

Supplement of

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

10 **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, the red being the most polluting, then the orange and followed by the green.

S.No.	Red	Orange	Green
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.

15

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, 2020 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	$\leq \pm 0.5$
	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	$\leq \pm 0.5$

WD (°)	GE	1.7	1.8	≤2.0
	RMSE	2.3	2.3	≤2.0
	PRE	176.7	172.7	
	OBS	179.5	176.1	
	MB	3.2	2.6	≤±10
RH (%)	GE	55.2	53.0	≤30
	RMSE	71.8	69.7	≤30
	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 which do not fall under the limits are shown as bold.

20

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)	$\frac{1}{N} \sum_{i=1}^N \frac{ P_i - O_i }{O_i}$	Reported as %
Mean normalized bias (MNB)	$\frac{\sum_{i=1}^N (P_i - O_i)}{\sum_{i=1}^N O_i}$	Reported as %
Mean normalized error (MNE)	$\frac{\sum_{i=1}^N P_i - O_i }{\sum_{i=1}^N O_i}$	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)

$$\frac{2}{N} \sum_{i=1}^N \frac{|P_i - O_i|}{(P_i + O_i)}$$

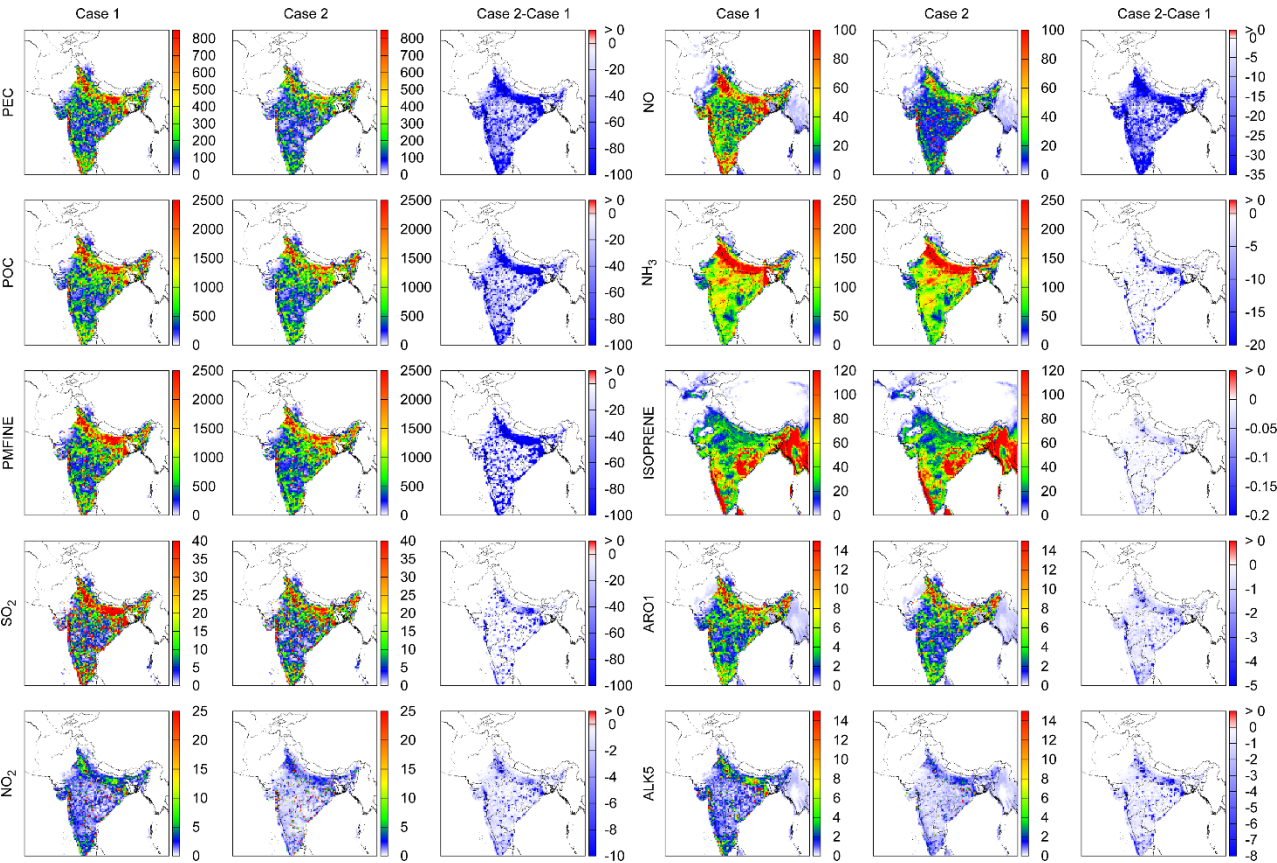
Reported as %

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

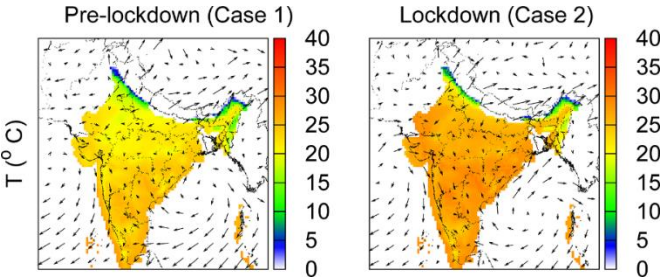
25 **Table S7: model performance of MDA8 O₃, PM_{2.5}, CO, and NO₂ at Delhi, Mumbai, Chennai, Hyderabad, and Bengaluru (OBS is mean observation; PRE is mean prediction; MFB is mean fractional bias; MFE is mean fractional error; MNB is mean normalized bias; MNE is mean normalized error).**

Variable	Statistics	Dehli	Mumbai	Chennai	Hyderabad	Bengaluru	ALL	Benchmark
O ₃	OBS	61.49	55.33	60.77	42.26	52.47	54.46	
	PRE	56.84	45.39	45.57	55.80	45.26	49.77	
