 8-hr and 24-hr averages (red lines) are calculated as a rolling mean from the 5-minute data. Colored bands for ozone and $PM_{2.5}$ show EPA 1-minute pilot categories.*

***Discussion: Intersection of WY 22 / US 89***

The intersection of WY 22 / US 89 (also known as the “Y”) is characterized by vehicle traffic (car / truck / heavy truck) on 6 lanes (4 travel lanes plus 2 turning lanes) with a 35 mph speed limit. This area tends to have heavy “rush-hour” periods, but can see busy traffic throughout the day during summer months. Although there are some non-vehicle emission sources nearby such as commercial kitchens and gas stations, the monitoring site is not in close proximity to these sources.

Ozone measurements show normal background levels throughout the period of measurement, with consistent diurnal cycles driven by photochemical production. Peak 5-minute ozone levels occur on August 1 – 2 (60 – 75 ppb), with increased ozone persisting until near midnight on both days. Peaks in the 5-minute data reach “medium” EPA 1-minute categories and are not significantly higher than peak levels on other days in the measurement period. There is no clear evidence to attribute these increases to traffic-related emission sources.

***Figure 3.19:*** *Time-lapse camera image of traffic conditions on Aug 1, 2018, with haze from wildfire smoke visible in the background.*

$PM_{2.5}$ and $PM_{10}$ levels are predominantly influenced by regional wildfire smoke at this site. Multi-day increasing and decreasing trends (best demonstrated by the 24-hr average) are associated with wildfire smoke that began to increase in the valley during late July and early August. Starting July 27, wildfires in the Redding/Shasta, CA area became large and uncontained, adding to smoke from various other fires in the western U.S. Throughout late July and early August reduced visibility periodically prevented views of the Gros Ventre Mountains from Wilson.

Surprisingly, this site appears to have had limited impact to PM concentrations from vehicle-related emissions, despite being located at the busiest intersection in Teton County (Figure 3.19). PM measurements during July 25 – 28, while wildfire smoke was still relatively light, show very limited spikes to higher PM levels.

Overall, this site shows mostly clean air quality, with higher levels of PM concentration predominantly attributed to wildfire smoke.

### 3.2.5 Intersection of Virginian Lane / Snow King Ave.


***Figure 3.20:*** *Air quality measurements were completed at the intersection of Virginian Lane / Snow King Ave. during August 17 – 31, 2018. The monitors were installed on a utility pole on the northeast corner of the intersection.*

