PNAS
www.pnas.org

Supplementary Information for

COVID-19 lockdowns cause global air pollution declines

Zander S. VENTER; Kristin AUNAN; Sourangsu CHOWDHURY; Jos LELIEVELD

Zander S. Venter
Email: zander.venter@nina.no

This PDF file includes:

Supplementary text
Figures S1 to S5
Tables S1

www.pnas.org/cgi/doi/10.1073/pnas.2006853117

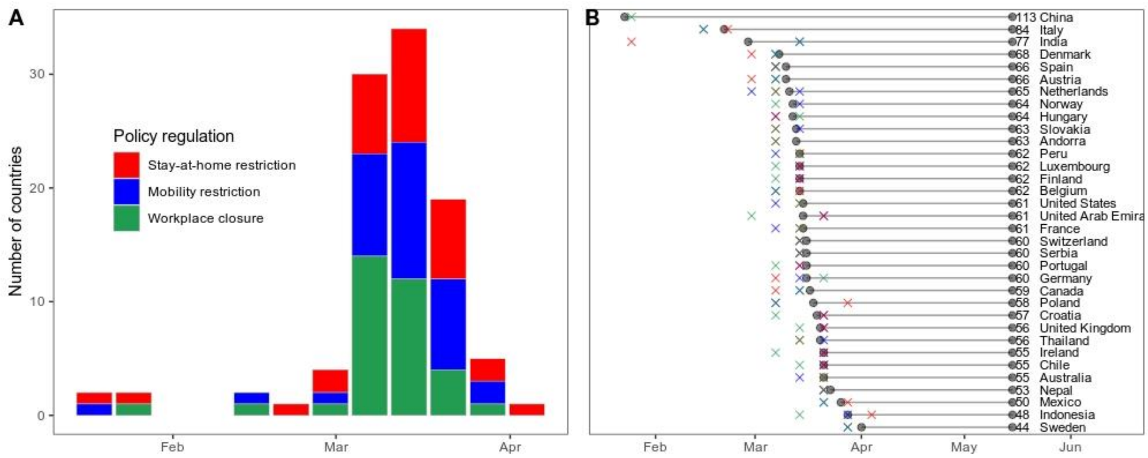


Fig. S1. Lockdown policy restrictions. The average date for the implementation of three types of policy restriction (A) were used to define country-specific lockdown start dates. Lockdown periods are indicated in B with horizontal lines up until 15 May 2020. Start dates of policy regulations are indicated wtih "x" in B.

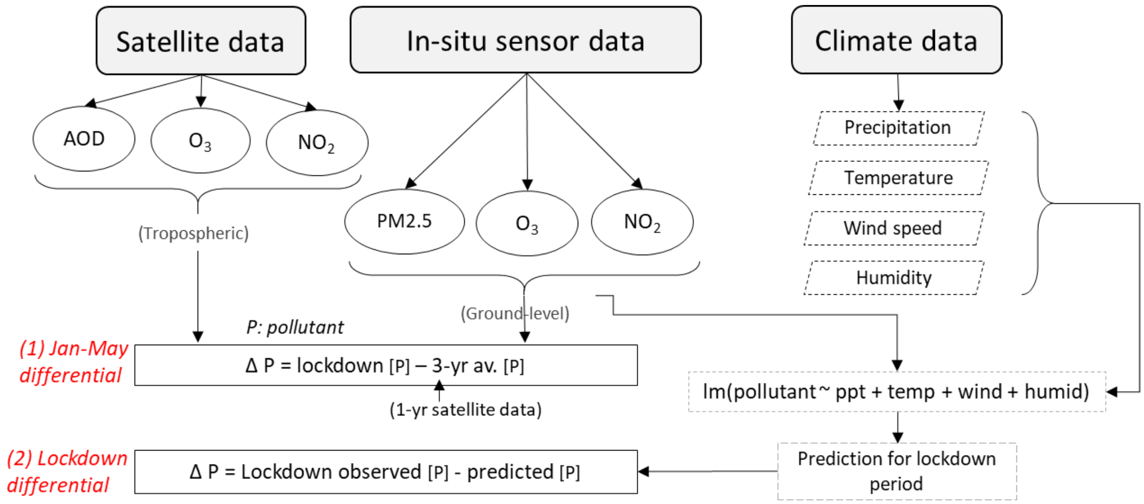


Fig. S2. Methodological workflow. Two types of air pollution (*P*) anomaly are calculated including *Jan-May differential* and *Lockdown differential*. The first is the difference between the Jan-May 2020 average and the average for the same days during the previous three years (2017-2019; ground-station data) or one year (2019; satellite data). The *Lockdown differential* is the difference between observed and predicted pollutant levels for lockdown dates. Predictions account for the confounding effects of weather variability using a regression model.

