Summary Report
For the
Juneau Saturation
Study
April – October 2019

DRAFT

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Air Quality Division

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&
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Executive Summary

The Department of Environmental Conservation (DEC) Division of Air Quality conducted a study from 4/19/19 to 10/7/19 in the downtown Juneau area to assess air quality impacts from the cruise ship industry. The study was initiated to address increasing public complaints regarding cruise ship emissions over the previous two years.

DEC designed a saturation study using a tightly-spaced grid of low-cost fine particulate matter ($PM_{2.5}$) monitors and passive sulfur dioxide (SO_2) samplers throughout downtown Juneau and 'the flats' in order to identify areas of high, medium and low impact. The Air Monitoring and Quality Assurance Program (AMQA) of the Air Quality Division chose the PurpleAir PA-II PM Sensor (https://www.purpleair.com/sensors) for measuring particulate matter and Ogawa Passive samplers for SO_2 measurements.

Figure ES-1. Cruise ship monitoring PurpleAir site locations. Red pins are PA site locations and green stars indicate sites used as SO2 sampling sites.

The AMQA Program selected pollutants for the study that have established National Ambient Air Quality Standards (NAAQS) for protection of public health. However, because the equipment used in the study does not meet the regulatory requirements needed to officially compare to the NAAQS, the Division is only able to qualitatively conclude that pollutant concentrations measured during the study were below the NAAQS. The main reason for selecting $PM_{2.5}$ and SO_2 for measurement is that low cost commercially available sampling

technology and standard sampling protocols exist, and the pollutants are good indicators of cruise ship emissions.

Results

Based on the particulate matter measurements from the Purple Air (PA) monitors, the air quality in Juneau during the study period can be considered as "Good" using the EPA Air Quality Index (AQI) classifications, with only a few days during wildfire smoke events considered as "Moderate" to "Unhealthy for Sensitive Groups".[1] While there is strong evidence cruise ships had short term impacts on air quality in downtown Juneau, there is no evidence to suggest the cruise ship industry air quality impacts in Juneau during the 2019 cruise ship season would have led to 24-hour $PM_{2.5}$ violations of the NAAQS.

Emissions in downtown Juneau did not originate from one consistent source during the study period. Besides cruise ship emissions, slash burning, outdoor food vendors, and residential activities had noticeable short-term impacts on air quality at sites throughout downtown Juneau. With different cruise ships in port every day, ships entering and leaving the port at different times, and inconsistent meteorological conditions, each study day was assessed independently for local air quality impacts. Webcam footage and data collected from downtown Juneau meteorological stations were used to locate likely sources during periods of elevated $PM_{2.5}$ concentrations observed at the PA sites. In addition to local sources, Juneau also experienced an above average influx of wildfire smoke from Western Canadian wildfires during the 2019 summer season. Each day during the study period was closely scrutinized to determine sources of air quality impacts and what sites or group of sites seemed to be the most affected.

Rather than discuss every day during the study period, DEC chose to detail our data analysis process by conducting a case study of the data collected on August 30th and 31st. These days represent a period in which cruise ship emission air quality impacts lasted for many hours each day. Light winds coming from southern directions blew emissions towards Juneau from multiple ships each day leading to increases in $PM_{2.5}$ concentrations across all sites, with greater spikes in $PM_{2.5}$ concentrations resulting from ships coming into port and leaving port. Webcam footage and meteorological data assisted in identifying emissions sources. In addition to cruise ship emissions, a large slash burning fire was identified as an emissions source leading to a sharp 1-hour increase in $PM_{2.5}$ concentrations at several sites. Large spikes in $PM_{2.5}$ concentrations affecting only one site were also observed during the case study and were likely the result of recreational activities such as grilling or bonfires.

During the six-month study, emissions events from cruise ships were typically brief and only lasted one or two hours. Although hourly peak $PM_{2.5}$ concentrations from cruise ship emissions

[1] AQI classifications are based on more accurate regulatory grade sampling equipment but are often used in the context of sensor measurements to describe air quality in general terms.

do not appear to cause sharp peaks like those observed in localized events, the PA grid was clearly able to detect air quality impacts from ship emissions.

Conclusion

Assessing short term air quality impacts from cruise ships in Juneau can be difficult due to varying emissions sources and meteorological conditions. Additionally, the Ogawa passive SO_2 samplers were not sensitive enough to detect short term increases in SO_2, which may have further helped to identify diesel emissions from ships. During the study period however, short term emissions plumes from cruise ships were detected by the PA monitors in the form of widespread elevated $PM_{2.5}$ concentrations affecting multiple sites simultaneously.

Early in the 2019 cruise season, cruise line companies worked together to reduce their impact on local air quality[2]. Two of the strategies used for reducing emissions were reducing idle times in the harbor and switching to a low sulfur marine fuel while in port. While it is difficult to compare Juneau's 2019 cruise ship related air quality impacts to previous year's impacts as no monitoring data exists for 2018, the 2019 season had less public complaints[3] than the previous two years.

Data collected did not identify a single maximum impact location in downtown Juneau or the flats that should be used for a follow-up study. But the data indicated that various parts of the downtown area and the flats were impacted by short term plumes, depending on weather conditions.

The PurpleAir saturation study provided information about areas of Juneau affected, and demonstrated the need to better assess short term impacts with at least 1-hour resolution. Furthermore, meteorological data from nearby meteorological stations and webcam footage proved to be valuable in identifying air impact sources. The Ogawa passive SO_2 samplers were unable to detect concentrations of SO_2 over short time periods needed to assess emissions plumes.

Next Steps

DEC has ordered several survey grade sensor pods capable of measuring PM, carbon monoxide (CO), nitrogen oxides (NO_x), and SO_2 to deploy at multiple locations in downtown Juneau, with at least one site in the elevated area and one site in the flats area. The new sensor pods will be assessed for accuracy and precision in a similar manner to the PurpleAir sensors before being installed in the community. While the new equipment is not regulatory grade, the addition of gaseous monitoring combined with onsite meteorological data will provide better and more detailed information for source identification. The new CO, NO_x, and SO_2 sensor technology allows for short term resolution with one hour averaging and will not only be capable of

[2] https://www.juneauempire.com/news/cruise-ship-complaint-numbers-for-this-year-may-surprise-you/
[3] https://dec.alaska.gov/media/19814/2019-cpvec-air-annual-report-final.pdf

measuring short term air quality impacts, but will also help to evaluate emission plume characteristics to determine possible sources.

With the new monitoring equipment and continued use of available webcam footage, DEC expects to better assess all emissions sources affecting the downtown area, and provide more accurate information regarding year to year air quality impacts from cruise ship emissions and other emission sources.

The saturation study only addressed air quality impacts at the port of Juneau. Air quality impacts from cruise ships at other port communities may also need to be addressed. While emissions mitigation plans put in place in 2019 by cruise line groups specifically for Juneau seemed to be effective, the impacts from cruise ship emissions at other Southeast Alaska port communities likely vary by location and remain unclear.

Introduction

During the 2019 Alaska summer cruise ship season, the Department of Environmental Conservation (DEC) Division of Air Quality conducted a study in the downtown Juneau area to assess air quality impacts from the cruise ship industry. The study was initiated to address increasing public complaints regarding cruise ship emissions over the previous two years.

The Air Monitoring and Quality Assurance Program (AMQA) conducted a saturation study in Juneau prior to and during the summer cruise season of 2019 focusing on the overall ambient air quality. The objectives of the Juneau saturation study were:

- to address ambient air quality complaints centered on cruise ship industry emissions;
- to determine which areas of downtown Juneau are most affected (maximum impact locations); and
- to assess if the scale in terms of frequency, duration, spatial variability and severity of these impacts has the potential to significantly affect public health and/or violate Clean Air Act air quality standards.

AMQA conducted sampling from 4/19/19 to 10/7/19. This report summarizes the findings of the six-month long study.

Background

Public interest in air quality impacts from cruise ship emissions has led to two previous studies in Juneau directed at measuring the criteria pollutants sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and fine particulate matter (particulate matter with an aerodynamic diameter of 2.5 micrometer or less, i.e. $PM_{2.5}$). Criteria pollutants are pollutants for which the U.S. Environmental Protection Agency (EPA) has developed health based standards, called the National Ambient Air Quality Standards (NAAQS). The 1995 study focused on SO_2 data collected from two sites from May through September. The study initiated in 2000 collected SO_2 and $PM_{2.5}$ data from three sites and NO_2 data from one site mid-August through September. This study was extended from approximately May 2001 through the end of the year. The results from both studies led to the same conclusions: air quality in the downtown Juneau area was considered good and pollutant concentrations were far lower than the NAAQS.

Over the past few years growing numbers of cruise ships and passengers visiting Alaska have increased public concerns about their potential impacts on port communities. 2017 and 2018 saw dramatic increases in complaints regarding cruise ship emissions and potential air quality degradation. The increase in complaints coincided with the increased use of Exhaust Gas Cleaning Systems (EGCSs, or Scrubbers) by cruise ships while in port. EGCSs are designed to

extract sulfur oxides from exhaust gas allowing vessels to achieve compliance with federal and international regulations while continuing to burn fuel with higher levels of sulfur.[4]

Since the early 2000s EPA has conducted several reviews of the NAAQS as required by the Clean Air Act. These reviews are intended to determine if the standards are still protective of public health and the environment. As a result of these reviews, EPA has either strengthened existing standards or created new ones. The 24-hour average $PM_{2.5}$ standard was changed from 65 $\mu g/m^3$ to 35 $\mu g/m^3$. For SO_2 and NO_2, EPA established one hour standards. These new short term standards are much more sensitive to localized pollution sources than the previous 24-hour average or annual average standards. The 2019 study was designed with these new standards and the one hour averaging period in mind.

