
Emissions and Air Quality Implications of Upstream and Midstream Oil and Gas Operations in Mexico

Supplemental Information

Elena McDonald-Buller ^{1,*}, Gary McGaughey ¹, John Grant ², Tejas Shah², Yosuke Kimura¹, Greg Yarwood²

¹ Center for Energy and Environmental Resources, The University of Texas at Austin, 10100 Burnet Road, Building 133, Mail Code R7100, Austin, Texas 78758, United States

² Ramboll, 7250 Redwood Boulevard, Suite 105, Novato, California, 94945, United States

* Correspondence: ecmb@mail.utexas.edu

Table S1. Oil and gas activity metrics mapped to EPA emission source classification codes.

SCC	Source	Well Type	Oil and Gas Activity Metric (annual basis)
2310000220	Drill Rigs	All	Spuds
2310000660	Hydraulic Fracturing Engines	All	Spuds
2310020600	Compressor Engines	All	Gas Production
2310021010	Storage Tanks: Condensate	Gas	Condensate Production
2310021030	Tank Truck/Railcar Loading: Condensate	Gas	Condensate Production
2310021100	Gas Well Heaters	Gas	Active Well Count
2310021101	Natural Gas Fired Two Cycle Lean Burn Compressor Engines < 50 HP	Gas	Gas Production
2310021102	Natural Gas Fired Two Cycle Lean Burn Compressor Engines 50 To 499 HP	Gas	Gas Production
2310021103	Natural Gas Fired Two Cycle Lean Burn Compressor Engines 500+ HP	Gas	Gas Production
2310021201	Natural Gas Fired Four cycle Lean Burn Compressor Engines <50 HP	Gas	Gas Production
2310021202	Natural Gas Fired Four cycle Lean Burn Compressor Engines 50 To 499 HP	Gas	Gas Production
2310021203	Natural Gas Fired Four cycle Lean Burn Compressor Engines 500+ HP	Gas	Gas Production
2310021251	Lateral Compressors 4 Cycle Lean Burn	Gas	Gas Production
2310021300	Gas Well Pneumatic Devices	Gas	Active Well Count
2310021301	Natural Gas Fired Four Cycle Rich burn Compressor Engines <50 HP	Gas	Gas Production
2310021302	Natural Gas Fired Four Cycle Rich burn Compressor Engines 50 To 499 HP	Gas	Gas Production
2310021303	Natural Gas Fired Four Cycle Rich burn Compressor Engines 500+ HP	Gas	Gas Production
2310021351	Lateral Compressors Four Cycle Rich burn	Gas	Gas Production
2310021400	Gas Well Dehydrators	Gas	Gas Production
2310021401	Nat Gas Fired Four Cycle Rich Burn Compressor Engines <50 HP w/NSCR	Gas	Gas Production
2310021402	Nat Gas Fired Four Cycle Rich Burn Compressor Engines 50 To 499 HP w/NSCR	Gas	Gas Production
2310021403	Nat Gas Fired Four Cycle Rich Burn Compressor Engines 500+ HP w/NSCR	Gas	Gas Production
2310021501	Fugitives: Connectors	Gas	Active Well Count
2310021502	Fugitives: Flanges	Gas	Active Well Count
2310021503	Fugitives: Open Ended Lines	Gas	Active Well Count
2310021504	Fugitives: Pumps	Gas	Active Well Count

SCC	Source	Well Type	Oil and Gas Activity Metric (annual basis)
2310021505	Fugitives: Valves	Gas	Active Well Count
2310021506	Fugitives: Other	Gas	Active Well Count
2310021600	Gas Well Venting	Gas	Gas Production
2310021603	Gas Well Venting - Blowdowns	Gas	Gas Production
2310121100	Mud Degassing	Gas	Spuds
2310121401	Gas Well Pneumatic Pumps	Gas	Active Well Count
2310121700	Gas Well Completion: All Processes	Gas	Spuds
2310021509	Fugitives: All Processes	Gas	Active Well Count
2310000330	Artificial Lift	Oil	Active Well Count
2310010100	Oil Well Heaters	Oil	Active Well Count
2310010200	Oil Well Tanks - Flashing & Standing/Working/Breathing	Oil	Oil Production
2310010300	Oil Well Pneumatic Devices	Oil	Active Well Count
2310011000	Total: All Processes	Oil	Total Well Counts
2310011020	Storage Tanks: Crude Oil	Oil	Oil Production
2310011100	Heater Treater	Oil	Active Well Count
2310011201	Tank Truck/Railcar Loading: Crude Oil	Oil	Oil Production
2310011450	Wellhead	Oil	Associated Gas Production
2310011501	Fugitives: Connectors	Oil	Active Well Count
2310011502	Fugitives: Flanges	Oil	Active Well Count
2310011503	Fugitives: Open Ended Lines	Oil	Active Well Count
2310011504	Fugitives: Pumps	Oil	Active Well Count
2310011505	Fugitives: Valves	Oil	Active Well Count
2310011506	Fugitives: Other	Oil	Active Well Count
2310111100	Mud Degassing	Oil	Spuds
2310111401	Oil Well Pneumatic Pumps	Oil	Active Well Count
2310111700	Oil Well Completion: All Processes	Oil	Spuds
2310011500	Fugitives: All Processes	Oil	Active Well Count

