

Supplementary Materials:

Lynsey Karen Parker, Jeremiah Johnson, John Grant, Pradeepa Vennam, Rajashi Parikh, Chao-Jung Chien and Ralph Morris *

Section S1. WRF Details

This section provides additional WRF details. WRF physics options are shown in Table S1-1. WRF performance benchmarks are provided in Table S1-2. The WRF model performance was typical for a good WRF application. The upper air temperature at the 850 mb pressure level (T850 mb) was evaluated against observed upper-air soundings from San Diego (Marine Corps Air Station Miramar; KNKX) and the Vandenberg Air Force Base (KVGB) and performance was good. When averaged across all sites in the SoCAB the WRF monthly surface meteorological performance met the most stringent simple model performance benchmarks except for temperature bias that fell between the simple and complex benchmarks. The WRF surface performance at some individual sites was not as good although it usually met the complex benchmarks and frequently met the simple benchmarks., , and WRF surface model performance plots for five sites within the basin: KLAX, KLGB, KSNA, KONT, KSBD, are shown in Figures S1-S5. Table S1-3 presents monthly mean bias and error of T805 mb for two upper air sites in the region KNKX and KVGB.

Table S1-1. WRF physics options used in the SoCAB 12-km and 4-km modeling

WRF Physics Option	Option Selected	Notes
Vertical Coordinate System	Hybrid Sigma-Pressure	Hybrid Sigma-Pressure coordinate (Park et al., 2019)
Microphysics	WRF Single-Moment 6-class (WSM6)	A scheme with ice, snow and graupel processes suitable for high-resolution simulations.
Longwave Radiation	RRTMG	Rapid Radiative Transfer Model. An accurate scheme using look-up tables for efficiency. Accounts for multiple bands, and microphysics species.
Shortwave Radiation	RRTMG	Rapid Radiative Transfer Model. An accurate scheme using look-up tables for efficiency. Accounts for multiple bands, and microphysics species.
Surface Layer Physics	MM5 similarity	Based on Monin-Obukhov with Carslon-Boland viscous sub-layer and standard similarity functions from look-up tables
LSM	Noah	NCEP/NCAR land surface model with soil temperature and moisture in four layers, fractional snow cover and frozen soil physics.
PBL scheme	Yonsei University (YSU)	Non-local-K scheme with explicit entrainment layer and parabolic K profile in unstable mixed layer
Cumulus parameterization	MSKF WRF	Multi-Scale Kain-Fritsch (MSKF) cumulus parameterization includes feedback of subgrid cloud information to the radiation schemes.

Table S1-2. WRF Model Performance Benchmarks.

Parameter	Emery et al. (2001)	Kemball-Cook et al. (2005)	McNally (2009)
Conditions	Simple	Complex	Complex
Temperature Bias	$\leq \pm 0.5$ K	$\leq \pm 2.0$ K	$\leq \pm 1.0$ K
Temperature Error	≤ 2.0 K	≤ 3.5 K	≤ 3.0 K

Parameter	Emery et al. (2001)	Kemball-Cook et al. (2005)	McNally (2009)
Humidity Bias	$\leq \pm 0.8$ g/kg	$\leq \pm 1.0$ g/kg	$\leq \pm 1.0$ g/kg
Humidity Error	≤ 2.0 g/kg	≤ 2.0 g/kg	≤ 2.0 g/kg
Wind Speed Bias	$\leq \pm 0.5$ m/s	$\leq \pm 1.5$ m/s	(not addressed)
Wind Speed RMSE	≤ 2.0 m/s	≤ 2.5 m/s	(not addressed)
Wind Dir. Bias	$\leq \pm 10$ degrees	(not addressed)	(not addressed)
Wind Dir. Error	≤ 30 degrees	≤ 55 degrees	(not addressed)

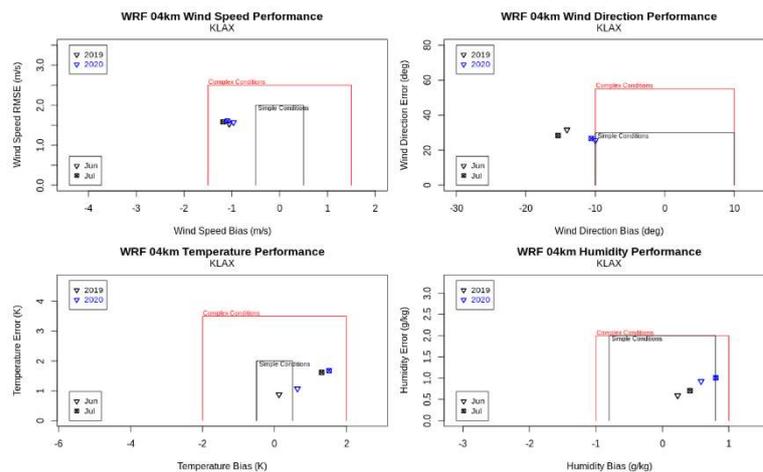


Figure S1-1. WFR MPE for KLAX.

