Impacts of the 2020 COVID-19 Shutdown Measures on Ozone Production in the Los Angeles Basin

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TOC Graphic

Abstract (186 of 200 words)

In the spring of 2020, unprecedented shifts in human activity in response to the COVID-19 pandemic led to observable changes in the natural environment, specifically air pollutant concentrations. In March and April 2020, the South Coast Air Basin of California (USA) experienced noticeable declines in on-road activity and primary traffic-related pollutant emissions. However, secondary ozone concentration trends were not consistent across the basin. The upwind site in Pasadena, CA experienced overall increases in maximum daily 8-hour ozone (MDA8) during the shutdown, whereas the downwind site in Crestline, CA experienced an overall decrease in MDA8. Typically, the highest MDA8 concentrations are observed at locations downwind of the Los Angeles city center, indicating a shift in the spatial peak of ozone production due to major decreases in precursor emissions during the COVID-19 shutdown. Higher temperatures in late April led to higher than average MDA8 concentrations in both locations. The COVID-19 shutdown provided a preview of the potential impacts of large scale emissions reductions strategies on ozone formation in the South Coast Air Basin. This study highlights the spatial shift in peak MDA8 that may accompany future mitigation efforts.

Introduction

On Thursday, March 19, 2020, California Governor Gavin Newsom mandated a shelter-at-home order with exceptions for essential functions, including but not limited to healthcare workers, emergency services, food and animal agriculture workers, energy sector support, water and wastewater support, and construction. The University of California, Davis Road Ecology Center estimated that traffic volumes were reduced by up to 60% on some California highways.[1] The Port of Los Angeles reported that cargo volume is 80% of normal (as of 5/2/2020), and the Port of Long Beach reported a slight decrease in first quarter cargo compared to the first quarter of 2019 (as of 5/2/2020). California energy demand has decreased by up to 9% in response to the shutdown of non-essential services.

The 2016 Air Quality Management Plan estimated that on- and off-road vehicles are responsible for 88% of nitrogen oxides (NOx) and 58% of volatile organic compound (VOC) emissions in the South Coast Air Basin (SoCAB) in 2012. Emissions in the Basin have been impacted during the 2020 COVID-19 shutdown, as a significant fraction of emitters are not operating at normal capacities. Recently released NASA images of surface-level nitrogen dioxide (NO_2) levels agree with the observed reductions in ground-level NO_2.[2] Of critical importance is the effect of these reductions in certain parts of a region where ozone levels are historically governed by emissions of VOCs, which is also known as a VOC-limited regime.[3,4]

Coastal Southern California experienced a wet March 2020 (4.11 in. at LAX), as reported by the California Nevada River Forecast Center. This led to frequent washout events in the Basin and obscured the impact of emissions reductions on ozone level. A warmer, drier April 2020 (2.68 in. at LAX) has provided a window to more clearly observe the nonlinear impacts of emissions reductions on ozone levels in the Basin. Consequently, it is hypothesized that reductions of on-road emissions led to higher ozone production in the western Basin, which was further exacerbated by increasing temperatures. To test the hypothesis, a generalized additive model (GAM) for maximum daily 8-hour average (MDA8) ozone was fit using meteorology and emissions as inputs for the 1990–2019 period at two key monitoring sites in SoCAB.[5,6]

Materials and Methods

Monitoring Site Descriptions

Data were obtained from the California Air Resources Board (CARB) Air Quality and Meteorological System Database in May of 2020 for a total of six monitoring locations in SoCAB. Two of the sites were used for GAM analysis. The first site is located in the central portion of the Basin in Pasadena, CA, 10 miles northeast of Los Angeles, and is classified here as an upwind urban background site (**Figure 1**). The second site is located downwind of the urban areas in the San Bernardino Mountains in Crestline, CA. It is important to note that Crestline was designated as the 8-hour ozone design value site in 2017 (112 ppb) and 2018 (111 ppb), indicating that Basin-wide ozone concentrations peaked in the eastern mountains during those ozone seasons, as found before.[7]

Four additional sites were used to understand the impacts of traffic reductions at near road and non-near-road locations. Anaheim and Ontario (at Etiwanda Avenue) are near road sites that monitor along major highways, I-5 and CA-60, respectively. Azusa and San Bernardino are non-near-road sites and represent urban background locations. Azusa is approximately 1 mile from a major highway (I-210). The San Bernardino site is located near a large railyard and is heavily influenced by heavy-duty vehicle traffic that services the railyard.

