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Impact of reduced anthropogenic emissions during COVID-19 on air quality in India

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Table S1: Scaling factors of the energy sector for different states to convert emissions from 2010 to 2019.

State	PM	VOCs	NO_x	SO_2
Andhra Pradesh	1.203	1.226	1.230	1.225
Arunachal Pradesh	1.203	1.380	1.380	1.357
Assam	1.308	1.238	1.545	1.244
Bihar	2.016	2.059	2.063	2.063
Chhattisgarh	1.955	2.142	2.157	2.141
Capital Region	0.445	1.416	0.445	0.445
Goa	1.696	0.881	0.881	0.881
Gujarat	1.696	1.904	1.941	1.898
Haryana	1.366	1.547	1.720	1.546
Himachal Pradesh	1.190	1.190	1.190	1.190
Jammu&kashmir	1.190	1.190	1.190	1.190
Jharkhand	2.578	2.642	2.641	2.638
Karnataka	1.674	1.702	1.737	1.712
Kerala	1.190	1.190	1.190	1.190
Madhya Pradesh	1.704	1.928	1.950	1.933
Maharashtra	1.509	1.737	1.760	1.731
Manipur	1.704	1.785	1.785	1.785
Meghalaya	1.216	1.226	1.269	1.227
Mizoram	1.216	1.309	1.309	1.309
Nagaland	1.216	1.464	1.464	1.464
Odisha	1.247	1.345	1.363	1.351
Punjab	0.791	1.012	1.012	1.012
Rajasthan	1.344	1.583	1.652	1.580
Sikkim	1.344	1.131	1.131	1.131
Tamil Nadu	2.211	2.332	2.382	2.331
Telangana	3.956	3.998	4.010	3.994
Tripura	1.461	1.202	1.202	1.202
Uttar Pradesh	1.461	1.595	1.616	1.598
Uttarakhand	1.596	2.404	2.409	2.409
West Bengal	1.361	1.499	1.502	1.501

Table S2: Scaling factors of on-road and off-road sectors for different states to convert emissions from 2010 to 2019.

State	PM	VOCs	NO_x	SO_2
Andhra Pradesh	1.000	1.186	1.138	1.355
Arunachal Pradesh	1.195	1.424	1.405	1.641
Assam	1.020	1.210	1.153	1.379
Bihar	0.985	1.169	1.109	1.330
Chhattisgarh	1.167	1.389	1.352	1.593
Capital Region	1.097	1.326	1.559	1.591
Goa	0.787	0.925	0.802	1.028
Gujarat	1.133	1.352	1.342	1.560
Haryana	0.960	1.145	1.139	1.322
Himachal Pradesh	1.041	1.240	1.220	1.427
Jammu & Kashmir	1.036	1.233	1.194	1.413
Jharkhand	1.089	1.297	1.277	1.493
Karnataka	1.202	1.432	1.413	1.648
Kerala	1.140	1.359	1.348	1.568
Madhya Pradesh	1.069	1.270	1.222	1.452
Maharashtra	0.982	1.167	1.134	1.339
Manipur	1.579	1.877	1.795	2.144
Meghalaya	0.908	1.081	1.054	1.240
Mizoram	1.167	1.390	1.361	1.598
Nagaland	0.981	1.172	1.194	1.361
Odisha	1.000	1.186	1.134	1.354
Punjab	0.950	1.132	1.128	1.308
Rajasthan	1.159	1.379	1.353	1.586
Sikkim	0.857	1.014	0.952	1.152
Tamil Nadu	0.992	1.177	1.127	1.345
Telangana	1.000	1.186	1.138	1.355
Tripura	0.958	1.138	1.090	1.301
Uttar Pradesh	0.976	1.159	1.110	1.323
Uttarakhand	1.072	1.276	1.239	1.463
West Bengal	0.969	1.151	1.109	1.316

Table S3: Scaling factors of nationwide emissions of agriculture, industry, and residential sectors from 2010 to 2019.

	PM	VOCs	NO_x	SO_2
Agriculture	1.071	1.333	1.060	0.915
Industry	1.749	1.687	1.674	1.622
Residential	1.229	1.230	1.223	1.194

Table S4: The comprehensive list of the Indian industries. This classification based on the degree of air pollution caused, including very polluting (VP), medium polluting (MP), and low polluting (LP) industries.