Study Design

Downtown Juneau is located on Gastineau Channel which is oriented northwest to southeast and bordered by mountains on both sides. The local topography divides the residential areas of Juneau into a low lying "flats" area and a residential area at a higher elevation on the main hill of Juneau. The cruise ship docks and anchorages are located directly southeast of Juneau so that when winds blow from southern directions, the cruise ship emissions are transported to the downtown area. Air pollution levels will vary depending on meteorological conditions with higher levels expected to occur during clear, low wind periods and lower levels seen when rain and/or higher winds disperse air pollutants.

With multiple cruise ships arriving, positioning and departing almost continuously during the prime cruise ship season, it is impossible to pinpoint a main location of emission sources as is possible for stationary sources, such as power plants. The impacts will depend on the local meteorology, the number of ships docked or maneuvering around the docks, and the ship emissions. These emissions in turn depend on the various ship emission sources, their activity levels and type of fuel. Surrounding activities in the community also can contribute to localized pollution. Variability in weather and the emission source are the dominating factors on whether an area is impacted and for how long.

All these contributing factors make it difficult to predict the best location for a monitoring site without taking actual measurements on the ground as part of a short term study. These studies are usually saturation studies, intended to determine the locations of maximum impact in the community and to assess the frequency and severity of the impacts. A saturation study is a type of investigation that utilizes many samplers in a small geographic area over a limited amount of time. Saturation studies are often the first step in any air quality monitoring assessment. Saturation studies usually employ low cost sampling equipment to determine initially if an air

[4] https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-amendments-related-global-marine-fuel

quality problem exists or if the problem reaches the levels that warrant a more in depth and long term monitoring project.

Cruise ship air emissions consist predominantly of diesel exhaust. There are no direct measurement methods for diesel exhaust or human health standards. Instead diesel emissions contain a multitude of organic and inorganic pollutants, both in gaseous and particulate form. One of the gaseous pollutants in diesel is sulfur dioxide (SO_2). Fine particulate matter can also be used as a tracer, representing diesel plumes. Both of these pollutants have standards against which measurements can be compared.

The DEC saturation study used a tightly spaced grid of low-cost $PM_{2.5}$ monitors and several passive SO_2 samplers throughout downtown Juneau and the flats in order to identify areas of high, medium and low impact. New sensor[5] technology has greatly improved in accuracy and precision for particulate matter, but is still lagging behind for SO_2 and Nitrogen Dioxide (NO_2). Alternatively, other low cost sampling methods exist like passive samplers. The advantage of passive samplers is that they do not require electrical power and are less expensive and time intensive to operate than conventional gaseous analyzers. Currently, the passive sampling technology for SO_2 is more accurate with shorter collection time requirements than for NO_2. AMQA therefore focused on testing the SO_2 sampling method.

To aid in the identification of diesel sources contributing to the measurements, AMQA identified five meteorological sites around the study area. The sites were part of the MesoWest network. MesoWest is operated by the University of Utah Atmospheric Science Department. Additionally, AMQA used images and videos from publicly available webcams[6] to corroborate pollution events that may have been caused by cruise ship emissions. The data from the air sensors were analyzed with the data from the meteorological sites, along with the number of ships in the area at the time, their activity, the video observations, as well as any other available information about other potential sources.

AMQA engaged with the community for selection of appropriate sampling sites. Staff initially reached out to gather general information of where complaints had been registered in the previous years and compiled a list of potential volunteer study participants. At a public meeting in February 2019, the residents were able to identify areas of interest on a map and sign up to allow AMQA to place a sampler on their property. Ultimately, AMQA used a mix of public and private properties in downtown and the flats to create a grid-like sampling network. Sensors were installed prior to the arrival of the first cruise ship to establish a background and ran continuously from mid-April through early October. The map in **Figure 1** shows the sampler network of 22

[5] The term sensor is often used for lower cost, portable and generally easier to operate monitors than regulatory grade monitors used in the U.S.
[6] http://webcams.thesnowcloud.com/

$PM_{2.5}$ and 11 SO_2 sampling sites.

Figure 2. Cruise ship monitoring PurpleAir site locations. Red pins are PA site locations and green stars indicate sites used as SO2 sampling sites.

Monitoring Methods

Equipment

For this saturation study, AMQA chose the PurpleAir-II PM Sensor for $PM_{2.5}$ measurements (https://www.purpleair.com/sensors). The PurpleAir (PA) sensor uses a fan to draw air past a small laser. The reflections of the light from the particles in the air are counted. The PA-II is equipped with two sensors which measure and report particle concentrations in six sizes between 0.3µm and 10µm diameter. Each sensor measures a particle count every second and reports an averaged value every 80 seconds[7]. Temperature, relative humidity and pressure values are also recorded. The sensors are calibrated by the manufacturer to associate a particle size with particle mass and estimate total mass for $PM_{1.0}$, $PM_{2.5}$ and PM_{10}. Readings are then uploaded to a cloud network after every measurement where they are stored for download and display on the PurpleAir map.

The PA sensors were equipped with a cellular hotspot which reported the instantaneous reading to the PurpleAir website. Data were displayed on the PurpleAir map website in real time. AMQA

[7] https://www.atmos-meas-tech-discuss.net/amt-2019-396/amt-2019-396.pdf

created a second interactive map posted on the Air Quality website to display the hourly averaged data. The PA sensors are also equipped with a SD card that stores all data. These cards were downloaded to the state network periodically to ensure no data was lost in case of Wi-Fi failure. Nineteen of the twenty-one sites used a mobile Wi-Fi hotspot unit to upload the data to the PurpleAir online map. The other two sites used a connection to a local Wi-Fi network. The instrument properties and field set-up are detailed in Appendix A.

To protect the electronics from the elements for an outdoor installation, AMQA used weatherproof junction boxes. **Figure 2** and **Figure 3** show pictures of a typical PA installation.

Figure 3. Example of PurpleAir site set up. The PurpleAir unit attached to the junction box is indicated by the purple arrow.

Figure 4. PurpleAir unit and Ogawa SO2 passive sampler attached to the junction box housing.

AMQA selected the Ogawa samplers for SO_2 measurements. The Ogawa passive SO_2 samplers were collocated at 11of the PM sites, with one site housing two SO_2 samplers for precision information.

The small footprint of the samplers makes them easy to place in the field. A pre-coated collection pad is placed inside a weatherproof sampling cartridge and installed outside. As air moves through the sampling cartridge over the pad, the SO_2 molecules react with the chemical on the pad and are captured. After the desired exposure time, the collection pad is removed, the SO_2 is extracted into an aliquot of ultrapure water with hydrogen peroxide, prepared for shipment and analyzed in a lab. Typical exposure times range from 1 week for clean areas to 1 day for more polluted locations (https://ogawausa.com/).

The samplers were exposed to ambient air for at least 48 hours and up to 72 hours. The lab analysis showed that with those exposure times, concentrations were close to or below the detection limit.

Comparison to the National Ambient Air Quality Standards

While AMQA selected pollutants for the study ($PM_{2.5}$ and SO_2) that could be compared to the NAAQS, the equipment used in the study does not meet the specifications to fulfill federal monitoring requirements and officially compare to the NAAQS. However, the Division is able to qualitatively conclude that pollutant concentrations measured during the study were below the NAAQS. The main reason for selecting these pollutants for measurement is that low cost commercially available sampling technology and standard sampling protocols exist.

EPA revised the fine particulate matter standard in 2012, resulting in two standards, a 24-hour average standard of 35 microgram per cubic meter (35 $\mu g/m^3$) and an annual average standard of 12 $\mu g/m^3$. Cruise ship emissions include fine particulate matter but due to emission patterns, topography and local wind patterns during the cruise ship season in Juneau, AMQA considered it unlikely at the onset of the study that the impacts in downtown Juneau were severe and consistent enough to exceed a 24-hour standard at any given location. The expectations were that cruise ship plumes would create short term elevated values in the range from minutes to several hours, but not average out to levels that would exceed the standard. The PurpleAir sensors were selected to measure these short term spikes in $PM_{2.5}$, with the main focus on determining the frequency of elevated hourly concentrations and the locations most likely to receive repeated impacts, and the additional goal of identifying a future monitoring site.

EPA revised the SO_2 standard in 2010 creating a new 1-hour standard of 75 parts per billion (75 ppb). The passive SO_2 samplers require an exposure time from 1 day to 1 week and are not sensitive enough to provide data for hourly averages. While sensor technology exists for SO_2, none have the required precision, accuracy, and sensitivity at a cost that would have allowed AMQA to include them in this study. Therefore, the intent was to see if AMQA could detect elevated SO_2 emissions on days with multiple cruise ships in port compared to the background levels prior to the season.

Quality Assurance Analysis

Initial PA Unit Collocations

Upon initial receipt of the PA units, DEC conducted an indoor collocation to assess sensor performance and gain an understanding of operational requirements. Indoor particulate concentrations measured during the collocation period were low, but the sensors operated correctly and indicated similar trends.