Table S2. Emission factors for onshore oil and gas production well sites in the Sabinas and Burgos Basins.

SCC	Source		Emission Factor (lb/surrogate)				
			NO _x	VOC	CO	SO ₂	PM _{2.5}
(lb/MMSCF)							
2310021100	Gas Well Heaters		2,303	129	2,025	-	184
2310021400	Gas Well Dehydrators		80	2,266	282	3	34
2310021600	Gas Well Venting		-	2,541	-	-	-
2310021101	Natural Gas-Fired Compressor Engines	Two Cycle Lean Burn<50HP	229	18	59	0	4
2310021102		Two Cycle Lean Burn50-499HP	8,187	745	1,075	2	130
2310021103		Two Cycle Lean Burn500+HP	0	0	0	-	0
2310021201		Four Cycle Lean Burn<50HP	5	-	0	-	-
2310021202		Four Cycle Lean Burn50-499HP	40	1	2	-	-
2310021203		Four Cycle Lean Burn500+HP	19,459	806	2,730	4	17
2310021301		Four Cycle Rich Burn<50HP	506	5	495	0	2
2310021302		Four Cycle Rich Burn50-499HP	36,266	618	28,547	6	97
2310021401		Four Cycle Rich Burn<50HPw/NSCR	-	-	-	-	-
2310021402		Four Cycle Rich Burn50-499HP w/NSCR	625	21	173	0	8
2310021403		Four Cycle Rich Burn500+HP w/NSCR	105,128	1,690	16,494	4	57
(lb/active well count)							
2310021501	Fugitives	Connectors	-	62	-	-	-
2310021502		Flanges	-	26	-	-	-
2310021503		Open Ended Lines	-	28	-	-	-
2310021504		Pumps	-	43	-	-	-
2310021505		Valves	-	239	-	-	-
2310021506		Other	-	360	-	-	-
2310021300	Gas Well Pneumatic Devices		-	1,109	-	-	-
2310121401	Gas Well Pneumatic Pumps		-	510	-	-	-
(lb/spud)							
2310000220	Drill Rigs		15,587	2,619	9,637	1,982	1,754

SCC	Source	Emission Factor (lb/surrogate)				
		NO _x	VOC	CO	SO ₂	PM _{2.5}
2310000660	Hydraulic Fracturing Engines	14,672	2,317	9,170	1,353	1,834
2310121700	Gas Well Completion: All Processes	-	45,866	-	-	-

Table S3. Emission factors for onshore oil and gas production well sites in the Sureste, Tampico-Misantla, and Veracruz Basins.

SCC	Source			Emission Factor (lb/surrogate)				
			Well Type	NO _x	VOC	CO	SO ₂	PM _{2.5}
(lb/bbl)								
2310021010	Storage Tanks: Condensate		Gas	-	0.02	-	-	-
2310011020	Storage Tanks: Crude Oil		Oil	-	7.65	-	-	-
2310011201	Tank Truck/Railcar Loading: Crude Oil		Oil	<0.01	0.11	<0.01	-	-
(lb/MMSCF)								
2310021400	Dehydrators		Gas	0.03	0.89	0.11	<0.01	0.11
2310021600	Well Venting		Gas	-	7.97	-	-	-
2310021101	Natural Gas-Fired Compressor Engines	Two cycle lean burn < 50 HP	Gas	0.08	<0.01	0.02	-	<0.01
2310021102		Two cycle lean burn 50 To 499 HP	Gas	3.39	0.31	0.44	-	0.05
2310021203		Four cycle lean burn 500+ HP	Gas	9.82	0.41	1.36	<0.01	<0.01
2310021301		Four cycle rich burn <50 HP	Gas	0.18	-	0.16	-	-
2310021302		Four cycle rich burn 50 To 499 HP	Gas	13.49	0.23	10.66	<0.01	0.04
2310021403		Four cycle rich burn 500+ HP w/NSCR	Gas	38.99	0.63	6.10	<0.01	0.02
2310020600		Compressor Engines	All	0.03	<0.01	<0.01	-	<0.01
(100 lb/active well count)								
2310021300	Pneumatic Devices		Gas	-	1.27	-	-	-
2310121401	Pneumatic Pumps		Gas	-	2.83	-	-	-
2310021100	Gas Well Heaters		Gas	0.73	0.04	0.62	-	0.06
2310021501	Fugitives	Connectors	Gas	-	0.34	-	-	-

