Title
California air quality: An analysis of the impact of COVID19 and wildfire in indoor and outdoor emission measurements.

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CALIFORNIA AIR QUALITY: AN ANALYSIS OF THE IMPACT OF COVID-19 AND WILDFIRE THROUGH OUTDOOR EMISSION MEASUREMENTS

By

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Abstract

This report provides a comprehensive analysis on the spatiotemporal impacts of the Coronavirus Disease 2019 (COVID-19) and wildfires on air pollution in California, USA. With the lockdown response and statewide stay-at-home orders, a dramatic change in air pollutant emissions can be seen in particulate matter, carbon monoxide (CO), nitrogen dioxide (NO_2), and ozone (O_3) levels. The lockdown policy generally reduced the concentration of air pollutants whereas the reopening increased the emissions of air pollution towards a normal trend. 2020 was also the year where California experienced the worst wildfire season on record; with a combination of record-breaking heat waves and Santa Ana winds, levels of particulate matter rose significantly during August 2020. Data on particulate matter and other emissions will be compared between the years 2019 and 2020 to explain the events and factors leading to the significance of detected patterns. This work will also provide insights on how industrial production, transportation, and daily lives are impacted by the effects of COVID-19 and wildfires.

Acknowledgements

I would like to first thank my principal investigator and faculty mentor, Dr. David Cocker for his mentorship and guidance throughout my capstone project and undergraduate career at the University of California, Riverside. He has been supportive not only with developing my capstone, but also provided me opportunities to work within his research group at the Center for Environmental Research and Technology. I would like to thank graduate students, Chen Le, Qi Li, and Weihan Peng for giving me insights on secondary organic aerosol research, data analysis, as well as important lab techniques during my time in the research group. Lastly, I would also like to thank the UCR University Honors Program for their resources provided, as well as my peers for their endless support.

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1. Introduction

The lockdown as a result from COVID-19 have caused passenger traffic to plummet during the beginning of 2020. This can be seen when analyzing particulate matter, also known as atmospheric aerosol particles, which is a complex mixture of extremely small particles and liquid droplets including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles [1]. They are classified by PM2.5, which refers to particles that are two and one half microns are less, and PM10, which refers to particles 10 microns or smaller [2]. According to the EPA, the problem with particulate matter is that their small size is directly linked to health problems, in which the particles can pass throughout the body due to their small size. PM2.5 is more dangerous in which it can get deep into the lungs, and cause heart and breathing problems [3]. Particulate matters can either be emitted directly from sources (primary particles) or formed in the atmosphere through chemical reaction of gases (secondary particles) [2]. Other than health effects, particulate matter has also been shown to affect the climate, ecosystems, and damage stones and other materials. Some examples include reduced visibility (haze), depletion of nutrients in soil, acidic lakes and streams, and changing the nutrient balance in coastal waters and large river basins [3].

One of the leading contributors to particulate matter emissions (PM2.5 and PM10) is from vehicle emissions [4]; analysis of spatiotemporal patterns on particulate matter during COVID-19 can reflect how transportation was affected. Another contributing factor to particulate matter lies in the surge of wildfire in California during 2020. The data from the study will show the significance of wildfire and its effects on air quality in both urban and rural areas.

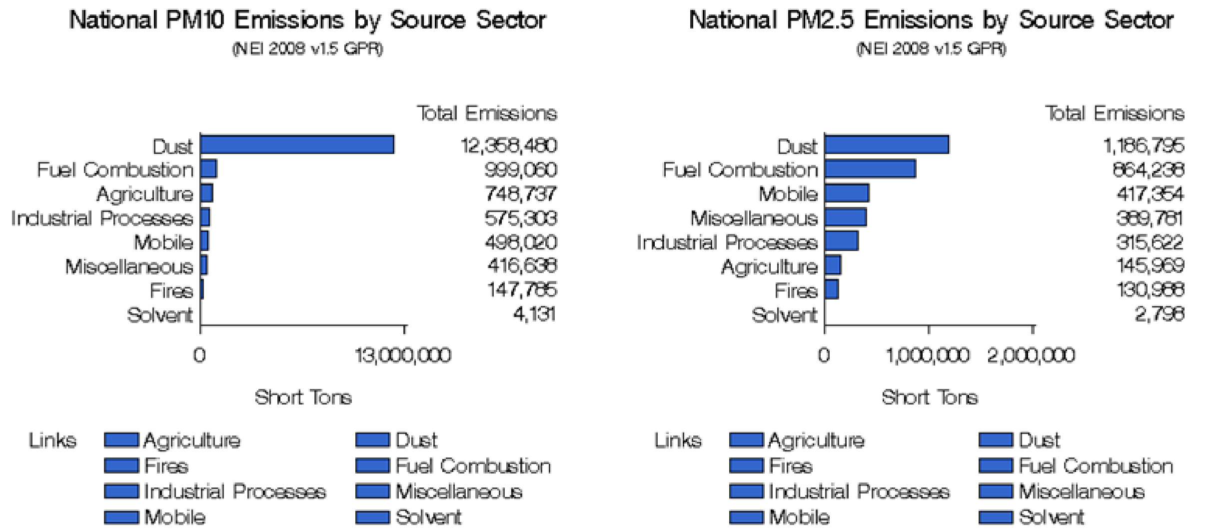

Figure 1: Particulate matter emissions by source sector [5]

Other air pollutants that are important indicators of economic and human activities include carbon monoxide (CO), nitrogen dioxide (NO_2), and ozone (O_3). A dominant carbon monoxide source comes from the incomplete combustion of carbonaceous fuel [7]. Since carbon monoxide can bind reversibly with hemoglobin in blood, this can impair the transportation of oxygen to the blood cells resulting in impair visual perception and fatigue. Nitrogen dioxide on the other hand is a respiratory irritant and is emitted through fossil fuel consumption [6].

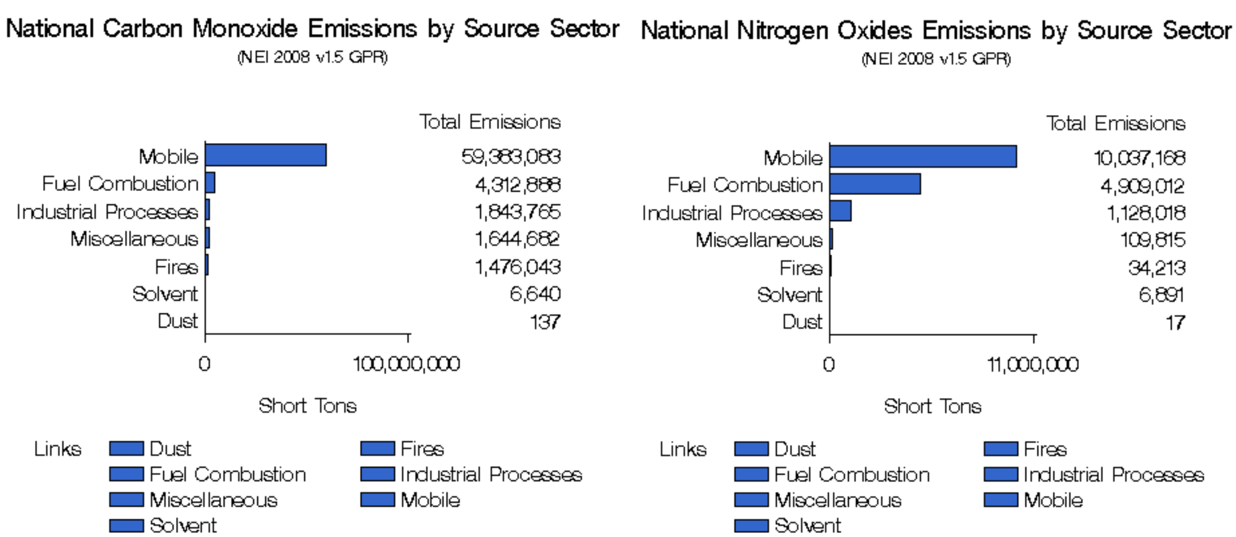

Figure 2: Carbon monoxide and nitrogen oxides emissions by source sector [6&7]

