Modeling the Impact of COVID-19 on Air Quality in Southern California: Implications for Future Control Policies

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Figures S1 to S5

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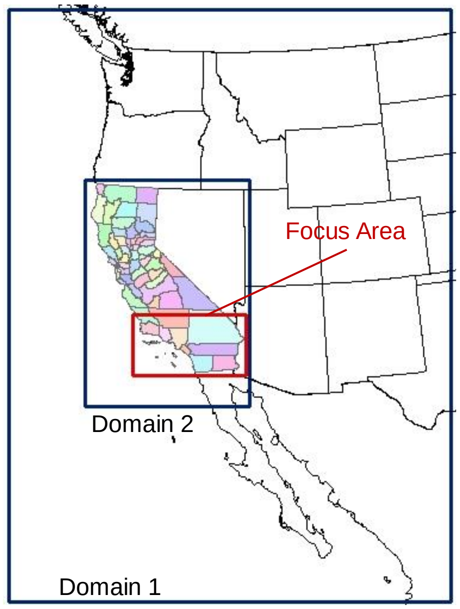

Figure S1. Simulation domains of this study. The red rectangle denotes the area of southern California where most analyses in this study focus on.

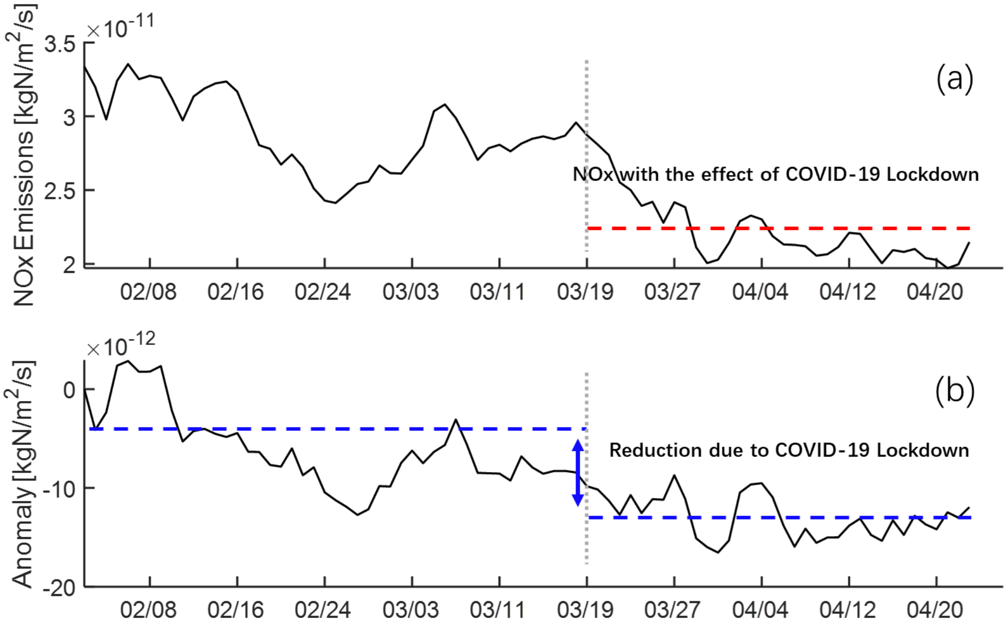

Figure S2. Satellite-derived NO_x emission estimates in southern California. (a) Daily NO_x emissions from February 1 to April 23, 2020. The red line represents the average emissions during the period after March 19. (b) NO_x emission changes due to the COVID-19, which is quantified using the difference between the real-world NO_x emissions and the emissions in a hypothetical scenario without considering the COVID-19. The emissions in the hypothetical scenario is estimated based on emission trends in prior years (2017–2019), using February 1 as a reference. The difference between two blue dashed lines represents the average reductions of NO_x emissions induced by the COVID-19 lockdown measures that took effect on March 19. The local valley between February 24 and March 3 is caused by retrieval uncertainties caused by unfavorable meteorology conditions and is thus excluded when we estimate the average NO_x emissions before the lockdown.