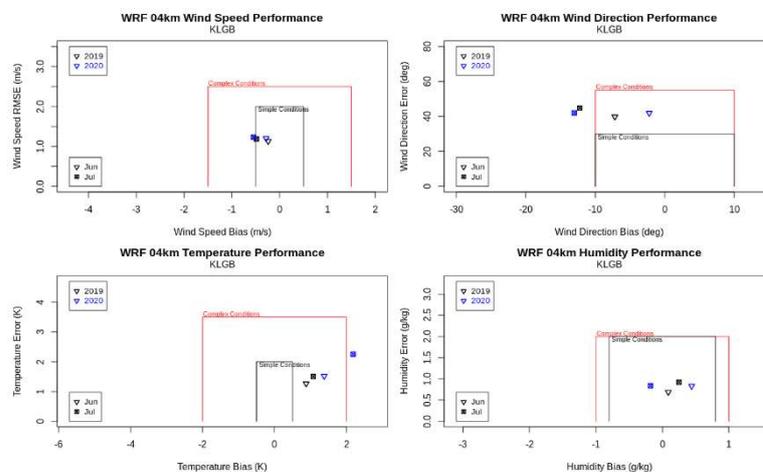


Figure S1-2. WFR MPE for KLGB.

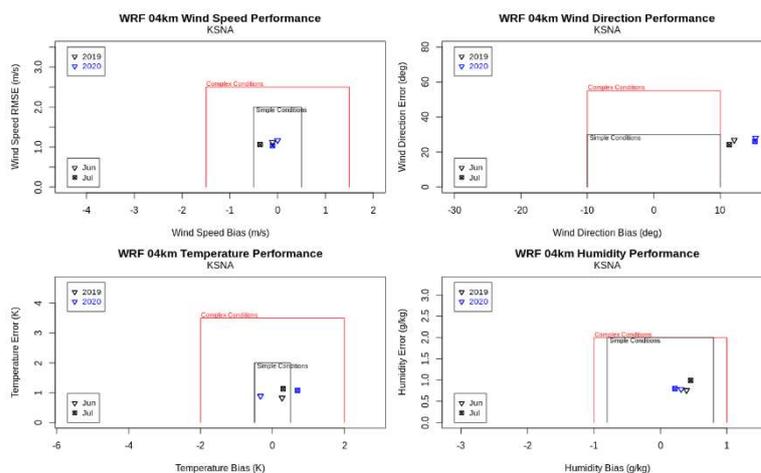


Figure S1-3. WFR MPE for KSNA.

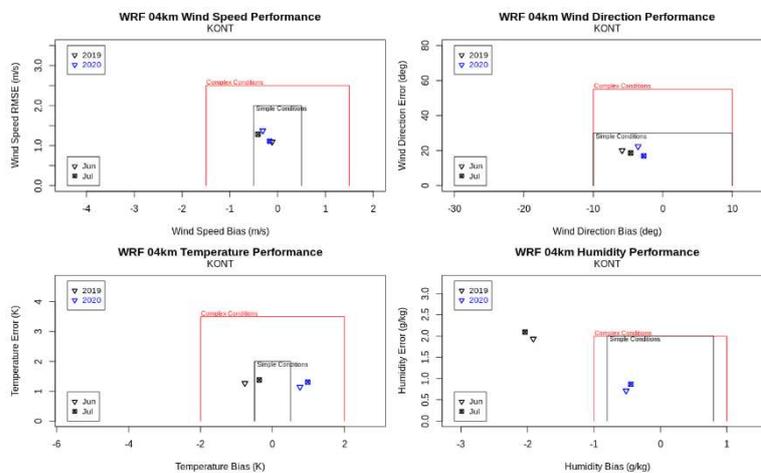


Figure S1-4. WFR MPE for KONT.