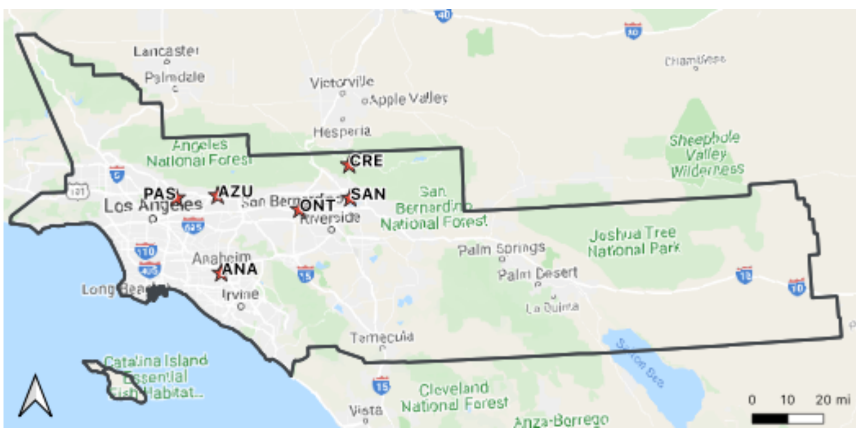

Figure 1. Map of the South Coast Air Quality Management District boundary (black) in Southern California. *Source: Google Maps*.

Modeled Predictions

The 1990-2019 GAM predicted daily March and April 2020 MDA8. Meteorological inputs include daily maximum temperature and average wind speed at Los Angeles International and Barstow-Daggett Airports, representative weather stations for Pasadena and Crestline, respectively; 12Z (0400 PST) 500 mbar wind speed and temperature, 850 mbar wind speed and direction, and 850 mbar dew point temperature and relative humidity at the Miramar weather station in San Diego, CA. Other model inputs include basin-wide NOx and reactive organic gas (ROG) emissions (historical and projected) from CARB, maximum solar radiation (SR), ENSO index, day of year (DOY), and day of week (DOW). Equations 1 and 2 represent the GAM for daily MDA8 for Pasadena and Crestline, respectively. Terms beginning with “ns” indicate natural cubic spline terms with the number of knots indicated within the parentheses; terms beginning with "bc" indicate circle spline with the number of knots and the period also indicated; "fv" indicates a factor variable.

$$MDA8_{Pasadena} = ROG^2 + NOx^2 + (NOx \times ROG) + ns(NOx, 3) + ns(ROG, 3) + ns(T_{max-Bar}, 3) + ns(T_{max-LAX}, 3) + ns(\overline{WS}_{Bar}, 3) + ns(\overline{WS}_{LAX}, 3) + ns(SR_{max}, 3) + bc(WD_{500-Mir}, 4, 360) + bc(WD_{850-Mir}, 4, 360) + WS_{850-Mir} + ns(DewT_{850-Mir}, 3) + ns(RH_{850-Mir}, 3) + ENSO + ns(DOY) + fv(DOW) \quad (1)$$

$$MDA8_{Crestline} = ns(NOx, 3) + ns(ROG, 3) + ns(T_{max-Bar}, 3) + ns(T_{max-LAX}, 3) + ns(\overline{WS}_{Bar}, 3) + ns(\overline{WS}_{LAX}, 3) + ns(SR_{max}, 3) + bc(WD_{500-Mir}, 4, 360) + ns(WS_{850-Mir}, 3) + ns(DewT_{850-Mir}, 3) + ns(RH_{850-Mir}, 3) + ns(T_{500-Mir}, 3) + ENSO + ns(DOY) + fv(DOW) \quad (2)$$

Observed (O) and predicted MDA8 for March and April 2020 were compared to the 2017–2019 average observed MDA8 to understand deviations from typical MD8A for this time of year. Three prediction scenarios of March and April 2020 MDA8 were simulated: CARB-projected 2020 emissions (P); projected emissions without on-road contributions, reflecting a basin-wide 50% reduction of total NOx and 30% reduction of total ROGs (R); and reduced emissions scenario with the 2017-2019 average temperature as counterfactual temperatures (T). Scenario P estimates the business as usual (BAU) case, scenario R simulates the impact of completely removing on-road emissions, and scenario T estimates the impact of both temperature deviations and reduced emissions.