After the initial indoor collocation of the PA units, DEC performed an outdoor collocation in Anchorage, AK. The data from the 8-day collocation period was collated into 5-minute averages and a mean of the concentrations recorded by all of the sensors in each 5-minute period was calculated. Average 5-minute concentrations ranged between 0 and 39 $\mu g/m^3$. The performance of each sensor was evaluated by calculating linear correlation statistics between data from each sensor and the mean concentration. The multiplicative bias amongst the individual sensors ranged between 0.87 and 1.12, the additive bias between -0.35 and 0.97 $\mu g/m^3$. The r-squared statistics ranged between 0.985 and 0.999, where an r-squared value of 0.95 is a very strong positive correlation and an r-squared value of 1 is a perfect correlation. The PA units containing pairs of sensors displaying the greatest degree of correlation to the mean concentrations were reserved for quality control purposes during the study including the mobile audit unit and the two collocated DEC building units.

Collocations of PA Units against the Floyd Dryden BAM

After arrival in Juneau, all PA units were collocated outdoors against the Federal Equivalent Method (FEM) $PM_{2.5}$ Beta Attenuation Monitor (BAM) at the Juneau Floyd Dryden site to obtain an initial study correlation over a five-day period in April. The data was collated into one-hour time periods to allow for comparison to the one-hour sample period of the BAM. While the PA units continued to show good correlation amongst themselves, they demonstrated poor correlation with the BAM. A linear correlation between the BAM and the mean of the PA sensors showed a multiplicative bias of 0.60, and additive bias of 4.1 µg /m3, and an r-squared statistic of 0.392. While the PA units often recorded similar concentration trends, they failed to demonstrate a response to several periods of elevated concentrations recorded by the BAM, which caused the low multiplicative bias. The maximum concentration recorded by the BAM during the course of the collocation was 12.0 µg/m3. This limited range of concentrations was not representative of the range of concentrations recorded throughout the study period.

The Audit PA device was collocated against the Floyd Dryden BAM to assess PA performance in comparison to the BAM at elevated concentrations during a seven-day period impacted by wildfire smoke beginning on July 9th. The maximum 1-hour concentration recorded by the BAM was 28.0 µg/m3. The multiplicative bias between the PA unit and BAM concentrations was 2.26, the additive bias was -1.32 µg/m3, and the r-squared value was 0.918. The PA unit and BAM

concentrations trends were well correlated, but over-reported by the PA unit. The PA unit reported values more than double those reported by the BAM at elevated concentrations.

The PA units were collocated against the Floyd Dryden BAM again at the end of the sampling season for 13 days in October. During this collocation, the mean of the PA sensor one-hour concentrations had a multiplicative bias of 1.35, an additive bias of -0.78 µg/m3, and an r-squared value of 0.525. Unlike the initial collocation, the PA units routinely showed a response to concentration variations recorded by the BAM, but frequently over-reported concentrations in comparison to the BAM, especially during periods of elevated concentrations.

Due to the difference between correlation statistics during the three periods of collocation at the BAM, DEC did not apply a correction factor to the entire PA dataset to normalize it to the BAM during data analysis. However, a correction factor was applied during the peak in wildfire smoke in an analysis to determine if PA sensors and the BAM were observing similar concentrations. **Figure 4** shows the linear correlations from the three PA Audit vs BAM collocation periods. The initial, wildfire-impacted, and final collocations each have significantly different correlation statistics.

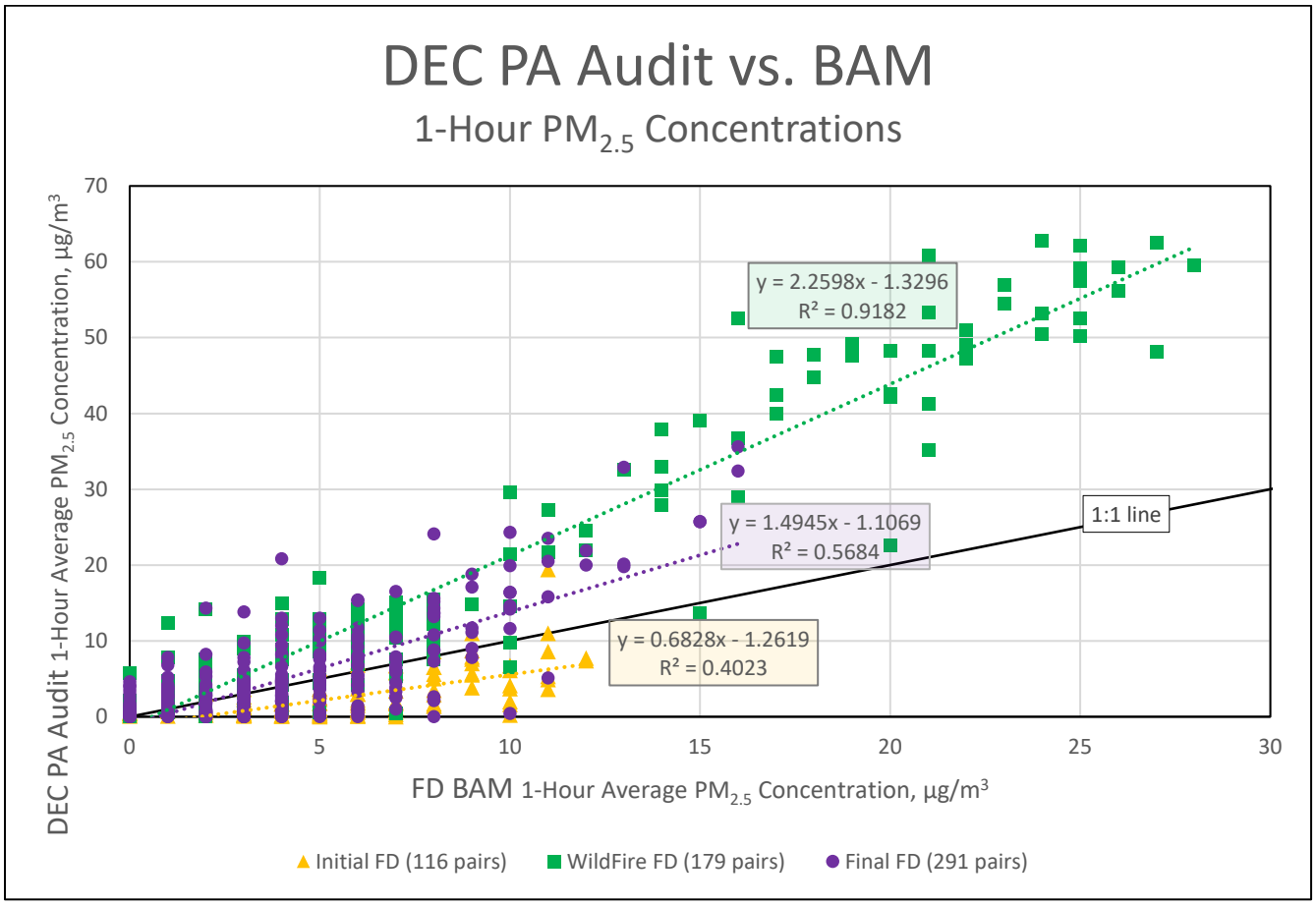

Figure 5. Linear correlations for three Audit – BAM collocations. Yellow is the initial collocation prior to the study period, green is during the peak wildfire event, and purple is a final collocation after the study period.

Collocated PA Units at the DEC Building

DEC collocated two PA units at the DEC Building, DEC Building 1 and DEC Building 2. They were used to determine the performance and comparability of PA units throughout the study period. The two PA units maintained excellent correlation throughout the study period, indicating that concentrations recorded by PA units are directly comparable to each other **(Figure 5)**. This confirmation of comparability indicated the PA units did not experience drift throughout the study period and that data could be compared between PA units. This is particularly important for a saturation study where the focus is on inter-comparison of the samplers within the network rather than absolute measurements.