The last emission to be measured is ozone (O_3), which is a photochemical oxidant and an important component in smog. The EPA listed ozone as a chemical that is harmful to the human's respiratory system, where ozone can aggravate asthma, chronic lung diseases, and cause permanent lung damage. Unlike the stratospheric ozone, ground-level ozone forms through the emission of nitric oxide, nitrogen dioxide, and volatile organic compounds that can result in ambient ozone concentrations up to three times the concentration considered protective of public health by the EPA [8]. Past research has shown that gasoline-burning engines are a major source of volatile organic compounds in urban areas, whereas nitrogen oxides are produced whenever fossil fuels are burned. Since ozone formation is dependent on sunlight, data shows that concentrations are typically highest during the summer months [9]. Large amounts of ozone can consequently act as a strong greenhouse gas, having impacts on precipitation rates, cloud formation, precipitation levels, and atmospheric circulation [10]. By analyzing the trends on these emissions, one can understand how industrial production, transportation, and daily lives are impacted by the effects of COVID-19 and wildfires.

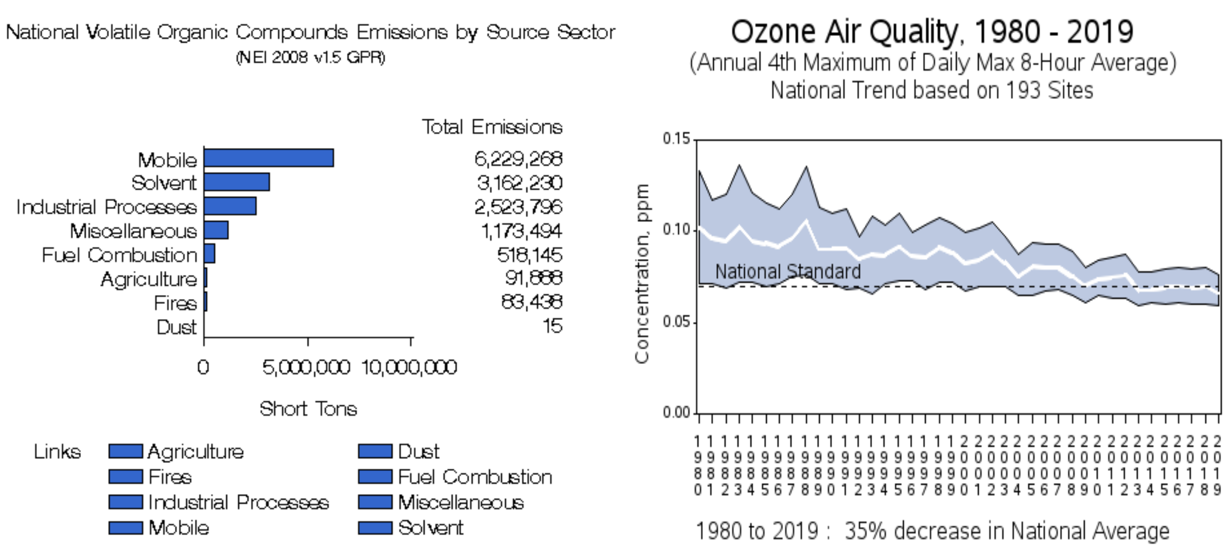

Figure 3: Volatile organic compounds emissions by source sector and national average ozone concentration from 1980-2019 [8]]

2. Materials and methods

2.1 Study Area

This study examines the emission data from Southern California, primarily Los Angeles County, Orange County, and Riverside County. From the American Lung Association, California has shown to have one of the highest concentrations of air pollutants in the nation [11]. This pollution is mainly due to the increased amount in the occurrence of wildfires. In 2020, CAL FIRE estimated that more than 4 million acres were burnt, leading to heavy smokes pouring into the atmosphere [12]. These incidents resulted in a blanket of smoke above mixed into the air that the population breathed at ground level. The report from the American Lung Association also highlights extreme ozone pollution and high short term particle pollution compared to other states [11].

2.2 Data

Data on particulate matter were analyzed using the tool PurpleAir and their sensors [13]. The information on PM2.5 and PM10 were recorded every hour and analyzed at the beginning of each year, starting from January 2019. The data were then averaged for each month with the monthly maximum and minimum concentrations recorded. For each specific county, an average of 20 different measurements were taken from outdoor sensors to ensure an accurate reading. All 20 sensors data were averaged to obtain the measurement mean for each county. All California counties were then averaged to obtain the mean for California as a whole.

Data on ozone, carbon monoxide, and nitrogen dioxide levels were taken from the Air Quality and Meteorological Information System (AQMIS) managed by the California Air Resources Board (ARB) [14]. The ARB uses the Emissions Inventory and Air Quality Models to evaluate air quality and reduce emissions in 35 local air districts. Daily data measurements on all 35 local air districts were extracted from 2019 to 2020, which are then analyzed using excel to find monthly averages. These values are then plotted to identify trends between 2019 to 2020 in particulate matter, carbon monoxide, nitrogen dioxide, and ozone. All averages for each local air district were then compiled to obtain the mean for California as a whole.

2.3 Data Analysis

The daily mean in the measurement of pollutants (1-h) were calculated by averaging all hourly measurements in [Eqn. 1]:

$$C_t = \frac{\sum_{i-1}^{n} C_{i,t}}{n}, t \qquad \text{[Eqn. 1]}$$

where C_t represents the daily mean concentration of pollutants, t represents the date, and n is the number of available data for the pollutant in that time span. The daily data were then averaged using [Eqn. 1] again to find the monthly average of each pollutant. These points were then plotted on a yearly graph, of which there are 2 series: 2019 and 2020.

EPA revised the level of the 24-hour PM2.5 standard to 35 micrograms per cubic meter (ug/m^3) and retained the level of the annual PM2.5 standard at 15 micrograms per cubic meter [15]. For ozone levels, EPA established that primary and secondary standards are 0.070 parts per million [16]. The national ambient air quality (NAAQS) for nitrogen oxides are a 1-hour standard at a level of 100 ppb and an annual standard at a level of 53 ppb [17]. Lastly, EPA has also defined the national ambient air quality standard for carbon monoxide as nine parts per million over an eight-hour period [18]. This information on standard air quality will be used to evaluate the current trends on both 2019 and 2020 to see if the recorded data match within the EPA requirements.

Further analysis will be needed specifically on particulate matter due to the significant number of wildfires in California 2020. The reason for this is because wildfire is a major source in high particulate matters. In 2020, five of the major ten largest fires by acreage in modern California occurred in this summer: The August Complex, SCU Complex, LNU complex, North Complex, and Creek fire [19].