Results and Discussion

Observed Trends

Reductions in traffic volumes during the March and April 2020 shutdown period led to observed reductions in near-road traffic-related air pollutants, most notably for carbon monoxide (CO). Diurnal profiles for the Anaheim near road site suggest that the monthly averaged (CO) concentrations were below the typical range of variability compared to the 2017-2019 average, and differences were comparable to those found between companion near-road and non-near-road locations (**Figure 2**).[8] CO concentrations were lower than the 2017-2019 average but within the range of variability at the Ontario near road location. As a result, it is conjectured that there was a greater reduction of commuters on the I-5 freeway (Anaheim) compared to CA-60 (Ontario), which services a region of the Basin with more essential workers. San Bernardino CO was also below the 2017-2019 range of variability. Evening CO at Azusa was outside the 2017-2019 range of variability in April, however March concentrations were lower and within the range of variability. Reductions in NOx concentrations were lower than the 2017-2019 average but within the range of variability for March and April at all locations, with the exception of Anaheim near road evening concentrations in April, 6:00-8:00 PM at Ontario, and 5:00-8:00 PM at Azusa (**Figure 3**).

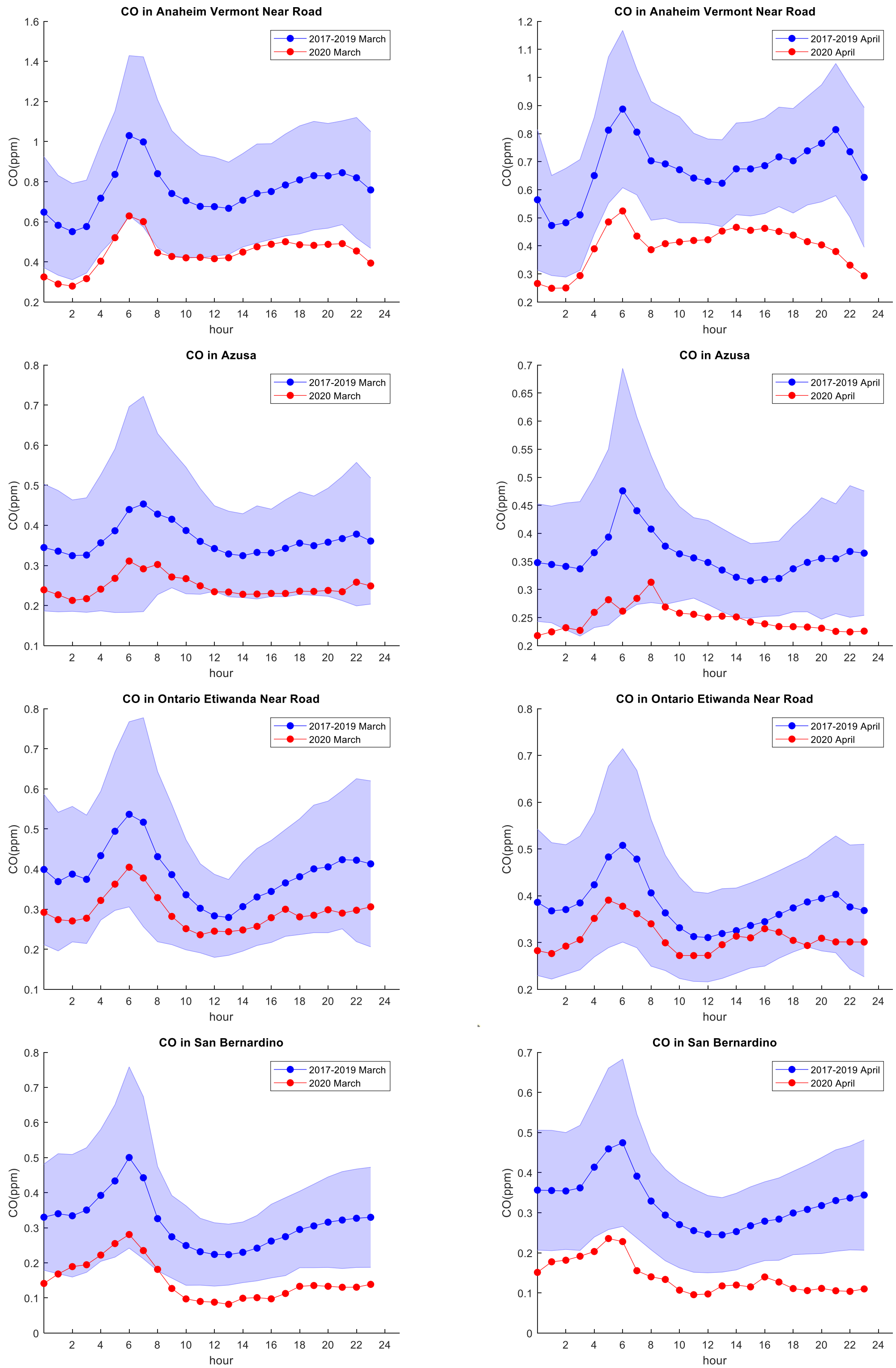

Figure 2. Monthly averaged diurnal profiles of 2017-2019 (blue) and 2020 (red) CO concentrations (ppm) at Anaheim (near road), Azusa, Ontario, and San Bernardino for March (left) and April (right). The shaded area is the standard deviation of the 2017-2019 measurements.