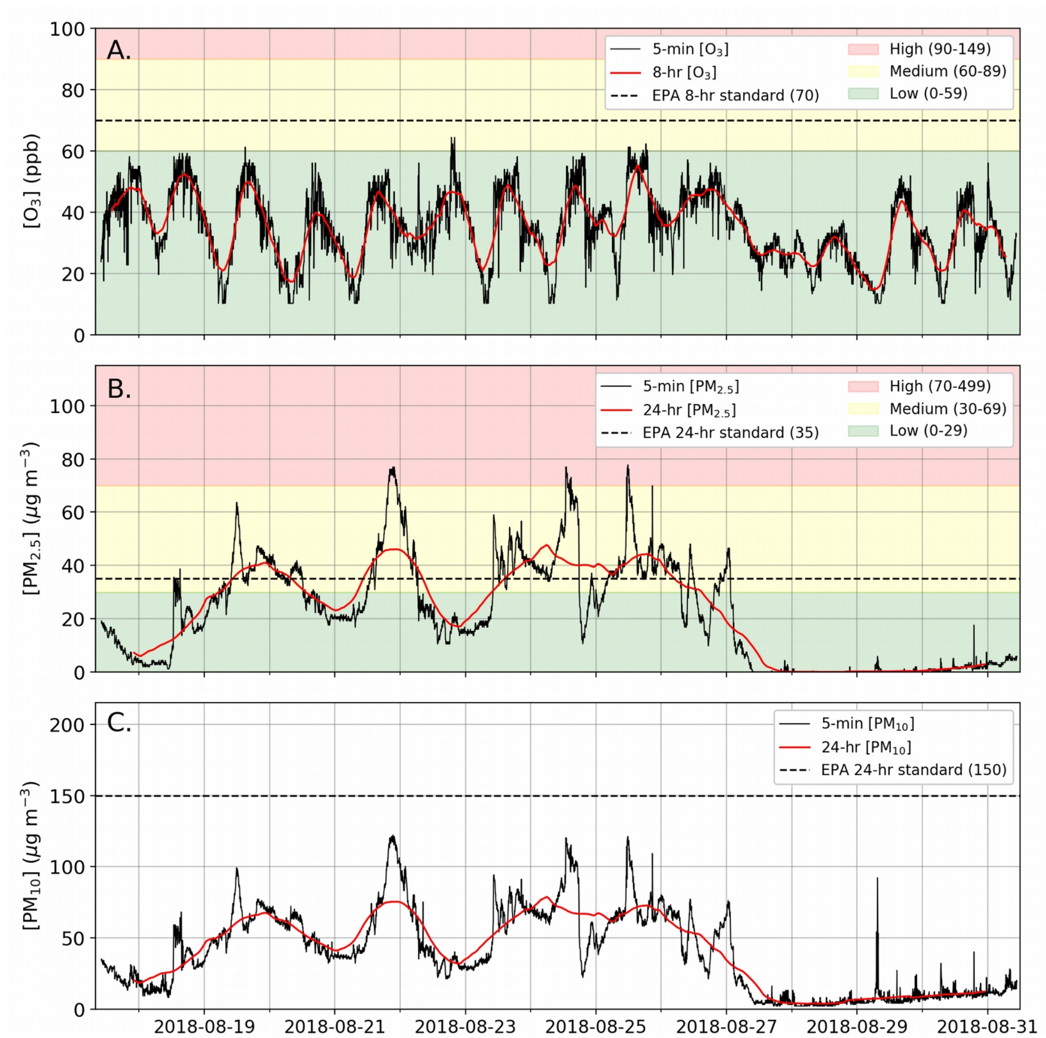



***Figure 3.21:*** *5-minute data for ozone (panel A.), $PM_{2.5}$ (panel B.), and $PM_{10}$ (panel C.) measured at the the intersection of Virginian Lane / Snow King Ave. 8-hr and 24-hr averages (red lines) are calculated as a rolling mean from the 5-minute data. Colored bands for ozone and $PM_{2.5}$ show EPA 1-minute pilot categories.*

**Discussion: Intersection of Virginian Lane / Snow King Ave.**

The intersection of Virginian Lane / Snow King Ave. is characterized by vehicle traffic (car / truck / heavy truck) on 2 lanes with a 25 mph speed limit. This area tends to have heavy "rush-hour" periods, but can see busy traffic throughout the day during summer months. There is moderate pedestrian traffic at this site related to the Teton County Library, located across Virginian Lane from the monitoring site.

Ozone measurements show mostly normal background levels throughout the period of measurement, with diurnal cycles driven by photochemical production. 5-minute ozone levels occasionally reach the "medium" EPA 1-minute category, but predominantly stay within the "low" category.

Similar to the WY 22 / US 89 site, $PM_{2.5}$ and $PM_{10}$ levels are predominantly influenced by regional wildfire smoke during this period, likely with limited addition from traffic-related sources. The period spanning August 19 – 27 were the smokiest days of the summer, with record-setting wildfire activity in northern California and throughout the western U.S. (Figure 3.22).