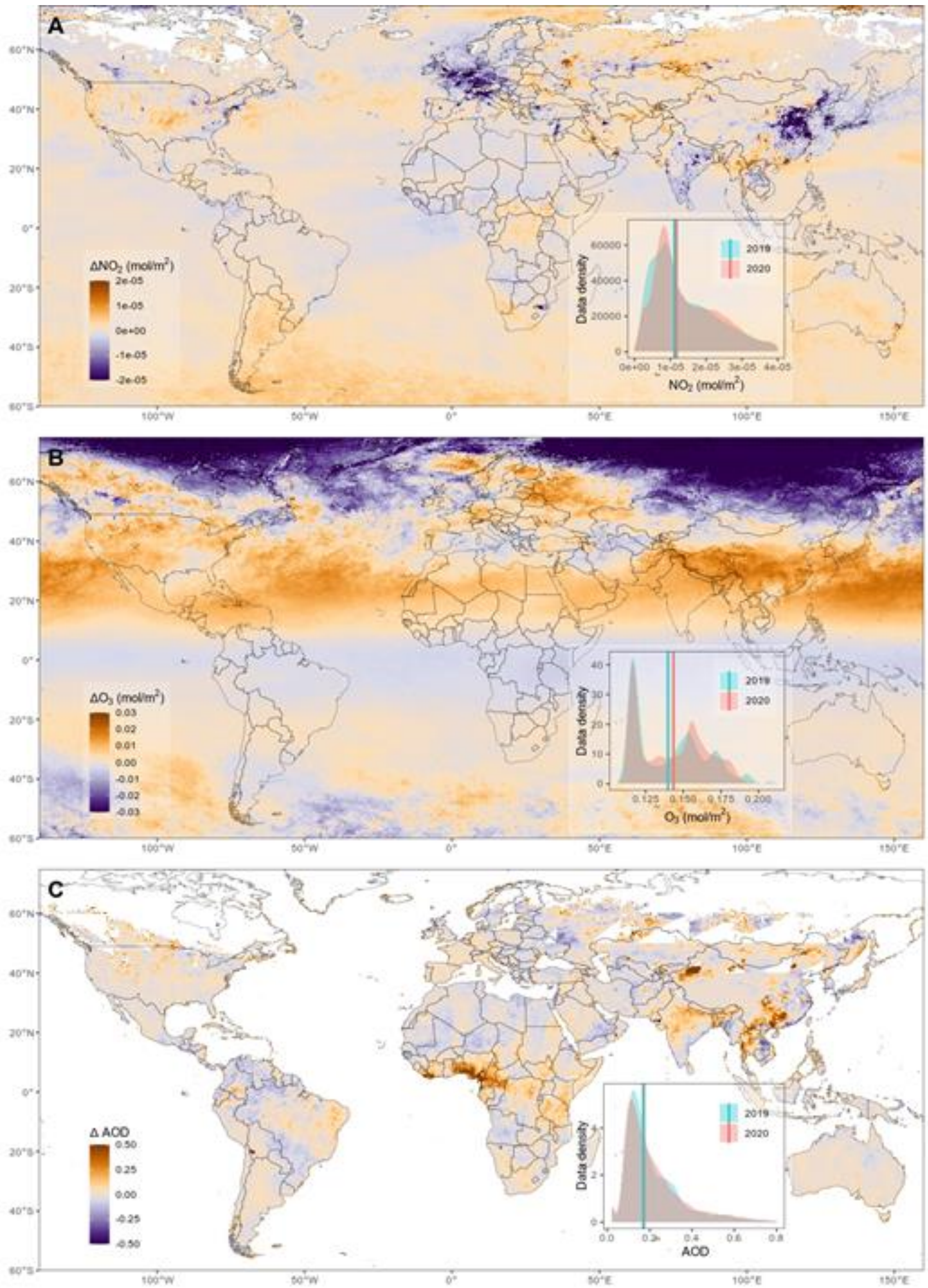