3. Results

3.1 Emission before and after COVID (2019 vs 2020)

3.1.1 PM2.5 (24 hr)

Particulate matter, PM2.5, was compared between the years 2019 and 2020 in California. The data was taken from the tool Purple Air and analyzed through excel. Figure 4 shows a representation of the monthly averages in micrograms/ cubic meters.

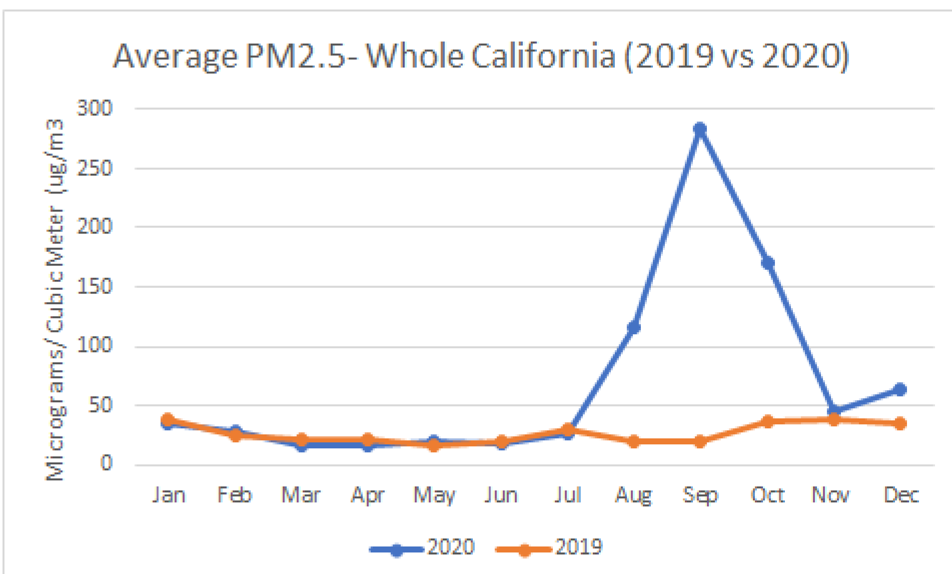

Figure 4: PM2.5 average monthly measurements for both year 2019 and 2020

The average emission in PM2.5 for 2019 was approximately 26.76 micrograms per cubic meter. This meets the EPA requirement of the 24-hour standard of 35 micrograms per cubic meter. However, 2020 shows an approximate 260% increase to 69.94 micrograms per cubic meter. From January to July, the average data were almost identical between the two years. From July 2020 onwards, a sudden spike can be seen up to an average of 290 micrograms per cubic meter in September. This sudden increase and bad air quality reflects the wildfire event in California: The August Complex fire which burned approximately 850,000 acres. Another contributor to the high levels of particulate matter is the strong wind that transport and disperse PM2.5 over long distances. Santa Ana winds originate inland and gain speed to warm and dry any area they pass through. As a result, these particulate matters can remain airborne for weeks and travel distances up to thousands of kilometers.

The graph in figure 4 illustrates a notable decrease in particulate matter at the start of lockdown. Between March to June 2019, a measurement of 21.5, 21.1, 16.9, and 19.9 micrograms per cubic meter was observed respectively for each month. During the initial lockdown period between March to June 2020, a measurement of 16.6, 16.2, 19.4, and 18.6 was observed respectively for each month. This depiction in data illustrates an approximate 10% decrease in PM2.5 due to COVID19. The maximum percentage decrease was seen in March and April, which both showed an approximate 23% decrease due to the strict restrictions and fear for COVID-19. Therefore, it can be concluded that PM2.5 concentrations did decrease during the lockdown period due to the decrease in traffic, daily activities, and restrictions set by the government.

3.1.2 Carbon monoxide (CO- 8 hr)

Figure 5 below illustrates the lockdown's impact on carbon monoxide emissions during COVID-19. Carbon monoxide (CO) is a colorless, odorless gas that can increase the severity of lung ailments, leading to dizziness, nausea, fatigue, and even death [18]. Since a dominant carbon monoxide source comes from the incomplete combustion of carbonaceous fuel, this can be linked to cars, trucks, and other machineries that burn fossil fuels. This can also include home appliances such as gas space heaters, wood stoves, and fireplaces. By comparing the data between 2019 and 2020, this will give a more accurate representation of how the transportation sector was impacted.

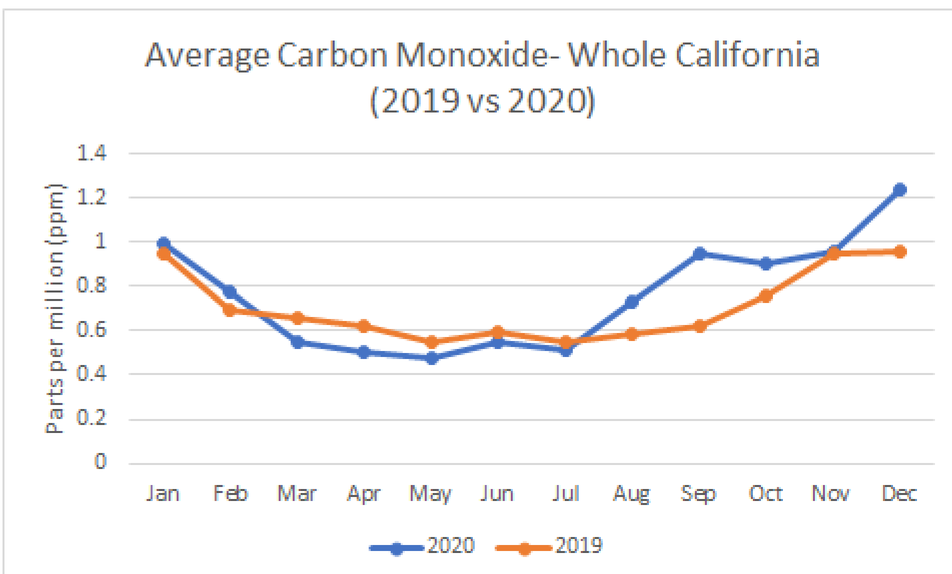

Figure 5: Carbon monoxide average monthly measurements for both years 2019 and 2020

The average emission for carbon monoxide in 2019 was approximately 0.70 parts per million (ppm). There is a slight increase in average carbon monoxide emissions in 2020 with a value of 0.76 parts per million. However this increase is caused during the later end of the year, representing local businesses, stores, and on-site jobs beginning to open back up to the public. It can also be seen that January and February follow very similar trends and data for both years since this was before the lockdown began.

As seen from figure 5, 2020 emissions on carbon monoxide did decrease during the months March, April, May, and June. This decrease represents the start of the lockdown; since carbon monoxide is linked to vehicles due to incomplete combustion, this data shows that there were fewer traffic and vehicle usage at the start of COVID-19. Comparing the data from 2020 to 2019, there was a decrease in carbon monoxide by 17% during March, 20% during April, 13% during May, and 10% during June. As a result, it can be concluded that carbon monoxide did decrease during the start of lockdown and started rising back to normal when places began to reopen during July.