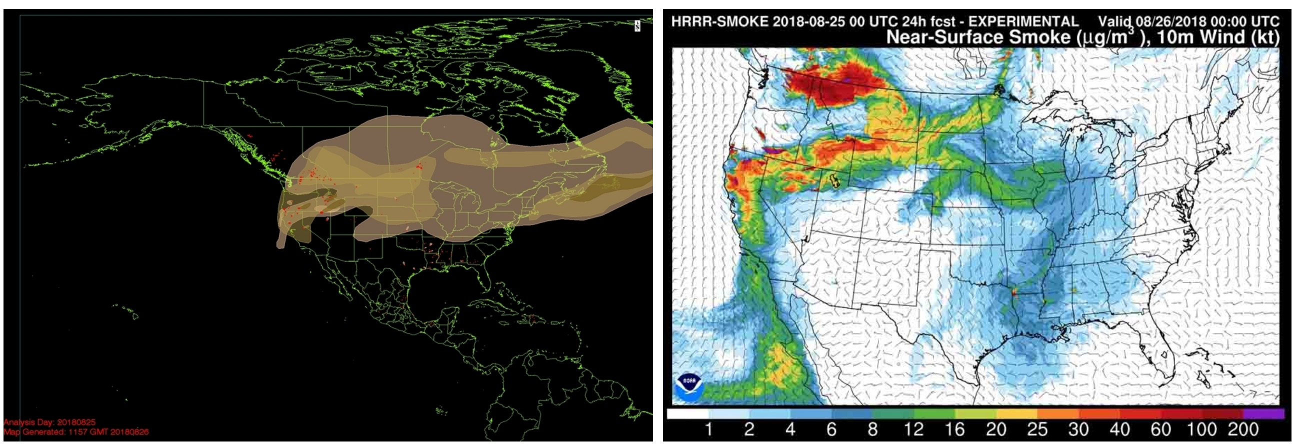



***Figure 3.22:*** *The NOAA Hazard Mapping System (HMS) smoke product (left) and the HRRR model near-surface smoke forecast (right) for August 25, 2018.*

The highest 24-hr average PM levels of the study were measured during this period, with Aeroqual measurements showing four days with $PM_{2.5}$ concentrations above the EPA 24-hr standard of 35 $\mu g/m^3$, and with 5-minute data reaching the "high" EPA 1-minute category (> 70 $\mu g/m^3$). The sharp drop in PM concentrations on Aug 27 is associated with a precipitation event (valley rain / mountain snow) that persisted throughout the day (Figure 3.23). In addition, there appears to be some correlation between ozone levels and PM trends (e.g. the decreasing trend on Aug 27), which has been demonstrated in previous work on the influence of fires on ozone concentration (Jaffe et al., 2008).

The WYDEQ Jackson Mobile 24-hr $PM_{2.5}$ data for this period shows lower levels than the Aeroqual 24-hr data, without exceedance of the 24-hr standard (Figure 3.23). Because wildfire smoke is regional in source, and should be relatively well-mixed in the near-surface boundary layer, we would expect PM concentrations measured at this site to be similar to those measured at the Jackson Mobile site on the Elk Refuge. This indicates that the corrections applied to the Aeroqual $PM_{2.5}$ data are likely not accurate for these higher concentrations, or the correction may not be a linear relationship throughout the range of data. Collection of co-location data over a larger range of concentrations and over a longer period of time would likely improve the mismatch between Aeroqual and WYDEQ 24-hr $PM_{2.5}$ data.