2310021502		Flanges	Gas	-	0.14	-	-	-
2310021503		Open Ended Lines	Gas	-	0.16	-	-	-
2310021504		Pumps	Gas	-	0.24	-	-	-
2310021505		Valves	Gas	-	1.67	-	-	
2310021506		Other	Gas	-	2.00	-	-	-
2310010300	Pneumatic Devices		Oil	-	39.29	-	-	-
2310111401	Pneumatic Pumps		Oil	-	8.80	-	-	-
2310000330	Artificial Lift		Oil	22.83	0.31	35.30	<0.01	0.19
2310011100	Heater Treater		Oil	0.90	0.05	0.76	<0.01	0.07
2310011501	Fugitives	Connectors	Oil	-	4.36	-	-	-
2310011502		Flanges	Oil	-	1.01	-	-	
2310011503		Open Ended Lines	Oil	-	1.64	-	-	-
2310011504		Pumps	Oil	-	6.07	-	-	-
2310011505		Valves	Oil	-	15.56	-	-	-
2310011506		Other	Oil	-	22.96	-	-	-
2310011000	Total: All Processes		All	0.02	0.06	0.09	0.18	-
(1000 lb/spud)								
2310121700	Completion		Gas	-	-	-	<0.01	-
2310111700	Completion		Oil	0.09	45.00	0.41	0.75	-
2310111100	Mud Degassing		Oil	-	25.77	-	-	-
2310000220	Drill Rigs		All	23.75	4.08	18.89	1.96	4.77
2310000660	Hydraulic Fracturing Engines		All	1.37	0.22	0.86	0.16	0.17

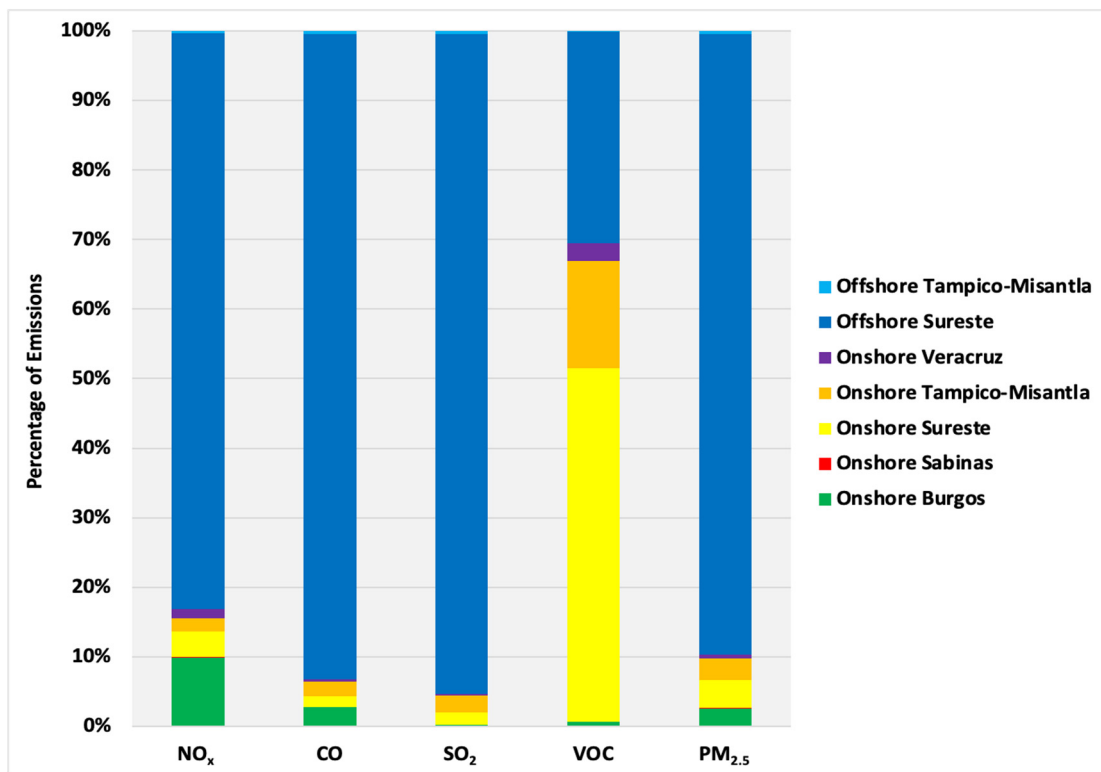
Table S4. Emissions per unit of production (lb/Mbbl/yr) from offshore oil and gas well sites.