3.1.3 Nitrogen dioxide (NO2- 1 hr)

Figure 6 below represents the lockdown's impact on nitrogen dioxide during COVID-19 through the comparison of nitrogen dioxide data from 2019 and 2020. Similar to carbon monoxide, gas power vehicles also directly emit NO2 as a combustion by-product. NOx plays a key role in atmospheric reactions with volatile organic compounds to generate ozone. When breathing in nitrogen dioxide, it can aggravate respiratory diseases such as asthma and cause respiratory infections [20]. NO2 can also interact with water, oxygen, and other chemicals in the atmosphere to form what is known as acid rain. By understanding the levels of nitrogen dioxide and how they are generated, this information will provide a more accurate representation of how COVID-19 impacted the transportation sector due to the combustion by-products.

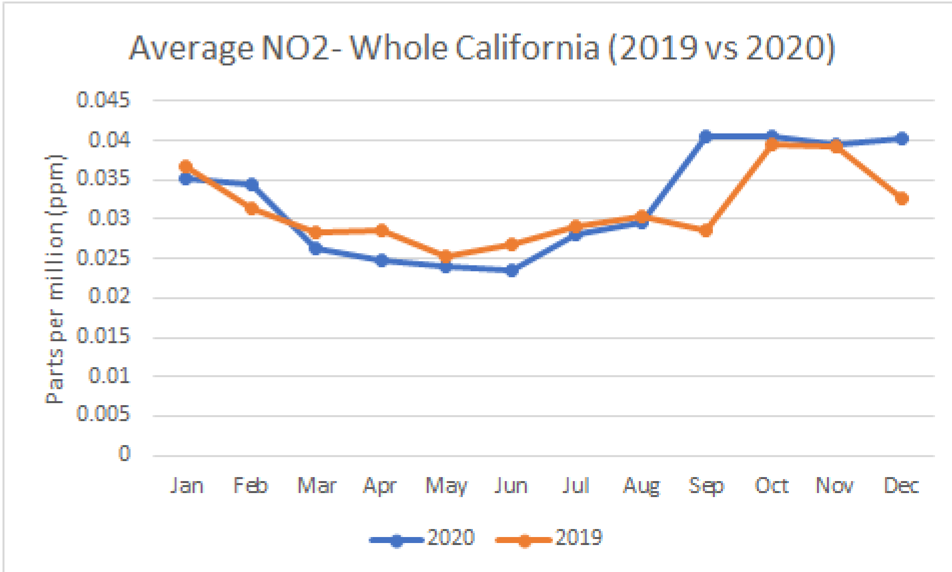

Figure 6: Nitrogen dioxide average monthly measurements for both years 2019 and 2020

Similarly to carbon monoxide, both graphs in figure 5 and 6 show a reduction pattern on emission during the months March to June. This data on nitrogen dioxide represents a 8% reduction in March, 14% reduction in April, 6% reduction in May, and 12% reduction in June. This pattern makes sense due to the low number of vehicles at the start of lockdown. However, the months of July to December represent when local restaurants, malls, and businesses start to open back up to the general public. As a result, nitrogen dioxide values in 2020 became very similar to 2019 due to similar vehicles operating and the transportation sector coming back to normal. Therefore, it can be concluded that both nitrogen dioxide and carbon monoxide follow identical trends due to the emission coming from vehicles' combustion; both figure 5 and 6 verify that the air quality did indeed become better at the start of lockdown.

3.1.4 Ozone (O3- 8 hr)

The last emission graph to be analyzed between 2019 and 2020 is ozone (O_3). Ozone is not emitted directly from any source but its concentration is still regulated; this is because ozone is a strong oxidant and is toxic when inhaled. Ground level O3 is considered one of the most harmful pollutants in terms of effects on human health. At 100ppb level, eyes and nose irritation will occur. At 2ppm level, severe coughing will start. As a result, the NAAQS has set the 8 hours average level to 75ppb [8]. Since ozone formation is dependent on sunlight, the graph in figure 7 shows how the concentrations are typically highest during the summer months.

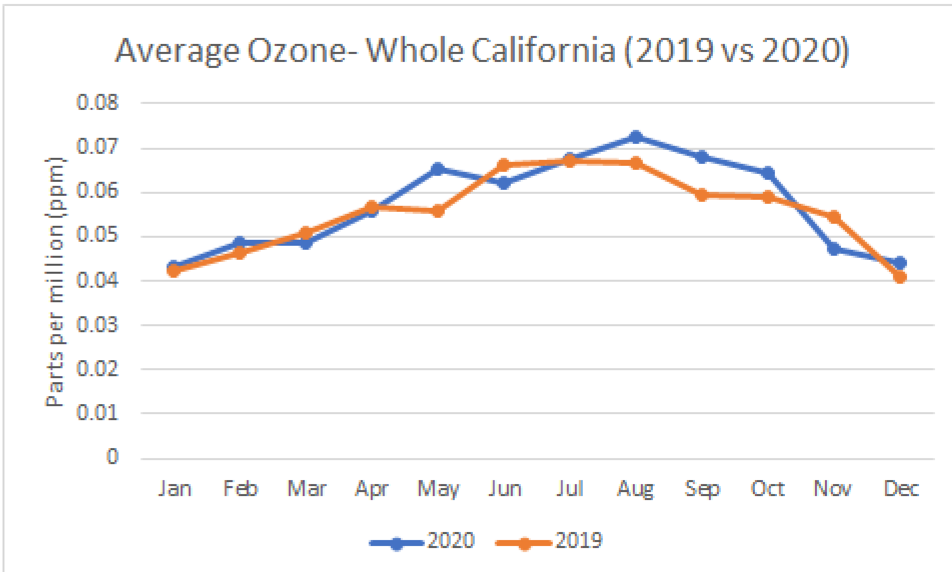

Figure 7: Ozone average monthly levels measurements for both years 2019 and 2020

Unlike emissions on carbon monoxide and nitrogen dioxide, levels on ozone did increase starting from the initial lockdown in March 2020. As seen in figure 7, there is an 18% increase in ozone levels during May, 9% increase in August, 14% increase in September, and 10% increase in October. In a recent paper, it was reported that O3 formation depends on the VOC-NOx ratio [21]. As a result, the reduction in NOx concentrations in figure 6 led to a higher VOC-NOx ratio and ultimately enhanced the O3 production. Furthermore, a reduction in PM2.5 at the start of lockdown resulted in higher solar radiation that favors O3 formation.

It is good to note that the non-linear VOC-NOx relation does not mean ozone will increase forever due to a decrease in NOx. Due to the nonlinear nature of the VOC-NOx graph in figure 8, ozone will eventually decrease.