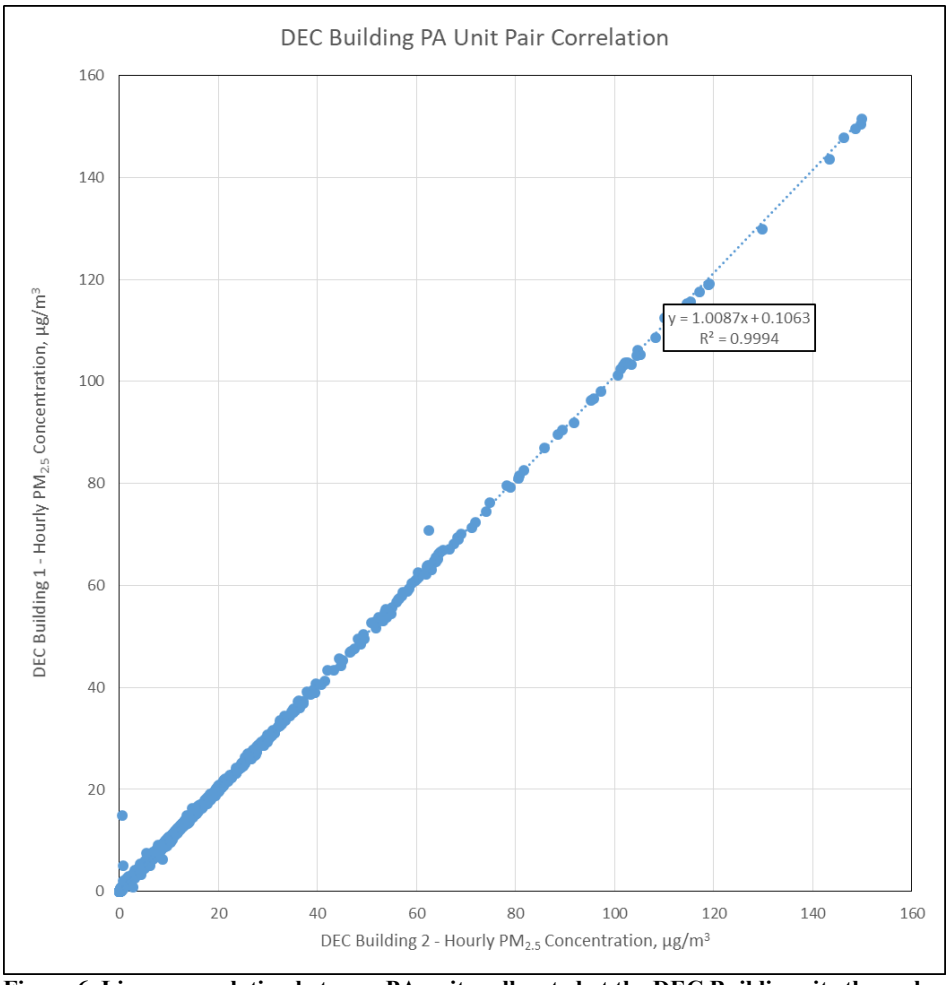

Figure 6. Linear correlation between PA units collocated at the DEC Building site throughout the study period.

Transient 'Audit' PA Monitor

DEC employed one PA monitor as an 'audit' device to assess sensor performance throughout the study and determine the validity of aberrant site readings. The audit monitor was transiently deployed to 11 sites and collocated with the Floyd Dryden BAM midseason during a portion of the wildfire-impacted period. As seen in Table 1, comparisons of hourly concentrations recorded by the audit and corresponding site PA monitor during collocation events showed excellent correlation over a wide range of concentrations.

Table 1. Results of PA site audits using the transient PA audit unit.

Site	Slope	Intercept	r^2	Total Hours	Maximum Concentration	Minimum Concentration	Standard Deviation
6th & Park St	0.995	-0.04	0.991	44	11.8	0.0	1.8
City Hall	1.015	0.09	0.994	66	34.2	0.0	5.9
N. Douglas Hwy	0.946	-0.19	0.993	67	7.5	0.0	1.3
W 8th & Calhoun Ave	1.018	0.03	0.999	76	19.7	2.8	3.7
12th & C	1.076	-0.32	0.997	68	18.1	4.7	2.7
Downtown Library	0.997	-0.04	0.995	172	42.3	0.0	6.4
Glacier Ave & Willoughby Ave	0.962	0.06	0.995	95	7.7	0.2	1.7
Customs	1.013	-0.06	0.999	127	27.0	0.7	4.5
City Museum	0.981	-0.80	1.000	188	140.0	9.7	32.1
DEC Building 1	1.005	-0.04	0.997	191	36.9	0.0	3.1
DEC Building 2	1.002	-0.13	0.997	189	37.1	0.0	3.1
NOAA Subport	0.951	0.99	0.980	938	29.6	0.4	4.1

Recommendations for future PA studies

DEC would recommend collocating a PA unit with any reference standard throughout a study period. While the PA unit Plantower sensors showed good correlation amongst themselves throughout all concentration ranges, DEC was unable to determine an appropriate correlation with the Federal Equivalence Method monitor that could be applied to the PA dataset. This prevented a direct comparison of concentrations between the Downtown sites and the Mendenhall Valley Floyd Dryden site. A PA unit at Floyd Dryden would have allowed a direct comparison between the Downtown study area and the Floyd Dryden site, which DEC could have treated as a background site. This could have provided more insight into possible air quality impacts of cruise industry activities that occur mainly in the Downtown study area which are unlikely to impact the Floyd Dryden site.

Results

Based on the particulate matter measurements from the PA, the air quality in Juneau during the study period can be considered as "Good" using the EPA Air Quality Index (AQI) classifications, with only a few days during wildfire smoke events considered as "Moderate" to "Unhealthy for Sensitive Groups".[8] While there is strong evidence cruise ships had short term impacts on air quality in downtown Juneau, there is no evidence to suggest the cruise ship industry air quality impacts in Juneau during the 2019 cruise ship season would have led to 24-hour $PM_{2.5}$ violations of NAAQS.

Emissions in downtown Juneau did not originate from a consistent source during the study period. In addition to cruise ship emissions, slash burning, outdoor food vendors, and residential activities had noticeable short term impacts on downtown Juneau air quality. $PM_{2.5}$ data collected from downtown Juneau PA sites can be difficult to interpret, and distinguishing between emissions sources requires supplemental information. With different cruise ships in port every day, ships entering and leaving the port at different times, and inconsistent meteorological conditions, each study day was assessed independently for local air quality impacts. Webcam footage and data collected from downtown Juneau meteorological stations were used to locate likely sources during periods of elevated $PM_{2.5}$ concentrations observed at the PA sites. In addition to local sources, Juneau also experienced abnormal influx of wildfire smoke from Western Canadian wildfires during the 2019 summer season. Each day during the study period was closely scrutinized to determine sources of air quality impacts and what sites or group of sites seemed to be the most affected.

Groups of sites in downtown Juneau seemed to be affected by emission plumes depending on their relative geographic location. PA sites located on the hill portion of downtown Juneau at an elevation of 70 feet and greater were grouped as "elevated sites," PA sites residing in the lower elevation portions in the area of Juneau known as the "flats" were grouped as "flats sites," and PA sites located along the waterline and docks were grouped as "waterline sites." The N. Douglas and City Hall sites were not grouped; the N. Douglas site due to the site's unique location and the City Hall site due to identified localized sources as discussed later in the report.

The following sections communicate the analysis process for separating and determining the sources for air quality impacts on downtown Juneau during the 2019 summer cruise ship season.

Wildfire Smoke

Wildfire smoke from South Central Alaskan and Western Canadian wildfires was the largest measured impactor of air quality in Juneau during the study period. Juneau and much of Southeast Alaska experienced unusual intermittent wildfire smoke from late May until early

[8] AQI classifications are based on the more accurate regulatory grade sampling equipment, but are often used in the context of sensor measurements to describe air quality in general terms.

September, although air quality alerts were only issued from July 5th through July 8th for Southeast Alaska. The peak in wildfire smoke occurred June 26th – July 15th. The Juneau Floyd Dryden BAM monitor also recorded a corresponding increase in $PM_{2.5}$ values over the same time period. Typically, Juneau PA sensors and the Floyd Dryden FEM BAM are not expected to observe similar PM concentrations due to the distance between the locations, varied terrain, meteorological conditions, and emission sources observed at each location. However, during wildfire smoke events, air is generally well mixed, and a similar background PM concentration is expected across all sites. If a consistent wildfire pollution background could be determined, it should be possible to separate out increases in $PM_{2.5}$ concentrations as a result of cruise ship emissions from above that of the overlying wildfire smoke.

PA sensors demonstrated a high concentration bias from wildfire smoke. During the last week of the peak wildfire smoke event, the audit PA was collocated next to the Floyd Dryden FEM BAM during the wildfire smoke event to assess whether a correction factor to the PA dataset could be applied.

The linear correction factor determined from the Audit-BAM collocation during heavy wildfire smoke was applied to PA data from 6/28/19 to 7/15/19, the peak of wildfire smoke in Juneau. Comparing corrected $PM_{2.5}$ concentrations from downtown PA sites to the Floyd Dryden BAM monitor shows a similar trend in concentrations **(Figure 6)**. During this wildfire smoke period, large increases in $PM_{2.5}$ concentrations observed at the downtown Juneau PA sites can be attributed to the expected background PM concentrations from the wildfire smoke. Emissions from cruise ships did not stand out beyond the expected PM concentrations from wildfire smoke. Only two hourly periods, 6/28 3:00 PM and 7/3 5:00 PM identified by arrows in **Figure 6**, had corrected PM concentrations for a group of PA sites 10 $\mu g/m^3$ greater than that of the FEM monitor. Both hourly PM spikes were identified to be the result of activities impacting a single PA site and therefore unlikely to be the result of cruise ship emissions.