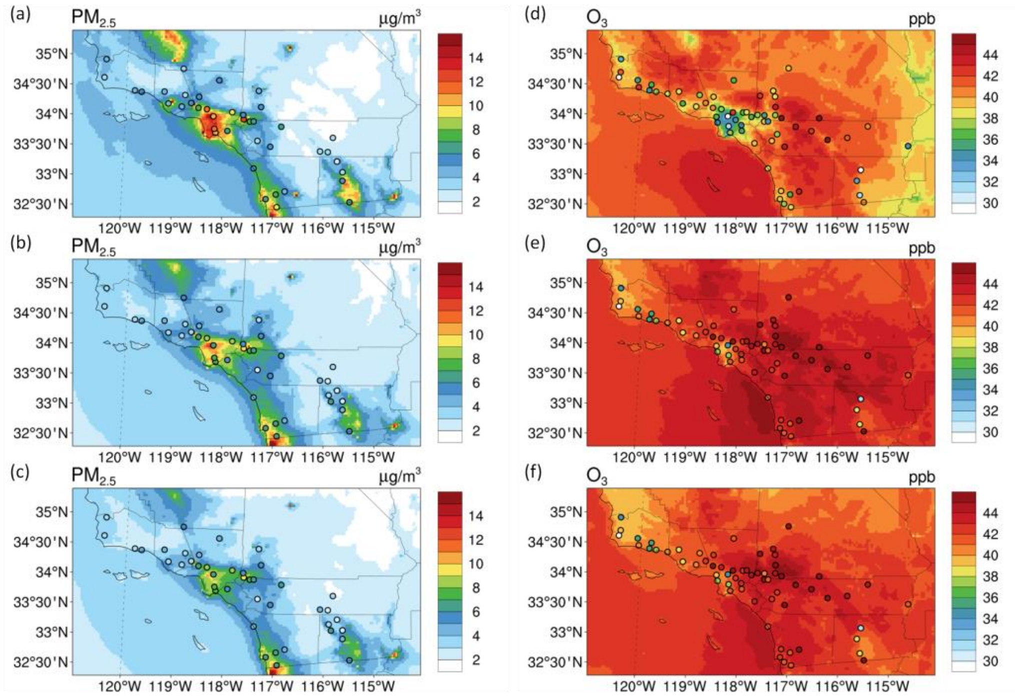

Figure S3. Overlay plots of the simulated (contour) and observed (circles) $PM_{2.5}$ and MDA8 O_3 concentrations in southern California. (a-c) are for $PM_{2.5}$ and (d-f) are for MDA8 O_3. (a, d) are for the pre-lockdown period (February 18 to March 18) under the Base scenario (Pre_{Base}); (b, e) are for the lockdown period (March 19 to April 23) under the Base scenario ($Post_{Base}$); (c, f) are for the lockdown period under the Lockdown scenario ($Post_{Lockdown}$).