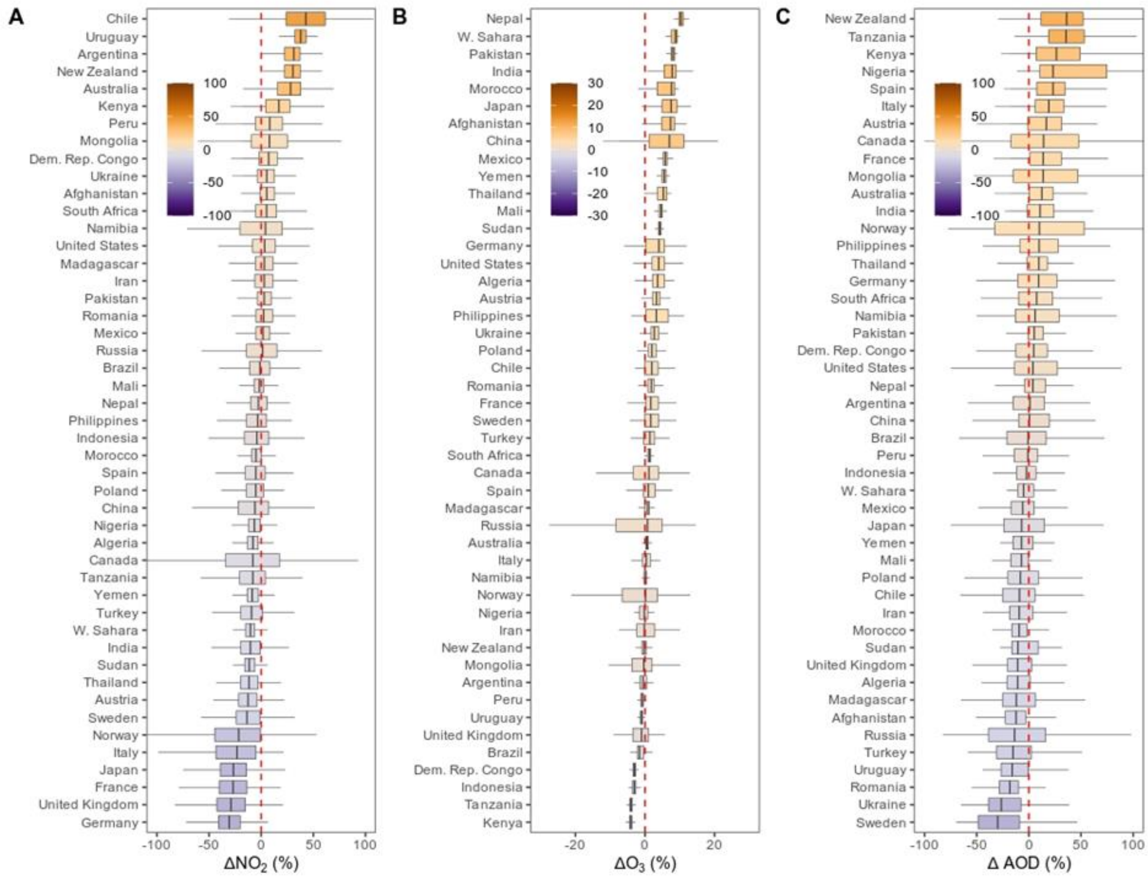