	MNB	-0.03	-0.13	-0.14	0.32	-0.12	-0.02	≤±0.15
	MNE	0.23	0.29	0.34	0.32	0.25	0.29	≤0.30
	MFB	-0.07	-0.20	-0.25	0.26	-0.20	-0.09	
	MFE	0.25	0.34	0.42	0.26	0.31	0.32	
PM _{2.5}	OBS	47.41	33.07	22.15	32.68	30.28	33.10	
	PRE	39.41	21.48	15.61	18.28	16.78	22.36	
	MNB	0.52	-0.27	0.52	-0.39	-0.33	0.01	
	MNE	1.04	0.46	1.06	0.46	0.52	0.71	
	MFB	-0.12	-0.46	-0.15	-0.57	-0.57	-0.37	≤±0.6
	MFE	0.61	0.59	0.6	0.62	0.69	0.62	≤0.75
NO ₂	OBS	16.49	4.02	5.91	10.28	12.38	9.82	
	PRE	6.92	9.68	4.36	3.04	7.99	6.40	
	MNB	-0.53	2.79	3.60	-0.72	-0.35	0.96	
	MNE	0.82	3.39	4.44	0.87	0.86	2.08	
	MFB	-1.10	0.13	-0.34	-1.42	-0.95	-0.74	
	MFE	1.25	1.14	1.03	1.49	1.20	1.22	
CO	OBS	0.67	0.86	0.42	0.31	0.75	0.60	
	PRE	0.26	0.16	0.12	0.13	0.13	0.16	
	MNB	-0.56	-0.78	-0.63	-0.36	-0.65	-0.60	
	MNE	0.59	0.78	0.68	0.62	0.69	0.67	
	MFB	-0.85	-1.31	-1.00	-0.67	-1.08	-0.98	
	MFE	0.87	1.31	1.03	0.77	1.10	1.01	

Note: * are benchmarks limits suggested by EPA (2007) for PM_{2.5} and EPA (2005) for O₃, data which do not fall under the limits are shown as bold.



30 **Figure S1: 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 < 2x10⁴ ppm⁻¹ min⁻¹; ALK5 means alkanes and other non-aromatic compounds that react only with OH, and have kOH greater than 1 x 10⁴ ppm⁻¹ min⁻¹.)**



35 **Figure S2: Distribution of simulated temperature (T) and wind fields in India before and during the lockdown period.**

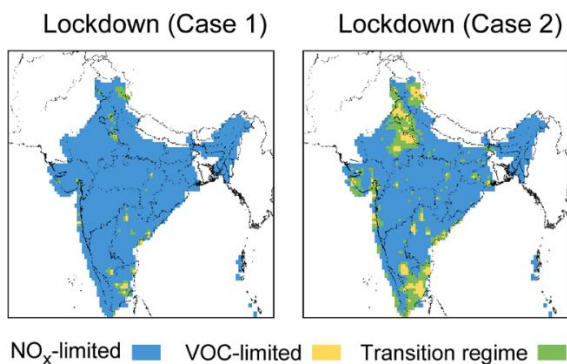


Figure S3: Spatial distributions of O₃ production sensitivity in India from March 24 to April 24, 2020.

References

- 40 Emery, C., Tai, E., and Yarwood, G.: Enhanced meteorological modeling and performance evaluation for two Texas ozone episodes, 2001.
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45