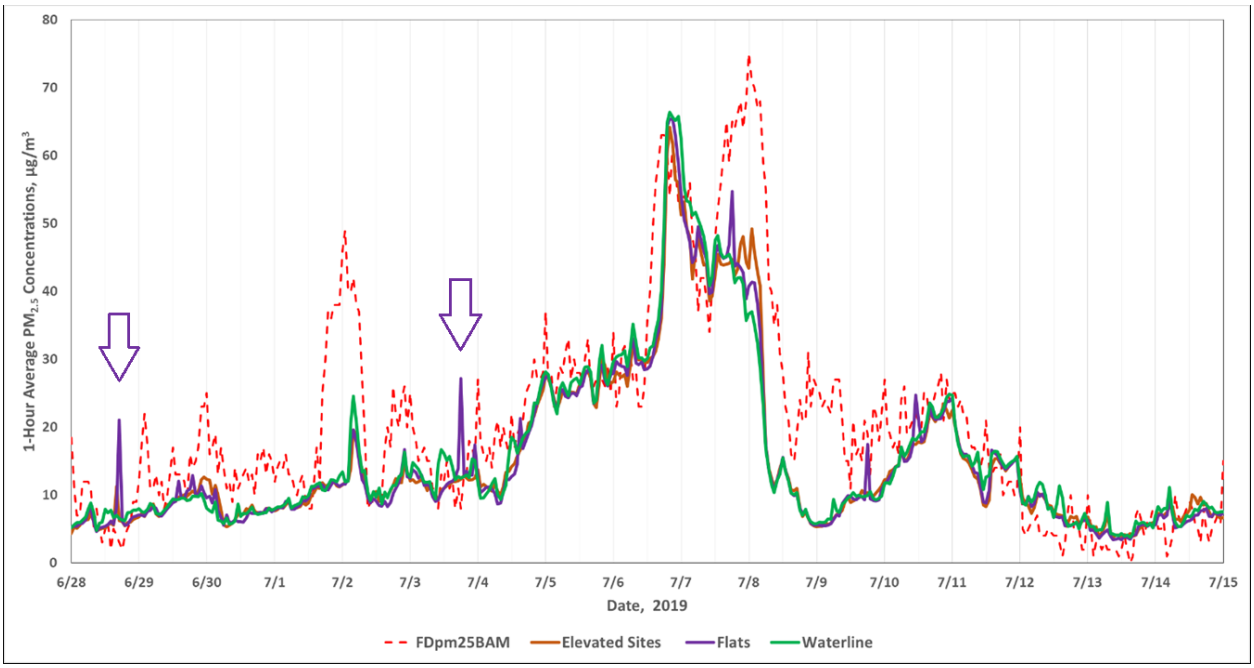

Figure 7. Hourly PM2.5 concentrations (µg/m3) for Juneau Floyd Dryden FEM BAM and PM2.5 concentration for downtown Juneau PA sites during the June 28th through July 15th wildfire smoke event. Purple arrows point to periods when a group of PA sites had a $PM_{2.5}$ concentration > 10 µg/m^3 than the FEM BAM.

City Hall Site

The City Hall PA site consistently recorded values above the rest of the downtown Juneau PA sites, with the greatest differences mostly occurring between 6:00 AM and 7:00 PM. Additionally, 84% of elevated values recorded by the City Hall PA site occurred when a nearby weather station located at the Downtown Library reported winds coming from southern direction. Frequently particulate matter is created at this location by outdoor grills serving food to passengers and crews coming off of the cruise ships. These vendors operate in Juneau's Marine Park, approximately 160 feet south of the City Hall PA site. Staff working inside the Juneau City Hall reported smelling the grills and were concerned the site would be biased by the grill impact. Particulate matter concentration spikes at the City Hall are observed on days when at least one cruise ship is in port, with the exception of May 4th which was the Juneau Maritime festival and featured many outdoor food vendors near Marine Park. Early morning spikes at the City Hall site many hours before the arrival of any cruise ships suggest there may be other localized emissions sources contributing to the elevated particulate matter.

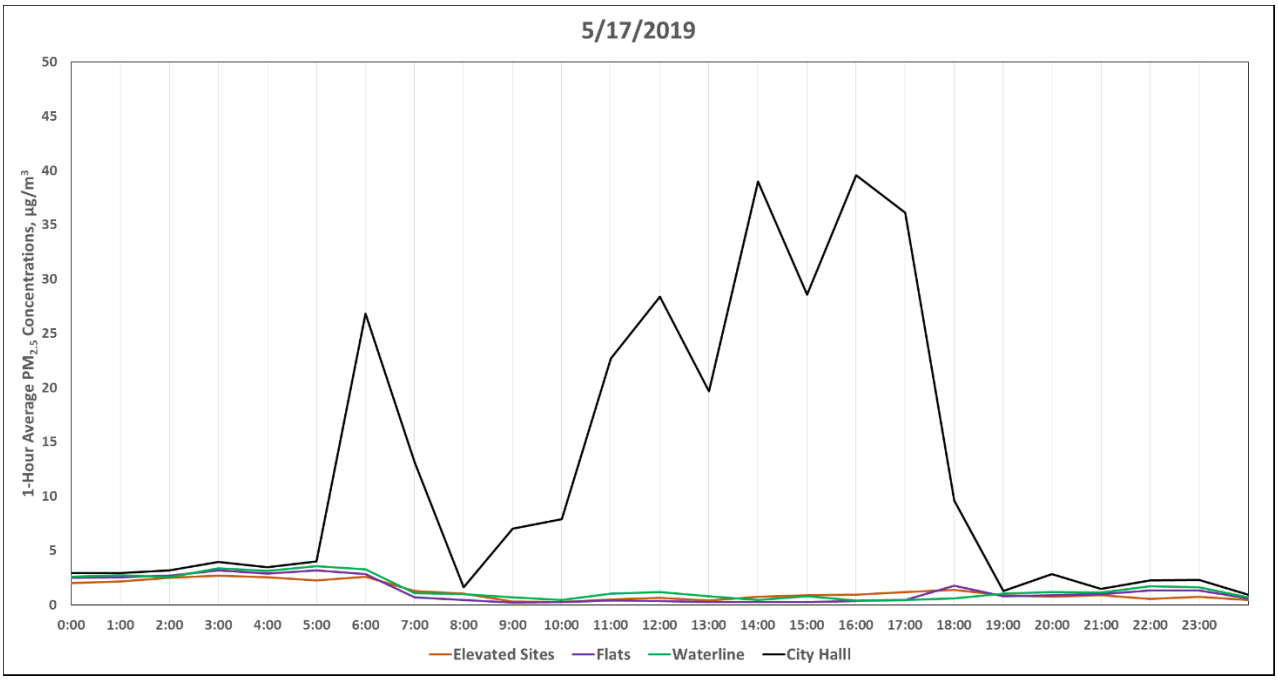

Figure 8. Study day May 17th demonstrating the difference between the City Hall site and all other PA sites.

Other PA sites near City Hall did not observe similar particulate increases (see **Figure 7**) during elevated City Hall concentrations. Furthermore, elevated particulate matter concentration at City Hall often would precede the arrival of any cruise ships by several hours further decoupling the site from direct cruise ship emissions. While $PM_{2.5}$ concentrations at City Hall are localized and likely not the result of direct cruise ship emissions, because the vendors only grilled when cruise ships were in port, these emissions are an incidental result of cruise ship activity.

Due to identified local biases during analysis of daily PA data sets, $PM_{2.5}$ concentrations at the City Hall site are not grouped with the flats, waterline, or elevated sites. However, when no ships are present, the City Hall site could be associated with the Waterline sites.

Recreational Emissions

During the study period brief spikes in $PM_{2.5}$ concentrations at one site occasionally occurred as a result of local recreational activity, such as grilling/smoking and slash burns/bonfires, typically occurring later in the evening. These events took place without warning and were often not observable using webcam data. During recreational events, $PM_{2.5}$ concentrations may spike to as high as 250 $\mu g/m^3$, though usually only data from one site was impacted. An example of a large localized spike in $PM_{2.5}$ concentration comes from the North Douglas site 6/5 – 6/8 **(Figure 8)**. Three consecutive nights the site observed brief spikes at the same time. Webcam footage does

not show any large emission plume coming from the site, therefore supporting the interpretation as emissions from localized recreational activity.

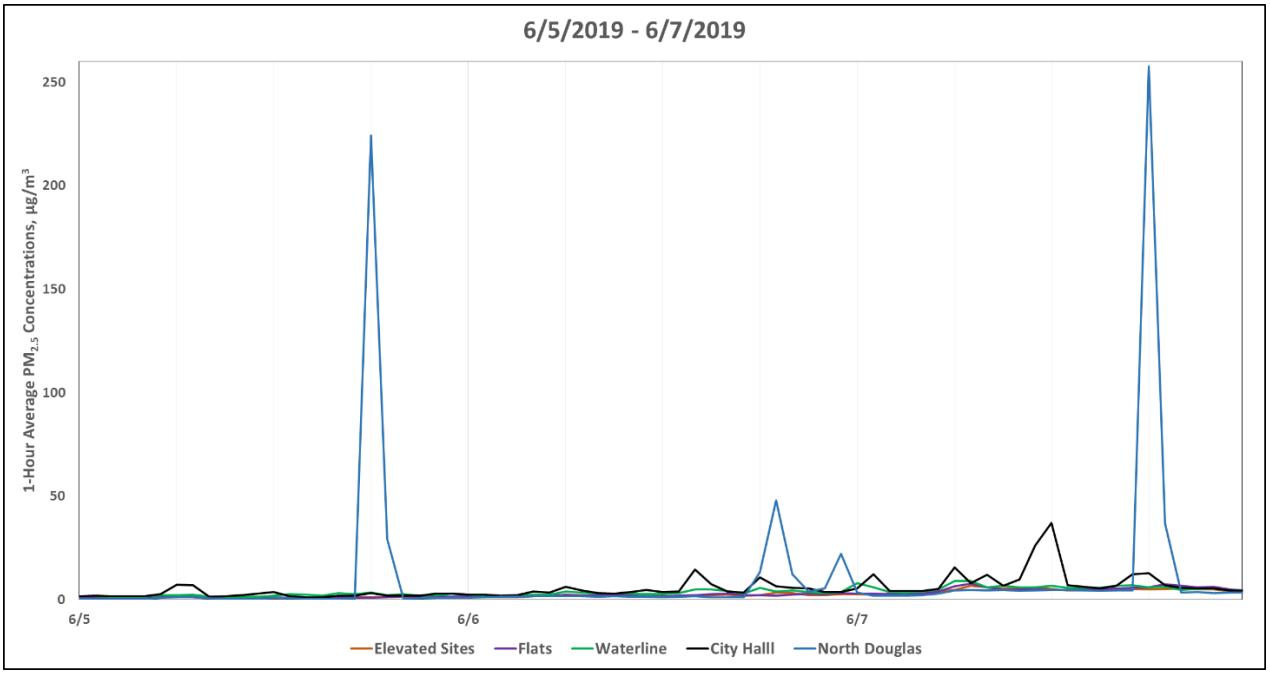

Figure 9. Study period from 6/5/19 to 6/8/19 displaying large evening spikes at the North Douglas site as a result of localized recreational activity.