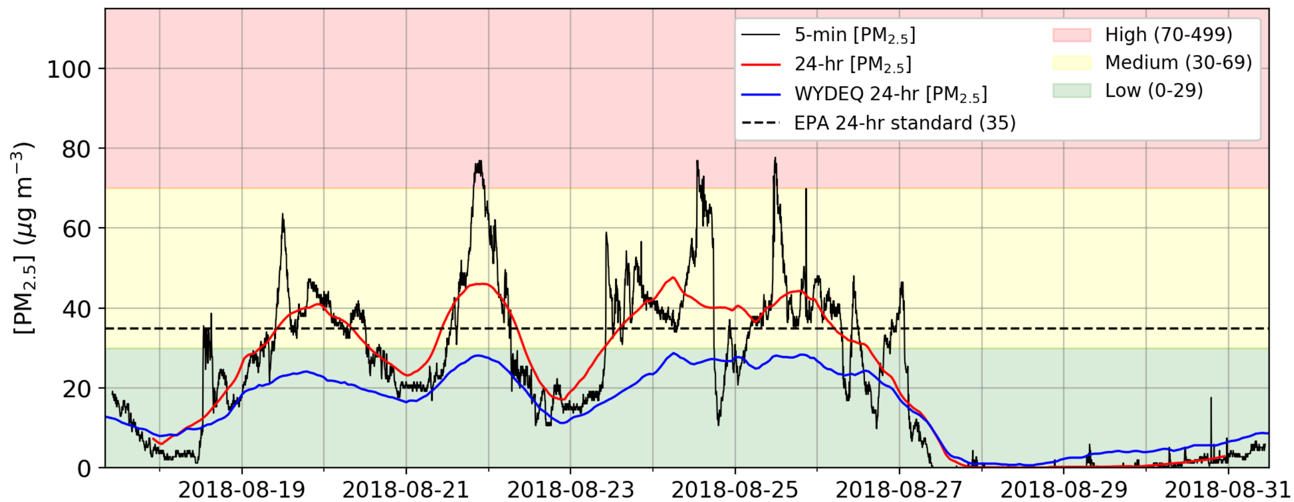



***Figure 3.23:*** *5-minute data for $PM_{2.5}$ measured at the the intersection of Virginian Lane / Snow King Ave. during Aug 17 – 31, 2018. The Aeroqual 24-hr average (red line) is calculated as a rolling mean from the 5-minute data. The WYDEQ Jackson Mobile 24-hr $PM_{2.5}$ data during this period shows slightly lower concentrations (blue line). Colored bands for ozone and $PM_{2.5}$ show EPA 1-minute pilot categories.*

Overall, measurements at the Virginian Lane / Snow King Ave. site show normal levels of ozone, and increased concentrations of PM due to heavy regional wildfire smoke. The period spanning August 19 – 27 showed the highest 24-hr $PM_{2.5}$ concentrations of the summer, with levels near or above the EPA 24-hr standard (depending on data source). 5-minute data remained in the “medium” EPA 1-minute category for multiple days, with several multi-hour periods at “high” levels. These prolonged periods of increased PM concentrations present the most hazard to public respiratory health.

# 4. Conclusions

Please see the Executive Summary for an overview of the project results.

***Areas for improvement and future study:***

The following list includes identified shortcomings and areas for potential improvement which could be addressed with future monitoring efforts:

- **Lack of nitrogen dioxide ($NO_2$) measurements.** Unfortunately, the Aeroqual S500 $NO_2$ data proved inaccurate despite attempts at several data correction techniques. Frequent field calibration with calibration gas may potentially address this issue. $NO_2$ is an EPA criteria pollutant that would be valuable for assessing the impact of vehicle emissions to air quality, both as a direct pollutant and as a precursor to ozone production.
- **Instrumentation.** Overall, the Aeroqual S500 ozone and $PM_{2.5}/PM_{10}$ sensors performed well, and demonstrated data that could be reliably corrected using co-location techniques. In particular, the Aeroqual ozone sensor showed high accuracy with co-location results over a large range of air temperatures. However, these monitors are intended for short duration “hot spot” checking rather than extended deployment. After this study had completed planning, funding, and instrumentation purchase, Aeroqual made available a new “micro” air quality monitor called the “AQY1”. This monitor could be well-suited for future studies, and is an “all-in-one” measurement platform for ozone, $PM_{2.5}/PM_{10}$, and $NO_2$. In addition, this monitor uses a different $NO_2$ sensor technology which may be more reliable than the S500 $NO_2$ sensor. Although this study was budget-restricted to low-cost portable monitors, higher accuracy monitors are available from Aeroqual and other manufacturers which could be deployed at locations of concern for higher emissions.
- **Increased co-location data.** Although the co-location data collected at the WYDEQ Jackson Mobile site in August and September, 2018 was sufficient to provide calibration for the purposes of this study, increased co-location measurements would add additional confidence to data accuracy. Longer duration co-locations over greater ranges of concentration would benefit future studies. In particular, co-locations scheduled both before and after the study would allow assessment of instrument drift.
- **Analysis of weather data.** Due to lack of time and funding, minimal effort was dedicated towards analysis of near-surface weather patterns. For detailed analysis of the impact of potential emission sources, trends in air temperature, relative humidity, wind speed, and wind direction should be further analyzed.

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