Applicability	Emissions Per Unit of Production (lb/Mbbl/yr)				
	VOC	CO	NO _x	SO ₂	PM _{2.5}
Cuencas Del Sureste and Tampico Misantla (Oil and gas production)	825	902	738	5.56	10.2
Tampico-Misantla (Dry gas production only)	32.4	40.7	30.9	0.353	0.217

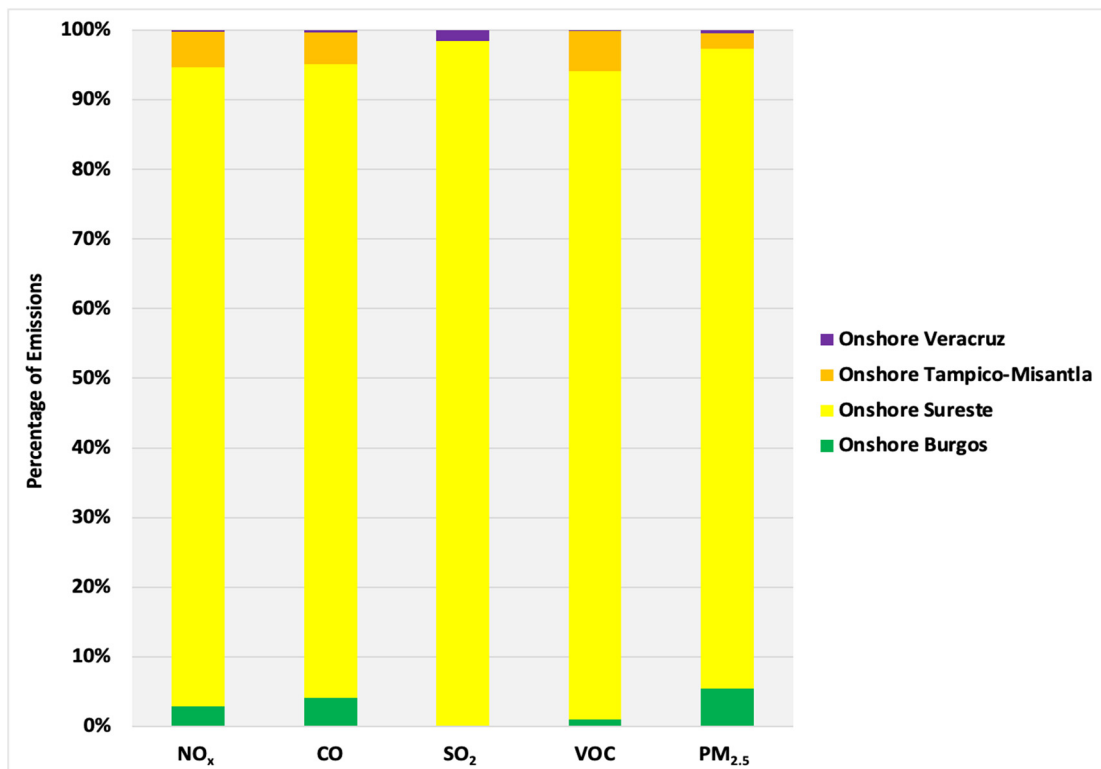


Figure S1. CAMx 36 km x 36 km horizontal modeling domain.