S.No.	VP	MP	LP
01.	Aluminum	Automobile	Advertising
02.	Cement	Cotton	**Agricultural**
03.	Construction	Hotel	Aviation
04.	Copper	Jute	Banking
05.	**Dairy**	**Pharmaceuticals**	Bio-Technology
06.	Diamond	Tractor	**Biscuit**
07.	Fashion	Weaving	**Chocolate**
08.	Fertilizer		Cosmetic
09.	Film		Cottage
10.	Granite		Electronic
11.	Jewelry		**Food Processing**
12.	Mining		Furniture
13.	Oil		Garment
14.	Paint		Insurance
15.	Paper		IT
16.	**Power**		Leather
17.	**Printing**		Music
18.	Rubber		Mutual Fund
19.	Silk		Pearl
20.	**Soap**		**Poultry**
21.	Steel		Plastic
22.	**Sugar**		Railway
23.	Textile		Real Estate

24.	Tobacco	Retail
25.	Zinc	Shipping
26.		Solar
27.		Telecom
28.		Television
29.		Tourism
30.		Toys
31.		Turbine

Note: The industries marked as bold are assumed to be functioning in the lockdown.

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Table S5: Model performance of meteorological parameters temperature at 2m above the surface (T2), wind speed (WS), wind direction (WD), and relative humidity (RH) from February 21 to April 24, 2020 (PRE is mean prediction; OBS is mean observation; MB is mean bias; GE is gross error; RMSE is root mean square error).

Variable	Statistics	Feb/21-Mar/23	Mar/24-Apr/24	Benchmark*
T2 (K)	PRE	279.6	283.9	
	OBS	281.0	285.1	
	MB	**-1.5**	**-1.2**	≤±0.5
	GE	**3.0**	**3.1**	≤2.0
	RMSE	4.3	4.3	
WS (m/s)	PRE	4.1	4.1	
	OBS	3.2	3.4	
	MB	**0.9**	**0.7**	≤±0.5
	GE	1.7	1.8	≤2.0
	RMSE	**2.3**	**2.3**	≤2.0
WD (°)	PRE	176.7	172.7	
	OBS	179.5	176.1	
	MB	3.2	2.6	≤±10
	GE	**55.2**	**53.0**	≤30
	RMSE	**71.8**	**69.7**	≤30
RH (%)	PRE	63.3	61.3	

OBS	67.0	66.8
MB	-3.7	-5.4
GE	12.3	13.1
RMSE	15.6	16.7

Note: * are benchmarks limits suggested by Emery et al. (2001), data that do not fall under the limits are shown as bold.

Table S6: Indices used to evaluate model performance.

Index	Definition*	Remarks
Mean bias (MB)	$\frac{1}{N}\sum_{i=1}^{N}(P_i-O_i)$	
Root mean square error (RMSE)	$\sqrt{\frac{1}{N}\sum_{i=1}^{N}(P_i-O_i)^2}$	Reported as %
Gross Error (GE)	$\frac{1}{N}\sum_{i=1}^{N}\frac{\lvert P_i-O_i\rvert}{O_i}$	Reported as %
Mean normalized bias (MNB)	$\frac{1}{N}\sum_{i=1}^{N}\frac{(P_i-O_i)}{O_i}$	Reported as %
Mean normalized error (MNE)	$\frac{1}{N}\sum_{i=1}^{N}\left\lvert\frac{P_i-O_i}{O_i}\right\rvert$	Reported as %
Mean fractional bias (MFB)	$\frac{2}{N}\sum_{i=1}^{N}\frac{(P_i-O_i)}{(P_i+O_i)}$	Reported as %
Mean fractional error (MFE)	$\frac{2}{N}\sum_{i=1}^{N}\frac{\lvert P_i-O_i\rvert}{(P_i+O_i)}$	Reported as %

Note: * i represents the pairing of N observations O and predictions P by site and time.

Table S7: model performance of O_3 (ppb), $PM_{2.5}$ (µg m^{-3}), CO (ppb), and NO_2 (ppb) at Delhi, Mumbai, Chennai, Hyderabad, and Bengaluru (OBS is mean observation; PRE is mean prediction; MFB is mean fractional bias; MFE is mean fractional error; MNB is mean normalized bias; MNE is mean normalized error).