Fig. S3. Global distribution of 2020 satellite air pollution anomalies. Satellite measures of NO_2 (A), O_3 (B), and aerosol optical depth (AOD; C) anomalies are mapped. Anomalies are defined as deviations in 2020 Jan-May averages from 2019 levels for the same dates. Inset plots show data density distributions for 2019 and 2020 periods.


A
B
C
ΔNO2 (%)
ΔO3 (%)
Δ AOD (%)
Chile
Uruguay
Argentina
New Zealand
Australia
Kenya
Peru
Mongolia
Dem. Rep. Congo
Ukraine
Afghanistan
South Africa
Namibia
United States
Madagascar
Iran
Pakistan
Romania
Mexico
Russia
Brazil
Mali
Nepal
Philippines
Indonesia
Morocco
Spain
Poland
China
Nigeria
Algeria
Canada
Tanzania
Yemen
Turkey
W. Sahara
India
Sudan
Thailand
Austria
Sweden
Norway
Italy
Japan
France
United Kingdom
Germany

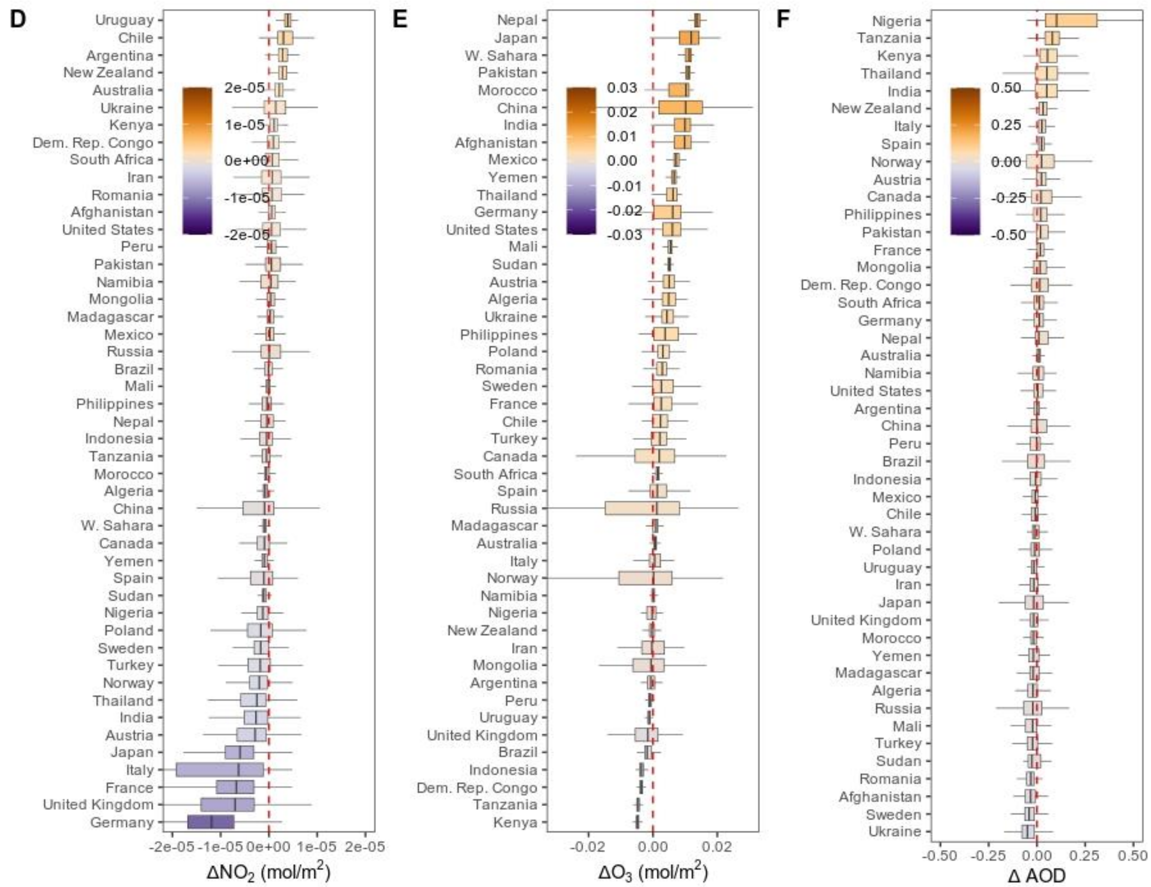


Fig. S4. Satellite-derived atmospheric air pollution Jan-May anomalies. Percentage (A. B. C) and absolute (D, E, F) temporal differentials (Jan-May 2020 vs Jan-May 2019) in atmospheric NO_2, O_3 and aerosol optical depth (AOD) per country. Box and whisker plots show the spread of the data (each data point is a satellite pixel within a country) around the median value.