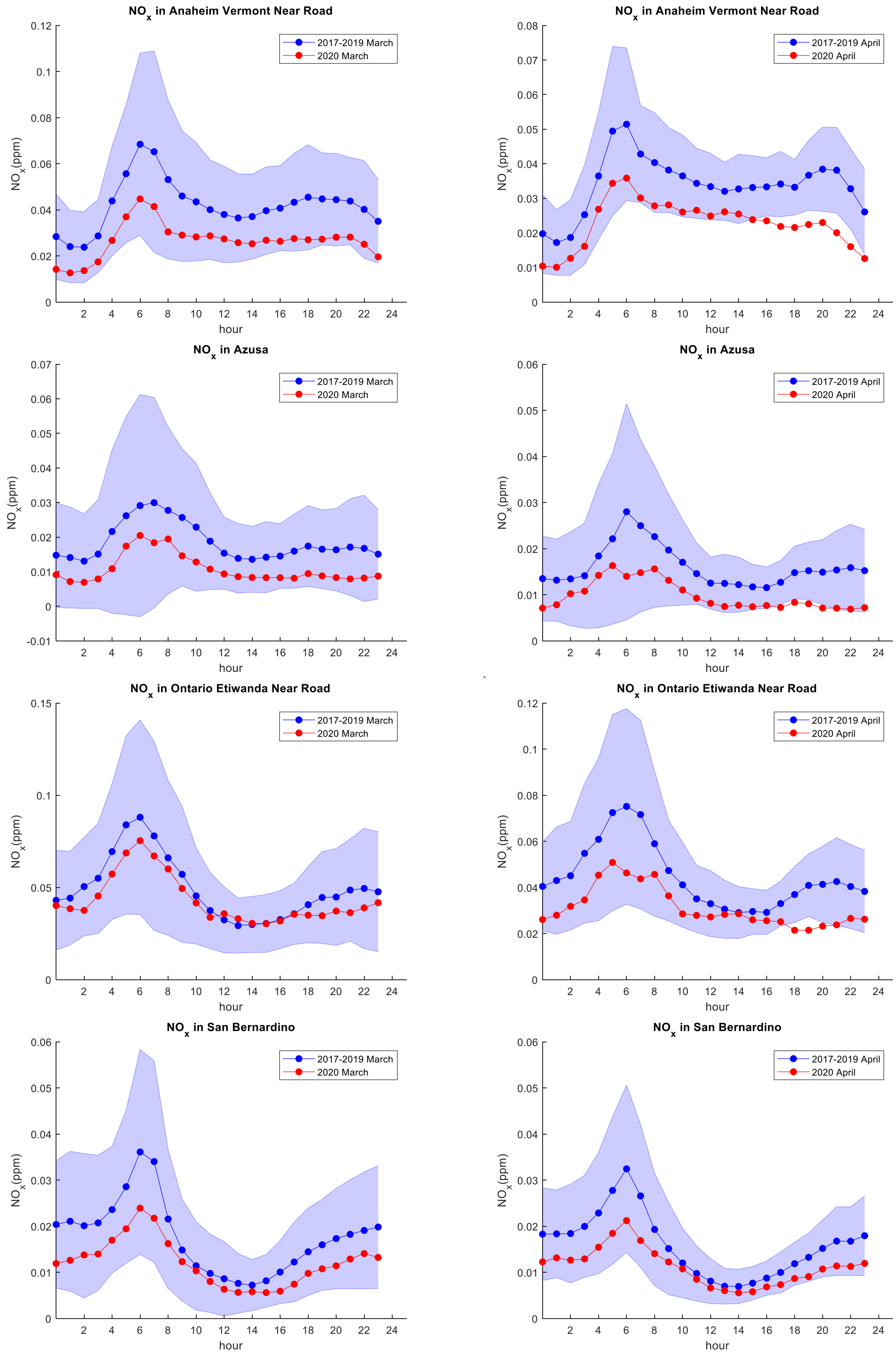

Figure 3. Monthly averaged diurnal profiles of 2017-2019 (blue) and 2020 (red) NOx concentrations (ppm) at Anaheim (near road), Azusa, Ontario, and San Bernardino for March (left) and April (right). The shaded area is the standard deviation of the 2017-2019 measurements.

Modeled Predictions

GAM MDA8 performance for the 1990-2019 period was optimal with a correlation of $r = 0.65$ for both Pasadena and Crestline and mean biases of -0.11 and -0.09 ppb, respectively (see Supplementary Material for other model performance metrics). Temporal trends in GAM predictions of March and April 2020 MDA8 at Pasadena ($r = 0.88$) and Crestline ($r = 0.88$) are generally well-captured using BAU emissions (**Figure 4**). For Pasadena, average MDA8 deviations from the 2017-2019 average were 3.72 ± 14.6 (O), 4.95 ± 17.4 (P), -5.90 ± 14.4 (R), and -6.73 ± 11.0 ppb (T). Observed and BAU deviations indicate that ozone is higher than expected for this time of year. MDA8 for both the R and T scenarios were lower than 2017-2019 MDA8, indicating that the absence of on-road contributions is predicted to reduce ozone levels. Interestingly, observed and predicted BAU MDA8 was higher than normal in late April due to the compounding effects of high temperatures and emissions reductions (R & T). On average, it is estimated that emissions reductions explain 92% of MDA8 deviations while temperature deviations explain 8% of MDA8 deviations (0.4 ºC average temperature increase in 2020 vs. 2017-2019). Further, NO_2 was lower than the 2017-2019 average during much of the shutdown.

For Crestline, average MDA8 deviations from the 2017-2019 average were -4.85 ± 15.2 (O), -1.50 ± 13.5 (P), -4.37 ± 12.8 (R), and -4.93 ± 8.4 ppb (T), indicating that MDA8 is lower than usual for this time of year. The R and T scenarios trend well with observations. Similar to Pasadena, late April observations