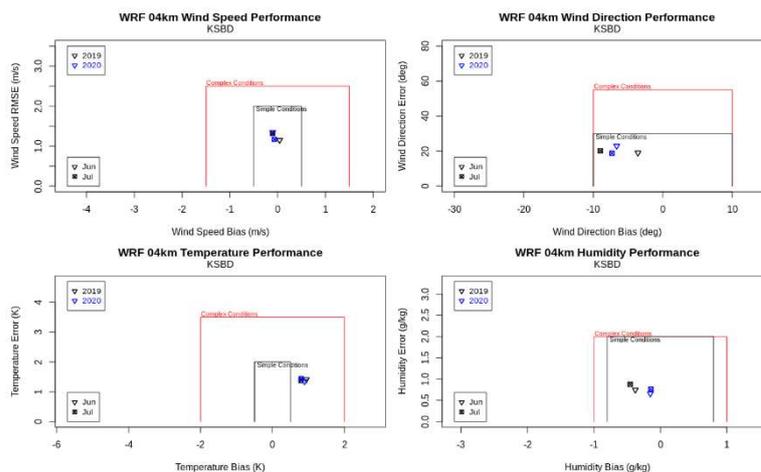


Figure S1-5. WFR MPE for KSBD.

Table S1-3. WFR T850 monthly mean bias (MB) and mean error (ME) at KNKX and KVBG for June and July for 2019 and 2020.

Station	June 2019		July 2019		June 2020		July 2020	
	MB (°C)	ME (°C)						
KSNA	-0.5	0.5	-0.5	0.5	-0.5	0.5	-0.5	0.5
KONT	-0.5	0.5	-0.5	0.5	-0.5	0.5	-0.5	0.5
KSBD	-0.5	0.5	-0.5	0.5	-0.5	0.5	-0.5	0.5

KNKX	-0.70	0.87	-0.06	0.41	-0.16	0.75	0.04	0.51
KVBG	-0.24	0.59	0.04	0.46	0.21	0.84	-0.11	0.51

Section S2. CMAQ options table

Table S2-1. CMAQ CCTM build science options and runscript options.

Science Module/Option	Option
Horizontal advection	Yamo
Vertical advection	wrf
Horizontal Diffusion	Multiscale
Vertical Diffusion	Acm2
Deposition Velocity	M3dry
Photolysis	Inline
Chemistry Mechanism	saprc07tc_ae6_aq
Aerosol Chemistry	Aero6
Cloud Chemistry	Acm_ae6
Gas Phase Chemistry Solver	Euler backward solver
Potential vorticity from free troposphere	Pv_O3
Inline wind blown dust	N
Lightning NOx	N
KZMIN (minimum Kz option)	Y
Ammonia bidirectional flux	N
Mercury bidirectional flux	N
Surface HONO interaction	Y

Section S3. Sector specific scaling factors and references and additional emissions onroad methodology

We developed adjustment factors to scale the BAU 2020 ARB emission inventory to actual activity and emission levels for the June-July 2020 period in the SoCAB region, to the extent feasible. The spatial and geographical specificity of the COVID-19 adjustment factors was determined by the extent to which applicable data was readily available for specific counties and months of interest. In certain instances, readily available data was limited to annualized and/or statewide activity.

The adjustment factors were developed for source categories shown in Table S3-1. Adjustment factors were applied to criteria air pollutants to adjust June and July 2020 emissions for all counties in the SoCAB 4-km modeling domain. Adjustment factors for each source category were cross-referenced to emission inventory source classification codes (SCC) to adjust the SCC-level ARB 2020 emission inventory. COVID-adjusted SCC-level emissions were then aggregated to the sector-level and sector-level COVID adjustment factors were estimated for application to model-ready emissions based on the ratio of COVID-adjusted to COVID-unadjusted sector-level emissions. **Error! Reference source not found.** provides detailed information on the basis and temporal and geographical coverage of the adjustment factors. Consumer product VOC emissions were estimated to go up 11% due to implementation of the 2020 COVID shelter-in-place orders due to COVID, which makes sense given people are at home more often under the 2020 COVID case than 2020 BAU case. Construction activity is down 5% that is consistent with the essential services coming back by June-July 2020. However, passenger rail activity is down approximately 50% due to COVID with freight rail down 20% and Los Angeles airport activity down 30%. Ocean Going Vessel (OGV) activity is down 6% to 73% depending on the type of OGV with the largest reduction for OGV passenger ships (e.g., cruise ships). Commercial heating/cooking is down ~10% and residential cooking/heating is up ~10% due to COVID.

Based mainly on reductions in gasoline and diesel sales between 2019 and 2020, the source sector that produced the largest emission reductions in June-July 2020 due to the COVID shelter-in-place orders was on-road mobile sources with a ~20% reduction.