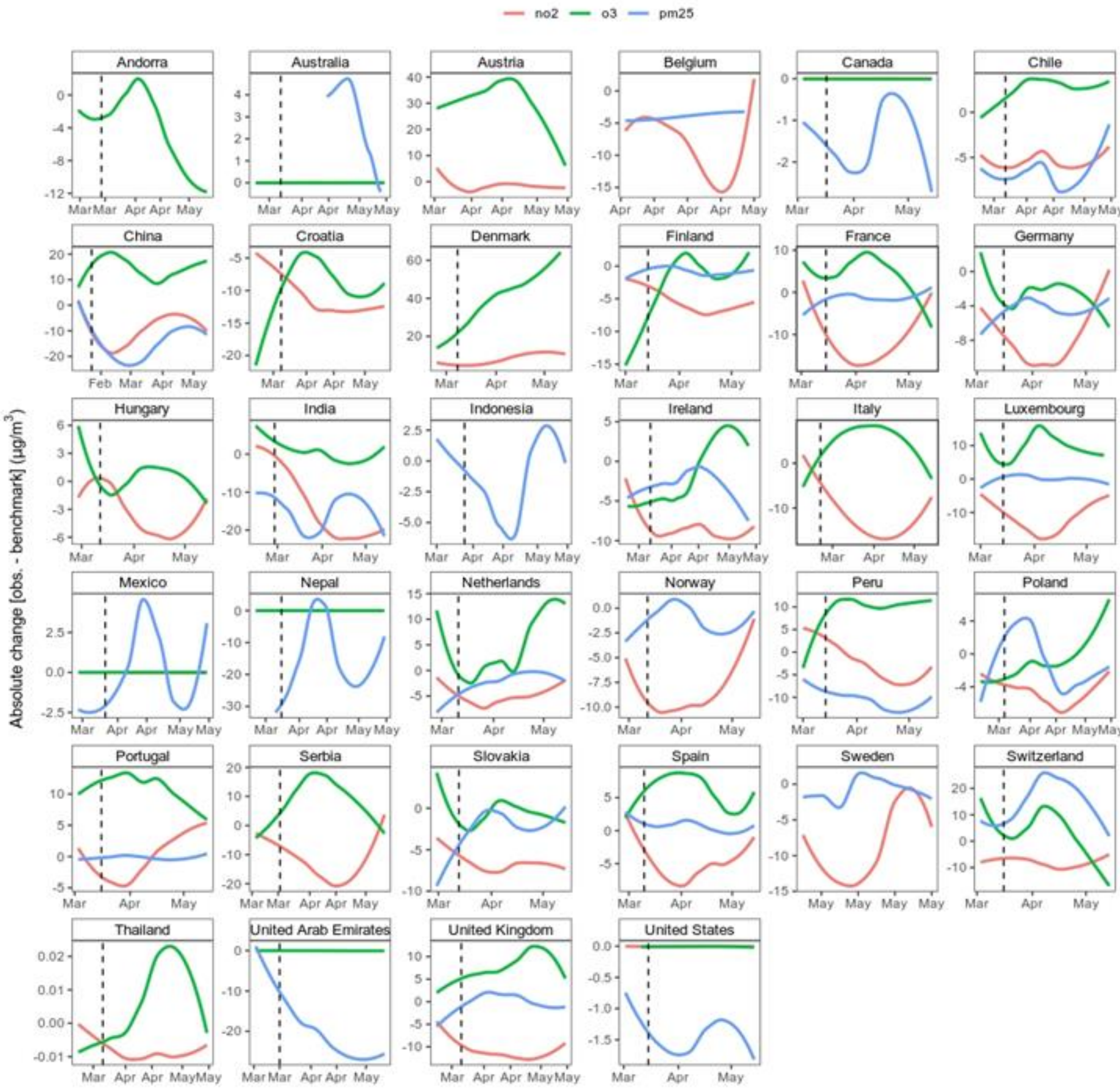


Fig. S5. Ground-level pollutant time series and lockdown dates. Daily time series of ground-level NO_2, O_3 and $PM_{2.5}$ anomalies (observed subtract benchmark model predicted values) per country with dates of lockdown indicated by vertical lines. Smoothed loess regression lines are fitted to indicate moving averages. Lines for each pollutant are plotted on the same Y-axis and thus pollutants with very small temporal variation from the benchmark appear flat (e.g. O_3 for Australia). Please consult interactive web application for individual plots: https://nina.earthengine.app/view/lockdown-pollution