and predictions were higher due to meteorology conducive to ozone formation. On average, it is estimated that emissions reductions explain 84% of MDA8 deviations while temperature deviations explain 16% of MDA8 deviations (2.1 ºC average temperature reduction in 2020 vs. 2017-2019).

Implications and Uncertainties

These findings have several implications. Pasadena experienced higher than expected ozone, even after correcting for meteorology, and reduced NO_2 during the shutdown. The emissions reduction simulation provides (R) an insightful analysis of the impact of reducing on-road contributions. Actual on-road emissions reductions are uncertain and not completely eliminated by shutdown activities, and therefore would not lead to the ozone impacts simulated by the emissions reduction scenario (R). Crestline is typically influenced by upwind urban emissions but experienced lower than expected ozone. Results elucidate a shutdown-induced westward spatial shift in peak MDA8, which is closer to the Los Angeles city center compared to normal peak location in the eastern Basin. Higher than normal temperatures at the end of April led to higher than usual ozone levels in both locations. Continued temperature anomalies are likely to exacerbate ozone during the 2020 ozone season.[9]

While significant emissions and ozone design value reductions have been achieved over the past several decades in SoCAB, changes in human activities and how the changes interact with meteorology can interfere with these achievements. Emissions of NOx, an important ozone precursor, decreased but those decreases were within the range of variability observed over the previous three years. Therefore, future ozone mitigation may require even larger emissions reductions than those observed in March and April 2020 to overcome meteorologically driven ozone exacerbation and bring SoCAB into attainment of the 8-hour NAAQS.