Variable	Statistics	Delhi	Mumbai	Chennai	Hyderabad	Bengaluru	ALL	Benchmark*

O_3	OBS	61.37	56.64	49.94	44.03	47.66	51.93	
	PRE	56.86	47.06	39.32	52.56	43.58	47.88	
	MNB	-0.04	-0.13	**-0.20**	**0.20**	-0.07	-0.05	≤±0.15
	MNE	0.20	0.28	0.29	0.22	0.26	0.25	≤0.30
	MFB	-0.08	-0.20	-0.27	0.17	-0.17	-0.11	
	MFE	0.21	0.32	0.36	0.18	0.33	0.28	
$PM_{2.5}$	OBS	58.08	33.10	23.09	33.09	33.79	36.23	
	PRE	38.10	21.46	15.57	18.28	16.29	21.94	
	MNB	-0.16	-0.28	-0.12	-0.41	-0.41	-0.28	
	MNE	0.54	0.44	0.46	0.47	0.51	0.48	
	MFB	-0.40	-0.46	-0.30	-0.59	**-0.66**	-0.48	≤±0.6
	MFE	0.62	0.59	0.51	0.63	0.73	0.61	≤0.75
NO_2	OBS	13.87	11.17	3.74	10.60	10.68	10.01	
	PRE	7.00	9.68	4.34	3.04	8.64	6.54	
	MNB	-0.51	0.42	0.46	-0.74	-0.30	-0.14	
	MNE	0.74	1.34	1.11	0.86	0.89	0.99	
	MFB	-1.00	-0.47	-0.20	-1.44	-0.90	-0.80	
	MFE	1.13	1.18	0.82	1.51	1.19	1.17	
CO	OBS	0.69	0.65	0.45	0.38	0.74	0.58	
	PRE	0.26	0.16	0.12	0.13	0.14	0.16	
	MNB	-0.59	-0.72	-0.71	-0.61	-0.78	-0.68	
	MNE	0.59	0.72	0.71	0.61	0.78	0.68	
	MFB	-0.88	-1.15	-1.13	-0.92	-1.32	-1.08	
	MFE	0.89	1.15	1.13	0.92	1.32	1.08	

Note: * are benchmarks limits suggested by EPA (2007) for $PM_{2.5}$ and EPA (2005) for O_3, data that do not fall under the limits are shown as bold.