The sector with the largest NO_x reductions is onroad and the primary data source used to derive the onroad scaling factor was the U.S. Energy Information Administration (EIA) refinery gasoline and diesel sales in California. Vehicle miles traveled (VMT) for June and July 2020 during COVID were derived using ARB's Emission FACTor (EMFAC) tool and the product of EMFAC 2019 average summer day VMT and the ratio of 2020 to 2019 EIA fuel sales volumes for June-July. EIA 2020/2019 fuel sale ratios were 77 % for gasoline and 84 % for diesel. We derived 2020 emissions factors by fuel type and vehicle type for the 2020 vehicle fleet with EMFAC and multiplied those by the 2020 COVID VMT to derive 2020 COVID onroad emissions. 2020 BAU onroad emissions were generate by interpolating 2019 and 2021 EMFAC onroad emissions since 2019 and 2021 were assumed not to be impacted by COVID in EMFAC. The ratio of 2020 COVID to 2020 BAU onroad emissions was the scaling factor that was applied uniformly to the model-ready ARB onroad emissions.

Table S3-1. Sector Specific Emissions scaling factors.

Source Category ^a	Region	Pollutant	Metric	Temporal	Adjustment Factor	Adjustment Factor Basis	Data Source
Consumer Products	Nationwide	All	Product sales, product production and household expenditures data	Episode Period (June - July)	1.105	Ratio of 2020 to 2019 production and household expenditures for the month of June and July	<p>NielsenIQ Reporting: https://nielseniq.com/global/en/insights/analysis/2021/which-pandemic-inspired-purchasing-shifts-are-here-to-stay/</p> <p>Media Reports: https://www.nature.com/articles/d41586-021-00251-4 https://www.perioimplantadvisory.com/clinical-tips/article/14206274/the-dangers-of-hand-sanitizer-use-and-misuse</p> <p>Industry Report: https://www.cleaninginstitute.org/covid19report</p> <p>Consumer Expenditure Government Report: https://www.bls.gov/news.release/cesan.nr0.htm</p>
Construction Equipment	California-wide	All	All Employees: Construction in California	Episode Period (June - July)	0.952	Ratio of total employees in 2020 to 2019 for the month June and July	<p>https://fred.stlouisfed.org/series/CACONS</p>

Source Category ^a	Region	Pollutant	Metric	Temporal	Adjustment Factor	Adjustment Factor Basis	Data Source
Passenger Rail	Los Angeles County	All	Total Passenger Miles	Episode Period (June - July)	0.497	Ratio of total passenger miles in 2020 to 2019 for the month June and July	https://isotp.metro.net/MetroRidership/Index.aspx
Freight Rail	Nationwide	All	Total Train Miles	Episode Period (June - July)	0.802	Ratio of total train miles in 2020 to 2019 for the month June and July	https://safetydata.fra.dot.gov/OfficeofSafety/publicsite/Query/rrstab.aspx
Aircraft	Los Angeles County	All	Total Operation	Episode Period (June - July)	0.702	Ratio of total operations in 2020 to 2019 for the month of June and July	https://aspm.faa.gov/opsnet/sys/main.asp
	San Bernardino County				0.780		
	Riverside County				0.803		
	Orange County				0.853		
	SoCAB	All	Total Operation	Episode Period (June - July)	0.739		
Ocean Going Vessels (OGV) - Container Ships	SoCAB	All	Twenty-foot Equivalent Unit (TEU)	Episode Period (June - July)	0.976	Ratio of total TEU in 2020 to 2019 (Port of Los Angeles (LA) and Long Beach (LB)) for the months of June and July	Port of LA: https://www.portoflosangeles.org/business/statistics/facts-and-figures Port of LB: https://polb.com/business/port-statistics/#tonnage-summary

Source Category ^a	Region	Pollutant	Metric	Temporal	Adjustment Factor	Adjustment Factor Basis	Data Source
OGV - Tankers	California-wide	All	Crude Oil Imports	Episode Period (June - July)	0.698	Total crude import ratio in California from 2020 to 2019 for the months of June and July	2020: https://www.energy.ca.gov/data-reports/energy-almanac/californias-petroleum-market/foreign-sources-crude-oil-imports/2020 2019: https://www.energy.ca.gov/data-reports/energy-almanac/californias-petroleum-market/foreign-sources-crude-oil-imports/2019-0
OGV - Auto Carriers/Roll On-Roll off Vessels	SoCAB	All	Automobiles (Units)	Annual	0.814	Ratio of annual automobile units (import and export) in 2020 to 2019 for the Port of LA	https://www.portoflosangeles.org/business/statistics/automobile-statistics
OGV - Bulk Cargo, Refrigerated Cargo and General Cargo	SoCAB	All	Metric Revenue Tons	Annual	0.941	Ratio of annual Toonage in 2020 to 2019 for the Port of LA and Port of LB	POLA: https://www.portoflosangeles.org/business/statistics/facts-and-figures POLB: https://polb.com/business/port-statistics/#tonnage-summary
OGV - Passenger Ships	SoCAB	All	Cruise Ship Calls	Annual	0.274	Ratio of annual cruise ship calls in 2020 to 2019 for the Port of LA	https://www.portoflosangeles.org/business/statistics/automobile-statistics