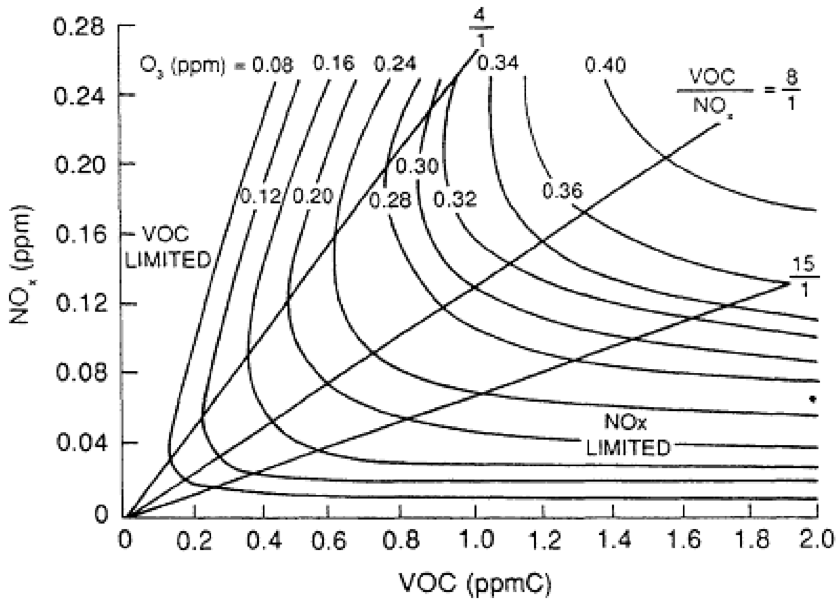

Figure 8: Nonlinear VOC-NOx relationship in a NOx vs VOC graph

3.2 PM 2.5: Wildfire Analysis

Wildfires produce a range of harmful pollutants, which can include cancer-causing substances to tiny particles that may harm the population's health. Among those pollutants tend to be particulate matter (PM2.5), which are very small smoke particles with diameters of 2.5 micrometers and smaller [1]. Due to their small size, these particles can easily get in the lungs and can even pass directly through the bloodstream. Health problems related to wildfire smoke can be mild as eye and lung irritant to serious heart and lung disease, including premature death.

Due to the increased large and intense fires in California in 2020, particularly the August Complex, SCU Complex, LNU complex, North Complex, and Creek fire, the air quality was reduced dramatically during the months of August through October [19]. CAL FIRE estimated that around 4 million acres were burnt, leading to heavy smokes pouring into the atmosphere.

This can be seen in figure 9, where the max PM2.5 concentration was recorded to be 660 micrograms per cubic meter on September 6th.

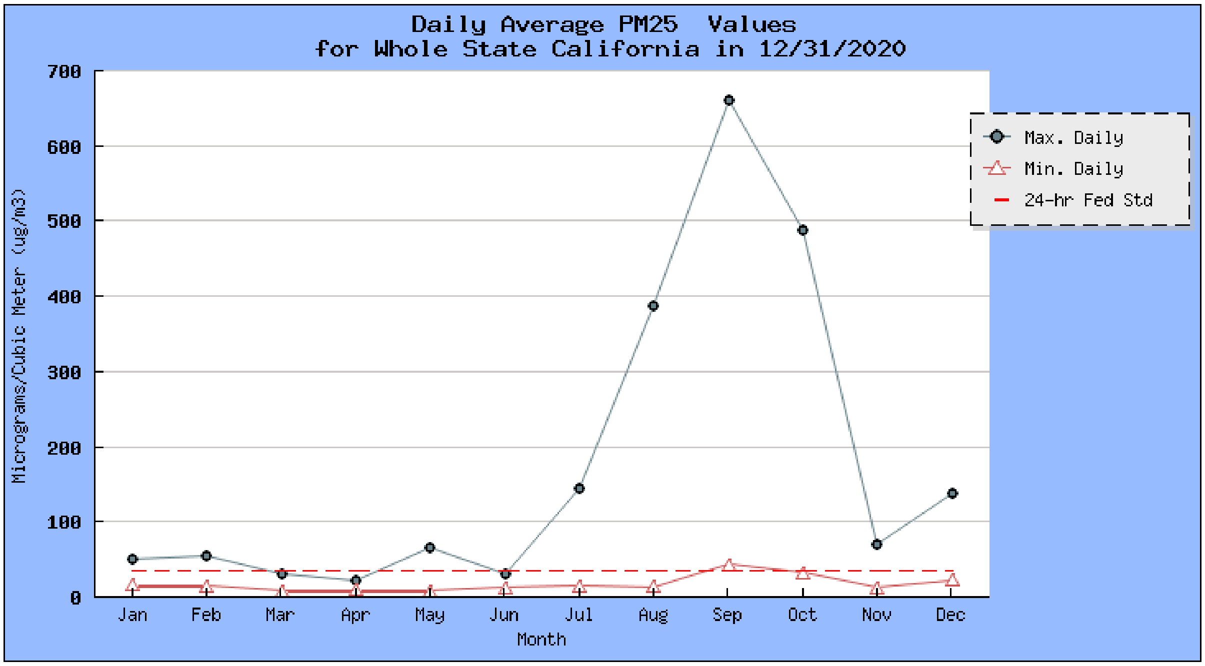

Figure 9: Visual representation of the max and min PM2.5 values during the year 2020

From the temperature data provided by the weather station in Southern California, the highest temperatures were seen during the months of July, August, and September. The temperature peaked on September 6th, where LA county exceeded 120 degrees [22]. The combination of the heat wave along with the influx of wildfires at the same time resulted in an average of 290 micrograms per cubic meter in September as seen in figure 4; this level is incredibly dangerous since the World Health Organization's safety guideline is set to only 10 ug/m^3 [23]. Compared to 2019, the concentration in particulate matter rose over 330% during September 2020. From the data on California's air quality, one can determine the intensity of the wildfires themselves.

Conclusion

It can be concluded that COVID-19 did reduce emissions on particulate matter, carbon monoxide, and nitrogen dioxide during the start of lockdown. During the months of March to June, particulate matter decreased by an average of 10% compared to 2019, carbon monoxide decreased by an average of 15%, and nitrogen dioxide decreased by an average of 10%. This is mostly caused by the decrease in transportation and daily outside activities due to regulations during the initial months. However, ozone did increase by 12% in 2020 due to the higher VOC-NOx ratio that enhanced the O3 production. However, ozone will eventually decrease due to this nonlinear VOC-NOx relationship.

Wildfires also impacted particulate matter greatly during the summer months between August to October. Due to the intense and widespread of several fires, much more smoke is produced, up to which particulate matter rose over 330% during September compared to 2019. Compared to the 10 ug/m^3 standard set by the World Health Organization, a PM2.5 reading of 660 ug/m^3 is astronomically high and considered hazardous by the EPA. This data trend can be seen in figure 10, 11, and 12, which represents Orange county, Riverside county, and LA county respectively.