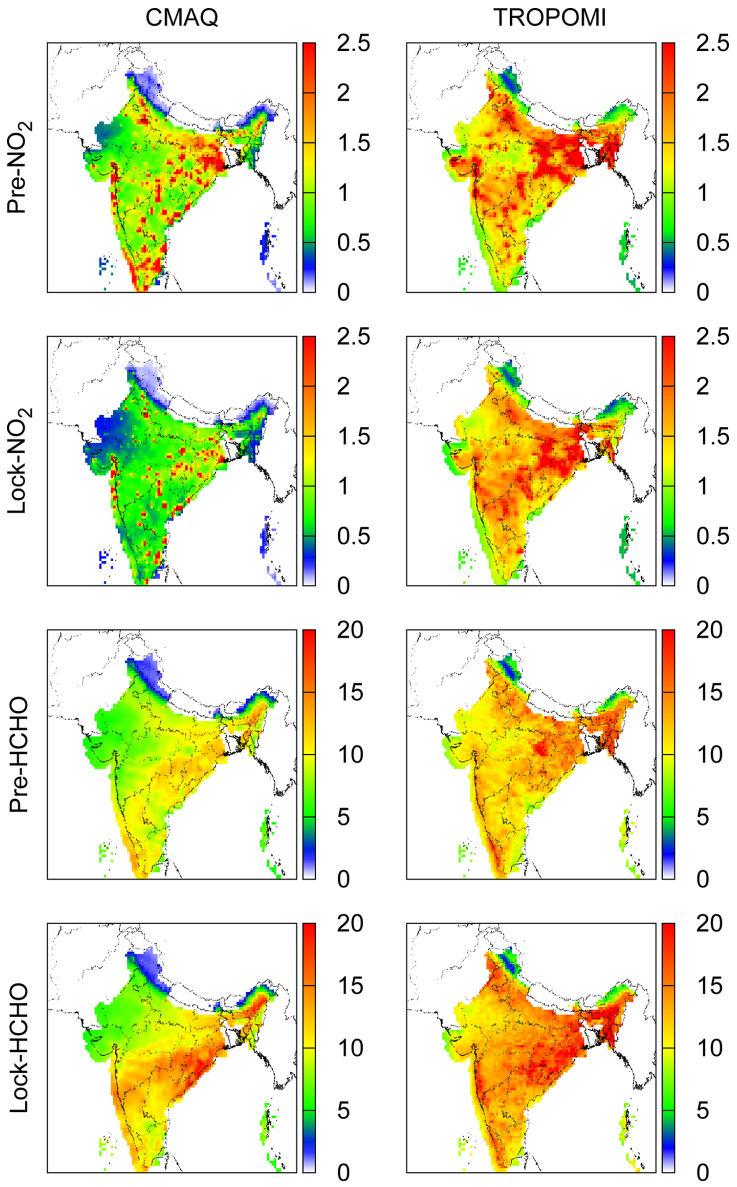

Figure S1: Comparison of the simulated and satellite-observed NO_2 and HCHO column number density before lockdown and during the lockdown in India. The unit is 10^{15} molec cm^{-2}.