The only time staff at DEC were explicitly informed of localized recreational activity occurred August 2nd at the 5th & N. Franklin PA site. Residents of the host site informed air monitoring staff of a fish smoker operating within several meters of the PA sensor from 11:15 AM to about 10:00 PM. The PA data shows a noticeable increase in particulate concentrations starting at 12:00 PM and remaining elevated until about 9:00 PM. Hourly $PM_{2.5}$ concentrations peaked at 7:00 PM at 39 µg/m3, nearly 28 µg/m3 greater than any other site, as shown in **Figure 9**. None of the other nearby sites observed noticeable increases due to the localized event.

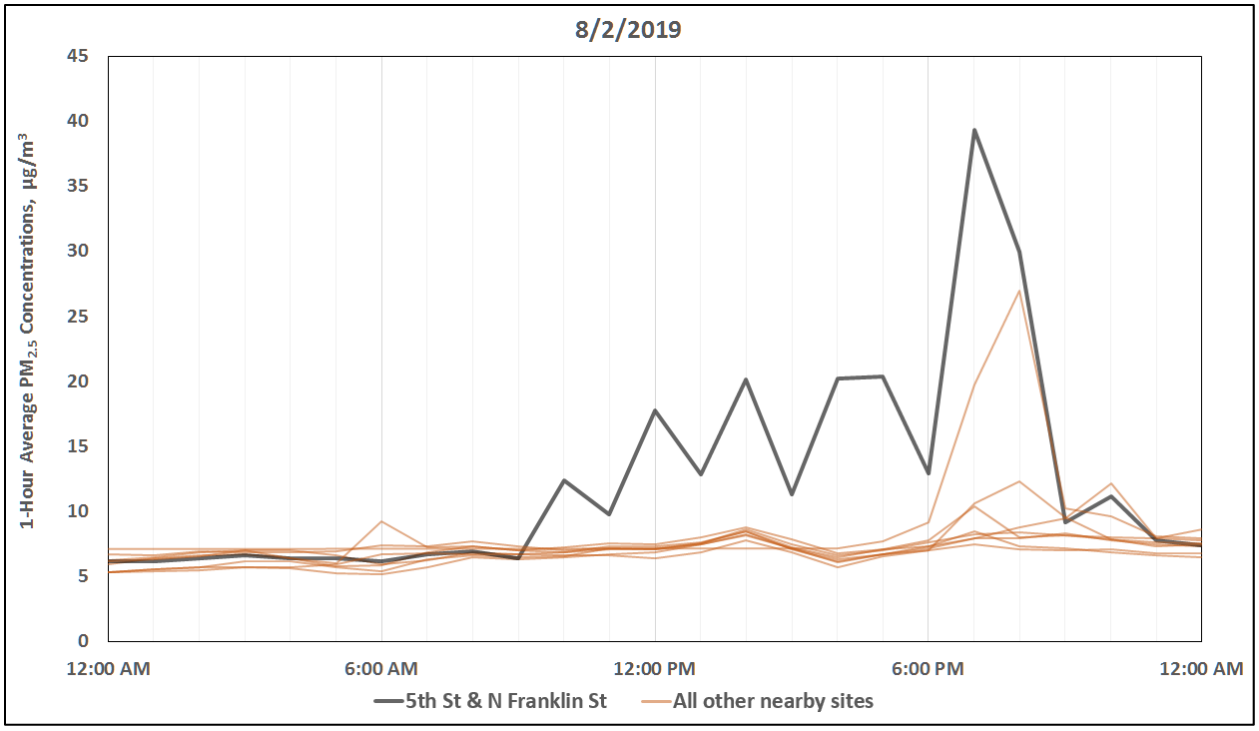

Figure 10. $PM_{2.5}$ concentrations for "elevated sites" August 2nd, 2019. 5th & N. Franklin St site reported elevated PM concentrations due to fish smoking, while all other nearby sites showed no comparable increase in PM concentrations.

Identifying recreational emissions is an important aspect of understanding the local air quality impacts and important for separating out these impacts from cruise ship emissions.

Cruise Ship Air Quality Impacts and Case Study

Short term impacts in air quality observed from both cruise ship emissions and other local emission sources often showed similar characteristics as measured by the PA sites. The magnitude of cruise ship air impacts was lower than expected based on public complaints during the 2017 and 2018 cruise ship seasons in Juneau and requires increased scrutiny. Nevertheless, cruise ship emission impacts could be identified using archived webcam footage, meteorological data from downtown Juneau stations, and $PM_{2.5}$ data collected by the PA sites.

Rather than discuss every day during the study period in this report, DEC chose to focus the data analysis process on a case study of the data collected on August 30th and 31st. This two day period is a good representation of data analysis for the cumulative study period and demonstrates how to distinguish between various emission sources. **Figure 10** shows 1-hour averaged $PM_{2.5}$ data from all downtown PA sites for August 30th and 31st.

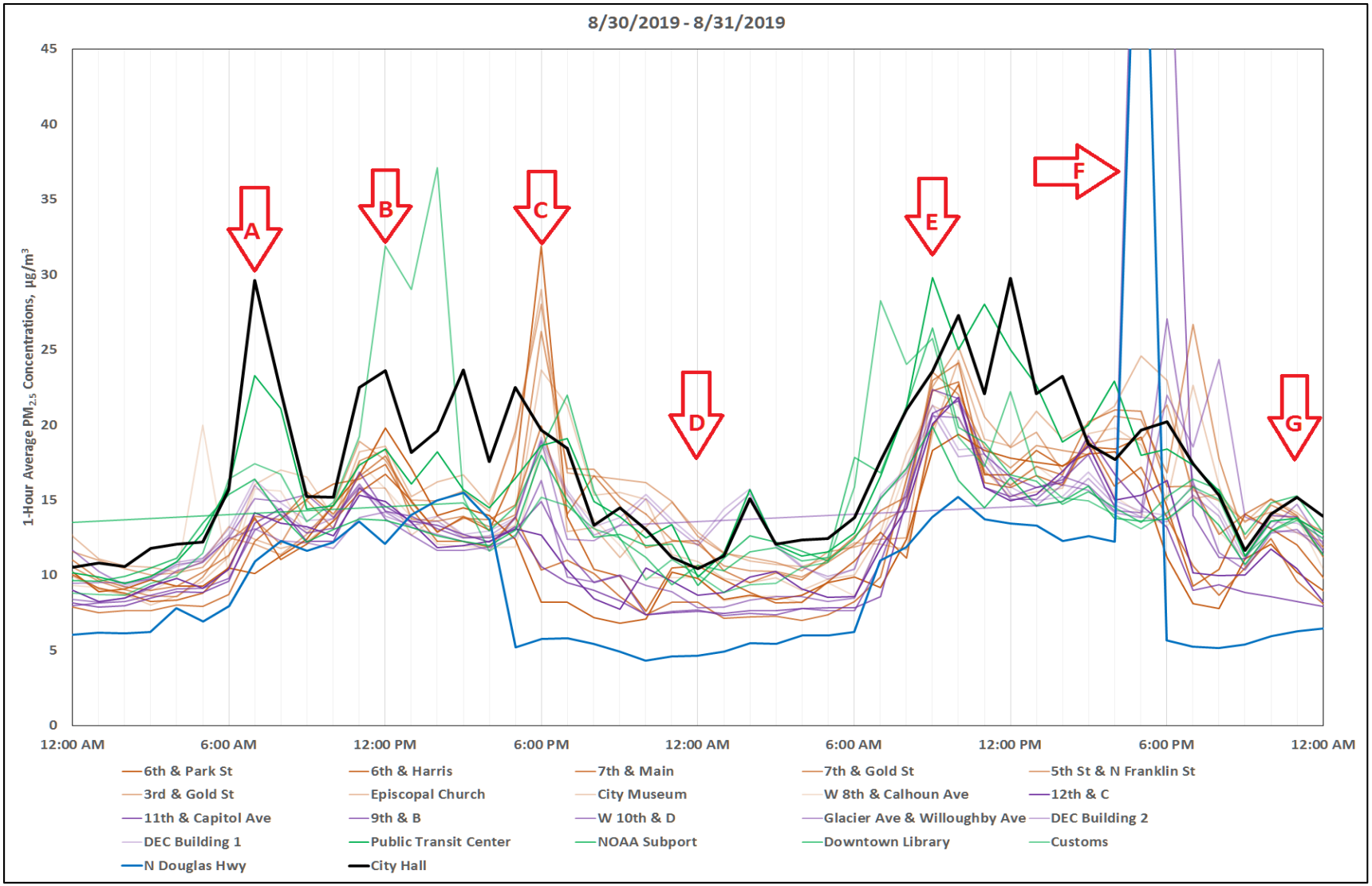

Figure 11. PM2.5 concentrations during the study days 8/30/19 and 8/31/19 observed at all PA sites. Arrows A-G point to periods of air quality impacts. Green lines are waterline sites, brown lines are elevated sites, and purple lines are flats sites. The thick black and blue line are the City Hall and N Douglas Hwy sites respectively.