(a)



(b)



(c)

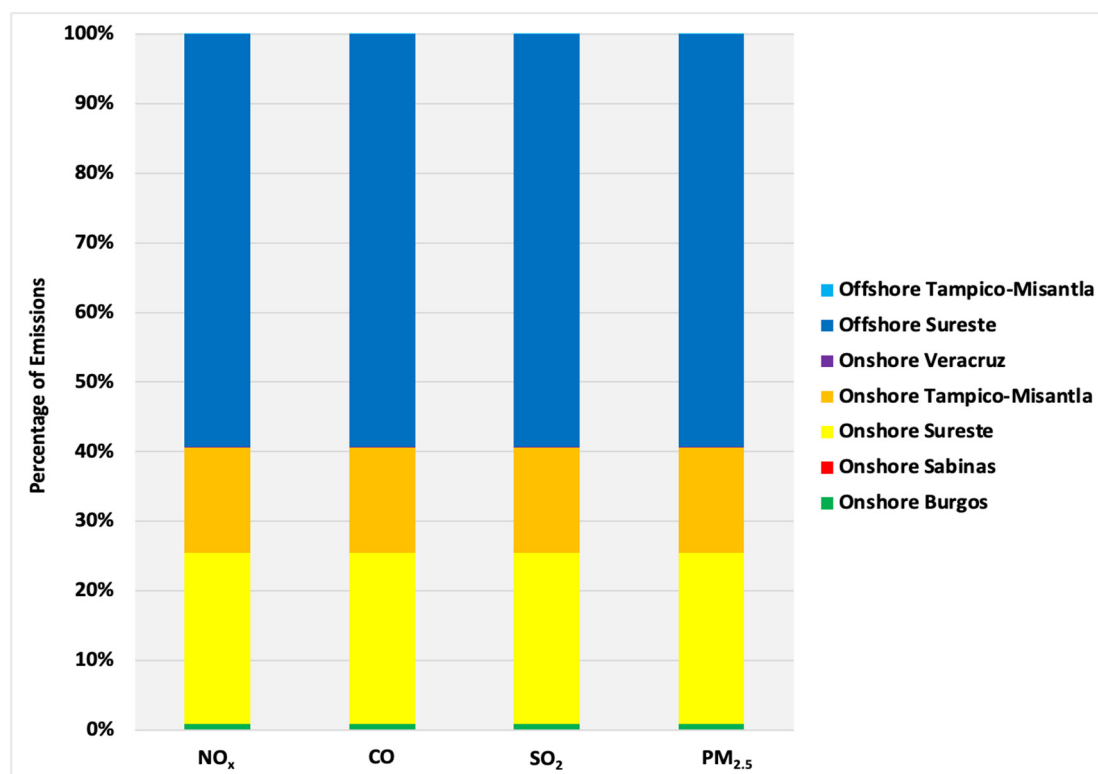


Figure S2. Contributions to NO_x, CO, SO₂, VOC, and PM_{2.5} emissions (%) from (a) onshore and offshore well sites, (b) natural gas processing facilities, and (c) flaring by basin.

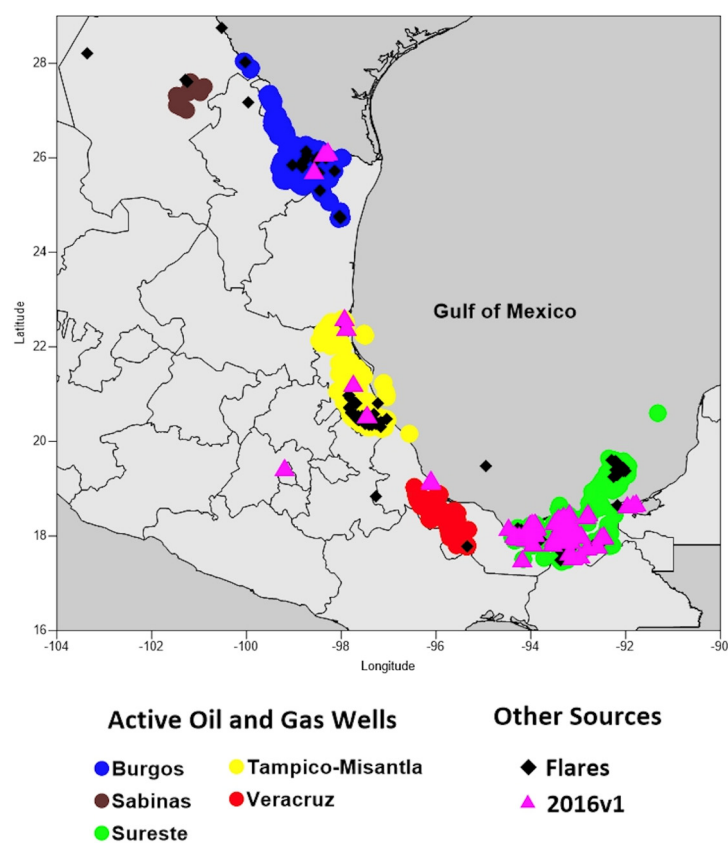


Figure S3. Locations of active 2016 oil and/or gas wells by basin and flaring in this study and oil and gas sector emission sources identified in the 2016v1 National Collaborative Emissions Modeling Platform.