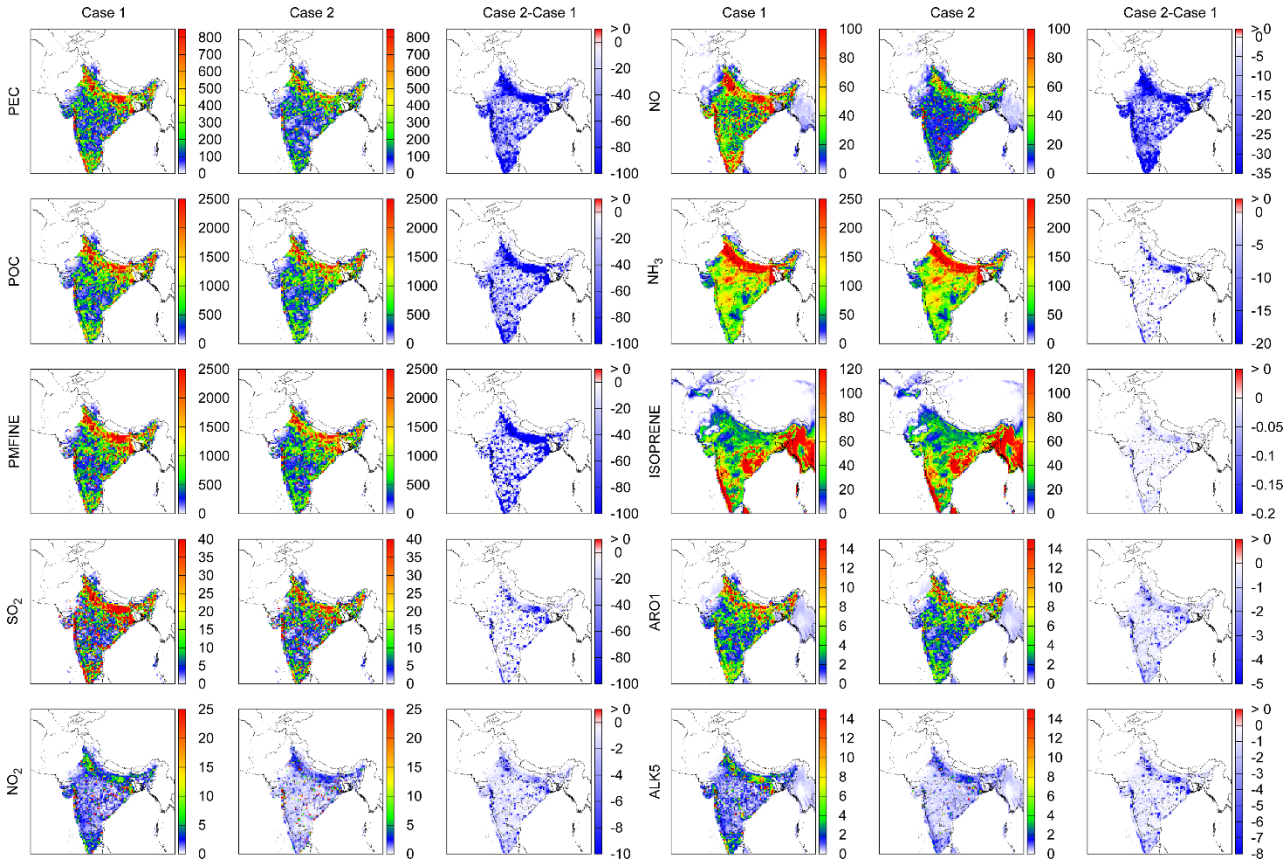

Figure S2: Comparison and difference of India's emissions before and after anthropogenic emission reduction on March 24, 2020; PEC, POC, and PMFINE are in the unit of g s^{-1} and the other parameters are in the unit of moles s^{-1}. (PEC is primary elemental carbon; POC is primary organic carbon; PMFINE is fine particulate matter; ISOPRENE is isoprene; ARO1 means aromatics with kOH < $2x10^4$ ppm^{-1} min^{-1}; ALK5 means alkanes and other non-aromatic compounds that react only with OH, and have kOH greater than 1 x 10^4 ppm^{-1} min^{-1}.) "Case2 - Case1" indicates (Case 2 – Case 1)/Case 1, reported as %.