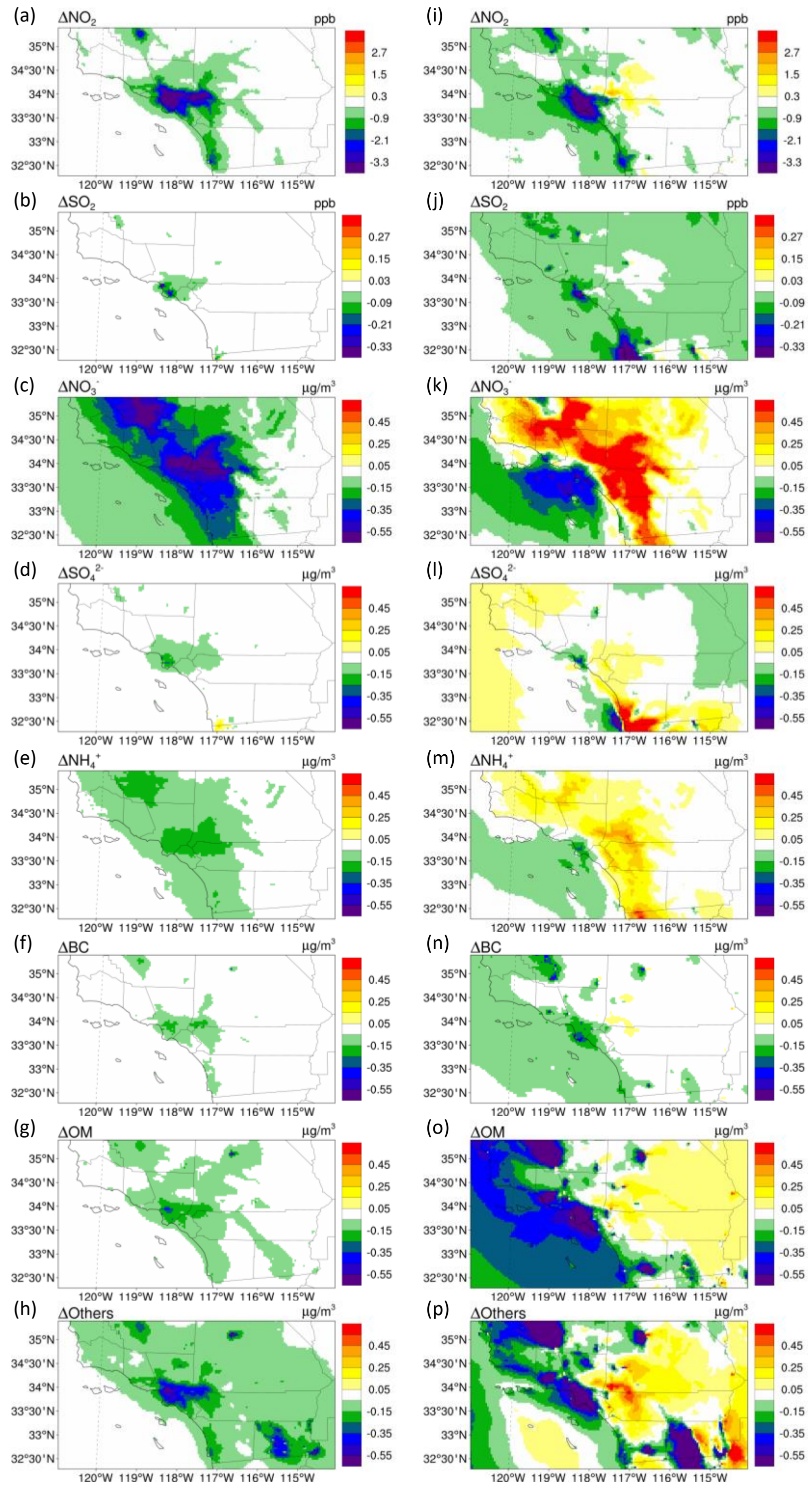

Figure S4. The same as Figs. 2e-h in the main text but for NO_2, SO_2, and different $PM_{2.5}$ chemical components.