Friday, August 30th 7:00 AM. From Figure 10, arrow A.

Starting early morning on August 30th, $PM_{2.5}$ concentrations at the downtown sites are all at slightly elevated levels, with an average near 10 $\mu g/m^3$, likely as a result of residual smoke from Canadian wildfires.

The first cruise ship arrived on Friday August 30th at 5:00 AM. As the ship arrives winds are slowly blowing the emissions away from downtown Juneau.

The second ship arrived at 7:30 AM as shown in **Figure 11** (webcam footage) and as the ship docked, winds began to stagnate and switched directions. From webcam footage, visible emissions plumes appeared to move toward downtown Juneau as the wind shifted. Emissions from construction work near the Transit Center site were also observed from webcam footage. All sites began to see increases in $PM_{2.5}$ with the public Transit Center and City Hall Sites seeing the largest increases. The City Hall site, for reasons previously discussed, typically reported $PM_{2.5}$ concentrations inconsistent with other sites. The emissions from the construction work seemed to only impact the Public Transit Center and possibly the City Museum PA sites; brief emissions can be seen coming from the construction site throughout the day possibly further impacting the Public Transit Center site.

Friday, August 30th 12:00 PM. From Figure 10, arrow B.

Two more cruise ships arrived between 11:00 AM and 12:00 PM as well as a large tanker ship which docked south of the Customs PA site between the two southernmost cruise ships. Additionally, as seen in **Figure 12,** the first ship to arrive in port started additional engines while preparing for its 1:00 PM departure. All sites reported increases in $PM_{2.5}$ concentrations during this time period, peaking during 12:00 PM, with Customs and 'Elevated' PA sites experiencing the largest increases. A large spike in $PM_{2.5}$ concentrations observed at the Customs site is likely the result of the tanker ship which arrived shortly before 12:00 PM and continued to produce visible emissions until 2:30 PM. Increases in $PM_{2.5}$ at the elevated sites, and most other sites, were likely the result of cruise ship emissions moving over Juneau which can be seen from various webcam angles.

Friday, August 30th 6:00 PM. From Figure 10, arrow C.

At 2:00 PM a large fire started on a beach across the channel from downtown Juneau on Douglas Island. The winds blew the smoke from the fire up the channel likely resulting in a small $PM_{2.5}$ increase at the N. Douglas PA site. At 5:30 PM the winds began to stagnate and the smoke from the large fire, and an additional smaller beach fire, began to accumulate in the middle of the channel. At 6:20 PM the winds shifted and the smoke moved towards town causing a sharp increase in $PM_{2.5}$ at nearly all sites, especially the 'elevated' sites. Webcam footage seen in **Figure 13** shows the densest part of the plume to be elevated, explaining why elevated sites seemed to be more affected.

Saturday, August 31th 12:00 AM. From Figure 10, arrow D

The three remaining cruise ships left between 9:30 PM and 10:30 PM. As the cruise ships were leaving, the wind appeared to be lightly blowing the emissions away from the downtown sites. From the time the ships leave August 30th at 10:30 PM until August 31st at 7:00 AM there did not appear to be any noticeable emissions sources. With little to no wind, $PM_{2.5}$ concentrations from all emissions sources slowly dispersed and concentrations decreased.

Saturday, August 31st 8:30 AM. From Figure 10, arrow E

On Saturday August 31st the first ship arrived at 6:30 AM. With low wind speeds, the ships emissions lingered in the channel south of Juneau as the ship came to port. Three other cruise ships came to the port before 8:30 AM, with each ship's emissions lingering in the channel south of Juneau. At 8:30 AM the winds shift direction and all of the emissions accumulating in the channel blow towards downtown Juneau, seen in Figure 14. All sites saw sharp increases over the next couple hours as winds slowly blew emissions towards the sites. Winds continue to blow cruise ship emissions towards downtown Juneau and all sites remain at elevated $PM_{2.5}$ concentrations. The smallest of the cruise ships boards at the Franklin Dock, a dock connected to Juneau's power grid. Typically ships at this dock connect to shore power instead of running additional generators, however on August 31st the cruise ship at the Franklin Dock appeared to continue running onboard generators.

Saturday, August 31st 5:00 PM. Figure 10, arrow F.

At 5:00 PM and 6:00 PM two sites, N. Douglas and 9th & B, reported large spikes in $PM_{2.5}$ concentrations. These spikes were not observed by other PA sites and were likely the result of localized residential activity.

Saturday, August 31st 10:00 PM. Figure 10, arrow G.

One final small spike occurred between 9:00 PM and 11:00 PM as the three remaining ships departed after which $PM_{2.5}$ concentrations decreased across all sites.

The above case study represents a period in which cruise ship emission air quality impacts lasted for many hours each day. During the five month study emissions events from cruise ships were typically brief and only lasted one or two hours. Although hourly peak $PM_{2.5}$ concentrations from cruise ship emissions do not appear to cause sharp peaks like those observed in localized events, the PA grid was clearly able to detect air quality impacts from ship emissions.

Figure 12. Webcam footage from Mendenhall Apartments on 8/30/19. A plume above the closest cruise ship and a plume from construction work on the right side of the image are indicated with red arrows.

Figure 13. Webcam footage from Mendenhall Apartments 8/30/19. Emissions blowing towards Juneau can be seen coming from all four cruise ships with a large plume over the ship furthest away in the image, marked with red arrow.

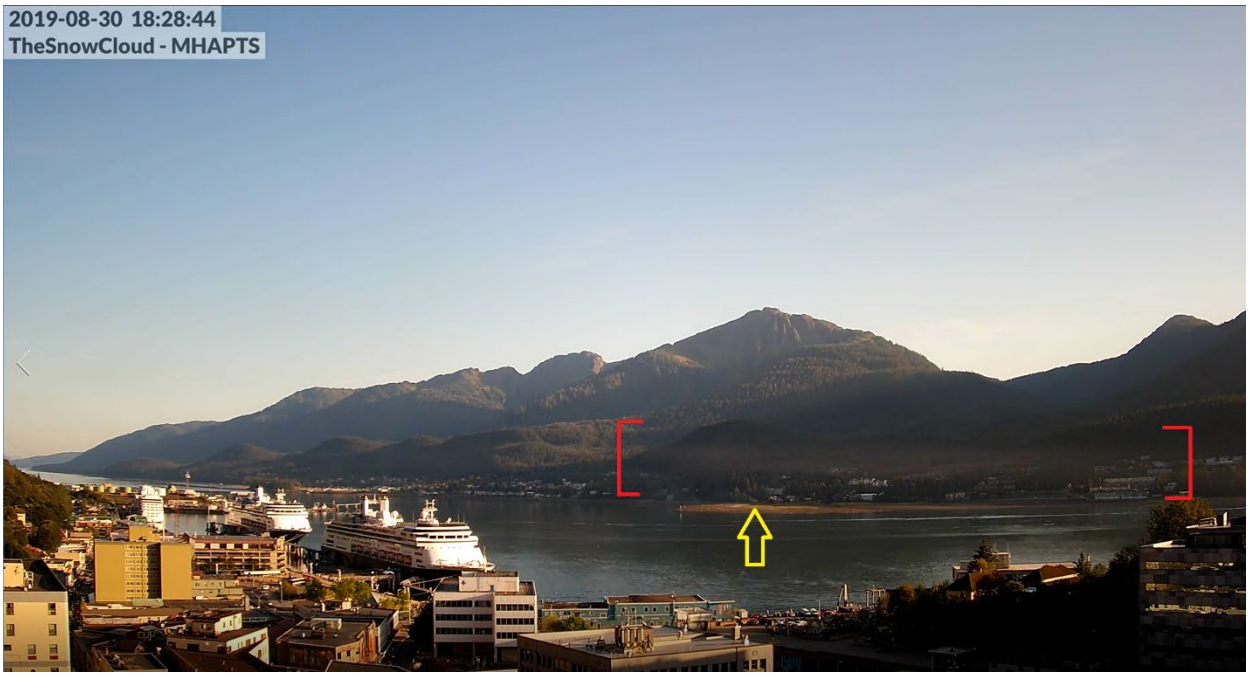

Figure 14. Webcam footage from Mendenhall Apartments 8/30/19. A large fire on Douglas Island (yellow arrow) creates a plume (red brackets) which is slowly transported towards Juneau as winds switch direction.