Source Category ^a	Region	Pollutant	Metric	Temporal	Adjustment Factor	Adjustment Factor Basis	Data Source
Cargo Handling Equipment (Port and Railyard)	SoCAB	All	Container Volume (TEU)	Episode Period (June - July)	0.976	Ratio of total TEU in 2020 to 2019 (Port of LA and LB) for the months of June and July	Port of LA: https://www.portoflosangeles.org/business/statistics/facts-and-figures Port of LB: https://polb.com/business/port-statistics/#tonnage-summary
Commercial Cooking and Heating	Los Angeles County	All	Google Mobility Trend (Average of Rail and Recreation, Grocery and Pharmacy and Workplace sectors)	2020 percent change from baseline activity	0.893	2020 percent change from baseline activity	https://www.gstatic.com/covid19/mobility/2020-05-09_US_California_Mobility_Report_en.pdf
	San Bernardino County				0.950		
	Orange County				0.910		
	Riverside County				0.940		
	SoCAB				0.910		
Residential Cooking and Heating	Los Angeles County	All	Google Mobility Trend (Residential)	2020 percent change from baseline activity	1.140	2020 percent change from baseline activity	https://www.gstatic.com/covid19/mobility/2020-05-09_US_California_Mobility_Report_en.pdf
	San Bernardino County				1.100		
	Orange County				1.140		

Source Category ^a	Region	Pollutant	Metric	Temporal	Adjustment Factor	Adjustment Factor Basis	Data Source
	Riverside County				1.110		
Refinery	California-wide	All	Weekly West Coast (PADD 5 ¹) Gross Inputs into Refineries	Episode Period (June - July)	0.708	Based on ratio of average daily input in 2020 to 2019 for the months of June and July	https://www.eia.gov/dnav/pet/pet_sum_snd_w_dcus_r50_w.htm
Electric Generation Unit (EGU)	Los Angeles County	All except SO ₂ ²	NO _x Error! Bookmark not defined. emissions	Episode Period (June - July)	0.802	Based on ratio of emissions in 2020 to 2019 for the months of June and July	https://ampd.epa.gov/ampd/
	Orange County				2.415		
	Riverside County				1.014		
	San Bernardino County				1.004		
	Los Angeles County	SO ₂ Error!	SO ₂ Error! Bookmark not defined. emissions	Episode Period (June - July)	0.960		
	Orange County	Bookmark not defined.			2.822		
	Riverside County	Bookmark not defined.			1.036		

¹ PADD: Petroleum Administration for Defense Districts

² SO₂: sulfur dioxide; NO_x: nitrogen dioxide; PM_{2.5}: particulate matter (PM) 2.5; PM₁₀: particulate matter 10; TOG: total organic gas; CO: carbon dioxide; NH₃: ammonia

Source Category ^a	Region	Pollutant	Metric	Temporal	Adjustment Factor	Adjustment Factor Basis	Data Source
	San Bernardino County				1.011		
On-road	SoCAB	NO _x ^{Err} or! Bookmark not defined.	Emissions and Vehicle Miles Traveled (VMT)	Summer Day	0.794	1) Estimated June-July 2020 VMT with COVID-19 impacts based on the product of EMFAC 2019 average summer day VMT and the ratio of 2020 to 2019 EIA fuel sales volumes for June-July. 2) Estimated 2020 EMFAC emissions per mile by fuel type for each vehicle classification. 3) Estimated 2020 COVID emissions based on the product of #1 and #2 above. 4) EMFAC includes annualized COVID adjustments for calendar year 2020. We estimated a 2020 COVID unadjusted emission inventory by interpolating EMFAC 2019 and 2021 emissions, which are assumed not to be impacted by COVID in EMFAC.	EMFAC2021 v1.0.1: https://arb.ca.gov/emfac/emissions-inventory/b8cfe2a8a4b5424be91e8e14748e8fde1de999c1 EIA Gasoline: https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=A103650061&f=M EIA Diesel : https://www.eia.gov/dnav/pet/pet_cons_reform_th_c_SCA_EPD2DXL0_mgalpd_m.htm
		PM _{2.5} ^{Err} or! Bookmark not defined.			0.787		
		PM ₁₀ ^{Err} or! Bookmark not defined.			0.784		
		TOG ^{Err} or! Bookmark not defined.			0.776		
		CO ^{Error} !			0.776		

Source Category ^a	Region	Pollutant	Metric	Temporal	Adjustment Factor	Adjustment Factor Basis	Data Source
		Bookmark not defined.				5) The on-road adjustment factor was estimated based on the product of #3 and #4 above.	
		SO ₂ Error! Bookmark not defined.			0.776		

Section S4. Additional CMAQ MPE.