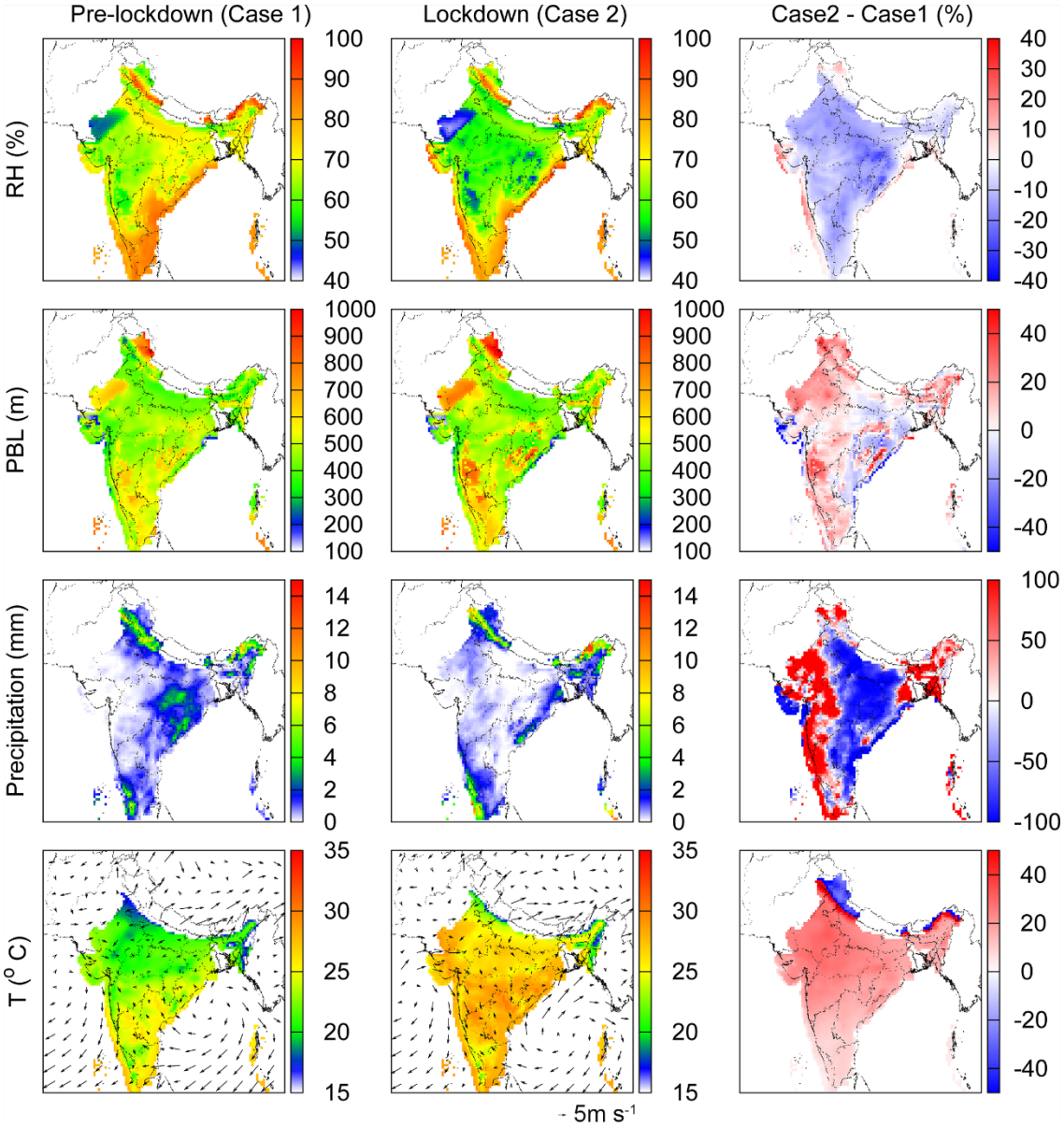

Figure S3: Distribution of simulated temperature (T), relative humidity (RH), planetary boundary layer (PBL) height, the average daily precipitation, and wind fields in India before and during the lockdown period. "Case2 - Case1" indicates (Case 2 – Case 1)/Case 1, reported as %.

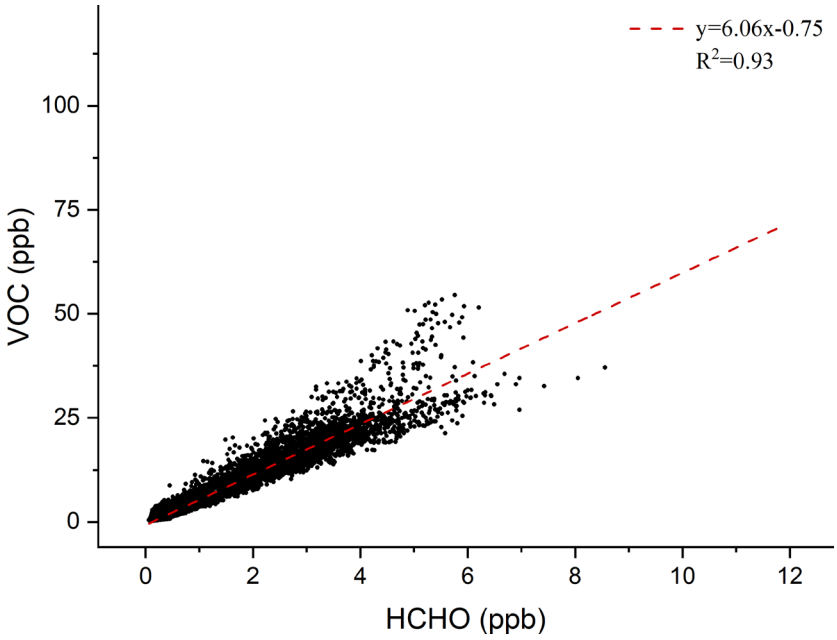

Figure S4: Scatter plots comparing the simulated average daily HCHO and the total VOCs at all 117×117 grids from February 21 to April 24, 2020.

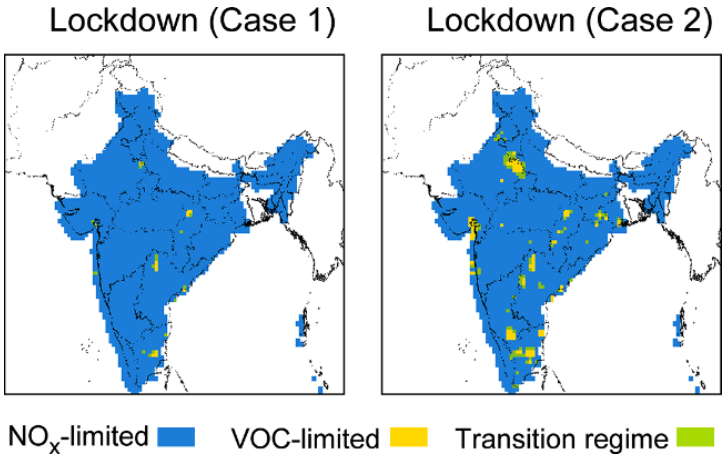

Figure S5: Spatial distributions of O_3 production sensitivity in India from March 24 to April 24, 2020.

References

Emery, C., Tai, E., and Yarwood, G.: Enhanced meteorological modeling and performance evaluation for two Texas ozone episodes, 2001.

EPA: Guidance on the Use of Models and Other Analyses in Attainment Demonstrations for the 8-hour Ozone NAAQS, 2005.

EPA, U. E. P. A., Office of Air Quality Planning Standards: Guidance on the use of models and other analyses for demonstrating attainment of air quality goals for ozone, $PM_{2.5}$, and regional haze, 2007.