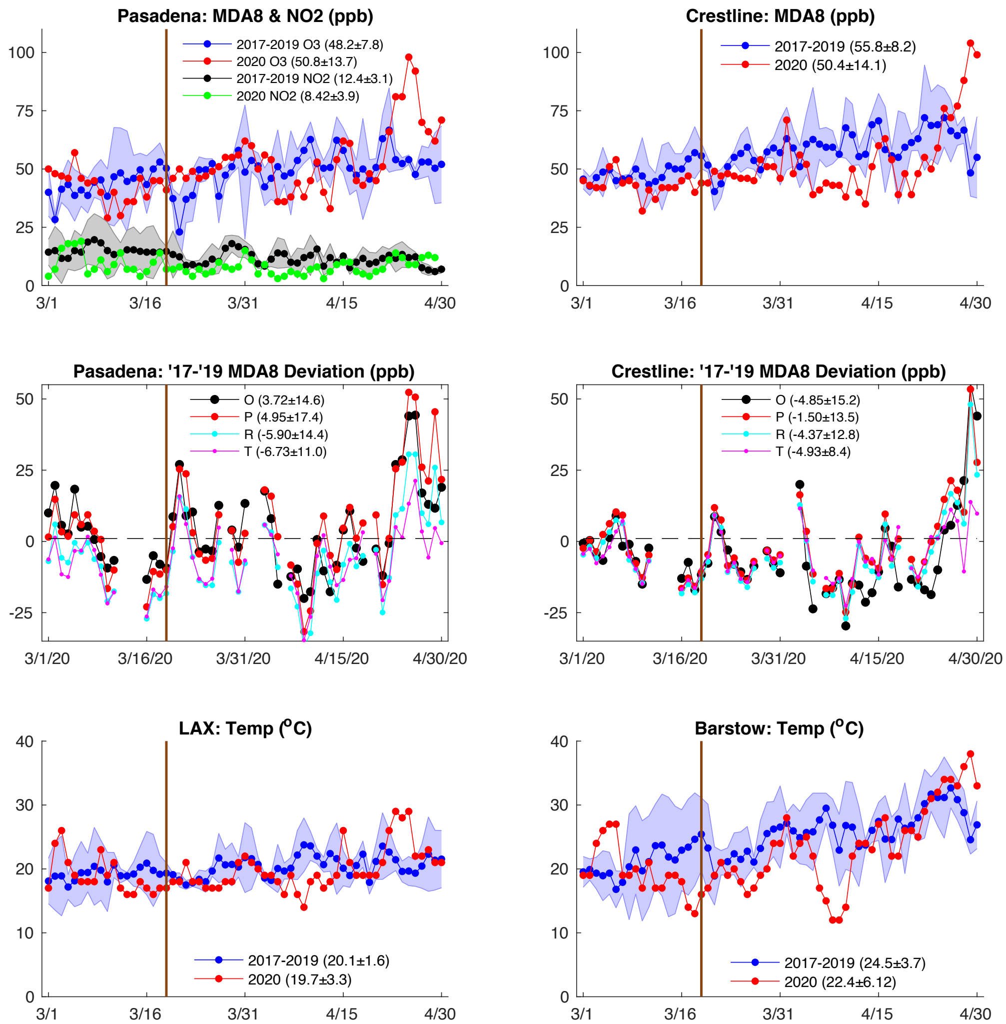

Figure 4. *Top*: Observed MDA8 at Pasadena (with NO_2) and Crestline. *Middle*: Mean and standard deviations of observed (O) and modeled (P, R, and T described in text) MDA8 deviations from the 2017-2019 average. *Bottom*: Daily maximum temperature at Los Angeles International and Barstow-Daggett Airports. (*Vertical line at March 19th*)

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Supplementary Material

Table S1: GAM Model Performance for the 1990-2019 MDA8 simulation

	OBS (ppbV)	SIM (ppbV)	R^2	Mean Bias (ppbV)	RMSE	NMSE	# of Days	Frac. Bias	Factor of 2
Pasadena	44.86	44.74	0.65	-0.11	9.47	0.35	1582	0.0025	0.99
Crestline	56.45	56.36	0.65	-0.09	9.43	0.35	1616	0.0016	1.0