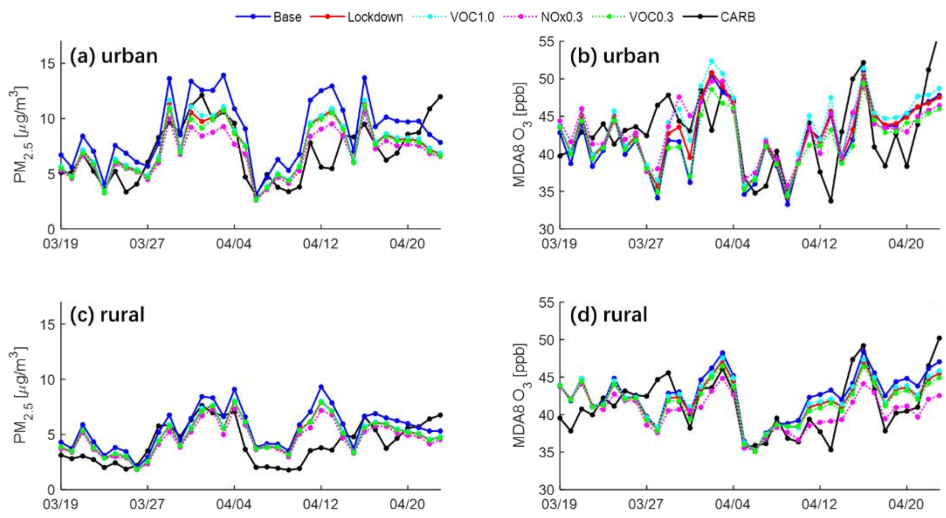

Figure S5. Time series of simulated and observed $PM_{2.5}$ concentrations (a, c) and MDA8 O_3 concentrations (b, d) under several sensitivity scenarios averaged across the CARB observational stations over the urban (a, b) and rural (c, d) areas of southern California during the lockdown period (March 19 to April 23). Black lines are surface observations from CARB networks. Blue, red, cyan, magenta, and green lines are simulated results for the Base, Lockdown, VOC1.0, NO_x0.3, and VOC0.3 scenarios. The definitions of all scenarios are summarized in Table S1.

Table S1. Summary of model scenarios developed in this study.

Scenario	Definition
Base	This scenario uses the default CARB emission inventory without considering the emission reductions induced by the COVID-19 lockdown. It provides a baseline for evaluating the effect of COVID-19 lockdown on air quality.
Lockdown	This scenario adjusts the CARB emission inventory to account for the emission reductions due to the COVID-19 lockdown. The difference between “Base” and “Lockdown” represents the effect of the COVID-19 lockdown.
VOC1.0	This scenario is the same as “Lockdown” except that the VOC emissions are kept at the level of the “Base” scenario. It is used to evaluate the relative contribution of VOC and NO_x reductions to COVID-19 induced O_3 concentration changes.
NO_x0.3	This scenario is the same as “Lockdown” except that the NO_x emissions are further reduced to 30% of those in the “Base” scenario. It is used to assess the potential effects of strengthened NO_x control measures.
VOC0.3	This scenario is the same as “Lockdown” except that the VOC emissions are further reduced to 30% of those in the “Base” scenario. It is used to assess the potential effects of strengthened VOC control measures.

Table S2. The percentage of changes in air pollutant emissions during the COVID-19 lockdown relative to a hypothetical scenario without the lockdown.

	VOC	**CO**	**NO_X**	**SO_X**	**PM_{10}**	**$PM_{2.5}$**	**NH_3**
Onroad transportation	-50%	-51%	-39%	-35%	-44%	-42%	-51%
Off-road transportation	-30%	-30%	-30%	-30%	-30%	-30%	-30%
Aircraft	-70%	-70%	-70%	-70%	-70%	-70%	-70%
Power plants	-7%	-7%	-7%	-7%	-7%	-7%	-7%
Industrial	-15%	-15%	-15%	-15%	-15%	-15%	-15%
Residential	10%	10%	10%	10%	10%	10%	10%
Commercial	-15%	-15%	-15%	-15%	-15%	-15%	-15%
Agriculture	0%	0%	0%	0%	0%	0%	0%

Table S3. Evaluation of meteorological simulation results as compared to observational data from the National Climatic Data Center.

Variable	**Index**	**Value**	**Ref[a]**	**Variable**	**Index**	**Value**	**Ref[a]**
Wind speed (m/s)	Mean observation	3.92		Temperature (K)	Mean observation	287.48	
	Mean simulation	3.69			Mean simulation	287.21	
	Mean Bias	-0.22	≤ ±0.5		Mean Bias	-0.28	≤ ±0.5
	Gross error	1.43	≤2		Gross error	1.76	≤2
	IOA[b]	0.76	≥0.6		IOA	0.93	≥0.8
Wind direction (deg)	Mean observation	243.45		Humidity (g/kg)	Mean observation	6.41	
	Mean simulation	232.90			Mean simulation	6.16	
	Mean Bias	1.48	≤ ±10		Mean Bias	-0.25	≤ ±1
	Gross error	44.53	≤30		Gross error	0.83	≤2
					IOA	0.84	≥0.6

[a] The reference values are taken from Emery et al. (2001).
[b] IOA = Index of Agreement.