Appendix

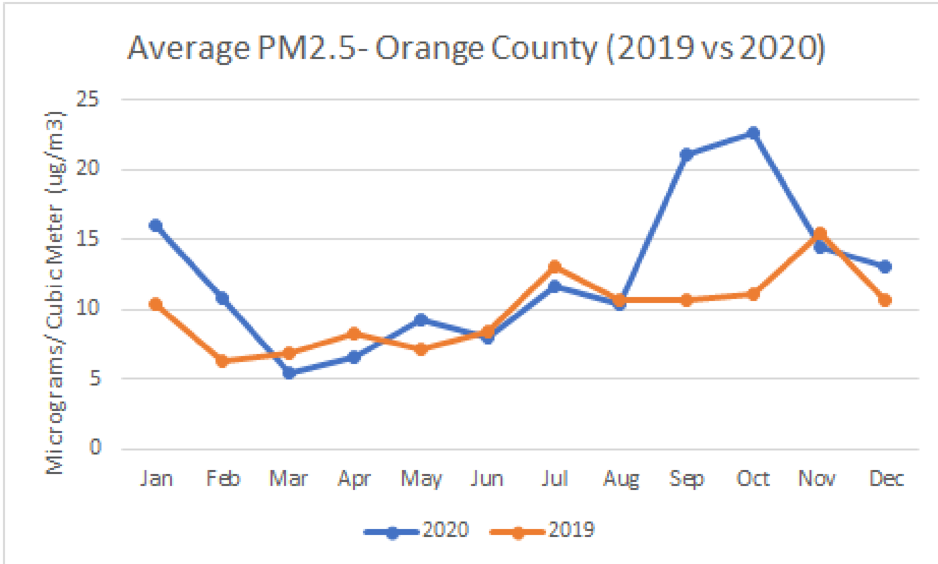

Figure 10: PM2.5 average monthly measurements in Orange County for 2019 vs 2020

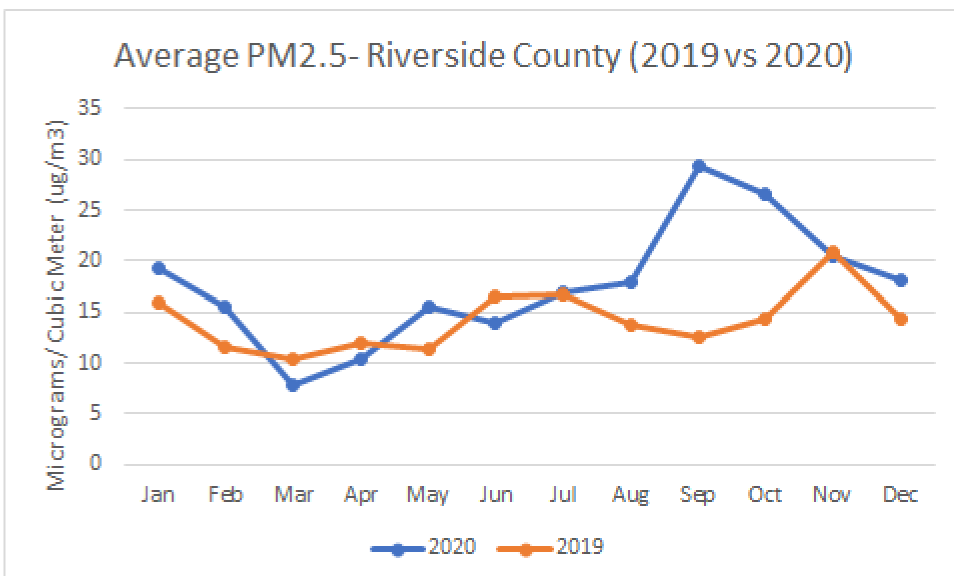

Figure 11: PM2.5 average monthly measurements in Riverside County for 2019 vs 2020

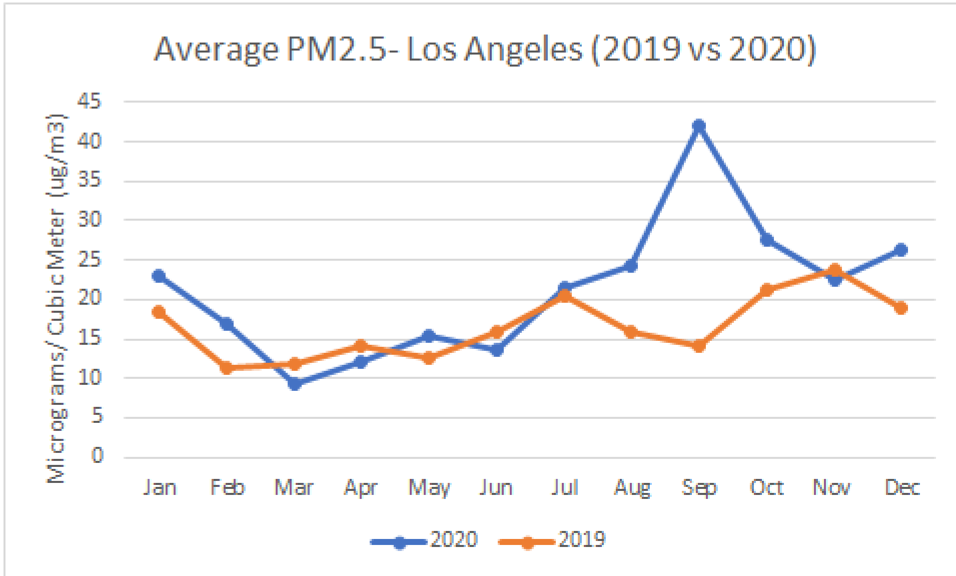

Figure 12: PM2.5 average monthly measurements in Los Angeles County for 2019 vs 2020

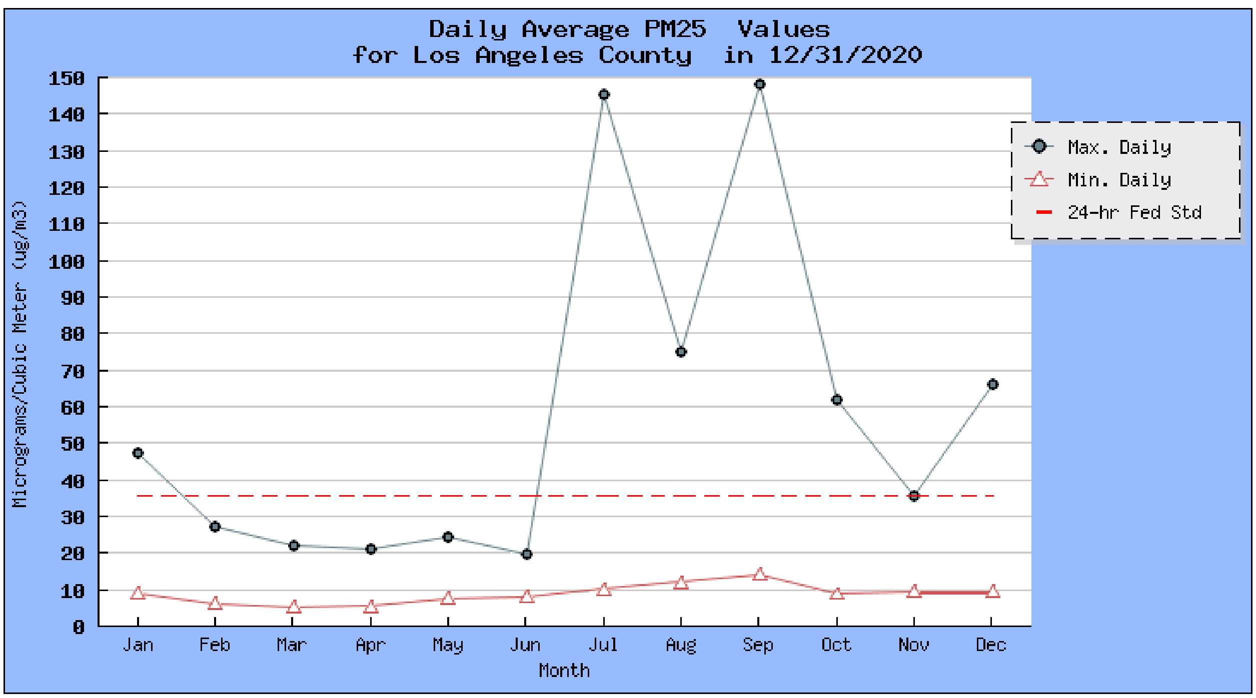

Figure 13: Visual representation of the max and min PM2.5 values in LA County 2020