Table S5. Annual emissions of CO, NO_x, PM_{2.5}, SO₂, and VOC (tons) from this study and the 2016v1 inventory for oil and gas exploration and extraction, natural gas processing facilities, and natural gas compressor stations (NAICS source categories 211110, 325110, and 221210, respectively).

Point Source Type	Pollutant	2016v1 (tons)	McDonald-Buller et al. (tons)
Oil and Gas Exploration and Extraction	CO	11,639	332,758
	NO _x	48,552	284,360
	PM _{2.5}	2,093	3,086
	SO ₂	433,054	74,408
	VOC	8,160	867,364
Natural Gas Processing Facilities	CO	5,847	6,624
	NO _x	16,122	18,073
	PM _{2.5}	1,118	1,159
	SO ₂	90,982	66,314
	VOC	439	435
Natural Gas Compressor Stations	CO	0	88,050
	NO _x	0	52,308
	PM _{2.5}	0	459
	SO ₂	0	14
	VOC	0	698

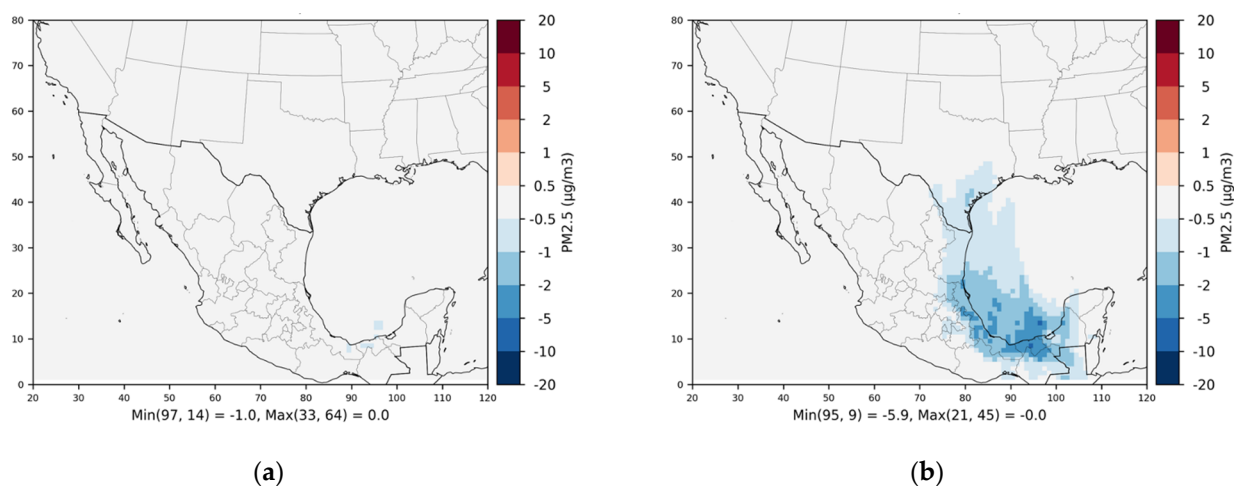
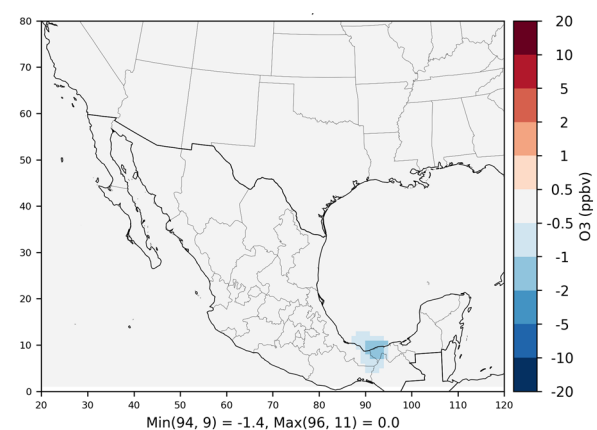
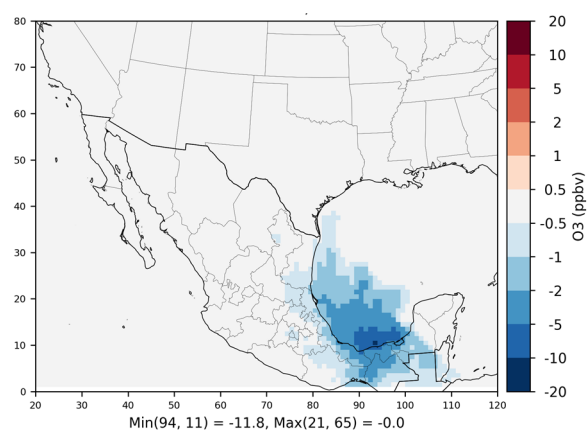