Table S1. Regression model performance. Air pollutant concentrations were regressed on daily 2017-2019 meteorological data (temperature, humidity, precipitation and wind speed) to predict what air pollutant concentrations were expected to be during lockdown dates. Separate models were built for each country and the resulting *R^2* and *p-values* are presented.*R^2* indicate the extent to which models were able to explain the temporal variance in air pollution and therefore how accurate their predictions over the lockdown period are expected to be.

	NO_2		**O_3**		**$PM_{2.5}$**	
Country	**R^2**	**p-value**	**R^2**	**p-value**	**R^2**	**p-value**
Andorra	-	-	0.685	3.E-167	-	-
Australia	0.267	5.E-55	0.414	6.E-102	0.178	2.E-20
Austria	0.467	2.E-04	0.506	3.E-06	-	-
Belgium	0.454	1.E-56	0.554	1.E-33	0.261	8.E-23
Canada	0.289	1.E-51	0.572	2.E-158	0.135	5.E-21
Chile	0.476	1.E-120	0.216	1.E-40	0.740	1.E-266
China	0.619	7.E-139	0.510	2.E-102	0.542	1.E-112
Croatia	0.444	5.E-96	0.647	7.E-163	-	-
Denmark	0.551	2.E-103	0.470	2.E-76	-	-
Finland	0.413	2.E-92	0.576	9.E-154	0.256	2.E-48
France	0.560	9.E-147	0.763	1.E-267	0.341	7.E-71
Germany	0.393	4.E-82	0.553	9.E-141	0.313	7.E-62
Hungary	0.478	2.E-111	0.693	5.E-210	-	-

	NO_2		O_3		$PM_{2.5}$	
Country	R^2	**p-value**	R^2	**p-value**	R^2	**p-value**
India	0.475	1.E-80	0.350	5.E-53	0.618	4.E-129
Indonesia	-	-	-	-	0.157	2.E-21
Ireland	0.462	1.E-87	0.742	9.E-104	0.340	2.E-13
Italy	0.738	9.E-211	0.815	5.E-283	-	-
Luxembourg	0.580	8.E-140	0.708	7.E-195	0.328	6.E-59
Mexico	0.510	1.E-68	0.409	1.E-89	0.254	5.E-47
Nepal	-	-	0.690	2.E-151	0.599	6.E-116
Netherlands	0.442	3.E-91	0.266	2.E-33	0.316	1.E-55
Norway	0.662	6.E-213	-	-	0.376	8.E-89
Peru	0.540	1.E-52	0.395	3.E-33	0.155	3.E-06
Poland	0.529	6.E-65	0.752	3.E-131	0.535	3.E-68
Portugal	0.670	7.E-171	0.480	5.E-98	0.283	1.E-45
Serbia	0.600	2.E-54	0.769	7.E-94	-	-
Slovakia	0.544	9.E-124	0.782	2.E-252	0.389	2.E-74
Spain	0.515	1.E-73	0.658	4.E-109	0.443	1.E-46
Sweden	0.373	8.E-34	-	-	0.200	2.E-07

	NO_2		O_3		$PM_{2.5}$	
Country	R^2	**p-value**	R^2	**p-value**	R^2	**p-value**
Switzerland	0.595	4.E-125	0.766	4.E-211	0.290	4.E-41
Thailand	0.598054	1.8E-174	0.533168	2.6E-146	-	-
United Arab Emirates	-	-	0.751776	1.73E-26	0.568429	1.61E-12
United Kingdom	0.689013	2.2E-232	0.643462	9.3E-207	0.242885	4.21E-49
United States	0.613242	3.2E-172	0.689224	3.5E-102	0.168472	2.01E-28