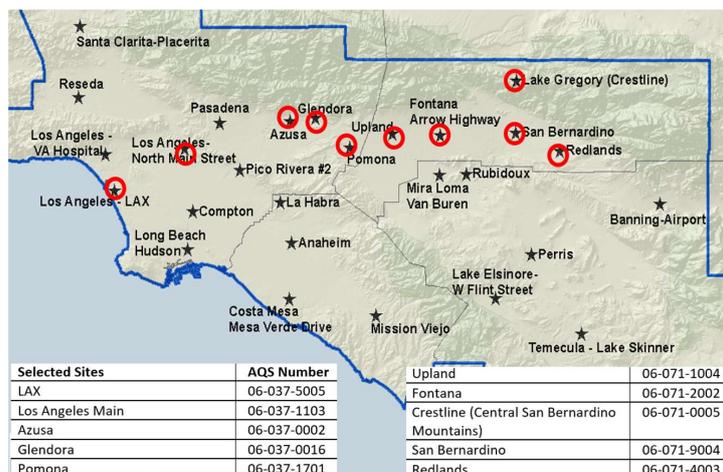


Figure S4-1. Map of SoCAB sites, and list of selected sites.

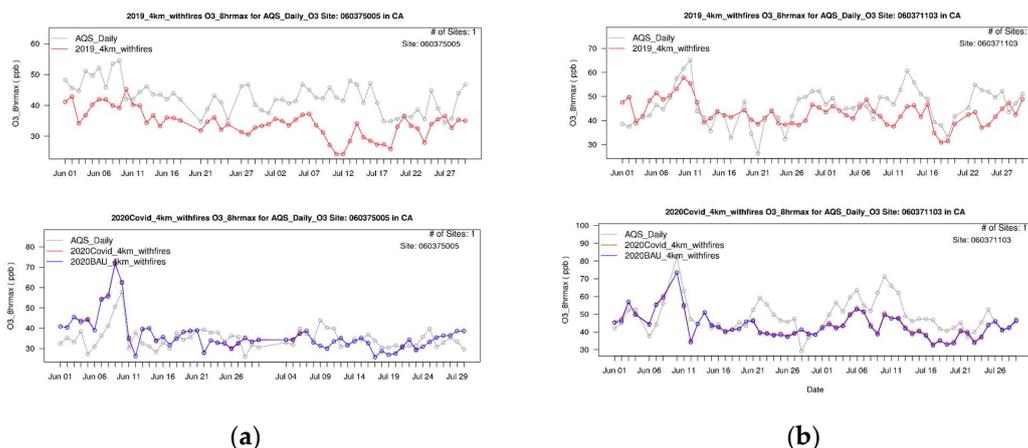


Figure S4-2. June 1 – July 31 MDA8 ozone time series plots. Upper plots are 2019 Base and lower plots are 2020 BAU and 2020 COVID: (a) LAX (AQS = 06037-5005); (b) Los Angeles Main (AQS = 06037-1103).

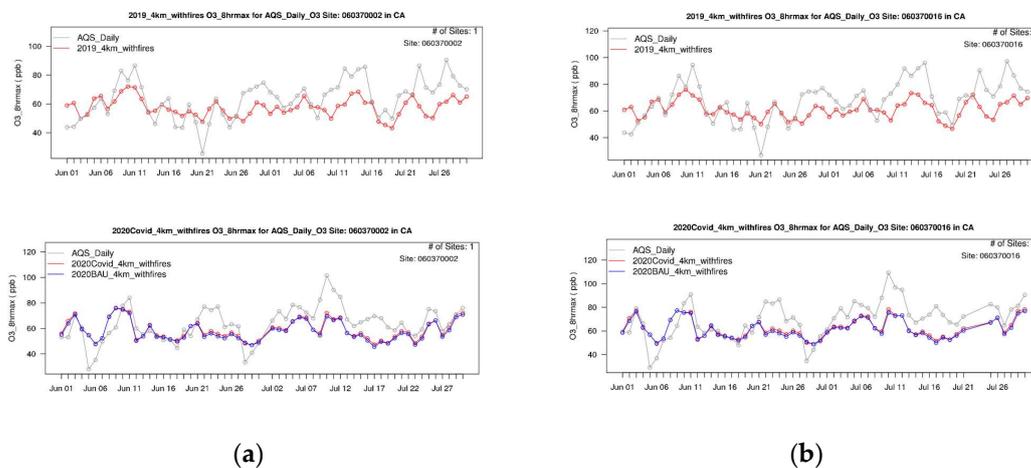


Figure S4-3. June 1 – July 31 MDA8 ozone time series plots. Upper plots are 2019 Base and lower plots are 2020 BAU and 2020 COVID: (a) Azusa (AQS = 06037-0002); (b) Glendora (AQS = 06037-0016).