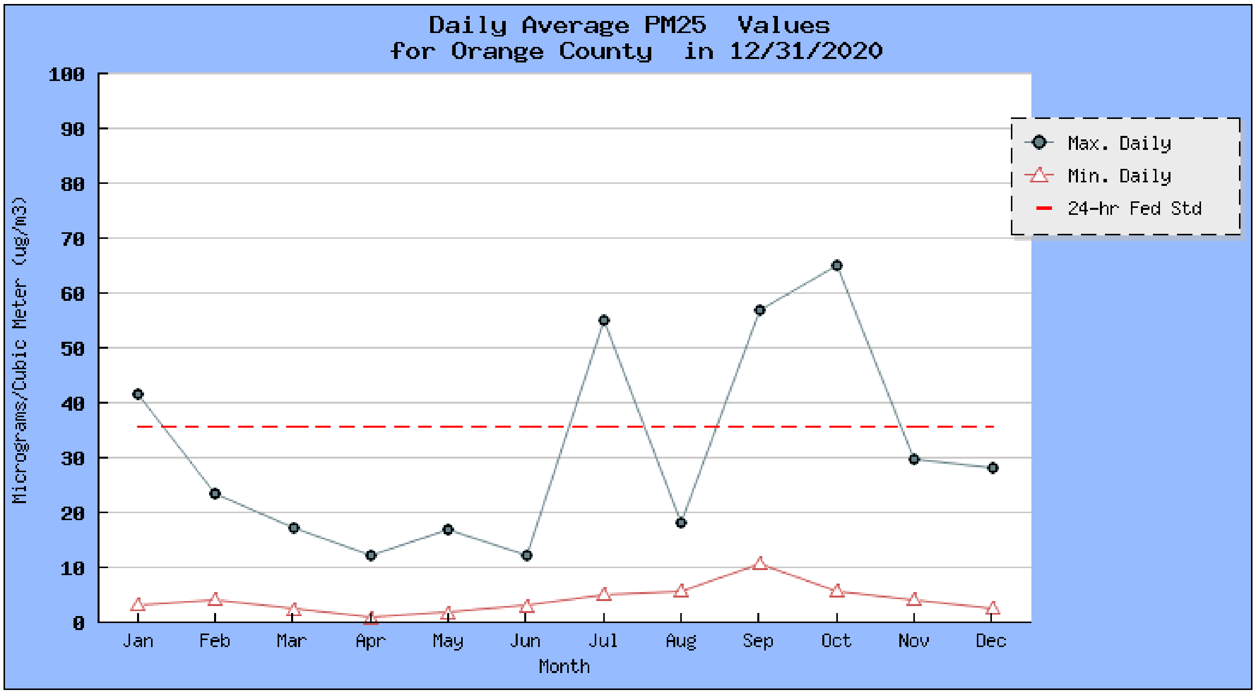

Figure 14: Visual representation of the max and min PM2.5 values in Orange County 2020

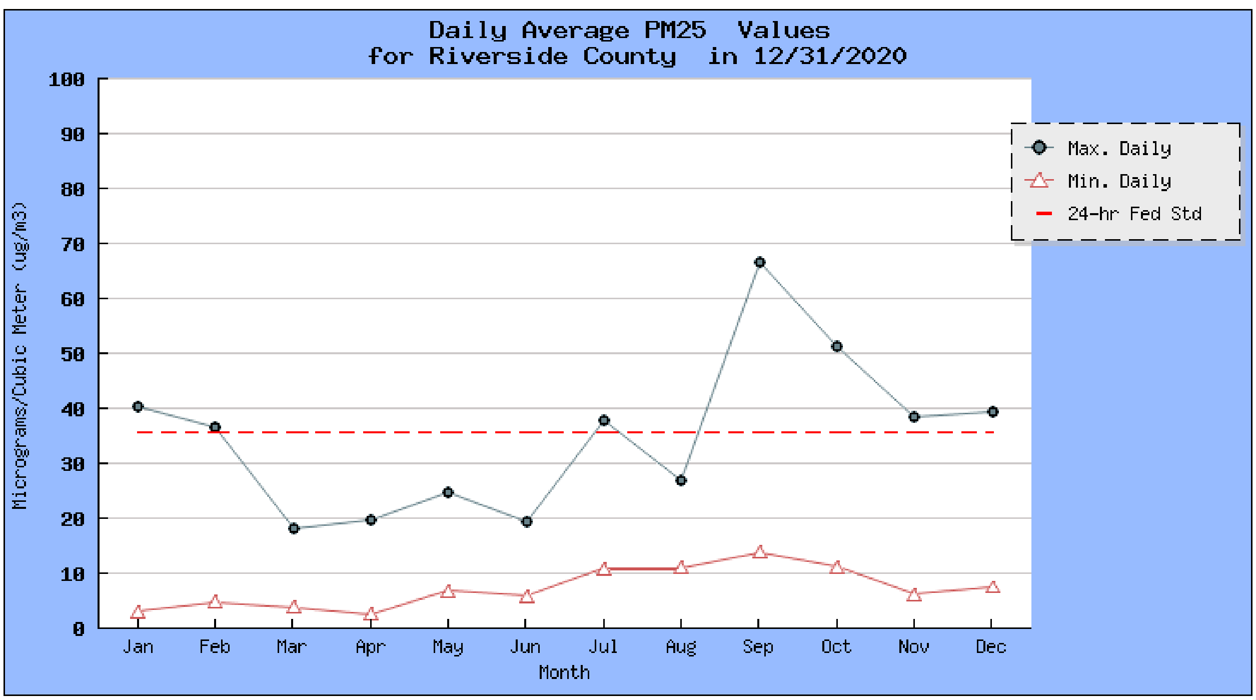

Figure 15: Visual representation of the max and min PM2.5 values in Riverside County 2020