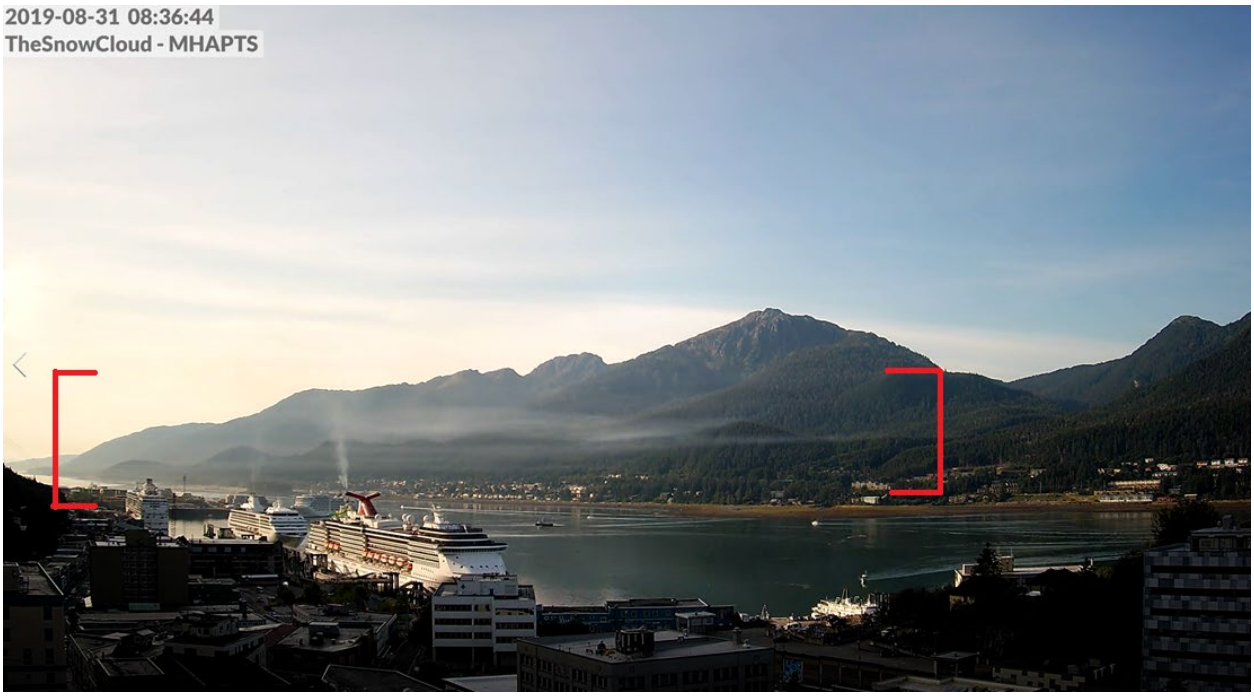

Figure 15. Webcam footage from Mendenhall Apartments 8/31/19. Cruise ship emission plumes can be seen accumulating and moving towards downtown Juneau. Plume identified in red brackets.

SO_2 Sampling

The purpose of the passive SO_2 sampling network was to help identify areas affected by diesel emissions from cruise ships. The lower than expected SO_2 concentrations necessitated longer than anticipated exposure period of the Ogawa passive samplers and therfore did not allow a resolution fine enough to identify short periods of SO_2 impacts. Ogawa samplers collocated with continuous Federal Reference Method SO_2 monitoring equipment at the Alaska National Core Multipollutant Site in Fairbanks, Alaska did not correlate well at low SO_2 concentrations and further demonstrated the inability of the Ogawa samplers to help in detecting SO_2 in emissions plumes during the study.

Conclusion

It is important to emphasize the Purple Air sensors used in downtown Juneau for this study are not regulatory monitoring equipment. While the sensors were precise and capable of detecting small variations in particulate levels, the PA sensors cannot be calibrated to local conditions and data should only be used to determine general observations and concentration trends.

Assessing short term air quality impacts from cruise ships in Juneau can be difficult due to varying emissions sources and meteorological conditions. Additionally, the Ogawa passive SO_2 samplers were not sensitive enough to detect short term increases in SO_2, which may have further helped to identify diesel emissions from ships. During the study period, however, short term emissions plumes from cruise ships were detected by the PA monitors in the form of widespread elevated $PM_{2.5}$ concentrations affecting multiple sites simultaneously.

Early in the 2019 cruise season, the cruise line companies were worked together to reduce their impact on local air quality.[9] Two of the strategies used for reducing emissions were reducing idle times and switching to a low sulfur marine fuel while in port. While it is difficult to compare Juneau's 2019 cruise ship related air quality impacts to previous year's impacts, the 2019 season had less public complaints than the previous two season.[10] Although the strategies were likely effective in reducing air quality impacts, it remains unclear whether those changes are permanent and if they apply to ports other than Juneau.

Data collected did not identify a single maximum impact location in downtown Juneau or the flats that should be used in any follow-up study. But the data indicated that, weather dependent, various parts of the downtown area and the flats were impacted by short term plumes. Emission plumes from cruise ships did not seem to impact one particular site in downtown Juneau but

[9] https://www.juneauempire.com/news/cruise-ship-complaint-numbers-for-this-year-may-surprise-you/
[10] https://dec.alaska.gov/media/19814/2019-cpvec-air-annual-report-final.pdf

rather, depending on meteorological conditions and locations of the emitting ship, would impact elevated sites, flats sites or often all sites.

The PurpleAir saturation study provided information about areas of Juneau affected, and demonstrated the need to better assess short term impacts with at least 1-hour resolution. Furthermore, meteorological data from nearby meteorological stations and webcam footage proved to be valuable in identifying air impact sources. The Ogawa passive SO_2 samplers were not sensitive enough to detect low concentrations of SO_2 over short time periods needed to assess emissions plumes.

Next Steps

DEC has ordered several survey-grade sensor pods capable of measuring PM, Carbon Monoxide (CO), Nitrogen Oxides (NO_x), and SO_2 to deploy at multiple locations in downtown Juneau, with at least one site to be located in the elevated area and one site in the flats area. The new sensor pods will be assessed for accuracy and precision in a similar manner to the PurpleAir sensors before being installed in the community. While the new equipment is also not regulatory grade, the addition of gaseous monitoring combined with onsite meteorological data will provide better and more detailed information for source identification. The new CO, NO_x, and SO_2 sensor technology allows for short term resolution of down to one hour averaging and will not only be capable of measuring short term air quality impacts, but will also help to evaluate emissions plumes characteristics to determine possible sources.

With the new monitoring equipment and continued use of available webcam footage, DEC expects to better assess all emissions sources affecting the downtown area and provide more accurate information regarding year-to-year air quality impacts from cruise ship emissions.

The saturation study only addressed air quality impacts at the port of Juneau. Air quality impacts from cruise ships at other port communities may need to be addressed. While emissions mitigation plans put in place by cruise line groups specifically for Juneau seemed to be effective, the impact from cruise ship emissions at other Southeast Alaska port communities remains unclear.

For additional information and access to all of the raw data please visit https://dec.alaska.gov/air/air-monitoring/juneau-cruise-ship-monitoring-project/.

Appendix A

PurpleAir PA II sensors

PurpleAir sensors were used for all $PM_{2.5}$ measurements. Each PurpleAir contains two Plantower PMS5003 laser particle counters, a Bosch BME280 temperature/humidity/pressure sensor, as well as an onboard SD card reader for data storage. Each individual Plantower sensor takes measurements on 80 second intervals and counts suspended particles in sizes of 0.3, 0.5, 1.0, 2.5, 5.0, and 10 µm with a counting efficiency of 50% at 0.3 µm and 98% at ≥0.5 µm. Particle bins are then processed into $PM_{1.0}$, $PM_{2.5}$, and PM_{10} mass concentrations in $\mu g/m^3$ with an effective range between 0 to 500 $\mu g/m^3$ and a maximum consistency error of ±10% at 100 to 500 $\mu g/m^3$ and ±10µg/m3 at 0 to 100 $\mu g/m^3$.

Table A-1. PurpleAir PA-II specifications

Range of measurement	0.3~1.0; 1.0~2.5; 2.5~10 Micrometer (µm)
Counting Efficiency:	50%@0.3µm 98%@>=0.5µm
Effective Range:	0~500 µg/m³
Maximum Range:	≥1000 µg/m³
Resolution:	1 µg/m³
Maximum Consistency Error:	±10%@100~500µg/m³ ±10µg/m³@0~100µg/m³
Standard Volume:	0.1 Liter (L)
Single Response Time:	≤1 Second
Total Response Time:	≤10 Seconds

Data Storage

PurpleAir sensors collected particle counts, mass concentrations, as well as temperature and relative humidity information, and reported averaged values on 80 second intervals. Data collected from the PurpleAir sensors was wirelessly transmitted to and stored through ThingSpeak network and cloud service. Additionally, all data was stored locally to an SD card.

Wireless Conectivity.

Nineteen of the 21 sites used a Novatel Wireless Mifi 6630 Mobile Hotspot unit to wirelessly connect the PurpleAir units to the ThingSpeak network. The other two sites used a connection to a local Wi-fi network.

Power

All PurpleAir units were powered by 110V AC power. Each site PurpleAir unit and Mi-fi hotspot were connected to a single USB hub powered through an extension cord. To avoid exposure to moisture, the extension cord terminal connecting the USB hubs was enclosed in the junction box to which the PurpleAir units were mounted.