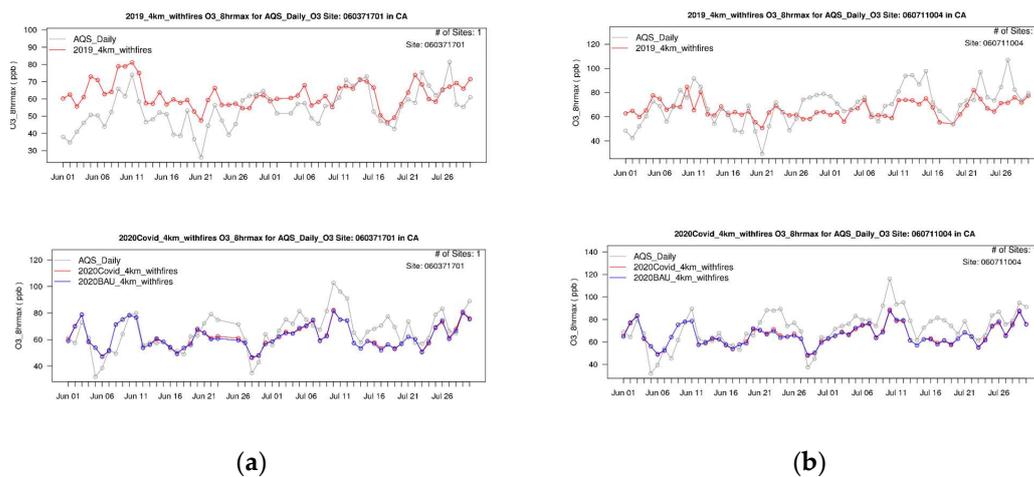


Figure S4-4. June 1 – July 31 MDA8 ozone time series plots. Upper plots are 2019 Base and lower plots are 2020 BAU and 2020 COVID: (a) Pomona (AQ5 = 06037-1701); (b) Upland (AQ5 = 06071-1004).

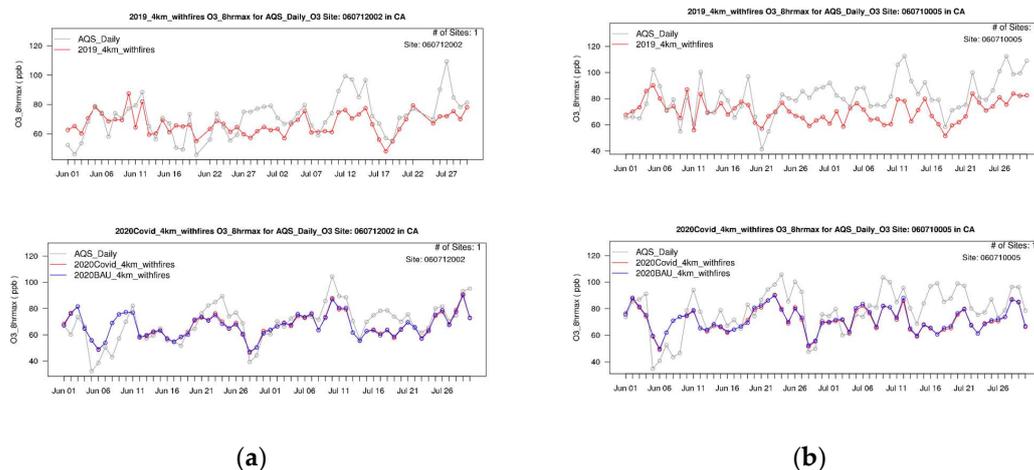


Figure S4-5. June 1 – July 31 MDA8 ozone time series plots. Upper plots are 2019 Base and lower plots are 2020 BAU and 2020 COVID: (a) Fontana (AQ5 = 06071-2002); (b) Crestline (AQ5 = 06071-0005).