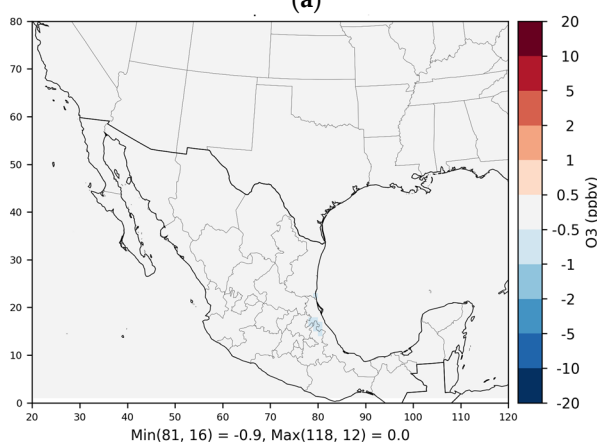
Figure S4. Predicted annual (a) average and (b) maximum differences in 24-hour PM_{2.5} concentrations by grid cell when emissions from offshore well sites in the Sureste Basin are zeroed relative to the 2016 base case. Negative values indicate reductions in concentrations relative to the base case and vice versa.



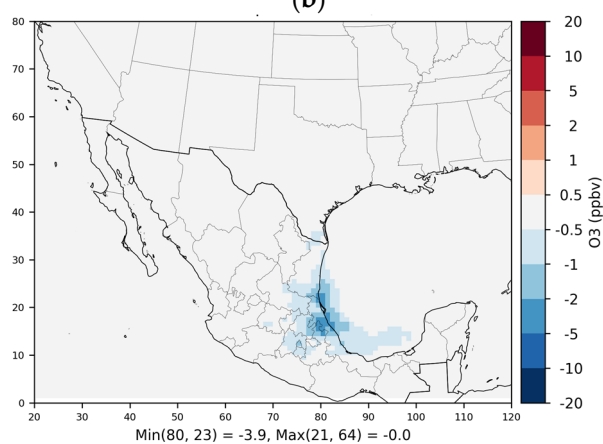
(a)



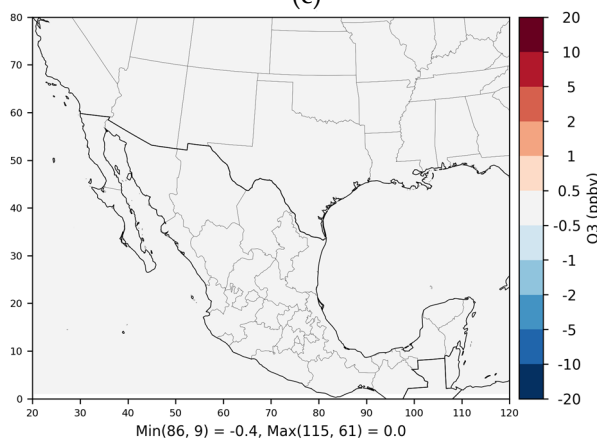
(b)



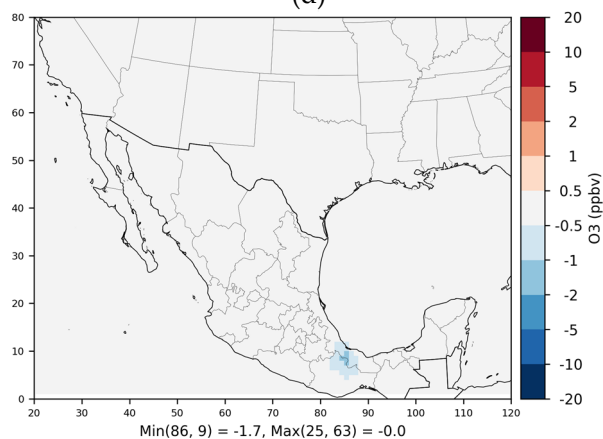
(c)