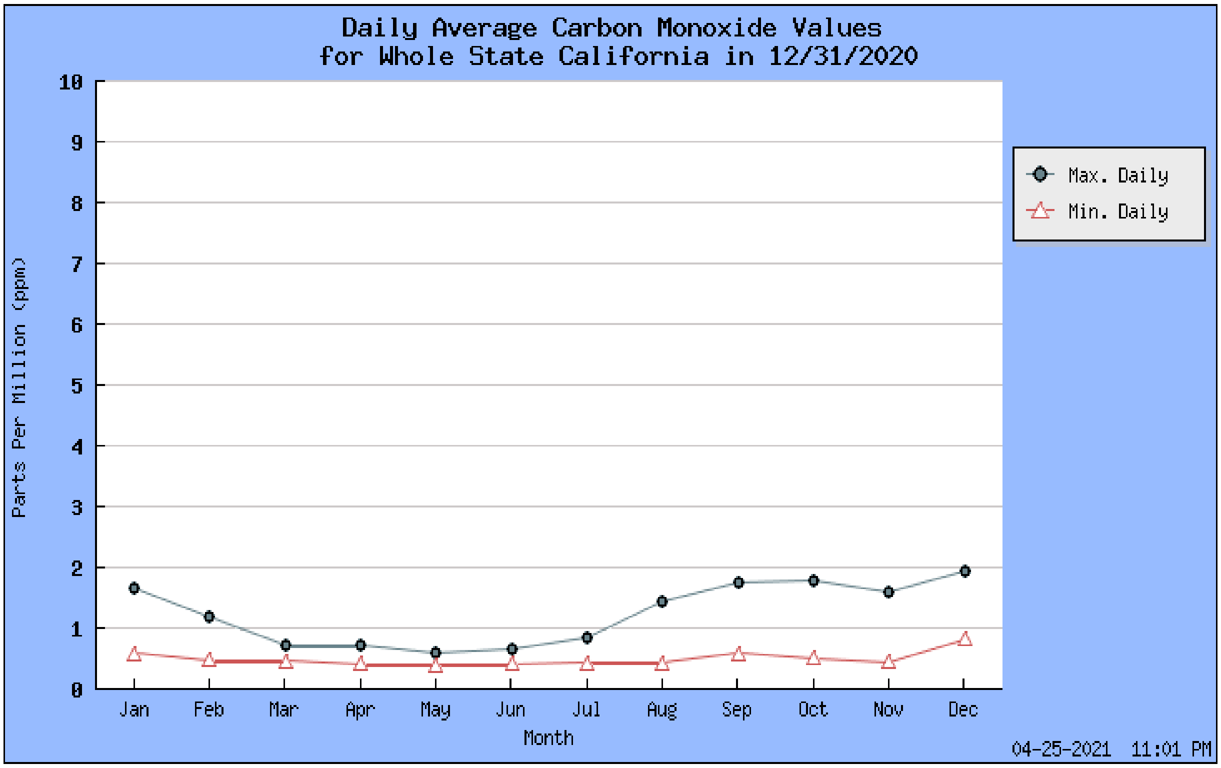

Figure 15: Visual representation of the max and min CO values in California 2020

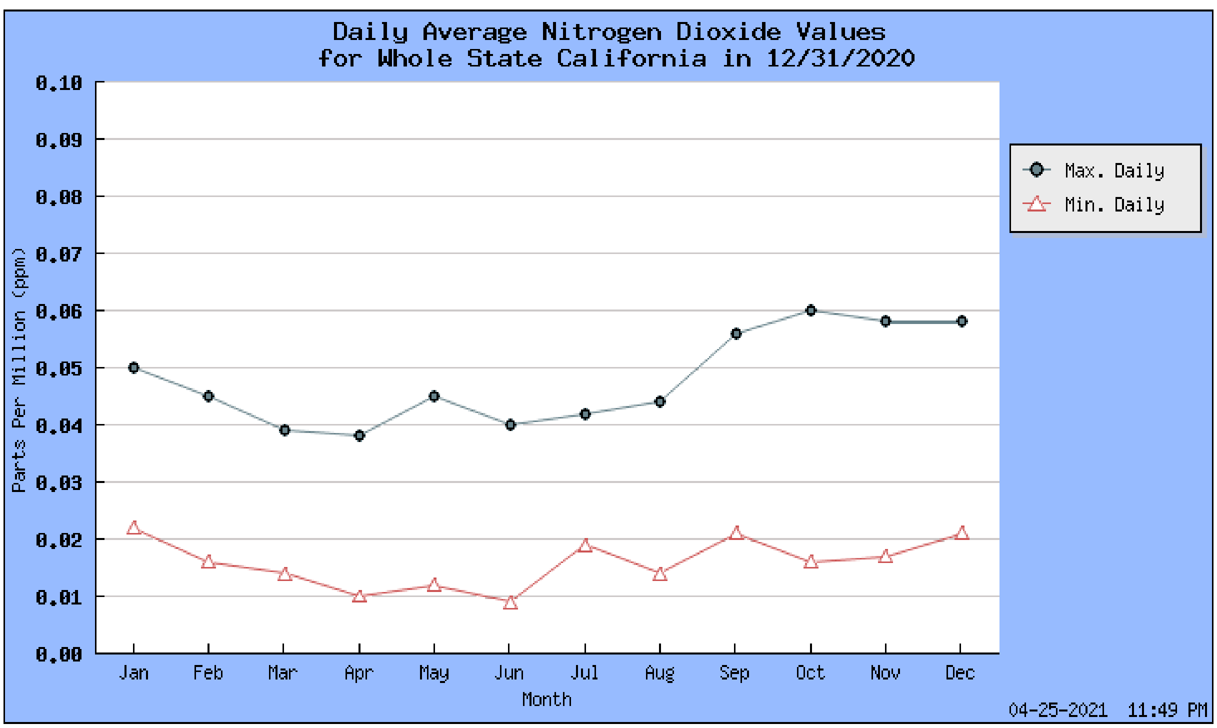

Figure 16: Visual representation of the max and min NO2 values in California 2020

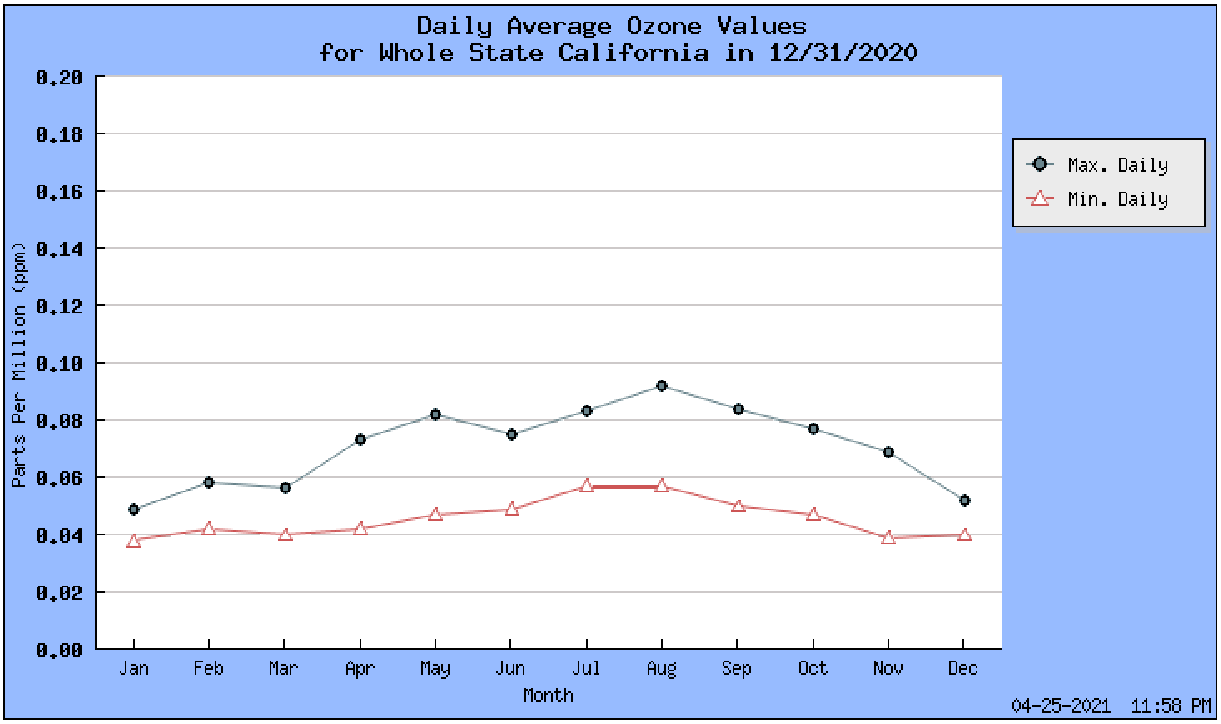

Figure 17: Visual representation of the max and min O3 values in California 2020

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