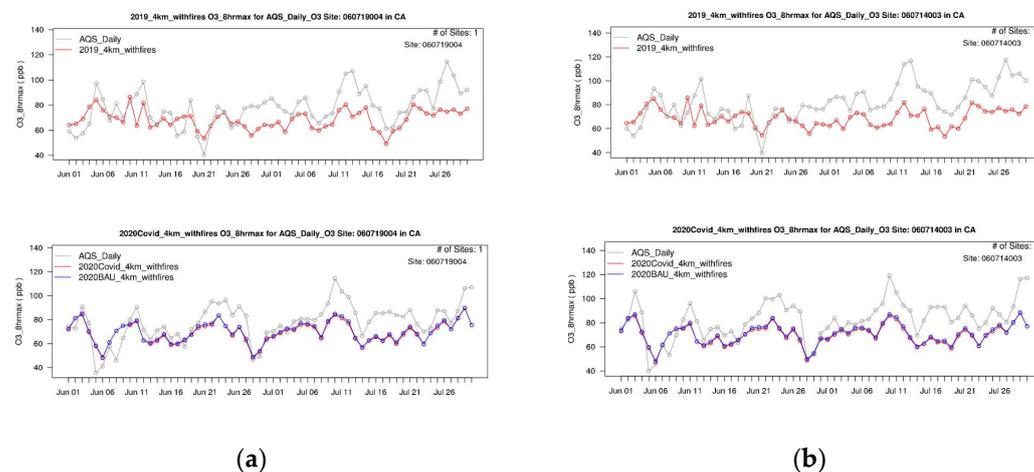


Figure S4-6. June 1 – July 31 MDA8 ozone time series plots. Upper plots are 2019 Base and lower plots are 2020 BAU and 2020 COVID: (a) San Bernardino (AQ5 = 06071-9004); (b) Redlands (06071-4003).

Table S4-1. Selected site MPE performance statistics for June and July. Green indicates that a monitor's statistics meets performance goals, brown indicates that a monitor's statistics meets performance criteria, and red indicates that a monitor's statistics do not meet performance criteria.

		----- 2019 -----					----- 2020 COVID -----					
Monitor	AQS	Obs.	Mod.	NMB	NME	COR	Obs.	Mod.	NMB	NME	COR	
		Mean	Mean				Mean	Mean				
June	LAX	603750051	44.4	36.7	-17.3	17.9	0.45	35.4	39.6	11.7	20.0	0.62
	L .A. Main	603711031	44.0	44.6	1.3	11.4	0.69	47.7	45.6	-4.5	12.3	0.67
	Azusa	603700021	57.9	57.6	-0.6	14.1	0.70	57.4	57.9	0.9	14.3	0.58
	Glendora	603700161	61.2	60.4	-1.3	14.2	0.68	62.1	60.5	-2.5	15.0	0.60
	Pomona	603717011	49.7	62.2	25.1	27.2	0.64	59.1	60.4	2.2	11.3	0.70
	Upland	607110042	63.2	65.0	2.8	15.6	0.55	64.8	63.7	-1.7	12.9	0.72
	Fontana	607120021	66.1	66.4	0.4	12.5	0.51	62.3	64.6	3.7	12.2	0.72
	Crestline	607100051	75.5	71.2	-5.7	12.8	0.58	73.9	71.0	-3.9	14.5	0.76
	San Bernardino	607190041	71.4	68.2	-4.5	13.7	0.52	71.5	67.5	-5.6	13.6	0.76
Redlands	607140031	72.4	68.8	-4.9	12.9	0.49	76.9	68.6	-10.8	14.9	0.78	
July	LAX	603750051	41.0	32.1	-21.8	22.2	0.06	34.3	33.2	-3.2	11.4	0.09
	L. A. Main	603711031	47.6	42.0	-11.8	13.2	0.51	49.9	42.4	-15.1	15.8	0.69
	Azusa	603700021	68.9	57.7	-16.2	17.0	0.59	70.0	59.6	-14.9	15.0	0.69
	Glendora	603700161	73.7	61.8	-16.2	17.1	0.66	78.2	64.3	-17.8	17.8	0.72
	Pomona	603717011	59.1	62.6	5.9	11.0	0.65	72.6	64.1	-11.7	12.9	0.78
	Upland	607110042	76.5	67.5	-11.7	12.9	0.69	79.1	68.6	-13.3	13.4	0.82
	Fontana	607120021	77.1	67.4	-12.6	13.1	0.74	75.6	69.4	-8.2	9.3	0.78
	Crestline	607100051	86.7	70.3	-18.9	18.9	0.76	83.8	71.6	-14.5	16.4	0.45
	San Bernardino	607190041	84.1	69.1	-17.9	17.9	0.78	84.8	71.1	-16.2	16.4	0.69
Redlands	607140031	91.1	69.3	-23.9	23.9	0.75	88.9	71.5	-19.6	19.7	0.68	