(d)



(e)



(f)

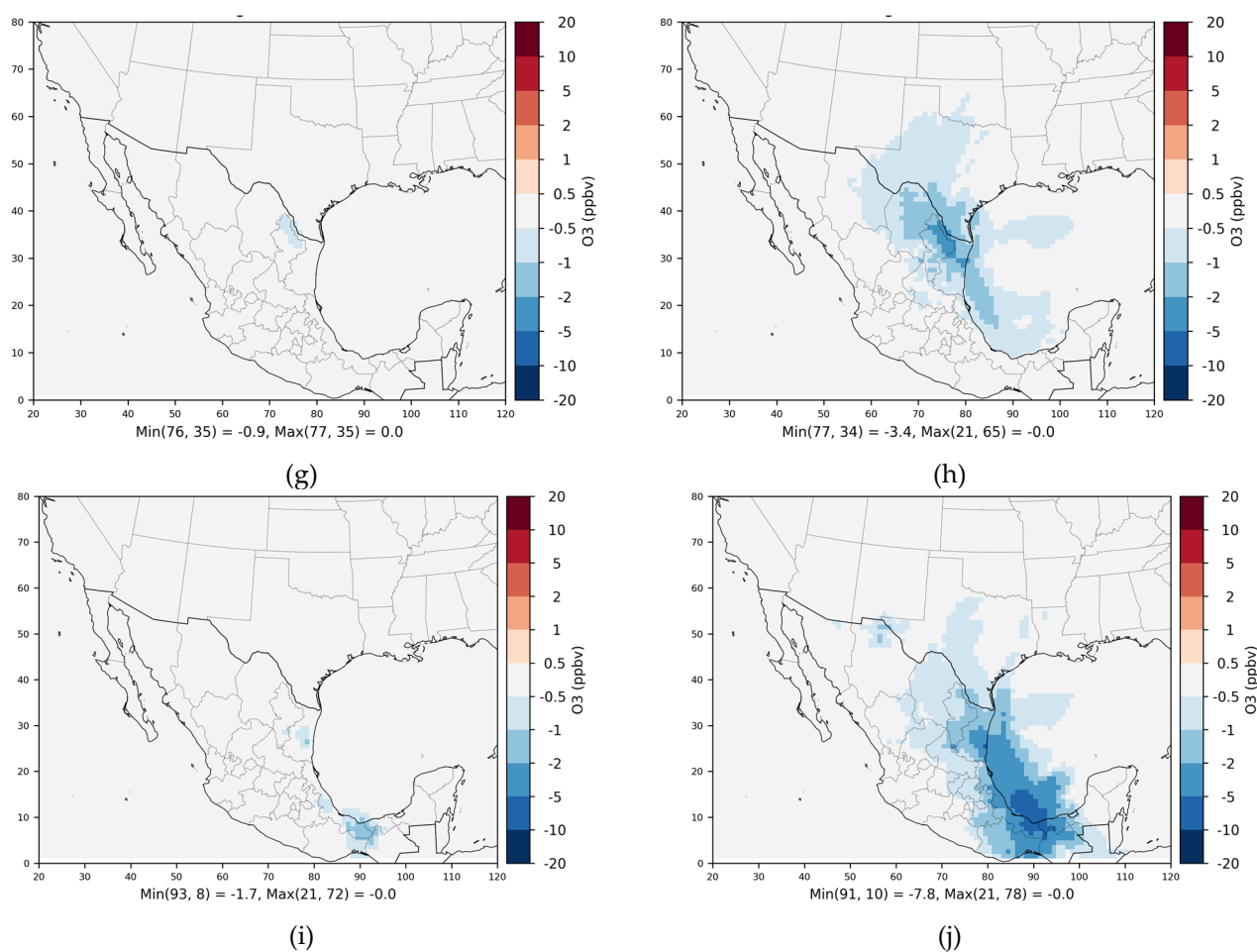


Figure S5. Predicted annual average differences (left) and maximum differences (right) in MDA8 ozone concentrations by grid cell when emissions from onshore well site operations in the (a/b) Sureste, (c/d) Tampico-Misantla, (e/f) Veracruz, and (g/h) Burgos and Sabinas Basins and from (i/j) midstream sources are zeroed relative to the 2016 base case. Negative values indicate reductions in concentrations relative to the base case and vice versa.